THE WEATHER RESEARCH AND FORECASTING MODEL: 2010 ANNUAL UPDATE

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1. INTRODUCTION

WRF Version 3.2 was released in April 2010, and includes several new features and options that have been added since the 3.1 release a year earlier. Changes to the WPS pre-processing package will also be described. All post-processing packages have been updated to work with WRF version 3.2. Additional changes related to bug-fixes and improvements for the existing schemes are listed fully on the Version 3.2 Updates page *(http://www.mmm.ucar.edu/wrf/users/wrfv3.2/updates-3.2.html)*. Separate papers will describe updates to WRF-Chem and WRFDA.

2. VERSION 3.2

2.1 New physics options

Compared to the 3.1 release, Version 3.2 has less new options. The Milbrandt-Yau double-moment microphysics option (*mp_physics=9*) was provided by Jason Milbrandt of Environment Canada. In terms of numbers of variables, this is the most sophisticated scheme yet, being doube-moment for all condensate species plus adding a hail category separate from graupel, making 13 moisture variables including vapor.

A new urban option called BEM (the Building Energy Model, *sf_urban_physics=3*) was added including detailed building anthropogenic terms, but otherwise closely related to the BEP option (Salamanca and Martilli, 2009).

For LES applications we have a new method of treating sub-grid stress called the Nonlinear Backscatter Anistropic (NBA) option (*sfs_opt=1,2*) provided by Jeff Mirocha (Lawrence Livermore National Lab). This modifies the sub-grid momentum part of the LES equations, and can be used with or without TKE.

WRF-Fire is released as part of V3.2 by Mandel, Beezley, Coen and Kim of CU and NCAR (Mandel et al., 2009, Clark et al., 2004). This is a sophisticated surface fire-spread model that interacts with the atmosphere. It comes with some idealized examples, but takes additional advanced datasets to be run in real-data situations.

2.2 Surface options

A new vegetation-height dependent thermal roughness length (Chen and Zhang, 2009) was added as an option (*iz0tlnd=1*) for surface-layer (*sf_sfclay_physics*) options 1 and 2 (*sfclay* and *myjsfc*). This was designed to better fit surface fluxes.

The Noah LSM added improvements to the age-dependent snow albedo.

The PX and RUC LSMs added sea-ice and lake-ice capabilities.

Slope and shading effects (*slope_rad* and *topo_shading*) were generalized to apply to all radiation options and land options, by moving the code to the surface driver. This is an option suitable for grid sizes less than about 2 km in complex terrain.

2.3 Hurricane physics

The ARW 1-dimensional ocean-mixed layer model (*omlcall=1*) can now be used with any land-surface option. Surface fluxes for cyclones now have option *isftcflx=2* to use the Garratt formulation which has less variation of the enthalpy exchange coefficient (Ck) with wind speed than the ramped-Ck option. This agrees better with more recent observations in hurricane sea conditions. Dissipative heating has also been added to both *isftcflx* options.

HWRF (the NMM-core version) was released with its specialized options in Version 3.2. The HWRF physics include new versions of the GFS PBL and SAS cumulus schemes, and slightly modified versions of GFDL radiation and Ferrier microphysics. Vortex-following code was also added.

2.4 Other new features

Shallow convection was added to the Grell-3 scheme (*ishallow=1*).

Observation-nudging has had some more flexibility added to how the vertical weighting is done in the nudging of surface observations.

The NMM dynamical core has had a sea-surface temperature update capability added.

A 4d array called *tracer* was added (others being *moist, chem* and *scalar*). This allows any number of tracers to be advected and diffused once a source or initial concentration is specified. This works best when a PBL is not used, and some additional code would be required for vertical mixing of the tracers if a PBL is used. We may add this in a future version, and plan to provide an example of a modified PBL scheme on the Web pages.

2.5 New output options

Flexibility was added to the input/output part of the code that allows a run-time choice of adding or subtracting fields from the model output streams. This avoids using the Registry, which required recompilation of the complete model.

ARW now has an option to output separate rainfall accumulations over specified periods (as NMM did previously). The periods can be specified using *prec_acc_dt*.

Time-averaged mass fluxes can now be output (code from Thomas Nehrkorn). This is beneficial for off-line transport models using WRF output winds, because the time-averaged fluxes obey mass continuity and will conserve in off-line advection (*do_avg_em. do_avg_cugd*).

2.6 Improvements

We have improved the top-of-the-model radiation assumptions in the RRTM longwave scheme (Cavallo et al. 2010). Often the model top cools unrealistically in the stratosphere due to the isothermal assumption being poor. The new method adds radiation layers above the model top with a better climatological lapse rate assumption that is effective in removing the bias.

Furthermore *ungrib* contributed to such biases by filling in relative humidities for missing levels above 50 hPa with values that were climatologically much too high, and this also enhanced the cool bias for some datasets, so *ungrib* and *real* are now modified to produce lower RH in the stratosphere when the data are missing.

The RRTMG ice cloud assumptions have been modified to respond to the snow in addition to ice microphysical category to provide better outgoing longwave radiation. This particularly impacts the Thompson scheme's OLR since this option produces more snow than ice in high clouds.

In microphysics, the WSM and WDM schemes have been modified to use semi-lagrangian fall terms instead of the time-splitting approach. This may help efficiency for low-resolution simulations that normally require many split steps.

The pressure field used by the physics has now been switched to a new hydrostatic pressure diagnostic done by *phy_prep*. Several physics options, mostly radiation, but some cumulus schemes, had their own hydrostatic pressure computations prior to this change, so this simplifies the code by pre-computing it for all physics. The 3d hydrostatic pressure is also now available in the output. It is defined in terms of mass of air and vapor in the column above a point, and differs from the nonhydrostatic pressure used in the dynamics that comes from the gas law (density and temperature) locally at each point.

2.7 Bug fixes

WSM and WDM microphysics options have been corrected for long time-steps (dt > 120 s) where non-convective rainfall going into the land-surface model was half its proper value. Note that there was no error for shorter steps.

The Kain-Fritsch cumulus schemes also had a correction for convective rainfall going into the land-surface models, but this error was only a few percent of the total.

Two-way nesting occasionally failed after long integrations over many time-steps due to a problem with the nest boundary's surface vertical motion becoming inconsistent with the parent domain in complex terrain. This was due to a slow drift that now has been corrected.

A minor correction for time-varying sea-ice is to reset albedo, snow-cover etc., to water values after the sea ice disappears.

The QNSE PBL had diagnostic 2m and 10 m fields that were not calculated consistently with the scheme, so these diagnostics have been corrected. Other results are not affected by this.

Further bug-fixes will be part of the 3.2.1 release due out in July/August. These will include an improvement to the WSM, WDM and Morrison microphysics to work properly in the upper stratosphere (p < 5 hPa) where the saturation vapor pressure needs modification.

3. PLANNED ADDITIONS

Development is ongoing for Version 3.3 due out in 2011. Several things are being worked on that may make it into this or future releases. With the aid of collaboration in Pacific Northwest Laboratory, we may get CCSM physics packages such as the new Zhang-McFarland cumulus scheme, and Bretherton-Park (UW) PBL scheme.

The SAS cumulus scheme (currently in NMM for HWRF) will be made available as an ARW option, together with the Tiedtke cumulus scheme (from Yuqing Wang, U. Hawaii).

The Simple SiB LSM is being contributed by UCLA (Y. Xue et al.).

4. ACKNOWLEDGMENTS

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5. REFERENCES

Cavallo, S. M., J. Dudhia, and C. Snyder, 2010: An improved upper boundary condition for longwave radiative flux in the stratosphere to correct model biases. Submitted to *Mon. Wea. Rev.*

Chen, F., and Y. Zhang, 2009: On the coupling strength between the land surface and the atmosphere: From viewpoint of surface exchange coefficients. *Geophys. Res. Lett.,* **36,** L10404.

Clark, T. L., J. Coen, and D. Latham, 2004: Description of a coupled atmosphere-fire model. *Intl. J. Wildland Fire,* **13,** 49-64.

Mandel, J., J. D. Beezley, J. L. Coen, and M. Kim, 2009: Data Assimilation for Wildland Fires: Ensemble Kalman filters in coupled atmosphere-surface models. *IEEE Control Systems Magazin,e* **29,** Issue 3, 47-65.

Milbrandt, J. A., and M.-K. Yau, 2005: A multimoment bulk microphysics parameterization. Part I: Analysis of the role of the spectral shape parameter *J. Atmos. Sci.,* **62,** 3051-3064.

Salamanca, F., and A. Martilli, 2009: A new Building Energy Model coupled with an Urban Canopy Parameterization for urban climate simulations._Part II: Validation with one dimension off-line simulations'. *Theor Appl Climatol*. DOI 10.1007/s00704-009-0143-8