Satellite Signatures of Six Tropical Cyclones Which Rapidly Intensified in Shear

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National Research Council, Monterey, CA

Friday, 2 September 2016

Acknowledgements: Josh Cossuth (NRL), James Doyle (NRL), Daniel Hodyss (NRL), Chris Velden (CIMSS), Derrick Herndon (CIMSS), Dave Stettner (CIMSS), Robert Hart (Florida State Univ.)

Introduction

- Hurricane Oddities and Outliers – like Joaquin
- Climatologically, tropical cyclones (TCs) like two things: warm SSTs greater than 26.5 °C and low vertical wind shear (Gray 1968)
  - VWS: $v_{200} - v_{850}$
- Today's focus – vertical wind shear
  - Specifically, what does a select subset, which undergoes rapid intensification (RI) in shear values that are generally considered unfavorable, look like on satellite?
    - "Unfavorable" = 5-10 ms^{-1} shear (Reasor et al. 2013)
    - Statistically, mean VWS for RI is 3.9 ms^{-1}, std. dev. is 1.5 ms^{-1} (Kaplan et al. 2008)
      - Two to four sigma events

Introduction (cont'd)

- Six TCs have been identified that all follow a similar pattern
  - 1997 Eastern Pacific (EPAC) Guillermo
  - 2008 EPAC Hernan
  - 2008 EPAC Norbert
  - 2012 EPAC Fabio
  - 2015 EPAC Hilda
  - 2015 Northern Atlantic (NATL) Joaquin

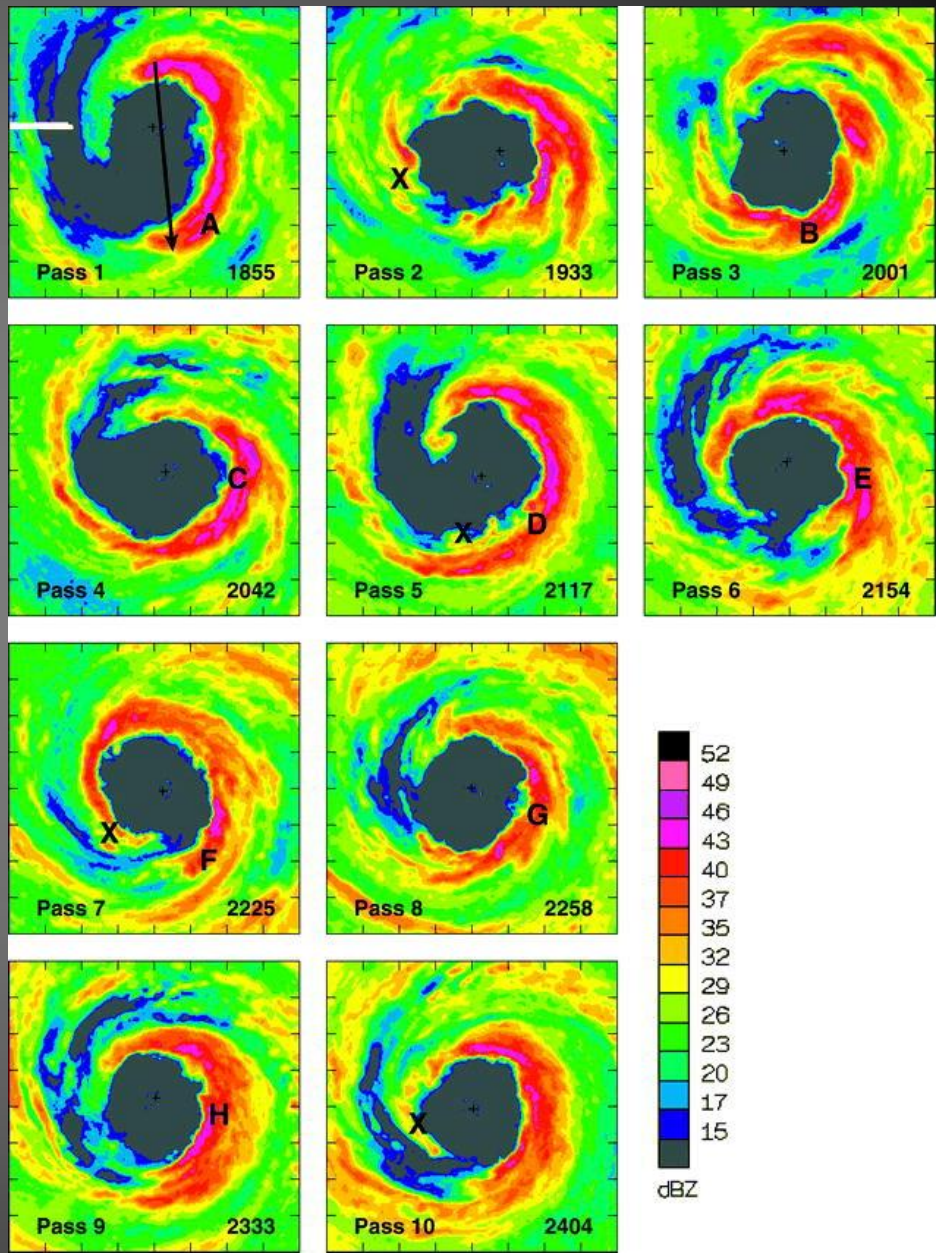
  - Bonus storms!
    - 2012 EPAC Daniel, 2016 EPAC Blas, 2016 EPAC Darby

1997 EPAC Guillermo References

- Eastin, Gray, and Black 2005: EGB05
- Sitkowski and Barnes 2009: SB09
- Reasor, Eastin, and Gamache 2009: REG09
- Reasor and Eastin 2012: RE12

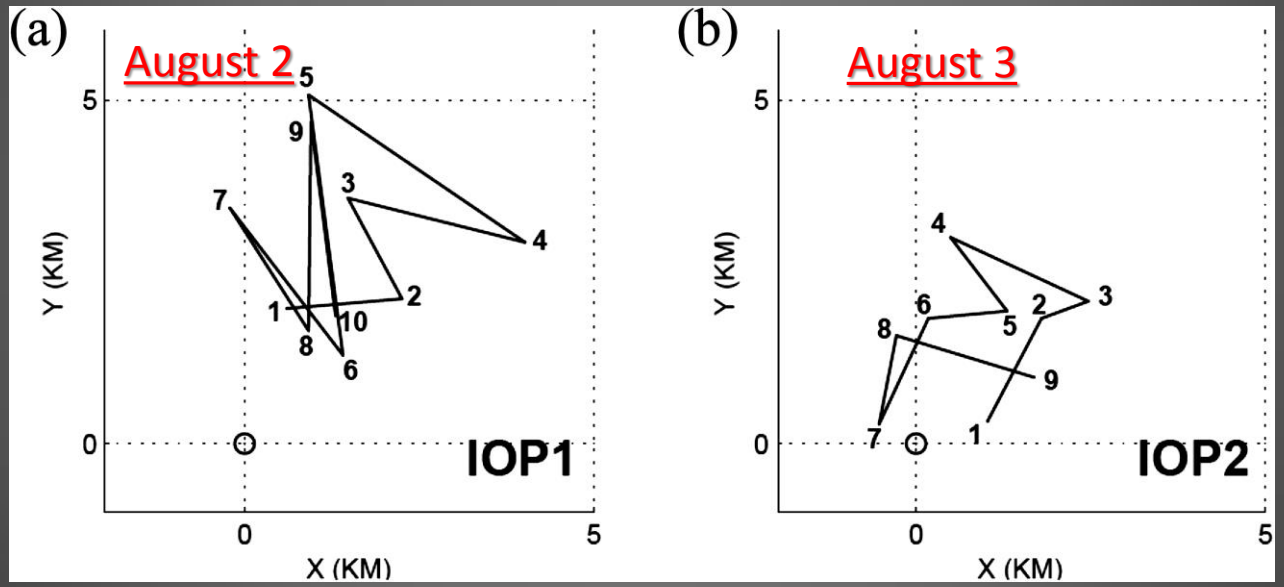
Revisiting 1997 EPAC Guillermo

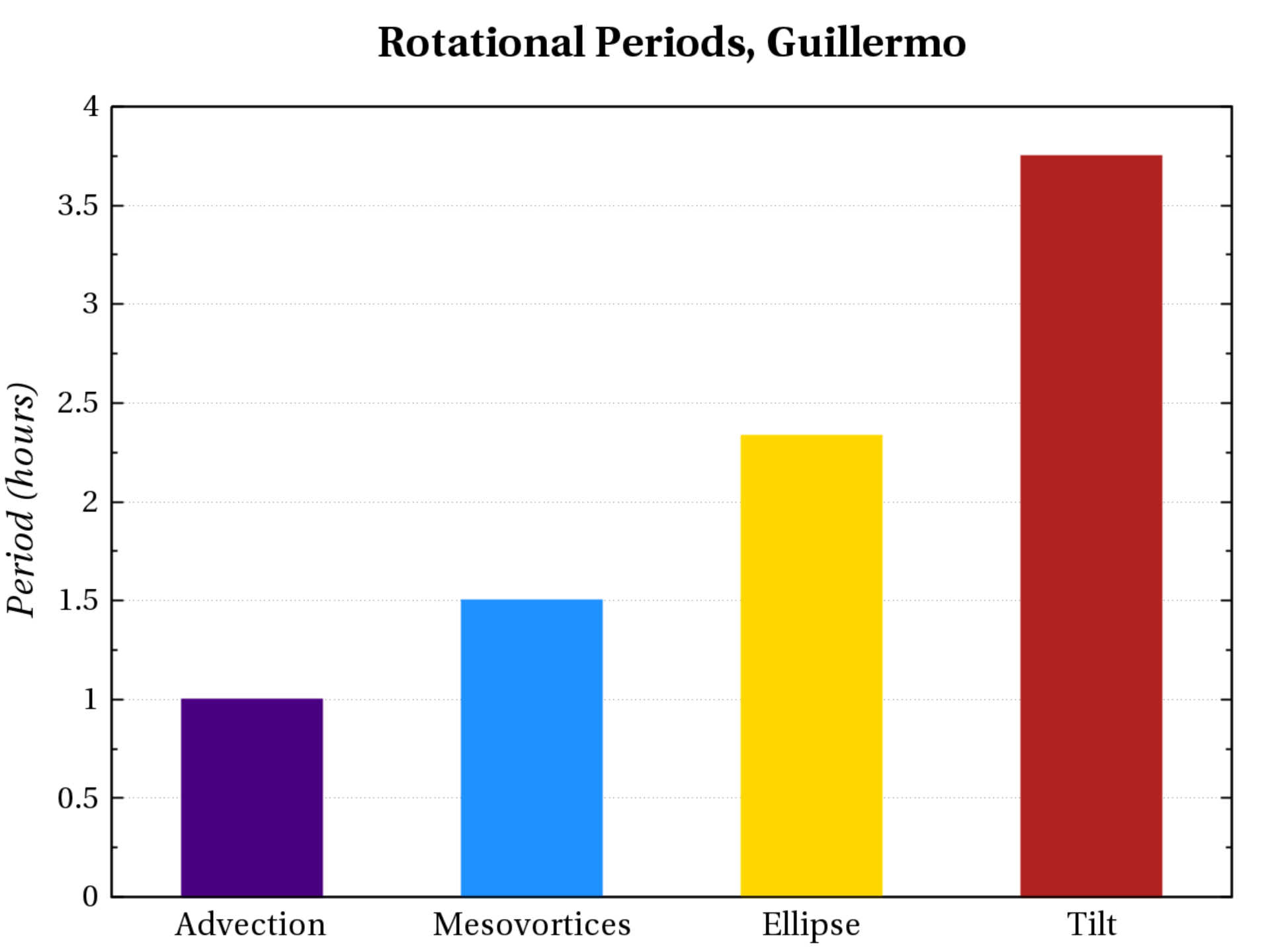
- 20 flights over two days: 02-AUG and 03-AUG
- Dual-Doppler radar data indicates presence of coherent vorticity asymmetries (mesovortices) at low levels (EBG05, REG09)
  - Can be coherently tracked in radar (the letters, see REG09 for more information)
  - Time periods
    - Advection at Radius of Maximum Winds (RMW): ~60 minutes
    - Mesovortices (WVN4): ~90 minutes
    - Elliptical eyewall (WVN2): ~140 minutes



Revisiting Guillermo (cont'd)

- Also allowed for continual measurement of the tilt (RE12)
  - Center = point at which the RMW is maximized
- Tilt precession period: 3.5 to 4 hours

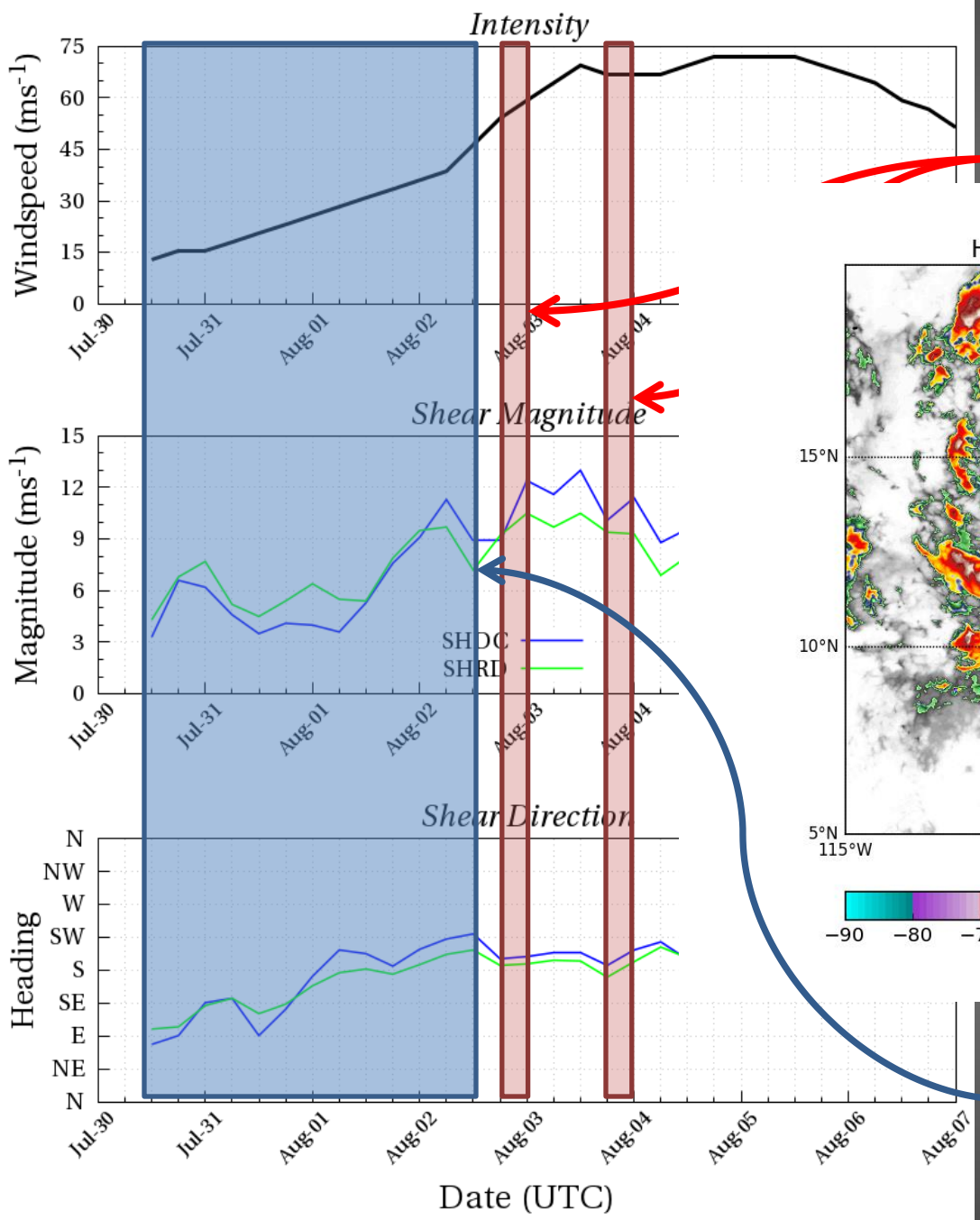


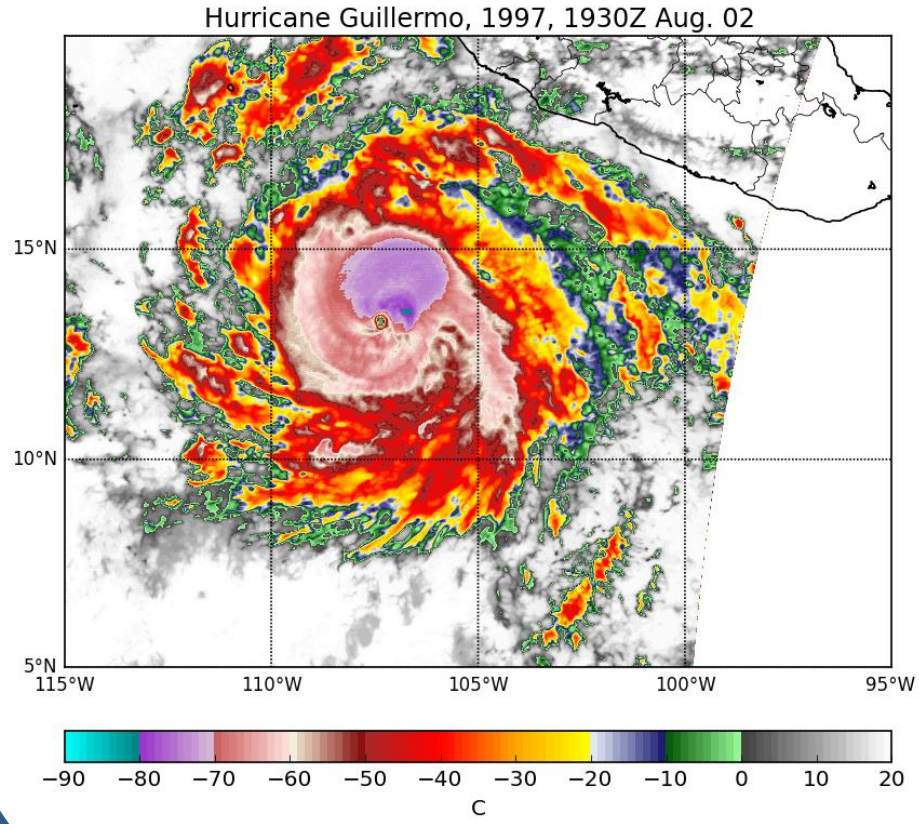

Rotational Periods, Guillermo
Period (hours)
4
3.5
3
2.5
2
1.5
1
0.5
0
Advection
Mesovortices
Ellipse
Tilt

Guillermo SHIPS Intensity and Shear

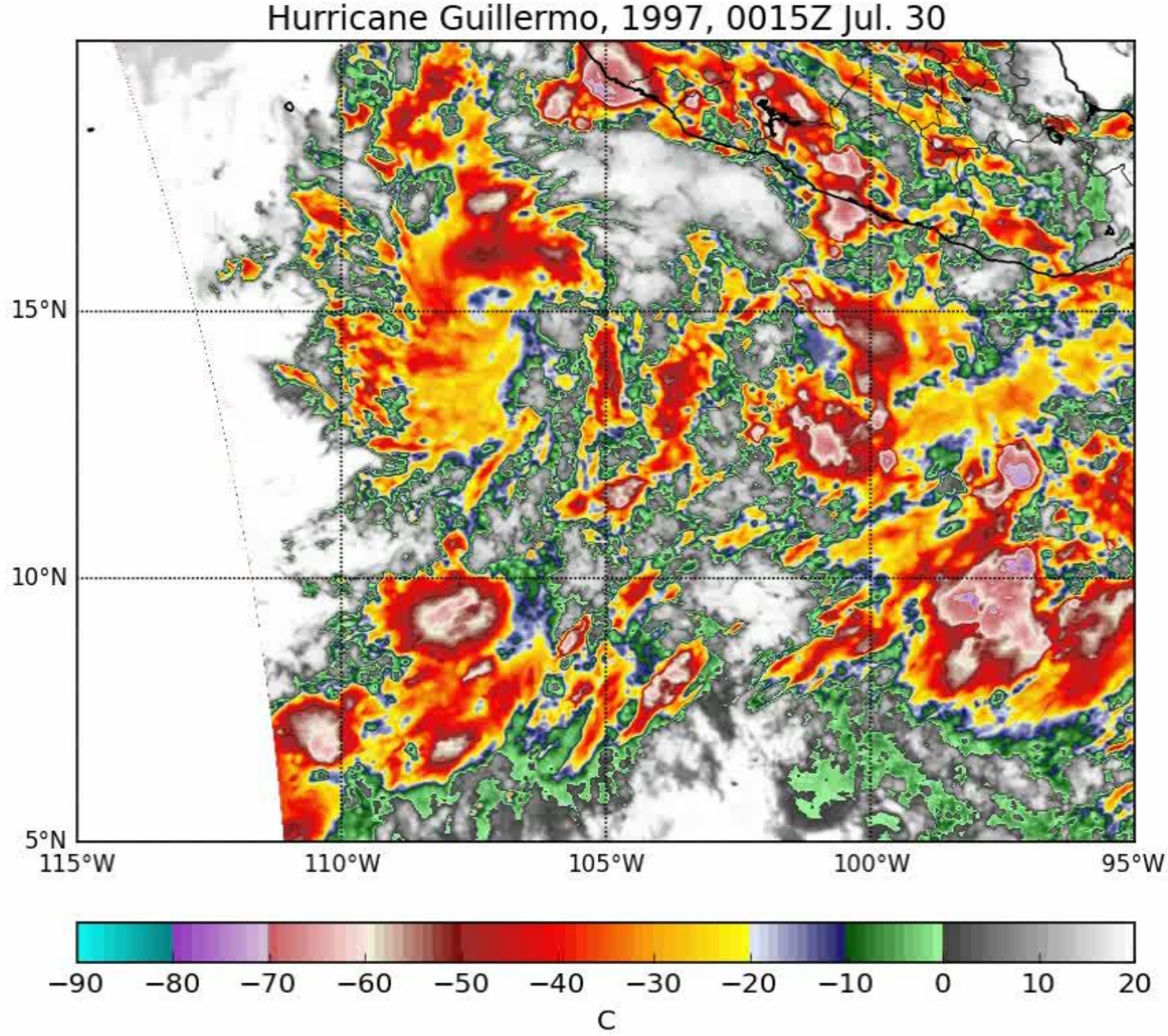
SHRD: Deep-layer (200 mb - 850 mb) shear
SHDC: Deep-layer shear, vortex removed

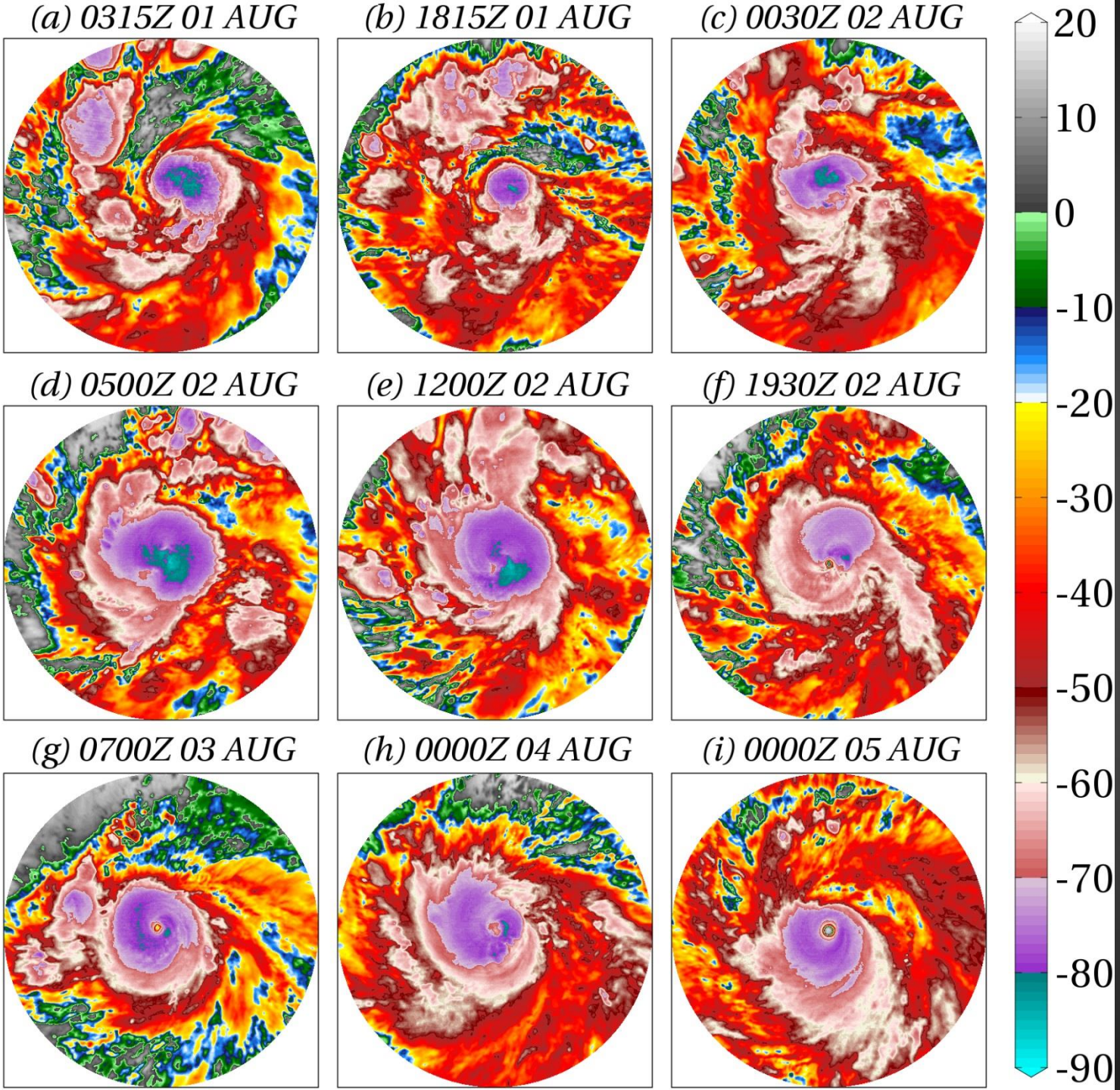
Flights

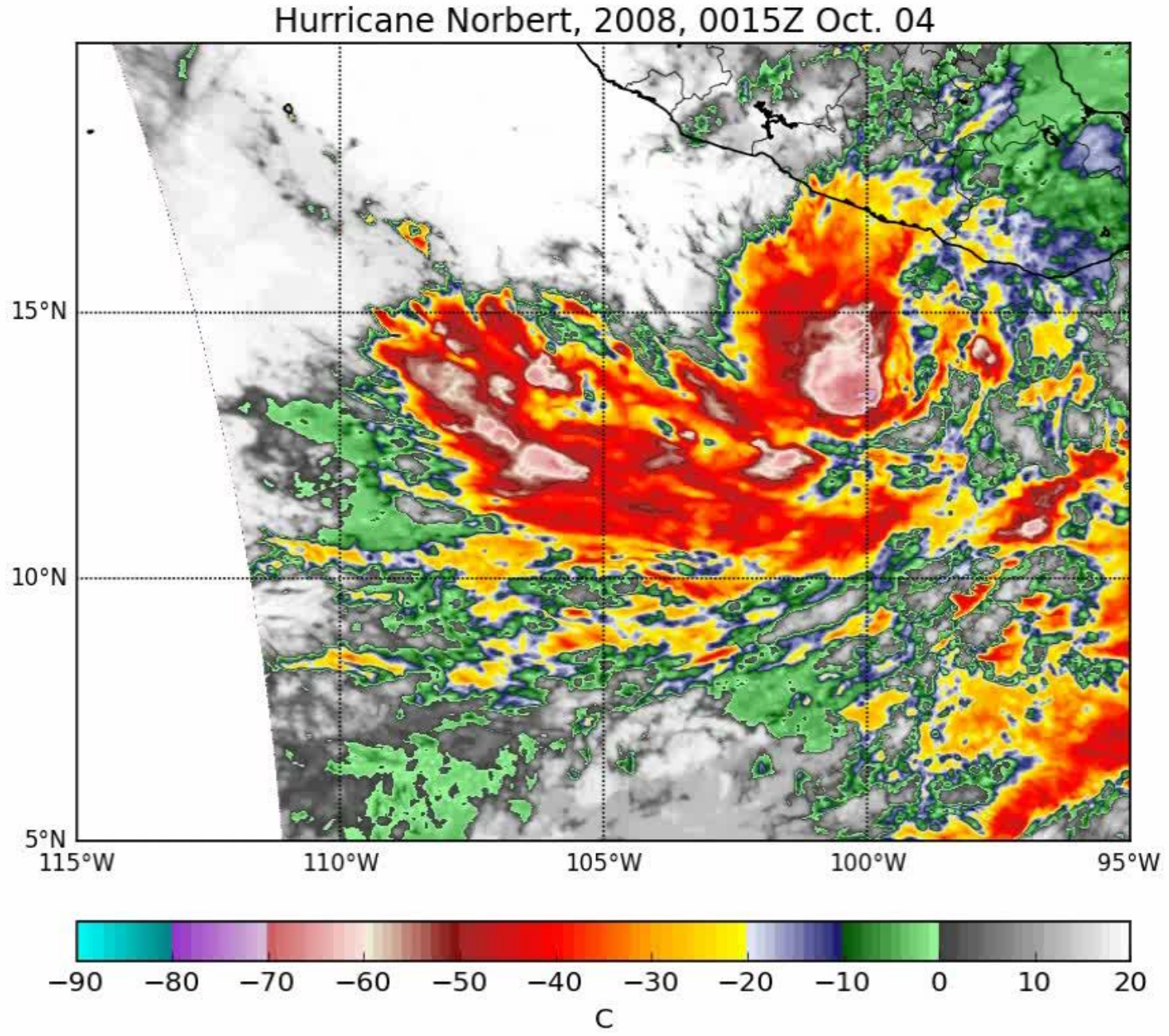


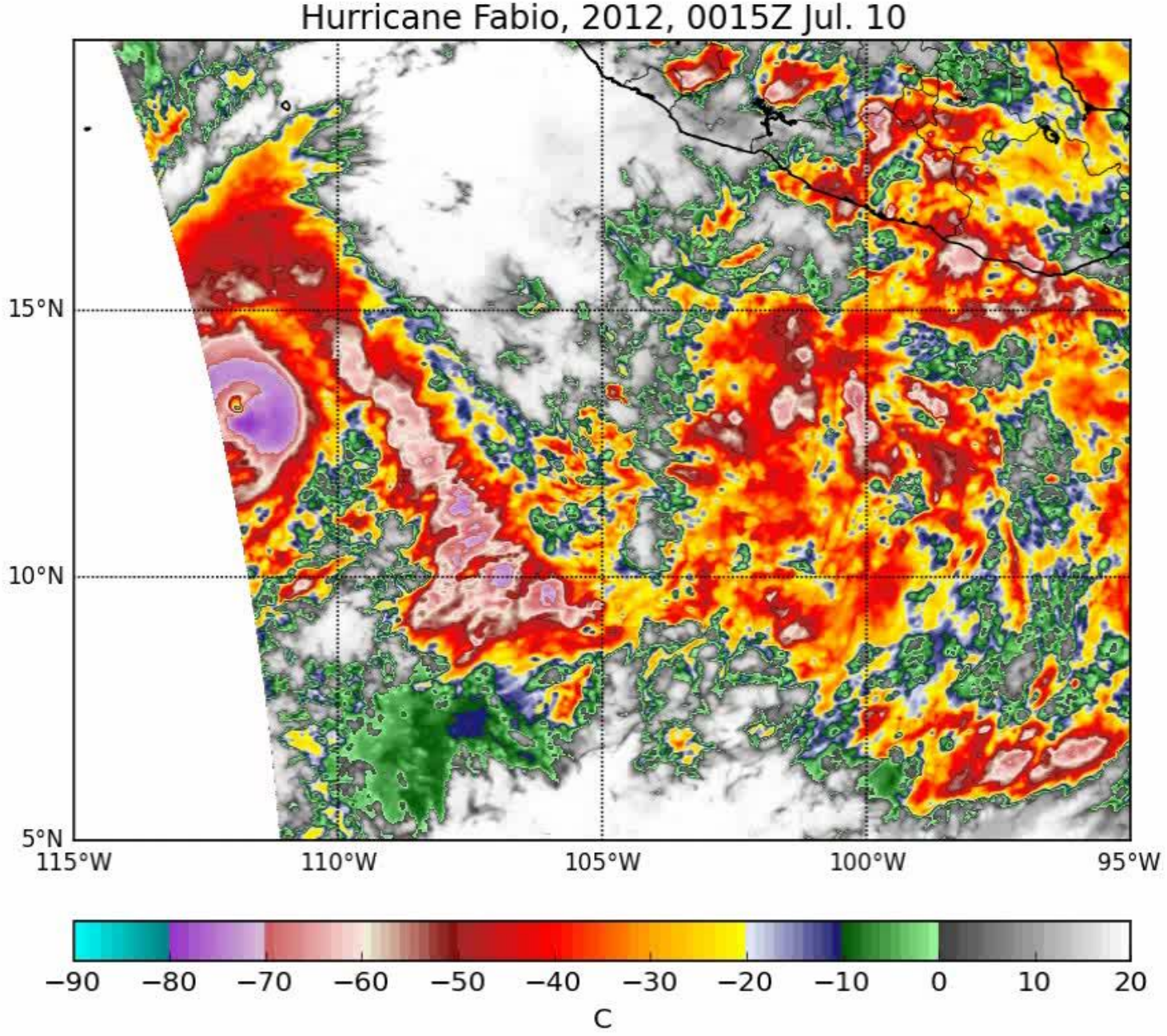


So what's happening here?


Hurricane Guillermo, 1997, 0015Z Jul. 30
15°N
10°N
5°N
115°W
110°W
105°W
100°W
95°W
−90
−80
−70
−60
−50
−40
−30
−20
−10
0
10
20
C


(a) 0315Z 01 AUG
(b) 1815Z 01 AUG
(c) 0030Z 02 AUG
(d) 0500Z 02 AUG
(e) 1200Z 02 AUG
(f) 1930Z 02 AUG
(g) 0700Z 03 AUG
(h) 0000Z 04 AUG
(i) 0000Z 05 AUG
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90


Hurricane Norbert, 2008, 0015Z Oct. 04
15°N
10°N
5°N
115°W
110°W
105°W
100°W
95°W
−90
−80
−70
−60
−50
−40
−30
−20
−10
0
10
20
C


Hurricane Fabio, 2012, 0015Z Jul. 10
15°N
10°N
5°N
115°W
110°W
105°W
100°W
95°W
−90
−80
−70
−60
−50
−40
−30
−20
−10
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10
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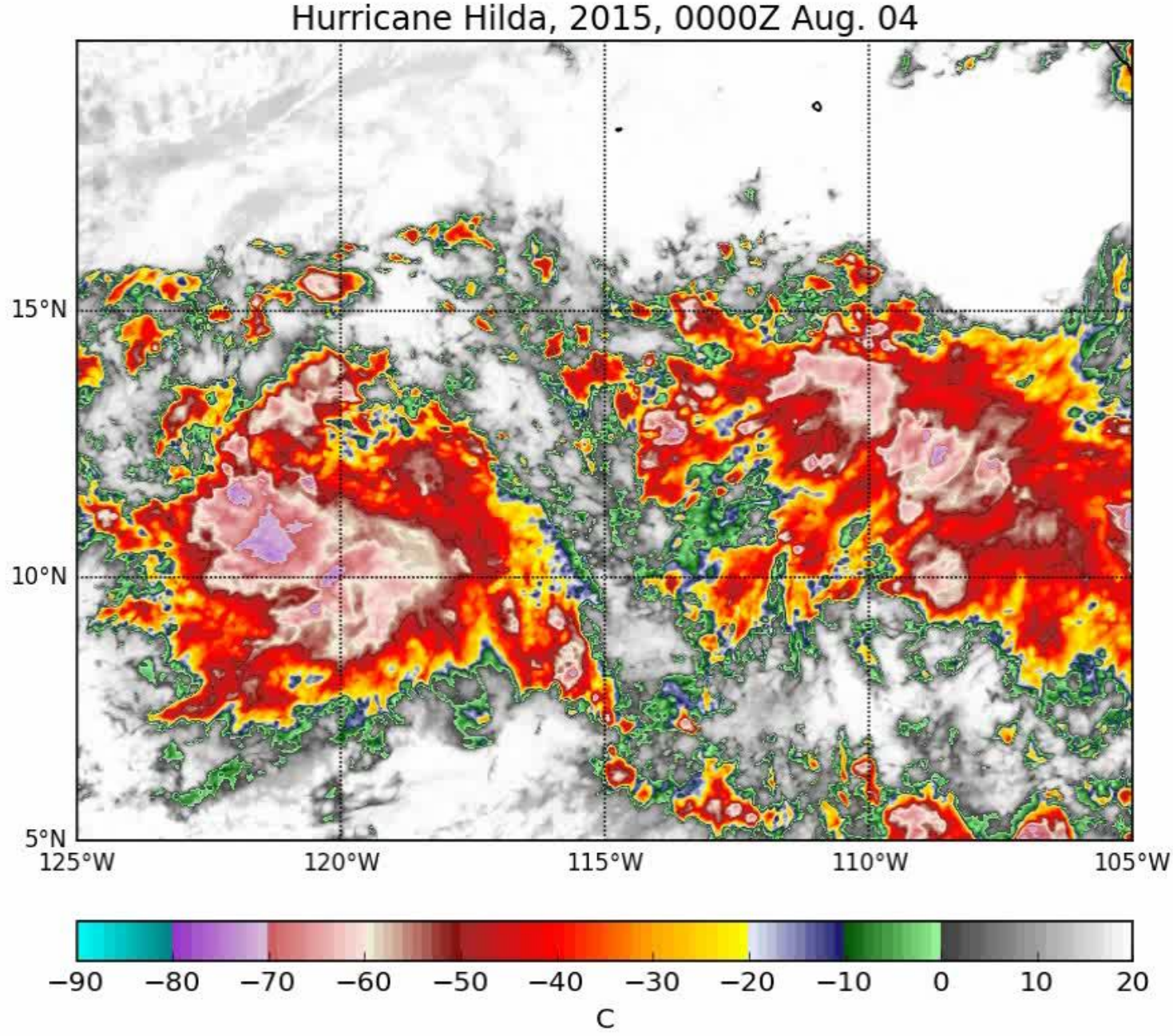
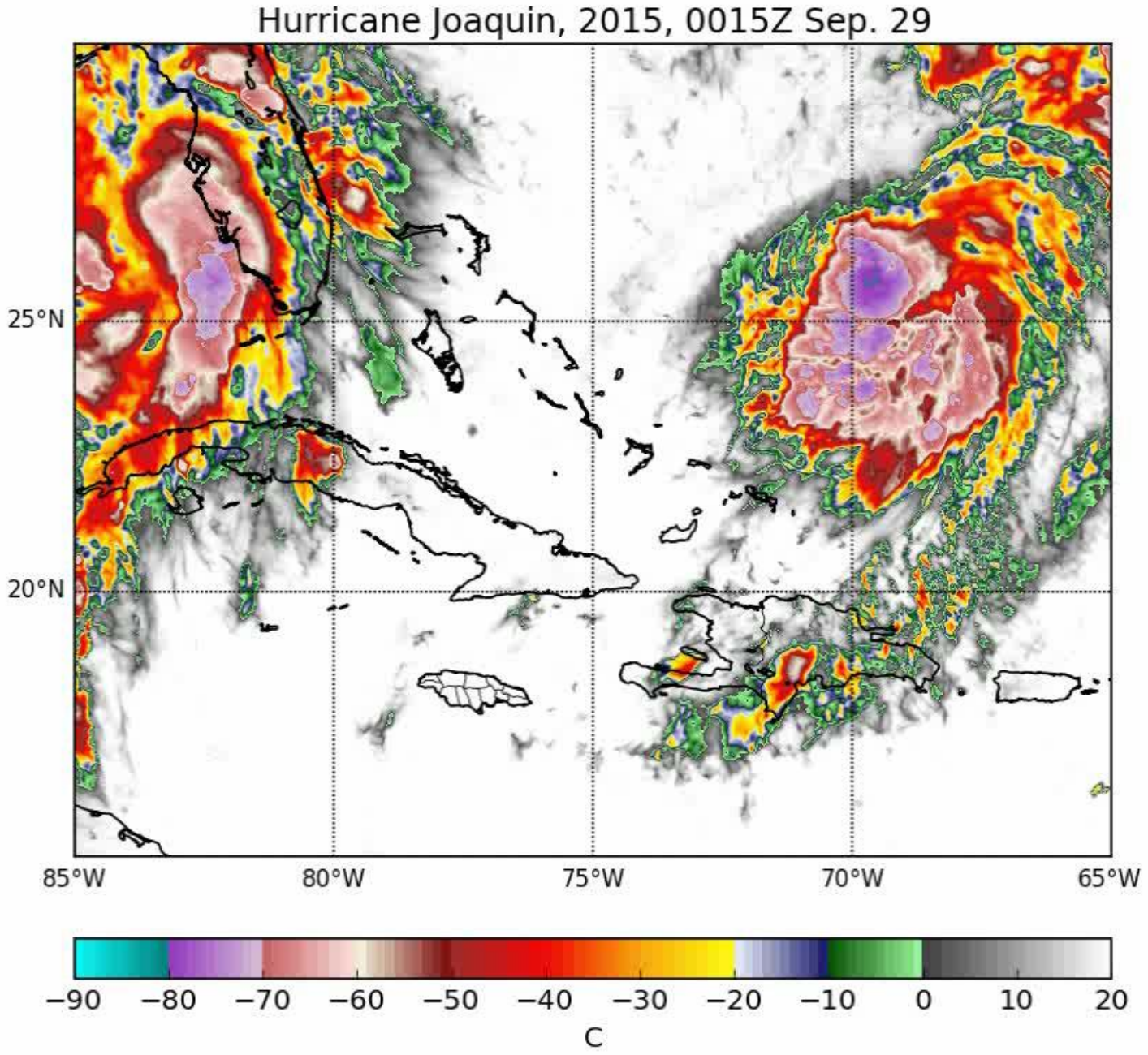
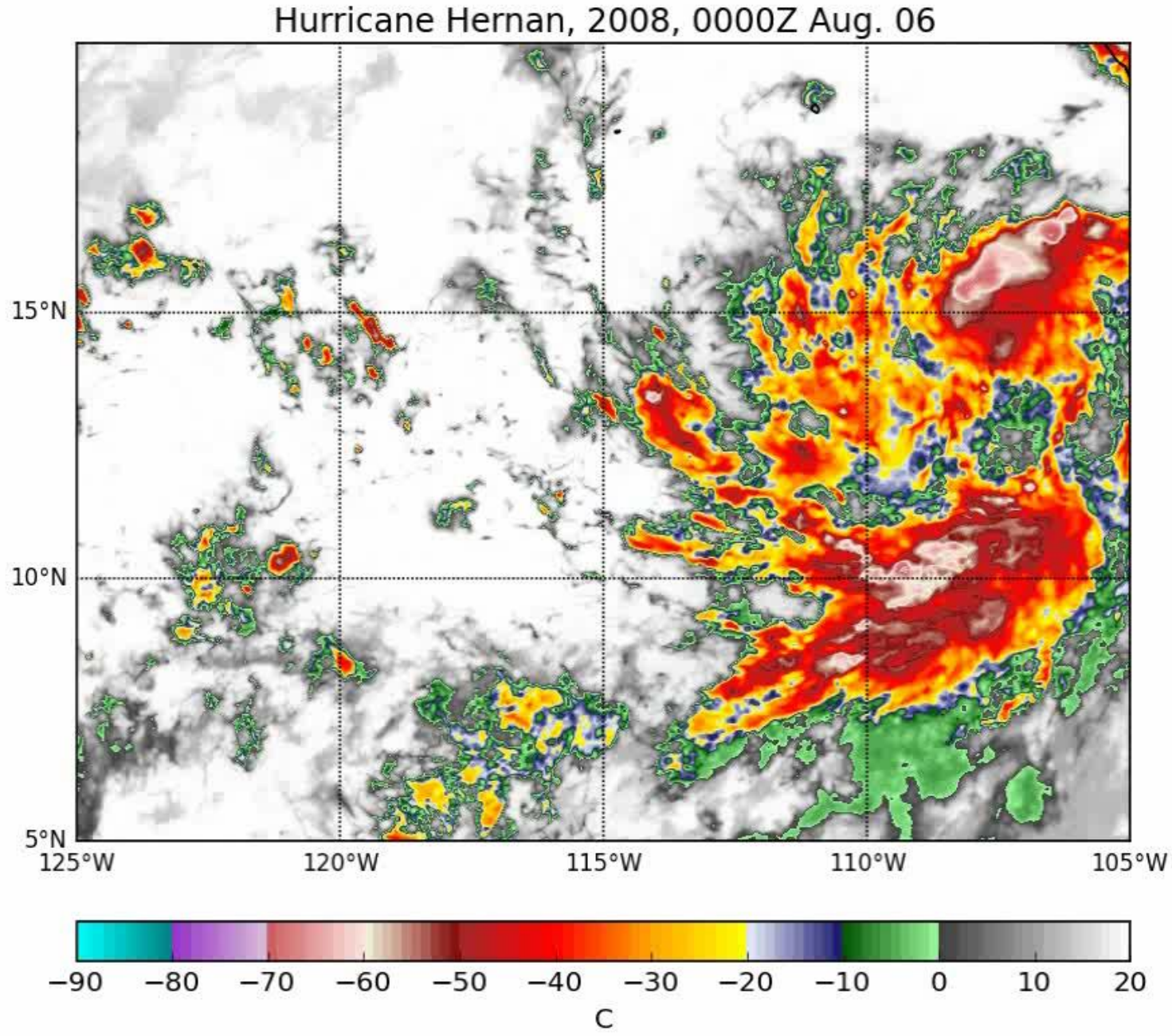
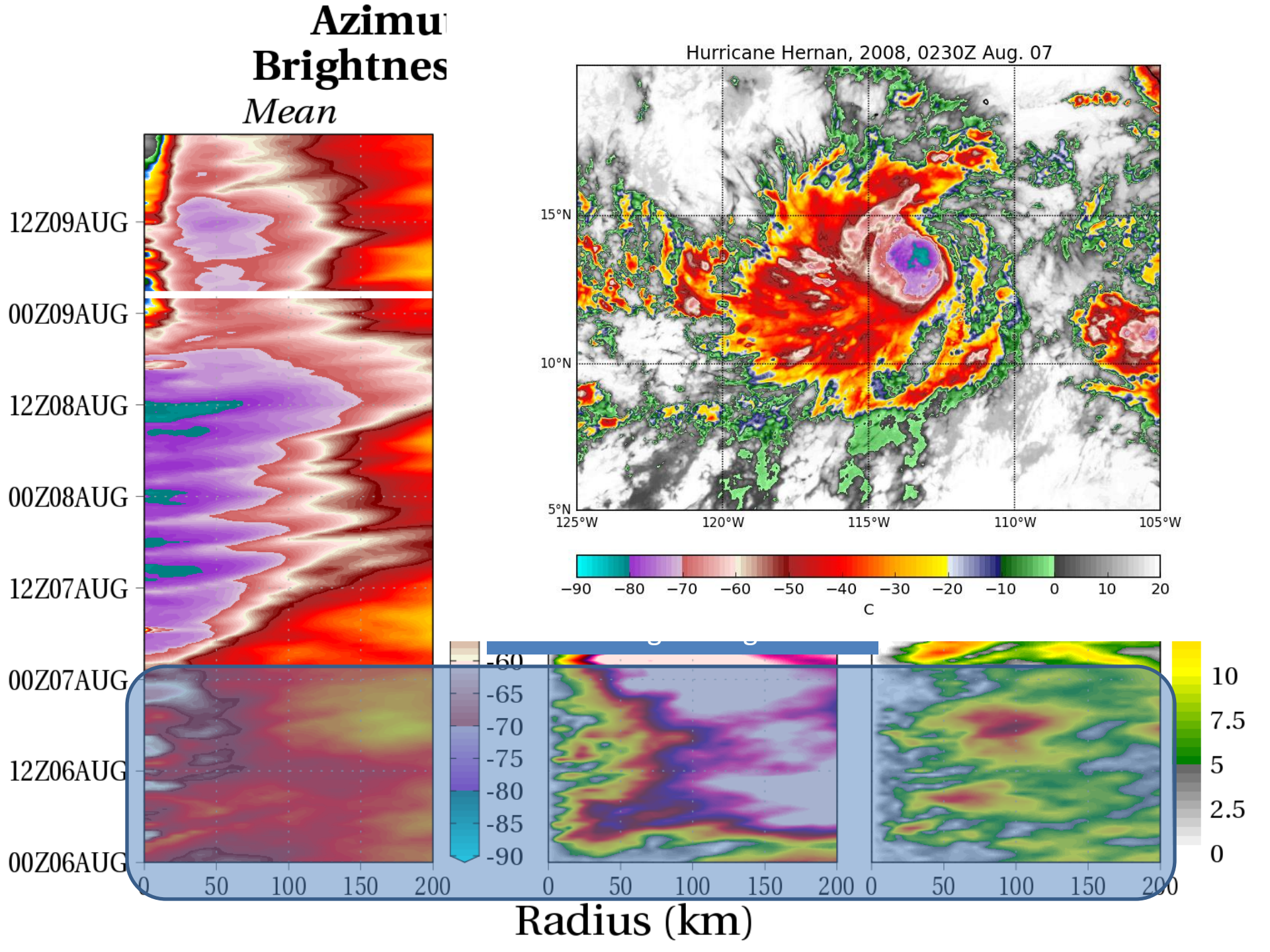
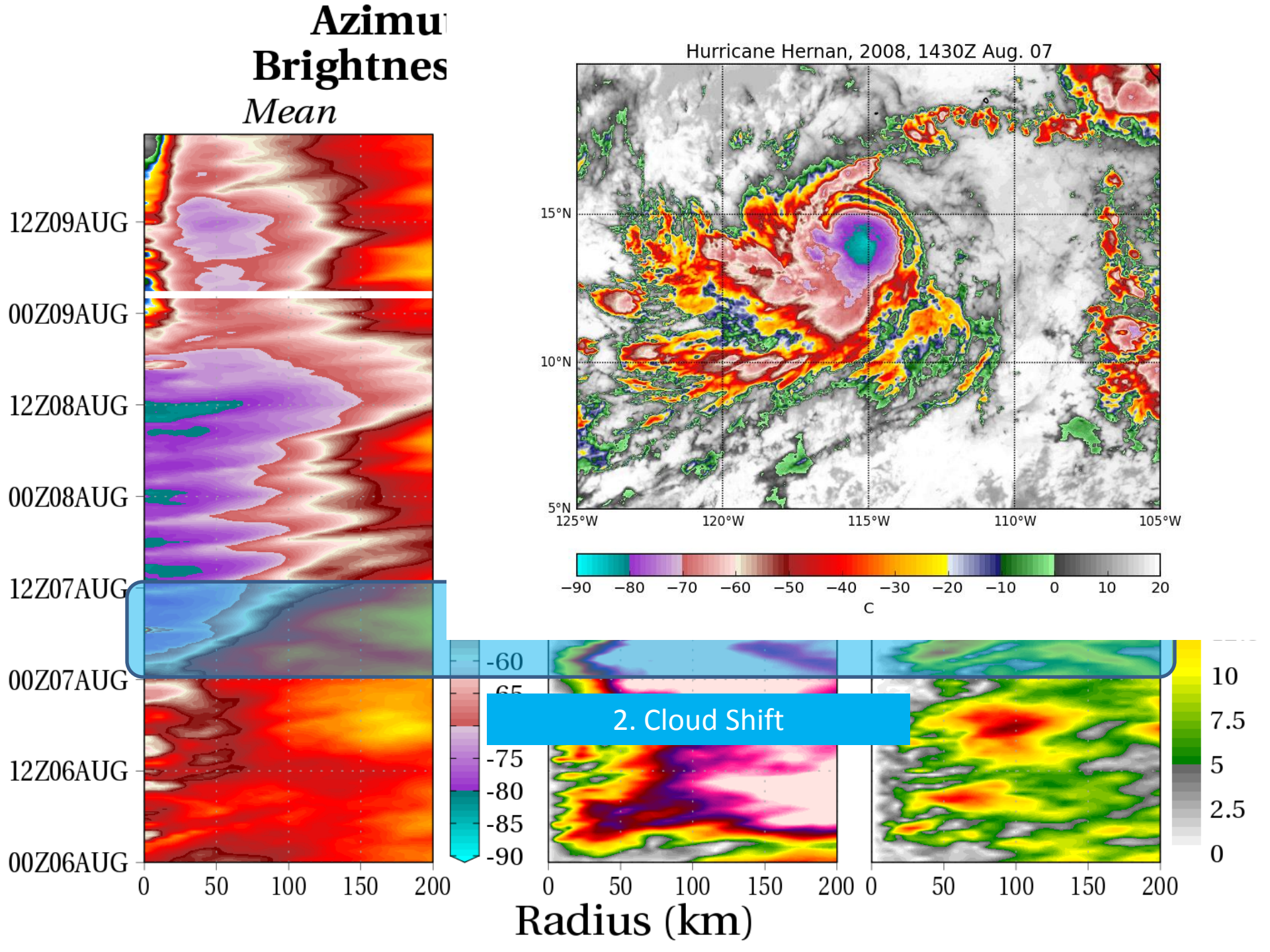
C

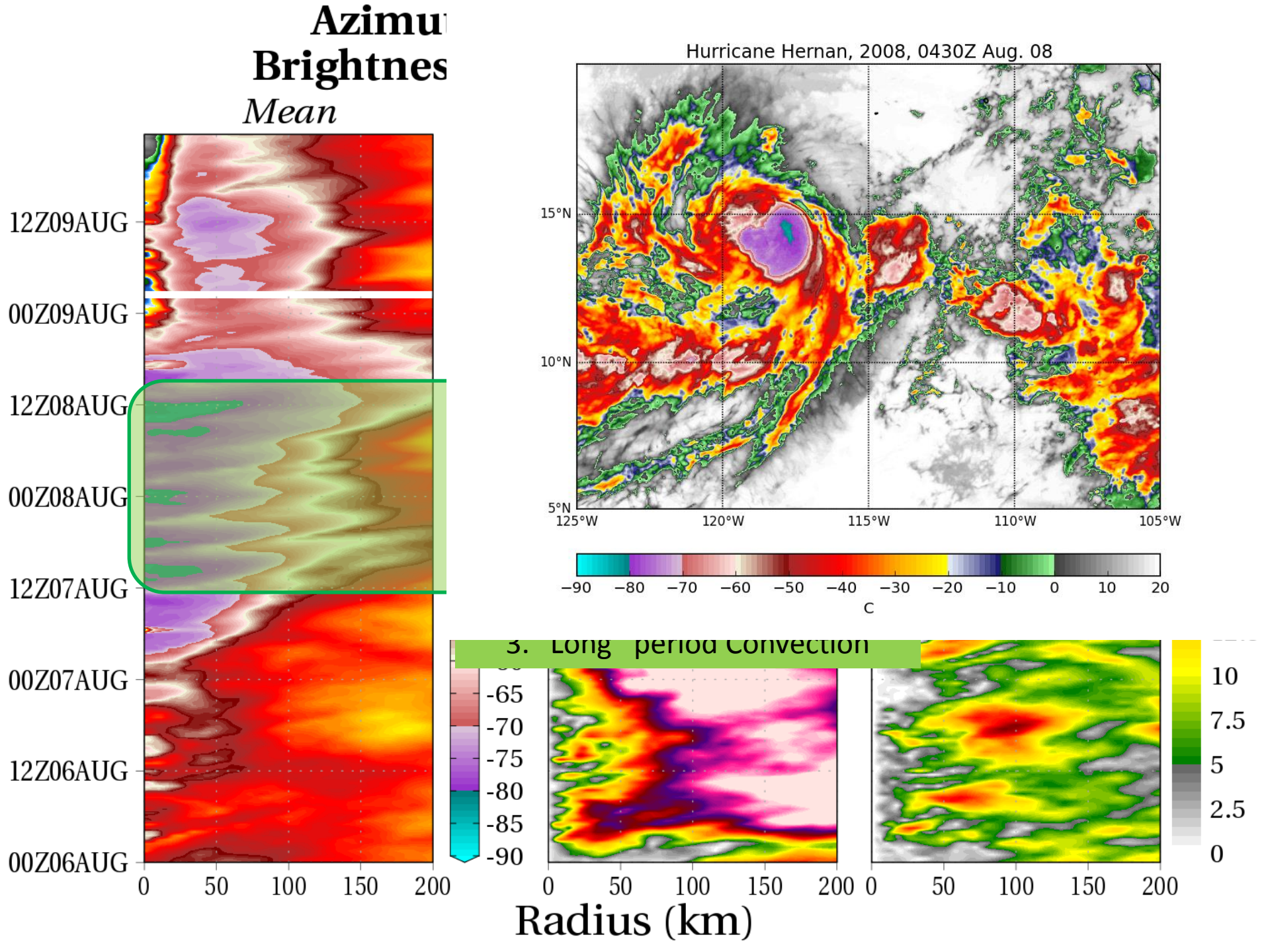

Hurricane Hilda, 2015, 0000Z Aug. 04
15°N
10°N
5°N
125°W
120°W
115°W
110°W
105°W
−90
−80
−70
−60
−50
−40
−30
−20
−10
0
10
20
C


Hurricane Joaquin, 2015, 0015Z Sep. 29
25°N
20°N
85°W
80°W
75°W
70°W
65°W
−90
−80
−70
−60
−50
−40
−30
−20
−10
0
10
20
C

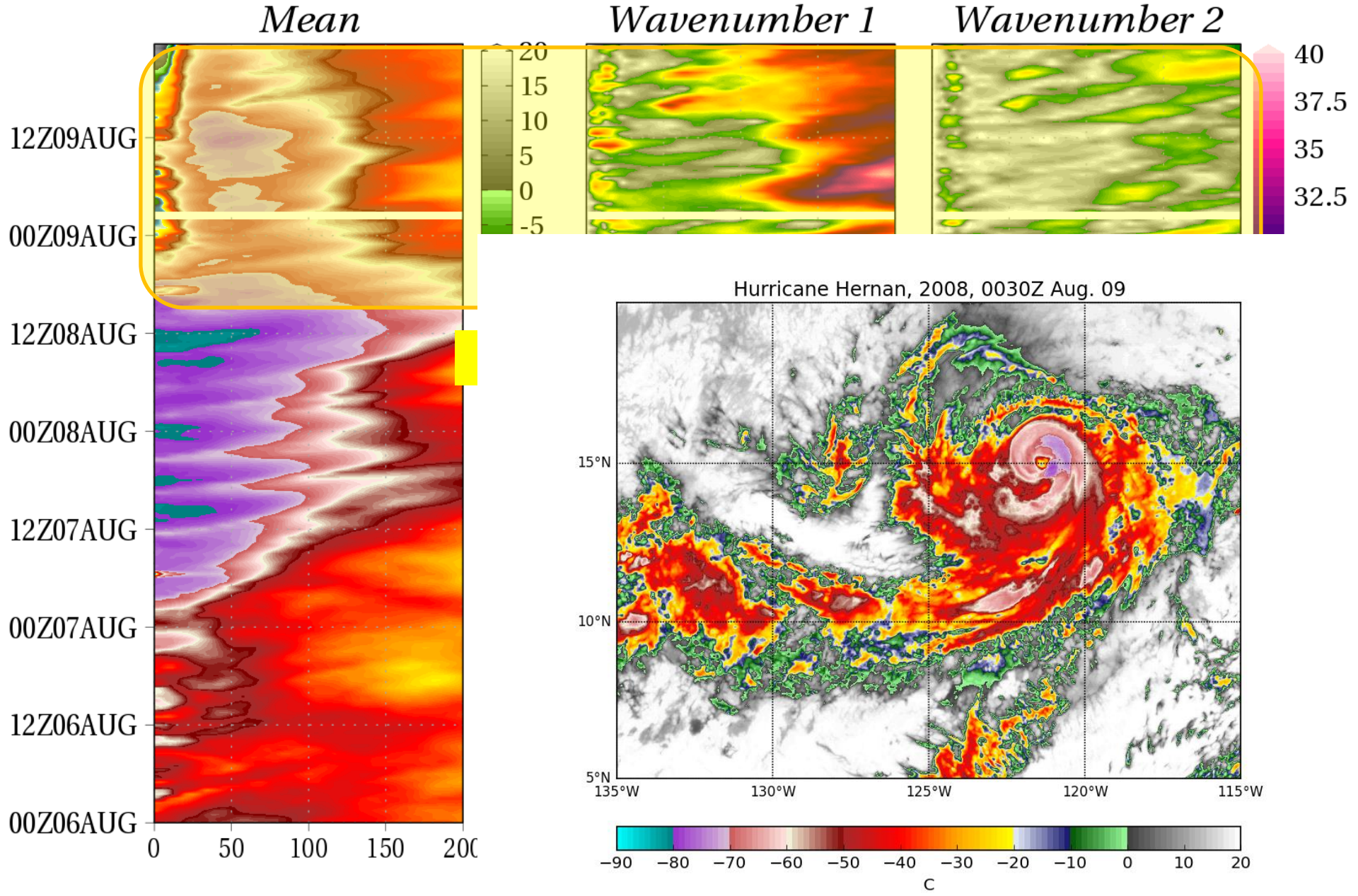

Hurricane Hernan, 2008, 0000Z Aug. 06
15°N
10°N
5°N
125°W
120°W
115°W
110°W
105°W
−90
−80
−70
−60
−50
−40
−30
−20
−10
0
10
20
C

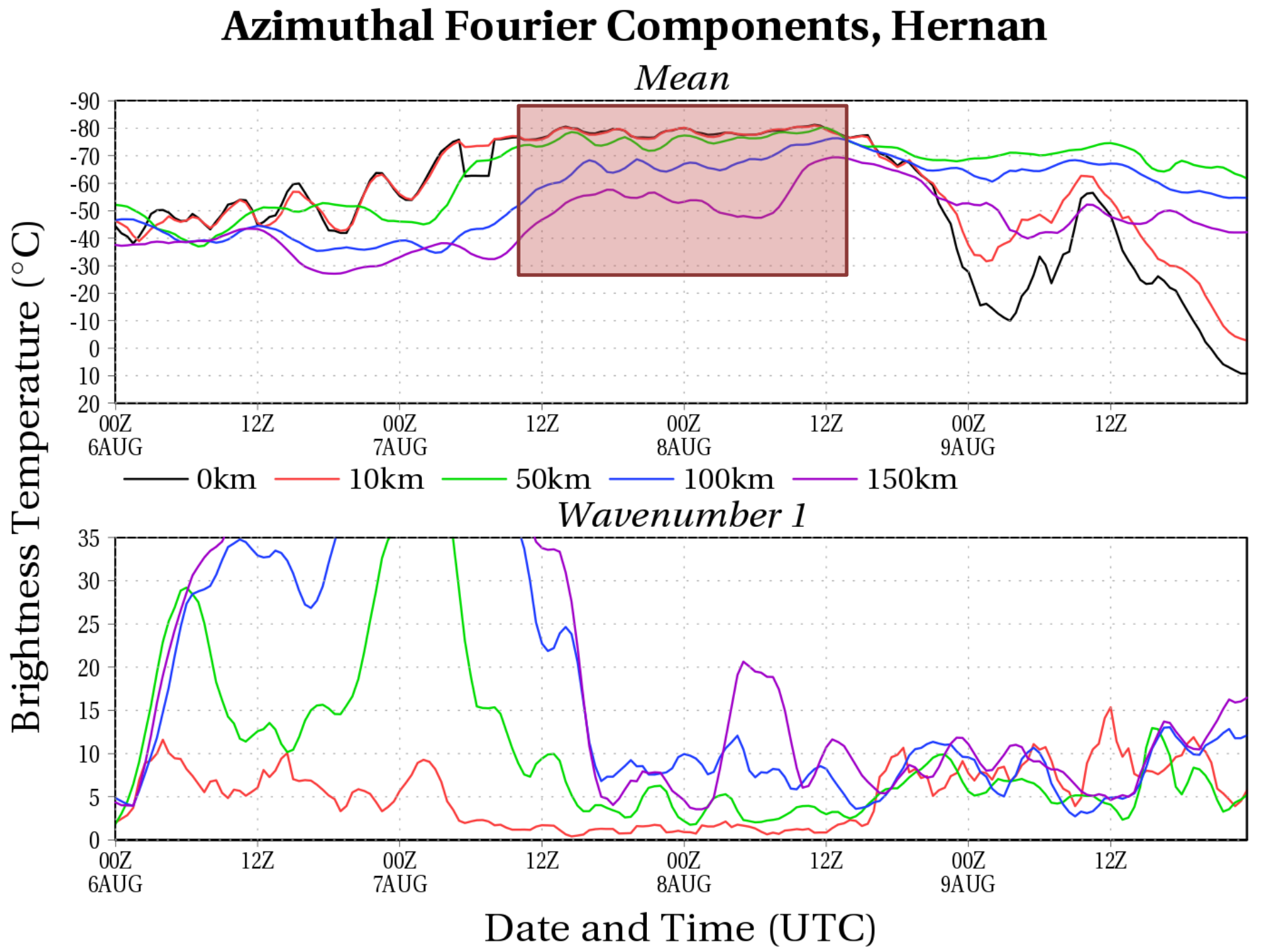

Azimu
Brightnes
Mean
Hurricane Hernan, 2008, 0230Z Aug. 07
15°N
10°N
5°N
125°W
120°W
115°W
110°W
105°W
−90 −80 −70 −60 −50 −40 −30 −20 −10 0 10 20
C
12Z09AUG
00Z09AUG
12Z08AUG
00Z08AUG
12Z07AUG
00Z07AUG
12Z06AUG
00Z06AUG
-60
-65
-70
-75
-80
-85
-90
10
7.5
5
2.5
0
0 50 100 150 200
0 50 100 150 200
0 50 100 150 200
Radius (km)


Azimu
Brightnes
Mean
12Z09AUG
00Z09AUG
12Z08AUG
00Z08AUG
12Z07AUG
00Z07AUG
12Z06AUG
00Z06AUG
0
50
100
150
200
-60
-75
-80
-85
-90
Hurricane Hernan, 2008, 1430Z Aug. 07
15°N
10°N
5°N
125°W
120°W
115°W
110°W
105°W
−90 −80 −70 −60 −50 −40 −30 −20 −10 0 10 20
C
10
7.5
5
2.5
0
2. Cloud Shift
Radius (km)

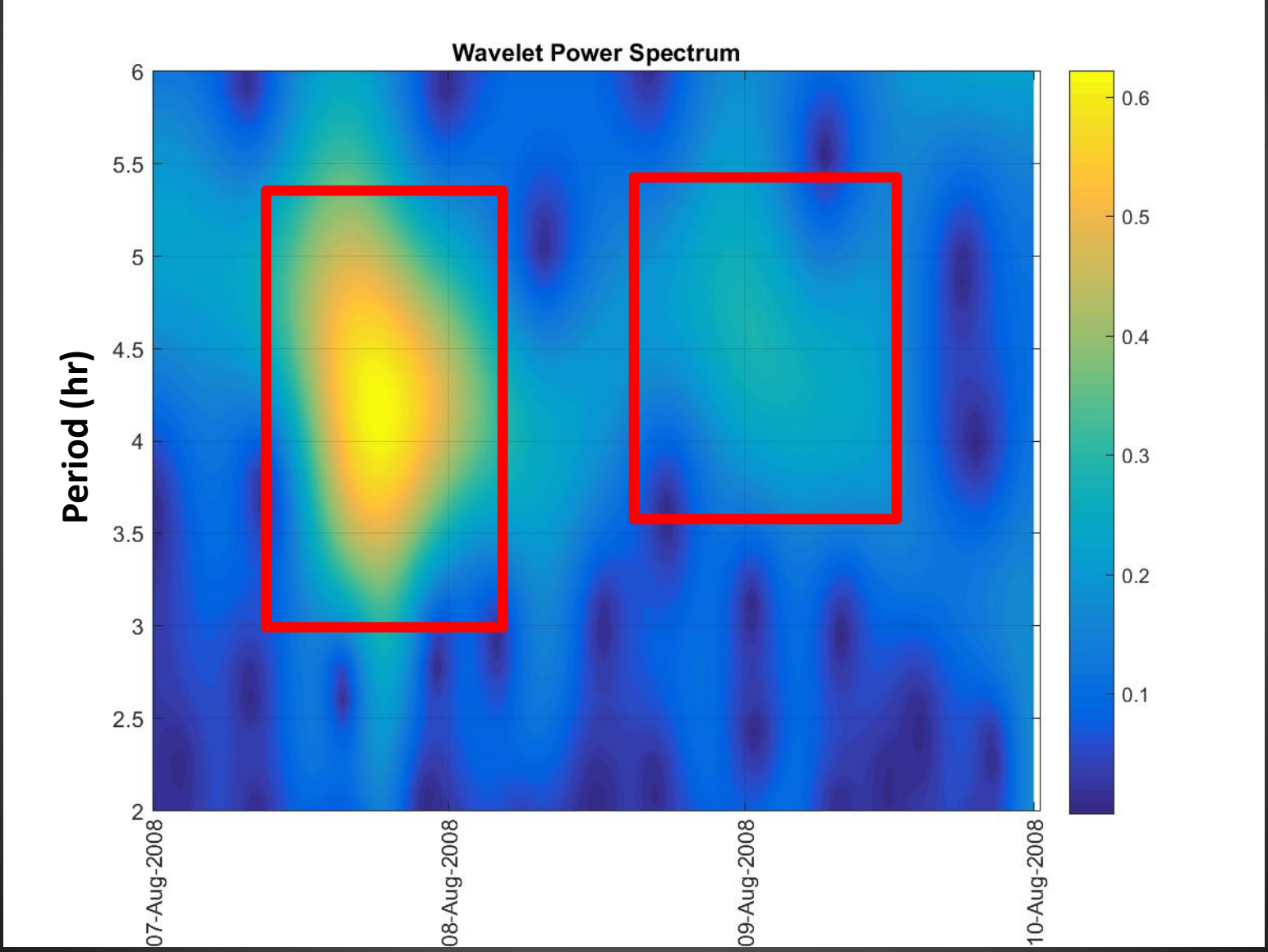

Azimu
Brightnes
Mean
12Z09AUG
00Z09AUG
12Z08AUG
00Z08AUG
12Z07AUG
00Z07AUG
12Z06AUG
00Z06AUG
0
50
100
150
200
Hurricane Hernan, 2008, 0430Z Aug. 08
15°N
10°N
5°N
125°W
120°W
115°W
110°W
105°W
−90 −80 −70 −60 −50 −40 −30 −20 −10 0 10 20
C
3. Long period Convection
-65
-70
-75
-80
-85
-90
10
7.5
5
2.5
0
Radius (km)

Azimuthal Fourier Components
Brightness Temperature (°C), Hernan

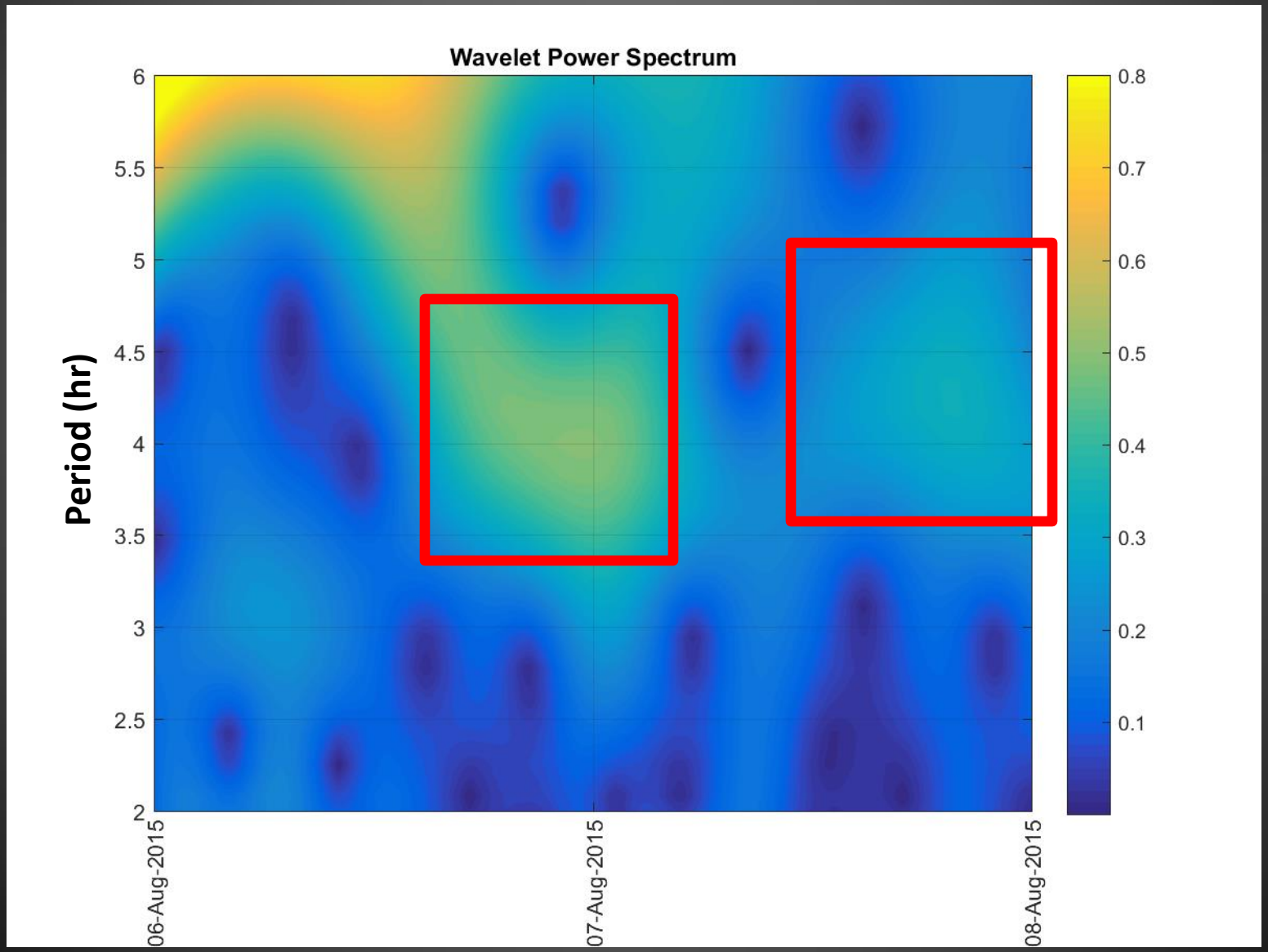



Azimuthal Fourier Components, Hernan
Mean
-90
-80
-70
-60
-50
-40
-30
-20
-10
0
10
20
00Z 6AUG
12Z
00Z 7AUG
12Z
00Z 8AUG
12Z
00Z 9AUG
12Z
0km
10km
50km
100km
150km
Wavenumber 1
35
30
25
20
15
10
5
0
00Z 6AUG
12Z
00Z 7AUG
12Z
00Z 8AUG
12Z
00Z 9AUG
12Z
Brightness Temperature (°C)
Date and Time (UTC)

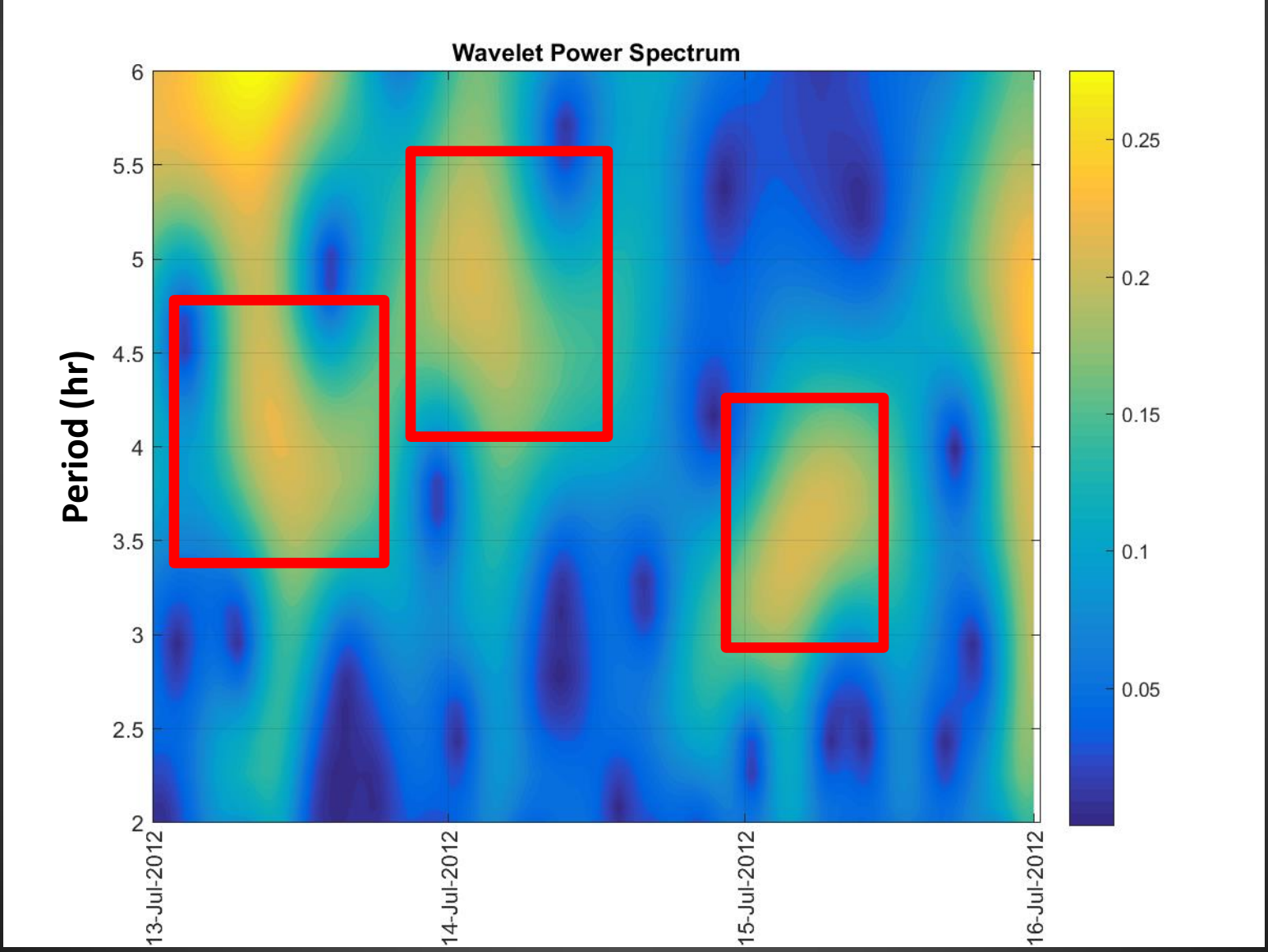
Hernan Satellite – Wavelet Power Spectrum (°C) (Radius = 100 km)



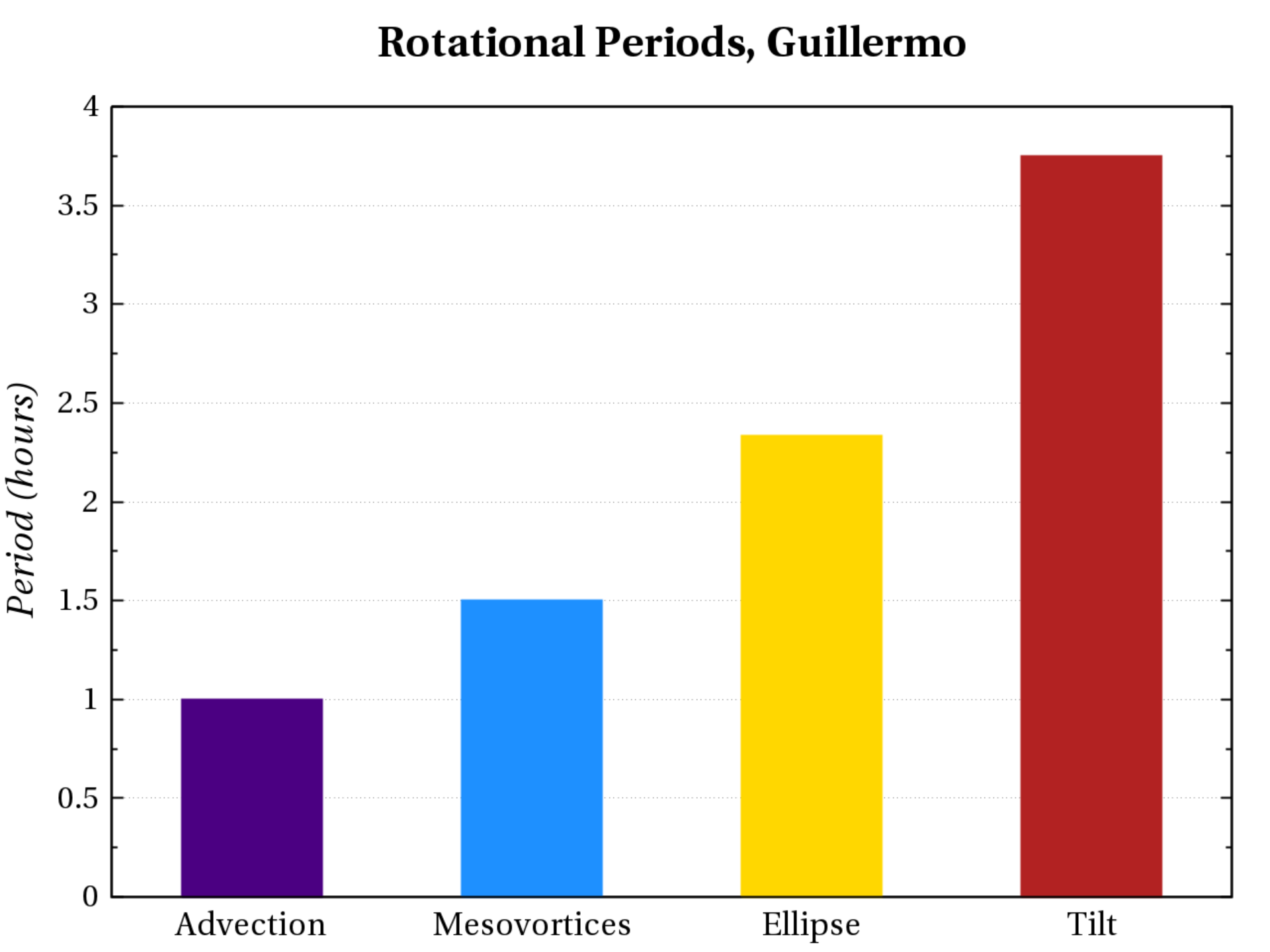
Hilda Satellite – Wavelet Power Spectrum (°C) (Radius = 10 km)



Fabio Satellite – Wavelet Power Spectrum (°C) (Radius = 100 km)

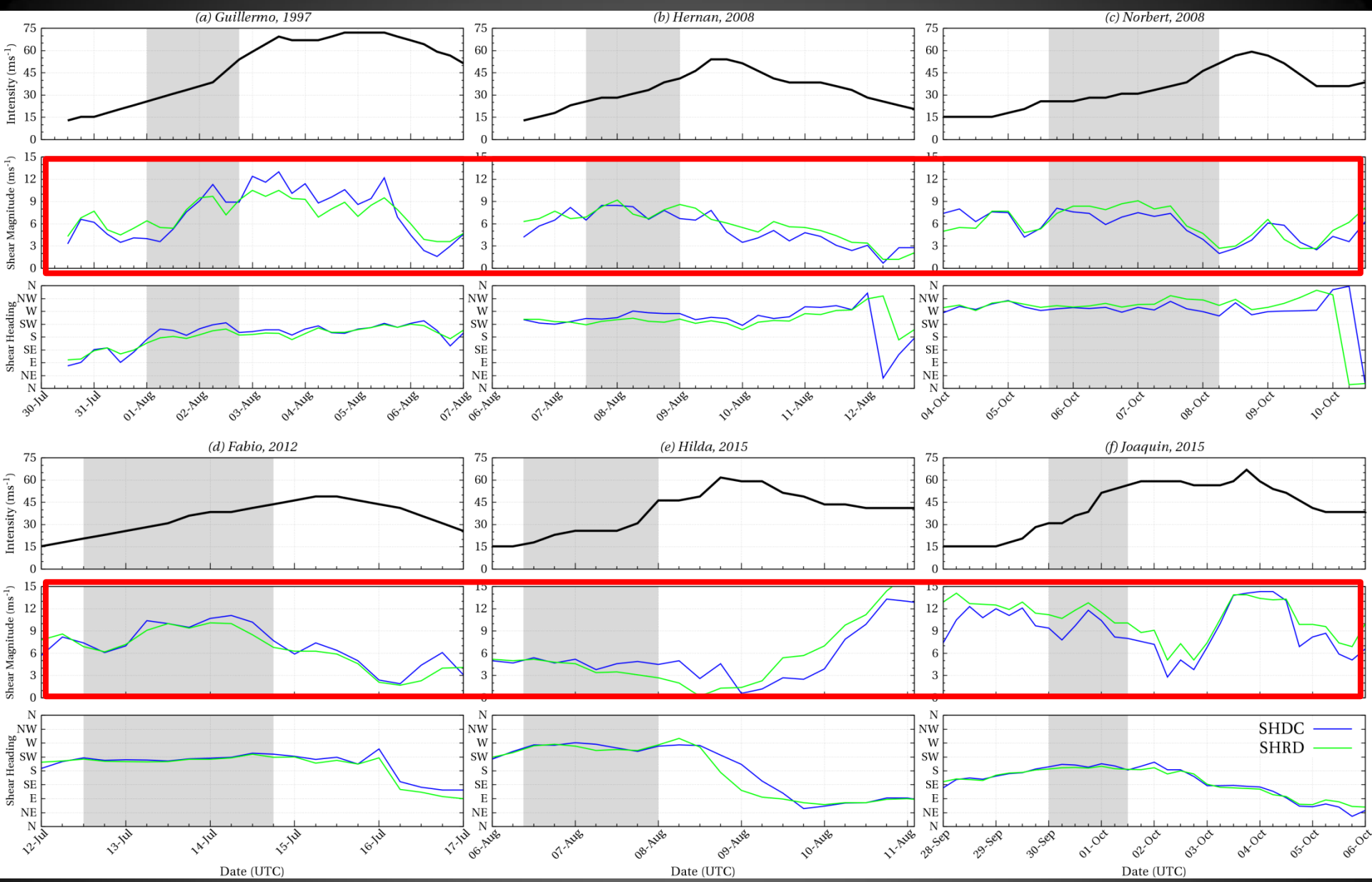


Storm	Periods (hr)
1997 Guillermo	4.5, 3.75
2008 Hernan	4.25, 4.5
2008 Norbert	N/A
2012 Fabio	4.5, 3.5
2015 Hilda	4.0, 4.25
2015 Joaquin	5.0, 3.0


Rotational Periods, Guillermo
Period (hours)
4
3.5
3
2.5
2
1.5
1
0.5
0
Advection
Mesovortices
Ellipse
Tilt

Cloud/Convective Time scales

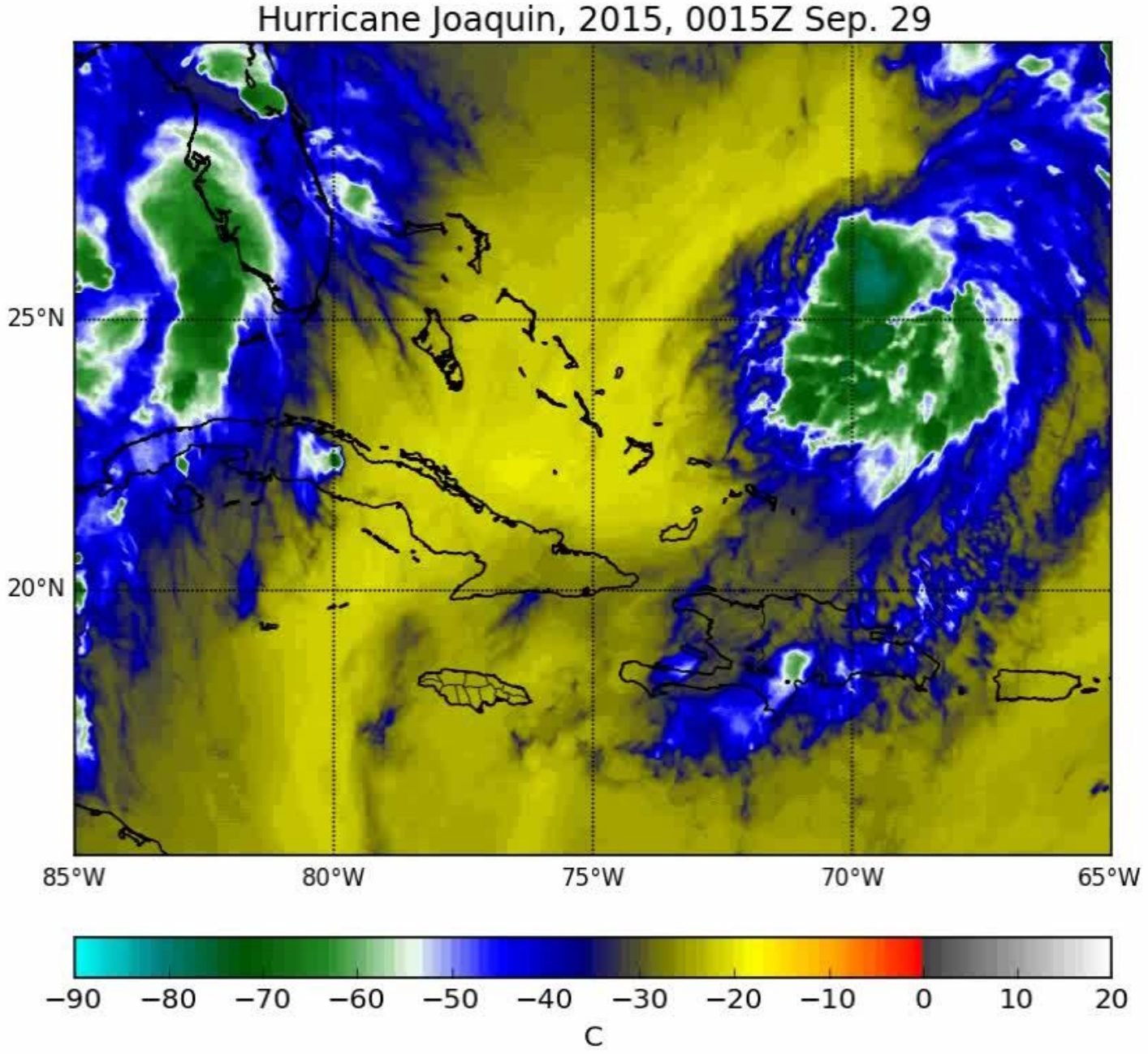
- So, *circumstantially*, it is *plausible* that the vertical tilt is modulating convection during Long Period times in these storms
  - Outside of Guillermo, there are no tilt observations, so a lot of this is based on those observations
- The period (~4 hours) is too slow for advective characteristics, mesovortices, and elliptical eyewalls

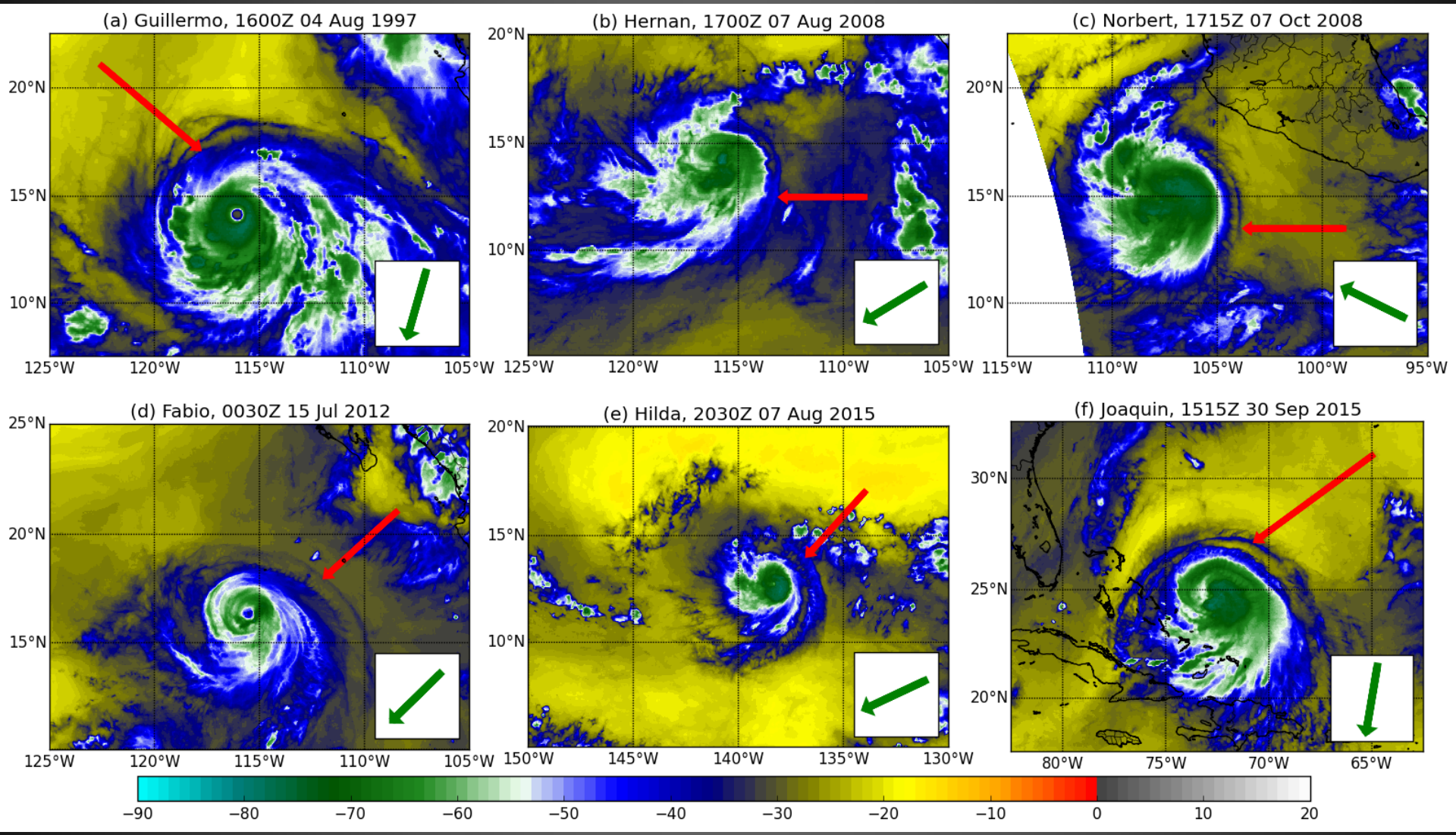


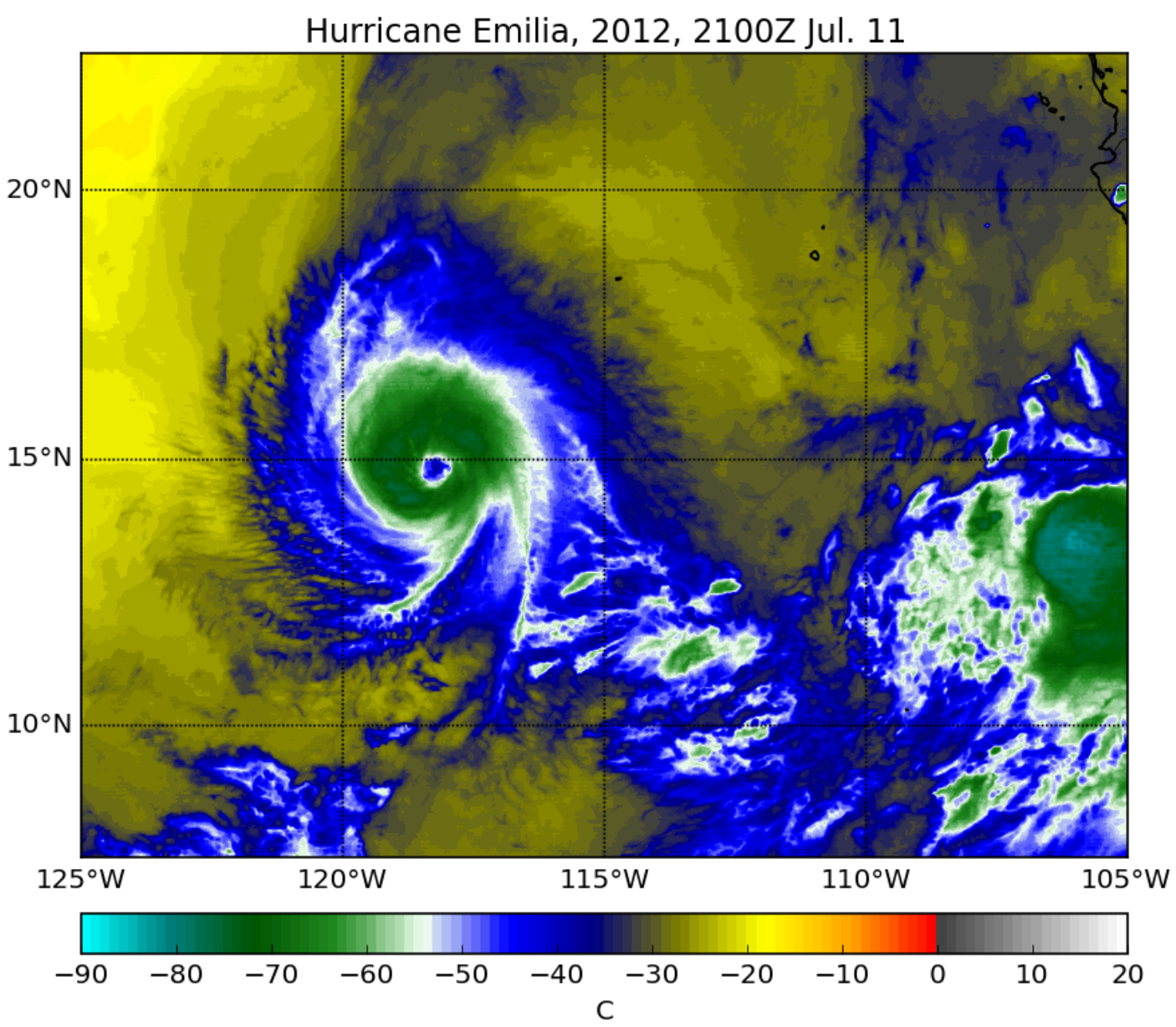
Average wind shear: 7.2327 ms^{-1} (SHDC); 7.5490 ms^{-1} (SHRD)

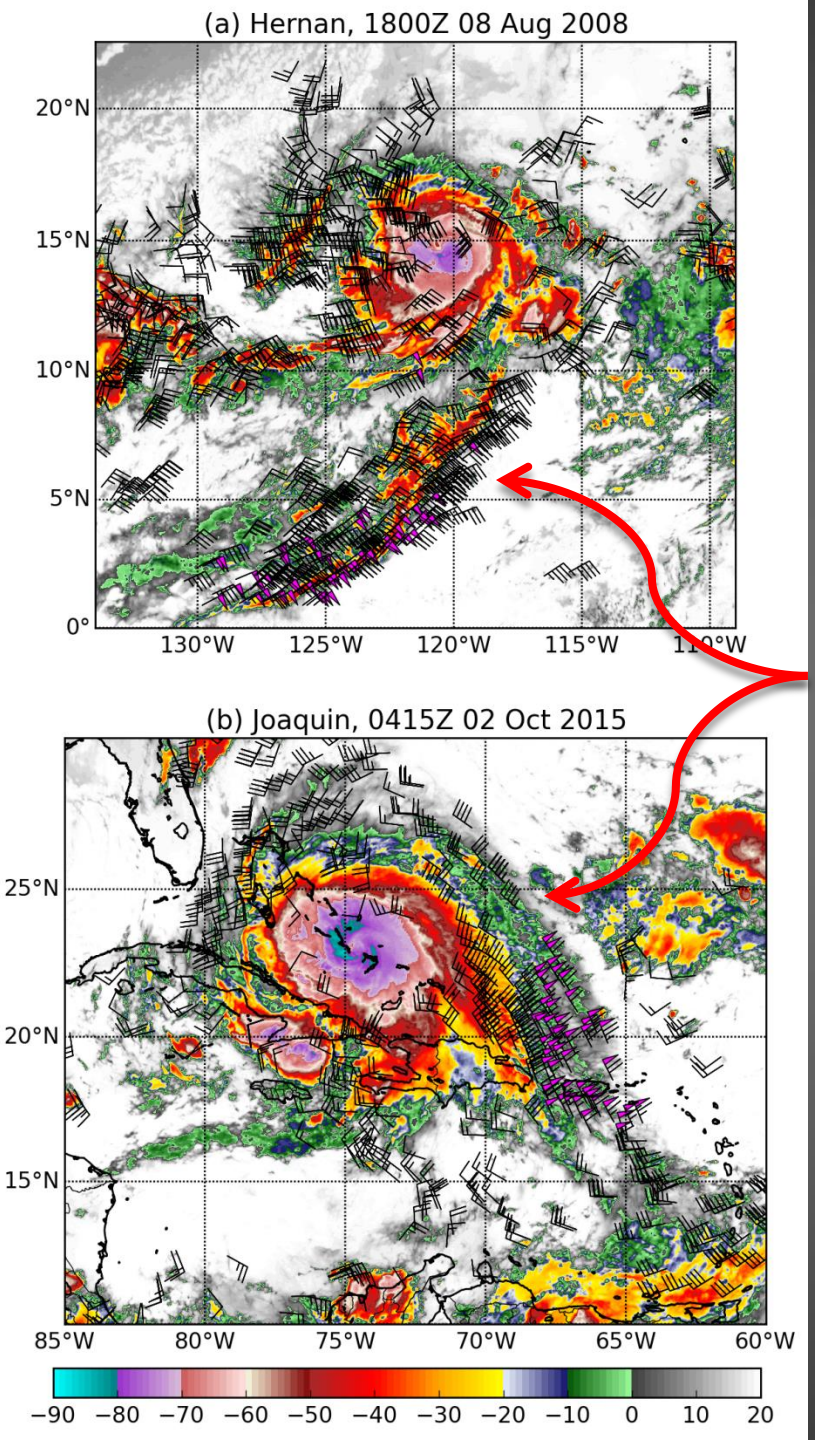
Additional Effects/Questions

- Convective wrapping
- Upper-level blocking
- Outflow Jet
- What is causing the shear?


Hurricane Joaquin, 2015, 0015Z Sep. 29
25°N
20°N
85°W
80°W
75°W
70°W
65°W
−90
−80
−70
−60
−50
−40
−30
−20
−10
0
10
20
C

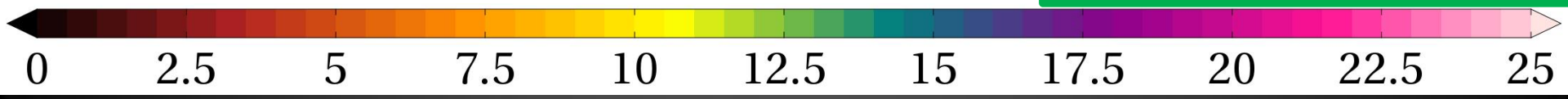

(a) Guillermo, 1600Z 04 Aug 1997
(b) Hernan, 1700Z 07 Aug 2008
(c) Norbert, 1715Z 07 Oct 2008
(d) Fabio, 0030Z 15 Jul 2012
(e) Hilda, 2030Z 07 Aug 2015
(f) Joaquin, 1515Z 30 Sep 2015
−90 −80 −70 −60 −50 −40 −30 −20 −10 0 10 20


Hurricane Emilia, 2012, 2100Z Jul. 11
20°N
15°N
10°N
125°W
120°W
115°W
110°W
105°W
−90
−80
−70
−60
−50
−40
−30
−20
−10
0
10
20
C

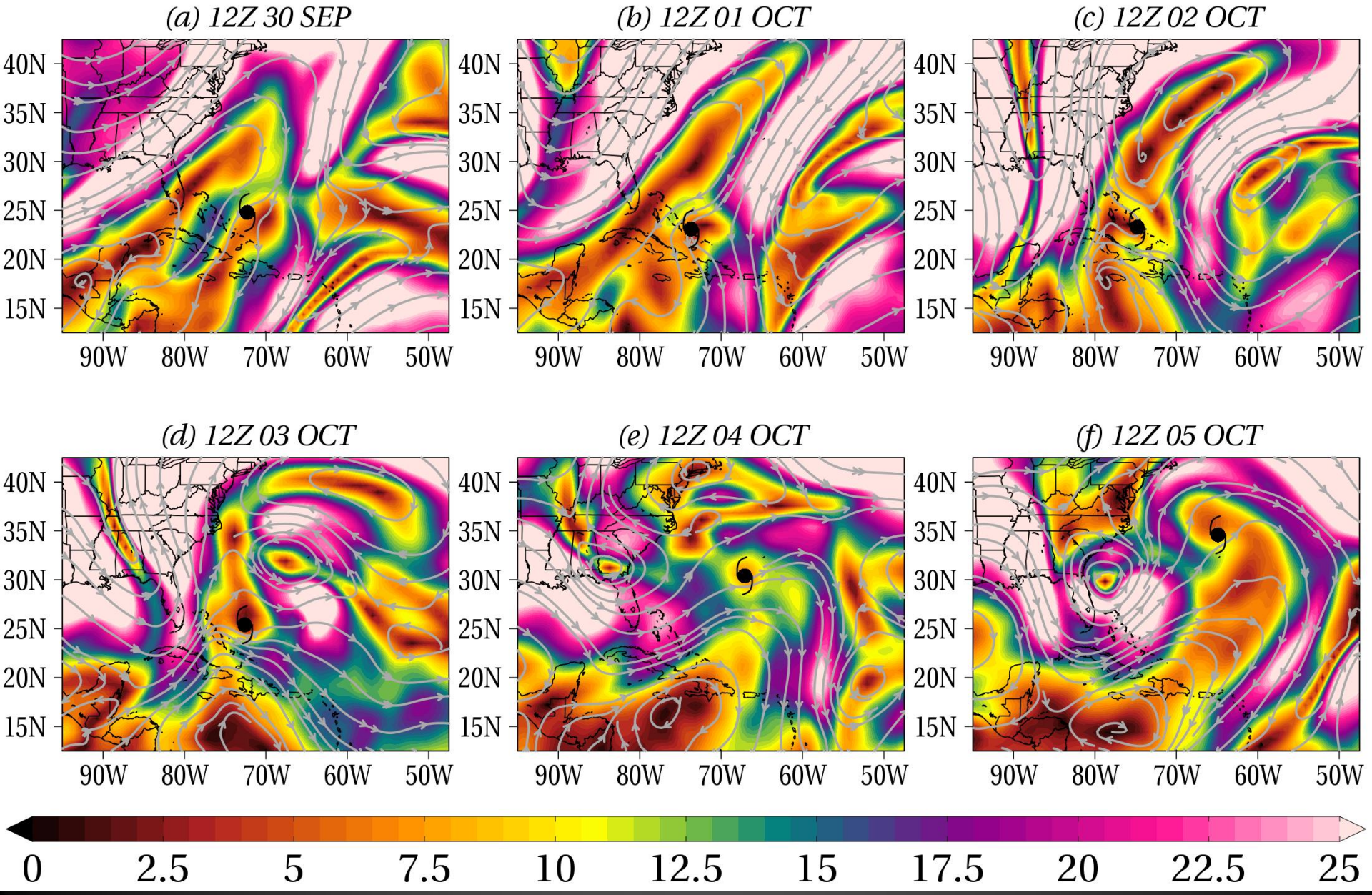


*Outflow jets are **LEFT** of the shear vector*

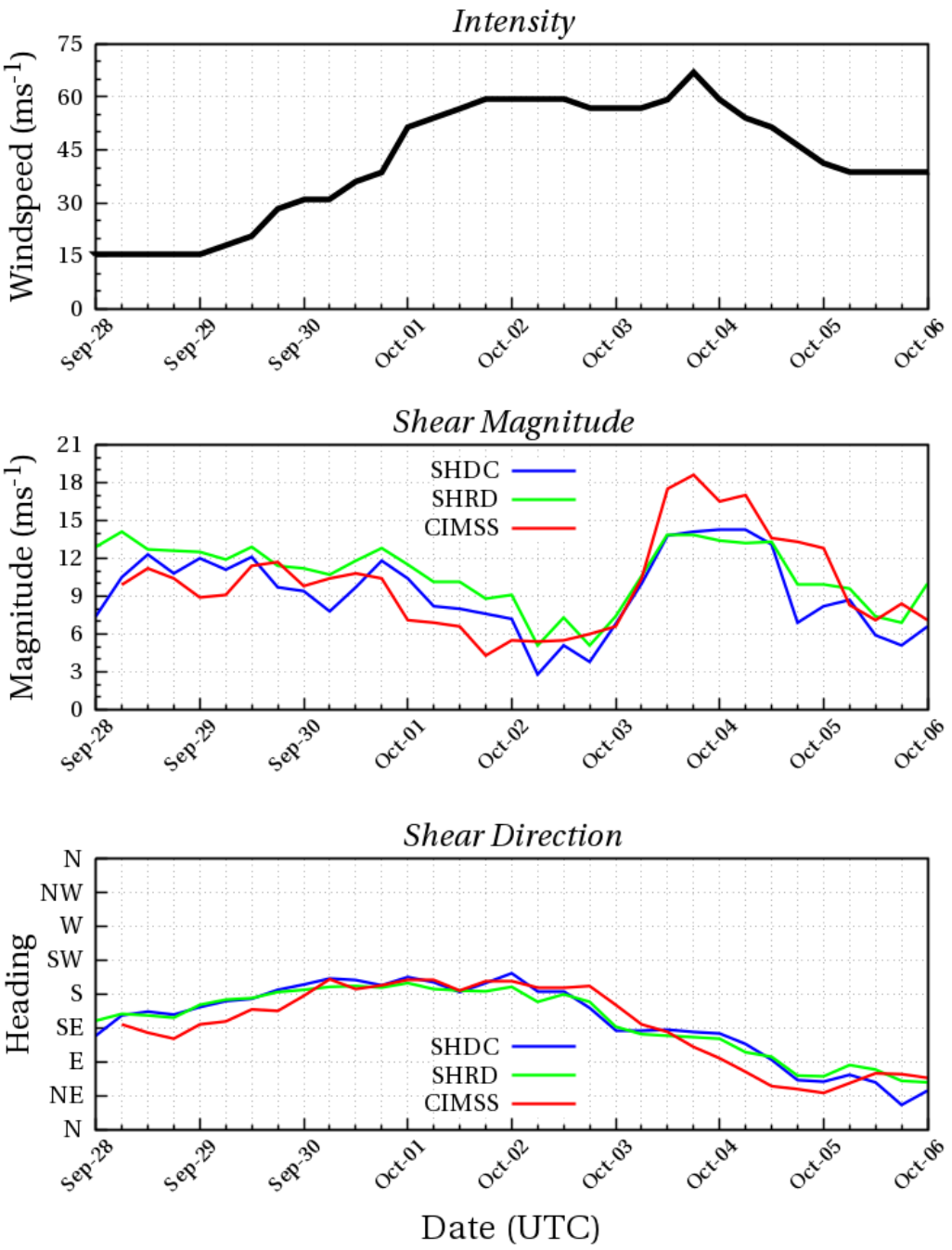
200 hPa winds (ms^{-1}), ERA-Interim

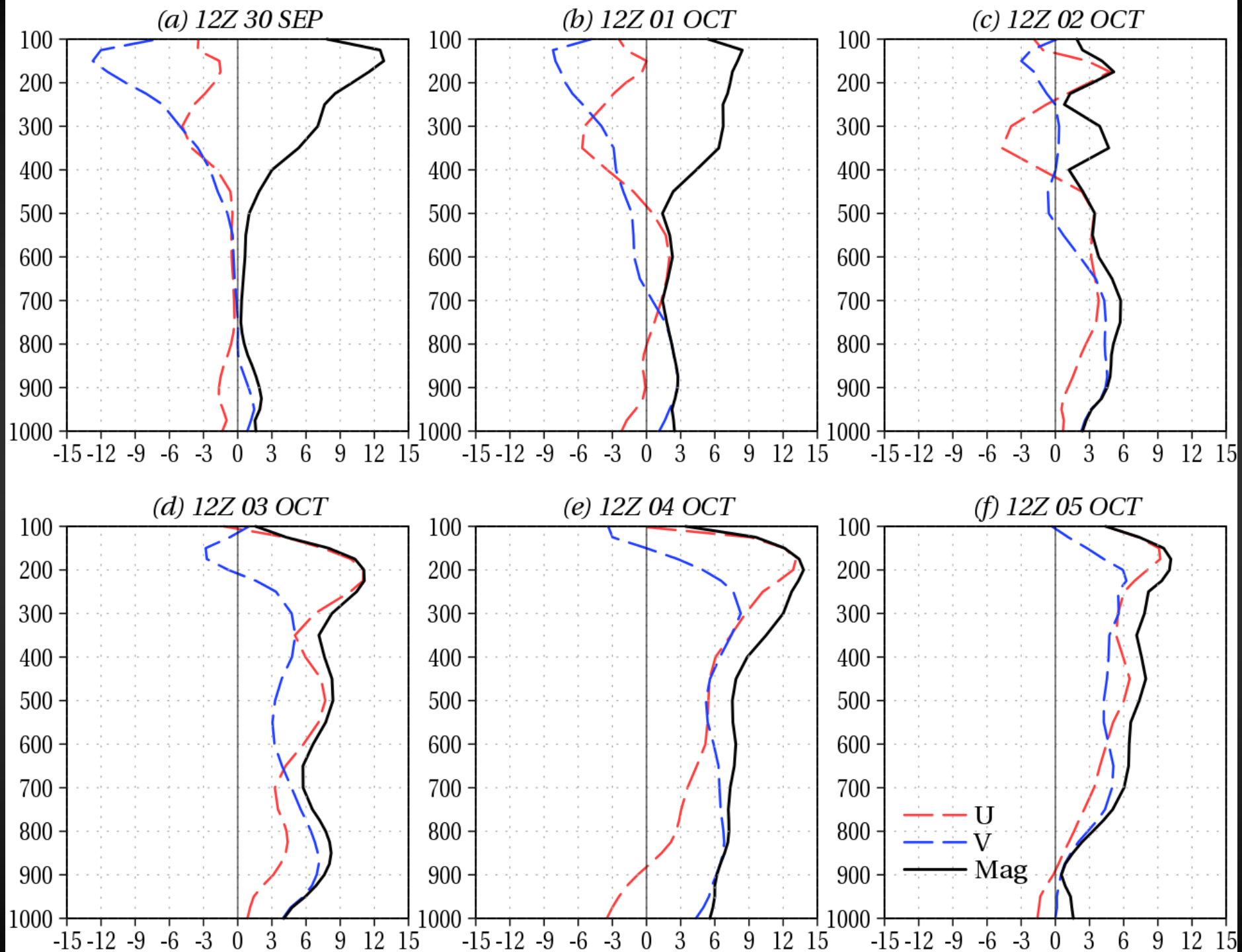


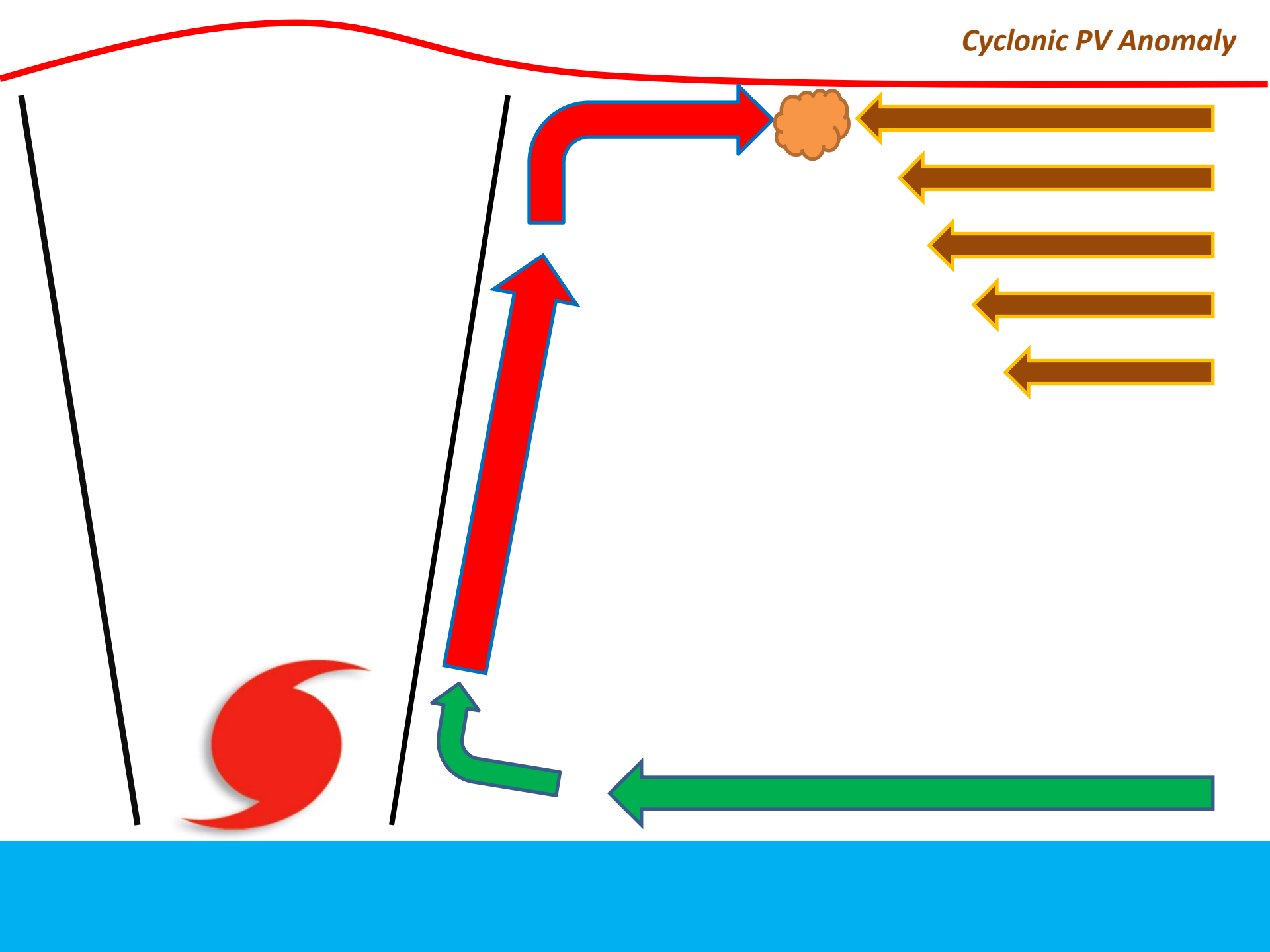
2015 Joaquin 200 hPa winds (ms^{-1}), ERA

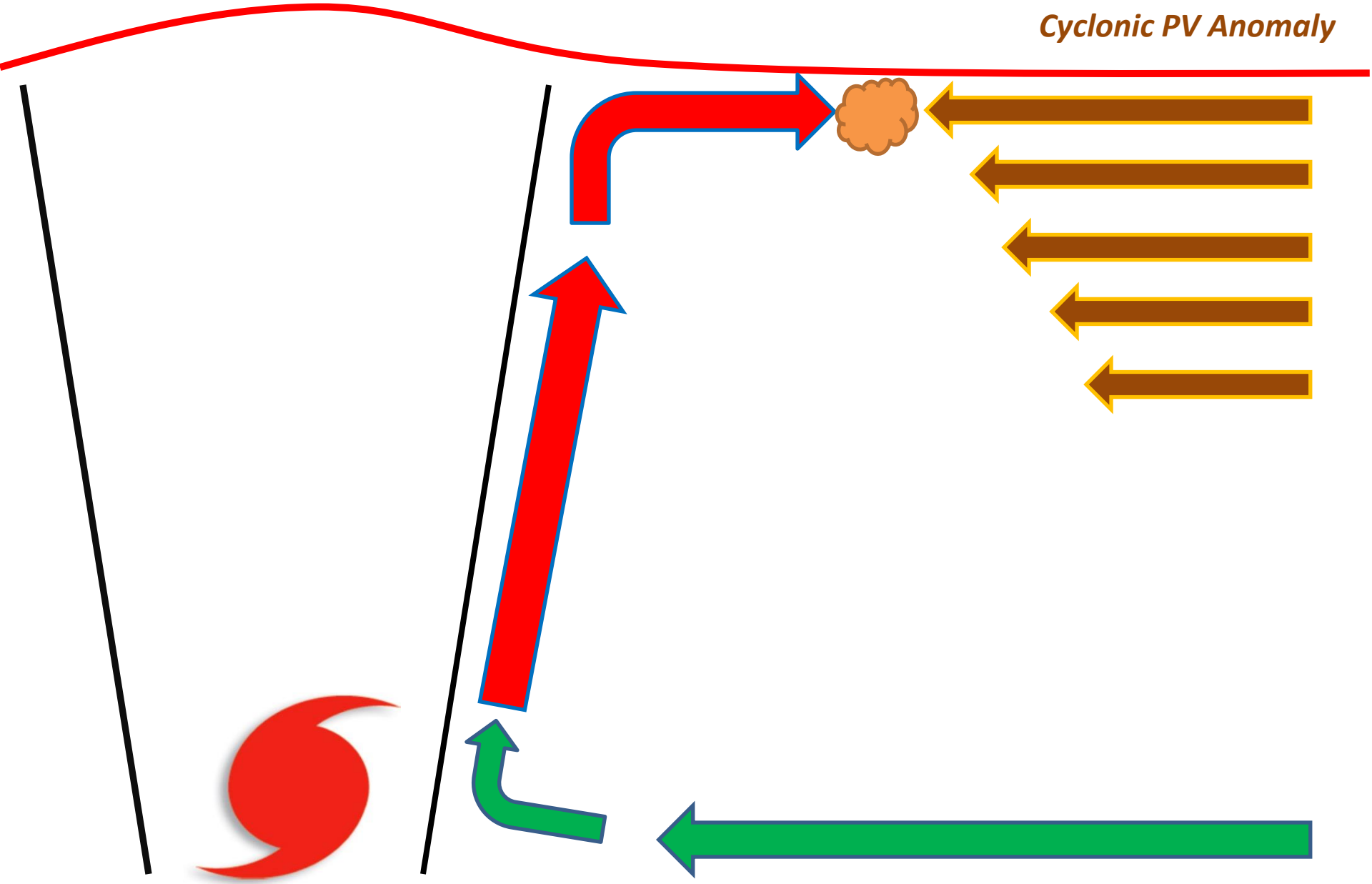


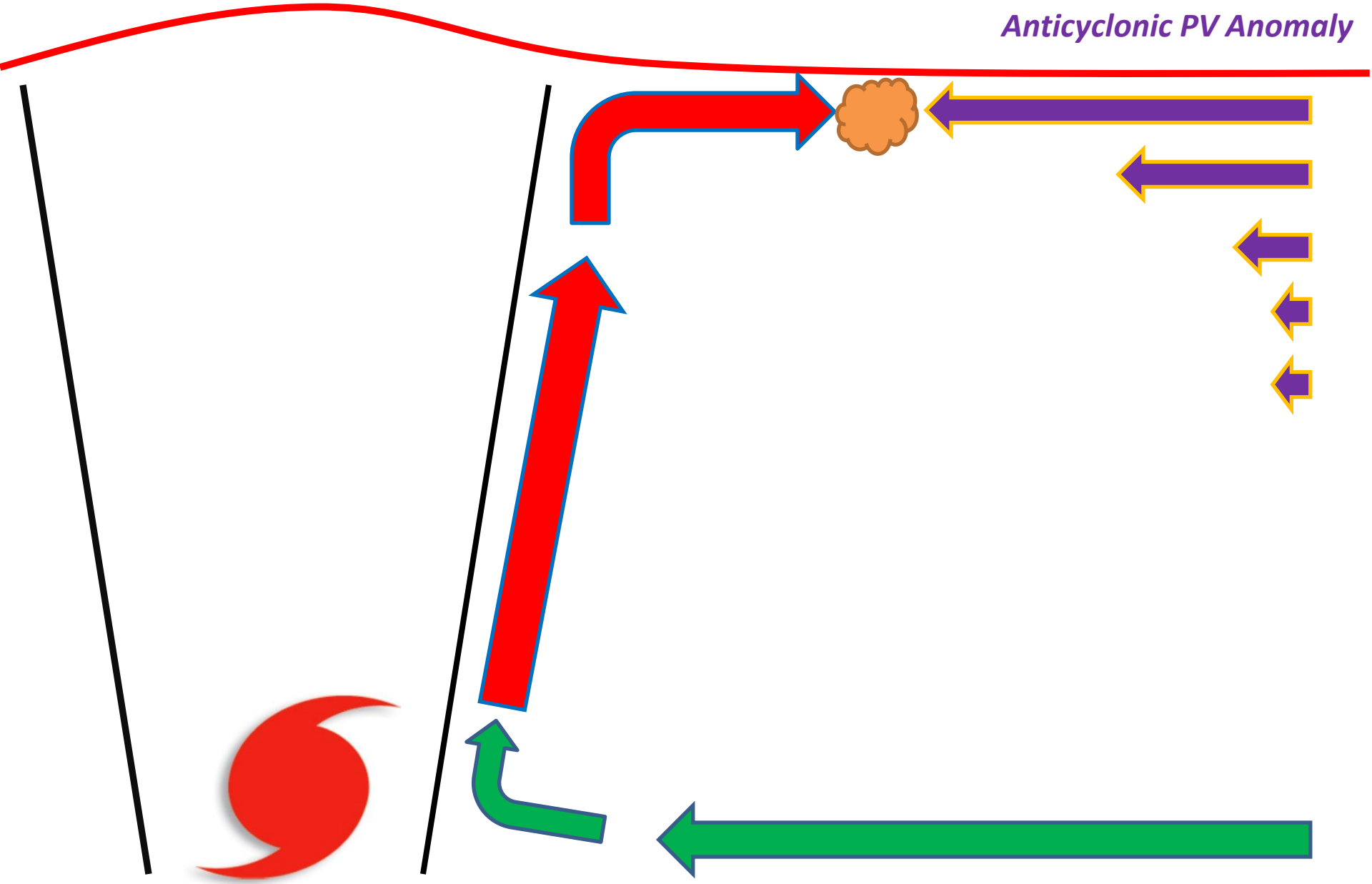
Joaquin SHIPS Intensity and Shear

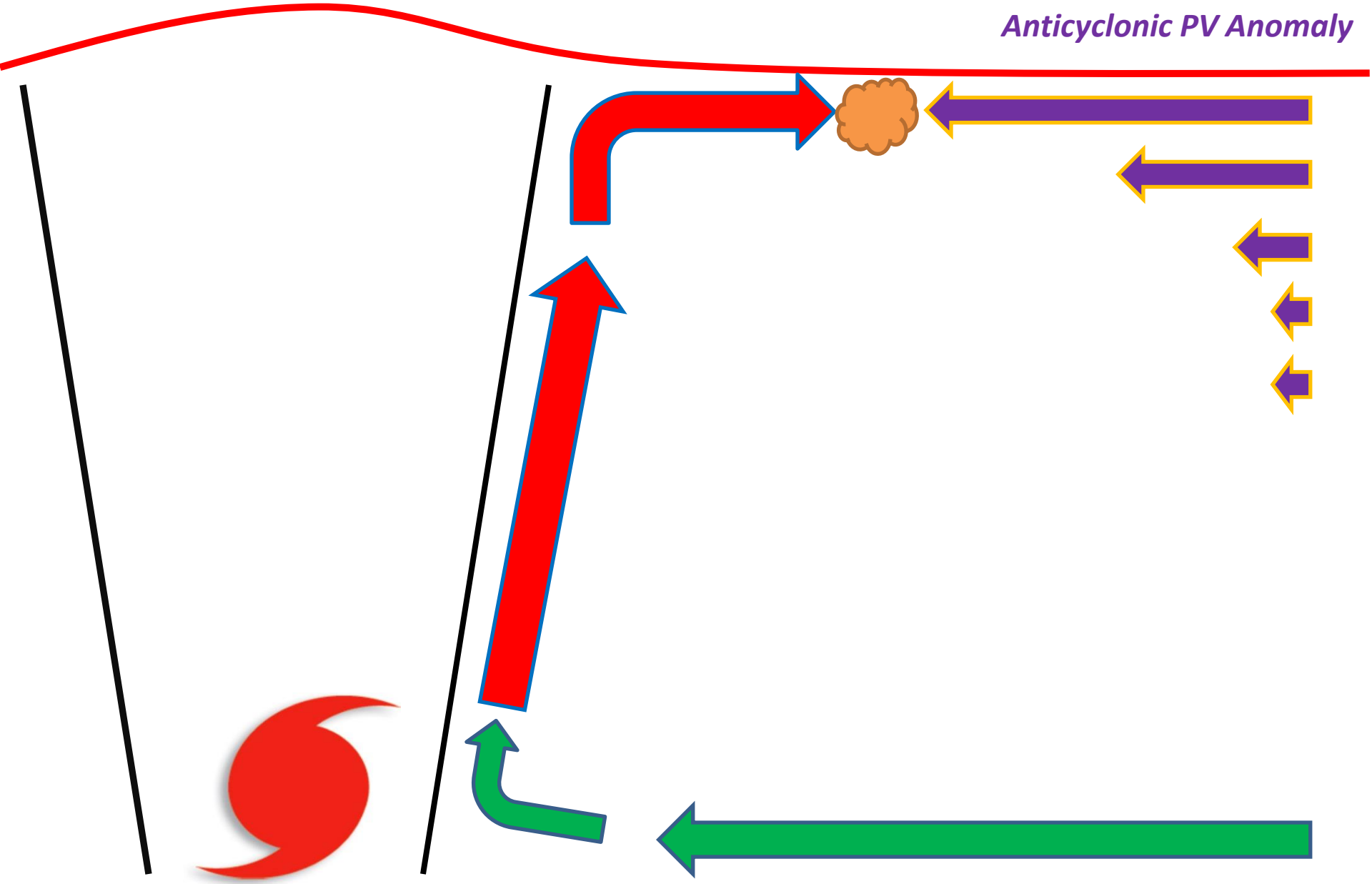



(a) 12Z 30 SEP
(b) 12Z 01 OCT
(c) 12Z 02 OCT
(d) 12Z 03 OCT
(e) 12Z 04 OCT
(f) 12Z 05 OCT
100
200
300
400
500
600
700
800
900
1000
-15 -12 -9 -6 -3 0 3 6 9 12 15
U
V
Mag


Cyclonic PV Anomaly

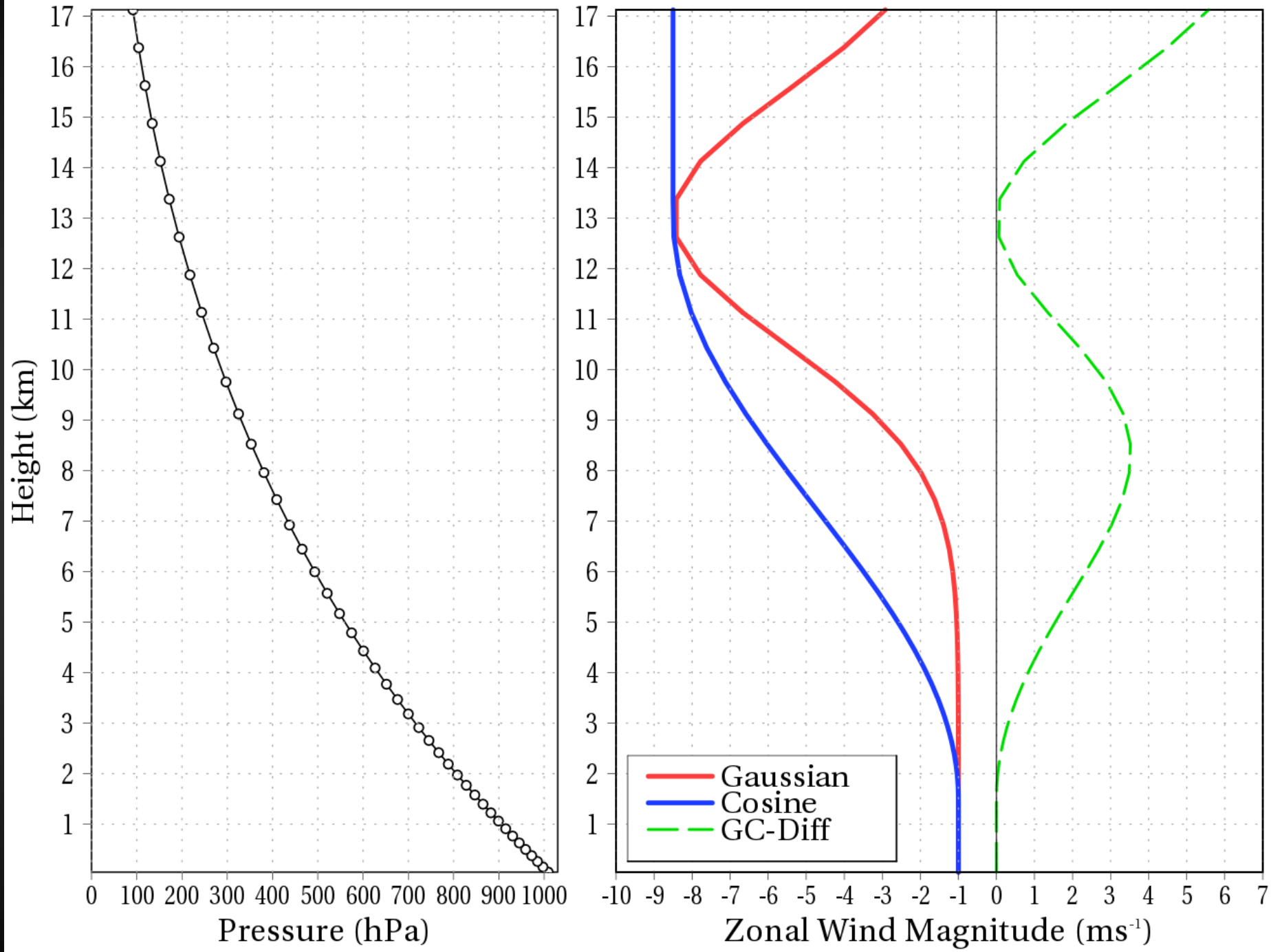

Cyclonic PV Anomaly


Anticyclonic PV Anomaly

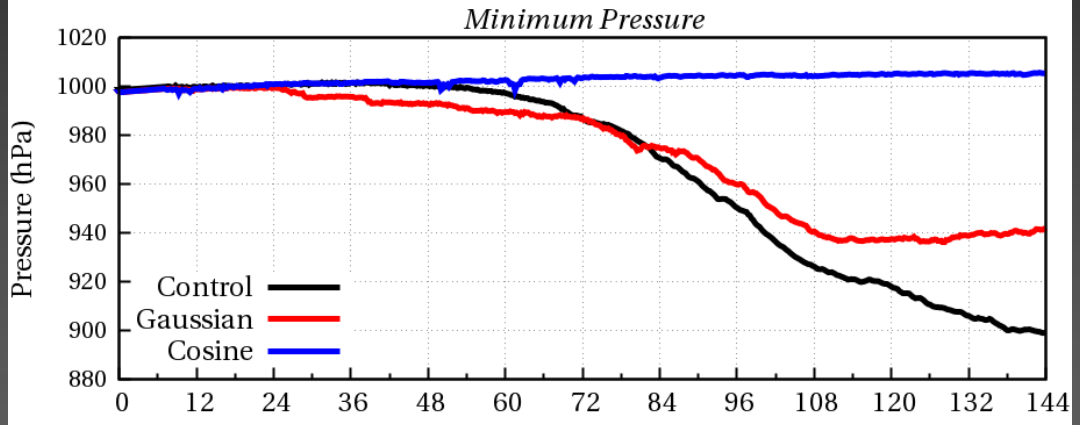

Anticyclonic PV Anomaly

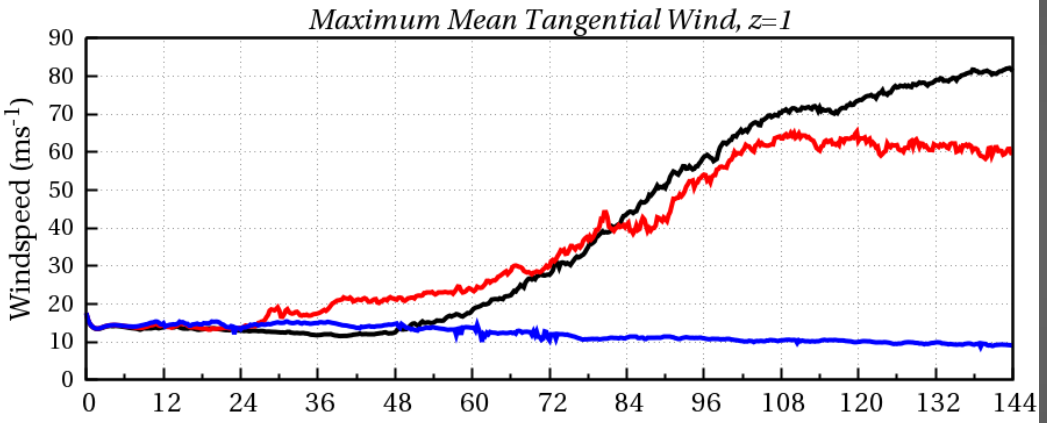
Idealized Simulations

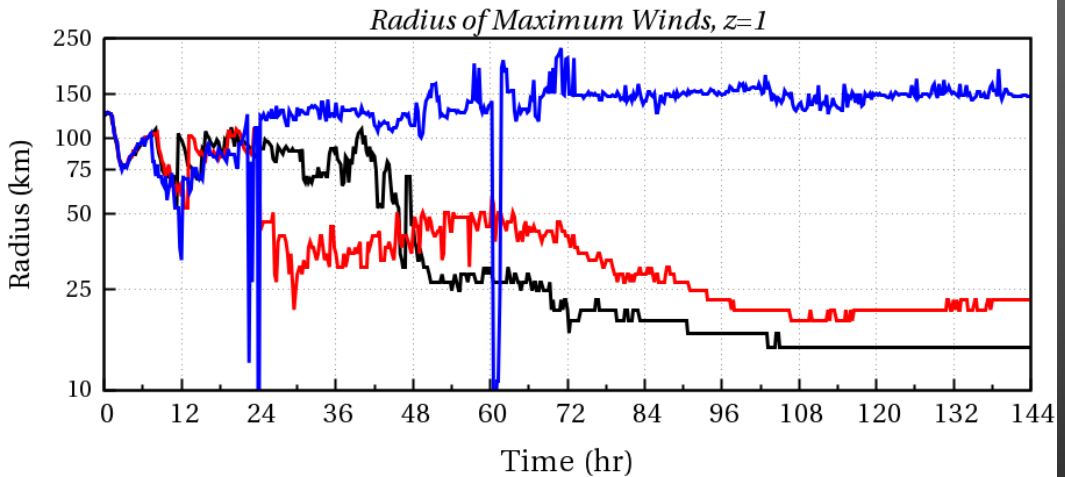
- Slightly modified CM1
  - Added cosine Coriolis terms
  - Added capability for background wind field in anelastic thermal wind balance (Ryglicki 2015)
- Explore different wind profiles


Height (km)
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0 100 200 300 400 500 600 700 800 900 1000
Pressure (hPa)
-10 -9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7
Zonal Wind Magnitude (ms-1)
Gaussian
Cosine
GC-Diff

Diagnostics

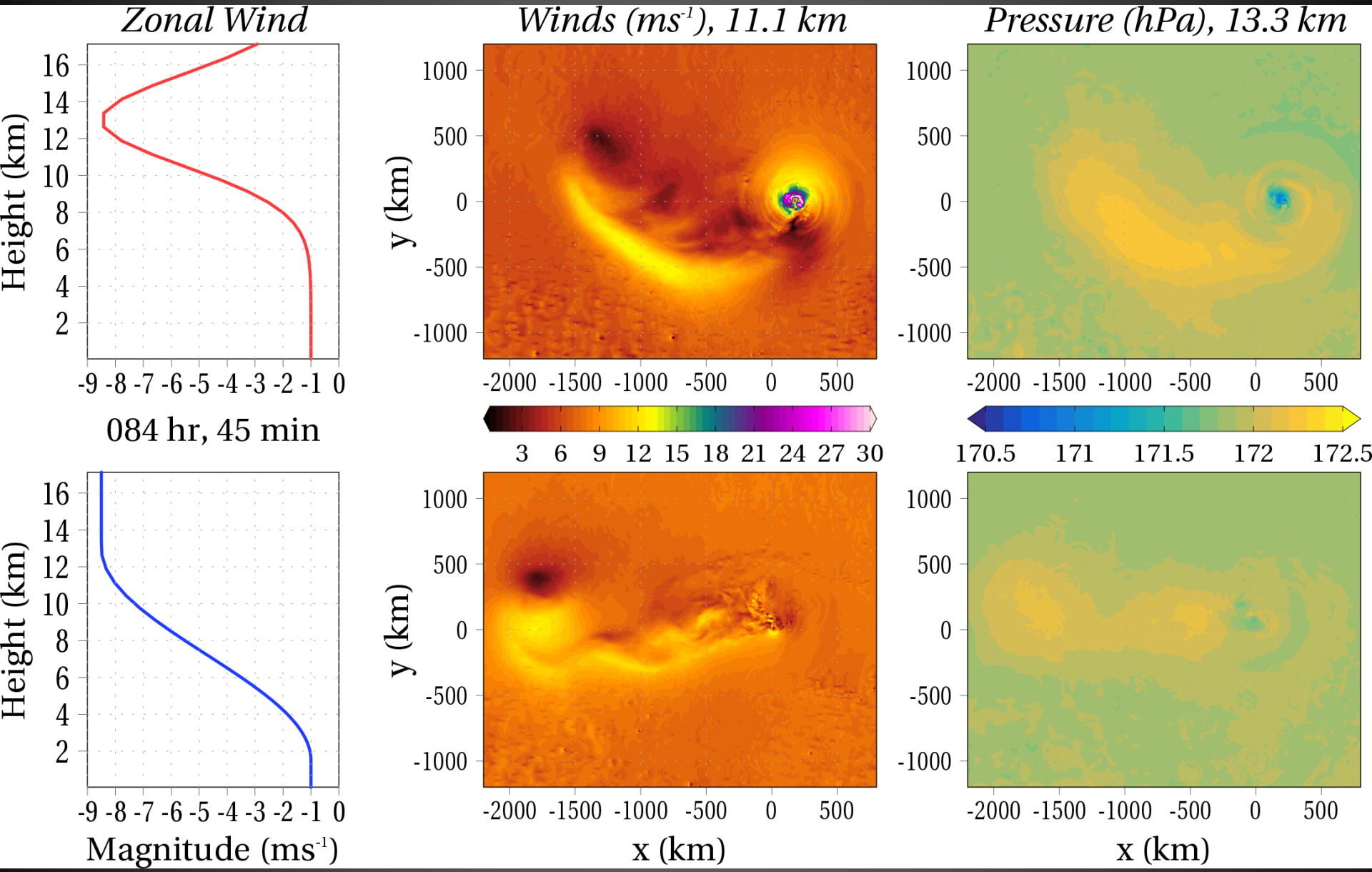






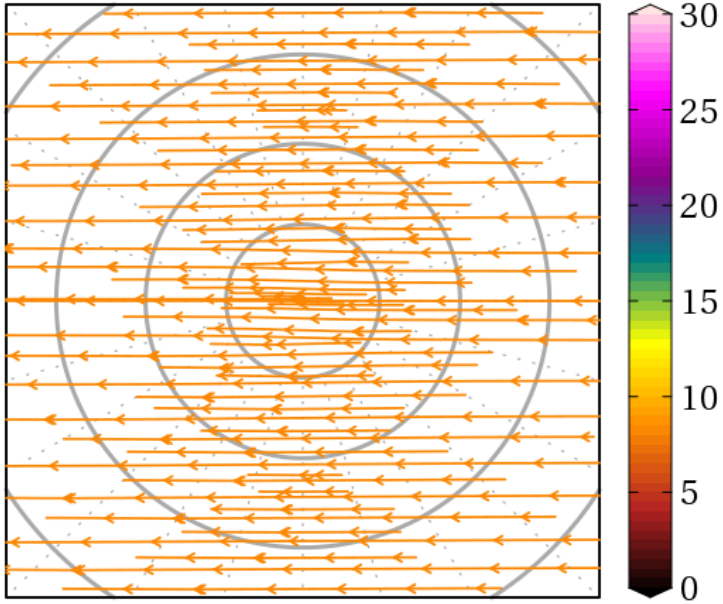
Identifying features

1. Outflow jet + upper-level blocking
2. Moisture minimum upshear
3. Convective envelopes (this will have to wait)

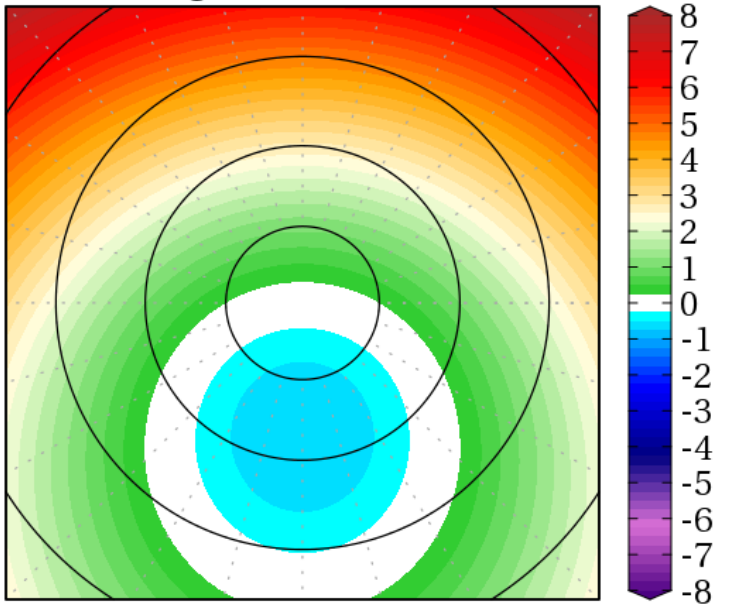

Zonal Wind
Winds (ms-1), 11.1 km
Pressure (hPa), 13.3 km
Height (km)
16
14
12
10
8
6
4
2
-9 -8 -7 -6 -5 -4 -3 -2 -1 0
084 hr, 45 min
Magnitude (ms-1)
y (km)
1000
500
0
-500
-1000
-2000 -1500 -1000 -500 0 500
3 6 9 12 15 18 21 24 27 30
170.5 171 171.5 172 172.5
x (km)

Time: 000 hr 00 min MMTW: 17.631 ms^{-1} RMW: 126.828 km

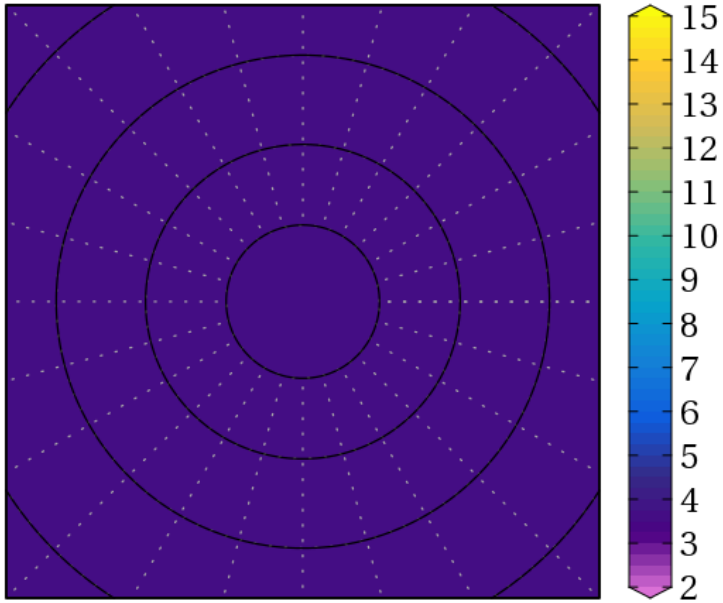
Winds (ms^{-1})



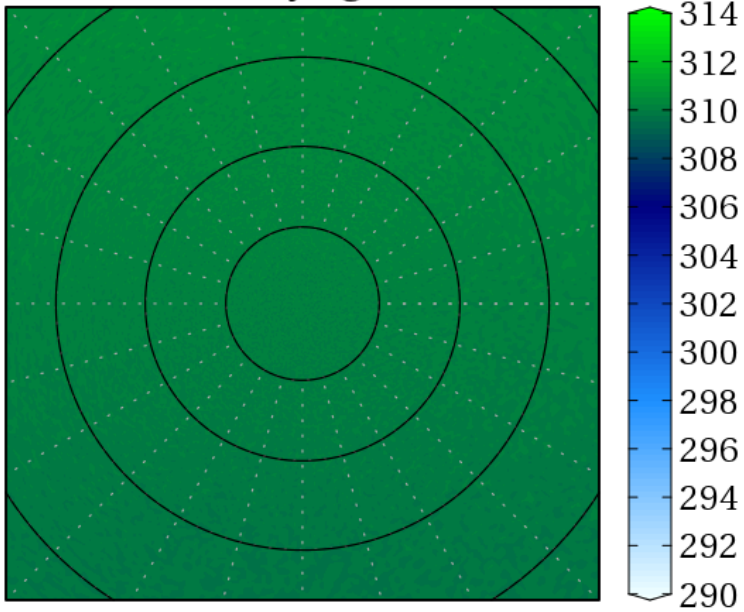
Abs. Ang. Mom. (10^6 m^2 s^{-1})



Vapor Mixing Ratio (10^{-5} g g^{-1})

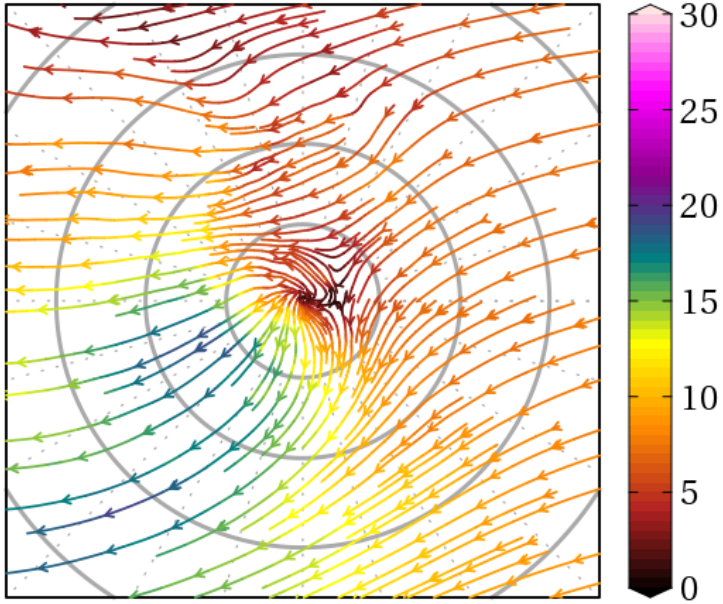


Density (g m^{-3})

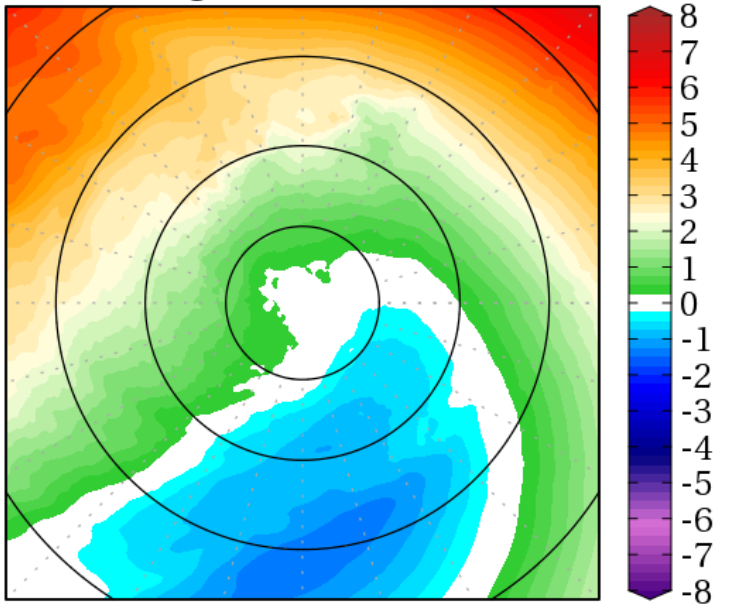


Time: 036 hr 00 min MMTW: 17.524 ms^{-1} RMW: 34.828 km

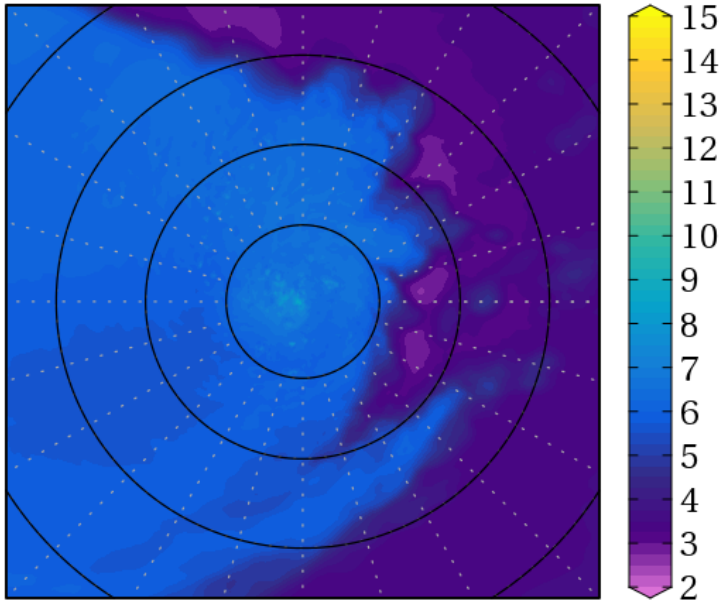
Winds (ms^{-1})



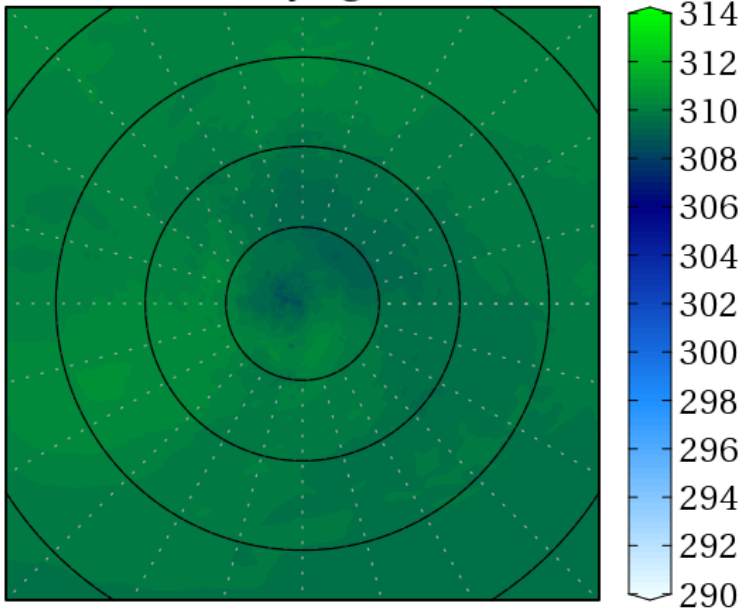
Abs. Ang. Mom. (10^6 m^2 s^{-1})



Vapor Mixing Ratio (10^{-5} g g^{-1})

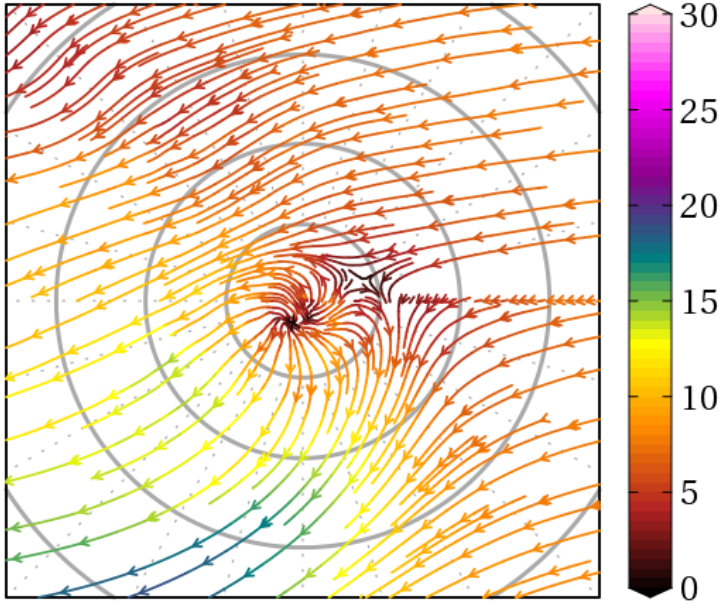


Density (g m^{-3})

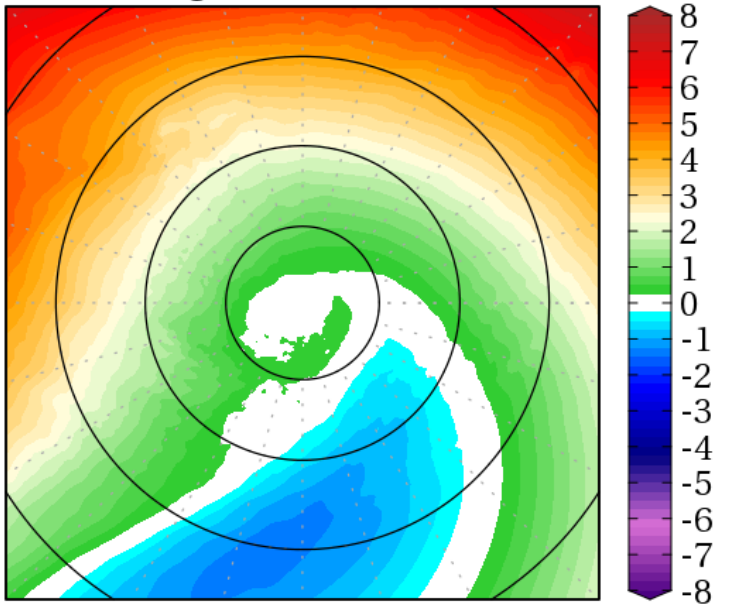


Time: 044 hr 00 min MMTW: 20.559 ms^{-1} RMW: 36.828 km

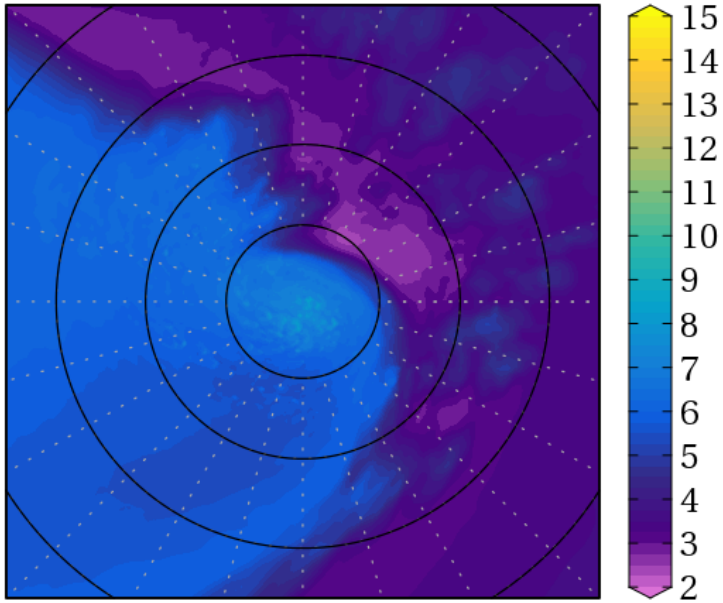
Winds (ms^{-1})



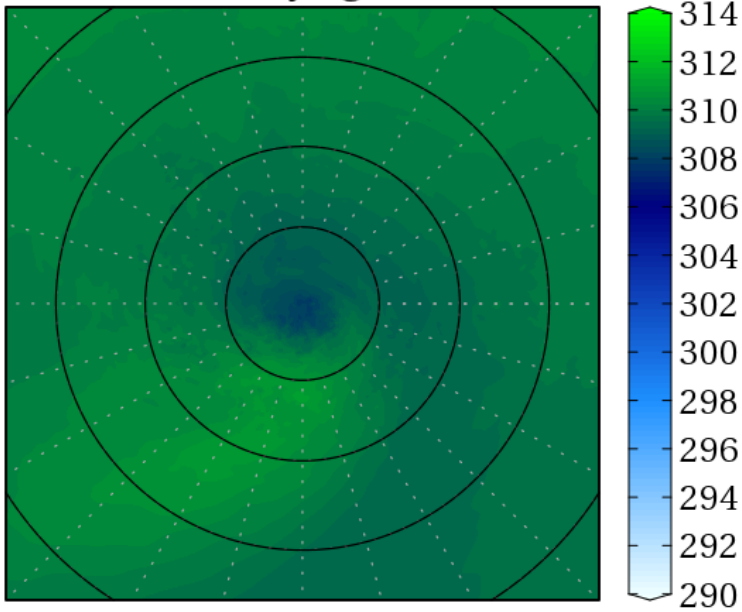
Abs. Ang. Mom. (10^6 m^2 s^{-1})



Vapor Mixing Ratio (10^{-5} g g^{-1})

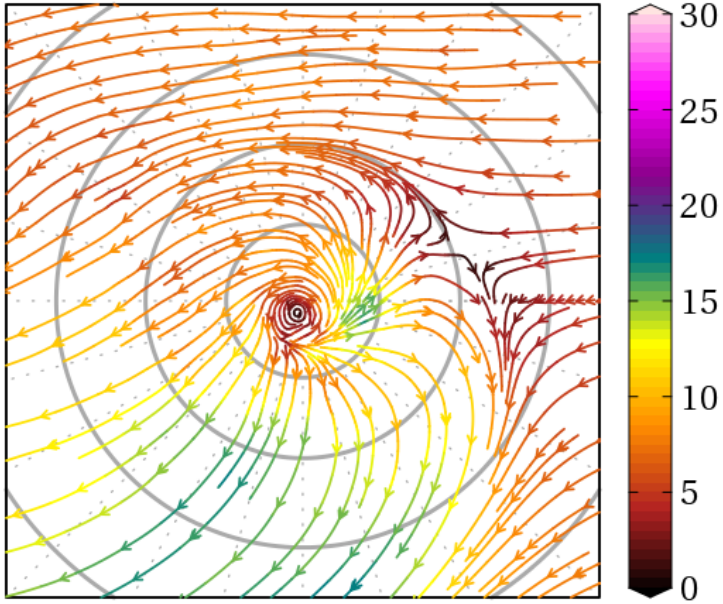


Density (g m^{-3})

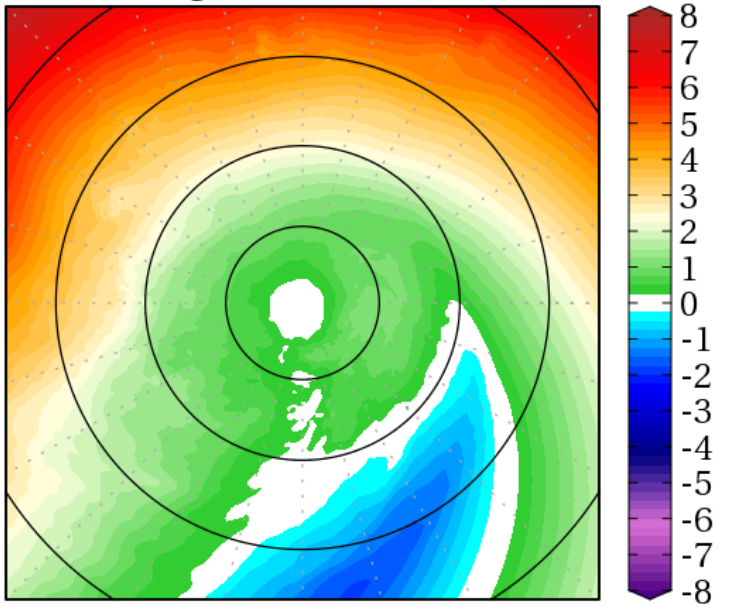


Time: 052 hr 30 min MMTW: 22.876 ms^{-1} RMW: 32.828 km

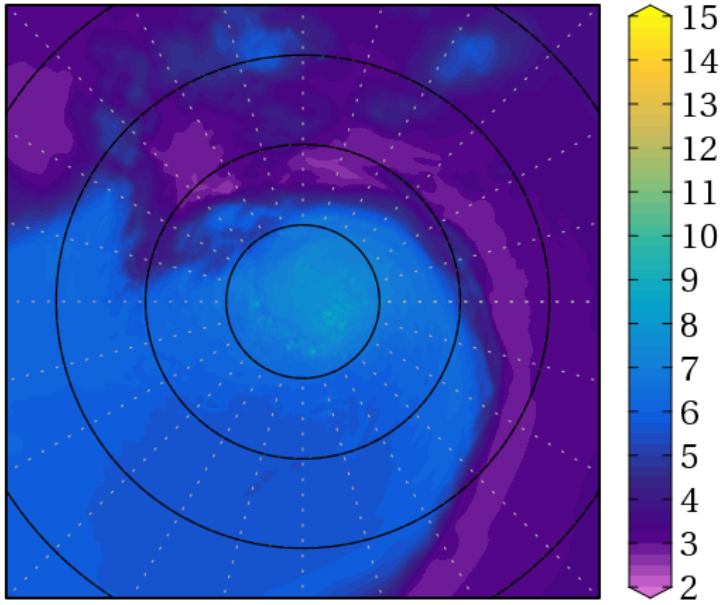
Winds (ms^{-1})



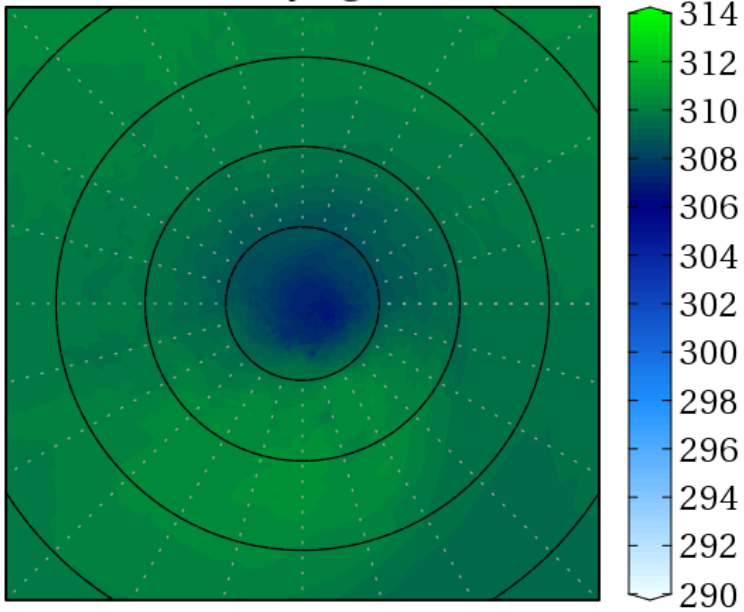
Abs. Ang. Mom. (10^{6} m^{2} s^{-1})



Vapor Mixing Ratio (10^{-5} g g^{-1})



Density (g m^{-3})



Summary & Conclusions

- The Process
  - Vorticity Aggregation
  - Cloud Shield Shift
  - "Long-Period" Convective Bursts
    - Push back against environment
  - Mesovortex-induced Convective Bursts
  - "Symmetric Processes"
- "Long-period" Convective Envelopes are likely tilt-induced
  - 4-hour period
  - Modeling results to come
- The anticyclone is the key to this problem


Questions/Comments?