UNIVERSITY OF MIAMI
ROSENSTIEL SCHOOL of MARINE & ATMOSPHERIC SCIENCE

Ensemble-based predictability and diagnostics of tropical cyclone outflow and structure change during the 2017 Atlantic hurricane season

Sharanya J. Majumdar

Rosenstiel School of Marine and Atmospheric Science, University of Miami,
4600 Rickenbacker Causeway, Miami, Florida 33149, USA

1. Past usage of ECMWF's forecasts

- **Targeted observations**: two decades of global collaborative research, largely driven by THORPEX, reviewed in Majumdar (2016)
  - **Mid-latitudes**: Majumdar et al. (2001, 2002a,b, 2010), Petersen et al. (2007), Sellwood et al. (2008)
  - **Tropical Cyclones**: Majumdar et al. (2006, 2011), Reynolds et al. (2007), Wu et al. (2009), Aberson et al. (2011), Hamill et al. (2013)
- **Diagnostics of ensemble perturbation growth** (Yamaguchi and Majumdar 2010)
- **Predictability of tropical cyclogenesis** (Komaromi and Majumdar 2014, 2015)
- **Probabilistic verification of tropical cyclone track and genesis** (Majumdar and Finocchio 2010, Majumdar and Torn 2014)
- **Aircraft mission planning** for NSF PREDICT field campaign (Montgomery et al. 2012) and Office of Naval Research TCI field campaigns (Doyle et al. 2017)

Selected Publications since 2010 (students underlined)

- Doyle, J. D. and CoAuthors, 2017: A View of Tropical Cyclones from Above: The Tropical Cyclone Intensity (TCI) Experiment. *Bull. Amer. Meteor. Soc.*, **98**, 2113-2134.
- Majumdar, S. J., 2016: A Review of Targeted Observations. *Bull. Amer. Meteor. Soc.*, **97**, 2287-2303.
- Komaromi, W. A. and S. J. Majumdar, 2015: Ensemble-Based Error and Predictability Metrics Associated with Tropical Cyclogenesis. Part II: Wave-Relative Framework. *Mon. Wea. Rev.,* **143**, 1665-1686.
- Majumdar, S. J. and R. D. Torn, 2014: Probabilistic verification of global and mesoscale ensemble forecasts of tropical cyclogenesis. *Wea. Forecasting*, **29**, 1181-1198.
- Komaromi, W. A. and S. J. Majumdar, 2014: Ensemble-based error and predictability metrics associated with tropical cyclogenesis. Part 1: Basin-wide perspective. *Mon. Wea. Rev*., **142**, 2879-2898.
- Majumdar, S. J., S.-G. Chen and C.-C. Wu, 2011. On the properties of Ensemble Transform Kalman Filter guidance for adaptive sampling in tropical cyclones. *Quart. J. Roy. Meteor. Soc.,* **137**, 503-520.
- Yamaguchi, M. and S. J. Majumdar, 2010: Using TIGGE data to diagnose initial perturbations and their growth for tropical cyclone ensemble forecasts. *Mon. Wea. Rev.*, **138**, 3634-3655.
- Majumdar, S. J., K. J. Sellwood, D. Hodyss, Z. Toth and Y. Song, 2010: Characteristics of target areas selected by the Ensemble Transform Kalman Filter for medium-range forecasts of high-impact winter weather. *Mon. Wea. Rev.*, **138**, 2803-2824.
- Majumdar, S. J. and P. M. Finocchio, 2010: On the ability of global Ensemble Prediction Systems to predict tropical cyclone track probabilities. *Wea. Forecasting*, **25**, 679-700.

2. Hypothesis and Approach

The U.S. Office of Naval Research Tropical Cyclone Intensity (TCI) Directed Research Initiative is largely focused on understanding the role of outflow in tropical cyclone structure and intensity change.

Our overarching hypothesis: Predictability of outflow (and TC structure) is largely modulated by the environment.

- **Phase** between TC and environmental features is critical in the establishment of outflow channels
- Modifications to **outflow structure** influence TC structure
- Perturbations to outflow and environment are crucial to create diversity in **ensemble perturbations**

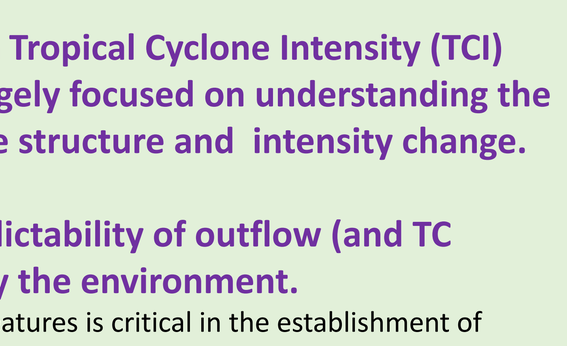
Approach

First, establish if there is a relationship between outflow and TC structure
  This poster: Correlations between variables
Next, establish relationships between outflow and environmental features
  e.g. distance between TC and trough; strength of trough
Finally, if possible, quantify forecast error growth in the context of these relationships

3. ECMWF Ensemble Forecasts

0 – 5 day forecasts from TIGGE

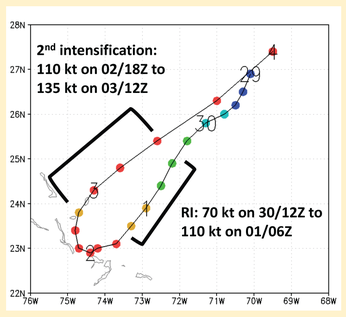
All fields on 1 x 1 grid
  51 ensemble forecasts
  Deterministic forecast
  Analysis (used as verification)



Variables Investigated

LOW-LEVEL CYCLONIC ***CIRCULATION***
  700-850 hPa layer mean relative vorticity, averaged over 3 x 3 gridpoints
12-H CHANGE IN CIRCULATION
THICKNESS ANOMALY *(WARM CORE)*
  200-850 hPa local Z minus environmental Z (averaged within r=1000 km)
MSLP
LAT/LON
200 hPa ***DIVERGENCE*** *and* ***OUTFLOW***
u, v only available at 200 hPa for outflow (streamlines and wind speed on above figure)

4. Initial Study: Hurricane Joaquin (2015)



Sep 29th and 30th: strong outflow channel towards S/SW prior to rapid intensification (RI)

Oct 1st: outflow becomes more oriented towards SE

Oct 2nd: interaction with upstream trough establishes northward component, just before 2nd intensification

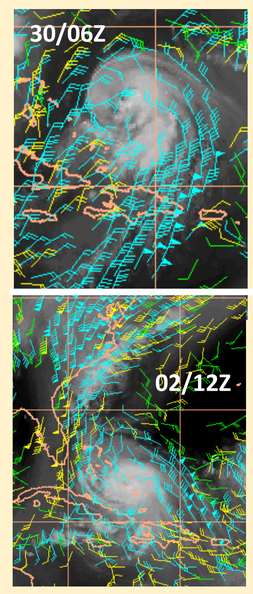
Conclusions based on correlations between variables in ECMWF ensemble

RI Phase: Predictability of initial track and RI is largely dependent on initial vortex structure

Deeper vortex <-> Lower latitude <-> Stronger southward outflow <-> RI

Predictability of 2nd intensification phase is associated with interaction with upstream trough

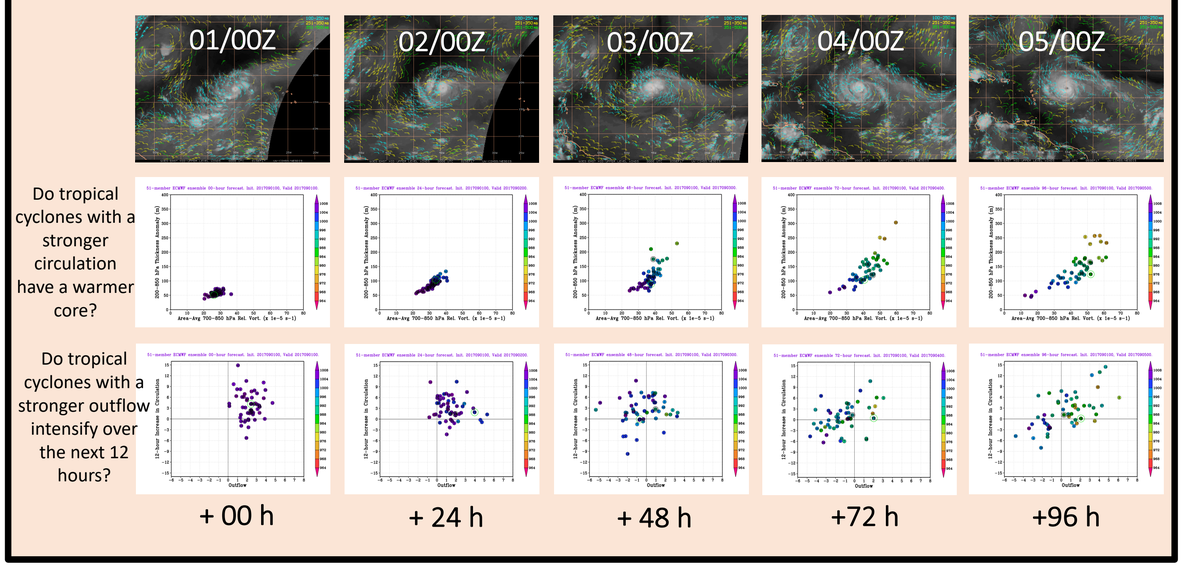
Outflow in NW quadrant <-> Intensifying hurricane



Atmospheric Motion Vectors (AMVs) provided by CIMSS / University of Wisconsin

5. Hurricane Irma (2017)

Example of relationships between variables across ECMWF ensemble forecast members initialized on 00Z Sep 1 2017



6. Preliminary Summary of 2017 Results

Circulation change (intensification) in the next 12 h correlated with
Harvey: Circulation (+), Longitude (+), Outflow (+)
Irma: Latitude (-), Outflow (+)
Jose: Circulation (-)
Katia: Circulation (-)
Lee: Outflow (+)
Maria: Circulation (-)

7. Remarks

Circulation is better correlated with **outflow** than divergence
  Caveat: sensitivity to outflow/divergence layers and radii
Modest positive correlations between outflow and intensification in next 12 hours
  Stronger correlations between outflow and previous 12-h intensification
Cannot "isolate" outflow in ensemble while keeping other conditions the same – **dependence on track** etc.
Asymmetry is important
  Need for in-situ observations in key quadrants to complement AMVs
Causality: does outflow play an **active role?**
  Hypothesis: Upper-level trough governs structure of upper-level outflow, leading to tropical cyclone structure change. Testing using idealized modeling.

Initial ensemble members usually display no relationship
  Ensemble needs 1-2 days to "adjust"
  Investigate physicality of initial ensemble TCs
  Limits scope of predictability study if analysis distribution is incorrect
Run-to-run **consistency?**

USING ECMWF'S FORECASTS (UEF 2018), 5-8 JUNE 2018, READING, UK