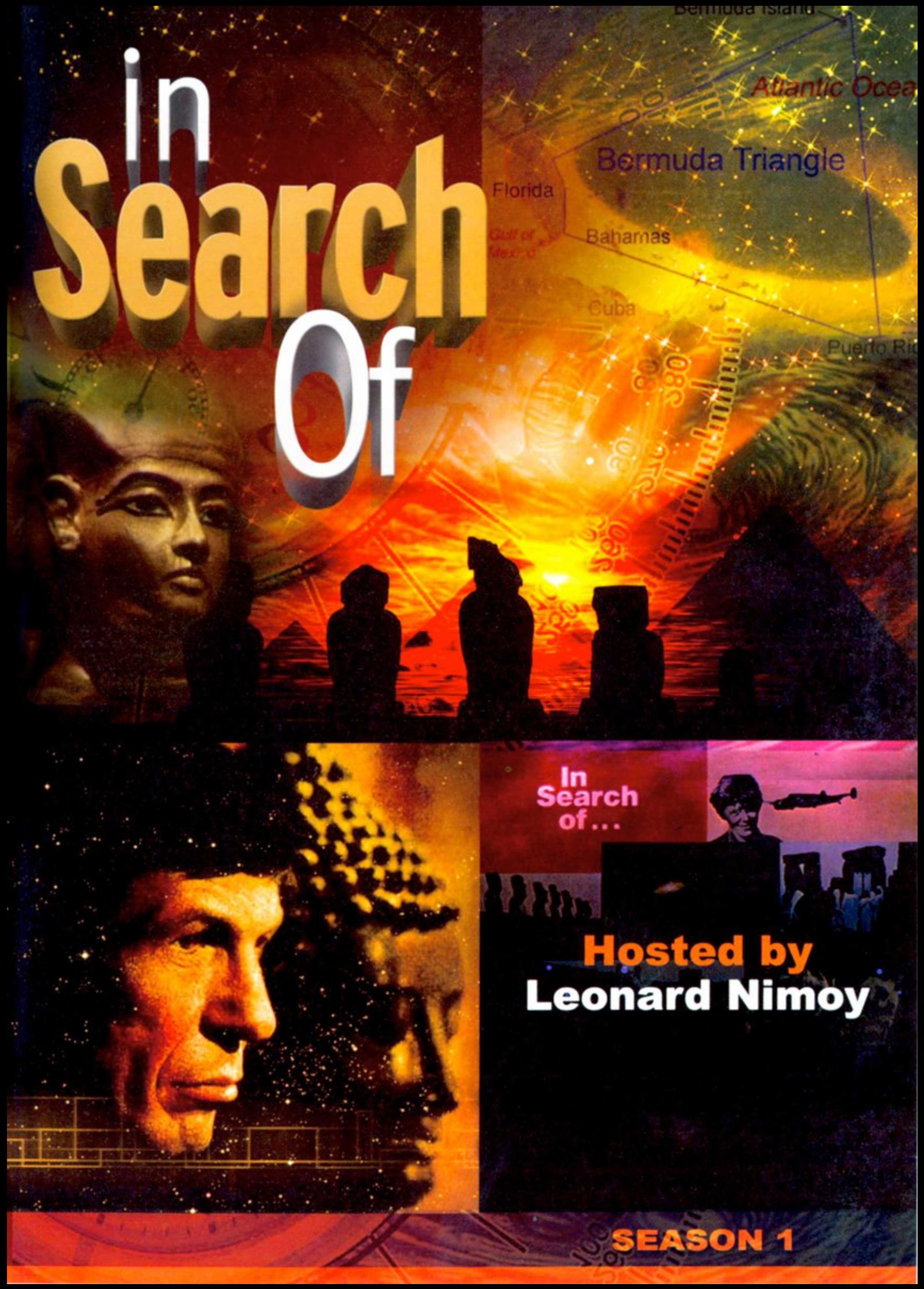
In Search of the Elusive Eyewall Me/iso-scale ?



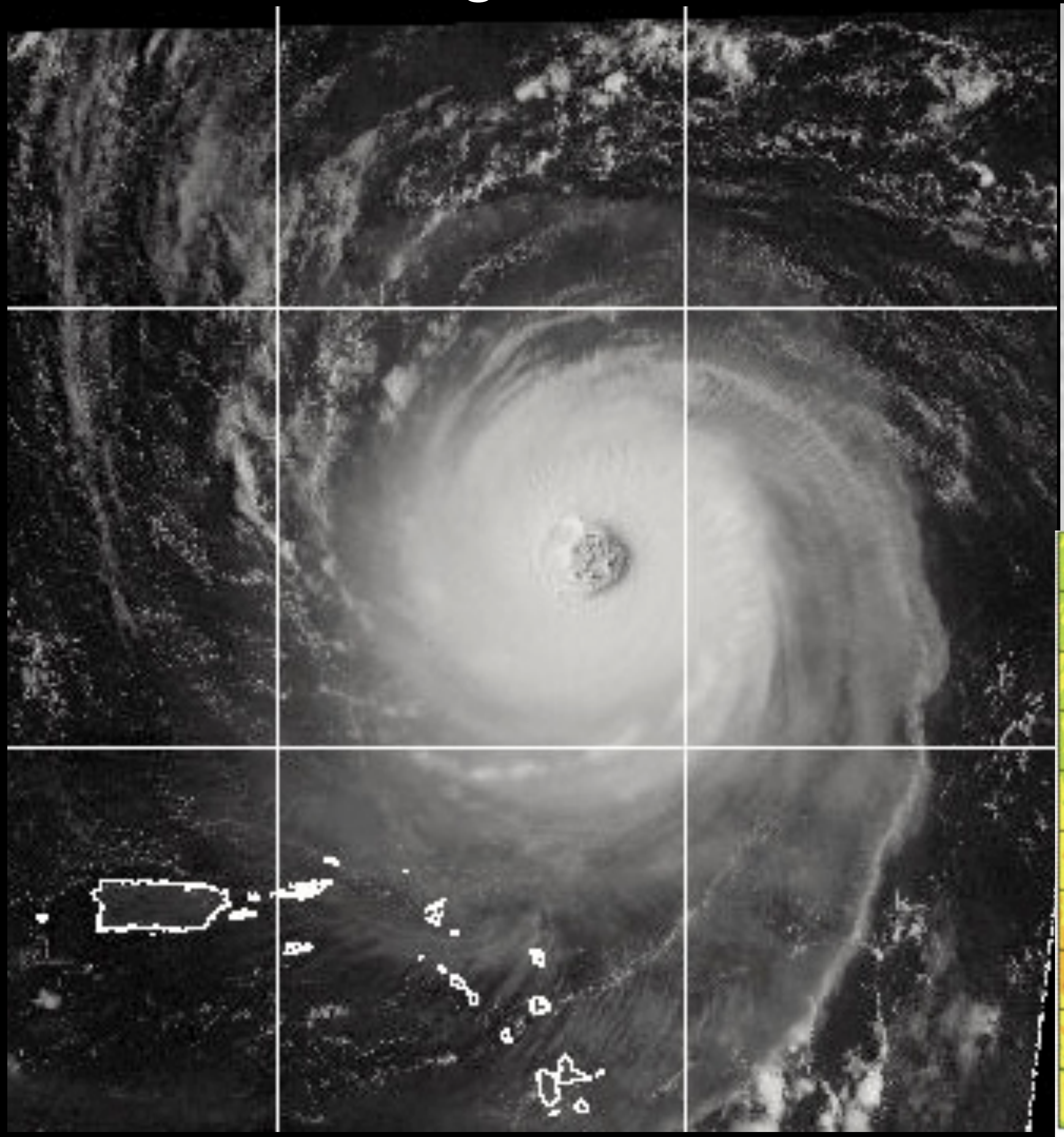
Sim Aberson
HRD Science Meeting
10 September, 2020

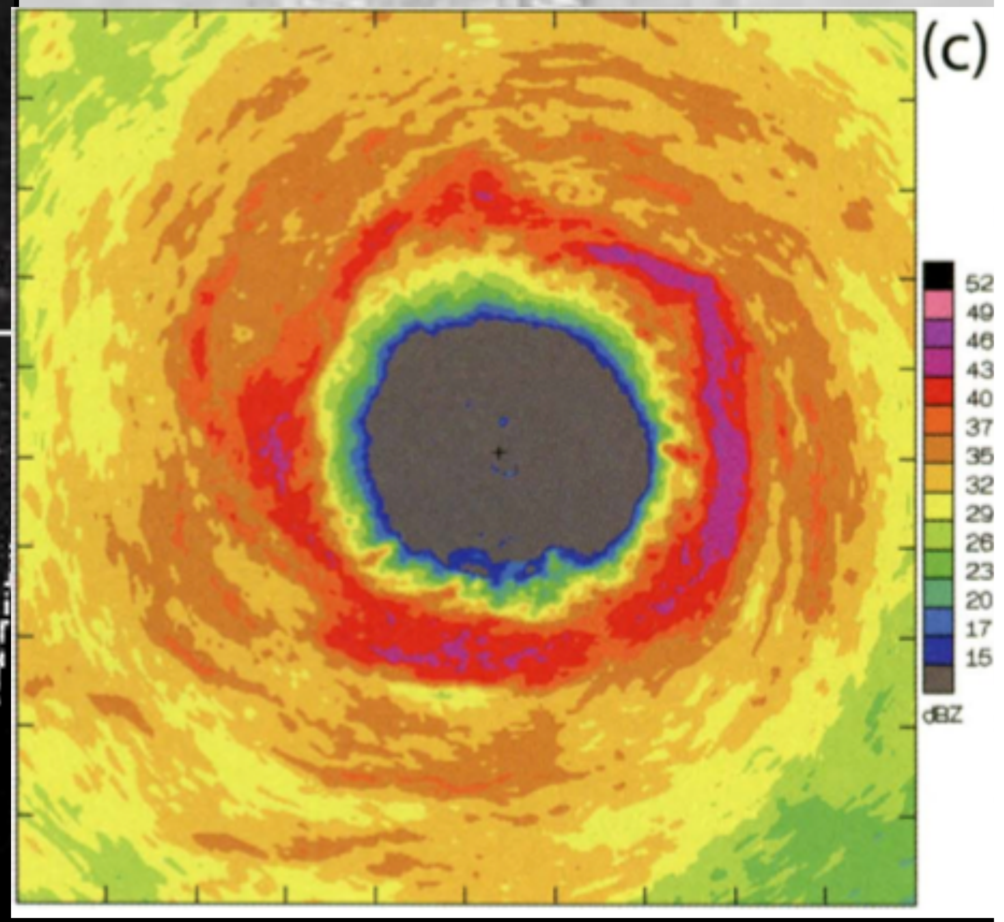
Me/iso-scale (example: Hurricane Isabel)

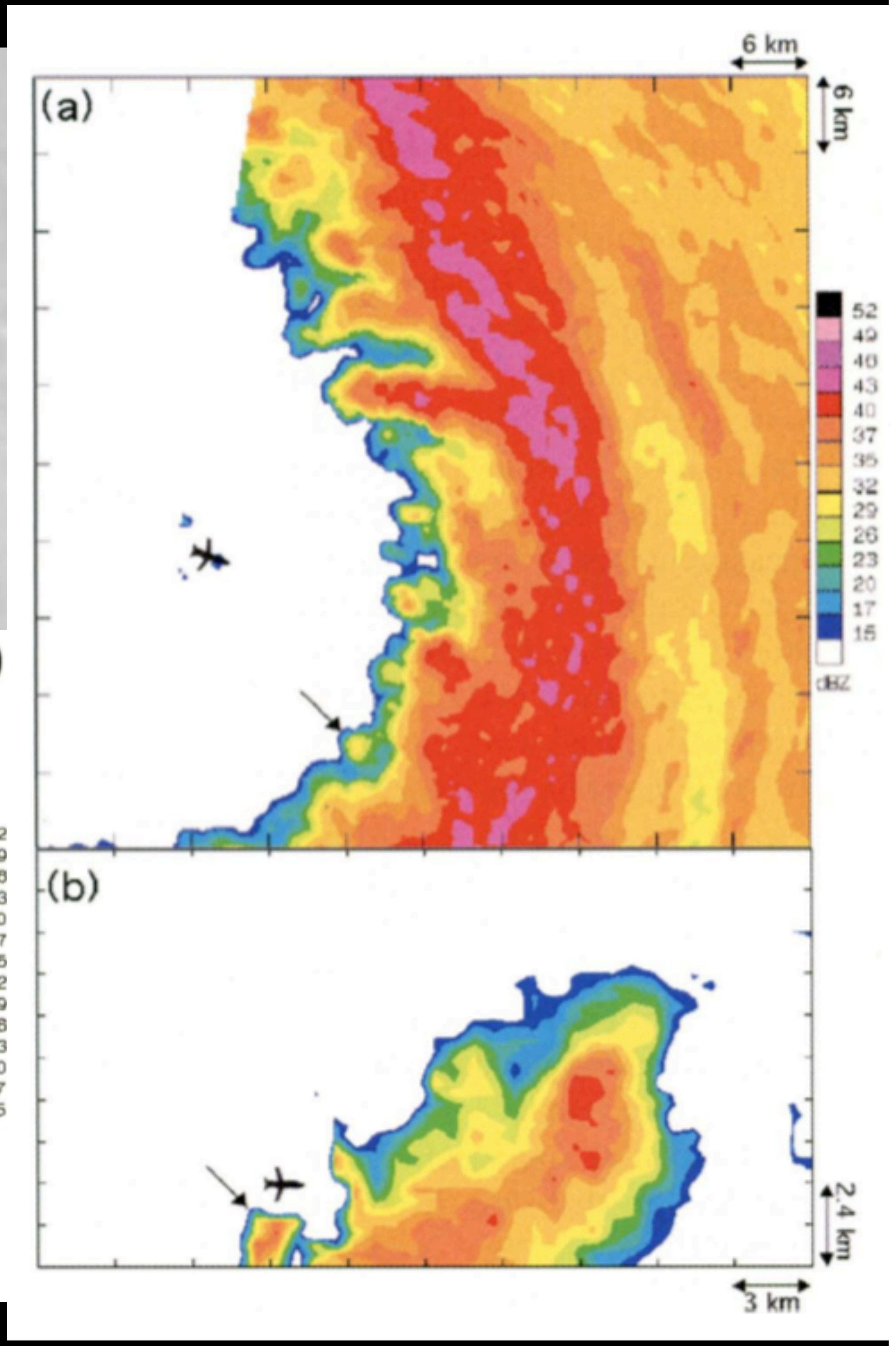
Meso-scale - having a horizontal scale of a few to several hundred km.

- Meso-alpha scale - 200-2000 km
- Meso-beta scale - 20 to 200 km
- Meso-gamma scale - 2 to 20 km

Miso-scale - having a horizontal scale of 40 m to 4 km.







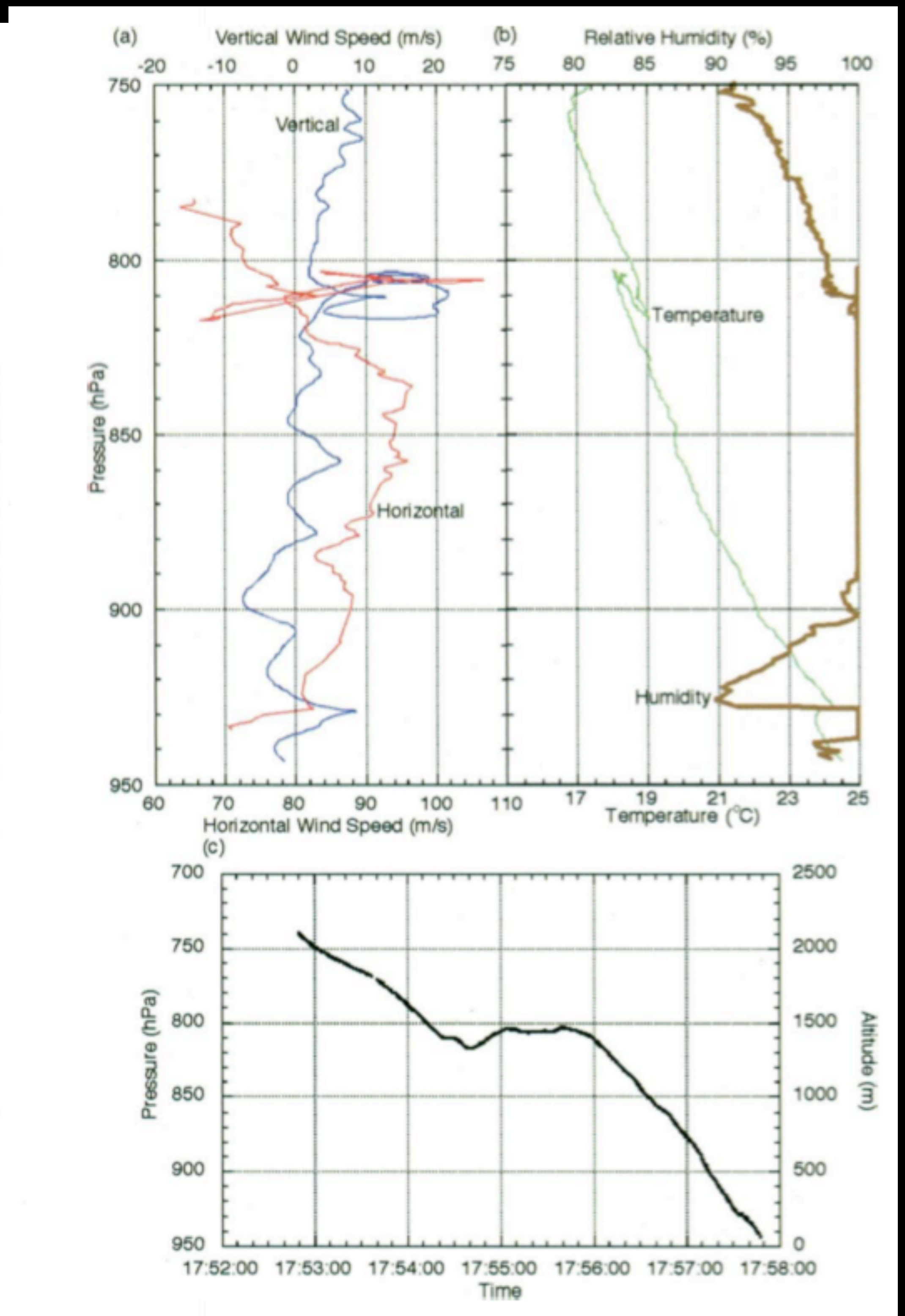


FIG. 1. Data obtained by the dropwindsonde released inside the inner edge of the eyewall of Hurricane Isabel at 1752 UTC 13 Sep 2003: (a) horizontal and vertical wind speeds as a function of pressure, (b) temperature and relative humidity as a function of pressure, and (c) altitude and pressure as a function of time.

http://glossary.ametsoc.org/

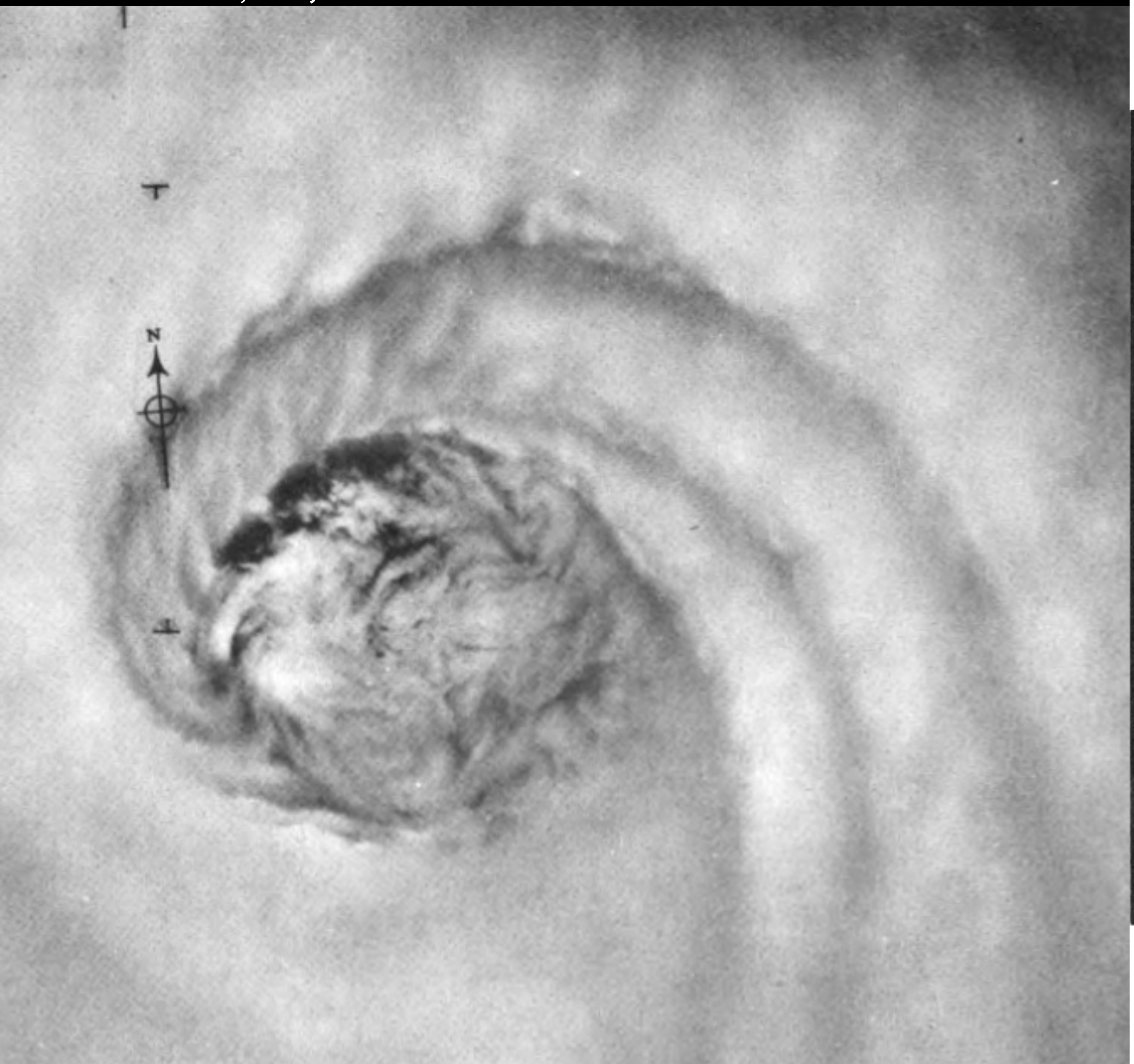
Orlanski, I., 1975: A rational subdivision of scales for atmospheric processes". *Bull. Amer. Met. Soc.*. 56, 527–530.

Fujita, T. T., 1981: Tornadoes and downbursts in the context of generalized planetary scales. *J. Atmos. Sci.*, 38, 1511–1534.

? (What to call them?)

Vortex: a flow with closed streamlines.
Cyclone: a cyclonic circulation, a closed circulation.
Low: an area of low pressure

Typhoon Ida (1958): First photographic evidence of small-scale features in the eye and eyewall.
Fletcher, R. D., J. R. Smith, and R. C. Bundgaard, 1961: Superior photographic reconnaissance of tropical cyclones. *Weatherwise,* **14,** 102-109.



Numerous intense hurricanes exhibit polygonal eyewalls, like Hurricane Betsy (1965), attributed to horizontally propagating internal gravity waves.

Polygonal Eye Walls and Rainbands in Hurricanes

B. M. Lewis[1] and H. F. Hawkins
National Hurricane Research Laboratory/NOAA
Gables One Tower
1320 S. Dixie Highway
Coral Gables, Fla. 33146

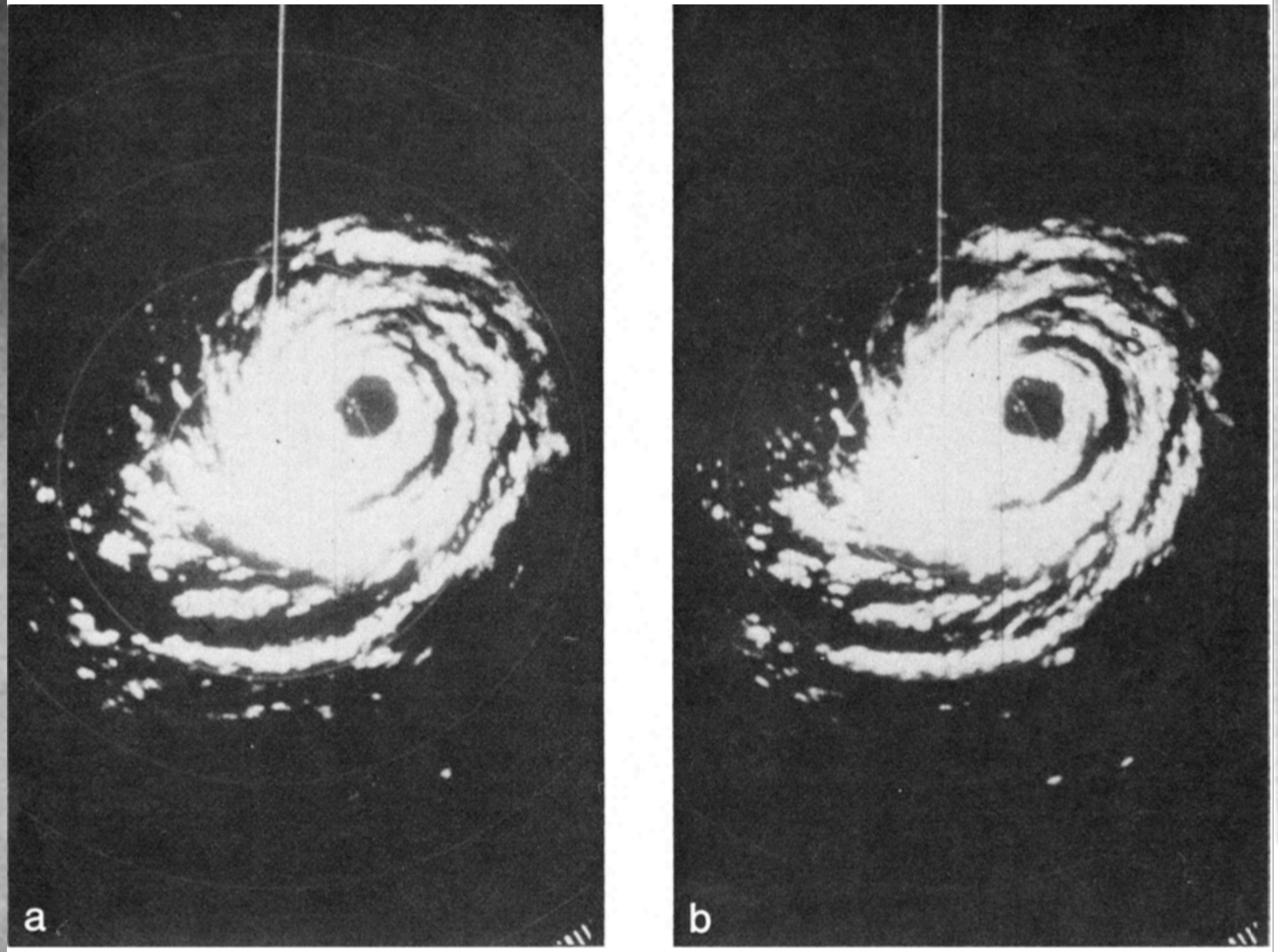


FIG. 1. Two examples of polygonal features observed by the Key West, Fla., WSR-57 radar in Hurricane Betsy: a) hexagonal eye at 0748 GMT on 8 September 1965 and b) square eye at 0803. In both cases, straight-sided bands are evident in the east side of the field of bands. (The polygonal aspect is enhanced for most viewers if the illustrations are rotated 90 degrees clockwise.)

Numerous intense hurricanes exhibit polygonal eyewalls, like Typhoon 8019, attributed to horizontally propagating internal gravity waves.

The Structure of Polygonal Eye of a Typhoon*

By Teruo Muramatsu

Japan Meteorological Agency, Forecast Division
(Manuscript received 10 June 1986, in revised form 8 October 1986)

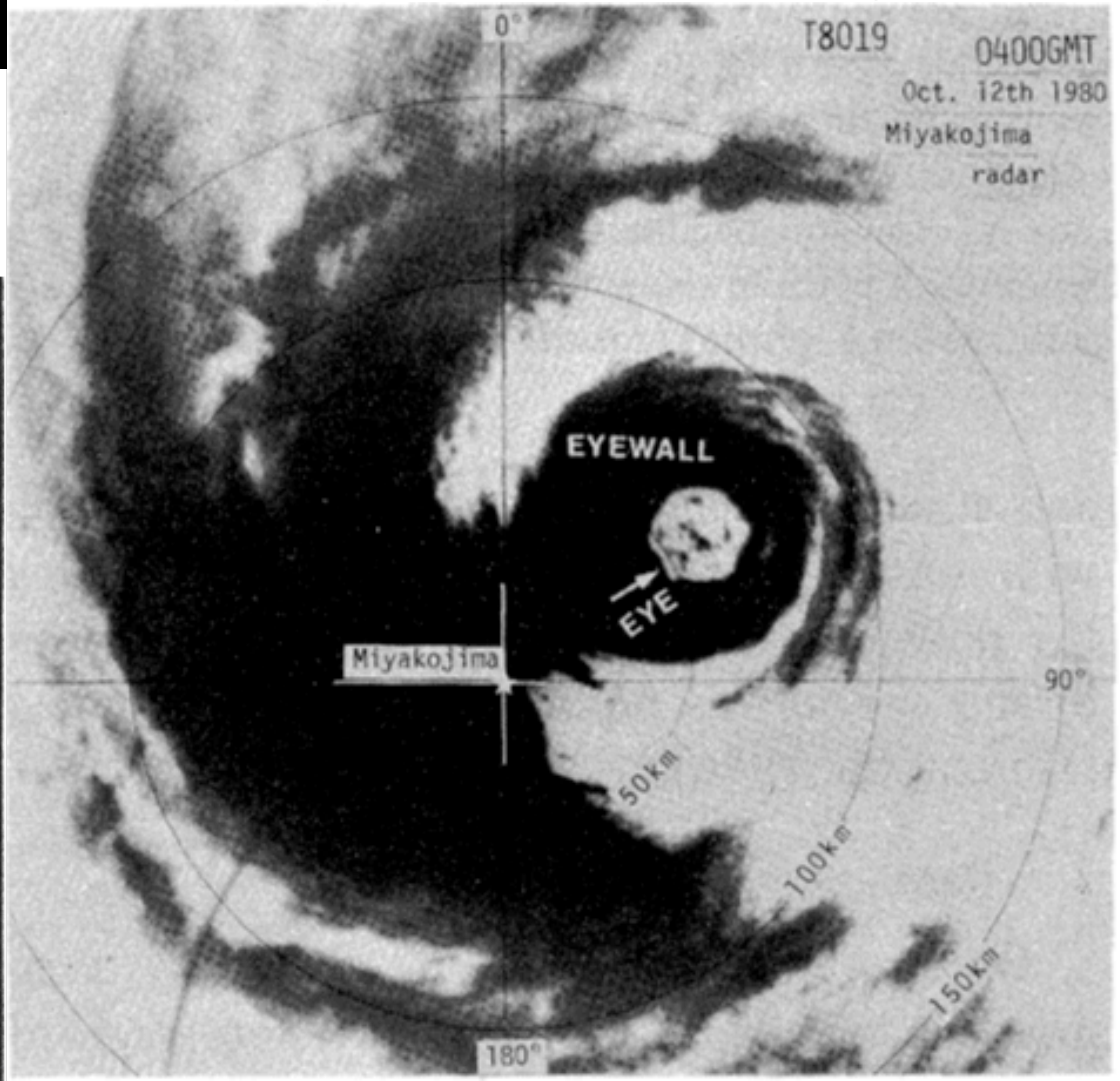


Fig. 2. Polygonal (hexagonal) eye of the typhoon 8019 on the PPI (plain position indicator), original (no-attenuation), at 0400 GMT October 12, 1980, by Miyakojima radar.

Hurricane Debby (1982): Doppler radar analysis shows small-scale circulation in developing eyewall of weak hurricane.

Airborne Doppler Radar Observations in Hurricane Debby

Frank D. Marks, Jr.[1] and Robert A. Houze, Jr.[2]

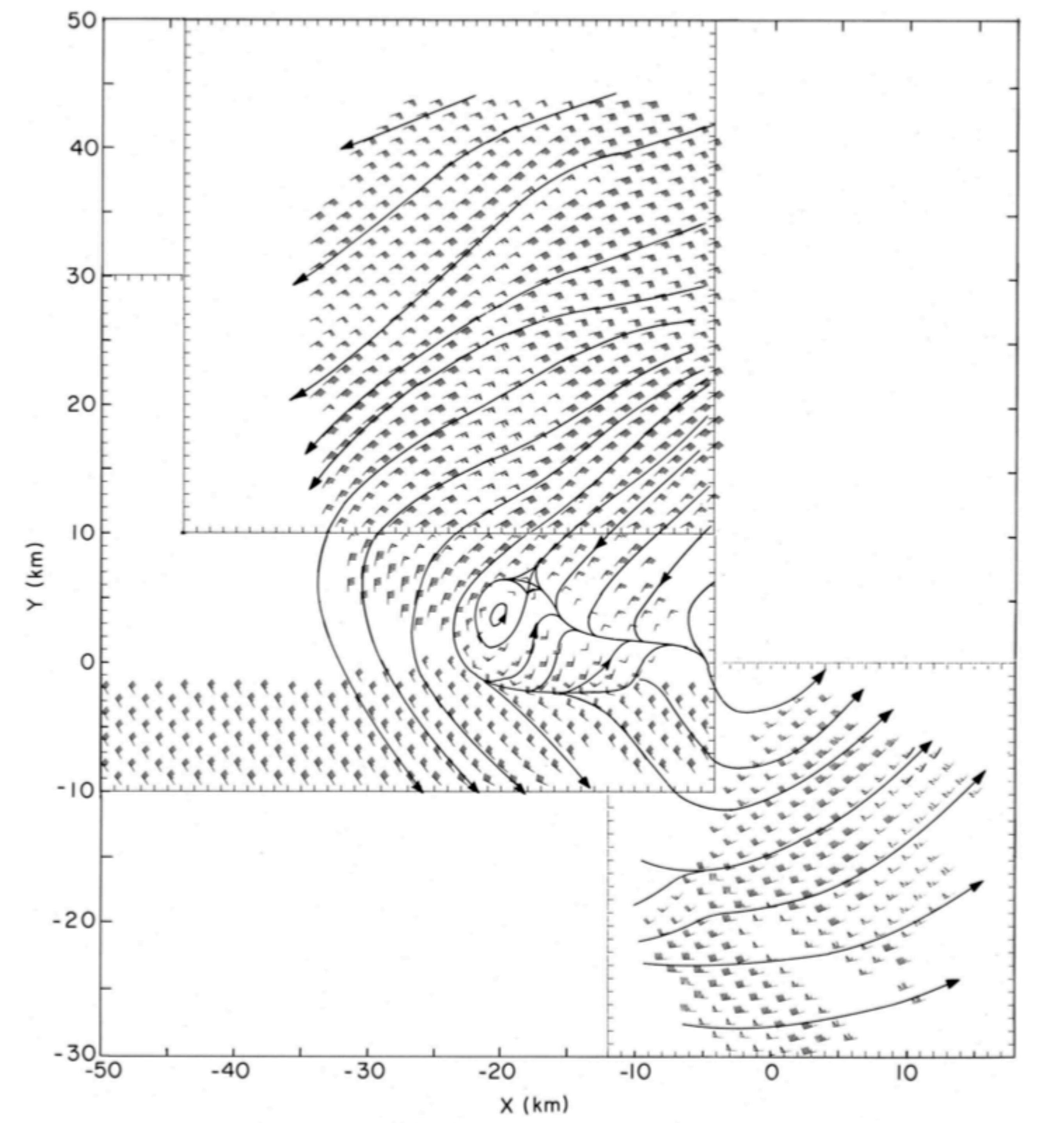


Fig. 7. Analysis of Doppler-derived winds at the 2.5 km level. The field is a mosaic of the wind patterns in Boxes 1, 3, and 4. Plotting convention same as in Fig. 2.

Small-scale features seen in eyes of intense tropical cyclones. Study “assumes that the cloud lines are approximately parallel to local streamlines.

Vortical Swirls in Hurricane Eye Clouds

JAMES P. KOSSIN

Cooperative Institute for Meteorological Satellite Studies, University of Wisconsin—Madison, Madison, Wisconsin

BRIAN D. MCNOLDY AND WAYNE H. SCHUBERT

Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado

11 April 2002 and 14 June 2002

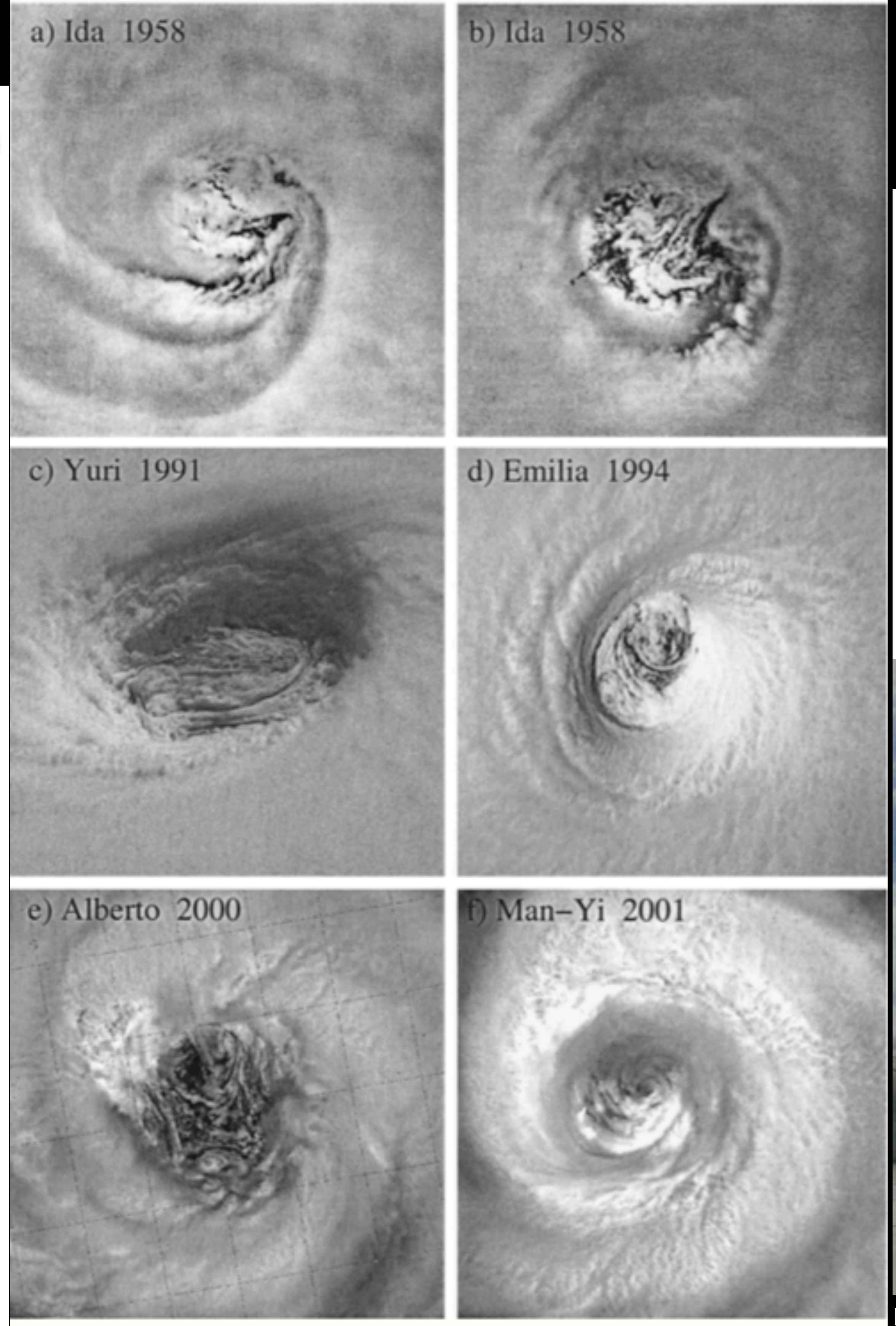


FIG. 2. Montage of images showing a variety of swirling patterns in hurricane eye clouds: (a),(b) high-altitude U-2 aircraft photographic reconnaissance (from Fletcher et al. 1961), (c),(d) photographs taken from the space shuttle, and (e)–(i) MODIS images.

Photograph of a wavenumber-2 pattern in Hurricane Erin (2011), but there was no evidence of vortices in the wind field.

NOTES AND CORRESPONDENCE

A Photograph of a Wavenumber-2 Asymmetry in the Eye of Hurricane Erin

SIM D. ABERSON

NOAA/AOML/Hurricane Research Division, Miami, Florida

JASON P. DUNION

CIMAS, University of Miami, Miami, Florida

FRANK D. MARKS JR.

NOAA/AOML/Hurricane Research Division, Miami, Florida

(Manuscript received 11 November 2003, in final form 1 October 2004)

Photograph taken by the lead author from the right window of the NOAA WP-3D aircraft while circling inside the eye of Hurricane Erin at a flight level of about 4500 m at 1822 UTC 10 Sep 2001.

Buoyancy of Convective Vertical Motions in the Inner Core of Intense Hurricanes. Part II: Case Studies

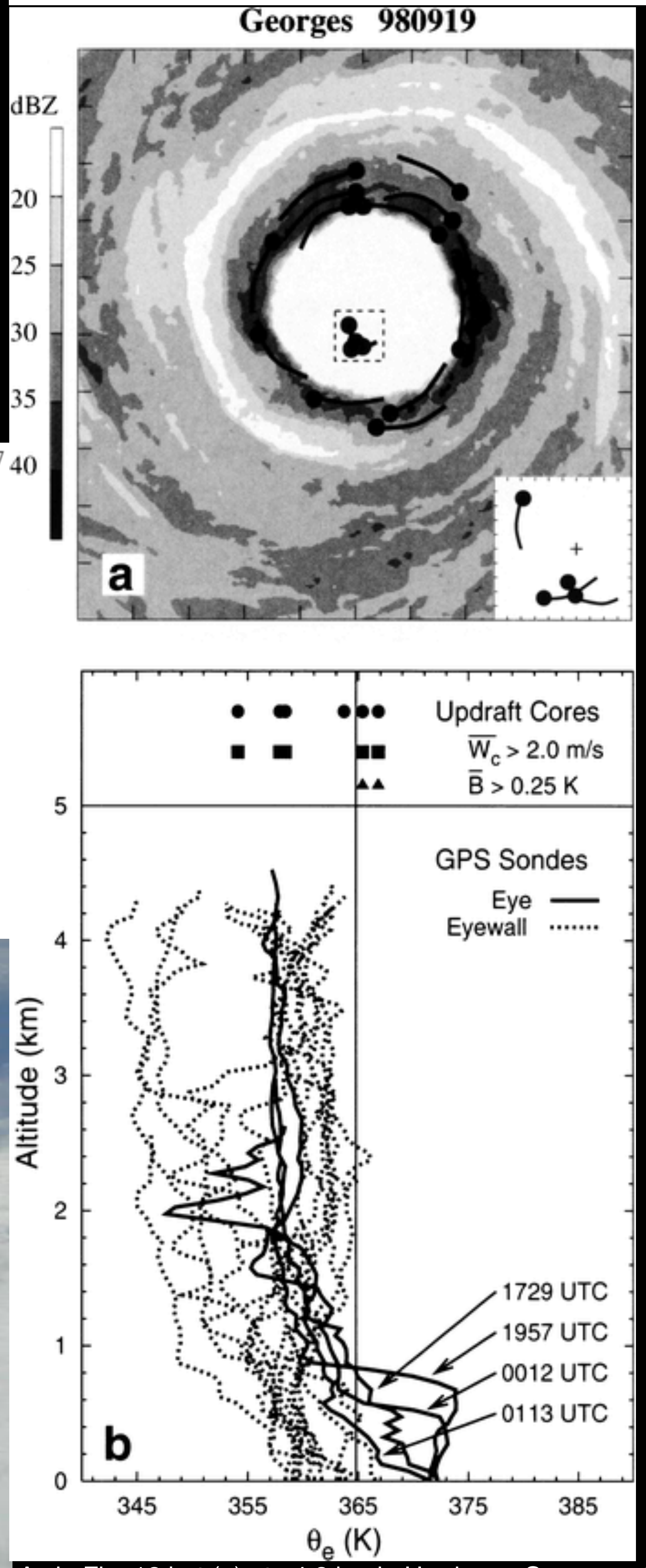
MATTHEW D. EASTIN AND WILLIAM M. GRAY

Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado

PETER G. BLACK

Hurricane Research Division, NOAA/AOML, Miami, Florida

(Manuscript received 19 December 2003, in final form 19 July 2004)



As in Fig. 12 but (a) at ~4.2 km in Hurricane Georges at 0041 UTC on 20 Sep 1998, and (b) for GPS sondes deployed in Hurricane Georges between 1900 UTC on 19 Sep and 0100 UTC on 20 Sep. Core average equivalent potential temperature θ_e values are only shown for eyewall updraft cores encountered at ~4.2-km altitude by the second aircraft between 2300 and 0100 UTC.

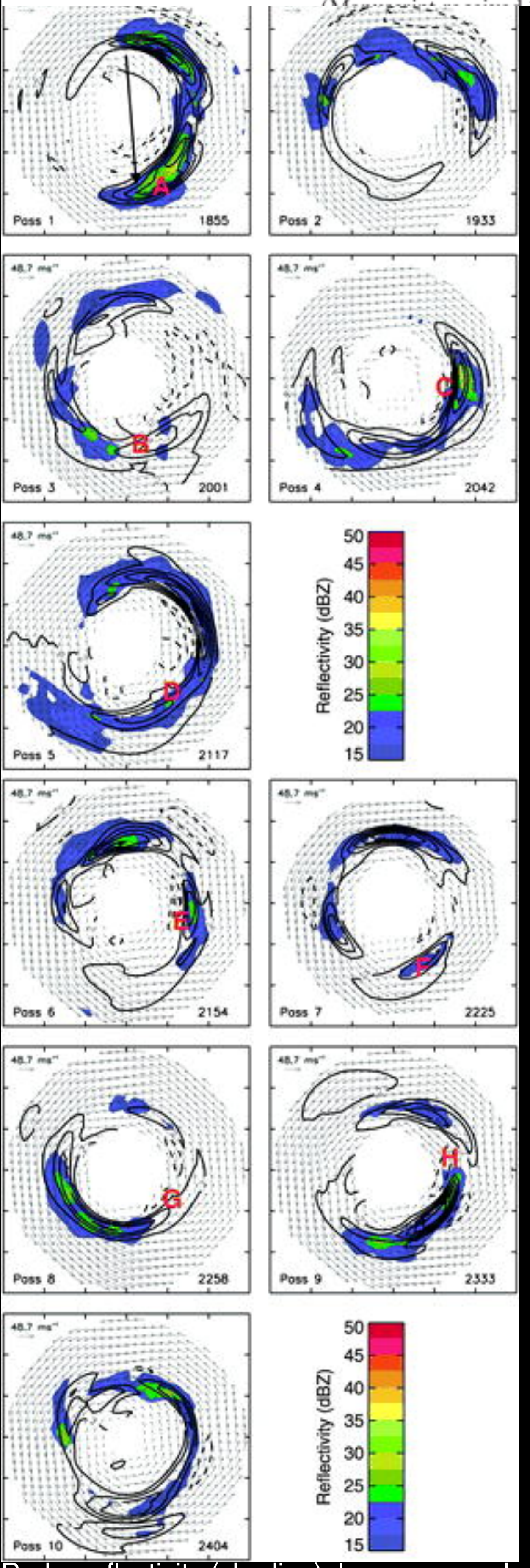
Study suggests that mesovortices may have been responsible for the outward advection of high-θ_e air into the eyewall. However, no mesovortices are seen in the data.

Rapidly Intensifying Hurricane Guillermo (1997). Part I: Low-Wavenumber Structure and Evolution

PAUL D. REASOR
Department of Meteorology, The Florida State University, Tallahassee, Florida

MATTHEW D. EASTIN
Department of Geography and Earth Sciences, University of North Carolina at Charlotte, Charlotte, North Carolina

JOHN F. GAMACHE
Hurricane Research Division, Atlantic Oceanographic and Meteorological Laboratory, NOAA, Miami, Florida



A look at the low-wavenumber structure of Hurricane Guillermo. Mesovortices are mentioned in the paper in relation to past studies, but not in relation to Guillermo. Wind-field figures too small to find circulations.

Radar reflectivity (shading), low-wavenumber (n = 0–4) vertical velocity (contours), and low-wavenumber horizontal winds (vectors) in the 9–11-km layer: pass 1–10. Only the highest values of reflectivity (>15 dBZ) have been shaded for clarity. The vertical velocity contour interval is 2 m s⁻¹. Negative values are indicated by the dashed contours. The domain is 120 km on a side with tick marks every 20 km. Regions with substantial wind coverage gaps are omitted from the analysis. Locations of convective clusters–bursts discussed in the text are labeled A–H.

Pattern resembles mesovortices, but they did not look at the Doppler data to confirm circulations.

PICTURE OF THE MONTH

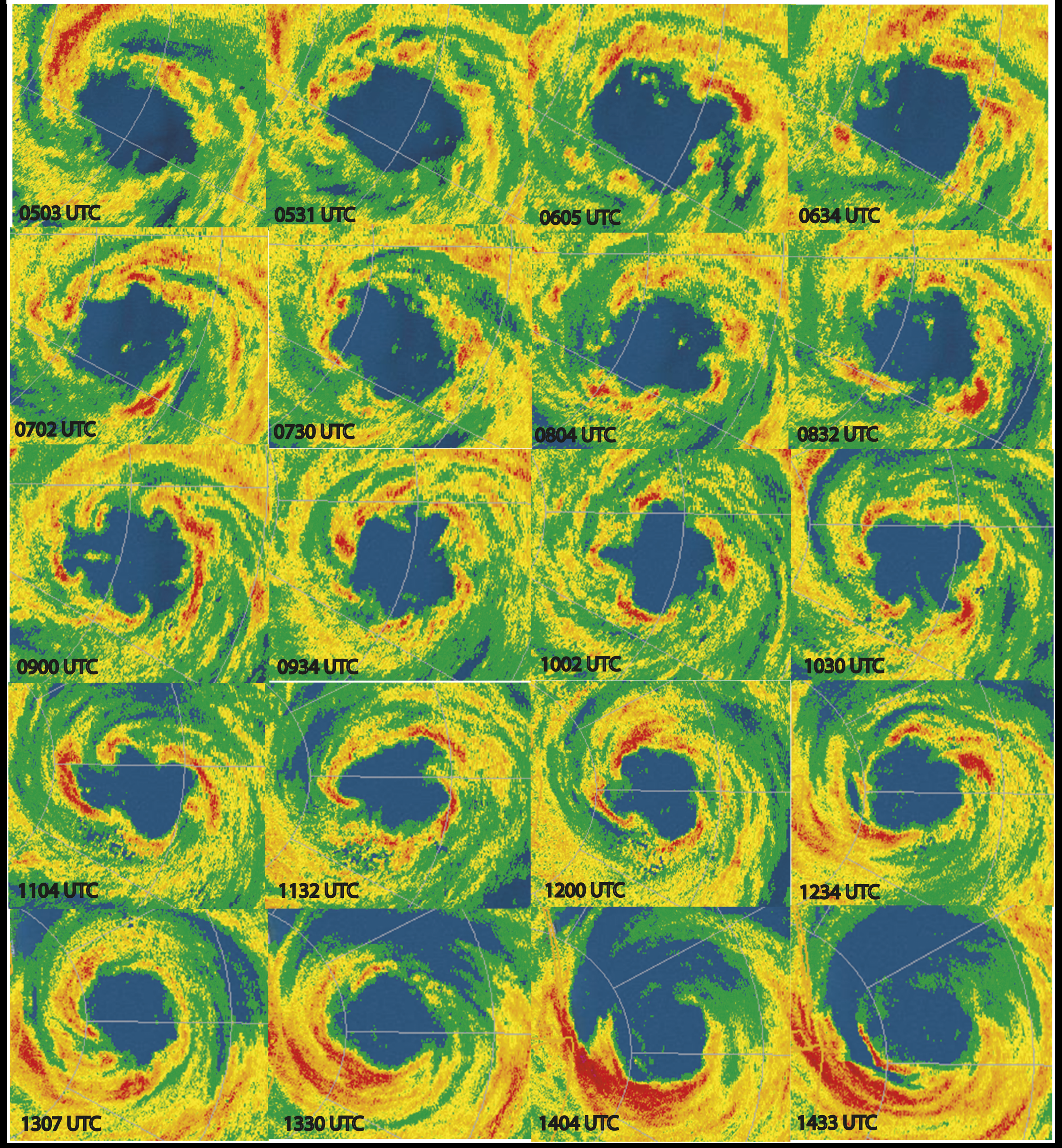
Observed Inner-Core Structural Variability in Hurricane Dolly (2008)*

ERIC A. HENDRICKS
Marine Meteorology Division, Naval Research Laboratory, Monterey, California

BRIAN D. MCNOLDY
Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, Florida

WAYNE H. SCHUBERT
Colorado State University, Fort Collins, Colorado

(Manuscript received 17 January 2012, in final form 22 June 2012)



Detailed temporal evolution of the eyewall of Hurricane Dolly. The first panel is at 0503 UTC 23 Jul, and each subsequent panel is approximately 30 min after the previous panel. Panels increase in time in the horizontal. The last panel is at 1433 UTC 23 Jul. The approximate diameter of the eyewall is 45–50 km.

Study describes mesovortices, but no closed circulations are found.

Estimation of the Tangential Winds and Asymmetric Structures in Typhoon Inner Core Region Using Himawari-8

Taiga Tsukada[1] and Takeshi Horinouchi[1,2]

[1]Graduate School of Environmental Science, Hokkaido University, Sapporo, Japan, [2]Faculty of Environmental Earth Science, Hokkaido University, Sapporo, Japan

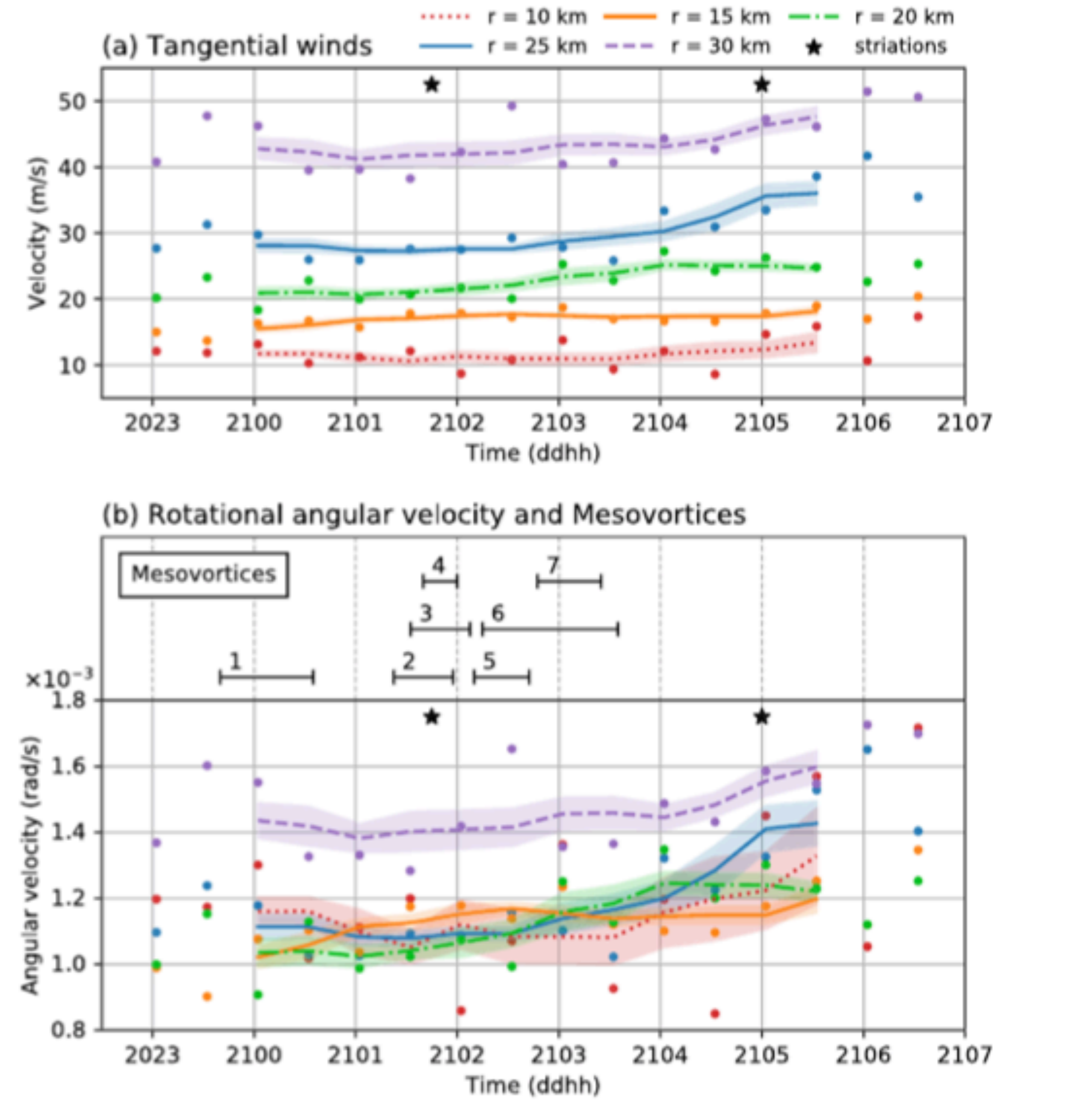


Figure 4. (a) Time variation of tangential winds and (b) rotational angular velocities at the radii of 10 (red), 15 (orange), 20 (green), 25 (blue), and 30 km (purple), respectively. Dots indicate the v_E every 30 min, while the solid curves show the running means with time over the five samples of v_E. The shading indicates ± the standard error computed from the variance among the five samples of v_E. Stars indicate the manually derived (angular) velocities of the cloud striations alongside the eyewall. The black lines at the top of (b) show the durations when the seven mesovortices were observed.

Small- (miso?-) scale features

Sloping striations seen on the inner edge of the eyewall in Hurricane Diana (1984).

2542 MONTHLY WEATHER REVIEW VOLUME 115

NOTES AND CORRESPONDENCE

On the Structure of the Eyewall of Hurricane Diana (1984): Comparison of Radar and Visual Characteristics

HOWARD B. BLUESTEIN
School of Meteorology, University of Oklahoma, Norman, OK 73019

FRANK D. MARKS, JR.
Hurricane Research Division, NOAA/AOML, Miami, FL 33149

18 December 1986 and 1 April 1987

FIG. 3. Photograph of the inside edge of the eyewall of Hurricane Diana at 1708 UTC 11 September 1984. The view is of the northeast side of the eye through a 28 mm lens (photograph by Howard B. Bluestein).

Kelvin-Helmholtz instability on the inner edge of the eyewall in Hurricane Erin (2001).

1036 MONTHLY WEATHER REVIEW VOLUME 134

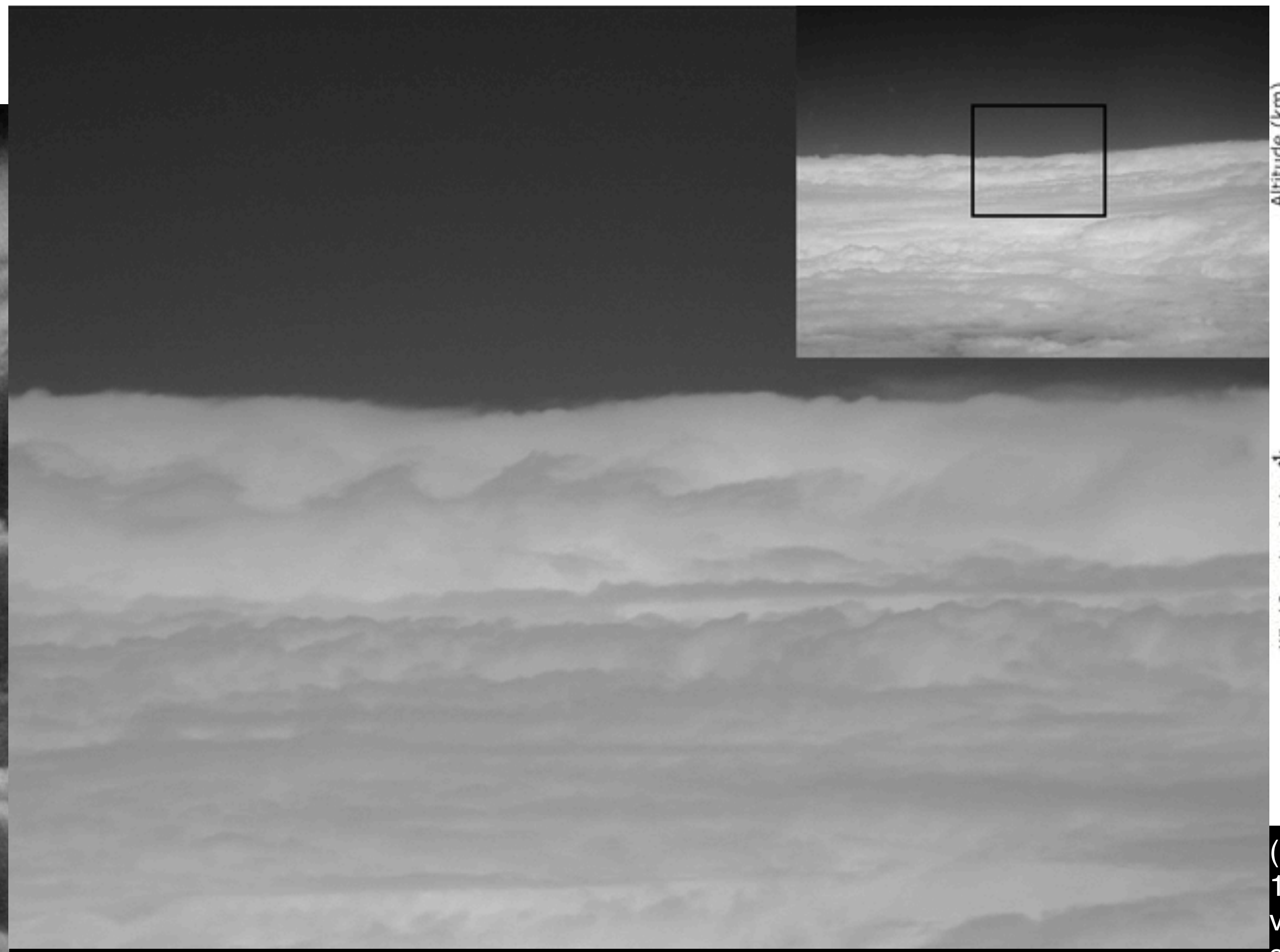
PICTURE OF THE MONTH

Kelvin–Helmholtz Billows in the Eyewall of Hurricane Erin

SIM D. ABERSON
NOAA/AOML/Hurricane Research Division, Miami, Florida

JEFFREY B. HALVERSON
Joint Center for Earth Systems Technology, NASA Goddard Space Flight Center, Greenbelt, Maryland

(Manuscript received 12 April 2005, in final form 27 July 2005)



Photograph of the eyewall of Hurricane Erin with Kelvin–Helmholtz waves at approximately 1815 UTC 10 Sep 2001. The image was taken from the NOAA P3 aircraft from an altitude of approximately 4500 m. The inset shows the entire photograph, with the approximate region of the close-up marked by the rectangle.

Distinct eyewall vorticity maximum identified with a scale of ~6 km. Wavenumber-1 wind-speed and pressure minima are found and tracked around the eye, though it is not a closed circulation. They are described as either roll vortices or vortex tubes.

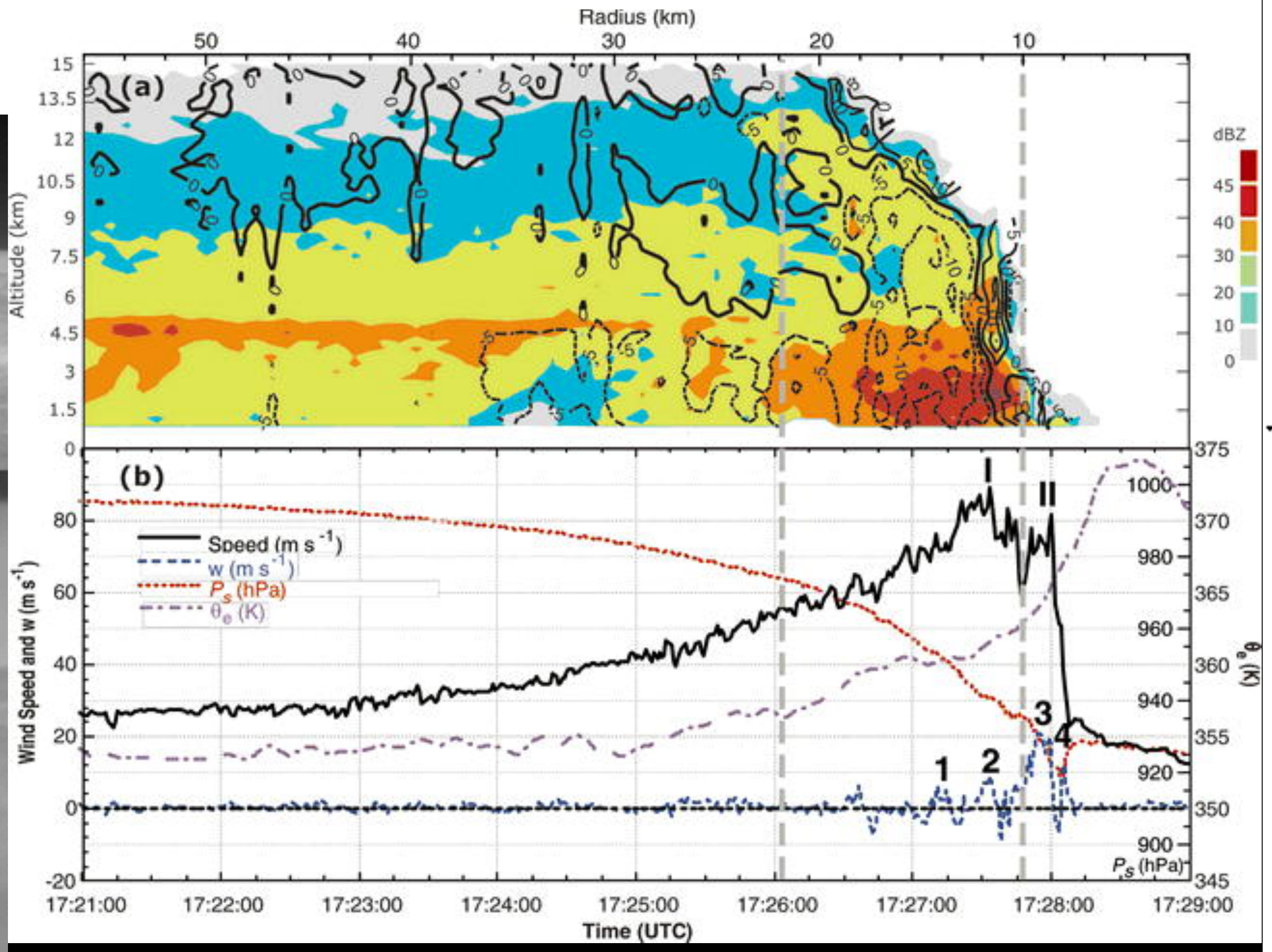
VOLUME 136 MONTHLY WEATHER REVIEW APRIL 2008

Structure of the Eye and Eyewall of Hurricane Hugo (1989)

FRANK D. MARKS AND PETER G. BLACK
Hurricane Research Division, NOAA/AOML, Miami, Florida

MICHAEL T. MONTGOMERY
Naval Postgraduate School, Monterey, California

ROBERT W. BURPEE*
Cooperative Institute for Marine and Atmospheric Studies, University of Miami, Miami, Florida



(a) Time–height cross section of vertical incidence tail radar reflectivity (dBZ) from LA for 1721–1728 UTC. The LA flight track was at 450 m. Solid and dashed lines denote vertical velocity, and radar reflectivity is denoted by colors using the color scale on the right. (b) Time series plots of w, horizontal wind speed, P_s, and θ_e for the period 1721–1730 UTC. Updrafts labeled 1, 2, 3, and 4 and wind speed peaks I and II are described in the text. The thick dashed lines in (b) approximately delineate the outer and inner radii of strong eyewall reflectivity maxima in the lower troposphere (1 < z < 5-km altitude).

Event similar to Hugo in Hurricane Felix

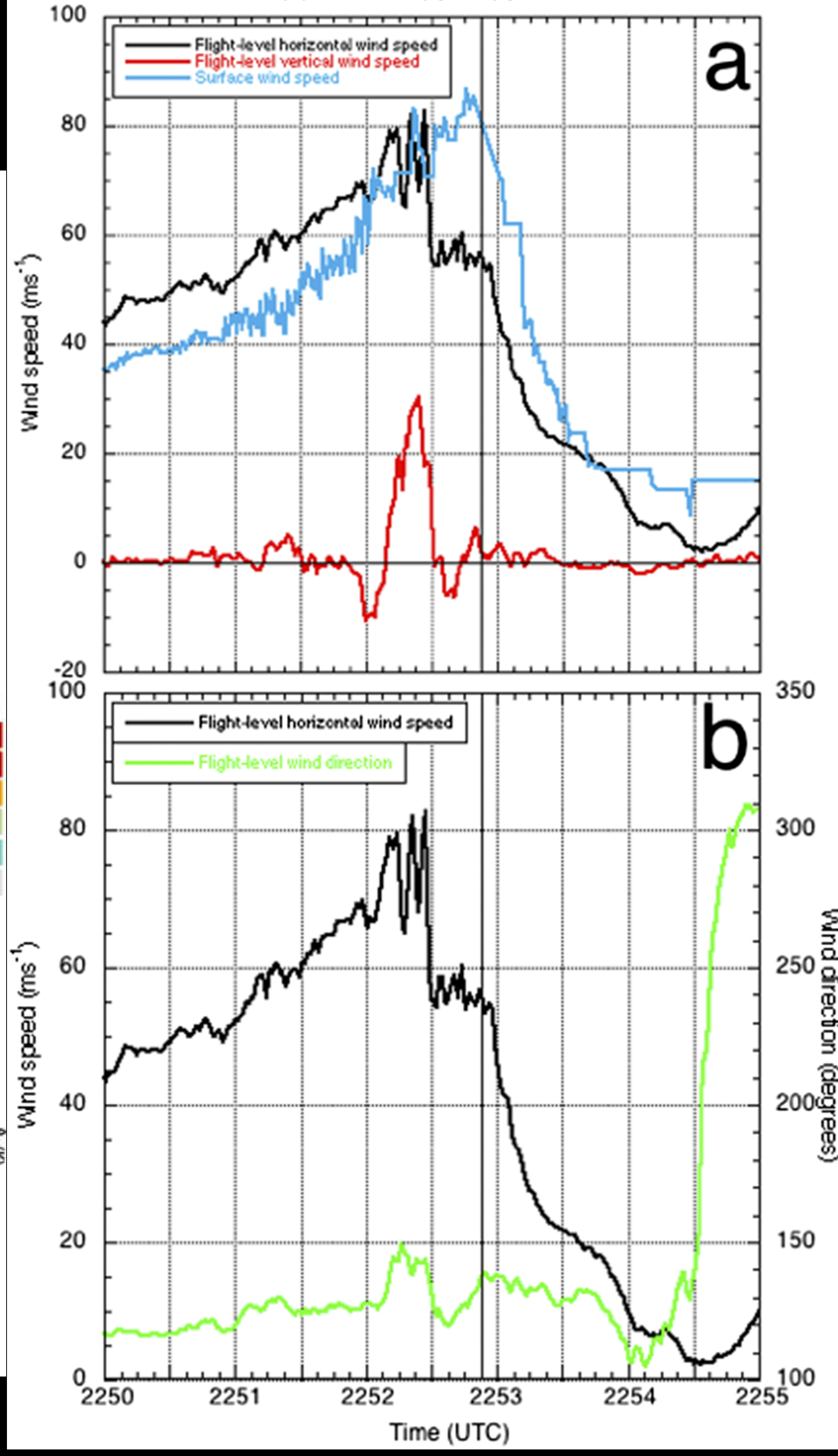
JUNE 2017 ABERSON ET AL. 2083

An Extreme Event in the Eyewall of Hurricane Felix on 2 September 2007

SIM D. ABERSON
NOAA/Atlantic Oceanographic and Meteorological Laboratory/Hurricane Research Division, Miami, Florida

JUN A. ZHANG
University of Miami/Cooperative Institute for Marine and Atmospheric Studies, and NOAA/Atlantic Oceanographic and Meteorological Laboratory/Hurricane Research Division, Miami, Florida

KELLY NUÑEZ OCASIO[a]
University of Puerto Rico at Mayagüez, Mayagüez, Puerto Rico



Flight-level and surface wind data during the inbound leg into Hurricane Felix: (a) flight-level horizontal wind speed, vertical wind velocity, and surface wind speed; and (b) flight-level horizontal wind speed and direction. The black vertical line corresponds to the time of the release of a dropwindsonde.

Model experiments show breakdown of the vortex on the inner edge of the eyewall, and closed wind centers (zero tangential wind). Wind and pressure centers are not in the same locations.

Rapid Filamentation Zones in Intense Tropical Cyclones

CHRISTOPHER M. ROZOFF, WAYNE H. SCHUBERT, AND BRIAN D. MCNOLDY
Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado

JAMES P. KOSSIN
Cooperative Institute for Meteorological Satellite Studies, University of Wisconsin—Madison, Madison, Wisconsin

(Manuscript received 11 November 2003, in final form 12 August 2004)

Polygonal Eyewalls, Asymmetric Eye Contraction, and Potential Vorticity Mixing in Hurricanes

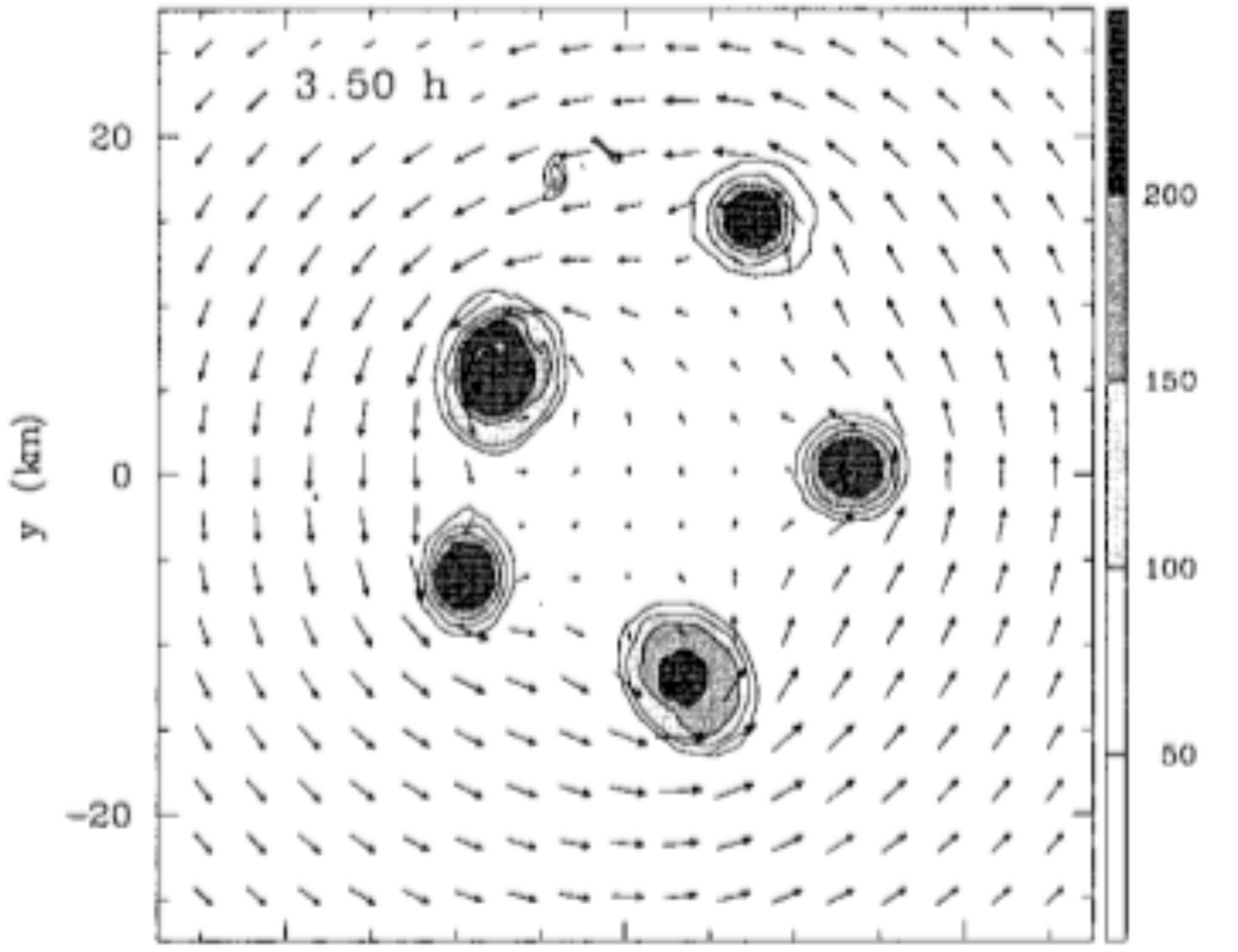
WAYNE H. SCHUBERT, MICHAEL T. MONTGOMERY, RICHARD K. TAFT, THOMAS A. GUINN,* SCOTT R. FULTON,+ JAMES P. KOSSIN, AND JAMES P. EDWARDS
Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado

Vortical Swirls in Hurricane Eye Clouds

JAMES P. KOSSIN
Cooperative Institute for Meteorological Satellite Studies, University of Wisconsin—Madison, Madison, Wisconsin

BRIAN D. MCNOLDY AND WAYNE H. SCHUBERT
Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado

11 April 2002 and 14 June 2002



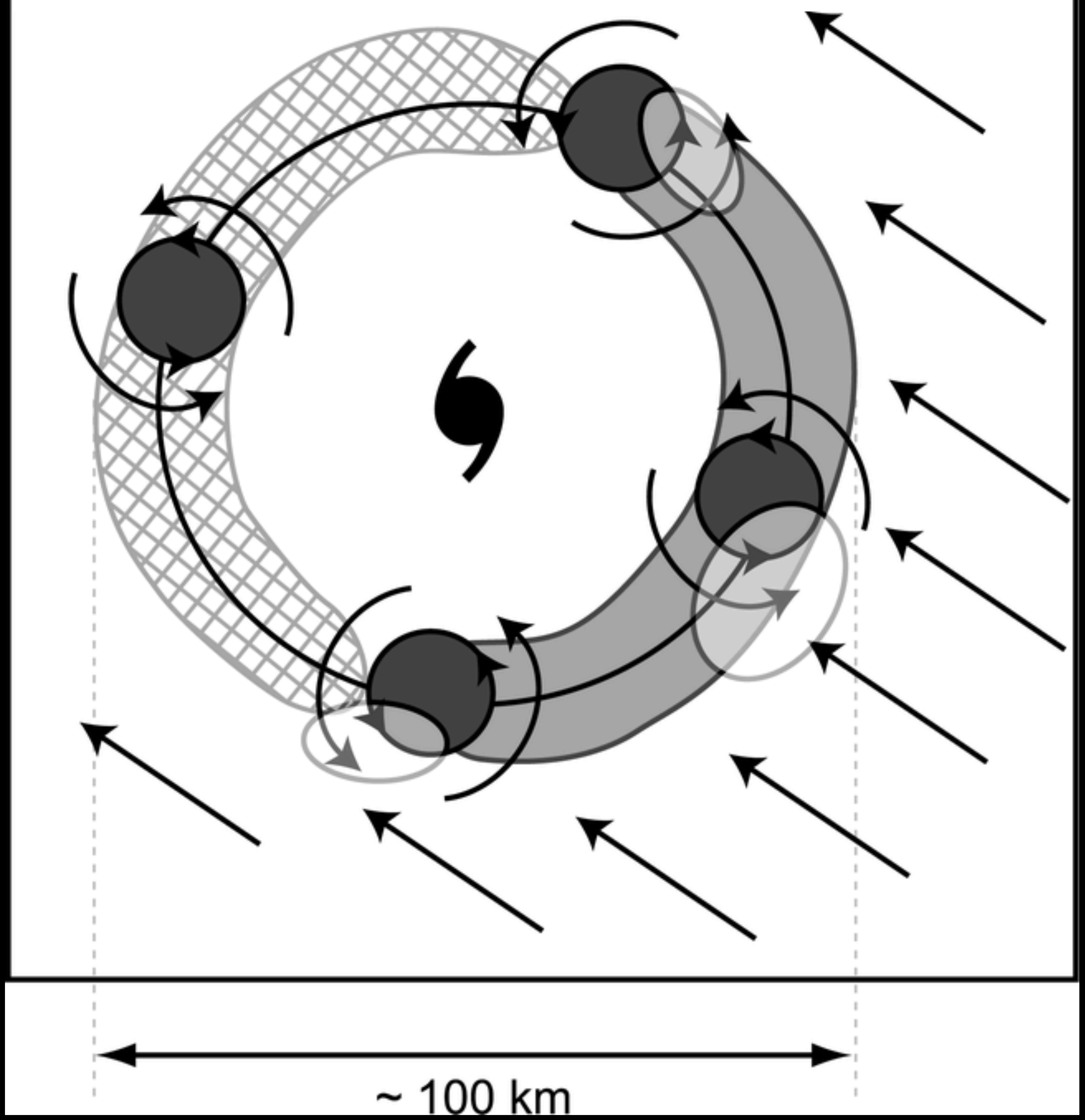
High-Resolution Simulation of Hurricane Bonnie (1998). Part I: The Organization of Eyewall Vertical Motion

SCOTT A. BRAUN
Mesoscale Atmospheric Processes Branch, Laboratory for Atmospheres, NASA Goddard Space Flight Center, Greenbelt, Maryland

MICHAEL T. MONTGOMERY
Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado

ZHAOXIA PU
Department of Meteorology, University of Utah, Salt Lake City, Utah

(Manuscript received 7 November 2003, in final form 8 October 2004)



Schematic diagram summarizing the interaction between eyewall mesovortices and the low-level inflow associated with the environmental wind shear. The elongated semicircular areas indicate where shear effects favor upward (light shading) and downward (cross hatching) motion. The relative flow associated with the environmental shear is indicated by the straight arrows, while the mesovortices and their local cyclonic circulations are indicated by darkly shaded circles and curved arrows. The semitransparent, lightly shaded ovals represent areas of enhanced low-level convergence and upward motion.

So:

Polygonal eyewalls are very common in intense tropical cyclones.

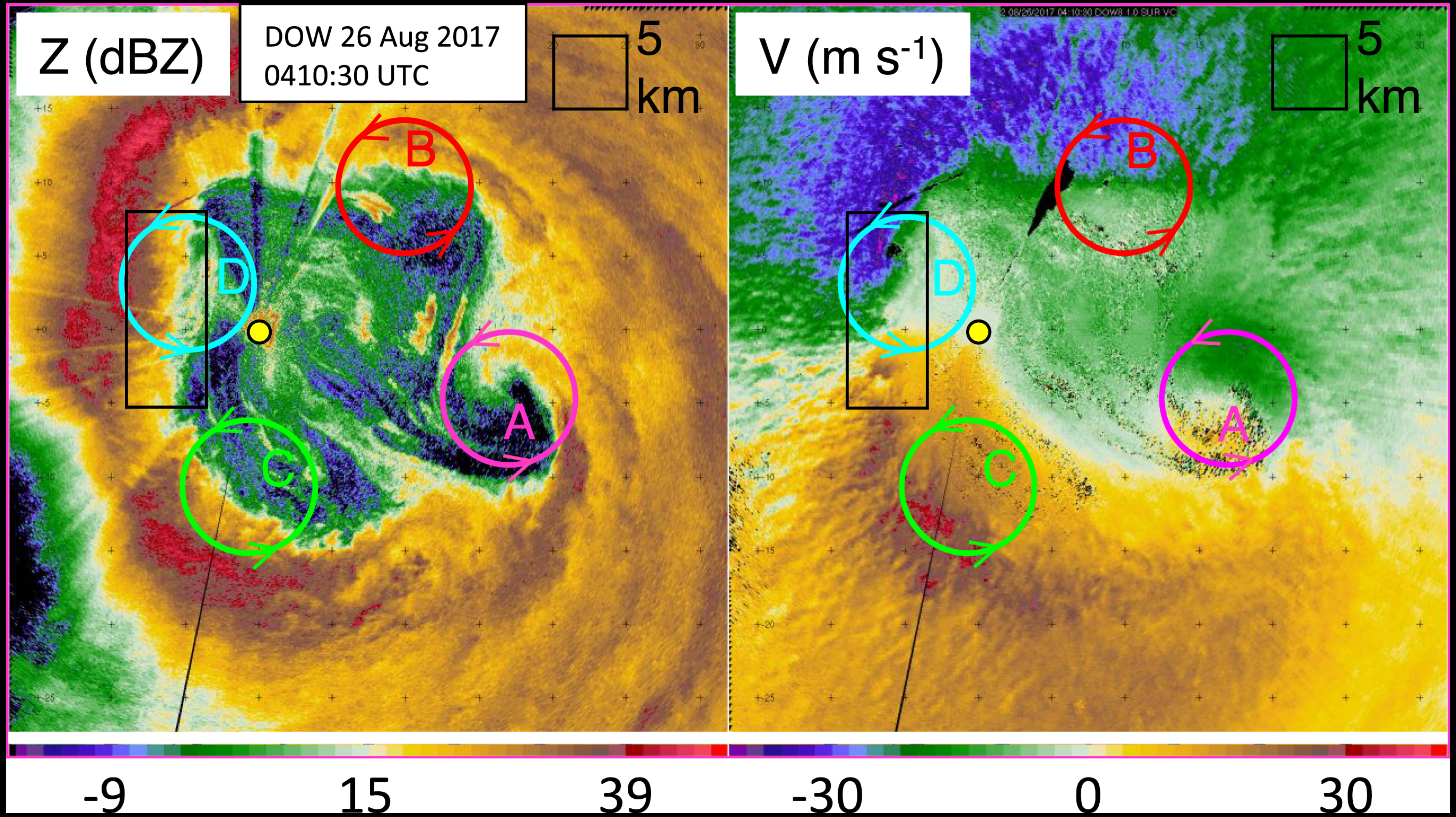
Low-level cloud lines and other patterns are common in intent tropical cyclones.

Polygonal eyewalls and low-level cloud liners are signatures of eyewall mesovortices.

Eyewall mesovortices play a role in bringing high-entropy air from the eye into the eyewall increasing buoyancy. Thus, they play a role in intensity change.

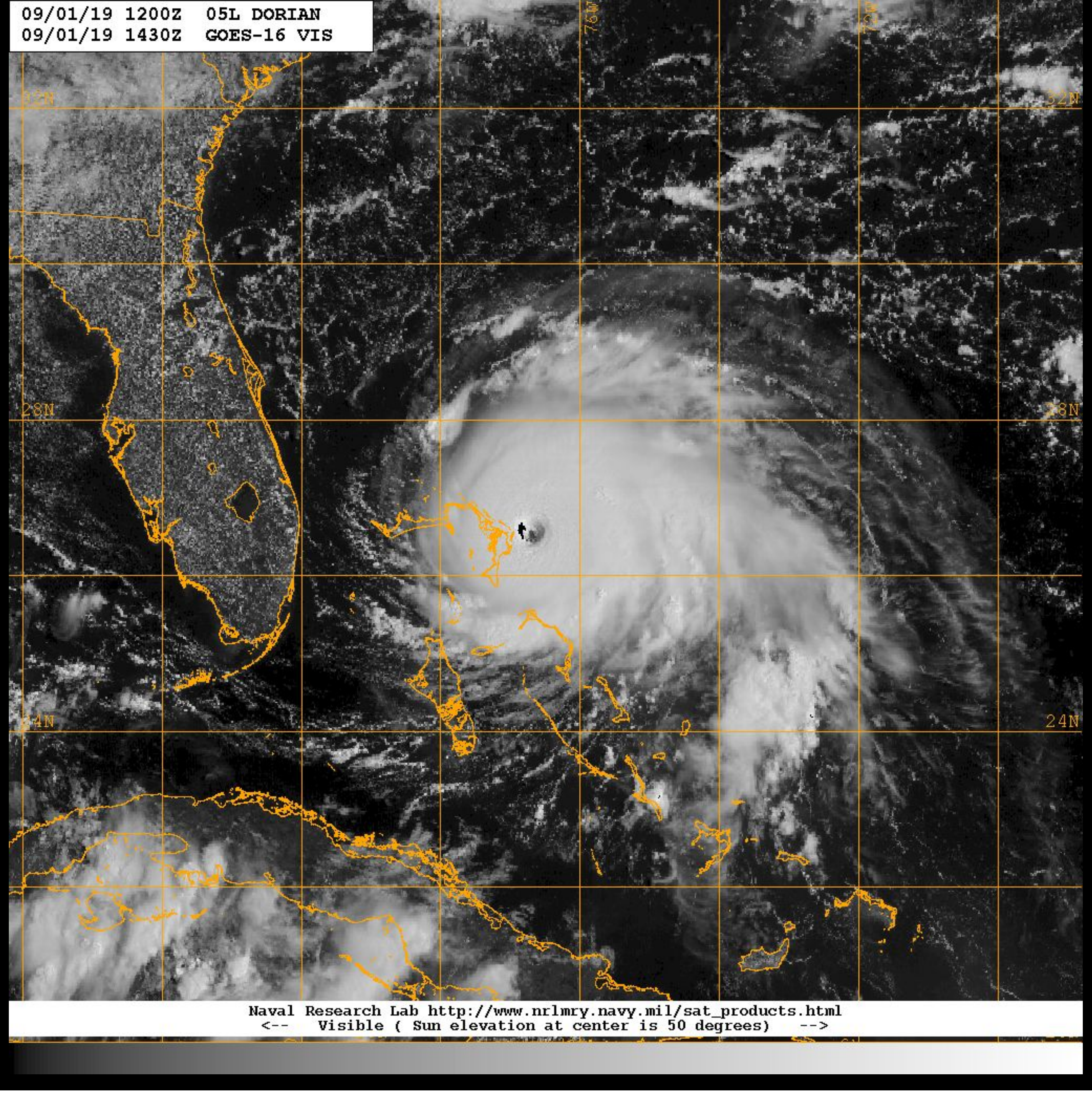
If this were all true, why don’t we see eyewall mesovortices when we cross the eyes of intense tropical cyclones in the P3?

“first direct evidence of MVs” and their role in enhancing surface winds



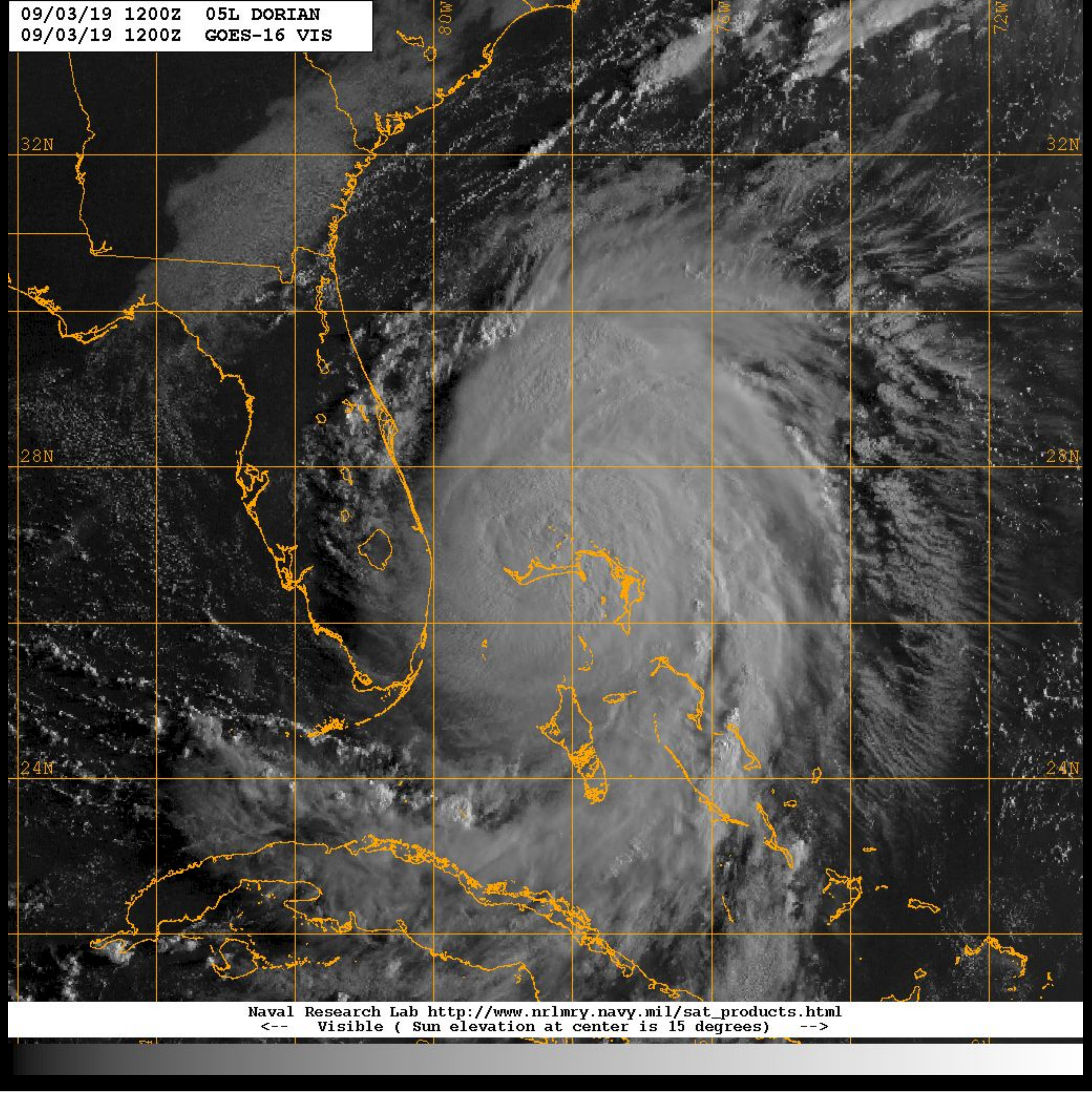
Finescale DOW radar imagery of hurricane eye and eyewall, including four MVs. (left) Radar reflectivity and (right) Doppler velocity measured from inside eye (DOW location indicated with yellow dot) at 0410:30 UTC 26 Aug 2017. Four MVs revolving about the eye are highlighted schematically with colored circles. Black rectangle is zoomed-in area shown in Fig. 6.

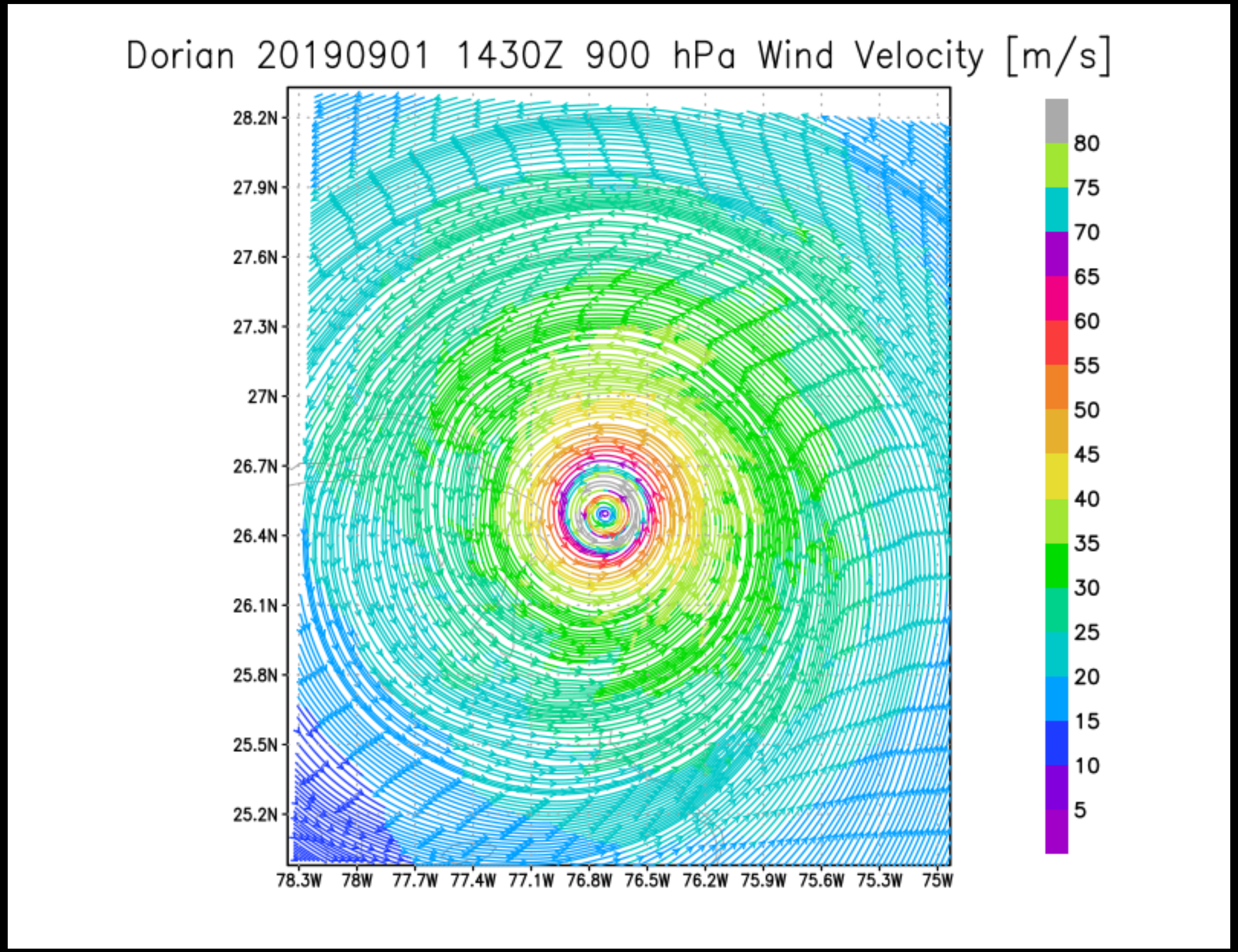
Wurman, J., and K. Kosiba, 2018: The Role of Small-Scale Vortices in Enhancing Surface Winds and Damage in Hurricane Harvey (2017). *Mon. Wea. Rev.*, 146, 713–722, https://doi.org/10.1175/MWR-D-17-0327.1.



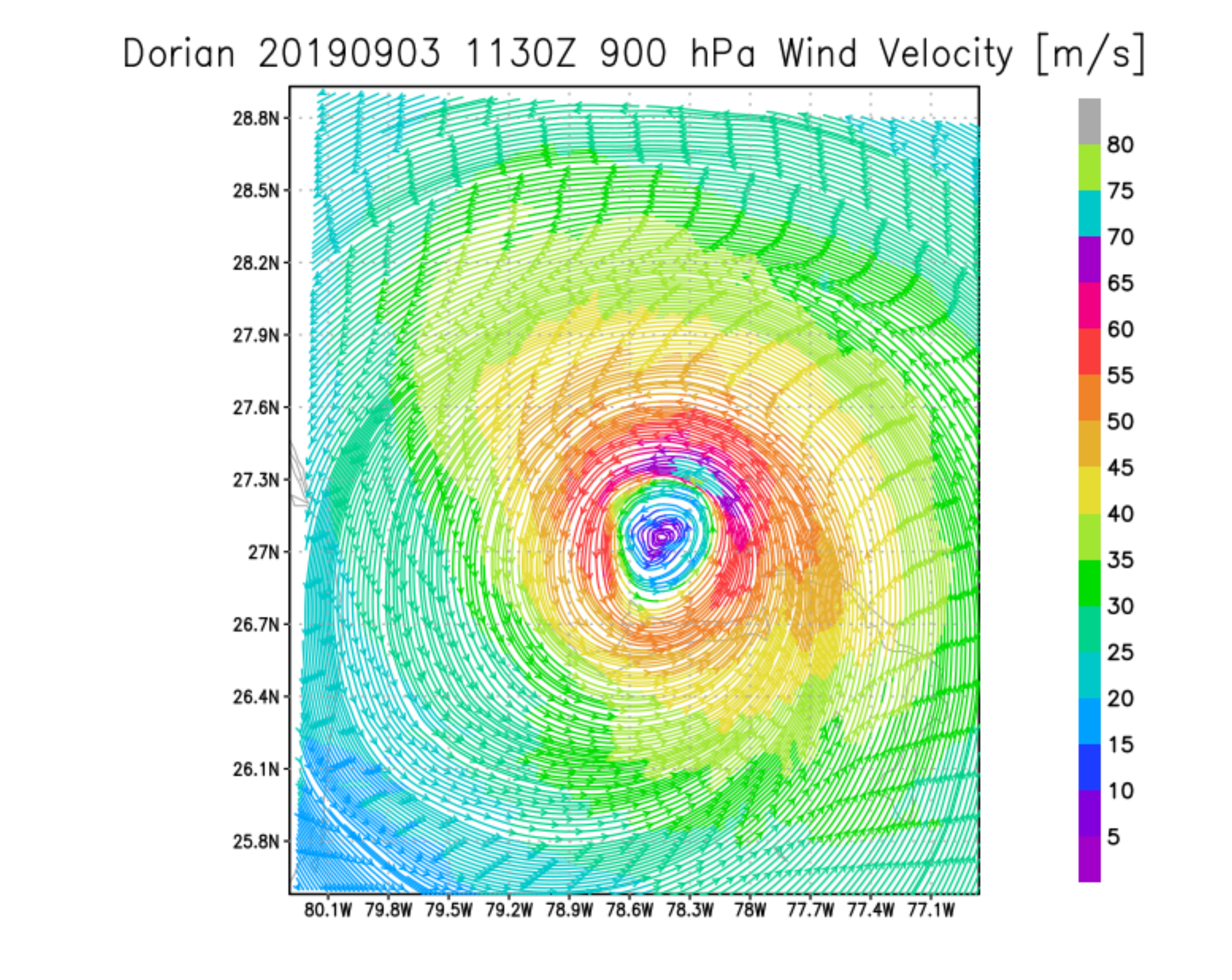
Hurricane Dorian, category 3
Wavenumber-3 structure in wind field
from Doppler radar

Hurricane Dorian, category 5
cloud lines seen in eye, Doppler radar
shows symmetric eyewall



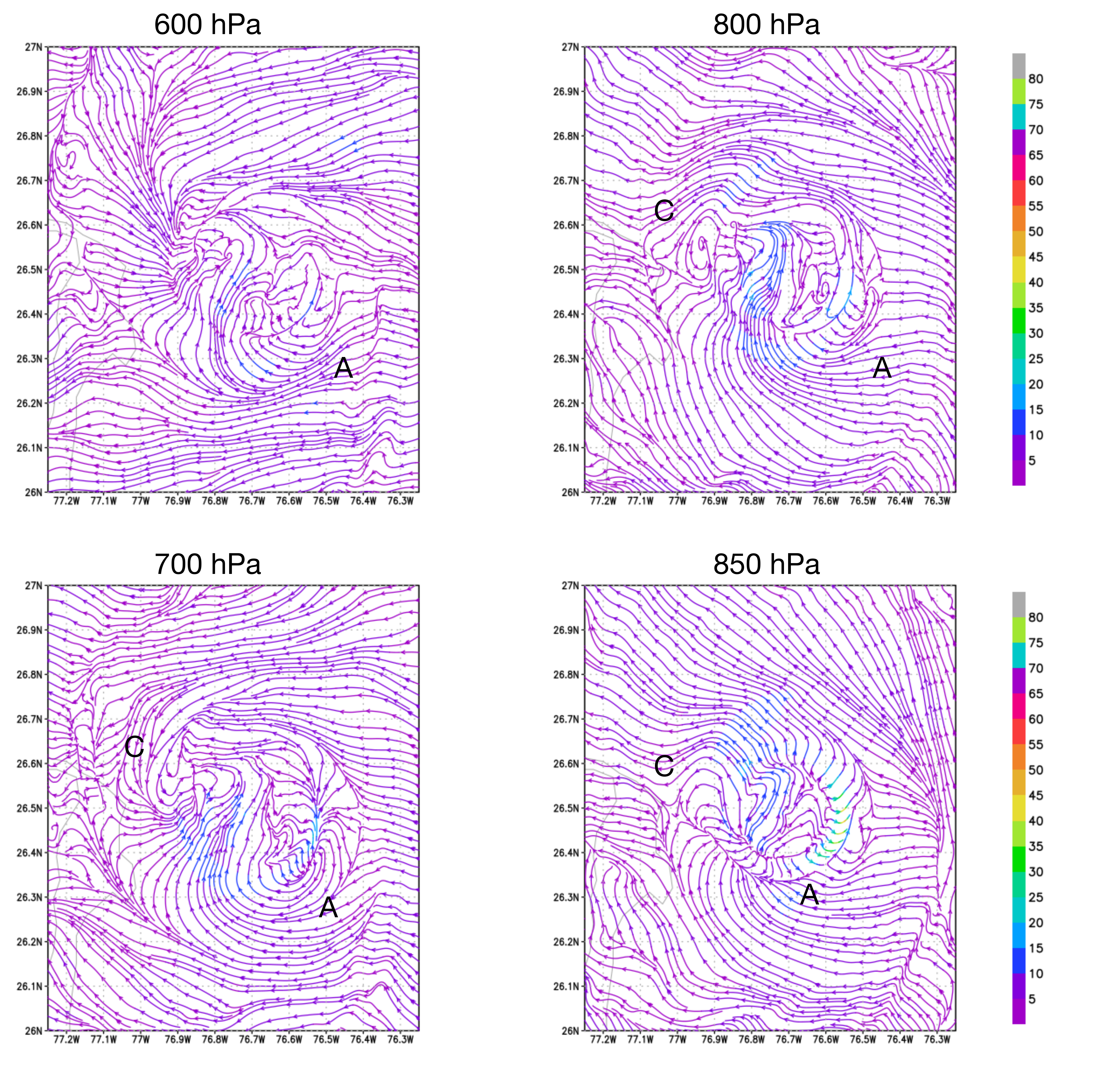


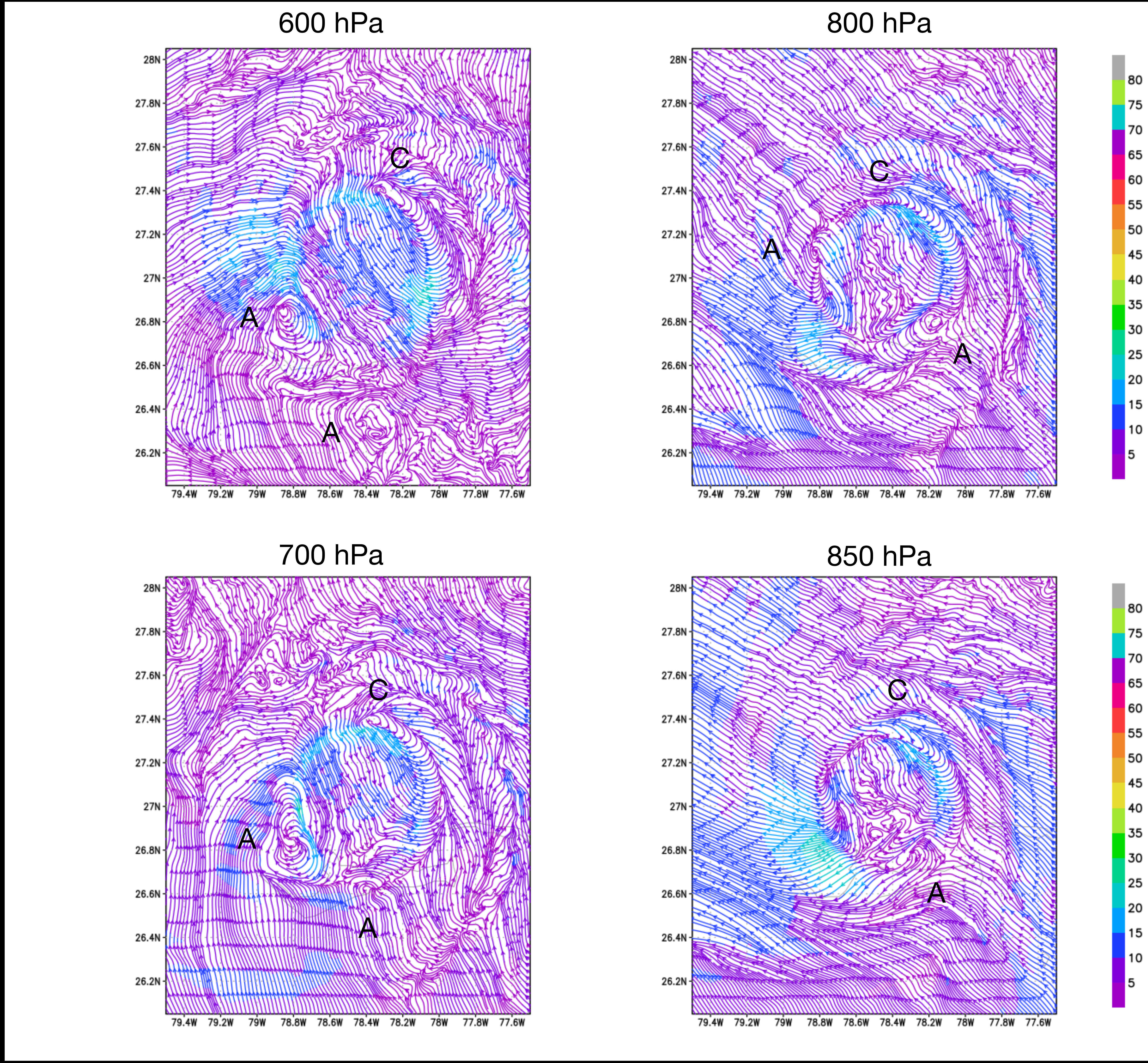
No closed circulations seen
(in any 1-km resolution
HEDAS analysis based on
Doppler and flight-level data)



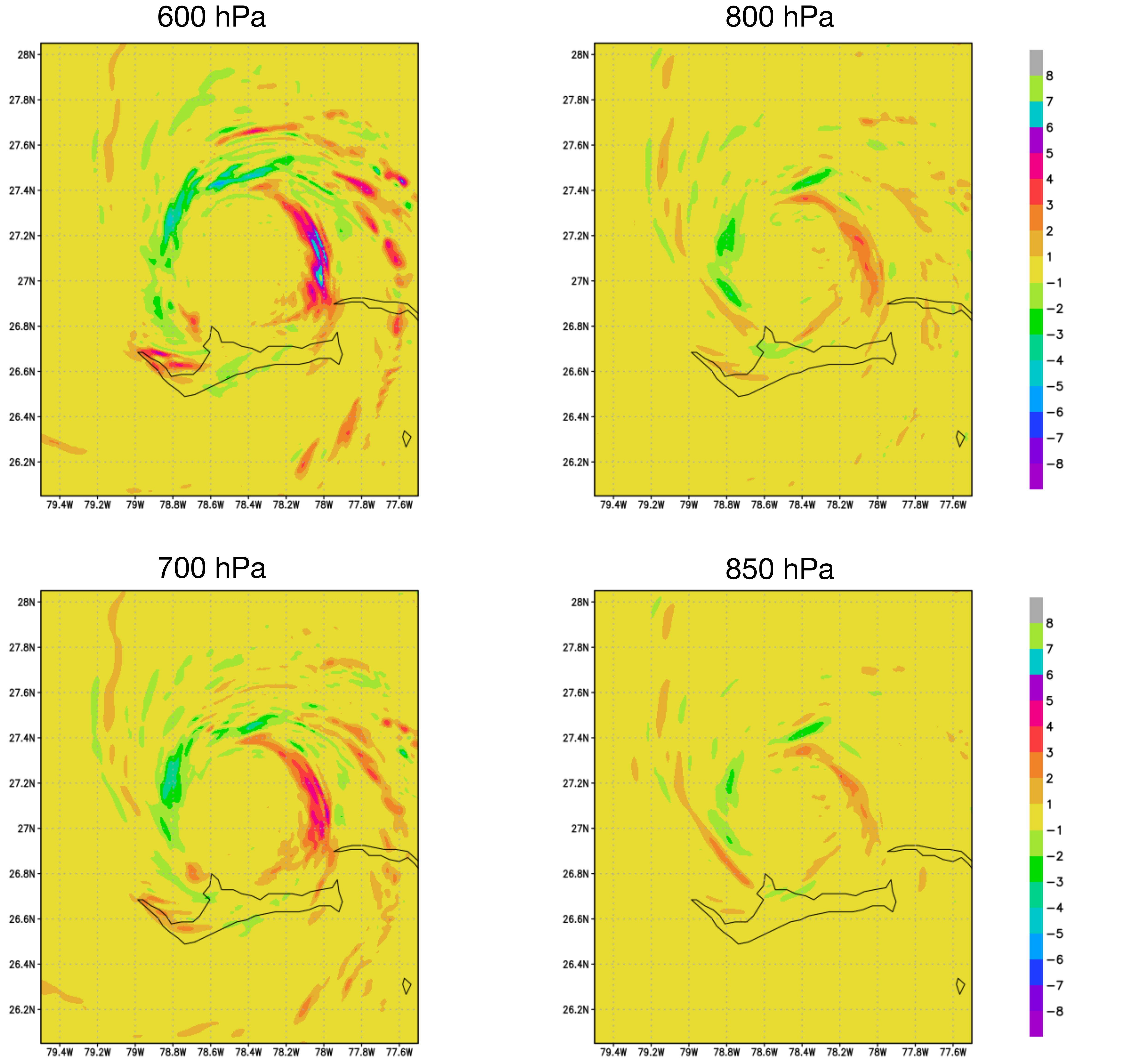
Residual flow (azimuthal mean removed)

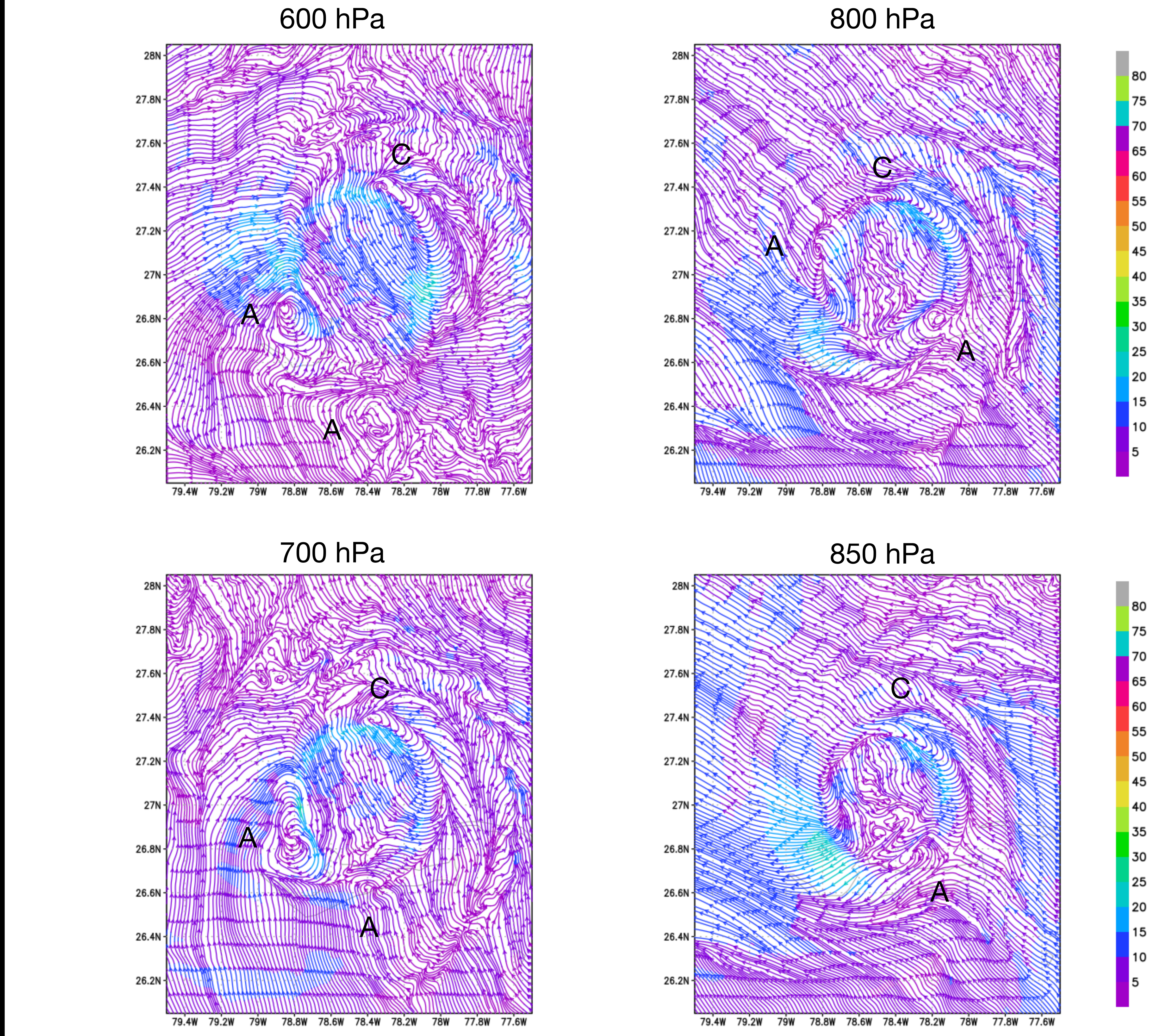
Some cyclonic and anticyclonic (!) circulations along the eyewall



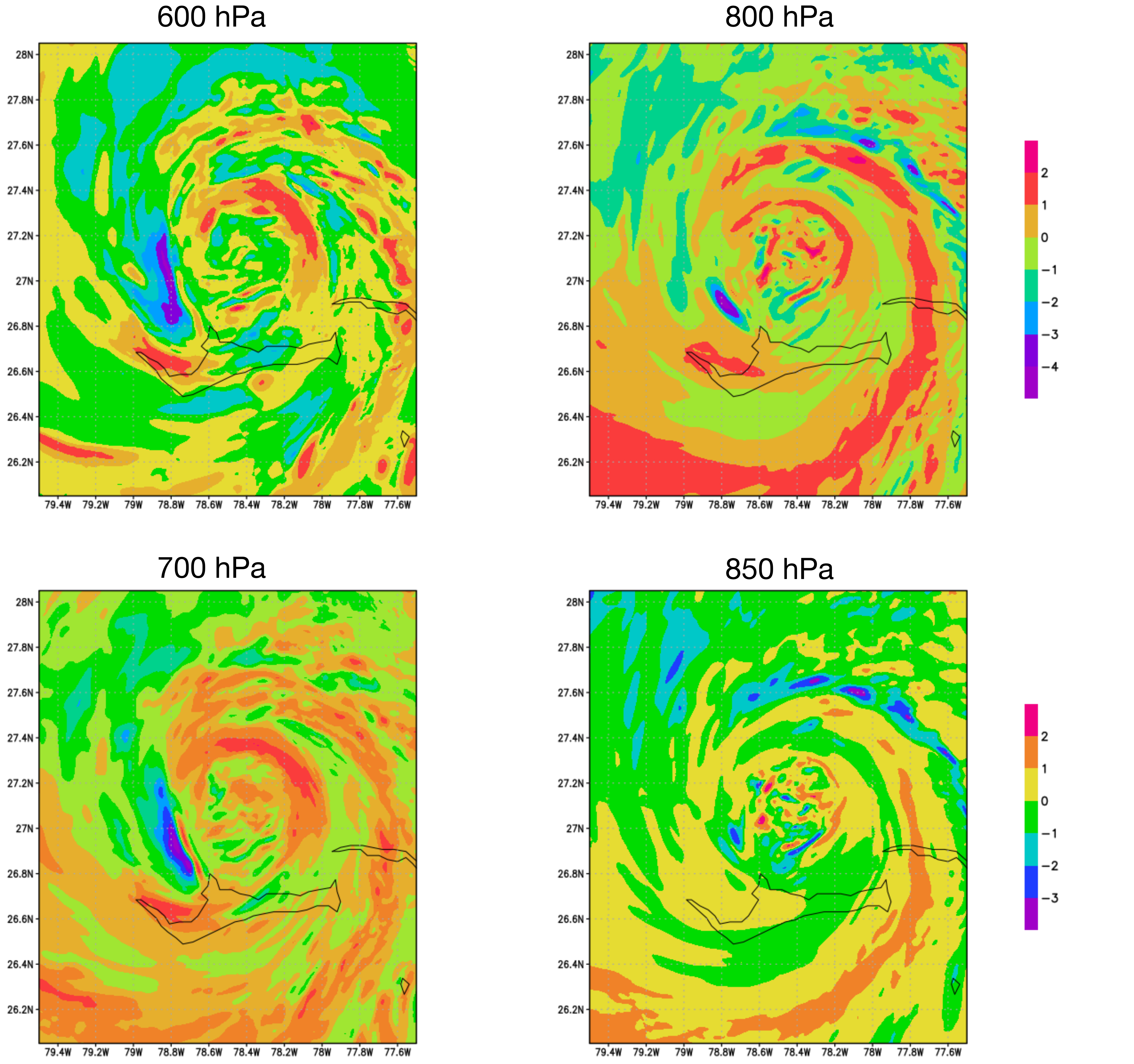


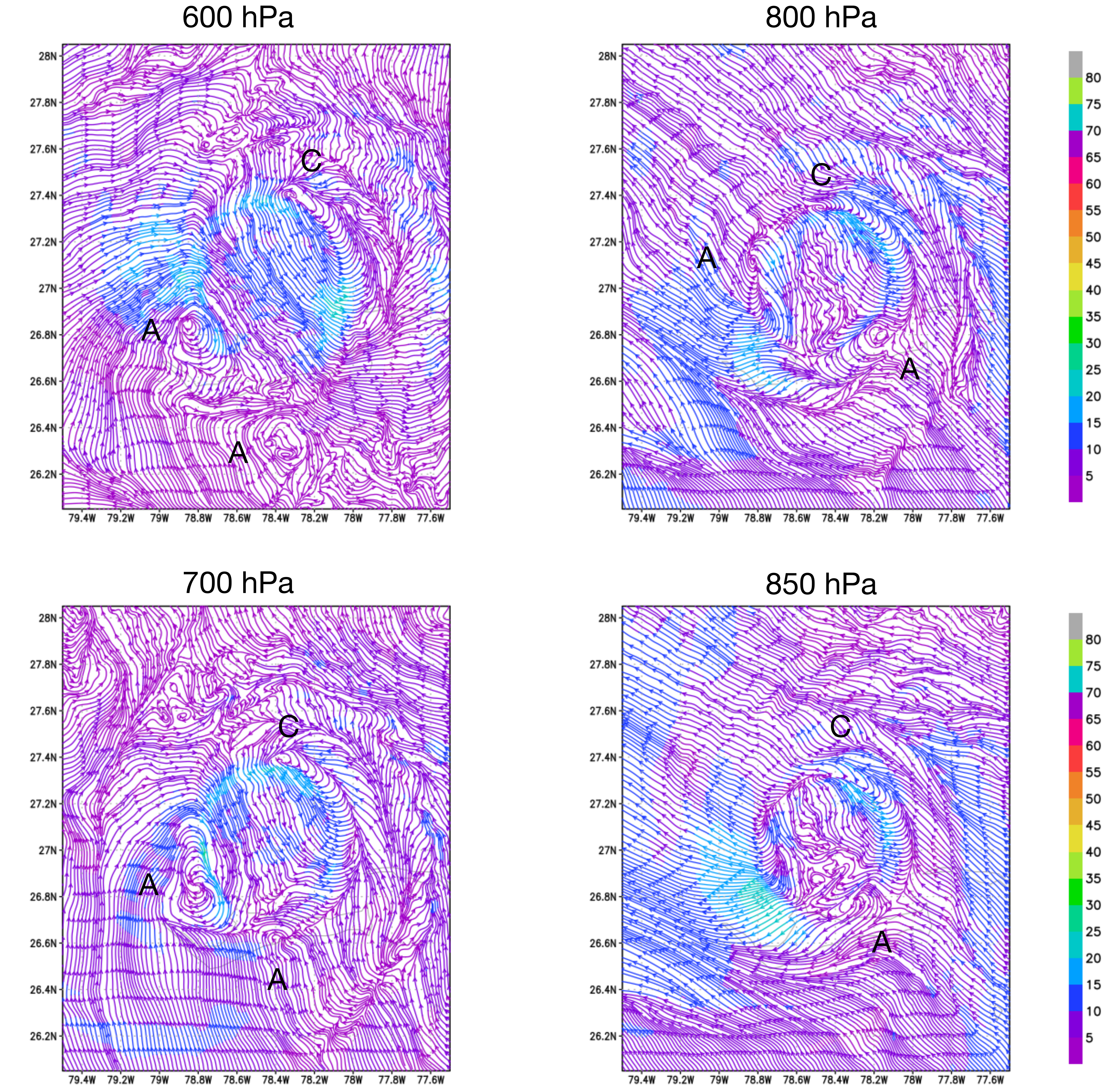
Upward motion extends upwind from the cyclonic vortex center
Downward motion extends upwind from the anticyclonic vortex center



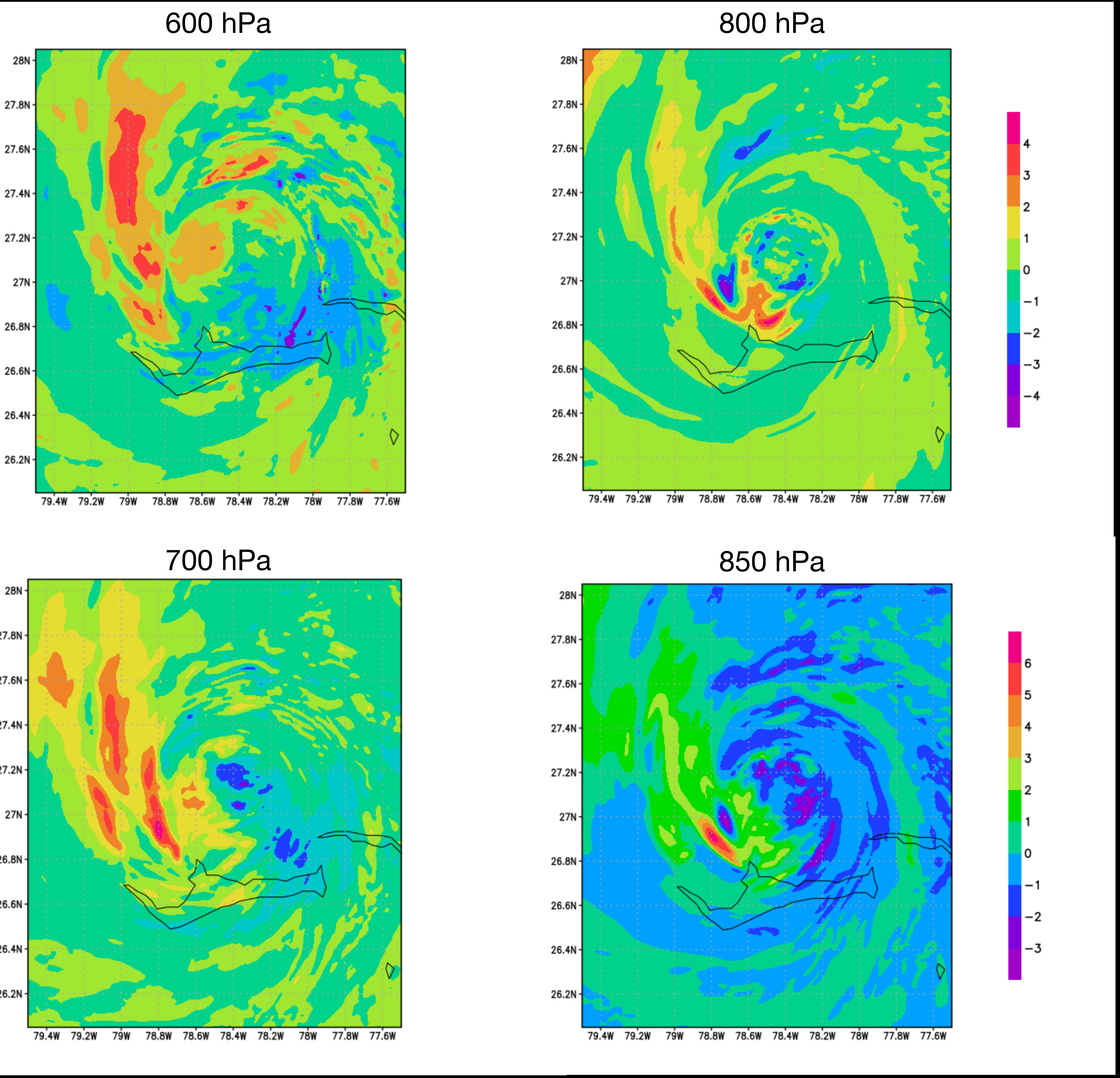


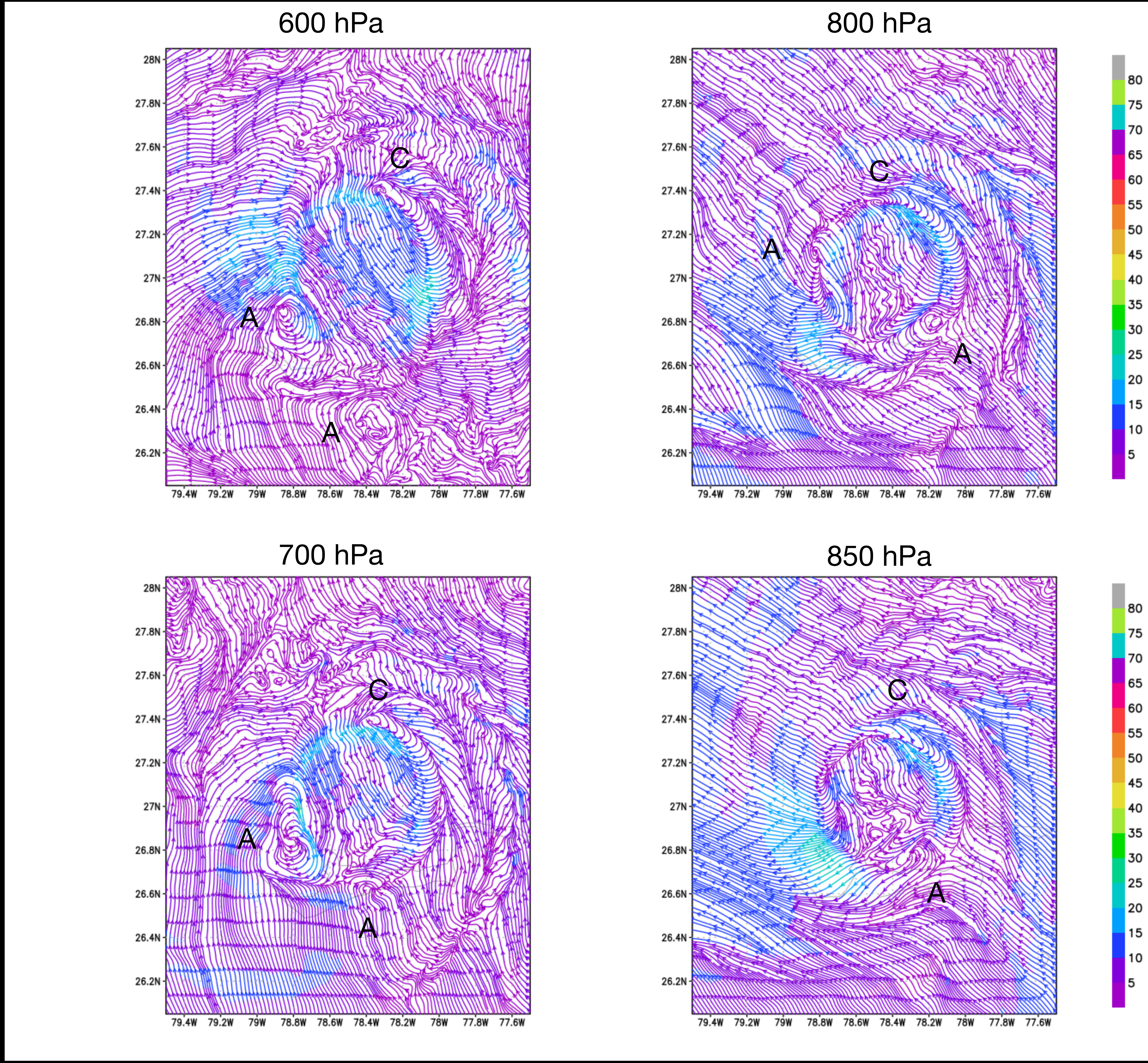
Relatively high dew point temperature where air flows from eye into eyewall
Relatively low dew point temperature where air flows from eyewall into eye



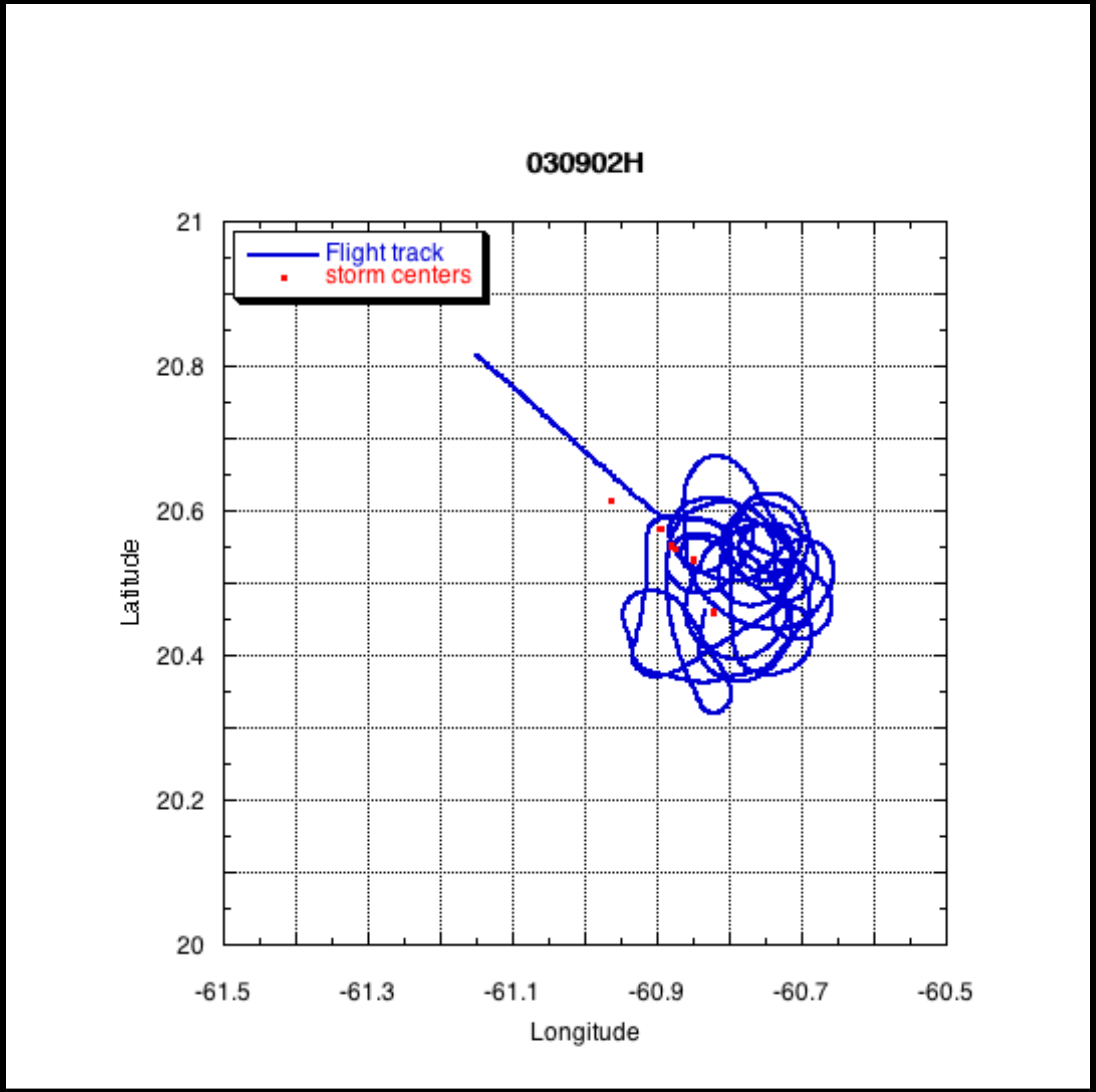


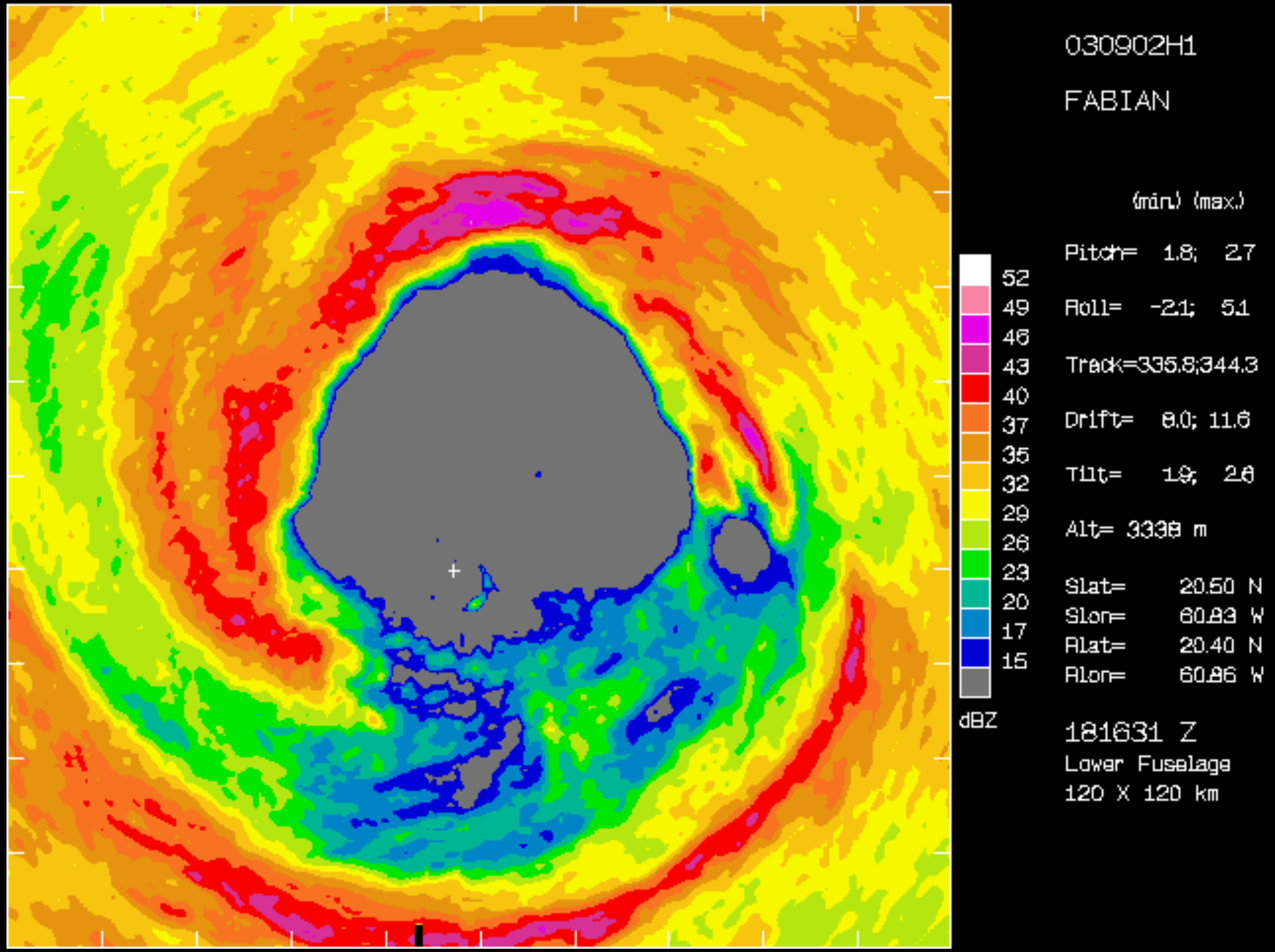
Temperature





Hurricane Fabian (2003) 120 kt
Both 42 and 43 circled in the eye for up to two hours
Eyewall changed from circular to triangular and back during that time.
Could not find any relationship between flight-level wind and vertices during the circling
Could not find relationship between wind and vertices in manual Doppler editing of TA data
Awaiting superobs to do HEDAS analyses





Do mesovortices exist?

- Only one clear set of observations of mesovortices in the eye and eyewall so far (Wurman and Kosiba, 2018)

Can we see mesovortices in

- Doppler data?
- Flight-level data?
- 1.5-km HWRF forecasts?
- 1-km HEDAS analyses?

If mesovortices are predicted and

- implied from satellite imagery, where are they? Are they mainly vortex-relative (so not closed circulations/ meso-vortices)?