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Simulation of the period 1979-2011 over China with the regional climate model COSMO-CLM

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SUMMARY The present study describes a simulation of the past period 1979-2011 performed with the regional climate model COSMO-CLM over the Chinese region. To carry out this simulation, the ERA-Interim Reanalyses have been used as forcing and a resolution of 0.125° (about 14km) has been adopted. The results have been validated by using the CRU observational dataset.
This activity has been conducted in the framework of WP 7.1.6 of the "B action" in the Gemina project, whose main aim is to develop high resolution climate projections over China for XXI century.

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INTRODUCTION

The need for climate change information at regional-to-local scale is one of the central issues within the global change debate. This is mainly due to the requirements of policy and decision makers by planning reliable and adequate strategies, plans and action of adaptation to the impacts caused by climate change.
As reported in the white paper of China government, China is one of the most susceptible countries to the adverse effects of climate change. It is interested by a variety of different climates due to its dimensions and its complex topography, with the presence of the highest mountains of the world. As a consequence, the usage of a Regional Climate Model (RCM) with a high horizontal resolution can be a useful tool for the description of its climate, providing a better description than Global Models (GCMs), that have a too coarse resolution for impacts and adaptation applications.
The activities of GEMINA WP7.1.6 represent the first attempt of CMCC ISC team to perform climate simulations in Asia, and in particular over China, with COSMO-CLM. For this reason, it was necessary to conduct a preliminary analysis [2] aimed to choose an optimal model set up, suitable to reproduce in a realistic way the present climate of the area under study.
The selected configuration of the model has then used to perform a climate simulation over the whole Chinese area for the past period 1979-2011, in order to assess the capabilities of COSMO-CLM to properly reproduce the recent climate of China. Initial and boundary conditions are provided by ERA-Interim reanalysis. This report contains a description of the simulation and an analysis of the results. The document is organized as follows: Section 2 is devoted to a brief description of the model, simulation set-up and observational datasets. In Section 3, results related to the analysis of two-meter temperature (mean, minimum and maximum values), precipitation and total cloud cover distribution are shown and compared with observations. In Section 4, finally, a summary of the main results and a discussion is presented.

2. THE REGIONAL CLIMATE MODEL AND OBSERVATION

COSMO-CLM

The CCLM [7] is the climate version of the COSMO model [10], the operational non-hydrostatic mesoscale weather forecast model developed at German Weather Service (DWD). Successively, the model has been modified by the CLM-Community, in order to develop also climatic applications. The updates of its dynamical and physical packages allow its application in cloud resolving scales.
The regional climate model COSMO-CLM can be used with a spatial resolution between 1 and 50 km even if the non hydrostatic formulation of dynamical equations in LM made it eligible especially for the use at horizontal grid resolution lesser than 20 km [1]. These values of resolution are usually close to those requested by impact modelers; in fact these resolutions allow describing terrain orography better than global models, where there is an over- and underestimation of valley and mountain heights, leading to errors in precipitation estimation, as this is closely related to terrain height. Moreover the non-hydrostatic modeling allows providing a good description of the convective phenomena, which are generated by vertical movement (through transport and turbulent mixing) of the properties of the fluid as energy (heat), water vapour and momentum. Convection can redistribute significant amounts of moisture, heat and mass on small temporal and spatial scales. Furthermore convection can cause severe precipitation events (as thunderstorm or cluster of thunderstorms).

The mathematical formulation of COSMO-CLM is made up of Navier-Stokes equations for a compressible flow [4]. Atmosphere is treated as a multicomponent fluid (made up of dry air, water vapour, liquid and solid water) for which the perfect gas equation holds, and subject to gravity and to Coriolis forces. The model includes several parameterizations, in order to keep into account, at least in a statistical manner, several phenomena that take place on unresolved scales, but that have significant effects on meteorological interest scales (for example, interaction with orography). The main features of COSMO-CLM are:

- Nonhydrostatic, full compressible hydro-thermodynamical equations in advection form.
- Base state is hydrostatic, at rest.
- Prognostic variables are: horizontal and vertical Cartesian wind components, pressure perturbation, temperature, specific humidity, cloud water content. Optionally: cloud ice content, turbulent kinetic energy, specific water content of rain, snow and graupel.
- The coordinate system is a generalized terrain-following height coordinate with rotated geographical coordinates and user defined grid stretching in vertical direction. Options for (i) base-state pressure based height coordinate, (ii) Gal-Chen height coordinate and (iii) exponential height coordinate (SLEVE) according to [8].
- Grid structure is an Arakawa C-grid with Lorenz vertical grid staggering.
- Time integration is based on a time splitting between fast and slow modes (Leapfrog, Runge-Kutta).
- Spatial discretization is performed with a second order accurate Finite Difference technique.
- Parallelization is based on a Domain Decomposition (MPI as message passing S/W).
- Parameterizations available are: Subgrid-Scale Turbulence, Surface Layer Parameterization, Grid-Scale Clouds and Precipitation, Subgrid-Scale Clouds, Moist Convection, Shallow Convection, Radiation, Soil Model, Terrain and Surface Data.

The versions used of INT2LM and COSMO-CLM are respectively: int2lm_091216_1.10_clm2 and cosmo_090213_4.8_clm19. In COSMO Model, the soil model `TERRA_ML` is implemented, which includes melting processes, while convection scheme used is the Tiedtke one.

THE AREA OF INTEREST

In the present work, numerical simulation has been performed over the domain (60 -130 E; 16 - 44 N), including the whole Chinese area (Fig. 1). A spatial resolution of 0.125° (about 14 km) has been employed.

The time period investigated by this numerical simulation is 1979-2011. The domain analyzed is discretized with a grid of 448 x 236 points, with 40 atmospherical vertical levels and 7 soil levels plus a climatological layer (depths of the different soil levels are 0.005, 0.02, 0.06, 0.18, 0.54, 1.62, 4.86 and 14.58 m). In order to neglect the error due the usage of global models, ERA-Interim Reanalysis [3] have been used as forcing data. ERA-Interim dataset is characterized by 512 x 256 grid points, 60 atmospherical

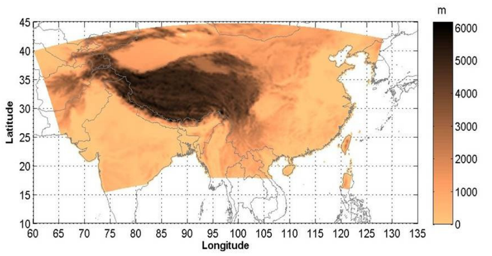


Figure 1:
Orography of the domain under study.

vertical level and 3 levels of soil and it has a horizontal resolution of 0.703° (about 80 km). Boundary conditions are updated every 6 hours, while results are saved every 6 hours. Time step has been set equal to 100 sec.

THE SELECTED NAMELIST

In order to find an optimal COSMO-CLM configuration for the Chinese area, a sensitivity analysis has been performed. Results have already been presented in [2]. Here we would like to remind that analysis was conducted running eight configurations, differing one another by one or more key parameters. COSMO-CLM model offers the opportunity to use different options for model domain, formulation of model physics and dynamics, by setting values of the so called NAMELIST Parameters, grouped in NAMELIST blocks of COSMO model, being more than 150 parameters. Previous studies have highlighted that configuration of a regional model in general cannot be transferred directly to other climatic areas straightforward, but rather making specific modifications requested in each case.

The activity was conducted considering a smaller domain located in north-east part of China (111 - 123 E; 29 - 41 N) over time period 1996-2000, forced by perfect boundary conditions ERA40 Reanalysis [11]. The selected configuration was the one characterized by: a standard implicit treatment of vertical diffusion in the solver for slow processes; Neumann boundary conditions for heat and moisture transport at the lower boundary (specified fluxes) instead of Dirichlet boundary conditions (specified values).

THE OBSERVATIONAL DATASET

Results have been compared with the Climate Research Unit (CRU) monthly mean global gridded dataset [5]: it has been developed at the University of East Anglia; it provides monthly observed data of several variables, such as mean, minimum and maximum temperature, total precipitation amount and cloud cover, at a resolution of 0.5° (about 60 km). It is based on in-situ measurements from a large number of stations from different sources. Climate surfaces have been constructed from station data, interpolated as a function of latitude, longitude and elevation using thin-plate splines.

3. ANALYSIS OF RESULTS

The main goal of this work is to assess the quality of climate model data through a comparison with the mentioned observational dataset. Two different periods have been considered for the analyses of results, according with the availability of observational data: for two-meter mean temperature and precipitation, the analyses have been conducted on the period 1980-2006, whereas for minimum and maximum temperature and for cloud cover the period analysed is 1980-2002. In both the cases, the first year (1979) of simulation has been neglected to exclude the spin-up period influenced by initial conditions.

Fig. 2 shows the mean two-meter temperature (T2m) bias distribution (°C) of COSMO-CLM with respect to the CRU dataset for the four

seasons. A high cold bias ($> 5^oC$ in absolute value) is observed over north-west part of Tibet and Himalaya, along with a hot bias over the Taklamakan desert in all seasons, especially in JJA. A better agreement is registered over central and eastern parts of the domain, especially in SON (in wide areas, bias is lesser than 0.5°C).The strong temperature bias found in some regions is similar to the one shown by Wang et al. (2013) [12], where a bias ranging between $\pm5\ K$ is shown, with extreme biases of $\pm10\ K$ over Himalaya and Karakorum.
In order to perform a deeper and local analysis, seasonal cycles of T2m have been evaluated over two sub-regions (Fig. 3), characterized by different orographic features: EAST domain, very similar to the one used for the sensitivity analysis (low altitude area), and WEST domain (high altitude area). Fig. 4 shows the seasonal cycles of T2m (a) and of its related bias (b) with respect to observations. It is evident that seasonal cycles are well captured for both areas. They show a slight overestimation in EAST domain and a slight underestimation in the WEST one. Nevertheless, the bias never exceeds $\pm2°C$.

Fig. 5 shows the seasonal cycles of minimum T2m (a) and of related bias (b) with respect to observations, highlighting a general overestimation in both the domains, with a bias ranging between 0.5^oC and 3^oC; concerning the maximum temperature (Fig. 6), instead, a slight overestimation occurs in EAST domain (average value of about 1^oC), while in WEST domain cold months are characterized by strong underestimation (up to 3.5^oC).

Fig. 7 shows the map of bias of 10^{th} (a) and 90^{th} (b) temperature percentile. They look very similar to the map of temperature bias; a more pronounced hot bias occurs over north west part of the domain for the 90^{th} percentile.

Fig. 8 shows the mean monthly total precipitation bias distribution (mm/month) of COSMO-CLM with respect to the CRU dataset for the four seasons. A good agreement is registered in DJF and SON, while higher bias are reported in MAM and JJA, with a strong overestimation (exceeding 150 mm/month) in the area on the boundary line among China, east India and Myanmar. The bias maps have similar pattern and same range as the results by Rockel and Geyer (2008) [6], although the setting of their simulation was quite different from the present one. The precipitation climatology of the area is well represented if compared with the results reported in [13] (in the cited paper, data from about 330 station are analyzed).
Precipitation seasonal cycles have been evaluated over the same sub-regions considered for T2m. Fig. 9 shows the seasonal cycles of total precipitation (a) and of its related bias (b) with respect to observations, which are quite well captured. In WEST domain, an overestimation occurs in all months (stronger in May, where a peak of 55 mm/month of difference is reached). EAST domain is also characterized by a general overestimation, with the exception of some months (January, July and from October to December). Generally, bias ranges between -15 and 55 mm/month.

Concerning the percentiles of monthly precipitation, the map of bias of 10^{th} percentile (Fig. 10 (a)) show a high negative bias over south-east (greater than 30 mm/month in absolute value), whereas the map of bias of 90^{th} percentile (Fig. 10 (b)) shows a general overestimation of the high precipitation values, with the exception of some area (in particular the north-west China).

Fig. 11 shows the total cloud cover bias distribution (%) of COSMO-CLM with respect to CRU dataset for the four seasons. DJF map is characterized by the highest differences with respect to the observations, with an overestimation in north-west and an underestimation in south-east (both with peaks higher than 30% in absolute values). Other seasons exhibit a less pronounced bias, with a very good agreement in JJA, where generally the error never exceeds 20%.

Finally, time series of mean, minimum and maximum T2m (°C) (Fig. 12) have been analyzed over the two above mentioned sub-domains (Fig. 3).
The minimum temperature shows the highest error, with a general overestimation in both domains (about $2°C$); mean values are better represented, especially in WEST sub-domain, where the error does not exceed $1°C$. Concerning trend values, CRU data are always higher for mean, minimum and maximum temperature and in both the sub-domains, although this difference is more evident for the minimum temperature.
It is important to highlight that, according to Mann-Kendall results, trends are statistically non significant, since p-values are always higher than 5%.

However, for a better and more deepened comprehension of the results, further analyses are necessary through the use of other observational datasets, with a higher resolution.

5. CONCLUSIONS

In the present work, a high resolution regional climate simulation over China performed with COSMO-CLM has been presented. The representation of Chinese climate is quite difficult, due to the large extension of this area and to the presence of different climate conditions. However, validation has highlighted quite good results, with a bias similar to those reported in other literature works.

Concerning temperature, high biases occur in the north-west part of the simulated domain, where sudden discontinuities between areas with hot and cold biases are evident. Better performances are shown on the eastern China. Concerning precipitation, JJA is characterized by the worst results, with an overestimation in the middle part of the domain and an underestimation in the other ones. In general, highest bias are related to high orography zones. For this reason, a correction based on the difference between the orography of observations and of the simulated domain will be performed. It is worth noting that the bias found can be attributed not only to the model, but also to the low quality of observational dataset in some areas.

Finally, a climate projection with COSMO-CLM forced by the global model CMCC-CM [9] over the time period 1979-2100, employing the RCP4.5 emission scenario, is currently under development.

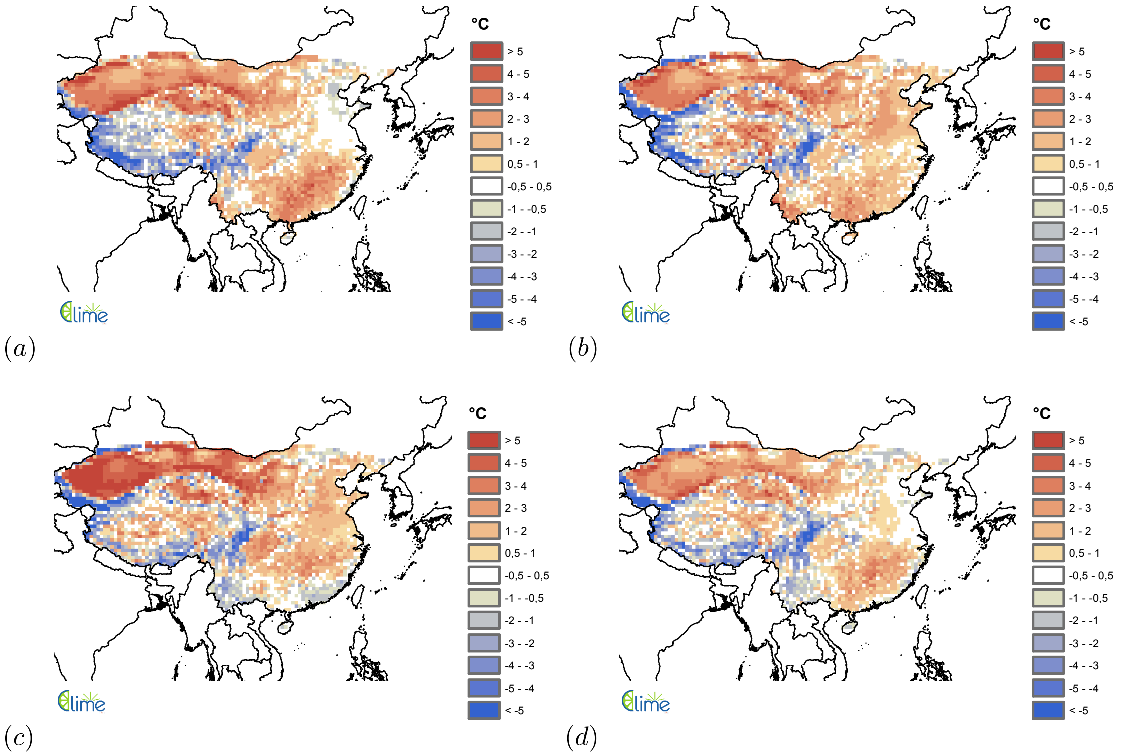


Figure 2:
Bias of two-meter temperature with respect to CRU dataset for DJF(a), MAM (b), JJA (c), SON (d)

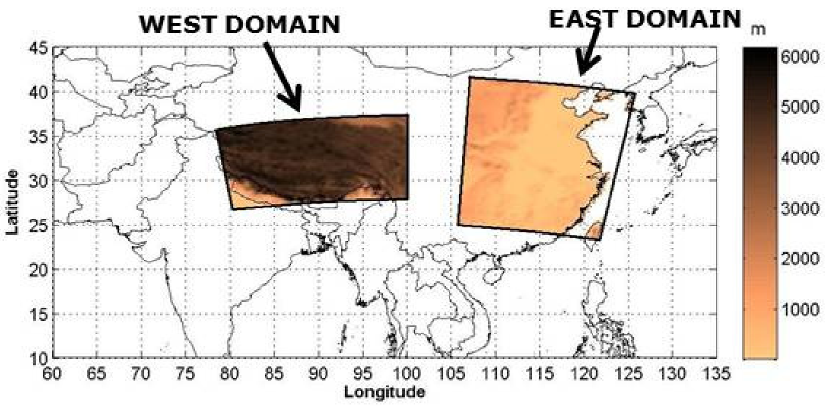


Figure 3:
Subdomains considered for evaluation of seasonal cycles and time series.

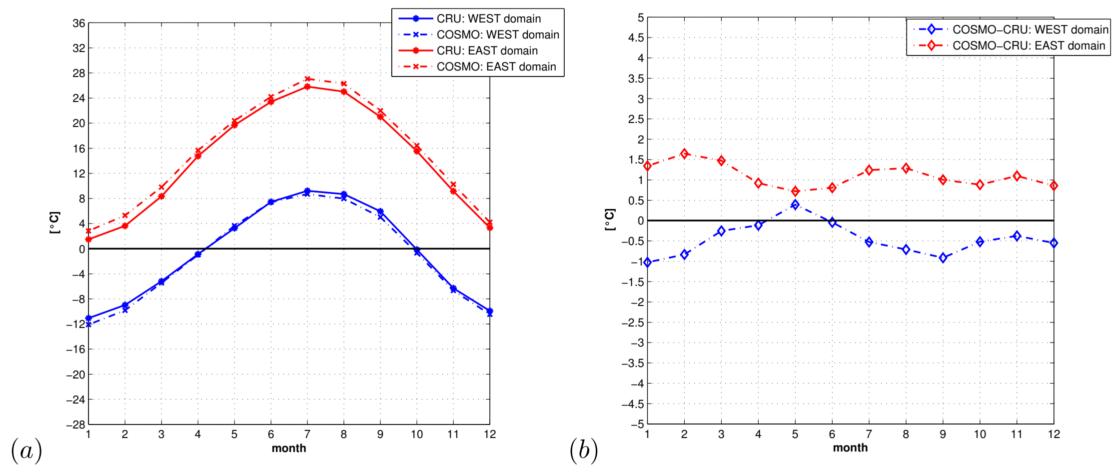


Figure 4:
Seasonal cycle of two-meter temperature for EAST and WEST domains (a) and related bias (b).

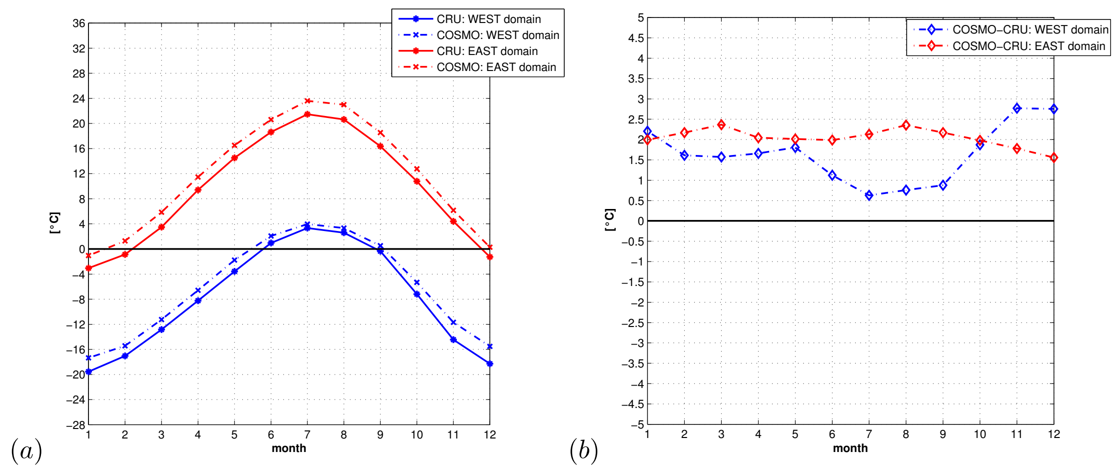


Figure 5:
Seasonal cycle of minimum two-meter temperature for EAST and WEST domains (a) and related bias (b).

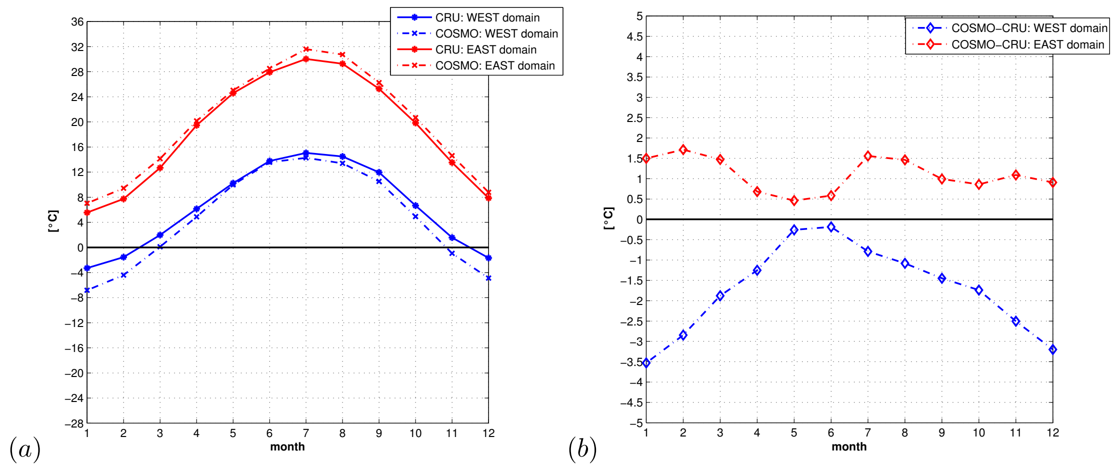


Figure 6:
Seasonal cycle of maximum two-meter temperature for EAST and WEST domains(a) and related bias (b).

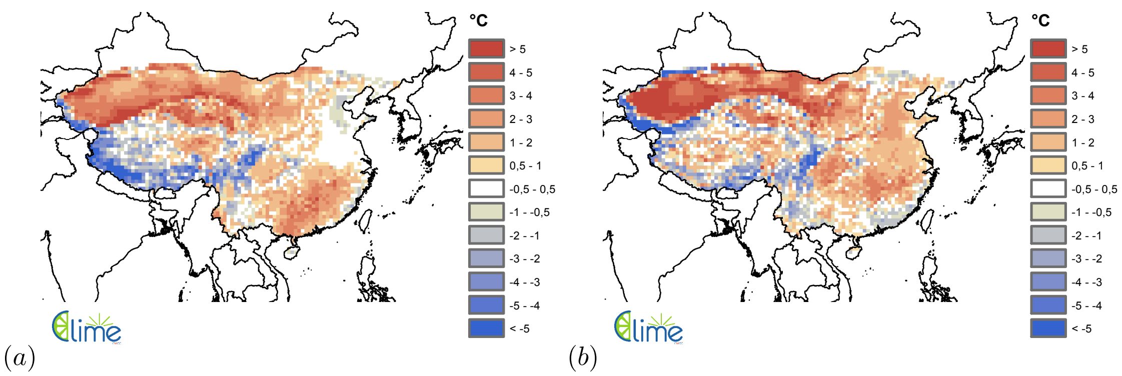


Figure 7:
Bias of (a) 10^{th} and (b) 90^{th} percentile of two-meter temperature.

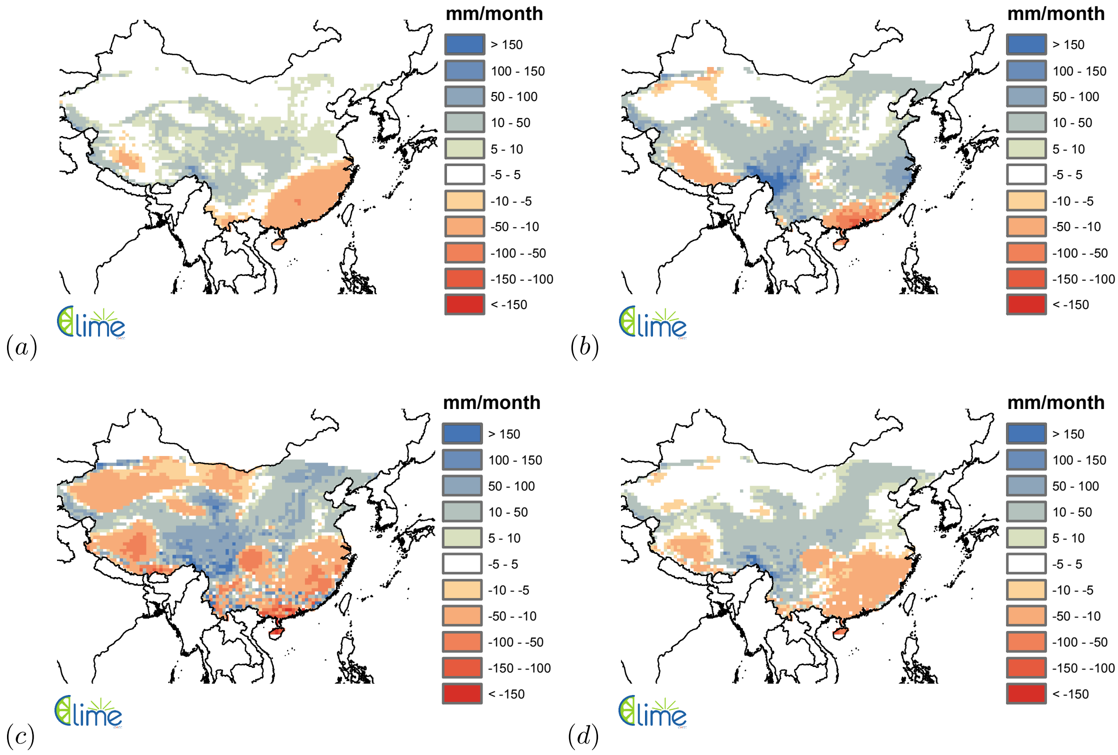


Figure 8:
Bias of precipitation (mm/month) for DJF(a), MAM (b), JJA (c), SON (d)

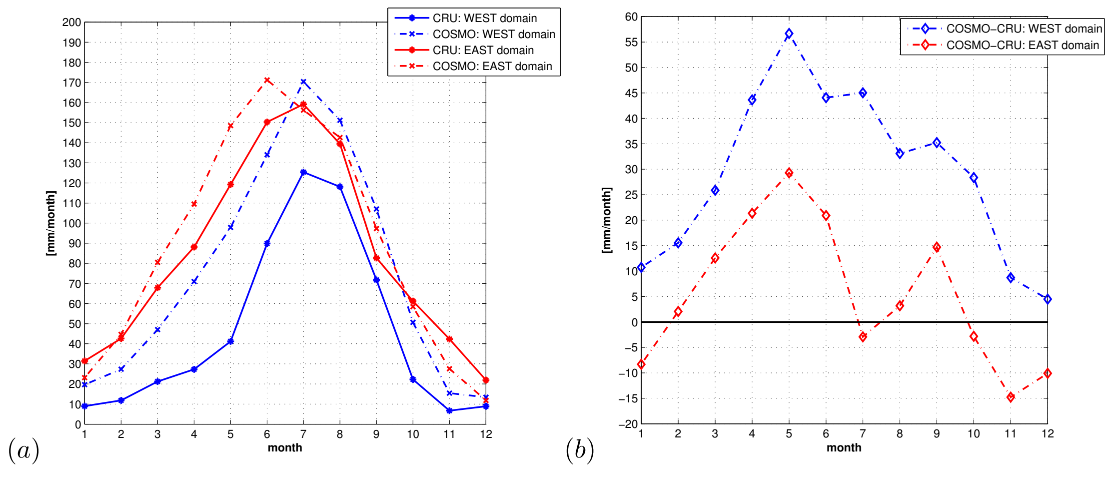
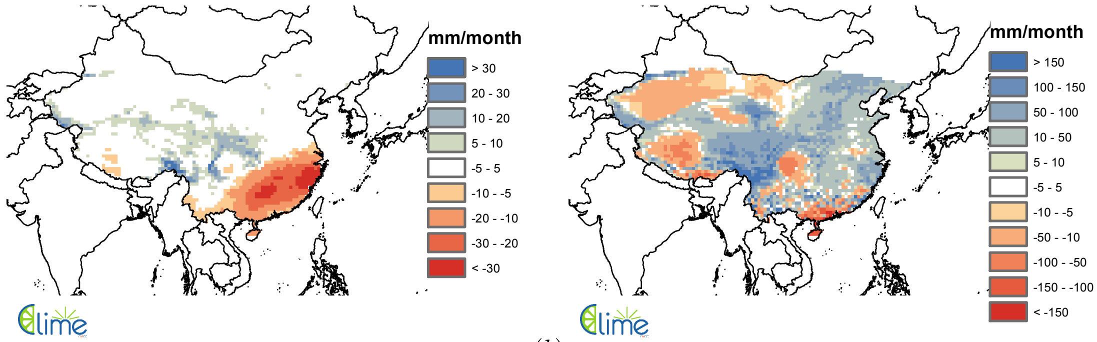
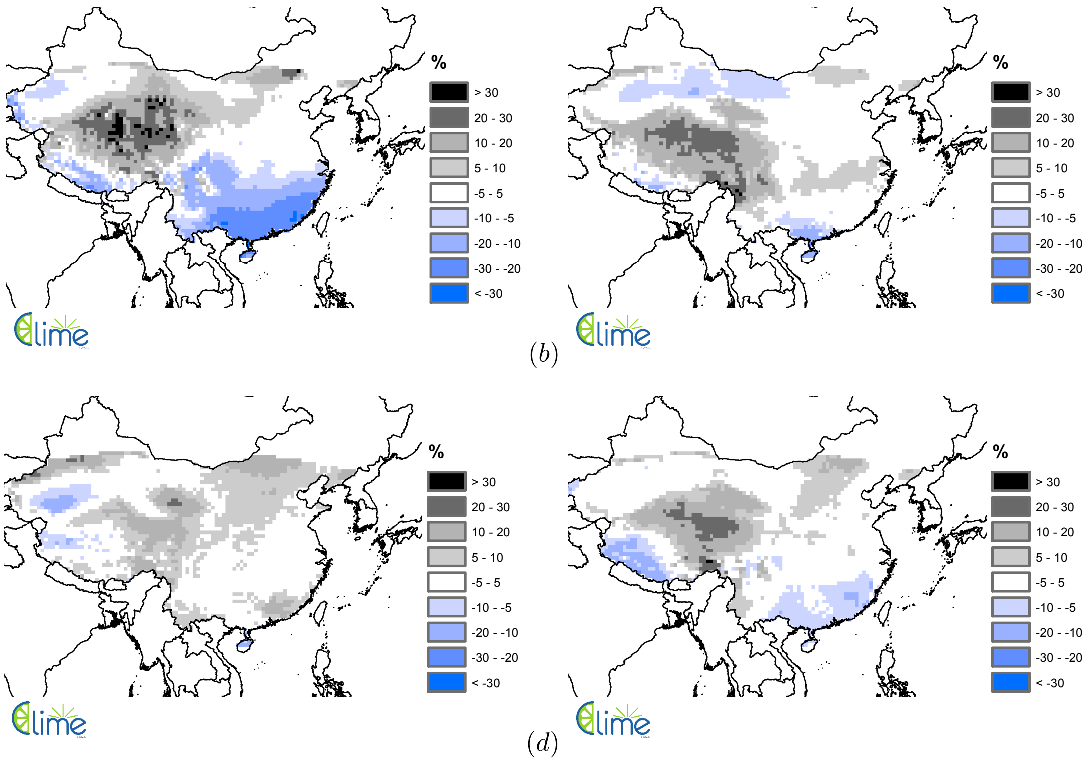


Figure 9:
Seasonal cycle of precipitation(a) and related bias (b).



(a) (b)

Figure 10:
Bias of (a) 10^{th} and (b) 90^{th} percentile of precipitation (mm/month).



(a) (b) (c) (d)

Figure 11:
Bias of total cloud cover (%) for DJF(a), MAM (b), JJA (c), SON (d)

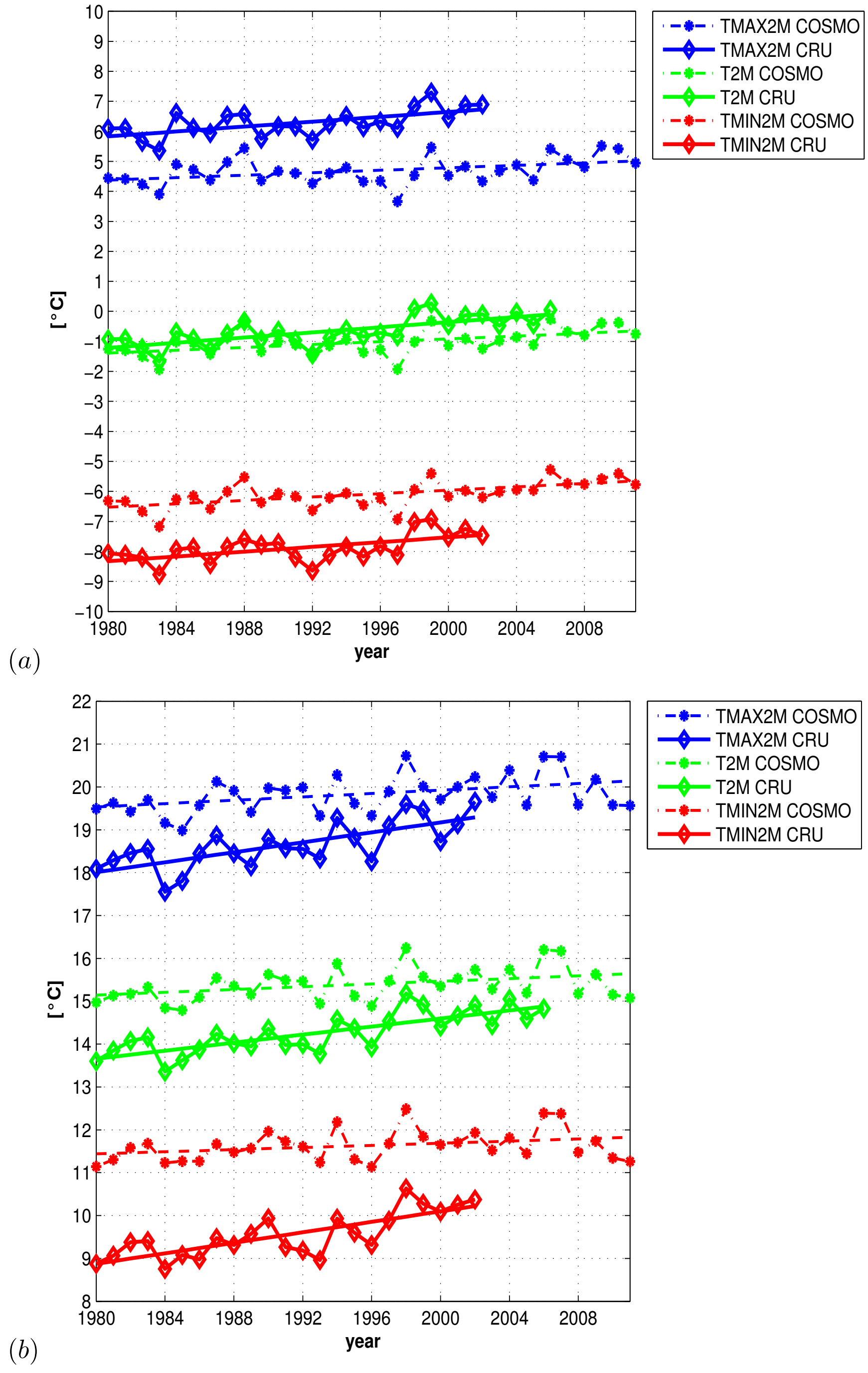


Figure 12:
Time series of two-meter (mean, minimum and maximum) temperature (°C) for WEST (a) and EAST (b) domains.

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