Supplementary Materials for "A Climatology of Hurricane Eye Formation"

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(Submitted to *Monthly Weather Review*, 23 April 2011, revised 30 September 2011, in final form 21 November 2011)

ABSTRACT

This supplement contains supporting materials and background to the accompanying journal article.

1. Introduction

Due to length considerations, it was not possible to include the full details of the data description in the main article. The purpose of this supplement is three-fold: to provide further background information, to more fully document the development of the VDM data set, and to provide supporting tables which complement the summary tables in the main article. This supplement is organized as follows. The next section frames the challenge of observing eye formation and lays out the merits of using reconnaissance aircraft. A brief history of instrumentation upgrades is also given. Section 3 provides online data sources and documentation for the various data sets that comprise the new structure and intensity data set. Section 4 gives additional background on the Best Track data set, while section 5 documents the format of the Vortex Data Messages (VDM) and details the methods by which the raw VDM messages have been translated into various intensity and structure parameters. Section 6 provides some figures that show the spatial and temporal distribution of the other case types that were not analyzed in the main article. Section 7 describe additional dynamical quantities which may be derived from the basic VDM parameters. Finally, supporting data follow in section 8. These tables include a catalog of the ranges of structure and intensity parameters for the lifetimes of all 205 TCs in the data set as well as full tables which complement the summary tables of the main text.

2. Observational background

a. The need for in situ *measurements*

One of the longstanding challenges of studying hurricane eye formation is that most TCs form an eye while well out at sea. The occasional ship, buoy, or island can provide surface data from which one may ascertain the TC's intensity or pressure deficit, but these data do not possess the spatial resolution necessary to characterize even the surface wind field, let alone the kinematic and thermal structure of the higher regions of the TC.[1] Time composites of radiosonde data (e.g., Jordan and Jordan 1954) can reveal the upper regions of the TC, but these observations are generally too sparse over the oceans to study the inner core. Geostationary satellites, such as the Geostationary Observational Environmental Satellite (GOES), provide frequent and detailed top-down views of the TC cloud structure, but the initial and intermediate stages of eye formation are often obscured from satellite view by a central dense

[†]The National Center for Atmospheric Research is sponsored by the National Science Foundation.

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[1]Although with some proper assumptions, one can deduce much about the upper thermal structure just from surface observations; see Haurwitz (1935).

overcast that often precedes the appearance of an eye in satellite imagery (Dvorak 1984; Zehr 1992; Steranka et al. 1986). The advent of space-based radar and passive microwave radiometers remove this impediment by revealing the distribution of warm rain and ice particles in the TC. From imagery constructed from multiple channels, one can infer rainbands and the presence of an eyewall (if it exists) beneath the upper cloud shield. Because there are now many satellites with microwave radiometers, such a view of the TC's convective morphology is available every few hours (the time between overpasses typically ranges between 1 and 7 hrs). Despite these advancements, the intensity of TCs that are observed only by satellites can be quite uncertain (Knaff et al. 2010; Walton 2009).

On the other hand, aircraft, with their on-board radars, *in situ* observations at flight level, and dropsondes, provide a much more definite characterization of both a TC's intensity and structure. Over the years, coordinated aircraft research missions have done much to advance the understanding of hurricane dynamics and energetics, but many of these campaigns have focused on intense TCs that already possessed well-defined eyes (e.g. Hawkins and Rubsam 1968; Hawkins and Imbembo 1976; Jorgensen 1984a,b). Only a handful of TCs have been studied *in situ* during the period after genesis but before they formed an eye. This list includes Hurricane Daisy in 1958 (Malkus et al. 1961; Riehl and Malkus 1958), Hurricane Debby in 1982 (Marks and Houze Jr. 1984), Hurricane Isabel in 1985 (Stossmeister and Barnes 1992), Typhoon Irma in 1987 (Ryan et al. 1992), and Tropical Cyclone Oliver in 1993 (Simpson et al. 1997, 1998). Of these, not all were well-observed during the actual period of eye formation. In addition to the dearth of good cases, the logistics of aircraft generally prohibit continuous research missions longer than thirteen hours (Henderson 1978). While TCs may clear out an eye in the upper cloud field in just a couple of hours, passive microwave satellite imagery often show an eye-like structure developing many hours prior to this time, so the period of interest for eye formation is likely considerably longer.

b. Basics of reconnaissance aircraft observations and instrumentation upgrades

The extensive aircraft reconnaissance over the last twenty years offers a veritable goldmine of data for studying TC structure and intensity. Whenever a TC threatens land in the Atlantic, Eastern Pacific, and Central Pacific basins, the United States Air Force Reserve's (AFRES) 53rd Weather Reconnaissance Squadron Hurricane Hunters[2] flies sorties primarily to determine the TC's location and intensity. The civilian National Oceanic and Atmospheric Administration Aircraft Operations Center (NOAA-AOC) planes are often tasked for dedicated reconnaissance missions as well. Due to the preponderance of Caribbean islands, the nearly land-locked Gulf of Mexico, and the vulnerable U. S. East Coast, TCs in the Atlantic basin are normally reconnoitered every 6 to 12 h once they move west of 55° or 60°W. Before an impending U. S. landfall, TCs may be monitored even more frequently. A typical reconnaissance mission flies an α-shaped pattern and penetrates the vortex center 4 times. The resulting meteorological data gathered during each "vortex fix" (or simply "fix") is transmitted in a Vortex Data Message (VDM). These messages provide a basic summary of the TC's gross kinematic and thermodynamic parameters every hour or two during the period the plane is in the TC (the contents of the VDMs are described in section 5). While the full flight-level data provide radial profiles of tangential wind, temperature, and moisture that would be very useful for studying the structural changes of eye formation, they do not contain a basic indication of whether an eye was present. Therefore, the historical records of VDMs are more complete, are well-suited to studying eye formation, and offer the greatest number of cases.

The instrumentation and data-gathering procedures of reconnaissance aircraft have undergone substantial improvements in recent years. During the 1970s and 80s, the determination of aircraft flight level winds relied on Doppler radar estimates of the plane's ground speed (see Henderson 1978). These measurements were inherently uncertain during high wind conditions because the sea surface is also moving (Sheets 1990). Many of the sensors had to be eye-balled by the flight meteorologist and converted to meteorological values using a hand calculator. The resulting data messages were transmitted by high frequency radio (personal communication, J. Talbot). By 1991, the on board instrumentation and recording system of all AFRES WC-130Hs had been upgraded to the Improved Reconnaissance Weather System (IRWS, Gray et al. 1991). That system's superior inertial navigation system allowed flight level wind speed to be measured more accurately since the ground speed was known to greater certainty. The IRWS data system automated some of the data-gathering tasks and displayed the meteorological values onscreen. Data messages were prepared on a PC workstation and transmitted via a satellite communications link. Between 2001 and the start of the 2005 season, the

[2] Previously, reconnaissance was also conducted by the 54th, 55th, and 815th Weather Reconnaissance Squadrons (Henderson 1978).

AFRES fleet was upgraded to WC-130J Hercules aircraft (personal communication, J. Talbot 2009) with an even more advanced computerized data collection system which augments the Inertial Navigation System (INS) with Global Positioning Satellites (GPS). The new system includes the angle of attack and the side slip in its wind calculation so that flight level wind speeds are even more accurate, especially in light winds (personal communication, J. Talbot 2009). Much of the data gathering and data message generation tasks are now automated with the flight meteorologist providing quality control. The NOAA WP-3D research aircraft have undergone similar instrumentation improvements over the years (Jorgensen 1984a; Griffin et al. 1992).

Until recently, the surface wind speed on both the AFRES and NOAA planes was estimated visually by the sea state, but in 2005, the WP-3D planes were outfitted with an operational version of the Stepped Frequency Microwave Radiometer (SFMR, Uhlhorn et al. 2007); in 2008, SFMR sensors were installed on the entire AFRES fleet of new WC-130J aircraft (Rappaport et al. 2009). These sensors allow for a more accurate measurement of surface wind speed, thus providing a precise determination of the radius of maximum winds at the surface. As a result of these improvements (and others not mentioned here), the last twenty years of Atlantic reconnaissance data are more accurate than were available to previous studies that used reconnaissance data from earlier eras.

3. Online data sources and documentation

The NHC archive best tracks are available for download at:
ftp://ftp.tpc.ncep.noaa.gov/atcf/archive/.
The combined abr-deck format used for both the a-decks and b-decks is documented at:
http://www.nrlmry.navy.mil/atcf_web/docs/database/new/abrdeck.html.

The Extended Best Track (EBT) data set and accompanying documentation may be downloaded at: http://rammb.cira.colostate.edu/research/tropical_cyclones/tc_extended_best_track_dataset/.
The EBT data set was prepared by M. DeMaria with partial support from the Risk Prediction Initiative. For more on the EBT data set, please see Demuth et al. (2006).

The SHIPS developmental data set and additional documentation may be downloaded at:
http://rammb.cira.colostate.edu/research/tropical_cyclones/ships/.
It should be noted that the relative humidity predictors from the NCAR reanalysis (1982-2000) are biased low by 5-10% (personal communication, M. DeMaria, 2009).

The National Hurricane Operations Plan (2009), which contains detailed procedures governing the reconnaissance of aircraft, is available online at:
http://www.ofcm.gov/nhop/09/nhop09.htm.
A table for decoding Vortex Data Messages (VDMs) is given in Table 5-2.

NHC's old recon archive can be accessed at:
ftp://ftp.nhc.noaa.gov/pub/products/nhc/recon/.
The new archive can be accessed at:
http://www.nhc.noaa.gov/archive/recon/.

The research-grade structure and intensity data set that was developed for this study will be made available at:
http://www.mmm.ucar.edu/people/jvigh/files/vdm/.
An updating archive of raw VDMs organized by storm can be accessed at:
http://www.ral.ucar.edu/hurricanes/structure/.

NCAR Command Language (NCL) is a free data processing and visualization language that was used in this study to combine and process the various data sets, compute the composites, and create the various plots. NCL is available as a free download at:
http://www.ncl.ucar.edu/.

4. Additional documentation of the BT data set

The National Hurricane Center (NHC) maintains a data set of TC positions, wind speeds, and pressures for Atlantic tropical cyclones since 1851 (and for Eastern Pacific tropical cyclones since 1949). This storm information is synthesized from a post-season analysis of all available observational data[3] subject to the then-current observational practices and standards. The resulting "best tracks" contain the smoothed TC center position (latitude and longitude), TC intensity (estimated 1-minute maximum sustained surface wind speeds, in knots), the minimum central pressure (hPa), and level of development (e.g., tropical, subtropical, etc.) for every 6 h (at 00, 06, 12, and 18 UTC) during its lifetime (McAdie et al. 2009). Smoothing is necessary to remove small-scale fluctuations of the TC center that are unrepresentative of the path of the larger-scale circulation (Jarvinen et al. 1984).

In recent years, NHC has been using both the HURDAT database and the Automated Tropical Cyclone Forecasting (ATCF; Miller et al. 1990, Sampson and Schrader 2000) System best track files (or "b-decks"[4]) to hold the official best track record (personal communication 2011, J. Franklin).[5] Besides the normal best track parameters given above, the b-decks format is capable of storing additional size parameters related to the TC's wind profile, such as the radius of maximum winds, the radius of the last closed isobar, the pressure of the last closed isobar, and the radii of 34-, 50-, and 64-kt winds in each quadrant of the TC. Some other important information are also stored, including the storm type, the level of development, and the radii of various wave height thresholds in each quadrant of the TC. In 2004 NHC began post-season best tracking of their 34-, 50-, and 64-kt wind radii (National Hurricane Center Forecast Verification, updated 6 October 2011, accessed 21 November 2011, http://www.nhc.noaa.gov/verification/verify2.shtml). The radius of maximum wind data are not best tracked, however.

[3]From McAdie et al. (2009), these data include surface observations from ocean buoys, land stations, and ships; upper air measurements from radiosondes; aircraft reconnaissance; coastal radars; and space-based polar-orbiting and geostationary satellite measurements of the cloud field in the visible and infrared channels, the distribution of hydrometeors as seen by the active radar on the Tropical Rainfall Measuring Mission satellite (TRMM, Kummerow et al. 1998) and passive microwave sensors, thermal profiles from the Advanced Microwave Sounder Unit (AMSU, Kidder et al. 2000), and the surface wind field from spaced-based scatterometers such as QuikSCAT.

[4]The ATCF files that contain the operational model guidance are called "a-decks".

[5]Eventually, the b-decks will become the authoritative source of best track information.

5. VDM format and processing

a. VDM format

This subsection details the VDM format and decodes the VDM from Hurricane Rita that was given in Fig. 1 of the main article. The first line of the VDM gives a header which contains information about the mission including the message code (URNT12 indicates this is a VDM for a TC in the Atlantic basin), the supervising office (KNHC), and the day of the month and time that the message was transmitted (0739 UTC on the 22nd day). The next line indicates that this is a full VDM.[6] The main section of the VDM contains regular items preceded by letters from the phonetic alphabet.[7] Item ALPHA gives the day of the month (22) and the time (07:14:30 UTC) that the vortex center was fixed. Item BRAVO gives the latitude and longitude of this fixed TC center (hereafter, the term *fix center* references the location of the TC center as determined by the aircraft at the vortex fix time). Item Charlie gives the minimum height (2208 m) at a standard atmospheric surface (in this case, the 700 mb pressure surface). The flight level variables reported in the remainder of the VDM are generally taken from this standard surface. Items DELTA and ECHO give the estimated maximum surface wind speed observed[8] on the inbound leg (not available in this case) and bearing and distance from the center to the location of the maximum surface wind speed, respectively. Item FOXTROT provides the direction (228°) and magnitude (148 kt) of the maximum flight level wind speed observed on the inbound leg. If a higher surface or flight level wind speed is subsequently observed on the outbound leg, a corrected VDM is sent with the updated values noted in the remarks section. Item GOLF gives the bearing (134°) and range (14 n mi) from the fix center to the location of the maximum flight level wind.

Item HOTEL gives the minimum sea level pressure (899 mb) observed during the vortex fix. This value is either computed from a dropsonde (which may not fall in the exact center of the eye) or extrapolated from flight level. Item INDIA gives the maximum flight level temperature (9 °C) and pressure altitude (3047 m) for the temperature which is deemed to be representative of the region immediately *outside* of the eyewall or maximum

[6]Abbreviated VDMs are occasionally transmitted with some lines left out.

[7]Before modern satellite communications became available, VDMs were relayed by voice via shortwave radio, so unambiguous vocal identifiers were used.

[8]Before 2005, nearly all of the surface wind speed measurements were visual estimates based on the sea state. Starting in 2005, the SFMR was used to obtain these values from the NOAA WP-3Ds, and in 2008, operational SFMRs were installed on all of the AFRES C-130J aircraft.

wind band. Item JULIET provides the maximum flight level temperature (31 °C) and pressure altitude (3043 m) observed *inside* the eye and within 5 n mi of the fix center. If a higher flight level maximum temperature is observed more than 5 n mi from the fix center, a supplementary maximum temperature will be indicated in the remarks section.[9] Item KILO gives the dew point temperature at the location of the maximum flight level temperature (−3 °C) and the SST (not available in this case) observed by a downward-pointing radiometric thermometer.

Item LIMA describes the character of the eyewall. If the radar eyewall feature completely surrounds the eye, 'CLOSED WALL' or simply 'CLOSED' is given. If the eyewall feature surrounds at least 50% of the eye, but less than 100%, 'OPEN' is given and the direction of the break(s) will be indicated. If eyewall coverage is less than 50%, 'NA' is given to indicate 'Not Available' and a mention of a partial eyewall or hub cloud may be given in the remarks section. Other characterizations may be given such as 'RAGGED' or 'POORLY DEFINED'. Item MIKE gives the eyewall diameter (16 n mi) and whether the eye was circular 'C', elliptical 'E', or concentric 'CO'. For an elliptical eye, both the major and minor diameters are given as well as the orientation of the major axis. Likewise, if concentric eyewalls are observed, diameters for both the inner eyewall and outer eyewall are given. Item NOEL indicates the methods which were used to fix the center; these include penetration '1', radar-indicated banding or curvature consistent with fix center '2', wind '3', pressure '4', and temperature '5'. The fix level is also given (700 mb in this case) and whether the surface center and flight level center are the same. Item OSCAR gives the navigational accuracy (0.02 n mi) and meteorological accuracy (1 n mi) of the center fix.

Item PAPA gives remarks that enhance or supplement the regular data items of the VDM. Five types of remarks are mandatory and must always be given if conditions warrant. The first required remark is the mission identifier, which includes the agency and aircraft number (AF307, an AFRES plane in this case), the mission and storm system indicator (the 16th sequential mission into storm number 18 in the Atlantic basin), the designated storm name (RITA) or mission type, and the observation number (11) for the current mission. The second required remark is the maximum flight level wind speed (165 kt) observed during the latest pass through any part of the TC, along with the time (05:34:00 UTC) and quadrant (northeast) of that observation. The third required remark is the maximum flight level wind just obtained on the outbound leg (if it is higher than the maximum from the inbound leg). The fourth required remark is the method of deriving the minimum sea level pressure (if extrapolated). The fifth required remark is the bearing and range of the surface center and/or the maximum flight level temperature if either of these are not within 5 n mi of the flight level center. In addition to these required remarks, the flight meteorologist may also provide optional remarks describing any other aspects of the TC which are unusual or which he/she thinks may be of use to the forecasters. These may include additional descriptors of the appearance of the eye, the presence of lightning, hail, or turbulence, and the presence of a secondary wind maximum in either the surface or flight level winds.

[9] A supplementary maximum temperature report provides a strong indication that the TC may have a *warm ring* structure, rather than a more simple warm core structure. From theoretical considerations, Schubert et al. (2007) postulated that a warm ring structure may be produced in the special case where the eye is dynamically large; that is, when the eye radius is at least twice as large as the minimum Rossby length. Appendix C of Vigh (2010) provides more information about how warm rings are defined and includes a table of observed warm ring cases.

b. Processing of VDMs into a usable data set

The creation of a usable data set from the raw VDMs was an involved and time-intensive process. In total, 183 variables are derived from the contents of the VDMs, including all of the data from the regular sections, all of the data from the required remarks, and many of the more important free-form optional remarks. Since this data set has substantial applicability beyond this study, this subsection provides an overview of the procedures which have been used to automatically read and process the VDMs. Nevertheless, because a complete documentation of the code is beyond the scope of this document (the code set for the entire project comprises more than 50,000 lines which is roughly equivalent to 625 pages of text), the author recommends the code itself as the most complete source of documentation for the particulars on how the parameters from the VDMs are translated into the variables of this data set. For this purpose, the code has been modularized and documented internally.

Before data processing could be accomplished, it was first necessary to collect the VDMs from various sources. These sources include the 'old' and 'new' archives of reconnaissance data located on NHC's ftp and http servers, an alternate archive maintained at Florida State University, and several archives maintained by Mark Zimmer and Steve Feuer. For several years of the study period, some VDMs from the pre-tropical storm stage may be missing. It also appears that a number of VDMs from NOAA research missions may be missing.[10] Once a common archive had been created of all available VDMs, the VDMs were organized into separate files by storm.[11] Many VDMs had to be “cleaned” (by script) to remove non-printable characters. In total, the collected VDMs comprise approximately 133,000 lines.

To accomplish the task of reading, processing, and combining the resulting VDM contents into a usable data set, a program was written in NCAR Command Language (NCL). Building an automated and robust code to accurately read the VDMs proved difficult and time-consuming for several reasons: VDM formats have undergone several changes over the years, the VDMs contain many irregularities and human-coding errors, and a great deal of string parsing is necessary to extract the desired data from both the regular sections and the free-form remarks. An alternative approach would have been to manually code the VDMs into a data set. This approach may actually have taken less time since it does not require teaching a computer how to interpret the intricacies and idiosyncrasies of the VDM format. Indeed, one previous study did use the manual approach. In his climatology of eye characteristics, Piech (2007) examined the aircraft reconnaissance data for 1989-2005 and chose to manually compile a VDM data set. Perhaps due to the tedious nature of this task, he only examined a subset of the VDM parameters (items DELTA, ECHO, FOXTROT, GOLF, and OSCAR are missing, as are the remarks). Most notably, his data set does not include the flight level wind data, which are essential to this study. His study also excluded VDMs for TCs with an intensity less than 45 kt. Since this study focuses on the eye formation period which begins at or just below this intensity threshold, it was necessary to compile a completely new VDM data set. Thus, an automated strategy was undertaken to read and process the VDMs. This approach has several advantages, including consistency in translating VDMs for the entire data set – if a translation error is discovered, or one would like to include additional parameters, the entire data set can be regenerated relatively painlessly. Another advantage of an automated code is that this opens the door to predictive applications which can use these data in real-time. Finally, a code approach will allow the data set to be extended in future years with minimal additional effort. Thus, a robust code has been written to automatically read and process the VDMs.

Once the VDMs were collected, the processing from raw data to finished results are accomplished in four stages: (1) each VDM is translated; (2) all of the translated VDMs for a particular TC undergo some initial processing, are combined with other storm data, and written out to a network Common Data Form (netCDF[12]) file; (3) all of the individual storm files are aggregated into one combined structure and intensity data set; and finally (4) additional post-processing and analysis steps are undertaken to arrive at the finished results, tables, and figures used in this study.

In the translation stage of processing (stage 1), each individual VDM is read and parsed to extract 183 VDM variables. Twenty of these variables are simply a copy of the raw data lines from the VDM. This information is included in the finished data set so that any future user can go back and check whether a particular VDM parameter has been read and translated correctly. Several more of the VDM variables are strings which have been parsed and expanded from individual data lines which contain multiple data items. The purpose for retaining these variables is again mainly for checking and debugging. Once the regular VDM data lines have been dissected into the expected data ‘fields’, these are parsed and read into the appropriate variables. Some basic checks are done at this stage (for instance, to ensure that expected units are present and that numerical items are in fact numerical). Many abbreviations have been used in the VDMs, some of which are mis-abbreviated or nonstandard. An ‘abbreviation map’ was created to expand all abbreviations into standard word sequences that the code keys off of. Because there were many non-standard spelling errors or human-coding errors (such as using the number ‘0’ and the letter ‘O’ interchangeably), some additional logic was necessary to accomplish the full translation, or in some cases, offending VDM errors had to be corrected by hand. Several ‘shorthand codes’ in the VDMs (such as flight levels and fix methods) have been translated to more user-friendly variables. Finally, it should be noted that the VDMs use a combination of nautical units (knots, nautical miles, millibars) and SI units. To allow for more effective quality control of these data, all of the translated VDM variables of this data set retain the original units of the raw VDMs. The original units of the VDMs will be used throughout this study. Note that $1\,\mathrm{kt} = 0.51444\,\mathrm{m\,s^{-1}}$, $1\,\mathrm{n\,mi} = 1.852\,\mathrm{km}$, $1\,\mathrm{mb} = 1\,\mathrm{hPa}$, and $^{\circ}\mathrm{C} = \mathrm{Kelvins} - 273.15$.

In the next processing stage (stage 2), the 183 VDM variables are read for all the vortex fixes for a

[10] The missing NOAA VDMs may exist in hard copy form at AOC but they were not available at the time of this study (personal communication, A. B. Damiano 2008).

[11] These storm-organized VDMs have been made available to the research community at: http://www.ral.ucar.edu/hurricanes/structure/vortex/.

[12] netCDF is a set of software libraries and machine-independent data formats that support the creation, access, and sharing of array-oriented scientific data. These libraries are freely available for download at: http://www.unidata.ucar.edu/software/netcdf/.

given TC. Additionally, 14 BT variables are read from the NHC b-deck file for that TC and checked against the equivalent values from the EBT data set; if the BT and EBT values differ, the EBT value has been used.[13] Likewise, when the BT radius of maximum wind value is missing, the EBT value is used. The 125 SHIPS variables (at $t = 0$ h) for the TC are also read. These variables include environmental and dynamical information about the storm and its environment, as well as a number of parameters based on IR satellite imagery. Each of the non-VDM data (BT, EBT, and SHIPS variables) have their own time dimensions. While the SHIPS and EBT data are just at the synoptic times (every 6 h), the BT data can have additional off-synoptic time points when a TC makes landfall or undergoes a rapid intensity change. The VDM data, on the other hand, exist on an irregular time dimension determined by the fix times of the VDMs. Once the VDMs have been read into memory, several additional steps are necessary to sort and merge the VDMs. First of all, some VDMs do not contain the storm name, the storm identification string, or any other obvious way of associating a VDM with a particular TC.[14] Additionally, none of the VDMs contain complete date information: the month is missing, and many VDMs also do not contain the year. A combination of time and space matching has been used to ensure that a particular VDM corresponds to the known best track of a given TC. Once the complete date, time, storm, and storm number are known, a unique identifier is assigned to each VDM message. Using these identifiers, the messages are sorted chronologically by fix time. Any VDM of a given fix time which was subsequently corrected by another VDM of the same fix time is superseded by the values from the corrected VDM.

[13]The EBT values were preferred because some of the b-deck files do not contain all of the size parameters. In actuality, the b-deck files should serve as the 'final' authoritative best track. Apart from missing data values, very few differences were found between the two data sets. When values did differ, most instances were minor differences that resulted because the version of the EBT data set used here includes the provisional best tracks for 2008, whereas the b-decks from that year contain the finalized best tracks. Only two differences were found for the parameter of $r_{\max}$, and these were both in Eastern Pacific TCs.

[14]The storm name is always included in the VDM once a TC has reached tropical storm intensity, but depression-stage or 'INVEST' (investigations of suspect areas) VDMs are troublesome in this regard. In NHC's old VDM archive, the individual file names of the individual VDM messages provided the necessary association to match VDMs to the correct TCs. In NHC's new VDM archive however, VDMs have not grouped by TC. Starting in 2007, the storm identification string is explicitly included in the VDM message, so VDMs from the depression stage onward are always associated with that TC. VDMs from the invest stage may still be missing.

Special effort has been made to extract all of the available maximum wind speed information from each VDM. Up to four maximum flight level wind speeds may be reported in each VDM. These include the inbound maximum flight level speed reported in item GOLF, the maximum flight level wind speed reported in the remarks, the outbound maximum flight level wind speed reported in the remarks, and the secondary maximum flight level wind speed reported in the remarks. Most of the non-wind VDM variables do not have a date/time associated with them, so these other variables are assumed to be valid at the time the center fix was taken. In contrast, the maximum wind speed information usually *does* have a separate observation time. Not infrequently, one of the maximum flight level wind speeds given in the remarks section (which is supposed to be from the latest pass) is actually several hours old, but may be the highest wind speed value. If one were to simply choose the highest wind speed, more recent wind information would sometimes be replaced (and therefore lost) by old wind information which was already included in the data set at a previous fix time. To prevent this from occurring, the date/time of every maximum wind report was determined (if possible) and the values were compared. The "combined" maximum wind speed value was stored at its indicated time (which does not necessarily correspond to the fix time). The individual maximum wind speed values are also retained so that no information is excluded. A similar method was used to arrive at a combined maximum surface wind speed.

The final part of stage two involves the calculation of derived quantities from VDM and BT data. These derived variables include the Coriolis parameter for the TC location, the minimum Rossby radius of deformation (calculated from the maximum wind speed and the associated radius of this maximum wind) at the surface and at flight level, the associated dynamical eye size, and the difference between the radius of maximum winds and the eye radius. All of the VDM, BT, EBT, and SHIPS variables (331 variables in total) for a particular TC are written out to an individual netCDF file. Table 3 of the main text provides a summary of many of the VDM parameters and the notation that will be used through the remainder of this study.

The aggregation stage (stage 3) involves reading in the 331 variables for all of the fixes and BT points of each TC and storing these in two-dimensional arrays (dimensioned by TC and either the number of fixes, the BT time points, or the SHIPS time points). The combined arrays are then written out to one large netCDF data file approximately 434 MB in size (or 190 MB for just the Atlantic). The combined intensity and structure data set contains approximately 413,000 valid, nonmissing data values.

The post-processing and analysis stage (stage 4) accomplishes a variety of 'lower level' tasks before the final results are obtained. First of all, minimum and/or maximum values are determined and stored for the lifetime of the TC for a variety of flight level variables including the maximum wind speed, the radius of maximum wind, the primary eye diameter,[15] the calculated minimum Rossby radius, the calculated dynamical eye size, the dew point depression in the eye, and the horizontal temperature difference across the eyewall (defined as the difference between the maximum flight level temperature in the eye and the flight level temperature just outside the eyewall). The BT maximum surface wind speed and BT minimum sea level pressure are also stored. These data will be summarized later in section 8.

6. Characteristics of other case types not examined in the main article

The main article presents an analysis of the spatial and temporal distributions of TCs, stratified by the four types of cases that had well-observed eye formations: rapid dissipation, intermittent formation, delayed formation, and sustained formation. Due to space constraints, the main article does not present the accompanying figures and analysis for the other case types. This section presents similar plots and a table for these other case types.

a. Spatial characteristics of other case types

Fig. S1 presents the spatial distribution of the tracks of TCs in the other case types: no aircraft data, no observed eye, insufficient data, and eye already present. Each panel displays the best tracks corresponding to TCs of a particular case type. The tracks of the TCs which were not reconnoitered by aircraft (the "no aircraft cases", panel a) fall into three groups: 1) TCs that formed so close to the coast that aircraft did not have a chance to reconnoiter them before landfall (or there was no need for reconnaissance due to the presence of land-based radar), 2) TCs that formed near or over the restricted airspace of Cuba, and 3) TCs that spent much of their lifetimes in the central and east Atlantic, well out of the range of aircraft reconnaissance. Satellite eyes were observed in many of these latter cases suggesting that many of these TCs were typical Cape Verde hurricanes that happened to recurve at longitudes outside of the range of aircraft.

Panel b of Fig. S1 displays the tracks of the TCs that were reconnoitered by aircraft, but for which an aircraft eye was never observed. Many of these cases were short-lived TCs that formed in the Gulf of Mexico or subtropics in the Sargasso Sea. Another group of TCs formed in the far east Atlantic and later dissipated in the vicinity of the Caribbean. These cases are consistent with the interpretation in the main article that many TCs are prevented from forming an eye due to several factors: adverse environmental conditions such as the marginal thermodynamic environment associated with TCs of subtropical origin, the strong shearing associated with the mid-Atlantic Tropical Upper Tropospheric Trough (TUTT), or proximity to land.

Panel c of Fig. S1 shows the cases for which aircraft data were too sparse to determine the time of eye formation. There are too few of these cases to make any generalizations, but it is clear that a well-timed aircraft fix could have resulted in some of these cases being included in the main study.

Panel d of Fig. S1 shows the tracks of TCs that already had an eye at the first aircraft fix. Overwhelmingly, these cases display the hallmarks of Cape Verde hurricanes that formed well east of the domain of aircraft reconnaissance and then took long recurving tracks into the Central Atlantic. A minority of these TCs took long tracks further west and eventually made landfall in the United States or the Caribbean.

b. Temporal distributions of eye formations and durations for other case types

As in the main article, we can also examine the temporal distribution of eye development during the TC life cycles of the other case types. To compare the eye formations of this diverse set of TCs, we chose a common reference time point. Taking this point to be the time when each TC first reaches tropical TC intensity (BT $v_{\max} > 34\,\mathrm{kt}$, or $17.5\,\mathrm{m\,s^{-1}}$), this reference time is then subtracted from the time of each eye development baseline. Each timeline in the resulting montage shows the relative timing of the eye development stages in days since that TC achieved tropical storm status. Fig. S2 shows these timelines for the cases that had no aircraft data. Of course, there are no aircraft timelines here, but one can see that many of these TCs did form eyes according to satellite imagery. Generally most of these TCs formed their satellite eyes formed within two to three days of reaching tropical storm strength. This bolsters our conclusion in the main article that TCs generally form eyes within the first few days of becoming a tropical storm.

[15] Note that in the case of elliptical eyes, the major and minor eye diameters have been averaged together to obtain one diameter value. This average primary diameter is used in the tabulation of the maximum and minimum statistics, the calculation of the minimum Rossby radius of deformation, and the determination of the presence of an eye.

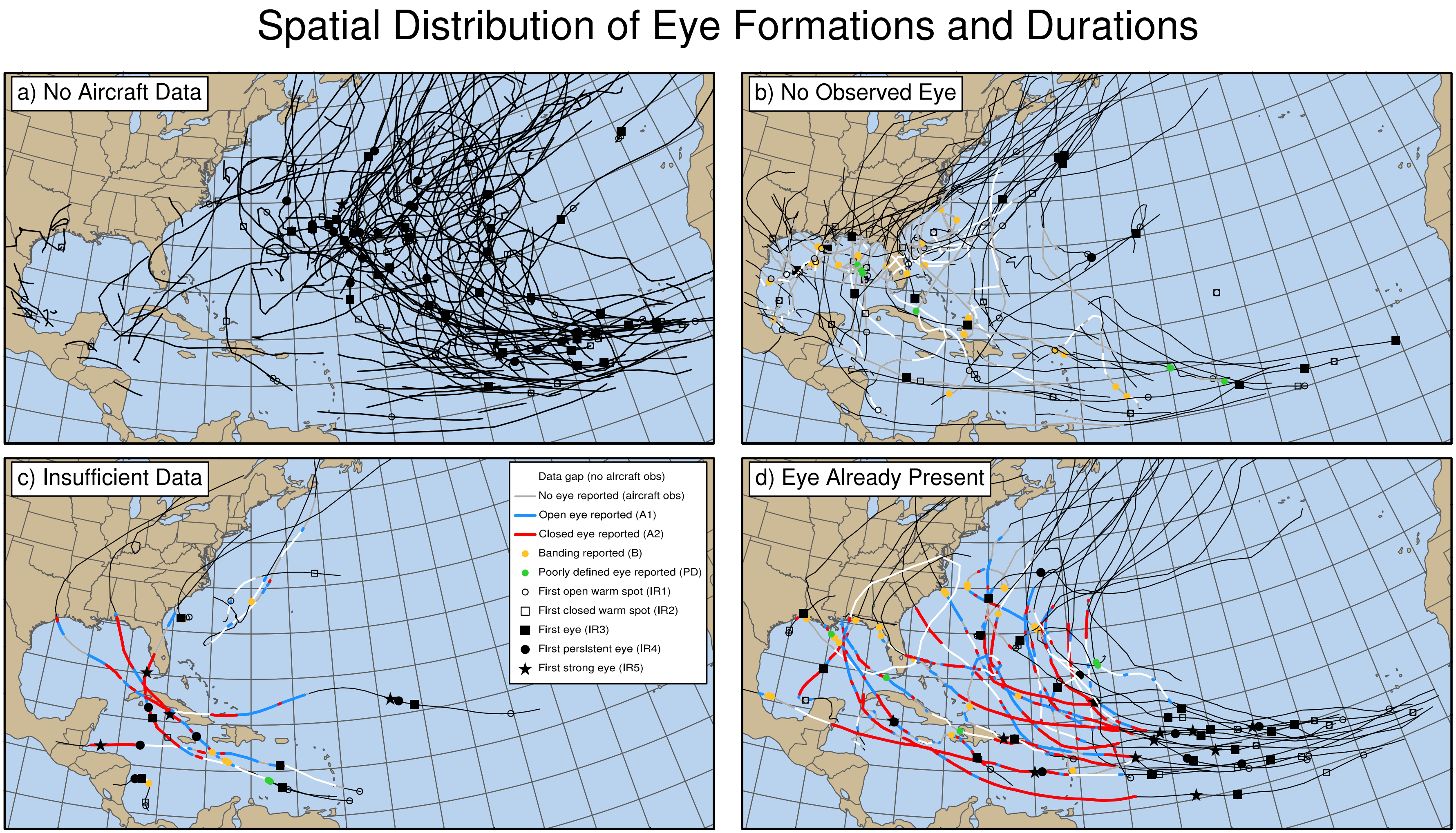

FIG. S1. Spatial distribution of the other cases types not examined in the main article. Each panel displays best tracks corresponding to TCs from the following case types: (a) "no aircraft data", (b) "no observed eye", (c) "insufficient data", and (d) "eye already present". Line colors for each track segment indicate the following: periods before and after the period of aircraft reconnaissance (black), data gaps of 12-h or greater that occurred *within* the reconnaissance period (white), periods when the TC was regularly reconnoitered but an eye was not reported (gray), periods of active reconnaissance when an open eye was reported (blue), and likewise, periods when aircraft reported a closed eye (red). Orange dots indicate specific fixes in which aircraft reported banding (but not an eye), while green dots indicate fixes in which a poorly defined eye was reported. Additionally, polymarkers indicate the locations when a TC first attained the following stages of IR eye development: open warm spot (IR1, hollow circle), closed warm spot (IR2, hollow square), first eye (IR3, filled square), first persistent eye (IR4, filled circle), and the first strong eye (IR5, filled star).

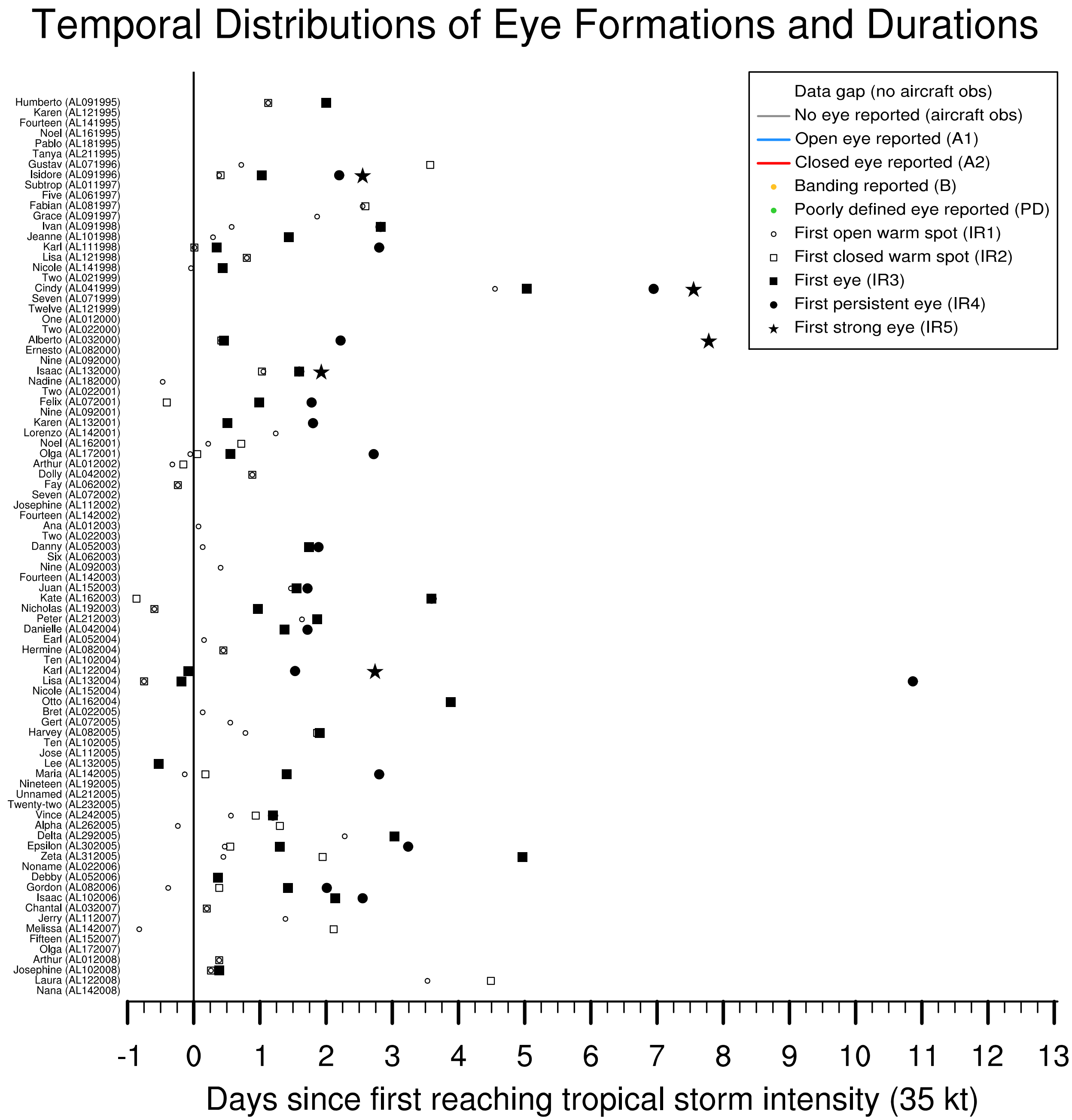

FIG. S2. Temporal distribution of all Atlantic TCs from 1995 onward that were not reconnoitered by aircraft during their lifetimes. Conventions are the same as in Fig. S1.

Fig. S3 shows the timelines of the TCs that were never observed by aircraft to possess an eye (the "no observed eye" cases). Periods when the TCs were reconnoitered by aircraft are indicated by thin gray lines. Generally, these TCs were short-lived, but they tended to be well-observed since many of them formed within the Gulf of Mexico or near the United States. Out of the 66 TCs after 1994, A total of 14 TCs (21%) displayed a satellite eye during their lifetimes. Given the possibility that the IR3 satellite eye could result in a false classification of eye presence, it is possible that some of these were not true eyes. We find it very encouraging however, that very few of these systems displayed a satellite eye (IR3) during the periods when they were under aircraft surveillance. In face, from a cursory examination of the periods during which TCs were observed by both satellite and aircraft, only 3 TCs (4.5%) displayed a satellite eye (IR3) during a period that aircraft may have had the opportunity to observed it. The pre-eyewall baseline of banding was much more commonly observed – aircraft reported banding in 14 (21%) of these TCs. Poorly defined eyewalls (without an eye diameter) were reported in 3 (4.5%) of these cases. This suggests that a small but significant number of these cases at least started the eye formation process.

Fig. S4 shows the timelines of the TCs for which aircraft data were insufficient to determine when eye formation actually occurred and the TCs which already had an eye at the first aircraft fix. Analyzing these two case types together and only including TCs for which there was satellite coverage (after 1994), 17 out of the 27 cases (63.0%) formed their satellite eyes within 2 d of reaching the tropical storm threshold. While these results are for the *satellite* eye, not the aircraft eye, they lend even further weight to one of the conclusions of the main paper: that most TCs form their eyes relatively soon. Furthermore, fully 14 out of the 27 cases (51.9%) displayed strong satellite eye signatures (IR5) within 3.5 d of reaching the tropical storm threshold. The fact that so many of these cases underwent rapid intensification to near major hurricane intensity within just a few days of becoming tropical storms indicates that these cases were in very favorable environments.

c. Geographic origin of other case types

Fig. S5 shows the geographic origin of the other cases. Panel a shows the formation locations of the "no aircraft data" cases. As already alluded to in the discussion on spatial characteristics, these cases include TCs that formed very near the coast in the Gulf of Mexico and northwest Caribbean Sea, a more widely disbursed group of TCs that formed in the subtropical central Atlantic, and a large cluster of TCs that formed in the eastern half of the Main Development Region (MDR). Meanwhile, the 'no observed eye' cases (panel b) formed primarily in the western half of the basin with a smaller cluster in the MDR. The "eye already present" cases (panel d) display a unique formation pattern, with fully 75% of these TCs originating in the MDR.

d. Basic statistics and life-cycles of other case types

In Table S1, we provide median values of the distributions of several parameters at the time that the first aircraft eye was reported (A). This allows comparison of the median values for parameters for the TCs in each case type. Parameters include: longevity (taken to be the number of hours that the TC spent above the tropical storm threshold using BT $v_{\max}$, excluding the extratropical and depression phases), intensity, minimum central pressure, the structure parameters $r_{\max}$ andd_{eye}, and the environmental parameters including the deep layer vertical shear of wind speed and SST. Since the first two case types (no aircraft data and no observed eye) preclude any reports of an aircraft eye by definition, the time of peak intensity (BT $v_{\max}$) is used as an alternative baseline to obtain the distributions over which the medians are taken.

Looking first at the longevity parameter (first row of Table S1), we see that the median longevity across the distribution of the full lifetimes of all TCs (excluding the depression and extratropical phases) was 96 h, while the median for the distribution of the full lifetimes of just the TCs in the four eye-forming case types was 132 h, nearly 1.5 d longer. The "no observed eye" cases were the shortest lived group of TCs, while the "eye already present" TCs had the longest median longevity. Both of these results are easy to understand in light of the geographic origins and typical tracks of these cases. Longevity generally increased as the duration and persistence of the eye increased across the case types.

A measure of the rate of sampling across the case types can be obtained by dividing the median longevity by the median number of aircraft fixes.(second row) The "delayed formation" cases were sampled most frequently (median of once every 3.8 h), while the "eye already present" cases were sampled with a median period of once every 8.8 h, owing largely to these TCs being well east of the range of aircraft reconnaissance during much of their lifetimes. The "no observed eye" cases were actually sampled at a higher rate (median of once every 5.7 h) than any of our selected eye-forming cases. Most likely, this is because many of these TCs formed close to land. This should dispel any notion that the reason eyes were not observed in these cases was due to infrequent sampling.

Examining the median latitude and longitudes of the various cases (third and fourth rows of Table S1), we see

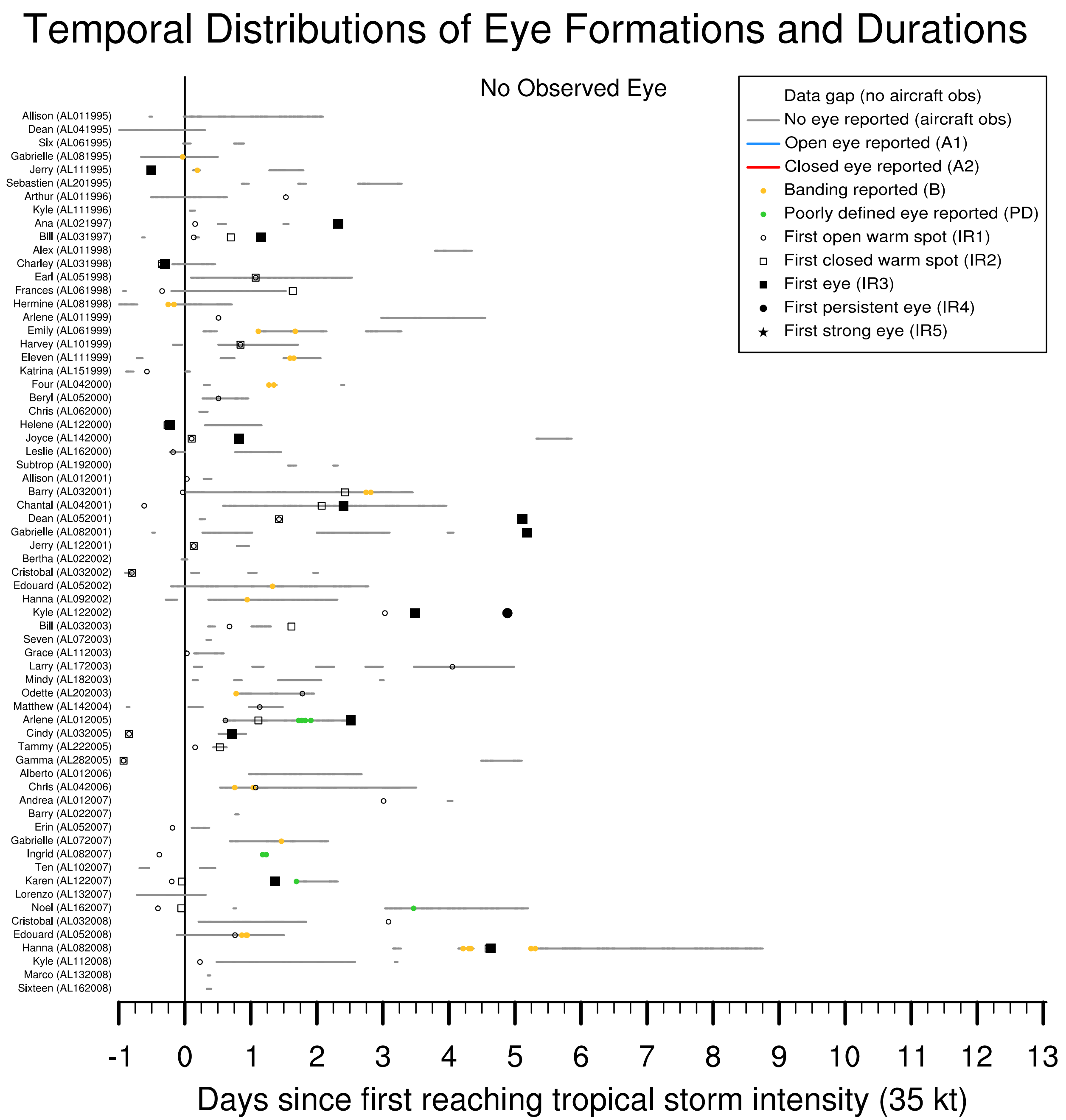

FIG. S3. Temporal distribution of all Atlantic TCs from 1995 onward for which an aircraft eye was never reported during the period of aircraft reconnaissance. Conventions are the same as in Fig. S2.

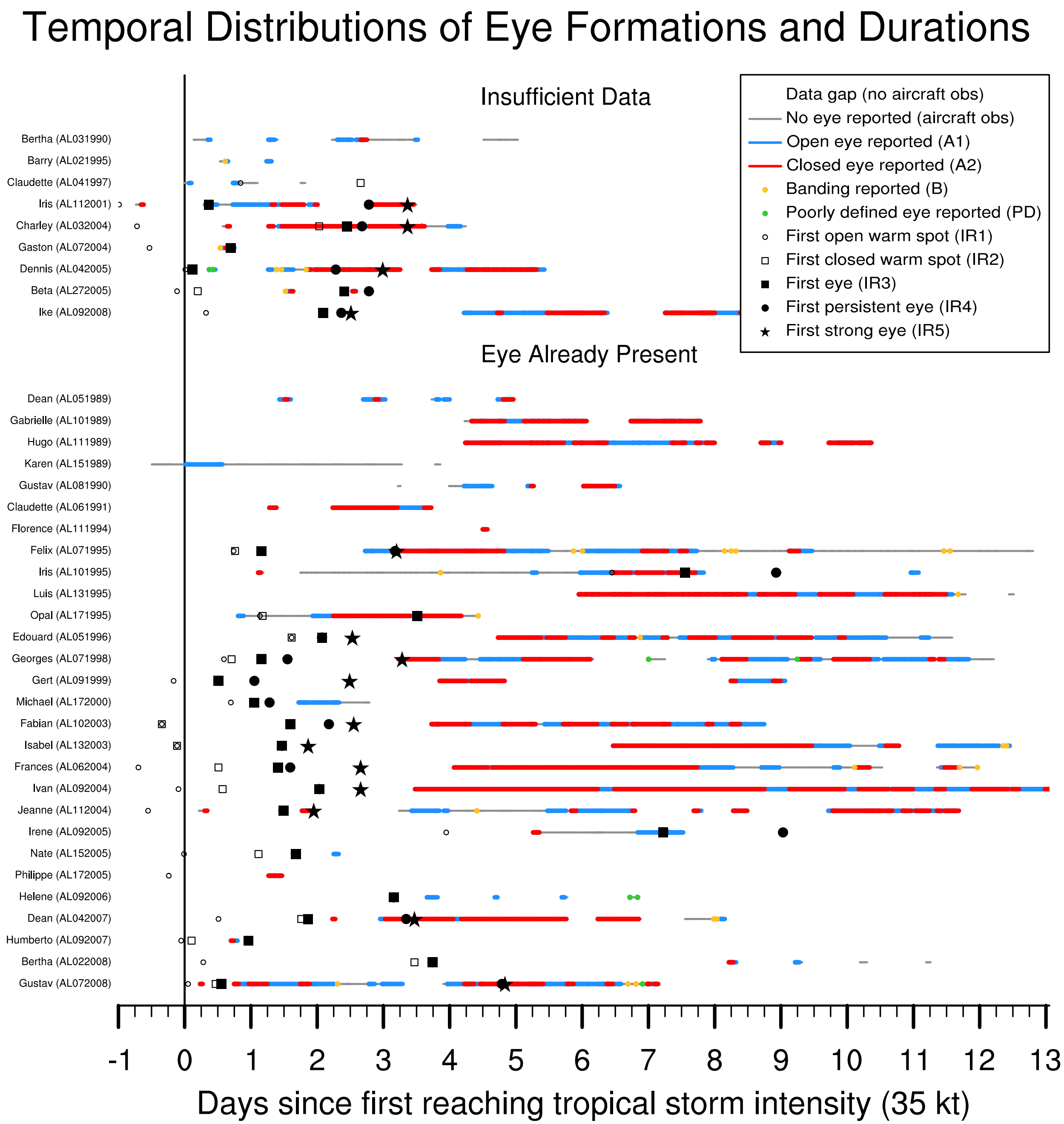

FIG. S4. Temporal distribution of all Atlantic TCs for which an aircraft eye was reported, but data were insufficient to determine the time of eye formation, or an eye was already present at the first aircraft fix. Conventions are the same as in Fig. S2.

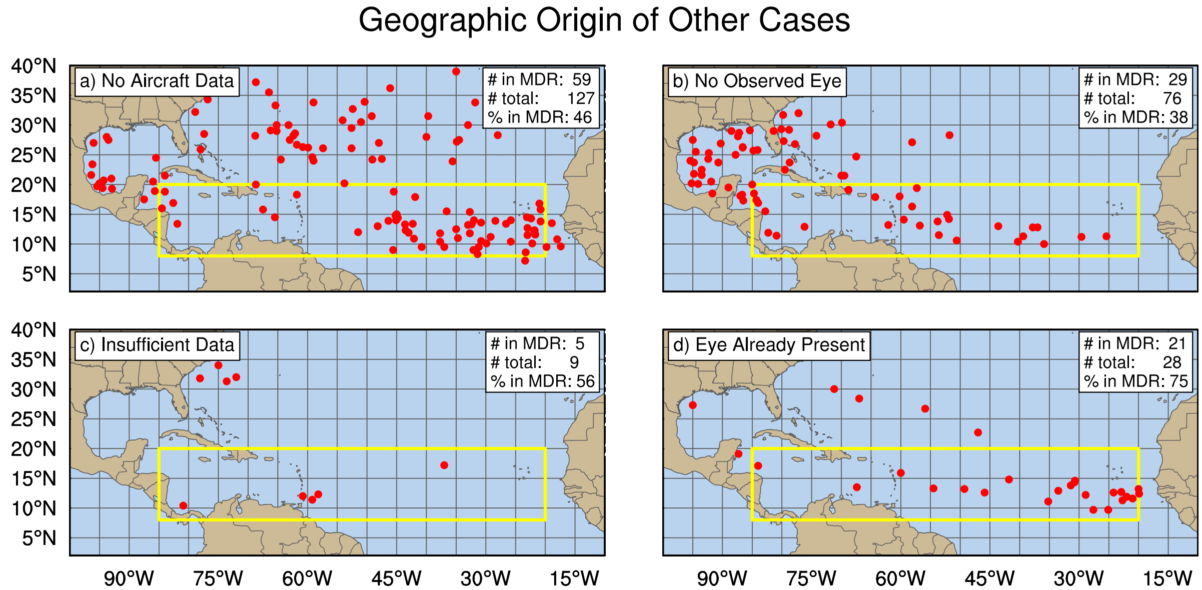

FIG. S5. Geographic origin of the 240 other cases. The origin of the TC is taken to be the first best track point (red dots). The modified Main Development Region (MDR, a box bounded by 8 – 20 °N and 20 – 85 °W) is indicated by the yellow box. Results are paneled for the following case types: a) no aircraft data, b) no eye observed, c) insufficient data, d) eye already present.

a marked stratification of eye duration and persistence with latitude: sustained and lasting eyes were much more likely to occur at lower latitudes, with shorter-lived eyes and many cases with no eyes at higher latitudes.

There were not many differences between the median translation speeds of the various case types other than the fact that the TCs with no aircraft data tended to move faster than the other case types. This reflects the predominance of these cases to be embedded in the relatively faster easterly low-level flow regime of the eastern Atlantic. .

Moving on to the median BT p_{min} and intensity parameters, important differences become apparent. The median p_{min} at the time of eye formation for four eye-forming case types all lie in a narrow range of 989.0 to 992.5 mb, which is vastly different from the 971.5 mb of the "eye already present" cases. This strongly suggests that the TCs in the latter case type did not merely form their eyes a few hours before the aircraft happened to come along – most of these were already fairly strong hurricanes by the time aircraft reached them. The median BT v_{max} of 79 kt (40.6 m s^{-1}) of these cases, compared with the range of 54.5 to 63.0 kt (28.0 to 32.4 m s^{-1}) of the eye-forming case types corroborates this. Interestingly, the median peak intensity of the "no observed eye" cases was just 50.0 kt (25.7 m s^{-1}), showing that TCs that never form eyes generally remain quite weak.

Examining the structure parameters FL r_{max} and d_{eye}, one can see that even at peak intensity, the "no observed eye" TCs had a larger r_{max} even at their peak intensity, while the median r_{max} of the eye-forming cases generally declines with more lasting and enduring eyes. The "eye already present" cases have the smallest r_{max}, which is consistent with these cases being well-defined hurricanes that have already undergone considerable contraction.

The SHIPS environmental parameters of vertical shear of wind speed (SHDC) and SST (RSST) show that the "no observed eye" cases experienced the largest wind shears, while the sustained formation cases had the lowest median shear. the "no aircraft data" cases experienced peak intensity over the lowest SSTs. This no doubt reflects the fact that these cases include TCs in both the east Atlantic and those in the subtropical regions, both of which feature lower SSTs than the western and southern portions of the basin. The sustained formation cases formed their eyes over the warmest median ST.

Taking all of this together, we see no compelling reason to think that our sample of eye-forming cases should not be representative of the larger set of all Atlantic TCs. While the geographic limitations of aircraft sampling preclude the inclusion of many Cape Verde hurricanes, they also preclude the weaker TCs that formed out in the central Atlantic. TCs that formed very near to land before they could be sampled by aircraft are also somewhat underrepresented in our sample. Yet our sample of eye-forming TCs still includes quite a few cases from all of these potentially under-sampled classes

TABLE S1. Summary of median values at selected baselines for the eight types of cases used to stratify the TCs in this study. This table includes data for all 310 Atlantic TCs that occurred from 1989 to 2008. For the "No Aircraft Data" (NAD) and "No Observed Eye" (NOE) cases, the baseline is taken to be the time when the TC reached its maximum intensity in the best track (BT $v_{\max}$). For the "Insufficient Data" (ID) and "Eye Already Present" (EAP) cases, the baseline is taken to be the time of the first aircraft fix that reported an eye. For the remaining eye formation cases, "Rapid Dissipation" (RD), "Intermittent Formation" (IF), "Delayed Formation" (DF), and "Sustained Formation" (SF), the baseline is also taken to be the time when aircraft first reported an eye. The first two columns give the parameter name and respective units that will be examined in each row. The next eight columns give the median value for each parameter (the rows) at the baseline time, computed from the distribution for all the TCs in that particular case type (indicated at the top of the column). The next to last column provides the median values for the entire lifetime of the eye-forming TCs, while the last column provides the median values over the lifetime of all TCs. (Note that these medians are taking from the full distribution that include the times when the TC was over land or in the extratropical phase). Parameters (row) are as follows: TC longevity (time with BT $v_{\max} \geq$ 35 kt, excluding the extratropical phase and tropical depressions); number of aircraft fixes taken during the lifetime of the TC; latitude at the baseline time (ϕ); longitude at the baseline time (λ); TC translation speed (c) at the baseline time; BT minimum central pressure at the baseline time (BT $p_{\min}$, raw); BT surface wind speed at the baseline time (BT $v_{\max}$, interpolated); range of maximum flight level wind at the baseline time (FL $r_{\max}$, raw); diameter of initial eye at the baseline time (VDM d_{eye}, raw); SHIPS environmental vertical wind shear (SHDC); SHIPS Reynolds SST (RSST).

Median Values											
		Other case types				**Selected eye-forming case types**				over all eye-forming TCs	over all TCs in data set
Parameter	Units	NAD	NOE	ID	EAP	RD	IF	DF	SF		
longevity	h	78.0	54.0	96.0	261.0	78.0	147.0	216.0	210.0	132.0	96.0
# of fixes			9.5	24.0	29.5	16.0	32.0	56.0	44.0	33.0	19.0
BT ϕ	$^\circ N$	24.3	26.8	23.1	18.7	25.8	23.1	21.8	18.6	25.4	26.4
BT λ	$^\circ W$	49.5	80.2	72.7	56.5	83.4	76.7	68.6	77.7	73.4	62.0
c	m s^{-1}	5.8	5.2	5.6	4.6	5.1	4.0	4.6	4.4	5.1	5.3
BT $p_{\min}$	mb	998.0	1000.0	994.0	971.5	991.0	992.5	991.5	989.0	996.0	999.0
BT $v_{\max}$	kt	45.0	50.0	53.0	79.0	58.0	54.5	59.0	63.0	50.0	45.0
FL $r_{\max}$	n mi		35.7	16.0	13.5	25.0	22.5	14.0	15.0	26.0	26.0
VDM d_{eye}	n mi			22.5	20.0	18.0	15.0	11.5	22.0	20.0	20.0
SHDC	kt	15.3	18.3	12.8	11.8	12.5	14.0	10.3	9.7	13.6	15.2
RSST	$^\circ C$	27.3	28.5	28.5	28.5	28.6	29.0	28.8	29.1	28.5	27.9

of TCs. Due to the sharp differences between TCs forming in the central subtropical Atlantic compared with those the Cape Verde TCs, the exclusion of such cases in our sample should tend to cancel out for parameters such as longevity and intensity. We speculate that overall, our sample may be somewhat biased towards the shorter-lived TCs owing to the inclusion of more Gulf of Mexico TCs at the expense of less Cape Verde hurricanes. If anything, such a bias would mean that eye structures would be even more likely to be observed if all TCs were frequently sampled by aircraft. Owing to the emphasis on TCs in the warmer western portion of the basin, our sample likely occurs over a somewhat higher SST than the median for the eye formations of all Atlantic TCs.

7. VDM parameters and derived quantities

To aid in the study of structural and thermodynamic changes, it is helpful to derive additional quantities from the VDM parameters. Table S2 lists the parameters which are obtained directly from the VDMs (first half) and the additional quantities which are derived from those parameters (second half). The following parameters are included: storm name, the number of fixes, the BT $p_{\min}$, the BT and FL $v_{\max}$, the maximum T_{eye} and $T_{\text{DEP,eye}}$, the maximum $\Delta T_{\text{eyewall}}$, the minimum FL $\lambda_{\text{R,min}}$, and the minimum and maximum values of $r_{\max}$, d_{eye}, and Ξ.

TABLE S2. Summary of directly-obtained VDM parameters and derived quantities. Columns are as follows: (1) symbolic notation used in this study; (2) parameter description; (3) corresponding section of the VDM that this variable was obtained from (1st part of table, section names use the original phonetic alphabet) or the expression used to compute the derived variable (2nd part of table); and (4) native units of the data set. The shorthand notation 'FL' indicates that the observation pertains to flight level.

Directly-obtained VDM Parameters			
Parameter	Description	VDM section	Units
VDM τ	Date and time of the vortex fix	ALPHA	UTC
VDM ϕ	Latitude of the fixed surface center	BRAVO	°North
VDM λ	Longitude of the fixed surface center	BRAVO	°West
FL SAS	Standard atmospheric surface of flight level for current fix	CHARLIE	mb or ft
FL H_{min}	Minimum height of the flight level SAS observed inside the center	CHARLIE	m
surface $v_{\mathrm{max,in}}$	Maximum surface wind speed observed during the inbound leg of current fix	DELTA	kt
surface r_{max}	Radius of maximum surface winds (range of surface $v_{\mathrm{max,in}}$ from center fix coordinates)	ECHO	n mi
surface $v_{\mathrm{max,out}}$	Maximum surface wind speed observed during the outbound leg of current fix	remarks	kt
surface v_{max}	Combined maximum surface wind speed (may be a wind speed from a recent previous fix)	DELTA or remarks	kt
FL $v_{\mathrm{max,in}}$	Maximum flight level wind speed observed during the inbound leg of current fix	FOXTROT	kt
FL r_{max}	Radius of maximum flight level winds (range of flight level $v_{\mathrm{max,in}}$ from center fix coordinates)	GOLF	n mi
FL $v_{\mathrm{max,out}}$	Maximum flight level wind speed from outbound leg of current fix	remarks	kt
FL v_{max}	Combined maximum flight level wind speed (may be a wind speed from a recent previous fix)	FOXTROT or remarks	kt
VDM p_{min}	Minimum sea level pressure (obtained by extrapolation or dropsonde)	HOTEL	mb
T_{out}	Maximum flight level temperature observed just outside the eyewall or maximum wind band	INDIA	°C
T_{eye}	Maximum flight level temperature observed within 5 n mi of center fix coordinates	JULIET	°C
T_{sup}	Supplementary maximum flight level temperature observed more than 5 n mi from center fix coordinates	remarks	°C
$T_{\mathrm{d,eye}}$	Dew point temperature observed at same location as T_{eye}	KILO	°C
d_{eye}	Diameter of primary eye	MIKE	n mi
Derived Parameters			
Parameter	Description	Expression	Units
$T_{\mathrm{DEP,eye}}$	Dew point depression in the eye at location and flight level of T_{eye}	$T_{\mathrm{eye}} - T_{\mathrm{d,eye}}$	°C
$\Delta T_{\mathrm{eyewall}}$	Temperature difference between eye and outside eyewall	$T_{\mathrm{eye}} - T_{\mathrm{out}}$	°C
f	Coriolis parameter computed using the latitude of the TC's fixed center (VDM ϕ)	$2\Omega \sin\phi$	$\times 10^{-5}\ \mathrm{s}^{-1}$
r_{eye}	Radius of primary eye	$\frac{d_{\mathrm{eye}}}{2}$	n mi
Υ	Dynamically-efficient heating region between flight level r_{max} and r_{eye}	$r_{\mathrm{max}} - r_{\mathrm{eye}}$	n mi
surface $\lambda_{\mathrm{R,min}}$	Minimum Rossby length computed from surface $v_{\mathrm{max,in}}$ and surface r_{max}	$\frac{f}{f + \frac{2(\mathrm{surface}\ v_{\mathrm{max}})}{(\mathrm{surface}\ r_{\mathrm{max}})}}$	dimensionless
FL $\lambda_{\mathrm{R,min}}$	Minimum Rossby length computed from flight level $v_{\mathrm{max,in}}$ and FL r_{max}	$\frac{f}{f + \frac{2(\mathrm{FL}\ v_{\mathrm{max}})}{(\mathrm{FL}\ r_{\mathrm{max}})}}$	dimensionless
surface M_{a}	Absolute angular momentum computed from surface $v_{\mathrm{max,in}}$ and surface r_{max}	$(\mathrm{surface}\ v_{\mathrm{max}})(\mathrm{surface}\ r_{\mathrm{max}}) + \frac{1}{2} f (\mathrm{surface}\ r_{\mathrm{max}})^2$	$10^6\ \mathrm{m}^2\ \mathrm{s}^{-1}$
FL M_{a}	Absolute angular momentum computed from flight level $v_{\mathrm{max,in}}$ and flight level r_{max}	$(\mathrm{FL}\ v_{\mathrm{max}})(\mathrm{FL}\ r_{\mathrm{max}}) + \frac{1}{2} f (\mathrm{FL}\ r_{\mathrm{max}})^2$	$10^6\ \mathrm{m}^2\ \mathrm{s}^{-1}$
Ξ	Dynamical eye size computed from r_{eye} and flight level $\lambda_{\mathrm{R,min}}$	$\frac{r_{\mathrm{eye}}}{(\mathrm{FL}\ \lambda_{\mathrm{R,min}})}$	dimensionless

Several additional variables of dynamical significance can be computed from combinations of the BT and VDM parameters. These include a Coriolis parameter computed for the latitude of the fixed surface center,

$$f = 2\Omega \sin\phi,$$

an approximation for the minimum Rossby radius of deformation (computed for both the surface and flight level),

$$\lambda_{\mathrm{R,min}} = \frac{f}{\left(f + \frac{2v_{\max}}{r_{\max}}\right)},$$

the absolute angular momentum (computed using the $v_{\max}$ and $r_{\max}$ from the surface or flight level),

$$M_{\mathrm{a}} = v_{\max} r_{\max} + \frac{1}{2} f {r_{\max}}^2,$$

the dynamical eye size,

$$\Xi = \frac{r_{\mathrm{eye}}}{\lambda_{\mathrm{R,min}}},$$

and the dynamically-efficient heating area, defined as the difference between the radius of maximum winds and the eye radius,

$$\Upsilon = r_{\max} - r_{\mathrm{eye}}.$$

8. Supporting data

From 1989-2008, a total of 4954 unique VDMs were available from 205 tropical cyclones in the Atlantic, Eastern Pacific, and Central Pacific basins. Table S3 provides a catalog of all TCs in the VDM data set (1989-2008) which underwent aircraft reconnaissance for at least two center fixes. Using *unadjusted* data from the 4954 unique VDMs, this table characterizes the observed ranges of various kinematic and thermodynamic parameters over each TC's lifetime. In the table, the storm identification (STORMID) is used to uniquely identify TCs. STORMID consists of an 8-character sequence which uniquely identifies a TC based on the basin in which it formed ('AL' for Atlantic, 'EP' for Northeast Pacific, 'CP' for Central Pacific), the final designated two-digit storm number it was assigned by the warning agency, and the 4-digit year in which the TC formed.

Two TCs (Gaston 2004 and Beta 2005) were objectively-classified as valid cases, but aircraft data were so sparse near the time of eye formation that we changed their classification to "insufficient data".

From Table S3, it is apparent that aircraft sometimes observed extremely low values for FL $r_{\max}$were observed during some point in the lives of several TCs. We caution readers to be aware that such values could be erroneous, for the following reasons. In the cases where a tropical cyclone is weak and asymmetric, erroneously low $r_{\max}$values could result from a failure to accurately fix the center of the ill-defined system. In cases where the vortex tilts substantially, erroneously small values would result since the VDM range to the flight level maximum is actually taken from the *surface* fix center, not the fix center.

Table S4 records the date and time that each eye formation baseline was achieved for all 183 Atlantic TCs that had at least 2 aircraft fixes.

Table S5 details the basic parameter values at the time of eye formation for each of the 70 individual eye formation cases in the climatology. These data supplement the summary tables in the main text. Likewise, Table S6 provides the environmental parameter values at the time of eye formation for each of the individual eye formation cases.

TABLE S3. Summary of all TCs in the VDM data set (1989-2008) for which there are at least two vortex fixes. Columns are as follows: (1) designated storm name; (2) storm identification (‘STORMID’); (3) abbreviated case type (NOE = No Observed Eye, ID = Insufficient Data, EAP = Eye Already Present, RD = Rapid Dissipation, IF = Intermittent Formation, DF = Delayed Formation, SF = Sustained Formation); (4) number of aircraft fixes; (5) min. BT p_{min}(hPa); (6) max. observed 700 hPa T_{eye}(°C); (7) min. observed 700 hPa $T_{\mathrm{d,eye}}$(°C); (8) max. observed $T_{\mathrm{d,eye}}$(°C); (9) max. observed $\Delta T_{\mathrm{eyewall}}$(°C); (10) max. BT max. sustained surface wind speed (‘BT’, kt); (11) max. observed max. FL wind speed (‘FL’, kt); (12) min. observed FL min. Rossby length ($\lambda_{\mathrm{R,min}}$, n mi); (13 and 14) min. and max. radii of max. wind as determined from the max. inbound FL wind report location (‘FL r_{max}’, n mi); (15) most complete eyewall stage; (16 and 17) min. and max. primary eye diameters (n mi); and (18 and 19) min. and max. dynamical eye sizes. Summary statistics for the values in each columns follow beneath the main table.

Storm Name	STORMID	Case Type	# of fixes	BT p_{min} hPa	Max FL 700 hPa T_{eye} °C	Min FL 700 hPa $T_{\mathrm{d,eye}}$ °C	Max $T_{\mathrm{eye}}-T_{\mathrm{d,eye}}$ °C	Max $T_{\mathrm{eye}}-T_{\mathrm{out}}$ °C	**Maximum wind speed** BT kt	FL kt	Min FL $\lambda_{\mathrm{R,min}}$ n mi	**FL r_{max}** Min n mi	Max n mi	Most complete eyewall stage	**Primary eye diameter** Min n mi	Max n mi	**Dynamical eye size** Min	Max
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
BARRY	AL031989	NOE	2	1005			2	1	45	48	11.7	10	15					
CHANTAL	AL041989	RD	14	984			5	3	70	82	16.2	12	50	closed	5	25	0.1	0.4
DEAN	AL051989	EAP	18	968	18	7	10	7	90	84	7.7	10	90	closed	15	25	0.2	1.3
GABRIELLE	AL101989	EAP	29	937	19	10	7	7	125	139	8.6	20	95	closed	15	50	0.4	1.9
HUGO	AL111989	EAP	44	918	24	3	19	13	140	162	1.3	5	60	closed	6	40	0.2	4.3
IRIS	AL121989	RD	12	1001			5	3	60	72	7.9	10	75	open	18	18	0.6	1.1
JERRY	AL141989	IF	22	983			6	9	75	73	8.3	6	85	open	10	10	0.2	0.6
KAREN	AL151989	EAP	25	1000			6	5	50	65	9.9	8	78	open	10	10	0.4	0.5
ARTHUR	AL021990	RD	12	995			18	9	60	87	4.2	6	70	open	9	9	0.8	0.8
BERTHA	AL031990	ID	24	973	15	6	9	5	70	88	33.4	22	133	closed	21	50	0.4	0.4
DIANA	AL051990	RD	13	980	15	7	8	7	85	111	5.9	13	83	open	28	30		
GUSTAV	AL081990	EAP	14	956	22	1	21	12	105	107	7.1	12	71	closed	23	40	0.2	1.5
KLAUS	AL131990	IF	38	985			9	7	70	72	5.9	8	115	open	5	25	0.1	0.4
LILI	AL141990	RD	12	987			5	3	65	76	24.7	10	70	open	25	25	0.5	0.5
MARCO	AL151990	NOE	16	989			5	3	55	62	10.6	5	28					
NANA	AL161990	DF	24	989	14	2	15	7	75	89	1.8	2	40	closed	8	28	0.1	0.9
BOB	AL031991	DF	43	950	18	10	8	10	100	119	2.6	2	70	closed	9	22	0.1	1.9
CLAUDETTE	AL061991	EAP	18	944	19	11	8	9	115	115	3.1	5	39	closed	6	22	0.2	1.6
GRACE	AL111991	RD	16				3	3	90	71	18.8	15	63	closed	25	35	0.3	0.7
ANDREW	AL041992	DF	64	922	22	3	19	12	150	170	1.9	2	89	closed	6	30	0.3	2.7
DANIELLE	AL071992	RD	23	1001			14	5	55	77	17.7	7	100	open	10	15	0.1	0.2
EARL	AL091992	IF	36	990			5	4	55	65	29.5	20	107	closed	10	10	0.1	0.2
ARLENE	AL021993	NOE	14	1000			3	2	35	42	32.7	21	115					
BRET	AL031993	NOE	11	1002			2	3	50	58	2.7	6	70					
CINDY	AL041993	NOE	10	1007			5	3	40	51	6.1	5	89					
EMILY	AL051993	IF	59	960	15	4	10	8	100	132	6.1	5	87	closed	2	45	0.0	2.4
FLOYD	AL071993	NOE	5	966			5	3	70	58	16.1	9	138					
GERT	AL081993	IF	15	970	18	8	10	9	85	101	15.3	29	90	closed	4	40	0.1	1.0
ALBERTO	AL011994	IF	23	993			5	5	55	67	11.7	11	101	closed	12	25	0.1	0.9
BERYL	AL031994	NOE	9	999			1	2	50	61	47.2	20	77					

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TABLE S3. *continued*

Storm Name	STORMID	Case Type	# of fixes	BT p_{min} hPa	Max FL 700 hPa T_{eye} °C	Min FL 700 hPa $T_{d,eye}$ °C	Max $T_{eye}-T_{d,eye}$ °C	Max $T_{eye}-T_{out}$ °C	**Maximum wind speed** BT kt	**Maximum wind speed** FL kt	Min FL $\lambda_{R,min}$ n mi	**FL r_{max}** Min n mi	**FL r_{max}** Max n mi	Most complete eyewall stage	**Primary eye diameter** Min n mi	**Primary eye diameter** Max n mi	**Dynamical eye size** Min	**Dynamical eye size** Max
CHRIS	AL041994	NOE	14	979	13	3	10	3	70	61	13.0	8	73					
FIVE	AL051994	RD	13				4	2	30	44	6.0	4	75	open	40	40	0.5	0.5
DEBBY	AL061994	NOE	5	1006			4	4	60	66	14.5	15	42					
FLORENCE	AL111994	EAP	2	972	11	5	6	4	95	72	23.9	21	29	closed	30	30	0.5	0.6
GORDON	AL121994	NOE	50	980	15	5	9	9	75	96	1.6	2	105					
ALLISON	AL011995	NOE	25	982	16	7	11	7	65	74	1.7	2	98					
BARRY	AL021995	ID	4	989			2	2	60	79	15.3	11	41	open	35	35	0.6	0.9
CHANTAL	AL031995	IF	40	991			12	8	60	67	4.6	3	105	closed	8	20	0.0	0.1
DEAN	AL041995	NOE	17	999			5	3	40	55	23.7	16	120					
ERIN	AL051995	IF	44	973	14	6	12	8	85	92	7.3	6	102	closed	20	40	0.3	1.6
SIX	AL061995	NOE	6				3	1	30	38	11.9	7	60					
FELIX	AL071995	EAP	70	929	19	11	8	6	120	140	2.9	6	117	closed	10	70	0.1	3.1
GABRIELLE	AL081995	NOE	11	988			4	3	60	73	8.4	3	105					
IRIS	AL101995	EAP	49	957	21	7	14	11	95	94	2.0	3	106	closed	15	35	0.4	1.2
JERRY	AL111995	NOE	9	1002			2	7	35	45	47.1	15	88					
LUIS	AL131995	EAP	47	935	21	10	10	10	120	146	6.0	14	80	closed	20	58	0.4	3.1
MARILYN	AL151995	SF	56	949	24	4	18	12	100	123	3.3	6	81	closed	10	40	0.1	3.3
OPAL	AL171995	EAP	38	916	26	11	14	14	130	152	3.2	4	94	closed	5	30	0.1	1.6
ROXANNE	AL191995	SF	72	956	20	7	11	10	100	111	4.9	4	108	closed	7	40	0.1	2.8
SEBASTIEN	AL201995	NOE	10	1001			6	3	55	50	3.5	3	97					
ARTHUR	AL011996	NOE	12	992			4	2	45	45	52.5	27	73					
BERTHA	AL021996	SF	58	960	19	6	13	11	100	122	7.5	8	104	closed	12	35	0.1	1.7
CESAR	AL031996	RD	15	985			5	4	75	74	10.8	24	88	closed	15	15	0.2	0.2
DOLLY	AL041996	RD	18	989			5	5	70	78	7.5	8	92	closed	10	25	0.1	0.4
EDOUARD	AL051996	EAP	67	933	22	7	14	10	125	140	3.9	7	101	closed	10	60	0.1	2.8
FRAN	AL061996	DF	71	946	18	8	12	8	105	114	5.8	7	86	closed	18	45	0.1	1.7
HORTENSE	AL081996	IF	17	935	14	7	7	6	120	89	8.6	8	82	closed	6	18		
JOSEPHINE	AL101996	IF	24	970			5	7	60	74	15.8	14	94	open	20	25	0.1	0.8
KYLE	AL111996	NOE	2	1001			2	1	45	49	8.3	8	14					
LILI	AL121996	IF	35	960	18	9	8	9	100	112	3.5	3	77	closed	5	40	0.2	1.3
MARCO	AL131996	RD	41	983	15	5	22	11	65	71	1.1	2	106	open	5	5	0.8	0.8
ANA	AL021997	NOE	4	1000			2	3	40	54	50.3	31	77					
BILL	AL031997	NOE	3	986			2	2	65	47	18.5	8	32					
CLAUDETTE	AL041997	ID	8	1003			3	2	40	50	16.3	6	56	open	30	30	0.9	0.9
DANNY	AL051997	SF	43	984			5	5	70	82	2.4	2	56	closed	6	20	0.2	1.4
ERIKA	AL071997	DF	33	946	19	6	14	9	110	111	8.0	13	98	closed	10	55	0.1	1.8
ALEX	AL011998	NOE	4	1002			2	0	45	43	70.4	35	66					
BONNIE	AL021998	SF	75	954	21	9	8	8	100	116	3.3	4	102	closed	10	50	0.1	1.7
CHARLEY	AL031998	NOE	7	1001			3	1	60	71	15.6	7	93					

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TABLE S3. *continued*

Storm Name	STORMID	Case Type	# of fixes	BT p_{min} hPa	Max FL 700 hPa T_{eye} °C	Min FL 700 hPa $T_{d,eye}$ °C	Max $T_{eye}-T_{d,eye}$ °C	Max $T_{eye}-T_{out}$ °C	**Maximum wind speed** BT kt	FL kt	Min FL $\lambda_{R,min}$ n mi	**FL r_{max}** Min n mi	Max n mi	Most complete eyewall stage	**Primary eye diameter** Min n mi	Max n mi	**Dynamical eye size** Min	Max
DANIELLE	AL041998	DF	43	960	17	8	9	7	90	97	4.9	6	89	closed	8	20	0.1	1.6
EARL	AL051998	NOE	23	964	16	5	28	5	85	104	18.6	8	94					
FRANCES	AL061998	NOE	14	990			4	5	55	59	36.8	23	130					
GEORGES	AL071998	EAP	79	937	24	6	17	15	135	146	3.0	5	105	closed	12	65	0.2	5.0
HERMINE	AL081998	NOE	24	999			4	3	40	56	4.7	2	86					
MITCH	AL131998	SF	48	905	22	5	17	12	155	168	1.6	6	94	closed	8	35	0.9	5.5
ARLENE	AL011999	NOE	8	1006			1	2	50	55	62.0	45	107					
BRET	AL031999	DF	42	944	20	9	10	9	125	134	2.7	2	102	closed	7	20	0.2	2.3
DENNIS	AL051999	DF	84	962	20	3	14	12	90	110	12.6	10	111	closed	20	45	0.1	1.3
EMILY	AL061999	NOE	14	1004			4	3	45	55	2.0	2	45					
FLOYD	AL081999	SF	69	921	26	4	22	15	135	149	5.6	12	107	closed	17	50	0.4	2.6
GERT	AL091999	EAP	13	930	17	12	4	6	130	127	7.9	18	94	closed	18	35	0.2	2.1
HARVEY	AL101999	NOE	15	994			8	4	50	58	8.8	1	61					
ELEVEN	AL111999	NOE	12				3	3	30	44	14.8	11	176					
IRENE	AL131999	IF	44	958			14	7	95	93	6.3	5	110	closed	3	20	0.0	0.4
JOSE	AL141999	IF	31	979	23	6	13	14	85	99	5.7	7	106	closed	20	40	1.0	3.1
KATRINA	AL151999	NOE	5	999			11	3	35	43	13.5	16	52					
LENNY	AL161999	SF	44	933	25	5	18	14	135	145	2.4	6	96	closed	15	55	0.8	6.1
FOUR	AL042000	NOE	6				2	2	30	47	10.6	6	33					
BERYL	AL052000	NOE	9	1007			4	4	45	55	20.6	20	89					
CHRIS	AL062000	NOE	3	1008			2	0	35	23	31.6	19	110					
DEBBY	AL072000	IF	26	993	16	5	11	9	75	88	7.1	4	123	closed	15	25	0.4	1.4
FLORENCE	AL102000	IF	22	985			9	6	70	79	17.4	12	119	open	3	25	0.1	0.1
GORDON	AL112000	RD	29	981	19	2	16	13	70	89	2.1	3	75	closed	30	30	0.2	0.7
HELENE	AL122000	NOE	15	986			9	7	60	67	19.6	10	58					
JOYCE	AL142000	NOE	3	975			2	0	80	40	26.1	16	58					
KEITH	AL152000	SF	34	939	25	2	23	16	120	133	2.3	4	87	closed	15	40	0.2	4.4
LESLIE	AL162000	NOE	11	973			7	6	60	52	29.0	9	124					
MICHAEL	AL172000	EAP	6	965			8	6	85	89	11.6	10	50	open	20	40	0.7	1.7
SUBTROP	AL192000	NOE	4	978			4	3	55	60	34.4	20	72					
ALLISON	AL012001	NOE	3	1000			2	1	50	55	25.4	13	55					
BARRY	AL032001	NOE	30	990	18	6	12	7	60	66	7.1	6	105					
CHANTAL	AL042001	NOE	29	997			9	4	60	82	5.8	3	110					
DEAN	AL052001	NOE	2	994			1	1	60	65	6.1	4	36					
ERIN	AL062001	SF	21	968	18	4	14	11	105	118	7.3	4	77	closed	28	50	0.8	2.0
GABRIELLE	AL082001	NOE	20	975	19	9	9	8	70	85	12.1	5	113					
HUMBERTO	AL102001	SF	8	970	21	0	21	13	90	86	13.1	11	37	closed	20	40	0.6	1.5
IRIS	AL112001	ID	30	948	18	7	9	8	125	134	0.5	1	53	closed	3	20	0.2	5.5
JERRY	AL122001	NOE	3	1004			5	2	45	56	12.0	22	70					

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TABLE S3. *continued*

Storm Name	STORMID	Case Type	# of fixes	BT p_{min} hPa	Max FL 700 hPa T_{eye} °C	Min FL 700 hPa $T_{d,eye}$ °C	Max $T_{eye}-T_{d,eye}$ °C	Max $T_{eye}-T_{out}$ °C	**Maximum wind speed** BT kt	FL kt	Min FL $\lambda_{R,min}$ n mi	**FL r_{max}** Min n mi	Max n mi	Most complete eyewall stage	**Primary eye diameter** Min n mi	Max n mi	**Dynamical eye size** Min	Max
MICHELLE	AL152001	SF	39	933	23	2	14	9	120	135	2.9	7	93	closed	9	50	0.6	3.0
BERTHA	AL022002	NOE	3	1007			2	2	35	47	34.5	13	34					
CRISTOBAL	AL032002	NOE	8	999			4	1	45	59	15.0	6	96					
EDOUARD	AL052002	NOE	23	1002			10	8	55	57	4.8	2	79					
GUSTAV	AL082002	RD	22	960			5	4	85	91	9.2	5	112	open	18	35	0.2	0.6
HANNA	AL092002	NOE	26	1001			7	8	50	59	11.4	5	108					
ISIDORE	AL102002	SF	73	934	23	9	13	11	110	122	2.7	5	158	closed	8	22	0.6	2.8
KYLE	AL122002	NOE	12	980			3	2	75	52	7.4	3	144					
LILI	AL132002	SF	67	938	26	6	20	13	125	141	2.6	2	94	closed	8	25	0.2	2.5
BILL	AL032003	NOE	8	997			2	5	50	66	18.2	10	94					
CLAUDETTE	AL042003	IF	57	979	16	6	10	11	80	85	1.7	3	119	closed	9	40	0.3	2.6
SEVEN	AL072003	NOE	2	1016			3	1	30	24	42.0	14	45					
ERIKA	AL082003	RD	16	986	16	8	8	7	65	67	2.9	1	101	closed	12	20	0.1	0.5
FABIAN	AL102003	EAP	30	939	22	10	12	11	125	140	3.9	8	35	closed	20	40	0.4	3.1
GRACE	AL112003	NOE	5	1007			8	2	35	40	25.3	7	136					
HENRI	AL122003	RD	27	997			7	4	50	46	10.5	4	120	open	22	22		
ISABEL	AL132003	EAP	35	915	21	12	8	11	145	158	6.1	15	73	closed	20	60	0.3	2.7
LARRY	AL172003	NOE	23	993			7	6	55	66	6.1	6	92					
MINDY	AL182003	NOE	10	1002			8	4	40	54	4.3	3	93					
ODETTE	AL202003	NOE	10	993	14	8	6	9	55	60	6.8	2	49					
ALEX	AL012004	SF	25	957	19	8	11	9	105	105	11.1	10	118	closed	10	60	0.3	1.2
BONNIE	AL022004	IF	29	1001	13	6	10	7	55	72	3.6	3	91	closed	8	20	0.2	0.8
CHARLEY	AL032004	ID	39	941	20	6	13	11	130	148	0.5	1	84	closed	5	40	0.3	5.5
FRANCES	AL062004	EAP	73	935	24	5	17	14	125	138	3.5	8	97	closed	12	60	0.2	3.3
GASTON	AL072004	ID	4	985			1	3	65	60	12.0	10	27	closed	35	42	0.8	0.9
IVAN	AL092004	EAP	107	910	24	7	12	13	145	161	1.3	4	44	closed	6	60	0.4	4.4
JEANNE	AL112004	EAP	58	950	18	5	7	7	105	113	6.1	7	103	closed	10	60	0.3	2.1
MATTHEW	AL142004	NOE	10	997			5	4	40	50	6.4	2	75					
ARLENE	AL012005	NOE	21	989			9	4	60	75	23.3	21	121	poor				
CINDY	AL032005	NOE	8	991			11	5	65	66	16.0	11	55					
DENNIS	AL042005	ID	53	930	21	8	11	12	130	150	2.0	4	97	closed	8	30	0.0	2.7
EMILY	AL052005	DF	68	929	23	4	19	16	140	153	1.6	4	99	closed	8	60	0.4	4.2
FRANKLIN	AL062005	IF	19	997			11	8	60	62	10.4	6	81	open	10	15	0.2	0.6
IRENE	AL092005	EAP	23	970			7	8	90	88	14.1	10	69	closed	8	80	0.1	0.9
KATRINA	AL122005	DF	56	902	29	6	23	16	150	166	4.5	7	58	closed	6	50	0.2	2.1
NATE	AL152005	EAP	2	979	14	8	6	7	80	85	19.4	18	27	open	34	35	0.6	0.9
OPHELIA	AL162005	IF	96	976	16	6	13	10	75	84	12.0	10	134	closed	10	90	0.1	1.0
PHILIPPE	AL172005	EAP	4	985	16	7	9	9	70	83	3.4	6	9	closed	16	20	1.6	2.4
RITA	AL182005	DF	71	895	31	−3	34	22	155	165	2.7	7	92	closed	14	50	0.4	3.8

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TABLE S3. *continued*

Storm Name	STORMID	Case Type	# of fixes	BT $p_{\min}$ hPa	Max FL 700 hPa T_{eye} °C	Min FL 700 hPa $T_{\mathrm{d,eye}}$ °C	Max $T_{\mathrm{eye}}-T_{\mathrm{d,eye}}$ °C	Max $T_{\mathrm{eye}}-T_{\mathrm{out}}$ °C	**Maximum wind speed** BT kt	**Maximum wind speed** FL kt	Min FL $\lambda_{\mathrm{R,min}}$ n mi	**FL $r_{\max}$** Min n mi	**FL $r_{\max}$** Max n mi	Most complete eyewall stage	**Primary eye diameter** Min n mi	**Primary eye diameter** Max n mi	**Dynamical eye size** Min	**Dynamical eye size** Max
STAN	AL202005	RD	12	977	18	7	9	9	70	69	2.9	2	111	open	16	16	2.0	2.0
TAMMY	AL222005	NOE	4	1001			1	3	45	53	102.6	75	143					
WILMA	AL252005	DF	56	882	24	8	14	14	160	168	0.6	2	97	closed	2	75	0.1	4.1
BETA	AL272005	ID	4	962	15	10	5	5	100	67	3.1	6	15	closed	10	15	1.1	1.6
GAMMA	AL282005	NOE	6	1002			2	6	45	49	8.7	8	77					
ALBERTO	AL012006	NOE	19	969	13	7	6	7	60	74	20.1	21	120					
BERYL	AL032006	RD	19	1000			5	6	50	67	33.1	23	71	open	35	35	0.3	0.3
CHRIS	AL042006	NOE	32	1001			13	12	55	67	4.2	5	110					
ERNESTO	AL062006	IF	55	985	14	3	16	8	65	78	3.6	3	99	open	6	25	0.2	0.5
FLORENCE	AL072006	IF	13	963	17	7	10	9	80	96	24.1	27	73	closed	25	45	0.4	0.4
HELENE	AL092006	EAP	7	955	19	13	6	4	105	111	8.7	12	30	open	40	50	1.8	2.3
ANDREA	AL012007	NOE	2	998			6	1	65	39	114.9	71	78					
BARRY	AL022007	NOE	2	990			4	3	50	54	9.4	8	10					
DEAN	AL042007	EAP	47	905	23	9	12	12	150	165	1.6	5	86	closed	10	25	0.4	4.8
ERIN	AL052007	NOE	4	995			10	13	50	43	8.8	3	75					
FELIX	AL062007	SF	23	929	26	4	22	17	150	162	0.9	3	52	closed	8	30	0.3	4.3
GABRIELLE	AL072007	NOE	13	1004			11	9	50	66	22.0	17	74					
INGRID	AL082007	NOE	2	1002				4	40	40	29.9	30	55	poor				
HUMBERTO	AL092007	EAP	4	985			27	10	80	79	4.3	4	10	closed	6	17	0.3	2.0
TEN	AL102007	NOE	6	1005			3	1	30	36	13.3	7	102					
KAREN	AL122007	NOE	5	988	16	8	8	6	65	68	23.9	29	96	poor				
LORENZO	AL132007	NOE	7	990			9	2	70	64	9.3	9	54					
NOEL	AL162007	NOE	21	965	15	7	10	7	75	90	18.4	22	155	poor				
BERTHA	AL022008	EAP	8	952	13	5	8	5	110	99	24.4	34	78	closed	50	55	0.6	1.1
CRISTOBAL	AL032008	NOE	16	998			6	3	55	58	9.4	4	82					
DOLLY	AL042008	IF	33	963	18	5	9	10	85	92	7.7	9	105	closed	11	25	0.2	1.3
EDOUARD	AL052008	NOE	21	996			6	7	55	68	14.7	7	100					
FAY	AL062008	IF	44	986	9	9	6	7	60	63	12.4	11	95	closed	8	50	0.2	0.8
GUSTAV	AL072008	EAP	58	941	23	5	16	12	135	143	4.5	6	93	closed	6	32	0.0	2.8
HANNA	AL082008	NOE	41	977			17	7	75	90	13.4	9	109					
IKE	AL092008	ID	70	935	22	5	12	9	125	129	4.0	4	99	closed	4	60	0.0	2.6
KYLE	AL112008	NOE	16	984	19	4	12	6	75	82	17.7	12	90					
MARCO	AL132008	NOE	2	998			7	4	55	61	1.8	2	4					
OMAR	AL152008	IF	19	958	21	5	12	13	115	132	2.2	3	69	closed	10	32	0.8	2.7
SIXTEEN	AL162008	NOE	2	1004			2	2	25	34	4.5	3	105					
PALOMA	AL172008	SF	27	944	23	5	24	16	125	142	3.1	8	77	closed	16	30	0.2	3.7
Measures of Central Tendency:																		
Mean			25.6	968.1	19.2	6.3	9.1	6.9	78.2	85.9	12.94	10.1	83.6		13.9	36.0	0.35	1.92
Median			19.0	983.0	19.0	6.0	8.0	7.0	70.0	75.0	8.03	7.0	89.0		10.0	35.0	0.23	1.63

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TABLE S3. *continued*

Storm Name	STORMID	Case Type	# of fixes	BT p_{min} hPa	Max FL 700 hPa T_{eye} °C	Min FL 700 hPa $T_{d,eye}$ °C	Max $T_{eye}-T_{d,eye}$ °C	Max $T_{eye}-T_{out}$ °C	**Maximum wind speed** BT kt	FL kt	Min FL $\lambda_{R,min}$ n mi	**FL r_{max}** Min n mi	Max n mi	Most complete eyewall stage	**Primary eye diameter** Min n mi	Max n mi	**Dynamical eye size** Min	Max
Measures of Spread:																		
Std dev			22.1	78.0	4.2	2.8	6.0	4.2	33.2	36.2	15.55	10.1	30.9		9.4	16.6	0.35	1.41
IQR			30	42	6	3	7	6	45	53	12.3	8	38		10	22	0.3	1.9
Measure of Symmetry:																		
Yule-Kendall			0.3	−0.3	0.0	0.3	0.1	−0.3	0.3	0.4	0.27	0.2	−0.2		0.5	−0.1	0.35	0.12
Additional Measures:																		
No. of records			183	179	89	89	182	183	183	183	183	183	183		107	107	104	104
Maximum			107	1016	31	13	34	22	160	170	114.9	75	176		50	90	2.0	6.1
75%			38	997	22	8	12	9	100	111	15.8	12	104		18	45	0.4	2.7
25%			8	955	16	5	5	3	55	58	3.5	4	66		8	22	0.1	0.8
Minimum			2		9	−3	1	0	25	23	0.5	1	4		2	5	0.0	0.1

TABLE S4. Dates and times of observed eye development baselines. The aircraft eye development baselines are as follows: first aircraft banding ('B'), first aircraft eye (open or closed, 'A'), first open aircraft eye ('A1'), first closed aircraft eye ('A2'). The eye development baseline stages obtained subjectively from IR satellite imagery are as follows: first open warm spot ('IR1'), first closed warm spot ('IR2'), first eye ('IR3'), first persistent eye ('IR4'), first strong eye ('IR5').

Storm	STORMID	Case Type	B	A	A1	A2	IR1	IR2	IR3	IR4	IR5
ONE	AL011989	NAD									
ALLISON	AL021989	NAD									
BARRY	AL031989	NOE									
CHANTAL	AL041989	RD		23:00 07/31		23:00 07/31					
DEAN	AL051989	EAP									
SIX	AL061989	NAD									
ERIN	AL071989	NAD									
FELIX	AL081989	NAD									
NINE	AL091989	NAD									
GABRIELLE	AL101989	EAP									
HUGO	AL111989	EAP									
IRIS	AL121989	RD		14:12 09/19	14:12 09/19						
THIRTEEN	AL131989	NAD									
JERRY	AL141989	IF		23:12 10/13	23:12 10/13						
KAREN	AL151989	EAP									
ONE	AL011990	NAD									
ARTHUR	AL021990	RD		17:00 07/25	17:00 07/25						
BERTHA	AL031990	ID				18:03 07/30					
CESAR	AL041990	NAD									
DIANA	AL051990	RD		17:19 08/07	17:19 08/07						
EDOUARD	AL061990	NAD									
FRAN	AL071990	NAD									
GUSTAV	AL081990	EAP									
HORTENSE	AL091990	NAD									
ISIDORE	AL101990	NAD									
ELEVEN	AL111990	NAD									
JOSEPHINE	AL121990	NAD									
KLAUS	AL131990	IF		21:38 10/04							
LILI	AL141990	RD		23:29 10/11	23:29 10/11						
MARCO	AL151990	NOE	11:09 10/11								
NANA	AL161990	DF		20:27 10/16	20:27 10/16	23:54 10/17					
ANA	AL011991	NAD									
TWO	AL021991	NAD									
BOB	AL031991	DF	17:16 08/16	11:42 08/17	11:42 08/17	14:26 08/17					
FOUR	AL041991	NAD									
FIVE	AL051991	NAD									
CLAUDETTE	AL061991	EAP									

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TABLE S4. *continued*

Storm	STORMID	Case Type	B	A	A1	A2	IR1	IR2	IR3	IR4	IR5
DANNY	AL071991	NAD									
ERIKA	AL081991	NAD									
FABIAN	AL091991	NAD									
TEN	AL101991	NAD									
GRACE	AL111991	RD		12:11 10/28		12:11 10/28					
UNNAMED	AL121991	NAD									
SUBTROP	AL011992	NAD									
ONE	AL021992	NAD									
TWO	AL031992	NAD									
ANDREW	AL041992	DF		06:13 08/21	06:13 08/21	13:12 08/21					
BONNIE	AL051992	NAD									
CHARLEY	AL061992	NAD									
DANIELLE	AL071992	RD		11:33 09/25	11:33 09/25						
SEVEN	AL081992	NAD									
EARL	AL091992	IF	05:11 09/30	13:59 09/30		13:59 09/30					
FRANCES	AL101992	NAD									
ONE	AL011993	NAD									
ARLENE	AL021993	NOE									
BRET	AL031993	NOE									
CINDY	AL041993	NOE									
EMILY	AL051993	IF	23:32 08/26	11:53 08/27	11:53 08/27	13:41 08/27					
DENNIS	AL061993	NAD									
FLOYD	AL071993	NOE									
GERT	AL081993	IF		00:20 09/20	00:20 09/20	04:01 09/20					
HARVEY	AL091993	NAD									
TEN	AL101993	NAD									
ALBERTO	AL011994	IF		11:47 07/02	11:47 07/02	17:15 07/02					
TWO	AL021994	NAD									
BERYL	AL031994	NOE									
CHRIS	AL041994	NOE									
FIVE	AL051994	RD	17:08 08/30	18:35 08/30	18:35 08/30						
DEBBY	AL061994	NOE									
ERNESTO	AL071994	NAD									
EIGHT	AL081994	NAD									
NINE	AL091994	NAD									
TEN	AL101994	NAD									
FLORENCE	AL111994	EAP									
GORDON	AL121994	NOE	23:56 11/17								
ALLISON	AL011995	NOE									
BARRY	AL021995	ID	20:43 07/07								

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TABLE S4. *continued*

Storm	STORMID	Case Type	B	A	A1	A2	IR1	IR2	IR3	IR4	IR5
CHANTAL	AL031995	IF	05:30 07/15	11:52 07/15	11:52 07/15	15:35 07/15					
DEAN	AL041995	NOE									
ERIN	AL051995	IF		15:46 07/31	15:46 07/31	16:10 08/02	21:15 07/31	19:15 08/01	22:45 07/31	02:45 08/02	
SIX	AL061995	NOE									
FELIX	AL071995	EAP					11:45 08/09	12:15 08/09	21:45 08/09	22:15 08/11	22:45 08/11
GABRIELLE	AL081995	NOE	11:13 08/10								
HUMBERTO	AL091995	NAD					09:00 08/23	09:00 08/23	06:00 08/24		
IRIS	AL101995	EAP					04:50 08/29	07:15 08/30	07:15 08/30	16:15 08/31	
JERRY	AL111995	NOE	16:34 08/23				23:45 08/22	23:45 08/22	23:45 08/22		
KAREN	AL121995	NAD									
LUIS	AL131995	EAP									
FOURTEEN	AL141995	NAD									
MARILYN	AL151995	SF		18:01 09/13		18:01 09/13	08:45 09/13	08:45 09/13	13:45 09/13	15:15 09/15	01:15 09/16
NOEL	AL161995	NAD									
OPAL	AL171995	EAP					15:15 10/01	16:15 10/01	00:15 10/04	00:15 10/04	
PABLO	AL181995	NAD									
ROXANNE	AL191995	SF	19:24 10/09	19:24 10/09		19:24 10/09	15:31 10/09	15:31 10/09	14:31 10/10	14:31 10/10	
SEBASTIEN	AL201995	NOE									
TANYA	AL211995	NAD									
ARTHUR	AL011996	NOE					12:45 06/20				
BERTHA	AL021996	SF		02:54 07/08	02:54 07/08	07:00 07/08	09:45 07/07	09:45 07/07	21:15 07/07	23:15 07/08	01:15 07/09
CESAR	AL031996	RD		02:56 07/28		02:56 07/28	04:45 07/27	04:45 07/27	04:45 07/28		
DOLLY	AL041996	RD		17:51 08/22	17:51 08/22	23:16 08/22	22:45 08/20	22:45 08/20	22:45 08/20	22:45 08/20	
EDOUARD	AL051996	EAP					20:45 08/23	20:45 08/23	07:45 08/24	07:45 08/24	18:45 08/24
FRAN	AL061996	DF		09:14 08/30	09:14 08/30	08:59 08/31	10:45 08/28	01:45 09/01	12:45 09/01	21:15 09/01	21:15 09/03
GUSTAV	AL071996	NAD					23:15 08/28	19:45 08/31			
HORTENSE	AL081996	IF		08:29 09/09		08:29 09/09	09:45 09/07	11:15 09/09	14:15 09/11	14:45 09/11	02:15 09/12
ISIDORE	AL091996	NAD					15:15 09/25	15:45 09/25	06:45 09/26	10:45 09/27	19:15 09/27
JOSEPHINE	AL101996	IF		11:35 10/07	11:35 10/07						
KYLE	AL111996	NOE									
LILI	AL121996	IF		23:25 10/16	23:25 10/16	08:39 10/19	23:45 10/15	04:15 10/18	16:15 10/18	16:15 10/18	
MARCO	AL131996	RD		07:27 11/22	07:27 11/22		05:45 11/19	05:45 11/19	08:45 11/22		
SUBTROP	AL011997	NAD									
ANA	AL021997	NOE					09:45 07/01	13:45 07/03	13:45 07/03		
BILL	AL031997	NOE					15:15 07/11	04:45 07/12	15:45 07/12		
CLAUDETTE	AL041997	ID					14:15 07/14	09:45 07/16			
DANNY	AL051997	SF		05:07 07/18	05:07 07/18	12:27 07/18	12:45 07/16	13:15 07/16	15:45 07/18	15:45 07/18	
FIVE	AL061997	NAD									
ERIKA	AL071997	DF		02:01 09/06	02:01 09/06	03:53 09/06	09:15 09/03	11:45 09/03	03:45 09/04	06:45 09/07	23:15 09/07
FABIAN	AL081997	NAD					07:15 10/08	08:15 10/08			

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TABLE S4. *continued*

Storm	STORMID	Case Type	B	A	A1	A2	IR1	IR2	IR3	IR4	IR5
GRACE	AL091997	NAD					20:45 10/16				
ALEX	AL011998	NOE					12:00 07/27	12:00 07/27	12:00 07/27		
BONNIE	AL021998	SF	23:51 08/21	05:35 08/22	05:35 08/22	01:24 08/23	06:46 08/20	08:15 08/20	08:15 08/20	08:15 08/22	08:15 08/23
CHARLEY	AL031998	NOE					09:15 08/21	09:45 08/21	10:45 08/21		
DANIELLE	AL041998	DF	01:41 08/27	13:19 08/27	13:19 08/27	01:26 08/28	14:30 08/24	14:30 08/24	09:15 08/25	22:15 08/30	
EARL	AL051998	NOE					19:45 09/01	19:45 09/01			
FRANCES	AL061998	NOE					09:45 09/09	09:15 09/11			
GEORGES	AL071998	EAP					02:15 09/17	05:00 09/17	15:45 09/17	01:15 09/18	18:46 09/19
HERMINE	AL081998	NOE	18:27 09/17								
IVAN	AL091998	NAD					07:45 09/21	13:45 09/23	13:45 09/23	13:45 09/23	
JEANNE	AL101998	NAD					01:00 09/22	04:30 09/23	04:30 09/23		
KARL	AL111998	NAD					00:15 09/24	00:15 09/24	08:15 09/24	19:15 09/26	
LISA	AL121998	NAD					01:15 10/06	01:15 10/06			
MITCH	AL131998	SF	18:16 10/23	07:53 10/24	07:53 10/24	17:38 10/24	23:15 10/23	04:15 10/24	04:15 10/24	15:15 10/24	22:45 10/24
NICOLE	AL141998	NAD					05:00 11/24	16:30 11/24	16:30 11/24		
ARLENE	AL011999	NOE					00:15 06/13				
TWO	AL021999	NAD									
BRET	AL031999	DF	11:36 08/19	23:20 08/19		23:20 08/19	13:15 08/19	13:15 08/19	13:15 08/19	22:15 08/21	00:15 08/22
CINDY	AL041999	NAD					07:15 08/25	18:45 08/25	18:45 08/25	16:45 08/27	07:15 08/28
DENNIS	AL051999	DF	15:14 08/25	20:19 08/26		13:43 08/27	01:15 08/25	01:15 08/25	03:45 08/28	14:15 08/28	
EMILY	AL061999	NOE	14:44 08/25								
SEVEN	AL071999	NAD									
FLOYD	AL081999	SF		18:17 09/10	18:17 09/10	17:41 09/11	18:15 09/07	00:45 09/08	00:45 09/08	19:45 09/11	11:15 09/12
GERT	AL091999	EAP					08:00 09/12	00:15 09/13	00:15 09/13	13:15 09/13	23:45 09/14
HARVEY	AL101999	NOE					20:15 09/20	20:15 09/20			
ELEVEN	AL111999	NOE	20:15 10/05								
TWELVE	AL121999	NAD									
IRENE	AL131999	IF	21:36 10/13	22:10 10/14	22:10 10/14	01:08 10/18	12:15 10/12	12:15 10/12	10:45 10/17		
JOSE	AL141999	IF		17:04 10/19	17:04 10/19	11:39 10/20	18:46 10/19	20:15 10/19	20:15 10/19		
KATRINA	AL151999	NOE					04:15 10/29				
LENNY	AL161999	SF	21:24 11/14	06:00 11/15		06:00 11/15	12:15 11/14	13:15 11/14	15:15 11/14		04:15 11/15
ONE	AL012000	NAD									
TWO	AL022000	NAD									
ALBERTO	AL032000	NAD					16:00 08/04	16:00 08/04	17:00 08/04	11:15 08/06	00:45 08/12
FOUR	AL042000	NOE	18:35 08/09								
BERYL	AL052000	NOE					18:15 08/14				
CHRIS	AL062000	NOE									
DEBBY	AL072000	IF		03:05 08/22		03:05 08/22	23:45 08/19	23:45 08/19			
ERNESTO	AL082000	NAD									
NINE	AL092000	NAD									

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TABLE S4. *continued*

Storm	STORMID	Case Type	B	A	A1	A2	IR1	IR2	IR3	IR4	IR5
FLORENCE	AL102000	IF		21:35 09/11	21:35 09/11		01:45 09/12	01:45 09/12	01:45 09/12	22:15 09/12	
GORDON	AL112000	RD	03:11 09/16	11:38 09/17		11:38 09/17	00:26 09/16				
HELENE	AL122000	NOE					23:45 09/20	23:45 09/20	00:45 09/21		
ISAAC	AL132000	NAD					01:15 09/23	00:45 09/23	14:15 09/23	14:15 09/23	22:15 09/23
JOYCE	AL142000	NOE					02:30 09/26	02:30 09/26	19:45 09/26		
KEITH	AL152000	SF		18:08 09/30		18:08 09/30	21:15 09/29	12:45 09/30	12:45 09/30	17:45 09/30	22:15 09/30
LESLIE	AL162000	NOE					07:45 10/05				
MICHAEL	AL172000	EAP					16:45 10/16	01:15 10/17	01:15 10/17	06:45 10/17	
NADINE	AL182000	NAD					00:45 10/20				
SUBTROP	AL192000	NOE									
ALLISON	AL012001	NOE					12:45 06/05				
TWO	AL022001	NAD									
BARRY	AL032001	NOE	11:54 08/05				17:15 08/02	04:15 08/05			
CHANTAL	AL042001	NOE					09:15 08/16	01:45 08/19	09:45 08/19		
DEAN	AL052001	NOE					22:15 08/23	22:15 08/23	14:45 08/27		
ERIN	AL062001	SF	06:20 09/07	19:30 09/08	19:30 09/08	06:10 09/09	18:01 09/01	18:01 09/01	23:30 09/01	21:45 09/08	
FELIX	AL072001	NAD					11:45 09/10	02:15 09/11	11:45 09/12	06:45 09/13	
GABRIELLE	AL082001	NOE					07:15 09/12	10:15 09/12	16:15 09/18		
NINE	AL092001	NAD									
HUMBERTO	AL102001	SF		06:48 09/23	06:48 09/23	19:14 09/23	02:45 09/22	08:45 09/25	13:45 09/25	00:45 09/26	
IRIS	AL112001	ID				20:45 10/06	12:15 10/04	20:45 10/05	20:45 10/05	06:45 10/08	20:45 10/08
JERRY	AL122001	NOE					03:15 10/07	03:15 10/07			
KAREN	AL132001	NAD					00:15 10/12	00:15 10/12	00:15 10/12	07:15 10/13	
LORENZO	AL142001	NAD					05:45 10/31				
MICHELLE	AL152001	SF		18:11 11/02		18:11 11/02	18:15 10/31	18:15 10/31	14:15 11/02	14:15 11/02	21:15 11/02
NOEL	AL162001	NAD					05:15 11/04	17:15 11/04			
OLGA	AL172001	NAD					22:45 11/23	01:15 11/24	13:15 11/24	17:15 11/26	
ARTHUR	AL012002	NAD					22:15 07/14	02:15 07/15			
BERTHA	AL022002	NOE									
CRISTOBAL	AL032002	NOE					22:45 08/05	22:45 08/05			
DOLLY	AL042002	NAD					15:15 08/30	15:15 08/30			
EDOUARD	AL052002	NOE	13:53 09/03								
FAY	AL062002	NAD					18:15 09/05	18:15 09/05			
SEVEN	AL072002	NAD									
GUSTAV	AL082002	RD		14:49 09/10	14:49 09/10		23:15 09/09	21:15 09/11			
HANNA	AL092002	NOE	04:41 09/13								
ISIDORE	AL102002	SF	08:03 09/19	08:03 09/19	08:03 09/19	17:54 09/19	02:45 09/18	02:45 09/18	22:15 09/18	12:15 09/21	01:45 09/22
JOSEPHINE	AL112002	NAD									
KYLE	AL122002	NOE					06:45 09/24	17:45 09/24	17:45 09/24	03:15 09/26	
LILI	AL132002	SF		23:56 09/28		03:38 09/29	14:45 09/26	14:45 09/26	15:15 09/28	21:15 10/01	02:15 10/02

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TABLE S4. *continued*

Storm	STORMID	Case Type	B	A	A1	A2	IR1	IR2	IR3	IR4	IR5
FOURTEEN	AL142002	NAD									
ANA	AL012003	NAD					07:45 04/19				
TWO	AL022003	NAD									
BILL	AL032003	NOE					04:15 06/30	02:45 07/01			
CLAUDETTE	AL042003	IF	05:36 07/09	12:01 07/10		12:01 07/10	10:15 07/08	13:15 07/10	04:15 07/15	11:15 07/15	
DANNY	AL052003	NAD					03:15 07/17	17:45 07/18	17:45 07/18	21:15 07/18	
SIX	AL062003	NAD									
SEVEN	AL072003	NOE									
ERIKA	AL082003	RD		02:20 08/16	02:20 08/16	05:22 08/16	00:45 08/15	00:45 08/15	00:45 08/15		
NINE	AL092003	NAD					03:45 08/22				
FABIAN	AL102003	EAP					03:45 08/28	03:45 08/28	02:15 08/30	16:15 08/30	01:15 08/31
GRACE	AL112003	NOE					18:45 08/30				
HENRI	AL122003	RD		07:42 09/05	07:42 09/05		14:15 09/04				
ISABEL	AL132003	EAP					03:15 09/06	03:15 09/06	17:15 09/07	17:15 09/07	02:45 09/08
FOURTEEN	AL142003	NAD									
JUAN	AL152003	NAD					11:15 09/26	13:15 09/26	13:15 09/26	17:15 09/26	
KATE	AL162003	NAD					12:15 09/26	21:15 09/26	08:15 10/01	08:15 10/01	
LARRY	AL172003	NOE					19:15 10/04				
MINDY	AL182003	NOE									
NICHOLAS	AL192003	NAD					03:45 10/14	03:45 10/14	17:15 10/15		
ODETTE	AL202003	NOE					12:45 12/06				
PETER	AL212003	NAD					09:15 12/09	14:45 12/09	14:45 12/09		
ALEX	AL012004	SF		17:04 08/02	17:04 08/02	00:18 08/03	21:45 07/31	07:15 08/02	18:45 08/03	14:15 08/04	
BONNIE	AL022004	IF		21:54 08/09		21:54 08/09	16:15 08/03	13:45 08/10			
CHARLEY	AL032004	ID				14:13 08/11	12:45 08/09	06:45 08/12	16:45 08/12	22:15 08/12	14:45 08/13
DANIELLE	AL042004	NAD					09:00 08/15	09:00 08/15	09:00 08/15	17:15 08/15	
EARL	AL052004	NAD					21:45 08/14				
FRANCES	AL062004	EAP					01:15 08/25	06:15 08/26	03:45 08/27	08:15 08/27	09:45 08/28
GASTON	AL072004	ID									
HERMINE	AL082004	NAD					22:45 08/29	22:45 08/29			
IVAN	AL092004	EAP					03:45 09/03	19:45 09/03	06:45 09/05	06:45 09/05	21:45 09/05
TEN	AL102004	NAD									
JEANNE	AL112004	EAP					22:45 09/13	23:45 09/15	23:45 09/15	23:45 09/15	10:45 09/16
KARL	AL122004	NAD					16:00 09/16	16:00 09/16	16:00 09/16	06:45 09/18	11:45 09/19
LISA	AL132004	NAD					18:00 09/19	18:00 09/19	07:30 09/20	08:45 10/01	
MATTHEW	AL142004	NOE					21:15 10/09				
NICOLE	AL152004	NAD									
OTTO	AL162004	NAD					03:15 11/30	03:15 11/30	03:15 11/30		
ARLENE	AL012005	NOE					20:45 06/09	08:45 06/10	18:15 06/11		
BRET	AL022005	NAD					01:15 06/29				

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TABLE S4. *continued*

Storm	STORMID	Case Type	B	A	A1	A2	IR1	IR2	IR3	IR4	IR5
CINDY	AL032005	NOE					09:45 07/04	09:45 07/04	23:15 07/05		
DENNIS	AL042005	ID	18:14 07/06			09:39 07/07	12:15 07/05	14:45 07/05	14:45 07/05	18:45 07/07	11:45 07/08
EMILY	AL052005	DF	13:35 07/13	11:49 07/14		11:49 07/14	18:45 07/12	18:45 07/12	16:15 07/14	16:15 07/14	20:45 07/14
FRANKLIN	AL062005	IF	14:20 07/22	01:48 07/23	01:48 07/23		18:45 07/21				
GERT	AL072005	NAD					19:15 07/24				
HARVEY	AL082005	NAD					00:45 08/04	02:45 08/05	03:45 08/05		
IRENE	AL092005	EAP					10:45 08/11	17:45 08/14	17:15 08/14	12:45 08/16	
TEN	AL102005	NAD									
JOSE	AL112005	NAD									
KATRINA	AL122005	DF		19:49 08/24	19:49 08/24	23:05 08/24	09:45 08/24	21:15 08/25	00:15 08/27	02:45 08/27	03:45 08/28
LEE	AL132005	NAD					06:15 08/29	23:15 08/30	23:15 08/30		
MARIA	AL142005	NAD					08:45 09/02	16:15 09/02	21:45 09/03	07:15 09/05	
NATE	AL152005	EAP					23:45 09/05	02:45 09/07	16:15 09/07	16:15 09/07	
OPHELIA	AL162005	IF		01:45 09/08	01:45 09/08	02:24 09/09	10:15 09/06	02:15 09/07	17:45 09/10	01:15 09/14	
PHILIPPE	AL172005	EAP					12:15 09/17				
RITA	AL182005	DF	02:13 09/20	12:03 09/20	12:03 09/20	13:30 09/20	03:15 09/18	03:15 09/18	06:45 09/20	21:45 09/20	00:45 09/21
NINETEEN	AL192005	NAD									
STAN	AL202005	RD	05:19 10/04	08:48 10/04	08:48 10/04		16:15 10/01	10:45 10/04			
UNNAMED	AL212005	NAD									
TAMMY	AL222005	NOE					09:45 10/05	18:45 10/05			
TWENTY-TWO	AL232005	NAD									
VINCE	AL242005	NAD					19:30 10/08	04:30 10/09	10:45 10/09	10:45 10/09	
WILMA	AL252005	DF		21:32 10/17	21:32 10/17	21:42 10/18	05:15 10/16	09:45 10/18	09:45 10/18	20:45 10/18	03:45 10/19
ALPHA	AL262005	NAD					12:15 10/22	01:15 10/24			
BETA	AL272005	ID									
GAMMA	AL282005	NOE					07:45 11/14	07:45 11/14			
DELTA	AL292005	NAD					00:45 11/23	18:45 11/23	18:45 11/23		
EPSILON	AL302005	NAD					17:15 11/29	19:15 11/29	13:15 11/30	11:45 12/02	
ZETA	AL312005	NAD					16:45 12/30	04:45 01/01	05:15 01/04		
ALBERTO	AL012006	NOE					10:15 06/06	10:15 06/06			
NONAME	AL022006	NAD									
BERYL	AL032006	RD		05:36 07/20	05:36 07/20		01:15 07/20	06:45 07/20	06:45 07/20		
CHRIS	AL042006	NOE	00:09 08/02				07:45 08/02				
DEBBY	AL052006	NAD					22:00 08/21	22:00 08/21	08:45 08/23		
ERNESTO	AL062006	IF		11:30 08/27	11:30 08/27		11:45 08/25	23:15 08/26	20:15 08/31		
FLORENCE	AL072006	IF		05:24 09/10		05:24 09/10	20:15 09/05	09:15 09/08	20:15 09/08	10:45 09/10	
GORDON	AL082006	NAD					02:45 09/11	21:15 09/11	22:15 09/12	12:15 09/13	
HELENE	AL092006	EAP					17:45 09/12	17:45 09/12	03:45 09/17	03:45 09/17	
ISAAC	AL102006	NAD					02:45 09/27	09:15 09/30	09:15 09/30	19:15 09/30	
ANDREA	AL012007	NOE					12:15 05/09				

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TABLE S4. *continued*

Storm	STORMID	Case Type	B	A	A1	A2	IR1	IR2	IR3	IR4	IR5
BARRY	AL022007	NOE									
CHANTAL	AL032007	NAD					10:45 07/31	10:45 07/31			
DEAN	AL042007	EAP					00:15 08/15	06:15 08/16	08:45 08/16	20:15 08/17	23:15 08/17
ERIN	AL052007	NOE					13:32 08/15				
FELIX	AL062007	SF		22:41 09/01	22:41 09/01	17:24 09/02	16:45 08/31	16:45 08/31	08:45 09/02	08:45 09/02	13:15 09/02
GABRIELLE	AL072007	NOE	11:07 09/09								
INGRID	AL082007	NOE					20:45 09/12				
HUMBERTO	AL092007	EAP					10:45 09/12	14:30 09/12	11:02 09/13		
TEN	AL102007	NOE									
JERRY	AL112007	NAD					15:15 09/24				
KAREN	AL122007	NOE					01:15 09/25	05:00 09/25	14:45 09/26		
LORENZO	AL132007	NOE					18:15 09/25	18:15 09/25			
MELISSA	AL142007	NAD					10:15 09/28	08:45 10/01			
FIFTEEN	AL152007	NAD									
NOEL	AL162007	NOE					02:15 10/28	10:45 10/28			
OLGA	AL172007	NAD									
ARTHUR	AL012008	NAD					09:15 05/31	09:15 05/31			
BERTHA	AL022008	EAP					18:45 07/03	23:15 07/06	05:45 07/07	05:45 07/07	
CRISTOBAL	AL032008	NOE					14:02 07/22				
DOLLY	AL042008	IF	17:11 07/21	11:29 07/22		17:06 07/22	00:45 07/21	00:45 07/21	18:15 07/22	00:15 07/23	
EDOUARD	AL052008	NOE	20:44 08/04				18:15 08/04				
FAY	AL062008	IF		06:54 08/19	06:54 08/19		13:25 08/19	15:15 08/19	15:15 08/19	15:15 08/19	
GUSTAV	AL072008	EAP					13:15 08/25	23:15 08/25	01:15 08/26	06:55 08/30	08:02 08/30
HANNA	AL082008	NOE	17:11 09/01				02:25 09/02	02:25 09/02	03:15 09/02		
IKE	AL092008	ID			18:56 09/05	06:55 09/06	19:45 09/01	14:15 09/03	14:15 09/03	20:45 09/03	00:15 09/04
JOSEPHINE	AL102008	NAD					12:15 09/02	12:15 09/02	15:15 09/02		
KYLE	AL112008	NOE					11:32 09/25				
LAURA	AL122008	NAD					12:45 09/29	11:45 09/30			
MARCO	AL132008	NOE									
NANA	AL142008	NAD									
OMAR	AL152008	IF	17:50 10/14	19:53 10/14	19:53 10/14	23:17 10/15	05:45 10/14	05:45 10/14	01:15 10/16	01:15 10/16	
SIXTEEN	AL162008	NOE									
PALOMA	AL172008	SF		17:07 11/06		17:07 11/06	15:15 11/06	23:15 11/06	23:15 11/06	17:25 11/07	23:25 11/07

TABLE S5. Basic statistics at the time of first aircraft eye report for the 70 Atlantic TCs which were well-observed during their eye formation periods, 1989-2008. The left-hand portion of the table gives identifying characteristics for each TC: name of storm, storm identifier, eye formation case type, # of fixes taken during the lifetime of the TC, and date/time of the first aircraft eye report. The right-hand portion of the table provides raw or interpolated values of various parameters at the time at which the first eye was reported. The parameters are: level of the fix, best track minimum central pressure (BT p_{min}, interpolated), minimum central pressure from extrapolation or dropsonde (VDM p_{min}, raw), TC translation speed computed from BT positions, latitude of fix (VDM ϕ, raw), longitude of fix (VDM λ, raw), maximum flight level wind speed on inbound leg (FL $v_{\mathrm{max,in}}$, raw), combined maximum flight level wind speed (FL v_{max}, raw), upper bound flight level wind speed reduced to surface equivalent (rFL v_{max}, interpolated), best track surface wind speed (BT v_{max}, interpolated), range of maximum flight level wind (FL r_{max}, raw), diameter of initial eye (d_{eye}, raw).

Storm	STORMID	Case Type	# of fixes	date / time of first eye fix UTC	VDM fix level	BT p_{min} hPa	VDM p_{min} hPa	storm translation speed m s^{-1}	VDM ϕ °N	VDM λ °W	FL $v_{\mathrm{max,in}}$ kt	FL v_{max} kt	rFL v_{max} kt	BT v_{max} kt	FL r_{max} n mi	d_{eye}. n mi
CHANTAL	AL041989	RD	14	31 Jul 1989 / 23:00	1500 ft	990	992	5.0	27.6	92.6	61	61	48	63	35	15
IRIS	AL121989	RD	12	19 Sep 1989 / 14:12	surface	1000	1003	6.5	19.5	58.5	70	70	71	60	20	18
JERRY	AL141989	IF	22	13 Oct 1989 / 23:12	1500 ft	990	991	4.7	23.6	93.5	66	66		53	25	10
ARTHUR	AL021990	RD	12	25 Jul 1990 / 17:00	1500 ft	995	995	7.0	13.1	63.5	56	87	65	58	10	9
DIANA	AL051990	RD	13	07 Aug 1990 / 17:19	850 mb	980	987	4.9	21.1	96.7	111	111		83	13	30
KLAUS	AL131990	IF	38	04 Oct 1990 / 21:38	1500 ft	996	996	1.4	17.0	60.8	47	47		54	30	20
LILI	AL141990	RD	12	11 Oct 1990 / 23:29	850 mb	994	996	10.6	30.0	66.3	67	69	59	64	25	25
NANA	AL161990	DF	24	16 Oct 1990 / 20:27	1500 ft	1003	1005	2.8	22.1	62.3	48	48		36	5	10
BOB	AL031991	DF	43	17 Aug 1991 / 11:42	1500 ft	995	996	3.6	28.3	76.8	35	35	40	54	10	10
GRACE	AL111991	RD	16	28 Oct 1991 / 12:11	1500 ft	982	984	0.6	32.3	68.4	43	43	46	64	15	30
ANDREW	AL041992	DF	64	21 Aug 1992 / 06:13	1500 ft	1009	1006	5.5	24.1	63.3	53	53	58	44	14	10
DANIELLE	AL071992	RD	23	25 Sep 1992 / 11:33	1500 ft	1000	1001	5.3	35.9	75.2	42	42	43	53	25	10
EARL	AL091992	IF	36	30 Sep 1992 / 13:59	1500 ft	997	1001	5.0	30.1	76.9	55	55	41	46	26	10
EMILY	AL051993	IF	59	27 Aug 1993 / 11:53	850 mb	991	993	2.4	26.3	63.5	56	56		59	67	2
GERT	AL081993	IF	15	20 Sep 1993 / 00:20	1500 ft	989	989	1.9	20.9	94.1	58	58	59	54	55	20
ALBERTO	AL011994	IF	23	02 Jul 1994 / 11:47	1500 ft	1002	1003	5.6	25.5	87.6	42	42	35	39	16	25
FIVE	AL051994	RD	13	30 Aug 1994 / 18:35	1500 ft		1007	3.5	21.4	96.5	35	35	26	29	29	40
CHANTAL	AL031995	IF	40	15 Jul 1995 / 11:52	1500 ft	1005	1006	4.3	22.8	67.6	51	51	38	45	105	20
ERIN	AL051995	IF	44	31 Jul 1995 / 15:46	850 mb	996	997	2.4	23.0	74.1	81	81	65	57	48	20
MARILYN	AL151995	SF	56	13 Sep 1995 / 18:01	1500 ft	989	990	5.9	12.6	56.5	64	64	48	59	17	22
ROXANNE	AL191995	SF	72	09 Oct 1995 / 19:24	1500 ft	992	990	3.1	18.6	83.0	47	60	44	52	26	10
BERTHA	AL021996	SF	58	08 Jul 1996 / 02:54	850 mb	986	988	8.8	17.2	60.9	78	91	73	74	33	30
CESAR	AL031996	RD	15	28 Jul 1996 / 02:56	850 mb	986	989	9.5	12.3	83.4	40	40		73	58	15
DOLLY	AL041996	RD	18	22 Aug 1996 / 17:51	1500 ft	992	993	2.7	20.4	94.2	59	59	44	49	66	15
FRAN	AL061996	DF	71	30 Aug 1996 / 09:14	850 mb	988	990	4.3	19.6	59.8	58	69		64	64	30
HORTENSE	AL081996	IF	17	09 Sep 1996 / 08:29	850 mb	985	986	2.3	16.0	64.5	89	89	71	69	33	6
JOSEPHINE	AL101996	IF	24	07 Oct 1996 / 11:35	1500 ft	980	981	8.9	26.9	87.4	55	55	49	58	14	25
LILI	AL121996	IF	35	16 Oct 1996 / 23:25	1500 ft	991	991	1.7	18.2	84.3	47	47	44	53	6	8
MARCO	AL131996	RD	41	22 Nov 1996 / 07:27	850 mb	984	985	1.9	15.9	75.8	71	71		55	6	5
DANNY	AL051997	SF	43	18 Jul 1997 / 05:07	1500 ft	991	994	2.3	29.1	90.0	60	63	57	63	10	20
ERIKA	AL071997	DF	33	06 Sep 1997 / 02:01	850 mb	986	990	5.1	17.8	59.5	77	77	62	66	45	14

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TABLE S5. *continued*

Storm	STORMID	Case Type	# of fixes	date / time of first eye fix UTC	VDM fix level	BT $p_{\min}$ hPa	VDM $p_{\min}$ hPa	storm translation speed m s^{-1}	VDM ϕ °N	VDM λ °W	FL $v_{\max,\text{in}}$ kt	FL $v_{\max}$ kt	rFL $v_{\max}$ kt	BT $v_{\max}$ kt	FL $r_{\max}$ n mi	d_{eye}. n mi
BONNIE	AL021998	SF	75	22 Aug 1998 / 05:35	1500 ft	988	987	7.6	21.7	68.6	76	76	57	69	27	20
DANIELLE	AL041998	DF	43	27 Aug 1998 / 13:19	700 mb	993	999	9.0	21.5	59.0	60	97		88	89	15
MITCH	AL131998	SF	48	24 Oct 1998 / 07:53	850 mb	988	988	2.8	14.1	77.8	91	91	73	67	23	30
BRET	AL031999	DF	42	19 Aug 1999 / 23:20	1500 ft	999	1000	0.1	19.8	94.7	35	35	32	38	2	9
DENNIS	AL051999	DF	84	26 Aug 1999 / 20:19		990	992	2.6	24.7	73.9	46	54	54	67	14	22
FLOYD	AL081999	SF	69	10 Sep 1999 / 18:17	700 mb	973	977	6.0	20.2	59.5	55	55	74	69	30	28
IRENE	AL131999	IF	44	14 Oct 1999 / 22:10	850 mb	990	988	4.5	23.1	82.7	38	38	46	59	8	10
JOSE	AL141999	IF	31	19 Oct 1999 / 17:04	850 mb	991	992	5.8	14.8	58.8	44	44	63	63	7	25
LENNY	AL161999	SF	44	15 Nov 1999 / 06:00	850 mb	977	977	5.2	15.5	77.7	71	71	59	75	10	25
DEBBY	AL072000	IF	26	22 Aug 2000 / 03:05	850 mb	993	991	8.7	17.2	60.9	70	70	58	67	12	20
FLORENCE	AL102000	IF	22	11 Sep 2000 / 21:35	1500 ft	993	993	1.2	30.1	72.4	70	70		64	31	
GORDON	AL112000	RD	29	17 Sep 2000 / 11:38	700 mb	985	987	5.8	27.1	84.2	52	52	67	65	54	30
KEITH	AL152000	SF	34	30 Sep 2000 / 18:08	850 mb	976	977	1.5	17.9	86.7	82	82		75	15	40
ERIN	AL062001	SF	21	08 Sep 2001 / 19:30	1500 ft	991	994	6.9	28.8	59.9	67	76	60	63	19	45
HUMBERTO	AL102001	SF	8	23 Sep 2001 / 06:48	1500 ft	993	994	4.4	30.2	67.3	65	65	49	55	13	25
MICHELLE	AL152001	SF	39	02 Nov 2001 / 18:11	850 mb	968	969	1.1	18.0	84.1	77	77	72	79	10	15
GUSTAV	AL082002	RD	22	10 Sep 2002 / 14:49	1500 ft	985	986	5.1	34.5	75.5	51	61	46	51	40	18
ISIDORE	AL102002	SF	73	19 Sep 2002 / 08:03	850 mb	989	990	4.7	19.8	80.7	53	58	50	52	5	15
LILI	AL132002	SF	67	28 Sep 2002 / 23:56	850 mb	1000	1001	2.5	18.8	76.0	50	50	40	44	18	8
CLAUDETTE	AL042003	IF	57	10 Jul 2003 / 12:01	850 mb	987	988	7.1	17.5	82.8	65	65	59	69	6	10
ERIKA	AL082003	RD	16	16 Aug 2003 / 02:20	700 mb	992	998	8.7	25.8	95.2	67	67	60	56	25	12
HENRI	AL122003	RD	27	05 Sep 2003 / 07:42	850 mb	998	1000	3.4	27.8	84.8	31	31		36	14	22
ALEX	AL012004	SF	25	02 Aug 2004 / 17:04	850 mb	992	993	2.7	31.6	78.7	50	56	52	49	13	20
BONNIE	AL022004	IF	29	09 Aug 2004 / 21:54	1500 ft	1005	1006	3.6	23.1	88.8	53	53	40	43	13	8
EMILY	AL052005	DF	68	14 Jul 2005 / 11:49	700 mb	980	980	8.8	12.4	63.2	53	53	78	83	6	10
FRANKLIN	AL062005	IF	19	23 Jul 2005 / 01:48	850 mb	1002	1003	3.7	28.2	76.4	39	56	44	46	21	15
KATRINA	AL122005	DF	56	24 Aug 2005 / 19:49	1500 ft	1001	1002	4.9	25.8	77.1	39	45	35	40	12	6
OPHELIA	AL162005	IF	96	08 Sep 2005 / 01:45	850 mb	993	995	0.4	28.9	79.3	48	54	46	45	24	18
RITA	AL182005	DF	71	20 Sep 2005 / 12:03	850 mb	984	985	7.1	23.7	80.3	69	69	71	69	44	45
STAN	AL202005	RD	12	04 Oct 2005 / 08:48	700 mb	981	979	5.2	19.0	94.4	67	67	62	66	6	16
WILMA	AL252005	DF	56	17 Oct 2005 / 21:32	850 mb	990	989	1.3	15.8	79.9	45	51	42	50	21	13
BERYL	AL032006	RD	19	20 Jul 2006 / 05:36	850 mb	1000	1002	4.1	37.3	73.3	44	44	50	49	37	35
ERNESTO	AL062006	IF	55	27 Aug 2006 / 11:30	700 mb	995	997	4.3	17.3	73.3	48	48		55	15	6
FLORENCE	AL072006	IF	13	10 Sep 2006 / 05:24	850 mb	980	981	5.7	27.0	65.2	45	45	75	69	29	30
FELIX	AL062007	SF	23	01 Sep 2007 / 22:41	700 mb	993	993	8.2	12.5	65.7	77	77	69	63	14	30
DOLLY	AL042008	IF	33	22 Jul 2008 / 11:29	700 mb	993	993	4.7	23.7	94.0	59	59	53	53	45	11
FAY	AL062008	IF	44	19 Aug 2008 / 06:54	850 mb	992	991	3.0	25.6	81.8	53	54	46	54	11	20
OMAR	AL152008	IF	19	14 Oct 2008 / 19:53	850 mb	982	986	2.3	13.9	68.7	41	56	51	61	11	10
PALOMA	AL172008	SF	27	06 Nov 2008 / 17:07	850 mb	994	997	3.6	15.9	81.9	41	61	49	51	8	18

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TABLE S5. *continued*

Storm	STORMID	Case Type	# of fixes	date / time of first eye fix UTC	VDM fix level	BT $p_{\min}$ hPa	VDM $p_{\min}$ hPa	storm translation speed m s^{-1}	VDM ϕ °N	VDM λ °W	FL $v_{\max,\text{in}}$ kt	FL $v_{\max}$ kt	rFL $v_{\max}$ kt	BT $v_{\max}$ kt	FL $r_{\max}$ n mi	d_{eye}. n mi
Measures of Central Tendency:																
Mean			37.0			990.7	992.2	4.54	22.28	76.04	57.3	60.4	53.9	58.1	25.0	18.7
Median			33.0			991.0	992.0	4.43	21.61	76.61	55.0	58.0	51.9	58.0	18.5	18.0
Measures of Spread:																
Std dev			21.0			7.8	8.0	2.46	6.08	11.72	15.3	16.0	12.3	12.0	20.3	9.8
IQR			29			9	10	3.3	9.6	19.5	22	21	17	16	19	15
Measure of Symmetry:																
Yule-Kendall			0.0			−0.1	0.0	−0.19	0.10	−0.24	0.1	0.0	0.1	0.0	0.2	−0.1
Additional Measures:																
No. of records			70			69	70	70	70	70	70	70	57	70	70	69
Maximum			96			1009	1007	10.6	37.3	96.7	111	111	78	88	105	45
75%			48			995	997	5.8	26.9	84.1	67	69	62	66	30	25
25%			19			986	987	2.5	17.3	64.5	45	48	44	50	11	10
Minimum			8			968	969	0.1	12.3	56.5	31	31	26	29	2	2

TABLE S6. Statistical summary of environmental parameters at the time of first aircraft eye report (A) for the 70 well-observed eye-forming Atlantic TCs (1989-2008). Parameters include: maximum potential intensity (VMPI); Reynolds SST (RSST); 1000 mb θ_E (200-800 km average, E000); 200 mb divergence (0-1000 km average, D200); 200 mb temperature (T200); 850-200 mb shear magnitude with vortex removed (0-500 km average, SHDC); average ($0-15$ km) vertical velocity of a parcel lifted from the surface (VVAV).

Statistics for SHIPS Environmental Parameters at A										
Storm	STORMID	Case Type	of first eye fix UTC	VMPI kt	RSST °C	E000 K	D200 10^{-7} s^{-1}	T200 °C	SHDC kt	VVAV m s^{-1}
CHANTAL	AL041989	RD	31 Jul 1989 / 23:00	108	28.6	359	18	−51.6	12	6
IRIS	AL121989	RD	19 Sep 1989 / 14:12	104	27.5	353	39	−51.8	32	7
JERRY	AL141989	IF	13 Oct 1989 / 23:12	139	28.7	350	19	−52.9	27	10
ARTHUR	AL021990	RD	25 Jul 1990 / 17:00	103	27.6	353	42	−52.9	11	6
DIANA	AL051990	RD	07 Aug 1990 / 17:19	125	29.4	359	12	−52.2	6	13
KLAUS	AL131990	IF	04 Oct 1990 / 21:38	135	28.7	352	17	−51.8	23	5
LILI	AL141990	RD	11 Oct 1990 / 23:29	125	27.8	345	−5	−53.2	22	5
NANA	AL161990	DF	16 Oct 1990 / 20:27	134	28.4	350	5	−52.4	11	10
BOB	AL031991	DF	17 Aug 1991 / 11:42	139	29.4	352	40	−54.1	4	15
GRACE	AL111991	RD	28 Oct 1991 / 12:11	70	24.0	341	48	−54.8	16	3
ANDREW	AL041992	DF	21 Aug 1992 / 06:13	129	28.7	350	−12	−54.1	17	9
DANIELLE	AL071992	RD	25 Sep 1992 / 11:33	91	25.8	321	1	−54.5	17	11
EARL	AL091992	IF	30 Sep 1992 / 13:59	126	28.1	335	19	−53.9	25	13
EMILY	AL051993	IF	27 Aug 1993 / 11:53	144	29.0	348	5	−54.9	13	11
GERT	AL081993	IF	20 Sep 1993 / 00:20	116	29.0	362	48	−51.4	4	18
ALBERTO	AL011994	IF	02 Jul 1994 / 11:47	133	28.7	351	21	−54.0	11	17
FIVE	AL051994	RD	30 Aug 1994 / 18:35	103	29.0	363	26	−52.9	16	15
CHANTAL	AL031995	IF	15 Jul 1995 / 11:52	137	28.8	350	15	−53.6	29	9
ERIN	AL051995	IF	31 Jul 1995 / 15:46	134	29.3	355	56	−52.2	21	10
MARILYN	AL151995	SF	13 Sep 1995 / 18:01	139	29.5	356	2	−52.1	13	10
ROXANNE	AL191995	SF	09 Oct 1995 / 19:24	137	29.4	357	54	−51.1	5	19
BERTHA	AL021996	SF	08 Jul 1996 / 02:54	113	27.6	352	44	−53.4	8	9
CESAR	AL031996	RD	28 Jul 1996 / 02:56	124	28.2	353	76	−52.1	10	17
DOLLY	AL041996	RD	22 Aug 1996 / 17:51	116	29.1	362	43	−52.3	12	20
FRAN	AL061996	DF	30 Aug 1996 / 09:14	112	27.7	353	18	−51.9	26	7
HORTENSE	AL081996	IF	09 Sep 1996 / 08:29	144	29.3	354	47	−52.3	18	18
JOSEPHINE	AL101996	IF	07 Oct 1996 / 11:35	148	29.0	344	83	−51.1	40	21
LILI	AL121996	IF	16 Oct 1996 / 23:25	132	29.0	357	47	−52.5	9	16
MARCO	AL131996	RD	22 Nov 1996 / 07:27	143	28.6	349	62	−52.3	23	18
DANNY	AL051997	SF	18 Jul 1997 / 05:07	155	30.4	354	−0	−53.9	21	21
ERIKA	AL071997	DF	06 Sep 1997 / 02:01	126	28.7	355	−5	−52.4	22	10
BONNIE	AL021998	SF	22 Aug 1998 / 05:35	130	29.5	359	−10	−50.9	11	8
DANIELLE	AL041998	DF	27 Aug 1998 / 13:19	122	28.5	354	13	−51.5	10	5
MITCH	AL131998	SF	24 Oct 1998 / 07:53	138	29.0	355	96	−52.1	6	19

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TABLE S6. *continued*

Storm	STORMID	Case Type	of first eye fix UTC	VMPI (kt)	RSST (°C)	E000 (K)	D200 ($10^{-7}\,s^{-1}$)	T200 (°C)	SHDC (kt)	VVAV ($m\,s^{-1}$)
				Statistics for SHIPS Environmental Parameters at A						
BRET	AL031999	DF	19 Aug 1999 / 23:20	124	29.0	358	48	−52.8	9	14
DENNIS	AL051999	DF	26 Aug 1999 / 20:19	132	29.6	359	21	−51.7	14	7
FLOYD	AL081999	SF	10 Sep 1999 / 18:17	132	29.2	357	86	−52.2	19	7
IRENE	AL131999	IF	14 Oct 1999 / 22:10	132	28.8	356	98	−53.2	23	12
JOSE	AL141999	IF	19 Oct 1999 / 17:04	133	29.0	356	73	−53.8	11	5
LENNY	AL161999	SF	15 Nov 1999 / 06:00	142	29.0	354	98	−51.9	21	18
DEBBY	AL072000	IF	22 Aug 2000 / 03:05	133	28.5	352	44	−53.6	20	11
FLORENCE	AL102000	IF	11 Sep 2000 / 21:35	129	28.0	347	−18	−53.6	11	8
GORDON	AL112000	RD	17 Sep 2000 / 11:38	147	29.3	336	93	−52.5	29	11
KEITH	AL152000	SF	30 Sep 2000 / 18:08	136	28.9	355	76	−53.1	1	14
ERIN	AL062001	SF	08 Sep 2001 / 19:30	147	29.1	347	39	−54.0	10	12
HUMBERTO	AL102001	SF	23 Sep 2001 / 06:48	128	27.9	348	14	−54.8	14	13
MICHELLE	AL152001	SF	02 Nov 2001 / 18:11	147	29.1	353	120	−52.5	6	14
GUSTAV	AL082002	RD	10 Sep 2002 / 14:49	121	27.6	345	13	−54.0	10	3
ISIDORE	AL102002	SF	19 Sep 2002 / 08:03	145	30.0	358	26	−52.3	12	18
LILI	AL132002	SF	28 Sep 2002 / 23:56	139	29.1	355	51	−52.1	7	12
CLAUDETTE	AL042003	IF	10 Jul 2003 / 12:01	127	28.0	350	67	−53.7	20	11
ERIKA	AL082003	RD	16 Aug 2003 / 02:20	132	29.5	358	13	−53.0	12	13
HENRI	AL122003	RD	05 Sep 2003 / 07:42	152	29.6	350	31	−52.8	21	17
ALEX	AL012004	SF	02 Aug 2004 / 17:04	122	28.5	354	30	−52.2	10	12
BONNIE	AL022004	IF	09 Aug 2004 / 21:54	140	29.4	355	10	−53.2	11	6
EMILY	AL052005	DF	14 Jul 2005 / 11:49	138	28.5	351	33	−54.4	7	15
FRANKLIN	AL062005	IF	23 Jul 2005 / 01:48	133	29.3	356	−6	−52.7	13	9
KATRINA	AL122005	DF	24 Aug 2005 / 19:49	151	30.5	357	13	−52.8	5	15
OPHELIA	AL162005	IF	08 Sep 2005 / 01:45	156	29.6	349	9	−51.9	12	10
RITA	AL182005	DF	20 Sep 2005 / 12:03	155	30.6	357	22	−52.5	10	15
STAN	AL202005	RD	04 Oct 2005 / 08:48	137	29.4	358	65	−51.5	13	20
WILMA	AL252005	DF	17 Oct 2005 / 21:32	145	29.4	355	84	−51.9	8	15
BERYL	AL032006	RD	20 Jul 2006 / 05:36	75	25.0	340	−33	−53.2	6	2
ERNESTO	AL062006	IF	27 Aug 2006 / 11:30	137	29.0	354	66	−53.0	15	14
FLORENCE	AL072006	IF	10 Sep 2006 / 05:24	138	29.2	355	68	−51.5	9	12
FELIX	AL062007	SF	01 Sep 2007 / 22:41	136	28.9	354	11	−53.8	7	14
DOLLY	AL042008	IF	22 Jul 2008 / 11:29	150	29.2	349	37	−52.8	5	15
FAY	AL062008	IF	19 Aug 2008 / 06:54	153	30.0	353	15	−52.9	15	18
OMAR	AL152008	IF	14 Oct 2008 / 19:53	148	29.4	354	74	−52.7	9	19
PALOMA	AL172008	SF	06 Nov 2008 / 17:07	151	29.0	350	116	−53.3	4	12
Measures of Central Tendency:										
Mean				131.7	28.78	352.3	37.0	−52.78	14.0	12.2
Median				134.0	29.00	353.6	32.1	−52.74	11.7	12.0

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TABLE S6. *continued*

Storm	STORMID	Case Type	of first eye fix UTC	VMPI kt	RSST °C	E000 K	D200 10^{-7} s^{-1}	T200 °C	SHDC kt	VVAV $m\,s^{-1}$
				Statistics for SHIPS Environmental Parameters at A						
Measures of Spread:										
Std dev				17.0	1.07	6.6	33.8	0.96	7.7	4.8
IQR				17	0.8	6	43	1.4	11	6
Measure of Symmetry:										
Yule-Kendall				−0.1	−0.20	−0.3	0.1	−0.17	0.5	0.0
Additional Measures:										
No. of records				70	70	70	70	70	70	70
Maximum				156	30.6	363	120	−50.9	40	21
75%				142	29.3	356	56	−52.1	19	15
25%				125	28.5	350	13	−53.6	9	9
Minimum				70	24.0	321	−33	−54.9	1	2

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