User's Guide for the NMM Core of the Weather Research and Forecast (WRF) Modeling System Version 3

Chapter 5: WRF NMM Model

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Introduction

The WRF-NMM is a fully compressible, non-hydrostatic mesoscale model with a hydrostatic option (Janjic et al. 2001, Janjic 2003a,b). The model uses a terrain following hybrid sigma-pressure vertical coordinate. The grid staggering is the Arakawa E-grid. The same time step is used for all terms. The dynamics conserve a number of first and second order quantities including energy and enstrophy (Janjic 1984).

The WRF-NMM code contains an initialization program ***(real_nmm.exe***; see Chapter 4) and a numerical integration program (***wrf.exe***). The WRF-NMM model Version 3 supports a variety of capabilities. These include:

- Real-data simulations
- Non-hydrostatic and hydrostatic (runtime option)
- Full physics options
- One-way and two-way nesting
- Applications ranging from meters to thousands of kilometers
- Digital filter initialization

WRF-NMM Dynamics in a Nutshell:

Time stepping:

Horizontally propagating fast-waves: Forward-backward scheme
Vertically propagating sound waves: Implicit scheme

Horizontal: Adams-Bashforth scheme
Vertical: Crank-Nicholson scheme
TKE, water species: Explicit, iterative, flux-corrected (called every two time steps).

Advection (space) for T, U, V:

Horizontal: Energy and enstrophy conserving, quadratic conservative, second order
Vertical: Quadratic conservative, second order
TKE, Water species: Upstream, flux-corrected, positive definite, conservative

Diffusion:

Diffusion in the WRF-NMM is categorized as lateral diffusion and vertical diffusion. The vertical diffusion in the PBL and in the free atmosphere is handled by the surface layer scheme and by the boundary layer parameterization scheme (Janjic 1996a, 1996b, 2002a, 2002b). The lateral diffusion is formulated following the Smagorinsky non-linear approach (Janjic 1990). The control parameter for the lateral diffusion is the square of Smagorinsky constant.

Divergence damping:

The horizontal component of divergence is damped (Sadourny 1975). In addition, if applied, the technique for coupling the elementary subgrids of the E grid (Janjic 1979) damps the divergent part of flow.

Physics Options

WRF offers multiple physics options that can be combined in many ways. The options typically range from simple and efficient to sophisticated and more computationally costly, and from newly developed schemes to well tried schemes such as those in current operational models. All available WRF System physics package options available in WRF Version 3 are listed below. Some of these options have not yet been tested for WRF-NMM. Indication of the options that have been tested, as well as the level of the testing, is included in the discussion below.

It is recommended that the same physics be used in all grids (coarsest and nests). The only exception is that the cumulus parameterization may be activated on coarser grids and turned off on finer grids.

Microphysics (*mp_physics*)

a. Kessler scheme: A warm-rain (i.e. no ice) scheme used commonly in idealized cloud modeling studies (*mp_physics* = 1).

b. Lin et al. scheme: A sophisticated scheme that has ice, snow and graupel processes, suitable for real-data high-resolution simulations (2).

c. WRF Single-Moment 3-class scheme: A simple efficient scheme with ice and snow processes suitable for mesoscale grid sizes (3).

d. WRF Single-Moment 5-class scheme: A slightly more sophisticated version of (c) that allows for mixed-phase processes and super-cooled water (4). (This scheme has been preliminarily tested for WRF-NMM.)

e. Eta microphysics: The operational microphysics in NCEP models. A simple efficient scheme with diagnostic mixed-phase processes. For fine resolutions (< 5km) use option (5) and for coarse resolutions use option (95). (This scheme is well tested for WRF-NMM, used operationally at NCEP.)

f. Eta HWRF microphysics: Similar to Eta microphysics (e), but modified to be suitable for the tropics (85). (This scheme is well tested and used operationally at NCEP for HWRF.) New in Version 3.2.

g. WRF Single-Moment 6-class scheme: A scheme with ice, snow and graupel processes suitable for high-resolution simulations (6). (This scheme has been preliminarily tested for WRF-NMM.)

h. Goddard microphysics scheme. A scheme with ice, snow and graupel processes suitable for high-resolution simulations (7). New in Version 3.0.

i. New Thompson et al. scheme: A new scheme with ice, snow and graupel processes suitable for high-resolution simulations (8). This adds rain number concentration and updates the scheme from the one in Version 3.0. New in Version 3.1. (This scheme has been preliminarily tested for WRF-NMM.)

j. Milbrandt-Yau Double-Moment 7-class scheme (9). This scheme includes separate categories for hail and graupel with double-moment cloud, rain, ice, snow, graupel and hail. New in Version 3.2.

k. Morrison double-moment scheme (10). Double-moment ice, snow, rain and graupel for cloud-resolving simulations. New in Version 3.0.

l. Stony Brook University (Y. Lin) scheme (13). This is a 5-class scheme with riming intensity predicted to account for mixed-phase processes. New in Version 3.3.

m. WRF Double-Moment 5-class scheme (14). This scheme has double-moment rain. Cloud and CCN for warm processes, but is otherwise like WSM5. New in Version 3.1.

n. WRF Double-Moment 6-class scheme (16). This scheme has double-moment rain. Cloud and CCN for warm processes, but is otherwise like WSM6. New in Version 3.1.

o. NSSL 2-moment scheme (17, 18). This is a two-moment scheme for cloud droplets, rain drops, ice crystals, snow, graupel, and hail. It also predicts average graupel particle density, which allows graupel to span the range from frozen drops to low-density graupel. There is an additional option to predict cloud condensation nuclei (CCN, option 18) concentration (intended for idealized simulations). The scheme is intended for cloud-resolving simulations (dx <= 2km) in research applications. New in Version 3.4.

p. CAM V5.1 2-moment 5-class scheme.

q. Thompson aerosol-aware (28). This scheme considers water- and ice-friendly aerosols. A climatology dataset may be used to specify initial and boundary conditions for the aerosol variables (Thompson and Eidhammer, 2014, JAS.) New in Version 3.6.

r. HUJI (Hebrew University of Jerusalem, Israel) spectral bin microphysics, full (32) and ‘fast’ (30) versions are available since Version 3.6.

Summary of Microphysics Options

mp_physics	Scheme	Reference	Added
1	Kessler	Kessler (1969)	2000
2	Lin (Purdue)	Lin, Farley and Orville (1983, JCAM)	2000

3	WSM3	Hong, Dudhia and Chen (2004, MWR)	2004
4	WSM5	Hong, Dudhia and Chen (2004, MWR)	2004
5	Eta (Ferrier)	Rogers, Black, Ferrier, Lin, Parrish and DiMego (2001, web doc)	2000
6	WSM6	Hong and Lim (2006, JKMS)	2004
7	Goddard	Tao, Simpson and McCumber (1989, MWR)	2008
8	Thompson	Thompson, Field, Rasmussen and Hall (2008, MWR)	2009
9	Milbrandt 2-mom	Milbrandt and Yau (2005, JAS)	2010
10	Morrison 2-mom	Morrison, Thompson and Tatarskii (2009, MWR)	2008
13	SBU-YLin	Lin and Colle (2011, MWR)	2011
14	WDM5	Lim and Hong (2010)	2009
16	WDM6	Lim and Hong (2010)	2009
17	NSSL 2-mom	Mansell, Ziegler and Brunning (2010)	2012
18	NSSL 2-mom w/CCN prediction	Mansell, Ziegler and Brunning (2010)	2012
19	NSSL 1-mom		2013
21	NSSL 1-momlfo		2013
28	Thompson aerosol-aware	Thompson and Eidhammer (2014, JAS)	2014
30	HUJI SBM ‘fast’	Khain et al. (2010, JAS)	2014
32	HUJI SBM full	Khain et al. (2004, JAS)	2014
85	Eta HWRF	Rogers, Black, Ferrier, Lin, Parrish and DiMego (2001, web doc)	2010
95	Eta (coarse)	Rogers, Black, Ferrier, Lin, Parrish and DiMego (2001, web doc)	2000

mp_physics	Scheme	Cores	Mass Variables	Number Variables
1	Kessler	ARW	Qc Qr	
2	Lin (Purdue)	ARW (Chem)	Qc Qr Qi Qs Qg	
3	WSM3	ARW	Qc Qr	

4	WSM5	ARW/NMM	Qc Qr Qi Qs	
5	Eta (Ferrier)	ARW/NMM	Qc Qr Qs (Qt*)	
6	WSM6	ARW/NMM	Qc Qr Qi Qs Qg	
8	Thompson	ARW/NMM	Qc Qr Qi Qs Qg	Ni Nr
9	Milbrandt 2-mom	ARW	Qc Qr Qi Qs Qg Qh	Nc Nr Ni Ns Ng Nh
10	Morrison 2-mom	ARW (Chem)	Qc Qr Qi Qs Qg	Nr Ni Ns Ng
13	SBU-YLin	ARW	Qc Qr Qi Qs	
14	WDM5	ARW	Qc Qr Qi Qs	Nn** Nc Nr
16	WDM6	ARW	Qc Qr Qi Qs Qg	Nn** Nc Nr
17	NSSL 2-mom	ARW	Qc Qr Qi Qs Qg Qh	Nc Nr Ni Ns Ng Nh
18	NSSL 2-mom +CCN	ARW	Qc Qr Qi Qs Qg Qh	Nc Nr Ni Ns Ng Nh
19	NSSL 1-mom	ARW	Qc Qr Qi Qs Qg Qh	Vg***
21	NSSL 1-momlfo	ARW	Qc Qr Qi Qs Qg	
28	Thompson aerosol-aware	ARW/NMM	Qc Qr Qi Qs Qg	Ni Nr Nwf Nif
30	HUJI fast	ARW	Qc Qr Qs Qg Qi	Nc Nr Ns Ni Ng Nn
32	HUJI full	ARW	Qc Qr Qs Qg Qh Qip Qic Qid Qnn	Nc Nr Ns Ng Nip Nic Nid Nn
85	Eta HWRF	ARW/NMM	Qc Qr Qs (Qt*)	
95	Eta (coarse)	ARW/NMM	Qc Qr Qs (Qt*)	

***** Advects only total condensates ** Nn = CCN number

Longwave Radiation (*ra_lw_physics*)

a. RRTM scheme: Rapid Radiative Transfer Model. An accurate scheme using look-up tables for efficiency. Accounts for multiple bands, trace gases, and microphysics species (*ra_lw_physics* = 1). For trace gases, the volume-mixing ratio values for CO2=330e-6, N2O=0. and CH4=0. in pre-V3.5 code; in V3.5, CO2=379e-6, N2O=319e-9 and CH4=1774e-9. See section 2.3 for time-varying option. (This scheme has been preliminarily tested for WRF-NMM.)

b. FDL scheme: Eta operational radiation scheme. An older multi-band scheme with carbon dioxide, ozone and microphysics effects (99). (This scheme is well tested for WRF-NMM, used operationally at NCEP.) ***Note:*** *If it is desired to run GFDL with a microphysics scheme other than Ferrier, a modification to module_ra_gfdleta.F is needed to comment out (!) #define FERRIER_GFDL.*

c. Modified GFDL scheme: Similar to the GFDL scheme (b) but modified to be suitable for the tropics (98). (This scheme is well tested and used operationally at NCEP for HWRF.) New in Version 3.2.

d. CAM scheme: from the CAM 3 climate model used in CCSM. Allows for aerosols and trace gases (3). It uses yearly CO2, and constant N2O (311e-9) and CH4 (1714e-9). See section 2.3 for the time-varying option.

e. RRTMG scheme. A new version of RRTM (4). It includes the MCICA method of random cloud overlap. For major trace gases, CO2=379e-6, N2O=319e-9, CH4=1774e-9. See section 2.3 for the time-varying option.

f. New Goddard scheme (5). Efficient, multiple bands, ozone from climatology. It uses constant CO2=337e-6, N2O=320e-9, CH4=1790e-9. New in Version 3.3.

g. Fu-Liou-Gu scheme (7). Multiple bands, cloud and cloud fraction effects, ozone profile from climatology and tracer gases. CO_2=345e-6. New in Version 3.4.

Shortwave Radiation (*ra_sw_physics*)

a. Dudhia scheme: Simple downward integration allowing efficiently for clouds and clear-sky absorption and scattering. When used in high-resolution simulations, sloping and shadowing effects may be considered (*ra_sw_physics* = 1). (This scheme has been preliminarily tested for WRF-NMM.)

b. Goddard shortwave: Two-stream multi-band scheme with ozone from climatology and cloud effects (2).

c. GFDL shortwave: Eta operational scheme. Two-stream multi-band scheme with ozone from climatology and cloud effects (99). (This scheme is well-tested for WRF-NMM, used operationally at NCEP.) ***Note:*** *If it is desired to run GFDL with a microphysics scheme other than Ferrier, a modification to module_ra_gfdleta.F is needed to comment out (!) #define FERRIER_GFDL.*

d. Modified GFDL shortwave: Similar to the GFDL shortwave (c), but modified to be suitable for tropics (98). (This scheme is well tested and used operationally at NCEP for HWRF.) New in Version 3.2.

e. CAM scheme: from the CAM 3 climate model used in CCSM. Allows for aerosols and trace gases (3).

f. RRTMG shortwave. A new shortwave scheme with the MCICA method of random cloud overlap (4). New in Version 3.1.

g. New Goddard scheme (5). Efficient, multiple bands, ozone from climatology. New in Version 3.3.

h. Fu-Liou-Gu scheme (7). multiple bands, cloud and cloud fraction effects, ozone profile from climatology, can allow for aerosols. New in Version 3.4.

i. Held-Suarez relaxation. A temperature relaxation scheme designed for idealized tests only (31).

j. *swrad_scat*: scattering turning parameter for *ra_sw_physics* = 1. Default value is 1, which is equivalent to 1.e-5 m^2/kg. When the value is greater than 1, it increases the scattering.

Input to radiation options

a. CAM Green House Gases: Provides yearly green house gases from 1765 to 2500. The option is activated by compiling WRF with the macro –DCLWRFGHG added in configure.wrf. Once compiled, CAM, RRTM and RRTMG long-wave schemes will see these gases. Five scenario files are available: from IPCC AR5: CAMtr_volume_mixing_ratio .RCP4.5, CAMtr_volume_mixing_ratio.RCP6, and CAMtr_volume_mixing_ratio.RCP8.5; from IPCC AR4: CAMtr_volume_mixing_ratio.A1B, and CAMtr_volume_mixing_ratio.A2. The default points to the RCP8.5 file. New in Version 3.5.

b. Climatological ozone and aerosol data for RRTMG: The ozone data is adapted from CAM radiation (ra_*_physics=3), and it has latitudinal (2.82 degrees), height and temporal (monthly) variation, as opposed to the default ozone used in the scheme that only varies with height. This is activated by the namelist option *o3input* = 2. The aerosol data is based on Tegen et al. (1997), which has 6 types: organic carbon, black carbon, sulfate, sea salt, dust and stratospheric aerosol (volcanic ash, which is zero). The data also has spatial (5 degrees in longitude and 4 degrees in latitudes) and temporal (monthly) variations. The option is activated by the namelist option *aer_opt* = 1. New in Version 3.5.

c. Aerosol input for RRTMG and Goddard radiation options (*aer_opt = 2*). Either AOD or AOD plus Angstrom exponent, single scattering albedo, and cloud asymmetry parameter can be provided via constant values from namelist or 2D input fields via auxiliary input stream 15. Aerosol type can be set too. New in V3.6.

Summary of Radiation Physics Options

ra_sw_physics	Scheme	Reference	Added
1	Dudhia	Dudhia (1989, JAS)	2000
2	Goddard	Chou and Suarez (1994, NASA Tech Memo)	2000
3	CAM	Collins et al. (2004, NCAR Tech Note)	2006
4	RRTMG	Iacono et al. (2008, JGR)	2009
5	New Goddard	Chou and Suarez (1999, NASA Tech Memo)	2011
7	FLG	Gu et al. (2011, JGR), Fu and Liou (1992, JAS)	2012
99	GFDL	Fels and Schwarzkopf (1981, JGR)	2004

ra_sw_ physics	Scheme	Cores+Chem	Microphysics Interaction	Cloud Fraction	Ozone
1	Dudhia	ARW NMM + Chem(PM2.5)	Qc Qr Qi Qs Qg	1/0	none
2	GSFC	ARW+Chem(τ)	Qc Qi	1/0	5 profiles
3	CAM	ARW	Qc Qi Qs	max-rand overlap	lat/month
4	RRTMG	ARW + Chem (τ), NMM	Qc Qr Qi Qs	max-rand overlap	1 profile or lat/month
5	New Goddard	ARW	Qc Qr Qi Qs Qg	1/0	5 profiles
7	FLG	ARW	Qc Qr Qi Qs Qg	1/0	5 profiles
99	GFDL	ARW NMM	Qc Qr Qi Qs	max-rand overlap	lat/date

ra_lw_physics	Scheme	Reference	Added
1	RRTM	Mlawer et al. (1997, JGR)	2000
3	CAM	Collins et al. (2004, NCAR Tech Note)	2006
4	RRTMG	Iacono et al. (2008, JGR)	2009

5	New Goddard	Chou and Suarez (1999, NASA Tech Memo)	2011
7	FLG	Gu et al. (2011, JGR), Fu and Liou (1992, JAS)	2012
31	Held-Suarez		2008
99	GFDL	Fels and Schwarzkopf (1981, JGR)	2004

ra_lw_ physics	Scheme	Cores+Chem	Microphysics Interaction	Cloud Fraction	Ozone	GHG
1	RRTM	ARW NMM	Qc Qr Qi Qs Qg	1/0	1 profile	constant or yearly GHG
3	CAM	ARW	Qc Qi Qs	max-rand overlap	lat/month	yearly CO2 or yearly GHG
4	RRTMG	ARW + Chem (τ), NMM	Qc Qr Qi Qs	max-rand overlap	1 profile or lat/month	constant or yearly GHG
5	New Goddard	ARW	Qc Qr Qi Qs Qg	1/0	5 profiles	constant
7	FLG	ARW	Qc Qr Qi Qs Qg	1/0	5 profiles	constant
31	Held-Suarez	ARW	none	none		none
99	GFDL	ARW NMM	Qc Qr Qi Qs	max-rand overlap	lat/date	constant

Surface Layer (*sf_sfclay_physics*)

a. MM5 similarity: Based on Monin-Obukhov with Carslon-Boland viscous sub-layer and standard similarity functions from look-up tables (*sf_sfclay_physics* = 1). (This scheme has been preliminarily tested for WRF-NMM.)

b. Eta similarity: Used in Eta model. Based on Monin-Obukhov with Zilitinkevich thermal roughness length and standard similarity functions from look-up tables (2). (This scheme is well tested for WRF-NMM, used operationally at NCEP.)

c. NCEP Global Forecasting System (GFS) scheme: The Monin-Obukhov similarity profile relationship is applied to obtain the surface stress and latent heat fluxes using a formulation based on Miyakoda and Sirutis (1986) modified for very stable and unstable situations. Land surface evaporation has three components (direct evaporation from the soil and canopy, and transpiration from vegetation) following the formulation of Pan and Mahrt (1987) (3). (This scheme has been preliminarily tested for WRF-NMM.)

d. Pleim-Xiu surface layer (7). New in Version 3.0.

e. QNSE surface layer. Quasi-Normal Scale Elimination PBL scheme's surface layer option (4). New in Version 3.1.

f. MYNN surface layer. Nakanishi and Niino PBL's surface layer scheme (5).

g. TEMF surface layer. Total Energy – Mass Flux surface layer scheme. New in Version 3.3.

h. Revised MM5 surface layer scheme (11): Remove limits and use updated stability functions. New in Version 3.4. (Jimenez et al. MWR 2012).

i. GFDL surface layer (88): (This scheme is well tested and used operationally at NCEP for HWRF.)

h. *iz0tlnd* = 1 (for *sf_sfclay_physics* = 1 or 2), Chen-Zhang thermal roughness length over land, which depends on vegetation height, 0 = original thermal roughness length in each sfclay option. New in Version 3.2.

Land Surface (*sf_surface_physics*)

a. 5-layer thermal diffusion: Soil temperature only scheme, using five layers (*sf_surface_physics* = 1).

b. Noah Land Surface Model: Unified NCEP/NCAR/AFWA scheme with soil temperature and moisture in four layers, fractional snow cover and frozen soil physics. New modifications are added in Version 3.1 to better represent processes over ice sheets and snow covered area (2). (This scheme is well tested for WRF-NMM, used operationally at NCEP.)

- In V3.6, a sub-tiling option is introduced, and it is activated by namelist *sf_surface_mosaic* = 1, and the number of tiles in a grid box is defined by namelist *mosaic_cat*, with a default value of 3.

c. RUC Land Surface Model: RUC operational scheme with soil temperature and moisture in six layers, multi-layer snow and frozen soil physics (3). (This scheme has been preliminarily tested for WRF-NMM.)

d. Pleim-Xiu Land Surface Model. Two-layer scheme with vegetation and sub-grid tiling (7). New in Version 3.0: The Pleim-Xiu land surface model (PX LSM; Pleim and Xiu 1995; Xiu and Pleim 2001) was developed and improved over the years to provide realistic ground temperature, soil moisture, and surface sensible and latent heat fluxes in mesoscale meteorological models. The PX LSM is based on the ISBA model (Noilhan and Planton 1989), and includes a 2-layer force-restore soil temperature and moisture model. the top layer is taken to be 1 cm thick, and the lower layer is 99 cm. Grid aggregate vegetation and soil parameters are derived from fractional coverage of land use categories and soil texture types. There are two indirect nudging schemes that correct biases in 2-m air temperature and moisture by dynamic adjustment of soil moisture (Pleim and Xiu, 2003) and deep soil temperature (Pleim and Gilliam, 2009).

Users should recognize that the PX LSM was primarily developed for retrospective simulation, where surface-based observations are available to inform the indirect soil nudging. While soil nudging can be disabled using the FDDA namelist.input setting "pxlsm_soil_nudge," little testing has been done in this mode, although some users have reported reasonable results. Gilliam and Pleim (2010) discuss the implementation in the WRF model and provide typical configurations for retrospective applications. If soil nudging is activated, modelers must use the Obsgrid objective re-analysis utility to produce a surface nudging file with the naming convention "wrfsfdda_d0*." Obsgrid takes WPS "met_em*" files and LittleR observation files and produces the "wrfsfdda_d0*" file. The PX LSM uses 2-m temperature and mixing ratio re-analyses from this file for the deep soil moisture and temperature nudging. If modelers want to test PX LSM in forecast mode with soil nudging activated, forecasted 2-m temperature and mixing ratio can be used with empty observation files to produce the "wrfsfdda_d0*" files, using Obsgrid, but results will be tied to the governing forecast model.

e. GFDL slab model. Used together with GFDL surface layer scheme (88). (This scheme is well tested and used operationally at NCEP for HWRF.) New in Version 3.2.

f. Noah-MP (multi-physics) Land Surface Model: uses multiple options for key land-atmosphere interaction processes (4). Noah-MP contains a separate vegetation canopy defined by a canopy top and bottom with leaf physical and radiometric properties used in a two-stream canopy radiation transfer scheme that includes shading effects. Noah-MP contains a multi-layer snow pack with liquid water storage and melt/refreeze capability and a snow-interception model describing loading/unloading, melt/refreeze, and sublimation of the canopy-intercepted snow. Multiple options are available for surface water infiltration and runoff, and groundwater transfer and storage including water table depth to an unconfined aquifer. Horizontal and vertical vegetation density can be prescribed or predicted using prognostic photosynthesis and dynamic vegetation models that allocate carbon to vegetation (leaf, stem, wood and root) and soil carbon pools (fast and slow). New in Version 3.4. (Niu et al. 2011). (This scheme has been preliminarily tested for WRF-NMM.)

g. SSiB Land Surface Model: This is the third generation of the Simplified Simple Biosphere Model (Xue et al. 1991; Sun and Xue, 2001). SSiB is developed for land/atmosphere interaction studies in the climate model. The aerodynamic resistance values in SSiB are determined in terms of vegetation properties, ground conditions and bulk Richardson number according to the modified Monin–Obukhov similarity theory. SSiB-3 includes three snow layers to realistically simulate snow processes, including destructive metamorphism, densification process due to snow load, and snow melting, which substantially enhances the model's ability for the cold season study. To use this option, *ra_lw_physics* and *ra_sw_physics* should be set to either 1, 3, or 4. The second full model level should be set to no larger than 0.982 so that the height of that level is higher than vegetation height. New in Version 3.4.

h. CLM4 (Community Land Model Version 4, Oleson et al. 2010; Lawrence et al. 2010): CLM4 was developed at the National Center for Atmospheric Research with many external collaborators and represents a state-of-the-science land surface process model. It contains sophisticated treatment of biogeophysics, hydrology, biogeochemistry, and dynamic vegetation. In CLM4, the land surface in each model grid cell is characterized into five primary sub-grid land cover types (glacier, lake, wetland, urban, and vegetated). The vegetated sub-grid consists of up to 4 plant functional types (PFTs) that differ in physiology and structure. The WRF input land cover types are translated into the CLM4 PFTs through a look-up table. The CLM4 vertical structure includes a single-layer vegetation canopy, a five-layer snowpack, and a ten-layer soil column. An earlier version of CLM has been quantitatively evaluated within WRF in Jin and Wen (2012; JGR-Atmosphere), Lu and Kueppers (2012; JGR-Atmosphere), and Subin et al. (2011; Earth Interactions) (*from Jin*). New in Version 3.5.

Urban Surface (sf_urban_physics – replacing old switch ucmcall)

a. Urban canopy model (1): 3-category UCM option with surface effects for roofs, walls, and streets.

b. BEP (2). Building Environment Parameterization: Multi-layer urban canopy model that allows for buildings higher than the lowest model levels. Only works with Noah LSM and Boulac and MYJ PBL options. New in Version 3.1.

c. BEM (3). Building Energy Model. Adds to BEP, building energy budget with heating and cooling systems. Works with same options as BEP. New in Version 3.2.

Lake Physics (sf_lake_physics)

a. CLM 4.5 lake model (1). The lake scheme was obtained from the Community Land Model version 4.5 (Oleson et al. 2013) with some modifications by Gu et al. (2013). It is a one-dimensional mass and energy balance scheme with 20-25 model layers, including up to 5 snow layers on the lake ice, 10 water layers, and 10 soil layers on the lake bottom. The lake scheme is used with actual lake points and lake depth derived from the WPS, and it also can be used with user defined lake points and lake depth in WRF (lake_min_elev and lakedepth_default). The lake scheme is independent of a land surface scheme and therefore can be used with any land surface scheme embedded in WRF. The lake scheme developments and evaluations were included in Subin et al. (2012) and Gu et al. (2013) (Subin et al. 2012: Improved lake model for climate simulations, J. Adv. Model. Earth Syst., 4, M02001. DOI:10.1029/2011MS000072; Gu et al. 2013: Calibration and validation of lake surface temperature simulations with the coupled WRF-Lake model. Climatic Change, 1-13, 10.1007/s10584-013-0978-y).

Planetary Boundary layer (*bl_pbl_physics*)

a. Yonsei University scheme: Non-local-K scheme with explicit entrainment layer and parabolic K profile in unstable mixed layer (*bl_pbl_physics* = 1). (This scheme has been preliminarily tested for WRF-NMM.)

b. Mellor-Yamada-Janjic scheme: Eta operational scheme. One-dimensional prognostic turbulent kinetic energy scheme with local vertical mixing (2). (This scheme is well-tested for WRF-NMM, used operationally at NCEP.)

c. NCEP Global Forecast System scheme: First-order vertical diffusion scheme of Troen and Mahrt (1986) further described in Hong and Pan (1996). The PBL height is determined using an iterative bulk-Richardson approach working from the ground upward whereupon the profile of the diffusivity coefficient is specified as a cubic function of the PBL height. Coefficient values are obtained by matching the surface-layer fluxes. A counter-gradient flux parameterization is included (3). (This scheme is well tested and used operationally at NCEP for HWRF.) Updated in Version 3.2.

d. MRF scheme: Older version of (a) with implicit treatment of entrainment layer as part of non-local-K mixed layer (99).

e. ACM2 PBL: Asymmetric Convective Model with non-local upward mixing and local downward mixing (7). New in Version 3.0.

f. Quasi-Normal Scale Elimination PBL (4). A TKE-prediction option that uses a new theory for stably stratified regions. New in Version 3.1. Daytime part uses eddy diffusivity mass-flux method with shallow convection (mfshconv = 1) which is added in Version 3.4.

g. Mellor-Yamada Nakanishi and Niino Level 2.5 PBL (5). Predicts sub-grid TKE terms. New in Version 3.1.

h. Mellor-Yamada Nakanishi and Niino Level 3 PBL (6). Predicts TKE and other second-moment terms. New in Version 3.1.

i. BouLac PBL (8): Bougeault-Lacarrère PBL. A TKE-prediction option. New in Version 3.1. Designed for use with BEP urban model.

j. UW (Bretherton and Park) scheme (9). TKE scheme from CESM climate model. New in Version 3.3.

k. Total Energy - Mass Flux (TEMF) scheme (10). Sub-grid total energy prognostic variable, plus mass-flux type shallow convection. New in Version 3.3.

l. *topo_wind*: Topographic correction for surface winds to represent extra drag from sub-grid topography and enhanced flow at hill tops (1) (Jimenez and Dudhia, JAMC 2012). Works with YSU PBL only. New in Version 3.4. A simpler terrain variance-related correction (2). New in Version 3.5.

Note: *Two-meter temperatures are only available when running with MYJ scheme (2).*

Summary of PBL Physics Options

bl_pbl_physics	Scheme	Reference	Added
1	YSU	Hong, Noh and Dudhia (2006, MWR)	2004
2	MYJ	Janjic (1994, MWR)	2000
3	GFS	Hong and Pan (1996, MWR)	2005
4	QNSE	Sukoriansky, Galperin and Perov (2005, BLM)	2009
5	MYNN2	Nakanishi and Niino (2006, BLM)	2009
6	MYNN3	Nakanishi and Niino (2006, BLM)	2009
7	ACM2	Pleim (2007, JAMC	2008

8	BouLac	Bougeault and Lacarrere (1989, MWR)	2009
9	UW	Bretherton and Park (2009, JC)	2011
10	TEMF	Angevine, Jiang and Mauriten (2010, MWR)	2011
12	GBM	Grenier and Bretherton (2001, MWR)	2013
99	MRF	Hong and Pan (1996, MWR)	2000

bl_pbl_ physics	Scheme	Cores	sf_sfclay_ physics	Prognostic variables	Diagnostic variables	Cloud mixing
1	YSU	ARW/ NMM	1		exch_h	QC,QI
2	MYJ	ARW/ NMM	2	TKE_PBL	EL_MYJ, exch_h	QC,QI
3	GFS (hwrf)	NMM	3			QC,QI
4	QNSE	ARW/ NMM	4	TKE_PBL	EL_MYJ, exch_h, exch_m	QC,QI
5	MYNN2	ARW	1,2,5	QKE	Tsq, Qsq, Cov, exch_h, exch_m	QC
6	MYNN3	ARW	1,2,5	QKE, Tsq, Qsq, Cov	exch_h, exch_m	QC
7	ACM2	ARW	1,7			QC,QI
8	BouLac	ARW	1,2	TKE_PBL	EL_PBL, exch_h, exch_m, wu_tur, wv_tur, wt_tur, wq_tur	QC
9	UW	ARW	2	TKE_PBL	exch_h, exch_m	QC
10	TEMF	ARW	10	TE_TEMF	*_temf	QC, QI

99	MRF	ARW/ NMM	1			QC,QI

Cumulus Parameterization (*cu_physics*)

a. Kain-Fritsch scheme: Deep and shallow convection sub-grid scheme using a mass flux approach with downdrafts and CAPE removal time scale (*cu_physics* = 1). (This scheme has been preliminarily tested for WRF-NMM.)

- kfeta_trigger = 1 – default trigger; = 2 – moisture-advection modulated trigger function [based on Ma and Tan (2009, Atmospheric Research)]. May improve results in subtropical regions when large-scale forcing is weak.

b. Betts-Miller-Janjic scheme. Operational Eta scheme. Column moist adjustment scheme relaxing towards a well-mixed profile (2). (This scheme is well tested for WRF-NMM, used operationally at NCEP.)

c. Grell-Devenyi ensemble scheme: Multi-closure, multi-parameter, ensemble method with typically 144 sub-grid members (moved to option 93 in V3.5). (This scheme has been preliminarily tested for WRF-NMM.)

e. Simplified Arakawa-Schubert scheme (4): Simple mass-flux scheme with quasi-equilibrium closure with shallow mixing scheme (and momentum transport in NMM only). Adapted for ARW in Version 3.3.

f. Grell 3D is an improved version of the GD scheme that may also be used on high resolution (in addition to coarser resolutions) if subsidence spreading (option cugd_avedx) is turned on (5). New in Version 3.0.

g. Tiedtke scheme (U. of Hawaii version) (6). Mass-flux type scheme with CAPE-removal time scale, shallow component and momentum transport. New in Version 3.3.

h. Zhang-McFarlane scheme (7). Mass-flux CAPE-removal type deep convection from CESM climate model with momentum transport. New in Version 3.3.

i. New Simplified Arakawa-Schubert (14). New mass-flux scheme with deep and shallow components and momentum transport. New in Version 3.3.

j. New Simplified Arakawa-Schubert (84). New mass-flux scheme with deep and shallow components and momentum transport. New in Version 3.4. (This scheme is well tested for HWRF, used operationally at NCEP.)

k. Grell-Freitas (GF) scheme (3): An improved GD scheme that tries to smooth the transition to cloud-resolving scales, as proposed by Arakawa et al. (2004). New in Version 3.5.

l. Old Kain-Fritsch scheme: Deep convection scheme using a mass flux approach with downdrafts and CAPE removal time scale (99). (This scheme has been preliminarily tested for WRF-NMM.)

Summary of Cumulus Parameterization Options

cu_physics	Scheme	Reference	Added
1	Kain-Fritsch	Kain (2004, JAM)	2000
2	Betts-Miller-Janjic	Janjic (1994, MWR; 2000, JAS)	2002
3	Grell-Devenyi	Grell and Devenyi (2002, GRL)	2002
4	Old SAS	(Pan and Wu 1995, Hong and Pan 1998, Pan 2003)	2010
5	Grell-3	-	2008
6	Tiedtke	Tiedtke (1989, MWR), Zhang et al. (2011, submitted)	2011
7	Zhang-McFarlane	Zhang and McFarlane (1995, AO)	2011
14	New SAS	Han and Pan (2011)	2011
84	Simplified Arakawa-Schubert	Han and Pan (2011)	2005/ 2011
93	Grell-Devenyi	Grell and Devenyi (2002, GRL)	2002
99	Old Kain-Fritsch	Kain and Fritsch (1990, JAS; 1993, Meteo. Monogr.)	2000

cu_physics	Scheme	Cores	Moisture Tendencies	Momentum Tendencies	Shallow Convection
1	Kain-Fritsch	ARW / NMM	Qc Qr Qi Qs	no	yes

2	BMJ	ARW / NMM	-	no	yes
3	GD	ARW	Qc Qi	no	no
4	Old SAS	ARW/NMM	Qc Qi	yes (NMM)	yes
5	G3	ARW	Qc Qi	no	yes
6	Tiedtke	ARW	Qc Qi	yes	yes
7	Zhang-McFarlane	ARW	Qc Qi	yes	no
14	NSAS	ARW	Qc Qr Qi Qs	yes	yes
84	SAS	ARW / NMM	Qc Qi	yes (NMM)	yes
93	GD	ARW	Qc Qi	no	no
99	Old KF	ARW	Qc Qr Qi Qs	no	no

Shallow convection option (shcu_physics)

a. *ishallow* = 1, shallow convection option on. Works together with Grell 3D scheme (cu_physics = 5) – will move to shcu_physics category in the future.

b. UW (Bretherton and Park) scheme (2). Shallow cumulus option from CESM climate model with momentum transport. New in Version 3.3.

c. GRIMS (Global/Regional Integrated Modeling System) scheme: it represents the shallow convection process by using eddy-diffusion and the pal algorithm, and couples directly to the YSU PBL scheme. New in Version 3.5.

Other physics options

a. *gwd_opt*: Gravity wave drag option. Can be activated when grid size is greater than 10 km. May be beneficial for simulations longer than 5 days and over a large domain with mountain ranges. Default *gwd_opt*=0.

b. *mommix:* Coefficient used in the calculation of momentum mixing tendency terms. Default *mommix*=0.7. Only used with old SAS cumulus scheme (4).

c. *h_diff:* Coefficient used in the calculation of horizontal momentum diffusion terms. Default *h_diff*=0.1. Only used when environment variable HWRF is set.

d. *sfenth*: Enthalpy flux factor. Default *sfenth*=1.0. Only used with GFDL surface scheme.

d. *co$_2$tf:* CO2 transmission coefficient option. Default *co$_2$tf*=0.

e. *sas_pgcon:* Convectively forced pressure gradient factor (SAS schemes 14 and 84) Default *sas_pgcon*=0.55.

f. *gfs_alpha:* Boundary layer depth factor. Default *gfs_alpha*=1 (GFS PBL scheme 3).

g. *sas_mass_flux:* Mass flux limit (SAS scheme). Default *sas_mass_flux*=$9*10^9$ (SAS scheme 84)

h. *var_ric*: Placeholder for the use of variable critical Richardson number (Ric) in GFS PBL scheme (will be available in HWRF V3.5a release). Default *var_ric*=0 to use constant Ric, else set *var_ric*=1 to use variable.

i. *coef_ric_l*: Placeholder for the coefficient used in the calculation of the variable critical Richardson number (Ric) in GFS PBL scheme. Default *coef_ric_l*=0.16.

j. *coef_ric_s*: Placeholder for the coefficient used in the calculation of the variable critical Richardson number (Ric) in GFS PBL scheme. Default *coef_ric_s*=0.25.

k. *sf_ocean_physics* = 1 (renamed from *omlcall* in previous versions): Simple ocean mixed layer model (1): 1-D ocean mixed layer model following that of Pollard, Rhines and Thompson (1972). Two other namelist options are available to specify the initial mixed layer depth (although one may ingest real mixed layer depth data) (*oml_hml0*) and a temperature lapse rate below the mixed layer (*oml_gamma*). Since V3.2, this option works with all *sf_surface_physics* options.

l. *sf_ocean_physics* = 2: New in V3.5. 3D Price-Weller-Pinkel (PWP) ocean model based on Price et al. (1994). This model predicts horizontal advection, pressure gradient force, as well as mixed layer processes. Only simple initialization via namelist variables *ocean_z, ocean_t*, and *ocean_s* is available in V3.5.

m. *isftcflx*: Modify surface bulk drag (Donelan) and enthalpy coefficients to be more in line with recent research results of those for tropical storms and hurricanes. This option also includes dissipative heating term in heat flux. It is only available for *sf_sfclay_physics* = 1. There are two options for computing enthalpy coefficients: *isftcflx* = 1: constant Z_{0q} (since V3.2) for heat and moisture; *isftcflx* = 2 Garratt formulation, slightly different forms for heat and moisture.

n. *windfarm_opt*: Wind turbine drag parameterization scheme. It represents sub-grid effects of specified turbines on wind and TKE fields. The physical charateristics of the wind farm is read in from a file and use of the manufacturers' specification is recommeded. An example of the file is provided in run/wind-turbine-1.tbl. The location of the turbines are read in from a file, windturbines.txt. See README.windturbine in WRFV3/ directory for more detail. New in Version 3.3, and in this version it only works with 2.5 level MYNN PBL option (*bl_pbl_physics*=5), and updated in V3.6.

o. Land model input options: *usemonalb*: When set to .true., it uses monthly albedo fields from geogrid, instead of table values. *rdlai2d*: When set to .true., it uses monthly LAI data from geogrid (new in V3.6) and the field will also go to wrflowinp file if *sst_update* is 1.

p. *no_mp_heating*: When set to 1, it turns off latent heating from microphysics. When using this option, *cu_physics* should be set to 0.

q. *icloud*: When set to 0, it turns off cloud effect on optical depth in shortwave radiation options 1, 4 and longwave radiation option 1, 4. Note since V3.6, this namelist also controls which cloud fraction method to use for radiation.

r. *isfflx*: When set to 0, it turns off both sensible and latent heat fluxes from the surface. This option works for *sf_sfclay_physics* = 1, 5, 7, 11.

s. *ifsnow*: When set to 0, it turns off snow effect in *sf_surface_physics* = 1.

Other dynamics options

a. *euler_adv*: Logical switch that turns on/off highly-conservative passive advection. Default *euler_adv*=.true. *(**Note:** ONLY compatible with Ferrier MP (5), else set to .false.)*

b. *codamp*: Divergence damping weighting factor (larger = more damping). Default *codamp*=6.4

c. *coac*: Horizontal diffusion weighting factor (larger = more diffusion). Default *coac*=1.6

d. *slophc*: Maximum model level slope (dZ/dy) for which horizontal diffusion is applied. Larger values applies horizontal diffusion over more mountainous terrain. Default *slophc*=6.363961e-3

e. *wp*: Off-centering weight in the updating of nonhyrostatic epsilon term in the nonhydrostatic solver. Very high-resolution runs (sub-1.5 km scale), particularly if model layers near the top of atmosphere are thick, will benefit from *wp* of about 0.10 (0.15 as an absolute upper limit) to stabilize the integration. Default *wp*=0.00

f. *vortex_tracker:* Vortex tracking algorithm for HWRF. Default *vortex_tracker*=1

g. *movemin:* Frequency with which nest tracker routine will be called in HWRF (multiples of nphs). Default *movemin*=10.

h. *nomove_freq*: To prevent noise in the output files, disable nest movement at initialization time or multiples of this interval, if this interval is set to a positive number (hours). By default, this is disabled (*nomove_freq=-1*).

Operational Configuration

Below is a summary of physics options that are well-tested for WRF-NMM and are used operationally at NCEP for the North-America Mesoscale (NAM) Model:

&physics	Identifying Number	Physics options
mp_physics (max_dom)	5	Microphysics-Ferrier
ra_lw_physics	99	Long-wave radiation - GFDL (Fels-Schwarzkopf)
ra_sw_physics	99	Short-wave radiation - GFDL (Lacis-Hansen)
sf_sfclay_physics	2	Surface-layer: Janjic scheme
sf_surface_physics	2	Noah Land Surface
bl_pbl_physics	2	Boundary-layer - Mellor-Yamada-Janjic TKE
cu_physics	2	Cumulus - Betts-Miller-Janjic scheme
num_soil_layers	4	Number of soil layers in land surface model

Description of Namelist Variables

The settings in the ***namelist.input*** file are used to configure WRF-NMM. This file should be edited to specify: dates, number and size of domains, time step, physics options, and output options. When modifying the ***namelist.input*** file, be sure to take into account the following points:

time_step: The general rule for determining the time step of the coarsest grid follows from the CFL criterion. If ***d*** is the grid distance between two neighboring points (in diagonal direction on the WRF-NMM's E-grid), ***dt*** is the time step, and ***c*** is the phase speed of the fastest process, the CFL criterion requires that:

(c*dt)/[d/sqrt(2.)] ≤1

This gives**: dt ≤ d/[sqrt(2.)*c]**

A very simple approach is to use ***2.25 x (grid spacing in km)*** or about ***330 x (angular grid spacing)*** to obtain an integer number of time steps per hour.

For example: If the grid spacing of the coarsest grid is 12km, then this gives *dt=27 s,* with a *dt=26 2/3 s* corresponding to 135 time steps per hour.

The following are pre-tested time-steps for WRF-NMM:

Approximate Grid Spacing (km)	**DELTA_X (in degrees)**	**DELTA_Y (in degrees)**	**Time Step (seconds)**
4	0.026726057	0.026315789	9-10s
8	0.053452115	0.052631578	18s
10	0.066666666	0.065789474	24s
12	0.087603306	0.075046904	25-30s
22	0.154069767	0.140845070	60s
32	0.222222222	0.205128205	90s

e_we and e_sn: Given WRF-NMM's E-grid staggering, the end index in the east-west direction **(*e_we*)** and the south-north direction (***e_sn***) for the coarsest grid need to be set with care and the ***e_sn*** value must be **EVEN** for WRF-NMM.

When using WPS, the coarsest grid dimensions should be set as:

e_we (namelist.input) = e_ew (namelist.wps),
e_sn (namelist.input) = e_sn (namelist.wps).

For example: The parent grid ***e_we*** and ***e_sn*** are set up as follows:

namelist.input	***namelist.wps***
e_we = 124,	***e_we*** = 124,
e_sn = 202,	***e_sn*** = 202,

Other than what was stated above, there are no additional rules to follow when choosing ***e_we*** and ***e_sn*** for nested grids.

dx and dy: For WRF-NMM, ***dx*** and ***dy*** are the horizontal grid spacing in degrees, rather than meters (unit used for WRF-ARW). Note that ***dx*** should be slightly larger than ***dy*** due to the convergence of meridians approaching the poles on the rotated grid. The grid spacing in ***namelist.input*** should have the same values as in ***namelist.wps***.

When using WPS,

dx (namelist.input) = dx (namelist.wps),
dy (namelist.input) = dy (namelist.,wps).

When running a simulation with multiple (*N*) nests, the namelist should have *N* values of ***dx***, ***dy***, ***e_we***, ***e_sn*** separated by commas.

For more information about the horizontal grid spacing for WRF-NMM, please see Chapter 3, WRF Preprocessing System (WPS).

nio_tasks_per_group: The number of ***I/O*** tasks ***(nio_tasks_per_group)*** should evenly divide into the number of compute tasks in the ***J-direction*** on the grid (that is the value of ***nproc_y***). For example, if there are 6 compute tasks in the ***J-direction***, then ***nio_tasks_per_group*** could legitimately be set to 1, 2, 3, or 6. The user needs to use a number large enough that the quilting for a given output time is finished before the next output time is reached. If one had 6 compute tasks in the ***J-direction*** (and the number in the ***I-direction*** was similar), then one would probably choose either 1 or 2 quilt tasks.

The following table provides an overview of the parameters specified in ***namelist.input***. Note that "***namelist.input***" is common for both WRF cores (WRF-ARW and WRF-NMM). Most of the parameters are valid for both cores. However, some parameters are only valid for one of the cores. Core specific parameters are noted in the table. In addition, some physics options have not been tested for WRF-NMM. Those options that have been tested are highlighted by indicating whether they have been "fully" or "preliminarily" tested for WRF-NMM.

Variable Names	**Value (Example)**	**Description**
&time_control		Time control
run_days	2	Run time in days
run_hours	0	Run time in hours Note: If run time is more than 1 day, one may use both ***run_days*** and ***run_hours*** or just ***run_hours***. e.g. if the total run length is 36 hrs, you may set ***run_days***=1, and **run_hours**=12, or ***run_days***=0, and ***run_hours***=36.
run_minutes	00	Run time in minutes

Variable Names	**Value (Example)**	**Description**
run_seconds	00	Run time in seconds
start_year (max_dom)	2005	Four digit year of starting time
start_month (max_dom)	04	Two digit month of starting time
start_day (max_dom)	27	Two digit day of starting time
start_hour (max_dom)	00	Two digit hour of starting time
start_minute (max_dom)	00	Two digit minute of starting time
start_second (max_dom)	00	Two digit second of starting time
end_year (max_dom)	2005	Four digit year of ending time
end_month (max_dom)	04	Two digit month of ending time
end_day (max_dom)	29	Two digit day of ending time
end_hour (max_dom)	00	Two digit hour of ending time
end_minute (max_dom)	00	Two digit minute of ending time
end_second (max_dom)	00	Two digit second of ending time **Note:** All end times also control when the nest domain integrations end. **Note:** All start and end times are used by ***real_nmm.exe***. One may use either ***run_days***/***run_hours*** etc. or ***end_year***/***month***/***day***/***hour*** etc. to control the length of model integration, but ***run_days***/***run_hours*** takes precedence over the end times. The program ***real_nmm.exe*** uses start and end times only.
interval_seconds	10800	Time interval between incoming real data, which will be the interval between the lateral boundary condition files. This parameter is only used by ***real_nmm.exe***.
history_interval (max_dom)	60	History output file interval in minutes
history_interval_d (max_dom)	1	history output file interval in days (integer only); used as an alternative to `history_interval`
history_interval_h (max_dom)	1	history output file interval in hours (integer only); used as an alternative to `history_interval`
history_interval_m (max_dom)	1	history output file interval in minutes (integer only); used as an alternative to `history_interval` and is equivalent to

Variable Names	Value (Example)	Description
		`history_interval`
history_interval_s (max_dom)	1	history output file interval in seconds (integer only); used as an alternative to `history_interval`
frames_per_outfile (max_dom)	1	Output times per history output file, used to split output files into smaller pieces
tstart (max_dom)	0	**This flag is only for the WRF-NMM core**. Forecast hour at the start of the NMM integration. Set to >0 if restarting a run.
analysis	.false.	**This flag is only for the HWRF configuration.** True: Nested domain will read in initial conditions from a file (instead of being initialized by interpolation from the coarse domain). False: Nested domain will get its initial condition by interpolation from the coarse domain. Will output an analysis file containing the variables with restart IO characteristics for the nested domain.
anl_outname	wrfanl_d02_yyyy-mm-dd_hh:mm:ss	specify the name of the analysis output file.
restart	.false.	Logical indicating whether run is a restart run
restart_interval	60	Restart output file interval in minutes
reset_simulation_start	F	Whether to overwrite simulation_start_date with forecast start time
io_form_history	2	Format of history file wrfout 1 = binary format (no supported post-processing software available) 2 = netCDF; 102 = split netCDF files on per processor (no supported post-processing software for split files) 4 = PHDF5 format (no supported post-processing software available) 5 = GRIB 1 10 = GRIB 2 11 = Parallel netCDF

Variable Names	Value (Example)	Description
io_form_restart	2	Format of restart file wrfrst 2 = netCDF; 102 = split netCDF files on per processor (must restart with the same number of processors)
io_form_input	2	Format of input file wrfinput_d01 2 = netCDF
io_form_boundary	2	Format of boundary file wrfbdy_d01 2 = netCDF
auxinput1_inname	***met_nmm_.d01.****<date>*	Name of input file from WPS
auxinput4_inname	***wrflowinp_d****<domain>*	Input for lower bdy file, works with ***sst_update***=1
auxinput4_interval (max_dom)	720	File interval, in minutes, for lower bdy file
debug_level	0	Control for amount of debug printouts 0 - for standard runs, no debugging. 1 - netcdf error messages about missing fields. 50,100,200,300 values give increasing prints. Large values trace the job's progress through physics and time steps.
nocolons	.false.	when set to .true. this replaces the colons with underscores in the output file names
ncd_nofill	.true.	(default) only a single write, not the write/read/write sequence (new in V3.6)
&Domains		Domain definition
time_step	18	Time step for integration of coarsest grid in integer seconds
time_step_fract_num	0	Numerator for fractional coarse grid time step
time_step_fract_den	1	Denominator for fractional coarse grid time step. Example, if you want to use 60.3 sec as your time step, set ***time_step***=60, ***time_step_fract_num***=3, and ***time_step_fract_den***=10

Variable Names	**Value (Example)**	**Description**
max_dom	1	Number of domains (1 for a single grid, >1 for nests)
s_we (max_dom)	1	Start index in x (west-east) direction (leave as is)
e_we (max_dom)	124	End index in x (west-east) direction (staggered dimension)
s_sn (max_dom)	1	Start index in y (south-north) direction (leave as is)
e_sn (max_dom)	62	End index in y (south-north) direction (staggered dimension). **For WRF-NMM this value must be even.**
s_vert (max_dom)	1	Start index in z (vertical) direction (leave as is)
e_vert (max_dom)	61	End index in z (vertical) direction (staggered dimension). This parameter refers to full levels including surface and top. Note: Vertical dimensions need to be the same for all nests.
dx (max_dom)	.0534521	Grid length in x direction, units in **degrees** for WRF-NMM.
dy (max_dom)	.0526316	Grid length in y direction, units in **degrees** for WRF-NMM.
p_top_requested	5000	P top used in the model (Pa); must be available in WPS data
ptsgm	42000.	Pressure level (Pa) in which the WRF-NMM hybrid coordinate transitions from sigma to pressure
eta_levels	1.00, 0.99, …0.00	Model eta levels. If this is not specified ***real_nmm.exe*** will provide a set of levels.
num_metgrid_levels	40	Number of vertical levels in the incoming data: type ***ncdump –h*** to find out
grid_id (max_dom)	1	Domain identifier.
parent_id (max_dom)	0	ID of the parent domain. Use 0 for the coarsest grid.
i_parent_start (max_dom)	1	Defines the LLC of the nest as this I-index of the parent domain. Use 1 for the coarsest grid.
j_parent_start (max_dom)	1	Defines the LLC of the nest in this J-index of the parent domain. Use 1 for the coarsest grid.

Variable Names	**Value (Example)**	**Description**
parent_grid_ratio (max_dom)	3	Parent-to-nest domain grid size ratio. **For WRF-NMM this ratio must be 3.**
parent_time_step_ratio (max_dom)	3	Parent-to-nest time step ratio. **For WRF-NMM this ratio must be 3.**
feedback	1	Feedback from nest to its parent domain; 0 = no feedback
smooth_option	0	no smoothing
	1	1-2-1 smoothing option for parent domain; used only with `feedback=1`
	2	(default) smoothing-desmoothing option for parent domain; used only with `feedback=1`
num_moves	-99	0: Stationary nest -99: Vortex-following moving nest throughout the entire simulation **This flag is only for the HWRF configuration.**
tile_sz_x	0	Number of points in tile x direction.
tile_sz_y	0	Number of points in tile y direction.
numtiles	1	Number of tiles per patch (alternative to above two items).
nproc_x	-1	Number of processors in x–direction for decomposition.
nproc_y	-1	Number of processors in y-direction for decomposition: If -1: code will do automatic decomposition. If >1 for both: will be used for decomposition.
&physics		Physics options
chem_opt	0	Chemistry option - not yet available
mp_physics (max_dom)	5	Microphysics options: 0. no microphysics 1. Kessler scheme 2. Lin et al. scheme 3. WSM 3-class simple ice scheme 4. WSM 5-class scheme (Preliminarily tested for WRF-NMM) 5. Ferrier (high res) scheme (Well-tested for WRF-NMM, used operationally at NCEP) 6. WSM 6-class graupel scheme (Preliminarily

Variable Names	Value (Example)	Description
		tested for WRF-NMM) 7. Goddard GCE scheme 8. Thompson graupel scheme (Preliminarily tested for WRF-NMM) 9. Milbrandt-Yau scheme (v3.2) 10. Morrison 2-moment scheme 13. SBU-YLin, 5-class scheme 14. Double moment, 5-class scheme 16. Double moment, 6-class scheme 17. NSSL 2-moment 18. NSSL 2-moment, with CCN prediction 19. NSSL 1-moment, 6-class 21. NSSL-LFO 1-moment, 6-class 28. aerosol-aware Thompson scheme with water- and ice-friendly aerosol climatology (new for V3.6); this option has 2 climatological aerosol input options: use_aero_icbs = .F. (use constant values), and use_aero_icbc = .T. (use input from WPS) 30. HUJI (Hebrew University of Jerusalem, Israel) spectral bin microphysics, fast version 32. HUJI spectral bin microphysics, full version 85. Etamp_hwrf scheme. Similar to Ferrier, modified for HWRF. (Well-tested, used operationally at NCEP for HWRF) 95. Ferrier (coarse) scheme (Well-tested for WRF-NMM, used operationally at NCEP) 98. Thompson (v3.0) scheme (Preliminarily tested for WRF-NMM)
do_radar_ref	0	allows radar reflectivity to be computed using mp-scheme- specific parameters. Currently works for `mp_physics` = 2,4,6,7,8,10,14,16 0: off 1: on
ra_lw_physics (max_dom)	99	Long-wave radiation options: 0. No longwave radiation 1. RRTM scheme (Preliminarily tested for WRF-NMM) 3. CAM scheme 4. RRTMG scheme 5. Goddard scheme 7. FLG (UCLA) scheme 31. Earth Held-Suarez forcing

Variable Names	**Value (Example)**	**Description**
		99. GFDL scheme (Well-tested for WRF-NMM, used operationally at NCEP) 98. modified GFDL scheme (Well-tested, used operationally at NCEP for HWRF)
ra_sw_physics (max_dom)	99	Short-wave radiation options: 0. No shortwave radiation 1. Dudhia scheme (Preliminarily tested for WRF-NMM) 2. Goddard short wave scheme (old) 3. CAM scheme 4. RRTMG scheme 5. Goddard scheme 7. FLG (UCLA) scheme 99. GFDL scheme (Well-tested for WRF-NMM, used operationally at NCEP) 98. modified GFDL scheme (Well-tested, used operationally at NCEP for HWRF)
nrads (max_dom)	100	**This flag is only for the WRF-NMM core**. Number of fundamental time steps between calls to shortwave radiation scheme. NCEP's operational setting: ***nrads*** is on the order of "3600/dt". For more detailed results, use: ***nrads=1800/dt***
nradl (max_dom)	100	**This flag is only for the WRF-NMM core**. Number of fundamental time steps between calls to longwave radiation scheme. Note that ***nradl*** must be set equal to ***nrads***.
tprec (max_dom)	3	**This flag is only for the WRF-NMM core**. Number of hours of precipitation accumulation in WRF output.
theat (max_dom)	6	**This flag is only for the WRF-NMM core**. Number of hours of accumulation of gridscale and convective heating rates in WRF output.
tclod (max_dom)	6	**This flag is only for the WRF-NMM core**. Number of hours of accumulation of cloud amounts in WRF output.
trdsw (max_dom)	6	**This flag is only for the WRF-NMM core**. Number of hours of accumulation of shortwave fluxes in WRF output.
trdlw (max_dom)	6	**This flag is only for the WRF-NMM core**.

Variable Names	**Value (Example)**	**Description**
		Number of hours of accumulation of longwave fluxes in WRF output.
tsrfc (max_dom)	6	**This flag is only for the WRF-NMM core**. Number of hours of accumulation of evaporation/sfc fluxes in WRF output.
pcpflg (max_dom)	.false.	**This flag is only for the WRF-NMM core**. Logical switch that turns on/off the precipitation assimilation used operationally at NCEP.
co2tf	1	**This flag is only for the WRF-NMM core.** Controls CO2 input used by the GFDL radiation scheme. 0: Read CO2 functions data from pre- generated file 1: Generate CO2 functions data internally
sf_sfclay_physics (max_dom)	2	Surface-layer options: 0. No surface-layer scheme 1. Monin-Obukhov scheme (Preliminarily tested for WRF-NMM) 2. Janjic scheme (Well-tested for WRF-NMM, used operationally at NCEP) 3. NCEP Global Forecast System scheme (Preliminarily tested for WRF-NMM) 4. QNSE 5. MYNN 7. Pleim-Xiu surface layer 10. TEMF 11. Revised MM5 surface layer scheme 88. GFDL surface layer scheme (Well-tested, used operationally at NCEP for HWRF)
iz0tlnd	0	Thermal roughness length for sfclay and myjsfc (0 - old, 1 - veg dependent Czil)
sf_surface_physics (max_dom)	99	Land-surface options: 0. No surface temperature prediction 1. Thermal diffusion scheme 2. Noah Land-Surface Model (Well-tested for WRF-NMM, used operationally at NCEP) 3. RUC Land-Surface Model (Preliminarily tested for WRF-NMM) 4. Noah-MP land-surface model (additional options under &noah_mp; preliminarily tested for WRF-NMM)

Variable Names	**Value (Example)**	**Description**
		5. CLM4 (Community Land Model Version 4) 7. Pleim-Xiu Land Surface Model (ARW only) 8. SSiB land-surface model (ARW only). Works with *ra_lw_physics* = 1, 3, 4 and *ra_sw_physics* = 1, 3, 4 88. GFDL slab land surface model (Well-tested, used operationally at NCEP for HWRF)
bl_pbl_physics (max_dom)	2	Boundary-layer options: 0. No boundary-layer 1. YSU scheme (Preliminarily tested for WRF-NMM) 2. Mellor-Yamada-Janjic TKE scheme (Well-tested for WRF-NMM, used operationally at NCEP) 3. NCEP Global Forecast System scheme (Well-tested, used operationally at NCEP for HWRF) 4. QNSE 5. MYNN 2.5 level TKE, works with ***sf_sfclay_physics***=1,2, and 5 6. MYNN 3rd level TKE, works with ***sf_sfclay_physics***=5 only 7. ACM2 scheme 8. BouLac TKE 9. Bretherton-Park/UW TKE scheme, use with sf_sfclay_physics=1,2 10. TEMF scheme 12. GBM TKE-type scheme (ARW only); use ***sf_sfclay_physics=1*** 99. MRF scheme (to be removed)
nphs (max_dom)	10	**This flag is only for WRF-NMM core**. Number of fundamental time steps between calls to turbulence and microphysics. It can be defined as: ***nphs=x/dt***, where ***dt*** is the time step (s), and ***x*** is typically in the range of 60s to 180s. (Traditionally it has been ***an even number***, which may be a consequence of portions of horizontal advection only being called every other time step.)
topo_wind (max_dom)	0	1=turn on topographic surface wind correction (Jimenez); requires extra input from geogrid, and works with YSU PBL scheme only (0 = off,

Variable Names	**Value (Example)**	**Description**
		default)
bl_mynn_tkebudget	1	adds MYNN tke budget terms to output
cu_physics (max_dom)	2	Cumulus scheme options: 0. No cumulus scheme (Well-tested for WRF-NMM) 1. Kain-Fritsch scheme (Preliminarily tested for WRF-NMM) 2. Betts-Miller-Janjic scheme (Well-tested for WRF-NMM, used operationally at NCEP) 3. Grell-Devenyi ensemble scheme (Preliminarily tested for WRF-NMM) 4. Simplified Arakawa-Schubert scheme (2010 operational HWRF scheme) 14. New GFS SAS from YSU (ARW only) 5. Grell 3d ensemble scheme 6. Tiedke scheme 7. Zhang-McFarlane from CESM (works with MYJ and UW PBL) 14. New GFS SAS from YSU (ARW only) 84. Simplified Arakawa-Schubert scheme (Well-tested, used operationally at NCEP for HWRF) 93. Grell-Devenyi ensemble scheme 99. Previous Kain-Fritsch scheme (Preliminarily tested for WRF-NMM)
mommix	0.7	momentum mixing coefficient (used in SAS cumulus scheme). **This flag is for the SAS scheme only.**
h_diff	0.1	Horizontal diffusion coefficient. **This flag is only for the HWRF configuration.**
sfenth	1.0	Enthalpy flux factor. **This flag is for the GFDL surface scheme only.**
ncnvc (max_dom)	10	**This flag is only for WRF-NMM core**. Number of fundamental time steps between calls to convection. ***Note that ncnvc should be set equal to nphs.***
isfflx	1	heat and moisture fluxes from the surface for real-data cases and when a PBL is used (only works with `sf_sfclay_physics=1, 5, 7, or 11`)

Variable Names	**Value (Example)**	**Description**
		1 = fluxes are on 0 = fluxes are off It also controls surface fluxes when diff_opt = 2 and km_opt = 3, and a PBL isn't used 0 = constant fluxes defined by tke_drag_coefficient and tke_heat_flux 1 = use model-computed u* and heat and moisture fluxes 2 = use model-computed u* and specified heat flux by tke_heat_flux
ifsnow	1	Snow-cover effects for "Thermal Diffusion scheme" (sf_surface_physics=1): 0. No snow-cover effect 1. With snow-cover effect
icloud	0	Cloud effect to the optical depth in the Dudhia shortwave (ra_sw_physics=1) and RRTM longwave radiation (ra_lw_physics=1) schemes. 0. No cloud effect 1. With cloud effect
swrad_scat	1	Scattering tuning parameter (default 1 is 1.e-5 m^2/kg) (only for *ra_sw_physics* = 1)
num_soil_layers	4	Number of soil layers in land surface model. Options available: 2. Pleim-Xu Land Surface Model 4. Noah Land Surface Model (Well-tested for WRF-NMM, used operationally at NCEP) 5. Thermal diffusion scheme 6. RUC Land Surface Model (Preliminarily tested for WRF-NMM)
maxiens	1	Grell-Devenyi and G3 only. **Note:** The following 5 are recommended numbers. If you would like to use any other number, consult the code, and know what you are doing.
maxens	3	G-D only
maxens2	3	G-D only
maxens3	16	G-D only
ensdim	144	G-D only.
mp_zero_out	0	For non-zero mp_physics options, to keep water vapor positive (Qv >= 0), and to set the other

Variable Names	Value (Example)	Description
		moisture fields smaller than some threshold value to zero. 0. No action is taken, no adjustment to any moist field. (conservation maintained) 1. All moist arrays, except for Qv, are set to zero if they fall below a critical value. (No conservation) 2. Qv<0 are set to zero, and all other moist arrays that fall below the critical value defined in the flag “mp_zero_out_thresh” are set to zero. (No conservation.) **For WRF-NMM, mp_zero_out MUST BE set to 0.**
gwd_opt	0	Gravity wave drag option; use with grid spacing > 10 km 0. Off (default) 1. ARW GWD on 2. NMM GWD on
sst_update	0	Option to use time-varying SST, seaice, vegetation fraction, and abledo during a model simulation (set before running ***real_nmm.exe***) 0. Off (default) 1. ***real_nmm.exe*** will create *wrflowinp_d01* file at the same time interval as the available input data. To use it in ***wrf.exe***, add *auxinput4_inname=wrflowinp_d<domain>* and *auxinput4_interval* under the ***&time_control*** namelist section
sas_pgcon	0.55	convectively forced pressure gradient factor (SAS schemes 14 and 84)
gfs_alpha	1	boundary depth factor for GFS PBL scheme (3)
var_ric	0	Placeholder for the use of variable critical Richardson number (Ric) in GFS PBL scheme (will be available in HWRF V3.5a release). Default var_ric=0 to use constant Ric, else set var_ric=1 to use variable.
coef_ric_l	0.16	Placeholder for the coefficient used in the calculation of the variable critical Richardson number (Ric) in GFS PBL scheme.
coef_ric_s	0.25	Placeholder for the coefficient used in the calculation of the variable critical Richardson

Variable Names	**Value (Example)**	**Description**
		number (Ric) in GFS PBL scheme.
sas_mass_flux	0.5	mass flux limit (SAS scheme 84)
vortex_tracker	1	Vortex Tracking Algorithm for HWRF 1. (default) follow vortex using MSLP (operational HWRF 2011 algorithm) 2. follow vortex using MSLP (revised) 3. track vortex in nest and use that result to move this domain 4. follow vortex using storm centroid 5. follow vortex using dynamic pressure 6. follow vortex using the tracking algorithm of the GFDL vortex tracker (operational HWRF 2013 algorithm, will be available in HWRF V3.5a release) . New vortex following algorithm (under development)
nomove_freq:	-1	Disable nest movement at certain intervals to prevent noise in the output files, so that nest will not move at analysis time or multiples of this interval, if this interval is set to a positive number.
movemin	5	Frequency with which nest tracker routine will be called in HWRF (multiples of nphs)
&noah_mp		***options for the Noah-MP land surface model ; see: http://www.rap.ucar.edu/research/land/technology/noahmp_lsm.php***
dveg	1	Dynamic vegetation option 1=off [LAI (Leaf Area Index) from table; FVEG (veg fraction) = shdfac (model variable for veg fraction)] 2=(default) on 3= off (LAI from table; FVEG calculated) 4= off (LAI from table; FVEG = maximum veg. fraction)
opt_crs	1	Stomatal resistance option 1=(default) Ball-Berry 2=Jarvis

Variable Names	**Value (Example)**	**Description**
opt_sfc	1	Surface layer drag coefficient calculation 1=(default) Monin-Obukhov 2=original Noah 3=MYJ consistent 4=YSU consistent
opt_btr	1	Soil moisture factor for stomatal resistance 1=Noah 2=CLM 3=SSiB
opt_run	1	1=(default) TOPMODEL with ground water 2=TOPMODEL with equilibrium water table 3=original surface and subsurface runoff (free drainage) 4=BATS (Biosphere-Atmosphere Transfer Scheme) surface and subsurface runoff (free drainage)
opt_frz	1	Supercooled liquid water option 1=(default)no iteration 2=Koren's iteration
opt_inf	1	Soil permeability option 1=(default) linear effect, more permeable 2=non-linear effect, less permeable
opt_rad	1	Radiative transfer option 1= modified two-stream 2=two-stream applied to grid cell 3=(default) two-stream applied to vegetated fraction
opt_alb	2	Ground surface albedo option 1=BATS 2=(default) CLASS (Canadian Land Surface Scheme)
opt_snf	1	Precipitation partitioning between snow and rain 1=(default) Jordan (1991) 2=BATS; snow when SFCTMP<TFRZ+2.2 3=show when SFCTMP<TFRZ
opt_tbot	2	Soil temp lower boundary condition 1=zero heat flux 2=(default) TBOT at 8m from input file
opt_stc	1	Snow/soil temperature time scheme 1=(default) semi-implicit

Variable Names	Value (Example)	Description
		2=fully-implicit
&fdda		Observation nudging (Not yet available in the WRF-NMM)
&dynamics		Dynamics options:
dyn_opt	4	4. WRF-NMM dynamics
non_hydrostatic	.true.	Whether running the model in hydrostatic or non-hydrostatic model.
euler_adv	.true.	Logical switch that turns on/off passive advection (new in v3.2 – **ONLY compatible with Ferrier MP (5), else set to .false.**)
idtadt	1	Dynamics timestep between calls to the passive advection for dynamics variables
idtadc	1	Dynamics timestep between calls to the passive advection for chemistry variables
codamp	6.4	Divergence damping weighting factor (larger = more damping)
coac	1.6	Horizontal diffusion weighting factor (larger = more diffusion)
slophc	6.364e-3	Maximum model level slope (dZ/dy) for which horizontal diffusion is applied
wp	0.15	Off-centering weight in the updating of nonhyrostatic eps
&bc_control		Boundary condition control.
spec_bdy_width	1	Total number of rows for specified boundary value nudging. **It MUST be set to 1 for WRF-NMM core.**
specified (max_dom)	.true.	Specified boundary conditions (only applies to domain 1)
&grib2		
&namelist_quilt		Option for asynchronized I/O for MPI

Variable Names	**Value (Example)**	**Description**
		applications.
nio_tasks_per_group	0	Default value is 0, means no quilting; value > 0 quilting I/O
nio_groups	1	Default is 1. May be set higher for nesting IO, or history and restart IO.
&dfi_control		Digital filter option control
dfi_opt	0	DFI option 0: No digital filter initialization 1: Digital Filter Launch (DFL) 2: Diabatic DFI (DDFI) 3: Twice DFI (TDFI) (Recommended)
dfi_nfilter	7	Digital filter type 0: uniform 1: Lanczos 2: Hamming 3: Blackman 4: Kaiser 5: Potter 6: Dolph window 7: Dolph (recommended) 8: recursive high-order
dfi_write_filtered_input	.true.	Whether to write ***wrfinput*** file with filtered model state before beginning forecast
dfi_write_dfi_history	.false.	Whether to write ***wrfout*** files during filtering integration
dfi_cutoff_seconds	3600	Cutoff period, in seconds, for filter. Should not be longer than the filter window
dfi_time_dim	1000	Maximum number of time steps for filtering period (this value can be larger than necessary)
dfi_bckstop_year	2005	Four-digit year of stop time for backward DFI integration. For a model that starts from 2005042700, this example specifies 1 hour backward integration.
dfi_bckstop_month	04	Two-digit month of stop time for backward DFI integration
dfi_bckstop_day	26	Two-digit day of stop time for backward DFI

Variable Names	**Value (Example)**	**Description**
		integration
dfi_bckstop_hour	23	Two-digit hour of stop time for backward DFI integration
dfi_bckstop_minute	00	Two-digit minute of stop time for backward DFI integration
dfi_bckstop_second	00	Two-digit second of stop time for backward DFI integration.
dfi_fwdstop_year	2005	Four-digit year of stop time for forward DFI integration. For a model that starts from 2005042700, and using the TDFI method, this example specifies the end of the 60-minute forward integration (the forward segment begins at 20050426/2330).
dfi_fwdstop_month	04	Two-digit month of stop time for forward DFI integration
dfi_fwdstop_day	27	Two-digit day of stop time for forward DFI integration
dfi_fwdstop_hour	00	Two-digit hour of stop time for forward DFI integration
dfi_fwdstop_minute	30	Two-digit minute of stop time for forward DFI integration
dfi_fwdstop_second	00	Two-digit second of stop time for forward DFI integration.
&logging		
compute_slaves_silent	.true.	Switch to enable (compute_slaves_silent=.false.) or disable (compute_slaves_silent=.true.) the wrf_message calls on the slave nodes (where the wrf_dm_on_monitor() =.false.)
io_servers_silent	.true.	Switch to enable (io_servers_silent=.false.) or disable (io_servers_silent=.true.) the wrf_message calls on the IO servers.
stderr_logging	0	Switch to enable (stderr_logging=1) or disable (stderr_logging=0) the output of stderr.

How to Run WRF for the NMM Core

Note: For software requirements for running WRF, how to obtain the WRF package and how to configure and compile WRF for the NMM core, see Chapter 2.

Note: Running a real-data case requires first successfully running the WRF Preprocessing System (WPS) (See Chapter 2 for directions for installing the WPS and Chapter 3 for a description of the WPS and how to run the package).

Running *wrf.exe*:

Note: Running ***wrf.exe*** requires a successful run of ***real_nmm.exe*** as explained in Chapter 4.

1. If the working directory used to run ***wrf.exe*** is different than the one used to run ***real_nmm.exe***, make sure ***wrfinput_d01*** and ***wrfbdy_d01,*** as well as the files listed above in the ***real_nmm.exe*** discussion, are in your working directory (you may link the files to this directory).

2. The command issued to run ***wrf.exe*** in the working directory will depend on the operating system:

On LINUX-MPI systems, the command is:

DM parallel build:	or	Serial build:
mpirun -np n wrf.exe		***./wrf.exe >& wrf.out***

where "***n***" defines the number of processors to use.

For batch jobs on some IBM systems (such as NCAR's IBM), the command is:

mpirun.lsf wrf.exe

and for interactive runs (Interactive MPI job is not an option on NCAR IBMs), the command is:

mpirun.lsf wrf.exe -rmpool 1 -procs n

where ***"n"*** stands for the number of processors (CPUs) to be used.

Checking *wrf.exe* output

A successful run of ***wrf.exe*** will produce output files with the following naming convention:

wrfout_d01_yyyy-mm-dd_hh:mm:ss

For example, the first output file for a run started at 0000 UTC, 23rd January 2005 would be:

wrfout_d01_2005-01-23_00:00:00

If multiple grids were used in the simulation, additional output files named
wrfout_d02_yyyy-mm-dd_hh:mm:ss
wrfout_d03_yyyy-mm-dd_hh:mm:ss
(…)
will be produced.

To check whether the run is successful, look for "SUCCESS COMPLETE WRF" at the end of the log file (e.g., ***rsl.out.0000***, ***wrf.out***).

The times written to an output file can be checked by typing:

ncdump -v Times wrfout_d01_2005-01-23_00:00:00

The number of ***wrfout*** files generated by a successful run of ***wrf.exe*** and the number of output times per ***wrfout*** file will depend on the output options specified in ***namelist.input*** (i.e***., frames_per_outfile*** and ***history interval***).

Restart Run

A restart run allows a user to extend a run to a longer simulation period. It is effectively a continuous run made of several shorter runs. Hence the results at the end of one or more restart runs should be identical to a single run without any restart.

In order to do a restart run, one must first create a restart file. This is done by setting namelist variable ***restart_interval*** (unit is in minutes) to be equal to or less than the simulation length in the first model run, as specified by ***run_**** variables or ***start_**** and ***end_**** times. When the model reaches the time to write a restart file, a restart file named ***wrfrst_d***<*domain*>_<*date*> will be written. The date string represents the time when the restart file is valid.

When one starts the restart run, the ***namelist.input*** file needs to be modified so that the ***start_**** time will be set to the restart time (which is the time the restart file is written). The other namelist variable that must be set is ***restart***, this variable should be set to ***.true.*** for a restart run.

In summary, these namelists should be modified:

start_*, end_*: start and end times for restart model integration
restart: logical to indicate whether the run is a restart or not

Hint*:** Typically, the restart file is a lot bigger in size than the history file, hence one may find that even it is ok to write a single model history output time to a file in netCDF format (frame_per_outfile=1***), it may fail to write a restart file. This is because the basic netCDF file support is only 2Gb. There are two solutions to the problem. The first is to simply set namelist option ***io_form_restart = 102*** (instead of 2), and this will force the restart file to be written into multiple pieces, one per processor. As long as one restarts the model using the same number of processors, this option works well (and one should restart the model with the same number of processors in any case). The second solution is to recompile the code using the netCDF large file support option (see section on "Installing WRF" in this chapter).

Configuring a run with multiple domains

WRF-NMM V2.2 supports stationary one-way (Gopalakrishnan et al. 2006) and two-way nesting. By setting the ***feedback*** switch in the ***namelist.input*** file to 0 or 1, the domains behave as one-way or two-way nests, respectively. The model can handle multiple domains at the same nest level (no overlapping nest), and/or multiple nest levels (telescoping). Make sure that you compile the code with nest options turned on as described in Chapter 2.

The nest(s) can be located anywhere inside the parent domain as long as they are at least 5 parent grid points away from the boundaries of the parent grid. Similar to the coarsest domain, nests use an E-staggered grid with a rotated latitude-longitude projection. The horizontal grid spacing ratio between the parent and the nest is 1:3, and every third point of the nest coincides with a point in the parent domain. The time step used in the nest must be 1/3 that of the parent time step.

No nesting is applied in the vertical, that is, the nest has the same number of vertical levels as its parent. Note that, while the hybrid levels of the nest and parent in sigma space coincide, the nest and the parent do not have the same levels in pressure or height space. This is due to the differing topography, and consequently different surface pressure between the nest and the parent.

Nests can be introduced in the beginning of the model forecast or later into the run. Similarly, nests can run until the end of the forecast or can be turned off earlier in the run. Namelist variables ***start_**** and ***end_**** control the starting and ending time for nests.

When a nest is initialized, its topography is obtained from the static file created for that nest level by the WPS (see Chapter 3). Topography is the only field used from the static file. All other information for the nest is obtained from the lower-resolution parent domain. Land variables, such as land-sea mask, SST, soil temperature and moisture are obtained through a nearest-neighbor approach.

To obtain the temperature, geopotential, and moisture fields for the nest initialization, the first step is to use cubic splines to vertically interpolate those fields from hybrid levels to constant pressure levels in each horizontal grid point of the parent grid. The second step is to bilinearly interpolate those fields in the horizontal from the parent grid to the nest. The third step is to use the high-resolution terrain and the geopotential to determine the surface pressure on the nest. Next, the pressure values in the nest hybrid surfaces are calculated. The final step is to compute the geopotential, temperature and moisture fields over the nest hybrid surface using a cubic spline interpolation in the vertical.

The zonal and meridional components of the wind are obtained by first performing a horizontal interpolation from the parent to the nest grid points using a bi-linear algorithm. The wind components are then interpolated in the vertical from the parent hybrid surfaces onto the nest hybrid surfaces using cubic splines.

The boundary conditions for the nest are updated at every time step of the parent domain. The outermost rows/columns of the nest are forced to be identical to the parent domain interpolated to the nest grid points. The third rows/columns are not directly altered by the parent domain, that is, their values are obtained from internal computations within the nest. The second rows/columns are a blend of the first and third rows/columns. This procedure is analogous to what is used to update the boundaries of the coarsest domain with the external data source. To obtain the values of the mass and momentum fields in the outermost row/column of the nest, interpolations from the parent grid to the nest are carried in the same manner as for nest initialization.

Most of options to start a nest run are handled through the namelist. **Note:** All variables in the ***namelist.input*** file that have multiple columns of entries need to be edited with caution.

The following are the key namelist variables to modify:

- ***start_*** and ***end_year/month/day/minute/second***: These control the nest start and end times
- ***history_interval***: History output file in minutes (integer only)
- ***frames_per_outfile***: Number of output times per history output file, used to split output files into smaller pieces
- ***max_dom***: Setting this to a number greater than 1 will invoke nesting. For example, if you want to have one coarse domain and one nest, set this variable to 2.
- ***e_we/e_sn***: Number of grid points in the east-west and north-south direction of the nest. In WPS, ***e_sw***. ***e_sn*** for the nest are specified to cover the entire domain of the coarse grid while, in file ***namelist.input***, ***e_we*** and ***e_sn*** for the nest are specified to cover the domain of the nest.
- ***e_vert***: Number of grid points in the vertical. No nesting is done in the vertical, therefore the nest must have the same number of levels as its parent.
- ***dx/dy***: grid spacing in **degrees**. The nest grid spacing must be 1/3 of its parent.
- ***grid_id***: The domain identifier will be used in the ***wrfout*** naming convention. The coarser grid must have ***grid_id*** = 1.

- ***parent_id***: Specifies the parent grid of each nest. The parents should be identified by their ***grid_id***.
- ***i_parent_start/j_parent_start***: Lower-left corner starting indices of the nest domain in its parent domain. The coarser grid should have ***parent_id*** = 1.
- ***parent_grid_ratio***: Integer parent-to-nest domain grid size ratio. **Note:** Must be 3 for the NMM.
- ***parent_time_step_ratio***: Integer parent-to-nest domain timestep ratio. **Note:** Must be 3 for the NMM. Since the timestep for the nest is determined using this variable, namelist variable ***time_step*** only assumes a value for the coarsest grid.
- ***feedback***: If feedback = 1, values of prognostic variables in the nest are fedback and overwrite the values in the coarse domain at the coincident points. 0 = no feedback.

In addition to the variables listed above, the following variables are used to specify physics options and need to have values for all domains (as many columns as domains: ***mp_physics, ra_lw_pjysics, ra_sw_physics, nrads, nradl, sf_sfclay_physics, sf_surface_physics, bl_pbl_physics, nphs, cu_physics, ncnvc***.

Note: It is recommended to run all domains with the same physics, the exception being the possibility of running cumulus parameterization in the coarser domain(s) but excluding it from the finer domain(s).

In case of doubt about whether a given variable accepts values for nested grids, search for that variable in the file ***WRFV3/Registry/Registry*** and check to see if the string ***max_doms*** is present in that line.

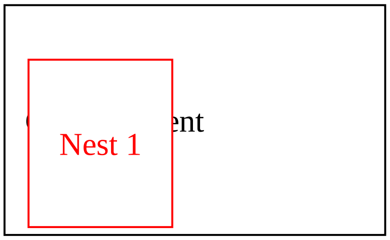
Before starting the WRF model, make sure to place the nest's time-invariant land-describing file in the proper directory.

For example, when using WPS, place the file ***geo_nmm_nest.l01.nc*** in the working directory where the model will be run. If more than one level of nest will be run, place additional files ***geo_nmm_nest.l02.nc***, ***geo_nmm_nest.l03.nc*** etc. in the working directory.

Examples:

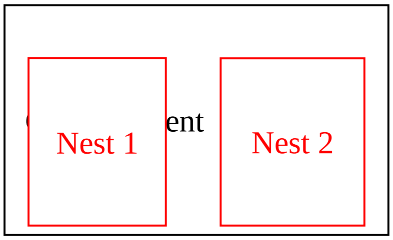
1. One nest and one level of nesting

WPS: requires file ***geo_nmm_nest.l01.nc***



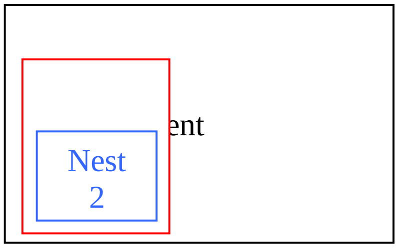
2. Two nests and one level of nesting

WPS: requires file ***geo_nmm_nest.l01.nc***



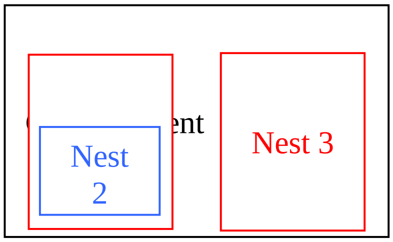
3. Two nests and two level of nesting

WPS: requires file ***geo_nmm_nest.l01.nc*** and ***geo_nmm_nest.l02.nc***

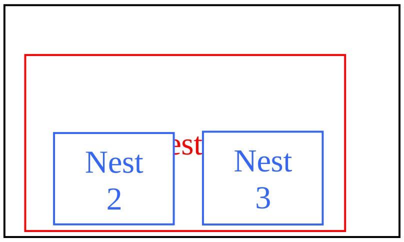


4. Three nests and two level of nesting

WPS: requires file ***geo_nmm_nest.l01.nc*** and ***geo_nmm_nest.l02.nc***



OR



After configuring the file ***namelist.input*** and placing the appropriate ***geo_nmm_nest**** file(s) in the proper directory(s), the WRF model can be run identically to the single domain runs described in Running wrf.exe.

Using Digital Filter Initialization

Digital filter initialization (DFI) is a new option in V3.2. It is a way to remove initial model imbalance as, for example, measured by the surface pressure tendency. This might be important when interested in the 0 – 6 hour simulation/forecast results. It runs a digital filter for a short model integration, backward and forward, and then starts the forecast. In the WRF implementation, this is all done in a single job. In the current release, DFI can only be used in a single domain run.

No special requirements are needed for data preparation. For a typical application, the following options are used in the ***namelist.input*** file:

dfi_opt = 3
dfi_nfilter = 7 (filter option: Dolph)
dfi_cutoff_seconds = 3600 (should not be longer than the filter window)

For time specification, it typically needs to integrate backward for 0.5 to 1 hour, and integrate forward for half of the time.

If option ***dfi_write_filtered_input*** is set to true, a filtered ***wrfinput*** file, ***wrfinput_initialized_d01***, will be produced.

If a different time step is used for DFI, one may use ***time_step_dfi*** to set it.

Using sst_update option

The WRF model physics does not predict sea-surface temperature, vegetation fraction, albedo and sea ice. For long simulations, the model provides an alternative to read in the time-varying data and update these fields. In order to use this option, one must have access to time-varying SST and sea ice fields. Twelve monthly values vegetation fraction and albedo are available from the ***geogrid*** program. Once these fields are processed via WPS, one may activate the following options in namelist record ***&time_control*** before running program ***real_nmm.exe*** and ***wrf.exe***:

sst_update = 1 in ***&physics***
io_form_auxinput4 = 2
auxinput4_inname = *"wrflowinp_d<domain>"* (created by ***real_nmm.exe***)
auxinput4_interval = 720,

Using IO Quilting

This option allows a few processors to be set alone to do output only. It can be useful and performance-friendly if the domain sizes are large, and/or the time taken to write a output time is getting significant when compared to the time taken to integrate the model in between the output times. There are two variables for setting the option:

nio_tasks_per_group: How many processors to use per IO group for IO quilting. Typically 1 or 2 processors should be sufficient for this purpose.

nio_groups: How many IO groups for IO. Default is 1.

Real Data Test Case: 2005 January 23/00 through 24/00

The steps described above can be tested on the real data set provided. The test data set is accessible from the WRF-NMM download page. Under "WRF Model Test Data", select the January data. This is a 55x91, 15-km domain centered over the eastern US.

- After running the ***real_nmm.exe*** program, the files ***wrfinput_d01*** and ***wrfbdy_d01***, should appear in the working directory. These files will be used by the WRF model.
- The ***wrf.exe*** program is executed next. This step should take a few minutes (only a 24 h forecast is requested in the ***namelist***),
- The output file ***wrfout_d01:2005-01-23_00:00:00*** should contain a 24 h forecast at 1 h intervals.

List of Fields in WRF-NMM Output

The following is edited output from the netCDF command '***ncdump'***:

```
ncdump -h wrfout_d01_yyyy_mm_dd-hh:mm:ss
```

An example:

```
netcdf wrfout_d01_2008-01-11_00:00:00 {

dimensions:
        Time = UNLIMITED ; // (1 currently)
        DateStrLen = 19 ;
        west_east = 19 ;
        south_north = 39 ;
        bottom_top = 27 ;
        bottom_top_stag = 28 ;
        soil_layers_stag = 4 ;
variables:
        char Times(Time, DateStrLen) ;
```

```
        float TOYVAR(Time, bottom_top, south_north, west_east) ;
        float LU_INDEX(Time, south_north, west_east) ;
        float HBM2(Time, south_north, west_east) ;
        float HBM3(Time, south_north, west_east) ;
        float VBM2(Time, south_north, west_east) ;
        float VBM3(Time, south_north, west_east) ;
        float SM(Time, south_north, west_east) ;
        float SICE(Time, south_north, west_east) ;
        float PD(Time, south_north, west_east) ;
        float FIS(Time, south_north, west_east) ;
        float RES(Time, south_north, west_east) ;
        float T(Time, bottom_top, south_north, west_east) ;
        float Q(Time, bottom_top, south_north, west_east) ;
        float U(Time, bottom_top, south_north, west_east) ;
        float V(Time, bottom_top, south_north, west_east) ;
        float DX_NMM(Time, south_north, west_east) ;
        float ETA1(Time, bottom_top_stag) ;
        float ETA2(Time, bottom_top_stag) ;
        float PDTOP(Time) ;
        float PT(Time) ;
        float PBLH(Time, south_north, west_east) ;
        float MIXHT(Time, south_north, west_east) ;
        float USTAR(Time, south_north, west_east) ;
        float Z0(Time, south_north, west_east) ;
        float THS(Time, south_north, west_east) ;
        float QS(Time, south_north, west_east) ;
        float TWBS(Time, south_north, west_east) ;
        float QWBS(Time, south_north, west_east) ;
        float TAUX(Time, south_north, west_east) ;
        float TAUY(Time, south_north, west_east) ;
        float PREC(Time, south_north, west_east) ;
        float APREC(Time, south_north, west_east) ;
        float ACPREC(Time, south_north, west_east) ;
        float CUPREC(Time, south_north, west_east) ;
        float LSPA(Time, south_north, west_east) ;
        float SNO(Time, south_north, west_east) ;
        float SI(Time, south_north, west_east) ;
        float CLDEFI(Time, south_north, west_east) ;
        float TH10(Time, south_north, west_east) ;
        float Q10(Time, south_north, west_east) ;
        float PSHLTR(Time, south_north, west_east) ;
        float TSHLTR(Time, south_north, west_east) ;
        float QSHLTR(Time, south_north, west_east) ;
        float Q2(Time, bottom_top, south_north, west_east) ;
        float AKHS_OUT(Time, south_north, west_east) ;
        float AKMS_OUT(Time, south_north, west_east) ;
```

```
float ALBASE(Time, south_north, west_east) ;
float ALBEDO(Time, south_north, west_east) ;
float CNVBOT(Time, south_north, west_east) ;
float CNVTOP(Time, south_north, west_east) ;
float CZEN(Time, south_north, west_east) ;
float CZMEAN(Time, south_north, west_east) ;
float EPSR(Time, south_north, west_east) ;
float GLAT(Time, south_north, west_east) ;
float GLON(Time, south_north, west_east) ;
float MXSNAL(Time, south_north, west_east) ;
float RADOT(Time, south_north, west_east) ;
float SIGT4(Time, south_north, west_east) ;
float TGROUND(Time, south_north, west_east) ;
float CWM(Time, bottom_top, south_north, west_east) ;
float RRW(Time, bottom_top, south_north, west_east) ;
float F_ICE(Time, bottom_top, south_north, west_east) ;
float F_RAIN(Time, bottom_top, south_north, west_east) ;
float F_RIMEF(Time, bottom_top, south_north, west_east) ;
float CLDFRA(Time, bottom_top, south_north, west_east) ;
float SR(Time, south_north, west_east) ;
float CFRACH(Time, south_north, west_east) ;
float CFRACL(Time, south_north, west_east) ;
float CFRACM(Time, south_north, west_east) ;
int ISLOPE(Time, south_north, west_east) ;
float DZSOIL(Time, bottom_top) ;
float SLDPTH(Time, bottom_top) ;
float CMC(Time, south_north, west_east) ;
float GRNFLX(Time, south_north, west_east) ;
float PCTSNO(Time, south_north, west_east) ;
float SOILTB(Time, south_north, west_east) ;
float VEGFRC(Time, south_north, west_east) ;
float SH2O(Time, soil_layers_stag, south_north, west_east) ;
float SMC(Time, soil_layers_stag, south_north, west_east) ;
float STC(Time, soil_layers_stag, south_north, west_east) ;
float HSTDV(Time, south_north, west_east) ;
float HCNVX(Time, south_north, west_east) ;
float HASYW(Time, south_north, west_east) ;
float HASYS(Time, south_north, west_east) ;
float HASYSW(Time, south_north, west_east) ;
float HASYNW(Time, south_north, west_east) ;
float HLENW(Time, south_north, west_east) ;
float HLENS(Time, south_north, west_east) ;
float HLENSW(Time, south_north, west_east) ;
float HLENNW(Time, south_north, west_east) ;
float HANGL(Time, south_north, west_east) ;
float HANIS(Time, south_north, west_east) ;
```

```
        float HSLOP(Time, south_north, west_east) ;
        float HZMAX(Time, south_north, west_east) ;
        float UGWDSFC(Time, south_north, west_east) ;
        float VGWDSFC(Time, south_north, west_east) ;
        float PINT(Time, bottom_top_stag, south_north, west_east) ;
        float W(Time, bottom_top_stag, south_north, west_east) ;
        float ACFRCV(Time, south_north, west_east) ;
        float ACFRST(Time, south_north, west_east) ;
        float SSROFF(Time, south_north, west_east) ;
        float BGROFF(Time, south_north, west_east) ;
        float RLWIN(Time, south_north, west_east) ;
        float RLWTOA(Time, south_north, west_east) ;
        float ALWIN(Time, south_north, west_east) ;
        float ALWOUT(Time, south_north, west_east) ;
        float ALWTOA(Time, south_north, west_east) ;
        float RSWIN(Time, south_north, west_east) ;
        float RSWINC(Time, south_north, west_east) ;
        float RSWOUT(Time, south_north, west_east) ;
        float ASWIN(Time, south_north, west_east) ;
        float ASWOUT(Time, south_north, west_east) ;
        float ASWTOA(Time, south_north, west_east) ;
        float SFCSHX(Time, south_north, west_east) ;
        float SFCLHX(Time, south_north, west_east) ;
        float SUBSHX(Time, south_north, west_east) ;
        float SNOPCX(Time, south_north, west_east) ;
        float SFCUVX(Time, south_north, west_east) ;
        float POTEVP(Time, south_north, west_east) ;
        float POTFLX(Time, south_north, west_east) ;
        float TLMIN(Time, south_north, west_east) ;
        float TLMAX(Time, south_north, west_east) ;
        float T02_MIN(Time, south_north, west_east) ;
        float T02_MAX(Time, south_north, west_east) ;
        float RH02_MIN(Time, south_north, west_east) ;
        float RH02_MAX(Time, south_north, west_east) ;
        int NCFRCV(Time, south_north, west_east) ;
        int NCFRST(Time, south_north, west_east) ;
        int NPHS0(Time) ;
        int NPREC(Time) ;
        int NCLOD(Time) ;
        int NHEAT(Time) ;
        int NRDLW(Time) ;
        int NRDSW(Time) ;
        int NSRFC(Time) ;
        float AVRAIN(Time) ;
        float AVCNVC(Time) ;
        float ACUTIM(Time) ;
```

```
float ARDLW(Time) ;
float ARDSW(Time) ;
float ASRFC(Time) ;
float APHTIM(Time) ;
float LANDMASK(Time, south_north, west_east) ;
float QVAPOR(Time, bottom_top, south_north, west_east) ;
float QCLOUD(Time, bottom_top, south_north, west_east) ;
float QRAIN(Time, bottom_top, south_north, west_east) ;
float QSNOW(Time, bottom_top, south_north, west_east) ;
float SMOIS(Time, soil_layers_stag, south_north, west_east) ;
float PSFC(Time, south_north, west_east) ;
float TH2(Time, south_north, west_east) ;
float U10(Time, south_north, west_east) ;
float V10(Time, south_north, west_east) ;
float LAI(Time, south_north, west_east) ;
float SMSTAV(Time, south_north, west_east) ;
float SMSTOT(Time, south_north, west_east) ;
float SFROFF(Time, south_north, west_east) ;
float UDROFF(Time, south_north, west_east) ;
int IVGTYP(Time, south_north, west_east) ;
int ISLTYP(Time, south_north, west_east) ;
float VEGFRA(Time, south_north, west_east) ;
float SFCEVP(Time, south_north, west_east) ;
float GRDFLX(Time, south_north, west_east) ;
float SFCEXC(Time, south_north, west_east) ;
float ACSNOW(Time, south_north, west_east) ;
float ACSNOM(Time, south_north, west_east) ;
float SNOW(Time, south_north, west_east) ;
float CANWAT(Time, south_north, west_east) ;
float SST(Time, south_north, west_east) ;
float WEASD(Time, south_north, west_east) ;
float NOAHRES(Time, south_north, west_east) ;
float THZ0(Time, south_north, west_east) ;
float QZ0(Time, south_north, west_east) ;
float UZ0(Time, south_north, west_east) ;
float VZ0(Time, south_north, west_east) ;
float QSFC(Time, south_north, west_east) ;
float HTOP(Time, south_north, west_east) ;
float HBOT(Time, south_north, west_east) ;
float HTOPD(Time, south_north, west_east) ;
float HBOTD(Time, south_north, west_east) ;
float HTOPS(Time, south_north, west_east) ;
float HBOTS(Time, south_north, west_east) ;
float CUPPT(Time, south_north, west_east) ;
float CPRATE(Time, south_north, west_east) ;
float SNOWH(Time, south_north, west_east) ;
```

```
        float SMFR3D(Time, soil_layers_stag, south_north, west_east) ;
        int ITIMESTEP(Time) ;
        float XTIME(Time) ;

// global attributes:
                :TITLE = " OUTPUT FROM WRF V3.1         MODEL" ;
                :START_DATE = "2008-01-11_00:00:00" ;
                :SIMULATION_START_DATE = "2008-01-11_00:00:00" ;
                :WEST-EAST_GRID_DIMENSION = 20 ;
                :SOUTH-NORTH_GRID_DIMENSION = 40 ;
                :BOTTOM-TOP_GRID_DIMENSION = 28 ;
                :GRIDTYPE = "E" ;
                :DIFF_OPT = 1 ;
                :KM_OPT = 1 ;
                :DAMP_OPT = 1 ;
                :KHDIF = 0.f ;
                :KVDIF = 0.f ;
                :MP_PHYSICS = 5 ;
                :RA_LW_PHYSICS = 99 ;
                :RA_SW_PHYSICS = 99 ;
                :SF_SFCLAY_PHYSICS = 2 ;
                :SF_SURFACE_PHYSICS = 2 ;
                :BL_PBL_PHYSICS = 2 ;
                :CU_PHYSICS = 2 ;
                :SURFACE_INPUT_SOURCE = 1 ;
                :SST_UPDATE = 0 ;
                :SF_URBAN_PHYSICS = 0 ;
                :FEEDBACK = 0 ;
                :SMOOTH_OPTION = 2 ;
                :SWRAD_SCAT = 1.f ;
                :W_DAMPING = 0 ;
                :WEST-EAST_PATCH_START_UNSTAG = 1 ;
                :WEST-EAST_PATCH_END_UNSTAG = 19 ;
                :WEST-EAST_PATCH_START_STAG = 1 ;
                :WEST-EAST_PATCH_END_STAG = 20 ;
                :SOUTH-NORTH_PATCH_START_UNSTAG = 1 ;
                :SOUTH-NORTH_PATCH_END_UNSTAG = 39 ;
                :SOUTH-NORTH_PATCH_START_STAG = 1 ;
                :SOUTH-NORTH_PATCH_END_STAG = 40 ;
                :BOTTOM-TOP_PATCH_START_UNSTAG = 1 ;
                :BOTTOM-TOP_PATCH_END_UNSTAG = 27 ;
                :BOTTOM-TOP_PATCH_START_STAG = 1 ;
                :BOTTOM-TOP_PATCH_END_STAG = 28 ;
                :DX = 0.289143f ;
                :DY = 0.287764f ;
                :DT = 90.f ;
```

```
:CEN_LAT = 32.f ;
:CEN_LON = -83.f ;
:TRUELAT1 = 1.e+20f ;
:TRUELAT2 = 1.e+20f ;
:MOAD_CEN_LAT = 0.f ;
:STAND_LON = 1.e+20f ;
:GMT = 0.f ;
:JULYR = 2008 ;
:JULDAY = 11 ;
:MAP_PROJ = 203 ;
:MMINLU = "USGS" ;
:NUM_LAND_CAT = 24 ;
:ISWATER = 16 ;
:ISLAKE = -1 ;
:ISICE = 24 ;
:ISURBAN = 1 ;
:ISOILWATER = 14 ;
:I_PARENT_START = 1 ;
:J_PARENT_START = 1 ;}
```

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