The Thermodynamic and Kinematic Lifecycle of Hurricane Edouard As Seen By Dropsonde Observations

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1. Introduction

Dropsonde observations from the NASA Global Hawk, as well as NOAA P3 and GIV aircraft, offer a unique opportunity to examine the spatial and temporal evolution of intensifying Hurricane Edouard (2014). Just as recent satellite and radar studies have documented a shear-induced precipitation asymmetry (and increase of symmetry during intensification) in tropical cyclones, ***the primary goal of this study is to describe the thermodynamic and kinematic asymmetry of the inner core, and how those properties relate to the spatial and temporal evolution of precipitation.***

2. Data and Methodology

- Each dropsonde is…
  ADJUSTED to the nearest 3-hourly interpolated best-track center
  ROTATED so oriented versus shear direction
  and unless otherwise noted, mean profiles are for within 200 km of center

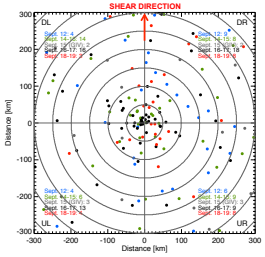
DL => DOWNSHEAR LEFT **DR** => DOWNSHEAR RIGHT
UL => UPSHEAR LEFT **UR** => UPSHEAR RIGHT

- Dropsondes are QC version released by NCAR on March 31, 2015 (thermodynamic properties only)
- Shear direction from 6-hourly SHIPS analysis
- Azimuthally-averaged rain rate is from NASA Tropical Rainfall Measuring Mission (TRMM)'s passive microwave-IR merged 3B42 product (3-hourly/0.25 deg.)

SFMR Estimated Radius of Maximum Wind (RMW)

Date	RMW (km)
9/12	61
9/13	56
9/14	39
9/15	30
9/16	35
9/17	85

Aircraft	Date	# of Drops
GH	11-12 Sept.	60
NOAA43	14 Sept.	8
GH	14-15 Sept.	80
NOAA43	15 Sept.	19
NOAA42	15 Sept.	14
NOAA49	15 Sept.	16
NOAA43	16 Sept.	23
NOAA42	16 Sept.	12
GH	16-17 Sept.	87
NOAA42	17 Sept.	17
GH	18-19 Sept.	50
	TOTAL	**386**

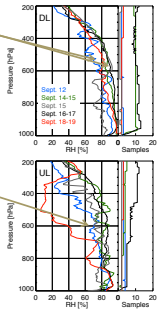


3. Thermodynamic Properties

pre-INT (12 Sept.) => pre-intensification; INT (14-15 Sept.) => intensifying
SS (15-16 Sept.) => steady state; WK (18-19 Sept.) => weakening

Global Hawk and NOAA GIV profiles only here

RH



DL *similar* to DR except perhaps somewhat ***less humid* pre-INT**, thus ***more humidification*** above 600 hPa **by INT**

=> Not surprising considering **DL** has the ***highest raining frequency***

UL *humidifies* at **midlevels (above 800 hPa)**, in each subsequent stage

Humidification must occur in the upshear quadrants if symmetrization (mature TC) is to occur

Humidification (10-20%) occurs **DR** from **pre-INT to INT**. ***Slightly less*** humid during SS

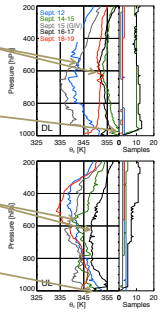
=> DR also has a ***higher raining frequency*** than **upshear** quadrants

Between pre-INT and INT, *little humidification* occurs in the **UR** quadrant

Most humidification in **UR** occurs **between INT and SS**

SS flight exhibits the most similar mean RH profiles for all quadrants (symmetric)

Theta-e (θ_E)



Most substantial ***increase*** is **DL from pre-INT to INT => *moistening***

Convective instability (vertical gradient of θ_E) ***decreases* from pre-INT to INT; near-sfc-θ_E *increases substantially***

Less increase throughout profile **UL** from **pre-INT to INT**. Not until **SS does the profile *increase and stabilize***

***Lowest* near-sfc-θ_E** is **UL during INT**

DR experiences ***less increase*** in **midlevel θ_E in each stage than DL**

***Highest* near-sfc-θ_E** is **DR during INT**

=> *Most unstable* mean profile of **all quadrants during INT** (favorable for convective initiation?)

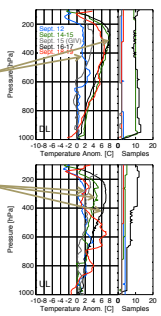
Increase in **θ_E** is ***most delayed* UR**.

Most significant increase is **between INT and SS**

Only during SS are the θ_E profiles similar for all quadrants (symmetric)

Temperature Anomaly

Anomaly uses the 300-700 km average profile



DL *warm anomaly develops* between pre-INT and INT. *Little change* from INT to SS

***Most progressive (day to day) increase* in anomaly above 600 hPa** is in **UL**

Warm anomaly at upper levels remains asymmetric throughout intensification; symmetry only achieved during most mature, intense stage

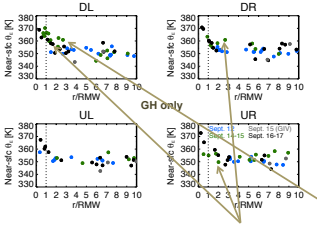
***Slightly warmer anomaly* DR** compared to DL during **pre-INT**. ***More progressive warming* from pre-INT to INT to SS in DR** than DL

Little warming between **pre-INT and INT (~2°C)**

***6°C warm anomaly* only observed UR during SS**; value is ***similar* to other quadrants**

Near-surface-θ_E

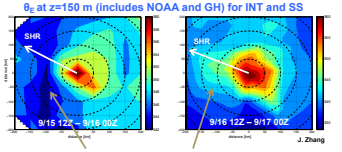
Lowest height available below 150 m



Near-sfc-θ_E is ***mostly uniform*** among quadrants during **pre-INT** (blue dots)

During **INT**, **near-sfc-θ_E increases inside 2×RMW (~70-80 km)**, with the **highest values downshear** (as much as 10K cooler upshear)

θ_E at z=150 m (includes NOAA and GH) for INT and SS



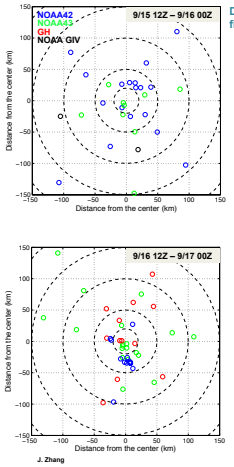
Compared to INT (left), the spatial distribution of ***high* near-sfc-θ_E at SS** (right) is ***more symmetric*** around the center

Although **near-sfc-θ_E** is ***highest*** **within the RMW during SS**, it is ***higher* 1-3×RMW during INT**

Near-sfc-θ_E is consistently *highest* downshear during INT, and *lowest* upshear

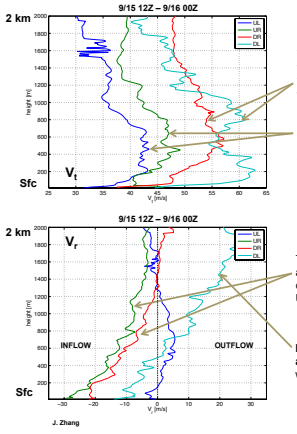
Near-sfc-θ_E is consistently *highest* during SS, and is *symmetric* among quadrants

4. Kinematic Properties



Dropsondes contributing to figures in this section

Comparison of the tangential and radial velocity between an INT period (9/15 12Z to 9/16 00Z) and an SS period (9/16 12Z to 9/17 00Z)

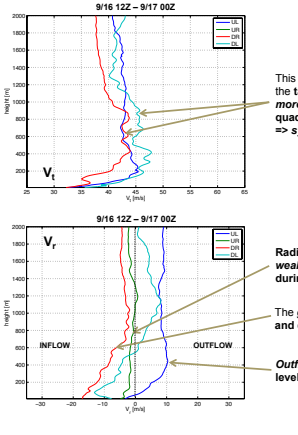


This **INT** period indicates that the **tangential velocity is *highest* DL, followed by DR**

Upshear quadrants exhibit a ***distinguishably lower* tangential velocity => *asymmetric***

The ***greatest inflow* (velocity and depth)** is **UR during INT**, closely followed by **DR**. **UL** has the ***shallowest inflow***

Radial flow is ***outward*** **above 500 m DL during INT** with only ***weak inflow*** below



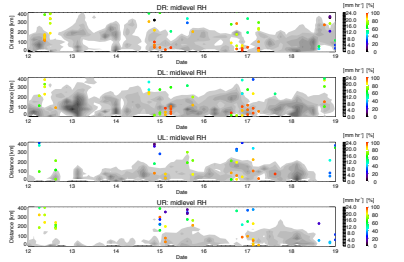
This **SS** period indicates that the **tangential velocity is *more uniform* among quadrants than INT => *symmetric***

Radial inflow UR is ***weakened substantially*** **during SS**

The ***greatest inflow* (velocity and depth)** is **DR during SS**

Outflow observed at **all levels in UL** quadrant

5. Early Conclusions



Midlevel (700-500 hPa) mean RH (colored dots) overlaid with 3B42 azimuthally-averaged rain rate in each quadrant

DL is the rainiest quadrant, followed by DR

Rainfall increases upshear in each subsequent burst period on 9/13 and 9/14

A more symmetric rainfall organization is not observed until later in the INT period (15 Sept.)

- **Humidification** must occur in the **upshear quadrants for symmetrization** (mature TC). This is likely tied to an **occurrence of rainfall upshear**, which **during INT** appears **more episodic**
- An **increase in θ_E** (from both **warming and moistening**) occurs **between pre-INT and SS**, however **preferentially at different times** in each quadrant – ***downshear quadrants earlier, upshear later***
- **Radial inflow is preferred below 2 km in all quadrants during INT**, but **strongest and deepest right of shear**
- **Thermodynamic and kinematic properties of the inner core remain asymmetric during the intensification process**, but do **appear symmetric when a mature, steady state** Edouard is observed