

The Impact of Multi-Satellite Data in a 4DVAR MM5 Simulation of Hurricane Lili's Rapid Weakening

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Introduction

This study focuses on the rapid weakening of Hurricane Lili over the Gulf of Mexico beginning early on 3 October 2002. During this time span, Lili rapidly weakened from category 4 to category 1, with its maximum sustained wind decreasing by 45 kt in the 13-h period until landfall in Louisiana (Fig. 1b). Operational models failed to predict this rapid weakening, and its physics is not well-understood. This rapid collapse is investigated using the MM5 4DVAR system. Sensitivity experiments are performed using GFS analysis initialization only, 4DVAR with vortex bogussing, and 4DVAR with vortex bogussing plus satellite data.

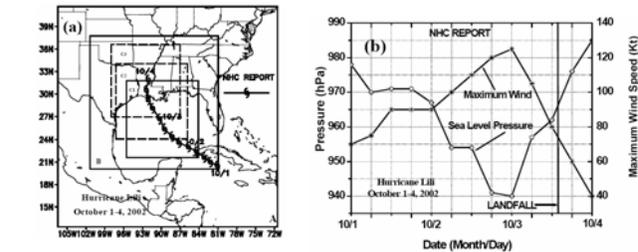


Fig. 1. National Hurricane Center (NHC) (a) best track positions and (b) intensity variation of hurricane CSLP (hPa, circle and solid line) and maximum wind speed (kt, asterisk and solid line) for Hurricane Lili during 1-4 October 2002. Landfall occurred at 1300 UTC 3 October. The three model domains used in this study are shown in (a).

MM5 Grid Configuration

The vertical MM5 grid contains 33 layers in the vertical with a model top at 50 hPa. The simulations are triple-nested with horizontal resolutions of 81 km (Domain A), 27 km (Domain B), and 9 km (Domain C). The coarse domain and the intermediate domain are fixed, while the inner domain moves with the hurricane track (Fig. 1a). The (x,y) dimensions are 48X50, 85X85, and 142X142, respectively.

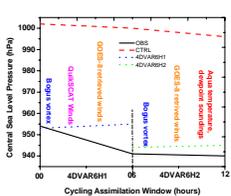


Fig. 2. Variations of central sea level pressure [CSLP (hPa)] analyzed by 4DVAR cycling experiment (dot dash), CTRL (dash), and the observation (solid).

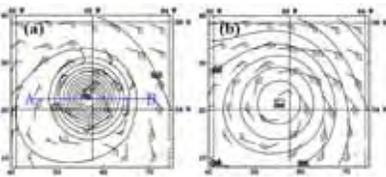


Fig. 3. The initial SLP (hPa) and model lowest level winds (ms^{-1}) of (a) 4DVAR6H1 and (b) CTRL at 1200 UTC 2 October. The CSLP of (a) is 953 hPa.

4DVAR Experiment Designs Using Cycling Mode

The 4DVAR experiments are performed in cycling mode in Domain B with two consecutive 6-h assimilation windows, labeled as 4DVAR6H1 and 4DVAR6H2. 4DVAR6H1 assimilates data from 1200 to 1800 UTC 2 October, and 4DVAR6H2 extends from 1800 UTC 2 October to 0000 UTC 3 October. In 4DVAR6H1, the first guess field is the interpolated GFS field (CTRL). 4DVAR6H2 uses the optimal solution (assimilation results) at the end of 4DVAR6H1 as the first guess. 4DVAR6H1 assimilates QuikSCAT winds at 1200 UTC, GOES-8 cloud drift/water vapor winds at 1145, 1315, and 1645 UTC, and a bogus vortex at 1200 UTC 2 October, while 4DVAR6H2 assimilates GOES-8 cloud drift/water vapor winds at 1915 and 2215 UTC, Aqua MODIS soundings at 1800 and 2000 UTC, and the bogus vortex at 1800 UTC 2 October.

Assimilation Window Impact on Intensity

After 4DVAR is performed, the CSLP is 953 hPa at Hour 0 in 4DVAR6H1 compared to 1002 hPa in the background (Fig. 2), and produces a stronger vortex (Fig. 3). However, the hurricane CSLP at the end of 4DVAR6H1 (1800 UTC 2 October) is about 14 hPa higher than observed. The second assimilation cycle 4DVAR6H2 then reduces the CLSP to 944 hPa at 1800 UTC; the observed 1800 UTC CSLP is 941 hPa. At the end of 4DVAR6H2, the CSLP is 945 hPa, close to the observation (940 hPa) (Fig. 2). In contrast, CTRL without data assimilation has a CSLP of 996 hPa at this time.

24-Hour Forecast Sensitivity to Satellite Data

A 24-h model integration was performed starting 0000 UTC 3 October with the optimal initial condition of 4DVAR6H2, labeled SATC. To examine the satellite data impact, another 24-h simulation was conducted using only vortex bogussing in the 4DVAR cycling, labeled BDAC. The initial intensity for SATC (assimilating satellite data and bogus) is closer to the observed than BDAC (assimilating bogus only). Moreover, SATC simulates the rapid weakening process for the first 6 h (Fig. 4) while BDAC does not. The 24-h track forecast is also improved for both SATC and BDAC compared to CTRL (Fig. 5). Note the vortex location at 0000 UTC 3 October is also improved, with no need to filter the GFS vortex, and implicitly includes beta gyres.

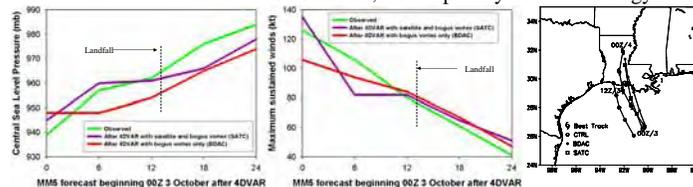


Fig. 4. MM5 CSLP (a) and maximum low-level wind speed (b) from 0000 UTC 3 October to 0000 UTC 4 October after 4DVAR data assimilation with vortex bogussing and satellite data from QuikSCAT surface winds, GOES-8 upper-level winds, and Aqua soundings. [SATC (purple)]; and 4DVAR with bogussing only [BDAC (red)]. Observed is also shown (green). Landfall occurred on 1300 UTC 3 October.

Dry Air Partially Responsible for Lili Weakening?

The hurricane's west side is drier than the first guess after including the Aqua MODIS sounding data in 4DVAR (Fig. 6). Low-level dry air propagates towards the hurricane center from the southwest quadrant, resulting in a weaker updraft in the southern eyewall at 1800 UTC 2 October, and an open western eyewall with downdrafts at 0000 UTC 3 October, when the hurricane begins to rapidly weaken (not shown).

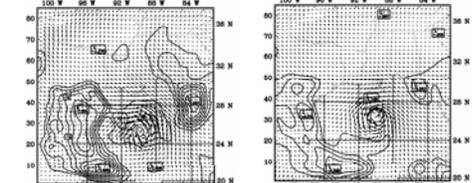


Fig. 6. Difference (4DVAR6H2 - 4DVAR6H1) of water vapor mixing ratio (solid line, $g\ kg^{-1}$) and wind vector ($m\ s^{-1}$) at 950 hPa at (a) 1800 UTC 2 October and (b) 0000 UTC 3 October.

Mean relative humidity (MRH) values 200 km from the storm center also support this hypothesis. Values from 1800 UTC 2 October to 0600 UTC 3 October are shown in Table 1 at model levels $\sigma=0.9735$, 0.9615 and 0.9475. Low-level MRH values decrease during this 12-h period.

Table 1. Mean Relative Humidity around hurricane center

| rh's / lev | 02/18 | 03/00 | 03/06 |
|-----------------|----------|----------|----------|
| $\sigma=0.9735$ | 99.74379 | 87.4904 | 83.05276 |
| $\sigma=0.9615$ | 96.30346 | 80.87632 | 75.13392 |
| $\sigma=0.9475$ | 90.29882 | 74.29162 | 73.94376 |

Conclusion

The numerical results led to the following conclusions:

- 1) The satellite data, particularly the Aqua data, makes an immediate impact on the hurricane intensity prediction. The satellite data assimilation experiment using MM5 4DVAR cycling mode captures the rapid weakening process for the first 6 h, while the 4DVAR with bogussing only keeps the pressure constant for the first 6 h, and a slower trend in wind decrease the first 6h. The track forecast with the satellite data is also more accurate than just using bogussing alone.
- 2) The low-level air on the hurricane's west side is drier after including the Aqua MODIS sounding data in 4DVAR. This simulation suggests dry air intrusion played a component in Lili's rapid weakening, and shows the value of the Aqua profile measurements.

Fig. 5. The predicted track of Hurricane Lili (2002) by CTRL, SATC, and BDAC, compared to the observed best track from 0000 UTC 3 to 0000 UTC 4 October.