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Loop Current warming by Hurricane Wilma

L.-Y. Oey, T. Ezer, D.-P. Wang, S.-J. Fan, and X.-Q. Yin

1. Introduction

[1] Hurricanes mix and cool the upper ocean, as shown here in observations and modeling of the Caribbean Sea and the Gulf of Mexico during the passage of hurricane Wilma. Curiously, the upper ocean around the Loop Current warmed prior to Wilma’s entrance into the Gulf. The major cause was increased volume and heat transports through the Yucatan Channel produced by storm-induced convergences in the northwestern Caribbean Sea. Such oceanic variability may have important impacts on hurricane predictions. Citation: Oey, L.-Y., T. Ezer, D.-P. Wang, S.-J. Fan, and X.-Q. Yin (2006), Loop Current warming by Hurricane Wilma, Geophys. Res. Lett., 33, L08613, doi:10.1029/2006GL025873.

2. Methodology

[4] To analyze the upper-ocean changes caused by Wilma, we use data from the National Data Buoy Center (NDBC; http://www.ndbc.noaa.gov/), including SST (at z = −1 m) and meteorological observations (Figure 1 shows buoy locations). We also use results of an ocean forecast (the “control” run) for the Caribbean Sea and the Gulf of Mexico [e.g., Oey et al., 2005b]. Though we estimate large surface heat losses (peak ≈ 1300 J m⁻²s⁻¹ at 42056, and 800 J m⁻²s⁻¹ at 42057; see hurricane Opal [Shay et al., 2000]), these have small effects in decreasing the temperatures of the upper ocean, which is cooled more by mixing [Price, 1981].

[5] The forecast is initialized with a nowcast ocean field (Loop Current and eddies) that has already been assimilated with satellite data up to Oct/16/2005, after which the model is run through Nov/06/2005 without data assimilation. Oey et al. [2005a, 2005b] and references quoted therein give details of the model and the data assimilation scheme. Besides the ‘control’ run, other auxiliary runs are also conducted using different wind and initial density fields as will be pointed out below. The original forecast used Global Forecast System winds [Caplan et al., 1997], but the model was rerun for this study using also the high-resolution analyzed winds (available at http://www.aoml.noaa.gov/hrd/). This rerun is still referred to as “forecast” to emphasize that it is free from satellite data assimilation. Wind stresses were computed using a bulk formula. We use a drag coefficient (C_d) that curve-fits data for low-to-moderate winds [Large and Pond, 1981] with data for high wind speeds [Powell et al., 2003]:

\[
C_d \times 10^3 = \begin{cases} 
1.2, & W \leq 11 \text{ m s}^{-1}; \\
0.49 + 0.065 \ W, & 11 < W \leq 19 \text{ m s}^{-1}; \\
1.364 + 0.0234 \ W - 0.0002 \ W^2, & 19 < W \leq 100 \text{ m s}^{-1}.
\end{cases}
\]

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3. Results

[6] To account for wind mixing on the OHC of an evolving ocean, a non-dimensional parameter $\Phi$ is used, where $\Phi$ is obtained by estimating the energy required to mix water in an upper layer of depth $Z_{26}$ with the cooler water in a subsurface layer of depth $h$, and comparing this energy to power dissipation by the wind:

$$\Phi = \left(\frac{1}{2} ghZ_{26}\Delta \rho \right) \gamma \int_0^T \rho_0 C_d W^2 dt.$$  \hspace{1cm} (2)

[7] Here, $Z_{26}$ is taken as the depth of the 26°C isotherm, $\Delta \rho$ is the initial density difference between the two layers ($\approx 2$ kg m$^{-3}$ from the model), $\gamma$ is the efficiency of work done by the wind, $\tau$ is a wind time scale, $\rho_0$ is air density, $t$ is time and $g$ is acceleration due to gravity. Figures 2b and 2c show observed and forecast sea-surface temperatures (SST's; at $z = -1$ m) and $\log_{10} \Phi$ for Wilma around 42056 during hurricane Wilma. The dotted curve in each panel is ($\log_{10} \Phi$) of the inverse wind power dissipation (see text); shaded are values $\leq 2$. The dash-dot curve in Figure 1c is SST for auxiliary model run A1 in which Wilma was turned off. The vertical dashed line in each panel indicates time when Wilma is closest to the respective station.

Figure 1. A color image of the forecast OHC on Oct/20/12 GMT/2005 (color-scale across top) during hurricane Wilma. Maximum OHC (blue asterisk south of Jamaica) is printed on the top-left corner of the page. Thick-black contour indicates $\text{OHC} = 60$ kJ/cm$^2$. Forecast currents at $z = -1$ m are shown as black trajectories (with arrows) launched from every other four grid points. Maximum speeds (which occurred in Yucatan Channel) at $z = -1$m and -60m are printed. Wilma’s path is shown colored with its maximum sustained wind speeds (color-scale at bottom-left). Numbers at the small asterisks indicate days in October and the large asterisk the position of the storm corresponding to this forecast date. Off the Yucatan coast, the path of an observed drifter shaded with temperature (scale across “Florida”) are marked daily with a crossed-square, from Oct/15 to Oct/25. Positions of the three NDBC stations are marked with plus signs.

Figure 2. Observed (red solid) and forecast (blue solid) SST (at $z = -1$ m) at NDBC stations (a) 42003, (b) 42056 and (c) 42057 during hurricane Wilma. The dotted curve in each panel is ($\log_{10} \Phi$) of the inverse wind power dissipation (see text); shaded are values $\leq 2$. The dash-dot curve in Figure 1a is SST for auxiliary model run A1 in which Wilma is turned off. The vertical dashed line in each panel indicates time when Wilma is closest to the respective station.
To decrease prior to the arrival of a hurricane, the temperature, and vertical (SST) shows a similar (but less dramatic) “remote” effect; it also shows the large decrease when the storm center passes. The model looses its predictability at 42056 beyond about Oct/30.

Cooling ahead of the storm also exists in the Loop Current especially in its core. However, strong advection around the Loop complicates the picture. Buoy 42003 is located in close proximity of the Loop. The Φ in Figure 2a suggests that wind mixing at 42003 played a minor role (Φ > 100) prior to Wilma’s arrival on Oct/23 ~ 24. The observed SST first decreased to a minimum on Oct/19 ~ 20; it then increased by about 0.4°C from Oct/20 through Oct/23 before dropping sharply (~0.8°C) on Oct/23 ~ 25 as Wilma passed south of the site. This final sharp drop is caused partly by wind-mixing (the Φ drops below 100), and partly by advection of cooler shelf/slope waters as Wilma moved toward Florida (not shown). The sharp drop agrees well with along-track data on Oct/24/15GMT from satellite ENVISAT (www.aoml.noaa.gov/phod/dataphod), which flew almost exactly over 42003 on that date and recorded a minimum SSHA ≈ −0.3 m. The initial decrease to the minimum SST on Oct/19 (Figure 2a) seems to be part of the natural (i.e., unrelated to Wilma) variability of the Loop Current, since the SST for the auxiliary run A1 (without Wilma) shows a similar decrease. However, the subsequent ~3-day (Oct/20 ~ 23) warming is unique for 42003. No such SST-rise was observed at 42056 and 42057 (Figures 2b and 2c), nor have similar phenomena been observed previously. The forecast (Figure 2a) shows a similar SST-variation of the rise of SST on Oct/20 ~ 23 and the subsequent sharp drop. In contrast, the SST decreases monotonically with time in the auxiliary run.
auxiliary run A1, on Oct/22/12GMT. (Subtracting the A1-solution minimizes contributions from background variability that is not related to Wilma. However, the general warming in the Loop and cooling in the Caribbean in Figure 4 remain if the initial condition is subtracted instead.) This shows warming (red) around the edge of the Loop where currents are strong and cooling (blue) in the Caribbean Sea to the right of Wilma’s path (Figure 2b). The asymmetry is striking. The warming is in part caused by localized wind-induced convergences especially at fronts, but a large part is by excess influx of warmer waters from the Caribbean. (To isolate localized advection by wind, a case that uses Wilma’s wind field at the northern tip of Yucatan (on Oct/23) was run. We found SST-rise ≈ 0.3°C in the Loop, or about 20% of the total shown in Figure 4.) Based on the excess heat influx (the Oct/18–23 average is 1.2 × 10^7 °C m^3 s⁻¹ (or 5 × 10^13 W), Figure 3) heat balance in an adiabatic stream-tube around the Loop Current (75 km wide × 150 m deep × 400 km long) from Oct/18 to 23 is computed; this yields an increase of 1°C in agreement with Figure 4. The Yucatan-Loop Current system plays an important role in distributing the heat far north into the Gulf (around the Loop); in their absence, warming occurs only near the channel. This was confirmed by forcing Wilma onto an initially quiescent ocean with level isopycnals. The surface then cannot show warming because there are no horizontal thermal gradients (and no surface heat flux), but there is subsurface warming of about 0.5°C at z = −50 m, caused by flow convergence, close to the channel mouth.

4. Discussion

[11] We have computed geostrophic transports through the Yucatan Channel based on satellite altimetry data (OASSH, not shown). Prior to Wilma’s entrance into the Gulf, the data shows an increased transport that is consistent with the model forecast shown in Figure 3, and the OASSH averaged over the Loop also increased. These data provide a tentative support of the warming observed at buoy 42003. Also, the model shows large subsurface (i.e., z < −150 m) transport into the Gulf days after Wilma has passed (Figure 3, green curve). Subsurface influx encourages Loop Current extension [Hurlburt and Thompson, 1980], and both model and OASSH maps show a more extended Loop following Wilma. The extension may be a response to the increased transport [Ezer et al., 2003], or (and) to the production of higher potential vorticity [Oey, 2004] by the intense cyclone that developed in the western portion of the Yucatan Channel when Wilma entered the Gulf.

5. Conclusion

[12] Summarizing, cooling was observed at a buoy hundreds of kilometers from, and days ahead of hurricane Wilma in the northwestern Caribbean Sea. A buoy in the northern edge of the Loop Current recorded SST-rise a few days prior to Wilma’s entrance into the Gulf. The model study indicates that the rise was part of an overall warming around the Loop due in part to an increased influx of warm water into the Gulf of Mexico while Wilma was in the Caribbean Sea. Hurricane intensity is sensitive to slight changes in SST [Emanuel, 2005]. Results presented here suggest that hurricane predictions may benefit from prognostic ocean forecasts that have realistic representations of strong flows such as the Loop Current (and eddies).

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References


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