Description and Procedures for using the Pleim-Xiu LSM, ACM2 PBL and Pleim Surface Layer Scheme in WRF

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Contents:

Brief Description of Physics Schemes (from WRF Technical Description)

ACM2
The ACM2 (Pleim, 2007) is a combination of the ACM, which is a simple transilient model that was originally a modification of the Blackadar convective model, and an eddy diffusion model. Thus, in convective conditions the ACM2 can simulate rapid upward transport in buoyant plumes and local shear induced turbulent diffusion. The partitioning between the local and nonlocal transport components is derived from the fraction of non-local heat flux according to the model of Holtslag and Boville (1993). The algorithm transitions smoothly from eddy diffusion in stable conditions to the combined local and non-local transport in unstable conditions. The ACM2 is particularly well suited for consistent PBL transport of any atmospheric quantity including both meteorological (u, v, θ, q_v) and chemical trace species.

Pleim Surface Layer
The PX surface layer scheme (Pleim, 2006) was developed as part of the PX LSM but can be used with any LSM or PBL model. This scheme is based on similarity theory and includes parameterizations of a viscous sub-layer in the form of a quasi-laminar boundary layer resistance accounting for differences in the diffusivity of heat, water vapor, and trace chemical species. The surface layer similarity functions are estimated by analytical approximations from state variables.

Pleim-Xiu Land Surface Model
The PX LSM (Pleim and Xiu, 1995; Xiu and Pleim, 2001), originally based on the ISBA model Noilhan and Planton (1989), 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. The PX LSM features three pathways for moisture fluxes: evapotranspiration, soil evaporation, and

evaporation from wet canopies. Evapotranspiration is controlled by bulk stomatal resistance that is dependent on root zone soil moisture, photosynthetically active radiation, air temperature, and the relative humidity at the leaf surface. Grid aggregate vegetation and soil parameters are derived from fractional coverages of land use categories and soil texture types. There are two indirect nudging schemes that correct biases in 2-m air temperature and RH by dynamic adjustment of soil moisture (Pleim and Xiu, 2003) and deep soil temperature (Pleim and Gilliam, 2008). Note that a small utility program (IPXWRF) can be used to propagate soil moisture and temperature between consecutive runs to create a continuous simulation of these quantities.

Suggested Applications

- The P-X LSM and ACM2 planetary boundary layer physics were originally developed in MM5 for use with air quality models, in particular, the Community Multi-Scale Air Quality (CMAQ) model. The ACM2 PBL scheme is also used for the mixing in the CMAQ model, so using this scheme in WRF alone or the WRF-CMAQ coupled model results in consistent mixing of the meteorology scalars like water vapor and pollutants.
- P-X LSM was designed for retrospective meteorological applications not a real-time forecasting because of the indirect soil nudging scheme. The indirect soil nudging requires accurate 2-m temperature and water vapor mixing ratio analyses (not available in real-time forecasting unless forecasted fields are used). These are computed by blending point surface observations and forecast model initial conditions using the Obsgrid pre-processor.
- ACM2 PBL and Pleim surface layer schemes have been successfully used with other land surface models such as NOAH and RUC in a variety of applications from weather forecasting to wind energy. These will likely also work in climate applications, but not specifically tested by the developers.

Pros and Cons

- PRO: The central benefit of the P-X LSM lies in the indirect soil temperature and moisture nudging algorithm that significantly improves error and bias of near-surface meteorology as long as accurate 2-m temperature and moisture analyses are provided as input.
- PRO: Since the P-X LSM was designed for retrospective applications, snow cover is not a simulated quantity. Snow cover is an input from forecast initial condition analyses every 3 to 6 hours or from a high resolution 1 km snow analysis like the SNOw Data Assimilation System (SNODAS). This ensures very accurate snow cover, although it can introduce an inconsistency in some cases, namely, if the model atmosphere is producing snow when the analysis has none, or vice-versa.
- PRO: Landuse properties are computed using landuse fractional weighting, which provides more realistic values, especially at grid scale much greater than the landuse dataset resolution (~250 m for NLCD and ~1 km for MODIS and USGS).

- PRO: New datasets like the ~250m resolution NLCD landuse, impervious surface and canopy fraction have been created for the P-X LSM. These provide more detailed landuse fractional data at typical model grid scales and the impervious and canopy fraction are used for better urban modeling.
- PRO: Snow albedo was updated (WRFV3.7) to use fractional landuse data and landuse specific snow albedo to compute a weighted snow albedo for each grid cell. Many LSM's use the dominate landuse class or coarse satellite data to specify snow albedo. This provides a more realistic snow albedo that adapts to varying model resolutions.
- CON: Snow cover surface physics are quite simple. Fractional snow cover is determined by landuse-based snow depth thresholds similar to the NOAH LSM (SNUP variable in WRF LANDUSE tables), above which, the surface is considered 100% covered. Surface specific heat capacity is weighted by the percent covered by snow and no snow. This is much simpler than the multi-layer NOAH or RUC snow scheme that accumulated, melts, sublimates and packs snow with age. This limits the usage to retrospective simulations where snow cover is known and does not allow for uses such as snow forecasting or future climate scenarios.
- CON: Snow albedo and density are constant. Snow density impacts the specific heat capacity and aged snow decreases snow albedo. Researchers do have plans to track snow age so the snow albedo and density can be adjusted.
- CON: The 40 class NLCD dataset prepared specifically for the P-X LSM only covers North America, covering the area of NCEP's NAM-12 km analysis. Users with larger domains or domains in other parts of the world should use the 20 class MODIS landuse, or USGS which are also compatible with the P-X LSM. On the same topic area, the impervious surface and canopy fraction data only cover the CONUS.

Best Practices

- Unless testing proves otherwise use the ACM2 and Pleim surface layer schemes with the P-X LSM. The P-X LSM does operate with the YSU PBL and base surface layer, but has not been extensively tested by developers and the former combination has been extensively tested for years.
- Always use the indirect soil nudging option in the &fdda section of the WRF namelist.input (*pxlsm_soil_nudge =1*), unless one wants to do a sensitive as to the effectiveness of the soil nudging.
- Allow for a soil spin-up period of 5 to preferably 10 days before the study period. At the start of the spin-up use the namelist.input (see namelist suggestions below) option *pxlsm_smois_init = 1* to initialize the deep soil moisture. After the spin-up period, make sure *pxlsm_smois_init =0*. This allows the soil moisture to stabilize before the main period of interest.
- For the spin-up period, initialize the deep soil temperature as the average 2-m air temperature for 5 to preferably 10 days. This can be accomplished using the *IPXWRF* utility distributed by NCAR. This utility also allow the user to update a wrfinput_d0*

files soil temperature and moisture with a wrfout_d01* file for propagation of soil temperature and moisture from one run to the next.

- Use *Obsgrid* objective analysis tool to blend surface observations from the MADIS observations system and WPS metgrid files (*met_em**) to produce a 2-m temperature and moisture re-analysis on the users WRF domain. Obsgrid produces this file named *wrfsfdda_d0**. See namelist section below for more details on settings including QC levels and radius of influence for various grid scales.
- For fine-scale simulations, where model analyses used to derive the wrfsfdda_d0* file(s) have a much coarser resolution than the WRF domain, the P-X soil nudging may suffer. This was originally discovered when 12 km analyses were used in 1 km WRF simulations. The background analysis, even when blended with observations, does not have the geographically induced details needed for quality soil nudging. This is most apparent in areas with dramatic variability in topography or complex coastlines. Users, if resources allow, may try an iterative nudging approach where an initial WRF simulation's 2-m temperature is recycled back through the *Obsgrid* objective analysis as first-guess and then re-blended or bias adjusted using the surface observations. This provides a better analysis field for the P-X soil nudging that has been shown to in many cases significantly reduced model error and bias of near-surface meteorology.
- Using mesonet surface observations available in the MADIS system along with the standard National Weather Service observations can improve the soil nudging by providing a significant number of additional data points (well over 8000 extra across the United States) and an improved surface meteorological analysis.

Namelist(s) Options

namelist.input (WRF)

&physics

bl_pbl_physics	= 7,	ACM2 PBL
sf_sfclay_physics	= 7,	Pleim Sfc. Layer
sf_surface_physics	= 7,	Pleim-Xiu LSM
num_soil_layers	= 2,	P-X two soil layer configuration
pxlsm_smois_init	= 0,	Use 1 for initialization and 0 after 10 day soil spin-up

&fdda

pxlsm_soil_nudge	= 1,	P-X soil nudging (1) or no soil nudging (0)
grid_sfdda	= 1,	Tell WRF to open wrfsfdda_d0* file for P-X nudging
sgfdda_inname	= "wrfsfdda_d01",	P-X soil and surface layer nudging file (*Obsgrid*)
sgfdda_end_h	= 99999999,	End hour of nudging (large here to always nudge)
sgfdda_interval_m	= 180,	Interval of nudging fields (min) typically 180 or 360

guv_sfc	= 0.0000,	Set to zero to enable P-X soil nudging, but disable
gt_sfc	= 0.0000,	surface layer nudging of wind, temp and moisture.
gq_sfc	= 0.0000,	This is recommended for most applications.

namelist.oa (Obsgrid)

&record4		Suggested setting for QC checks
qc_test_error_max	= .TRUE.	
qc_test_buddy	= .TRUE.	
qc_test_vert_consistency	= .TRUE.	
qc_test_convective_adj	= .FALSE.	
max_error_t	= 8	
max_error_uv	= 4	
max_error_z	= 4	
max_error_rh	= 20	
max_error_p	= 600	
max_buddy_t	= 6	
max_buddy_uv	= 4	
max_buddy_z	= 4	
max_buddy_rh	= 20	
max_buddy_p	= 800	
buddy_weight	= 0.75	
max_p_extend_t	= 1300	
max_p_extend_w	= 1300	

&record7		
use_first_guess	= .TRUE.	Use supplied model analysis as first guess
f4d	= .TRUE.	Produce *wrfsdda_d01* file for P-X LSM nudging
intf4d	= 10800	Time interval of surface analysis (sec)

&record9		
oa_type	= 'Cressman'	Cressman objective analysis method of blending
radius_influence	= 20,15,10,5	12 km domain suggestion
radius_influence	= 40,30,20,10	4 km domain suggestion
radius_influence	= 60,45,30,15	1 km domain suggestion

namelist.ipxwrf (IPXWRF)

&FILENAMES		
file_wrfout_last	= 'wrfout_d01'	wrfout used to replace soil temp./moist. in wrfinput_d01
file_wrfin_next	= 'wrfinput_d01'	wrfinput to alter
file_wrffdda_next	= 'wrfsfdda_d01'	wrfsfdda used to calculate avg. 2-m air temperature for

```
                                              deep soil temperature initialization
do_msoil              = .FALSE.          Replace wrfinput SMOIS with that of wrfout above
do_tsoil              =  .FALSE.         Replace wrfinput TSLB with that of wrfout above
do_tsoildeep_from2m = .TRUE.             Replace TSLB layer 2 with avg. air temperature
avg_period_2m         = 10               Number of days to average air temperature
&END
```

New Features in WRFV3.7

Wetlands treatment:

In WRFV3.7 the treatment of wetland areas was changed. It was not a full-fledged wetlands model, but rather, a simple lower limit on layer two soil moisture. If a grid cell is 100% wetlands, the soil moisture is not allowed to drop below soil saturation. If a grid cell is 25% wetlands, the soil moisture is not allowed to fall below 0.25 * soil saturation of that grid cell. This approximates the impact of the fractional wetland of a grid cell on soil behavior.

Snow Albedo:

Rather than existing WRF methods for snow albedo (satellite or dominant landuse values) the P-X LSM was updated to leverage fractional landuse to calculated a weighted snow albedo. Each landuse class has a maximum snow albedo defined in the module_sf_pxlsm_data.F file. The fractional landuse weights these for grid cell value. This provides a much more detailed/textured albedo of snow surfaces. Since the landuse data is resolved down to ~250 m, this fractional weighting method works well at most grid scales, especially compared to the default coarse satellite data method.

High-Resolution NLCD Dataset:

Several new datasets were prepared for the PX-LSM and other land-surface models, although testing of other LSM's has been limited to a simple run test using the NOAH LSM. The first is a 9 second, ~250 m National Land Cover Dataset valid for 2011. This dataset is an update to the NLCD40 (40 class) data (valid 2006) made available to the community in WRFV3.4. The old 2006 dataset was aggregated to 30 sec (~900 m), so the new 2011 NLCD40 provides much more detail for fine scale modeling, especially LSM that leverage fractional landuse like the PX LSM and NOAH-MP. We've also provided a 2006 version of this dataset at 9 s resolution. Since the NLCD is only available for the CONUS, areas of Canada and Mexico are defined using the 20 class MODIS scheme. The dataset is not global; it covers NCEP's North American Model (NAM) 12 km area, so only applicable to regional modeling centered on the CONUS or more local fine-scale US modeling. See LANDUSE.TBL or VEGPARM.TBL for details on the landuse classes. The data can be used by geogrid with specification: *geog_data_res = 'nlcd2006_9s+9s'* or *geog_data_res = 'nlcd2011_9s+9s'*.

Impervious surface and Canopy Fraction:

Two other datasets derived from NLCD 2011 are impervious surface and tree canopy fraction. Both of these WPS-read datasets are also provided at 9 second/~250 m resolution. Impervious surface are manmade structures, primarily features such as parking lots, roads and roofs and can be leveraged by land surface models for urban adjustments. Canopy fraction is straightforward, the fraction of tree cover in any particular grid cell. WPS Geogrid table file has been updated so these data can easily be gridded to WRF domains within the WPS structure. The Pleim-Xiu LSM (others may follow) in WRFV3.7+ is capable of leveraging these data for improved urban modeling.

Impervious data is used to adjust the surface heat capacity with the assumption that most of these structures are concrete and pavement with high heat capacity. The fractional impervious area and vegetation area are used via weighting for a grid cell average heat capacity. Civil engineering data were used to derive an estimate the heat capacity for impervious surface with the major assumption of concrete of a certain thickness. This number is documented in the main PX LSM physics module (module_sf_pxlsm.F). The highly accurate canopy fraction is used to adjust the grid cell vegetation fraction and leaf area index, which were originally based on distinct minimum and maximum annual values for each landuse class. The canopy fraction essentially adds more detail to those parameters. If these data are not supplied through a user's geogrid file, when the WRFV3.7 real.exe is completed, the wrfinput_d0* file(s) will produce the arrays with zero values and have no impact on any PX LSM simulations. Users should check wrfinput_d* files in case a particular compiler initializes with no-zero values.

References

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