Using ECMWF Ensemble Products in Tropical Cyclone Field Program Planning

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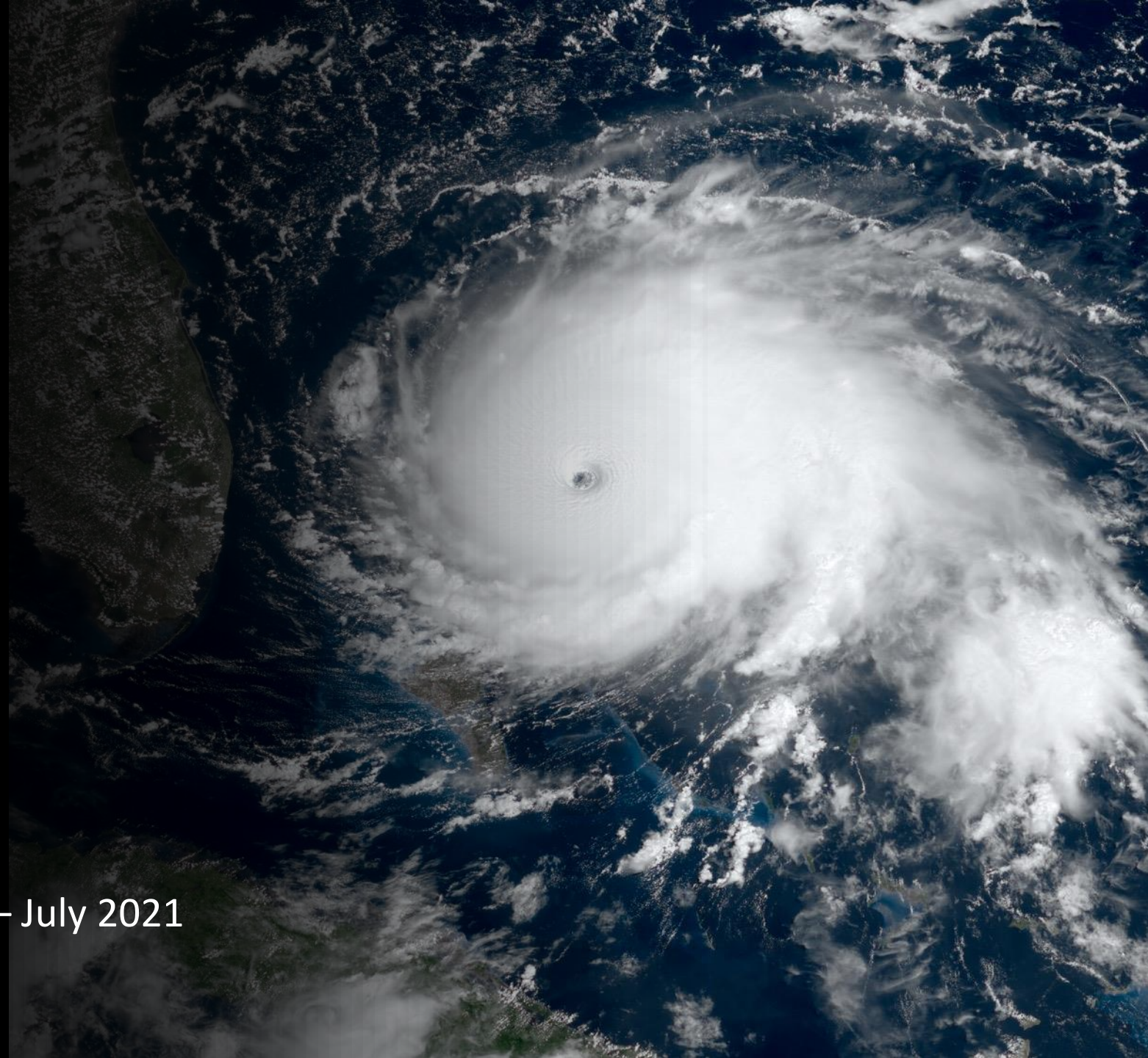
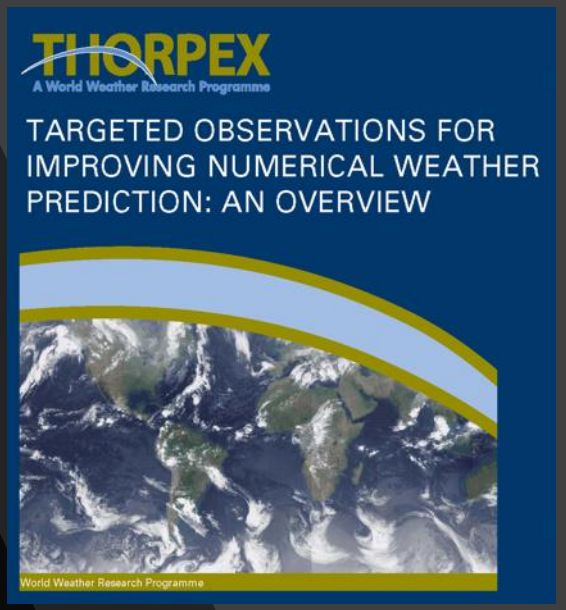
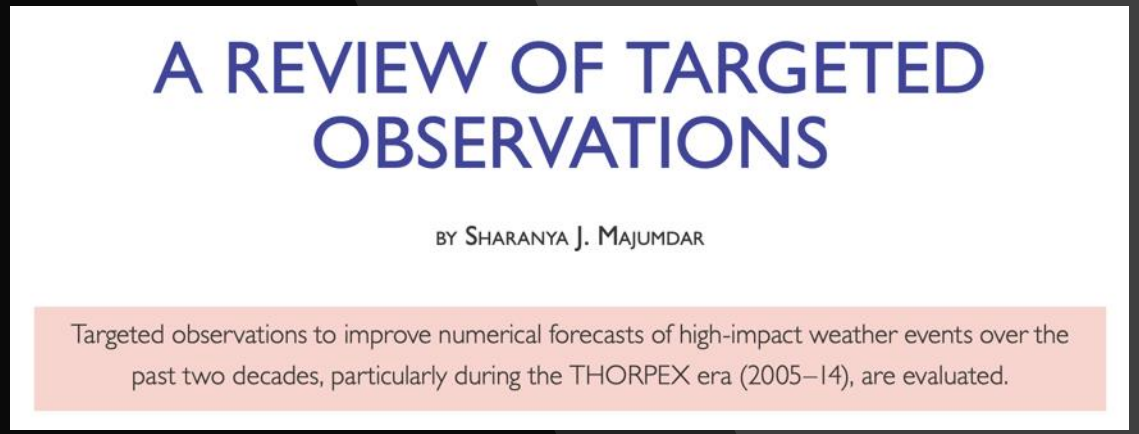


2000s: Targeted Observations to improve NWP

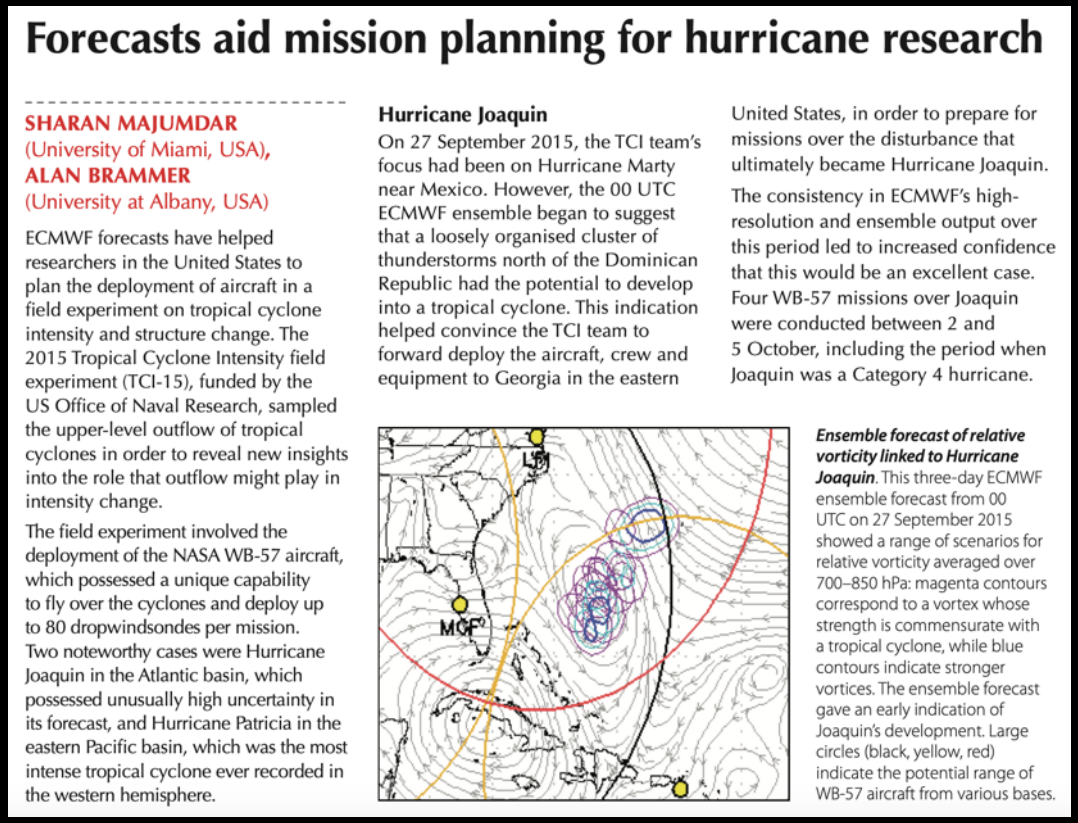
- **NOAA Winter Storm Reconnaissance**
  - Bishop et al. (2001), Szunyogh et al. (2000, 2002), Majumdar et al. (2001, 2002a, b, 2010), Petersen et al. (2007), Sellwood et al. (2008)
- **NOAA Tropical Cyclones / THORPEX**
  - Majumdar et al. (2006, 2011), Reynolds et al. (2007), Wu et al. (2009), Aberson et al. (2011)
- **Review Articles**
  - **Majumdar et al. (2011, WMO), Majumdar (2016, BAMS)**





2010s: Processes and Predictability

- **ONR Tropical Cyclone Structure (2008)**
  - Majumdar and Finocchio (2010), Yamaguchi and Majumdar (2010), Hoover et al. (2013)
- **NSF PREDICT (2010)**
  - Montgomery et al. (2012), Komaromi et al. (2014, 2015), Majumdar and Torn (2014)
- **ONR Tropical Cyclone Intensity (2015)**
  - **Majumdar and Brammer (ECMWF Newsletter, 2016),** Doyle et al. (2017), Majumdar (2020?)



Forecasts aid mission planning for hurricane research

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ALAN BRAMMER
(University at Albany, USA)

ECMWF forecasts have helped researchers in the United States to plan the deployment of aircraft in a field experiment on tropical cyclone intensity and structure change. The 2015 Tropical Cyclone Intensity field experiment (TCI-15), funded by the US Office of Naval Research, sampled the upper-level outflow of tropical cyclones in order to reveal new insights into the role that outflow might play in intensity change.

The field experiment involved the deployment of the NASA WB-57 aircraft, which possessed a unique capability to fly over the cyclones and deploy up to 80 dropwindsondes per mission. Two noteworthy cases were Hurricane Joaquin in the Atlantic basin, which possessed unusually high uncertainty in its forecast, and Hurricane Patricia in the eastern Pacific basin, which was the most intense tropical cyclone ever recorded in the western hemisphere.

Hurricane Joaquin

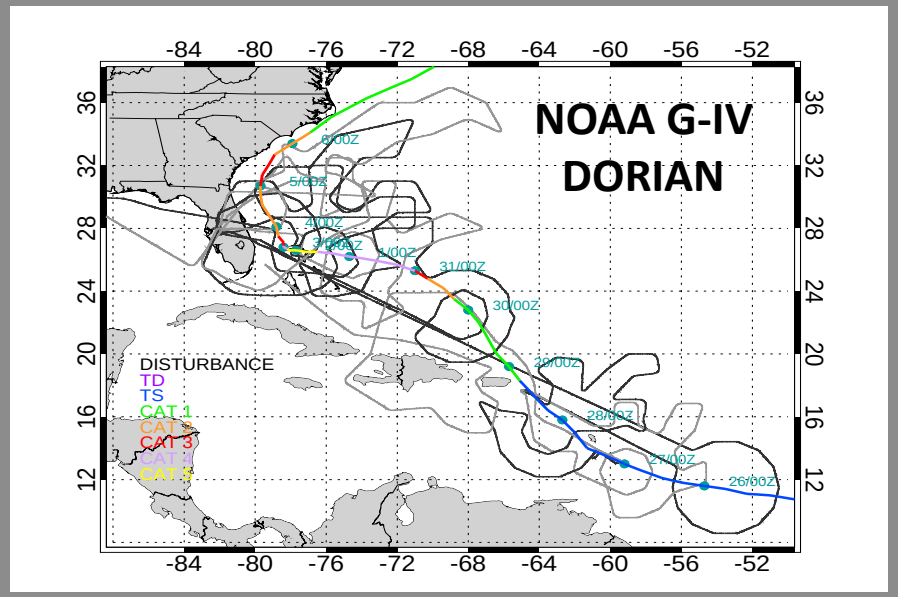
On 27 September 2015, the TCI team's focus had been on Hurricane Marty near Mexico. However, the 00 UTC ECMWF ensemble began to suggest that a loosely organised cluster of thunderstorms north of the Dominican Republic had the potential to develop into a tropical cyclone. This indication helped convince the TCI team to forward deploy the aircraft, crew and equipment to Georgia in the eastern United States, in order to prepare for missions over the disturbance that ultimately became Hurricane Joaquin.

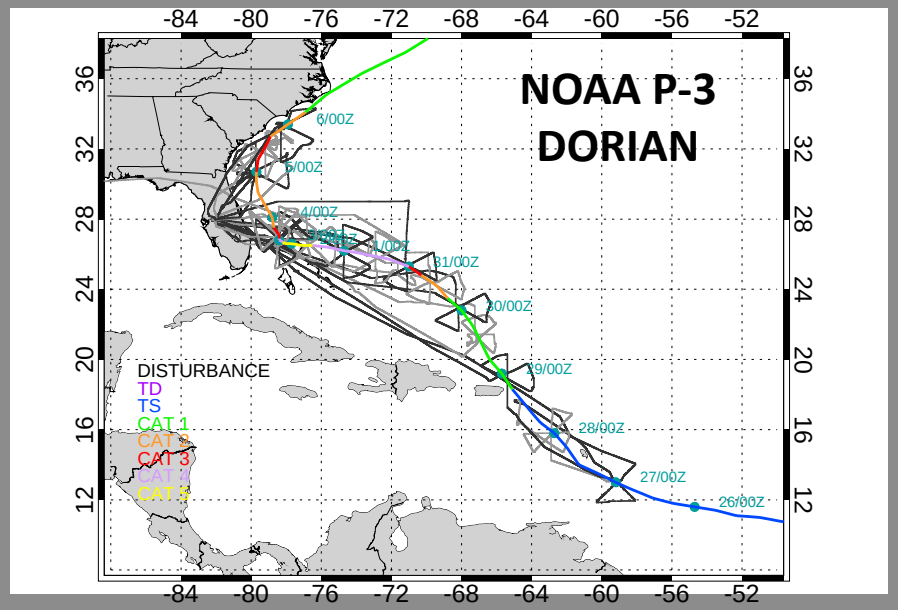
The consistency in ECMWF's high-resolution and ensemble output over this period led to increased confidence that this would be an excellent case. Four WB-57 missions over Joaquin were conducted between 2 and 5 October, including the period when Joaquin was a Category 4 hurricane.

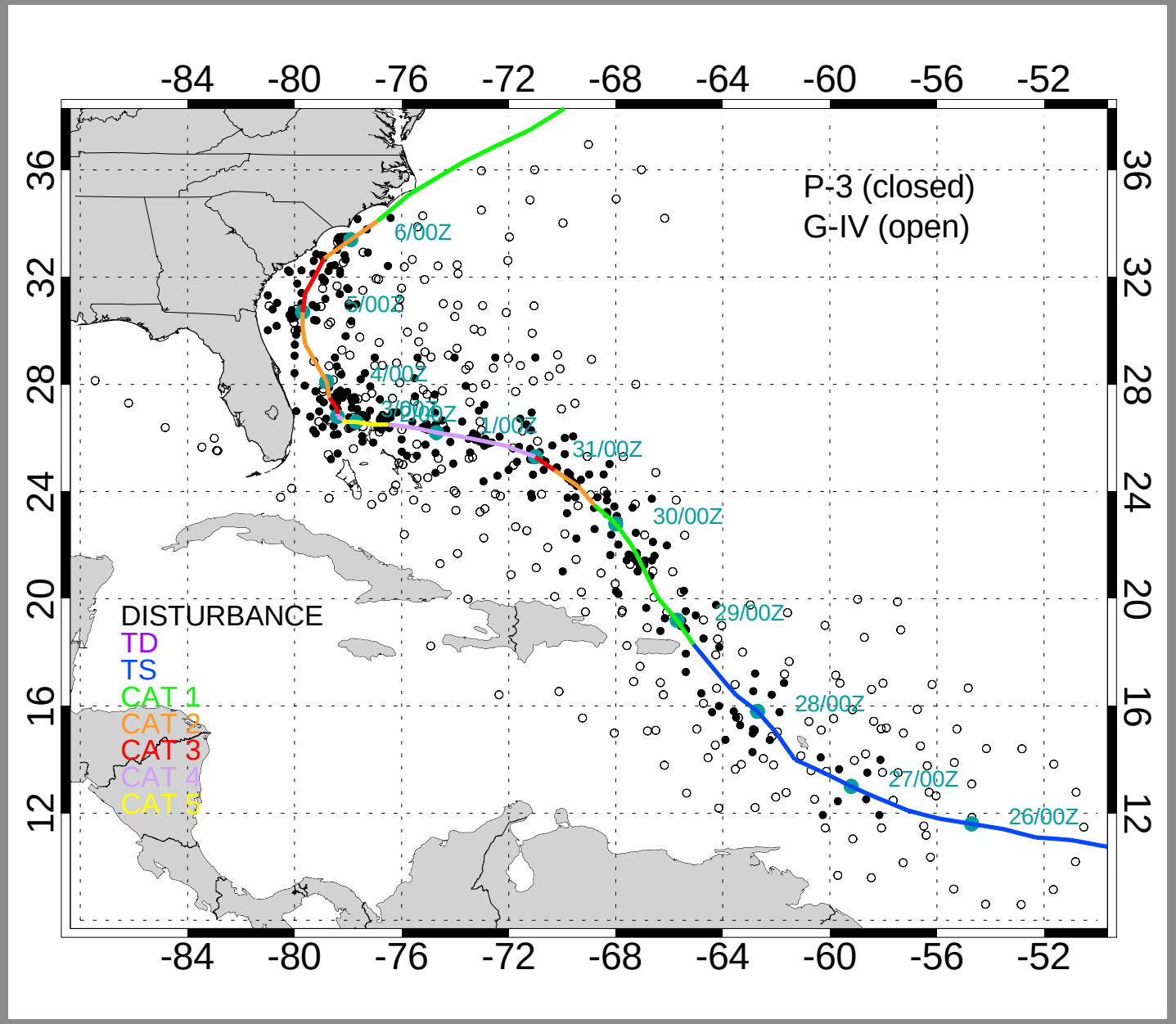
Ensemble forecast of relative vorticity linked to Hurricane Joaquin. This three-day ECMWF ensemble forecast from 00 UTC on 27 September 2015 showed a range of scenarios for relative vorticity averaged over 700–850 hPa: magenta contours correspond to a vortex whose strength is commensurate with a tropical cyclone, while blue contours indicate stronger vortices. The ensemble forecast gave an early indication of Joaquin's development. Large circles (black, yellow, red) indicate the potential range of WB-57 aircraft from various bases.

Aircraft (NOAA, NASA, NSF, US Air Force, US Navy)

Examples of instrumentation: Doppler radars, dropwindsondes, lidar, radiometers …







Jon Zawislak, UM/CIMAS/NOAA

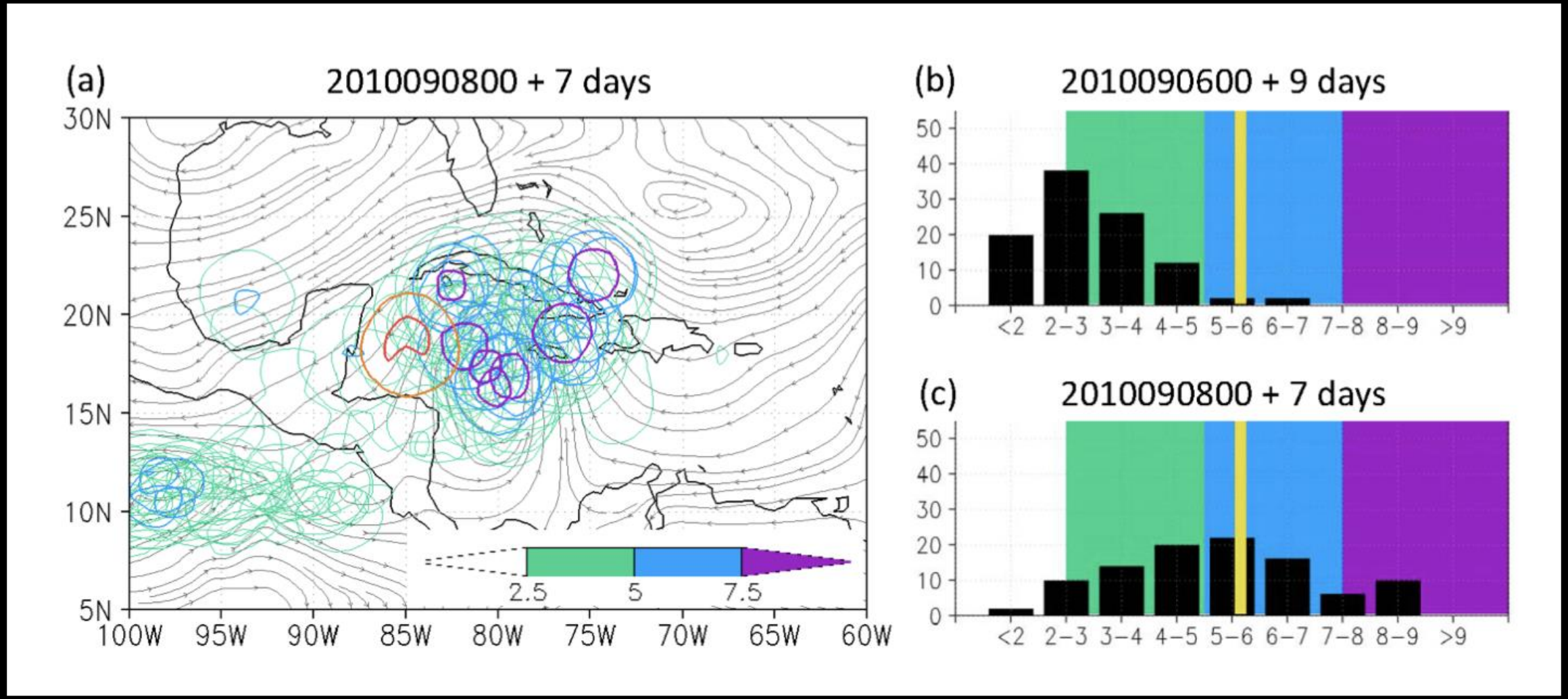
Research Mission Planning

Use **medium-range outlooks** to make decisions on deployment

- 0-10-day ECMWF ensemble forecasts
- Many other models

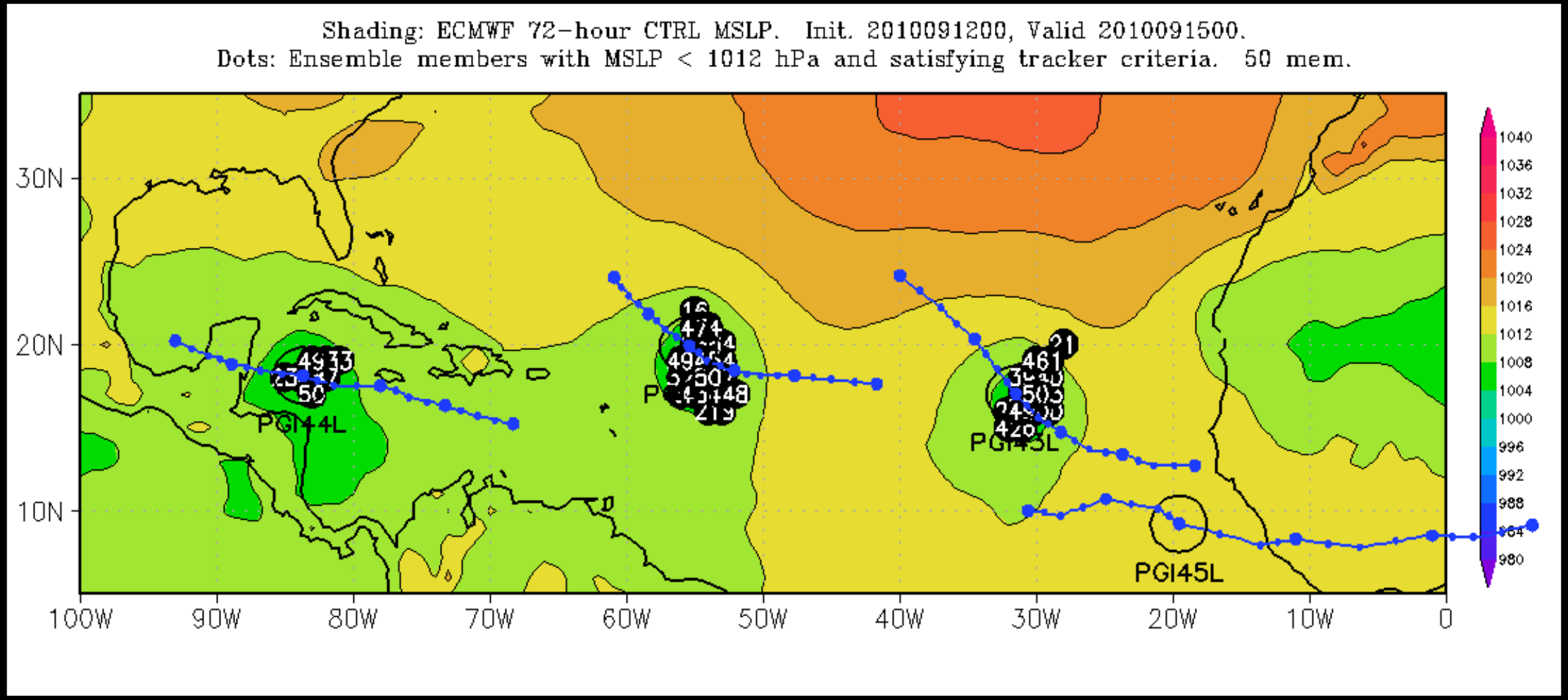
Challenges

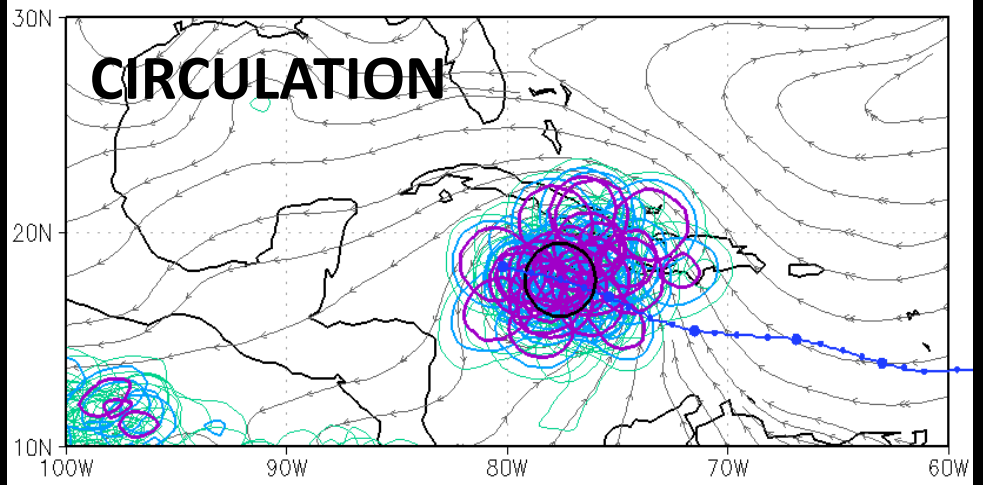
- Accurate probabilities of hurricane formation and intensification?

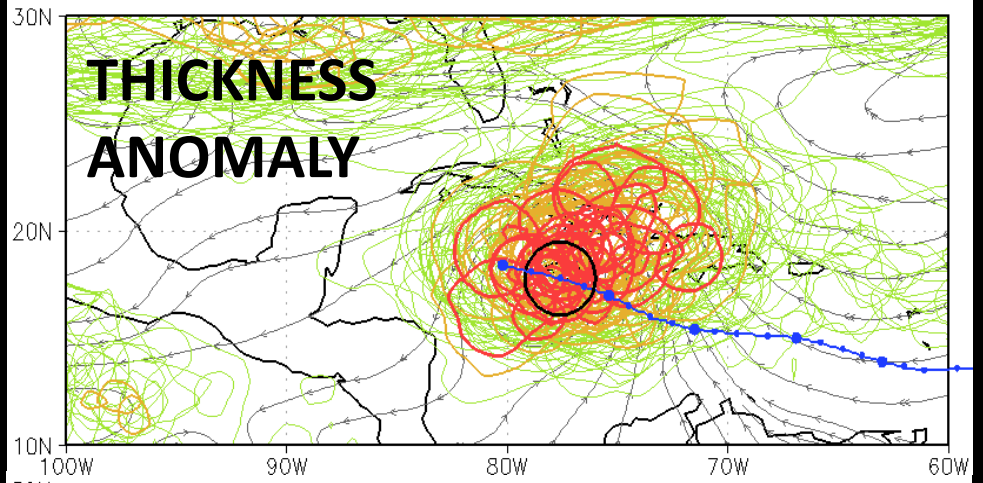


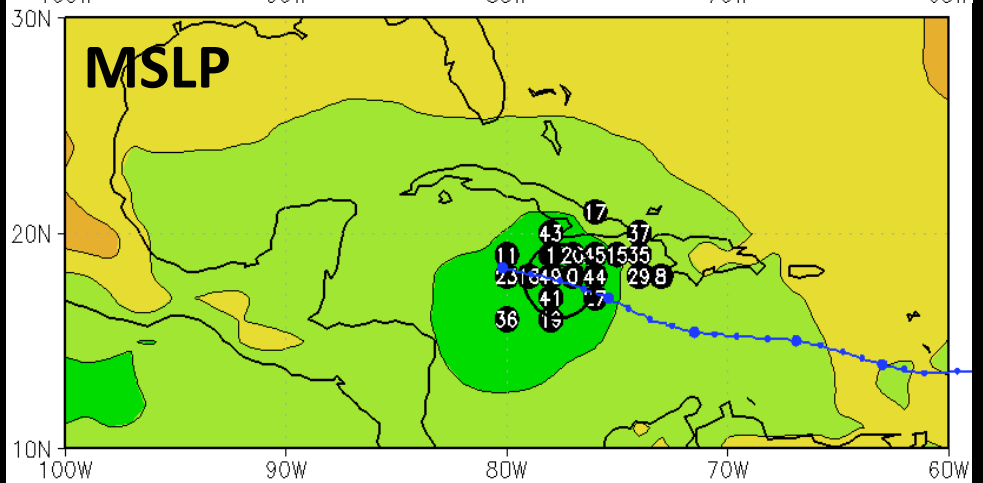
Genesis: Critical Contours of 700-850 hPa Circulation

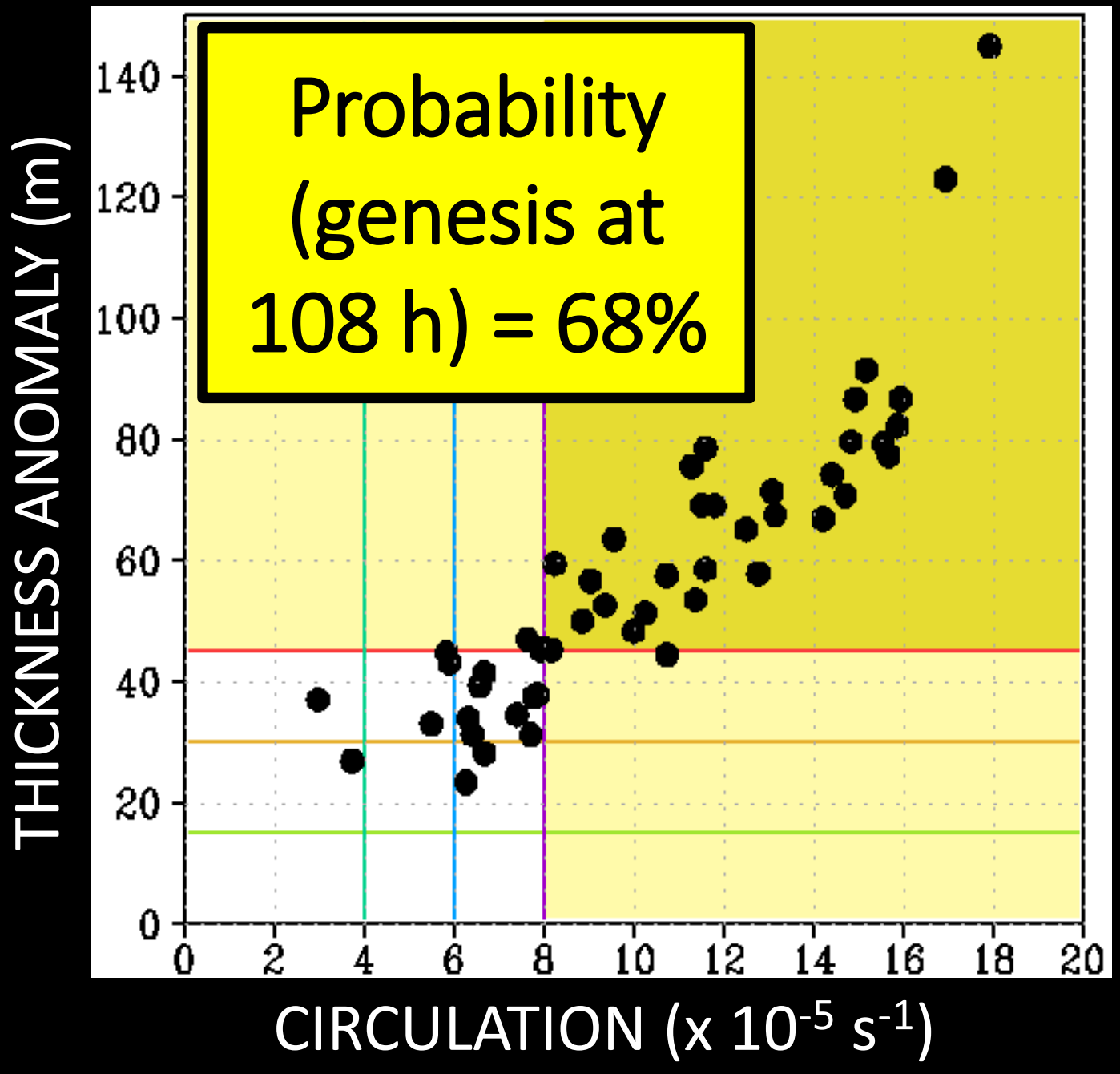
Individual Ensemble Member TC Centres and MSLP



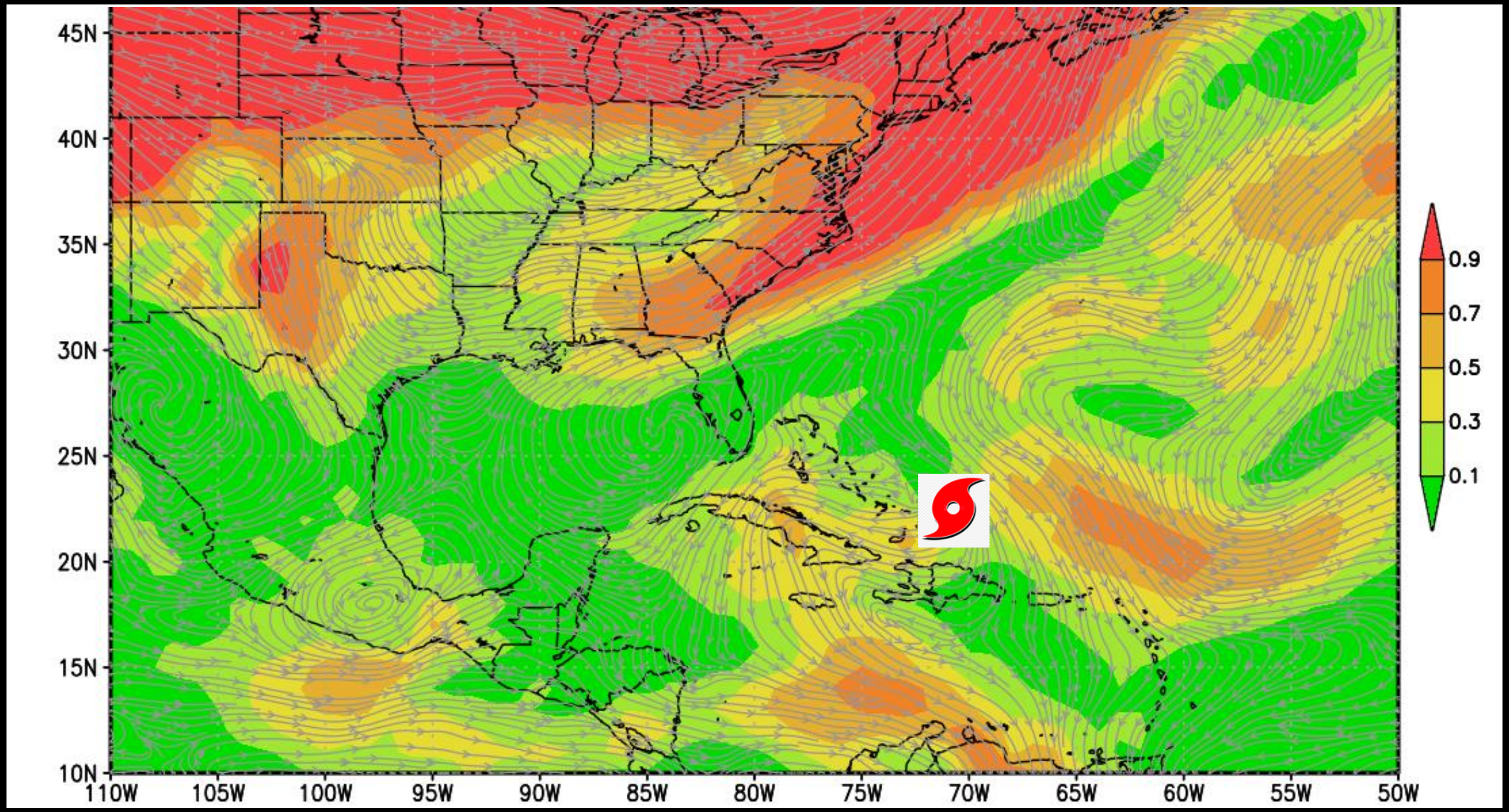

CIRCULATION
30N
20N
10N
100W
90W
80W
70W
60W


THICKNESS
ANOMALY
30N
20N
10N
100W
90W
80W
70W
60W

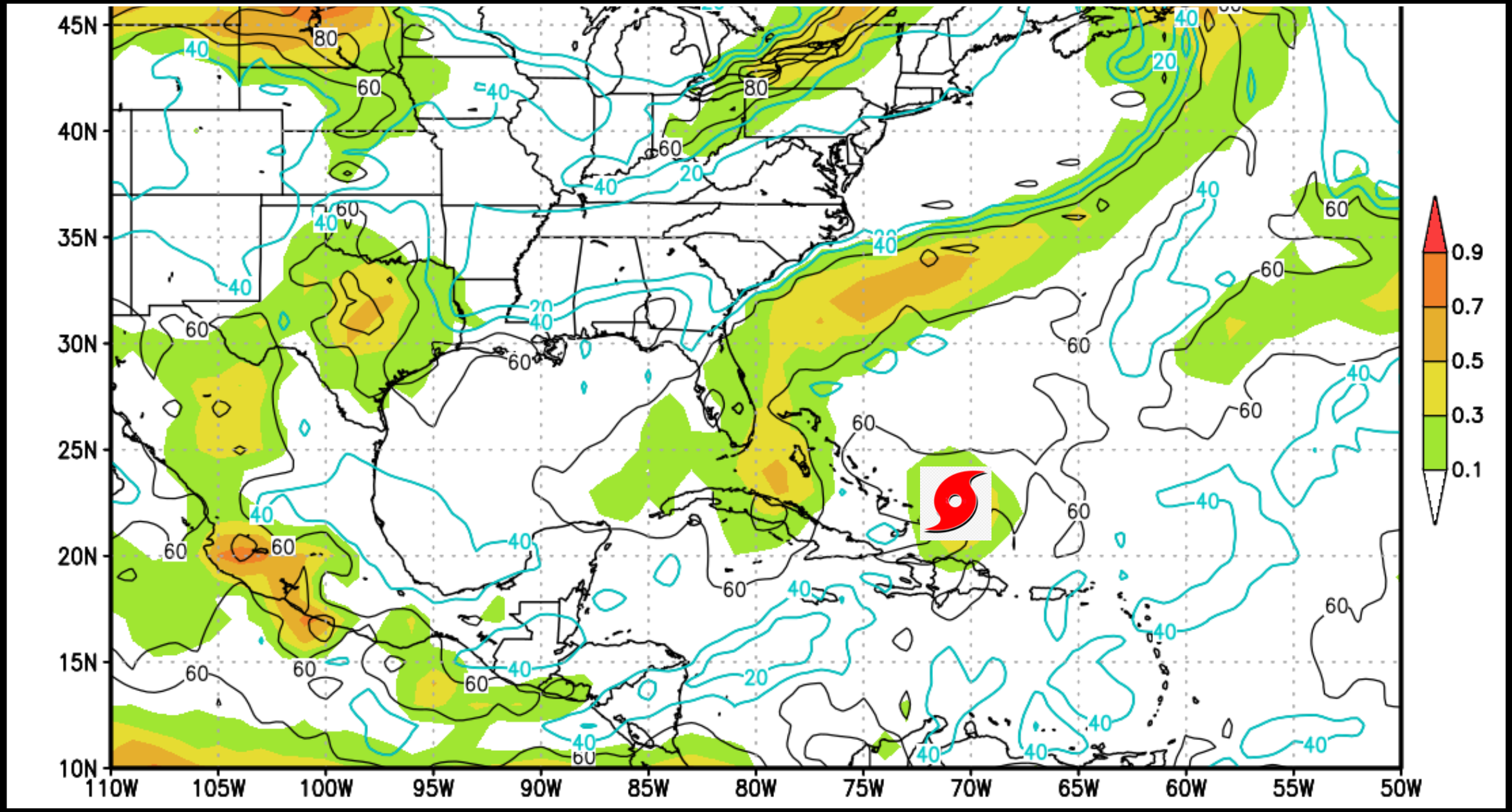

MSLP
30N
20N
10N
100W
90W
80W
70W
60W


Probability
(genesis at
108 h) = 68%
THICKNESS ANOMALY (m)
0
20
40
60
80
100
120
140
0
2
4
6
8
10
12
14
16
18
20
CIRCULATION (x 10-5 s-1)

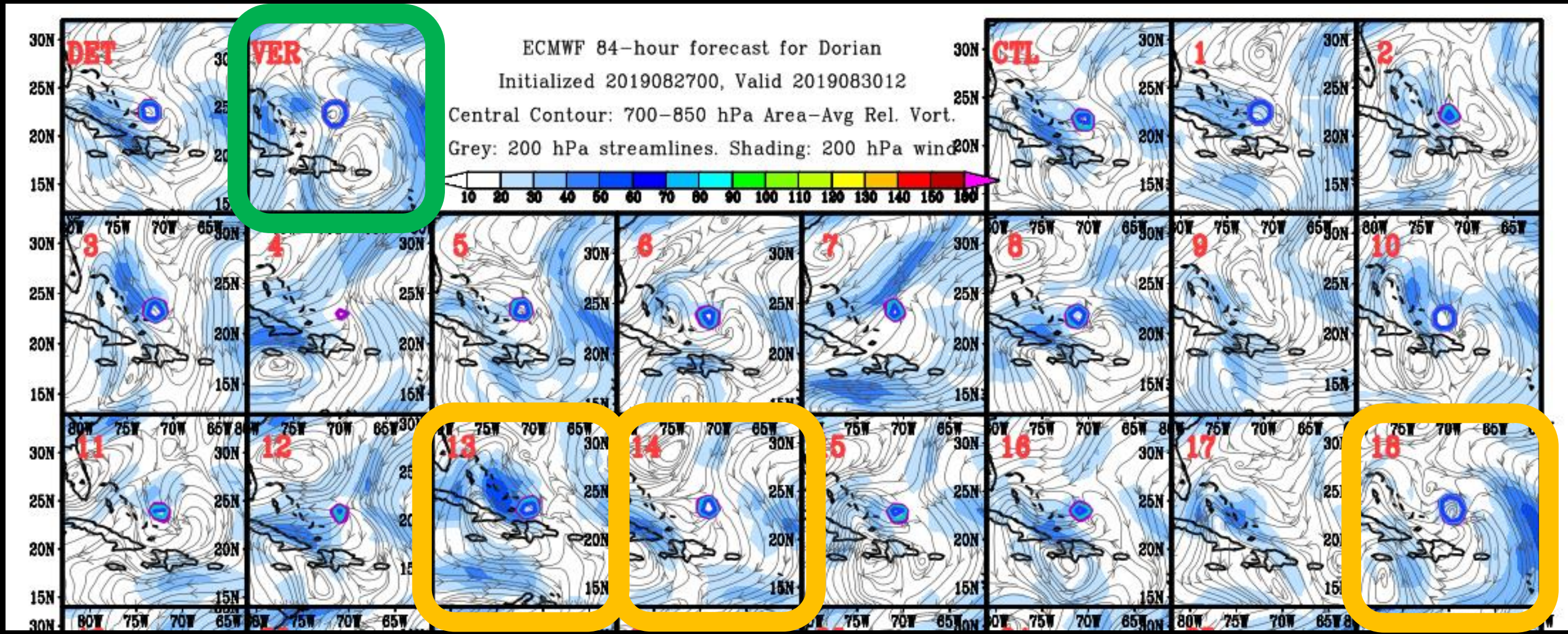
Probability of 200-850 hPa Wind Shear > 15 m/s : Dorian (2019)



Probability of 700 hPa Relative Humidity Exceeding 70% : Dorian (2019)



Is the Outflow an Agent for Intensification?



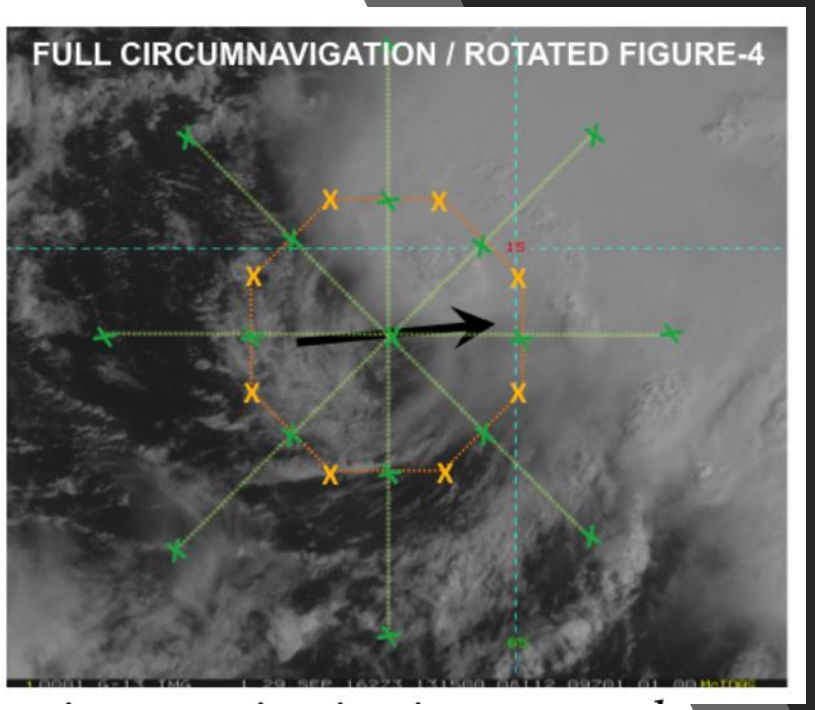
Remarks

ECMWF ensembles have been important in mission planning for over two decades.

Field campaigns accelerated the use and evaluation of experimental probabilistic products on tropical cyclone track and genesis.

New studies on predictability and processes have been advanced through the use of ECMWF ensembles in field campaigns.

2020s: Processes and Predictability



- **NOAA Hurricane Field Program**
  - Wide range of flight modules
- **ONR TC Rapid Intensification**
  - Primary and secondary circulation, size, asymmetries, surface wind field
  - Intensification rates
  - Environmental profiles
- **NSF Tropical Cyclogenesis**
  - Inner-core and environmental influences on genesis from African Easterly Waves

2020s: Hypothesis-Driven Ensemble Diagnostics and Evaluations

- **Physical Diagnostics of Tropical Cyclone and Environmental Structure**
  - (Beyond track and intensity)
  - **Surface wind structure**
  - **Environmental vertical wind, moisture profiles**

- **Ensemble Evaluations**
  - **Genesis probabilities**
  - **Probabilistic intensification rates**