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THE WEATHER RESEARCH AND FORECASTING MODEL: 2009 ANNUAL UPDATE

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1. INTRODUCTION

WRF Version 3.1 was released in April 2009, and includes many new features and options that have been added since the 3.0 release a year earlier. Changes to the pre- and post-processing, including WPS and graphics tools, will also be described. Additional changes related to bug-fixes and improvements for the existing schemes are listed fully on the Version 3.1 Updates page. Separate papers will describe updates to WRF-Chem and WRF-Var.

2. VERSION 3.1

2.1 Planetary Boundary Layer

Version 3.1 includes several new planetary boundary layer schemes developed and added largely in response to previous recognized shortcomings of WRF's existing options, and this will hopefully enable interesting future intercomparisons of the options now available. The new schemes are all TKE-based, i.e. using turbulent kinetic energy as a prognostic variable.

The QNSE PBL (Sukoriansky et al. 2005) has been designed to improve the turbulence in stably stratified conditions based on a new theory for such turbulence.

Level 2.5 and Level 3 PBL schemes by Nakanishi and Niino (2006) were also incorporated as part of a DTC project by M. Pagowski (NOAA/ESRL).

Finally, the Bougeault and Lacarrère (1989) (BouLac) scheme was added by A. Martilli (CIEMAT, Spain) as part of a project to include a multi-layer urban model (see later).

2.2 Surface options

The MODIS 20-category landuse from around 2001 is now available with global 30" resolution as an update to the USGS categories that date to 1993. The MODIS landuse uses more recent images and newer techniques to derive categories from satellite data.

The Noah LSM has had several significant improvements added for 3.1 (see also workshop paper by Tewari et al.). Noah now exclusively uses the `VEGPARM.TBL` for albedo, roughness length, and emissivity properties, and furthermore has replaced the previous summer/winter values of these properties with gradually changing values based on the vegetation fraction annual cycle. Also, snow albedo has been updated to account for snow age following the Livneh technique, which helps alleviate a bias in the melting rate.

A new multi-layer urban model called BEP (Building Environment Parameterization, Martilli et al., 2002) was added by A. Martilli and S. Grossmann-Clarke (CIEMAT and Arizona State U, respectively). This uses additional sub-grid building height and area information, and can spread urban influences through multiple layers when the model levels are below building roofs. This can be used with the MYJ or

BouLac PBL schemes. This is now selected with *sf_urban_physics=2,* while the previous urban canopy model is now selected with *sf_urban_physics=1.*

For polar regions, there is a new sea-ice fraction implementation that can treat sub-grid partitioning of fluxes over sea-ice and open water (*fractional_seaice=1*).

2.3 Microphysics

The Thompson microphysics option (*mp_physics=8*) has been updated significantly to include double-moment rain in addition to the previous double-moment ice. The previous scheme is still available as option 98.

WDM5 and WDM6 (Lim and Hong, 2009) are new double-moment versions of WSM5 and WSM6 that additionally predict cloud-condensation nuclei, cloud-droplet number concentration, and rain number concentration to account for warm-rain/aerosol effects.

2.4 Regional Climate options

New accurate and efficient radiation schemes have been provided by AER, Inc. as both shortwave and longwave options. These are called RRTMG and the longwave scheme is significantly updated (Iacono et al., 2008) from the RRTM scheme implemented in MM5 ten years ago. They also use the new Monte Carlo Independent Cloud Approximation (MCICA) technique to efficiently represent sub-column cloud effects.

Other capabilities developed for the NRCM project have been incorporated as options in ARW. These include Zeng and Beljaars (2005) ocean skin-temperature diurnal effects (*sst_skin*), and deep-soil temperature variation (*tmn_update*), CO_2 concentration as a function of year in CAM radiation, and a compile-time (CPP) capability for removing leap years for driving WRF with CCSM data. An option also now exists for rainfall and radiation budget accumulations that use the idea of buckets to maintain round-off accuracy for large numbers that may be generated in continuous decadal runs.

2.5 Other additions

Gravity-wave drag following Kim and Arakawa (1995) was added for ARW by H.-Y. Shin and S.-Y. Hong, (YSU), and separately for NMM in Version 3.1 (*gwd_opt=1,2* respectively). This is particularly valuable for medium-range or seasonal, large-area or global, simulations as it eliminates biases associated with neglecting sub-grid orographically induced momentum transport primarily in the mid-latitude jet streams.

Surface analysis-nudging has been added by Penn State to the previous upper-air grid-nudging to enable use of higher temporal resolution surface analyses in the nudging. These analyses are generated by the *obsgrid* program from standard observations and first-guess analyses.

Spectral nudging was added by G. Miguez-Macho (U. Santiago de Compostela, Spain) as *grid_fdda=2.* This is a form of analysis nudging that only nudges at selected larger scales leaving finer scales alone.

Monotonic advection has been added to improve scalar transports. It prevents overshooting and undershooting that may occur with advection schemes. To accommodate this, *pd_moist,* etc. namelist logicals have been replaced with *moist_adv_opt,* etc. integer switches, where 0 is plain advection, 1 is positive definite and 2 is the new monotonic option.

A single-column version of WRF that can be forced with specified time-dependent terms has been added by J. Hacker (NCAR/RAL) as a new idealized option in ARW under directory *test/em_scm_xy*.

2.6 Pre- and Post-processing

The WPS *geogrid* program has been updated to allow for a MODIS landuse option in addition to USGS, and also to add the extra sub-grid topographic information needed for orographic gravity-wave drag in the model.

A capability for using a diurnally averaged surface-air temperature to initialize lake temperatures has also been added, but requires special landuse category datasets that distinguish oceans from lakes that can be provided to users. This diurnal temperature can also be used when there is no skin temperature available.

The *obsgrid* program has been enhanced and improved. It now outputs files suitable for surface-analysis nudging and observational nudging inputs to WRF.

A tropical-cyclone (TC) bogusing program (*tc.exe*) has been ported from MM5 for Version 3.1. The method involves removal of an existing vortex and replacement with an idealized specified one to correct position and intensity in the *metgrid* initial conditions.

The real-data base state has been made more flexible by allowing for a stratosphere-like isothermal layer at the top. This allows the model top to be extended above 10 hPa, and decreases the magnitude of the perturbation geopotential heights in the stratosphere.

The NCL graphics package has many enhanced WRF features in its new Version 5.1.0, and the workshop includes a tutorial to update NCL users. The VAPOR and IDV graphics and MET verification software support teams are also offering tutorials at this workshop.

3. PLANNED ADDITIONS

Development is ongoing for Version 3.2 due out in 2010. Sub-filter scale turbulence parameterization and methods for fine scales are being developed at LLNL (J. Mirocha and J. Lundqvist). Work on developing high-resolution vertical nesting will also be presented from Arizona State (M. Moustaoui and A. Mahalov). Other work related to fine scales involve several groups developing and using microphysics bin models in WRF, e.g. A. Khain and B. Lynn at HUJ (Israel).

The core of WRF usage is at the weather scale, and the recent development of more PBL options reflects one area of priority for improvement in surface forecasts. Work is also active in the land-surface modeling for the same reason, particularly in the area of improving surface fluxes and properties. A growing area of applications and funding is wind energy where there is a need for accurate, but localized, surface forecasts. Surface fluxes also pertain over the ocean, especially for the application of tropical cyclone prediction at high resolution.

Microphysics development has also been focused on improving quantitative precipitation forecasts, and is moving more towards double-moment models, some of which are added in Version 3.1, with possibly more in Version 3.2.

Another area of growing WRF usage, and an area of particular priority at NCAR, is regional climate modeling. Work is starting on incorporating CCSM physics into WRF, so that WRF can be used as a regional version of CCSM, and can be used to evaluate climate-model physics against its other options, which would also allow for use as a testbed for new climate physics options. In particular, this would include the CCSM cloud physics, cumulus parameterization, and planetary boundary layer schemes that are to be used for the next IPCC simulations. Related work involves coupling WRF to the ocean, sea-ice and land components in the CCSM system.

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