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Evaluation of parameterization schemes in the Weather Research and Forecasting (WRF) model: A case study for the Kaiga nuclear power plant site

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ABSTRACT

In this study, the Weather Research and Forecasting (WRF) model performance with various combinations of parameterization schemes is analyzed in predicting surface and upper air meteorology around the Kaiga nuclear power plant site. The case studies selected for simulation correspond to occurrences of annual maximum, minimum temperature and maximum wind speed in the years (2004–2007). Based on the collective performance of the various combinations of the schemes in reproducing observed winds, temperature and relative humidity at Kaiga site, the most suitable combination of parameterization schemes are identified. For temperature and relative humidity, the combination consisting of Asymmetric Convective Model (ACM2) as the Planetary Boundary Layer (PBL) scheme, the Monin Obhukhov as the surface layer (SL) scheme and the 5 layer thermal diffusion model as the land surface model (LSM) is found to be better than other combinations whereas the combination consisting of Mellor Yamada Janjic (Eta) as the PBL scheme, Monin Obhukhov Janjic (Eta) as the SL scheme and Noah LSM performs reasonably well in reproducing the observed wind conditions. This indicates that the selection of parameterization schemes may depend on the intended application of the model for a given site.

1. Introduction

Atmospheric dispersion models are frequently utilized at nuclear power plant sites to study the dispersion of radioactive effluents released during the normal operating conditions as well as in the case of accidental conditions (Huh et al., 2013). Generally site specific measured meteorological data are used as input in these models. Many times prognostic numerical weather prediction models like the Weather Research and Forecasting (WRF), Mesoscale Meteorological Model-5 (MM5) are used as meteorological drivers to atmospheric dispersion models (Wu et al., 2012), to have either a forecast of the impact of the released pollutant or to incorporate spatial variation of meteorological parameters in atmospheric dispersion estimates. These models provide a four dimensional flow field of the atmosphere by solving the primitive equations numerically. However, the resolution at which these models are integrated is too coarse for the exact treatment of many physical processes like turbulence, cumulus convection, heat transfer etc. and hence these processes are parameterized. Thus parameterization schemes form an inherent component of all numerical weather prediction models. With the availability of better computing infrastructure and resources, higher resolution weather forecasts are possible. However, there are several physical processes and scales of motion that are still unresolved at that resolution and need to be parameterized. A weather model includes parameterization schemes for radiation, surface layer fluxes, turbulence, cumulus convection, clouds etc. Generally there are six to seven schemes available for representation of each of these processes with its own merits and demerits.

In the past several studies have been carried out dealing with sensitivity of model results on the choice of parameterization schemes on different geographical and climatic regions of the globe. Zhang and Zheng (2004) studied the effect of five PBL parameterization schemes of MM5 model on the diurnal cycle of surface and PBL wind and temperature in the continental United States by comparison with surface observations and upper air soundings. Similarly Mao et al. (2006) carried out such studies in two 37 day episodes of summer and winter over the continental

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United States. Both these studies had utilized a coarse grid resolution of 36 km. A similar work utilizing a fine grid domain was that by Berg and Zhong (2005) wherein the sensitivity of MM5 simulation to three Planetary Boundary Layer (PBL) parameterizations was tested. They had utilized observations from two field campaigns conducted in summer and autumn over parts of United States. Such studies were also carried out using the Weather Research and Forecasting (WRF) model. Hu et al. (2010) simulated the meteorological conditions in Texas region during the summer of 2005 using WRF Version 3.0.1. Observations collected during TexAQS2 (Texas Air Quality Study) were used for model validation. The PBL schemes tested in this study were the Yonsei University (YSU), Mellor Yamada Janjic (MYJ) and Asymmetric Convective Model (ACM2) scheme. Borge et al. (2008) carried out a comprehensive sensitivity analysis of the WRF model for air quality applications over the Iberian Peninsula. Evans et al. (2011) had evaluated the performance of a 36 member WRF physics ensemble over South East Australia. Kwun et al. (2009) studied the sensitivity of MM5 and WRF model predictions of surface winds in a typhoon to planetary boundary layer parameterizations. Ruiz et al. (2010) tested the WRF model in different configurations over South America to identify the one that gives the best estimates of observed surface variables. Shin and Hong (2011) carried out an intercomparison of planetary boundary layer parameterizations using the WRF model for a single day from the Cooperative Atmosphere Surface Exchange Study (CASES-99) field program. Zhiwei et al. (2008) compared the meteorological predictions by five MM5-PBL parameterizations in combination with three land surface models. The effect of urban surface parameterization schemes in the WRF model was investigated by Lee et al. (2011) using measurements during the Texas Air Quality Study 2006 field campaign.

Similar studies dealing with evaluation of physical parameterizations were also carried out for the Indian region. For example, Mohan and Bhati (2011) had analyzed the WRF model performance over subtropical region of Delhi during summer and winter months. Deb et al. (2008) had evaluated the WRF model performance in simulation of heavy precipitation events over Ahmedabad during August 2006. Rama Rao et al. (2007) used high resolution Eta and WRF models to forecast heavy precipitation events over India. Srinivas et al. (2007a) used the MM5 model to simulate the Andhra Severe Cyclone of 2003 and tested the model sensitivity to the boundary layer and convective parameterizations. Likewise Srinivas et al. (2007b) also applied the same model to test the sensitivity of mesoscale simulations of land–sea breeze to boundary layer turbulence parameterization. A common conclusion which can be derived from all these studies is that the choice of schemes for a good simulation is governed by the specific application intended and geographical location of the site. Hence sensitivity studies are required to focus on the right combination of such schemes for a given region.

The present study focuses on the evaluation of parameterization schemes in the WRF model for Kaiga site. Kaiga is one of the sites where nuclear power plants are operated for generation of electricity by Nuclear Power Corporation of India Ltd (NPCIL). It is a complex site with tall hills, evergreen forests, a reservoir, etc. Weather forecasting is important in the nuclear industry because of the aid it can provide in handling an emergency situation. However the weather forecast model needs to be validated/tuned with proper selection of parameterization schemes for it to be used in case of an emergency situation. In order to have a proper selection of parameterization schemes in the WRF model for Kaiga site, the case studies selected for simulation correspond to occurrences of annual maximum, minimum temperature and maximum wind speed in the years 2004–2007. The extreme cases are chosen as they are likely to have a significant impact on atmospheric dispersion of pollutants and moreover they also provide an opportunity to select days from different months of the year. The description of the WRF model and parameterization schemes is given in Section 2. The model domains chosen for simulation and numerical experiments carried out are described in Section 3. Results are presented in Section 4 along with the methods for selecting the optimal physics combination.

2. Description of the WRF model and parameterization schemes

The Weather Research and Forecasting (WRF) is an atmospheric model developed for both research and operational applications and can be used for simulations across varying spatial scales from few km to hundreds of km. The model was developed as a collaborative effort among various institutes like the National Centre for Atmospheric Research (NCAR), the National Centers for Environmental Prediction (NCEP), the National Oceanic and Atmospheric Administration (NOAA), the Forecast Systems Laboratory (FSL) and the Air Force Weather Agency (AFWA). In most atmospheric models, sub grid scale processes which are not explicitly resolved by the model are represented by parameterization schemes. For example, the cloud microphysics schemes are used to model the microphysical processes that govern cloud particle formation, growth and dissipation on small scales (Stensrud, 2007). The effect of sub grid scale clouds are represented by cumulus parameterization schemes. The short and long wave radiation schemes provide the atmospheric heating profiles and estimation of net radiation for the ground heat budget. The surface layer (SL) schemes are used to calculate the friction velocity and exchange coefficients that enable the estimation of heat, momentum and moisture fluxes by the land surface models (LSM). Finally, the Planetary Boundary Layer (PBL) schemes determine the flux profiles within the convective boundary layer, the stable layer and thus provide atmospheric tendencies of temperature, moisture and momentum in the entire atmospheric column.

In this study, the sensitivity analysis of the WRF simulation is carried out for LSM, PBL schemes and parameterization schemes. Two LSM were used in this study namely the thermal diffusion (Dudhia, 1996) and the Noah LSM (Chen and Dudhia, 2001). The five layer thermal diffusion model is a simple soil temperature model. The layers are 1, 2, 4, 8 and 16 cm thick. Below this the temperature is fixed at a deep layer average. The soil moisture is also fixed with a land use and season dependent constant value and no explicit vegetation effects are included. The Noah LSM on the other hand predicts soil temperature and moisture in 4 layers extending 10 cm, 30 cm, 60 cm and 100 cm from the surface and summing up to 2 m below the surface. It includes land use, monthly vegetation fraction and evapotranspiration in the estimation of sensible and latent heat fluxes. The PBL schemes tested are Yonsei University (YSU) (Hong et al., 2006), Mellor Yamada Janjic Eta (MYJ) (Janjic, 1990, 2002), Asymmetric Convective Model (ACM2) (Pleim, 2007), Quasi Normal Scale Elimination (QNSE) (Sukoriansky et al., 2005, 2006) and Mellor Yamada Nakanishi Niino (MYNN) (Nakanishi and Niino, 2004). The SL schemes used are Monin Obhukhov (Monin and Obhukhov, 1954), Monin Obhukhov Janjic Eta (MYJ) (Monin and Obhukhov, 1954; Janjic, 1996), Quasi Normal Scale Elimination (QNSE) (Sukoriansky et al., 2005, 2006) and Mellor Yamada Nakanishi Niino (MYNN) (Nakanishi and Niino, 2004).

The other physical parameterizations are identical for all the experiments which are Rapid radiation Transfer Model for long-wave radiation (RRTM) (Mlawer et al., 1997), Dudhia (Dudhia, 1989) for short-wave radiation, Kain Fritsch scheme for cumulus parameterization (Kain and Fritsch, 1990; Kain, 2004) and Ferrier new Eta (Ferrier et al., 2002) scheme for representing micro physical processes in the clouds.