Sensitivity Assessment of WRF Model Simulation Performance over the Tianshan Region (Postprint)

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Abstract

To explore the optimal combination of parameterization schemes in the WRF (Weather Research and Forecasting) model for climate simulation in the Tianshan region, six sets of seasonal-scale sensitivity experiments were designed for physical parameterization schemes, including cloud microphysics (MIC), cumulus convection (CS), planetary boundary layer/surface layer (PBL/SLS), land surface (LSM), and longwave/shortwave radiation (LSW) schemes. The simulation period was set from November 28, 2014, to December 1, 2015. The simulated daily maximum temperature, minimum temperature, and precipitation were validated using observations from ground meteorological stations and GPM (Global Precipitation Measurement) satellite precipitation data (R 0.6). The results indicate that the WRF model demonstrates good performance in simulating temperature, and for daily maximum temperature (0.8

WRF model, climate simulation, physical parameterization scheme, sensitivity assessment, Tianshan region, Central Asia

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Full Text

Evaluation of WRF Model Sensitivity to Physical Parameterizations in the Tianshan Mountains

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Abstract

This study conducted a sensitivity analysis of the Weather Research and Forecasting (WRF) model to different physical parameterization options in the Tianshan Mountains to identify the optimal configuration combination. Year-long seasonal-scale simulations were performed from November 28, 2014, to December 1, 2015. Station observations and Global Precipitation Measurement (GPM) satellite precipitation data (with correlation coefficient R 0.6) were used to validate simulated daily extreme temperatures and precipitation. Results demonstrated that WRF simulated temperature well, with daily maximum temperature (T2max, $0.8 < R < 0.95$) showing better agreement than daily minimum temperature (T2min, $0.62 < R < 0.88$). T2min exhibited sensitivity to both land surface and cloud microphysics schemes. Precipitation simulations were less satisfactory, with relatively low correlation coefficients (R 0.6) that varied across different schemes. The WSM6-class microphysics scheme performed well for precipitation simulation. The Kain-Fritsch cumulus/convective scheme proved unsuitable for capturing strong convection and complex terrain in the Tianshan Mountains, producing large T2min biases and negative precipitation values in summer. The optimal configuration combination consisted of: WSM6-class (Cloud Microphysics), Betts-Miller-Janjic (Cumulus/Convective), Mellor-Yamada-Janjic scheme/Monin-Obukhov (Janjic Eta) (Planetary Boundary Layer/Surface Layer), NOAH (Land Surface Model), and Community Atmosphere Model (Longwave and Shortwave Radiation).

Keywords: WRF; climate simulation; physical parameterization; sensitivity evaluation; Tianshan Mountains; Central Asia

1 Introduction

The Weather Research and Forecasting (WRF) model is a next-generation mesoscale numerical weather prediction system developed for both atmospheric research and operational forecasting applications. WRF includes multiple physical parameterization schemes representing various atmospheric processes: cloud microphysics (MIC), cumulus/convective schemes (CS), planetary boundary layer/surface layer schemes (PBL/SLS), land surface models (LSM), and longwave/shortwave radiation schemes (LSW). Previous sensitivity studies have systematically evaluated WRF performance across different regions and identified optimal parameterization combinations for specific applications.

In complex terrain regions such as the Tianshan Mountains, model performance is particularly sensitive to physical parameterization choices. Argüeso et al. [8] evaluated WRF parameterizations for climate studies over southern Spain using multi-step regionalization, finding significant sensitivity to land surface and cloud microphysics schemes. Moon et al. [9] assessed WRF sensitivity to parameterization schemes for European regional climates during 1990–1995, demonstrating that Mellor-Yamada-Janjic PBL and Kain-Fritsch cumulus schemes produced notable differences in temperature and precipitation simulations. Kala et al. [13] investigated WRF sensitivity to driving data and physics options on seasonal timescales in southwestern Australia, revealing that minimum temperature biases were closely related to land surface scheme selection, while precipitation patterns varied with cumulus and microphysics parameterizations.

The Tianshan Mountains present unique modeling challenges due to their extreme topographic complexity and harsh climate conditions. Crétat et al. [10] examined uncertainties in simulating southern Africa' s regional climate with WRF, showing that parameterization choices significantly affected precipitation distribution and intensity. For the Tianshan region specifically, the combination of high elevation, steep gradients, and strong convective activity requires careful scheme selection. Studies have shown that WSM6-class microphysics can effectively simulate precipitation characteristics, while the Kain-Fritsch cumulus scheme may overestimate convective activity in mountainous terrain, leading to substantial temperature biases and unrealistic negative precipitation values during summer months.

This study aims to systematically evaluate WRF sensitivity to physical parameterizations in the Tianshan Mountains and identify the optimal scheme combination for regional climate simulation. Through year-long seasonal simulations validated against observational and satellite data, we assess model performance for temperature and precipitation extremes across different parameterization configurations.

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Note: Figure translations are in progress. See original paper for figures.