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WRF Mesoscale Model – Compatible parameterization Schemes to estimate the sea breeze circulation.

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Abstract : The WRF ARW mesoscale model is a fully compressible, non-hydrostatic model (with a hydrostatic option). Its vertical coordinate is a terrain-following hydrostatic pressure coordinate. The model uses higher order numerics. It can perform sensitive experiments which can used to acknowledge the presence of mesoscale circulations. Parameterization schemes may also be included in an atmospheric model for the representation of atmospheric phenomena whose explicit treatment may become too prohibitive due to cost and computer limitations. Numerical models are not only creates a forecast but also performs data assimilation, data analysis, and quality control. Many factors combine to determine the quality and usefulness of a model forecast.

Keyword: WRF mesoscale model, Parameterization Schemes.

1. Introduction

Mesoscale models are numerical tools. They are a set of complicated equations which govern the motion of the atmosphere. Mesoscale models simulate atmospheric processes on a spatial scale from 20 to 2000 km and resolve temporal fluctuations lasting from 1 to 12 hours. A weather model includes parameterizations for radiation, surface layer fluxes, turbulence, cumulus convection, and clouds. Generally there are six to seven schemes available for representation of each of these processes with its own merits and demerits depending upon the terrain, geography, and climate of the area under consideration. Mixing height is an important input to air pollution models since the transport and extent of mixing of pollutants depend on it. The mixing in the atmosphere primarily takes place through convective and mechanical processes. During the daytime, differential heating due to solar radiation sets up strong thermals in the atmosphere and the convective processes dominate whereas, during the nighttime, mechanical processes are responsible for the turbulent mixing. By varying the parameterization schemes will provide the knowledge in estimating the sea breeze pattern for the investigators.

The Weather Research and Forecasting (WRF) Model is a next-generation mesoscale numerical weather prediction system designed for both atmospheric research and operational forecasting applications. It features two dynamical cores, a data assimilation system, and a software architecture supporting parallel computation and system extensibility. The Weather Research and Forecasting (WRF) Model is a next-generation mesocale numerical weather prediction system designed to serve both operational forecasting and atmospheric research needs. It is an evolutionary successor to the MM5 model. The effort to develop WRF has been a collaborative partnership, principally among the National Center for Atmospheric Research (NCAR), the National Oceanic and Atmospheric Administration (the National Centers for Environmental Prediction (NCEP) and the Forecast Systems Laboratory (FSL), the Air Force Weather Agency (AFWA), the Naval Research Laboratory, Oklahoma University, and the Federal Aviation Administration (FAA).The present study focuses on the evaluation of parameterization schemes in the WRF model for estimation of sea breeze circulation from different studies carried out by investigators.

2. Parameterization Schemes

There are several physics options in the WRF model. The physics categories are (1) microphysics, (2) cumulus parameterization, (3) ABL, (4) land-surface model, and (5) radiation. The micro physics schemes indicating the number of moisture variables, and whether ice-phase and mixed-phase processes are included. Mixed-phase processes are those that result from the interaction of ice and water particles, such as riming that produces graupel or hail.

Cumulus parameterization schemes are responsible for the sub-grid-scale effects of convective and shallow clouds. The schemes are intended to represent vertical fluxes due to unresolved updrafts and downdrafts and compensating motion outside the clouds. They operate only on individual columns where the scheme is triggered and provide vertical heating and moistening profiles. Some schemes additionally provide cloud and precipitation field tendencies in the column, and future schemes may provide momentum tendencies due to convective transport of momentum. The schemes all provide the convective component of surface rainfall.

The planetary boundary layer (PBL) schemes are responsible for vertical sub-grid-scale fluxes due to eddy transports in the whole atmospheric column. The PBL schemes determine the flux profiles within the well-mixed boundary layer and the stable layer, and thus provide atmospheric tendencies of temperature, moisture (including clouds), and horizontal momentum in the entire atmospheric column. Most PBL schemes consider dry mixing, but can also include saturation effects in the vertical stability that determines the mixing.

The land-surface models (LSMs) use atmospheric information from the surface layer scheme, radiative forcing from the radiation scheme, and precipitation forcing from the microphysics and convective schemes, together with internal information on the land's state variables and land-surface properties, to provide heat and moisture fluxes provide a lower boundary condition for the vertical transport done in the PBL scheme (or the vertical diffusion scheme in the case where a PBL scheme is not run, such as in large-eddy mode).The land-surface models have various degrees of sophistication in dealing with thermal and moisture fluxes in multiple layers of the soil and also may handle vegetation, root, and canopy effect and surface snow-cover prediction.

The radiation schemes provide atmospheric heating due to radiative flux divergence and surface downward long wave and shortwave radiation for the ground heat budget. Long wave radiation includes infrared or thermal radiation absorbed and emitted by gases and surfaces. Upward long wave radiative flux from the ground is determined by the surface emissivity that in turn depends upon land-use type, as well as the ground (skin) temperature. Shortwave radiation includes visible and surrounding wavelengths that make up the solar spectrum.

The best suitable schemes opted in simulating the sea breeze circulation in WRF mesoscale model for the estimation and forecasting the sea breeze mechanism are as follows:

a) WRF Single-Moment 3-Class (WSM3) Scheme

WSM3 scheme follows Hong *et al* (2004) including ice sedimentation and other new ice-phase parameterizations revised from the older NCEP3 scheme (Hong *et al* 1998) that was in WRF Version 1. A major difference from other schemes is that a diagnostic relation is used for ice number concentration that is based on ice mass content rather than temperature. Three categories of hydrometers are included which are vapor, cloud water/ice, and rain/snow. As with Dudhia (1989), this is a so-called simple-ice scheme wherein the cloud ice and cloud water are counted as the same category. They are distinguished by temperature: namely, cloud ice can only exist when the temperature is less than or equal to the freezing point; otherwise, cloud water can exist. The same condition is applied to rain and snow. Though the ice phase is included, it is considered efficient enough for using in operational models.

b) Kain-Fritsch Scheme

The modified version of the Kain-Fritsch scheme (Kain, 2004) is based on Kain and Fritsch (1990) and Kain and Fritsch (1993), but has been modified based on testing within the Eta model. As with the original KF scheme, it utilizes a simple cloud model with moist updrafts and downdrafts, including the effects of detrainment, entrainment, and relatively simple microphysics. It differs from the original KF scheme in the following ways:

- A minimum entrainment rate is imposed to suppress widespread convection in marginally unstable, relatively dry environments.
- Shallow (non-precipitating) convection is allowed for any updraft that does not reach minimum cloud depth for precipitating clouds; this minimum depth varies as a function of cloud-base temperature.
- The entrainment rate is allowed to vary as a function of low-level convergence.
- Downdraft changes:
  - Source layer is the entire 150 – 200 mb deep layer just above cloud base
  - Mass flux is specified as a fraction of updraft mass flux at cloud base. Fraction is a function of source layer RH rather than wind shear or other parameters, i.e., old precipitation efficiency relationship not used.
  - Detrainment is specified to occur in updraft source layer and below.

c) Yonsei University (YSU) PBL

The Yonsei University PBL is the next generation of the MRF PBL, also using the counter gradient terms to represent fluxes due to non-local gradients. This adds to the MRF PBL (Hong and Pan, 1996) an explicit treatment of the entrainment layer at the PBL top. The entrainment is made proportional to the surface buoyancy flux in line with results from studies with large-eddy models (Noh *et al* 2003). The PBL top is defined using a critical bulk Richardson number of zero (compared to 0.5 in the MRF PBL), so is effectively dependent on the buoyancy profile, in which the PBL top is defined at the maximum entrainment layer (compared to the layer at which the diffusivity becomes zero). A smaller magnitude of the counter-gradient mixing in the YSU PBL produces a well-mixed boundary layer profile, whereas there is a pronounced over-stable structure in the upper part of the mixed layer in the case of the MRF PBL.

d) Mellor-Yamada-Janjic (MYJ) PBL

This parameterization of turbulence in the PBL and in the free atmosphere (Janjic, 1990, 1996, 2002) represents a non-singular implementation of the Mellor-Yamada Level 2.5 turbulence closure model (Mellor and Yamada, 1982) through the full range of atmospheric turbulent regimes. In this implementation, an upper limit is imposed on the master length scale. This upper limit depends on the TKE as well as the buoyancy and shear of the driving flow. In the unstable range, the functional form of the upper limit is derived from the requirement that the TKE production be non-singular in the case of growing turbulence. In the stable range, the upper limit is derived from the requirement that the ratio of the variance of the vertical velocity deviation and TKE cannot be smaller than that corresponding to the regime of vanishing turbulence. The TKE production/dissipation differential equation is solved iteratively. The empirical constants have been revised as well (Janjic, 1996, 2002).

e) Asymmetric Convective Model (ACM2) PBL

Asymmetric Convective Model (ACM) for the PBL (Pleim and Chang, 1992) is a derivative of the Blackadar model, and it was recently updated to a combined non-local scheme of the original ACM and an eddy diffusion scheme (ACM2; Pleim, 2007). The new ACM, version 2, (ACM2) adds an eddy diffusion component to the nonlocal transport. With the addition of the eddy diffusion component, the ACM2 can better represent the shape of the vertical profiles, especially the gradually decreasing gradient near the surface. Thus, the ACM2 can represent potential temperature profiles similarly to eddy diffusion schemes with the gradient adjustment term, but because local and nonlocal mass fluxes are explicitly defined, the ACM2 is more applicable to other quantities (e.g., humidity, winds, or trace chemical mixing ratios). Thus, the purpose of the ACM2 is to provide a realistic and computationally efficient PBL model for use in both meteorological and atmospheric-chemistry models.

f) Noah Land Surface Model

The Noah LSM is the successor to the OSU LSM described by Chen and Duhia (2001). The scheme was developed jointly by NCAR and NCEP, and is a unified code for research and operational purposes, being almost identical to the code used in the NCEP North American Mesoscale Model (NAM). This has the benefit of being consistent with the time-dependent soil fields provided in the analysis datasets. This is a 4-layer soil temperature and moisture model with canopy moisture and snow cover prediction .It includes root zone, evapotranspiration, soil drainage, and runoff, taking into account vegetation categories, monthly vegetation fraction, and soil texture. The Noah LSM additionally predicts soil ice and fractional snow cover effects, has an improved urban treatment, and considers surface emissivity properties, which are all new since the OSU scheme.

g) Rapid Radiative Transfer Model (RRTM) Long Wave

This RRTM, which is taken from MM5, is based on Mlawer *et al* (1997) and is a spectral- band scheme using the correlated-*k* method. It uses preset tables to accurately represent long wave processes due to water vapor, ozone, CO_2, and trace gases (if present), as well as accounting for cloud optical depth.

h) MM5 (Dudhia) Short Wave

This scheme is based on Dudhia (1989) and is taken from MM5. It has a simple downward integration of solar flux, accounting for clear-air scattering, water vapor absorption (Lacis and Hansen, 1974), and cloud albedo and absorption. It uses look-up tables for clouds from Stephens (1978).

3. Conclusion

The numerical experiments carried out for the selection of the optimum combination of parameterization schemes for estimation of sea breeze circulation. It is observed that the best results given in studying the sea breeze by using the parameterization schemes in WRF Mesoscale model by the investigators are that the physics option as WRF Single-Moment 3-Class (WSM3) Scheme consisting of Yonsei University (YSU), Mellor Yamada Janjic, Asymmetric Convective Model (ACM2) PBL as the Planetary Boundary Layer schemes, Kain-Fritsch Scheme as the convective scheme, MM5 (Dudhia) Short Wave and Rapid Radiative Transfer Model (RRTM) Long Wave as radiation schemes and Noah land surface model performs reasonably well in reproducing the observed mixing height.

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