P 1.47 SENSITIVITY OF SHORT RANGE NUMERICAL WEATHER PREDICTION TO DATA AVAILABILITY DURING THE NORTH AMERICAN MONSOON EXPERIMENT

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1. INTRODUCTION

Integrating vast amounts of data into a Numerical Weather Prediction (NWP) model requires extensive computational resources and time. When using an NWP model for short range prediction purposes, time constraints and computation resources may be considered. The usefulness of an NWP model for on-site incident forecasting depends on these considerations. Therefore, data reduction techniques can be applied to limited computing applications such as incident forecasting. This research will investigate how much we can reduce the data being ingested into a locally-run NWP model and still achieve results that are operationally useful. This approach has applications for local modeling efforts where only a single computer may be available to run the model.

The number of observations that can be ingested into a model varies. Some areas have extensive data that can be ingested (e.g., radar, aircraft, wind profilers, rawinsonde and METAR). Other areas, possibly remote locations, may have very few observations and data sources available. Utilizing all available observations may capture more information on the current state of the atmosphere. However, integrating these potentially large data sets can be very computationally expensive and impractical for time-sensitive fast computing applications with limited computing resources such as a single workstation at a field site. So even where copious amounts of data are available it may be impractical to ingest all the data for on-site NWP.

Forecasting in general involves many different time and spatial scales. Of particular interest is the forecasting for a particular event or incident. For example, an Incident Meteorologist on a wildfire has the responsibility of forecasting weather conditions for a given area, often remote. A great forecasting tool to an Incident Meteorologist is the use of an NWP model that can resolve mesoscale atmospheric and topographic features that may affect an incident. The data must be available to the Incident Meteorologist in a timely manner. In order to accomplish this timely delivery of the data, reduction techniques must be implemented.

2. NWP AND INCIDENT METEOROLOGY

There are issues associated with using NWP models for Incident Meteorology purposes. Data must be available, transmitted, and processed in a timely manner so that the Incident Meteorologist can create up-to-date model output. One of the biggest concerns is the accuracy of the NWP output when applying data reduction methods. Reducing the amount of data being ingested into the model will have an impact on the output. Issues associated with data reduction will be addressed in this research through investigating the impacts of using increasingly reduced data ingested into an NWP model.

2.1 Availability and Frequency of Observations

The availability and frequency of observations of meteorological data can play a crucial role in NWP. Douglas and Stensrud (1996) stated that the skill of NWP models is linked with the realism of the model physical parameterization schemes and the realism of the initial and boundary conditions provided to the model. In light of this, one would expect that increasing the accuracy and possibly the spatial resolution of observations being ingested into a model may have a positive impact on NWP. In a study by Zheng *et al.* (1995), it was found that small changes in the model initial conditions can produce significant changes in the development and evolution of model convective activity.

Surface observations are generally available every hour, with upper air observations available twice a day, 12 UTC and 00 UTC. During an incident, observations may be available more often. For example, the North American Monsoon Experiment (NAME) (Higgins *et al*. 2006), provided a data set with hourly surface observations. Upper air observations were taken four times a day during standard operations, and six times a day during significant weather. Often such a data set is not readily available for ingesting into a NWP

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model. In this case the NWP model may need to be run simply using a previous run from a large-scale NWP model, or one may be able to also use a limited amount of observations collected from the incident or a nearby area.

3. PROJECT BACKGROUND

The data used in this research was collected in August 2004 during NAME, whose overall goal was to improve the understanding of the key physical processes that must be parameterized for more realistic simulations and accurate predictions with coupled Ocean Atmosphere Land models, especially for the North American Monsoon circulation (Higgins *et al.* 2006). The topography in Western Mexico and numerous data sets provided by the NAME project created an excellent opportunity to model atmospheric phenomena near complex terrain during a warm season scenario. The experiment ran from June to September 2004. The period between July 15, 2004 and August 15, 2004 consisted of what is known as an Intense Operations Period or (IOP). During this IOP, there was an enhanced frequency of observations at specified sites. Field instruments for collecting observations consisted of wind profilers, radars, rawinsondes, research vessels, buoys, rain gauges, soil moisture sensors, and research aircraft.

In this area the phenomena known as the North American monsoon provides the driving force for convective activity. The summertime circulation over the continental United States coupled with the land-sea regime found along the gulf coasts of Mexico and the southwestern United States (Reiter and Tang 1984) can be together, referred to as the North American monsoon system (Barlow *et al.* 1998).

Mesoscale Convective Systems (MCS's) develop quite frequently over western Mexico during the monsoon season. MCS's provide a unique environment that can be modeled using NWP. The MCS development over western Mexico often occurs in the absence of strong forcing. The best approach to modeling this convection as accurately as possible may lie in the ability to use large data sets that contain numerous surface and upper air observations. Past studies have shown that for summertime situations, under large-scale weak gradients, detailed temperature and moisture fields appear to be more important than the detailed wind fields in determining the development and evolution of deep convection (Zhang and Fritsch 1986). In light of this one would expect that data reduction, especially to the temperature and moisture fields, will cause significant differences in the models' prediction of convection in the monsoon region.

4. METHODOLOGY

There are three primary objectives we seek to accomplish in this research. The first of these is to investigate the impact of reduced data integration into an NWP model over complex terrain. The second objective is to find where model output differences arise and the magnitude of these differences. The third objective is to identify output that may be applicable to incident meteorology. In this research we will use the Fifth-Generation NCAR / Penn State Mesoscale Model (MM5) (Grell *et al.* 1994) to conduct several modeling simulations.

4.1 Initialization and Boundary Conditions

In this research we will be creating three sets of initialization first guess fields. The first will be the optimal scenario using the North American Regional Reanalysis (NARR) (Messinger *et al.* 2006). The NARR will serve as the optimal initialization and boundary condition fields for this study. Thus both the initial conditions and boundary conditions throughout the model run will be based on large-scale analysis fields rather than forecasts.

The second first guess field was created using a Continental Scale MM5 simulation. This will provide a large-scale forecast based on the same NARR analysis. This MM5 run is being initialized from the NARR first guess fields and all available surface and upper air observations provided by NCAR. The model is run over the North American continent at a resolution of 40-km grid spacing with a size of 115 x 200 grid cells centered over 40°N, 107°W. The model output is taken every hour. The simulation is then stripped of all microphysics information that may interfere with subsequent initializations of MM5 using this simulation. The result of this model output is then post-processed by a program in MM5 known as INTERPB. This program takes the complete 115 x 200 40-km field and changes the vertical coordinates from MM5-sigma into pressure coordinates for subsequent initializations into MM5.

The third first guess field was created applying data reduction to the Continental Scale MM5 run. The data reduction is applied both horizontally and vertically. The reduction technique consists of horizontally reducing the Continental Scale MM5 run to 0.5-degree resolution and placing it into a smaller spatial domain centered over the NAME field program areas. The data is then reduced vertically to a height-above-ground vertical coordinate system to a specified set of vertical increments. This reduction in resolution results in the original MM5 40-km horizontal resolution and 32 vertical layers, being reduced to 55-km horizontal resolution and 13 vertical layers. This product represents what might be delivered to field meteorologists during a particular incident with limited transmission bandwidth.

4.2 MM5 Model Set Up

We have created three domains centered over Los Mochis, Mexico (Fig. 4.1). Domain one, 45-km spacing; Domain two, 15-km spacing; and Domain three, 5-km spacing. Simulations were conducted using 32 vertical layers. A convective case was chosen to model a strongly-forced environment. An additional case where no convection occurred was also simulated. Four different start times were chosen for all the simulations (Fig. 4.2). The four different modeling times were chosen primarily to investigate the impact of varying the model start times, and the staleness of the observations and first guess fields. We chose August 4, 2004 0900 UTC to August 5, 2004 0900 UTC for a null case because this was a day where very little convection occurred anywhere in our modeling domains. We chose August 5, 2004 0900 UTC to August 6, 2004 0900 UTC for the convective case because this was a period where a strong MCS developed south of Los Mochis and moved northwest during our simulation.

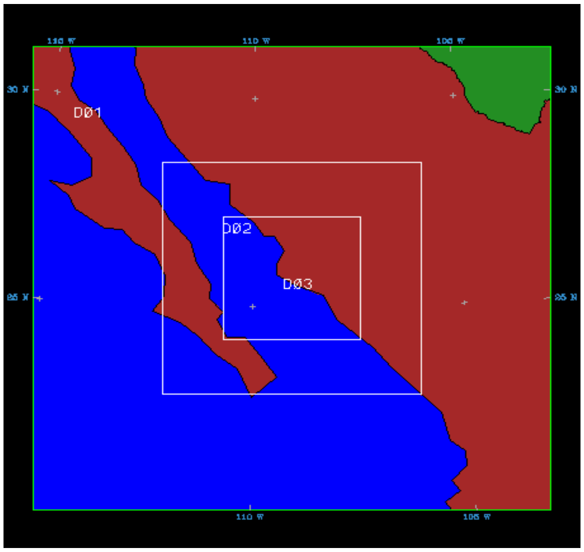

Fig. 4.1. Three domains centered over Los Mochis, Mexico.

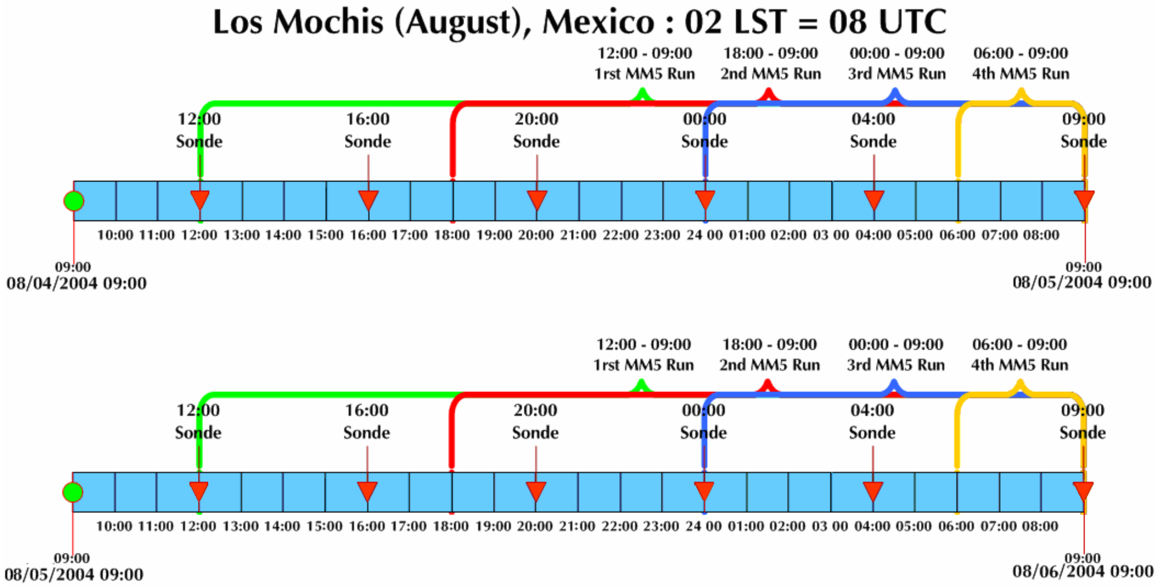

Fig. 4.2. MM5 simulation times and observation times in UTC. Top timeline represents the null case while the bottom timeline represents the MCS case. Arrows indicate when radiosonde observations were available for ingesting into the MM5 model.

Four different modes were created for conducting MM5 simulations. The first mode is known as the *research mode*. The research mode is driven by the NARR analysis as discussed above. This mode ingests all available observations throughout the simulation period. The research mode serves as the control to compare reduced forecast simulations against. This mode performed exceptionally well in all simulations when compared to observations.

The second mode was labeled the *forecast mode*. The forecast mode is initialized with the North American MM5 run as discussed above. This mode ingests surface observations and radiosonde observations from a single site prior to forecast initiation. This mode represents the typical operational mesoscale forecast mode.

The third MM5 mode is known as the *reduced forecast with observations*. The reduced forecast with observations mode is initialized with the horizontally reduced resolution as discussed above. This mode, like the forecast mode, ingests surface observations and radiosonde observations from a single site prior to forecast initiation.

The fourth MM5 mode is known as the *reduced forecast without observations*. The same reduced MM5 initialization and boundary conditions are applied as in the reduced forecast with observations mode. However, this mode does not ingest any observations. This mode represents another approach that might be used by Incident Meteorologists. In this mode an additional run is conducted using only 19 vertical levels instead of 32.

The particular physics options for each mode are summarized in Tables 4.1, 4.2, and 4.3. Physics options for research and forecast simulations were chosen with consideration to NWP best practices. The physics options for degraded forecast simulations were chosen with consideration to complexity and computational time.

Table 4.1 MM5 physics options for MM5 research mode.

Physics Option	Domains Applied	Scheme Used
Cumulus parameterization	ALL	Kain-Fritsch 2 (Kain 2002)
PBL scheme	ALL	Hong and Pan (1996)
Explicit moisture scheme	ALL	Reisner graupel (Reisner *et al.* 1998)
Radiation scheme	ALL	Cloud-radiation
Surface Scheme	ALL	Noah LSM (Chen and Dudia 2001)

Table 4.2 MM5 physics options for MM5 forecast mode.

Physics Option	Domains Applied	Scheme Used
Cumulus parameterization	ALL	Grell (Grell *et al.* 1994)
PBL scheme	ALL	Hong and Pan (1996)
Explicit moisture scheme	ALL	Reisner mixed-phase (Reisner *et al.* 1998)
Radiation scheme	ALL	Cloud-radiation
Surface Scheme	ALL	Five-Layer Soil Model (Dudhia 1996)

Table 4.3 MM5 physics options for MM5 reduced forecast modes.

Physics Option	Domains Applied	Scheme Used
Cumulus parameterization	1,2	Grell (Grell *et al.* 1994)
PBL scheme	ALL	Hong and Pan (1996)
Explicit moisture scheme	ALL	Simple Ice
Radiation scheme	ALL	Simple cooling
Surface Scheme	ALL	Five-Layer Soil Model (Dudhia 1996)

5. RESULTS

Preliminary results show that the loss of data in going from the research mode to the reduced forecast mode without observations has been shown to adversely affect the precipitation. The MM5 precipitation output from the research mode is summarized in Figure 5.1. Notice how the coverage of the precipitation produced by the MCS is represented by the wide swath of precipitation and the maximum amounts in areas of higher terrain, west of Los Mochis. Figure 5.2 shows precipitation for the forecast mode. Notice how the coverage of precipitation produced by the MCS is once again represented by a swath of precipitation. However, the intensity and coverage is less than in the research mode. The reduced forecast mode with observations (Fig. 5.3) does not show the same swath of precipitation produced by the research mode and forecast mode. The precipitation is patchy and the precipitation produced by the MCS is not resolved. In the reduced forecast mode without observations (Fig. 5.4) the precipitation is again patchy. Notice how the exclusion of a sounding has little impact on the pattern of the precipitation when in the reduced forecast mode.

The prediction of wind in short range numerical weather prediction is significantly impacted by reducing the initialization and boundary conditions and reducing the number of observations being ingested into the model. Figure 5.5 shows 69.1 meter (MSL) winds during the convective case simulation at 03 UTC. All four different modeling modes' wind barbs are shown in plan view. Notice how the forecast and reduced forecast with and without observations have wind directions that differ when compared to the research mode. However, the wind speeds in the forecast and reduced forecast modes are comparable to the research mode. The wind directions and speeds in the forecast mode and reduced forecast mode with and without observations are comparable. This also happens to be the case for winds in the mid-levels of the model (Fig. 5.6) and even for the winds in the upper levels of the model near the tropopause (Fig. 5.7). Later during this same simulation, forecast and reduced forecast mode with and without observations become more in agreement with the research mode. Figure 5.8 shows the wind barbs plotted at 69.1 meters MSL at 08 UTC. Notice how the four different modeling mode winds are in fairly good agreement over the ocean. There are some differences along the coast when comparing the forecast mode and reduced forecast mode with and without observations to the research mode. This is also the case for winds at 1000 meters (Fig. 5.9). Differences are once again noted in the winds near the tropopause level at 08 UTC (Fig. 5.10).

The prediction of winds in the absence of an MCS was also investigated. Figure 5.11 shows winds from the four different modeling modes plotted in plan view at 69.1 meters (MSL) during the null simulation. Notice how the predicted winds in the forecast mode and reduced forecast mode with and without observations have some differences in wind direction when compared to the research mode. The winds are more in agreement along coastal areas. The prediction of wind speeds is similar when comparing the forecast and reduced forecast modes to the research mode. This is also the case at 1000 meters. Better agreement between the four different modeling modes is noted near areas of complex terrain (Fig. 5.12). The winds near the tropopause level during the null case showed good agreement in the western half of domain 3 (Fig. 5.13). The eastern half of the domain indicated significant wind direction differences when comparing the forecast mode, and reduced forecast mode with and without observations to the research mode. Similar findings were noted later into the simulation at 08 UTC.

In the reduced forecast mode without observations, reducing the vertical levels from 32 to 19 in the MM5 also has an impact on the NWP output. There are differences in the wind speed when comparing the use of 32 vertical levels versus 19. Figure 5.14 shows a 3-D image of differences in the U and V wind components within domain 3, looking east. The cyan shading shows differences in wind speed of 8 m/s between the 32-level reduced forecast run without observations and a 19-level reduced forecast without observations. The largest differences in wind speed are in the upper and middle levels of the model output. Smaller differences are noted closer to the surface. This may have important implications because decreasing the number of vertical levels in the NWP model significantly decreases computation time. Reducing the number of vertical layers could be a very beneficial consideration to Incident Meteorology applications but in this case significant differences in upper level winds occurred.

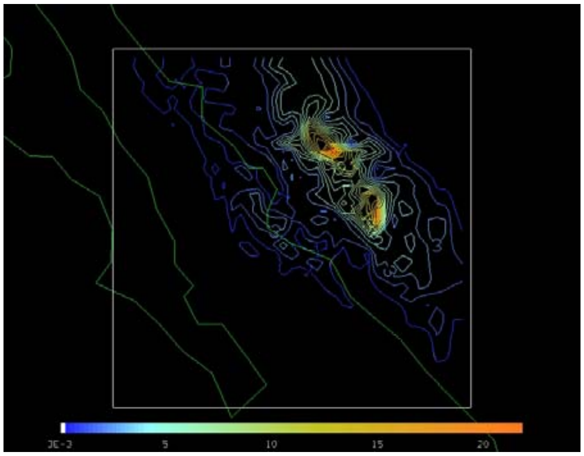

Fig. 5.1. Convective and non convective precipitation in millimeters within domain 2 for convective case *research mode* on August 6, 2004 at 09 UTC. Run initialized on August 5, 2004 at 00 UTC. The coverage of the precipitation produced by the MCS is captured.

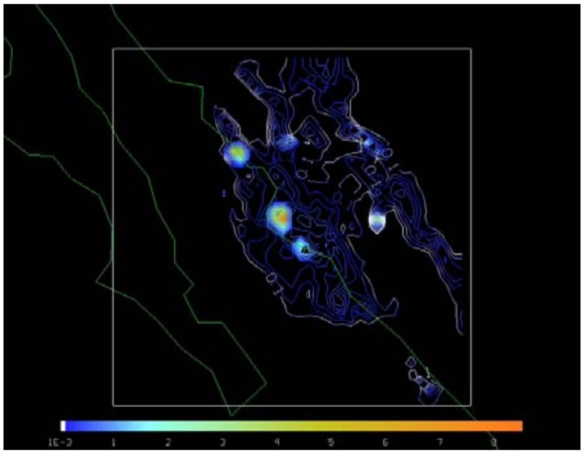

Fig. 5.2. Convective and non-convective precipitation in millimeters within domain 2 for convective case *forecast mode* on August 6, 2004 at 09 UTC. Run initialized on August 5, 2004 at 00 UTC. The coverage of the convective precipitation produced by the MCS is less than in the research mode.

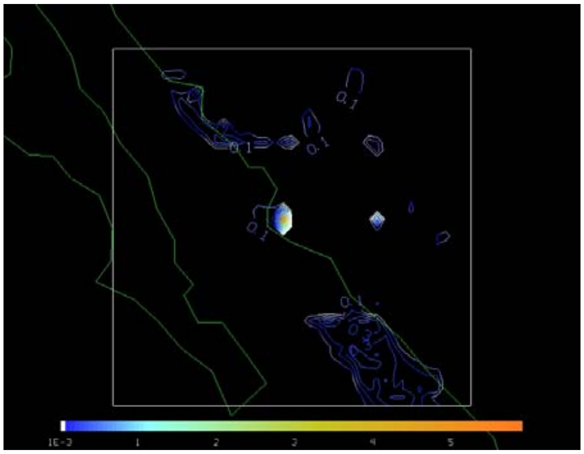

Fig. 5.3. Convective and non-convective precipitation in millimeters within domain 2 for convective case *reduced forecast with observations mode* on August 6, 2004 at 09 UTC. Run initialized on August 5, 2004 at 00 UTC. The total precipitation produced in this mode is patchy and the pattern of the precipitation produced by the MCS is not captured.

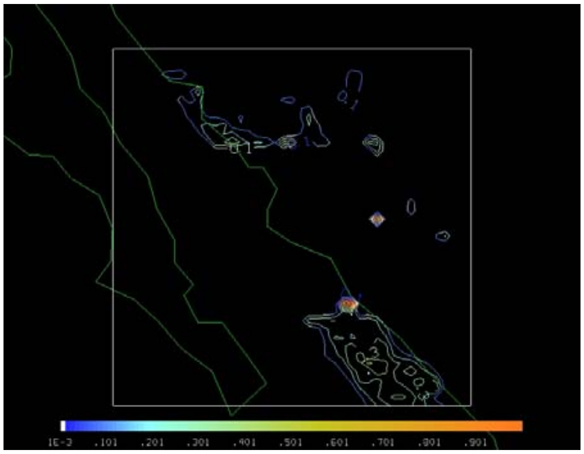

Fig. 5.4. Convective and non-convective precipitation in millimeters within domain 2 for convective case *reduced forecast without observations mode* on August 6, 2004 at 09 UTC. Run initialized on August 5, 2004 at 00 UTC. Again the pattern of the precipitation produced by the MCS is not resolved. Also, notice how the exclusion of a sounding does not significantly impact the pattern of the precipitation. However, the amount of precipitation is less when compared to the reduced forecast with observations mode.

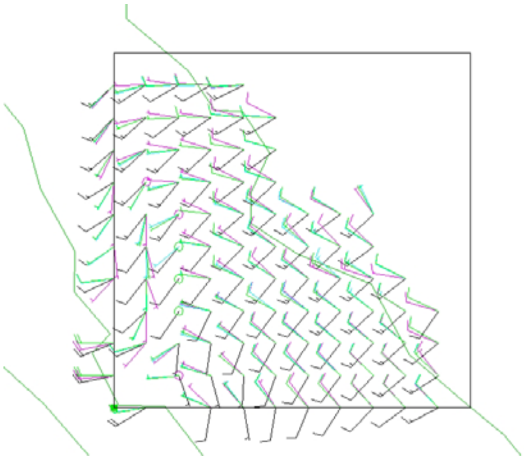

Fig 5.5. Domain three 69.1 meter (MSL) winds in plan view during convective case run at 03 UTC initialized at 00 UTC. Research (Black), Forecast (Purple), Reduced forecast with observations (Green), Reduced forecast without observations (Cyan). At this time there are differences between the research runs and the forecast runs over both land and water.

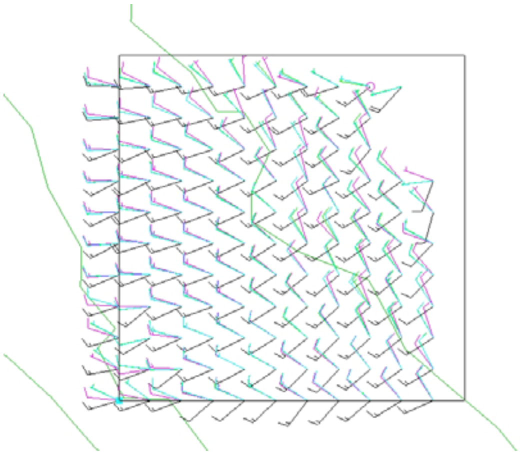

Fig. 5.6. Domain three 1000 meter (MSL) winds in plan view during convective case run at 03 UTC initialized at 00 UTC. Research (Black), Forecast (Purple), Reduced forecast with observations (Green), Reduced forecast without observations (Cyan). Differences are similar to the surface winds.

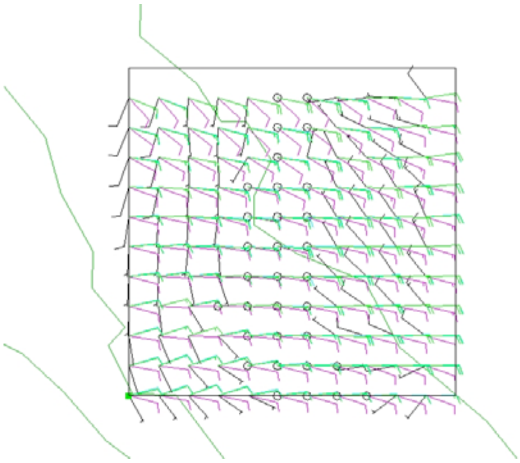

Fig. 5.7. Domain three 14800 meter (MSL) winds in plan view during the convective case run at 03 UTC initialized at 00 UTC. Research (Black), Forecast (Purple), Reduced forecast with observations (Green), Reduced forecast without observations (Cyan). Here there are differences in the wind directions when comparing the research run to the forecast runs.

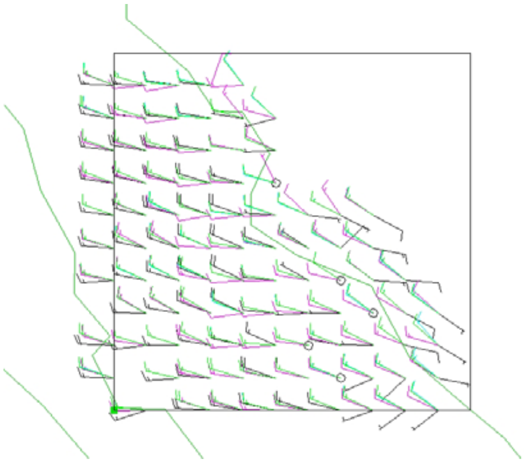

Fig 5.8. Domain three 69.1 meters (MSL) winds in plan view during convective case run at 08 UTC initialized at 00 UTC. Research (Black), Forecast (Purple), Reduced forecast with observations (Green), Reduced forecast without observations (Cyan). At this time the winds are in much closer agreement with each other over water than at 03 UTC. There are some differences over land in wind speed and direction when comparing the research run to the forecast runs. However, wind speed and direction are comparable in the forecast modes.

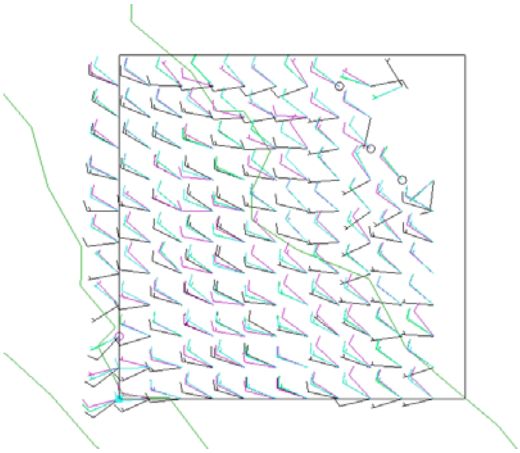

Fig. 5.9. Domain three 1000 meter (MSL) winds in plan view during convective case run at 08 UTC initialized at 00 UTC. Research (Black), Forecast (Purple), Reduced forecast with observations (Green), Reduced forecast without observations (Cyan). Differences in wind are similar to those noted at 69.1 meters MSL.

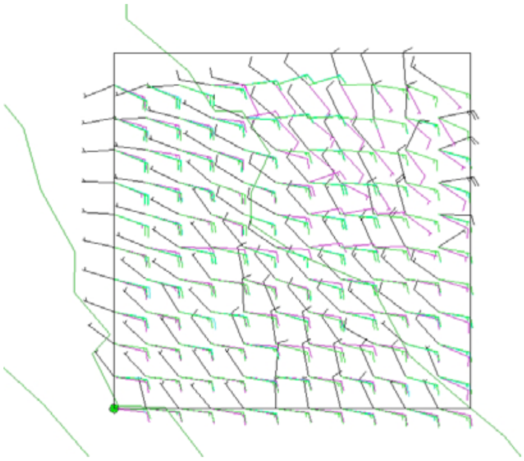

Fig. 5.10. Domain three 14800 meter (MSL) winds in plan view during convective case run at 08 UTC initialized at 00 UTC. Research (Black), Forecast (Purple), Reduced forecast with observations (Green), Reduced forecast without observations (Cyan). Differences in both wind speed and direction are noted during this time.

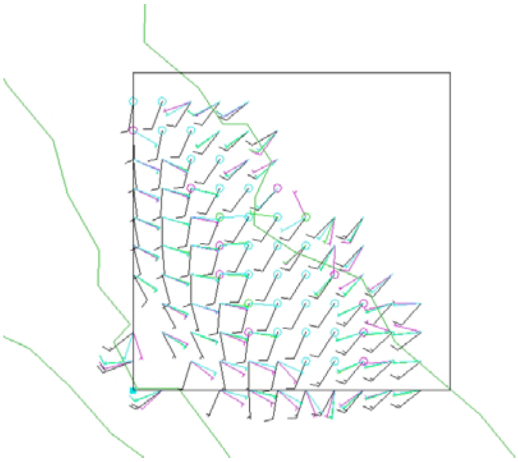

Fig. 5.11. Domain three 69.1 meter (MSL) winds in plan view during the null case run at 03 UTC initialized at 00 UTC. Research (Black), Forecast (Purple), Reduced forecast with observations (Green), Reduced forecast without observations (Cyan). Differences between the research run and the forecast runs are much greater over water in both direction and speed versus along the coastline.

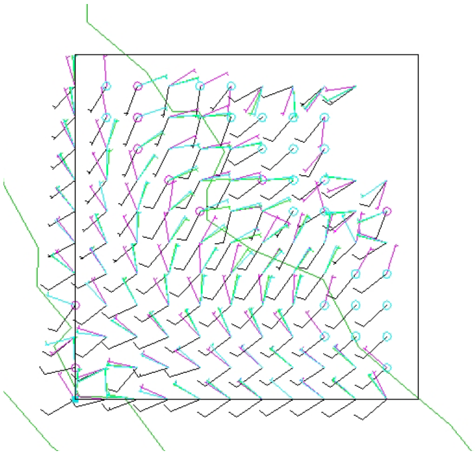

Fig 5.12. Domain three 1000 meter (MSL) winds in plan view during the null case run at 03 UTC initialized at 00 UTC. Research (Black), Forecast (Purple), Reduced forecast with observations (Green), Reduced forecast without observations (Cyan). Substantial differences are again noted over land and water when comparing the research run to the forecast runs. However, notice that the forecast mode, and forecast mode with and without observations are in better agreement with the research mode in areas of complex terrain (upper right quadrant of domain 3).

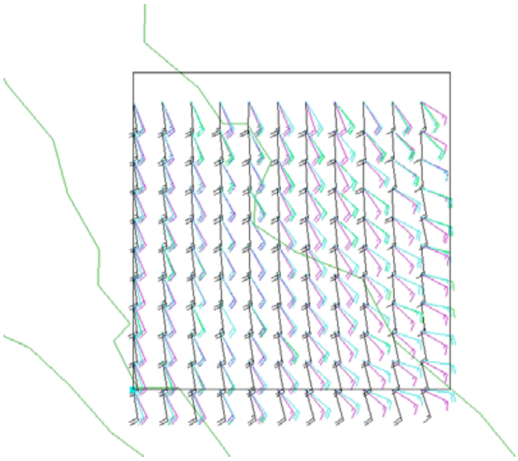

Fig 5.13. Domain three 14800 meter (MSL) winds in plan view during the null case run at 03 UTC initialized at 00 UTC. Research (Black), Forecast (Purple), Reduced forecast with observations (Green), Reduced forecast without observations (Cyan). Winds near the tropopause level in the four different modeling modes are in better agreement than the winds in the lower levels of the model in the absence of convection. Notice as we approach areas in complex terrain larger differences in the wind directions become apparent.

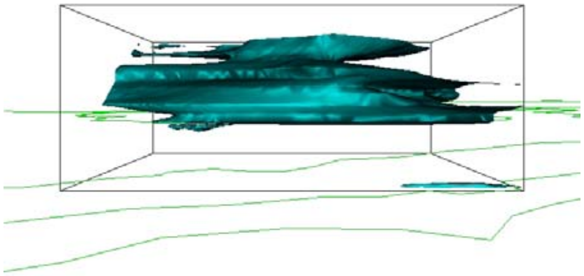

Fig. 5.14. Differences between reduced forecast modes without observations comparing 32 levels versus 19 levels. Blue shading indicates differences of 8 m/s in the U and V wind speeds during convective case event at 03 UTC initialized at 00 UTC. The largest differences are noted in the mid to upper layers of the model. Smaller differences are noted near the surface.

6. FUTURE WORK

Additional MM5 comparisons will be made with the simulations already conducted. A comparison of the local area forecast to the output from the large scale forecast run could be made. Also, more runs could be conducted applying horizontal and vertical degradation techniques to the analysis and forecast initialization fields. This may provide additional insight as to where the tradeoffs may be in considering data degradation for NWP applications.

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