Hurricane Ian (2022) Intensification on the West Florida Shelf

Alexander K. Nickerson, Jun A. Zhang[1], Robert H. Weisberg, Boris Galperin, Yonggang Liu

College of Marine Science, University of South Florida, St. Petersburg, FL (Email: anickerson@usf.edu)

[1]NOAA/Atlantic Oceanographic and Meteorological Laboratory/Hurricane Research Division, Miami, FL

Abstract

- Hurricane Ian made landfall in southwest Florida while a category 5 hurricane.
- The Hurricane Weather Research Forecast (HWRF) model provides an accurate timeline of Ian's rapid intensification (RI) over the West Florida Shelf.
- Ian underwent RI in an unfavorable environment characterized by high shear, shallow water, and relatively low humidity; despite this, Ian's RI is still driven by high latent heat fluxes.
- Latent heating leads to an increase in storm core diabatic heating; diabatic heating in turn drives an inward advection of momentum; the increase in momentum leads to an increase in wind speed.

Area of Study & Storm Characteristics

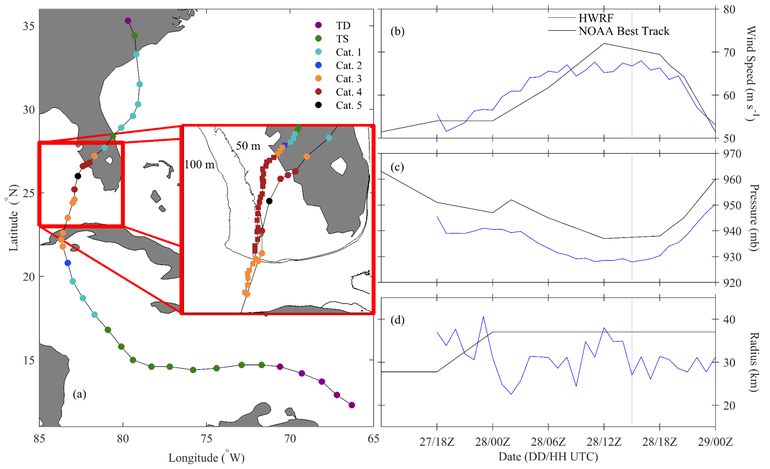

Fig. 1 (a) Actual (circles) and HWRF predicted (squares) storm track of Ian with inset showing its path over the West Florida Shelf. The color code indicates the Saffir-Simpson storm category. (b) The HWRF (blue) predicted and the NOAA Best Track (black) wind speed. (c) The predicted and actual minimum central pressure. (d) The predicted and actual radius of maximum wind speed.

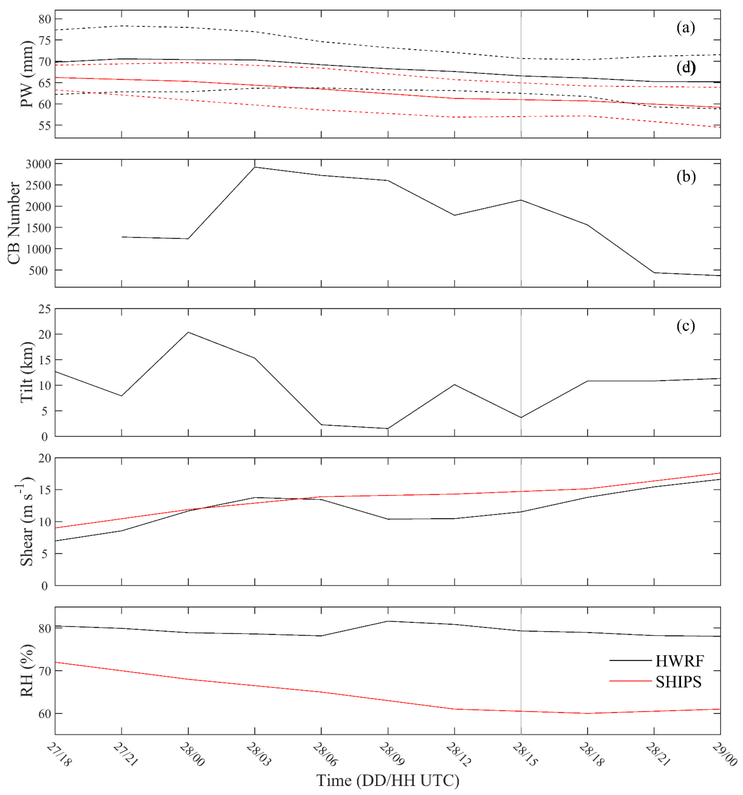

Fig. 2 (a) Mean precipitable water (solid line) from HWRF (black) and SHIPS (red) and its first standard deviation range (dashed lines) within 200 km of the storm center; (b) cloud burst number within 200 km of the storm center; (c) 900 to 300 mb axial tilt; (d) 850 to 200 mb storm shear; (e) 850 to 700 average relative humidity for 200 to 800 km from the storm center

Important Equations

Moist static energy (MSE)

$$h = c_pT + gz + L_vq$$
$$k = c_pT + L_vq$$

Absolute Angular Momentum

$$M = rv + 0.5fr^2$$

$$\frac{\partial\langle k\rangle}{\partial t} = -\langle \mathbf{u}\cdot\nabla_p k\rangle - \left\langle \omega\frac{\partial h}{\partial p}\right\rangle + Q_{AS} + \left\langle c_p\left(\frac{\partial\theta}{\partial t}\right)_R\right\rangle \qquad \frac{\partial\bar{M}}{\partial t} = -\bar{u}\frac{\partial\bar{M}}{\partial r} - \bar{\omega}\frac{\partial\bar{M}}{\partial p} - \overline{u'\frac{\partial M'}{\partial r}} - \overline{\omega'\frac{\partial M'}{\partial p}} + F_r$$

Moist Static Energy

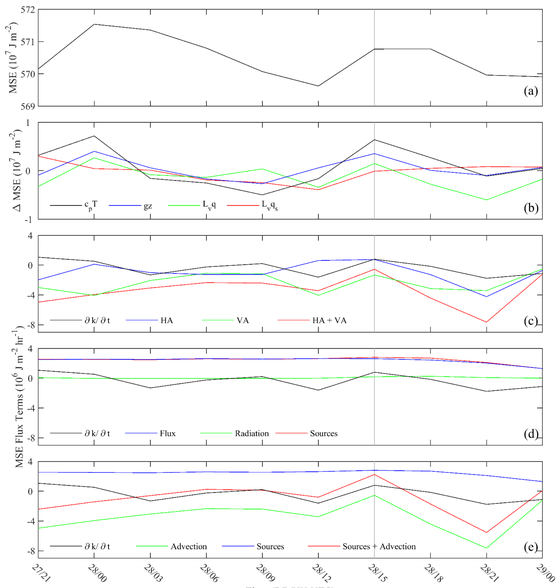

Fig. 3 (a) MSE. (b) Components of MSE. (c) Local and advection terms of MSE. (d) Evolution of MSE. (e) Combination of the above terms. The gray line in all of the panels represents the end of rapid intensification.

Diabatic Heating and Absolute Angular Momentum

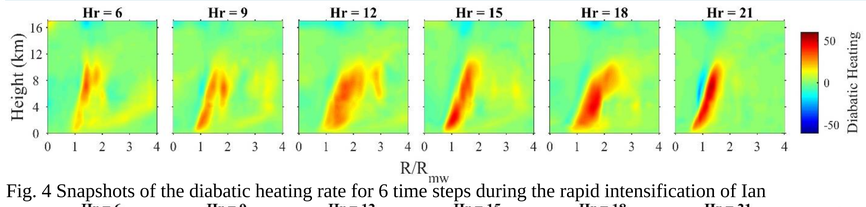

Fig. 4 Snapshots of the diabatic heating rate for 6 time steps during the rapid intensification of Ian

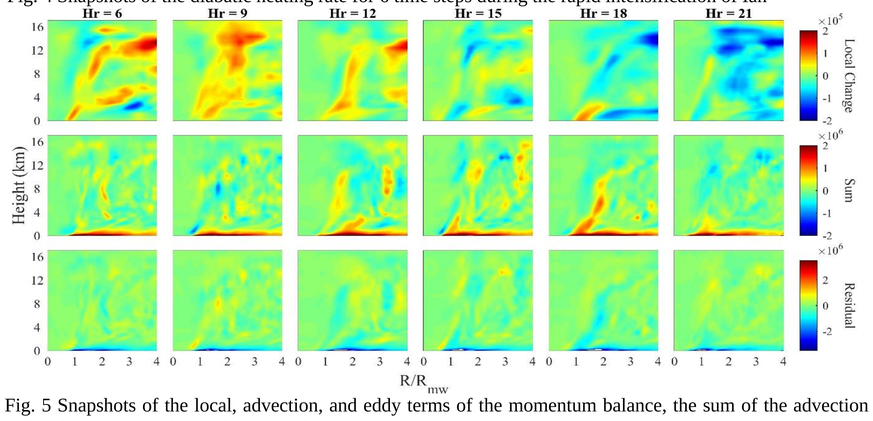

Fig. 5 Snapshots of the local, advection, and eddy terms of the momentum balance, the sum of the advection and eddy terms, and the model residual. Units are m s^{-2} hr^{-1}.

Combining Diabatic Heating and Momentum Budget

Following Ooyama (1982), positive diabatic heating (Fig. 4) can be connected to the momentum budget; the heating is dominated by advection. In the theory of spin-up, heating in the interior of the storm (e.g. inside the eyewall and eye) leads to a contraction of the eyewall that drives radial advection (Fig. 5) and an increase in wind speed. The residual is small, showing that the model scheme has approximate closure within the storm except for the planetary boundary layer (Zhang et al., 2001).

The MSE budget (Fig. 3) shows balance during the run (e.g. Chen et al., 2019), with the total MSE decreasing slightly. The latent heat term remains large and positive, showing this helped drive the intensification.

West Florida Shelf Heat Sources

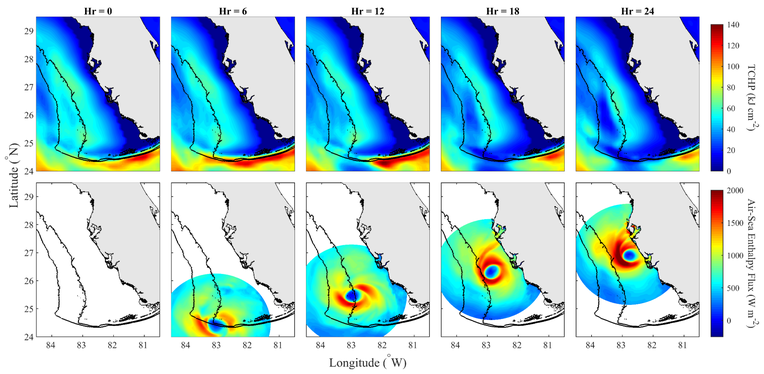

Fig. 6 Contours of tropical cyclone heat potential (kJ cm^{-2}) and air-sea enthalpy flux (W m^{-2})

Convection and Mesoscale Controls

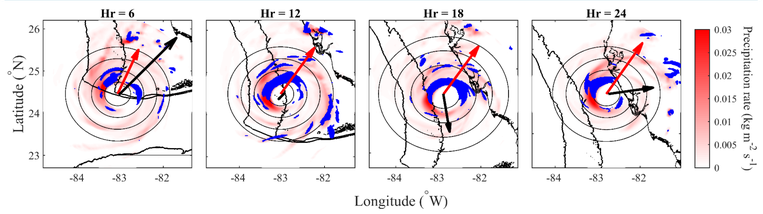

Fig. 7 Snapshots of the cloudburst (vertical velocity is greater than 3 m s^{-1}) distribution (blue) and the precipitation rate (red, kg m^{-2} s^{-1}). Black circles show radii of 1, 2, 3, and 4 times the radius of maximum wind. The red arrow is the mean 850-200 mb wind shear vector, and the black arrow is the direction of axial tilt. 50 and 100 m depth contours and coastlines are shown.

Combining the information

- The HWRF and the NOAA Best Track agree on Ian's intensity (Fig. 1).
- The HWRF and the NOAA Best Track agree on the pattern of the central pressure decrease but not on the magnitude (Fig. 1).
- Ian underwent RI despite being in a dry, high shear environment (Fig. 2).
- An increase in convection (cloud bursts) accompanies intensification (Fig. 2).
- Latent heating (Fig. 3) is large and positive in the eyewall, balancing the negative effects of advection.
- Large bands of cloud bursts and large precipitation rates (Fig. 6) support that the diabatic heating (Fig. 4) is driven by convection .
- The radial momentum advection (Fig. 5) is large and positive (inward).
- The bands of cloud bursts and precipitation (Fig. 6) show inward advection during the model run in support of the conclusions from Fig. 4.
- Tropical cyclone heat potential is small (Fig. 7).
- Air-sea enthalpy fluxes, primarily from latent heating, remain large throughout the forecast period (Fig. 7).
- Latent heating drives diabatic heating; diabatic heating leads to eyewall contraction; eyewall contraction leads to radial momentum advection; radial momentum advection leads to increased wind speeds.
- Understanding what leads to RI and what the model got right and wrong leads to model improvements that improve future forecasts

Acknowledgments

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References

Chen, X., J. A. Zhang, and F. D. Marks, 2019: A Thermodynamic Pathway Leading to Rapid Intensification of Tropical Cyclones in Shear. *Geophysical Research Letters*, **46**, 9241-9251.

Ooyama, K.V. (1982). Conceptual Evolution of the Theory and Modeling of the Tropical Cyclone. *Journal of the Meteorological Society of Japan*, **60(1)**, 369-380.

Zhang, D.-L., Y. Liu, and M. K. Yau, 2001:Amulti-scale numerical study of Hurricane Andrew (1992). Part IV: Unbalanced flows. *Monthly Weather Review*, **129**, 92–107.

Zhang, J.A., and R. F. Rogers: Effects of Parameterized Boundary Layer Structure on Hurricane Rapid Intensification in Shear. *Monthly Weather Review*, **147**, 853-871.