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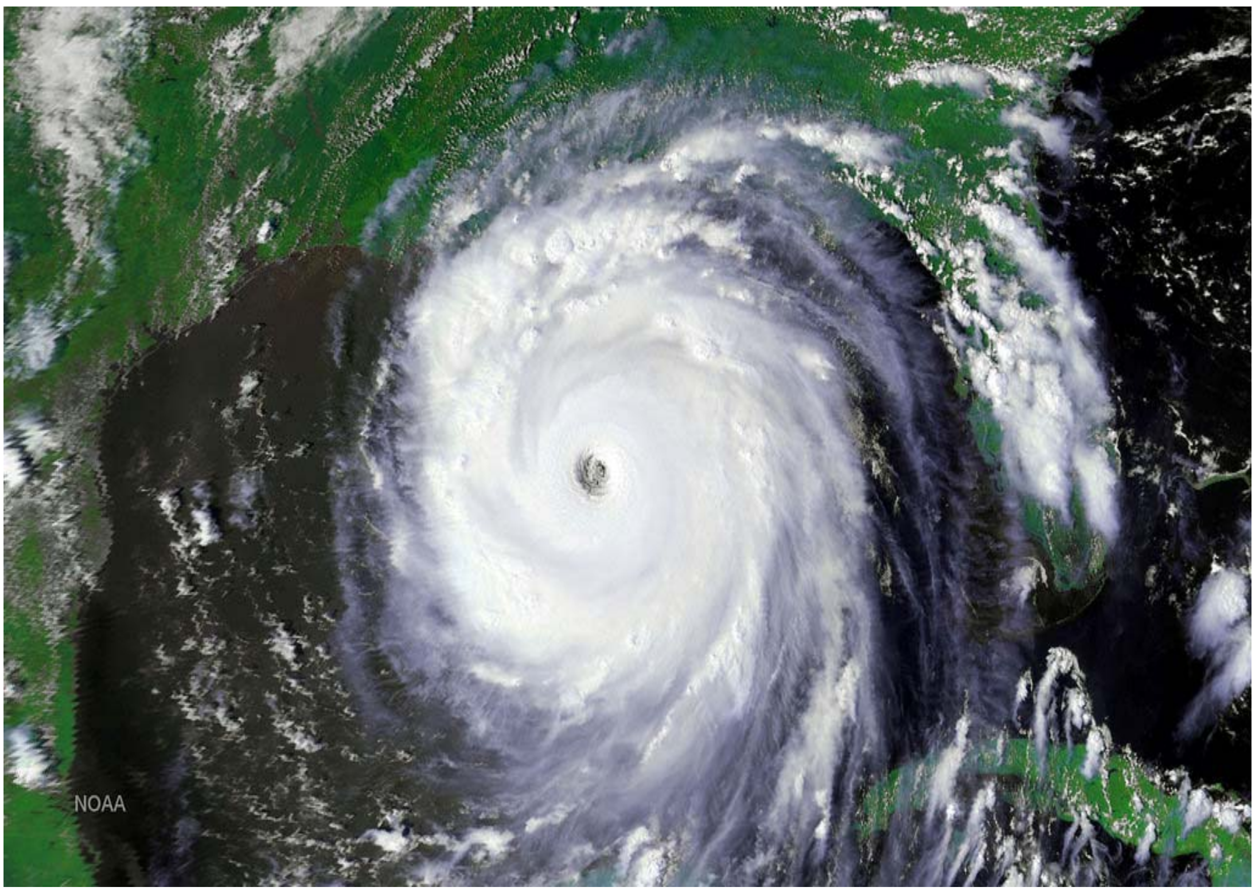
RESEARCH AND INNOVATION

NUMERICAL WEATHER PREDICTION STUDY OF THE HURRICANE KATRINA EVENT



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NUMERICAL WEATHER PREDICTION STUDY OF THE HURRICANE KATRINA EVENT

A Final Report in the Numerical Weather Forecast Models Module
in partial fulfilment of the requirements for
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By

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ABSTRACT

In a world of unpredictable weather patterns over a particular region, it has become very important to achieve relevant insight and knowledge from numerical weather forecast model predictions. Using the weather research and forecasting (WRF) or numerical weather prediction (NWP), we are able to create system designs to serve both atmospheric research and operational forecasting needs. And based on the awareness of improvement of these needs, we can now use historical real weather data, analyze it, make predictions, and learn from it.

The report will be an experimental study with a motivation to successfully assess/evaluate the use of the WRF-ARW model. The focus will be on the numerical methods of simulating the Katrina Hurricane event with real data observation period between 28th August, 2005 at 00:00 and 30th August, 2005 at 00:00.

The characterizations of single and multiple domain methods were investigated, established and implemented. Meteorological Magnitude Weather Variables - Model Pressure (hPa), Sea Levelp Pressure (hPa), High Cloud Fraction (%), Wind Speed (m s-1), Relative Humidity (%) and Temperature (C) were used in the assessment of the post-processing procedure with the exhibition of data visualizations and simulations. Results of weather trajectories and altered parametrizations discovered were also deliberated.

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INTRODUCTION

Hurricanes are the most ferocious storms on Earth. They created over warm ocean waters and occasionally they strike terrestrial areas. They provide strong winds and extreme rainfall, while producing abnormal rise in sea levels and flooding. They are also given names so they can be identified quickly, for instances, Hurricane Katrina etc.

Hurricane Katrina has devastated Louisiana on 29th of August, 2005. It was a category five (5) hurricane with winds greater than 252 km/h and become one of the most powerful hurricane ever seen in history.

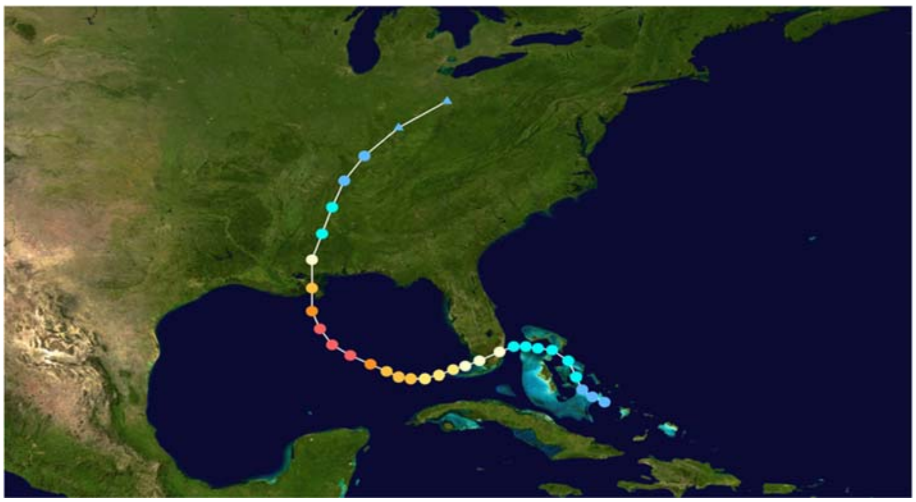


Figure 1: Comprehensive trajectory of the historical Hurricane Katrina event.

Figure 1, provides a comprehensive trajectory of Hurricane Katrina. It shows where Hurricane Katrina started in The Bahamas on 23rd of August, created by the merge of two tropical waves. Then crossed south Florida to go in the Gulf of Mexico on 26th of August, where the storm strengthened into a Category 5 hurricane. It later weakened into a category 3 hurricane, with winds greater than 178 km/h, when it arrived on the Louisiana coast. Finally, it went into an easterly direction of the Unitied States of America to eventually disappear in the Great Lakes region on 31th of August, 2005.

Total property damage was estimated at $125 billion dollars and at least 1836 people died because of the historical hurricane event.

Perhaps with a good forecast, we could have predicted the power and the trajectory of the hurricane to reduce human losses.

OBJECTIVES

Our focus will be to study the WRF-ARW model on the process of predict the evolution of the hurricane katrina from 28th August at 00:00 to 30th August at 00:00. More specifically, with computer tools (WPS, WRF, ARWPost, GrADs etc.), we will create a meteorological model in order to predict the evolution of the historial hurricane event.

We will use the dataset from for our simulations of the Katrina Hurricane historical event from the National Centers for Environmental Prediction (NCEP), USA at the National Weather Service, USA.

In this report, we will first investigate, establish and implement a Single Model Domain run to understand the main characteristics of our predicted simulations using selection initial parametrizations. We will apply a second approach via Two-Way Nesting Run, with one input file, with some small changes; while keeping all other parameters values identical. Then we will apply a final approach similar to the second approach with altered parameters to see if we can make an improvement of the our predicition of the Katrina Hurricane historical event.

SIMULATION DESCRIPTION AND METHODS

To conduct our numerical weather prediction study of the Hurricane Katina event, the entire process involved in the execution of our simulation of the Huricane Katrina event must be defined; with an understanding of the importance of the static geographical data.

The static geographical data with the hightest resolution of each mandatory fields has been used in the simulation together with the gridded meteorological data (Katrina Hurricane event). It was obtained from the UCAR website **[7]**.

In Figure 2, this is seen where the data was transferred to metgrid.exe with the access of the namelist.wps file to be used by the geogrid.exe and ungrib.exe applications, as required.

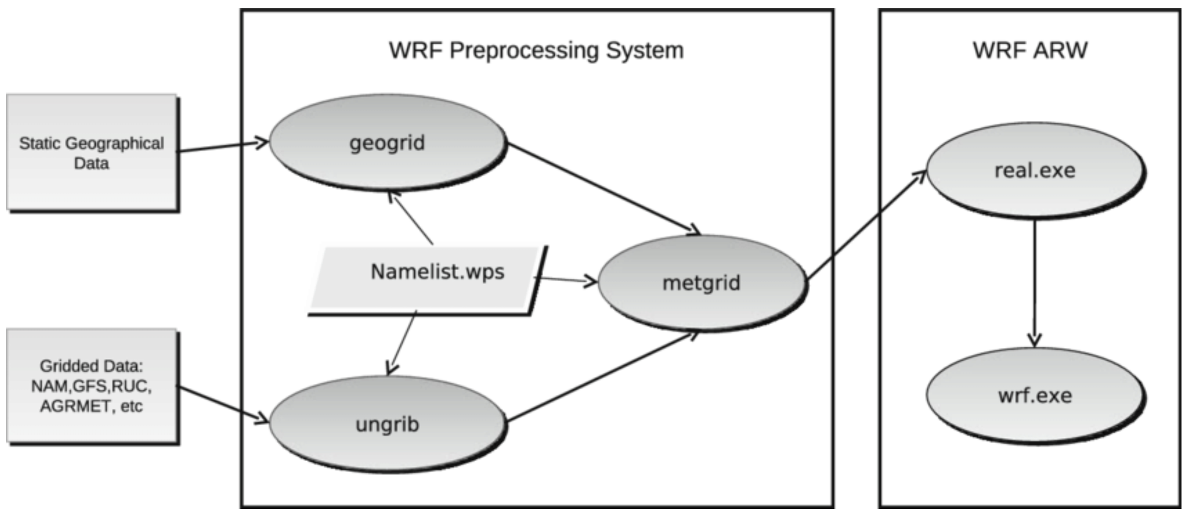


Figure 2: Preprocessing & Initialization and WRF – ARW Model Stages

In this report, there are three (3) main stages of our simulation process, 1) Preprocessing and Initialization, 2) WRF – ARW Model and 3) Post-Processing.

1) **Preprocessing and Initialization**

   - **Defining model Domains**

The namelist file (namelist.wps) is used to define the domain for the simulation and set all the required parameters. This namelist file contains values of all parameters that are required by each of the WRF Preprocessing System (WPS) programs as shown below.

There are main types of domain cases, however, we focus our attention on two type of domains. They are the Single Domain and Two Nesting Run Cases.

The Single Domain Cases can be called “The Basic Runtime Option”. This is because it provides a base for all run cases, as in Figure 2.

Two Way Nesting Run Cases emphases more on multiple domains at different grid resolutions with runs conducted simultaneously to interconnect with each other. Within the boundary values for nesting, it is important to turned on in the "namelist.input" file parameter feedback (=1). This helps the coarser domain to provide these boundary values for the feeding of calculations to the same coarser domain configuration. The main parameters are modified for the purpose of this simulation are shown in the next section.

In the report, the important parameters are the number of domains being considered for the simulation, the start and end dates, the interval in seconds. The grid resolution, as in Figure 2, size is also set from the same namelist.wps file.

The "namelist.input" file has been modified to reflect the scenarios we want to study. Details of the parameters used for our simulation are detailed in the simulation data overview section.

To run the nested case, the namelist file has been modified by including additional values for some of the parameters, with a set of variables for each nest.

After the variables are modified as required and saved, the geogrid.exe application is run.

After a successful execution of the geogrid.exe application, results in the generation of the "geo_em.d01.nc, geo_em.d02,…." file.

Running the geogrid.exe application with the updated parameters interpolates the static geographical data (such as terrain, landuse and soil) to the model domain.

- **Degribbing and interpolating meteorological data from another model to the simulation domain**

The ungrib.exe application is used to extract the meteorological data required for the model from the GRIB files and translate them into an intermediate format that can be used by the metgrid application.

Two tasks are performed before running the ungrib application.

This includes:
- linking the appropriate VTABLE file to specify, which fields of the meteorological data in the GRIB files should be extracted and written to the intermediate format.
- linking the downloaded input GRIB data with the help of the link_grib.csh script.

The "namelist" file is modified to reflect the required parameters we are interested and depending on the type of simulation being run (nested or not).

We proceed to run the ungrib.exe file to obtain the intermediate files.

The metgrid.exe application is run to horizontally interpolate the intermediate format meteorological data produced by the ungrib application to the model domains.

This concludes the pre-processing stage of the simulation.

2) **WRF – ARW Model**

Using the met_*** files generated after the pre-processing phase, we proceed to run the real.exe application from the WRF directory(real) **[3]**. We will have to link the met_*** files into the WRF directory. We then proceed to edit the "namelist.input" file to ensure the variables match the case we want to run.

Running the real.exe application (***./real.exe***) results in the creation of the following files:

wrfinput_d01
wrfbdy_d01

We proceed to run the wrf.exe application (***./wrf.exe)*** which results in the creation of the wrfout* file(s). A second one is created for the 2nd domain if nesting is being considered.

After this we proceed to post-processing stage with the output files.

3) **Post-Processing**

Post-processing and visualisation of the results has been performed using the ARWpost package and the GrADs application.

Before running the ARWpost program, the "namelist.ARWpost" file is edited to specify which parameters and the times (start_date, end_date, interval_seconds etc) we want to post-process.

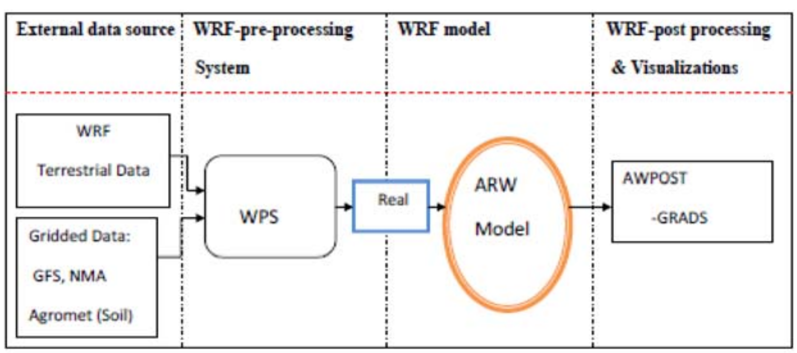


Figure 3: Three (3) main stages of our simulation process with external static geographical data.

This results in the creation of the .dat and.ctl files which can be visualised by the GrADS software. Figure 3, shows the characteristics a successful WRF-ARW model via ARWpost results. The graphical outputs from the GrADS software are presented and explained in detail in the next section.

SIMULATION DATA OVERVIEW

Data Description

As discussed earlier, we use a dataset for our simulations of the Katrina Hurricane historical event from the National Centers for Environmental Prediction (NCEP), USA at the National Weather Service, USA.

The dataset is an older dataset that was ran at NCEP from a AVN (AViatioN) model. The AVN is run four times daily, at 0000, 0600, 1200, and 1800 GMT/UTC. On 24 April 2002 the NCEP AVN model was renamed to the GFS (Global Forecast System). The name AVN is still used on operational NWS FTP servers to describe GFS model data sets.

This dataset will be used as input to the WRF-ARW Model for our simulations; containing several files of GRIB1 data with a resolution of 1deg global data, 6 hourly data frequency and 26 pressure levels (1000-10hPa; excluding surface). The historical data observation period is available between 28th August, 2005 at 00:00 and 30th August, 2005 at 00:00 [**8**].

Data Input Parameters

There are many parameters that exist within the "namelist.wps", "namelist.input" and "namelist.ARWpost". However, in this project, we focus our attention to the "namelist.input" to implement are analysis and assessment of the Katrina Hurricane historial event simulations.

In this project, during the nesting process, we will focus our attention on &physics and &dynamics part of the "namelist.input" file. Table 1 displays the assessment parameters.

&physics	**&dynamics**
mp_physics - Micro-physics option	**base_pres** - Base state surface pressure (Pa)
ra_lw_physics - Longwave radiation option 1	**base_temp** - Base state sea-level (surface) temperature (in K)
ra_sw_physics - Longwave radiation option 2	**base_lapse** - lapse rate (K)
radt - Minutes between radiation physics calls	**iso_temp** - reference temp in stratosphere
cu_physics - Cumulus parameterization option	
cudt - Minutes between cumulus physics calls	
co2tf - CO2 transmission function flag for GFDL radiation only	
isftcflx - Cd formulation for tropical storm application	
ifsnow - snow-cover effects	

Table 1: List of input parameters deliberated in the "namelist.input" of all model runs.

Data Domain Configuration

For all WRF-ARW Models runs, it is very important to ensure the domain is in the right location.

Figure 4, shows the domain configurations for both single domain and nesting model runs.

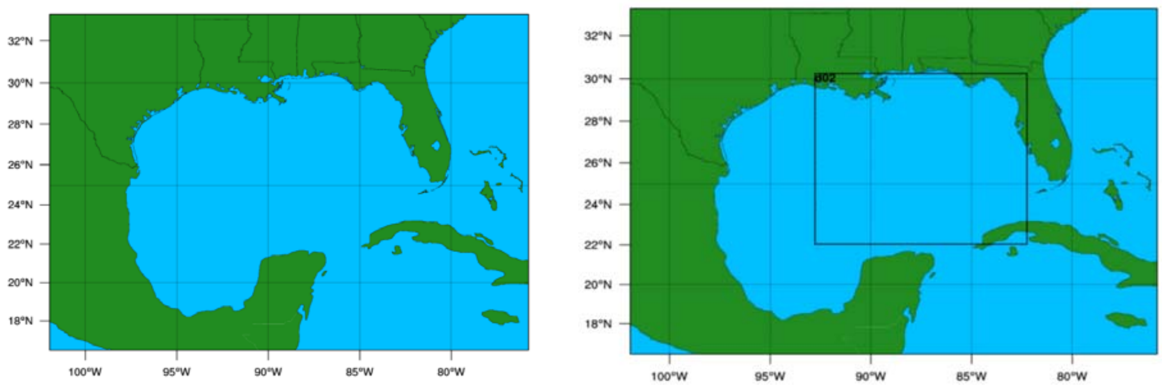


Figure 4: WRF Single and Two Way Nested Domain Configurations

Data GrADS Variables

During the Post-Processing Process, the Grid Analysis and Display System (GrADS) Version 2.0.a9, Copyright (c) 1988-2010 by Brian Doty and the Institute for Global Environment and Society (IGES) was used for our data visualization.

Table 2 shows the variables we will use in all simulation visualizations.

GrADS Variables
Pressure - Model pressure (hPa)
Slp - Sea Levelp Pressure (hPa)
Clfhi - High Cloud Fraction (%)
Wspd - Wind Speed (m s-1)
Rh - Relative Humidity (%)
Tc - 29 0 Temperature (C)

Table 2: Selected GrADS Variables used for all data visualizations.

To better understand the Katrina Hurricane historical event, we display the initial date of 28th August, 2005 at 00:00 of our assessment variables with GrADS.

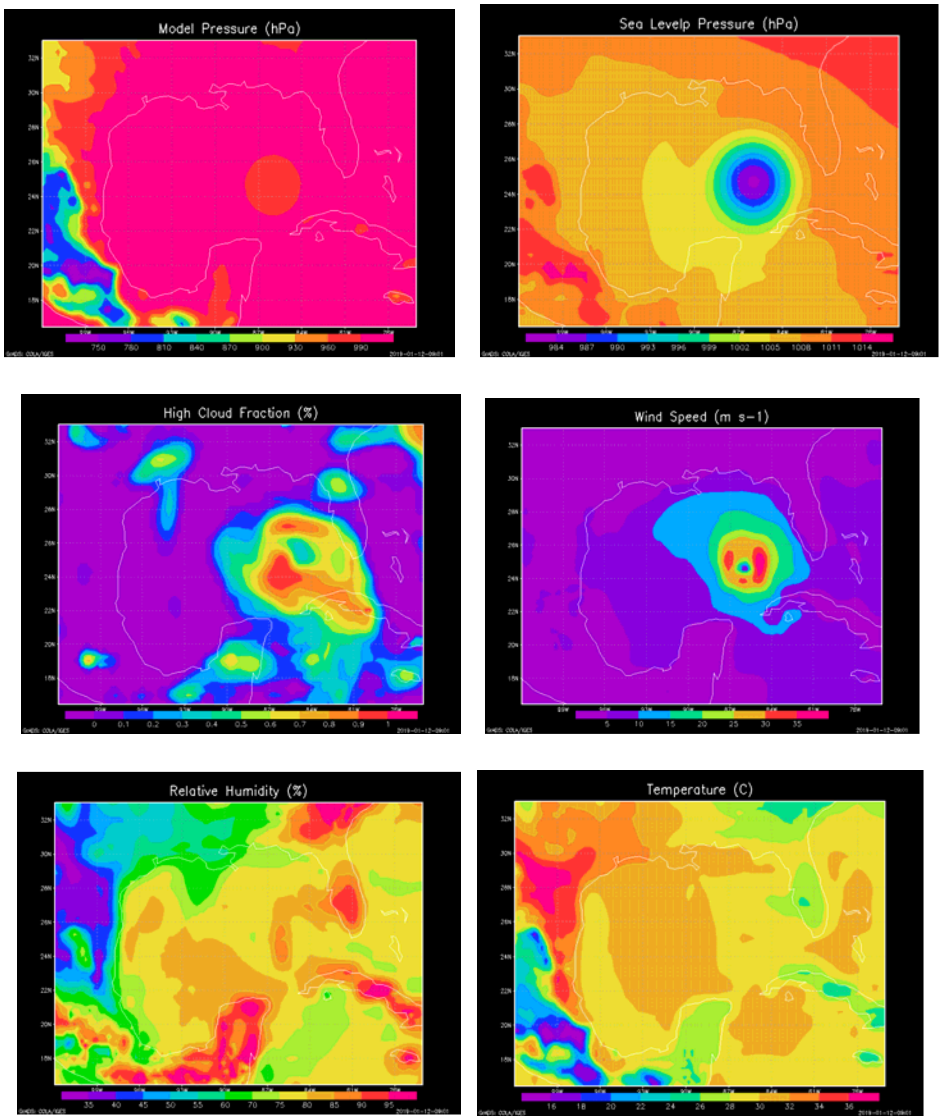


Figure 5: GrADS Visualizations on 28th August, 2005 at 00:00.

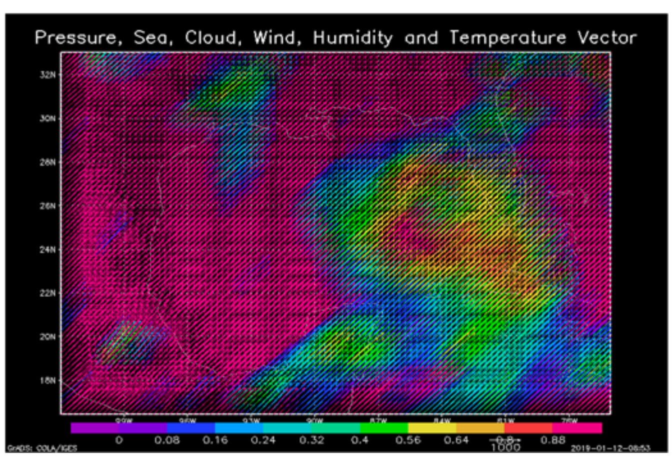


Figure 6: GrADs Vector Visualizations of all six (6) variables on 28th August, 2005 at 00:00.

SIMULATION ANALYSIS AND RESULTS

We now present a thought process of the predictions from the WRF-ARW Model Runs.

As explained and stated before, we have decided to conduct three types of model runs.

They are as followed:

1) **Single Model Domain Run** (max_dom = 1, d01 and initial parameters)
2) **Two-Way Nested Run, With One Input File** (max_dom = 2, d01 & d02 and initial parameters)
3) **Two-Way Nested Run, With One Input File** (max_dome = 2, d01 & d02 and new parameters)

More specifically, we will also present predicted simulations of the Katrina Hurricane event.

Single Model Domain Run, Initial Parameters Until 30th August, 2005 at 00:00

In our first run, we begin with a single model domain case with a historical data observation period is available between 28th August, 2005 at 00:00 and 30th August, 2005 at 00:00 [**8**].

We focus our attention on the following initial parameter values below in the namelist files.

&share	&physics	&dynamics	&io
wrf_core = 'ARW'	**mp_physics =** 3	**base_pres** = N/A	**plot** = 'list'
max_dom = 1	**ra_lw_physics =** 1	**base_temp =** 290.	**fields** = 'pressure,slp,clfhi, wspd, rh, tc'
start_date = '2005-08-28_00:00:00'	**ra_sw_physics =** 1	**base_lapse =** N/A	
end_date = '2005-08-30_00:00:00'	**radt** = 30	**iso_temp =** N/A	
interval_seconds = 21600	**cu_physics** = 1		
	cudt = 5		
	co2tf = N/A		
	isftcflx = N/A		
	ifsnow = 1		

Table 3: Initial parameter values in the "**namelist.wps", "namelist.input**" and "**namelist.ARWpost**" files.

After running the Single Model Run, we have achieved the visualizations from our selected GrADS Variables, Meteorological Magnitude Weather Variables – Model Pressure (hPa), Sea Levelp Pressure (hPa), High Cloud Fraction (%), Wind Speed (m s-1), Relative Humidity (%) and Temperature (C) that were used in the assessment of the post-processing procedure.

We use the ARWpost, a Fortran program, that reads the WRF-ARW input and output files, then generates GrADS output files for our visualizations.

A time stamp observation on "**28th August, 2005 at 00:00**", "**29th August, 2005 at 00:00"** and "**30th August, 2005 at 00:00"** for each weather variable are displayed respectively.

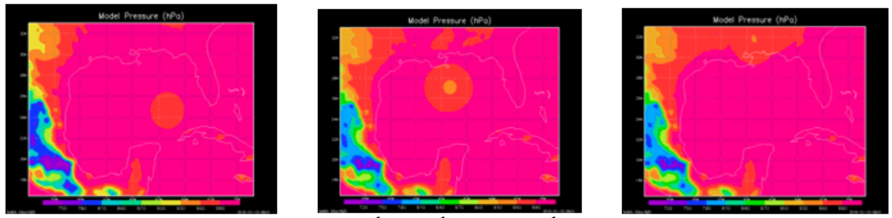


Figure 7: Model Pressure (hPa) at 28th, 29th and 30th of August at 00:00, respectively.

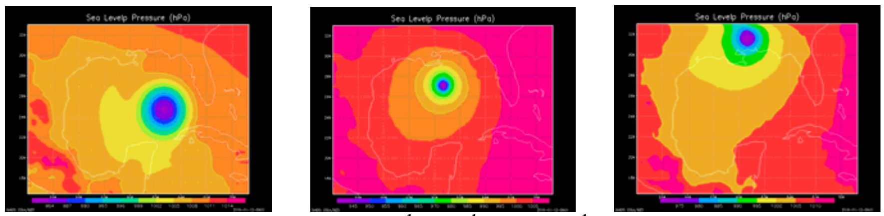


Figure 8: Sea Levelp Pressure (hPa) at 28th, 29th and 30th of August at 00:00, respectively.

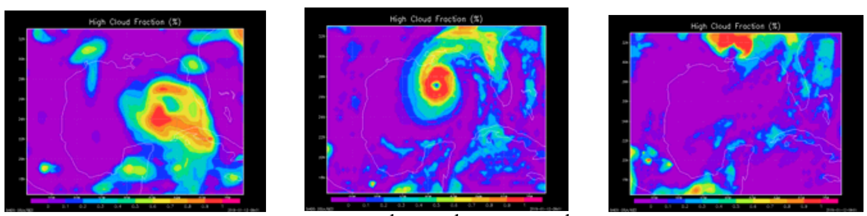


Figure 9: High Cloud Fraction (%) at 28th, 29th and 30th of August at 00:00, respectively.

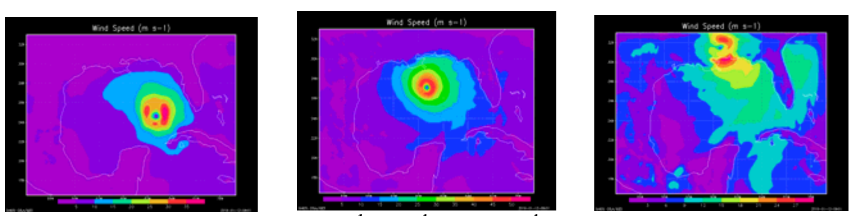


Figure 10: Wind Speed (m s-1) at 28th, 29th and 30th of August at 00:00, respectively.

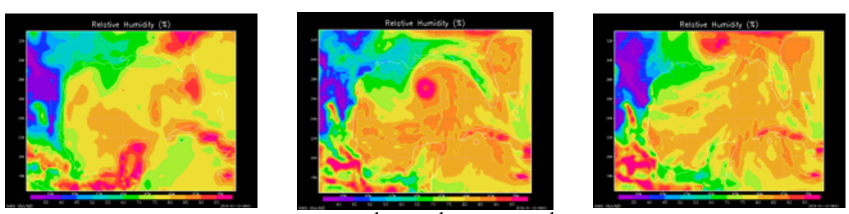


Figure 11: Relative Humidity (%) at 28th, 29th and 30th of August at 00:00, respectively

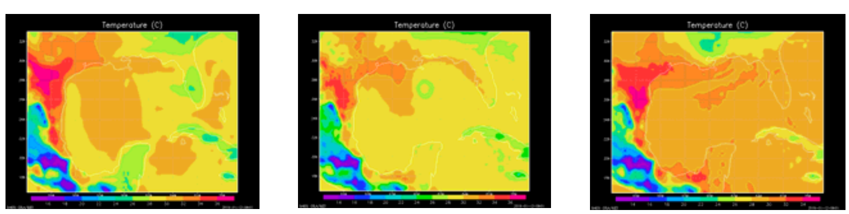
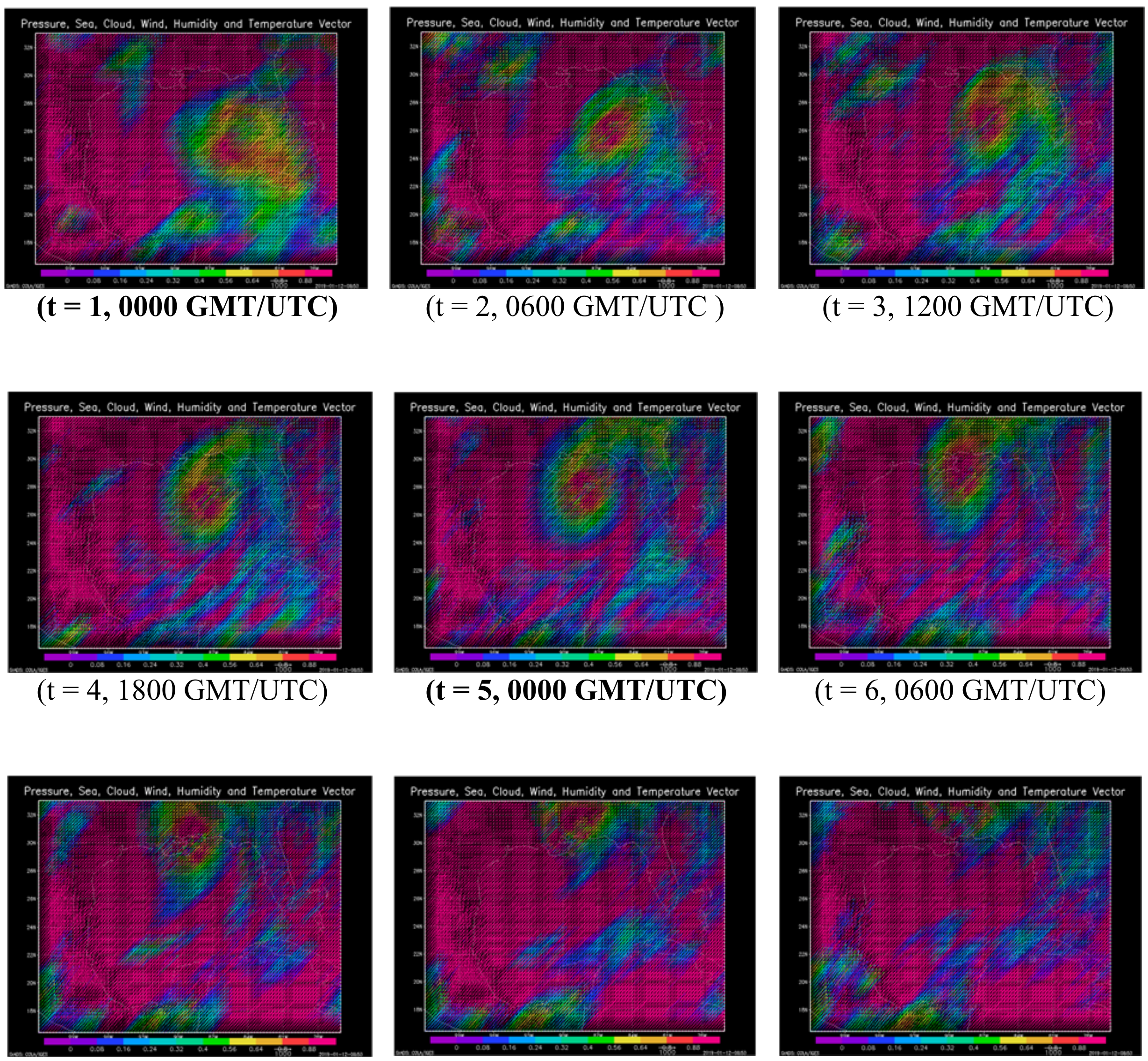


Figure 12: Temperature (C) at 28th, 29th and 30th of August at 00:00, respectively

Specifically, we now display a vector combination simulation of all six weather variables with GrADS between 28th August, 2005 at 00:00 and 30th August, 2005 at 00:00 [**8**].



(t = 1, 0000 GMT/UTC) (t = 2, 0600 GMT/UTC) (t = 3, 1200 GMT/UTC)

(t = 4, 1800 GMT/UTC) **(t = 5, 0000 GMT/UTC)** (t = 6, 0600 GMT/UTC)

(t = 7, 1200 GMT/UTC) (t = 8, 1800 GMT/UTC) **(t = 9, 0000 GMT/UTC)**

Figure 13: Vector simulation of all six weather variables during a 6 hourly data frequency.

Figure 13, give us an excellent idea of have well our selected variables can work together in this weather prediction.

Figure 14: Satellite Image of Katrina Hurricane hitting land fall on between 29th, August 2005.

Comparing, Figure 14 with Figure 7-13, we can say that our prediction of the Katrina Hurricane event provides us with excellent results.

Two-Way Nested Run, With One Input File, Initial Parameters Until 29th August, 2005 at 00:00

In our second run, we keep all variables and initial parameters unchanged with some changes in Table 4. This activates our Two-Way Nested run procedure as mentioned earlier. Our data observation period will be between 28th August, 2005 at 00:00 and 29th August, 2005 at 00:00. We choose this observation period to get a better understanding of the strength of the hurricane.

&share	&time_control	&domains
max_dom = 2	**input_from_file** = .true., **.false.**	**max_dom** = 2
start_date = '2005-08-28_00:00:00',**'2005-08-28_00:00:00'**		
end_date = **'2005-08-29_00:00:00','2005-08-28_00:00:00'**		

Table 4: Changed parameter values in the "**namelist.wps**" and "**namelist.input**" files.

As you can see, for this type of Two-Way Nesting Run, we will need to change the input_from_file to ".false." for domain 2. This informs the real program that we only need a wrfinput file for d01, since all values will be interpolated down from d01. For this reason, we keep start_date and end_date equal at the start_date of domain 1. This is called the Two-Way Nested Run, With One Input File.

After executing the second run successfully, we use the ARWPost and the GrADS output files for our visualizations of the Weather Variables – Model Pressure (hPa), Sea Levelp Pressure (hPa), High Cloud Fraction (%), Wind Speed (m s-1), Relative Humidity (%) and Temperature (C) that were used in the assessment of the post-processing procedure.

A time stamp observation on "**28th August, 2005 at 12:00"** for each weather variable are displayed for domain 1 (**d01**) and domain 2 (**d02**) respectively.

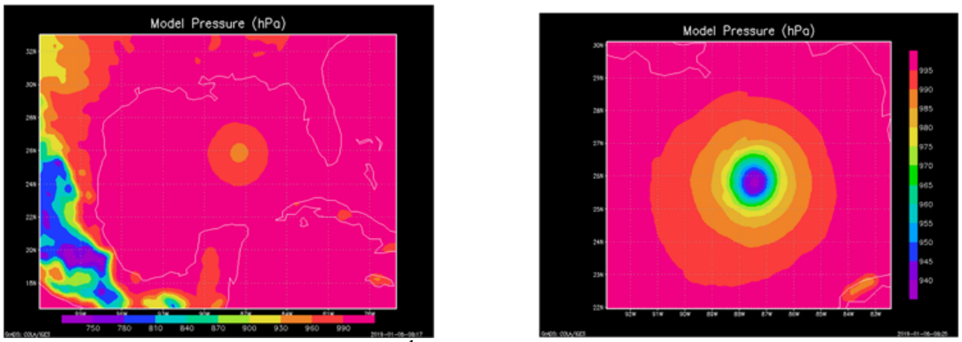


Figure 15: Model Pressure (hPa) on 28th of August at 12:00 for d01 and d02, respectively.

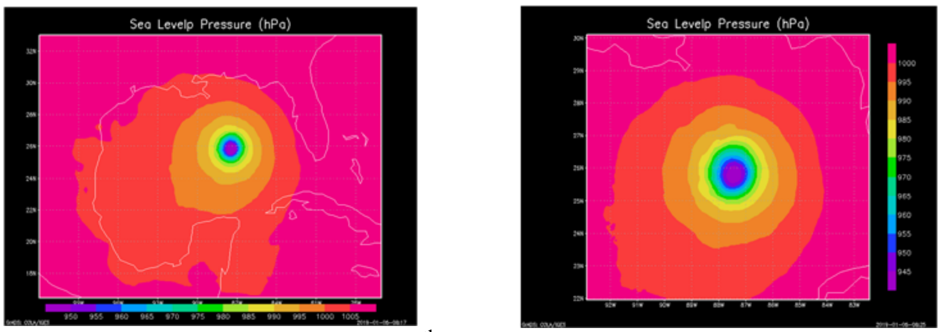


Figure 16: Sea Levelp Pressure (hPa) on 28th of August at 12:00 for d01 and d02, respectively.

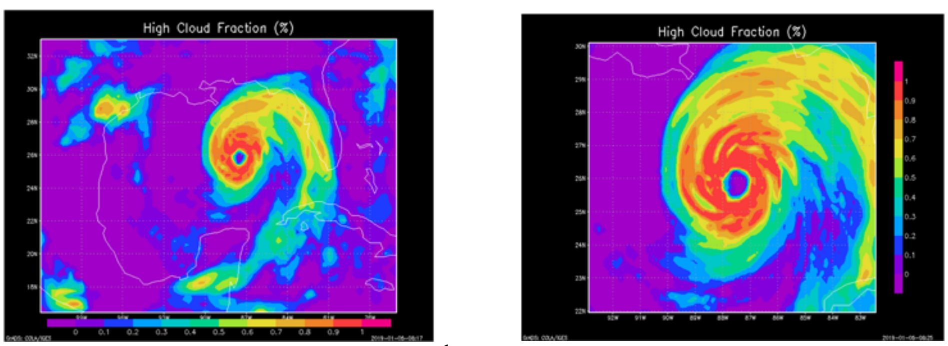


Figure 17: High Cloud Fraction (%) on 28th of August at 12:00 for d01 and d02, respectively.

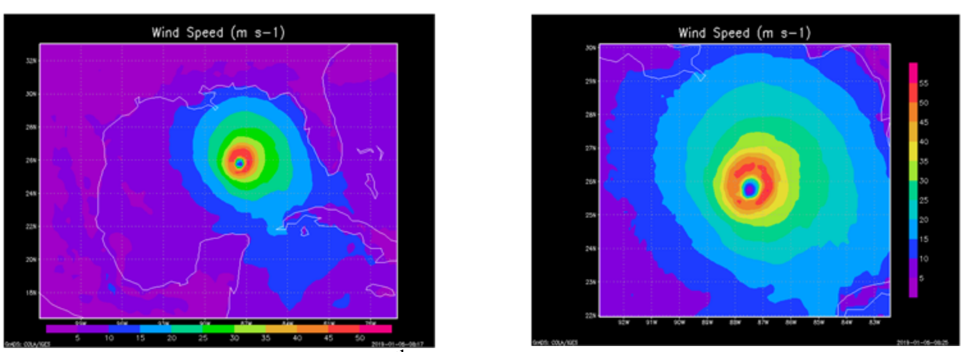


Figure 18: Wind Speed (m s-1) on 28th of August at 12:00 for d01 and d02, respectively.

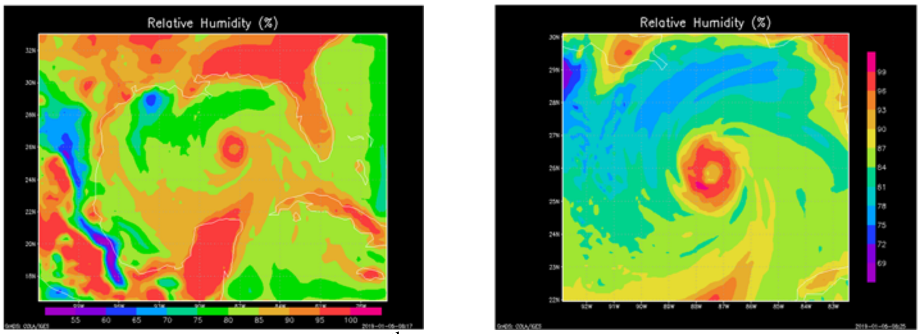


Figure 19: Relative Humidity (%) on 28th of August at 12:00 for d01 and d02, respectively.

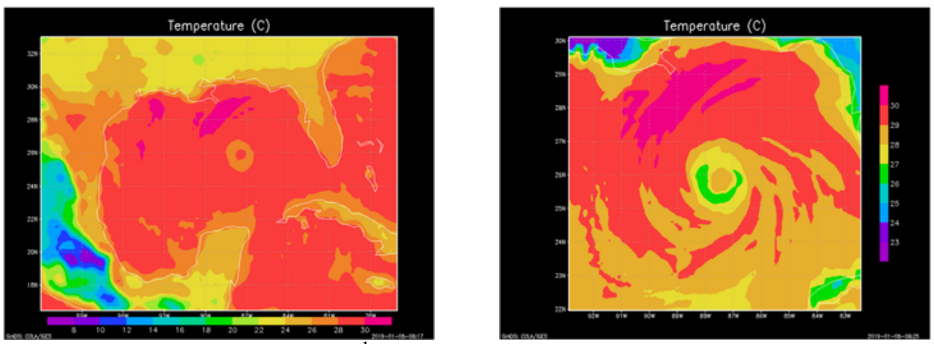
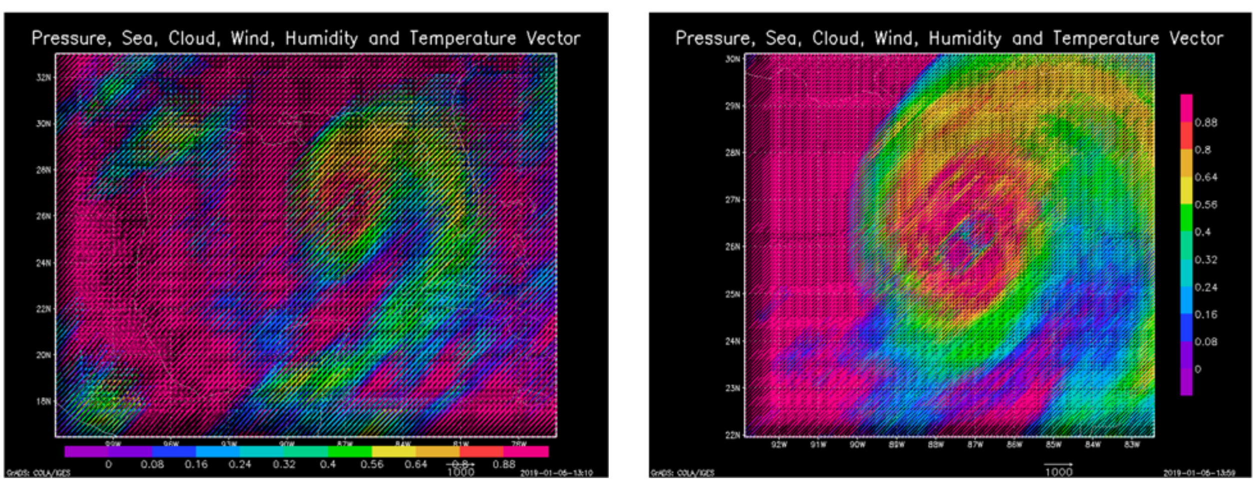


Figure 20: Temperature (C) on 28th of August at 12:00 for d01 and d02, respectively.

Specifically, we now display a vector combination simulation of all six weather variables with GrADS on 28th of August at 12:00 for d01 and d02, respectively.



(d01- t = 3, 1200 GMT/UTC) (d02 - t = 3, 1200 GMT/UTC)

Figure 21: Vector simulation showing 28th of August at 12:00 for d01 and d02, respectively.

Comparing, Figure 14, with Figure 15-21, we can say that our prediction of the Katrina Hurricane event provides us with excellent results.

Two-Way Nested Run, With One Input File, Changed Parameters Until 29th August, 2005 at 00:00

For our final run, we conduct an observation of effects of making changes in the "**namelist.input**" in two areas &physics and &dynamics, with a focus on domain 2.

With that said, we keep everything the same and change some parameters as in Table 5.

&physics (physics options)
mp_physics = 4 - WRF Single-Moment (WSM) 5-class scheme. A slightly more sophisticated version of option 3 that allows for mixed-phase processes and super-cooled water.
ra_lw_physics = 4 - rrtmg scheme (Longwave). Based on calculations with the AER radiative transfer models.
ra_sw_physics = 4 - rrtmg scheme (Shortwave). Based on calculations with the AER radiative transfer models.
radt = 10 - minutes between radiation physics calls. Recommend 1 minute per km of dx (e.g. 10 for 10 km grid).
cu_physics = 6 - Tiedtke scheme: More precise scheme but more computationally expensive. Takes into account tropical effects.
cudt = 0 - minutes between cumulus physics calls. For example, 10.0 minutes. 0 = call every time step.
co2tf = 1 - CO2 transmission function flag for GFDL radiation only. Set it to 1 for ARW, which allows generation of CO2 function internally.
isftcflx = 1 - alternative Ck, Cd formulation for tropical storm application (0=default, 1=new).
ifsnow = 0 - snow-cover effects (only works for sf_surface_physics = 1) 0 = without snow-cover effect; 1 = with snow-cover effect.
&dynamics (Diffusion, damping, advection options)
base_pres = 100000. **-** Base state surface pressure (Pa), real only. Do not change.
base_temp = 290. **-** Base state sea level temperature (K), real only.
base_lapse = 50. **-** lapse rate (K), real-data only, Do not change.
iso_temp = 0 **-** reference temp in stratosphere, real-data, em only.

Table 5: Changed parameter values and there meanings in the "**namelist.input**" files.

The difference between the second and final run, we are assuming a focus on insightful effects to our model. We can except a more accurate, yet time consuming process, with better detailed prediction of the Katrina Hurricane historical event. As you can see in Table 5, we have also decided to include more diffusion, damping, advection options that focuses on real data, via compiled WRF - Real Data Cases. This in our view, we except to achieve more realistic results.

After executing the final run successfully, we use the ARWPost and the GrADS output files for our visualizations of the Meteorological Magnitude Weather Variables – Model Pressure (hPa), Sea Levelp Pressure (hPa), High Cloud Fraction (%), Wind Speed (m s-1), Relative Humidity (%) and Temperature (C) that were used in the assessment of the post-processing procedure.

A time stamp observation on "**28th August, 2005 at 12:00**" for each weather variable are displayed, showing a comparison of the second and final run for domain 2 (**d02**) respectively.

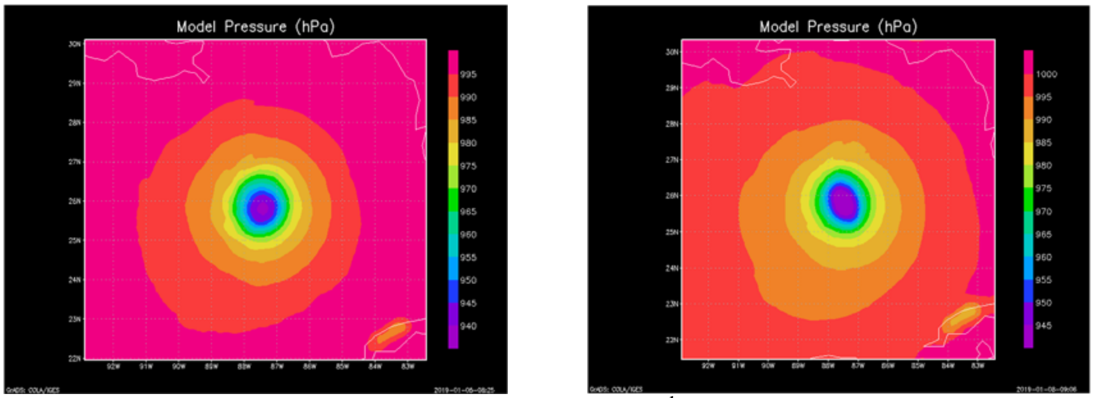


Figure 22: Model Pressure (hPa) on 28th of August at 12:00
for d02 (second run) and d02 (final run), respectively.

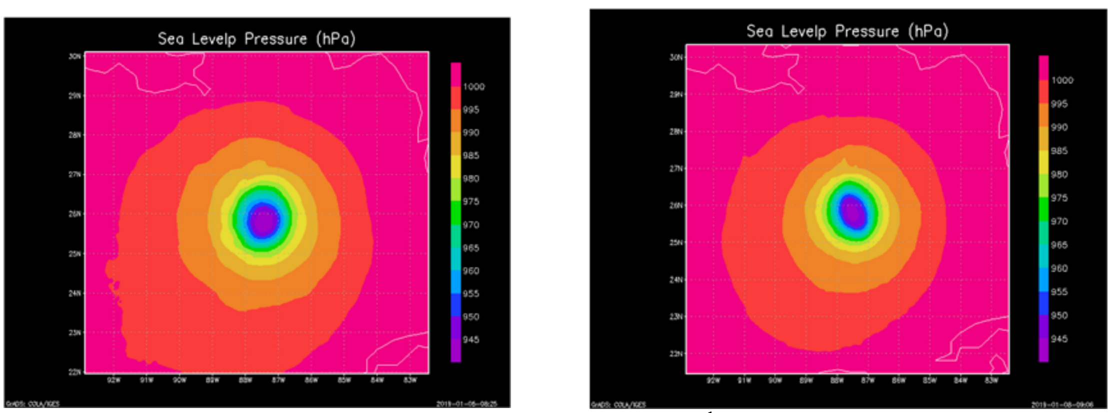


Figure 23: Sea Levelp Pressure (hPa) on 28th of August at 12:00
for d02 (second run) and d02 (final run), respectively.

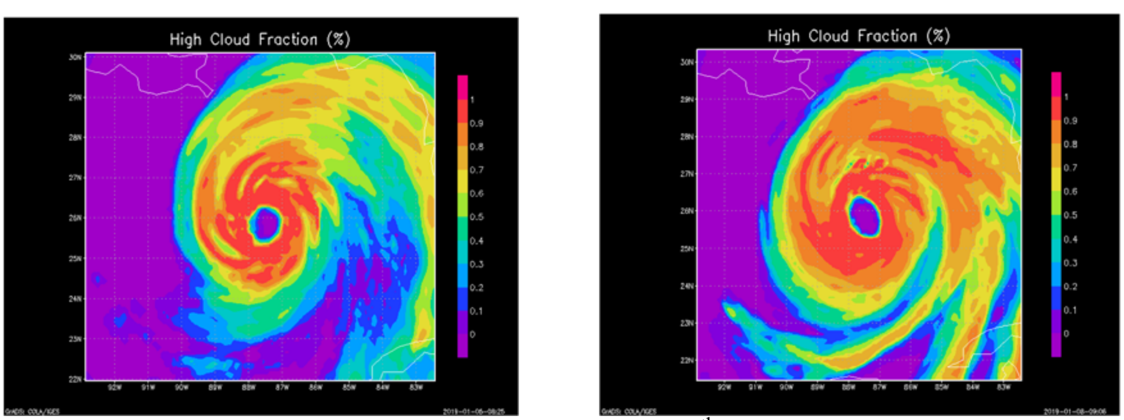


Figure 24: High Cloud Fraction (%) on 28th of August at 12:00
for d02 (second run) and d02 (final run), respectively.

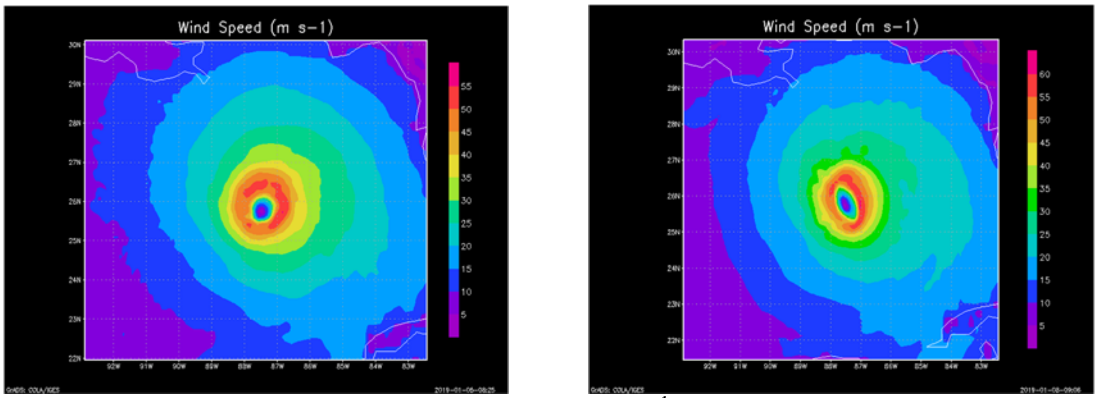


Figure 25: Wind Speed (m s-1) on 28th of August at 12:00
for d02 (second run) and d02 (final run), respectively.

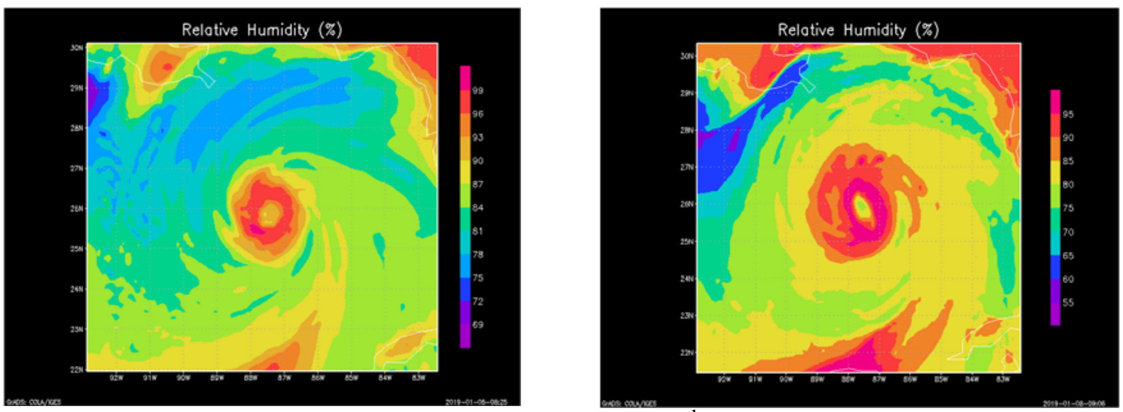


Figure 26: Relative Humidity (%) on 28th of August at 12:00
for d02 (second run) and d02 (final run), respectively.

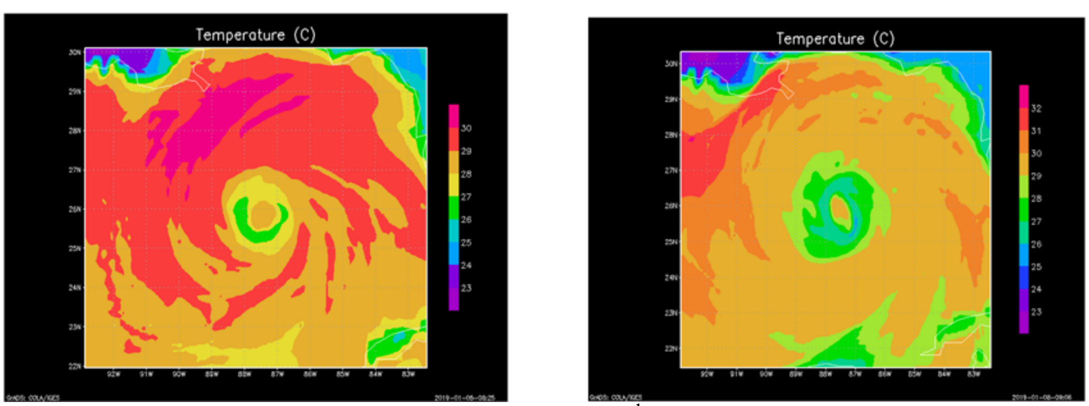
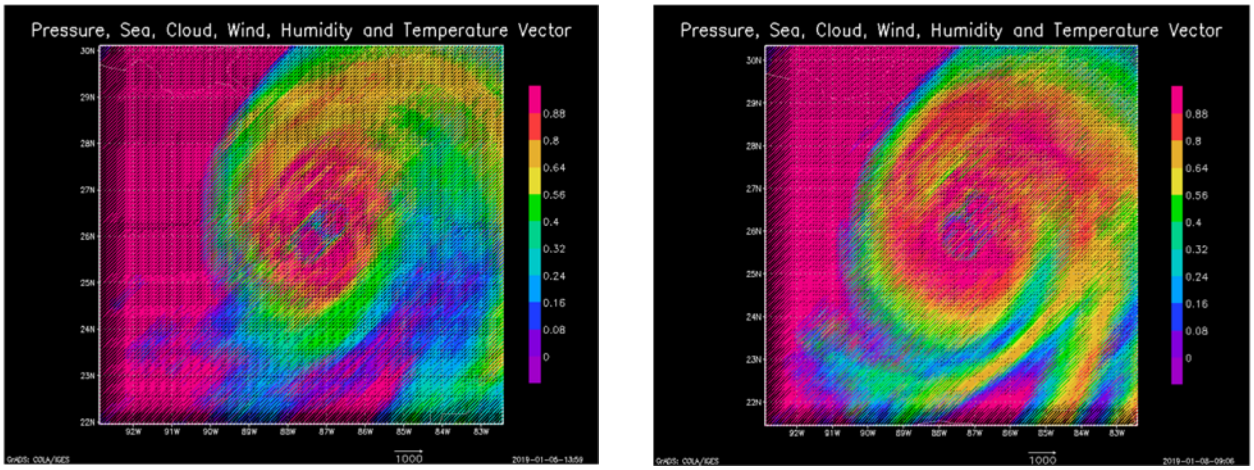


Figure 27: Temperature (C) on 28th of August at 12:00
for d02 (second run) and d02 (final run), respectively.

Specifically, we now display a vector combination simulation of all six weather variables with GrADS on 28th of August at 12:00 for d02 (second run) and d02 (final run), respectively.



(d02 - t = 3, 1200 GMT/UTC - second run) (d02 - t = 3, 1200 GMT/UTC - final run)

Figure 28: Vector simulation showing 28th of August at 12:00
for d02 (second run) and d02 (final run), respectively.

Comparing, Figure 14 with Figure 22-28 for d02 (second run) and d02 (final run), we can say d02 (final run) provide a better and more accurate prediction of the Katrina Hurricane event.

Additional, we have observed a drastic change in the movement and shape of the eye of the storm. This is a very good indication that we have improved our model predictions to represent realistic conditions, storm transformations and overall weather development; before historical landfall.

CONCLUSION

In this project, the performance of the WRF Model as applied to predictions of the Katrina Hurricane historical event has been observed. Visualizatons and Results points to an observable enhancement of realistic weather trajectories; with the usage of altered parametrizations and real data observations.

The WRF Model was envisioned to be used for both reseach and operations. For this kind of simulating phenomena, the drive is the importance of strong vertical accelerations of realistic weather tragectories. In this situation, nesting of these domains, one-way and two-way communication, are very essential due to the information flowing from both directions between domain grids; where parameterizing physical processes too small, too brief, too complex, or too poorly understood must be explicitly represented.

We have seen from our thought process of the predictions from our single and multiple domain WRF-ARW Model Runs, providing us an excellent idea of having importance on the selection of interrelated variables in any weather prediction. Such interrelationship can also be noticed in our two areas of parametrizations “&physics” and “&dynamics”, with a magnified process we know as “Two-Way Nesting”.

While six selected meteorological magniture weather variables have been used in this study, it is still recommended to investigate the usage and results of all the other variables executed within the Post-Processing Stage; with an awareness of accurate perception of realistic hurricane events.

A task such as this, can arisen with a computational price, due to our serial configuration selection and data observation period. This was further detected when we reduced our data observation period between 28th August, 2005 at 00:00 and 29th August, 2005 at 00:00 for our second and final case runs, which was drastically less computational expensive.

In such a computational circumstance, if future longer data observation periods are desired, it is expected to notice very inefficient data processing. Nevertheless, it might be recommended to attempt the usage of a parallel configuration selection or parrellel programming techingues for situations like this that exist.

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