Analysis of SCRIP conservative remapping in OASIS3-MCT – Part A

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1. Introduction

This report analyses the impact of different normalisations available for the SCRIP conservative remapping (CONSERV) for different grids. This impact is evaluated based on the global conservation of surface-integrated quantities from the source to the target grid. We start by describing the new support of cell fractions (section 2), which allow for a much more exact conservation of surface-integrated quantities. The impact of the DESTAREA and FRACAREA normalisations are first analysed for different grids, as implemented in the original OASIS3-MCT_4.0 release (section 3). The impact of activating the Lambert projection above a certain latitude (section 4) and of a new bugfix, the so-called "lcoinc fix", (section 5) are then analysed. A new option for the conservative normalisation, i.e. the "True Area" correction, is evaluated in section 6. Finally, the impact of the different options for the specific case of the Gaussian Reduced grid are presented in section 7. The report ends with a series of conclusions summarizing the different findings (section 8).

The grids tested are the ones used in the low-resolution coupled model at IPSL, IPSL-CM6_LR, and at CNRM, CNRM-CM6-1, i.e. NEMO for the ocean and LMDz, DYNAMICO, or the Gaussian Reduced for the atmosphere:

- NOGT : NEMO ORCA1 logically rectangular grid, 362x294 points
    - columns with i=1,2 overlap columns with i=361,362 and columns with i=1 and i=362 are masked ;
    - row with j=294 is masked as it overlaps row with j=293 ;
    - cell 105970 is a "polar" cell in the SCRIP sense since a cell border between the corners located at (253.0, 89.6213) to (73.0 , 89.9417) crosses the North pole.
- BGGD : LMDz regular latitude-longitude grid, 143x144 points

    - its last latitude row is formed of 143 degenerated triangular cells going to the pole (the two original upper corners overlap); there is no polar cell in the SCRIP sense.
- ICOS : DYNAMICO icosahedral grid, 15212 points
    - cell 15211 covering the North pole is a "polar" cell in the SCRIP sense as it covers the pole.
- SSEA : ARPEGE T127 Gaussian Reduced, 24572 points;
    - its last latitude row is formed of 20 degenerated triangular cells going to the pole; there is no polar cell in the SCRIP sense.

We note here that a "polar" cell in the SCRIP sense is a cell covering the pole or a cell with one border crossing the pole.

We also note that the so-called the “true” area of the grid cells is the cell surface as it is considered in the model. This “true” area should be provided for the grid in the auxiliary file `areas.nc.` Note that this “true” area must be expressed in square radians if the TR correction (see section 6) is activated.

In all this report, numerical results are provided with 4 fractional digits. The same results with 9 fractional digits can be found at https://inle.cerfacs.fr/projects/oasis3-mct/wiki/Summary_of_analysis_of_SCRIP_CONSERV_including_True_Area_(TR)_normalisation .

2. Cell fractions and best practice to define them

Since July 2019, additional conventions are adopted in OASIS3-MCT auxiliary file masks.nc for the support of cell fractions. Indeed, cell fractions allow for a much more exact conservation of surface-integrated quantities. Here are few details about fractions:

- If present, fractions must be provided in OASIS auxiliary file `masks.nc`; the fractions field must be called `${grid}.frc` , where `${grid}` is the grid prefix.
- If present, fractions are considered in the calculation of the global conservation operation CONSERV (not to mistake with the SCRIP CONSERV remapping). If fractions are not present, only the mask is considered in the global CONSERV.
- If a mask exists, fractions and mask must be coherent, i.e. the mask must be 1 where the fraction is null and it must be 0 where the fraction is > 0 (following OASIS counterintuitive but historical convention of 1 for masked invalid points and 0 for non-masked valid points. If fractions and mask are not coherent, OASIS3-MCT will abort with an error message.
- Of course, upward compatibility is ensured and the previous convention without cell fractions works as before.

In principle, the fractions can be defined for both the source and target grids. But for ocean-atmosphere coupling, we strongly encourage the following best practice for a consistent ocean-atmosphere coupled system. Indeed, to have a well-posed coupled problem, the ocean and the atmospheric total surfaces must be the same allowing global conservation of integrated quantities. To do so, the original ocean mask should be taken as it is from the ocean model and the global water surface is then the sum of the “true” areas (as defined in the auxiliary file `areas.nc`) of the non-masked active cells. For the atmosphere, cell fractions should be defined by the conservative remapping of [1 - ocean mask] on the atmospheric grid, retaining fractions above a certain threshold, that can be fixed by the user. These atmospheric cell fractions should be used in the atmospheric model to define the % of ocean (water) subsurface to be considered. Then the atmospheric coupling mask should be adapted associating a non-masked index (i.e. 0) to all cells with a water fraction above the chosen threshold. The global water surface as seen by the atmosphere model is then the sum of its cell areas multiplied by its respective cell fractions. Note that masked atmospheric cells should have null ocean fractions.

If we follow this best practice, the atmospheric cell fractions and mask will be specific to the coupling with each particular ocean grid. As specific attribute named “coherent_with_grid” indicating the grid prefix of the “companion” grid may be defined for mask and fractions. If the OASIS API is used to define the mask and fractions, this can be done via the optional argument “`companion`” indicating the grid prefix of the “companion” grid.

In most of the following examples, we use NOGT for the "ocean" side but we also made few additional tests considering the icosahedral DYNAMICO grid (ICOS) for the ocean. In all tests described in this report, the atmospheric cell fractions were computed following the best practice described above, i.e. remapping [1 – ocean model mask] on the atmospheric grid using the SCRIP first order conservative remapping with the DESTAREA normalization and a Lambert projection for latitudes above 1.45 rad (83 deg) N (see section 3. and 4. below). Only fractions above 0.01 (1%) are retained and the coupling atmospheric mask was adapted accordingly, as proposed above.

3. Original impact of DESTAREA and FRACAREA normalisations

We provide here a detailed analysis of the DESTAREA and FRACAREA normalisations for the couple of grids BGGD-NOGT, ICOS-NOGT and BGGD-ICOS, as implemented in the original OASIS3-MCT_4.0 release. The only aspect that is additional to OASIS3-MCT_4.0 is the use of atmospheric cell fractions, presented in section 2., so to have a meaningful comparison of area-integrated coupling quantities between the source and the target grids.

We recall that two types of normalisation exist originally in the SCRIP library. With DESTAREA, the total target cell area (`grid2_area`) is used to normalise each target field value even if its corresponding cell only partly intersects non-masked source grid cells; local flux conservation is ensured, but unreasonable field values may result. With FRACAREA, the sum of the non-masked source cell intersected areas (`grid2_frac`) is used to normalise each target field value; the flux is not locally conserved, but the flux value itself is reasonable.

To analyse the quality of the SCRIP conservative remapping, we used the `test_interpolation` environment, provided with the OASIS3-MCT sources (see `oasis3-mct/examples/test_interpolation`), in which a coupling field defined by an analytical function is exchanged and remapped between two toy components.

For some remappings, we observed problems for the "polar" cell (in the SCRIP sense, see 1. Introduction above). To analyse these problems, we report in the table below:

Commented [MOU2]: Further analysis reported in TR-CMGC-19-155 showed that problems occur for other cells than the polar one; comments added in this revised version make the link with these additional observations.

- the "true" target polar cell area, from the auxiliary file `areas.nc` (NP target cell - true area)
- the target polar cell area calculated by the SCRIP (NP target cell - grid2_area)

- the sum, for the target polar cell, of the non-masked source cell intersected areas, `grid2_frac`, used for normalisation in FRACAREA (NP target cell - grid2_frac)
- the value at the target polar cell center of the analytical function giving the value that the target polar remapped value should have (NP value analytical)
- the target polar cell remapped value with DESTAREA (NP value - DESTAREA)
- the target polar cell remapped value with FRACAREA (NP value - FRACAREA)
- the total energy[1] on the source grid (Energy on source grid)
- the total energy on the target grid with DESTAREA (Energy on target grid - DESTAREA)
- the total energy on the target grid with FRACAREA (Energy on target grid - FRACAREA)

The total energy is computed by OASIS3-MCT global conservation operation CONSERV (with GLOBAL option) **without Lambert projection nor any of the modifications discussed below**. The total energy is therefore the sum of the field value on non-masked cells multiplied by the true surface in radians and, for atmospheric grids, by the atmospheric cell fractions. As the atmospheric cell fractions were adapted so to have a coherent sea-land mask (see section 2.) and as the remapping should be conservative, the total energy on the source and on the target grids should be very close.

		BGGD->NOGT	NOGT->BGGD	ICOS->NOGT	NOGT->ICOS	BGGD->ICOS	ICOS->BGGD
NP target cell	true area	5.4131 E-05	-	5.4131 E-05	5.9258 E-04	5.9258 E-04	-
	grid2_area	-6.2830 shifted to 1.0072 E-04	-	-6.28307 shifted to 1.14552 E-04	-6.2824 shifted to 7.8295 E-04	-6.2824 shifted to 7.8295 E-04	-
	grid2_frac	-4.1886	-	-6.2830 shifted to 1.1455 E-04	-6.2824 shifted to 7.8295 E-04	7.8295E-04	-
NP value analytical		1.7391	1.7411	1.7391	1.7411	1.7411	1.74118
NP value	DESTAREA	-72406.8029	-28423.3448	1.7411	1.7409	1.7411	1.7411
	FRACAREA	1.7411	1.7391	1.7411	1.7409	1.7411	1.7411
Energy on source grid		16.6109	16.6119	16.6110	16.6119	17.6178	17.6184
Energy on target grid	DESTAREA	12.6921	9.0042	16.6115	16.2824	17.6180	17.4046
	FRACAREA	16.6119	16.6110	16.6119	16.6110	17.6183	17.6178

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[1] We suppose that the coupling field is a flux of energy and therefore the area-integrated field on non-masked cells represents the energy leaving the source grid or entering the target grid.

Note that a “-“ in this table and the following ones simply means that we did not register the corresponding values and do not have them at hand anymore.

The following conclusions and remarks can be made at this point:

- A problem occurs with DESTAREA for BGGD->NOGT and NOGT->BGGD as shown by the obviously wrong value of the polar cell value and the too low total energy on the target grid (in red in the table). A deeper analysis leads to the conclusion that some BGGD source cells that should contribute are not considered in the calculation of the intersections between the BGGD cells and the NOGT polar cell. This calculation is particularly tricky as the BGGD last latitude row is formed of 143 degenerated triangular cells going to the pole with two corners overlapping at the pole.
- Surprisingly, FRACAREA gives good results for all grids studied here, i.e. BGGD<->NOGT, ICOS<->NOGT and ICOS<->BGGD. Further analysis shows that in this case, as in DESTAREA, some BGGD source cells that should contribute are not considered. However, the final result is good because the normalisation involving `grid2_frac` leads to a compensation of errors in the calculation of the field value, at the numerator, and of `grid2_frac`, at the denominator.
- The remapping involving ICOS and NOGT or ICOS and BGGD give good results for both DESTAREA and FRACAREA; indeed, as ICOS has a mesh covering the pole (i.e. no border crossing the pole and no corner at the pole), the calculation of the intersection with NOGT polar cell or with BGGD triangular cells is not problematic; DESTAREA and FRACAREA give very close results which is expected as no cells are masked in this region near the North pole.
- We observe (even if we don't understand the justification) that :
    - when NOGT or ICOS is the target grid, the `grid2_area` polar cell value is "shifted" by 2*Pi. In the SCRIP code, the criteria for the shift is "`grid2_area < -3/2*Pi`", which is fulfilled for NOGT and ICOS polar cell.
    - when the remapping involves both NOGT and ICOS, the `grid2_frac` polar cell value is also "shifted" by 2*Pi. Indeed, in the SCRIP code, the criteria for the shift is “there is a polar cell in both the source and target grids”.

These shifts will have an impact on the true area normalisation, as we will see in section 6.

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Commented [MOU4]: This is coherent with TR-CMGC-19-155, see Fig 2b and Fig 3b (no Lambert projection, FRACAREA for bggd<->nogt and icos<->nogt ; cases icos<->bggd are not addressed there)

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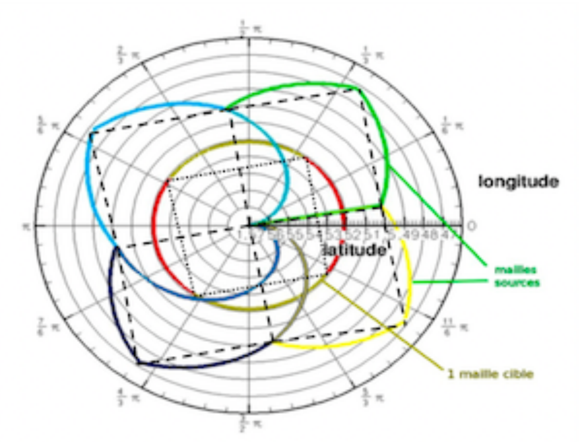
4. Impact of Lambert projection

For the SCRIP CONSERV (1st order conservative remapping), the weight of a source cell is proportional to the area of the source cell intersected by the target cell. Using the divergence theorem, the SCRIP library evaluates this area with the line integral along the cell borders enclosing the area. As the real shape of the borders is not known (only the location of the corners/vertices of each cell is known), the library assumes that the borders are linear in latitude and longitude between two corners. For most grids, this assumption becomes less valid closer to the pole. For example, the next figure shows in colour the borders considered by the SCRIP for 4 "diamond" source cells covering the North pole region, each one having one top corner at the North Pole, two corners at 85.944 deg N and 90 deg apart in longitude, and one bottom corner at 84.225 deg N; we see that the cells get very distorted and do not correspond to the intuitive vision of cells equally covering the North Pole region (illustrated in dashed lines on the figure).



Therefore, for latitudes above/below a certain threshold (`north_thresh/south_thresh` values that can be adapted by the user, see `oasis3-mct/lib/scrip/remap conserv.F90`) the library calculates the intersection between two borders using a Lambert equivalent azimuthal projection. In section 3., the Lambert projection was not activated. The results activating the Lambert projection above 83.08 deg N (1.45 radians) are compared to the results without Lambert in the following table.

			BGGD->NOGT	NOGT->BGGD	ICOS->NOGT	NOGT->ICOS	BGGD->ICOS	ICOS->BGGD
NP target cell	Lambert	true area	5.4131 E-05	-	5.4131 E-05	5.9258 E-04	5.9258 E-04	-
		grid2_area	-6.2831 shifted to 7.3098 E-005	-	-6.2830 shifted to 1.1455 E-004	-	-	-
		grid2_frac	7.3098 E-005	-	-6.2830 shifted to 1.1455E-004	-	-	-
NP value analytical			1.7391	1.7411	1.7391	1.7411	1.7411	1.7411
NP value	no Lambert	DESTAREA	-72406.8029	-28423.3448	1.7411	1.7409	1.7411	1.7411
		FRACAREA	1.7411	1.7391	1.7411	1.7409	1.7411	1.7411
	Lambert	DESTAREA	1.7411	-28423.3448	1.7411	1.7409	1.7411	1.7411
		FRACAREA	1.7411	1.7391	1.7411	1.7409	1.7411	1.7411
Energy on source grid			16.6109	16.6119	16.6110	16.6119	17.6178	17.6184
Energy on target grid	no Lambert	DESTAREA	12.6921	9.0042	16.6115	16.2824	17.6180	17.4046
		FRACAREA	16.6119	16.6110	16.6119	16.6110	17.6183	17.6178
	Lambert	DESTAREA	16.6117	13.3296	16.6115	16.2824	17.6180	17.4046
		FRACAREA	16.6113	16.6110	16.6119	16.6110	17.6183	17.6178

The following conclusions and remarks can be made at this point:

- For BGGD->NOGT, the Lambert projection solves the problem observed in section 3 but it does not for NOGT->BGGD (we will see in section 5 that the "lcoinc fix" is needed to do so). We observed that for BGGD->NOGT, the Lambert projection ensures, both for FRACEARA and DESTAREA, that all BGGD source cells that should contribute do contribute; grid2_area and grid2_frac are now more or less equal (even if not close to the “true” area), which is expected as there are no masked cells in the polar region (but it may happen that the calculation precision gives slightly different results).
- Besides the effect on BGGD->NOGT, the Lambert projection has very low or no impact on the other remappings.
- For few cases, results for the NP value with DESTAREA and FRACAREA are strictly the same (e.g. for ICOS->NOGT and NOGT->ICOS); once again, this is expected as there are no masked cells in the polar region.

Commented [MOU6]: This is coherent with TR-CMGC-19-155 which shows that combination of Lambert projection and lcoinc fix give good results for bggd<->nogt.

Commented [MOU7]: TR-CMGC-19-155 gets to the same conclusion.

5. Impact of "lcoinc fix"

The remaining problem for the NOGT->BGGD remapping, not solved by the Lambert projection, lead us to look into more details on this case. When interpolating from NOGT to BGGD with DESTAREA target values at polar cells can become unrealistic. We observed that, in this case, even if there are no masked points for both grids around the North Pole, `grid2_frac` and `grid2_area` values (for BGGD) differ (not shown on the table above). Looking at how these two quantities are cumulated during the integrations, we noticed that more source-target cell intersections are considered in the calculation of `grid2_area` than in the calculation of `grid2_frac` : for some source-target cell pairs, a condition on coincidence of segments (that we will call the “lcoinc" condition) is (erroneously) true and the corresponding source-target intersection is not considered.

Looking further at this problem, we observed that when the lcoinc condition is verified (i.e. is set to true) it is not reinitialised for the next cell ! We provided a bug fix, ensuring that the lcoinc is reinitialised to `.false.` for each cell, and re-run the cases. Note that you can find a detailed analysis of this lcoinc condition for the NOGT->SSEA case at the end of the page https://inle.cerfacs.fr/projects/oasis3-mct/wiki/Discussion_about_specific_treatments_of_polar_cells_in_scrip_CONSERV_interpolation

We observe that the lcoinc fix does not change the results for any remapping, except for NOGT->BGGD, where it solves the remaining problem observed in section 4. With the lcoinc fix:

- the "NP value DESTAREA Lambert" is now 1.7402 (wrt to -28423.3448 without the lcoinc fix) for an analytical value of 1.7411
- the "Energy on target grid DESTAREA Lambert" is now 16.2891 (wrt to 13.3296 without the lcoinc fix) for an analytical value of 16.6119

The following table summaries the results obtained using both the Lambert projection and with the lcoinc fix:

			BGGD->NOGT	NOGT->BGGD	ICOS->NOGT	NOGT->ICOS	BGGD->ICOS	ICOS->BGGD
NP value analytical			1.7391	1.7411	1.7391	1.7411	1.7411	1.7411
NP value	Lambert + lcoinc fix	DESTAREA	1.7411	1.7402	1.7411	1.7409	1.7411	1.7411
		FRACAREA	1.7411	1.7391	1.7411	1.7409	1.7411	1.7411
Energy on source grid			16.6109	16.6119	16.6110	16.6119	17.6178	17.6184
Energy on target grid	Lambert + lcoinc fix	DESTAREA	16.6117	16.2891	16.6115	16.2824	17.6180	17.4046
		FRACAREA	16.6113	16.6110	16.6119	16.6110	17.6183	17.6178

In conclusion, for the couple of grids studied here (BGGD-NOGT, ICOS-NOGT, BGGD-ICOS) the Lambert projection with a `north_thresh` = 1.45 is recommended and the lcoinc fix is mandatory.

Commented [MOU8]: TR-CMGC-19-155 gets to a more specific, although not contradictory, conclusion, that the Lambert projection + lcoing fix are mandatory for bggd<->nogt but that the Lambert projection has almost no impact on other couple of grids.

6. Impact of True Area (TR) correction

As seen above, the interpolated values around the non-masked North Pole suffer from the numerical approximations in the SCRIP routines: even if we adopt a Lambert projection to simplify the segment intersections detection (see section 4), the line integrals follow straight segments that do not fit the real curvature of the cell borders considered by the model itself. These approximations act both on the computation of the weights for each "link" (defined as each contribution from a source cell to a target cell) and on the estimation of the cell areas. To have an exact conservation of the fluxes exchanged, a normalisation with the "TRue" (TR) area of the cells, i.e. cell areas considered by the model and provided in auxiliary file areas.nc, is therefore in principle mandatory. We note here that this is also an official requirement for the CMIP6 regridding weight files possibly used in the data post-processing.

Since June 2019, three new normalisation options are available for the SCRIP CONSERV interpolation in OASIS3-MCT, i.e. DESTARTR, FRACARTR, and FRACNNTR. These are based on DESTAREA, FRACAREA and FRACNNEI normalisation adding what we call the “TR correction” that accounts for discrepancies between the cell surface estimates computed by SCRIP and the true cell areas considered by the models. Equations from Chavas et al. 2013 (eqn. (27) in particular) are implemented. To activate these options, it is therefore mandatory to provide the true cell areas in the `areas.nc` auxiliary file (in square radians).

Special care has to be taken for "polar" cells in the SCRIP sense. As seen above in sections 3. and 4., the SCRIP detects cells encompassing a pole or cells with a side going through a pole as "polar" cells and a specific treatment may be applied (e.g. a shift of 2 * Pi for `grid2_area`). The resulting estimated area serves as a normalisation factor but its value is not representative of the true surface of the cell anymore. For this reason, if a source cell or a destination cell of a link is detected as "polar" and undergoes such specific treatment, we cannot apply the full TR correction to the normalisation factor.

Moreover, in the case of a polar cell with a side passing through the pole, we have to remember that there is also a companion cell, neighbouring the polar cell along this side, for which the surface estimate cannot either be directly compared to the true surface; yet the SCRIP does not flag this cell with a specific “polar” attribute. As an example, for NOGT, cell 105970 is detected as "polar" since the segment from its corners located at (253.0, 89.6213) and (73.0 , 89.9417) crosses the North pole, but cell 105801, which shares the same segment isn't. For this companion cell the estimated area is 3.5245 E-05 while the true surface is 5.4131 E-05.
We therefore introduced criteria for the detection of cells which the true area correction should not be applied[2]

- for polar cells, either source or target, as detected by SCRIP, the TR correction is not applied;
- for other cells, either source or target, we check if the ratio between the estimated and true areas stays the range [0.8, 1.2]; if it does not, the TR correction is not applied.

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[2] Details can be found at https://inle.cerfacs.fr/projects/oasis3-mct/wiki/Evaluation_of_the_two_variants_of_the_TR_workaround_at_Poles; note that what we describe in the current report as the TR correction corresponds to the TR2 correction on that page.

Note that these criteria are automatically applied by OASIS3-MCT and the user does not have to specify anything in particular.

To validate and evaluate the impact of the TR correction we compare the DESTARTR and FRACNNTR results with respectively the DESTAREA and FRACNNEI ones for all pair of grids studied above. For the "ocean" side of these tests, we use either NOGT or ICOS. The atmospheric cell fractions are calculated as detailed in section 2. As explained above, the atmospheric cell fractions, and therefore the water surface of an atmospheric grid, depend on the mask of the ocean model to which it is coupled. The resulting ocean water surface are given in the following table. In particular, we notice the different water surfaces for BGGD when it is coupled to two different oceanic grids, NOGT and ICOS.

Ocean model	**Ocean water surface (rad^2)**	**Atmos model**	**Atmos water surface (rad^2)**	**Misfit %**
NOGT	8.9350	SSEA	8.9345	-0.00605%
NOGT	8.9350	ICOS	8.9345	-0.00608%
NOGT	8.9350	BGGD	8.9345	-0.00606%
ICOS	9.5311	BGGD	9.5308	-0.00319%

In the next paragraphs, we compare the total energy on the source and target side. We recall that the field on the source grid is defined by the value of analytical function at the grid points and the field on the target side is the remapped field using the different normalisation options.

For all tests, we use a 1st order SCRIP CONSERV remapping activating the Lambert projection (see section 4) when computing intersections at latitudes over 1.45 rad (83 deg) North. The lcoinc fix is applied in the original SCRIP implementation in order to prevent the false detection of coincident segments (see section 5).

NOGT as a source ocean grid

Norm	**Energy on NOGT**	**Energy on ICOS**	**Misfit %**
DESTAREA	16.6119	16.2824	-1.9838 %
DESTARTR	16.6119	16.2830	-1.9802 %
FRACNNEI	16.6119	16.6111	-0.0054 %
FRACNNTR	16.6119	16.6116	-0.0017 %

Norm	**Energy on NOGT**	**Energy on BGGD**	**Misfit %**
DESTAREA	16.6119	16.2891	-1.9434 %
DESTARTR	16.6119	16.2899	-1.9387 %
FRACNNEI	16.6119	16.6110	-0.0058 %
FRACNNTR	16.6119	16.6118	-0.0009 %

NOGT as a target ocean grid

Norm	**Energy on ICOS**	**Energy on NOGT**	**Misfit %**
DESTAREA	16.6110	16.6115	+0.0034 %
DESTARTR	16.6110	16.6109	-0.0004 %
FRACNNEI	16.6110	16.6119	+0.0054 %
FRACNNTR	16.6110	16.6112	+0.0016 %

Norm	**Energy on BGGD**	**Energy on NOGT**	**Misfit %**
DESTAREA	16.6109	16.6117	+0.0048 %
DESTARTR	16.6109	16.6109	0.0000%
FRACNNEI	16.6109	16.6119	+0.0058 %
FRACNNTR	16.6109	16.6111	+0.0009 %

ICOS as a source ocean grid

Norm	**Energy on ICOS**	**Energy on BGGD**	**Misfit %**
DESTAREA	17.6184	17.4046	-1.2135 %
DESTARTR	17.6184	17.4048	-1.2119 %
FRACNNEI	17.6184	17.6178	-0.0031 %
FRACNNTR	17.6184	17.6181	-0.0015 %

ICOS as a target ocean grid

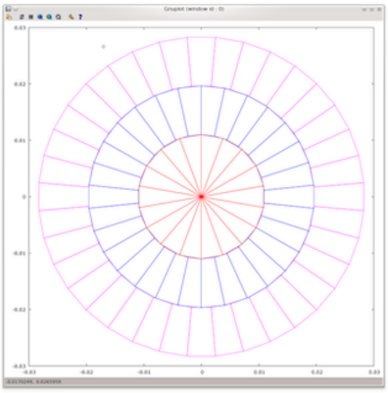
Norm	**Energy on BGGD**	**Energy on ICOS**	**Misfit %**
DESTAREA	17.6178	17.6180	+0.0015 %
DESTARTR	17.6178	17.6178	0.0000%
FRACNNEI	17.6178	17.6183	+0.0031 %
FRACNNTR	17.6178	17.6180	+0.0015 %

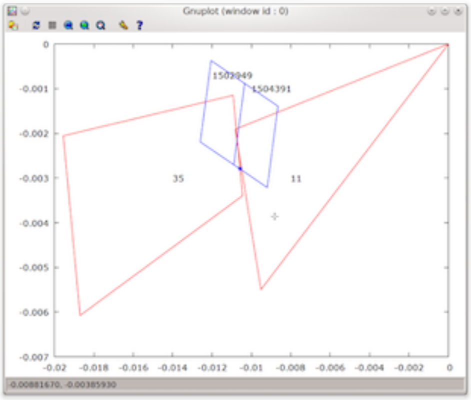
In conclusion, the TR correction is validated, as it always reduces the misfit and sometimes by several order of magnitude. But it has to be mentioned that, for the couples of grids used in the above tests, which take into account a proper definition of coupling masks and fractional areas, the misfit is always small even without the TR correction. Furthermore, the fact that the TR correction cannot be applied to the “polar” cells (in the SCRIP sense), because the area of these cells is transformed by the SCRIP and is not representative of a surface anymore, reduces also its interest.

7. Analysis of conservative remapping for the Gaussian Reduced grid

The conservative remapping of coupling fields involving a Gaussian Reduced grid has always been, and still is, a challenge. This is linked to the fact that the corners of Gaussian Reduced grid cells on a specific latitude row do not necessarily coincide with the corners of the cells of the upper or lower latitude rows in the reduced part of the grid. We therefore devote an entire section to this special case, detailing the specific problems occurring with this grid, evaluating the impact of the Lambert projection and lcoinc fix presented above.

The figures below show the cells of the SSEA grid in the Lambert equivalent azimuthal projected space. The left one shows 3 latitude rows around the pole. The right one shows two cells of the SSEA grid in red and two cells of the NOGT grid in blue.





We can see that, as the corners of a cell do not match the corners of a neighbour cell, the cells do not completely cover the globe; some holes are indeed present. The calculation of the cell border intersections between source and the target cells in the Lambert projected space will therefore most likely not work properly when the SSEA grid is involved.

7.1. Impact of Lambert projection and lcoinc fix

We analyse here the SCRIP conservative remappings involving the SSEA grid coupled to the NOGT grid, without or with the Lambert projection (see section 4) and without or with the lcoinc fix (see section 5). Results are summarised in the table below. For the SSEA grid, the 18th of the 20 degenerated triangular cells on the upper latitude row is (arbitrarily) considered here as being the north polar (NP) cell.

			SSEA->NOGT	NOGT->SSEA (cell 18)
NP target cell area			**5.4131 E-05**	**1.4935 E-04**
NP target cell	no Lambert	grid2_area	-6.2830 shift to 1.0112 E-04	-
	no Lambert	grid2_frac	-3.76981	-
	Lambert	grid2_area	-6.2831 shift to 6.2701 E-05	1.4766 E-04
	Lambert	grid2_frac	6.2701 E-05	-
NP value analytical			**1.7391**	**1.7323**
NP value	no Lambert	DESTAREA	-64819.5707	-3656.5343
		FRACAREA	1.7387	1.7391
	Lambert	DESTAREA	1.7345	-3662.0388
		FRACAREA	1.7345	1.7390
	Lambert lcoinc fix	DESTAREA	1.7345	1.8510
		FRACAREA	1.7345	1.8510
Energy on source grid			**16.6109**	**16.6119**
Energy on target grid	no Lambert	DESTAREA	13.1029	9.7771
		FRACAREA	16.6119	16.6110
	Lambert	DESTAREA	16.6135	11.3759
		FRACAREA	16.6119	16.6110
	Lambert lcoinc fix	DESTAREA	16.6135	16.3335
		FRACAREA	16.6119	16.6110

Globally, the conclusions are the same than for BGGD<->NOGT remappings. This is not so surprising as SSEA and BGGD have the same grid structure near the pole with the northern most latitude formed of degenerated triangular cells going to the pole.

- Without Lambert nor lcoinc fix, problems occur with DESTAREA for SSEA->NOGT and NOGT->SSEA (red values in the table); as for BGGD, some SSEA source cells that should contribute are not considered.
- For SSEA->NOGT, the Lambert projection solves the problem observed with DESTAREA problem (the projection ensures that all sources cells are considered; this can also be deduced by the fact that `grid2_frac = grid2_area` in that case), but it does not for NOGT->SSEA.
- The lcoinc fix solves the remaining problem observed with DESTAREA for NOGT -> SSEA.
- As for BGGD, results with FRACAREA for SSEA->NOGT and NOGT -> SSEA seem fine even without Lambert nor lcoinc fix; but we observed that this is because the normalisation involving `grid2_frac` leads to a compensation of errors included

Commented [MOU9]: This is coherent with TR-CMGC-19-155

Commented [MOU10]: In TR-CMGC-19-155, SSEA is ssea4v. This report shows that Lambert projection does not solve all problems; for ssea4v->nogt, the maximum error is 100% without Lambert but goes up ~1000% with Lambert; for nogt->ssea4v, the maximum error is 100% without Lambert but is still ~10% with Lambert

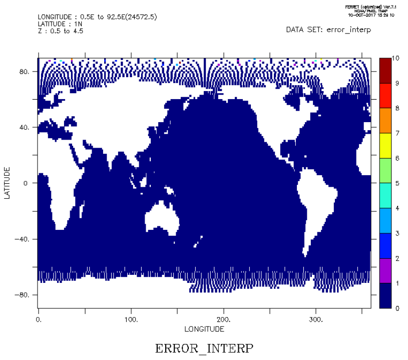
Commented [MOU11]: TR-CMGC-19-155 conclusions are stronger in the sense that it shows that Lambert should not be activated for FRACEAREA for ssea4v<->nogt: for ssea4v->nogt, the maximum error is ~0.5% without Lambert whereas it is 10.6% for ssea4v->nogt with Lambert; for nogt->ssea4v
a maximum error of ~9% occurs if Lambert is activated, where as it is ~1% (i.e. acceptable) without Lambert.

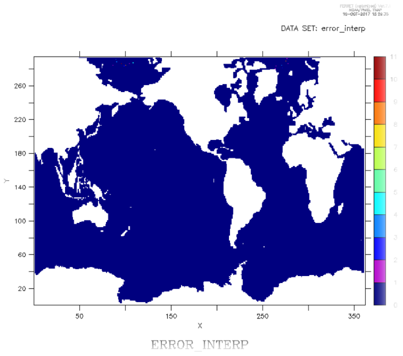
in the calculation of the field value, at the numerator, and in the calculation of `grid2_frac`, at the denominator.

- Including the fix for lcoinc, the result of the value at the pole per se seems worse for FRACAREA (1.8510 vs 1.7390) but this is because of a greater sum of approximations.

These results look somewhat contradicting with what we stated above (about the Lambert projection most likely not working properly when the SSEA grid is involved), but this is because we looked only at the NP value and the total energy. A more specific analysis over the whole domain shows that the FRACAREA maximum error, which is less than 1% without the Lambert projection, can reach about 10% when it is activated, in both directions. This is shown on the figure below for NOGT -> SSEA on the left and for SSEA -> NOGT on the right.

Commented [MOU12]: This analysis is presented in TR-CMGC-19-155; for FRACEAREA with Lambert projection, the maximum error is 10.6% for ssea4v->nogt, and ~9% for nogt->ssea4v





These tests show that for FRACAREA with the Lambert projection, the error maximum is not located at the North pole but around the pole (more exactly on cell (68,1) on SSEA and (96, 286) on NOGT, although this is not easy to detect on the above figure) and this is why we don’t notice them in the above table.

7.2. Impact on TR correction

We compared the activation of the TR correction for the SSEA and NOGT couple of grids, in the same conditions than the ones described in section 6 above. The results are summarised in the tables below:

NOGT as a source ocean grid

Norm	**Energy on NOGT**	**Energy on SSEA**	**Misfit %**
DESTAREA	16.6119	16.3335	-1.6760 %
DESTARTR	16.6119	16.3361	-1.6606 %
FRACNNEI	16.6119	16.6110	-0.0056 %
FRACNNTR	16.6119	16.6136	+0.0098 %

NOGT as the target ocean grid

Norm	**Energy on SSEA**	**Energy on NOGT**	**Misfit %**
DESTAREA	16.6109	16.6135	+0.0153 %
DESTARTR	16.6109	16.6109	-0.0000 %
FRACNNEI	16.6109	16.6119	+0.0058 %
FRACNNTR	16.6109	16.6112	+0.0019 %

Once again, the conclusions are globally the same than for a coupling between BGGD and NOGT: activating the TR correction always reduces the misfit and sometimes by several order of magnitudes, but the misfit is always small even without this correction.

However, we want to stress here that this last conclusion has to be taken with precautions as we observed that important discontinuities may happen in polar region for conservative remapping involving SSEA grid when the TR correction is applied.

With the default normalisations, the interpolation weights for a given target cell always sum up to 1.0 (rounding the numerical approximations). Each weight results from the sum of several (the number depends on the local respective resolutions of the two grids) contributions from line integrals. Enclosed areas are estimated as a difference of larger areas sitting on the left hand of the cell sides (spanned counter-clockwise). In the polar region, for the conservative remapping involving the SSEA grid, we observed that the weights can be large and some are negative, but they compensate each other and still sum up to 1.0 for each target; to our knowledge, these anomalous large negative weights happen only when the SSEA grid is involved[3]. Weighting every link independently with its own TR coefficient, the positive and negative large weights do not compensate anymore and this causes important discontinuities in the resulting field.

As an example, in the NOGT to SSEA case, the 3rd SSEA cell (a cell with two corners at the North Pole) receives contributions from 11 NOGT cells. Even if the TR coefficient does not change any single weight by more than 3%, the weight from cells 104887 and 105249 pass from -12.390052261137 and 12.6586245858448 to -12.0806806663939 and 12.9150544398472. The total sum passes from 1.00000000000072 to 1.90448147129462 and the interpolated value from 1.87536732691114 to 3.43060037123959 (to be compared to the analytical value of 1.72901502565689).

In conclusion, even if it gives proper results regarding the conservation of the global energy per se, the TR correction should not be used when the SSEA grid is involved as field discontinuities may happen in polar region.

7.3. Conservative remapping between unmasked Gaussian Reduced and regular latitude-longitude grids

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[3] A detailed study confirming this assertion can be found at https://inle.cerfacs.fr/attachments/6822/interpolErrors_SCRIP_LR_3.0branch_nneiF.pdf

In order to further test the impact Lambert projection for SSEA, we performed additional remappings between SSEA and BGGD, considering them as fully non masked (and therefore with no fractional coefficients) grids. Results are summarised in the next table.

			SSEA-> BGGD	BGGD->SSEA
NP value analytical			**1.7411**	**1.7323**
NP value	No Lambert	DESTAREA	1.7458	-
		FRACAREA	1.7458	-
	No Lambert lcoinc fix	DESTAREA	1.7458	1.7321
		FRACAREA	1.7458	1.7321
	Lambert lcoinc fix	DESTAREA	-28533.0960	-101.66955
		FRACAREA	1.7458	1.7413
Energy on source grid			**22.3777**	**22.3777**
Energy on target grid	No Lambert	DESTAREA	22.3777	-
		FRACAREA	22.3777	-
	No Lambert lcoinc fix	DESTAREA	22.3777	22.3777
		FRACAREA	22.3777	22.3777
	Lambert lcoinc fix	DESTAREA	22.1493	22.1467
		FRACAREA	22.3777	22.3777

Conclusions:

- The two grids (SSEA and BGGD) share 327 coincident segments which are correctly detected also with the lcoinc fix, which provides a further test of the safety of that fix.
- However, since the reduced SSEA grid is not correctly mapped by the Lambert projection, the Lambert projection has to be deactivated for conservative remapping between SSEA and BGGD grids.

8. Conclusions

We analysed the SCRIP 1st order conservative remapping (CONSERV) for different couple of grids and for different normalisation options. The conclusions of this analysis are the following:

- Without Lambert projection, problems occur for the couple of grids BGGD-NOGT in both directions with DESTAREA. For remapping from BGGD to NOGT, activating the Lambert projection solves the problem. For remapping from NOGT to BGGD, the Lambert projection only does not solve the problem; a bugfix on the condition on coincidence of segment the "lcoinc" fix is also needed.
- Without Lambert projection, FRACAREA gives good results for the couple of grids BGGD-NOGT only because the normalisation leads to a compensation of errors included in the field value, at the numerator, and the normalisation factor (`grid2_frac`), at the denominator.
- In summary, for logically rectangular (NOGT), regular latitude-longitude (BGGD) and icosahedral (ICOS) grids, the SCRIP conservative remapping with the

Commented [MOU13]: Same conclusion in TR-CMGC-19-155

Commented [MOU14]: TR-CMGC-19-155 gets to the conclusion that for bggd<->nogt, FRACAREA gives good and same results with and without Lambert projection.

DESTAREA and FRACAERA normalisations give proper results when the Lambert projection and the “lcoinc” bugfix are activated.

- Besides this positive effect on the conservative remappings involving the BGGD and NOGT grids, the Lambert projection has very low or no impact on the other remappings but gives proper results.

Commented [MOU15]: The reader is referred to TR-CMGC-19-155 provides a more detailed analysis of the benefits and drawbacks of the Lambert projection for the different couples of grids.

- The True Area (TR) correction is validated for all couple of grids studied here, except when the SSEA grid is involved (see below); this correction always reduces the original misfit and sometimes by several order of magnitude. However, in all cases studied here, the original misfit is very small anyway. Furthermore, the fact that the TR correction cannot be applied to the “polar” cells (in the SCRIP sense), because the area of these cells is transformed by the SCRIP and is not representative of a surface anymore, reduces also its interest.
- Special care has to be taken for remapping involving the Gaussian Reduced grid SSEA
    - The calculation of the cell border intersections using a Lambert projection will not work properly for that grid as the corners of the cells of a specific latitude row do not coincide with the corners of the cells of the upper or lower latitude rows in the reduced part of the grid; this results in holes i.e. grid cells not covering the entire globe in the projected space.
    - The conclusions of the analysis of the SCRIP conservative remapping for the North pole value and global energy for the SSEA-NOGT couple of grid are the same than for BGGD-NOGT. However, a more specific analysis over the whole domain shows that the FRACAREA maximum error, which is less than 1% without the Lambert projection, can reach about 10% when it is activated, in both directions. The Lambert projection must therefore not be turned on when the SSEA grid, with corners as defined in this study, is involved.

Commented [MOU16]: The reader is referred to TR-CMGC-19-155 provides a more detailed analysis of the benefits and drawbacks of the Lambert projection for the different couples of grids.

    - For the unmasked SSEA-BGGD remapping, the Lambert projection has to be deactivated; here the specific structure of the SSEA grid causes specific problems with the Lambert projection when it is coupled to the BGGD grid.
    - Regarding the TR normalisation, proper results are obtained when looking at the conservation of the global energy per se; however, the TR normalisation should not be used when the SSEA grid, with cell corners as currently defined, is involved as field discontinuities may happen in polar region.
    - The only clean way to support the conservative remapping for the SSEA grid should be to redefine the corners of the cells so that a cell on one latitude row include also the original corners of the upper and lower latitude rows. Tests with the corners redefined as such are currently going on.

Commented [MOU17]: Contrary to what was expected, TR-CMGC-19-155 shows that this redefinition of the corners is far from solving all problems for conservating remappings involving the ssea grid. See details in there.