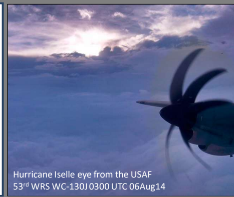
Evolution of the Upper-Level Outflow During Hurricanes Iselle and Julio (2014) in the Navy Global Environmental Model (NAVGEM) Analyses

Sara C. Reynolds, Elizabeth R. Sanabia, and Bradford S. Barrett – Oceanography Department, U.S. Naval Academy, Annapolis, MD

Data

- Navy Global Environment Model (NAVGEM) data for July – August 2014 were obtained from the U. S. Global Data Assimilation Experiment (USGODAE).
  - Spatial Resolution: 0.5° lat
  - Temporal Resolution: 6 h
- Tropical cyclone track and intensity data were provided by the National Hurricane Center (NHC) and the Central Pacific Hurricane Center (CPHC).
- Infrared and water vapor satellite imagery and Google Earth tracks were provided by the Naval Research Laboratory – Monterey, CA (NRL-MRY).



Hurricane Iselle eye from the USAF 53rd WRS WC-130J 0300 UTC 06Aug14

Synoptic Overview

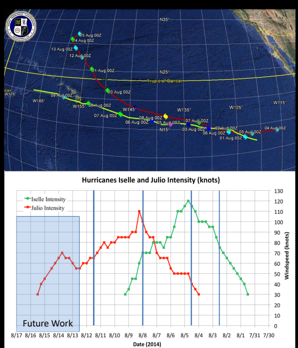


Fig. 1. The NHC and CPHC (a) track (in Google Earth courtesy NRL MRY), and b) intensity (kts) for Hurricanes Iselle (in green) and Julio (in red) from 31 July - 15 August 2014.

From 31 July to early August 2014, the eastern Pacific Ocean was dominated by a *ridge-trough-ridge* pattern within the *subtropical jet*. These ridges and the breaking trough greatly impacted the tracks and intensities of Hurricanes Iselle and Julio.

- At 1200 UTC 02 August 2014 (Figs. 1, 2a), Iselle was located just south of the leading edge of a subtropical ridge. Northerly flow from this ridge contributed to a predominantly equatorward outflow from Iselle. The ridge moved east as Iselle moved west.
- By 1200 UTC 04 August 2014 (Figs. 1, 2b),
  - Iselle was located at the ridge's trailing edge, and outflow from the TC was drawn northward. West of Iselle, the wave then broke at the trough axis, closing off an anti-cyclone. This created two distinct and prominent outflow channels, one northeast and one southwest from the center of Iselle.
  - To the east, Julio was located well south of the ridge's leading edge. Outflow was focused equatorward, enhanced by flow from an anticyclone to the northeast.
- On 0000 UTC 08 August 2014 (Fig. 1, 2c),
  - As Iselle made landfall, the anticyclone west of Hawaii weakened, as did the equatorward outflow from Iselle. With connection to the eastern ridge lost, the poleward component of Iselle's outflow was nearly nonexistent.
  - The outflow from Julio, however, flowed northwest into the trailing edge of the ridge (to the northeast), creating a weak poleward outflow channel in addition to the established equatorward flow. Julio then moved north through a break in the ridge.
- By 1200 UTC 11 August 2014 (Fig. 1, 2d), Julio was south of the trailing edge of the ridge, and outflow was channeled poleward.

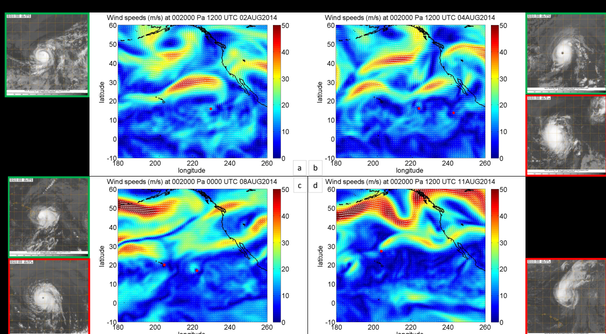


Fig. 2. The 200-hPa wind speed (shaded) and direction (white arrows) from the NAVGEM operational analysis and the geostationary infrared imagery of Hurricanes Iselle (outlined in green) and Julio (outlined in red) from (a) 1200 UTC 02 August 2014 (b) 1200 UTC 04 August 2014 (c) 0000 UTC 08 August 2014, and (d) 1200 UTC 11 August 2014. Red dots indicate storm center locations.

Methods

- Analyzed tracks and intensities for Hurricanes Iselle and Julio in NHC and CPHC forecast products and NRL-MRY water vapor and infrared satellite imagery.
- Analyzed large-scale wind, height, and pressure patterns in NAVGEM model data, including:
  - 9 pressure levels (100 hPa, 150 hPa, 200 hPa, 250 hPa, 300 hPa, 500 hPa, 700 hPa, 850 hPa, 1000 hPa)
  - 4 times each day (0000 UTC, 0600 UTC, 1200 UTC, 1800 UTC) for 17 days (31 July – 16 August 2014).
- Visually identified and quality controlled TC circulation centers for each pressure level at each time step in the NAVGEM analyses.
- Storm-centered NAVGEM data, converting winds from Cartesian to cylindrical coordinates (u- and v-components to U_r and U_θ components).
- Isolated and examined TC outflow at upper levels (based on $U_r>0$), then stratified outflow by meridional direction (poleward / equatorward).
- Subjectively identified the level of maximum outflow (200 hPa).
- Created Hovmollers of 200-hPa radial and azimuthal variation in outflow for each storm as well as Hovmollers of radial variation in poleward and equatorward outflow.

Introduction

During the summer of 2014, a group of midshipmen flew through Hurricane Iselle and Julio with the TROPIC internship with the United States Naval Academy. During the internship, the group flew through the eye wall of both hurricanes on multiple occasions. Stemming from this experience, interest grew in regards to the outflow mechanisms of a TC. Tropical cyclone outflow remains an active area of research in the meteorology community. Despite this, not much is known about the relationship between TC outflow, structure, and intensity. TC outflow is defined as the outward branch of the TC's secondary circulation, and outflow is typically located in the upper troposphere. One way to further research this area is with model output, including Navy Global Environmental Model (NAVGEM) derived images depicting the centers of Hurricane Iselle (2014) and Hurricane Julio (2014). These images were used to examine the outflow and intensity. The focus of this study was to observe relationships between TC outflow and intensity.

Hurricane Iselle

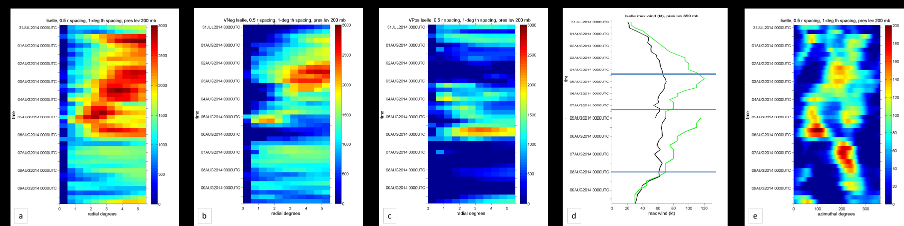


Fig. 3. Radial variation in the (a) total, (b) equatorward, and (c) poleward outflow derived from 200-hPa NAVGEM analyzes for Hurricane Iselle (shaded, scale at right). (d) Best track intensity (kts) for Hurricane Iselle. (e) As in (a), except for azimuthal variation. All plots extend from 0000 UTC 31 July 2014 to 0000 UTC 10 August 2014.

Total Outflow

- ***Greatest*** from 3-5 August 2014, as Iselle's wind speed ***increased***
- ***Reduced*** after 5 August 2014, as Iselle's wind speed ***decreased***
- During the ***strong outflow*** period, the location of the outflow ***maximum*** moved ***radially inward.***
- During the ***weaker outflow*** period, the outflow was ***consistent,*** though reduced, ***across*** nearly ***all radii***.

Equatorward Outflow

- From 1-5 August 2014, strong equatorward outflow was present, and the outflow maximum shifted toward the TC center.
- On 6 August 2014, equatorward outflow was mostly absent.
- After 6 August 2014, equatorward outflow was present again at most radii.

Poleward Outflow

- On 31 July 2014, weak northward outflow was present at most radii.
- From 1-3 August 2014, little poleward outflow was present.
- From 3-6 August 2014, poleward outflow was strong at most radii, and was greatest on 05 August at 2-5 degrees from the TC center.
- From 6-9 August 2014, poleward outflow was mostly absent.

Intensity

- The ***greatest intensity*** occurred at 0000 UTC 05 August 2014 and corresponded to the time when the ***outflow was closest*** to the storm center.
- The intensity generally ***increased*** as the outflow maximum moved ***closer*** to the storm center.

Outflow Channels

- From 1-3 August 2014, a broad outflow channel shifted from the *southeast* to the *northwest* side of the TC center.
- From 4-6 August 2014, there were two distinct channels: one north and one south of the TC center.
- From 6-9 August 2014, only the southern channel remained.
  - This abrupt shift followed the wave break in the subtropical ridge and disconnect from the ridge to the east.

Hurricane Julio

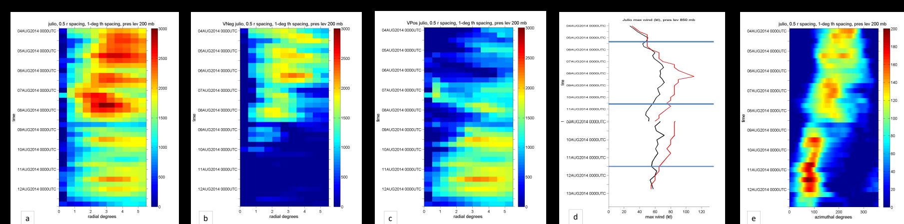


Fig. 4. Radial variation in the (a) total, (b) equatorward, and (c) poleward outflow derived from the NAVGEM data for Hurricane Julio (shaded, scale at right). (d) Best track intensity (kts) for Hurricane Julio. (e) As in (a), except for azimuthal variation. All plots extend from 0000 UTC 04 August 2014 to 0000 UTC 14 August 2014.

Total Outflow

- ***Greatest*** from 4-7 August 2014 as Julio wind speed ***increased***
- ***Reduced*** after 8 August 2014 as Julio wind speed ***decreased***
- During the ***strong outflow*** period, the location of the outflow ***maximum*** moved ***radially inward.***
- During the ***weaker outflow*** period, the outflow was ***consistent,*** *though reduced,* ***across*** nearly ***all radii***.

Equatorward Outflow

- From 4-8 August 2014, equatorward (southward) outflow was fairly high at most radii.
- From 8-9 August 2014, outflow weakened at outer radii, but was strong 1-3 degrees from the TC center.
- From 10-12 August 2014, southward outflow was notably absent.

Poleward Outflow

- From 4-6 August 2014, poleward (northward) outflow was minimal.
- On 7 August 2014, the intensity of the poleward outflow increased and became located a greater distance from the center.
- From 9-12 August 2014, the maximum shifted radially inward, and values remained higher over a greater range of radii.

Intensity

- The ***greatest intensity*** occurred at 0600 UTC 08 August 2014 and corresponded to the time when the ***outflow was closest*** to the storm center.
- The intensity generally ***increased*** as the outflow maximum moved ***closer*** to the storm center.

Outflow Channels

- From 4-8 August 2014, a broad outflow channel shifted from the *southeast* to the *northwest* side of the TC center.
  - This shift corresponded to the alignment of the outflow with the trailing edge of the subtropical jet.
  - When the maximum outflow was west of the TC center, outflow was directed both poleward and equatorward.
- From 9-13 August 2014, the channel narrowed as outflow intensified north of the TC center.

References

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Acknowledgements

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Background

Recent theory suggests that the TC life cycle, including rapid intensification (RI), is associated with environmentally forced outflow jet interactions

The evolution of these interactions, particularly for recurving systems, is comprised of three phases:

I. TC development: Single Equatorward-directed Jet
II. Intensification and RI: Dual Equatorward and Poleward Jets
III. Mature & decay: Primary, single Poleward-directed Jet

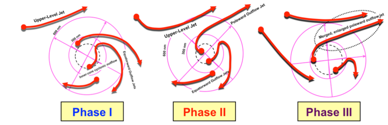

Fig. 5. Conceptual evolution of tropical cyclone outflow jets, including interaction with environmental flow (from Black et al. 2014).

Results

Location of TC outflow:

1. Vertical: Maximum outflow was consistently near 200-hPa.
   - Subjective analysis of Hovmollers for each of the 9 vertical levels revealed the outflow magnitude was greatest at 200 hPa over time.
2. Horizontal: Radial location of the maximum outflow varied.
   - Outflow extended radially more than 500 km from the TC center.

Relationship between outflow and TC intensity:

3. The TC intensity increased:
   a. during periods of greater outflow
   - There were clear shifts in outflow magnitude.
     - Iselle: 90-kt intensification during the first 102 h of greater outflow
     - Julio: 80-kt intensification within 102 h of greater outflow
   b. when the maximum outflow was located closer to the storm center
   - There were radially inward progressions of the outflow maximum.
     - Iselle: Nearly 300 km shift toward the TC center over a 102-h period
     - Julio: Nearly 200 km shift toward the TC center over a 72-h period
4. The TC intensity was greatest when dual outflow channels were present
   - The dual outflow channels originated from either one (Julio) or two (Iselle) distinct locations around the TC center.

Relationship between TC track, jet features, and outflow channels:

5. Outflow channels were greatly impacted by adjacent large-scale environmental features.
   - Iselle and Julio transited nearly identical tracks (beneath the same subtropical ridge) early in their respective lifecycles. The outflow patterns for this stage were similar for both systems
     - *equatorward* while *south of the leading edge* of the ridge
     - *poleward* while *south of the trailing edge* of the ridge
   - Iselle remained on a westward track, while Julio turned northward behind a break in the ridge.
     - Iselle's outflow refocused *equatorward* upon encountering northerly flow on the eastern side of an anticyclone
     - Julio's outflow remained *poleward* as the TC moved toward the ridge.

Future Work

- **Extend the analysis of Hurricane Julio through the end of the TC lifecycle**
  - Are results consistent with trends detected during intensification periods at lower latitudes during Iselle and the earlier lifecycle of Julio?
  - What is the role of the midlatitude wave train north of the subtropical jet?
- **Expand the analysis to include observations in addition to model data**
  - Data to investigate include CIMSS Atmospheric Motion Vectors satellite data, along with 53rd WRS and NOAA dropwindsondes and other aircraft data.
  - Are relationships identified in the observations captured in the models?
- **Examine quantitatively the relationships between TC outflow and intensity**
  - Are the outflow magnitude and TC intensity mathematically correlated?
  - Do changes in outflow magnitude lead or lag changes in intensity?
- **Determine relationships between TC outflow and ocean thermal structure**
  - Is the amount cooling in the upper ocean related to outflow magnitude?
  - Are there linkages between the branches of the secondary circulation?