Assignment #4: Lateral Boundary Condition Resolution Sensitivity

Due: 26 October 2017

Objectives

In this assignment, we use the WRF-ARW model to run two nearly-identical simulations in which only the resolution of the lateral boundary condition varies to quantify, for this case, the extent to which how well features are resolved on the lateral boundaries influences the model solution on the interior of the simulation domain. This assignment is also designed to give you experience in configuring and running a state-of-the-art numerical model as well as with posing and testing robust hypotheses related to how numerical model configuration variation influences the forecast. We will use *comet* to do so.

Helpful Resources

WPS User's Guide:
http://www2.mmm.ucar.edu/wrf/users/docs/user_guide_V3.9/users_guide_chap3.htm

WRF User's Guide:
http://www2.mmm.ucar.edu/wrf/users/docs/user_guide_V3.9/users_guide_chap5.htm

ARWpost User's Guide:
http://www2.mmm.ucar.edu/wrf/users/docs/user_guide_V3.9/users_guide_chap9.htm#_ARWpost_3

Simulation Information: Domain Configuration

Your first model simulation uses 0.25° GFS analysis and forecast data to provide initial and lateral boundary conditions for a simulation over the conterminous United States.

- **Duration**: 72 h (0000 UTC 19 September 2017 to 0000 UTC 22 September 2017)
- **Lateral Boundary Data Frequency**: 6 h (21,600 s)
- **Domain Size (E-W x N-S x levels)**: 240 x 150 x 30
- **Horizontal Grid Spacing**: 20 km (20,000 m)
- **Map Information**: usgs_lakes+2m geographic data; Lambert conic map projection, center point of 38.0°N, 97.0°W; secant latitudes: 30.0°N and 60.0°N, standard longitude: 97.0°W.

1. (4 pts) Edit namelist.wps in your WPS directory to account for the information above. Include a printout of this file with your assignment. Run geogrid.exe for this domain and include a screen capture of the output from doing so with your assignment. Use ncl and the plotgrids_new.ncl script in the util subdirectory to create a plot of the model domain, and

include a copy of this plot with your assignment.

2. (4 pts) The 0000 UTC 19 September 2017 GFS model analysis and forecast provides the initial and lateral boundary conditions for your simulations. This requires linking the GFS model data files and linking the GFS variable table to your WPS directory before running ungrib.exe for this simulation.

   The necessary GFS model data files are available in /home/evans36/WRF/grib/hw4. You will want to link over *only* the files named gfs.t00z.pgrb2.0p25.*; you do not want to also link the files named gfs.t00z.pgrb2.1p00.* at this time. The link_grib.csh program in your WPS directory is used to link over files to your WPS directory, i.e.,

   ./link_grib.csh /path/to/data/files

   where /path/to/data/files is replaced by the full path to the desired data. At the end of this path should be a unique identifier for all of the files in that directory that you wish to link.

   The GFS variable table is given by a file named Vtable.GFS in the ungrib/Variable_Tables/ subdirectory of your WPS directory. It must be linked over to a file called Vtable in your WPS directory. You can create this link with ln -sf, i.e,

   ln -sf /path/to/file/to/link linkname

   where /path/to/file/to/link is the path to the file to be linked and linkname is what you wish to name this file (in your current directory).

   Complete these two steps, then run ungrib.exe. After ungrib.exe completes, run ls -al in your WPS directory. Include a screen capture of the resulting output with your assignment.

3. (4 pts) Unlike for the Tutorial case, and unlike for geogrid.exe and ungrib.exe above, we do not wish to run metgrid.exe directly. Instead, we wish to use a job submission script, as we did for real.exe and wrf.exe for the Tutorial, to do so. A template submission script is available as metgrid.sbatch in /home/evans36/WRF/WPS. Copy it to your WPS directory, then submit it to the job scheduler as you did for real and wrf during the Tutorial. Once the job successfully completes, run ls -al in your WPS directory. Include a screen capture of the resulting output with your assignment.

Simulation Information: Model Configuration

Note: all WRF-related tasks should be done in the WRF_run directory you created for Assignment 1. You will need the information below and from the domain configuration section when updating *your namelist for the model simulation you will conduct.*

- **History Interval**: 3 h (180 min)
- **Time Step**: 6 * Δ*x*, where Δ*x* is in km
- **num_metgrid_levels**: 32
- **Physics Suite**: the standard CONUS suite, without any overriding of the physics options
- **Physics Time Steps**: 0 for boundary layer, equal to Δ*x* (in km) for radiation and convection
- **num_land_cat**: 28
- **Gravity Wave Drag Option**: off (0)

4. (4 pts) Edit namelist.input to account for the information in both the domain and model configuration sections. Include a printout of this file with your assignment.

5. (4 pts) Link over the met_em.d01* files from your WPS directory. Submit the submission script for real.exe. Once this completes successfully – the timestamps on the wrfbdy_d01 and wrfinput_d01 files should be in the present (note that *comet* uses Pacific, not Central, time), which you can check with ls -al – submit the submission script for wrf.exe.

   Successful completion will create a new wrfout_d01_2017-09-19_00:00:00 file. Rename this to wrfout_0p25_2017-09-19_00:00:00 using mv:

   mv oldfile newfile

   Once this is done, use ls -al to list the contents of the directory. Include a screen capture of the output with your assignment.

   Note: delete the rsl.error. and rsl.out.* files before each of the steps above. If something goes wrong, you can look inside rsl.error.0000 (e.g., using nano) to debug the error(s).*

At this point, you have completed your first, or control, simulation.

Configuring and Running the Perturbed Simulation

Your second simulation uses 0.25° GFS model data for initial conditions and 1.0° GFS model data for lateral boundary conditions. Note that the 1.0° data are from the same model run as the 0.25° data – they have only been coarsened after the model runs to the lower resolution. Thus, the only difference between this and your control simulation is the resolution of the lateral boundary data.

6. (4 pts) Return to your WPS directory. Edit prefix (under &ungrib) in namelist.wps so that it reads 'ONEDEG'. Once done, repeat Question 2 except for the gfs.t00z.pgrb2.1p00.*

data. After running ungrib.exe, run ls -al in the WPS directory and include a screen capture of the output with your assignment.

7. (4 pts) Edit fg_name (under &metgrid) in namelist.wps so that it reads 'FILE','ONEDEG'. In your WPS directory, remove all FILE:* entries *except* for 2017-09-19_00. Remove only the ONEDEG entry at 2017-09-19_00. Once done, repeat Question 3. After the scheduled metgrid job completes, run ls -al in the WPS directory and include a screen capture of the output with your assignment.

8. (4 pts) Repeat Question 5, except rename the resulting wrfout_d01_2017-09-19_00:00:00 file to wrfout_1p00_2017-09-10_00:00:00. Again, once done, use ls -al to list the contents of the directory and include a screen capture of the output with your assignment.

At this point, you have completed your second simulation. We now wish to post-process and view the output using ARWpost and GrADS.

Post-Processing Simulation Output

Note: the following questions use ARWpost and GrADS to post-process and visualize the output from both model simulations. Other tools exist to post-process and/or visualize model output, but we focus here on these tools given their comparative ease of use and sufficiency for this evaluation. ARWpost converts model data from the staggered model to a single output grid; it also allows for selected derived parameters to be computed. GrADS can read and visualize ARWpost output.

9. (4 pts) Return to the directory in which the WPS and WRFV3 directories are located. The ARWpost source code may be downloaded from:

   http://www2.mmm.ucar.edu/wrf/src/ARWpost_V3.tar.gz

   I recommend using wget to download this file straight to *comet*. Once downloaded, unpack it (with tar -zxvf or gunzip and tar -xvf) and change into the resulting ARWpost directory. Run the configure script, choosing option 2 (Intel compiler). Next, edit Makefile in the src subdirectory, revising line 19 so that it also includes -lnetcdff at its end. Once done, return to the main ARWpost directory and run the compile script. Once done, use ls -al to list the contents of the directory and include a screen capture of the output with your assignment.

10. (7 pts) Output parameters are specified in the namelist.ARWpost file. Use the following information to guide your edits to this file:

- **Start and End Dates**: Same as for your model simulation.
- **Output Interval**: Same as the history interval for your model simulation.

- **Input File Name**: The full path to *one* of your model output (wrfout) files.
- **Output File Name**: The full path to where you want your post-processed model data saved. This should be directed to your scratch directory, which should be one directory level up from your WRF_run directory in which the wrfout files reside. Include a unique filename prefix (i.e., without file extension) at the end of the desired output filename.
- **Output Variables**: Only the following list (case-sensitive) – U, V, W, T2, U10, V10, RAINC, RAINNC, QVAPOR, height, tc, td, td2, rh, slp.
- **Interpolation Method**: To pressure (isobaric) surfaces.
- **Interpolation Levels**: 1000-900 hPa, every 20 hPa; 900-800 hPa, every 25 hPa; 800-100 hPa, every 50 hPa.

As with metgrid, real, and wrf, we do not run ARWpost directly but instead submit it using a job submission script. A template submission script is available in the /home/evans36/WRF/ARWpost directory as ARWpost.sbatch. Copy this file to your ARWpost directory and submit it with sbatch. Once done, edit namelist.ARWpost for your second model simulation and run ARWpost as for the first simulation. Include a copy of the final namelist.ARWpost file with your assignment. Change into the directory where you directed ARWpost to save its output. Run ls -al in this directory and include a screen capture of the output with your assignment.

Visualizing Simulation Output

To make GrADS available to you on *comet*, you must load the GrADS module. To do so, issue the following command:

module load grads

As with the module statements in Assignment 1, I recommend that you add this to your ~/.bashrc file. Once you do so, log off of and then back onto *comet*. Doing so will make GrADS available to you on each log in without having to manually load its module.

The GrADS Tutorial provides a general introduction to using GrADS:

http://cola.gmu.edu/grads/gadoc/tutorial.html

I recommend that you complete it prior to using GrADS to visualize your model output. Note that you can use wget to download the tutorial sample data straight to *comet*, as we've done elsewhere in this and earlier assignments.

Although not discussed in the Tutorial, GrADS can save images to files using gxprint:

gxprint filename.<ext> x#### y####

where filename can be replaced by what you wish to call the file, <ext> is replaced by one of eps, ps, pdf, png, gif, or jpg (png is recommended), and x#### and y#### specify the output file size (e.g., x1280 y1024 will save a 1280x1024 image).

High-resolution geographic data, including state borders, can be specified with:

set mpdset hires

And a white, rather than black, display background can be specified with:

set display color white
clear

For reference, the full GrADS documentation index is available at:

http://cola.gmu.edu/grads/gadoc/gadocindex.html

11. (7 pts) In GrADS, open the control file describing the output from your first simulation. Set the display color to white, clear the screen, and specify high-resolution geographic data. Create a plot valid at the model initialization time that contains three elements:

- **Color Shaded**: 300 hPa wind speed (m s^{-1})
- **Black Contoured Every 60 m**: 500 hPa height (note that height from ARWpost is in km)
- **White Vectors**: 300 hPa wind (m s^{-1})

You should display fields in that order. Include a color bar to provide a legend for your shaded field; you can do so by running the cbar.gs script in the ARWpost/scripts/ directory. You should display only every 10^{th} wind vector, which can be done with skip, e.g.,

d skip(u,10,10);skip(v,10,10)

Describe the meteorological pattern (e.g., the positions, horizontal scales, and intensities of troughs, ridges, and jet streaks, particularly near the domain boundaries) indicated by the plot you have created. Save the plot to a file and include the file with your assignment.

12. (10 pts) Repeat Question 11, except at 0000 UTC 20 September, 0000 UTC 21 September, and 0000 UTC 22 September. Take care to specify the shading levels for the 300 hPa wind speed so that they are identical to those in your plot from Question 11, as GrADS will not

do this automatically for you. Discuss the evolution of the meteorological pattern during the simulation period. Save each plot to files and include each with your assignment.

13. (10 pts) While still in GrADS with the control file describing the output from your first simulation open, open the control file describing the output from your second simulation. Variables from this file can be referred to by appending a .2 at the end of their name; e.g.,

    d u.2 (displays the *u*-wind from the second opened file)

    Create a plot valid at 0000 UTC 22 September containing the following elements:

- **Color Shading**: 300 hPa wind speed from the first simulation minus 300 hPa wind speed from the second simulation (m s^{-1}; include a color bar)
- **Black Contours every 1 m s^{-1}**: 300 hPa wind speed from the first simulation

Focus on the jet streak along the western lateral boundary, a few hundred kilometers west of Los Angeles. Describe how the representation of this feature varies between the first and second model simulations. How does the magnitude of the difference between simulations at this location and time compare to the examples from class and the course text? What do you believe could contribute to this? Include a copy of your plot with your assignment.

14. (10 pts) Create a plot valid at 0600 UTC 20 September containing the following elements:

- **Color Shading**: 300 hPa wind speed from the first simulation minus 300 hPa wind speed from the second simulation (m s^{-1}; include a color bar)
- **Black Contours at 5, 15, 25, and 50 mm**: 3-h accumulated precipitation from the first simulation (note that RAINC+RAINNC is the accumulated precipitation to a given time, not since the last model output time)

Where do you see the largest 300 hPa wind speed differences between the two simulations? How well does this correspond to the 3-h accumulated precipitation forecast? From your understanding of atmospheric dynamics, why do you believe the correspondence exists (or does not exist, as the case may be)? What, if anything, does the existence of the 300 hPa wind speed differences say about how well precipitation and deep, moist convection can be predicted, given the differences in how the model simulations are configured? Include a copy of your plot with your assignment.

15. (10 pts) Create a plot valid at 1800 UTC 20 September containing the following elements:

- **Color Shading every 4 hPa**: sea level pressure from the first simulation (include a color bar)

- **Black Contours at ±1, 2, 3, 4, 5 hPa**: sea level pressure from the first simulation minus sea level pressure from the second simulation

Where do you see the largest sea level pressure differences between the two simulations? Of what sign are these differences? Discuss the potential role of lateral boundary data resolution on the forecast differences at this time indicated by the analysis. Include a copy of your plot with your assignment.

16. (10 pts) Taking into consideration the analyses conducted in Questions 13-15, as well as any you might conduct on your own to further assess differences between the simulations, describe the overall nature (e.g., magnitude, scale, persistence, etc.) of forecast differences between the two simulations. Does varying lateral boundary data resolution have a small, medium, or large forecast impact? Justify your answer. For a small impact, hypothesize why the impact is not larger. For a large impact, hypothesize why the impact is relatively large.