A revised ocean-atmosphere physical coupling interface

and about technical coupling software

S. Valcke (CERFACS)
E. Guilyardi (IPSL/LOCEAN & CGAM)
with numerous contributions from the community

Outline

Part I – On an revised ocean-atmosphere physical coupling interface

- Context and guidelines for the design of a new physical interface
- The physical exchanges
- Time sequence of exchanges

Part II - About technical coupling software

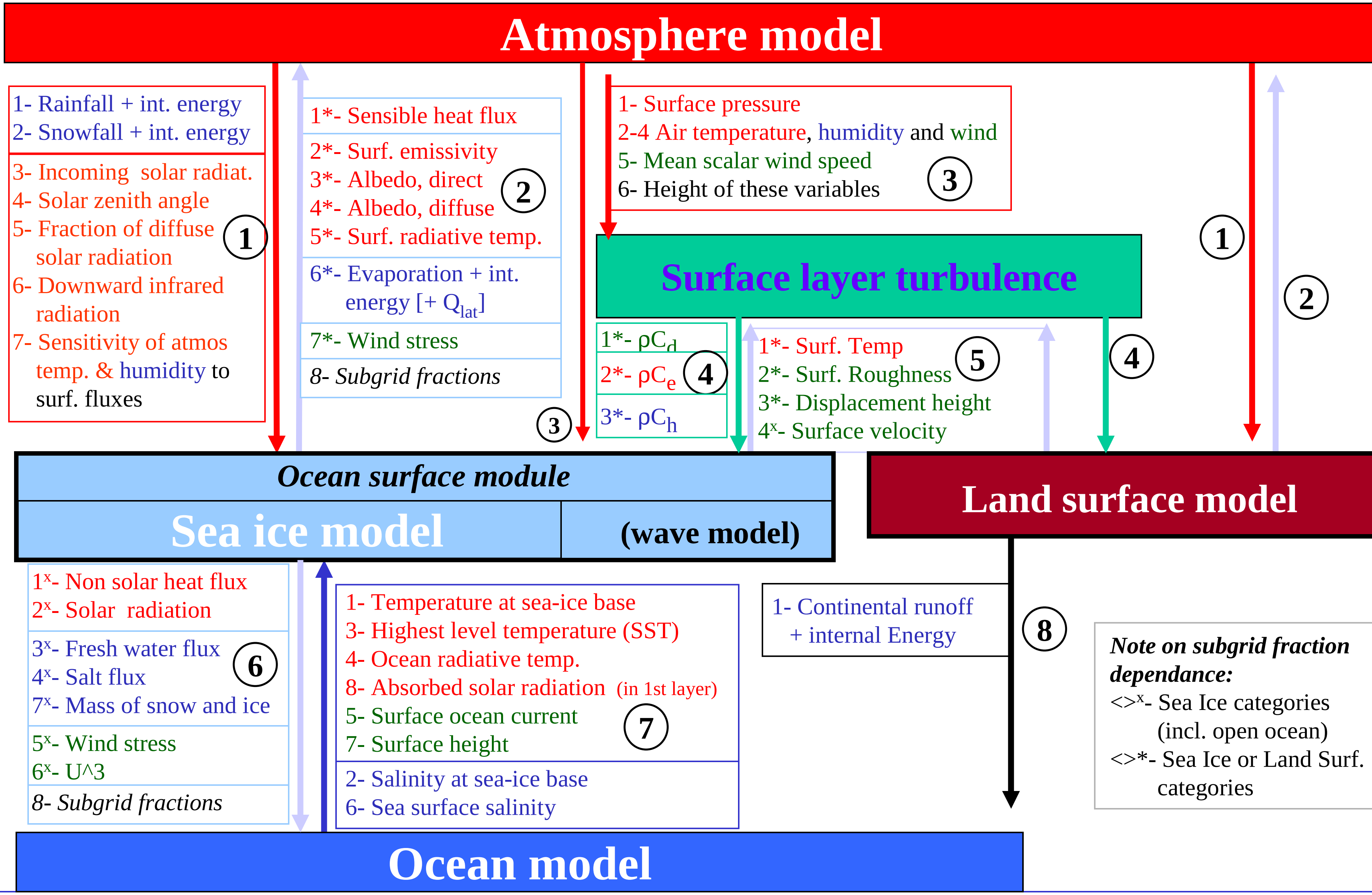
- Different technical solutions to assemble model codes
- The OASIS coupler (historic, community, …)
- Regridding algorithms in OASIS
- 1st order conservative remapping (2^{nd} order, SUBGRID)
- Non-matching sea-land mask
- Vector interpolation

I.1 Context and guidelines for the design of a revised interface

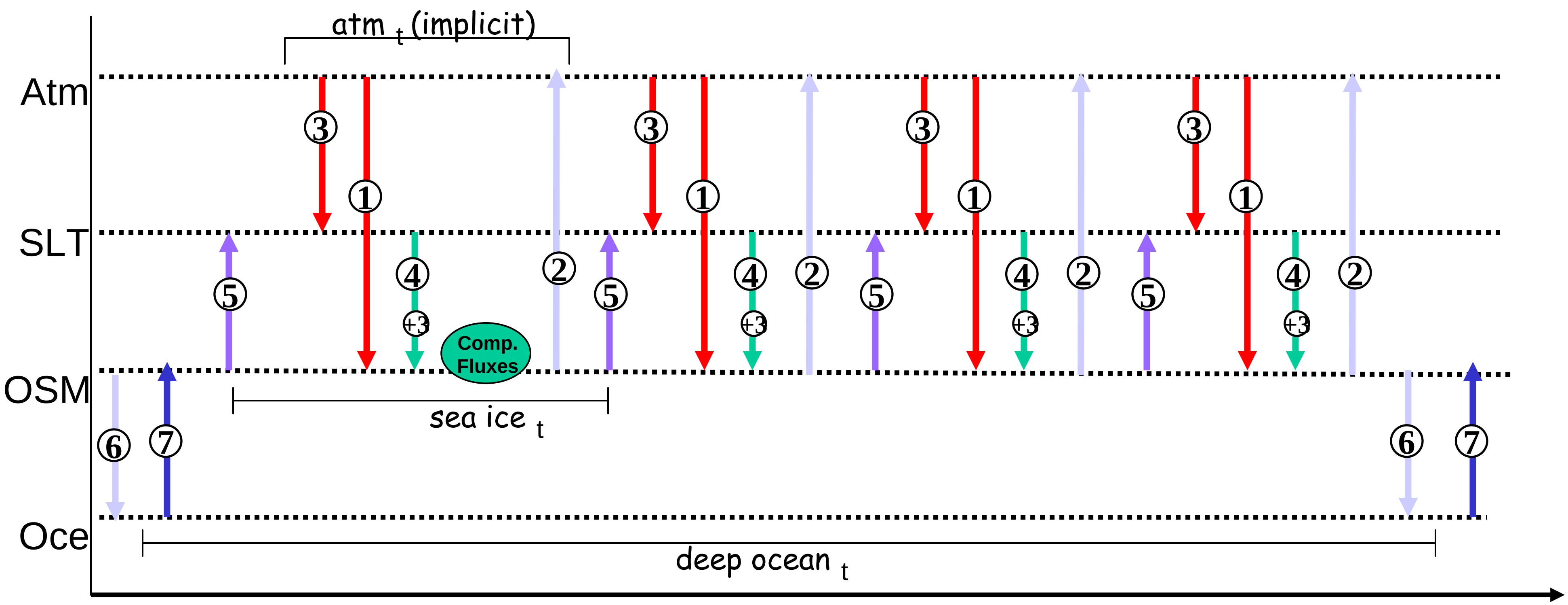
- Proposition discussed during the EU PRISM project (definition of "standard" physical interfaces), following the PILPS experience (Polcher et al 1998)
- J.Polcher (LMD), T. Fichefet (UCL), G. Madec (LOCEAN), O. Marti (LSCE), S. Planton (Meteo-France), E. Guilyardi (LOCEAN)
- Guidelines:
  - physically based interfaces across which conservation of mass, momentum and energy can be ensured
  - which process should be computed by which component/module
  - numerical constraints (stability, regridding, subgrid issues, local conservation,…)
  - historical and practical constraints

Part I - On a revised ocean-atmosphere physical coupling interface

I.2 The physical exchanges



I.3 Time sequence of exchanges



Frequency of coupling exchanges:

$$\underbrace{F_7 = F_6}_{\text{slow}} < \underbrace{F_5 = F_3 = F_1 = F_4 = F_2}_{\text{fast}}$$

Comments and conclusions

- Increased modularity with SLT and OS modules.
- SLT runs on finer grid and computes surface turbulent coefficient.
- OS computes radiation and turbulent fluxes.

✓ Separation of fast ocean + sea ice surface processes involving heat, water and momentum exchanges with the atmosphere from slower deeper ocean processes.

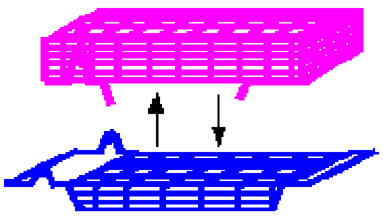
✓ Calculation of fluxes at the resolution of the surface (would be non-physical to regrid the turbulent exchange coefficients C_d, C_e, C_h).

✓ Implicit calculation of energy fluxes from the base of the sea-ice to the top of the atmosphere.

Part II - About technical coupling software

Why couple ocean and atmosphere (and sea-ice and land and …) models?

- Of course, to treat the Earth System globally



What does "coupling of codes" imply?

- Exchange and transform information at the code interface
- Manage the execution of the codes

What are the constraints?

- ✓ The coupling should be easy to implement
- ✓ The coupling should be flexible
- ✓ The coupling should be efficient
- ✓ The coupling should be portable
- ✓ We start from independently developed existing codes

II.1 Different technical solutions to assemble model codes:

1. <u>merge the codes:</u>

```
program prog1
…
call sub_prog2(data)
…
end prog1
```

→

~~program prog2~~
```
subroutine sub_prog2(data)
…
end prog2
```

- ☹ ~~easy~~
- ☹ ~~flexible~~
- ☺ efficient
- ☺ portable
- ☹ ~~existing codes~~
- ☹ no use of generic transformations

2. <u>use existing communication protocole</u> (MPI, CORBA, UNIX pipe, files, …)

```
program prog1
…
call xxx_send (prog2, data, …)
end
```

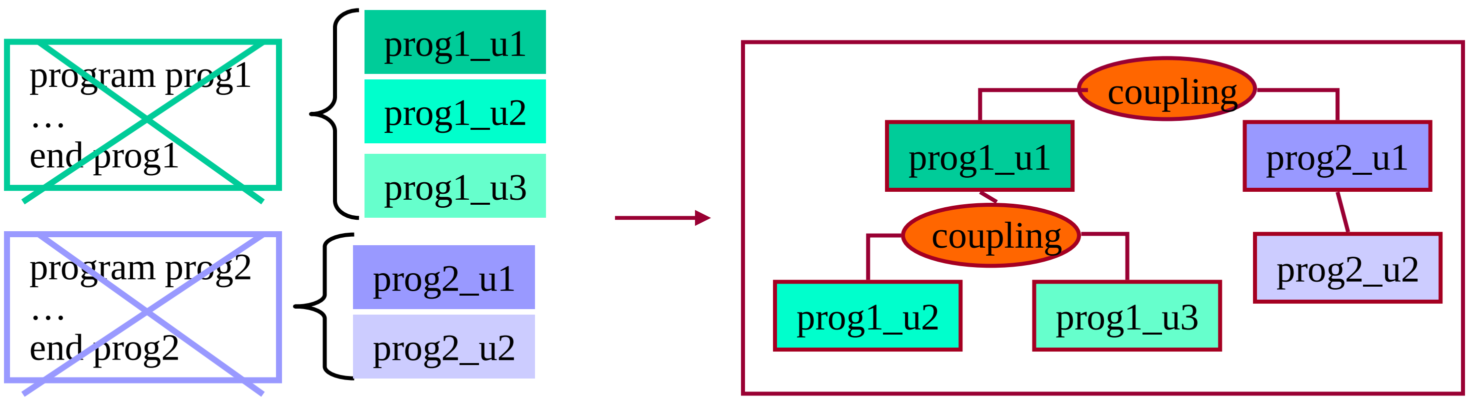
```
program prog2
…
call xxx_recv (prog1, data)
end
```

- ☹ ~~easy~~
- ☹ ~~flexible~~
- 😐 (efficient)
- 😐 (portable)
- ☺ existing codes

Part II - About technical coupling software

3. use coupling framework (ESMF, FMS, …)

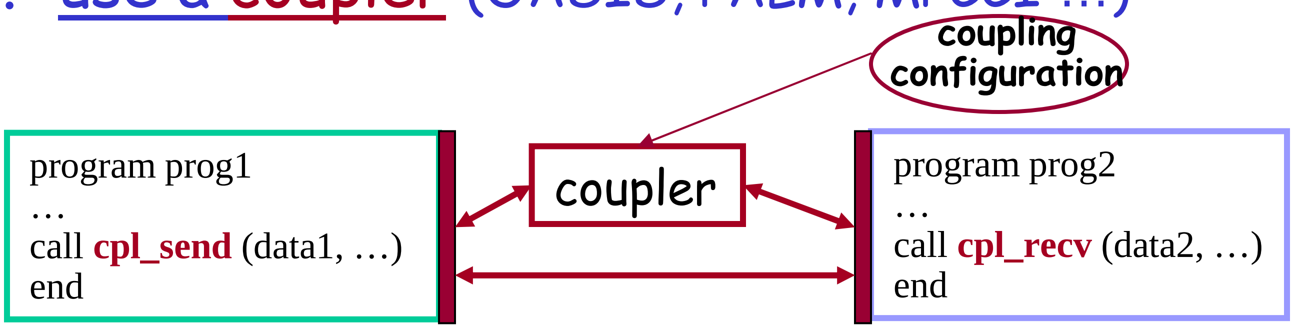
- Split code into elemental units
- Write or use coupling units
- Use the framework to build and control a hierarchical merged code
- Adapt code data structures



- 😐 (easy)
- ☺ flexible
- ☺ efficient
- ☺ portable
- 😐 (existing codes)

→ probably best solution in a controlled development environment

4. use a coupler (OASIS, PALM, MPCCI …)



- 😐 (easy)
- ☺ flexible
- 😐 (efficient)
- ☺ portable
- ☺ existing codes

→ probably best solution to couple independently developed codes

II.2 The OASIS coupler

- developed by CERFACS since 1991 to couple existing GCMs
- currently an active collaboration between NLE-IT, CNRS and CERFACS

1991			2001
|--→			|--- PRISM →
OASIS 1 →	OASIS 2	→	OASIS3→
		→	OASIS4 →

OASIS1, OASIS2, OASIS3:

•low resolution, low number of 2D fields, low coupling frequency:

→flexibility very important, efficiency not so much!

- New OASIS3_3 release in the next few weeks!

OASIS4:

•high resolution parallel models, massively parallel platforms, 3D fields

→need to optimise and parallelise the coupler

- OASIS4 beta version available

II.2.1 OASIS community today

•CERFACS (France)	ARPEGE3-ORCA2/LIM, ARPEGE4-NEMO/LIM-TRIP
•METEO-FRANCE (France)	ARPEGE4-ORCA2, ARPEGE3-OPAmed ARPEGE3-OPA8.1/GELATO
•IPSL- LODYC, LMD, LSCE (France)	LMDz-ORCA2/LIM LMDz-ORCA4 ORCA4
•MPI-M&D (Germany)	ECHAM5-MPI-OM, ECHAM5-C-HOPE, PUMA-C-HOPE, EMAD-E-HOPE
•ECMWF	IFS - CTM (GEMS), IFS - ORCA2 (MERSEA)
•MET Office (UK)	MetOffice ATM - NEMO
•IFM-GEOMAR (Germany)	ECHAM5 - NEMO (OPA9-LIM)
•NCAS / U. Reading (UK)	ECHAM4 - ORCA2 HADAM3-ORCA2
•SMHI (Sweden)	RCA(region.) – RCO(region.)
•NERSC (Norway)	ARPEGE - MICOM, CAM - MICOM
•KNMI (Netherlands)	ECHAM5 - TM5/MPI-OM
•INGV (Italy)	ECHAM5 – MPI-OM
•ENEA (Italy)	MITgcm - REGgcm
•JAMSTEC (Japan)	ECHAM5(T106) - ORCA ½ deg
•IAP-CAS (China)	AGCM - LSM
•KMA (Korea)	CAM3 – MOM4
•BMRC (Australia)	BAM3-MOM2, BAM5–MOM2, TCLAPS-MOM
•CSIRO (Australia)	Sea Ice code - MOM4
•RPN-Environment Canada (Canada)	MEC - GOM
•UQAM (Canada)	GEM - RCO
•U. Mississippi (USA)	MM5 - HYCOM
•IRI (USA)	ECHAM5 - MOM3
•JPL (USA)	UCLA-QTCM - Trident-Ind4-Atlantic

II.3 Regridding algorithms available in OASIS

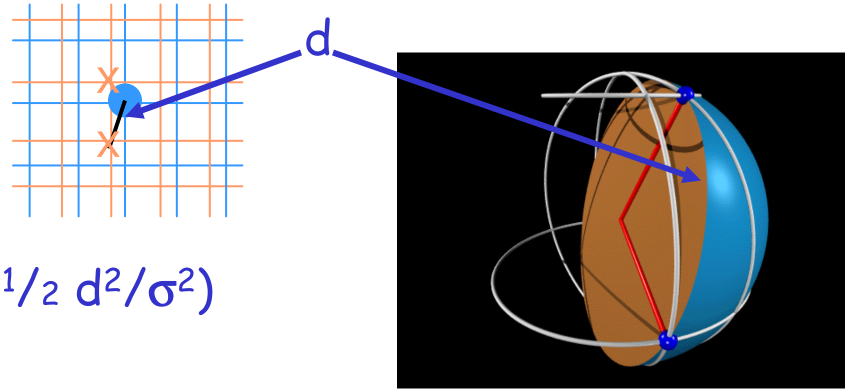
(Los Alamos SCRIP library, Jones 1999)

x: source grid point
● target grid point

- n-nearest-neighbours: weight(x) α 1/d

  d: great circle distance on the sphere:

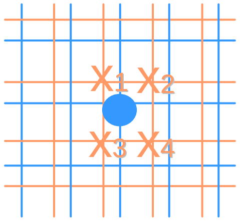
  d = arccos[sin(lat1)*sin(lat2) + cos(lat1)*cos(lat2) * cos(lon1-lon2)]



- gaussian weighted n-neighbours: weigth(x) α $\exp(-{}^{1}/_{2}\, d^2/\sigma^2)$

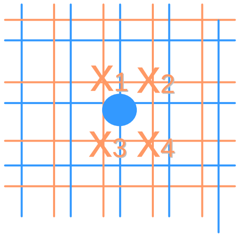
- bilinear interpolation

  - general bilinear iteration in a continuous local coordinate system using f(x) at x_1, x_2, x_3, x_4

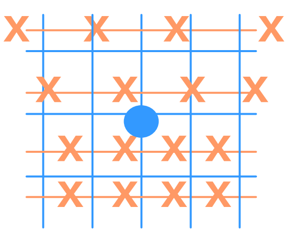


- bicubic interpolation: conserves 2nd order properties such as wind curl

  - general bicubic iteration continuous local coordinate system: f(x), δf(x)/δi, δf(x)/δj, δ²f/δiδj in x_1, x_2, x_3, x_4 for logically-rectangular grids (i,j)

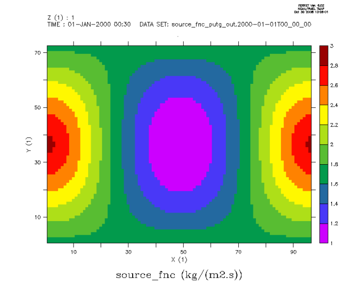


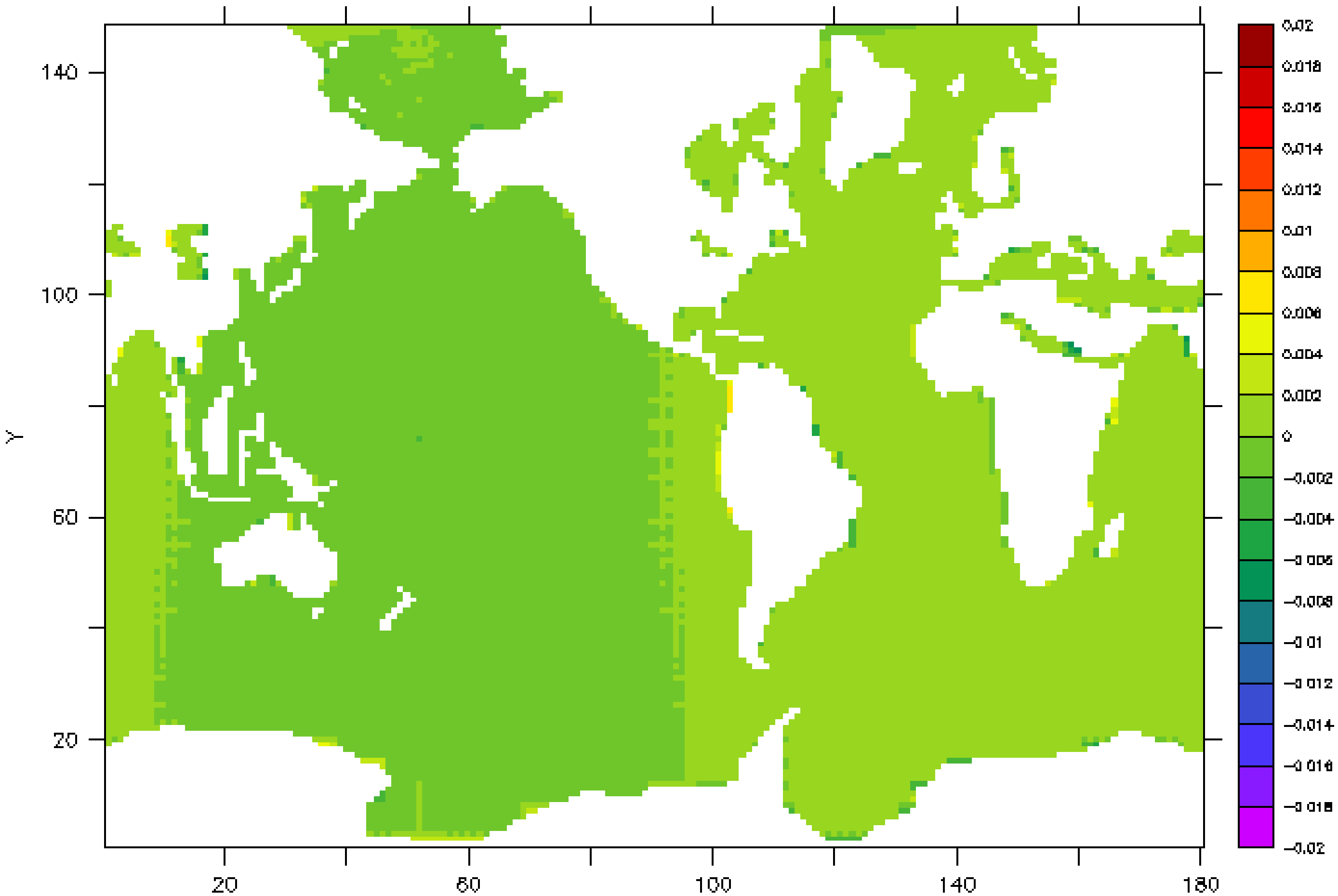
  - standard bicubic algorithm: 16 neighbour points for Gaussian Reduced grids



One example of bilinear interpolation error

F = 2 + cos[π * acos(cos(lon)cos(lat)] LMDz grid (96 x 72) -> ORCA2



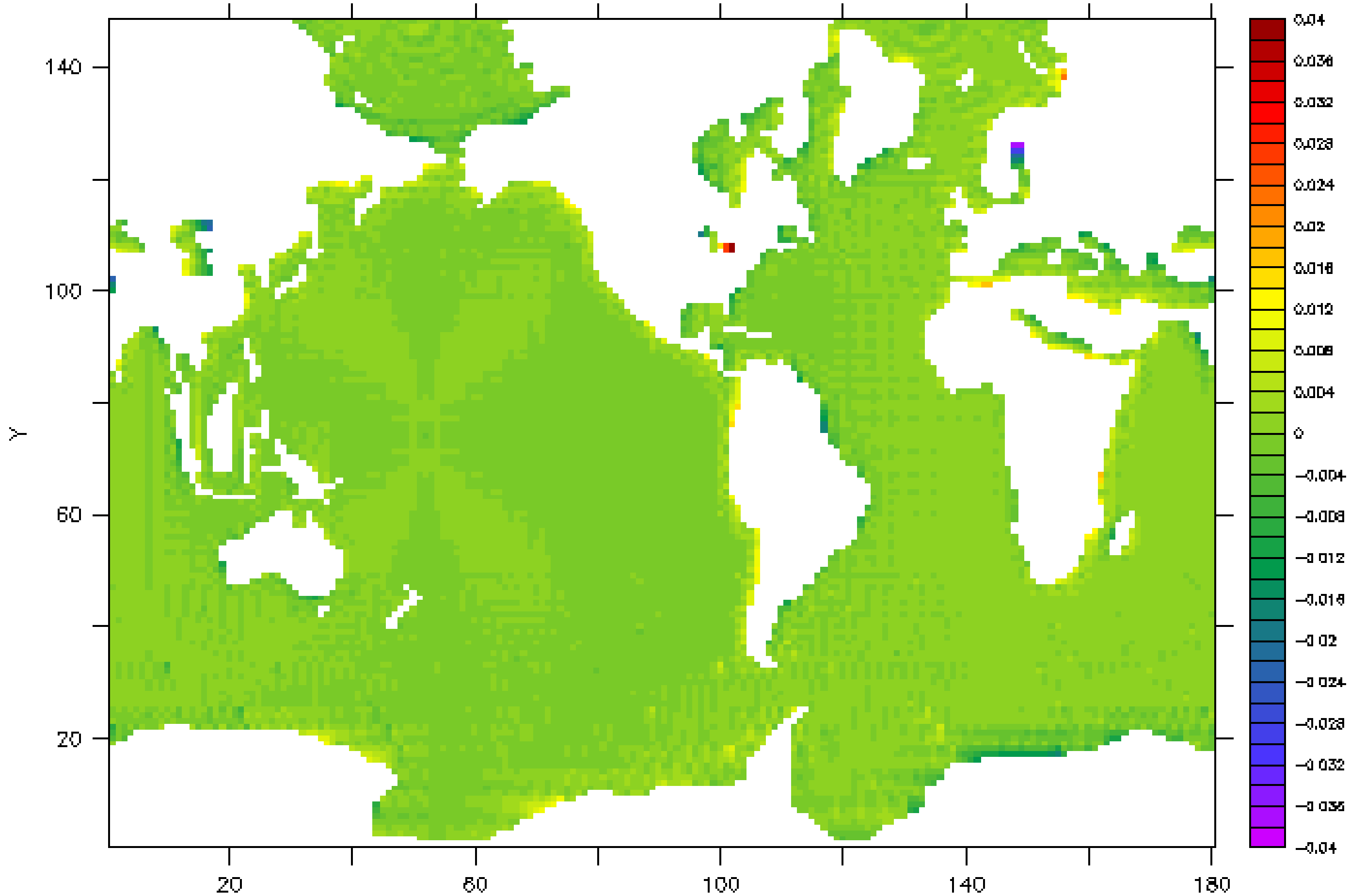


- < 0.2% whole domain; ~1% near the coastline

- One example of bicubic interpolation error

F = 2 – cos[π * acos(cos(lon)cos(lat)]

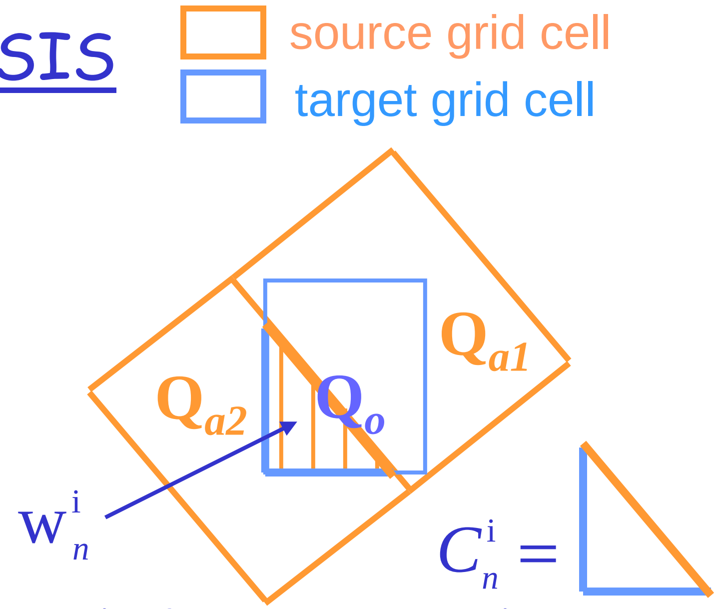
BT42 Gaussian red. -> ORCA2



- < 0.2% in equatorial and tropical regions,
  < 0.4% at higher or lower latitudes (where the Gaussian grid is effectively reduced),
  up to 4% near the coastline

II.3 Regridding algorithms available in OASIS

(Los Alamos SCRIP library, Jones 1999)



- 1st order conservative remapping:
  - ➢ conserves integral of extensive properties
  - ➢ weight of a source cell α to intersected area

$$Q^i_o = \frac{1}{A_o}\sum_{n=1}^{N} Q_{an} w^i_n \quad \text{with} \quad w^i_n = \oint_{C^i_n} -\sin(\text{lat})\,d\text{lon}$$

- ❖ assumes borders are linear in (lat,lon)
  - ➢ Lambert equivalent azimuthal projection near the pole for intersec. calc.

Actual limitations:

- assumes sin(lat) linear function of lon (for line integral calculation)
  - ➢ need to use a projection near the pole (as done for intersect. calc.)
- exact calculation is not possible as "real shape" of the borders are not known
  - ➢ could use of border middle point
  - ➢ to ensure conservation, need to normalize by true area of the cells

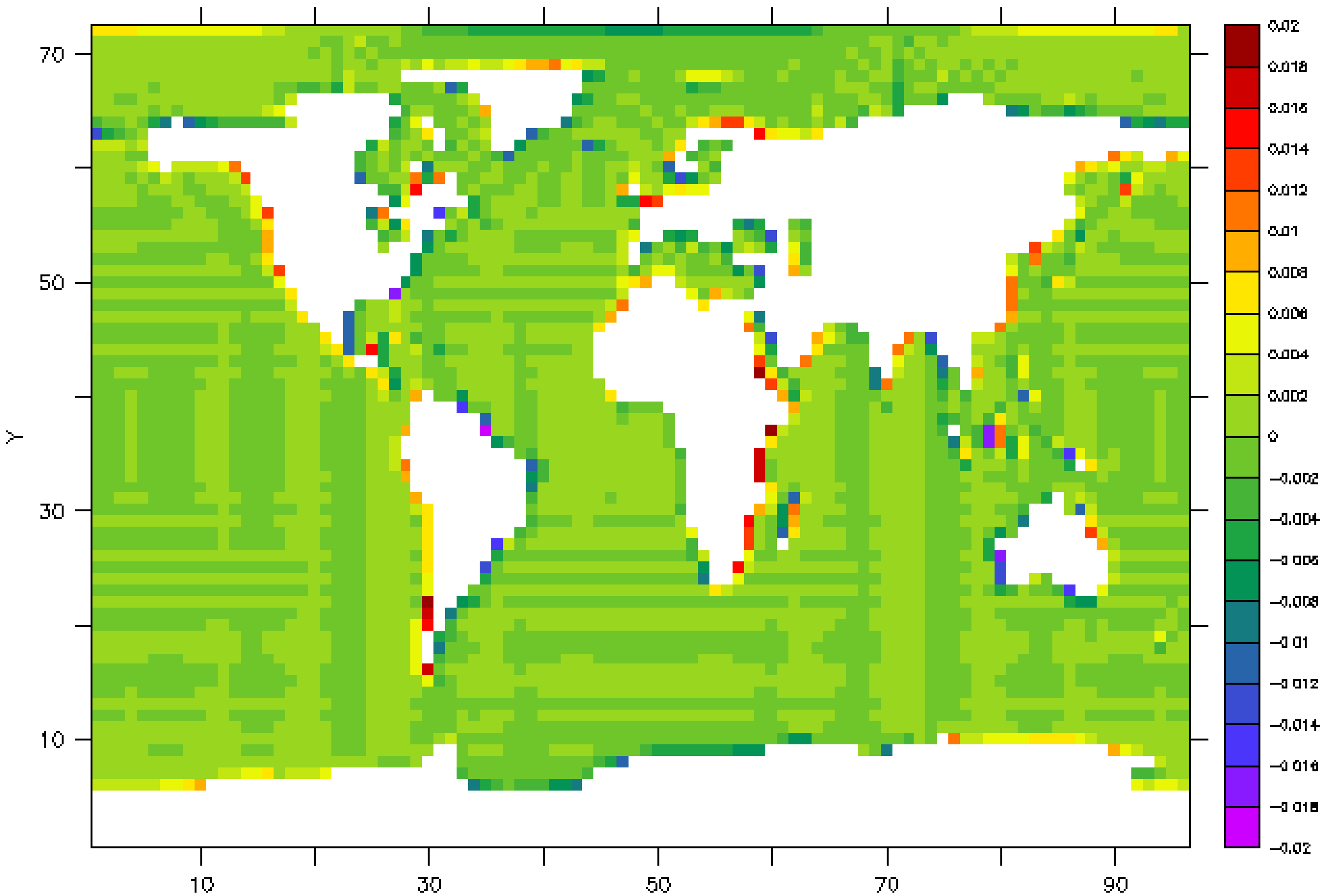
Other methods e.g.:

- Monte Carlo random walk
- Projection of the source and target polygons on a plane (IPSL)

- One example of conservative remapping error

$F = 2 - \cos[\pi * \mathrm{acos}(\cos(lon)\cos(lat))]$

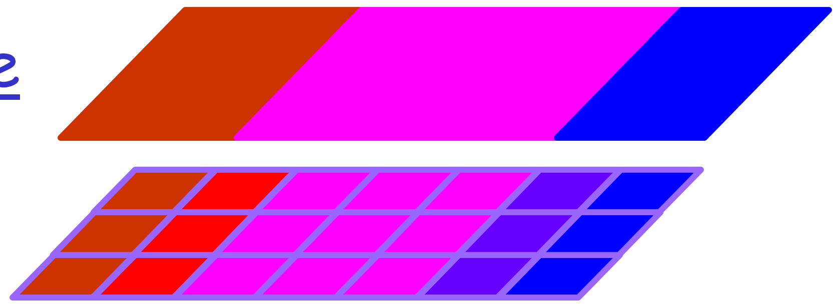
ORCA2 -> LMDz (96x72)



- < 0.2% everywhere except
  ~ 0.8% for LMDz last row close to the North pole
  ~ 2% near the coastline

II.4 Problem with 1st order conservative remapping

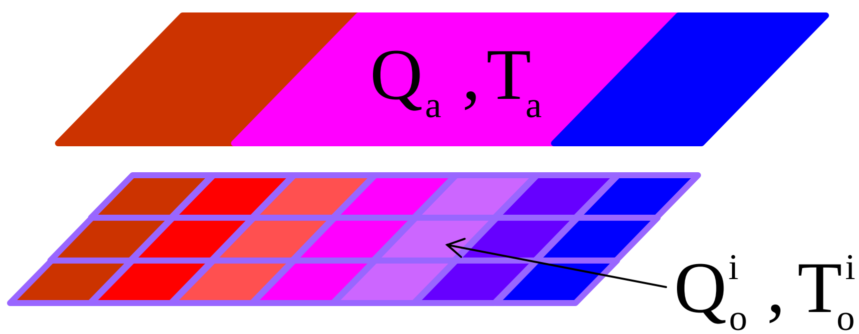
(low to high resolution) :



- Solution 1: use 2nd order conservative remapping:

$$Q_o^i = Q_a w_1^i + \frac{\partial Q_a}{\partial lat} w_2^i + \frac{1}{\cos(lat)} \frac{\partial Q_a}{\partial lon} w_3^i$$

- Solution 2: use SUBGRID transformation:



Solar type: $$Q_o^i = \frac{(1-\alpha_o^i)}{(1-\alpha_a)} Q_a$$

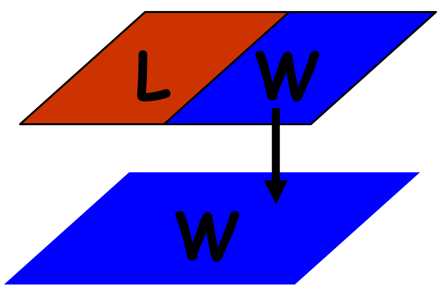
Non-solar type: $$Q_o^i = Q_a + \left.\frac{\partial Q_a}{\partial T}\right|_{T=T_a} (T_o^i - T_a)$$

*conservative if α_a / T_a correspond to conservative remapping of α_o^i / T_o^i

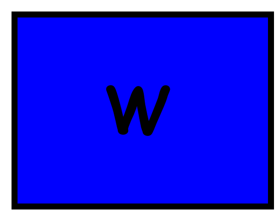
II.5 Problem with non-matching sea-land masks

$$Q_o^i = \frac{1}{A_o} \sum_{n=1}^{N} Q_{a_n} w_n^i$$

1- Ideally: Support subsurfaces in the atmosphere
and use the ocean land-sea mask in the atmosphere to determine the fractional area of each type of surface

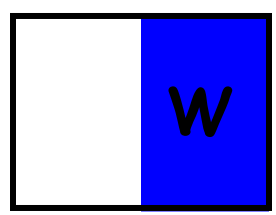


2-“DESTAREA” option

$A_o =$ 

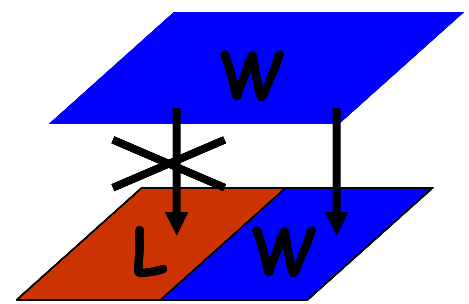
- _local flux conservation
- possibly unrealistic flux values

3-“FRACAREA” option

$A_o =$ 

- no local conservation of flux
- realistic flux values

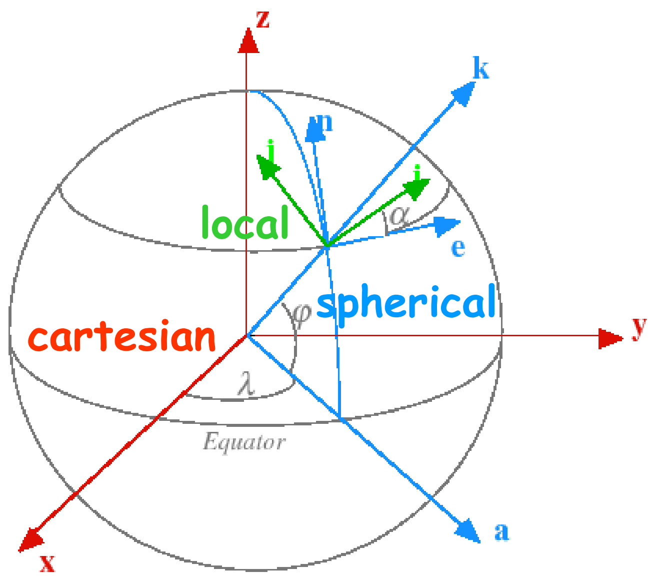
+ nearest non-masked value for ocean cells covered only with masked atmospheric cells



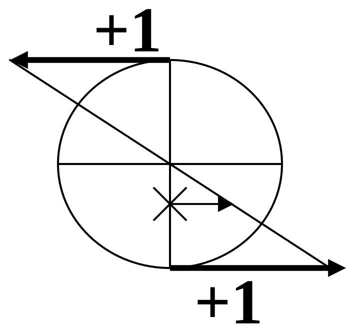
- no local conservation of flux
- global conservation can be artificially imposed

II.6 Vector interpolation (winds, currents, …)

❖ interpolation of vectors component per component is not accurate, especially where the referential changes rapidly



Example interpolation of a zonal wind in the spherical referential near the pole



➢At x, one would expect a zonal wind between 0 and 1.

➢Interpolation comp. per comp. -> zonal wind of 1.

Solution (proposed by O. Marti, LSCE, implemented in OASIS):

• "turn" the vector in the spherical referential and project the resulting vector in a cartesian referential

• interpolate the 3 components in the cartesian referential

• project back in the spherical referential; check that k component is zero

• possibly "turn" the resulting vector in the target local referential

Conclusions

- Different technical solutions to assemble model codes:
  - Coupling framework (e.g. ESMF):
    - ➢ best solution in a controlled development environment
  - Coupler (e.g. OASIS):
    - ➢ best solution to couple independently developed codes

- The OASIS coupler :
  - Coarse to fine grid remapping: subgrid variability with 2nd order remapping or SUBGRID (1st order Taylor expansion)
  - Non-matching sea-land masks:
    - DESTAREA: local flux conservation but unrealistic flux values
    - FRACAREA: no local flux conservation but realistic flux values
    - Global conservation can be artificially imposed
  - Vector interpolation: need to project components in a cartesian referential before interpolation.

The end