Parameterization induced error-characteristics in Regional Climate Models: An ensemble based analysis

Nauman K. Awan* H. Truhetz and A. Gobiet

Wegener Center for Climate and Global Change (WegCenter), Institute for Geophysics, Astrophysics, and Meteorology (IGAM), University of Graz, Austria

1. Introduction

In the past few years implementation of many parameterization schemes in regional climate models (RCMs) has not only given the researchers a broad range of choice in model configuration but has also provided an opportunity to identify deficiencies in these schemes by validation. In published literature one can find a non-exhaustive list of different parameterizaiton schemes depicting the same physical process. The fact that each of these schemes is based on many assumptions, and these assumptions may fail or give an inadequate response to certain synoptic forcing not only limits their usefullness, but also acts as a source of errors in the model results. The error-range associated with the choice of different physical parameterization is identified in our work by using two RCMs; the Pennsylvania State University / National Center for Atmospheric Research (PSU/NCAR) mesoscale model MM5 (Dudhia 1993) and National Center for Environmental Prediction / National Center for Atmospheric Research (NCEP/NCAR) Weather Research Forecast (WRF) (Skamarock et al. 2007) modeling system. The use of MM5 model in climate research is shown by Zhu and Liang (2007), Fernández et al. (2007), while studies like Done et al. (2004) and Done et al. (2005) explored promising opportunity for researchers to use WRF in regional climate studies.

Physical parameterizations as a source of error in model results have been a topic of numerous studies done with MM5 and WRF mostly focusing on short-term weather events. Studies from Pan et al. (1996), Ferretti et al. (2000), Kotroni and Lagouvardos (2001), Jankov et al. (2005), Otkin and Greenwald (2008) give a good overview on the different physical parameterizations available in these models and their response to different synoptic conditions. Although these studies give an overview of what can be expected in terms of model performance, whether the underlying assumptions within the parameterizations hold or fail in long term simulations is inconclusive. The investigation of this open question requires long term climate simulations with different available model configurations. In our study we have tried to identify errors associated with the choice of physical parameterizations and its consequent effect on long term climate simulations in the European Alps and its surroundings. In order to achieve our goals we have used two mixed physics ensembles created with MM5 and WRF model. We present here an overview of the error-spread.

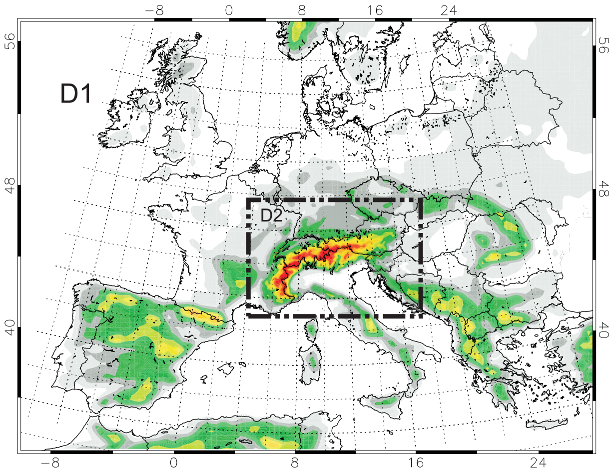

Fig. 1. The nested cascade showing the topography of the fine (30km) D1 and high–resolution (10km) D2. The highest point of the model grid (D2) is located at 2945.82 meters; Mont Blanc, the highest peak of the European Alps has 4808 meters.

2. Alpine simulations

The European Alps extend in the form of an arc of 800 km, with a mean width and an average ridge height of approximately 200 km and 2.5 km, respectively. The study area is shown in figure (Fig. 1). The model domain

*Corresponding author address: REgional and LOcal CLImate Modelling Group, Wegener Center for Climate and Global Change Leechgasse 25, A-8010, GRAZ, Austria
E-mail: nauman.awan@edu.uni-graz.at

Table 1. The MM5 ensemble members with key parameterization settings

Exp	Physical Parameterization Settings
RE	KF, REISNER 1, RRTM, ETA PBL, NOAH LSM, shallow convection, Vertical levels: 30, SST & Feedback Off, Pressure at model top: 100 mb
HD	Zängel z–diffusion
CU1	BM
CU2	GR (no shallow convection)
SS	MRF PBL
MP	REISNER 2
VE1	Vertical Levels: 40
VE2	Vertical Levels: 20
FB	Feedback On
L2A	REISNER 2, MRF PBL
L3A	REISNER 2, MRF PBL, Feedback On
L3B	REISNER 2, MRF PBL, Feedback On, Vertical Levels: 40
L3C	REISNER 2, MRF PBL, Feedback On, Vertical Levels: 20

Table 2. The WRF ensemble members with key parameterization settings

Exp	Physical Parameterization Settings
RE	GD, FERRIER, GODDARD, RRTM, MOJ, NOAH, MYJ, Vertical levels: 30, SST & Feedback On, Pressure at model top: 50 mb
PT	Pressure at model top: 100 mb
CU1	KF
CU2	BMJ
MP1	WSM6
DA	Model filter: Damping on
SW1	DUDHIA
SW2	GFDL
SS	MOS, YSU
VE	Vertical Levels: 20
L2A	BMJ, WSM6
L2B	KF, MOS, YSU
L2C	KF, DUDHIA
L3A	KF, MOS, YSU, DUDHIA
L3B	KF, MOS, YSU, DUDHIA, WSM6
L3C	KF, MOS, YSU, DUDHIA, THOMSON

1 (D1) is a fine resolution domain (30 km grid-spacing) covering most parts of Europe, Mediterranean Sea and some part of Atlantic ocean. D1 is providing the synoptic features and general circulation patterns to the high-resolution (10 km) domain 2 (D2). D2 covers the Alps and its surroundings. The fine (high) resolution domain has 100 (79) grid-points in the south-north direction and 124 (109) grid-points in the west-east direction. The datasets provided by the United States Geological Survey (USGS) was used to provide the topography, land use and land-water masks information. The static fields from USGS $2' \times 2'$ and $30'' \times 30''$ were used for D1 and D2 respectively. The USGS 24-category land classification data was used to represent dominant vegetation types. The re-analysis dataset ERA-40 provided by the European Centre for Medium-Range Weather Forecasts (Uppala et al. 2005) with 6 hourly temporal and $1.125° \times 1.125°$ grid-spacing is used to provide initial and boundary conditions in both models. The relaxation zone for MM5 (WRF) model is set to 7 (5) grid points. The sea surface temperatures (SSTs) are updated every six hours for both models while the vegetation fraction is updated every month (six hours) for MM5 (WRF). The temporal resolution for output of coarse (fine) domain is 6 hours (1 hour). The evaluated ensemble members have a common simulation period which was simulated with a spin up of three months, the simulations start at September 1, 1998, 00 UTC and end at January 1, 2000, 00 UTC.

The available options for microphysics, radiation, convection and planetary boundary layer in MM5 and WRF models offers a broad range of configuration settings to users. A total of 13 (16) experiments with MM5 (WRF) using different available configurations were carried out to find the range of errors. At first a complete year was simulated which is referred to as reference simulation (RE). The simulations carried out in level 1 (L1) represent the simulations which have only one change in parameterization from the RE configuration while level 2 (L2) and level 3 (L3) experiments represent two and more than two alterations with respect to the RE configurations respectively.

The table 1 and table 2 show the detail of experiments conducted in all three levels for MM5 and WRF respectively.

3. *Results*

The dataset that we have used to compare the T_{2m} is the European Climate Assessment & Dataset (ECA&D) (Haylock et al. 2008) (referred to as ECA dataset). The results show that MM5 ensemble has a cold bias in T_{2m} for the whole year but it is lesser for winter season while WRF simulations have a warm bias in winter and the results for the rest of year have a larger response to the changes in parameterization resulting in a positive as well as negative deviations especially in the spring and summer seasons. The general overview on the impact of different configuration combinations on daily, monthly and annual mean T_{2m} can be inferred from Fig. 2. The Fig. 2 (a,c) depicts the monthly deviations of area-averaged values of T_{2m} from ECA dataset of both models for the complete ensemble. The area-averaged values of mean daily T_{2m} are compared with the reference observational data and results are shown

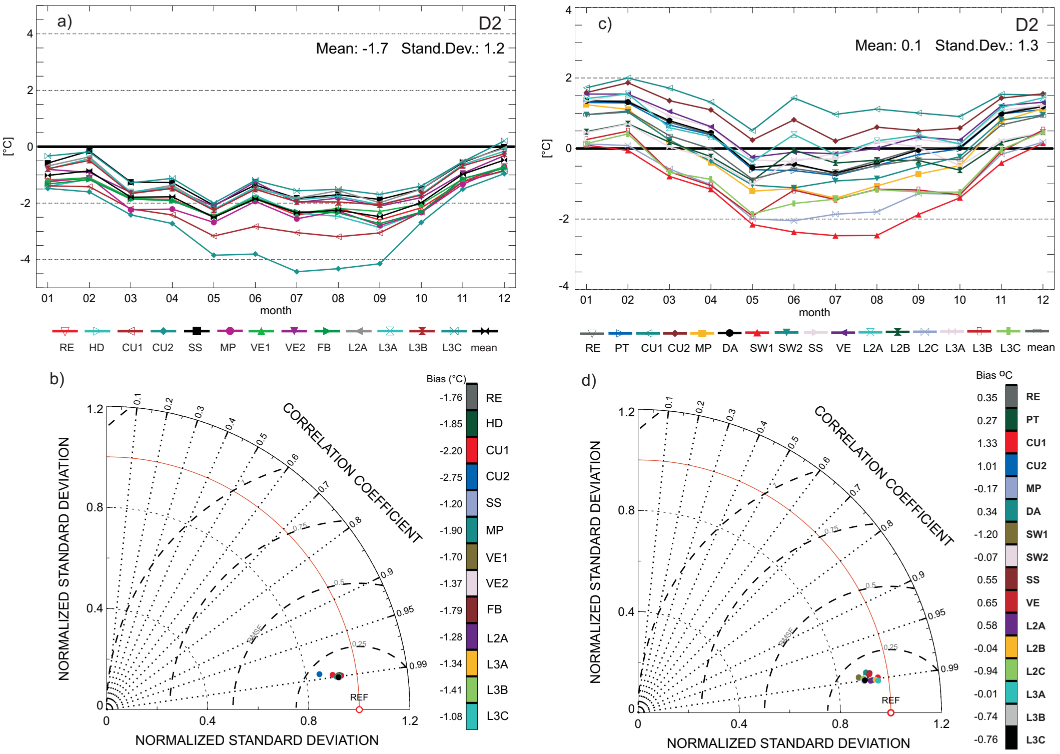

FIG. 2. The monthly mean biases in T_{2m} with respect to ECA dataset. a) MM5, c) WRF. In the bottom using the Taylor–plot to show temporal correlation, centered RMSE and normalized standard deviations calculated on daily basis. The colors bar represents annual mean biases corresponding to each ensemble member

in terms of temporal correlation, normalized standard deviation and centered root mean square error values. From Fig. 2 (b,d) we can see that the variability in T_{2m} is being underestimated in both the models. All the members of ensemble for both the models have a very high correlation (> 0.98) and centered root mean square values between 0.1 and 0.2. The range of errors in the annual mean temperature ranges between -2.75 °C and -1.08 °C (-1.20 °C and 1.33 °C) for MM5 (WRF) respectively. The other noticeable result is that the MM5 T_{2m} is lesser affected with respect to changes in model configuration while WRF modeled T_{2m} is relatively more sensitive.

The comparison of high resolution (10 km grid spacing) modeled surface precipitation is done with a dataset provided by the Swiss Federal Institute of Technology (ETH) Zürich generated by Frei and Schär (1998), Frei et al. (2006) (referred as ETH dataset). The precipitation results revealed that both model are over-estimating precipitation in most parts of the domain (especially in the inner Alpine region) in all seasons with relatively less error in winter and autumn season. The spread of deviations (Fig. 3) suggests that there is less effect of parameterization in winter and autumn than in spring and summer seasons. It is also evident that MM5 results have less spread within the ensemble members and the error range is also much lesser than WRF modeled precipitation. We can infer from Fig. 3 (b,d) that MM5 simulations improve in terms of variability while there is less change in correlation co-efficient. On the other hand WRF results depict that higher correlation can be achieved and overestimation of variability can also be improved by choosing a suitable setting. The overall range of errors in precipitation lies between to 0.80 mm/day and 0.27 mm/day (1.51 mm/day and 0.13 mm/day) for MM5 (WRF).

4. Summary and concluding remarks

The complex terrain of the Alps gives rise to many complex physical processes and from the phenomenological point of view it was expected that model results will have different errors in different regions with the same configuration. No parameterization setting has performed ideally for all the regions (sub-region results not shown here, please refer to the talk for these results) and in all seasons but our results suggest that depending on the focused region significant improvements can be acheived by choosing a suitable parameterizations settings. The annual mean error for recommended settings of MM5 (WRF) is 0.27 mm/day and -1.41 °C (0.1 mm/day and 0 °C) for precipitation and temerature respectively however seasonal and

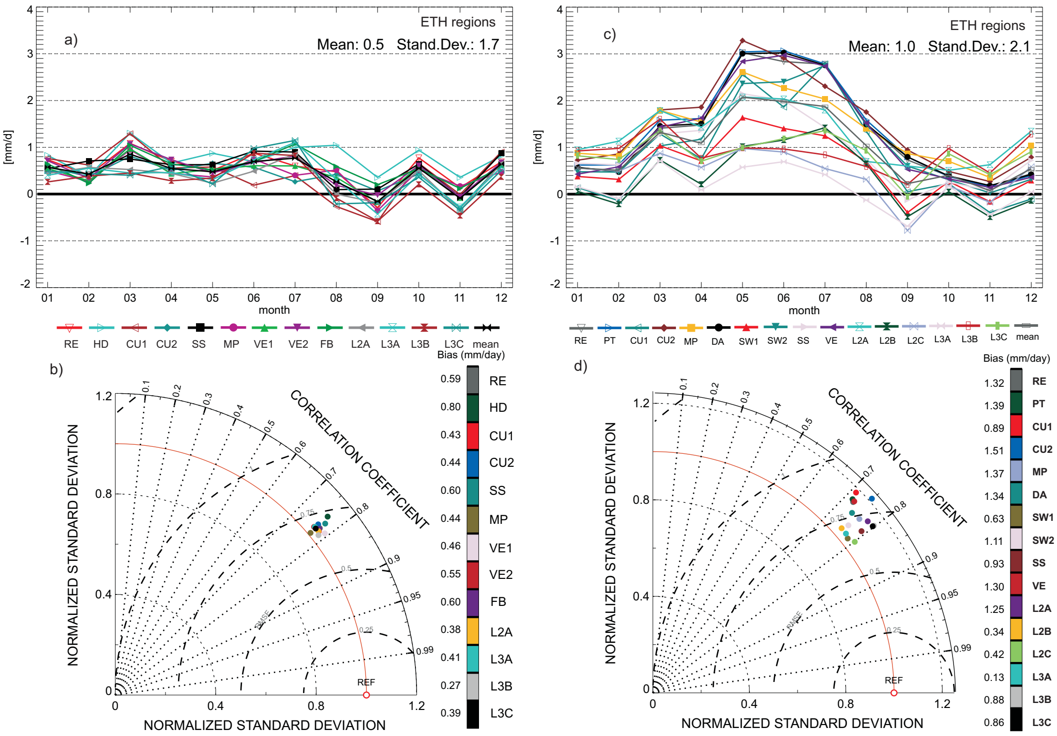

FIG. 3. The same as Fig. 2 but for precipitation errors in the ETH regions

sub–regional errors are larger. The effect of parameterizations is larger on precipitation as compared to T_{2m}. There is a strong convective response to orography resulting in an over-estimation of precipitation in summer, this is more prominent in WRF simulations than MM5 .

Due to the historical evolution of RCMs originating from and still closely connected to NWP-models parameterizations (especially cloud-parameterizations) are optimized for coarser resultions, in general. Simply increasing the resolution to grid-spacing of $\sim$ 10 km and beyond only partly reduces model errors in complex terrain. The parameterizations have to be adopted as well to achieve further reduction in errors. In order to extend the investigation of high resolution climate simulations a project called Local Climate Modelling Intercomparison Project (LocMIP, www.wegcenter.at) has been initiated which will focus on added value of high resolution simulations carried out with 10 km and 3 km grid-spacing. Future work also includes long term high resolution climate simulations which will be conducted out to include the effect of long term processes and further investigations focusing on process-oriented analyses in order to relate the model's shortcomings to important climate processes are also required.

Acknowledgement
This study is supported by Austrian Science Fund (FWF), Austrian Exchange Service (ÖAD) and Higher Education Commission (HEC) of Pakistan. The authors acknowledge the Swiss Federal Institute of Technology Zürich (ETH, Zürich, Switzerland). We also thank European Climate Support Network (ECSN) and the Network of European Meteorological Services (EUMETNET) for supporting the European Climate Assessment and Dataset (ECA&D) project.

REFERENCES

Done, J., L. Leung, C. Davis, and B. Kuo, 2004: Regional climate simulations using the WRF model. *5th WRF/14th MM5 user's workshop*, Boulder.

Done, J., L. Leung, C. Davis, and B. Kuo, 2005: Simulation of warm season rainfall using WRF regional climate model. *6th WRF / 15th MM5 user's workshop*, Boulder.

Dudhia, J., 1993: A nonhydrostatic version of the Penn state/NCAR mesoscale model: validation tests and simulation of an Atlantic cyclone and cold front. *Mon. Wea. Rev.*, **121**, 1493–1513.

Fernández, J., J. P. Montávez, J. Sáenz, J. F. González-Rouco, and E. Zorita, 2007: Sensitivity of the MM5 mesoscale model to physical parameterizations for regional climate studies : Annual cycle. *J. Geophys. Res.*, **112**, doi:10.1029/2005JD006649.

Ferretti, R., T. Paolucci, W. Zheng, G. Visconti, and P. Bonelli, 2000: Analyses of the precipitation pattern on the Alpine region using different cumulus convection parameterizations. *J. Appl. Meteor.*, **39**, 182–200.

Frei, C. and C. Schär, 1998: A precipitation climatology of the Alps from high-resolution rain-gauge observations. *Int. J. Climatol.*, **18**, 873–900.

Frei, C., R. Schöll, S. Fukutome, J. Schmidli, and P. Vidale, 2006: Future change of precipitation extremes in Europe: An intercomparison of scenarios from regional climate models. *J. Geophys. Res.*, **111**, D06 105.

Haylock, M., N. Hofstra, A. K. Tank, E. Klok, P. Jones, and M. New, 2008: A European daily high-resolution gridded data set of surface temperature and precipitation for 1950–2006. *J. Geophys. Res.*, **113**, D20 119, doi:10.1029/2008JD010201.

Jankov, I., W. A. G. Jr., M. Segal, and S. E. Koch, 2005: The impact of different WRF model physical parameterizations and their interactions on warm season MCS rainfall. *Weather and Forecasting*, **20**, 1048–1060.

Kotroni, V. and K. Lagouvardos, 2001: Precipitation forecast skill of differrent convective microphysical schemes: Application for the cold season over Greece. *Geophys. Res. Lett.*, **28**, 1977–1980.

Otkin, J. A. and T. J. Greenwald, 2008: Comparison of WRF model-simulated and MODIS-derived cloud data. *Monthly Weather Review*, **136**, 1957–1969.

Pan, Z., E. Takle, M. Segal, and R. Turner, 1996: Influences of parameterization schemes on the response of rainfall to soil moisture in the central United States. *Mon. Weath. Rev.*, **124**, 1786–1802.

Skamarock, W. C., J. B. Klemp, J. Dudhia, D. O. Gill, D. Barker, W. Wang, and J. Powers, 2007: A description of the advanced research WRF version 2,. Tech. rep., Natl. Cent. for Atmos. Res., Boulder, Colo.

Uppala, S. M., et al., 2005: The ERA-40 re-analysis. *Q. J. R. Meteorol. Soc.*, **131**, 2961–3012.

Zhu, J. and X.-Z. Liang, 2007: Regional climate model simulations of U.S. precipitation and surface temperature during 1982–2002: Interannual variation. *Journal of Climate*, **20**, 218–232.