Modeling of the Mediterranean climate system and climate projections

by Antonella SANNA

This paper synthesizes the main results of a recently ended EU funded project: the CIRCE project. The main objective of this project was the investigation and analysis of the Mediterranean climate under present and future scenario conditions, by means of numerical simulations. The different scenarios are presented.

Context

The Mediterranean region is particularly interesting from the climatological point of view due to its position, in a transitional area between tropical and mid-latitude variability, and to its complex orography and coastlines. Moreover, it is a very densely populated area, especially along the coasts, and was recently identified as one of the major hot-spots for climate change (GIORGI 2006).

In recent years, scientific community has devoted a strong interest on the Mediterranean region and its climate, through a number of international projects, such as the EU PRUDENCE (CHRISTENSEN *et al.* 2007) and ENSEMBLES (CHRISTENSEN *et al.* 2009). Those projects tackled the Mediterranean climate variability and future characterization from the atmospheric point of view, using atmospheric models, forced with prescribed lower boundary conditions (BC) and, thus, not taking into account any air-sea feedbacks. Moreover, the sea-surface temperatures (SSTs) used as BC for the air-sea interface come from results of global circulation models (GCMs), thus have a too coarse resolution to correctly reproduce the small-scale features of the Mediterranean dynamics. On this regard, MARCOS and TSIMPLIS (2008), analyzing the CMIP3 climate projections over the Mediterranean Sea along the 21[st] century, concluded that their resolution was too coarse to realistically simulate present climate Mediterranean dynamics. Consequently those models are not reliable as far as scenario projections are concerned.

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SOMOT *et al.* (2008), performing a series of simulations over the Mediterranean region, using a GCM coupled with an interactive high-resolution marine module for the Mediterranean Sea simulation, found results in good agreement with observations, as far as present climate is concerned. In their findings, Mediterranean region proved to be rather sensitive to the dynamics of its internal sea, in terms of climate change signal.

The CIRCE experiment was conceived following the spirit of SOMOT *et al.* (2008) and has been devoted to the analysis and understanding of climate variability and change over Mediterranean region.

CIRCE models

The modeling approach of CIRCE is a rather new one, gathering both global climate GCMs and regional climate models (RCMs). The main novel factor in the involved models is the presence of an interactive marine component at very high resolution for the realistic simulation of the Mediterranean sea dynamics.

CIRCE models have a typical spatial resolution ranging from 25km to 80km, as far as the atmospheric component is concerned, while the Mediterranean module resolution ranges from 7km to 12km. All models start from ocean initial conditions provided by climatological values (Levitus -Levitus 1982- or MedAtlas-II-MEDAR Group 2002). Atmospheric components restart from AMIP-type simulations. Model integrations start from an equilibrium state, obtained after a spin-up period with permanent greenhouse gasses (GHGs) concentrations, corresponding to 1950s conditions. Then the models have been integrated for the period 1951-2050, using prescribed GHGs according to observations until 2000 and to A1B SRES scenario from 2001 to 2050. More details on the project and the participating models can be found in GUALDI *et al.* (2012 and 2013).

All results here presented come from previously published papers (GUALDI *et al.* 2012, GUALDI *et al.* 2013, DUBOIS *et al.* 2012).

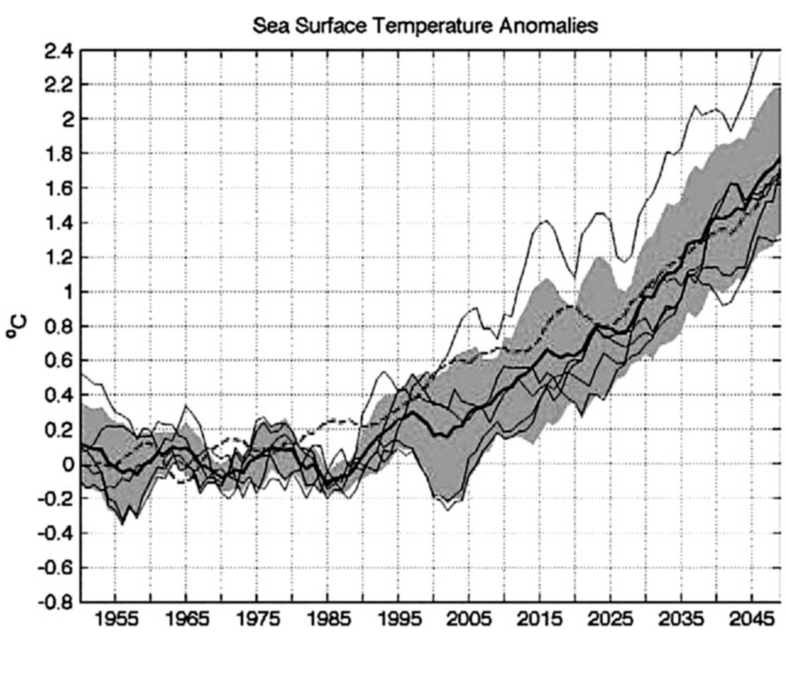


Fig. 1: Evolution of the SST anomalies (wrt 1961-1990) as simulated with the CIRCE models (thin black lines) and with the CMIP3 models (dashed line). The thick black curve is the CIRCE multimodel mean, whereas the shading is the CIRCE multimodel standard deviation wrt the multimodel mean. To highlight the long-term trends, the interannual variability has been filtered by applying a 5-year running mean. *(from Gualdi et al. 2013)*

Model validation: present climate

CIRCE model validation focuses on the surface fields of 2-meter temperature (T2m) and precipitation (evaluated in boreal summer and winter seasons), for the atmosphere, and the SST and mass and heat fluxes, for the marine component.

The observational dataset used for T2m and precipitation is the CRU TS 3 gridded observations (MITCHELL and JONES 2005). As far as the marine component is evaluated, heat and mass budget at Gibraltar are evaluated against results obtained in two recent papers, SANCHEZ-GOMEZ *et al.* (2011), who used the NOCS and HOAPS estimates, and Pettenuzzo et al. (2010), who used a statistical downscaling of ERA40-reanalysis. The present climate SST is contrasted against different datasets (ERA40-reanalises, Reynolds OI RSSTv2, ENEA OISST, MedAtlas-II).

Model results are compared also with the state-of-art CMIP3 GCMs, both for the atmospheric and the oceanic components, in order to highlight possible improvements or shortcomings deriving from the particular experimental set-up chosen within CIRCE project. Atmospheric fields and air-sea fluxes are compared also to ENSEMBLES project results, which are characterized by higher resolution.

Atmosphere

The present climate main features are reasonably well reproduced by CIRCE models. The major seasonal features of the observed T2m and precipitation fields (not shown) are quite well reproduced, especially in terms of spatial distributions. Compared with the state-of-the-art CMIP3 GCMs, seasonal mean precipitation appears to be improved, especially when related to the orographic forcing (see GUALDI *et al.* 2012 for further details).

However, systematic model errors remain substantial, both in terms of T2m and precipitation (more details can be found in ULBRICH *et al.* 2012 and GUALDI *et al.* 2012). CIRCE models are generally colder than observations by about 2°C, while, in terms of precipitation, they tend to overestimate rainfall over central Europe and to underestimate it over the Alpine region.

Mediterranean Sea

CIRCE models are characterized by a realistic structure of the Mediterranean SST (not shown), especially in terms of its gradients. However, all the models are affected by a cold bias wrt the observations.

The CIRCE set-up appears to be particularly beneficial when heat and mass budget over the basin are evaluated (not shown). For all of the models the net heat budget is negative at the Mediterranean surface, giving indication of a heat loss heat through the surface, which compensates the heat gain from the Atlantic at the Strait of Gibraltar. This behavior is in good agreement with the observations and is in contrast with the majority of the ENSEMBLES models.

In terms of water budget (not shown), CIRCE results confirm the evaporative character of the Mediterranean basin, known by the available observations. The net loss of water through the surface (especially in the eastern part of the basin) is compensated by a net water mass inflow from the Atlantic through the Strait of Gibraltar.

More details and figures can be found in DUBOIS *et al.* (2012), GUALDI *et al.* (2012), GUALDI *et al.* (2013).

Future scenario projections

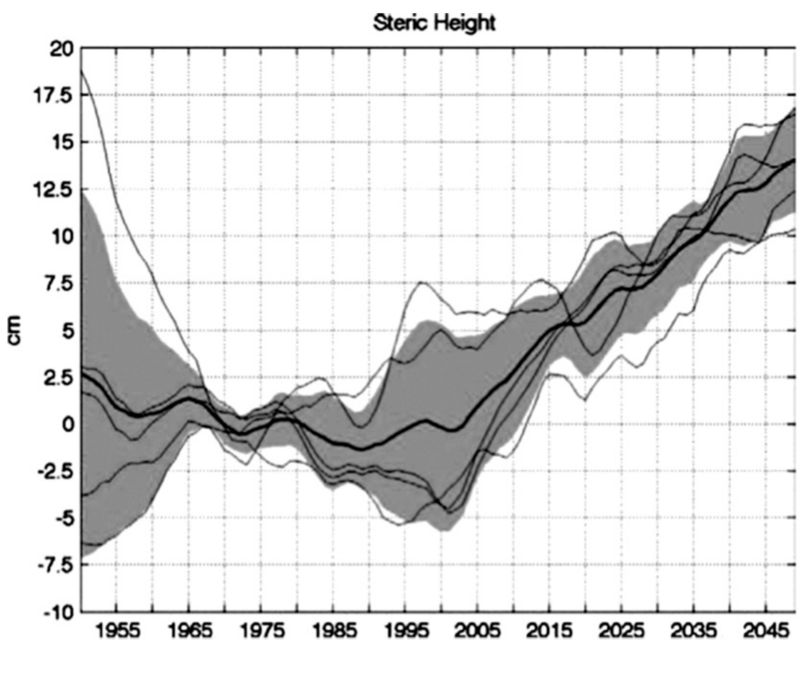
Future projections are evaluated for the IPCC scenario A1B. Specifically, climate change signal is expressed in terms of difference (or percentage difference, for precipitation) between mean values over the future period (2021-2050) wrt the reference period (1961-1990).

Model projections suggest a steady increase of the near-surface temperature (not shown), together with a positive trend in SST (from the second half of the 1980s, Figure 1). The change in precipitation is toward reduction (approximately -5%, not shown).

The water budget (not shown) will change toward an increase of the evaporative character of the Mediterranean basin, compensated by a more consistent Atlantic water inflow at Gibraltar.

The projected response for the heat budget (not shown) shows, in all of the models, an increase in short-wave heat gain (related to reduced cloud cover), a decrease in the long-wave heat loss (more radiation trapped in the atmosphere due to the greenhouse effect prevailing on the increased outgoing radiation due to the higher SSTs), a decrease in the sensible heat loss (the air-sea temperature gradient decreases) and an increase in the latent heat loss (due to increased evaporation). The mean simulated heat budget for

Fig. 2:
As Figure 1 but for the steric component of the sea level change.
(from Gualdi et al. 2013)



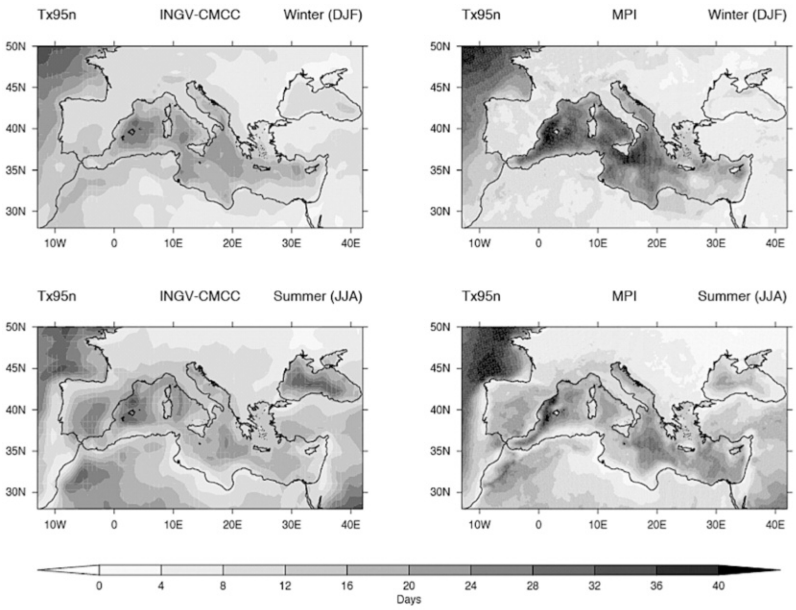


Fig. 3: Changes in the number of very hot days in winter (upper panels) and summer (lower panels) from a CIRCE GCM (left hand panels) and a CIRCE RCM (right hand panels) simulations for the A1B scenario. *(from Gualdi et al. 2012)*

the future period is of about -0.8 W/m2, leading to a weaker cooling of the ocean by the atmosphere.

All of the CIRCE models show significant positive trends of the steric sea level change (Figure 2), with a sea level rise in the range of +6 and +12 cm, in 2021-2050 wrt 1961-1990.

Changes in temperature extremes have been assessed using statistical indices. Figure 2 shows the climate change in the number of extremely hot days (with T2m exceeding the 95th percentile) in two CIRCE models: one GCM (INGV, left panels) and one RCM (MPI, on the right). For land areas, the largest increases in the number of very hot days are projected in summer and over the Iberian Peninsula. The 95th percentile threshold values for the reference period (1961-1990) are, however, lower over land than over sea, and hence the largest frequency increase in the number of very hot days appears over the sea areas. The increase in the hot day frequency comes along with a similar increase in the very hot night number and with longer warm spells and heat waves (not shown). On the other hand, consistently, the number of very cold days and very cold nights, together with cold spell duration, are projected to decrease (not shown).

As far as extreme precipitation events are concerned (not shown), in the southern Mediterranean region the intensity of heavy precipitation events is projected to decrease, due presumably to the increase of temperature, which reduces the soil moisture content in spring. In the northern Mediterranean region, on the other hand, model results suggest an intensification of heavy precipitation events, in all seasons but summer, presumably because the convective activity is enhanced. Those changes are not likely to be related to changes in large scale circulation, with the exception of south-eastern Mediterranean, where, by contrast, during all seasons but summer, the projected changes in the large-scale circulation will act to suppress the intensity of heavy precipitation events.

Conclusions

For the first time, the evolution of some key sea variables (e.g. SST, sea level, and water and heat fluxes) has been obtained at high resolution over the Mediterranean Sea and with a high degree of physical consistency, due to coherent air–sea flux interactions.

Compared with the CMIP3 simulations, the CIRCE models show some improvement in reproducing the seasonal means of T2m, precipitation and SST. However, the CIRCE simulations still show significant systematic errors in T2m and precipitation. Such errors are locally larger than those obtained with regional high-resolution atmospheric-only models (e.g., the ENSEMBLES models).

The CIRCE models provide a reasonably good estimate of the Mediterranean water budget and especially of the surface heat budget. In contrast with most of the ENSEMBLES models, the total heat budget in all of the CIRCE simulations is negative for the present period, with values in good agreement with observations, satisfying the heat closure budget controlled by the heat transport through Gibraltar.

The CIRCE projections indicate that remarkable changes in the Mediterranean region climate might occur already in the early few decades of the scenario. A substantial warming (almost 1.5°C in winter and almost 2°C in summer) and a significant decrease of precipitation (about 5%) might affect the region in the 2021-2050 period compared to the reference period (1961-1990), in an A1B emission scenario.

The projected surface net heat loss decreases in the future period, leading to a weaker cooling of the Mediterranean Sea by the atmosphere. In contrast, the water budget appears to increase in the next decades, leading the Mediterranean Sea to lose more water through its surface than in the past.

Furthermore, according to the CIRCE projections, the climate change might induce a 2021-2050 mean steric sea level rise that ranges between +6 and +12 cm, with respect to the period of reference.

CIRCE results represent a seminal effort in order to provide more physically consistent simulations for the Mediterranean region. The new international projects of HyMeX (Drobinski and Ducrocq, 2008) and MED-CORDEX (Ruti *et al.* 2011), currently on going, will continue and improve the CIRCE coupling approach, with the advantage of higher atmospheric resolutions.

A.S.

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Summary

This paper synthesizes the main results of a recently ended EU funded project: the CIRCE project. The main objective of this project was the investigation and analysis of the Mediterranean climate under present and future scenario (A1B) conditions, by means of numerical simulations. A plethora of climate models, ranging from global to regional, participated to CIRCE, with the common feature of an interactive high-resolution module, for the realistic simulation of the Mediterranean Sea dynamics. Model results show a realistic representation of the observed spatial patterns of the 2 meter-temperature and precipitation, despite quite substantial biases. Heat and mass fluxes over the Mediterranean basin are realistically simulated. The CIRCE projections for the twenty-first century suggest that remarkable changes in the climate of the Mediterranean region might occur already in the next few decades, with a tendency toward a warmer and dryer climate.

Résumé

Cet article résume les principaux résultats d'un projet financé par l'Union européenne, le projet CIRCE. L'objectif principal de CIRCE a été la recherche et l'analyse du climat méditerranéen actuel et dans les conditions du futur (scénario A1B), à travers des simulations numériques. De nombreux modèles climatiques, soit globaux soit régionaux, ont participé à CIRCE, avec comme caractéristique commune la présence d'un module à haute résolution pour la simulation réaliste de la dynamique en Méditerranée. Les résultats des modèles indiquent une représentation réaliste des structures de la température à 2 mètres et de la précipitation observées, malgré des biais non négligeables. Les flux de chaleur et masse sur la Méditerranée sont simulés de manière réaliste. Les projections de CIRCE pour le XXI^{e} siècle indiquent que des changements climatiques importants vont se produire dans la région méditerranéenne et ses alentours, dès les prochaines décennies, avec une tendance vers un climat plus chaut et sec.