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Building and Running TDAAPS Models: Nudged WRF Hindcasts

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ABSTRACT

This work is a follow-on guide to running the Weather Research and Forecasting (WRF) model from Aur et al., (2018), *Building and Running TDAAPS Models: WRF Postdictions*. This guide details running WRF in a nudged configuration, where the u and v wind components, temperature, and moisture within a specified spatial and temporal window, are adjusted towards the observations, radiosonde observations in this case, using WRF's observation nudging technique. The primary modification to this methodology from Aur et al. (2018), is the use of the OBSGRID program to generate the nudging files and the updates to the *namelist.input* file. These steps, combined with those outlined in Aur et al. (2018), will generate a nudged WRF hindcast (or postdiction) simulation.

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1. OVERVIEW OF THE WRF MODEL SETUP

This section briefly describes the WRF model setup and the context for the nudging steps described in Section 2.

Using the Weather Research and Forecasting mode (WRF) version 3.9.1 (Skamarock et al. 2008), dynamically downscaled hindcasts were run for a domain encompassing the Source Physics Experiment (SPE) site. National Centers for Environmental Prediction North American Regional Reanalysis (NCEP NARR) is used as the initial and boundary conditions for both cases. The outermost domain (d01) is run at 6.25 km resolution for a 40 x 40 grid. The horizontal grid resolution for each concentric nest increases by five-fold, where the inner-most domain (d04) is run at 50 m resolution for a 111 x 151 grid (table 1). The simulations were run in a one-way nesting configuration.

Two sets of hindcasts were run for the SPE-2, -3, -5, and -6, which are referred to as the control and nudged cases. These cases are identical in their model setup except that radiosonde observations are assimilated into the nudged simulation. In the nudged simulation the u and v wind components, temperature, and moisture within a specified spatial and temporal window, are adjusted towards the radiosonde observations. Table 2 includes a list of the experiments and the corresponding radiosonde observation. Nudging is applied over a 5 km horizontal radius and an 80-minute time window. Nudging is strongest at the spatial and temporal location of the observation.

The physics and dynamics for these simulations are based on model configurations in Rai et al. (2017) and Talbot et al. (2012) (table 3). The mesoscale (d01 and d02) and microscale (d03 and d04) domains share the following in common: the WSM 6-class graupel scheme, the RRTMG shortwave and longwave radiation schemes used RRTMG, Noah-MP land-surface model, and the MYNN2 surface-layer. For the mesoscale domains, the MYNN 2.5 level TKE scheme is used for the boundary layer parameterization with Horizontal Smagorinsky first order closure, as recommended for real-data cases, and the Kain-Fritsch deep and shallow convection scheme. For the microscale domain, the simulations use the 1.5 order TKE closure (3D) for the eddy coefficient. More on the implementation of these parameterizations can be found in the WRF guide, Chapter 5 (NCAR, 2017), and the references therein.

Table 1-1. Experiment and observation date and times.

Experiment ID	Experiment date and time	Atmospheric observation date and time
2	10/25/2011 at 19:00Z	10/25/2011 at 18:50Z
3	07/24/2012 at 18:00Z	07/24/2012 at 17:49Z
5	04/26/2016 at 20:49Z	4/26/2016 at 19:30Z
6	10/12/2016 at 18:36Z	10/12/2016 at 17:36 and 19:32Z

Table 1-2. WRF model domain setup.

Model	Domain	nx x ny x nz	Dx (m)	Dt (s)
Mesoscale	D01	40 x 40 x 109	6250	36
Mesoscale	D02	61 x 61 x 109	1250	7.2
Microscale	D03	101 x 101 x 109	250	1.44
Microscale	D04	111 x 151 x 109	50	0.29

Table 1-3. WRF model physics and dynamics setup for the mesoscale and microscale domains.

Microphysics	WSM 6-class graupel scheme
Radiation	RRTMG
Surface-layer	MYNN2
Land Surface Model	Noah-MP
Mesoscale	
Planetary Boundary Layer	MYNN 2.5 level TKE scheme
	Horizontal Smagorinsky first order closure
Cumulus	Kain-Fritsch
Microscale	
	1.5 order TKE closure (3D)

2. OBSERVATION NUDGING PROCEDURE

This section details the steps that should be taken to run WRF in the observation nudging configuration. To avoid confusion, any steps listed by Arabic numeral, correspond to those in Aur et al. (2018), new steps outlined in this document are listed in Roman numerals. Briefly, the user will prepare the observations and run OBSGRID as in steps 19-22, edit the *namelist.input*, adding the *&fdda* section to the end of the file, copy the *OBS_DOMAIN* files to the WRF run directory, and proceed to run REAL and WRF as in steps 33 and 34. More details on the WRF nudging technique can be found in the WRF Observation Nudging Guide at http://www2.mmm.ucar.edu/wrf/users/wrfv3.1/How_to_run_obs_fdda.html.

I. Prepare the observations as in steps 19-22 and run OBSGRID. This should generate OBS_DOMAIN files for each domain ID. Note, in this configuration, the *metoa_em** files are no longer needed to run WRF.

II. Copy each *OBS_DOMAINnnn* file that contains the atmospheric observations, now on the model grid, over into the WRF run directory.

cp OBS_DOMAINnnn ../wrf_run_dir/

III. Once the *OBS_DOMAINnnn* files have been transferred to the run directory, rename the input files so that the first digit after "OBS_DOMAIN" is the domain ID, and the next two digits are the sequential order that the observations should be read into WRF. Since only one sounding is being incorporated, and there are four nudged domains in this work, the input files would be *OBS_DOMAIN101, OBS_DOMAIN201, OBS_DOMAIN301,* and *OBS_DOMAIN401.*

mv OBS_DOMAINnnn OBS_DOMAIN101

IV. Observation nudging is activated through updating the obs_nudge_opt flag(s) in the *namelist.input*.

a. Add the following to the &time_control section of the *namelist.input*:

```
auxinput11_interval   = 1, 1, 1, 1,
auxinput11_end_h      = 99999, 99999, 99999, 99999,
```

b. Add the following to the end of the *namelist.input*:

```
&fdda
obs_nudge_opt      = 1,1,1,1,0
max_obs            = 150000,
fdda_start         =    0.,    0.,    0.,    0.,    0.
fdda_end           = 99999., 99999., 99999., 99999., 99999.
obs_nudge_wind     = 1,1,1,1,1
obs_coef_wind      = 6.E-3,6.E-3,6.E-3,6.E-3,6.E-3
obs_nudge_temp     = 1,1,1,1,1
obs_coef_temp      = 6.E-3,6.E-3,6.E-3,6.E-3,6.E-3
obs_nudge_mois     = 1,1,1,1,1
obs_coef_mois      = 6.E-3,6.E-3,6.E-3,6.E-3,6.E-3
obs_rinxy          = 125.,25.,5.,5.,180
obs_rinsig         = 0.1,
```

```
obs_twindo        = 0.667,0.667,0.667,0.667,
obs_npfi          = 10,
obs_ionf          = 2, 2, 2, 2, 2,
obs_idynin        = 0,
obs_dtramp        = 40.,
obs_prt_freq      = 10, 10, 10, 10, 10,
obs_prt_max       = 10
obs_ipf_errob     = .true.
obs_ipf_nudob     = .true.
obs_ipf_in4dob    = .true.
obs_ipf_init      = .true.
```

More details and the descriptions for these fields can be found in the WRF User's guide, but briefly, the *obs_nudge_opt* turns observation nudging on or off depending on the user setting, 0 = off, 1 = on, *obs_nudge_** is used to indicate whether or not observation nudging is on for that variable and the corresponding *obs_coef_** is the nudging coefficient for that variable, *obs_rinxy* is the spatial radius of influence, and *obs_twindo* is the half temporal range of influence in hours.

V. Skip steps 31 and 32, as the *metoa_em** files are no longer needed to run real and WRF. Follow steps 33 and 34 to complete the simulation and run real and WRF.

3. RECOMMENDATIONS FOR MODEL EVALUATION

This section outlines two recommendations to verify that observation nudging was applied to the simulation and to compare the observations and model output to determine whether the influence of nudging is sufficient or requires additional iterations of model evaluation.

To verify that the nudged simulation results are different from the control simulation, run the above steps for a single domain case without nudging applied (a control) and with nudging applied. This should be computationally inexpensive and complete rather quickly if the domain isn't too large and timestep isn't too small. Once this is complete, use the *diffwrf* executable to compare the two files. Pick a timestep that should be within the window of observation nudging.

./diffwrf wrfout_control wrfout_nudged

If the nudged simulation is indeed different, diffwrf will indicate the number of different points within the output files for each of the model variables. An example of a successful observation nuding simulation output and the subsequent *diffwrf* output is listed below:

```
Diffing /path_to_file/wrfout_control /path_to_file/wrfout_nudged
 Next Time 2016-10-12_20:10:00
    Field   Ndifs    Dims       RMS (1)            RMS (2)      DIGITS    RMSE      pntwise max
       U   1814735    3   0.1505586489E+02   0.1505575912E+02   5   0.2683E+00   0.2164E+00
       V   1810437    3   0.8408531820E+01   0.8408546705E+01   5   0.2878E+00   0.5741E+00
       W   1814999    3   0.2524566893E+00   0.2622701872E+00   1   0.2600E+00   0.1281E+01
      PH   1798223    3   0.2781388720E+04   0.2781230176E+04   4   0.2687E+01   0.5872E-02
      QVAPOR   1797896    3   0.1317140196E-02   0.1316602523E-02   3   0.6353E-04   0.3091E+00
      QICE    318669    3   0.8084237592E-05   0.8075070126E-05   2   0.2982E-06   0.9148E-01
```

Additionally, WRF output can be validated by directly comparing the model output to the observations for both the control and nudged simulations. This is similar to step 37 in Aur et al. (2018). This step is summarized below.

Using MATLAB or NCL, find the nearest point in the model domain to the observation. NCL contains a function wrf_user_ll_to_ij that can provide the model location that corresponds to the input latitude and longitude. Using MATLAB or NCL, generate a line or scatter plot of the radiosonde variables and the output from the WRF simulation. Depending on how well the model and observations agree, determine whether or not to adjust the *namelist.input* nudging options to bring the simulation results closer to the observations. Figure 3-1 is an example of model-observation comparison for the lower 4 km between the nudged and control simulations. From these simulations, surface temperature is approximately 2 to 3 degrees C cooler than the observation in both the control and nudged simulation. In order to nudge the model temperature closer to observations, run WRF again, this time adjusting *obs_coef_temp*.

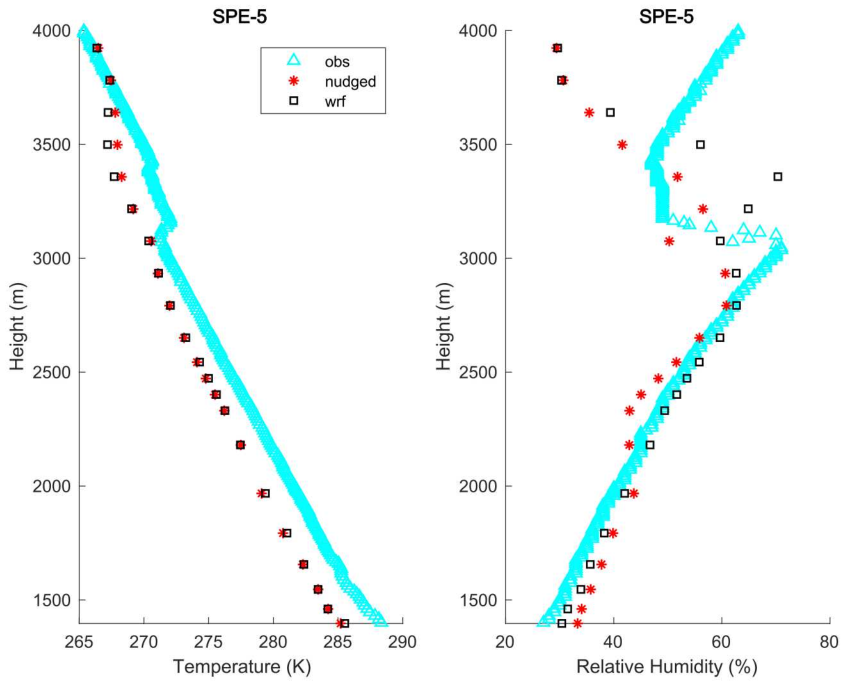

Figure 3-1. Comparison of control and nudged simulations for SPE-5 and the radiosonde profiles of temperature (left) and relative humidity (right). Observations are shown by the blue triangle, the nudged simulation output is shown in the red stars, and the control simulation is shown in the black squares.

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