EUROPEAN COMMISSION
Executive Agency for Small and Medium-sized Enterprises
H2020 Environment & Resources

ANNEX 1 (part A)

Research and Innovation action

NUMBER — 821003 — 4C

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1.1. The project summary

Project Number [1]	821003	Project Acronym [2]	4C

One form per project

General information	
Project title [3]	Climate-Carbon Interactions in the Current Century
Starting date [4]	01/06/2019
Duration in months [5]	48
Call (part) identifier [6]	H2020-LC-CLA-2018-2
Topic	LC-CLA-08-2018 Addressing knowledge gaps in climate science, in support of IPCC reports
Fixed EC Keywords	Biogeochemistry, biogeochemical cycles, environmental chemistry, Climatology and climate change
Free keywords	Global carbon cycle; Climate carbon feedbacks; Earth System Models; cumulative emissions; emergent constraints

Abstract [7]

4C addresses the crucial knowledge gap in the climate sensitivity to carbon dioxide emissions, by reducing uncertainty in our quantitative understanding of carbon-climate interactions and feedbacks. This will be achieved through innovative integration of models and observations, providing new constraints on modelled carbon-climate interactions and climate projections, and supporting IPCC assessments and policy objectives. To meet this objective, 4C will (a) provide a step change in our ability to quantify the key processes regulating the coupled carbon-climate system, (b) use observational constraints and improved processes understanding to provide multi-model near-term predictions and long-term projections of the climate in response to anthropogenic emissions, and (c) deliver policy-relevant carbon dioxide emission pathways consistent with the UNFCCC Paris Agreement (PA) goals.

To achieve its goals, 4C will develop and use: state-of-the-art Earth System Models (ESMs) including biogeochemical processes not included in previous IPCC reports; novel observations to constrain the contemporary carbon cycle and its natural variability; ESM-based decadal predictions including carbon-climate feedbacks and novel initialisation methods; novel emergent constraints and weighting methods to reduce uncertainty in carbon cycle and climate projections; and novel climate scenarios following adaptive CO2 emission pathways.

4C will support two central elements of the PA. First, the PA global stocktakes, by providing policy-relevant predictions of atmospheric CO2 and climate in response to the national determined contributions. Second, the PA ambitions to keep global warming well below 2°C, by providing robust estimates of the remaining carbon budgets and available pathways. 4C will bring together leading European groups on climate modelling and on carbon cycle research, uniquely securing Europe’s leadership in actionable science needed for the IPCC assessments.

1.2. List of Beneficiaries

Project Number [1]	821003	Project Acronym [2]	4C

List of Beneficiaries

No	Name	Short name	Country	Project entry date[8]	Project exit date
1	THE UNIVERSITY OF EXETER	UNEXE	United Kingdom		
2	UNIVERSITY OF EAST ANGLIA	UEA	United Kingdom		
3	ECOLE NORMALE SUPERIEURE	ENS	France		
4	MAX-PLANCK-GESELLSCHAFT ZUR FORDERUNG DER WISSENSCHAFTEN EV	MPG	Germany		
5	EIDGENOESSISCHE TECHNISCHE HOCHSCHULE ZUERICH	ETHZ	Switzerland		
6	BARCELONA SUPERCOMPUTING CENTER - CENTRO NACIONAL DE SUPERCOMPUTACION	BSC	Spain		
7	DEUTSCHES ZENTRUM FUER LUFT - UND RAUMFAHRT EV	DLR	Germany		
8	UNIVERSITAET BREMEN	UBREMEN	Germany		
9	UNIVERSITAET BERN	UBERN	Switzerland		
10	CICERO SENTER KLIMAFORSKNING STIFTELSE	CICERO	Norway		
11	THE CHANCELLOR, MASTERS AND SCHOLARS OF THE UNIVERSITY OF OXFORD	UOXF	United Kingdom		
12	COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES	CEA	France		

1.3. Workplan Tables - Detailed implementation

1.3.1. WT1 List of work packages

WP Number[9]	WP Title	Lead beneficiary[10]	Person-months[11]	Start month[12]	End month[13]
WP1	Understanding the contemporary carbon cycle	2 - UEA	275.10	1	48
WP2	Predicting the carbon cycle and climate for the global stocktake to the horizon of 2030	4 - MPG	155.00	1	48
WP3	Projecting the required mitigation effort over the 21st century	9 - UBERN	250.40	1	48
WP4	Synthesis, dissemination and policy dialogue	6 - BSC	119.85	1	48
WP5	Project Management	1 - UNEXE	43.00	1	48
WP6	Ethics requirements	1 - UNEXE	N/A	1	48
		Total	843.35		

1.3.2. WT2 list of deliverables

Deliverable Number[14]	Deliverable Title	WP number[9]	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
D1.1	Draft O2 and APO budgets (T1.1.1)	WP1	2 - UEA	Report	Public	18
D1.2	Global O2 and APO budget for 1991-2018 time-period using observations and models (T1.1.1)	WP1	2 - UEA	Report	Confidential, only for members of the consortium (including the Commission Services)	36
D1.3	Draft Isotopic-constrained atmospheric carbon budget (T1.1.2)	WP1	9 - UBERN	Report	Public	18
D1.4	Isotopic-constrained atmospheric carbon budget and sink flux estimates (T1.1.2)	WP1	9 - UBERN	Report	Confidential, only for members of the consortium (including the Commission Services)	36
D1.5	Satellite-based atmospheric CO2 dataset (T1.1.3)	WP1	8 - UBREMEN	Report	Public	24
D1.6	New constraints on ocean carbon (T1.2.1 and T1.2.2)	WP1	4 - MPG	Report	Public	18
D1.7	New constraint on land carbon (T1.2.3-5)	WP1	12 - CEA	Report	Public	21
D1.8	Report on historical simulations (T1.3)	WP1	5 - ETHZ	Report	Public	36
D1.9	Report on the benchmarking and evaluation of simulated carbon budgets (T1.4.1 and T.1.4.2)	WP1	12 - CEA	Report	Public	36
D1.10	Inclusion of new benchmarking in ESMValTool (T1.4.3)	WP1	8 - UBREMEN	Demonstrator	Public	42
D1.11	Report on the reduction of the global carbon budget imbalance (T1.4.4)	WP1	2 - UEA	Report	Confidential, only for members of the consortium (including the Commission Services)	45
D1.12	Report on the factorial attribution analysis (T1.5)	WP1	1 - UNEXE	Report	Confidential, only for members of the consortium (including the	45

Deliverable Number[14]	Deliverable Title	WP number[9]	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
					Commission Services)	
D2.1	Assessment of carbon cycle potential predictability (T2.1.2)	WP2	6 - BSC	Report	Public	24
D2.2	Initial conditions for retrospective predictions (T2.2)	WP2	3 - ENS	Report	Public	16
D2.3	Assessment of predictability of the C cycle in C-driven simulations (T2.3.1 and T2.3.2)	WP2	4 - MPG	Report	Public	32
D2.4	Assessment of predictability of atmospheric CO2 and C sinks in E-driven simulations (T2.3.3)	WP2	6 - BSC	Report	Public	36
D2.5	Draft report on predictions of next year atmospheric CO2 (T2.4)	WP2	4 - MPG	Report	Public	22
D2.6	Prediction of atmospheric CO2, carbon sinks and climate for the next decade (including next year prediction) (T2.4)	WP2	3 - ENS	Report	Confidential, only for members of the consortium (including the Commission Services)	45
D3.1	Draft report on emergent constraints for carbon processes and biogeochemical feedbacks (T3.1.1 and T.3.1.2)	WP3	5 - ETHZ	Report	Public	18
D3.2	Report on emergent constraints for carbon processes and biogeochemical feedbacks (T3.1.1 and T.3.1.2)	WP3	5 - ETHZ	Report	Confidential, only for members of the consortium (including the Commission Services)	36
D3.3	Draft report on TCRE assessment including non-CO2 emissions and observational constraints (T3.2.1 and T.3.2.2)	WP3	11 - UOXF	Report	Public	18
D3.4	Report on TCRE assessment including non-CO2 emissions	WP3	11 - UOXF	Report	Confidential, only for members of the consortium	30

Deliverable Number[14]	Deliverable Title	WP number[9]	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
	and observational constraints (T3.2.1 and T.3.2.2)				(including the Commission Services)	
D3.5	Report on the robustness of different weighting schemes for CO2 projections (T3.3)	WP3	7 - DLR	Report	Public	42
D3.6	Report on adaptive scenarios compatible with the Paris Agreement (T3.4.2)	WP3	9 - UBERN	Report	Confidential, only for members of the consortium (including the Commission Services)	45
D4.1	ScienceBrief Carbon Cycle updated with IPCC AR6 results and 4C publications, with platform update informed by evaluation (T4.1.2)	WP4	2 - UEA	Websites, patents filling, etc.	Public	42
D4.2	Summary report on engagement with policymakers (T4.2)	WP4	10 - CICERO	Report	Public	45
D4.3	Animated infographic about the carbon cycle (T4.3.3)	WP4	6 - BSC	Websites, patents filling, etc.	Public	16
D4.4	Web based explorable explanation (T4.3.4)	WP4	6 - BSC	Websites, patents filling, etc.	Public	40
D4.5	Visual identity and project website available (T4.4.1)	WP4	6 - BSC	Websites, patents filling, etc.	Public	6
D4.6	Communication, Dissemination and Engagement Plan (T4.4.3)	WP4	6 - BSC	Report	Public	9
D4.7	First Update of Communication, Dissemination and Engagement Plan (T4.4.3)	WP4	6 - BSC	Report	Public	18
D4.8	Second Update of Communication, Dissemination and Engagement Plan (T4.4.3)	WP4	6 - BSC	Report	Public	36
D4.9	Summary report on the communication,	WP4	6 - BSC	Report	Public	45

Deliverable Number[14]	Deliverable Title	WP number[9]	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
	dissemination and engagement activities (T4.4)					
D5.1	Project risk and quality assurance management plan (T5.1)	WP5	1 - UNEXE	Report	Public	4
D5.2	Data Management Plan (T5.1)	WP5	1 - UNEXE	ORDP: Open Research Data Pilot	Public	6
D5.3	First update on Data Management Plan (T5.1)	WP5	1 - UNEXE	ORDP: Open Research Data Pilot	Public	18
D5.4	Second update on Data Management Plan (T5.1)	WP5	1 - UNEXE	ORDP: Open Research Data Pilot	Public	36
D6.1	H - Requirement No. 1	WP6	1 - UNEXE	Ethics	Confidential, only for members of the consortium (including the Commission Services)	1
D6.2	POPD - H - Requirement No. 2	WP6	1 - UNEXE	Ethics	Confidential, only for members of the consortium (including the Commission Services)	3
D6.3	POPD - Requirement No. 3	WP6	1 - UNEXE	Ethics	Confidential, only for members of the consortium (including the Commission Services)	6

1.3.3. WT3 Work package descriptions

Work package number [9]	WP1	**Lead beneficiary [10]**	2 - UEA
Work package title	Understanding the contemporary carbon cycle		
Start month	1	**End month**	48

Objectives

The objective of WP1 is to make a step-change in our quantitative understanding of the carbon cycle over the historical period, and to improve the same models that will be used for near-term predictions and long-term projections of climate-carbon interactions. This will be achieved by developing new methods, using new observations and data products to constrain estimates of the land and ocean carbon fluxes and their variability. These new constraints will be combined with model simulations of the land and ocean carbon sinks over the past 120 years to improve our understanding of underlying processes. We focus particularly on the response of carbon fluxes to anthropogenic CO_2, seasonal to decadal climate variability, and climatic extremes. Specifically, we will:

- develop new observational-based constraints of the variability and trends of the land and ocean CO_2 sinks and their underlying processes;
- determine the origin and cause(s) of the large and unexplained global carbon budget imbalance (BIM) identified through the Global Carbon Budget annual synthesis, and reduce the BIM by 50%;
- provide new model simulations over the 1900-present using improved models of the land and ocean carbon cycle, evaluated with new metrics that provide insights into the origin and causes of the BIM;
- make a step-change in our quantitative understanding of nutrient limitations, permafrost and wildfires on land, and mesoscale transport, biological export, and internally and externally-induced ocean variability;
- attribute the observed variability in land and ocean CO_2 fluxes to underlying climatic and non-climatic drivers.

Description of work and role of partners

WP1 - Understanding the contemporary carbon cycle [Months: 1-48]
UEA, UNEXE, ENS, MPG, ETHZ, BSC, DLR, UBREMEN, UBERN, CICERO, CEA
Work package lead Corinne Le Quéré (UEA), deputy lead Stephen Sitch (UNEXE)

WP1 will provide, and make freely available, new observational constraints on the processes responsible for the trends and variability in the land and ocean CO_2 fluxes, using both observations that integrate land and oceans (T1.1) and observations of specific processes (T1.2) (see Tables 1.1a and 1.1b). Datasets, along with estimates of uncertainty, from T1.1 and T1.2 will be provided and contribute to the ESMValTool13, adding a recommended and agreed set of process-oriented diagnostics and performance metrics to enhance the evaluation of the carbon cycle and its climate interactions (T1.4). WP1 will produce new model simulations for the land and ocean CO_2 fluxes using state-of-the-art models (T1.3), and evaluate these model simulations (T1.4) with available observational constraints from T1.1 and T1.2. T1.3 and T1.4 will be repeated every year of the project, delivering land and ocean C-budget to the GCB annual updates, and incorporating new datasets from T1.1 and T1.2 as they become available, therefore working to improve the GCB annual budget and not just update it, as is currently the case. Annual evaluation (T1.3) includes the land and ocean models from CMIP6 and their new and evolving generation (CMIP6+) that represent additional processes like permafrost, nutrient limitations, wildfires, diffuse light and ozone effects and land cover change; mesoscale circulation and explicit representation bacterial processes, trophic interactions, and variable stoichiometry in the ocean (Table 1.2). Model evaluation will guide further model improvement and development available for the following year. Finally, factorial simulations will be conducted to identify the climatic and non-climatic drivers for the trends and variability in CO_2 fluxes (T1.3). The attribution analysis T1.5 will be conducted twice, once at the start of the project with the current set of land and ocean models from CMIP6, and again at the end of the project, with the improved and evaluated new generation of carbon cycle models including consolidated new process representations.

T1.1: New observational constrains on the global carbon cycle (M1-M36) UEA (lead), ETHZ, UBREMEN, UBERN, CICERO, CEA.
Task 1.1 will develop new observational constraints on the combined global and regional land and ocean CO_2 fluxes to support quantitative understanding. Integrated constraints will provide independent information on the partitioning of land and ocean fluxes, and help determine the origins and causes of the carbon budget imbalance. The first set of constraints will apply the global carbon budget approach to atmospheric oxygen (O_2) and to carbon isotopes. The second set of constraints will be based on new satellite XCO_2 column retrieval.

T1.1.1: Global O_2 and Atmospheric Potential Oxygen (APO) Budgets (M1-M36) UEA, CICERO
We propose to establish the atmospheric budget for O_2 and for APO since 1991, when the first O_2 measurements began, to provide additional constraints on the ocean and land responses to climatic drivers on semi-decadal time-scales. We will combine existing and new atmospheric observations of O_2 from multiple stations including continuous measurements to infer the atmospheric O_2 growth rate, and combine this with the CO_2 growth rate to infer the APO growth rate. We will build the global budgets of O_2 and APO consisting of their atmospheric growth rate, the known contribution of fossil combustion, and the residual ocean+land fluxes (for O_2) and ocean fluxes (for APO). The contribution of fossil combustion will be estimated using the fossil fuel emissions from the Global Carbon Budget[2], accounting for the different O_2 combustion rates associated with different types of fuel (coal, oil, gas). We will also estimate the O_2 and APO changes driven from land-use change, assuming the O_2/CO_2 ratio of biospheric exchanges. The uncertainties will be propagated considering uncertainties in all fluxes and ratios, as well as an assessment of the oceanic heat flux to O_2 fluxes and their uncertainties[49] with updated heat flux estimates using Argo floats. We will analyse the resulting trends and variability, including the changes in seasonal duration, considering the uncertainties in all estimates. The resulting observational-based global O_2 and APO fluxes and their uncertainties will be used in T1.4 to evaluate net fluxes from global land and global ocean as simulated by models over multiple time scales, identify the origin of the global carbon budget imbalance (BIM) and infer underlying processes where possible.

T1.1.2: 13C observations and the global budget of 13C: independent constraint on carbon sink variability and future projections (M1-M36) UEA, ETHZ, UBERN, CICERO, CEA
We will establish the atmospheric budget of 13C(CO_2) over the industrial period and investigate spatial and temporal trends in the seasonal cycle of 13C and its amplitude, to provide independent constraint on decades-to-century trends in the land and ocean carbon sinks. Isotopic data will be applied together with results from forced isotope-enabled land and ocean model simulations, performed in T1.3 and evaluated in T1.4, in a probabilistic Bayesian Monte Carlo framework[62] to establish the 13C-based carbon budget. 13C data from the atmosphere (NOAA/ESRL data), the ocean[51], tree rings[53], leaves[54], and ice cores[52] will be used. The distribution of C3 and C4 plants and crops, featuring very different 13C signatures, will be explicitly considered for 13C flux computations. Uncertainties will be propagated as in T1.1.1. The compiled 13C data and its uncertainty will be used in T1.4 for model evaluation.

T1.1.3: Satellite-based atmospheric CO_2 dataset (M1-M30) UBREMEN.
We will generate satellite-derived column-averaged dry-air CO_2 mole fraction (xCO_2) data to be used in Task 1.4 for ESM evaluation and Task 3.1 to develop emergent constraints. The product will be monthly and global, at 2 by 2° spatial resolution, but with gaps due to clouds and incomplete sampling of the satellites. It will cover at least the 2003-2017 time-period, and will be extended during the project. It will be based on the merging of an ensemble of existing latest version individual satellite Level 2 products (SCIAMACHY, GOSAT, OCO-2). The data will also contain an estimate of the xCO_2 uncertainty defined as standard error of the average including single sounding noise and potential seasonal and regional biases.

Task 1.2: New and improved data-based products (M1-M36), MPG (lead), ETHZ, CEA.
We will provide new and extended data-based products for ocean and land carbon, to evaluate specific processes in T1.4 and support subsequent model improvement. We will build on statistical and machine learning methods to interpret observations and adapt the resulting observation-based products to the specific needs to guide and improve process representations in ESMs.

T1.2.1: Neural Network-based air-sea CO_2 flux (M1-M30) MPG
We will apply a 2-step neural network approach[24] to reconstruct the air-sea CO_2 flux based on the large collections of surface ocean CO_2 measurements from SOCAT[119]. New CO_2 data from the Argo program will also be used to improve data coverage, particularly in the Southern Ocean. This will provide an improved estimate of the mean and seasonal to decadal variability of the ocean carbon sink, to be used for model evaluation in T1.4.2. Additionally, an improved representation of the uncertainty of the air-sea exchange will be provided accounting both for the uncertainty derived from the kinetic gas transfer term (using a variety of gas transfer formulations) and the uncertainty derived from the neural network data interpolation. The latter will be established (a) using a random subsampling or bootstrapping approach, (b) with synthetic data using internally consistent output from an ocean model simulation and (c) using alternative observational data interpolation approaches.

T1.2.2: Ocean Interior based estimates of the ocean carbon flux and storage (M1-M36) MPG, ETHZ
We will employ the extended multiple linear regression (eMLR(C*)) method[120] and a newly developed ocean interior interpolation method for dissolved inorganic carbon on the basis of neural networks to estimate the change in the ocean carbon stock over the last few decades using ocean interior observations collected by the GO-SHIP and related programs[39]. This will provide a strong 3-D constraint on the time-integrated ocean CO_2 sink over 1994 through ~2020, to be used for models evaluation (T1.4.2) and process attribution (T1.5.2). To estimate the uncertainties of these

estimates, we will use an ensemble approach, where the uncertainty associated with the choices that one needs to make to build a statistical model is determined through defining a set of plausible assumptions/parameter values and then creating an ensemble of estimates from this set. We will also use classical error propagation methods and Monte Carlo techniques. The typical uncertainty associated with these different products is around ±20%.

T1.2.3: Observation-based land water fluxes (M1-M30) ETHZ
We will develop observation-based estimates of land water fluxes and water storage, which will be used as validation constraints for land carbon exchanges, as these are strongly tied to plant transpiration and soil water stress. Land water mass estimates are available from GRACE from 200241, with a statistical extension available for the whole 20th century42. In addition, we will also use compiled observational datasets of evapotranspiration43. Similar to the reconstruction of air-sea CO2 fluxes, the land water products will also include their spatio-temporal uncertainty estimates. The derived land water and evapotranspiration datasets will be used for the evaluation of land carbon-water interaction (T1.4.2), particularly on interannual to decadal time scales, for attribution of drivers (T1.5.2), as well as for new emergent constraints in WP3.

T1.2.4: New constraint on land gross carbon uptake from atmospheric COS and plant fluorescence observations (M1-M30) CEA
We will develop a new framework to evaluate GPP of the land carbon models, which will support a better quantitative understanding of the processes responsible for CO2 variability on land. Recent measurements of atmospheric COS, combined with existing atmospheric CO2 measurements, provide new large-scale (i.e. continental) and seasonal constraints on GPP46, while ice core COS data provide further constraints on the 20th century GPP enhancement121. Additionally, SIF data from satellite observations (OCO-2 and GOME2) bring complementary constraint at finer spatial and temporal scales45. Uncertainty associated to the COS diagnostic will make use of different estimates of the 'leaf relative uptake' of COS versus CO2, a critical parameter in the COS budget. For SIF, we will use the range of the different satellite products as a measure of the uncertainty. We will combine these two constraints, and provide a new framework to evaluate the GPP simulated by the ensemble of CCiCC land models (T1.4.2).

T1.2.5: Machine-learning based forest net CO2 flux data (M7-M36) CEA
We will develop observation-based estimates of forest net CO2 flux (NBP) based on machine learning algorithms applied to flux towers including climate, remote sensing, GPP and a global age distribution of forests accounting for land management. This product will provide a new observation based estimate of the forest NBP and its spatial distribution. The spatial patterns of forest NBP will be provided as an average over the last decade at 0.5 by 0.5° spatial resolution, including uncertainty in the training dataset from FLUXNET sites and the up-scaling method, using different climate and FLUXNET based GPP products44. Uncertainties on decadal mean NBP will be estimated by using a leave one out cross validation procedure for the training dataset of eddy covariance44. This new product will be used in T1.4.2 for evaluation of the simulated land C sink. In addition, Vegetation Optical Depth (VOD) data from the SMOS mission in the L-band will be provided as calibrated above-ground biomass (AGB) maps for the period of 2010 to 2018 for evaluation of simulated biomass (T1.4.2). Random uncertainties will be estimated from the standard deviation from different reference calibration maps of above ground biomass (AGB) used to convert L-VOD into AGB.

Task 1.3. Simulating the global carbon cycle from 1900 to 2020 (M9-M42) ETHZ (Lead), UNEXE, UEA, ENS, CNRS, MPG, BSC, UBERN, CEA
In T1.3, a series of model simulations will be performed using the latest CMIP6+ model improvements and forcing on an annual basis. This includes historical simulations with the land and ocean carbon models, forced by the observed atmospheric conditions of the 120 years. The uncertainty associated with the atmospheric forcing will be investigated by using different reconstructions of the atmospheric state. T1.3 includes also historical simulations with the CCiCC ESMs in emission-driven mode. The results from all simulations will be carefully evaluated in T1.4 using the constraints from T1.1 and T1.2. Also a set of factorial historical experiments will be conducted, where different forcings (e.g., atmospheric CO2, nitrogen deposition, climate change) are selectively turned on or off, forming the basis for attribution of processes driving the land and ocean carbon sinks in T1.5.

T1.3.1: Historical simulations of the land carbon cycle (M9-M42) UNEXE, MPG, BSC, UBERN, CEA
The land carbon models will be forced over the period 1700-2020, with historical observed atmospheric CO2 from a global network of monitoring stations, changing climatology (6-hourly JRA model reanalysis aligned with CRU observation-based monthly climatology from 1900), land-use and land cover changes (LUH2 as used in CMIP6), and derived nitrogen deposition, fertiliser and manure application, following the TRENDY protocol122. At least one model will explore C-cycle uncertainty associated with applying alternative historical climate forcing (e.g. using precipitations from WFDEI), and the impact of diffuse light effects (e.g. Mt Pinatubo eruption), on the unexplained carbon budget imbalance (BIM) in T1.4. The following land carbon models (with host ESM in parenthesis) will participate using their CMIP6+ configuration (see Table 1.2): JULES, ORCHIDEE (IPSL-ESM), LPX (BERN3D-LPX), LPJ-GUESS

(EC-Earth ESM), JSBACH (MPI-ESM). ORCHIDEE and LPX-BERN also include the modelling of 13C for the land atmosphere fluxes. Multiple single-forcing simulations will be made for the attribution analysis in T1.5. Single forcing variables include, atmospheric CO_2, land-use change, nitrogen (deposition, fertiliser, manure application) and climate (trends, variability and extremes).

T1.3.2: Historical simulations of the ocean carbon cycle (M9-M42) UEA, ENS, MPG, ETHZ, BSC
The ocean models will follow the CMIP6 OMIP protocol and be forced by variable winds and buoyancy fluxes (heat and water fluxes) from reanalysis data, and with prescribed atmospheric CO_2. At least one ocean model will be used in a high-resolution, eddy-permitting configuration, for a shorter 30-year simulation, with a physical transport model that represents the mesoscale eddy response explicitly. The following ocean models (with host ESM in parenthesis) will participate using their CMIP6+ configuration (see Table 1.2): NEMO-PlankTOM10 at two resolutions, PISCES (IPSL ESM), HAMOCC (MPI-ESM), POP2 (NCAR-CESMS2), PISCES (EC-Earth). The simulations will be initialised from fully spun-up pre-industrial state, except for the high-resolution NEMO-PlankTOM10 which will be initialised from observations64. Internally and externally-induced variability will be assessed by: (1) using the NEMO-PlankTOM10 (low-resolution) and POP2 (NCAR-CESM2) to test externally-forced variability using multiple forcing reanalysis products including CORE2 and JRA and sea-ice-driven freshwater forcing, and (2) using the NEMO-PlankTOM10 (low-resolution) to quantify variability triggered by internal conditions by using different initial conditions based on observations, including inorganic carbon using ocean interior carbon observations from T1.2.2. In addition to the standard historical simulations, all groups will run factorial single-forcing simulations for the attribution analysis in T1.5. Single forcing variables include climate, winds, atmospheric CO_2.

T1.3.3: Historical simulations of the Earth's carbon cycle with ESMs (M9-M42) ENS, MPG, BSC, UBERN, CEA
The ESM simulations will follow the CMIP6 historical protocol123 with prescribed CO_2 emissions from fossil fuel combustion, land-cover changes, and the other radiatively active constituents as prescribed for CMIP6. The following CMIP6+ ESMs will conduct these simulations: IPSL-ESM, EC-Earth ESM, MPI-ESM, GFDL ESM2M and NCAR CESM2. The NCAR CESM2.0 and IPSL-ESM models include the cycling of 13C. These simulations will be evaluated in T1.4, but also serve as initial conditions for future scenario simulations in T3.4

Task 1.4. Model evaluation (M13-M48) CEA (lead), UNEXE, UEA, MPG, ETHZ, DLR, UBERN
Land and ocean model simulations will be evaluated using both established observations and benchmarking methods used for coupled models in ESMValTool124 (land, ocean and atmosphere evaluation), as well as the new observations and data-driven products, proposed in T1.1 and T1.2. We will perform a comprehensive evaluation of simulations described in T1.3, for forced land and ocean carbon models (T1.3.1, T1.3.2) and CMIP6+ ESMs (T1.3.3), to evaluate model performance, to improve process understanding, and guide model improvement. We will assess models in reproducing regional to global trends in the carbon sink (including improvements compared to published versions2), the response to internal climate variability and climate extremes (e.g. ENSO, volcanic eruptions etc.) and compare CMIP6, and CMIP6+ model versions. From these evaluations, specific recommendations for model improvements and potentially also observational strategies will be derived.

T1.4.1: Land/Ocean model evaluation using established observations and benchmarks (M13-M48) UNEXE, ENS, MPG, CEA
Existing evaluation packages will be used to get a first order evaluation of all participating land and ocean models. A key objective is to assess skills of CMIP6 vs the latest CMIP6+ model versions, and to identify model deficiencies. Key model parameters will be revised to improve model skill along the 4 years of the project. The observations already included in the evaluation packages include site level and grid-based data-driven estimates of LAI, evapotranspiration, GPP as well as above ground biomass, soil carbon stocks, ocean CO_2 concentration (pCO_2), and ocean chlorophyll concentration and derived productivity (see Table 1.1a). We will also use atmospheric inversions of NBP combined with observed climate variability to constraint the seasonal and interannual climate sensitivity of land carbon models125. Additionally, we will use other observations, currently not included in ESMValTool, to define a more comprehensive set of benchmarks. Among them we will include burned areas from wildfire, biomass and soil carbon turnover rates, permafrost extend, as well as results from field manipulation experiments (e.g. CO_2 fertilization response using Free Air CO_2 Enrichment sites). The model evaluation will account for the assessed observation uncertainty.

T1.4.2: Land/Ocean model evaluation using new observations and new benchmarks (M13-M48) MPG, ETHZ, CEA
We will use the new updated observations from T1.1 and the improved data based products from T1.2 to develop new benchmarks and evaluation metrics. The global budgets of O_2 and APO (T1.1.1) will be used to evaluate the net land and ocean fluxes, especially their amplitude over several time scales to provide insight on the origin of the global carbon budget imbalance. APO will also be used to assess physical and biological processes in the ocean. The dataset of 13C observations compiled in T1.1.2 (ocean, tree ring, leaves, etc.) will be used for evaluation of the 13C enabled carbon models. Trend in atmospheric 13C, diagnosed from simulated land and ocean 13C net fluxes will be compared

to ice-core 13C observations. For the land, we will also include i) new constraints from land water fluxes (T1.2.3) to evaluate the simulated water cycle and its control on the inter-annual variability in carbon fluxes, ii) the new framework to evaluate simulated GPP using COS and SIF data (T1.2.4) and iii) data-driven estimates of forest net CO2 flux and above-ground biomass from satellite VOD data (T1.2.5). For the ocean, the model simulated inventories of natural and anthropogenic CO2 for 1994, 2007, and ~2020 (vertical and horizontal spatial patterns) together with the spatio-temporal variability of the air-sea CO2 fluxes will be evaluated using both data-driven air-sea flux estimates (T1.2.1) and ocean interior based products (T1.2.2).

T1.4.3: Incorporate results from new benchmarks in ESMValTool (M13-M48) DLR
In this task, the protocols to include observations and their uncertainty from T1.1 and 1.2 that have been tested and validated in T1.4.2 will be incorporated as routine diagnostics into the ESMValTool, if their performances prove to inform uncertain processes in carbon cycle models. The new metrics will be coded in ESMValTool and thus be available to other land and ocean simulations as part of international comparison programmes. A specific focus will be placed on the estimates of observational uncertainty from 4C products in integrated measures of performance and by using multiple datasets for comparison48.

T1.4.4: Evaluating the global carbon budget imbalance using new integrated observational constraints UEA, UNEXE, ETHZ, UBERN
Using results from T1.1 and model simulations from T1.3, we will examine the BIM in model simulations, using the new constraints for the land+ocean fluxes based on O2 and 13C data, and for the ocean fluxes based on APO. We will use the combination of new atmospheric tracers to analyse the imbalance as a function of time (seasonal to decadal) and relate the imbalance to the land and/or oceanic origin, where possible regionally, and to variability in climate and underlying drivers, such as temperature, wind and rainfall. We will assess if specific processes (e.g. high-resolution ocean model simulations) lead to improvements in the imbalance of some of these elements, and identify which evaluation metrics constrain best the models that produce the smallest BIM. We expect the combination of imbalance from multiple tracers to be particularly powerful at providing insights into the origin of the CO2 imbalance, and therefore lead to its subsequent resolution. If justified by the analysis, we will reassess the BIM using a smaller set of models that perform best given the existing and new evaluation metrics. We will also quantify what is the smallest possible BIM given the uncertainty in the various observations.

Task 1.5. Attribution of changes in the contemporary carbon cycle (M19-M48) UNEXE (lead), UBERN, UEA, MPG, ETHZ, CEA
This task will attempt to quantify the contributions of different environmental drivers (e.g. climate, CO2, land-use, nitrogen deposition) to historical and contemporary carbon sinks. This will be achieved by comparing the factorial model simulations (T1.3) with the latest observational data. We will apply detection & attribution (D&A) methods, which has been so successful in attributing the causes of global warming to natural and anthropogenic factors. We will use the factorial single-forcing model simulations to attribute the spatio-temporal changes in land and ocean carbon sinks to drivers. This will also inform WP3 on the development of the most appropriate emergent constraints, by demonstrating where particular drivers are dominant and therefore where univariate emergent constraints are most likely to exist.

T1.5.1: Observed changes in the contemporary carbon cycle (M19-M48) UNEXE, UEA, MPG, ETHZ, UBERN, CEA
We use the new observational constraints derived in T1.1 and 1.2 along with existing datasets to provide a summary of the observed changes in the contemporary carbon cycle. The D&A analysis will use information on hydrological changes (including precipitation, river runoff, gridded evapotranspiration products, terrestrial water storage), biomass (VOD), leaf area (MODIS), NBP from atmospheric inversions, CO2 seasonal cycle at the global network of monitoring stations (NOAA) area burnt (GFED), water-use efficiency (tree-ring and eddy flux data), N-cycle changes (fertiliser and deposition), air-sea CO2 fluxes, and long-term changes in the ocean carbon inventory (GO-SHIP). Datasets will be selected that are long enough (>10years) to see changes at the semi-decadal timescale to also inform on BIM (T1.4.4).

T1.5.2: Attribution of biogeochemical changes (M19-M48) UNEXE, UEA, MPG, ETHZ, UBERN, CEA
The single forcing simulations of T1.3 will be analysed using Principal Component Analysis to reveal the unique spatio-temporal fingerprint of each driver. The D&A approach involves finding, for each model, a linear combination of these patterns which optimally fits the observational constraints provided by T1.5.1. We will attribute the pattern of greening trends to processes and forcing variables (climate, CO2, land-use). We will attribute observed changes in the seasonal cycle amplitude (high latitude ecosystems; variables amplitude increase at different stations) and changing land sensitivity to interannual variability. Attribution analysis will also focus on the effect of N cycle changes (fertiliser and deposition) on the regional land carbon balance, and evaluating their realism using observed C-N sensitivities as well as ancillary evaluation of simulated N cycle trends. Finally, we will attribute changes in the land water cycle, evapotranspiration, soil moisture and river runoff to gain a more complete understanding of the coupled land carbon and water cycles. Likewise for the ocean, we will attribute the temporal and spatial patterns in CO2 fluxes and inorganic

carbon distribution (particularly vertical profiles) to forcing variables (winds, buoyancy fluxes, CO2), and elucidate the role of biological export and internal and external induced variability.

Participation per Partner

Partner number and short name	WP1 effort
1 - UNEXE	45.00
2 - UEA	43.40
3 - ENS	3.00
CNRS	7.00
4 - MPG	46.00
5 - ETHZ	35.00
6 - BSC	9.50
7 - DLR	12.00
8 - UBREMEN	20.00
9 - UBERN	25.00
10 - CICERO	3.00
12 - CEA	26.20
Total	275.10

List of deliverables

Deliverable Number[14]	Deliverable Title	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
D1.1	Draft O2 and APO budgets (T1.1.1)	2 - UEA	Report	Public	18
D1.2	Global O2 and APO budget for 1991-2018 time-period using observations and models (T1.1.1)	2 - UEA	Report	Confidential, only for members of the consortium (including the Commission Services)	36
D1.3	Draft Isotopic-constrained atmospheric carbon budget (T1.1.2)	9 - UBERN	Report	Public	18
D1.4	Isotopic-constrained atmospheric carbon budget and sink flux estimates (T1.1.2)	9 - UBERN	Report	Confidential, only for members of the consortium (including the Commission Services)	36
D1.5	Satellite-based atmospheric CO2 dataset (T1.1.3)	8 - UBREMEN	Report	Public	24

List of deliverables

Deliverable Number[14]	Deliverable Title	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
D1.6	New constraints on ocean carbon (T1.2.1 and T1.2.2)	4 - MPG	Report	Public	18
D1.7	New constraint on land carbon (T1.2.3-5)	12 - CEA	Report	Public	21
D1.8	Report on historical simulations (T1.3)	5 - ETHZ	Report	Public	36
D1.9	Report on the benchmarking and evaluation of simulated carbon budgets (T1.4.1 and T.1.4.2)	12 - CEA	Report	Public	36
D1.10	Inclusion of new benchmarking in ESMValTool (T1.4.3)	8 - UBREMEN	Demonstrator	Public	42
D1.11	Report on the reduction of the global carbon budget imbalance (T1.4.4)	2 - UEA	Report	Confidential, only for members of the consortium (including the Commission Services)	45
D1.12	Report on the factorial attribution analysis (T1.5)	1 - UNEXE	Report	Confidential, only for members of the consortium (including the Commission Services)	45

Description of deliverables

D1.1 Draft O2 and APO budgets (T1.1.1) (UEA, R, PU, M18)
D1.2 Global O2 and APO budget for 1991-2018 time-period using observations and models (T1.1.1) (UEA, R, PU, M36)
D1.3 Draft Isotopic-constrained atmospheric carbon budget (T1.1.2) (UBERN, R, PU, M18)
D1.4 Isotopic-constrained atmospheric carbon budget and sink flux estimates (UBERN, R, PU, M36)
D1.5 Satellite-based atmospheric CO2 dataset (T1.1.3) (UBREMEN, R,PU, M24)
D1.6 New constraints on ocean carbon (T1.2.1 and T1.2.2) (MPG, R, PU, M18)
D1.7 New constraints on land carbon (T1.2.3-5) (CEA, R, PU, M21)
D1.8 Report on historical simulations (ETHZ, R, PU, M36)
D1.9 Report on the benchmarking and evaluation of simulated carbon budgets (T1.4.1 and T.1.4.2) (CEA, R, PU, M36)
D1.10 Inclusion of new benchmarking in ESMValTool (T1.4.3) (UBREMEN, DEM, PU, M42)
D1.11 Report on the reduction of the global carbon budget imbalance (T1.4.4) (UEA, R, PU, M48)
D1.12 Report on the factorial attribution analysis (T1.5.1 and T1.5.2) (UNEXE, R, PU, M45)

D1.1 : Draft O2 and APO budgets (T1.1.1) [18]

Draft O2 and APO budgets

D1.2 : Global O2 and APO budget for 1991-2018 time-period using observations and models (T1.1.1) [36]

Global O2 and APO budget for 1991-2018 time-period using observations and models

D1.3 : Draft Isotopic-constrained atmospheric carbon budget (T1.1.2) [18]

Draft Isotopic-constrained atmospheric carbon budget

D1.4 : Isotopic-constrained atmospheric carbon budget and sink flux estimates (T1.1.2) [36]
Isotopic-constrained atmospheric carbon budget and sink flux estimates

D1.5 : Satellite-based atmospheric CO2 dataset (T1.1.3) [24]
Satellite-based atmospheric CO2 dataset

D1.6 : New constraints on ocean carbon (T1.2.1 and T1.2.2) [18]
New constraints on ocean carbon

D1.7 : New constraint on land carbon (T1.2.3-5) [21]
New constraint on land carbon

D1.8 : Report on historical simulations (T1.3) [36]
Report on historical simulations

D1.9 : Report on the benchmarking and evaluation of simulated carbon budgets (T1.4.1 and T.1.4.2) [36]
Report on the benchmarking and evaluation of simulated carbon budgets

D1.10 : Inclusion of new benchmarking in ESMValTool (T1.4.3) [42]
Inclusion of new benchmarking in ESMValTool

D1.11 : Report on the reduction of the global carbon budget imbalance (T1.4.4) [45]
Report on the reduction of the global carbon budget imbalance

D1.12 : Report on the factorial attribution analysis (T1.5) [45]
Report on the factorial attribution analysis

Schedule of relevant Milestones

Milestone number[18]	**Milestone title**	**Lead beneficiary**	**Due Date (in months)**	**Means of verification**
MS1	First set of offline historical simulations of the land and ocean carbon cycle (T1.3.1 and T1.3.2)	5 - ETHZ	16	Simulations available
MS2	First set of online historical simulations of the global carbon cycle (T.1.3.3)	3 - ENS	21	Simulations available
MS3	Enhanced ESMValTool version with new 4C observation diagnostics (T1.4.3)	8 - UBREMEN	24	Software available

Work package number [9]	WP2	Lead beneficiary [10]	4 - MPG
Work package title	Predicting the carbon cycle and climate for the global stocktake to the horizon of 2030		
Start month	1	**End month**	48

Objectives

The objective of this WP is to develop the capability of 3 European ESMs to predict the near-term evolution of carbon sinks, atmospheric CO2, and climate in response to future emissions consistent with the Nationally Determined Contributions adopted by the countries that adhered to the Paris Agreement on climate. To achieve this goal the following specific objectives are to:

• improve understanding of processes driving predictability of climate-carbon cycle system on decadal timescales;

• perform an extensive assessment in retrospective mode of the current predictive skill of 3 ESMs over 1-to-10 years for the land and ocean carbon sinks and for atmospheric CO2;

• perform emission-driven decadal predictions of atmospheric CO2, global carbon cycle and climate response, providing unique predictions of the outcome of NDCs in time for the UNFCCC 2023 global stocktake;

• inform evolving ambition by providing a methodology to attribute the future evolution of atmospheric CO2 to NDCs vs natural variability.

Description of work and role of partners

WP2 - Predicting the carbon cycle and climate for the global stocktake to the horizon of 2030 [Months: 1-48]
MPG, UNEXE, ENS, BSC, UOXF, CEA
Work package lead Tatiana Ilyina (MPG), deputy lead Raffaele Bernardello (BSC)

In this WP we will first enhance our understanding of the mechanisms driving decadal predictability of the global carbon cycle by performing process-oriented predictions in a perfect model framework (T2.1). Next we will produce a reconstruction of the recent past (T2.2) to provide initial conditions for retrospective near-term predictions that will allow the quantification of the predictability of 3 European modelling systems (T2.3). Finally, in T2.4 we will provide original emission-driven predictions of the near-future evolution of atmospheric CO2 comparing a future in which emissions follow a middle of the road scenario with one in which emissions follow NDCs ambitions. This will enable us to anticipate and explain the near-term evolution of atmospheric CO2 increase and climate response in time for the first global stocktake in 2023. Analysis in this WP will rely on initialized prediction systems based on both CO2 concentration-driven simulations and the newly developed CO2 emission-driven simulations. The work within this WP will strengthen the predictive skill of the climate-carbon system in three major European ESM-based prediction systems. Moreover, this is the first step forward towards semi-operational climate-carbon predictions.

Task 2.1. Assessment of the potential predictability of carbon sinks and of their main drivers (M1-M24) BSC (lead), ENS, CNRS, MPG, CEA
Potential predictability is here assessed in a perfect model framework, i.e. using multi-century pre-industrial control simulations and ensembles of decadal simulations starting from slightly perturbed conditions of the control simulations. The potential predictability is assessed by the duration over which a simulated variable starting from perturbed initial conditions follows the same evolution as the one starting from unperturbed initial conditions. To improve our understanding of the processes driving the low-frequency variability of global carbon cycle we will also estimate the contribution of the specific regions to the potential predictability of the climate-carbon system.

T2.1.1 Potential predictability of carbon sinks (M1-M24) BSC, ENS, MPG, CEA
We will select 5 starting dates from the multi-century preindustrial control simulations of the 3 ESMs (using CO2 concentration-driven model configurations), and will run for each starting date a 15-member ensemble of 10 years, with slightly perturbed initial conditions. Starting dates will be selected from the preindustrial control to cover a variety of climate modes. Potential predictability of the land and ocean carbon sinks will be assessed using these simulations and inter-compared across models.

T2.1.2 Potential Predictability: processes, drivers and key regions (M9-M24) MPG, BSC
We will re-run the same predictions described in Sub-Task 2.1.1 but in a pacemaker setup focusing on the key regions that determine the variability of surface carbon fluxes. In such pacemaker experiments, only the regions of interest will be subject to perturbed initial conditions (as in T2.1.1), enabling us to quantify the impact of such hot spot regions on the potential predictability of atmospheric CO2. This variability hotspot includes for instance, the North Atlantic, the

Southern Ocean, or the equatorial Pacific. Such simulations will enable us to assess the regional vs. global effects on the carbon cycle and the pathways in the climate-carbon system through which the variability drivers are expressed.

Task 2.2 Generation of initial conditions for retrospective near-term predictions (M1-M16) BSC (lead), ENS, MPG, CEA
The generation of initial conditions involves assimilation of observations. We will test several options that we will evaluate using observation-based products from WP1. At the moment the three groups follow different procedures (described below). As carbon cycle prediction is a new field that builds upon an existing system of climate predictions, techniques for carbon cycle initialization have to be coherent with the techniques already used for physical variables. However, we will design at least one common procedure to be tested by all three groups. The characteristics of such common procedure will be defined after analysing the results from the standard procedure from each group. The reconstructions will cover the period from 1958 to present.

Strategy for model initialization:

BSC (EC-Earth) will start an ocean only NEMO-LIM3-PISCES experiment using fields (physical and biogeochemical) coming from the CMIP6 historical simulation. This ocean-only simulation will be forced with reanalysis atmospheric forcing and will combine together 3D ocean nudging of temperature and salinity126 and an Ensemble Kalman Filter for the sea-ice127. Ocean biogeochemical fields will be computed by PISCES in response to the constrained ocean physics. The land vegetation fields will be produced offline by LPJ-GUESS (starting from year 1958 of the CMIP6 historical) using the same atmospheric forcing used for the ocean. The datasets used for the oceanic data-assimilation and atmospheric forcing will be re-analyses from the ECMWF (European Centre for medium Range Weather Forecasts): ORAS4 and ERA40 / ERA-interim covering the period 1958-present.

MPG (MPI-ESM) will start an assimilation run from year 1958 of the historical simulation. For the MPI-ESM ocean component MPIOM, 3D temperature and salinity anomalies are restored towards the ECMWF ocean reanalysis system 4. For the atmosphere component ECHAM6, full-field temperature, vorticity, divergence, and surface pressure are restored towards ECMWF ERA40 and ERA-Interim reanalysis data in order to avoid model drift. As both the land and ocean biogeochemical processes slowly adjust to the new model physical states due to data restoring, several decades of a spin-up type simulation are foreseen.

ENS and CEA (IPSL-ESM) start an assimilation run from year 1958 of the historical simulation using the full ESM. To avoid any large drifts due to the assimilation procedure, the assimilation within the IPSL-ESM consists in restoring to SST (and potentially SSS, surface winds) temporal anomalies constructed using ocean reanalysis/ocean observations. As for BSC and MPG, the restoring does not include ocean and land carbon cycle data.

Task 2.3. Assessment of actual predictability with retrospective near-term predictions (M17-M36) MPG (lead), ENS, CNRS, BSC, CEA
We will perform a series of ESM-based retrospective decadal predictions with starting dates every year over the 1981-present period. These predictions will be initialized from a realistic state of climate and carbon stocks, obtained from the reconstructions produced in Task 2.2. For each starting date we will generate 15 ensemble members by either using initial conditions with 1-day lag centered on the starting date or by randomly perturbing sea surface temperature. All time-series of predicted anomalies will be computed for each member/model separately by removing the bias at each forecast time while prediction averages will be calculated afterwards. This bias-correction procedure and skill score evaluation will be applied to surface temperature as well as air-sea and air-land CO2 flux and atmospheric pCO2 (in the case of the CO2 emission-driven predictions, T2.3.3). The work required has been distributed among three subtasks.

T2.3.1 Predictability of the carbon cycle using CO2-concentration-driven ESMs and carbon reconstructions (M17-M32) ENS, MPG, BSC, CEA
We will quantify the predictive skills of CO2 concentration-driven ESMs against the best-performing reconstruction from T2.2. We will use model fields calculated in the assimilation run as a proxy to quantify the predictive skill.

T2.3.2 Predictability of the carbon cycle using CO2 concentration-driven ESMs and carbon observations (M20-M36) ENS, MPG, BSC, CEA
Quantification of the predictive skills of CO2 concentration-driven ESMs against available observations will be performed regarding variations in the air-sea and air-land CO2 fluxes (using the observation-based products from WP1), and surface temperature (using an independent data set not used for the reconstruction). Here, we will interact with WP1 in assessing uncertainties in models and observational products. The outcome of this task will be an assessment of the predictability of the carbon cycle.

T2.3.3 Predictability of the carbon cycle using CO2 emission-driven ESMs (M23-M36) ENS, MPG, BSC, CEA

Here we will use ESMs driven by CO2 emission to determine the predictive skill for atmospheric CO2 and assess the role of land and ocean carbon sink variability. Analogous to T2.3.2 we will assess the predictive skill of the climate-carbon system against the available observational products (air-sea flux, land carbon fluxes, etc.).

Task 2.4. Decadal predictions of future atmospheric CO2 over the stocktake period following future climate change scenarios (M18-M48) ENS (lead), UNEXE, MPG, CNRS, BSC, CEA, UOXF
We will perform original decadal forecasts, with ESMs initialised with present-day state of the carbon and climate system. ESMs will be driven by CO2 emissions using the Global Carbon Project (GCP) CO2 emission prediction for next year, merged with emissions reductions following the NDCs for the following decade. Emissions of other radiatively active gases and aerosols will be assumed to follow a SSP1 sustainable scenario128. With these decadal forecasts, we will assess the impact of NDCs emissions on atmospheric CO2, carbon sinks and climate response, also quantifying the uncertainty (15 ensembles, 3 ESMs). We will use the simulated atmospheric CO2 from these experiments to detect the timing of CO2 emissions peak (accounting for the natural variability of the climate-carbon system).
The ensemble ESMs forecast will be repeated the last 3 years of the 4C project, with the year 1 forecast providing a semi-operational system for predictions of next-year atmospheric CO2, and exploited for dissemination (WP4). Lastly, we will perform additional ESMs decadal forecasts, using SSP2-4.5 CO2 and non-CO2 emissions as a baseline middle-of-the-road scenario, to assess in the NDCs simulations the skills to detect the expected changes in atmospheric CO2 and climate due the implementation of the Paris Agreement.

Participation per Partner

Partner number and short name	WP2 effort
1 - UNEXE	4.00
3 - ENS	13.00
CNRS	10.00
4 - MPG	42.00
6 - BSC	66.00
11 - UOXF	4.00
12 - CEA	16.00
Total	155.00

List of deliverables

Deliverable Number[14]	Deliverable Title	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
D2.1	Assessment of carbon cycle potential predictability (T2.1.2)	6 - BSC	Report	Public	24
D2.2	Initial conditions for retrospective predictions (T2.2)	3 - ENS	Report	Public	16
D2.3	Assessment of predictability of the C cycle in C-driven simulations (T2.3.1 and T2.3.2)	4 - MPG	Report	Public	32
D2.4	Assessment of predictability of	6 - BSC	Report	Public	36

List of deliverables

Deliverable Number[14]	Deliverable Title	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
	atmospheric CO2 and C sinks in E-driven simulations (T2.3.3)				
D2.5	Draft report on predictions of next year atmospheric CO2 (T2.4)	4 - MPG	Report	Public	22
D2.6	Prediction of atmospheric CO2, carbon sinks and climate for the next decade (including next year prediction) (T2.4)	3 - ENS	Report	Confidential, only for members of the consortium (including the Commission Services)	45

Description of deliverables

D2.1 Assessment of carbon cycle potential predictability (T2.1.2) (BSC, R, PU, M24)
D2.2 Initial conditions for retrospective predictions (T2.2) (ENS, R, PU, M16)
D2.3 Assessment of predictability of the C cycle in C-driven simulations (T2.3.1 and T2.3.2) (MPG, R, PU, M32)
D2.4 Assessment of predictability of atmospheric CO2 and C sinks in E-driven simulations (T2.3.3) (BSC, R, PU, M36)
D2.5 Draft report on predictions of next year atmospheric CO2 (T2.4) (MPG, R, PU, M22)
D2.6 Prediction of atmospheric CO2, carbon sinks and climate for the next decade (including next year predictions) (T2.4) (ENS, R, PU, M45)

D2.1 : Assessment of carbon cycle potential predictability (T2.1.2) [24]

Assessment of carbon cycle potential predictability

D2.2 : Initial conditions for retrospective predictions (T2.2) [16]

Initial conditions for retrospective predictions

D2.3 : Assessment of predictability of the C cycle in C-driven simulations (T2.3.1 and T2.3.2) [32]

Assessment of predictability of the C cycle in C-driven simulations

D2.4 : Assessment of predictability of atmospheric CO2 and C sinks in E-driven simulations (T2.3.3) [36]

Assessment of predictability of atmospheric CO2 and C sinks in E-driven simulations

D2.5 : Draft report on predictions of next year atmospheric CO2 (T2.4) [22]

Draft report on predictions of next year atmospheric CO2

D2.6 : Prediction of atmospheric CO2, carbon sinks and climate for the next decade (including next year prediction) (T2.4) [45]

Prediction of atmospheric CO2, carbon sinks and climate for the next decade (including next year prediction)

Schedule of relevant Milestones

Milestone number[18]	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification
MS4	Completion of simulations in perfect model framework (T2.1.1)	6 - BSC	18	Data available

Schedule of relevant Milestones

Milestone number[18]	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification
MS5	Completion of retrospective predictions including computation of bias correction (T2.3.1 and T2.3.2)	4 - MPG	28	Simulations available
MS14	First set of future decadal predictions for NDC and baseline scenario (T2.4)	3 - ENS	22	First set of future decadal predictions for NDC and baseline scenario

Work package number [9]	WP3	Lead beneficiary [10]	9 - UBERN
Work package title	Projecting the required mitigation effort over the 21st century		
Start month	1	**End month**	48

Objectives

The objective of this WP is to deliver observationally-constrained estimates of 21st century cumulative carbon emissions consistent with the Paris Agreement aims at limit warming to 1.5°C. This will be achieved by developing novel emergent constraints on the land and ocean carbon cycle, by weighting individual Earth system model projections with these emergent constraints and additional observations, and by ultimately delivering policy-relevant, adaptive CO2 emission pathways consistent with the Paris Agreement ambitions. Specifically, we will :

• reduce uncertainty in carbon and climate projections through developing observation-based constrains of key biogeochemical dynamics and feedback processes;

• reassess TCRE using novel CMIP6 and CMIP6+ simulations, and overshoot scenarios including non-CO2 greenhouse gases;

• develop observational-constrained estimates of 21st century cumulative CO2 emissions consistent with the ambitions of the Paris Agreement to limit warming to 2°C or to 1.5°C;

• deliver policy-relevant, adaptive CO2 emissions pathways, fully consistent with the Paris Agreement, accounting for Earth system feedbacks, and methodologies for updating them in the light of the evolving response.

Description of work and role of partners

WP3 - Projecting the required mitigation effort over the 21st century [Months: 1-48]
UBERN, UNEXE, ENS, MPG, ETHZ, BSC, DLR, UBREMEN, CICERO, UOXF, CEA
Work package lead Thomas Frölicher (UBERN), deputy lead Veronika Eyring (DLR)

WP3 will develop process-based emergent constraints on the carbon cycle to obtain observation-based improved understanding of the carbon cycle dynamics in order to reduce uncertainty on TCRE and carbon cycle feedbacks (T3.1), and to provide origin weighting of multi-model and large ensemble climate projections (T3.3). In order to avoid spurious relationships that can arise from blind data-mining, the emergent constraints will be based on sound process-understanding, and tested 'out of sample' (Eyring et al., 2019, Nature Climate Change).The magnitude and robustness of the TCRE will be assessed using ESMs simulations accounting for non-CO2 greenhouse gases forcing (T3.2) and also for overshoot scenarios. Novel 21st century climate adaptive scenarios will be performed where emissions are revised on a 5 year basis to ensure that global warming remains below 1.5°C or 2°C, providing our best estimate on the associated remaining carbon budget (T3.4). WP3 will use standard scenario from CMIP6, novel observations from WP1 and additional model simulations with CMIP6+ ESMs with improved representation of key biogeochemical processes.

Task 3.1 Emergent constraints for carbon and biogeochemical feedbacks (M1-M48) ETHZ (lead), UNEXE, ENS, DLR, UBREMEN, UBERN, CEA
We will develop and apply process-based emergent constraints on the carbon cycle using a wide range of observational products. A particular focus will be placed on a sound scientific basis for an emergent relationship, the consideration of observational uncertainty, and on assessing the robustness of the constraints across different ensembles (e.g. CMIP5 versus CMIP6) and scenarios. The emergent constraints will be further tested towards the end of the project with extended data from WP1, and the new adaptive simulations performed under T3.4 with the CMIP6+ ESMs. All diagnostics will be implemented in the ESMValTool for further use in T3.2 and 3.3.

T3.1.1 Emergent constraints on land carbon processes (M1-M48) ETHZ, UNEXE, DLR, UBREMEN, CEA
Several constraints will be assessed for the land carbon cycle. One focus will be on the land water cycle based on the extended datasets produced in WP1 (T1.2), including new satellite-based estimates and reconstructions of global terrestrial water storage (TWS)34 and evapotranspiration41,43 and new constraints on gross land carbon uptake using atmospheric COS and SIF data. Emergent constraints on tropical and extra-tropical response to CO2 (CO2 fertilization effect), CO2 emissions from tropical wildfires, and response of mid and high latitude carbon to climate change (climate-carbon feedback) including constraints on permafrost carbon loss will be developed using the temporal (e.g. growth rate, seasonal cycle amplitude) as well as spatial (e.g. latitudinal) patterns of satellite data of CO2 (T1.1.3). The potential of using present-day spatial variability as emergent constraint for future dynamic will also be investigated, as recently done for permafrost extension109.

T3.1.2 Emergent constraints on ocean carbon processes (M1-M48) ENS, ETHZ, UBERN

For the ocean carbon uptake, CFC-11, CFC-12 and SF6 distribution in CMIP6 historical and future simulations will be assessed to develop emergent constraints for ocean carbon uptake with a focus on the Southern Ocean and North Atlantic, where the model uncertainty in the CMIP5 models were largest129. In addition, the seasonal cycle of the surface ocean carbon systems, as the source of an emergent constraint for future ocean carbon uptake and for ocean biological productivity will be used. Further constraints will be explored based on the level of interannual to decadal variability of the ocean carbon uptake determined in WP1.2, as well as the changes in the seasonality38. The emergent constraints will be further extended to biological carbon export and the biological carbon pump. Parameterization ensemble simulations, conducted with Redfield and variable stoichiometry versions of the PISCES ocean biogeochemical model130 will be performed to identify the mechanistic controls on carbon export emergent relationships and inform model development.

Task 3.2 TCRE reassessment including non-CO2 emissions and overshoot scenarios (M1-M30) UOXF (lead), UNEXE, ETHZ, DLR, UBERN, CICERO

T3.2.1 Assessment of TCRE (M1-M30) UNEXE, DLR, UBERN, UOXF
The transient climate response to cumulative carbon emissions (TCRE) will be assessed in CCiCC and CMIP6 simulations providing an initial revision of the previous CMIP5 TCRE estimate. Focus will be given to CMIP6 scenarios with stabilizing and/or declining greenhouse gas concentrations and emissions (i.e. overshoot scenarios from ScenarioMIP131), but also to the new 4C adaptive scenarios performed under T3.4. We will work on both the climate and carbon cycle components of TCRE. The constraints on the climate response involve differential responses to different forcing agents, land-sea contrast, meridional profile of surface warming and vertical profile of ocean warming; while the constraints on the carbon cycle will involve factors controlling the rates of change in CO2 airborne fraction and land/ocean carbon storage. The magnitude and timescales dependences of the land and ocean carbon feedbacks will be assessed in available CMIP6 simulations (1%CO2/year, biogeochemically and radiatively coupled from C4MIP132). Drivers of changes in the TCRE relationship will be assessed and emergent constraints included in the ESMValTool. The potential for regional TCRE constraints will be explored by combining global-scale constraints on the carbon cycle and regional-scale constraints for regional forcing and feedback processes.

T3.2.2 TCRE and non-CO2 forcing (M1-M30) ETHZ, DLR, CICERO, UOXF
An enhanced methodology that applies the TCRE concept to non-CO2 emissions expressed as cumulative CO2-forcing-equivalent emissions37 will be extended and developed. Building on this new concept, CO2-forcing-equivalent emissions will be diagnosed from a broad range of CMIP5/6(+) simulations and scenarios. The new method will be included in the ESMValTool. The path dependencies for regional responses when accounting for non-CO2 forcings, e.g. through biogeophysical effects of land use133 will also be explored.

Task 3.3 Observationally constrained estimates of CO2 projections and fluxes (M13-M42) DLR (lead), UNEXE, ETHZ
To improve the reliability of projections from a large ensemble of models such as the CMIP6 simulations, weights reflecting the respective skills or the confidence we put into them will be assigned to individual models. The underlying assumption is that the reliability of a large ensemble can be improved giving greater weights to 'better performing' models. We will then compare projections from the un-weighted multi-model ensemble to different weighting schemes and test the robustness of weighting approaches considering both model performance and interdependence117,118 while fully exploiting observations from WP1 and considering their uncertainties. Specifically, using a multiple diagnostic regression method134,135, we will develop a formal process-oriented statistical model to weight CO2 flux projections based on their ability to reproduce key processes of the historical carbon cycle and climate, from observation analysed in WP1 and from new emergent constraints developed in T3.1. We will compare this method to a weighting scheme similar to Knutti et al117 and to the unweighted multi-model mean. In addition, targeted weights for specific processes will also be investigated in coordination with T3.1, in particular in the case where models are shown to have systematic biases, such as the controls of water availability and droughts on land carbon exchanges34.

Task 3.4 Exploration of adaptive CO2 scenarios meeting the Paris Agreement climate ambitions (M18–M48) UBERN (lead), UNEXE, ENS, MPG, BSC, CICERO, UOXF, CEA
CMIP6 scenarios, with emissions pathways prescribed a priori, regardless of the simulated climate response, are not ideal tools to ensure consistency with the Paris Agreement ambitions to limit warming to 1.5°C to 2°C. We go beyond this limitation by exploring adaptive CO2 scenarios with the 4C models, also accounting for Earth system feedbacks. In these scenarios, CO2 emissions will be revised every 5 years in order to ensure global warming remain below a predefined temperature target pathway. Adaptive scenarios allow adapting the mitigation effort along the way, according to the realized warming to date136, similarly to what would probably happen in the real world. We will explore different adaptive scenarios, compliant with the NDCs ambitions, allowing or preventing from small overshoot to occur, also accounting for the effect of non-CO2 forcing. For consistence with the decadal predictions done in WP2, the NDC compliant scenarios for the first 15 years (up to 2030) will be provided from WP2 (T2.4). From 2030 onward, we will implement the new adaptive scenarios, with emissions being revised every 5 years. Such new simulations with adaptive

scenarios will be first performed with a reduced complexity model to test our method, before being implemented in the CMIP6+ 4C ESMs. A key challenge in the development of adaptive mitigation algorithms will be that short-lived climate pollutants affect temperature trajectories much more rapidly than CO2, this will be accommodated using the CO2-forcing-equivalent emissions concept developed in T3.2.

T3.4.1 Proof of concept (M18–M32) UBERN, CICERO, UOXF
Simulations with adaptive scenarios will be first performed with the Bern3D-LPX reduced complexity model in order to test adaptive control methods ensuring (a) continuity in emissions and (b) absence of numerical oscillations in the emissions. We will test adaptive control methods (e.g. using a feedback control approach136), the frequency of emissions revisions (5 years), and the method to diagnose the warming to date (ex. estimating the global human-induced warming137). We will test these methodologies on scenarios aiming to always remain below 1.5°C or 2°C, as well as on scenarios with some level of overshoot of these targets.

T3.4.2 Adaptive scenarios with 4C ESMs (M18–M48) UNEXE, ENS, MPG, BSC, UBERN, CEA
The adaptive scenarios following the methodology developed in T3.4.1 will be performed with 4C ESMs. The temperature and carbon cycle trajectories simulated by the ESMs will be used to intercompare among the models the land and ocean carbon sinks and to calculate the cumulative carbon emissions for the respective temperature scenarios, providing our best estimate and uncertainty of the future CO2 emissions compatible with the Paris Agreement long-term temperature goals. The new emergent constraints developed in T3.1 and the weighting schemes developed in T3.3 will be used here to further refine these estimates.

Participation per Partner

Partner number and short name	WP3 effort
1 - UNEXE	41.40
3 - ENS	23.00
4 - MPG	18.00
5 - ETHZ	14.00
6 - BSC	9.00
7 - DLR	37.00
8 - UBREMEN	19.00
9 - UBERN	38.00
10 - CICERO	9.00
11 - UOXF	30.00
12 - CEA	12.00
Total	250.40

List of deliverables

Deliverable Number[14]	Deliverable Title	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
D3.1	Draft report on emergent constraints for carbon processes and biogeochemical feedbacks (T3.1.1 and T.3.1.2)	5 - ETHZ	Report	Public	18

List of deliverables

Deliverable Number[14]	Deliverable Title	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
D3.2	Report on emergent constraints for carbon processes and biogeochemical feedbacks (T3.1.1 and T.3.1.2)	5 - ETHZ	Report	Confidential, only for members of the consortium (including the Commission Services)	36
D3.3	Draft report on TCRE assessment including non-CO2 emissions and observational constraints (T3.2.1 and T.3.2.2)	11 - UOXF	Report	Public	18
D3.4	Report on TCRE assessment including non-CO2 emissions and observational constraints (T3.2.1 and T.3.2.2)	11 - UOXF	Report	Confidential, only for members of the consortium (including the Commission Services)	30
D3.5	Report on the robustness of different weighting schemes for CO2 projections (T3.3)	7 - DLR	Report	Public	42
D3.6	Report on adaptive scenarios compatible with the Paris Agreement (T3.4.2)	9 - UBERN	Report	Confidential, only for members of the consortium (including the Commission Services)	45

Description of deliverables

Deliverables
D3.1 Draft report on emergent constraints for carbon processes and biogeochemical feedbacks (T3.1.1 and T.3.1.2) (ETHZ, R, PU, 18)
D3.2 Report on emergent constraints for carbon processes and biogeochemical feedbacks (T3.1.1 and T.3.1.2) (ETHZ, R, PU, 36)
D3.3 Draft report on TCRE assessment including non-CO2 emissions and observational constraints (T3.2.1) (UOXF, R, PU, 18)
D3.4 Report on TCRE assessment including non-CO2 emissions and observational constraints (T3.2.2) (UOXF, R, PU, 30)
D3.5 Report on the robustness of different weighting schemes for CO2 projections (T3.3) (DLR, R, PU, 42)
D3.6 Report on adaptive scenarios compatible with the Paris Agreement (T3.4.2) (UBERN, R, PU, 45)

D3.1 : Draft report on emergent constraints for carbon processes and biogeochemical feedbacks (T3.1.1 and T.3.1.2) [18]

Draft report on emergent constraints for carbon processes and biogeochemical feedbacks

D3.2 : Report on emergent constraints for carbon processes and biogeochemical feedbacks (T3.1.1 and T.3.1.2) [36]

Report on emergent constraints for carbon processes and biogeochemical feedbacks

D3.3 : Draft report on TCRE assessment including non-CO2 emissions and observational constraints (T3.2.1 and T.3.2.2) [18]

Draft report on TCRE assessment including non-CO2 emissions and observational constraints

D3.4 : Report on TCRE assessment including non-CO2 emissions and observational constraints (T3.2.1 and T.3.2.2) [30]

Report on TCRE assessment including non-CO2 emissions and observational constraints

D3.5 : Report on the robustness of different weighting schemes for CO2 projections (T3.3) [42]

Report on the robustness of different weighting schemes for CO2 projections

D3.6 : Report on adaptive scenarios compatible with the Paris Agreement (T3.4.2) [45]

Report on adaptive scenarios compatible with the Paris Agreement

Schedule of relevant Milestones

Milestone number[18]	**Milestone title**	**Lead beneficiary**	**Due Date (in months)**	**Means of verification**
MS6	New set of emergent constraints implemented i?n the ESMValTool GitHub repository (T3.1.1 and T.3.1.2)	7 - DLR	24	Software available
MS7	Weighting methods for CO2 projections available (T3.3)	7 - DLR	30	Software available
MS8	Temperature trajectories for adaptive scenarios with reduced complexity models (T.3.4.1)	9 - UBERN	30	Simulations available

Work package number [9]	WP4	Lead beneficiary [10]	6 - BSC
Work package title	Synthesis, dissemination and policy dialogue		
Start month	1	**End month**	48

Objectives

The objective of WP4 is to assess, synthesise, and disseminate 4C scientific findings to foster a broader understanding of climate-carbon interactions and accurate interpretation in support of scientific assessments and policymaking. WP4 builds on findings from WPs 1, 2 and 3 and the knowledge generated, elaborating it to make the information easy to access, and transferring it to targeted stakeholders using tailored techniques. The main objectives are to:
• develop novel communication, dissemination and engagement activities and foster a broad range of activities, to facilitate knowledge transfer and support international scientific assessments such as IPCC, IPBES, GCP, WMO State of the Climate, UNEP Emissions Gap Report, and similar assessments;
• ensure accurate interpretation by policymakers of scientific findings in the context of the UNFCCC Paris Agreement;
• broaden the public understanding of the carbon cycle and of the risks of climate-carbon interactions for enhancing climate change;
• increase visibility of 4C and its outcomes in Europe and beyond to support Europe's leadership in climate science.

Description of work and role of partners

WP4 - Synthesis, dissemination and policy dialogue [Months: 1-48]
BSC, UNEXE, UEA, MPG, ETHZ, DLR, UBREMEN, UBERN, CICERO, UOXF
Work package lead Isadora Jiménez (BSC), deputy lead Glen Peters (CICERO)

WP4 will consist of 4 tasks, each aiming a specific audience. T4.1 will provide the knowledge transfer of 4C science to IPCC and other international scientific assessments. T4.2 will target decision and policymakers, while T4.3 will target the broader audience (general public and media). T4.4 will manage the project's general communication and dissemination activities.

Task 4.1: Knowledge transfer to support major international scientific assessments (M1-M48) UEA (lead), UNEXE, BSC, MPG, ETHZ, DLR, UBREMEN, UBERN, CICERO, UOXF
4C will aim to provide direct support to international assessments. Given the strict deadlines, the first priority of this task will be to contribute to IPCC AR6. 4C will build on the ScienceBrief platform specifically aimed at synthesising the rapidly-evolving science on the global carbon cycle to support major international activities such as IPCC, IPBES but also GCP, UNEP or WMO periodic assessments.

T.4.1.1: Supporting IPCC AR6 (M1-M29) UNEXE, UEA, MPG, ETHZ, BSC, DLR, UBREMEN CICERO, UOXF
This task will focus on a fast-track support to IPCC AR6 during the first year of 4C. This will be done through an expert workshop at the 4C kickoff meeting on climate-carbon feedbacks that will include two elements. First, we will organise a discussion with the 4C IPCC lead authors of AR6 to facilitate a consultation with all 4C researchers on how to better contribute to AR6, address the issues raised on the on-going AR6 drafts (WG1 First Order Draft will be reviewed in spring 2019), and identify key issues that will unlikely be resolved by AR6 and can be addressed within 4C. Second, we will use ScienceBrief to harvest the latest scientific finding by engaging the 4C researchers and the broader community in the submission of recently published papers ahead of the kick-off meeting, and we will provide an overview of the results to the group at the expert workshop.

T4.1.2 Improving ScienceBrief user experience and reach (M1-M48) UNEXE, UEA, UBERN
This task will conduct an evaluation of the ScienceBrief Carbon Cycle pilot (conducted in 2018-2019 prior to 4C), and use the results to improve the user experience and therefore enhance their involvement and the reach of the platform. The evaluation will be done through a quantitative and qualitative analysis, i.e., by considering the number of users and submissions, and success of their interactions with the website. We will conduct a survey targeting all (platform) contributors, as well as interviews with key users from the stakeholder communities (including policymakers and media groups). The anticipated developments include: the (addition of) visual graphics of the carbon cycle and the inclusion of a carbon news channel. Besides, linkages with other ScienceBrief topics are envisaged, such as the emerging topic on Science to support the Paris Agreement (also a pilot on ScienceBrief), and with external relevant assessments such as IPBES and the annual Global Carbon Budget updates. As IPCC AR6 approaches its publication date, we will work with IPCC authors to develop an update of the carbon cycle statements that are posted on ScienceBrief, therefore ensuring the platform is always up-to-date, includes all results from 4C, and serves the next IPCC cycle AR7 and beyond.

T4.1.3 Supporting post-AR6 and other international assessments (M1-M48) UNEXE, UEA, BSC, CICERO
We will present 4C results at conferences and workshops at national, EU, and international levels, in particular at the annual conference of the European Geophysical Union (EGU). We will work on engaging the broad community in contributing to ScienceBrief, particularly early career researchers, as ScienceBrief will provide them with a unique opportunity to contribute to IPCC assessments. The use of ScienceBrief will enable natural linkages between assessments to be made, particularly IPCC, IPBES, and GCP which share common interests, for example in carbon stocks and cumulative emissions.

Task 4.2: Providing added value to decision and policymakers (M1-M48) CICERO (lead), UNEXE, UEA, BSC
T4.2 will engage with decision and policymakers to add value by translating the emerging scientific consensus (T4.1) into usable formats.

T4.2.1: Fact sheets and knowledge base contents (M1-M48) UNEXE, UEA, BSC, CICERO
4C will generate many scientific publications. To facilitate decision and policymakers to use this knowledge, we will utilise different communication approaches. We will develop at least three fact sheets presenting the main concepts to understand the outcomes of 4C science. This will build the knowledge base of project users – from fellow scientists to policymakers – and build trust and encourage close engagement with 4C results. Some potential topics include: the carbon cycle and its uncertainties, new observations of the carbon cycle, decadal predictions versus long-term projections, emergent constraints and carbon cycle feedbacks, remaining carbon budgets for climate targets.

T4.2.2: Policy brief and executive summaries (M13-M48) UNEXE, UEA, BSC, CICERO
Towards the end of the project we will provide a policy brief presenting 1) the most relevant results of the project regarding anthropogenic emissions and climate-carbon interactions; 2) an overview of the current policies on emissions and climate implications, and 3) a set of policy recommendations based on the two previous points. In addition, based on project publications and public deliverables we will produce at least three science summaries. These pieces of information will highlight the relevant results and translate them for use by decision and policy makers. This task will also include contributions to the Global Carbon Budget, UNEP Emissions Gap Report, and WMO State of the Climate, and similar.

T4.2.3: Carbon outlooks (M13-M48) UNEXE, UEA, BSC, CICERO
Key 4C outcomes will be published as "carbon outlooks" in partnership with the high-profile annual Global Carbon Budget. They will be released every autumn of the project duration (from 2020 to 2023). The focus will be on the carbon budget for the recent years (T1.4) and the forecast for the coming year (T2.4), including an assessment of past performances. This activity will be a collaborative effort with the Global Carbon Budget to ensure broad outreach. Each year the activity will be supported by a news story on the 4C website.

T4.2.4: Events organised by 4C (M1-M48) UNEXE, UEA, BSC, CICERO
We will organize (or co-organize with GCP, when applicable) events to communicate key findings to policymakers and hear their perspectives and wishes. This will preferably be held during the UNFCCC inter-sessional meetings in Bonn (SBSTA, May/June each year) or Conference of the Partiers (COP, November/December each year), where 4C investigators have been invited to present on multiple occasions in the past. We will also organise (or-co-organise) briefings for EU and national policymakers around emerging topics, particularly those outputs of T4.2.1 and 4.2.2. In particular, we will organise (or co-organise) a workshop in Brussels targeting EU policymakers toward the end of the project. Emerging topics from 4C that are relevant for stakeholders will be at the centre of the discussion. This will help the interaction between scientists and stakeholders allowing for bi-directional exchange of ideas. We will seek and foster networking and collaboration with other initiatives and projects related to the topic.

Task 4.3. Climate-carbon interactions for the broad audiences (M1-M48) BSC (lead), UNEXE, UEA, CICERO
Selected material from T4.1 and 4.2 will be further adapted for a general audience and used to create outreach pieces in diverse formats (e.g. opinion editorials, interviews, videos, info-graphics) in addition to social media actions leveraging the existing profiles of researchers in the project. This task will also continually assess and communicate material emerging outside the project, but of relevance to the project audiences.

T4.3.1: Media coverage (M1-M48) UNEXE, UEA, BSC, CICERO
We will work with 4C contacts in large news agencies (e.g. Nature News, CarbonBrief, Vox, Associated Press) to identify emerging news stories and encourage their media coverage through press releases or direct contact with journalists.

T 4.3.2: Communications content for platforms (M1-M48) UNEXE, UEA, BSC, CICERO
We will produce attractive content in different formats (posts, interviews, opinion editorials, videos, infographics, social media content, etc.). This will vary in length and content, depending on the targeted audience and expected understanding by the broader community. Content will be created in close collaboration with the participants of other WPs. The material

will also put 4C findings into the context of other research in the area. This activity will build on the project "Rapid Response for Energy and Climate Policy" that has undertaken similar activities at CICERO.

T4.3.3: Animated infographic about the carbon cycle (M7-M40) BSC
This visualization will be made as a short animated video (30' sec to 1 min), and as a static poster, reusing content for both media. The poster will be more suitable for press releases, reports, supporting material for presentations, and even conferences, while the animated video will work best as a standalone explanation of the project in YouTube, website, etc., but also as supporting material in live presentations.

T 4.3.4: Web based explorable explanation of the outcomes of the project (M25-M40) BSC
This interactive application will start with an intro from the previous infographic, and then guide the users through the project results and simulations, while providing the context to understand the project: challenges, motivations, and outcomes. Explorable explanations are one of the best ways to communicate scenario-based predictions, as interaction allows the users to ingrain the response of the underlying models to different changes. Both T4.3.3 and T4.3.4 tasks will rely strongly on the visualization of quantitative information.

Task 4.4. Communication and dissemination management (M1-M48) BSC (lead), UNEXE, CICERO
This task will manage general communication tasks such as the creation and periodic revision of a communication, dissemination and user engagement plan; the creation of a recognizable visual identity for all project materials; design of a website and set up of social media; production of online and printed PR materials; and support media liaison for the project.

T4.4.1: Visual identity (M1-M12) BSC
A coherent and recognizable visual identity will be designed to be used in all project materials. This task includes the following work: design of visual identity (including design elements, logo, colours and fonts), design of templates for letters, presentations, reports and newsletters.

T4.4.2: Website (M1-M48) UNEXE, BSC
A website will be designed to contain and offer the project description and its various outputs like public reports, general information, and news and dissemination material.

T4.4.3: Communication, Dissemination and Engagement Plan (M1-M48) UNEXE, BSC, CICERO
An outline of the Communication, Dissemination and Engagement Plan (CDEP) is provided in section 2.2 "Measure to maximize impact" and will be further developed at the start of the project. The document will provide detailed information about the activities planned along the lifetime of the project. The document will offer an overview of key messages, detailed target audiences, communication platforms and activities, as well as practical information such as branding of the project, logo, templates, etc. It will also provide a full framework for communication and stakeholder engagement activities detailing target stakeholders, effective mechanisms for engagement and temporal implementation plan of the communication and engagement activities. Key Performance Indicators (KPI) for each dissemination and engagement activity will be defined and reported ensuring the traceability of the WP activities that are not listed under a particular Deliverable or Milestone. This plan will be a living document revised twice during the project, described in deliverables D4.7 (M18), D4.8 (M36) and D4.9 (M45), in order to be included in the periodic reports.

T4.4.4: Communication and PR materials (M1-M48) UNEXE, BSC
We will produce roll-ups, a poster and a project brochure in physical formats to give visibility to the project following the visual identity defined in T4.4.1. The project will focus on the use of online material (T4.3) and try to minimize the use of papers.

Participation per Partner

Partner number and short name	WP4 effort
1 - UNEXE	10.60
2 - UEA	16.00
4 - MPG	3.00
5 - ETHZ	2.00
6 - BSC	53.25
7 - DLR	2.00

Partner number and short name	WP4 effort
8 - UBREMEN	2.00
9 - UBERN	1.00
10 - CICERO	26.00
11 - UOXF	4.00
Total	119.85

List of deliverables

Deliverable Number[14]	Deliverable Title	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
D4.1	ScienceBrief Carbon Cycle updated with IPCC AR6 results and 4C publications, with platform update informed by evaluation (T4.1.2)	2 - UEA	Websites, patents filling, etc.	Public	42
D4.2	Summary report on engagement with policymakers (T4.2)	10 - CICERO	Report	Public	45
D4.3	Animated infographic about the carbon cycle (T4.3.3)	6 - BSC	Websites, patents filling, etc.	Public	16
D4.4	Web based explorable explanation (T4.3.4)	6 - BSC	Websites, patents filling, etc.	Public	40
D4.5	Visual identity and project website available (T4.4.1)	6 - BSC	Websites, patents filling, etc.	Public	6
D4.6	Communication, Dissemination and Engagement Plan (T4.4.3)	6 - BSC	Report	Public	9
D4.7	First Update of Communication, Dissemination and Engagement Plan (T4.4.3)	6 - BSC	Report	Public	18
D4.8	Second Update of Communication, Dissemination and Engagement Plan (T4.4.3)	6 - BSC	Report	Public	36
D4.9	Summary report on the communication, dissemination and	6 - BSC	Report	Public	45

List of deliverables

Deliverable Number[14]	Deliverable Title	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
	engagement activities (T4.4)				

Description of deliverables

D4.1 ScienceBrief Carbon Cycle updated with IPCC AR6 results and 4C publications, with platform update informed by evaluation (T4.1.2) (UEA, DEC, PU, M42)
D4.2 Summary report on engagement with policymakers (T4.2) (BSC, R, PU, M45)
D4.3 Animated infographic about the carbon cycle (T4.3.3) (BSC, DEC, PU, M16)
D4.4 Web based explorable explanation (T4.3.4) (BSC, DEC, PU, M40)
D4.5 Visual identity and project website available (T4.4.1) (UNEXE, DEC, PU, M6)
D4.6 Communication, Dissemination and Engagement Plan (T4.4.3) (BSC, R, PU, M9)
D4.7 First update of Communication Dissemination and Engagement Plan (T4.4.3) (BSC, R, PU, M18)
D4.8 Second update of Communication Dissemination and Engagement Plan (T4.4.3) (BSC, R, PU, M36)
D4.9 Summary report on the communication, dissemination and engagement activities (T4.4) (BSC, R, PU, M45)

D4.1 : ScienceBrief Carbon Cycle updated with IPCC AR6 results and 4C publications, with platform update informed by evaluation (T4.1.2) [42]

ScienceBrief Carbon Cycle updated with IPCC AR6 results and 4C publications, with platform update informed by evaluation

D4.2 : Summary report on engagement with policymakers (T4.2) [45]

Summary report on engagement with policymakers

D4.3 : Animated infographic about the carbon cycle (T4.3.3) [16]

Animated infographic about the carbon cycle

D4.4 : Web based explorable explanation (T4.3.4) [40]

Web based explorable explanation

D4.5 : Visual identity and project website available (T4.4.1) [6]

Visual identity and project website available

D4.6 : Communication, Dissemination and Engagement Plan (T4.4.3) [9]

Communication, Dissemination and Engagement Plan

D4.7 : First Update of Communication, Dissemination and Engagement Plan (T4.4.3) [18]

First Update of Communication, Dissemination and Engagement Plan

D4.8 : Second Update of Communication, Dissemination and Engagement Plan (T4.4.3) [36]

Second Update of Communication, Dissemination and Engagement Plan

D4.9 : Summary report on the communication, dissemination and engagement activities (T4.4) [45]

Summary report on the communication, dissemination and engagement activities

Schedule of relevant Milestones

Milestone number[18]	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification
MS9	Workshop on IPCC AR6 key issues on climate-carbon interactions (T4.1.1)	1 - UNEXE	3	Minutes available

Schedule of relevant Milestones

Milestone number[18]	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification
MS10	Evaluation of ScienceBrief Carbon pilot, recommendations for further developments (T4.1.2)	2 - UEA	24	Evaluation results available
MS11	Workshop in Brussels (T4.2.4)	10 - CICERO	40	Minutes available

Work package number [9]	WP5	Lead beneficiary [10]	1 - UNEXE
Work package title	Project Management		
Start month	1	End month	48

Objectives

The management of 4C will be provided by the Management Support Team (project coordinator and project manager), supported by the UNEXE EU research team for the legal and financial aspects of the project.
The objectives of this work package are to:
• provide appropriate management of project partners to ensure that the project objectives are achieved on time and at the requested high quality;
• organise the projects meetings such as the Kick-off Meeting, the annual General Assemblies, and the project governance and advisory meetings;
• provide the requested scientific, administrative, financial and contractual coordination at project level, including all contractual reporting to the European Commission;
• ensure effective relation and communication with the European Commission;
• provide efficient communication between all project partners and with the project External Advisory Board (EAB);
• represent the project towards external parties when needed or when suggested by the European Commission;
• ensure active and beneficial collaboration with relevant other EU projects and international bodies such as IPCC, UNFCCC, WMO, etc.
The Management Support Team will also devote a significant fraction of their project-funded time to external project dissemination. Person months allocated to this task, as well as the work involved, are detailed in WP4, to ensure regular interaction with the Synthesis, dissemination and policy dialogue WP.

Description of work and role of partners

WP5 - Project Management [Months: 1-48]
UNEXE, UEA, ENS, MPG, ETHZ, BSC, DLR, UBREMEN, UBERN, CICERO, UOXF, CEA
Work package lead Pierre Friedlingstein (UNEXE)
WP5 will provide the management of the whole project, including reporting to the EC.
Task 5.1 Management (M1-M48) UNEXE (Lead), and all project partners

This task aims to ensure smooth running of the project, supervising progress and completion of each partner's tasks, in order to achieve the project objectives on time and to cost in the most efficient way. The Management Support Team (MST) will carry out the day-to-day management of the project, in liaison with the General Assembly (GA), the Executive Board (EB) and the External Advisory Board (EAB) (see section 3.2 for a detailed description of these boards). The MST will directly communicate with the European Commission (EC). Management involves the following main tasks:
• Establishing mechanisms for effective communication, time and resources management and scientific production within and across the project work packages. This will include development of project templates for WP reporting, maintenance of detailed WP-level Gantt charts, maintenance of online record of decisions and list of actions lists following virtual and face-to-face meetings.
• Scheduling, organising, chairing and taking actions from the Kick-off Meeting, providing minutes and sharing these with the EC EASME Project Officer.
• Scheduling, organising, chairing and taking actions from GA meetings (annual), in order to report on progress from past year, coordinate science and dissemination objectives for the coming year, and address any outstanding issues not resolved at the EB level.
• Scheduling, organising, chairing and recording actions from EB meetings (4 monthly) in order to support WP leaders and partners to achieve planned objectives, and address potential scientific issues.
• Scheduling, organising, chairing and taking actions from annual meeting with the EAB, in order to benefit from their advice on project science and dissemination. We will provide feedback from the EAB at the EB meetings and also to the EC and external reviewers, via minutes of meetings, as part of the 4-monthly progress teleconferences with the EC officer and/or in the periodic reporting.
• Collaborating with WP4 for the development and content provision of the public-facing project website, project identities and external visibility activities, also liaising from the UNEXE Press Office team. The project website will

present in a clear and concise way the overall and detailed objectives, including the multiple detailed (and quantified) ambitions as stated in section 1.4 of the proposal;
• Facilitating the development of collaborations and interactions outside of the project (with EU projects funded under the same call, other EU funded projects, as well as with international programmes).
• Review of project dissemination materials and scientific publications to ensure quality and adherence to EC guidelines
• Ensuring all reports, milestones, and deliverables are prepared and delivered on time and are of high quality.
• Managing and mitigating any risks that arise in the course of the project.
• Ensuring the project stays within budget and comply with all the audits and contractual obligations.

Task 5.2 Reporting and interfacing with the European Commission (M1-M48) UNEXE (lead)
The Coordinator will be ultimately responsible for the timely submission of periodic reporting on the scientific and financial progress of the project, as well as for direct interfacing with the European Commission (EC). This includes responsibility for submissions of the project Milestones and Deliverables as listed in Tables 3.1c and 3.2a respectively. The Coordinator will also be the main contact point for the EC for the project and related activities. This task will ensure appropriate follow-up of specific obligations deriving from the EC contract, in terms of reporting (finance and science), communication and general management procedures. It will inform the EC of project achievements and any deviations from the agreed plans. In case of major difficulties, it will instigate a dialogue with the EC in order to find an appropriate solution.
4-monthly tele-conferences including the project coordinator and the EC EASME PO, will be scheduled shortly after each EB meeting in order to discuss the progress and main planned events. Minutes of the EB meeting will be shared with the PO before these tele-conferences. Feedback from the EAB will also be shared with EC & reviewers, either in the minutes of meetings and/or via the period reports.
The clear management structure described in section 3.2 will ensure efficient communication between all project partners, with the advisory board, and with the EC.

Participation per Partner

Partner number and short name	**WP5 effort**
1 - UNEXE	32.00
2 - UEA	1.00
3 - ENS	1.00
4 - MPG	1.00
5 - ETHZ	1.00
6 - BSC	1.00
7 - DLR	1.00
8 - UBREMEN	1.00
9 - UBERN	1.00
10 - CICERO	1.00
11 - UOXF	1.00
12 - CEA	1.00
Total	43.00

List of deliverables

Deliverable Number[14]	Deliverable Title	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
D5.1	Project risk and quality assurance management plan (T5.1)	1 - UNEXE	Report	Public	4
D5.2	Data Management Plan (T5.1)	1 - UNEXE	ORDP: Open Research Data Pilot	Public	6
D5.3	First update on Data Management Plan (T5.1)	1 - UNEXE	ORDP: Open Research Data Pilot	Public	18
D5.4	Second update on Data Management Plan (T5.1)	1 - UNEXE	ORDP: Open Research Data Pilot	Public	36

Description of deliverables

D5.1 Project risk and quality assurance management plan (T5.1) (UNEXE, R, PU, M4)
D5.2 Data Management Plan (T5.1) (UNEXE, ORDP, PU, M6)
D5.3 First update of Data Management Plan (T5.1) (UNEXE, ORDP, PU, M18)
D5.4 Second update of Data Management Plan (T5.1) (UNEXE, ORDP, PU, M36)

D5.1 : Project risk and quality assurance management plan (T5.1) [4]

Project risk and quality assurance management plan

D5.2 : Data Management Plan (T5.1) [6]

Data Management Plan

D5.3 : First update on Data Management Plan (T5.1) [18]

First update on Data Management Plan

D5.4 : Second update on Data Management Plan (T5.1) [36]

Second update on Data Management Plan

Schedule of relevant Milestones

Milestone number[18]	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification
MS12	Kick off meeting (T5.1)	1 - UNEXE	3	Minutes available
MS13	Project monitoring completed (T5.2)	1 - UNEXE	18	Report available

Work package number [9]	WP6	Lead beneficiary [10]	1 - UNEXE
Work package title	Ethics requirements		
Start month	1	**End month**	48

Objectives

The objective is to ensure compliance with the 'ethics requirements' set out in this work package.

Description of work and role of partners

WP6 - Ethics requirements [Months: 1-48]
UNEXE
This work package sets out the 'ethics requirements' that the project must comply with.

List of deliverables

Deliverable Number[14]	Deliverable Title	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
D6.1	H - Requirement No. 1	1 - UNEXE	Ethics	Confidential, only for members of the consortium (including the Commission Services)	1
D6.2	POPD - H - Requirement No. 2	1 - UNEXE	Ethics	Confidential, only for members of the consortium (including the Commission Services)	3
D6.3	POPD - Requirement No. 3	1 - UNEXE	Ethics	Confidential, only for members of the consortium (including the Commission Services)	6

Description of deliverables

The 'ethics requirements' that the project must comply with are included as deliverables in this work package.

D6.1 : H - Requirement No. 1 [1]

- The procedures and criteria that will be used to identify/recruit research participants must be submitted.

D6.2 : POPD - H - Requirement No. 2 [3]

- The informed consent procedures that will be implemented for the participation of humans and in regard to the processing of personal data must be submitted as a deliverable. - Templates of the informed consent/assent forms and information sheets (in language and terms intelligible to the participants) must be kept on file.

D6.3 : POPD - Requirement No. 3 [6]

- A description of the security measures that will be implemented to prevent unauthorised access to personal data or the equipment used for processing must be submitted as a deliverable.

Schedule of relevant Milestones

Milestone number[18]	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification

1.3.4. WT4 List of milestones

Milestone number[18]	Milestone title	WP number[9]	Lead beneficiary	Due Date (in months)[17]	Means of verification
MS1	First set of offline historical simulations of the land and ocean carbon cycle (T1.3.1 and T1.3.2)	WP1	5 - ETHZ	16	Simulations available
MS2	First set of online historical simulations of the global carbon cycle (T.1.3.3)	WP1	3 - ENS	21	Simulations available
MS3	Enhanced ESMValTool version with new 4C observation diagnostics (T1.4.3)	WP1	8 - UBREMEN	24	Software available
MS4	Completion of simulations in perfect model framework (T2.1.1)	WP2	6 - BSC	18	Data available
MS5	Completion of retrospective predictions including computation of bias correction (T2.3.1 and T2.3.2)	WP2	4 - MPG	28	Simulations available
MS6	New set of emergent constraints implemented i?n the ESMValTool GitHub repository (T3.1.1 and T.3.1.2)	WP3	7 - DLR	24	Software available
MS7	Weighting methods for CO2 projections available (T3.3)	WP3	7 - DLR	30	Software available
MS8	Temperature trajectories for adaptive scenarios with reduced complexity models (T.3.4.1)	WP3	9 - UBERN	30	Simulations available
MS9	Workshop on IPCC AR6 key issues on climate-carbon interactions (T4.1.1)	WP4	1 - UNEXE	3	Minutes available
MS10	Evaluation of ScienceBrief Carbon pilot, recommendations for further developments (T4.1.2)	WP4	2 - UEA	24	Evaluation results available

Milestone number[18]	Milestone title	WP number[9]	Lead beneficiary	Due Date (in months)[17]	Means of verification
MS11	Workshop in Brussels (T4.2.4)	WP4	10 - CICERO	40	Minutes available
MS12	Kick off meeting (T5.1)	WP5	1 - UNEXE	3	Minutes available
MS13	Project monitoring completed (T5.2)	WP5	1 - UNEXE	18	Report available
MS14	First set of future decadal predictions for NDC and baseline scenario (T2.4)	WP2	3 - ENS	22	First set of future decadal predictions for NDC and baseline scenario

1.3.5. WT5 Critical Implementation risks and mitigation actions

Risk number	Description of risk	WP Number	Proposed risk-mitigation measures
1	Delay in recruitment (Low)	WP1, WP2, WP3, WP4, WP5	All partners have extensive experience in running national and EU projects, and hence have a very strong track record of staff recruitment. Open positions will be advertised widely via jobs mailing lists (e.g. climlist, metjobs), via our own network, and posted on partners and project website. In addition we will share the pool of applicants across all partners.
2	WP leader unavailable (sickness, travel, changed position / circumstances) (Low)	WP1, WP2, WP3, WP4, WP5	Each WP has a leader and deputy leader to reduce this risk.
3	Difficulties in reducing the BIM. The risk of achieving no reduction in the BIM is Low, while the risk of achieving reductions of less than 50% (the aspiration of WP1) is Medium	WP1	Hypotheses have already been formulated in the proposal on processes that need improvements that could be responsible for the BIM (e.g. land variability associated with water availability and fires, ocean variability associated with small-scale physical transport, external and internally-forced variability). These hypotheses will evolve with the annual updates and related improvements in models. Risks are also reduced by the introduction of O2, APO, and 13C budget, which will provide independent constraints on the land and ocean partitioning of the BIM and the underlying processes. Finally, the detailed evaluation of the models in T1.4 based on existing and new observations will provide key information to select models based on their performance, which should lead to reductions in the BIM.
4	Not delivering predictions for 2020-2030 (Medium)	WP2	Skillful predictions for the next decade depend on the timely design and delivery of prediction systems and establishing predictive skills including bias correction (M2.2). If a delay in reaching this milestone is foreseen, additional resources will be devoted to T2.2 and T2.3. This will include adjustment of initialization parameters in prediction systems, as well as evaluation of various bias correction methodologies in terms of their suitability for land and ocean carbon cycle predictions.
5	Difficulties in reducing the uncertainty on TCRE. The risk of achieving no reduction in the TCRE uncertainty is Low, while the risk of achieving reductions of less than 50% (the aspiration of WP3) is Medium	WP3	We will use ESMs with much improved processes in comparison to AR5/CMIP5, such as nitrogen limitation, permafrost and wildfires in the land components, and variably stoichiometry and high-resolution physics in the ocean components. We will make use of new observations to constrain these new processes and the land and ocean carbon fluxes over the historical period and will in parallel develop new emergent constraints to reduce the uncertainty on climate-carbon feedbacks in the future. Finally, the use of models

Risk number	Description of risk	WP Number	Proposed risk-mitigation measures
			performances to weight projections should also contribute to a reduction of TCRE uncertainty.
6	Delays in supporting the IPCC AR6 because literature cut-off dates too close to the beginning of 4C project (Medium)	WP1, WP2, WP3, WP4	A workshop for fast-track support to IPCC AR6 is scheduled at Month 3 (M4.1). It will bring together IPCC lead authors and 4C researchers to highlight priorities and key challenges, aligning efforts accordingly. Moreover, the extensive experience and involvement of 4C partners in IPCC assessments process will ensure smooth advancements. If selected for funding, the project needs to start as early as possible to reduce this risk. With delays, the proposed workshop can be held in Month 1 with some additional funding costs.
7	Difficulties to engage stakeholders (Low)	WP4	Dissemination and communication strategies have been carefully planned. Additionally, 4C benefits on the one hand of partners with solid reputation among scientific stakeholders (covering high-responsibility roles in various panels, projects etc.), and on the other hand of partners with science communication experience to involve society (from policymakers to citizens). Many project participants (and their institutions) have extensive networks, and this risk has been minimised by the selection of relevant project partners.

1.3.6. WT6 Summary of project effort in person-months

	WP1	WP2	WP3	WP4	WP5	WP6	Total Person/Months per Participant
1 - UNEXE	45	4	41.40	10.60	32	✓	133
2 - UEA	43.40	0	0	16	1		60.40
3 - ENS	3	13	23	0	1		40
· CNRS	7	10	0	0	0		17
4 - MPG	46	42	18	3	1		110
5 - ETHZ	35	0	14	2	1		52
6 - BSC	9.50	66	9	53.25	1		138.75
7 - DLR	12	0	37	2	1		52
8 - UBREMEN	20	0	19	2	1		42
9 - UBERN	25	0	38	1	1		65
10 - CICERO	3	0	9	26	1		39
11 - UOXF	0	4	30	4	1		39
12 - CEA	26.20	16	12	0	1		55.20
Total Person/Months	275.10	155	250.40	119.85	43		843.35

1.3.7. WT7 Tentative schedule of project reviews

Review number [19]	Tentative timing	Planned venue of review	Comments, if any
RV1	20	to be defined	
RV2	38	to be defined	
RV3	48	to be confirmed	

1. Project number

The project number has been assigned by the Commission as the unique identifier for your project. It cannot be changed. The project number **should appear on each page of the grant agreement preparation documents (part A and part B)** to prevent errors during its handling.

2. Project acronym

Use the project acronym as given in the submitted proposal. It can generally not be changed. The same acronym **should appear on each page of the grant agreement preparation documents (part A and part B)** to prevent errors during its handling.

3. Project title

Use the title (preferably no longer than 200 characters) as indicated in the submitted proposal. Minor corrections are possible if agreed during the preparation of the grant agreement.

4. Starting date

Unless a specific (fixed) starting date is duly justified and agreed upon during the preparation of the Grant Agreement, the project will start on the first day of the month following the entry into force of the Grant Agreement (NB : entry into force = signature by the Commission). Please note that if a fixed starting date is used, you will be required to provide a written justification.

5. Duration

Insert the duration of the project in full months.

6. Call (part) identifier

The Call (part) identifier is the reference number given in the call or part of the call you were addressing, as indicated in the publication of the call in the Official Journal of the European Union. You have to use the identifier given by the Commission in the letter inviting to prepare the grant agreement.

7. Abstract

8. Project Entry Month

The month at which the participant joined the consortium, month 1 marking the start date of the project, and all other start dates being relative to this start date.

9. Work Package number

Work package number: WP1, WP2, WP3, ..., WPn

10. Lead beneficiary

This must be one of the beneficiaries in the grant (not a third party) - Number of the beneficiary leading the work in this work package

11. Person-months per work package

The total number of person-months allocated to each work package.

12. Start month

Relative start date for the work in the specific work packages, month 1 marking the start date of the project, and all other start dates being relative to this start date.

13. End month

Relative end date, month 1 marking the start date of the project, and all end dates being relative to this start date.

14. Deliverable number

Deliverable numbers: D1 - Dn

15. Type

Please indicate the type of the deliverable using one of the following codes:

R	Document, report
DEM	Demonstrator, pilot, prototype
DEC	Websites, patent fillings, videos, etc.
OTHER	
ETHICS	Ethics requirement
ORDP	Open Research Data Pilot
DATA	data sets, microdata, etc.

16. Dissemination level

Please indicate the dissemination level using one of the following codes:

PU	Public
CO	Confidential, only for members of the consortium (including the Commission Services)
EU-RES	Classified Information: RESTREINT UE (Commission Decision 2005/444/EC)
EU-CON	Classified Information: CONFIDENTIEL UE (Commission Decision 2005/444/EC)
EU-SEC	Classified Information: SECRET UE (Commission Decision 2005/444/EC)

17. Delivery date for Deliverable

Month in which the deliverables will be available, month 1 marking the start date of the project, and all delivery dates being relative to this start date.

18. Milestone number

Milestone number:MS1, MS2, ..., MSn

19. Review number

Review number: RV1, RV2, ..., RVn

20. Installation Number

Number progressively the installations of a same infrastructure. An installation is a part of an infrastructure that could be used independently from the rest.

21. Installation country

Code of the country where the installation is located or IO if the access provider (the beneficiary or linked third party) is an international organization, an ERIC or a similar legal entity.

22. Type of access

VA	if virtual access,
TA-uc	if trans-national access with access costs declared on the basis of unit cost,
TA-ac	if trans-national access with access costs declared as actual costs, and
TA-cb	if trans-national access with access costs declared as a combination of actual costs and costs on the basis of unit cost.

23. Access costs

Cost of the access provided under the project. For virtual access fill only the second column. For trans-national access fill one of the two columns or both according to the way access costs are declared. Trans-national access costs on the basis of unit cost will result from the unit cost by the quantity of access to be provided.