

ESTIMATING THE RADIUS OF MAXIMUM WINDS VIA SATELLITE DURING HURRICANE LILI (2002) OVER THE GULF OF MEXICO

S. A. Hsu

Coastal Studies Institute
Louisiana State University
Baton Rouge, Louisiana 70803

Adele Babin
Naval Oceanographic Office
1002 Balch Boulevard
Code N213
Stennis Space Center, Mississippi 39522

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Abstract

Using a single case from Hurricane Lili (2002), a technique is described to estimate the radius of tropical cyclone maximum winds (R) utilizing satellite data. For the satellite estimation of R , the distance between the coldest cloud-top temperature surrounding the eye and the warmest temperature in the eye of the hurricane measured 29 km. National Data Buoy Center (NDBC) wind speed measurements at 10 m height yielded a distance of 28.5 km when substituted into an empirical equation of the radial variation of tangential wind speed in a hurricane with the typical exponent of 0.7 for higher altitude. Both determinations of R were in excellent agreement, thus providing confidence that the satellite method may offer a reliable way to estimate R in some cases.

1. Introduction

According to Holton (1992), the kinetic energy of hurricanes is maintained in the presence of boundary layer dissipation by conversion of latent heat energy acquired from the underlying ocean. This potential energy conversion is carried out by a transverse secondary circulation associated with the hurricane. This circulation consists of boundary layer inflow into a region of enhanced convection surrounding the storm center that is referred to as the eyewall, ascent within convective cloud towers that tend to be concentrated in the narrow outward-sloping eyewall, radial outflow in a thin layer near the tropopause, and gentle subsidence at large radius (r). The eyewall surrounds a central eye of radius 5-50 km that is often calm and cloud free.

The radius of maximum wind (R) associated with a hurricane is an important parameter in atmospheric dynamics and tropical cyclone forecasting. According to Anthes (1982), vorticity is $2(V_{\max})/R$, where V_{\max} in m s^{-1} is the maximum wind defined by

$$V_{\max} = 6.3(1013 - P_0)^{1/2}, \quad (1)$$

where P_0 is the minimum sea-level pressure in mb (see, e.g., Simpson and Riehl, 1981). In the forecasting of sea state, R is needed for the calculation of significant wave height and period. According to Anthes (1982), the radial variation of the tangential wind speed beyond R in mature tropical cyclones is often described by the empirical function

$$V_r = V_{\max} \left(\frac{R}{r} \right)^x, \quad (2)$$

when $R \leq r \leq r_0$, and r_0 is a large radial distance near the edge of the area disturbed by the storm, V_r is the wind speed at r , and the exponent x has a typical value of 0.7 (x varies with height from 0.5 for surface to 0.7 for higher elevations). A demonstration using $x = 0.5$ for surface during Hurricane Lili is provided in Hsu (2003).

Traditionally, the radius of maximum wind has been measured directly by aircraft or by the pressure distribution at the sea surface. More recently, Hsu et al. (2000) proposed that R could possibly be determined from satellite measurements based on the distance between the coldest cloud-top temperature near the eye and the warmest section within the eye of the hurricane. This satellite method has limitations. A discernable eye is necessary so that the satellite infrared temperature measurement within the eye is a positive value. This method estimates an upper-level R value under the assumption that the coldest cloud-top temperature near the eye represents the highest level clouds and most intense convection within the eyewall. Additional case study verification using Eq. (2) is limited at this time because there is a lack of tropical cyclones with clear eye structure passing near two buoys measuring 10 m wind speed. The Gulf of Mexico is the only location affected by tropical cyclones where multiple buoys are measuring wind speed at 10 m height. No tropical cyclones other than Lili were found to fit the empirical equation conditions of 10 m wind speed measurements at the two specific locations, within 20 km of the eye and on the fringe of the storm.

The purpose of this research paper is to apply the method of estimating R via satellite data to the Hurricane Lili case and compare the output R values from in-situ buoy data and aircraft reconnaissance. Note that the average period for the wind speed measured from a buoy is 8 minutes versus the maximum winds from Air Force Reconnaissance being obtained instantaneously from aircraft instrumentation.

2. Results

A visual depiction of the satellite method is provided in Fig. 1. During Hurricane Lili in 2002, two National Data Buoy Center (NDBC) buoys were operational and measuring wind speed at 10 m. Buoy 42001 was located near R and buoy 42003 was located due east along 26°N and approximately 280 km from 42001. Buoy data (National Data Buoy Center 2002) showed that at

2000 UTC 2 October 2002 buoy 42001 measured $P_0 = 956.1$ mb. Substituting this P_0 into Eq. (1) yields $V_{\max} = 47.5 \text{ m s}^{-1}$, and is in excellent agreement with the maximum wind speed of 47.2 m s^{-1} measured at buoy 42001 closest to the center of Lili. Therefore, Eq. (1) is satisfied for this case. At the same time, the measured 10 m wind speed at buoy 42003 was 9.2 m s^{-1} . For this case, V_{\max} is the maximum wind speed measured at buoy 42001 closest to the center of Lili, V_r is the wind speed at buoy 42003 near the outer edge of the storm, and r is the distance between the two stations. Substituting these values ($V_{\max} = 47.2 \text{ m s}^{-1}$, $V_r = 9.2 \text{ m s}^{-1}$, $r = 280 \text{ km}$, and $x = 0.7$ (a typical value for higher altitude, according to Anthes (1982, p. 25)), into Eq. (2) and solving for R yields

$$R = r \left(\frac{V_r}{V_{\max}} \right)^{1/x} = 280 \left(\frac{9.2}{47.2} \right)^{1/0.7} = 280(0.20)^{1.42} \quad (3)$$

$$R = 28.5 \text{ km} \quad (4)$$

As shown by the green dot and asterisk in Fig. 1, the satellite measured distance was 29 km between the coldest cloud-top temperature and the warmest temperature within the eye, and solving for R agrees with Eq. (4). For additional verification during Lili, aircraft reconnaissance data was obtained from the NHC (National Hurricane Center, 2002) for 2013 UTC 2 October 2002. R values were 11.1 km at the surface and 16.7 km at the 700 mb flight level located at 2,568 m height. As mentioned earlier, the satellite estimation should be representative of levels higher than aircraft reconnaissance. So combined, the aircraft measured R and the satellite estimated R values demonstrate the well known concept of R increasing with height. Table 1 details the various methods and the resultant R values presented in this paper. Though the surface and 10 m level values do not demonstrate R increasing with height, the values are reasonably similar (0.5 km difference) considering the surface value was estimated manually by a flight meteorologist. The empirical equation method at 10 m is assumed more accurate as it utilizes instrument measured wind speeds. Since the proposed satellite method is based on the cloud-top temperature using infrared determination, it works best at the cloud-top altitude.

Table 1. R values determined by various methods and the representative atmospheric level.

R (km)	Atmospheric Level	Method To Determine R
29	Cloud-Top Altitude	Satellite Method
28.5	Upper Level	Empirical Equation (10 m buoy and 0.7 exponent appropriate for upper level)
16.7	2500 m	Aircraft Reconnaissance (instrument flight level measurement)
10.6	10 m	Empirical Equation (10 m buoy data and 0.5 exponent appropriate for 10 m level)
11.1	Surface	Aircraft Reconnaissance (visually estimated from sea foam characteristics)

3. Conclusions

A method to determine the radius of maximum wind using satellite data is proposed. This method involves measuring the distance between the coldest cloud-top temperature near the eye and the warmest temperature inside the eye. The method does have limitations due to the lack of available case studies and the acknowledgement of possible error in asymmetric tropical cyclones such as those under conditions of relatively strong vertical shear where the colder cloud tops may be displaced or those storms where the eye is obscured by cloud canopy. It is thus suggested that this technique be offered as a supplement to other methods.

4. References

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Authors

Dr. S. A. Hsu has been a Professor of Meteorology at Louisiana State University since 1969, after he earned his Ph.D. in Meteorology from the University of Texas at Austin. He is the author of Coastal Meteorology (Academic Press, 1988) and numerous papers on coastal and marine meteorology and air-sea interaction. Dr. Hsu is also an AMS Certified Consulting Meteorologist. Dr. Hsu can be contacted at the LSU Coastal Studies Institute, 308 Howe-Russell Geoscience Building, Baton Rouge, LA 70803-7527. Email: sahsu@antares.esl.lsu.edu

Adele Babin is an oceanographer and image analyst at the Naval Oceanographic Office. She began her remote sensing career at Louisiana State University in 1995. She completed extensive research of Hurricane Lili culminating in a Master of Natural Sciences degree from LSU in 2004. Ms. Babin has co-authored a variety of papers on oceanographic and meteorological remote sensing. She may be contacted at the Naval Oceanographic Office, 1002 Balch Blvd., Code N213, Stennis Space Center, MS 39522. Email: adele.babin@navy.mil.

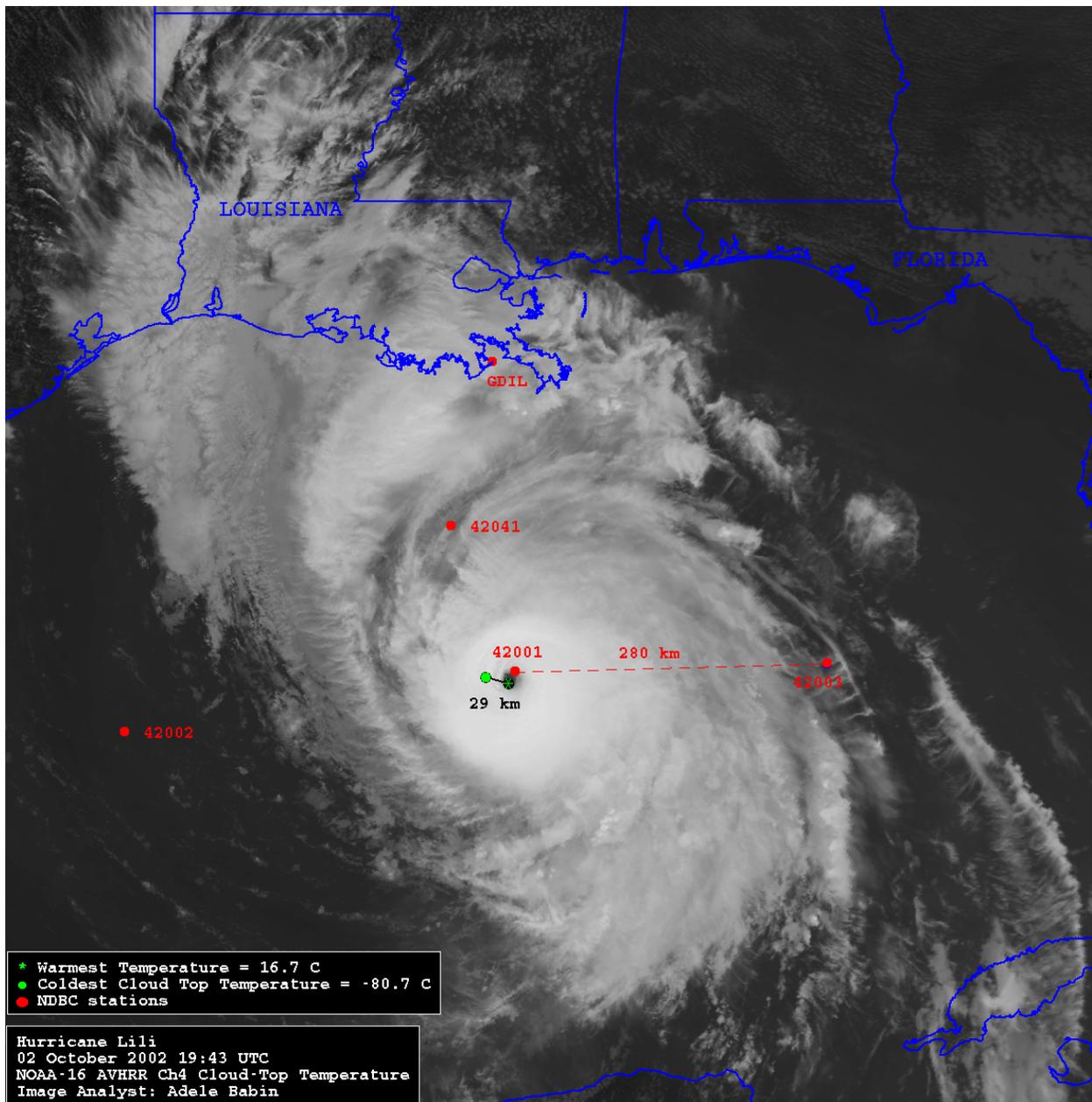


Figure 1. Satellite estimation of the radius of maximum wind during Hurricane Lili 2002. Symbol descriptions are detailed in the figure legend.