High-Impact Weather and Reduced Predictability over the U.S. Associated with the Recurvature of Western North Pacific TC Malakas (2010)

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Background

- As a tropical cyclone (TC) recurves into the midlatitudes and undergoes extratropical transition (ET), its divergent outflow can perturb the midlatitude jet stream such that a Rossby wave train is excited or amplified (e.g., Riemer et al. 2008; Harr and Dea 2009)

- Downstream development accompanying the wave train may lead to high-impact weather associated with onset of large-scale flow anomalies well downstream of TC

Background

- Western North Pacific (WNP) TC recurvature episodes have been linked to episodes of reduced predictability (e.g., Jones et al. 2003; Harr et al. 2008; Anwender et al. 2008, 2010; Torn 2010)

- Such reduced predictability may arise from
  - Rapid evolution of TC structure and precipitation distribution during ET
  - High sensitivity of ET and downstream flow response to phasing of TC with an upstream trough

Purpose

- Consider characteristic downstream response to recurving WNP TCs (1979–2009) to provide context for downstream response to recurvature of WNP TC Malakas on 23 Sep 2010
- Examine how the recurvature of Malakas served as an antecedent to record heat in western U.S. and heavy rain in eastern U.S. between 26 Sep and 1 Oct 2010
- Explore the role of recurvature of Malakas in subsequent increases in model error and ensemble model spread downstream of TC

Part 1: Characteristic Downstream Response to Recurving WNP TCs

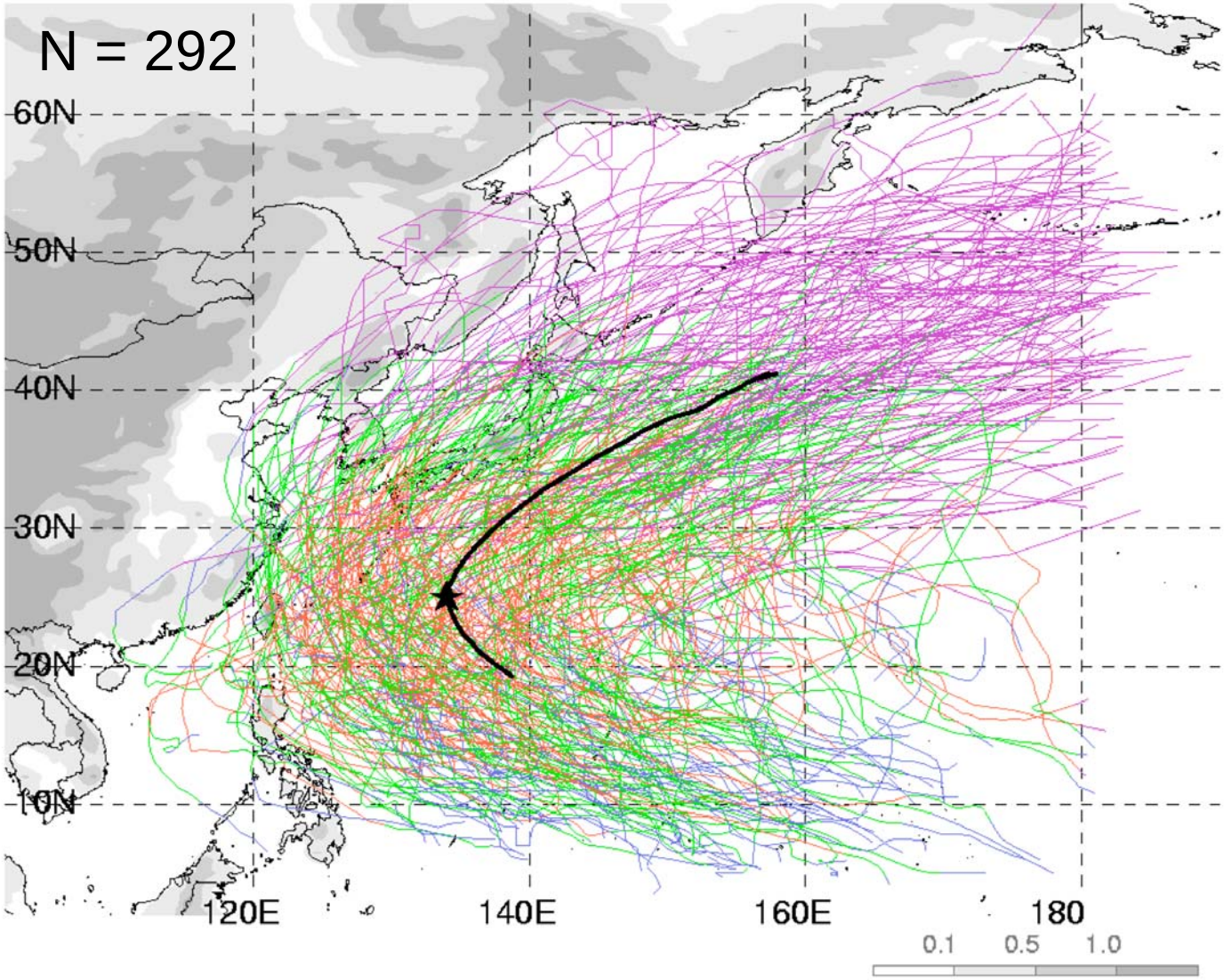
Data and Methodology

- Recurvature defined as when a poleward-moving TC changes motion from westward to eastward (i.e., TC is at most westward position)

- Recurving WNP TCs for 1979–2009 identified using Japan Meteorological Agency (JMA) best-track data

- TC must be a TS or stronger at recurvature and eventually complete ET (i.e., be designated as extratropical by JMA)

Recurving WNP TC Tracks

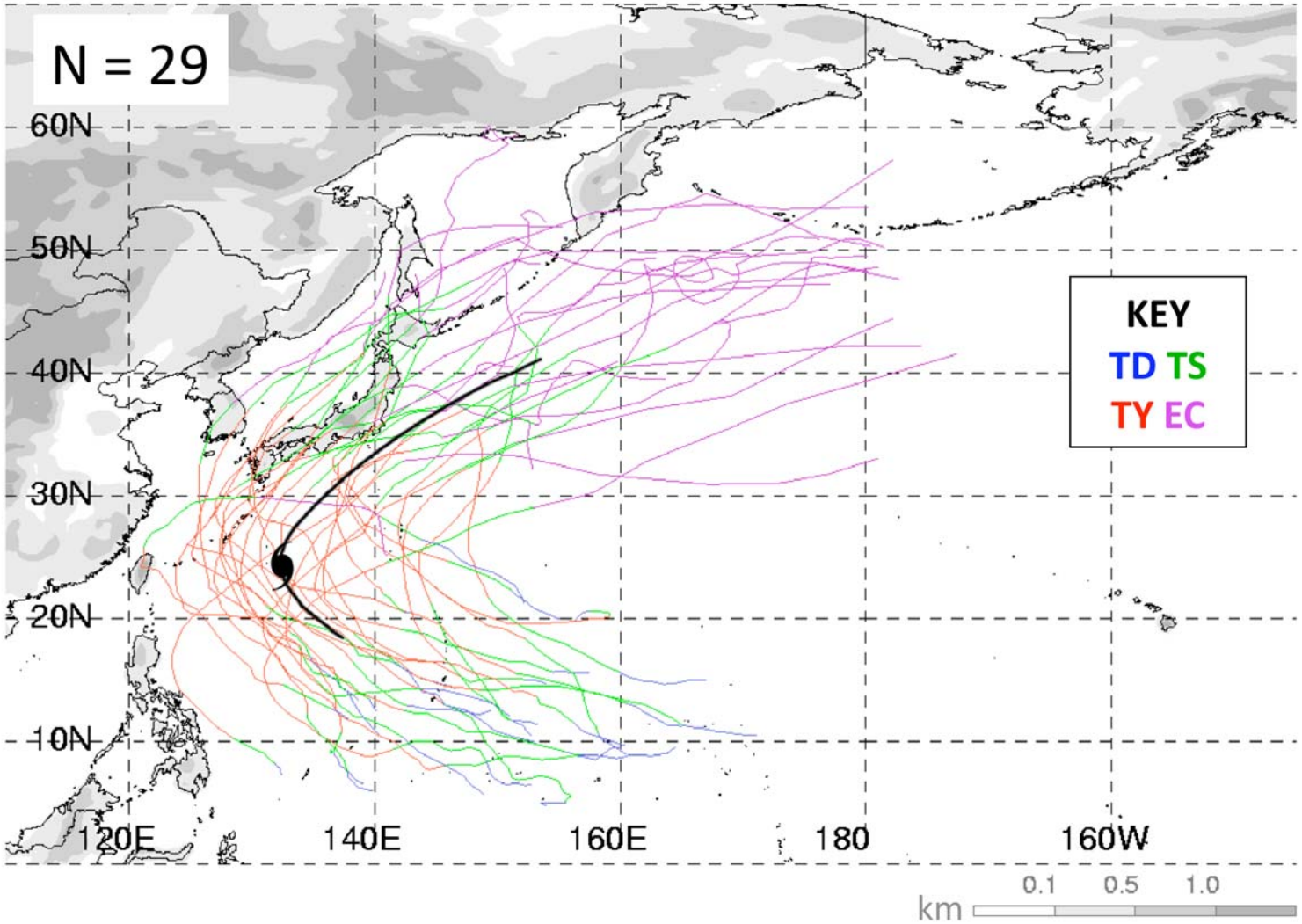


Data and Methodology

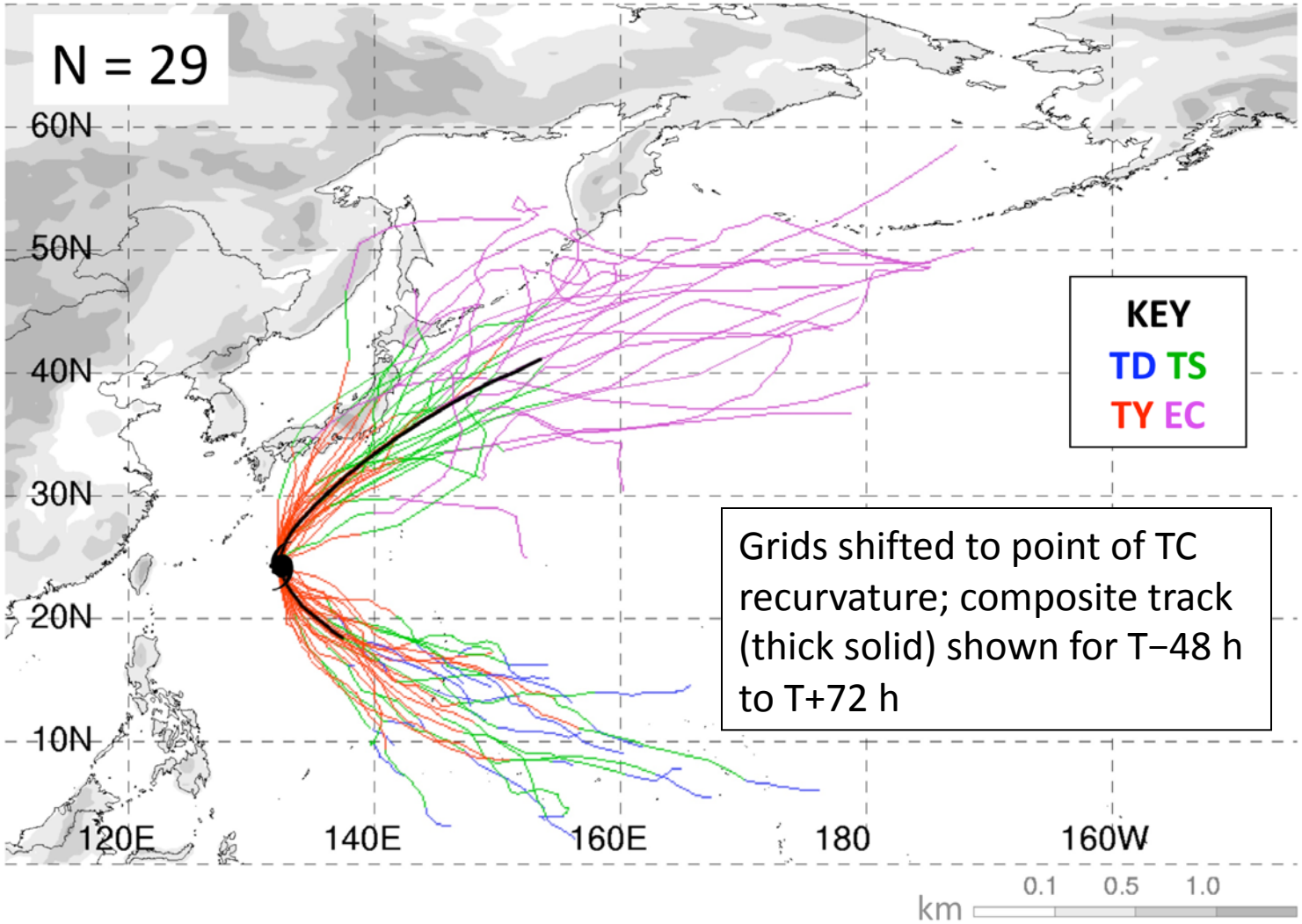
- 2.5° NCEP–NCAR reanalysis used to perform “recurvature-relative” compositing

- Meridional wind anomalies computed using a recurvature-relative climatology constructed from 21-day long-term (1979–2009) means

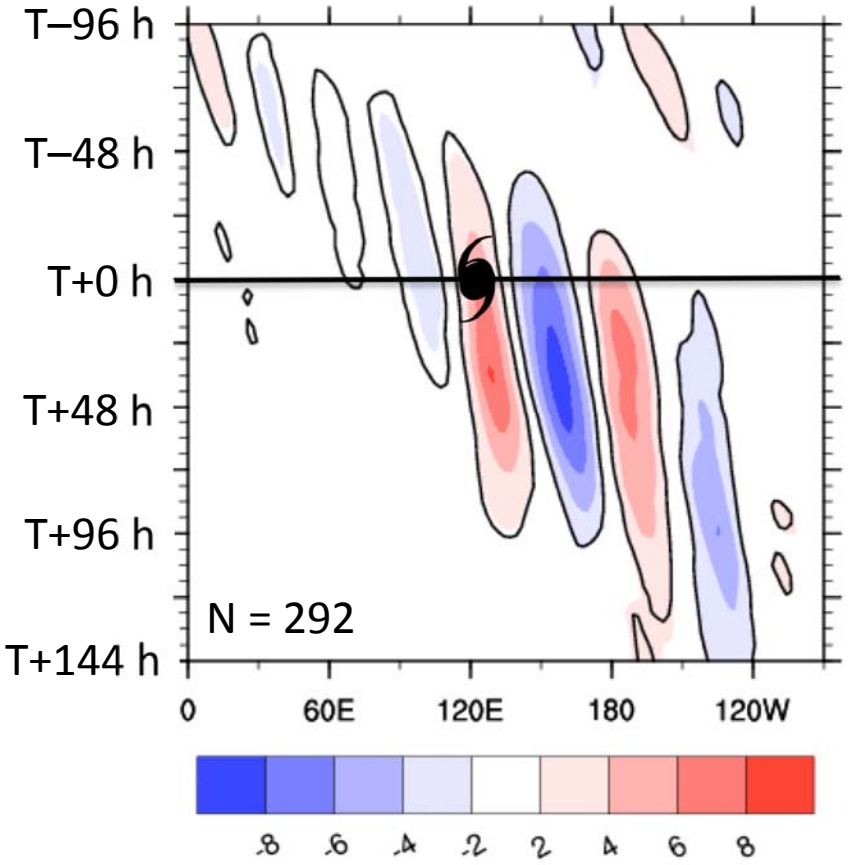
Illustrative Example of "Recurvature-Relative" Compositing Procedure

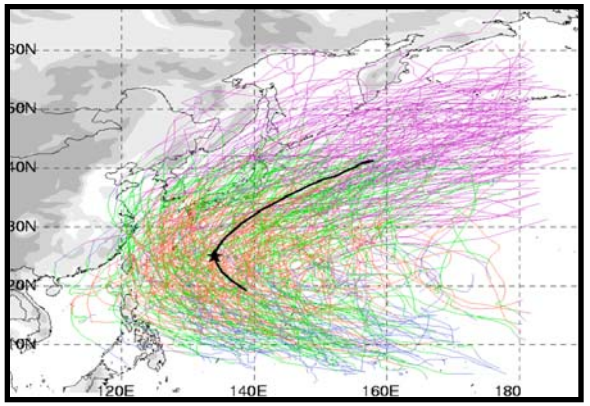


Illustrative Example of "Recurvature-Relative" Compositing Procedure



Recurvature-Relative Composite Rossby Wave Train

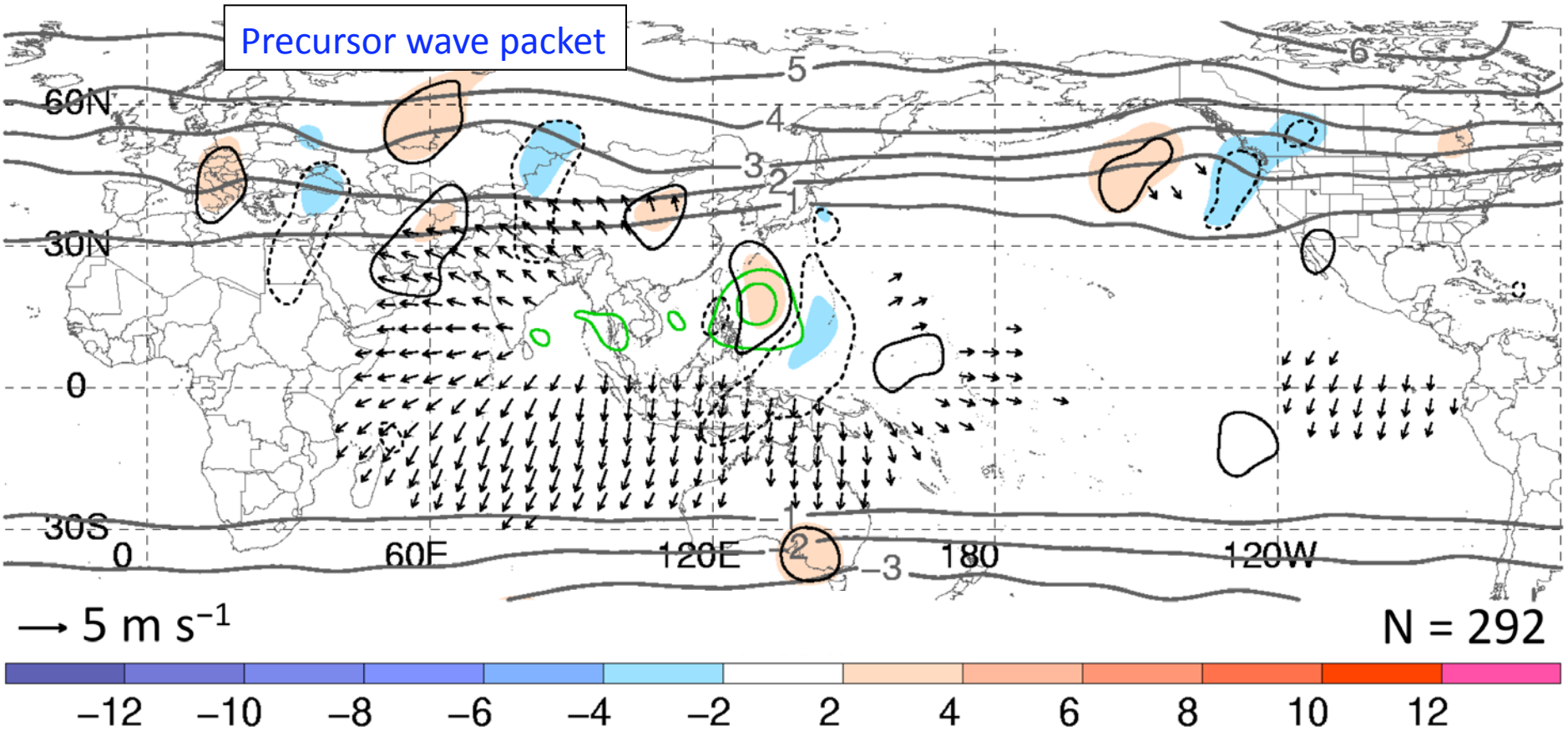




Recurvature-relative composite of 35°–55°N 250-hPa meridional wind anomalies (shaded, m s^{-1}) surrounding WNP TC recurvature; contours denote 99% statistical significance

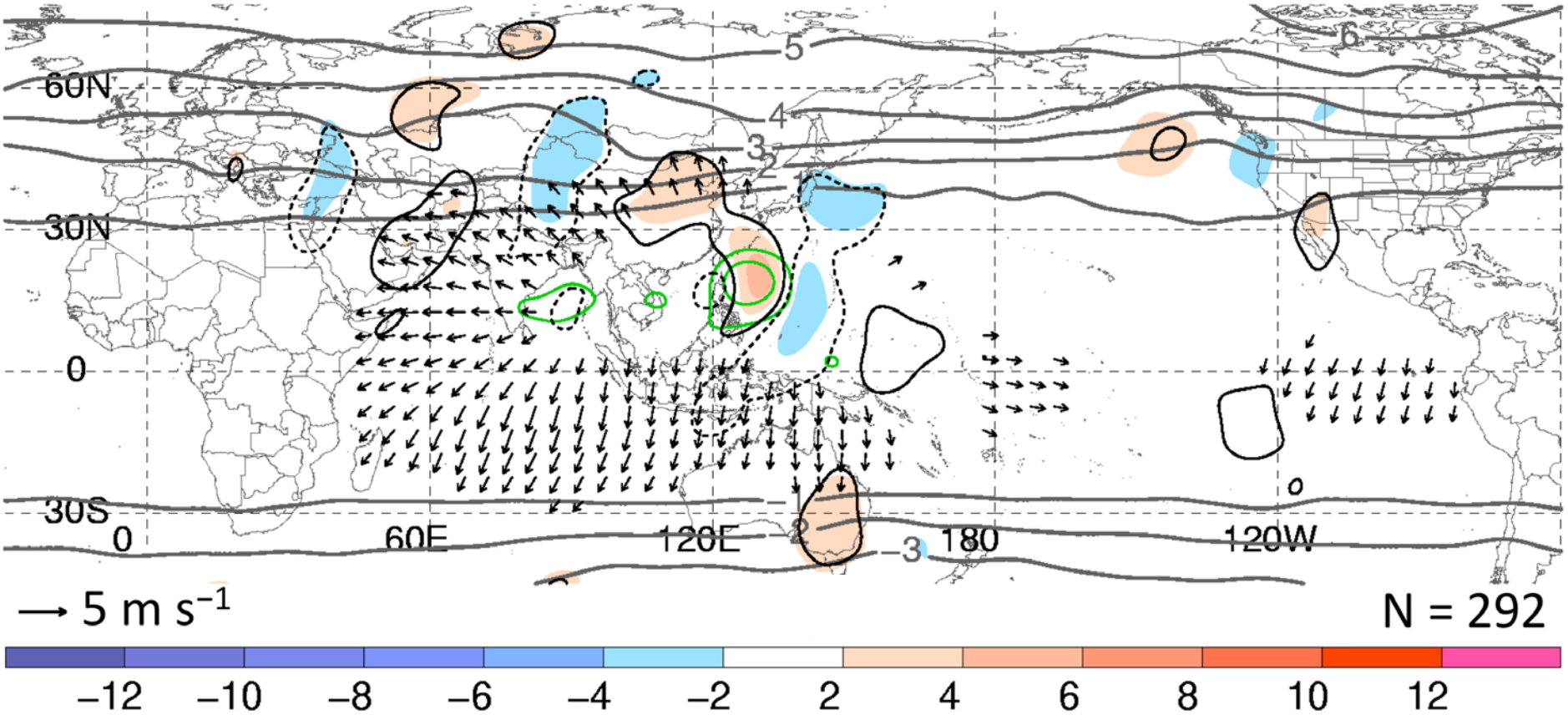
- Pronounced Rossby wave train signature associated with WNP TC recurvature

Recurvature-Relative Composite: T−60 h



250-hPa meridional wind anomaly (shaded, m s^{-1}; thin black contours denote 99% stat. sig.), potential vorticity (gray, every 1 PVU), and irrotational wind (vectors, starting at 1.5 m s^{-1}); 500-hPa ascent (green, every 0.5 × 10^{-3} hPa s^{-1})

Recurvature-Relative Composite: T−48 h



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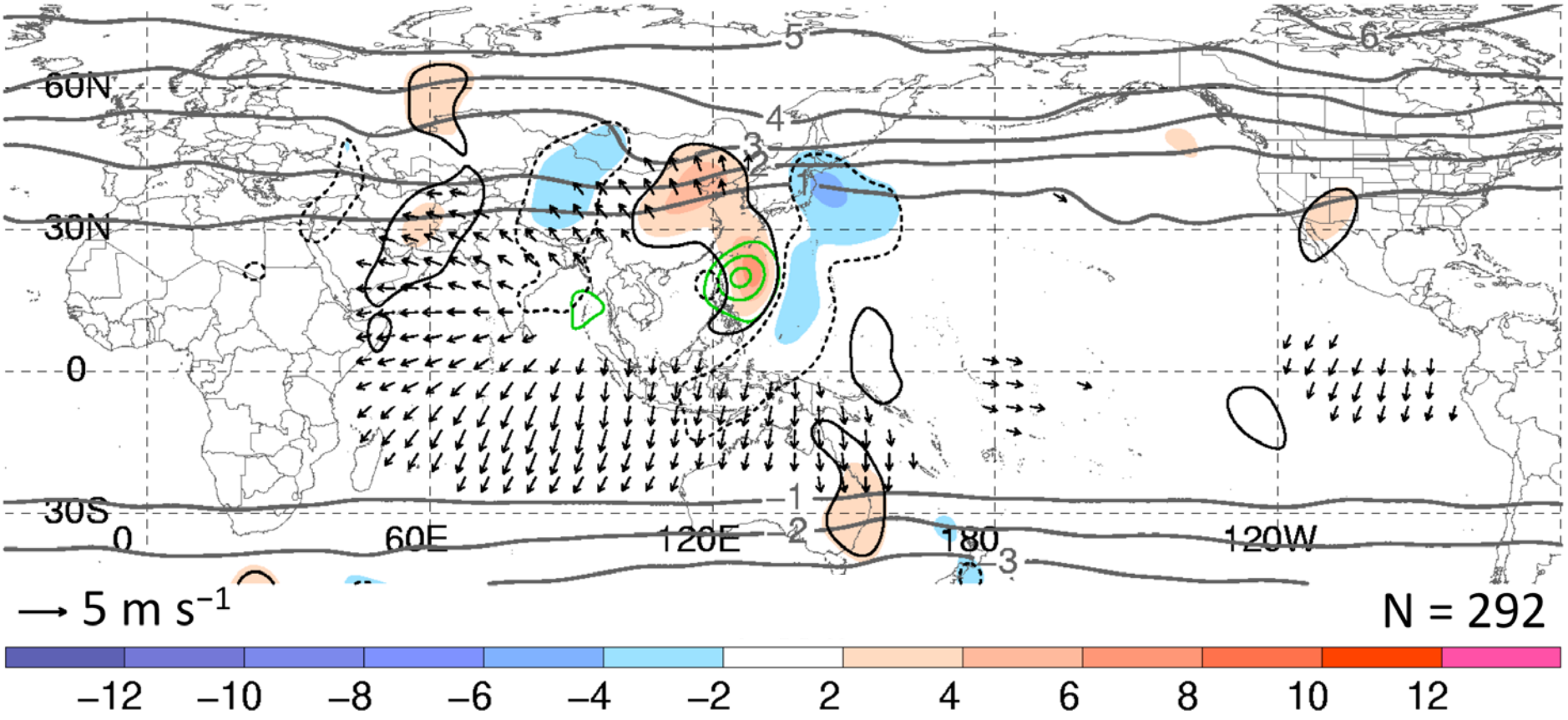
Recurvature-Relative Composite: T−36 h



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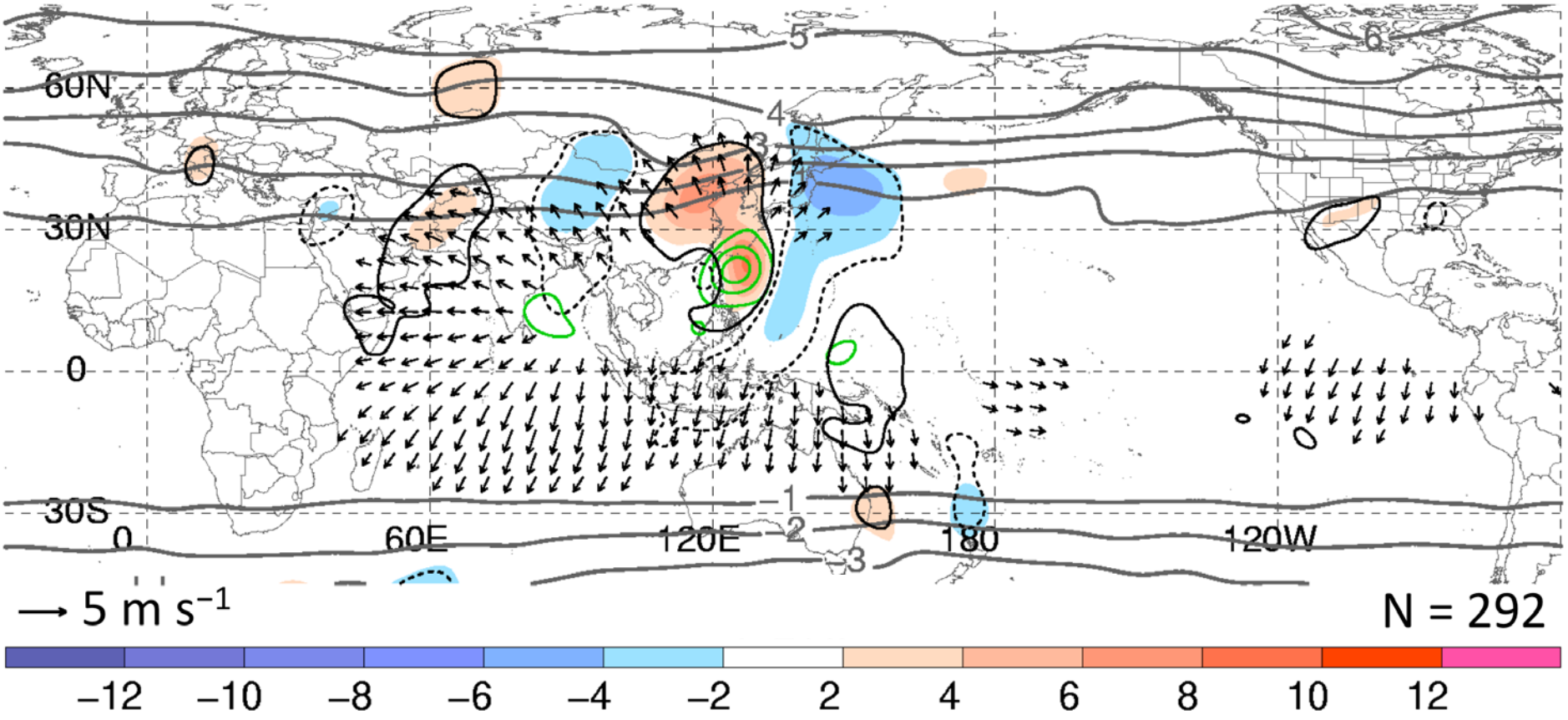
Recurvature-Relative Composite: T−24 h



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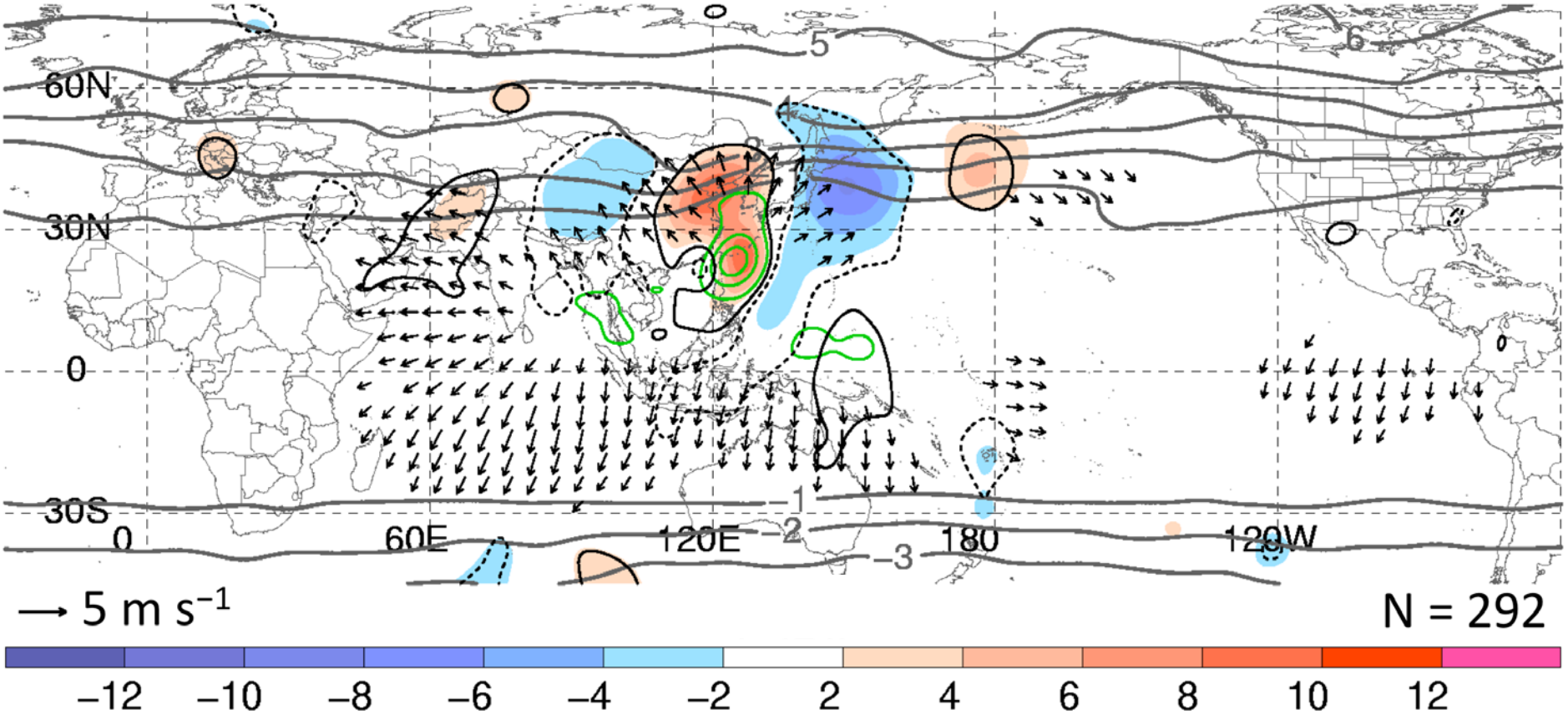
Recurvature-Relative Composite: T−12 h



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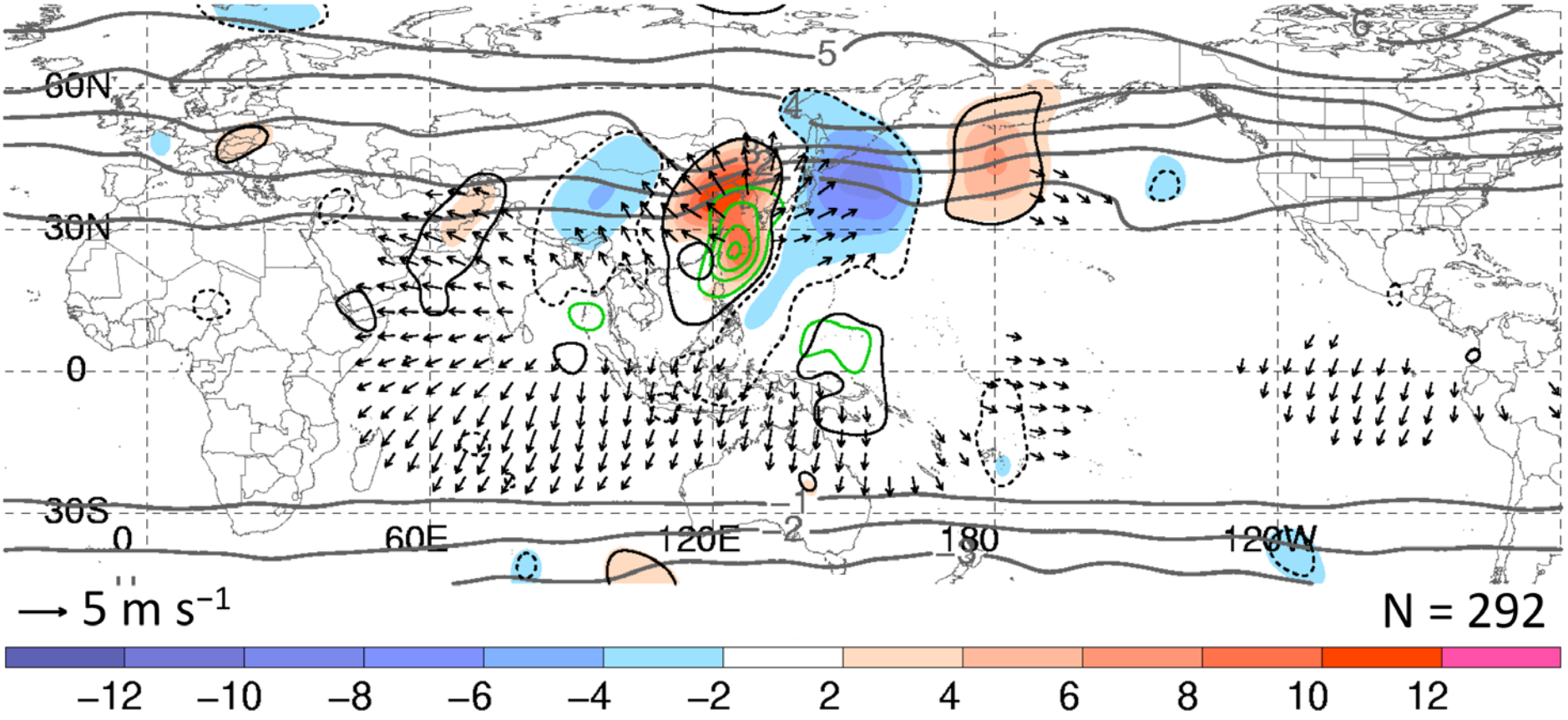
Recurvature-Relative Composite: T+0 h



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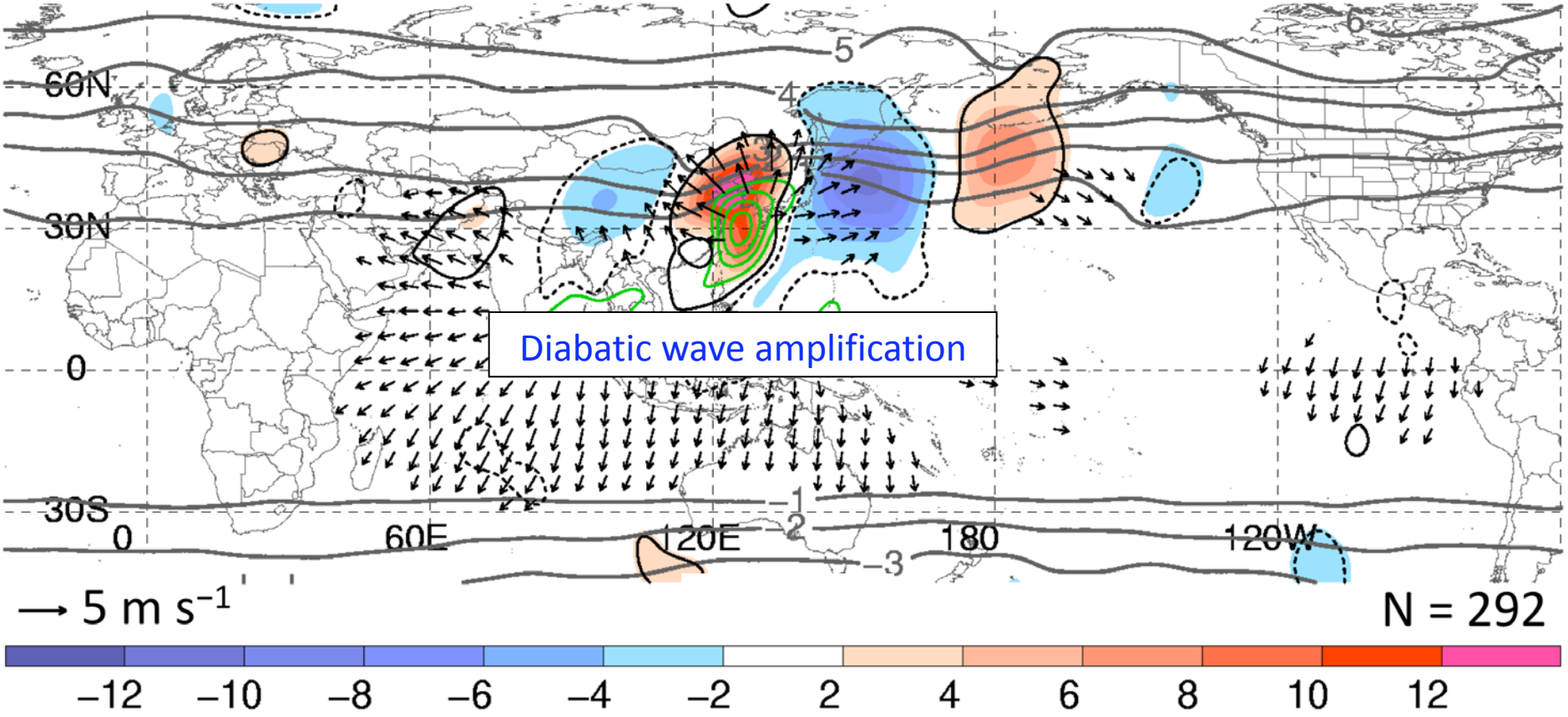
Recurvature-Relative Composite: T+12 h



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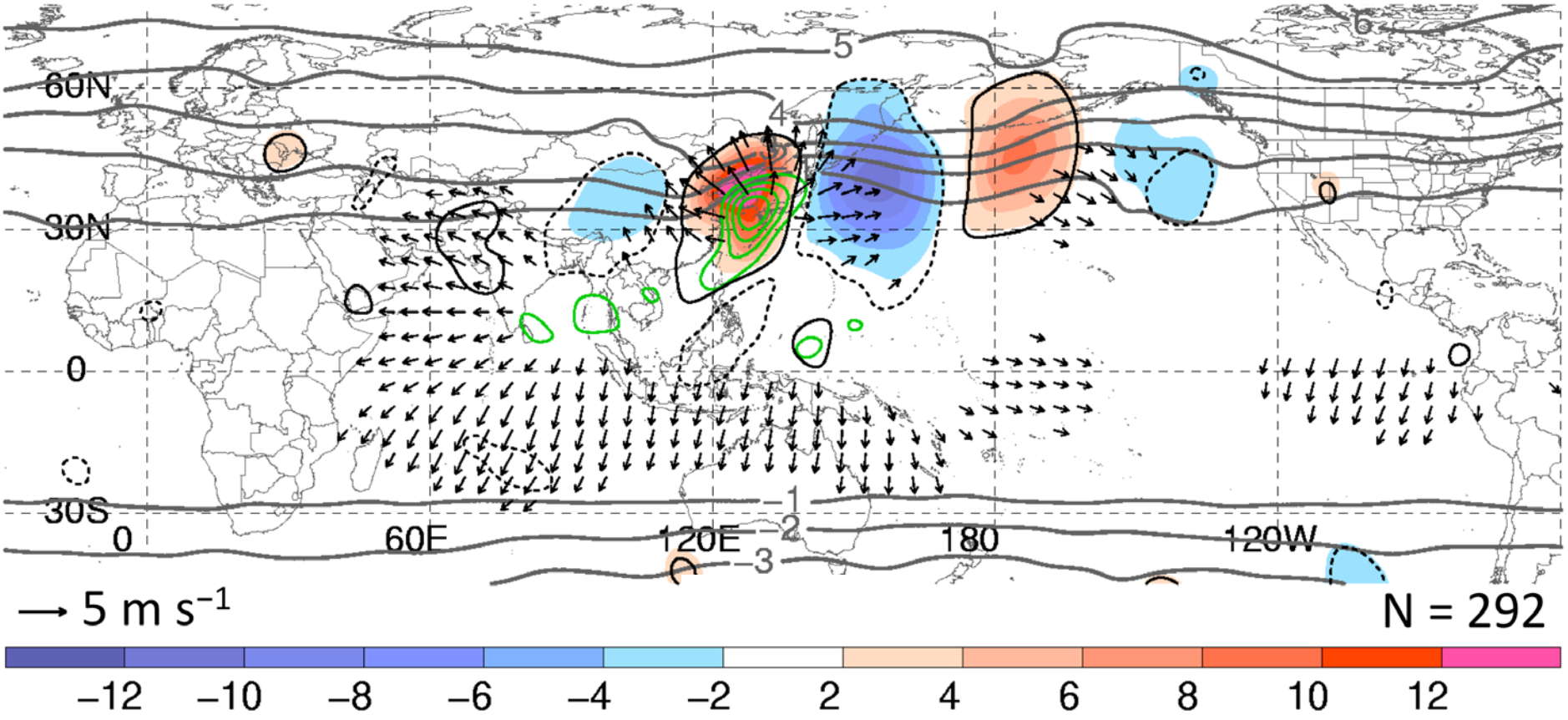
Recurvature-Relative Composite: T+24 h



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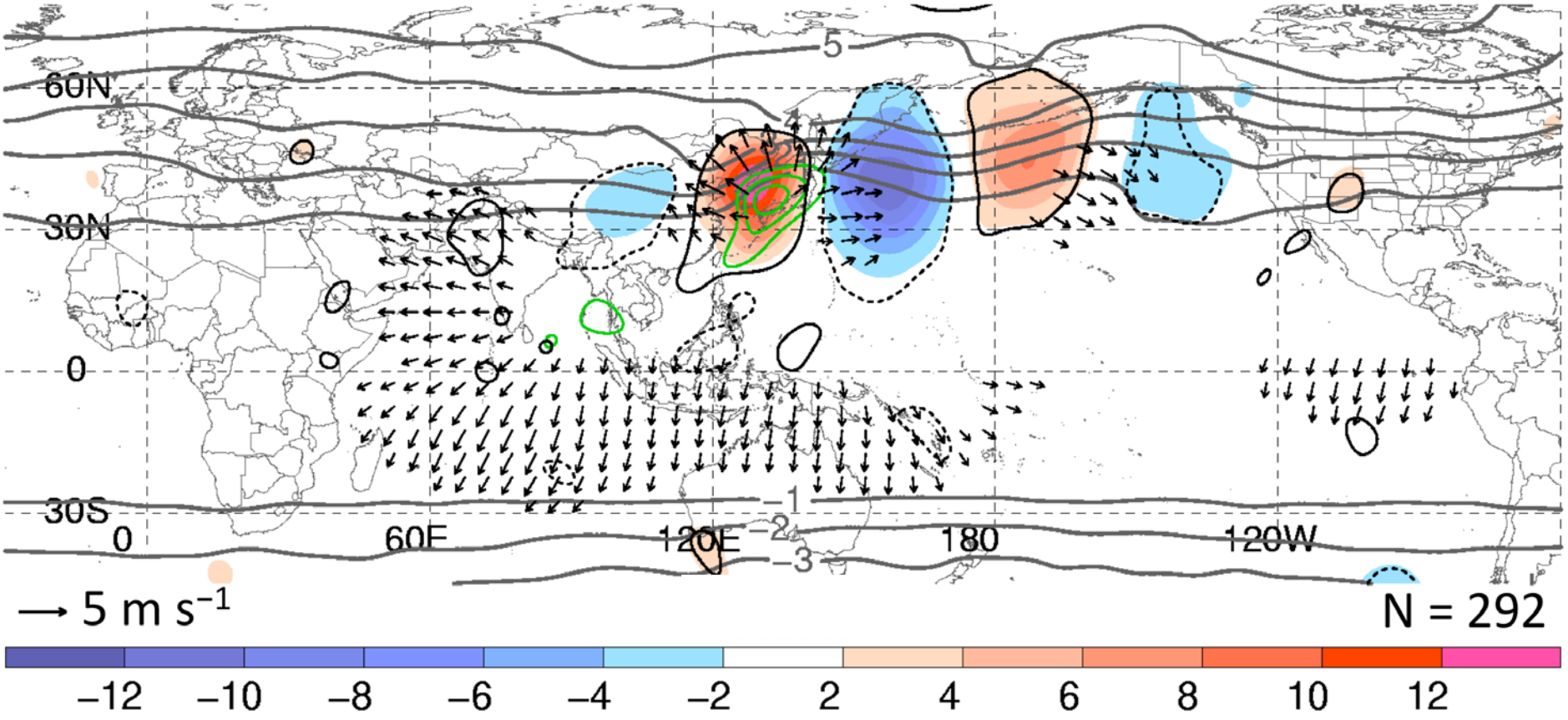
Recurvature-Relative Composite: T+36 h



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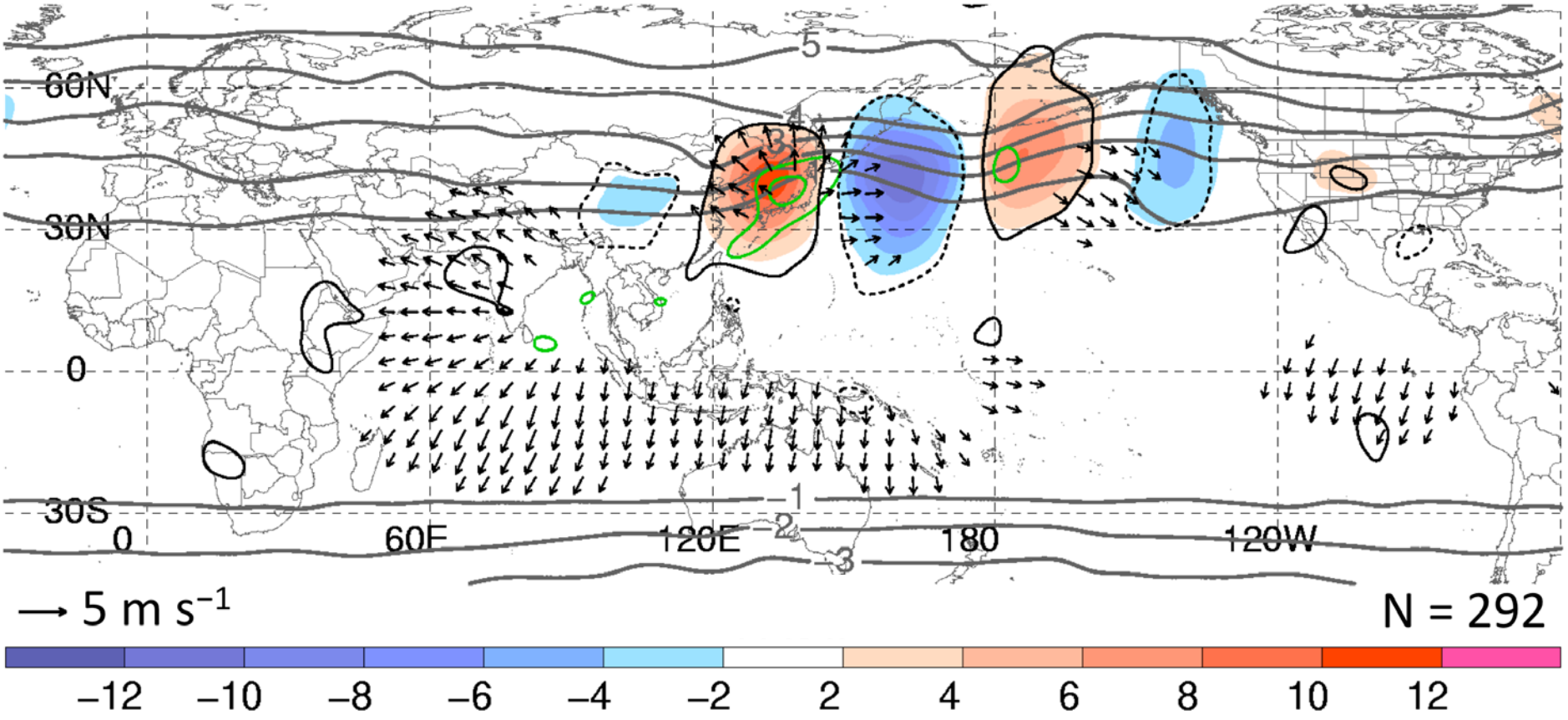
Recurvature-Relative Composite: T+48 h



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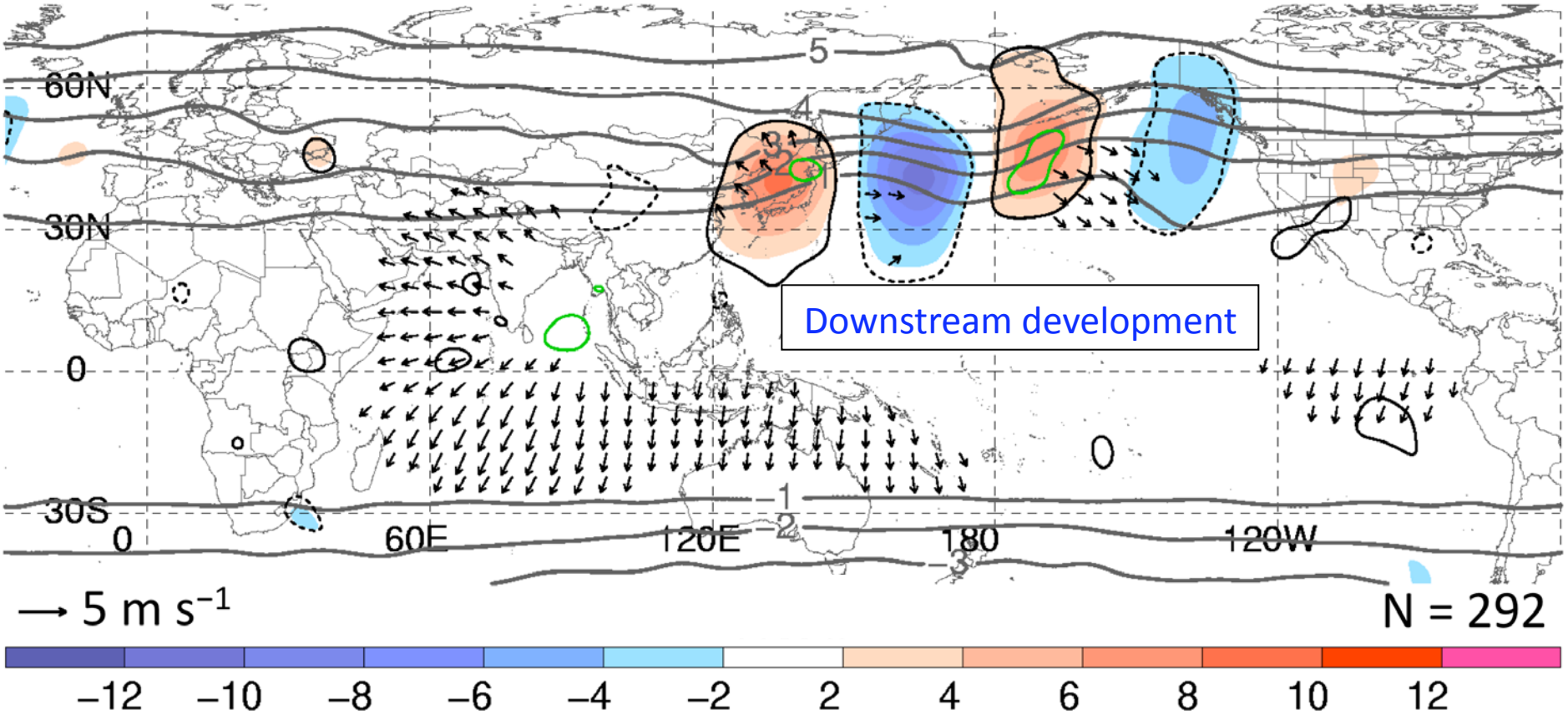
Recurvature-Relative Composite: T+60 h



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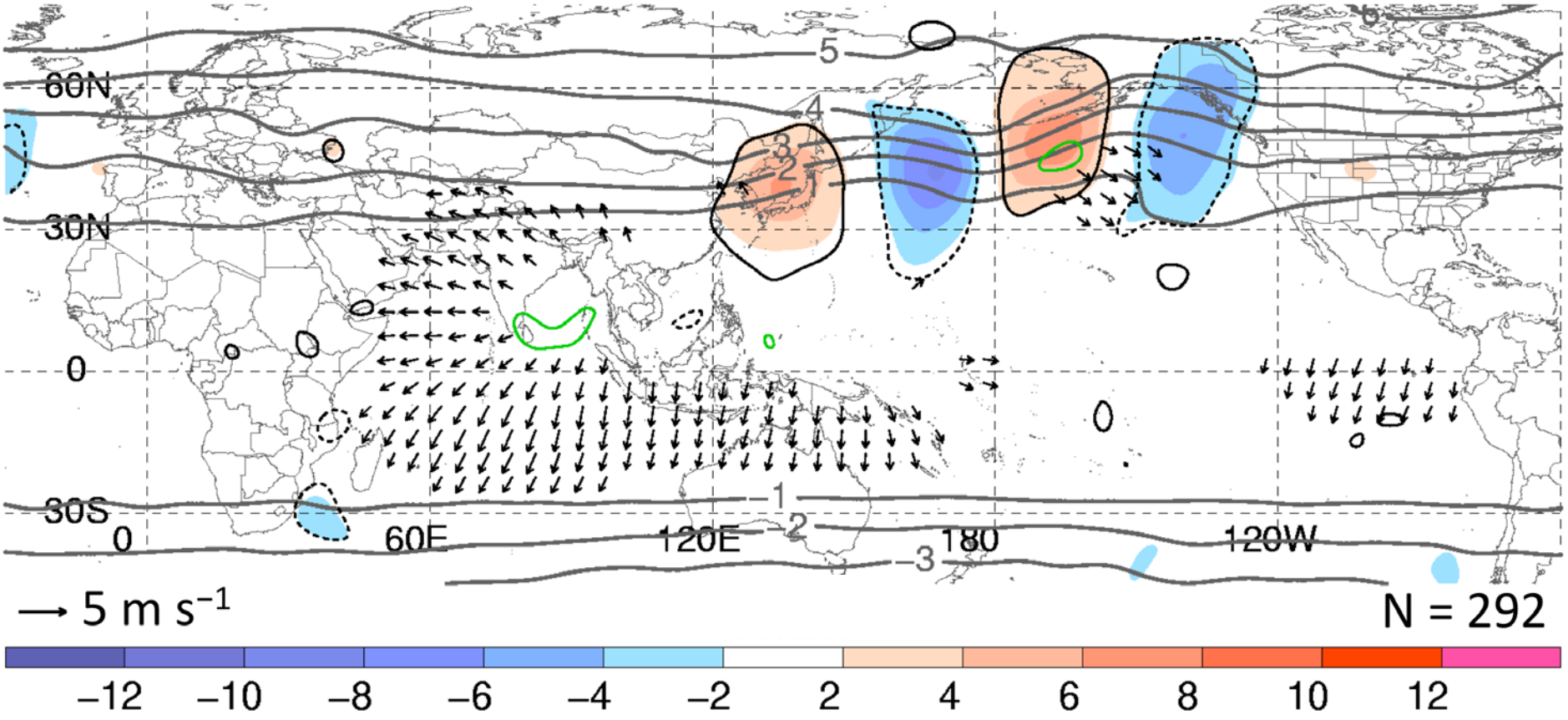
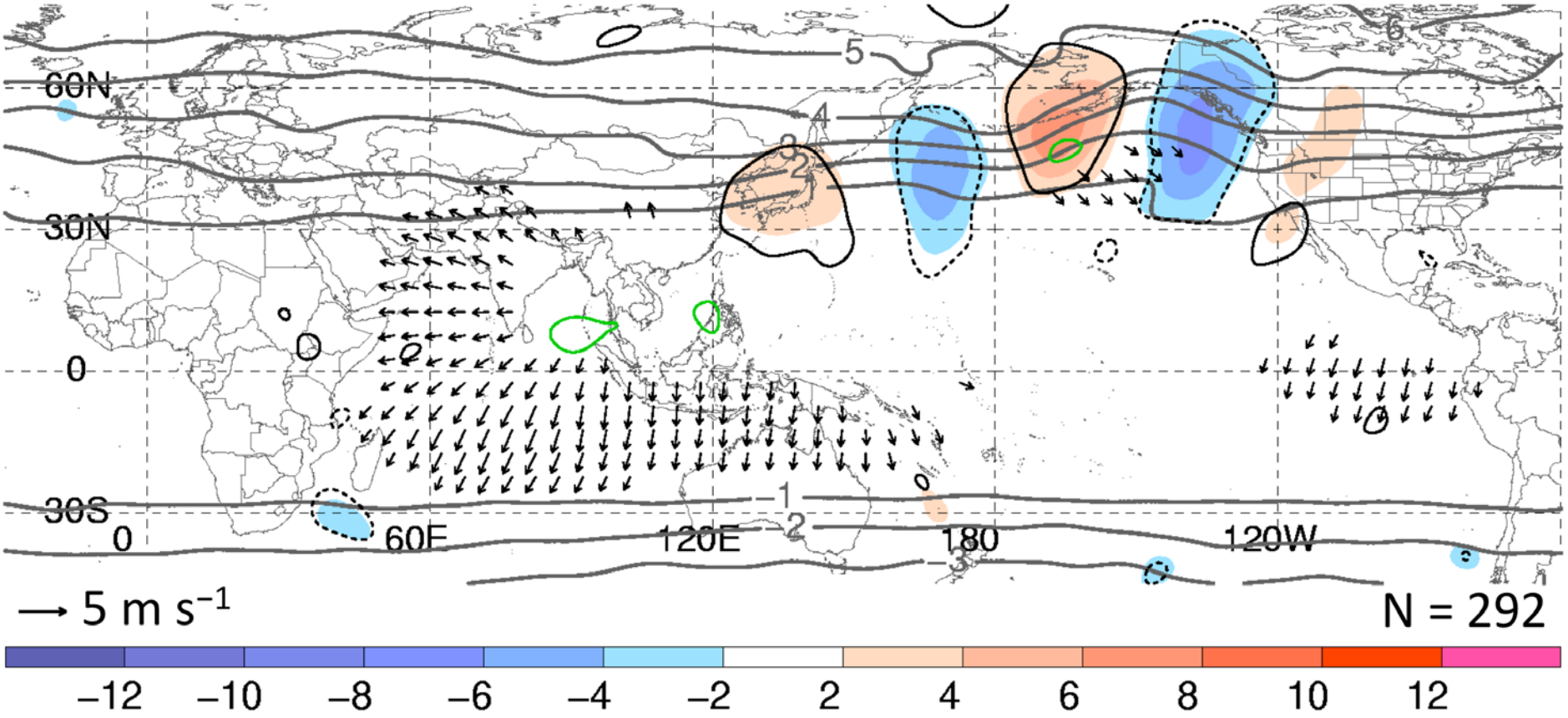
Recurvature-Relative Composite: T+72 h



250-hPa meridional wind anomaly (shaded, m s^{-1}; thin black contours denote 99% stat. sig.), potential vorticity (gray, every 1 PVU), and irrotational wind (vectors, starting at 1.5 m s^{-1}); 500-hPa ascent (green, every 0.5 × 10^{-3} hPa s^{-1})

Recurvature-Relative Composite: T+84 h



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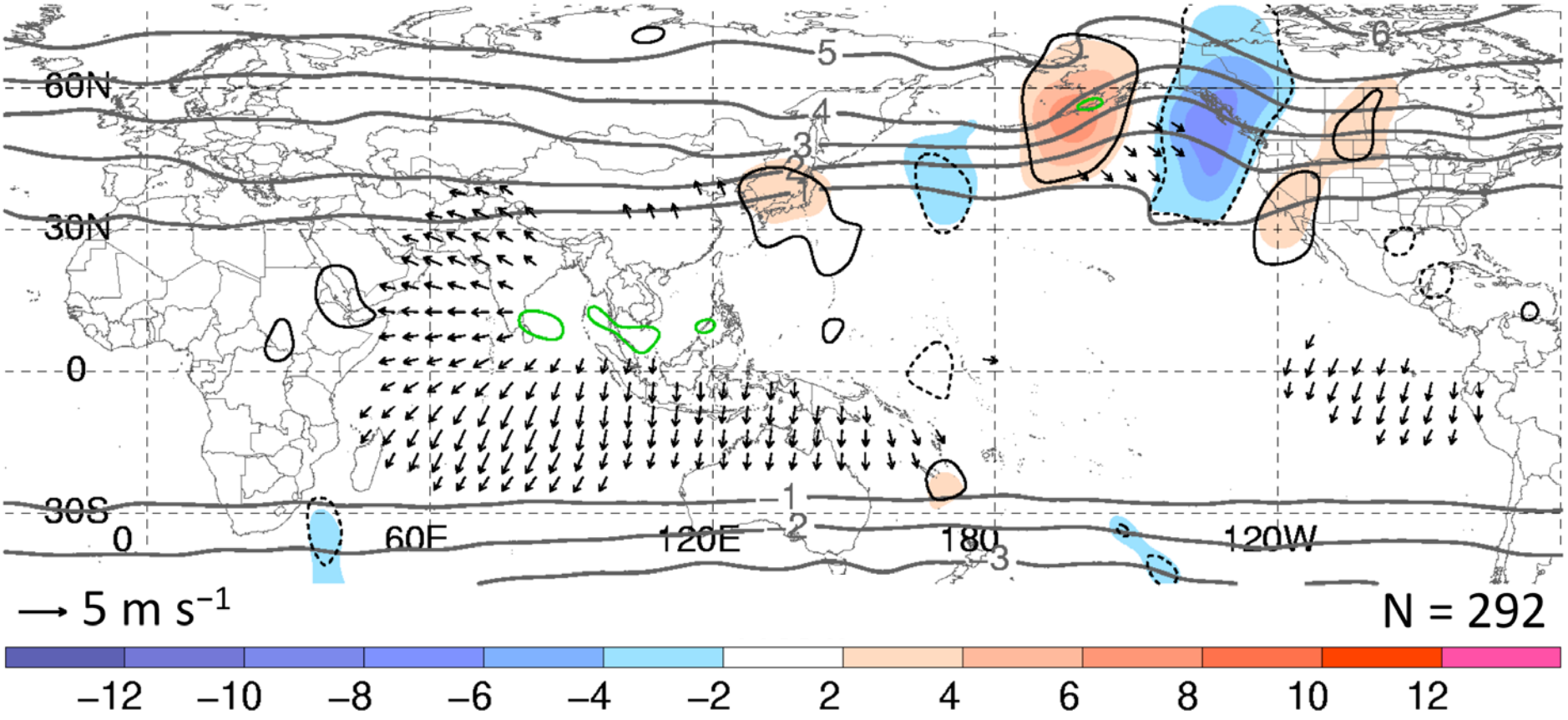
Recurvature-Relative Composite: T+96 h



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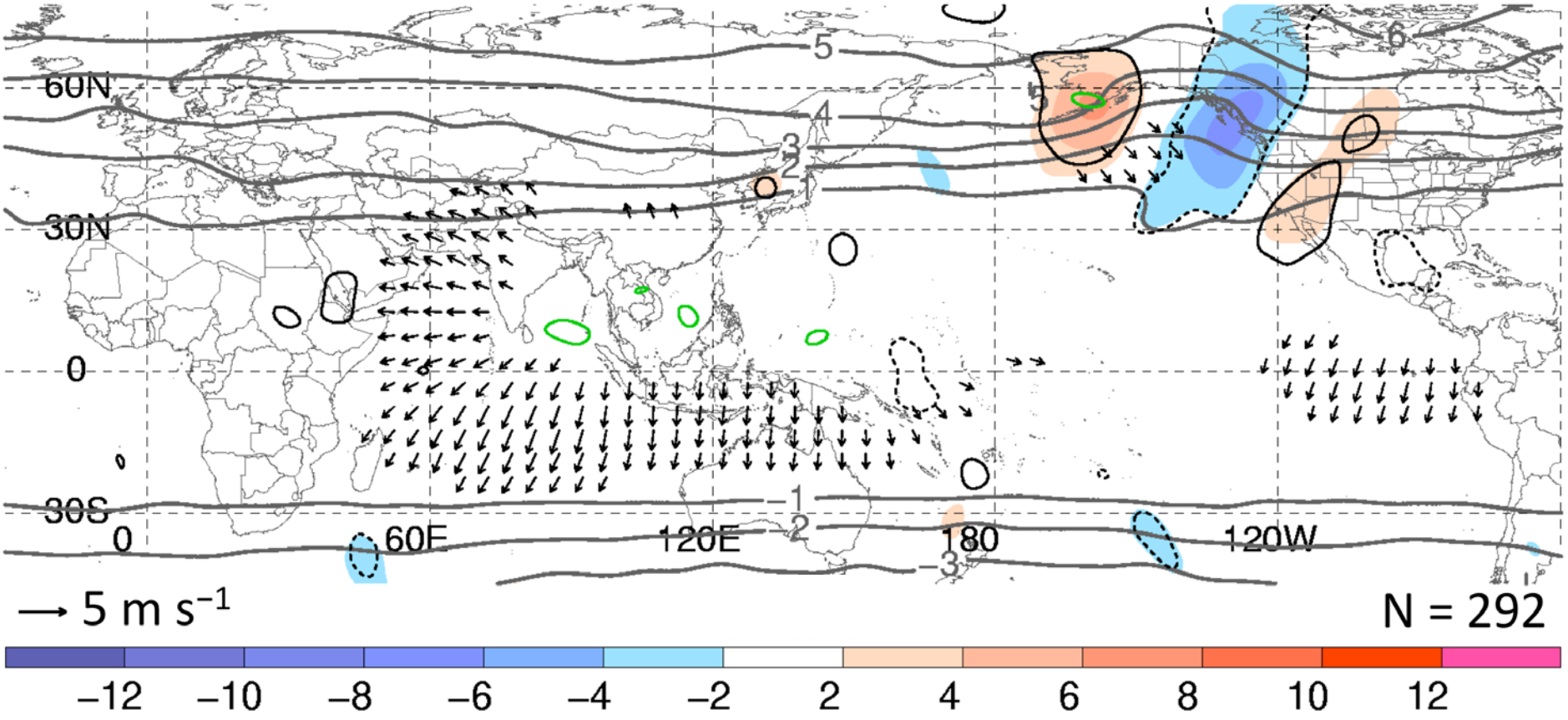
Recurvature-Relative Composite: T+108 h



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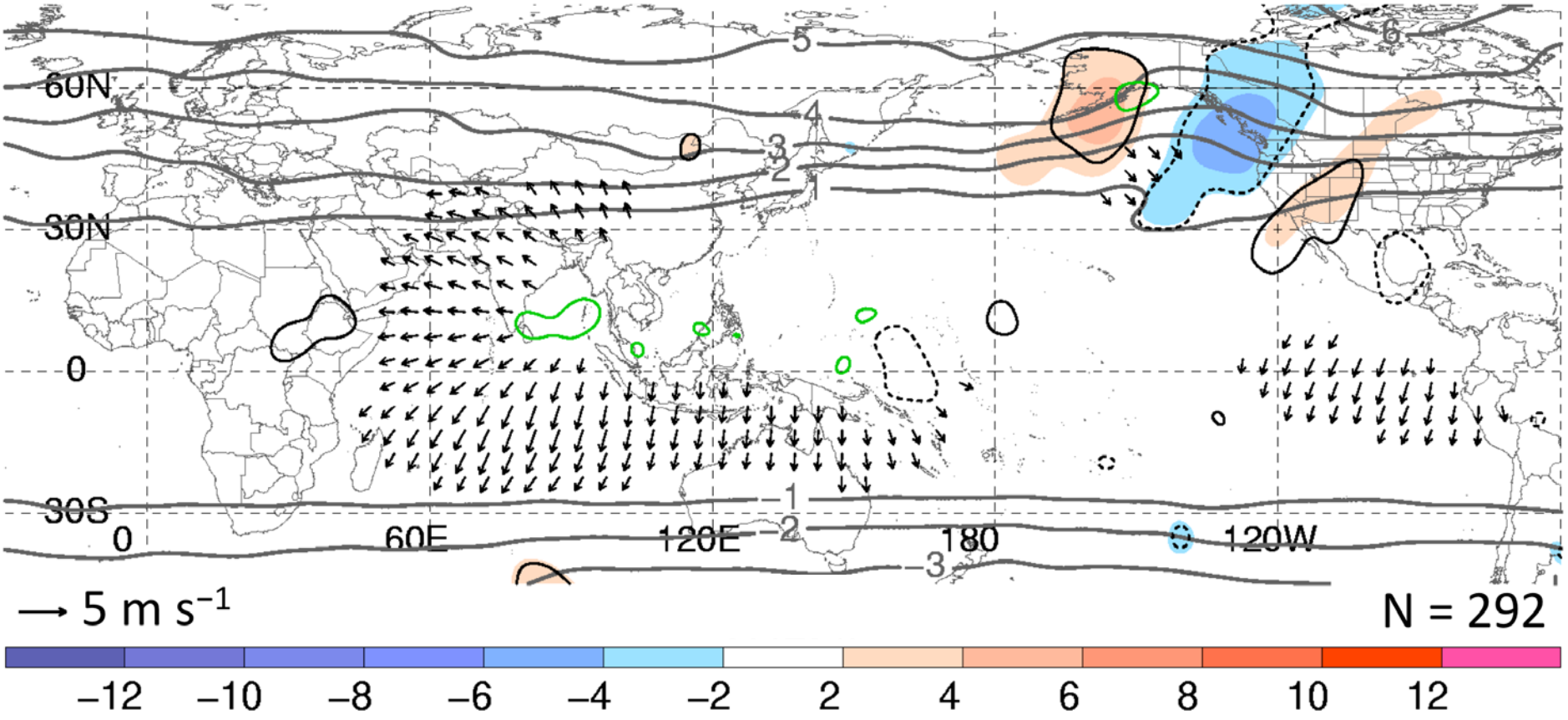
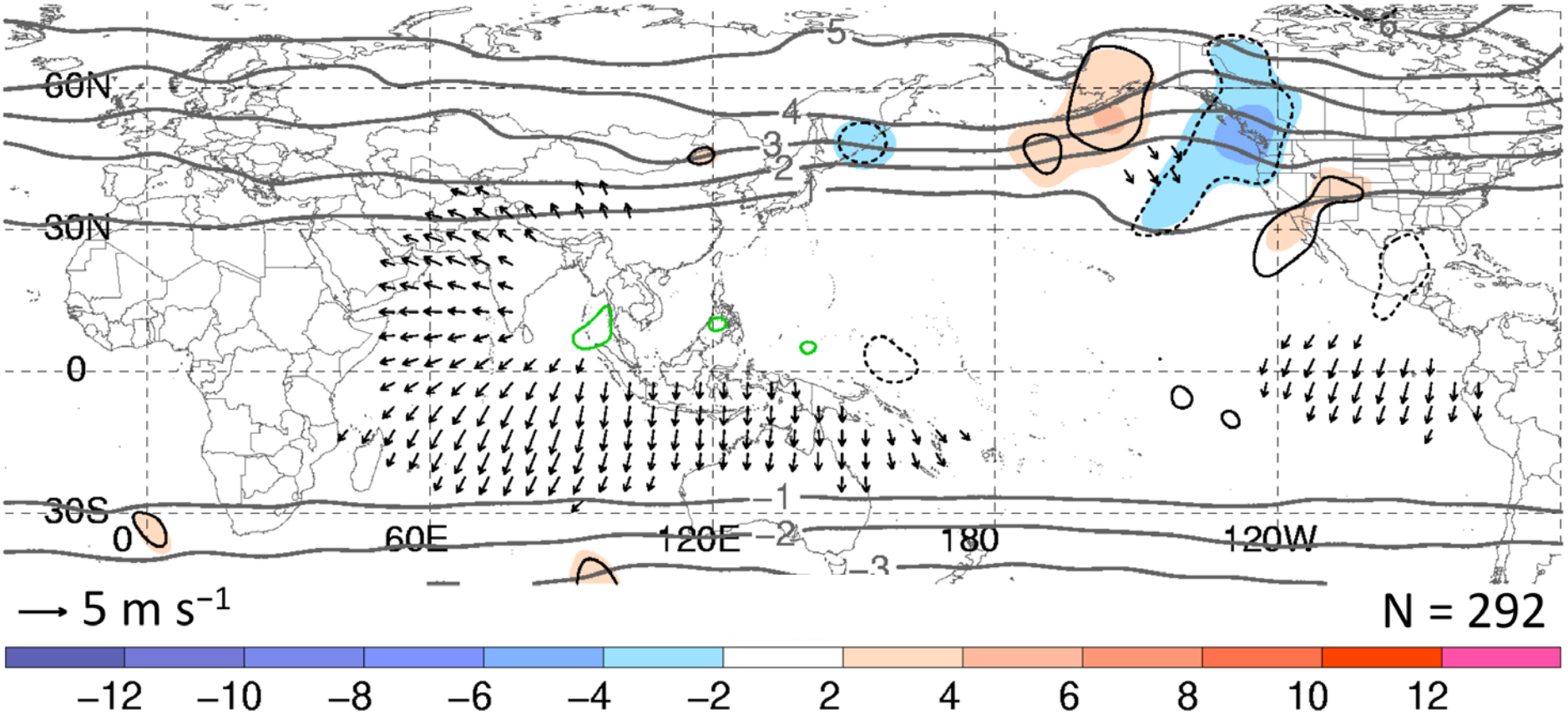
Recurvature-Relative Composite: T+120 h



250-hPa meridional wind anomaly (shaded, m s^{-1}; thin black contours denote 99% stat. sig.), potential vorticity (gray, every 1 PVU), and irrotational wind (vectors, starting at 1.5 m s^{-1}); 500-hPa ascent (green, every 0.5 × 10^{-3} hPa s^{-1})

Recurvature-Relative Composite: T+132 h



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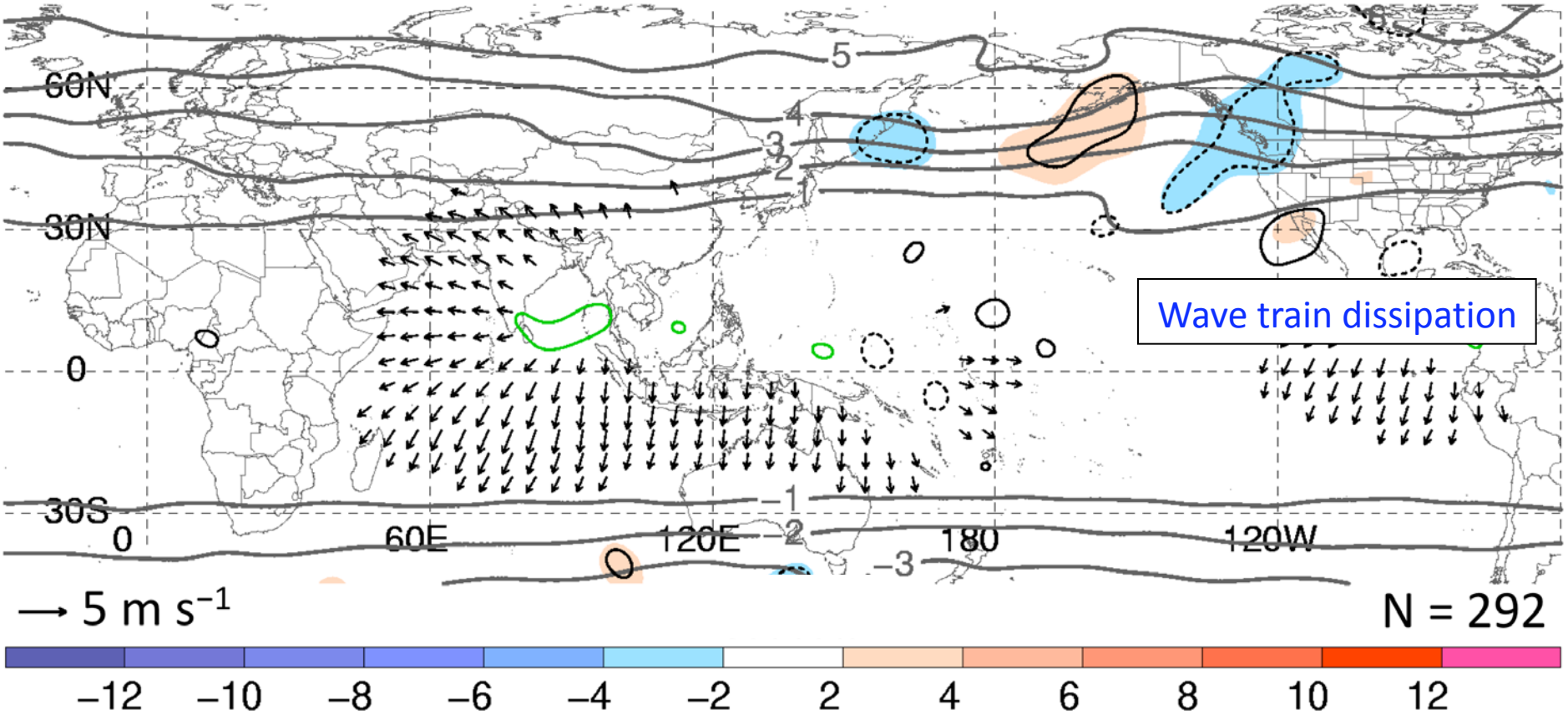
Recurvature-Relative Composite: T+144 h



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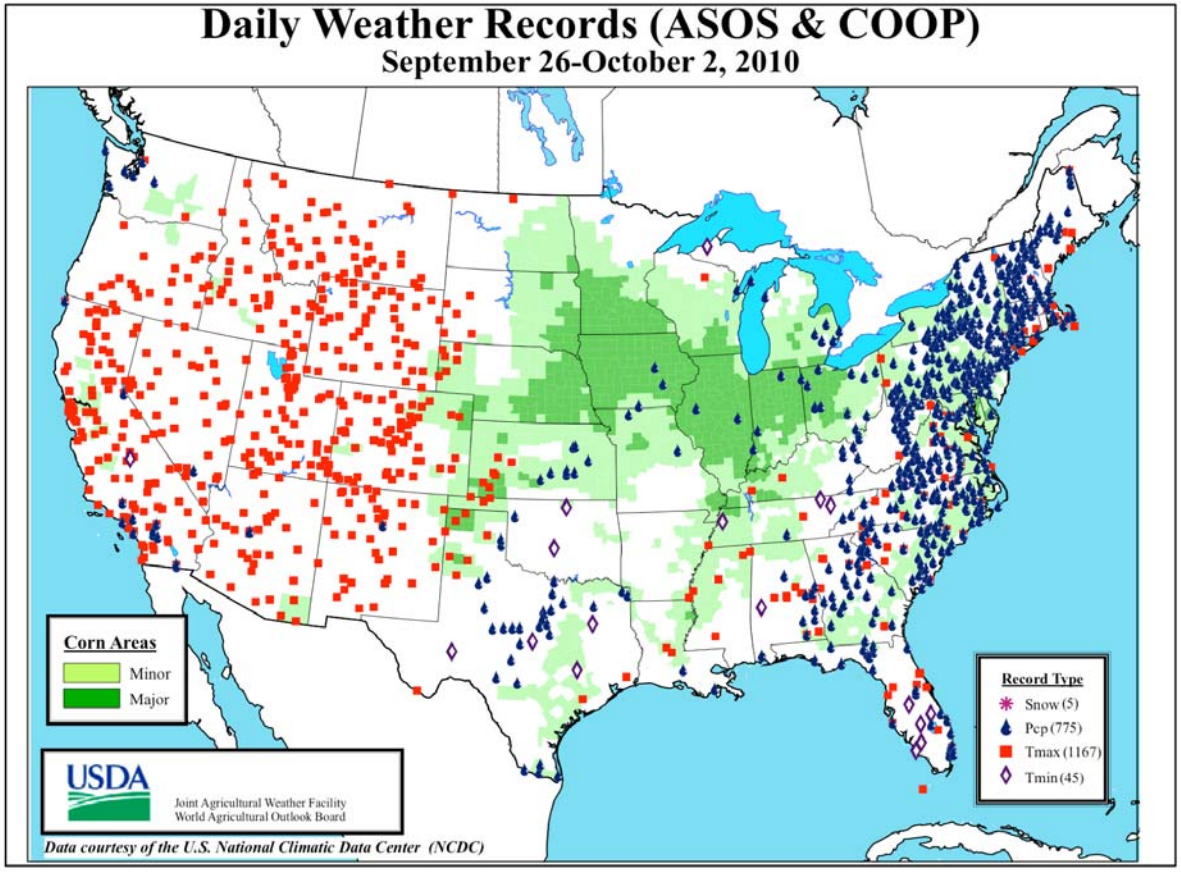
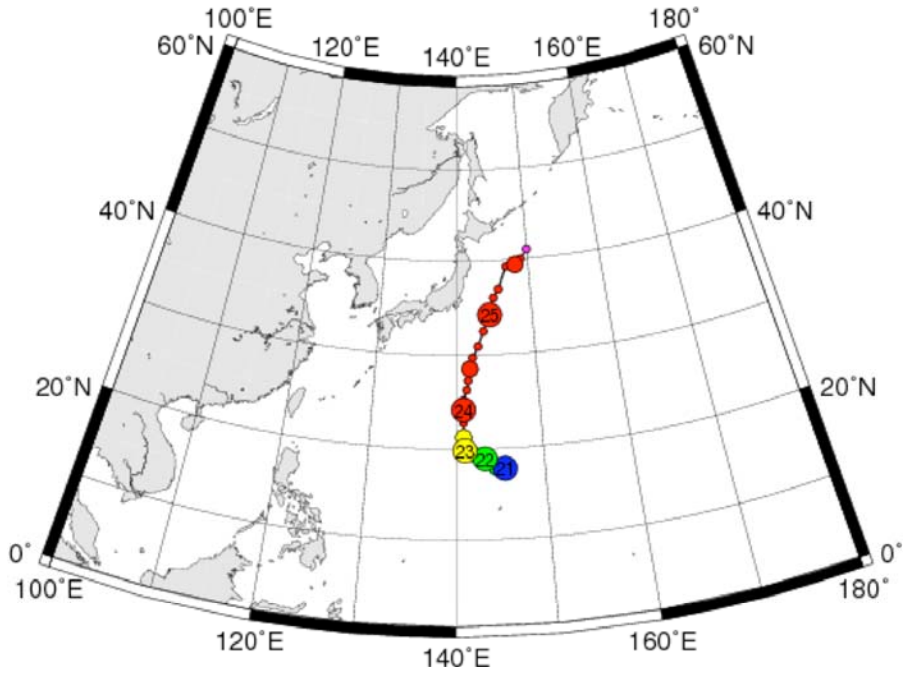
Part 2: Recurvature of TC Malakas as an antecedent to downstream development and high-impact weather (22 Sep–1 Oct)

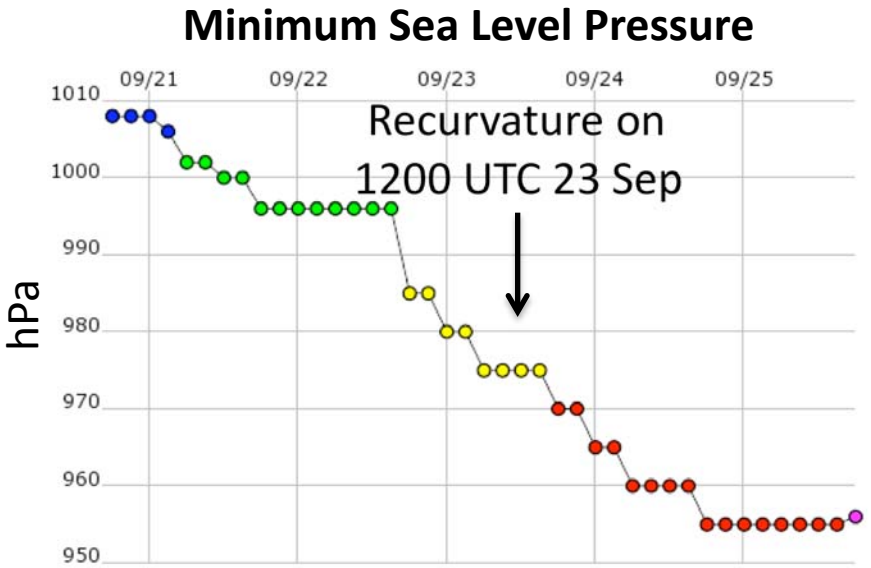
Summary of U.S. High-Impact Weather



- All-time high temperature record of 45°C (113°F) set in downtown Los Angeles on 27 Sep

TC Malakas JMA Best-Track Data



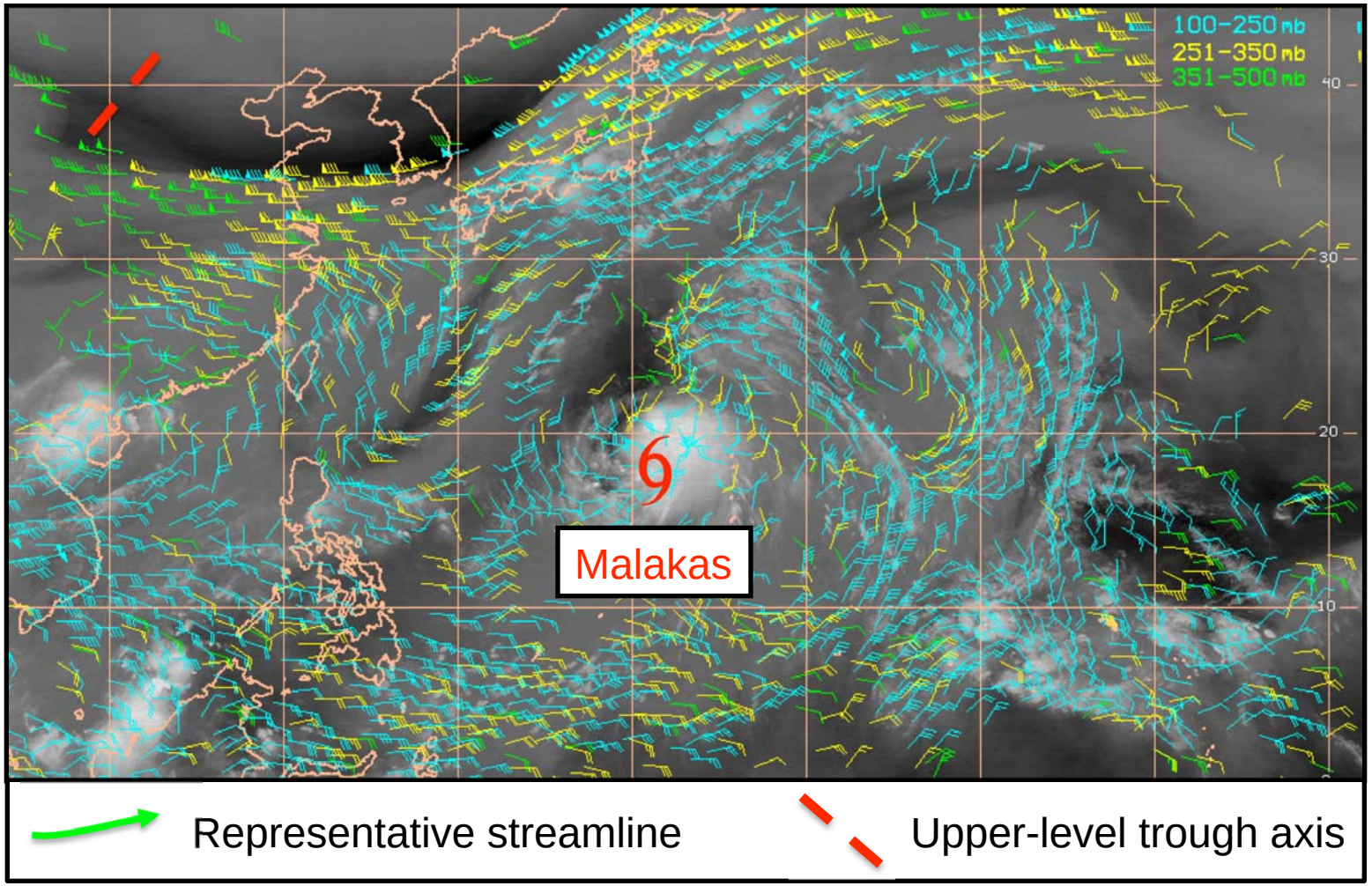


Typhoon Severe Tropical Storm Tropical Storm
Tropical Depression Extratropical Low

Obtained from http://agora.ex.nii.ac.jp/digital-typhoon/

TC–Jet Stream Interaction

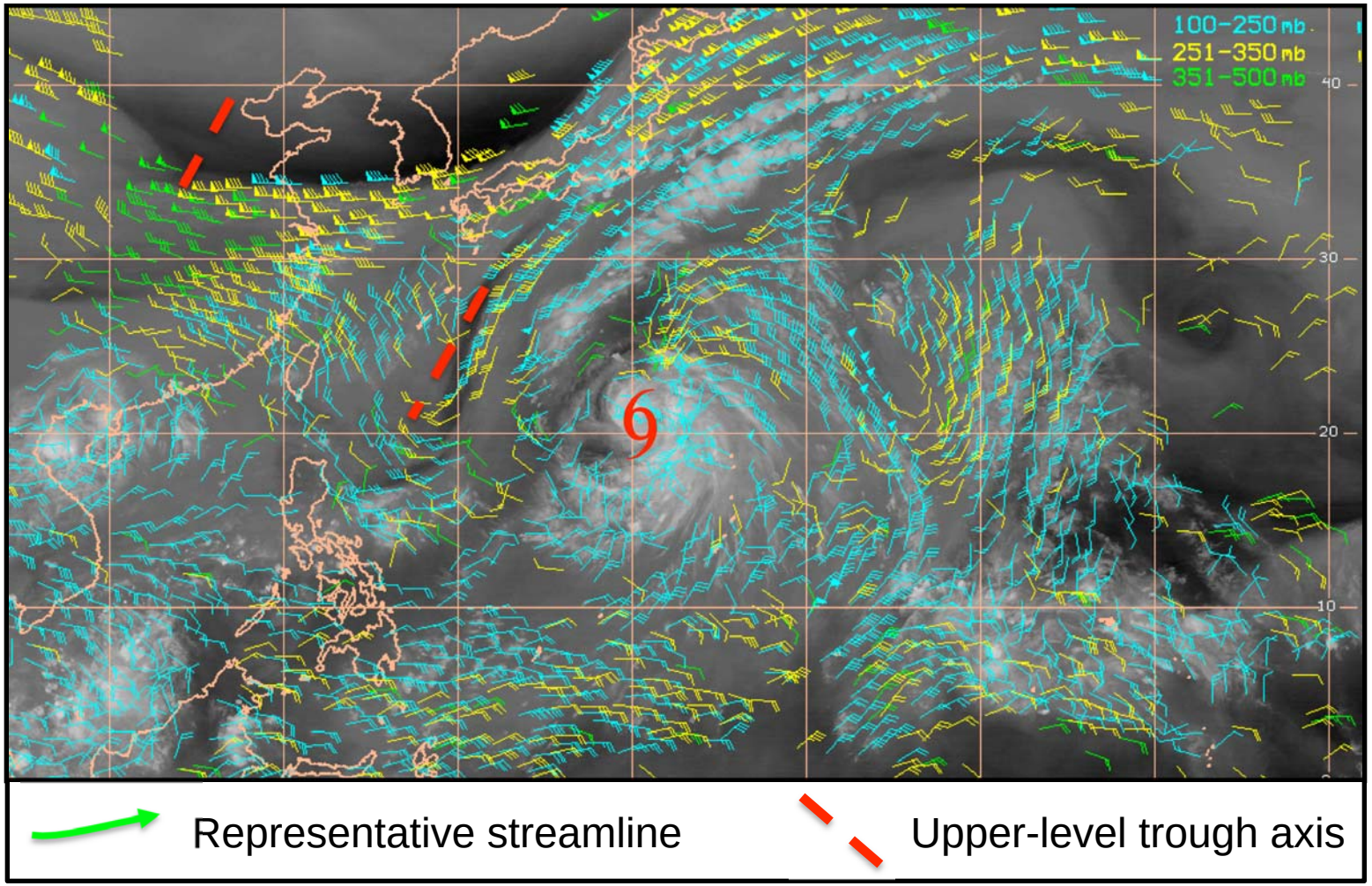
T–12 h: 0000 UTC 23 Sep



CIMSS water vapor imagery and cloud-track upper-level winds

TC–Jet Stream Interaction

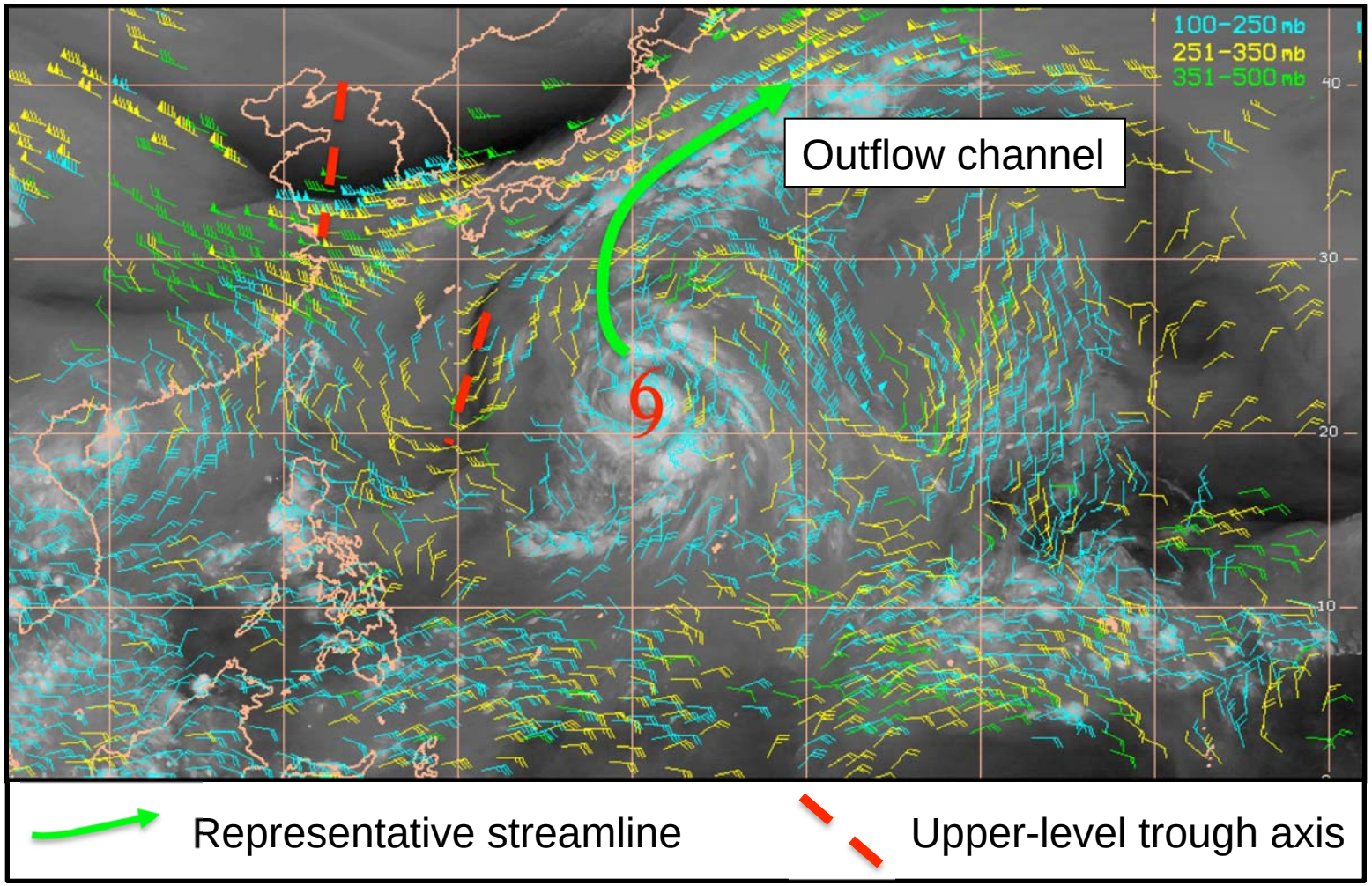
T–6 h: 0600 UTC 23 Sep



CIMSS water vapor imagery and cloud-track upper-level winds

TC–Jet Stream Interaction

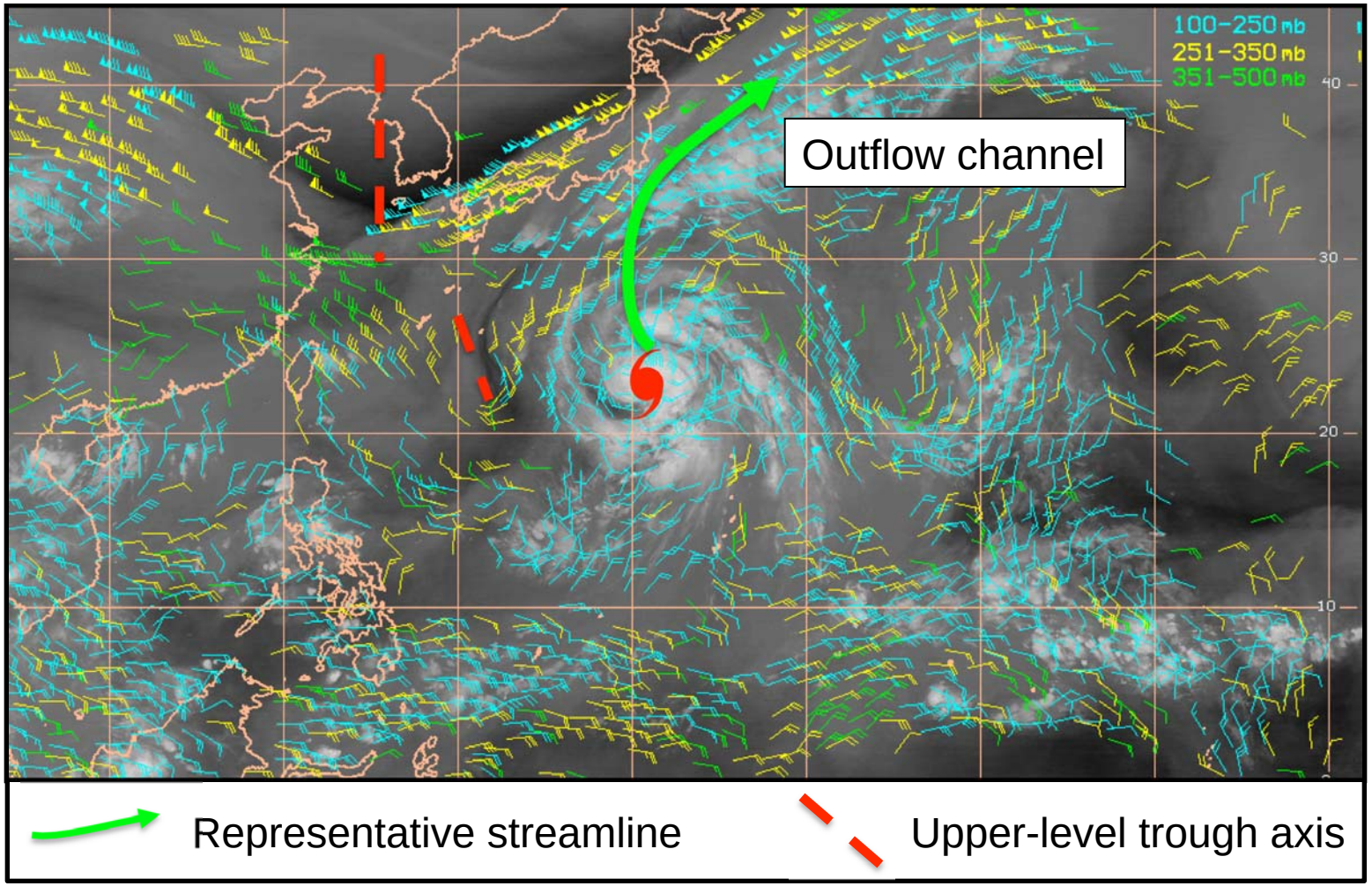
T+0 h: 1200 UTC 23 Sep



CIMSS water vapor imagery and cloud-track upper-level winds

TC–Jet Stream Interaction

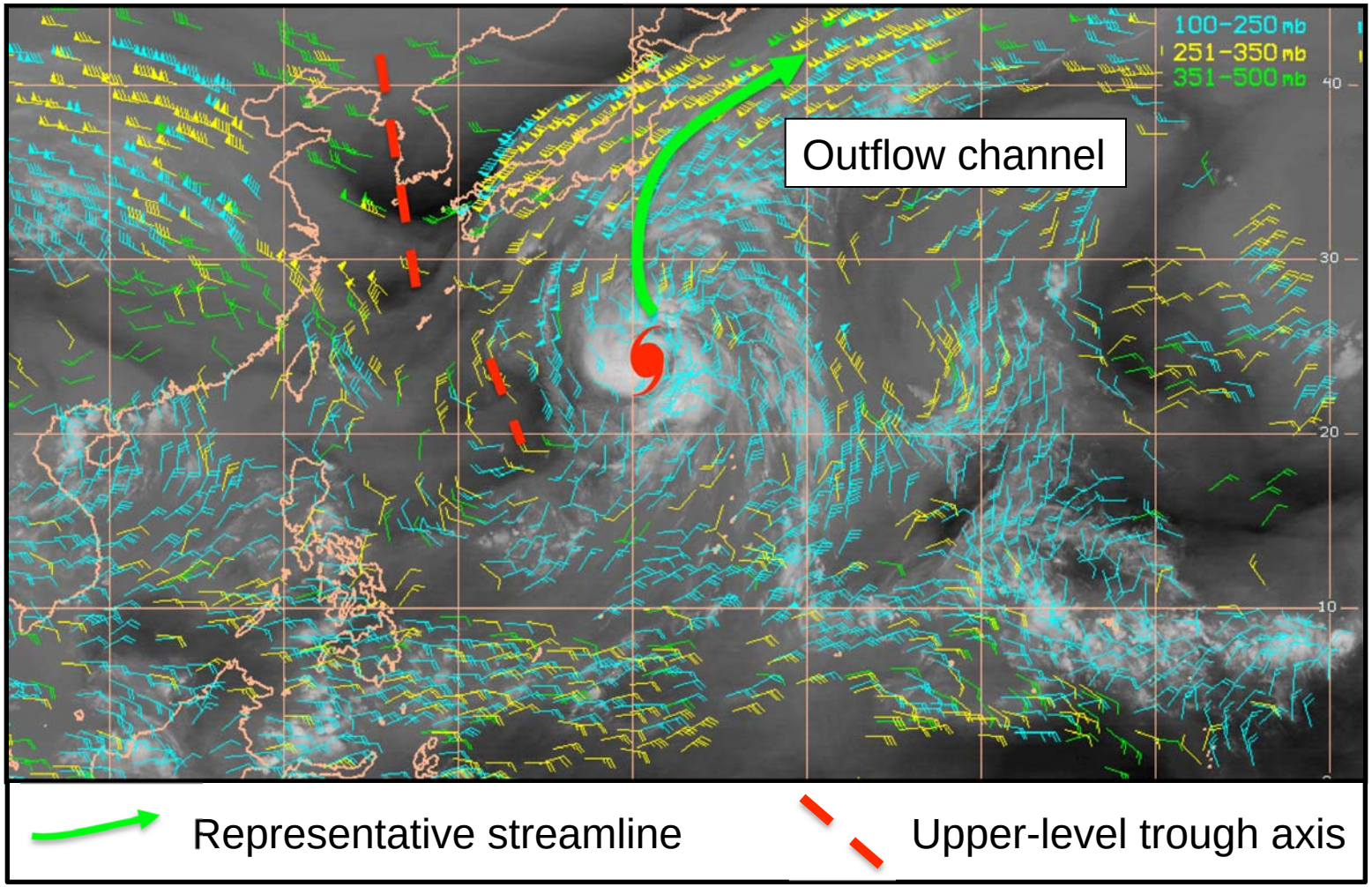
T+6 h: 1800 UTC 23 Sep



CIMSS water vapor imagery and cloud-track upper-level winds

TC–Jet Stream Interaction

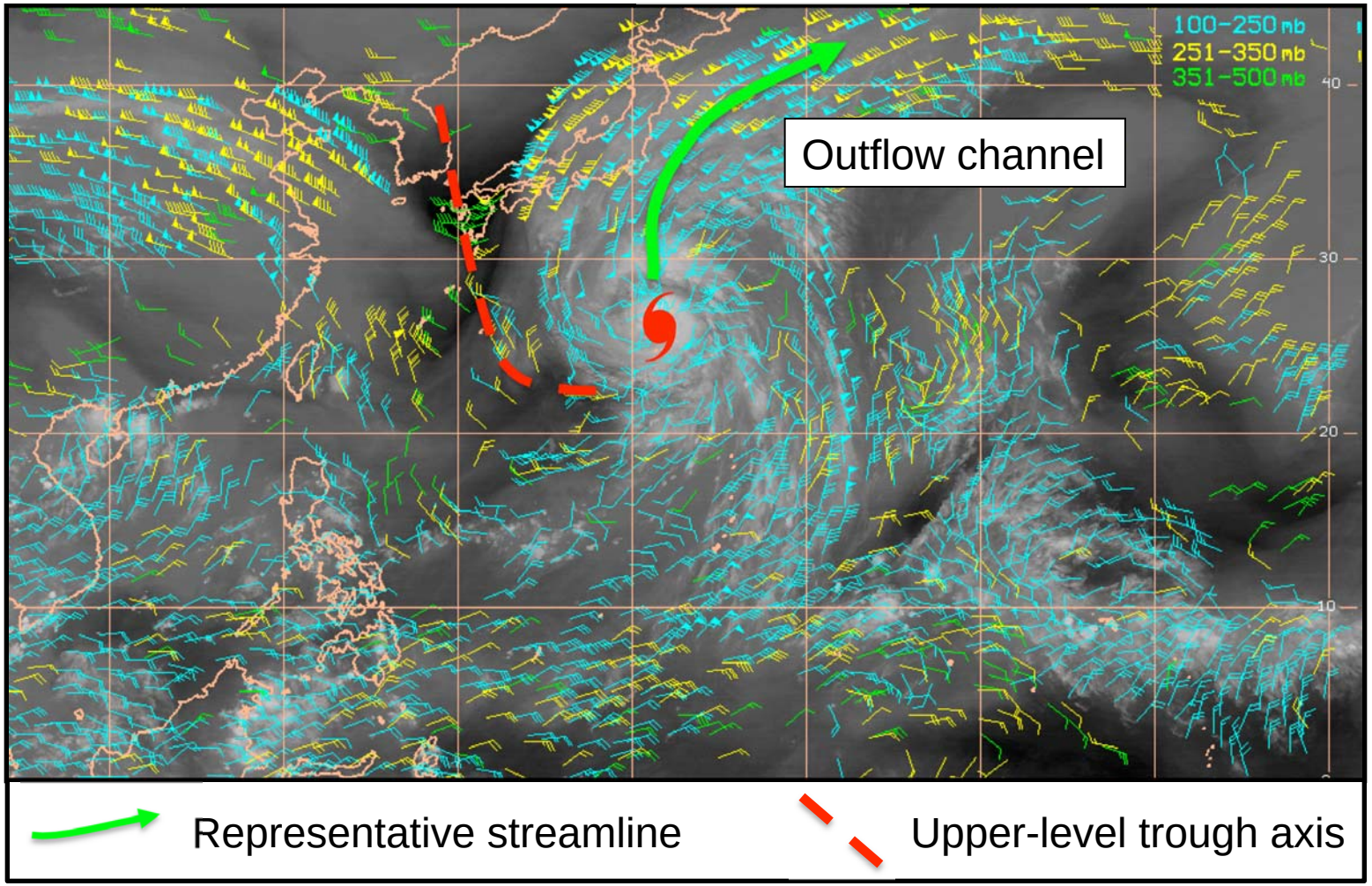
T+12 h: 0000 UTC 24 Sep



CIMSS water vapor imagery and cloud-track upper-level winds

TC–Jet Stream Interaction

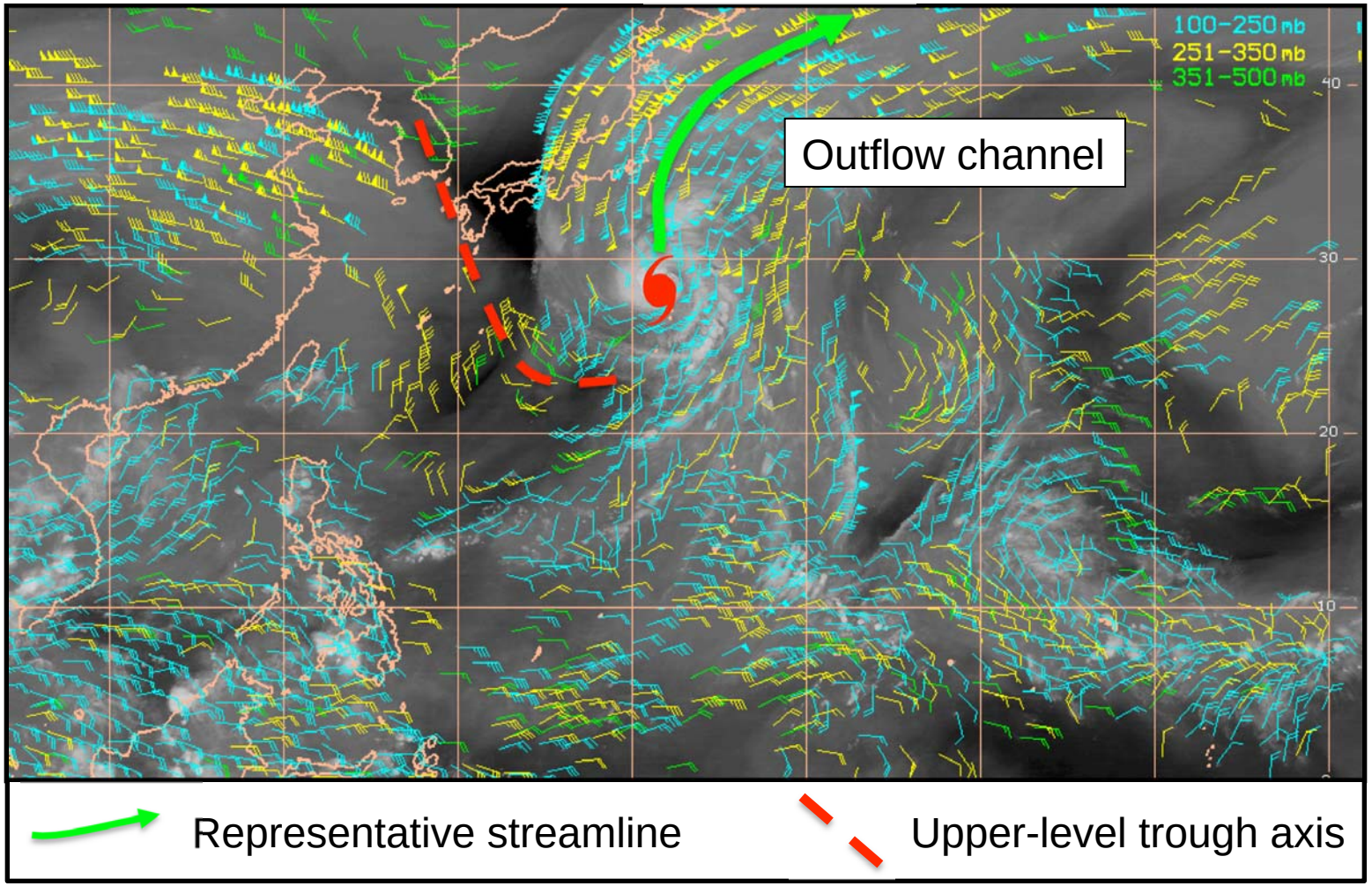
T+18 h: 0600 UTC 24 Sep



CIMSS water vapor imagery and cloud-track upper-level winds

TC–Jet Stream Interaction

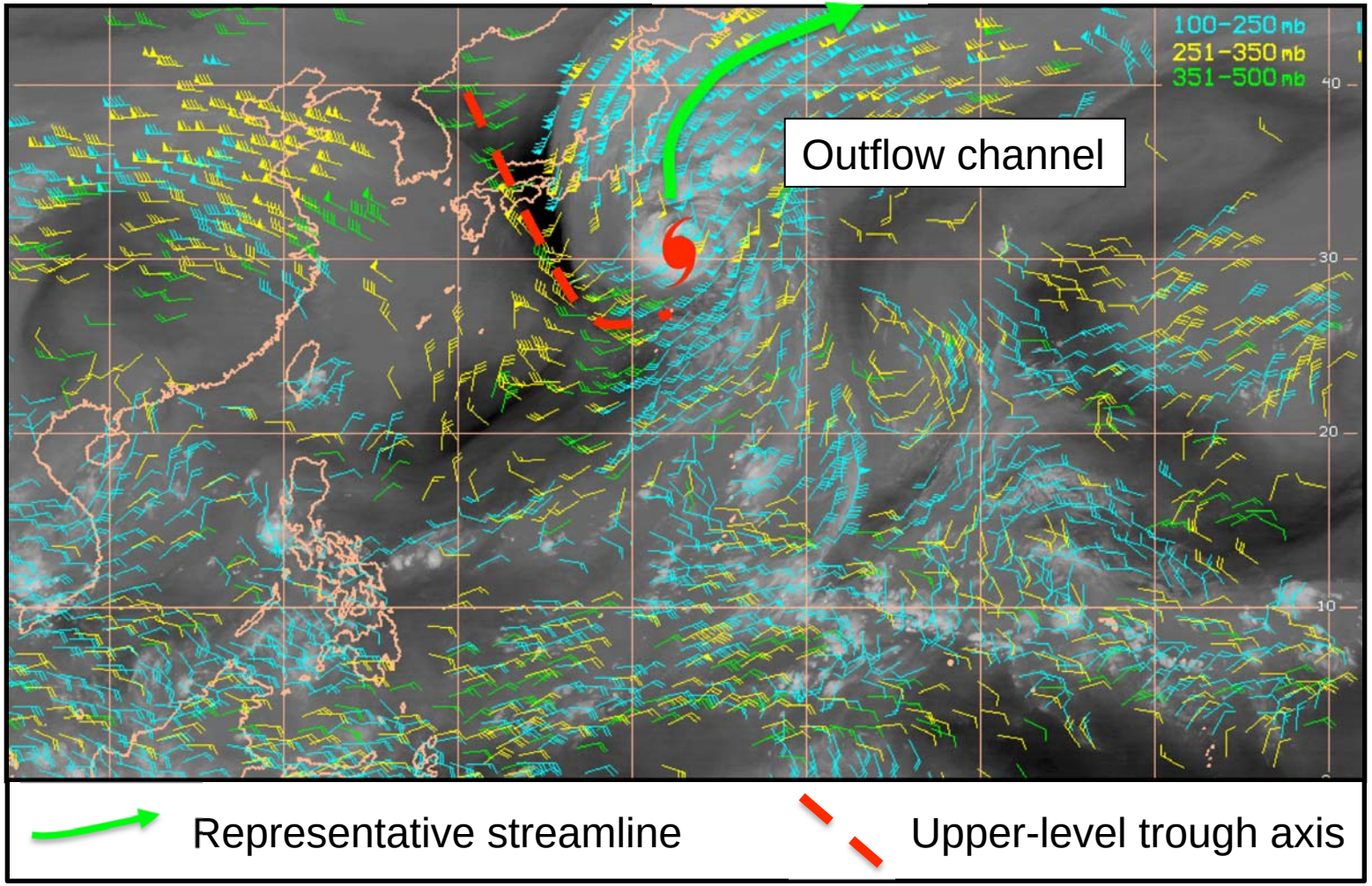
T+24 h: 1200 UTC 24 Sep



CIMSS water vapor imagery and cloud-track upper-level winds

TC–Jet Stream Interaction

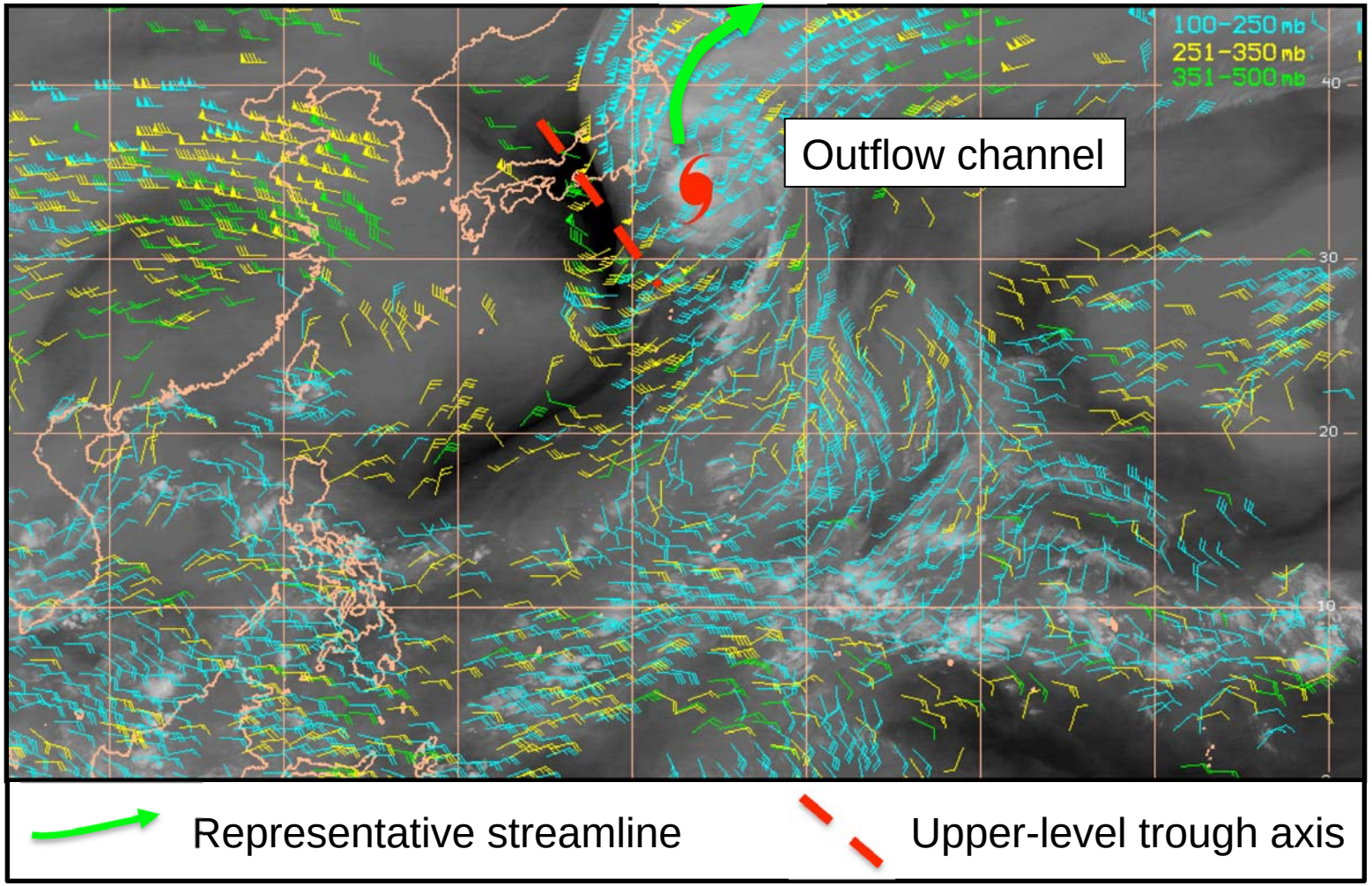
T+30 h: 1800 UTC 24 Sep



CIMSS water vapor imagery and cloud-track upper-level winds

TC–Jet Stream Interaction

T+36 h: 0000 UTC 25 Sep

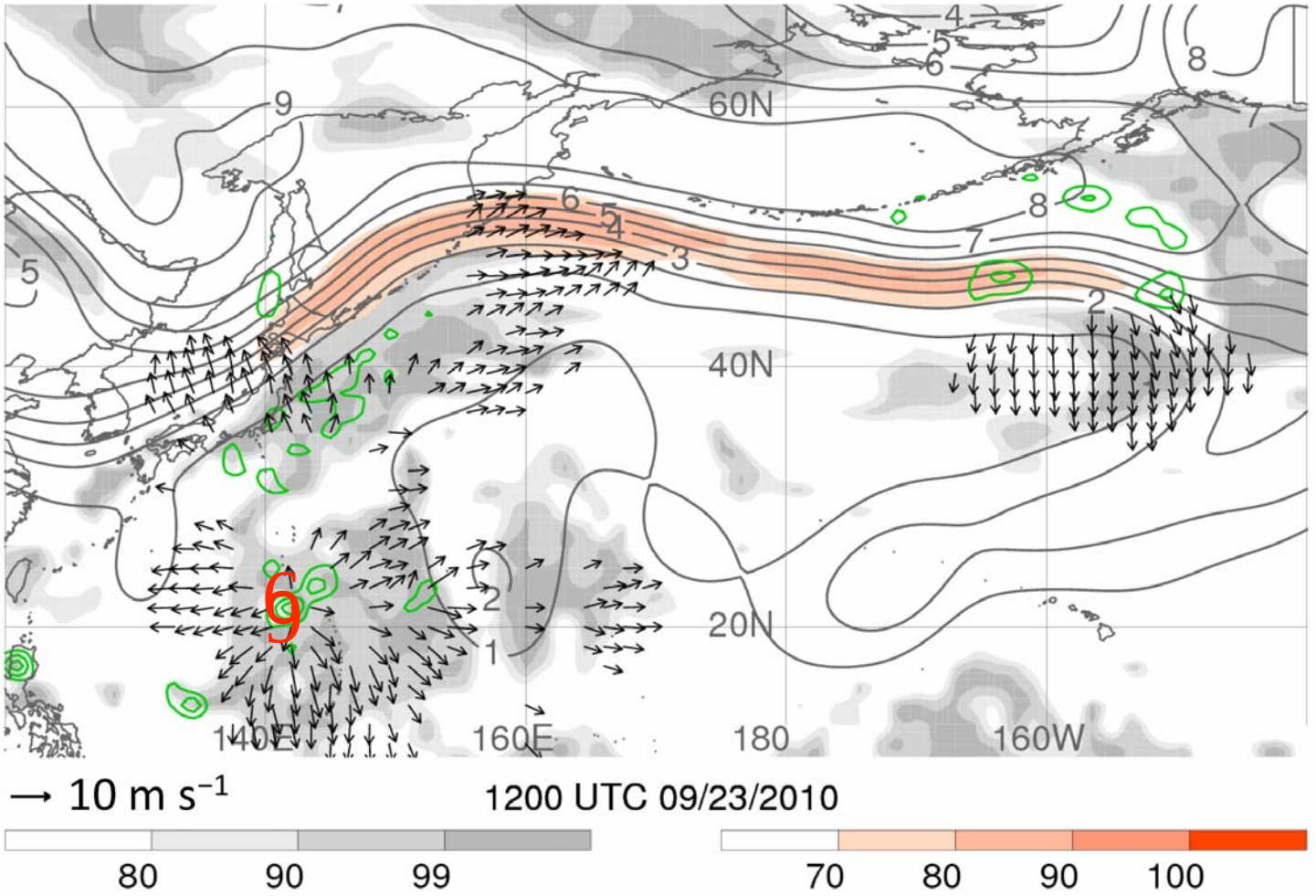


CIMSS water vapor imagery and cloud-track upper-level winds

0.5° GFS analysis

Rossby Wave Excitation by TC

T+0 h: 1200 UTC 23 Sep

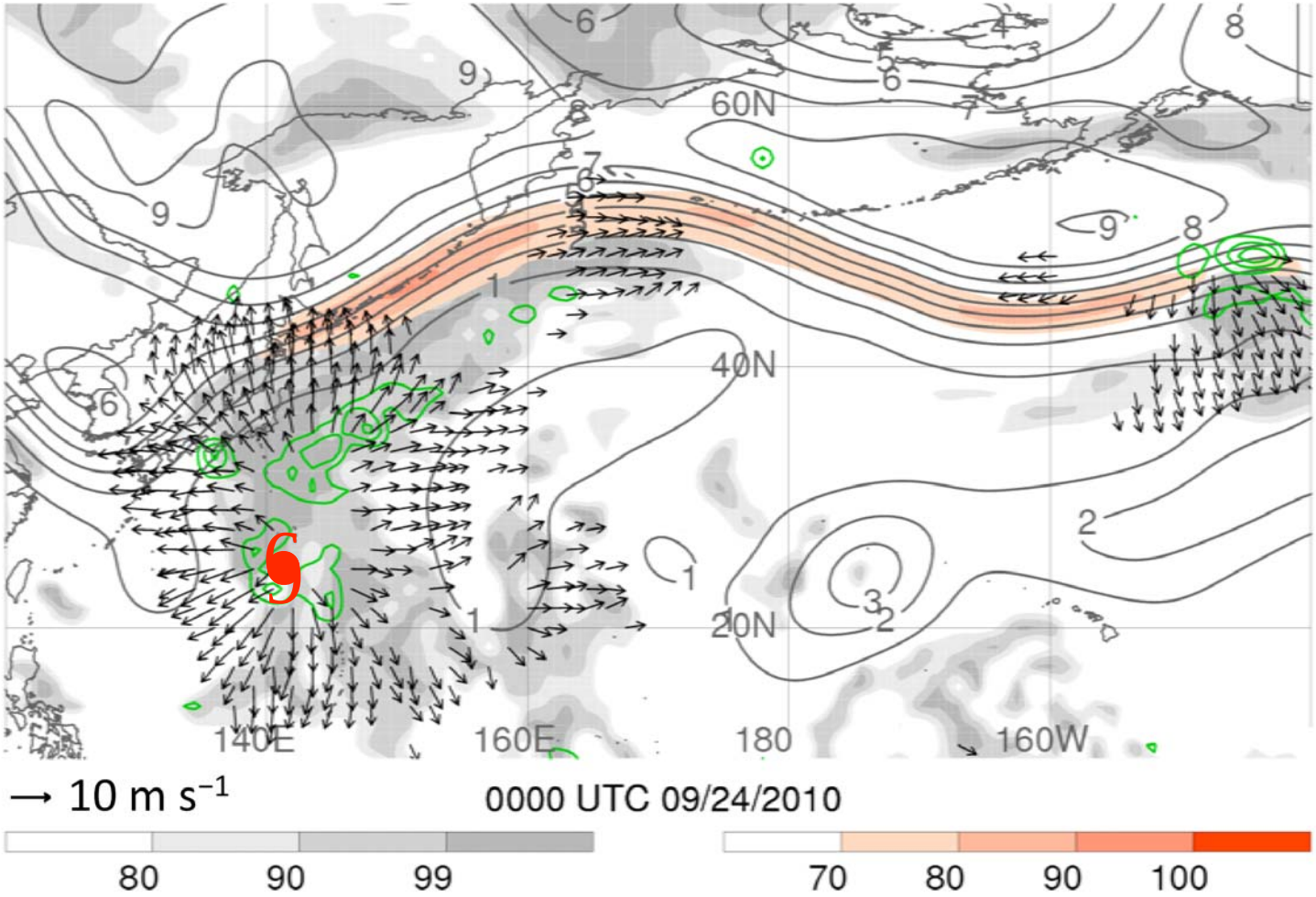


250-hPa wind speed (color shading, m s^{-1}), relative humidity (gray shading, %), potential vorticity (gray contours, PVU), and irrotational wind (vectors, starting at 5 m s^{-1}); 500-hPa ascent (green, every 5 × 10^{-3} hPa s^{-1})

0.5° GFS analysis

Rossby Wave Excitation by TC

T+12 h: 0000 UTC 24 Sep



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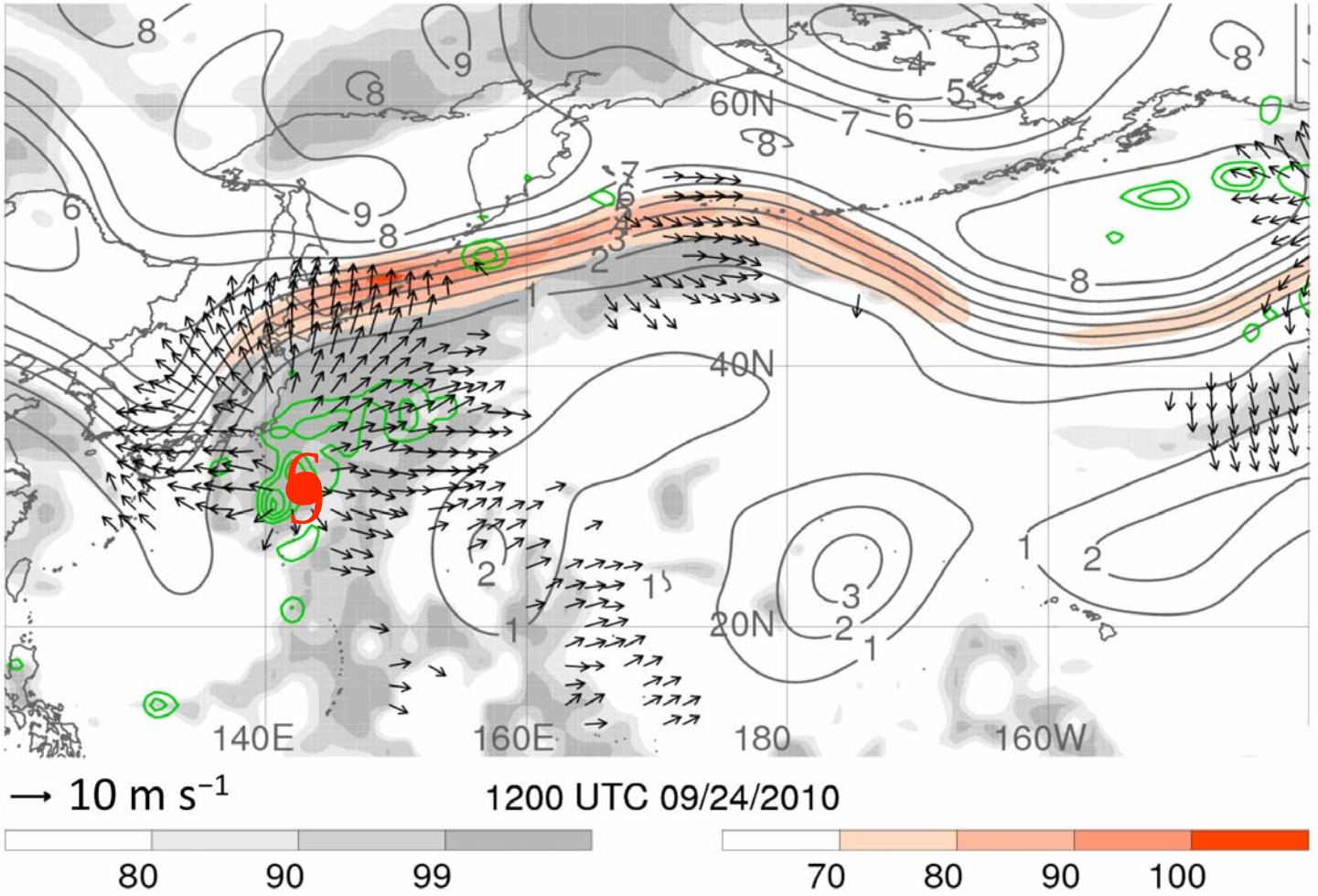
0.5° GFS analysis

Rossby Wave Excitation by TC

T+24 h: 1200 UTC 24 Sep

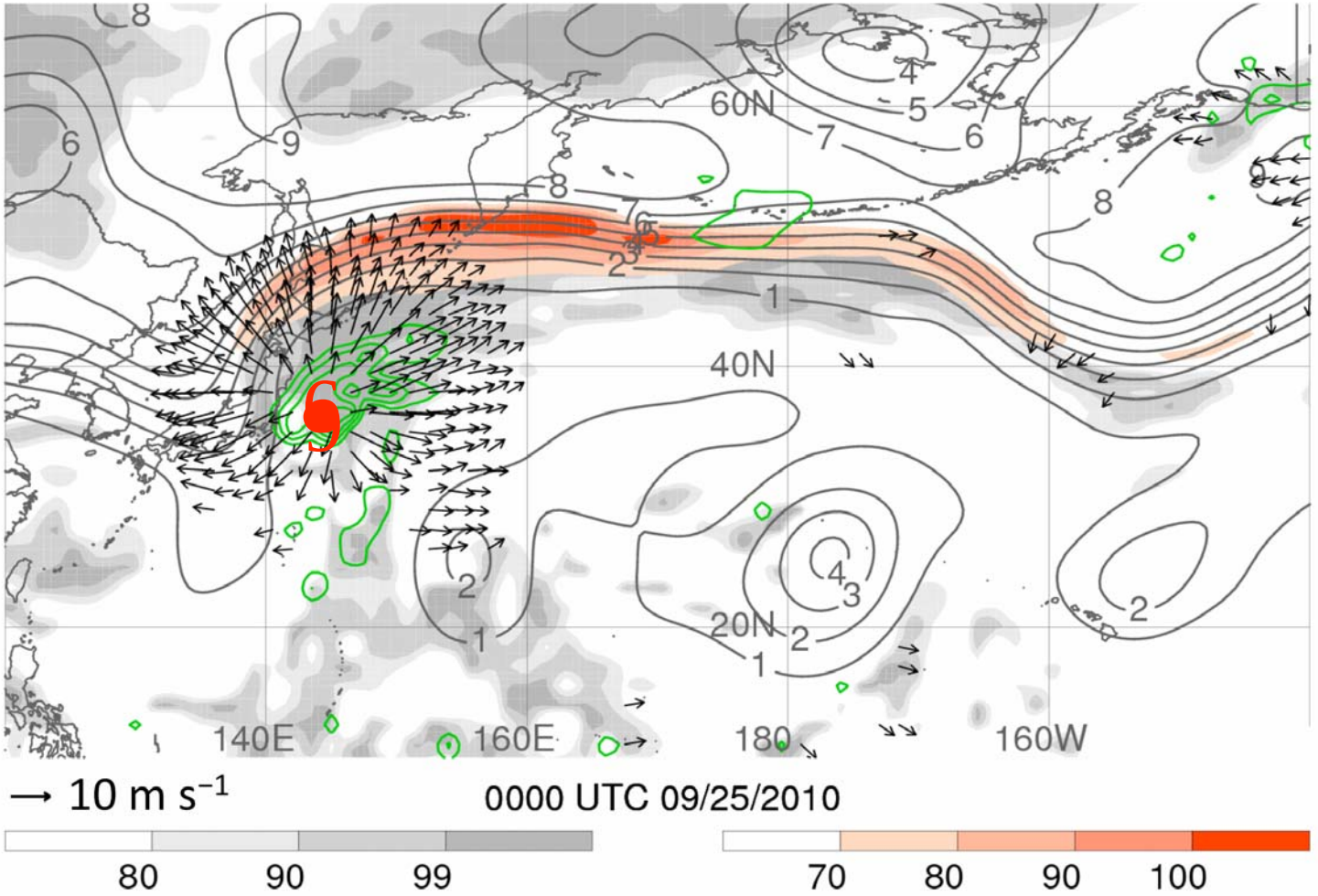


250-hPa wind speed (color shading, m s^{-1}), relative humidity (gray shading, %), potential vorticity (gray contours, PVU), and irrotational wind (vectors, starting at 5 m s^{-1}); 500-hPa ascent (green, every 5 × 10^{-3} hPa s^{-1})

0.5° GFS analysis

Rossby Wave Excitation by TC

T+36 h: 0000 UTC 25 Sep

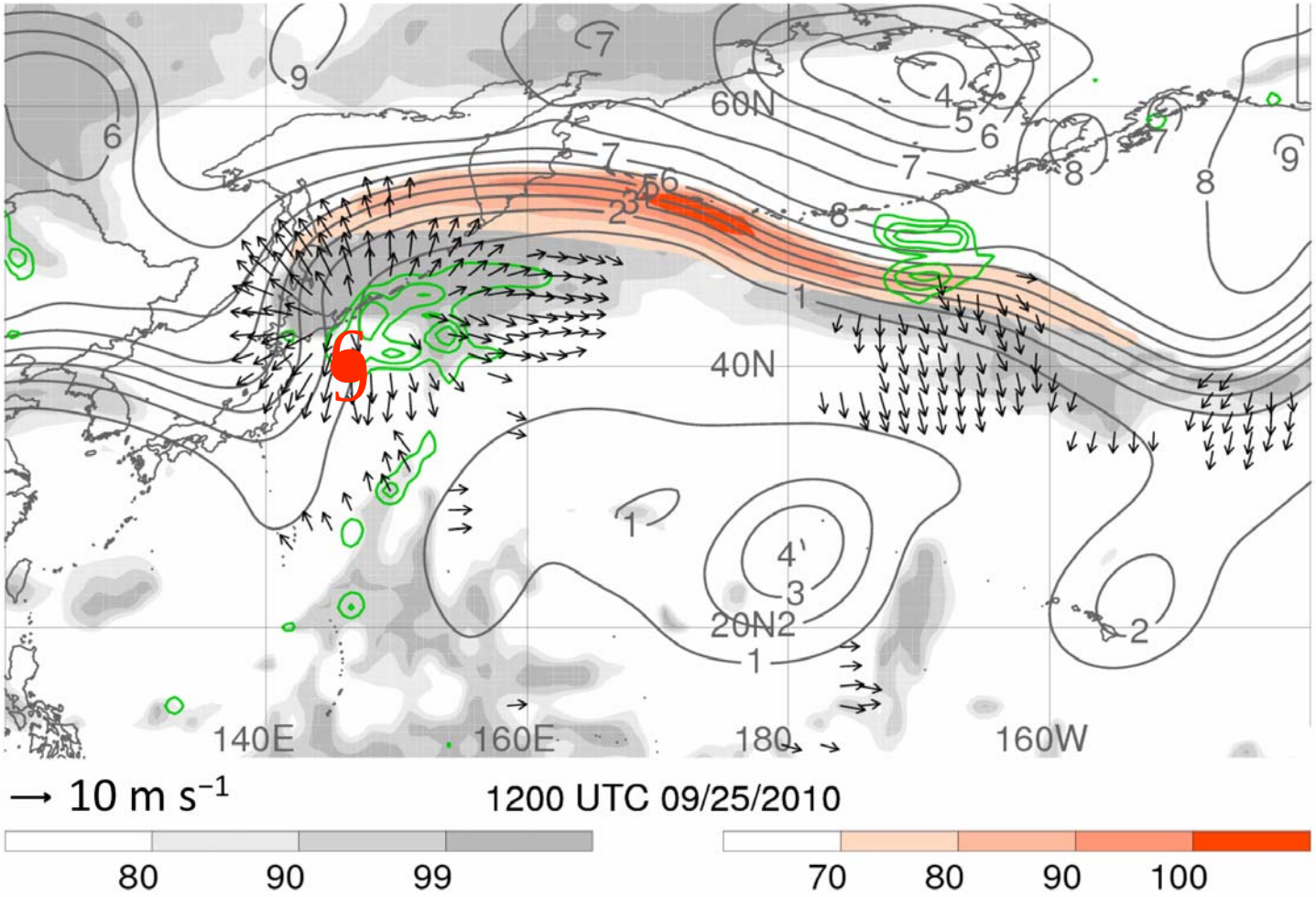


250-hPa wind speed (color shading, m s^{-1}), relative humidity (gray shading, %), potential vorticity (gray contours, PVU), and irrotational wind (vectors, starting at 5 m s^{-1}); 500-hPa ascent (green, every 5 × 10^{-3} hPa s^{-1})

0.5° GFS analysis

Rossby Wave Excitation by TC

T+48 h: 1200 UTC 25 Sep

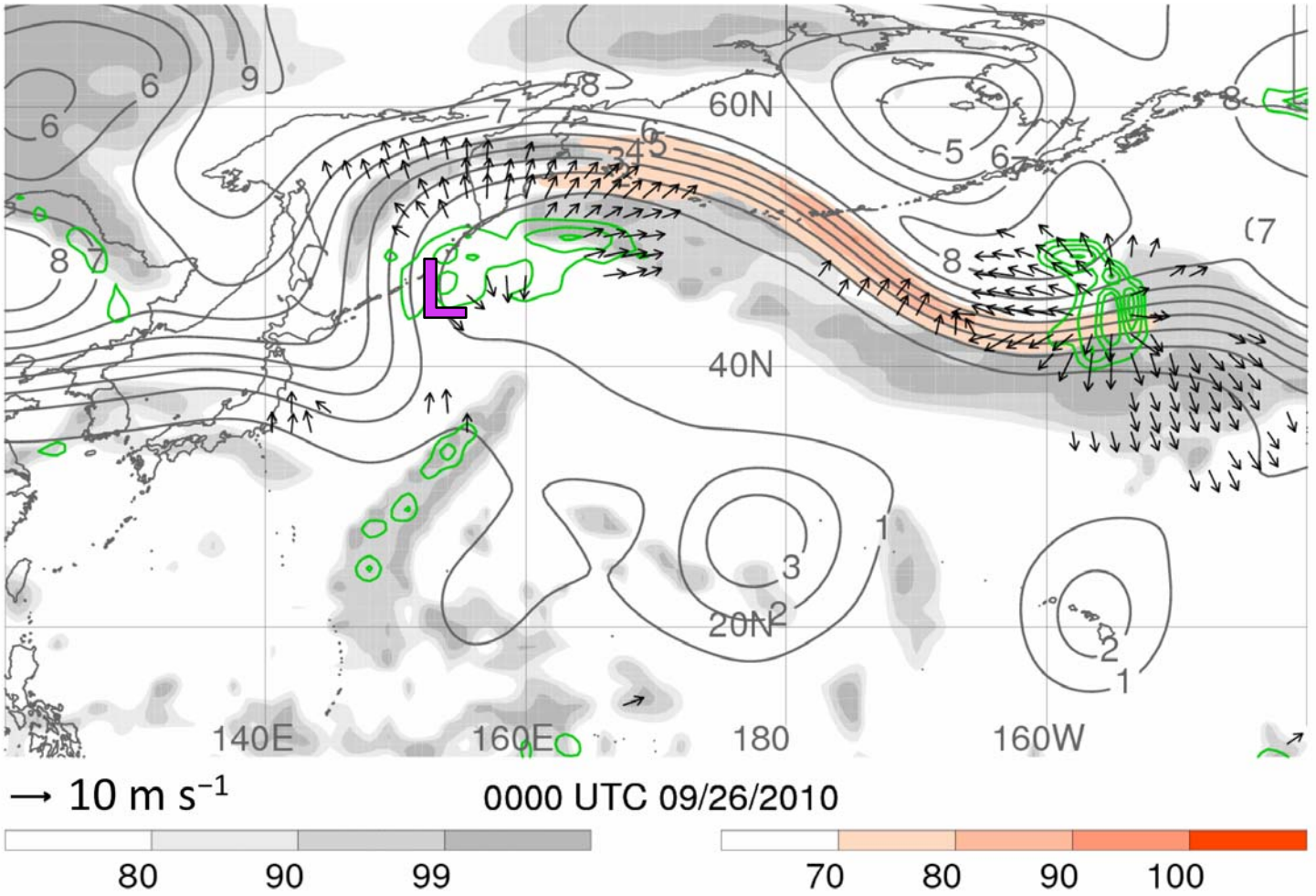


250-hPa wind speed (color shading, m s^{-1}), relative humidity (gray shading, %), potential vorticity (gray contours, PVU), and irrotational wind (vectors, starting at 5 m s^{-1}); 500-hPa ascent (green, every 5 × 10^{-3} hPa s^{-1})

0.5° GFS analysis

Rossby Wave Excitation by TC

T+60 h: 0000 UTC 26 Sep

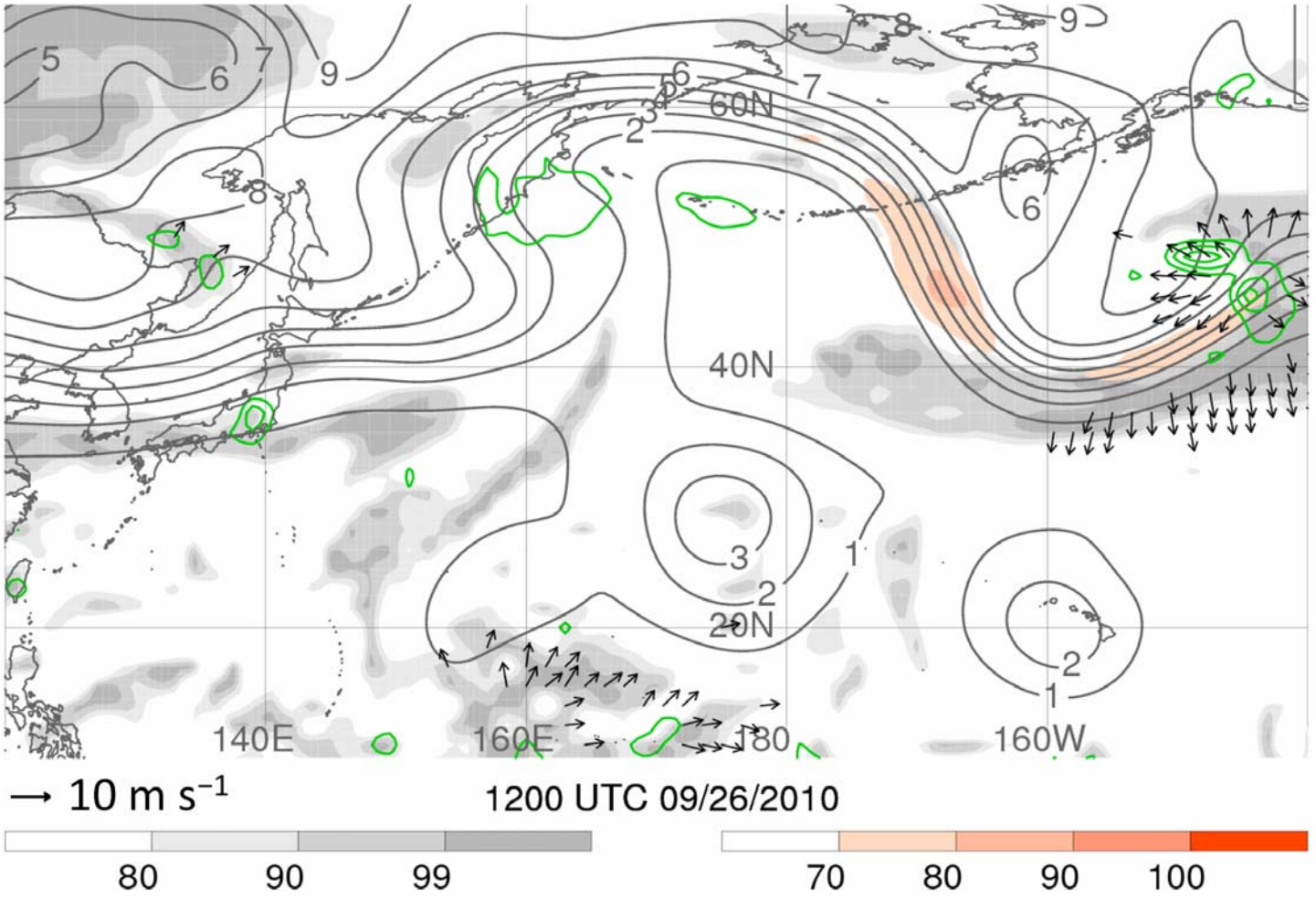


250-hPa wind speed (color shading, m s^{-1}), relative humidity (gray shading, %), potential vorticity (gray contours, PVU), and irrotational wind (vectors, starting at 5 m s^{-1}); 500-hPa ascent (green, every 5 × 10^{-3} hPa s^{-1})

0.5° GFS analysis

Rossby Wave Excitation by TC

T+72 h: 1200 UTC 26 Sep

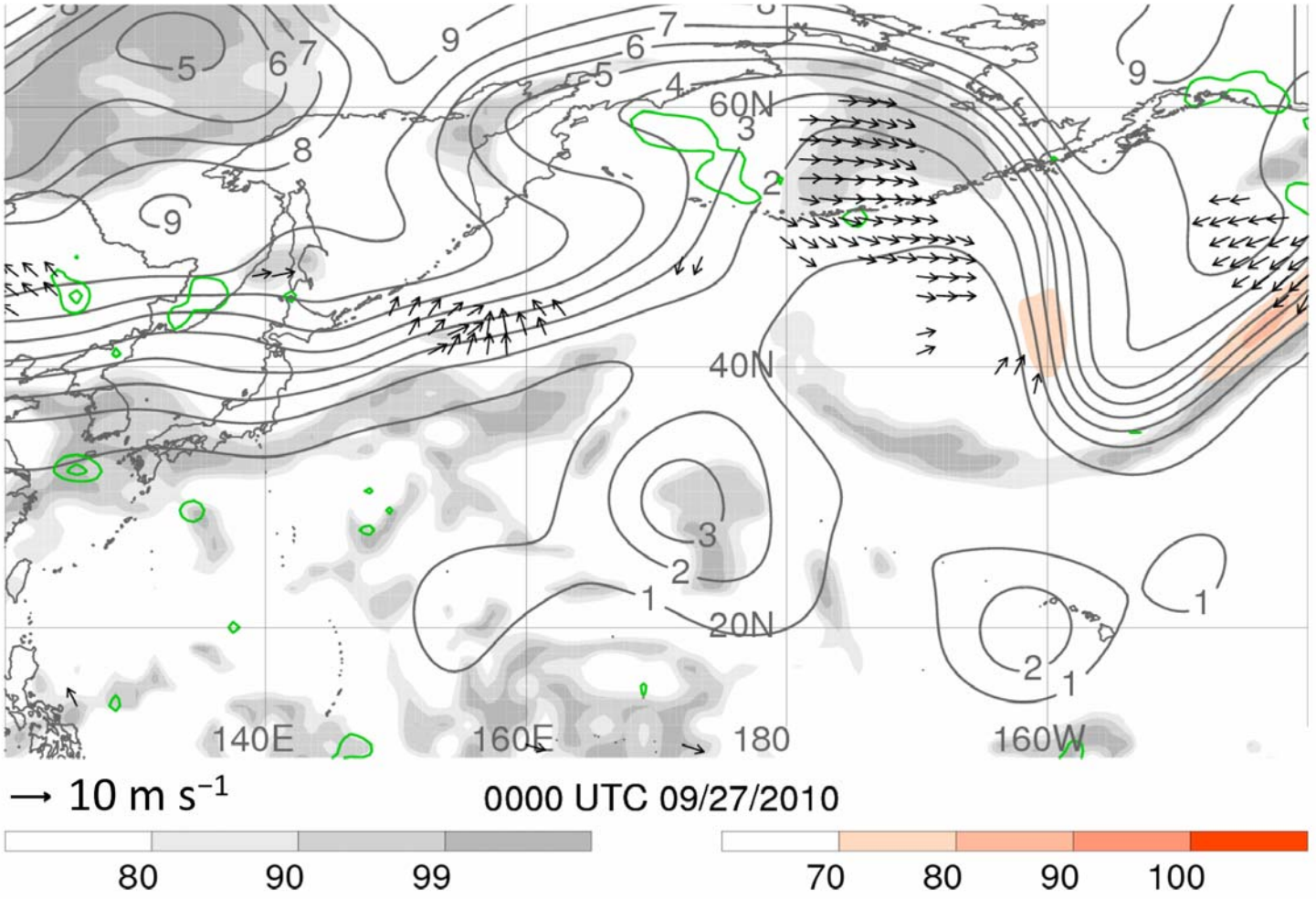


250-hPa wind speed (color shading, m s^{-1}), relative humidity (gray shading, %), potential vorticity (gray contours, PVU), and irrotational wind (vectors, starting at 5 m s^{-1}); 500-hPa ascent (green, every 5 × 10^{-3} hPa s^{-1})

0.5° GFS analysis

Rossby Wave Excitation by TC

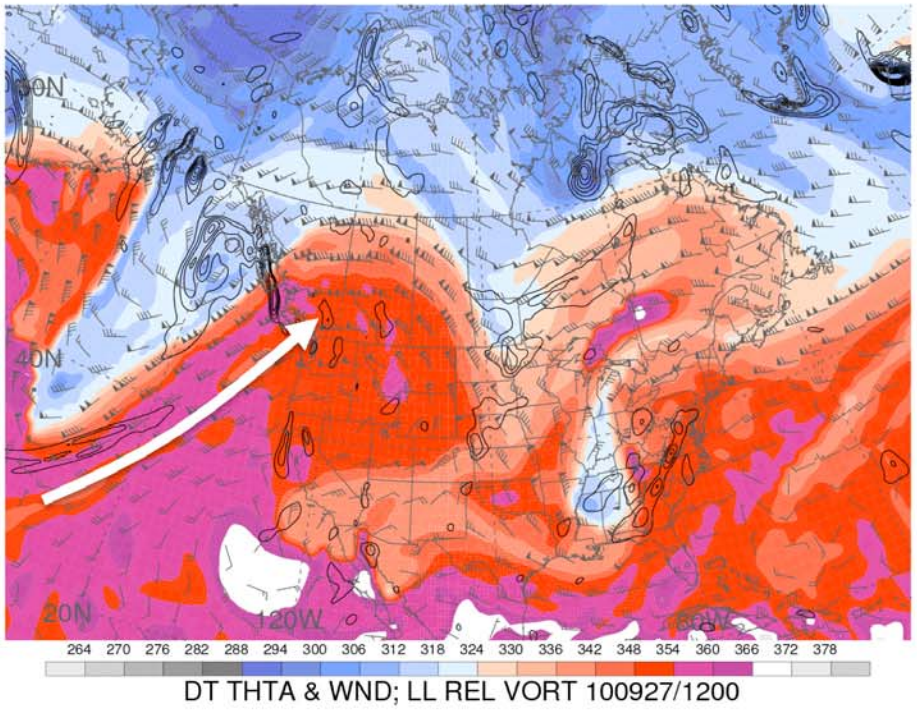
T+84 h: 0000 UTC 27 Sep



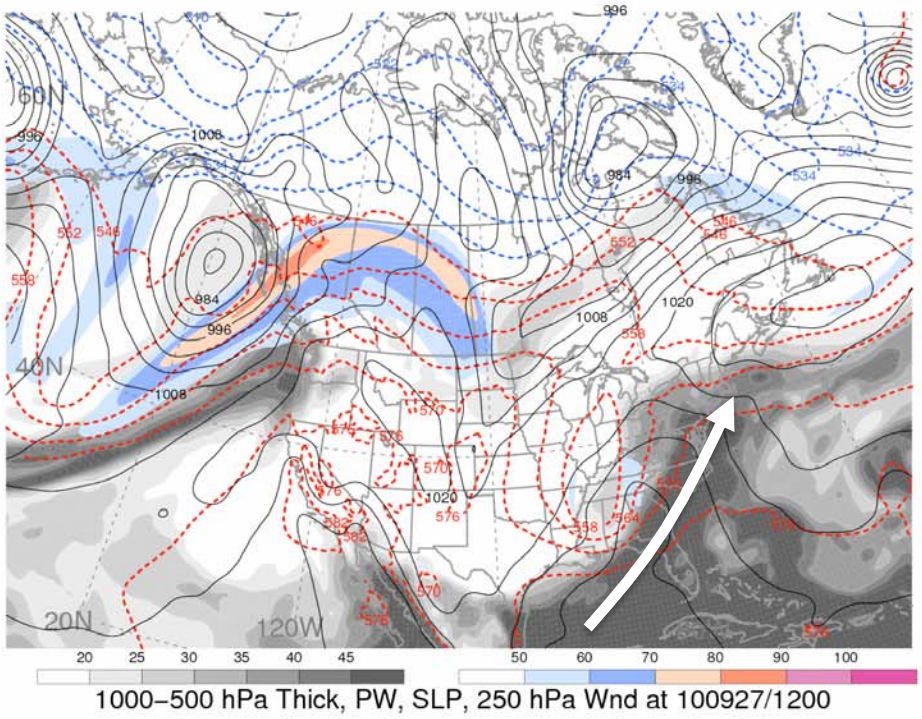
250-hPa wind speed (color shading, m s^{-1}), relative humidity (gray shading, %), potential vorticity (gray contours, PVU), and irrotational wind (vectors, starting at 5 m s^{-1}); 500-hPa ascent (green, every 5 × 10^{-3} hPa s^{-1})

Downstream Development

T+96 h: 1200 UTC 27 Sep



DT potential temperature (shaded, K) and wind (barbs); 925–850-hPa cyclonic relative vorticity (black, every 5 x 10^{-5} s^{-1})

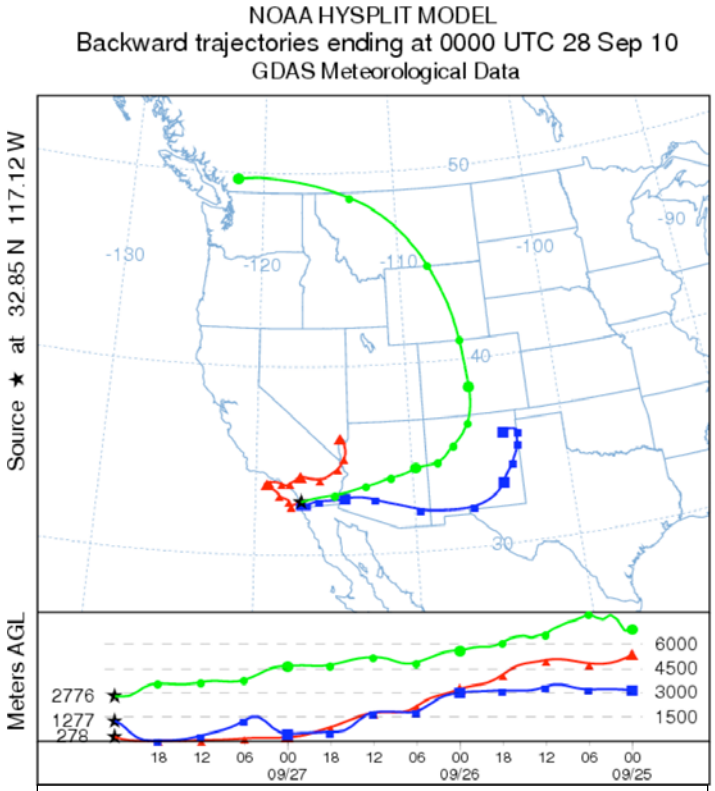


Precipitable water (gray shading, mm), 250-hPa wind speed (color shading, m s^{-1}), 1000–500-hPa thick. (dashed, dam), and SLP (solid, hPa)

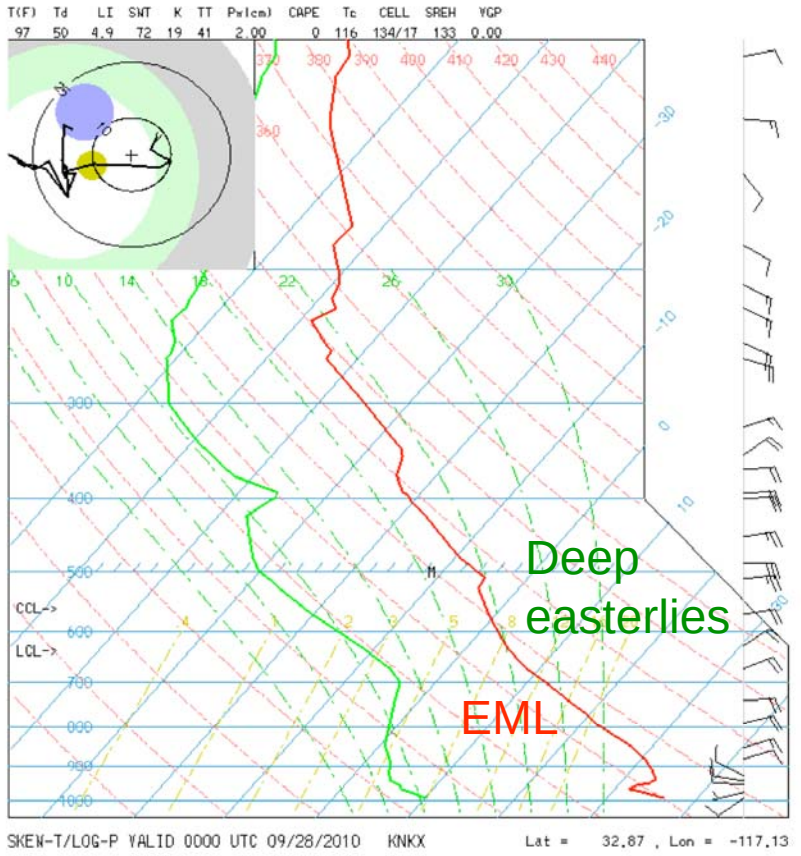
0.5° GFS analysis

Southern CA Heat – San Diego

T+108 h: 0000 UTC 28 Sep



Descending and anticyclonically turning air parcels

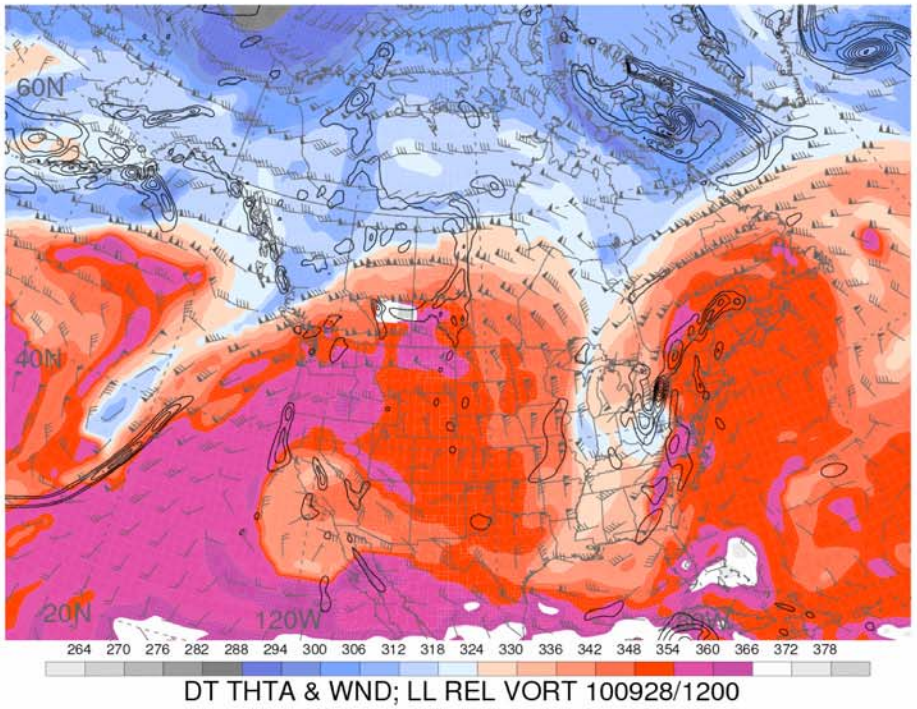


http://ready.arl.noaa.gov/HYSPLIT.php

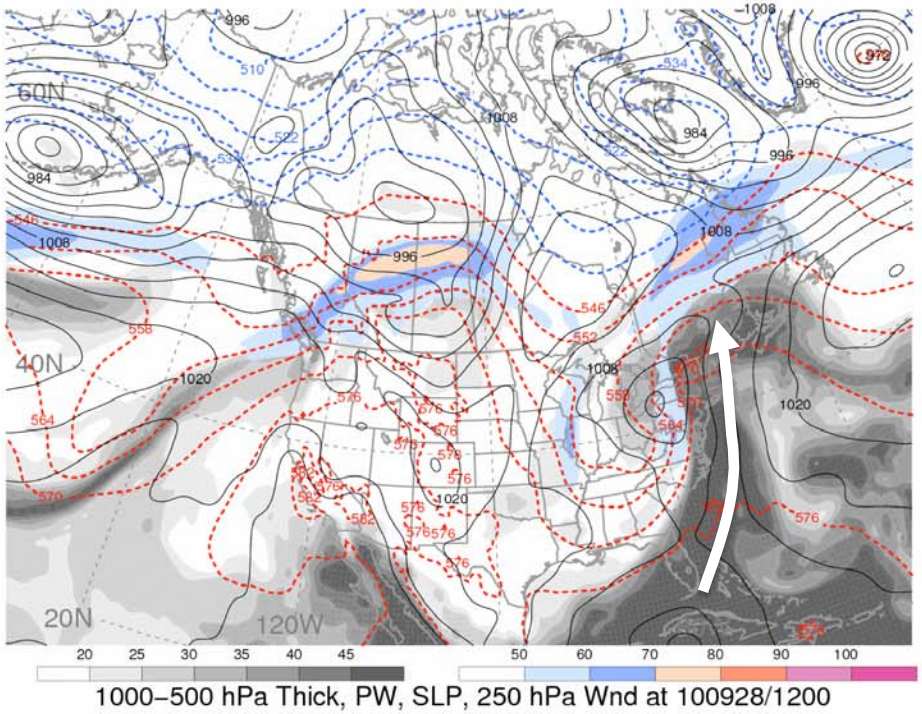
http://www.rap.ucar.edu/weather/upper/

Downstream Development

T+120 h: 1200 UTC 28 Sep



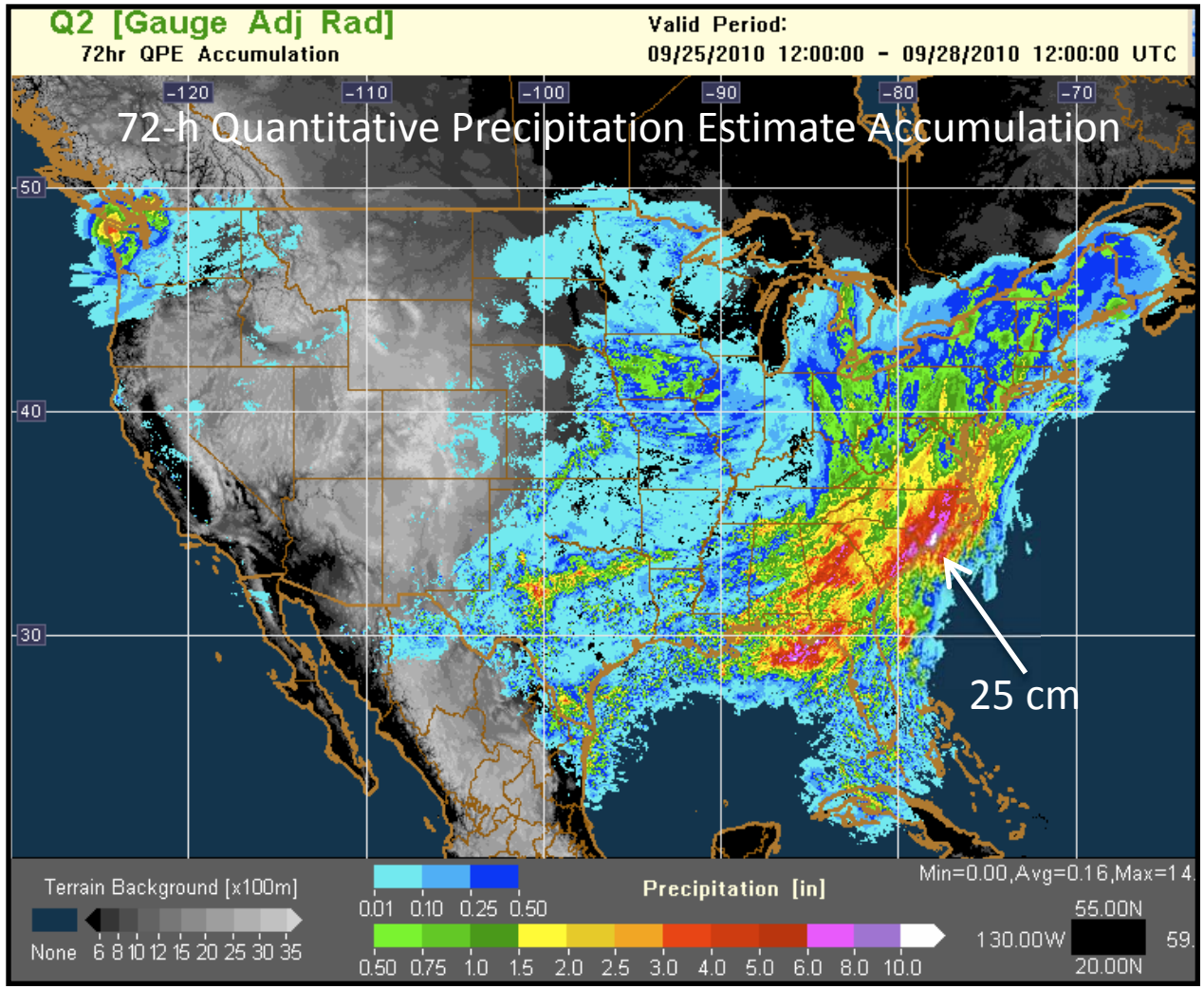
DT potential temperature (shaded, K) and wind (barbs); 925–850-hPa cyclonic relative vorticity (black, every 5 x 10^{-5} s^{-1})



Precipitable water (gray shading, mm), 250-hPa wind speed (color shading, m s^{-1}), 1000–500-hPa thick. (dashed, dam), and SLP (solid, hPa)

0.5° GFS analysis

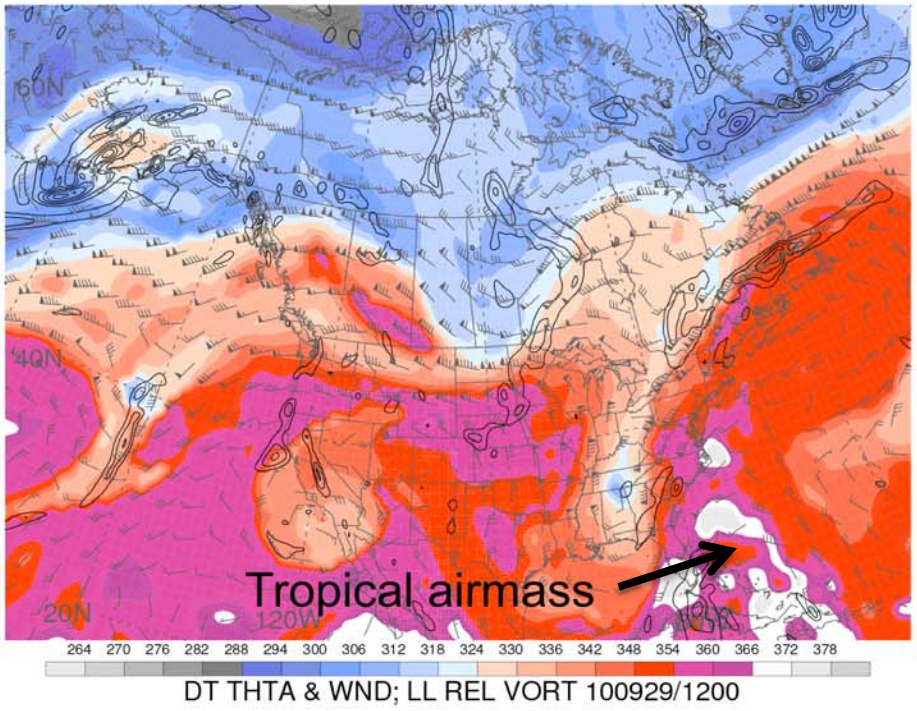
Heavy Rain Along the U.S. East Coast: 72-h Accumulation Ending 1200 UTC 28 Sep



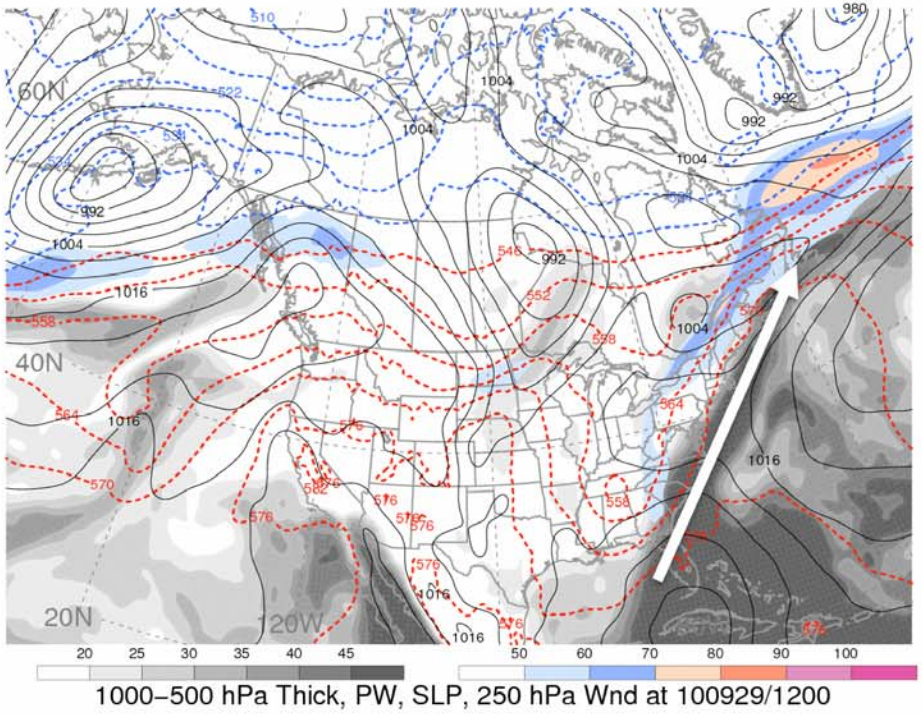
Obtained from the National Mosaic & Multi-Sensor QPE at http://nmq.ou.edu/

Downstream Development

T+144 h: 1200 UTC 29 Sep



DT potential temperature (shaded, K) and wind (barbs); 925–850-hPa cyclonic relative vorticity (black, every 5 x 10^{-5} s^{-1})

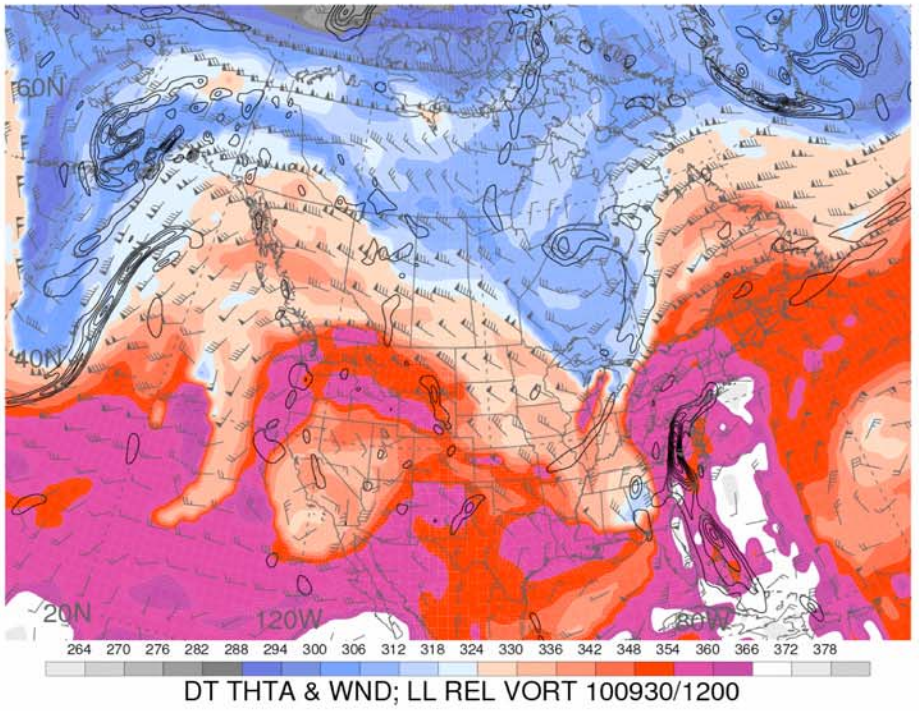


Precipitable water (gray shading, mm), 250-hPa wind speed (color shading, m s^{-1}), 1000–500-hPa thick. (dashed, dam), and SLP (solid, hPa)

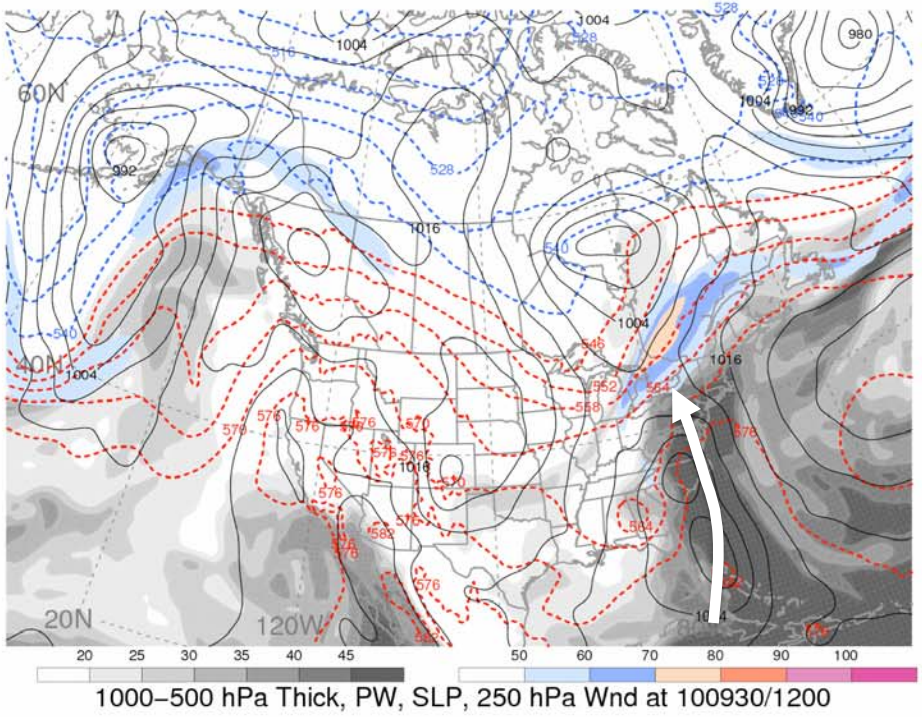
0.5° GFS analysis

Downstream Development

T+168 h: 1200 UTC 30 Sep



DT potential temperature (shaded, K) and wind (barbs); 925–850-hPa cyclonic relative vorticity (black, every 5 x 10^{-5} s^{-1})

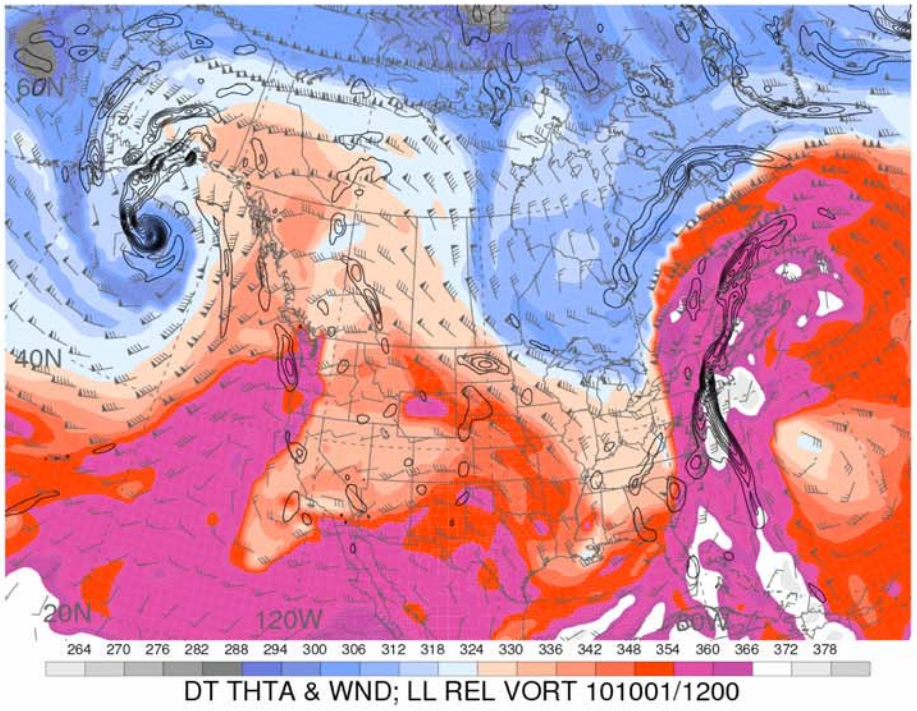


Precipitable water (gray shading, mm), 250-hPa wind speed (color shading, m s^{-1}), 1000–500-hPa thick. (dashed, dam), and SLP (solid, hPa)

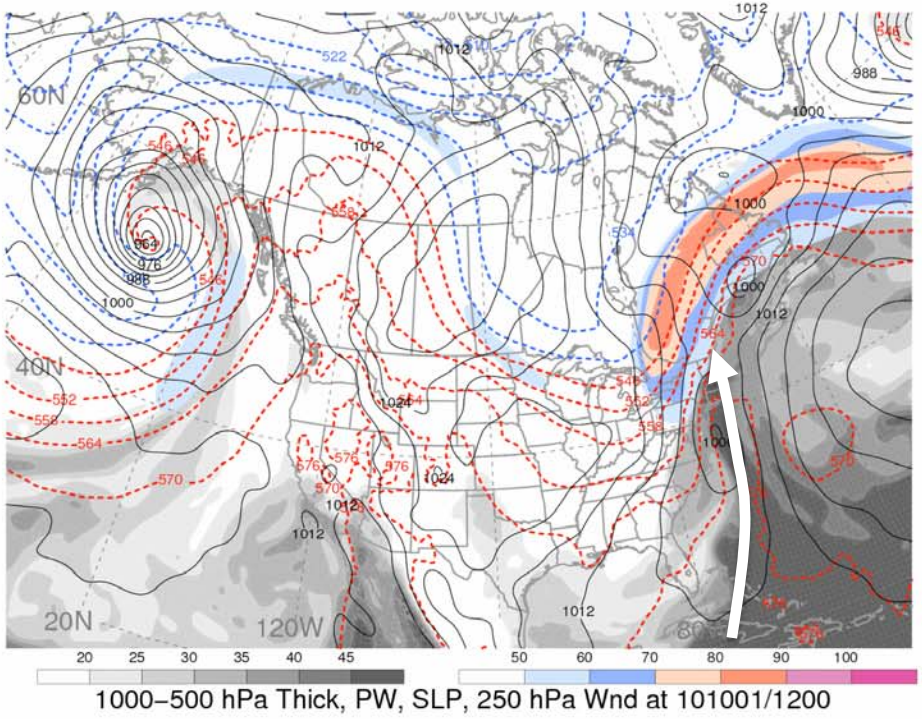
0.5° GFS analysis

Downstream Development

T+192 h: 1200 UTC 1 Oct



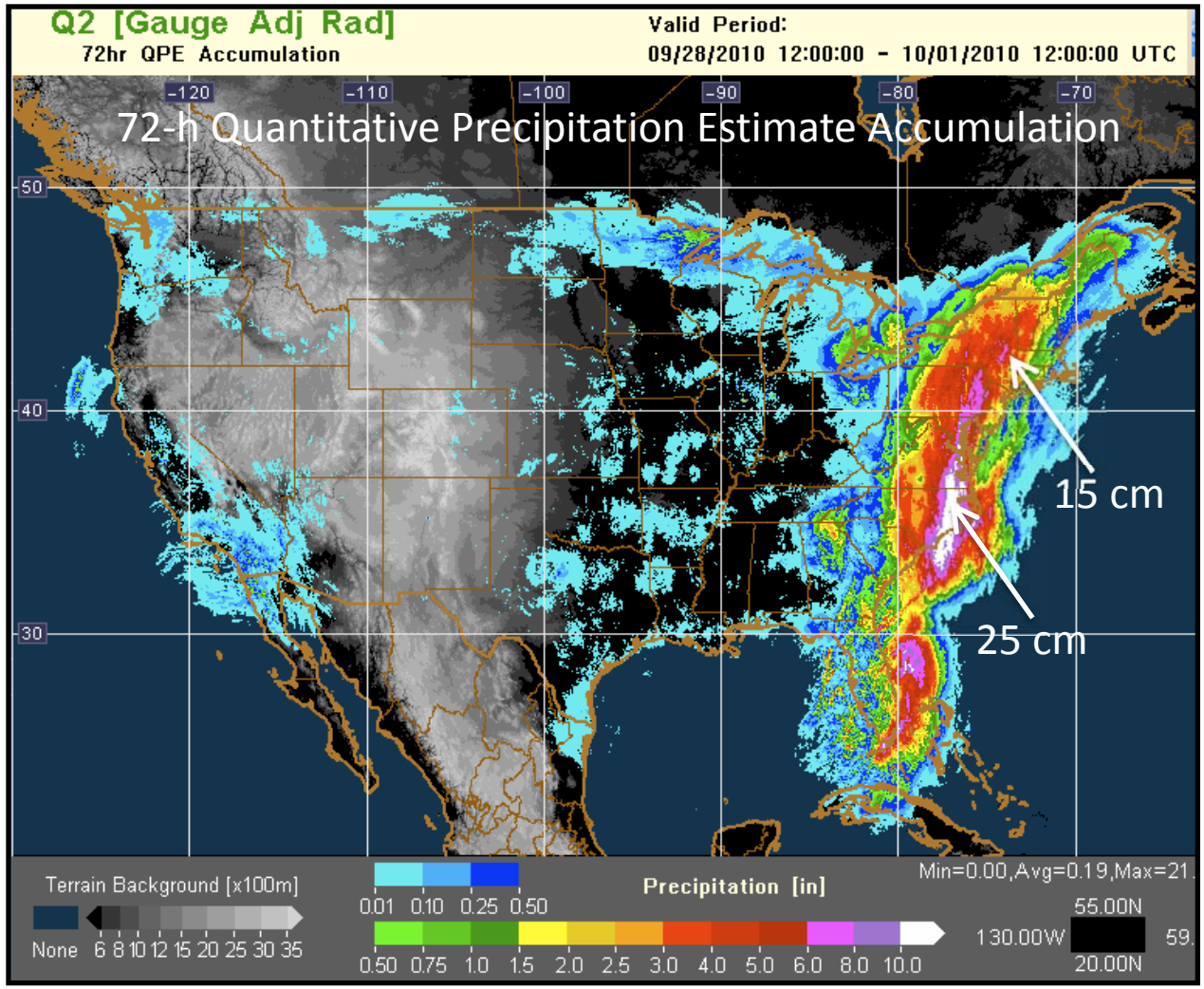
DT potential temperature (shaded, K) and wind (barbs); 925–850-hPa cyclonic relative vorticity (black, every 5 x 10^{-5} s^{-1})



Precipitable water (gray shading, mm), 250-hPa wind speed (color shading, m s^{-1}), 1000–500-hPa thick. (dashed, dam), and SLP (solid, hPa)

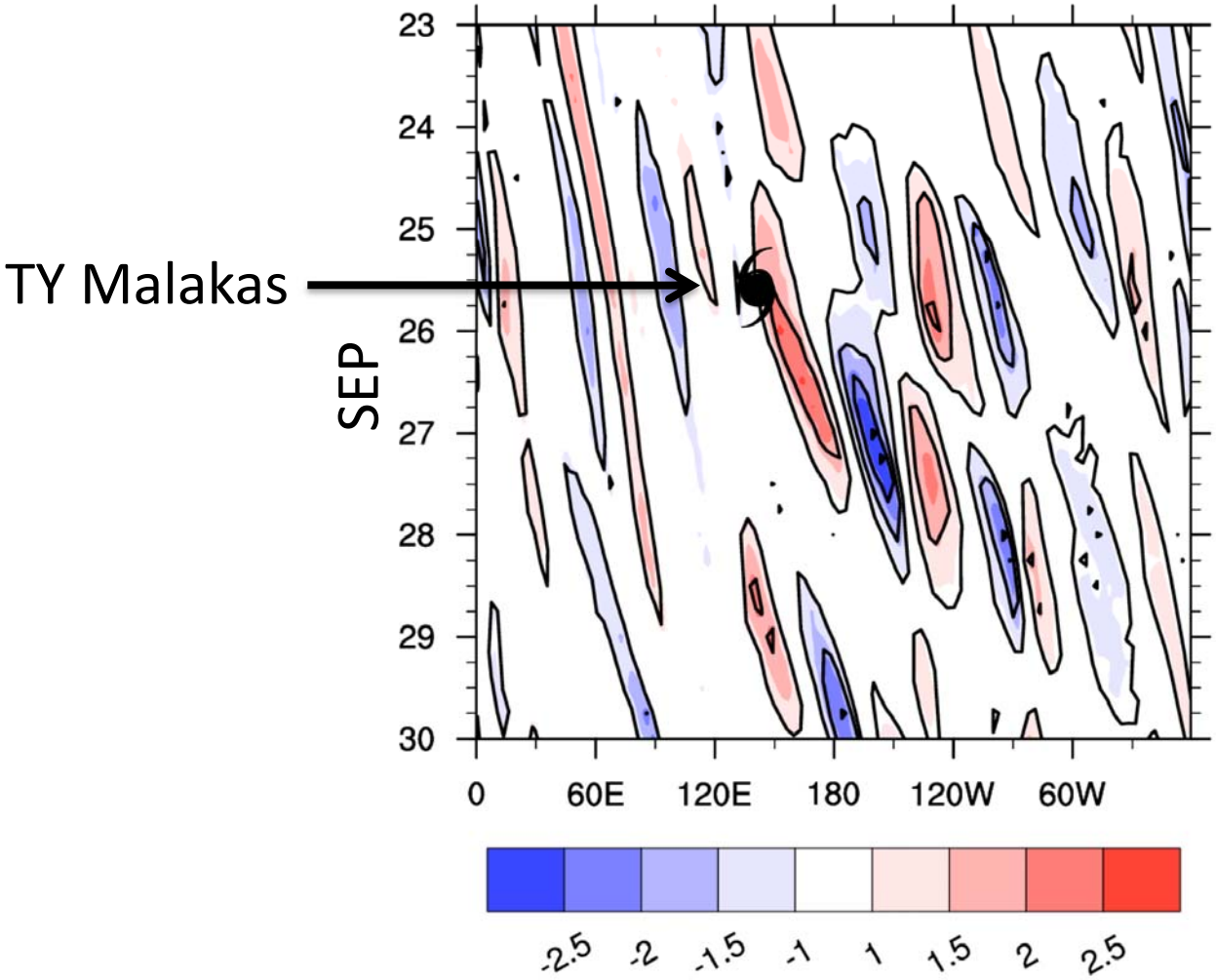
0.5° GFS analysis

Heavy Rain Along the U.S. East Coast: 72-h Accumulation Ending 1200 UTC 1 Oct



Obtained from the National Mosaic & Multi-Sensor QPE at http://nmq.ou.edu/

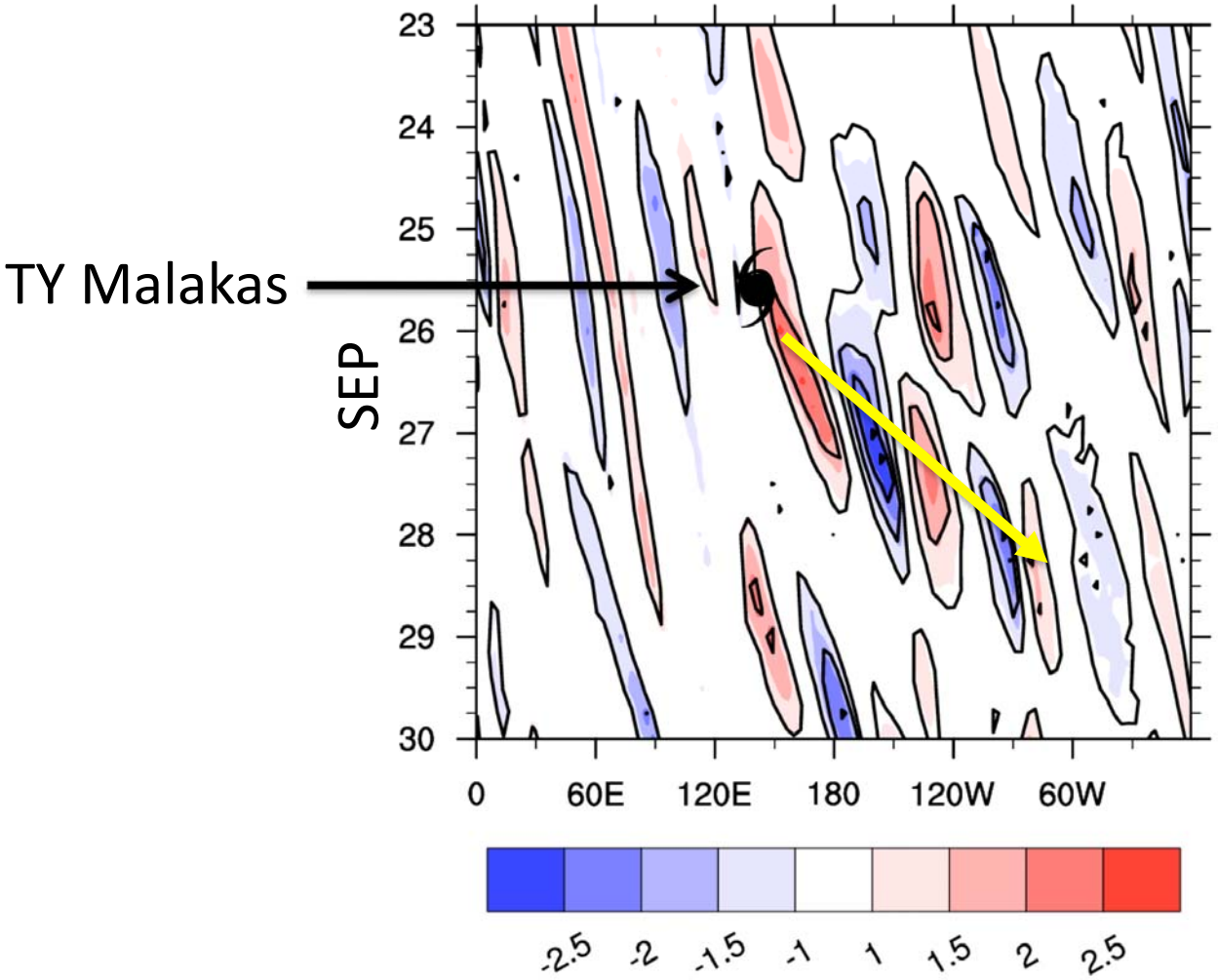
Downstream Development (23–30 Sep 2010)



0.5° GFS analysis and 2.5° NCEP– NCAR reanalysis (climatology)

40°–60°N 250-hPa meridional wind anomaly (shaded, std dev) and abs. value of departure from climo (solid, every 15 m s^{-1}, zero line omitted)

Downstream Development (23–30 Sep 2010)

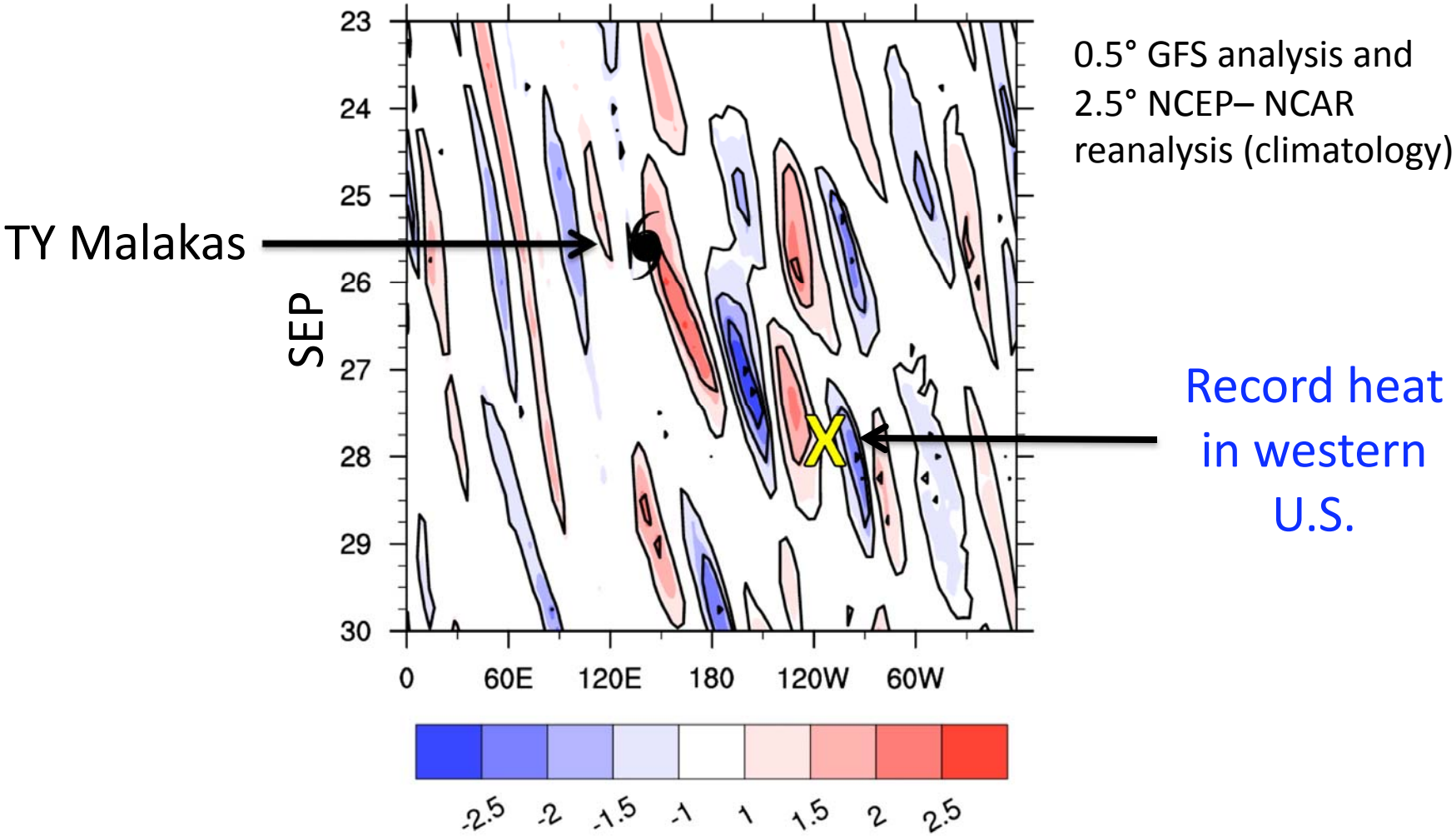


0.5° GFS analysis and 2.5° NCEP– NCAR reanalysis (climatology)

Downstream development across North Pacific into North America

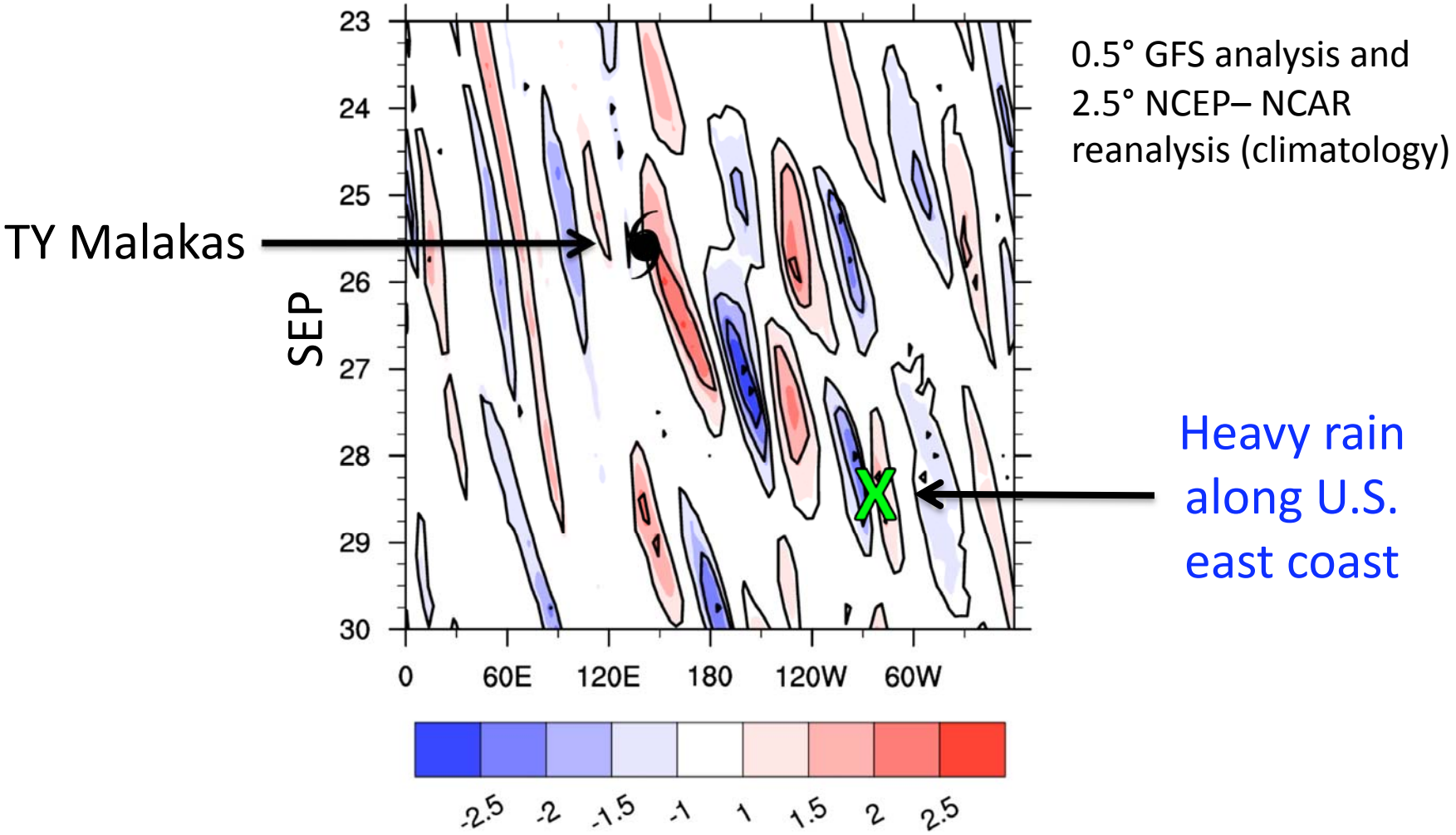
40°–60°N 250-hPa meridional wind anomaly (shaded, std dev) and abs. value of departure from climo (solid, every 15 m s^{-1}, zero line omitted)

Downstream Development (23–30 Sep 2010)



40°–60°N 250-hPa meridional wind anomaly (shaded, std dev) and abs. value of departure from climo (solid, every 15 m s^{-1}, zero line omitted)

Downstream Development (23–30 Sep 2010)



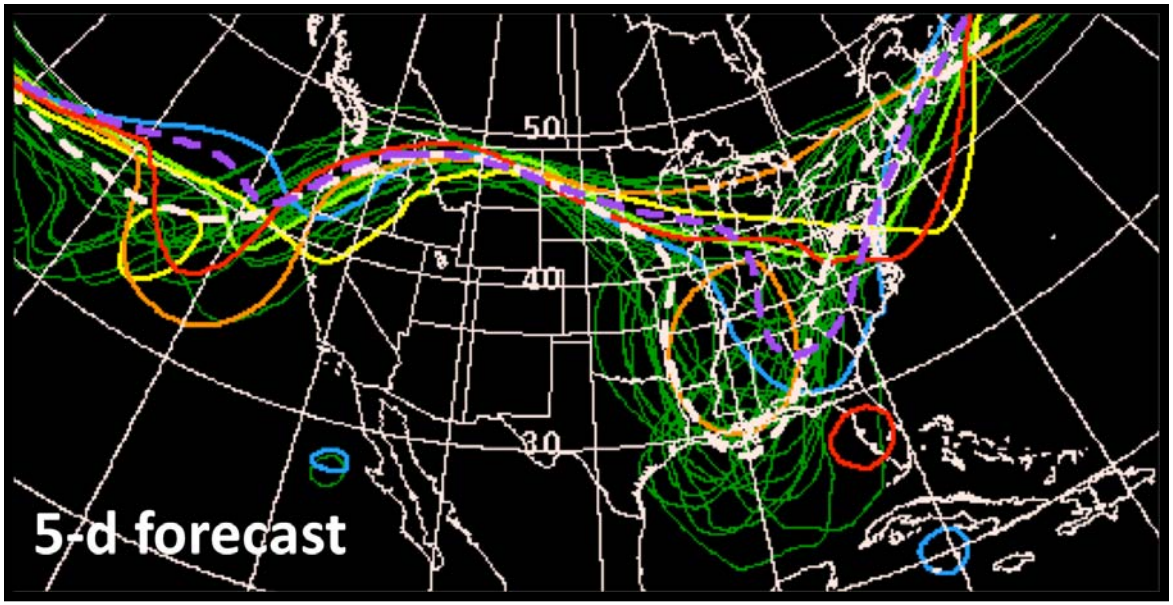
0.5° GFS analysis and 2.5° NCEP– NCAR reanalysis (climatology)

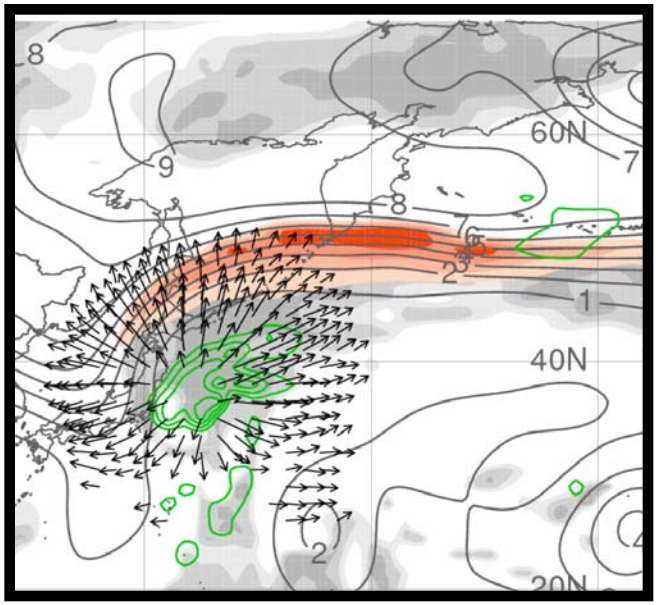
Heavy rain along U.S. east coast

40°–60°N 250-hPa meridional wind anomaly (shaded, std dev) and abs. value of departure from climo (solid, every 15 m s^{-1}, zero line omitted)

Part 3: Role of TC Malakas in reduced predictability of large-scale flow pattern (21 Sep–1 Oct)

579-dam 500-hPa Geopotential Height Spaghetti Plot Verifying 0000 UTC 30 Sep





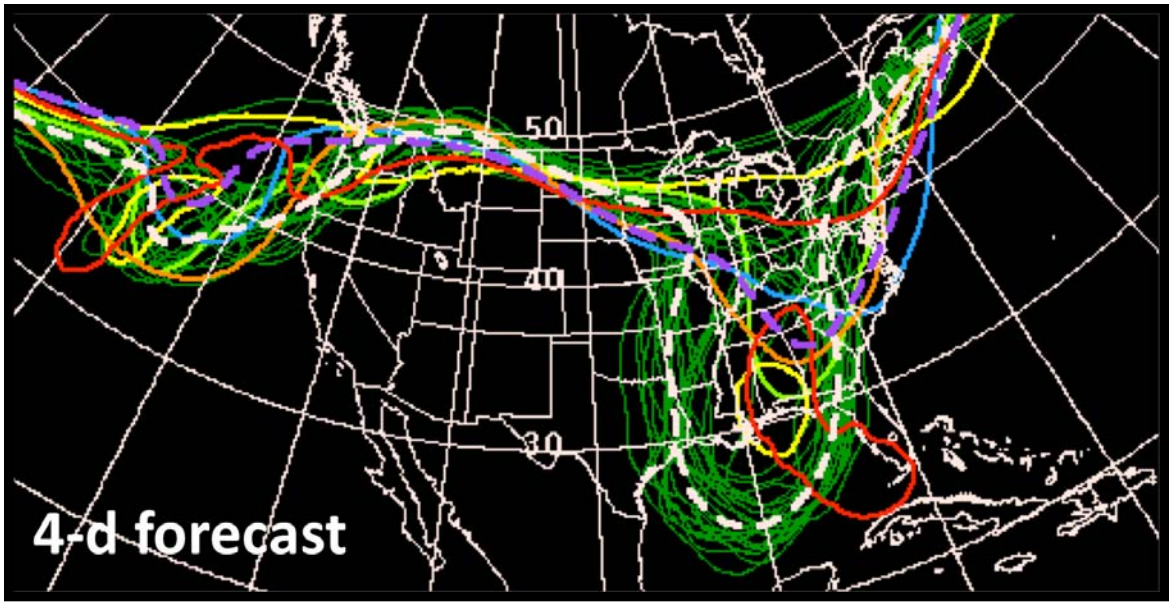
GFS GEFS members GEFS mean
ECMWF ECMWF ensemble mean
UKMET NOGAPS CMC

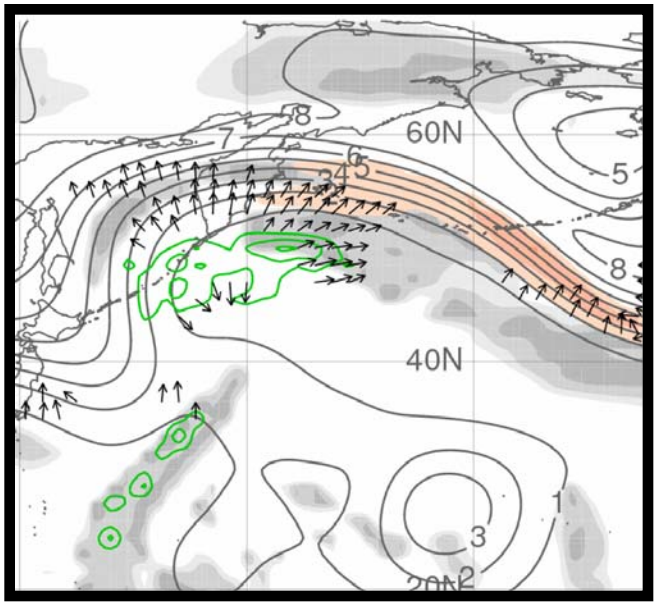
0000 UTC 25 Sep
0.5° GFS analysis

- Large uncertainty in amplitude and position of eastern U.S. trough prior to Rossby wave train excitation

Source: Mike Brennan at NHC

579-dam 500-hPa Geopotential Height Spaghetti Plot Verifying 0000 UTC 30 Sep





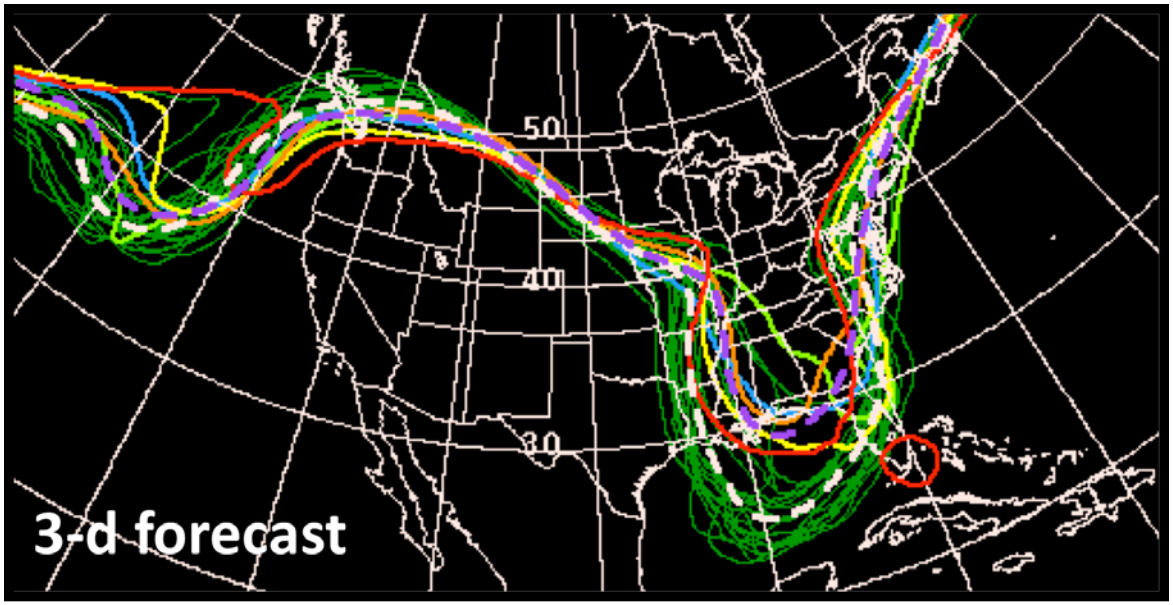
GFS GEFS members GEFS mean
ECMWF ECMWF ensemble mean
UKMET NOGAPS CMC

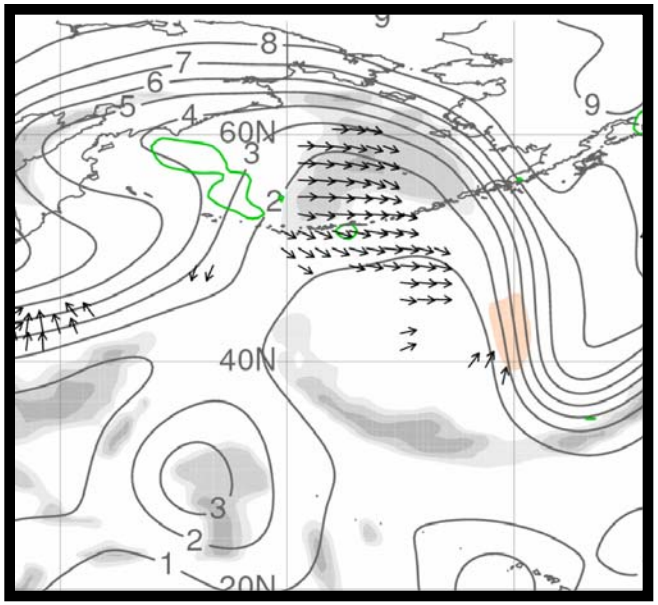
0000 UTC 26 Sep
0.5° GFS analysis

- More certainty in amplitude and position of eastern U.S. trough after Rossby wave train excitation

Source: Mike Brennan at NHC

579-dam 500-hPa Geopotential Height Spaghetti Plot Verifying 0000 UTC 30 Sep





GFS GEFS members GEFS mean
ECMWF ECMWF ensemble mean
UKMET NOGAPS CMC

0000 UTC 27 Sep
0.5° GFS analysis

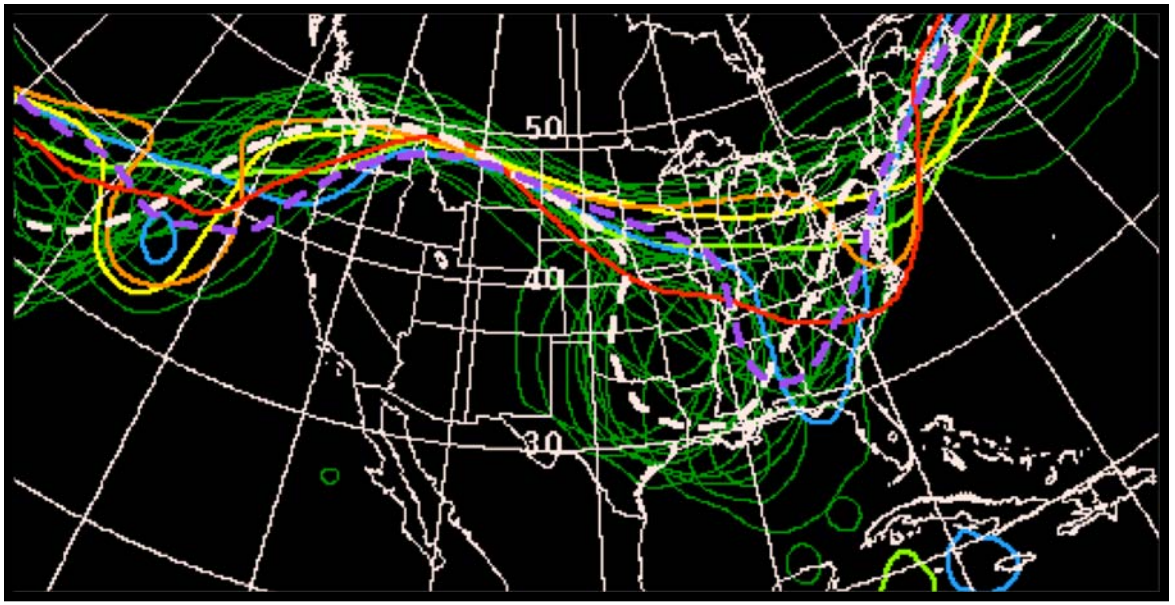
- More certainty in amplitude and position of eastern U.S. trough after Rossby wave train excitation

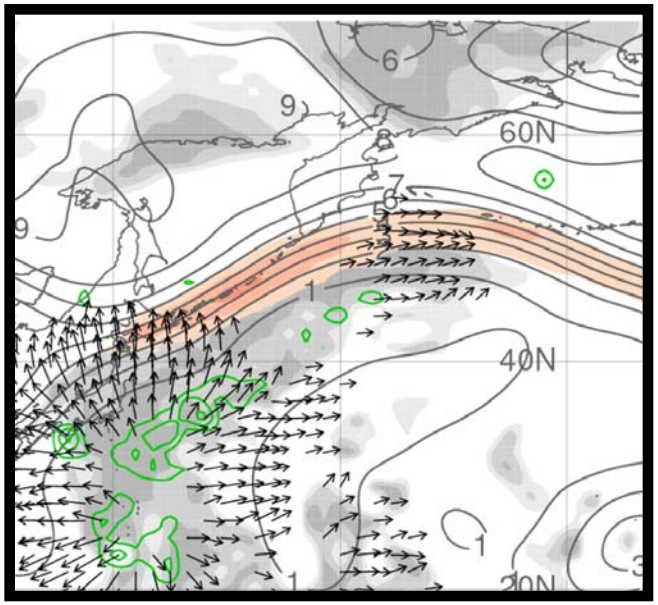
Source: Mike Brennan at NHC

Conclusions

- Similar to composite, Rossby wave train excitation accompanying recurvature of Malakas leads to downstream development across North Pacific into North America
- Onset of flow anomalies over North America provides favorable large-scale conditions for record heat in western U.S. and heavy rain in eastern U.S.
- Large forecast uncertainty prior to wave train excitation may be linked to diabatic ridge amplification associated with recurvature of Malakas

579-dam 500-hPa Geopotential Height Spaghetti Plot Verifying 0000 UTC 30 Sep





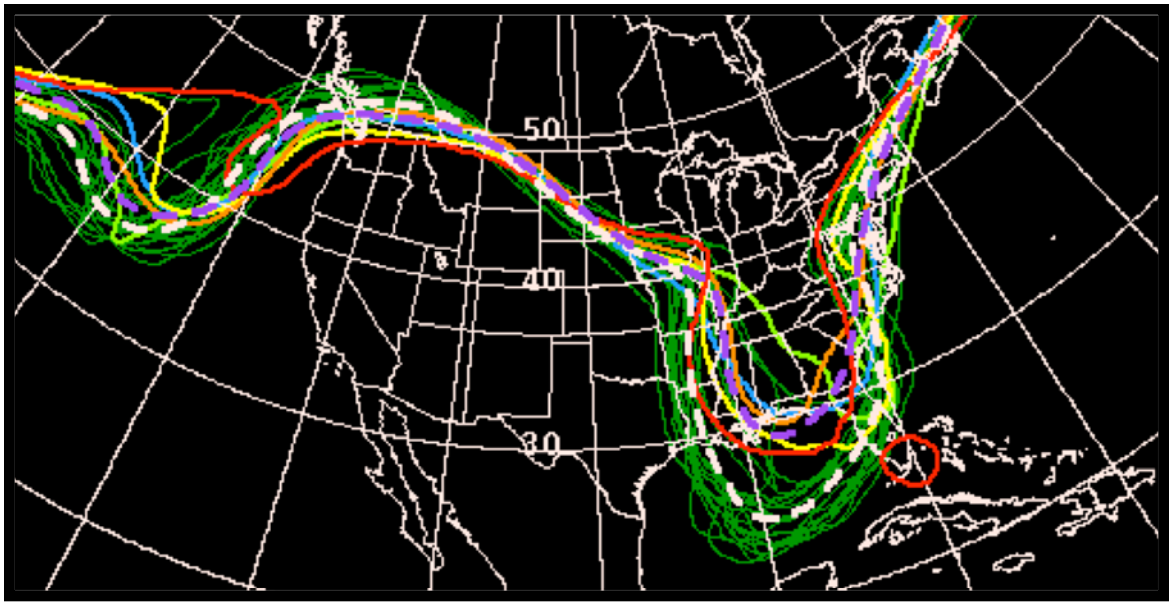
GFS GEFS members GEFS mean
ECMWF ECMWF ensemble mean
UKMET NOGAPS CMC

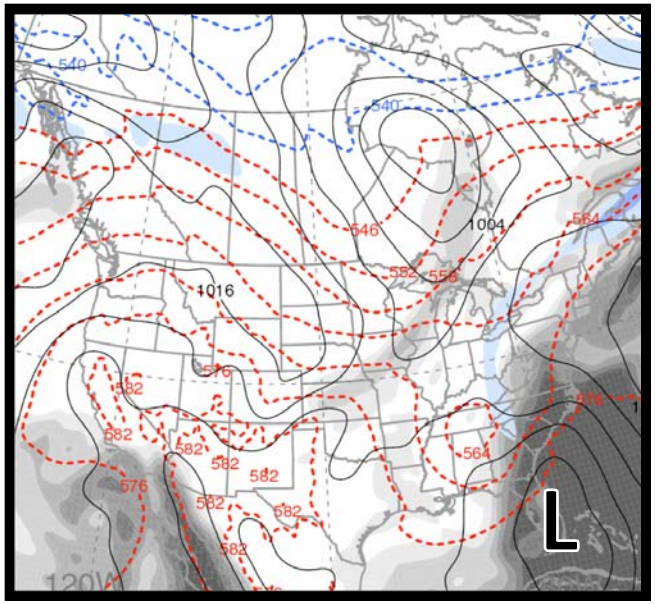
0000 UTC 24 Sep
0.5° GFS analysis

- Large uncertainty in amplitude and position of eastern U.S. trough prior to Rossby wave train excitation

Source: Mike Brennan at NHC

579-dam 500-hPa Geopotential Height Spaghetti Plot Verifying 0000 UTC 30 Sep





GFS GEFS members GEFS mean
ECMWF ECMWF ensemble mean
UKMET NOGAPS CMC

0000 UTC 30 Sep
0.5° GFS analysis

- More certainty in amplitude and position of eastern U.S. trough after Rossby wave train excitation

Source: Mike Brennan at NHC