UNCA Undergraduate Research

Convection and Numerical Modeling

Submitted by
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Knowing exactly where and how hard a hurricane will strike is a goal many researchers are trying to achieve through numerical modeling. My research deals with the Weather Research and Forecasting (WRF) model and its output characteristics with simulations of Hurricane Charley that struck the Florida coast in August of 2004. More specifically, I dealt with the WRF model's convective scheme: the Kain-Fritsch (K-F) convective parameterization (Kain and Fritsch, 1993). My purpose in this research was to study the triggering mechanisms of convection and its impact on the development of hurricane Charley by running a simulation of Charley through the WRF model and changing several variables within the parameterization. In addition, I looked at how Charley's intensity, track and precipitation distribution were affected by changes in how convection is triggered. Finally, testing how sensitive Charley's intensity, track and precipitation distribution were to my changes in the convective trigger mechanism was important in hypothesizing the best trigger mechanism for a more accurate method of predicting convection

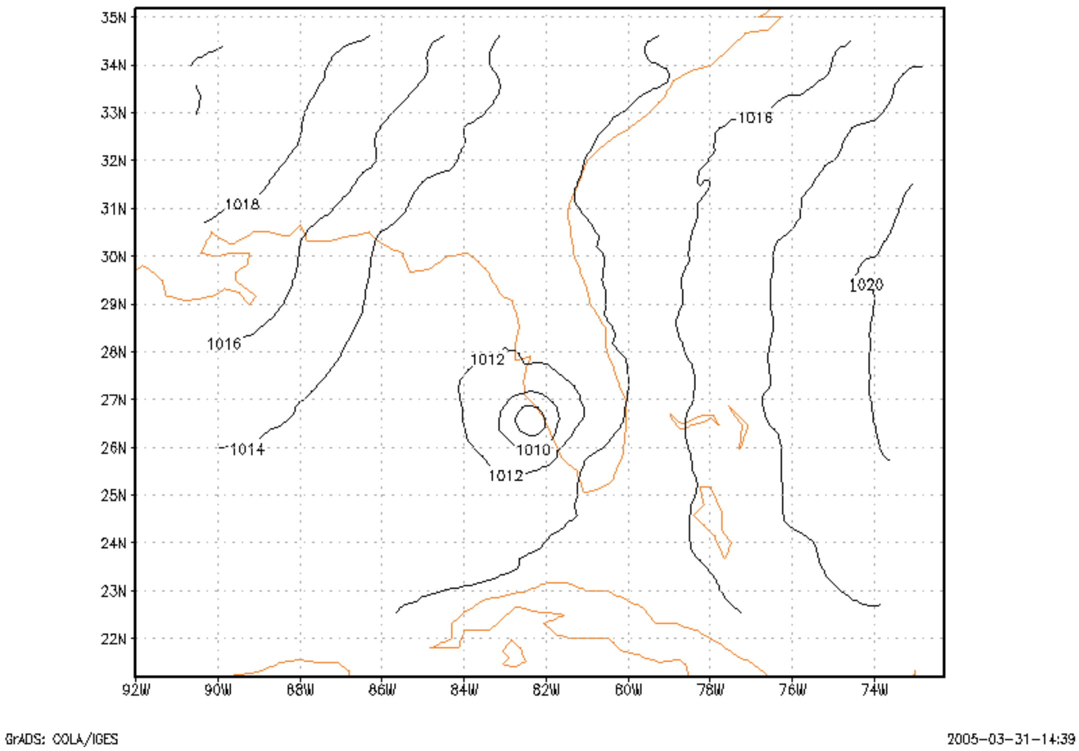
The methodology used to complete these tests included experimenting with "hard-wired" convection triggering thresholds coded in WRF to test the sensitivity of the simulated Charley development to those thresholds. To display and compare the WRF model outputs a program called Grid Analysis and Display System (GrADS) was utilized. The K-F convective parameterization trigger mechanism is represented by the following function:

$$T_S - T + \Delta T \quad \begin{cases} = \text{Buoyant} & \text{if} > 0 \\ = \text{Stable} & \text{if} \leq 0 \end{cases}$$

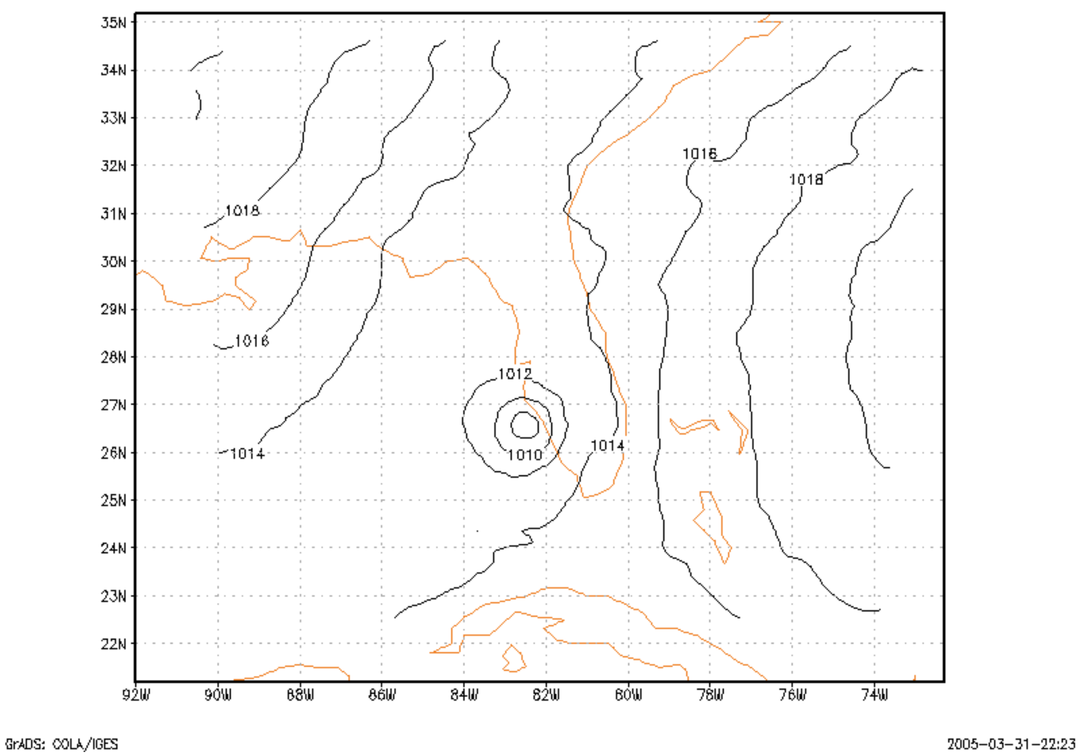
Where T_S (K) is the temperature of a theoretical parcel of air, T (K) is the environmental temperature of the surrounding atmosphere and ΔT (K) is the low-level convergence term, which is equal to an arbitrary constant, C_1, which in the parameterization is equal to 4.64 (K/[m s^{-1}]) multiplied by the vertical velocity, W_G (m s^{-1}), of the surrounding air in the planetary boundary layer.

Two initial tests were run adjusting the arbitrary constant to be larger by an order of magnitude (Test 1, make convection more probable) and smaller by an order of magnitude (Test 2, make convection less probable). The initial intent of these tests was to "break" the model and show a significant difference in the intensity, track and precipitation distribution of hurricane Charley and then measure the sensitivity of these differences. The results were surprisingly unresponsive to the changes in C_1. The explanation for the lack of sensitivity of the tests has to do with the dynamics of the convective parameterization. There is a convective threshold that if exceeded ("Buoyant" in the parameterization) yields a higher probability of producing convection and, when not exceeded, ("Stable" in the parameterization) will prevent convection from forming. Most of the grid points within the model already had values that did not exceed the convective thresholds and so by decreasing the C_1 term in Test 2 there was almost no noticeable change between the results and that of the control.

WRF Control Sea-Level Pressure Output:

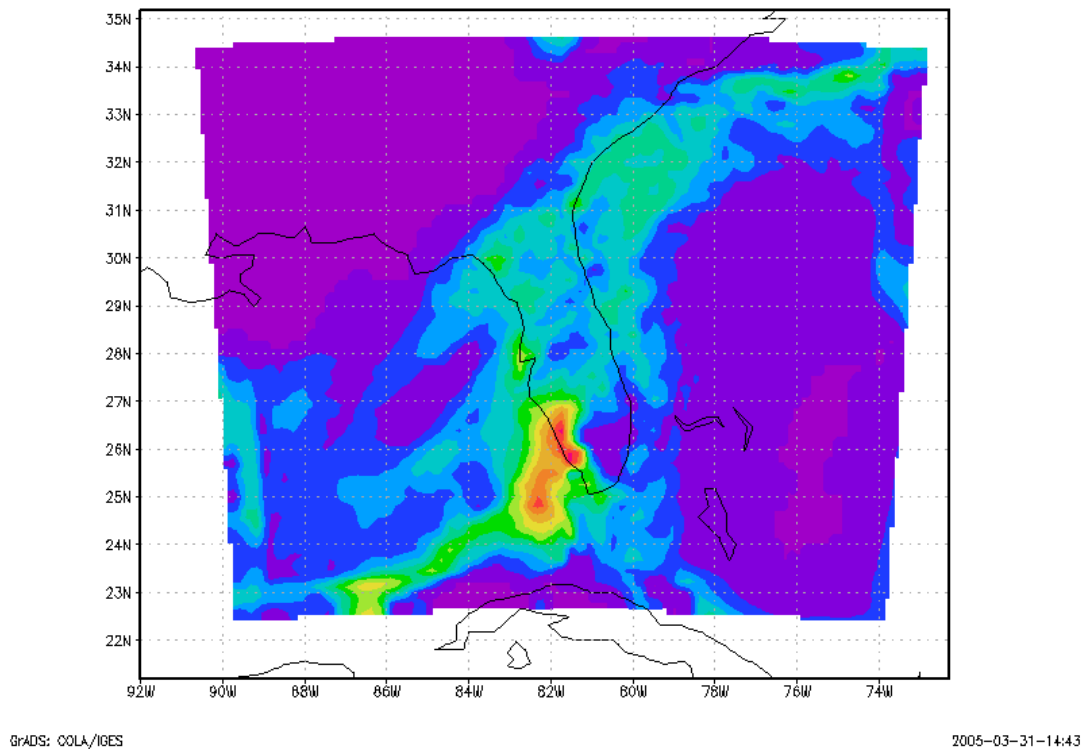


WRF Test 2 Sea-Level Pressure Output:

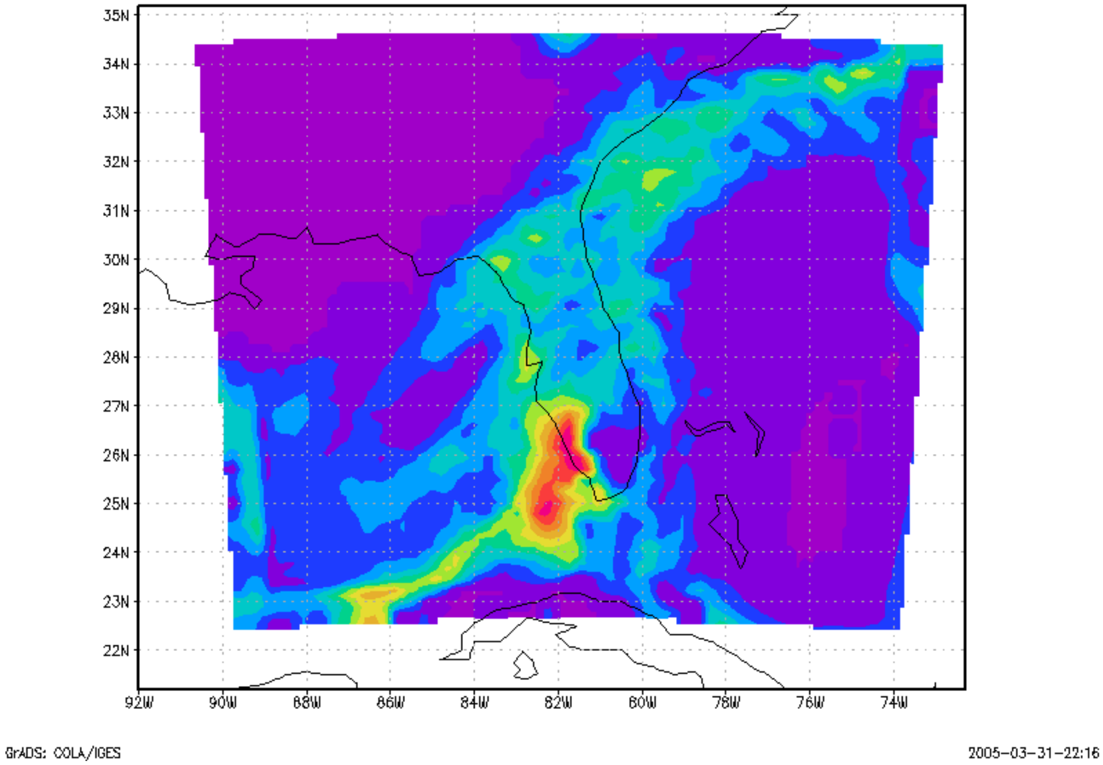


Test 1 saw the most noticeable differences between the control and the test run, but were still not that much different from the control. The sub-grid scale (convective) precipitation saw higher values at some grid points, however, no significant changes were seen in the track of Charley. The higher C_1 term pushed some grid point values above the convective thresholds and supported more convection, but because it is not sensitive to how much the threshold is exceeded, differences were minimal.

WRF Control Sub-Grid Scale Precipitation Output:

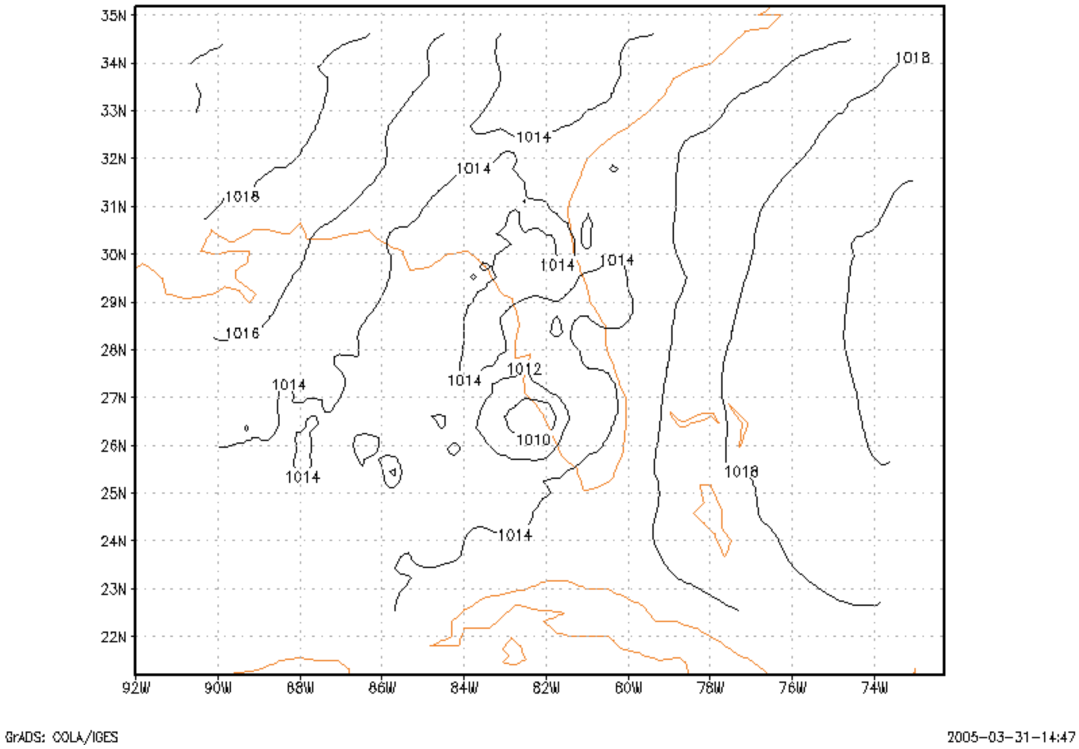


WRF Test 1 Sub-Grid Scale Precipitation Output:



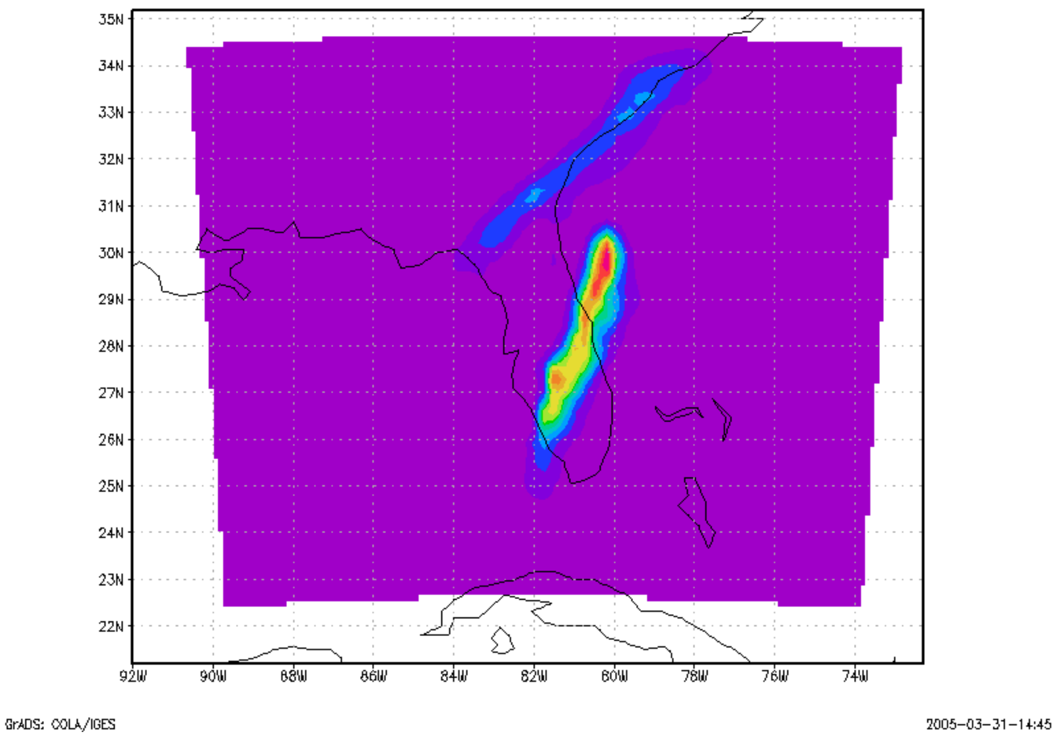
With the lack of significant change within the model, another variable within the K-F scheme was altered in an attempt to "break" the model. This time the W_G term was forced to have positive vertical motion in all grid points (Test 3) and negative vertical motion in all grid points (Test 4). Test 4 yielded similar results to that of Test 2 for the same reason. The majority of the grid points were already below the convective threshold and therefore when vertical motion was hindered, changes were minimal. Charley's intensity, however, weakened by a magnitude of two hPa.

WRF Test 4 Sea-Level Pressure Output:

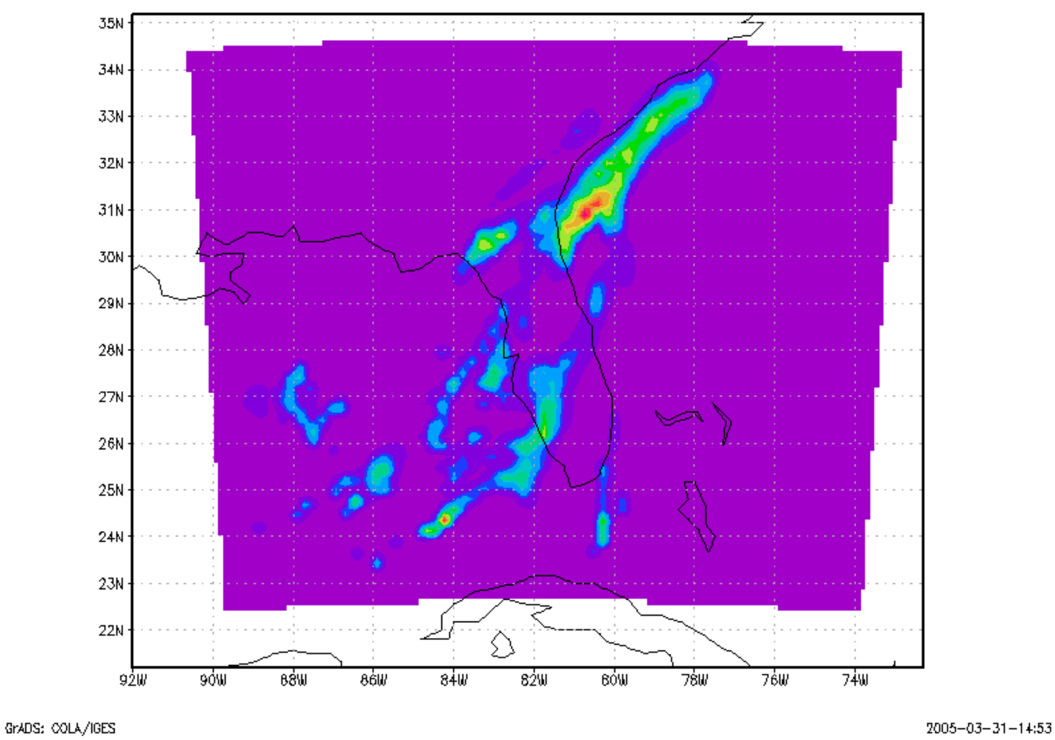


The grid-scale precipitation saw a slight increase only because all convection was hindered which resulted in more water vapor being available to the grid-scale moisture scheme. In addition, grid scale precipitation maxima within the Test 4 run drastically changed positions from that of the control. The WRF Control run displayed a main primary band of grid scale precipitation across central Florida with a band of lesser intensity along the Southeastern coastline. Whereas the WRF Test 4 run exhibited a reversal with the primary grid scale rain band located along the Southeastern United States coast line and a secondary band located along central Florida.

WRF Control Grid Scale Precipitation Output:



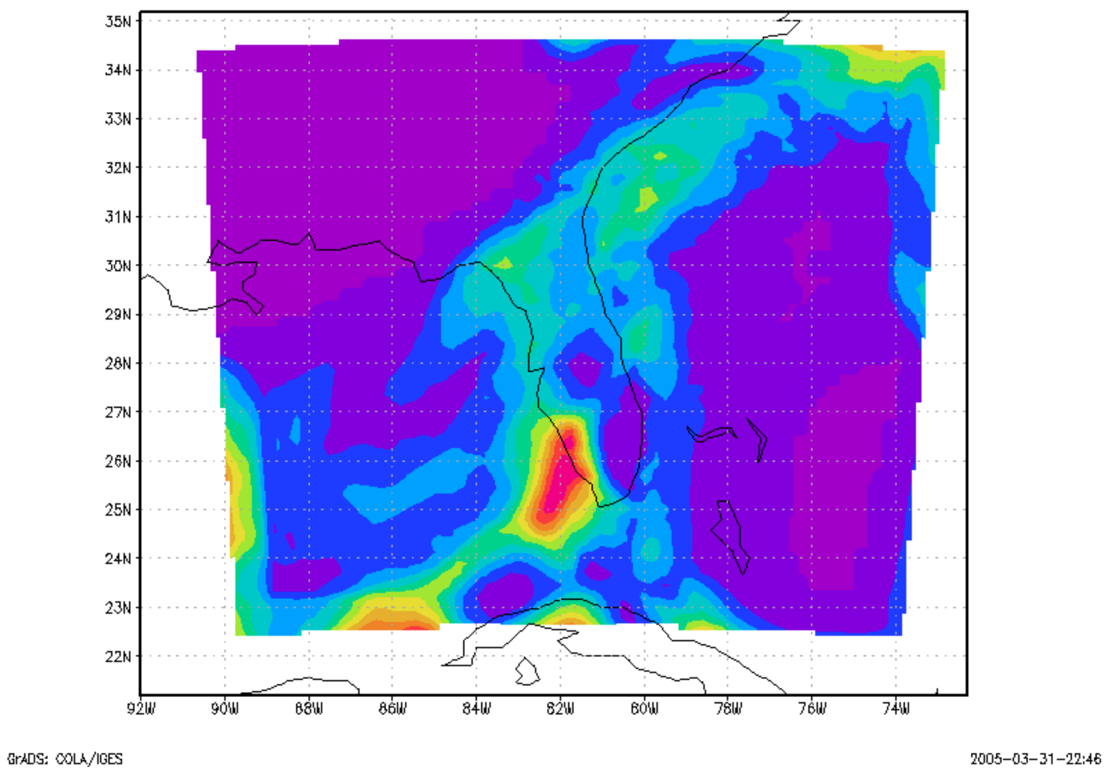
WRF Test 4 Grid Scale Precipitation Output:



Spotty areas of grid scale precipitation also formed between the primary and secondary rain bands and into the Gulf of Mexico in the Test 4 run. This further illustrates the increase in the available grid scale moisture scheme.

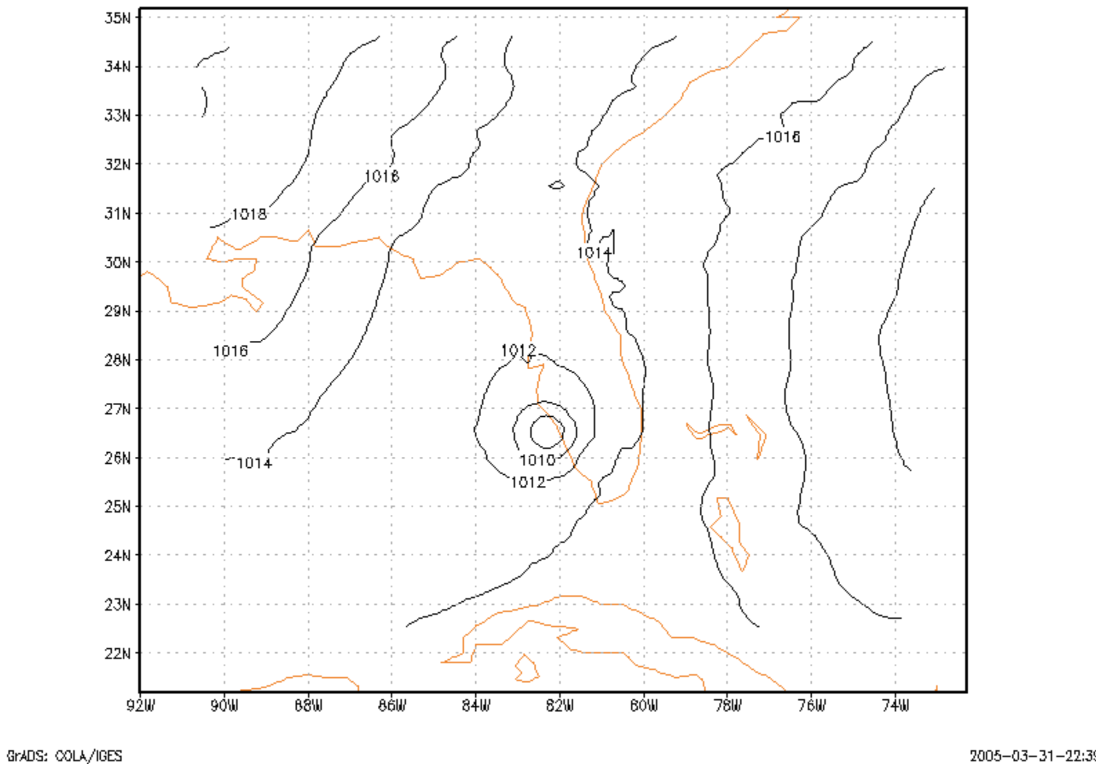
The Test 3 run saw the most significant difference between the test and the control. In sub-grid scale precipitation, the maximum values were larger in several areas and the horizontal spread of precipitation increased. As a result, since a given amount of model moisture is first made available to the sub-grid scale precipitation scheme, higher values of grid scale precipitation were created. Also, the grid scale precipitation appears less spotty and more banded in the Test 3 run of Charley.

WRF Test 3 Sub-Grid Scale Precipitation Output:



Charley's intensity was unresponsive to the alterations made in Test 3 as shown by the Test 3 Sea-level pressure output from WRF.

WRF Test 3 Sea-Level Output:



The results of these test runs, although not yielding what was hypothesized, were helpful in determining the sensitivity of alterations in the K-F convective scheme triggering mechanism within the WRF model. Noteworthy results include a lack of sensitivity in how much the convective threshold is exceeded in relation to producing more convection and strengthening Charley. Also, little-to-no change in Charley's track or timing throughout the runs was noted. Finally, only noteworthy changes in precipitation distribution occurred once vertical motion at the planetary boundary layer was either altered to positive or negative values at all grid points. These findings should be valuable in starting related research of convective systems using the K-F convective parameterization scheme in the future.

References:

Kain, J. S., and J. M. Fritsch, 1993: Convective Parameterization for Mesoscale Models: *The Representation of Cumulus Convection in Numerical Models*, K. A. Emanuel and D. J. Raymond, Eds., American Meteorological Society,165-170.