SPECIAL PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

Reporting year	2023
Project Title:	OpenIFS Modeling of the Atmospheric Carbon Cycle
Computer Project Account:	spnlpete
Principal Investigator(s):	Etienne Tourigny
Affiliation:	Barcelona Supercomputing Center
Name of ECMWF scientist(s) collaborating to the project (if applicable)	Marcus Koehler, Anna Agusti-Panareda, Gianpaolo Balsamo
Start date of the project:	01/01/2023
Expected end date:	12/31/2024

Computer resources allocated/used for the current year and the previous one

(if applicable)

Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	N/A	N/A	21M	187,962
Data storage capacity	(Gbytes)	N/A	N/A	?	?

Summary of project objectives

The main objective of this Special Project is to build the foundations of a strong community focused on GHG modelling with OpenIFS (within the EC-Earth4 framework) including land-atmosphere feedbacks in the terrestrial biosphere, land-use change (LUC) scenarios that include short-(aerosol) and long-term (CO2) climate impacts, and coupled carbon-water exchange for climate modelling, multi-tracer simulations, fast chemistry-schemes, ensemble predictions, and data assimilation (outside the scope of ECMWF's NWP setting). 3 sub-projects have been designed in order to achieve these goals: (1) CO2 transport in coupled climate model with OpenIFS (BSC) ; (2) CO2 transport in long-window data assimilation with OpenIFS (WUR) ; (3) Decadal multi-flux evaluations for CO2 with OpenIFS (MPI). We have set up a CONFLUENCE space for the OpenIFS/CC project to track developments and document our meetings, which is available at https://confluence.ecmwf.int/pages/viewpage.action?pageId=226496552.

Summary of problems encountered

Our project has suffered somewhat from delays in the first release of EC-Earth 4. Also, since this is an unfunded project the availability of key persons has limited progress.

Summary of plans for the continuation of the project

The Co2 Flux Data Coupler using the Data Coupler interface (see section on results) will be improved to add support for a number surface CO2 fluxes (vegetation, land, fire, ocean and emissions). We will implement a standalone tool to generate initial CO2 model level data for OpenIFS from the mole fraction time series of the CarbonTracker-Europe (CTE) dataset, based on an existing method for interpolating ERA5 nudging reference files. In parallel, we will modify the OpenIFS source code to update the CO2 flux tendencies by values received from the CO2 Flux Data Coupler. Finally during late fall we will conduct a number of 10-year simulations nudged to ERA5 using the different CO2 fluxes supported by the CO2 Flux Data Coupler.

List of publications/reports from the project with complete references

CONFLUENCE documentation:
https://confluence.ecmwf.int/pages/viewpage.action?pageId=333793125
https://confluence.ecmwf.int/pages/viewpage.action?pageId=283545358
https://confluence.ecmwf.int/pages/viewpage.action?pageId=338480445

Git repositories:
https://github.com/AWI-ESM/inp-scripts/tree/ecmwf-hpc2020
https://git.smhi.se/etienne.tourigny/ecearth4/-/tree/dev/co2
https://earth.bsc.es/gitlab/es/python-amip-reader/-/tree/data-coupler/sources/data-coupler

Summary of results

The snplpete has made progress on a number of fronts. New members have joined the group : Christopher Danek and Judith Hauck from AWI and Vitus Benson from MPI-Jena. Also the MPI-BGC from Jena has officially joined the EC-Earth consortium, therefore all members of the project are able to use the EC-Earth-4 model. Etienne Tourigny and Iria Ayan participated in the

“6th OpenIFS User Meeting” hosted by the BSC and ongoing work has been presented byt Etienne Tourigny.

Second, a method has been devised to easily and rapidly obtain nudging (Newtonian Relaxation) reference files from ECMWF ERA5 reanalysis at any supported OpenIFS resolution (e.g. Tco95L91) on the ECMWF HPC2020 system. This has been made possible by a collaboration between AWI and BSC and is available in AWI’s repository at https://github.com/AWI-ESM/inp-scripts/tree/ecmwf-hpc2020 and a copy is stored on the ECMWF HPC2020 system : /perm/c3et/nudging/inp-scripts . The method is separated in 2 scripts running on the HPC2020 ECS complex, one which downloads a month of ERA5 reanalysis data (key variables at 6hr frequency) and the second script which does horizontal and vertical interpolation using cdo. Reference files for 2014 and 2015 at Tco95L91 resolution are stored at /ec/res4/hpcperm/c3et/nudging/data/era5_/TCO95L91. Details on using the method have been shared with Marcus Koehler of OpenIFS so it may be used in the OpenIFS Data Hub for all OpenIFS users.

Third, the EC-Earth4 model is now running smoothly on the ECMWF HPC2020 system in AMIP and GCM modes, with support for CO2 tracer, mass fixer and CO2 output from XIOS in netcdf format and spectral nudging (Newtonian relaxation) - a foundation of the so-called EC-Earth4-CC-lite version of EC-Earth (see Figure 1). Code for running the model in this configuration is available at https://git.smhi.se/etienne.tourigny/ecearth4/-/tree/dev/co2. Example output of 2-year runs can be found on the HPC2020 system at /hpcperm/c3et/run. The following experiments are available: TE01: with co2 tracer and nudging ; TE02: with co2 tracer, no nudging ; TE03: no co2 tracer, no nudging. Documentation on running the model is available in the CONFLUENCE page https://confluence.ecmwf.int/pages/viewpage.action?pageId=333793125.

Fourth, some progress has been made on the development of the CO2 Flux Data Coupler to be used in the EC-Earth4-CC-lite configuration. The current implementation is able to read CEDS emissions from input4MIPS and store them in a “CO2 box model” (Figure 2) and/or send the emissions to a IFS toy model (Figure 3). Code is available at https://earth.bsc.es/gitlab/es/python-amip-reader/-/tree/data-coupler/sources/data-coupler.

Initial support for land and ocean fluxes has been added, but are not reading actual datasets at this time. Work has commenced on reading land vegetation fluxes (SiB4v2_BioFluxes), GFAS fire fluxes, GridFED emissions (GCP-GridFEDv2022) and CarboScope ocean flux. Example files are available on the ECMWF HPC2020 system at /hpcperm/rujh/data/2014.

Finally, the project members met virtually during a workshop organised by the BSC on June 26th. During this workshop, the Special Project members learned to run the EC-Earth4 model with CO2 tracer with mass fixer and nudging. They were also introduced to the Data Coupler and its use to implement the CO2 Flux Data Coupler. First steps have been taken to add support from other surface fluxes (SiB4v2_BioFluxes, GFAS fire fluxes, GridFED emissions and CarboScope ocean fluxes).

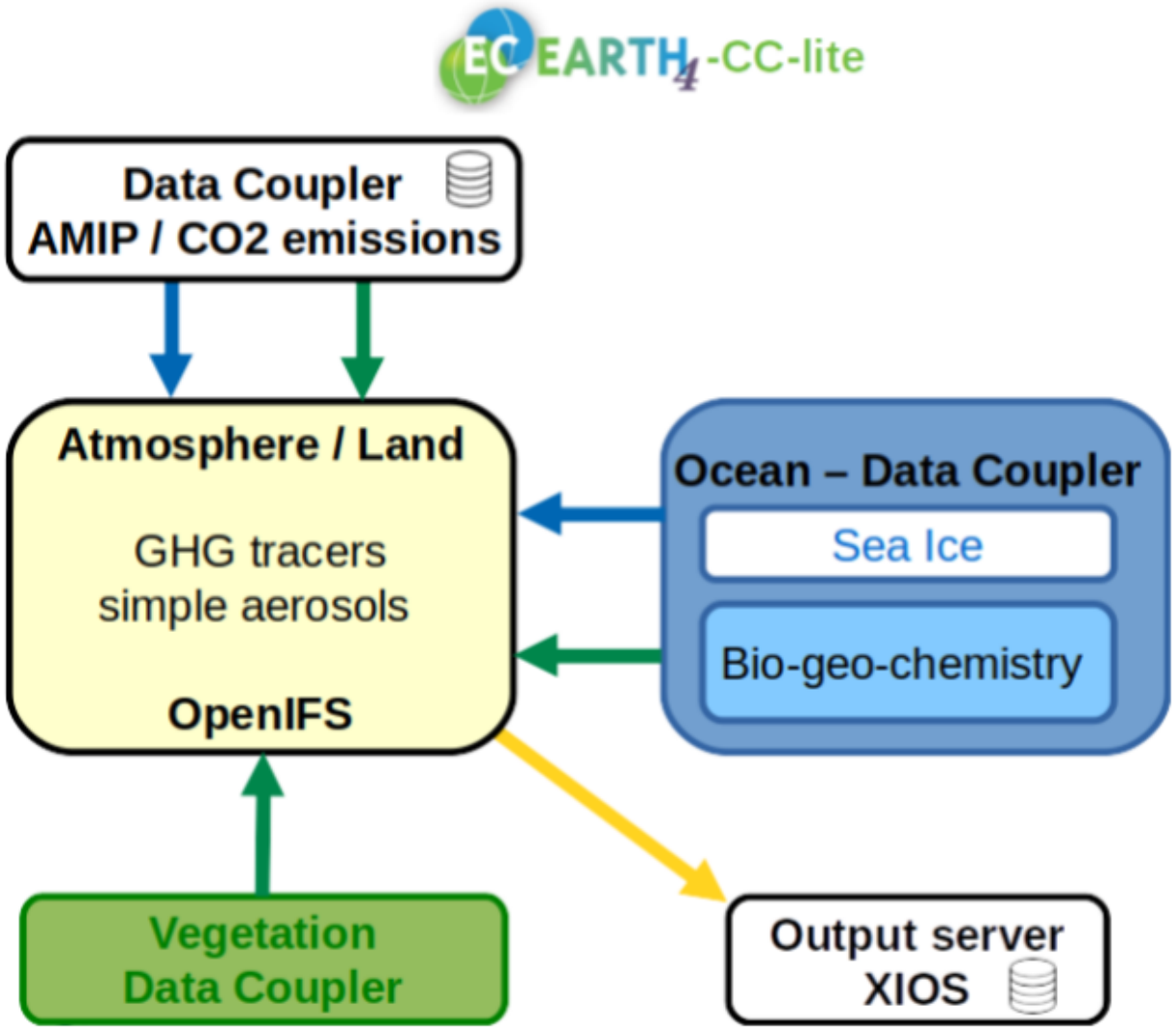

Figure 1: Schematic of the EC-Earth4-CC-lite configuration of EC-Earth4

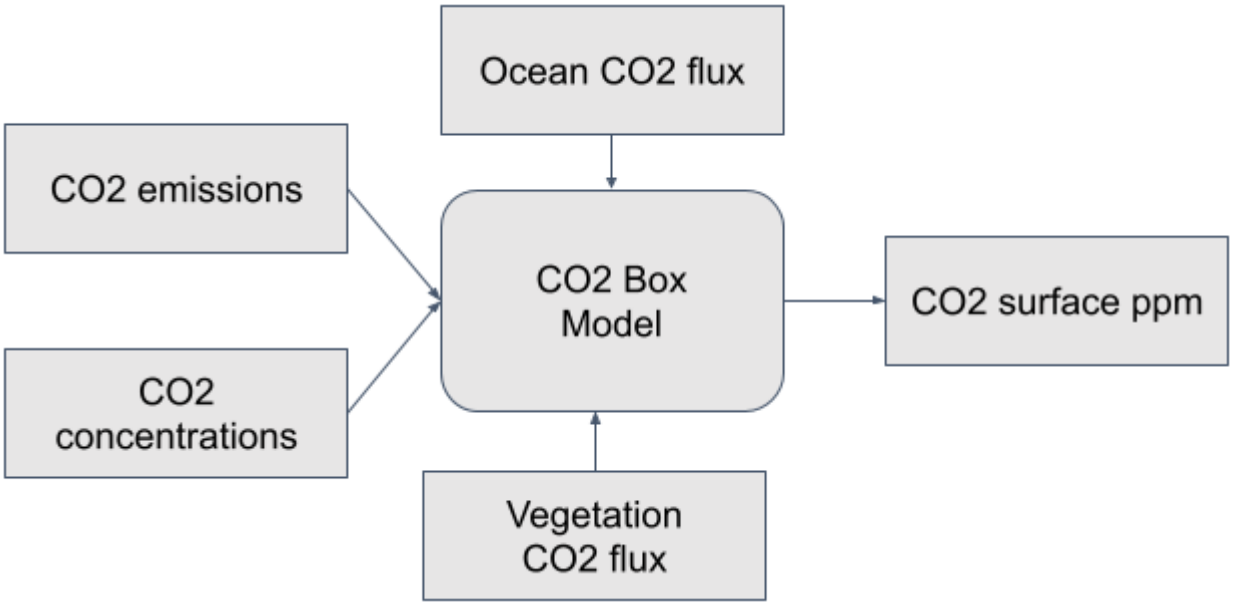

Figure 2 : Schematic of the CO2 Box Model.

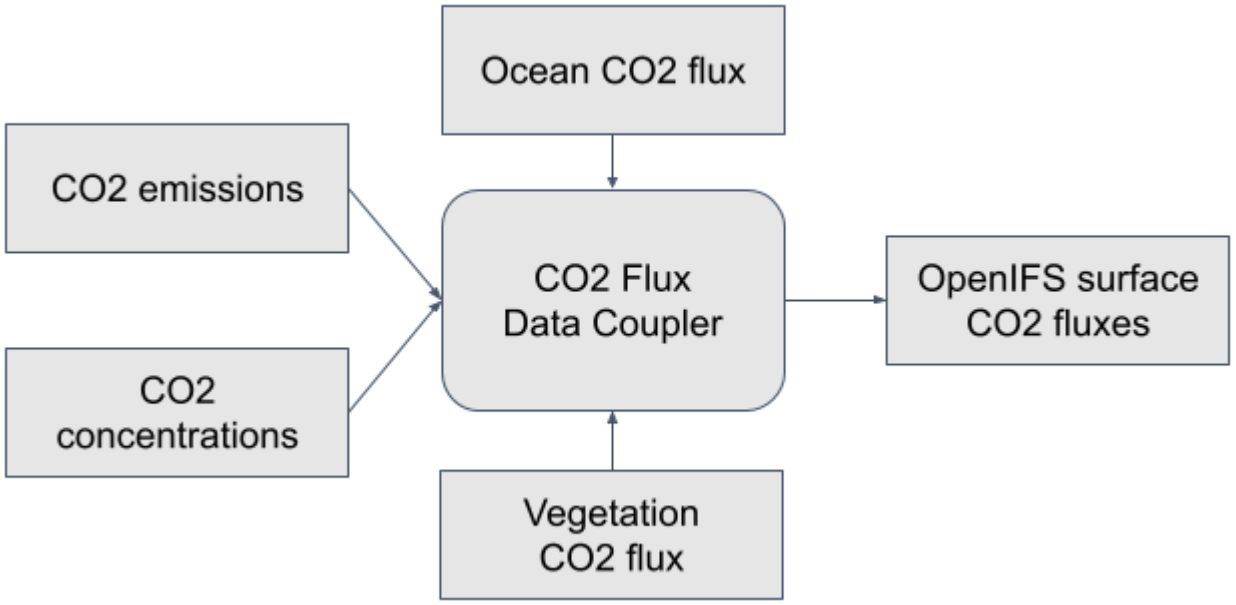

Figure 3: Schematic of the CO2 Flux Coupler.