Installation and Testing of the Regional Climatic Model COSMO-CLM (CCLM) at the Hellenic National Meteorological Service

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Abstract As a founding member of the COSMO Consortium, the Hellenic National Meteorological Service considers the climatic version (CCLM) of the COSMO Model as a suitable candidate towards the investigation of the climate of the wider area of Greece as well as a potential tool for seasonal forecasting. Of particular importance is the non-hydrostatic formulation of the Model that makes it applicable for downscaling at a horizontal spatial resolution between 1 and 20 km. The model performance is examined at the 0.0625^0 resolution for the wider area of Greece. The forcing was applied by employing dynamical downscaling on the existing results of CCLM over the MENA-CORDEX domain at 0.22^0. These data were provided by CMCC Foundation, where CCLM was forced by the CMCC-CM global model over the period 1979-2005 for the historical simulation. At a later stage, the goal is to go beyond this period by using the results from GCM CMCC-CM for scenario simulations over the 21st century according to the IPCC RCP4.5 scenario.

1 Introduction

Over the last twenty years, regional climate (RCM) models have been developed as the natural complement of their global counterparts (GCM) mainly towards the direction of dynamical downscaling (Giorgi and Mearns, 1991). A principal motivation of this development stands on the possibility to resolve climatological issues on the local scale, a critical endeavor from the scientific perspective but also in relevance to the various resulting policies regarding long-term environmental issues. Furthermore, high resolution allows the possibility to obtain more detailed climate analysis and scenarios, which can be useful for several applications, especially as input for impact models (Rianna et al., 2016). The significance of these features is highlighted by the WCRP (**W**orld **C**limate **R**esearch **P**rogramme) of WMO (World Meteorological Organization) through the CORDEX

(**CO**o**R**dinated Climate **D**ownscaling **Ex**periment) (Giorgi et al., 2009). Within this framework, the climatic version of COSMO numerical weather prediction model CCLM (COSMO Climatic Limited-area Model, https://www.clm-community.eu/) (Rockel et al. 2008) is addressing state of the art climatic studies almost in every CORDEX designated area and in a wide range of applications (Jacob et al., 2014). As a founding member of COSMO (Consortium of Small Scale Modeling, http://www.cosmo-model.org/), the Hellenic National Meteorological Service (HNMS) considers CCLM as a suitable candidate to cover the ever increasing need for high level climatological products. Upon the successful installation of CCLM at the Cray XC super-computing system of ECMWF (European Center for Medium Range Forecast), it was considered to test the model pragmatically by downscaling the CCLM results obtained by CMCC (Centro EuroMediterraneo sui Cambiamenti Climatici) Foundation for the wider MENA CORDEX domain (Bucchignani et al. 2016b, Bucchignani et al. 2018). More specifically, a high-resolution simulation (0.0625°) was performed over the wider Eastern Mediterranean area with an emphasis on Greece for the period 1979-2005 (Figure1) nested into the MENA-CORDEX domain at 0.22° resolution.

Fig.1. MENA-CORDEX domain (left). The orange line indicates the domain used to perform the simulations at 0.0625^0. The right figure denotes the positions of the considered meteorological stations along with the last three digits of their international code numbers.

As an indication of the model performance, the computed average monthly mean values for 2-meter Temperature (T2m) has been considered, being the most basic climatic variable. Modeled T2m values were found to be in fair agreement with those provided by the climatological database of HNMS for nine selected meteorological stations spread over the whole area of Greece. Moreover, the seasonal variability was consistent with the climatological values and is represented for four stations.

2 Data and Methodology

The domain under consideration covers the wider area of Central and Eastern Mediterranean with Greece in the middle (orange frame in Figure 1) discretized with a horizontal grid of 0.0625^0 (~6.5 km) (360x260 points), 40 vertical levels and 40 seconds integration time-step. The model was forced with data provided by CMCC related to a GCM driven simulation with CCLM over the MENA-

CORDEX domain shown on the left part of Figure 1 (Bucchignani et al , 2016b) discretized to 524x226 points under a horizontal grid of 0.22^0 (~25 km) 40 vertical levels and 40 second time-step.

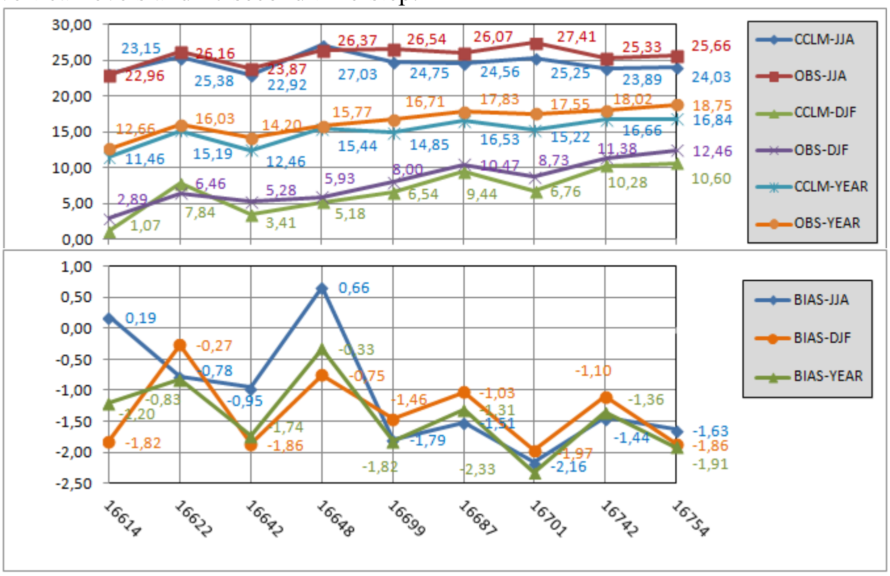

Fig.2. (Upper panel) Mean monthly T2m averages (deg C) over the period 1979-2005 of model and observed values. CCLM-JJA and OBS-JJA (summer months). CCLM-DJF and OBS-DJF (winter months) CCLM-YEAR and OBS-YEAR (whole year) – (Lower panel) corresponding mean biases BIAS-JJA, BIAS-DJF and BIAS-YEAR respectively for the selected Greek meteorological stations displayed in the right part of figure 1.

The GCM used is CMCC-CM (Scoccimarro et al., 2011), a coupled atmosphere-ocean general circulation model, which was developed in the framework of European project CIRCE. The atmospheric model component is ECHAM5 (Roeckner et al., 2003) with a T159 horizontal resolution (about 80 km). The version 5.0_clm9 of CCLM was used in this investigation. The model ran at ECMWF's High Performance Computing Facility (HPCF) on the Cray XC40 system which is currently rated 36th among world's top 500 supercomputer systems (http://www.top500.org/list/2018/06/). This outstanding resource completed a 27-year run covering the period 1979-2005 using 40 nodes of the system providing 10 Terabytes of data stored at ECFS (**EC**MWF's **F**ile **S**torage system). Due to the very recent completion of the runs, the manipulation of these data is expected to be a formidable task and is left at a later stage. However, as a first attempt to gauge the soundness of the model, hourly meteograms of sixty metereological stations over Greece were produced based on the nearest grid point to their geographical coordinates. From these meteograms, nine stations were selected and their mean monthly T2m were compared with those of the existing climatological database of HNMS. The selected meteorological stations are spread over the whole domain of Greece to address the model performances in reference to the various climatological features of the country. The stations of Thessaloniki (LG16622), Nea Filadelphia (LG166701) and Heraklion (LG16754) were chosen as a skeleton regarding the zonal nature of the mainland as well as the main metropolitan areas of Greece. Some of the continental climatic features are addressed via the choice of the stations of Kastoria (LG16614), Ioannina (LG16642) and Larissa (LG16648). The station of Araxos (LG16687) positioned relatively closer to the coastline is also considered along with the island station of Kos (LG16742) and the station of Tanagra (LG16699) positioned north of Attica and the metropolitan area of Athens.

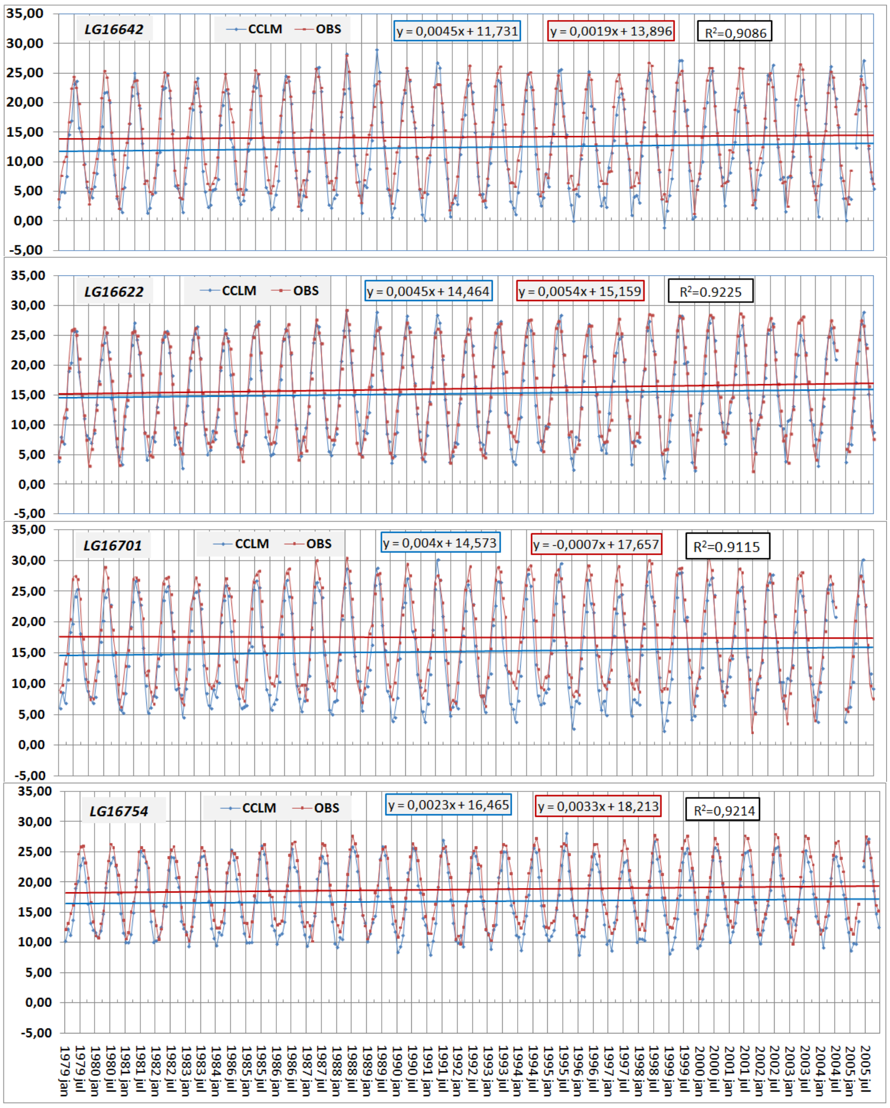

Fig.3. Monthly average T2m (deg C) over the period 1979-2005 for stations LG16642 (upper panel), LG16622 (middle panel), LG16701 (third from top) and LG16754 (bottom panel) for CCLM against observations along with the corresponding trend lines and coefficients of determination R^2.

3 Results

In the upper part of figure 2, the average mean monthly values over the period 1979-2005 as well as for the summer and winter months are presented against the corresponding values derived from the climatological database of HNMS, for some of the selected stations. The seasonal and annual trends provided by the model are consistent and in fair agreement with the climatological values. In principle, the model underestimates T2m with the exception of summer months for Larissa (LG16648) and Kastoria (LG16614) stations where the mean bias (Bias-JJA) is positive however small (i.e. 0.19^0C and 0.66^0C respectively) as it can be seen in the lower panel of figure 2. With the exception of these cases, the overall mean bias is negative, ranging from -0.27^0C for Thessaloniki (LG16622) station winter bias (BIAS-DJF) to -2.33^0C for Nea Filadelphia (LG166701) station. A part of this bias has been inherited by the GCM, as already shown in similar works (Bucchignani et al., 2016a). The shortcoming of COSMO-CLM, leading to underestimation of winter temperature especially at high altitudes, has already been highlighted in several works, such as Kotlarski et al. (2014), and could be due to inadequate representation of complex orographic areas. Another feature is related to the overall temperature range, which is lower for the stations that refer to the islands of Kos (LG16742) and Crete regarding Heraklion (LG16754) than the continental stations of Kastoria (LG16614), Ioannina (LG16642) and Larissa (LG16648). This can also be verified in figure 3 where the monthly average T2m values are displayed over the period 1979-2005 for the selected stations, with an emphasis to latitude positions from north to south. There is a clear difference between the average monthly variability of approximately 25^0C (0^0 - 25^0) in Ioannina to 15^0C (10^0 - 25^0) in Heraklion. A addition, the seasonal variability is clearly shown for all stations in figure 3 and in relatively good agreement with observations within the limitations addressed by the mean biases of figure 2.

4 Conclusions

Although this effort was mainly devoted to testing purposes regarding the installation and implementation of COSMO-CLM at HNMS, the results are encouraging justifying the substantial computational resources used so far. The model looks generally able to simulate the climatological features of Greece, leaving plenty of space for improvement. However, a more systematic testing is necessary in compliance with the standards demanded by the community of climatology, in particular considering other variables besides temperature. It is worth noting that MENA-CORDEX domain could not be the best choice for Greece, since Greece lies relatively far from its center to its north side, but the results look realistic. This acts as a motivation for further climatic simulations behind the presented run that will cover the whole 21st century, a work actually in progress, considering the IPCC RCP4.5 scenario (Moss et al., 2010). Such an endeavor could be also used as a benchmark for further downscaling activities. In particular, EURO-CORDEX domain data could be used as forcing, since Greece is better placed close to the center of this domain. This might lead to a substantial improvement towards the understanding of the development of the climate of Greece and the Mediterranean in general on the local scale.

Acknowledgments

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