THE WEATHER RESEARCH AND FORECAST MODEL VERSION 2.0: PHYSICS UPDATE

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1. INTRODUCTION

WRF has a well-defined physics interface, the main feature of which is the physics driver. The driver is called from the solver routine (*solve_em* in the mass-coordinate core), and calls all of the physics options. Version 2.0 has separate drivers for (i) the surface driver for the surface layer and land-surface, and (ii) the planetary boundary layer (PBL) driver, instead of just the PBL driver that was in Version 1.3. The other three drivers remain the same (cumulus, radiation, microphysics). The physics modules associated with the surface driver have been accordingly renamed *module_sf_** instead of *module_bl_**, with a similar name change for the namelist variable selecting these options. The other change in the drivers was to put the OpenMP loops inside them instead of around the driver call in the solver. In a related change, the drivers' local arrays are now not allowed to be "tile-sized", and should be "memory-sized" instead.

Physics options each have their own module and obey certain rules to fit within the WRF physics interface. A typical physics module would have specific constants for that package defined at the head of the module, an initialization routine, and the main physics routines that provide a physical tendency or update of the model state variables. The main rules relate to three sets of indices. The indices refer to domain, memory, and tile dimensions. Domain dimensions are typically only used to check for physical domain boundaries. Memory dimensions are used to declare the state variables, and tile dimensions are used for local arrays and for the do-loops within the model layer.

WRF physics falls into three distinct categories: diffusion, column tendencies, and microphysical adjustments.

Diffusion includes options for horizontal and vertical mixing that have varying sophistication. The simplest is a constant-K approach that diffuses on coordinate surfaces, and the most complex has K determined from a prognostic turbulent kinetic energy (tke) equation, where the horizontal diffusion has metric terms to allow for the coordinate slopes. This latter approach is designed for high-resolution cloud-resolving and eddy-resolving simulations, for which WRF has potential application. In full-physics numerical weather prediction mode, WRF can use horizontal diffusion schemes based on the Smagorinsky approach, while the vertical diffusion is included in the column physics.

The column physics includes the planetary boundary layer with vertical mixing and surface fluxes, the land surface model, radiation, and convective parameterization schemes. These physics schemes, together with the microphysics, are written with plug-compatible interfaces to the dynamical core, such that the physics is insulated from core-specific variables and staggering. The interface also allows for multiple options within the basic categories: cumulus, radiation, surface, boundary layer, and microphysics. The column physics provides physical tendencies of the model's state variables.

The microphysics in WRF is handled as an adjustment after the variables have been stepped forwards near the end of the solver. This separate treatment is because these schemes include a saturation adjustment that needs to be at the end of the solver to maintain accurate saturated vapor mixing ratios.

2. SUMMARY OF VERSION 2.0 PHYSICS

Below are the current available options in WRF Version 2.0.

WRF Version 2.0 Physics Options (new options)*

Microphysics

1. Kessler
2. Lin et al.
3. WSM3*
4. WSM5*
5. EGCP01 (Eta, Ferrier)
6. WSM6*

Longwave Radiation

1. RRTM
2. GFDL (Eta)

Shortwave Radiation

1. Dudhia (MM5)
2. Goddard
3. GFDL (Eta)

Surface Layer

1. Similarity (MM5)
2. Eta similarity (Janjic)

Land Surface

1. 5-layer slab (MM5)
2. Noah LSM*
3. RUC LSM*

Boundary Layer

1. YSU*
2. Mellor-Yamada-Janjic (Eta)

Cumulus Parameterization

1. Kain-Fritsch (KF2)
2. Betts-Miller-Janjic (Eta)
3. Grell-Devenyi ensemble*

In addition to the new options, all of the schemes originally from the Eta or NMM NCEP models have been updated to remain consistent with the operational schemes as of summer 2003.

Some older schemes are still available but will be phased out in future versions (old KF cumulus, NCEP3 and NCEP5 microphysics, MRF PBL). The Oregon State University LSM is no longer available, having been replaced by the new Noah LSM, and the Zhao-Carr (old Eta) microphysics is no longer available.

3. NEW PHYSICS OPTIONS

3.1 WSM microphysics options

The WRF Single-Moment (WSM), 3-class, 5-class and 6-class microphysics options are a new set of schemes to replace the NCEP3 and NCEP5 options. WSM3 and WSM5 are described by Hong, Dudhia and Chen (2004). The primary change is the separation of ice *crystal* number concentration from ice *nuclei* number concentration, with the former now depending on ice mass content rather than temperature. This gives more realistic crystal concentrations and sizes that are now compatible with the fall speeds, which was not the case before or with many standard single-moment schemes. The new crystal sizes affect the rates of microphysics processes, and consistent changes were made to the ice initiation process. The snow distribution's intercept parameter's temperature dependence was also extended to colder temperatures by effectively removing the upper limit. Hong et al. (2004) showed that these improvements help to give more realistic vertical profiles of ice cloud and snow, and can help with the cloud cover and radiative properties of the cirrus shields. As with the NCEP3 and NCEP5, WSM5 differs from WSM3 in allowing mixed-phase processes by separating the cloud/ice and snow/rain arrays.

WSM6 by Lim and Hong (2003 WRF workshop) is an extension of these schemes to include graupel processes as the sixth class. The processes mostly follow those in Lin et al. (1983), but with modified accretion rates and other changes. Compared to WRF's implementation of the Lin scheme, WSM6 appears to produce less focused precipitation maxima at the surface, and broader anvil regions in propagating systems.

3.2 YSU PBL

Hong and Dudhia (2003 WRF workshop) introduced a next-generation version of the MRF PBL that addresses some commonly found problems in that scheme. The new scheme, known as the Yonsei University (YSU) PBL, has an explicit representation of entrainment at the PBL top which is derived from large-eddy modeling (Noh et al. 2003). The new scheme alleviates a problem with too much entrainment in the early phase of PBL growth, and provides a more realistic sounding within and just above the PBL as a result. The scheme also adds nonlocal momentum mixing to provide a better wind profile in the PBL.

The YSU scheme has also now been updated with a change to remove the influence of convective velocity on the surface stress, which will alleviate a day-time low-windspeed bias.

3.3 Grell-Devenyi cumulus

Grell and Devenyi (2002) have introduced a new ensemble approach to cumulus parameterization into WRF. The idea is to take an ensemble average of typically more than 100 types and variants of cumulus parameterization. The types include different closures, such as CAPE removal, quasi-equilibrium, and moisture convergence, and variants include changes to parameters for entrainment, cloud radius, maximum cap and precipitation efficiency/shear relations. These variants multiply to give a wide range of cumulus schemes called for each grid cell, but despite this the scheme remains efficient because many of the calculations overlap. Currently the ensemble average is taken, and has been shown to perform better than any individual member, but in principal the use of weights, statistically based on training, could enhance the skill of the scheme for different regions or times of day.

3.4 Noah LSM

The Noah land-surface model replaces the OSU LSM, and represents a collaborative effort between NCAR, NCEP and AFWA. The basic features are similar to the OSU scheme with four layers of soil temperature and soil moisture, but the new scheme allows for fractional snow cover and frozen soil effects, together with some other updates. Tewari et al. (2004, this workshop) will present more details and verification of this scheme.

3.5 RUC LSM

Smirnova (2004, this workshop) will present more details and verification of this scheme. The RUC LSM has a detailed snow cover treatment and has been running as part of the RUC system for several years, so it is a mature model that is now available for use in WRF. The WRF initialization was also modified to account for the new inputs required by this model.

3.6 Other physics changes

As mentioned, the Eta physics suite was updated to the summer 2003 versions. The main changes in result appeared to be from the MYJ surface and MYJ PBL updates which affected surface temperatures both over land and water.

The surface layer scheme (*sfclay)* has been updated to use the Beljaars formulation for convective velocity, which is more dependent on the flux and PBL height, and less dependent on the ground temperature than the previous (MM5) formulation.

The sub-grid mixing schemes have had several bug-fixes and the turbulent kinetic energy scheme is improved for use in large-eddy modeling through the efforts of several MMM scientists and visitors.

4. PHYSICS PLANS

One area of development for WRF is regional climate modeling. We are currently working on incorporating the new CAM radiation from the CCSM into WRF to make its radiative properties compatible with CAM, which is desirable for regional climate runs driven by CAM boundary conditions. The Common Land Model (CLM) from CCSM is also going to be coupled to WRF as part of this effort.

A next-generation version of MM5's Reisner 2 graupel scheme is also being tested at NCAR/RAP for release in a future WRF version. This is a double-moment scheme, capable of representing all number concentrations explicitly.

5. ACKNOWLEDGMENTS

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