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	2024
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)	21M	15,8 M	29M	5,1 M
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 (CO_2) 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) CO_2 transport in coupled climate model with OpenIFS (BSC) ; (2) CO_2 transport in long-window data assimilation with OpenIFS (WUR) ; (3) Decadal multi-flux evaluations for CO_2 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 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

During the second half of 2024 we will perform a more rigorous evaluation of our results with our partners from WUR, UU and MPI-BGC. We will add support for additional CO_2 fluxes in the CO_2 Flux Data Coupler, such as GFED v5 fire emissions. We will conduct additional simulations nudged to ERA5 using other flux datasets, such as GFED v5.

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/iria.ayan/ecearth4/-/tree/develop_co2
https://git.smhi.se/ec-earth/ec-earth-data-coupler/
https://github.com/JJDHooghiem/vremap

Presentations:
Iria Ayan, Implementing Carbon cycle in EC-Earth4 / OpenIFS 43r3 framework, 7th OpenIFS User Meeting, 15th May 2024.
https://confluence.ecmwf.int/download/attachments/226496552/EC-Earth4-CC.pptx.pdf?version=1&modificationDate=1720955845932&api=v2

Summary of results

The CO2 Flux Data Coupler using the Data Coupler interface (see section on results) has been improved to add support for a number of surface CO2 fluxes (vegetation, land, fire, ocean and emissions). It can be obtained from https://git.smhi.se/ec-earth/ec-earth-data-coupler/.
Currently the following datasets are supported, thanks to the contribution of Joram Hoogheim from WUR:

- CEDS CO2 emissions (monthly)
- GridFED gridded emissions from the Global Carbon Project (monthly)
- SiB4v2 vegetation fluxes (daily)
- GFAS surface CO2 fluxes from fires (daily)
- CarboScope ocean flux (monthly and daily)

Joram Hoogheim implemented a standalone tool vremap (Vertical remapping tool for atmospheric trace gases 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. We thus are able to initialize OpenIFS with realistic mole fractions of CO2 at 7-daily intervals from 2000 to 2020. The tool can be obtained from https://github.com/JJDHooghiem/vremap.

We have modified the OpenIFS source code to update the CO2 flux tendencies by values received from the CO2 Flux Data Coupler. We discovered an inconsistency in the sign convention of the different CO2 flux input in OpenIFS: the fire flux (co2fire) is defined as positive into the atmosphere, while for the other fluxes (vegetation/co2nbf, ocean/co2of and anthropogenic/co2apf) are defined as negative into atmosphere. We also found a missing namelist parameter (LTRCMFIX_PS=true) in our configuration to ensure CO2 tracer mass conservation. The updated code can be found at https://git.smhi.se/iria.ayan/ecearth4/-/tree/develop_co2.

Finally we performed a long AMIP-style (atmosphere only at TL159 resolution, forced by AMIP dataset) simulation from 2014 to 2022, initialized from the CarbonTracker-Europe (CTE) dataset, nudged to ERA5 using the different CO2 fluxes supported by the CO2 Flux Data Coupler outlines above. Figure 1 shows the surface (1000 hPa) global average monthly CO2 concentration over ocean points, compared to the NOAA Global Monthly Mean CO2 (obtained from https://gml.noaa.gov/ccgg/trends/global.html), and the bias of our simulation compared to observations. We seea small bias of less than 1ppm in the first month, and higher biases in Boreal summer (with peak value of 2.5ppm in July) and the absence of trend in the biases. We hypothesise that the mean bias comes from initialization and that the peaks in July could be attributed to errors in the vegetation and/or fire fluxes. In Figure 3 we plot results but focusing on the results at the spatial location of the Mona Loa observatory, with slightly higher biases and more variability. We will investigate improving the initial state and using alternate vegetation and fire fluxes, particularly using GFED fire fluxes which are more realistic than GFAS which are not constrained by observations.

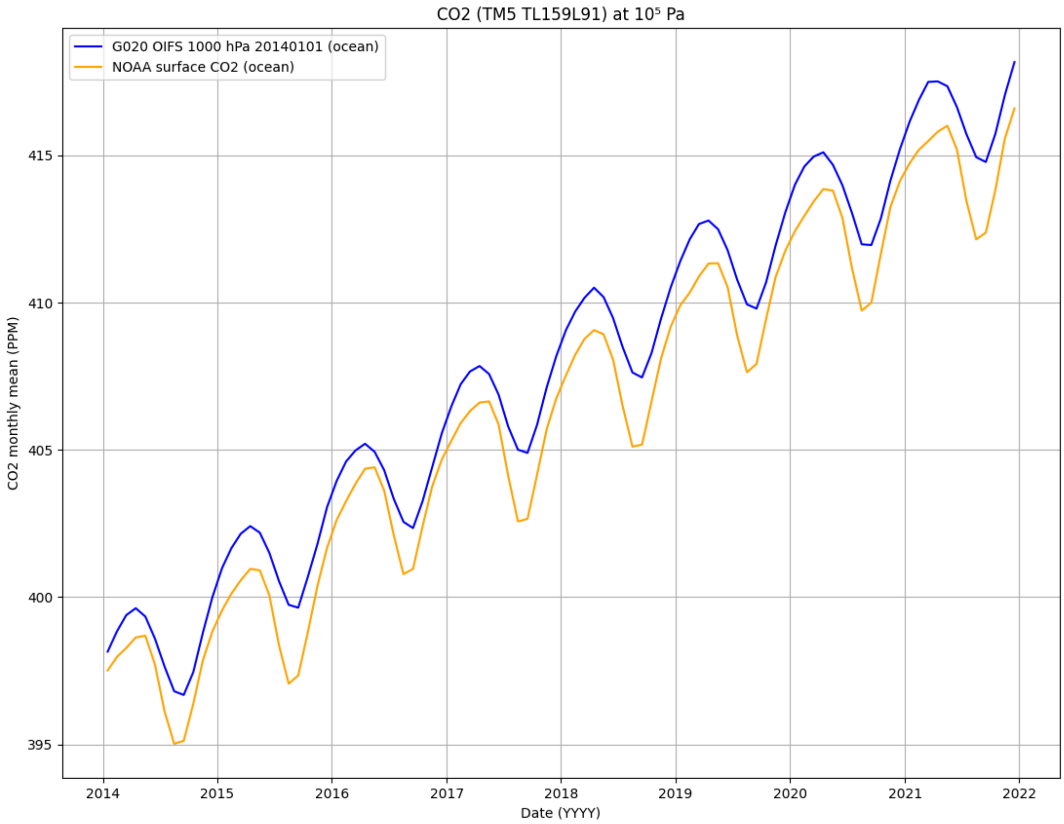

Figure 1: globally averaged ocean surface (1000hPa) CO_2 concentrations from our ERA5-nudged simulation, compared to NOAA Global Monthly Mean CO_2

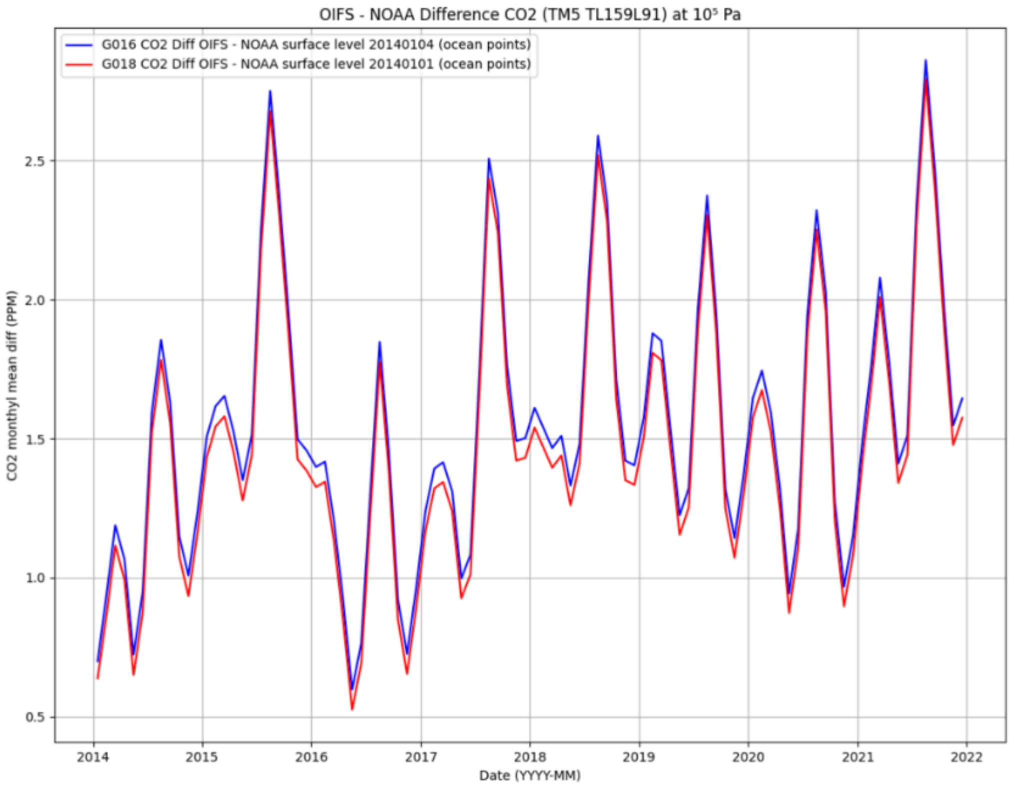

Figure 2: as Figure 1 but bias of 2 simulations (G018 initialised with model fraction from CarbonTracker-Europe on Jan 7st, G016 initialised on Jan 4th).

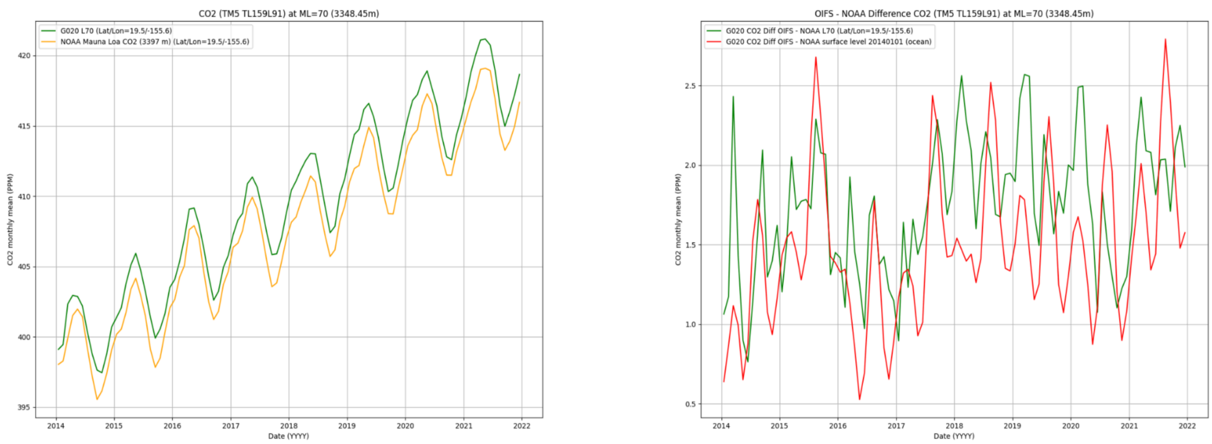

Figure 3: Left panel: Monthly mean CO2 concentration at the same gridpoint (and ML 70)as the Mauna Loa observatory, compared to the NOAA Monthly Average Mauna Loa CO2 observations. Right panel: differences between our model results with NOAA data at Mona Loa observatory (green) and global differences (red).