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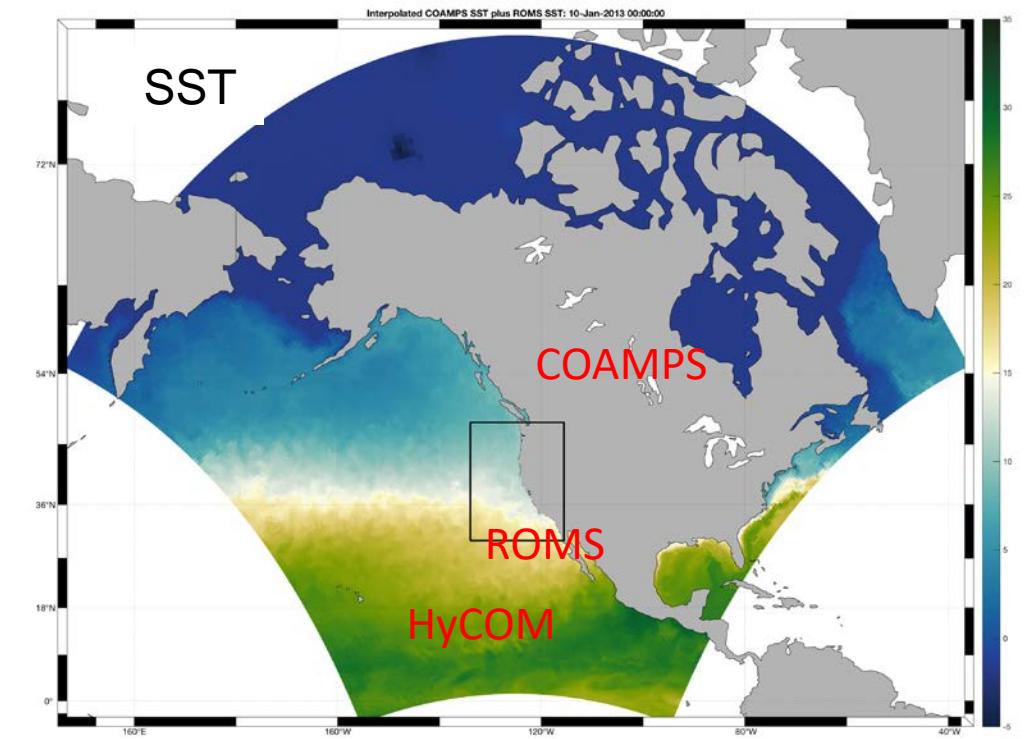
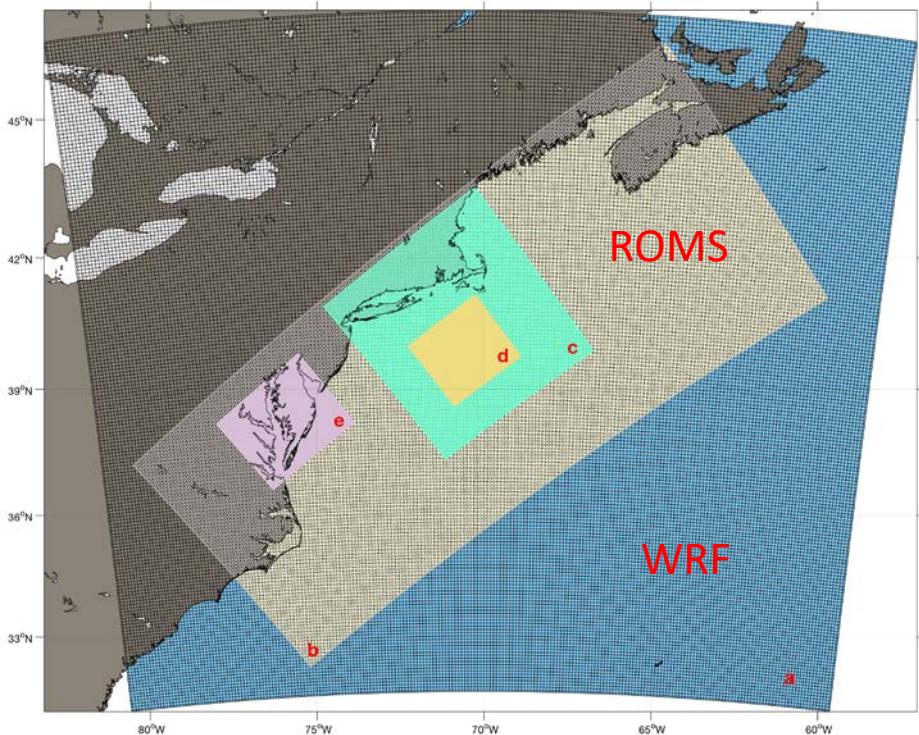
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OF NEW JERSEY

## ROMS ESMF/NUOPC Coupling Framework

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## Collaborators

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# **ESMF Coupling Revisited**

- Rewrote ROMS coupling interface to **ESMF** Library Version 7.0 or higher.
- Using the **National Unified Operational Prediction Capability (NUOPC)** Layer.

The **NUOPC** layer is a simplified infrastructure on top of the **ESMF** library that provides conventions and templates to facilitate the easy coupling between Earth System Models (**ESMs**).

- The **NUOPC** layer consist of four generic components:

## **Driver**

Controls Models, Mediators, and Connectors. Coordinates initialization and time-stepping.

## **Model**

Earth System Models: Atmosphere, Ocean, Sea Ice, Waves, etc.

## **Mediator**

Custom coupling code between models: Flux calculations, scaling, averaging, etc.

## **Connector**

Connects pair of components: Model to/from Model, Model to/from Mediator. Computes transformations and re-gridding.

# **ROMS ESMF/NUOPC Coupling Modes of Operation**

- Driver Mode: ROMS provides all the interfaces needed to couple to other ESM components including:
  - Main Driver (`esmf_driver.h`)
  - NUOPC-based generic ESM component services (`esmf_esm.F`)
  - Utility module (`mod_esmf_esm.F`) defining structures and variables for ESM coupling. It includes several support routines.
  - Model gridded components or NUOPC model cap files (`esmf_atm.F`, `esmf_data.F`, `esmf_ice.F`, `esmf_roms.F`, and `esmf_wav.F`)
  - Connectors between components for re-gridding source and destination fields (`esmf_coupler.h`)
  - Coupling input script (`coupling_esmf.in`) and import/export fields metadata management (`coupling_esmf.dat`)
- Component Mode: A NUOPC ROMS cap module (`esmf_roms.F`) is provided which can be adapted and incorporated into other NUOPC-based coupling systems.

A NUOPC Model cap is a Fortran module layer that sits on top of the ESM component, making calls into it (*initialize*, *run*, and *finalize* phases).

# ROMS NUOPC cap File

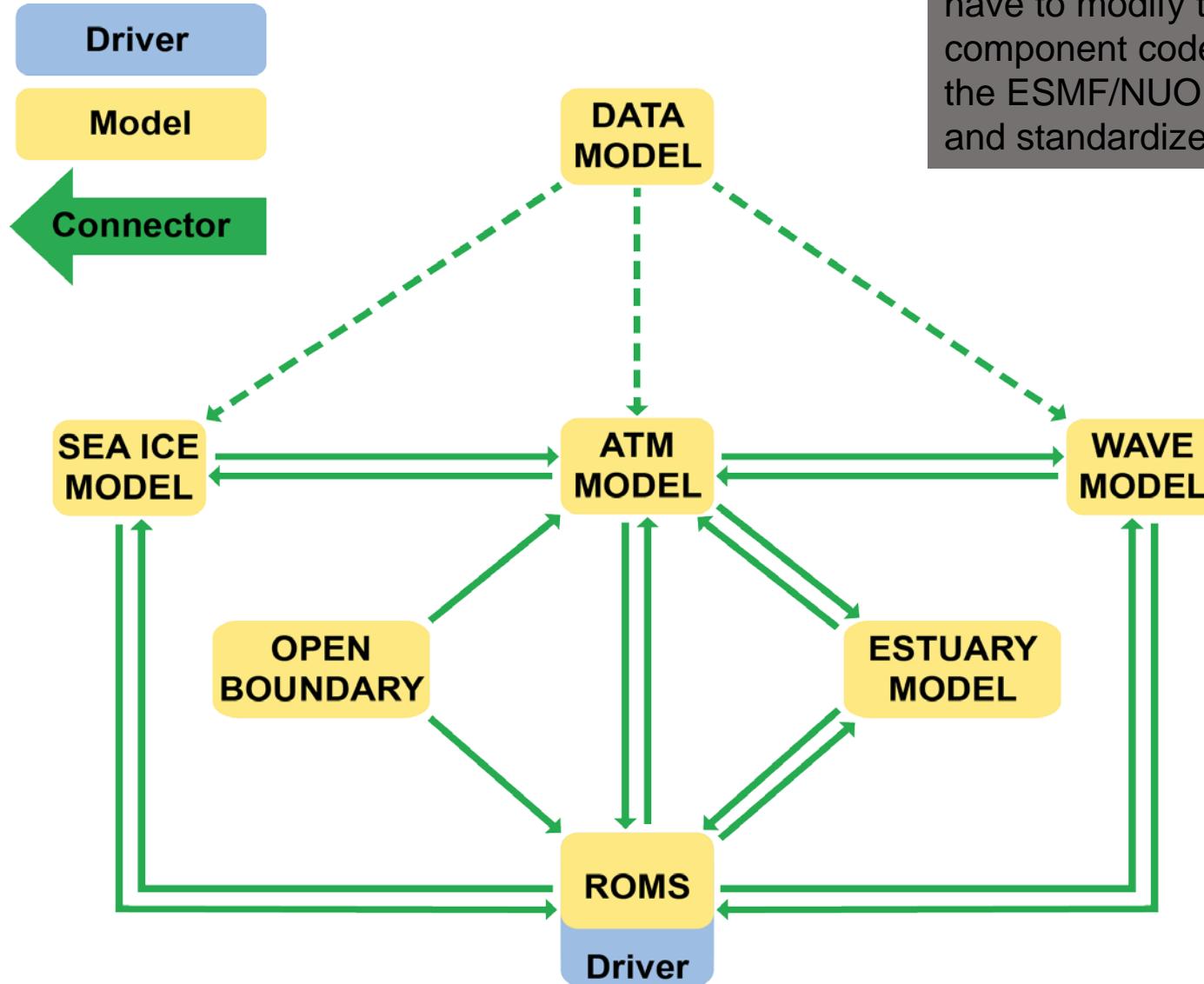
`esmf_roms.F:`

**MODULE esmf\_roms\_mod**

<code>ROMS_SetServices:</code>	Sets shared-object entry points using NUPOC generic methods for <b>initialize</b> , <b>run</b> , and <b>finalize</b> kernel routines (PUBLIC routine)
<code>ROMS_SetInitializeP1:</code>	Phase 1 initialization: <b>advertise import</b> and <b>export</b> fields long- and short-names
<code>ROMS_SetInitializeP2:</code>	Phase 2 initialization: <b>Initializes</b> solution, sets application grid arrays, and registers fields into <b>import state</b> and <b>export state</b>
<code>ROMS_Datalinit:</code>	<b>Exports fields</b> during initialization or restart
<code>ROMS_SetClock:</code>	Sets calendar, start and stop times, and coupling interval
<code>ROMS_SetRunClock;</code>	Sets ROMS run clock manually
<code>ROMS_CheckImport:</code>	Checks if <b>import field</b> is at the correct time
<code>ROMS_SetGridArrays:</code>	Sets staggered, horizontal grid arrays, grid area, and land/sea masks
<code>ROMS_SetStates:</code>	Realize fields into <b>import</b> and <b>export states</b> by allocating and initializing pointers
<code>ROMS_ModelAdvance:</code>	<b>Advances</b> kernel for a coupling interval and <b>calls import</b> and <b>export</b> routines
<code>ROMS_SetFinalize:</code>	Finalizes execution
<code>ROMS_Import:</code>	<b>Imports fields</b> from other connected components
<code>ROMS_Export:</code>	<b>Exports fields</b> to other connected components

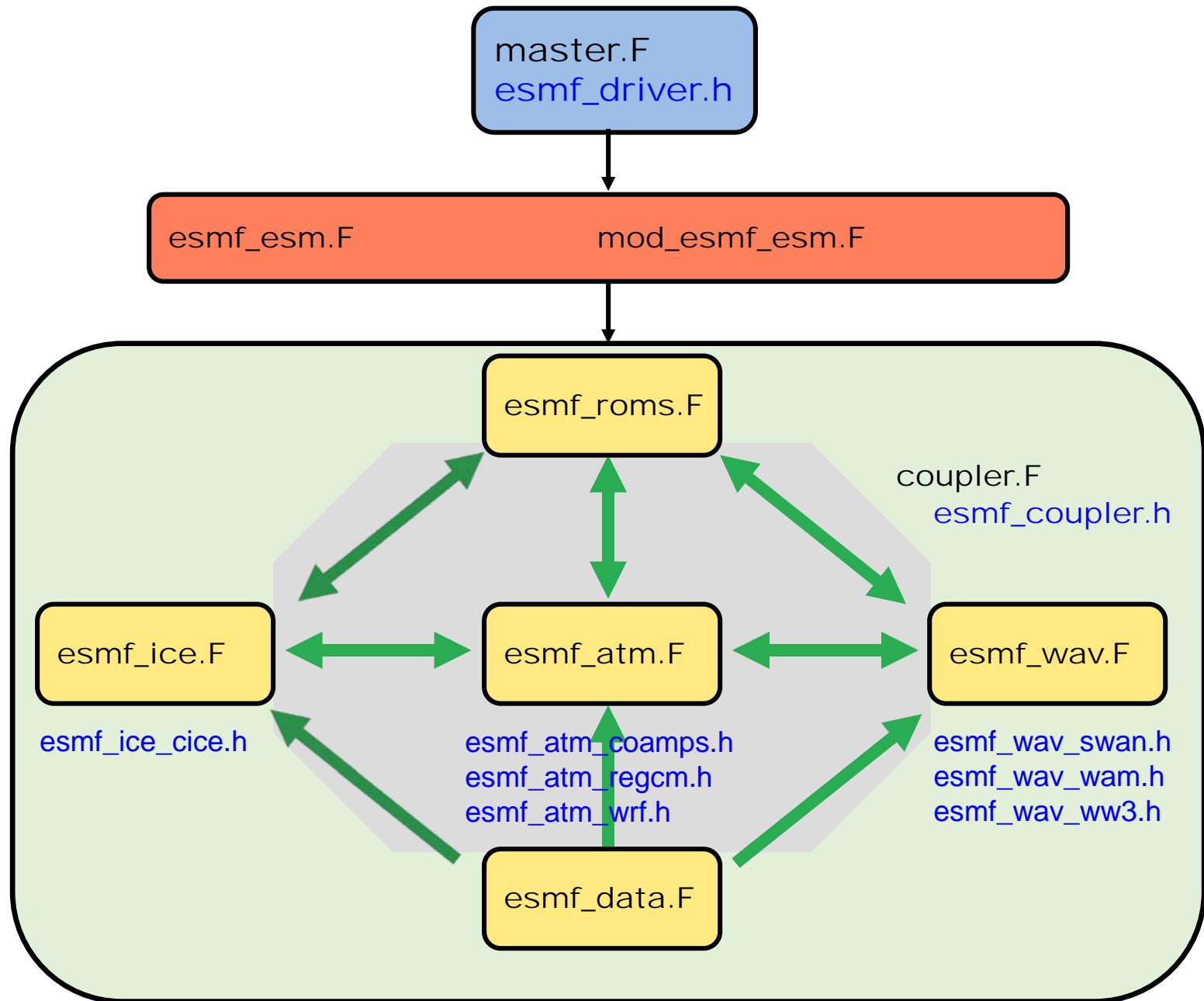
**END MODULE esmf\_roms\_mod**

# ROMS Coupling Framework: Driver Mode



If done correctly, we don't have to modify the ESM component code. Just need the ESMF/NUOPC cap files and standardized metadata!

# ROMS Coupling Infrastructure



# ROMS Coupling: Driver Mode

master.F:

```
#if defined MODEL_COUPLING
# if defined MCT_LIB
# include "mct_driver.h"
# elif defined ESMF_LIB
# include "esmf_driver.h"
# else
    PROGRAM master
    END PROGRAM
# endif
#else
# include "ocean.h"
#endif
```



coupler.F:

```
#if defined MODEL_COUPLING
# if defined MCT_LIB
# include "mct_coupler.h"
# elif defined ESMF_LIB
# include "esmf_coupler.h"
# endif
#else
    MODULE coupler_mod
    END MODULE coupler_mod
#endif
```

ROMS is coupled to other external software and drivers not written by us (like RegESM; Turuncoglu and Sannino, 2016)

# ROMS Coupling: Atmosphere Model NUOPC Cap Files

esmf\_atm.F:

```
# if defined ATM_COUPLING
# if defined COAMPS_COUPLING
# include "esmf_atm_coamps.h"
# elif defined REGCM_COUPLING
# include "esmf_atm_regcm.h"
# elif defined WRF_COUPLING
# include "esmf_atm_wrf.h"
# else
# include "esmf_atm_void.h"
# endif
# else
    MODULE esmf_atm_mod
    END MODULE esmf_atm_mod
# endif
#else
    MODULE esmf_atm_mod
    END MODULE esmf_atm_mod
#endif
```

**COAMPS:** Coupled Ocean-Atmosphere Mesoscale Prediction System (Hodur, 1997; Chen *et al.*, 2014). It can be used for both free and restricted NRL versions.

**RegCM:** Regional Climate Model (Elguindi *et al.*, 2014), Version 4.5 (RegCM4) and up. Maintained by the International Centre for Theoretical Physics (ICTP), Trieste, Italy. It was build upon the NCAR-PSU Mesoscale Model version 4 (MM4; Dickinson *et al.*, 1989; Giorgi, 1989).

**WRF:** Weather Research and Forecasting model (Skamarock *et al.*, 2005). Maintained by a consortium of US agencies and institutions (NCAR, NCEP, FSL, AFWA, NRL, FAA, and University of Oklahoma).

# ROMS Coupling: Wave Model NUOPC Cap Files

esmf\_wave.F:

```
# if defined WAV_COUPLING
# if defined SWAN_COUPLING
# include "esmf_wav_swan.h"
# elif defined WAM_COUPLING
# include "esmf_wav_wam.h"
# elif defined WW3_COUPLING
# include "esmf_ww3_wam.h"
# else
# include "esmf_wav_void.h"
# endif
# else
    MODULE esmf_wav_mod
    END MODULE esmf_wav_mod
# endif
#else
    MODULE esmf_wav_mod
    END MODULE esmf_wav_mod
#endif
```

**SWAN**: Simulating Waves Nearshore (Booij *et al.*, 1999).

**WAM**: Wave Modelling (WAMDI Group, 1998).

**WW3**: WaveWatch III (Tolman, 2009).  
Developed at MMAB/NCEP.

# ROMS Coupling: Sea Ice Model NUOPC Cap Files

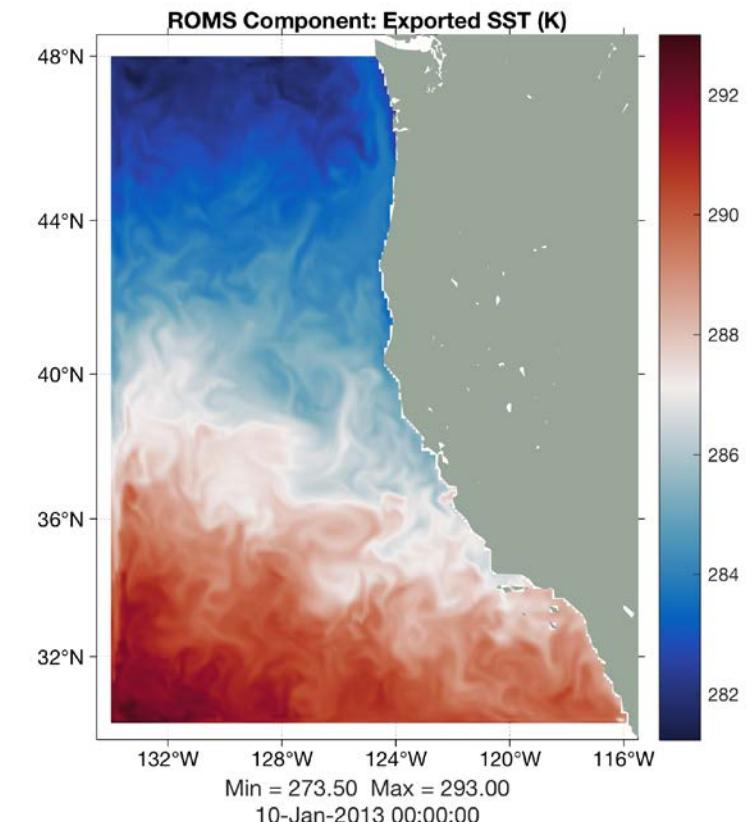
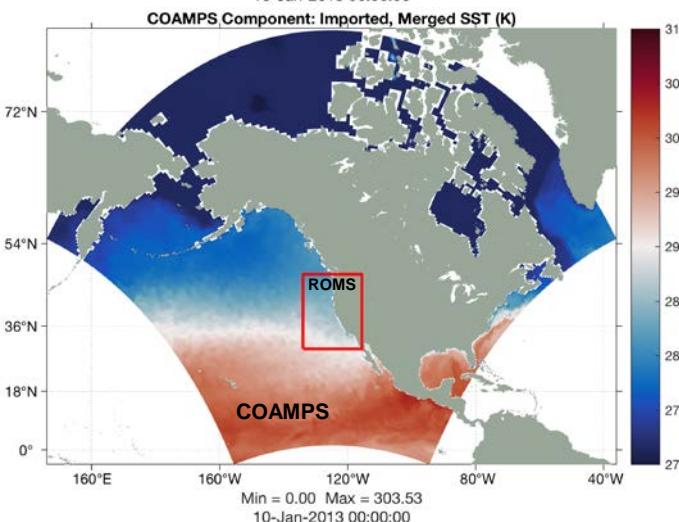
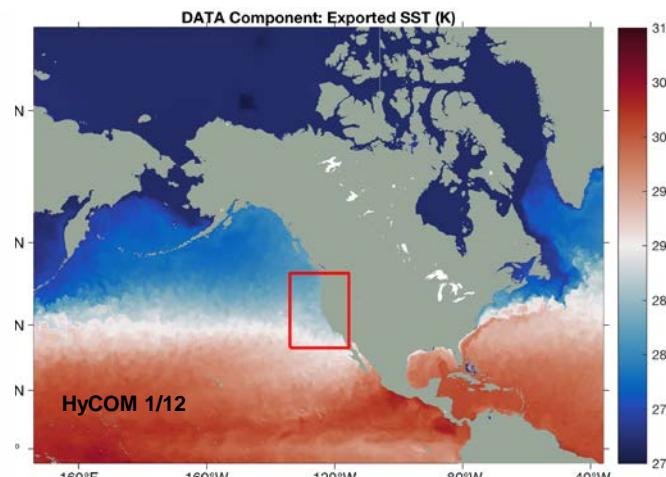
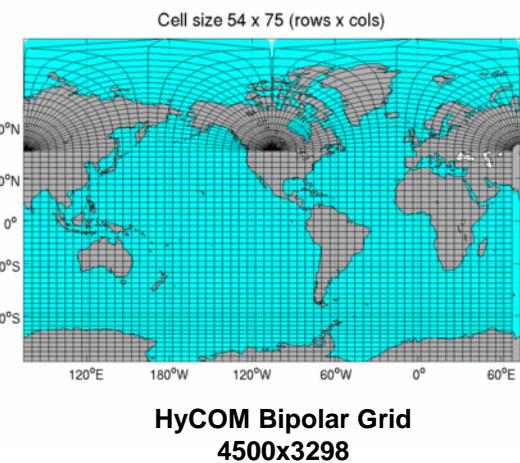
esmf\_ice.F:

```
# if defined ICE_COUPLING
# if defined CICE_COUPLING
# include "esmf_ice_cice.h"
# else
# include "esmf_ice_void.h"
# endif
# else
    MODULE esmf_ice_mod
    END MODULE esmf_ice_mod
# endif
#else
    MODULE esmf_ice_mod
    END MODULE esmf_ice_mod
#endif
```

CICE: Los Alamos sea ice model (Hunkle *et al.*, 2015).

# ROMS Coupling: DATA Model NUOPC Cap Files

`esmf_data.F`: The DATA Model is used to provide coupling fields to the ESM components at locations not covered by the other ESM components because smaller grid coverage (incongruent meshes) or lack of input data interface



# ROMS Coupling: Import/Export Metadata

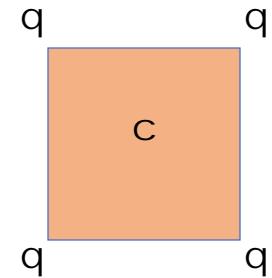
'Uwind'  
'zonal\_wind\_height\_lowest'  
'near surface zonal wind component'  
'ifld\_u10\_true', 'COAMPS'  
'm s-1'  
'Center'  
'Uair', 'ROMS'  
'm s-1'  
'Center'  
'Uair'  
'bilinear'  
.FALSE.  
.TRUE.  
0.0d0  
1.0d0

'Vwind'  
'merid\_wind\_height\_lowest'  
'near surface meridional wind component'  
'ifld\_v10\_true', 'COAMPS'  
'm s-1'  
'V'  
'Vwind', 'ROMS'  
'm s-1'  
'Center'  
'Vair'  
'bilinear'  
.FALSE.  
.TRUE.  
0.0d0  
1.0d0

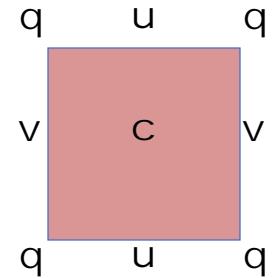
! short name  
! standard name  
  
! source variable, COAMPS  
! source units  
! source grid-cell  
! destination variable, ROMS  
! destination units  
! destination grid-cell  
! DATA model file variable  
! re-gridding method  
! extrapolation support  
! connected to coupler  
! importing add offset  
! importing scale

! short name  
! standard name  
  
! source variable, COAMPS  
! source units  
! source grid-cell  
! destination variable, ROMS  
! destination units  
! destination grid-cell  
! DATA model file variable  
! re-gridding method  
! extrapolation support  
! connected to coupler  
! importing add offset  
! Importing scale

Arakawa B-grid



Arakawa C-grid



c center-point

q corner-point

u u-point

v v-point

# COAMPS-ROMS ESMF Coupling

Coupling Input Parameters File Name = `coupling_esmf_bulk_flux.in`  
 Coupling Input Metadata File Name = `./coupling_esmf_coamps.dat`  
 ROMS Input Parameters File Name = `roms_wc12_120hours.in`

```

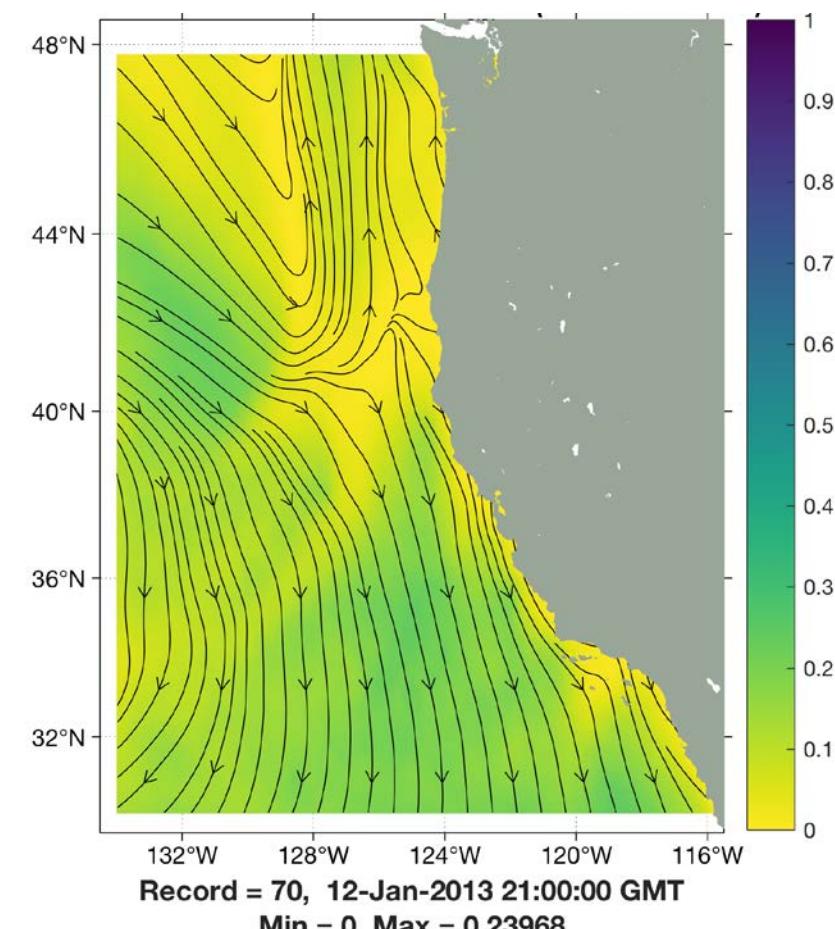
T IsActive(roms)           ROMS component for grid: 01.
T IsActive(atmos)          COAMPS_01 component for grid: 01.
T IsActive(atmos)          COAMPS_02 component for grid: 02.
T IsActive(data)            DATA component.
F IsActive(seaice)         ICE component.
F IsActive(waves)          WAV component.
T Coupled(ATM-OCN)        components COAMPS_01 and ROMS_01 are connected.
T Coupled(OCN-ATM)        components ROMS_01 and COAMPS_01 are connected.
T Coupled(DAT-ATM)        components DATA and COAMPS_01 are connected.
1 CouplingType             Semi-Implicit coupling method.
CONCURRENT PETlayoutOption Concurrent, each model runs on a subset of PETs.
1 ItileD                   DATA model tile partition in the I-direction.
1 JtileD                   DATA model tile partition in the J-direction.
4 Nthreads(roms)           Assigned number of PETs for ROMS, grid: 01.
                           Coupling Driver PETs: 0 to 3
4 Nthreads(atmos)          Assigned number of PETs for COAMPS_01.
                           Coupling Driver PETs: 4 to 7
1 Nthreads(data)           Assigned number of PETs for DATA, ItileD * JtileD.
                           Coupling Driver PETs: 8
gregorian Calendar          ESM components date calendar.
1900-01-01 00:00:00 ReferenceTime   Coupling driver reference time.
2013-01-10 00:00:00 StartTime     Simulation start time.
2013-01-10 00:00:00 RestartTime   Simulation re-start time.
2013-01-15 00:00:00 StopTime     Simulation stop time.
0000-00-00 00:10:00 Timestep      Driver coupling time interval.
0.000000E+00 WeightDAT        DATA component weight coefficient for merging.
1.000000E+00 WeightESM        ESM component weight coefficient for merging.
1 DebugLevel               Debugging level flag.
0 traceLevel               Execution tracing level flag.
8 Nimport(roms)             Number of ROMS component import fields.
                           01: dLWrad
                           02: SWrad
                           03: Pair
                           04: Tair
                           05: Qair
                           06: rain
                           07: Uwind
                           08: Vwind
1 Nexport(roms)            Number of ROMS component export fields.
                           01: SST
2 Nimport(atmos)           Number of COAMPS_01 component import fields:
                           01: SST
                           02: dsST
8 Nexport(atmos)           Number of COAMPS_01 component export fields:
                           01: dLWrad
                           02: SWrad
                           03: Pair
                           04: Tair
                           05: Qair
                           06: rain
                           07: Uwind
                           08: Vwind
1 nDataExport(atmos)       Number of export DATA model fields to COAMPS_01 component:
                           01: dsST
1 nDataFiles(atmos)        Number of source DATA model files for COAMPS_01 component:
                           01: ../../Data/HyCOM/archv.2013_009-020_3zt.nc

```

#### ESM IMPORT Fields Metadata Dictionary:

Model	Short Name	Standard Name	G	I	E	C	add_offset	scale_factor
ROMS	dLWrad	surface_downward_longwave_flux	1	1	F	T	0.00000E+00	1.00000E+00
ROMS	SWrad	surface_net_shortwave_flux	1	1	F	T	0.00000E+00	1.00000E+00
ROMS	Pair	inst_pres_height_lowest	1	1	F	T	0.00000E+00	1.00000E-02
ROMS	Tair	inst_temp_height_lowest	1	1	T	T	-2.73150E+02	1.00000E+00
ROMS	Qair	inst_spec_humid_height_lowest	1	1	F	T	0.00000E+00	1.00000E+00
ROMS	rain	precipitation_flux	1	1	F	T	0.00000E+00	1.00000E+00
ROMS	Uwind	inst_zonal_wind_height_lowest	1	1	T	T	0.00000E+00	1.00000E+00
ROMS	Vwind	inst_merid_wind_height_lowest	1	1	T	T	0.00000E+00	1.00000E+00

## Surface Wind Stress (Pa)

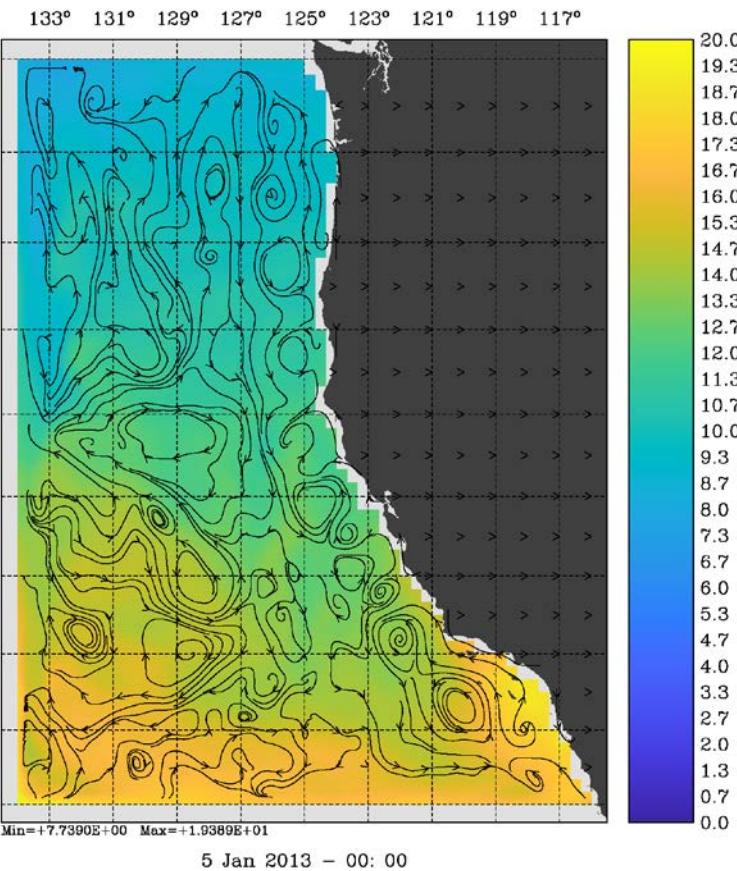


G: Grid cell location, 1=Center, 2=Corner, 3=U-point, 4=V-point  
 I: Regridding method, 1=bilinear, 2=conservative, 3=nearest  
 E: Extrapolation support, F=none, normal regridding, T=two step extrapolated  
 C: Connected to coupler, F=derived from other, T=exchanged/regridded

# DATA-ROMS ESMF Coupling

DATA Component	<pre>DATA_ncread - ESMF: reading 'ULM', 2013-01-01 12:00:00.00   'Uwind': surface zonal wind component (m s-1)   (Target: ROMS_01, Rec=0000003, SnapshotIndex=1, File: nogaps.0.5c-2013_00hr.ulm.nc)   (Tmin= 41273.0000 Tmax= 41637.7500) t = 41273.5000   (Dmin=-2.42991219E+01 Dmax= 2.53927078E+01)  DATA_ncread - ESMF: reading 'VLM', 2013-01-01 12:00:00.00   'Vwind': surface meridional wind component (m s-1)   (Target: ROMS_01, Rec=0000003, SnapshotIndex=1, File: nogaps.0.5c-2013_00hr.vlm.nc)   (Tmin= 41273.0000 Tmax= 41637.7500) t = 41273.5000   (Dmin=-2.16223812E+01 Dmax= 2.33120899E+01)  DATA_export - ESMF exporting 'Uwind' -&gt; 'ROMS_01', 2013-01-01 12:00:00.00   (Dmin=-2.42991219E+01 Dmax = 2.53927078E+01 SnapshotIndex = 1)   DATA_export - ESMF exporting 'Vwind' -&gt; 'ROMS_01', 2013-01-01 12:00:00.00   (Dmin=-2.16223812E+01 Dmax = 2.33120899E+01 SnapshotIndex = 1)</pre>
	<pre>ESMF Coupler - DATA-TO-ROMS_01: regrid Uwind [Center] to Uwind [Center] &gt;&gt; BLIN ESMF Coupler - DATA-TO-ROMS_01: time Uwind [2013-01-01 12:00] to Uwind [2013-01-01 12:00] ESMF Coupler - DATA-TO-ROMS_01: regrid Vwind [Center] to Vwind [Center] &gt;&gt; BLIN ESMF Coupler - DATA-TO-ROMS_01: time Vwind [2013-01-01 12:00] to Vwind [2013-01-01 12:00]</pre>
ROMS Component	<pre>ModelAdvance - ESMF, Running ROMS: 2013-01-01 06:00:00 =&gt; 2013-01-01 12:00:00, Phase: 1 [21600.00 s] ROMS_import - ESMF: importing field 'Uwind' 2013-01-01 12:00:00.00   (Dmin=-9.45327451E+00 Dmax = 4.81209573E+00 SnapshotIndex = 1) ROMS_import - ESMF: importing field 'Vwind' 2013-01-01 12:00:00.00   (Dmin=-7.14938337E+00 Dmax = 1.32653319E+01 SnapshotIndex = 1)</pre>
	<pre>ModelAdvance - ESMF, Running DATA: 2013-01-01 06:00:00 =&gt; 2013-01-01 12:00:00, Phase: 1 [21600.00 s] DATA_ncread - ESMF: reading 'ULM', 2013-01-01 18:00:00.00   'Uwind': surface zonal wind component (m s-1)   (Target: ROMS_01, Rec=0000004, SnapshotIndex=2, File: nogaps.0.5c-2013_00hr.ulm.nc)   (Tmin= 41273.0000 Tmax= 41637.7500) t = 41273.7500   (Dmin=-2.16280365E+01 Dmax= 2.47355804E+01)  DATA_ncread - ESMF: reading 'VLM', 2013-01-01 18:00:00.00   'Vwind': surface meridional wind component (m s-1)   (Target: ROMS_01, Rec=0000004, SnapshotIndex=2, File: nogaps.0.5c-2013_00hr.vlm.nc)   (Tmin= 41273.0000 Tmax= 41637.7500) t = 41273.7500   (Dmin=-2.34216156E+01 Dmax = 2.66080170E+01)  DATA_export - ESMF exporting 'Uwind' -&gt; 'ROMS_01', 2013-01-01 18:00:00.00   (Dmin=-2.16280365E+01 Dmax = 2.47355804E+01 SnapshotIndex = 2)   DATA_export - ESMF exporting 'Vwind' -&gt; 'ROMS_01', 2013-01-01 18:00:00.00   (Dmin=-2.34216156E+01 Dmax = 2.66080170E+01 SnapshotIndex = 2)</pre>
DATA Component	<pre>ESMF Coupler - DATA-TO-ROMS_01: regrid Uwind [Center] to Uwind [Center] &gt;&gt; BLIN ESMF Coupler - DATA-TO-ROMS_01: time Uwind [2013-01-01 18:00] to Uwind [2013-01-01 18:00] ESMF Coupler - DATA-TO-ROMS_01: regrid Vwind [Center] to Vwind [Center] &gt;&gt; BLIN ESMF Coupler - DATA-TO-ROMS_01: time Vwind [2013-01-01 18:00] to Vwind [2013-01-01 18:00]</pre>
	<pre>ModelAdvance - ESMF, Running ROMS: 2013-01-01 12:00:00 =&gt; 2013-01-01 18:00:00, Phase: 1 [21600.00 s] ROMS_import - ESMF: importing field 'Uwind' 2013-01-01 18:00:00.00   (Dmin=-8.78069213E+00 Dmax = 4.88166645E+00 SnapshotIndex = 2) ROMS_import - ESMF: importing field 'Vwind' 2013-01-01 18:00:00.00   (Dmin=-6.99230418E+00 Dmax = 1.56992515E+01 SnapshotIndex = 2)</pre>
ROMS Kernel	<pre>NL ROMS/TOMS: started time-stepping: (Grid: 01 TimeSteps: 000000000000 - 000000000036)</pre>
	<pre>TIME-STEP YYYY-MM-DD hh:mm:ss.ss KINETIC_ENRG POTEN_ENRG TOTAL_ENRG NET_VOLUME C -&gt; (i,j,k) Cu Cv Cw Max Speed   0 2013-01-01 12:00:00.00 7.855554E-03 2.013191E+04 2.013192E+04 7.603057E+15   (041,179,42) 1.186608E-01 5.365095E-03 0.000000E+00 1.791413E+00   ...   36 2013-01-01 18:00:00.00 7.836322E-03 2.013195E+04 2.013196E+04 7.603081E+15   (002,055,36) 7.285516E-04 2.509459E-02 3.297078E-01 1.709440E+00</pre>

WC13 Surface Temperature (C)

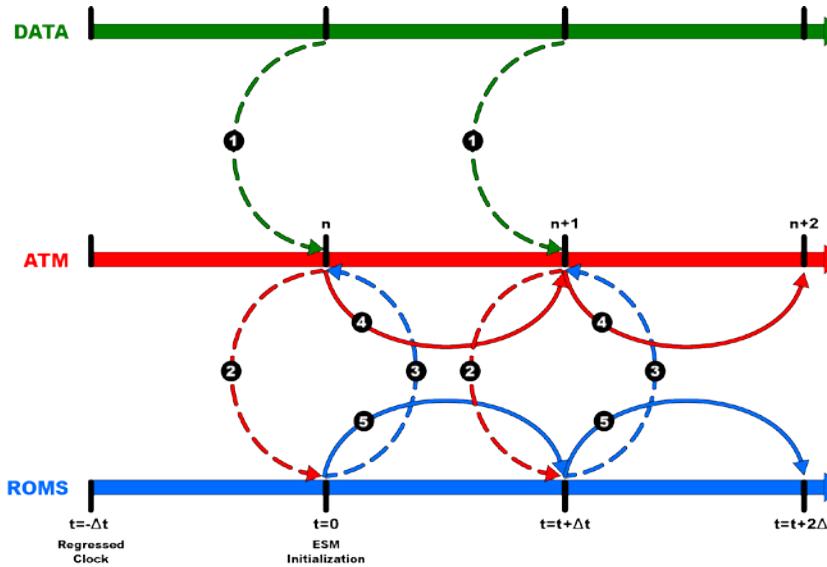


DATA source: NOGAPS

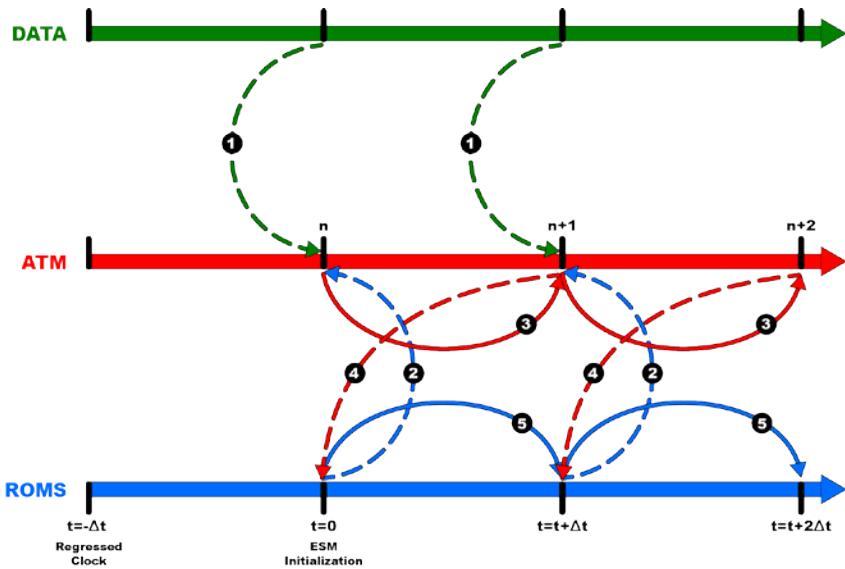
# ROMS Coupling Framework Summary

- The ROMS coupling framework via the ESMF/NUOPC library can be executed **sequentially** or **concurrently**:
  - In sequential mode, all the coupled model components are executed on all of the specified Persistent Execution Threads (PETs).
  - In concurrent mode, each coupled model component is executed on non-overlapping sets of PETs.
- The coupling type can be **explicit** or **implicit**:
  - In **explicit** coupling, the exchange fields at the next time-step ( $n+1$ ) are defined using known values from the time-step ( $n$ ) before it. Explicit methods require less computational effort and are accurate for small coupling time windows.
  - In **implicit** coupling, the exchange fields are defined using values for the next time-step ( $n+1$ ) in both the source and destination models. Implicit methods are stable and allow longer coupling time-step but are more expensive sometimes.
  - Usually, the atmosphere-ocean coupling is **semi-implicit**: the exchange in one direction is explicit (**ocean-to-atmosphere**) and in the reverse direction is implicit (**atmosphere-to-ocean**).
- The REGRID interpolation method between source and destination fields can be **bilinear** or **conservative**. A nearest neighbor interpolation is possible between land/sea boundaries. Also, there is an option for two-step extrapolation support during re-gridding.
- Since ROMS nesting is so unique and complex, **each nested grid is considered a separate component**. Nowadays, the NUOPC Connector recognize different grids and transfer data to a connected component including nest-to-nest, if both components have refined grids. Or it can regrid between a finer grid in one component and a coarser grid in another.

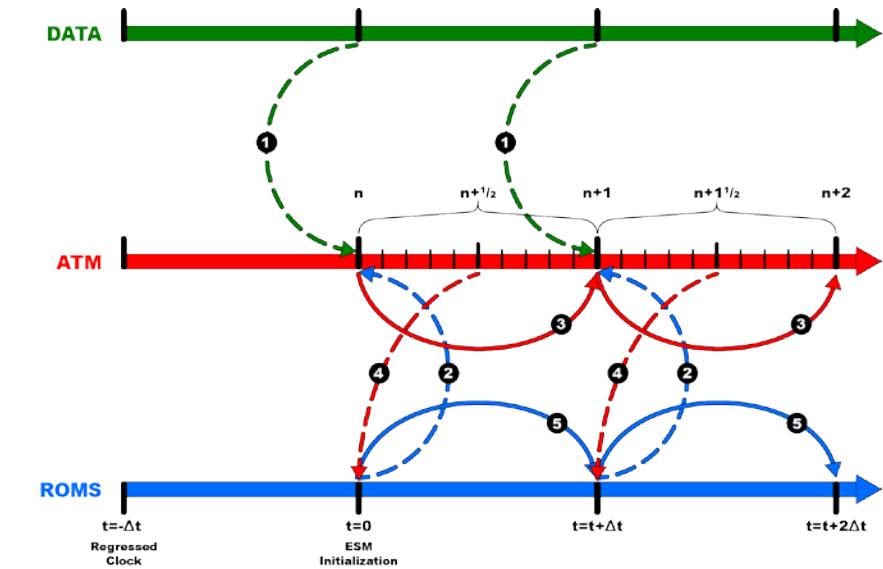
# Coupling Run Sequence: DATA-ATM-ROMS



Explicit

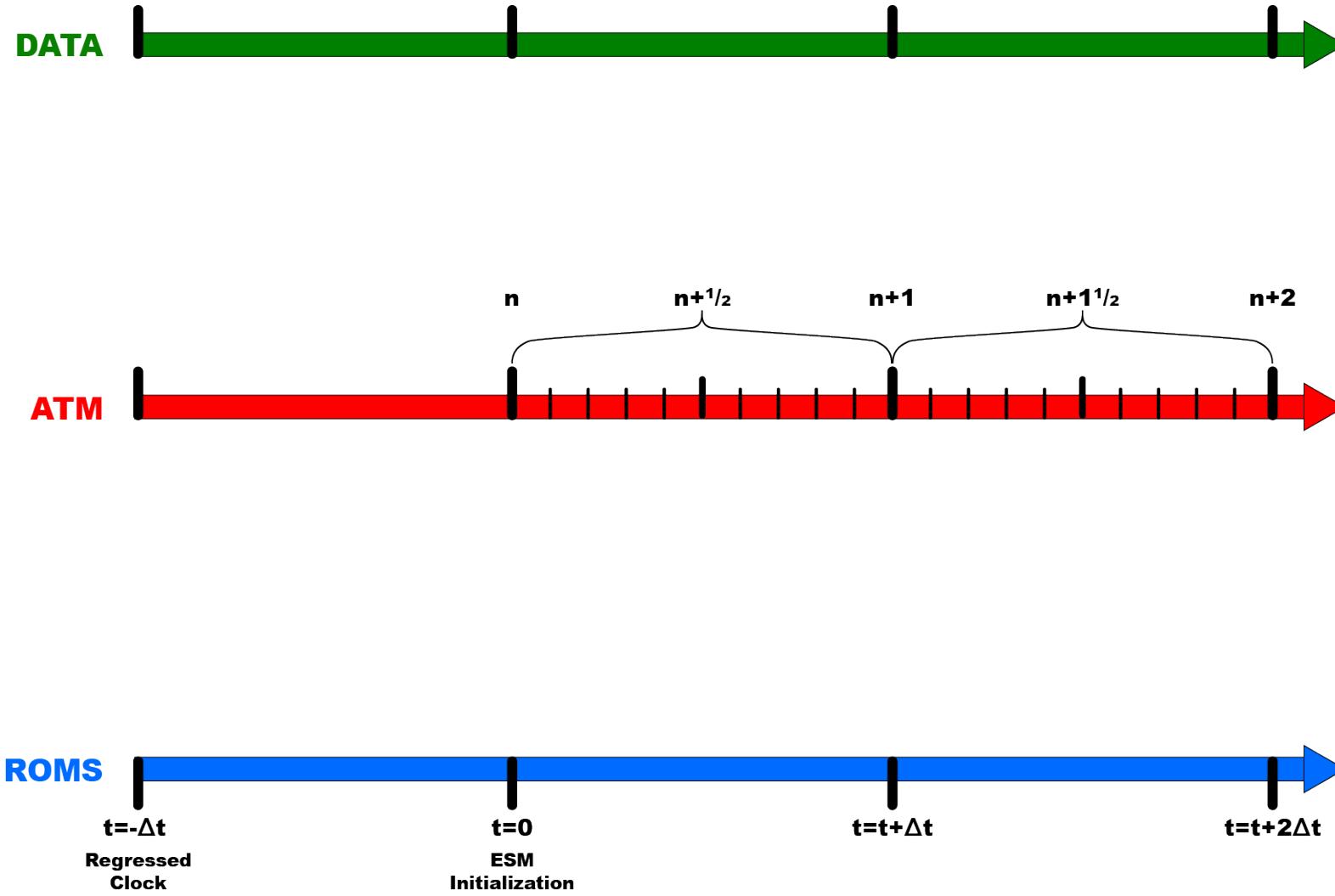


Semi-Implicit, ATM instantaneous



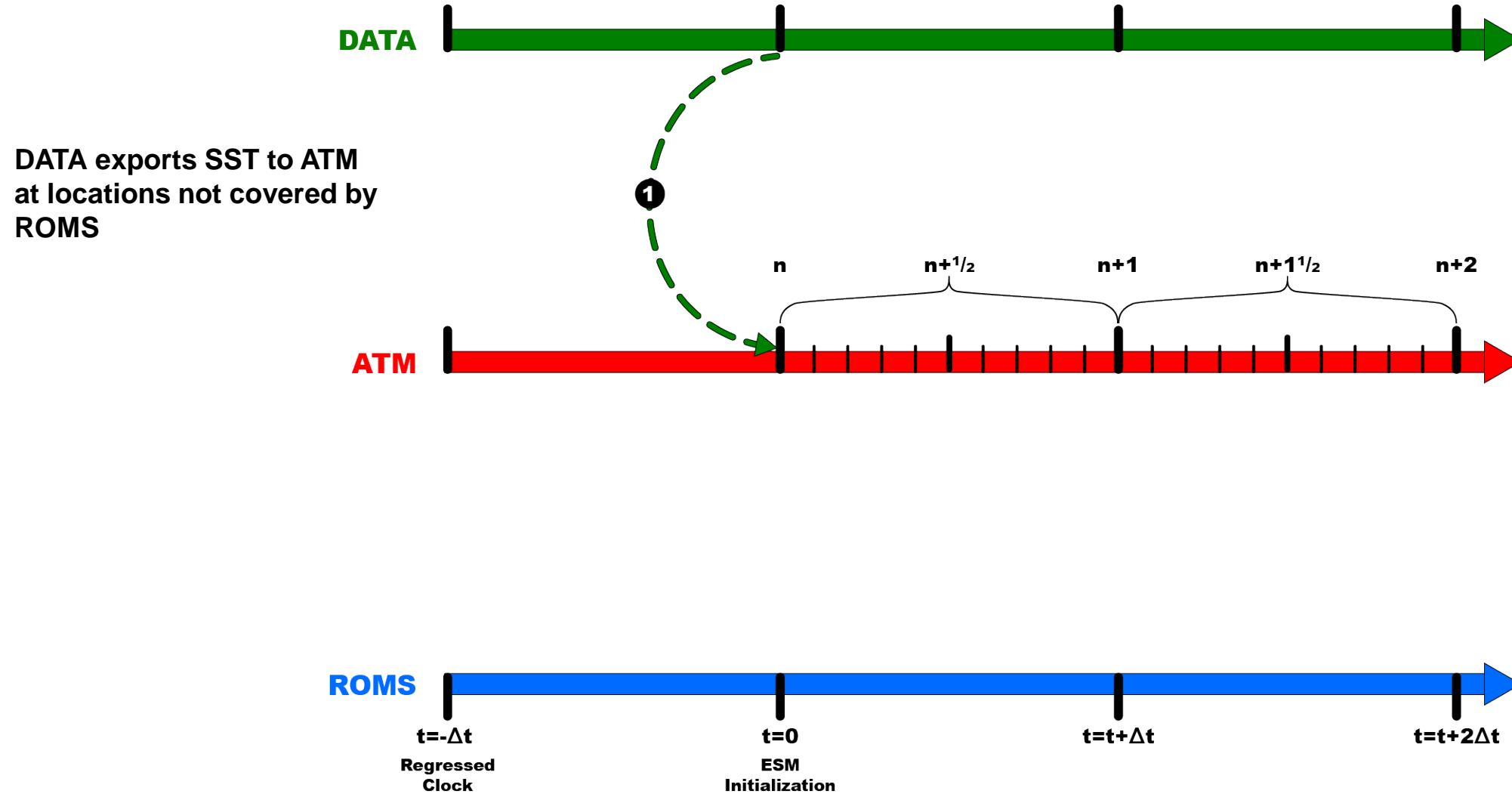
Semi-Implicit, ATM average

# Coupling Run Sequence: DATA-ATM-ROMS Semi-Implicit

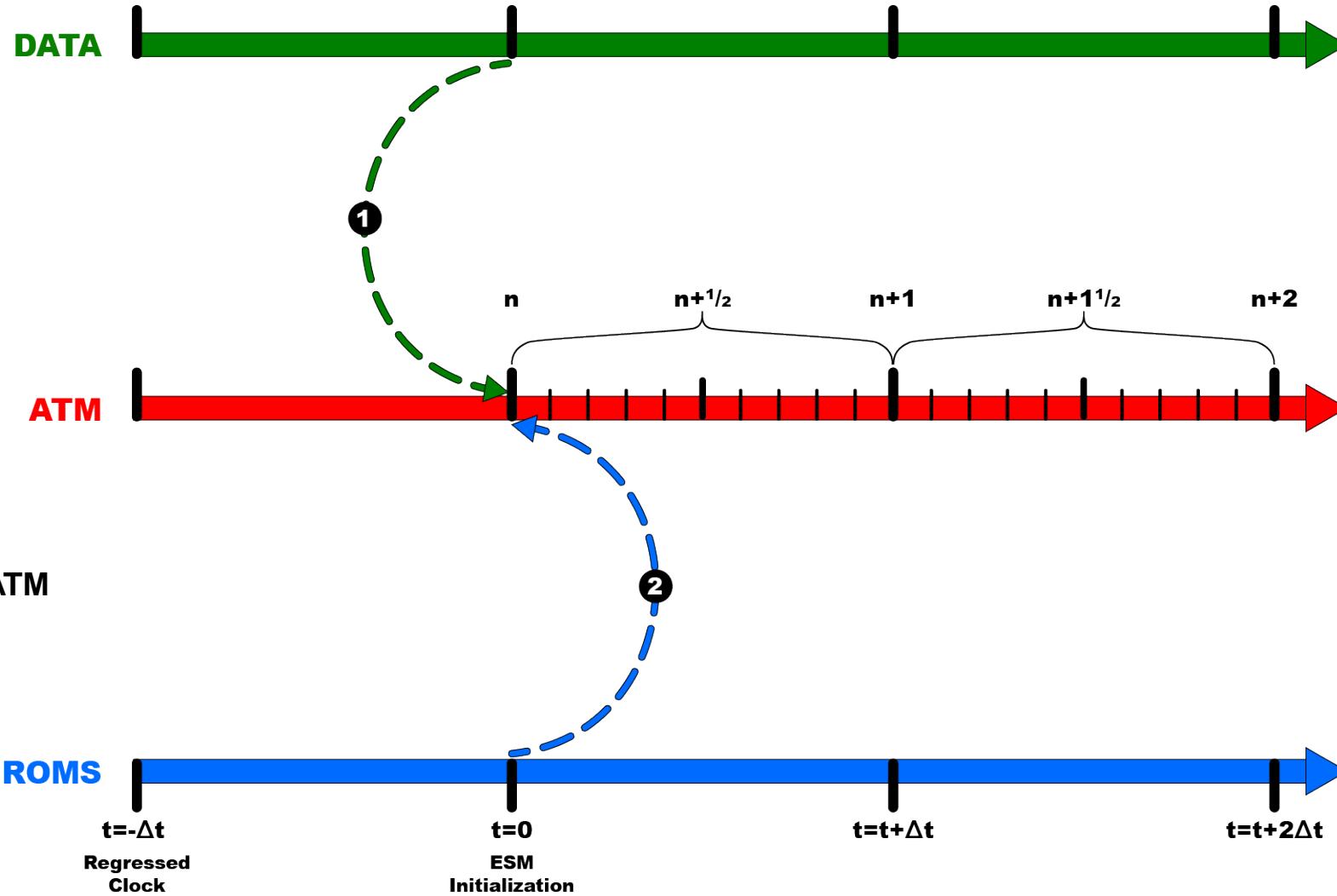


# Coupling Run Sequence: DATA-ATM-ROMS

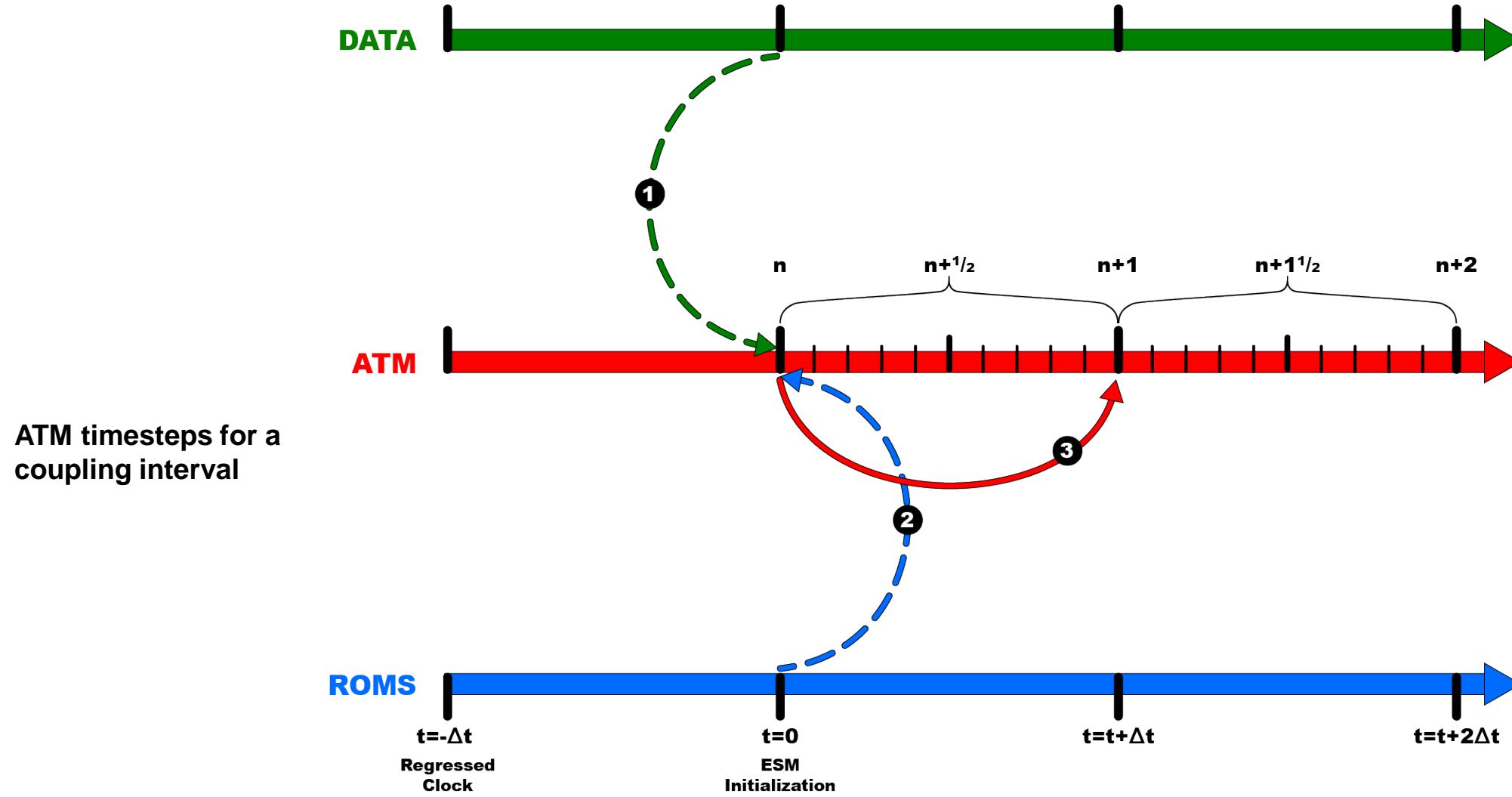
## Semi-Implicit, ATM Average



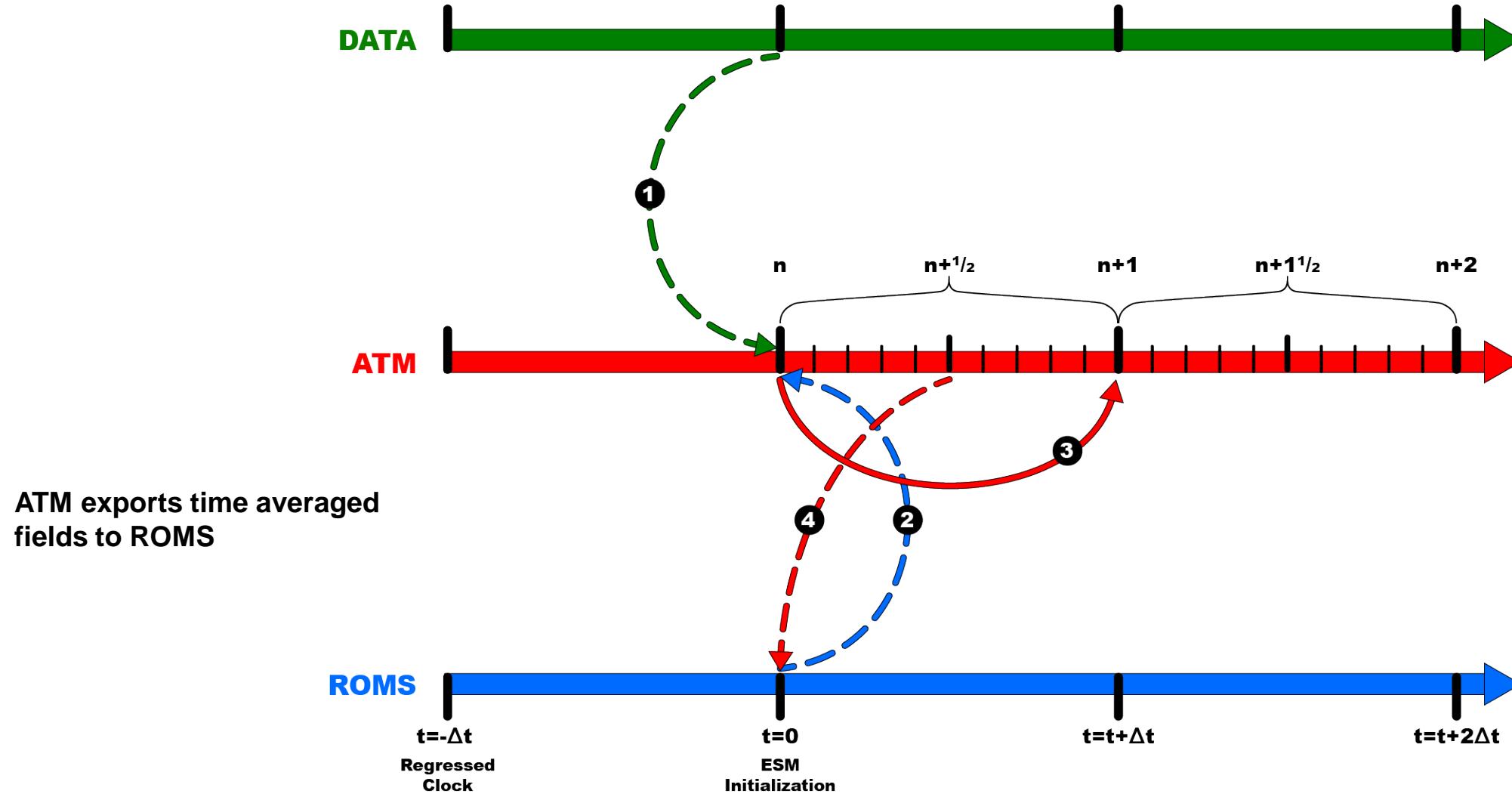
# Coupling Run Sequence: DATA-ATM-ROMS Semi-Implicit



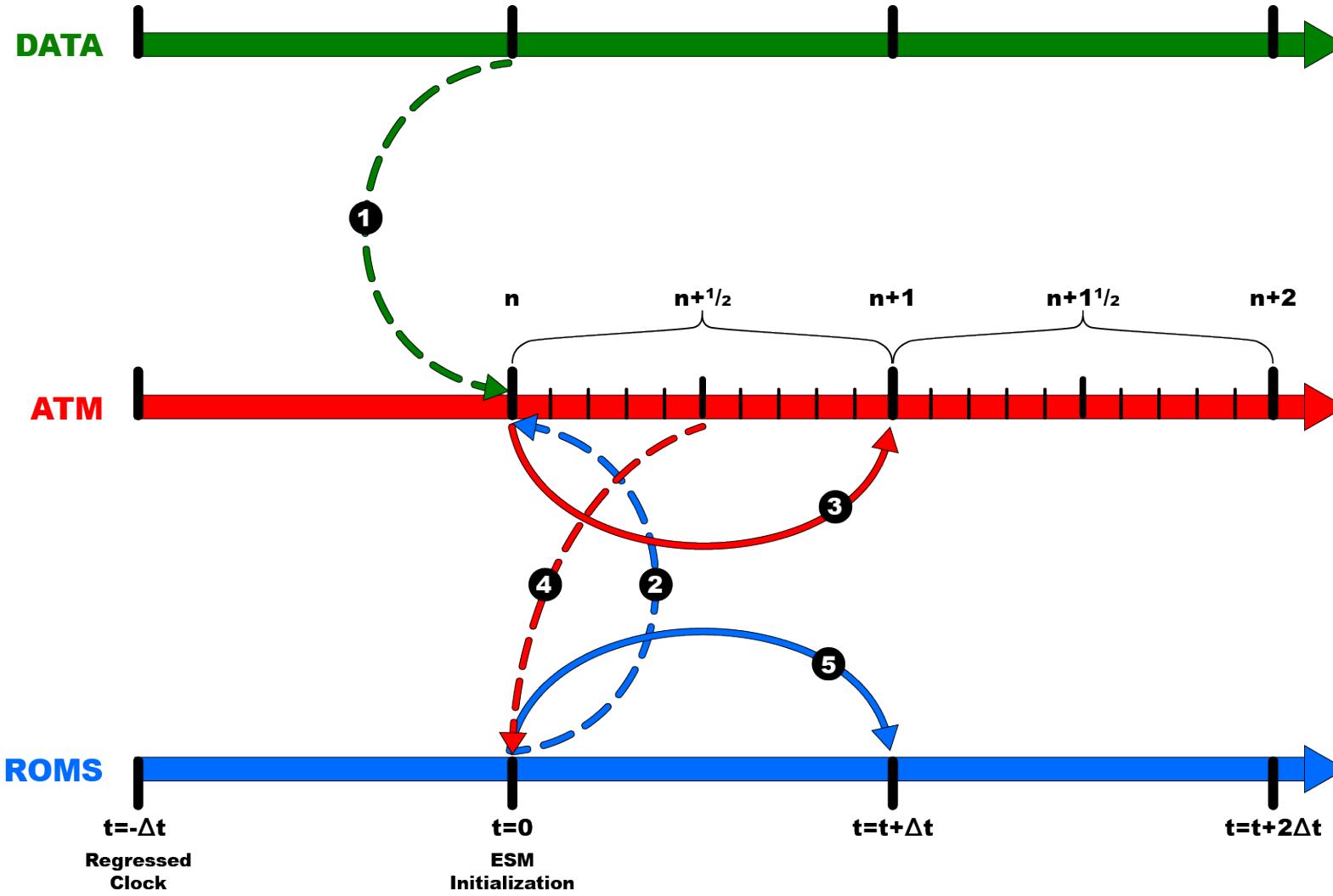
# Coupling Run Sequence: DATA-ATM-ROMS Semi-Implicit



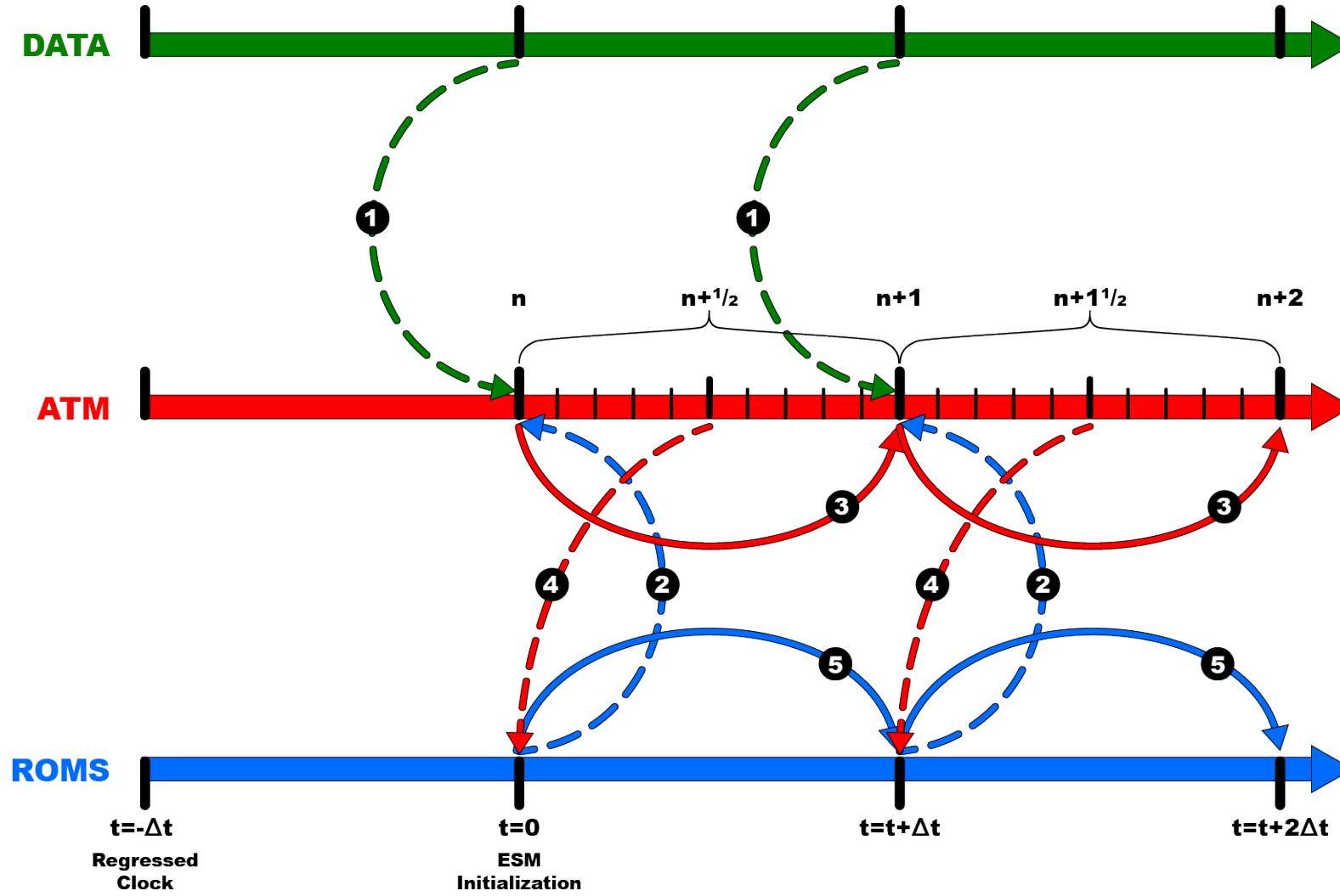
# Coupling Run Sequence: DATA-ATM-ROMS Semi-Implicit



# Coupling Run Sequence: DATA-ATM-ROMS Semi-Implicit



# Coupling Run Sequence: DATA-ATM-ROMS Semi-Implicit



# WRF namelist.input: Time Averaging Fluxes

```
&time_control
run_days           = 0,
run_hours          = 120,
run_minutes         = 0,
run_seconds         = 0,
start_year          = 2005, 2005, 2005,
start_month         = 09, 09, 09,
start_day           = 01, 01, 01,
start_hour          = 00, 00, 00,
start_minute         = 00, 00, 00,
start_second         = 00, 00, 00,
end_year            = 2005, 2005, 2005,
end_month           = 09, 09, 09,
end_day             = 06, 06, 06,
end_hour            = 00, 00, 00,
end_minute          = 00, 00, 00,
end_second          = 00, 00, 00,
interval_seconds    = 86400 ! incoming OBC data (daily)
input_from_file     = .true., .false., .false.,
input_inname         = "./Data/joe_tc_wrf_inp_d<domain>.nc"
input_bdy_inname     = "./Data/joe_tc_wrf_bdy_d<domain>.nc"
force_use_old_data  = .true.
history_outname     = "joe_tc_wrf_his_d<domain>_<date>.nc"
history_interval    = 60, 60, 60,
frames_per_outfile   = 7200, 7200, 7200,
restart             = .false.,
rst_outname          = "joe_tc_wrf_RST_d<domain>_<date>.nc"
restart_interval_d  = 5,      ! days
io_form_history      = 2       ! 1: binary, 2: NetCDF, 5: GRIB1
io_form_restart       = 2       ! 1: binary, 2: NetCDF, 5: GRIB1
io_form_input         = 2       ! 1: binary, 2: NetCDF, 5: GRIB1
io_form_boundary      = 2       ! 1: binary, 2: NetCDF, 5: GRIB1
debug_level          = 0
nocolons             = .true.

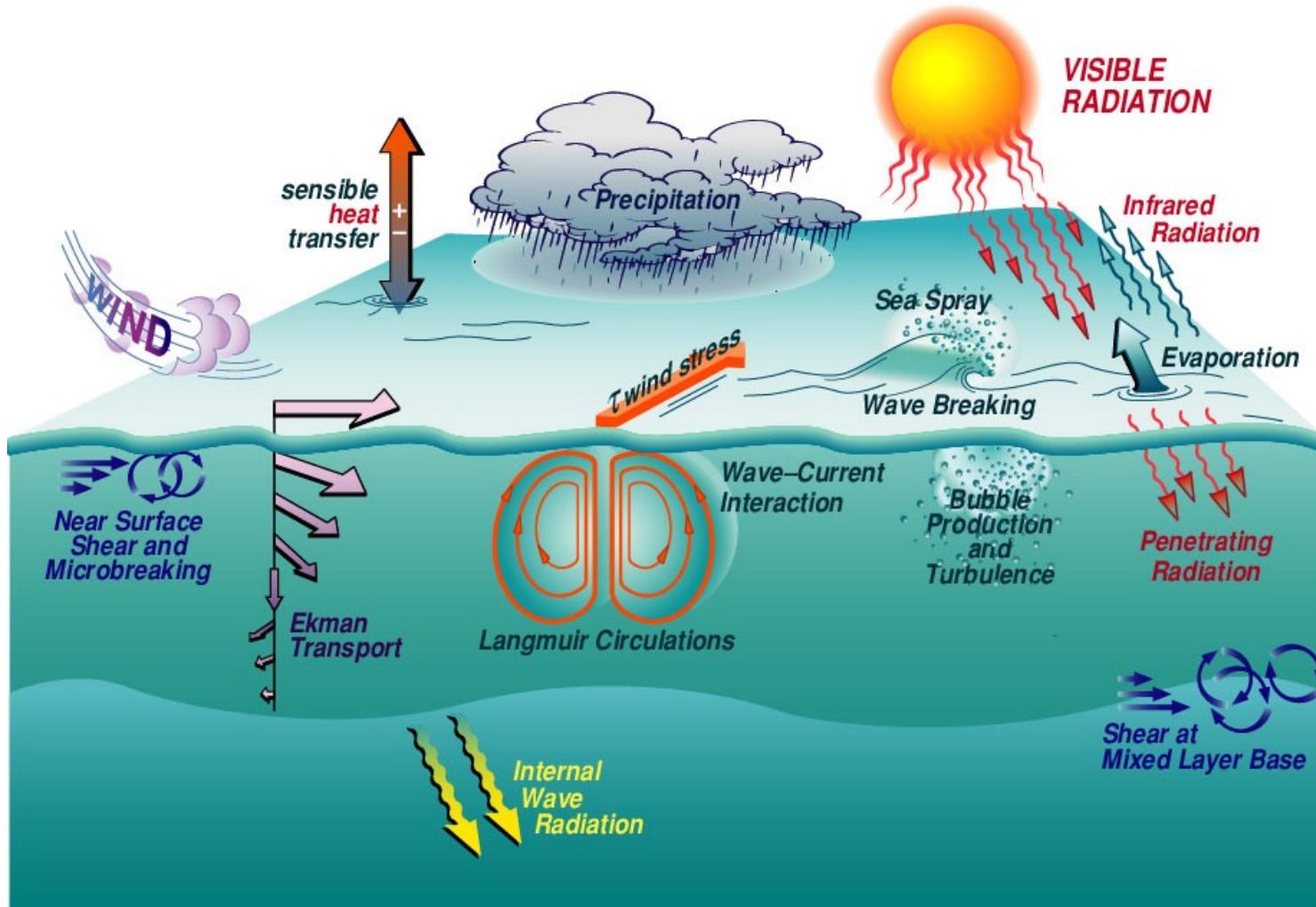
mean_diag            = 1      ! RAMS averaged diagnostics (1:yes 0:no)
mean_diag_interval   = 0      ! time-averaged interval (minutes)
mean_diag_interval_s = 100    ! (1 ROMS DT is 100 seconds, average 4 WRF DT for coupling)
mean_diag_interval_m = 0
mean_diag_interval_h = 0
mean_diag_interval_d = 0
mean_diag_interval_mo= 0
auxhist5_outname     = "joe_tc_wrf_diag_d<domain>_<date>.nc"
io_form_auxhist5     = 2      ! 0: no file, 2: NetCDF

! Surface (2m) air temperature (K).
!
CASE ('tsfc', 'Tair')
MyFmin(1)= MISSING_dp
MyFmax(1)=-MISSING_dp
DO j=Jstr,Jend
  DO i=Istr,lend
    # ifdef WRF_TIMEAVG
      Fval=grid%t2_mean(i,j)
    # else
      Fval=grid%t2(i,j)
    # endif
    MyFmin(1)=MIN(MyFmin(1),Fval)
    MyFmax(1)=MAX(MyFmax(1),Fval)
    ptr2d(i,j)=Fval
  END DO
END DO
```

# DATA-COAMPS-ROMS Coupled Application

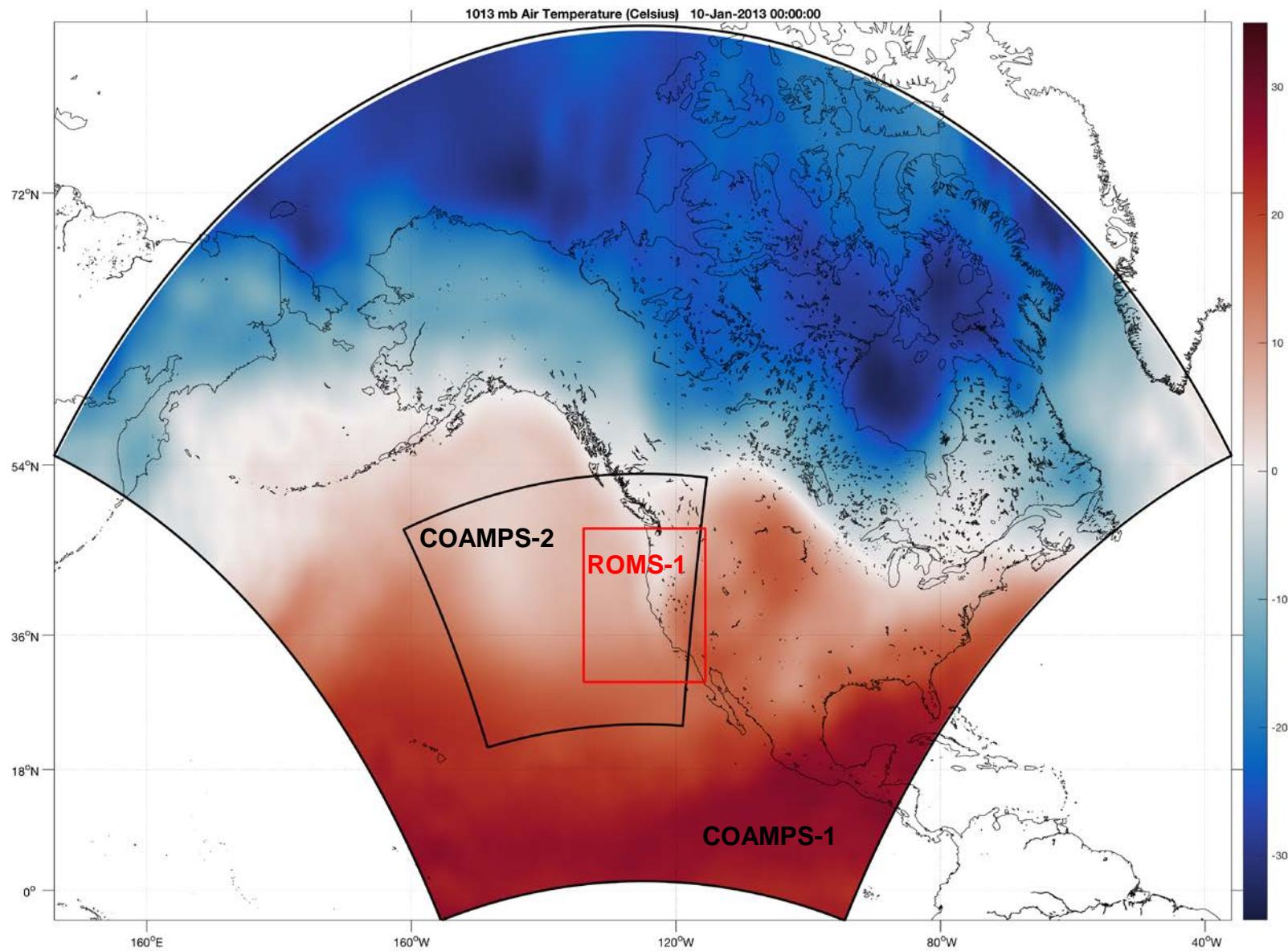
- WC12 application 184x179x42, mean resolution  $dx = 8.5 \text{ km}$  and  $dy = 11.0 \text{ km}$
- COAMPS application 201x204x60 with  $dx=dy=45 \text{ km}$  (coarser), and 214x217x60 with  $dx=dy=15 \text{ km}$  (finer)
- Time stepping: COAMPS 60 s, ROMS 600 s
- **Coupling Simulation C01:** Using ROMS bulk fluxes parameterization
  - Sequential and semi-implicit coupling
  - Non nested COAMPS, just coarser grid
  - Coupling interval: 600 s, COAMPS exports time-averaged fields
  - COAMPS imports SST from DATA and ROMS components
  - DATA component reads SST from HyCOM 1/12 dataset, 4500x3298
  - ROMS activates **BULK\_FLUXES, COOL\_SKIN, EMINUSP, LONGWAVE\_OUT, WIND\_MINUS\_CURRENT**
  - ROMS imports **dLWrad, SWrad, Pair, Tair, Qair, rain, Uwind, and Vwind**
- **Coupling Simulation C02:** Using COAMPS surface fluxes parameterization
  - Same as C01 but ROMS deactivates **BULK\_FLUXES, COOL\_SKIN, EMINUSP, LONGWAVE\_OUT, WIND\_MINUS\_CURRENT**
  - ROMS imports **SWrad, shflux, swflux, sustr, svstr**
- **Coupling Simulation C03:** Using ROMS bulk fluxes parameterization
  - Same as C01 but COAMPS includes nesting of finer 15 km grid
- **Coupling Simulation C04:** Using COAMPS surface fluxes parameterization
  - Same as C02 but COAMPS includes nesting of finer 15 km grid

# AIR-OCEAN INTERACTION



Source: CBLAST WHOI

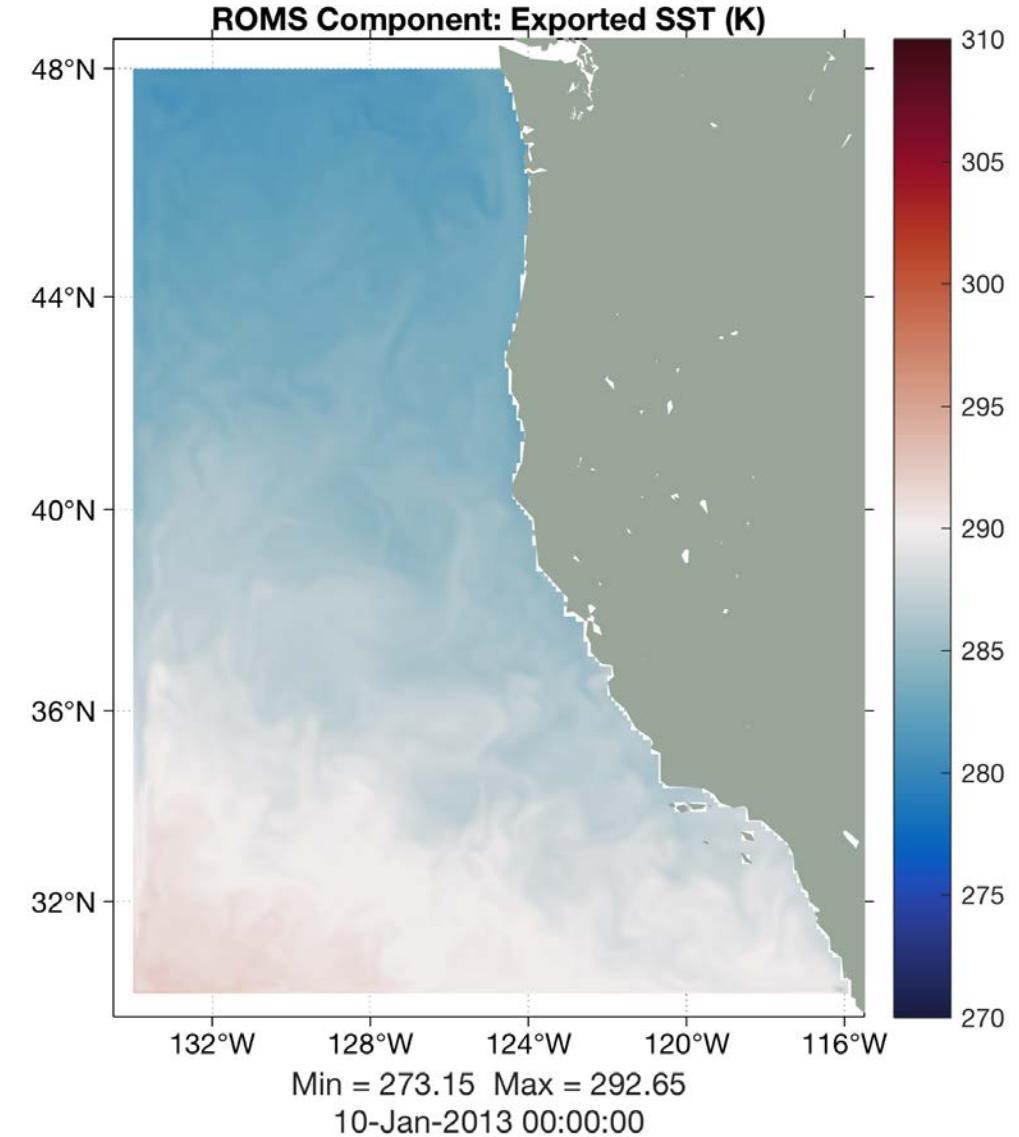
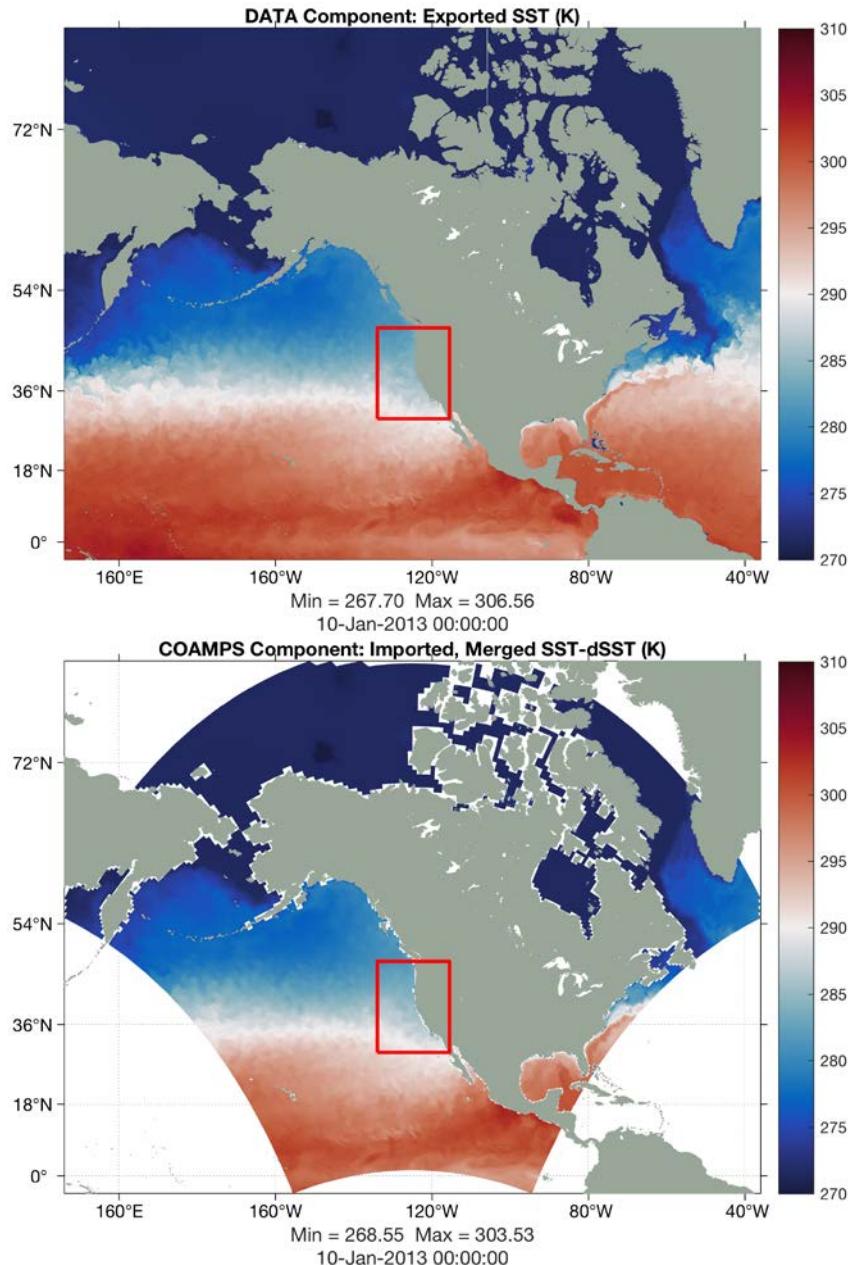
# COAMPS and ROMS Grids



**COAMPS-1: 45 km  
COAMPS-2: 15 km  
ROMS-1: 8.5x11 km**

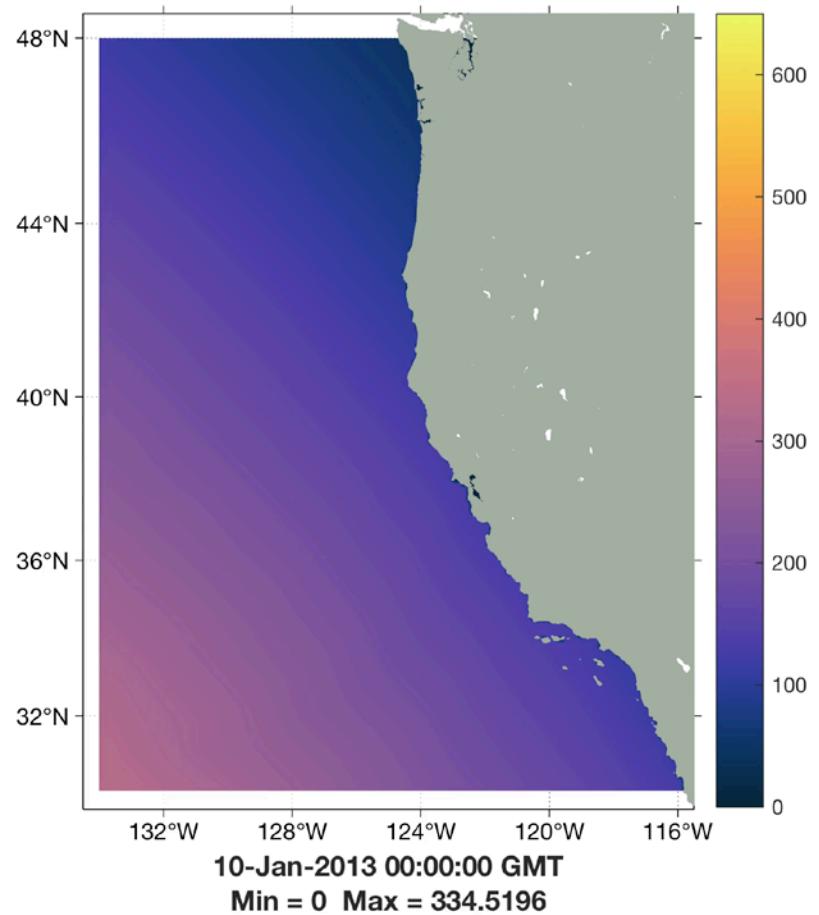
1013 mb Air Temperature (°C): 10-Jan-2013 00:00:00 GMT

# Merged Sea Surface Temperature (K): COAMPS Import

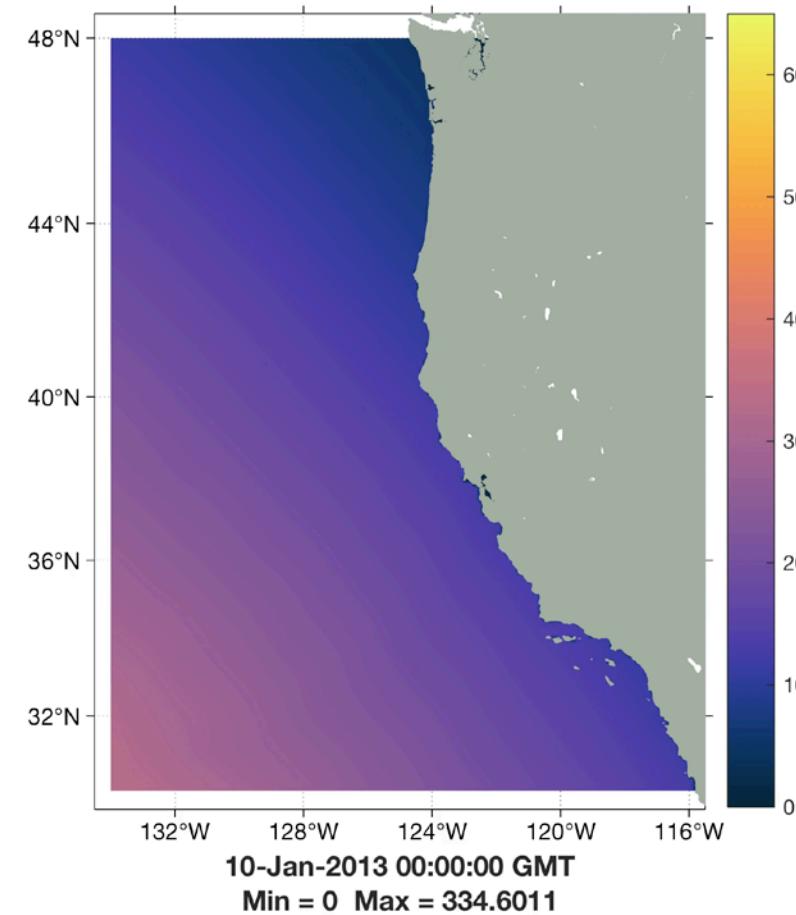


# Surface Shortwave Radiation Flux ( $\text{W/m}^2$ ): Subtract 8 hours for PST

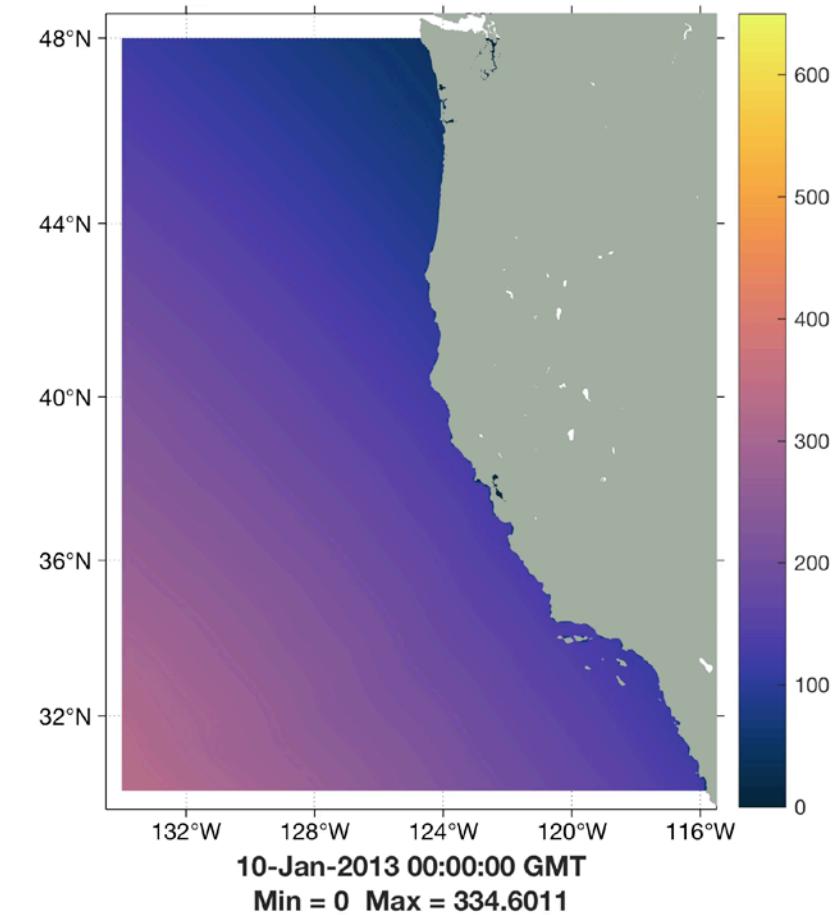
DATA-COAMPS-ROMS  
Non Nested



DATA-COAMPS-ROMS  
Nested



DATA-COAMPS-ROMS  
Nested



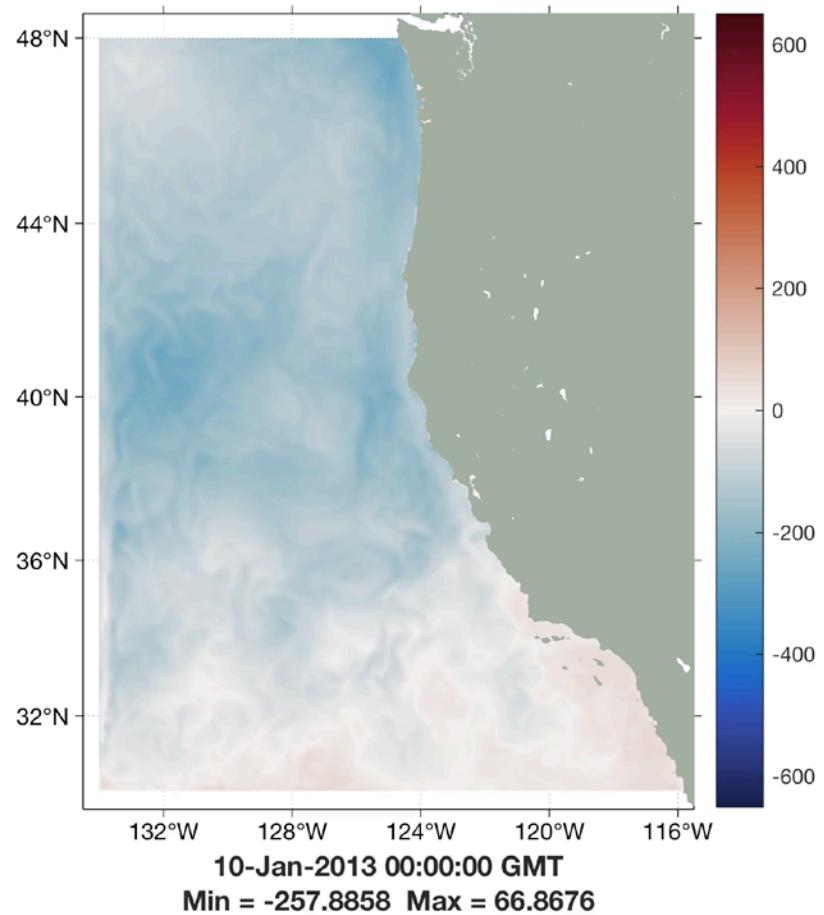
ESMF Coupling: 600 s  
BULK\_FLUXES

ESMF Coupling: 600 s  
BULK\_FLUXES

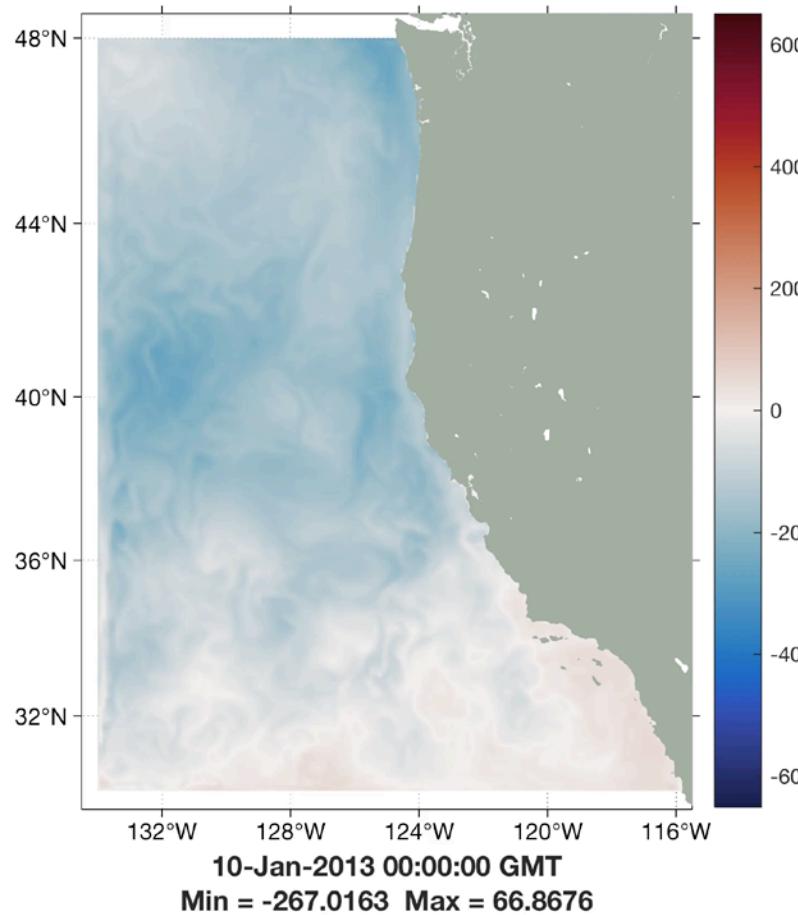
ESMF Coupling: 600 s  
ATM SBL

# Coupled Net Surface Heat Flux ( $\text{W/m}^2$ )

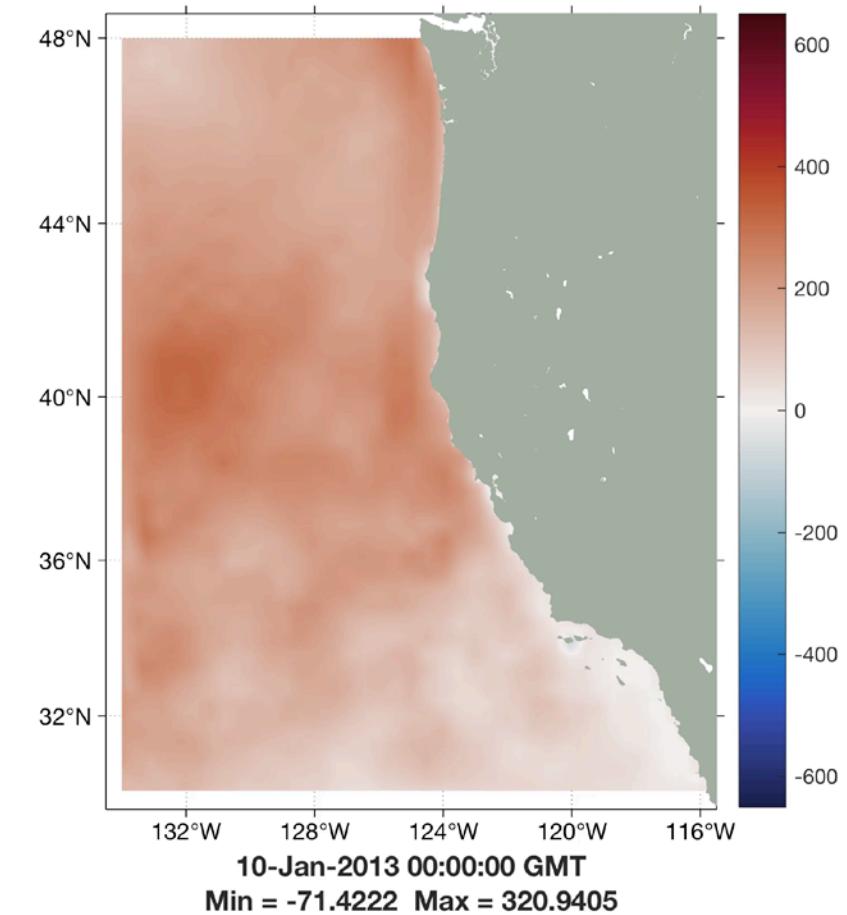
DATA-COAMPS-ROMS  
Non Nested



DATA-COAMPS-ROMS  
Nested



DATA-COAMPS-ROMS  
Nested



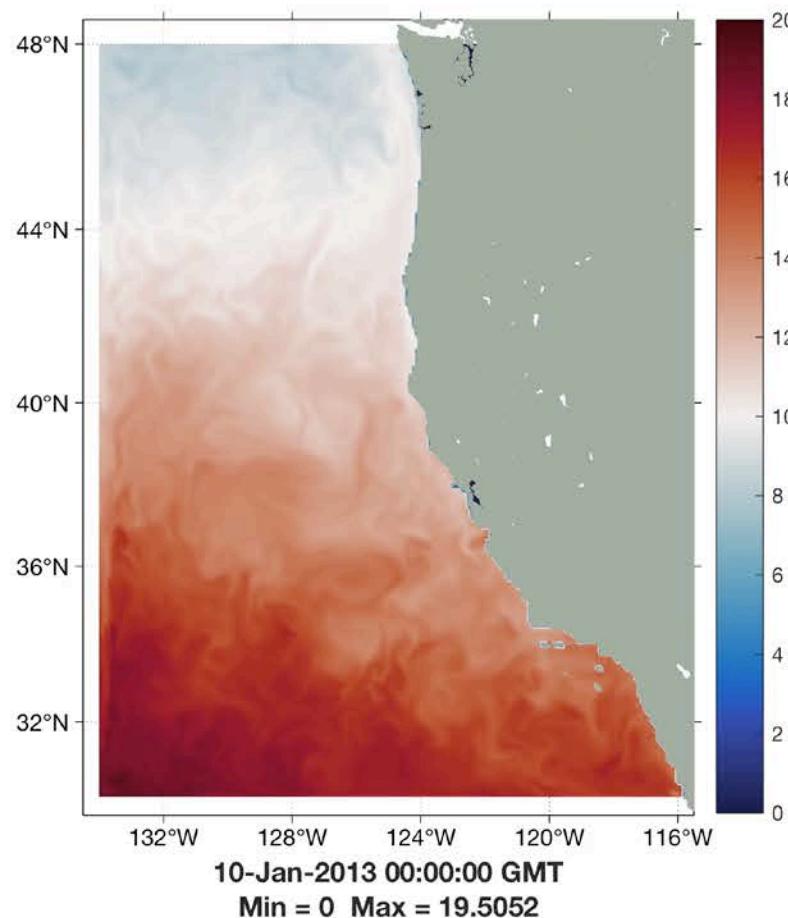
ESMF Coupling: 600 s  
BULK\_FLUXES

ESMF Coupling: 600 s  
BULK\_FLUXES

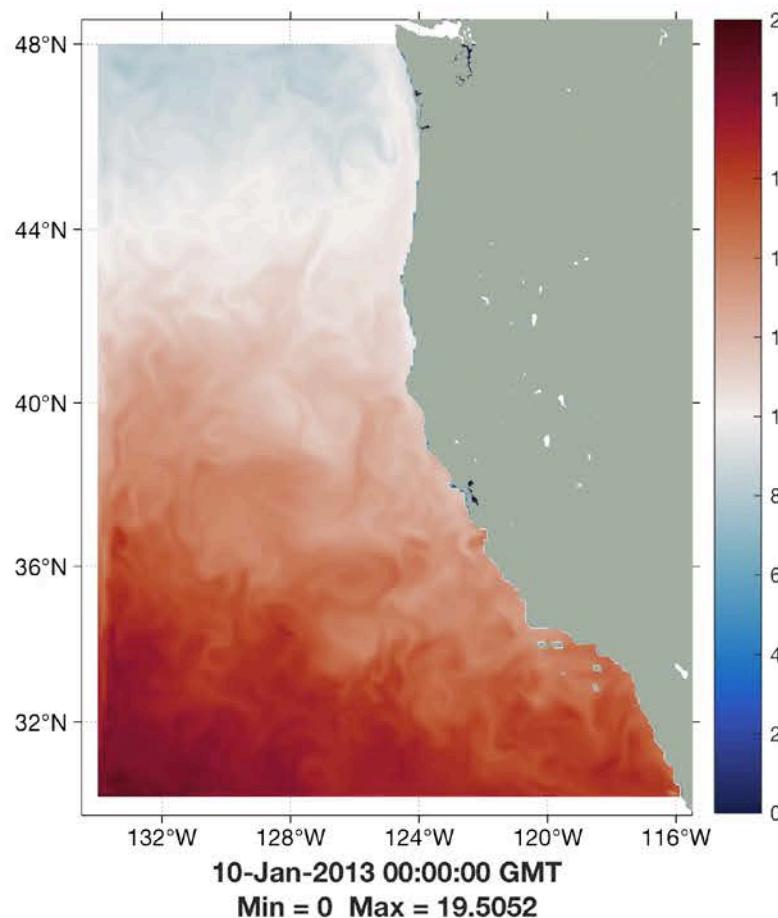
ESMF Coupling: 600 s  
ATM SBL

# Coupled Surface Temperature (°C)

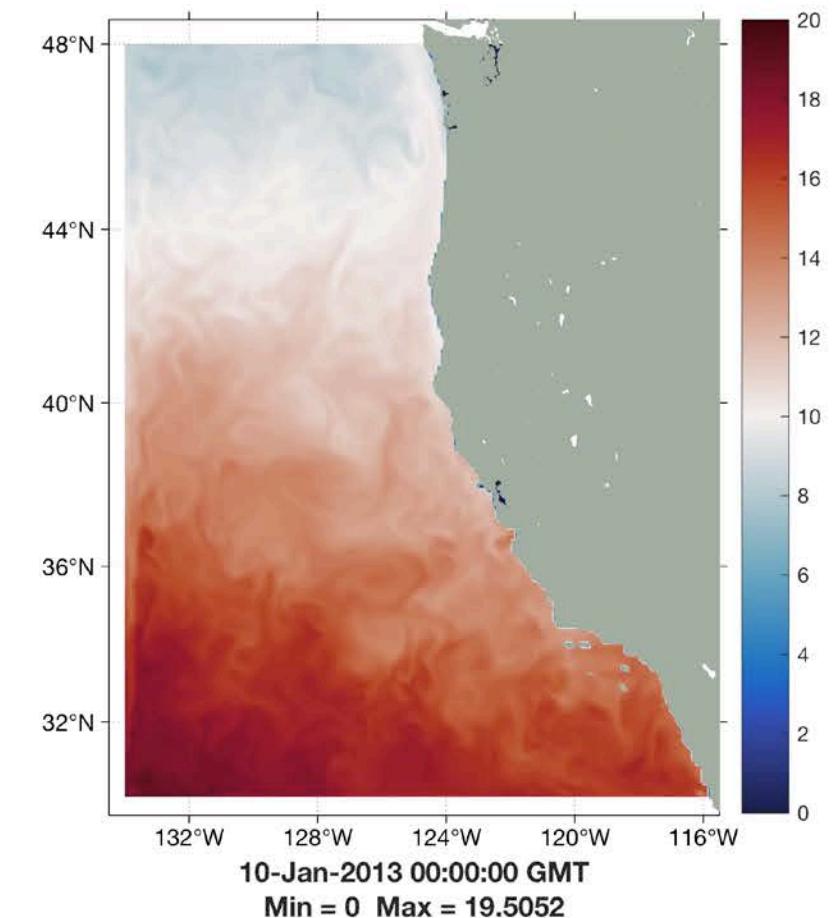
DATA-COAMPS-ROMS  
Non Nested



DATA-COAMPS-ROMS  
Nested



DATA-COAMPS-ROMS  
Nested



ESMF Coupling: 600 s  
BULK\_FLUXES

ESMF Coupling: 600 s  
BULK\_FLUXES

ESMF Coupling: 600 s  
ATM SBL

# Coupled Surface Freshwater Flux (m/day): (E-P)\*salt

DATA-COAMPS-ROMS  
Non Nested

DATA-COAMPS-ROMS  
Nested

DATA-COAMPS-ROMS  
Nested



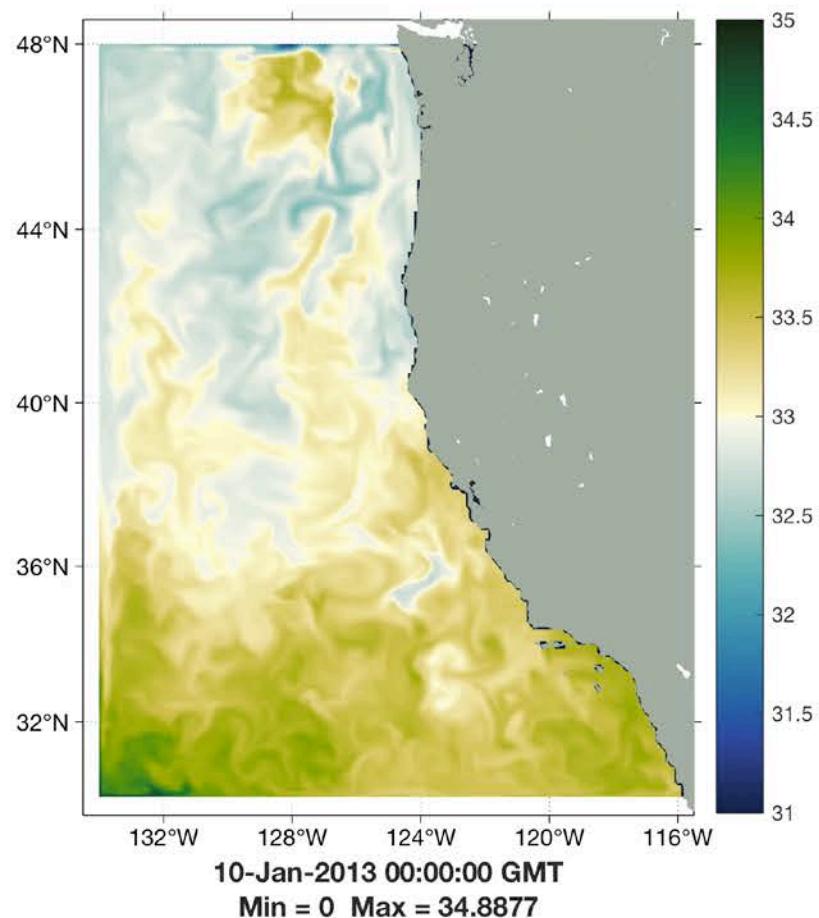
ESMF Coupling: 600 s  
BULK\_FLUXES

ESMF Coupling: 600 s  
BULK\_FLUXES

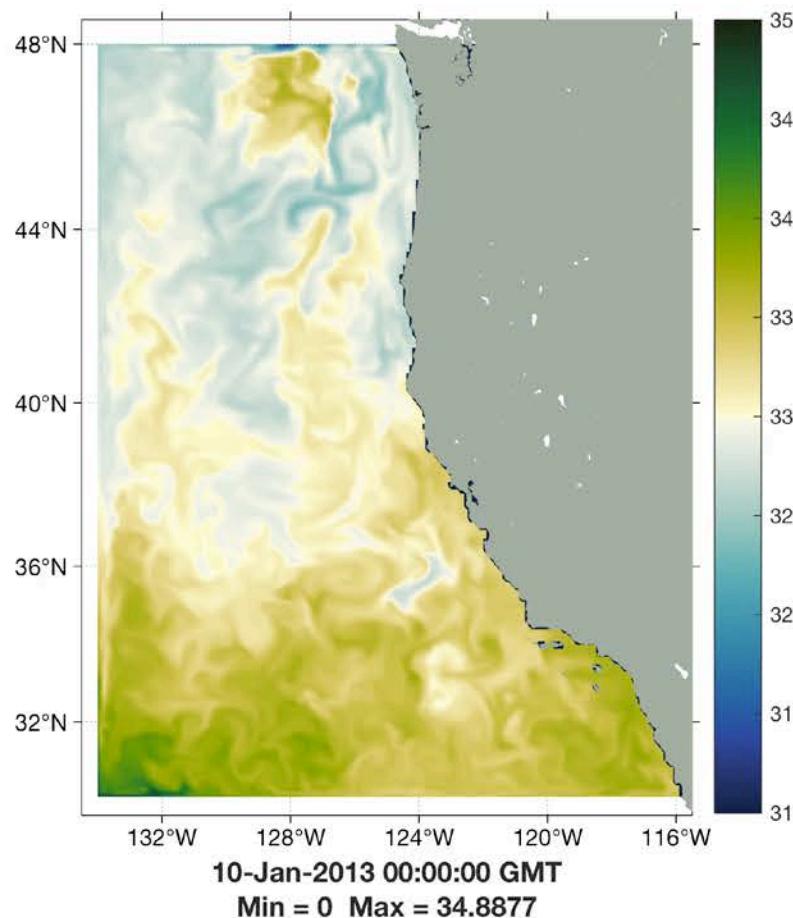
ESMF Coupling: 600 s  
ATM SBL

# Coupled Surface Salinity

DATA-COAMPS-ROMS  
Non Nested



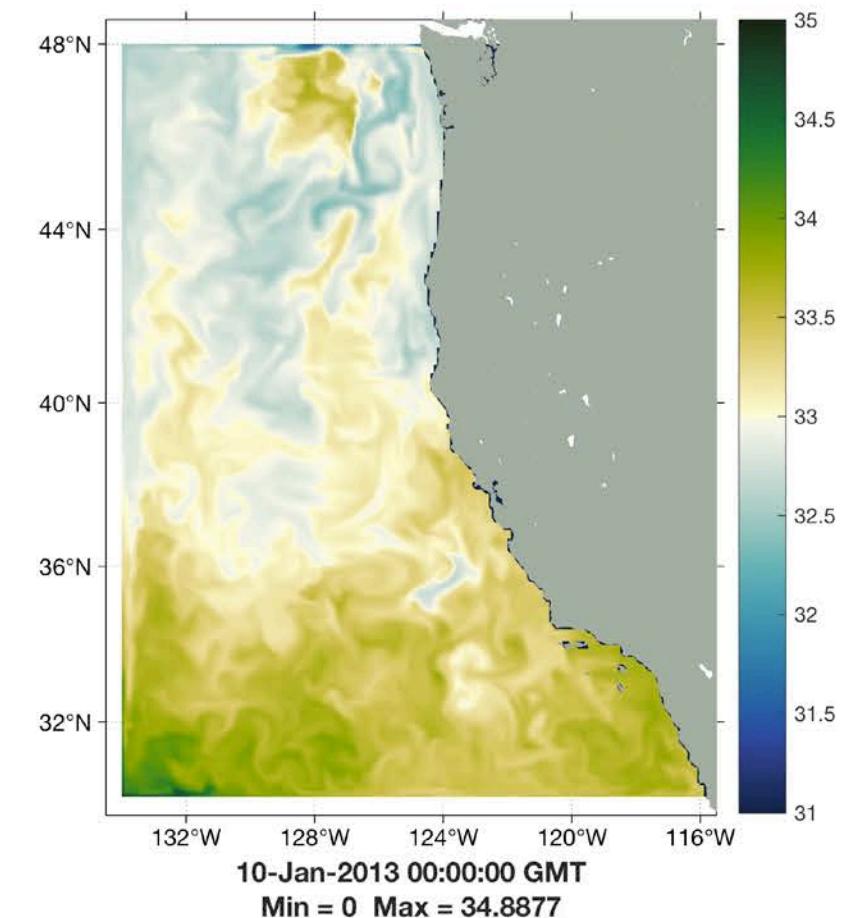
DATA-COAMPS-ROMS  
Nested



ESMF Coupling: 600 s  
BULK\_FLUXES

ESMF Coupling: 600 s  
BULK\_FLUXES

DATA-COAMPS-ROMS  
Nested



ESMF Coupling: 600 s  
ATM SBL

# Coupled Surface Wind Stress ( $\text{N/m}^2$ )

DATA-COAMPS-ROMS  
Non Nested

DATA-COAMPS-ROMS  
Nested

DATA-COAMPS-ROMS  
Nested

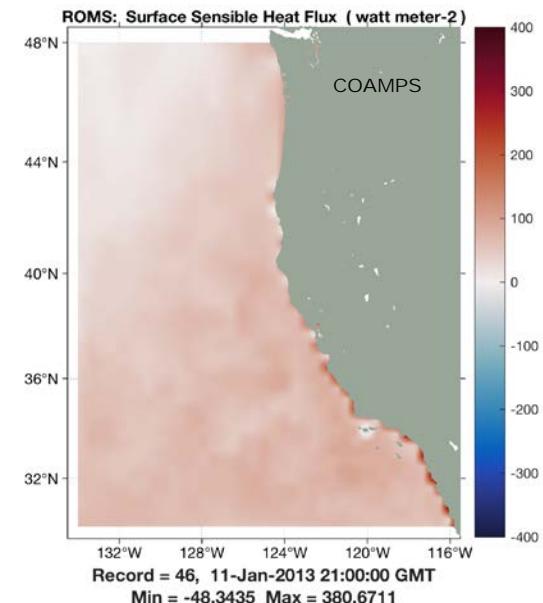
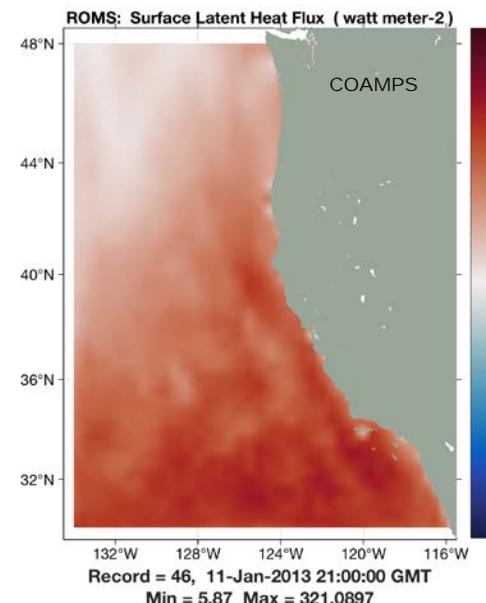
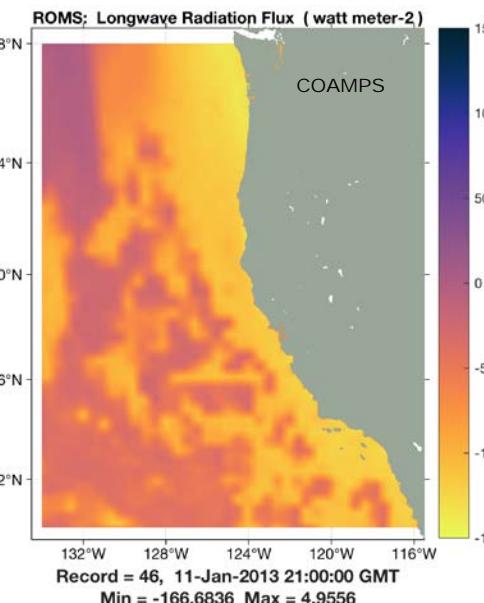
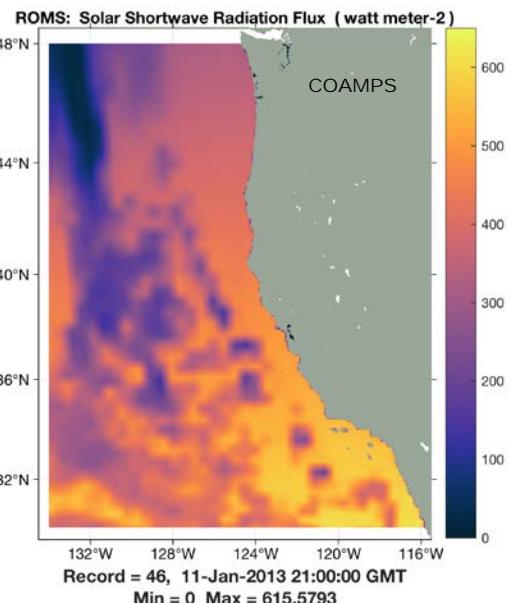
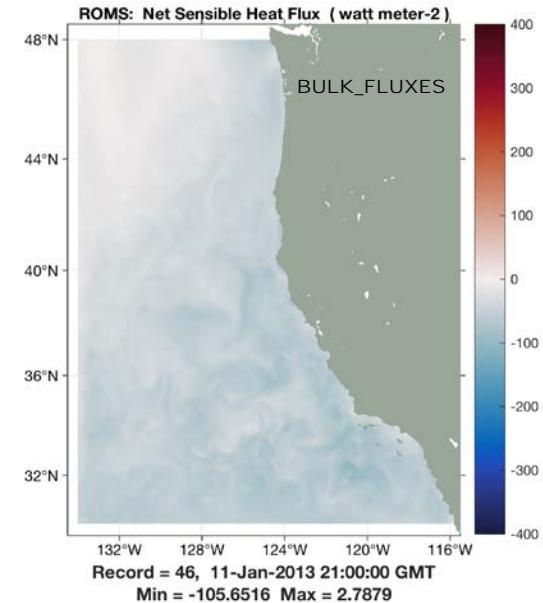
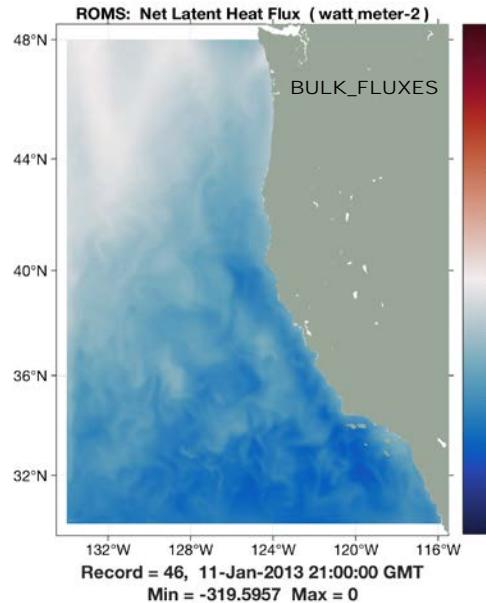
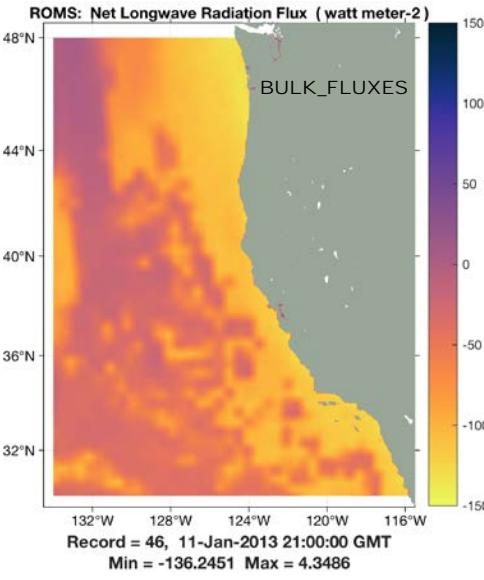
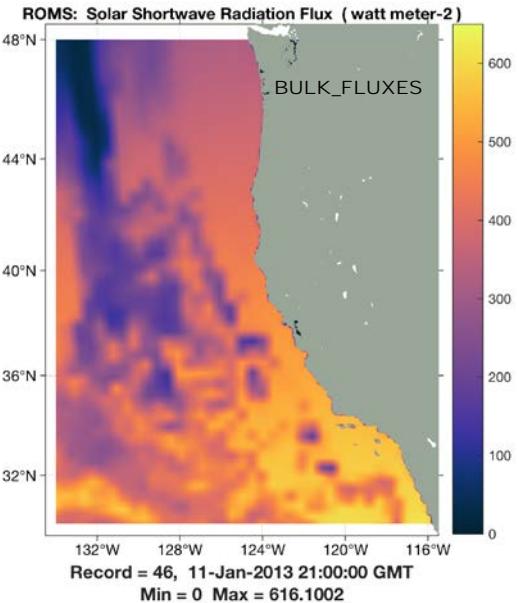


ESMF Coupling: 600 s  
**BULK\_FLUXES**

ESMF Coupling: 600 s  
**BULK\_FLUXES**

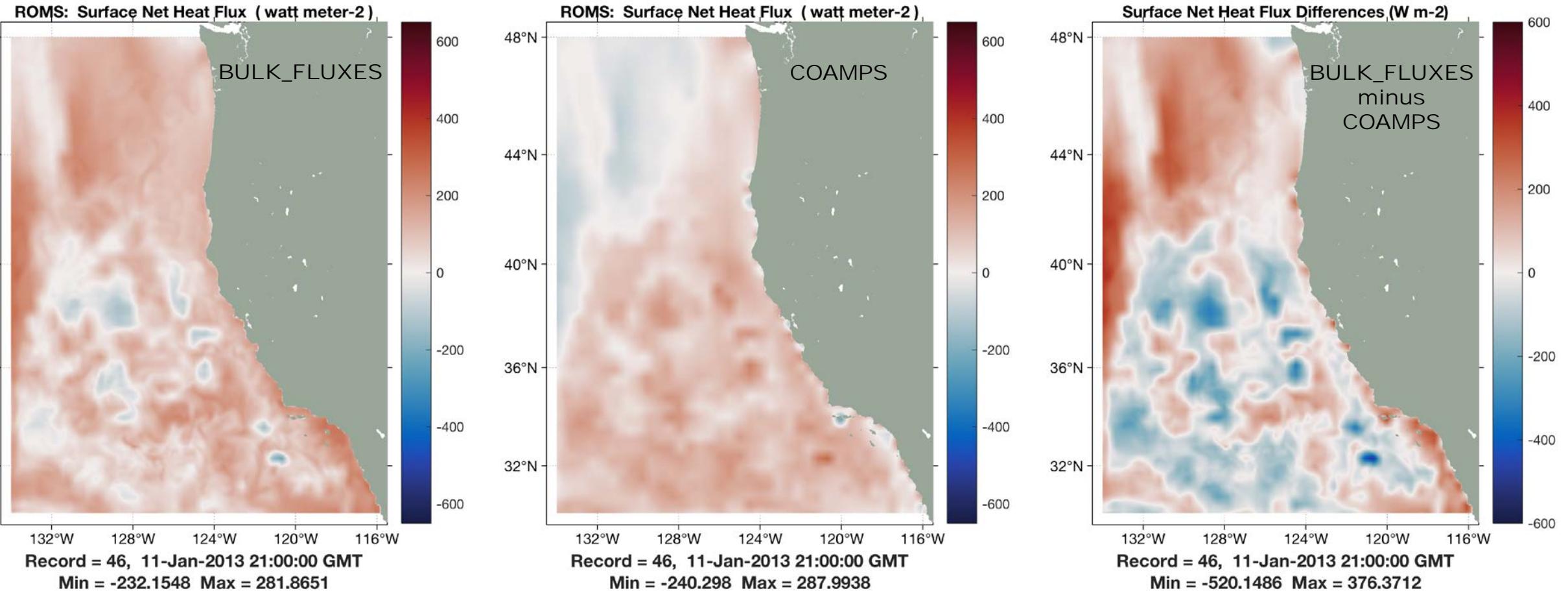
ESMF Coupling: 600 s  
**ATM SBL**

# Heat Flux Components Analysis: Nested C03 and C04



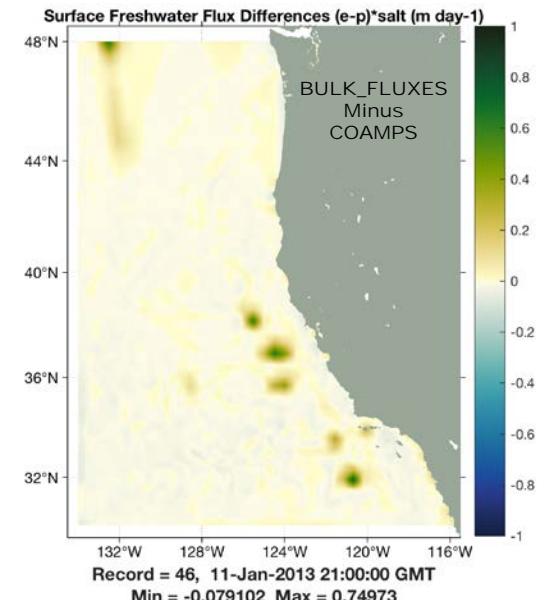
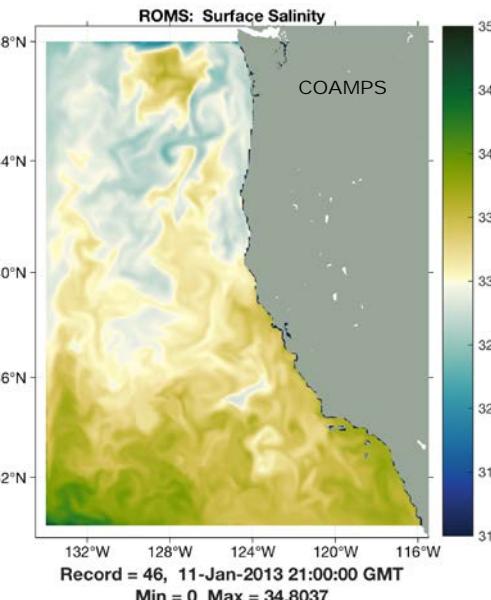
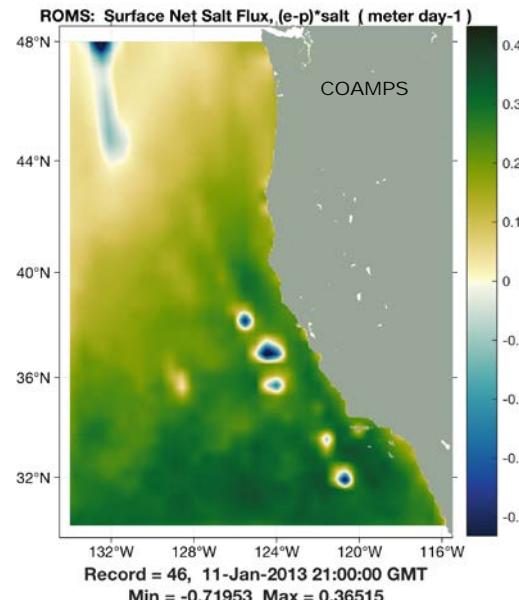
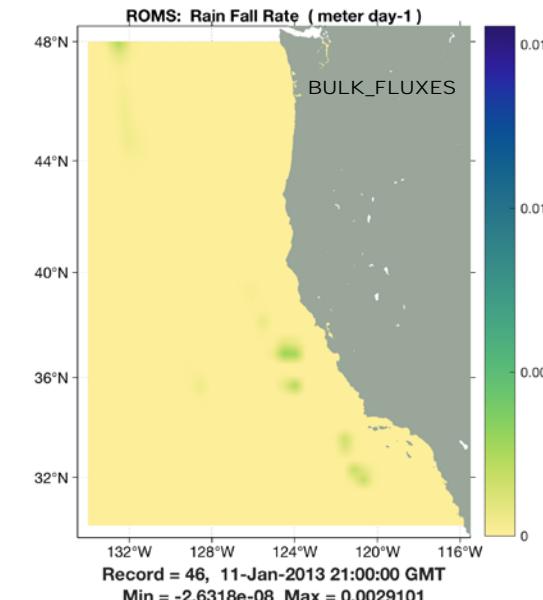
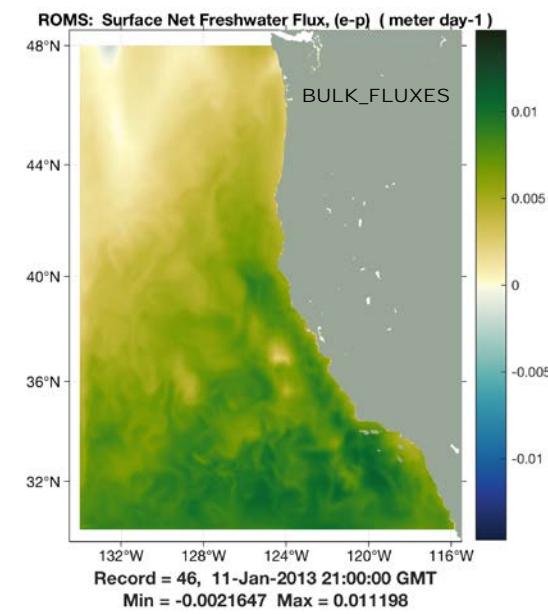
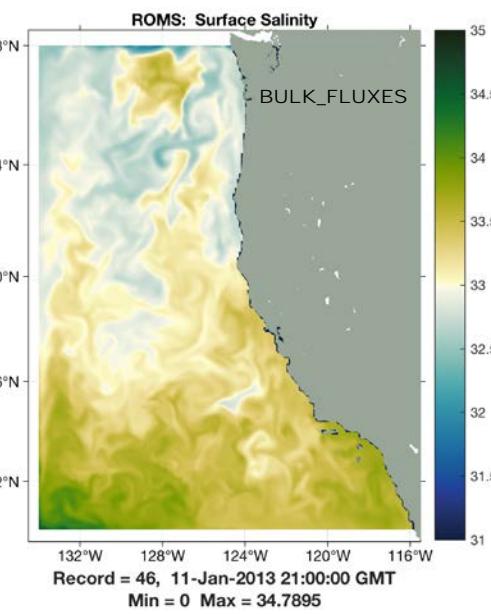
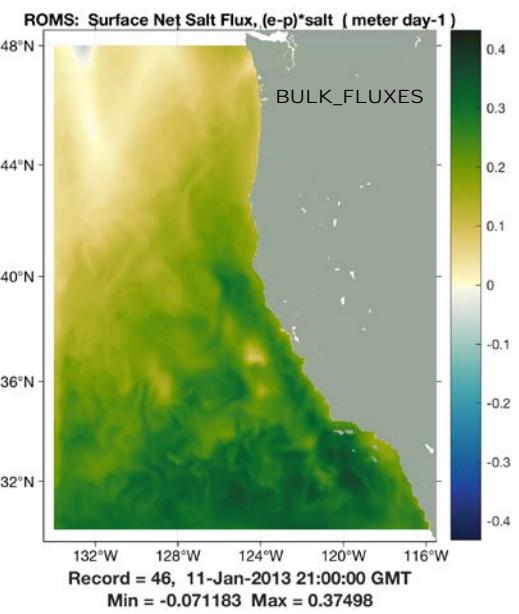
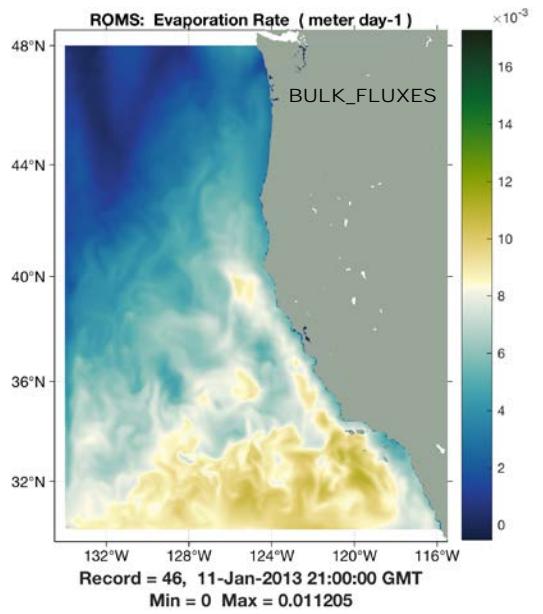
11-Jan-2013 13:00:00 PST

# Computed Surface Net Heat Flux (W/m<sup>2</sup>)

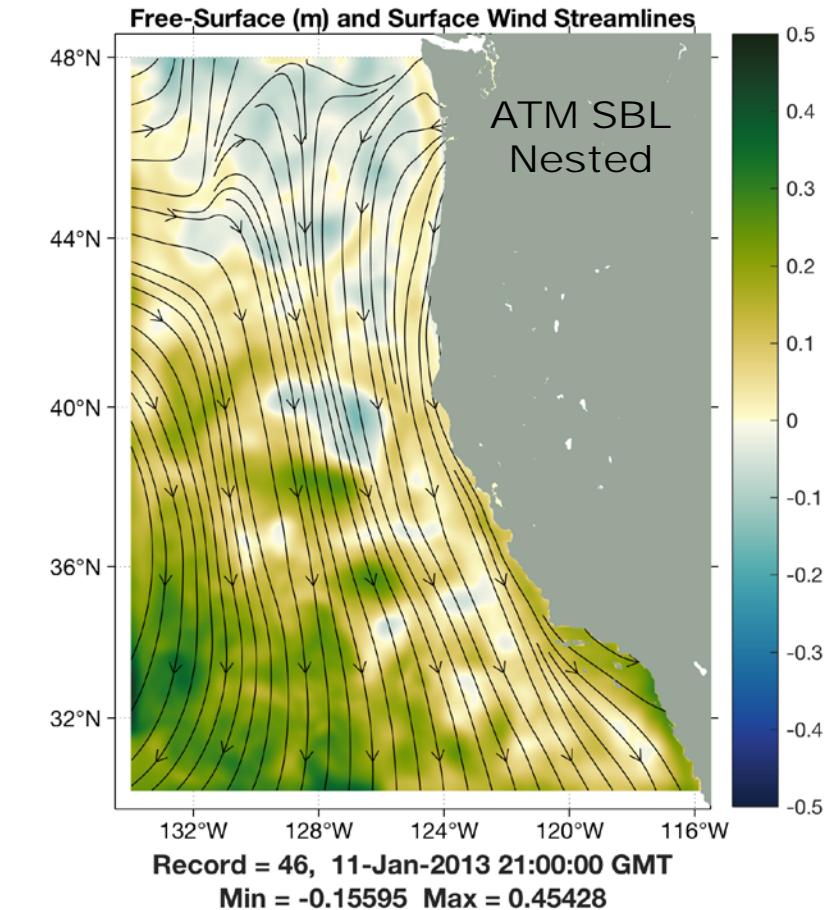
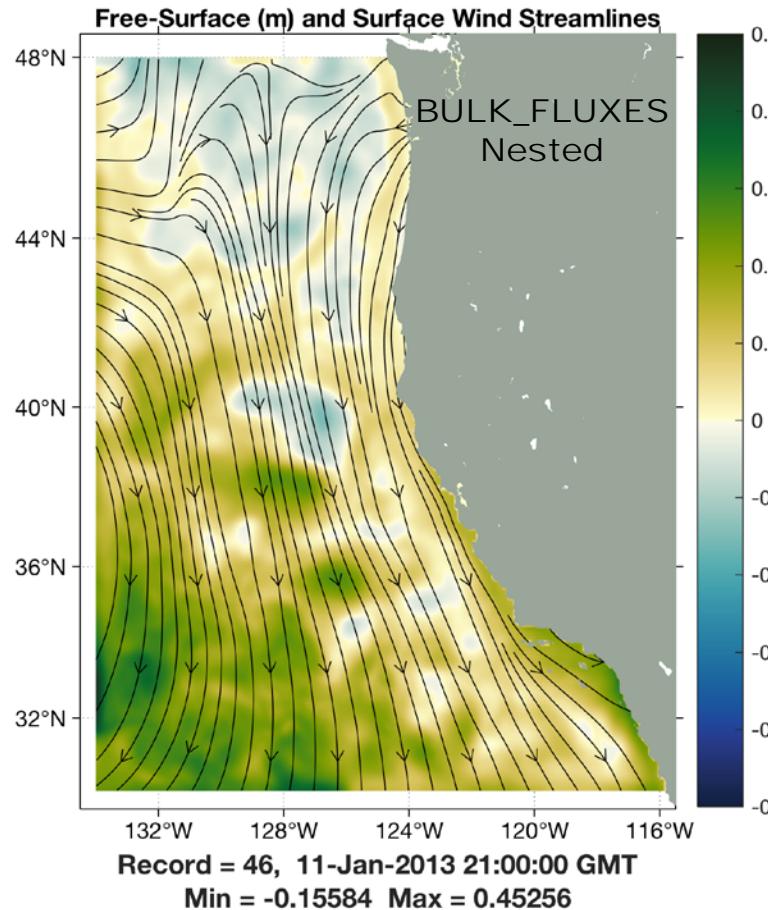
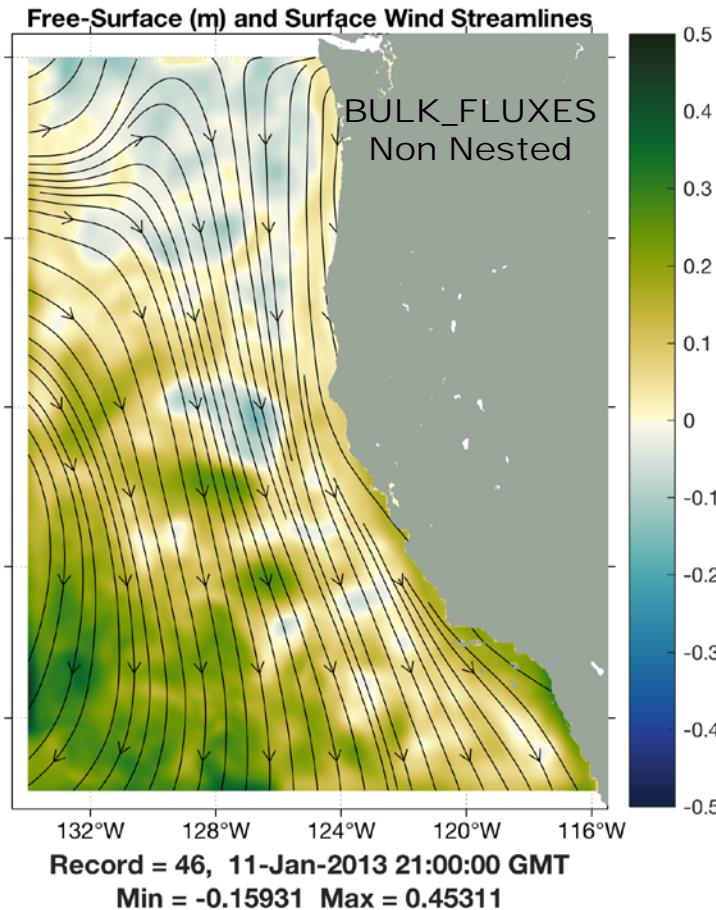


11-Jan-2013 13:00:00 PST

# Freshwater Flux Analysis: Nested C03 and C04



# Free-Surface (m) and Surface Wind Streamlines: C01, C03, C04



11-Jan-2013 13:00:00 PST

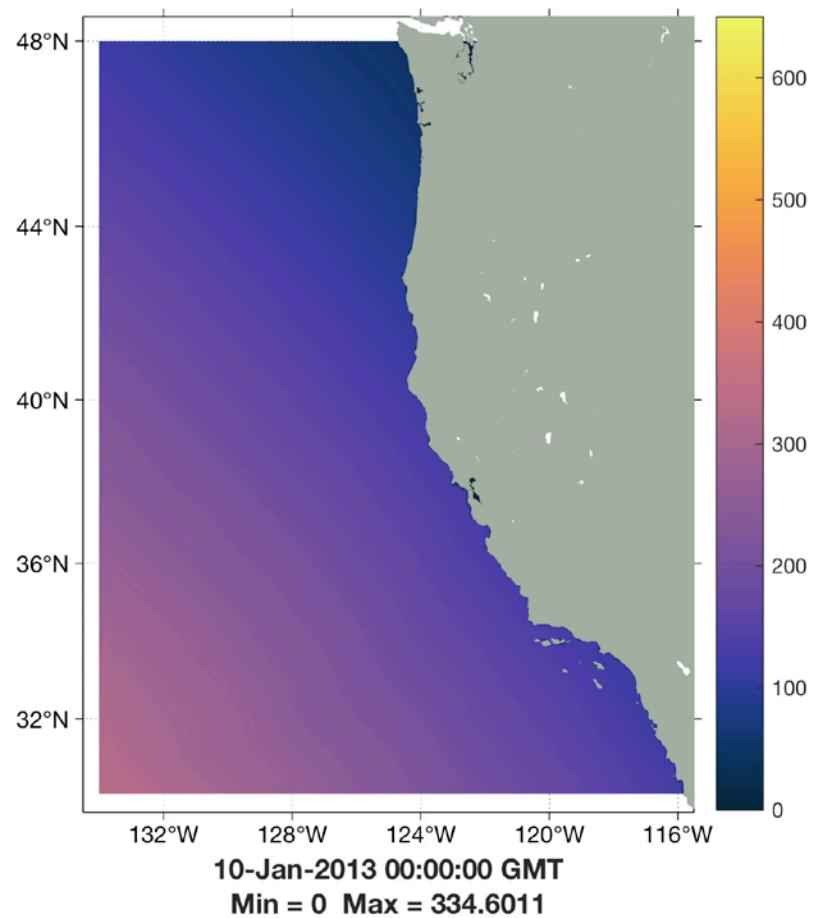
# Coupled and Uncoupled Simulations Comparison

- WC12 application 184x179x42, mean resolution  $dx = 8.5 \text{ km}$  and  $dy = 11.0 \text{ km}$
- DATA-COAMPS-ROMS **coupled simulation C03**: COAMPS includes a 15 km grid nest and ROMS bulk fluxes parameterization
- ERA5-ECMWF dataset
- **Uncoupled Simulation U01: Using ROMS bulk fluxes parameterization**
  - COAMPS daily-averaged dataset
  - ROMS activates **BULK\_FLUXES, COOL\_SKIN, EMINUSP, LONGWAVE\_OUT, WIND\_MINUS\_CURRENT**
  - ROMS activates **DIURNAL\_SRFLUX**
- **Uncoupled Simulation U02: Using ROMS bulk fluxes parameterization**
  - ERA5-ECMWF hourly dataset
  - ROMS activates **BULK\_FLUXES, COOL\_SKIN, EMINUSP, LONGWAVE\_OUT, WIND\_MINUS\_CURRENT**
- **Uncoupled Simulation U03: Using ROMS bulk fluxes parameterization**
  - NOGAPS global dataset every 6 hours at 0.5 degree resolution
- **Uncoupled Simulation U04: Using ATM surface fluxes parameterization**
  - ERA5-ECMWF hourly dataset
  - ROMS deactivates **BULK\_FLUXES, COOL\_SKIN, EMINUSP, LONGWAVE\_OUT, WIND\_MINUS\_CURRENT**

The comparison is between **C03**, **U02**, and **U04**

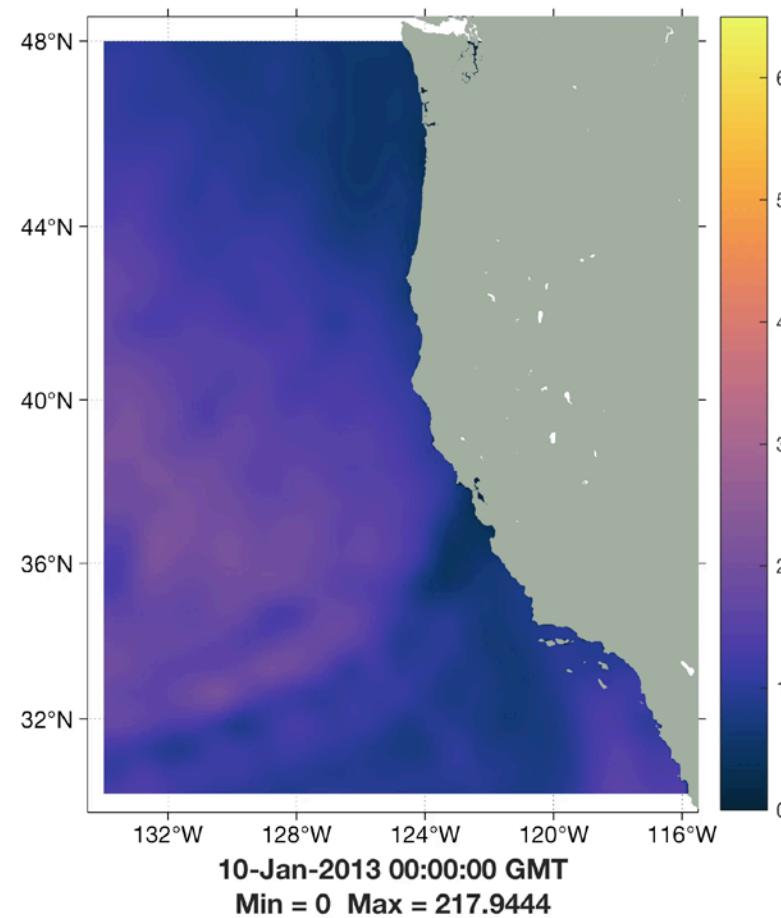
# Surface Shortwave Radiation Comparison ( $\text{W/m}^2$ )

DATA-COAMPS-ROMS



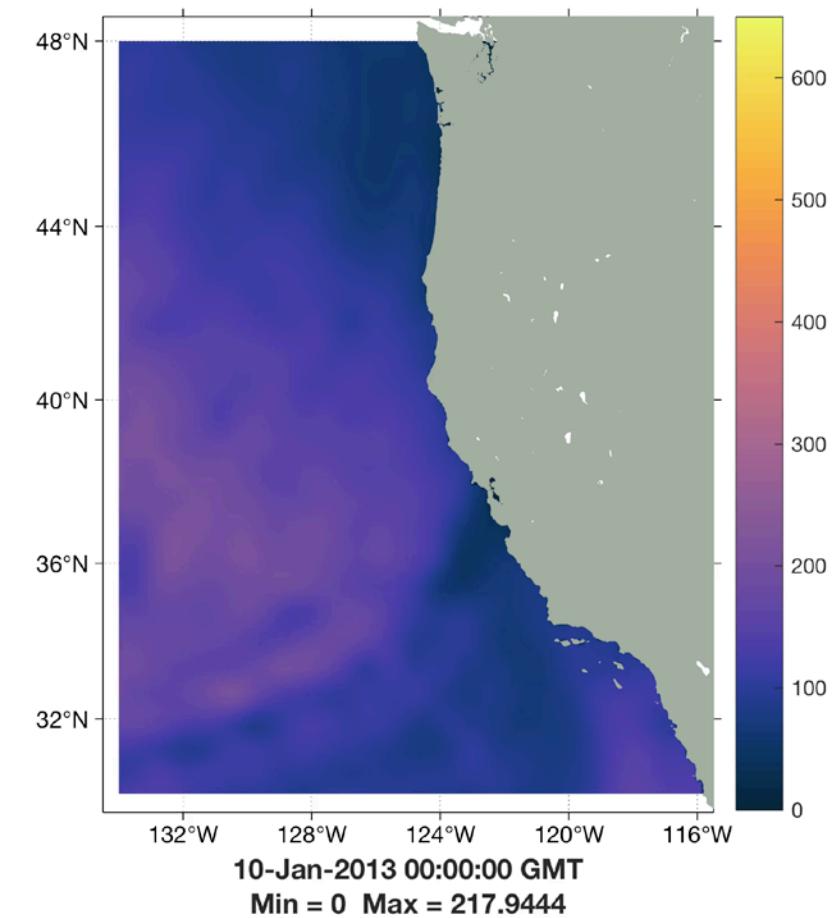
ESMF Coupling: 600 s  
**BULK\_FLUXES**

ERA5-ECMWF DATA



Uncoupled: hourly  
**BULK\_FLUXES**

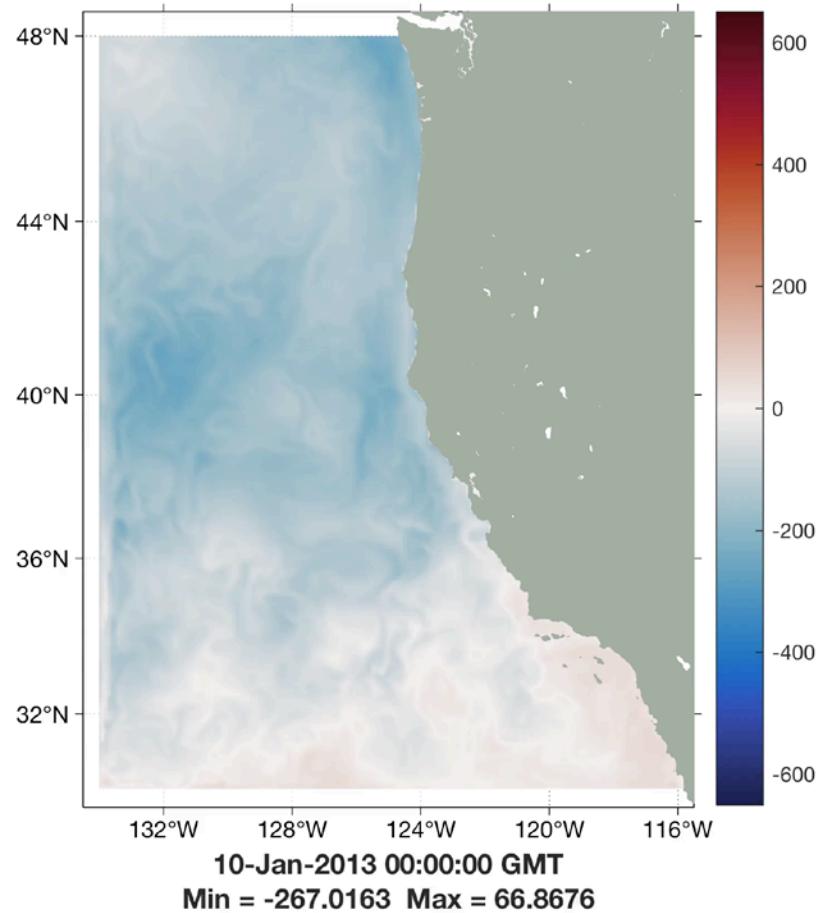
ERA5-ECMWF DATA



Uncoupled: hourly  
**ATM SBL**

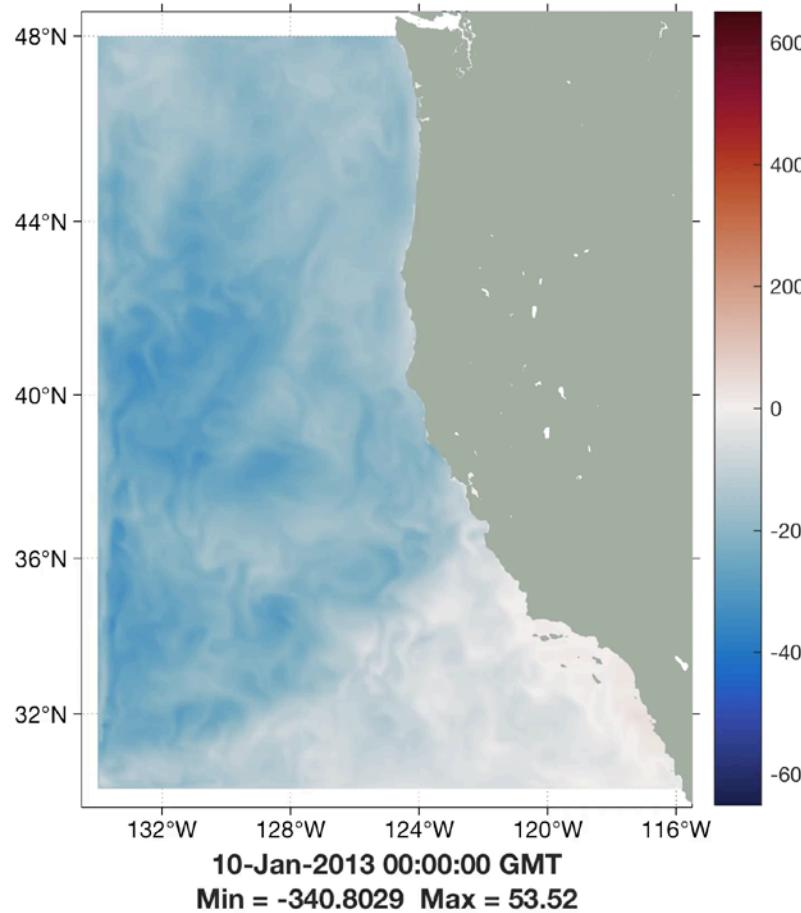
# Surface Net Heat Flux Comparison ( $\text{W/m}^2$ )

DATA-COAMPS-ROMS



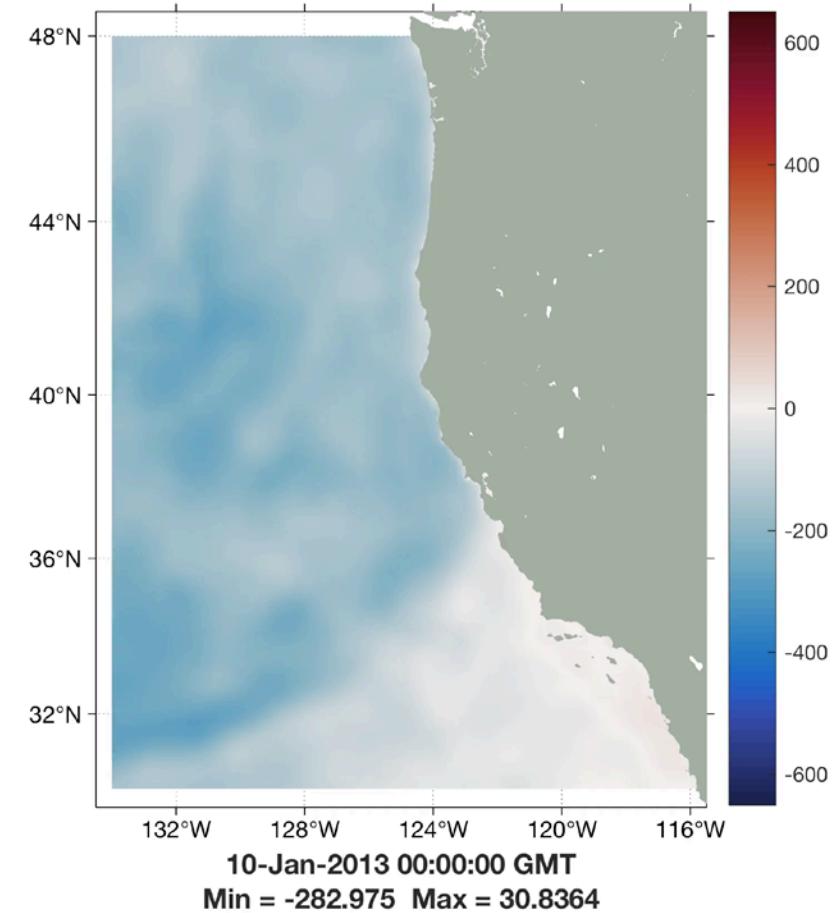
ESMF Coupling: 600 s  
**BULK\_FLUXES**

ERA5-ECMWF DATA



Uncoupled: hourly  
**BULK\_FLUXES**

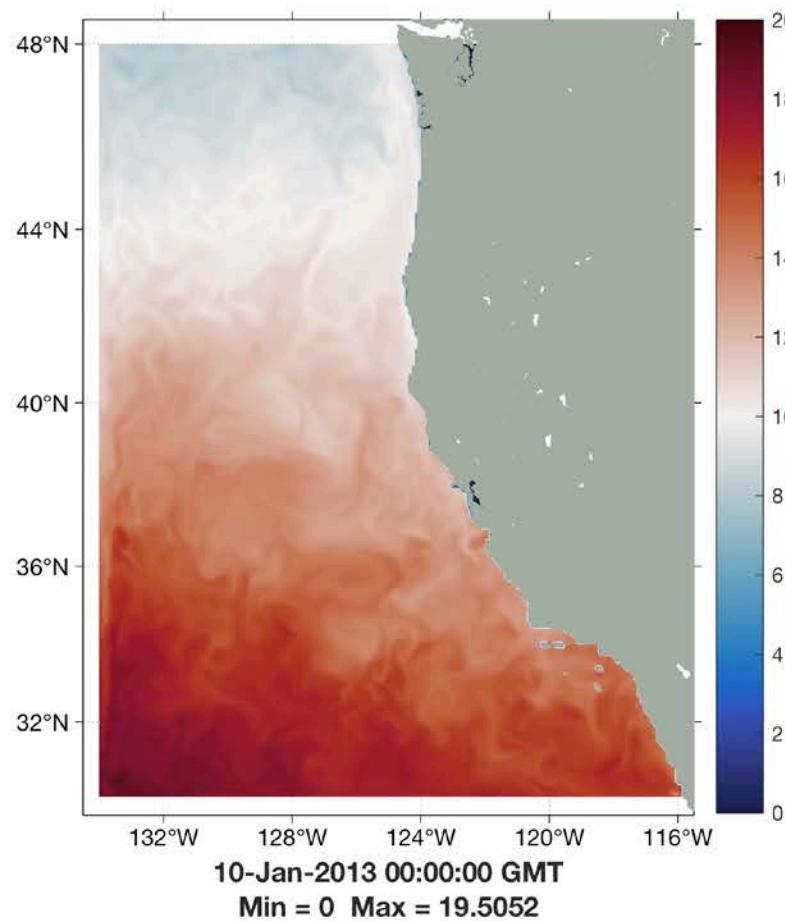
ERA5-ECMWF DATA



Uncoupled: hourly  
**ATM SBL**

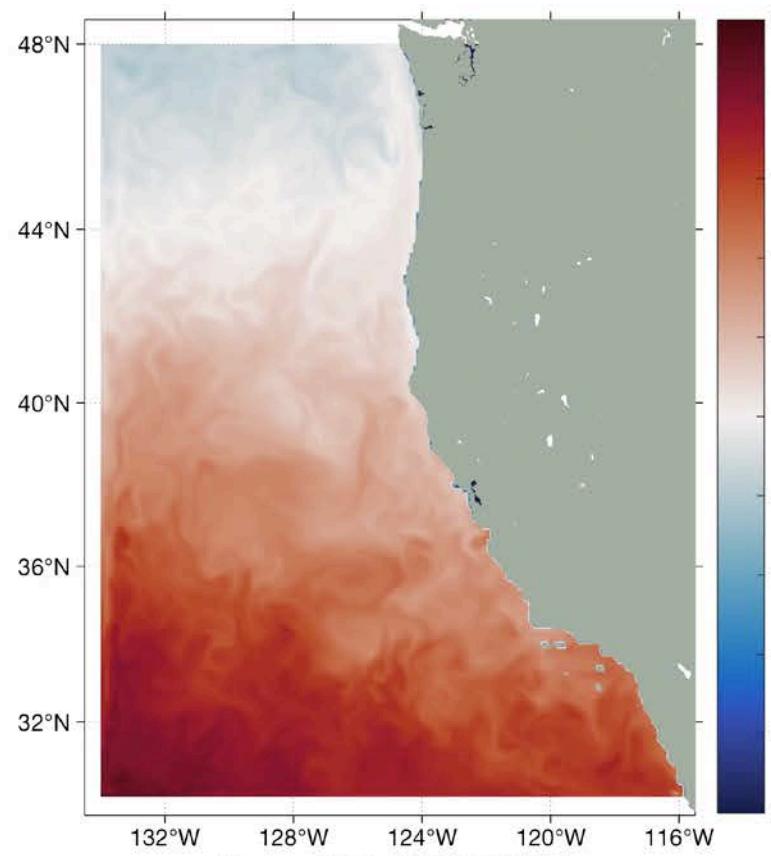
# Surface Temperature Comparison (°C)

DATA-COAMPS-ROMS



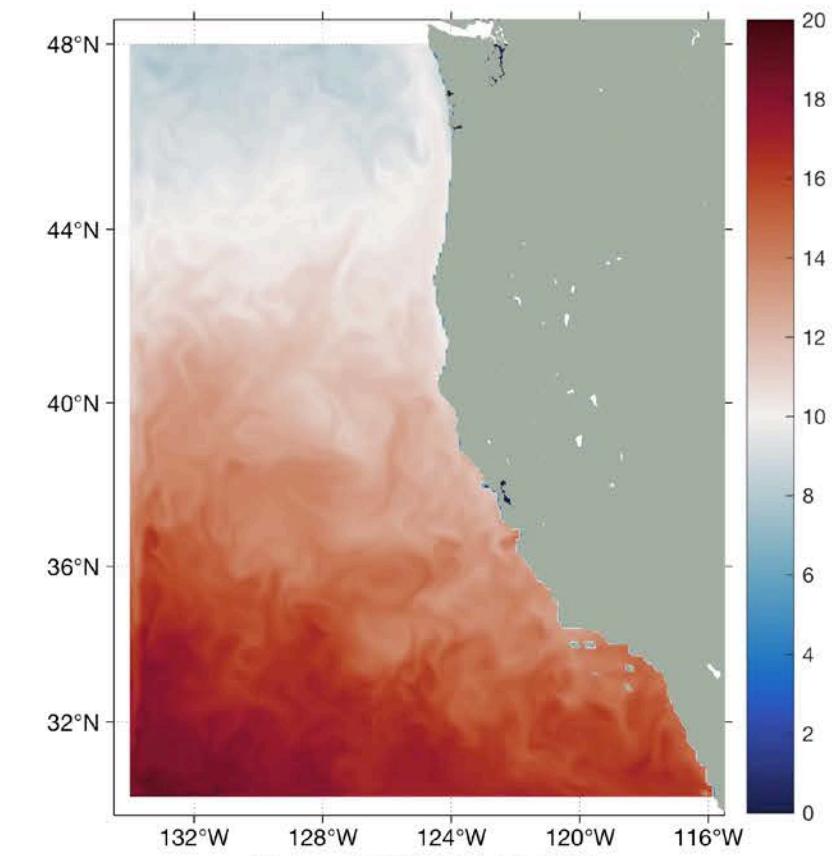
ESMF Coupling: 600 s  
**BULK\_FLUXES**

ERA5-ECMWF DATA



Uncoupled: hourly  
**BULK\_FLUXES**

ERA5-ECMWF DATA



Uncoupled: hourly  
**ATM SBL**

# Surface Freshwater Flux Comparison (m/day): (E-P)\*SSS

DATA-COAMPS-ROMS

ERA5-ECMWF DATA

ERA5-ECMWF DATA



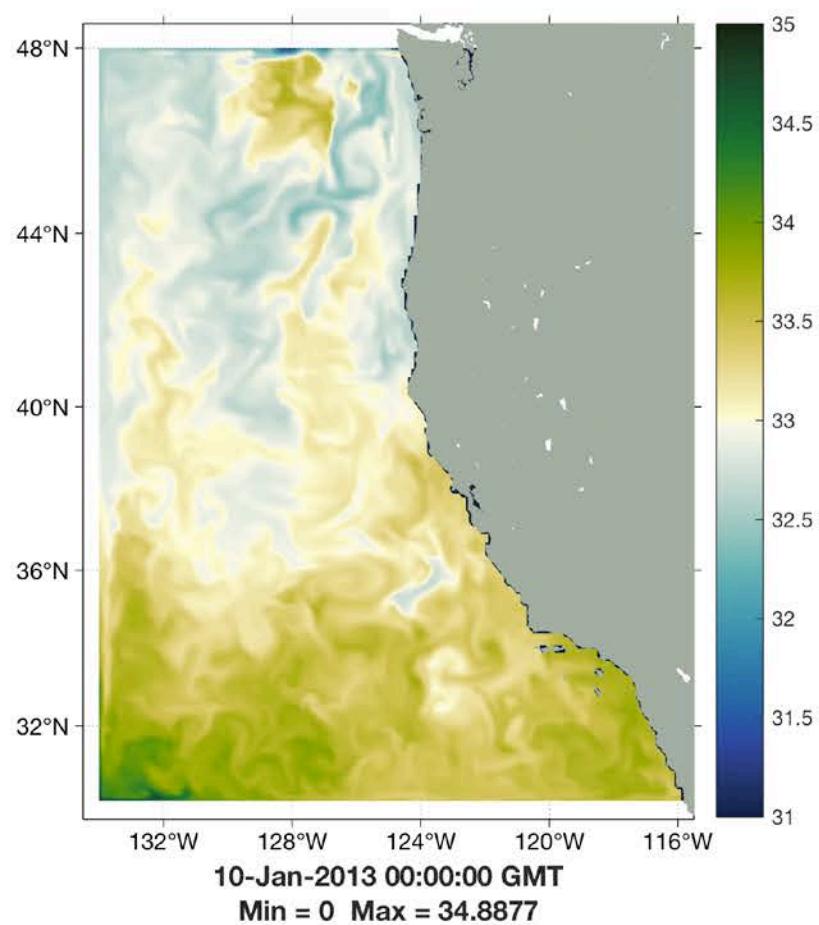
ESMF Coupling: 600 s  
**BULK\_FLUXES**

Uncoupled: hourly  
**BULK\_FLUXES**

Uncoupled: hourly  
**ATM SBL**

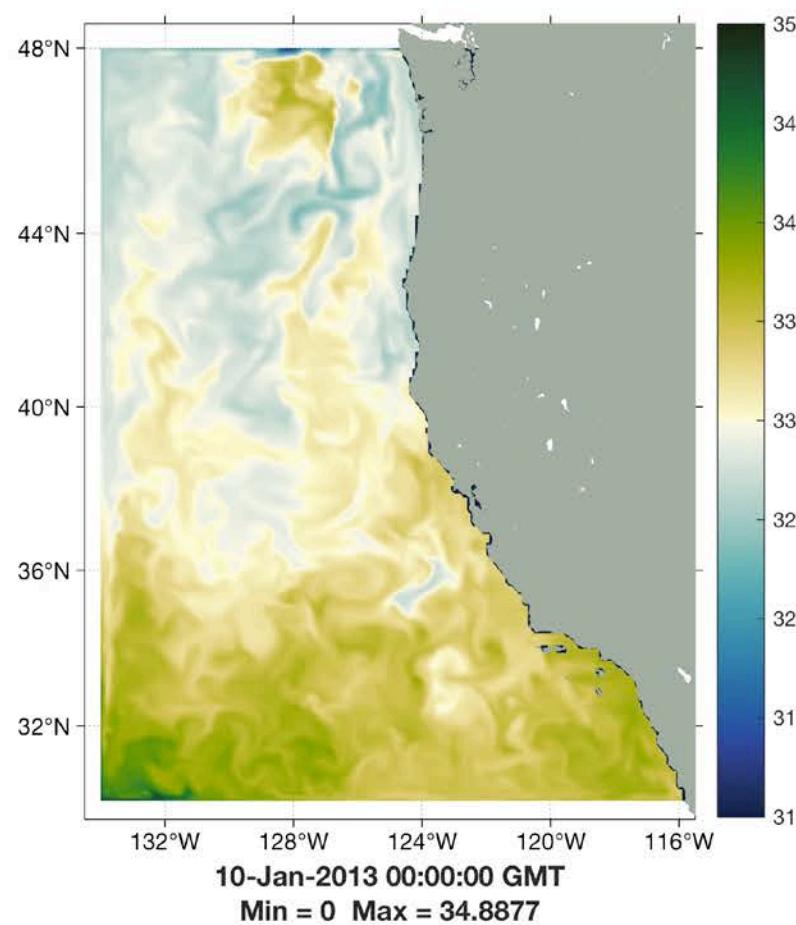
# Surface Salinity Comparison

DATA-COAMPS-ROMS



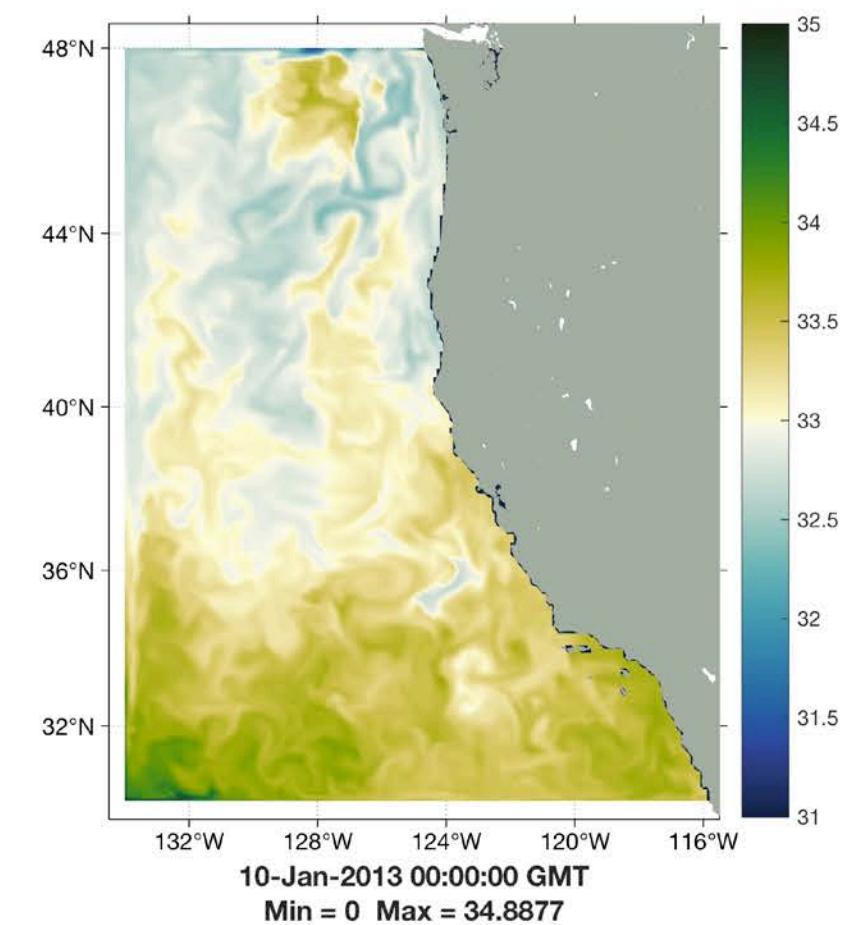
ESMF Coupling: 600 s  
**BULK\_FLUXES**

ERA5-ECMWF DATA



Uncoupled: hourly  
**BULK\_FLUXES**

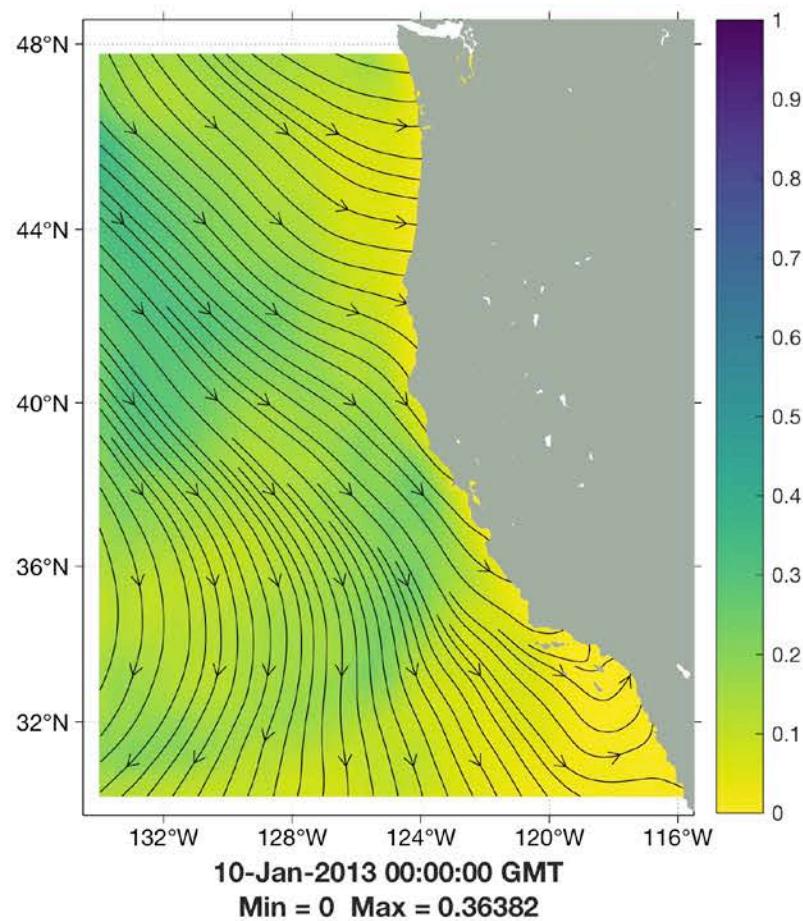
ERA5-ECMWF DATA



Uncoupled: hourly  
**ATM SBL**

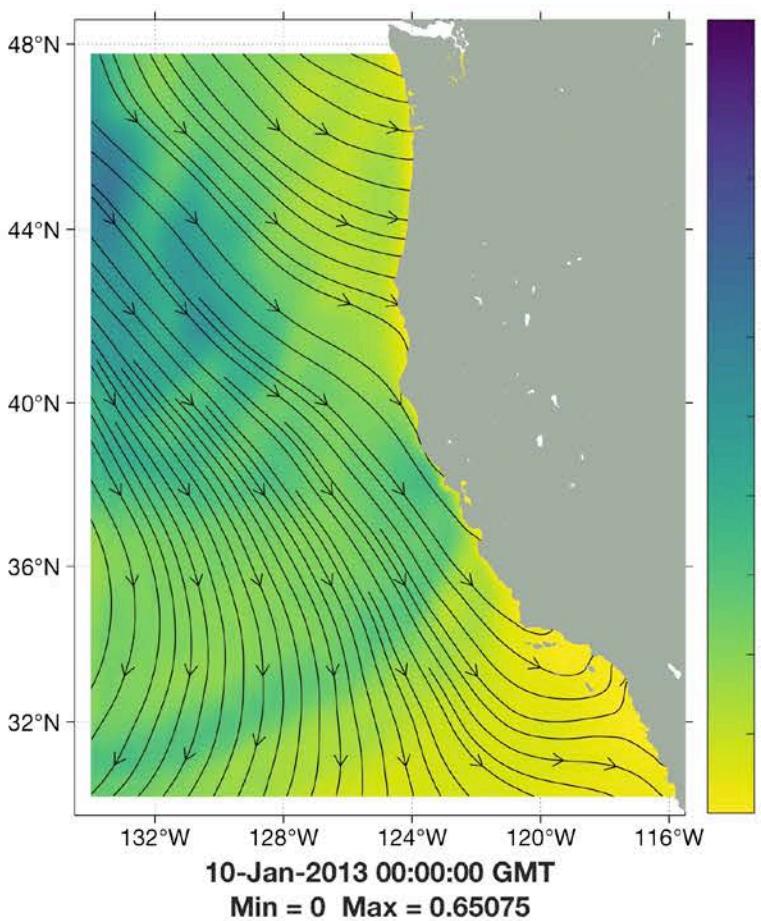
# Surface Wind Stress Comparison ( $\text{N/m}^2$ )

DATA-COAMPS-ROMS



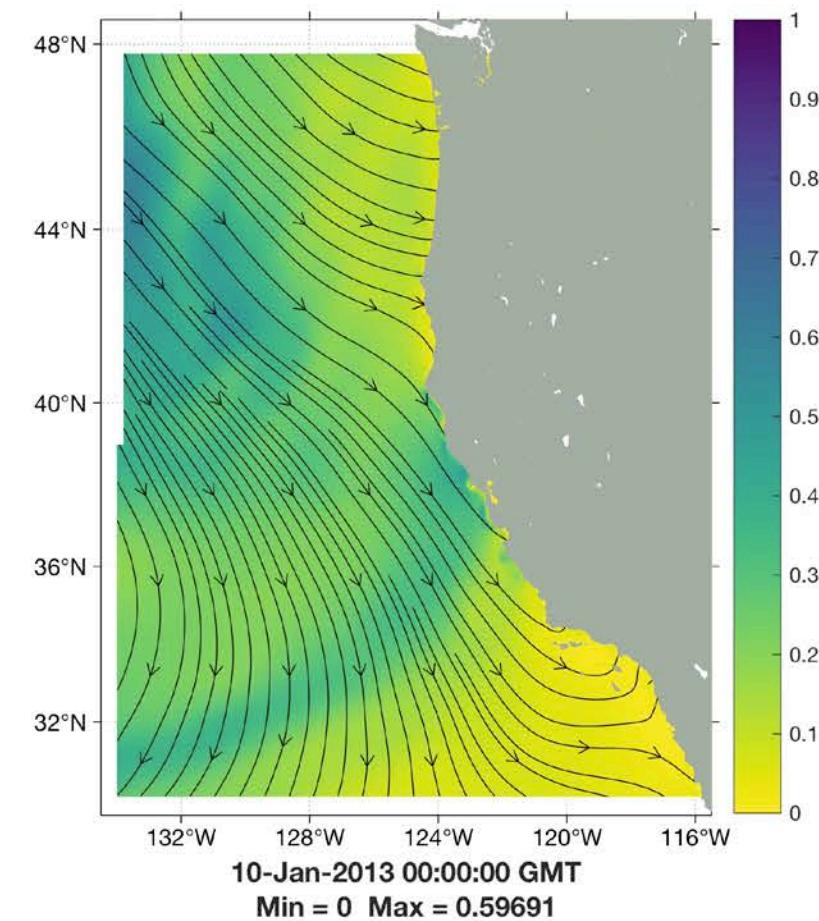
ESMF Coupling: 600 s  
**BULK\_FLUXES**

ERA5-ECMWF DATA



Uncoupled: hourly  
**BULK\_FLUXES**

ERA5-ECMWF DATA

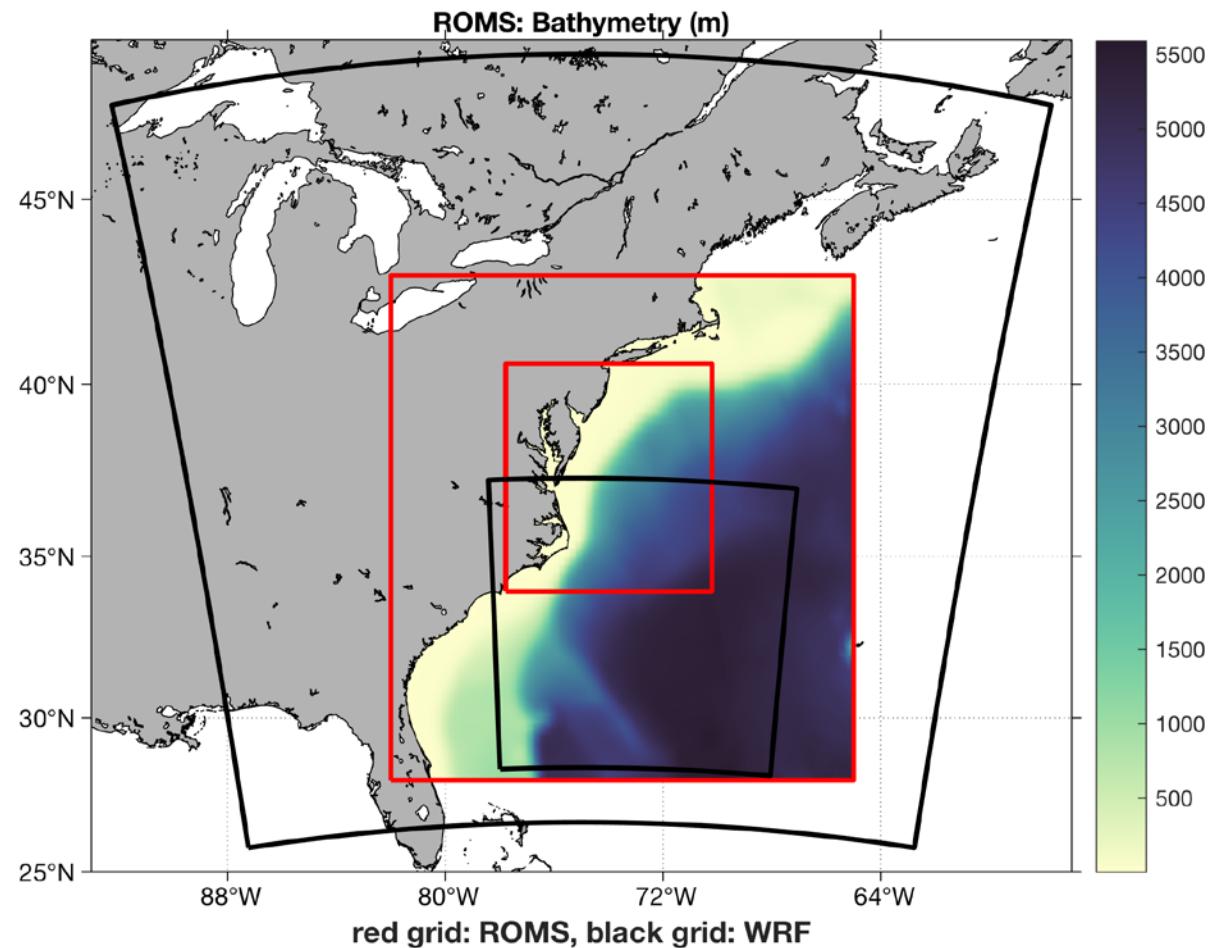
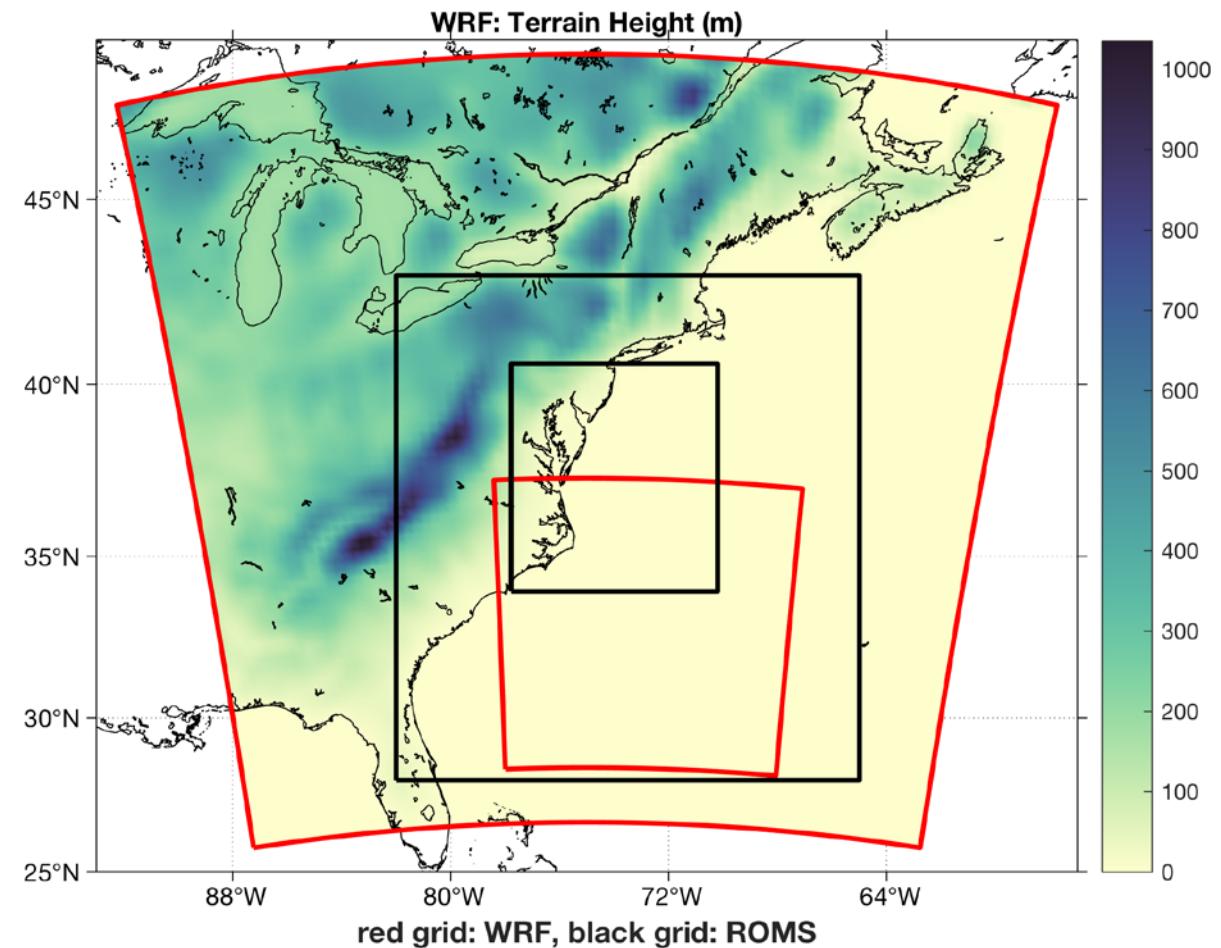


Uncoupled: hourly  
**ATM SBL**

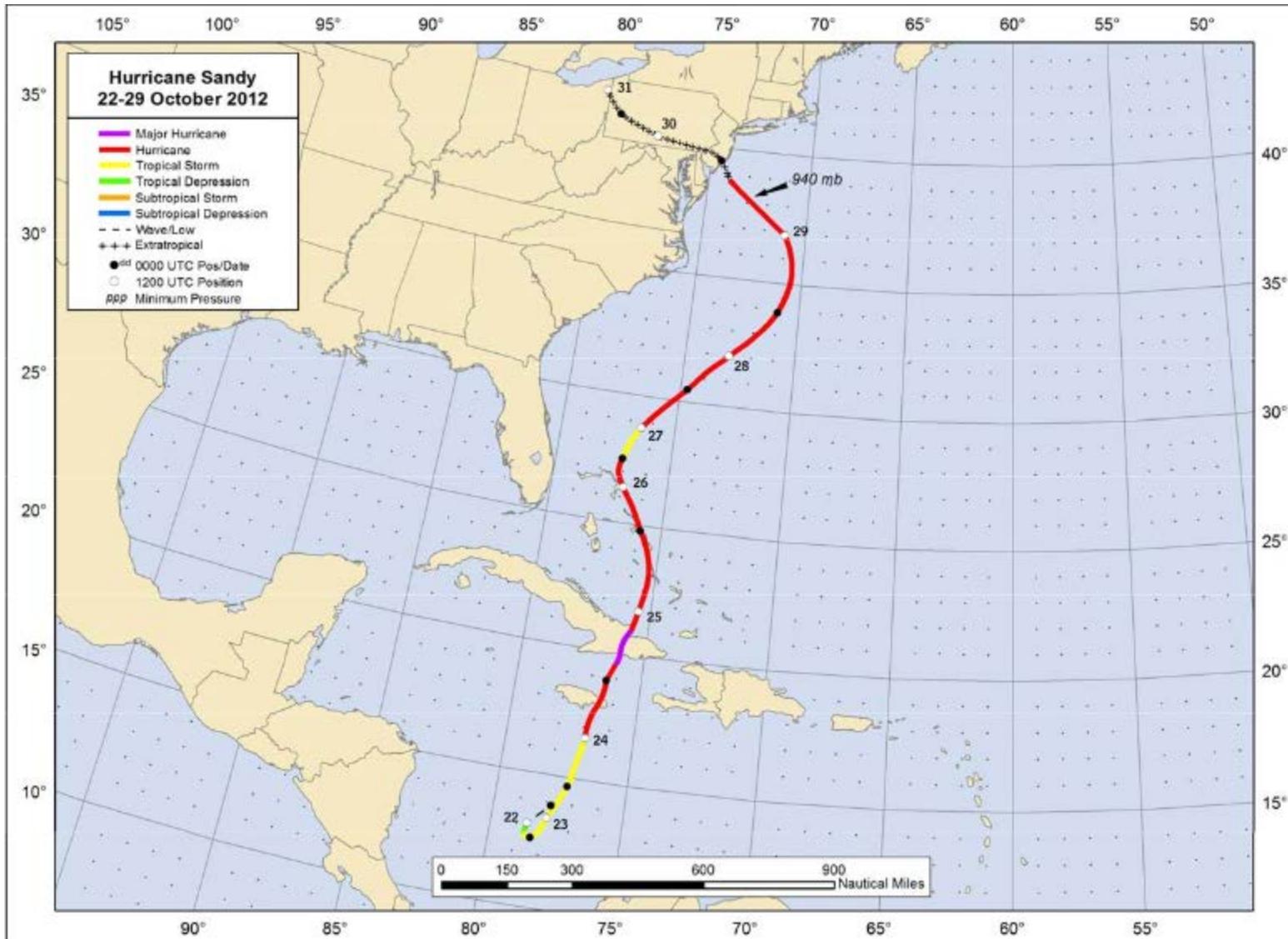
# DATA-WRF-ROMS Coupled Application: Hurricane Sandy

- SANDY COAWST application 87x65x65 with dx~18 km and dy~24 km (coarser), and 116x86x16 with dx~6 km and dy~8 km (finer)
- WRF COAWST application 85x82x48 with dx=dy=30 km (coarser), and 100x100x48 with dx=dy=15 km (finer)
- Time stepping: WRF 180 and 60 s, ROMS 30 and 15 s
- **Coupling Simulation E03:** Using ROMS bulk fluxes parameterization
  - Sequential and semi-implicit coupling, No Nesting, ESMF/NUOPC library
  - Non nested WRF, just coarser grid
  - Coupling interval: 180 s (every 6 ROMS timesteps), WRF exports instantaneous fields
  - WRF imports SST from DATA and ROMS components
  - DATA component reads SST from HyCOM 1/12 dataset, 4500x3298
  - ROMS activates **BULK\_FLUXES, EMINUSP, LONGWAVE\_OUT**
  - ROMS imports **dLWrad, SWrad, Pair, Tair, Qair, rain, Uwind, and Vwind**
- **Coupling Simulation E02:** Using WRF surface fluxes parameterization
  - Same as E03 but ROMS deactivates **BULK\_FLUXES, EMINUSP, LONGWAVE\_OUT**
  - ROMS imports **SWrad, Pair, shflux, swflux, sustr, svstr**
- **Coupling Simulation M01:** Using WRF surface fluxes parameterization
  - Concurrent nested coupling, COAWST MCT library
  - Coupling interval: 180 s, WRF exports instantaneous fields
  - ROMS activates **ATM2OCN\_FLUXES** and **EMINUSP**

# DATA-WRF-ROMS Coupling: Hurricane Sandy



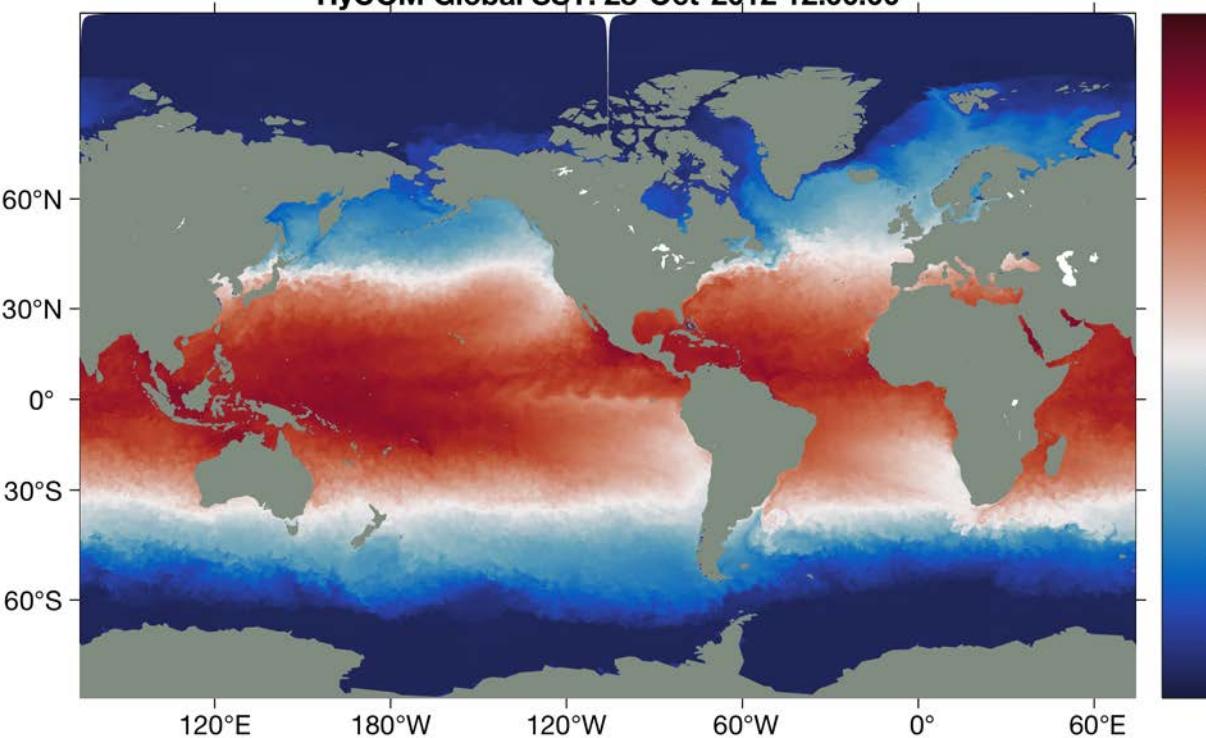
# DATA-WRF-ROMS Coupling: Hurricane Sandy Track



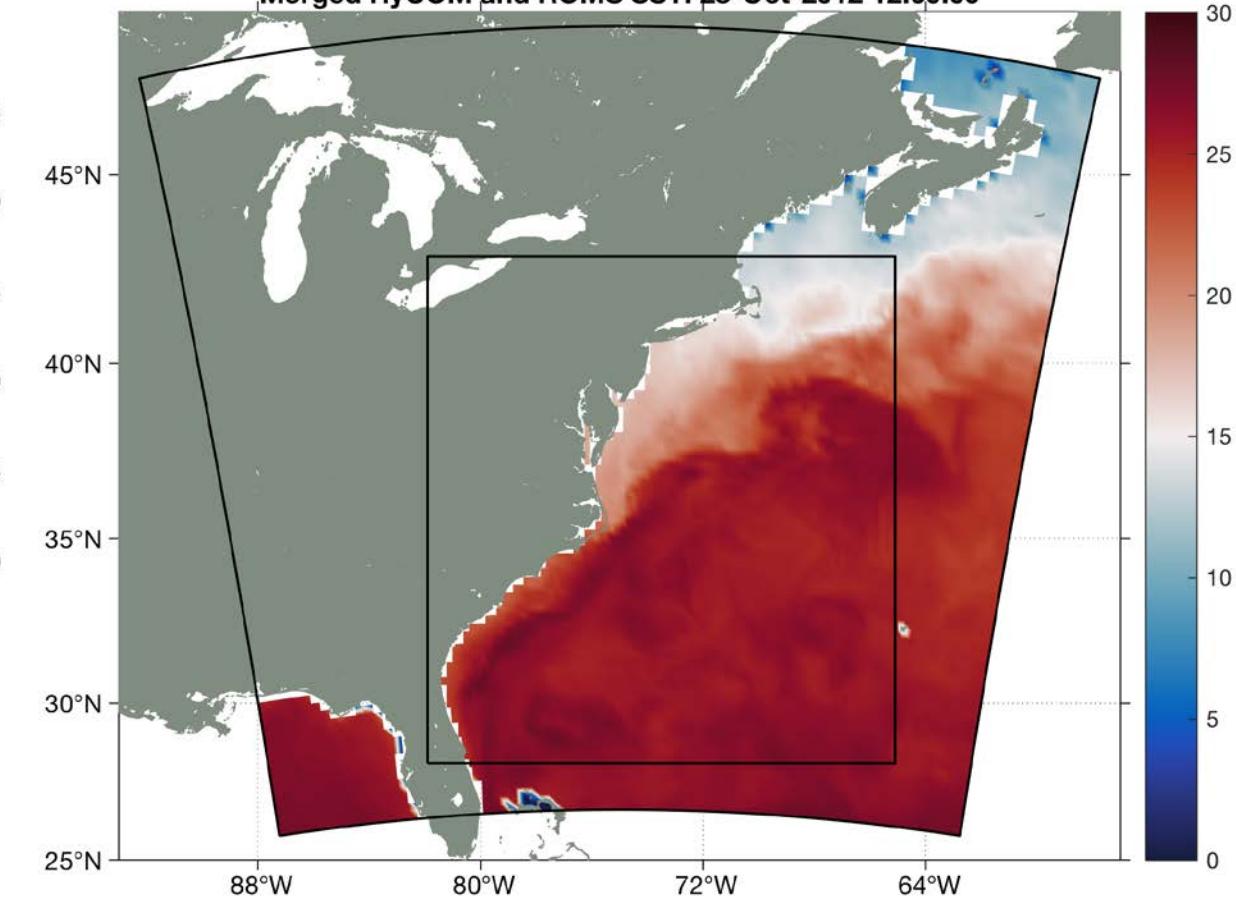
Source: NOAA's National Weather Service

# Merged Sea Surface Temperature (°C): WRF Import

HyCOM Global SST: 28-Oct-2012 12:00:00

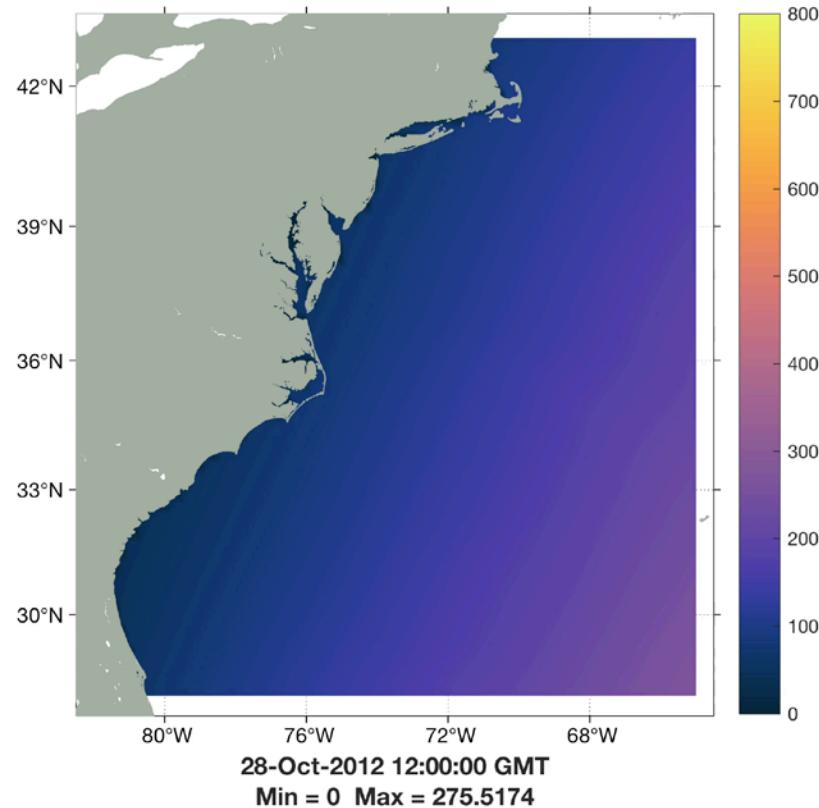


Merged HyCOM and ROMS SST: 28-Oct-2012 12:00:00

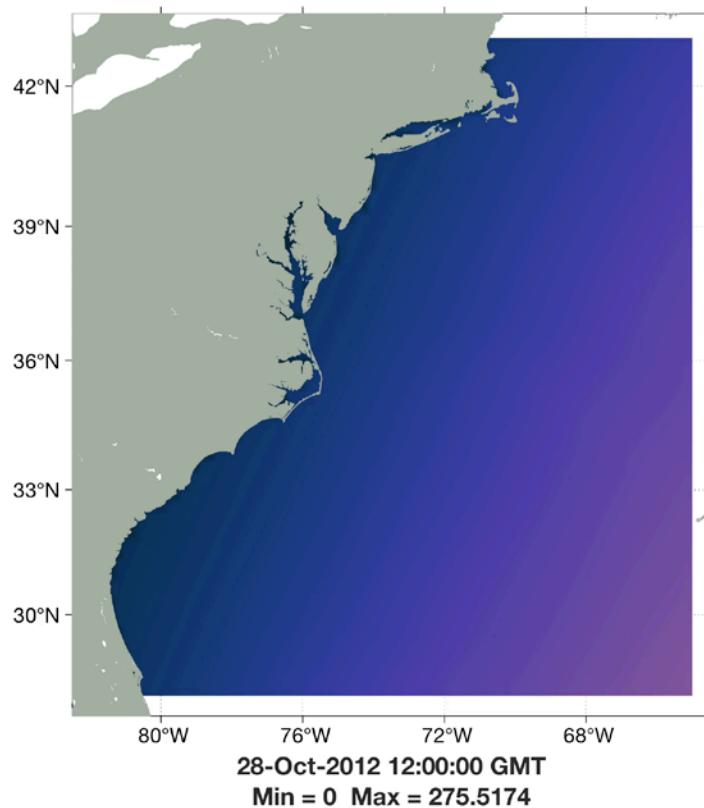


# Surface Shortwave Radiation Comparison ( $\text{W/m}^2$ )

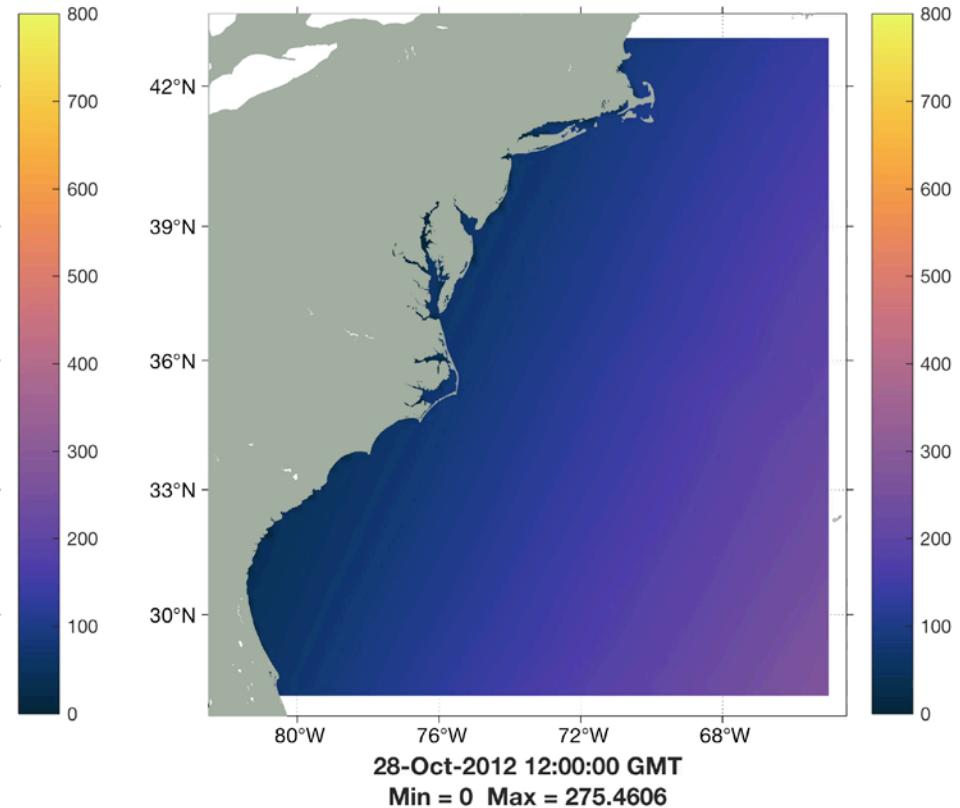
DATA-WRF-ROMS  
No Nesting



DATA-WRF-ROMS  
No Nesting



WRF-ROMS  
Nested



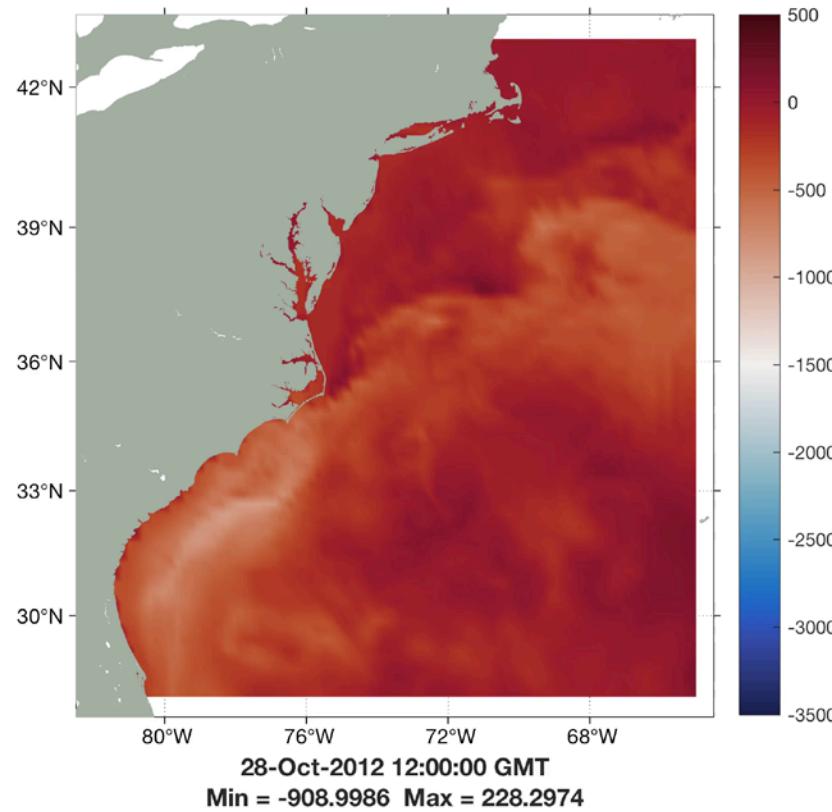
ESMF Coupling: 180 s  
**BULK\_FLUXES**

ESMF Coupling: 180 s  
**ATM SBL**

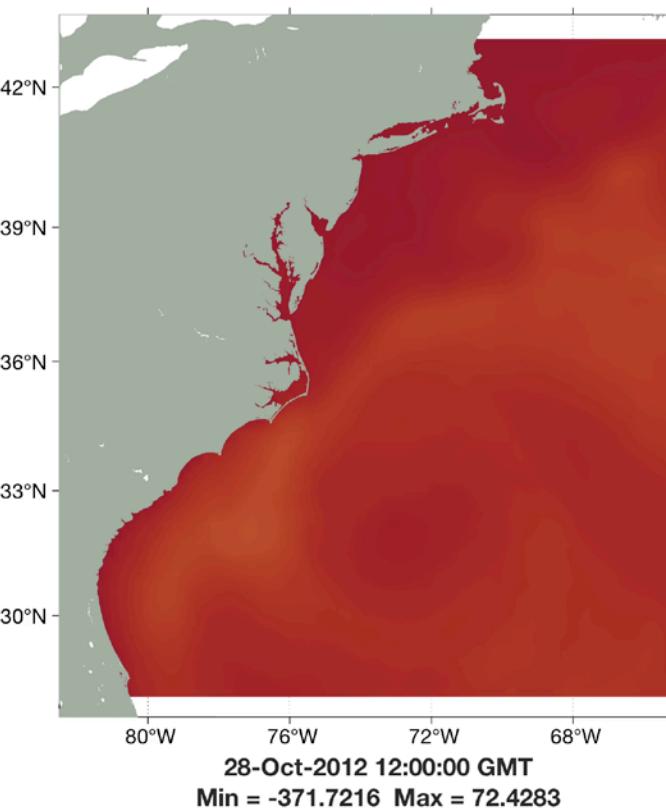
COAWST MCT Coupling: 180 s  
**ATM SBL**

# Surface Net Heat Flux Comparison ( $\text{W/m}^2$ )

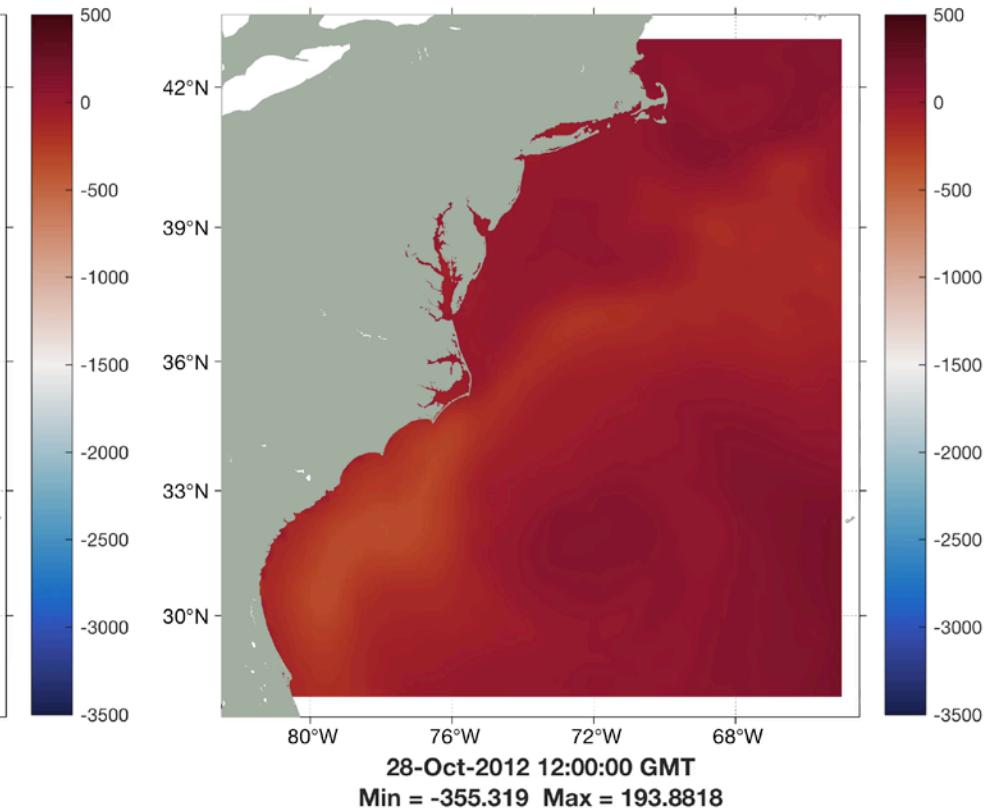
DATA-WRF-ROMS  
No Nesting



DATA-WRF-ROMS  
No Nesting



WRF-ROMS  
Nested



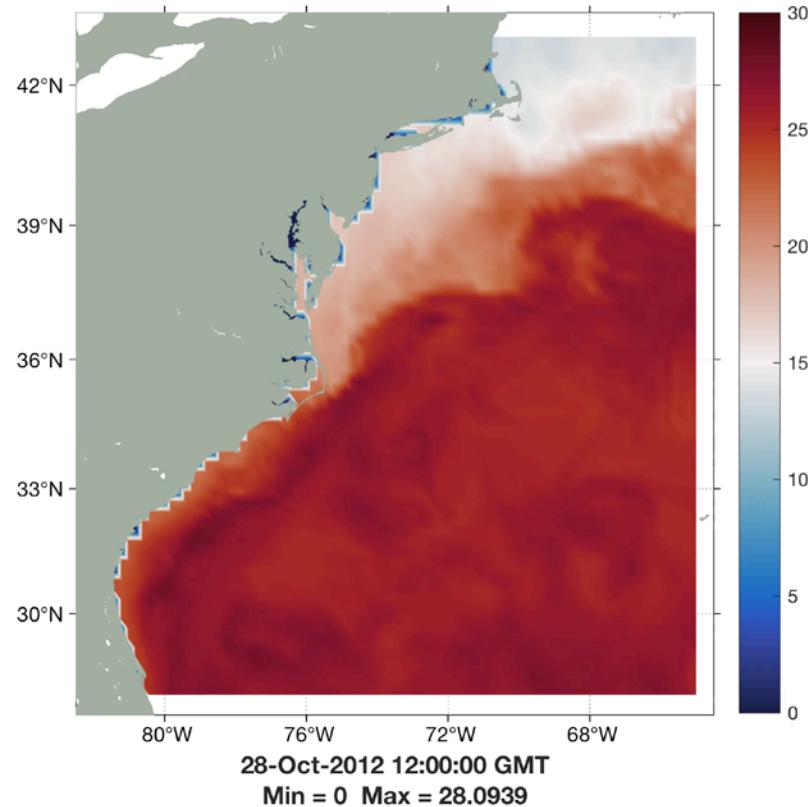
ESMF Coupling: 180 s  
**BULK\_FLUXES**

ESMF Coupling: 180 s  
**ATM SBL**

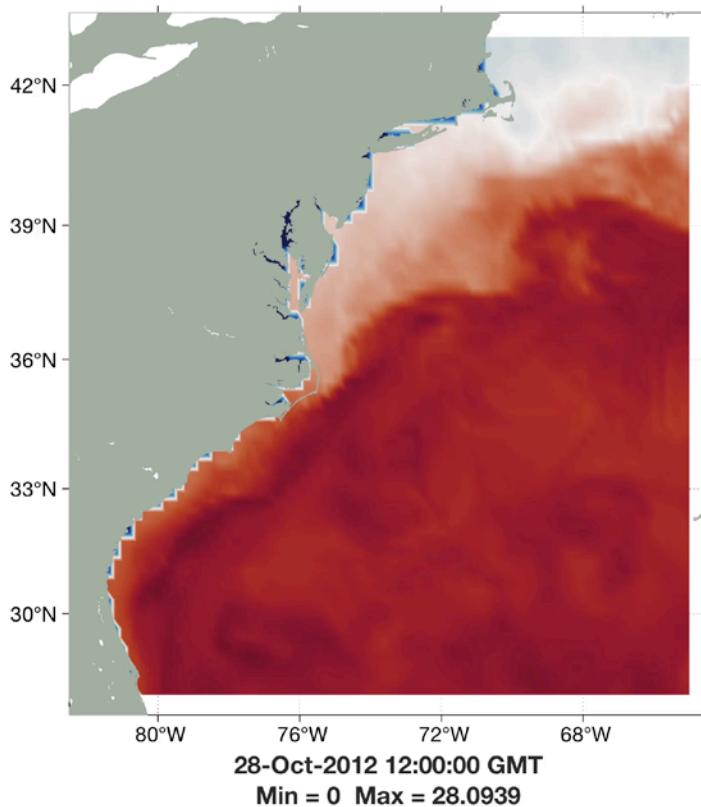
COAWST MCT Coupling: 180 s  
**ATM SBL**

# Surface Temperature Comparison (°C)

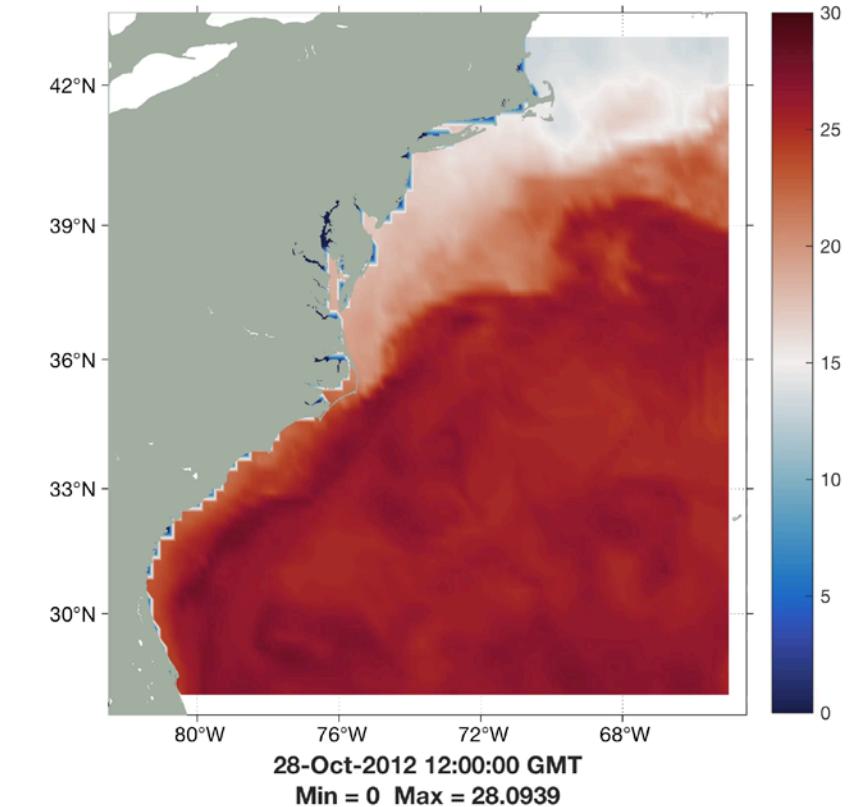
DATA-WRF-ROMS  
No Nesting



DATA-WRF-ROMS  
No Nesting



WRF-ROMS  
Nested



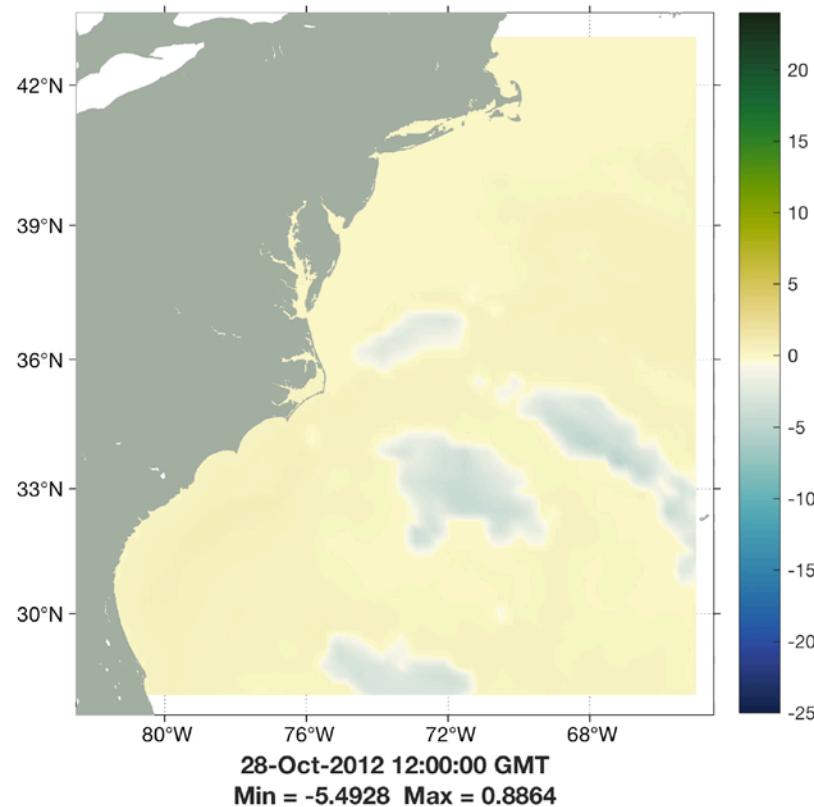
ESMF Coupling: 180 s  
**BULK\_FLUXES**

ESMF Coupling: 180 s  
**ATM SBL**

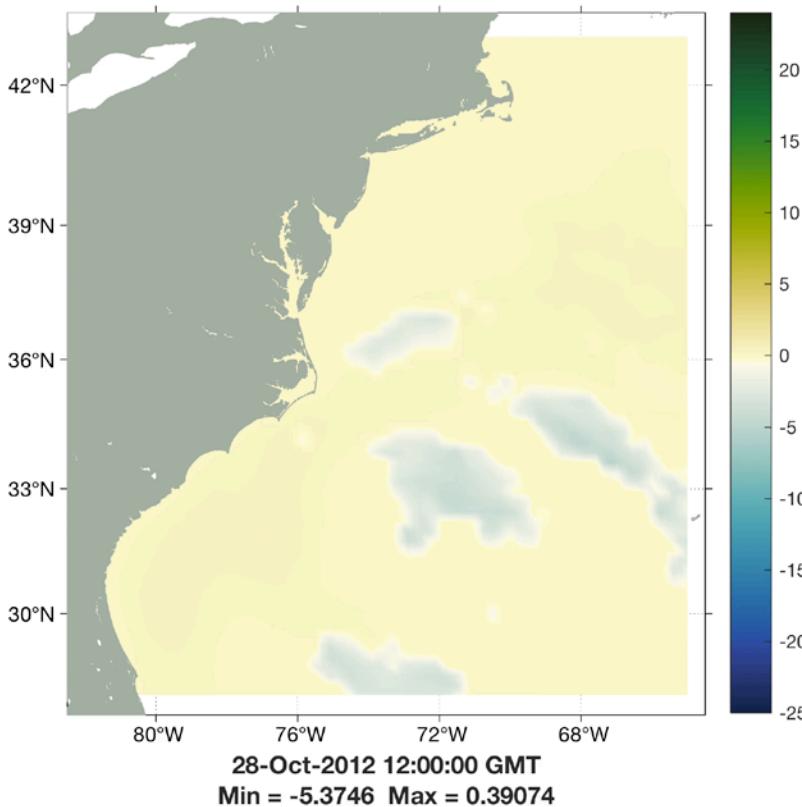
COAWST MCT Coupling: 180 s  
**ATM SBL**

# Surface Freshwater Flux Comparison (m/day): (E-P)\*SSS

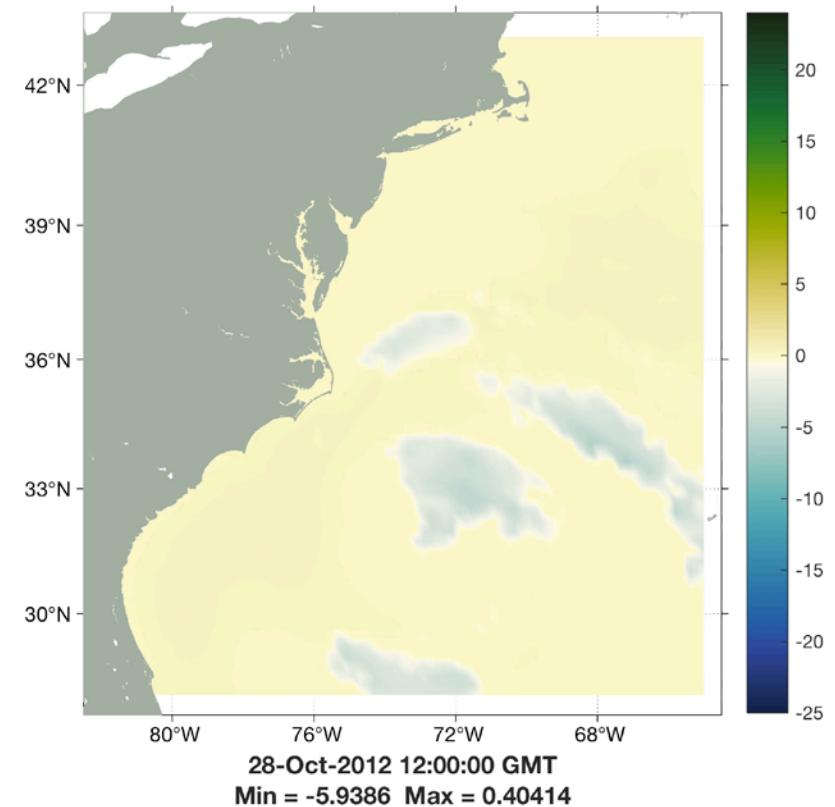
DATA-WRF-ROMS  
No Nesting



DATA-WRF-ROMS  
No Nesting



WRF-ROMS  
Nested



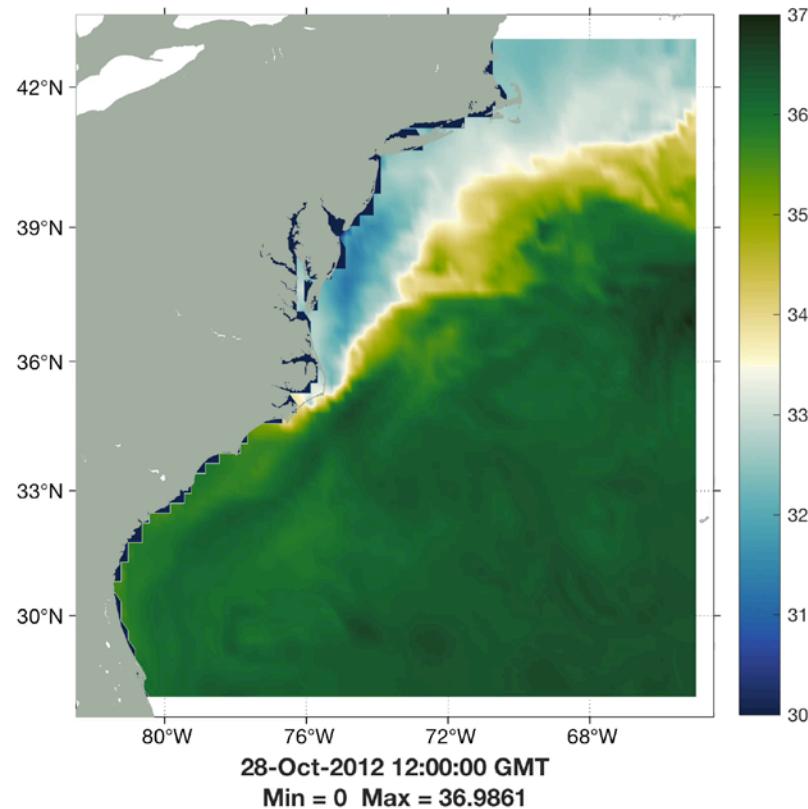
ESMF Coupling: 180 s  
**BULK\_FLUXES**

ESMF Coupling: 180 s  
**ATM SBL**

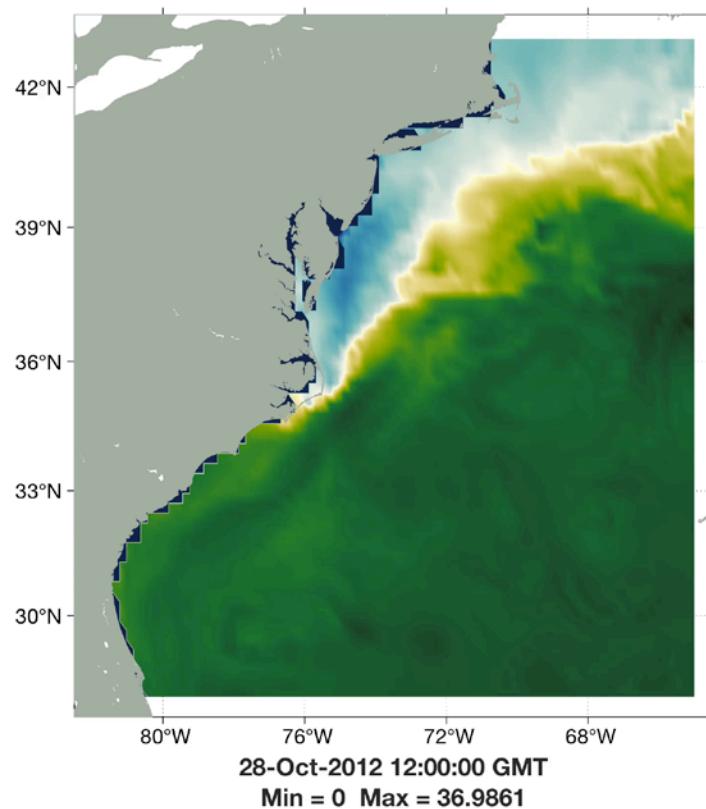
COAWST MCT Coupling: 180 s  
**ATM SBL**

# Surface Salinity Comparison

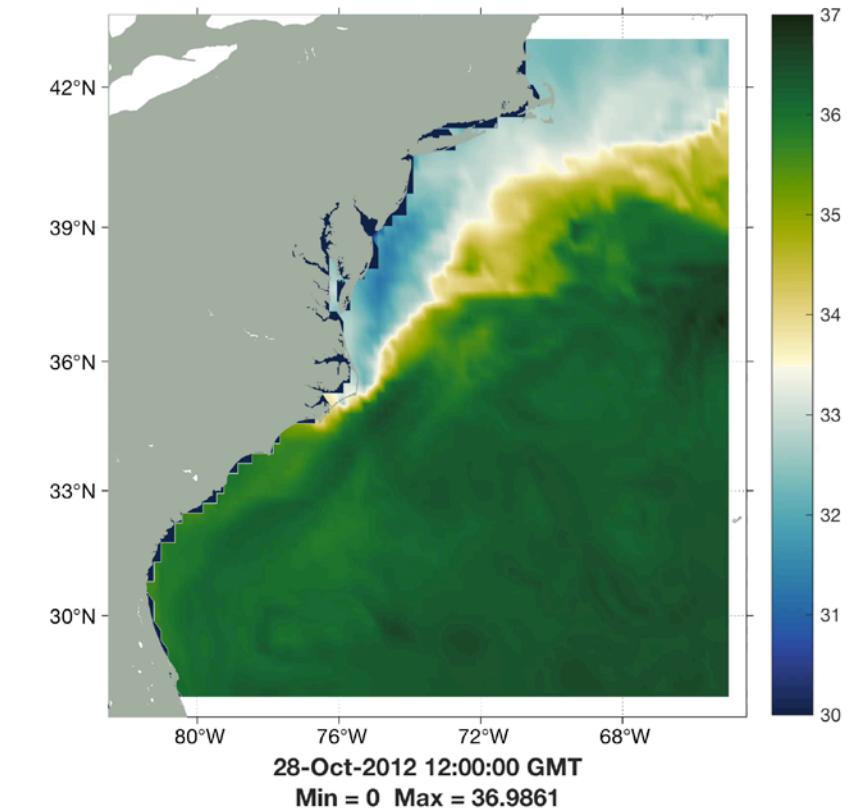
DATA-WRF-ROMS  
No Nesting



DATA-WRF-ROMS  
No Nesting



WRF-ROMS  
Nested



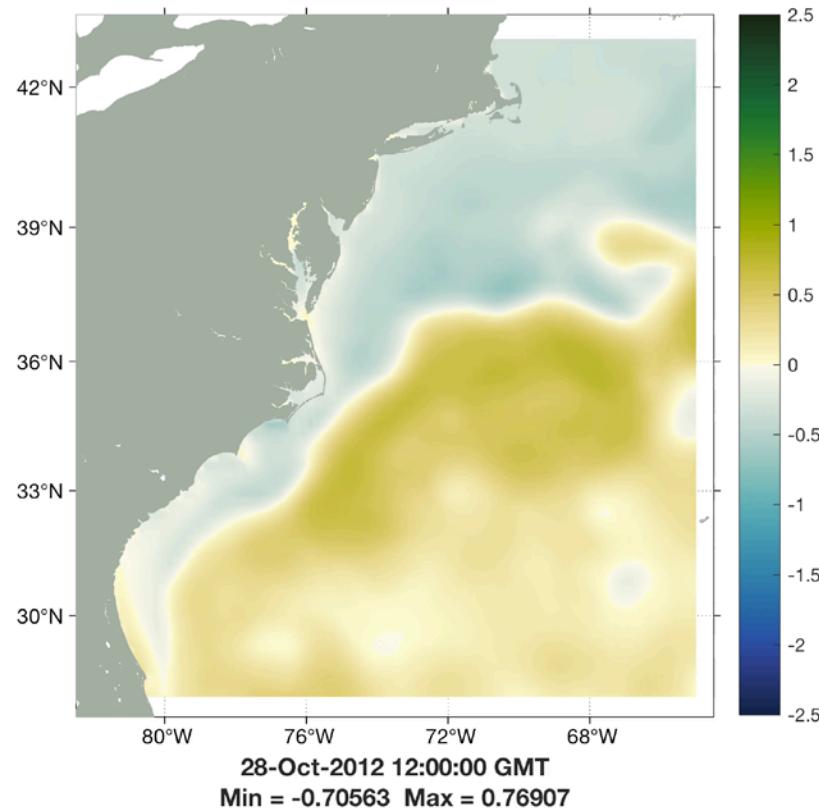
ESMF Coupling: 180 s  
**BULK\_FLUXES**

ESMF Coupling: 180 s  
**ATM SBL**

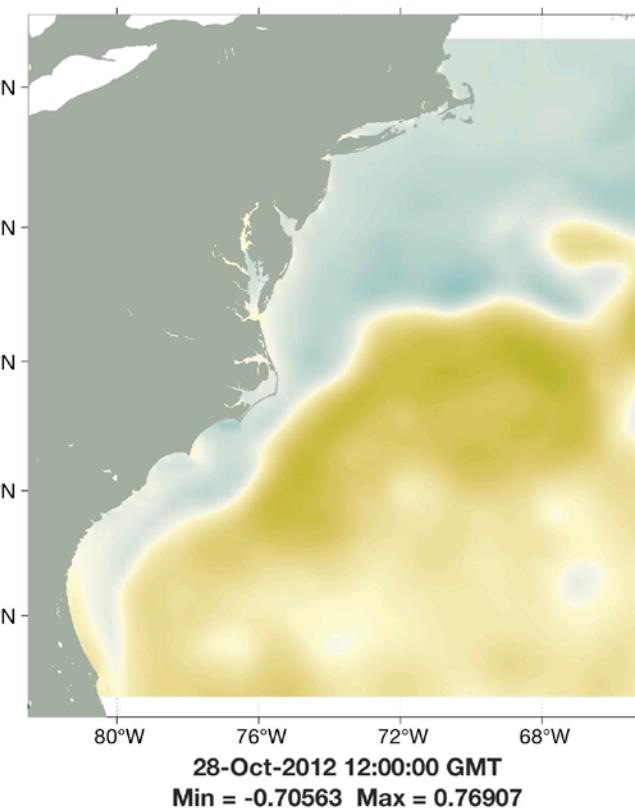
COAWST MCT Coupling: 180 s  
**ATM SBL**

# Free-Surface Comparison (m)

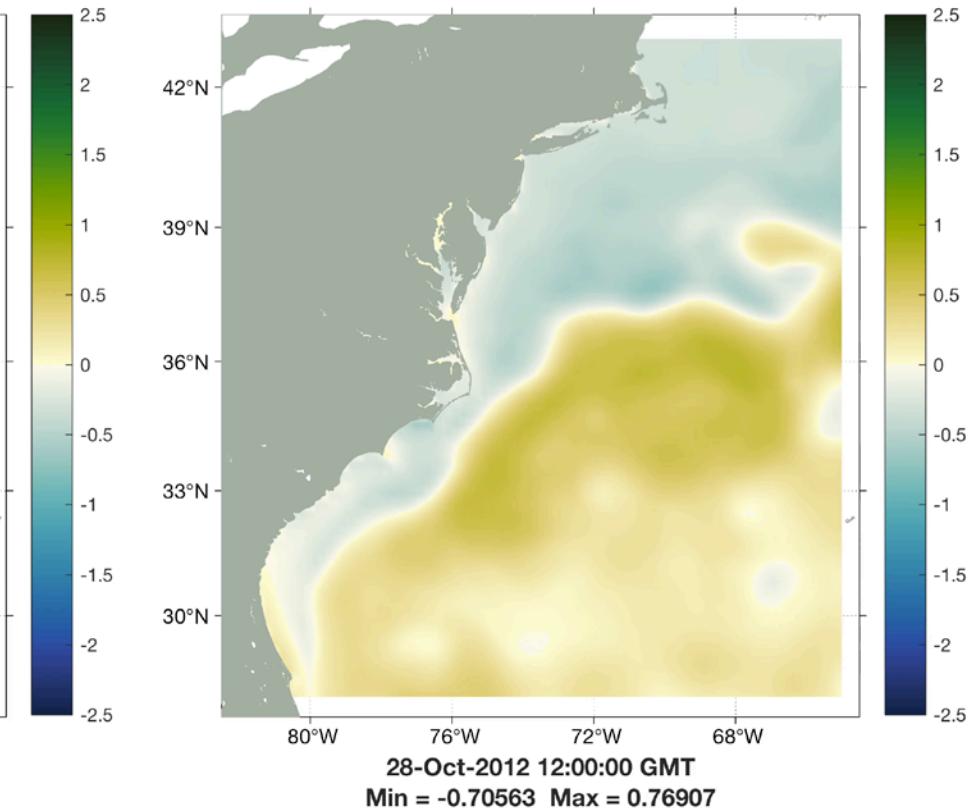
DATA-WRF-ROMS  
No Nesting



DATA-WRF-ROMS  
No Nesting



WRF-ROMS  
Nesting



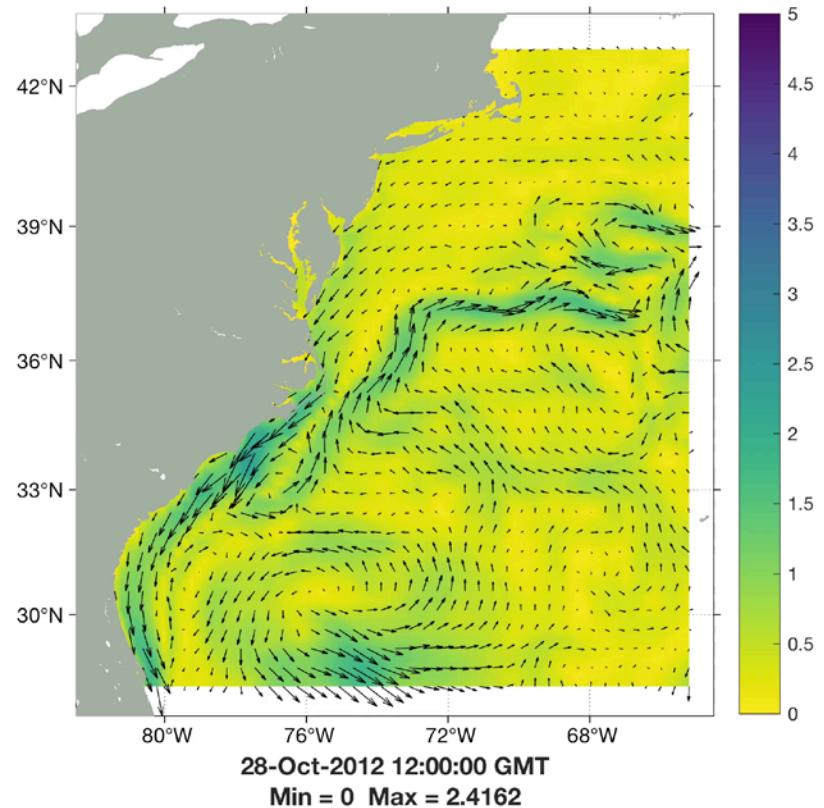
ESMF Coupling: 180 s  
**BULK\_FLUXES**

ESMF Coupling: 180 s  
**ATM SBL**

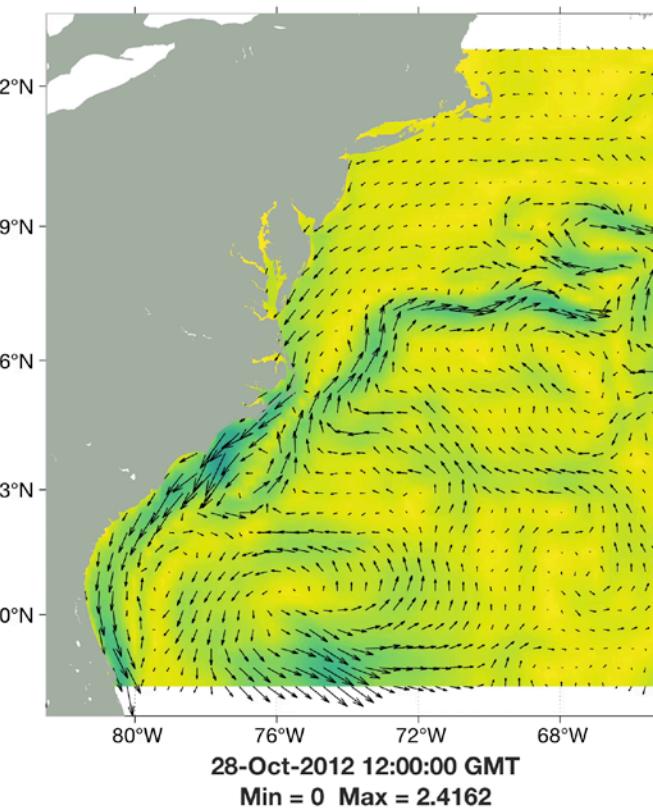
COAWST MCT Coupling: 180 s  
**ATM SBL**

# Surface Current Comparison (m/s)

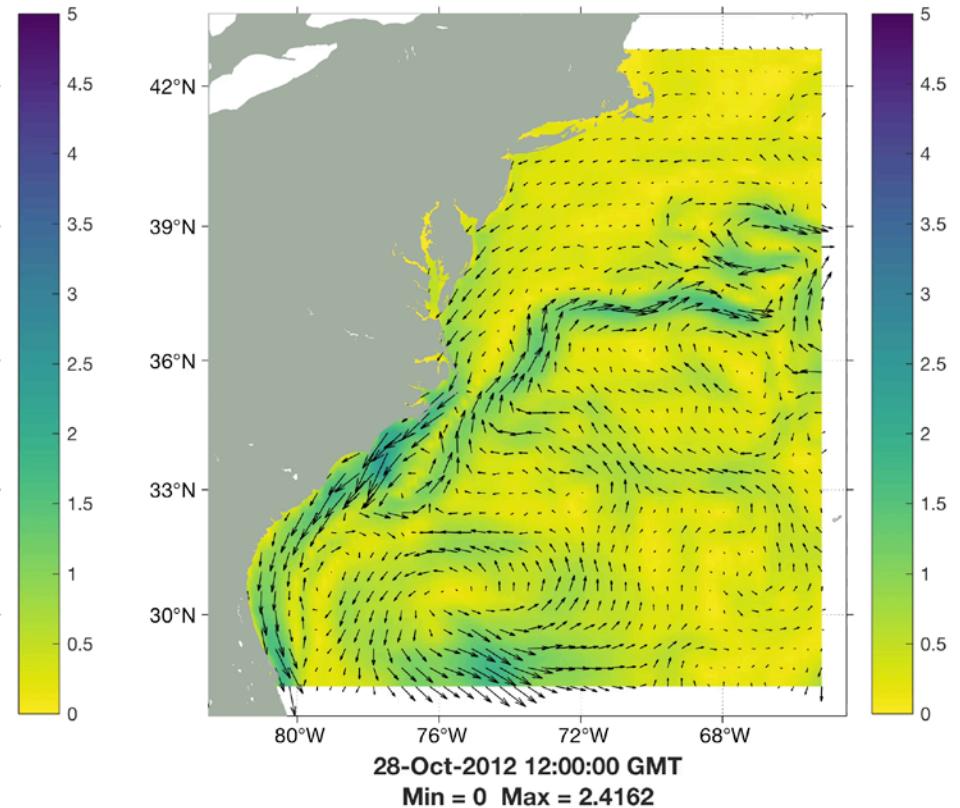
DATA-WRF-ROMS  
No Nesting



DATA-WRF-ROMS  
No Nesting



WRF-ROMS  
Nested



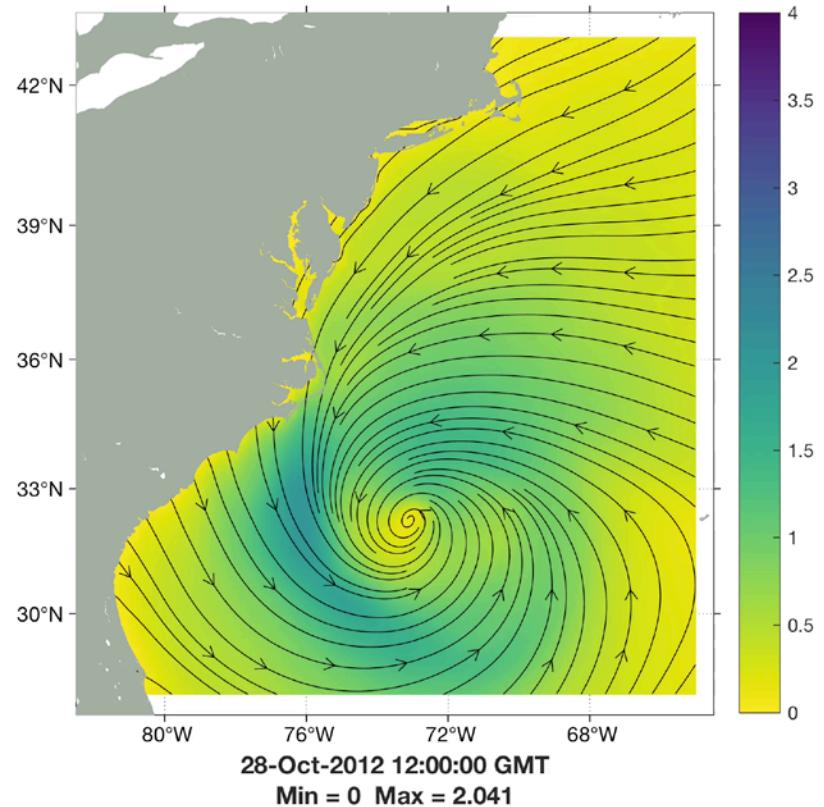
ESMF Coupling: 180 s  
BULK\_FLUXES

ESMF Coupling: 180 s  
ATM SBL

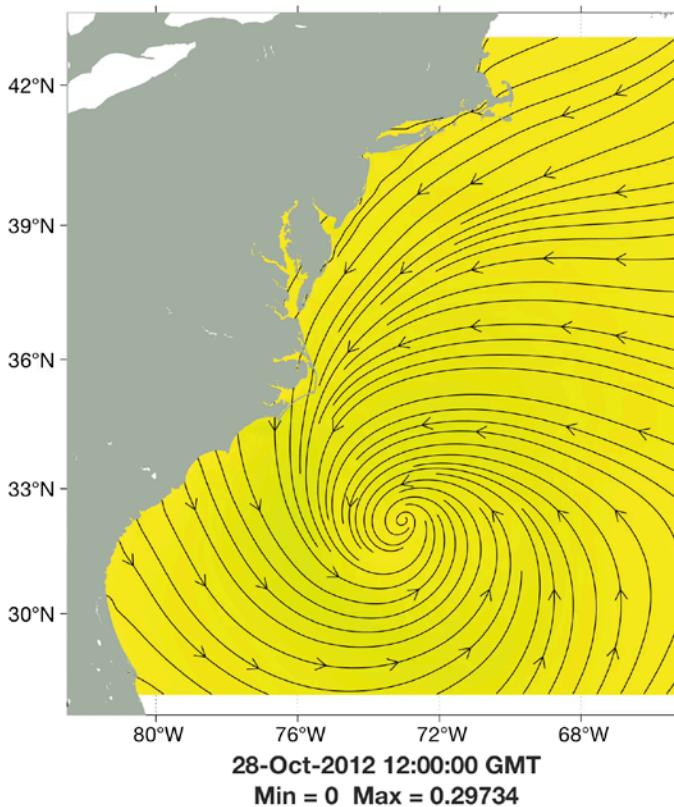
COAWST MCT Coupling: 180 s  
ATM SBL

# Surface Wind Stress Comparison ( $\text{N/m}^2$ )

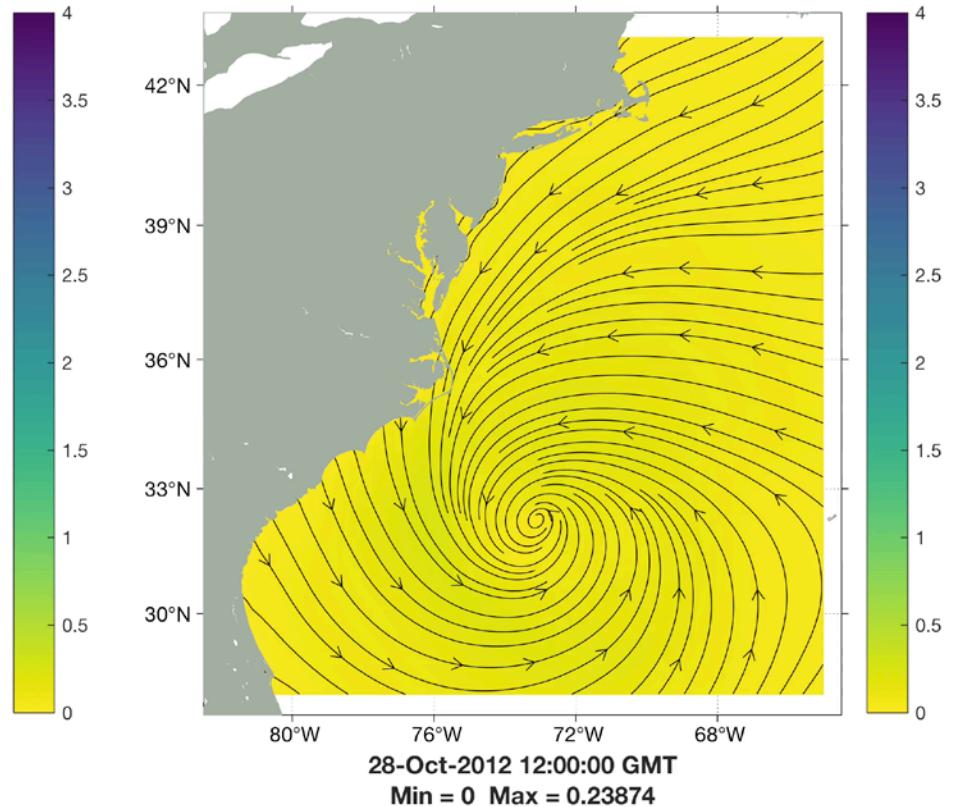
DATA-WRF-ROMS  
No Nesting



DATA-WRF-ROMS  
No Nesting



WRF-ROMS  
Nested

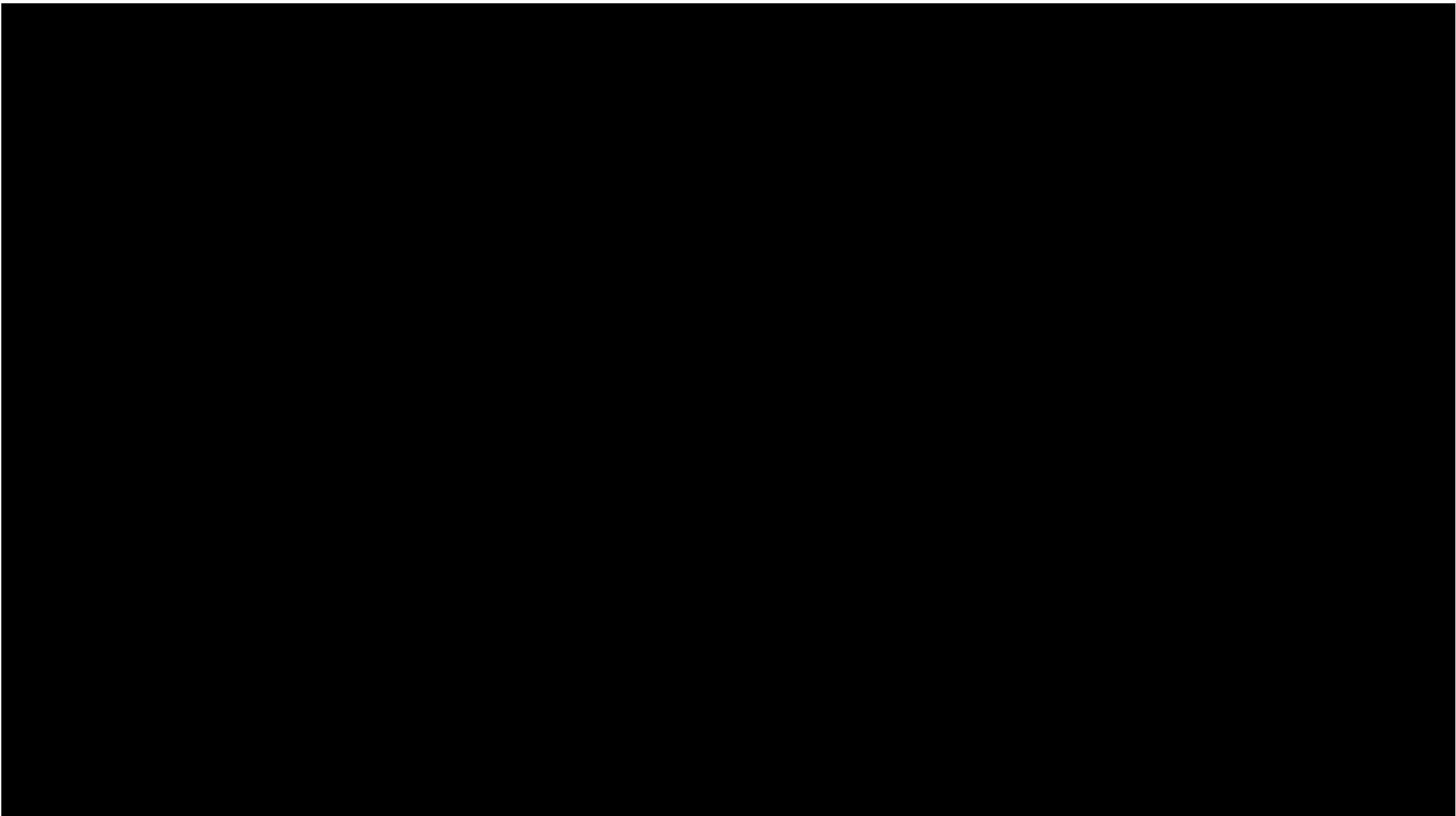


ESMF Coupling: 180 s  
**BULK\_FLUXES**

ESMF Coupling: 180 s  
**ATM SBL**

COAWST MCT Coupling: 180 s  
**ATM SBL**

# NASA GEOS-5 Global Atmosphere Model: Oct 26-31, 2012



# NASA GOES Satellites: Hurricane Sandy 23-31 October 2012



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**Thank you!**