



ISTITUTO NAZIONALE
DI OCEANOGRAFIA E DI GEOFISICA SPERIMENTALE



14-18 OCTOBER 2019 BEIJING, CHINA

ICRC-CORDEX 2019

International Conference On Regional Climate



The Abdus Salam
International Centre
for Theoretical Physics

Evaluation of the Mediterranean climate and marine biogeochemistry with the Regional Earth System Model RegCM-ES

**M.Reale^(1,2), F. Giorgi⁽¹⁾, C. Solidoro⁽²⁾, V. Di Biagio⁽²⁾, F. Di
Sante^(1,2), L. Mariotti⁽²⁾, R. Farneti⁽¹⁾, G. Sannino⁽³⁾**

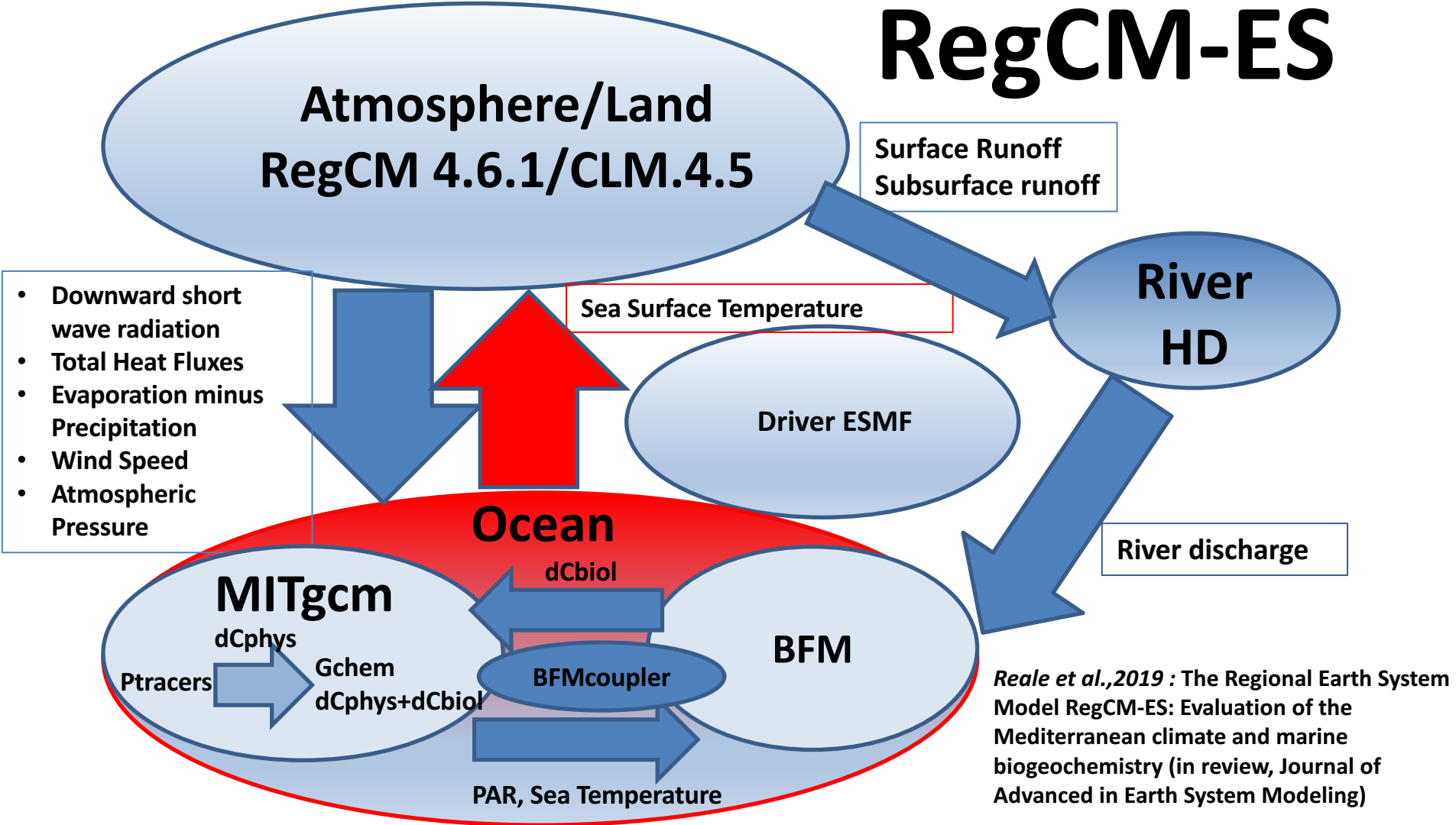
(1) ICTP Abdus Salam, Trieste, Italy

(2) OGS, Trieste, Italy

(3) ENEA, Roma, Italy

Contact : reale.marco82@gmail.com

RegCM-ES



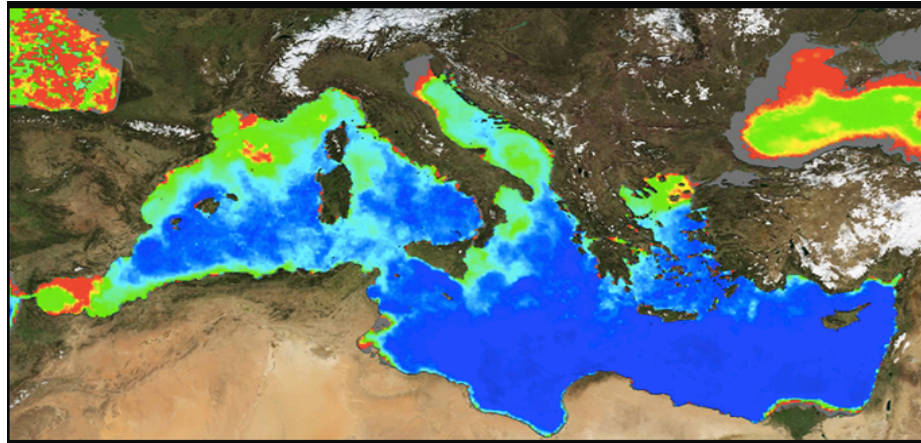
The Mediterranean region (1)



- Due to the high population density along the coastline is particularly sensitive to extreme events
- HOT SPOT for climate change (Giorgi , 2006)
- A semi inclosed basin which acts as source of moisture and heat for atmosphere and complex distribution of land sea
- Influenced by both sub-tropical and mid-latitude dynamics
- Characterized by a peculiar thermohaline circulation associated with strong air-sea interactions and exchange of water at Gibraltar strait



The Mediterranean region (2)



Mediterranean Sea Ocean Colour 2011 – Courtesy of CMEMS. Ocean colour is used to map the abundance of tiny marine plants (phytoplankton) the basis of the marine food chain. On the image, red indicates highest abundance of phytoplankton and blue indicates lowest abundance.

*One of the most
oligotrophic
areas in the world*

Ocean colour satellite analysis clearly
indicates a decreasing **west-east**
trophic gradient in productivity

Major source of nutrients is represented
by **rivers** , **atmospheric deposition** and
winter mixing in some areas

*High levels of biodiversity
and some hot spots for fisheries*

*High impacts due to **pollution** and
overexploitation of marine resource*



Numerical settings (a)

Atmosphere

- *RegCM.4.6.1/CLM.4.5*
- *Hydrostatic*
- *Horizontal resolution : 30km*
- *Vertical resolution : 23 sigma levels*
- *Initial/Lateral conditions : ERA-Interim 0.75°*
- *Timestep : 30 s*

Driver ESMF

- *1 hr (Ocean/Atmosphere), 1 day (Atmosphere/River and River/Ocean)*

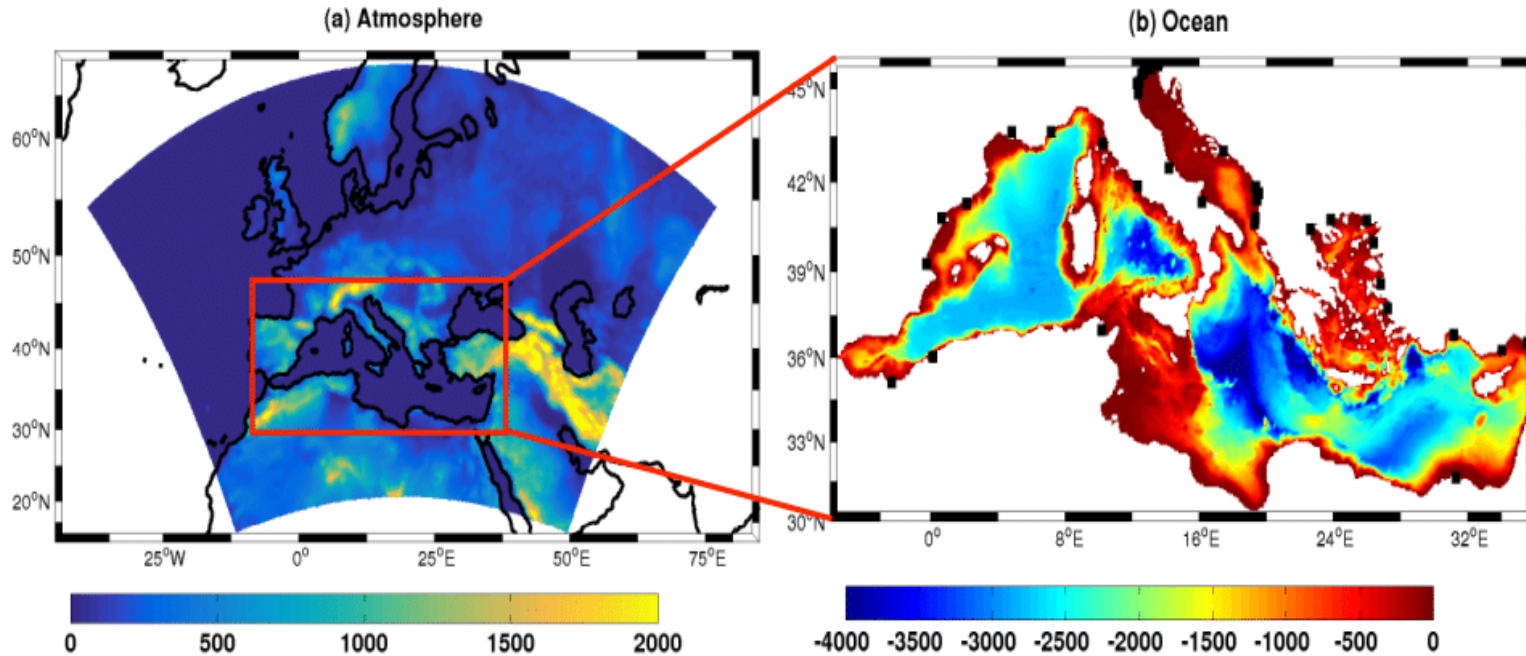
Ocean/Biogeochemistry

- *MITgcm/BFM*
- *Hydrostatic*
- *Horizontal resolution 1/12°*
- *Vertical resolution : 75 Zeta vertical levels*
- *Initial/Lateral conditions : Rixen climatology for temperature and salinity/MEDAR-MEDATLAS dataset for dissolved oxygen, NO₃, PO₄ and silicate /BFM standard values for all the others biogeochemical variables. Levitus climatology for temperature and salinity/World Ocean Atlas 2013 for dissolved oxygen, phosphate, nitrate and silicate/ Huertas et al. (2009) and Dafner et al. (2001b) for alkalinity and dissolved inorganic carbon/equal to Initial conditions for all the others biogeochemical variables/Atmospheric deposition from Ribera d'Alcala et al,(2009)/River biogeochemical input from Ludwig et al., (2009)/pCO_{2atm} based on A1B scenario*
- *Timestep : 120s*

River

- *HD 0.5° together with MedCordex Protocol (only for Nile River)/ Kourafalou and Barbopoulos (2003) (only for Dardanelles strait)*

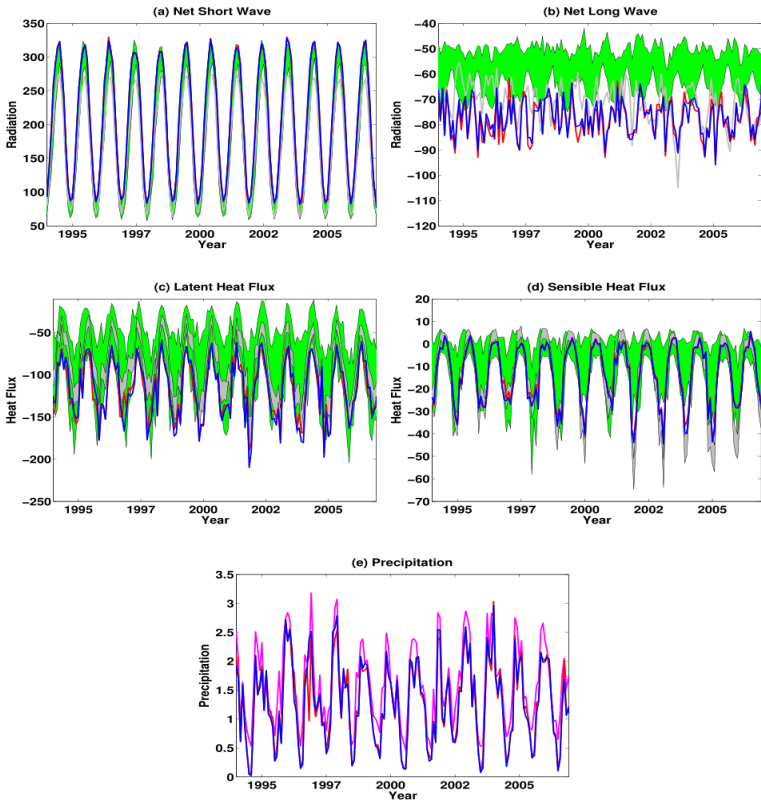
Numerical settings (b)



RegCM-ES domain over the Mediterranean region, topography and ocean model bathymetry. (a) Domain an topography (in m) of RegCM4. (b) Ocean model bathymetry (in m) and the river locations defined in the model (black squares).

Reale et al., 2019 : The Regional Earth System Model RegCM-ES: Evaluation of the Mediterranean climate and marine biogeochemistry (in review, Journal of Advanced in Earth System Modeling)

Atmosphere:Air-Sea Interaction



Time series of net monthly averaged heat fluxes and precipitation: net shortwave (a), net longwave (b), latent (c), sensible (d) and precipitation (e) in the period 1994-2006: ATM (blue line), CPL (red line), OA (gray line) and NOCS (green line) and GPCP (magenta line). Uncertainties in the observations are represented by the spread of the average curves. Units are W/m² and mm/day.

	Net Short Wave (in W/m²)	Net Long Wave (in W/m²)	Latent Heat Flux (in W/m²)	Sensible Heat Flux (in W/m²)
ATM	206.29	-77.08	-117.22	-13.18
CPL	206.85	-77.73	-116.54	-12.56
OAflux	172.24	-70.54	-87.73±9.37	-12.79±3.14
NOC	187.35±23.00	-58.26±8.19	-83.53±39.33	-7.56±9.86

Table 2: Mean value over the Mediterranean Sea (in W/m²) in the period 1994-2006 of net short wave, net long wave, latent, sensible heat fluxes in ATM, CPL and Observations (NOC, OA). Units are in W/m²

Reale et al.,2019 : The Regional Earth System Model RegCM-ES: Evaluation of the Mediterranean climate and marine biogeochemistry (in review, Journal of Advanced in Earth System Modeling)

Atmosphere: Precipitation/Evaporation

GPCP

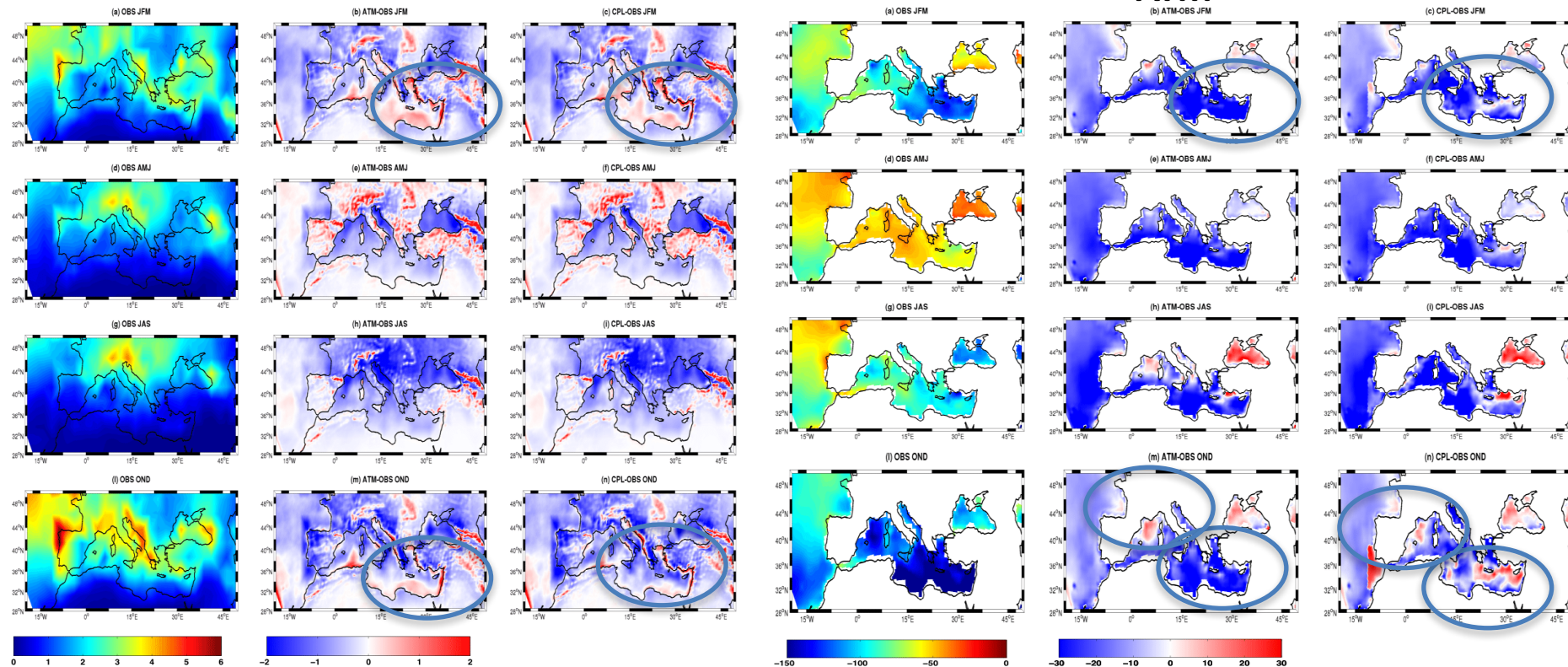
ATM

CPL

GPCP

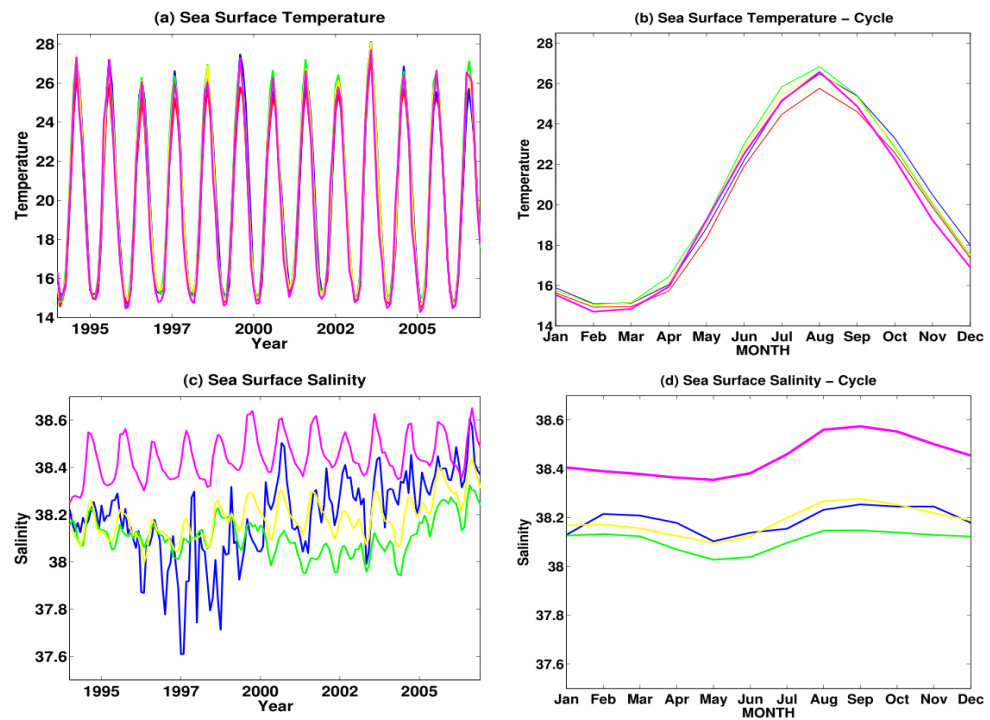
ATM

CPL



Reale et al., 2019 : The Regional Earth System Model RegCM-ES: Evaluation of the Mediterranean climate and marine biogeochemistry (in review, Journal of Advanced in Earth System Modeling)

Ocean: Sea Surface Temperature/Salinity



Time series of net monthly averaged (first column) and annual cycle (second column) of SST (first row) and SSS (second row) in the period 1994-2006: RegCM-ES (magenta), Satellite SST (red), EN4 (blue), CMEMS (green) and MyOcean (yellow). Units are in °C and psu respectively.

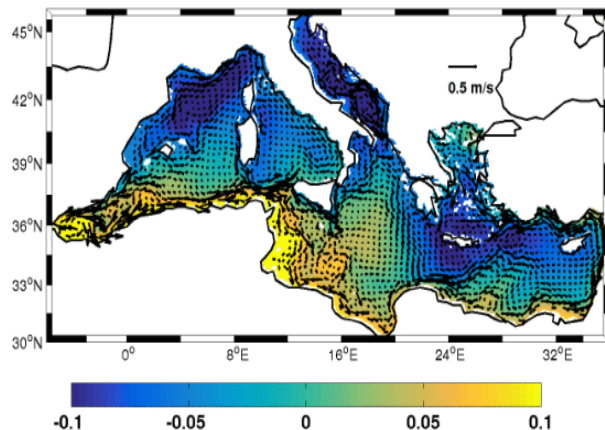
Data	SST	SSS
RegCM-ES	19.81	38.44
Satellite SST	19.80±0.46	
EN4	20.16±0.62	38.19±0.20
CMEMS	20.26±(0.82±0.42)	38.10±(0.25±0.12)
MyOcean	20.33±(0.65±0.37)	38.28±(0.20±0.10)

Mean value and RMSD for SST and SSS over the Mediterranean Sea in the period 1994-2006 in RegCM-ES and available observational/reanalysis products (EN4, SST from satellite, CMEMS and MyOcean). Units are in °C and psu.

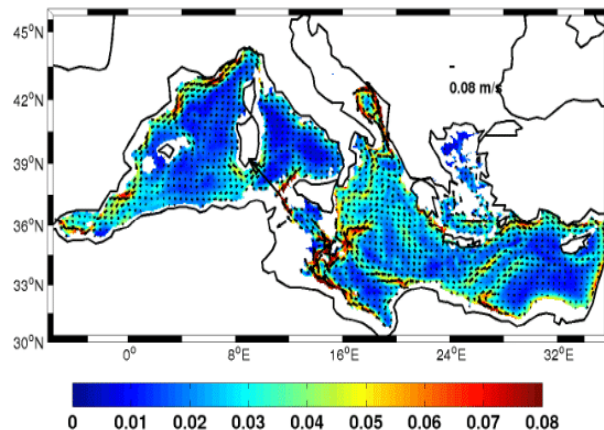
Reale et al.,2019 : The Regional Earth System Model RegCM-ES: Evaluation of the Mediterranean climate and marine biogeochemistry (in review, Journal of Advanced in Earth System Modeling)

Ocean: Sea Surface Height and Circulation

(a) SSH/current speed at 25 m



(b) current speed at 200 m



- **RegCM-ES reproduces the flow of Atlantic Water through the Gibraltar Strait, the two anticyclonic gyres in the Alboran Sea and the Algerian current and its two branches**
- **In the Western Mediterranean, we observe the negative signal associated with the SSH and cyclonic circulation in the area of Gulf of Lions and in the Southern Adriatic, both marker of deep water formation processes**
- **At 200 m high values of current speed are shown south of Rhodes, in the Southern Adriatic along the Gulf of Lion and towards the Gibraltar strait**

Mean sea surface height (SSH, contours) and the surface/intermediate circulation field (at 25 m and 200 m, arrows) as simulated by RegCM-ES in the period 1994–2006 . Units are in m for SSH and m/s for the velocity field.

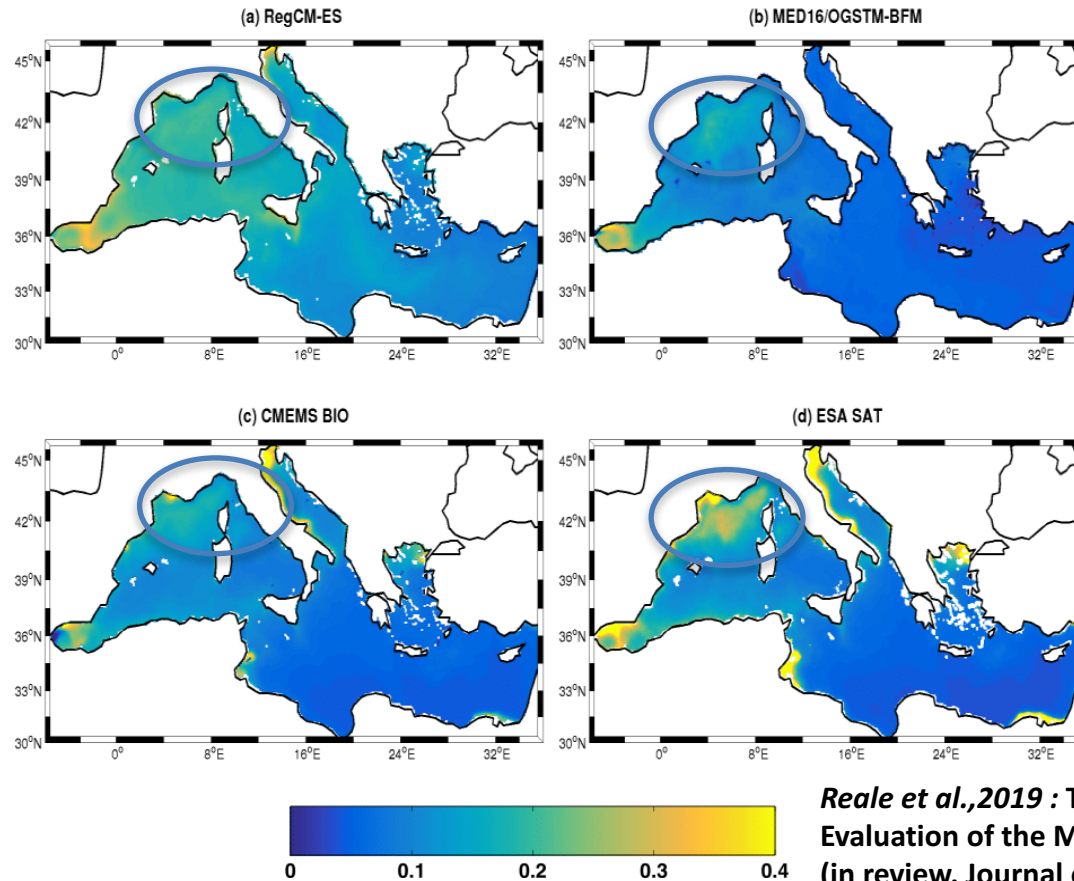
Reale et al.,2019 : The Regional Earth System Model RegCM-ES: Evaluation of the Mediterranean climate and marine biogeochemistry (in review, Journal of Advanced in Earth System Modeling)

Biogeochemistry :Net primary production

	Med Sea	Western Med	Eastern Med	Alboran Sea	South Western Med	North Western Med	Tyrrhenian	Ionian	Levantine
RegCM-ES	105±21	115±21	97±16	122±33	125±14	104±16	115±16	107±11	91±14
MedMIT12-BFM	104	120	97	151	120	120	109	99	94
MED16/OGSTM-BFM	98	131	76	274	140	116	92	77	76
CMEMS-BIO	136	x	x	214	170	164	152	115	117
Other Models	205 ⁽ⁱ⁾	120 ^(e) 190 ⁽ⁱ⁾	56 ^(e) 220 ⁽ⁱ⁾	24-207 ^(f)	x	32-273 ^(f) 175-192 ^(g)	x	27-153 ^(f)	97 ^(h) 36-158 ^(f)
SAT1	68	79	61	105	x	80	67	61-63	59-60
SAT2	90	112	86	179	107	115	90	79	72
SAT3	135	163	121	x	x	x	x	x	x
In Situ	80-90 ^(a)	x	x	x	x	86-232 ^(b) 140-150 ^(c)	x	62 ^(d)	x

Table : Horizontal means of the 0-200 m integrated net primary production (in units of gC /m²/yr) in the Mediterranean Sea and related sub-basins as annual climatologies: according to RegCM-ES (with the spatial standard deviation), other models and reference data. MedMIT12-BFM (Di Biagio et al., 2019), MED16/OGSTM-BFM (Lazzari et al.,2012), CMEMS (Teruzzi et al.,2016), SAT1 (Uitz et al,2012), SAT2 (Colella, 2007), SAT3 (Bosch et al.,2004). In situ and Others models: (a) Sournia (1973), (b) Marty et Chiaverini (2002), (c) Conan et al., (1998), (d) Boldrin et al., (2002), (e) Crispi et al., (2002), (f) Allen et al., (2002), (g) Kessouri et al., (2018), (h) Napolitano et al., (2000), (i) Mattia et al., (2013).

Biogeochemistry: Chlorophyll-a (horizontal pattern)



- RegCM-ES captures the west–east trophic gradient that characterizes the **Mediterranean marine ecosystem**
- RegCM-ES captures the maximum of chlorophyll-a in the gulf of Lions, along the Adriatic coastline and in the Alboran Sea

Mean chlorophyll-a in the first 10m in RegCM-ES (a, averaged over the period 1994-2006), MED16/OGSTM-BFM (b, Lazzari et al., 2012, averaged over the period 1998-2004), CMEMS (c, averaged over the period 1999-2006) and ESA satellite data (d, averaged over the period 1998-2006). Units are in mgChl/m³

Reale et al., 2019 : The Regional Earth System Model RegCM-ES: Evaluation of the Mediterranean climate and marine biogeochemistry (in review, Journal of Advanced in Earth System Modeling)

Biogeochemistry : Chlorophyll-a (vertical structure)

- **RegCM-ES captures the west-east gradient in the vertical structure of chlorophyll-a**

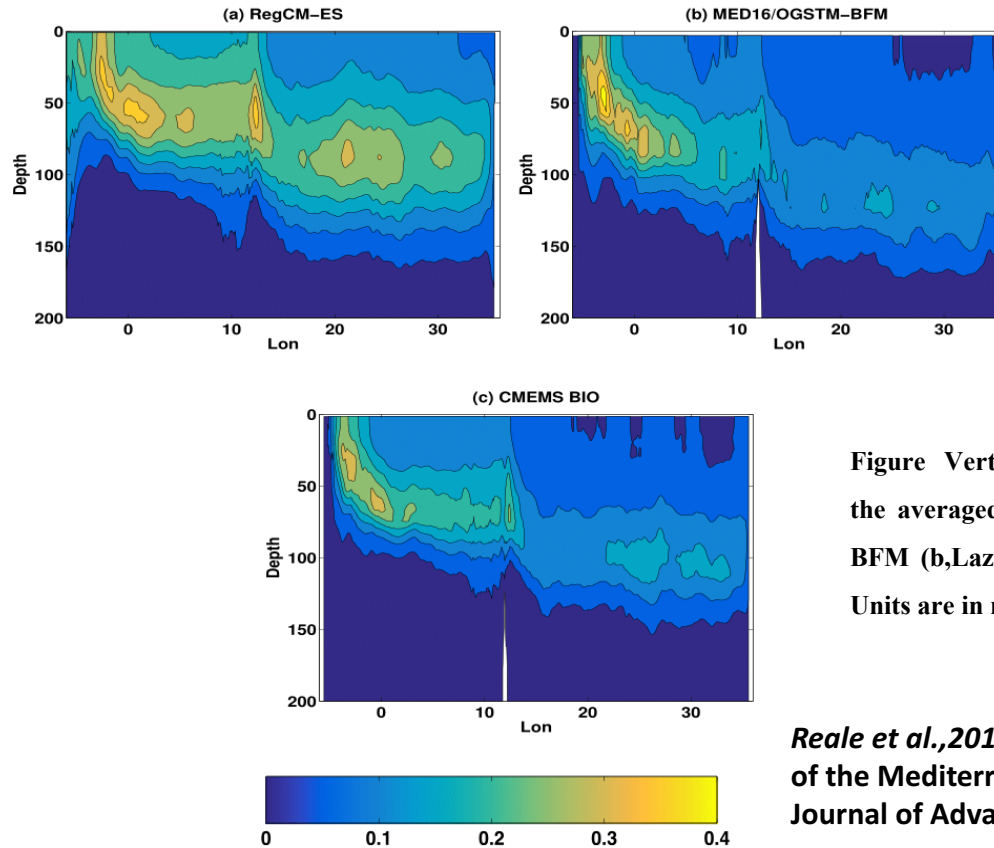


Figure Vertical section from the Gibraltar strait to the Levantine Basin of the averaged chlorophyll-a : RegCM-ES (a, 1994-2006), MED16/OGSTM-BFM (b, Lazzari et al, 2012; 1998-2004) and CMEMS-BIO (c, 1999-2006). Units are in mgChl/m³

Reale et al., 2019 : The Regional Earth System Model RegCM-ES: Evaluation of the Mediterranean climate and marine biogeochemistry (in review, Journal of Advanced in Earth System Modeling)

Biogeochemistry: Dissolved nutrients (horizontal structure)

PO₄

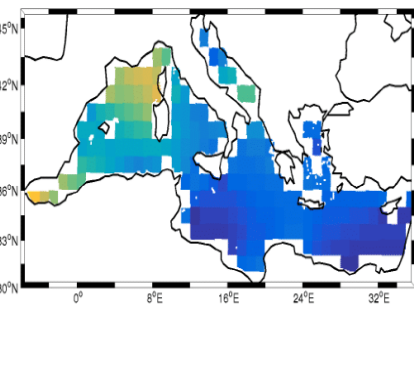
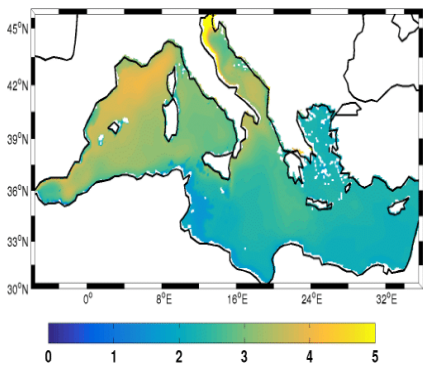
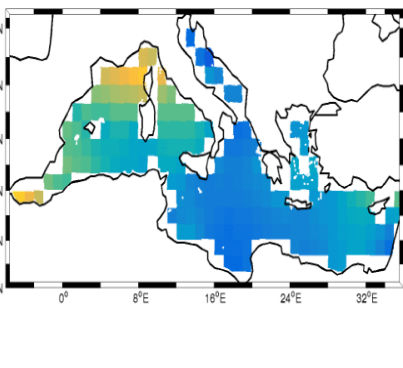
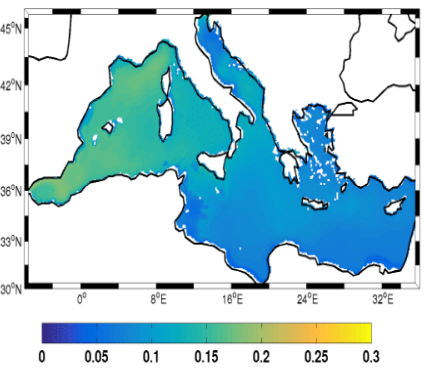
NO₃

MODEL

OBS WOA

MODEL

OBS WOA

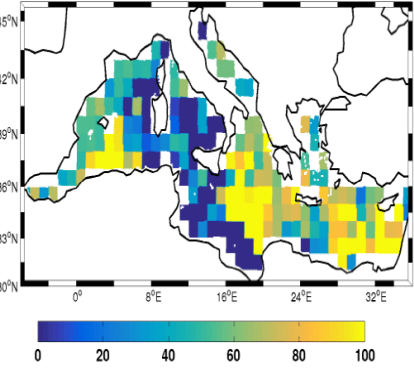
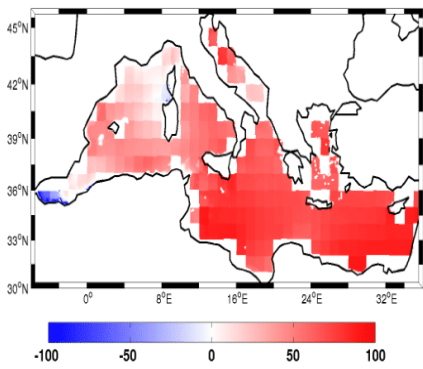
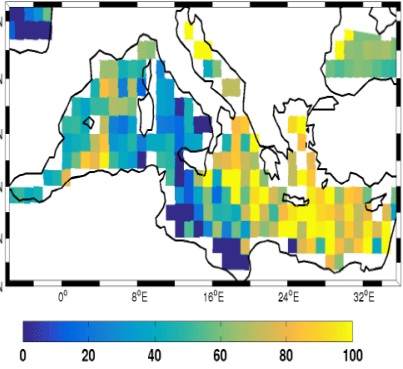
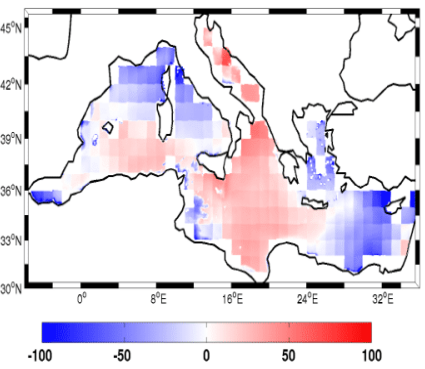


(c) BIAS %

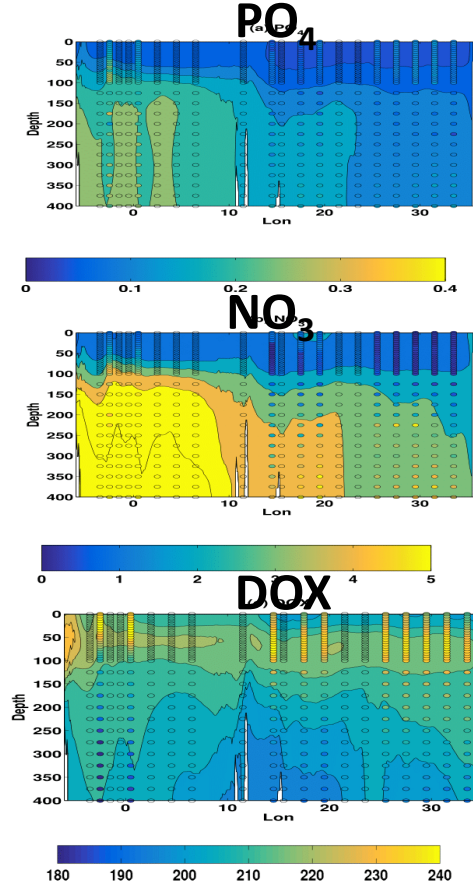
STD OBS %

(d) BIAS %

STD OBS %



Biogeochemistry : Dissolved nutrients and oxygen(vertical structure)



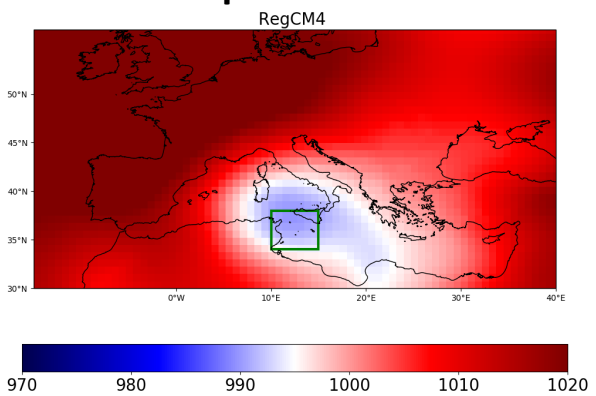
- Concentrations and vertical structures of both nutrients are very well simulated by RegCM-ES in the western Mediterranean
- RegCM-ES reproduces the progressive deepening of the nutricline associated with the depletion of nutrients from the euphotic zone associated with estuarine inverse circulation and phytoplankton growth.
- RegCM-ES reproduces the peak of dissolved oxygen in the Mediterranean Sea which follows the Depth chlorophyll maximum

Phosphate (a), Nitrate (b) and Dissolved oxygen (c) mean vertical concentration (first 400 m) calculated by the RegCM-ES (background colors) and from observations (WOA, colored dots). Units are in mmol/m³

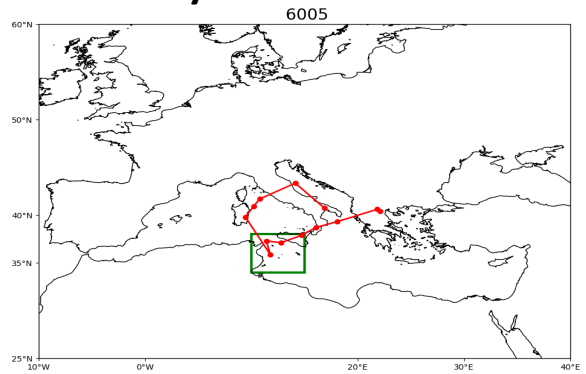
Reale et al., 2019 : The Regional Earth System Model RegCM-ES: Evaluation of the Mediterranean climate and marine biogeochemistry (in review, Journal of Advanced in Earth System Modeling)

Intense cyclone 2003-04-04-12UTC 989 hPa

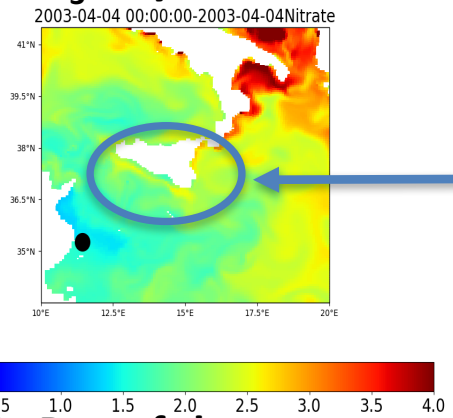
MSLP at the peak of the event



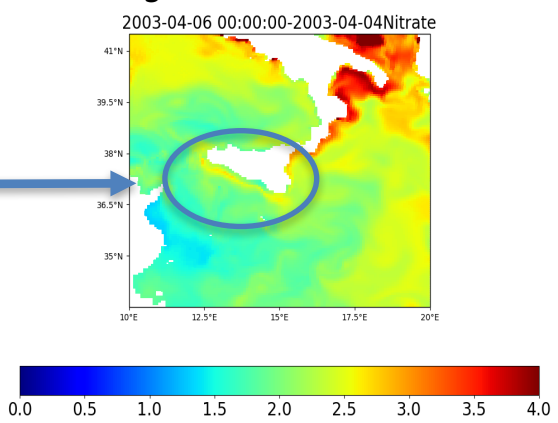
Cyclone track



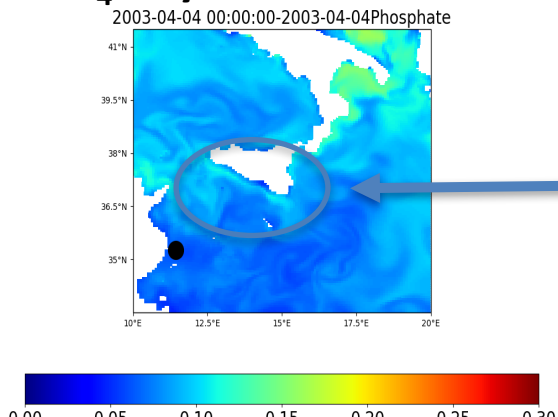
NO₃ Day of the event



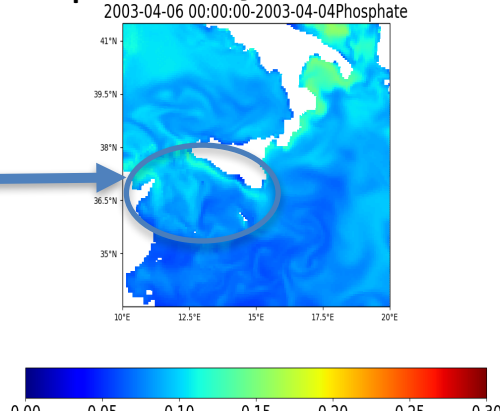
NO₃ Two Days after



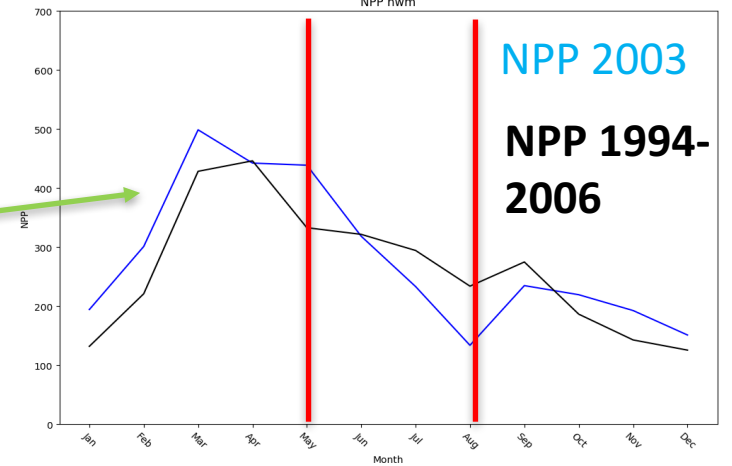
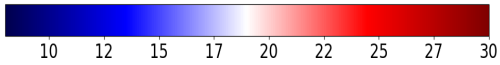
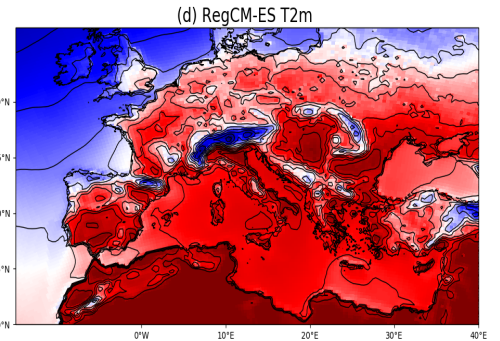
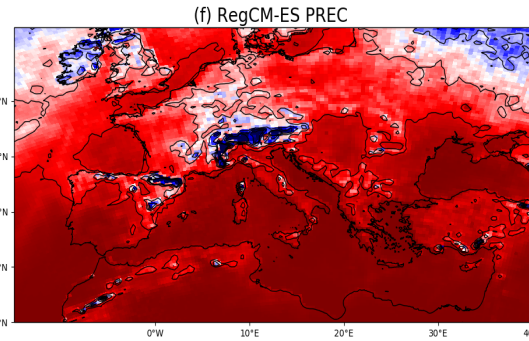
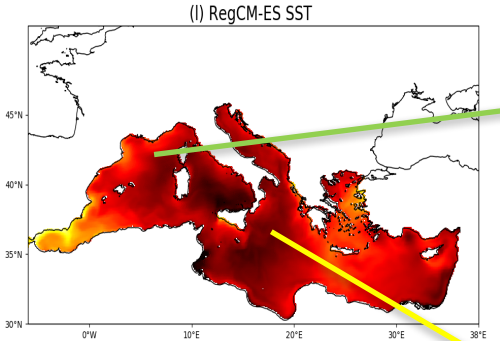
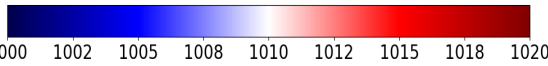
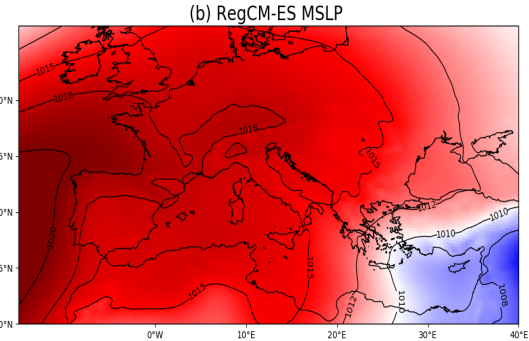
PO₄ Day of the event



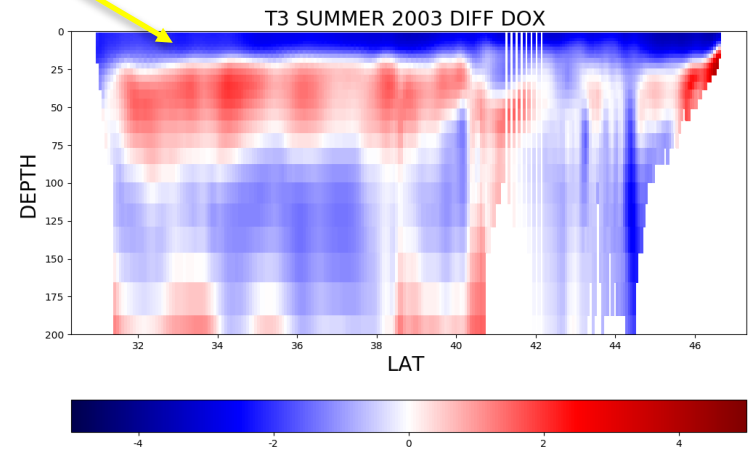
PO₄ Two days after



Application : 2003 Marine Heatwave (working in progress)



DOX 2003-DOX 1994/2006





Conclusions and future developments

- There is a new version of Regional Earth System Model RegCM-ES which has been tested for the first time over the Mediterranean region, and despite some persistent biases, showing an improvement in the simulated precipitation over the sea, evaporation, sea surface temperature and surface temperature (not shown) in the region with respect to previous versions or other Regional Earth System Model
- The model shows good skills in reproducing net primary production, chlorophyll-a, dissolved nutrients and oxygen patterns in the basin.

..thus there is a new modeling tool which potentially can apply in other regions of the world and suitable to be used in the study related to past variability/future climate changes including the biogeochemical dynamics.



Conclusions and future developments

We are still working on improving this new modeling tool..in particular we wish to include in our system:

- the simulation of river load of NO_3 using the carbon-nitrogen package included in the CLM4.5
- the use of high resolution ChyM river model for the simulation of the river discharge
- the activation of an advanced aerosol module available in the RegCM4 system
- the settings of O_2/CO_2 exchanges between atmosphere and ocean
- the use of the physical reanalysis ORAP and more advanced biogeochemical reanalysis as initial and lateral boundary conditions of the ocean and biogeochemical modules.



ISTITUTO NAZIONALE
DI OCEANOGRAFIA E DI GEOFISICA SPERIMENTALE

WCRP
CORDEX

14-18 OCTOBER 2019 BEIJING, CHINA

ICRC-CORDEX 2019

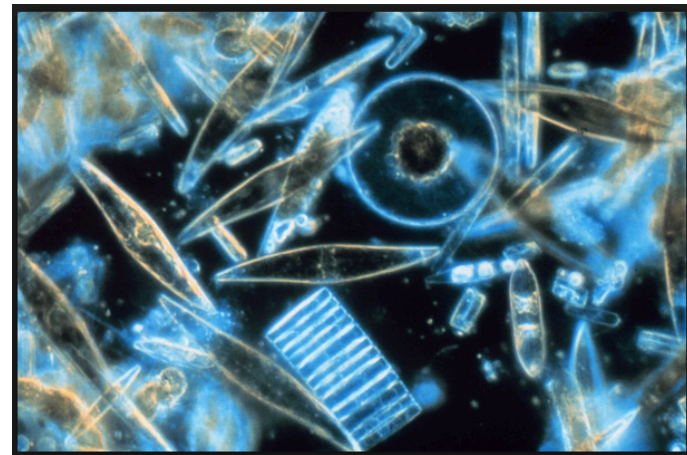
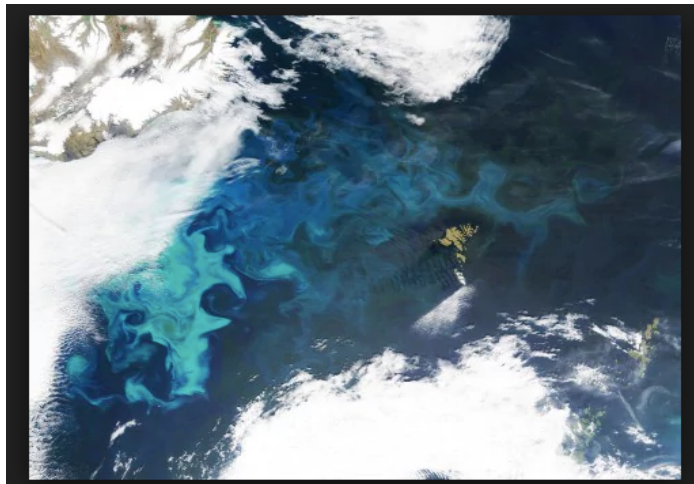
International Conference On Regional Climate



The Abdus Salam
International Centre
for Theoretical Physics

HPC Training and Research for Earth Sciences (HPC-TRES)

Let's keep in touch !!!!



M.Reale

reale.marco82@gmail.com

Thanks a lot for your attention!!!

Reale et al.,2019 : The Regional Earth System Model RegCM-ES: Evaluation of the Mediterranean climate and marine biogeochemistry (in review, Journal of Advanced in Earth System Modeling)