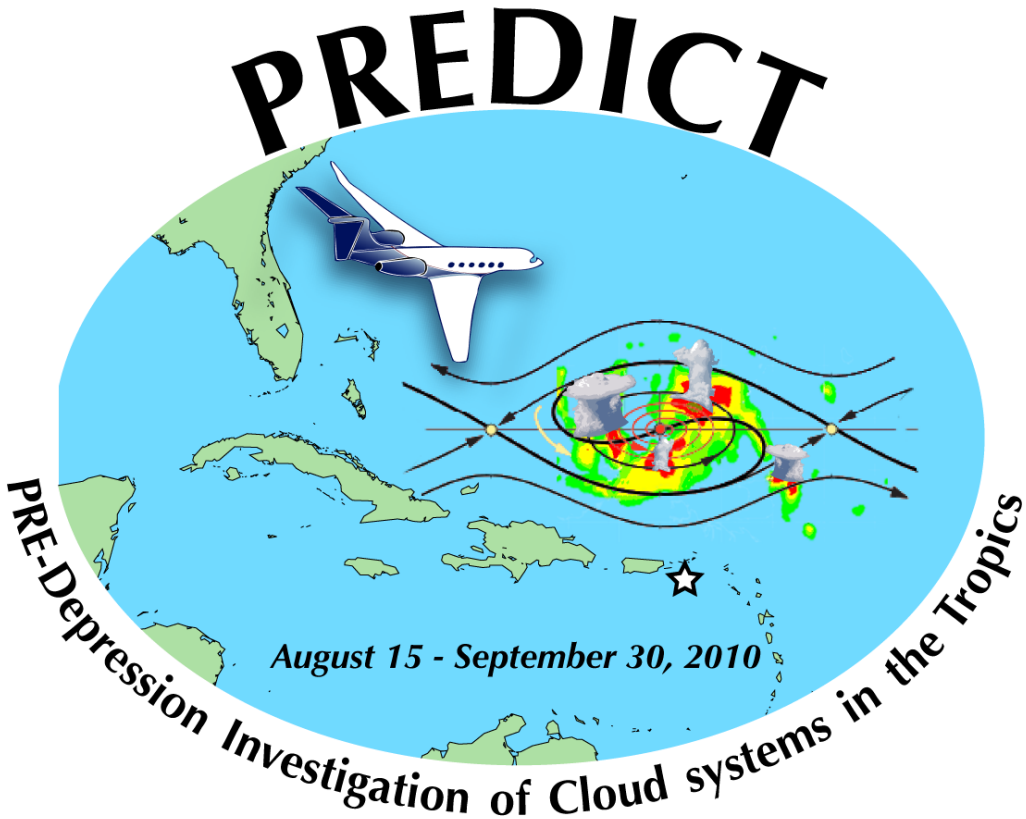

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Science Steering Committee: Chris Davis (NCAR), Lance Bosart (Albany, SUNY), Andy Heymsfield (NCAR), Michael Montgomery,(NPS), Rob Rogers (NOAA/HRD)

Participating Universities and Organizations: NPS, NWRA, Albany, Miami, Wisconsin, Penn State, Purdue, Munich, Illinois, Howard, CU, Oregon State, Princeton

(Material presented here based on PREDICT TEAM contributions and detailed in BAMS mss. available at: http://met.nps.edu/~mtmontgo/publications.html)

This presentation is in collaboration with:

Tim Dunkerton, Roger Smith, Zhuo Wang, Mark Boothe, Chris Davis, Blake Rutherford and the PREDICT team.

The Pre-Depression Investigation of Cloud Systems in the Tropics (PREDICT) Experiment: Scientific Basis, New Analysis Tools and Some First Results

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[i] The National Center for Atmospheric Research is sponsored by the National Science Foundation.

The PRE-Depression Investigation of Cloud-systems in the Tropics (PREDICT) Field Campaign: Perspectives of Early Career Scientists

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Cody Fritz (University of Illinois-Urbana/Champaign, Urbana, Illinois)

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John Sears (University of Wisconsin, Madison, Wisconsin)

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Submitted 11 January 2011 for consideration as an article to the *Bulletin of the American Meteorological Society*

**The National Center for Atmospheric Research is sponsored by the National Science Foundation.*

Tropical cyclogenesis within synoptic-scale disturbances

The development of tropical depressions is inextricably linked to synoptic-scale disturbances that come in a variety of forms.

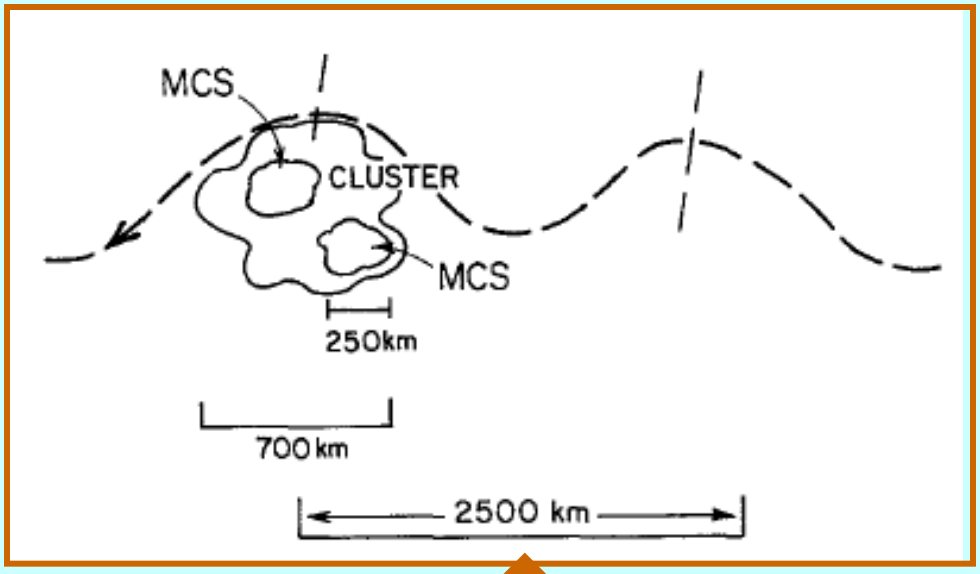
The most prominent in the Atlantic are African easterly waves.

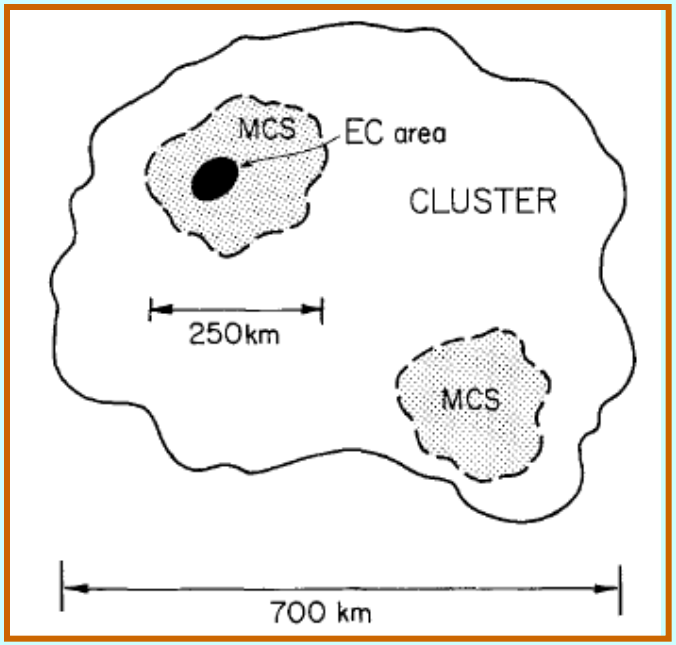
Typically, they have periods of 3-5 days and wavelengths of 2000-3000 km (e.g. Reed et al. 1977).

Questions:

- **Which tropical waves (or other disturbances) will evolve into a tropical depression?**
- **What is different about developing waves?**
- **Can this difference be identified, and on what time scale?**
- **Why do so few disturbances develop?**
- **Where will the focal point for genesis be?**

Multi-scale nature of tropical cyclogenesis within tropical waves



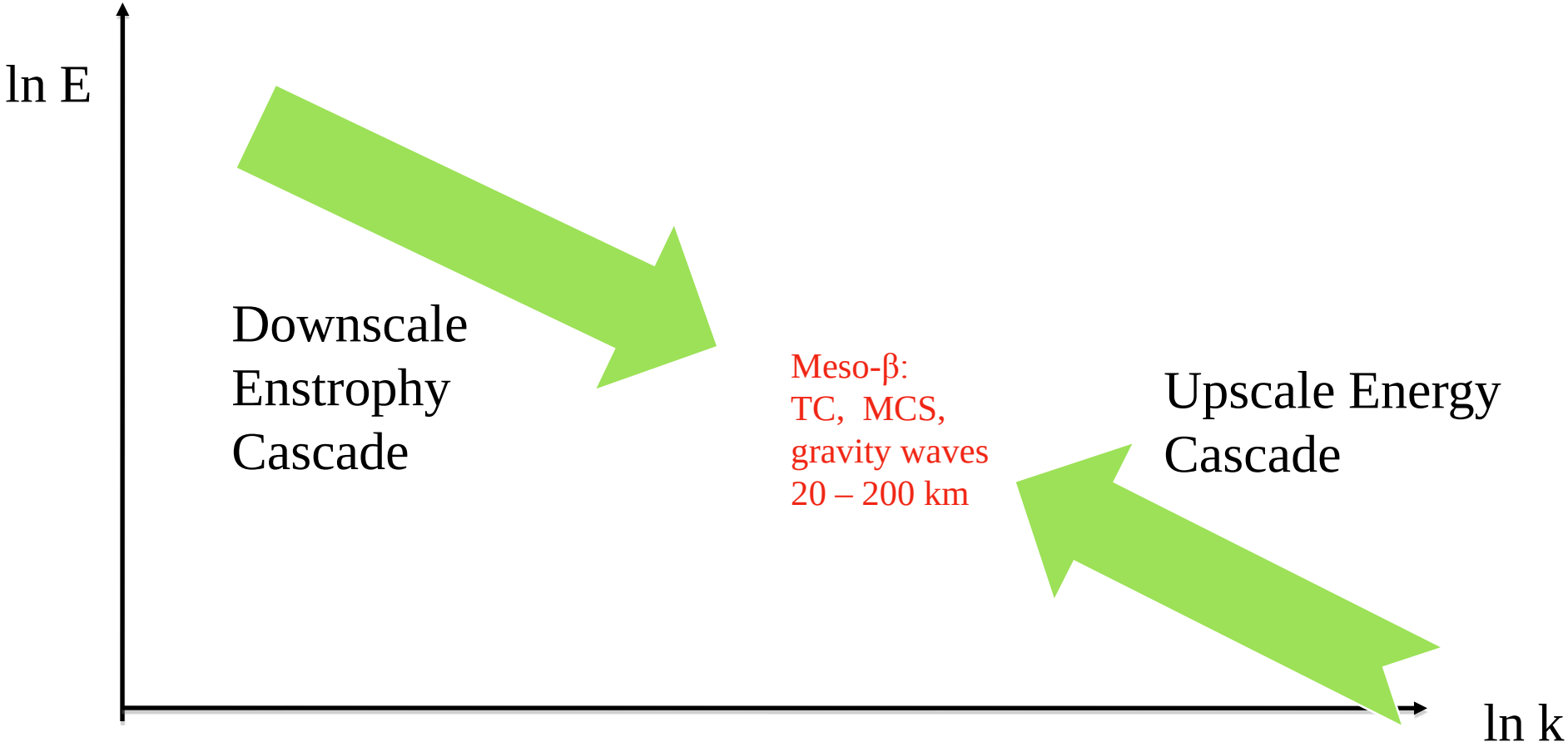


Schematic of synoptic-scale flow through an easterly wave (dashed) with an embedded cluster of convection in the wave trough.

The cluster contains mesoscale convective systems (MCSs) and extreme convection (EC, black oval) within one of the MCSs.

From Gray (1998).

Consideration of horizontal scales exposes the challenging nature of the problem



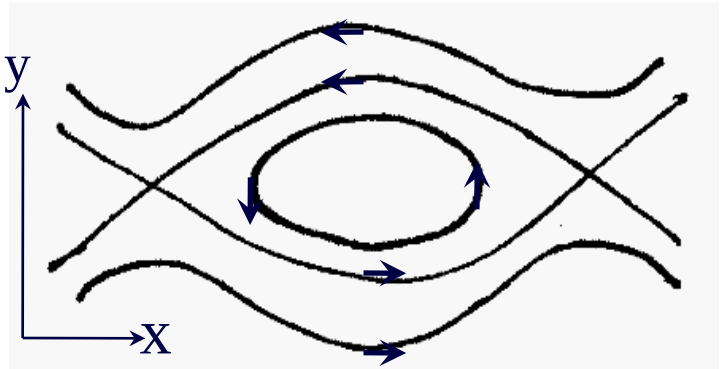
Synoptic
Easterly Waves
Hydro instability of ITCZ
Subtropical intrusions
2,000 – 8,000 km

Meso-α:
Easterly wave critical layer
Isolated recirculation regions
Inertia gravity waves
200 – 2,000 km

Meso-γ:
VHTs, Congestus, Precip.
Driven downdrafts, Gust
fronts
2 – 20 km

Moist Critical Layer

- Critical latitude/surface: locus where c=U or equivalently where wave intrinsic frequency = 0
- Critical layer: A layer of finite width due to the nonlinear interaction of the wave with its own critical surface
- Kelvin Cat's eye: Recirculating flow within CL wherein air parcels are trapped and the fluid is isolated from its surroundings



3 New Hypotheses

- H1: Wave breaking or roll-up of cyclonic vorticity near the critical surface in the lower troposphere (>600 hPa) provides favorable environment and focal point for aggregation of convectively-generated cyclonic vorticity anomalies.

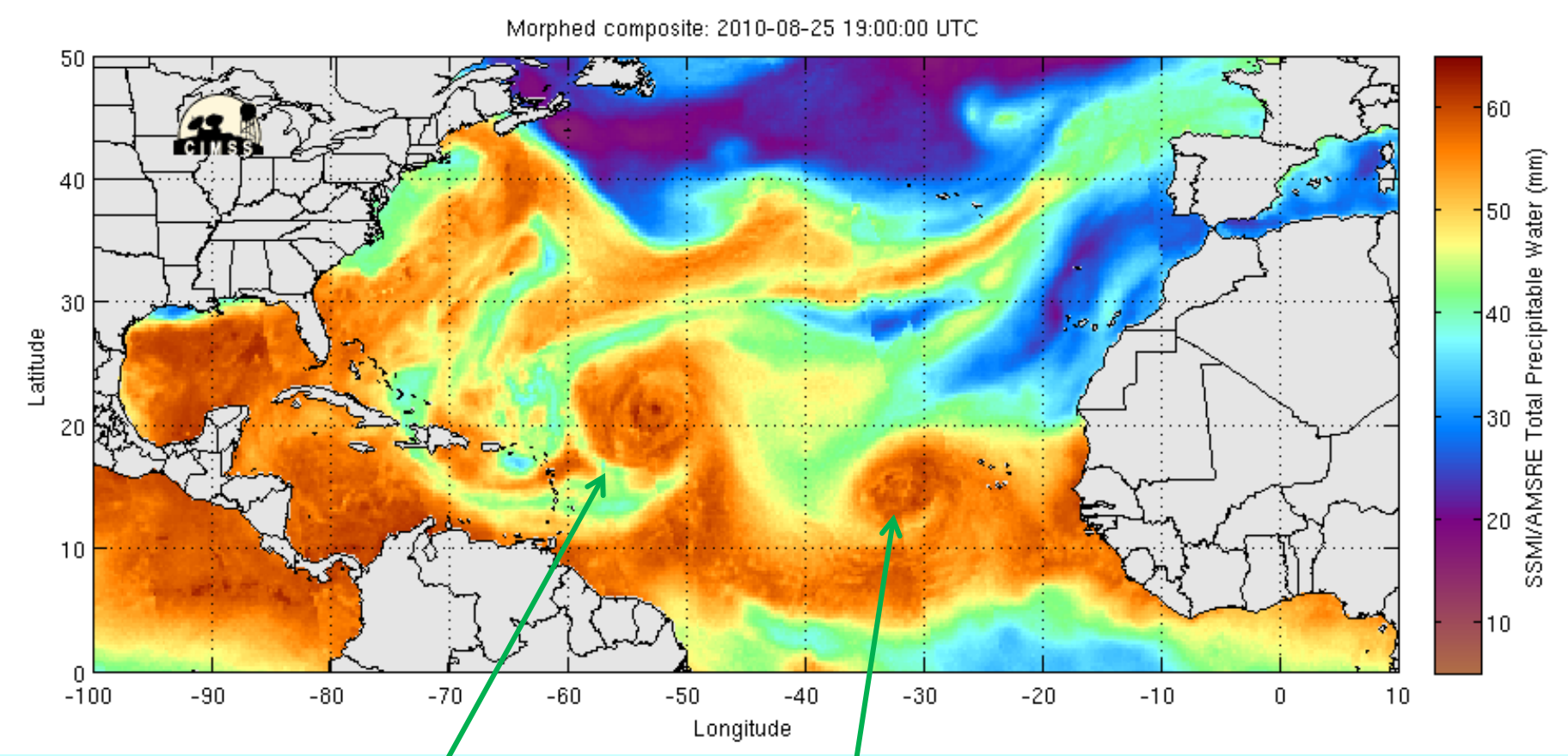
- H2: The wave critical layer is a region of closed circulation, where air is repeatedly moistened by deep convection and also protected from dry air entrainment to some extent.

- H3: The parent wave is maintained and possibly enhanced by diabatically amplified mesoscale vortices within the wave. (Heating is most effective when intrinsic frequency --> 0.)

The “baby” proto-vortex is carried along in the “pouch” (CL cat’s eye) by the “mother” wave until it is strengthened into an independent and self-sustaining vortex.

Our hypothetical pathway for genesis via tropical waves may be regarded as a marsupial theory of tropical cyclogenesis in which the “juvenile” proto-vortex is carried along by the “mother” wave until it is ready to be “let go” as an independent & self-sustaining vortex.

Total precipitable water signature of wave roll up



Hurricane Danielle **Pre Hurricane Earl**

Okubo-Weiss parameter

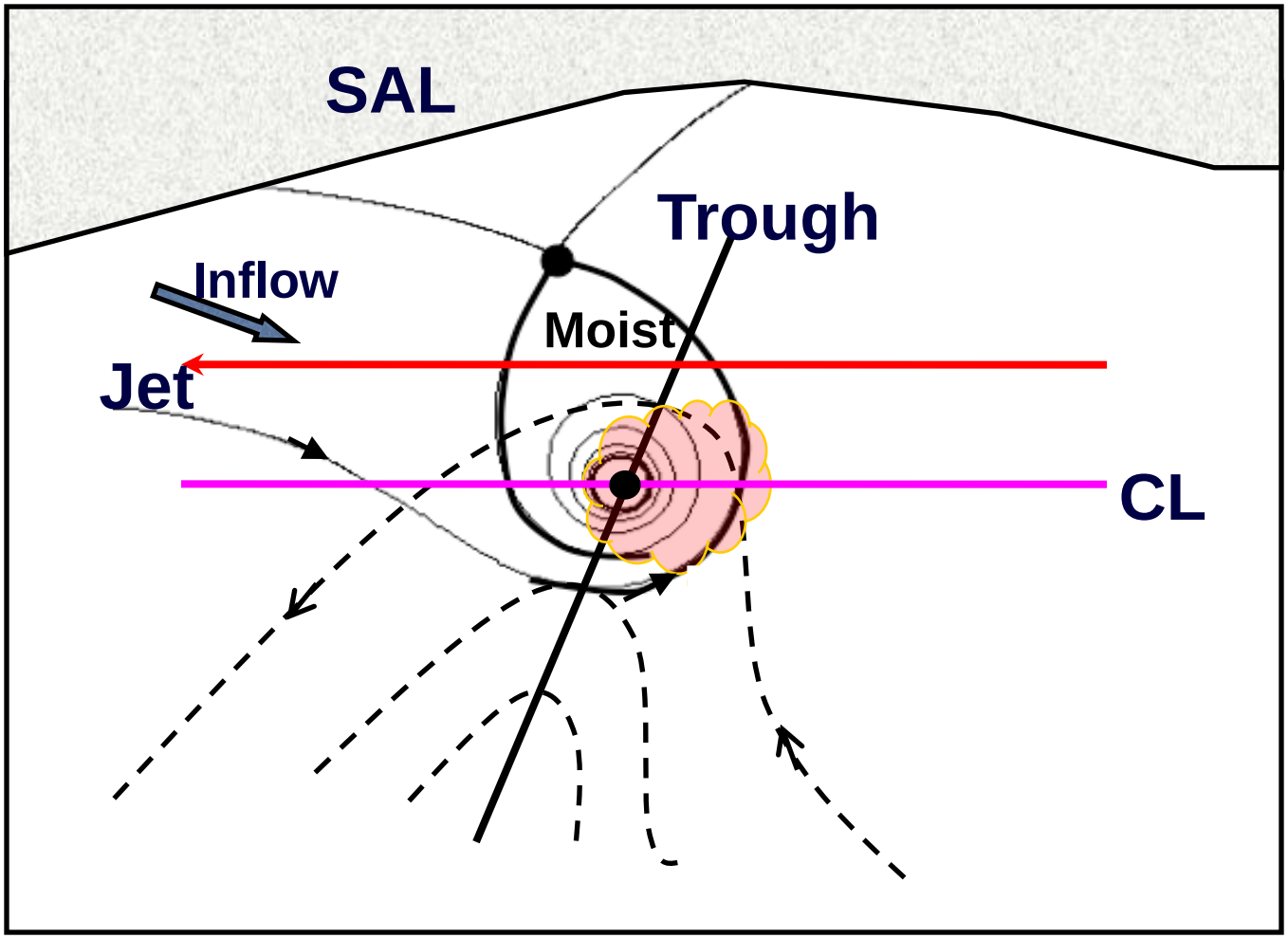
A useful quantity for real-time wave tracking applications is the Okubo-Weiss (*OW*) parameter, defined here as "vorticity squared minus strain rate squared"

$$OW = \zeta^2 - (E^2 + F^2)$$

- **Significantly positive *OW* values indicate strongly curved (cyclonic or anticyclonic) flow with minimal shearing deformation and approximate shape preservation.**
- **The wave pouch is characterized by significantly positive** OW **and cyclonic rotation, and provides a favorable environment for vortical convection to persist and vorticity aggregation to proceed.**

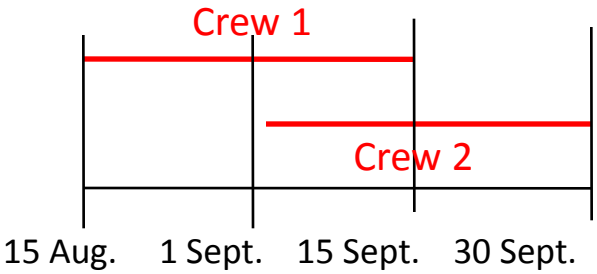
Here $\zeta = \dfrac{\partial v}{\partial x} - \dfrac{\partial u}{\partial y}$ $\quad E = \dfrac{\partial u}{\partial x} - \dfrac{\partial v}{\partial y}$ $\quad F = \dfrac{\partial v}{\partial x} + \dfrac{\partial u}{\partial y}$

Schematic of the "Pouch"



PREDICT (PRE-Depression Investigation of Cloud-systems in the Tropics)

- 15 August – 30 Sept. 2010
- Base: St. Croix Virgin Islands
- NCAR G-V: ~173 research hours used
- 26 flights, 8 disturbances
  - Test (1)
  - PGI27 (2)
  - PGI30 (2)
  - PGI36 – Fiona – (3)
  - PGI38 – ex-Gaston- (5)
  - PGI44 – Karl – (6)
  - PGI46 – Matthew – (4)
  - PGI50 – Nicole – 2
  - PGI48 (1)
- 537 dropsondes used



Double-crewed G-V, 2-15 Sept.

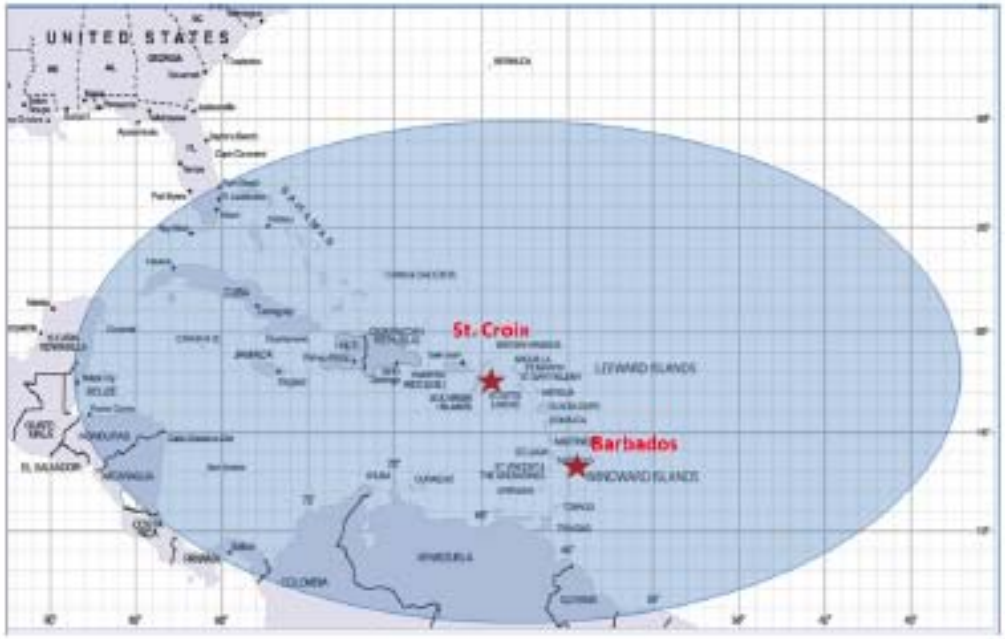
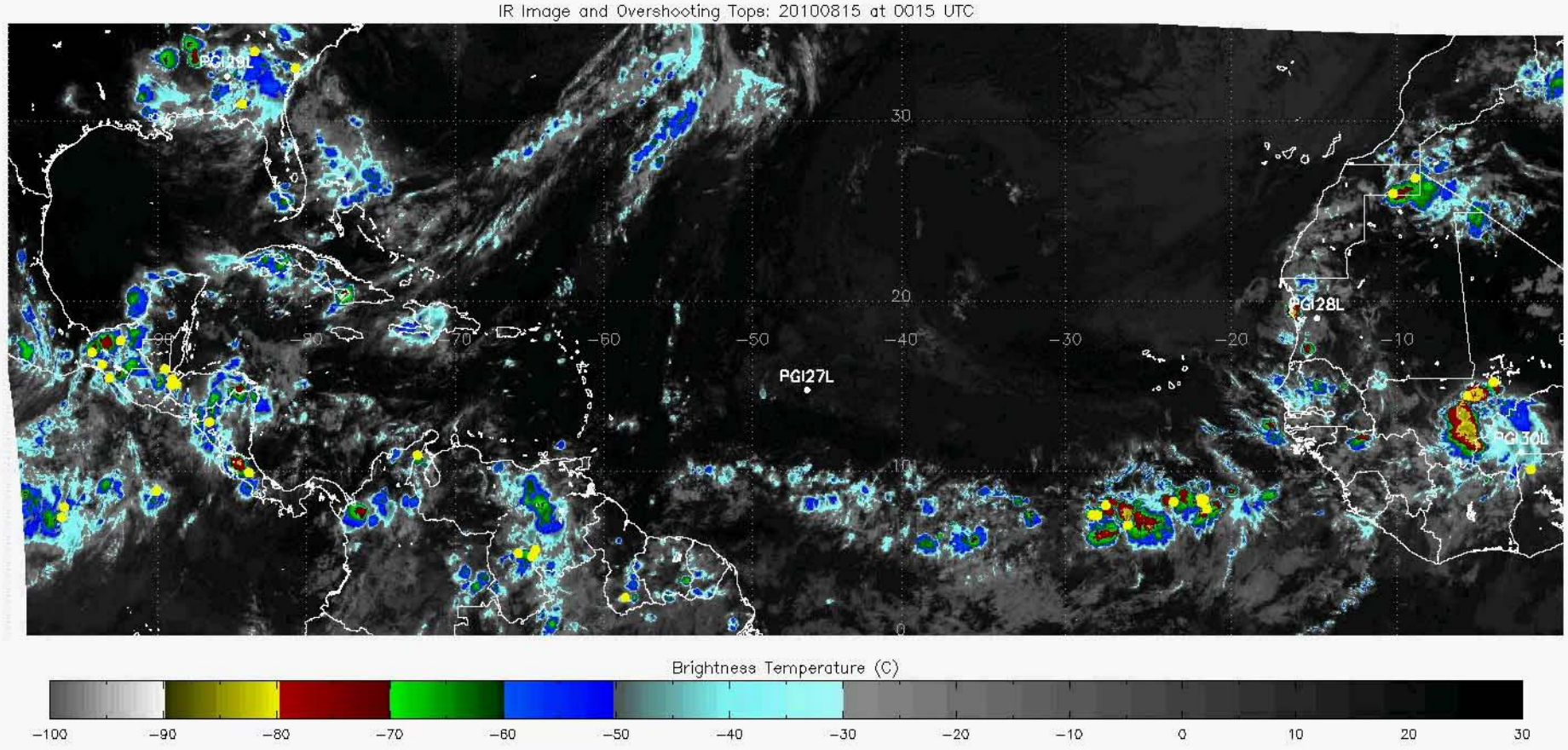
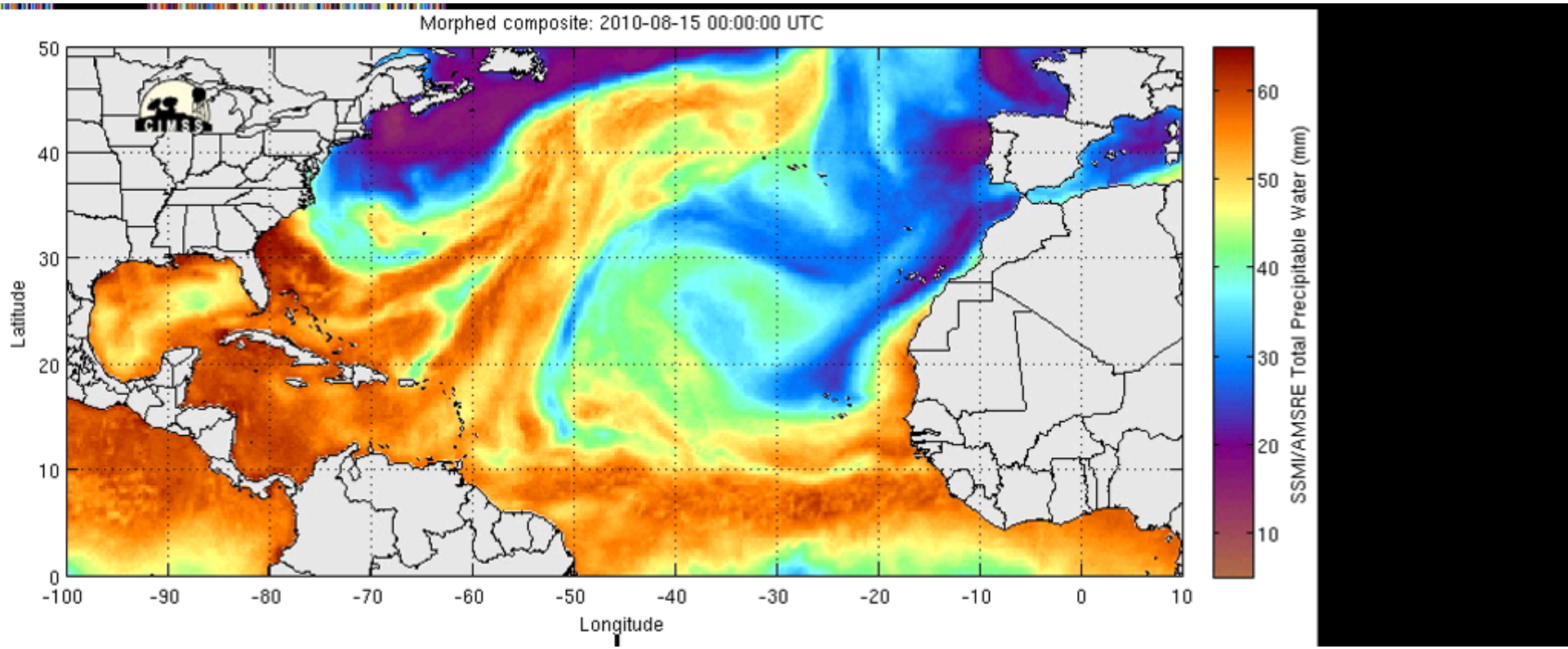


Figure 1. PREDICT domain. The primary base of operations was St. Croix, USVI, with an alternate of Barbados.

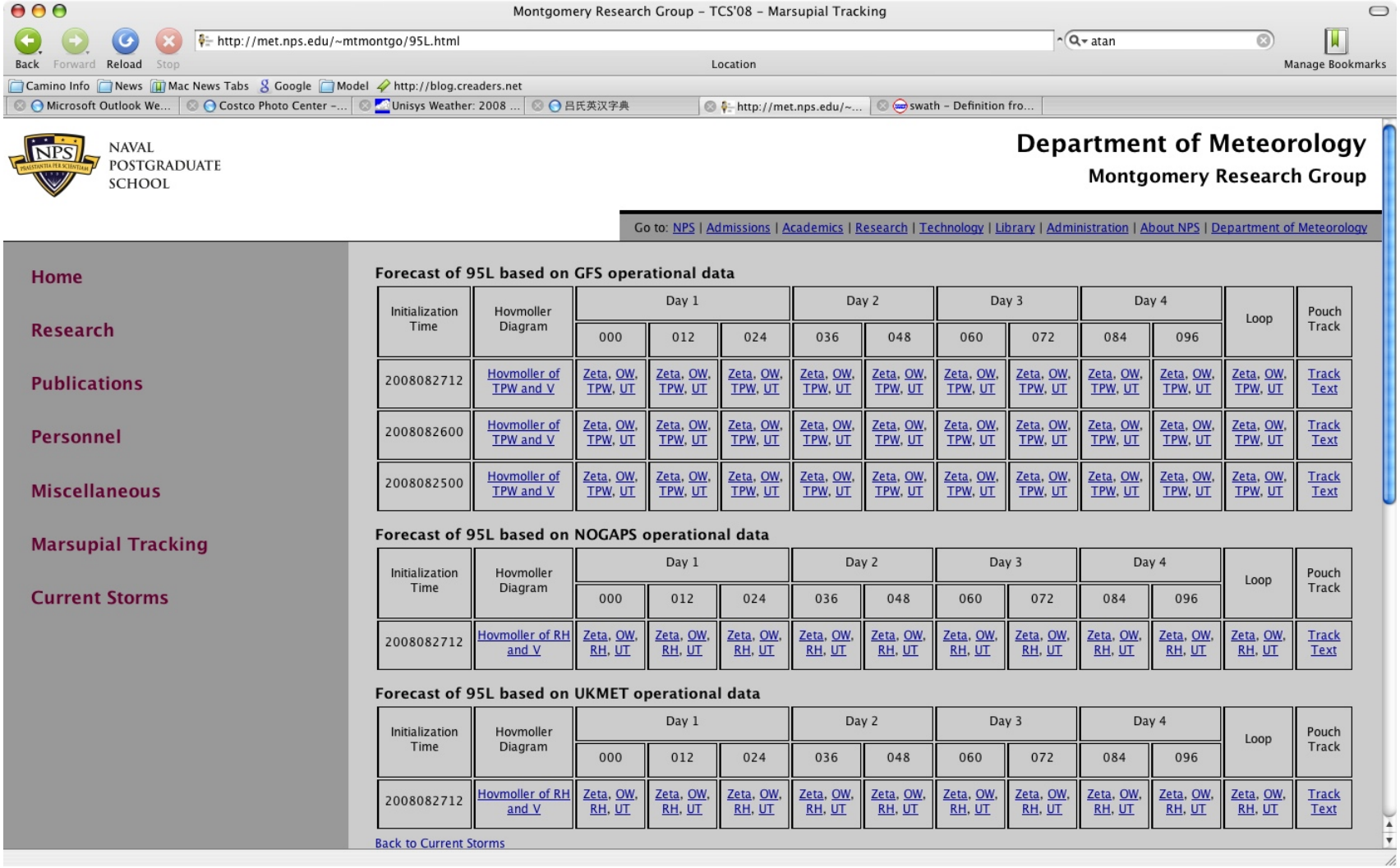
PREDICT Highlights

- Sampled both developing and non-developing tropical disturbances
- Flew many consecutive days on several systems (2 in one day during Karl)
- Six flights into Pre-Karl (over five days): tropical cyclogenesis occurred during last flight
- Gaston downgraded, Fiona upgraded as result of dropsonde data
- Initially flew into pre-Matthew before Invest declaration
- Significant collaboration with NASA and NOAA (Gaston, Karl and Matthew)
- First extensive investigation of genesis predictability using a variety of model ensembles
- Successful deployment of G-V based on forecast and near-real-time pouch products

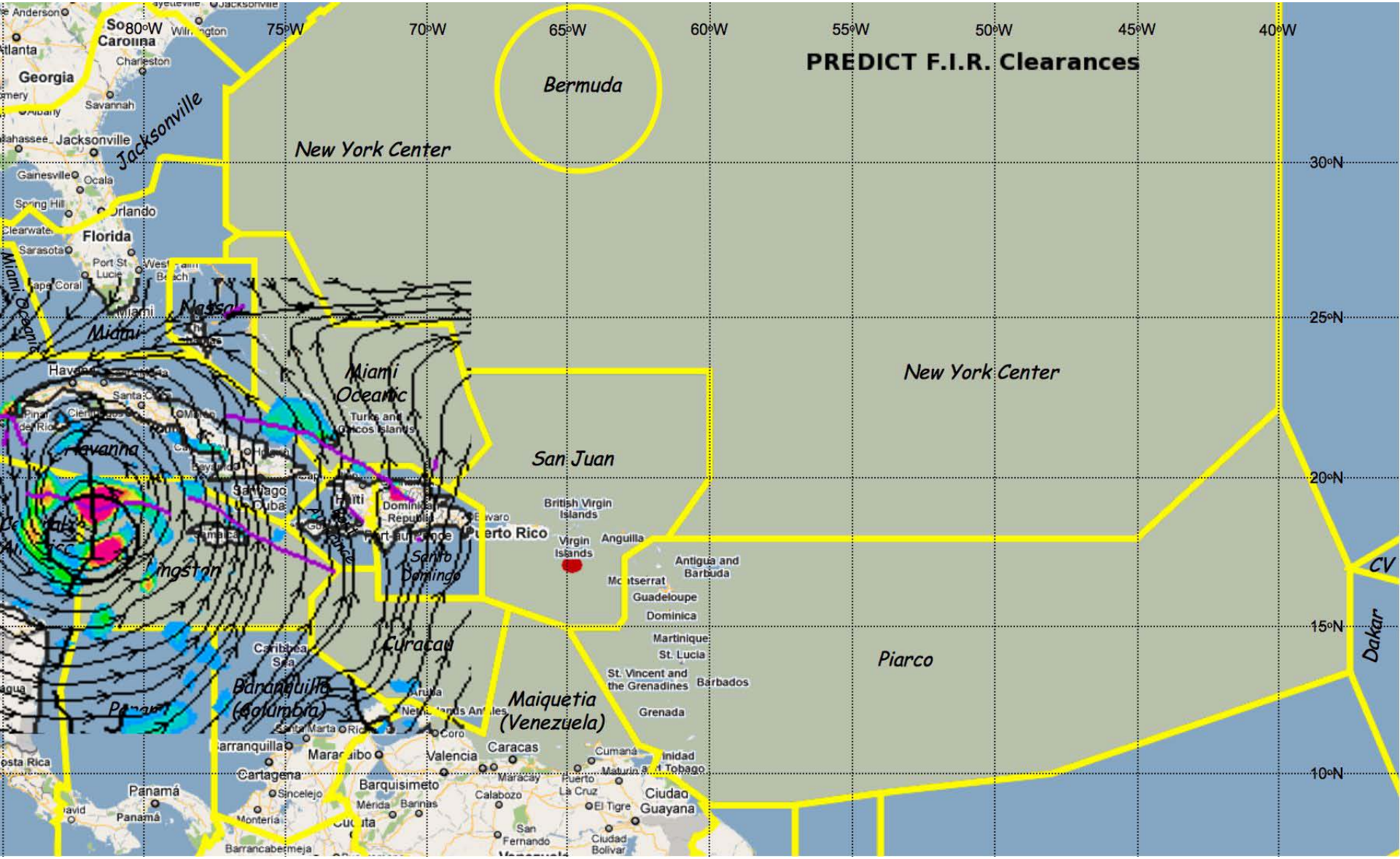

IR Image and Overshooting Tops: 20100815 at 0015 UTC
PGI29L
PGI27L
PGI28L
PGI30L
30
20
10
0
-90
-80
-70
-60
-50
-40
-30
-20
-10
Brightness Temperature (C)
-100
-90
-80
-70
-60
-50
-40
-30
-20
-10
0
10
20
30


Morphed composite: 2010-08-15 00:00:00 UTC
Latitude
Longitude
50
40
30
20
10
0
-100
-90
-80
-70
-60
-50
-40
-30
-20
-10
0
10
60
50
40
30
20
10
SSMI/AMSRE Total Precipitable Water (mm)

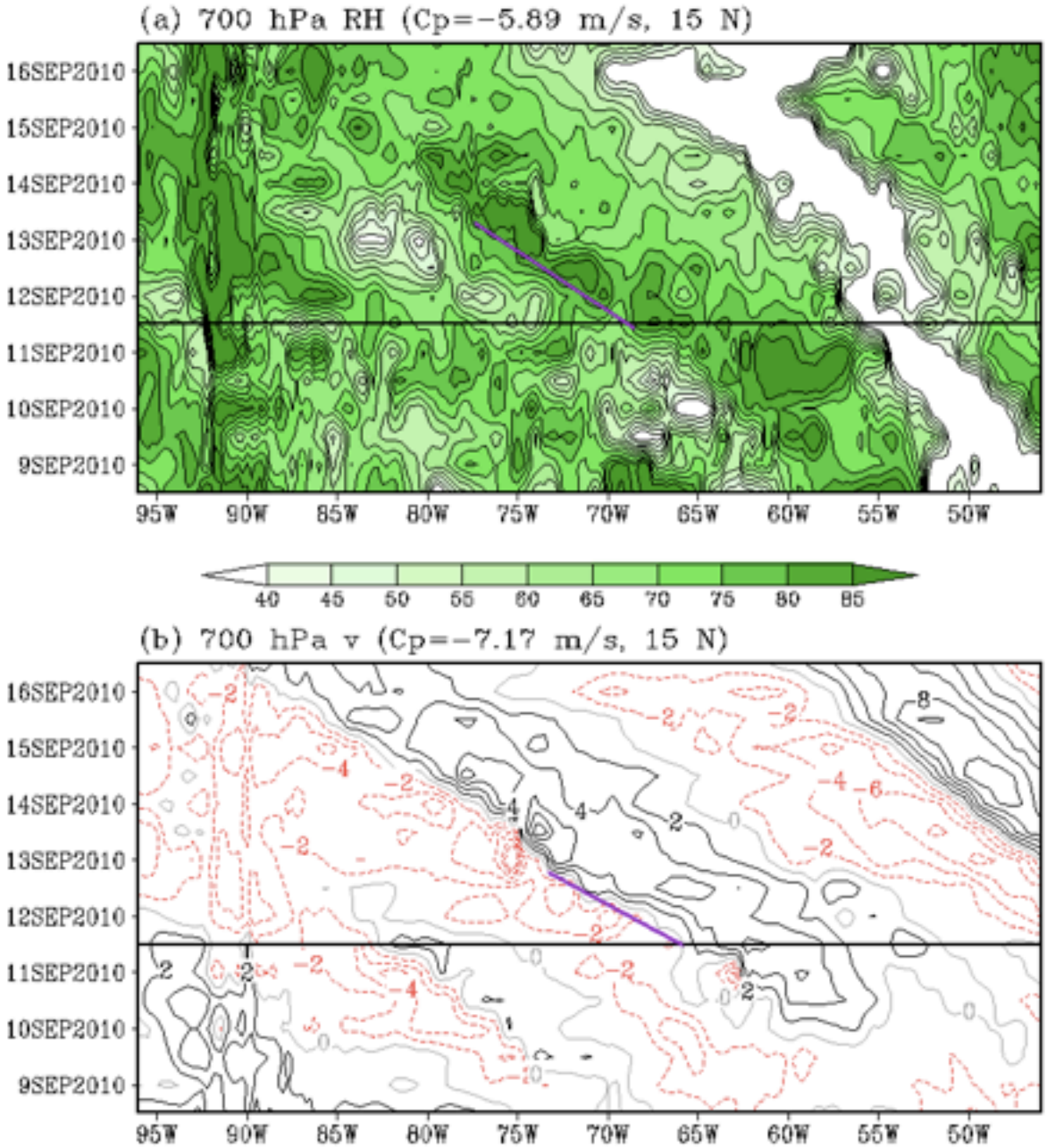
Website for the Real-time Forecasts

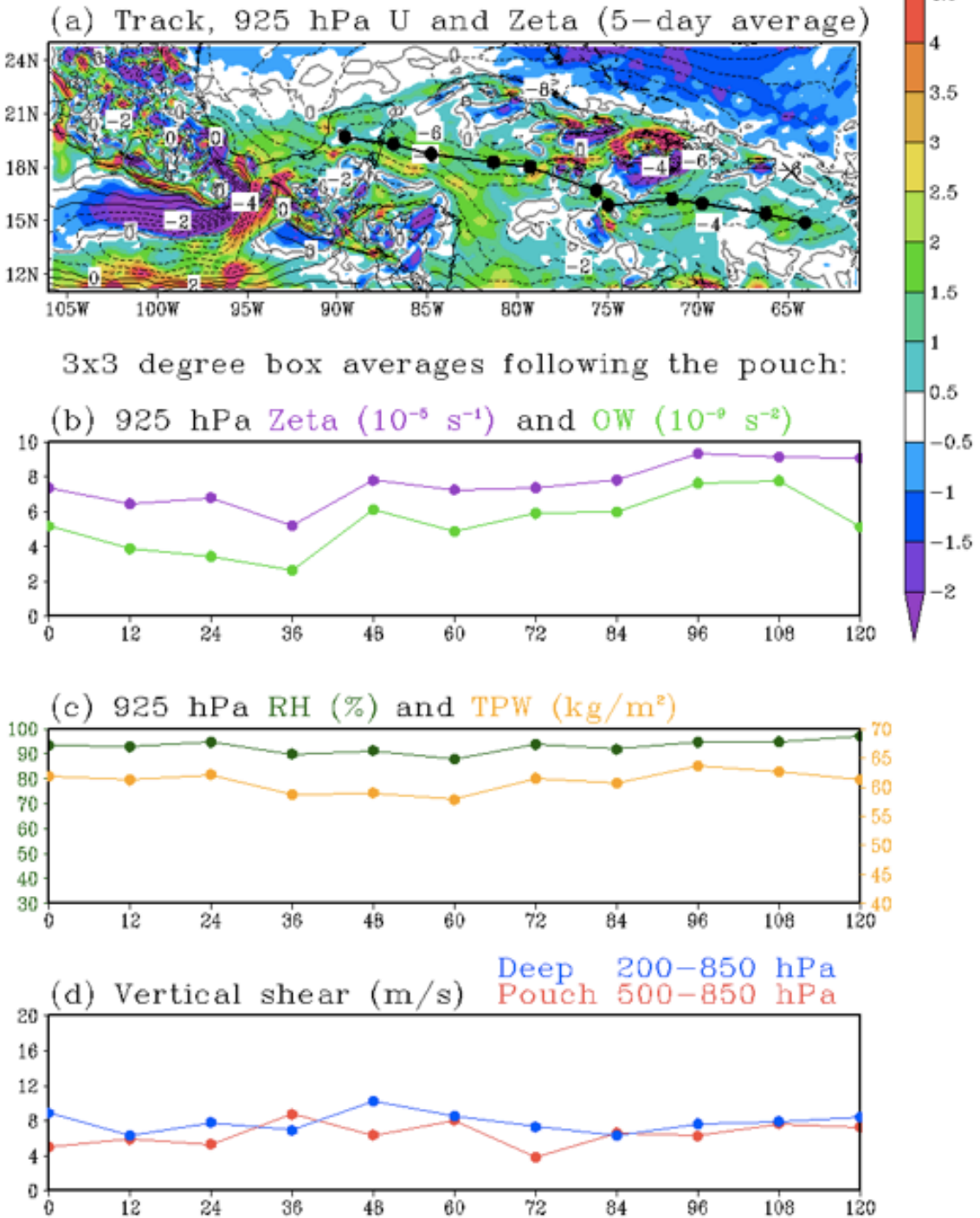


➢Website: http://www.met.nps.edu/~mtmontgo/storms.html


PREDICT F.I.R. Clearances
80°W
75°W
70°W
65°W
60°W
55°W
50°W
45°W
40°W
30°N
25°N
20°N
15°N
10°N
Bermuda
New York Center
New York Center
Jacksonville
Miami
Miami Oceanic
San Juan
Havanna
Kingston
Curacao
Barranquilla (Colombia)
Maiquetia (Venezuela)
Piarco
CV
Dakar
Georgia
Florida
Jacksonville
Orlando
Miami
Havana
Santiago de Cuba
Haiti
Dominican Republic
Puerto Rico
Santo Domingo
British Virgin Islands
Virgin Islands
Anguilla
Antigua and Barbuda
Montserrat
Guadeloupe
Dominica
Martinique
St. Lucia
St. Vincent and the Grenadines
Barbados
Grenada
Trinidad and Tobago
Caribbean Sea
Aruba
Netherlands Antilles
Caracas
Valencia
Maracaibo
Barranquilla
Cartagena
Barquisimeto
Merida
Cumaná
Maturin
Puerto La Cruz
El Tigre
Ciudad Guayana
Calabozo
San Fernando
Ciudad Bolivar
Panamá
Sincelejo
Montería
Cúcuta
Barrancabermeja
Costa Rica

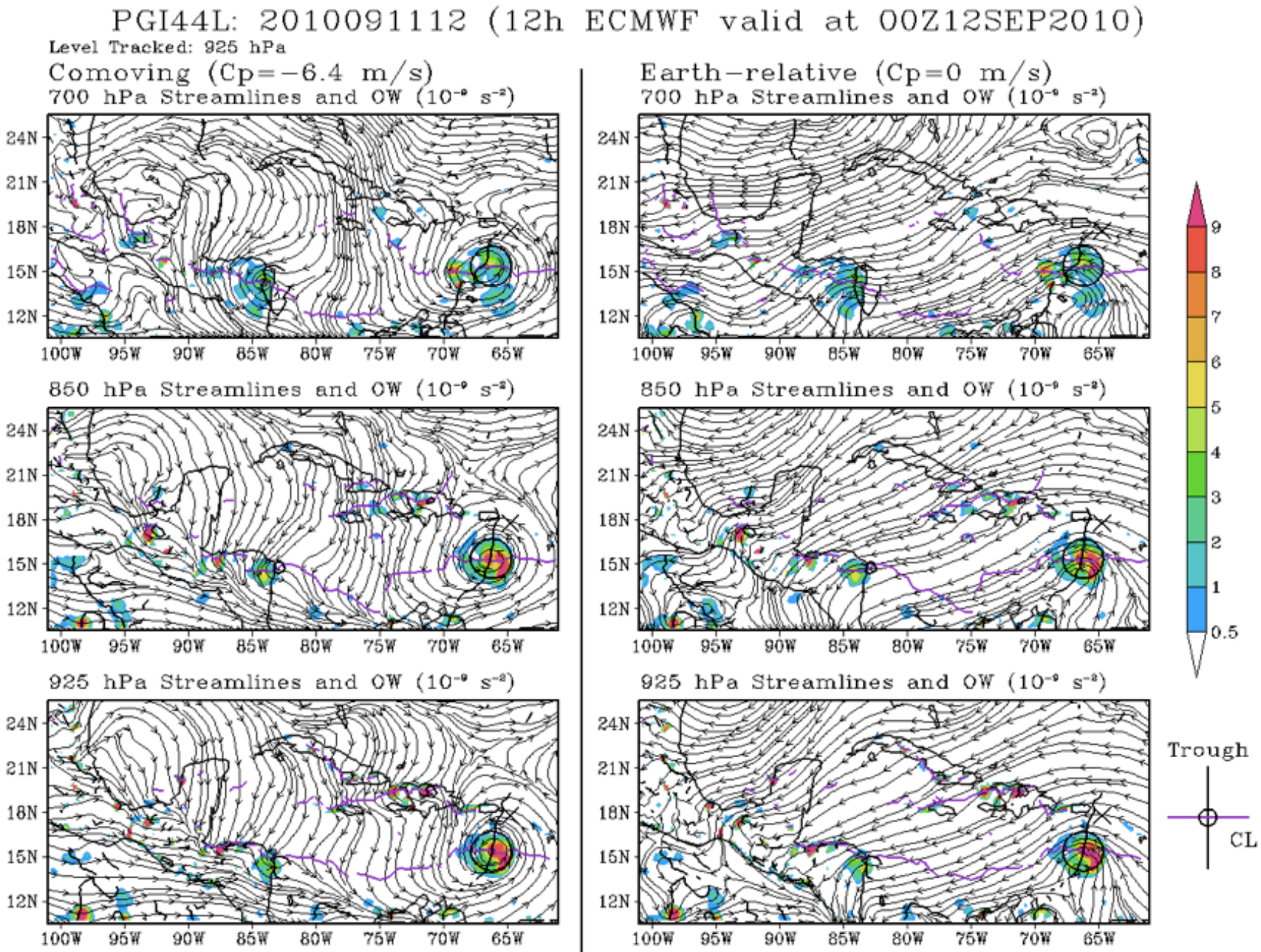
ecmwf initialized at 2010091112

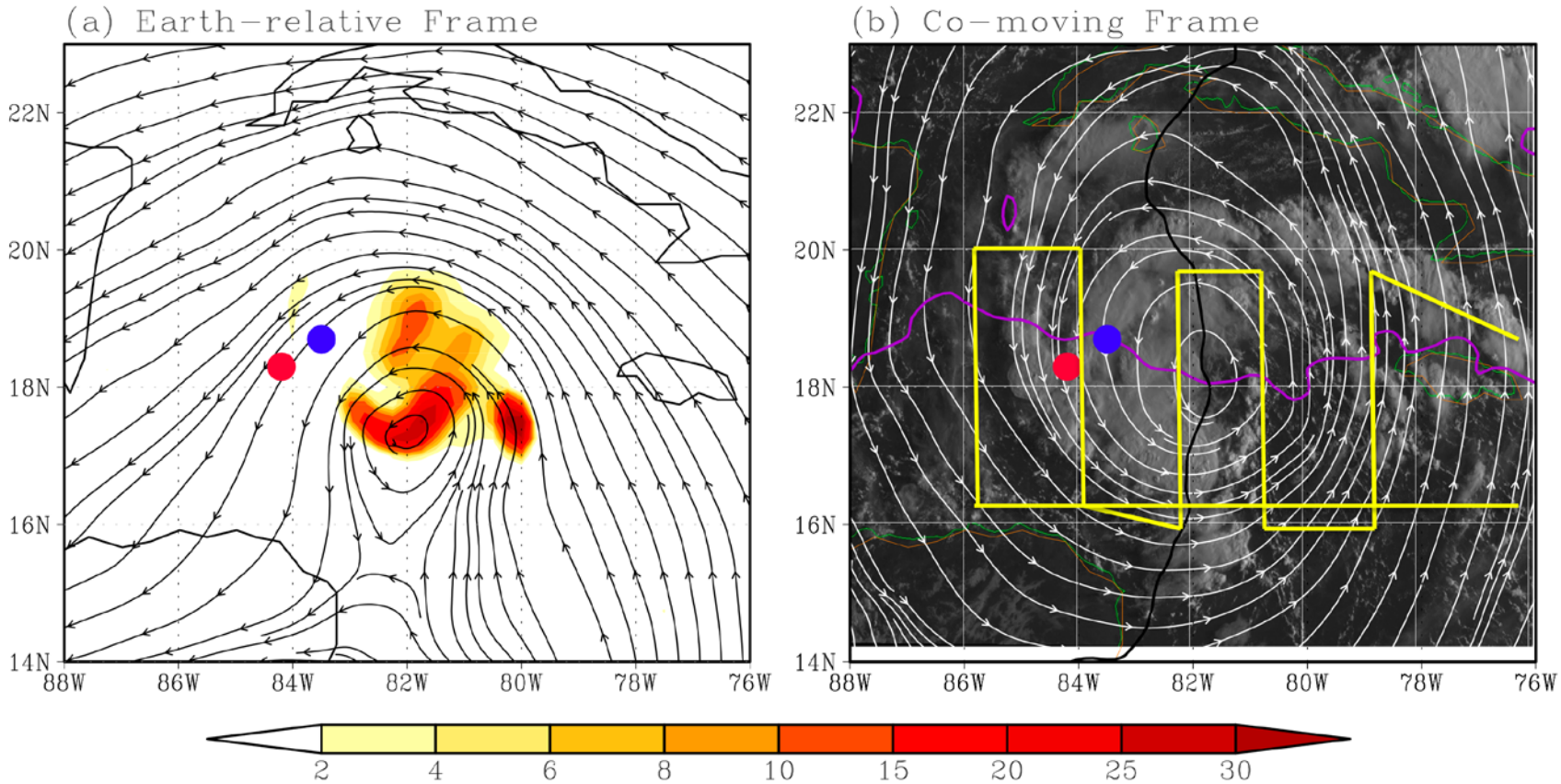



(a) Track, 925 hPa U and Zeta (5-day average)
24N
21N
18N
15N
12N
105W
100W
95W
90W
85W
80W
75W
70W
65W
4
3.5
3
2.5
2
1.5
1
0.5
−0.5
−1
−1.5
−2
3x3 degree box averages following the pouch:
(b) 925 hPa Zeta (10^{-5} s^{-1}) and OW (10^{-9} s^{-2})
(c) 925 hPa RH (%) and TPW (kg/m^2)
(d) Vertical shear (m/s)
Deep 200−850 hPa
Pouch 500−850 hPa

ECMWF Forecast in the Marsupial Framework for storm PGI44L

Loop Mode		Animate Frames			Dwell First		Dwell Last		Adjust Speed		Advance One		Frame Number: 2
NORMAL	SWEEP	REW	STOP	FWD	DEC	INC	DEC	INC	--	++	-1	+1	





Left: ECMWF 36-hour forecast of 700-hPa earth-relative streamlines and OW (shading; units: 10-9 s-2) centered on wave-pouch PGI44L/AL92 (pre-Karl) valid at 12 UTC 14 September 2010. Right: Same as left except for a co-moving frame of reference (phase speed of -6.2 m/s). The black line represents the trough axis, and the purple line the local critical latitude. GOES visible imagery at 1225 UTC and the G-V flight pattern (yellow track) are shown in the co-moving frame (right). The red dot represents the actual genesis location, and the blue dot is the ECMWF 700-hPa pouch center position (or predicted genesis location) at 21 UTC 14 September 2010.

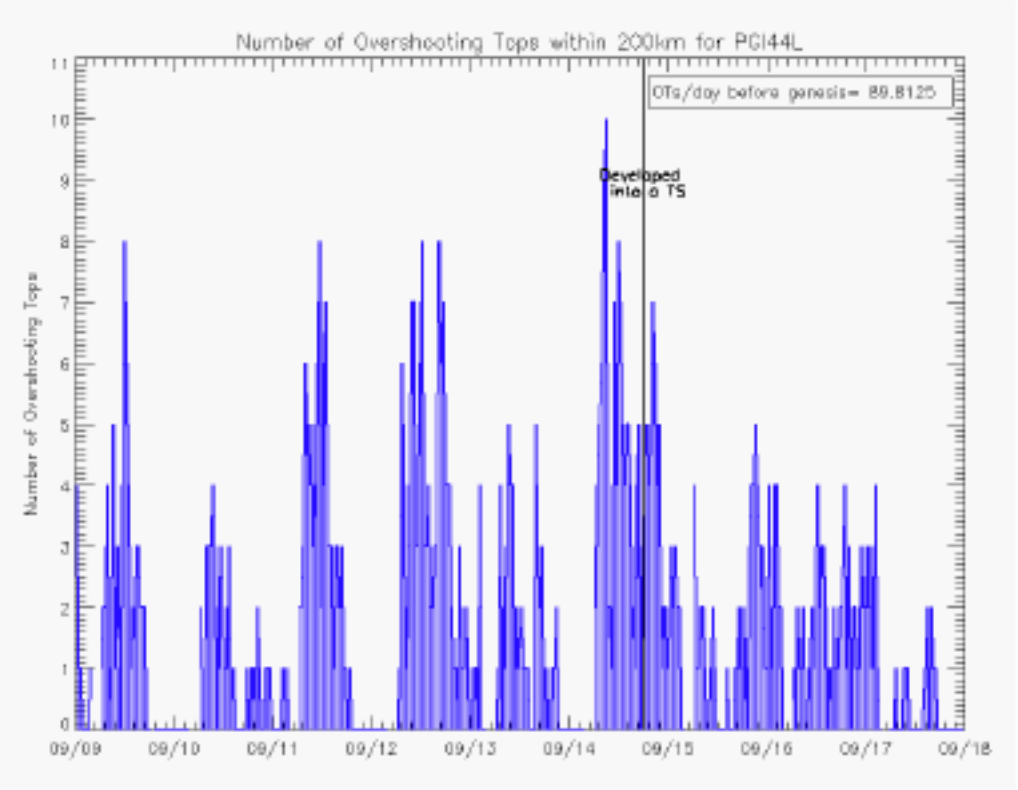
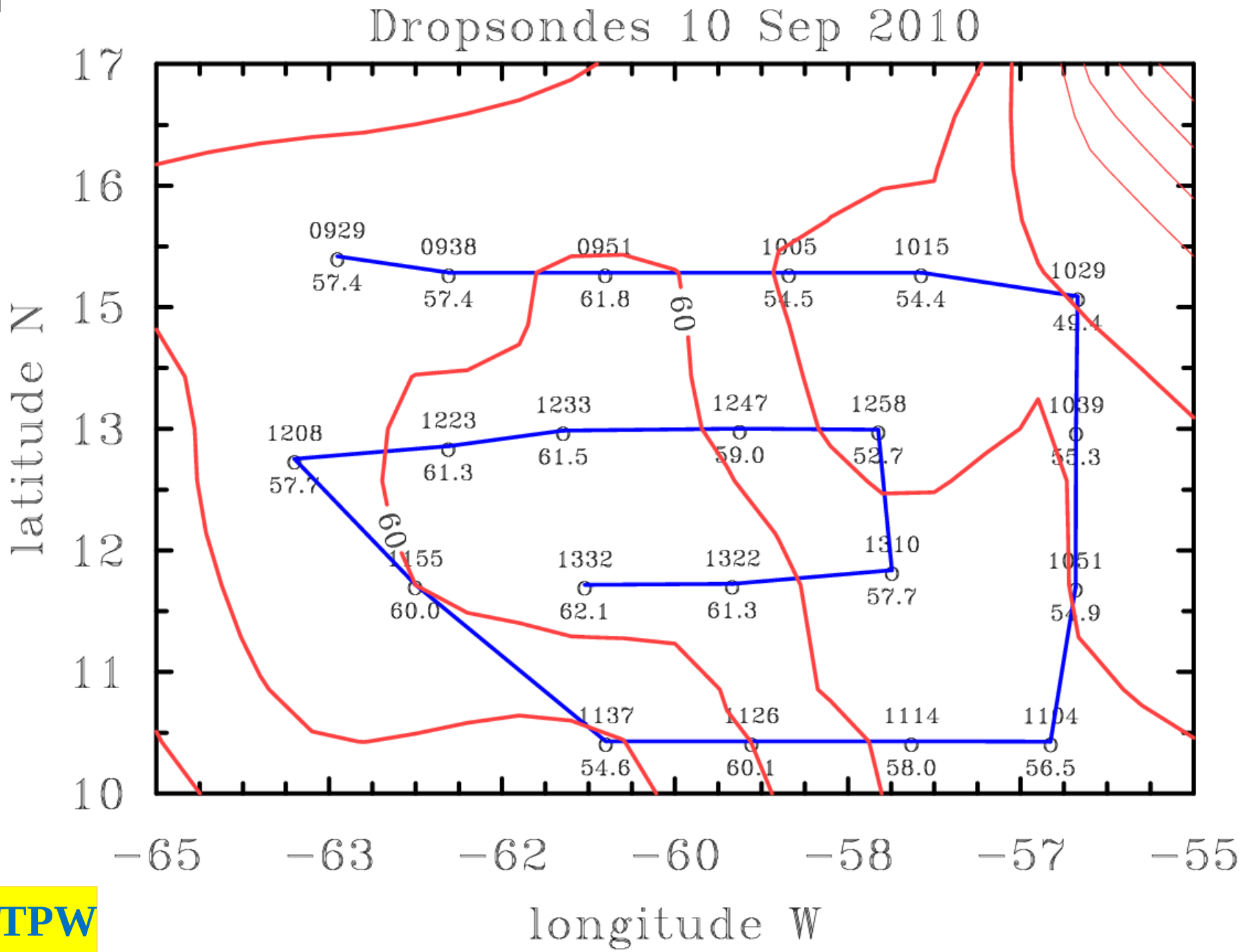
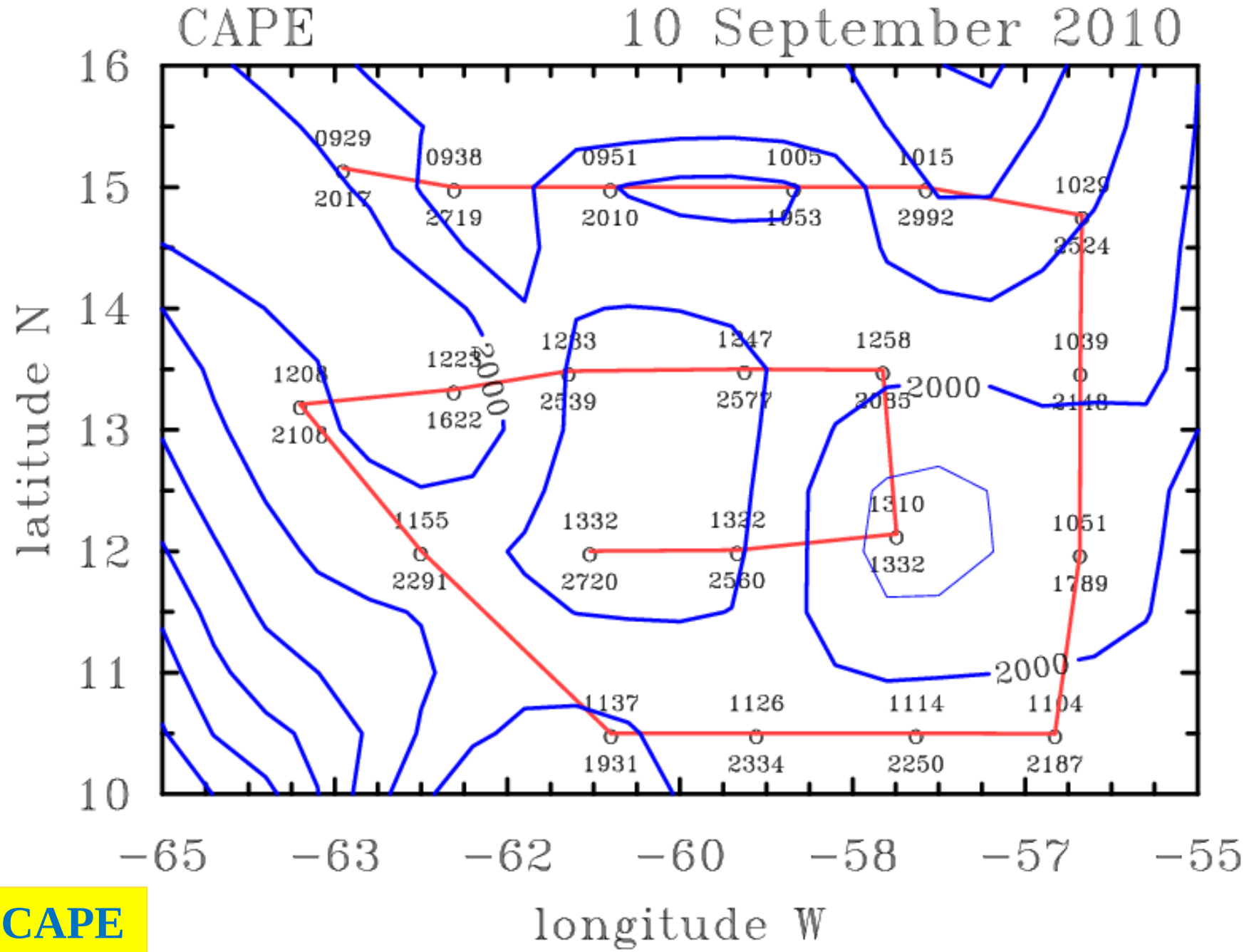


Figure 2. Time-series of overshooting tops derived from the CIMSS cloud-top product prior to and during the genesis of Karl (PGI44).


Dropsondes 10 Sep 2010
latitude N
longitude W
17
16
15
13
12
11
10
−65
−63
−62
−60
−58
−57
−55
0929
57.4
0938
57.4
0951
61.8
1005
54.5
1015
54.4
1029
49.4
1208
57.7
1223
61.3
1233
61.5
1247
59.0
1258
52.7
1039
55.3
1155
60.0
1332
62.1
1322
61.3
1310
57.7
1051
54.9
1137
54.6
1126
60.1
1114
58.0
1104
56.5
60
60

TPW


CAPE
10 September 2010
latitude N
longitude W
16
15
14
13
12
11
10
−65
−63
−62
−60
−58
−57
−55
0929
2017
0938
2719
0951
2010
1005
1053
1015
2992
1029
2524
1208
2108
1223
1622
1233
2539
1347
2577
1258
2085
1039
2148
2000
1155
2291
1332
2720
1322
2560
1310
1332
1051
1789
1137
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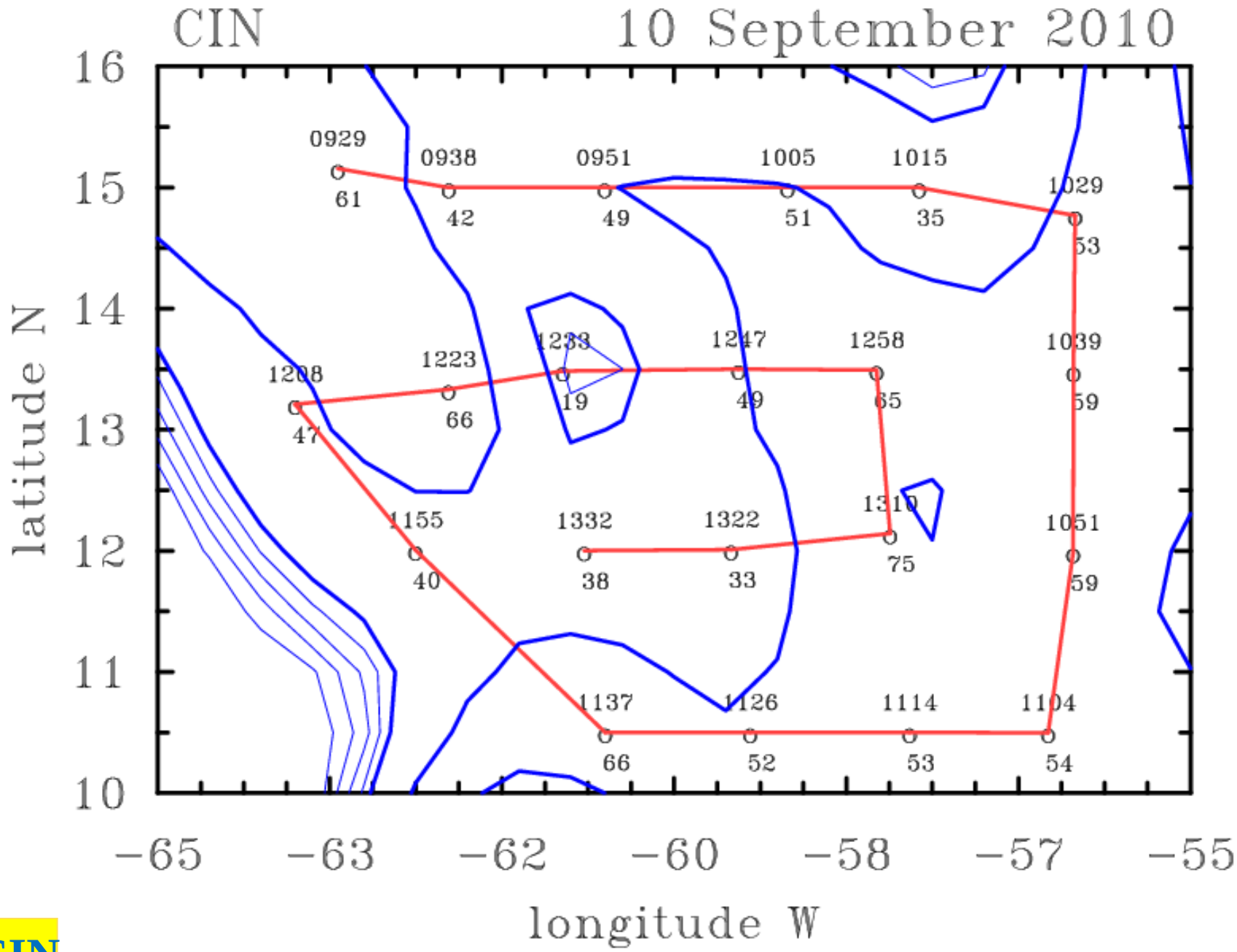
1126
2334
1114
2250
1104
2187

CAPE


CIN
10 September 2010
latitude N
longitude W
16
15
14
13
12
11
10
−65
−63
−62
−60
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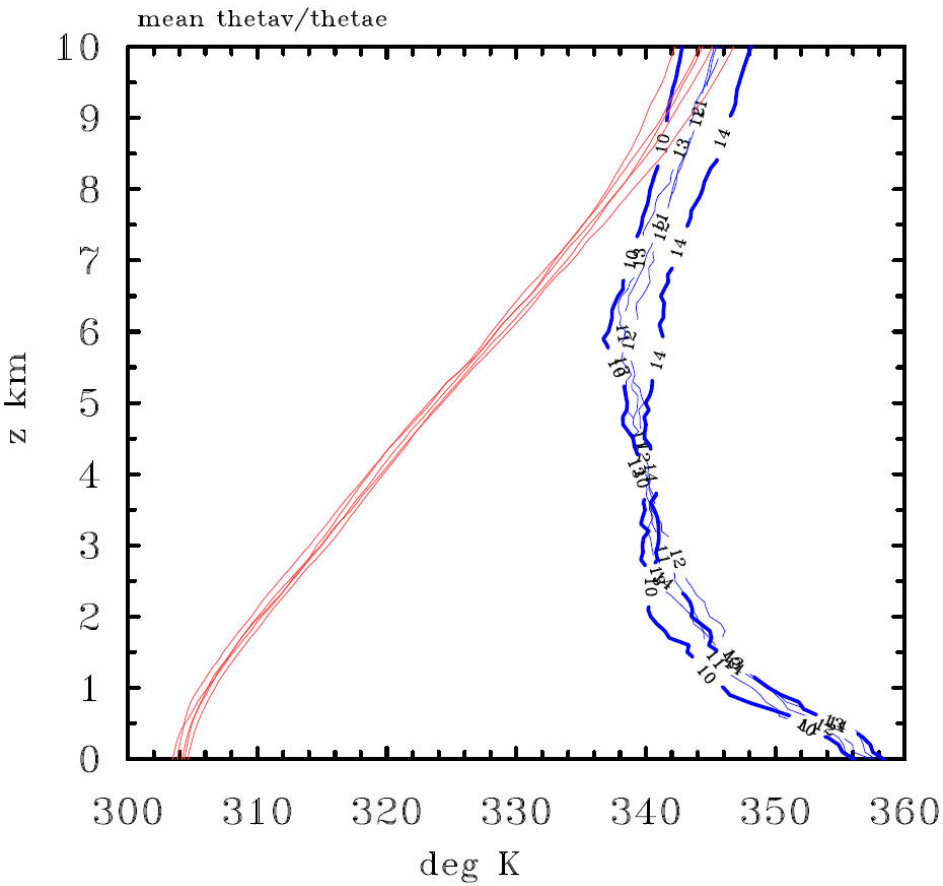
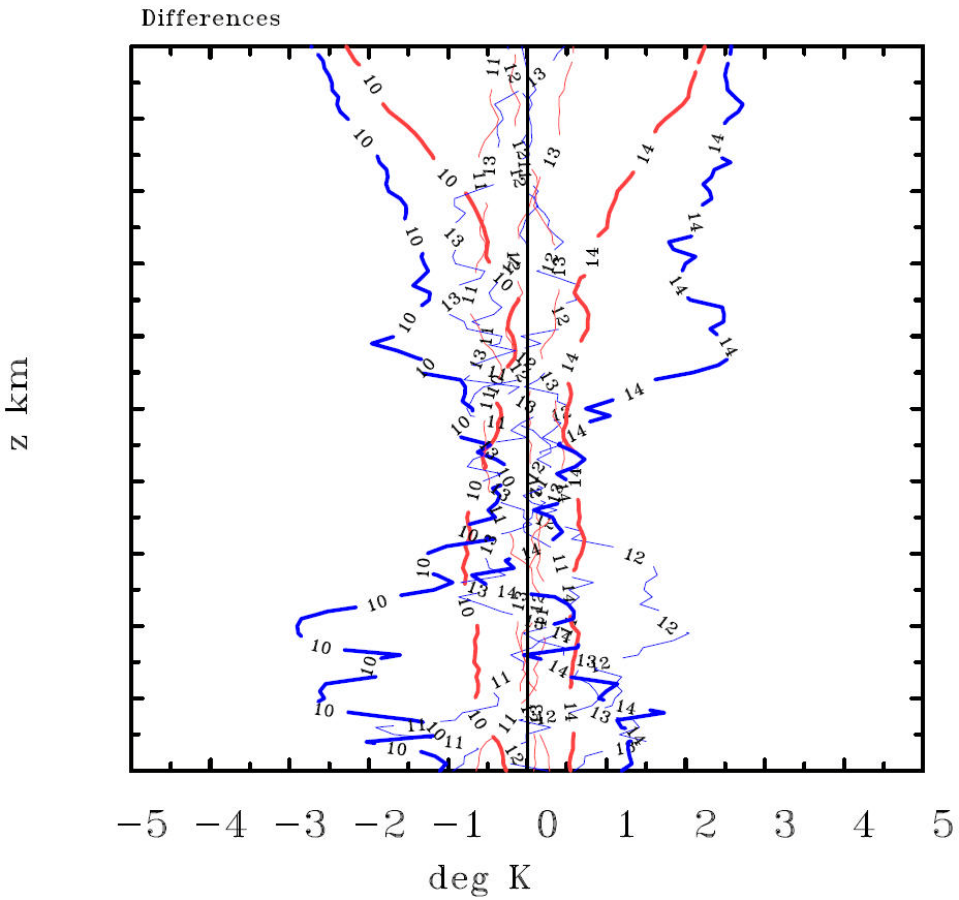
−57
−55
0929
61
0938
42
0951
49
1005
51
1015
35
1029
53
1208
47
1223
66
1233
19
1247
49
1258
65
1039
59
1155
40
1332
38
1322
33
1310
75
1051
59
1137
66
1126
52
1114
53
1104
54

CIN

PGI44L pre-Karl

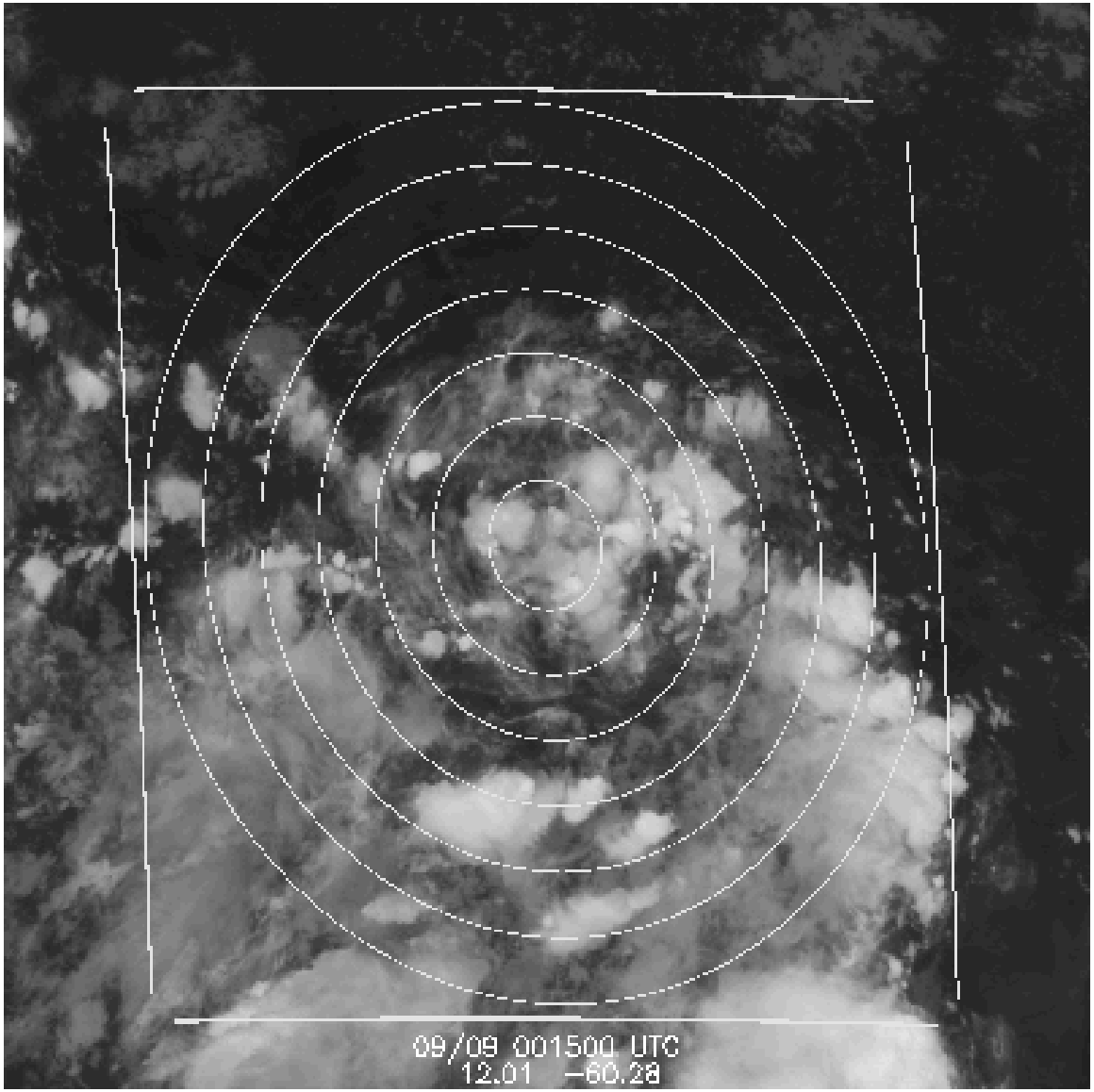


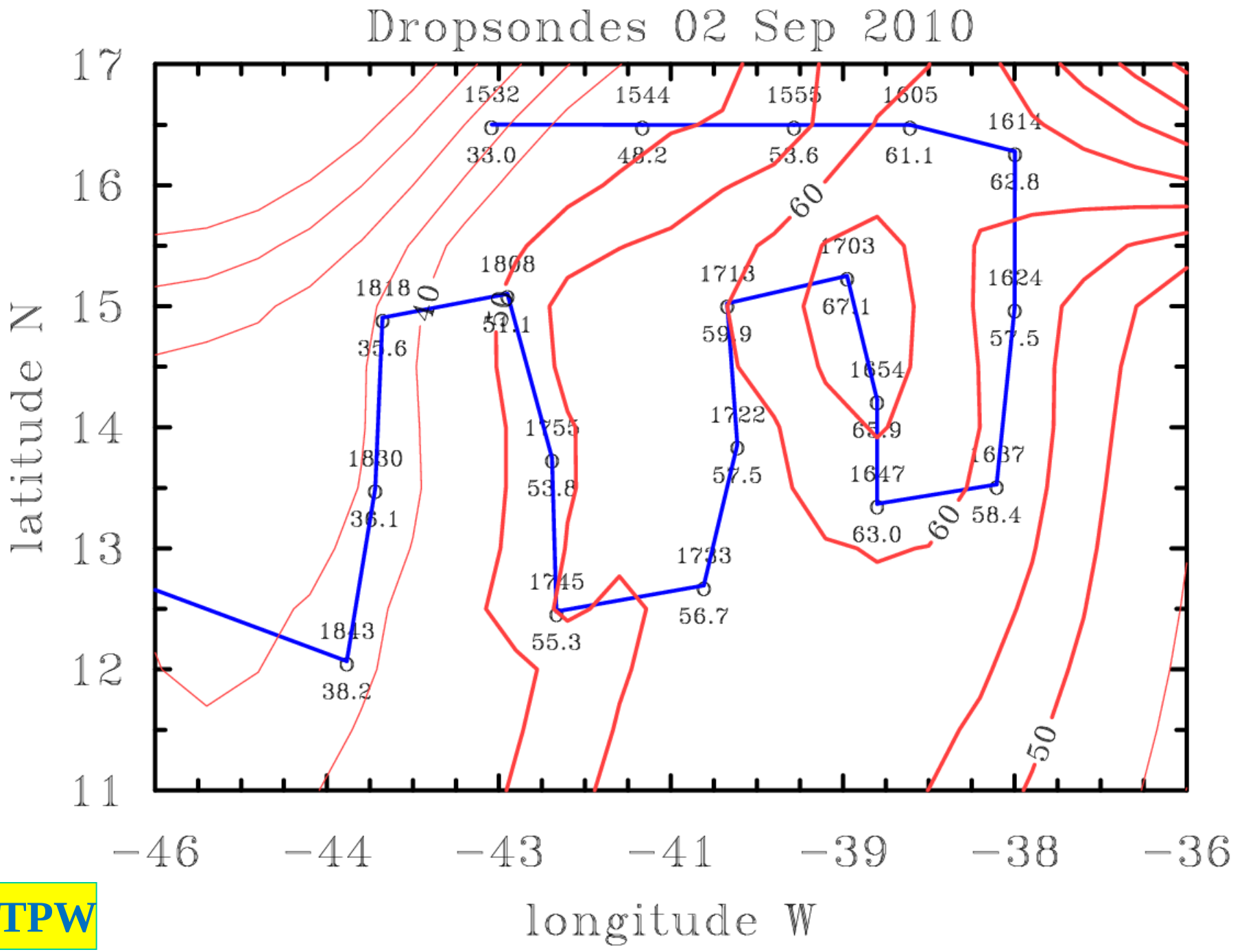


~15 K

Pouch centric movie of pre-Karl's moist convection viewed through IR cloud top temperatures

Courtesy of Dave Ahijevych & Chris Davis NCAR-MMM


09/09 001500 UTC
12.01 -60.28


Dropsondes 02 Sep 2010
latitude N
longitude W
17
16
15
14
13
12
11
−46
−44
−43
−41
−39
−38
−36
1532
33.0
1544
48.2
1555
53.6
1505
61.1
1614
62.8
1703
67.1
1624
57.5
1713
59.9
1808
51.1
1818
35.6
1654
65.9
1722
57.5
1755
53.8
1830
36.1
1637
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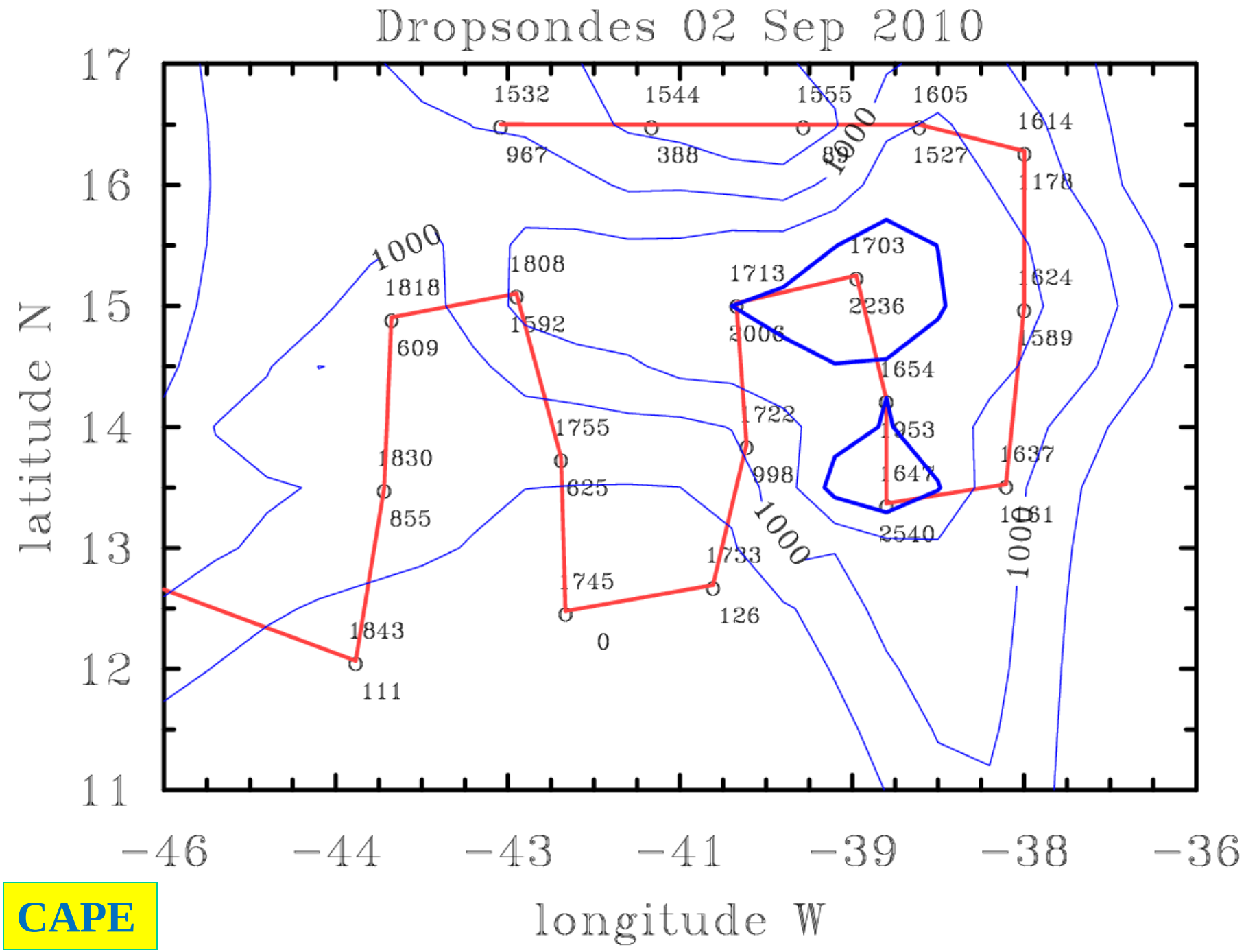
63.0
1733
56.7
1745
55.3
1843
38.2
60
60
60
50
TPW


Dropsondes 02 Sep 2010
latitude N
longitude W
17
16
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12
11
−46
−44
−43
−41
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−36
1532
1544
1555
1605
1614
967
388
89
1527
1178
1000
1808
1818
1713
1703
1624
1592
2006
2236
1589
609
1654
1722
1953
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1733
1745
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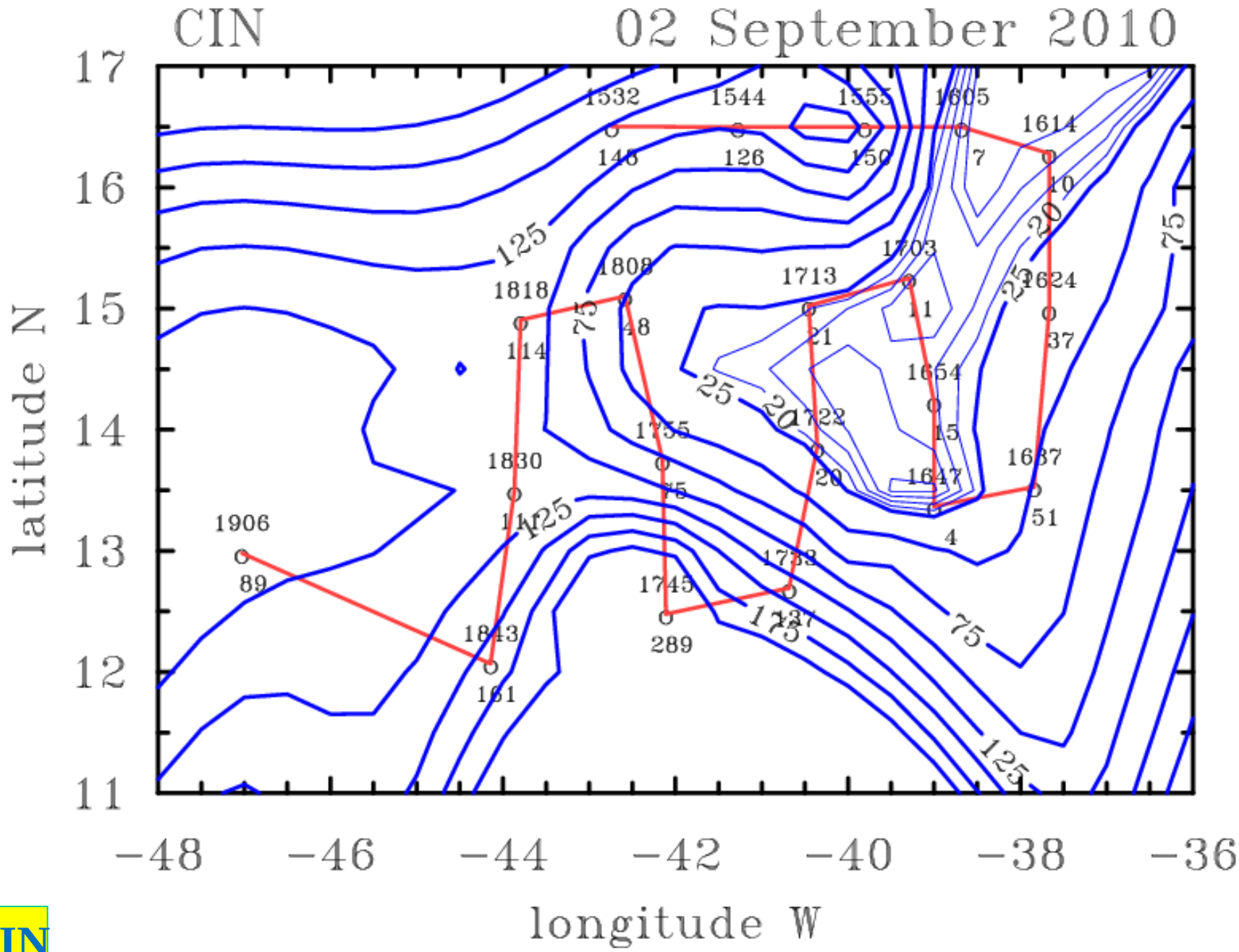
1843
0
111

CAPE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02 September 2010
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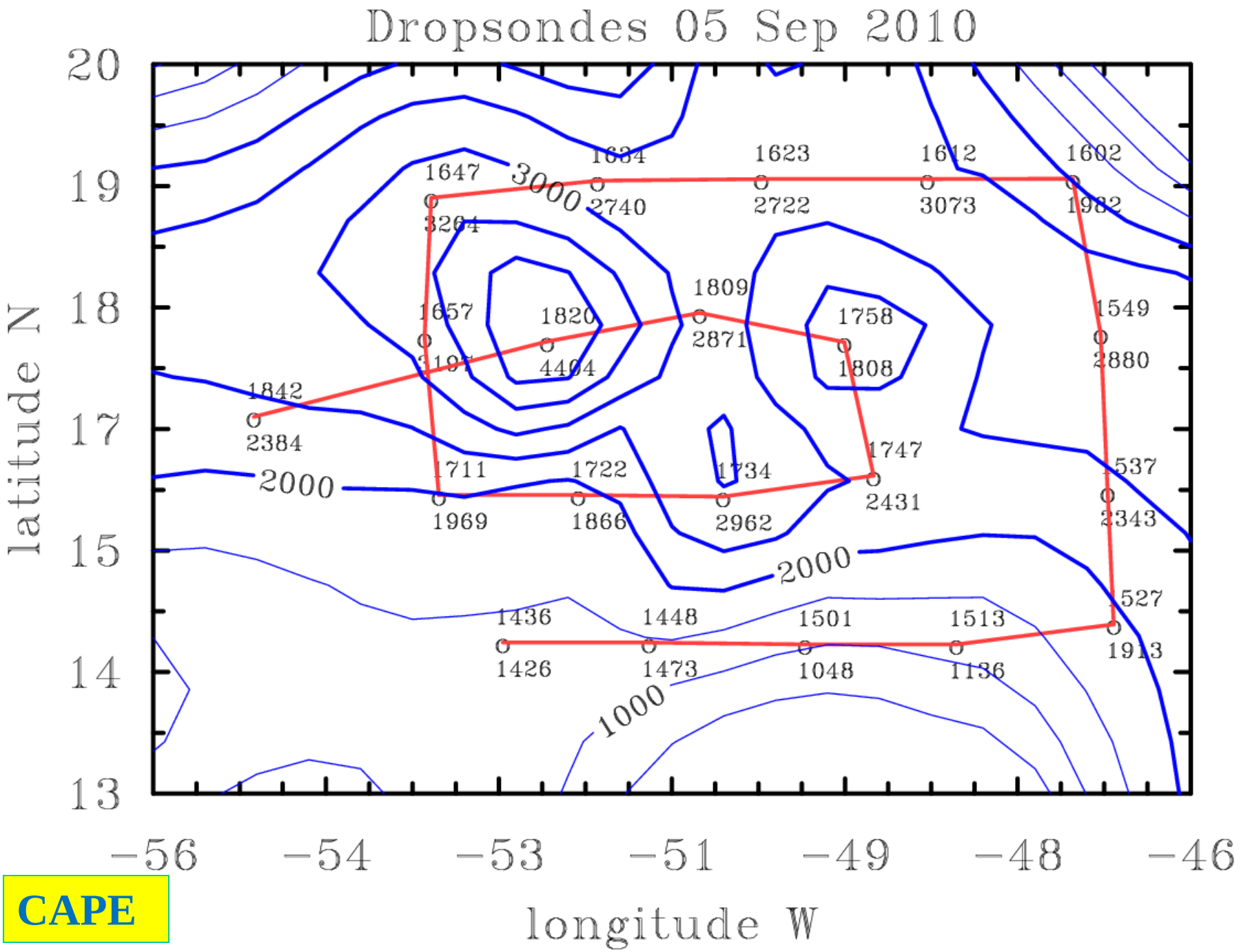
CIN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longitude W
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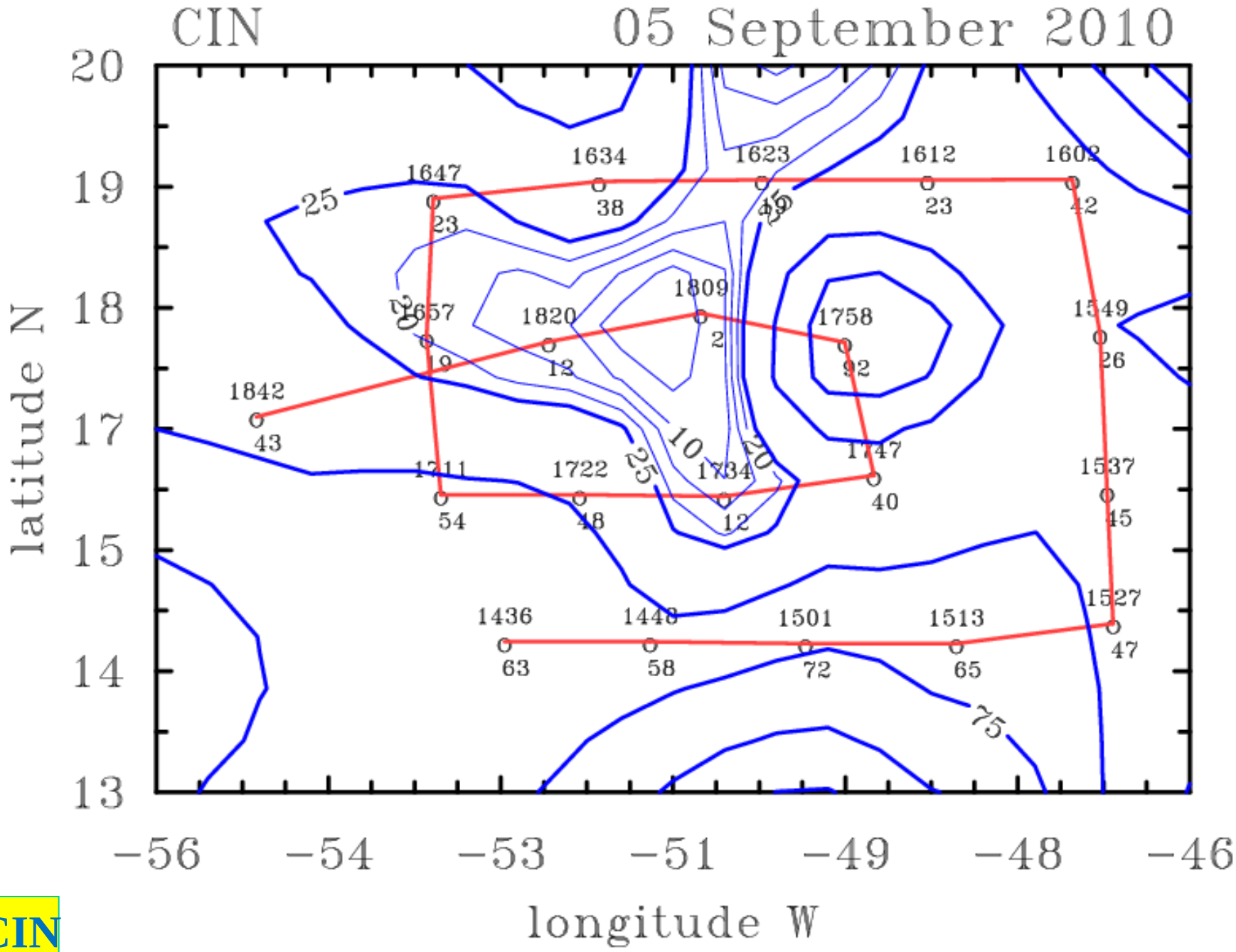
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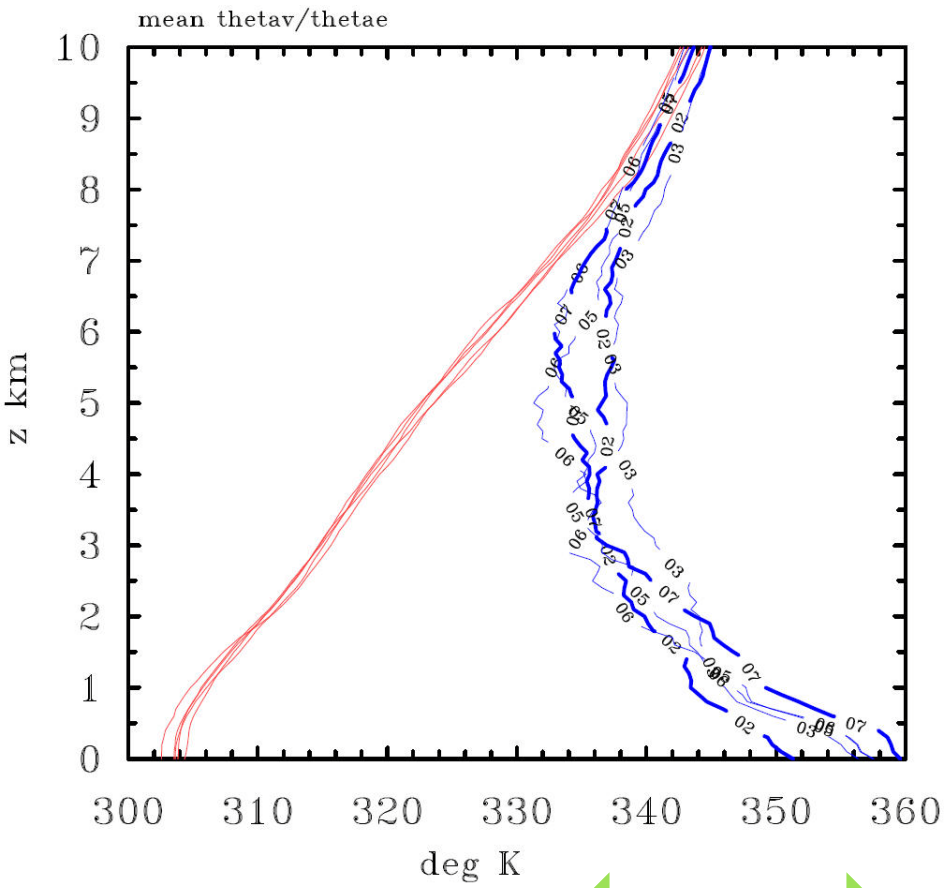
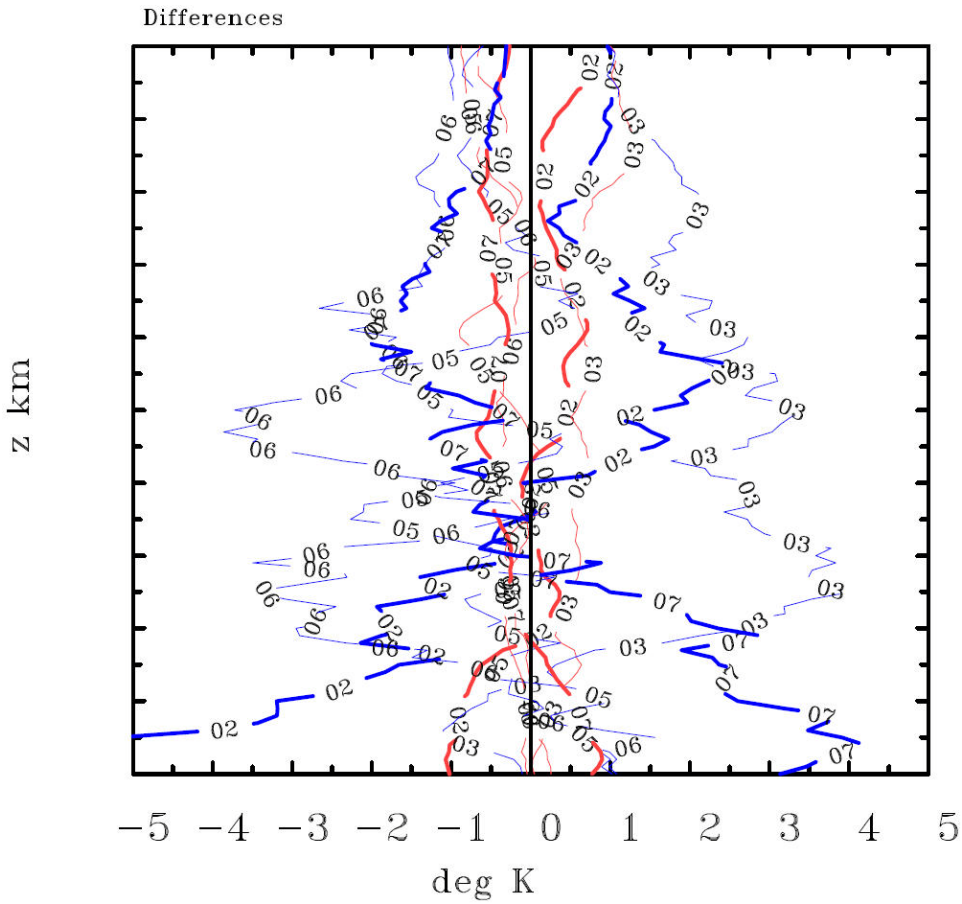
CIN

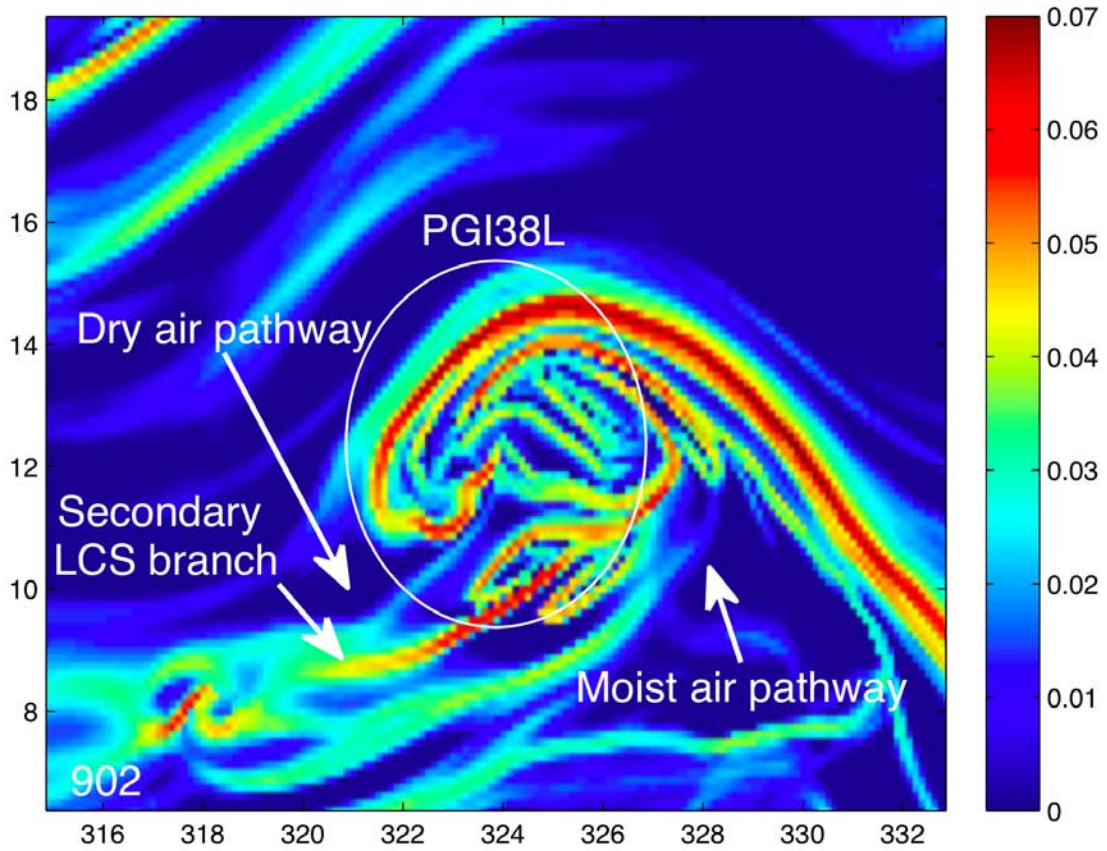
PGI38L (ex-GASTON)





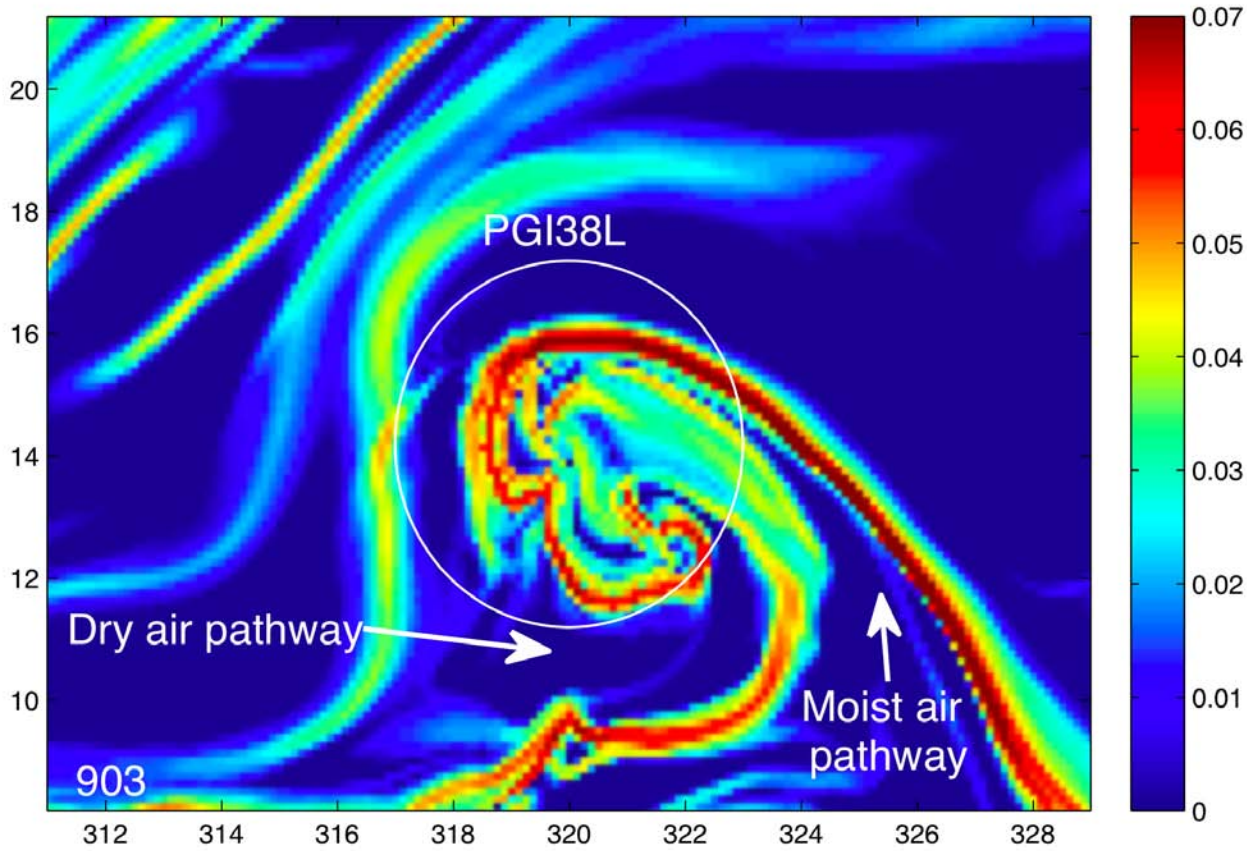
~25 K

ex-Gaston, FTLE fields, 2 Sep



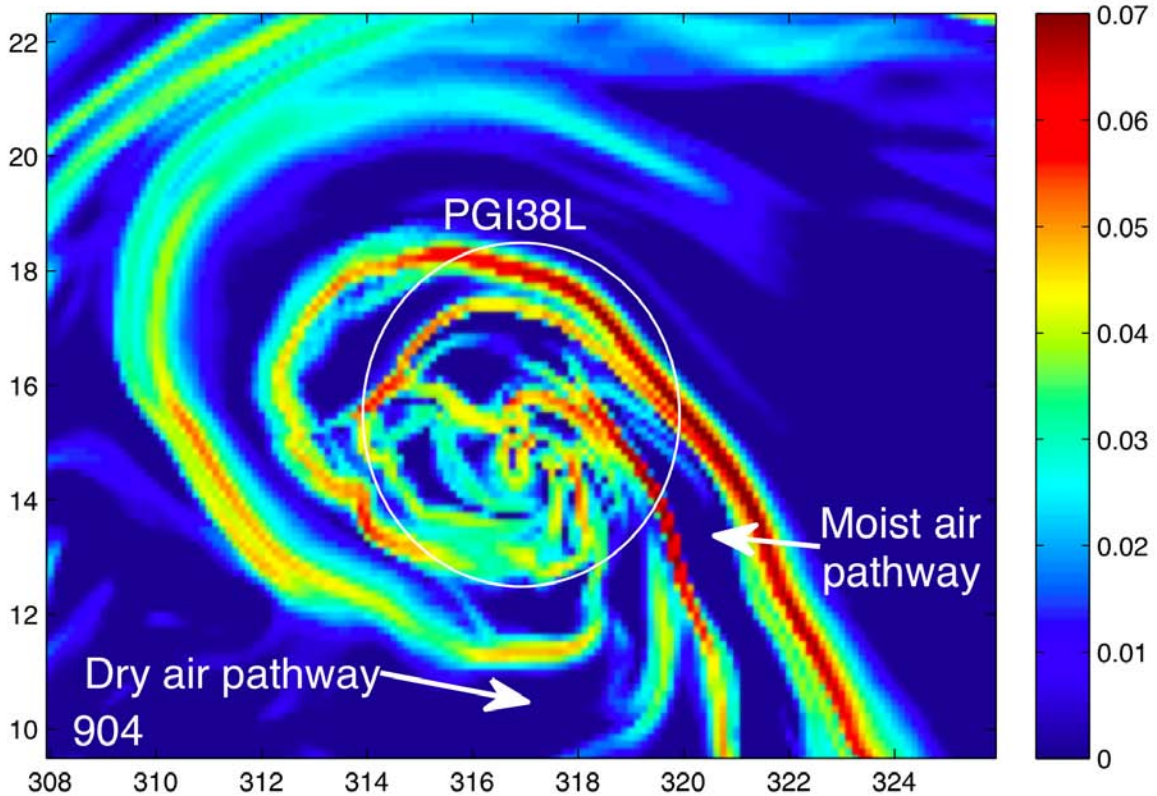
Attracting LCSs using 25 km ECMWF analysis data
Blake Rutherford, NRC post doc

Ex-Gaston, FTLE fields, 3 Sep



Attracting LCSs using 25 km ECMWF analysis data
Blake Rutherford, NRC post doc

Ex-Gaston, FTLE fields, 4 Sep



Attracting LCSs using 25 km ECMWF analysis data
Blake Rutherford, NRC post doc

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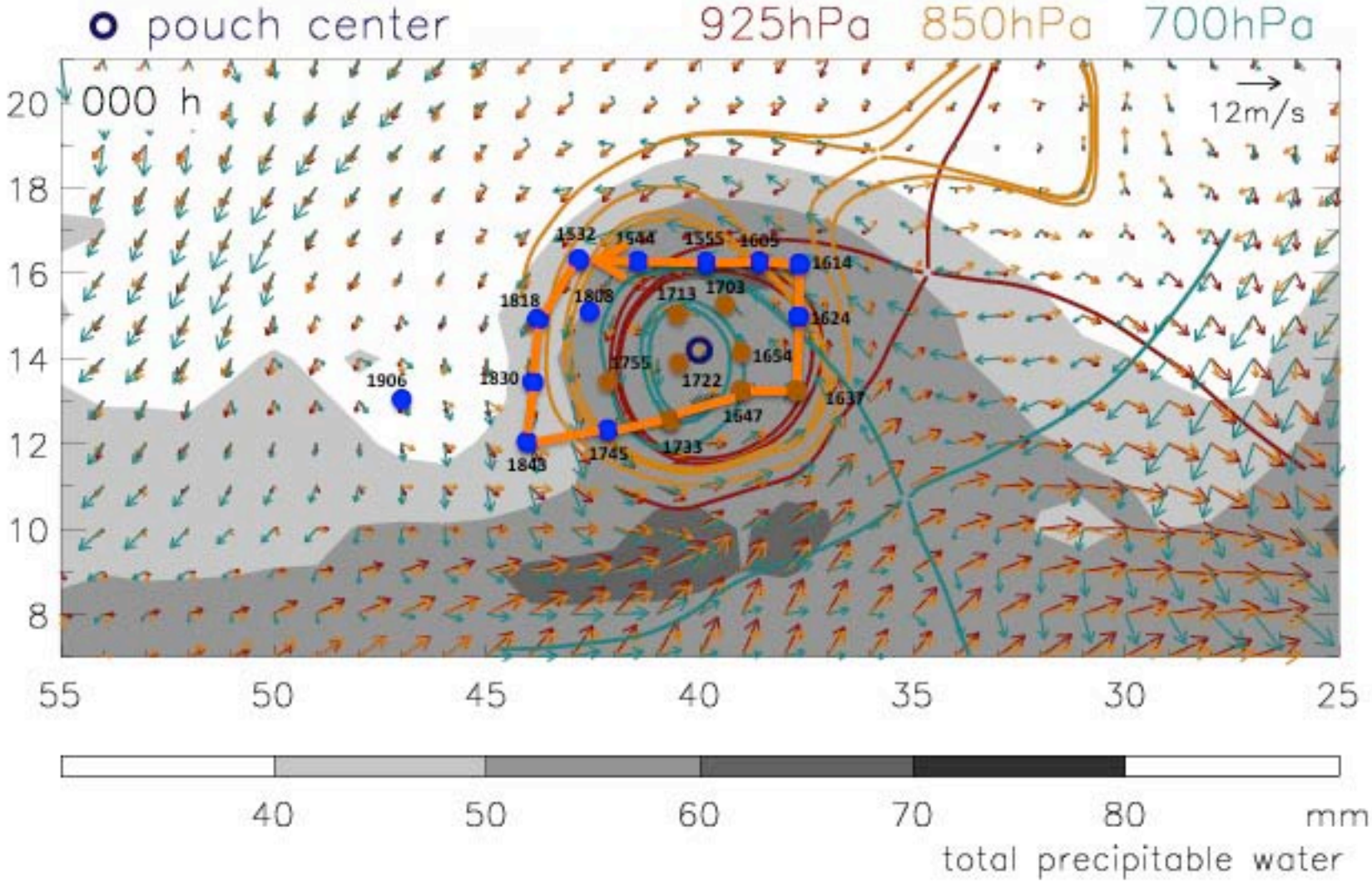
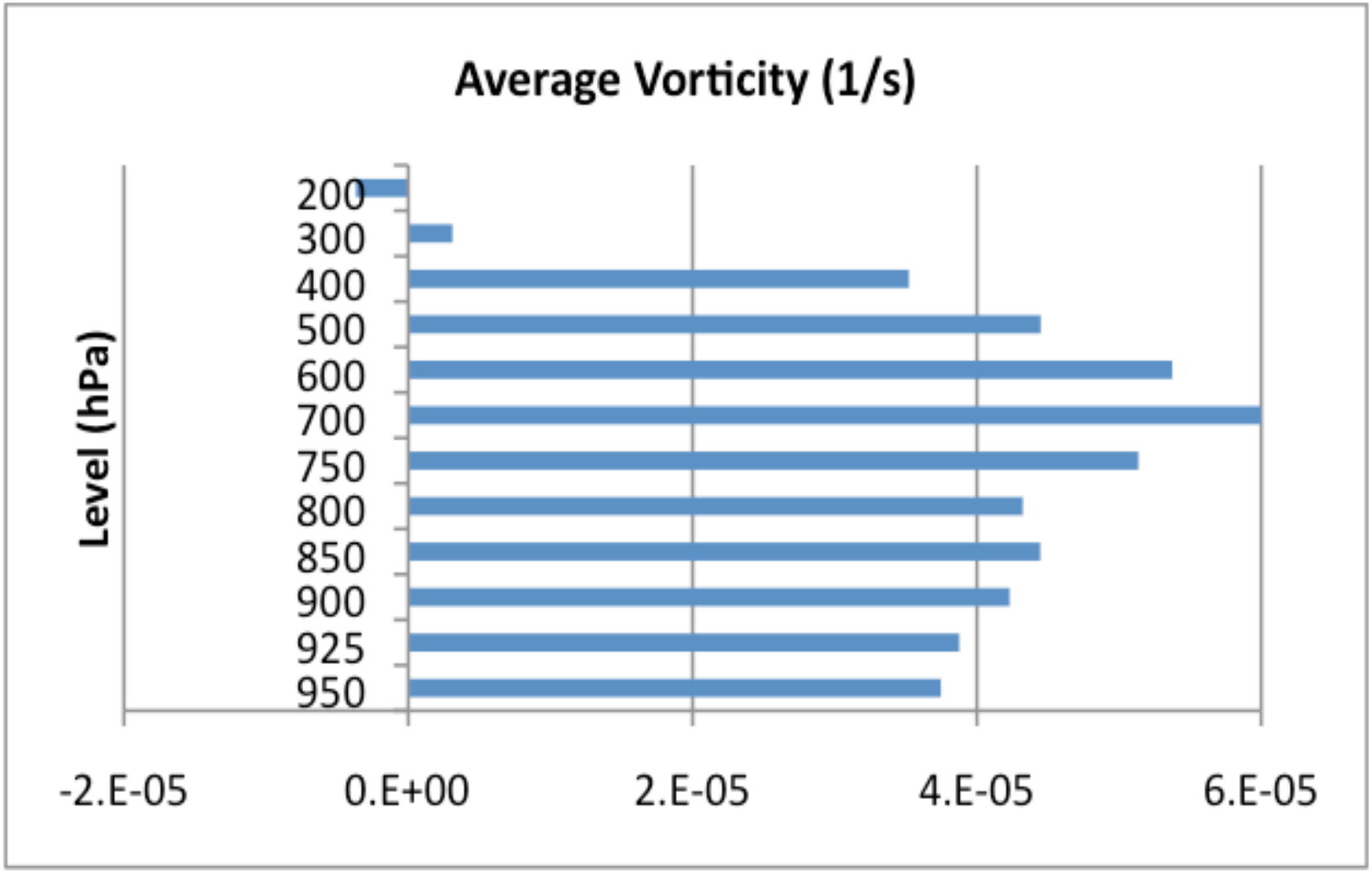
RF09 Drops: 20100902 1532-1906 Z 4:54-8:28 hours before



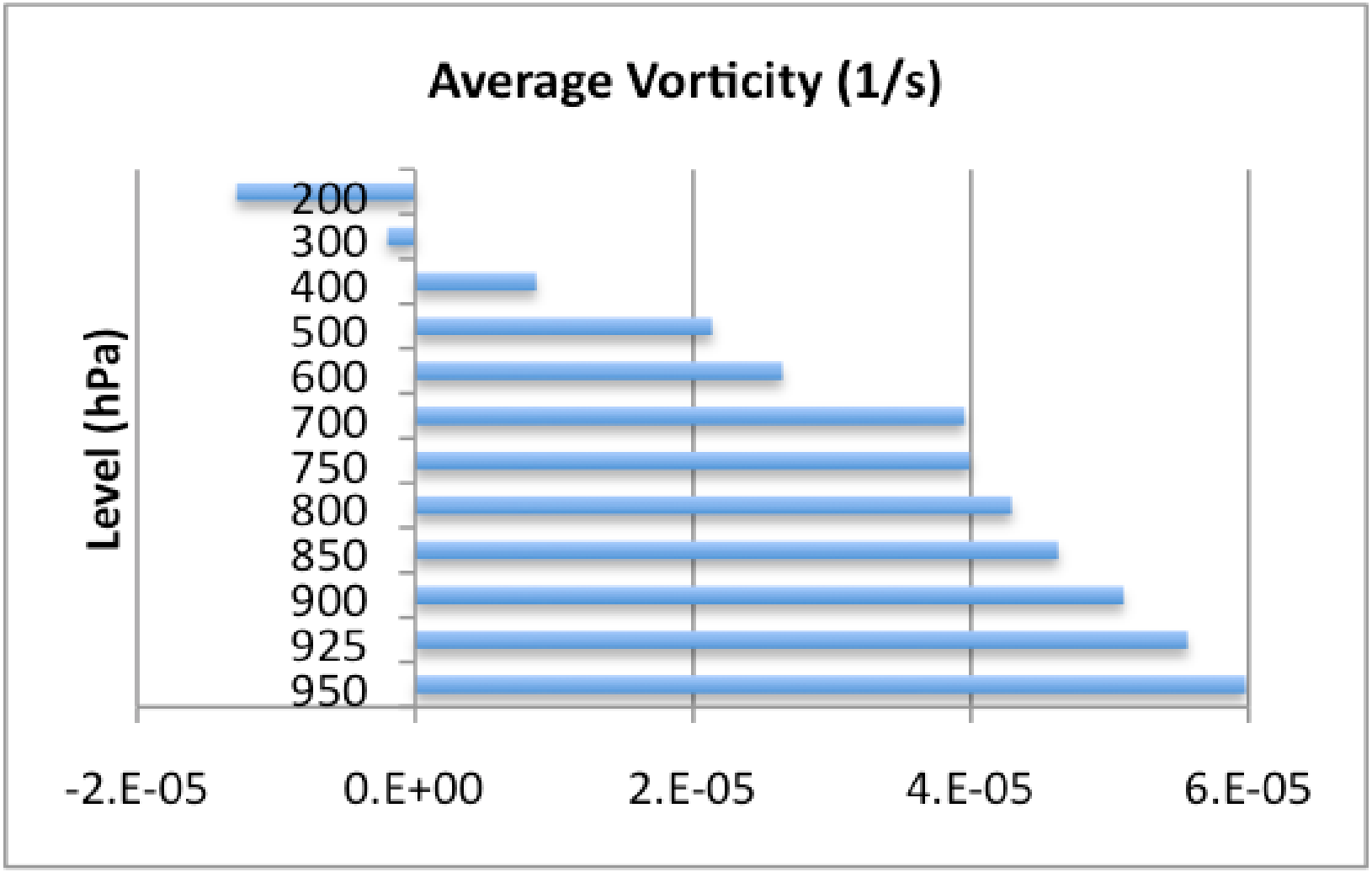
Mark Boothe, NPS

Ex-Gaston September 2



Mark Boothe, NPS

September 3



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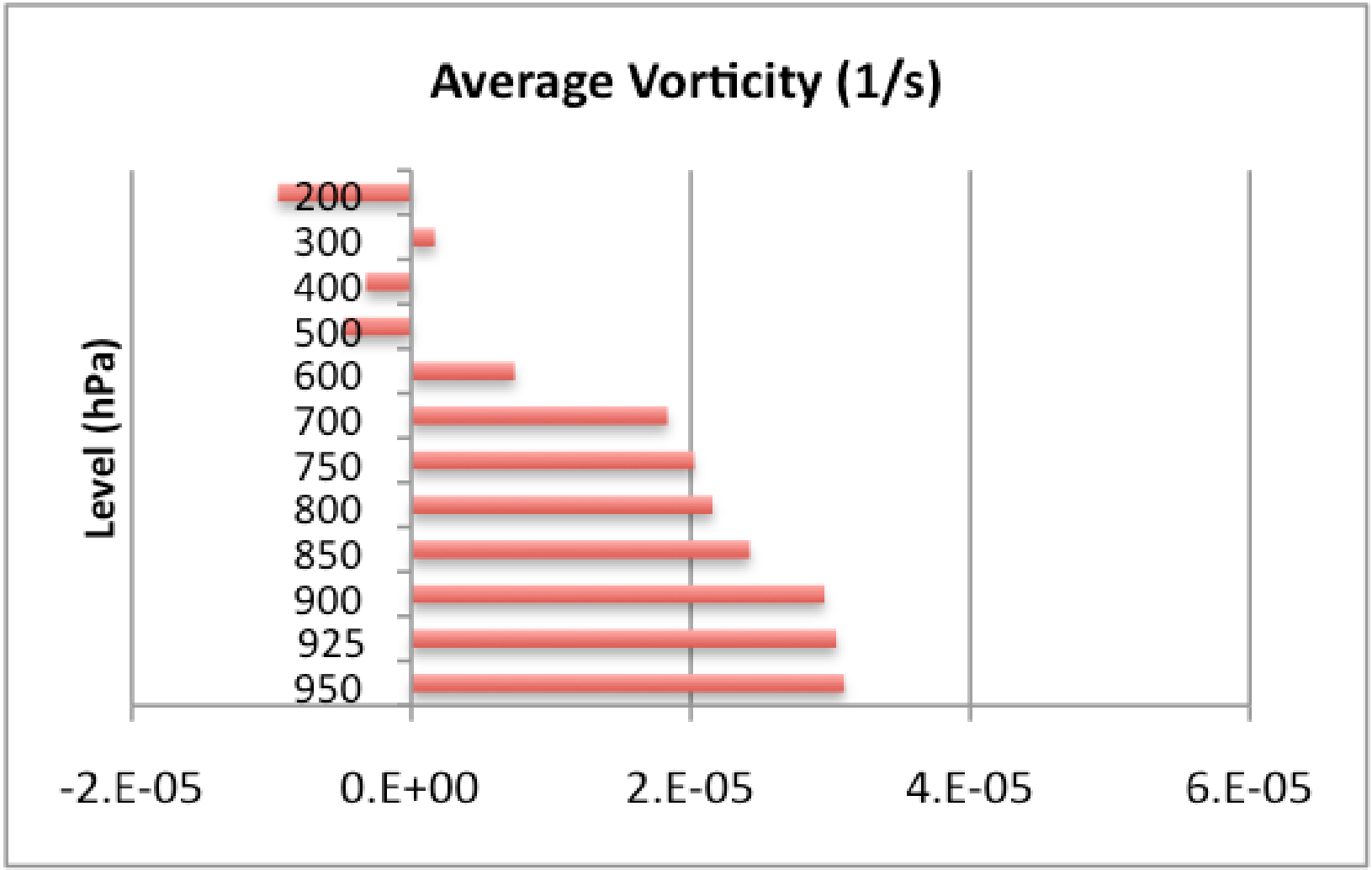
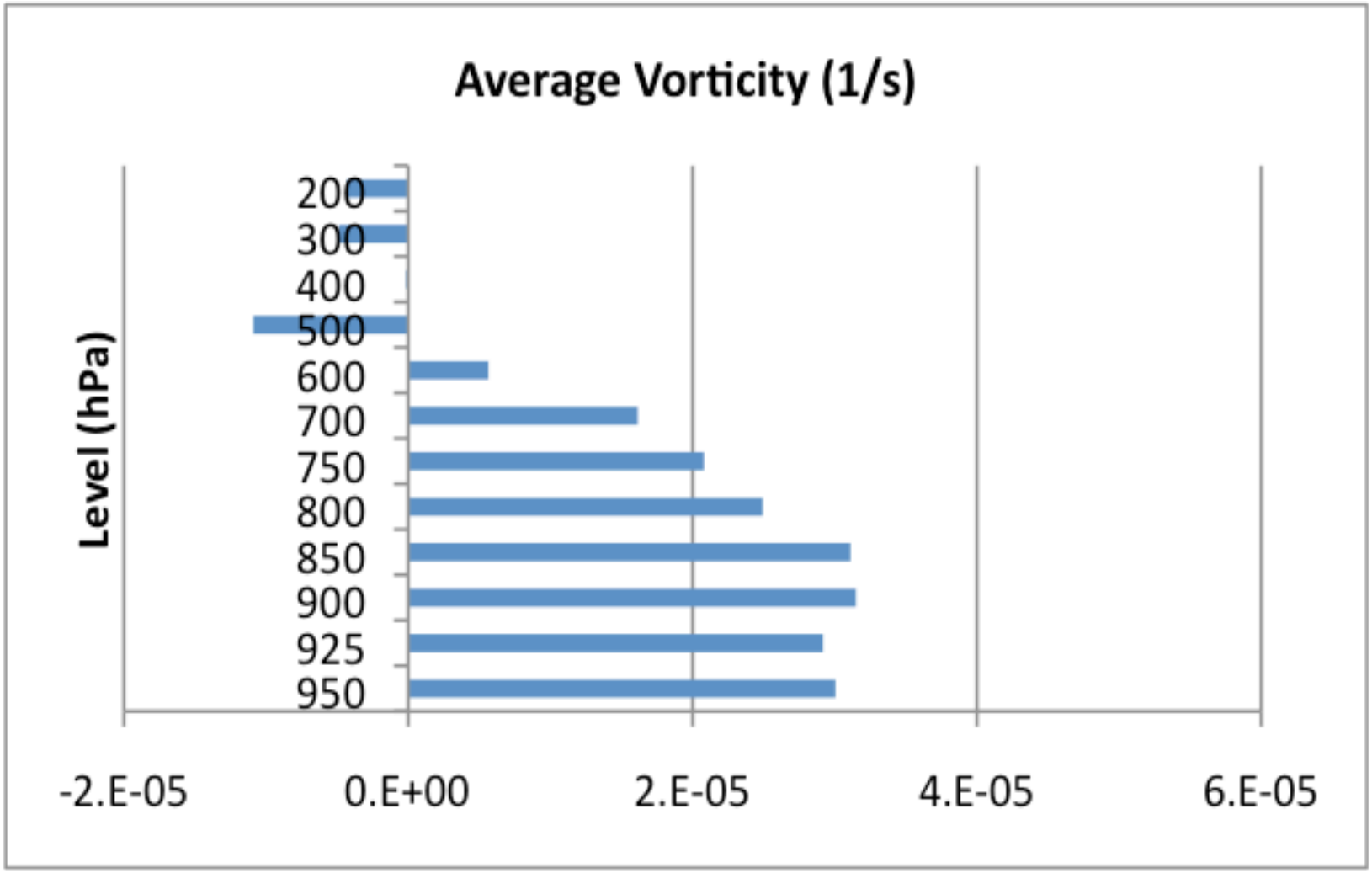
September 5



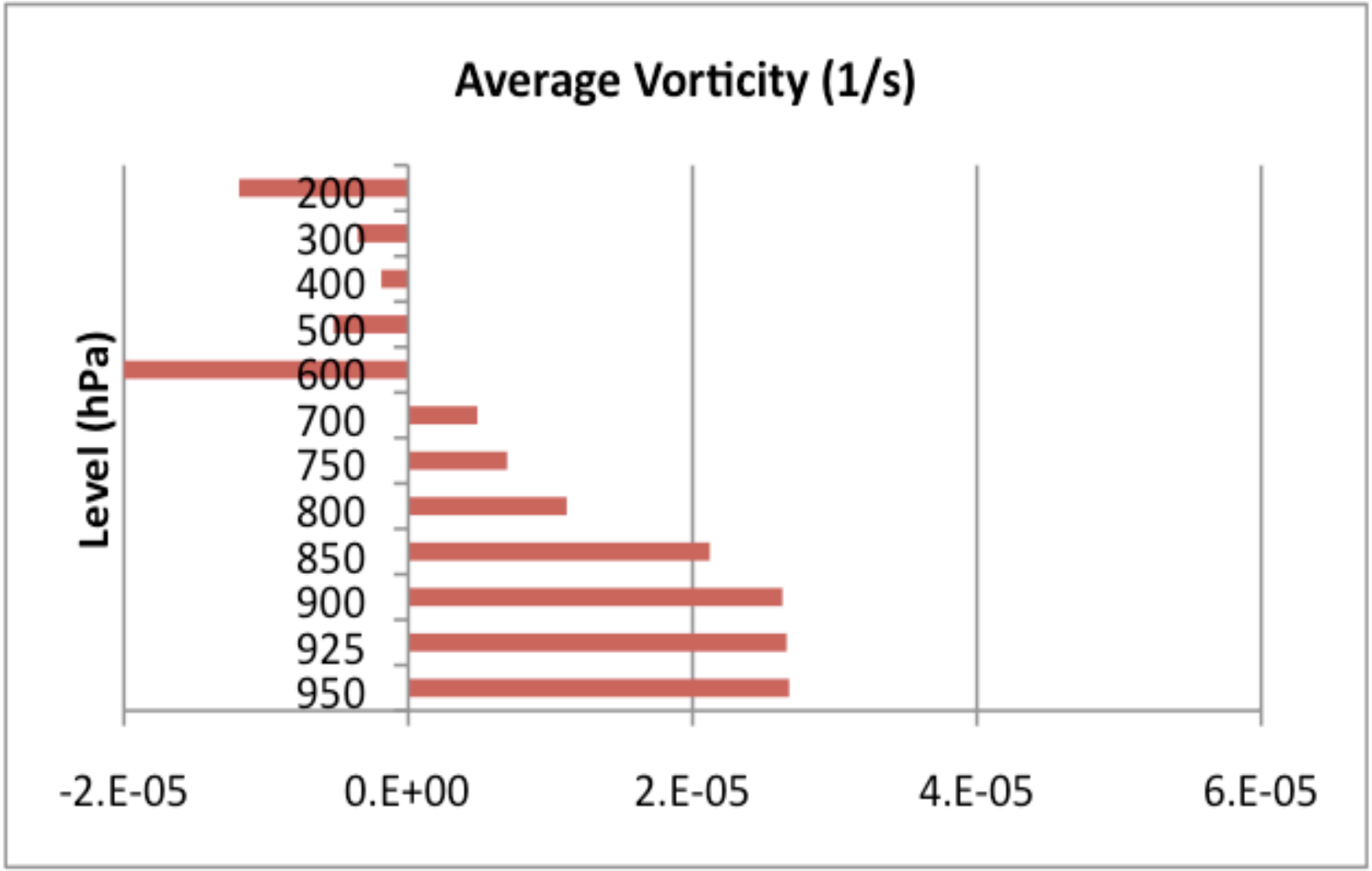
Mark Boothe, NPS

September 6



Mark Boothe, NPS

September 7



Mark Boothe, NPS

Other Publications on the 'Marsupial' Paradigm

1. Dunkerton, T.J., M.T. Montgomery, and Z. Wang, 2009: Tropical cyclogenesis in a tropical wave critical layer: Easterly waves. *Atmos. Chem. & Phys., 9, 5587-5646*.
2. Wang, Z., M. T. Montgomery, and T. J. Dunkerton, 2009: A dynamically-based method for forecasting tropical cyclogenesis location in the Atlantic sector using global model products, *Geophys. Res. Lett.*, 36, L03801, doi:10.1029/2008GL035586.
3. Montgomery, M. T., Z. Wang, and T. J. Dunkerton, 2009: Coarse, Intermediate and High Resolution Numerical Simulations of the Transition of a Tropical Wave Critical Layer to a Tropical Depression. *Atmos. Chem. & Phys., 10, 10803-10827*.
4. Wang, Z., M. T. Montgomery, and T. J. Dunkerton, 2010: Genesis of Pre-hurricane Felix. Part I: The Role of the Wave Critical Layer. *J. Atmos. Sci., **67**, 1711–1729.*
5. Wang, Z., M. T. Montgomery and T. J. Dunkerton, 2010: Genesis of Pre-hurricane Felix (2007). Part II: Warm core formation, precipitation evolution and predictability, *J. Atmos. Sci., **67**, 1730–1744*.
6. Montgomery, M. T., L. L. Lussier III, R. W. Moore and, and Z. Wang, 2009: The Genesis of Typhoon Nuri as Observed During the Tropical Cyclone Structure 08 (TCS-08) Field Experiment. Part I: The Role of the Easterly Wave Critical Layer. *Atmos. Chem. Phys., **10**, 9879-9900.*
7. Wang, Z., M. T. Montgomery, and C. Fritz, 2010: A first look at the structure of the wave pouch during the 2009 PREDICT-GRIP "dry run" over the Atlantic, *Mon. Wea. Rev., in review*.
8. Wang, Z., T. J. Dunkerton and M. T. Montgomery, 2011: Application of the Marsupial Paradigm to Tropical Cyclone Formation from Northwestward Propagating Disturbances, *Mon. Wea. Rev., Accepted subject to revision.*

Website: http://www.met.nps.edu/~mtmontgo/publications

End of Presentation

Thank you!