Four-Dimensional Variational Data Assimilation of Satellite Retrieval Data for Hurricane Lili(2002)

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1. Introduction

Many researches have proved that remote-sensing data over oceans can improve the tropical cyclone initialization. Hurricane Lili happened in the period of 21 September - 04 October 2002. Its rapid weakening just before landfall, which was not predicted accurately, is still not well understood. Was it caused by an inner mechanism, or by vertical wind sheer or other environmental influences such as moisture, stability? We try to assimilate some available Satellite Retrieval Data for this case by MM5 4DVAR to explain the reason.

In this research, the available satellite data include QuickScat wind, GOES Cloud drift wind, AMSR, SSM/I and TMI water vapor, and Terra temperature and dewpoint temperature profile.

2. Overview of Hurricane Lili Case

Lili originated from a tropical wave that moved over the tropical Atlantic Ocean from the west coast of Africa on September 16th. The center of the hurricane moved over the southwest tip of the Isle of Youth on the morning of October 1st, and over western mainland Cuba a few hours later, with wind speeds as high as 90 knots. Gradually accelerating its forward speed to about 15 knots, Lili turned northward and made landfall on the Louisiana coast on the 3rd, with an estimated 80-knot maximum wind speed. However, between Cuba and Louisiana, Lili intensified to 125 knots early on the 3rd over the north-central Gulf of Mexico and then rapidly weakened to 80 knots during the 13 hours until landfall. Lili was absorbed by an extratropical low on the 4th while moving northeastward near the Tennessee/Arkansas border. Fig.1 and Fig.2 shows the track and intensity change of Lili.

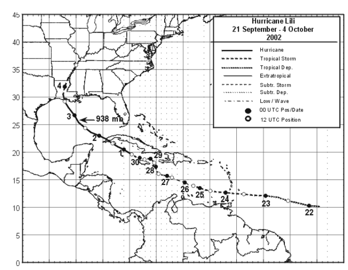

Fig. 1. Best track positions for Hurricane Lili, 21 September - 4 October 2002

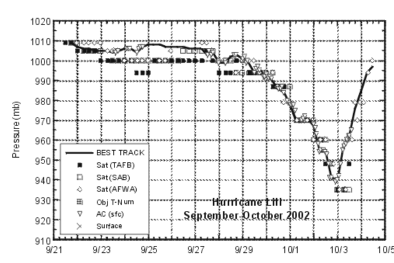

Fig.2. intensity Change for Hurricane Lili, 21 September - 4 October 2002

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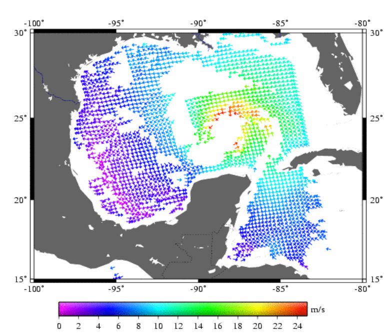

Fig.3 QSCAT Vector at October 2,2002 12Hrs

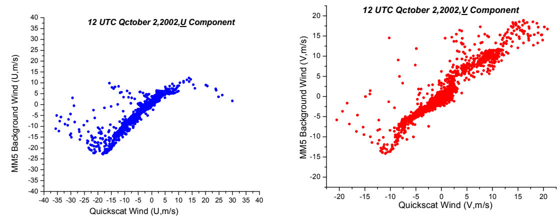

Fig.4. Scatter for QSCAT U and V Vector

3. Satellite dataset and assimilation methodology

a. QuickScat Wind

The microwave scatterometer SeaWinds was launched on the QuikBird satellite in June 1999. The primary mission of these Sea Winds scatterometers is to measure winds near the ocean surface. SeaWinds scatterometers are essentially radars that transmit microwave pulses down to the Earth's surface and then measure the power that is scattered back to the instrument. This "backscattered" power is related to surface roughness. For water surfaces, the surface roughness is highly correlated with the near-surface wind speed and direction. Hence, wind speed and direction at a height of 10 meters over the ocean surface are retrieved from measurements of the scatterometer's backscattered power.

b. QuickScat Wind at 1200 UTC 02 October 2002

The QuickScat(QSCAT) Wind data at this time are distributed over the entire vortex area. But it's only one level wind almost at 10m heights (Fig.3). QSCAT is very consistent with the MM5 first guess (Fig.4). This kind of surface wind showed a positive impact on tropical cyclones in the research of S. Mark (2003).

c. GOES-8 Cloud Drift Wind

The tracking of persistent, identifiable cloud features in GOES satellite imagery can provide an estimation of the ambient wind flow. This dataset is obtained from the University of Wisconsin. A height is assign-ned for a particular "wind." Data can be obtained from visible, infrared, and water vapor satellite images. The algorithm was described in Velden et al. (2000). The data are distributed over the entire troposphere, but largely concentrated in the upper troposphere, at or above 400hPa.

d. Terra Temperature and Dewpoint Temperature Profile

The profiles of temperature and dewpoint temperature data come form the Moderate Resolution Imaging Spectroradiometer (MODIS). MODIS is the key instrument aboard the Terra and Aqua satellites. It is an optical scanner that views the Earth in 36 channels with spatial resolution ranging from 250 meters to 1 kilometer. MODIS yields unique amounts and quality of data on the three spheres that human life depends on land, oceans, and atmosphere. The profile has 20 vertical layers with 5km horizontal resolution

e. *4DVAR Experiments*

Starting from 1200 UTC 02 October 2002, 30 minutes assimilation window is used to assimilate QSCAT. For the QSCAT only distributed at 1200 UTC, we incorporate it every 5 minutes in the assimilation window. The four-dimensional variational data assimilation is carried out by minimizing the cost function is:

$$
\begin{aligned}
J(x_0) = &\frac{1}{2}[\mathbf{X}(t_0) - \mathbf{X}_b]^T \mathbf{B}^{-1}[\mathbf{X}(t_0) - \mathbf{X}_b] \\
&+ \sum_t \sum_r \{[\mathbf{H}_l u - u^{QSCAT}]^T W_u [\mathbf{H}_l u - u^{QSCAT}] \\
&+ [\mathbf{H}_l v - v^{QSCAT}]^T W_u [\mathbf{H}_l v - v^{QSCAT}]
\end{aligned} \tag{1}
$$

The second experiment incorporates a bogus vortex every 5 minutes with QSCAT together in 30 minutes assimilation window. Here, we use the BDA method developed by Xiao et al. (2000) .The cost function is as following:

$$
\begin{aligned}
J(x_0) = &\frac{1}{2}[\mathbf{X}(t_0) - \mathbf{X}_b]^T \mathbf{B}^{-1}[\mathbf{X}(t_0) - \mathbf{X}_b] \\
&+ \sum_t \sum_r \{[\mathbf{H}_l u - u^{QSCAT}]^T W_v [\mathbf{H}_l u - u^{QSCAT}] \\
&\qquad + [\mathbf{H}_l v - v^{QSCAT}]^T W_v [\mathbf{H}_l v - v^{QSCAT}]\} \\
&+ \sum_t \sum_\Omega \sum_k \{[\mathbf{H}_l u - u^{bogus}]^T W_v [\mathbf{H}_l u - u^{bogus}] \\
&\qquad + [\mathbf{H}_l v - v^{bogus}]^T W_v [\mathbf{H}_l v - v^{bogus}]\} \\
&+ \sum_t \sum_\Omega [\mathbf{P}(r) - \mathbf{P_0}(r)]^T W_p [\mathbf{P}(r) - \mathbf{P_0}]
\end{aligned} \tag{2}
$$

Both of the QSC and QSC_B are conducted over a grid mesh of 85* 85 with 27-km grid distance. The wallclock for 30 iterations for each experiment is about 9 hours.

The GOES-8 cloud drift wind data assimilation starts from 1200 UTC 02 October 2002, a 6 hours assimilation window is used to include all data distributed in 1200 UTC to 1800UTC.Some other relevant researches have been done by Xiao et al. (2001). Before assimilating the data, we did the quality control according to the research of Kenneth (2001).

The temperature and dewpoint temperate-ure profile data assimilation use a 2 hours window, starting from 1800UTC. We incorporate the data at 1800UTC and 2000UTC.

4. Experimental Design

Control Run (CTRL) experiment only use the AVN analysis data as the initial field. QSC experiment only assimilates QuickScat Wind data at the initial time. Another experiment named QSC_B, use the optimal initial field both assimilating QSCAT and Bogus together. Experiment only assimilating bogus is the BDA. All Starting from 120 UTC 2 October 2002, it forecasts 36 hours.

5. Results

5.1 CTRL

At 12 UTC on 2 October 2002, the central Sea Level Pressure (CSLP) of Hurricane Lili is 954mb, which was reported by the National Hurricane Center. But the AVN data analysis for this time is 1002mb. There is a 48mb difference in the initial field. So the forecast with this initial field shows a great error during 1200 UTC 2 October 2002 through 4 October 00 UTC both in intensity and track prediction. It's hard to simulate Hurricane Lili's rapid weakening at 3 October 00 UTC (Fig 6).

5.2 QSC

After assimilate QuickScat wind data, not only the initial Surface Wind was improved, bur also the temperature and humidity was improved at the lower level. It recalls a little inner warm and moisture structure of hurricane. The positive impact is obvious on the intensity and track prediction.

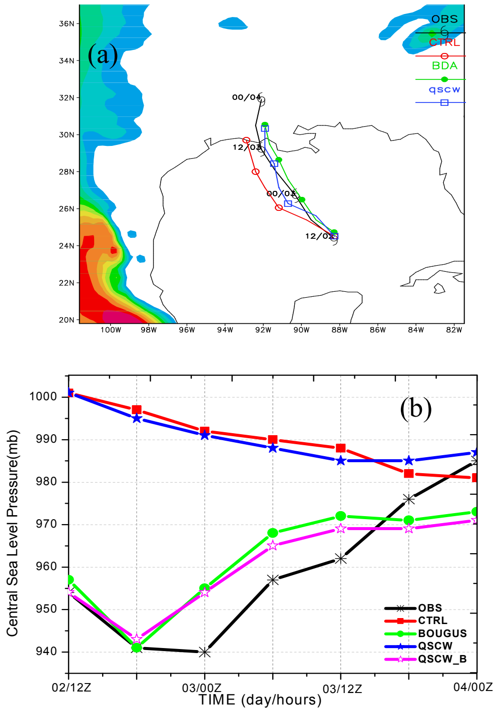

Fig.6. 36 hours track(a) and intensity (b)

5.3 QSC_B

QuickScat Wind has only one level. In order to improve the hurricane initialization, we conduct an experiment, which assimilates both the bogus vortex and QuickScat wind. QSC_B shows a great improvement on intensity prediction. Compare with only bogus, it also shows a little improvement in 36 hours intensity prediction**.**

The result of GEOS-8 cloud drift wind and temperature profile data assimilation will not be shown here.

6.Summery and Conclusion

Using the MM5 4DVAR system, we studied the impact of satellite retrieval data on hurricane Lili's initial fields and intensity and track forecast.

a. Initial inner structure was re-constructed in the experiment with QSCAT wind, compared with the experiment without the data. Intensity prediction was improved slightly, and the improvement of track prediction is obvious by QSCAT.

b. Assimilating both bogus vortex and QUSCAT is better than only bogus on intensity prediction.

c. Cloud drift wind has a positive impact on the track prediction, but we don't see more change for intensity prediction.

d. 3DVAR cycling experiments are also underway using Terra dewpoint information, and HRD dropsonde data. These results will be presented at the conference.

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