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OBJECTIVE IDENTIFICATION OF ANNULAR HURRICANES USING GOES AND REANALYSIS DATA

Thomas A. Cram[1*], John A. Knaff[2], Mark DeMaria[3], and James P. Kossin[4]

[1]Department of Atmospheric Science, Colorado State University, Fort Collins, CO
[2]CIRA, Colorado State University, Fort Collins, CO
[3]NOAA/NESDIS/RAMM, Fort Collins, CO
[4]CIMSS, University of Wisconsin-Madison, Madison, WI

1. INTRODUCTION

Annular hurricanes are a category of tropical cyclone characterized in satellite infrared (IR) imagery by a large circular eye feature surrounded by a nearly uniform, axisymmetric ring of deep convection and a distinct lack of deep convection features outside this ring (Knaff et al. 2003). They have also been shown to exist in only specific environmental conditions favorable for the development and maintenance of robust, axisymmetric hurricanes. If the environmental conditions are maintained, the annular phase can persist for days at a nearly constant intensity, which would potentially lead to large intensity forecast errors. The ability to objectively identify annular hurricanes, therefore, will reduce these forecast errors.

The purpose of this study is to develop an objective technique for identifying annular hurricanes in the National Hurricane Center (NHC) area of responsibility. The initial version of the product will produce a diagnostic annular hurricane index at the current analysis time.

2. DATA AND APPROACH

The data used in the product development include the NCEP environmental fields and Geostationary Satellite (GOES) IR imagery for the period 1995-2002. The NCEP environmental data is read in from the Statistical Hurricane Intensity Prediction Scheme (SHIPS) predictor files for the Atlantic and East Pacific basins, and are provided at 6 h intervals corresponding to the NHC extended best track times. The data through 2000 are NCEP reanalysis fields and from operational analyses for 2001-2002. The GOES IR imagery is taken from the CIRA Tropical Cyclone IR Archive (Zehr 2000) and were re-navigated to storm-centric coordinates using cubic-spline interpolated best track positions (Kossin 2002). The images are Mercator projections at 4 km horizontal resolution. The time interval between images is generally 30 minutes, with the exception of the satellite "eclipse" periods which last 1-3 hours. The annular hurricane identification product described here uses 6-hour time averages of the IR data, corresponding to the 6 hours prior to the analysis time, which correspond to the NHC best track times.

*Corresponding author address: Thomas A. Cram, Department of Atmospheric Science, Colorado State University, Fort Collins, CO 80523; e-mail: tcram@atmos.colostate.edu

3. ALGORITHM DEVELOPMENT

As described in Knaff et al. (2003), annular hurricanes occur in specific environmental conditions, characterized by a combination of weak easterly or southeasterly vertical wind shear, easterly flow and relatively cold temperatures at 200 mb, sea surface temperatures (SST) ranging between 25.4° C and 28.5° C, and relatively small 200-mb relative eddy flux convergence (REFC) due to environmental actions. Furthermore, the presentation of annular hurricanes in GOES IR imagery separate the population of annular hurricanes from the larger population of non-annular hurricanes.

A linear discriminant analysis (LDA; see Wilks 1995) is developed as a means to take advantage of these differences between the annular and non-annular hurricane populations. The environmental discriminators used in the LDA are 1) the deep-layer (850-200 mb) vertical wind shear magnitude (SHRD), 2) the generalized 850-200 mb shear magnitude (SHRG; takes into account all levels), 3) the 200-mb zonal wind (U200), and 4) the REFC (100-600 km average). The IR discriminators used are 1) the radius of coldest brightness temperature (RCTb; determined from the azimuthally averaged brightness temperature profile), 2) the azimuthal standard deviation of the brightness temperature at the RCTb (SDTb), 3) the variance of the azimuthally averaged brightness temperature profile (IRV), and 4) the brightness temperature difference between the warmest eye pixel and that in the cold ring (WEYE). All of the above discriminators were chosen due to the statistically significant differences between the group data means of the annular and non-annular cases. The storm cases chosen to belong to the group of annular hurricanes in the LDA development are the six storm cases subjectively determined to be annular in Knaff et al. (2003).

Before the LDA is carried out, however, a set of "selection" rules are determined to eliminate cases where annular hurricanes are unlikely given the environmental conditions and IR characteristics; these criteria are

listed in Table 1. The criteria for the NCEP environmental discriminators represent ± one standard deviation from the sample mean. The exception is the lower threshhold on U200; this value represents the minimum value of the annular cases and is 1.25 standard deviation from the sample mean. The threshhold for storm intensity and RCTb are based on the ranges of the annular sample. Although not a significant discriminator, the SST is used as another criterion to eliminate non-annular cases and its threshhold values are based on the SST range of the annular group sample. After the selection rules were applied, there were 36 annular cases and 143 non-annular cases in the data sample. The original full data sample contained 2570 cases.

Shown in Table 2 are the normalized parameter weights determined by the LDA, which provides the weights for the linear combination of the input variables that best differentiates between annular and non-annular cases. All data have been standardized prior to carrying out the LDA by subtracting the sample mean and then dividing by the sample standard deviation for each discriminator. Standardizing in this manner allows one to understand the relative importance of each parameter in the LDA.

The linear combination of the discriminator weights and the input variables for both annular and non-annular cases are then calculated to determine the value of the discriminator function at each analysis time. Although the LDA is designed to produce a "YES/NO" indicator, the range of values of the discriminator function performed on the dependent data sample allows us to assign a normalized annular hurricane index value to each case. This index will be a number ranging from zero to 1.0 and will be an indicator of how "annular" a particular case will be.

4. FUTURE PLANS

The data from the 2003-2005 hurricane seasons will be used as an independent sample for evaluation of the annular hurricane index product. The algorithm is planned to be used as an experimental NHC product–updated four times per day–for the upcoming 2006 hurricane season. The algorithm is also planned to be combined with a similar index that diagnoses the formation of secondary eyewalls in strong tropical cyclones, and is being developed at UW-Madison/CIMSS. Since storms undergoing secondary eyewall formation exhibit more intensity variance than annular hurricanes, such a combined index would be a useful tool in forecasting intensity change.

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Table 1: *Summary of selection rules used to identify when an annular hurricane event is unlikely.*

Parameter	**Source**	**Elimination criterion**
RCTb	GOES Imagery	< 50 km
SHRD	NCEP analysis	> 23.9 kt
SHRG	NCEP analysis	> 30.7 kt
U200	NCEP analysis	< -11 or > 17.2 kt
REFC	NCEP analysis	< -4.4 or > 8.4 m s^{-1} day^{-1}
SST	NCEP analysis	< 25.4°C or > 28.5°C
Intensity	NHC Best track	<85 or >125 kt

Table 2: *Normalized parameter weights from the linear discriminant analysis of annular hurricane identification.*

Parameter	**Value**	**Parameter**	**Value**
RCTb	-0.41	SHRD	-0.40
SDTb	0.70	SHRG	0.38
IRV	0.19	U200	1.53
WEYE	0.13	REFC	-0.26
Intensity	-0.21		

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