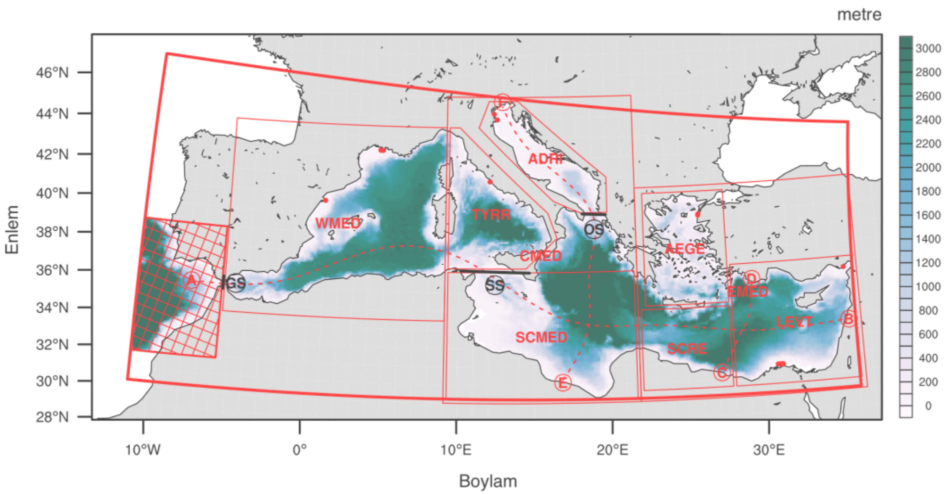

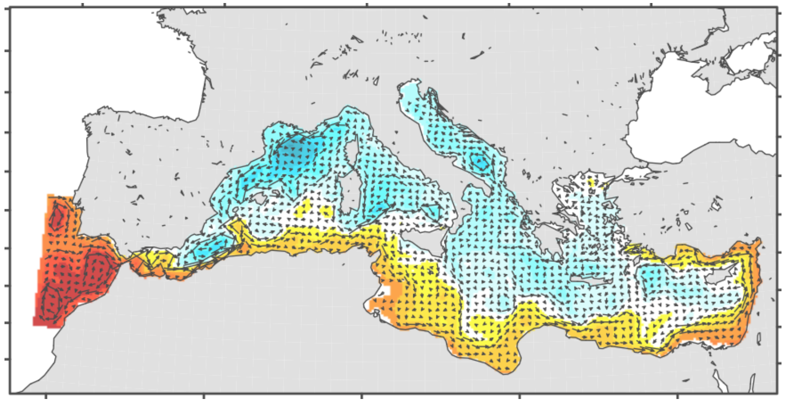

Design and Use of **RegESM**: **Reg**ional **E**arth **S**ystem **M**odel

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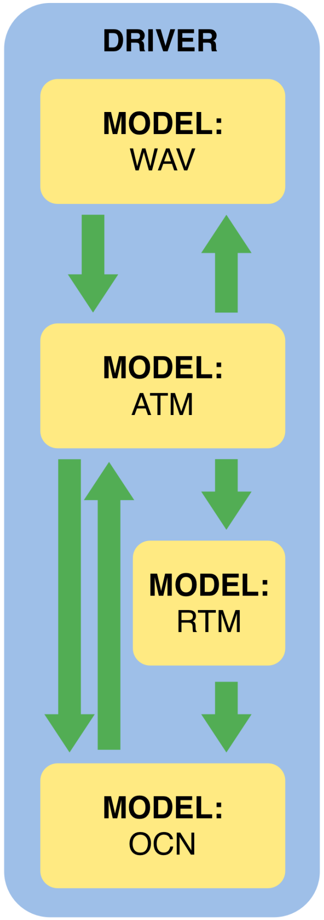
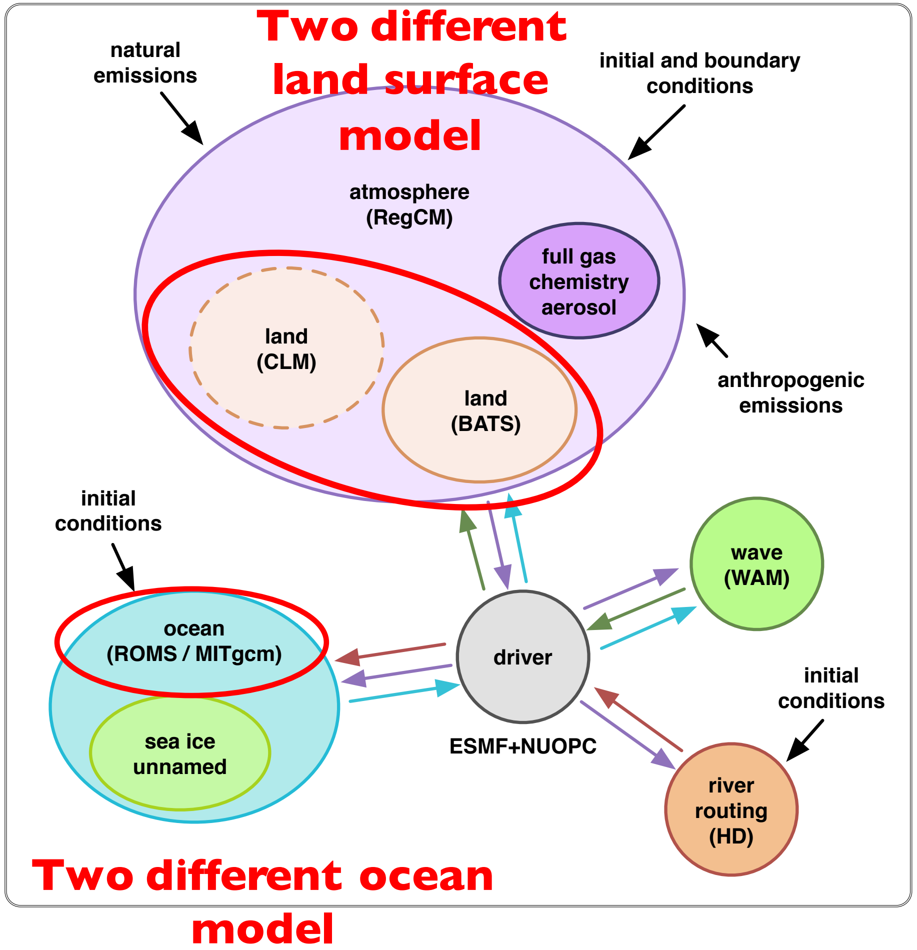
RegESM Design

- Model components merged with ESMF/NUOPC





ATM:
ICTP's RegCM 4.4 / 4.5

OCN:
Rutgers Univ.
ROMS (r737)
MITgcm (63s / 64s)

WAV:
ECMWF's WAM
4.5.3 MPI

RTM:
Max Planck's HD
(1.0.2 modified)
Special thanks to
Prof. Stefan Hagemann

 # Following combination of model components can be used: 2 component: ATM-OCN, ATM-WAV, 3 component: ATM-OCN-RTM, 4 component: ATM-OCN-WAV-RTM

Driver

- It is a translator between different earth system models
- Assumed as a separated model component without any physical code
- Allows minimal code change in the model components
- It basically responsible
    - exchanging data among the model components (i.e. atmosphere, ocean, land)
    - synchronization of model components (run order)
    - performing interpolation to the data (basically exchange fields) from one component to others (different interpolation techniques can be supported)
    - applying unit conversion to exchange fields (i.e. from Kelvin to degree Celsius)
    - applying rotation of wind components (curvilinear grid)
    - applying flux correction / adjustment

Earth System Modeling Framework

- It is high-performance, flexible software infrastructure for building and coupling weather, climate and related Earth science applications.
- It defines an architecture for composing complex, coupled modeling systems and includes data structures and utilities for developing individual models.
- The basic idea behind ESMF is that complicated application should be broken up into coherent pieces or components with standardized calling interfaces (**initialize**, **run** and **finalize**)
- It includes toolkits for building components and applications such as regridding software (bilinear, nearest-neighbour, patch recovery and conservative), calendar management, parallel communications etc.

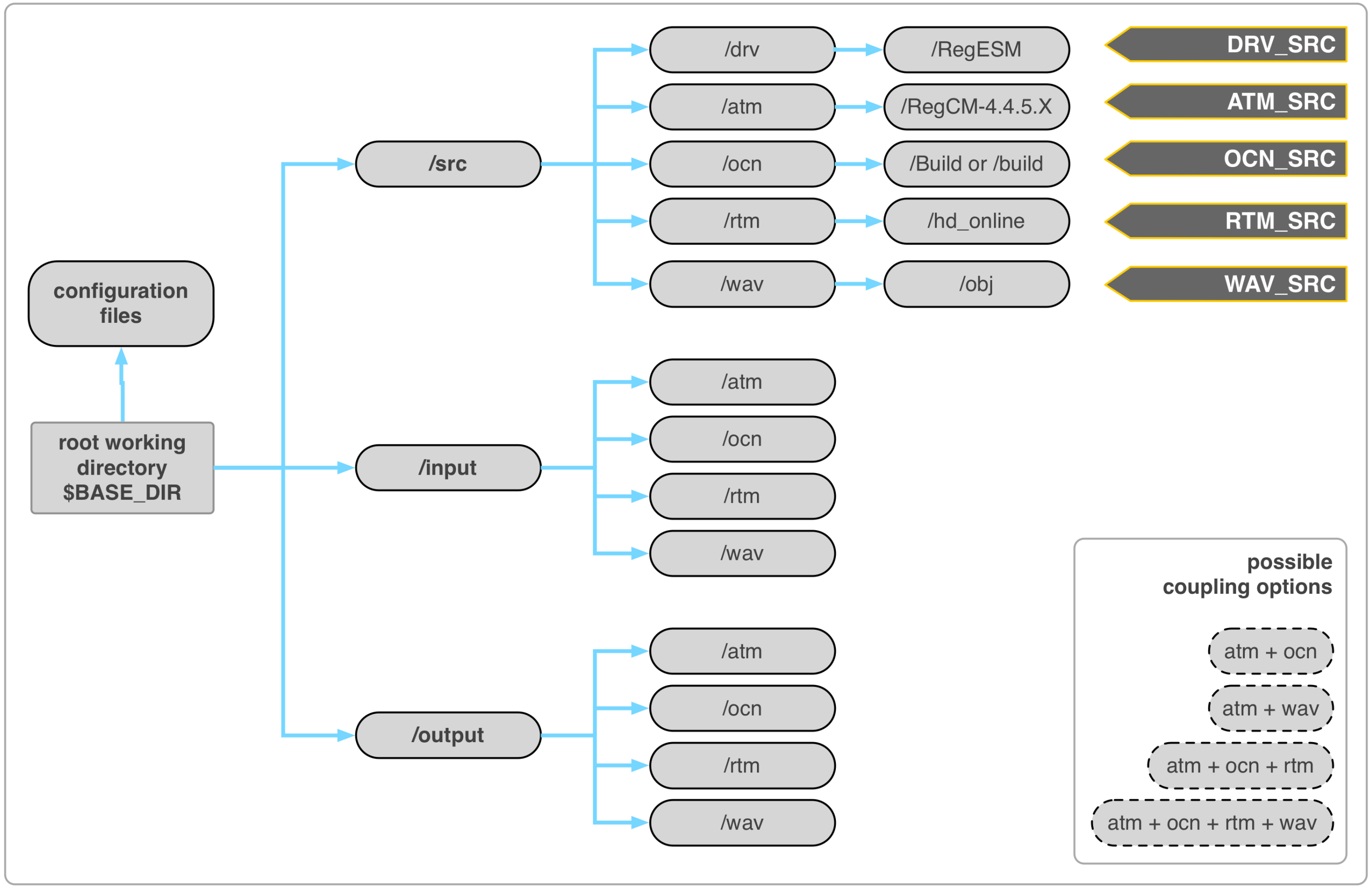
https://www.earthsystemcog.org/projects/esmf/

Installation

- Requirements
  - C/C++ and Fortran compiler (GNU, Intel etc.)
  - MPI (OpenMPI, Intel MPI etc.)
  - Zlib
  - HDF
  - NetCDF - Fortran/C/C++ interfaces
  - Xerces for ESMF (XML library)
  - ESMF > 7.0
- Model components
  - Every model component must support coupling
  - RegCM 4.5 already supports coupling (out-of-box)
  - ROMS, MITgcm, HD and WAM are modified to work with RegESM driver (contact with RegESM developer)
- install-deps.sh might help to install dependencies (still testing)

Installation …

- The installation of the coupled model can be little bit confusing at the beginning. To that end, it is better to follow the conventions based on experience
- Suggested directory structure of RegESM installation



Bit-to-bit reproducibility

- It is very important concept and hard to reach especially for the parallel codes (MPI and/or OpenMP)
- Think about following situations:
  - reveal the added value of the model coupling, you might need to compare the standalone and coupled model results
  - having sensitivity test to get insight about the effect of the coupling interval
- The model might give slightly different results even if you keep initial and boundary conditions same due to the floating point arithmetic
- The order of the numbers in reduction operators (+, -, * and /) might affect the result in the computer. Think about MPI_Reduce?
- The modern compilers could handle this issue by providing mechanisms to achieve bit-to-bit reproducible results

Bit-to-bit reproducibility …

- The modern compilers have flags to overcome this issue
  - Intel: **-fp-model precise** and **–fp-model source**
  - Gnu: **-fno-fast-math**
- So, the user must compile all model components (including driver) and also ESMF library with these options
- This options is not default in ESMF and also RegCM < 4.5
- For ESMF, user need to modify following file
  build_config/Linux.intel.default/build_rules.mk
  it depends on used architecture and compiler (Linux+Intel)

```
...
...
ifeq ($(ESMF_ABISTRING),x86_64_small)
ESMF_CXXCOMPILEOPTS      += -m64 -mcmodel=small -fp-model precise
ESMF_CXXLINKOPTS         += -m64 -mcmodel=small -fp-model precise
ESMF_F90COMPILEOPTS      += -m64 -mcmodel=small -fp-model precise
ESMF_F90LINKOPTS         += -m64 -mcmodel=small -fp-model precise
endif...
...
```

Installation …

- … model components and required libraries are already installed
- The Git repository - https://github.com/uturuncoglu/RegESM
- You might need to install git package
- To install driver:

```
git clone https://github.com/uturuncoglu/RegESM.git
cd RegESM
./bootstrap.sh (it will create the configuration script)
./configure --prefix=[HOME] --with-atm=[ATM_HOME]
                            --with-ocn=[OCN_HOME]
                            --with-rtm=[RTM_HOME]
                            --with-wav=[WAV_HOME]
make
make install
```

Usage

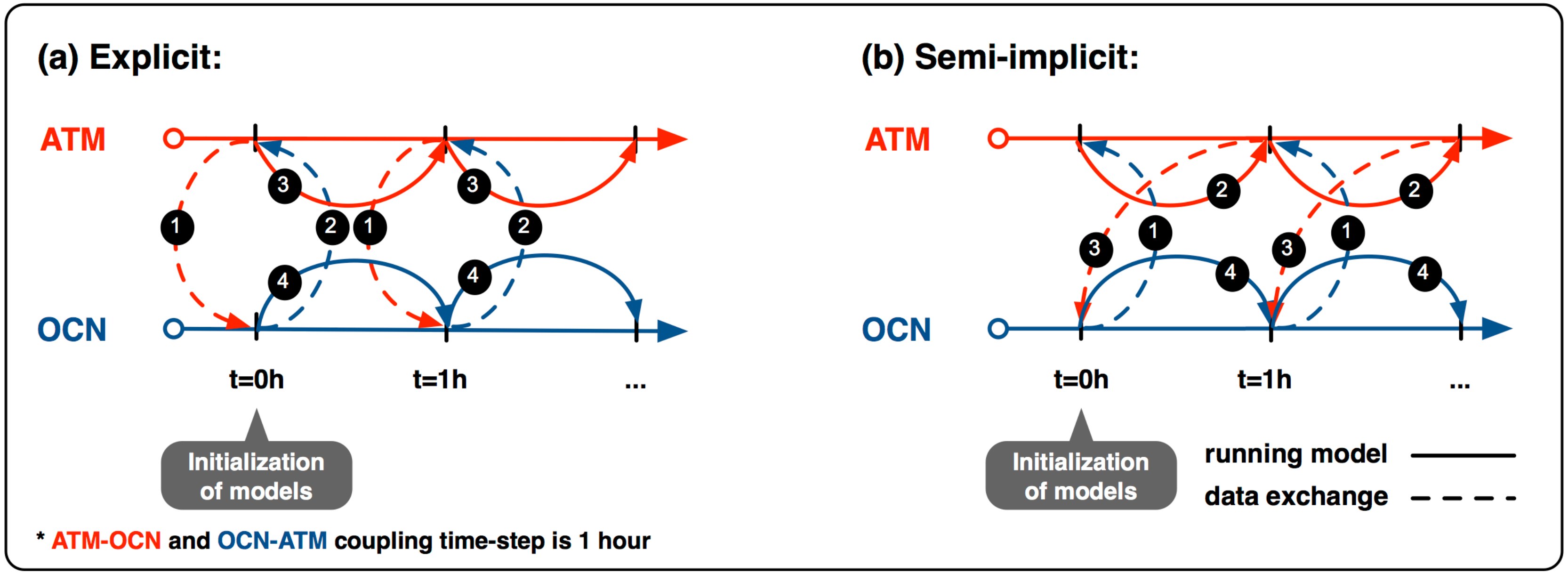
- Suggestions
  - Setup and tune individual model components in standalone mode to find their best configuration
  - Try to add new components one by one and test the performance of the modeling system
  - You might need to do extra fine tuning of the coupled model at the end due to the complex two-way interaction between model components
  - The coupling might put extra complexity to the overall system
  - Sometimes, it might be hard to identify the added value of the coupling
  - The debug options (writing grid information in VTK format etc.) can be used to identify problems
  - Check stdout and PET* log files to find the error. In general, problem can be identified easily by looking those files
  - If you really think that there is a bug, send a mail to me ☺

Driver Configuration File (namelist.rc)

- It is used to control driver (RegESM)
  - Resource distribution among model components (PET: Persistent Execution Thread - CPUs)
  - PET layout (sequential vs. concurrent)
  - Coupling type (explicit vs. semi-implicit)
  - Extrapolation support (unaligned land-sea mask)
  - Debugging
  - High level definition of time related configuration of simulation (start, stop, restart time and calendar)
  - Coupling time-step to exchange data among the model components (fast vs. slow)
  - Representation of rivers (source vs. surface boundary condition)
  - List of active rivers and their configurations (locations, effective radius etc.)

Driver Configuration File (namelist.rc)

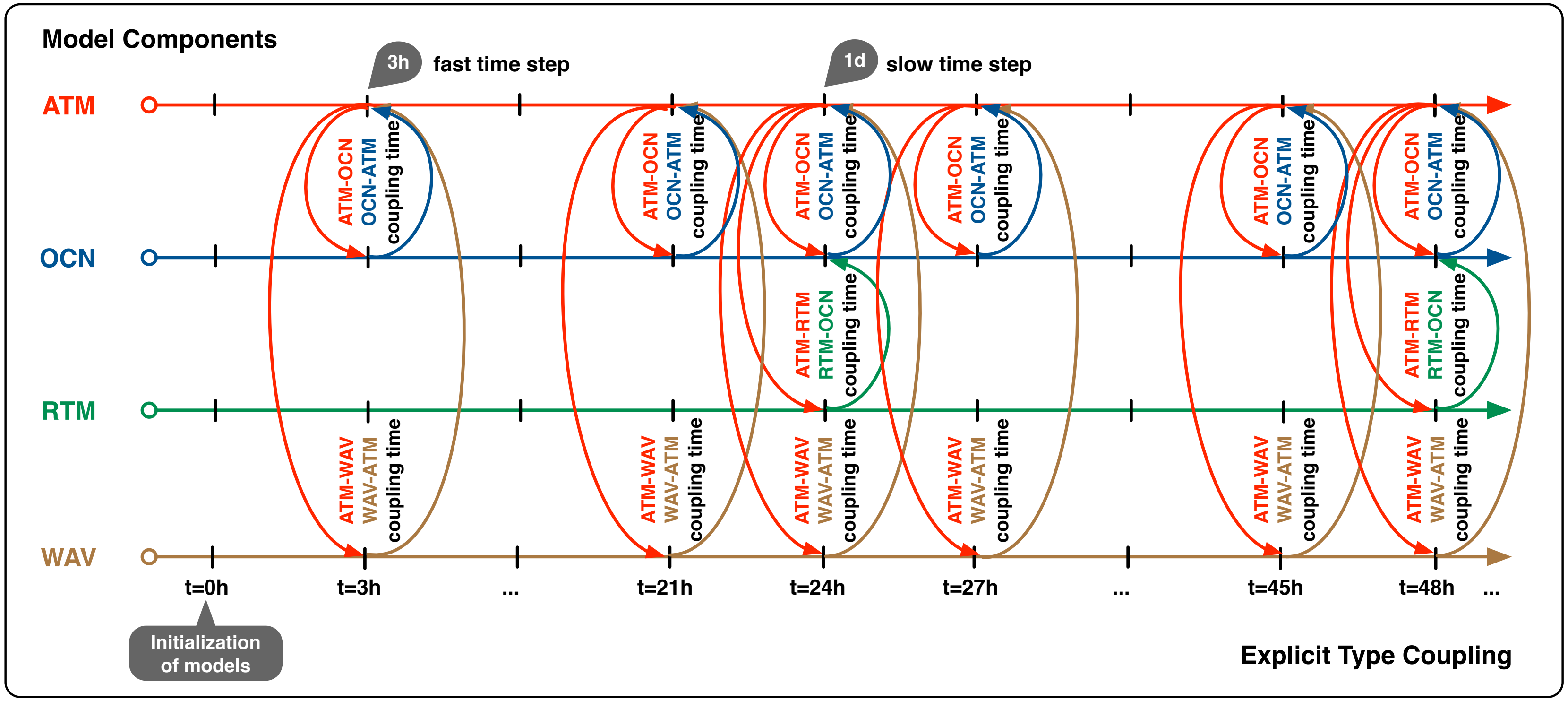
- Explicit vs. Semi-implicit (leapfrog) coupling type



- It allows different interaction mechanisms between ATM and OCN model components
- The fully implicit type coupling also exists (not supported!)
- The CouplingType namelist parameter is used for this purpose

Driver Configuration File (namelist.rc)

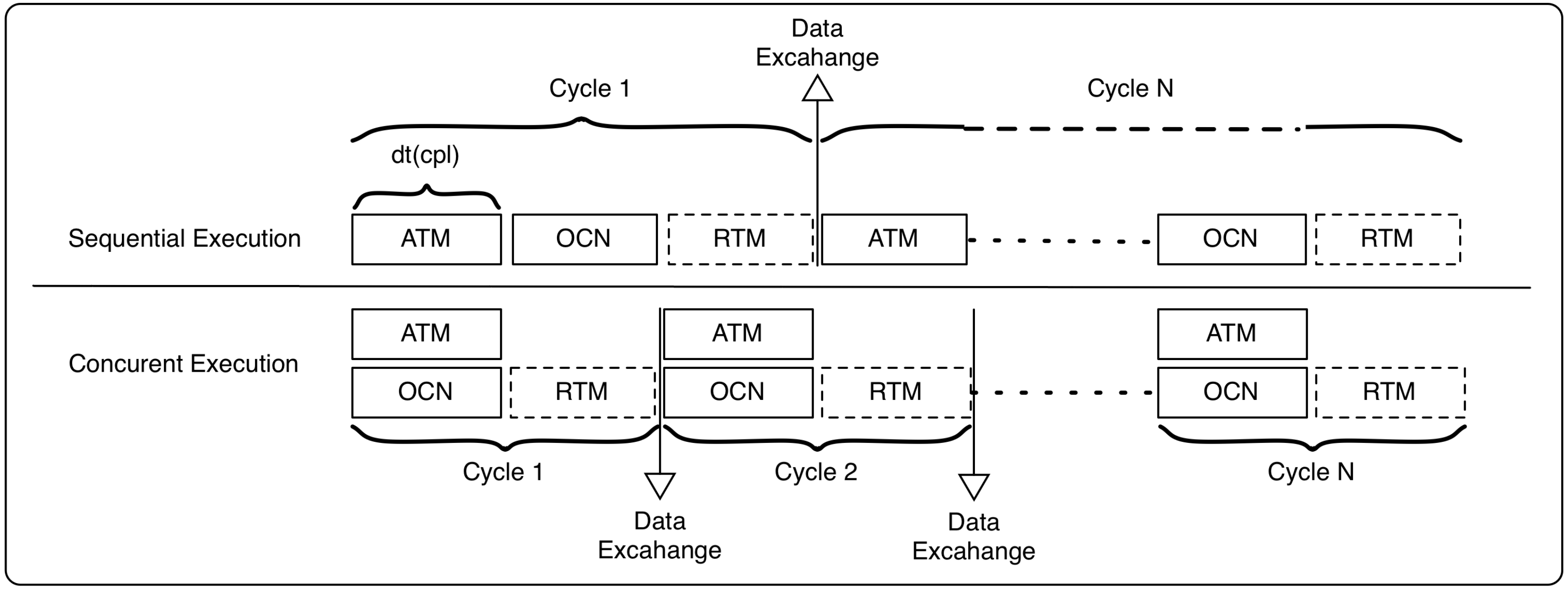
- Fast vs. slow coupling time step



- It is used to define slow coupling time step for RTM component (daily)
- The DividerForTStep namelist parameter is used

Driver Configuration File (namelist.rc)

- Sequential vs. Concurrent



- In sequential mode, model components shares same resources and run in an order
- In concurrent model, each model has its own resource and run in parallel (load balance become important!)
- The PETLayoutOption namelist parameter is used

Exchange Field Table (exfield.tbl)

- It basically designed to simplify the definition of exchanged fields among the model components
- The flexible design allows to create different coupled modeling applications without any code change in driver and model components
- The pool of exchange fields are defined but new variables might be added w/o major code development
- The ASCII formatted exchange field table includes
- Structure:
  - It contains a separate section for each coupling direction (or interaction) such as ATM-OCN, OCN-ATM or ATM-WAV
  - Each section contains the list of fields (along with unit conversion parameters, conservation option etc.) that will be transferred between model component

Exchange Field Table (exfield.tbl)

- Four component (ATM-OCN-RTM-WAV) example:

field list

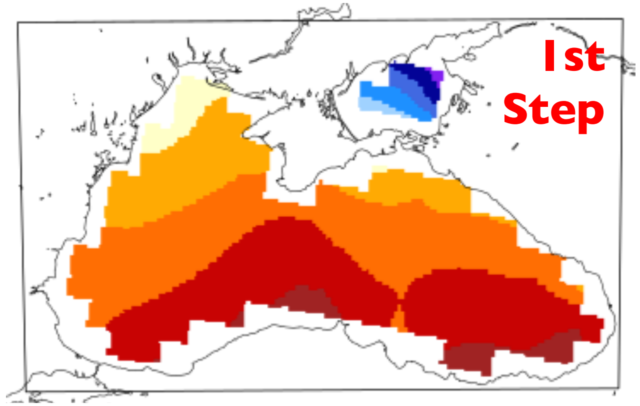
```
6 atm2ocn T
taux:eastward_10m_wind_stress:bilinear:cross:u:N/m2:m2/s2:cf3:0.0:F
tauy:northward_10m_wind_stress:bilinear:cross:v:N/m2:m2/s2:cf3:0.0:F
psfc:surface_air_pressure:bilinear:cross:cross:mb:mb:1.0:0.0:F
swrd:shortwave_radiation:bilinear:cross:cross:W/m^2:Cm/s:cf2:0.0:T
sflx:water_flux_into_sea_water:bilinear:cross:cross:kg/m^2s:m/s:0.001:0.0:T
nflx:surface_heat_flux:bilinear:cross:cross:W/m^2:Cm/s:cf2:0.0:T
1 ocn2atm T
sst:sea_surface_temperature:bilinear:cross:cross:C:K:1.0:273.16:F
2 atm2rtm F
rnof:surface_runoff:bilinear:cross:cross:mm/s:m/s:0.001:0.0:F
snof:subsurface_runoff:bilinear:cross:cross:mm/s:m/s:0.001:0.0:F
1 rtm2ocn F
rdis:river_discharge:nearstod:cross:cross:m^3:m^3:1.0:0.0:F
2 atm2wav T
wdir:wind_direction:bilinear:cross:cross:m/s:m/s:1.0:0.0:F
ustr:friction_velocity:bilinear:cross:cross:m/s:m/s:1.0:0.0:F
2 wav2atm T
zo:roughness_length:bilinear:cross:cross:m:m:1.0:0.0:F
```

[number of exchange field] [coupling direction] [support for extrapolation]

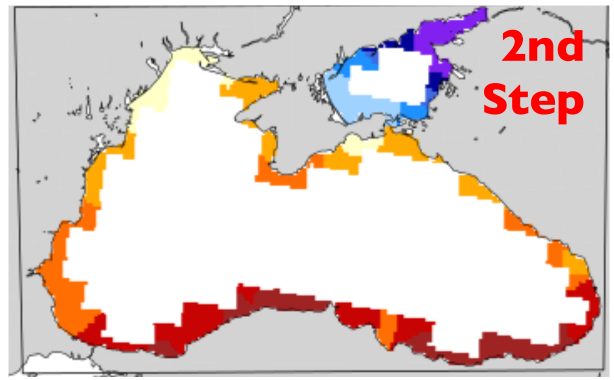
[variable name]:[standard name]:[interpolation type]:[type of source stencil]:[type of destination stencil]:[scale factor]:[add offset]:[support for conservative interpolation]

Extrapolation Support

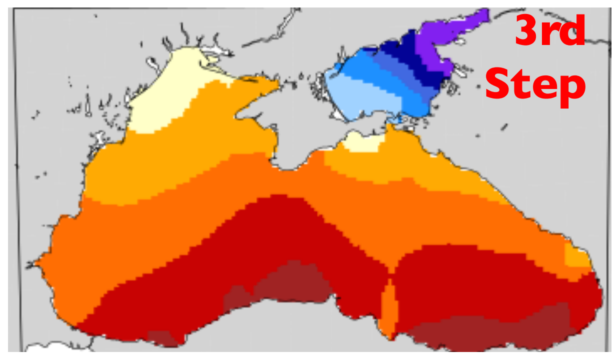
- It is used to overcome unaligned land-sea mask problem
- Interpolation from 50 km atmosphere to 7 km ocean model



Step 1 / Bilinear interpolation from ATM to OCN only over sea



Step 2 / Nearest-neighbour (NN) type interpolation from OCN to OCN (It uses result of previous step)

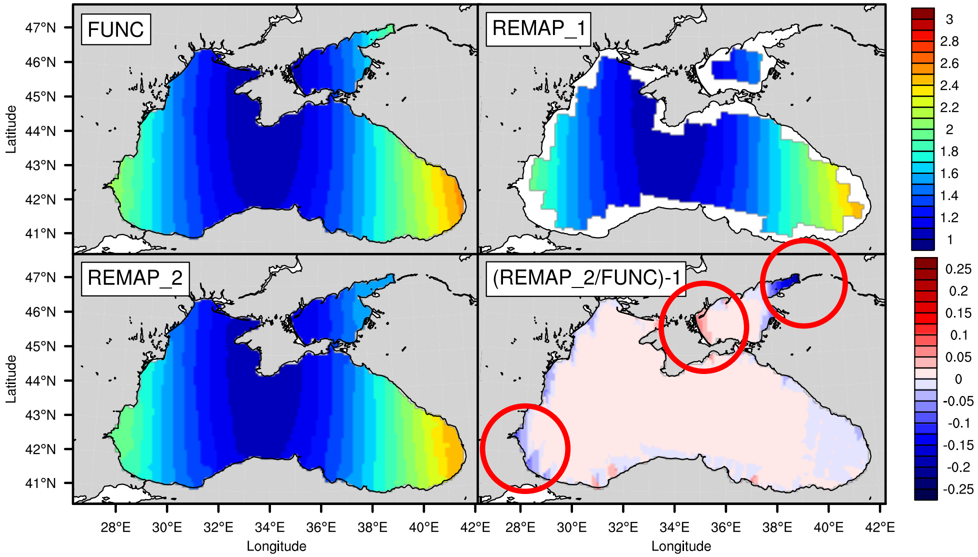


Step 3 / Merging step 1 and 2 to have a complete exchange field

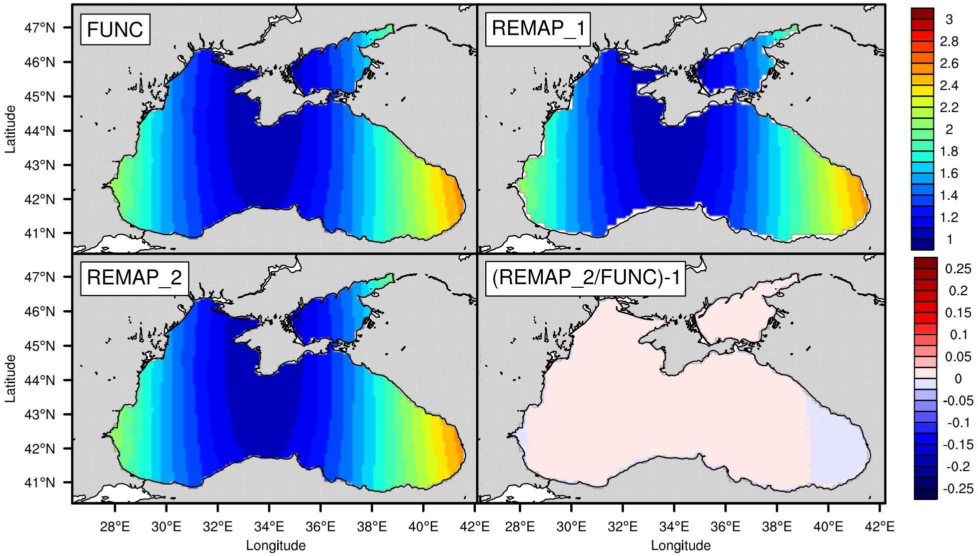
Extrapolation Error

- The simplest type extrapolation (NN) is used

LRES ATM - 50km



HRES ATM - 10km



Pseudo Spherical Harmonics

SCRIP: L=32 and M=16

$$f = 2 + sin^{16}(2\theta)\cos(16\phi)$$

θ, latitude

ϕ, longitude

Relative Error:

([Model]/[Analytic])-1

LRES:

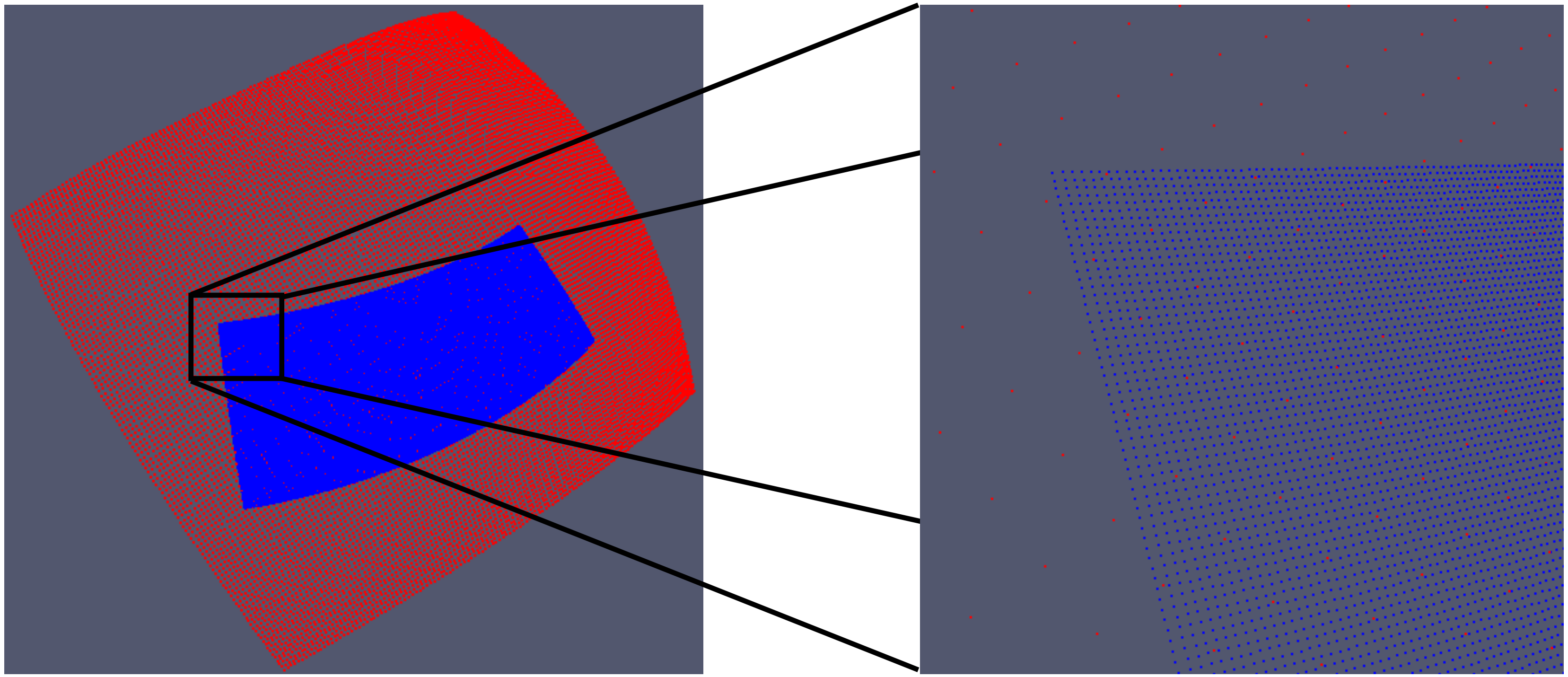
min: -0.207 / max: 0.071

HRES:

min: -0.025 / max: 0.014

Conservative Interpolation

- Conservative type interpolation is suitable for area-integrated fields such as water or heat fluxes
- Global conservation:



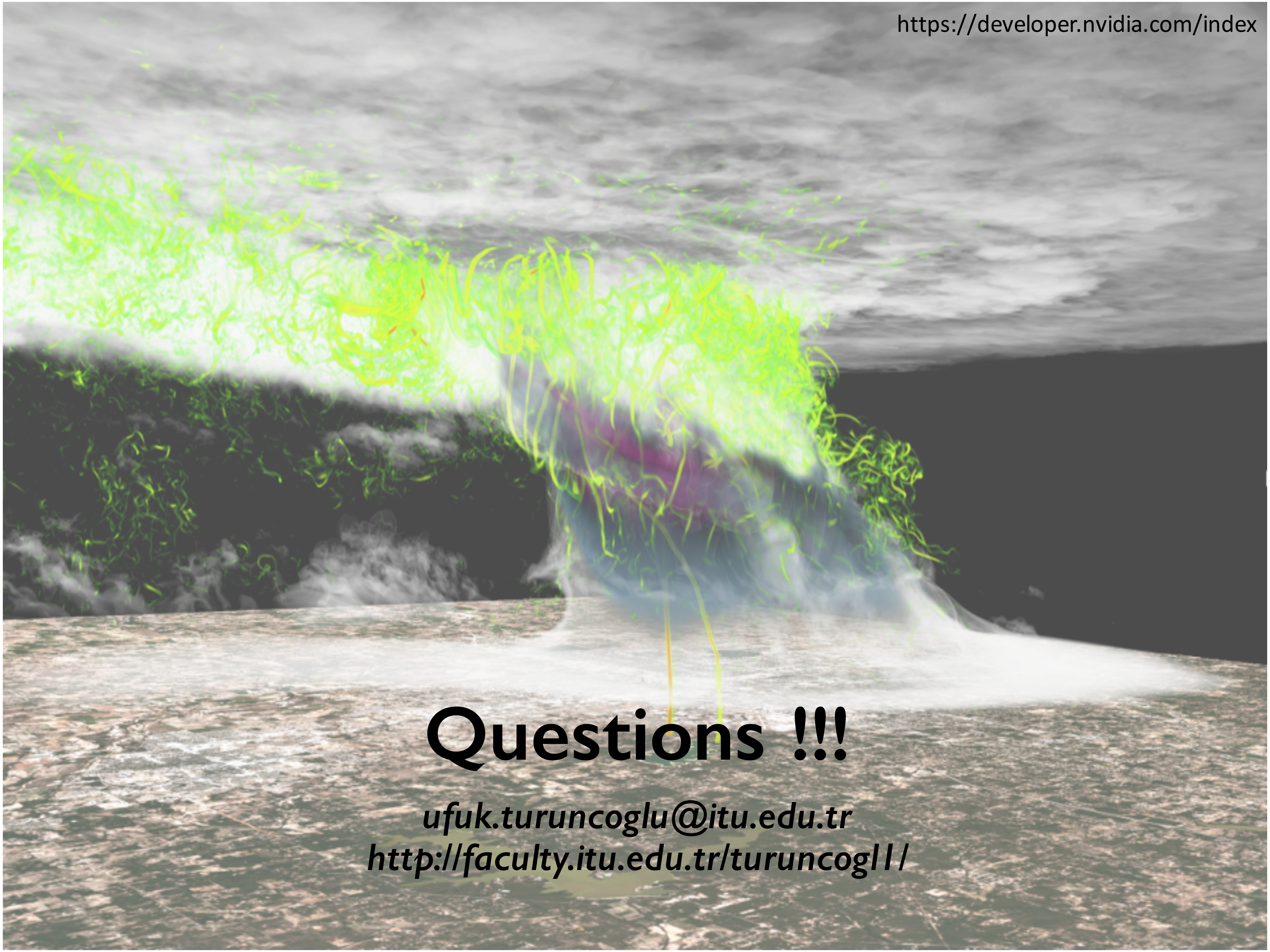
$$\Delta = \int destination\ field - \int source\ field$$

$$destination\ field = destination\ field - \frac{\Delta}{A_{ocn}}$$

bilinear
+
conservation

Project Home and Repository

- The open source RegESM modeling system (only driver) is hosted by GitHub
- We are currently testing Travis-ci as automatic build mechanism to have a Continuous Integration (CI) with Github
- Project Home: https://github.com/uturuncoglu/RegESM
- User documentation is ready for use (version 1.0e)
  - Distributed along with the source code (under docs/ directory)
  - Basic design of the modeling system
  - Requirements (libraries etc.) and their installation
  - Detailed information about the configurations files
  - Known bugs and limitations
  - Bugs:
    - Issue tracking is also handled by GitHub
    - Please report any bug or new feature request by GitHub



Questions !!!

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