Exchange grid & multi-ice categories coupling: comparison of two flux computation strategies

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Abstract

We evaluate the impact on fluxes over ice, particularly non solar heat, and the coupled effects to the NEMO/GELATO ocean/sea-ice model, of a separate flux calculation by SURFEX for each of the five ice categories represented in the GELATO ice model. We compare these effects with those produced by a flux computing via an exchange grid. The significance of the results is too small to conclude to the relative level of relevance of an implementation in ARPEGE of the exchange grid in one hand, and of the separate coupling of multi-ice category surface field on the other hand, but it could be established that (i) spatial ice temperature variability under atmosphere mesh is bigger than variability of per category ice temperature interpolated on the same atmosphere grid point, but its average temperature is smaller and, consequently, (ii) one year integrated effect of exchange grid fluxes in ocean modifies, although marginally, total ice volume in both Arctic and Antarctic regions, which is less significantly the case for multi-ice category coupling

We propose to evaluate the impact on fluxes over ice, particularly non solar heat, and the coupled effects to the NEMO/GELATO ocean/sea-ice model, of a separate flux calculation by SURFEX for each of the five ice categories represented in the GELATO ice model. We will compare these effects with those produced by a flux computing via an exchange grid. We will deduce which strategy would be worth implementing first in the official ARPEGE release

1. Adaptation of multi-SURFEX coupled model to reproduce multi-ice category flux computing

We previously implemented an OASIS based coupled system [1] including n instances of the same SURFEX stand-alone (excluding ARPEGE) model. In this system, each instance calculates fluxes of the nth part of every ocean mesh intersected by each atmosphere mesh.

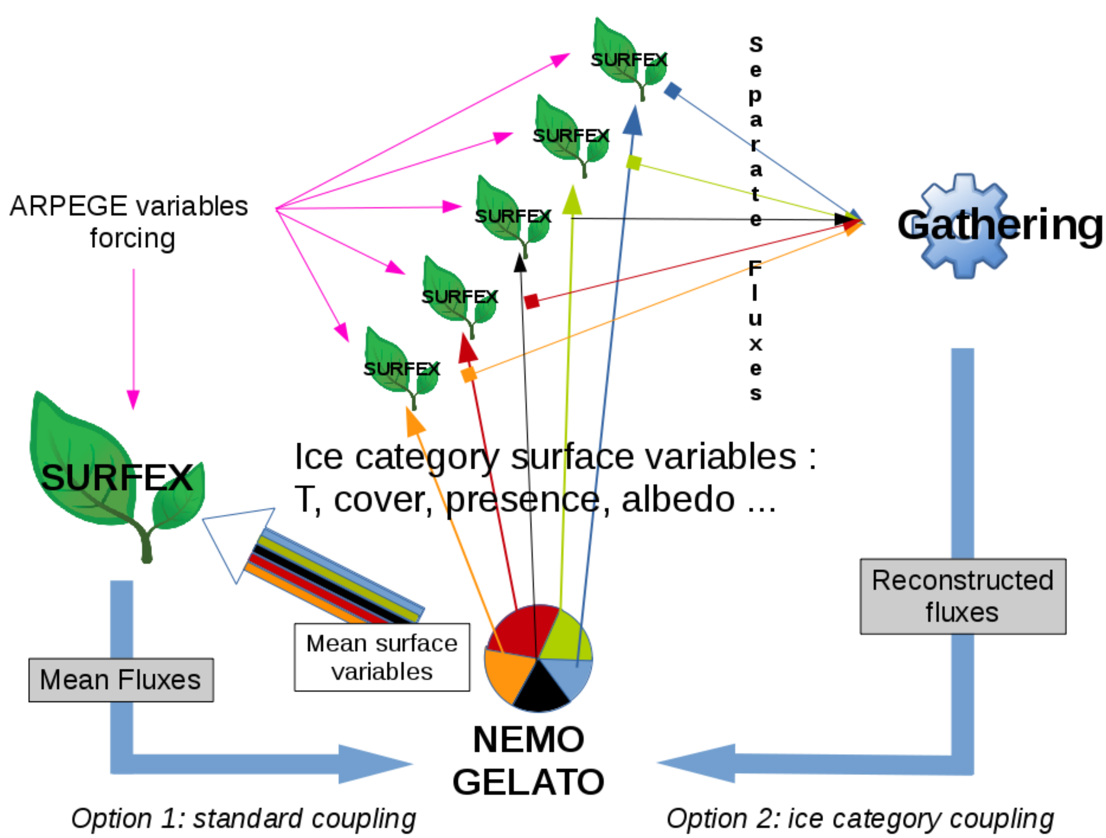


Figure 1: Coupled system implemented to execute n parallel flux calculation with n SURFEX for n ice category surface variables

This configuration is modified in such a way that five instances of the SURFEX model take as input the five different ice cover, temperature and albedo of the five different ice categories (or layers) computed by the GELATO sea-ice model. The new five different fluxes are gathered in a separate executable (named 'GCT', see [1]), also coupled to the system via OASIS (Option 2, Fig 1). The five ice cover, temperature and albedo are also provided to the GCT, for further computations. As previously, an extra SURFEX executable computes standard surface variables (averaged on atmosphere grid via the standard OASIS interpolation) and is able to provide the corresponding fluxes to NEMO (option 1, Fig 1).

2. Multi-ice category temperatures

In a first step, the fluxes based as usual on the interpolated surface fields are sent back to the ocean (see option 1 in Fig 1). We first evaluate the standard deviation of ice temperature, since it was previously demonstrated that this variable is highly correlated to a negative shift of the non solar (particularly latent and sensible) heat flux over ice. To do so, the five ice temperatures of the five ice category contributions are weighed by their respective ice cover. When an atmosphere mesh does not intersect any ice from the ocean grid, the ice temperature is equal to the frozen water temperature and variance is set to zero.

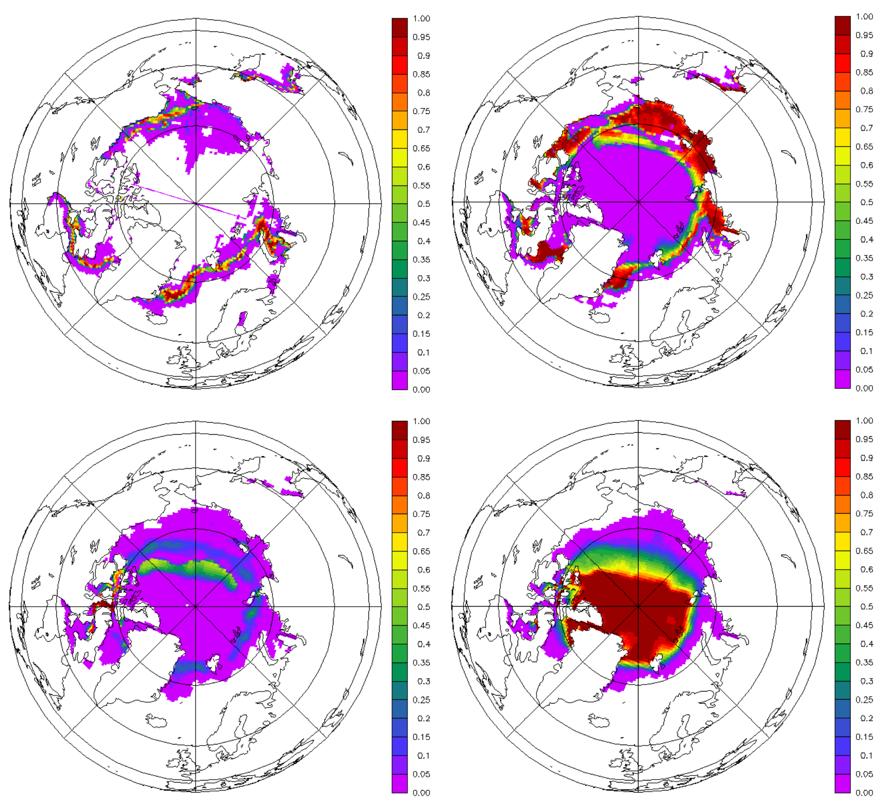


Figure 2: Ice cover by category (1 to 5) from an arbitrary coupling time step, Arctic ocean. White = no ice

For each ice category, the ice temperature coupling field, as produced by GELATO and sent to SURFEX by OASIS, is equal to

- ice temperature if ice cover is non zero
- frozen water temperature if not.

The interpolation from the ocean to the atmosphere grid, which is coarser, necessarily introduces a bias in ice temperature, proportional to the inverse of ice presence below any atmosphere mesh. It means that this bias affects every ice category on large sea-ice category marginal regions: marginal areas are located here at every ice category margins (see Fig 2).

To avoid this mixing of ice and frozen water temperature during interpolation, we chose to replace, on ocean grid, the frozen water temperature by zero on every grid point covered by less than 0.01% of sea ice. In addition, we introduce a new coupling field in our system: the ice presence. This field is equal to

- 1 if the sea ice cover of this point is bigger than 0.01%
- 0 if not

Interpolated on atmosphere grid points, this presence will fill SURFEX grid points with the percentage of the corresponding ocean grid point covered by ice. The coupled ice temperature (mixed with zero values) is then divided by this percentage to rebuilt the ice temperature on the atmosphere grid point, which represents the ice temperature of the corresponding ocean grid points that are covered by (more than 0.01% of) ice.

The same bias also pollutes the ice albedo. In this later case, the coupling field is not the raw albedo quantity but the ice cover weighted quantity. In SURFEX, the outgoing short wave radiation is calculated with an underestimated albedo because of (i) a mixing with water albedo performed on ice category marginal areas and (ii) a lower ice cover weight because this is the ice category cover that is used to weight the coupling field instead of the total ice cover. The first bias source can be reduced using the same strategy than for the ice temperature coupling. The second source of error can be reduced by multiplying each per-category-albedo by the total ice cover instead of the corresponding category albedo.

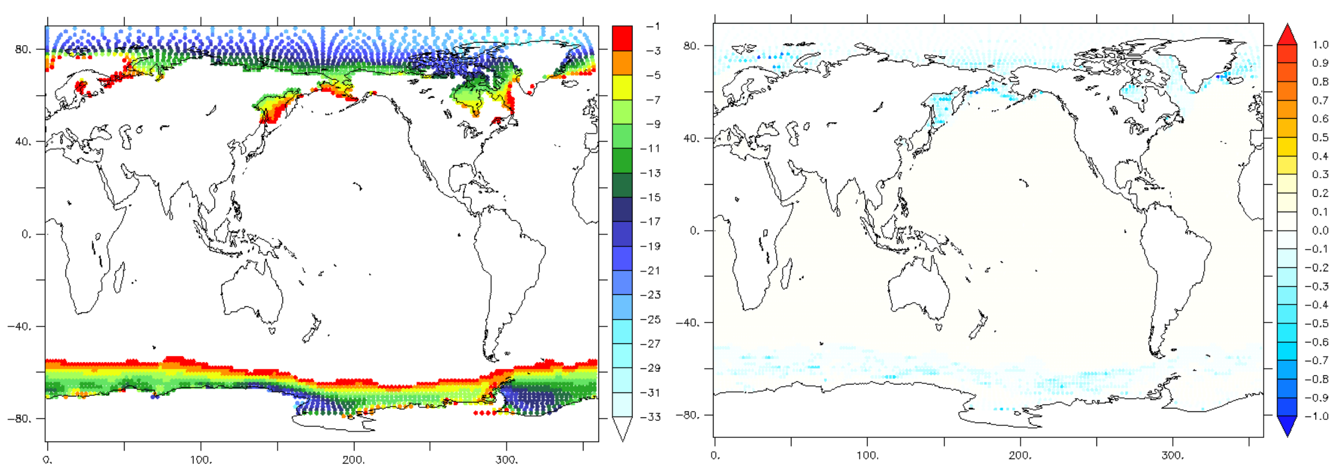


Figure 3: One year average of reconstructed ice temperature (C°) from exchange grid contributions (left) and difference between ice category temperature reconstruction and previous exchange grid result (right). Values calculated on atmosphere grid.

In Figure 3, we show the ice temperature averaged during the whole one year simulation, resulting from the previous EXG exchange grid simulation (left) and differences between the new multi-ice category simulation (ICA) and EXG (right). In both simulations, the fluxes calculated in the standard way are prescribed to the ocean. A small negative bias of less than 1 degree is observed in marginal areas in ICA ice temperatures compared to EXG.

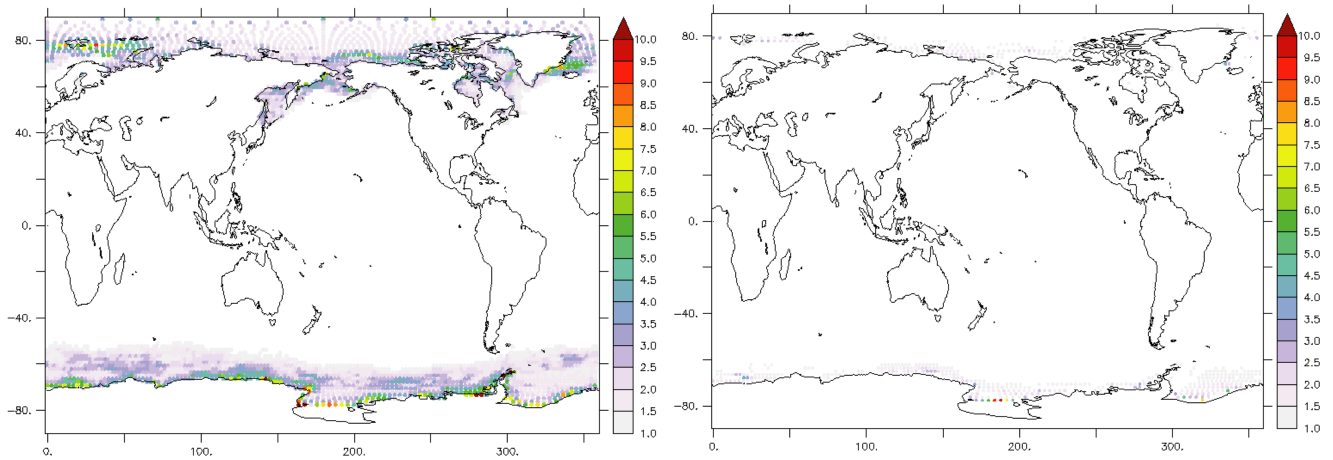


Figure 4: One year average of reconstructed ice temperature standard deviation (K) from exchange grid contributions (left) and from ice category contributions (right). Values calculated on atmosphere grid

Comparison of variance (standard deviation) of EXG ice temperatures shown in Figure 4 (right) and the same variance but for ICA simulation ice temperatures (left) revealed much higher values in EXG. On every atmosphere grid point, there is less variance (weighted by ice cover) between temperatures of various ice categories than between ice temperatures of the various ocean grid points interpolated to the atmosphere grid point mesh.

In addition, the maximum of ICA variance is not located near ice pack marginal area, but over regions where more than 1 ice category are present.

During the standard way coupling simulation, three modes of computation are used to produce fluxes that are saved in NetCDF format files:

- standard calculation using ocean surface fields interpolated on the atmosphere mesh (STD)
- separate calculation on the exchange grid (EXG) and gathering on the atmosphere grid (smoothing)
- separate calculation using the 5 ice category surface fields (ICA) and recombining

The difference with STD are annually averaged. Differences in non solar fluxes over ice are plotted in Figure 5. A negligible shift is observed in solar fluxes over ice (not shown).

As expected, over regions that host multi-ice categories, the absolute value of the non solar flux is increased in smaller proportion than in EXG. This can be again attributed to ice temperature variability.

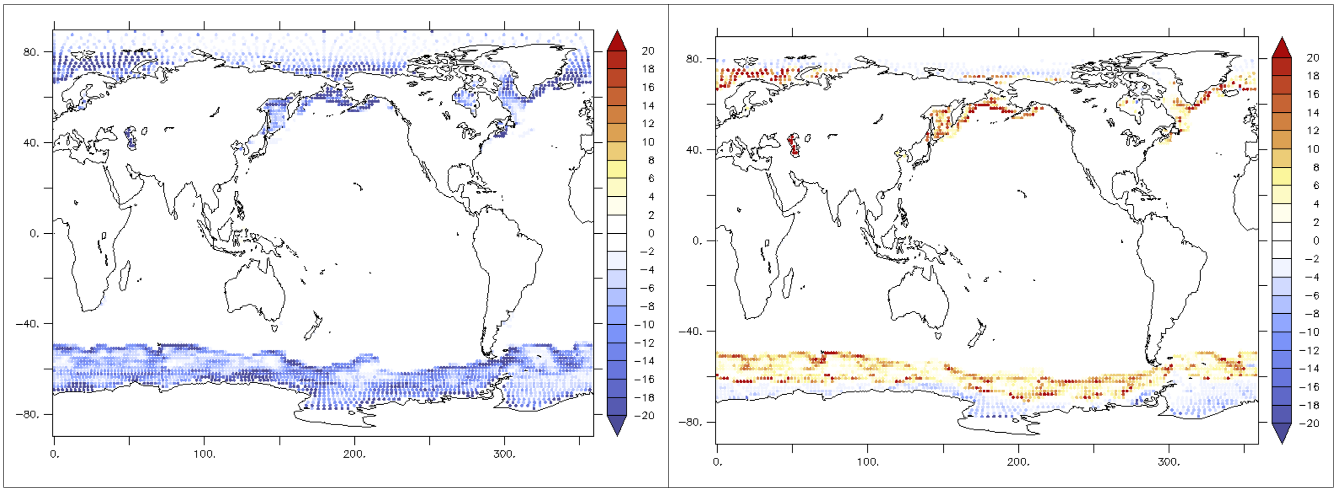


Figure 5: Non solar heat flux (W/m2), annual average, differences between exchange grid and standard calculation (left) and between multi-ice category and standard calculation (right). Flux on atmosphere grid

A major discrepancy appears on marginal areas between EXG and ICA. In the first case, flux values coming from iced and water-only ocean grid points are used by our reconstruction to create a flux on atmosphere grid points (that are then interpolated back to the ocean grid points). As already studied in [1], latent and sensible heat fluxes are increased in absolute values when iced and high temperature values (bigger than air temperatures) are taken into account. These non solar flux values are mixed, during interpolation onto atmosphere grid, with fluxes calculated over water. The combined effects lead to higher ocean losses of non solar energy in marginal areas.

At the opposite, in ICA, fluxes are calculated with ice temperatures only. They are mixed with ocean values only at last stage, during interpolation back to ocean. On the atmosphere grid (before this last interpolation), marginal areas fluxes are clearly different from EXG (and STD) because they are not mixed with (larger) fluxes calculated over water. Even though some ice category temperatures could be larger than air temperatures, which leads to larger latent and sensible heat flux, this effect will be more than compensated in marginal areas with the non mixing of these values with values calculated over water. This is why the differences between ICA and EXG can be clearly separated in two areas:

1. inner iced regions, where non solar heat flux is always larger, in absolute value, than STD but bigger in EXG than in ICA
2. marginal regions, where the non mixing with fluxes calculated over water lead to positive anomaly in ICA, where negative values are observed with EXG (same effect than in the other regions)

3. Multi-ice category flux coupling

In a second step, fluxes calculated with multi-ice category surface fields are sent back to the ocean (see option 2 in Fig 1). In the exchange grid case, fluxes gathered in the atmosphere grid are then interpolated to the ocean grid, to remove the numerical noise attributed to the resolution difference between atmosphere and ocean grids (see SMO simulation definition in [1]). In this new configuration, the computation of flux with multi-ice category surface field is necessarily performed on the atmosphere grid and interpolated back to the ocean. This new dataset is called SMI. For comparison, fluxes calculated in the standard way are also produced and saved in files (STI).

	Data set
Standard simulation	Standard fluxes: **STD** Exchange grid fluxes (not used): **EXG** Multi-ice category fluxes (not used): **ICA**
Exchange grid simulation (see [1])	Exchange grid fluxes: **SMO**
Multi-ice category simulation	Standard flux (not used): **STI** Multi-ice category fluxes: **SMI**

Table 1: Acronym of dataset produced

In this simulation, SMI fluxes are calculated by the GCT executable, in the atmosphere grid, using F_n values coming from the 5 different SURFEX models. All fluxes F are calculated according to the respective ice cover percentage C_n and normalised to the total cover of the cell.

$$F = \sum_{n=1,p} (C_n \cdot F_n) / \sum_{n=1,p} (C_n)$$

Be careful that less than 5 ice category fluxes (p) can be used. If the % of ice (category) presence is less than 0.01%, fluxes are not calculated by SURFEX with ice temperature but with a standard 0° Celsius temperature. To avoid taking into account these values, the only contributions considered are also those where ice (category) presence percentage is bigger than 0.01%

When total ice cover is zero, fluxes calculated by one of the SURFEX model (e.g. number 1) is selected.

We can compare the SMI fluxes calculated and transmitted to NEMO by the GCT and the STI fluxes usually calculated in atmosphere grid with interpolated value of sea-ice temperature, albedo and cover. Figure 6 shows that SMI-STI differences over ice are negative for solar flux and positive and negative for non solar flux. These differences are coherent with the previous simulation:

- higher values of albedo (no mixing with water values) lead to smaller solar flux
- variance of ice temperature should lead to higher absolute values of non solar heat flux, what is happening on inner part of the ice shelf. But on marginal areas, lower ice temperatures lead to smaller absolute values of non solar fluxes (positive anomalies)

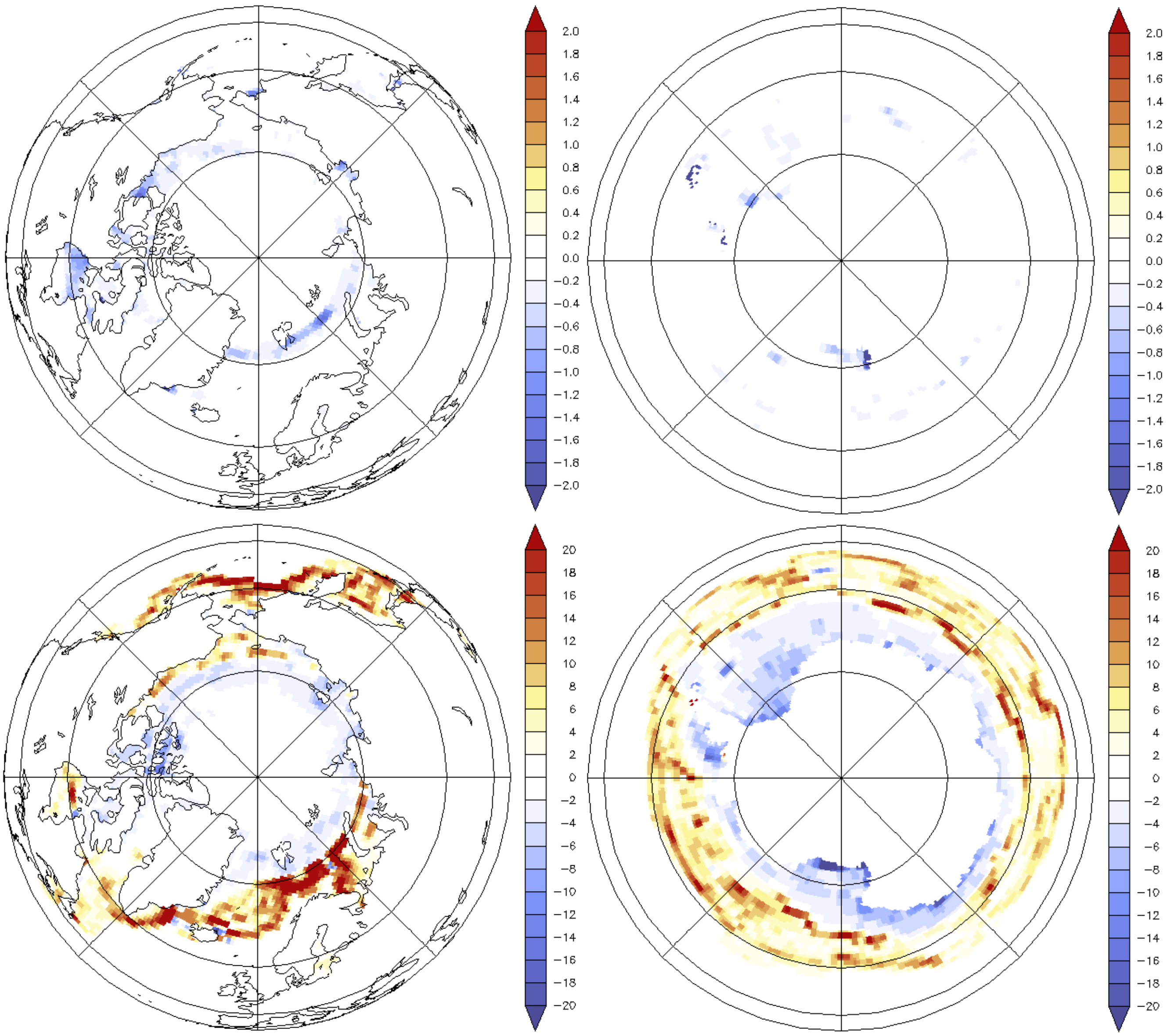


Figure 6: Solar over ice (W/m2, upper) and non solar over ice (lower) flux differences (calculated with multi-ice category surface variables - calculated with averaged surface variables) during multi-ice category simulation exchanging multi-ice category surface variables (SMI – STI), annual average, flux interpolated on ocean grid

Since differences in non solar flux are one order of magnitude higher than differences on solar flux, the resulting impact on ice should be a total decrease of its volume on marginal areas, and possibly an increase at inner part of the ice shelf.

It is not possible to directly compare fluxes with the exchange grid ones (SMO), because sea ice cover, which changes flux, is modified differently with fluxes calculated by the exchange grid and with fluxes calculated by multi-ice categories. We compare ice cover and volume from data set STD (reference simulation), SMO (flux calculated by exchange grid) and SMI (flux calculated by multi-ice categories). The opposite sign of differences for solar and non solar flux has opposite influence. In Figure 7, we see that melting is accelerated in SMI compared to SMO and STD, which can be an effect of less negative non solar flux values. Freezing seems as strong in SMI as in SMO compared to STD. But stronger melting leads to smaller ice cover in SMI, particularly over Arctic marginal areas, where non solar flux is smaller (Figure 8). However, local ice cover differences are too small to clearly conclude to significantly higher effect of the exchange grid flux calculation.

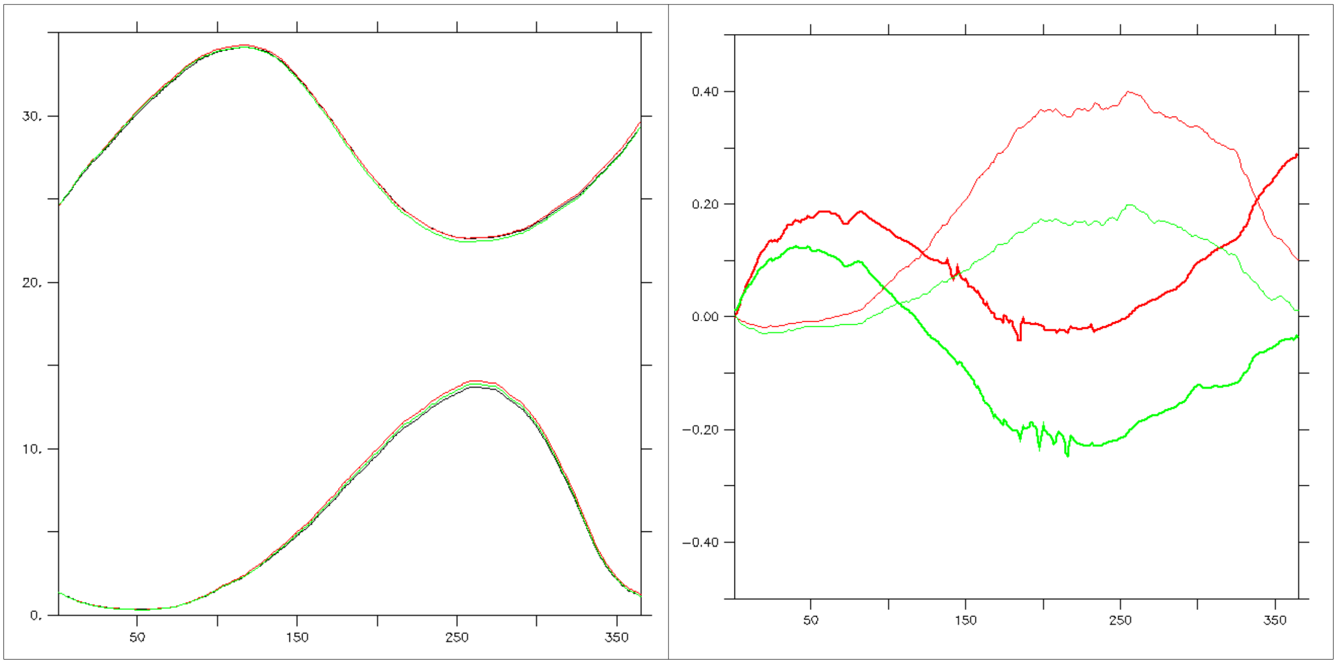
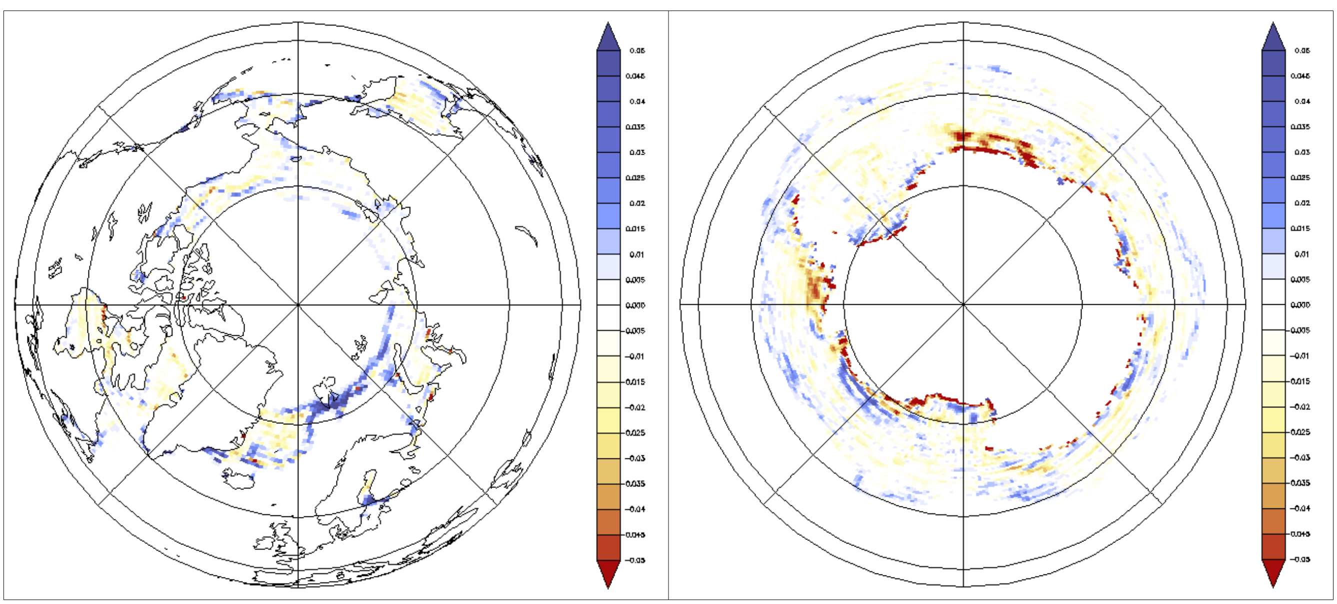


Figure 7: Sea ice volume (1000xKm3) in STD (black), SMO (red) and SMI (green) during he one year long simulation (time unit: days). Right: raw values. Left: Anomalies compared to STD, for Arctic (bold) and Antarctic (thin)



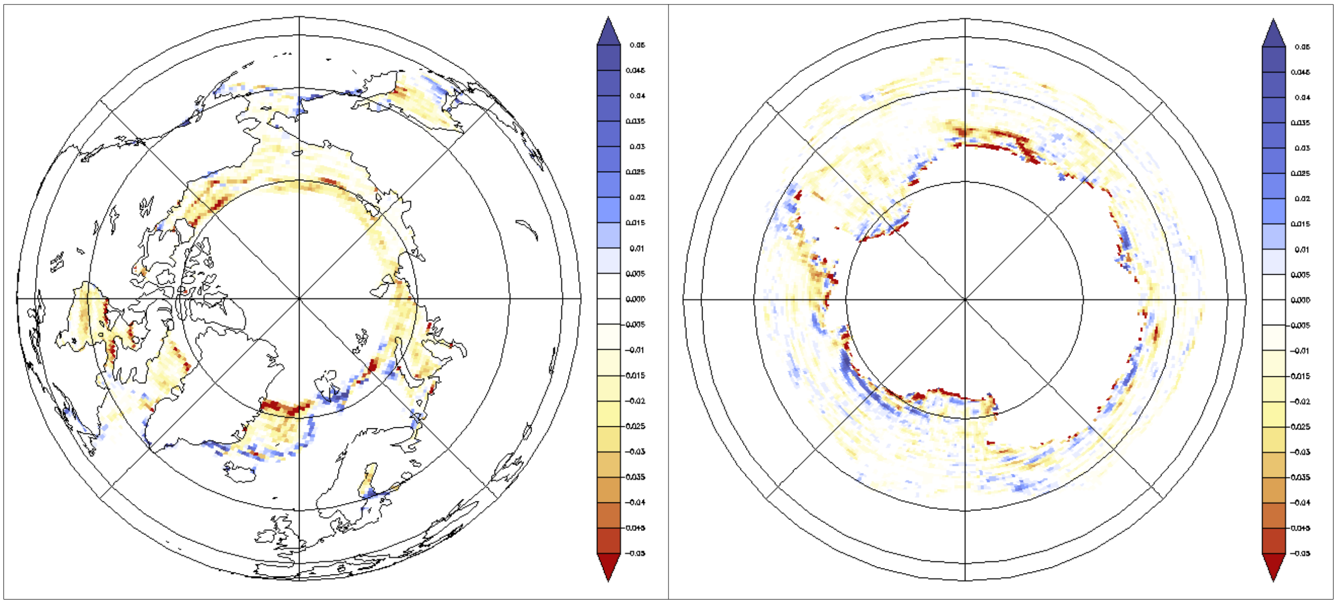


Figure 8: Sea ice cover (%) anomaly compared to STD for SMO (upper) and SMI (lower), annual average

4. Conclusion

Even if it seems difficult to rely on this study to conclude to the level of relevance of an implementation in ARPEGE of the exchange grid in one hand, and of the separate coupling of multi-ice category surface field on the other hand, it could be established that:

- spatial ice temperature variability under atmosphere mesh is bigger than variability of per category ice temperature interpolated on the same atmosphere grid point
- one year integrated effect of exchange grid fluxes in ocean is modifying total ice volume in both Arctic and Antarctic regions, which is less significantly the case for multi-ice category coupling (even though in the later case, regional differences are observed)

This suggest that a priority implementation of the exchange grid coupling technique would bring bigger improvements of the non solar heat flux coupling representation.

Nevertheless, would this conclusion be the same if, on one hand, exchange grid fluxes would be received by the ocean without filtering (spatial smoothing) and if, on the other hand, ice category flux would be received by its category without average with the other category fluxes ?

What would happen if both effects (exchange grid + multi-ice category) would be added ?

In any case, we would like to emphasise the relative value of ice volume impact of both coupling strategy: less than 0.4 MKm3, to be compared with a maximum ice volume of 30 MKm3. Isn't this value comparable to the spread produced by many ocean/ice parameter uncertainty ? This question necessarily needs to be investigated before any huge modification (although probably smaller in the multi-ice category case) of the SURFEX-ARPEGE code.

Reference

[1] Maisonnave, E. and Voldoire, A., 2018: Exchange grid: implementation of a test configuration to evaluate fluxes modification, Working Note, **WN/CMGC/18/47**, CECI, UMR CERFACS/CNRS No5318, France