# Ensemble-based diagnostics of tropical cyclone outflow

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Collaborators: Chris Velden (CIMSS / U. Wisconsin)
Jim Doyle, Will Komaromi et al. (NRL)


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# Hypotheses in Original Proposal

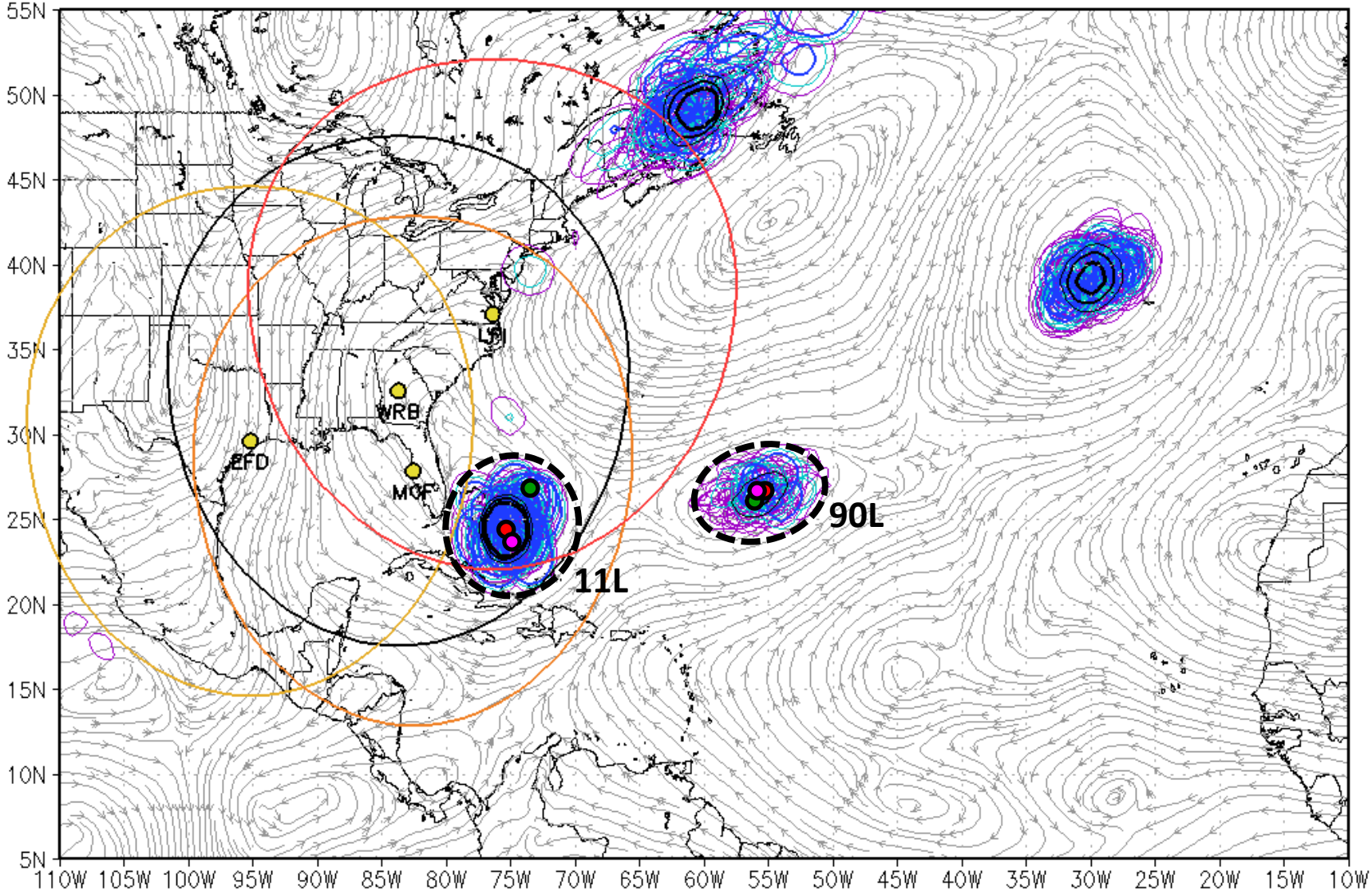
**The predictability of the outflow (and thereby TC structure) is largely modulated by the environment.**

- Development of outflow channels is sensitive to small perturbations in the mid-latitude jet
- Relative phase between TC and environmental features is critical in the establishment of outflow channels
- Modifications to outflow structure influence both TC structure and environmental features
- Perturbations to outflow and environment are crucial to create diversity in ensemble perturbations

# Research Group Efforts

- Ensemble-based guidance in TCI field campaigns (Majumdar)
- Ensemble diagnostics (Majumdar and NRL)
- Use TCI observations to inform of outflow layer wind profiles (McNoldy and CIMSS)
- Perturbation and sensitivity studies (Dai)

Gray: ECMWF 72-hour DETERM streamlines of 700-850 hPa ave wind. Init. 2015092900, Valid 2015100200.
Color: ENSEMBLE 700-850 hPa area-avg rel. vort. 50 members. Black: DETERM.




This plot is shared with the TCI team as per a licence with ECMWF. Please do not disseminate the plots or login info outside TCI personnel.

**Valid 02/00z (Thursday evening)**

- 29/00z ECdet (978 mb)
- 29/00z GFSdet (mb)
- 29/12z ECdet (972 mb)
- 29/12z GFSdet (997 mb)

Gray: ECMWF 84-hour DETERM streamlines of 700-850 hPa ave wind. Init. 2015092900, Valid 2015100212.
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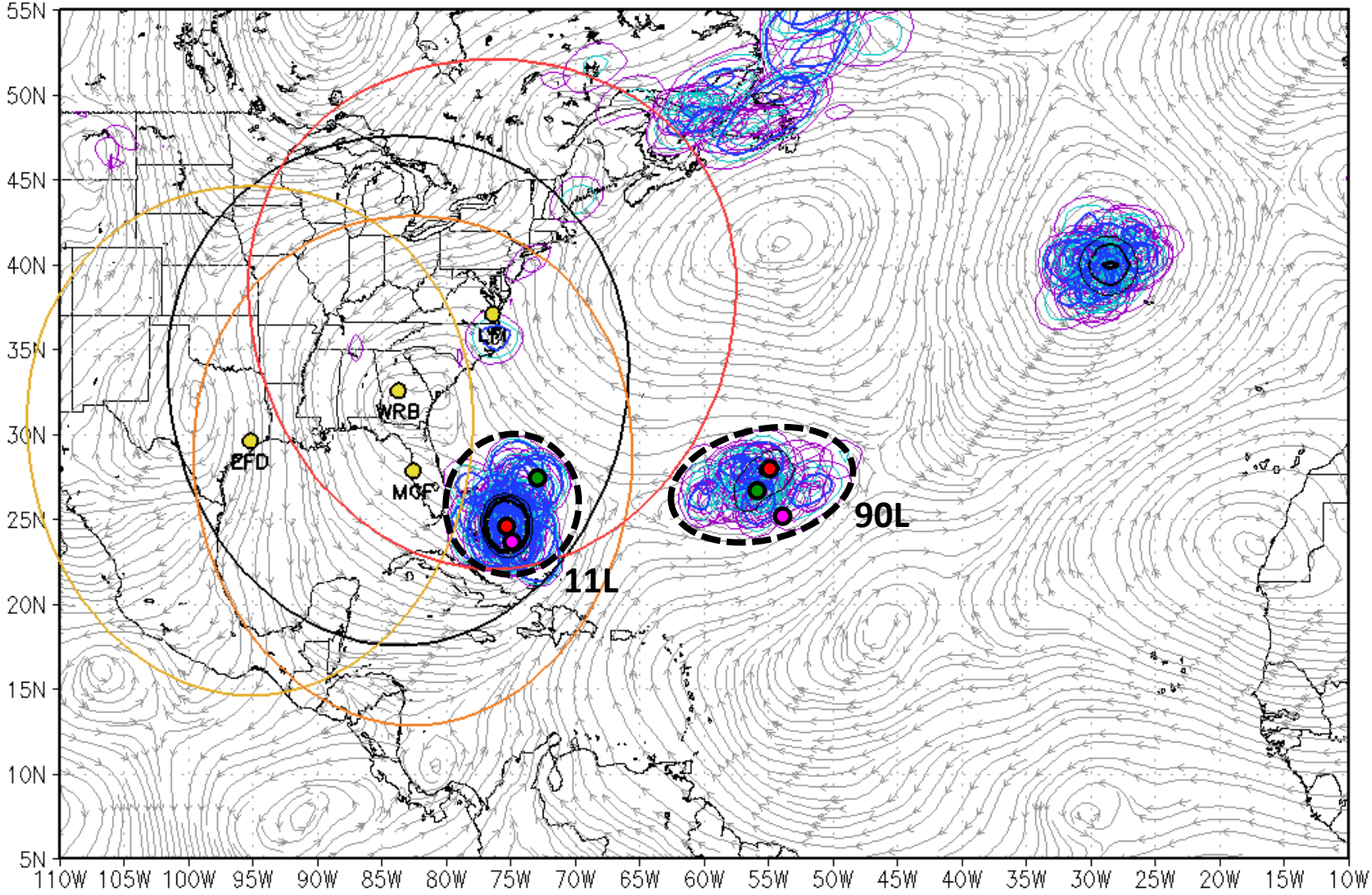


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**Valid 02/12z (Friday morning)**

- 29/00z ECdet (965 mb)
- 29/00z GFSdet (mb)
- 29/12z ECdet (958 mb)
- 29/12z GFSdet (996 mb)

Gray: ECMWF 96-hour DETERM streamlines of 700-850 hPa ave wind. Init. 2015092900, Valid 2015100300.
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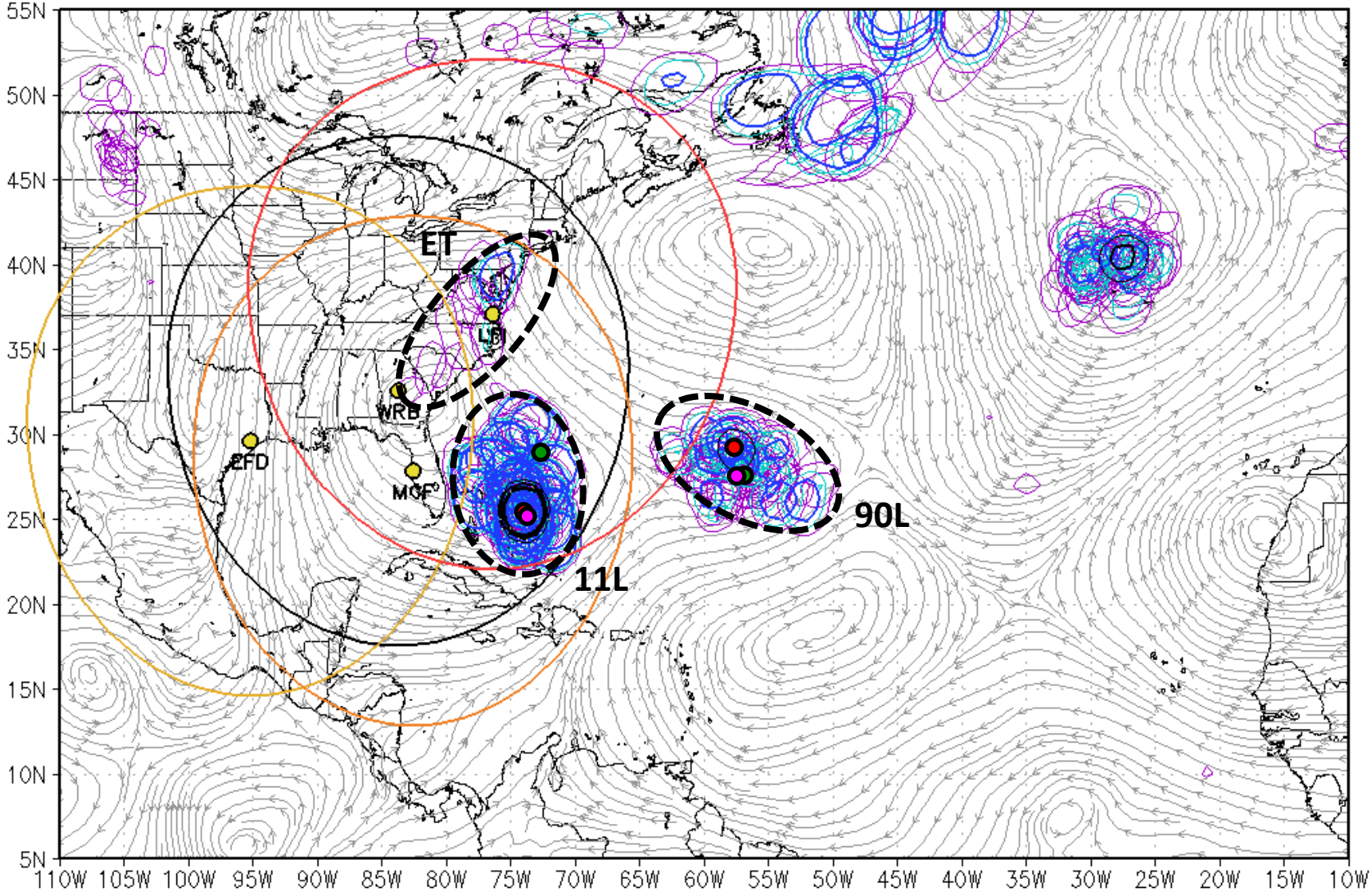


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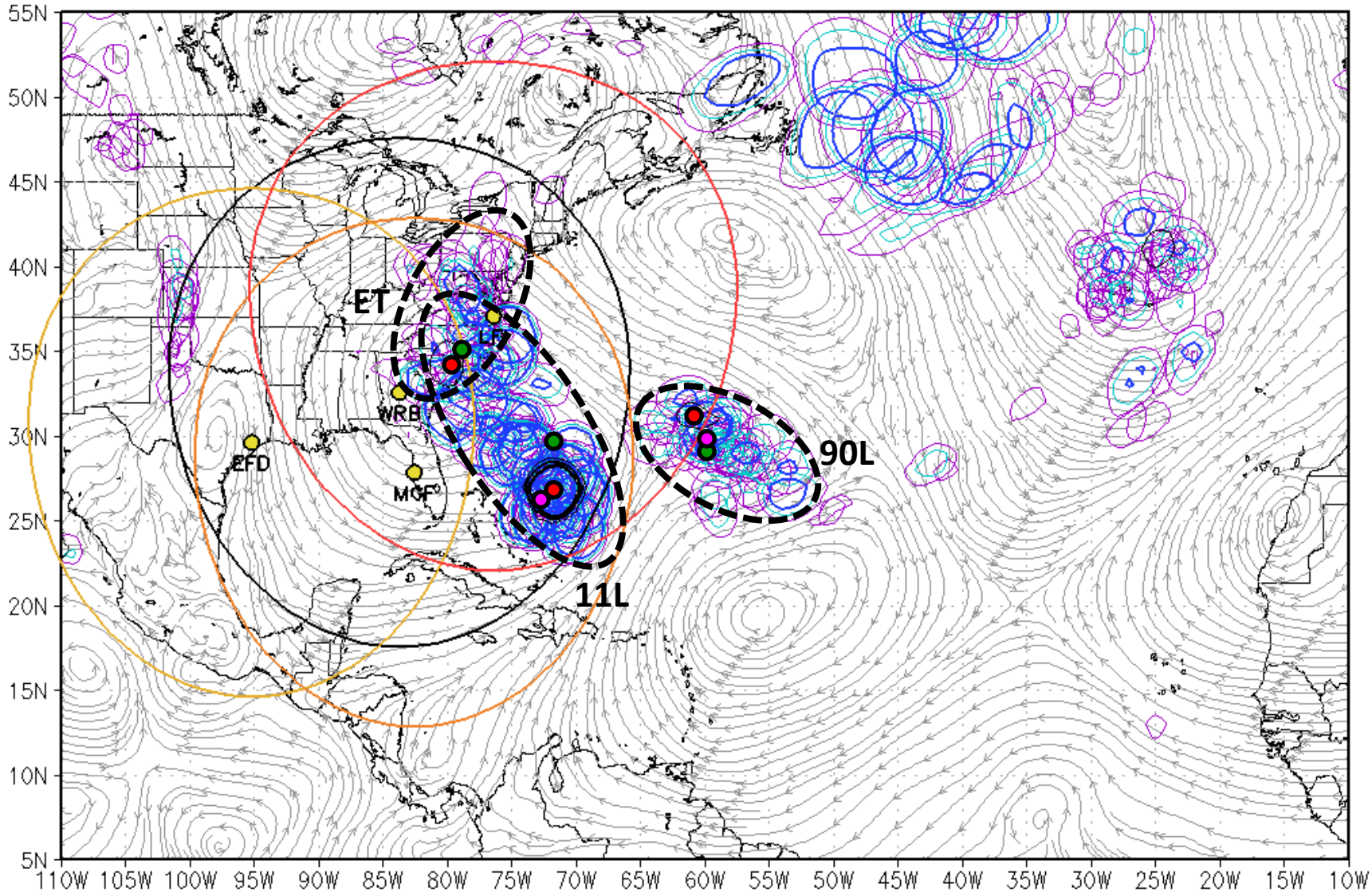
**Valid 03/00z (Friday evening)**

- 29/00z ECdet (964 mb)
- 29/00z GFSdet (mb)
- 29/12z ECdet (958 mb)
- 29/12z GFSdet (996 mb)

Gray: ECMWF 108-hour DETERM streamlines of 700-850 hPa ave wind. Init. 2015092900, Valid 2015100312.
Color: ENSEMBLE 700-850 hPa area-avg rel. vort. 50 members. Black: DETERM.

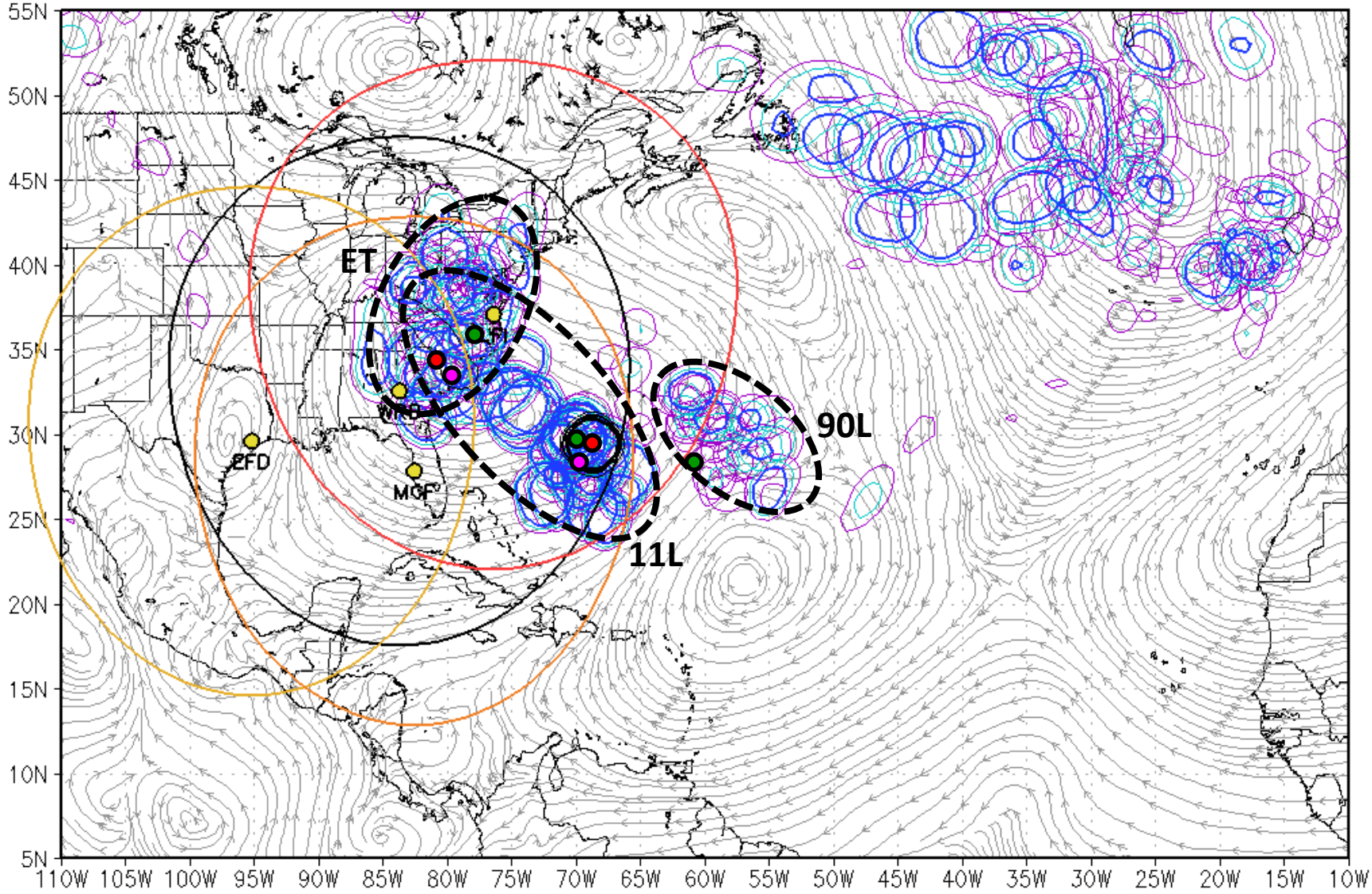



This plot is shared with the TCI team as per a licence with ECMWF. Please do not disseminate the plots or login info outside TCI personnel.

**Valid 03/12z (Saturday morning)**

- 29/00z ECdet (959 mb)
- 29/00z GFSdet (mb)
- 29/12z ECdet (951 mb)
- 29/12z GFSdet (995 mb)

Gray: ECMWF 120-hour DETERM streamlines of 700-850 hPa ave wind. Init. 2015092900, Valid 2015100400.
Color: ENSEMBLE 700-850 hPa area-avg rel. vort. 50 members. Black: DETERM.

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**Valid 04/00z (Saturday evening)**

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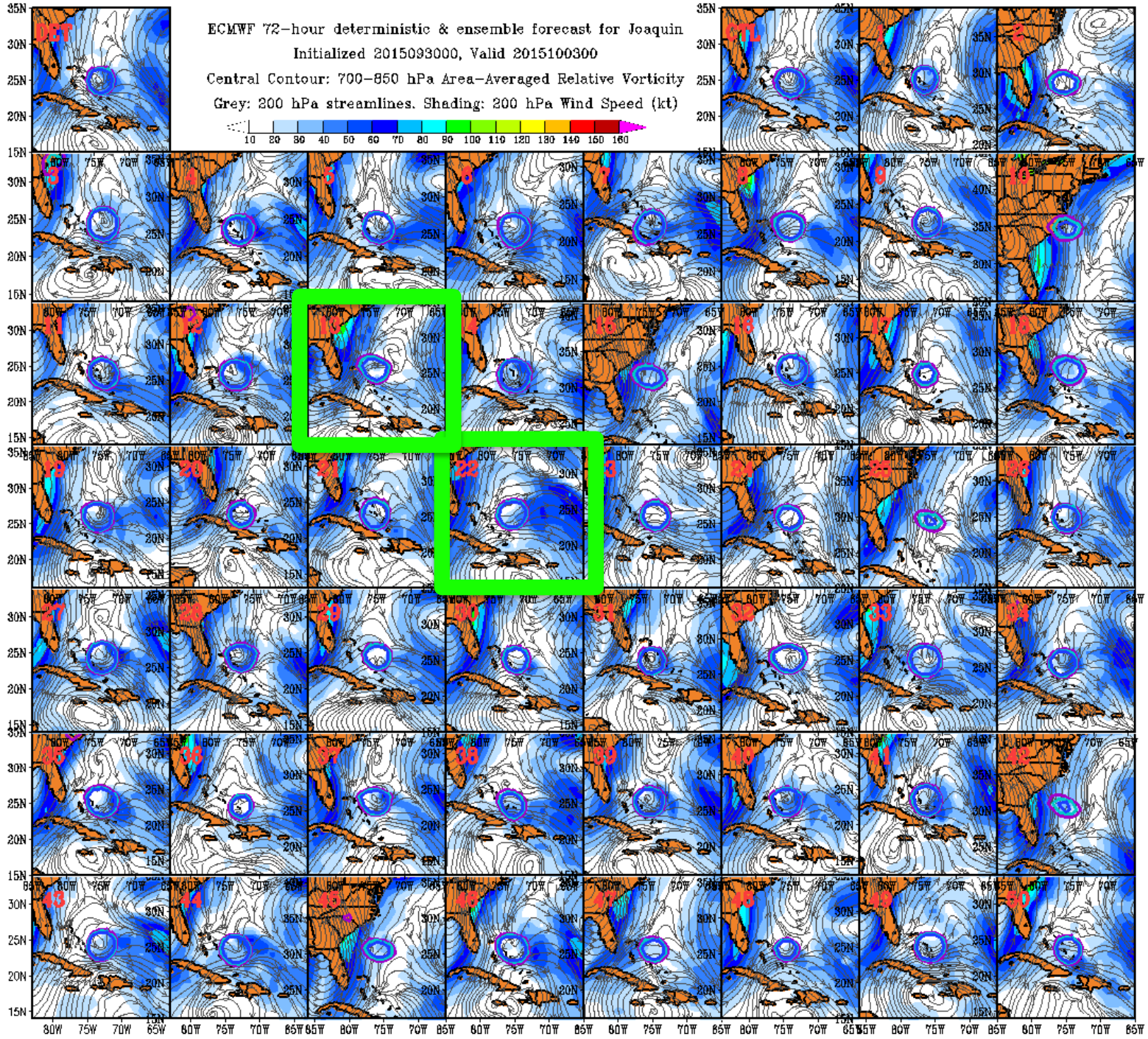
- 29/00z GFSdet (mb)
- 29/12z ECdet (960 mb)
- 29/12z GFSdet (997 mb)


ECMWF 72-hour deterministic & ensemble forecast for Joaquin
Initialized 2015093000, Valid 2015100300
Central Contour: 700-850 hPa Area-Averaged Relative Vorticity
Grey: 200 hPa streamlines. Shading: 200 hPa Wind Speed (kt)
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160
DET
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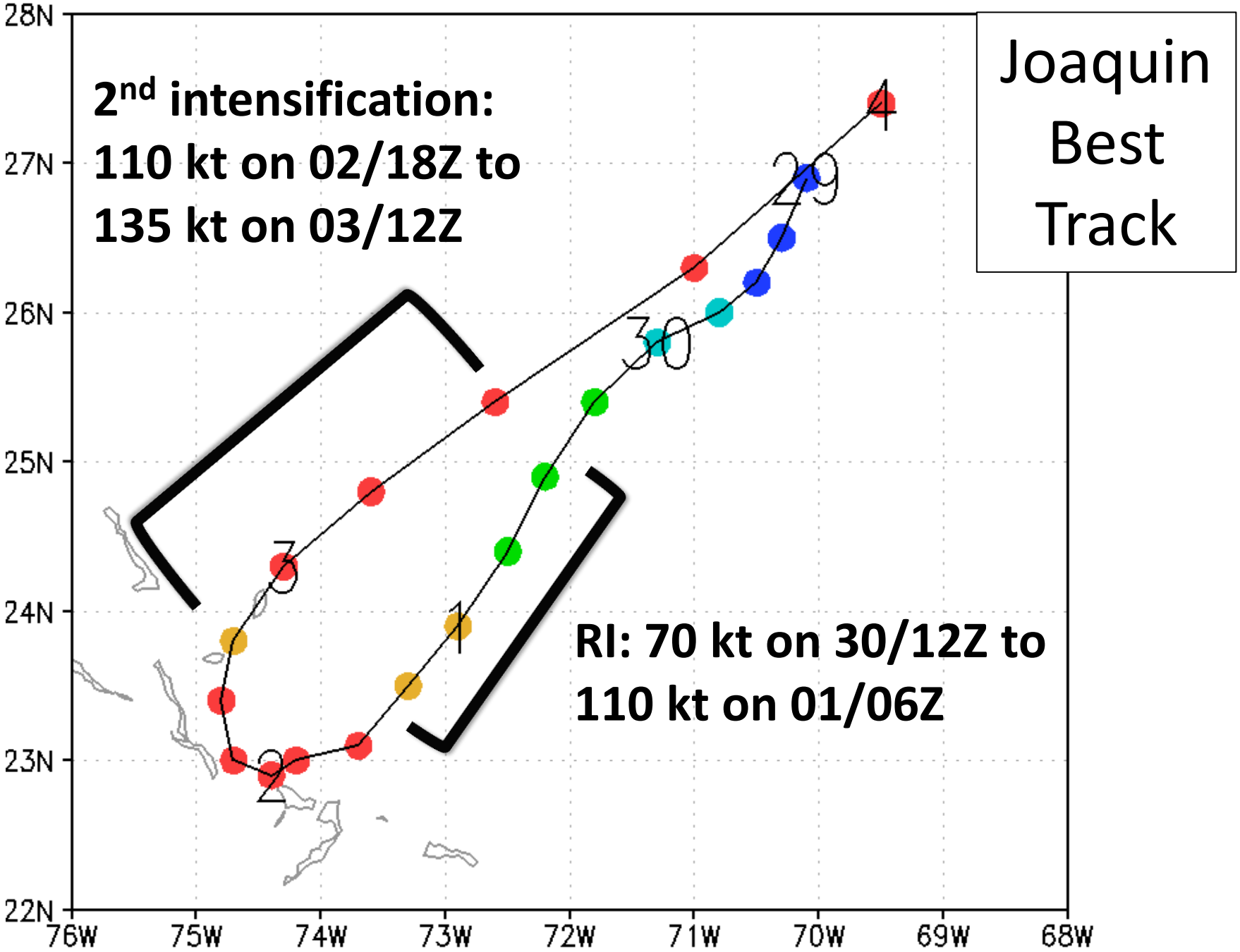
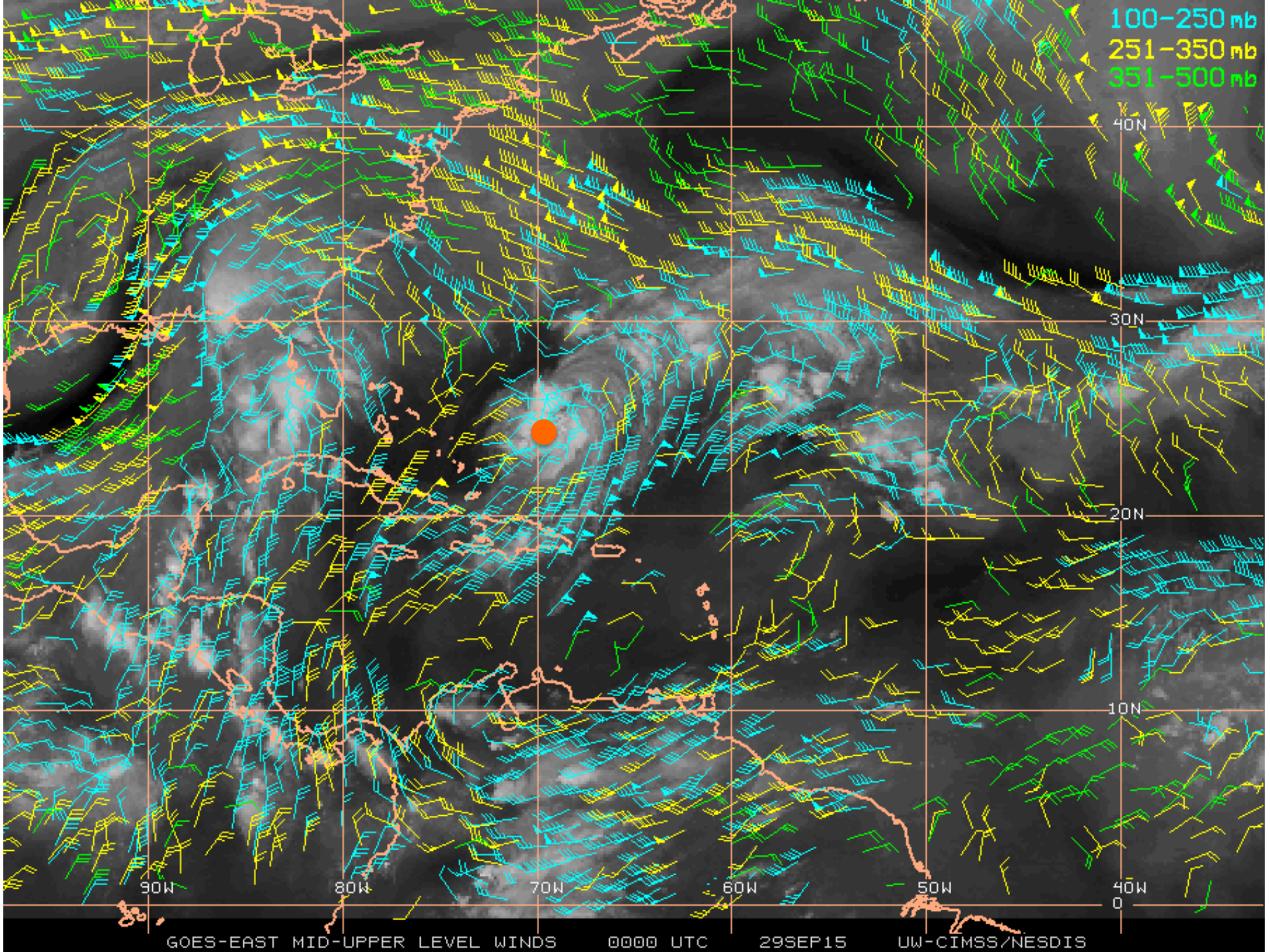
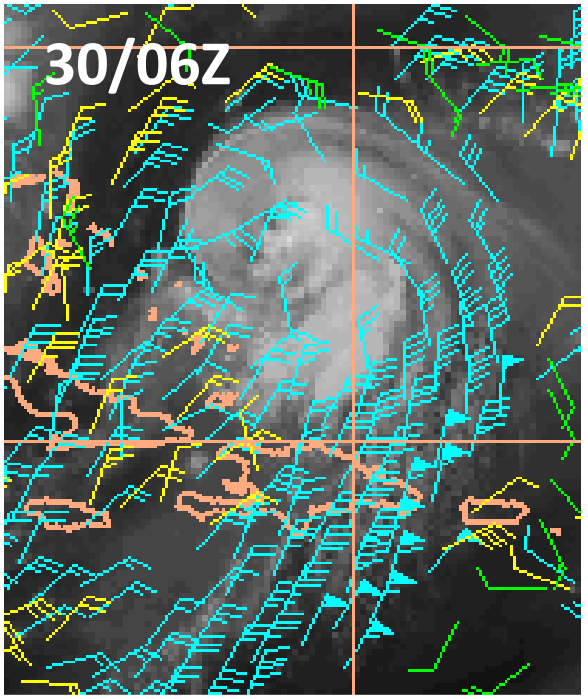
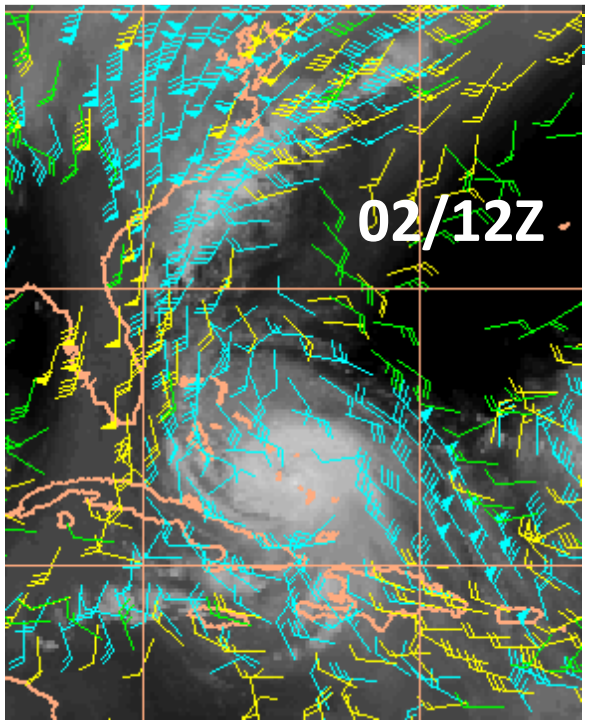

Joaquin
Best
Track
2nd intensification:
110 kt on 02/18Z to
135 kt on 03/12Z
RI: 70 kt on 30/12Z to
110 kt on 01/06Z
28N
27N
26N
25N
24N
23N
22N
76W
75W
74W
73W
72W
71W
70W
69W
68W
29
30
1
2
3
4


100-250 mb
251-350 mb
351-500 mb
40N
30N
20N
10N
0
90W
80W
70W
60W
50W
40W
GOES-EAST MID-UPPER LEVEL WINDS 0000 UTC 29SEP15 UW-CIMSS/NESDIS

# Outflow

- **Sep 29th and 30th:** strong outflow channel towards S/SW prior to RI
- **Oct 1st:** outflow becomes more oriented towards SE
- **Oct 2nd:** interaction with upstream trough establishes northward component, just before 2nd intensification

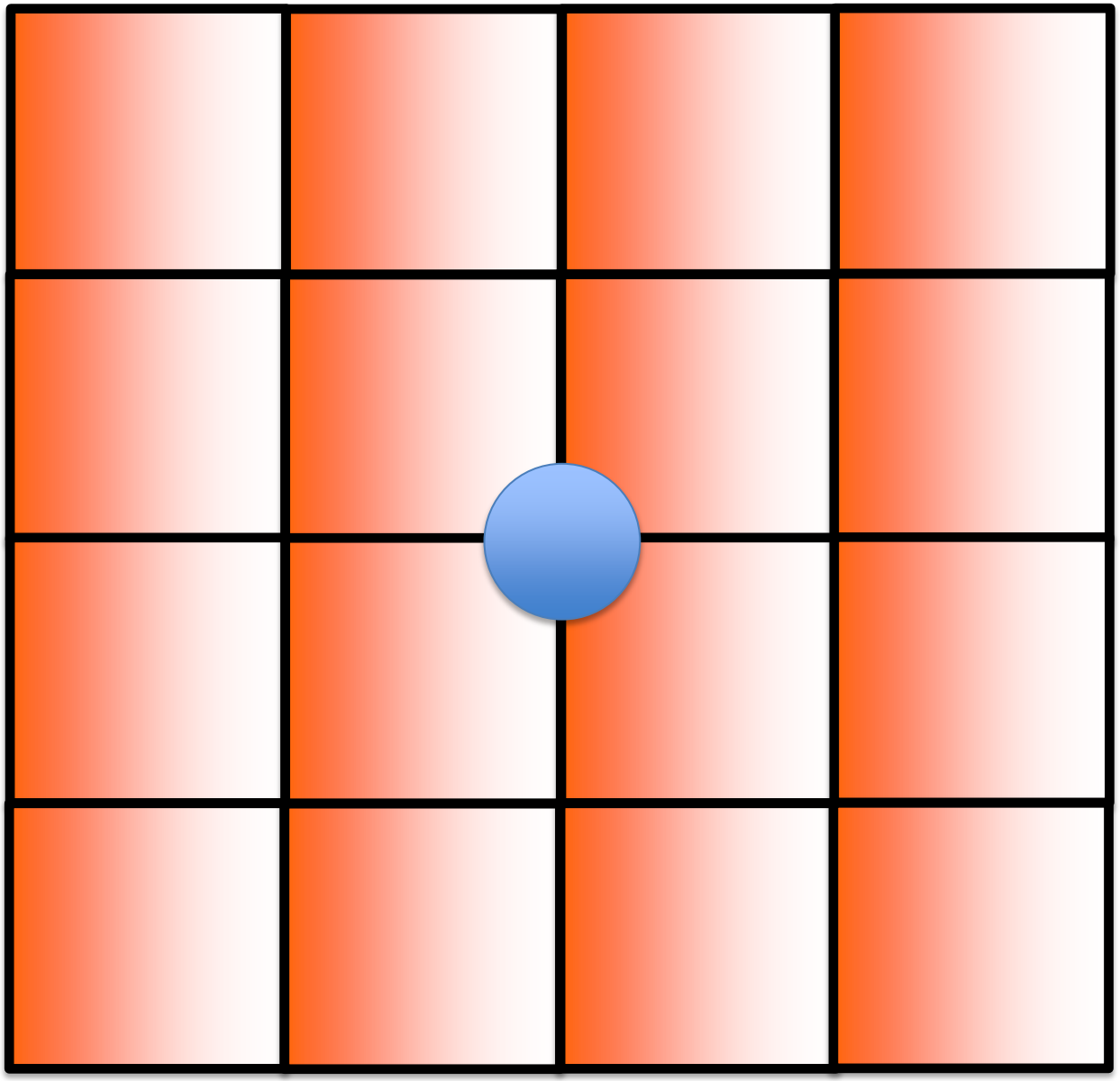


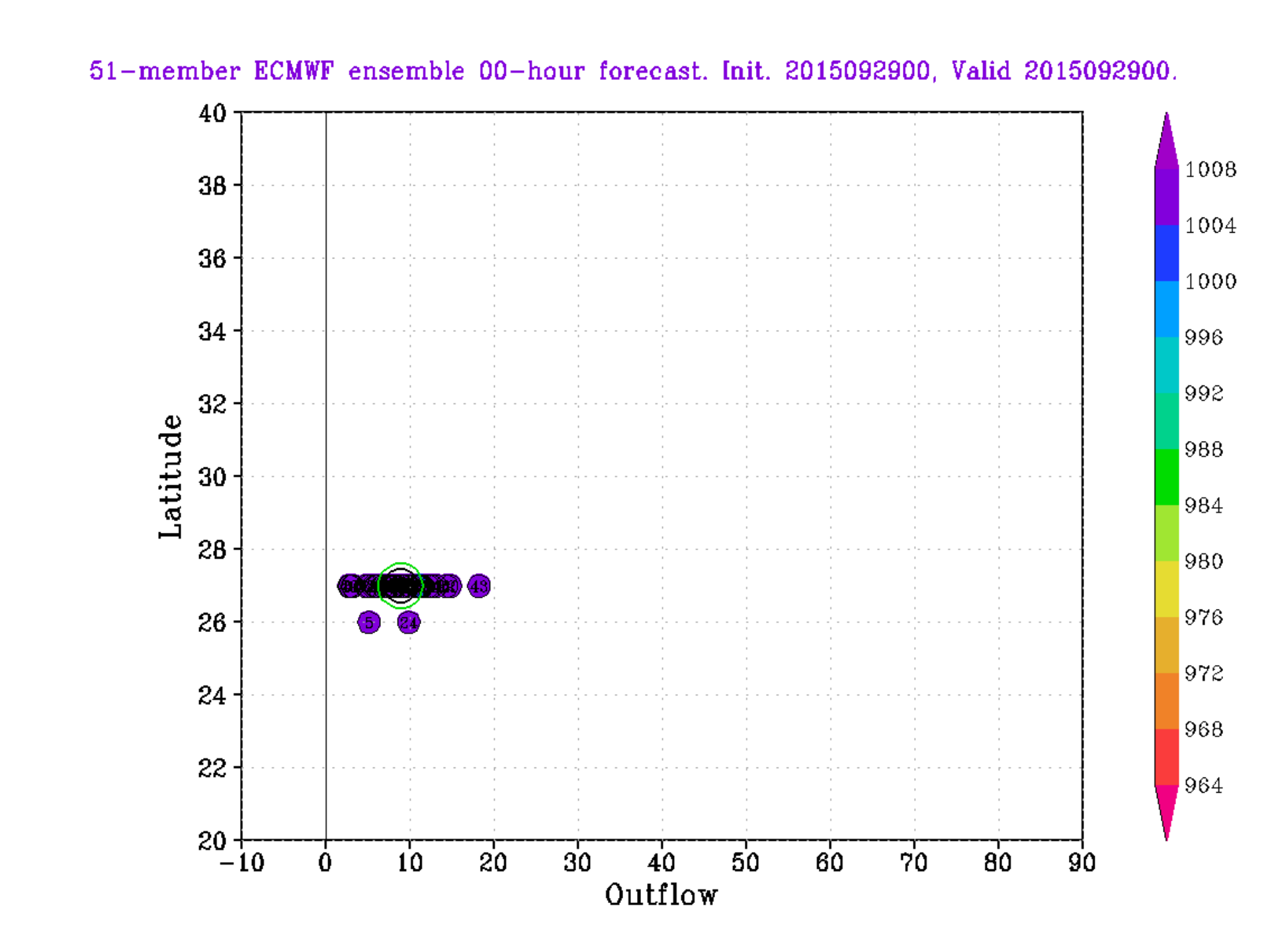
# ECMWF Data

- Fields on 1 x 1 grid
  - 51 ensemble forecasts
  - High-resolution (deterministic) forecast
  - ECMWF analysis (used as verification)

# Crude Computation of 100-300 hPa Outflow



For the 1st intensification: Is outflow correlated with intensity and latitude?


51-member ECMWF ensemble 00-hour forecast. Init. 2015092900, Valid 2015092900.
Latitude
Outflow
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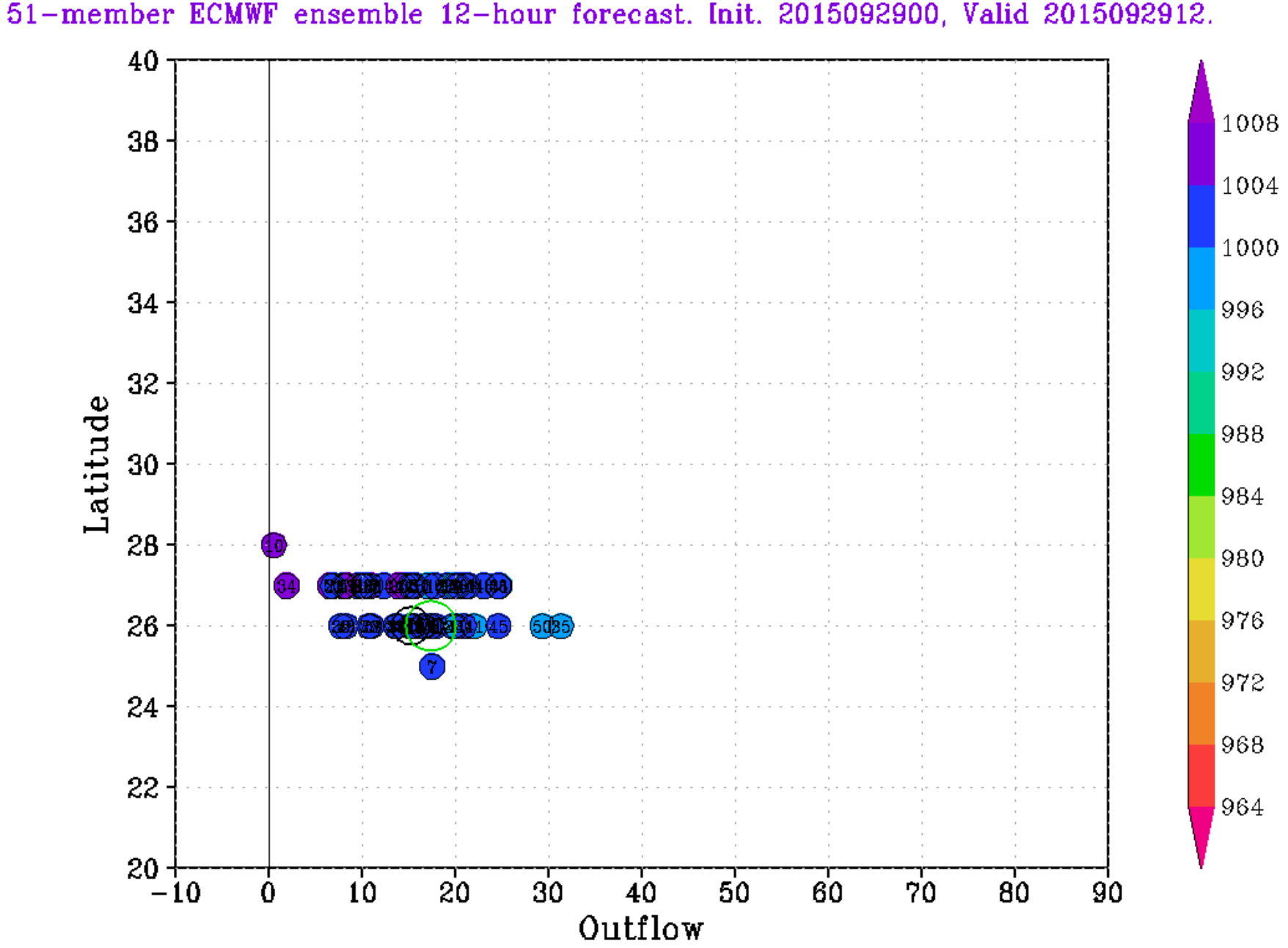
51-member ECMWF ensemble 12-hour forecast. Init. 2015092900, Valid 2015092912.
Latitude
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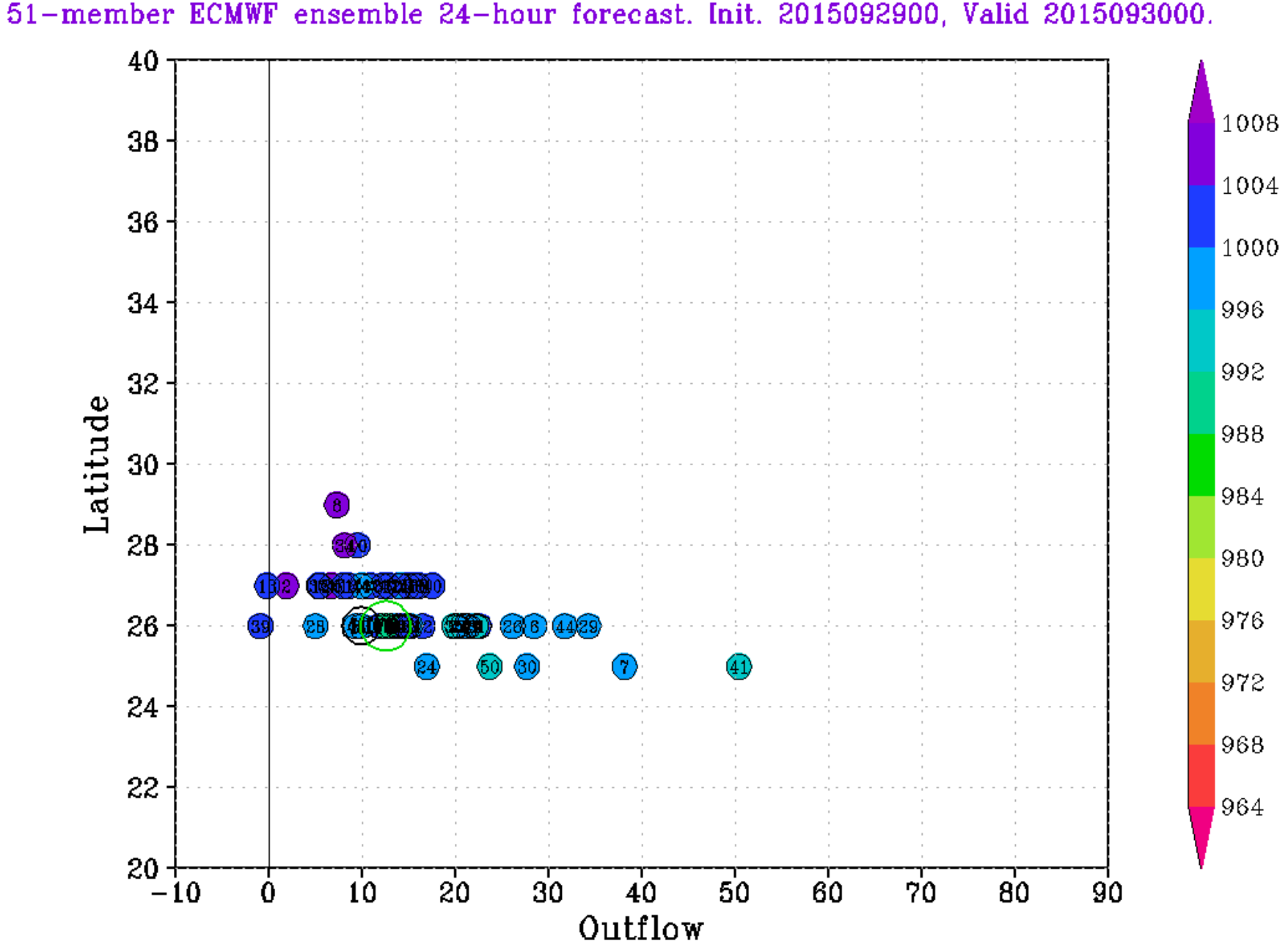
51-member ECMWF ensemble 24-hour forecast. Init. 2015092900, Valid 2015093000.
Latitude
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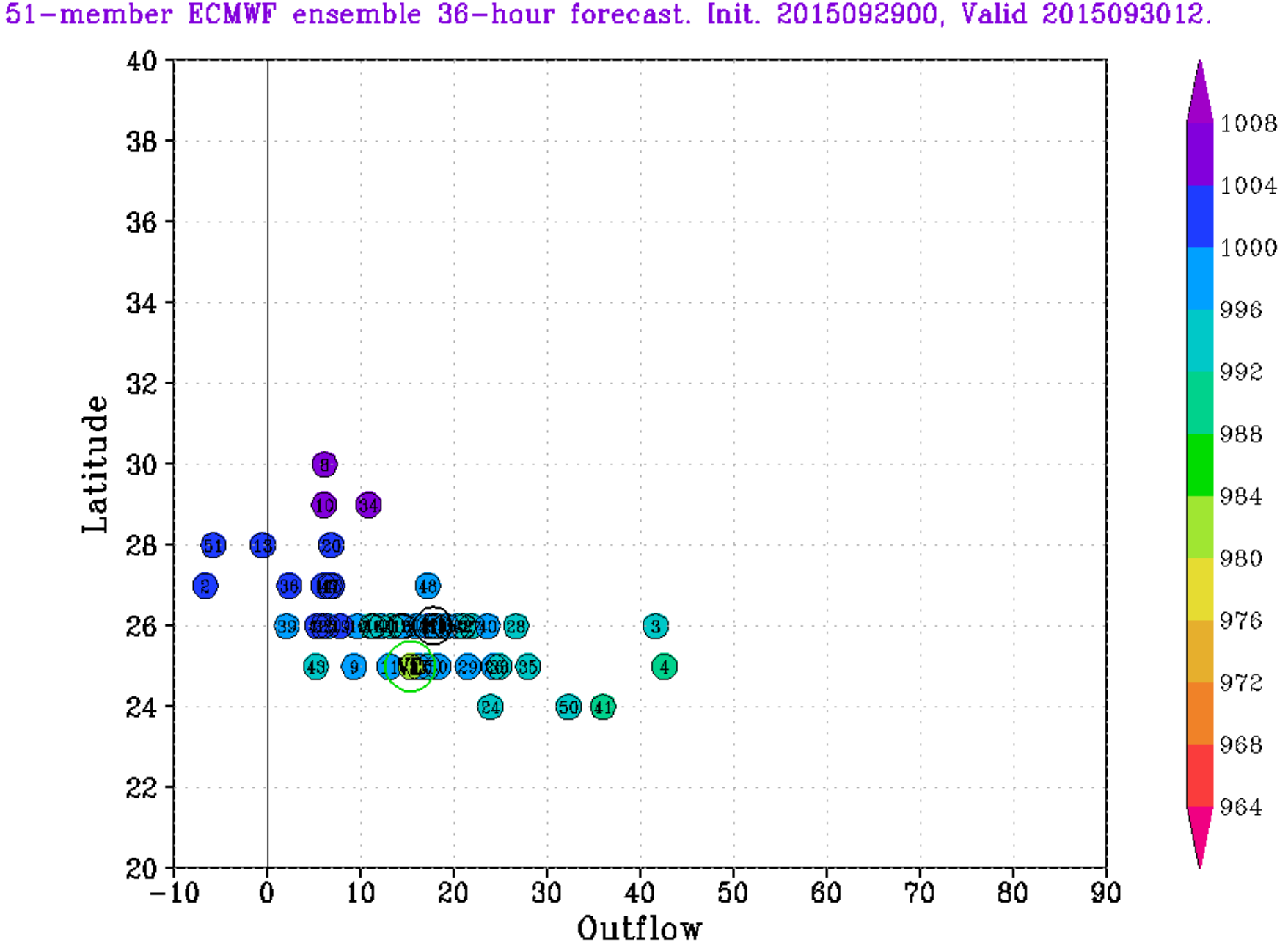
51-member ECMWF ensemble 36-hour forecast. Init. 2015092900, Valid 2015093012.
Latitude
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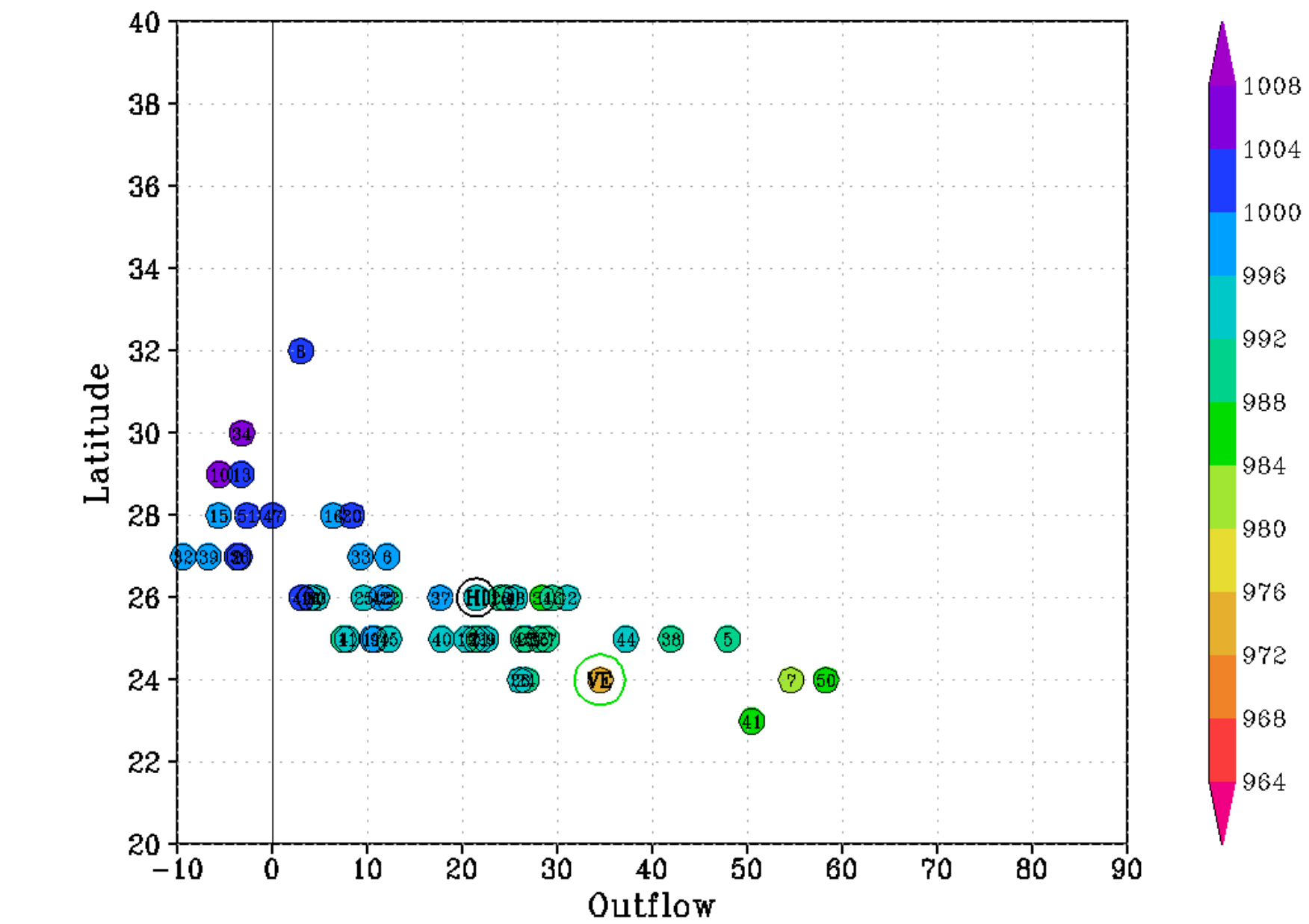
51-member ECMWF ensemble 48-hour forecast. Init. 2015092900, Valid 2015100100.
Latitude
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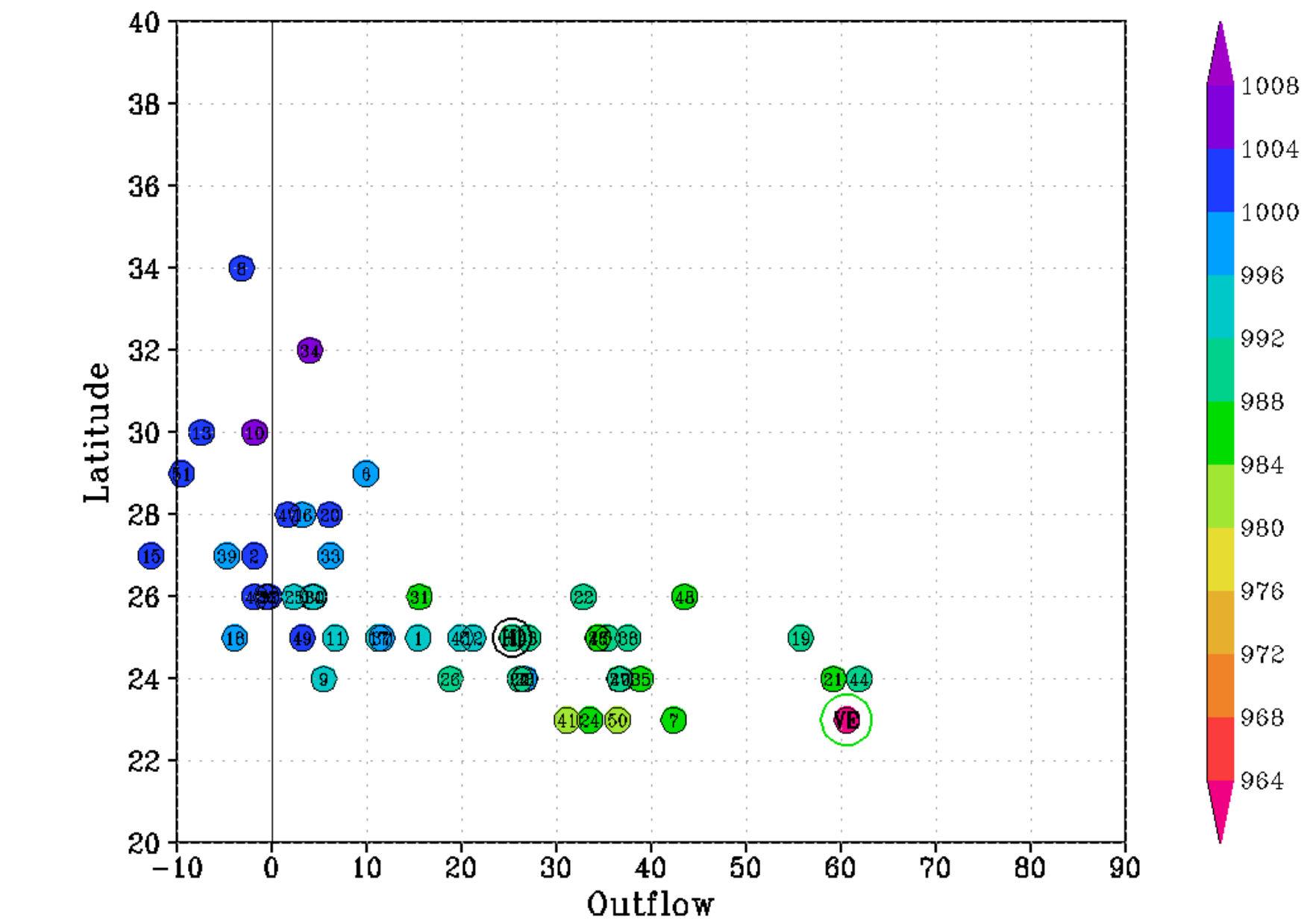
51-member ECMWF ensemble 60-hour forecast. Init. 2015092900, Valid 2015100112.
Latitude
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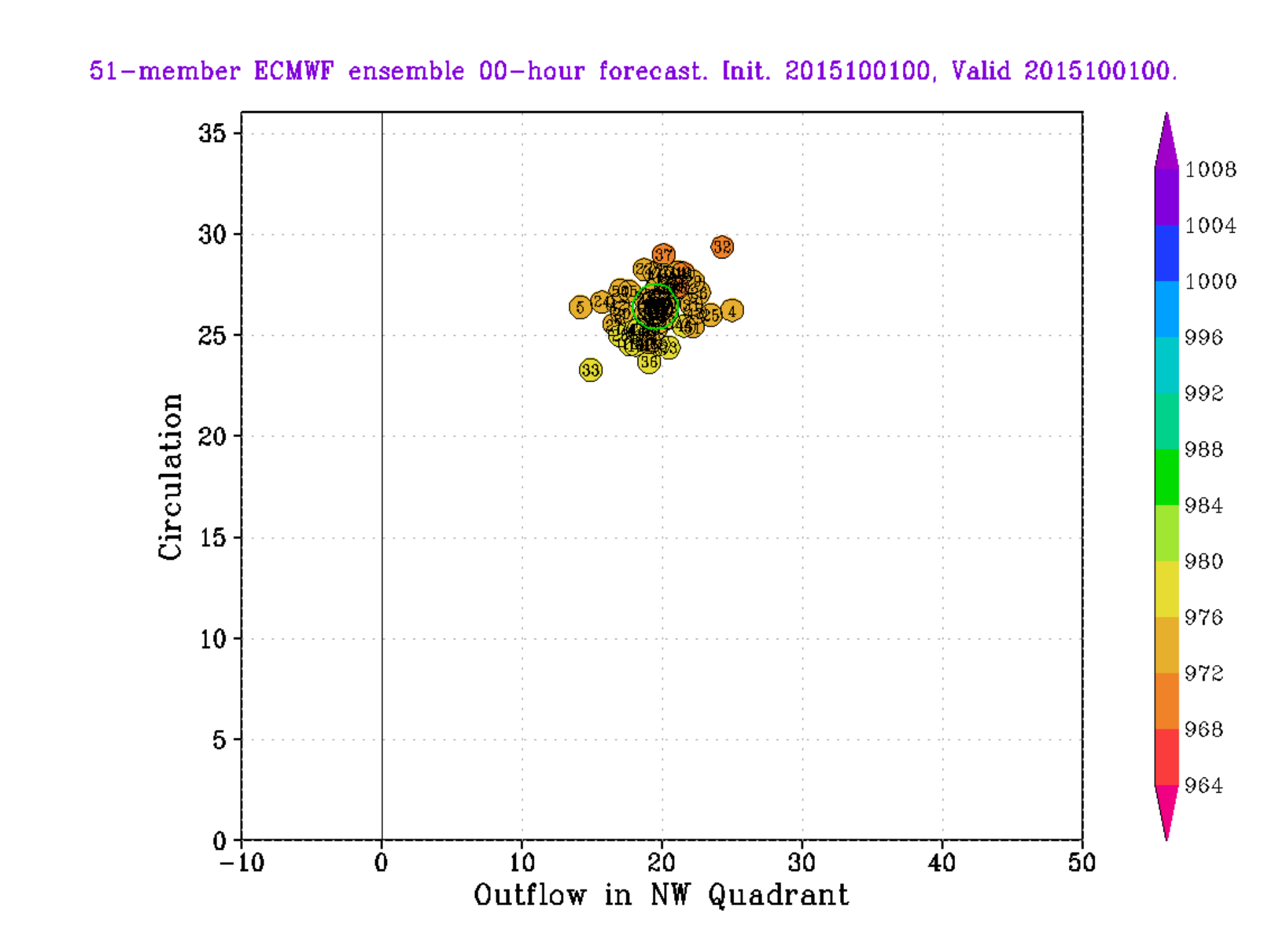
For the 2nd intensification: Is the NW quadrant of outflow correlated with high lower-tropospheric circulation?


51-member ECMWF ensemble 00-hour forecast. Init. 2015100100, Valid 2015100100.
Circulation
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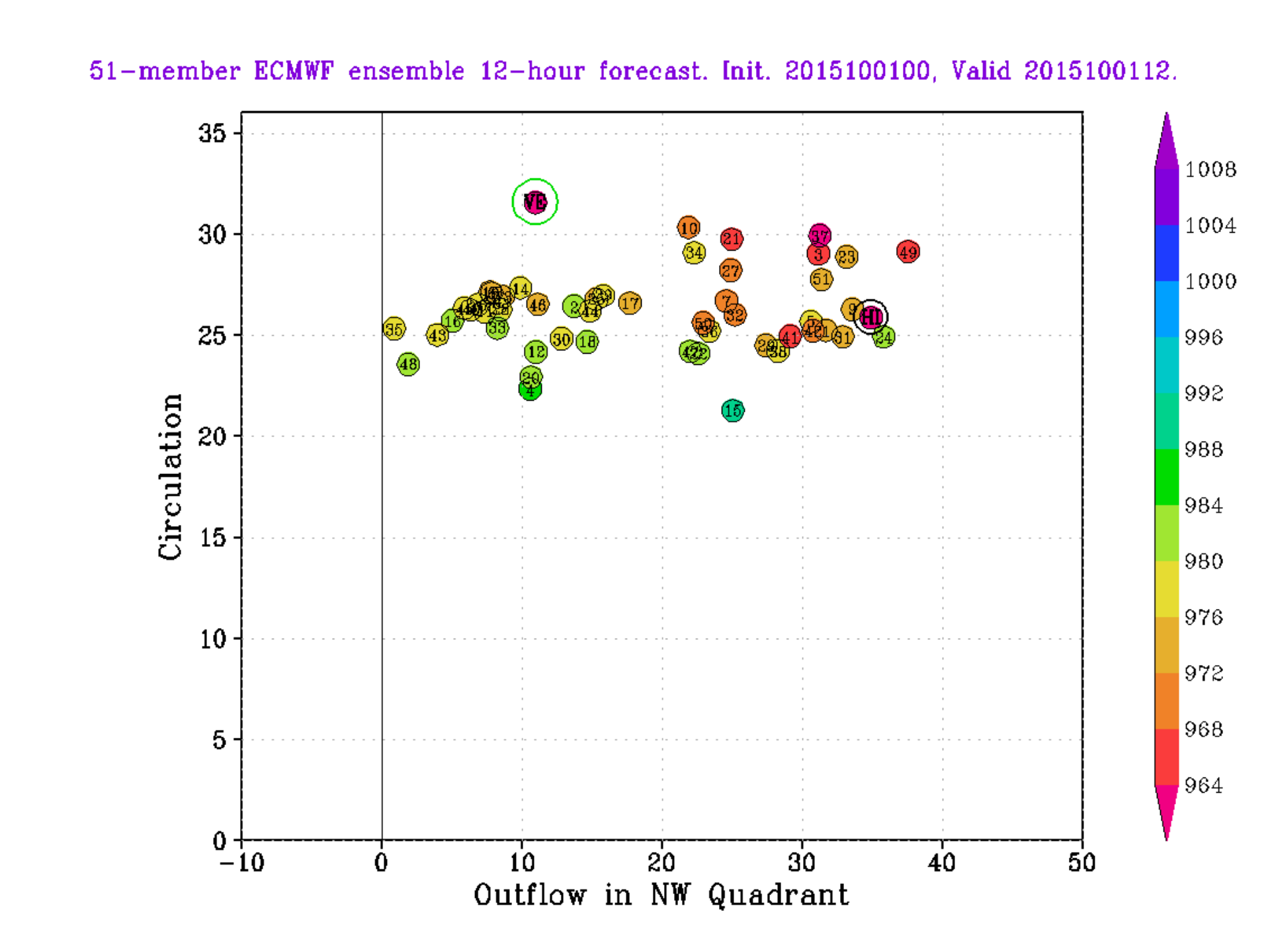
51-member ECMWF ensemble 12-hour forecast. Init. 2015100100, Valid 2015100112.
Circulation
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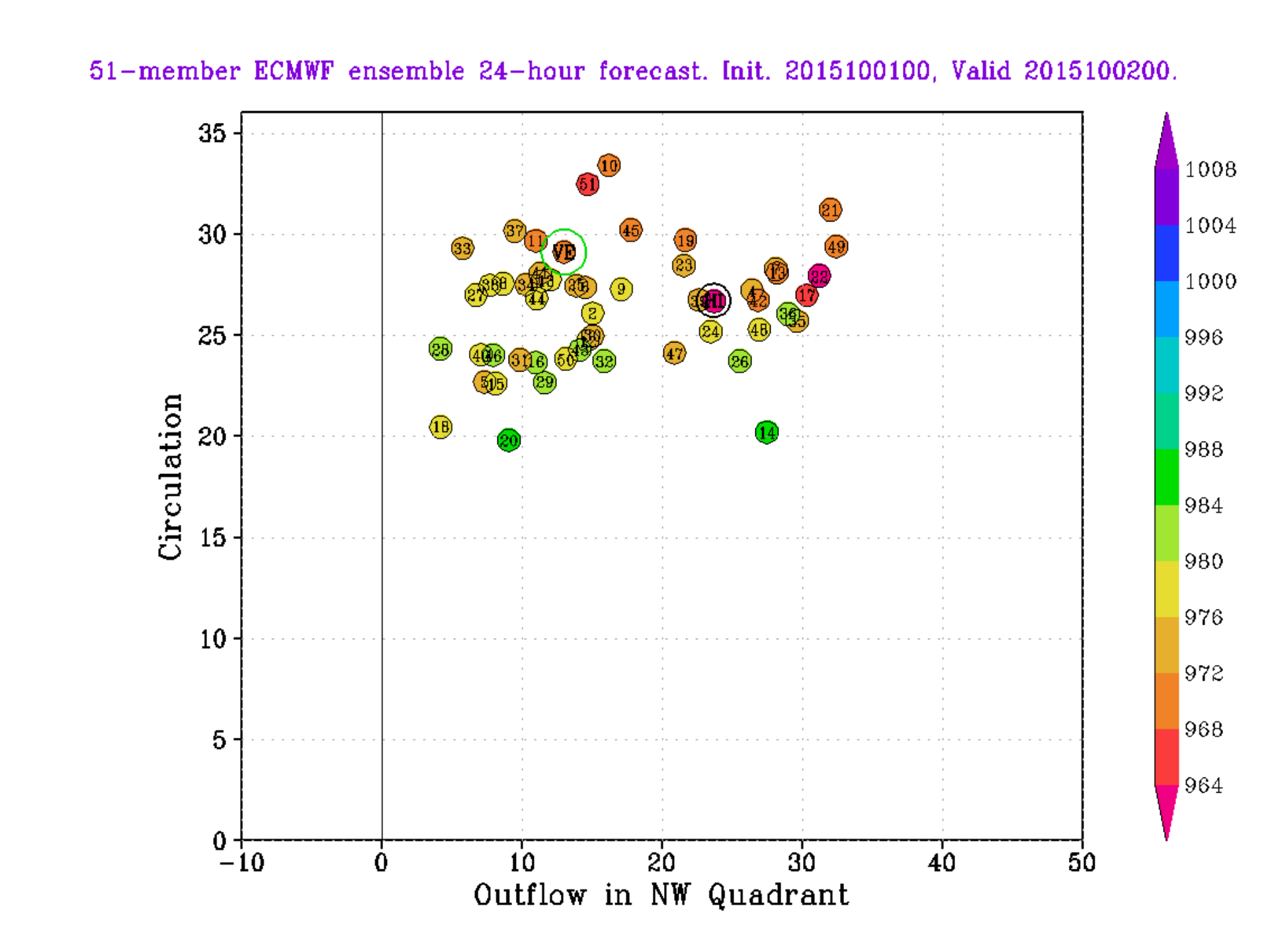
51-member ECMWF ensemble 24-hour forecast. Init. 2015100100, Valid 2015100200.
Circulation
Outflow in NW Quadrant
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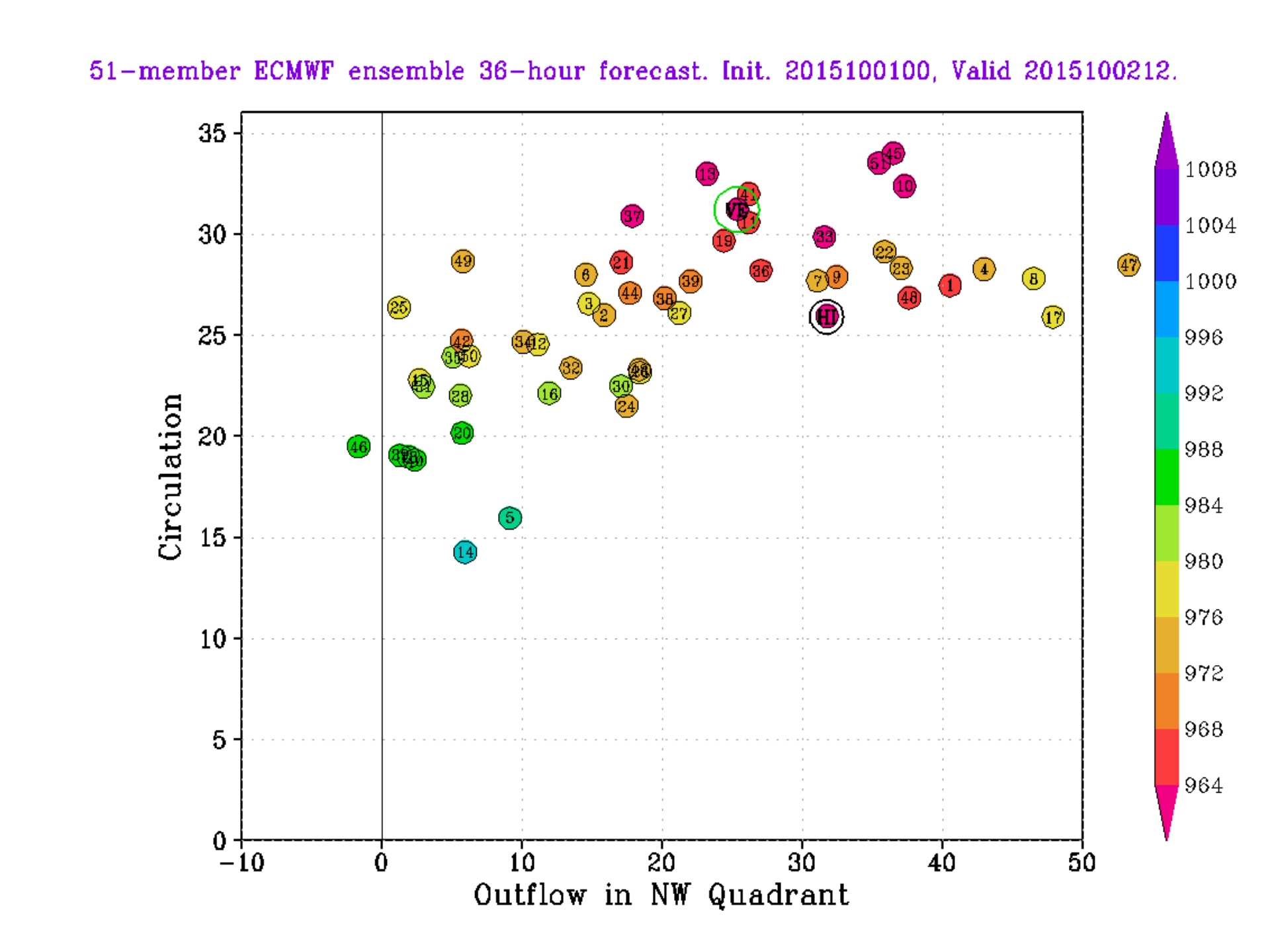
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Circulation
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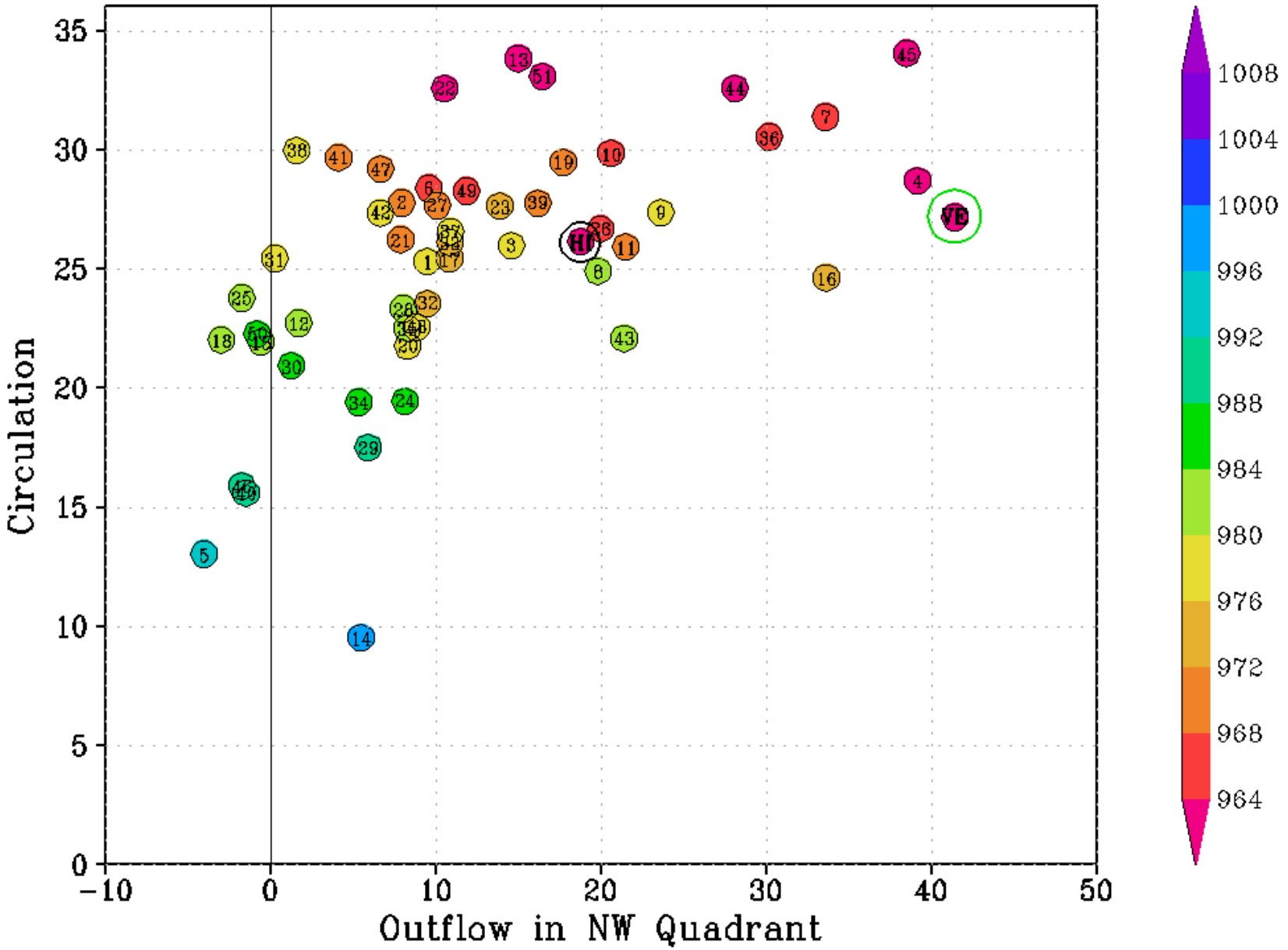
51-member ECMWF ensemble 48-hour forecast. Init. 2015100100, Valid 2015100300.
Circulation
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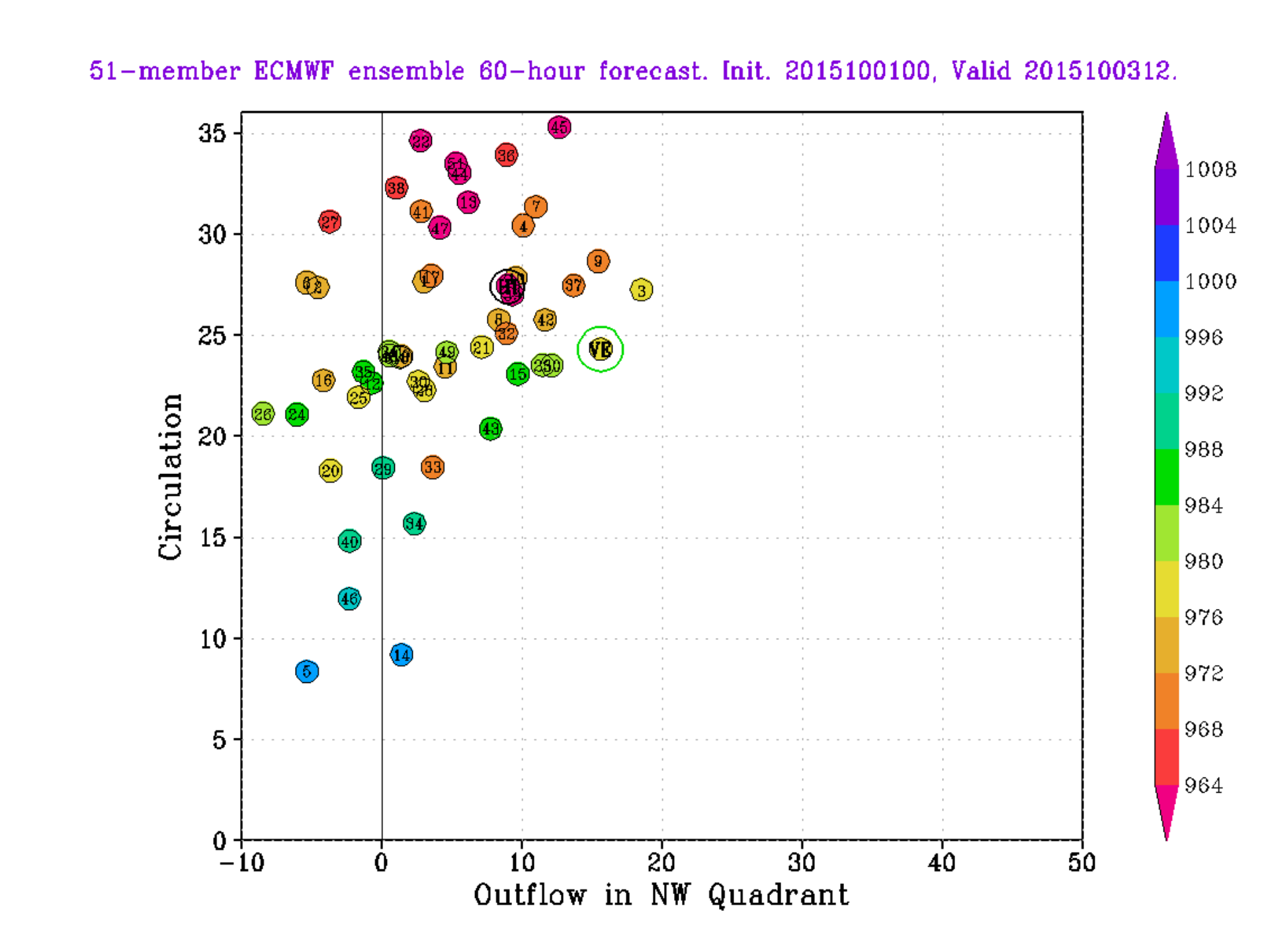
51-member ECMWF ensemble 60-hour forecast. Init. 2015100100, Valid 2015100312.
Circulation
Outflow in NW Quadrant
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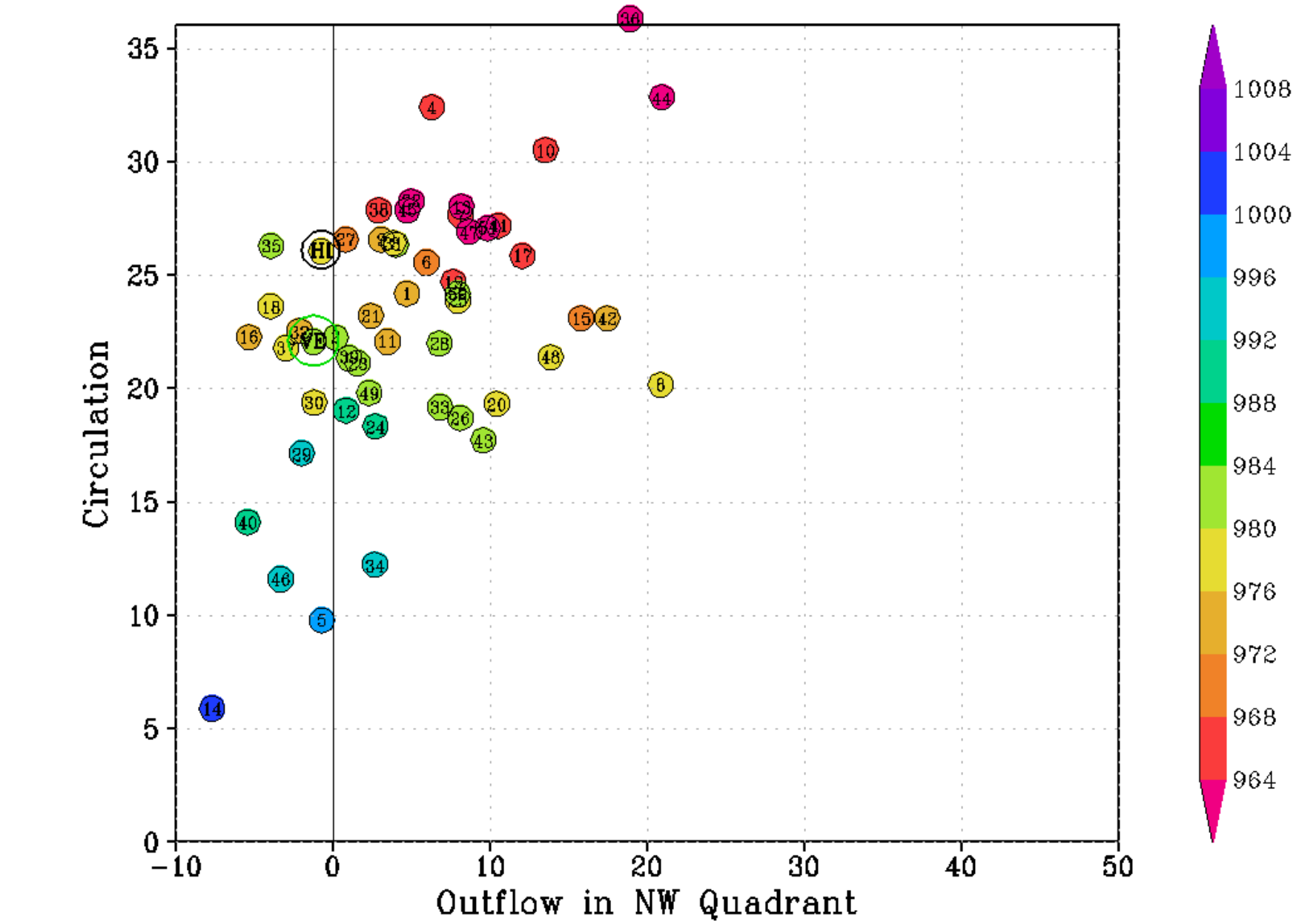
51-member ECMWF ensemble 72-hour forecast. Init. 2015100100, Valid 2015100400.
Circulation
Outflow in NW Quadrant
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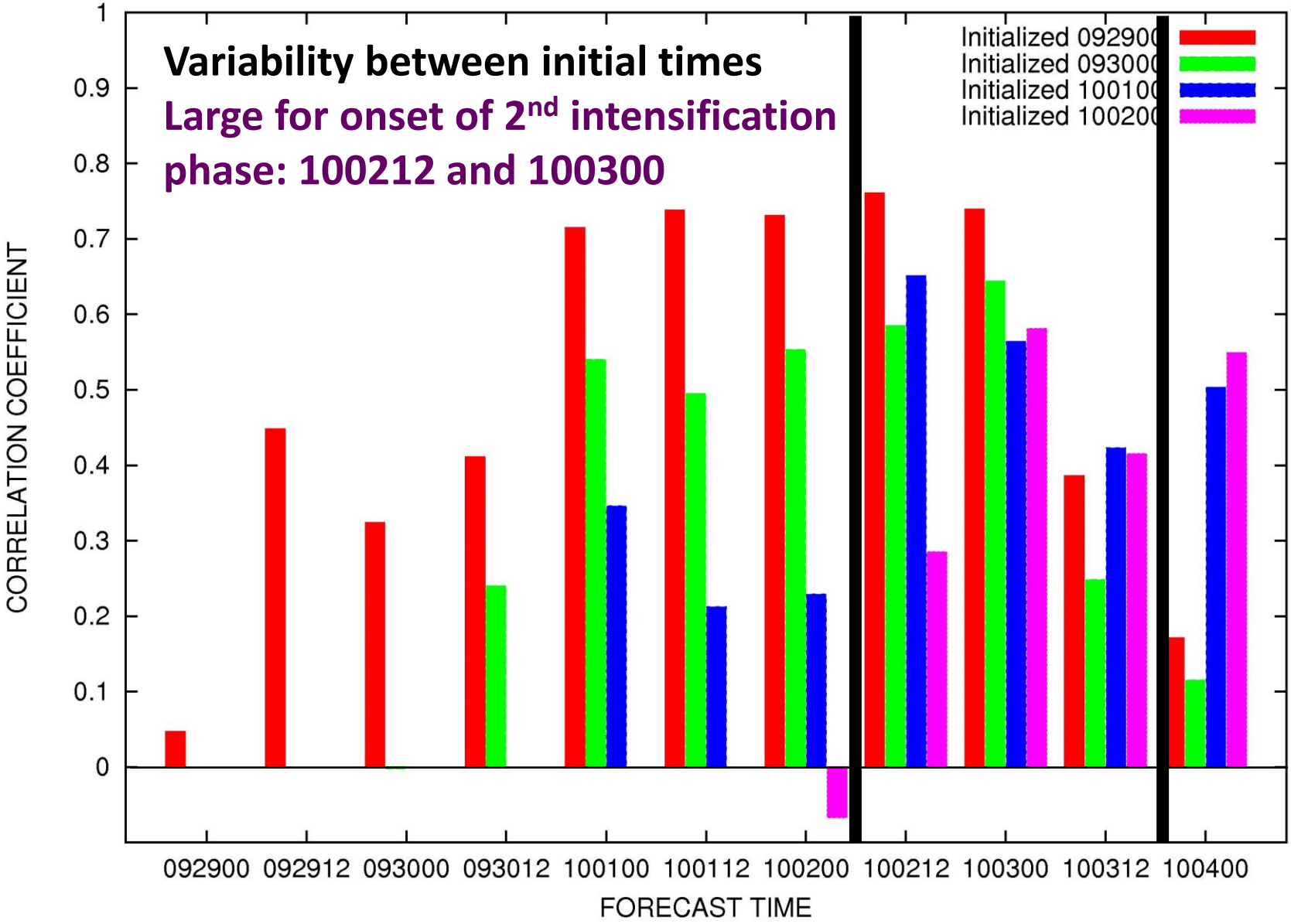
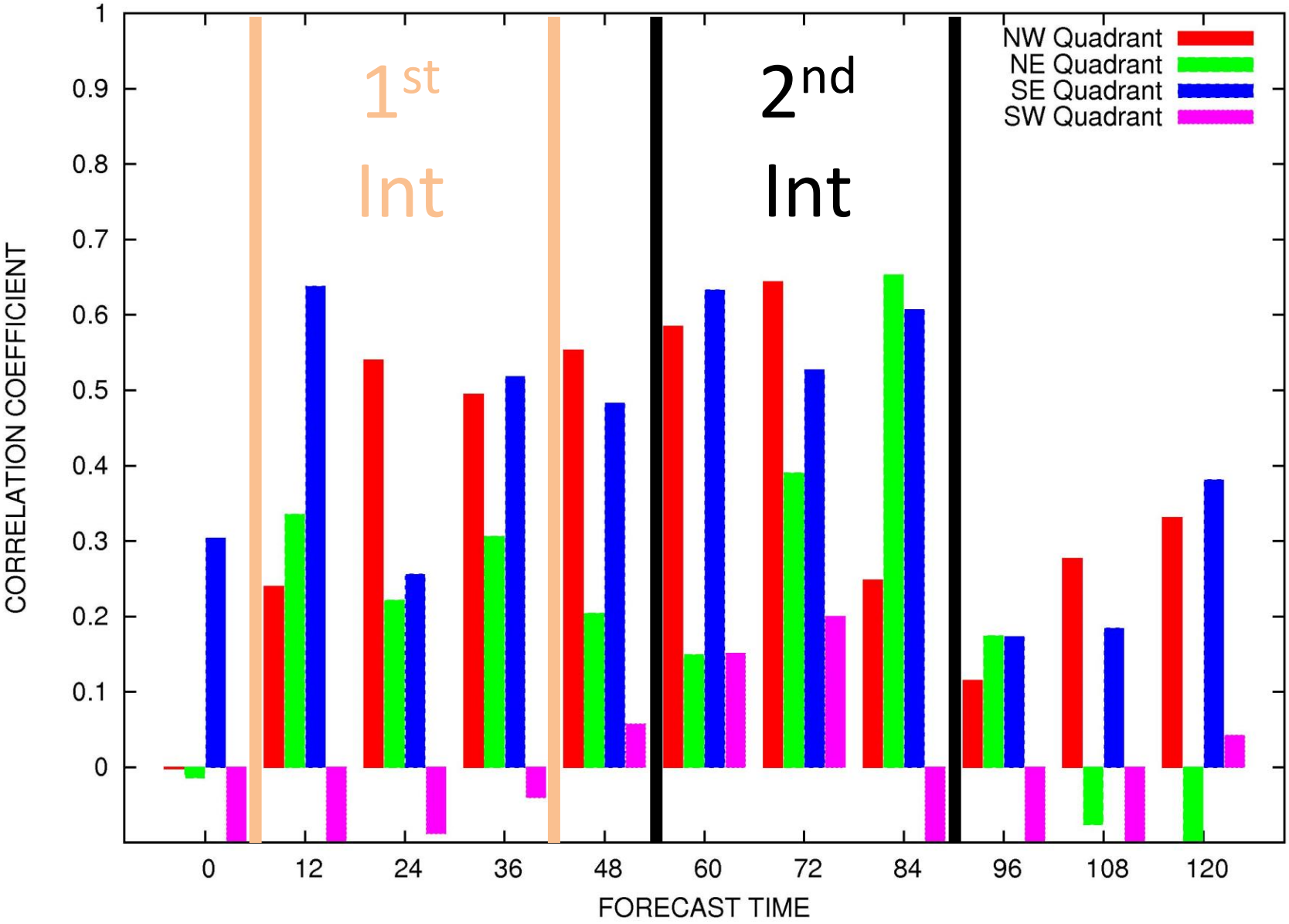
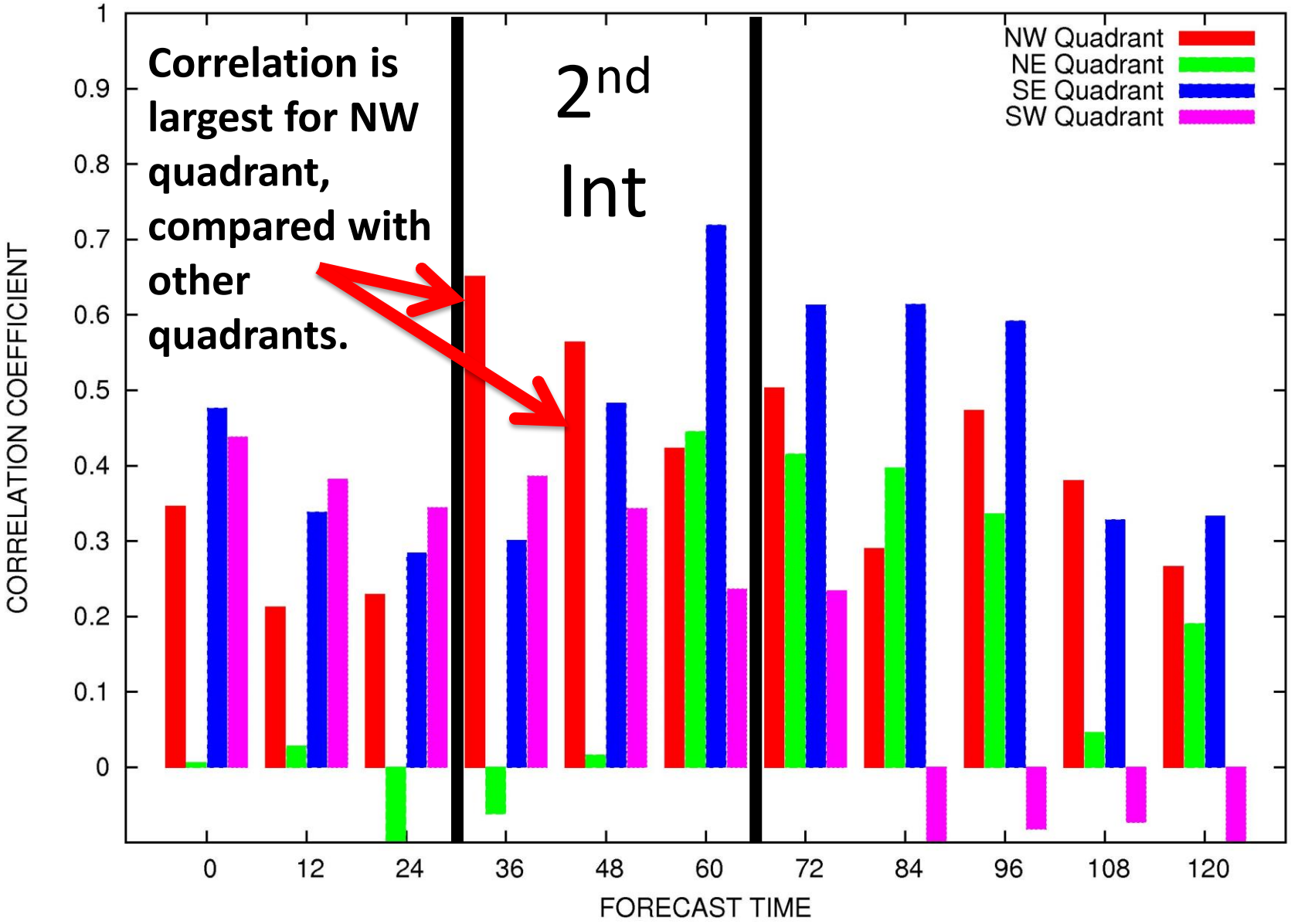
# Correlation coefficient between NW Quadrant outflow and 700-850 hPa Circulation



# Correlation coefficient between outflow and 700-850 hPa Circulation, init. 2015093000



# Correlation coefficient between outflow and 700-850 hPa Circulation, init. 2015100100



# Preliminary Conclusions

- **Predictability of initial track and RI is largely dependent on 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
- **Error characteristics: ensemble members often too weak, though comparisons between members can yield insights**

# Future Work

- Investigate **causality:** does outflow play an active role?
    - Is the 2nd intensification **governed** by the trough's modification of the outflow, which in turn modifies the intensity?
- Improve quantification of outflow
- Diagnose ensemble members and clusters
- Expand to large sample of TCs (e.g. Matthew)
- Examine using COAMPS-TC

U.S. NAVAL RESEARCH LABORATORY

# Diagnosing forecast uncertainty associated with Hurricane Joaquin (2015) using the COAMPS-TC EPS

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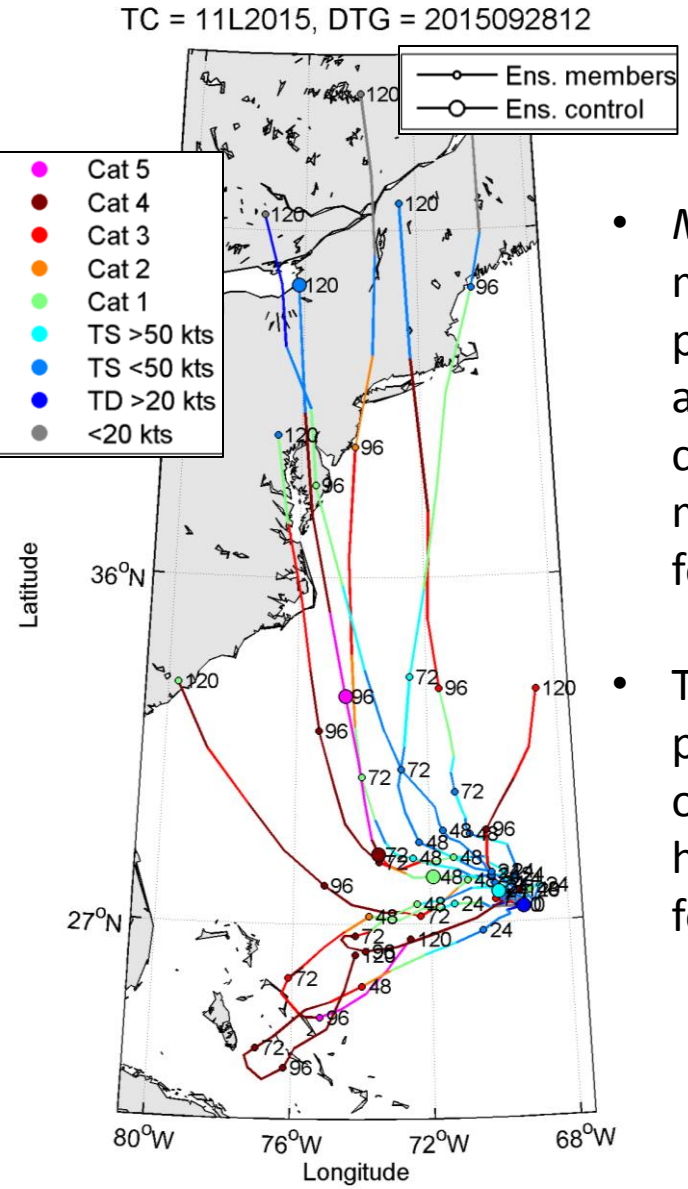
*Naval Research Lab - Monterey*
*will.komaromi@nrlmry.navy.mil*

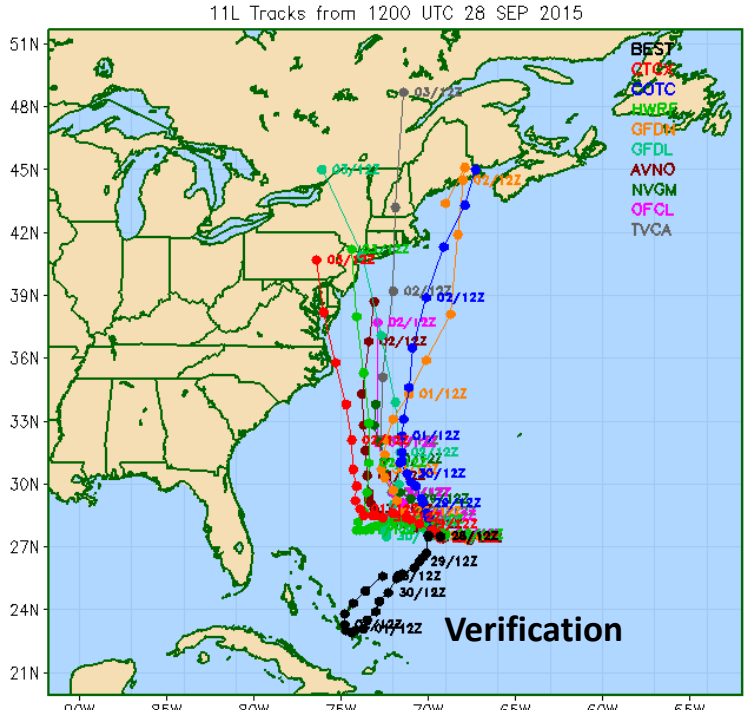
*TCI Science Meeting*
*18 October 2016*

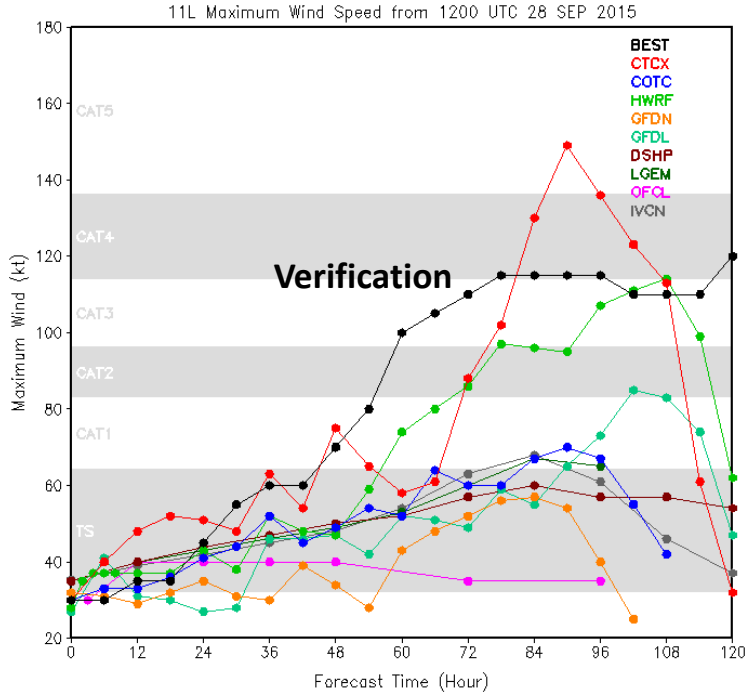
# Hurricane Joaquin forecasts: 2015-09-28 12Z

## COAMPS-TC ENS



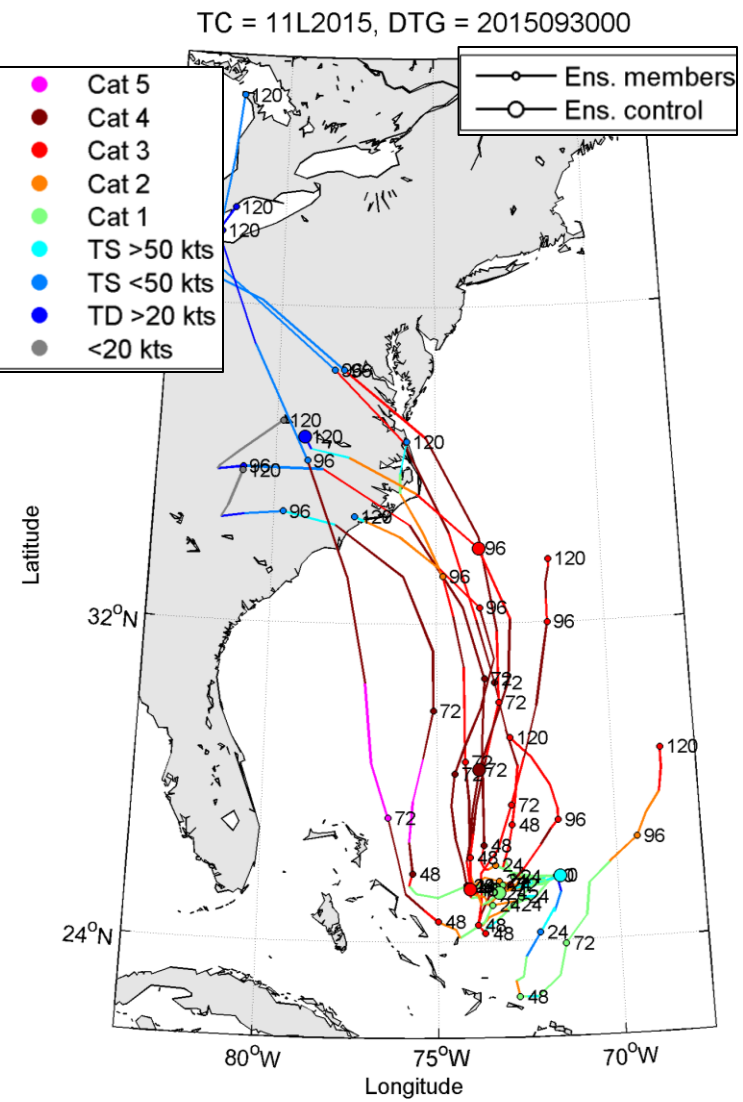

- *Most* ensemble members *incorrectly* predict due westward and/or NW track, consistent with global models and NHC forecast
- Two members *correctly* predict slow SW track over Bahamas as major hurricane in consecutive forecasts



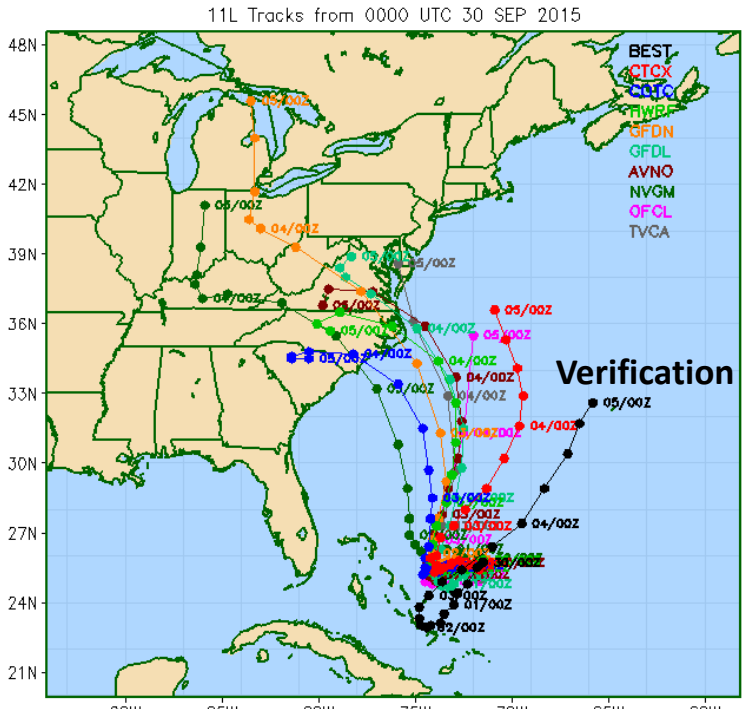



# Hurricane Joaquin forecasts: 2015-09-30 00Z

## COAMPS-TC ENS

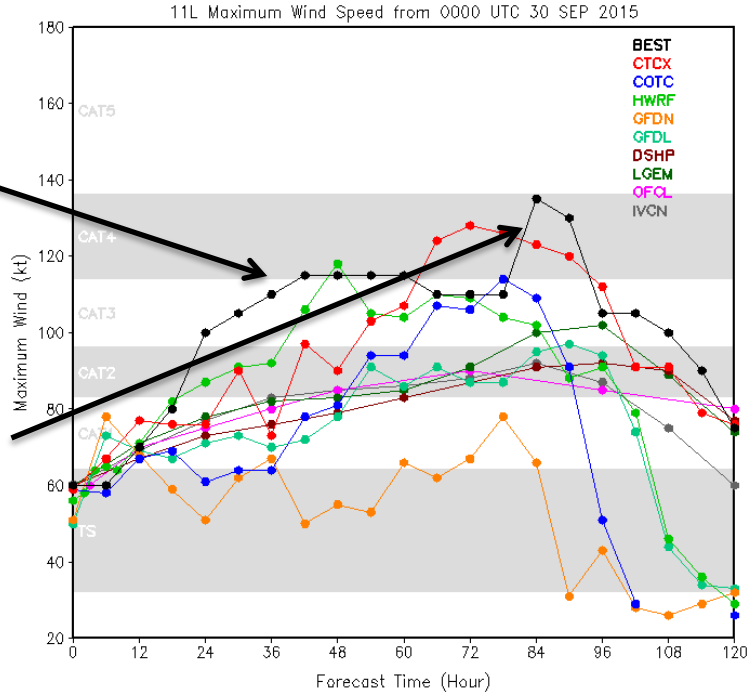



- Most members incorrectly make landfall along U.S. East Coast and fail to capture 2nd period of intensification associated with trough interaction




Initial intensification period

Second intensification associated with trough interaction



# Hypotheses and preliminary findings

- Two forecast periods for Hurricane Joaquin (2015) associated with particularly high uncertainty
- 1st period: most ensemble members incorrectly predict due westward and/or NW track, consistent with global models and NHC forecast
- Two members correctly predict slow SW track over Bahamas as major hurricane in consecutive forecasts
  - Preliminary results suggest **subtle differences in steering flow between different ensemble "clusters"**
- 2nd period: most members incorrectly make landfall along U.S. East Coast and fail to capture 2nd period of intensification associated with trough interaction
  - **Hypothesis: insufficient ensemble spread during trough interaction fails to capture re-intensification and correct TC motion**
- Currently in the process of further analyzing both of these periods