The Weather Research and Forecasting Model: 2021 Annual Update

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NCAR/MMM

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WRF Community Model Releases

- Version 1.0: WRF was first released December 2000
- Version 2.0: May 2004
- Version 3.0: April 2008
- Version 4.0: June 2018 (add hybrid vertical coordinate)
- Version 4.1: April 2019
- Version 4.2: April 2020
  - Version 4.2.1: July 2020
  - Version 4.2.2: January 2021
- Version 4.3: May 2021

Outline

- Recap of new features in V4.2 (2020)
- Bug-fix releases since V4.2
- New in V4.3
- Some release verification tests for V4.3

Recap: Added in Version 4.2

Version 4.2 April 2020

Details at https://github.com/wrf-model/WRF/releases/tag/v4.2

- 3d TKE PBL scheme (*km_opt=5*), X. Zhang et al., 2018, MWR.
- Irrigation options in Noah LSM (*sf_surf_irr_scheme = 1, 2, 3*), A. Valmassoi et al., 2020, GMD.
- FARMS surface solar radiation (*swint_op=2*), Y. Xie et al., 2016, Solar Energy, and Jimenez et al., 2016, BAMS (WRF-Solar).
- New WRF-Solar diagnostics package (*solar_diagnostics = 1*)
- Fast Spectral Bin Microphysics significantly upgraded (*mp_physics=30*), K. Shpund et al., 2019, JGR-Atmosphere.

Bug-Fix Releases Since V4.2

- V4.2.1 July 2020
  - MYNN + wind-turbine scheme
    - Since V3.6 this option has not advected tke that was generated by the wind farm.
    - However fixing this led to too much tke from the wind farm, so an empirical correction factor of 0.25 derived from LES studies was also added
    - Archer et al. (University of Delaware)
    - See PR #1235 on github for details
  - Fixed m_opt diagnostics used with sub-grid-scale turbulence option
    - Matthias Goebel (University of Innsbruck)
    - See PR #1214
  - Time of T2max and T2min occasional error
    - Christopher Thomas (Climate Change Research Centre, UNSW Australia)
    - See PR #1208

Bug-Fix Releases Since V4.2

- V4.2.2 January 2021
  - Diffusion surface heat flux
    - Minor fix for heat budget be consistent with theta_m
    - Matthias Goebel (University of Innsbruck)
  - Sub-filter-scale diffusion option (sfs_opt=1)
    - Minor fix for vertical staggering of density
    - R. Arthur and J. Mirocha (LLNL)
  - Fractional sea-ice for MYJ and QNSE surface layers
    - QSFC was not weighted correctly (minor effect)
    - Xin-Zhong Liang (U. of Maryland)
  - FARMS shortwave scheme
    - Effective radius for unresolved clouds fixed
    - WRF-Solar team

Bug-Fix Releases Since V4.2

- V4.2.2 January 2021 continued
  - Noah irrigation scheme
    - Channel scheme fixed to provide water to LSM
    - Arianna Valmassoi (U. Bonn, Germany)
  - Deng shallow convection scheme
    - Several important fixes to improve behavior
    - WRF-Solar Team
    - See PR #1277 for details

- Other fixes for V4.2.1 and V4.2.2 not listed here can be found on WRF/releases page at github site

New Physics in Version 4.3

- E-epsilon PBL scheme
  - *bl_pbl_physics=16*
  - Chunxi Zhang, NCEP
- NTU (National Taiwan University) microphysics
  - *mp_physics=56*
  - Tzu-Chin Tsai and Jen-Ping Chen (NTU)
- P3 new 3-moment 1-ice microphysics
  - *mp_physics=53*
  - Hugh Morrison (NCAR) and Jason Milbrandt (Environment Canada)
- GSL enhanced scale-aware orographic drag
  - *gwd_opt=3*
  - Mike Toy (GSL/NOAA)

Enhancements in V4.3

- Solar eclipse capability for RRTMG, Goddard, Dudhia SW
  - *ra_sw_eclipse=1*
  - Alex Montornès et al. (U. Barcelona, Spain)
- BEP and BEM multi-layer urban model extended to YSU PBL
  - Eric Hendricks et al. (NCAR/RAL)
- Local Climate Zone urban category capability in urban models consistent with WUDAPT (www.wudapt.org)
  - Andrea Zonato (U. Trento, Italy)
- Urban capabilities for green roofs and solar panels
  - Andrea Zonato and Cenlin He (RAL)
- NoahmP irrigation option
  - *opt_irr*
  - Prasanth Valayamkunnath (RAL visitor)
- Initial CTSM coupling capability
  - Negin Sobhani et al. (NCAR/CGD)

Enhancements in V4.3

- Implicit-Explicit Vertical Advection (IEVA)
  - *zadvect_implicit = 1*
  - Lou Wicker (NSSL)
- Vertical geopotential advection option
  - *phi_adv_z = 2*
  - Matthias Goebel (University of Innsbruck, Austria)
- Height-level output now can include pressure
  - *p_zl* in output
  - Jared Lee (RAL)
- MAD-WRF initial clouds
  - *madwrf_opt =1,2*
  - Pedro Jimenez at al. (RAL)
- Clear-sky 3d radiative tendencies for most schemes
  - *RTHRATLWC* etc in output
  - James Huppert (Penn State U)

Updates and Bug-fixes in V4.3

- Updates have occurred in
  - NSSL microphysics options
  - Thompson microphysics
  - Deng shallow cumulus
  - FARMS surface solar radiation scheme
- Restarts have been fixed for certain nested configurations
  - Issues related to ozone and smoothing feedbacks
- Adaptive time step bug sometimes making dt=0 fixed
- Vertical nesting fixed for hybrid vertical coordinate

More found at https://github.com/wrf-model/WRF/releases

New: E-epsilon PBL scheme (EEPS)

- Talk by Chunxi Zhang (NCEP) on Thursday
- Published: C. Zhang, Y. Wang, and M. Xue (2020, MWR)
- First PBL scheme in WRF to predict both turbulent kinetic energy (E) and dissipation (ε)
- This scheme also advects both E and ε
  - Only MYNN and LES options also advect tke
  - Other tke PBL schemes keep prognostic tke in local column

New: National Taiwan University (NTU) Microphysics

- Tzu-Chin Tsai, Jen-Ping Chen (NTU)
- Published: T.-C. Tsai and J.-P. Chen (2020, JAS)
  - Condensation nuclei (CN) and ice nuclei (IN) are tracked separately for the processes of cloud/rain activation and ice deposition-nucleation using predicted supersaturation;
  - Applying the triple-moment (the zeroth, second, and third moments) closure method to describe the evolution of ice particle's spectrum;
  - Solid-phase hydrometeors' classification (pristine ice, snow aggregate, rimed ice, and hailstone) is redefined according to their key formation mechanisms;
  - Ice crystals' shape and apparent density can evolve gradually according to the growth conditions;
  - Fall speed of each moment for frozen particles depends on shape and density.
- 6 hydrometeor variables, 21 extra scalars

New: P3 Triple-Moment Microphysics Option

- See talk by Jason Milbrandt on Thursday
- Hugh Morrison (NCAR) and Jason Milbrandt (Environment Canada)
- Published: J. A. Milbrandt, H. Morrison, D. T. Dawson II, and M. Paukert (JAS, 2021)
  - Main update is to add 3-moment option for P3
  - P3 2-moment uses rimed ice mass and rimed ice volume as additional variables to mass and number concentration
  - P3 3-moment adds 6^{th} moment of size (like reflectivity) to allow evolution of size spectrum
  - This uses the same P3 module so that all 4 versions (MP options 50, 51, 52, 53) use the same code base. Also added new lookup tables.

New: NOAA/GSL Enhanced Orographic Drag Scheme

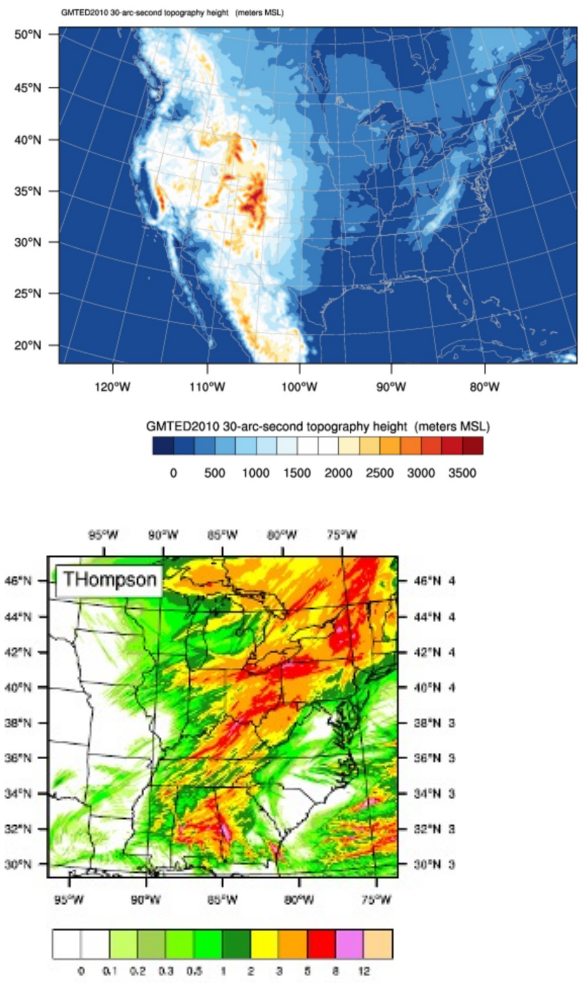
- See talk by Michael Toy (NOAA/GSL) on Wednesday
- Also implemented for operational use in RAP/HRRR system and UFS
- Previous large-scale orographic drag and flow blocking in (gwd_opt=1) are enhanced in gwd_opt=3 with
  - small-scale gravity wave drag
  - turbulent orographic form drag
- Some of these processes also are needed at high resolution so the scheme is made scale-aware to phase out large-scale part at high resolution

New: Implicit Explicit Vertical Advection (IEVA)

- Louis Wicker (NOAA/NSSL)
- Method to allow longer time-steps in cloud-permitting resolutions (up to ~50% longer) where WRF time step is typically limited by convective updrafts in high vertical resolution
- Vertical advection split into explicit and implicit parts making it unconditionally stable

Verification of WRFV4.3

- The WRF ARW tests are conducted for the periods 1-31 May 2017 and 1-28 February 2017 over a single domain at the resolution of 15km
- Three extra runs at 3km resolution are conducted for 9 cases in the period 1-31 May 2017 for predicted particle property (P3) bulk microphysics and Thompson for reference
- Results are verified against GFS analysis



15km (upper) and 3km (bottom) domains

Experiments

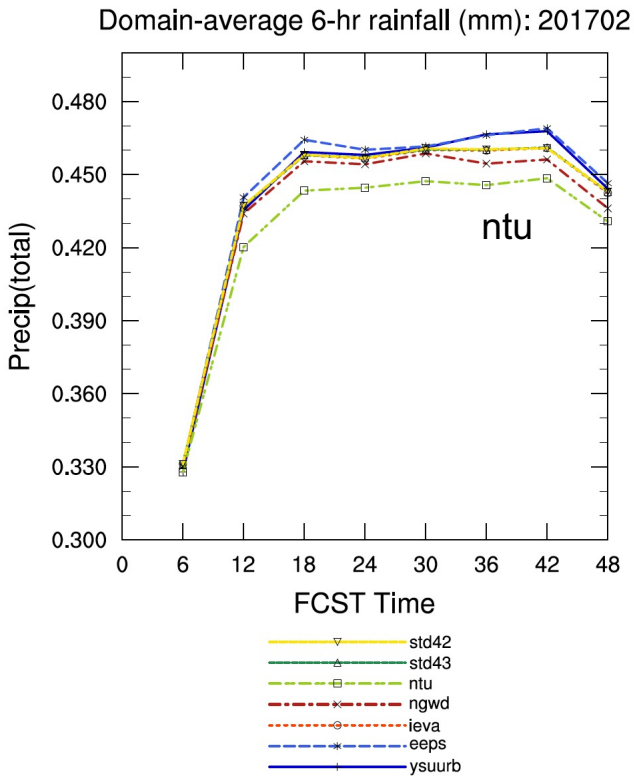
- Initial and boundary conditions are extracted from the NCEP GFS analysis product, which are in global 0.25 degree grids and at 6-hour intervals.
- Each single case is initialized daily at 0000UTC and run for 48-hour forecast.
- 28 cases are conducted for May and the February 2017.
- Various combinations of physics options are tested with the focus on new features of WRFV4.3.
- Baseline tests with the CONUS suite were conducted using WRFV4.2 and WRFV4.3 for comparison.

Table 1 Configurations for tests conducted, unless specified, all tests are based on WRFV4.3 and differences from CONUS suite are red

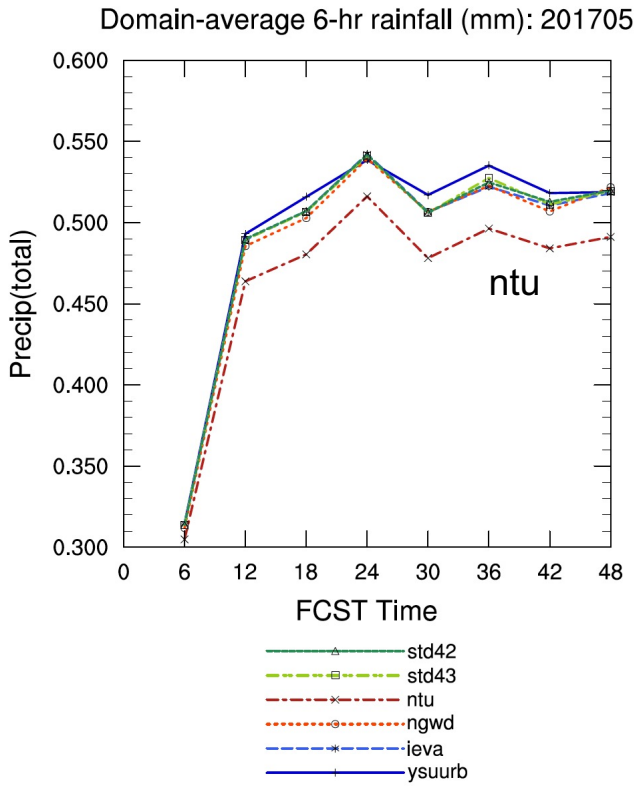
Name	Radiation	Cumulus	MP_PHYS	SFCLAY	LAND	PBL
Conus 4.2 and 4.3	RRTMG	Tiedtke	Thompson	MYJanjic	Noah	MYJ
eeps	RRTMG	Tiedtke	Thompson	MM5 Monin-Obukhov	Noah	EEPS
P3 (3-mom)	RRTMG	Tiedtke	P3 (3-mom)	MY Janjic	Noah	MYJ
ntu	RRTMG	Tiedtke	NTU	MY Janjic	Noah	MYJ
ngwd	RRTMG	Tiedtke	Thompson	MY Janjic	Noah	MYJ+GWD3
ysuurb	RRTMG	Tiedtke	Thompson	MM5 Monin-Obukhov	Noah + BEP/BEM	YSU
irrigation	RRTMG	Tiedtke	Thompson	MY Janjic	NoahMP +opt_irr	MYJ
ieva	RRTMG	Tiedtke	Thompson	MY Janjic	Noah	MYJ

Precipitation comparison (6-hr totals)

winter

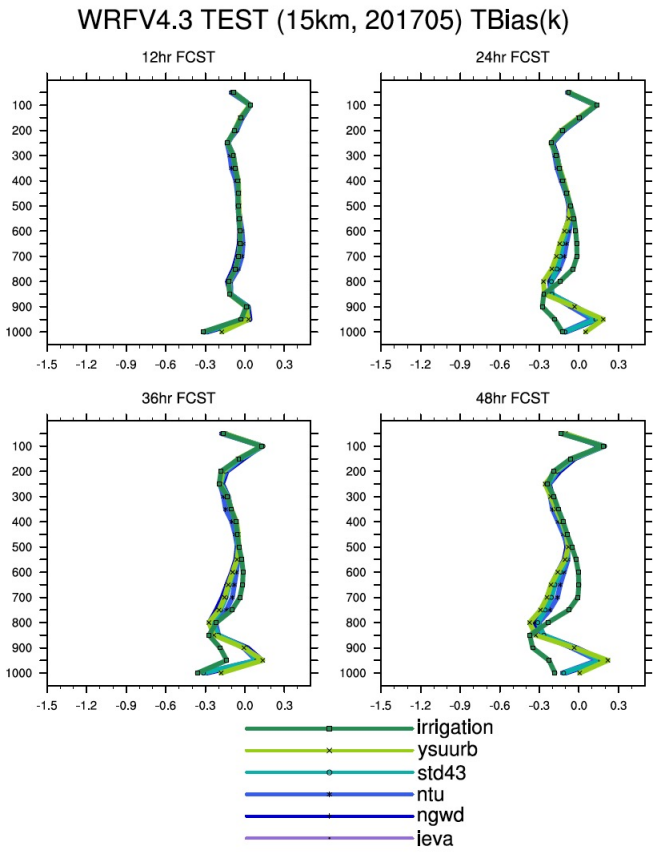


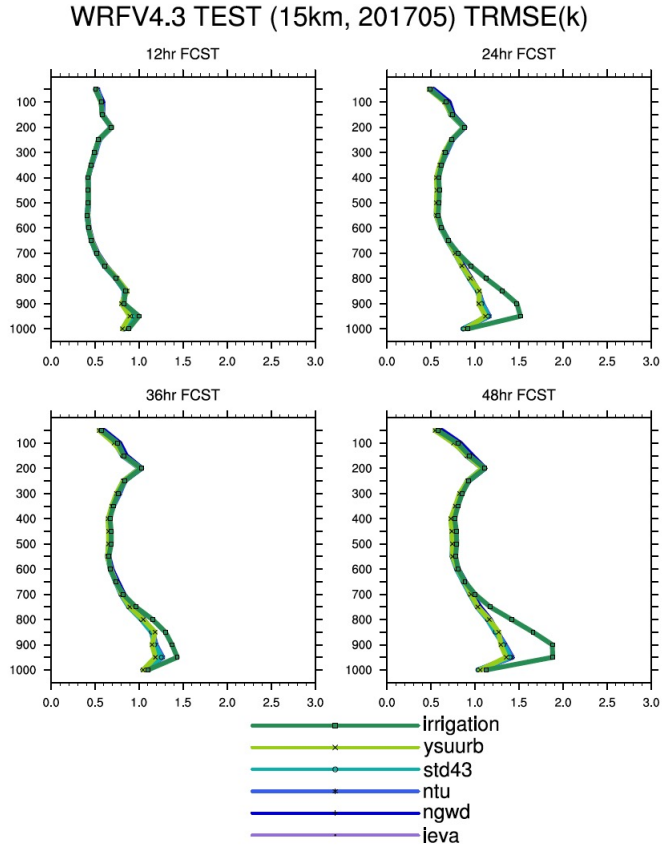
summer



Verification against GFS surface and upper air analyses

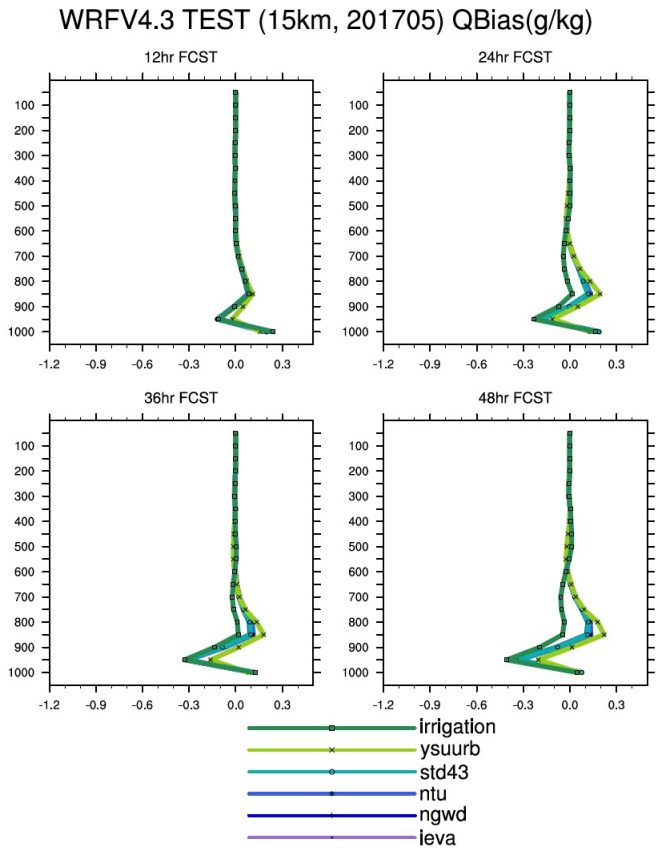
T Bias and RMS Summer

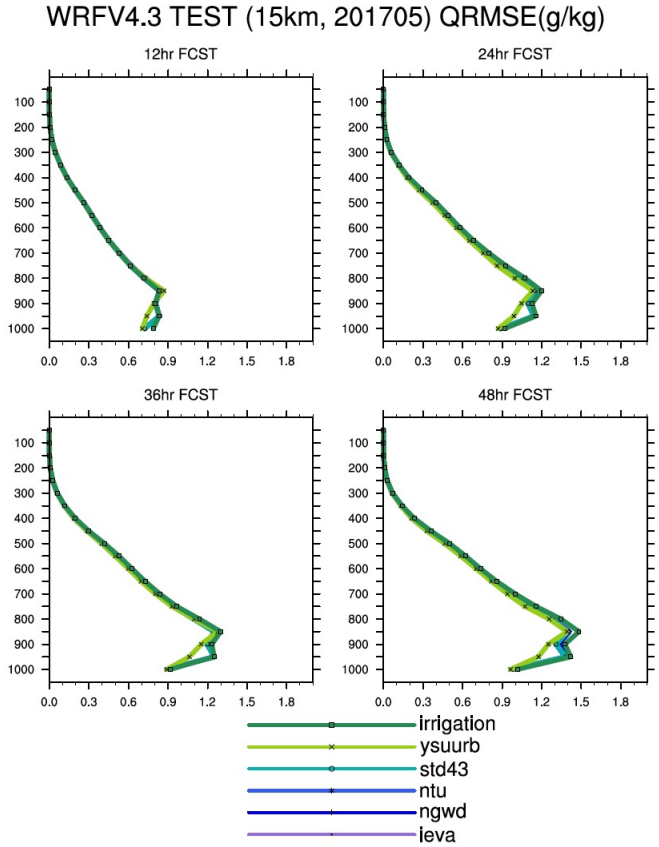




Irrigation shows low bias but high rms

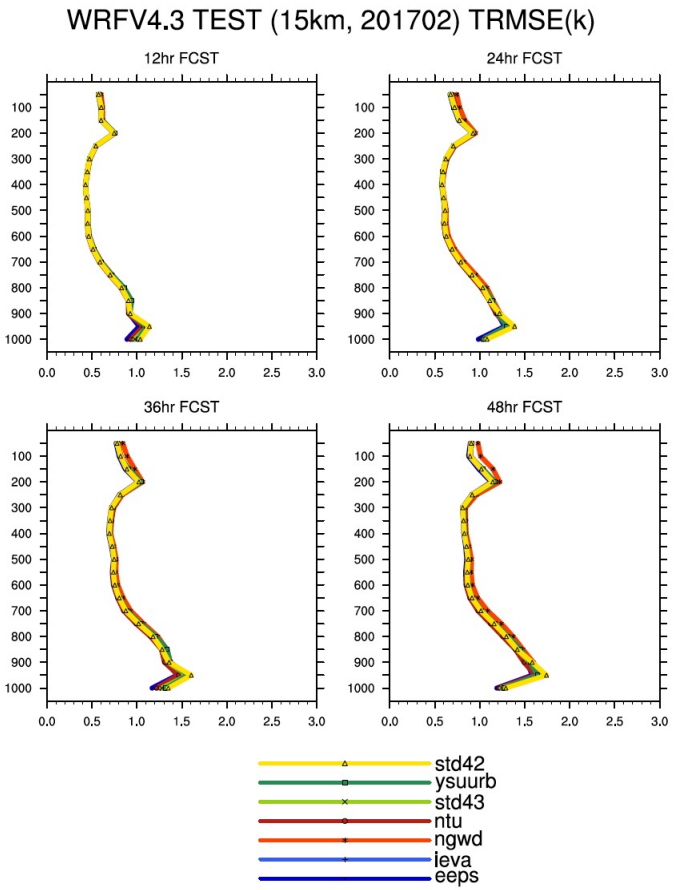
Q Bias and RMS summer

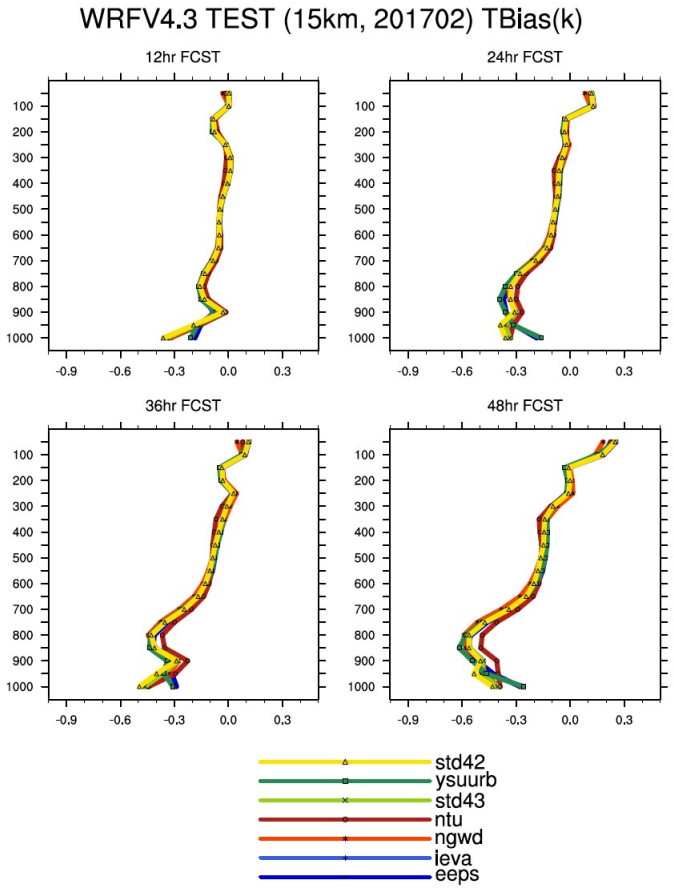




Irrigation shows low bias
YSU urb shows low rms

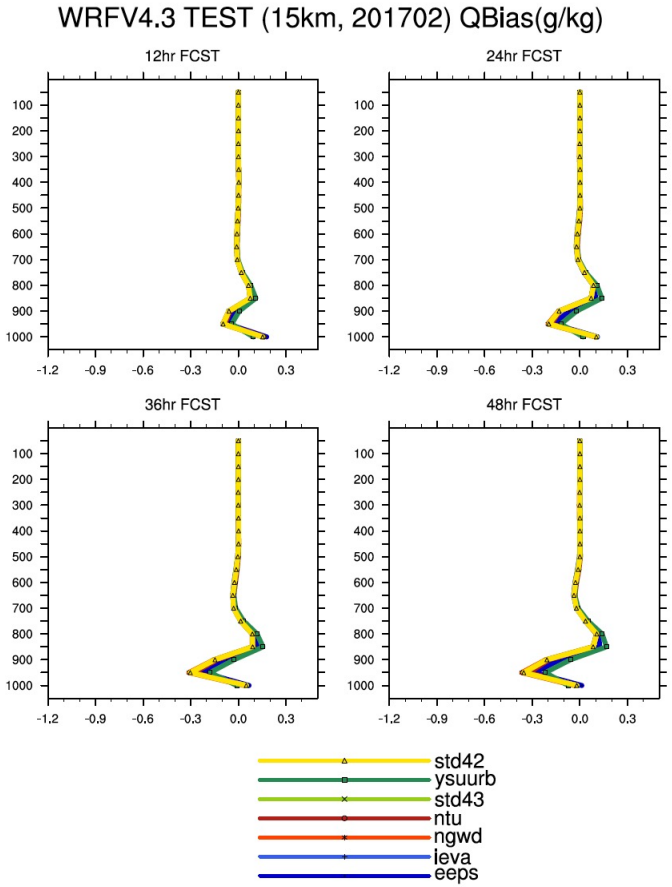
T Bias and RMS Winter

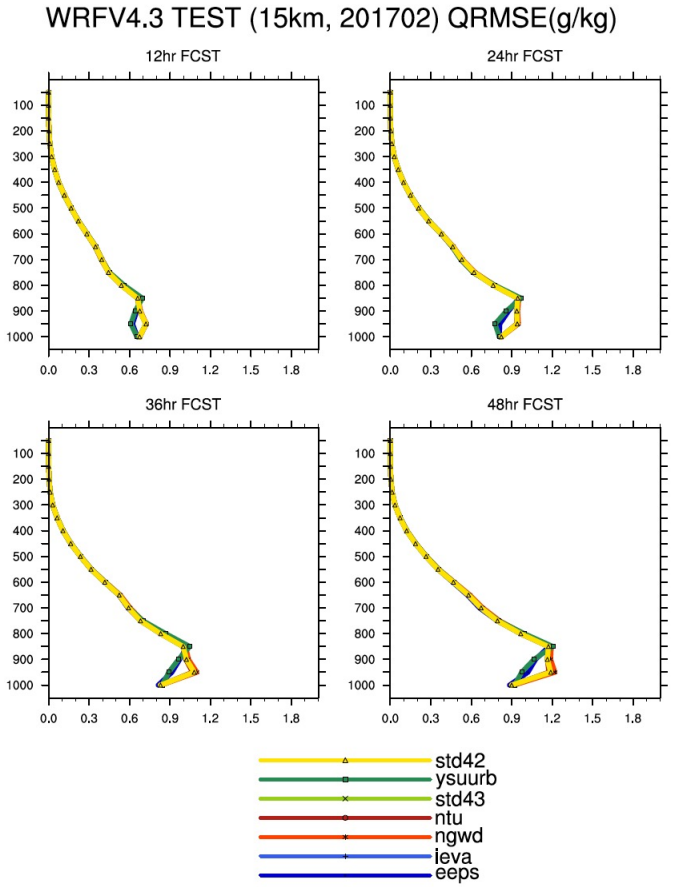




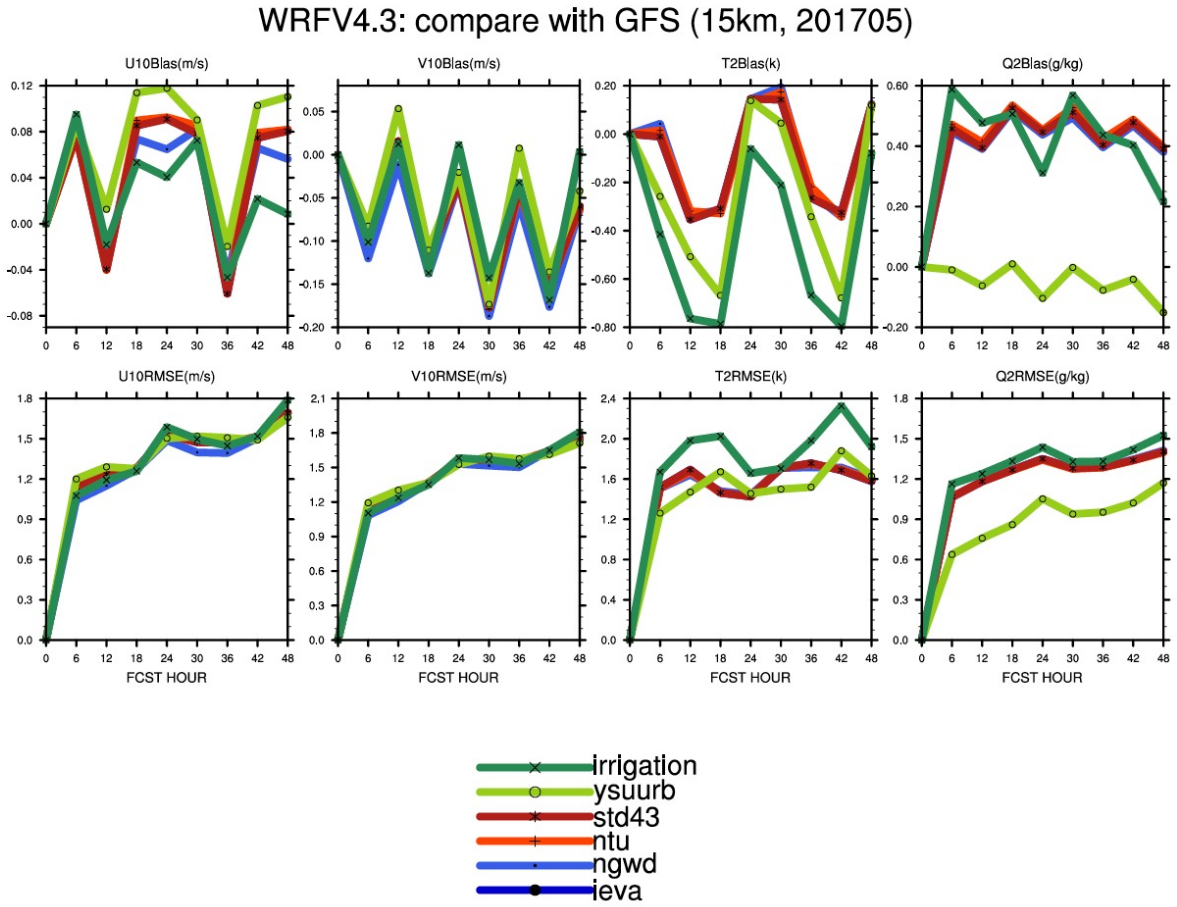
YSU urb and EEPS use same MM5 sfclay scheme

Q Bias and RMS Winter



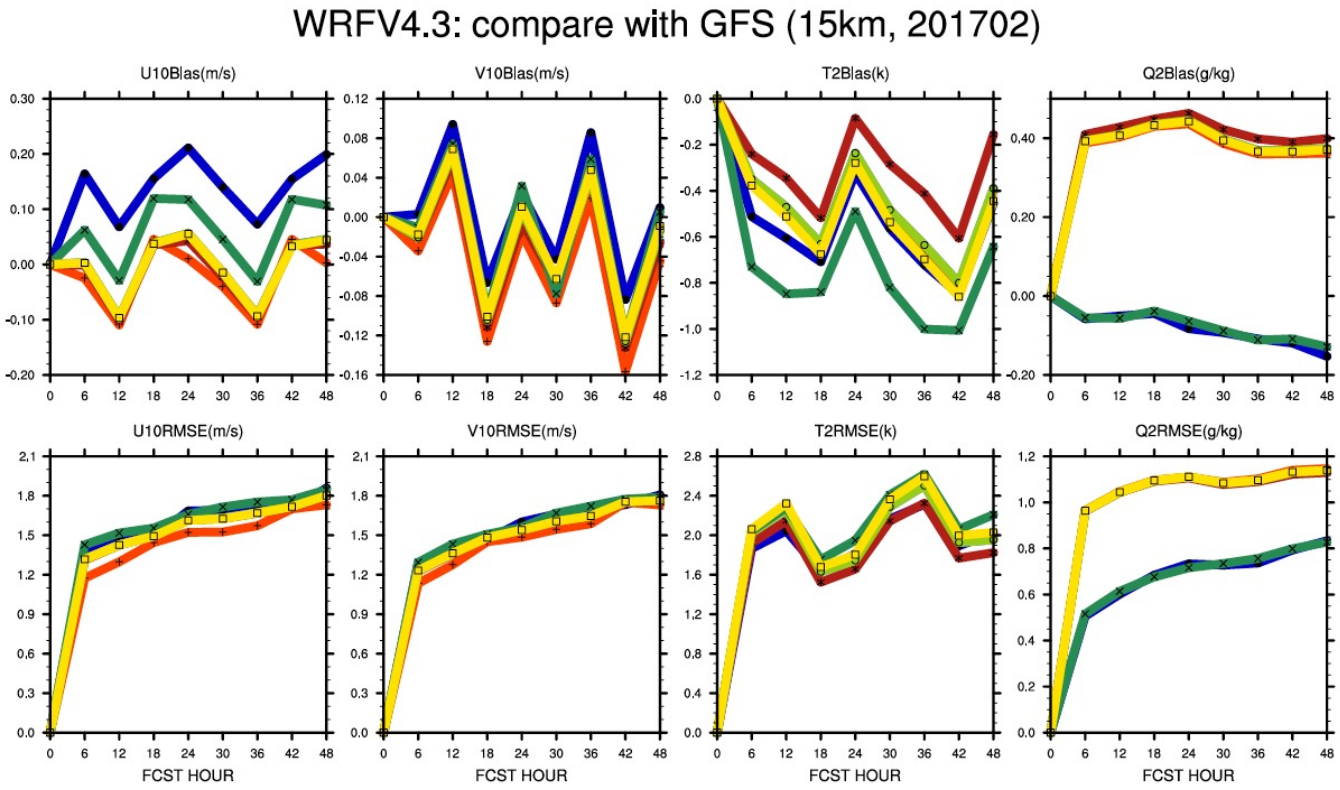


YSU urb and EEPS use same MM5 sfclay scheme



Surface Summer

YSU urb uses MM5 sfclay scheme



Surface Winter

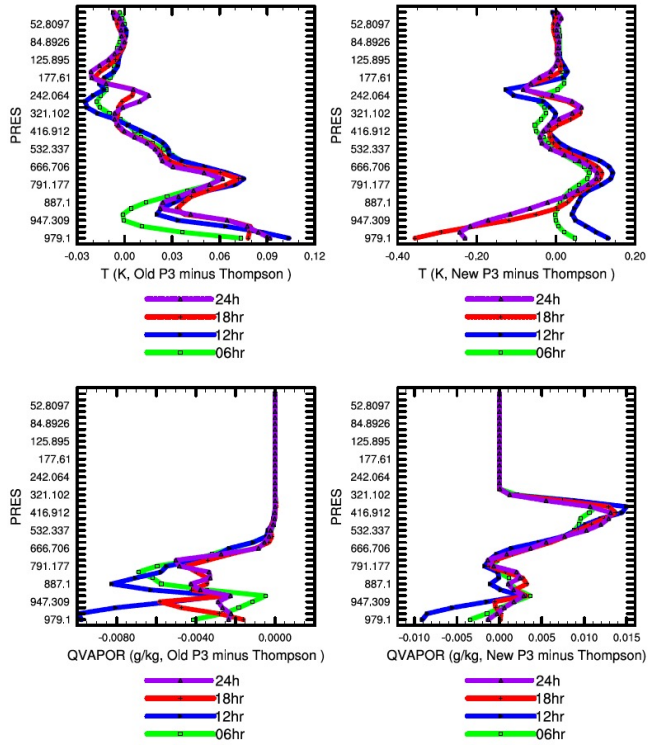
YSU urb and EEPS use same MM5 sfclay scheme

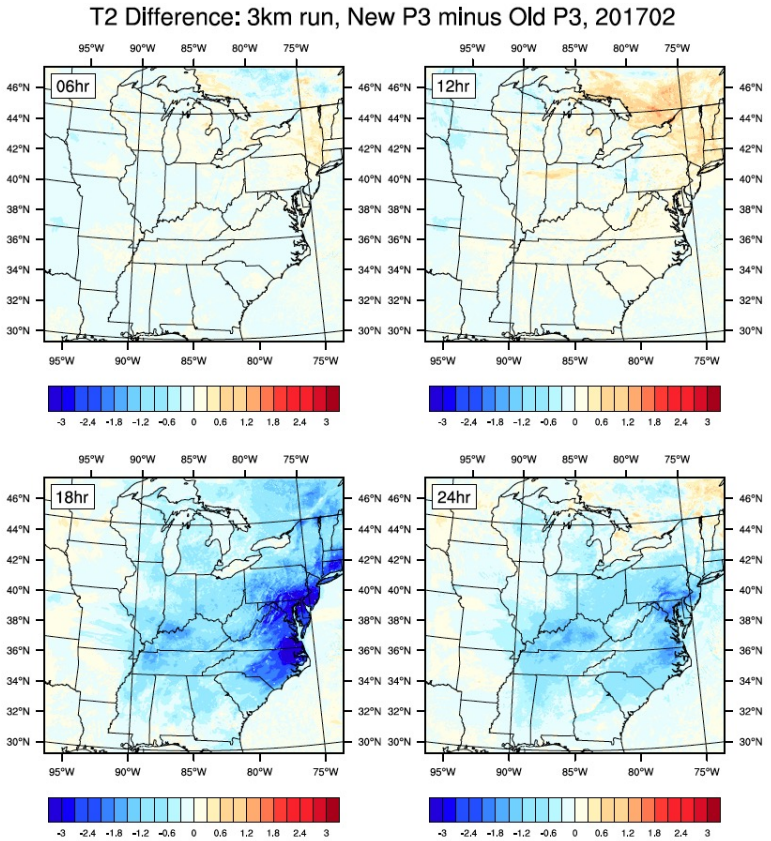
Results of Testing

- WRFV4.3 and WRFV4.2 CONUS suite behaves same
- New schemes behave within expected range
- But
  - Initially EEPS was tested with MYJ but showed outlier behavior (not shown) so we recommend using with MM5 sfc layer scheme for now
  - P3 3-moment has outlier behavior at 15 km (not fully coupled with convective scheme yet)
  - Additional P3 3-moment tests at 3 km were done and also show outlier behavior compared to both P3 standard and Thompson

P3 3-moment Tests

Difference between P3 and Thompson Results

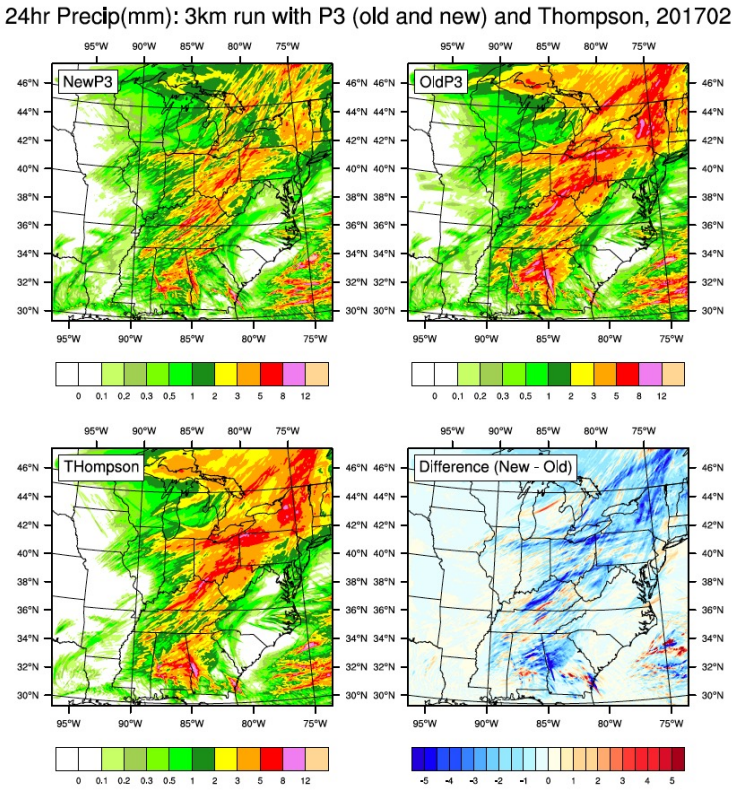




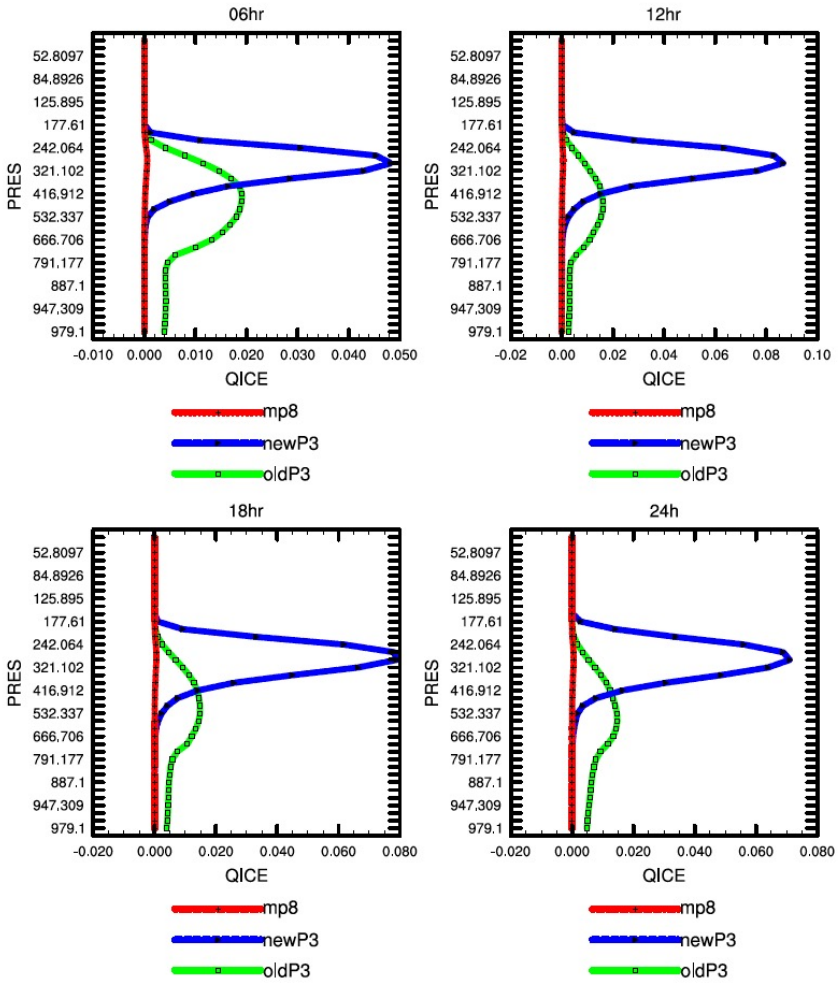
Cold surface bias

P3 3-moment tests

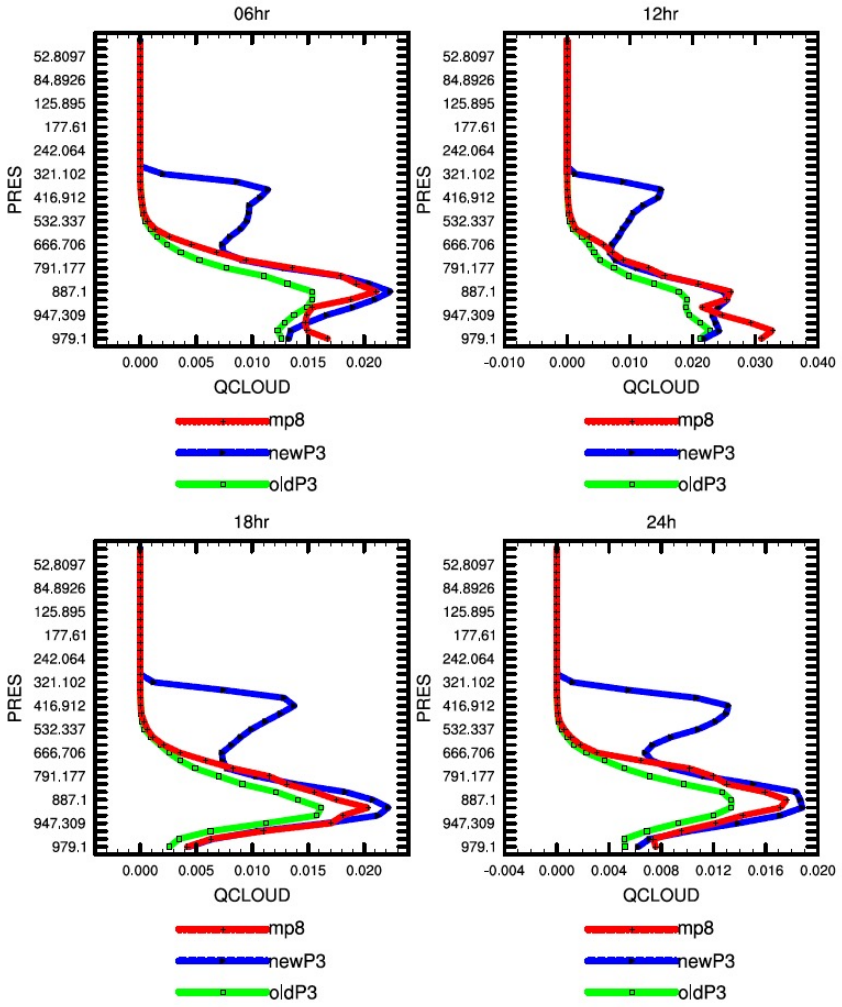
- Less rainfall in 3-moment scheme



3km Test: P3 and Thompson (201702)



3km Test: P3 and Thompson (201702)



More ice cloud and much supercooled liquid cloud

Credits

Ming Chen for verification