Technical Summary and Progress Report for a coupling WRF and ROMS model using ESMF library

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This document aims to give brief introduction about preliminary results of the coupled ROMS (**R**egional **O**cean **M**odeling **S**ystem[1]) and WRF (**W**eather **R**esearch and **F**orecasting[2]) models using ESMF library. The compute environment that is used in this study is NCAR's Bluefire cluster (operating system is **AIX** and used compiler is **IBM XL**).

The content of this document divided into three sections. The first section contains a summary of the ROMS model related studies such as bug fixes, modifications and etc. The second section contains the similar information as previous one but in this case model is WRF. Finally, in the last section summarizes the generating SCRIP[3] weight files, preparing initial and lateral boundary conditions for both model, preliminary results of the coupled system and conclusions.

1 ROMS

1.1 Requirements

In this study, the ROMS with SVN revision number **382** is used. The listed modifications can be also valid for later versions of ROMS but in this case, additional modifications and fixes can be required. In this study, the ROMS model is compiled with ESMF version **3.1.0rp2**.

1.2 Modification and Bug Fixes

The following table summarizes the modifications and bug fixes to enable ESMF coupling in ROMS model. The ROMS model contains all necessary files (except atmospheric model and coupler components) to couple WRF and ROMs models. The reader must also note that the table is not in the actual order of the modification that has to be done.

No	File Name	Type	Comments
1	ROMS/Utils/abort.F and Master/esmf_coupler.h	Bug	The subroutine gives error, as Number of arguments is not permitted for the INTRINSIC procedure "abort". because Fortran has intrinsic function with that name. The problem can be solved with renaming file name and the subroutine name (must be same with filename). The error message can be different in other platforms. The older "abort" subroutine calls are also replaced with that new subroutine name in Master/esmf_coupler.h file.
2	Compilers/AIX-	Modification	The location of WRF model specific object files

[1] http://www.myroms.org/index.php

[2] http://www.mmm.ucar.edu/wrf/users/

[3] http://climate.lanl.gov/Software/SCRIP/

	xlf.mk or other platform specific file		and libraries must be defined in here. The newly created Master/esmf_wrf.F specific compile time definitions is also placed in here.
3	Master/esmf_wrf.F	Created	This module is created to handle WRF specific init, run and finalize methods. It is already defined in use section of Master/esmf_coupler.h but it does not exist as file in ROMS source tree and the error "Unable to access module symbol file for module esmf_wrf. Check path and file permissions of file. Use association not done for this module." occurs in compile time. It also handles creating of ESMF arrays for ESMF states to exchange fields with ROMS.
4	ROMS/Nonlinear/main3d.F	Bug	Using ESMF_LIB and WRF_COUPLING combination causes the following error message ""main3d.f90", line 28.11: 1513-119 (S) Identifier ocn2atm_coupling appeared in a USE statement but is not publicly accessible from this module.". The reason of the error is empty ocean_coupler.f90 file and non-existing definition of ocn2atm_coupling. This routine is necessary for ocean_coupler.F and MCT coupling. It basically contains subroutines for accruing data between atmosphere and ocean components. The MCT_LIB CPP definitions added into code just after AIR_OCEAN definitions.
5	Master/esmf_roms.F	Bug	The changed ESMF interface causes the following error ""esmf_roms.f90", line 523.36: 1513-068 (E) Argument keywords may only be used for procedures with an explicit interface. The keyword will be ignored." ESMF_StateAdd must replace all ESMF_StateAddArray CALLs.
6	Master/esmf_roms.F	Bug	The esmf_roms.f90 gives error, as "Argument keyword "mpicomm" does not match a dummy argument specified in the explicit interface for procedure "roms_initialize"". The first argument must be replaced by logical variable (defined in the beginning of the routine as variable "first") that is value set to TRUE because first argument is defined as intent INOUT in ROMS_initialize routine.
7	ROMS/Modules/mod_coupler.F	Bug	The code gives following error on AIX and IBM XL compiler combination, "A variable declared in the scope of a module, config, that is of a derived type with default initialization, must have the SAVE attribute." and it can be solved adding "save" clause to all variable definitions that uses derived data types
8	ROMS/Drivers/nl_o	Bug	Using ESMF_LIB and WRF_COUPLING

	cean.h or other used driver routine or core		combination causes the following error message ""ocean_control.f90", line 42.11: 1513-119 (S) Identifier initialize_ocn2atm_coupling appeared in a USE statement but is not publicly accessible from this module.". The reason same with bug **#4** and it can be solved with same way.
9	Master/esmf_roms.F	Bug	The error message is ""esmf_roms.f90", line 1.0: 1513-191 (S) A variable declared in the scope of a module, romsdistgrid, that is of a derived type with default initialization, must have the SAVE attribute." and it can be solved with same way that is described in bug **#8**.
10	Master/esmf_roms.F	Bug	The code gives ""esmf_roms.f90", line 385.19: 1516-064 (S) Operands to the == operator must be compatible with the intrinsic uses of the operator, or with a specific interface within an accessible defined operator generic interface." and user can solve it by deleting equality to zero because Master definition is in logical data type.
11	Master/esmf_roms.F	Bug	The error ""esmf_roms.f90", line 505.16: 1513-062 (S) Generic procedure reference can not be resolved due to incorrect actual argument attributes." is generated by incorrect argument definition of ESMF_ArrayGet CALLs. The farrayPtr= must be added at the beginning of the pointer argument in all ESMF_ArrayGet CALLs.
12	Master/esmf_roms.F	Bug	The misspelling of field names SWrad and LWrad causes ""esmf_roms.f90", line 1060.46: 1514-088 (S) Invalid component name. "esmf_roms.f90", line 1114.46: 1514-088 (S) Invalid component name." errors. The solution is replacing swrad with srflx and lwrad with lrflx.
13	Master/esmf_roms.F	Bug	The subroutine parameter "MyRank" is same with module content and this causes following error "myrank to be accessed by use association, has the same name as another entity that has been referred to in this scoping unit. Use association will not be done.". Replace MyRank veriable in ROMS_PutExportData and ROMS_PutGridData with some other variable name such as localPet.
14	ROMS/Utility/inp_par.F	Bug	The model gives "MOD_COUPLER - Number assigned processors: 001not equal to spawned MPI nodes: 004" or similar error. To solve it, modify line 736 else if statement and replace 'waves' with 'atmos' if it is exist.
15	Master/esmf_coupler.h	Bug	In the gridded component initialization phase each component must be wait to each other. The

			coupled model internal clock calculation gives error because some PETs faster. The blockingflag=ESMF_BLOCKING argument is added to gridded component initialization calls. By this way, all PETs reach the clock calculations in same time and clock data are exists for each component.
16	Master/esmf_cpl.F	Created	This module is created to handle interpolation between ROMS and WRF models using SCRIP generated weights. ESMF uses these weights to create interpolated field data using SMM (Sparse Matrix Multiply). The interpolation from ROMS to WRF is called as forward and WRF to ROMS is called as backward.

17	Master/esmf_roms.F	Modification	The DistGrid definition of ROMS model is modified for SCRIP interpolation. The exclusive region must be exactly same dimension with SCRIP weight file to perform interpolation correctly. To solve the problem, modify deBlockList definition as,
			IF (tile .EQ. NtileI(ng)*NtileJ(ng)-1) THEN
			deBlockList(2,2,tile+1)=BOUNDS(ng)%Jend (tile)+2
			ELSE
			deBlockList(2,2,tile+1)=BOUNDS(ng)%Jend (tile)
			END IF
			and all **TLWidth, TUWidth, CLW_r, CUW_r, CLW_u and CLW_v** to zero.

18	ROMS/External/coupling.dat	Modification	**SST**, add offset (273.16d0) to convert form C to K because ROMS export in C and WRF needs K. **Pair**, add scale (0.01d0) to convert from Pa to hPa or mb. **rain**, add scale (0.1d-6) to convert from mm/s to m/s.
19	Master/esmf_roms.F	Bug	The ROMS gives following error when it tries to exchange the import states, MP_EXCHANGE2D - communication buffer too small, EWsize = 957 501 To solve this problem, modify following lines in ROMS_GetImportData routine, **LBj=BOUNDS(ng)%LBi(MyRank)** **UBj=BOUNDS(ng)%UBi(MyRank)** as, **LBj=BOUNDS(ng)%LBj(MyRank)** **UBj=BOUNDS(ng)%UBj(MyRank)**
20	coupling.dat	Modification	Latent heat and sensible heat variables are added
21	esmf_roms.F	Modification	Latent heat and sensible heat variables are added

* **Note:** some of bugs can be related with compiler or operating system!

1.3 Other Issues

The following list of comments can be used to prevent possible errors that come form ROMS model and ESMF coupler.

- User must set TIME_REF parameter in ROMS ocean configuration file (such as, ocean.in) to use Gregorian calendar. If it is in default value (0.0), the model can be give error about setting ESMF clocks properly. In coupled model, all clock calendars must be same and with this way it can be set to ESMF_CAL_GREGORIAN. This is necessary to compare time interval or other clock variables. Otherwise ESMF throw error messages like "Invalid argument, calendar required for both time interval arguments". The get_date.F file is also modified to get correct time limits from model.

- The number of CPU that is allocated to each modeling component can be defined with coupler.in file and the sum of these CPU counts must be total number of CPU that is defined in coupled ROMS+WRF run job submission file. The ESMF gridded component initialize routine distributes all PETS into each component in a way that defined in couple.in (coupler configuration file). For example, to run coupled model in 4 CPU user must define Nthreads(ocean) = 2 and Nthreads(atmos) = 2 in coupler.in and set tiles parameter in ocean.in as NtileI == 1 and NtileJ == 2.

- Each gridded component runs on different set of PETs. For example, the coupled model runs on 4 PETs (0, 1, 2, 3) and coupler distribute these PETs based on values that are found in coupler.in file. If number of PET is set to 2 for each gridded component and ocean component gets 0,1 PETs and atmospheric component gets 2, 3 PETs. General structure of the design can be seen in Figure 1.

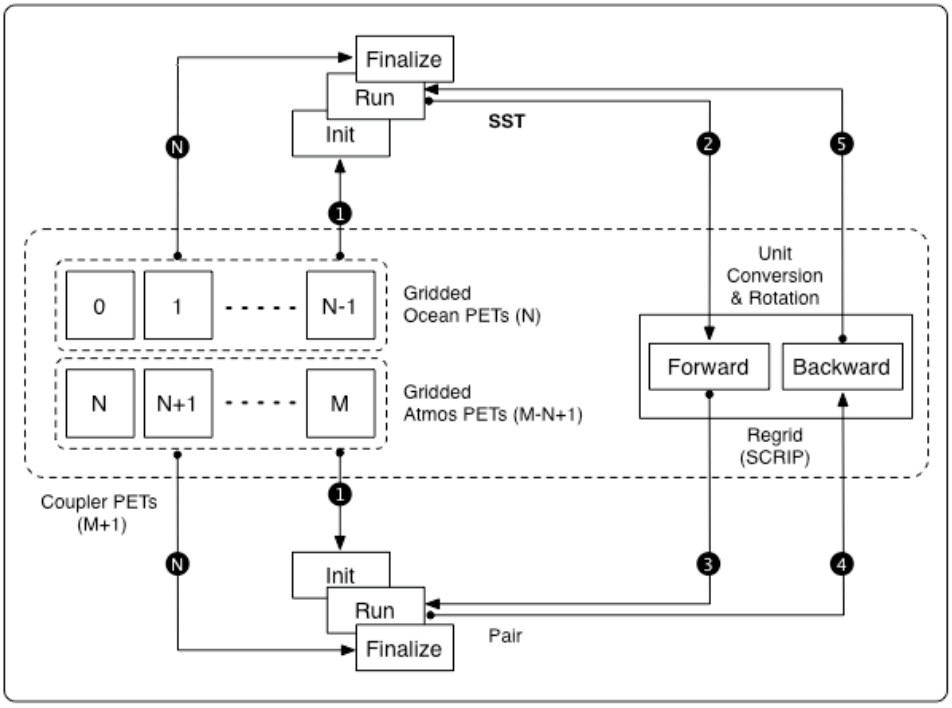

Figure 1 General design of coupled system

- Using different PETs for each gridded component triggers a problem of sharing clocks of each gridded component clocks between different PETs. To have consistent view of clock information the gridded component start time, stop time and time step is pack into an integer array and this array is sent to PETs (using ESMF_WMSend and ESMF_VMRecv routines) that do not have other gridded components clock information. Using these time values, component can create the other components clocks. This is required because ROMS used all gridded component clock information to calculate coupler component clock. The readers note that this problem only appears in ESMF 3.0.1rp2 because there is no way to attach time information into component state object as attribute. The StateReconcile method does not distribute attribute information that is attached into state. In ESMF 4.0.0r, the StateReconcile method has extra flag to do that but in this study, ROMS and WRF are implemented with ESMF 3.0.1rp2.

- To create SCRIP weight file for ROMS, a new Fortran program is written to convert ROMS grid file to SCRIP formatted input grid. This file is used to create mapping weight between ROMS and WRF model. The current program only converts RHO (cell center) points of ROMS grid but future implementation will be contain grid generation capability for U and V points.

2 WRF

2.1 Requirements

The latest version of WRF (**3.1.1**) is used in this study. The WRF is compiled with experimental ESMF IO support using latest public release of ESMF (**3.1.0rp2**) because of the compatibility of WRF ESMF IO and ESMF.

2.2 Modification and Bug Fixes

The following table summarizes the modifications and bug fixes to enable ESMF coupling in WRF model.

No	File Name	Type	Comments
1	main/ wrf_ESMFMod.F	Bug	The file is replaced with newer version to support ESMF (**3.1.0rp2**). The main difference between old and new file is change nl_get_io_form_sgfdda calls to nl_get_io_form_auxinput9 and config_flags%sgfdda_inname variable to config_flags%auxinput9_inname.
2	Makefile	Bug	In NCAR's Bluefire machine (AIX) the build log file (./compile em_real >&log.build) contains following error. … ld: 0711-317 ERROR: Undefined symbol: .MPI_Wait ld: 0711-345 Use the -bloadmap or -bnoquiet option to obtain more information. make[2]: [diffwrf] Error 8 (ignored) make[2]: Leaving directory `/ptmp/turuncu/coupled/atm/WRFV3.1.1/extern

			al/io_int' modify Makefile framework target from FC="$(SFC) $(FCBASEOPTS)" to FC="$(FC) $(FCBASEOPTS)"

3	external/RSL_LITE/ module_dm.F	Modification	To enable rsl.out and rsl.error logging the following part else statement added into routine init_module_dm.
			…
			CALL wrf_set_dm_communicator (MPI_COMM_WORLD)
			ELSE
			CALL wrf_termio_dup
			ENDIF

4	phys/module_surface _driver.F	Modification	The coupler mainly exports SST data from ROMS to WRF to update the SST data in WRF but when ROMS domain smaller than WRF (in many case) and SST update option is enabled, some part of the WRF domain does not get SST data from ROMS model. In this case, these regions have missing SST value (or zero value) and this triggers the problem in calculation of WRF surface temperature and its related variables (such as Q2).
			
			To solve this problem, the WRF surface driver code is modified. If the SST data in specific water point is below than zero then the SST data in that point will be assigned using TSK (surface temperature). By this wat the missing SST values can be filled. In "! Update SST" section of code, do following
			! IF (XLAND(i,j) .GT. 1.5) THEN
			IF ((XLAND(i,j) .GT. 1.5) .AND. (SST(i,j) .GT. 250.0)) THEN
			TSK(i,j) =SST(i,j)
			TSLB(i,1,j)=SST(i,j)
			ELSE
			SST(i,j) =TSK(i,j)
			ENDIF

5	namelist.input	Edit	If coupler component WRf gives following error, ---------- FATAL CALLED ---------- > ext_esmf_open_for_write: export state not empty, io_esmf is currently > limited to only one auxhist stream Increase the following parameter or other that is used for ESMF-IO (the default value is 10), **frames_per_auxhist5 = 100000,** This is a bug in WRF-ESMF-IO.
6	namelist.input	Edit	Set

To exchange fields with ROMS using ESMF-IO, the import and export fields must be entered into Registry/Registry.EM file (see Table 1) and WRF must be compiled with ESMF-IO support. The ESMF-IO creates ESMF Arrays and attaches them into import and export states automatically. The interval to exchange fields with other ESMF components is also defined in WRF namelist.input file but in this implementation the ROMS parameter is used to define coupling interval.

Table 1 Registry file modifications

```
state   real  Q2          ij    misc      1       -    irh05d     "Q2"              "QV at 2 M"        "kg kg-1"
state   real  T2          ij    misc      1       -    irh05d     "T2"              "TEMP at 2 M"      "K"
state   real  PSFC        ij    misc      1       -    i01rh05d   "PSFC"            "SFC PRESSURE"     "Pa"
state   real  U10         ij    misc      1       -    irh015d    "U10"             "U at 10 M"        "m s-1"
state   real  V10         ij    misc      1       -    irh015d    "V10"             "V at 10 M"        "m s-1"
state   real  SST         ij    misc      1       -    i01245rhd=(interp_mask_water_field:lu_index)  "SST"          "SEA SURFACE
TEMPERATURE" "K"
state   real  PRATEC      ij    misc      1       -    rh05       "PRATEC"          "PRECIP RATE FROM CUMULUS SCHEME"
"mm s-1"
state   real  GSW         ij    misc      1       -    rh05d      "GSW"             "NET SHORT WAVE FLUX AT GROUND SURFACE"
"W m-2"
state   real  GLW         ij    misc      1       -    rh05d      "GLW"             "DOWNWARD LONG WAVE FLUX AT GROUND
SURFACE"          "W m-2"
state   real  HFX         ij    misc      1       -    rh05       "HFX"             "UPWARD HEAT FLUX AT THE SURFACE"          "W m-2"
state   real  LH          ij    misc      1       -    rh05       "LH"              "LATENT HEAT FLUX AT THE SURFACE"          "W m-2"
```

3 Conclusion

3.1 Information about Design/Implementation

The general design of coupled atmosphere-ocean modeling system (see Figure 1) contains three different components and one main driver code. The components are the atmospheric model, ocean model and coupler component, which provide interpolation (via SCRIP weights), unit conversion and rotation of the wind components between different gridded components.

In WRF side, the ESMF-IO capability is used to create import and export states for exchanging data between gridded components through coupler component. The variables that are exported from atmospheric model can be seen in registry file content (Table 1). The ESMF-IO is similar to conventional IO methods but it creates the ESMF fields and attaches them into a ESMF state object rather than writing to a output file. The ESMF-IO is still in development phase but in this study it works as it is expected.

As it discussed before, the SCRIP generated weight files are used to perform interpolation between gridded components. The SCRIP needs the grid representation of each gridded component in a special structured file. The file is in NetCDF type and it contains information about each cell (cell corner locations, cell area and cell mask value). To generate this file from conventional ROMS and WRF grid files, two additional Fortran program are added into SCRIP/grid directory. The current versions only support RHO points in ROMS model and mass points in WRF. Using these grid files SCRIP is used to generate two mapping files (WRF→ROMS and ROMS→WRF) between grids.

The SCRIP tool can create mapping weights for bilinear, bicubic, distance weight and conservative interpolation methods but only distance weight interpolation is worked in this study because SCRIP tool is not designed to work with regional models. To create much more accurate mapping weights the SCRIP tool is modified.

For the debugging purpose, the **WriteCouplingFields** flag (esmf_cpl.F) can be activated to write out fields of forward and backward coupling stages to check the interpolation results. If this flag is set to **TRUE** the coupling fields are written into NetCDF files based on PET number and

coupling direction. This flag must be set as FALSE in higher PET count and long simulations because each PET will be write it's own part to the separate NetCDF file. This effects the overall model performance and disk usage very badly.

3.2 Use case

The coupled modeling systems are widely used to study effects of climate change in a global scale and the multi-component global circulation models (GCMs) are the main part of these studies. The one of the most important problem that the climate scientist have to deal, is their resolutions are very coarse to define or study regional effect of the climate change using dynamical downscaling approach. In this approach, the regional climate models (RCMs) are used to downscale the output of GCMs that based on specific IPCC SRES scenarios but the results show that the standalone RCMs and another approach is required to represent regional climate much more accurate.

To solve the problem that are mentioned before, the coupled regional atmosphere and ocean models can be used because of the needs of the climate change scenarios for impact studies in the basis of regional scale. Like GCMs, the coupled regional climate model can predict the behavior of regional climate adding earth system components into model.

To test newly designed coupled modeling system, the both model are configured to simulate Mediterranean region climate using CCSM IPCC AR4 output and dynamical downscaling approach. The test simulation length is 1 month and it uses 20C (b30.030e) CCSM data between 1999-07-01_00:00 and 1999-07-31_18:00. The atmospheric model internal time step is 180 s, the ocean model internal time step is 300 s and the coupling interval is chosen as 300 s between the models. The atmospheric model contains 210x144x27 grid points and ocean model has 319x159x32 grid points in horizontal and vertical.

As it can see in Figure 2, WRF model is forced by CCSM CAM and CLM component 6 hourly output data and initial and lateral boundary conditions for ROMS model is interpolated horizontally and vertically from CCSM POP component monthly data.

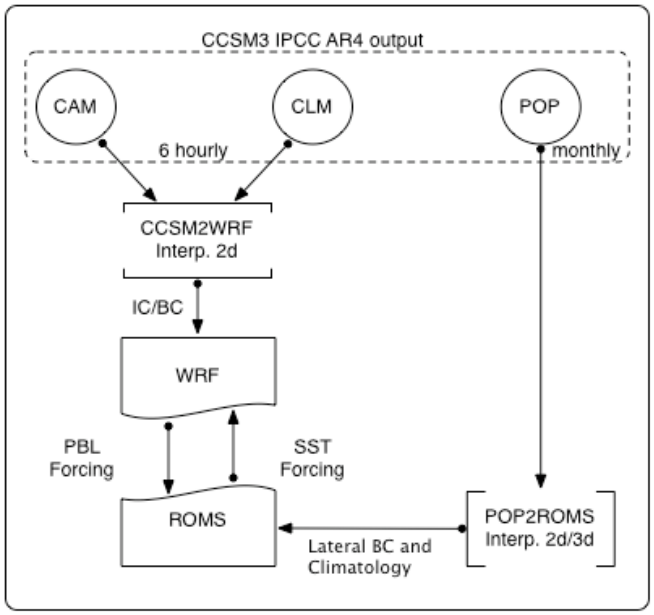

Figure 2 Design of use case

The domain setup for both models can be seen in Figure 3 and 4. The atmospheric model domain covers whole ocean model domain. For this reason, some of the regions (water points) in WRF model do not receive SST data from ocean model. To solve this problem, the missing SST data is replaced with surface skin temperature in WRF. In the future versions, these regions will be smoothed in the ocean model boundaries to prevent inconsistencies between SST and skin temperature data.

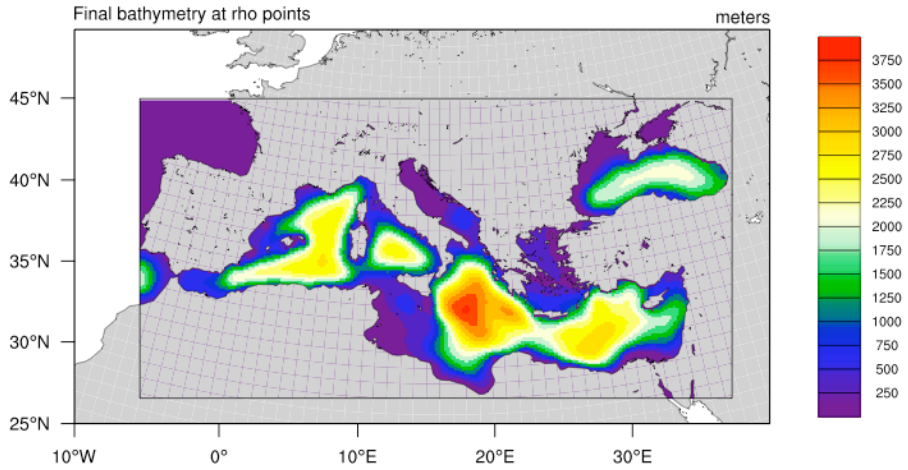

Figure 3 Domain and bathymetry data of ocean component (ROMS)

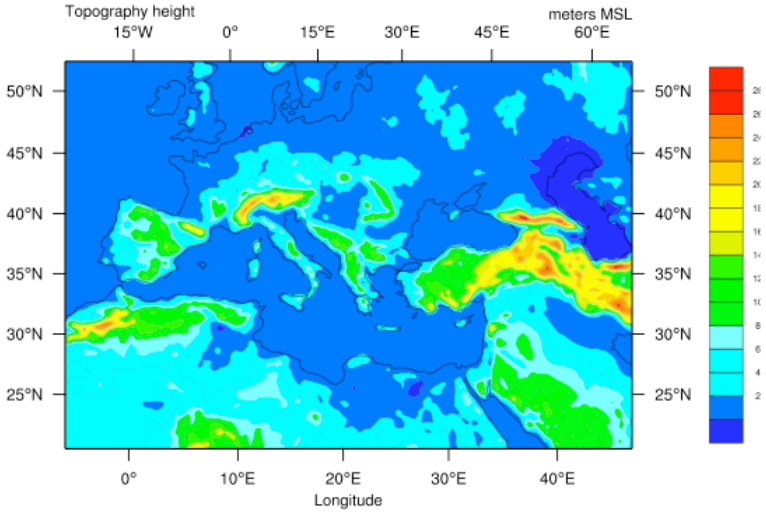

Figure 4 Domain and topography data of atmospheric component (WRF)

3.3 Initial Results

The following figures show the preliminary results of the coupled modeling system. The results of coupled modeling system are compared with standalone runs of the each gridded component model. The first figure (Figure 5) shows the comparison of runs at the beginning of the simulation. In this case, the ocean model is forced by output of the CCSM POP and CAM components and atmosphere model is forced by CCSM CAM and CLM output. The Figure 5a and 5b shows the results of the surface potential temperature in t=0 and Figure 5c and 5d show the sea surface temperature of atmosphere models. As it expected, the coupled and standalone models initial states are the same.

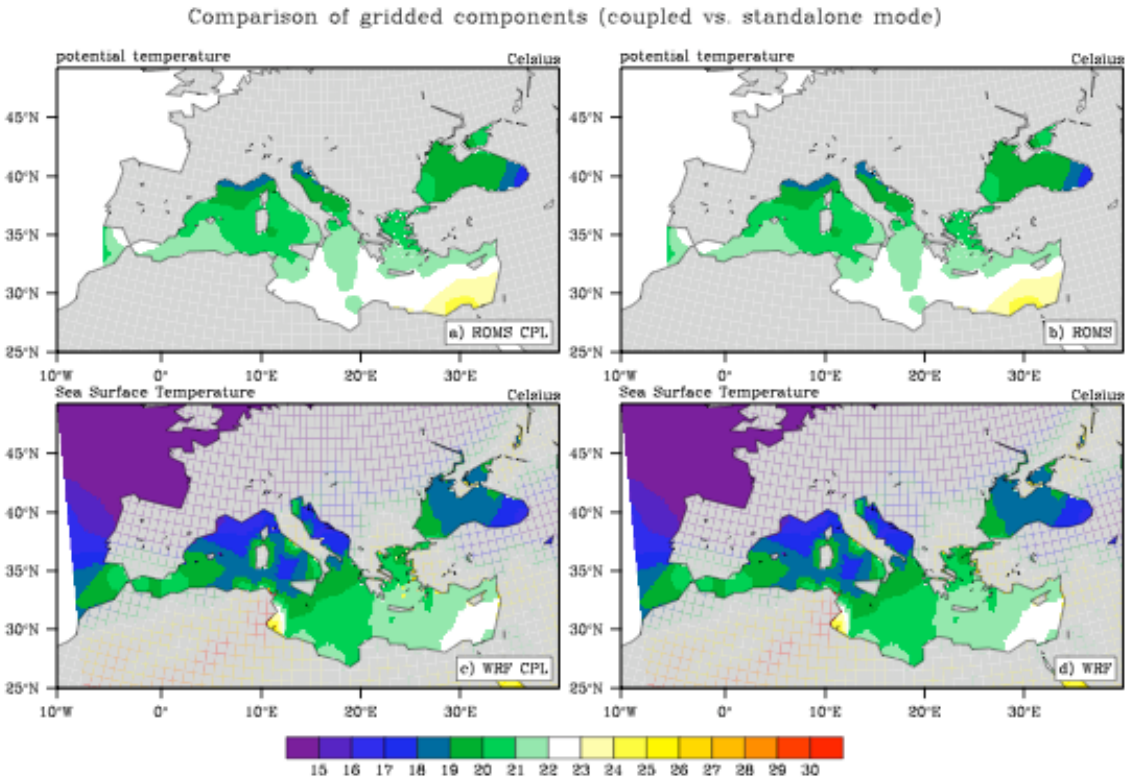

Figure 5 Comparison of gridded components (1999-07-01 00:00, SST vs. Potential Temperature)

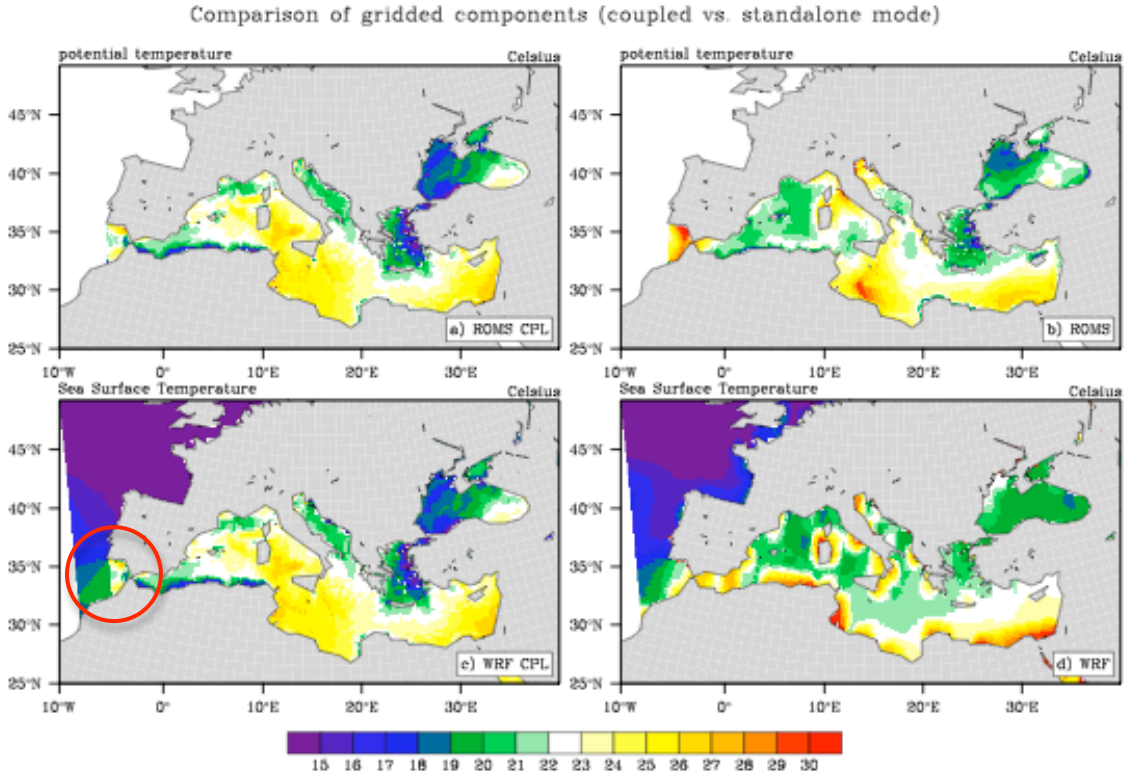

Figure 6 Comparison of gridded components (1999-07-15 00:00, SST vs. Potential Temperature)

The next figure (Figure 6) shows the gridded component results in coupled and standalone mode at 1999-07-15 00:00. The fields are the same with Figure 5. The results indicate that the sea surface temperature that comes from ocean model is correctly imported into atmospheric model.

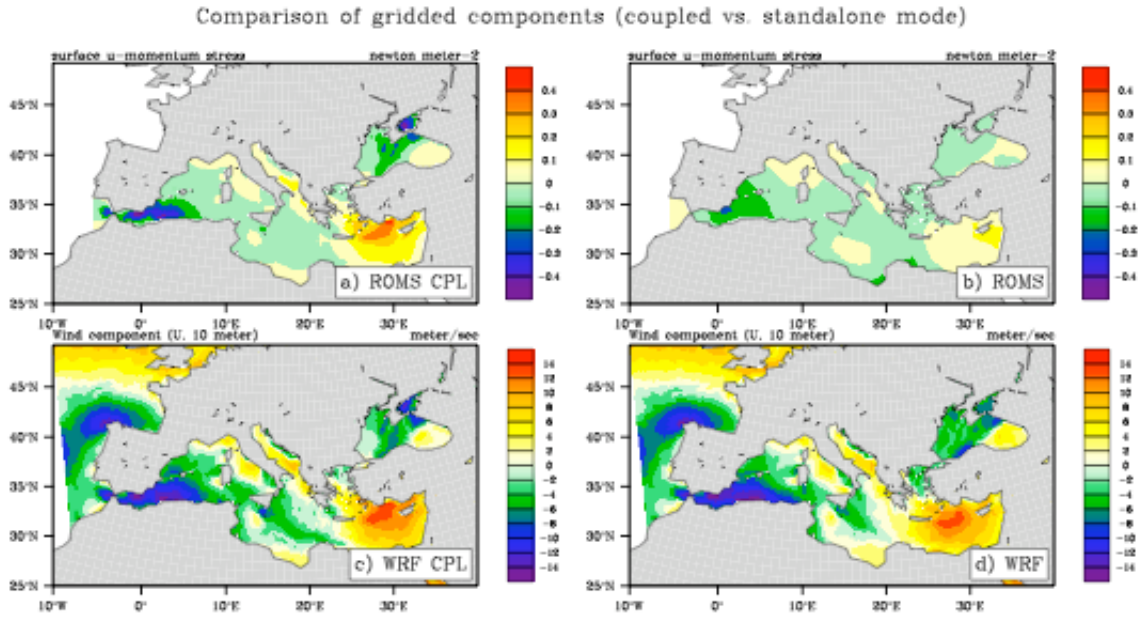

Figure 7 Comparison of gridded components (1999-07-15 00:00, U10 vs. ustr)

3.4 Restrictions and Comments

The following section contains the list of restrictions in the coupled modeling system. User needs to pay attention to the list before running coupled system.

- The coupler time step must be same with ROMS initial time step. This is required because there is no any interpolation routine (like using forcing file) between any successive ROMS time step. Otherwise ROMS model gives error like "Blowing-up: Saving latest model state into RESTART file". The coupling interval must be set to same value in also WRF namelist.input file because WRF ESMF-IO creates the ESMF States based on this value.

- In this version, the interpolation method is distance weight but the flux variables must be interpolated using conservative methods. This will be implemented in the future.

- In this case, there is a discontinuity zone in the near of Strait of Gibraltar (between Atlantic and Mediterranean Sea, see red circle on Figure 6c) because of the oceanic model domain does not cover whole atmospheric model domain. This will be corrected in the future versions. The correction can be made with applying simple filter into the ocean model boundaries.

- In this study the interpolation routine uses SCRIP generated weight files. Bu the interpolation can be done with using each model grid information and ESMF regrid capability without using SCRIP weights.