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THE WEATHER RESEARCH AND FORECASTING MODEL: 2011 ANNUAL UPDATE

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1. INTRODUCTION

WRF Version 3.3 was released in April 2011, and includes several new features and options that have been added since the 3.2 release a year earlier. Additional changes related to bug-fixes and improvements for the existing schemes are listed fully on the Version 3.3 Updates page. Separate papers will describe updates to WRF-Chem and WRFDA.

2. VERSION 3.3

2.1 New physics options

This release has seen a large growth in physics options, particularly in the area of cumulus parameterization, which remains an important area of development with applications in regional climate and large-scale data assimilation. We have gathered together several of the newest state-of-the-science cumulus schemes from climate and global forecast models.

A major development effort centered at Pacific Northwest National Lab has resulted in several CESM/CAM climate model physics packages becoming available in Version 3.3. These include the current versions of the Zhang-McFarlane (Zhang and McFarlane 1995) deep convection scheme *(cu_physics=7)*, and the University of Washington (Bretherton-Park) shallow convection *(shcu_physics=2,* Park and Bretherton 2009*)* and PBL schemes *(bl_pbl_physics=9,* Bretherton and Park 2009*)*. They have also coupled RRTMG radiation and Morrison microphysics to the WRF-Chem model, working with the developers of those schemes.

Further enhancements to cumulus parameterization came from the University of Hawaii (Zhang et al., 2011) who provided their version of the Tiedtke (1989) cumulus scheme (*cu_physics=6)*, and a version of Simplified Arakawa-Schubert cumulus with shallow convection that works in the ARW dynamical core *(cu_physics=4)*.

The NCEP GFS model has an updated Simplified Arakawa-Schubert (named as NSAS for NCEP SAS, *cu_physics=14*) that was provided in the WRF physics framework by the group at Yonsei University, Korea. This new version has a new shallow convection scheme and updated deep scheme.

For the Kain-Fritsch cumulus scheme, we have added a new optional trigger function *(kfeta_trigger=1)* based on the work of Ma and Tan (2009) and Yu and Lee (2010).

Of the new schemes, the NSAS, Zhang-McFarlane and Tiedtke cumulus schemes all include momentum transports, while the SAS, NSAS and Tiedtke schemes include shallow convection.

The new Total Energy Mass Flux (TEMF, Angevine et al., 2010) PBL *(bl_pbl_physics=10)* scheme was provided by NOAA/ESRL, and this incorporates a shallow-convective mass flux component.

One new microphysics scheme from Stonybrook University (the SBU_YLIN scheme, *mp_physics=13,* Lin and Colle 2011) has also been added in this release. This incorporates the idea of a riming intensity to handle the transition between snow and graupel.

NASA Goddard have provided a new version of their shortwave radiation scheme *(ra_sw_physics=5,* Chou and Suarez 1999*)* along with a new longwave radiation *(ra_lw_physics=5,* Chou and Suarez 2001*)* scheme. The older shortwave scheme is also retained because that is currently the only Goddard radiation scheme coupled to WRF-Chem.

Additionally a wind-farm parameterization scheme (*windturbine_spec* in namelist, from U. Bergen, Norway) has been added and works with the MYNN PBL option. The wind-farm feeds back to the momentum through added drag, and to the PBL's turbulent kinetic energy (TKE) that affects mixing. TKE advection was also activated for this PBL option.

2.2 Other new features

We have added a stochastic kinetic energy backscatter method *(stoch_force_opt=1,* Berner et al., 2011*)* similar to one implemented by ECMWF. This represents a random up-scale energy transfer that has been shown to realistically help ensemble spread to represent uncertainty in ensemble forecast applications.

The digital filter initialization (DFI) was extended to work in 1-way nested mode.

To speed up the *real.exe* code, calculations for boundary conditions after the initial time will now exclude computations from the interiors of the domains if they are not needed.

A new idealized case has been added to provide a 3d balanced vortex for tropical cyclone studies (*test/em_tropical_cyclone* directory).

2.3 improvements and bug-fixes

Numerous minor improvements and bug-fixes have been made in the physics packages. The Thompson microphysics scheme was updated significantly from the previous release, and the old option *(mp_physics=98)* was removed. The TKE and length-scale variables associated with most of the PBL schemes (MYJ, QNSE, BouLac, and CAM UW) have been given a unified name TKE_PBL and EL_PBL. A PBL height diagnostic was added for the BouLac PBL. The Noah LSM has added roughness length to the seasonally changing variables for long-term simulations that previously included vegetation fraction, leaf-area index, emissivity and albedo. Also a correction was made for using *tmn_update* with adaptive time-steps. The model-top radiation improvement applied in V3.2 to RRTM radiation was this year added to the RRTMG longwave scheme. A potentially important bug was fixed for the switch allowing slope effects on radiation for cases where it was not used on all domains. Finally, the single-column version of the model has been enhanced to allow surface and large-scale forcing.

3. PLANNED ADDITIONS

Development is ongoing for the next version due out in 2012. Several things are being worked on that may make it into this or future releases.

The pressure-based terrain-following vertical coordinate in the ARW core is being generalized to allow it to become a pure pressure coordinate at upper levels.

The Simple SiB LSM is being contributed by UCLA (Y. Xue et al.), as well as their radiation scheme.

We are also working on a microphysics-consistent reflectivity output, and new optional outputs for regional climate that includes mean and extreme values and standard deviations of surface quantities.

Other ongoing work is to allow for advected ozone, when the analysis provides it that interacts with the radiation options. We would also like to

add yearly changing CO2 values to radiation options as opposed to the current constant values used in all schemes except for CAM radiation.

4. ACKNOWLEDGMENTS

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