Towards an Exchange Grid Implementation within the UFS

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The CMEPS Mediator is developed collaboratively:
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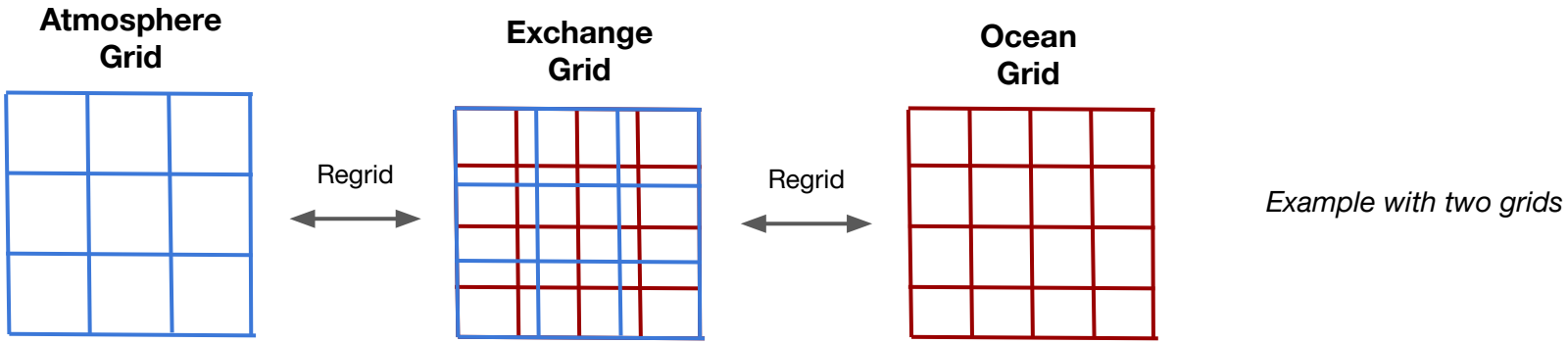
Exchange Grid

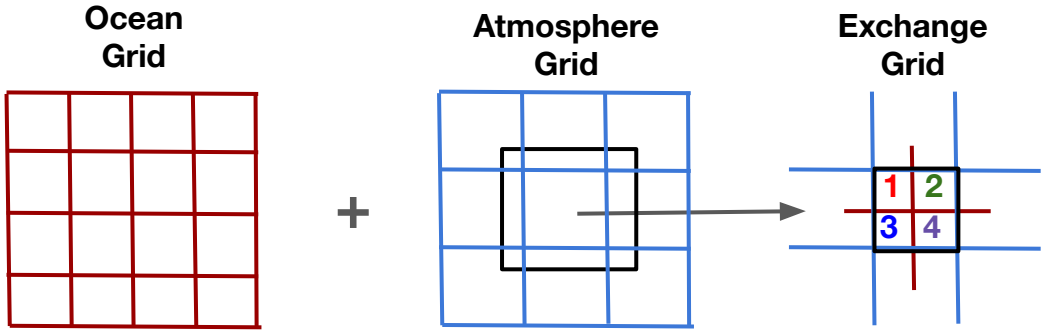
- Originally developed by GFDL and then ESMF Exchange grid is introduced to make it available easily and support different modeling applications
- The exchange grid is the set of intersecting cells formed from the union of all vertices in two (or more) parent grids



Example with two grids

Balaji, V., Anderson, J., Held, I., Winton, M., Durachta, J., Malyshev, S., & Stouffer, R. (2006). The Exchange Grid: A mechanism for data exchange between Earth System components on independent grids. https://extranet.gfdl.noaa.gov/~vb/pdf/xgridpaper.pdf

Computing surface fluxes: component vs. exchange grid



- Fluxes (**F**) are computed at finest possible grid resolution with exchange grid
  - Avoids computing fluxes using average of state (**S**) variable
  - The flux computation could be also easily done in the selected component grid (atm, ocn etc.)

Specific model component such as ATM

1 - Interpolation

$$S_{atm} = S_{ocn}*w_1 + S_{ocn}*w_2 + S_{ocn}*w_3 + S_{ocn}*w_4$$

2 - Flux computation

$$F_{atm} = \text{calc\_flux}(S_{atm})$$

Exchange grid

1 - Flux computation

$$F_{ocn} = \text{calc\_flux}(S_{ocn})$$
$$F_{ocn} = \text{calc\_flux}(S_{ocn})$$
$$F_{ocn} = \text{calc\_flux}(S_{ocn})$$
$$F_{ocn} = \text{calc\_flux}(S_{ocn})$$

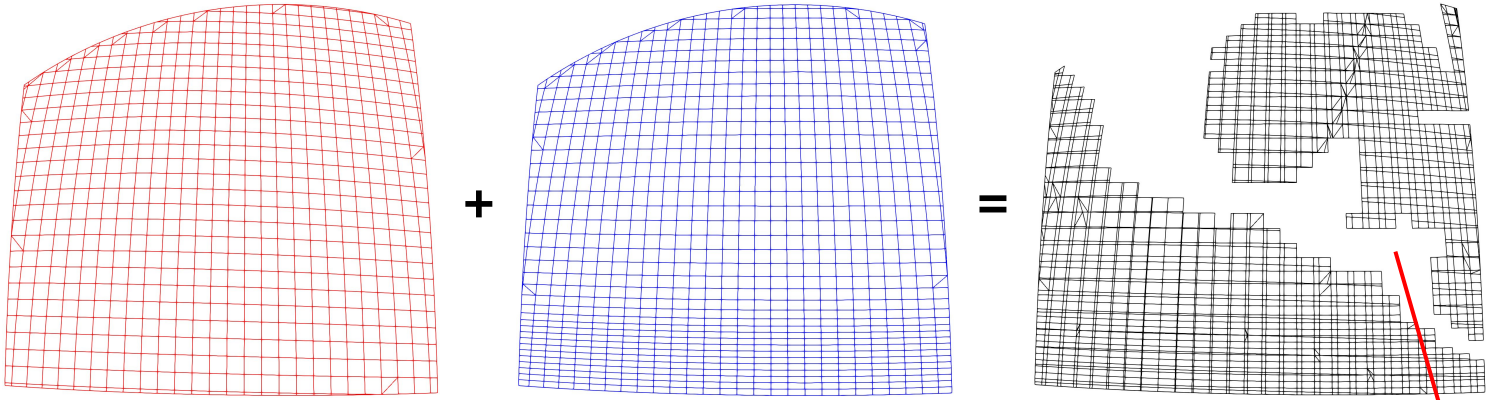
S: State variable such as SST

F: Flux such as LW(up)

2 - Interpolation

$$F_{atm} = F_{ocn}*w_1 + F_{ocn}*w_2 + F_{ocn}*w_3 + F_{ocn}*w_4$$

UFS Weather Model: example exchange grid (1)

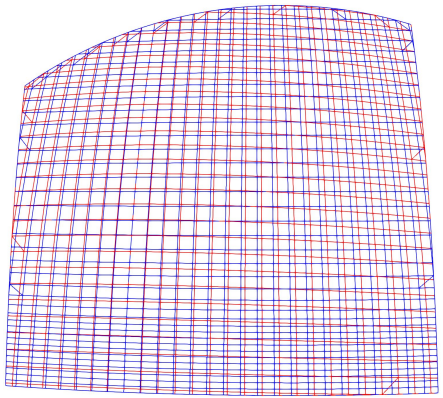


ATM, C96
agrid

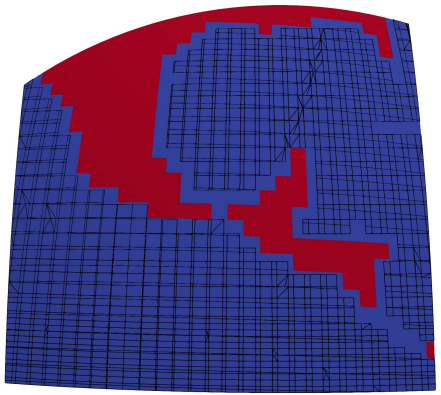
OCN, 1.0 deg.
ogrid

Exchange Grid
xgrid

no mesh over land since UFS only calculates atmosphere-ocean fluxes on exchange grid at this point



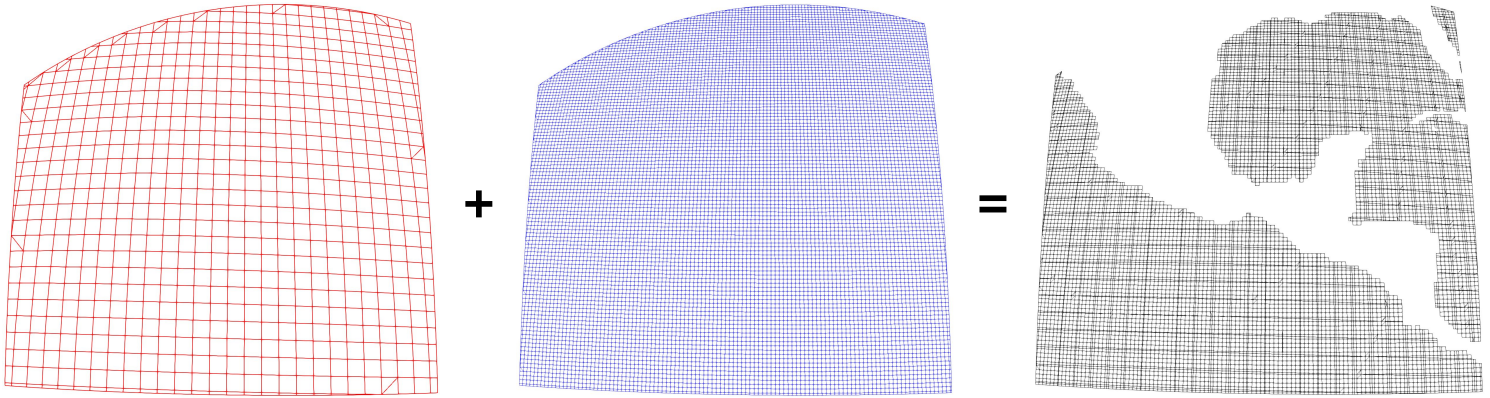
ATM + OCN



ATM Mask + Exchange Grid

* subsetted over Central America

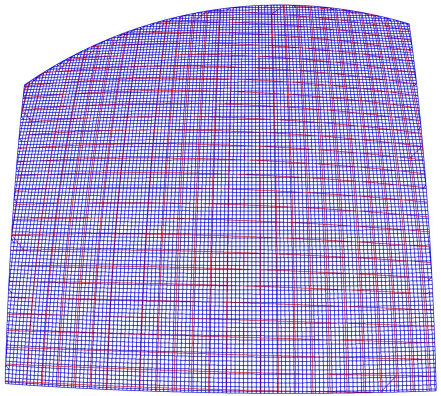
UFS Weather Model: example exchange grid (2)



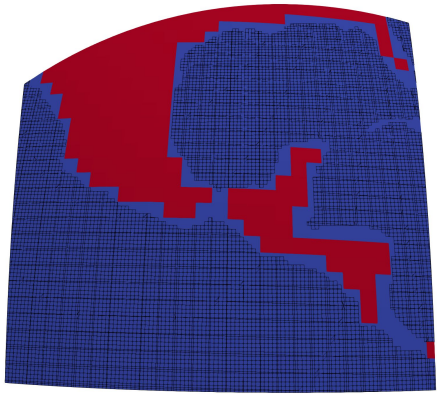
ATM, C96
agrid

OCN, 0.25 deg.
ogrid

Exchange Grid
xgrid



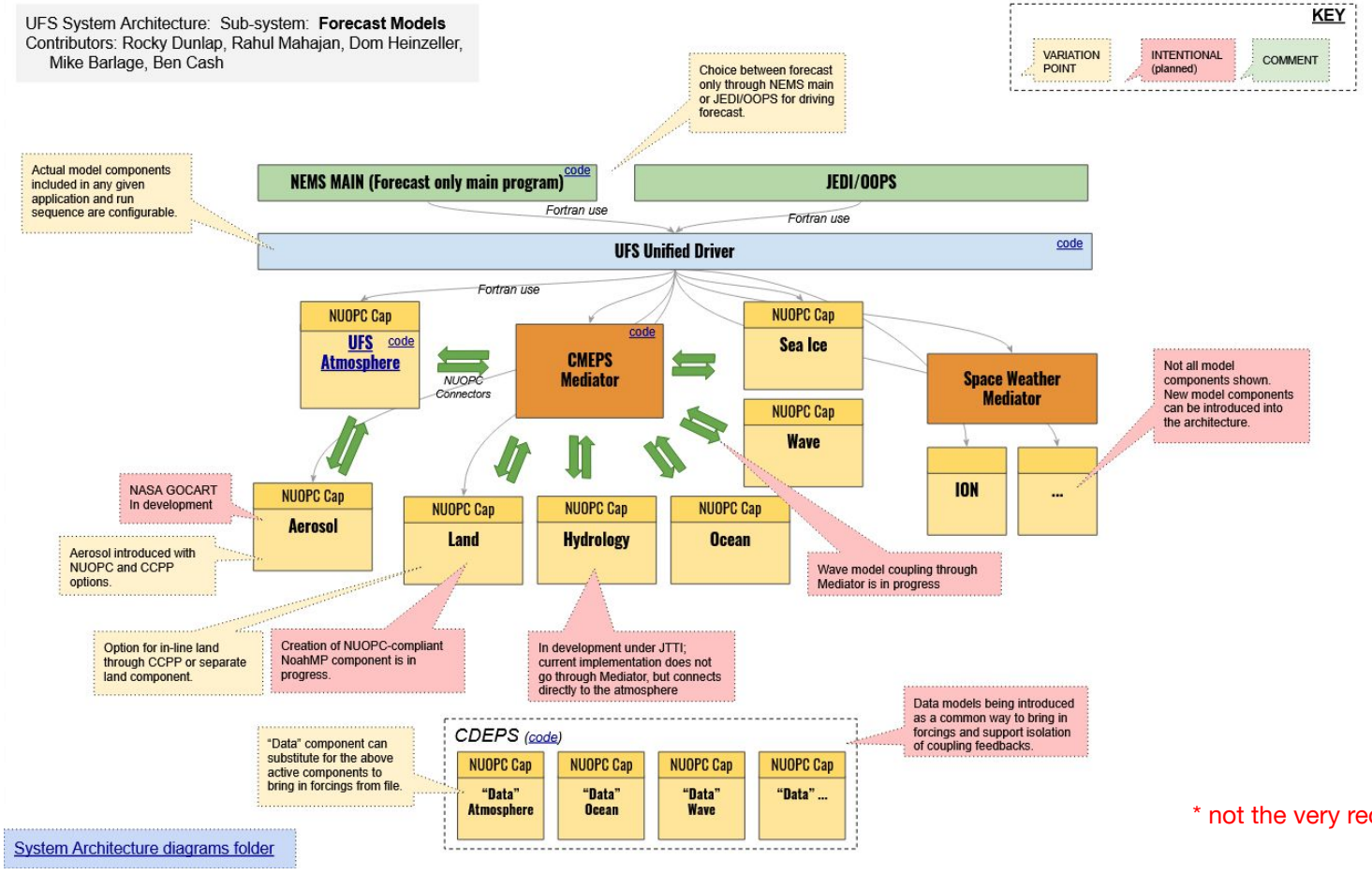
ATM + OCN



ATM Mask + Exchange Grid

* subsetted over Central America

UFS Weather Model



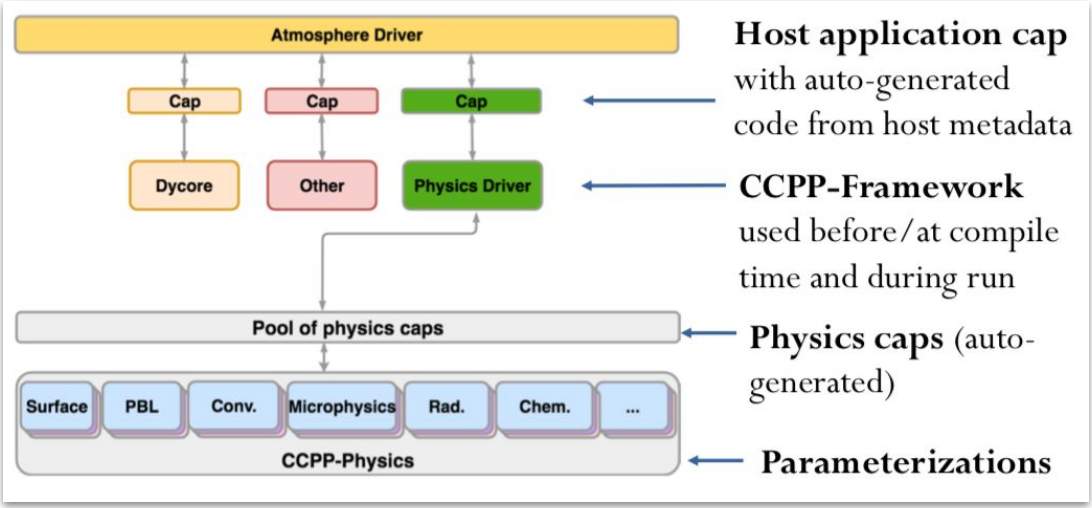
* not the very recent version

Motivation for CMEPS Exchange Grid Implementation

- Computing surface fluxes on the exchange grid guarantee that fluxes are computed at the highest possible resolution regardless of the relative grid resolutions of the atmosphere and ocean
- Facilitate scientific experimentation
    - Runtime options to calculate fluxes on different grids: **atmosphere, ocean** and **exchange**
    - Different configurations of the model can be tested/validated to reveal best configuration for the given application
- Develop the infrastructure to support more tightly coupled configurations, such as cross-component implicit coupling and coupling that takes into account sub-grid scale heterogeneity at the surface (see [1] and [2] for description of the GFDL approach).
- Expand the community mediator (CMEPS) to support **a key data structure and coupling paradigm** currently used in systems outside of the UFS. The application that uses CMEPS as a mediator could also use exchange grid without extra effort.
- Build on and continue a collaboration between GFDL, NCAR, and ESMF to develop CMEPS as a flexible coupler supporting a range of different coupling strategies.

Closer Look to Atmosphere-Ocean Flux Calculation in UFS WM

- FV3ATM is responsible to calculate atmosphere-ocean fluxes in the Common Community Physics Package (CCPP, sfc_ocean.F and on FV3ATM grid)

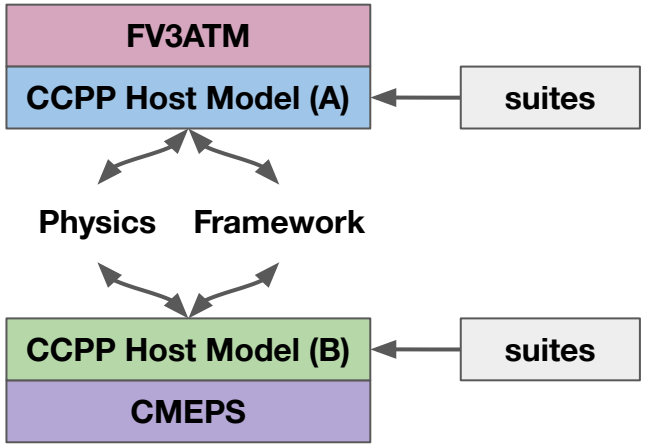


- The CCPP composite step combines (or merges) fluxes coming from different components based on their fractional grid representation (i.e. %50 ocean and %50 land), which is defined in FV3ATM

Using Exchange Grid under UFS WM

- The exchange grid is constructed in the mediator component (CMEPS)
- This requires enabling atmosphere-ocean flux calculation in mediator
- Two approaches:
  - Use existing atmosphere-ocean flux scheme in CMEPS. This approach is used by NCAR CESM model and also UFS WM data atmosphere specific configurations
  - **Enable CCPP host model under CMEPS mediator** to calculate atmosphere-ocean fluxes with the same way, which is done in FV3ATM/CCPP
    - This is required to perform side-by-side validation of surface fluxes that are computed on CMEPS mediator and FV3ATM/CCPP on atmospheric grid (*agrid*)
    - In this case, very simple CCPP suite file can be used to calculate the atmosphere-ocean fluxes
    - Also enables to calculate land fluxes in the future just by adding to the suite file

Enabling CCPP Host Model under CMEPS



- This is the first application that utilizes two different CCPP host application under same modeling system
- Both share same CCPP code base but they call different CCPP suite files

```
1   <?xml version="1.0" encoding="UTF-8"?>
2
3   <suite name="FV3_sfc_ocean" version="1">
4     <group name="physics">
5       <subcycle loop="1">
6         <scheme>GFS_surface_composites_pre</scheme>
7       </subcycle>
8       <subcycle loop="2">
9         <scheme>sfc_diff</scheme>
10        <scheme>GFS_surface_loop_control_part1</scheme>
11        <scheme>sfc_ocean</scheme>
12        <scheme>GFS_surface_loop_control_part2</scheme>
13      </subcycle>
14      <subcycle loop="1">
15        <scheme>GFS_surface_composites_post</scheme>
16        <scheme>sfc_diag</scheme>
17      </subcycle>
18    </group>
19  </suite>
```

CMEPS/ufs/ccpp/suites/suite_FV3_sfc_ocean.xml

Setup and run the xgrid regression test (RT)

- As a part of the project a new RT is developed: *cpld_control_c96_noaero_p8_agrid*
  - The test uses *agrid* (atmospheric model grid) to calculate fluxes in mediator by default
  - It is based on existing three-component configuration, *cpld_control_c96_noaero_p8*
  - It runs the model 1 day by providing atmosphere-ocean fluxes from mediator
    - The mediator uses its internal CCPP host model to drive simple suite file
    - The suite file uses CCPP physics *sfc_ocean* scheme
- The default grid to calculate atmosphere-ocean fluxes can be changed simply by editing *aoflux_grid* parameter in the *parm/nems.configure.cpld_agrid.IN*
  - The parameter could get *xgrid* (exchange grid), *ogrid* or *agrid* as option
- The regression test can be run with *./rt.sh -k -n cpld_control_c96_noaero_p8_agrid*
  - This will keep the run directory for future reference

Validation Runs

- The following simulations were performed on NCAR's Cheyenne platform
- In all simulations, CMEPS CCPP host model reads initial condition from INPUT/sfc* files

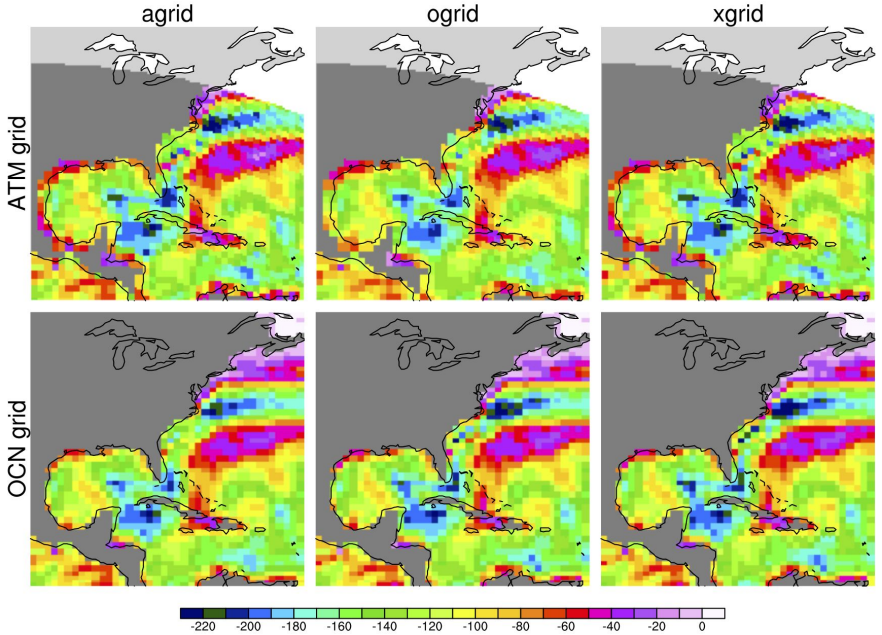
Run ID	Component Resolutions	Length	Description
REF_100*	**A: C96 O/I: 1 deg.**	35-days	**Side-by-side run, FV3 computes its own fluxes**
AGRID_100	same	35-days	CMEPS calculates fluxes on *agrid* and send to FV3
OGRID_100	same	35-days	CMEPS calculates fluxes on *ogrid* and send to FV3
XGRID_100	same	35-days	CMEPS calculates fluxes on *xgrid* and send to FV3
REF_025*	**A: C96 O/I: 0.25 deg.**	35-days	**Side-by-side run, FV3 computes its own fluxes**
AGRID_025	same	35-days	CMEPS calculates fluxes on *agrid* and send to FV3
OGRID_025	same	35-days	CMEPS calculates fluxes on *ogrid* and send to FV3
XGRID_025	same	35-days	CMEPS calculates fluxes on *xgrid* and send to FV3

***** Additional 2-days simulation by enabling high temporal resolution mediator history output (every coupling interval, 720 s)
***** In side-by-side runs (REFs) CMEPS calculates fluxes on agrid to make direct comparison with FV3
* All cases uses single coupling interval (slow coupling time step = fast coupling time step, 720 s) to write mediator history files in fast loop

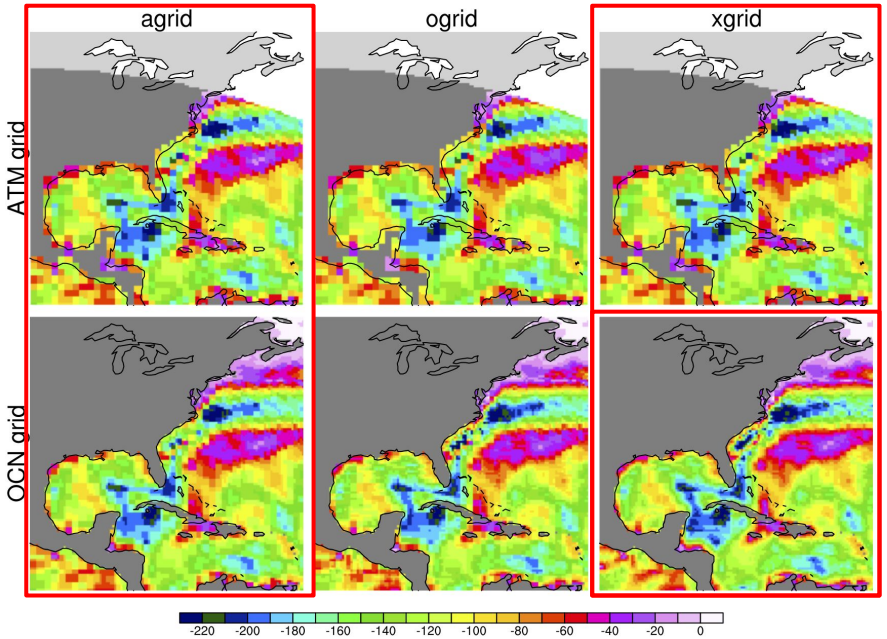
Computing fluxes on different grid

- Comparison of *Med_aoflux_atm_Faox_lat* and *Med_aoflux_ocn_Faox_lat* @ first coupling interval

1.0 deg. ocean



0.25 deg. ocean



Interpolation types:

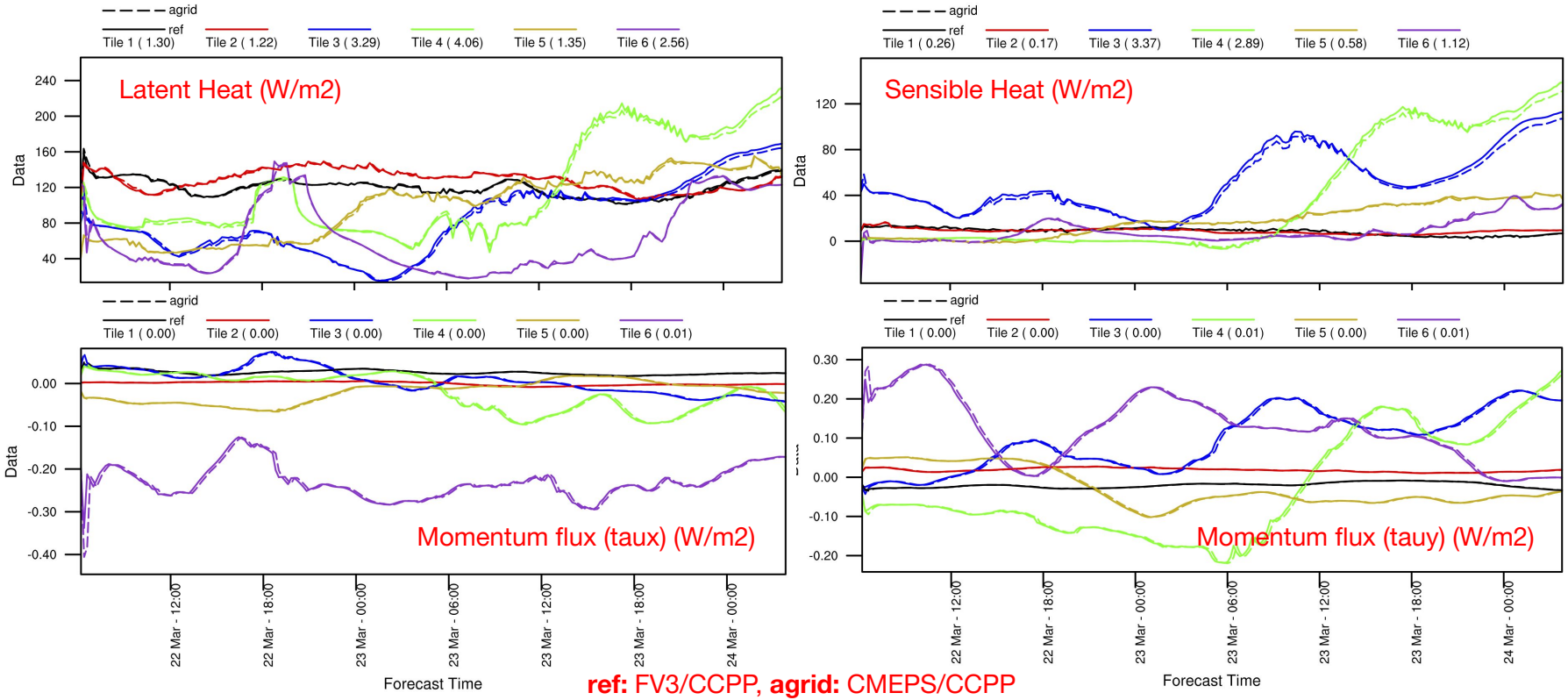
atm -> xgrid: 1st order conservative except u and v, u and v uses 2nd order

xgrid -> atm: 1st order conservative

xgrid -> ocn & ocn -> xgrid: 1st order conservative

Side-by-side run comparisons (1)

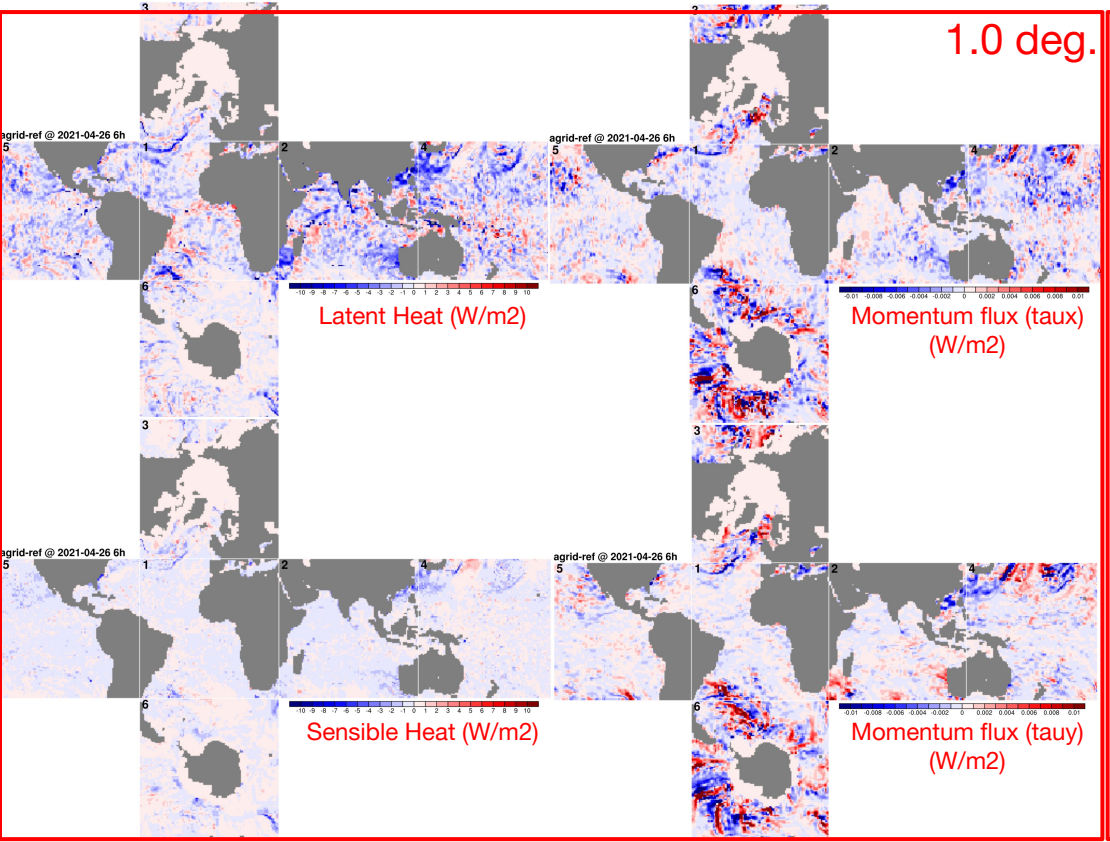
- Results from *side-by-side* AGRID_100: single point in each tile (far from icy regions) + for 2-days

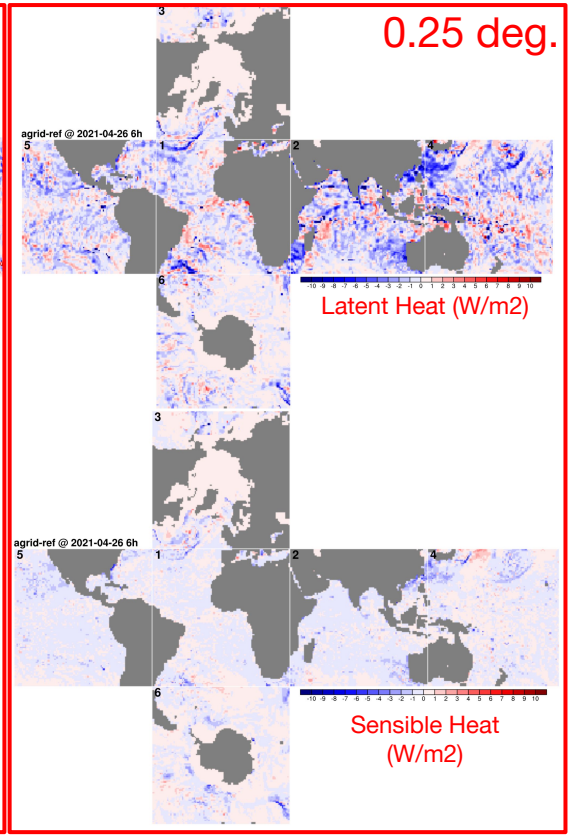


ref: FV3/CCPP, **agrid:** CMEPS/CCPP

Side-by-side run comparisons (2)

- Results after 35-days *side-by-side* *AGRID_100* and *AGRID_025* simulations





The differences are very similar for AGRID_100 and AGRID_025

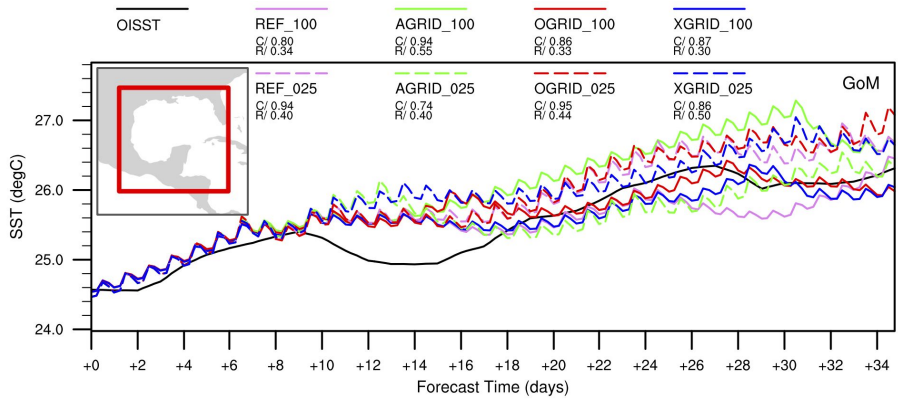
Upward longwave flux is also almost identical

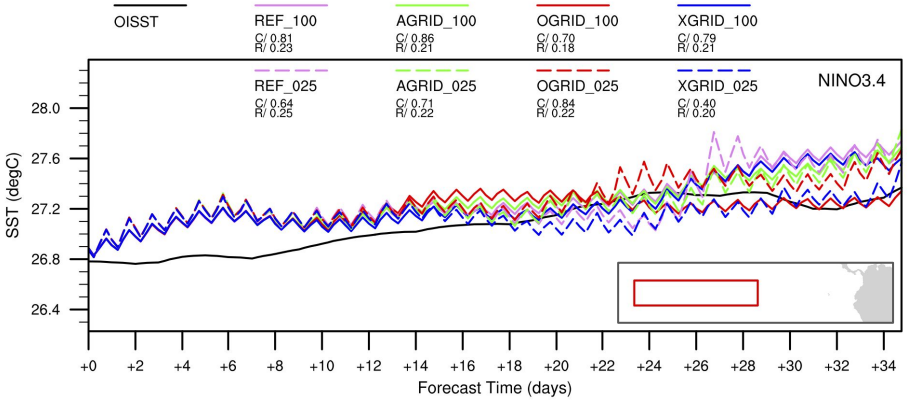
Differences between FV3/CCPP and CMEPS/CCPP is probably related to the atmospheric input **since CMEPS and FV3 are not calling the flux computation in same place**.

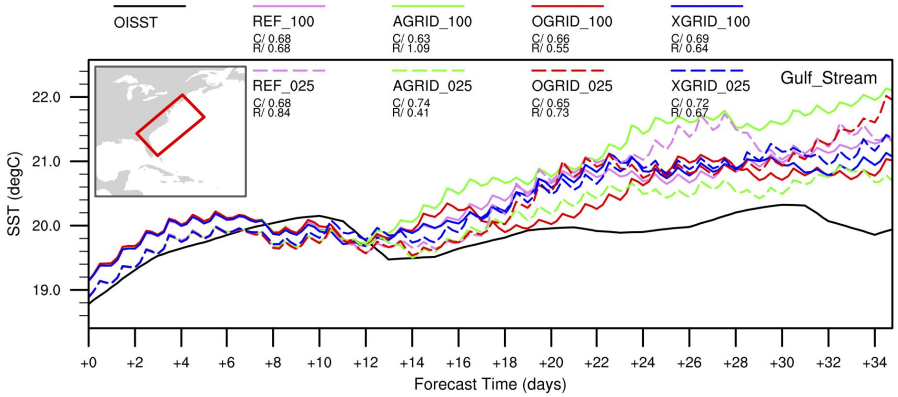
Splitting physics could eliminate resolve these differences.

Temporal evolution of SST on different regions

- SST averaged over sub-regions (calculated using MOM6 output)



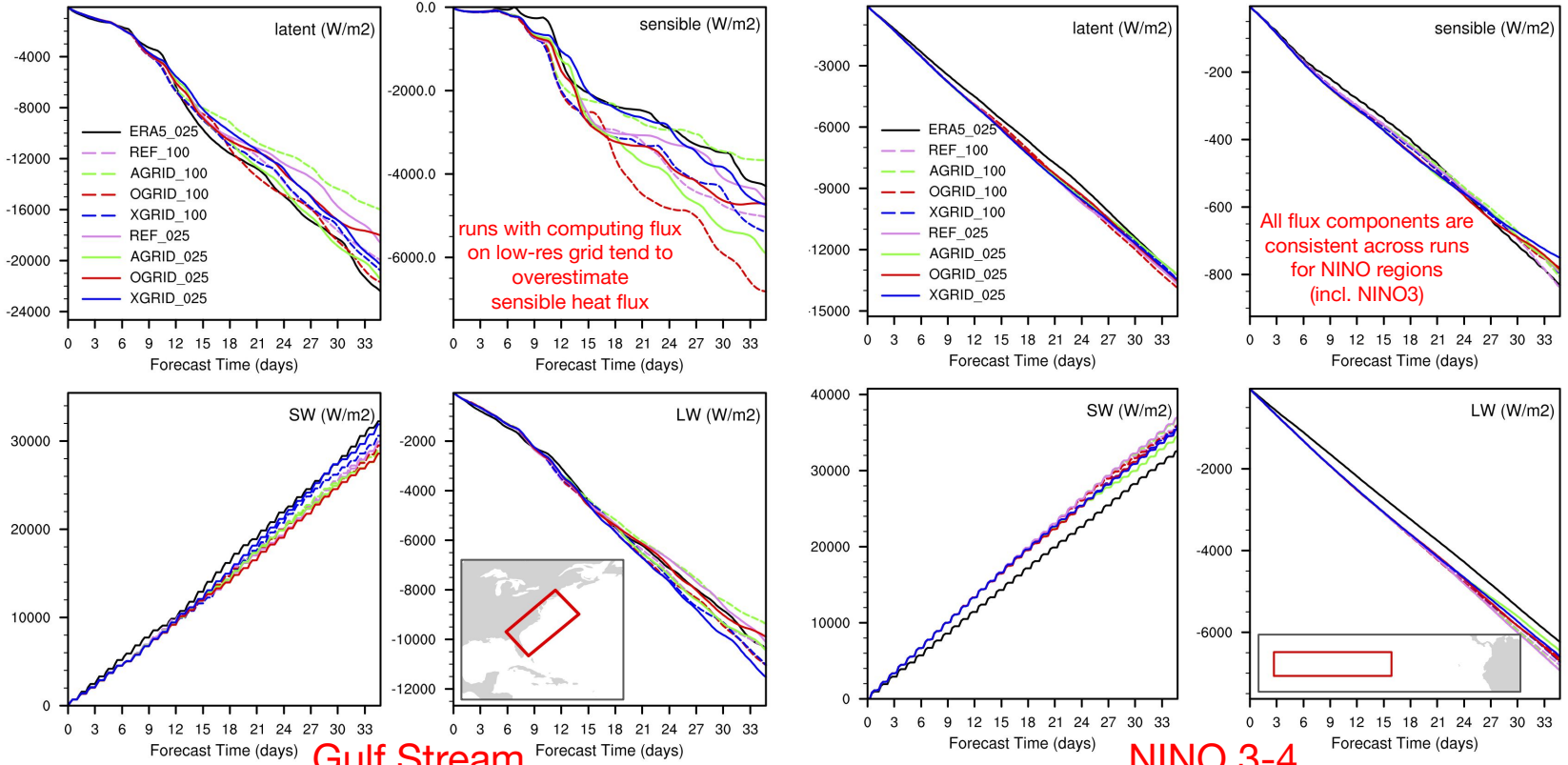




- All configurations shows similar temporal behaviour
- The results of different configurations start to diverge after 10-days of simulation.

Accumulated Flux Components

- It is calculated using 6 hourly MOM6 output for each run and ERA5 (land is masked out)



Potential Future Development Steps

- **Identify applications and configurations of UFS that would benefit from the exchange grid.**
  - UFS application teams enable the exchange grid capability in their configurations and perform evaluations specific to the application.
  - Adding component version of land model to exchange grid and calculate fluxes
  - Future proposals for application development (e.g., S2S) can leverage the exchange grid in their projects.
- **Some improvements to the CMEPS-CCPP integration could simplify the design:**
  - Split calls to CCPP physics by the UFS atmosphere into multiple phases
    - This would allows to computing atmosphere-ocean fluxes in the same place that is currently called under FV3ATM. This might eliminate minor differences seen in the calculated fluxes.
  - Define CCPP as a external component (develop ESMF/NUOPC cap top of it)
    - This could eliminate duplication of code in CMEPS and FV3 sides
    - Allows running CCPP in any grid/mesh (components transfer their data and grid information)
  - Extending CCPP to include I/O capability and rich metadata
    - The CCPP could be responsible for its own I/O routines to read initial conditions and write restart/history information
    - In the current design, the CCPP host model under CMEPS also includes I/O routines to enable CCPP restart capability
    - The CCPP metadata can be enriched to include information about fields required for restart

Questions?

Backup Slides

ESMF/NUOPC Exchange Grid Support

- **Creation:**

```
xgrid = ESMF_XGridCreate(sideAGrid=<list of grids>, sideAMesh=<list of meshes>,
                         sideBGrid=<list of grids>, sideBMesh=<list of meshes>,
                         Optional Grid and Mesh prioritization inputs,
                         Optional Masking inputs, …)
```

- **Regridding data to/from side Field to XGrid Field:**

```
ESMF_FieldRegridStore(xgrid, ! Like the usual FieldRegridStore(), but with xgrid
                         srcField=<field built on side or xgrid>,     dstField=<field
                         built on side or xgrid>,        routeHande=rh, ! Output
                         routeHandle  …)

ESMF_FieldRegrid(srcField, dstField, rh, …) ! Apply routeHandle as usual
```

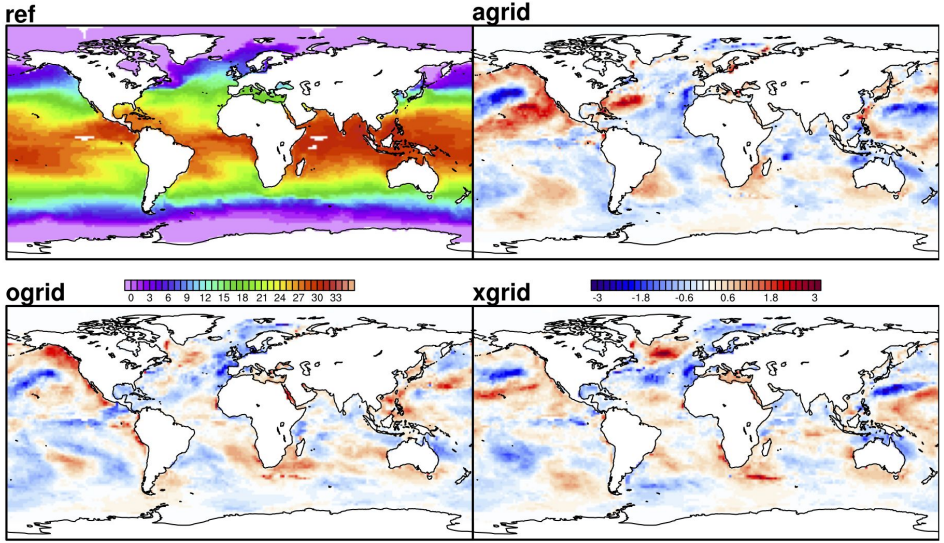
- **Retrieve information:**

```
ESMF_XGridGet(xgrid, area, centroid, ! Areas and centroids of XGrid cells
              sparseMatX2A, sparseMatA2X, ! Sparse matrices
              … and more …)
```

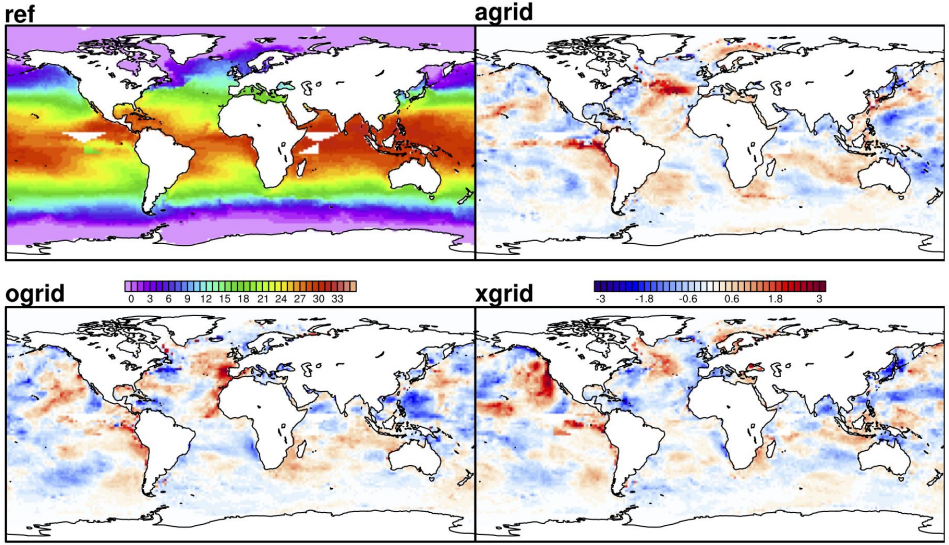
Spatial SST differences

- 1.0 and 0.25 deg. Ocean and difference after 35-days of simulation

1.0 deg.



0.25 deg.



The results indicates that there is no particular issue in implementation since all the configurations produces similar results except some spatial differences

As it also shown in temporal plots, agrid, ogrid and xgrid have similar temporal and spatial behaviour first week and then solutions start to diverge

Ice related variables (*AGRID* vs. *XGRID*)

- Calculated using 6 hourly CICE6 output for each run (averaged over entire simulation)

xgrid in the labels need to be diff: xgrid-agrid

1.0 deg.

0.25 deg.

aice_h (area: 0-1)

hi_h (thickness: m)