SUBCONTRACT

For Contracted Work under ESA Project

"ESA-DTE-B-01-LEAD DTCS DEVELOPMENT ACTIONS AND ESA-DTE-B-02 EARLY DTCS DEVELOPMENT ACTIONS" (DTC Forest)

(Hereinafter referred to as Subcontract)

PARTIES

VTT Technical Research Centre of Finland Ltd
P.O. Box 1000, FI-02044 VTT, Finland
Business ID: 2647375-4
(hereinafter VTT)

And

Global Change Research Institute CAS (CzechGlobe)
Belidla 986/4a, 603 00 Brno, Czech Republic
Business ID: 86652079
(hereinafter the Subcontractor)

Hereinafter each referred to as a Party and jointly as Parties

Have agreed as follows:

1 BACKGROUND AND PURPOSE

VTT has entered into a contract with European Space Agency (ESA) for the purpose of carrying out a Project called "ESA-DTE-B-01-LEAD DTCS DEVELOPMENT ACTIONS AND ESA-DTE-B-02 EARLY DTCS DEVELOPMENT ACTIONS" (hereinafter "Project"), Contract number ESA Contract No. 4000146395/24/I-KE (the contract and its annexes and appendices referred to in the contract hereinafter referred to as "ESA Contract"). General Clauses and Conditions for ESA Contracts, reference ESA/REG/002, rev. 3 (hereinafter referred to as GCC) is an integral part of the ESA Contract. ESA Contract shall hereby become an integral part of this Subcontract and shall be attached hereto as Appendix 1.

The purpose of this Subcontract is to agree upon work to be performed by the Subcontractor on behalf of VTT in the Project and the terms related thereto.

2 SUBCONTRACTED WORK AND COMMITMENT TO THE TERMS OF THE ESA CONTRACT

The Subcontractor shall carry out the work described as Subcontractor's tasks, hereinafter "Work", in Appendix 1 and as specified further in Appendix 2 attached hereto and in VTT's Project Proposal (reference 233304-24) attached hereto as Appendix 3. The Subcontractor shall also be bound by and comply with VTT Supplier Code of Conduct attached as Appendix 4 hereto.

According to GCC, the conditions of any subcontract shall secure to ESA all rights provided for it under the ESA Contract. Therefore the Subcontractor hereby commits to all obligations arising out of the ESA Contract that concern Subcontractor's Work. The Subcontractor shall be responsible towards VTT of all of its obligations as if it was the contractor with ESA. Subcontractor's responsibilities towards ESA and rights of ESA shall be regarded as responsibilities towards VTT and rights of VTT. All remedies available to ESA are also available to VTT. These responsibilities and remedies include but are not limited to the following listed key obligations to the extent provided in the GCC and amended in the ESA Contract:

- Addition 8.8 to Clause 8 of the GCC
- Additions A and B to Clause 10 of the GCC
- Inspections (Clause 8.2 of GCC)
- Changes (Clause 13 of GCC)
- Time-limits for the provision of deliverables and services (Clause 14 of the GCC)
- Handling, packing and transport, transfer of ownership and risk (Clause 15 of GCC)
- Penalties for late delivery (Clause 17 of GCC)
- Warranties (Clauses 21 & 22 of GCC)
- Pricing (Clause 27 of the GCC)
- PART II: Conditions concerning intellectual property rights for ESA study, research and development contracts.
    - Part II Option A of the GCC shall apply, as modified by special provisions below.
    - The free licences provided for the benefit of ESA in the ESA Contract and in Part II of the GCC shall be deemed granted through signature of the ESA Contract and without the need to implement a separate licence.
- Termination (Chapter VIII of GCC)

The Subcontractor hereby commits to carry out the Work in accordance with the deadlines agreed upon in the ESA Contract and this Subcontract and in the manner that VTT is able to perform its duties under the ESA Contract.

The Subcontractor shall exercise all reasonable skill, care and diligence in the performance of the Work and shall carry out all of its responsibilities

under this Subcontract in accordance with recognized professional standards and applicable laws.

The Subcontractor's personnel allocated to the Work is specified in Appendix 2. Any changes to the identities or workload of key personnel or non-key personnel shall be first indicated to VTT, for subsequent discussion with ESA in a progress meeting. Concerning key personnel, the procedure included in the ESA Contract additionally applies.

The Subcontractor shall cooperate with VTT and supply VTT without delay with any information which VTT may need concerning the implementation of the Work. VTT has the right to supervise Subcontractor's Work. The Subcontractor shall observe all reasonable directions given by VTT in relation to carrying out the Work.

The Subcontractor may not without VTT's express written acceptance use any subcontractor for carrying out the Work. The Subcontractor shall remain liable for the work of its subcontractors as it is liable for its own Work.

3 PAYMENTS AND INVOICING

ESA shall credit the account of VTT to VTT's benefit and to the benefit of the Subcontractor(s). VTT shall be responsible for paying the accounts of the Subcontractor, for this Subcontract, within thirty (30) working days from receipt of payment from the ESA. The details relating to the payments including VTT's and the Subcontractor's duties related to the invoices, payments and required deliverables have been identified in the ESA Contract (Appendix 1) in Article 3. Payment plan for the subcontractor is included in Appendix 2.

All invoices shall be submitted to VTT in electronic form (PDF format) to maija.kaivola@vtt.fi and renne.tergujeff@vtt.fi, referring to provided purchase order number and addressed as follows:

VTT Technical Research Centre of Finland Ltd
P.O. Box 8003
00071 OSTOLASKUT
Finland

The Subcontractor shall promptly after signatures provide its payment details to VTT. Payments shall be made by VTT in EURO.

4 CONFIDENTIALITY

The Parties hereby commit towards each other to the same obligations relating to confidentiality as has been agreed upon in GCC Clause 38.

5 LIABILITY

The liability provisions as described in the GCC Chapter IV shall apply to this Subcontract and the Subcontractor shall provide ESA and VTT with the rights and obligations provided therein.

The Subcontractor shall be solely liable for the Work carried out by it within the limits of liability stated in the GCC.

6 OTHER TERMS

Should the ESA Contract be terminated under the provisions of the GCC, VTT shall have the right to terminate this Subcontract.

The Subcontractor shall not assign or otherwise transfer this Subcontract in whole or in part without VTT’s express written consent.

This Subcontract supersedes all oral or written proposals, prior agreements and other communications between the Parties concerning the subject matter of this Subcontract.

Amendments or changes to this Subcontract shall be valid only if made in writing and signed by the Parties.

If any of the terms of this Subcontract is found to be invalid, such invalidity does not affect the validity of the other terms. The Parties shall replace the invalid term with a valid term that to the best extent possible describes the original purpose of the invalid term.

In case of discrepancies between this Subcontract and its appendices, the order of preference shall be the following:

1. ESA Contract (Appendix 1)
2. This Subcontract
3. Appendix 2
4. Appendix 3.
5. Appendix 4.

This Subcontract is subject to the laws of Finland, excluding its choice of law provisions.

The arbitration proceedings referred to in Clause 35 of the GCC shall take place in Helsinki, Finland.

7 DURATION OF THE SUBCONTRACT

This Subcontract shall come into force on the date of the signature of the Subcontract by the Parties, but shall then have retroactive effect as from the effective date of the ESA Contract.

The Subcontract shall be in force until the completion of the Work and the payments due hereunder, unless earlier terminated in accordance with this Subcontract, except for the clauses that are meant to survive the termination or expiration of the Subcontract.

8 CONTACT INFORMATION

All correspondence for VTT in technical matters shall be addressed to: [redacted] <[redacted]>, with copy to: [redacted]

All correspondence for VTT in contractual and administrative matters shall be addressed to: [redacted], with copy to: [redacted]

All correspondence for the Subcontractor in technical matters shall be addressed to: [redacted], with copy to: [redacted]

All correspondence for the Subcontractor in contractual and administrative matters shall be addressed to: [redacted] with copy to: [redacted]

9 SIGNATURES

The Parties shall sign this Subcontract in an electronic signature system (DocuSign). The Subcontract signed and delivered via the electronic signature system shall have the same force and effect as an agreement with original handwritten signatures. Each Party receives a fully executed copy of the Subcontract. Each Party warrants that the person(s) signing the Subcontract is authorized to sign the Subcontract in the name of said Party.

VTT TECHNICAL RESEARCH CENTRE OF FINLAND LTD

Date:	28 January 2025
Signature:	[redacted]
Name:	Erja Turunen
Title:	Executive Vice President

GLOBAL CHANGE RESEARCH INSTITUTE CAS (CZECHGLOBE)

Date:	10 January 2025
Signature:	[redacted]
Name:	Michal V. Marek
Title:	Director

APPENDICES:

Appendix 1	ESA Contract
Appendix 2	Specification of Subcontractor's tasks, allocated personnel and payment plan
Appendix 3	Project Proposal
Appendix 4	VTT Supplier Code of Conduct

ESA Contract No. 4000146395/24/I-KE

with

VTT Technical Research Centre of Finland, Ltd.

ESA-DTE-B-01-LEAD DTCS DEVELOPMENT ACTIONS AND ESA-DTE-B-02 EARLY DTCS DEVELOPMENT ACTIONS

CONTRACT

Between:

The EUROPEAN SPACE AGENCY,

(hereinafter called the “Agency” or “ESA”),

having its seat at: 8-10 rue Mario Nikis, CS 45741, 75738 Paris CEDEX 15, France,
represented by its Director General, Mr Josef Aschbacher,

acting through its establishment:

The European Space Research Institute (ESRIN),

located at: Largo Galileo Galilei 1,
00044 Frascati (RM),
Italy,

of the one part,

and:

VTT Technical Research Centre of Finland, Ltd.,

(hereinafter called the “Contractor” or “VTT”),

whose registered office is at:

Tekniikantie 21,
Espoo 02044,
Finland

represented by its Executive Vice President, Ms Erja Turunen,

of the other part,

the following has been agreed:

Contents

ARTICLE 1 SUBJECT OF THE CONTRACT – APPLICABLE DOCUMENTS

1.1 Subject of the Contract

The Contractor, as further described in the Statement of Work in APPENDIX 2, undertakes to develop and demonstrate, to a pre-operational stage, an EO-based Digital Twin Component (DTC) as an advanced digital replica of a key component of the Earth system and the interactions with human activities and ecosystems, with a strong focus on valorising the role of Earth Observation capabilities.

1.2 Applicable Documents

The work shall be performed in accordance with the following documents, listed in order of precedence, in case of conflict;

a) The Articles of this Contract with its PDP Annex and its APPENDIX 1 (Payment Plan and Advance Payment(s) and other Financial Conditions);

b) The General Clauses and Conditions for ESA Contracts (herein referred to as the “GCC”), reference ESA/REG/002, rev. 3, not attached hereto but known to both Parties and available on https://esastar-publication.sso.esa.int/supportingDocumentation, under “Reference Documentation” – “Administrative Documents”, as amended by this Contract;

c) APPENDIX 2 hereto: The Statement of Work, reference ESA-EOP-SG-SOW-0508, issue 1, revision 0, dated 25 January 2024;

d) The Contractor’s Proposal reference 233304-24, issue 1, revision 0, dated 12/04/2024, as complemented by its replies of 2 September and 10 October 2024 to the ESA negotiation letter. not attached hereto but known to both Parties.

ARTICLE 2 DELIVERY

2.1 Place and Dates of Delivery

2.1.1 Documents
The Contractor shall, during the performance of this Contract, deliver all documentation and reports specified in APPENDIX 2, in an electronic file. These shall be sent to the Agency's Technical Officer mentioned in ARTICLE 5, Clause 5, Sub-Clause 5.1 a) of the Contract, unless otherwise specified, in accordance with the following specific provisions:

2.1.1.1 The draft versions of the final documents as defined in APPENDIX 2 shall be submitted for approval, in electronic searchable, indexed and not encrypted PDF and native (WORD) format, to the Agency's Technical Officer specified in ARTICLE 5, Clause 5, Sub-Clause 5.1 a) of the Contract, as defined in APPENDIX 2.

2.1.1.2 The finalised versions thereof shall be issued in electronic searchable, indexed and not encrypted PDF and native (WORD) format not later than four (4) weeks after the approval of the draft versions and shall be sent by email to:

- The Agency's Technical Officer specified in ARTICLE 5, Clause 5, Sub-Clause 5.1 a) of the Contract; and
- the ESA Information and Documentation Centre – ESTEC Library (email: esa.ids@esa.int).

ARTICLE 3 Price and Payment

3.1 Price

The price of this Contract amounts to:

1,500,000 EUR
(One Million Five Hundred Thousand Euro),

broken down per Contractor and Subcontractor(s) as follows:

Company Name	ESA Entity Code	Type P/Prime SI/Subco Indirect	Country (ISO Code)	Total Amount in Euro
VTT Technical Research Centre of Finland, Ltd.	1000001603	P	FI	654,860
Yucatrote Ltd	1000037600	SI	PT	205,000
Terramonitor Ltd	1000026282	SI	FI	328,000
Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences	1000001618	SI	DE	128,000
Global Change Research Institute CAS	1000002611	SI	CZ	100,000
Forest Science and Technology Centre of Catalonia	1000036105	SI	ES	84,140
TOTAL				**1,500,000**

The Agency may decide that certain items produced or purchased under the Contract during its implementation (see ARTICLE 4 below) shall become ESA Fixed Assets. Such items shall be identified as becoming ESA Fixed Assets by means of a Contract Change Notice.

3.1.1 The type of price is the following:

A Firm Fixed Price as defined in Section 2.1 of Annex II to the GCC.

3.1.2 The above-mentioned price does not include any taxes or duties in the Member States of the Agency.

The price is deemed to include all applicable fees for licences to be purchased and delivered in the frame of the Contract, indicating the Agency as the end user. The price is further deemed to include any and all licence fees payable according to Sub-Clause 43.7 of the GCC.

3.1.3 The price is Delivered Duty Paid for all deliverables, exclusive of import duties and VAT in accordance with the INCOTERMS® 2020, to the addressees specified in ARTICLE 5, Clause 5, Sub-Clause 5.1 a) of the Contract. Reference to INCOTERMS® in this provision is exclusively for the purpose of price definition.

3.2 Payment

3.2.1 General provisions

The Payment Plan and Advance Payment(s) off-setting conditions applicable to this Contract are specified in APPENDIX 1 hereto.

The Advance Payment constitutes a debt of the Contractor to the Agency until it has been set-off against subsequent milestone(s) as shown in APPENDIX 1 hereto.

In the event that the achievement of a milestone is delayed but the milestone is partially met at the milestone planning date foreseen, the Agency may, as an exception, effect a payment against an approved confirmation of the partially achieved milestone, not exceeding the value of the work performed at the date of payment.

When releasing the payment for a given milestone, if applicable, the Agency's payment shall be made after due deduction of the corresponding off-set of the Advance Payment(s) as per the conditions of APPENDIX 1 to the Contract (Payment plan and Advance Payment(s) and other Financial Conditions).

In case of partial payment, the Agency shall deduct from the corresponding invoice(s) relative to the same milestone any outstanding amount of the Advance Payment(s) still to be off-set.

Payments shall be made within thirty (30) calendar days of submission via esa-p to ESA of the required documents and fulfilment of the requirements as specified in Article 3.2.2 below[1]. Only upon fulfilment of these requirements shall the invoice be regarded as due by the Agency.

Payments shall be made by the Agency in EURO to the account specified by the Contractor. Such account information shall clearly indicate the IBAN (International Bank Account Number) and BIC/SWIFT (Bank Identification Code). The Parties agree that payments shall be considered as effected by the Agency on time if the Agency's orders of payment reach the Agency's bank within the payment period stipulated in the paragraph above.

Any special charges related to the execution of payments will be borne by the Contractor.

Any questions concerning the latest status of due invoices can be addressed to the ESA Payment Officer (mail to: esa.payment.officer@esa.int).

If applicable, invoices shall separately show all due taxes or duties.

In the case of invoices submitted by the Contractor which are free of VAT, reference shall be made to the number indicated on the VAT Exemption Form which the Agency provided to the Contractor when forwarding the present Contract for signature. On invoices submitted via esa-p, the number shall be put in the respective field "VAT Exemption Number".

3.2.2 Requirements for Advance Payment Requests (APR) and invoices being regarded as due[2]:

Advance Payment (if any):

APR: to be submitted after signature of this Contract by both Parties.

Progress Payment(s):

- Milestone Achievement Confirmation (MAC/GRN) hereinafter referred to as "confirmation" with supporting documentation attached in esa-p. The supporting documentation shall justify the actual achievement of the milestone(s) as defined in the Payment Plan specified in APPENDIX 1 hereto.

and

- Invoice(s).

Final Settlement:

- Confirmation, with supporting documentation attached in esa-p. The supporting documentation shall justify the actual achievement of the milestones as defined in the Payment Plan specified in APPENDIX 1 hereto;

and

- Invoice(s);

and

- Receipt and/or acceptance, by the Agency, of all deliverable items, of the services to be rendered and other obligations to be fulfilled, in accordance with the terms of this Contract;
- The Final Report.

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1 This is reflected in esa-p as "30 days upon receipt by ESA, in esa-p, of both the confirmation and the invoice", see in esa-p GUIDE Frequently Asked Questions & Answers for Suppliers at: http://esa-p-help.sso.esa.int/FAQ_for_Suppliers.pdf.

2 For detailed information on how to submit and approve confirmations, invoices and APR in esa-p, you may consult the following two Quick Guides: http://esa-p-help.sso.esa.int/Quick_Guide_How_to_submit_a_Confirmation_or_Invoice_or_APR.pdf http://esa-p-help.sso.esa.int/Quick_Guide_How_to_approve_a_Confirmation_or_Invoice_or_APR.pdf.

3.2.3 Implementation of Payments conditions

The Contractor shall ensure that all APR, invoices and confirmations are submitted for payment exclusively through the Agency's esa-p system.

The Contractor undertakes to adhere strictly to the instructions contained in esa-p (including those for billing taxes and duties, where applicable) when submitting APR, invoices and confirmations through the esa-p system.

The Agency shall credit the account of the Contractor to the Contractor's benefit and to the benefit of the Contractor's Subcontractor(s).

The Contractor shall be responsible for approving or rejecting, within ten (10) calendar days of receipt, the relevant Subcontractor('s)(s') invoices and related supporting documents (e.g. MACs/GRNs, Cost Reports). The Contractor shall also be responsible for paying the accounts of its Subcontractor(s) for this Contract in accordance with the applicable law and normal commercial practices.

The Contractor shall indemnify the Agency against any claims arising from such Subcontractor(s), caused by the Contractor's failure to pay the Subcontractor(s). The Contractor shall supply to the Agency, upon request, evidence of the payment(s) made to its Subcontractor(s).

The Agency reserves the right to visit the Contractor's and/or Subcontractor('s)(s') premises and ascertain the progress of the work being performed under the Contract, prior to making the progress payment concerned.

The Contractor shall, upon request at any time by the Agency, submit the payment conditions/provisions of individual subcontracts to the Agency for approval (if requested before the subcontract is placed) or verification.

3.2.4 Absence of user account for esa-p

If the Contractor has no access to the Agency's esa-p system at the time of signature of the present Contract, an immediate request for an esa-p user account shall be made by the Contractor to the ESA Helpdesk (esait.Service.Desk@esa.int), specifying a contact name, the company name and the ESA Contract number.

3.2.5 In case of esa-p not being operative

Should the Contractor find the Agency's esa-p system technically inoperative at the moment of submission of the confirmation, the Contractor may submit the confirmation by email to the Agency's Technical Officer mentioned in ARTICLE 5, Clause 5, Sub-Clause 5.1 a) of the Contract. A template confirmation form can be obtained upon request to the ESA Helpdesk (esait.Service.Desk@esa.int).

3.2.6 Questions related to the esa-p system

Any questions concerning the operation of esa-p shall be addressed to the ESA Helpdesk (esait.Service.Desk@esa.int).

ARTICLE 4 MANAGEMENT AND CONTROL OF INVENTORY ITEMS/FIXED ASSETS UNDER THE CONTRACT

The following provisions apply to any items other than those items which fall within the scope of ARTICLE 2 of the Contract.
The Contractor shall specify, record, manage and control any and all customer items and ESA Fixed Assets under construction (reference is made to Article 3.1 above) that are subject to this Contract. Such items are:

(i) items produced or purchased under the Contract, including electronic components, special jigs, tools, test equipment, which are paid for under the Contract with an individual or batch value (value of group of items) in the national currency equivalent to or above Five Thousand (5,000) Euro;
(ii) if any, items identified as becoming ESA Fixed Assets in ARTICLE 3 above or in a subsequent Contract Change Notice (CCN);
(iii) if any, Customer Furnished Items (see ARTICLE 5, Clause 11 of the Contract) and/or Items Made Available by the Agency (see ARTICLE 5, Clause 12 of the Contract).

The Contractor shall operate an inventory control system ("Inventory Control System") of all the above-mentioned items and shall mark them as falling under this Article of the Contract.
The Inventory Control System shall:

- record the existence, location, operational status and condition of all inventory items, and
- record the value and estimated life duration of all inventory items, and
- record changes in inventory value, and
- enable financial reconciliation to be made and status reports to be prepared for incorporation of the relevant data into the Agency's annual financial accounts.

The Contractor shall, as part of the Inventory Control System, maintain an Inventory/Fixed Asset Record (in an electronic tool of its choice) which shall, as a minimum, contain the information as shown in APPENDIX 4 to this Contract.

The Inventory/Fixed Asset Record shall be kept updated by the Contractor. It shall be made available to the Agency upon request but as a minimum yearly during the execution of the Contract (and at completion of each Project Phase as per ECSS-M-ST-10 if applicable). A final consolidated record shall be submitted with the final contractual deliverables as foreseen in APPENDIX 4 to this Contract.

If the Inventory/Fixed Asset Record also includes any of those items which fall within the scope of ARTICLE 2 of the Contract, these items are to be clearly set apart.

Items, for which no place of delivery has been identified in ARTICLE 2 of this Contract, are subject to the following provisions:

Upon completion of the work specified in the Contract, the Agency shall take decisions regarding the final destination and final ownership of each item listed in the Inventory/Fixed Asset Record. The Agency shall be free to choose amongst the following options with respect to the final destination and final ownership of such items:

a) the right to claim delivery to the Agency and transfer of ownership (the latter if applicable) with issue of appropriate instructions concerning packing and shipment (at the Contractor's expense);
b) the right to claim or retain ownership and to negotiate with the Contractor a Loan Agreement if the Contractor is interested in keeping and using an item, with loan conditions making the Contractor responsible for the custody, the delayed delivery and the risks involved (at the Contractor's expenses);
c) the right to extend the custody of an item to the Contractor and to postpone its delivery to the Agency and the associated transfer of ownership – on conditions to be negotiated;
d) the renunciation of any rights to claim delivery and to claim transfer of ownership, leaving the item definitively in the possession and in the ownership of the Contractor, with or without financial compensation for the Agency (e.g. repurchase by the Contractor) and with or without special instruction,
e) the right to request the Contractor to dispose of an item on conditions to be negotiated.

Should the Agency decide to transfer an ESA Fixed Asset to a Third Party(ies) or to dispose of the Fixed Asset, the Contractor shall provide the full inventory information of the Fixed Asset to the Agency and complete the transfer or disposal forms to be provided by the Agency upon request by the Contractor. The information to be given by the Contractor in the forms shall be agreed with the Agency.

The decisions taken by the Agency shall lead to instructions or negotiations, as the case may be.

ARTICLE 5 COMPLEMENTS AND AMENDMENTS TO THE GCC

The General Clauses and Conditions for ESA Contracts, ref. ESA/REG/002., rev. 3 (GCC), apply to this Contract with the following complements and amendments:

PART I: CONDITIONS APPLICABLE TO ESA CONTRACTS

CLAUSE 2: APPROVAL AND ENTRY INTO FORCE

For the purpose of this Contract, the authorised representative of the Director General is Ms Simonetta Cheli, Director of Earth Observation Programmes.

CLAUSE 4: ORIGINALS OF THE CONTRACT

The following provision is added to Clause 4 of the GCC:
The Parties agree that electronic signature of this Contract shall have the same force and effect as hand-signed originals and shall be binding on both Parties to this Contract.

CLAUSE 5: THE PARTIES' REPRESENTATIVES

Sub-Clause 5.1: The Agency's Representatives

The Agency's representatives are:

a) Mr Stephen Plummer (EOP-SGS) for technical matters or a person duly authorised by him (the "Technical Officer").

All correspondence for technical matters shall be addressed as follows:

	To:	With copy to:
Name	[redacted]	
Telephone No.	[redacted]	
Email Address	[redacted]	[redacted]
Mail Address	ESA – ESRIN Largo Galileo Galilei 1 00044 Frascati Italy	

b) Ms Katrien Espagnet (CIC-COE) for contractual and administrative matters or a person duly authorised by them (the "Contracts Officer").

All correspondence for contractual and administrative matters (with the exception of invoices as mentioned in Article 3.2 above) shall be addressed as follows:

	To:	With copy to:
Name	[redacted]	
Telephone No.	[redacted]	
Email Address	[redacted]	[redacted]
Mail Address	ESA – ESRIN Largo Galileo Galilei 1 00044 Frascati Italy	

c) Personal Data Protection matters shall be addressed to the ESA Data Protection Officer at the following email address: dpo@esa.int

Sub-Clause 5.2: The Contractor's Representatives

The Contractor's representatives are

a) Mr Renne Tergujeff for technical matters or a person duly authorised by him (the "Technical Officer").

All correspondence for technical matters shall be addressed as follows:

	To:	With copy to:
Name	[redacted]	
Telephone No.	[redacted]	[redacted]
Email Address	[redacted]	[redacted]
Mail Address	PO BOX 1000, FI-02044 VTT, Finland	

b) Mr Jukka Kiviniemi for contractual and administrative matters or a person duly authorised by him (the "Contracts Officer").

All correspondence for contractual and administrative matters shall be addressed as follows:

	To:	With copy to:
Name	[redacted]	
Telephone No.	[redacted]	[redacted]
Email Address	[redacted]	[redacted]
Mail Address	PO BOX 1000, FI-02044 VTT, Finland	

c) Personal Data Protection matters shall be addressed to the Data Protection contact point as follows:

	To:
Name	[redacted]
Telephone No.	[redacted]
Email Address	[redacted]
Mail Address	PO BOX 1000, FI-02044 VTT, Finland

CLAUSE 6: PUBLICITY RELATING TO CONTRACTS

The link to the ESA logo in this clause is replaced with the following link: https://brand.esa.int/logo.

CLAUSE 8: GENERAL CONDITIONS OF EXECUTION

The following provision is added to Clause 8 of the GCC:

8.8 The Contractor shall, in accordance with the Agency's Policy on the Prevention, Detection and Investigation of Fraud, to the extent allowed by applicable national law, cooperate with the Agency's investigation team in any investigation of fraud initiated by the Agency and inform its personnel of their obligation to cooperate accordingly. The Contractor shall ensure that this provision is duly reflected in all subcontracts entered into for the purpose of this Contract.

CLAUSE 9: KEY PERSONNEL

9.1 The Contractor's Key Personnel is listed in the Contractor's Proposal referred to in Article 1.2 above.

9.2 The procedure described in this clause 9.2 shall be implemented through an exchange of letters. The letter may be sent electronically by email to the responsible Agency's representatives identified in sub-clause 5.2 hereabove. The comprehensive qualification description and professional profile of the new key personnel shall be included in the email, in an encrypted file.

CLAUSE 10: SUBCONTRACTS

Part of the work is to be subcontracted to the Subcontractor(s) listed in Article 3.1 above.

In relation to Article 3.2.3 above, the following provisions are added to Clause 10 of the GCC:

The Contractor shall ensure that provisions A) and B) hereunder are duly reflected in all subcontracts entered into for the purpose of this Contract. It is explicitly understood that the communication channel described below shall not replace the normal communication lines within the consortium nor the overall responsibility of the Contractor to ensure proper and timely placing of subcontracts and processing of payments throughout the consortium:

A. With a view to optimise Subcontractors' time to payment and financial coverage, and to facilitate, when needed, the resolution of such issues, the Agency has established a dedicated centralised email address.

Should any Subcontractor encounter serious difficulties in the process leading to:
(i) timely payment of due invoices (i.e. related to a milestone already achieved) to be made by the Subcontractor's direct customer (i.e. not ESA),
(ii) contractual coverage of activities already kicked-off, the said Subcontractor may directly contact the Agency at: indirectpayments@esa.int.

B. Any Subcontractor contacting the Agency through the above email shall document the steps already taken towards its direct customer in the consortium in order to resolve the issue and shall document that the Contractor has been informed of the issue.

In doing so, such Subcontractor shall attach the Standard Contact Form available at: https://esastar-publication.sso.esa.int/supportingDocumentation properly filled in or provide the same information in the body of the email.

In case any Subcontractor has SME status, as per the definition of SMEs given by the European Commission: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32003H0361&from=EN,
the Contractor shall ensure that the relevant subcontract foresees an automatic grant of a 35% Advance Payment.

The Contractor shall have the responsibility of obtaining the self-certification of the Subcontractor('s)(s') SME status as per certification model provided in the tender documentation.

CLAUSE 11: CUSTOMER FURNISHED ITEMS (CFI)

It is not foreseen that the Agency will provide any Items in accordance with Clause 11 of the GCC to the Contractor.

CLAUSE 12: ITEMS MADE AVAILABLE BY THE AGENCY

It is not foreseen that the Agency will make any Items available to the Contractor in accordance with Clause 12 of the GCC.

CLAUSE 13: CHANGES

The following provisions are added to Sub-Clause 13.4.1:

Only changes agreed in accordance with this procedure are deemed valid changes of the Contract.

Any changes that may impact the contractual baseline shall be implemented through a CCN.
Specifically, the Contractor shall always submit a CCN proposal for the changes in the non-exhaustive list below:

- cancellation or changes to any work package included in the contractual baseline;
- subcontractors' replacements or ceasing their involvement in the activity;
- changes in the breakdown of the Contract price between the Prime and the Subcontractor(s).

The template of a Contract Change Notice (CCN) is attached hereto as APPENDIX 3.

Any Change Request submitted to the Agency shall be addressed to the Agency's Contracts Officer.

CLAUSE 14: TIME-LIMITS FOR THE PROVISION OF DELIVERABLES AND SERVICES
The Contractor may mark the deliverables documents with the following:

"© [COMPANY NAME] [YEAR OF PUBLICATION]
The copyright in this document is vested in [COMPANY NAME].

This document may only be reproduced in whole or in part, or stored in a retrieval system, or transmitted in any form, or by any means electronic, mechanical, photocopying or otherwise, either with the prior permission of [COMPANY NAME] or in accordance with the terms of ESA Contract No. 4000xxxxxx/XX/XX/xx."

CLAUSE 15: HANDLING, PACKING AND TRANSPORT, TRANSFER OF OWNERSHIP AND RISK

The following provision is added as Sub-Clause 15.3.6 of the GCC:

Should in the execution of the Contract a need arise to provide the Agency with information which is subject to export control laws and regulations, the Contractor shall secure that such information is only passed on to the Agency in accordance with the provisions of such export control laws and regulations.

CLAUSE 17: PENALTIES/INCENTIVES

Penalties for late delivery do not apply, and similarly they will not apply in the subcontract(s) that may be placed by the Contractor.

CLAUSE 27: PRICING

Sub-Clauses 27.3 and 27.4 do not apply, unless in case of termination as per Clause 30 of the GCC.

CLAUSE 34: APPLICABLE LAW

The substantive law referred to in Clause 34 of the GCC is the law of Finland. The scope of its applicability is as laid down in the said Clause of the GCC.

CLAUSE 35: DISPUTE RESOLUTION
The arbitration proceedings referred to in Clause 35 of the GCC shall take place in Helsinki, Finland.

PART II: CONDITIONS CONCERNING INTELLECTUAL PROPERTY RIGHTS FOR ESA STUDY, RESEARCH AND DEVELOPMENT CONTRACTS
For the purpose of this Contract:

- Part II, Option A of the GCC shall apply, as modified by the special provisions below.

- The free licences provided for the benefit of ESA in the present Contract and in Part II of the GCC shall be deemed granted through signature of the present Contract and without the need to implement a separate licence.

The following provisions are added:

CLAUSE 36: GENERAL

The following provision is added to Sub-Clause 36.2 of the GCC:

The term "documentation" as defined in Annex IV to the GCC shall be interpreted to also include data files, CAD files, EXCEL® files and similar electronic files, which shall not be considered as "software" in the sense of Clause 42 of the GCC.

The electronic files containing these items shall be delivered to the Agency in the format agreed with the ESA Technical Officer specified in ARTICLE 5, Clause 5, Sub-Clause 5.1 a) of the Contract.

CLAUSE 37: INFORMATION TO BE PROVIDED

The following provision is added to Sub-Clause 37.2 of the GCC:

The Contractor shall not mark any documents as “Proprietary Information” unless agreed in advance with the Agency. Any request from the Contractor shall be submitted accompanied by an appropriate justification.

ACCESS TO INFORMATION

The following provisions are added to Sub-Clause 37.4 of the GCC:

a) The Agency shall have the right to disclose, at any time including throughout the duration of this Contract, the technical part of the Contractor’s Proposal and any information generated in the frame of this Contract, to any Contractor/Subcontractor(s) performing work for the Agency in the context of the DTE Programme Element.

b) If approved by the Member/Participating States, the Agency’s right of dissemination is also extended to non-Member States and to individuals, companies, bodies or organisations residing in non-Member States, collaborating or participating in official activities or programmes of the Agency, provided that the information concerned is exclusively used for the purpose of the said activities or programmes, namely the DTE Programme Element.

CLAUSE 38: DISCLOSURE

The following provision is added to Sub-Clause 38.2 of the GCC:

The access rights granted to the Agency’s employees under Sub-Clause 38.2 of the GCC are hereby extended to contractor personnel providing technical, management, legal or administrative support to ESA as long as they have signed an engagement of confidentiality.

CLAUSE 43: BACKGROUND INTELLECTUAL PROPERTY RIGHTS

In pursuance of the requirements of Sub-Clause 43.1 of the GCC, the following is recorded:

The Agency, on the basis of evidence provided by the Contractor, recognises the following information, expected to be provided by the Contractor, as Background Intellectual Property:

Exact name of BIPR Item	**Owner**	**Description**	**Patent # or Ref./Issue/ Revision/ Version # (*)**	**Contract/ Funding Details under which the IPR was created (**)**	**Date of creation of the version of the BIPR listed here**	**Type of Licence (Third Party IP) (***)**	**Affected deliverable with comments (****)**	**Protected Format (Y/N) (*****)**
Normalized digital surface model for Czechia	Forest Management Institute (CZ)	NDSM for use case Czechia, for tree height estimation, biomass estimation, validation purposes	Not applicable.	Not applicable.	Not applicable	Third Party	No deliverable affected. Not to be included in DEDL and shared outside this project.	Not applicable

The Contractor shall include the Background Intellectual Property and shall mark them conspicuously as ‘Background Intellectual Property – Proprietary Information’. ESA shall protect those deliverables under Clause 38 of the GCC. All other deliverables shall not contain any Proprietary Background Information, shall not be marked ‘Proprietary Information’, and shall not fall under the protection of Clause 38 GCC.

a) Notwithstanding the above, the following is agreed:

- If the Contractor, after the signature of the Contract, invokes the existence of any additional Background Intellectual Property to be used for the purposes of the present Contract, the Contractor shall provide conclusive evidence to the Agency of the existence of this Background Intellectual Property and shall justify the reasons for which the existence of this Background Intellectual Property was not invoked before the Contract signature.
- If conclusive evidence and appropriate justification are provided by the Contractor for such additional Background Intellectual Property, the Parties shall formalise a Contract Change Notice to specify in detail which Information has been recognised as Background Intellectual Property.
- Conversely, if such evidence and justification are not provided, such additional information shall be deemed as having been generated in the frame of the Contract.

b) If, by the end of the Contract, the Contractor has not identified the effective use of Background Intellectual Property Rights, all Intellectual Property Rights used during the execution of the Contract shall be deemed as arising from work performed under the Contract, unless and until the Contractor provides the Agency with evidence of the relevant use of Background Intellectual Property Rights.

Sub-Clauses 43.4 and 43.7:

For the purpose of Sub-Clauses 43.4 and 43.7 of the GCC, the term “Agency Project” shall refer to all present and future activities in the context of the DTE Project.

Electronically signed by the Parties to this Contract,

On:	On: .....
For VTT	For the European Space Agency (ESA)
----------	----------
Erja Turunen	Simonetta Cheli
Executive Vice President	Director of Earth Observation Programmes

Annex - Personal Data Processing (the "PDP") of the European Space Agency ("ESA" or the "Agency")

This "Personal Data Processing" Annex governs:

1) the processing of the Personal Data identified in Article 3.1, entrusted to the Contractor under the Contract, whereby the Contractor acts as Data Processor on behalf of the Agency and the Agency acts as Data Controller;
2) the processing of the Personal Data identified in Article 3.2, exchanged by the Parties, acting as separate Controllers.

Such Annex forms an integral part of the Contract. In case of conflict between the terms and conditions of the Contract and the terms and conditions of this Annex, the terms and conditions of this Annex shall prevail.
This Annex survives the expiration or termination of the Contract for as long as the Personal Data are protected by the Data Privacy Regulations.

1. DEFINITIONS

The following specific definitions apply:

(i) "Agreed Territory" (of Processing) means:
- a) ESA Member States, as they are listed in the ESA website at URL: https://www.esa.int/About_Us/Corporate_news/Member_States_Cooperating_States
- b) European Union;
- c) countries recognized by the European Commission as ensuring an Adequate Level of Protection of Personal Data under the European Union's legal framework.

(ii) "Data Privacy Regulations" means respectively:
- a) ESA PDP Framework, i.e. the Personal Data Protection Framework applicable to ESA and available on ESA website at URL: http://www.esa.int/About_Us/Law_at_ESA/Highlights_of_ESA_rules_and_regulations
- b) the Personal Data protection laws and regulations applicable to the Contractor in the Agreed Territory of Processing which provide an Adequate Level of Protection under the ESA PDP Framework (e.g. EU Regulations in the field of personal data protection, including but not limited to the General Data Protection Regulation (Regulation (EU) nr. 2016/679) (hereinafter "GDPR").

(iii) "Personnel" means:
- a) with respect to the Contractor: any employee, agent or representative acting under the responsibility of the Contractor or, if subcontracting is permitted, of Contractor's subcontractors;
- b) with respect to ESA: any employee, agent or representative acting under the responsibility of ESA (e.g. staff members and seconded agents, consultants experts or employees of third parties).

With respect to terms used with capitals in this Annex (e.g. "Controller", "Personal Data" etc.) but not defined above, reference is made to the definitions set forth in the Data Privacy Regulations applicable according to Article 2 below.

2. GENERAL

2.1 Each Party is responsible for complying with the level of protection resulting from its Data Privacy Regulations in relation to Personal Data, being recognised that:
- a) the Contractor is governed by the Personal Data protection laws and regulations applicable to the Contractor in the Agreed Territory of Processing, which provide an Adequate Level of Protection under the ESA PDP Framework (e.g. EU Regulations in the field of personal data protection, including but not limited to the GDPR.
- b) ESA is governed by PDP Framework, i.e. the Personal Data Protection Framework applicable to ESA and available on ESA website at the URL: http://www.esa.int/About_Us/Law_at_ESA/Highlights_of_ESA_rules_and_regulations

2.2 With respect to the processing of the Personal Data identified in Article 3.1 below, entrusted to the Contractor as part of the work under the Contract, the Contractor acts as Data Processor on behalf of the Agency, who acts as Data controller.

2.3 With respect to the processing of the Personal Data identified in Article 3.2 below, the Parties are considered separate Data Controllers, with each Party being able to determine the purpose within the boundaries of Article 2.4 and the means of Processing the Personal Data under its control in accordance with its privacy statement.

2.4 The Personal Data will be processed only for:
- a) the performance of the Contract, including the execution, management, monitoring of the work as well as audits and the fulfilment of the obligations set out in this Annex;
- b) the management of the relationship of the Parties in relation to the Contract, notably for administrative, financial, audit or for communication purposes;
- c) the compliance with any legal or regulatory obligation to which a Party is subject;
- d) the compliance, in case the performance of the Contract requires access to the Parties' premises, with the health, safety and security requirements, legal or regulatory obligations applicable to the respective Party in such matters.

3. PERSONAL DATA

3.1 The Personal Data to be processed by the Data Processor during the execution of the work under the Contract are identified in the Statement of Work.

3.2 The Personal Data exchanged by the Parties for the performance of the Contract are as follows:
- a) the Agency shall communicate to the Contractor only the Personal Data concerning ESA representatives/contact persons including name,

work address, email and telephone numbers;

b) the Contractor shall communicate to the Agency only:
   (i) Personal Data concerning the Supplier's representatives/contact persons including name, work address, email and telephone numbers;
   (ii) Personal Data concerning the Supplier's key Personnel, including title, name, work address, email, telephone numbers, education, professional experience, description of the person's job and responsibilities and the precise assignment of the person to the activity under the Purchase Order.
   (iii) Sensitive Personal Data concerning the Contractor's Personnel, performing work on-site ESA premises or having the need to access information provided by the Agency which is subject to security restrictions.

4. PARTY'S OBLIGATIONS

4.1 **When acting as Data Controller**, each Party is individually and separately responsible for complying with the level of protection resulting from its Data Privacy Regulations in relation to Personal Data, including the collection and update of the Personal Data that it communicates to the other Party, the lawfulness and the quality of such Personal Data and for the means by which they were collected. Should the legal basis for the collection of the Personal Data cease to exist or the quality of the Personal Data be affected, the Party will inform the other Party without undue delay.

The Parties shall preserve the rights and legal remedies of the Data Subject as recognised and protected in the Data Privacy Regulations applicable respectively to each Party. In particular, the Data Controller which disclosed the Personal Data to the other Party will respond to enquiries from Data Subjects and, as the case may be, from any competent authority concerning the data processing of the relevant Personal Data.

In case the Parties engage Processors to support their internal operations, including the Processing of the Personal Data exchanged, it is the responsibility of that Party to ensure that its Processors assume obligations consistent with the Data Privacy Regulations applicable to the respective Party, in order to guarantee an adequate level of protection of Personal Data.

4.2 **When acting as Data Processor**, such Party shall:

a) process the Personal Data:
   - in compliance with this PDP Annex and, generally, with the level of protection resulting from the Data Privacy Regulations then in force;
   - solely for the purpose and the instructions defined by the Data Controller;
   - solely in the Agreed Territory;
   - without exceeding the retention period;
   - in such a way as to minimize, by means of suitable preventive security measures, the risk of accidental or unlawful destruction, loss, alteration, unauthorized disclosure or access, or Processing operations that are either unlawful or inconsistent with the purpose.

b) promptly investigate any reasonable suspicion of Personal Data Breach and act in accordance with Article 11 below.

c) cooperate with the Data Controller to enable the latter to guarantee to every Data Subject or his/her delegates the possibility to exercise the rights granted to him/her by the Data Privacy Regulations. The Data Processor acknowledges that Data Subject rights shall be exercised through the Data Controller. Therefore, the Data Processor undertakes to immediately notify the Data Controller of any request that Data Subjects address directly to the Data Processor, and will not respond to any such request or take any other related action, until authorized by the Data Controller.

d) Immediately inform the Data Controller if, in its opinion, an instruction from the Data Controller infringes any provision on the Processing of Personal Data under the present Annex.

5. DATA RETENTION

5.1. The Parties shall not retain or process the Personal Data exchanged longer than is necessary to carry out the purpose described in Article 2.4 herein, unless required otherwise:

a) under the Data Privacy Regulations, (e.g. in the frame of audits, inspections and incidents) or
b) under the Party's statutory obligations.

5.2. The retention period shall be defined in the privacy notices of the Parties.

5.3. All Personal Data must be, effectively destroyed/deleted upon expiration of the retention period, unless conservation of such data is required for compliance with any legal or regulatory obligation to which the Party having received the Personal Data from the other Party is subject.

6. CONFIDENTIALITY

The Parties shall ensure the confidentiality of the Personal Data processed by protecting them against unauthorized or unlawful access, acquisition, use and disclosure, in particular by:

a) limiting access to the Personal Data of the other Party only to their Personnel, that:
   - are required or authorized to access such Personal Data;
   - have committed themselves to confidentiality or are under a statutory obligation of confidentiality;
   - have received the appropriate Personal Data protection training.

b) taking into consideration, in terms of IT tools, product, applications, the principles of personal data protection by design and by default.

7. SECURITY

The Parties shall adopt appropriate technical and organisational security measures, giving due regard to the risks inherent in the Processing and to the nature, scope, context and purpose of the Processing, in order to ensure the following as appropriate:

a) the on-going confidentiality, integrity, availability and resilience of Processing systems and services;
b) measures to protect Personal Data from accidental, unlawful or unauthorized access, use, destruction, loss, modification or transfer.

8. DATA PROTECTION OFFICER/CONTACT POINT

For any Personal Data protection matters, the Parties shall involve their specific contact points identified in the Contract.

9. TRANSFER

The Party having received the other Party's Personal Data under the Contract shall Process (and have processed by its authorised subcontractors or sub-processors) such Personal Data only in the Agreed Territory of Processing. In case the Parties agreed otherwise, transfer of Personal Data outside the Agreed Territory shall only take place in accordance with Article 13 below.

10. SUBCONTRACTORS

10.1 The Contractor is authorised to disclose Personal Data received from the Agency to its Subcontractors provided that:

a) subcontracting is specifically authorised by Contract and the Subcontractors are indicated in the Contract;
b) all the conditions set forth in this Annex are flown down and fulfilled by the Sub-contractors in their respective area of responsibility; in particular the Processing of the Personal Data by the Subcontractors is performed for the purpose described in Article 2.4 herein and the Personal Data are not transferred outside the Agreed Territory.

10.2 Disclosure of the Agency's Personal Data to other third Parties requires prior approval of the Agency.

11. PERSONAL DATA BREACHES

11.1 After becoming aware of a Personal Data Protection Breach falling in its area of responsibility, and affecting the Personal Data communicated by the other Party, the Party shall notify the other Party within 48 hours.

11.2 The Parties will provide each other reasonable assistance to facilitate the handling of the Personal Data Breach and accurate information about the breach, in particular (but not only) in case a complaint is, or likely to be, lodged by a Data Subject in relation to the Breach.

12. LAW DISPUTE RESOLUTION

Concerning Personal Data protection matters, notwithstanding any other provisions on the governing law set forth elsewhere in the Contract, the provisions set forth in the Data Privacy Regulations, as defined herein, will apply as mentioned in Article 2 herein and will prevail in case of conflict. Without prejudice to the foregoing, disputes between the Parties on Personal Data protection matters shall be settled in accordance with Article 1.3.3 of the Contract.

13. EU STANDARD CONTRACTUAL CLAUSES

13.1. Under the ESA Personal Data Protection Framework, the transfer of Personal Data towards a country not recognized as offering an Adequate Level of Protection may only be done after being authorised by the ESA Data Protection Officer (DPO) and subject to "adequate safeguards with respect to the protection of the Personal Data and data subject's rights".

13.2. As "adequate safeguards", the Parties agreed to adopt the level of protection resulting from the provisions of the EU Standard Contractual Clauses for the Transfer of Personal Data to Third Countries pursuant to Regulation (EU) 2016/679, in their latest version released / approved by the European Commission (hereinafter "EU SCC"), which shall be deemed included, by reference, in the Contract, together with the Annexes of EU SCC filled in as appropriate, subject always to the prevailing principles applicable in relation to ESA:

a) the provisions of EU SCC will apply mutatis mutandis, only to the extent compatible with the specific statute of ESA as international intergovernmental organisation and always subject to the application of ESA Convention, in particular its Annex I "Privileges and immunities" and its legal framework, including by PDP Framework available at http://www.esa.int/About_Us/Law_at_ESA/Highlights_of_ESA_rules_and_regulations which shall prevail in particular in case of conflict, ambiguity or inconsistency;
b) any provision of the EU SCC referring a dispute to a national court or another national or international forum is deemed not applicable, given that the Parties agree that:
   (i) any Personal Data-related incidents or disputes shall be submitted to the independent Data Protection Supervisory Authority established by ESA Council Resolution, in which case the Rules of Procedure for the Data Protection Supervisory Authority, as set forth ESA PDP Framework, shall apply;
   (ii) any other matter giving rise to a dispute shall be referred to arbitration as per Article 1.3.3 of the Contract.
c) such transfer shall only take place after obtaining the written authorisation by the ESA Data Protection Officer (DPO) in consideration of the :
   (i) annexes of the EU SCC, added to the Contract in particular:
   - Annex I.A [List of Parties : data exporter/data importer]

- Annex I.B [Description of the transfer(s)]
- Annex I.C [Competent Supervisory Authority]
- Annex II [Technical and organisational measures, including Technical and Organisational Measures to Ensure the Security].
- Annex III [List of Sub-processors]

(ii) the following selected module(s) provided by the EU SCC, which are contractually agreed to by the Parties are applicable:

(to be selected as appropriate)
Module One of the EU SCC: Transfer Controller to Controller
Module Two of the EU SCC: Transfer Controller to Processor

APPENDIX 1
PAYMENT PLAN AND ADVANCE PAYMENT(S) AND OTHER FINANCIAL CONDITIONS

Milestone (MS) Description	Schedule Date	Payments from ESA to Prime Contractor (in Euro)	Country (ISO code)
Progress (MS 1): Upon successful completion of Tasks and successful acceptance of the deliverable items: Requirement Baseline Document, ver. 1 Design and Technical Specifications Document, ver. 1 Research and Development Report, ver. 1 Integration and Implementation Report (plan) Validation Report (plan) Progress Reports	1 February 2025	196,600	FI
Progress (MS 2): Upon successful completion of Tasks and successful acceptance of the following deliverable items: Requirement Baseline Document, draft ver. 2 Design and Technical Specifications Document, draft ver. 2 Research and Development Report, draft ver. 2 Integration and Implementation Report, draft ver. 1 Validation Report, draft ver. 1 Impact Assessment Report, draft ver. 1 Dissemination and Outreach Summary report, draft ver. 1 Scientific and Technical Roadmap, draft ver. 1 Coordination and Synergy Report, draft ver. 1 Progress Reports	1 May 2025	196,600	
Progress (MS 3): Upon successful completion of Tasks, including prototype demonstration, and successful acceptance of the following deliverable items: Requirement Baseline Document, ver. 2 Design and Technical Specifications Document, ver. 2 Research and Development Report, ver. 2 Integration and Implementation Report, ver. 1 Validation Report, ver. 1 Impact Assessment Report, ver. 1 Dissemination and Outreach Summary report, ver. 1 Scientific and Technical Roadmap, ver. 1 Coordination and Synergy Report, ver. 1 MidTerm review Report Progress Reports	1 November 2025	356,800	
Progress (MS 4): Upon successful completion of Tasks and successful acceptance of all related deliverable items. Requirement Baseline Document, draft ver. 3 Design and Technical Specifications Document, draft ver. 3 Research and Development Report, draft ver. 3 Integration and Implementation Report, draft ver. 2 Validation Report, draft ver. 2 Impact Assessment Report, draft ver. 2 Dissemination and Outreach Summary report, draft ver. 2 Scientific and Technical Roadmap, draft ver. 2 Coordination and Synergy Report, draft ver. 2 Progress Reports	1 May 2026	393,200	

Milestone (MS) Description	Schedule Date	Payments from ESA to Prime Contractor (in Euro)	Country (ISO code)
Final Settlement (MS 5): Upon the Agency's acceptance of all deliverable items due under the Contract and the Contractor's fulfilment of all other contractual obligations including submission of the signed Final Report and pre-operational demonstration	1 November 2026	356,800	
TOTAL CONTRACT		**1,500,000**	

Advance Payment(s) and other Financial Conditions:

Prime (P)	Company Name	ESA Entity Code	Country (ISO code)	Advance Payment (in Euro)	Offset against[3]	Offset by Euro	Condition for release of the Advance Payment
P	VTT Technical Research Centre of Finland, Ltd.	1000001603	FI	476,650	MS 4	317,767	Upon signature of the Contract by both Parties
					MS 5	158,883	

[3] An SME has the right to request offset of the 35% advance at the end of the Contract, i.e. the two last milestones (ideally 25% at the last milestone and 10% at the preceding milestone), if this can be justified in view of the economic progress in the Contract.

For information purposes only, distribution by the Prime Contractor of ESA's Advance Payments between the Prime Contractor and the Subcontractor(s):

For information purposes only: Amounts in Euro for Contractor and Subcontractor(s)							
Prime (P) or (SI)	**Company Name**	**ESA Entity Code**	**Country (ISO code)**	**Advance Payment (in Euro)**	**Offset against**[4]	**Offset by Euro**	**Condition for release of the Advance Payment**
P	VTT Technical Research Centre of Finland, Ltd.	1000001603	FI	196,458	MS 4	130,972	Upon signature of the Contract by both Parties
					MS 5	65,486	
SI	Yucatrote Ltd	1000037600	PT	71,750	MS 4	47,833	Upon signature of the Contract by both Parties
					MS 5	23,917	
SI	Terramonitor Ltd	1000026282	FI	114,800	MS 4	76,533	Upon signature of the Contract by both Parties
					MS 5	38,267	
SI	Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences	1000001618	DE	38,400	MS 4	25,600	Upon signature of the Contract by both Parties
					MS 5	12,800	
SI	Global Change Research Institute CAS	1000002611	CZ	30,000	MS 4	20,000	Upon signature of the Contract by both Parties
					MS 5	10,000	
SI	Forest Science and Technology Centre of Catalonia	1000036105	ES	25,242	MS 4	16,828	Upon signature of the Contract by both Parties
					MS 5	8,414	

[4] An SME has the right to request offset of the 35% advance at the end of the Contract, i.e. the two last milestones (ideally 25% at the last milestone and 10% at the preceding milestone), if this can be justified in view of the economic progress in the Contract.

APPENDIX 2

STATEMENT OF WORK

ESA ESRIN
Largo Galileo Galilei 1
00044 Frascati
Italy

SOW - STATEMENT OF WORK

ESA-DTE-B-01-LEAD DTCS DEVELOPMENT ACTIONS AND ESA-DTE-B-02 EARLY DTCS DEVELOPMENT ACTIONS

Document Type	SOW - Statement of Work
Reference	ESA-EOP-SG-SOW-0508
Issue/Revision	1 . 0
Date of Issue	25/01/2024
Status	Final

TABLE OF CONTENT

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1 INTRODUCTION

1.1 Overview

This document describes the activities to be executed and the deliverables required by the European Space Agency (ESA) in relation to the activity ESA EO-based Digital Twin Components (DTCs) ITT under the ESA Earthwatch programme – ESA Digital Twin Earth (DTE) Programme Element.

This document will be part of the Contract and shall serve as an Applicable Document throughout the execution of the work.

This ITT includes two distinct types of activities (Development Actions):

1. **Lead DTCs Development Actions**: aimed at developing and demonstrating, in a pre-operational environment, a set of EO-based Digital Twin Components addressing 8 priority Themes (see Appendix A). Each project will deliver an independent thematic pre-operational end-to-end system implementation, validation and demonstration.

As a result of this ITT ESA expect to start **up to 8 different contracts (Lead DTC Development Actions) of a maximum price of 1.5MEuro each and of 24 months duration addressing one of the 8 primary thematic priorities described in Appendix A.**

Tenderers can bid for more than one Theme but always through independent proposals. Tenders received will be evaluated per Theme. The competition for each individual Theme will be independent of each other. Consequently, **each Tender shall be self-standing and exclusively dedicated to one Theme.** Tenderers shall create a separate Bidder Restricted Area and submit a separate, self-contained proposal for each Theme they wish to address.

Proposals may address aspects related to other Themes related to the main one selected. In fact, it is expected that synergies and complementariness exist across the different Themes. These synergies and complementarities shall be addressed by the Contractor through dedicated Tasks as described in Section 4. However, the core of the proposal shall address the specific scientific and operational needs and goals associated to the selected Theme (see Appendix A).

ESA plans to place one contract for each of the Themes. However, only proposals with an overall weighted mark of 60 (Good) or above may be recommended by the evaluation board. Therefore, ESA reserves the right to award more than one contract for a given Theme in case all offers for a given Theme have a weighted score below 60 (Good), and more than one very good (marking of 75 or higher) quality proposal exists for another Theme.

2. **Early DTCs Development Actions**: focused on secondary Themes (see Appendix A) aimed at advancing their maturity and readiness levels, engage stakeholders in the development process and implement a feasibility study and prototype and demonstration.

As a result of this ITT ESA expect to start **up to 6 different contracts (Early DTC Development Actions) of a maximum price of 0.5MEuro each and 12 months duration addressing secondary thematic priorities described in Appendix A**

Tenderers can bid for more than one Theme but always through independent proposals. Only proposals with an overall weighted mark of 60 (Good) or above may be recommended by the evaluation board. ESA will evaluate the received proposals per theme and **select the 6 highest ranked proposals so**

that one contract per Theme will be placed. This means that the Agency might place a contract with the top ranked proposal in a particular Theme even if such proposal is ranked lower than another proposal from another Theme.

Tenders received for **Early Development Actions** will be evaluated per Theme. The competition for each individual Theme will be independent of each other. Consequently, **each Tender shall be self-standing and exclusively dedicated to one Theme.** Tenderers shall create a separate Bidder Restricted Area and submit a separate, self-contained proposal for each Theme they wish to address.

ESA reserves the right to award more than one contract per Theme in case offers for some of the Themes are marked below 60 (Good) and more than one very good (marking of 75 or higher) quality proposal exists for another Theme.

1.2 Applicable and Reference Documents

RD1: https://destination-earth.eu/
RD2: https://esastar-publication-ext.sso.esa.int/ESATenderActions/details/50529DPNR
RD3: https://github.com/SercoSPA/DESP-Documentation
RD4: https://destination-earth.eu/wp-content/uploads/2023/07/DESP-For-DEUC-Webinar_final.pdf
RD5: https://destination-earth.eu/wp-content/uploads/2023/06/DESP-YOUR-GATEWAY-TO-THE-DESTINATION-EARTH-INITIATIVE.pdf
RD6: https://esastar-publication-ext.sso.esa.int/ESATenderActions/details/53289
RD7: https://www.ovhcloud.com/en-ie/public-cloud/prices/
RD8: https://www.esa.int/Applications/Observing_the_Earth/FutureEO/Boosting_Earth_science

1.3 Acronyms and Abbreviations

AAS:	Advanced Applications and Services
AI:	Artificial Intelligence
DEDL:	DestinE Data Lake
DESP:	DestinE Core Service Platform
DestinE:	Destination Earth
DT:	Digital Twin
DTC:	Digital Twin Component
DTE:	Digital Twin Earth
DTO:	Digital Twin of the Ocean
EC:	European Commission
ECMWF:	European Centre for Medium-Range Weather Forecasts
EO:	Earth Observation
EoI:	Expression of Interest
ESA:	European Space Agency
EUMETSAT:	European Organisation for the Exploitation of Meteorological Satellites
HPC:	High Performance Computing
ICT:	Information and Communication Technology
ITT:	Invitation To Tender
ML:	Machine Learning
MS:	Member States

SoW: Statement of Work
TPM: Third Party Mission

2 BACKGROUND

Climate change represents one of the most urgent challenges facing society at the onset of this century. The impacts of climate change on the Earth system and society, including rising sea levels, increasing ocean acidification, more frequent and intense extreme events such as floods, heat waves and droughts, are expected not only to have a significant impact across different economic sectors and natural ecosystems, but also to endanger human lives and property, especially for most vulnerable populations. In addition, population growth is expected to amplify current pressures on critical resources such as freshwater and food, intensify the stress on land and marine ecosystems, and increase environmental pollution, impacting health and biodiversity.

Responding to these challenges requires a quantum leap in the way we observe, understand and predict the dynamic evolution of the Earth system and its complex interaction with human activities and ecosystems. Digital Twins (DTs) have recently emerged as a ground-breaking solution to these needs. Based on an effective integration of heterogeneous data, advanced models, AI, digital data services and high-performance computing capabilities, Digital Twins shall offer high-precision digital replicas of Earth system components, boosting our capacity to understand the past and monitor the present state of the planet, assess changes, and simulate the potential evolution under different (what-if) scenarios at scales compatible with decision making.

The European Commission (DG CONNECT) launched “Destination Earth (DestinE)” [RD1] to address this challenging and ambitious goal. Since December 2021, the DestinE Programme has been jointly implemented by ESA, ECMWF, and EUMETSAT with progressive development of the core service platform, data lake and first digital twins on climate change adaptation and weather-induced extremes. DestinE plans to advance towards a full digital replica of the Earth in 2030 by gradually integrating additional DTs in subsequent phases of the programme. In addition, several other Digital Twin initiatives have been launched at international (e.g., WCRP Digital Earths, NASA DT activities), European (e.g., Digital Twin of the Ocean, Horizon Europe projects) and national levels.

The new ESA Digital Twin Earth (ESA DTE) element aims at contributing to this process by ensuring that the latest Earth Observation (EO) satellite capabilities may play a major role in the design and implementation of future operational Digital Twins ecosystems, including the potential future evolution of DestinE and other operational DT initiatives in Europe.

2.1 Destination Earth (DestinE)

DestinE is a flagship initiative of the European Commission to develop a highly accurate digital model of the Earth (a digital twin of the Earth) to model, monitor and simulate natural phenomena, hazards and related human activities. These groundbreaking features assist users in designing accurate and actionable adaptation strategies and mitigation measures.

DestinE unlocks the potential of digital modelling of the Earth system at a level that represents a real breakthrough in terms of accuracy, local detail, speed of access to information and interactivity.

By pushing the limits of computing and climate sciences, DestinE is an essential pillar of the European Commission’s efforts towards the Green Deal and Digital Strategy.

DestinE will allow users to access thematic information, services, models, scenarios, simulations, forecast and visualization.
The main components of the DestinE system are:

- DestinE Core Service Platform (DESP): A user-friendly platform that provides users with evidence-based policy and decision-making tools, applications, and services, based on an open, flexible, scalable, and evolvable secure cloud-based architecture. This service is implemented by ESA.
- DestinE Data Lake (DEDL): A space fulfilling the storage and access requirements for any data that is offered to DestinE users. It provides DESP users with a harmonized access to datasets, regardless of data type and location, as well as with near-data processing capabilities. This service is implemented by EUMETSAT.
- DestinE Digital Twins (DT) and Digital Twin Engine (DTE): ECMWF is implementing the Digital Twin Engine, the complex software and data services needed for Earth System digital replicas, as well as the first two digital twins; Climate Change Adaptation, which will provide multidecadal simulations, and the Weather-induced Extremes twin, with both high-resolution forecasts and on-demand simulations. An engine capable of providing a common system approach to a unified orchestration of Earth-system simulations, delivering data from digital replicas of the Earth through the fusion of observations with models.

The first phase of delivery (Dec 2021-June 2024) covered the preparation, piloting and implementation of all main components of the DestinE system, including the first two Earth-system Digital Twins, Digital Twin Engine, Data Lake and Core Service Platform. In June 2024, DestinE will enter its second phase, which will evolve the DestinE system and ramp-up operations, with a focus on consolidation, maintenance, and continuous evolution of the components of the DestinE system. DestinE is expected to evolve in subsequent phases of the initiative by creating several digital replicas covering different aspects of the Earth system and based on state-of-the-art observations and simulations.

For more information on DestinE, please, visit the DestinE website at: https://destination-earth.eu/

ESA has selected the open DestinE core Service Platform (DESP) to host the ESA DTE activities including the development, implementation, and demonstration of the DTCs benefitting from the functionalities of the DestinE platform and ecosystem and those of Copernicus and ESA FutureEO.

The DESP is under development at the time of this ITT and will gradually enter into operation during 2024. **Appendix B provides a description of the services and capabilities that the DESP will offer and the assumptions to be made to prepare and implement the activities to be undertaken under this ITT though the ESA DTE Element.**

2.2 The ESA Digital Twin Earth Element

Latest advances in EO-based science and R&D activities are opening the door to a new generation of EO data products, novel applications and scientific breakthroughs offering a novel, advanced and holistic view of the Earth system, its processes, and its interactions with human activities and ecosystems. These emerging capabilities offer unique opportunities for an enhanced and extensive use of EO technology in the development of digital twins.

In particular, those EO developments together with new advances in sectorial modelling, computing capabilities, Artificial Intelligence (AI) and digital technologies offer excellent building blocks to realise novel EO-based Digital Twin Components (EO DTCs) that may contribute and maximise the impact of

EO satellite technology in the design and implementation of future operational Digital Twins: through DestinE or other operational European or national Digital Twin initiatives.

With the new ESA DTE Element, ESA aims at supporting ESA Member States (MSs) to create the conditions for a strong uptake of novel EO capabilities in the future design and implementation of future operational digital twins ecosystems (through DestinE or other operational initiatives).

The ESA DTE programme aims developing and demonstrating, at to a pre-operational stage, a set of EO-based DTCs as advanced replicas of key components of the Earth system and their interactions with human activities and ecosystems, designed to serve a wide variety of users and with a strong focus on valorising the role of EO capabilities.

To achieve these goals, the ESA DTE programme element will be articulated across two main pillars:

- **Implementing an ESA EO Data Space** (ESA DTE Framework) supporting DTCs developments and offering the relevant ESA ecosystem of Earth Observation data and digital services, adopting the DestinE core Service Platform (DESP) as the supporting platform for the ESA DTE programme element and expanding its capabilities: e.g., availability of ESA Earth Explorer-, Heritage- and relevant Third Party Mission (TPM)-data for seamless ingestion into Digital Twins.

- **Implementing a set of EO-based Digital Twin Components** addressing different thematic priorities and offering an advanced interactive digital reconstruction of the Earth system at a level that represents a real breakthrough with respect to existing systems and solutions.

ESA DTE Element will be implemented in two Phases. The initial phase is considered a phase-in and is planned to last about two years with the following objectives:

- On the platform side, the phase-in will consist of the building of a dedicated EO data space (the ESA DTE Framework) as part of the DestinE ecosystem that can host EO DTC activities, develop key functions to enable EO DTCs development, bring ESA (and third party) EO missions as a contribution to DestinE.

- On the EO DTC development side, the phase-in will consist of the development and implementation of an initial set of DTCs focusing on specific Themes, as described below.

This ITT refers only to the latter programmatic pillar: Implementing a set of EO-based Digital Twin Components and covers **two distinct types of development actions**:

1. **Lead DTCs Development Actions for the initial set of priority Themes:** Up to 8 projects focussing on **8 different thematic priorities** identified through community consultation (see Appendix A) and considered to be mature enough to start large activities. Each project shall deliver an independent, end-to-end pre-operational system, fully implemented, conceptually and technically mature, scientifically validated, and fully tested by a representative set of early adopters. There shall be strong evidence of community benefits and the system shall be ready for verification as part of the DESP platform. This shall include a community roadmap for a potential evolution and scale-up in subsequent phases of the programme element and transfer towards operational scenarios.

With this set of projects, ESA aims at establishing an initial ecosystem of EO DTCs, strongly based on advanced EO capabilities, and allowing for its potential evolution towards 1) the operational stage of

the most mature services through DestinE or other European or national operational programmes, and 2) the establishment of an ESA DTE development framework supporting scaling-up, further advances and evolution of DTCs in subsequent phases of the programme element.

2. **Early DTC Development Actions for secondary Themes**: Up to 6 activities supporting feasibility studies, early definition, and demonstration of a set of prototype DTCs focused on additional secondary themes (see Appendix A) that may require more development work and consolidation in terms of concept definition, community building, and level of maturity of scientific and technical aspects. Each activity shall deliver an independent feasibility and preliminary protype demonstration, scientifically validated and tested by an initial set of early adopters, with evidence of an enlarging community and stakeholder support.

This set of activities shall provide a scientific and technical roadmap for potential development of future DTCs focusing on new thematic domains in subsequent phases of the programme.

An ESA DTE Open Workshop will be organised at the end of 2024 (or early 2025) as an open community consultation to present, assess and discuss the preliminary results of the programme and collect recommendations to define its evolution.

2.3 Thematic priorities

Following the request of MSs, ESA launched a Call for Expressions of Interest (EoI), inviting the community to express their support for the development of a specific EO-based DTC. The vision of the community has represented a fundamental input to support ESA in defining a set of initial priorities and the potential evolution of the programme.

The received inputs (more than 80 EoIs) have been assessed and synthesised into large thematic priorities capturing wide community interests, while responding to different criteria in terms of relevance, expected benefits, value of EO, scientific excellence, potential operationalisation, and complementarity to DestinE. An initial set of wide priority domains have been selected covering the aggregated scope of several EoIs submitted by the community. This prioritisation was not based on the relative importance of the theme, but rather the combined assessment of several criteria as described above.

2.3.1 Initial Priority Themes for Lead Development Actions

In particular, 8 Themes were identified as initial priorities for this ITT. These include:

- **Terrestrial biosphere and carbon cycle**: An advanced digital replica of the land-biosphere with focus on the carbon cycle and the impacts of climate variability and extremes on terrestrial carbon pools and fluxes.
- **Agriculture**: Advance capacity to respond to agricultural needs under climate change, determine the response of crop growth, stress/health and yield production to many co-occurring stressors, and support adaptation and management tools for a sustainable climate-neutral agriculture.
- **Forests**: An advanced replica of forest systems and the response to climate change and forest management strategies. Including components of health, disturbances, deforestation, and links to carbon.

- **Hydrology and hydro-hazards**: An advanced, holistic, and high-resolution representation of the hydrological cycle at continental and regional/basin scale, including mountain regions with focus on supporting water management and responses to hydro-climatic hazards.
- **Ice Sheets and regional/global impacts**: An advanced dynamic reconstruction of ice sheets (with focus on Greenland and/or Antarctica) as critical components of the Earth system, supporting enhanced scientific understanding of processes, including responses to climate change, land-ice-atmosphere-ocean interactions, onset and amplitude of abrupt changes, and its regional and global impacts.
- **Coastal processes and extremes**: An advanced dynamic reconstruction of coastal processes and coastal changes, including coastal hazards (flood and erosion risk, coastal vulnerability), impacts of climate change and human interventions on coastal communities and ecosystems as well as the feedback with the Earth system.
- **Data-driven Ocean**: A data-driven reconstruction of key ocean processes in support of the Digital Twin of the Ocean (DTO) developments, including enhanced data-driven 4D reconstruction of processes, improved characterisation of ocean extremes, upper-ocean dynamics, ocean health, ocean carbon and ecosystems and enhanced characterisation of the links between the physical ocean and the ocean biogeochemistry in support of advanced science and sustainable management action.
- **Land Biodiversity**: An advanced integration of EO data and biodiversity ecosystem models to assess current biodiversity changes, causal drivers, vulnerability and understand responses to natural/climate and anthropogenic pressures. To support and evaluate scenarios for conservation schemes and restoration.

The Contractors shall address the specific scientific and operational needs associated to the selected Theme (see Appendix A). It is expected however that significant synergies and complementariness may exist across the different Themes. These synergies and complementarities shall be addressed by the Contractor through dedicated Tasks as described in Section 4.

2.3.2 Secondary Priority Themes for Early Development Actions:

In addition to these priority themes, another 9 Themes have been identified for Early Development Actions to be further consolidated at feasibility and prototyping level in terms of community building, concept definition or scientific/technical elements before potentially starting larger activities. These Themes are *Air quality & health, Arctic (land and ocean), Energy sector, Geo-hazards, Mountain glaciers, Solid Earth, Urban areas and smart cities, Transport and regional spatial and infrastructures planning and Wildfires.*

3 ESA EO-BASED DIGITAL TWIN EARTH COMPONENTS BASIC PRINCIPLES AND FUNCTIONAL ELEMENTS

ESA EO DTCs **shall provide advanced replicas of key components of the Earth system and their interactions with human activities and ecosystems serving a wide variety of users, and with a strong focus on valorising the role of EO data and capabilities.**

They shall maximise the potential offered by the latest advances in EO capabilities and the wide variety of novel satellite data available to provide an advanced reconstruction of the past, present and potential future evolution of the Earth system with unprecedented levels of detail and accuracy.

They shall serve as a new generation of advanced scientific support tools and decision support systems offering a wide community of users with enhanced access to state-of-the-art geo-information, data analytics capabilities, advanced simulations, and what-if scenarios serving major scientific goals, policy needs and assisting in the design of actionable adaptation strategies and mitigation measures across different sectors.

EO DTCs may follow different architectures and implementation approaches and offer a wide variety of services to different users. However, they shall respect a number of basic principles and conform to fundamental functional design elements. The Contractor shall ensure that, as minimum, the following basic principles and functional elements are followed throughout the design and implementation of the DTCs and during the execution of the project.

3.1 EO DTCs Basic Principles

- [BP1] EO DTCs shall focus on key components (Themes) of the Earth system (and their interactions with human activities and ecosystems), scientific domains, and application/policy areas where EO satellite data and especially novel and emerging EO capabilities play a major role in observing and characterising key processes and systems (natural and/or anthropogenic), providing unique opportunities for the design and implementation of future operational DTs ecosystems. A preliminary description of the selected Themes for this ITT is provided in Appendix A.

- [BP2] EO DTCs shall clearly valorise the capacity and maximize the use of EO data to provide a comprehensive description of the specific Earth system component (relevant the Theme selected) and maximise the use of EO data in the design of the digital twin capabilities and services.

- [BP3] EO DTCs design shall be rooted in scientific excellence and offer an enhanced and scientifically sound representation of the Earth system as the basis to provide advanced scientific support tools and science-based decision support capabilities, including enhanced simulations and what-if scenarios, responding to the needs of the scientific community and decision makers to address the urgent environmental challenges of our time beyond the capacity of existing operational systems and solutions.

- [BP4] EO DTCs shall be developed in view of becoming potential additional elements and/or services of future operational Digital Twins ecosystems. Therefore, they shall ensure complementarity to DestinE and other existing (e.g., European, national, or regional) initiatives.

- [BP5] EO DTCs shall mainly focus on major scientific and policy/societal challenges of today and address temporal scales where EO data provides a significant impact in improving the representation of natural phenomena and/or human activity. This includes maximising the use of EO data to ensure enhanced simulations and driving/informing what-if scenarios.

- [BP6] DTCs shall address the complex interactions in the Earth system including its connections with human activities (and when relevant ecosystems). Therefore, DTCs shall capitalise on

advanced EO data products, models and processing elements that are able to properly characterise those complex processes at suitable spatial and temporal scales.

- [BP7] EO DTCs shall fully exploit the potential offered by the state-of-the-art EO capabilities for observing and characterising natural processes and/or human activities at resolutions in space and time compatible with decision making needs.

- [BP8] EO DTCs shall be developed following high scientific and technical standards, ensuring the use of state-of-the-art data, AI, models, and data-driven processing based on thorough and scientifically sound validation and uncertainty characterisation processes.

- [BP9] EO DTCs shall be based on a strong community support and shall be developed in view of serving a wide variety of stakeholders. This may include (depending on the scope of the selected Theme):

    - **The scientific community**: offering a unique set of advanced data and simulation tools supporting advances in Earth science, deepening our understanding of the Earth system, facilitating open science and advanced community efforts, and potentially the active intervention of the scientific community in the continuous evolution of the DTCs scientific scope and capabilities.

    - **Policymakers, international and national public institutions**: delivering policy relevant and actionable information, supporting resource management and decision-making through dedicated what-if scenarios and supporting the development of sustainable adaptation strategies and mitigation measures across different sectors.

    - **Value-added companies/industry**: offering the DTCs as a basis for building additional commercial solutions and services and as a source for business information and intelligence.

    - **Citizens**: supporting education and citizen information, outreach of science and policy relevant communication, inspiration of young generations and engagement of society in the programme.

- [BP10] EO DTCs may also be potentially used by ESA and other space agencies as reference tools for scientific activities, research and to support the definition, design and impact assessment of future observing systems.

- [BP11] Users shall be able to interrogate the DTC system with advanced and high levels of interactivity (e.g., through notebooks, interactive dashboards, immersive visualisation) to facilitate the access, exploration and exploitation of the data and the multiple simulation capabilities and (what-if) scenarios, such as simulations of natural events or legislative/management or other human interventions to assess the impacts across the whole interconnected system.

- [BP12] DTCs shall offer different levels of access and interoperability to different categories of users; from specialised expert access to low level data, code and processing tools, to dashboard-based dynamic information mining for scientific data synthesis and policy making, or immersive visualisation capabilities for public information, education and outreach.

- [BP13] DTCs shall ensure complementarity with ongoing relevant initiatives and programmes, including other Digital Twin activities related to DestinE and other European (e.g., Digital Twin of the Ocean) or national activities.

- [BP14] DTC design shall maximise the use of open science and FAIR principles, ensuring the design choices of the DTC are oriented to establish an Open Community System where different building blocks (modelling elements, AI elements, data analytics), datasets and workflows could be further developed and expanded in time by the community.

3.2 DTCs Basic Functional Elements

The definition of the end-to-end architecture and functional elements of the EO-based Digital Twin Components may vary depending on several factors (theme, overarching goal, use cases, functional building blocks). The description below provides only an initial high-level overview of the essential functional components required to develop such a system.

EO DTCs shall represent a quantum leap in the way we conceive decision support systems with the potential to revolutionize Europe's capability to monitor, assess and predict environmental changes, human impacts, and feed-back actionable insights at unprecedented resolutions in time and space. Such an ambitious system can only be possible by a significant acceleration and effective integration of different emerging technologies, advanced data, models, AI and science results, including:

- Latest advances in High Performance Computing (HPC) and Information and Communication Technology (ICTs), allowing the handling and computation of extreme scale data;
- The unique and synergistic observational potential offered by the expanding suit of complementary sensors on board of the EO satellite systems (e.g., Copernicus sentinels, Earth Explorers, meteorological mission, national missions, new space), in-situ networks, citizen science and socio-economic information.
- The latest advances in Earth system science and process understanding, including emerging research to incorporate human activities as part of a holistic Earth system.
- The latest advances in modelling capabilities providing advanced very high-resolution modelling of the Earth system and its processes.
- The potential of data-driven approaches, AI and ML, to drive a paradigm shift in the current description of the Earth system and its processes, moving towards a new data-driven, physically coherent approach that may overcome current limitations in modelling and forecasting of complex systems.
- Advanced user oriented front-end data analytics, dashboards, and visualisation techniques offering users an effective, interactive and attractive access to a wide variety of data, information and tools.

In particular, EO DTCs shall be underpinned by at least the following functional elements:

1) **Advanced Data and Digital Services**: advanced data space, digital services, and cloud computing capabilities that unlock the potential for enhanced digital analysis and simulation of the Earth system at a level that represents a real breakthrough in terms of accuracy, holistic understanding, access-to-information, and interactivity.

   ESA has selected the open DestinE core Service Platform (DESP) to host the ESA DTE activities, including the development, implementation, and demonstration of the DTCs benefitting from the functionalities of the DestinE platform and ecosystem.

The Contractor shall maximise the use of the DESP platform services. DTCs shall be integrated in whole or in part into the DestinE DESP and, as a minimum, the final demonstration services shall be offered through the DESP to the user community. **Appendix B provides reference material on the DESP and what the interfaces may look like and will help guide DTC development until the point that further details on the DESP are made available**.

2) **Multivariate data-driven reconstruction (by advanced Earth Observation data):** ESA DTE element focuses on the development of DTCs that valorise and maximize the use of EO-based data. Therefore, a major element in the design of EO DTCs shall be a **4D (space-time) reference multivariate dataset** of high-level products (e.g., a data cube) offering an advanced, holistic, and dynamic reconstruction of the target Earth system component and its different processes and interactions with human activities.

   These **4D multivariate datasets** shall provide a comprehensive description of the Earth system and its natural and anthropogenic processes with coverage, and spatial and temporal resolutions that are compatible with the needs and requirements of target community including scientific goals, environmental management and policy making support.

   The development of such a **4D reference multivariate dataset shall**:

   - Maximise the use of the novel capabilities offered by European missions such as the Sentinels, Earth Explorers, national missions in ESA MSs, and meteorological missions to provide the most comprehensive and advanced multi-variate dataset as possible describing the specific processes and Earth system elements to be address by the selected EO DTC.
   - The use of commercial EO data (e.g., very high-resolution data) is allowed as a complement to the above when needed and shall be properly justified.
   - Capitalise on an emerging new generation of EO products based on novel missions, new methods and advanced algorithms that fully exploit the innovative and emerging capabilities: e.g., novel datasets developed in the context of ESA scientific and research activities such as the ESA Science Clusters, Science for Society activities or the ESA Climate Change Initiative.
   - When relevant, ensure a sound integration of multiple and heterogeneous data sources (satellite-based products, in-situ data, citizen observations) into a coherent multi-variate and multi-temporal data structure ensuring consistency across variables and accounting for spatial-temporal covariations.
   - Exploit, when relevant, the datasets offered by Copernicus, the DestinE Data Lake and DestinE existing DTs.

   As a minimum, the 4D reference multivariate dataset shall be made available to the user community through the DESP.

3) **Scientifically sound processing blocks, simulation elements and workflows:** DTCs shall be underpinned by a scientifically sound set of workflows and processing layers connecting data (the 4D reference multivariate dataset) and state-of-the-art physically based models, geophysical model functions, AI and hybrid methods allowing advanced reconstruction of the Earth system, digital simulations and the creation of what-if scenarios serving the user community.

   The increasing amount and quality of EO satellite data and in-situ data available opens the door to a paradigm shift, moving from the traditional physically based approach towards new data-

driven approaches, based on novel AI techniques, ML and hybrid physical-coherent methods. Therefore, EO DTCs shall capitalise on those advances ensuring:

- Enhanced representation of the Earth system and its processes at **higher spatial and temporal resolution** compatible with the demands for policy making and resources and/or risk management.
- Improved the representation of poorly known processes, including enhanced coupling of interactions across different components of the Earth system and improved representation of human activities as well as, when relevant, ecosystems as part of the Earth system.
- When possible, the design shall be based on a **modular approach** allowing for the cross-comparison and substitution of different elements of the workflow: e.g., as part of the design process and its potential evolution and encouraging the use of ensembles of different methods engaging the community in the design.
- Selection of workflow elements (e.g., models, AI processing elements) shall be based on **scientific excellence**, justified by a thorough validation and testing approach with appropriate error propagation assessment and uncertainty characterisation.
- When possible, the DTC design shall be based on **open science principles** allowing for a community approach to the design and development of the DTC functional elements through the active participation of the community in the process (specially for its future evolution).

The Contractors shall maximise the use of the DESP to host and run the different processing elements and workflows. Deviation from this approach shall be properly justified (e.g., the DESP will not provide HPC capabilities during the execution of this project) and communicated to ESA in due time.

4) **User-driven interactive capabilities, data analytics and visualisation layer**: DTC development shall be driven by the needs and requirements of a wide variety of users and stakeholders including decision makers, environmental managers, local and regional administrations, national agencies, industry, scientific institutions, and citizens.

Therefore, key to the success of the EO DTCs will be the active community and stakeholder engagement. Users shall be in the driving seat for the initiative, being the main motivator for its functionality and capabilities. This will require a dedicated action to define suitable layers for interactions with the user community.

EO DTCs shall provide users with a fast, intuitive, and interactive access to data, results, simulation, and advanced visualisation capabilities that exceed current decision support systems and put the full capacity of DTCs in the hands of the users.

This will require a significant development effort not only to ensure DTCs are fit for purpose but also to offer users with advanced front-end interactive capabilities and tools that may capitalise on the latest ITC, advanced interactive graphic visualisation technologies and simulations.

These user interactive capabilities and visualisations shall be implemented in the DESP and shall maximise the use of the tools and services offered by DESP.

4 Objectives

4.1 Objectives for Lead DTC development Actions (Initial Priority Themes)

For Lead DTC development Actions focused on initial priority themes (see Appendix A):

- Bring together scientists, industry, ICT experts, modellers, and policy makers to jointly define, prototype and demonstrate and end-to-end realisation of a DTC with focus on one of the priority Themes described in Appendix A and maximising the valorisation of EO capabilities.

- Engage the user and stakeholder communities including a wide range of categories: scientists, citizens, industry and policymakers to ensure a user-driven approach and jointly define the needs and gaps to be addressed by the DTC as well as the expected benefits & impacts. This community engagement activity shall be used to identify DTC Use Cases to be addressed in the DTC demonstration.

- DTC Use Cases shall be co-designed with the users and shall address different needs and gaps both scientific and policy driven. The spatial and temporal coverage shall be defined to ensure a proper assessment of the technical and scientific validity of the DTCs to address the targeted set of needs and gaps over different regions and temporal scales. **At least 4 Use Cases shall be defined and implemented.**

- Use Cases shall cover sizable geographic regions and temporal scales representative of the scope of problem to be faced and when relevant, implementation shall be done over different regions to demonstrate performance under different conditions and potential scaling up and portability capabilities. This may include country, continent- or region-wide (large basin) full DTC implementation and demonstrations. Furthermore, preferably, DTCs should focus on European areas involving European users and stakeholders, or alternatively, on regions in developing countries, where the significance and usability of the DTC is clearly demonstrated. Alternative regions are acceptable if properly justified.

- Co-design with users an effective and efficient architecture of the DTC functional blocks and data flows that bridge together the latest advances in EO capabilities, AI, modelling, data analytics, ICT and HPC capacity, and visualisation capabilities, maximising the use of the DESP, DestinE datasets and the services offered through the DESP.

- Undertake a dedicated research and development plan aimed at consolidating and advancing current limitations in the scientific and technical elements required to implement and demonstrate the target DTCs. The Contractors shall implement a thorough experimental and development plan to ensure that the most advanced and fit-for-purpose datasets and methods (i.e., processing schemes, models, AI) are incorporated into the final design. Specific efforts shall focus on the development and selection of each element (i.e., datasets, models, AI processes) through cross-comparison, validation and uncertainty assessment, ensuring final choices offers clear advances with respect to existing systems and operational solutions.

- Implement, integrate and validate an end-to-end pre-operational realisation of the DTC with particular focus on the Use Cases identified and co-designed with the Users. The developed DTC shall be integrated in whole or in part into the DestinE DESP through the ESA DTE Framework3. The DestinE DESP is currently under development, and therefore the exact interfaces, services and applications offered are not available at the time of this ITT. **Appendix**

B provides reference material on the DESP and the interfaces and services that will be available to the team and will help guide DTC developments until the point that further details on the DESP will be provided by ESA. **All developments activities including data processing and storage shall be costed in the budget available for this ITT** (as a reference for the prices of the DESP services the Contractor can use the OVH cloud services, as described in Appendix B).

- Maximise the use of open science and FAIR principles, ensuring the design choices of the DTC are oriented to establish an Open Community System where different building blocks (modelling elements, AI elements, data analytics), datasets and workflows could be further developed and expanded in time by the community (e.g., through dedicated ESA, national or European scientific activities) in subsequent phases of the programme. Open science capabilities shall be included in the proposed demonstration.

- Undertake through all phases of the project a detailed validation and error characterisation ensuring a thorough testing, verification, assessment and representation of the errors and uncertainties associated with all the EO datasets, models, processing elements and all other inputs and outputs of the DTCs. This shall also include how those errors are propagated through the system and represented appropriately as uncertainties in outputs and final user information.

- Perform a complete and engaging demonstration of the pre-operational DTC highlighting how the DTC would be used in an operational capacity, responding to the needs of the different users, and how it could be integrated into an operational environment such as DestinE. The demonstration should provide solutions to the Use Cases motivated by user engagement and clearly identify the impact/benefit in comparison to existing or traditional methods. As part of the demonstration, the service offered by the DTC shall be open to a wide set of users, including the general-public for a demonstration period.

- Elaborate a community roadmap proposing both a plan with realistic options for advancing towards a full operational DTC and a dedicated Scientific and Technical Agenda covering all the relevant R&D requirements: e.g., EO data needs and limits in retrieval capabilities, data handling and integration, process understanding and knowledge gaps in Earth system science, limits in current modelling capabilities, uses of AI, infrastructure capabilities, etc. In addition, the roadmap shall address potential options for the full or partial integration or connections of different DTCs in the future, exploring synergies and complementarity in both the user categories addressed, the scientific goals, the policies served, and the scientific and technical solutions proposed.

- Ensure proper coordination and collaboration with the relevant activities and projects in Europe (e.g., DestinE, Horizon Europe activities, DTO) and Member States ensuring complementarity, exploiting synergies, and potential joint actions. This shall also include other relevant ESA activities such as science and R&D projects undertaken in the contest of the ESA Science Clusters, Science for Society and ESA's CLIMATE Space.

- In addition, coordination across the different DTCs projects shall be implemented specially to explore and exploit, when possible, existing synergies and potential interdependencies across different Themes, especially in view of defining the evolution of the proposed DTCs towards an effective Digital Twin Earth ecosystem in the future.

- Maximise the communication and dissemination of the projects results and benefits within the stakeholder community including the scientific community, policymakers and general public,

through suitable communication and media material, and specially through the demonstration cases, including interactive and engaging tools and advanced visualisation capabilities.

4.2 Objectives for Early DTC development Actions (Secondary Priorities)

For Early DTC Development Actions focused on secondary priority Themes (see Appendix A):

- Bring together scientists, industry, ICT experts, modellers and policymakers to jointly define, prototype and propose a potential realisation of a future DTC.
- Engage the user and stakeholder community to ensure a user-driven approach and assess needs and gaps with special attention to identify the expected benefits & impacts of the DTC by the user community.
- Develop a preliminary design of a potential DTC identifying all the scientific and technical limits to be addressed in further developments and implementation.
- Build upon existing capabilities and emerging developments to prototype and validate an instance of the proposed DTC and demonstrate its potential on at least 2 representative Use Cases including a corresponding user assessment.
- Elaborate a community roadmap proposing a Scientific and Technical Agenda to develop an end-to-end DTC in a subsequent phase of the ESA DTE element, covering all the relevant R&D requirements and demonstrating community and stakeholder support.
- Maximise the use of DESP services during DTC implementation and demonstration.

5 WORK TO BE PERFORMED

In the following sections, a description for each of the tasks to be carried out in the context of the EO DTC development is provided. The Contractor shall justify any possible departure from the presented structure in its proposal.

For Lead DTC Development Actions focused on initial priority themes the projects shall be completed within 24 months.

- All Tasks below shall be implemented in parallel following an agile project management approach during the full duration of the project. Activities shall be implemented following two annual cycles with a mid-term review after KO+12.

- A first deliverable is expected at KO+3 including a first version of key documents providing a preliminary description of the DTC objectives, Use cases, DTC design and developments, and validation plans, as described in the Task description below,

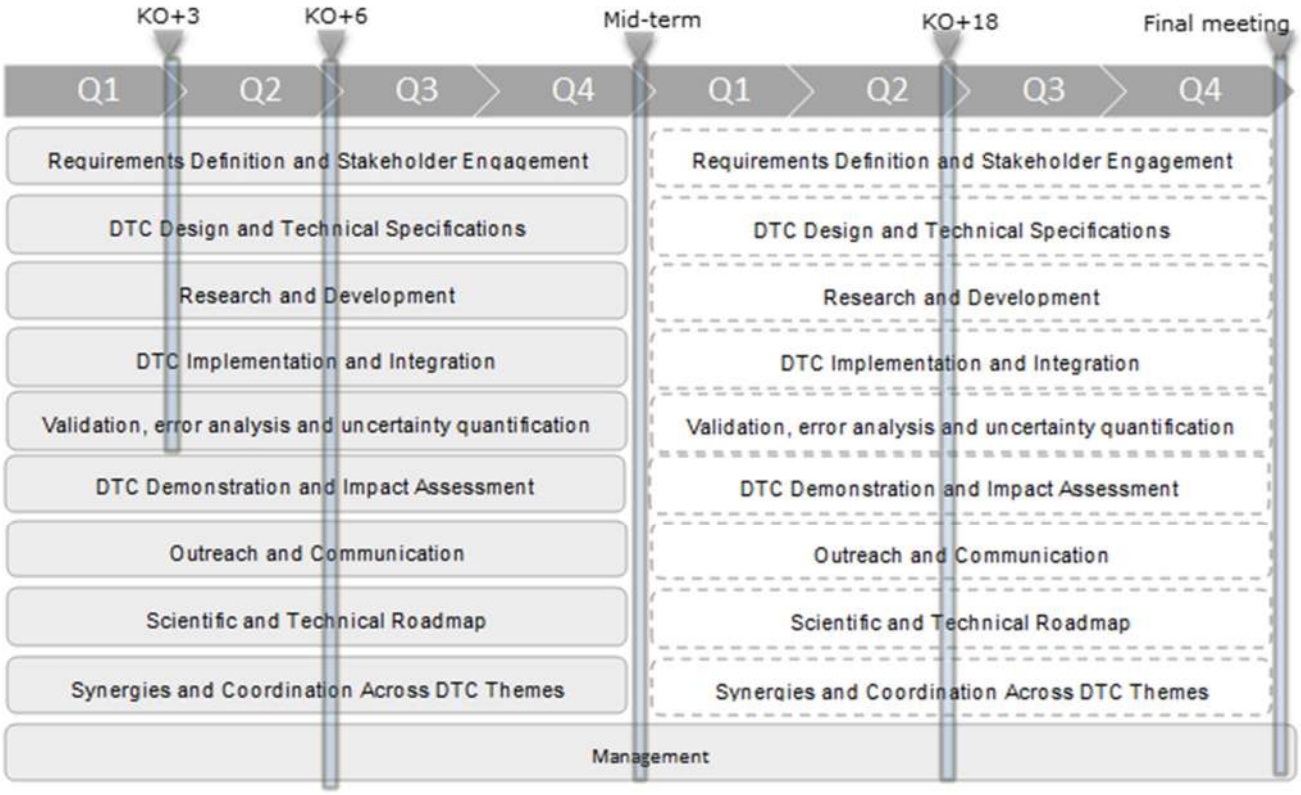
- Main milestones including project reviews shall be organised every 6 months. Those meetings will include a co-location meeting (of one day) involving all the selected DTC teams resulting from this ITT. In principle this meeting will take place at ESRIN. Meetings will be hybrid to allow maximum participation of team members in the event. However, key members of the team shall participate to the collocation meetings (participants may vary depending on the progress in the project).

- A mid-term review shall take place at KO+12 where the activities undertaken during the first year and corresponding deliverables (see Table 1 below) will be formally reviewed and the plans for year 2 will be assessed by ESA. To this end, a plan of activities for year 2 shall be proposed to ESA. A decision will be taken by ESA to proceed with the 2nd year activities of the project (as a new contractual phase) based on the approval of all the deliverables submitted in Year 1.

The tasks are as follows:

- Task 1: Requirements Definition and Stakeholder Engagement
- Task 2: DTC Design and Technical Specifications
- Task 3: Research and Development
- Task 4: DTC Implementation and Integration
- Task 5: Validation, error analysis and uncertainty quantification
- Task 6: DTC Demonstration and Impact Assessment
- Task 7: Outreach and Communication
- Task 8: Scientific and Technical Roadmap
- Task 9: Synergies and Coordination Across DTC Themes

In addition, a Task dedicated to management shall be implemented during the full duration of the projects as described below.



For Early DTC Development Actions focused on secondary priority themes the projects shall be completed within 12 months.

As a minimum, the Contractors shall implement a dedicated Work Plan based on a **tailored version** of the Tasks below:

- Task 1: Requirements Definition and Stakeholder Engagement
- Task 2: DTC Design and Technical Specifications
- Task 4: DTC Implementation and Integration
- Task 5: Validation, error analysis and uncertainty quantification
- Task 6: DTC Demonstration and Impact Assessment
- Task 8: Scientific and Technical Roadmap

The tailored Work Plan shall ensure that the Tasks and activities described below are adapted to the goals and objectives of the Early Development Activities (feasibility and early prototyping nature), ensuring all project objectives and goals are complete within 12 months including a final end-to-end demonstration at the Final meeting. In addition, due to the limited timeframe of this projects and its feasibility nature, the Contractor shall consider the following elements:

- Early DTC Development Actions shall propose, implement, and demonstrate **2 Use Cases.**
- Because of the limited timeframe of Early Development Actions, a dedicated Task on research and development is not required. However, it is expected that some R&D activities are needed to implement the proposed DTC demonstration. Any development activity and research, and subsequent validation, shall be done as part of Task 4 (DTC Implementation and Integration). For each Task, at least all the deliverables expected during the first year as described below shall be delivered.

- Expected deliverables at KO+12 shall be the Final deliverables of the project.
- In addition, the required final demonstration shall be done at the Final meeting of the project at KO+12.
- The Management Activity as described in Section 6 is required.
- Early Development Actions are also required to participate at the collocation meeting that will take place at KO+6 in ESRIN involving all the teams.
- In addition, Early Development Actions are expected to present their preliminary results at the ESA DTE Open Workshop expected to take place at the end of 2024 or early 2025.

5.1 Task Description

5.1.1 Task 1: Requirements definition and stakeholder engagement

Description:

This task shall consolidate the definition of the goals, objectives, and specific requirements to be addressed by the DTC, including the target users and stakeholder community, all the required scientific, technical and policy background information and knowledge required to design a fit for purpose DTC.

The Contractors shall bring together scientists, industry, ICT experts, NGOs, policymakers, national and international authorities to jointly define, assess and identify the needs and gaps to be addressed by the DTC as well as the expected benefits & impacts.

This shall also include the detailed consolidation of the Use Cases (preliminary provided in the proposal). To this end, the Contractor shall work in close and continuous interaction with the Target Stakeholder Group (a critical mass of representative stakeholders and users) including a strong involvement and dialogue with authoritative representatives of the user community (i.e., scientists, policy makers, general public, industry, etc…).

At least 4 Use Cases shall also be identified by the Contractors and consolidated, together with the user community, to be addressed in the DTC demonstration.

In particular, the Contractor shall:

- Elaborate, in close collaboration with the Target Stakeholder Group, a detailed definition of the Theme under consideration including all the scientific, technical, and operational challenges to be addressed, and the overarching and specific goals of the EO DTC to be developed.
- Assessment of the different categories of users and stakeholders that the EO DTC will serve, their needs and expectations and list the representative set of institutions that are engaged in the project activities (e.g., supporting the definition and assessing the results of the Use Cases).
- Perform a detailed analysis of the state-of-the-art to identify the main scientific challenges and knowledge gaps that the DTC shall address.
- Elaborate an analysis of the main policy drivers and associated requirements that the DTC shall address and explicitly identify all aspects that cannot be provided by current information and decision support systems.
- Engage users and stakeholders to identify the information needs, knowledge gaps, operational gaps, functional needs and requirements for the DTC during the project lifetime (as drivers for the development) and in the future.
- Define, based on user/stakeholder requirements and needs, at least 4 representative Use Cases to drive the development of the DTC and the demonstration. To this end, the Contractor shall define in close collaboration with the Target Stakeholder Group the list of

specific user requirements in terms of final information and expected DTC functionality. This shall include a detailed description of, at least:
  - The expected output data, information and targeted user services and functionality.
  - Target geographical areas of interest for the Use Case implementation and demonstration.
  - Temporal range for the Use Case implementation and demonstration.
  - Target accuracy and expected uncertainty vs user needs.

- These “target” requirements and Use Cases shall explicitly include needs (scientific, policy driven, technical) and capabilities that cannot be covered today by existing information and decision support systems. The Contractors shall provide a clear description of the added value of the proposed work with respect to existing activities, knowledge, operational systems and products.

- The clear reporting and description of the user requirements shall be structured to enable:
  - clear traceability to the main design drivers of the DTC
  - use as a reference to assess the validity of the proposed approach and to derive conclusion for future development needs.

- Survey current and ongoing national, European, and international initiatives and projects relevant to the investigated theme.

This activity shall be implemented during the full duration of the project, ensuring a continuous engagement with users and stakeholders throughout the lifetime of the project to involve users in the development of DTC Use Cases, to assess the evolution in user requirements and receive feedback on DTC developments.

Feedback from users/stakeholders shall be incorporated in subsequent tasks of the DTC demonstration activities, modifying, if needed, the target user requirements and Use Cases and impacting the development tasks and demonstration.

Engagement with Stakeholders and Users will likely involve the processing of personal data. This personal data shall be handled in accordance with the relevant data protection requirements in the Contract.

The activities under this Task shall be reported in the Requirements Baseline Document. This document shall be delivered to ESA in different versions during the execution of the project as described below.

At the end of Year 1, this document shall also collect the plan of activities and revision of the User Cases (if needed) to be implemented in the second year of activities.

Deliverables:

KO +3: Requirement Baseline Document (RBD) V1. First version of the document describing the preliminary set of scientific, technical and user requirements, policy analysis, stakeholders and Use Cases that will drive the first year of activities of the project.

This document shall be continuously updated based on the results of the above Task and delivered to ESA in the following versions:

KO +6: Draft RBD V2. Draft of the first-year version (V2)

KO +12: RBD V2. Complete report of all the activities and results carried out during the first year of activities. This version shall also include a plan of activities for year 2.

KO +18: Draft RBD V3. Draft of the final (second year) version (V3)

KO +24: RBD V3. Final document reporting all the final findings of this Task implemented during the project.

5.1.2 Task 2: DTC Design and Technical Specifications

Description:

In this Task the Contractor shall translate the requirements and objectives of the proposed DTC from Task 1 into a technical specification and a fit-for-purpose complete end-to-end design of all the different elements of the DTC to be developed and implemented with focus on the specific goals, objectives and user needs identified.

To this end, based on the requirements defined in Task 1, The Contractor shall design an effective and efficient architecture of the DTC including all the input data, workflows, processing components (e.g., models, AI elements, data analytics), output data, and interfaces with the DESP.

The design shall also include a complete definition of the different functionalities that the DTC shall provide, the user interface and the description of the different levels of interactivity of the system for different categories of users.

The design shall also include the expected output information and output products including the target accuracies and uncertainties.

Finally, the design shall also clearly define the metrics and validation protocol for the final assessment and acceptance test of the system implementation including both a scientific and technical assessment of the results as well as the assessment by the users and stakeholder community as part of the demonstration.

The design shall include a high-level description of the Data-Flow Diagram as well as a detailed description and definition of all the inputs, outputs and processing elements and components.

This shall also include the identification and assessment of the requirements for data exchange with the DestinE system, and what relevant digital services and facilities are available from the DestinE platform, and how they will be used by the DTC.

A detailed and dedicated design shall be prepared for each of the Use Cases. This shall include a clear description of the:

- Workflows and functional tools to address Use Cases.

- DestinE infrastructure and functionality to be utilised.
- Data-Flow Diagrams including:
  - Required datasets: EO, in-situ, etc
  - Required modelling/AI/analytics capabilities.
  - Required digital services, ICT and HPC
- Expected output and target accuracies and validation data and metrics.

The Contractor shall identify all the requirements for R&D activities to be developed in Task 3 and adapt the design to consider the findings and results of these development activities.

The design choices shall drive the DTC Integration and Implementation activities of Task 4 and potential trade-offs and difficulties identified in Task 4 that may impact the design shall be taken into account in revised versions of the design.

The Contractor shall also define the metrics, validation activities, acceptance testing and final qualification of the final implementation, Use Cases and demonstration.

This Task shall include a detailed risk analysis pointing out which risk areas could affect all the different design, development, and implementation choices, with proposed solutions to address and mitigate.

The design and technical specifications shall be updated during the project to reflect the response to evolving user requirements, emerging scientific advances and technical capabilities, project progress and feedback.

At the end of Year 1, this document shall include a plan of activities for Year 2, including any revision of the design to address any evolution in the objectives, goals and Use Cases (if needed) to be implemented in the second year of activities.

Deliverables:

KO +3: Design and Technical Specifications Document (DTSD) V1. A first version of the DTSD shall be delivered at KO+3 including design and definition to address the Use Cases and research needs, specially focusing on activities to be implemented during the first year.

This document shall be continuously updated based on the results of the above Task and delivered to ESA in the following versions:

KO +6: Draft DTSD V2

KO +12: DTSD V2

KO +18: Draft DTSD V3

KO +24: DTSD V3

5.1.3 Task 3: Research and Development

Description:

Even though the DTCs shall be based on state-of-the-art data products, advanced science, mature techniques and models, the significant ambitions of the programme and the expected DTC performance, with respect to existing capabilities, will require dedicated R&D Tasks to address some of the major scientific and technical limitations requited to develop the target DTC.

Therefore, in this task the Contractor shall develop and implement a detailed research and development plan to address all the scientific and technical challenges required for the implementation of the DTC. This will involve advancing current capabilities, developing and validating all the functional blocks and elements of the workflows required to implement and demonstrate the DTC, as defined in Task 2, with special attention to the Use Cases.

The plan shall be based on scientific excellence and a thorough experimental, validation analysis including error characterisation and uncertainty assessment that shall ensure the best available datasets and methods are selected for DTC implementation, with clear justification for the selection of each element.

For each of the target developments, the research and development plan shall be based on the detailed review of the state-of-the-art including:

- a compilation and analysis of the latest relevant publications
- assessment and cross-comparison of existing relevant alternative products, datasets, methods, models, and AI algorithms including a review of their related range of validity limitations, drawbacks, gaps and challenges.
- existing relevant ESA and non-ESA scientific activities, projects and initiatives that may contribute to this effort.
- Identification of test areas and related validation datasets.

Based on such analysis, the Contractor shall explore, develop, test and finally select the necessary data, methods, algorithms, models and workflows required to implement the DTC. This will include providing tools to address the Use Cases, representing Earth system processes and What-If scenarios serving the user community.

To this end, the Contractor shall perform a thorough and systematic experimental assessment and cross comparison of different methods, techniques, modelling approaches and data over different test sites and target scales. In particular:

- A detailed experimental error analysis for testing and verifying all the different implementation choices. This shall evaluate the accuracy and reliability of the developed methods and products on different validation sites.

- Proposed test sites shall provide a wide representation of different conditions that may affect or influence the performances of the methods and the final accuracy of the products. This will ensure the most complete assessment of the range of validity and robustness of the tested methods.

- The experimental work shall cover a wide range of methodological options based on different data types and multi-mission approaches (depending on the specific theme), EO-based products, including the use of models.

- The final methods and algorithms shall be selected on the basis of a detailed experimental analysis of the potential alternative methods and approaches supported by a sound inter-comparison and validation.

- A detailed description of the final version of the algorithms (including related data sources, processing steps and output data) shall be reported by the Contractor in the form of an ATBD (Algorithm Theoretical Basis Document: as a dedicated Chapter in the Research and Development Report (R&DR)). This shall also include a scientific analysis of the results that have led to specific development choices and trade-offs (including technical considerations justifying the selected methodologies).

- In addition, a detailed cross-comparison of the resulting products/estimates or models with existing equivalent/alternative datasets/models or processing elements shall be performed to gain a thorough understanding of the range of validity, limits and benefits of the DTC approach.

- The Contractor shall report a detailed description of the error analysis, validation activities and any cross-comparison exercises and its results into the relevant ATBD.

This Task shall be implemented during the duration of the project addressing new R&D requirements whenever identified during the design and implementation tasks, and as a result of the different reviews and interactions with the users and stakeholders that may impact the design and implementation choices.

The activities of this Task shall be reported in a **Research and Development Report (R&DR)** including a detailed description of the R&D Plans, the experimental work performed, the final ATBD and related validation. The document shall be updated throughout the lifetime of the project to reflect the latest activities of this Task.

At the end of Year 1, this document shall also include a plan of activities during Year 2, including any revision of the Research and Development Plan, and new research and development activities when needed.

Deliverables:

KO +3: Research and Development Report (R&DR) V1. A first version of the R&DR shall be delivered at KO+3 including the description of the research and development plans for each of the target developments and the proposed validation sites. This document shall be further developed during the lifetime of the project including the description of the results, the final description of the methods and the validation results. One chapter of this document should be the ATBD (Algorithm Theoretical Basis Document), and another should be dedicated to validation (Product Validation Report (PVR)).

KO +6: Draft R&DR V2

KO +12: R&DR V2

KO +18: Draft R&DR V3

KO +24: R&DR V3

5.1.4 Task 4: Implementation and Integration

Description:

In this Task the Contractor shall implement and integrate all the different elements of the end-to-end realisation of the DTC as defined in Task 2, with particular focus on the Use Cases. This task shall result in a pre-operational system that can be demonstrated and assessed by the user community.

The Contractor shall ensure all DTC elements are integrated and interact in an efficient and coherent manner (satellite data, workflows, models, AI/ML, etc, user interface) such that the system functions as a single entity with clearly defined inputs and outputs.

The Contractor shall develop and test all the end-to-end DTC functionality to address the Use Cases based on the existing capabilities and novel scientific/technical developments resulting from the research and development in Task 3.

Therefore, this Task shall involve an agile and rapid development and testing process in close connection with Task 3, including:

- The development and integration of the 4D Reference Multi-variate Datasets and additional input data sources (in situ, socio-economic data, etc.).
- The development and integration of all elements and workflows of the EO DTC including existing and new advanced processing elements and workflows developed in Task 3.
- The development and integration of the user interactive capabilities including data analytics, user interactive capabilities, visualisation tools, etc.

The Contractor shall also process all the required data, run the models and processing elements required to deliver the final output products that will represent the basis for the Use Cases and the final demonstration of the user functionalities, digital simulations and what-if scenarios.

The DTC shall be integrated in whole or in part into the DESP. How the DTC, or components of the DTC, will be integrated into the DESP shall be agreed upon with ESA prior to implementation. Therefore, this Task shall take into account the developments of the DESP and its gradual operationalisation of its functionalities and services.

The Contractors shall also ensure the effective integration and availability of all the other required additional digital services, capabilities (e.g., HPC, visualisation) and other infrastructure elements not provided by DESP. These elements shall be included in the design plan and their use shall be timely communicated to ESA.

All development, processing and integration activities implemented under this Task shall include an appropriate testing and validation of the results including appropriate error propagation and uncertainty analysis based on the protocols and metrics defined in Task 5.

This Task shall be implemented during the full lifetime of the project in an agile manner and in full coordination with the other activities of the project. Activities shall be adapted to the gradual availability of the DESP services.

The implementation of the Task shall be designed to reach the goals, and respect the scheduling, of the Demonstration and Impact Assessment (Task 6), which foresees a first preliminary demonstration at the Mid-Term review (KO+12).

A final qualification and acceptance test of the system (accuracies, functionalities, integration aspects in the DESP) shall be done with ESA prior to the final demonstration to be performed at the end of the project.

All the activities shall be reported in a DTC Integration and Implementation Report as defined below.

At KO +3, the Contractor shall provide a plan outlining the proposed integration and implementation activities for the first year of the project in the form of a Plan DTC Integration and Implementation Report (IIR). This document shall evolve to reflect the progress and outputs of the activities, and at the end of Year 1 shall also include a plan of activities for Year 2.

Deliverables:

KO +3: Plan DTC Integration and Implementation Report (IIR).

KO +6: Draft DTC IIR V1.

KO +12: DTC IIR V1.

KO +12: Draft DTC IIR V2.

KO +18: DTC IIR V2.

5.1.5 Task 5: Validation, error analysis and uncertainty quantification

Description:

The scientifically sound validation of the accuracy, error characterisation and assessment of the uncertainties of the final outputs of the DTCs is a priority for the ESA DTE element. These activities shall be implemented across all the development and integration aspects of this project. However, due to its high importance a dedicated Task shall be implemented by the contractor to ensure the maximum level of attention to validation, error analysis and uncertainty quantification.

In particular, the Contractors shall undertake dedicated actions to ensure validation, assessment and representation of errors and uncertainties associated with all the EO datasets, models, and processing elements. The Contractor shall ensure that errors are propagated through the system and represented appropriately as uncertainties in outputs.

The Contractors shall define a scientifically-sound set of metrics, testing and validation protocols to assess errors and uncertainties during the project lifetime and all relevant Tasks. This validation approach shall be clearly documented in the Validation Report (VR).

The Contractor shall gather independent validation datasets and use them for cross-comparisons and validation within the research, development and pre-operational implementation stages of DTC development.

Focused attention shall be paid to error analysis and uncertainty quantification. This shall allow errors associated with observations, data, methods, and models to be quantified throughout the system and propagated through the system to be presented alongside results/outputs.

The Contractor shall implement the DTC at the range of spatial and temporal scales identified in the scientific and technical Use Cases. This will result in a large and sizable coverage in space and time allowing an assessment of the scientific objectives of the project. This scaling-up activity shall also demonstrate the scalability and potential operationalisation of the proposed techniques.

Specific tasks include:

- Compilation of validation datasets over representative test sites.
- Assess validity of datasets/methods with comparison/testing of outputs with validation datasets.
- Ensure method is not biased towards specific choice of temporal or spatial window.
- Identify errors/uncertainties associated with datasets and methods.
- Investigate and apply appropriate methods for error/uncertainty propagation.
- Consider steps for minimising errors/uncertainty.
- Perform a detailed error analysis for testing and verifying all the implementation choices. This shall evaluate the accuracy and reliability of the developed methods and products on the different selected test regions, paying close attention to the representation errors intrinsic to the comparison of satellite data vs in-situ data that resolve different spatial and temporal scales.
- Effectively present/display errors to the user within the DTC.

The detailed description of the cross-comparisons and the validation results shall be described in a Validation Report (VR).

At KO +3, the Contractor shall provide a plan outlining the proposed validation, error analysis and uncertainty quantification activities for the first year of the project in the form of a Plan Validation Report (VR). This document shall evolve to reflect the progress and outputs of activities, and at the end of Year 1 shall also include a plan of activities for Year 2.

Deliverables:

KO +3: Plan Validation Report (VR)

KO +6: Draft VR V1

KO +12: VR V1

KO +18: Draft VR V2

KO +24: VR V2

5.1.6 Task 6: DTC Demonstration and Impact Assessment

Description:

In this Task, the Contractor shall perform a full demonstration of the pre-operational DTC capabilities highlighting how the DTC would be used in an operational capacity responding to the needs of the different users identified in Task 1 and how it could be further integrated into DestinE or other operational Digital Twin programmes (e.g., national programme).

The demonstration shall focus on the Use Cases defined in Task 1 and shall clearly identify the impact/benefit in comparison to existing or traditional methods, systems and services.

The quality of the results, its usability and impact shall be thoroughly assessed with the full engagement of the stakeholder community including different categories of users as identified in Task1.

The demonstration shall be developed in an agile manner in close connection with the research, development, implementation and integration activities of the project in two annual phases with a preliminary demonstration of the DTC at the end of the first year.

The demonstration shall be interactive, attractive, and engage the community. The community and stakeholder shall actively participate in the impact assessment. The assessment shall include four aspects:

1. Scientific quality and accuracy of the final outputs, errors, and related uncertainties vs the state-of-the-art and alternative existing approaches.
2. The impact of the developed datasets, simulations, and what-if scenarios for different user categories and user needs.
3. The usability of functionality to facilitate a fast, attractive, and engaging access to the final information for the different categories of users.
4. The effective integration of the DTC as part of the DESP.

The Contractor shall demonstrate the functionality of the DTC system and assess the response of the user community and the impact at (as a minimum) ESA dedicated DTE events and workshops. At least two workshops will be organised to present the mid-term and final results. The DTCs shall also be demonstrated at open community events, such as ESA's Living Planet Symposium.

The demonstration shall clearly show the performance and functionality of the DTC while responding to the specific goals, objectives and target user needs identified in Task 1, especially those identified for each of the Use Cases.

At the end of Year 1, this document shall also include a plan of activities for Year 2.

Deliverables:

KO +6: Draft Impact Assessment Report (IAR) V1

KO +12: Prototype DTC demonstration V1

KO +12: IAR V1

KO +18: Draft IAR V2

KO +24: Final DTC demonstration V2

KO +24: IAR V2

5.1.7 Task 7: Outreach and Communication

Description:

The Contractor shall maximise the communication and dissemination of the project results and benefits to stakeholders and wider community. Using suitable communication and media material, and through the demonstration of Use Cases, including the use of interactive tools, visualisation and advanced media material.

The Contractors shall ensure wide public, stakeholder and scientific visibility of the DTC development through the following sub-tasks.

- Create and keep updated an attractive and professional project website, regularly updated and offering relevant material and information.
- Disseminate project results through presentations at relevant conferences (including ESA Living Planet Symposium), workshops, and at other relevant meetings.
- Publish project results in peer-review journals.
- Demonstrate DTC capabilities at relevant events, workshops, and conferences, especially those relevant to the stakeholder and target user communities.

DTCs are expected to provide attractive and efficient ways to present relevant information and interactive capabilities to citizens. Therefore, dedicated attention shall be paid to promote and present the DTC to the wider public through dedicated open web-based functionalities that may maximize the use of advanced visualisation methods and tools for outreach, education and public information.

In addition, the Contractor is expected to participate at the ESA DTE Open Workshop to be organised by ESA (end of 2024 or early 2025) as an open community consultation to present, assess and discuss the preliminary results of the programme and collect recommendations to define its evolution.

The undertaken outreach and communication activities shall be reported to ESA in the form of a Dissemination and Outreach Summary report (DOR). At the end of Year 1, this report shall also include planned activities for Year 2 and shall be reviewed by ESA and approved at the Mid-Term review.

Deliverables:

KO +3: Project website (WEB) – Updated at monthly intervals.

KO +12 onwards: Demonstration of DTC capabilities to stakeholders and wider community (OUT)

KO +6: Draft Dissemination and Outreach Summary report (DOR) V1

KO +12: DOR V1

KO +18: Draft DOR V2

KO +24: DOR V2

5.1.8 Task 8: Scientific and Technical Roadmap

Description:

In collaboration with the scientific community and stakeholders the Contractor shall develop a scientific and technical roadmap proposing a detailed scientific and technical plan for advancing towards a fully operational EO-based DTC.

This roadmap shall be based on a comprehensive assessment of the experience gained during the project and interactions with the users and community including the impact assessment conducted in Task 6 and all the validation and uncertainties assessment activities.

The roadmap shall be based on a comprehensive assessment of the current performances and capabilities, limits, development needs, science gaps, technological constrains and implementation limitations of:

1) the individual scientific and technical elements,
2) the integrating aspects to establish an end-end system,
3) the operational aspects of the DTC.

The roadmap shall consist of the following key elements.

1. Assessment of the impact and benefits realized by the stakeholders resulting from the demonstration of DTC capabilities.

2. Review the scope, goals and user requirements and needs that may drive DTC developments in the future, identifying the current gaps in capabilities of existing operational information and decision support systems and how the DTC is expected to overcome such gaps.

3. In consultation with the stakeholder groups, provide details, in the context of the DTC and user requirements, of the following:
   - **Gaps in current capabilities of EO-based products** and other observations to represent such processes.
   - **Gaps in the data access and data handling** capabilities.
   - **Gaps in the scientific understanding** of critical components of the relevant Earth system processes.
   - **Gaps in simulations and modelling capabilities** with respect to providing an accurate and scientifically sound representation of the key Earth system processes and their interactions.

- **Gaps in the AI capabilities** to support data enhancement, feature engineering, data integration, modelling, forecasting and inference (including explicit consideration of gaps in training datasets).
- **Gaps in the validation and uncertainties capabilities** with respect to measurements and analyses.
- **Gaps in the underlying infrastructure including HPC and cloud computing capabilities** to ensure each of the DTC elements can operate to the required level of performance.
- **Gaps in the digital platform services** and implementation/integration process and interoperability aspects.
- **Gaps in user interfaces, visualisation, and interactivity.**

4. Review the relevant initiatives, programmes, and projects at European or national level that may contribute to the potential further development of the DTC in the future and its potential transfer into an operational context.

As a result of such an analysis the Contractor shall provide, as a minimum:

- A detailed description of the goals, objectives, and target stakeholder group for a full operational DTC.
- A detailed description of the expected target functionalities, capabilities and outputs.
- A detailed description of a potential high-level architecture and functional description, including input data, workflows, processing elements (models), output data and expected levels of accuracy and uncertainties.
- A detailed description of the data and digital infrastructure required beyond existing services provided by the DESP.
- A detailed description of the expected data budget in terms of storage, inputs and outputs for a full operational scenario.
- A detailed description of all the links and dependencies with existing or planned relevant activities and programmes (e.g., DestinE).
- A detailed scientific and technical development roadmap including all aspects needed for further development towards a fully operational Digital Twin in the future. This shall cover all aspects: data, science needs, methodological needs, technical advancement that may be addressed by ESA science programmes (or by other European or national R&D programmes).

In addition, when relevant, the Contractor shall provide an assessment of the potential synergies and complementarities across different Digital Twin Components. As a result of this assessment, the Contractor shall provide a plan for potential integration and/or merging of different DTCs into a larger EO Digital Twin with a wider scope that may capitalise on the synergistic and complementary aspects of different DTCs.

Finally, the Contractor shall provide a detailed description of:

- The elements and services that are considered to be scientifically and technically mature and rely on sufficient proved quality and user acceptance to be transfer to an operational environment and a potential plan for such a transition (e.g., through DestinE of other operational programmes).

- A full development plan for a potential scale-up, expansion of functionalities and follow-on research and development of the proposed EO DTC functionalities and scope in subsequent phases of the ESA DTE programme for the timeframe 2026-2029.

The Scientific and Technical Roadmap shall be updated at six-month intervals, incorporating both short- and long-term development needs, some of which will be addressed in the remaining activities of the project.

At the end of Year 1, a plan of activities for Year 2 shall be proposed to ESA to be reviewed and approved at the Mid-Term review.

Deliverables:

KO +6: Draft Scientific and Technical Roadmap (STR) V1

KO +12: STR V1

KO +18: Draft STR V2

KO +24: STR V2

5.1.9 Task 9: Synergies and Coordination Across DTC Themes

Description:

In this task the Contractor shall ensure coordination, and when possible, collaboration, with other relevant projects, initiatives and activities that may benefit the project result and its impact.

In particular, the Contractor shall ensure coordination with the relevant DestinE activities including participation in the relevant workshops and events.

In addition, the Contractor shall ensure coordination with other relevant international, European and national programmes and activities relevant of the execution and impact of the project. This may include:

- Different user categories and representative of stakeholder groups.
- Other Digital Twin developments at international, European and national level.
- Relevant international scientific groups.
- Relevant ESA projects and activities including ESA scientific projects (e.g., ESA Science Cluster, Science for Society activities, CCI).
- Community representatives of relevant actors including scientists, industry, NGOs, policymakers, local, regional and authorities, international organisations, etc.
- Major international scientific groups.

ESA envisage many commonalities and potential synergies across different DTC projects addressing related Themes. This Task aims to identify these synergies and work towards joint solutions in view of developing an effective and efficient ecosystem of Digital Twins in subsequent phases of the programme. This may involve the joint definition and use of digital

services, interfaces, sharing of data and processing elements, including the potential to developed joint larger DTs in the future.

The Contractors shall actively coordinate with the relevant projects to identify those communities and potential joint solutions to be further developed in subsequent phases of the programme.

Coordination across DTC themes will be facilitated by ESA through DTC collocation workshops (every 6 months), where each team will present an outline of their DTC, including input datasets, methods, workflows, and Use Cases. As part of this workshop a dedicated activity to discuss and identify commonalities across DTC themes will be organised.

In addition, the Contractors may at any time during the project propose to ESA joint activities to be undertaken by different projects in view of reinforcing synergies and potential joint outputs. As an option, this can be further facilitated by ESA by hosting team members of different projects for a period of time (e.g., a few months) at the ESA Science Hub [RD8] as Visiting Scientists to work together and consolidate a joint view for the future.

Coordination activities shall be implemented during the full lifetime of the projects and shall be reported in DTC Coordination and Synergies Report as described below.

At the end of Year 1, a plan of activities for Year 2 shall be proposed to ESA to be reviewed and approved at the Mid-Term review.

Deliverables:

KO +6: Draft Coordination and Synergy Report (CSR) V1

KO +12: CSR V1

KO +18: Draft CSR V2

KO +24: CSR V2

6 REQUIREMENTS FOR MANAGEMENT, REPORTING, MEETINGS AND DELIVERABLES (TASK 10)

The project management shall ensure that the project activities are completed within the planned schedule and budget. It shall guarantee timely identification of issues arising during the project execution and work with the Agency Technical Officer to ensure appropriate mitigation measures are put in place. Finally, it shall ensure that all deliverables are of the required quality and available within the agreed schedule.

The following are the requirements for Management, Reporting, Meetings and Deliverables applicable to the present activity.

6.1 Management Requirements

6.1.1 Project Manager

The Contractor shall implement effective and economical management for the Project. Its nominated Project Manager shall be responsible for the management and execution of the work to be performed and, in the case of an industrial team, for the coordination and control of the industrial team's work.

6.1.2 Science Lead

The Contractor shall nominate a Science Lead, who will be responsible for the scientific excellence, direction, content and scientific soundness of the deliverables of the project.

6.1.3 Access

a) During the course of the Contract, the Agency shall be afforded free access to any plan, procedure, specification or other documentation relevant to the programme of work. Areas and equipment used during the development/testing activities associated with the Contract shall also be available for inspection and audit.

b) The Contractor shall notify the Agency at least three (3) weeks before any planned public demonstration, or as mutually agreed, in order to enable the Agency to select those demonstrations that it wishes to witness. The Agency shall notify the Contractor of its visit at least one (1) week in advance.

6.2 Reporting Requirements

6.2.1 Minutes of Meeting

a) The Contractor is responsible for the preparation and distribution of the minutes of the meetings held in connection with the Contract. Electronic versions shall be distributed to all participants within five (5) working days of the meeting occurring and signed no later than ten (10) working days after the meeting concerned.

b) The minutes shall clearly identify all agreements made and actions accepted at the meeting together with an update of the Action Item List (AIL) and the Document List.

6.2.2 Documents List

The Contractor shall create and maintain a Document List, recording all the documents produced during the work, including reports, specifications, plans and minutes. The list shall indicate the document reference (with unique identifier), type of document, date of issue, status (draft or approved by the Agency), confidentiality level and distribution. This list shall be maintained under configuration control.

6.2.3 Action Item List (AIL)

The Contractor shall maintain an Action Item List recording all actions agreed with the Agency. Each item shall be uniquely identified with reference to the minutes of the meeting at which the action was agreed and the AIL will record generation date, due date, originator and the person instructed to take action. The AIL shall be reviewed at each Progress Meeting.

6.2.4 Gantt Chart Schedule

a) The Contractor shall be responsible for maintaining the Gantt chart for work carried out under the Contract, as agreed with the Agency.

b) The Contractor shall present an up-to-date chart for review at all consequent meetings, indicating the current status of the Contract activity (WPs completed, documents delivered, etc.).

c) Major modifications of the schedule shall be contractually binding only if approved in writing by the Agency's representative for contractual and administrative matters.

6.2.5 Risk Register

a) The Contractor shall be responsible for maintaining a risk register, agreed at the kick-off meeting. This risk register shall identify potential risks, their likelihood and severity, and propose meaningful mitigation measures.

b) The Contractor shall present an up-to-date risk register in its Progress Reports for review at Progress Meetings.

6.2.6 Progress Reports

Every two months, the Contractor shall provide a Progress Report to the Agency's representatives, covering the activities carried out under the Contract. This report shall refer to the current activities shown on the latest issued Gantt chart and shall give:
action items completed during the reporting period;

1. a status report on all delivery items;
2. a description of progress: actual vs. schedule, milestones and events accomplished;

3. reasons for slippages and/or problem areas, if any, and corrective actions planned and/or taken, with revised completion date per activity;
4. events anticipated during the next reporting period (e.g. milestones reached);
5. expected date for major schedule items;
6. milestone payment status; and
7. status of risks.

Progress reports at KO+12 and KO+24, will act as Midterm Review and Final Reports.

6.2.7 Problem Notification

The Contractor shall notify the Agency's representatives (Technical Officer and Contracts Officer) of any problem likely to have a major effect on the time schedule of the work or to significantly impact the scope of the work to be performed (due to e.g. procurement problems, unavailability of facilities or resources, etc.).

6.3 Meetings Requirements

a) The Kick-Off meeting, Progress Meetings and Reviews shall be held in accordance with Section 6.5 below (Project Milestones and Deliverables).

b) The kick-off meeting shall take place at the Agency's premises.

c) Progress Meetings shall be held at approximately 2-monthly intervals, by video- or teleconference or at the Contractor premises for those indicated in Section 2.1.

d) The final presentation/demonstration shall take place at the Agency's premises.

e) Additional meetings may be requested either by the Agency or the Contractor.

f) The Contractor shall give to the Agency prior notice of any meetings with Third Party(ies) to be held in connection with the Contract. The Agency reserves the right of participation in such meetings.

g) With due notice to the Contractor, the Agency reserves the right to invite Third Party(ies) to meetings to facilitate information exchange.

h) For all meetings with the Agency, the Contractor shall ensure that proper notice is given at least two (2) weeks in advance. For all other meetings, the Contractor shall inform the Agency, which reserves the right to participate. The Contractor is responsible for ensuring the participation of its personnel and those of the Subcontractor(s), as needed.

i) For each meeting, the Contractor shall propose an agenda in electronic form and shall distribute an electronic version of the presentation given at the meeting.

6.4 Documentation Requirements

a) Technical documents from Subcontractor(s) shall be submitted to the Agency only after review and acceptance by the Contractor and shall be passed to the Agency via the Contractor's formal interface to the Agency.

b) All documentation deliverables mentioned hereunder (including all their constituent parts) shall be delivered in electronic form (uploaded to SharePoint / delivered by email to Technical Officer) in native format and as a searchable, indexed and not encrypted PDF.

c) The documentation shall be sent to the Technical Officer in electronic format not later than two (2) weeks before the documentation is to be presented.

d) All documents shall bear the appropriate copyright notice as specified in the Contract. In all cases, this shall include the ESA activity name, ESA Contract number, deliverable number, date, status (draft), version and/or revision number. The information shall be repeated consistently in the header or footer of every page.

6.5 Project Milestones and Deliverables

Deliverables	Milestones							
	MS 1	MS 2		MT		MS 4		FM
	KO+3	KO+6	KO+9	KO+12	KO+15	KO+18	KO+21	KO+24
RBD	V1	Draft V2		V2		Draft V3		V3
DTSD	V1	Draft V2		V2		Draft V3		V3
R&DR	V1	Draft V2		V2		Draft V3		V3
IIR	Plan	Draft V1		V1		Draft V2		V2
VR	Plan	Draft V1		V1		Draft V2		V2
P-DTC				V1				
PO-DTC								V1
DTC Demonstration				V1				V2
IAR		Draft V1		V1		Draft V2		V2
DOR		Draft V1		V1		Draft V2		V2
STR		Draft V1		V1		Draft V2		V2
CSR		Draft V1		V1		Draft V2		V2
WEB	x	x	x	x	x	x	x	x
OUT				x	x	x	x	x
MOM	x	x	x	x	x	x	x	x
PR	x	x	x	x	x	x	x	x
Co-location Meeting		x		x		x		x
MTR				x				
FR								x

See following section for definitions of deliverables and documentation acronyms.

For Early Development DTC activities, Contractors should complete relevant Tasks up to MT at KO+12.

6.6 Deliverables-Documentation Overview

- RBD: Requirements Baseline Document – Task 1
- DTSD: Design and Technical Specifications Document – Task 2

- R&DR: Research and Development Report (including ATBD: Algorithm Theoretical Basis Document, and PVR: Product Validation Report) – Task 3
- IIR: DTC Integration and Implementation Report – Task 4.
- VR: Validation Report – Task 5
- P-DTC: Protype DTC – Task 6
- PO-DTC: Pre-operational DTC – Task 6
- IAR: Impact Assessment Report – Task 6
- DOR: Dissemination and Outreach Summary report – Task 7
- STR: Scientific and Technical Roadmap – Task 8
- CSR: DTC Coordination and Synergy Report – Task 9
- WEB: Website updates – Task 7
- OUT: Outreach activities – Task 7
- MOM: Minutes of meetings – Task 10
- PR: Progress Reports – Task 10
- MTR: Midterm Review Report – Task 10
- FR: Final Report – Task 10

APPENDIX A. DTC THEMES

A.1. Priority Themes

A.1.1. Theme 1 – Agriculture

Agriculture is vital for food production and feeding the global population. As the climate changes, it has become especially important to understand how harvests may be affected by anthropogenic and natural processes. Today, food systems are under increasing pressure, amongst others, due to population growth, changing dietary habits, weather extremes or the competition with biofuels over remaining fertile lands. The critical relevance of food systems also results from the fact that they are intrinsically linked to carbon, water, biodiversity and global biogeochemical cycles.

The overriding goal of an Agriculture focused DTC or DTC-Agriculture, is to create a comprehensive virtual replica of agricultural systems from global to local scale (e.g. field scale) that will support the scientific community to enhance our understanding of agriculture under multiple stressors (including climate change and human interventions), and deliver science-based solutions to support monitoring, assessment and simulation of crop behaviour, and modelling growth dynamics under different conditions and stress factors.

An important aspect of any future agriculture DTC is the ability to implement ‘what-if’ scenarios, to allow various stakeholders to make decisions on future agricultural practices and assess their impact.

DTC-Agriculture shall be relevant for responding to SDGs and key European agricultural policy including the CAP, and Green Deal, which dedicates special attention to food systems and in particular to *designing a fair, healthy and environmentally-friendly food system (the ‘Farm to Fork’ strategy).*

Although the transition to more sustainable systems has started, feeding a fast-growing world population remains a challenge with current production practices. Food production results in air, water and soil pollution, contributes to the loss of biodiversity and climate change, and consumes significant amounts of natural resources, while a significant amount of food produced is wasted. Consequently, several key challenges of the 21st century directly relate to agricultural production and food systems. Tackling these key challenges are priority areas to be addressed by DTE, e.g.:

- Provide novel information capabilities to develop effective science-based solutions to increased crop productivity towards healthy food for all, while facilitating the transition towards sustainable agricultural practices.
- Advancing simulation of yield production at local/district, national and global scale under different scenarios.
- Determining the response of crops and food production to co-occurring stressors (water resources, soil degradation, pollinator decline, pests) including climate adaptation and resilience.
- Enhancing our understanding of the interactions between food systems, water, carbon and ecosystems.
- Designing sustainable strategies to respond to water scarcity (droughts) and extreme weather events (e.g., flooding, heatwaves, storms).
- Supporting the assessment of National Strategic Plans with respect to agro-environmental and climatic policy impact, such as nitrate leaching reduction or soil carbon storage.

DTC-Agriculture shall cover a wide range of spatial, and temporal scales, allowing for near real-time assessment, as well as past-casts and forecasts. These monitoring and prediction capabilities shall make use of a range of data sources, including a wide variety of EO satellite missions including Sentinels 1 and 2, novel hyperspectral and thermal data, together with in-situ data (e.g., advanced in-situ sensors at field level), statistical data and advanced modelling frameworks, data analytics methods, AI and ML approaches. These data can be also combined with Very-High-Resolution commercial data on specific sites to serve specific user demands.

A.1.2. Theme 2 – Land Biodiversity

Preserving the integrity and health of natural land ecosystems (terrestrial and freshwater biodiversity) and the biodiversity they host is crucial, not only for the vital services they provide to sustain human well-being and the functioning of our societies (e.g., climate regulation, food supply, water and air purification, flood protection, plant pollination), but also because natural ecosystems with a high degree of integrity and diversity tend to exhibit remarkable levels of productivity and resilience. The intricate interplay of ecosystems and biodiversity influences various facets of the Earth System and is a key factor in understanding many of its processes.

The global biodiversity assessment conducted in 2019 by the Intergovernmental Platform on Biodiversity and Ecosystem Service (IPBES) highlighted that, despite the increasing awareness that sustainable development cannot be achieved without adequate attention to the protection of ecosystems and the safeguard of biodiversity, and despite the encouraging steps taken around the world to tackle biodiversity loss at many levels, the overall progress is still largely insufficient. As a response, the Kunming-Montreal Global Biodiversity Framework (GBF), which represents the most ambitious and transformative global agenda, aims at stabilising biodiversity loss by 2030 and allowing for the recovery of natural ecosystems, ensuring that by 2050 all of the world's ecosystems are restored, resilient, and adequately protected. Advancing to such an ambitious goal will require:

- *Better quantification and characterisation of the changes in biodiversity and related ecosystem services and attribution of its main drivers.*
- *Better assessment of the status and resilience of natural ecosystems and quantification of the impacts of the main direct drivers of changes.*
- *Enhanced understanding of the adverse impacts of climate change on biodiversity and ecosystem functioning.*
- *Help understanding the main evolutionary changes of biodiversity and better prediction of their trajectories.*
- *Enhanced collective capacity to explore the pathways of transformative changes and the effects of "nature-based solutions" with respect to "no intervention scenarios".*
- *Better prioritisation, design and monitoring of conservation and restoration actions.*

DTC-Biodiversity shall fundamentally contribute to the development of a consistent and reliable system for monitoring ecosystems, the biodiversity they host, and the services they provide to society, detecting biodiversity changes and attributing these to causal drivers, improving our understanding of the ecological processes, helping the understanding of the main evolutionary changes of biodiversity, and predicting biodiversity trajectories. It shall contribute to filling major knowledge gaps in biodiversity, including: e.g.,

- *Knowledge of the global changes in ecosystem structure, functioning and in ecosystem integrity, and of their evolutionary changes.*

- *Assessing the resilience of biodiversity hot-spots and quantification of the impact of the main direct and indirect drivers of changes to biodiversity, and attribution of biodiversity changes to the causal drivers. e.g., climate, disturbance, and management factors.*
- *Enhanced simulations of land biodiversity responses to projected seasonal anomalies.*
- *Analysis of the adverse climate change effects on biodiversity and ecosystems functioning.*
- *Knowledge of the areas of the world projected to experience significant negative effects from global changes in biodiversity.*
- *Scenarios and pathways for better management of biodiversity (including ecosystem restoration and conservation): e.g., impact on land spatial planning affecting fragmentation of ecosystems and ecological competition.*

DTC-Biodiversity will require the effective integration of observations from a variety of data sources (including satellite and field observations) and covering different aspects of biodiversity (e.g., ecosystem structure, ecosystem functioning, community composition, species traits, species population, genetic composition), and their integration into biodiversity models in order to comprehend the underlying ecological processes in ecosystems and predict their changes.

DTC-Biodiversity shall be implemented in the framework of existing Global biodiversity monitoring networks and international efforts such as those of the Group on Earth Observation Biodiversity Observation Network (GEO BON), which are rapidly improving our ability to observe and understand patterns of biodiversity change worldwide, thanks also to the increasing use of satellite Earth Observation datasets.

A.1.3. Theme 3 – Terrestrial biosphere & carbon cycle

Significant improvements have been made in the estimation of the terrestrial carbon budget (CO2), in particular the change to the concept of ‘imbalance’ through the quantification and parameterisation of differences between methods for estimating the carbon budget (top-down, bottom-up etc). Advances have also been made in the determination of the budgets of the two other major greenhouse gases, methane (CH4) and nitrous oxide (N2O). However, there remains a strong need for improved knowledge and representation of natural (e.g., extremes) and anthropogenic impacts on the terrestrial carbon cycle as these directly impact global carbon budgets. They also have strong regional variability and are expressions of the mechanisms by which interventions by humans will be made to move towards net-zero carbon balance and reduce the anthropogenic carbon footprint.

Advanced EO satellite data is opening the door to major advances in the range and provision of high-resolution information from satellites (e.g., from Sentinel 1 and 2) to better characterise the land biosphere and the terrestrial pools and fluxes of carbon, for example high-resolution land cover and land cover change maps, vegetation variables such as cover fraction, albedo, land surface temperature, soil moisture, evapotranspiration, leaf area, fAPAR as well as novel observations of solar induced fluorescence (SIF), vegetation optical depth (VOD), vegetation height and estimates of global forest structure, biomass (e.g., by novel SAR systems such as BIOMASS, NISAR, SAOCOM) and related disturbances such as fires. This will continue through the long-term commitment to observations (especially the Sentinel series and the new generation and expansion Sentinel missions) as well as improved observations from many relevant scientific national and commercial systems. Such Earth Observation datasets, **together with in-situ data and ground networks**, provide rich observational resources to improve high-resolution land surface and carbon assessment and simulations and help increase the resolutions of model representations to be more compatible with decision making and policy implementation needs.

DTC-Terrestrial Biosphere with a particular focus on the Carbon Cycle is a wide-ranging topic that involves understanding the interaction between soils, vegetation and the atmosphere and the impact on them, of both direct and indirect human interventions. This shall be based on the advanced capacity offered by the wide set of novel high-resolution satellite observations to establish advanced 4D dynamic data-driven reconstruction of the terrestrial biosphere including a comprehensive set of variables characterising the numerous land-surface processes involved in the terrestrial carbon cycle, its pools, and fluxes, and their response to more frequent and intense extremes in weather and climate as well as capacity to characterise perturbation by human activities, both direct and indirect.

The DTC shall serve the scientific community in allowing the understanding and quantification of the land related carbon pools and fluxes to be advanced further and to characterise their responses to both hydro-climatic extremes and human interventions. The objectives in developing the DTC are to provide policymakers with advanced science-based design support tools, simulations and what-if scenarios to enhance tracking carbon for verification, accounting and analysing vulnerability of carbon stocks to different stressors and to support definition of sustainable adaption and mitigation practices.

The DTC shall also be developed to potentially serve ESA (and other space agencies) as a tool for science and application research, novel product benchmarking, to assess the impact of novel datasets, and to support the design of future observing systems.

A DTC of the terrestrial biosphere and carbon should be conceived to operate at the scales of observation of high-resolution satellites and advanced high-resolution models of the Earth System (e.g., from 10s of metres to 1 km resolutions) enhancing current capabilities to characterise natural process and human interactions at fine resolution in space and time both at global and regional scales. For this ITT, priority shall be given to bottom-up approaches, in view of expanding potentially to a combined approach with top-down methods (atmospheric inversions) as soon as CO2M is launched.

A DTC on terrestrial carbon shall be based on advanced **data-driven and hybrid methods** fostering a land hybrid modelling paradigm combining, in an effective and scientifically-sound manner, state-of-the-art EO data and ground data (e.g., flux towers) with physically-based process models and AI/ML elements in a modular manner accounting for the complexity and linkages (or cascade) of processes in the carbon cycle.

DTC-Terrestrial biosphere & carbon cycle shall play a major role in assessing the impact on the carbon cycle of climate, weather and human interventions through: e.g.,

- Enhanced capacity to estimate carbon pools and fluxes of the land biosphere and track carbon stocks.
- Enhanced assessment of vulnerability of carbon stocks to different anthropogenic stressors: e.g., intensity and type of land use and the frequency of change.
- Determining the carbon impact of change in LULUCF practices, spatial planning and management/policy interventions.
- Support for assessment of the carbon impact of National Strategic Plans on LULUCF comprising their national, regional, and global impacts.
- Enhanced understanding and assessment of vulnerability of response of terrestrial carbon ecosystems to climate change with special attention to hydro-climatic extremes: e.g., heatwaves, drought, and flooding.
- Enhanced representations of feedbacks between water, vegetation, carbon, nutrient cycles and the atmosphere at the spatial resolution of land decision making.

A DTC of the Terrestrial Biosphere and Carbon may develop suitable interactions with other DTCs to exchange relevant information (and or services) (e.g., water, forest, biodiversity, agriculture).

A.1.4. Theme 4 – Coastal processes and extremes

Around 10% of the world's population live in coastal regions and these areas attract a wide set of economic and social activities. However, they are highly vulnerable to climate change being particularly affected by rises in sea level, erosion, and extremes such as storm surges and floods. They also play a key role in the Earth system as the interface between the land and the ocean and are of fundamental importance to account for the fluxes of carbon, nutrients, pollutants, and freshwater between the land and sea. They also represent a reservoir for biodiversity, fisheries and other economic sectors.

The Digital Twin Component (DTC) for coastal processes shall offer a virtual dynamic replica and interactive reconstruction, at high spatial and temporal resolution, of the coastal environment. It shall address the complex dynamical processes and interactions to support enhanced scientific understanding of this region under climate change and human interventions. The DTC should support assessment, simulations and what-if scenarios of natural and human activity to enhance management and policy implementation, including adaptation and mitigation actions to climate change.

A DTC of Coastal process and extremes shall provide an enhanced and comprehensive 4D data-driven reconstruction of coastal regions and the complex processes based on EO-based data of physical and bio-chemical variables including bathymetry and coast line characterisation, coastal sea level, waves, winds, SST, SSS, coastal currents, ocean colour and biochemistry, ecosystem characterisation, carbon pools and fluxes, land-sea transports, etc.

EO-based data shall be complemented with in-situ data and socio-economic information to represent a fundamental building block that together with advanced coastal models, AI and hybrid methods may offer advanced science-based solutions, simulations and what-if scenarios capabilities to a wide set of stakeholders across scientific and policy sectors. Relevant activities in this context include, e.g.,

- Enhanced assessment capabilities of the exposure of coastal communities to extremes events and climate-related hazards, including intensified marine heatwaves, storm surges, extreme sea levels and flooding, coastal erosion, salinity intrusion, in combination with adverse effects from human activities on ocean and land.
- Supporting coastal spatial planning and offering enhanced tools for the assessment of critical exposure, risk and vulnerability of coastal social-ecological systems. This shall allow the evaluation of resilience and support the definition of effective coastal adaptation strategies on lives and livelihoods.
- Enhanced capabilities to characterise and assess the impacts of land-sea transport of marine pollution including land-based pollution, such as contaminants from industrial sewage, run-off of nutrients and pesticides from urban and agricultural exploitations.
- Identification and characterization of suitable parameters/indicators for monitoring water quality, pollution, and harmful events such as HAB/Sargassum proliferation.
- Better characterisation of the related processes and predictions of coastal biodiversity under climate change and potential future shifts in coastal ecosystems, including fish distribution, decreases in their abundance and fisheries catch potential.
- Enhanced understanding and characterisation of the role of coastal areas in the Earth and climate system, with special attention to the characterization and projection of the various

coastal carbon pools and fluxes, including blue carbon and related components such as mangroves and salt marshes.

The DTC of coastal areas shall be based on a comprehensive high-resolution data-driven reconstruction of coastal regions and its processes based on the latest EO capabilities and especially the exploitation of the large and increasing set of different sensors offering high-resolution data over the world's coastal areas. Such a large set of satellite-based observation shall be complemented with dedicated in-situ networks and advanced observation systems (e.g., unmanned system) for a complete and comprehensive description of processes.

The DTC of coastal regions shall contribute to the European Digital Twin of the Ocean and relevant international efforts such as DITTO a digital twin initiative of the UN Decade of Ocean Science for Sustainable Development. The Contractors shall ensure appropriate coordination with these initiatives during the execution of the project.

A.1.5. Theme 5 – Data-driven Ocean

This Theme shall contribute to the international efforts to develop a Digital Twin of the Ocean and in particular to the European DTO initiative, under the umbrella of the EC, which aims to model the ocean's multiple components, provide knowledge and understanding of the past and present, and create trustable predictions of its future behaviour.

In particular, this Theme represents ESA efforts to contribute to developing a DTO and especially to advancing and maximising the use of state-of-the-art EO data to provide an advanced and comprehensive digital representation of the ocean, based on real-time and historical EO data products and in-situ data from a wide range of sources, together with advanced modelling (Physics, Biogeochemistry, Ecosystems), AI and hybrid methods.

It shall complement existing efforts (e.g., European DTO and related Horizon Europe activities) to advance towards a DTO and provide tools for a wide range of stakeholders to explore ocean information and processes, enhance scientific understanding, and provide knowledge to empower science-based decision making. It shall also contribute to the DITTO a Digital Twin initiative of the UN Decade of Ocean Science for Sustainable Development. The Contractors shall ensure appropriate coordination with these initiatives during the execution of the project.

This specific Theme shall address crucial and identifiable Use Cases, advancing the understanding of the ocean's role in the climate system and its responses to management actions to contribute to reverse the decline in ocean health and improve conditions for sustainable development of the Ocean.

Use Cases shall focus, among others, on key regional domains including European relevant areas such as the Mediterranean, the Atlantic and the Baltic.

Expected benefits from a data-driven Ocean DTC are multiple, ranging from advanced scientific capabilities to improve the understanding of key ocean processes and interactions with the rest of the Earth system, to offering to a wide set of stakeholders advanced science-based decision-making tools based on simulations and "What-if" scenarios in the wider context of ocean conservation, SDGs and climate change. This includes e.g.,

- *Upper ocean dynamics and ocean circulation, including an enhanced 4D reconstruction, characterization and simulation of currents, waves, sea-level, SST and SSS and their interactions.*
- *Ocean Extremes – enhanced characterization of the frequency, detectability and predictability of extreme events such as Heatwaves, Tropical Cyclones, Medicanes and Polar Lows, and its impacts in the Earth system and ocean ecosystems.*
- *Multi-stressors – characterization of the severity, intensity and extent of compound multi-stressors such as MHW, ocean acidification and deoxygenation.*
- *Enhanced simulation and what-if scenarios of Ocean carbon, offering an advanced data-driven characterisation of the various carbon pools and fluxes.*
- *Air-sea-ice fluxes/exchanges – enhanced characterization of air-sea-ice processes and exchanges, and their impact in the Earth and climate systems, especially under extreme conditions.*
- *Better understanding, characterisation and prediction of the role of the ocean in climate, including impacts and feedbacks with ocean circulation, ocean carbon and acidification, ocean heat content, feedbacks of climate and ocean biology, etc.*
- *Enhanced characterisation of ocean biodiversity and ocean ecosystems under multiple stressors, including climate change and human activities.*
- *Better characterisation of the related processes and predictions of future shifts in fish distribution, changes in their abundance and fisheries catch potential.*

A.1.6. Theme 6 – Forests

Forests are valuable and irreplaceable ecosystems, which play an important role from an ecological, social, and economic perspective. They cover about 30% of the global land area and serve as habitats for two thirds of terrestrial animal and plant species, and are home to many indigenous people. By absorbing and storing atmospheric carbon, they are essential for mitigating the effects of climate change. Forests are reservoirs of biodiversity and regulate the terrestrial water cycle, and provide livelihoods and resources of income for communities around the globe.

The aim of DTC-Forests is to develop a virtual replica of real-world forest systems, with representation across a range of spatial scales (from individual trees (1 m – 10 m), whole forests (100 m – 1 km), to the global scale), allowing for a deep and previously unachievable comprehensive view of forest dynamics. This approach should capture feedback across scales and understand the impact of climate change, deforestation, invasive species, storms and wildfires.

This will be achieved through insights into forest parameters such as: structural characteristics (tree count, tree height and diameter, stem volume, canopy cover, etc); carbon sequestration; water fluxes/stress; productivity; plant species composition; fire fuel loading; resilience to potential disturbances (storms, pests, fire) and human pressure for change in land use. In addition, processes that underlie forest dynamics including mortality, health, harvest, disturbance regime.

The DTC should be based on an advanced data-driven and dynamic reconstruction of the forest ecosystems from a wide range of EO data sources, including, but not limited to, the free and open Sentinels-1, -2 and -3, hyperspectral missions (e.g. EnMAP and PRISMA), and upcoming FLEX and BIOMASS missions, as well as very high-resolution instruments and other non-ESA missions (e.g. ALOS, Landsat, SAOCOM, NISAR). This should be complimented by additional data from in-situ and ground-based observations. Modelling could simulate the behaviour of individual trees integrated into data-driven, physics-constrained and hybrid models that can simulate the behaviour of forests and its responses to climate change and human intervention (e.g., management practices). Furthermore,

enabling data assimilation and physically-based data fusion for forest variables at high spatial resolution will allow forest information to be accessed in a standardized manner.

Using these elements, DTC-Forests shall allow for the testing of 'what if' scenarios, based on historical and current trends, in order to test forest management strategies for adaptation and mitigation, predict future environmental changes providing input for planting forests, and support the sustainable management of forests. Furthermore, helping forest managers and policymakers to balance the competing demands of various stakeholders, such as timber production, conservation, and recreation, and the pressures of changing climate and disturbance regimes. The validation of the DTC-Forests would be crucial to ensure its reliability and accuracy.

A DTC of Forest may develop suitable interactions with other DTCs to exchange relevant information (and or services) (e.g., water, carbon, biodiversity).

A.1.7. Theme 7 – Hydrology & hydro-hazards

This Digital Twin Component is motivated by the urgent need to develop advanced science-based solutions to respond to the present-day water challenges and to optimally observe, understand, monitor, and manage water resources (i.e., for drinking, sanitation, irrigation, hydropower, recreation & tourism) and provide innovative decision-support tools to address the risks associated with the hydrology cycle (e.g., floods, droughts, landslides) under a changing climate.

Central to the development of this DTC is the need to establish a scientifically sound and advanced capacity to:

- Enhance our scientific knowledge and capacity to better observe and model hydrological processes with high levels of accuracy at high resolution in space and time over large regions (basin and continental scales).
- Capture the interactions of the hydrology system with human activity (agriculture, industry, energy and reservoir management, flood protection, human and animal water consumption) at appropriate spatial and temporal scales.
- Assess responses to changes in hydrological patterns derived from climate change, which has made hydrology-related extreme events more frequent and severe in several regions of the world, such as heavy rainfall and subsequent flooding, and conversely heatwaves and drought.

An EO DTC on hydrology shall be based on the latest advances in EO data to provide a 4D data-driven, comprehensive, and scientifically sound dynamic reconstruction of the hydrological cycle capturing all its different components and related variables in a consistent manner at resolutions in scale and time compatible with decision making, especially targeting the sub-basin scales.

In particular, the DTC on hydrology shall target high spatial (e.g., < 1 km) and temporal (e.g., < 1 day) resolution over large regions and basins, overcoming the capacity of existing systems. Datasets shall include a combination of the most advanced state-of-the-art EO data products & in-situ and ground observations including, but not limited to: river and lake level (satellite altimetry), soil moisture, evaporation, precipitation, snow water equivalent, river discharge, runoff, flooded areas, land surface temperature, groundwater, irrigation, river/lake ice cover and additional information such as land cover and land use, topography and land motion (e.g., subsidence).

As such, satellite Earth Observation datasets need to be integrated with advanced high-resolution hydrology models, hydraulic models and other simulation tools (e.g., for land-slides) in a set of scientifically sound workflows including an effective, flexible and modular combination of process-based, AI and hybrid approaches, to characterize processes from the sub-kilometre scale (infiltration, surface and subsurface runoff, etc) up to the catchment-scale (river fluxes, lake status, etc), at sub-daily temporal resolution.

A DTC on hydrology shall address the needs of a wide set of stakeholders including the scientific community, basin authorities, policymakers and the general public. Examples of possible capabilities within this DTC may include, but are not limited to:

- *Enhanced understanding of the hydrological cycle under climate change from basin to global scales with special attention to the extremes and its related hazards.*
- *Enhanced scientific understanding and characterisation of the impacts of human activities in the hydrological cycle from basins to global scales.*
- *Advanced stimulations of the hydrological cycle and what-if scenarios supporting advanced water management and resolution in space and time compatible with decision making.*
- *Advanced decision support tools, simulations, and what-if scenarios to support the response to hydro-climatic extremes with special focus on floods.*
- *Advanced decision support tools, simulations, and what-if scenarios to support the response to related hazards such as landslides, droughts, heat waves.*
- *Providing suitable simulations and advanced what-if scenarios that may support decision making and the definition of suitable adaptation and mitigation strategies to cope with hydro-climatic disruptions.*

A DTC of Hydrology may develop suitable interactions with other DTCs to exchange relevant information (and or services) on water and water relevant uses (e.g., agriculture, carbon, biodiversity).

It may also serve ESA (and other space agencies) as a tool for science and application research, novel product benchmarking, to assess the impact novel data and to support the design of future observing systems.

A.1.8. Theme 8 – Ice Sheets and regional/global impacts

Ice sheets play an important role in many elements of the Earth System influencing the global climate, atmospheric and ocean circulation, global sea level, solid earth deformation and ecosystems. Both the Greenland and Antarctic ice sheets are currently experiencing significant change, with increases in melting and mass loss triggered by atmospheric and ocean warming. Furthermore, there are large uncertainties in their future evolution and stability. Improving our understanding of the current state of ice sheets, the underlying processes, and our ability to predict future change will be vital for communities, governments, and businesses worldwide, due to implications for sea-level rise and changes to atmospheric and ocean circulation.

DTC Ice Sheets shall focus on Antarctica and/or Greenland and should harness the wide range of mature and pre-operational EO data products for ice sheets including ice velocity, surface elevation change, EO-based mass balance estimates, snow properties, surface melting, calving front location, grounding line location, supraglacial lake area (and volume), ice damage/crevasses, ice-shelf basal melt, ice discharge, subglacial lake activity, intra-glacial temperature, subglacial heat flux, and others…

These datasets offer a unique opportunity to develop an advanced interactive data driven reconstruction of the ice sheet system.

This DTC shall bring these advanced datasets together with physically based models (e.g., regional climate models, ice sheets models, ocean models), AI and hybrid approaches to provide an advanced and up to date holistic reconstruction of the ice sheets and its dynamics including all its components (from the lithosphere to the surface, the atmosphere and the ocean) as an interconnected system with focus on critical ice-sheet processes and its evolution under climate change (i.e., ice sheet mass balance, ice-shelf stability and interactions with the sea-ice and the ocean, freshwater budget, supraglacial melting processes, iceberg calving, glacier velocity changes, subglacial hydrology, etc).

DTC shall serve the scientific community as a reference community tool to better assess and understand ice-sheet dynamics and their implications for near-future projections and the wider Earth System. Therefore, Users should be able to interrogate the system based on historical records and the present-day state to identify significant events, the onset and magnitude of changes, anomalies and potential tipping points and derive insights into the underling processes, drivers, and potential future evolution. The DTC should also represent how ice-sheet processes are interconnected and evolving, and how they link to the wider Earth System, such as the atmosphere, sea-ice, and ocean.

It is expected the DTC is based on a modular approach including an effective combination of data and data processing elements, well constrained physical-based models, ensembles, AI and hybrid approaches that brings together the latest scientific results into a reference community tool supporting science, benchmarking activities, community efforts and offering state of the art data, information and simulation capabilities.

DTC should facilitate access to data, tools and “What if scenarios” that are relevant for scientists, but also to other stakeholders, and policymakers, that help understand observed changes and its impacts on, for example, global sea-level rise, ecology, changes in ocean circulation, and when relevant economic activities such as fishing, shipping, or energy.

The DTC should harness scientific advances and insights from recently finished and ongoing international science activities, such as those of ESA Polar Cluster or national, European or international science activities.

A.2. Secondary Themes

Early development activities may focus on demonstrating the value of EO capabilities to develop DTCs addressing the following topics:

- **Arctic land and ocean:** Enhancing the comprehensive characterisation, understanding and prediction capacity of the different changes taken place in the Arctic region (Land and/or Ocean) as a system, their root causes and its future impacts on society and ecosystems. This shall provide a tool to prepare local communities and Europe to deal with climate disruptions, assist citizens in better understanding, preparing for and managing climate related risks. Furthermore, this Theme may address different components including ocean-sea-ice-atmosphere interactions, permafrost and methane emissions, etc.

- **Air quality and health**: Advancing the high-resolution (in space and time) characterisation of air quality from local (city level) to regional scales by enhanced integration of satellite, ground-

based information, advanced models and AI to offer a holistic view of pollution sources, air quality and other environmental stressors to human health risks.

- **Energy Sector**: Advancing towards an interactive simulation of the Earth system in support of the Energy sector, as well as, in the holistic simulation of the impact of Energy systems in the Earth and climate systems.

- **Geo-hazards**: Advancing the global simulation and assessment of risks and predictions of geo-hazards through an effective integration of state-of-the-art EO data (e.g., surface displacement), ground-based information, suitable models (including local and regional/global solid Earth components) and AI capabilities to characterise the structure and behaviour of volcanoes and/or earthquakes.

- **Glaciers**: Holistic digital high-resolution reconstruction of the global glacier systems in high mountain ranges, their dynamic behaviour, responses to climate change and impacts on downstream water availability (Earth's water towers), enhancing current capabilities for monitoring and predicting glacier changes on a regional and global scale, helping to support decision making (e.g., managing related hazards, support downstream water management) and science.

- **Solid Earth**: Advancing towards a holistic dynamic simulation of the solid earth from the core to the crust, focusing on establishing appropriate connections across the different components with special attention to enhancing the characterisation of dynamic process, including the links between the deep components and surface processes.

- **Transport and Infrastructure**: Advancing towards DTCs supporting regional and national planning of transport networks and infrastructure, including the management and design of sustainable transport infrastructure, assessment of its impacts on the Earth and climate system, as well as supporting national and regional authorities to design adaptation and mitigation plans to cope with climate change.

- **Urban**: Advancing towards DTCs to support the monitoring and planning (e.g., green spaces) of urban areas, assessing impacts of climate change to support adaptation and mitigation actions, and defining what if scenarios for address climate related disruptions such as urban heating and flooding.

- **Wildfires**: Advancing towards a dedicated DTC to support the understanding, monitoring, prevention, and responses to wildfires. This DTC shall support wildfire management at all stages of the fire management cycle, including dedicated advanced dynamic data-driven reconstruction and modelling for prevention and mitigation.

APPENDIX B. INTERFACING WITH DESP

The DESP [RD2] is the DestinE entry point for users. It provides access to the data available from the DEDL (DestinE Data Lake) and the complex simulations generated by the DestinE Digital Twins, as well as dedicated digital services. DESP shall foster the development of user activities and the hosting of complementary services within the scope of the DestinE objectives.

The DESP framework is designed as an open framework that promotes the development of an ecosystem of users, or third-party activities, that are also interoperable with other ecosystems, such as other European initiatives or programs (e.g., Copernicus).

DESP is therefore conceived with the capability to support the growth of a large ecosystem of users and services. It will rely on several capabilities, including [RD3,4,5,6]:

- Users and service providers, supporting services like IAM service (Identity & Access Management), Service Desk, monitoring, operational dashboard, DestinE-related information content, etc.,
- Access to cloud infrastructure (i.e., storage, network, or compute resources) through the OVH cloud,
- Platform as a Service (PaaS), Software as a Service (SaaS), Function as a Service (FaaS),
- Data management services like discovery, catalogues, data retrieval, data extraction and transformation, data cache, traceability, visualisation, etc.,
- Interoperability with complementary ecosystems of users or services.

These services shall be available for all potential users as well as for any potential Third-Party applications or services, in the context of this SoW, pre-operational DTC demonstrators. DESP development is currently ongoing and is expected to become active by the middle of 2024; Contractors are advised to keep apprised of developments published on the DestinE website [RD1], with the overall concepts identified in [RD2,6], where the following terminology is adopted:

- The term “application” refers to a software package that performs a specific function for an end-user or for another application. In particular, software libraries, add-ons or drivers, software client or servers are considered as “applications”.

- The term “service” refers to a specific function or application operated by a Service Provider based on a service-level agreement (SLA) that defines the expected level of performance, laying out the metrics by which service is measured, as well as the solutions for underperformance.

B.1. DESP ARCHITECTURE AND SERVICES

The DESP Framework consists of services, applications, tools, and functionalities bringing together Information Technologies and DestinE-related European actors. Its main objectives are:

- exploiting the DestinE-produced data,
- enhancing the end-user experience, by providing targeted tools and services to boost productivity,

- limiting commercial and technical lock-in,
- maximising performances and operations reliability and promoting the development of related Third-Party and European initiatives.

A description of the services and applications to be made available, as a part of the currently under development DESP are described in [RD3,4,5,6]. As a preliminary description, Contractors can expect the following services and applications to be available in the DESP:

Core Services - basic services for platform operability, including the role of DESP provider, coordinating all services at DESP, including

- Platform Management Services: these services covering the platform operations and maintenance into operational conditions, e.g. identity management, service desk, basic reporting of platform activity and resources via public dashboard, etc.

- Data Management Services: services covering the primary needs for data management and exploitation, including data access and IaaS.

DESP Advanced Services - applications provided under contract with ESA or by third-party providers, making use of DESP Core Services, including:

- Advanced Services: services covering the provision of DestinE data related environments (PaaS) offering frameworks for the information extraction and decision making, e.g., data, modelling, and simulation services (visualisation, notebooks, modelling environment, etc.)

- Collaborative Services: Platform services supporting exchanges between users and collaboration between projects.

- ESA EO Data Space, services for integrating the Earth Observation DTCs into DestinE. These services will support DTCs developments and ingestion into the DESP, providing access to the DESP ecosystem, while expanding the capability of the DESP, e.g. expanded Earth Observation data and digital services, additional availability of ESA Earth Explorer, Heritage and relevant TPM-data.

During this activity, the Contractor in charge of implementing and operating DESP Core Services will be available to provide support for facilitating the adaptation of the DTC to DestinE's Platform architecture and functionalities. At this stage the DESP and the DTE related digital services are under development.

Tenderers shall take into account the following assumptions and requirements in the execution of the project until new information will be provided by ESA:

- The Contractor shall maximize the use of the DESP and new DTE related digital services during the execution of the projects and especially during the demonstration of the Use cases.

- As a minimum the Contractor shall use ensure the access to the DTC capabilities to the users during the final demonstration through the DESP as dedicated DESP services.

- It is important to note that today, the DESP will not provide HPC capability. The Contractors shall ensure suitable access to HPC capabilities if required to implement and complete the DTC implementation, integration, and demonstration as part of their proposal.

- The DESP and DTE digital services will include computing storage and processing, visualisation capabilities, notebooks, etc. The Contractor shall maximise the use of those services but can also bring additional capabilities when required by the DTC to be developed.

- **All developments activities under this contract including data processing and storage shall be costed in the budget available for this ITT** (as a reference for the prices of the DESP services the Contractor can use the OVH cloud services).

- Any additional or alternative platform capability proposed to be used by the Contractors shall be communicated to ESA at the time of the proposal and be properly justified.

APPENDIX 3
CONTRACT CHANGE NOTICE

For submission of a change as per Clause 13 of the General Conditions, the Contractor shall submit its proposal in the format of a CCN using the cover page included below. The form shall be filled with the following information as a minimum:

- The Contractor's name and the ESA Contract number;
- The title of the area affected by the change (Work Package reference, new work, etc.);
- The name of the initiator of the change (Contractor or ESA);
- The description of the change (including Work Package Descriptions, WBS, etc.);
- The reason for the change;
- The price breakdown in Euro (€), if any (breakdown by company, Phase, etc., including PSS A2 and PSS A8 forms);
- The Milestone Payment Plan for the CCN, if any;
- Effect on other Contract provisions;
- Start of work - end of work (including contractual delivery dates and overall planning, milestones, etc.);
- A CCN Form, as per the format below, signed by the Contractor's representatives.

The Contractor shall, on request of the Agency, provide additional documentary evidence. At the request of either Party, the proposed change may be discussed at a Change Review Board, consisting of both the Contracts Officer and the Technical Officer of each Party.

<table>
<tr><td colspan="2">  </td><td>DIRECTORATE:</td><td>Contractor:</td></tr>
<tr><td colspan="3"></td><td>ESA Contract No. 4000146395/24/I-KE</td></tr>
<tr><td colspan="3">CONTRACT CHANGE NOTICE No.</td><td>DATE:</td></tr>
<tr><td colspan="3" rowspan="2">TITLE OF AREA AFFECTED (WORK PACKAGE ETC):</td><td>WP REF:</td></tr>
<tr><td>INITIATOR OF CHANGE:</td></tr>
<tr><td colspan="4">DESCRIPTION OF CHANGE</td></tr>
<tr><td colspan="4">REASON FOR CHANGE</td></tr>
<tr><td colspan="4">PRICE BREAKDOWN (Currency)/PRICE-LEVEL</td></tr>
<tr><td colspan="3" rowspan="2">EFFECT ON OTHER CONTRACT PROVISIONS</td><td>START OF WORK</td></tr>
<tr><td>END OF WORK</td></tr>
<tr><td colspan="2">CONTRACTOR’S TECHNICAL OFFICER:

DATE:</td><td colspan="2">CONTRACTOR’S CONTRACTS OFFICER:

DATE:</td></tr>
<tr><td colspan="4">[DISPOSITION RECORD OR OTHER AGREED CONDITION RECORDED WITH THE CCN APPROVAL]</td></tr>
<tr><td colspan="2">ESA TECHNICAL OFFICER:

DATE:</td><td colspan="2">ESA CONTRACTS OFFICER:

DATE:</td></tr>
</table>

APPENDIX 4
INVENTORY/FIXED ASSET RECORD

1.1. Content of electronic Inventory/Fixed Asset Record

The Contractor shall establish an electronic Inventory/Fixed Asset Record with, as a minimum, the following information:

For all items:
- Contract number/subcontract number if applicable;
- unique item number;
- confirmation that the item has been marked with the unique item number;
- description of item;
- part number/serial number/type code;
- quantity;
- system/subsystem;
- property owner;
- manufacturer;
- classification (category – see section 1.2 below);
- acquisition value (i.e. original purchase price or price at Contract signature as applicable);
- date of purchase or production ("in service date" if not corresponding with date of purchase/production);
- in-service date;
- foreseen useful life (to be agreed with ESA);
- physical location (e.g. facility, building, room);
- entity responsible for care and custody;
- related WBS code or other identifier to be coordinated with the Agency);
- description and date of any change to the property item;
- planned method of disposal (if applicable).

In addition to the above, the following information shall be added to those items that are identified as becoming ESA Fixed Assets in Article 3 of the Contract, as applicable:
- Acquisition value
  - revision of this value as a result of change(s) to the asset;
- Impairment report of each ESA Fixed Asset remaining in the custody of the Contractor after its acceptance by ESA (using the template that will be provided by the Agency upon announcement by the Contractor that the item has been impaired);
- date of acceptance by ESA (planned date of acceptance);
- foreseen handling after ESA's acceptance (e.g. transfer to ESA, continuing in custody of the Contractor).

1.2. Classification of Inventory/Fixed Assets items

For the purpose of Inventory/Fixed Asset Control, items shall be classified into five (5) categories, according to the source and intended use of the items, as follows:

Source/Purpose	**Supplier-acquired Items**	**Customer-furnished Items**
Consumable items (e.g. parts, materials, supplies)	Class 1	Class 2
Capital items/production support equipment and tools (e.g. instruments, jigs, fixtures)	Class 3	Class 4
Items purchased by the supplier or its lower tier suppliers on their own account but amortised under the Contract	Class 5	

Note 1: Consumable items are parts, materials, supplies, components, modules, minor expendable tools, assemblies, units and subsystems, which through the production process lose their identity and are absorbed directly or indirectly by the system/product to be provided under the Contract.

Note 2: Consumable items are in principle not capitalised per item; however, before consumption they are identified as assets of the Agency under the collective term “Consumable”.

Note 3: Capital items/production support equipment and tools are jigs, fixtures, devises, apparatus, instruments, machines, installations, technical facilities, buildings, computer programmes, documentation, models, samples or any other item, which, after their use in or in conjunction with the production process under the Contract, are expected to have a residual utility or other value for the Agency.

Note 4: Capital items have a useful life of more than one (1) year and are identified as individual items in the supplier’s and its lower tier suppliers’ list of Agency’s assets.

ESA-DTE-B-01-LEAD DTCS DEVELOPMENT ACTIONS AND ESA-DTE-B-02 EARLY DTCS DEVELOPMENT ACTIONS – DTC Forest

Subcontract for Contracted Work under ESA Project 4000146395/24/I-KE

Global Change Research Institute CAS (CzechGlobe)

Appendix 2. Specification of Subcontractor's tasks, allocated personnel and payment plan

Specification of tasks

- Main responsibility over conducting Use Case Czechia, including:
  - Coordination of all activities concerning the Use Case
  - Implementation of use case demonstration
  - Provision of data
  - Provision of access to required software
  - Stakeholder engagement
  - WP 1: Contribute to the deliverable document Requirement Baseline Document (RBD)
  - WP 2: Required theoretical developments
  - WP 2: Contribution to the Research and Development Report (R&DR) concerning the Use Case activities, particularly in the Algorithm Theoretical Basis Document (ATBD)
  - WP 4: Support in uncertainty estimation; contribution to Validation Report (VR)
  - WP 5: Support in impact assessment; contribution to Impact Assessment Report (IAR)
- Contribute to other work packages as needed, including:
  - WP 6: Contribute to the deliverable document Scientific and Technical Roadmap (STR)
  - WP 6: Participate in outreach and communication
- Participate in project meetings and other activities relevant for the partner role
- Contribute to the Progress Reports, Midterm Review Report and Final Report

Allocated personnel

Table 1 lists the key personnel and non-key personnel (in italics) allocated for the project by the Subcontractor during project negotiations with ESA, as well as their workload in hours per work package and percentage of work time dedication.

Table 1. Key personnel and non-key personnel (in italics) and their workloads in hours

Name	Role in the activity	WP0	WP1	WP2	WP3	WP4	WP5	WP6	TOTAL	Percentage time dedication
[redacted]	UC CZ lead		50	50		50	60	60	270	8 %
[redacted]	b.beetle modelling		120	250		150	210	130	860	26 %
[redacted]	data expert		50	100		60	100	50	360	11 %
[redacted]	*Forest remote sensing expert*		*60*	*50*		*50*	*30*	*40*	*230*	*7 %*
[redacted]	*biomass, productivity modelling*		*60*	*140*		*90*	*110*	*80*	*480*	*15 %*
[redacted]	*Data handling, quality control*			*400*		*150*	*100*		*650*	*20 %*
[redacted]	*b.beetle and other data pre-processing, programming*			*250*		*165*	*110*	*100*	*625*	*19 %*
[redacted]	*database handling*			*200*		*100*			*300*	*9 %*
[redacted]	*Project management*		*12*	*12*		*12*	*12*	*12*	*60*	*2 %*

Payment plan

Subcontractor's payment plan is presented in Table 2.

Table 2. Subcontractor's payment plan

Milestone	Indicative schedule	Payment	Note
Advance Payment	KO	30 000 €	30 %
MS 1	KO+3	13 649 €	
MS 2	KO+6	13 649 €	
MS 3	KO+12	22 702 €	
MS 4	KO+18	7 298 €	27 298 € - 20 000 € advance offset
MS 5	KO+24	12 702 €	22 702 € - 10 000 € advance offset
TOTAL		**100 000 €**	

From: **VTT Technical Research Centre of Finland, Ltd.**

Date: **15 April 2024**

To: EUROPEAN SPACE AGENCY (ESA),

The European Space Research Institute (ESRIN),
Largo Galileo Galilei 1,
00044 Frascati (RM),
Italy,

Attn: [redacted] ***(CIC-COE)***

Subject: **ESA AO/1-12108/24/I-KE**
ESA-DTE-B-01-LEAD DTCS DEVELOPMENT ACTIONS AND ESA-DTE-B-02 EARLY DTCS DEVELOPMENT ACTIONS

Category: ESA Standard Procurement

Our Ref.: Proposal No. 233304-24
Development Action: **Lead DTCs Development Actions**
Theme: **6 – Forests**

Dear Sir/Madam,

With reference to the above Invitation to Tender ("ITT"), we are pleased to present this Proposal:

1. The Tenderer (potential Contractor) is:
   VTT Technical Research Centre of Finland, Ltd.
   Tekniikantie 21, Espoo, Finland
   Postal address: PO Box 1000, 02044 VTT, Finland
   Telephone: +358 20 722 111
   Nationality (according to ESA Convention's criteria): Finland
   VAT Number: **FI26473754**
   ESA Entity Code: 1 000 001 603

2. The Prime Contractor and Subcontractor(s) participating to the activity is (are):

Proposed Team and Price Breakdown Information:

	Prime Contractor	Sub-contractor 1	Sub-contractor 2	Sub-contractor 3	Sub-contractor 4	Sub-contractor 5
Economic Operator Complete Name and Legal Nature	**VTT Technical Research Centre of Finland, Ltd.**	**Yucatrote**	**Terramonitor**	**Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences**	**Global Change Research Institute CAS**	**Forest Science and Technology Centre of Catalonia**
SME	**NO**	**YES**	**YES**	**NO**	**NO**	**NO**
Large Space Integrator	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**
ESA Entity Code	**1000001603**	**1000037600**	**1000026282**	**1000001618**	**1000002611**	**1000036105**
ESA Business Unit Code	**8000012719**	**8000043356**	**8000029291**	**8000015202**	**8000016171**	**8000041579**
Country (ISO code)	**FI**	**PT**	**FI**	**DE**	**CZ**	**ES**
Price Type	**FFP**	**FFP**	**FFP**	**FFP**	**FFP**	**FFP**
Total price in Euro per Prime/Sub	654 860	205 000	328 000	128 000	100 000	84 140
CONTRACT GRAND TOTAL	**1 500 000 EURO**					

3. **Geographical Distribution within the Proposed Team**
(for the Prime and Subcontractor(s) only, not for suppliers):

Country (2-letter ISO code)	Percentage of total amount
Finland (FI)	66 %
Portugal (PT)	14 %
Germany (DE)	9 %
Czech Republic (CZ)	7 %
Spain (ES)	6 %

4. Our Firm Fixed Price for the activity in accordance with the funding conditions stated in the ITT, amounts to: ***1,500,000*** **Euro** *(one million five hundred thousand Euro)*, all included with the sole exception of any import duties and value added taxes in the Agency's Member States.

5. The contact details of the Tenderer for this tender are the following:

Contact person to whom all communications related to the tender should be addressed:	Name: Telephone no.: Email address: Postal address:	[redacted] [redacted] [redacted] P.O. Box 1000 FI-02044 VTT, Finland
Author(s) of the tender:	Name: Job title: Name: Job title: Name: Job title:	[redacted] Principal Scientist [redacted] Senior Scientist [redacted] Senior Scientist
Person who will be responsible for the **Technical management** of any resulting Contract and who would be nominated as such in the Contract:	Name: Telephone no.: Email address: Postal address:	[redacted] [redacted] [redacted] P.O. Box 1000 FI-02044 VTT, Finland

Person who will be responsible for the **Contractual management** of any resulting Contract and who would be nominated as such in the Contract:	Name: Telephone no.: Email address:	[redacted] [redacted] [redacted] [redacted] [redacted] [redacted]
	Postal address:	P.O. Box 1000 FI-02044 VTT, Finland
Data Protection contact point:	Name: Telephone no.: Email address: Postal address:	[redacted] [redacted] [redacted] P.O. Box 1000, FI-02044 VTT, Finland

Person that will **sign** any resulting Contract:	Name: Job title:	[redacted] Executive Vice President

For each Subcontractor:

Name of Subcontractor:	Name: Address:	Yucatrote Rua Antonio Gavina 49 8600-214 Lagos, Portugal
Contact person for the purposes of their bid to the Prime Contractor:	Name: Telephone no.: Email address:	[redacted] [redacted] [redacted]

Name of Subcontractor:	Name: Address:	~~Terramonitor (Oy)~~ Opastinsilta 6 A 00520 Helsinki, Finland
Contact person for the purposes of their bid to the Prime Contractor:	Name: Telephone no.: Email address:	[redacted] [redacted] j[redacted]

Name of Subcontractor:	Name: Address:	Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences Telegrafenberg, 14473 Potsdam, Germany
Contact person for the purposes of their bid to the Prime Contractor:	Name: Telephone no.: Email address:	[redacted] [redacted] [redacted]

Name of Subcontractor:	Name: Address:	Global Change Research Institute CAS (CzechGlobe) Bělidla 986/4a, 603 00 Brno, Czech Republic
Contact person for the purposes of their bid to the Prime Contractor:	Name: Telephone no.: Email address:	[redacted] [redacted] [redacted]

Name of Subcontractor:	Name: Address:	Forest Science and Technology Centre of Catalonia Ctra Sant llorenç de Morunys km2 Solsona E-25280 Lleida, Spain
Contact person for the purposes of their bid to the Prime Contractor:	Name: Telephone no.: Email address:	[redacted] [redacted] [redacted]

6. Regarding the scientific technical and management contents of this Proposal, we hereby certify that this tender fully complies with the technical and management requirements of the subject ITT, including the latter's Statement of Work (SoW) and all other Appendices and/or Annexes.

   In addition, the scientific and technical contents of this Proposal are free from any plagiarism. When use is made of material being quotations or citations from existing public literature, such use is clearly indicated, and due reference indications (source and author) are provided.

7. We hereby state that we have read and understood all the terms and conditions of the Draft Contract included in the subject ITT and that we accept such terms and conditions without any reservations.
   We also confirm that any sales conditions of our own shall not apply.

   We hereby explicitly state that we have read, understood and accepted the Personal Data Processing Annex (the "PDP Annex") to the Draft Contract.

   Financial conditions:
   The VTT rates used in the PSS forms are not based on a completed audit. As a temporary solution, VTT now uses inflation-adjusted rates in ESA tenders. Please see more detailed description in the Proposal document Section 5.2.1.2.

8. In regard to the required statements concerning free competition, we hereby certify that:
   a) the prices in this Proposal have been arrived at independently without consultation, communication or agreement for the purpose of restricting competition;
   b) unless otherwise required by law, the prices quoted in this tender have not knowingly been disclosed, directly or indirectly, to any other Tenderer or competitor and, likewise, will not be disclosed until we have been informed of the results of the ITT;
   c) no attempt has been made or will be made to induce any other Tenderer or competitor to submit or abstain from submitting a tender, for the purpose of restricting competition; and
   d) no exclusive teaming arrangement with Third Party(ies) has been made which would restrict competition due to any of the following reasons:
      - where the teaming partner could be considered to be a single source due to technical reasons or other considerations such as legal or geographical (e.g. an extremely limited number of potential participants as a consequence of industrial return requirements); or
      - where the industrial category of the teaming partner restricts other choices for industrial policy reasons; for instance, when the fact of being an SME is very important and there are few potential participants in this category.

9. By submitting the Proposal, I/we the undersigned herewith officially declare that the Proposal fulfils the Key Acceptance Factors, as indicated in section 3 of the subject ITT Cover Letter and in the dedicated section of the esa-star Tendering.

Done and signed for and on behalf of VTT Technical Research Centre of Finland, Ltd.

Signature:

Name and title of the signatory: **Erja Turunen** (Executive Vice President) duly authorised to commit the tendering entity and its proposed Subcontractor(s) if any, for this purpose.

DETAILED PROPOSAL

1) BACKGROUND AND FACILITIES

1.1 Background of the company(ies)

VTT Technical Research Centre of Finland Ltd. (VTT) provides a wide range of technology and applied research services for its clients, private companies, institutions and the public sector. VTT was established in 1942. Originally, VTT was a government organisation established by law and was until recently operating under the auspices of the Finnish Ministry of Economic Affairs and Employment. In 2015, VTT turned into a not-for-profit, fully state-owned limited company. VTT has its headquarters in Espoo and has other main locations in Tampere, Oulu and Jyväskylä with more than 2200 employees. Finland's national metrology institute and national standards laboratory MIKES is part of VTT. In 2022, the net turnover of VTT was 165 M€. VTT is a long-standing partner of ESA, and is hosting together with Aalto University MilliLab, an ESA External Laboratory on Millimetre Wave Technology. The Remote Sensing team of VTT has been active in several recent and ongoing ESA-funded projects related to the current ITT, where VTT has developed a user-oriented platform for forest-related tasks with Earth Observation data, implemented processing chains for producing forest variable maps at regional to national scales, and demonstrated the possibility to estimate the productivity and growth of forests at the time of observation and in the future.

Key relevant projects coordinated by VTT:

- **Forestry Thematic Exploitation Platform** (Forestry TEP, 2015–2022, ESA) is an online processing platform for the forestry community, enabling efficient utilization of satellite data in forest analysis tasks. Global satellite data and computation services are provided; users can upload and share their data and services (https://f-tep.com)
- **Forest Flux** (2018–2020, Horizon 2020) fostered the development of the Copernicus Earth Observation (EO) market and improve the profitability of forest management by implementing a world-first service of high-resolution maps of forest carbon fluxes, storage, and their development over time. (https://www.forestflux.eu/)
- **Forest Digital Twin Earth Precursor** (2019–2020, ESA) prototyped a digital twin of forests using state-of-the-art scientific knowledge and capabilities for the upcoming Destination Earth infrastructure. (https://foresttwin.org)
- **Forest Carbon Monitoring** (2021–2025, ESA) developed a prototype of a reliable monitoring and accounting platform for forest carbon stock, which maximizes the synergetic use of Earth Observation data and responds to policy needs with direct added-value for operational and user organizations. (https://www.forestcarbonplatform.org/)

Yucatrote is an SME based in Portugal. Yucatrote applies modern computational techniques to simulate the dynamics of forests under changing environmental conditions. By means of process-based models the company carries out analyses on forest growth, Carbon balance and biodiversity functioning under climate change, alternative management options and disturbance risks. Using Bayesian methods, model data fusion and data assimilations, Yucatrote is able to integrate multiple data sources in the forest modelling framework. Modelling analyses are performed at different spatial and temporal resolutions. Uncertainty and sensitivity analyses are an integral part of the modelling tools.

Yucatrote has also developed a data assimilation (DA) system that allows to integrate remotely sensed data in model predictions in an iterative way.

Key relevant projects:

- Forest Carbon Monitoring (2021–2025, ESA) (https://www.forestcarbonplatform.org/)
- ForestNavigator (Navigating forests & bioeconomy sustainably to climate goals (forestnavigator.eu))
- C-Neut (2022–2024, academy of Finland) (https://www.syke.fi/en-US/Research__development/Research_and_development_projects/Projects/Evaluating_integrated_spatially_explicit_carbonneutrality_for_boreal_landscapes_and_regions_CNEUT)
- IBC-carbon (2017–2023, academy of Finland) (https://www.ibccarbon.fi)

Terramonitor is one of the pioneering companies in downstream applications utilising satellite-based data in Finland. Terramonitor has been working in the domains of forestry, urban development and electricity distribution applications since beginning 2016. The company has knowledge working within the forestry industry and with the main contractor VTT, and has the process and networks to provide the service for the project. We have build scalable cloud-based systems for managing the processes in infrastructures such as AWS (Amazon Web Services) and F-TEP (Forestry Thematic Exploitation Platform). Terramonitor has previous expertise with private companies, research institutes and public authorities incl. projects with ESA. In the forestry domain, we have processed data for large geographical areas and supporting customers with their processing needs.

Key relevant projects:

- First ever comprehensive up to date mosaic of the world (https://business.esa.int/news/terramonitor-launches-satellite-based-map-stream-planet-earth)
- Finnish Forest Act monitoring was changed to monitor forest use in Finnish forests in 2019 (https://sentinel.esa.int/web/success-stories/-/copernicus-sentinel-2-supports-forestry-in-finland),
- SATNETMONITOR (ESA, 2022), subcontractor to develop satellite based monitoring for electricity distribution networks (https://business.esa.int/projects/satnetmonitor)
- Providing large scale analysis ready satellite data for Forestry TEP platform (https://www.forestcarbonplatform.org/) in 2023

Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences (GFZ) is Germany's national research centre for the Earth Sciences with the mission to deepen the knowledge of the dynamics of the solid Earth, and to develop solutions for grand challenges facing society. The section for remote sensing geoinformation is led by Prof. Dr. Martin Herold. The Section has the scientific lead of the German hyperspectral satellite mission EnMAP. The working group Global Land Monitoring, led by Prof. Dr. Martin Herold specializes in the domain of quantitative, physical and statistical based retrieval of land surface parameters relevant for earth system science, and land monitoring and assessments for a number of applications.

Key relevant projects:

- **RemoTrees** (2023-2027, HE): RemoTrees: develop and test a new in-situ observation system based on Internet of Things (IoT) technology and satellite communication, specifically designed for hard-to-reach forest areas.
- **StrucNet** (2022-2027, Helmholtz): A GFZ funded long-term monitoring program for at least 10 forest sites worldwide to track dynamics with near sensing (terrestrial LIDAR, drone, sensorwebs) technologies. There is a particular focus on biomass and change.
- **IDEAS-QA4EO** (2019-2024, ESA): Development of novel cal/val technologies, in particular UAV hyperspectral sensing, for space-borne hyperspectral missions.
- **ForestScan** (2019-2023, ESA): Implementation of forest biomass super-sites with novel sensor technologies (terrestrial lidar, unoccupied aerial vehicle lidar), formulation of best practice guidelines for forest biomass cal/val.

The Global Change Research Institute of the Czech Academy of Sciences (CzechGlobe) is a public research institute that conducts comprehensive research on issues of global climate change and its impacts on the atmosphere, terrestrial ecosystems and human society. CzechGlobe has more than 300 employees and has worked on more than 280 national and international projects, including 13 projects for ESA. The institute operates networks of ecosystem research stations and experimental sites contributing to ICOS-ERIC, AnaEE-ERIC, ACTRIS. Develops early warning systems such as drought monitoring and forecasting, forest fire risk assessment, agronomic risk assessment. The airborne remote sensing research platform (FLIS) regularly supports ESA campaigns (SurfSense, FLEXSense, TOMOSense). This project involves two research teams, the Dept. of Remote Sensing and the Dept. of Xylogenesis and Biomass. The Dept. of Remote Sensing has a strong background in airborne remote sensing, combining laser scanning with hyperspectral data. Both teams cooperate closely in the assessment of forest ecosystems in the Czech Republic using field monitoring and remote sensing methods.

Key relevant projects:

- Forest4Society (2021-2024, TACR, Norway and Lichtenstein Funds) – establishing the Dendronet forest biomonitoring network and assessment of forest productive and regulation functions in CR and Norway using EO methods (https://forest4future.czechglobe.cz/).
- CHIME L2 processor (2023 – 2028, ESA) – L2 algorithm and processor prototyping and development, cal/val of L2B high priority products.
- Operational assessment of aboveground biomass in forest ecosystems using advanced remote sensing methods (2019 – 2022, national funding).
- Hyperspectral Analysis and Heterogeneous surface modelling (2015 – 2017, ESA) – forest radiative transfer modelling and retrieval of forest trait from hyperspectral data.

The Forest Science and Technology Centre of Catalonia (CTFC) is a public consortium created in 1996 with the mission of contributing to the modernization and competitiveness of the forest sector, promoting (i) economic and social development of rural areas, (ii) bioeconomy along value-chains, (iii) climate change mitigation, and (iv) sustainable management of the environment, and integrating the valorisation of natural resources into socioeconomic models, through excellence in research and transfer of knowledge and technology to society. CTFC's employs over 160 professionals and has become a centre of reference in the Mediterranean and Southern European context. This project involves researchers from the Multifunctional Forest Management and the Landscape dynamics and

biodiversity programmes. The former undertakes research on the ecology of fire, the capacity of forest systems to adapt and respond to natural disturbances, and the prevention of large forest fires, whereas the latter develops models to assess the occurrence and effect of fires on forested landscapes and their related economic and ecological processes, as well as decision-support tools to optimize forest management in order to develop fire prevention plans that reduce impacts.

Key relevant projects, coordinated by CTFC:

- SINTETIC (H2020, 2023-2027) Single item identification for forest production, protection and management (https://cordis.europa.eu/project/id/101082051)
- DECISIONES (H2020, 2021-2026) Decision Support for the Supply of Ecosystem Services under Global Change (https://cordis.europa.eu/project/id/101007950)
- FIRE-RES (H2020, 2021-2025) Innovative technologies and socio-ecological-economic solutions for fire resilient territories in Europe (https://cordis.europa.eu/project/id/101037419/es)

1.2 Overall Team composition, Proposed Key Personnel

Project Manager: Renne Tergujeff (VTT)
Scientific Lead: Matti Mõttus (VTT)

Key personnel:

1. Matti Mõttus (VTT)
2. Renne Tergujeff (VTT)
3. Laura Sirro (VTT)
4. Lauri Häme (Terramonitor)
5. Juho Häme (Terramonitor)
6. Joni Norppa (Terramonitor)
7. Francesco Minunno (Yucatrote)
8. Lucie Homolová (CzechGlobe)
9. Vojtěch Bárta (CzechGlobe)
10. Jan Krejza (CzechGlobe)
11. Martin Herold (GFZ)
12. Benjamin Brede (GFZ)
13. José Ramón González (CTFC)
14. Miriam Piqué (CTFC)
15. Eduard Busquets (CTFC)

1.3 Curricula Vitae of Key Personnel

The CVs of all key personnel are uploaded to esa-star detailing their position in the organization and current activities outside Forest DTC. The assignments and roles of the key personnel in the current project are as follows:

1. **Matti Mõttus** (VTT) will be the Scientific Lead of the project and manager of WP 6 *Outreach, roadmap and synergies*. Dr. Mõttus was the PI of the Forest Digital Twin Earth Precursor project and his tasks will be supervision of the scientific activities (research, validation) in the project. His background is in scientific research related to remote sensing of the status and functioning of forests. He has been the principal and co-

investigator for numerous research projects and is a member of the scientific advisory groups for the EnMAP and FLEX missions.

2. **Renne Tergujeff** (VTT) will be the Project Manager of Forest DTC and the manager of WP 1. *Requirements and DTC design*. Mr. Tergujeff is a Certified Project Manager according to IPMA Level C. He has strong background in managing research and development projects, incl. development and maintenance of the Forestry TEP funded originally by ESA, and he is also familiar with agile software development in an environment similar to that of Forest DTC.
3. **Laura Sirro** (VTT) will be the manager of WP 5 *DTC Demonstration and Impact Assessment*. Ms Sirro ha sample experience in developing and implementation of forest-related algorithms working close to users. She has acted as a deputy manager in the EU-funded Forest Flux project and implemented use cases similar to the ones in Forest DTC. She will be the coordinator of the Finnish use case in Forest DTC.
4. **Lauri Häme** (Terramonitor), Manager of WP 3 *Integration and implementation*, and CTo of Terramonitor, will be responsible for the selection and design of the technical solutions in Forest DTC. He has extensive experience in forest and EO-related software solutions for customers from different backgrounds.
5. **Juho Häme** (Terramonitor) is a Senior Software Architect responsible for the practical development of the software on the DESP platform. He has experience from numerous ESA-funded projects at Terramonitor.
6. **Joni Norppa** (Terramonitor) has close to 20 years of experience in managing customer-oriented projects in the remote sensing industry with specific focus in forestry. Mr. Häme will be responsible for developing the customer-friendly interfaces in Forest DTC.
7. **Francesco Minunno** (Yucatrote), Manager of WPs 2 *Research and development* and 4 *Validation, error analysis and uncertainty quantification* is the CEO and co-founder of Yucatrote. Dr. Minunno has a strong background in forest science with specific focus on modelling. He has obtained his academic degrees in different top European universities and as a postdoc worked on the development of the modelling chains used in Forest DTC – among other forest modelling related activities.
8. **Lucie Homolová** (CzechGlobe), Head of Department of Remote Sensing at Global Change Research Institute, will coordinate the activities at Czechglobe related to development of bark beetle simulations, implementation of forest growth models and management of forest-related data from the Czech Republic. Dr. Homolová has successfully managed many international projects (incl. ones involving ESA) related to remote sensing of vegetation with special focus on forests.
9. **Vojtěch Bárta** (CzechGlobe) is a researcher working on identifying bark beetle infestations in Czech Republic and their mapping with remote sensing data. Dr. Bárta will be the key researcher on the topic in Forest DTC.
10. **Jan Krejza** (CzechGlobe) studies wood production and carbon sequestration, including long-term monitoring of forests. Dr. Krejza is the PI of DendroNetwork, providing detailed data on forest growth and productivity. His role in ForestDTC will be supporting the Czech use case with expertise in forest productivity and tree mortality.
11. **Martin Herold** (GFZ), Section head at GFZ Helmholz GeoResearch Center Potsdam and Professor at University of Potsdam, will be the scientific lead of the scientific use case based on well-studied forest research sites in Europe. Prof. Herold is well-networked within the scientific community studying in detail the roles of forests in the carbon cycle. He will provide the project long-term experience in satellite-based monitoring of biomass and carbon emissions, integrating ground and satellite

observations, and accuracy assessment procedures and uncertainty management for remote sensing data products.

12. **Benjamin Brede** (GFZ) will coordinate the practical work on the extensive datasets on the experimental forests making up the scientific use case. Dr. Brede will be the key researcher on integrating these data with the scientific use case.
13. **José Ramón González** (CTFC), Senior Researcher at the Forest Sciences Centre of Catalonia will be the scientific leaf of the Catalan use case focusing on fire disturmance risk mapping. Dr. González has strong scientific background in mapping and modelling forest fires in the Mediterranean basin and across Europe.
14. **Miriam Piqué** (CTFC) will be the fire modelling researcher in Forest DTC. Dr. Piqué has ample experience in this type of scientific activities using different modelling tools.
15. **Eduard Busquets** (CTFC) will act as a data expert, helping to integrate the numerous data sources required for running the fire simulations in Catalonia and elsewhere in Europe.

1.4 Tenderer's facilities for the execution of the work

VTT operates and develops the Forestry TEP platform (f-tep.com), an online environment for efficient utilisation of satellite data in forest analysis tasks. VTT is inviting researchers and service providers to on-board their algorithms to the platform as new value-adding services. The goal is to grow the Forestry TEP into a leading collaborative platform for research, development and innovation in the field of remote sensing of forests.

Forestry TEP provides continuous access to current and archive satellite data globally, including the global optical and radar data from the Copernicus Sentinel satellite instruments. Users can upload their own data as well, and access to hosted VHR data can also be arranged by request. A selection of data processing services is available, and popular tools such as QGIS and ESA SNAP can also be used on the platform. The platform is hosted on the CREODIAS cloud computing and data provision infrastructure, in the context of the Copernicus Data Space Ecosystem. Apart from the online user interface, all the platform features and processing services can be efficiently accessed from external systems via the F-TEP API interface or a client-side Python library.

For researchers and value-adding service providers, Forestry TEP offers a powerful online application development environment based on Linux and Docker. Developers can craft their software using any programming language and build them online to produce processing services that exploit the data on the platform. An extended data catalogue is available in service development, including digital elevation models (DEMs), Copernicus Land Monitoring Service (CLMS) data and more. The developers can also link to externally hosted datasets. The platform is actively exploited by many research and development projects that are building new processing tools and chains on the platform, including Forest Carbon Monitoring, EO4SDG Forest and PEOPLE-ER.

A major architectural revision for the platform is in the works through implementing the Earth Observation Exploitation Platform Common Architecture (EOEPCA). This includes a new processing service concept and developer tooling, based on the OGC Best Practice for Earth Observation Application Package. While the development is being finalised, selected subscription options already include access to a beta release of the new offering.

GFZ Remote Sensing and Geo-information UAV pool (https://www.gfz-potsdam.de/en/section/remote-sensing-and-geoinformatics/infrastructure/uav-pool) includes a range of sensors including high-resolution optical (RGB), multi-spectral, hyperspectral, LiDAR and radar, all specifically designed for UAV applications and fitted with auxiliary equipment and ground stations. These sensors are carried by platforms reaching from light weight to heavy lift (up to 20 kg payload).

GFZ StrucNet is a research infrastructure focussing on the observation of forests. StrucNet consists of permanent monitoring sensors, including monitoring lidar and GNSS vegetation optical depth, and movable campaign instruments, including terrestrial and UAV laser scanning. StrucNet focusses on data acquisition at already equipped sites, e.g. the ICOS network, thereby fostering the supersite character, better linking ground and EO data, and supplying near-real time data where possible.

CzechGlobe operates the following research facilities and services:

- Flying Laboratory of Imaging Systems (https://olc.czechglobe.cz/en/flis-2/*):* an operational airborne infrastructure allowing for synchronous acquisition of hyperspectral data (CASI sensor for VNIR, SASI sensor for SWIR, TASI sensor for TIR) with airborne laser scanning (Riegl LMS Q780). The infrastructure is certified for HyPlant fluorescence sensor. It has been used to support Cal/Val activities of PRISMA (Priscav project), FLEX (e.g. FlexSense campaigns). Team maintains archive of airborne data.
- Observation network and campaign data: national observation network of ecosystem stations with continuous measurements of ecosystem fluxes, meteorology, biophysical parameters of main forest types and croplands (contributing to ICOS-ERIC and eLTER-RI networks). DendroNetwork for continuous biomonitoring of forest vitality and productivity (https://forest4future.czechglobe.cz/dendronetwork/)
- Computing resources*:* Linux and Windows computing serves.
- Early warning and forecasting systems: drought, forest fires, agricultural risks, crop yield forecasting (https://www.czechglobe.cz/en/media-and-pr/early-warning-systems/).
- The institute was awarded by HR Excellence in Research Award in 2019 and it also has ISO certifications for quality management ISO 9001:2015 and environmental management ISO 14001:2015.

2) TECHNICAL/SCIENCE PART

2.1 Understanding of the requirements and main objectives of the ITT

Within the DestinE framework, Forest DTC will implement, integrate and validate an end-to-end pre-operational realisation of a digital replica of the World's forests. Forest DTC will be implemented on the Destination Earth Core Service Platform (DESP) using open science and FAIR principles. Forest DTC will use data available on DESP and, to the extent necessary for efficient operational activities, other online platforms, e.g. Destination Earth Data Lake (DEDL) and Forestry Thematic Exploitation Platform (Forestry TEP).

The current proposal relies largely on the earlier work undertaken in this direction by the members of the consortium. In the Forest Digital Twin Earth Precursor project (funded by ESA in 2020–2021, lead contractor VTT), a pre-operational precursor version was demonstrated, based on numerous research projects involving users from private, public and research sectors. The shortcomings and scientific advances addressed in this proposal are largely based on the user analyses and roadmapping activities reported in the project deliverables to ESA. The key results on the methodology of implementing a digital twin of the Earth's Forests were published by Mõttus et al. (2021). The proposed advances are detailed in the subsection *Proposed scientific and technical* advances below.

Forest DTC will be developed for the forest community with strong community support. The Expression of Interested submitted to ESA by the Consortium lead included support letters from the following stakeholder organizations:

- Food and Agriculture Organization of the United Nations
- Climate Leadership Coalition (CLC), the largest non-profit climate business network in Europe
- Integrated Carbon Observation System (ICOS) Finland

Community support is also visible from the surveys and dissemination activities in the Forest Digital Twin Earth Precursor project and related projects, such as Forest Carbon Monitoring. Community needs were incorporated based on the study carried out by the Precursor project published in GI Journal by Mõttus et al. (2021).

The approach proposed here matches fully the basic principles of the DTC specified in the Statement of Work as described in the following section.

2.2 Proposed approach to reach the main technical objectives of the ITT and proposed technical and scientific approach.

Forest DTC will be implemented as a set of algorithms implemented in common computer languages such as Python, R, and C. The algorithms are packaged as docker images which can be ported to different cloud platforms to be run on virtual computers. The algorithms are parameterized using configuration files which contain the inputs including links to locations of input and output data. The dockerised algorithms are set up (i.e., their configuration files are created), started and monitored by a scriptable module -- e.g., by a "notebook" stated in SoW, or a graphical user interface defining the processing conditions, input data sources and storage locations – running on a separate virtual computer on the cloud. The algorithms and the control script are highly adapted to the specific platform (DESP), cloud architecture and software environment it's operated in. Ultimately, the

controlling system will be a part of DESP initialized and controlled by the platform and instantiated on demand automatically (regular re-runs) or via user interaction (on-demand what-if processing).

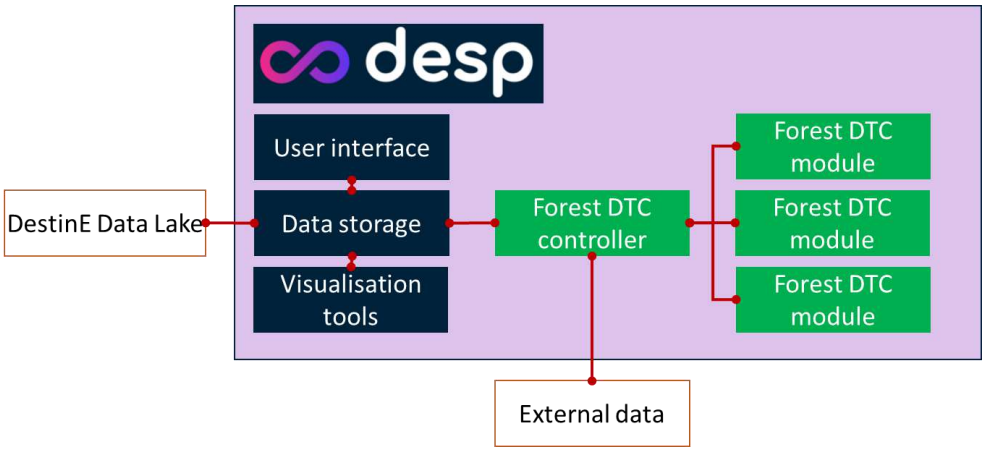


Figure 1. The processing with Forest DTC.

The output of the simulations will be stored on the DESP. The Forest DTC controlling script or other UI will prompt the user when the data are available or indicate if an error has occurred, and – if instructed so – will call the visualization tools available on DESP. Forest DTC will be implemented as open source software.

The Forest DTC is based on the scientific understanding that the growth and development of every tree making up the overstory in a forest depends on the boundary conditions determined by the state of the atmosphere and the soil, and the way the neighbouring trees alter them (absorb radiation, drain the soil). A forest model is thus an ecosystem model which focuses on the largest organisms in the given system, trees, and their interaction with other organisms characterized as biotic processes, and abiotic factors. The modelling development of each individual is only meaningful if it is done inside a group of other individuals functioning under similar boundary conditions and interacting with each other. Also, forests are more than trees with soil functions are parameterized using fluxes of water and carbon; other life forms supported by trees can be modelled indirectly (e.g., via a specialized biodiversity model or an external biodiversity digital twin).

A modular approach will be used to determine the carbon fluxes using meteorological and biophysical (leaf area index, LAI; fraction of absorbed photosynthetically active radiation, fAPAR) variables, and spatial forestry data produced in the previous step (Figure 2).

DTC functional elements and preliminary architecture

Advanced Data and Digital Services: the data space for Forest DTC will be a part of the DESP data space, including forest parameter maps and other forest data sets (e.g. field plot data sets, ground and airborne lidar data) which can be used to initialize the models and/or improve existing forest parameter maps. Such data sets may contain privately-owned data from forest owners or consultancy companies, which may provide these for more detailed analysis of specific areas. The DESP cloud computing capabilities will unlock the potential for these data to produce novel products for users from all sectors of human activity. The enhanced visualization tools will allow to study the details of interest or combine it with other data available from the DTE or other DTCs.

The 4D multivariate forest parameter datasets produced by the Forest DTC will provide a comprehensive description of the forest subsystem and allow to model its development into the future. The key variables, provided as raster maps, include species composition, age, tree density, basal area, dominant tree height, and site type. The derived variables, based on model simulation, include above- and belowground biomass estimates and various productivity metrics (e.g., GPP, NPP and NEE). The input variables are derived from field data and Earth Observation imagery, primarily from Sentinel-2, which is the most suitable operational data source for forest variable mapping (Astola et al., 2019). Where available, airborne laser scanning and hyperspectral data (for species mapping) will be used. When available, chlorophyll fluorescence data can be used for calibrating forest model phenology for improved predictions of annual productivity. In the future, commercial Very High Resolution (VHR, resolution 1 m or better) images are foreseen as relevant sources of data for automatic mapping of forest variables and their visual verification on Forest DTC.

The spatial and temporal resolutions of the system will be designed to match the needs of the user community as determined by Mõttus et al. (2021): the current Sentinel-2 spatial resolution of 10 m will be used as the baseline with the possibility of improving to 5 m (Sentinel-2 NG) analysed based on scientific literature. However, the concept of forest as a community of trees and other organisms is corroborated by the finding that a window size of 30 × 30 m2 was optimal for mapping boreal forest parameters (Mõttus et al., 2021b). The reference multivariate datasets quantifying the temporal development of forests for the demonstration areas will be made available for the duration of the weather data simulated by the DTE.

Scientifically sound processing blocks, simulation elements and workflows: the forest productivity will be computed using daily (measured or modelled) weather data, but by default aggregated over one year. Also, the temporal resolution (time step) of the forest base map will be initially one year. As the natural undisturbed change in forest is slow, this fulfils the scientific requirements of the models, the long-term prediction needs of the users, and will be sufficient for data assimilation studies for evaluation of model performance. Additionally, a change detection tool will be available on the system allowing to determine and quantify deviations from the yearly baseline. This tool, limited by the frequency of remote sensing acquisitions, will enable daily to weekly disturbance mapping.

User-driven interactive capabilities, data analytics and visualisation layer: Forest DTC will implement user interactive capabilities and visualisations in the DESP and will maximise the use of the tools and services offered by DESP. As all the DTC will be working with geospatial data, Forest DTC will benefit from the three- and four-dimensional visualization capabilities of the platform. Whenever possible, common data formats with other DTCs will be used to enable data sharing and combined visualization of variable maps from the different components at the same time.

Use of EO data

The Forest DTC will rely heavily on EO data for initializing and updating the forest models and producing the inputs required for user models (disturbances, ecosystem services, etc.). Homogeneous EO data only globally available from satellites will be the backbone of the Forest DTC. However, recomputation on local to regional scales can be done if more detailed data are available, e.g., laser scanning or field plots.

The initial (global, continental) forest maps will be produced based on Earth Observation and field plot data either inside the Forest DTC or externally. For the latter case, the DTC will have components for linking to external data sources. A good example are multisource national forest inventories (NFIs, e.g., Mäkisara et al., 2022) which produce continuous and accurate forest variable maps. Although the output variables of NFIs are not standardized, work in this field is ongoing.

The forest maps available to users are usually not up to date, but rather associated with a specific inventory or mapping period. EO data will be used to update the available maps to the starting moment of simulations in Forest DTC, assuming that the underlying relationships between spectral reflectance and forest variables has not changed. For areas with no forest data available, EO-based estimation tools such as those demonstrated in the Forest Digital Twin Earth Precursor project will be used. These tools will be made available as part of the DESP. However, the option to perform the computations in an environment specifically designed for this – such as the Forestry Thematic Exploitation Platform (TEP) will be considered and the relevant interfaces set up in DESP.

The most suitable operationally available EO data for forest variable mapping is the high-resolution multispectral imagery produced by Sentinel-2 and Landsat. When applicable, SAR data with similar spatial resolution will be used (e.g., Sentinel-1), especially for change detection in cloudy areas. During the Forest DTC project, hyperspectral imagery will not be available for the full extent of all use cases, use of such imagery is foreseen in the future allowing improved species classification and forest health mapping.

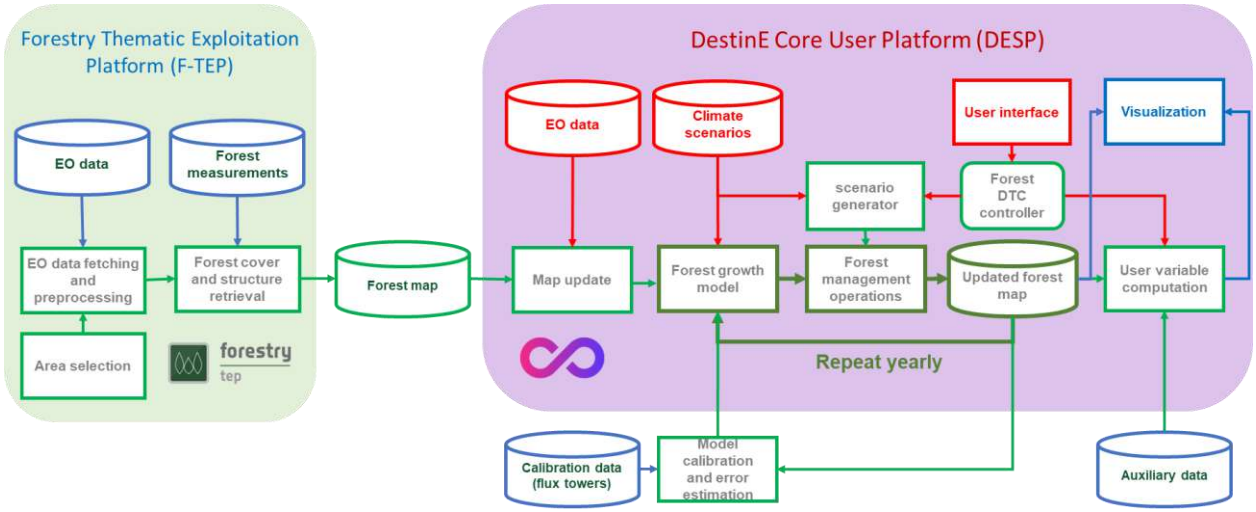


Figure 2. The proposed forest mapping and prediction system.

Models, AI and processing elements

The following models will make up the carbon flux processing chain (Figure 3):

- **PreLes**: model for tracing daily gross primary productivity (GPP), water fluxes (ET) and forest physiology status (stress conditions) using weather data and minimal stand structure information (Minunno et al., 2016; Tian et al., 2020).
- **CROBAS**: a stand growth module based on carbon balance which translates the gross primary productivity into net primary productivity (NPP) and stemwood growth;

when combined with observations on stand structure, also provides litter fall rates (Valentine & Mäkelä, 2005; Minunno et al., 2019).

- **YASSO**, the soil carbon model, which, in combination with the other modules, will provide estimates of net ecosystem exchange (NEE) (Liski et al., 2005; Tuomi et al., 2009).

PreLes will be used to determine GPP and evapotranspiration (ET) using LAI, fAPAR, and daily weather data. Next, NPP, C allocation, forest growth and current litter fall will be estimated using relationships between stand structural variables (mean stand height, mean diameter at breast height and basal area) and respiration and litter fall described by the forest growth model CROBAS. Finally, the soil carbon model YASSO will be used to estimate NEE from litter data (provided by CROBAS) and meteorological data and soil maps.

Besides predicting the current state of carbon storages and fluxes, PreLes, CROBAS and YASSO – combined into the PREBASSO model – will be used to predict the future state of the forest structural variables and the carbon attributes under different climate scenarios prescribed by the user. The system proposed here has been demonstrated to be useable for mapping of forest processes on a large area (Miettinen et al. 2021).

We will use in Forest DTC the bark beetle phenology development models PHENIPS (Baier et al, 2017) and RITY (Ogris et al., 2019) modified for Czech Republic conditions (Berec et al., 2013, Bárta et al. 2022). The model estimates potential bark beetle loads, indicators like onset of infestation, time of completing n-filial / n-sister generations, number of bark beetle generation developed in a year. The model is primarily driven by daily temperature data available in the DTE system. In combination with forest species maps and age distribution, hotspots of bark beetle infestation in coniferous forest will be determined.

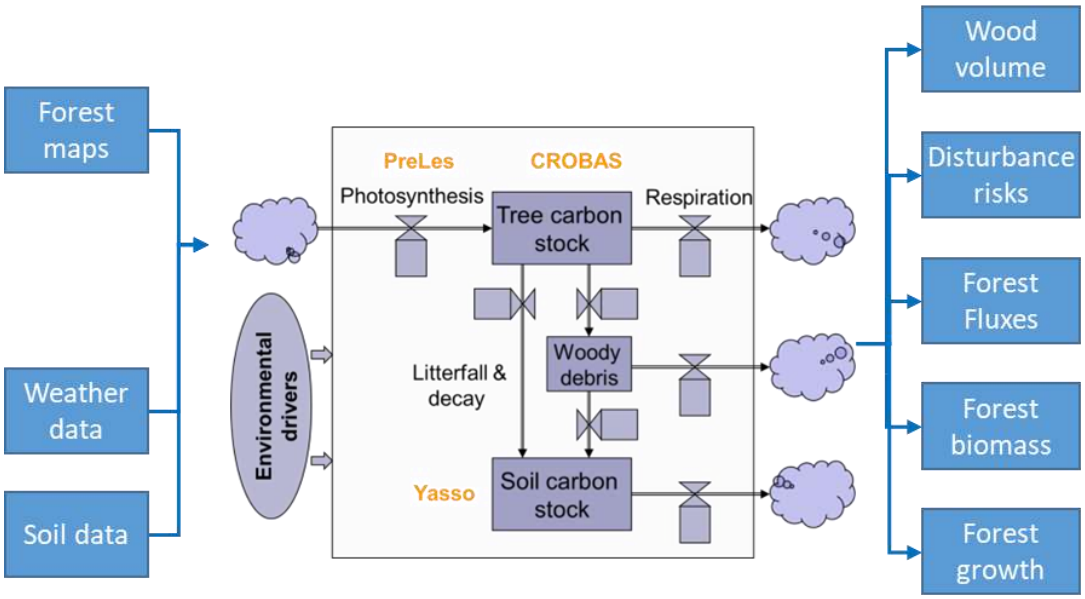


Figure 3. The biochemical and -physical modelling system of Forest DTC.

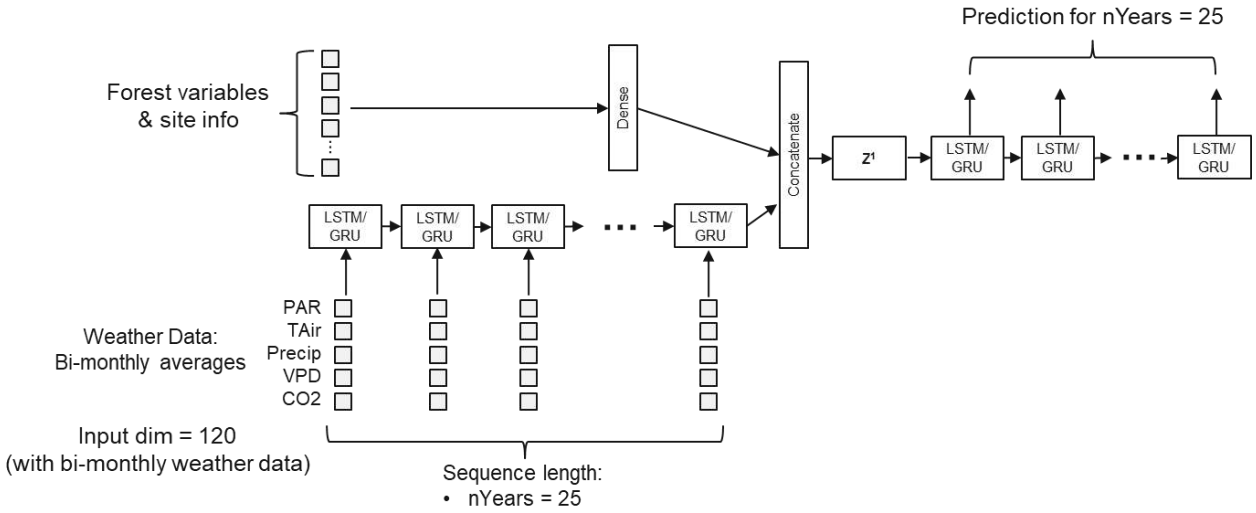


Figure 4. A proposed AI architecture for emulating the PREBASSO system: a seq2seg encoder/decoder network with LSTM/GRU combined with a fully connected section.

Advanced machine learning (Artificial Intelligence, AI) methods will be used throughout the Forest DTC processing chain. An emulator for the PREBASSO-based forest growth and modelling chain is being developed and tested at VTT under separate research funding from the Research Council of Finland (ARTISDIG project, sensillence.github.io/ARTISDIG/, Figure 4). The results of the ARTISDIG project will be available by the end of 2024. If the approach proves useful, it will be implemented on the DESP platform. AI will also be used in mapping forest variables using EO imagery, with special benefit expected from transfer learning for areas where field plot data are scarce (e.g., Ge et al., 2023); however, the scientifically proven methods used as the baseline in the Forest DTC are based on “shallow” methods such as random forest. Similar machine learning methods will be used in identifying and quantifying the changes in forest variable maps in comparison with the imagery from the starting date of Forest DTC simulations.

Detailed description of the Use Cases and demonstration

The Forest DTC will be demonstrated in four use cases:

1. **Czech Republic**: special focus on bark beetle phenology modelling and growth model validation with dendrometer plots;
2. **Catalonia**: special focus on fire risk modelling;
3. **Finland**: special focus on old-growth forests and forest management pathways;
4. **Use Case Science**: special focus on diverse forest types, experimental modelling techniques and data sources.

The use cases were chosen to satisfy the requirement in the SoW to *cover sizable geographic regions and temporal scales representative of the scope of problem to be faced and when relevant, implementation shall be done over different regions to demonstrate performance under different conditions and potential scaling up and portability capabilities*. The first three use cases are proposed for the wider target stakeholder group as specified in the first iteration of Task 1 below. While scientifically relevant for the use variables (forest disturbance modelling, carbon balance studies), they do not immediately advance forest modelling research. To account for this, we propose the Use Case Science which, while

not geographically continuous or extensive, will extend Forest DTC demonstrations in the feature space of forest variables and, most importantly, will expand the number of modelling techniques and data sources involved in Forest DTC.

Use Case #1: Czech Republic

Forest type:	Temperate, montane
Managing partner:	CzechGlobe
End user involved:	Forest Management Institute (www.uhul.cz), forest owner University Forest Enterprise Masaryk Forest in Křtiny (www.slpkrtiny.cz/en)
Study area extent:	Whole Czech Republic with selected areas for detailed validation purposes (approx. 10 Sentinel-2 tiles)
Special focus:	Bark beetle infestations, forest growth modelling

A baseline scenario will be simulated with the DTC. The system will be parameterized for the AOI for a baseline year, e.g. 2020. Forest model will be run in forward mode for different climate scenarios for a specified time period, e.g. 40 years (depending on the prediction horizon of the DTE system). Standard forest management scenarios will be used with no disturbances. The differences between the scenarios will be analyzed. The scenario will produce predictions for key forest variables: basal area by species, stem volume, above- and below-ground biomass, GPP, NPP, NEE.

The potential of bark beetle development will be simulated over different climate scenarios by several variants of a bark beetle phenology models – PHENIPS (Baier et al. 2017, Berec et al. 2013) and RITY (Ogris et al. 2019). The model estimates potential bark beetle loads, i.e. indicators like onset of infestation, time of completing n-filial / n-sister generations or number of bark beetle generation developed in a year (Figure 5). In combination with forest species composition and age structure, potential hotspots of bark beetle infestation in coniferous forests will be mapped. The method will be implemented as part of Forest DTC.

Two types of simulations will be performed:

1. Short-term simulation from approx. 2017 (i.e., start of a large-scale bark beetle infestation) based on existing field data (e.g., data from different campaigns around 2020, depending on data availability). Validation will be done against growth plot data and bark beetle damage maps in 2020s. The study area will be determined by the locations of the plots and data availability on bark beetle damage, the two validations maybe done for different subareas of AOI.
2. Long time series simulation will be attempted. This requires simultaneous EO data (Sentinel-2 or Landsat) together with a large number (>100) field plot data, but allows comparing bark beetle loads from a large number of sites. Multiple baselines can be established if data are available. Likely, full AOI will not be covered.

Risk and benefit assessment estimation, and validation against measurements and other modelling approaches will be performed. The exact approach will depend on data availability and will be fully developed during the project. The independent validation sources will include:

- Field data on forest productivity from the CzeCOS/ICOS ecosystem observations and from the DendroNetwork monitoring (Figure 6).

- Maps of forest biomass derived at the local scale from airborne laser scanning (Brovkina et al., 2022) or at the whole country scale derived from normalized digital surface model (under development, Novotný et al, in prep) (Figure 7)
- Maps of conifer forest clearcuts and dead trees resulting from the bark beetle infestation produced by the Forest Management Institute of the Czech Republic 2-3 times per year from Planet data (dataset is part of DEFID2, Forzieri et al., 2023).

Input data summary:

- EO data (mainly Sentinel-2) and other maps from existing projects, or cooperations
  - ALS data and AGB estimates for local validation
  - Forest species composition maps
- Climate data from DTE on climate change adaptation
  - Backup: existing ERA5 or 6
- Field data
  - Detailed tree growth and tree water deficit data (DendroNetwork, forest4future.czechglobe.cz/dendronetwork/) 100 plots
    - one field inventory data
    - tree core data for historic growth
    - time series from dendrometers since 2016, most plots from 2021/22
  - Forest inventory data (DendroNetwork + existing projects): single measurements in last 5 yrs.
  - Forest productivity data: 3 to 4 flux tower sites – CzeCOS/ICOS observation network (one site damaged by bark beetle and harvested). Repeated field forest inventory measurements each year for ten yrs.
  - Standard forest management practices followed, although bark beetle and other disturbances have caused irregularities

Output data summary:

1. Yearly maps of key forestry variables and productivity for the modelled area.
2. Yearly maps of protentional bark beetle threat/activity over AOI bark beetle load
3. Assessment of risk & benefit for forest stands resulting from the forest productivity and bark beetle threat (Analysis of uncertainty propagated through the forest productivity and bark beetle model)

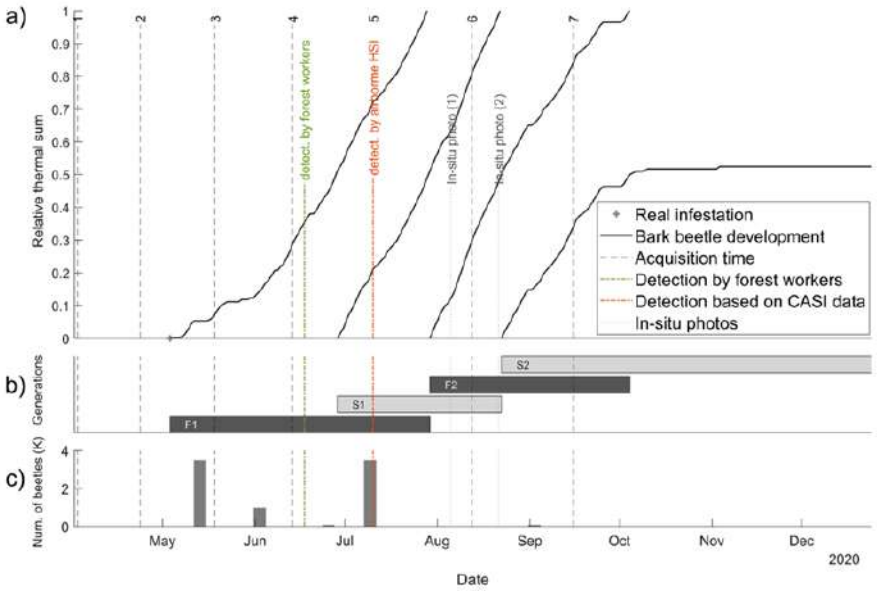


Figure 5. (a) Monitoring of bark beetle development on a site since the first (fallen and uprooting) trees were infested (i.e. since 3 May 2020), (b) number of generations, two filial (F1, F2) and two sister (S1, S2) generations, simulated by model RITY, (c) number of catches from pheromone traps on the site. Source: Bárta et al. 2022.

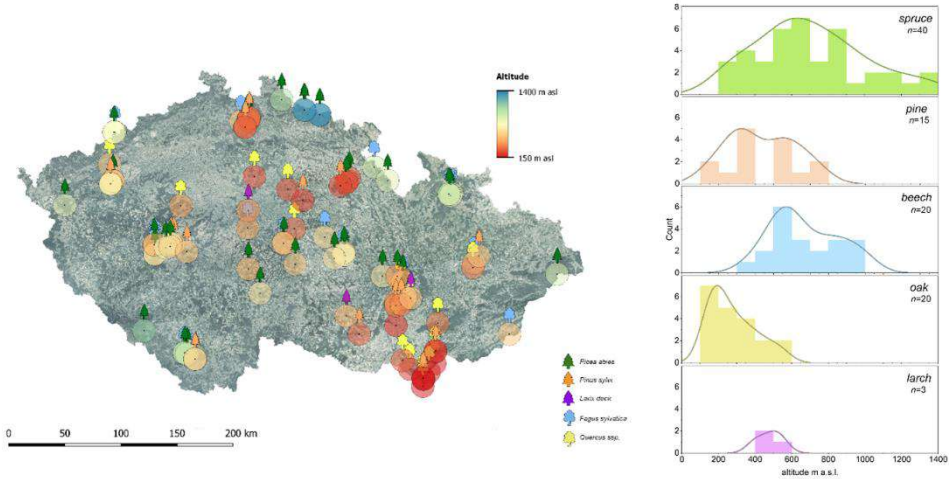


Figure 6. DendroNetwork for forest growth and drought stress monitoring. Plots are distributed along the elevation gradient and dominant tree species in the Czech Republic.

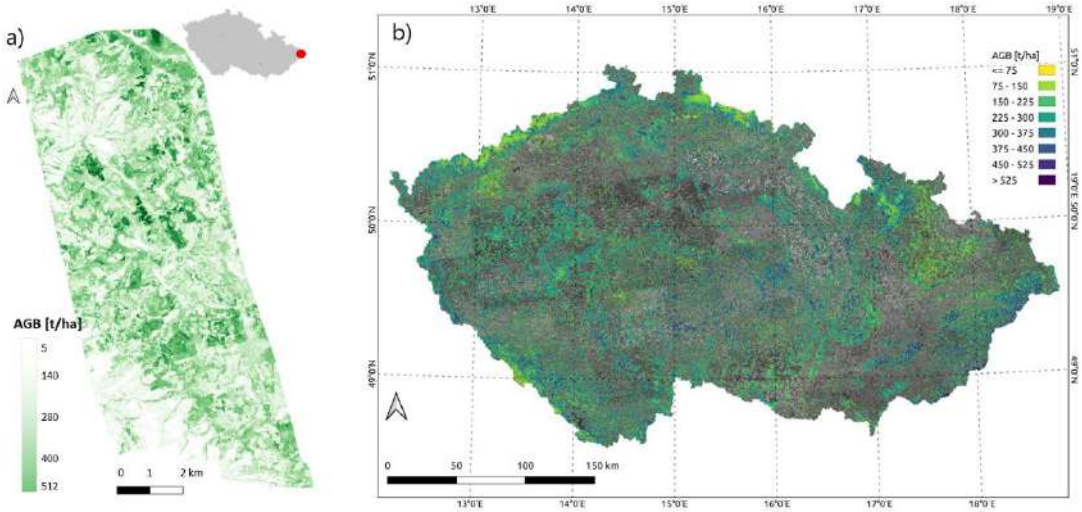


Figure 7. Maps of forest aboveground biomass derived from (a) airborne laser scanning data for Těšínské Beskydy Mts. and (b) normalized digital surface model at the whole country scale.

Use Case #2: Catalonia

Forest type:	Mediterranean
Managing partner:	CTFC
End users involved:	Forest Science and Technology Centre of Catalonia (CTFC) – both a research institute and an end user, in supporting administration on decision making; Forest administration from the Catalonian government.
Study area extent:	Whole Catalonia
Special focus:	Evaluating fire fuel hazard modelling and generating fire risk assessments at regional level

Approx. 65 % of the surface area of Catalonia is categorized as forest area, since 1993 to 2018 this has increased by 6 % (+ 121.000 ha). Approximately 1.332.000 ha of Catalan land are categorized as wooded forest areas.The primary tree species in terms of abundance include Pinus halepensis, Quercus ilex and Pinus sylvestris. 51.5 % of the wooded forest area is represented by conifers, 36 % by broadleaves and 12.5 % by mixtures. The region exhibits significant orographic variation, encompassing altitudes spanning from sea level to over 3000 meters. These elevational differences exert considerable impacts on the local climate, which ranges from semi-arid conditions to subarctic climates with Mediterranean influences. The forest are classified into 162 different Tree Forest Typologies and 49 categories of shrub and grasslands formations making Catalonia a very diverse landscape for fire fuel modelling. Over the past three decades, Catalonia has experienced the detection of 21,686 forest fires, resulting in the scorching of approximately 265,000 hectares of wooded terrain (Figure 8).

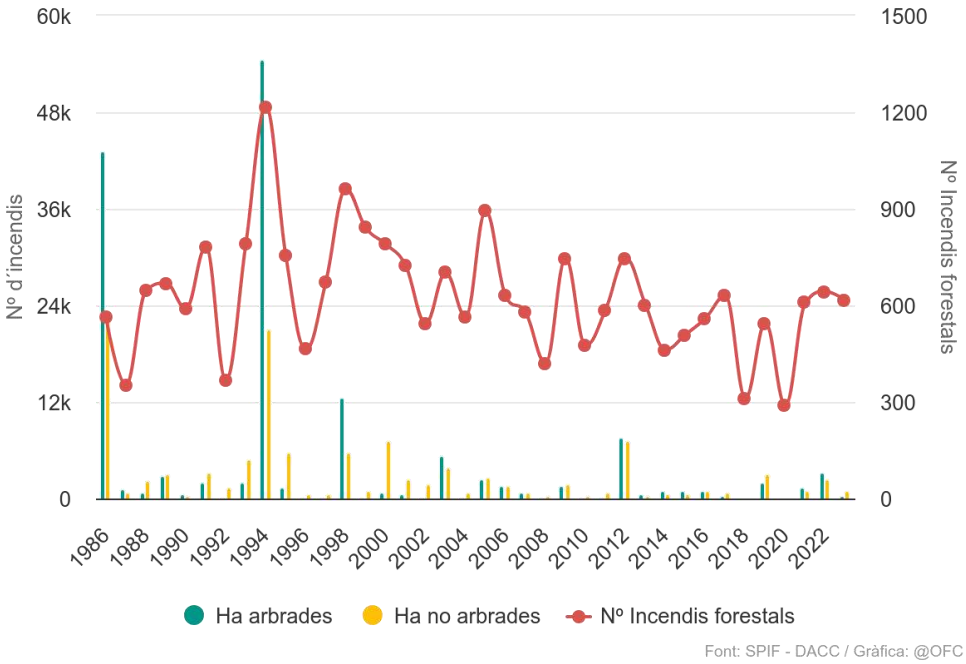


Figure 8. Number of fires (red dot) and burned areas either on forest land (green dot) or non-forest land (yellow dot) during the 1986 till 2022 period in Catalonia.

Several fire modelling frameworks exist for the study area. These are based different satellite EO products to quantifying the availability and characteristics of forest fuels. Using radar backscatter median annual values from Sentinel-1 and ALOS-2; and optical (annual

composites of vegetation indices per pixel – EVI and NDVI – obtained from Sentinel-2) it is possible to define the biomass and tree species composition across the region. These cases use a spatial resolution of approx. 100 m, within the requirements of strategic and operational fuel hazard assessment without overstretching the capacity of current satellite data. Higher spatial resolutions are also possible (Figure 9). In order to identify fire danger conditions, climatic info are currently derived from METEOCAT weather stations or AEMET to generate indexes like the Fire weather index or study modifications of its components like the drought code. In the Forest DTC, the use of the weather information will be the DTE digital twins; connections to external data sources will be preserved for redundancy.

Any fire risk metric and maps generated through the project can be validated either by using more accurate fuel maps (derived from airborne lidar, and adjusted with a combination of expert knowledge, national forest inventory and forest maps), and fire specific weather scenarios and fire simulations generated at a scale of 20 meters for the whole Catalonia: the repository at previncat.ctfc.cat/en/index.html has data to run any fire simulators. A similar Europe-wide database is under development and will likely be available during the Forest DTC project. Additional validation info can be obtained from the dates, and allocation of historical fires, that also can be used to generate additional ignition allocation models to further enhance fire risk assessments.

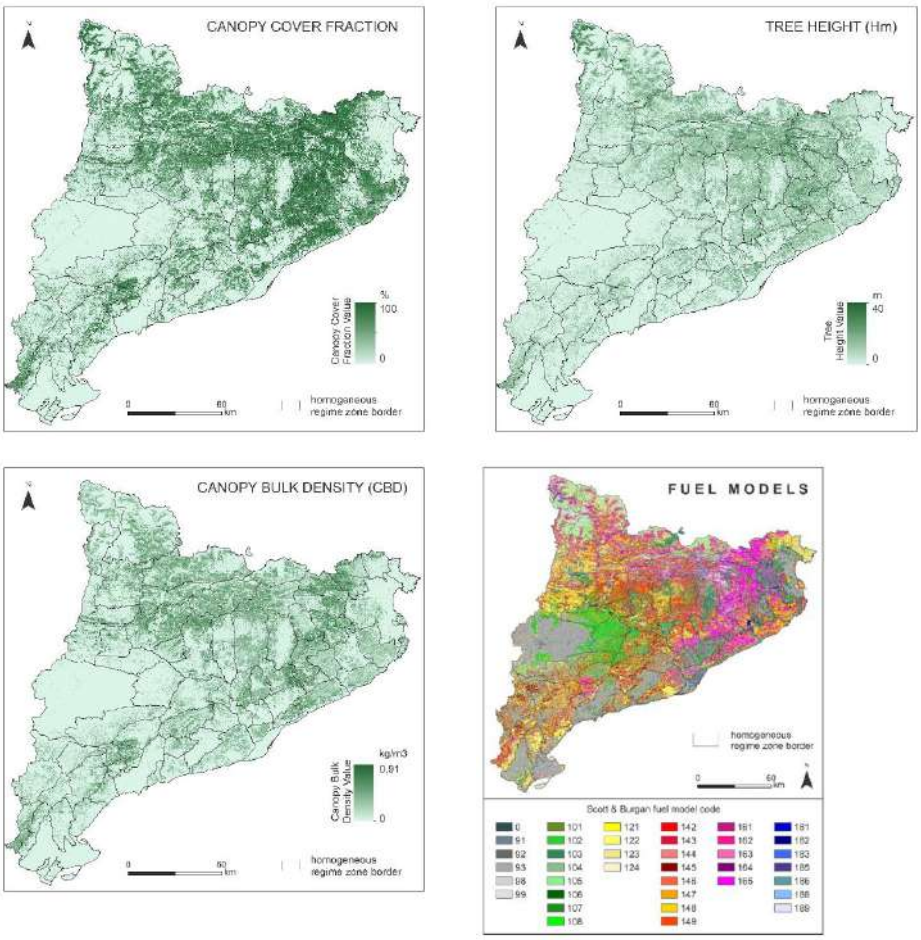


Figure 9. Fuel related variables across the region of Catalonia (20 By 20 meter) derived from Airborne LiDAR.

Input data summary (resolution 100 m):

- biomass
- tree species
- ALS data, expert knowledge
- national forest inventory
- Climatic data (precipitation history, temperature, etc.)
- Validation data:
  - fire simulations generated at a scale of 20 meters for the whole Catalonia
  - historic fire data

Output data summary:

- Fire weather index
- fuel maps
- fire risk & hazard assessment

Use Case #3: Finland

Forest type:	Boreal
Managing partner:	VTT
End user involved:	Finnish Forest Centre (Metsäkeskus)
Study area extent:	Central Finland, 3 by 3 Sentinel-2 tiles
Special focus:	Temporal development of forest resources and carbon balance under different management scenarios, old-growth forest

In Finland, forests are generally managed as forest stands where trees are of a similar age according to a regeneration cycle extending from planting or natural regeneration to the final harvesting phase. Four tree species are naturally predominant in Finland's forests: Scots pine, Norway spruce, Downy birch and Silver birch. These species also dominate in commercially managed stands, and exotic tree species are not widely grown. The length of the regeneration cycle can be between 50 and 120 years, depending on the tree species and the location of a forest stand. However, stands can be managed to consist of trees of differing ages, particularly in recreational forests or landscape forests. Alternative method for even-aged forestry is uneven-aged forestry, where no final felling is performed. Younger commercially managed forests are typically thinned out periodically, with some 25−30% of the trees removed during thinning. The increasing demand for wood for bioenergy has created new markets for the trees cut during such thinnings, and for logging residues such as branches and stumps which earlier used to be left in the forest. In any case, the biodiversity of forests is being promoted by maintaining the characteristics of the valuable habitats.

Old-growth forests in Finland are coniferous forests (consisting of spruce and pine) that have remained in their natural state. Typical features of these forests are trees of different ages, an abundance of dead and decaying trees, and small continuous changes (i.e. no abrupt disturbances such as clear-cutting or storm felling). Often, a small number of deciduous trees such as birch and aspen are interspersed with conifers. In Southern Finland, most forests are used for forestry and there are few old-growth forests left. Thus, their protection is important to preserve their ecosystems and biodiversity.

Finland has one of the world's best forest information systems with regular forest inventories. Additionally, all forest operations need planning and informing the authorities;

data on management operations are regularly reported. Finnish Forest Centre maintains an up-to-date map of forest resources for all forests in Finland based on nationwide airborne laser scanning, field plot data and forest management notices. Although they target small forest owners, the data are available openly online, including all field plot data and nationwide parameter maps. Known biodiversity hotspots (e.g., streams, old-growth forest patches) are mapped and their preservation is monitored.

The demonstration area (Figure 10) is selected as it is representative of the Finnish boreal forest zone, largely covered by forest (most agricultural activity is in Western Finland) and contains a number of recent field plots by Finnish Forest Centre.

Figure 10. The preliminary area of the Finnish use case (blue dashed line). Red lines are Sentinel-2 tiles.

Input data summary:

1. Forest field plot data
2. Sentinel-2 imagery from two years covering Eastern Finland (Northern Savo, Southern Savo, Northern Karelia) for 2015 and 2022 (preliminary, exact years TBD)
3. Forest growth model parameters
4. Climate data
    a. actual climate since the year of first Sentinel-2 images
    b. forecast beyond 2023 for three different scenarios

5. Existing data on
    a. old-growth forests
    b. other variables found relevant by the end user

Output data summary:

1. Yearly maps of key forestry variables and productivity for the modelled area.
2. Maps of specific target variables at different time steps as agreed with the end user
3. Analysis of uncertainty propagated through the forest productivity model
4. Empirical assessment of forest productivity model accuracy using images from the two years and field plot data

Use Case #4: Science

Forest type:	Gradient from tropical to continental
Managing partner:	GFZ
End users involved:	STRUCNET team; Satellite cal/val teams (i.e. BIOMASS, ENMAP/CHIME); ICOS/FluxCom communities
Study area:	Well-described and monitored forest stands along a geographic gradient
Special focus:	Evaluating a) A monitoring and modelling system for scientific observation networks and studying forests b) Ways to improve forest representation and reduce uncertainties in forest analysis and modelling, also in light of integrating with future satellite missions

The study sites will be selected from the list of European ICOS forest stations under consideration of auxiliary data availability and while covering a climatic gradient, and a gradient in forest structure and functioning. Table 1 shows a preliminary selection with promising candidate sites. All sites are equipped with permanently operating Eddy covariance (EC) measurements systems for direct measurement of NEE, and indirectly GPP and ecosystem respiration. Additionally, micro-climatic data are routinely collected. All sites are routinely measured with near-sensing structural campaigns using terrestrial, drone or airborne LIDAR, and spectral data. Having these datasets are key to study forest structure and dynamics for carbon assessments and for integration with new satellite data measurements.

Table 1. Preliminary sites chosen for Use Case Science

Site	**Guyaflux (GF-Guy)**	**Hainich (DE-Hai)**	**Hohes Holz (DE-HoH)**	**Loobos (NL-Loo)**	**Las Majadas de Tiétar (ES-LMa)**
Climate	tropical rainforest climate (Af)	Humid continental, warm summer (Dfb)	Marine west coast (Cfb)	Marine west coast (Cfb)	Hot-Summer Mediterranean Climate (Csa)
Ecosystem	Evergreen Broadleaf Forests	Deciduous Broadleaf Forests	Deciduous Broadleaf Forests	Evergreen Needleleaf Forests	Savanna

TLS survey	2023*	2023**	2024*	2011**, 2021**	2015**, 2018**
UAV-LS survey	2019**	—	2024*	—	—
ALS survey	2019**	2012+, 2017+, exp 2024+	—	2010+, 2018+, 2022+	2010+, 2015+
Airborne high-res RGB	2019**	annual+	Uneven years+	annual+	Every 3 years+

+open data *GFZ owned **owned by collaborator

The Forest DTC will be parameterized for the AOIs for suitable baseline years for which detailed data will be prepared

a) using multispectral imagery and basic forestry variables (basal area, tree density, mean height, species) – the baseline scenario.
b) using best available data on the individual tree level, including laser scanning (see Table 1) and hyperspectral imagery – advanced model input scenario.

An area of at least 500 x 500 m around each fluxtower will be characterized in order to match the typical footprint of the EC system. Multi-temporal TLS in sub-plots will be used to assess changes in forestry-related digital twin parameters, such as basal area, height, stem volume and above-ground biomass. These TLS surveys are already scheduled in StrucNet activities. Hyperspectral space-borne data will be acquired via proposals to the German EnMAP mission. Where possible and necessary airborne or UAV borne hyperspectral data will be collected. Local species maps will be derived from suitable data sources, such as airborne orthomosaics or dedicated UAV high-resolution RGB data.

The forest model will be run in forward mode for different climate scenarios for a specified time period, e.g. 40 years (depending on the prediction horizon of the whole digital twin system) with no unexpected disturbances. The scenario will produce predictions for key forest variables: basal area by species, stem volume, above- and below-ground biomass, GPP, NPP, NEE.

The output from the cases a and b will be used to evaluate the accuracy of the modelling system against the measured data and the marginal benefit of having more detailed (in practice, best possible) stand and weather data as input for the modelling.

Input data summary:

- Earth observation data
  - Sentinel-1/2 time series
  - Hyperspectral data (satellites, i.e. ENMAP, drone sensors)
  - LIDAR data (satellite: GEDI, ALS, drone, TLS)
- Forest structural data
  - Average (over stand/segment) forest data
  - Detailed forest data (individual trees; distributions of height, basal area, etc.)
- Climate and weather data
  - From in situ measurements
  - from Climate digital twin with backup from existing ERA5 or 6
- Growth and/or productivity data (flux tower, repetitive measurements)

Output data summary:

1. Maps of key forestry variables and productivity for the modelled area at different resolutions
2. Analysis of uncertainty propagated through the forest productivity model caused by inaccurate parameterization and lack of detail

Proposed scientific and technical advances

The baseline system demonstrated in the Forest DTE Precursor project exceeds the current standard of land use class-based forest change detection. Compared with the Forest DTE precursor, the following further advances are foreseen in the Forest DTC project:

- Moving towards a more operational system implemented on a new, dedicated DestinE infrastructure platform: use of actual DTE climate simulation data, improved visualization tools and interfaces.
- Ability to use advanced forest parameter products by updating them a desired simulation date using artificial intelligence and Earth Observation imagery – enabling (near real time) disturbance (change) detection compared to a well-defined baseline of forest development.
- A more scientifically developed forest growth and productivity model with well-defined interfaces, allowing it to be replaced with alternative modelling system.
- Addressing the potential of machine learning (including Artificial Intelligence, AI) in analysis of EO data and modelling of forest processes.
- Development of a more advanced validation scheme based on a variety of data sources for a variety of forest types.
- Addressing new data sources (lidar, hyperspectral imagery) which will be operationally available at the time when the DTE is operational.
- A broader target user group, focusing more on institutional users as required by the ITT.
- Including new state-of-the-art models on forest disturbance simulation into the general forest simulation architecture with specific focus on fire and pests.

Overall, the Forest DTC presents a system which will allow multiscale studies phenomena and processes involving forests in an unprecedented manner answering many scientific and policy/societal challenges. It will integrate the knowledge dispersed between the different actors in forest science, incl. wood production, carbon science, fire modelling, Earth system science, forest health studies, etc., creating an environment for exchanging ideas, information and data on the relevant topics. It will valorise various existing and upcoming EO data products (synthetic aperture radar, lidar, hyperspectral, chlorophyll fluorescence) allowing them to be connected with the biophysical and -chemical processes in the world's forests.

Proposed validation and uncertainty characterisation approaches

Uncertainty analyses will include propagation of uncertainty through the forest growth and productivity models. The sources of uncertainty that will be considered are: forest structural variables, initial soil C and climate inputs (Junttila et al., 2023).

Forest structural variables uncertainty. The field data used in forest parameter retrieval will be assumed to be error-free. Errors will be introduced into the forest parameter maps which

will then be propagated to the output maps of simulated forest structure, carbon storage and fluxes. This will allow to estimate the sensitivity of the twinning use case to variations in input data.

Empirical uncertainty studies will be performed using historical image data. Forest structural information will be retrieved for a historic date, from where forest development will be simulated onwards towards a recent satellite image acquisition (preferably accompanied by forestry field data) using actual historical weather data. This nowcasting will allow to estimate the uncertainties related to internal model parameterization. Simultaneously, model parameterization can be improved to accounts for local variations.

SoilC. The initial state of soil C is a crucial variable for the NEP quantification. Soil C depends on site characteristics, climatic conditions and past management. The uncertainty quantification of initial soil C will be explored by mean of repeated modelling simulations that will vary site characteristics (site fertility) and historical management. Soil C uncertainty will be compared with available global databases of soil carbon content.

Climate inputs. The uncertainty associated to climate inputs will be explored using scenario analyses. Three representative concentration pathways (RCP2.6, RCP4.5 and RCP8.5), simulated using alternative global climate models (e.g., CanESM2, CNRM, GFDL), will be used to generate the inputs for the forest model.

The importance of the three factors (i.e., forest structural variables, soilC and climate inputs) on forest model predictions will be explored using global sensitivity analyses based on multivariate analyses (canonical correlations analyses) or variance decomposition methods (Sobol indeces).

Proposed implementation and integration aspects, etc.

The proposed implementation strategy will adopt a multifaceted approach, leveraging Python and JavaScript as primary programming languages for backend and frontend development, respectively. Python's versatility and extensive libraries make it well-suited for processing satellite data, constructing time series datacubes, and implementing backend functionalities such as data management, analysis, and API development. The implementation will follow agile development methodologies, emphasizing iterative development cycles, continuous integration, and feedback-driven improvements. By breaking down the project into manageable sprints, it ensures flexibility and adaptability to evolving requirements, while frequent interactions with stakeholders facilitate alignment with their needs and expectations. Following agile development, stakeholders, collaborators and early adopters will be kept in the loop from the beginning and updated with monthly progress and next steps reports.

Integration with the Digital Earth Service Platform will be approached through standardized interfaces and protocols to ensure seamless interoperability and data exchange. RESTful APIs will facilitate communication between the forest-themed digital twin and the Digital Earth Service Platform, enabling the exchange of data and metadata in a structured and efficient manner. Additionally, JavaScript-based interfaces supporting webRTC will be developed to enable users to interact with both platforms seamlessly, providing a unified experience for accessing and analyzing geospatial data. Continuous integration and automated testing pipelines will be established to ensure the reliability and stability of the

integrated system. Moreover, an agile approach to integration will prioritize incremental enhancements and refinements, allowing for the gradual incorporation of new features and functionalities while maintaining system integrity and performance.

Programmatic access and access via a GUI will use the same interface to access the data management platform (DMP) implemented in the Forest DTC controller. Programmatic access will be used by external systems such as F-TEP and external validation tools. This also allows the implementation of independent validation and verification (IV&V) processes. The GUI and visualization tools will be the primary access points to the Forest DTC controller.

The demonstration applications will be implemented following a standardized pattern operated by the Forest DTC controller. Standardization makes it easier and faster to develop additional modules later. External data sets such as forestry and soil data will be accessed via a data harvester, that ensures data access in a unified, documented, format: GeoTIFF for raster data and GeoJSON for vector data. As external datasets are updated, the unification process will ensure seamless integration into the existing DTC modules.

Finally, we will conduct a final qualification and acceptance test of the system with ESA prior to the final demonstration at the end of the project, encompassing accuracies, functionalities, and integration aspects in the DESP.

Proposed approach to respond to the basic functional elements described in the SoW

The general approach to the functional elements of the Forest DTC is described in Section 2.2 *Proposed approach to reach the main technical objectives of the ITT and proposed technical and scientific approach* above. The following actions will be taken to implement them:

- Advanced Data and Digital Services: will be made available by implementing the system in the Destination Earth Core Service Platform, DESP, leveraging the services available there. Forest DTC will be linked with external data sources available on other platforms, such as the Forestry Thematic Exploitation Platform, making the forest data stored there by various users also accessible on DESP, if the owners of the data give permission. Ultimately, Forest DTCs will be integrated into the DESP.
- Multivariate data-driven reconstruction, including a reference 4D dataset: The data set will combine layers of forest information including structural (forest biomass, stand density, etc.) and biophysical variables (productivity, carbon and water fluxes), EO imagery (inc. chlorophyll fluorescence and hyperspectral imagery whenever available), and basic climate data. Links to datasets in external storage services will be provided (e.g., airborne laser scanning and aerial imagery, Copernicus vegetation product subsets).
- Scientifically sound processing blocks, simulation elements and workflows: The workflows of Forest DTCs will be implemented as computer code implemented Docker images, controlled by configuration files and sharing data via data files. The scientifically cutting-edge algorithms will allow an advanced reconstruction of the forest system, digital simulations and the creation of what-if scenarios serving the user community.

- User-driven interactive capabilities, data analytics and visualisation layer: Forest DTC will use the interactive capabilities and visualisations available on the DESP, and thus will maximise the use of the tools and services offered by DESP. As all the DTC will be working with geospatial data, Forest DTC will benefit from the three- and four-dimensional visualization capabilities of the platform. Whenever possible, common data formats with other DTCs will be used to enable data sharing and combined visualization of variable maps from the different components at the same time.

2.3 First Iteration of ALL the Tasks

The first iteration of the tasks is based on the outcomes of the Forest Digital Earth Precursor project funded by ESA in 2020 – 2021 (consortium lead: VTT).

Task 0: Management

The prime contractor, VTT, will implement effective and economical management for the Forest DTC project. Senior Scientist Renne Tergujeff, who is a Certified Project Manager according to IPMA Level C, will be appointed as Project Manager (PM) responsible for the coordination and control of the work of the Consortium. Principal Scientist Dr. Matti Mõttus will be the Science Lead, responsible for the scientific excellence, direction, content and scientific soundness of the deliverables of the project.

PM will maintain an Action Item List (AIL) recording all actions agreed with the Agency uniquely identified with reference to the minutes of the meeting at which the action was agreed. AIL will record generation date, due date, originator and the person instructed to take action. PM will also be responsible for maintaining a risk register identifying potential risks, their likelihood and severity, and propose meaningful mitigation measures.

A Progress Report will be provided every two months to the Agency's representatives including:

1. action items completed during the reporting period;
2. a status report on all delivery items;
3. a description of progress: actual vs. schedule, milestones and events accomplished;
4. reasons for slippages and/or problem areas, if any, and corrective actions planned and/or taken, with revised completion date per activity;
5. events anticipated during the next reporting period (e.g. milestones reached);
6. expected date for major schedule items;
7. milestone payment status;
8. status of risks.

Midterm Review and Final Report will be the Progress Reports at KO+12 and KO+24, respectively.

PM and Scientific lead will oversee the presentation of the Forest DTC at the kick-off meeting at the Agency's premises. Progress Meetings will be organized at approximately 2-monthly intervals by videoconference to discuss project advances, the content of the Progress Reports, and update the Action Item List and the Risk Register. Additional meetings will be arranged if either requested by the Agency or a need appears to discuss

with all consortium members and/or the Agency. The PM and Scientific Lead will oversee the final presentation and demonstration at the Agency's premises.

For all meetings with the Agency, VTT will ensure that proper notice is given at least two weeks in advance. VTT will also give to the Agency prior notice of any meetings with Third Party(ies) to be held in connection with the Contract. For each meeting, VTT will propose an agenda in electronic form. All documentation to be discussed in the meeting will be sent to the Technical Officer in electronic format. PM will be responsible for the preparation and distribution of the minutes of the meetings. The minutes will identify all agreements made and actions accepted at the meeting together with an update of the AIL and the Document List. Electronic versions of the minute will be distributed to all participants within five working days of the meeting occurring and signed no later than ten working days after the meeting concerned.

VTT will create and maintain a Document List, recording all the documents produced during the work, including reports, specifications, plans and minutes. The list will indicate the document reference (with unique identifier), type of document, date of issue, status (draft or approved by the Agency), confidentiality level and distribution. This list will be maintained in VTT Sharepoint with version control.

All documentation deliverables will be delivered in electronic form to the Agency in native format and as a searchable, indexed and not encrypted PDF. All documents will bear the appropriate copyright notice as specified in the Contract. In all cases, this will include the ESA activity name, ESA Contract number, deliverable number, date, status (draft/final), version and/or revision number. The list of the deliverables is given in Section 3.2.1 *Deliverable Items* below.

Task 1: Requirements Definition and Stakeholder Engagement

The tasks #1 (*Requirements Definition and Stakeholder Engagement*) #2 (*DTC Design and Technical Specifications*) will be combined in a common Work Package (WP 1. *Requirements, Design and Technical Specification*) as they aim for the same general goal – specifying the foundations of a user-driven digital twin of the World's forests. This grouping will provide towards a balanced distribution of work between the WPs of the Forest DTC project.

The overarching goal of the Forest DTC will be to serve as an advanced scientific support tool for a wide community of users interested in forests and/or forestry from different viewpoints. It will serve major scientific undertakings, policy needs and design of actionable adaptation strategies as well as mitigation measures to global change across different sectors of human activity with information related to the current and future state of the World's forests.

The Forest Digital Twin Earth Precursor project focused on land use of a carbon neutral Europe. Similarly, the Forest DTC will incorporate carbon and water exchange between soil, vegetation and atmosphere in a forest ecosystem throughout the different development stages of a forest, and the carbon sources and sinks related to conversion of land to and from forest. Via add-on user variable models, it will allow to analyse other aspects of forests and the related ecosystem services from different ecological, social, and economic perspectives, e.g., old-growth forests and biodiversity, economic value, recreational utility.

We propose to implement models for fire, pest and storm disturbances. For the scientific community, the Forest DTC will be interfaced with detailed 3D forest models, operating at the scale of individual trees, to pinpoint the bottlenecks and improvement opportunities of the DTC modelling system and integrate new biophysical and -chemical processes (e.g., fluxes of methane, emissions of aerosol-forming volatile organic compounds).

The primary technical goal of the Forest DTC will be to act as a spatially explicit simulation tool, which can be initialized using a snapshot of data, including EO imagery, environmental data, and field measurements of forestry parameters. It will give users tailored access to high-quality information, services, models, scenarios, forecasts and visualizations as required by DestinE. Hence, it simulates the forest systems as they progress according to a multitude of scenarios, defined by splitting points in their development paths (alternative climate scenarios, management practices, forest policies). The DTC is foreseen as a global system, with focus on Europe during this project. As a simulation system, Forest DTC will support continuous comparison of the observed state of forests with an uninterrupted simulated development thus enabling near real time forest monitoring.

Forest DTC will serve a wide user community including major institutions at international and European levels and the directorates of the European commission that deal with forests. The target users include for example the Food and Agriculture Organization (FAO) of the United Nations, the European Commission Joint Research Centre and the European Environment Agency (EEA). Additionally, the Forest DTC will serve the following key user groups identified during the Forest Digital Twin Earth Precursor project:

1. Forestry enterprises (privately owned of different sizes, community-owned or large public companies). State Forest Enterprises are responsible for the management of almost a half of European forests (44%), while the other half is managed by private owners (56%). About 76% of private forest areas are owned by individuals or families and to a lesser amount by business entities.
2. Governmental and non-governmental bodies, international organisations (at state, national and EU level working in forestry, environmental and wood industry sectors). Governmental forestry bodies contain ministries, state forestry commissions and administrations both at national and county level. They form the formal institutional framework for forest regulations, policies, legislations, technical norms and operational guidelines.
3. Forest and wood industry. The wood industry is an industry concerned with forestry, logging, timber trade, and the production of wood-based and other forest products. The forest and wood-based industry is a strong economic sector in Europe in terms of revenue and employment impacts.
4. Forest service companies (forest management and harvesting, forest consulting). Forest service companies offer specific services in the forest sector. These include forest management services, harvesting services, carbon balancing, digital solutions, etc. These companies might be technical operators or forest consulting companies.
5. Scientific users, any private or legal entities involved in forest science. This involves universities, scientists, students, etc., and also international, national, regional, county or provincial level research organisations dealing with forest monitoring, policy advice, training and knowledge transfer. Most of them have a legal mandate for their research and advising role.

Based on the priorities stated in SoW, Forest DTC focuses on further development in the following key scientific gap areas identified during the Forest DTE Precursor project are (Forest DTE Precursor, Deliverable 6: Scientific and Technical Roadmap):

- *Soil carbon*: New, updated soil maps used in forest models.
- *Forest productivity models*: Continuous development and testing, validation against field data and (demonstration in Czechia) and flux towers (scientific demonstration).
- *Forest health, biohazards and disturbance risks*: operationalized algorithms for key damages (pests, fires) linked with existing models of pest dynamics.
- *Determination of species distribution*: Testing of advantages of hyperspectral data in species mapping and modelling (scientific demonstration).
- *Management policy*: Effects of management under different climate scenarios studied.
- *Availability of standardized and representative forestry field data*: In collaboration with other projects, we will study the use of forest maps created from NFI data via spectral feature banks.
- *Validation capabilities at the spatial and temporal resolution of the Forest DTE outputs*: test data will be available as 3D forest models (scientific demonstration) and time series growth data on individual trees (demonstration in Czechia).
- *Integration with other DTCs*: Implementation on DESP will enable coordination of data interfaces and data sharing between the DTCs.
- *Ease of use*: Forest DTC will be integrated into the DESP with designated visualization tools and

Quantification and modelling of forest health and biodiversity into the Forest DTC are clear gaps in the current scientific understanding. Forest health, diversity and pest or pathogen attacks are directly linked, not only with each other, but with the primary production of the forest. In the long run, it would be essential for the forest DTC to have information on forest health status and potential damages as a standard input to the system. The number of forest pathogens and damages is large, which complicates their monitoring and the development of a single model to account for all of them. Extensive research is required in this area. During the Forest DTC project, forest disturbance risk model will be integrated with the productivity and growth models, so future projections of disturbance occurrence would be based on disturbance statistics computed from the future climates of the climate pathways, and not historical data. The system will be tested with bark beetle data from Czechia.

The development of the Forest DTC with the specific capacity to monitor, understand and forecast the development of the forest ecosystems and the various services it provides, can be traced to several key EU documents and international agreements.

- The **EU Updated Bioeconomy Strategy** (European Commission, 2018) and **EU Biodiversity Strategy for 2030** (European Commission, 2018) require mapping and monitoring of the biologically diverse natural old-growth forests. Although direct mapping of old-growth forests is a challenging task, Forest DTC can be used to model the temporal trajectories of forests under past and future climates and identify similar forests in long time series of Earth Observation data.
- Forest DTC would support sustainable practices for agroforestry and forestry, foreseen by the abovementioned strategies, under variable climate and allow

efficient detection of abnormal developments al large scales, allowing to undertake mitigation actions.

- The system would support improvement of the resilience and adaptive capacity of forest ecosystems by enabling development of management scenarios adapted to future climates, considering also the human pressure, thus ensuring a long-term supply of primary material and ecosystem services as required by the EU bioeconomy strategy.
- EU Biodiversity Strategy directs to take action to identify products, manufacturing of which causes forest degradation, and to prevent and respond to major forest fires. The Forest DTC will provide the infrastructure for mapping forest degradation and link it with wood processing chains. It also will include a tool for mapping forest fire fuel and demonstrate it at regional scale in Europe.
- The **EU Forest Strategy 2030** (European Commission, 2021) foresees the creation of a new monitoring which "could also benefit from the EU Destination Earth (DestinE) initiative in the form of a dedicated digital twin, which can be considered a new step-change for Earth system modelling and data assimilation across different but interconnected thematic areas". Forest DTC directly answers this call.
- In addition to the European policies, international initiatives such as the **UN Sustainable Development Goals (SDG)** and the various **UN Conventions**, most importantly the **Framework Convention on Climate Change (UNFCCC)**, require monitoring and forecasting of forest resources. The Forest DTC will for example enable countries with enhanced analyses capabilities to respond to the requirements of the **SDG 15 'Life on Land'** related to sustainable management of forests, land degradation, biodiversity loss etc.

The Forest DTC will provide the tools to analyse the effects of climate change and different management practices, thus answering the fundamental needs foreseen in the strategies mentioned above. It will also allow computation of various local information products such as biodiversity using local knowledge and models, a few demonstrations will be included in the DTC. However, further development also beyond FTC is needed to better answer the need to map and monitor old-growth forests, requiring the use of very long time series and other (not EO-based) geographical data; also, integration of wood processing chains and products requires analyses, tools and registries which have not been integrated into forest mapping and prediction systems.

The approach for user engagement during the project will include two levels: 1) activating a wide user community and 2) tightly involving a core user group. This division of the target stakeholders into two levels will facilitate gathering of requirements, experiences and feedback from a wide community of different types of users, while at the same time allowing intense cooperation with the core users in the four use cases to maximize user involvement in the development and demonstrate the usability of the system for the users. The prime contractor of the proposal submitted an Expression of Interest (EoI) for the development of a Forest Digital Twin as a part of the DestinE framework. The EoI was accompanied by support letters from the following organizations:

- Food and Agriculture Organization of the United Nations (https://fao.org)
- Climate Leadership Coalition (https://clc.fi/), the largest non-profit climate business network in Europe
- Integrated Carbon Observation System (ICOS; https://www.icos-cp.eu/) Finland

In addition, during the proposal preparation, several organizations have indicated their initial interest towards the Forest DTC and given non-binding agreements to join the user community. These include for example:

- European Commission Joint Research Centre (EC-JRC; https://joint-research-centre.ec.europa.eu/index_en)
- European Forest Institute (EFI; https://efi.int/)
- Forest Europe (https://foresteurope.org/)
- CzechGlobe – research institution (https://www.czechglobe.cz/en/);
- University Forest Enterprise Masaryk Forest in Křtiny – forest owner (https://www.slpkrtiny.cz/en/)
- Repsol Foundation (https://www.fundacionrepsol.com/en/)

The wide user community will be built during the early stages of the project using the networks of consortium members and public sources to ensure representation of all the user categories listed above. The community will be kept open and expanded during the project. All interested Forest DTC users are invited to provide inputs for the system requirements and feedback during user workshops and/or 1:1 interviews. The wide user community will play a key role in the early stages of the project in the system requirement fine-tuning, and again in the later stages of the project providing feedback based on the four use cases and identifying further development needs. The interested users will be kept updated on the development of the system throughout the project.

The core users will be involved closely in the development of the system. In addition to taking part in all the wide user community activities, each of the core users will be linked to one of the four use cases. These use cases will be designed and implemented to meet the specific needs of the core users. The core users for the four use cases will be:

- *Finland*: **Finnish Forest Centre** (https://www.metsakeskus.fi/en), a state-funded organisation tasked with promoting forestry and related livelihoods, advising landowners on how to care for and benefit from their forests and the ecosystems therein, collecting and sharing data related to Finland's forests and enforcing forestry legislation.
- *Catalonia*: **Forest Ownership Centre** (https://cpf.gencat.cat/es/inici/), a public agency that promotes the sustainable management of private forests in Catalonia and reports to the regional government on the level and effects of forest management in the Catalan private forests. Also **Forest Bioengineering Solutions SA** (http://www.fbs.cat/) and **Consorci Forestal de Catalunya** (forest owners association; https://www.forestal.cat/web/) will be directly involved.
- *Use Case Science*: **FluxCom** (https://www.fluxcom.org/), an initiative to upscale biosphere-atmosphere fluxes from FLUXNET sites to continental and global scales with machine learning methods that integrate site level observations, satellite remote sensing, and meteorological data.
- *Czech Republic*: **Forest Management Institute** (https://www.uhul.cz/?lang=en), a government organization established by the Ministry of Agriculture with the main tasks of implementing the National Forest Inventory and maintaining a central database with information about forests of the Czech Republic.

The role of the core users is essential in the project as they act as early adopters of the system and will become change champions promoting the use of Forest DTC in the wider community. The workshops and interviews in the latter part of the project, based on the information and knowledge generated during the four demonstrations in Forest DTC, will not only be used to acquire information on further development needs but also to demonstrate the usability of the system to the wide user community through the experiences of the core users. The four use cases are detailed in the Section '2.*2 Proposed approach to reach the main technical objectives of the ITT and proposed technical and scientific approach'*.

In the Forest DTE Precursor project, four main topics were identified prioritising the requirements of the interviewed 29 stakeholders as follows:

1. Climate-Forest interaction: quantification and presentation of forest carbon fluxes and other climate impacts of forests. Annual carbon balance monitoring was seen as key requirements – providing up-to-date information for policy makers.
2. Forest disturbances: detection of change in forest status, including, but not limited to pests, fires, storms, drought.
3. Optimising forest management: simulation and visualisation of different forest management scenarios to provide reliable information on forest ecosystem development under climate change in order to continue with a sustainable forest management, while ensuring sustainable wood supply.
4. Change in forest areas: reliable information on forest ecosystems under climate change and visualisation of the dynamics and extent of changes in the forest species composition under climate change scenarios.

As a cross-cutting theme, monitoring of forest biodiversity and health status, enabling evaluation and modelling of forest sustainability, was mentioned by a smaller number of interviewees. These topics will be re-evaluated with the target stakeholder groups (including the wide community and core users) during the early stages of the project and revised and amended if needed.

The initial design requirements, based on the Forest DTE Precursor project, were as follows:

1. Very high spatial resolution, with potential benefits down to the level of a single tree or group of trees (in case of small trees).
2. Long-term simulation: 86% of the interviewed stakeholder mentioned the need for long-term simulation with the average timespan of 54 years. Legal obligations often require simulations of at least 40 years.
3. Acceptance of user datasets and models: not one out of the 29 organisations interviewed would generally refuse sharing their data or models with ESA / the FDTE model developers. In addition, the users have a variety of process models, which would benefit a digital twin of the Earth by providing more accurate predictions regionally.
4. Compatibility with existing systems owned by third parties:
    - The System for earth observations, data access, processing & analysis for land monitoring – SEPAL – is an open-source project by the Open Foris team in Forestry Department of FAO. It is a cloud-computing platform to process

and analyse satellite data (e.g. Landsat or Sentinel). Used in general for geo-data processing.
- The European Forest Fire Information System – EFFIS.

A general requirement for any modelling system is the need for verification and quantified uncertainty with features like provision of a verification mechanism with reference sites, focusing on harmonisation and standardisation of datasets, with particular focus on uncertainties and errors. These considerations have been considered in the preliminary design of the Forest DTC system. However, the temporal horizon of the model will depend on the data horizon in the DestinE digital twin engine. Alternative climate scenario sources will be considered during the project.

The user needs identified in the Forest DTC will be systematised. The needs not addressed in the Forest DTC project will be identified and specific recommendations will be developed to address them in further development of the operational digital twin of forests.

The following initiatives and projects are seen as potentially relevant to the Forest DTC:
- ESA Forest Carbon Monitoring
- Other ESA DTC projects
- EU Pathfinder
- EU ForestPaths
- EU Forest Navigator
- EU FORWARDS
- WRI Global Forest Watch
- FAO SEPAL
- European Forest Fire Information System (EFFIS)
- Forest Information System for Europe (FISE)

A full analysis of relevant initiatives will be carried out after project kick-off. The list will be used to establish the needs on data an algorithm interoperability. When fully operational, the added value of Forest DTC to the existing ecosystem of forest monitoring project will be its open interfaces and standards and the capacity to model forest development in a consistent manner across the globe.

Task 2: DTC Design and Technical Specifications

This Task will be a part of the Work Package *Requirements, Design and Technical Specification*. The design is driven by the tasks set forth for the system and the current understanding of the DestinE infrastructure, composed of a Digital Twin Engine, Data Lake and a Core User Platform.

The Forest DTC will initially be implemented in a cluster within OVHcloud and moved to DESP (also within OVHcloud) as its resources become available. It is installed as a set of component deployments in a dynamically scaled Kubernetes cluster. The Forest DTC will have a modular design where its components can be replaced with the services offered by DESP as they become available. In the initial phase it will make use of the components developed as part of the Earth Observation Exploitation Common Architecture (EOEPCA) project (https://github.com/EOEPCA) and the subsequent EO Platform Interoperable

Building Block Evolution project (EOEPCA+). VTT has prior experience in implementing and integrating the EOEPCA, having performed a full deployment of all its components.

The overall architecture is shown in Figure 11, which makes distinction between new developments for the Forest DTC and the use of existing components – initially based on EOEPCA/EOEPCA+ and later replaced by the DESP components.

The core of the system is the Forest DTC Controller that manages the configurations and workflows of the system. The Controller is managed through a browser based graphical user interface (GUI), and it can also be managed via an API that enables programmatic access from external systems. A separate visualization user interface is also provided. System access through these interfaces is controlled via the Identity & Access Management component.

The Forest DTC Controller manages the Application Deployment & Execution Service (ADES), an EOEPCA-based component that is responsible for executing computational processes as a set of concurrent jobs. The identified processes are (with reference to section 2.2 and Figure 2):

- Forest map update
- Forest growth model
- Forest management operations
- User variable computation

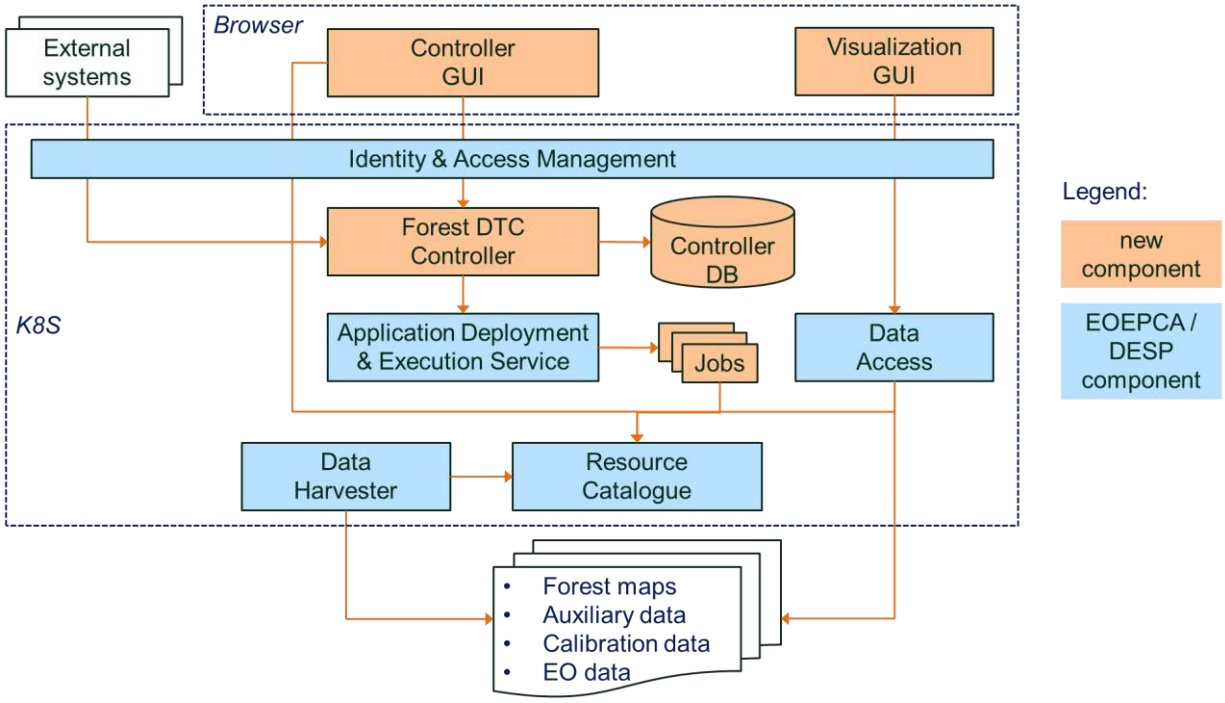


Figure 11. The proposed overall architecture of Forest DTC.

The various data sources used by the Forest DTC – including EO data, calibration data, auxiliary data and the forest maps from Forestry TEP and potentially other sources – are harvested for catalogue information by the Data Harvester component. This builds a catalogue repository that is controlled through the Resource Catalogue component and is populated also with the output data. The Resource Catalogue is accessed by the

processing jobs as well as by the Controller GUI and by the Data Access component, which serves the Visualization GUI.

Task 3: Research and Development

The following actions need to be taken to implement Forest DTC according to the Roadmap developed in the precursor stage:

1. Creation of a reference forest dataset for accurate mapping of forests with EO data. This could include collection of a public dataset of geolocated forestry field data, both historical and current, accompanied by EO imagery. The data should be in a standardized, machine-readable format. Due to the restrictions and data protection (mostly the protection of the exact coordinates of national forest inventory plots) set by national forest inventories and the different approaches to quantifying forest structure (i.e., the measured set of variables), this is not achievable during the proposed project. However, such activities involving national forest inventories are ongoing. Instead, we propose to make best use of existing forest maps based on the confidential plot data (e.g., the PATHFINDER project), building standardized data interfaces and links to existing data, and providing interfaces for creating (regional) forest variable maps based on user data. Such maps for the demonstration areas will be made available as a part of the 4D reference dataset.
2. Creating a validation scheme for Forest DTC by a scientific analysis of the uncertainties in input values and their propagation to Forest DTC outputs. The validation scheme will be based on a data assimilation scheme of existing flux towers, forest productivity monitoring sites and EO data, and is a part of the research done during the project.
3. Investigating the use of hyperspectral and other data sources for retrieving a more detailed distribution of forest overstory species. Currently, space-borne hyperspectral data are scarce, but this will change before 2030, most notably due to the Sentinel-10 CHIME. We will use hyperspectral data, both from satellite (EnMAP, PRISMA) and airborne platforms for the test regions in the scientific demonstration to develop a future-proof system, ready for accepting the forthcoming routine spaceborne hyperspectral imagery.
4. AI tools will need to be developed to make use of the forestry field and EO data in automated prediction of forest variables, speed up simulation computations, make full use of optical VHR imagery (where individual tree crowns are visible) or pre-process EO imagery. However, forest variable retrieval does not require deep neural networks; instead, more traditional machine learning methods such as random forest will be used in producing the forest maps to be included in the 4D reference dataset. In the proposed project, AI will be used in updating the forest maps (determining and quantifying change) and tested for emulating the physical forest growth modelling chain. An analysis on the application of the very recent developments in the use of AI in large-scale mapping of forest variables using Very High Resolution (VHR, pixel size < 1 m) imagery (e.g., Reiner et al. 2023; Mugabowindekwe et al. 2022) will be done during roadmapping.
5. The specialized digital twins, or DTCs, will need to be designed with compatibility and co-operation in mind. This requires constant exchange of information during the development process, as a part of the Task *Synergies and Coordination Across DTC Themes*.

The research activities of the Forest DTC project will also include model development, validation, and integration of the disturbance modelling to be implemented in the use cases.

A detailed description of the theoretical work to be performed on the main modelling system is given in the subsection *Proposed scientific and technical advances* above. The user-specific additions to Forest DTC (pest and fire disturbance modelling) are detailed in the respective Use Case descriptions above. Finally, the Use Case Science focuses on the cross-disciplinary advancement of forest modelling, model parameterization and uncertainty quantification for the test sited used in the demonstrations in collaboration with the numerous research activities ongoing there.

Task 4: DTC Implementation and Integration

Key elements of Forest DTC are:

- Access to Data Lake, a collection of historical and real-time EO data collected, e.g. from satellite platforms and observation networks.
- User interface – either specific to Forest DTC or a subsystem to the Digital Twin on Climate Change Adaptation. This includes visualization tools of forest simulation results and the resulting impacts.
- Comprehensive forest system model that allows to infer forest state from EO data and simulate forest development (growth, disturbances and management actions) at regular time steps based on environmental information.

The information produced by Forest DTC can be utilized by tools that quantify the impact of simulated forest development on the various services and benefits of forest (e.g. economic or societal). The data can also be interfaced with the data processing systems of the users.

The goal of the first iteration of implementation and integration is to produce a Minimum Viable Product (MVP). All parts will be initialized and organized as a skeleton that supports unit and end-to-end tests. MVP development will focus on building an outline for a user interface and integrating it to the Destination Earth Core Service Platform (DESP) rather than developing value adding functions and methods. This helps to gather user feedback and works as a central communication medium to harmonize further development directions. Meetings with the technical collaborators, stakeholders and end users will be conducted from the start of the project by applying an agile methodology.

Building a functional skeleton requires understanding of the ways to integrate multiple technically separate elements, such as DESP, Identity and Access Management (IAM) and external systems such as Forestry Thematic Exploitation Platform (Forestry TEP). The architecture of the functional skeleton will follow the reference documentation produced in the tender actions Destination Earth DestinE Core Service Platform Framework Platform Data Management (SoW RD2) and the DestinE Core Service Platform Framework Advanced Application and Services. The DestinE Service Platform (DESP) Documentation Repository (SoW RD3) will be used as a starting point for the first iteration of the implementation of the MVP.

The first iteration of Task 4 will enable the effective and secure integration of external services, such as Forestry TEP, to DESP and the Forest DTC. The integration framework is based on IAM through token-based authorization and authentication using standard protocols (OpenID Connect and Security Assertion Markup Language). More specifically, the integration of external services is implemented using the following step-by-step process supported by DESP. First, the IAM admin enables the permissions for the service provider to configure a client for the service in the IAM. Then, the IAM admin sends a client identifier and client secret to the service provider, which are configured in the external service using the Keycloak documentation (www.keycloak.org/docs/22.0.3/securing_apps/). The IAM admin creates and assigns a specific role for the service provider and informs the service provider of the new role via email. Finally, the service is published in the service registry by the DESP administrator. This integration process is then implemented for all digital services defined in Task 2 which are not provided by DESP. In addition to Forestry TEP, these services include the Controller and Visualization graphical user interfaces (see Figure 11).

The Forest Digital Twin Component will initially be implemented in a cluster within OVHcloud and moved to DESP (also within OVHcloud) as its resources become available. It is installed as a set of deployments in a dynamically scaled Kubernetes cluster. In the initial phase it uses the components developed as part of the Earth Observation Exploitation Common Architecture (EOEPCA) project and the subsequent Earth Observation Platform Interoperable Building Block Evolution Framework.

Task 5: Validation, error analysis and uncertainty quantification

The total uncertainty of the carbon storage and flux products is a compilation of uncertainties in the input datasets and model uncertainties. The level of uncertainty of the initial state of the forests (i.e. input uncertainty) is quantified by the accuracy assessment of the EO based forest structural variables provided with the forest structural data. The accuracy of input data which also defines the basic level of accuracy for the initial carbon storage and flux varies with input data (e.g., whether airborne laser scanning is used) and region type (e.g., relatively sparse boreal forest with a limited number of overstory species vs. closed tropical forest with tens of species). In the precursor project, the accuracy of the key structural variables (expressed as RMSE) in large-scale mapping with satellite data was estimated to be between 40 and 100% with a bias below 10%. The variables relevant for biomass and carbon were found to be at the lower end of the range.

For the accuracy assessment of carbon storage and flux variables, reference data will be used whenever available, e.g. from established flux towers nearby or measurements conducted by the user. However, while these data are available for the use cases here with excellent data sets being provided for the scientific use case. The estimates from the use cases will be documented for different forest types and used in uncertainty assessments also for other areas.

A first estimate on the uncertainties can be based on earlier activities with the same forest modelling system. The gross primary production (GPP) predictions were calibrated and tested for the boreal region (Minunno et al. 2016). PREBAS model that was used in the computation of the estimates has been calibrated and tested using an extensive dataset that covered a wide range of climatic conditions and management practices across Finland (Minunno et al. 2019). The model showed a robust predictive capacity for forest variable development and forest growth. The model was also tested at country level using statistics

from the Finnish forestry regions (Holmberg et al. 2019). YASSO has been tested in several studies in Finland (e.g. Rantakari et al. 2012). The linkage of modules in Rprebasso has been tested at two eddy covariance sites in southern and northern Finland (Hyytiälä and Sodankylä, respectively). The uncertainties from these studies were summarized during the precursor project and are given in Table 2.

Table 2. Accuracy estimations for carbon storage and flux products

Output variable	Unit	Uncertainty quantification	Accuracy
Above-ground wood biomass	tC/ha	Use of reference data when available, or evaluation of input accuracy & model confidence intervals	30% RMSE% ±10% Bias%
Below-ground biomass	tC/ha	Use of reference data when available, or evaluation of input accuracy & model confidence intervals	50% RMSE% ±20% Bias%
Carbon in woody biomass	tC/ha	Use of reference data when available, or evaluation of input accuracy & model confidence intervals	25% RMSE% ±10% Bias%
Soil carbon	tC/ha	Use of reference data when available, or evaluation of input accuracy & model confidence intervals	50% RMSE% ±20% Bias%
GPP	tC/ha	Use of reference data when available, or evaluation of input accuracy & model confidence intervals	10% RMSE% ±5% Bias%
NPP	tC/ha	Use of reference data when available, or evaluation of input accuracy & model confidence intervals	20% RMSE% ±10% Bias%
Evapotranspiration	l/m^2	Use of reference data when available, or evaluation of input accuracy & model confidence intervals	15% RMSE% ±7% Bias%
Annual stem volume increment	tC/ha	Use of reference data when available, or evaluation of input accuracy & model confidence intervals	40% RMSE% ±20% Bias%
NEE	tC/ha	Use of reference data when available, or evaluation of input accuracy & model confidence intervals	40% RMSE% ±20% Bias%
Carbon stock in trees at the start of the period	tC/ha	Use of reference data when available, or evaluation of input accuracy & model confidence intervals	30% RMSE% ±10% Bias%
Carbon stock in soil at the start of the period	tCt/ha	Use of reference data when available, or evaluation of input accuracy & model confidence intervals	50% RMSE% ±30% Bias%

The accuracy of carbon storage and flux model predictions can be improved if errors in the input variables and model calibration are reduced. The structural and parametric model uncertainties are quantified and minimised during the PREBAS calibration process for all use case areas by means of Bayesian statistics. Bayesian calibration provides a joint probability distribution of model parameters and model structural error.

The DTC will be implemented at the range of spatial and temporal scales identified in the Use Cases, from nationwide analyses to detailed analyses of experimental forest sites. This scaling-up from local plot-level measurements will be done in a semi-operational manner using interfaces built in DESPO. The results of the various forest simulations will be cross-compared against user-provided local data.

Task 6: DTC Demonstration and Impact Assessment

The use cases are detailed in the section 2.2 Proposed approach to reach the main technical objectives of the ITT and proposed technical and scientific approach. The task will be carried out in WP 5.

The use cases will be implemented in an agile manner in cooperation between VTT, the consortium member responsible for the use case, and a stakeholder representative (a core user). The use cases will be defined in detail during the first three months of the project. After this, the required input data sets will be collected and a first practical implementation of the simulations will be done with the core user by KO+6. The feedback from this activity will lead to a full first demonstration before KO+12. The feedback of the wider stakeholder community and the experience gained by the partner responsible for the use case will be collected and reported. Based on this the data and user interfaces will be improved for the second iteration of the use cases with initial analyses together with core user before KO+18 and a final demonstration report by KO+24.

The following aspects will be included in the impact assessment at all iterations of the use cases:

1. Scientific quality and accuracy of the final outputs, errors, and related uncertainties will be compared against the state-of-the-art systems in place by the stakeholders, tuned to the specific local forest properties.
2. The impact of the developed datasets, simulations, and what-if scenarios (management and climate scenarios) for different user categories and user needs. The results are evaluated first with the core stakeholders involved in the user case simulations (by KO+6 and KO+18 for the first and second iterations, respectively), improved upon and presented to the wider stakeholder groups at user seminars (at approx. KO+12 and KO+24). The feedback from the user seminars will be used to share experience across the four use cases and harmonize the requirements for user and data interfaces.
3. The functionality to facilitate a fast, attractive, and engaging access to the final information for the different categories of users. The target stakeholder groups involve representatives from different sectors with varying expectations to the user and data interfaces. Algorithms will be implemented to share the data between platforms, extract time series and aggregate it based on different variables, scenarios or geographic regions.
4. The effective integration of the Forest DTC as part of the DESP. The Forest DTC will be implemented on DESP from the beginning, thus ensuring full use of the emerging capabilities of the platform.

Task 7: Outreach and Communication

The outreach activities will be carried out in WP 6, *Outreach, roadmap and synergies*.

Based on experience with similar projects, we will prepare graphical material and informational texts to be sent to potential stakeholders, used in presentations in scientific and trade meetings, and potential scientific collaborators. These will include presentation material, descriptions of demonstrations, the required input and output data, illustrative diagrams, etc. As the project evolves, the material will include visualization videos, short

video clips, and scientific papers presented at different conferences. The material will be designed to address all stakeholder groups identified in WP 1. The material will be linked to press releases, allowing to create visually attractive and informative articles in online and printed media.

We will create and maintain an attractive and professional project website on easily accessible platform. The domain name and the used infrastructure will be coordinated with ESA and other DTC projects. Project manager will be responsible for maintaining and updating the site with all partners having access for adding news on new presentations, publications, press coverage, etc.

All partners will participate in disseminating the results via through presentations at relevant national and international conferences (including ESA Living Planet Symposium), workshops, and at other relevant meetings. In addition to presenting the results, the goal of the presentations (especially during the first year of the project) will be raising awareness of the opportunities provided by the DestinE initiative; in later stages, more emphasis will be on the demonstration of the possibilities of the DTC system. The presentations will be made in synergy with other projects, also costs will be shared and are hence not fully visible in the proposed budget. The scientific results presented in the meetings will be published in peer-reviewed scientific journals. Special attention will be paid to reaching out the forestry community, including people and institutions involved in the social effects of forests and forested landscapes.

The material prepared in this WP will be provided to media representatives and press releases will be issued when first results of the project will be achieved. This will allow to promote the DestinE digital twin system in a wider public. Synergy with other projects and DestinE activities will be targeted, e.g. the DestinE activities supported by ECMWF and EUMETSAT. The DTC will be presented as a part of the larger DestinE Digital Twin of the Earth, creating a completer and more attractive picture for the general audience. The advanced visualization methods developed during the project by Forest DTC and other DestinE components will be used to draw attention to DestinE activities.

Forest DTC will participate in the ESA DTE Open Workshop to be organised by ESA and other DestinE-related events (e.g., DesinE User Exchanges) for networking with interested parties and the developers of the DestinE system also via ECWMF and EUMETSAT.

Task 8: Scientific and Technical Roadmap

The roadmapping activities will be carried out in WP 6, *Outreach, roadmap and synergies*. The activities in Forest DTC are tightly related to the goals and timeline of the DestinE activity (Figure 12). To implement a fully functional digital twin of the forest, the scientific and technical limitations (preliminarily outlined in the section *2.4 Scientific and Technical Problem Areas* below) and also analysed during the Forest Digital Twin Earth Precursor project funded by ESA in 2020 – 2021.

The Precursor project identified several developments in the fields of forest modelling, data availability, computer science and societal (administrative) management (Figure 13). The challenges will be analysed in full detail during the Forest DTC project.

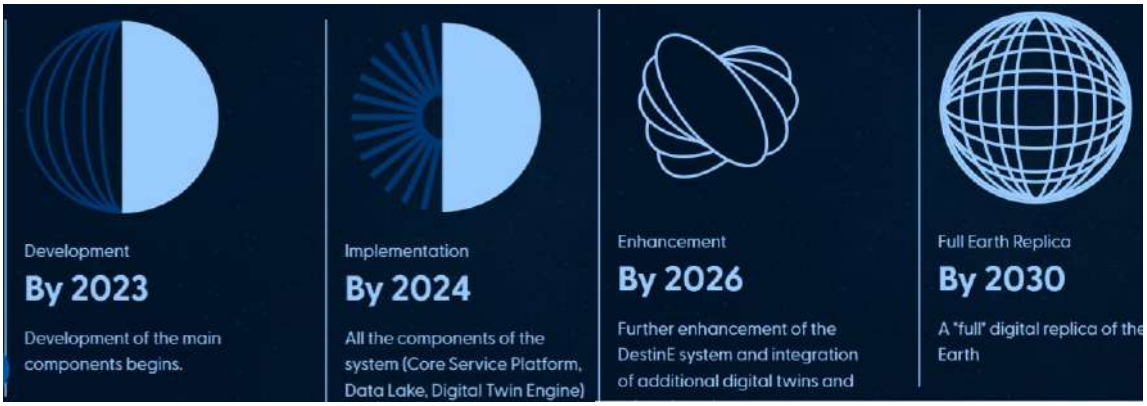


Figure 12**.** The timeline of DestinE digital twin of the Earth (source: DestinE website).

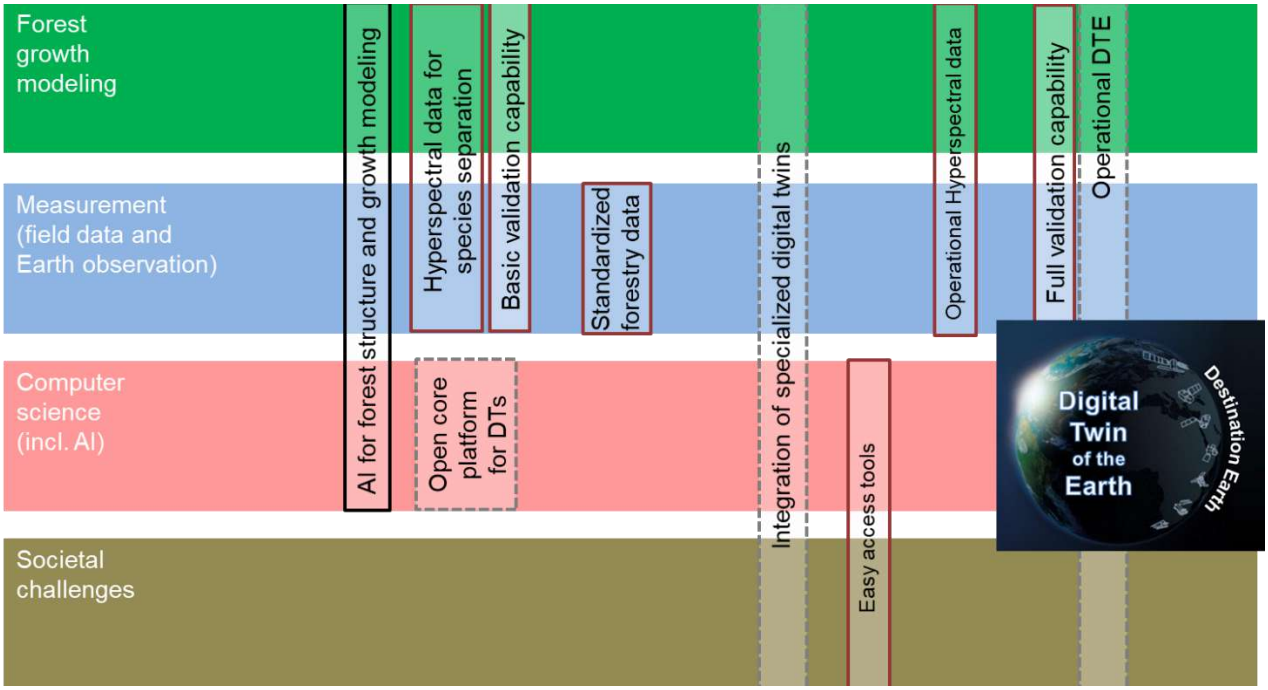


Figure 13**.** The Forest DTE roadmap created in Forest Digital Twin Earth Precursor project funded by ESA (2020 – 2021).

A fundamental decision is the relationship of the Forest DTC with the DestinE infrastructure. As a partial Earth system model, its outputs can be fed back to the digital twin on climate change mitigation, providing a better characterization of the forested land surface. This may require implementation of the Forest DTC on the digital twin engine with only the user and data interfaces on the DESP. However, it will likely require a more stable algorithmic base (local modifications cannot be made by users), heavy modification of the code base, and reduce the possibility for users to run what-if scenarios.

Task 9: Synergies and Coordination Across DTC Themes

Activities promoting synergies and coordination across DTC themes will be carried out in WP 6, *Outreach, roadmap and synergies*.

During the implementation and demonstration of Forest DTC, we will ensure coordination, and collaboration with the other DTCs and DestinE-related activities funded via other programs. Various events will be used for networking, e.g., DestinE User Exchanges, the workshops and twice-yearly DTC collocation workshops arranged by ESA, scientific conferences and online seminars. Coordination will not only be carried out with DestinE-related activities, but other large-scale forest-related projects. A sample list is given in the first iteration of Task 1: *Requirements Definition and Stakeholder Engagement*. Special attention will be paid to relevant ESA projects and activities including ESA scientific projects (e.g., ESA Science Cluster, Science for Society activities, CCI)

The Forest DTC project will actively coordinate with the relevant projects to identify communities of relevant stakeholders and scientist for finding joint solutions.

2.4 Scientific and Technical Problem Areas

2.4.1 Identification of the main scientific challenges and proposed solutions

Initial identification of the main scientific challenges likely to be encountered have been presented in Table 3, including also proposed solutions to mitigate the effects of the challenge. The initial analysis is based on the Forest DTE precursor project and will be updated during the proposed project as needed. In general level, the broad experience of the consortium provides several layers of protection against any of the challenges turning into severe risks during the project. Minimum feasible implementation of the algorithms has already been proven by the consortium, while the enhanced approaches planned to be used in the proposed project will allow overcoming the scientific challenges even more effectively.

An initial analysis of the gaps in scientific knowledge was performed in the Forest Digital Twin Earth Precursor project funded by ESA in 2020 – 2021. The key challenges from the roadmap produced during the precursor and the proposed answers in the Forest DTC project are given in Table 3.

Table 3. Scientific challenges from the Forest DTE Precursor project and solutions proposed for Forest DTC.

Scientific challenge	Proposed solution
Forest parameter retrieval	We will use the forest variable maps available via other projects. For example, national forest inventory (NFI) plot data are commonly not provided to external users. Collaboratively, this information can still be used to produce more accurate forest maps if the processing are performed by NFI partner, thus avoiding the need to share the sensitive data. As such maps are not up to date, a remote sensing-based updating algorithm will be implemented in the Forest DTC.
Soil carbon estimation	New, updated soil maps have become available at global scale, allowing a better estimation of the soil biogeochemical composition.
Forest productivity model capabilities	The model used in the study has been continuously developed. Further, the interfaces between Forest DTC components will be designed to allow the use of different forest growth and productivity models.
Coherent representation of	A large part of the Forest DTC project will be dedicated to integration of forest disturbance models into the digital twin. The modules will be

forest health, biohazards and disturbance risks	tested using actual forest data and compared against state-of-the art forest disturbance data sets.
Determination of species distribution	Current remote sensing data does not allow robust large-scale mapping of overstory species. With the development of hyperspectral sensors, this will become possible by 2030. In Forest DTC, we will develop and test the use of hyperspectral data for the scientific use case.
Biodiversity assessment and monitoring	Biodiversity will not be directly addressed in Forest DTC. However, a theoretical analysis on the potential of the Forest DTC output variables in biodiversity assessment will be done as a part of the roadmap.
Modelling peatland forest dynamics	The RPREBASSO model has been developed to include the key aspects of peatland forests. These experimental features will be evaluated during Forest DTC.
Inclusion of management policy feedbacks	The Finnish use case will be mainly devoted to analysing management policy feedbacks and discussed with the core stakeholders. Different management scenarios will be evaluated also for other use cases. The target stakeholder group will include policymakers to better understand the possible feedbacks of increased knowledge on forest policy formation.
Insufficient validation capabilities	Great emphasis will be placed in Forest DTC on improvement of the validation schemes. The use cases include well-monitored forests at flux towers. Also, time series of more than a hundred plots equipped with dendrometers will be modelled – such data were not available during the Precursor project, allowing a new insight into model accuracy.

2.4.2 Identification of the main technical problem(s) or problem area(s) likely to be encountered in performing the activity and proposed solutions.

Initial identification of the main technical challenges likely to be encountered have been presented in Table 4, including also proposed solutions to mitigate the effects of the challenge. The initial analysis is based on the Forest DTE precursor project and will be updated during the proposed project as needed. In general level, the long experience of the consortium in implementing technical solutions for scientific computing in cloud environment provides solid foundation for finding viable alternative solutions in case any technical challenges start to threaten smooth implementation of the project.

Table 4. Technical challenges and proposed solutions.

Technical challenge	**Proposed solution**
Some methods cannot be implemented into DESP.	Find solutions to develop the environment during the project. Set up approaches to temporarily run part of the processes outside DESP as long as it is fully developed.
Required input data is not available.	Main sources of key datasets have been identified and verified during the proposal stage. In case of negative developments, adapt approaches to utilise alternative data sources.
Integration with other DTCs and platforms	Technical tools and protocols with standard interfaces will be developed for a smooth flow of data.
Ease of use	In coordination with the developers of DESP and other DTCs, attractive control and visualization tools will be created.
Making best use of	We will actively participate in the networking events and collaborate with

DESP capabilities	other developers to keep up with the rapidly developing software environment of DESP and the overall DestinE infrastructure.

2.4.3 Proposed trade-off analyses and identification of possible limitations or non-compliances

We consider our proposal to be fully compliant with the ITT SoW.

2.5 Reservations –Compliance

2.5.1 Technical Compliance Matrix (Statement of Work/Technical Requirements)

REQUIREMENT (*)	COMPLIANT (Y/N/P) (**)	REMARKS (***)
Section 1.1 Overview, Lead DTCs Development Actions		
p. 4: self-standing tender	Y	
p. 4: exclusive to the Forest theme	Y	
p. 4: address synergies and complementarities	Y	
p. 4: address the specific scientific and operational needs and goals associated to the selected Theme	Y	
Section 2 Background		
p. 6: high-precision digital replica of an Earth system component	Y	
Section 2.2 The ESA Digital Twin Earth Element, Lead DTCs Development Actions		
p. 8: deliver an independent, end-to-end pre-operational system, fully implemented, conceptually and technically mature, scientifically validated, and fully tested by a representative set of early adopters	Y	
p. 8: strong evidence of community benefits	Y	
p. 8: ready for verification as part of DESP	Y	
p. 8: community roadmap for potential evolution and scale-up	Y	
Section 2.3.1 Initial Priority Themes for Lead Development Actions		
p. 9: advanced replica of forest systems and the response to climate change and forest management strategies; components of health, disturbances, deforestation, and links to carbon	Y	
p. 10: address specific scientific and operational needs associated to the selected Theme	Y	
p. 10: address synergies and complementarities across different Themes	Y	
Section 3 ESA EO-BASED DIGITAL TWIN EARTH COMPONENTS BASIC PRINCIPLES AND FUNCTIONAL ELEMENTS		
p. 10: advanced replica of a key component of the Earth system and its interactions with human activities and ecosystems	Y	
p. 11: maximise the potential offered by the latest advances in EO capabilities	Y	
p. 11: serve as a new generation of advanced scientific support tools and decision support systems	Y	

p. 11: respect a number of basic principles and conform to fundamental functional design elements	Y	
p. 11: ensure that the following basic principles and functional elements are followed	Y	
Section 3.1 EO DTCs Basic Principles		
BP1 – focus on a key component (Theme) of the Earth system	Y	
BP2 – valorise the capacity and maximize the use of EO data	Y	
BP3 – root the design in scientific excellence	Y	
BP4 – develop in view of becoming potential additional elements and/or services of future operational Digital Twins ecosystems	Y	
BP5 – focus on major scientific and policy/societal challenges of today; address temporal scales	Y	
BP6 – address complex interactions	Y	
BP7 – fully exploit the potential offered by the state-of-the-art EO capabilities	Y	
BP8 – develop following high scientific and technical standards	Y	
BP9 – strong community support and development in view of serving a wide variety of stakeholders	Y	
BP10 – use by space agencies as a reference tool	Y	
BP11 – advanced and high levels of interactivity	Y	
BP12 – different levels of access and interoperability to different categories of users	Y	
BP13 – complementarity with ongoing relevant initiatives and programmes	Y	
BP14 – maximise the use of open science and FAIR principles	Y	
Section 3.2 DTCs Basic Functional Elements		
p. 13: represent a quantum leap in the way we conceive decision support system	Y	
p. 13: functional element 1 – advanced data and digital services	Y	
p. 14: functional element 2 – multivariate data-driven reconstruction	Y	
p. 14: functional element 3 – scientifically sound processing blocks, simulation elements and workflows	Y	
p. 15: functional element 4 – user-driven interactive capabilities, data analytics and visualisation layer	Y	
Section 4.1 Objectives for Lead DTC development Actions		
p. 16: bring together scientists, industry, ICT experts, modellers, and policy makers	Y	
p. 16: engage the user and stakeholder communities	Y	
p. 16: co-design Use Cases with the users; address different needs and gaps	Y	
p. 16: cover sizable geographic regions and temporal scales in Use Cases	Y	

p. 16: co-design with users an effective and efficient architecture of the functional blocks and data flows	Y	
p. 16: dedicated research and development plan aimed at consolidating and advancing current limitations; implement a thorough experimental and development plan; specific efforts on the development and selection of each element	Y	
p. 16: implement, integrate and validate an end-to-end pre-operational realisation of the DTC; integrate in whole or in part in DESP; include all data processing and storage costs etc. in the tender budget	Y	
p. 17: open science and FAIR principles	Y	
p. 17: validation and error characterisation	Y	
p. 17: complete and engaging demonstration of the pre-operational DTC; provide solutions to the Use Cases motivated by user engagement; clearly identify the impact/benefit; open the demonstration service to a wide set of users, including the general public for a demonstration period	Y	
p. 17: community roadmap proposing both a plan with realistic options for advancing towards a full operational DTC and a dedicated Scientific and Technical Agenda; address potential options for the full or partial integration or connections of different DTCs	Y	
p. 17: coordination and collaboration with relevant activities and projects in Europe; include other relevant ESA activities	Y	
p. 17: coordination across the different DTC projects	Y	
p. 17: communication and dissemination of the projects results and benefits within the stakeholder community	Y	
Section 5 WORK TO BE PERFORMED		
p. 19: justify any possible departure from the presented structure in its proposal	Y	
p. 19: project duration 24 months	Y	
p. 19: parallel implementation of tasks; agile project management; two annual cycles	Y	
p. 19: first set of deliverables at KO+3	Y	
p. 19: milestones including project reviews every 6 months; participation in co-location meetings	Y	
p. 19: mid-term review at KO+12; plan of activities for year 2;	Y	
p. 19: nine tasks and a management task	Y	The tasks are combined into seven Work Packages to reduce management overhead
Section 5.1.1 Task 1: Requirements definition and stakeholder engagement		
p. 22: consolidate the definition of the goals, objectives, and specific requirements	Y	

p. 22: bring together scientists, industry, ICT experts, NGOs, policymakers, national and international authorities to jointly define, assess and identify the needs and gaps to be addressed by the DTC as well as the expected benefits & impacts	Y	
p. 22: close and continuous interaction with the Target Stakeholder Group	Y	
p. 22: identify at least 4 Use Cases	Y	
p. 22: consolidate the Use Cases, together with the user community, for the DTC demonstration	Y	
p. 22: detailed definition of the Theme	Y	
p. 22: assess the different categories of users and stakeholders, their needs and expectations; list the representative set of institutions that are engaged in the project activities	Y	
p. 22: detailed analysis of the state-of-the-art	Y	
p. 22: analysis of the main policy drivers and associated requirements; identify all aspects that cannot be currently provided	Y	
p. 22: engage users and stakeholders to identify the information needs, knowledge gaps, operational gaps, functional needs and requirements	Y	
p. 22: define at least 4 representative Use Cases to drive the development of the DTC and the demonstration; define the list of specific user requirements, including expected outputs, information and services, target areas of interest, temporal range and target accuracy and uncertainty vs user needs	Y	
p. 23: include needs (scientific, policy driven, technical) and capabilities that cannot be covered today by existing information and decision support systems; provide a clear description of the added value	Y	
p. 23: clear reporting and description of user requirements structured for clear traceability and for use as a reference to assess the validity of the proposed approach and to derive conclusion for future development needs	Y	
p. 23: survey relevant current and ongoing initiatives and projects	Y	
p. 23: implement the activity during the full duration of the project, ensuring a continuous engagement with users and stakeholders	Y	
p. 23: incorporate feedback from users/stakeholders	Y	
p. 23: handle personal data in accordance with the relevant data protection requirements in the Contract	Y	
p. 23: report the activities in the Requirements Baseline Document; deliver to ESA in different versions during the project; at the end of year 1, include the plan of activities and revision of the Use Cases for year 2	Y	
p. 23: deliverable Requirement Baseline Document (RBD) and its revisions	Y	
Section 5.1.2 Task 2: DTC Design and Technical Specifications		
All requirements within this Task	Y	
Section 5.1.3 Task 3: Research and Development		

All requirements within this Task	Y	
Section 5.1.4 Task 4: Implementation and Integration		
All requirements within this Task	Y	
Section 5.1.5 Task 5: Validation, error analysis and uncertainty quantification		
All requirements within this Task	Y	
Section 5.1.6 Task 6: DTC Demonstration and Impact Assessment		
All requirements within this Task	Y	
Section 5.1.7 Task 7: Outreach and Communication		
All requirements within this Task	Y	
Section 5.1.8 Task 8: Scientific and Technical Roadmap		
All requirements within this Task	Y	
Section 5.1.9 Task 9: Synergies and Coordination Across DTC Themes		
All requirements within this Task	Y	
Appendix A.1.6 Theme 6 – Forests		
p. 49: virtual replica of real-world forest systems, with representation across a range of spatial scales	Y	
p. 49: capture feedback across scales	Y	
p. 49: understand the impact of climate change, deforestation, invasive species, storms and wildfires	Y	
p. 49: insights into forest parameters	Y	
p. 49: processes that underlie forest dynamics	Y	
p. 49: advanced data-driven and dynamic reconstruction of the forest ecosystems	Y	
p. 49: wide range of EO data sources	Y	
p. 49: additional data from in-situ and ground-based observations	Y	
p. 49: modelling of individual trees and forests	Y	
p. 50: data assimilation and physical-based data fusion for forest variables at high spatial resolution	Y	
p. 50: allow for the testing of ‘what if’ scenarios, based on historical and current trends	Y	
p. 50: help forest managers and policymakers to balance competing demands	Y	
p. 50: validation to ensure reliability and accuracy	Y	
p. 50: interactions with other DTCs to exchange relevant information	Y	
Appendix B INTERFACING WITH DESP		
p. 54: monitor the developments published on the DestinE website, noting the application vs service terminology	Y	
Appendix B.1 DESP ARCHITECTURE AND SERVICES		
p. 55: maximize the use of the DESP and new DTE related digital services	Y	

p. 55: ensure access to the DTC capabilities to the users during the final demonstration through the DESP as dedicated DESP services	Y	
p. 55: ensure access to HPC capabilities if required to implement and complete the DTC implementation, integration, and demonstration as part of the proposal	Y	
p. 56: maximise the use of DESP and DTE digital services	Y	
p. 56: include all data processing and storage costs etc. in the tender budget	Y	
p. 56: at the time of the proposal, communicate and justify to ESA any additional or alternative platform capability proposed to be used	Y	

2.6 Existing own concepts/products to be used (Prime and Subcontractors)

Software module	Owner	Description	Type of Licence
Forestry TEP and related utilities	VTT	The Forestry TEP platform and related modules, used for forest data access	Open
Autochange*	VTT	Method and software to detect, quantify, and identify change using two-temporal satellite data.	Closed
PREBASSO: PreLes+CROBAS+ Yasso	University of Helsinki / FMI / Yucatrote	Software for computing forest gross primary production, growth, autotrophic respiration and litter production; computing forest soil carbon stock and heterotrophic respiration.	Open
	Consortium partners	Various algorithms for computing user-specific variables selected during the project. Details determined during initial phase of the project.	Open
Previncat server	CTFC	Fire fuel models and additional fuel variables	Open
Normalized digital surface model for Czechia	Forest Management Institute (CZ)	NDSM for use case Czechia, for tree height estimation, biomass estimation, validation purposes	Third Party

** Required for data assimilation to detect forest disturbances and management events. In the operational forest digital twin beyond this use case, a full time series analysis, possibly based on a forest reflectance model, will be implemented.*

2.7 Third Party's concepts/products (outside of the consortium which is composed by the Prime Contractor and Subcontractor/s) intended to be used

Only standard Third Party libraries and products such as operating system and the standard python libraries will be used in Forest DTC.

2.8 Personal Data Processing

The only personal data foreseen to be handled during the Forest DTC project will be the lists of Stakeholders and Users. This personal data shall be handled in accordance with the relevant data protection requirements in EU according to the standard practices of VTT.

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3) IMPLEMENTATION

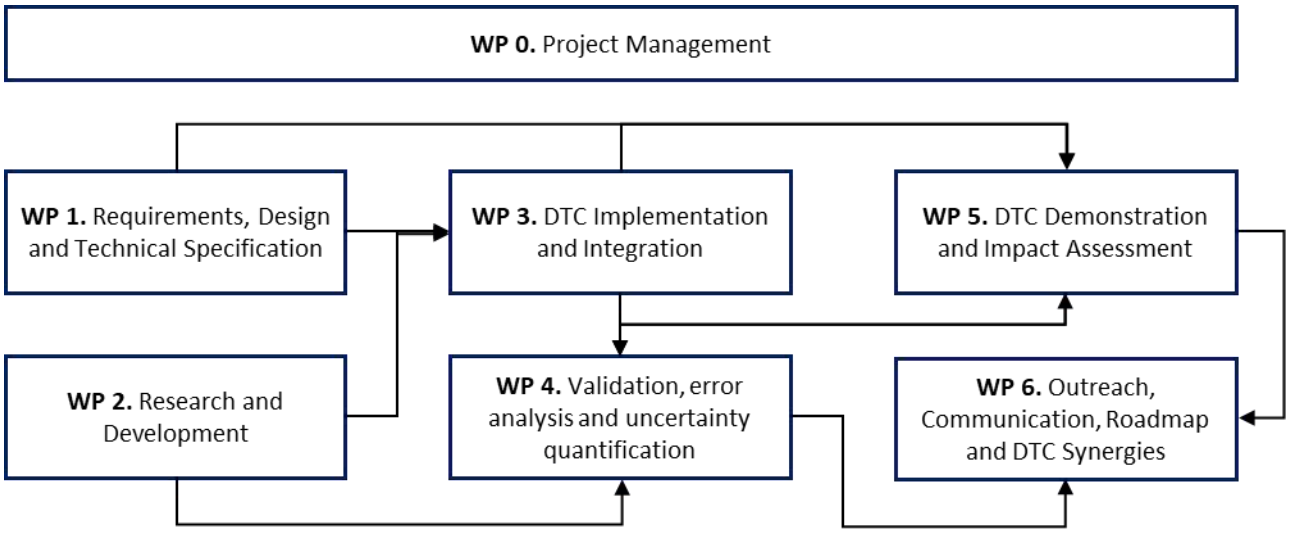
3.1 Technical Implementation/Programme Of Work

3.1.1 Proposed Work Logic

The Tasks 1 – 9 prescribed in the ITT will be carried out in six Work Packages as follows:

Task	Work Package
1 Requirements Definition and Stakeholder Engagement	1 Requirements, Design and Technical Specification
2 DTC Design and Technical Specifications	1 Requirements, Design and Technical Specification
3 Research and Development	2 Research and Development
4 DTC Implementation and Integration	3 DTC Implementation and Integration
5 Validation, error analysis and uncertainty quantification	4 Validation, error analysis and uncertainty quantification
6 DTC Demonstration and Impact Assessment	5 DTC Demonstration and Impact Assessment
7 Outreach and Communication	6 Outreach, Communication, Roadmap and DTC Synergies
8 Scientific and Technical Roadmap	6 Outreach, Communication, Roadmap and DTC Synergies
9 Synergies and Coordination Across DTC Themes	6 Outreach, Communication, Roadmap and DTC Synergies

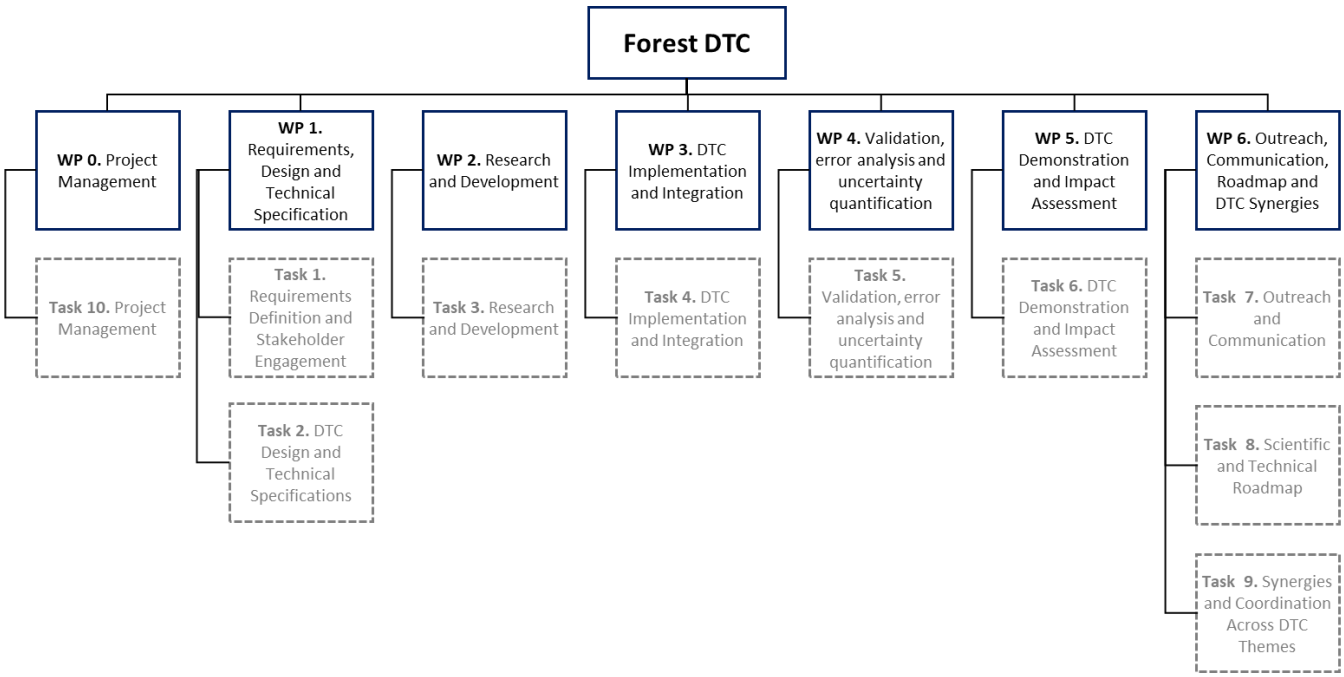
Additionally, Task 10 will be undertaken in WP 0.



3.1.2 Contents of the proposed work

3.1.2.1 *Work Breakdown Structure ("WBS")*

The Work Breakdown Structure including all Work Packages and Tasks in presented below:



3.1.2.2 *Work Package Description ("WPD")*

PROJECT: Forest DTC	WP: 0
WP Title: Project Management Company: VTT Technical Research Centre of Finland WP Manager: Renne Tergujeff Start Event: KO Planned Date: 01.10.2024 End Event: KO+24 Planned Date: 30.09.2026	Issue Ref 001 Issue Date 15.4.2024

Objectives:
Successful and frictionless enactment of the Research Plan of Forest DTC in and efficient and agile manner.

Inputs:

- Statement of Work
- Project proposal

Tasks:

- Overall management of project work and the communication between the Partners and ESA
- Arranging and preparing project meetings
- Preparation and distribution of the minutes of meetings
- Creating and maintaining a Document List, recording all the documents produced during the work, including reports, specifications, plans and minutes
- Maintaining an Action Item List recording all actions agreed with the Agency
- Maintaining a risk register
- Providing Progress Reports to the Agency's representatives, covering the activities carried out under the Contract
- Notifying the Agency's representatives (Technical Officer and Contracts Officer) of any problem likely to have a major effect on the time schedule of the work or to significantly impact the scope of the work to be performed
- Overseeing the communication of technical documentation
- Overseeing fulfilment of the Milestone Payment Plan

Outputs:

Bi-monthly: Progress Report, Minutes of the Meeting
KO +3: Progress Report, Minutes of the Meeting
KO +6: Progress Report, Minutes of the Meeting
KO +12: Mid-term Review Report
KO +18: Progress Report, Minutes of the Meeting
KO +24: Final Report

PROJECT: Forest DTC		WP: 1
WP Title: Requirements and DTC design Company: VTT Technical Research Centre of Finland WP Manager: Renne Tergujeff Start Event: KO End Event: KO+24	 Planned Date: 01.10.2024 Planned Date: 30.09.2026	Issue Ref 001 Issue Date 15.4.2024

Objectives:
This WP will consolidate the definition of the goals, objectives, and specific requirements to be addressed by the Forest DTC and translate the requirements and objectives into a technical specification and a fit-for-purpose complete end-to-end design of all the different elements of the Forest DTC to be developed and implemented with focus on the specific goals, objectives and user needs identified.

Inputs:

- Statement of Work
- Project proposal

Tasks:

- Bring together scientists, industry, ICT experts, NGOs, policymakers, national and international authorities to jointly define, assess and identify the needs and gaps to be addressed by the Forest DTC as well as the expected benefits & impacts.
- Elaborate, in close collaboration with the Target Stakeholder Group, a detailed definition of the Forest theme including all the scientific, technical, and operational challenges to be addressed, and the overarching and specific goals of the EO Forest DTC to be developed.
- Compile a representative list of institutions that are engaged in the project activities (e.g., supporting the definition and assessing the results of the Use Cases).
- Perform a detailed analysis of the state-of-the-art to identify the main scientific challenges and knowledge gaps that the Forest DTC shall address, incl. a survey of relevant national, European, and international initiatives and projects.
- Analyse the main policy drivers and associated requirements that the Forest DTC shall address and explicitly identify all aspects that cannot be provided by current information and decision support systems.
- Engage users and stakeholders to identify the information needs, knowledge gaps, operational gaps, functional needs and requirements for the Forest DTC during the project and in the future.
- Define, at least four representative Use Cases with specific user requirements to drive the development of the Forest DTC and the demonstration. The requirements and Use Cases will include also needs (scientific, policy driven, technical) and capabilities that cannot be covered today by existing information and decision support systems.
- Provide a clear description of the added value of the proposed work with respect to existing activities, knowledge, operational systems and products to enable traceability to the main design drivers of the Forest DTC and to be used as a reference to assess the validity of the proposed approach and to derive conclusion for future development needs.

- Ensure a continuous engagement with users and stakeholders throughout the lifetime of the project to involve the users and incorporate user feedback in the development of Forest DTC Use Cases and demonstrations.

- Design an effective and efficient architecture of the Forest DTC including all the input data, workflows, processing components (e.g., models, AI elements, data analytics), output data, and interfaces with the DESP. The design will include:
    - A complete definition of the different functionalities that the Forest DTC will provide, the user interface and the description of the different levels of interactivity of the system for different categories of users.
    - Expected output information and output products including the target accuracies and uncertainties.
    - Clear definition of the metrics and validation protocol for the final assessment and acceptance test of the system implementation including both a scientific and technical assessment of the results as well as the assessment by the users and stakeholder community as part of the demonstration.
    - A high-level description of the Data-Flow Diagram as well as a detailed description and definition of all the inputs, outputs and processing elements and components.
    - Identification and assessment of the requirements for data exchange with the DestinE system, and what relevant digital services and facilities are available from the DestinE platform, and how they will be used by the Forest DTC.

- Design for each of the four Use Cases, including clear description of:
    - Workflows and functional tools to address Use Cases.
    - DestinE infrastructure and functionality to be utilised.
    - Data-Flow Diagrams including required datasets, modelling/AI/analytics capabilities and digital services, ICT and HPC.
    - Expected output and target accuracies and validation data and metrics.

- Identification of the requirements for R&D activities to be developed in WP 2 and adaption of the design to consider the findings and results of these development activities.

- Conduct a detailed risk analysis pointing out which risk areas could affect all the different design, development, and implementation choices, with proposed solutions to address and mitigate.

- Update the design and technical specifications during the project to reflect the response to evolving user requirements, emerging scientific advances and technical capabilities, project progress and feedback.

Outputs:
KO +3: Requirement Baseline Document (RBD) V1. First version of the document describing the preliminary set of scientific, technical and user requirements, policy analysis, stakeholders and Use Cases that will drive the first year of activities of the project.
KO +3: Design and Technical Specifications Document (DTSD) V1. A first version of the DTSD including design and definition to address the Use Cases and research needs, specially focusing on activities to be implemented during the first year.
KO +6: Draft RBD V2. Draft of the first-year version (V2)
KO +6: Draft DTSD V2
KO +12: RBD V2. Complete report of all the activities and results carried out during the first year of activities. A plan of activities for year 2.
KO +12: DTSD V2
KO +18: Draft RBD V3.
KO +18: Draft DTSD V3
KO +24: RBD V3.
KO +24: DTSD V3

PROJECT: Forest DTC		WP: 2
WP Title: Research and development Company: Yucatrote WP Manager: Francesco Minunno Start Event: KO End Event: KO+24	 Planned Date: 01.10.2024 Planned Date: 30.09.2026	Issue Ref 001 Issue Date 15.4.2024

Objectives:
This WP will develop and implement a detailed research and development plan to address all the scientific and technical challenges required for the implementation of the Forest DTC. The plan will be based on scientific excellence and a thorough experimental, validation analysis including error characterisation and uncertainty assessment.

Inputs:

- Statement of Work
- Project proposal

Tasks:

- Define key scientific and technical challenges that need to be addressed for the implementation of the Forest DTC. The analysis will be on scientific excellence and a thorough experimental, validation analysis including error characterisation and uncertainty assessment that shall ensure the best available datasets and methods are selected for Forest DTC implementation, with clear justification for the selection of each element.

- Create an R&D plan for each of the target developments, based on detailed review of the state-of-the-art including: relevant publications, products, datasets, methods, models, and AI algorithms as well as existing relevant ESA and non-ESA scientific activities, projects and initiatives that may contribute to this effort. Test areas and related validation datasets will be identified.

- Explore, develop, test and finally select the necessary data, methods, algorithms, models and workflows required to implement the Forest DTC. This will include providing tools to address the Use Cases, representing Earth system processes and What-If scenarios serving the user community.

- Perform a systematic experimental assessment and cross comparison of different methods, techniques, modelling approaches and data over different test sites and target scales, including:

    - An experimental error analysis for testing and verifying different implementation choices including evaluation the accuracy and reliability of the developed methods and products on different validation sites.

    - Wide representation of different conditions that may affect or influence the performances of the methods and the final accuracy of the products.

    - The range of methodological options based on different data types and multi-mission approaches, EO-based products, including the use of models.

    - Selection of final methods on the basis of a detailed experimental analysis of the potential alternative methods and approaches supported by a sound inter-comparison and validation.

- A detailed description of the final version of the algorithms (including related data sources, processing steps and output data) reported in the ATBD, including analysis of the results that have led to specific development choices and trade-offs (including technical considerations).
- Perform a cross-comparison of the resulting products/estimates or models with existing equivalent/alternative datasets/models or processing elements to gain understanding of the range of validity, limits and benefits of the Forest DTC approach.
- Report the error analysis, validation activities and cross-comparison exercises in the ATBD.

Outputs:
KO +3: Research and Development Report (R&DR) V1, incl. ATBD and PVR.
KO +6: Draft R&DR V2
KO +12: R&DR V2, including a plan for Year 2 activities.
KO +18: Draft R&DR V3
KO +24: R&DR V3

PROJECT: Forest DTC	WP: 3
WP Title: Integration and implementation Company: Terramonitor WP Manager: Lauri Häme Start Event: KO Planned Date: 01.10.2024 End Event: KO+24 Planned Date: 30.09.2026	Issue Ref 001 Issue Date 15.4.2024

Objectives:
This WP will implement and integrate all the different elements of the end-to-end realisation of the Forest DTC as defined in WP1 and including the new scientific/technical developments from WP2, with particular focus on the Use Cases. The WP results in a pre-operational system that can be demonstrated and assessed by the user community.

Inputs:

- Statement of Work
- Project proposal
- Intermediate outputs of WP1 and WP2: RBD, DTSD R&DR V1 and V2

Tasks:

Set up an agile and rapid development and testing process in close connection with WP2 to ensure all Forest DTC elements are integrated and interact in an efficient and coherent manner.

- Process all the data sets defined in WP1 and WP2, run the models and processing elements to deliver the final output products that will represent the basis for the Use Cases and the demonstration of the user functionalities, digital simulations and what-if scenarios.

- Integrate the Forest DTC into the DESP in a manner agreed upon with ESA, taking into account the developments of DESP and the gradual operationalisation of its functionalities and services.

- Ensure the effective integration and availability of all the other required additional digital services, capabilities and other infrastructure elements not provided by DESP, such as Forestry Thematic Exploitation platform and related services.

- Implement testing and validation processes for all development, processing and integration activities.

- Perform final qualification and acceptance test of the system with ESA prior to the final demonstration to be performed at the end of the project.

Outputs:
KO +3: Plan DTC Integration and Implementation Report (IIR).
KO +6: Draft DTC IIR V1.
KO +12: DTC IIR V1, including a plan for Year 2 activities.
KO +12: Draft DTC IIR V2.
KO +18: DTC IIR V2.

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PROJECT: Forest DTC	WP: 4
WP Title: Validation, error analysis and uncertainty quantification Company: Yucatrote WP Manager: Francesco Minunno Start Event: KO Planned Date: 01.10.2024 End Event: KO+24 Planned Date: 30.09.2026	Issue Ref 001 Issue Date 15.4.2024

Objectives:
This WP will undertake actions to ensure validation, assessment and representation of errors and uncertainties associated with all the EO datasets, models, and processing elements. Errors will propagated through the system and represented appropriately as uncertainties in outputs.

Inputs:

- Statement of Work
- Project proposal
- Intermediate outputs of WP2, WP3 and WP5: R&DR V1 and V2; IIR and IAR V1

Tasks:

- Define a scientifically-sound set of metrics and testing/validation protocols to assess errors and uncertainties during the project lifetime and all relevant WPs.
- Gather independent validation datasets and use them for cross-comparisons and validation within the research, development and pre-operational implementation stages of Forest DTC development.
- Define error analysis and uncertainty quantification process, allowing errors associated with observations, data, methods, and models to be quantified throughout the system and propagated through the system to be presented alongside results/outputs.
- Analyse the outputs of the Forest DTC at the range of spatial and temporal scales used in the Use Cases.
- The error analysis and uncertainty quantification will include at least:
    - Compilation of validation datasets over representative test sites.
    - Assessment of validity of datasets/methods with comparison/testing of outputs with validation datasets.
    - Ensuring that the method is not biased towards specific choice of temporal or spatial window.
    - Identification of errors/uncertainties associated with datasets and methods.
    - Investigation and implementation of appropriate methods for error/uncertainty propagation.
    - Consideration of steps for minimising errors/uncertainty.
    - Presentation/display of errors to the user within the Forest DTC.
- Perform a detailed error analysis for testing and verifying all the developed methods and products on the different selected test regions..

Outputs:
KO +3: Plan Validation Report (VR)
KO +6: Draft VR V1
KO +12: VR V1, including a plan for Year 2 activities.
KO +18: Draft VR V2
KO +24: VR V2

PROJECT: Forest DTC	WP: 5
WP Title: DTC Demonstration and Impact Assessment Company: VTT Technical Research Centre of Finland WP Manager: Laura Sirro Start Event: KO Planned Date: 01.10.2024 End Event: KO+24 Planned Date: 30.09.2026	Issue Ref 001 Issue Date 15.4.2024

Objectives:
This WP will perform a full demonstration of the pre-operational Forest DTC capabilities highlighting how the Forest DTC would be used in an operational capacity responding to the needs of the different users identified in WP1 and how it could be further integrated into DestinE or other operational Digital Twin programmes (e.g., national programme).

Inputs:

- Statement of Work
- Project proposal
- Intermediate outputs of WP1, WP3 and WP4: RDB V1, V2 and V3; VR and IIR V1

Tasks:

- Design and implement an agile approach in close connection with the research, development, implementation and integration activities of the project to conduct four demonstrations focusing on the Use Cases defined in WP1 in two annual phases with a preliminary demonstration of the Forest DTC at the end of the first year. The demonstrations will clearly show the performance and functionality of the Forest DTC while responding to the specific goals, objectives and target user needs identified in WP1.

- Implement demonstrations in an interactive and attractive manner, engaging the community and stakeholder to actively participate in the assessment of the quality, usability and impact of the results. Identify the impact/benefit in comparison to existing or traditional methods, systems and services.

- Include at least the following four aspects in the impact assessment:
  1. Scientific quality and accuracy of the final outputs, errors, and related uncertainties vs the state-of-the-art and alternative existing approaches.
  2. The impact of the developed datasets, simulations, and what-if scenarios for different user categories and user needs.
  3. The usability of functionality to facilitate a fast, attractive, and engaging access to the final information for the different categories of users.
  4. The effective integration of the Forest DTC as part of the DESP.

- Demonstrate the functionality of the Forest DTC system and assess the response of the user community and the impact at open community events, such as ESA's Living Planet Symposium and at ESA dedicated DTE events and workshops.

Outputs:

KO +6: Draft Impact Assessment Report (IAR) V1
KO +12: Prototype DTC demonstration V1
KO +12: IAR V1, including a plan for Year 2 activities.
KO +18: Draft IAR V2
KO +24: Final DTC demonstration V2
KO +24: IAR V2

PROJECT: Forest DTC		WP: 6
WP Title: Outreach, roadmap and synergies Company: VTT Technical Research Centre of Finland WP Manager: Matti Mõttus Start Event: KO End Event: KO+24	 Planned Date: 01.10.2024 Planned Date: 30.09.2026	Issue Ref 001 Issue Date 15.4.2024

Objectives:
This WP will focus on the outreach activities, roadmap creation and coordination with relevant activities. The WP aims to maximise the communication and dissemination of the project results and benefits to stakeholders and wider community. Scientific and technical plan for advancing towards a fully operational EO-based Forest DTC will be documented in a roadmap created in collaboration with the scientific community and stakeholders. Coordination and potential collaboration with other relevant projects, initiatives and activities (particularly in the context of DestinE) that may benefit the project result and its impact will be ensured.

Inputs:
- Statement of Work
- Project proposal
- All intermediate outputs of WP1–5.

Tasks:

Outreach
- Define suitable communication and media material to maximise the communication and dissemination of the project results, benefits and Use Cases to stakeholders and wider community, including the use of interactive tools, visualisation and advanced media material.

- Ensure wide public, stakeholder and scientific visibility of the Forest DTC development through the following activities:
    - Create and keep updated an attractive and professional project website, regularly updated and offering relevant material and information.
    - Disseminate project results through presentations at relevant conferences (including ESA Living Planet Symposium), workshops, and at other relevant meetings.
    - Publish project results in peer-review journals.
    - Demonstrate Forest DTC capabilities at relevant events, workshops, and conferences, especially those relevant to the stakeholder and target user communities.

- Define and implement attractive and efficient approaches to promote towards the wider public using attractive and efficient ways to present relevant information and interactive capabilities to citizens maximizing the use of open web-based functionalities with advanced visualisation methods and tools for outreach, education and public information.

- Participation in the ESA DTE Open Workshop to be organised by ESA (end of 2024 or early 2025) as an open community consultation to present, assess and discuss the preliminary results of the programme and collect recommendations to define its evolution.

Roadmap
- Perform comprehensive assessment of the current performances and

- capabilities, limits, development needs, science gaps, technological constrains and implementation limitations of:
    1. the individual scientific and technical elements,
    2. the integrating aspects to establish an end-end system,
    3. the operational aspects of the Forest DTC.

- Based on a comprehensive assessment on the experiences gathered during the project, develop a scientific and technical roadmap in collaboration with the scientific community and stakeholders proposing a detailed scientific and technical plan for advancing towards a fully operational EO-based Forest DTC. The roadmap will consist of the following key elements:

    1. Assessment of the impact and benefits realized by the stakeholders.
    2. Review the scope, goals and user requirements and needs that may drive Forest DTC developments in the future, identifying the current gaps and how the Forest DTC is expected to overcome such gaps.
    3. Provision of details, in consultation with the stakeholder groups and in the context of the Forest DTC and user requirements, on current scientific and technical gaps affecting the Forest DTC.
    4. Review the relevant initiatives, programmes, and projects at European or national level that may contribute to the potential further development of the Forest DTC in the future and its potential transfer into an operational context.

- Provide within the roadmap:
    - A description of the goals, objectives, and target stakeholder group for a full operational Forest DTC.
    - A description of the expected target functionalities, capabilities and outputs.
    - A description of a potential high-level architecture and functional description, including input data, workflows, processing elements (models), output data and expected levels of accuracy and uncertainties.
    - A description of the data and digital infrastructure required beyond existing services provided by the DESP.
    - A description of the expected data budget in terms of storage, inputs and outputs for a full operational scenario.
    - A description of all the links and dependencies with existing or planned relevant activities and programmes (e.g., DestinE).
    - A scientific and technical development roadmap including all aspects needed for further development towards a fully operational Digital Twin in the future. This will cover all aspects: data, science needs, methodological needs, technical advancement that may be addressed by ESA science programmes (or by other European or national R&D programmes).
    - An assessment of the potential synergies and complementarities across different Digital Twin Components with a plan for potential integration and/or merging of different DTCs into a larger EO Digital Twin with a wider scope that may capitalise on the synergistic and complementary aspects of different DTCs.
    - A description of the elements and services that are considered to be scientifically and technically mature and rely on sufficiently proved quality and user acceptance to be transfered to an operational environment and a potential plan for such a transition (e.g., through DestinE of other operational programmes).
    - A description of a full development plan for a potential scale-up, expansion of functionalities and follow-on research and development of the proposed EO Forest DTC functionalities and scope in subsequent phases of the ESA DTE programme for the timeframe 2026-2029.

Synergies

- Analyse and set up coordination and collaboration (when possible) with other relevant projects, initiatives and activities (in particular in the context of DestinE) that may benefit the project result and its impact.

- Create and maintain coordination with other relevant international, European and national programmes and activities, including potentially e.g.:
    - Different user categories and representative of stakeholder groups.
    - Other Digital Twin developments at international, European and national level.
    - Relevant international scientific groups.
    - Relevant ESA projects and activities including ESA scientific projects (e.g., ESA Science Cluster, Science for Society activities, CCI).
    - Community representatives of relevant actors including scientists, industry, NGOs, policymakers, local, regional and authorities, international organisations, etc.
    - Major international scientific groups.

- Identify commonalities and potential synergies across different DTC projects addressing related Themes and work towards joint solutions in view of developing an effective and efficient ecosystem of Digital Twins in subsequent phases of the programme. This may involve the joint definition and use of digital services, interfaces, sharing of data and processing elements, including the potential to developed joint larger DTs in the future.

- Participate in the DTC collocation workshops (every six months) and discuss with other DTCs to identify commonalities across different themes.

- Consider proposing to ESA joint activities to be undertaken by different projects in view of reinforcing synergies and potential joint outputs, potentially facilitated by ESA by hosting team members of different projects for a period of time (e.g., a few months) at the ESA Science Hub as Visiting Scientists to work together and consolidate a joint view for the future.

Outputs:
KO +3: Project website (WEB) – Updated at monthly intervals.

KO +6: Draft Dissemination and Outreach Summary report (DOR) V1
KO +6: Draft Scientific and Technical Roadmap (STR) V1
KO +6: Draft Coordination and Synergy Report (CSR) V1

KO +12: DOR V1, including a plan for Year 2 activities.
KO +12: STR V1, including a plan for Year 2 activities.
KO +12: CSR V1, including a plan for Year 2 activities.
KO +12 onwards: Demonstration of DTC capabilities to stakeholders and wider community (OUT)

KO +18: Draft DOR V2
KO +18: Draft STR V2
KO +18: Draft CSR V2

KO +24: DOR V2
KO +24: STR V2
KO +24: CSR V2

3.2 Deliverable Items – Specification of any Non-Conformance

3.2.1 Deliverable Items

We are compliant with the deliverable requirements in the Statement of Work (in task descriptions, in section 6.5 Project Milestones and Deliverables and in section 6.6 Deliverables-Documentation Overview). As for DTC Integration and Implementation Report (IIR), we propose to follow the schedule in SoW section 6.5. The complete set of deliverable items is presented in Table 5.

Table 5. Deliverable Items

Deliverable acronym	Deliverable title	Task	WP	Milestones and deliverable versions
RBD	Requirements Baseline Document	Task 1	WP 1	MS 1: V1 MS 2: Draft V2 MT: V2 MS 4: Draft V3 FM: V3
DTSD	Design and Technical Specifications Document	Task 2	WP 1	MS 1: V1 MS 2: Draft V2 MT: V2 MS 4: Draft V3 FM: V3
R&DR	Research and Development Report (including ATBD: Algorithm Theoretical Basis Document, and PVR: Product Validation Report)	Task 3	WP 2	MS 1: V1 MS 2: Draft V2 MT: V2 MS 4: Draft V3 FM: V3
IIR	DTC Integration and Implementation Report	Task 4	WP 3	MS 1: Plan MS 2: Draft V1 MT: V1 MS 4: Draft V2 FM: V2
VR	Validation Report	Task 5	WP 4	MS 1: Plan MS 2: Draft V1 MT: V1 MS 4: Draft V2 FM: V2
P-DTC	Prototype DTC	Task 6	WP 5	MT: V1
PO-DTC	Pre-operational DTC	Task 6	WP 5	FM: V1
DEMO	DTC Demonstration	Task 6	WP 5	MT: V1 FM: V2
IAR	Impact Assessment Report	Task 6	WP 5	MS 2: Draft V1 MT: V1 MS 4: Draft V2 FM: V2
DOR	Dissemination and Outreach Summary report	Task 7	WP 6	MS 2: Draft V1 MT: V1 MS 4: Draft V2 FM: V2
STR	Scientific and Technical Roadmap	Task 8	WP 6	MS 2: Draft V1 MT: V1 MS 4: Draft V2 FM: V2
CSR	DTC Coordination and Synergy Report	Task 9	WP 6	MS 2: Draft V1 MT: V1 MS 4: Draft V2 FM: V2
WEB	Website updates	Task 7	WP 6	MS 1 … FM
OUT	Outreach activities	Task 7	WP 6	MT … FM
CLM	Co-location Meeting	Task 9	WP 6	MS 2 MT MS 4 FM
MOM	Minutes of meetings	Task 10	WP 0	MS 1 … FM
PR	Progress Reports	Task 10	WP 0	MS 1 … FM
MTR	Midterm Review Report	Task 10	WP 0	MT
FR	Final Report	Task 10	WP 0	FM

3.2.2 Non-conformances/limitations/additions regarding deliverable items

None.

3.3 Assessment of Major Areas of Risk

A risk register, in the format agreed upon in the kick-off meeting, will be maintained throughout the project. This risk register will at least identify potential risks, their likelihood and severity, and propose meaningful mitigation measures. Initial format and already identified potential risks have been provided in Table 6. Note that all the scientific and technical challenges described in Section 2.4 *Scientific and Technical Problem Areas* of the proposal will also be considered as potential risks, monitored throughout the project and added to the risk register in the earliest signs of potential effects on the project implementation.

Table 6. Initial risk register.

ID	Area	Description	Likeli-hood	Sever-ity	Mitigation measures
RSK1	Data	Forest field data not available	2	4	Start data negotiations at KO
RSK2	Users	User staff not available for agile development at times when needed	2	4	Advanced planning of activities containing user interaction
RSK3	Users	User organisation changes service requirements during the project	4	2	Flexibility incorporated into the system. Reasonable limitations to be clearly communicated to users.
RSK4	Users	User organisation withdraws from project	1	3	Find out the motives and try to reason with them. Continue the use case for a different user, find a new area/user or self–assess use case.
RSK5	Manage-ment	A key person with a specific expertise leaves the project.	2	3	The consortium is versatile and large enough to minimise the impact by quickly finding a replacement.

4) MANAGEMENT PART

4.1 Planning

4.1.1 Proposed schedule and milestones

Preliminary start and end dates are suggested as follows:
Start Event: KO Planned Date: 01.10.2024
End Event: KO+24 Planned Date: 30.09.2026
However, as all DTC projects will kick off at the same colocation meeting, the final dates will be determined by ESA.

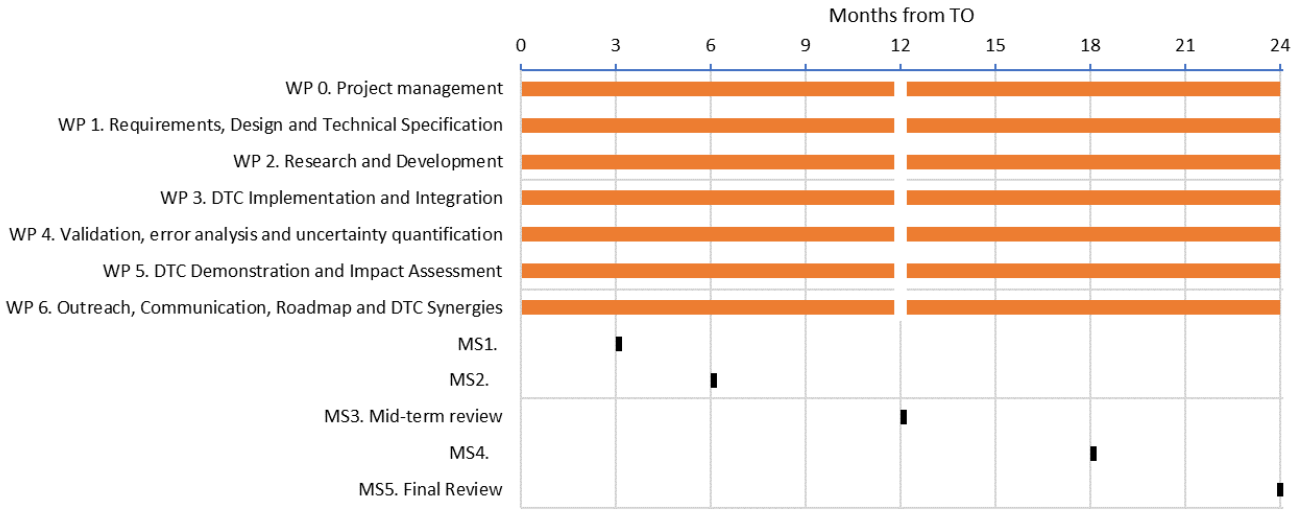
At least the following meetings are foreseen by the lead contractor:

- Kickoff (KO) 01.10.2024 at ESA
- MS 1 KO+3
- MS 2 KO+6 at ESA
- MS 3 (mid-term review) KO+12 at ESA premises
- MS 4 KO+18 at ESA
- Final Meeting KO+24 at ESA
- bi-monthly online Progress Meetings

Arranged in accordance with the requirements set forth in the SoW.

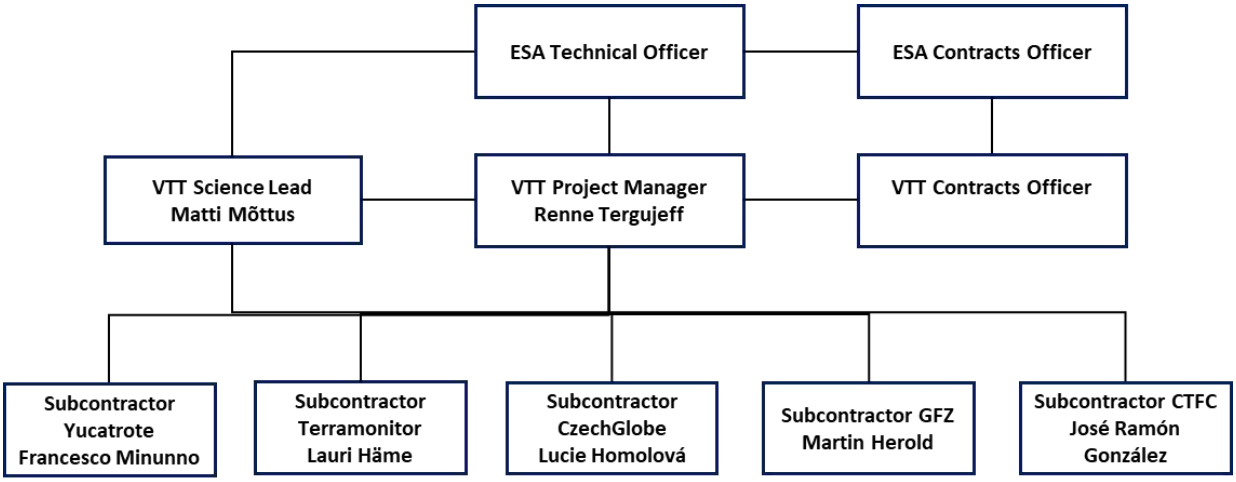
Additional WP meetings will be arranged on demand, preferably online.

4.1.2 Gantt chart

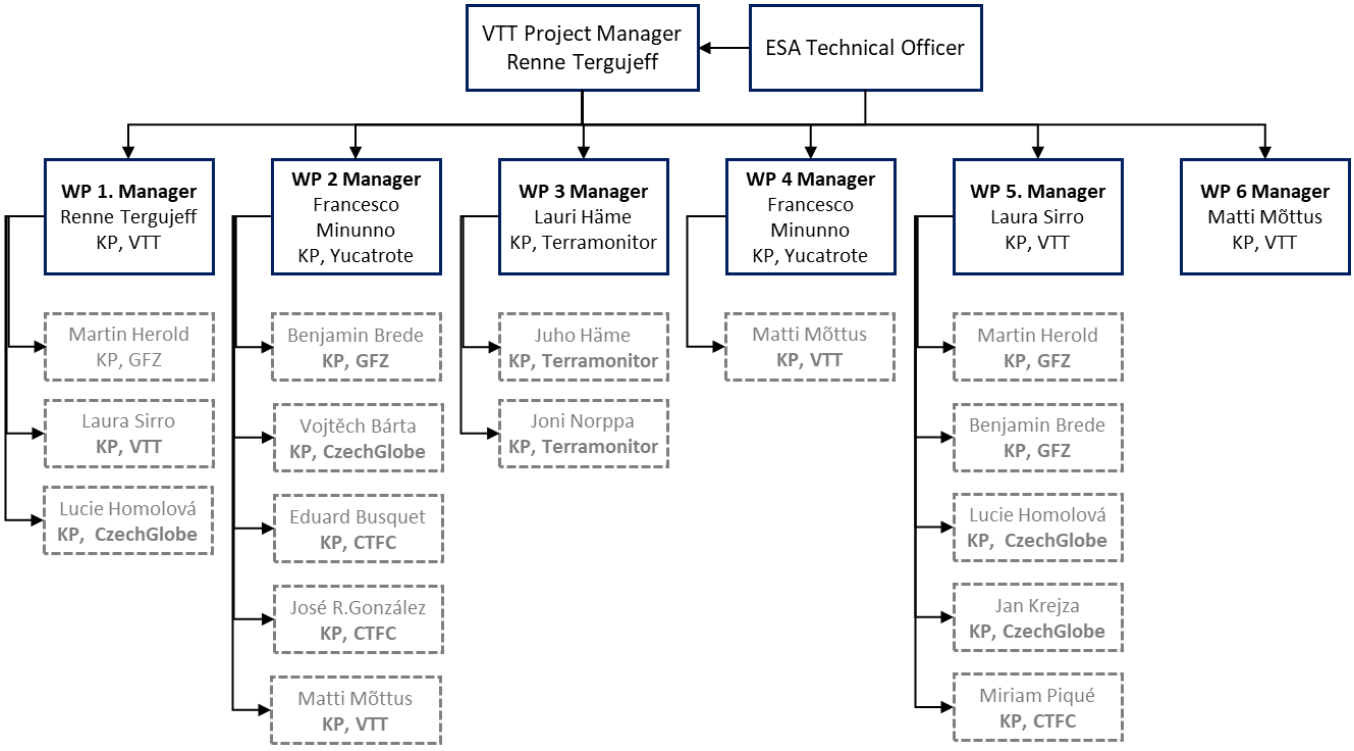


4.2 Organization and management of the activity

The overall management chain of the consortium will be as follows:



The reporting lines including Key Personnel are presented in the following diagram:



4.3 Time dedication of the Key Personnel

Key personnel	Role in the activity	WP0	WP1	WP2	WP3	WP4	WP5	WP6	TOTAL	Percentage time dedication (Time of activity/Total working time)
[redacted]	Scientific lead		175	350		100	50	108	783	24%
	Project Manager	952	100					108	1160	35%
	WP Manager		375				250	159	784	24%
	WP Manager		320	80	1120			45	**1585**	49%
	Software Architect		300	80	960	5	10	33	**1388**	43%
	User needs specialist		85	10	480	10	10	75	**670**	21%
	WP Manager		90	760	20	600		150		
[redacted]	UC Science lead		120					40	**160**	5%
	GFZ expert		40	370		240	370	40	**1060**	33%
	UC CZ lead		50	50		50	60	60	**270**	8 %
[redacted]	b.beetle modelling		120	250		150	210	130	**860**	27 %
	Data expert		50	100		60	100	50	**360**	11 %
	Data expert		80	340		100	140	40	**700**	22 %
	UC Cat. Lead		40	200		70	112	20	**442**	14 %
[redacted]	Fire modelling		40	70		70	100	20	**300**	9 %
Non-Key Personnel										
			242	1 377	720	1 082	1 437	388	5246	
TOTAL		**952**	**2 227**	**4 037**	**3 300**	**2 537**	**2 849**	**1 466**	**17 368**	

5) FINANCIAL PART

5.1 Price Quotation for the Contemplated Contract

The total price for the work proposed here is One Million Five Hundred Thousand Euro (1,500,000€)

5.2 Detailed Price Breakdown

5.2.1 PSS costing forms

5.2.1.1 PSS A2 (Breakdown of total price per participating company or institute), including Exhibit A and Exhibit B form, if applicable: The signed and scanned or printed PSS A2 forms together with the Exhibit A and Exhibit B forms are attached to the Financial part of the proposal. The Excel files containing the A2 forms are uploaded to esa-star under category “OTHER”. Please note that one Excel file is uploaded per consortium member, containing also the A2 forms separately for each year.

The individual digitally signed versions of the PSS forms (if provided by a Consortium member) are available on request from consortium lead partner.

5.2.1.2 PSS A1 (Company rates and overheads): The signed and scanned or printed PSS A1 forms are attached to the Financial part of the proposal. The Excel files containing the A1 forms are uploaded to esa-star under category “OTHER”. Please note that one Excel file is uploaded per consortium member, containing also the A1 form.

Note that the latest VTT rates agreed with ESA are for 2020. In VTT's interpretation, the audit process regarding new rates has not been finalized. VTT has not been able to accept the rates proposed by ESA, as they are not in line with the requirements of VTT's statutory auditor, which in turn are derived from domestic and EU legislation. As a temporary solution, VTT now uses inflation-adjusted rates in ESA tenders. The used inflation factor has been received from ESA’s auditing department. However, the adjusted rates have not been ratified by ESA’s auditing department. Please note that the current rates are based on the cost level of year 2023, and we have not yet applied any inflation correction for the ongoing year.

The individual digitally signed pdfs of the PSS forms (if provided by a Consortium member) are available on request from consortium lead partner.

5.2.1.3 PSS A8 (Company manpower and price summary per WP; using the same identifiers as in the proposed WBS/WPD)

The signed and scanned PSS A8 forms together with the Exhibit A and Exhibit B forms are attached the Financial part of the proposal. The Excel files containing the A8 forms are uploaded to esa-star under category “OTHER”. Please note that one Excel file is uploaded per consortium member, containing also the A8 forms separately for each year.

5.3 Payments

5.3.1 Milestone Payment Plan

Milestone (MS) Description (Lead Development Actions)	Schedule Date	Payments from ESA to (Prime) Contractor (in Euro)	Country (ISO code)
Progress (MS 1): Upon successful completion of Tasks and successful acceptance of all related deliverable items.	KO + 3 months	196 600	FI
Progress (MS 2): Upon successful completion of Tasks and successful acceptance of all related deliverable items.	KO + 6 months	196 600	
Progress (MS 3): Upon successful completion of Tasks and successful acceptance of all related deliverable items, including prototype demonstration.	KO + 12 months	393 200	
Progress (MS 4): Upon successful completion of Tasks and successful acceptance of all related deliverable items.	KO + 18 months	356 800	
Final Settlement (MS 5): Upon the Agency's acceptance of all deliverable items due under the Contract and the Contractor's fulfilment of all other contractual obligations including submission of the signed Final Report and pre-operational demonstration.	KO + 24 months	356 800	
TOTAL		1 500 000	

Prime (P)	Company Name	ESA Entity Code		Country (ISO code)	Advance Payment (in Euro)	Offset against[1]	Offset by Euro	Condition for release of the Advance Payment
P	VTT Technical Research Centre of Finland, Ltd.	1000001603		FI	186 550	MS 4 MS 5	53 300 133 250	Upon signature of the Contract by both Parties

[1] An SME has the right to request offset of the 35% advance at the end of the Contract, i.e. the last two milestones (ideally 25% at the last milestone and 10% at the preceding milestone), if this can be justified in view of the economic progress in the Contract.

For information purposes only, distribution by the Prime Contractor of ESA's payments between the Prime Contractor and the Subcontractor(s):

For information purposes only: Amounts in Euro for Contractor and Subcontractor(s)						
Milestone	**VTT Technical Research Centre of Finland, Ltd.**	***FI***	**Yucatrote**	***PT***	**Terramonitor**	***FI***
MS 1	82 637		25 500		47 815	
MS 2	82 637		25 500		47 815	
MS 3	165 274		51 000		95 630	
MS 4	162 156		51 500		68 370	
MS 5	162 156		51 500		68 370	
TOTAL	**654 860**		**205 000**		**328 000**	

Milestone	**Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences**	***DE***	**Global Change Research Institute CAS**	***CZ***	**Forest Science and Technology Centre of Catalonia**	***ES***
MS 1	15 750		13 649		11 249	
MS 2	15 750		13 649		11 249	
MS 3	31 500		27 298		22 498	
MS 4	32 500		22 702		19 573	
MS 5	32 500		22 702		19 573	
TOTAL	**128 000**		**100 000**		**84 140**	

For information purposes only, distribution by the Prime Contractor of ESA's Advance Payments between the Prime Contractor and the Subcontractor(s):

For information purposes only: Amounts in Euro for Contractor and Subcontractor(s)							
Prime (P) or (SI)	**Company Name**	**ESA Entity Code**	**Country (ISO code)**	**Advance Payment (in Euro)**	**Offset against[2]**	**Offset by Euro**	**Condition for release of the Advance Payment**
SI	Yucatrote	1000037600	PT	71 750	MS 4 MS 5	20 500 51 250	Upon signature of the Contract by both Parties
SI	Terramonitor	1000026282	FI	114 800	MS 4 MS 5	32 800 82 000	Upon signature of the Contract by both Parties

[2] An SME has the right to request offset of the 35% advance at the end of the Contract, i.e. the last two milestones (ideally 25% at the last milestone and 10% at the preceding milestone), if this can be justified in view of the economic progress in the Contract.

6) CONTRACTUAL PART

6.1 Compliance with Contract conditions

We hereby state that the Contract conditions have been read, are understood and accepted, and that any sales conditions of our own do not apply.

6.2 Use of existing Intellectual Property Rights of the Tenderer and Third Party(ies) commitments

No particular conditions related to Background Intellectual Property Rights (BIPR) and Third Party(ies) commitments apply.

Any items to which existing Intellectual Property Rights owned by Consortium members or by any other Third Party are stated in the tender and the dedicated table “List of Items covered by Background Intellectual Property Rights (BIPR) which are proposed to be used for the present activity”. No such items will be included in project Deliverables.

TABLE - List of items covered by Background Intellectual Property Rights (BIPR) which are proposed to be used for the present activity

Exact name of BIPR Item	Owner	Description	Patent # or Ref./Issue/ Revision/ Version # (*)	Contract/ Funding Details under which the IPR was created (**)	Date of creation of the version of the BIPR listed here	Type of Licence (Third Party IP) (***)	Affected deliverable with comments (****)	Protected Format (Y/N) (*****)
Normalized digital surface model for Czechia	Forest Management Institute (CZ)	NDSM for use case Czechia, for tree height estimation, biomass estimation, validation purposes	Not applicable	Not applicable	Not applicable	Third Party	No deliverable affected. Not to be included in DEDL and shared outside this project	Not applicable

6.3 Insurance Waiver

A negotiation on the waiver of subrogation rights from an insurance company will be initiated if required by ESA during project negotiations.

6.4 Statement relating to export/import licences/authorisations and related documentation

No particular conditions apply to export/import licences/authorisations and no related documentation are required for the work carried out under this Proposal.

VTT's Supplier Code of Conduct

Business Integrity

VTT's supplier, service provider or any business partner (hereinafter "Supplier") must observe local laws, regulations and good industry practice.

VTT is expecting that Supplier also observes VTT's Code of Conduct.
https://www.vttresearch.com/en/corporate-responsibility-core-all-vtt-operations

This Supplier Code of Conduct sets minimum standards for VTT's Supplier, Supplier's employees and Supplier's supply chain and subcontractors. Supplier responsibility is to ensure that its employees and its subcontractors are informed, and they comply with these VTT's requirements.

Business ethics

Supplier must not engage in bribery, money laundering, corruption, fraud, extortion, nepotism or other related crimes or unethical conduct. Personal relations or considerations will never influence decision-making. Supplier must promote fair competition and follow applicable competition laws and regulations. Supplier must also protect VTT's or third parties' Intellectual Property Rights and any confidential information provided by VTT or VTT's business partners.

In research services we expect to follow national and international guidelines for good scientific principles.

Working safely, professionally and respecting environment

Occupational safety and health

Supplier must comply with all applicable statutory occupational safety and health regulations. Supplier must actively seek to prevent accidents and injuries in the workplace to increase occupational safety.

Human rights and labor conditions

The Supplier will respect internationally recognized human rights and ensure fair labor conditions. Supplier must treat all their employees fairly and respectfully. Discrimination, intimidation, bullying or harassment in any form are not allowed. Supplier respects the employees' freedom of association and to negotiate collectively.

Child labor, compulsory or forced labor are not accepted. Supplier will also comply with the applicable laws and regulations regarding maximum working hours, minimum wage and other elements of compensation.

Environment

Supplier must observe applicable international and national environmental laws, regulations and principles. Supplier must be aware of the environmental impacts of their actions and proactively seek to reduce adverse environmental impacts.

Compliance builds on joint actions

Supervision of compliance and auditing

Supplier will comply with this Supplier Code of Conduct during the term of the agreement with VTT or VTT's business partners, and report to VTT any concerns or activities, which might violate the compliance. (compliance.officer@vtt.fi)

The Supplier will provide and help VTT with necessary information in order to verify that the Supplier complies with this Supplier Code of Conduct.

VTT reserves the right to terminate the business relationship with the Supplier, if VTT has reason to believe that Supplier has substantially breached this Supplier Code of Conduct.

Certifikát dokončení

ID obálky: 57938E2D-6349-4B9C-8FA6-ADBCFA4B45EB

Stav: Dokončeno

Předmět: Complete with Docusign: DTC Forest - Subcontract - CzechGlobe

Obálka zdroje:

Stránky dokumentu: 173

Podpisy: 2

Původce obálky:

[redacted]

Stránky certifikátu: 2

Iniciály: 0

Tekniikantie 21, Espoo

AutoNav: Povoleno

., . P.O Box1000, FI-0204

Razítkování ID obálky: Povoleno

[redacted]

Časové pásmo: (UTC+02:00) Helsinki, Kyiv, Riga, Sofia, Tallinn, Vilnius

Adresa IP: 130.188.17.16

Sledování záznamu

Stav: Originál

10 ledna 2025 | 10:48

Majitel: [redacted]

Lokace: DocuSign

Události podepisující osoby	Podpis	Časová známka
[redacted] Executive vice president VTT Technical research ce Úroveň zabezpečení: E-mail, Ověření účtu (žádné), Digitální certifikát **Detaily poskytovatele podpisu:** Typ podpisu: DocuSign Protect & Sign (Client ID: DDE5E85D-4085-40B6-8785-DA3CCD16D81E) Vydavatel podpisu: DocuSign Cloud Signing CA - SI1 Ověření: SMS (+358 50 3809671) **Informace o elektronickém záznamu a podpisu:** Není nabízeno v rámci služby Docusign	[redacted] Přijetí podpisu: Předem vybraný styl Pomocí adresy IP: 91.159.243.33 Umístění poskytovatele podpisu: https://ps-ws.dsf.docusign.net/ds-server/s/noauth/psm/tsp/sign	Odesláno: 10 ledna 2025 | 10:57 Znovu odesláno: 16 ledna 2025 | 12:23 Znovu odesláno: 24 ledna 2025 | 11:04 Zobrazeno: 28 ledna 2025 | 06:00 Podepsáno: 28 ledna 2025 | 06:00
[redacted] Director Úroveň zabezpečení: E-mail, Ověření účtu (žádné), Digitální certifikát **Detaily poskytovatele podpisu:** Typ podpisu: DocuSign Protect & Sign (Client ID: DDE5E85D-4085-40B6-8785-DA3CCD16D81E) Vydavatel podpisu: DocuSign Cloud Signing CA - SI1 Ověření: SMS (+420 724 112 675) **Informace o elektronickém záznamu a podpisu:** Není nabízeno v rámci služby Docusign	[redacted] Přijetí podpisu: Předem vybraný styl Pomocí adresy IP: 62.46.23.218 Umístění poskytovatele podpisu: https://ps-ws.dsf.docusign.net/ds-server/s/noauth/psm/tsp/sign	Odesláno: 10 ledna 2025 | 10:57 Znovu odesláno: 10 ledna 2025 | 12:13 Znovu odesláno: 10 ledna 2025 | 12:42 Zobrazeno: 10 ledna 2025 | 12:44 Podepsáno: 10 ledna 2025 | 12:44

Události podepisující osoby s osobní účastí	Podpis	Časová známka

Události doručení editora	Stav	Časová známka

Události doručení agenta	Stav	Časová známka

Události doručení zprostředkovatele	Stav	Časová známka

Události certifikovaného doručení	Stav	Časová známka

Události kopie	**Stav**	Časová známka
[redacted] [redacted] Director Úroveň zabezpečení: E-mail, Ověření účtu (žádné) **Informace o elektronickém záznamu a podpisu:** Není nabízeno v rámci služby Docusign	**Zkopírováno**	Odesláno: 10 ledna 2025 | 10:57 Zobrazeno: 10 ledna 2025 | 11:13

Události svědka	**Podpis**	Časová známka

Události notáře	**Podpis**	Časová známka

Události souhrnu obálky	**Stav**	Časové známky
Obálka odeslána	S algoritmem hash/šifrováno	10 ledna 2025 | 10:57
Obálka byla aktualizována	Zabezpečení zkontrolováno	10 ledna 2025 | 12:13
Obálka byla aktualizována	Zabezpečení zkontrolováno	10 ledna 2025 | 12:13
Obálka byla aktualizována	Zabezpečení zkontrolováno	10 ledna 2025 | 12:33
Obálka byla aktualizována	Zabezpečení zkontrolováno	10 ledna 2025 | 12:33
Obálka byla aktualizována	Zabezpečení zkontrolováno	10 ledna 2025 | 12:33
Obálka byla aktualizována	Zabezpečení zkontrolováno	10 ledna 2025 | 12:42
Obálka byla aktualizována	Zabezpečení zkontrolováno	10 ledna 2025 | 12:42
Obálka byla aktualizována	Zabezpečení zkontrolováno	10 ledna 2025 | 12:42
Obálka byla aktualizována	Zabezpečení zkontrolováno	10 ledna 2025 | 12:42
Certifikováno a doručeno	Zabezpečení zkontrolováno	10 ledna 2025 | 12:44
Podepisování dokončeno	Zabezpečení zkontrolováno	10 ledna 2025 | 12:44
Dokončeno	Zabezpečení zkontrolováno	28 ledna 2025 | 06:00

Platební události	**Stav**	Časové známky