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Assessment of COSMO-CLM model parameter sensitivity for extreme events over the eastern states of India †

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Abstract: The present study focusses to identify the model parameters from Consortium for Small-scale Modelling in CLimate Mode (COSMO-CLM) regional climate model that strongly control the prediction of extreme events. In this work, eleven extreme weather events are selected over West Bengal (WB), India and its adjoining areas observed between 2013 to 2018 to evaluate the performance of the model. Performance Score (PS) identifies the most persuasive parameters out of the 25 adjustable parameters on selective meteorological variables based on the type of extreme events. Out of the six parameterization schemes, few parameters representing land surface process is sensitive to 2m-temperature (T2M). Parameters from microphysics, convection and radiation plays significant role in producing precipitation (TP) and cloud cover (TCC) fields.

Keywords: COSMO-CLM; Regional climate model; Model Evaluation; Parameter Sensitivity; Eastern India

1. Introduction

In the recent past, India has observed numerous extreme weather events resulting human casualties, infrastructural damage, as well as economic losses. These events include intense and frequent heat waves, increase in extreme rainfall events, storms ([1-7]. Coastal areas of India are vulnerable to tropical cyclones which bring heavy rainfall and high-speed winds over the coastal land originating over Arabian Sea and Bay of Bengal [7-10]. Several studies have reported that India and its coastal states are vulnerable to such extreme weather events in near future due to climate change and human-induced warming [11-15]. Therefore, well advance accurate predictions of these weather events are crucial in reducing the damage caused by extreme events.

To our best knowledge, no evaluation study had been made using COSMO-CLM in simulating extreme weather events particularly in the eastern Indian sector. In this paper, the COSMO-CLM parameter sensitivity was performed, after selecting eleven extreme events from the eastern part of India testing a range of inputs for an extensive number of model parameters. The primary aim of this work is to identify the most sensitive model parameters for the study domain in favour having the ideal model configuration.

The article is organized as follows: Section 2 is devoted to a general description of the model setup for COSMO-CLM, and the simulation domain. Section 3 describes the datasets from model output and observations and methodology used. In section 4, results are discussed and illustrated. The last section outlines the conclusions and plans for future research and development related to the presented results.

2. Model & Design of Experiments

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The COSMO-CLM, a three-dimensional non-hydrostatic regional model was optimized using parameter sensitivity analysis over eastern India and adopted for all the simulations presented in this work[16]. The COSMO-CLM version used in this work is COSMO-CLM 5.0_clm6 [17, 18]. The model configuration for all the simulations were performed over the domain (81.25° - 94.64° E, 15.87° - 27.76° N) shown as red box in Figure 1 employing a 0.10° spatial resolution with a third order Runge-Kutta scheme. The study focusses on the extreme weather events during 2013 to 2018 over West Bengal and its adjoining regions. After identifying the keydate for each of the extreme events, COSMO-CLM was used to simulate each event for 11-day period spanning 5-day before and after the keydate at 3 h interval. Accordingly, eleven events were identified for the evaluation of the impact of parametric uncertainty on the 11-day forecasts. We identified 25 adjustable tunable parameters from six parameterization such as sub-grid scale turbulence, land-surface parameterization, microphysics, radiation, convection and the soil scheme that may have influence on 2m-temperature, surface latent heat flux (SLH), precipitation and cloud cover for each event. The comprehensive list of parameters of different physical schemes with their physical meanings and their allowable physical ranges are presented in Table 1. The sensitivity analysis requires a sufficient set of values of the parameters that were assigned to the COSMO-CLM model following which simulations were performed. The examined model parameters spread across plausible maximum, minimum and intermediate values and generate 64 parameter samples out of 25 tunable parameters. When the value of each tunable parameters was set at default, then the simulation is referred to as reference simulation. These parameters sets were assigned in the COSMO-CLM model, and a total of 11× (64+1) =715 simulations were performed across eleven extreme events.

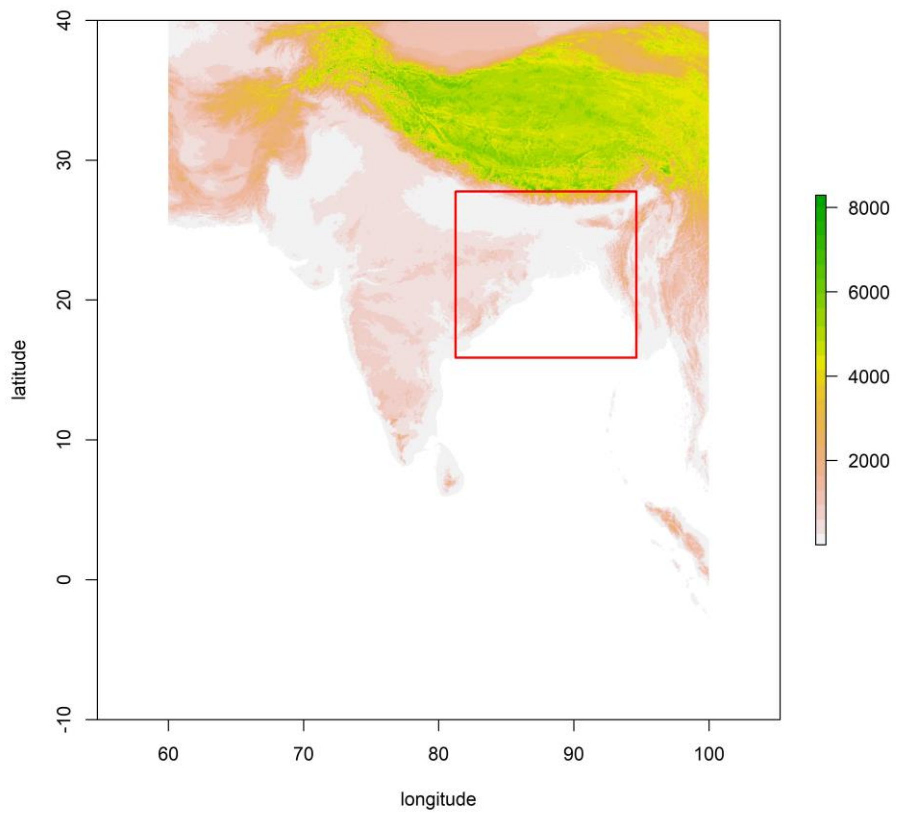

Figure 1. The computational domain in red and orography of the Indian region (in m) considered.

Table 1. List of tuning parameters for different parameterization schemes.

Parameter	Description
Turbulence	
tkhmin	minimal diffusion coefficients for heat
tkmmin	minimal diffusion coefficients for momentum
tur_len	maximal turbulent length scale
d_heat	factor for turbulent heat dissipation
d_mom	factor for turbulent momentum dissipation
c_diff	factor for turbulent diffusion of TKE
q_crit	critical value for normalized oversaturation
clc_diag	cloud cover at saturation in statistical cloud diagnostic
Land Surface	
rlam_heat	scaling factor of the laminar boundary layer for heat
rat_sea	ratio of laminar scaling factors for heat over sea and land
rat_can	ratio of canopy height over z0m
rat_lam	ratio of laminar scaling factors for vapour and heat
c_sea	surface area density of the waves over sea [1/m]
c_lnd	surface area density of the roughness elements over land
z0m_dia	roughness length of a typical synoptic station
pat_len	length scale of subscale surface patterns over land
e_surf	exponent to get the effective surface area
Convection	
entr_sc	mean entrainment rate for shallow convection
Microphysics	
cloud_num	cloud droplet number concentration
qi0	cloud ice threshold for autoconversion
v0snow	factor for fall velocity snow
Radiation	
uc1	parameter for computing amount of cloud cover in saturated conditions
radfac	fraction of cloud water/ice used in radiation scheme
Soil	
soilhyd	multiplication factor for hydraulic conductivity and diffusivity
fac_rootdp2	uniform factor for the root depth field

3. Data and Methodology

The output variables from each simulations have to be validated with the observation data to verify the reliability of the simulations. In this study, the fifth-generation reanalysis popularly known as ERA-5, released by ECMWF was employed for model evaluation. ERA-5 reanalysis is an upgraded version of Era-Interim and it is better than Modern Era Representative analysis for Research and Applications (MERRA) and Era-Interim in terms of horizontal resolution[19, 20]. Simulated 2TM and SLH were validated against ERA-5 gridded data sets for heat wave events. CC from the same reanalysis source have been used to validated heavy rainfall events and cyclonic storm events produced by the model. The reanalysis data set provides 3-hourly daily data with $0.25° \times 0.25°$ spatial resolution. Simulated TP is validated against Integrated Multi-satellitE Retrievals for GPM (IMERG) dataset [21]. Performance Index (PI) metric, which has been deduced from the Climate Performance Index based on scaled root mean square error (RMSE) [22-28]. With the estimated PI, Performance Score (PS) is estimated [27, 29]. PS is used as an estimate of the model sensitivity to every single tested parameter.

4. Results

2m-temperature, surface latent heat flux were used to evaluate the sensitivity of the model parameters for the extreme heat wave events. For cyclones and heavy rainfall events, total precipitation and cloud cover were considered. Initially, PS was calculated for each variable influenced by the tuning parameters. The sensitivity plots with 2m-temperature and surface latent heat flux are presented in Fig. 2. The most sensitive parameters for the study region in simulating 2m-temperature and surface latent heat flux are exponent to get the effective surface area (e_surf). The next set of parameters which have an appreciable influence on latent heat flux by PS is the scaling factor of the laminar boundary layer for heat (rlam_heat), the ratio of laminar scaling factors for heat over sea and land (rat_sea). No parameters from turbulence, convection, radiation and soil scheme influence PS in simulating 2m-temperature and surface latent heat flux. For both precipitation and cloud cover, the most noteworthy variation in PS is observed for cloud ice threshold for auto conversion (qi0) from the microphysics process. It is also observed that for qi0, the changes in PS in simulating cloud cover, show reverse character to precipitation. The mean entrainment rate for shallow convection (entr_sc) from the convection scheme and parameter for computing the amount of cloud cover in saturated conditions (uc1) from the radiation scheme influence the variation of PS in computing the cloud cover.

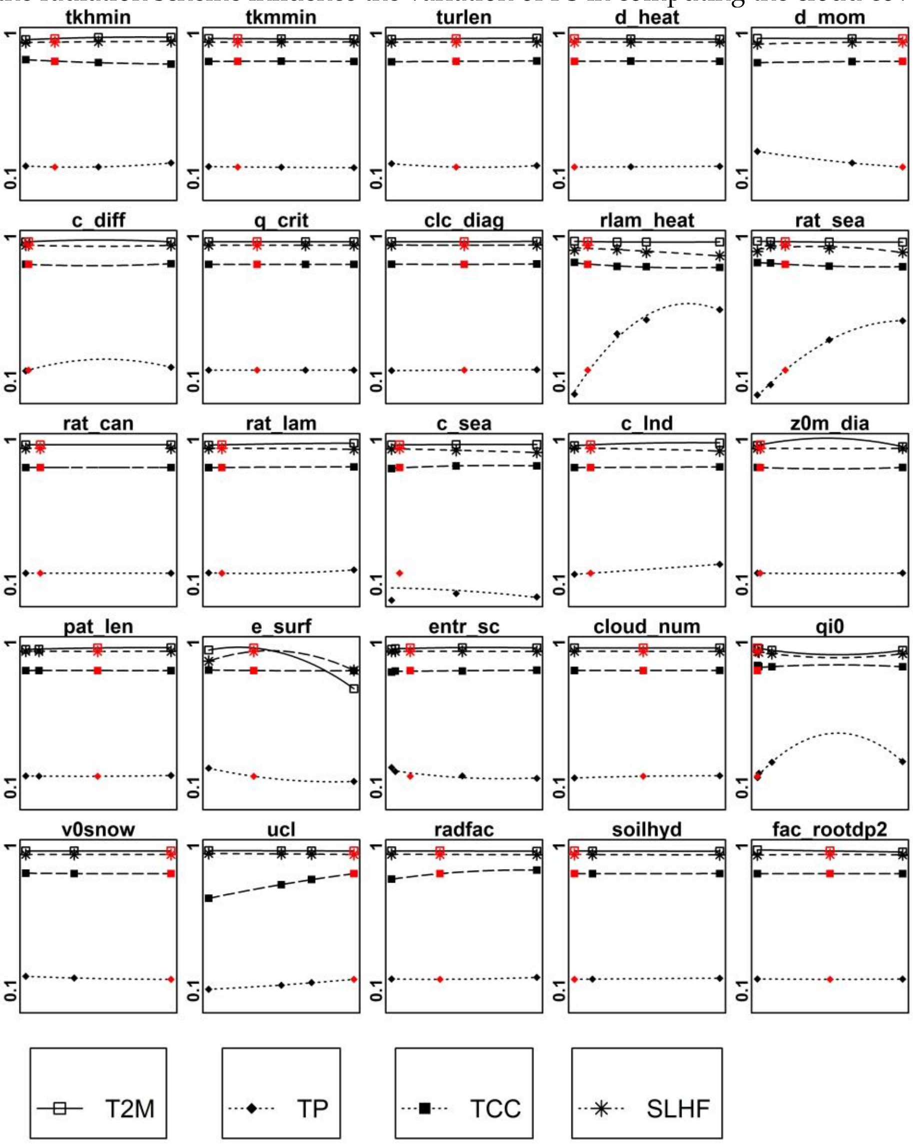

Figure 2. Performance Score (PS) are computed separately for 2m-temperature (T2M: solid line with square), surface latent heat flux (SLHF: dotted line with asterisk) for all the considered parameter values over the entire study region in heat wave events. For heavy rain events and cyclones, PS are computed separately for total precipitation (TP: dotted line with filled diamond) and cloud cover (TCC: dotted line with filled square) over the entire domain of study. The red points show the calculated PS value for the default model configuration.

5. Conclusions

In this study, we examined 25 model parameters in extreme weather events observed over the eastern region of India, simulated using COSMO-CLM with various values of model parameters from different physical schemes. The simulated T2M, SLH, TP, and TCC are compared against reanalysis employing PS metric presented by [27]. The exponent to get the effective surface area (e_surf) from the land surface has a large impact on T2M. Parameters such as cloud ice threshold for auto conversion (qi0) from microphysics, mean entrainment rate for shallow convection (entr_sc) from convection and parameter for computing the amount of cloud cover in saturated conditions (uc1) from radiation play a significant role in producing TP, and TCC fields. A recent study identified the same set of sensitive parameters over the Central Asian CORDEX region similar to the present work [27]. The ability of the model worsens from the entire domain to the subdomain against all the variables (not shown here). Introducing Skill Score (SS) metric in future analysis might explain the model performances against the model with default parameters.

Author Contributions: S.B. imitated each simulation by the COSMO-CLM model and analysed the output data. I.K. supervised the entire work and was also involved in setting up the model. S.B. and I.K. wrote the manuscript and agreed to the published version of the manuscript.

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Conflicts of Interest: The author declares no conflict of interest.

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