Exchange grid: implementation of a test configuration to evaluate fluxes modification

E. Maisonnave, A. Voldoire*

* Centre national de recherches météorologiques, Toulouse

WN/CMCG/18/47

Abstract

The ANR COCOA work package 2 aims to evaluate the impact of a new flux calculation location, performed on each ocean/atmosphere grids intersection instead of on the coarse atmosphere grid. This document describes the implementation and validation of an intermediate complexity coupled model including NEMO and various instances of the SURFEX surface module of ARPEGE, where flux calculations are performed. Major impacts affect non solar heat flux, particularly in the marginal zone, during ice production phase, which is increased.

Rationale

Quantities are exchanged between atmosphere/ocean models to perform a climate simulation: ocean surface variables (temperatures, albedo, currents …) and fluxes (wind stress, heat, water). Usually, the model grids are different (position, resolution). The CNRM-CM6 [1] low resolution components show large difference in resolution (ratio of ~1/5), particularly in the equatorial band (Fig 1).

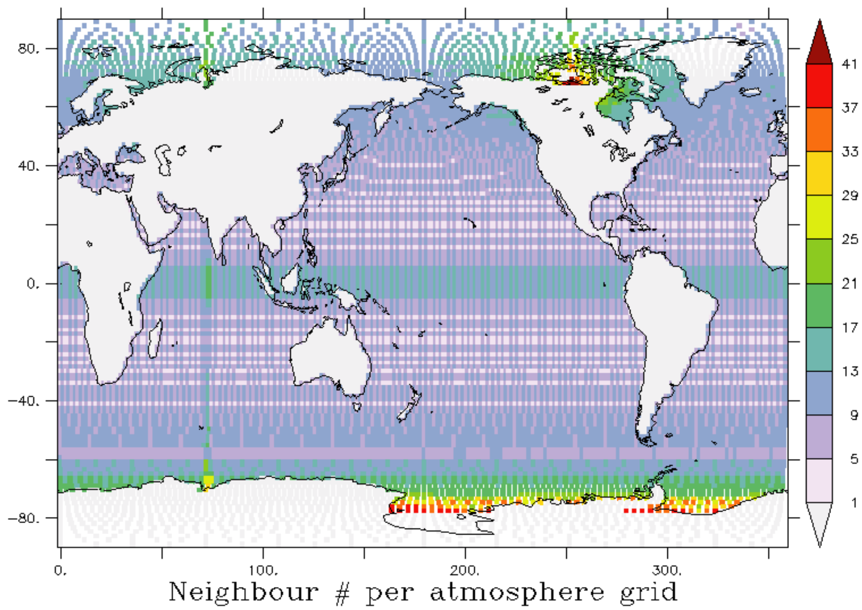


Figure 1: # of ocean grid point intersected per atmosphere grid point, ORCA1 to T127 grid interpolation, SCRIP [2] "CONSERV" method

In this model, atmosphere cells are bigger than ocean cells. These differences lead to errors during flux calculation: one single mean ocean surface value is used, instead of separate values for each ocean grid cells. Errors are the consequences of the calculation non-linearities.

This study proposes to investigate the solution implemented at GFDL [3]: fluxes in calculated at every atmosphere/ocean grids intersection and a resulting flux is re-built on the oceanic cell.

The WP2 of COCOA project [4] aims to investigate how the CNRM-CM6 coupled system behavior is modified by this "exchange grid" technique. To do so, the model currently developed for CMIP6 is used at standard (LR) resolution. This model is based on the ocean model NEMO3.6 in the ORCA1 configuration (i.e. 100 km resolution on average with a refinement to about 30 km at the equator) coupled to the ARPEGE-ClimatV6 atmosphere[1] model with a resolution of about 150

1 Version based on beaufix:/home/gmgec/mrgu/colin/rootpacks/arp602_prep.07.IMPI512IFC1601.2cz

km (T127).

Proposed solution

Various options were investigated during the project definition. Some of them would have lead to major modifications in the ARPEGE code. This document describes an intermediate complexity test bed (simulator) implementation and validation: the SURFEX model, where fluxes are calculated, is used separately (without the ARPEGE atmosphere code) and coupled to NEMO . The atmosphere feedback is disabled and replaced by atmosphere forcing, calculated during a previous full CNRM-CM6 (ARPEGE-SURFEX-NEMO) coupled simulation. The coupled fields exchanged between atmosphere and ocean are the same in CNRM-CM6 and in SURFEX-NEMO configuration[2].

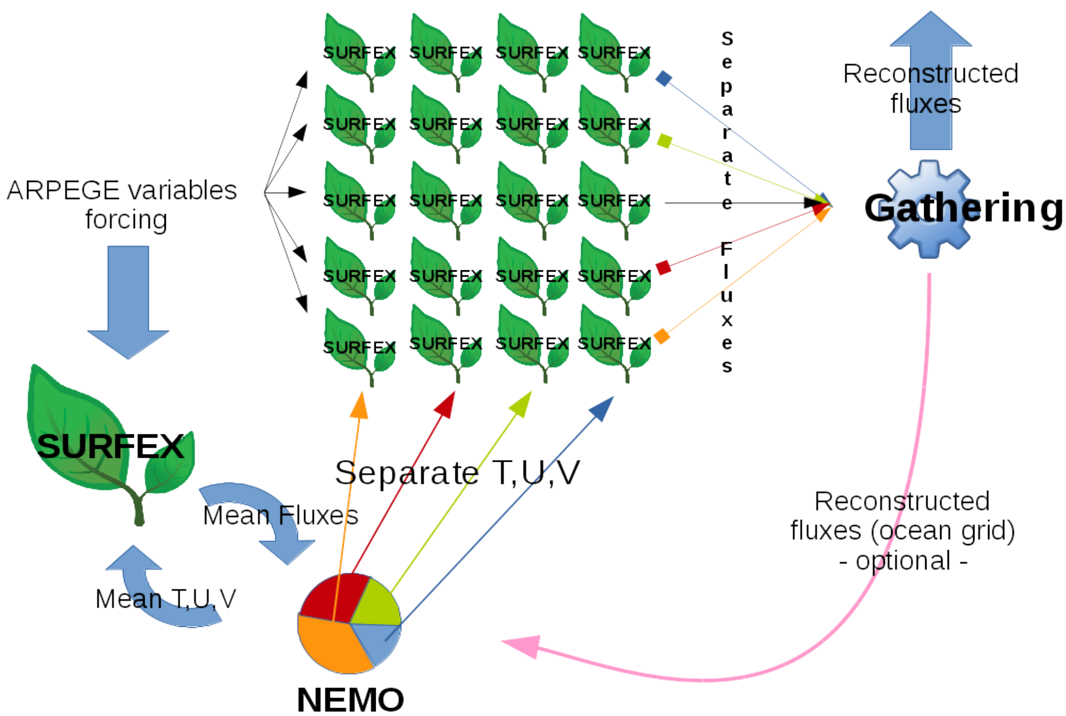


Figure 2: Exchange grid simulator implemented to produce mean ocean surface variables (interpolated on the SURFEX grid), mean atmospheric fluxes (interpolated on the NEMO grid) and ocean surface variables at each cell of the exchange (SURFEX-NEMO intersection) grid. A toy model gathers the fluxes calculated by SURFEX clone models (one per intersected cell). The resulting fluxes can be sent back to the NEMO ocean model. Coupled fields from/to SURFEX clones, NEMO and toy models are exchanged/interpolated through the OASIS3-MCT library

In this SURFEX-NEMO simulator, fluxes are calculated at every ocean cell intersected by an

2 In particular, ocean/ice fluxes are exchanged following the rules defined by the parameters LSEAICE_2FLX=.TRUE. in SURFEX and sn_snd_temp='oce and ice' in NEMO (ice and mixed fluxes)

atmosphere cell: each calculation on each sub-cell is managed by a separate SURFEX executable ("clone"). Then, the NEMO model is coupled with as many SURFEX clones as the maximum number of ocean cell intersected per atmosphere cell.

Fluxes are combined in an additional executable to rebuild one flux per atmosphere cell. This new set of fluxes is finally compared to the fluxes calculated in a standard way. Fluxes are also combined to build the fluxes as seen by the ocean. Rebuilding of fluxes on atmosphere and ocean grid differs. On the atmosphere grid, it is performed doing an average of the contribution coming from the exchange grid. On the ocean grid, the former ocean to atmosphere 'CONSERV'ative interpolation is used to identify the fluxes that could be used on each ocean grid point. Among these fluxes, only those involved in the former atmosphere to ocean interpolation are used, with the corresponding weights.

A relatively short simulation of a few years is realized to technically validate the exchange grid implementation and estimate the flux differences (**EXG** simulation). On a second step, the atmospheric rebuilt fluxes are used by NEMO in a second simulation to evaluate the feedback in the ocean (**SMO** simulation).

Input setup

Calculation of atmosphere variable

The SURFEX model, used in stand alone mode, needs forcing (atmosphere variables). These variables are calculated during a preliminary simulation using CNRM-CM6 (coupled model). The saved variable output (using XIOS, hourly frequency) during simulation are:

- near-surface air temperature at 2m
- near-surface specific humidity at 2m
- Eastward near-surface near surface at 10m
- Northward near-surface near surface at 10m
- long wave downward radiation
- short wave downward radiation
- near-surface near surface at 10m
- surface_air_pressure
- liquid precipitation
- solid precipitation

A CNRM FORTRAN program[3] calculates forcing quantities for SURFEX (netcdf format, hourly frequency):

- Near_Surface_Air_Temperature
- Near_Surface_Specific_Humidity
- Wind_Speed

3 local: /wkdir/globc/eric/evian/Projets/COCOA/Sources/Convert_Input/

- Surface_Indicent_Direct_Shortwave_Radiation
- Surface_Incident_Diffuse_Shortwave_Radiation
- Surface_Incident_Longwave_Radiation
- Surface_Pressure
- Rainfall_Rate
- Snowfall_Rate
- Near_Surface_CO2_Concentration
- Wind_Direction

OASIS interpolation file for intersected cell

The identification of ocean cells intersected per atmosphere cell is done by OASIS: information can be deduced from the SCRIP "CONSERV" interpolation, calculated for CNRM-CM6 during interpolation of ocean surface quantities to atmosphere/SURFEX grid. The number of intersected cell for each atmosphere cell can be produced during the identification (see Figure 1). The maximum of this quantities is the number of SURFEX clones (*ns*) we will need in our new SURFEX-NEMO simulator. Each SURFEX clone receives the ocean surface variables of one ocean intercepted cell per SURFEX cell. Some SURFEX cells of the SURFEX clones receive duplicated information (where the number of intercepted cells is lower than *ns*). This duplicated information is not taken into acount during the flux rebuilding phase. A new FORTRAN program[4] performs the splitting of existing weight&address OASIS interpolation file into *ns* new weight&address files (each SURFEX cell has now only one source cell, with weight equal to 1).

Exchange grid simulator

Simulator implementation

The OASIS based simulator that will calculates the new fluxes includes:

- **one** NEMO executable (MPI //)
- **one** SURFEX executable
- ***ns*** SURFEX clones
- **one** coupled tool that gathered independent fluxes from *ns* SURFEX clones

The gathering coupled tool (GCT) code is developed in FORTRAN[5]. It receives fluxes from SURFEX clones and rebuilds a flux using the original OASIS "CONSERV" interpolation weight&address (NEMO to SURFEX grid). This new set of fluxes is saved in a NETCDF file using OASIS (OUTPUT option). The coupling frequency is set to one hour. The reference NEMO-

4 local: /wkdir/globc/eric/evian/Projets/COCOA/Sources/Ventilateur/

5 local: /wkdir/globc/eric/evian/Projets/COCOA/Sources/New_neomeris/

SURFEX simulation is running at the same time and reference fluxes are also saved in NETCDF with OASIS (EXPOUT option). This allows an easy comparison of reference/rebuilt fluxes. The SURFEX code is modified to make possible a parallel run of (*ns*+1) clones: each SURFEX reads the same forcing, restart and namelist, but only reference SURFEX produces restart/output. NEMO is also modified to be able to receive new rebuilt fluxes but it is using the standard one (**EXG** simulation). In **SMO** simulation, the atmosphere rebuilt fluxes are interpolated to the NEMO grid and used by this model (feedback).

Parallelism & performances

The EXG 1 year long simulation is performed (after a 1 year long spinup phase) with our simulator. NEMO is decomposed following 88 MPI parallel sub-domains. 56 SURFEX clones are coupled (*ns* = 56). The coupled system is completed with GCT and XIOS, in single processor mode. 5 BEAUFIX nodes (40 cores) are needed to keep the system into the memory limits. A specific mapping of the process allows NEMO sub-domains & SURFEX clones to share nodes. Due to the sequentiality of the exchanges, the maximum speed of the system we can reach is equal to 2 SYPD (5 times less than CNRM-CM6). Possible enhancements would imply a reduction of SURFEX clone number to 1, on a new grid reduced to the total number of ocean intersected cells (157,796). This would reduce calculations (at the moment, calculation are made on 56 clones, using 24572 T127 Gaussian grid points = 1,376,032) and corresponding communications. This enhancement was not necessary with the resolution needed in this study.

Validation

Rebuilt atmospheric fluxes of EXG are averaged over the 1 year long simulation and compared to the standard fluxes calculated at the same time. Differences (and standard deviations) are plotted in figures 3. Systematic differences occur for non solar fluxes (negative), particularly over ice. In figure 4, it appears that major contributions to this difference are given by latent and sensible heat fluxes.

In figure 5, lower left (c) figure shows the difference between EXG and standard sea ice cover fields. This field is not modified by SURFEX. The quasi zero difference proves that EXG fields are rebuilt on the ARPEGE grid with the right weights and addresses structure. The systematic difference observed on non solar heat flux is clearly an effect of the new exchange grid flux calculation.

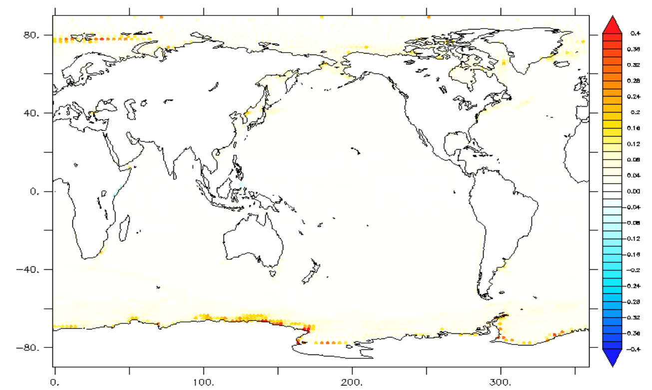
This effect cannot be explained by a different current contribution. An analysis of a test simulation with no current coupling exhibits new (positive) differences on the Tropics, but identical (negative) differences over ice, as shown in page 1, lower right (d) figure.

A closer look (figure 5, upper left – b- figure) to one of the grid point with major differences and variability (Greenland Sea) reveals a strong correlation between differences EXG minus standard non solar heat fluxes (black line) and variability of ice temperature between the 4 ocean grid points contributing to the EXG flux calculation (red line). This explains the major contribution of latent and sensible heat fluxes (dependent to Tair/Tsurface differences) to the difference EXG minus standard non solar heat flux. Notice that the 4 contributing ocean grid points are permanently covered by ice during the considered period (January) but with different %age (see upper figure 7).

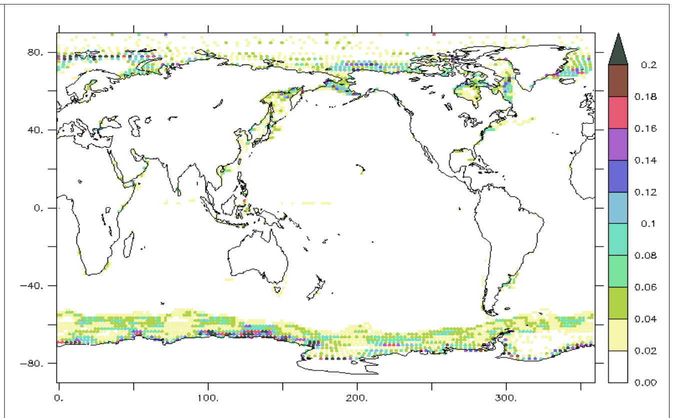
To better explain the phenomena, the four latent and sensible heat flux contributions are plotted in figure 7 (weighted fields on the upper figures, non weighted fields below) during the whole January month. Grid point interpolation weights of the red, green, blue and cyan lines are respectively equal to 0.1963, 0.2221, 0.3143 and 0.2650. EXG weighted averaged flux is in bold black, standard flux in pink and flux differences EXG minus standard in dotted black. In lower figure 8, same information is given for ice temperature, except that bold dotted black line represents air temperature of the atmosphere grid point. It is clear that maximum differences occur when ice temperatures of some contributing ocean grid points exceed air temperature.

From observation during a longer duration (monthly evolution of non solar flux during one year, shown in right figures 8), we can affirm that the differences are maximum during sea ice production. This seems confirmed by the effect observed when the feedback to ocean is switched on. As shown on figure 10, the complementary simulation (SMO) exhibits extra ice volumes (more clearly in Arctic) during wintertime and this difference is a consequence of higher production before and during winter. The major part of this extra ice volume comes from the marginal zone (see figure 11).

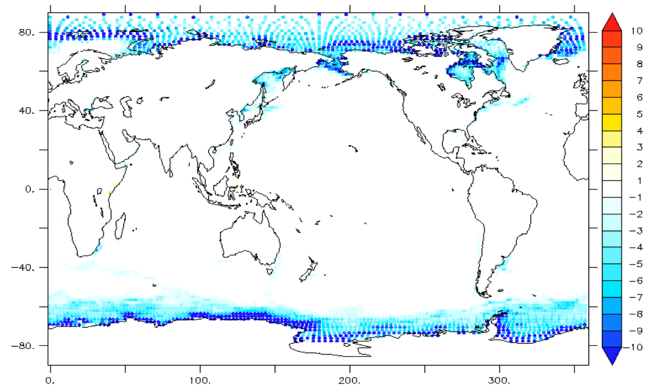
The SMO simulation applies ocean fluxes averaged on atmosphere grid points, instead of fluxes gathered on ocean grid points. This is justified by the high level of noise observed on the latter. In figure 9, non solar heat flux (ocean grid, fluxes gathered on ocean grid points) over a non iced grid points, close to the South African coast, is shown. These grid points (longitudinal section) are among the most sensible to the so called noise. The contributions to the non solar flux (blue line) decomposed into longwave (black line), sensible (red line) and latent (green line) fluxes are in the left figure for standard fluxes and in the right figure for the EXG fluxes. The standard fluxes exhibits some equal consecutive values (pairs), which correspond to fluxes calculated with the same SSTs on a large atmosphere mesh covering the pair of ocean grid points. These ocean grid points receive different values during EXG flux calculation. But the sign of the derivative introduced is the opposite of the longitudinal section one, which produces the noise visible on the right figure. Again, longwave is not affected and latent and sensible heat fluxes only show this noise. This proves that air-sea temperature differences are again the origin of this effect. In our case (Southern Ocean), the southernmost ocean grid point of our 2 consecutive values has now lower temperatures than the northernmost, and maximizes the difference with air temperature (which remains constant because ARPEGE is not coupled to SURFEX). Consequently, the southernmost (northernmost) ocean grid point has an artificial bigger (lower) non solar heat flux than the previous standard average. This should not be solved by a coupling with ARPEGE, considering that the 10m temperature, used by SURFEX in the bulk formula at atmosphere resolution, will remain the same for all fluxes of our exchange grid.



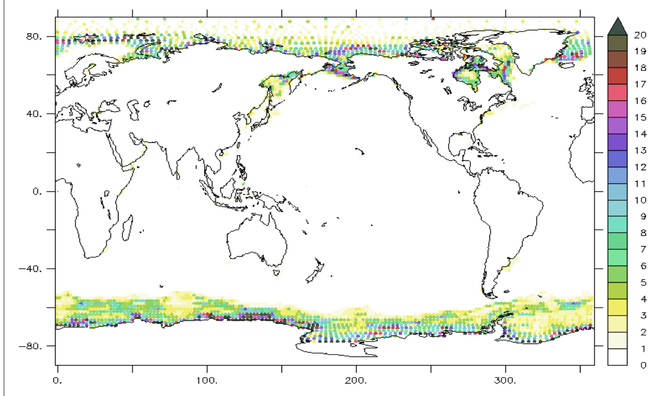
Evaporation mean (mm/day)



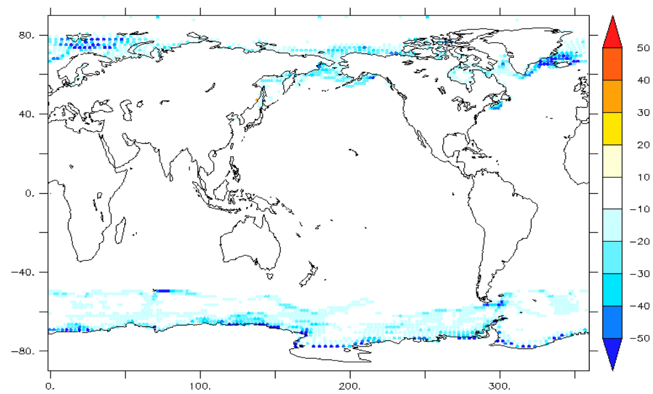
Evaporation standard dev (mm/day)



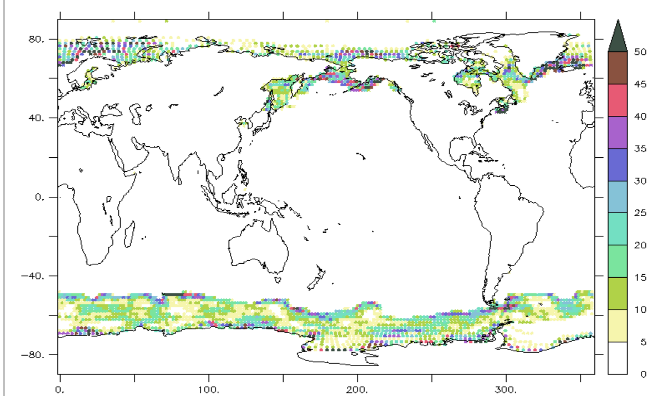
Non solar heat flux (total) mean (W/m2)



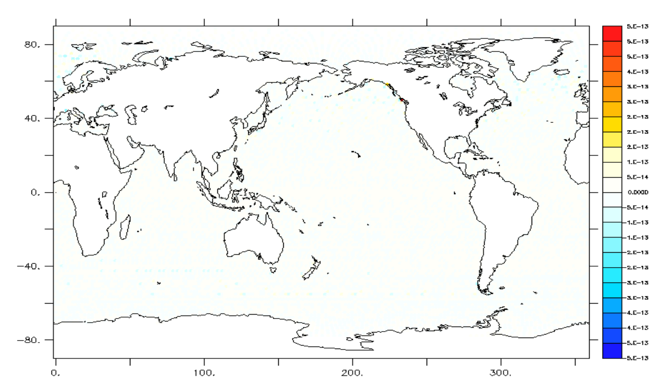
Non solar heat flux (total) standard dev (W/m2)



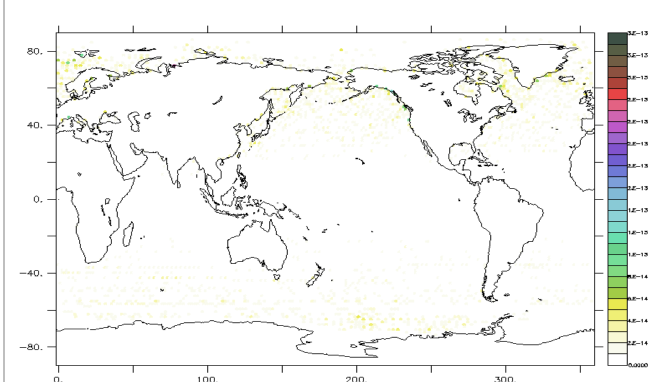
Non solar heat flux (ice) mean (W/m2)



Non solar heat flux (ice) standard dev (W/m2)



Precipitation mean (mm/day)



Precipitation standard dev (mm/day)

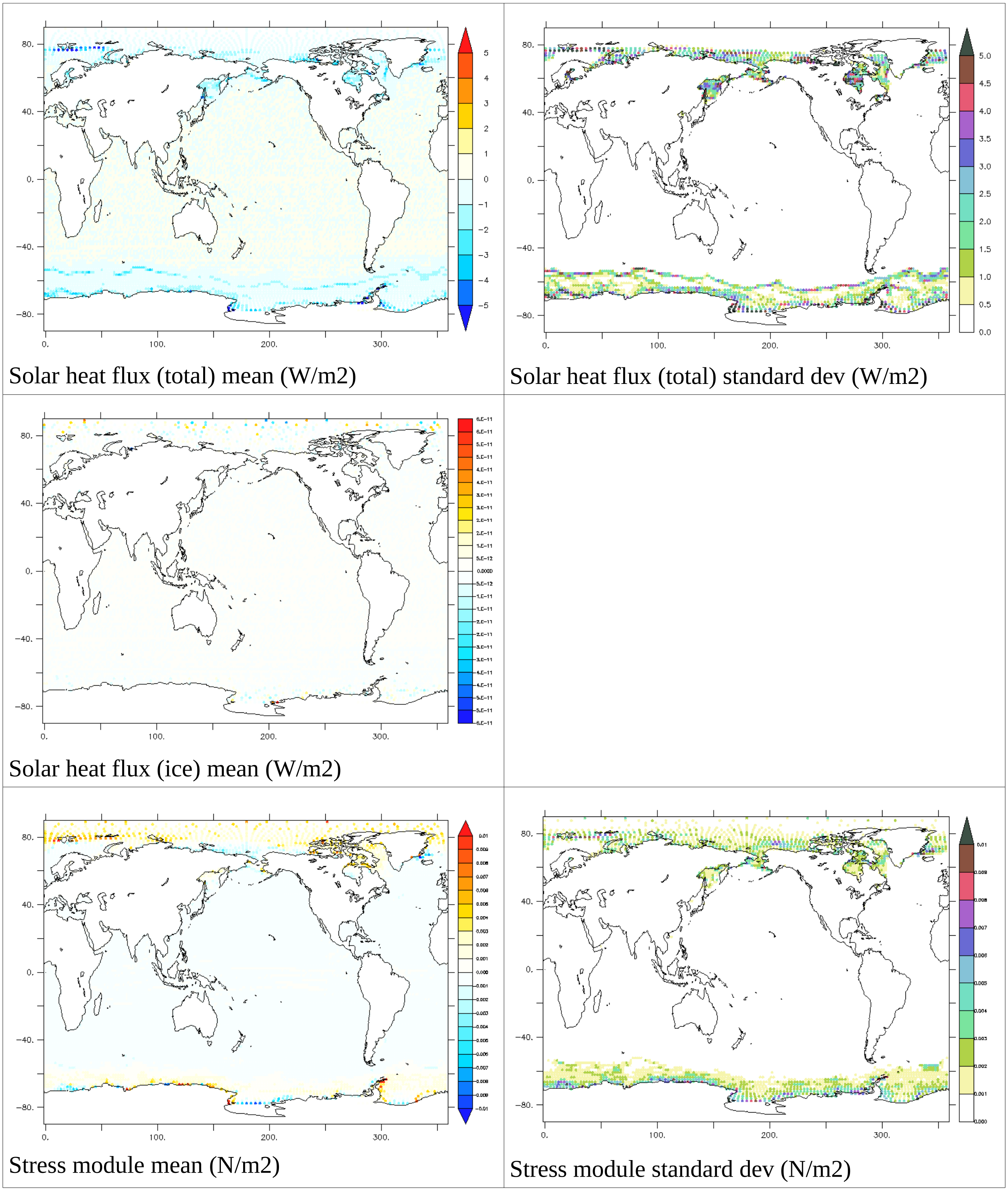


Fig 3: Difference field rebuilt on exchange grid – reference (1 year long average and standard deviation from monthly mean)

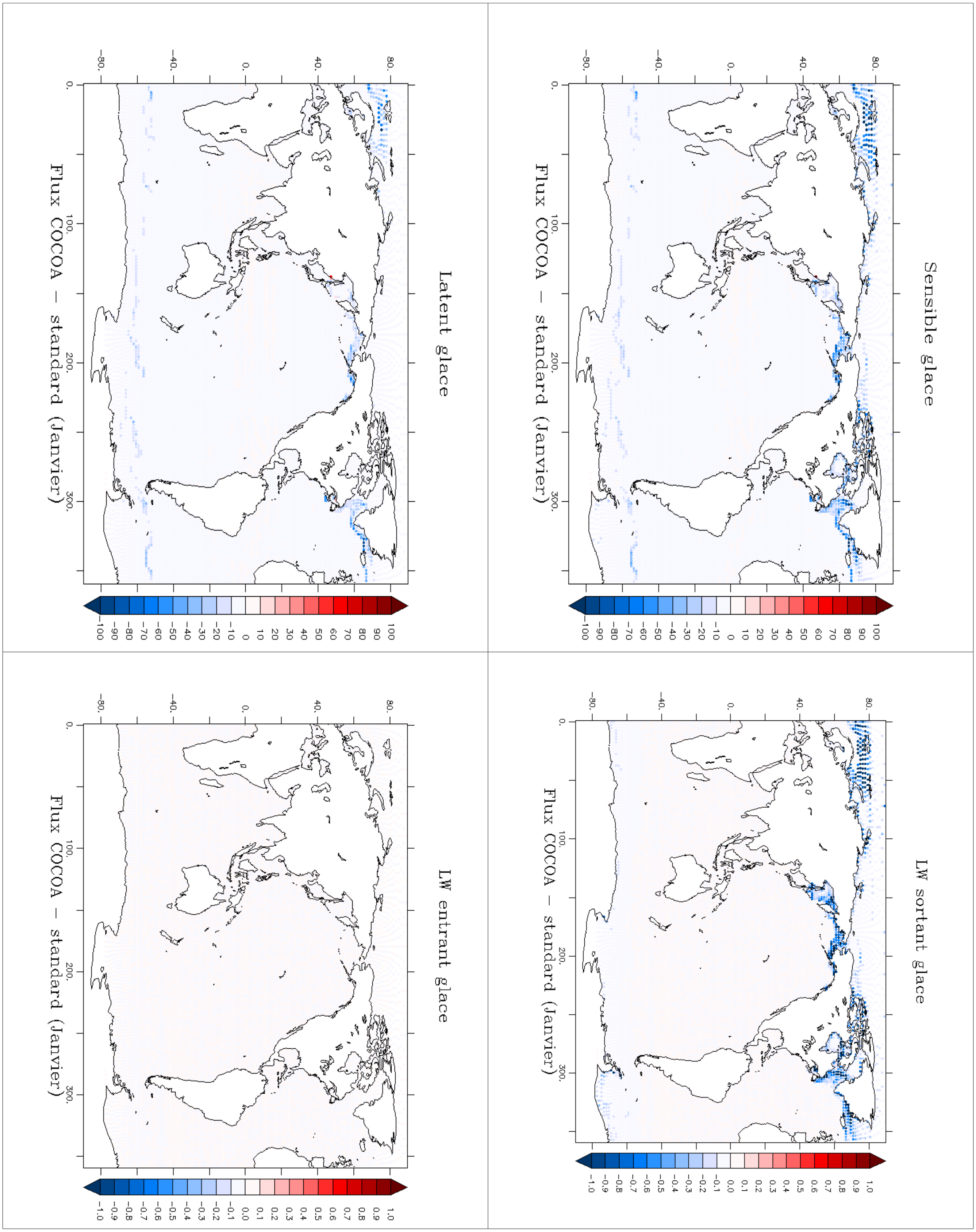


Fig 4: Same than Fig 3 but January average only and for contributions to non solar heat flux on ice

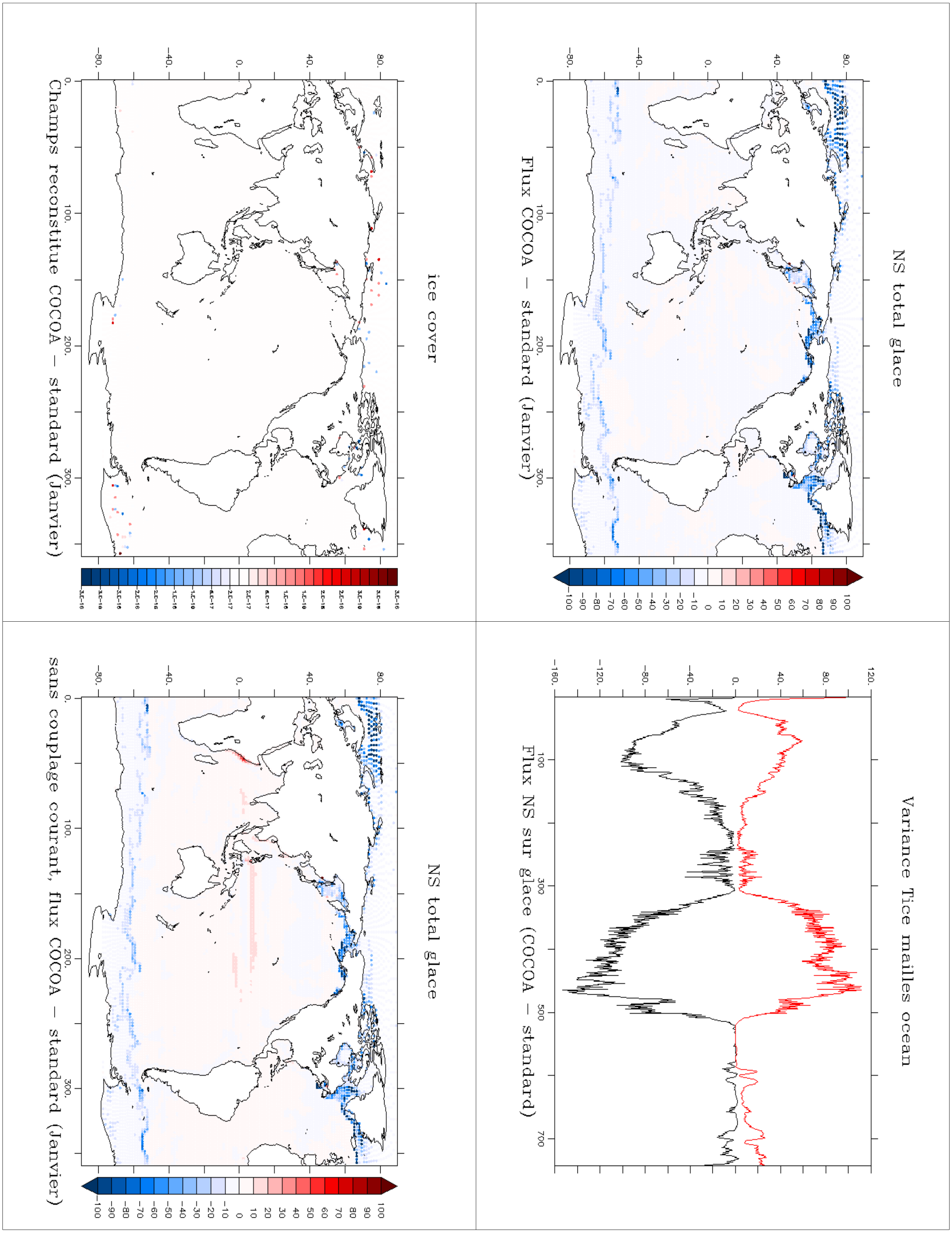


Fig 5: a) Same than Fig 4 for sum of contributions to non solar heat flux on ice, c) same for Ice cover, d) Same for total non solar heat flux on ice but without surface current coupling (specific simulation) and b) for a Greenland Sea SURFEX grid point, comparison between (i) field rebuilt on exchange grid – Reference of non solar heat flux on ice and (ii) ice temperature variance of the 4 ocean grid point contributions

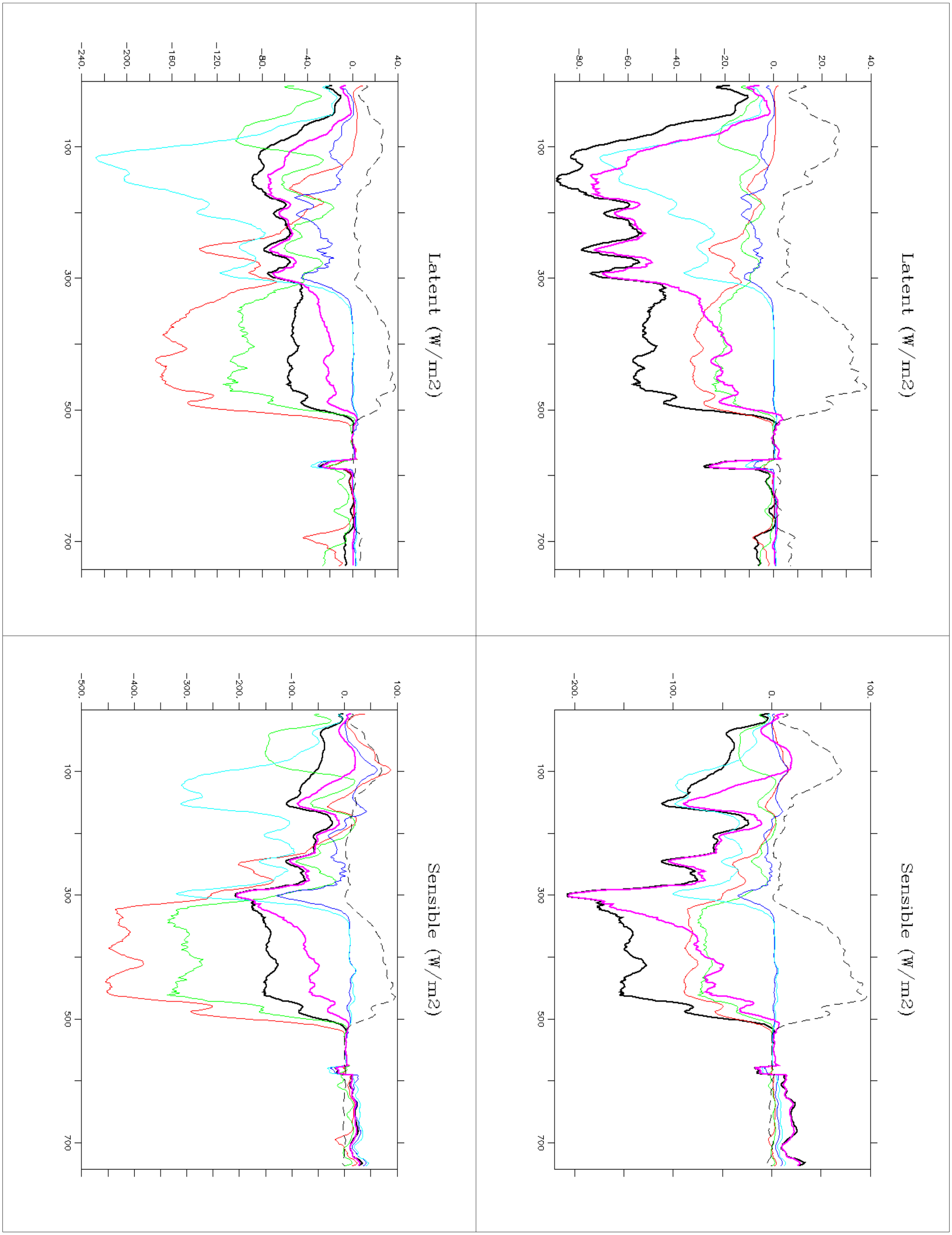
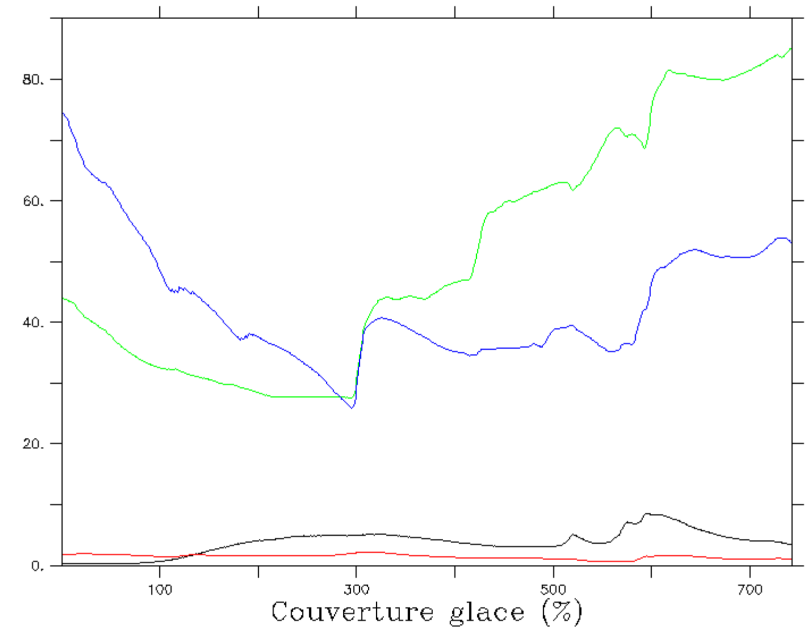


Figure 6: upper) For a Greenland Sea Strait SURFEX grid point, latent/sensible heat flux rebuilt on exchange grid (black bold), reference (pink), difference (black dotted), weighted contributions from the 4 ocean grid points (red, green, light and dark blue) and lower) Same with non-weighted contributions



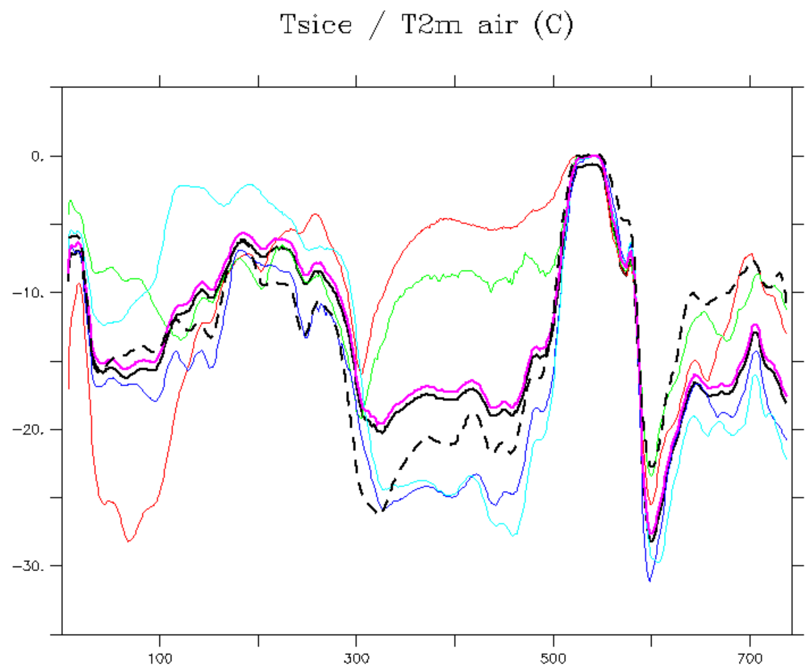


Figure 7: lower) same than lower fig 6, for ice temperature, except bold dotted black (air temperature) and upper) for a Greenland Sea SURFEX grid point, ice cover of the 4 ocean grid point contributions

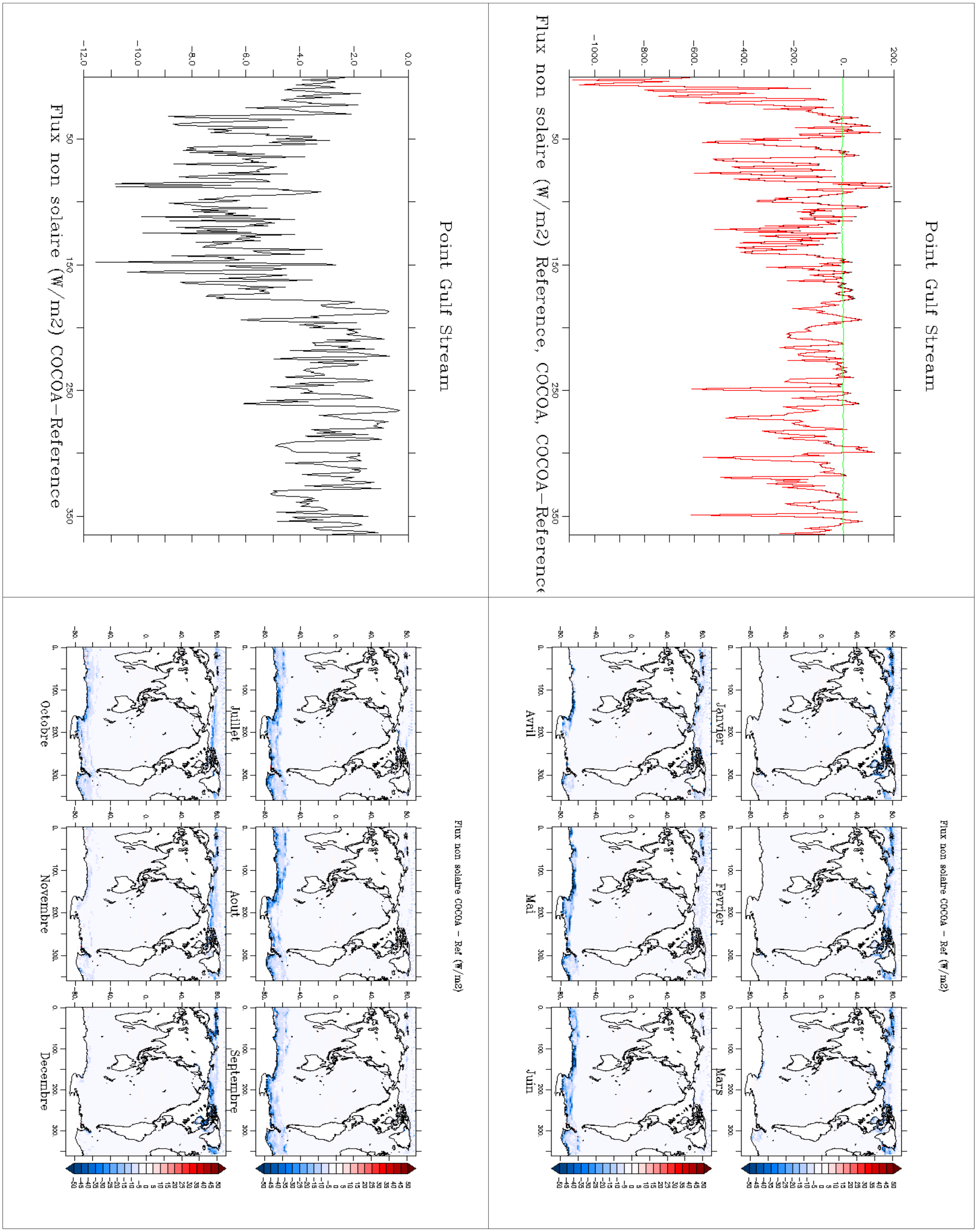


Figure 8: a) Total non solar flux on a Newfoundland banks grid point, field rebuilt on exchange grid (black), reference (red) and difference (green), c) Same but for difference only, b) and d) difference field rebuilt on exchange grid – reference for non solar flux on ice, monthly mean from January to December

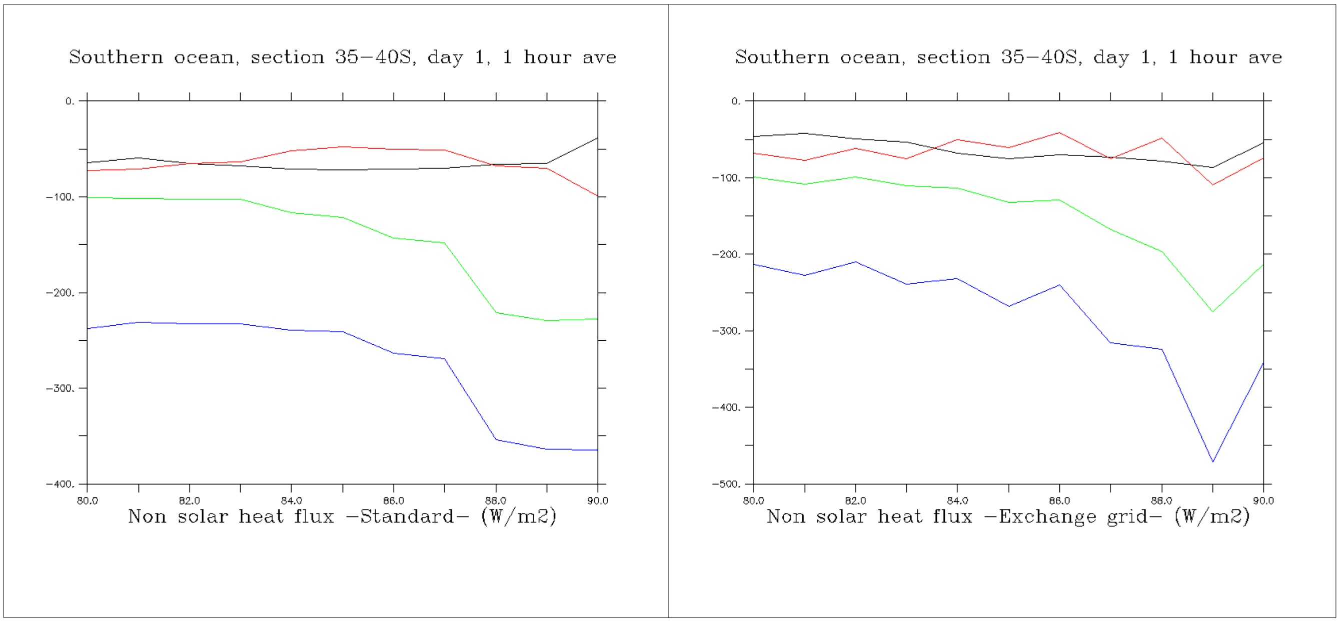


Figure 9: Non solar heat flux (blue line) decomposed into longwave (black line), sensible (red line) and latent (green line) fluxes, longitudinal section south of South African coast, from South to North, after 1 day of simulation, 1 hour average (coupling frequency), ocean grid, with standard (a) and field rebuilt on exchange grid, b) setup. Exchange grid fluxes are calculated but not applied to NEMO.

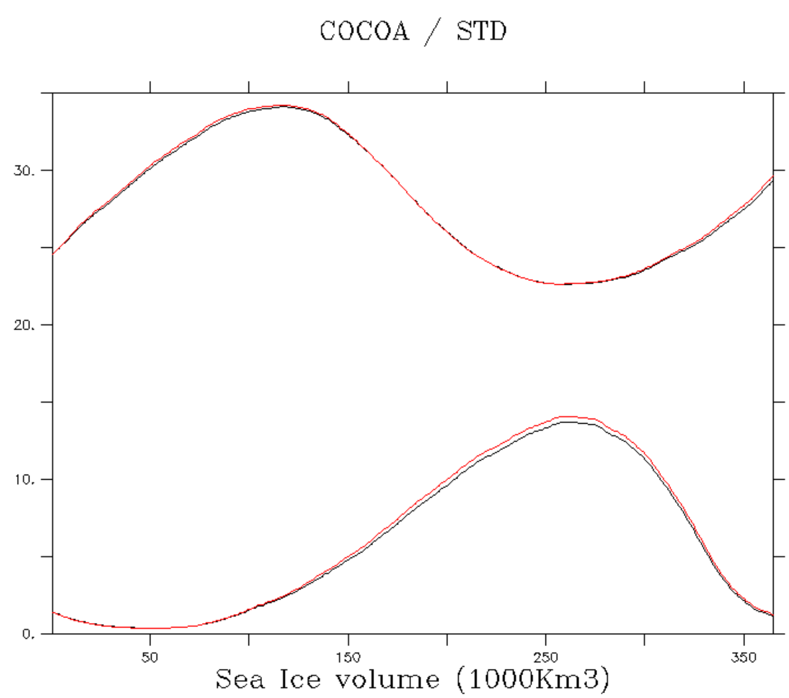


Figure 10: sea ice volume during a 1 year long simulation (days in x axis) with standard (black) and exchange grid (red) setup. Exchange grid fluxes are applied to NEMO.

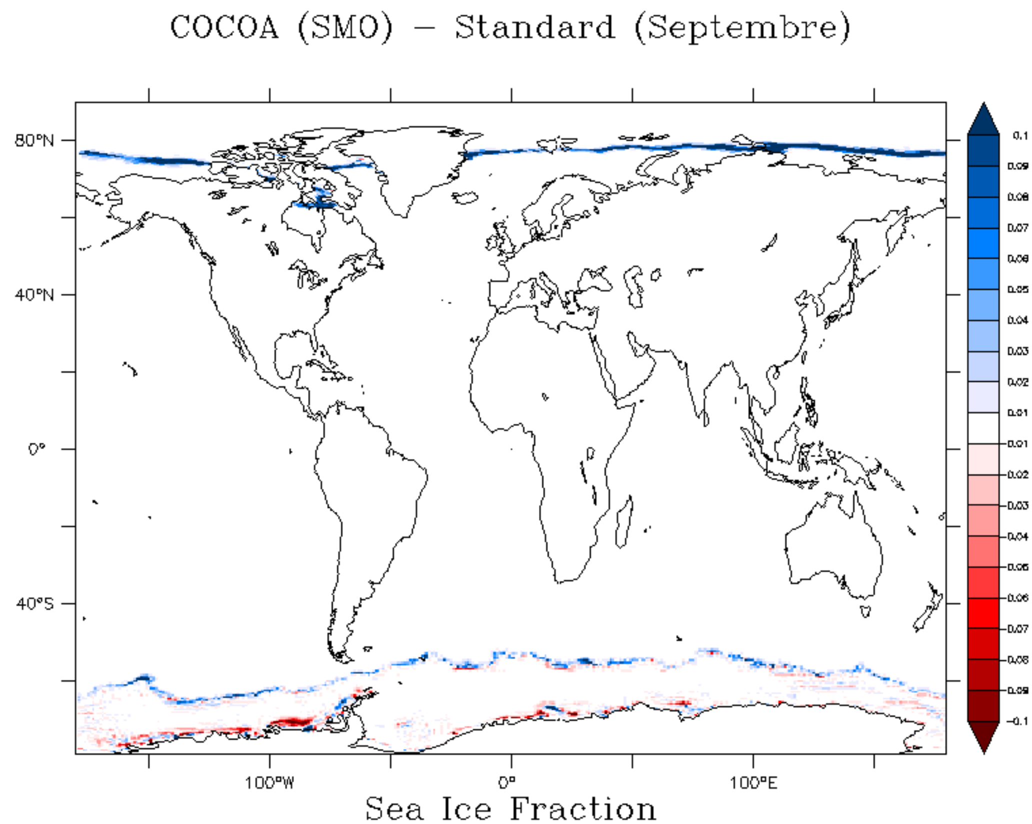


Figure 11: Sea ice extend difference between SMO and reference simulations, after 9 months (September mean value)

References

[1] Voldoire, A., Decharme, B., Pianezze, J., Lebeaupin Brossier, C., Sevault, F., Seyfried, L., Garnier, V., Bielli, S., Valcke, S., Alias, A., Accensi, M., Ardhuin, F., Bouin, M.-N., Ducrocq, V., Faroux, S., Giordani, H., Léger, F., Marsaleix, P., Rainaud, R., Redelsperger, J.-L., Richard, E., and Riette, S., 2017: SURFEX v8.0 interface with OASIS3-MCT to couple atmosphere with hydrology, ocean, waves and sea-ice models, from coastal to global scales, Geosci. Model Dev., 10, 4207-4227, https://doi.org/10.5194/gmd-10-4207-2017

[2] Jones, P., 1999: Conservative remapping: First- and second-order conservative remapping, Mon Weather Rev, 127, 2204-2210

[3] Balaji, V., Anderson, J., Held, I., Winton, M., Durachta, J., Malyshev, S., and Stouffer, R. J., 2006 : The Exchange Grid: a mechanism for data exchange between Earth System components on independent grids, in: Proceedings of the 2005 International Conference on Parallel Computational Fluid Dynamics, College Park, MD, USA, Elsevier

[4] http://www.agence-nationale-recherche.fr/?Projet=ANR-16-CE01-0007