# Characteristics of meteorological parameters associated with Hurricane Isabel

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Received 19 September 2004; revised 21 November 2004; accepted 21 January 2005; published 16 February 2005.

[1] The present study focuses on the air-sea interactions associated with Hurricane Isabel, which landed on the east coast of the United States on September 18, 2003. Hurricane Isabel is considered to be one of the most significant and severe tropical cyclones, as it affected the entire east coast in many ways. We have analyzed various meteorological parameters associated with the hurricane in different stages such as evolution, intensification and landfall. Analysis of surface latent heat flux (SLHF) and precipitation rate (PR) associated with the hurricane, based on the categorization in different stages, is carried out. SLHF and PR increase anomalously prior to landfall as compared to when the hurricane was at its maximum intensity (category 5). Wind speed (WS) and rain-rate data from satellite observations show breakup of the eye-wall and asymmetric structure leading to increased precipitation prior to landfall. **Citation:** Gautam, R., G. Cervone, R. P. Singh, and M. Kafatos (2005), Characteristics of meteorological parameters associated with Hurricane Isabel, *Geophys. Res. Lett.*, *32*, L04801, doi:10.1029/2004GL021559.

## 1. Introduction

[2] Hurricanes in the Atlantic Ocean are very common phenomena and are generally formed over warm ocean waters during June through November. Surface winds play a very important role in hurricane formation as a result of tropical disturbances. In general, the Atlantic hurricanes are developed by the convergence of easterly winds that form over Western Africa regions [*Alliss et al.*, 1993; *Mo et al.*, 2001]. Cumulus convection acts as a major source of latent heat release that enhances the radial circulation within a cyclone by conserving the angular momentum of rotating air [*Smith*, 2000]. The effect of boundary layer structure on the intensity of hurricanes has been discussed in the past [*Black and Holland*, 1995; *Smith*, 2000]. Several studies have shown the role of latent heat in the motion and intensity of cyclones derived from multi-sensor satellite observations [*Guinn and Schubert*, 1993; *Rodgers et al.*, 1998; *Jones et al.*, 2003]. *Rodgers et al.* [1998] have shown the release of latent heat occurred in the eye-wall region of Hurricane Opal during intensification and decay stages as well. Latent heat flux estimation depends on various geophysical parameters such as sea surface temperature (SST), water vapor (WV) and WS [*Schulz et al.*, 1996]. The dependence of SLHF on the above parameters can be obtained from the following equation:

$$LE = \rho E C_D (u_s - u_a)(q_s - q_a), \quad (1)$$

where the subscript $a$ corresponds to a reference altitude, $s$ stands for surface quantities, $C_D$ is the bulk transfer coefficient, $q$ is the specific humidity, $u$ the scalar wind and $\rho$ and $E$ are constants.

[3] Significant increase in precipitation near the storm center is known and influences the intensity of hurricanes [*Karyampudi et al.*, 1998]. The intensification process is driven by the occurrence of spiral bands of convection as well, by maintaining the potential vorticity of hurricanes [*Guinn and Schubert*, 1993; *Davis and Bosart*, 2001]. *Cerveny and Newman* [2000] have found strong relationships between rainfall accumulations and maximum surface WS associated with tropical cyclones. Numerous landfalling hurricanes have been analyzed to understand the formation of heavy precipitation and its distribution in the decay stages of hurricanes [*Atallah and Bosart*, 2003; *Chen and Yau*, 2003]. Recent studies have shown that SST cooling has a direct impact on the air sea fluxes under high wind conditions and can effectively alter the maximum total enthalpy flux [*Cione and Uhlhorn*, 2003; *Perrie et al.*, 2004]. Numerical simulations involving different geophysical parameters have been carried out to improve the understanding of track estimation and intensity variations [*Frank and Ritchie*, 1999; *Hong et al.*, 2000; *Zhang et al.*, 2002; *Li et al.*, 2003].

[4] Currently, estimation of tracks is well determined but large uncertainties exist in the estimation of intensity of the hurricanes. In this paper, we focus on the intensity variations of Isabel at different stages by analyzing various meteorological parameters such as WS, SLHF and PR, and their variability. The results show that these meteorological parameters are closely related to each other and control the intensity of the hurricane. Similar results were found for Hurricane Frances (2004).

## 2. Hurricane Isabel

[5] Hurricane Isabel formed as result of a tropical wave that moved westward from the coast of Africa on September 1, 2003. On September 7, the tropical depression intensified into a hurricane. The intensity of Isabel on the Saffir-Simpson Hurricane scale was category 5 during September 11–15. After September 15, Isabel lost its intensity and changed its path to north-northwestward and finally made landfall on September 18 on the outer banks of North Carolina as a category 2 hurricane. Shear winds and

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0094-8276/05/2004GL021559$05.00

very high rainfall associated with the hurricane resulted in enormous damage and even casualties (50 deaths). The total damage from Isabel is estimated to be around 3.37 billion dollars.

[6] Numerical modeling of the hurricane produced exceptional forecasts of its track and the landfall information because of the large cloud size and the slow movement through the central and east Atlantic in a relatively predictable steering pattern. But the intensity of Isabel at latter stages was still somewhat uncertain when the hurricane lost much of its intensity and made landfall.

## 3. Data Sets

[7] The SLHF and PR data were taken from http://iridl.ldeo.columbia.edu/SOURCES/.NOAA/.NCEP-NCAR/ for the month of September 2003. The data set is in the form of global grid of 1.8° × 1.8° resolution. Validation and detailed description of the reanalysis of NCEP SLHF data have been discussed by *Kalnay* [1996].

[8] Other rainfall measurements including rain-rate data were obtained from the TRMM (Tropical Rainfall Measuring Mission) Microwave Imager (TMI). The resolution of TMI data ranges from 5 km at 85.5 GHz to 45 km at 10.65 GHz providing the spatial distribution of rainfall at fine scale (http://lake.nascom.nasa.gov/data/dataset/TRMM/).

[9] WS data were taken from the passive microwave scatterometer QuikSCAT that measures near-surface WS and direction (ftp://podaac.jpl.nasa.gov). This Level-3 data is in the form of global grid of 0.25° × 0.25° resolution.

## 4. Results and Discussion

[10] We have analyzed different meteorological parameters associated with Hurricane Isabel along its track (Figure 1a). A clear change in direction is seen between September 15–16 when the hurricane lost much of its intensity and transformed from a category 5 status to category 3.

[11] Figure 1b shows the WS over the Atlantic Ocean on September 11, 13, 16 and 18, 2003. The size of the wind swath has been found to be significantly increased in the ascending order of days. Isabel reached its maximum intensity (category 5) on September 11 which is obvious from the WS plot (Figure 1b). Winds associated with the hurricane are converging around the center of the hurricane causing its intensification. During September 11 and 15, Isabel maintained a powerful category 5/4 status, while the wind structure around the eye-wall split up causing divergence of winds in different directions on September 16 and 18, when the eye-wall of the hurricane broke up, causing considerable loss in the intensity of Isabel. The increase in vertical wind shear on 15 September has been found to have played a significant role in the loss of intensity of Isabel (NHC/TPC Tropical Cyclone Report). Wind measurements play a significant role in determining the amount of SLHF in the environment. The drastic change in the wind structure is found to directly affect the SLHF in the overall hurricane energy system from September 16 onwards (Figure 1c).

[12] Other factors affecting latent heat flux include air temperature and humidity. Here, we have only analyzed WS to show the coupling between the two parameters. When the hurricane was at high intensity, the associated SLHF was

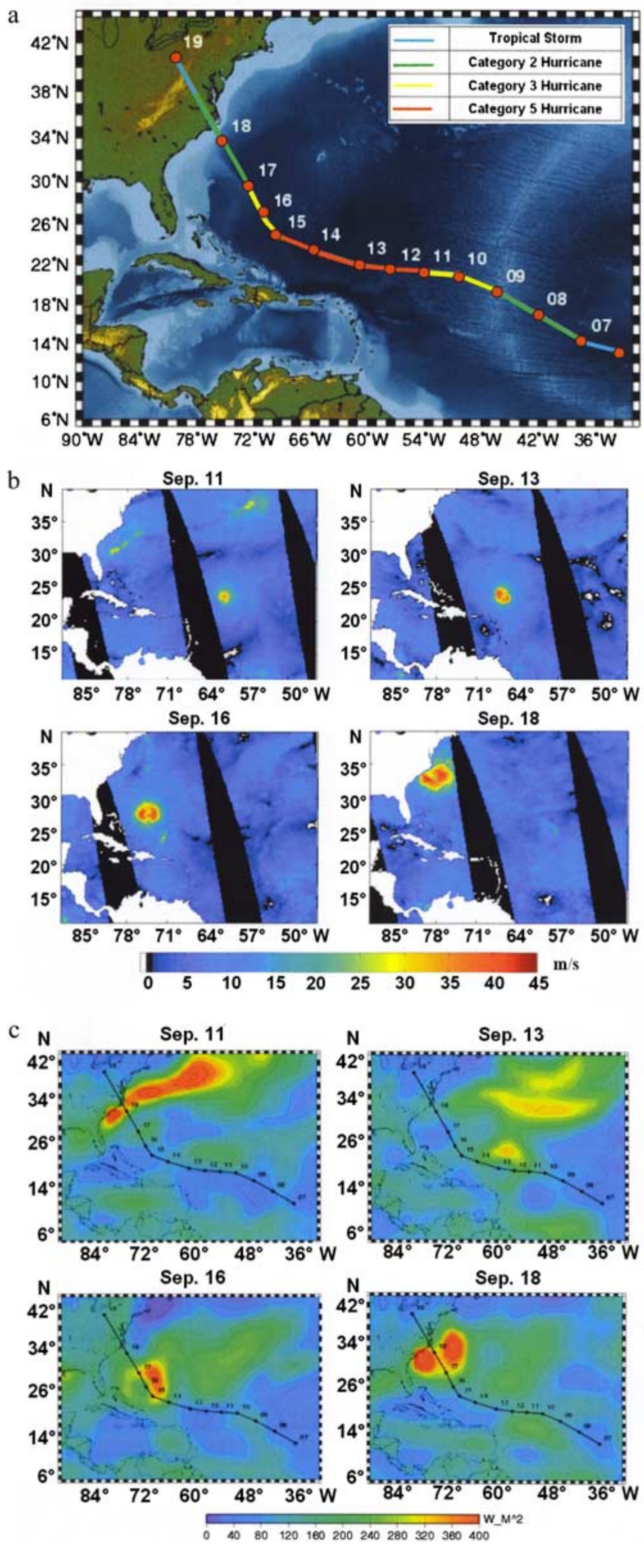


**Figure 1.** (a) Track of Hurricane Isabel (September 7–18, 2003) with its intensity at different stages, (b) WS associated with Hurricane Isabel on September 11, 13, 16 and 18, 2003 and (c) SLHF associated with Hurricane Isabel on September 11, 13, 16 and 18, 2003.

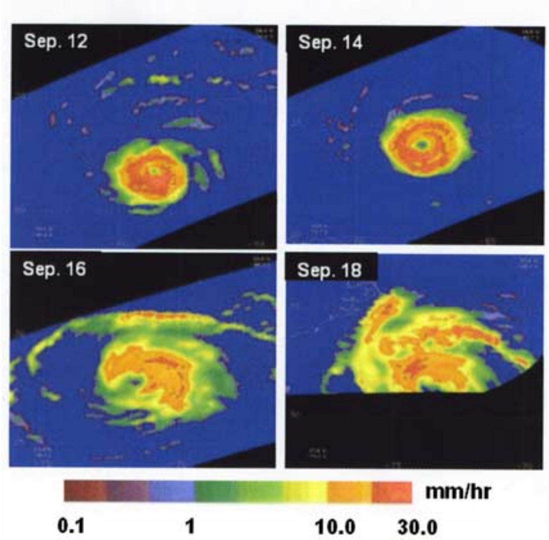


**Figure 2.** Rainfall rate variations associated with Hurricane Isabel from TMI on September 12, 14, 16 and 18, 2003. Highly precipitable rain bands can be seen in outer regions of the hurricane on September 16 and 18.

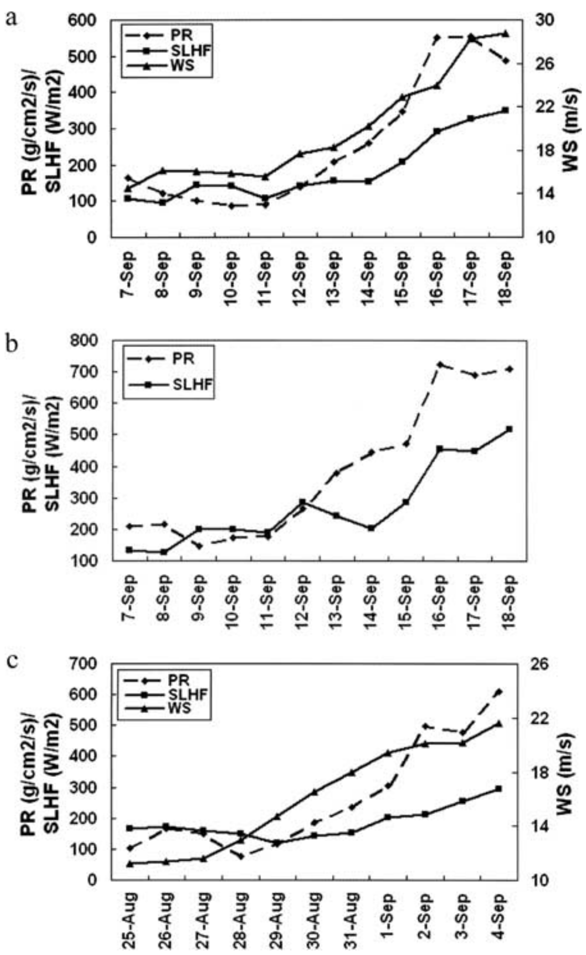


**Figure 3.** (a) Time series of PR, SLHF and WS for hurricane Isabel from September 7–18, 2003, (b) time series of maximum values of PR and SLHF from September 7–18, 2003 and (c) time series of PR, SLHF and WS for hurricane Frances from September 25–August 4, 2004.

**Table 1.** Categorization of Hurricane Isabel in Three Stages A, B and C Based on Its Intensity

| Stage | Date | Description |
|---|---|---|
| A | September 7–10, 2003 | Weak tropical cyclone |
| B | September 11–15, 2003 | Strong category 5/4 hurricane |
| C | September 16–18, 2003 | Pre - landfall stage |

found to be relatively low, while anomalously high values of SLHF have been found from September 16 onwards. The SLHF is found to be distributed around the eye-wall of the hurricane, where the maximum rainfall occurs. Increase in the cloud cover size and splitting of wind structure around the eye-wall resulted in very high rainfall in this region (Figure 2). Latent heat releases in the atmosphere are fundamentally based on the principle of condensation of atmospheric WV into cloud liquid water. Thus, increase in the wind swath and the resulting increase in the cloud cover have been found to increase the PR and SLHF anomalously in the latter stages of Hurricane Isabel and the resulting significant reduction in its intensity.

[13] Figure 3a shows the variations of PR, SLHF and WS during September 7–18 along the hurricane track. We have taken a constant grid size of $5.4° \times 5.4°$ area, centered on the hurricane eye, at different dates during September 7–18, 2003. We have compared all three parameters by computing the average values inside the fixed grid along the hurricane track. Both PR and SLHF values are found to be extremely low during September 7–10, when Isabel was a weak hurricane (category 2/3). PR and SLHF are found to have significantly increased after September 11 i.e., when Isabel became a category 5 hurricane. We have tried to quantify our observations by dividing the whole time series of PR, SLHF and WS into three parts A, B and C as shown in Table 1. The values among these phases are averaged and the percentage increase among the three phases is calculated (Table 2). The percentage increase in the PR and SLHF from B to C is found to be much higher compared to the increase from A to B; this implies that the SLHF and PR were associated with the intensification and also with the decay stages of Hurricane Isabel. We have also compared the maximum values of PR and SLHF by taking a fixed grid centered on the hurricane eye (Figure 3b). We find that for both cases (average and maximum), PR and SLHF follow a similar trend, and are found to be high during hurricane intensification and decay periods. Moreover, both parameters show higher values in the decay stage when compared to the intensification stage.

[14] Correlation analysis was performed to determine the strength of the relationships among these parameters. Maximum correlation coefficient ($r$) values between PR/SLHF and WS/SLHF were found at 1-day lag (Table 3). A student $t$ test was performed to test the statistical significance of the $r$ values; p-values are found to be less than 0.05 (Table 3).

**Table 2.** Percentage Increase in PR and SLHF From Stage A to B, Stage B to C and Stage C to A

| | PR | SLHF | WS |
|---|---|---|---|
| (B-A)/A % | 77.3 | 26.3 | 20.8 |
| (C-B)/B % | 154.1 | 111.1 | 42.6 |
| (C-A)/A % | 350.6 | 166.8 | 72.4 |

**Table 3.** Results From Correlation Analysis for Hurricanes Isabel and Frances; Between PR and SLHF, WS and SLHF at 1-day Lag

| | Isabel | | Frances | |
|---|---|---|---|---|
| | *r* | p-Value | *r* | p-Value |
| PR/SLHF | 0.95 | $0.0082 * 10^{-3}$ | 0.95 | $0.0267 * 10^{-3}$ |
| WS/SLHF | 0.97 | $0.00051 * 10^{-3}$ | 0.79 | 0.0058 |

This result suggests that PR and WS are found to be leading SLHF by one day along the track of the hurricane.

[15] In order to further investigate such relationship between PR, SLHF and WS, similar analysis was carried out for the recent Hurricane Frances (August 25–September 4, 2004). Results indicate similar relationship among these parameters associated with this hurricane (Table 3 and Figure 3c).

## 5. Conclusions

[16] Meteorological parameters such as PR and SLHF associated with Hurricane Isabel (September 7–18, 2003) are found to be strongly coupled and are associated with the intensity variations of the hurricane along its track. In both the intensifying and decay stages of Isabel, PR and SLHF are observed to be very high. Moreover, the two parameters assumed higher values prior to landfall as compared to when Isabel became category 5 hurricane. PR and WS were found to be leading SLHF by one day along the hurricane track. A similar relationship among these parameters was found to be associated with Hurricane Frances (2004). Based on the results from the two hurricanes and visual linkages among the three parameters for other hurricanes, we believe that these parameters exhibit strong coupling and similar relationship in general for landfalling hurricanes. Further, a detailed analysis of such parameters may provide better insight about the intensity of hurricanes. The high resolution (TMI) rainfall rate associated with Isabel shows an increase in the amount of rainfall due to the formation of highly precipitable rain bands in its outer regions. Divergence of winds resulting in breaking up of the eye-wall has also been found to be responsible for the weakening of Hurricane Isabel.

[17] **Acknowledgments.** The authors are grateful to the anonymous reviewer and to Dr. Saburo Miyahara, Editor, for their useful comments in improving the earlier version. We are grateful to S. Dasgupta for his kind tips with the data analysis. Work is supported by NASA VAccess/MAGIC project NAG13-03019.

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