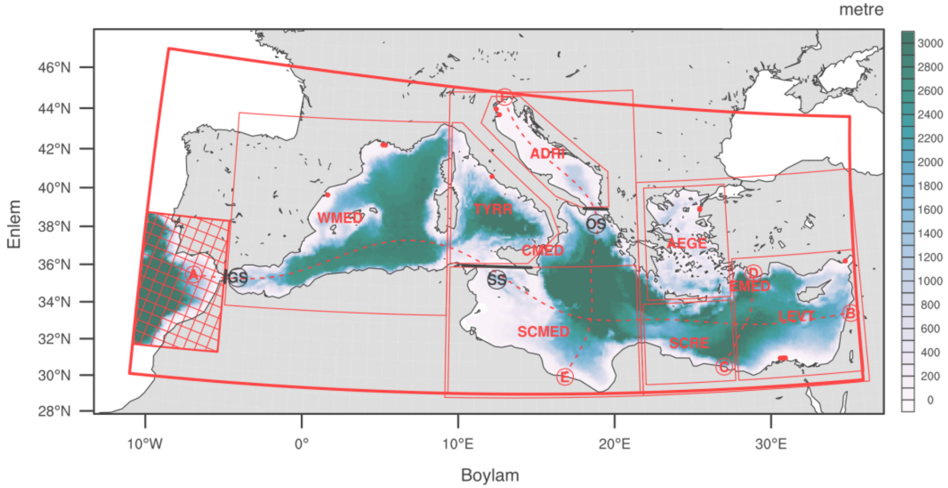

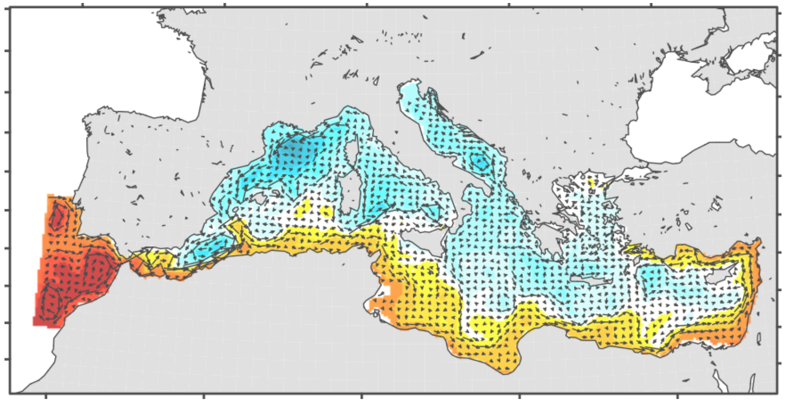

Recent developments in **RegESM** modeling system and plans to support higher resolution and multi-component applications

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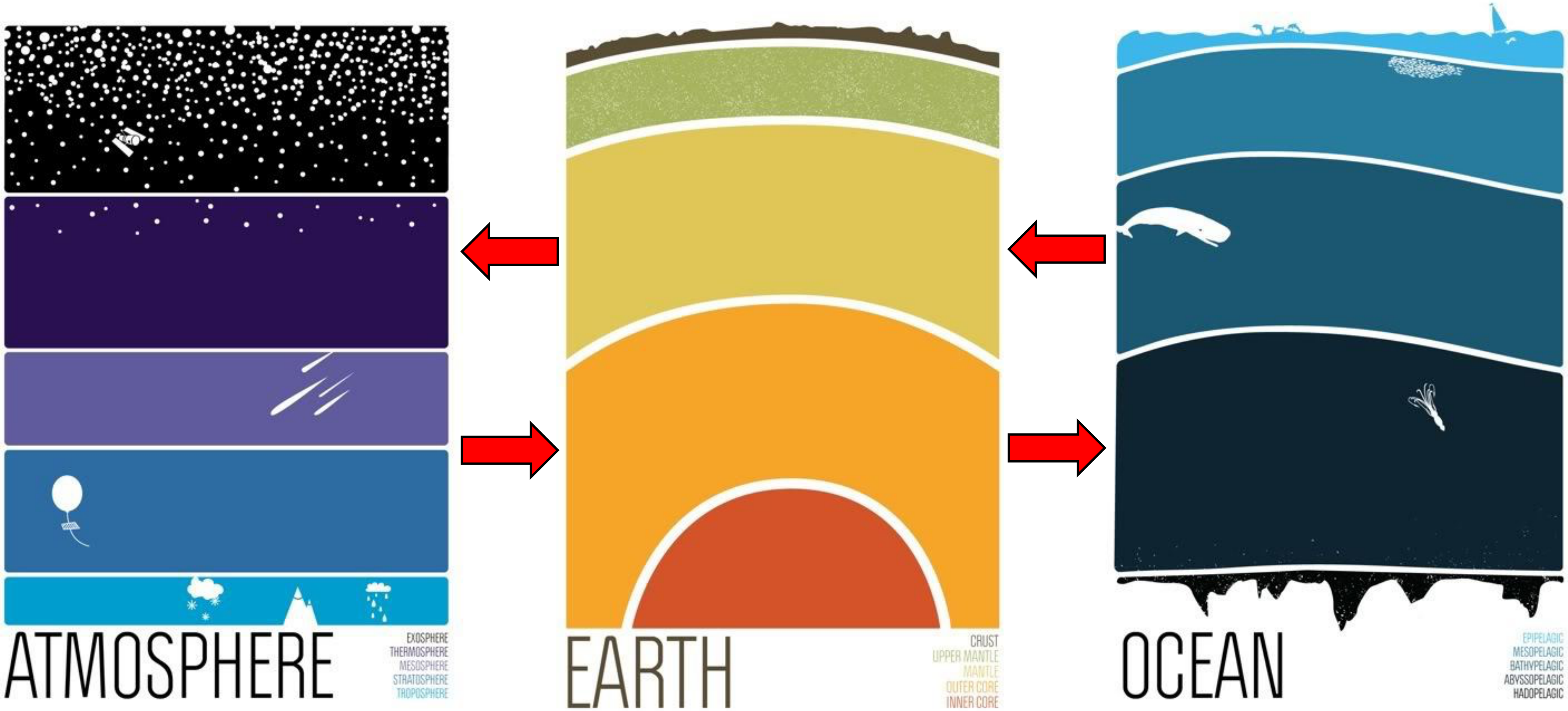
(2) ICTP, ESP Section

İTÜ INFORMATICS INSTITUTE

Eighth ICTP Workshop on the Theory and Use of Regional Climate Models | 23 May – 3 June 2016

Earth System

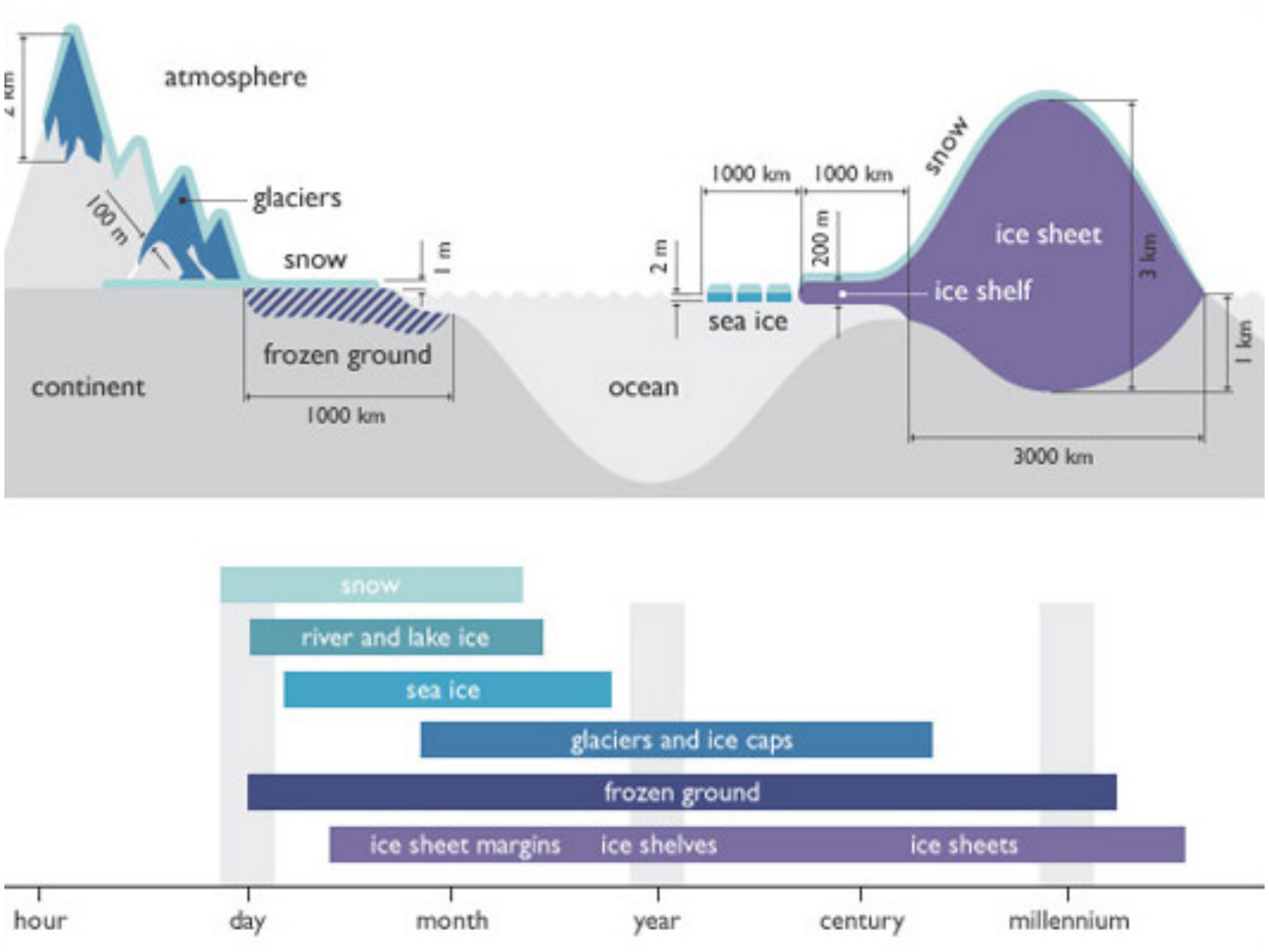
- It is represented by complex and non-linear interaction between different elements (atmosphere, hydrosphere, geosphere and biosphere).
- All the processes have different spatial and temporal scales



http://wearebrainstorm.com/products/earth-science-set-of-4-prints

Earth System …

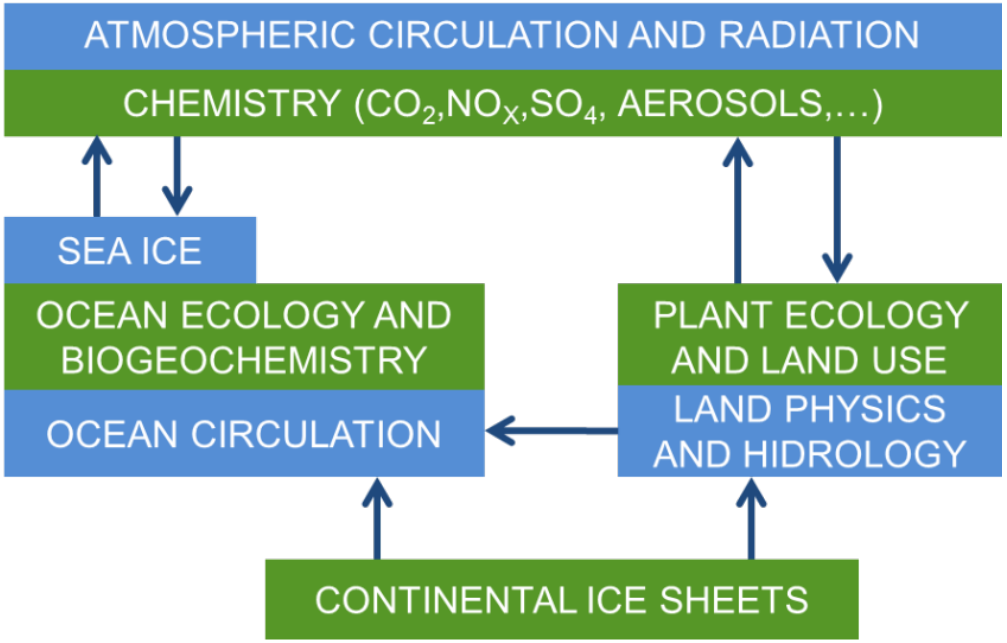
- All the processes have different spatial and temporal scales
- Response time under forcing also differs



IPCC Report

Earth System Models

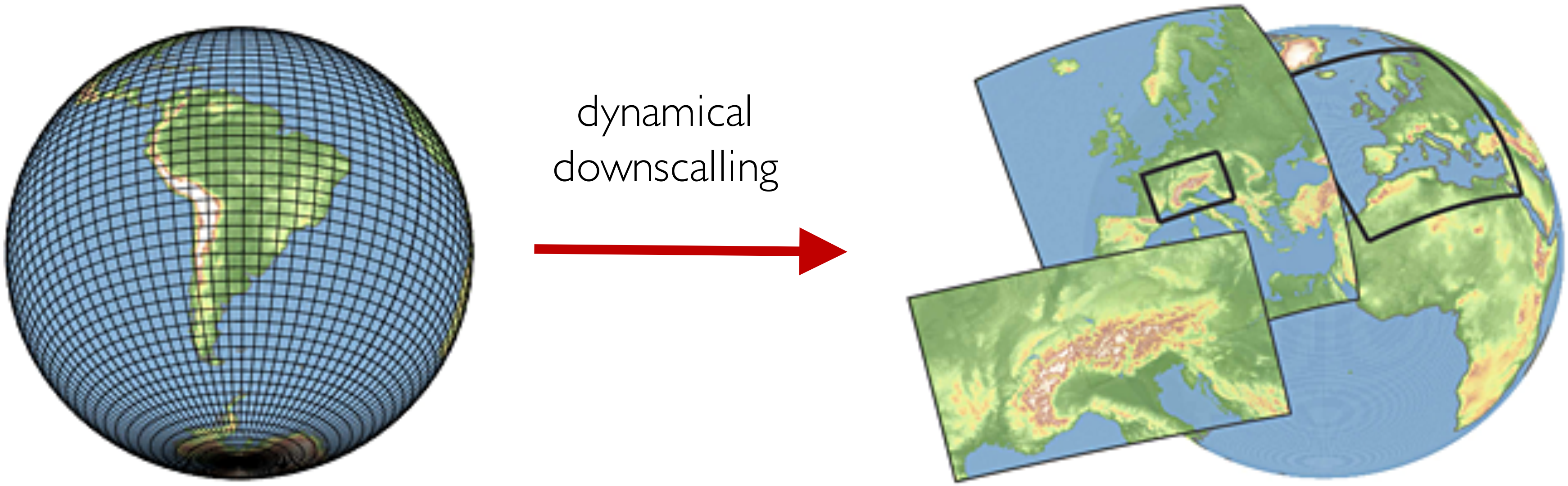
- Defines interaction between components to simulate the state of the climate system in regional and global scale
- ESMs include processes, impacts, and complete feedback cycles; for example, they can simulate droughts as well as the resulting change in plant cover due to the drought, which may lead to more or less drought (Heavens et al, 2013).
- Climate Model vs. Earth System Model



blue boxes represent the processes included in a **climate model**; green boxes represent the additional components that may be included in an **Earth System Model**

Regional Earth System Modeling (RESM)

- Higher resolution representation of physical processes
- Includes more sophisticated physical parameterizations and additional processes along with their non-linear interactions
- It might also include human behavior (pollution, irrigation etc.)
- Apart from the global ESMs, they require boundary condition (global ESMs, reanalysis datasets etc.), which adds extra complexity to the system



Prein et al., 2015 @ Reviews of Geophysics

RESM@ITU and @ICTP - History

Year	Description	Domains
2012	• No driver RegCM is hosting also ocean component • Single ocean model is supported (ROMS) • Poor mass and energy conservation for exchange fields • No automatized extrapolation (unaligned land-sea masks !!!) • Hard to include additional components such as river, wave etc.	Caspian Sea (Turuncoglu et al., 2013; GMD)

RESM@ITU and @ICTP - History

Year	Description	Domains
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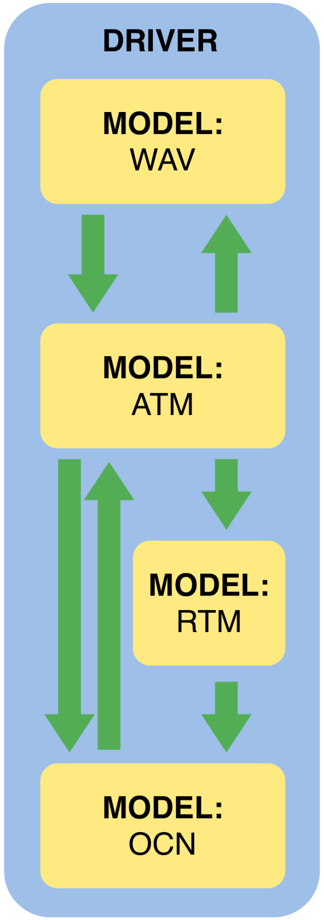
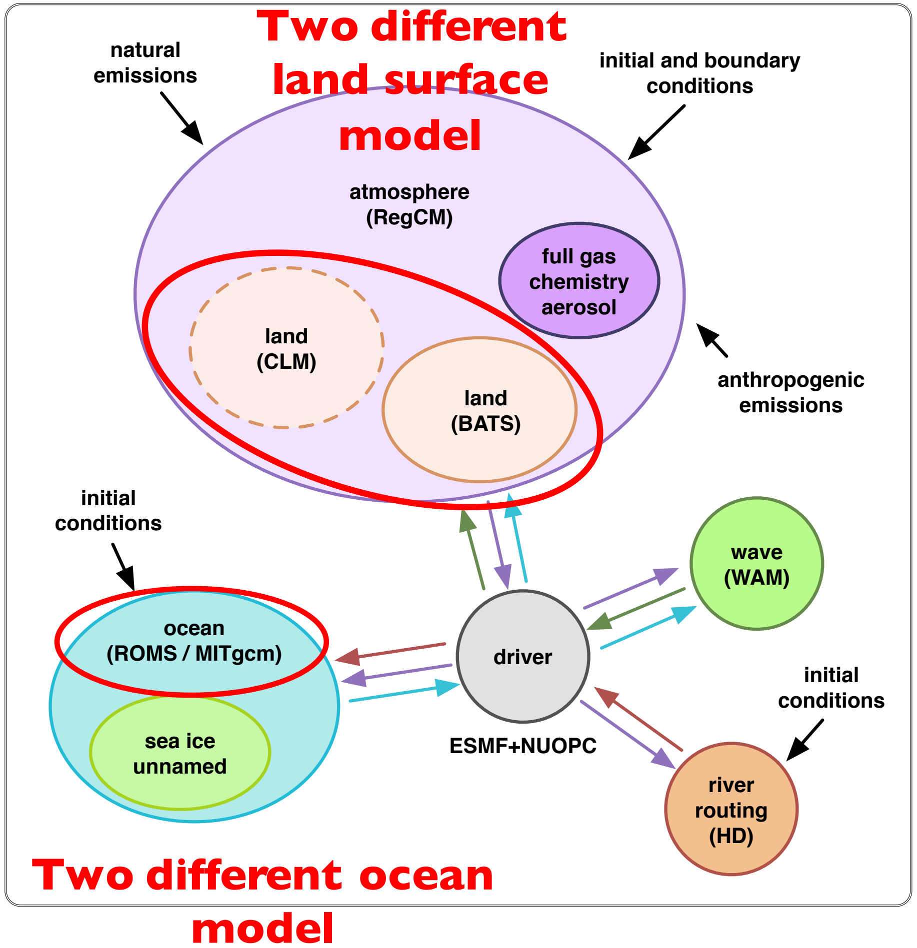
2013	• Centralized driver using ESMF's NUOPC layer (via connectors) • All components are plugged into the driver • Added support for two different ocean model component (ROMS and MITgcm) • Mass and energy conservation is improved via customized bilinear interpolation along with global conservation support • Support for extrapolation (unaligned land-sea masks) • River Routing (Max Planck's HD) component is included	Med. Sea
2014 2015	• The wave component (ECMWF's WAM) is included (Surenkok & Turuncoglu, 2015; EGU) • Extensive benchmarking (PRACE – 2010PA2442)	Med. Sea Black Sea
2016	• ESMF library is updated to 7.0.0 • Validation for Mediterranean domain (Turuncoglu & Sannino, 2016; CD – under revision) • Extensive validation with different configuration (2/3/4 component, different coupling intervals etc.) – paper is on-the-way	Med. Sea Caribbean Indian Ocean South Atlantic

RegESM Design

- Model components merged with ESMF/NUOPC





ATM:
ICTP's RegCM 4.4 / 4.5

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

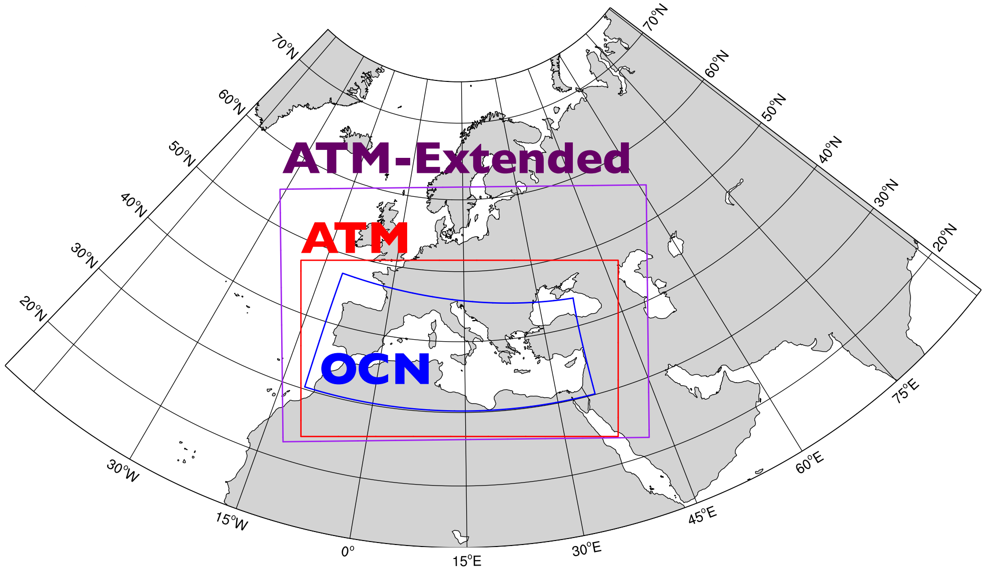
WAV:
ECMWF's WAM
4.5.3 MPI

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

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

Performance Benchmark @ PRACE

- Test with Mediterranean domain (Standard + Extended)



ATM: 12 km - 24 layer

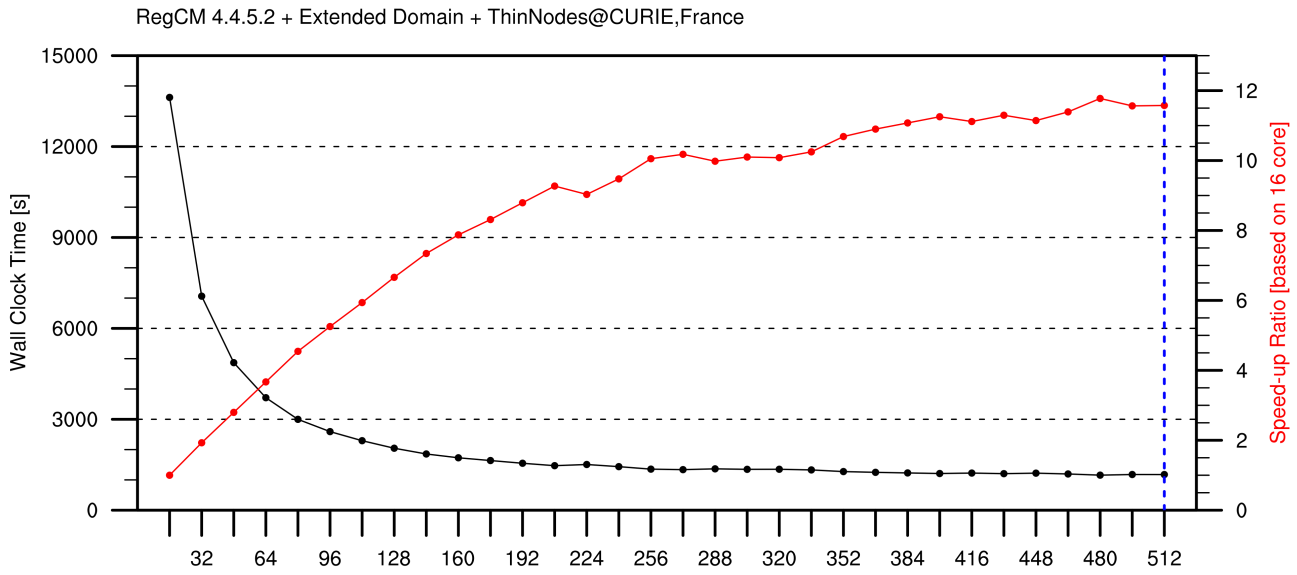
OCN: 1/12 deg. - 32 layer (ROMS)

extended domain is configured to feed the computational resources

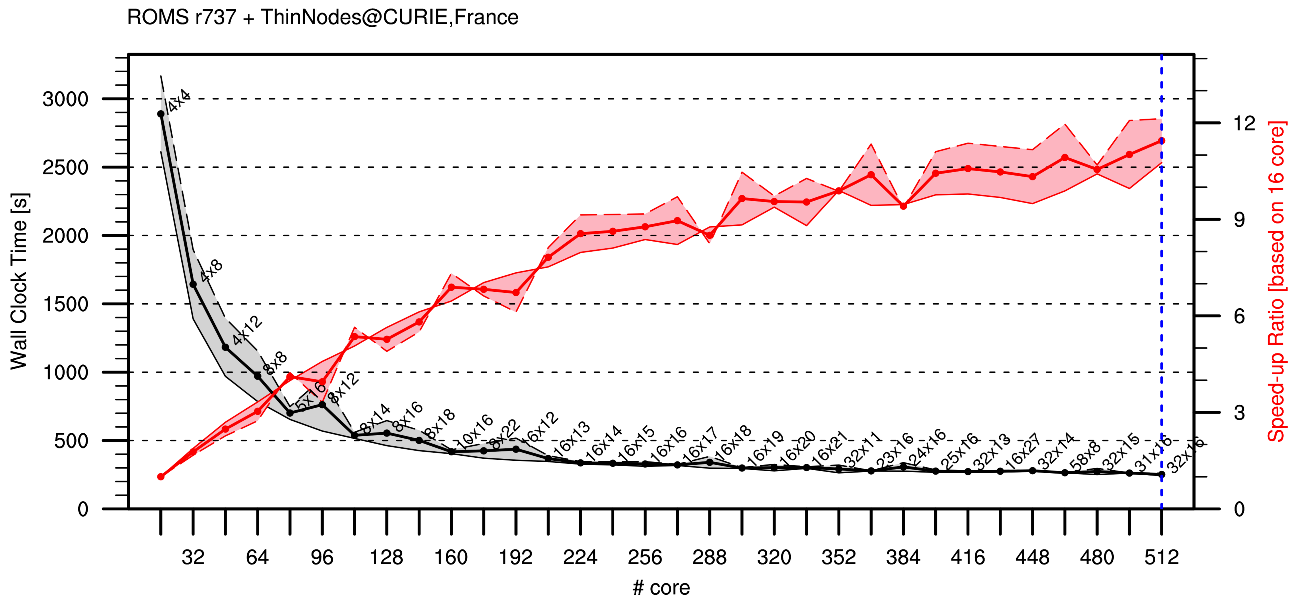
- Tests:
  - Different coupling interval (30 min., 1 hour, 3 hours)
  - Different execution type (sequential vs. concurrent)
  - Different number of component (ATM-OCN, ATM-OCN-RTM)
- Test Environment:
  - CURIE @ France (PRACE – 2010PA2442)

Performance Benchmark …

- Individual model components



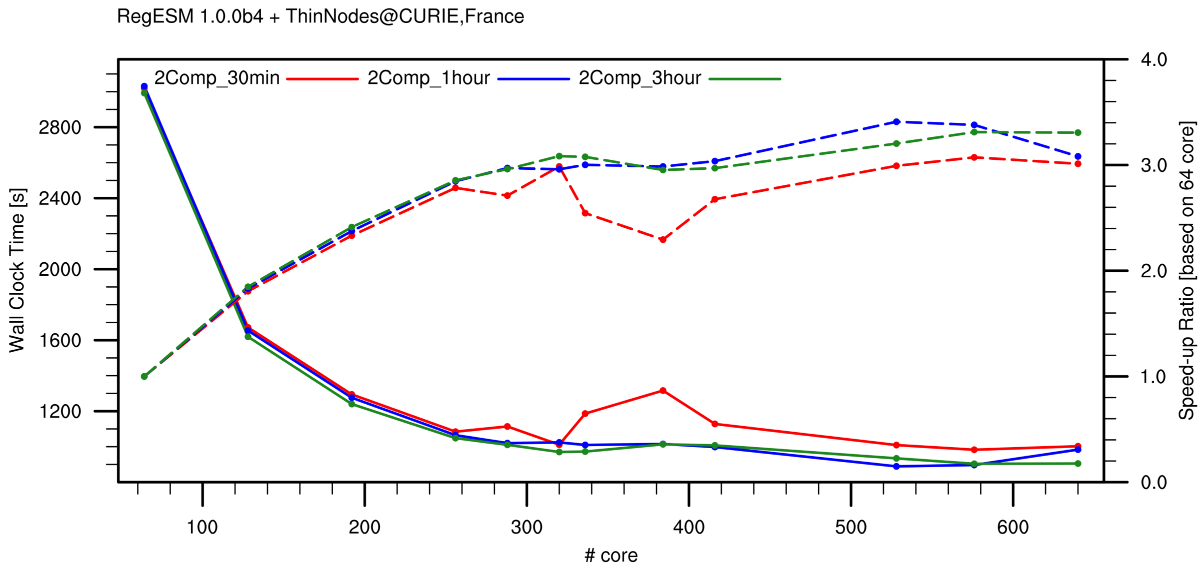
Better scaling results for extended domain



To find best 2d decomposition parameters for ROMS

Performance Benchmark …

- Coupling interval (only two component)

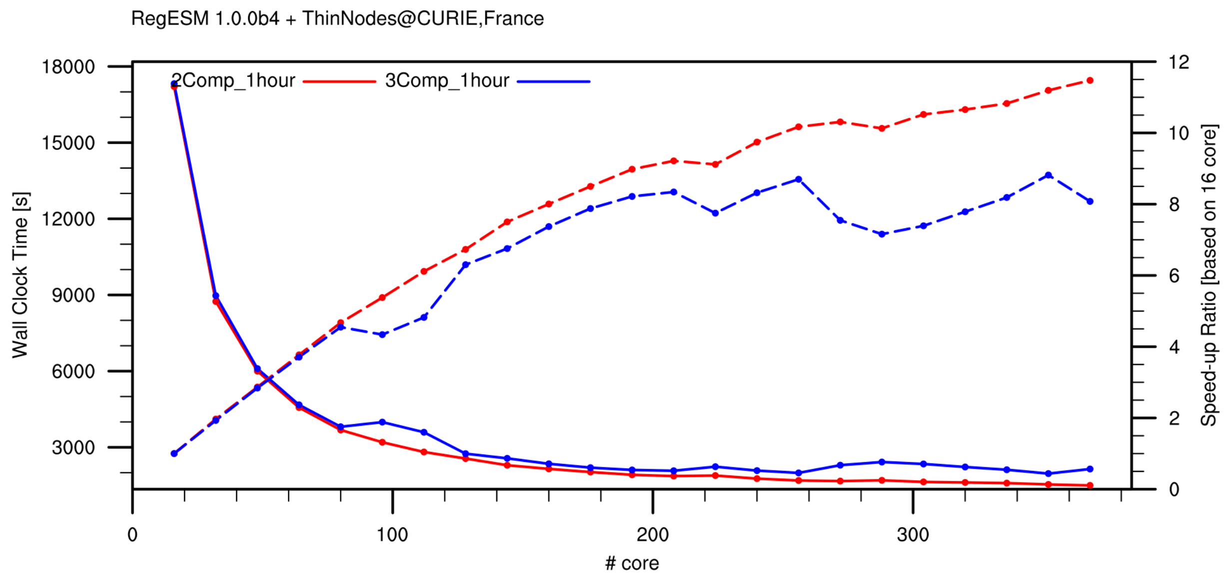


# core	% diff 30m/1hr	% diff 3hr/1hr
64	-0.38	1.29
128	1.06	2.15
192	1.45	2.89
256	1.86	1.58
288	9.20	0.95
320	-1.27	5.55
336	17.50	3.84
384	29.66	0.18
416	13.04	-0.92
528	13.50	-4.83
576	9.57	-0.75
640	1.93	8.68
AVG	**8.09**	**1.72**

- The effect of coupling interval is very limited ☺
- 30 min case has more fluctuations (it might be related with the overload of the cluster)
- It is better to repeat tests couple of time to take more reliable measurements ☹

Performance Benchmark …

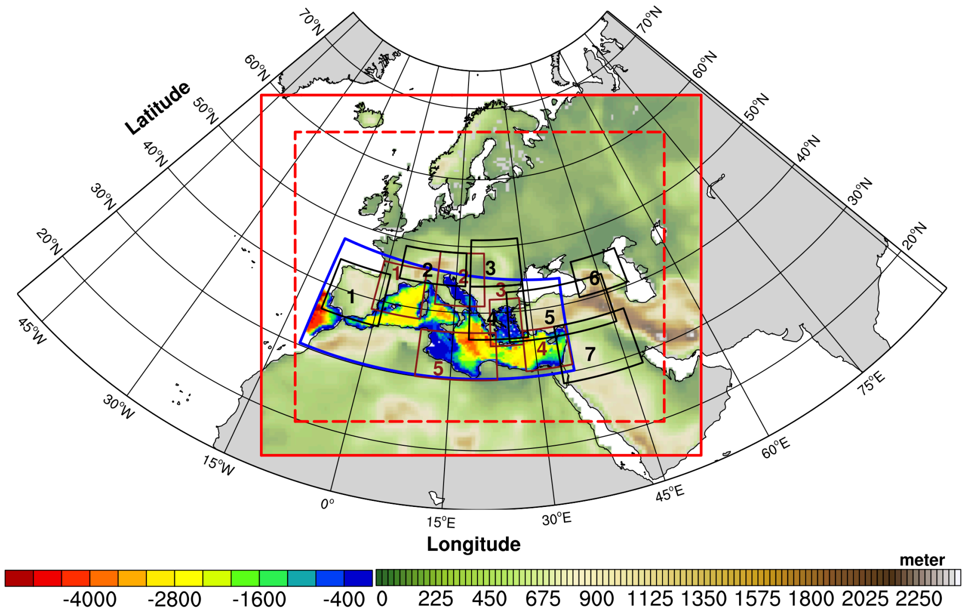
- Number of model components (const. coupling time step)



Sequential coupling

- Last processor is shared between OCN and RTM
- RTM component reduces the performance ~ 30% in higher processor counts ☹
- Solutions:
  - Integrated RTM component (with RegCM4, i.e. Chym)
  - Using higher resolution and parallelized (MPI) RTM component such as RAPID etc. It could also help to improve river rep.

Model for Mediterranean Basin



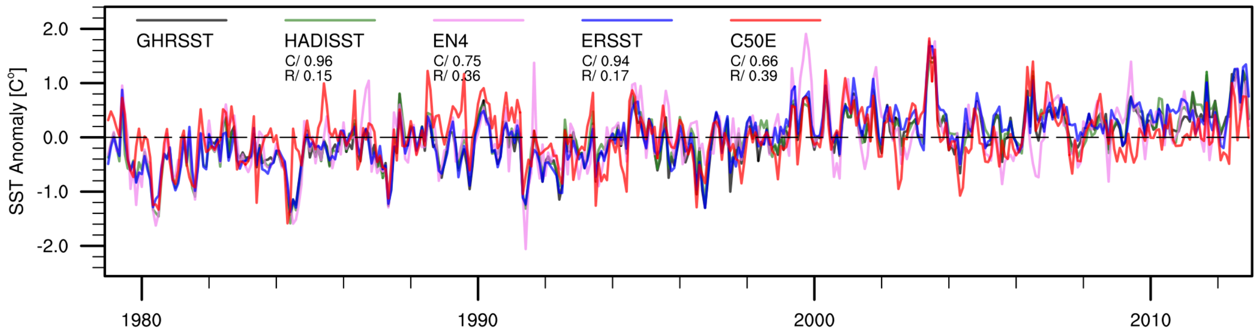
The Scientific and Technological Research Council of Turkey (TUBITAK) founded 2 year project (under grant 113Y108), ended in Dec. 2015

- Atmosphere: RegCM4 revision 4283 (~50 km)
- Ocean: ROMS revision783 (1/12 deg. ~ 9 km)
  - Closed boundary in Atlantic – used as a buffer zone
  - The coupling time step is 3 hour
  - ATM-OCN: wind stress, net heat and freshwater flux (E-P), shortwave rad., surface pressure and OCN-ATM: sea surface temperature
  - Prescribed river discharge (generated by Max Planck HD model)

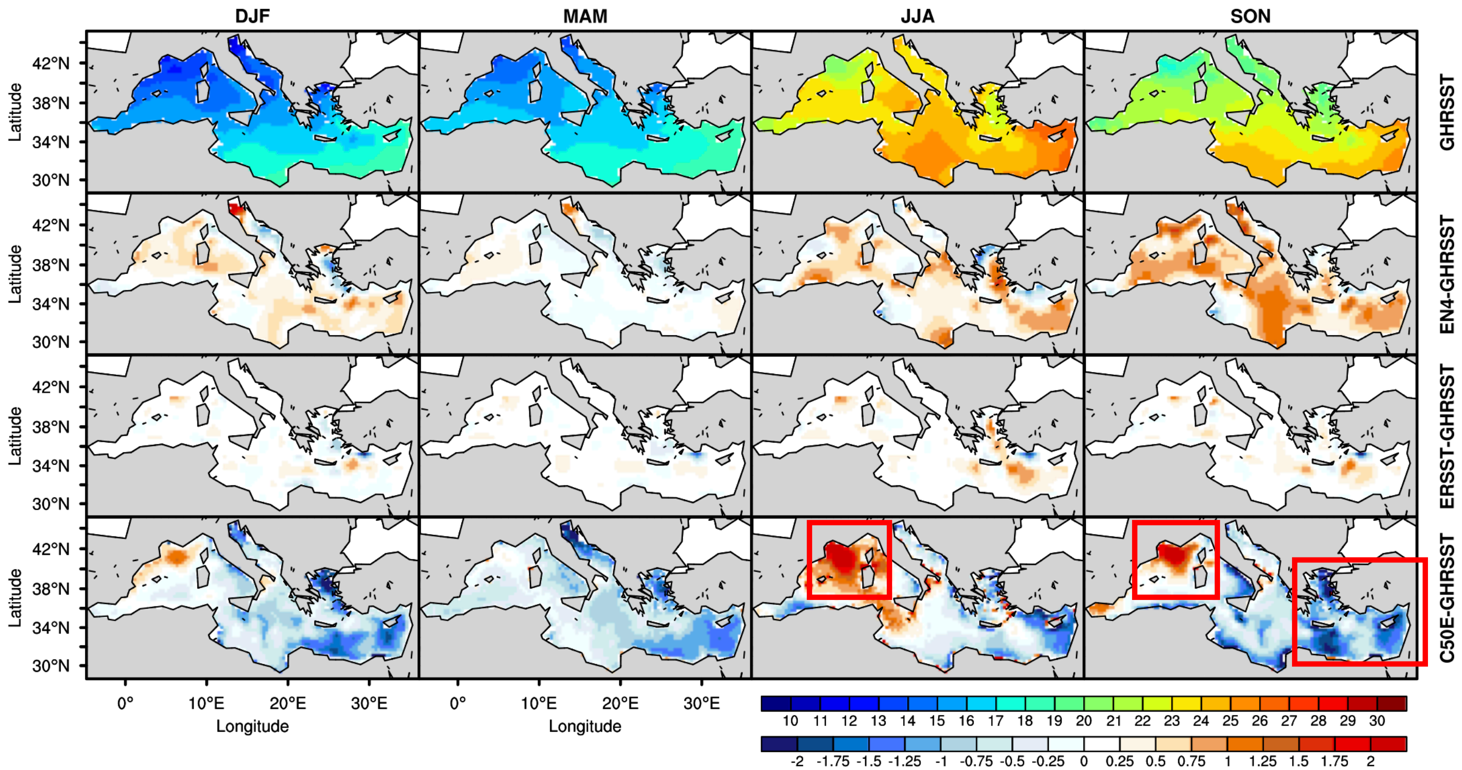
 # It is the first attempt for the validation of ROMS (Regional Ocean Modeling System) ocean model for Med.

Validation

- Sea Surface Temperature



SST anomaly over Med. Sea



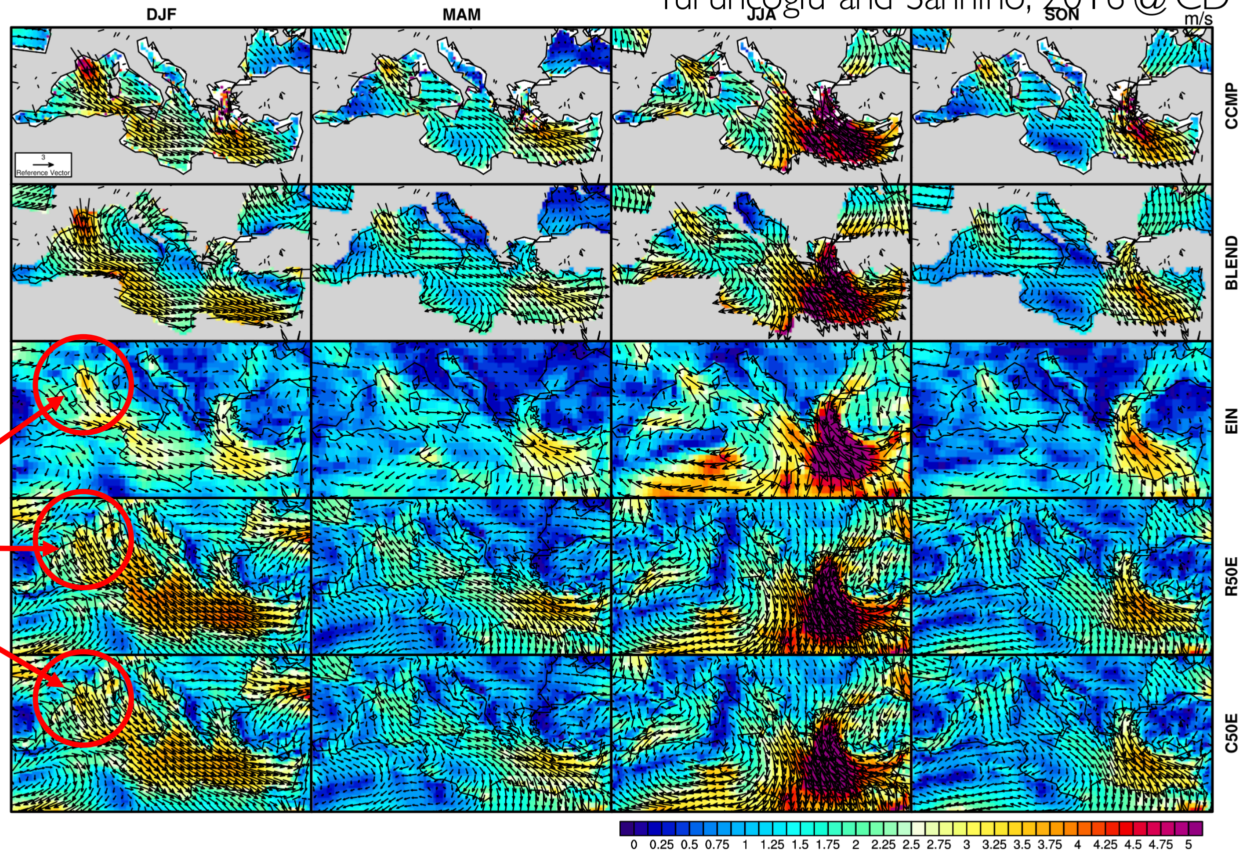
Seasonal SST Climatology

ERSST used in standalone simulation

Turuncoglu and Sannino, 2016 @ CD

Validation …

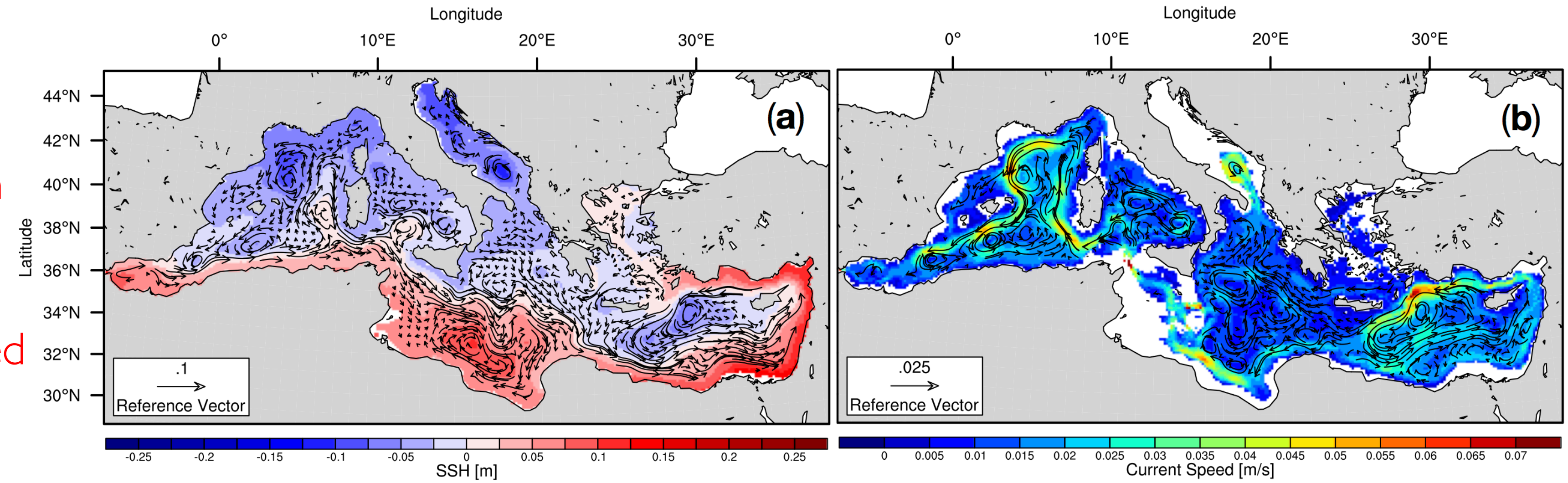
- Surface Wind and Circulation



Wind speed underestimated over Gulf of Lion

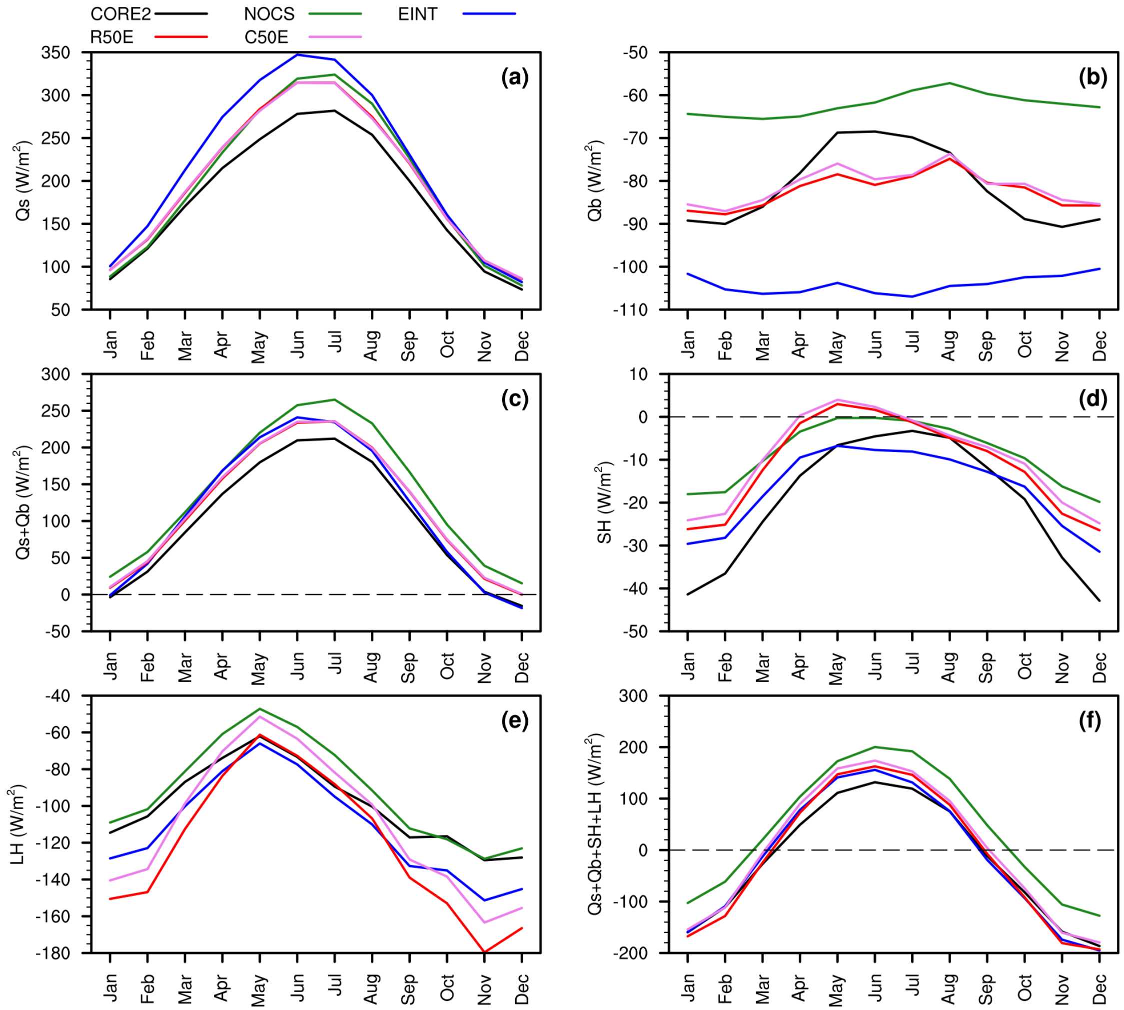
 # coupled model tends to decrease wind speed over the sea when it is compared with standalone simulation

Surface and 300 m circulation is well represented



Validation …

- Heat flux components over Med.
- Coupled and Standalone model simulations are very similar except LHF
- The net heat flux is in the range for both CPL and STD runs



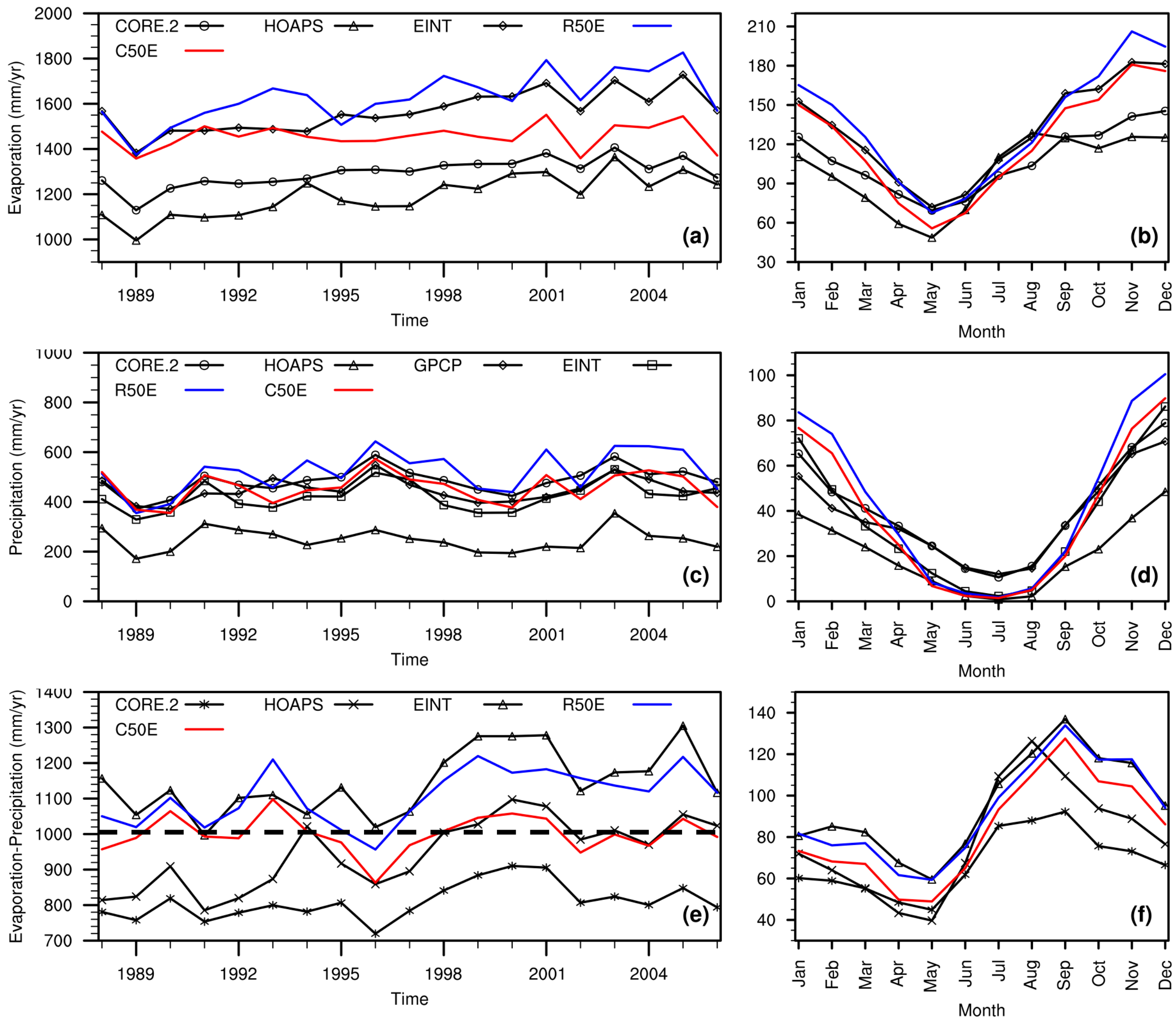
	SWF	LWF	SWF+LWF	SH	LH	NET
CORE.2	180.41	-81.24	99.17	-20.18	-99.80	-20.81
NOCS	200.02	-62.21	137.81	-8.79	-91.93	37.10
EINT	218.26	-100.14	114.12	-17.03	-112.12	-15.03
R50E	200.75	-82.34	118.41	-11.38	-121.72	-14.70
C50E	200.70	-81.31	119.39	-9.85	-110.52	-0.99

The coupled model reduces LH over Mediterranean Sea

Turuncoglu and Sannino, 2016 @ CD

Validation …

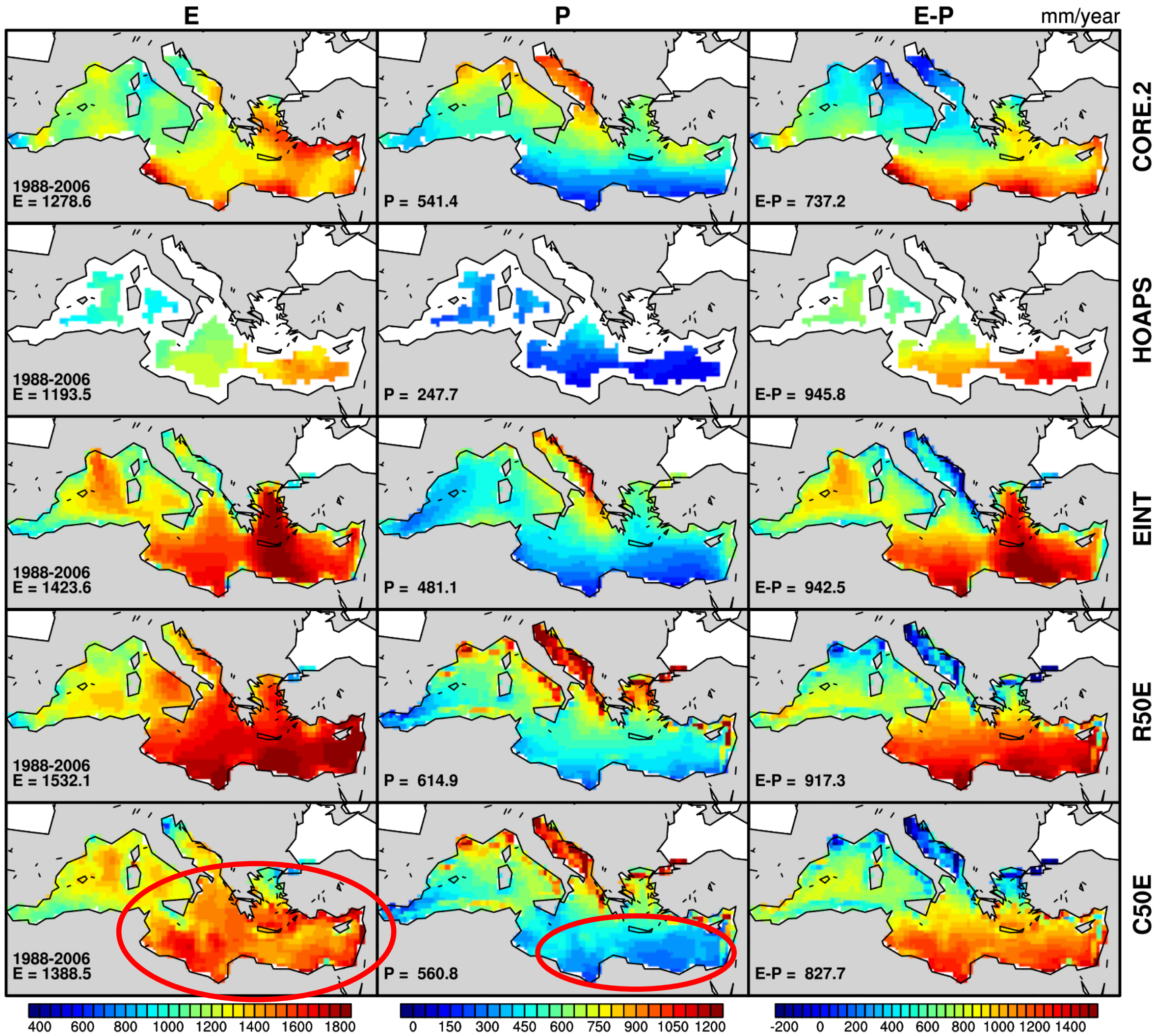
- E, P and E-P over Med.
- Coupled model tends to reduce evaporation
- The monthly distribution of E, P and E-P are very similar for STD and CPL
- The accepted E-P is 1000 mm/yr



Turuncoglu and Sannino, 2016 @ CD

Validation …

- Spatial distribution of E, P and E-P
- The effect of coupled model is more apparent in EMED
- The CPL model has more P in south of EMED
- The E-P estimates are consistent with available obs. for CPL model

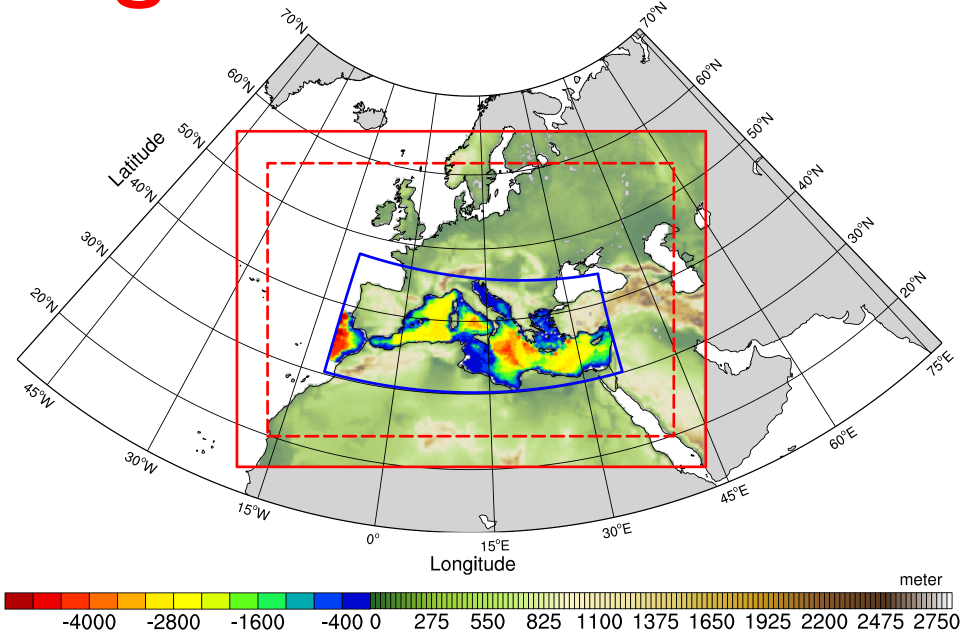


Turuncoglu and Sannino, 2016 @ CD

Data Access

- Currently, ITU is a data provider for MedCORDEX project
- Both coupled (RegCM4+ROMS) and standalone model simulations (RegCM4) are uploaded
  - Spatial resolution is MED44
  - Daily and monthly averages of surface variables
  - Monthly average of atmospheric variables (ua, va, ta, z) at 850 and 500 mb
- Documentation of simulations
  - ITU-RegCM4 - http://mistrals.sedoo.fr/?editDatsId=1434
  - ITU-RegESM1 - http://mistrals.sedoo.fr/?editDatsId=1433
  - Turuncoglu and Sannino, 2016 @ Climate Dynamics
- Data Access
  - It is distributed via MedCORDEX database
  - https://www.medcordex.eu/medcordex_help_get.php

High Res. Model for Med. Basin

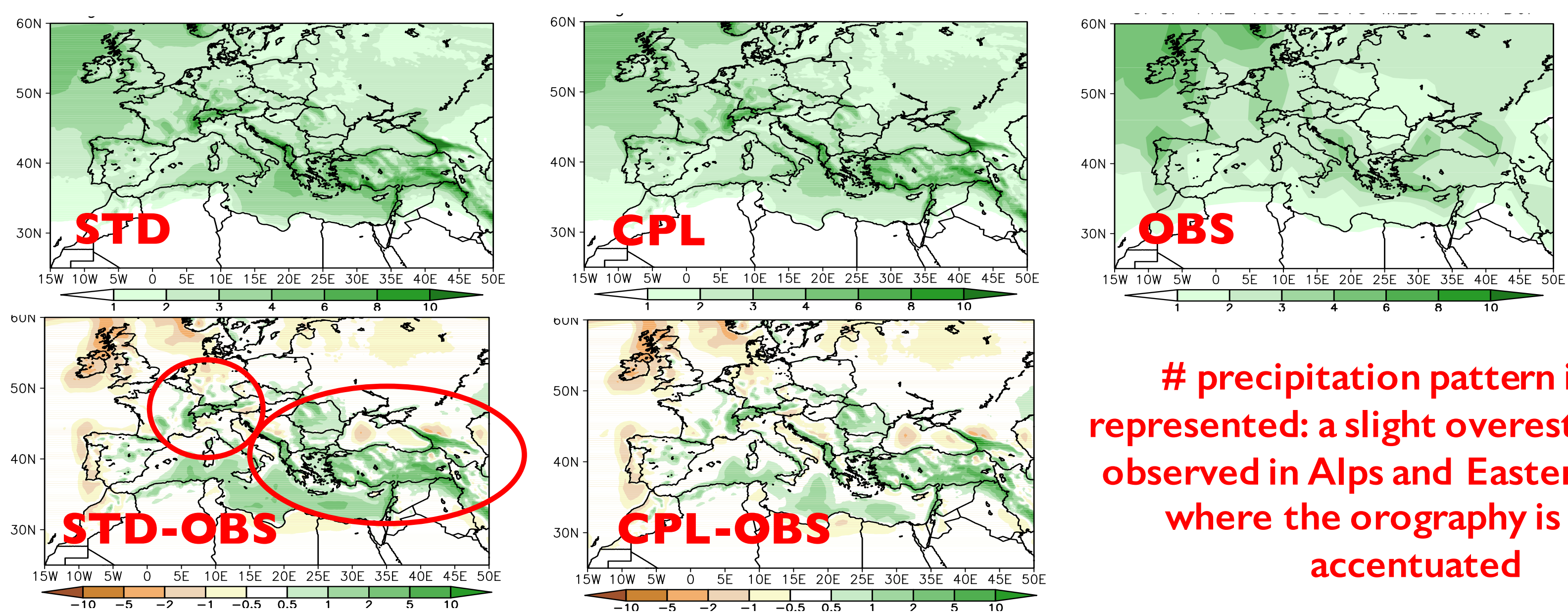


Collaboration between
ICTP
ENEA
ITU
to create three component model (Mariotti et al. 2016 @ CORDEX 2016)

- Atmosphere: RegCM4.4 (20 km)
- Ocean: MITgcm (1/12 deg. ~ 9 km)
    - Closed boundary in Atlantic – used as a buffer zone
    - The coupling time step is 3 hour
    - ATM-OCN: wind stress, net heat and freshwater flux (E-P), shortwave rad., surface pressure and OCN-ATM: sea surface temperature
- River Routing: Max Planck's HD model (17 major rivers)

Validation

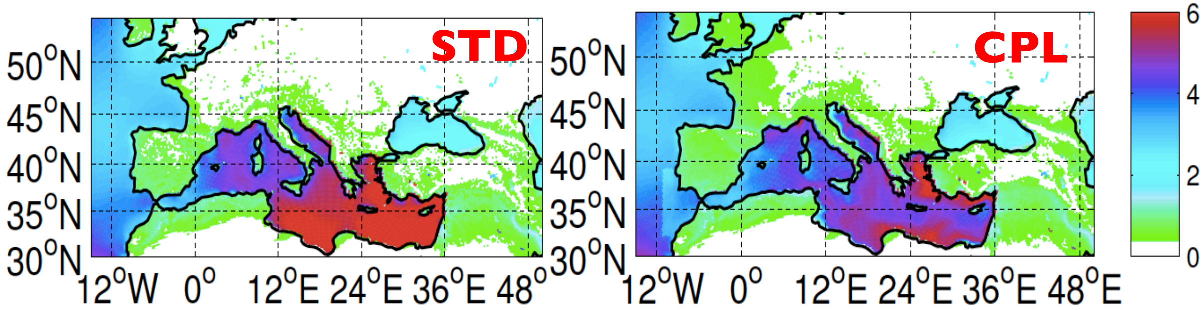
- Precipitation (1979-2013 climatology)



precipitation pattern is well represented: a slight overestimation is observed in Alps and Eastern Europe where the orography is more accentuated

coupled model (CPL) reduces the bias over Med. Basin compared with GPCP observations respect to the same comparison with standalone model simulation (STD).

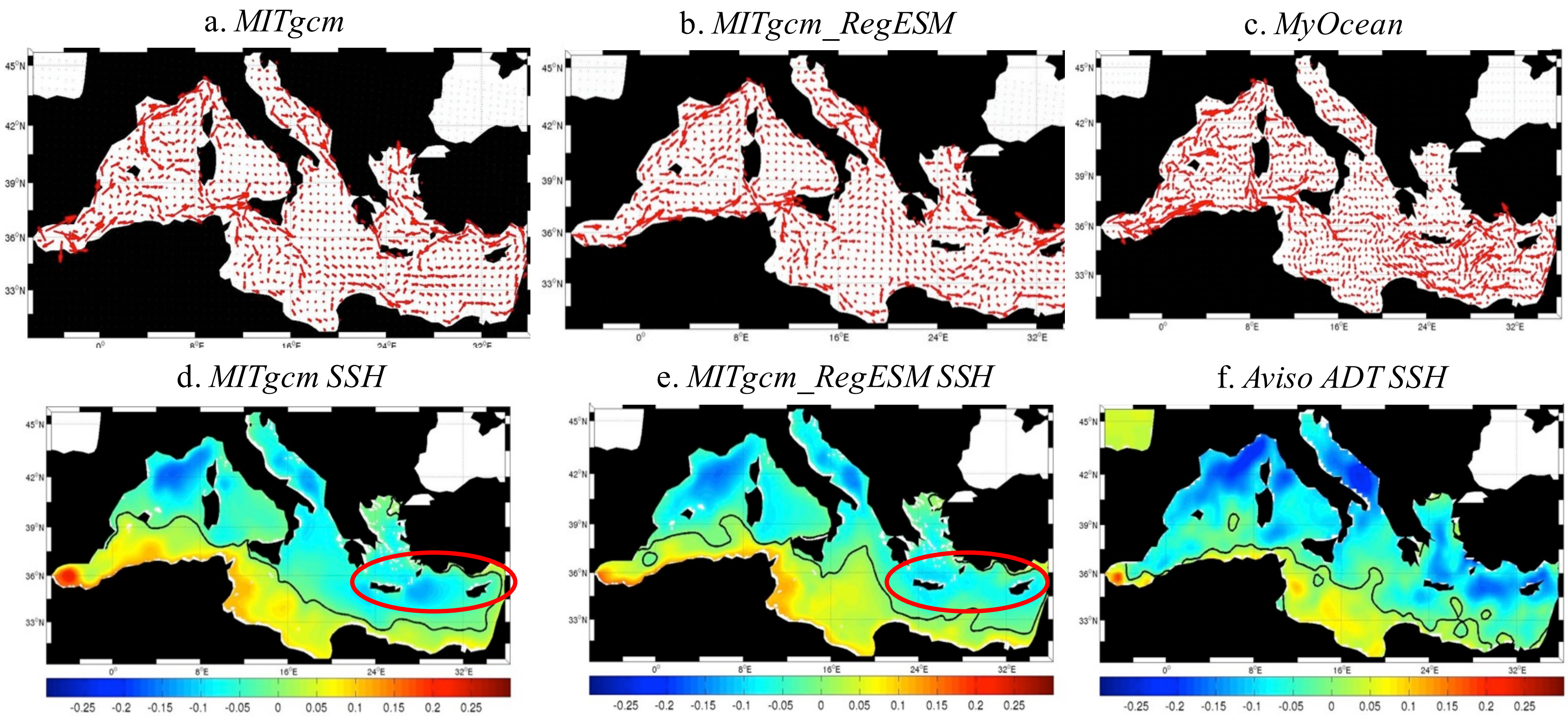
- Evaporation



This reduction is mainly associated with a decrease of evaporation over the sea

Validation …

- Circulation at 20 m and Sea Surface Height (SSH)

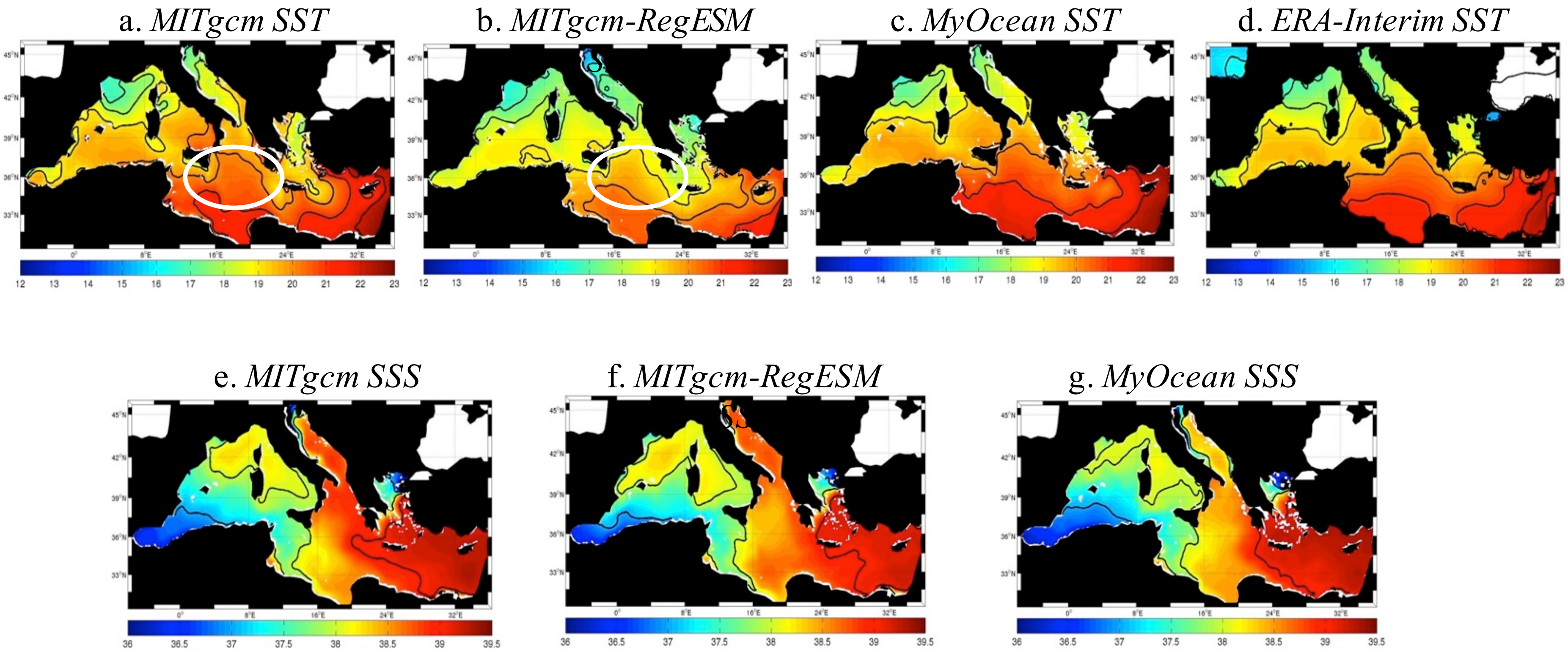


 # Surface circulation (m/s) is well represented in both standalone and coupled model with respect to MyOcean Med. Reanalysis (1987-2012) and Aviso (1993-2012) datasets.

 # Reduced evaporation (Eastern-Med.) affects the strength of Rhodes Gyre.

Validation …

- Sea Surface Temperature (SST) and Salinity (SSS)

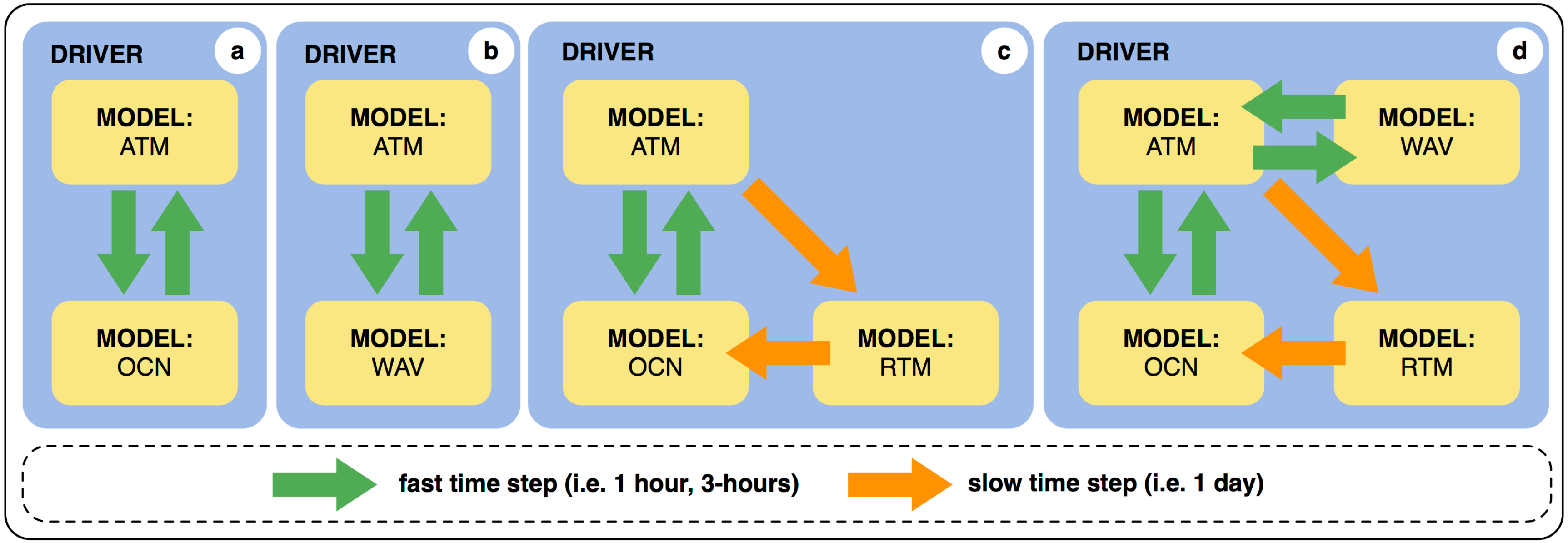


 # Both coupled and standalone exhibit both positive/negative significant biases (up to 1°C) in the SST with respect MyOcean and Era-Interim SST in areas where air-sea interactions are dominant (Adriatic Sea, Gulf of Lions, Rhodes Gyre, Aegean Sea).

 # Spatial distribution of SSS is well represented except Adriatic Sea where both models overestimate the SSS

 # In the Ionian the northward shift of MAW in the coupled and MyOcean lead to lower values of SSS with respect the standalone.

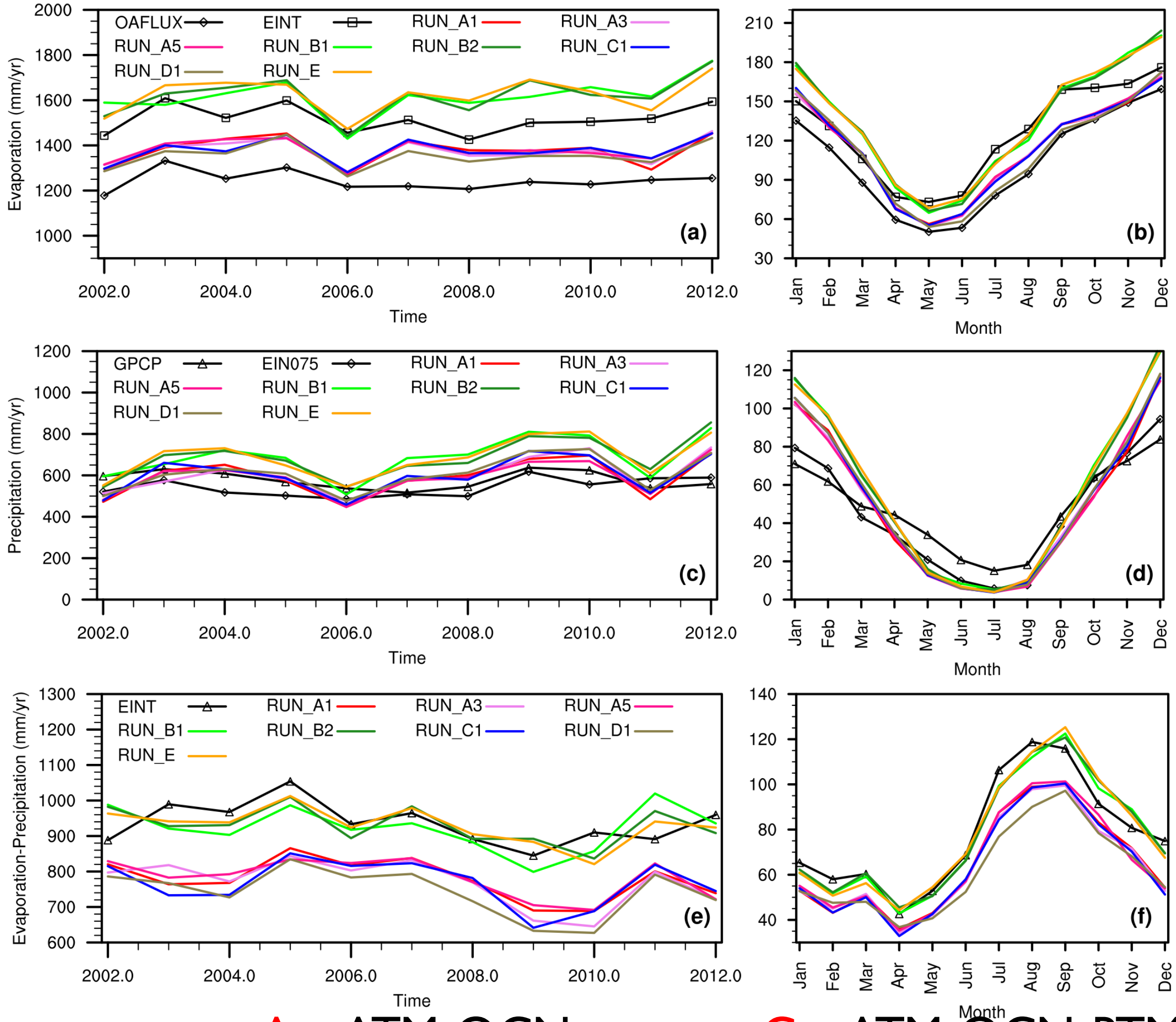
Extensive Testing of Modeling System



Run Short Name	Run Id	Coupling Type	Coupling Time Step	Active Models	Description
AO1	A1	Explicit	30 mins	ATM+OCN	
AO2	A2	Explicit	1 hour	ATM+OCN	
AO3	A3	Explicit	3 hours	ATM+OCN	base run
AO4	A5	Semi-implicit	3 hours	ATM+OCN	
AW1	B1	Explicit	3 hours	ATM+WAV	u and v <-> rough.
AW2	B2	Explicit	3 hours	ATM+WAV	wdir, friction vel.<-> rough.
AOR	C1	Explicit	3 hours	ATM+OCN+RTM	river discharge as SBC
AORW	D1	Explicit	3 hours	ATM+OCN+RTM+WAV	
Standalone	E, F, G, H	-	-	ATM/OCN/RTM/WAV	

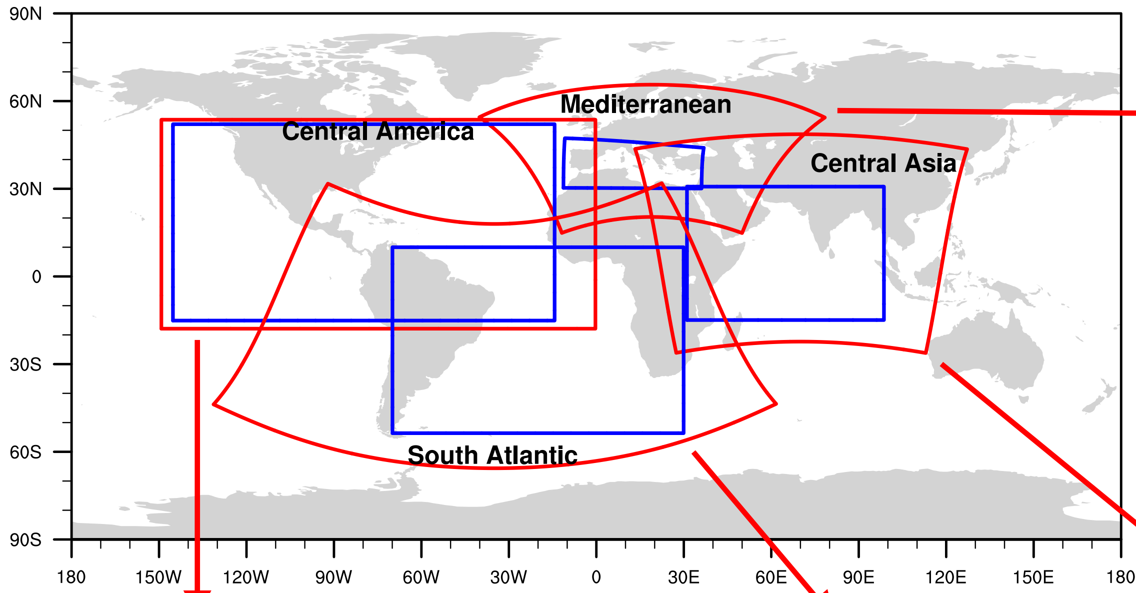
Comparison based on # used models

- Inter-annual variability and monthly climatology of E, P and E-P
- The effect of WAV component is minimal in E, P and E-P
- The OCN mainly affects the E-P balance by reducing E and P
- The monthly climatology is also modified



A – ATM-OCN
B – ATM-WAV
C – ATM-OCN-RTM
D – ATM-OCN-RTM-WAV

Applications



Mediterranean

	ATM	OCN	RTM
Models	RegCM 4.4.5.7	MITgcm c64s	HD
Res.	20 km, 23L 353x253	1/12º, 75L 276x408	0.5º global
ICBC	ERA-Int ERSST	12 km ALADIN	online ATM
Details	BATS Grell+MIT	GGL90	17 major rivers

- Coupled with RegESM driver
- 3 hours coupling interval between ATM and OCN and 1 day in interaction with RTM
- 1979-2013 (35 years)

Central America

	ATM	OCN	RTM
Models	RegCM 4.4.5.9	MITgcm c63s	HD
Res.	50 km, 23L 308x170	1/8º, 40L 1050x540	0.5º global
ICBC	ERA-Int ERSST	0.25º MOM	online ATM
Details	CLM, Grell, KF	KPP	10 major rivers

- Coupled with RegESM driver
- 3 hours coupling interval between ATM and OCN and 1 day in interaction with RTM
- ?

South Atlantic

	ATM	OCN	RTM
Models	RegCM 4.4.5.9	MITgcm c63s	HD
Res.	50 km, 23L 330x206	1/8º, 40L 800x510	0.5º global
ICBC	ERA-Int ERSST	0.25º MOM	online ATM
Details	CLM, UW-PBL, MIT	KPP	7 major rivers

- Coupled with RegESM driver
- 3 hours coupling interval between ATM and OCN and 1 day in interaction with RTM
- ?

Central Asia

	ATM	OCN	RTM
Models	RegCM 4.4.5.9	MITgcm c63s	HD
Res.	50 km, 18L 170x216	1/6º, 45L 276x408	0.5º global
ICBC	ERA-Int ERSST	0.25º MOM	online ATM
Details	CLM, UW-PBL, MIT	KPP	30 major rivers

- Coupled with RegESM driver
- 3 hours coupling interval between ATM and OCN and 1 day in interaction with RTM
- 1979-2007 (25 years)

RegESM Modeling System

1/ easy to use and extend flexible modeling system
2/ model components can be upgraded easily
3/ state-of-art driver design that follows common conventions / standards
4/ ready to use with new non-hydrostatic core
5/ supports both CLM and BATS

1/ only global conservation is supported and might have a problem for large domains
2/ the bottleneck due to sequential RTM component
3/ WAM uses 1d decomposition and limits higher number of processor for seq. type coupling

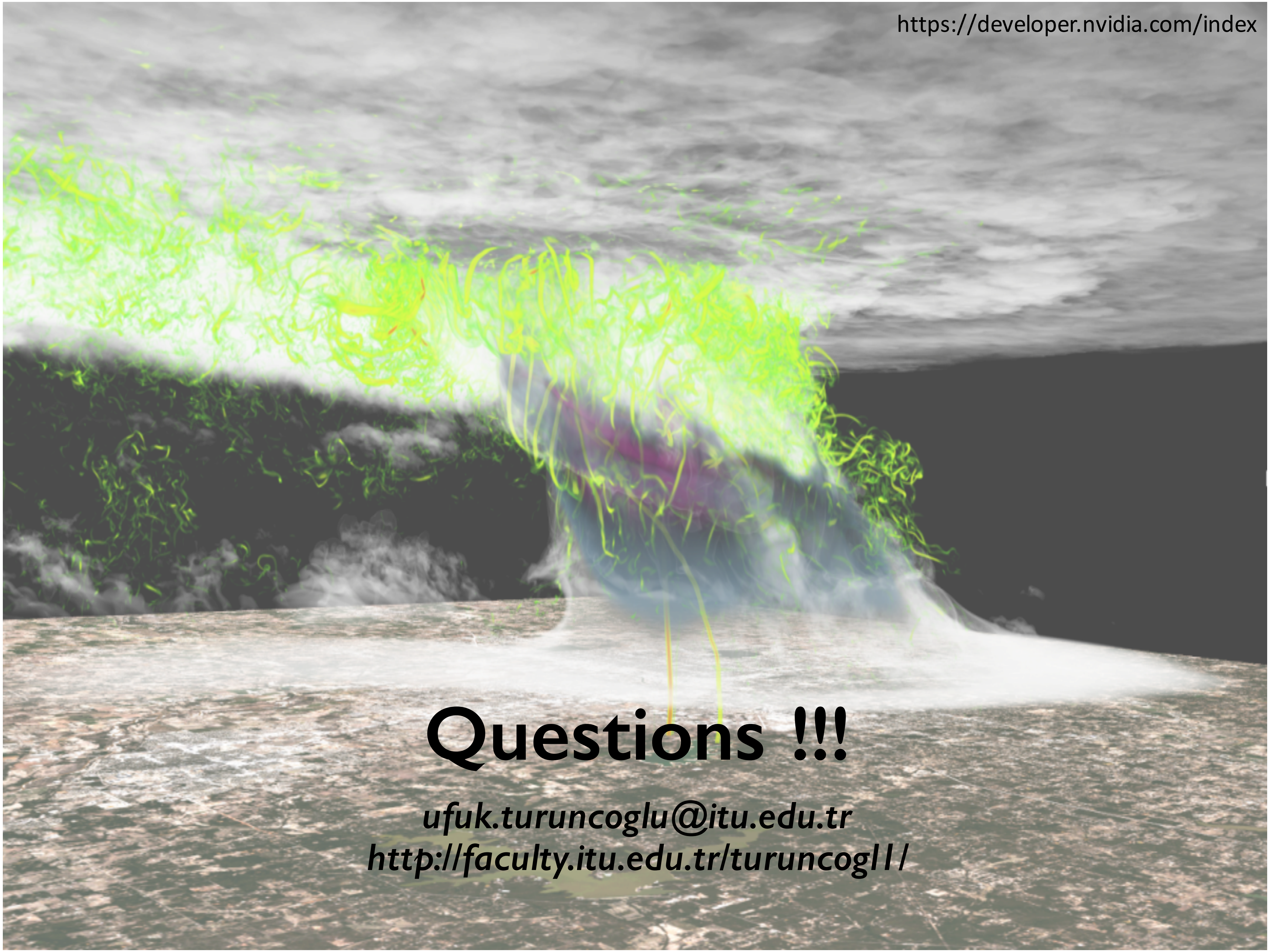
1/ sharp gradient between interactive and prescribed SST (issue #12)
2/ no wind rotation algorithm for Polar Stereographic (POLSTR) projection (issue #14)

Plans: Short - Mid - Long

#	Description	Domains
1	• Using modeling system for different applications and domains • Future climate scenarios using CMIP5 models	Med. Sea. Black Sea Caspian Sea
2	• New applications using hydrostatic core at higher spatial (3-12 km) and temporal resolution for Med-CORDEX-2, extreme events and fast-moving processes	Med. Sea.
3	• Wave effect on current (WEC): 1) gradient of radiation stress tensor or 2) vortex force (VF) • Additional wave component such as WW3 to support curvilinear grids in the wave component. It will allow to cover whole atmospheric model domain • Higher resolution river routing component for better representation of rivers (i.e. Chym, CaMa-Flood etc.)	

4	• Continuous Integration (CI)
	    • Standardization of model installation (integrate with **Travis-ci** to test the build)
	    • Usage of virtualization technologies such as Docker containers to run and test modeling system in the cloud (Google, Azure, Amazon etc.)	

5	• New approaches to analyze fast-moving processes in high res.	


https://developer.nvidia.com/index
Questions !!!
ufuk.turuncoglu@itu.edu.tr
http://faculty.itu.edu.tr/turuncogl1/