Impact of AQUA Satellite Data on Hurricane Forecast: Danielle 2010

Travis J. Elless[1, 2], Xuguang Wang[3], Ting Lei[4], and Govindan Kutty Mohan Kumar [4]

[1]National Weather Center Research Experiences for Undergraduates Program

[2]Valparaiso University

[3]School of Meteorology, University of Oklahoma

[4] Center for Analysis and Prediction of Storms
University of Oklahoma, Norman, Oklahoma

ABSTRACT

This study focuses on the impact of AQUA satellite data from AIRS and AMSU on the forecast of hurricane Danielle by the Global Forecast System (GFS) model. The data assimilation method adopted to ingest the data is the Gridpoint Statistical method (GSI) which is based on the three dimensional variational (3DVAR) data assimilation technique. Two experiments were carried out to investigate the impact of AQUA satellite radiance observation on the forecast of the hurricane Danielle. The first experiment (Control), assimilated all the available data while the second experiment (No AQUA) incorporated all the observations but the AQUA satellite data. Data assimilation cycling started one week prior to hurricane genesis, on 15 August 2010 06 UTC. The root mean square track forecast error shows slightly negative impact at the early lead time and slightly positive impact at later lead time. However, the root mean square intensity forecast errors by the Control are shown to be lower than No AQUA for all forecast hours, indicating positive impact of the AQUA data on the intensity forecast.

1. Introduction

When originally launched in May of 2002, the National Aeronautics and Space Administration (NASA) polar orbiting satellite *AQUA* was equipped with three instruments, the Atmospheric Infrared Sounder (AIRS), the Advanced Microwave Sounding Unit (AMSU), and the Humidity Sounder for Brazil (HSB), to provide accurate temperature and humidity profiles of the atmosphere. Unfortunately, the HSB ceased operation in February 2003 which has reduced the efficiency of the AQUA satellite, but AQUA still provides data that has helped improve numerical weather prediction forecasts. The assimilation of AQUA data, especially the AIRS data, has improved the placement and intensity of cyclones located over the world's oceans (Chahine et al. 2006, Le Marshall et al. 2006, and Reale et al. 2009).

Reale et al. (2006) has shown that the assimilation of AIRS improved the track forecast of the tropical cyclone Nargis. The present study evaluates the impact of AQUA data on the track forecast of the 2010 Atlantic Ocean hurricane, Danielle. We will use two different experiments, one which assimilates all the available data (Control) while the other experiment assimilates all the available data except the AQUA satellite data (No AQUA), to study the impact of the AQUA data on the forecast of Hurricane Danielle 2010 using the operational Global Forecast System (GFS) and its data assimilation system GSI.

[1] *Corresponding author address:* Travis J. Elless, 216 N. Washington St. PO Box 177 Ladoga, IN 47954
E-mail: travis.elless@valpo.edu

2. Background

Information in this section will focus on the life cycle of Hurricane Danielle and will also give a brief overview of AQUA's data availability.

2.1 Hurricane Danielle

Hurricane Danielle was first detected as a tropical wave passing off the coast of Senegal on 18 August 2010. Danielle formed into Tropical Depression Six at 18UTC 21 August 2010 as the tropical wave became more organized after interacting with a disturbance in the Intertropical Convergence Zone (ITCZ). Danielle was upgraded to a tropical storm twelve hours after being classified a depression and intensified into a hurricane at 18 UTC 23 August 2010. The storm's speed and direction varied as the subtropical ridge would weaken and strengthen. Danielle reached maximum intensity as a Category 4 Hurricane with winds in excess of 115kt at 18UTC 27 August 2010. Danielle weakened as a mid-latitude cyclone increased shear and accelerated Danielle over cooler waters as the storm gained extratropical characteristics.

Due to the storm remaining over the open waters of the Atlantic Ocean, satellite data were the primary form of observations. Kimberlain (2010) confirms that there was only one ship or buoy to make an observation on Danielle while the cyclone was in its beginning and mature stages. Observations became more numerous once the cyclone began to weaken in the mid-latitude waters.

2.2 AQUA Satellite

Due to AQUA being a polar orbiting satellite, data is not available for collection at all times. Availability of the AQUA data can be seen in Fig.1 for the four model run times. Each swath is taken in a six hour window centered on the model initialization time to allow for the assimilation process. The AQUA satellite collects data over the Atlantic Hurricane Basin that is made available for the 06UTC and 18UTC model runs, whereas data is unavailable for assimilation into the 00UTC and 12UTC model runs. However, due to data assimilation cycling, the impact of data at these two times can still be propagated to the region where Danielle resided.

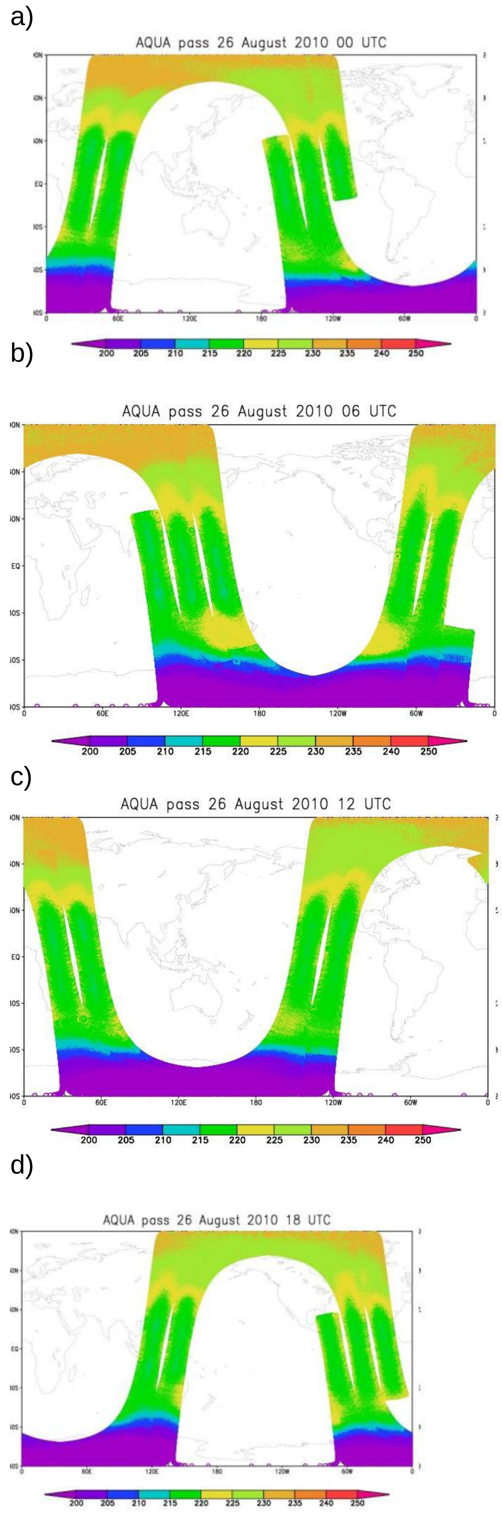
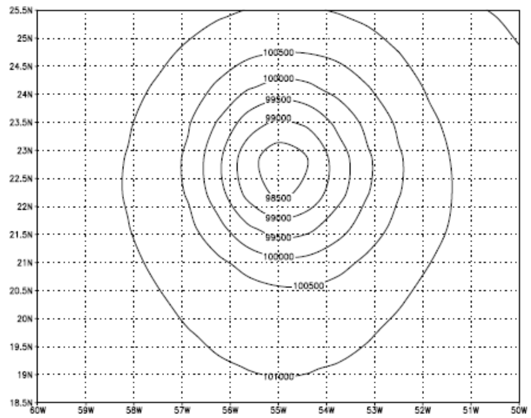


Fig. 1 AQUA data availability shown by colored swaths for (a) 00UTC 26 August 2010, (b) 06 UTC 26 August 2010, (c) 12 UTC 26 August 2010, and (d) 18 UTC August 2010. The parameter shown is brightness temperature.

a)



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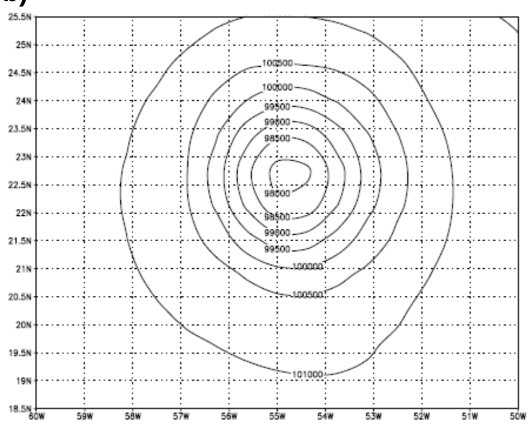

Figure 2, Mean Sea Level Pressure analysis for (a) No AQUA and (b) Control for 06 UTC 26 Augustu 2010. The center for No AQUA is 22.7ºN 55.0ºW and for Control is 22.5ºN 54.8ºW. Central pressure for No AQUA is 982hPa and 978hPa for Control.

3. Assimilation methodology and hurricane tracker

This study utilizes the Gridpoint Statistical Interpolation (GSI, Wu et al. 2002) system for assimilating satellite observations. GSI is a three dimensional variational (3DVAR) data assimilation scheme used by US National Weather Service's operational numerical weather prediction.

The GFDL tracker mainly developed by NCEP (Marchok, 2002) is used in this work. This piece of software calculates the hurricane center by averaging positions analyzed by the parameters of MSLP, vorticity at 10m, 700hPa, and 850hPa, and geopotential heights of 700hPa and 850hPa.

4. Experimental design

The data assimilation cycle starts one week prior to the hurricane genesis. The data sets are ingested in six hour interval starting from 06 UTC 15 August 2010 up to 18 UTC30 August 2010 with and without AQUA satellite data. The numerical model used in the present study is from the National Center for Environmental Prediction (NCEP) Global Forecast System (GFS) model. The model is run with a spectral resolution of T190 with 64 vertical levels (T190L64).

The output of the hurricane track from both the Control and No AQUA forecasts are compared with the best track positioning for Hurricane Danielle determined by Kimberlain (2010). Root Mean Square Error (RMSE) of the forecast track is calculated for the model runs beginning with 00UTC 24 August 2010 and completing with 18UTC 28 August 2010. These values are compared to showthe impact of *AQUA* satellite data in the forecast of Hurricane Danielle.

The impact of AQUA data on the intensity forecast was also studied by verifying the forecast of the minimum mean sea level pressure (MSLP). Like the track error, RMSE is calculated from 00UTC 24 August 2010 to 18UTC 28 August 2010.

5. Results

5.1 Comparison of Analysis

Figure 2 shows an example of the difference of the analyses on 06 UTC 26 August 2010 from Control and NoAQUA. In this example, both the No AQUA and Control run presented roughly the same position for Hurricane Danielle for the initial hour forecast . The two models placed the storm a distance of approximately 0.2º in both latitude and longitude from each other. The center of both storms, No AQUA at 22.7ºN 55.0ºW and Control at 22.5ºN 54.8ºW, fall within the ring of the smallest analyzed pressure contouring for each respective storm. This confirms that the GFDL tracker is working properly.

The major difference between Control and No AQUA in this example is the difference in minimum sea level pressure. The analysis shows a central pressure of 4 hPa lower in the Control experiment.

5.2 Track Error

To quantify the impact of AQUA satellite data on the forecast hurricane Danielle, RMSE of the track forecast up to 5 day lead time was calculated (Fig. 3). Both experiments, Control and No AQUA produce similar results. Only a slight difference is noticeable for the 24-66 hour forecast range, where the No AQUA is marginally better. For the 78-102 hour forecast, the Control experiment outperforms No AQUA slightly. However, we cannot give the error much significance as the difference in errors between the two experiments was smaller than the 70 km grid spacing. To expose the similarities/differences between the two experiments, two different times are evaluated and reported in Section 5.4 and 5.5.

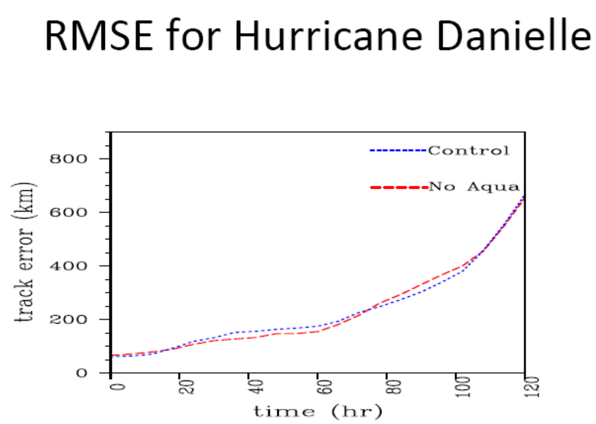

Figure 3. Root Means Square Error for Hurricane Danielle's track over the period beginning 00UTC 24 Aug. 2010 and ending 18UTC 28 Aug. 2010.

5.3 Intensity Error

The error of intensity forecast for Danielle (Fig.4) produces a more noticeable advantage for the assimilation of AQUA satellite data. A difference of 1-3 hPa is observed between the two experiments Control consistently outperforms No AQUA during the entire 120 hour forecast.

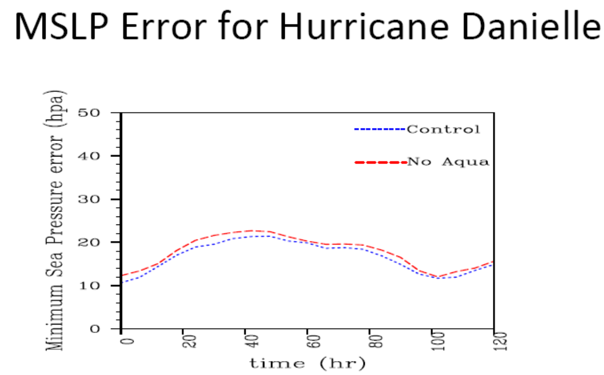

Figure 4. Root Mean Square Error for the mean sea level pressure for Hurricane Danielle for the same time frame as Fig. 3.

5.4 Study of 18 UTC 24 August 2010

At 18 UTC 24 August 2010, Danielle was still a weak hurricane, with maximum sustained winds only of 65 knots. The hurricane track plots (Fig. 5) shows the experiments initializes away from Danielle's observed position. Both forecasts take the storm in a northwest motion, with the Control having a more westerly trajectory in the early stages. The No AQUA follows the best track of Danielle fairly closely during the middle forecast period while the Control parallels just west of the best track. When Danielle turns northeast after interacting with a mid-latitude trough later in the forecast period, No AQUA handles the change in direction more quickly and forecasts the change to the northeast while the Control takes a northerly track.

The RMSE confirms No AQUA handles this forecast exceptionally well. Figure 6 shows both storms initializing in approximately the same location and Control having a slight advantage for the first twenty-four hours. As the Control takes the more westerly track, No AQUA quickly gains an advantage from the 24-90hour forecast. A significant advantage for No AQUA can be seen for the last several forecast hours as it handles the northeast curve of Danielle better than Control.

The MSLP error (Fig.7) observed with this forecast shows a larger difference between the two experiments. The Control outperforms No AQUA by 2-6 hPa for the majority of the forecast. The only exception is in the latter part where the model tries to handle the northeasterly turn. Due to the Control not handling the affects of the mid-latitude trough as well as No AQUA, the data denial experiment result in a slight advantage for the final 24 hours of the forecast.

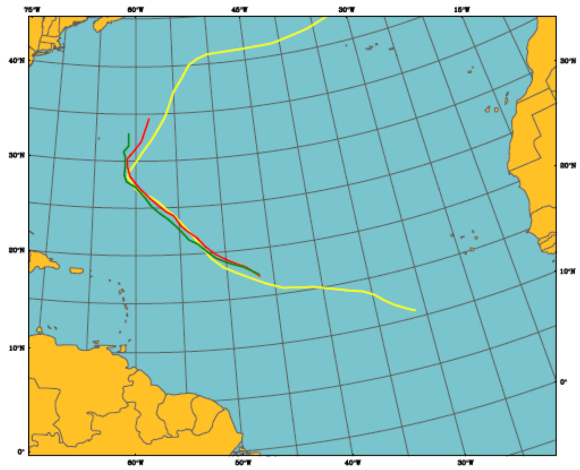

Figure 5. Hurricane track forecasts for Control (green line) and No AQUA (red line) experiments. The best track for Danielle (yellow line) is also plotted for comparison.

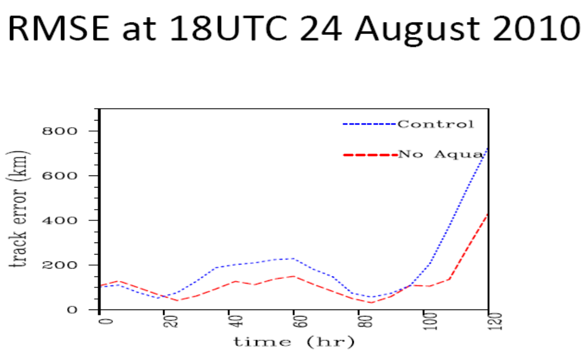

Figure 6. Root mean square error observed at 18 UTC 24 Aug. 2010 for Hurricane Danielle's track forecast.

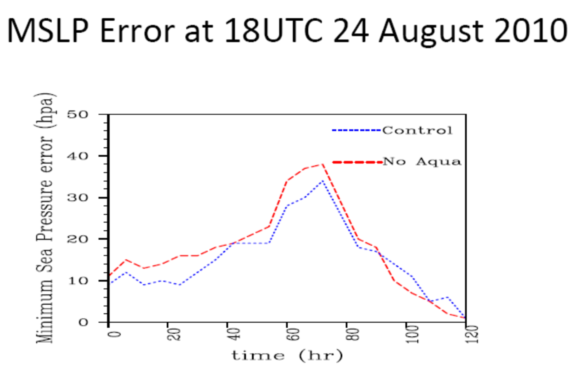

Figure 7. Root mean square error for Hurricane Danielle's intensity forecast observed with the 18UTC 24 Aug. 2010 forecast.

5.5 Study of 00 UTC 28 August 2010

Danielle was a strong category 3 storm at 00 UTC 28 August 2010 with winds of 105 knots. Figure 8 shows, like the previous case, both experiments initialize in approximately the same location. Both experiments follow the northeast track of Danielle. Control has more variability whereas No AQUA keeps roughly a straight path paralleling the best track. As Danielle makes a more easterly turn on 30 August, the Control handles the direction change much better with this forecast as it follows the best track fairly closely. The No AQUA experiment makes the turn too late and to the north which causes the forecast to be further to the north and west than the Control.

Figure 9 quantitatively shows the difference between the two experiments. It shows No AQUA having a slight advantage at initiation and the advantage becomes more significant as experiments approach the 36 hour forecast. The advantage is caused by the No AQUA run having the straighter path along the northeast track. However, as Control begins to make the easterly turn before No AQUA, the Control begins to receive a significant advantage. The latter part of the forecast period allows the greatest difference as No AQUA continues to move further away from the best track.

The MSLP error (Fig. 10) shows like the track error the No AQUA experiment has a slight advantage at the beginning of the forecast. Between the 18 and 78 hour forecast range, major fluctuations are observed in the No AQUA error while the Control has some fluctuations but at a very low error level. The errors blossoms during the last 42 hours of the forecast as the experiments are measuring Danielle in its extratropical stage.

5.6 Discussion

In this paper only one case, Hurricane Danille, was adopted. More cases need to be examined to make general conclusion of the impact of AQUA on hurricane forecast. The impact of the data can also be dependent on the data assimilation method. Work is ongoing to repeat the experiment but using the hybrid ensemble variational data assimilation system(Wang et al. 2008ab, Wang 2010, Wang 2011).

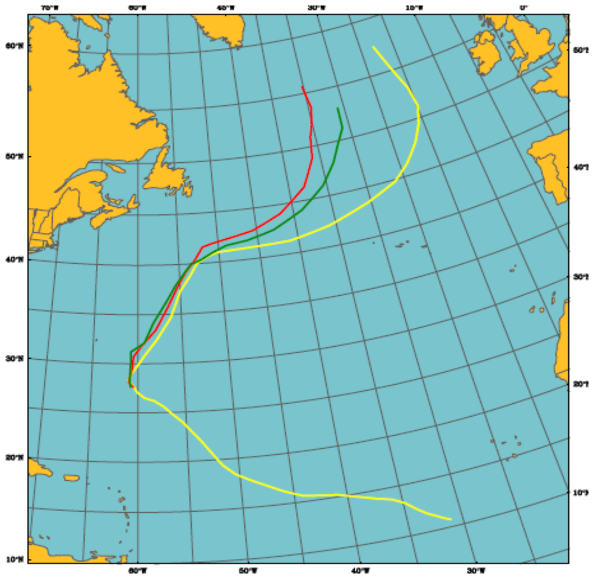

Figure 8. Same as Fig. 5 except shown with the 00UTC 28 Aug. 2010 forecast.

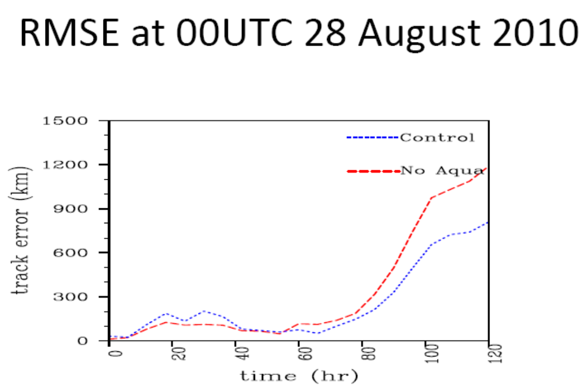

Figure 9. Same as Fig. 6 except with the 00UTC 28 Aug. 2010 forecast.

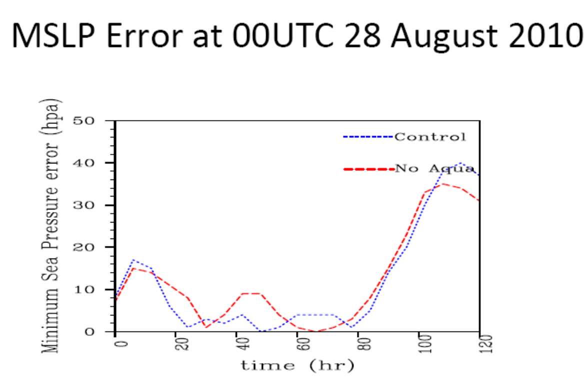

Figure 10. Same as Fig. 7 except with the 00UTC 28Aug. 2010 forecast.

6. Conclusions

The present study focuses on the impact of AQUA satellite data on the forecast of hurricane Danielle through a data denial experiment. The results of the study show that the assimilation of AQUA satellite observations has improved the forecast of the intensity of the hurricane, although the impact on track forecast is minimum.

7. ACKNOWLEDGMENTS

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