The Regional Earth System Model (RegESM): design and evaluation over the MED-CORDEX domain during the ERA-interim period 1980 - 2012

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Abstract

In the framework of global climate studies, there is an growing concern about the vulnerability of the Mediterranean region, where high population density and intense exploitation activities pose severe questions on the sustainability of terrestrial water management, both for the present and the future. On the other hand, also global feedback processes are expected in the Atlantic Ocean through the altered Mediterranean thermohaline circulation under conditions of global greenhouse warming (Thorpe et al, 2000, Somot et al. 2006). Due to the socioeconomic relevance of the expected climate impacts in the region, including water shortages, floods, and extreme winds, both experimental and numerical efforts have been devoted in the last years to fill the gaps of our knowledge of the current and future Mediterranean climate and its variability, in order to provide robust climate change information for use in vulnerability–impact–adaptation assessment studies.

The **Hydrological Cycle in Mediterranean Experiment (HyMeX) [1]** program is a 10-yr concerted experimental effort at the international level that aims to advance the scientific knowledge of the water cycle variability in all compartments (land, sea, and atmosphere) and at various time and spatial scales. It also aims to improve the processes-based models needed both for forecasting hydro-meteorological extremes and for predicting regional climate variability and evolution.

The **Mediterranean Coordinated Regional Downscaling Experiment (Med-CORDEX) [2]** initiative aims at coordinating the Mediterranean climate modeling community toward the development of fully coupled regional climate simulations, improving all relevant components of the system from atmosphere and ocean dynamics to land surface, hydrology, and biogeochemical processes. The primary goals of Med-CORDEX are to improve understanding of past climate variability and trends and to provide more accurate and reliable future projections, assessing in a quantitative and robust way the added value of using high-resolution and coupled regional climate models. In particular, the coupled Regional Climate System Models (RCSM) simulations will constitute the baseline runs in the forthcoming phase 2 of the Med-CORDEX initiative.

We present the results of the climate simulations performed at the Climate Modeling laboratory of ENEA with the **Regional Earth System Model (RegESM) [3]** in the framework of the Med-CORDEX initiative. Although state of the art climate models, implemented on high performing computing resources, can reach very high spatial resolution, many physical processes still take place on scales smaller than the one explicitly resolved, and physical parameterizations are needed. The choice between different available parameterizations for the same physical processes, as well as an accurate tuning of the parameters in a range of allowed values, are critical in order to model climate of a given region. The performance of the model has been tested against recent past climate using an evaluation run, i.e. a realistic simulation based on the regional downscaling of the ERA-interim re-analyses [4].

Experiment design

In its current configuration, RegESM active components are the 20 km horizontal resolution atmosphere (**RegCM 4.5**)[5], 1/12° ocean (**MITgcm**)[6] and river routing (**HD**)[7], all of them merged and managed by the driver, the Earth System Modeling Framework (**ESMF**) which is responsible for the interaction between the components (i.e. boundary data exchange, regridding) and their synchronization. A ***hindcast*** simulation on the MedCORDEX domain has been run with the objective of calibrating the parameterizations of the atmospheric component of the RegESM model and to evaluate the possible biases of the model, that must be properly taken into account when future scenario simulations are performed. The ERA-interim reanalysis dataset is used as initial and lateral boundary condition for the atmosphere.

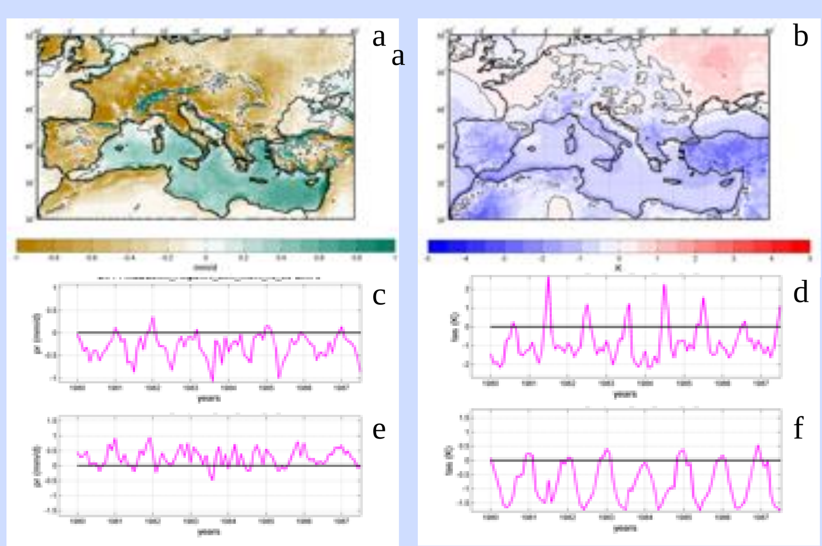

Figure 1. The RegCM4.5 systematic bias for rainfall (left column) and temperature (right column) in the calibrated configuration. The panels show the mean annual bias (a,b); the seasonal bias over land (c,d) and over sea (e,f).

By default, land emissivity is computed in the Biosphere Atmosphere Transfer Scheme BATS[8] by adopting a formula which relates emissivity to the corresponding estimated values of albedo. For desert and semi-desert regions, land surface emissivity has been set to the values estimated from direct satellite retrievals (column *Exp2* in Table 1) [9], and then slightly corrected to reduce the temperature model bias over the desert area which represent a large fraction of the entire model domain. The values of land surface emissivity adopted for our final configuration are reported in Table 1 under the column *Exp3*

BATS param	Soil type	Exp0	Exp1	Exp2	Exp3
Indemiss(11)	Emissivity - Semidesert	def	0.97	0.85	0.91
Indemiss(8)	Emissivity - Desert	def	0.965	0.76	0.86
Indemiss(19)	Emissivity - Forest/Mosaic field	Def	0.981	0.981	0.985

Table 1. Tuning of the land-surface emissivity

The model is run on **CRESCO4** in a sequential mode on 256 cpus, which turns out to be the best choice in terms of scalability of the models, over the given domain at the given resolution. The average CPU time for one year of simulation is around 1 day. However, given the relatively low requirements in terms of CPUs, multiple ensemble simulation might be performed.
Three-dimensional 6-hourly output data is stored during the model simulation. Therefore, the amount of storage required for the whole hindcast simulation, covering the years from 1980 to 2013, is of the order of 10 Tb. NetCDF libraries are used by RegESM to manage I/O format.

Present Climate Simulation 1980 - 2013

We run two simulations covering the whole period 1980-2013: fully coupled (CPL) and atmosphere stand alone (SA). Results are compared both to observations on the available common periods and among the two simulations, CPL and SA, in order to highlight the effects of the direct exchange of energy and fresh water between air and sea.

Atmospheric circulation

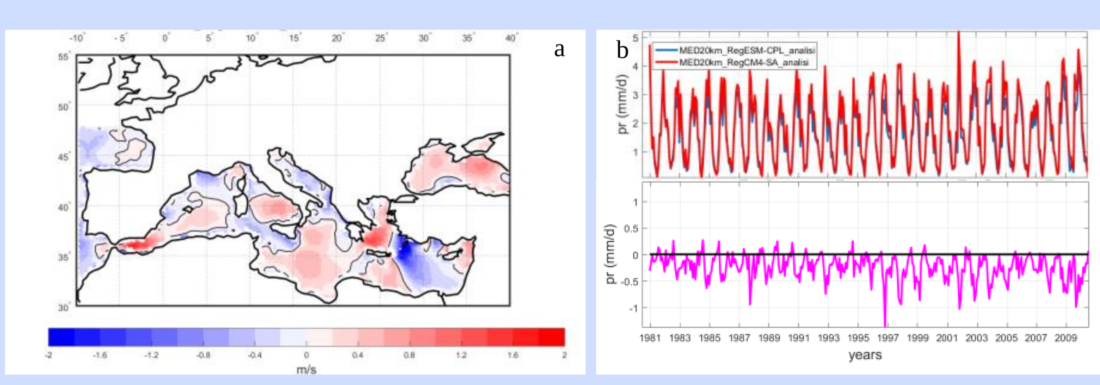

Figure 2. (a) Near surface wind speed over sea, JJA mean for the years 2000-2010. Difference Between CPL simulation and satellite observations from QuickSCAT .
(b) Time series of precipitation over the Mediterranean Sea: blue - CPL simulation, red - SA simulation, pink – difference CPL - SA

Wind speed over sea is in good agreement with satellite observations and the difference between the two datasets is mostly below ± 0.5 m/s, with the exception of the Aegean Sea region where such difference increases up to ± 2 m/s. Such discrepancy is due to the moderate horizontal resolution of the atmospheric model (20 km) that is not sufficient to describe the complex orography in the Cretan Sea and subsequently the peculiar wind circulation of the region.
The direct coupling affects the air-sea interactions, resulting in a general reduction of precipitation over the sea in the CPL simulation.

Sea Surface Temperature

The Sea Surface Temperature (SST) is a crucial variable to monitor in coupled climate simulations, as it at the same time regulates and is affected by the air sea fluxes. Figure 3 shows the difference (CPL – SA) of climatological (1981-2010) atmospheric surface temperature (ts) over the whole domain of the simulation. We note that the stand alone simulation uses the 6-hourly ERA-Interim SST dataset as a surface boundary condition. Over land this difference is lower than half degree, while over sea a general cold bias is detectable, more localized in the Eastern basin. The seasonal cycle and the time series of ts, averaged over the sea, show that the cold bias is higher during fall, winter and spring season. The time series of the difference between CPL simulation and the ERA-interim SST dataset do not show a significant trend. The cold bias over sea is quite common in climate coupled simulations, coherently with other experiments [3, 11].

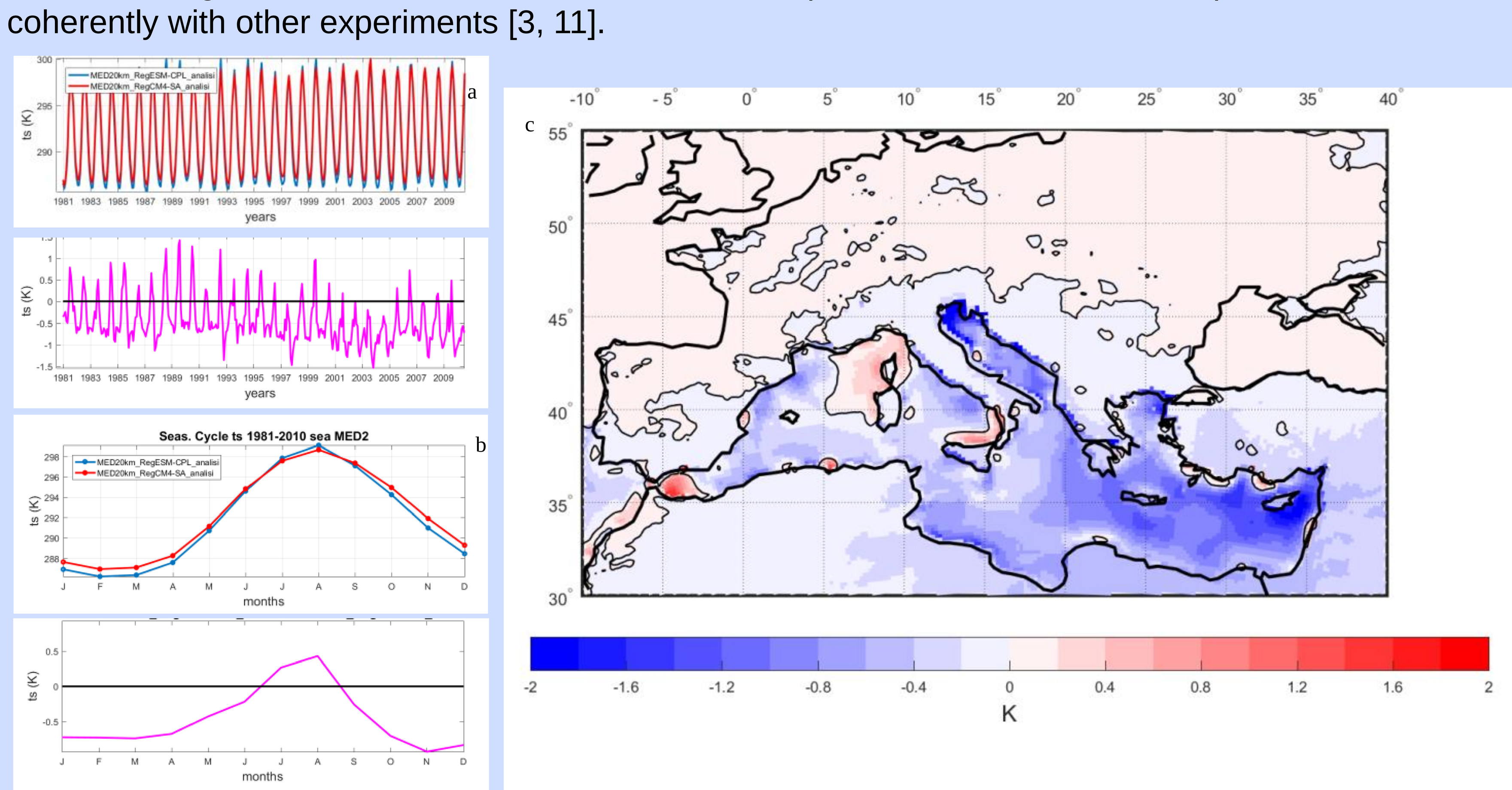

Figure 3. (a) Time series (1981 – 2010 of near surface temperature, blue - CPL simulation, red - SA simulation, pink – difference CPL – SA. (b) Seasonal cycle, colors as in (a). (c) Map of the difference of the surface temperature climatology CPL – SA.

Ocean Circulation

The Mediterranean Sea is a marginal sea characterized by its own peculiar thermohaline circulation (THC). Both winds and buoyant fluxes are important forcing for the Mediterranean Sea and an effort is required to study the regional climate as a unique atmosphere-ocean coupled system. The peculiarity of the Mediterranean Sea is to act as a machine that modifies the incoming fresh Atlantic Water (AW) into a denser Mediterranean water through a series of complex processes of sinking and mixing both in the open ocean and on the shelves. AW enters the basin at the Gibraltar Strait, where is first trapped in the Alboran Gyre, then follows the African coast flank. At Sicily Channel the flux splits in two parts, one enters the Tyrrenian Sea and the other enters the Eastern Basin where undergoes processes of dense water formation. The intermediate and deep waters so formed go back to the Western basin and close the THC of the Mediterranean with an outflow to the Atlantic Ocean in the intermediate levels, acting as a modulating signal for the global ocean circulation. The main deep water formation sites of the Med Sea are the Gulf of Lion, the Adriatic, the Levantine, clearly reproduced in our simulations.

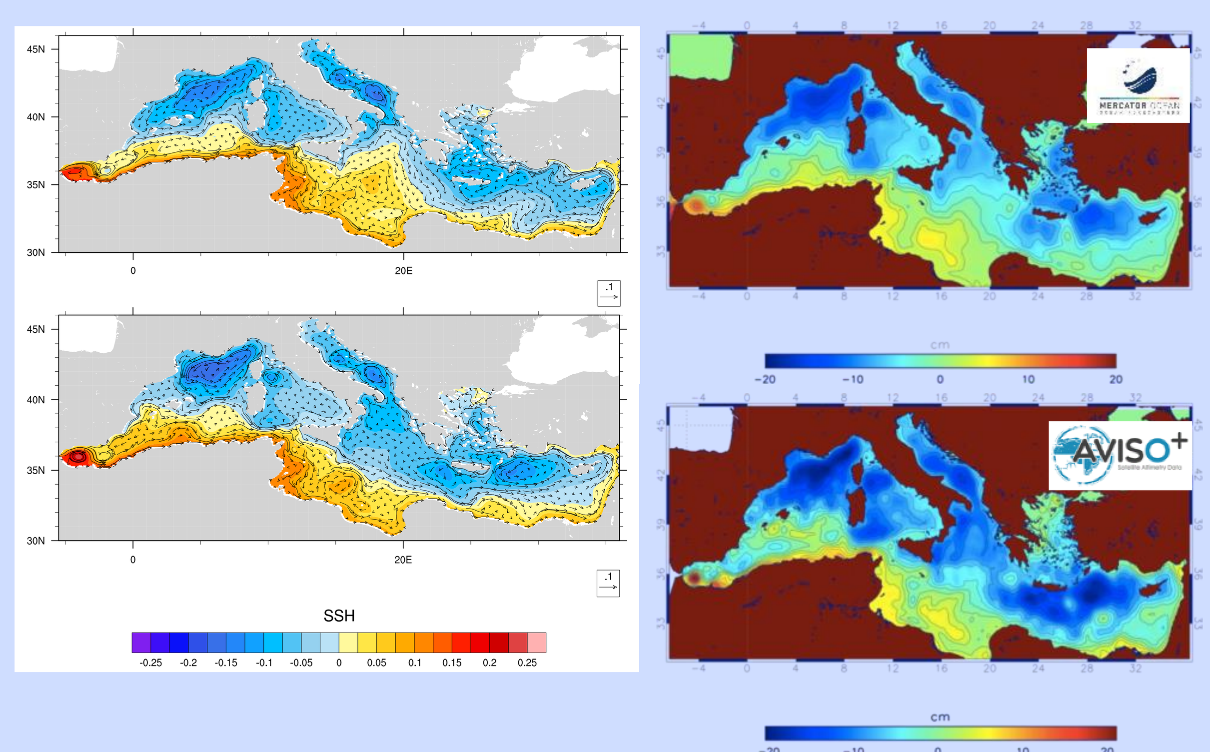

Figure 4
Left panels: Mediterranean surface circulation (15 m depth) and Sea Surface Height (color shadow). **Top** climatic mean 1980 – 2012 from CPL simulation. **Bottom** climatic mean 1980 – 2012 of a stand alone simulation at the same resolution.
Right panels: Sea surface height 1990 – 2013 from reference datasets.
Top: Ocean reanalysis by Mercator [12]
Bottom: Satellite observations from AVISO dataset [13]

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