3.2A A NUMERICAL MODEL INVESTIGATION OF INTENSITY FORECAST ERRORS FOR HURRICANE LILI (2002)

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1. INTRODUCTION

Tropical cyclone track forecasts have improved significantly over the past decades due to advances in numerical modeling and an increase in the amount of remote and in situ observational data (McAdie and Lawrence 2000). However, there has been limited improvement in tropical cyclone intensity forecasts (DeMaria and Kaplan 1999), especially for storms that exhibit rapid intensification and/or weakening.

From a forecast perspective, a particularly problematic case was that of Hurricane Lili, 2002. Operational models were able to predict the track of Lili. However, they failed to predict the rapid intensification of the storm over a 24-hour period from a category 2 hurricane to a category 4 hurricane with maximum winds of 125 kts. Furthermore, operational models failed to predict the even more rapid weakening of the system during its subsequent 13-hour traverse over the Gulf of Mexico to landfall on the Louisiana coast. During this time, the storm weakened to a category 1 hurricane with maximum winds below 80 kts.

A series of numerical modeling experiments using the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS^{TM}) (Hodur, 1997) have been conducted in order to identify and understand the contributing factors and physical processes that lead to the rapid decay of Hurricane Lili prior to landfall. The control simulation results are presented in section 2. Section 3 discusses the sensitivity test results with varied environmental factors, including the sea surface temperature and vertical wind shear. The summary is given is section 4, followed by the acknowledgement and reference list.

2. CONTROL SIMULATION

All the simulations presented here use triply nested grids (45km/15km/5km) (Fig.1a) with the inner-most domain as a moving mesh automatically following the movement of Lili (Liou and Holt, 2003). The Kain-Fritsch cumulus parameterization scheme is activated for the outer two domains, but the 5-km inner mesh uses only the explicit microphysics. This newly implemented microphysics package adds predictive equations for two new microphysical variables: graupel and drizzle, in addition to the original five variables: vapor, ice, snow, rain, and cloud water (Hodur and others, 2003). The 48-hour simulation is initialized with the NOGAPS analysis as the first-guess at 00Z 2 October 2002. The SST field (Fig. 1) is from the COAMPS ocean analysis that incorporates MCSST retrievals, surface ship, and fixed and drifting buoy data.

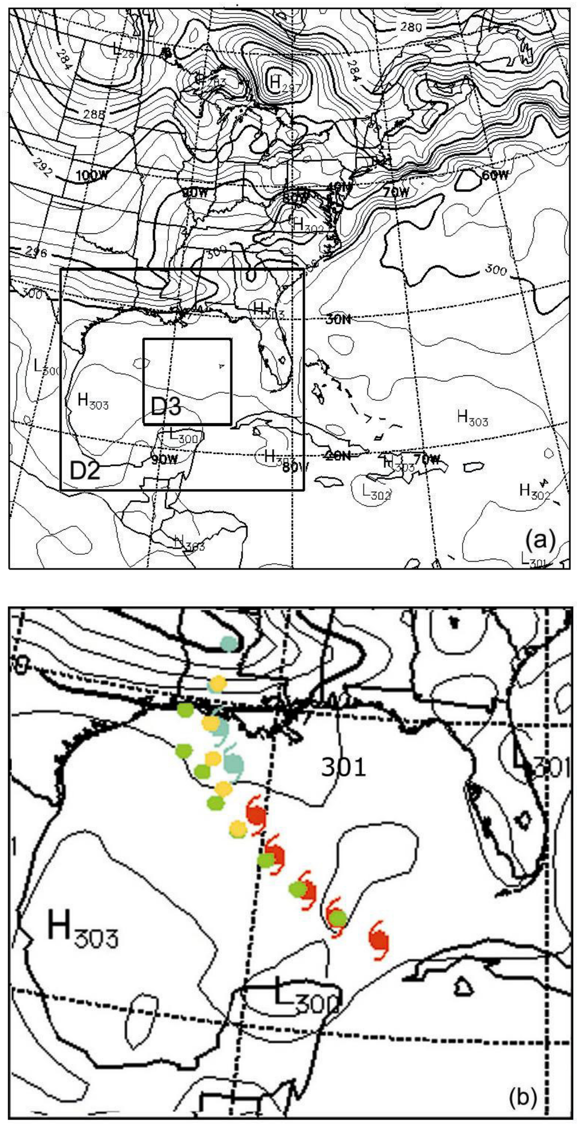

Fig. 1. SST and surface temperature field analyzed for (a) 00Z 2 October and (b) 00Z 3 October, contoured at 1 K intervals. Observed locations of Lili are depicted in (b) by red (intensifying stage) and aqua (weakening stage) dots every 6 hours from 00Z 2 October to 00Z 4 October. The forecast track from the control run is indicated by green dots. The yellow dots indicate the TC locations over the last 30 hours of the WST test (see section 3).

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The SST field remains the same for the 48-hour duration of the control simulation.

The forecast track follows the observed track very well with the track errors less than 50 nm for the first 24 hours (Fig. 1b). The simulated TC reaches its maximum intensity after 24 hours of simulation, which is also consistent with the strongest observed TC system at 00Z 3 October. The high resolution and new microphysics scheme of COAMPS help produce well-simulated hydrometeor fields (Fig. 2). For the first 9, hours the model produces large amounts of graupel (with the maximum mixing ratio above 9 g kg^{-1}) at the mid to upper levels of the atmosphere, one to two times more than the other two major hydrometeors: ice and rain. The eye wall seen in the hydrometeor fields is very evident and symmetric when the system is developing over the first day of the forecast, but it goes through a process of constant re-organizing later into the simulation. The vertical motion reaches a maximum value of 12 m s^{-1} along the eye wall after 12 hours into the simulation. This control run captures about 70% of the observed precipitation estimated from TRMM data (Figs. 3 & 4), and accounts for about 80% of the total pressure drop over the initial 24 hours (Table 1).

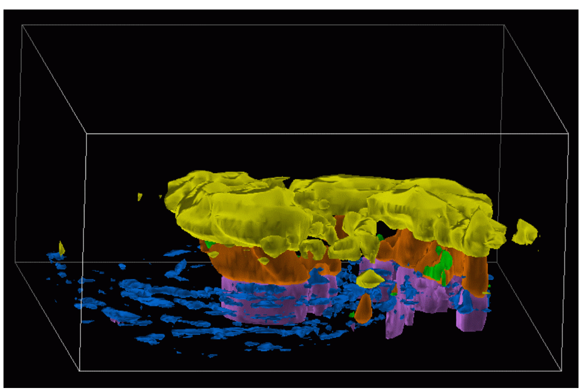

Fig. 2. Simulated hydrometeor fields at 12 hr from the control run valid at 12Z 2 October. Shown are isosurfaces of 0.5 g/kg mixing ratio of ice (yellow), snow (green), graupel (brown), rain (purple), and cloud water (blue).

The track errors, however, increase substantially over the next 24 hours (Table 2). This control run also maintains the maximum strength during this later period (third row of Table 1) and misses completely the observed rapid weakening stage of Lilil. In the following section we examine the possible roles of SST and environmental vertical wind shear on the weakening of Lili.

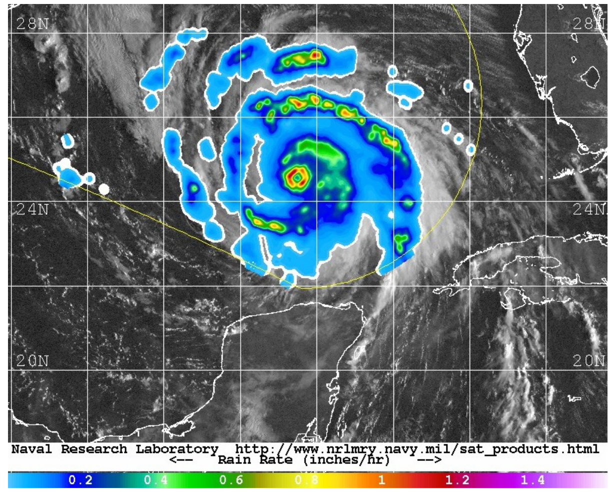

Fig.3. TRMM estimated surface rain rate (inches hr^{-1}) at 1254Z 2 October.

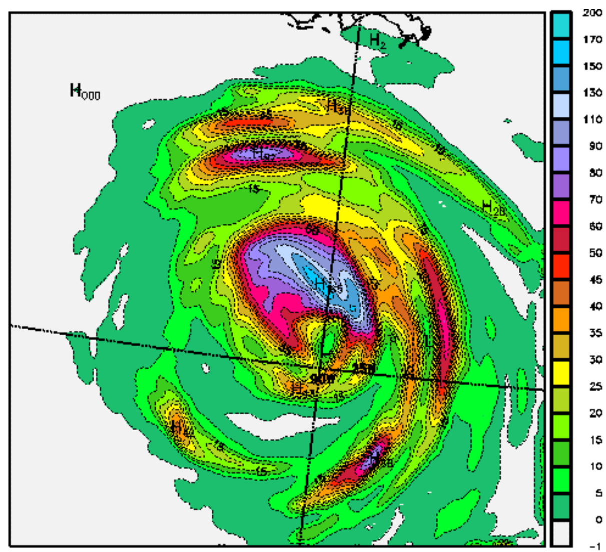

Fig. 4. COAMPS 6-hour accumulated precipitation (mm) from 18Z 2 October to 00Z 3 October from the 5-km domain of the control run.

Table 1. Observed mean sea level pressure (SLP) (hPa) for Lili (2002) every 12 hour from 00Z 2 October. Also listed are SLP from the control (CNTL), SST, and WST runs in domain 2 (D2) of 15-km resolution and domain 3 (D3) of 5-km resolution.

Hours	0	12	24	36	48	∆P(36-24)	∆P(48-36)
OBS	967	954	940	962	985	22	23
CNTL (D2,D3)	986, 986	973, 971	970, 965	971, 967	972, 965	1, 2	1, -2
SST (D2,D3)	986, 986	972, 968	970, 965	973, 969	975, 969	3, 4	2, 0
WST (D2,D3)	986, 986	973, 971	968, 964	973, 969	980, 976	5, 5	7, 7

Table 2. Track errors (NM) for domain 2 (D2) and domain 3 (D3) from the CNTL, SST, and WST runs initialized at 00Z 2 October.

Hours	12	24	36	42	48
CNTL (D2,D3)	8, 14	46, 47	100, 94	136, 138	156, 154
SST (D2,D3)	8, 13	46, 48	102, 93	135, 128	155, 155
WST (D2,D3)	8, 14	45, 44	61, 58	73, 71	80, 77

3. SENSITIVITY TESTS

3.1 *SST*

SST analyses were produced every 6 hours for the 48-hour period starting from 00Z 2 October. The SST fields did not change significantly until 00Z 3 October when the 301 K contour near the Louisiana shoreline extended southward (see Figs.1a & b). The SST decreased by about 1 K in this localized region by 00Z 3 October. Further examination of the SST data collected at buoy stations in this area confirms the onset and magnitude of this SST cooling. The observed track indicates (see Fig.1b) that Lili began its rapid weakening stage just when it was moving into this relatively cold SST (< 301 K) area, as shown in Fig. 1b. This coincidence prompted our interest in investigating the relationship between the cooling of SST and the onset of the rapid weakening of Hurricane Lili.

In this SST sensitivity test, the SST fields are updated every 6 hours in the two outer domains using the SST analysis fields. The TC's peak strength and track errors from the SST experiment results are similar to those from CNTL (see Table 1). There is no significant difference in the precipitation fields between these two runs. However, the intensity of the storm measured by the central SLP does show some difference between these two runs after the 24 hour forecast period. In the SST run, the model improves its performance for the weakening stage of the storm, accounting for 14% of the total weakening observed in domain 2 and 21% in domain 3 from hours 24 to 36. This improvement in the intensity forecast is associated with the aforementioned SST change occurring at 00Z 3 October.

If we assume that similar model performance during the intensification stage (80% of observed intensification) would also be realized during Lili's weakening stage, the maximum increase in SLP captured by the model would be ΔPmax=21hPa*80%$\approx$17 hPa. The 4 hPa increase in SLP in the SST run for domain 3 would account for 24% of the total increase in SLP values during the weakening stage. The same estimate applied for domain 2 would yield a very similar number: about 23% of the total increase in SLP. Based on this sensitivity test, SST cooling was not the major contributing factor in bringing Lili to its quick demise.

3.2 *Vertical Wind Shear*

Previous observations and numerical studies suggested that vertical wind shear between 800 and 200 hPa on the order of 10 to 15 m s^{-1} is adequate to have major adverse effects on storm intensity (e.g., Zehr, 1992; Frank and Ritchie, 2001). Examination of sounding data at several stations close to the Louisiana coastline (from archives at Univ. of Wyoming) indicates that Lili had a very minor influence on the atmospheric conditions at Corpus Christi International Airport (CRP) during the 48-hour period from 00Z 2 to 00Z 3 October. Therefore, the CRP sounding can be used to represent the upstream environmental conditions to the northwest of Lili's track. The CRP soundings show that starting from 18Z 2 October westerly winds of 5-10 kts developed within the layer from 400-200 hPa and persisted through the next 30 hours (Fig. 5), whereas in the COAMPS soundings of the control run (Fig. 6a) there are weak easterly or northerly winds (< 5 kts) from 00Z to 12Z 3 October, which is in a very different direction from the observed winds. A sensitivity test (WST) is designed to nudge the model wind and temperature fields toward this CRP sounding from 18Z 2 October to 00Z 3 October over a small area in both domain 1 (19x19 grid points) and domain 2 (26x29 grid points) centered around the CRP location. The nudging coefficients are determined so that they are equivalent to a forcing time scale of approximately 36 minutes (Xu et al., 2002).

By the end of the 6-h nudging, the vertical wind profiles in the targeted area are very similar to the observed profile and acquire the desired westerly component between 300 and 200 hPa (Fig. 6b). The temperature profiles (Fig. 7) remains essentially the same below 100 hPa before and after the nudging because it is very well simulated in the control run already.

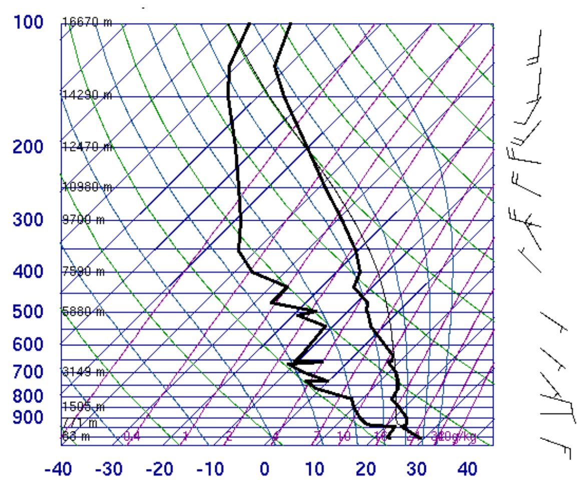

Fig. 5. Observed sounding at 00Z 3 October at Corpus Christi International Airport.

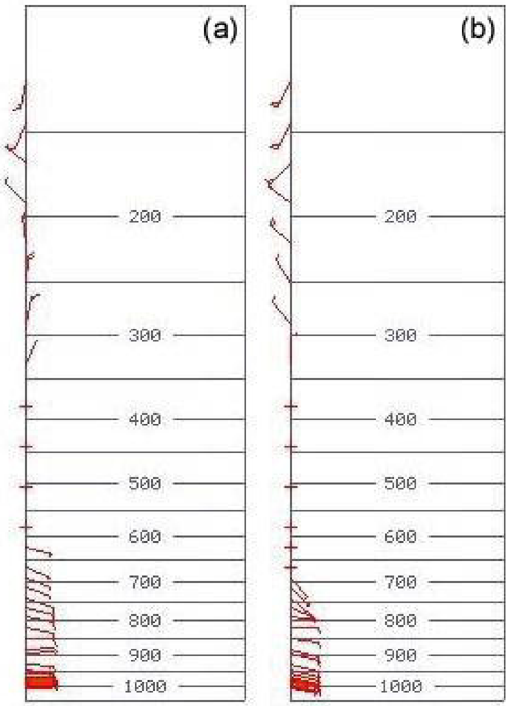

Fig. 6. The forecast CRP wind profiles at hour 24 valid for 00Z 3 October from: (a) the control run, and (b) the WST sensitivity run.

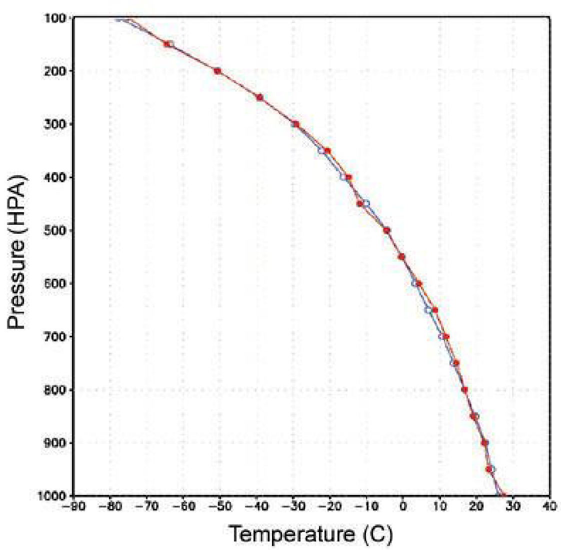

Fig. 7. As in Fig. 6, except for vertical temperature profiles from the control run (blue circles) and WST run (red dots).

Surprisingly, the most significant improvement from the WST run is seen in the track forecast in all three domains (see Table 2 for domains 2 and 3). The track forecast errors are reduced by 40% or more at hours of 36 and 42, and by 50% hour 48. The intensity forecast during the weakening stage is improved to some extent. If we use the same estimation method for measuring the intensity forecast skills for the SST run, this WST run captures about 27% of the observed weakening during the 12-hour period from forecast hours 24-36 and about 35% over the last 12 hour of forecast.

4. SUMMARY AND FUTURE WORK

The results of the control simulation indicate that the model successfully forecasts the rapid deepening of the cyclone but maintains the peak intensity of the storm until landfall, in contrast to the observed rapid weakening. Our sensitivity tests suggest that adding the 15 m s^{-1} vertical wind shear between 400 and 200 hPa to the Lili's upstream environmental flow has a very significant impact on the track forecast. However, the intensity weakening process to a large extent remains unresolved. Additional model simulations with different environmental conditions and physical parameterization methods are being conducted as our on-going effort.

5. ACKNOWLEDGEMENT

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