1A.2 A COMPARISON OF TRMM AND WRF MODEL HINDCASTS OF RAINFALL IN THE CARIBBEAN

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1. INTRODUCTION

Extreme rainfall events have the capacity to [1]cause significant loss of life and damage to infrastructure. From an insurance perspective, determining the frequency of such events, as well as assessing the return period of any specific event for the purpose of triggering a payout, are of paramount importance. Unfortunately, such determinations are difficult. They require long observation periods, preferably in excess of 30 years. The fragmented and regional nature of rain events is another difficulty. A further complication is the nature of rain observations. Although the rain gauge is considered the gold standard for rain observations, gauges are usually relatively far apart, especially in the developing world. Convective rain events are often quite spotty in nature—very often some gauges will show no precipitation while nearby gauges show extreme amounts, depending on the exact motion of a given storm cell. Finally, gauges are sometimes not checked or read consistently, have maintenance issues, or have been relocated over time, complicating the spatial and temporal analyses.

In support of the development of an extreme rainfall index system for the Caribbean Catastrophe Risk Insurance Facility, a comparison was made between remotely sensed data, numerical models, and rain gauges using data in the Caribbean and Central America, including Florida and Puerto Rico. This paper describes an analysis of the performance of the Tropical Rainfall Measurement Mission 3B42 data sets and various configurations of two dynamical cores in the Weather Research and Forecasting (WRF) model Version 3.3.1. After initial experiments, configurations were selected for the Advanced Research core (ARW) and the Nonhydrostatic Mesoscale Model (NMM) core. Various input boundary data sets were also run and the differences evaluated, focusing on real time GFS initial time, the GFS final analysis data sets, and data from the NCAR/NCEP Reanalysis Project.

For the final analysis configuration, a set of scripts was developed to automate the process of running single day hindcasts from the models for a given day, fetching the TRMM and observations, and generating a set of standard outputs designed to facilitate the assessment of the simulations. The standardized outputs consist of the modeled rainfall from each of the two WRF cores, the TRMM 3B42 rainfall, and available station reports for that day derived from the National Climate Data Center (NCDC) Global Summary of the Day (GSOD) archives. Individual station data were compiled and analyzed using the R statistics package. Correlations were computed between several output variables (Temperature, Dew Point, Mean Sea Level Pressure, and Rainfall), and a scatter plot then created and incorporated in a Google Earth file (KML) as well as traditional data sets for further analysis using JMP software. The KML format and Google Earth facilitated the quick review of any of the hundreds of simulations generated by this study.
Neither the TRMM data or either numerical model estimates generated what could be considered as good correlations with the individual daily gauge reports, especially for Caribbean stations. Correlations (Pearson's *r*) between gauge and either satellite or model results were on average below 0.5. However, this is not entirely surprising. Previous studies (Chokngamwong and Chiu, 2007, for example) show relatively poor correlations between rain gauges and modeled or satellite remote sensing precipitation estimates for specific events, with much better correlations for climatology or areal averages.

This study verifies and expands these findings. There are several key reasons for this phenomenon, and the apparently poor direct correlation between the rain gauges and either modeling or remote sensing techniques must be carefully understood in the context of what exactly each sensor is measuring and the application to which it is to be applied. In particular, the fact that gauges are measurements at a point whereas both the satellite and model outputs are spatial averages is a significant source of the difference. In controlled analyses of closely located sets of stations (those within a single model or satellite grid cell), correlations rose dramatically. The study concluded that the hindcast produced by the NMM core produced the best correlations, closely followed by the ARW core. Both WRF configuration hindcasts were noticeably superior to the TRMM outputs when using GFS Final analysis data sets for boundary conditions. Comparisons with known extreme rainfall events in Guyana and Barbados were made, with the WRF hindcasts again proving superior to the TRMM data.

Based on these results, a final configuration was selected for use in the CCRIF index system study that

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uses both numerical models as well as the TRMM observations.

2. METHODOLOGY OVERVIEW

Despite its limitations, the individual rain gauge is the primary tool for rainfall analysis, especially for climatology studies where other area measuring techniques such as radar are not available. The primary source of rain gauge observations for this study is the Global Summary of the Day (GSOD) data from the US National Climatic Data Center (NCDC). The GSOD data sets are summaries from a variety of sources, and include precipitation as well as daily average temperature, dew point, wind, and surface pressure data. Additional detailed historical rain gauge data was obtained from NCDC for US and overseas military sites, as well as from MeteoFrance for stations in French territories in the Caribbean. Long term (defined as over 30 years) observations present numerous challenges. There are signifiant data processing issues surrounding these data sets. Sensors have moved or changed over time, and older style numerical coding techniques have reduced the usefulness of the data. For example, many stations use the same codes for missing data as are used to indicate no observed rainfall. This makes computing frequencies difficult. In the developing world stations are frequently off line for extended periods. Out of over 9000 stations worldwide, only 954 stations passed a basic quality control (QC) with the following criteria:

- unambiguous coding of missing data;
- station did not move more than 4km over the period;
- no more than 30 missing days in any given year;
- no more than 15 consecutive missing days.

In the Caribbean, only 32 non-US/Puerto Rico stations passed QC, mostly operated by MetoFrance or the UK government.

For operational runs, observations, surface and upper air data from the NOAAPORT satellite feeds are used and archived. These consist of surface reports (SYNOP and METAR), as well as upper air (UPA), ship and buoy reports. There are normally between 125 and 150 stations available within the Caribbean domain for routine daily analysis.

The Tropical Rainfall Monitoring Mission (TRMM) is a joint mission between the National Aeronautics and Space Administration (NASA) of the United States and the Japan Aerospace Exploration Agency (JAXA). The satellite was launched in November of 1997 and is currently continuing to operate. It is in a low inclination orbit covering the tropics between approximately 40S to 40N latitude. The primary rainfall sensors on board the TRMM spacecraft include the 13.8 GHz Precipitation Radar (PR) and the TRMM Microwave Imager (TMI). In addition, TRMM carries the Visible and Infrared Radiometer (VIRS), the Clouds and Earth's Radiant Energy System (CERES), and the Lightning Imaging System (LIS). The CERES instrument failed after only a few months of operation, but the other instruments are continuing to operate providing detailed information of rainfall over the tropics. The current TRMM data flow is shown in Figure 1. For this study, the Level 3 data set 3B42 is used. This is a multi-sensor composite using data from TRMM as well as other microwave sensors and infrared satellite precipitation estimates. The near real time daily composites are created automatically and are normally available for download by 12 GMT the following day. The final quality controlled daily composites are available approximately 6 months after the acquisition date.

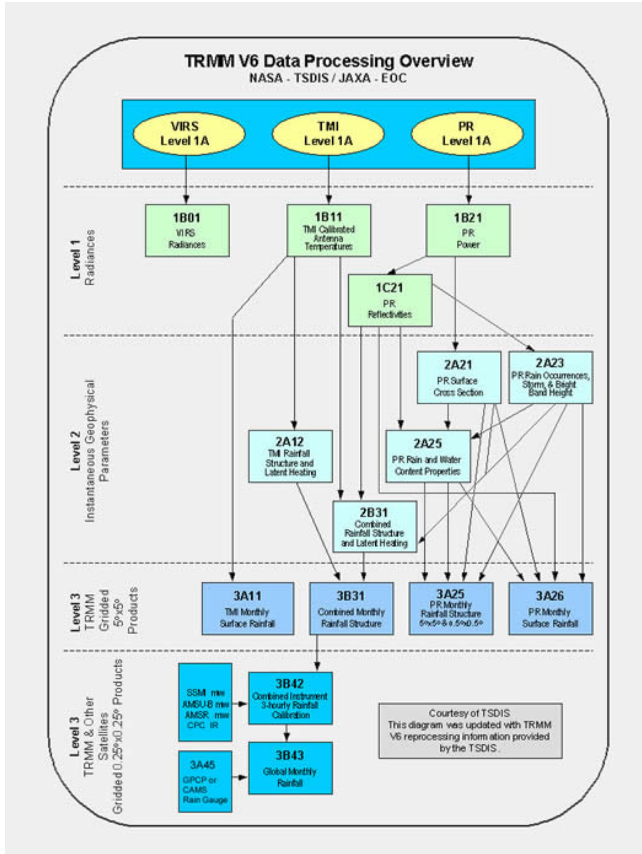

Figure 1: TRMM Data Processing (from NASA/GSFC)

Two additional satellite remote sensing based systems were briefly evaluated. First was the CPCMORPH system. The CPCMORPH data used in this study are from the Research Data Archive (RDA) which is maintained by the Computational and Information Systems Laboratory (CISL) at the National Center for Atmospheric Research (NCAR). NCAR is sponsored by the National Science Foundation (NSF). The original data are available from the RDA (http://dss.ucar.edu) in dataset number ds502.0. The second alternative satellite derived rainfall system is the PERSIANN rainfall estimation system (Sorooshian et al, 2000). The system outlined here can ingest the outputs of either system , however, neither appeared to have any significant operational advantages for the initial system.

Data from the San Juan Puerto Rico NEXRAD Doppler radar was used at various times during the testing phase. This data was extremely useful for assessing the relative performance of various model physics options in a Caribbean context. Unfortunately, other radar coverage in the region is intermittent, and not available for a long enough period of time to permit climatology assessments. However, as the number of stations and availability of data in the Caribbean region improves, ground radar data will certainly contribute to improving modeling and climatology studies, as they have in other regions.

The Weather Research and Forecasting (WRF) Model is a next-generation mesoscale numerical weather prediction system designed to serve both operational forecasting and atmospheric research needs. It features multiple dynamical cores, a 3-dimensional variational (3DVAR) data assimilation system, and a software architecture allowing for computational parallelism and system extensibility. WRF is suitable for a broad spectrum of applications across scales ranging from meters to thousands of kilometers. Two dynamical cores are used in the rainfall system: the Non-hydrostatic Mesoscale Model (NMM), and the Advanced Research WRF (ARW). Technical details on the NMM version may be found in Janjic, 2003, while NCAR Technical Note NCAR/TN-475 describes the ARW model. The two WRF models are the core of the simulation system.

Of vital importance for mesoscale/regional numerical models are the data sources and grids used for model initialization and boundary conditions during the simulation. Three sources were used in this study: real time GFS, GFS Final Analysis, and the NCEP/NCAR Reanalysis Projects data sets.

The Global Forecast System (GFS) and its predecessor, the Aviation Model, is the premier global weather forecasting model developed by the US National Weather Service. The GFS is run operationally 4 times per day. For operational mesoscale/regional modeling, the GFS model is the only publicly available source of real time global initial and boundary conditions. The GFS data is available in 0.5 and 1.0 degree data sets over the internet from the NWS NOMADS servers.

This project uses the GFS Final data as boundary conditions and initialization for the WRF models in our daily operational runs as well as medium term (12 year) history simulations for comparison with the TRMM archives. From the data archive:

> These NCEP FNL (Final) Operational Global Analysis data are on 1.0x1.0 degree grids prepared operationally every six hours. This product is from the Global Data Assimilation System (GDAS), which continuously collects observational data from the Global Telecommunications System (GTS), and other sources, for many analyses. The FNLs are made with the same model which NCEP uses in the Global Forecast System (GFS), but the FNLs are prepared about an hour or so after the GFS is initialized. The FNLs are delayed so that more observational data can be used. The GFS is run earlier in support of time critical forecast needs, and uses the FNL from the previous 6 hour cycle as part of its initialization.

The GFS Final Analysis data for this study are from the Research Data Archive (RDA) which is maintained by the Computational and Information Systems Laboratory (CISL) at the National Center for Atmospheric Research (NCAR). NCAR is sponsored by the National Science Foundation (NSF). The original data are available from the RDA (http://dss.ucar.edu) in dataset number ds083.2.

The NNRP data sets from 1948 to the present were used as boundary conditions and initialization for finer scale regional numerical models for our long term history simulations. From the data archive web site:

> The NCEP/NCAR Reanalysis Project is a joint project between the National Centers for Environmental Prediction (NCEP, formerly "NMC") and the National Center for Atmospheric Research (NCAR). The goal of this joint effort is to produce new atmospheric analyses using historical data (1948 onwards) and as well to produce analyses of the current atmospheric state (Climate Data Assimilation System, CDAS).

The NNRP data used in this study are from the Research Data Archive (RDA) which is maintained by the Computational and Information Systems Laboratory (CISL) at the National Center for Atmospheric Research (NCAR). NCAR is sponsored by the National Science Foundation (NSF). The original data are available from the RDA (http://dss.ucar.edu) in dataset number ds090.0.

3. NUMERICAL MODEL OVERVIEW

A set of scripts has been developed to automate the process of running the models for a given day and generating a set of standard outputs designed to facilitate the assessment of the simulations. The standardized outputs consist of the modeled rainfall from each of the two WRF models, the TRMM 3B42 rainfall, and any available station reports for that day derived from the GSOD archives. The KML format and Google Earth facilitated the quick review of any of the hundreds of simulations generated by this study. Figure 2 shows a typical run output and station comparison.

Individual station data are compiled and analyzed using the R statistics package. Correlations are computed between each of the key output variables (Temperature, Dew Point, Mean Sea Level Pressure, and Rainfall), and a scatter plot then incorporated in the Google Earth file.

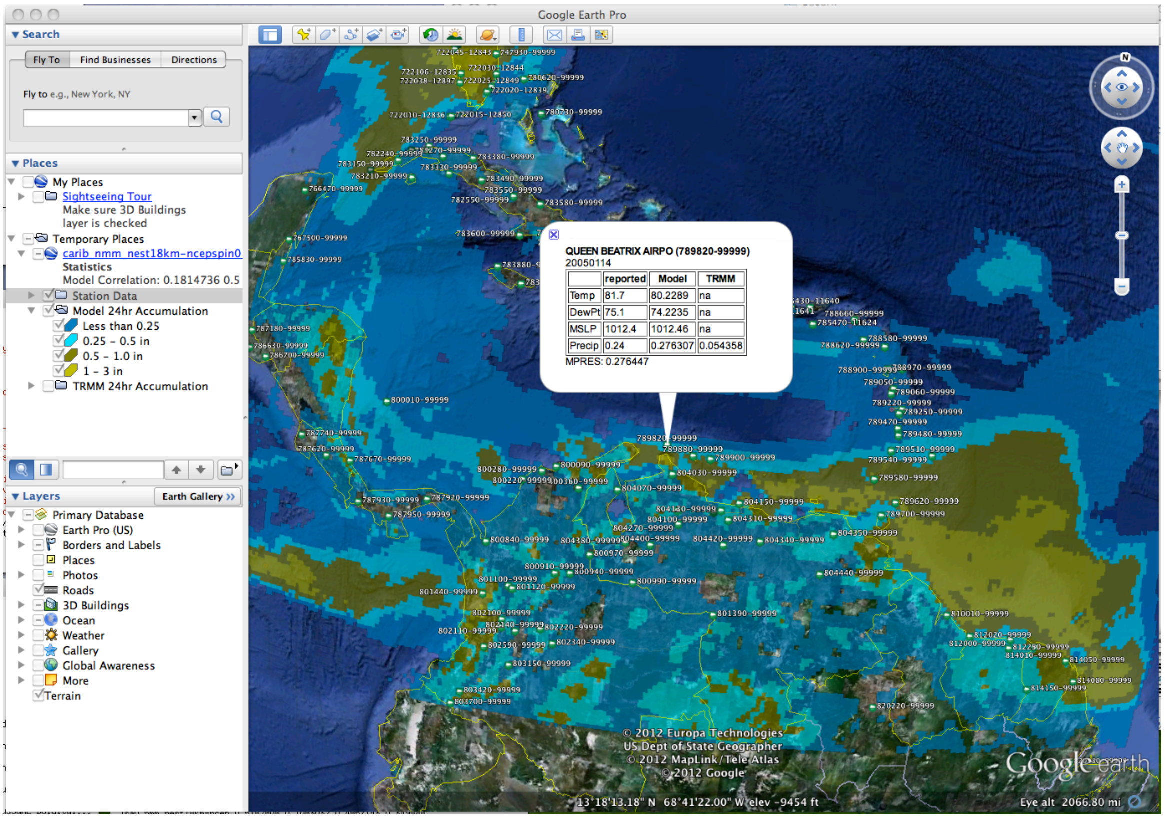

Figure 2: KML Output Package

Assessment Metrics

Multiple model runs were compared with observations and satellite derived remote sensing. The correlation coefficient (Pearson's ρ) was computed for each run and run set as follows. For precipitation, three principle correlations are computed:

ρ(model, GSOD)
ρ(TRMM, GSOD)
ρ(model,TRMM)

For decision making purposes, the ρ(model,GSOD) was our primary diagnostic, followed by an assessment of how well the run depicted the meteorological pattern of the day in question. The ρ(model, TRMM) correlation was also considered an important diagnostic. The false positive and false negative precipitation rate (using a threshold of 2.54mm/0.1") was also computed with respect to gauge reports. As additional tests, the daily average temperature, dew point temperature, and sea level pressure correlations were computed from the model outputs and compared to Global Summary of the Day reports.

4. RESULTS OVERVIEW

Appendix 1 describes the experiments with various numerical model configurations in the Caribbean region, while Appendix 2 describes similar experiments over the much more densely instrumented state of Florida as well as the northeastern US. Neither the TRMM data or numerical model estimates generated what could be considered as good correlations with the individual daily gauge reports, especially for Caribbean stations. However, this is not entirely surprising. Previous studies (Chokngamwong and Chiu, 2007, for example) show relatively poor correlations between rain gauges and modeled or satellite remote sensing precipitation estimates for specific events, with much better correlations for climatology or areal averages. This study verifies and expands these findings. There are several key reasons for this phenomena, and the apparently poor direct correlation between the rain gauges and either modeling or remote sensing techniques must be carefully understood in the context of what exactly each sensor is measuring and the application to which it is to be applied.

A properly working rain gauge is an isolated single point sample of a phenomena that is highly variable both spatially and temporally. The TRMM 3B46 approach is to estimate the rain rates over an area approximately 0.25 degrees square (28km) at the time of the pass via microwave radar, and to use infrared satellite precipitation estimates, calibrated with the most recent microwave data, between microwave sensor passes. These 3 hour "snapshots" of rain rates are then used to compute the daily rain total within a given grid cell. The CPCMORPH algorithm uses a bit more sophisticated algorithm, estimating the movements and rates of change of individual rain cells between snapshots. The numerical models are computing the average rainfall across a given model grid cell (25km for ARW and 18km for NMM in our test configurations). Thus, while often treated as the same thing, in reality the daily total rainfall from these sources are somewhat different measurements.

The variability of individual gauge measurements may be assessed by examining gauges in close proximity to one another. Even relatively reliable, nearly adjacent gauges can generate significantly different readings for individual rain events. For example, the rain gauges at Key West International Airport and Key West Naval Air station showed a ρ of only 0.436 for the 10 year period from 2000 to 2009. This result for identical sensors located only 7km apart in relatively homogeneous terrain places the TRMM and model outputs comparisons to rain gauges in a firmer context. The correlation between these gauges to modeling and TRMM, individually, are all less than 0.35. However, the correlation between the mean of the two gauges and TRMM jumps to over 0.55, and to the ARW and NMM models 0.48 and 0.61 respectively. A near identical result was obtained from examining two stations in the Georgetown, Guyana area. In total, 10 years of data from seventy pairs of stations in the Southeastern US and Caribbean located less than 20 km apart have been examined. The correlations were found to range from nearly zero to 0.933. Ninety percent of the correlations were less than 0.61, with half below 0.42. The average correlation was 0.375 – similar to the correlations seen by the modeling and remote sensing across the Caribbean and southeast US. In the case of Miami, Jacksonville, and Tampa areas, where there were 3 or more stations located within a 20km box, the correlation of the average of the stations to either TRMM or the two numerical models was higher than to any individual gauge. Therefore, for purposes of assessing the damage inflicted by excess rainfall, it could be argued that the areal averaging of the TRMM and numerical model techniques is actually superior to an isolated rain gauge in that they are giving a better picture of the overall rain accumulating in the region. Other comparison metrics were assessed, some of which are discussed in the appendices.

Other issues further cloud the direct correlation between rain gauges and other methods. Chief among these is that gauges are often not read or emptied at intervals consistent with model simulation intervals or satellite observations. It is interesting to note that correlations are substantially better over the US and Europe than in other areas, in part due to the density and consistency of the observation network (as rain readings are now mostly automated). This strongly argues for the evaluation and improvement of the Caribbean meteorological observation networks, an effort in progress under the sponsorship of CCRIF. Another consideration that must be taken in to account is that some specific weather systems may make consistent gauge readings unlikely. For example, during convective events substantial rain cells may either miss a gauge or directly pass over a gauge. A model or remote sensing system may correctly depict the system in general, but be off by one or more grid cells, selectively causing a miss (or hit). For a wide scale flood event likely to cause an insurance triggering event, this may be of little consequence, although it is more an issue for small island nations with micro-environments susceptible to small scale events that areal averaging might miss. This aspect is discussed further in the conclusions.

Another approach to assessing the correctness of the models is their performance with respect to other meteorological variables that are not as susceptible to measurement irregularities and small scale variability. Correlation between modeled and observed temperature, Dew Point, and mean sea level pressure values routinely scored above 0.9 and rarely fell below 0.8 in all of the tests. In addition, the selected model configurations, especially the NMM, did a good job in reproducing the synoptic meteorological situation. Finally, while the estimated rainfall did not precisely match gauge reports, it was encouraging that high rainfall events according to the gauges corresponded to high rainfall events in the models and, to an extent, TRMM. Therefore the results were sufficiently encouraging to proceed to the next phase, conducting the climatology runs and conducting comparisons with historical damage producing events to assess the performance of the return period system.

5. FINAL CONFIGURATION

Based on the Caribbean tests and the above considerations, the following model configurations were selected for both the operational daily hindcasts and climatological runs:

NMM: NCEP operational configuration, 56/18km nest, 6 hour spinup.

ARW: Eta Microphysics, Yonsei University PBL physics, Kain-Fritsch Cumulus Parameterization. 25Km resolution, DFI with no spinup, adaptive time stepping and FDDA options enabled. Observation initialization off.

Including the TRMM 3B42 data sets, three rainfall estimates per day are available for index calculations. It should be noted that the TRMM based data sets are outperformed in gauge correlation by both numerical models in most cases, despite being an “observation”. This is consistent with the conclusions of the CCRIF feasibility study conducted by the Caribbean Institute for Meteorology and Hydrology (CIMH, 2010), and is due to the differences in measurement discussed earlier. However, given that it is the only consistent regional observation system presently available, is widely used in global hydrology studies, and the relative ease with which the analysis could be implemented, it was felt that TRMM should be analyzed for climatology and included as one of the operational indices.

Appendix 1: Physics and Resolution Experiments in the Caribbean

A series of experiments was conducted using combinations of model physics and options with both the NMM and ARW configurations, as well as varying resolution from 4 to 25 km. In total over 1000 distinct simulations were conducted. Several time frames were analyzed in detail. The year 2008 was analyzed in its entirety, as all of the required boundary data sets were available for testing and comparison. The two case studies given by CIMH in their study, " Feasibility Study for Flood Risk Insurance in the Caribbean", were also studied in detail. These were the November 22-24th 2004 floods in Barbados, and the severe flood events experienced by Guyana during January 2005 (especially January 12th through 16th). Finally, the period from September 14th through September 24th 2011 were analyzed in near real time as part of final system development process.

Basic grid definition, nesting, and resolution tests

The simulation grid for the Caribbean was defined so as to encompass the CCRIF countries, with the exception of Bermuda. If was felt that including Bermuda directly in the master grid would result in excessive run times for climatology, and that a separate climatology run should be made for that study area, especially given the somewhat different climatology for that region. Figure 1.1 shows the master grid used for the ARW core, while Figure 1.2 shows the master grid for the NMM core.

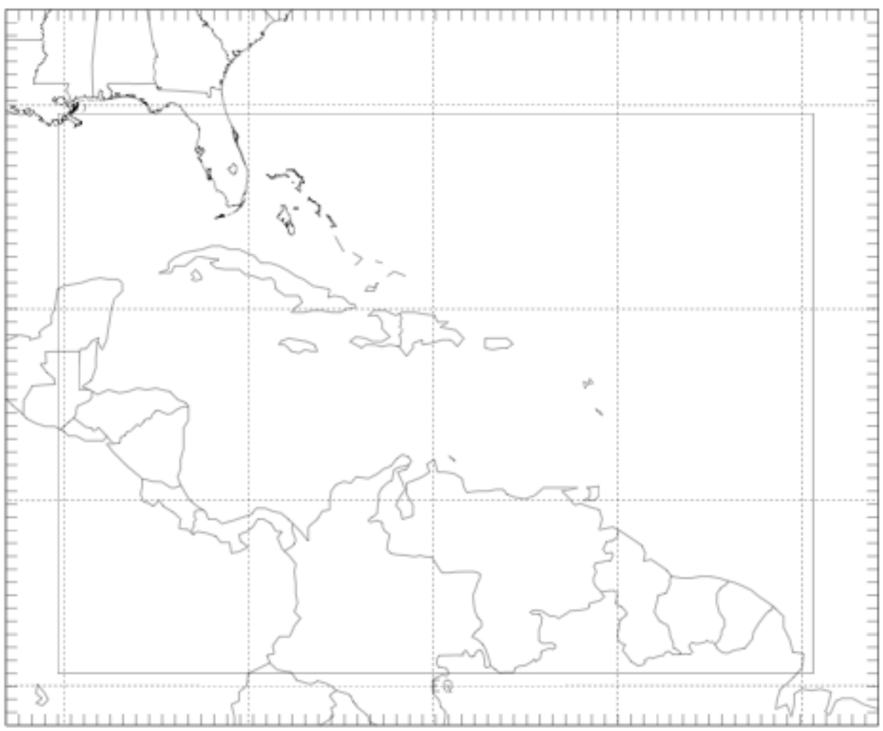

Figure 1.1: ARW Master Caribbean Domains

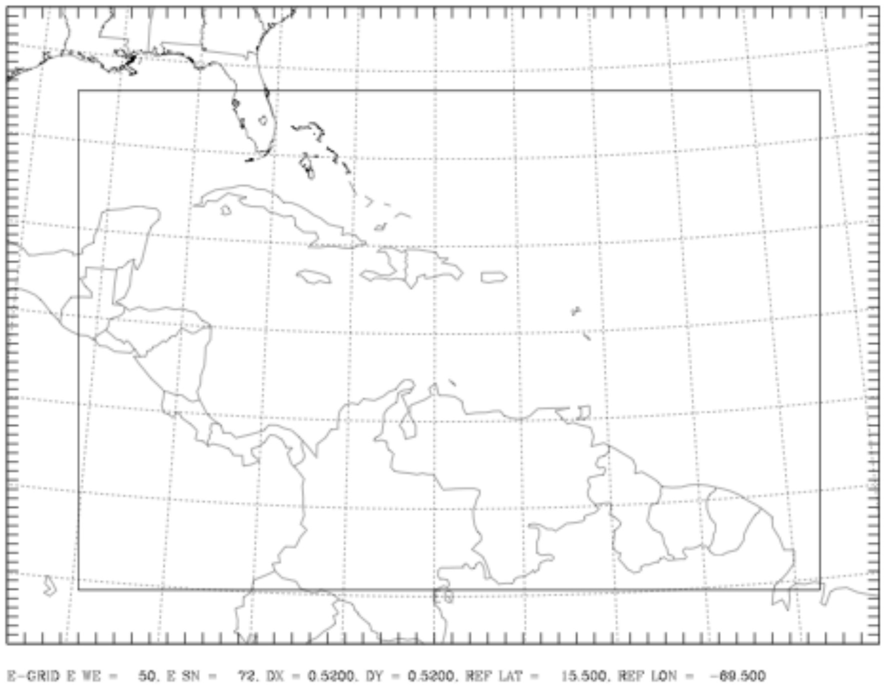

Figure 1.2: NMM Master Caribbean Domains

Increasing resolution (with appropriate physics changes) did not uniformly improve correlations. Table 1.1 shows the results for the September 11, 2011 simulations. In all cases examined, the NMM simulation using a 56km outer domain with an 18km inner domain (as depicted in Figure 1.2) had the best correlation with observations. The ARW 75km/25km grid (as shown in Figure 1.1) was the best ARW configuration in most, although overall the single 25km with FDDA performed almost as well.

Configuration	correlation	falsepos	falseneg	trmmcor
NMM 56/18km nest	0.312	0.474	0.268	0.243
ARW 36/12km nest	0.263	0.392	0.381	0.109
ARW 75/25km nest	0.262	0.453	0.405	0.261
NMM 12km single domain	0.231	0.359	0.444	0.234
NMM 27/09km nest	0.230	0.302	0.439	0.264
NMM 18km single domain	0.194	0.424	0.455	0.186
ARW 25km single domain	0.181	0.279	0.370	0.119
ARW 12km single domain	0.124	0.333	0.468	0.003
TRMM	0.328	0.239	0.532	1.000

Table 1.1: Impact of resolution and nesting for September 14, 2011 simulations

Microphysics, Cumulus, and PBL options

The WRF models have numerous possible options for initialization, model physics, and simulation. While there have been prior studies on the impact of model physics selection and initialization on quantitative precipitation forecasts (for example, Jankov, Gallus, Segal, and Koch, 2007), these studies concentrated on specific events and do not assess the performance of physics combinations across a wide range of events and seasons such as is needed for an operational insurance index system.

In this study, 32 different physics configuration of ARW and 12 NMM configurations were tested before selecting the operational configuration. Table 1.2 shows the performance of some of the ARW configurations for the Barbados flood event, as well as the TRMM 3B42 data sets.

Configuration	correlation	falsepos	falseneg	trmmcor
carib_arw_25km-cu1mp6pbl1	0.444	0.336	0.231	0.431
carib_arw_25km-cu1mp5pbl1	0.441	0.300	0.231	0.453
carib_arw_25km-cu1mp1pbl1	0.435	0.245	0.346	0.502
carib_arw_25km-cu1mp16pbl1	0.369	0.291	0.231	0.331
carib_arw_25km-cu1mp1pbl2	0.341	0.273	0.346	0.552
carib_arw_25km-cu1mp16pbl2	0.338	0.382	0.308	0.485
carib_arw_25km-cu1mp6pbl2	0.335	0.345	0.269	0.482
carib_arw_25km-cu1mp5pbl2	0.328	0.355	0.269	0.489
carib_arw_25km-cu2mp5pbl1	0.280	0.309	0.346	0.236
carib_arw_25km-cu2mp1pbl1	0.266	0.173	0.692	0.217
carib_arw_25km-cu3mp5pbl1	0.245	0.300	0.423	0.181
carib_arw_25km-cu2mp1pbl2	0.222	0.218	0.538	0.219
carib_arw_25km-cu5mp5pbl1	0.217	0.282	0.308	0.187
carib_arw_25km-cu5mp1pbl2	0.206	0.182	0.538	0.178
carib_arw_25km-cu2mp16pbl2	0.192	0.282	0.385	0.225
carib_arw_25km-cu5mp6pbl1	0.192	0.273	0.385	0.188
carib_arw_25km-cu2mp6pbl2	0.190	0.300	0.346	0.213
carib_arw_25km-cu3mp6pbl1	0.190	0.264	0.385	0.175
carib_arw_25km-cu5mp16pbl1	0.189	0.309	0.308	0.184
carib_arw_25km-cu2mp5pbl2	0.189	0.318	0.423	0.213
carib_arw_25km-cu5mp1pbl1	0.179	0.200	0.538	0.154
carib_arw_25km-cu3mp16pbl1	0.178	0.318	0.346	0.223
carib_arw_25km-cu3mp1pbl1	0.165	0.218	0.654	0.125
carib_arw_25km-cu3mp16pbl2	0.162	0.355	0.308	0.218
carib_arw_25km-cu3mp1pbl2	0.161	0.282	0.462	0.201
carib_arw_25km-cu5mp6pbl2	0.152	0.318	0.269	0.151
carib_arw_25km-cu3mp5pbl2adaptdfi	0.150	0.364	0.346	0.231
carib_arw_25km-cu5mp5pbl2	0.146	0.336	0.308	0.137
carib_arw_25km-cu3mp5pbl2adapt	0.137	0.364	0.365	0.191
carib_arw_25km-cu5mp16pbl2	0.136	0.336	0.308	0.173
carib_arw_25km-cu3mp5pbl2	0.126	0.368	0.365	0.193
carib_arw_25km-cu3mp6pbl2	0.094	0.318	0.346	0.237
carib_arw_25km-cu3mp5pbl2base	0.088	0.382	0.385	0.163
TRMM	0.467	0.209	0.308	1.000

Table 1.2: Physics Tests

Initialization, boundary considerations

There was surprisingly little difference in performance between using the 1.0 degree (111 km) and the 0.5 degree (56km) data sets generated by the NCEP real time GFS runs. In fact, the 1.0 degree data sets showed slightly better correlations with rain gauge observations than the 0.5 degree data sets, possibly due to the greater likelihood of introducing noise on the grid boundaries. The one exception was tropical cyclones, where the 0.5 degree data sets resulted in a better initial depiction of the storm, although position errors were comparable.

Comparisons between the NNRP and GFS data sets again showed distinct differences for tropical cyclone events due to the differences in initial conditions of the tightly structure systems that were not resolved at the much more coarse 1.9 degree NNRP data. Structure rapidly improved using FDDA (ARW) or a 12 hour spin-up (NMM). Position errors were significant in all cases. However, for other systems such as diffuse tropical lows and frontal passages, the differences were relatively minor. While this is not an issue with respect to developing climatology, which is the primary purpose of the NNRP data sets, it does make 1:1 comparisons with historical events somewhat problematic for tropical cyclones.

Again somewhat surprisingly, using surface stations to improve initialization had the opposite effect in the 18 to 25km resolution runs, noticeably decreasing correlations across the board in the Caribbean. It is suspected that this is due to the fact that the environment on smaller islands is substantially different from the surrounding atmosphere and is therefore not representative of the mesoscale conditions, so that using these stations distorted the initial conditions. At higher resolutions, less than 10km, surface station initialization did improve the runs. Surface stations were therefore not used for initialization in our operational simulations.

DFI, FFDA, and spin-up time

A series of tests were conducted on individual events to assess the impact of model spin up time and dynamic filter initialization (DFI) on correlation and precipitation rates. Table 1.3, generated for September 14 2011, is a "bad case" example. Overall, for ARW initialization via DFI with no spin up, and a 12 hour spin up for NMM was selected for the operational configurations.

					Correlations	
Experiment	**Model**	**Domain**	**Resolution**	**Spin up**	**Gauge**	**TRMM**
carib_arw_25km_0hr	ARW	Caribbean	25 km	0 hr	0.165	0.263
carib_arw_25km_6hr	ARW	Caribbean	25 km	6 hr	0.157	0.260
carib_arw_25km_12hr	ARW	Caribbean	25 km	12 hr	0.187	0.257
carib_arw_25km_18hr	ARW	Caribbean	25 km	18 hr	0.135	0.262
carib_arw_25km_24hr	ARW	Caribbean	25 km	24 hr	0.101	0.284
carib_nmm_25km_0hr	NMM	Caribbean	56/18 Nest	0 hr	0.243	0.267
carib_nmm_25km_6hr	NMM	Caribbean	56/18 Nest	6 hr	0.190	0.276
carib_nmm_25km_12hr	NMM	Caribbean	56/18 Nest	12 hr	0.362	0.163
carib_nmm_25km_18hr	NMM	Caribbean	56/18 Nest	18 hr	0.250	0.174
carib_nmm_25km_24hr	NMM	Caribbean	56/18 Nest	24 hr	0.163	0.105

Table 1.3: Impact of model spin up time on gauge correlations

The use of observations and four dimensional data assimilation and nudging was tested in the ARW configuration. The results of a 10 day test run using the operational Caribbean grid are shown in table 1.4. Again, the NMM NCEP configuration has the best correlation with gauge measurements. Between the use of FDDA nudging and observation tweaking, using FDDA nudging resulted in significant improvements in correlations while using observations had a significant net decrease in both correlation and the overall depiction of the meteorology.

Configuration	Gauge Corr	FalsePos	FalseNeg	TRMMCOR
NMM NCEP Configuration	0.518	0.108	0.486	0.350
ARW Using FDDA	0.425	0.061	0.556	0.422
ARW No Observations or FDDA	0.249	0.089	0.583	0.113
ARW With Observations Only	0.168	0.058	0.861	0.119
TRMM	0.357	0.064	0.583	1.000

Table 1.4: Incorporation of Observations and FDDA

The use of adaptive time steps in ARW significantly reduced run times, with no discernible degradation of model correlations with observations or meteorological depiction. Adaptive time steps and FDDA nudging are not presently available in NMM, however, NMM is more efficient and therefore run times between the two cores are similar.

Summary of final configuration tests on CIMH events

The synoptic situation and impacts of these two primary test events are described in CIMH, 2010. Table 5 shows the aggregated performance of representative model configurations on the CIMH events. Higher resolution subgrids over both Guyana and Barbados failed to produce significantly better correlations with observed, and in many cases produced worse correlations, as noted in table 1.5.

Experiment	Model	Domain	Resolution	Cumulus	Microphysics	PBL	Correlations Gauge	TRMM
carib_nmm_nest18km-ncep	NMM	Caribbean	56/18 Nest	NCEP NAM Operational Configuration			0.425	0.362
carib_arw_25km-cu5mp6pbl2	ARW	Caribbean	25 km	Grell-3	WSM 6	MYJ	0.254	0.159
carib_arw_25km-cu3mp5pbl2	ARW	Caribbean	25 km	Grell-Devenyi	Eta (Ferrier)	MYJ	0.238	0.141
carib_nmm_nest12km-ncep	NMM	Caribbean	36/12 Nest	NCEP NAM Operational Configuration			0.220	0.340
carib_arw_12km-cu5mp6pbl2	ARW	Caribbean	12.5 km	Grell-3	WSM 6	MYJ	0.190	0.146
carib_arw_12kma-cu3mp5pbl2	ARW	Caribbean	12.5 km	Grell-Devenyi	Eta (Ferrier)	MYJ	0.187	0.059
carib_nmm_nest09km-ncep	NMM	Caribbean	27/9 Nest	NCEP NAM Operational Configuration			0.162	0.232
carib_nmm_nest18km-cu3mp5pbl2	NMM	Caribbean	56/18 Nest	Grell-Devenyi	Eta (Ferrier)	MYJ	0.050	0.149

Table 1.5: Performance of regional grids on CIMH Events

Appendix 2: Physics and Resolution Experiments in Florida

Given the sparsity of consistent station reports in the Caribbean, a set of simulations was made across the state of Florida using several tropical and non-tropical events as a confidence building measure and independent check on the conclusions reached from the Caribbean wide modeling. These simulations used several combinations of input options for both the NMM and ARW configurations, as well as several domain resolutions for the ARW configurations. This examination of the models performance was accomplished in two separate parts. For the first component of this experiment, three different tropical events that impacted Florida were used to evaluate the performance of the model runs. These events were Hurricane Wilma, October 15-25 2005, Tropical Storm Alberto, June 10-14 2006, and Tropical Storm Claudette, August 16-17 2009. These storms were selected because they cover a variety of intensities and each one occurred at a different time during the typical hurricane season. For the second part of this study, the performances of the ARW and NMM configurations were tested on six different non-tropical events that brought precipitation to Florida during the fall of 2011. The dates analyzed were September 24 2011, September 26-27 2011, and October 8-10 2011.

Correlations for Tropical Events in Florida

Because the correlation of precipitation estimates from the WRF models with the observations were low, it was necessary to determine if this was caused by the lack of stations in the Caribbean domain. It was also decided that to further analyze the model performance, it was necessary to check the correlation values for other parameters such as temperature, dew point temperature, and surface level pressure.

In this study, several different correlation values were determined for the WRF models. Two different ARW domains were tested, a 25km domain and a nested 75km/25km domain. These correlations included the precipitation correlation with the gauge, the precipitation correlation with the TRMM model prediction, temperature, dew point temperature, and surface pressure correlation. Table 2.1 shows the performance of the ARW and NMM models for the three different tropical events studied.

					Correlations				
Experiment	**Model**	**Domain**	**Resolution**	**Spin up**	**Gauge**	**TRMM**	**Temperature**	**Dew Point Temp.**	**Pressure**
fla_arw_nest75km_wilma	ARW	Florida	75/25 Nest	0 hr	0.431	0.610	0.964	0.966	0.970
fla_arw_25km_wilma	ARW	Florida	25 km	0 hr	0.516	0.656	0.958	0.981	0.965
fla_nmm_18km_wilma	NMM	Florida	56/18 Nest	0 hr	0.648	0.720	0.962	0.964	0.986
fla_nmm_18km_alberto	NMM	Florida	56/18 Nest	0 hr	0.448	0.744	0.891	0.940	0.744
fla_arw_25km_alberto	ARW	Florida	25 km	0 hr	0.563	0.470	0.910	0.940	0.820
fla_arw_nest75km_alberto	ARW	Florida	75/25 Nest	0 hr	0.571	0.452	0.896	0.940	0.932
fla_arw_25km_claudette	ARW	Florida	25 km	0 hr	0.454	0.491	0.808	0.882	0.865
fla_arw_nest75km_claudette	ARW	Florida	75/25 Nest	0 hr	0.463	0.391	0.838	0.795	0.924
fla_nmm_18km_claudette	NMM	Florida	56/18 Nest	0 hr	0.509	0.465	0.781	0.771	0.940

Table 2.1: Tropical Storm Tests

Storm Intensity Considerations for Tropical Events

There was little difference in performance between all three tropical events, however it was noticeable that the models did not perform as well on Tropical Storm Claudette. This led to an examination of the intensity of each event to determine if this had an impact on the model performance. This was done by examining station data in Florida for each tropical event. Table 2.2 shows the station data that was available in the National Hurricane Center's archive. The only information of interest was the amount of precipitation and the strongest wind gust measured at each station.

Hurricane Wilma, 10/15-25/05		
Station	Gust (kt)	Rain (in)
Fort Lauderdale (KFLL)	86	3.04
Fort Myers (KRSW)	69	5.44
Fort Pierce (KFPR)	68	5.47
Key West (KEYW)	72	2.02
Leesburg (KLEE)	35	4.88
Loxahatchee (LXWS)	98	3.12
MacDill AFB (KMCF)	37	2.53
Melbourne (KMLB)	52	4.25
Miami (KMIA)	80	0.76
Naples (KAPF)	71	6.63
Orlando (KORL)	43	3.88
Punta Gorda (KPGD)	61	3.93
St. Petersburg (KPIE)	43	1.64
Sanford (KSFB)	37	3.59
Sarasota (KSRQ)	42	3.81
Tampa (KTPA)	38	1.44
West Palm Beach (KPBI)	88	1.07

Tropical Storm Alberto, 6/10-14/2006		
Station	Gust (kt)	Rain (in)
Brooksville (KBKV)	37	2.60
St. Petersburg (KPIE)	44	3.97
Tampa (KTPA)	39	3.46
Sarasota (KSRQ)	38	4.51
Punta Gorda (KPGD)	40	2.32
MacDill AFB (KMCF)	49	3.39
Tallahassee (KTLH)	33	3.25
Jacksonville (KJAX)	38	2.89
Ocala (KOCF)	37	1.31
Melbourne (KMLB)	49	2.32
Orlando (KORL)	37	3.48
Sanford (KSFB)	46	4.03
Daytona Beach (KDAB)	32	3.61
Leesburg (KLEE)	40	2.38

Tropical Storm Claudette, 8/16-17/2009		
Station	Gust (kt)	Rain (in)
Apalachicola (KAAF)	45	3.15
Crestview (KCEW)	34	0.00
Destin/Ft. Walton (KDTS)	39	0.00
Panama City (KPFN)	34	2.11
Tallahassee (KTLH)	34	0.00
Tyndall AFB (KPAM)	37	0.00
Valparaiso (KVPS)	39	0.00

Table 2.2: Station Data for Tropical Events

Correlations for Non-tropical Events in Florida

For the next part of this study, a series of tests were conducted on individual non-tropical rain events to assess the impact of modifying the inputs and the GFS resolution on both configurations. Observations were either used to modify the inputs to meteorological grids prior to generating the model initial conditions or they were not used at all. In addition, the GFS degree was set to either 0.5 or 1. Three different domain resolutions were used for the ARW model to also determine if the resolution made a significant impact on the correlation values. Table 2.3 shows the results for the three dates studied in September while Table 2.4 shows the results for the three dates studied in October.

							Correlations	
Date	Experiment	Model	Domain	Resolution	GFS degree	Obs.	Gauge	TRMM
09/24/11	fla_arw_12p5km_yes0p5_yesobs	ARW	Florida	12.5 km	0.5	yes	0.098	0.155
09/24/11	fla_arw_25km_yes0p5_nobs	ARW	Florida	25 km	0.5	no	0.106	0.154
09/24/11	fla_arw_12p5km_no0p5_nobs	ARW	Florida	12.5 km	1	no	0.107	0.144
09/24/11	fla_arw_12p5km_yes0p5_nobs	ARW	Florida	12.5 km	0.5	no	0.115	0.167
09/24/11	fla_arw_25km_yes0p5_yesobs	ARW	Florida	25 km	0.5	yes	0.117	0.159
09/24/11	fla_arw_12p5km_no0p5_yesobs	ARW	Florida	12.5 km	1	yes	0.125	0.198
09/24/11	fla_arw_25km_no0p5_yesobs	ARW	Florida	25 km	1	yes	0.134	0.203
09/24/11	fla_arw_25km_no0p5_nobs	ARW	Florida	25 km	1	no	0.136	0.209
09/24/11	fla_nmm_18km_yesp0p5	NMM	Florida	56/18 Nest	0.5	N/A	0.147	0.503
09/24/11	fla_nmm_18km_no0p5	NMM	Florida	56/18 Nest	1	N/A	0.166	0.495
09/24/11	fla_arw_75nest_yes0p5_yesobs	ARW	Florida	75/25 Nest	0.5	yes	0.177	0.291
09/24/11	fla_arw_75nest_no0p5_yesobs	ARW	Florida	75/25 Nest	1	yes	0.190	0.281
09/24/11	fla_arw_75nest_yes0p5_nobs	ARW	Florida	75/25 Nest	0.5	no	0.207	0.300
09/24/11	fla_arw_75nest_no0p5_nobs	ARW	Florida	75/25 Nest	1	no	0.233	0.310
09/26/11	fla_arw_12p5km_no0p5_yesobs	ARW	Florida	12.5 km	1	yes	0.133	0.261
09/26/11	fla_arw_12p5km_no0p5_nobs	ARW	Florida	12.5 km	1	no	0.150	0.228
09/26/11	fla_arw_12p5km_yes0p5_nobs	ARW	Florida	12.5 km	0.5	no	0.178	0.241
09/26/11	fla_arw_12p5km_yes0p5_yesobs	ARW	Florida	12.5 km	0.5	yes	0.205	0.269
09/26/11	fla_nmm_18km_no0p5	NMM	Florida	56/18 Nest	1	N/A	0.270	0.240
09/26/11	fla_nmm_18km_yesp0p5	NMM	Florida	56/18 Nest	0.5	N/A	0.281	0.236
09/26/11	fla_arw_75nest_no0p5_nobs	ARW	Florida	75/25 Nest	1	no	0.315	0.234
09/26/11	fla_arw_75nest_no0p5_yesobs	ARW	Florida	75/25 Nest	1	yes	0.328	0.33
09/26/11	fla_arw_75nest_yes0p5_yesobs	ARW	Florida	75/25 Nest	0.5	yes	0.333	0.324
09/26/11	fla_arw_75nest_yes0p5_nobs	ARW	Florida	75/25 Nest	0.5	no	0.346	0.222
09/26/11	fla_arw_25km_yes0p5_yesobs	ARW	Florida	25 km	0.5	yes	0.386	0.428
09/26/11	fla_arw_25km_yes0p5_nobs	ARW	Florida	25 km	0.5	no	0.388	0.423
09/26/11	fla_arw_25km_no0p5_nobs	ARW	Florida	25 km	1	no	0.402	0.436
09/26/11	fla_arw_25km_no0p5_yesobs	ARW	Florida	25 km	1	yes	0.402	0.437
09/27/11	fla_arw_12p5km_yes0p5_yesobs	ARW	Florida	12.5 km	0.5	yes	0.047	-0.010
09/27/11	fla_nmm_18km_yesp0p5	NMM	Florida	56/18 Nest	0.5	N/A	0.063	0.090
09/27/11	fla_arw_12p5km_yes0p5_nobs	ARW	Florida	12.5 km	0.5	no	0.064	-0.059
09/27/11	fla_nmm_18km_no0p5	NMM	Florida	56/18 Nest	1	N/A	0.070	0.115
09/27/11	fla_arw_12p5km_no0p5_nobs	ARW	Florida	12.5 km	1	no	0.080	-0.050
09/27/11	fla_arw_12p5km_no0p5_yesobs	ARW	Florida	12.5 km	1	yes	0.100	-0.080
09/27/11	fla_arw_25km_yes0p5_nobs	ARW	Florida	25 km	0.5	no	0.145	0.230
09/27/11	fla_arw_25km_yes0p5_yesobs	ARW	Florida	25 km	0.5	yes	0.146	0.232
09/27/11	fla_arw_25km_no0p5_nobs	ARW	Florida	25 km	1	no	0.153	0.205
09/27/11	fla_arw_25km_no0p5_yesobs	ARW	Florida	25 km	1	yes	0.154	0.207
09/27/11	fla_arw_75nest_no0p5_nobs	ARW	Florida	75/25 Nest	1	no	0.181	0.358
09/27/11	fla_arw_75nest_yes0p5_nobs	ARW	Florida	75/25 Nest	0.5	no	0.184	0.330
09/27/11	fla_arw_75nest_no0p5_yesobs	ARW	Florida	75/25 Nest	1	yes	0.263	0.275
09/27/11	fla_arw_75nest_yes0p5_yesobs	ARW	Florida	75/25 Nest	0.5	yes	0.278	0.243

Table 2.3: Non-tropical tests for September

Date	Experiment	Model	Domain	Resolution	GFS degree	Obs.	Correlations Gauge	Correlations TRMM
10/08/11	fla_arw_25km_no0p5_nobs	ARW	Florida	25 km	1	no	0.353	0.537
10/08/11	fla_arw_25km_yes0p5_nobs	ARW	Florida	25 km	0.5	no	0.366	0.540
10/08/11	fla_arw_25km_no0p5_yesobs	ARW	Florida	25 km	1	yes	0.387	0.570
10/08/11	fla_arw_25km_yes0p5_yesobs	ARW	Florida	25 km	0.5	yes	0.411	0.573
10/08/11	fla_arw_12p5km_no0p5_nobs	ARW	Florida	12.5 km	1	no	0.483	0.681
10/08/11	fla_arw_12p5km_yes0p5_yesobs	ARW	Florida	12.5 km	0.5	yes	0.488	0.713
10/08/11	fla_arw_12p5km_no0p5_yesobs	ARW	Florida	12.5 km	1	yes	0.495	0.691
10/08/11	fla_arw_12p5km_yes0p5_nobs	ARW	Florida	12.5 km	0.5	no	0.520	0.732
10/08/11	fla_nmm_18km_yesp0p5	NMM	Florida	56/18 Nest	0.5	N/A	0.530	0.660
10/08/11	fla_arw_75nest_no0p5_yesobs	ARW	Florida	75/25 Nest	1	yes	0.540	0.706
10/08/11	fla_arw_75nest_yes0p5_yesobs	ARW	Florida	75/25 Nest	0.5	yes	0.553	0.723
10/08/11	fla_nmm_18km_no0p5	NMM	Florida	56/18 Nest	1	N/A	0.545	0.670
10/08/11	fla_arw_75nest_yes0p5_nobs	ARW	Florida	75/25 Nest	0.5	no	0.571	0.735
10/08/11	fla_arw_75nest_no0p5_nobs	ARW	Florida	75/25 Nest	1	no	0.573	0.728
10/09/11	fla_arw_12p5km_no0p5_nobs	ARW	Florida	12.5 km	1	no	0.595	0.779
10/09/11	fla_arw_75nest_yes0p5_nobs	ARW	Florida	75/25 Nest	0.5	no	0.614	0.603
10/09/11	fla_arw_75nest_no0p5_nobs	ARW	Florida	75/25 Nest	1	no	0.615	0.582
10/09/11	fla_arw_75nest_no0p5_yesobs	ARW	Florida	75/25 Nest	1	yes	0.630	0.587
10/09/11	fla_arw_12p5km_no0p5_yesobs	ARW	Florida	12.5 km	1	yes	0.631	0.780
10/09/11	fla_arw_12p5km_yes0p5_nobs	ARW	Florida	12.5 km	0.5	no	0.634	0.755
10/09/11	fla_arw_25km_yes0p5_yesobs	ARW	Florida	25 km	0.5	yes	0.638	0.766
10/09/11	fla_arw_25km_yes0p5_nobs	ARW	Florida	25 km	0.5	no	0.642	0.766
10/09/11	fla_arw_75nest_yes0p5_yesobs	ARW	Florida	75/25 Nest	0.5	yes	0.643	0.597
10/09/11	fla_arw_25km_no0p5_nobs	ARW	Florida	25 km	1	no	0.644	0.756
10/09/11	fla_arw_25km_no0p5_yesobs	ARW	Florida	25 km	1	yes	0.655	0.757
10/09/11	fla_arw_12p5km_yes0p5_yesobs	ARW	Florida	12.5 km	0.5	yes	0.661	0.765
10/09/11	fla_nmm_18km_no0p5	NMM	Florida	56/18 Nest	1	N/A	0.683	0.648
10/09/11	fla_nmm_18km_yesp0p5	NMM	Florida	56/18 Nest	0.5	N/A	0.696	0.635
10/10/11	fla_arw_25km_no0p5_yesobs	ARW	Florida	25 km	1	yes	0.250	0.308
10/10/11	fla_arw_25km_no0p5_nobs	ARW	Florida	25 km	1	no	0.253	0.317
10/10/11	fla_arw_25km_yes0p5_yesobs	ARW	Florida	25 km	0.5	yes	0.280	0.353
10/10/11	fla_arw_25km_yes0p5_nobs	ARW	Florida	25 km	0.5	no	0.282	0.344
10/10/11	fla_arw_12p5km_no0p5_yesobs	ARW	Florida	12.5 km	1	yes	0.346	0.580
10/10/11	fla_arw_12p5km_no0p5_nobs	ARW	Florida	12.5 km	1	no	0.350	0.368
10/10/11	fla_arw_12p5km_yes0p5_yesobs	ARW	Florida	12.5 km	0.5	yes	0.386	0.356
10/10/11	fla_arw_12p5km_yes0p5_nobs	ARW	Florida	12.5 km	0.5	no	0.387	0.351
10/10/11	fla_nmm_18km_no0p5	NMM	Florida	56/18 Nest	1	N/A	0.388	0.364
10/10/11	fla_nmm_18km_yesp0p5	NMM	Florida	56/18 Nest	0.5	N/A	0.390	0.352
10/10/11	fla_arw_75nest_yes0p5_nobs	ARW	Florida	75/25 Nest	0.5	no	0.421	0.404
10/10/11	fla_arw_75nest_no0p5_yesobs	ARW	Florida	75/25 Nest	1	yes	0.422	0.392
10/10/11	fla_arw_75nest_no0p5_nobs	ARW	Florida	75/25 Nest	1	no	0.426	0.403
10/10/11	fla_arw_75nest_yes0p5_yesobs	ARW	Florida	75/25 Nest	0.5	yes	0.428	0.394

Table 2.4: Non-tropical tests for October

Storm Intensity Considerations for Non-Tropical Events

There was a surprisingly large difference in correlation values between the six non-tropical events. This led to an examination of the intensity of each date to determine if this had an impact on how the models performed. This was done by examining station data from six different stations across Florida as well as the TRMM precipitation predictions from each station. The gauge rainfall data was collected from the GSOD information for each station. Table 2.5 shows the gauge rainfall amount as well as the TRMM predictions in inches for each station.

	Miami		Orlando		Tampa		Melbourne		Naples		Gainesville	
	Gauge	TRMM	Gauge	TRMM	Gauge	TRMM	Gauge	TRMM	Gauge	TRMM	Gauge	TRMM
Sept. 24th	0.53	0.14	2.14	0.00	0.01	0.11	0.24	3.01	0.00	0.00	0.37	0.08
Sept. 26th	0.08	0.66	0.00	0.00	0.19	0.04	0.00	0.19	2.30	2.16	0.02	0.22
Sept. 27th	0.24	0.13	0.19	0.13	0.22	0.04	0.11	0.27	1.58	0.00	0.00	0.00
Oct. 8th	3.20	2.74	1.24	1.54	0.09	0.03	1.68	3.09	0.00	0.00	0.00	0.37
Oct. 9th	2.94	1.36	5.17	1.12	0.39	0.67	4.58	1.49	0.04	0.13	0.39	0.35
Oct. 10th	0.10	0.00	0.69	0.00	1.43	0	0.41	2.17	0.27	0.68	1.57	3.76

Table 2.5: Gauge data and TRMM precipitation predictions for non-tropical events

Examination of Input Modification on Non-Tropical Model Correlations

For the next analysis, the date with the largest rainfall amount, October 9 2011, was looked at to further test the impact of input modifications. The only model of interest was the ARW at a domain resolution of 25 km. Three different input options were examined: using observations to modify the inputs to meteorological grids prior to generating the model initial conditions, using data assimilation to directly modify the model initial conditions, and not using any observations or data assimilation in the model run. Table 2.6 shows the correlation results of these three different input options for the October 9 event.

							Correlations				
Date	Experiment	Model	Domain	Resolution	GFS degree	Obs. Or DA	Gauge	TRMM	Temp.	Dew Point Temp.	Pressure
10/09/11	fla_arw_25km_no0p5_useobs	ARW	Florida	25 km	1	Obs.	0.601	0.770	0.895	0.951	0.960
10/09/11	fla_arw_25km_no0p5_useda	ARW	Florida	25 km	1	DA	0.640	0.767	0.893	0.950	0.960
10/09/11	fla_arw_25km_no0p5_nobs	ARW	Florida	25 km	1	none	0.645	0.756	0.887	0.950	0.962

Table 2.6: Impact of input modifications

Effect of nesting feedback option

The next topic of interest was the impact of changing the feedback option and the result that this would have on the correlation values. The feedback option causes the outer nest to be modified by the results of the interior nest. This was tested using both the nested ARW and nested NMM domains for the tropical events as well as the non-tropical events. The values of interest were the gauge, TRMM, temperature, dew point temperature, and pressure correlations. The results for the three tropical events are shown in Table 2.7 while the results for the six non-tropical events are shown in Table 2.8. Once the correlations were determined, the percentage of the change caused by turning on the feedback option was calculated. The results for the tropical and non-tropical events were combined and are shown in Table 2.9.

						Correlations				
Experiment	Model	Domain	Resolution	Spin up	Feedback	Gauge	TRMM	Temperature	Dew Point Temp.	Pressure
fla_arw_nest75km_yesfb_wilma	ARW	Florida	75/25 Nest	0 hr	yes	0.431	0.610	0.961	0.966	0.970
fla_arw_nest75km_nofb_wilma	ARW	Florida	75/25 Nest	0 hr	no	0.457	0.593	0.960	0.964	0.976
fla_nmm_nest18km_nofb_wilma	NMM	Florida	56/18 Nest	0 hr	no	0.632	0.686	0.962	0.964	0.990
fla_nmm_nest18km_yesfb_wilma	NMM	Florida	56/18 Nest	0 hr	yes	0.648	0.720	0.962	0.964	0.986
fla_nmm_nest18km_nofb_alberto	NMM	Florida	56/18 Nest	0 hr	no	0.391	0.730	0.898	0.939	0.947
fla_nmm_nest18km_yesfb_alberto	NMM	Florida	56/18 Nest	0 hr	yes	0.448	0.744	0.891	0.937	0.937
fla_arw_nest75km_nofb_alberto	ARW	Florida	75/25 Nest	0 hr	no	0.486	0.388	0.892	0.937	0.932
fla_arw_nest75km_yesfb_alberto	ARW	Florida	75/25 Nest	0 hr	yes	0.571	0.452	0.896	0.939	0.932
fla_arw_nest75km_nofb_claudette	ARW	Florida	75/25 Nest	0 hr	no	0.350	0.266	0.808	0.781	0.923
fla_arw_nest75km_yesfb_claudette	ARW	Florida	75/25 Nest	0 hr	yes	0.463	0.391	0.838	0.795	0.925
fla_nmm_nest18km_nofb_claudette	NMM	Florida	56/18 Nest	0 hr	no	0.500	0.445	0.787	0.772	0.941
fla_nmm_nest18km_yesfb_claudette	NMM	Florida	56/18 Nest	0 hr	yes	0.509	0.465	0.781	0.771	0.940

Table 2.7: Impact of feedback options on tropical events

							Correlations				
Date	Experiment	Model	Domain	Resolution	Spin up	Feedback	Gauge	TRMM	Temp.	Dew Point Temp.	Pressure
09/24/11	fla_arw_nest75km_nofb	ARW	Florida	75/25 Nest	0 hr	no	0.140	0.375	0.941	0.961	0.500
09/24/11	fla_nmm_nest18km_yesfb	NMM	Florida	56/18 Nest	0 hr	yes	0.206	0.541	0.945	0.961	0.500
09/24/11	fla_arw_nest75km_yesfb	ARW	Florida	75/25 Nest	0 hr	yes	0.210	0.371	0.943	0.963	0.451
09/24/11	fla_nmm_nest18km_nofb	NMM	Florida	56/18 Nest	0 hr	no	0.231	0.517	0.948	0.961	0.547
09/26/11	fla_nmm_nest18km_yesfb	NMM	Florida	56/18 Nest	0 hr	yes	0.278	0.268	0.928	0.970	0.796
09/26/11	fla_nmm_nest18km_nofb	NMM	Florida	56/18 Nest	0 hr	no	0.293	0.305	0.928	0.968	0.806
09/26/11	fla_arw_nest75km_nofb	ARW	Florida	75/25 Nest	0 hr	no	0.321	0.270	0.900	0.961	0.658
09/26/11	fla_arw_nest75km_yesfb	ARW	Florida	75/25 Nest	0 hr	yes	0.336	0.277	0.901	0.961	0.663
09/27/11	fla_nmm_nest18km_yesfb	NMM	Florida	56/18 Nest	0 hr	yes	0.023	0.123	0.926	0.957	0.451
09/27/11	fla_nmm_nest18km_nofb	NMM	Florida	56/18 Nest	0 hr	no	0.035	0.151	0.925	0.958	0.495
09/27/11	fla_arw_nest75km_yesfb	ARW	Florida	75/25 Nest	0 hr	yes	0.183	0.392	0.935	0.951	0.267
09/27/11	fla_arw_nest75km_nofb	ARW	Florida	75/25 Nest	0 hr	no	0.290	0.270	0.934	0.952	0.247
10/08/11	fla_nmm_nest18km_yesfb	NMM	Florida	56/18 Nest	0 hr	yes	0.537	0.690	0.894	0.967	0.980
10/08/11	fla_nmm_nest18km_nofb	NMM	Florida	56/18 Nest	0 hr	no	0.554	0.681	0.893	0.967	0.983
10/08/11	fla_arw_nest75km_yesfb	ARW	Florida	75/25 Nest	0 hr	yes	0.561	0.721	0.881	0.960	0.973
10/08/11	fla_arw_nest75km_nofb	ARW	Florida	75/25 Nest	0 hr	no	0.621	0.736	0.881	0.960	0.973
10/09/11	fla_arw_nest75km_nofb	ARW	Florida	75/25 Nest	0 hr	no	0.579	0.592	0.901	0.957	0.972
10/09/11	fla_arw_nest75km_yesfb	ARW	Florida	75/25 Nest	0 hr	yes	0.618	0.580	0.908	0.958	0.970
10/09/11	fla_nmm_nest18km_yesfb	NMM	Florida	56/18 Nest	0 hr	yes	0.707	0.590	0.908	0.966	0.982
10/09/11	fla_nmm_nest18km_nofb	NMM	Florida	56/18 Nest	0 hr	no	0.708	0.632	0.908	0.967	0.984
10/10/11	fla_nmm_nest18km_nofb	NMM	Florida	56/18 Nest	0 hr	no	0.346	0.351	0.927	0.960	0.976
10/10/11	fla_nmm_nest18km_yesfb	NMM	Florida	56/18 Nest	0 hr	yes	0.376	0.342	0.927	0.960	0.972
10/10/11	fla_arw_nest75km_yesfb	ARW	Florida	75/25 Nest	0 hr	yes	0.425	0.406	0.900	0.942	0.947
10/10/11	fla_arw_nest75km_nofb	ARW	Florida	75/25 Nest	0 hr	no	0.469	0.448	0.895	0.940	0.950

Table 2.8: Impact of feedback options on non-tropical events

Date	Experiment	Model	Resolution	% Change turning on feedback
10/24/05	fla_arw_nest75km_wilma	ARW	75/25 Nest	-2.4
10/24/05	fla_nmm_nest18km_wilma	NMM	56/18 Nest	2.5
06/13/06	fla_arw_nest75km_alberto	ARW	75/25 Nest	8.3
06/13/06	fla_nmm_nest18km_alberto	NMM	56/18 Nest	12.7
08/17/09	fla_arw_nest75km_claudette	ARW	75/25 Nest	1.7
08/17/09	fla_nmm_nest18km_claudette	NMM	56/18 Nest	1.8
09/24/11	fla_arw_nest75km	ARW	75/25 Nest	12.6
09/24/11	fla_nmm_nest18km	NMM	56/18 Nest	-12.1
09/26/11	fla_arw_nest75km	ARW	75/25 Nest	0.8
09/26/11	fla_nmm_nest18km	NMM	56/18 Nest	-5.4
09/27/11	fla_arw_nest75km	ARW	75/25 Nest	25.5
09/27/11	fla_nmm_nest18km	NMM	56/18 Nest	-52.2
10/08/11	fla_arw_nest75km	ARW	75/25 Nest	-5.3
10/08/11	fla_nmm_nest18km	NMM	56/18 Nest	-3.2
10/09/11	fla_arw_nest75km	ARW	75/25 Nest	-2.0
10/09/11	fla_nmm_nest18km	NMM	56/18 Nest	-0.1
10/10/11	fla_arw_nest75km	ARW	75/25 Nest	-1.0
10/10/11	fla_nmm_nest18km	NMM	56/18 Nest	8.0

Table 2.9: Change due to feedback option in percentages

Discussion: Correlations for Tropical Events in Florida

Despite the models not performing well for Claudette, there was still little difference in performance between the three tropical events. Temperature, dew point temperature, and surface pressure all had high correlations compared to the precipitation correlations. For these three parameters, the ARW models appeared to perform slightly better for a majority of the correlations. Between the two ARW domains, the nested domain outperformed the 25 km domain for a majority of the correlations.

The precipitation correlations were not as high, however some of the values were high enough that the correlations could still be considered significant. For precipitation, the NMM model produced superior results for both the gauge correlations and the TRMM correlations. Between the two ARW domains, the nested domain again outperformed the 25 km domain.

An examination of the intensity of each tropical event showed that Hurricane Wilma was the most intense, with the largest rainfall amount and the strongest wind gusts recorded. Tropical Storm Claudette was the least intense, with the least amount of rainfall and the weakest wind gusts. When the storm intensity was taken into consideration it was found that the most intense event had the best correlations while the weakest storm had the worst correlations.

Discussion: Correlations for Non-tropical Events in Florida

For a majority of the dates in September, both the gauge correlations and the TRMM correlations were inconsequential. However, a few of the results from September 26 had correlations that could be considered marginally significant. Out of the three September days, the 25 km ARW runs had the best correlations, and nested domain performed the best out of all three ARW domains for a majority of the dates. There was not a significant difference between the 0.5 degree or 1 degree GFS correlations. The use of observations for the September days also did not have a significant impact.

For all of the dates in October, the correlations were more significant than the September results. For a majority of the October days, the ARW nested domain runs produced more significant correlations, however the NMM results were more significant than the other two ARW domains. The 25km ARW run seemed to perform the worst out of all the runs. As with the September results, the different GFS degrees did not have a significant impact on the correlations. However, using observations generally increased a few of the correlations, but not by a substantial amount.

An examination of the event intensity showed that the October dates predominantly had more precipitation. Out of the three dates in October, October 9 had the largest amount of precipitation while October 10 had the least amount of precipitation. Out on the three dates in September, September 24 had the largest amount of precipitation while September 27 had the least amount of precipitation. When the storm intensity was taken into consideration it was found that overall the most intense dates had the best correlations while the weakest dates had the worst correlations.

Discussion: Examination of Input Modification on Non-Tropical Model Correlations

Only October 9 was examined due to the fact that it had the largest precipitation amount out of the non-tropical dates analyzed. As seen in the tropical event correlations, the temperature, dew point temperature, and surface pressure correlations were all extremely high. The precipitation correlations were higher than in the tropical event part of this study, but they still were still the lowest out of all the correlations examined. The run that did not use any observations had the highest correlation with the gauge but the smallest correlation with the TRMM model, while the run that used observations had the smallest correlation with the gauge but the highest correlation with the TRMM model. The run that used observations also ended up performing slightly better for the temperature, dew point temperature, and surface pressure correlations. However, all of these values were close together, meaning that there was not a significant difference in any of the runs.

Discussion: Effect of nesting feedback option

For the tropical events, the ARW correlations exceeded the NMM correlations for a majority of the runs. It was also discovered that most of the gauge and TRMM correlations increased when the feedback option was turned on. Table 2.9 shows that the percentages for the change in correlations for the tropical events was normally small, with Alberto having larger percentages than the other two storms. For the temperature, dew point temperature, and pressure correlations, the changes in value were typically small enough that the impact caused by the feedback could be considered insignificant.

For the non-tropical events, the ARW runs produced higher correlations for a slight majority of the runs. It was also found that a large number of the gauge and TRMM correlations decreased when feedback was turned on, as opposed to tropical events which had an increase in correlation. Overall the percentages for the change in correlations for the non-tropical events were larger than those for the tropical events, with September 27th, 2011 having the largest percentages. Again it was discovered that the temperature, dew point temperature, and pressure correlation differences caused by the changes in feedback were negligible.

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