Assignment #5: Cumulus Parameterization Sensitivity

Due: 14 November 2017

Objectives

In this assignment, we use the WRF-ARW model to run two nearly-identical simulations in which only the cumulus parameterization varies to quantify, for this case, the extent to which varying the treatment of both deep and shallow cumulus clouds influences a three-day forecast over a tropical to subtropical model domain. This assignment is also designed to give you additional 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. As in the most recent assignment, we will use *comet* for this task.

A Preliminary Task

To complete the analysis portions of this assignment, we must modify the WRF-ARW model code so that it outputs four variables that are computed by but not typically output from the model. This involves modifying the WRF-ARW Registry, which documents all model variables and their input and output characteristics.

1. (5 pts) On *comet*, change into the Registry subdirectory of your WRFV3 directory. Open Registry.EM_COMMON with a text editor. Search (in nano, using Ctrl-W) for the entries for h_diabatic and qv_diabatic. Change the eighth column for each variable so that it reads rhdu. Search for the entries for RTHCUTEN and RQVCUTEN. Change the eighth column for each variable so that it reads rh. Save the file, then exit the text editor and return to your WRFV3 directory. Clean the earlier code installation by running ./clean -a. Recompile the model following the steps from Assignment 1. Once this completes successfully, change into the test/em_real/ subdirectory and copy its contents to your WRF_run directory. After doing so, change into the WRF_run directory, use ls -al to list its contents, and include a screen capture with your completed assignment.

Simulation Information: Domain and Model Configuration

Both model simulations use the same 0.25° GFS analysis and forecast data as in Assignment 4 to specify the initial and lateral boundary conditions.

- **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)**: 200 x 200 x 30
- **Horizontal Grid Spacing**: 20 km (20,000 m)

- **Map Information**: usgs_lakes+2m geographic data; Mercator map projection, center point of 25.0°N, 75.0°W; tangent latitude: 0.0°N, standard longitude: 97.0°W.
- **History Interval**: 3 h (180 min)
- **Time Step**: 5 * Δx, where Δx is in km
- **num_metgrid_levels**: 32
- **Physics Suite**: the standard CONUS suite for simulation #2 and the standard CONUS suite with a new cu_physics = 1, -1, -1, entry for simulation #1. The standard CONUS suite uses the Tiedtke cumulus parameterization, whereas cu_physics = 1 specifies the Kain-Fritsch cumulus parameterization. Both are low-level control parameterizations that parameterize both deep and shallow cumulus clouds but differ in how they determine if, when, and where both types of clouds exist (e.g., in their trigger functions).
- **Physics Time Steps**: 0 for boundary layer, equal to Δx (in km) for radiation and convection
- **num_land_cat**: 28
- **Gravity Wave Drag Option**: off (0)

2. (5 pts) Edit namelist.wps in your WPS directory and namelist.input in your WRF_run directory to account for this information. Include copies of each file with your assignment. Use plotgrids_new.ncl in the WPS/util/ subdirectory to create a plot of the model domain, and include a copy of this plot with your assignment.

3. (5 pts) Complete and run both simulations. This includes running geogrid.exe, ungrib.exe, metgrid.exe, real.exe, and wrf.exe (the latter three all by job submission script), as you did for Assignment 4. Rename the output from your first simulation as wrfout_kf_2017-09-19_00:00:00 before running the second simulation. Rename the output from your second simulation as wrfout_tiedtke_2017-09-19_00:00:00. After both simulations are complete, run ls -al in your WRF_run directory and include a screen capture of the output with your assignment.

4. (5 pts) As in Assignment 4, use ARWpost to post-process both simulations. The ARWpost namelist is configured similarly to in Assignment 4, except the output variable list should have H_DIABATIC, QV_DIABATIC, RTHCUTEN, RQVCUTEN, and QVAPOR added before post-processing each 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.

Simulation Analysis and Diagnosis

As in Assignment 4, we will use GrADS to visualize the post-processed model output to be able to gain insight into forecast sensitivity to the chosen cumulus parameterization.

5. (16 pts) Create plots, every 3 h from 0300 UTC 19 September to 0300 UTC 20 September, of the difference (Kain-Fritsch minus Tiedtke) in 700 hPa temperature (contours at ±4, 3, 2, and 1°C). Title each plot with the time of the analysis, and include each with your assignment. In the analysis to come, focus on three regions:

- within +/- 5° of tropical cyclones Jose (35.2°N, 71.3°W) and Maria (15.5°N, 61.4°W)
- over the western Atlantic Ocean between, but more than 5° away from, Jose and Maria
- over the southeastern United States excluding the Florida peninsula

Describe the sign, magnitude, and temporal variation in the 700 hPa temperature difference in each area. In particular, discuss similarities and differences, and advance a physically-based hypothesis as to why they exist, in the temporal variation between the second and third regions listed above.

6. (16 pts) Create three time-height cross-sections, each as separate images, from 0300 UTC 19 September to 0000 UTC 22 September between 1000-300 hPa (with a logarithmic vertical axis):

- area-averaged (between 30-35°N, 89-81°W; over the southeast United States) temperature difference (Kain-Fritsch minus Tiedtke; contours at ±2.5, 2, 1.5, 1, and 0.5°C)
- area-averaged (again between 30-35°N, 89-81°W) difference (Kain-Fritsch minus Tiedtke) in the potential temperature tendency due to the cumulus parameterization (RTHCUTEN, which is in K s^{-1}; plot with contours at ±5, 4, 3, 2, and 1 K day^{-1})
- area-averaged (again between 30-35°N, 89-81°W) difference (Kain-Fritsch minus Tiedtke) in the water vapor mixing ratio tendency due to the cumulus parameterization (RQVCUTEN, which is in g g^{-1} s^{-1}; plot with contours at ±3, 2, and 1 g kg^{-1} day^{-1})

Title each image appropriately and include copies with your assignment. Discuss the sign/magnitude, vertical structure, and temporal evolution of the differences indicated by each plot. Given the altitude(s) at which they are predominantly found, do you believe each to result primarily from shallow or deep cumulus parameterization? Why? Given this answer and what you know about the physical role(s) of shallow or deep cumulus in the atmosphere, hypothesize as to what physical process(es) are parameterized differently between the Kain-Fritsch and Tiedtke parameterizations to result in these differences.

Note: ARWpost post-processes the longitude information for Mercator projections relative to °E, such that 90°W = 270°E and 60°W = 300°E. Further, as the requested plot varies in the z and t dimensions, the x and y dimensions must be fixed to a single x-y/lon-lat point to create the desired plot. It does not matter which single point is chosen.

7. (16 pts) Create the same three plots as in the previous question, except for the area-average between 27-33°N, 75-65°W, or over the western Atlantic Ocean, between 1200 UTC 19 September and 0000 UTC 22 September. Title each image appropriately and include copies with your assignment. Describe how the altitude(s) of and temporal variability in the differences vary between in this analysis and that in the previous question. Hypothesize as to physically why the altitude(s) and temporal variability varies between over land in the previous question and over water in this question.

8. (16 pts) Create a plot at 0600 UTC 19 September of the 1000-100 hPa (with a logarithmic vertical axis), area-averaged (between 14.25-17.25°N, 63-59.5°W; centered on tropical cyclone Maria) potential temperature tendency due to the cumulus parameterization (RTHCUTEN; convert from K s^{-1} to K day^{-1}) for the Kain-Fritsch simulation (default black line) and Tiedtke simulation (default green line). Title the plot appropriately and include a copy with your assignment.

   Discuss similarities and differences in the vertical structure of this diabatic heating term between the two simulations. As both parameterizations trigger deep, moist convection in an attempt to locally eliminate CAPE over a specified time interval, based on this analysis which parameterization will be more effective at doing so – whether physically or non-physically – over a short time interval? Why?

   Tropical cyclone intensification is theorized to result from surface latent heat fluxes, with deep, moist convection acting as a conduit for lofting this heat, which is released primarily upon condensation, into the middle to upper troposphere. If the diabatic heating profiles at this time are representative of those at other times, in which simulation do you believe the simulated Maria will become the strongest? Why? Create a plot of sea level pressure from each simulation (contours every 4 hPa; Kain-Fritsch in rainbow colors, Tiedtke in blacks) at 0000 UTC 22 September over the domain 15-27°N, 77-62°W. Title this image appropriately and include a copy with your assignment. Does this plot support your answer? If not, hypothesize why.

9. (16 pts) To first order, tropical cyclones are steered by the synoptic-scale wind averaged between the lower and middle/upper troposphere (e.g., 850-300 hPa). Consider the area-averaged, time-height cross-section of temperature difference that you created in Question 6. From this analysis, would you expect the area-averaged horizontal wind in the 850-300 hPa layer to be more anticyclonic, more cyclonic, or about the same in the Kain-Fritsch simulation versus the Tiedtke simulation? Why?

   Create a plot at 0000 UTC 22 September of vertically-averaged (from 850-300 hPa) horizontal wind difference (Kain-Fritsch minus Tiedtke; barbs every fifth grid point in kt, noting that u and v are provided in m s-1) between 24-33°N, 80-60°W. Title this image appropriately and include a copy with your assignment. What does this analysis indicate? Does it support your original answer? Consider again the sea level pressure analysis at 0000 UTC 22 September from the previous question. Given your answers to this question, discuss why the simulated Maria position differences exist between the two simulations.