An Overview of Research Activities Related to the Influence of Stratospheric Intrusions on High Impact Non-Convective Wind Events

NASA SPoRT Seminar

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Dr. Emily Berndt

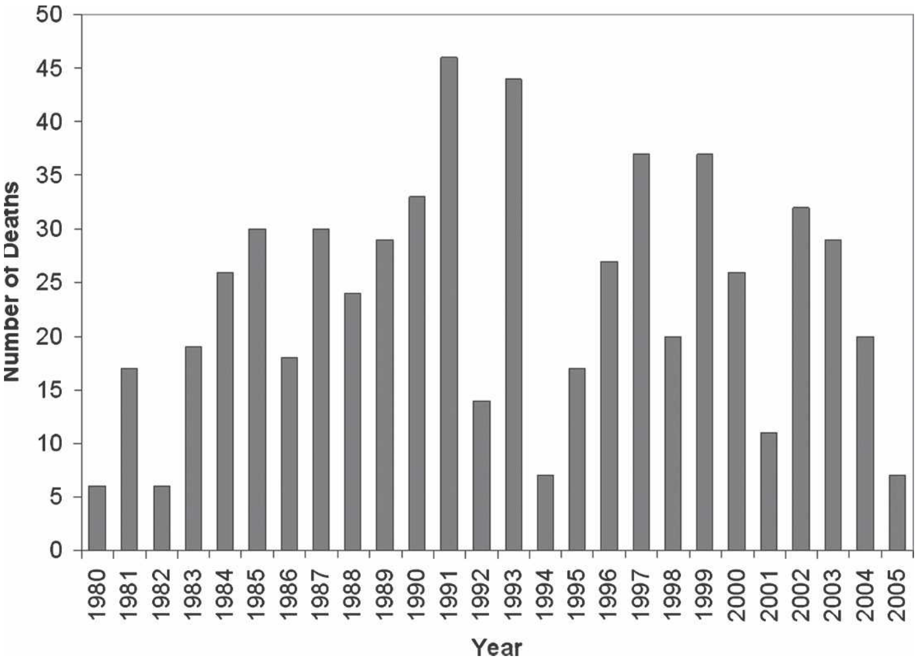
National Space Science and Technology Center, Huntsville, AL

The Problem

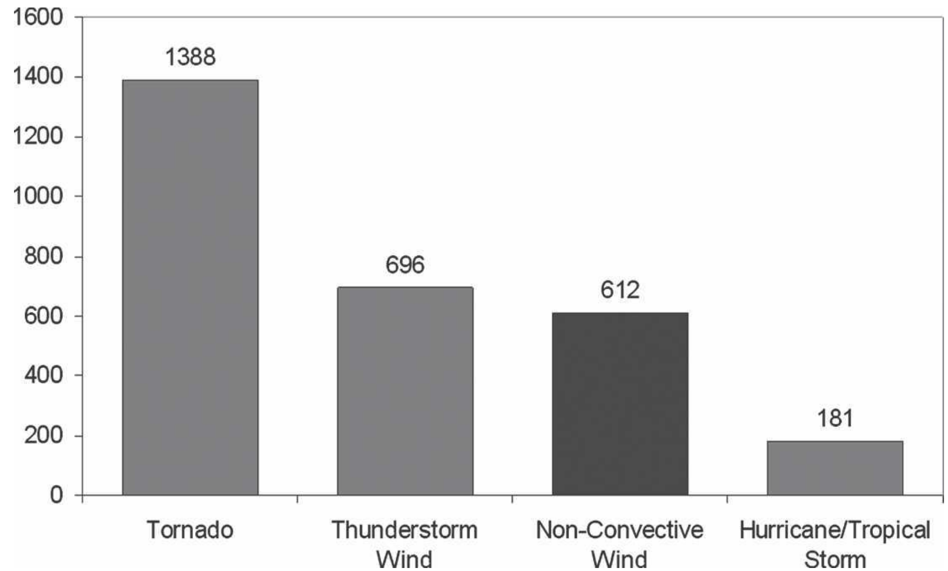
- **Non-convective** winds cause fatalities in the U.S. every year
- They can occur with clear, sunny skies so **people continue daily activities despite the risk**
- Most **fatalities occur in vehicles or outdoors** where objects can be blown over
- **More than 83%** of all **non-convective wind fatalities** are **associated with** the passage of **extratropical cyclones**

(Ashley and Black 2008)

The Problem



Number of non-convective wind fatalities by year, 1980-2005 (Ashley and Black 2008)



Fatalities due to various wind-related hazards, 1980-2005 Tropical system fatalities only include deaths due to wind (Ashley and Black 2008)

Notable Non-Convective Wind Events

Date	Location	Min. SLP (hPa)	Max. wind gust (m/s)	Fatalities	Damage	Comments
5–7 February 1978	New England USA	984	41	13	$1 billion	High winds and record snowfall produced one of the most memorable blizzards in US history; tides 3–4 feet above normal; coastal flooding and erosion; numerous lighthouses damaged
30–31 October 1991	Eastern North America	972	35	5	$200 million	'The Perfect Storm'; a strong coastal cyclone joined with the remnants of Hurricane Grace; wave heights reached 35 feet; long-duration event (114 h) with high wind and waves extending over 3500 km of coastline
29 November 1991	Southern California	1003	34	17	N/A	High winds over the San Joaquin Valley produced a major dust storm that resulted in multiple collisions involving 164 cars along sections of Interstate-5
12–13 March 1993	Eastern USA	960	45	300	$6 billion	'Superstorm' or 'Storm of the Century'; blizzard conditions in New England; high winds, westerly gales behind cold front across mid-Atlantic and southern USA; coastal erosion from Florida to New England
10 November 1998	Great Lakes	963	42	10	$40 million	'Witch of November'; exactly 23 years to the day of the 1975 storm that sank the *Edmund Fitzgerald*
10–11 August 2000	Barrow, Alaska	989	33	0	$7.7 million	Record winds at Barrow; $6 million dredge destroyed, 40 buildings unroofed; Prudhoe Bay recorded near-100-year storm surge
25–27 October 2010	Upper Midwest U.S.	955	35	1	N/A	One of most intense extratropical cyclones on record in lower 48 United States; widespread high winds across upper Midwest

(Knox et al. 2011)

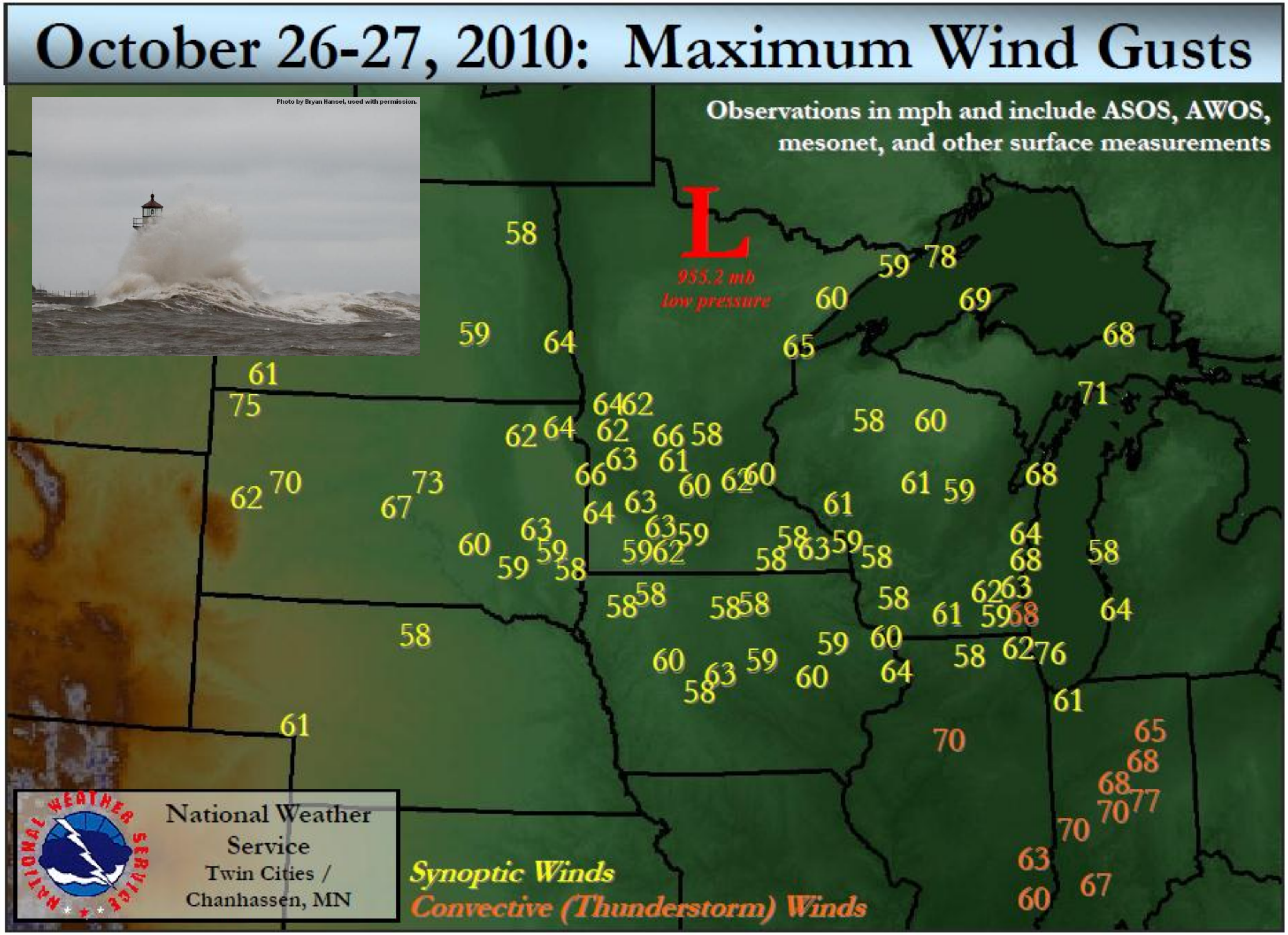
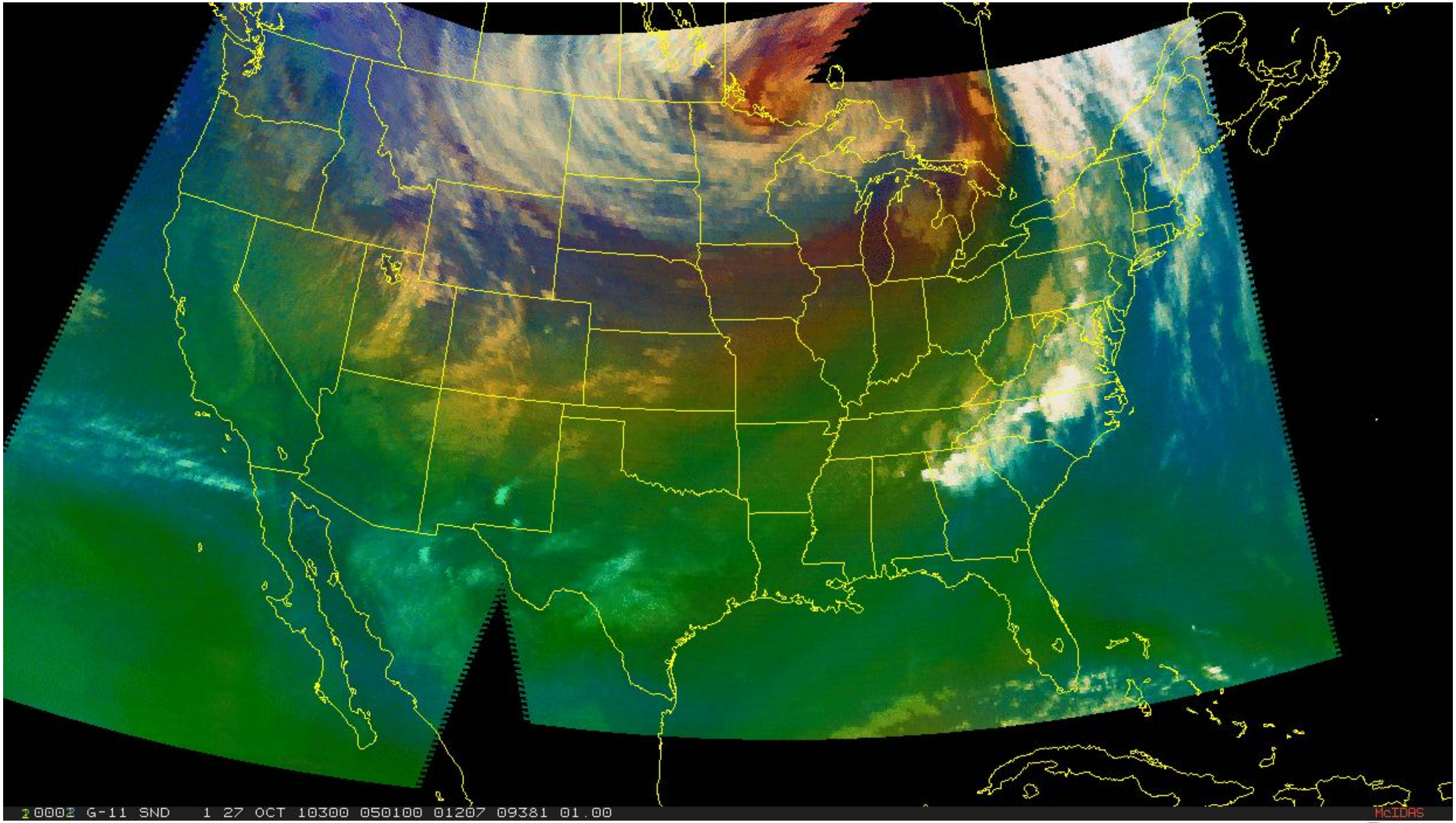


Figure from [Duluth, MN NWS]

[Examples of Damage with European Storms]

Extreme Event 26-27 Oct 2010

How would this imagery help you anticipate strong winds?



The Problem

- Intense extratropical cyclones are often associated with non-convective high winds
- There is no commonly accepted explanation for non-convective high winds but physical explanations include:

Topography

Isallobaric Wind

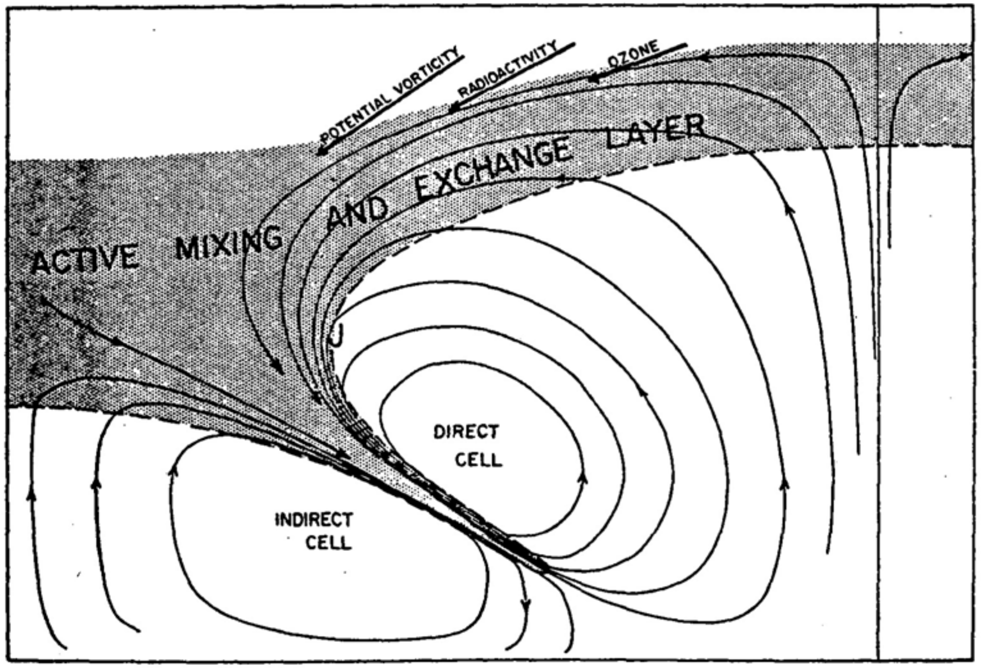
Tropopause Folds

The Sting Jet

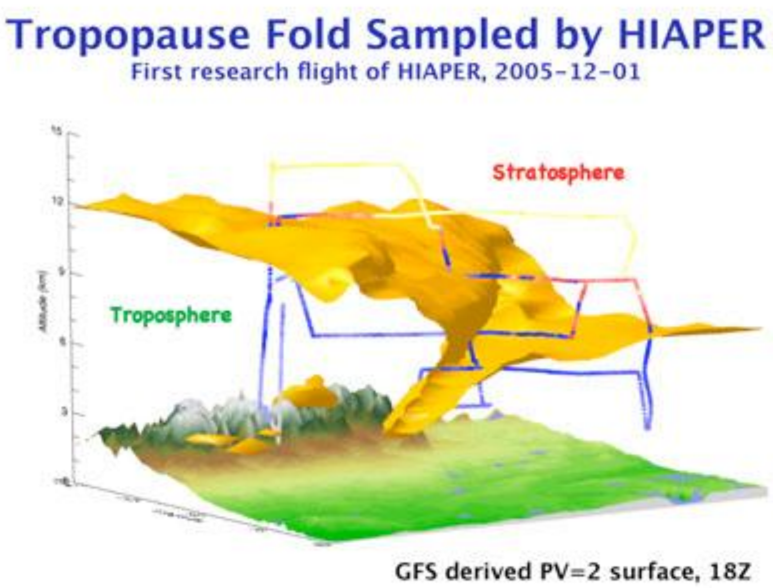
(Knox et al. 2011)

Stratospheric Intrusions & Tropopause Folds

- Stratospheric intrusions and tropopause folds can be identified by the presence of high potential vorticity and warm, dry, ozone-rich air



(Danielson 1968)



(Image by Laura Pan, NCAR, in collaboration with Kenneth Bowman of Texas A&M University.)

Potential Vorticity

- Potential vorticity is a measure of the ratio of absolute vorticity to the depth of the vortex
  - The effective depth is the distance between potential temperature surfaces $-\frac{\partial \theta}{\partial p}$

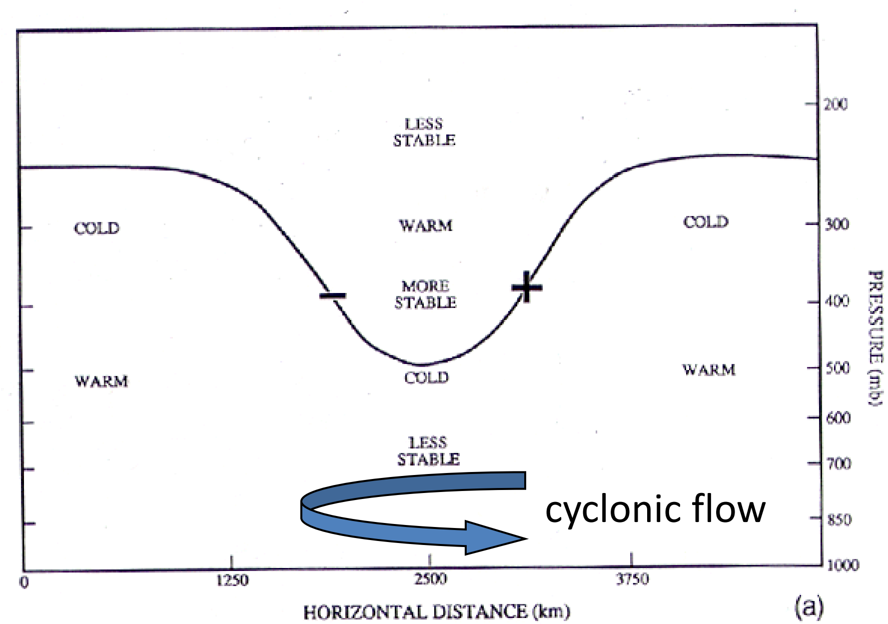
$$P = g(\zeta_\theta + f)\left(-\frac{\partial \theta}{\partial p}\right)$$

Units:
PV = 10^{-6} m^2 s^{-1} K kg^{-1} = 1 PV unit or 1 PVU

  - PV is the product of **absolute vorticity** and **static stability**

Potential Vorticity

- Potential vorticity **increases** rapidly from the troposphere to **stratosphere** due to the **change in static stability**
- **1.5 to 2 PVU** represent the dynamic **tropopause**
- An abrupt **folding** or lowering of the dynamic **tropopause** can also be **called an upper-level PV anomaly**
- Tropopause folding is **most vigorous** during the **winter and spring and** is closely related to strong upper-tropospheric jet streaks



Bluestein (1993, Synoptic-Dynamic Met., vol. II)

Potential Vorticity

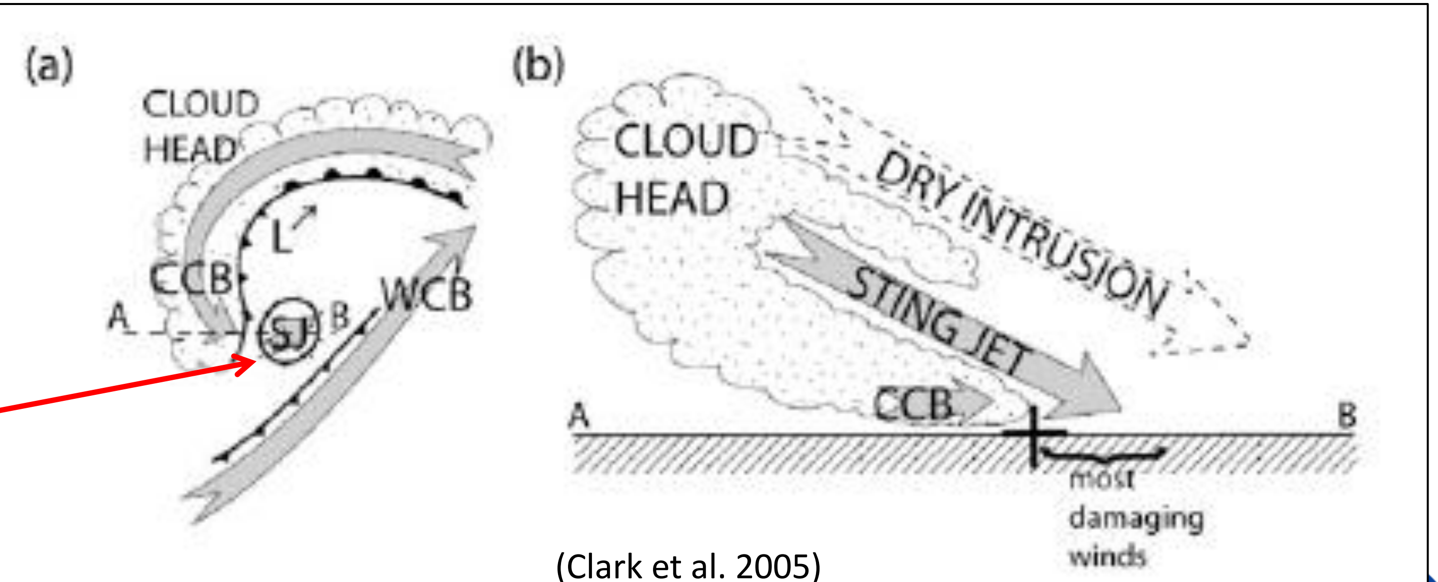
- **High potential vorticity** in the **stratosphere** is attributed to **large static stability**:
  - **Diabatic heating** due to ozone in the stratosphere
  - **Cooling due** to long-wave radiation in the troposphere
- **PV anomalies** can be identified as dark regions on water vapor imagery due to **low relative humidity values**
- **Will assimilation** of satellite **temperature and moisture profiles improve model representation** of stratospheric intrusions/folds?

The Sting Jet

- The Sting Jet is a mesoscale phenomenon believed to cause damaging winds in Oceanic/European cyclones
- Can produce hurricane force wind speeds
- Global distribution of Sting-Jet cyclones is unknown (Martinez-Alvarado et al. 2012)

Defined as "accelerating, drying airflows that descend from the cloud head beneath the dry intrusion (Martinez-Alvarado et al. 2012)

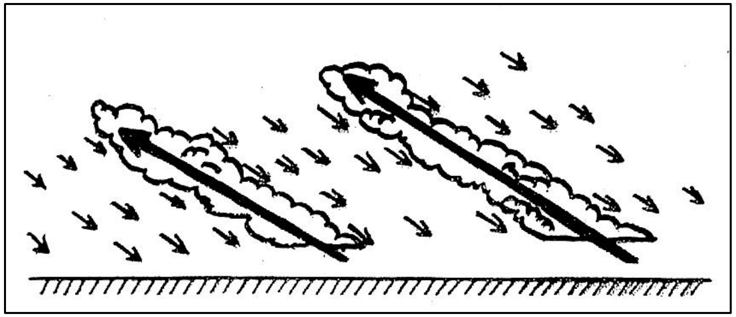
Damaging winds originate from the tip of the comma head cloud



(Clark et al. 2005)

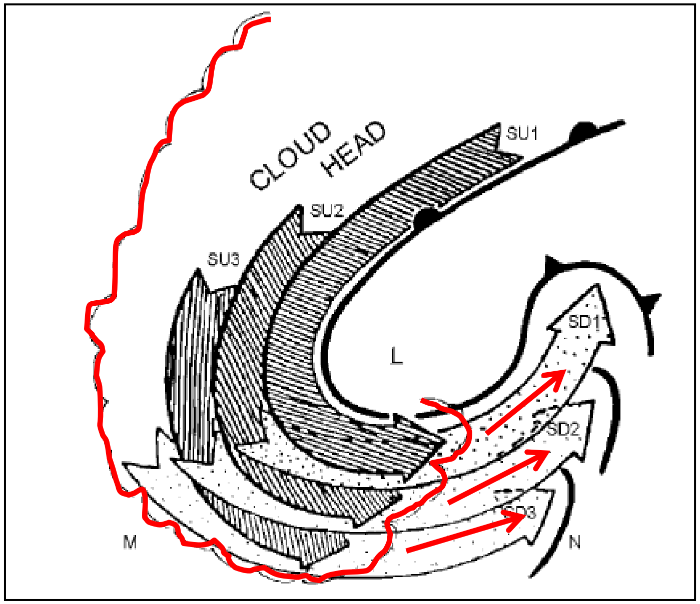
How Can the Sting Jet be Identified?

- The release of Conditional Symmetric Instability (CSI)
  - CSI is a moist instability that occurs when the atmosphere is stable wrt vertical and horizontal displacements and unstable to slantwise displacements



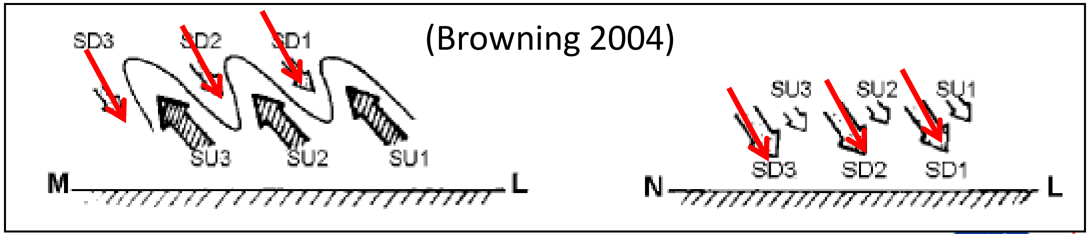
(Emanuel 1984)

Large scale ascent such as frontogenesis and sufficient moisture are necessary to "realize" CSI



Cloud head develops a banded appearance and descent extends beyond the tip of the cloud head

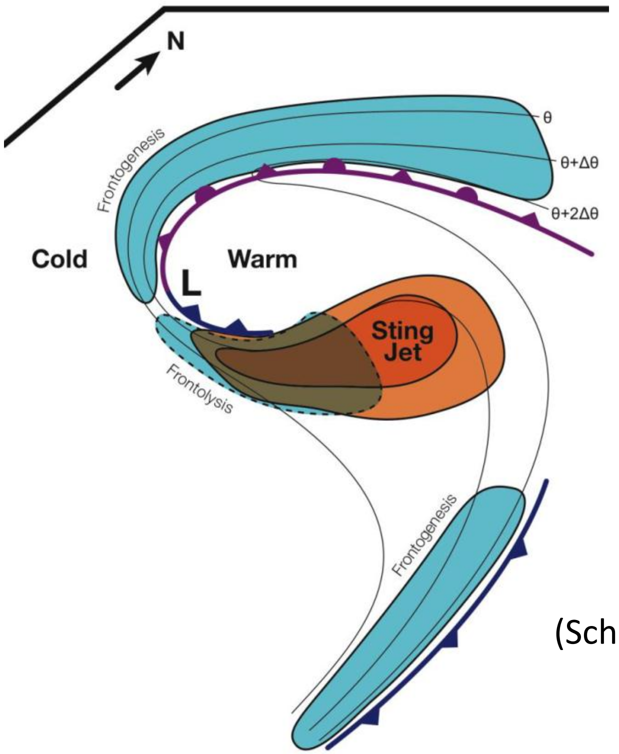
Downdraft Slantwise Convective Available Potential Energy (DSCAPE) has been used to diagnose CSI in Sting Jet cyclones (Martinez-Alvarado et al. 2011)



(Browning 2004)

How Can the Sting Jet be Identified?

- Identify regions of Frontolysis
  - A new hypothesis to explain the physical mechanism of the sting jet.
  - Previous studies identify the release of CSI as the cause of the sting jet, but the mechanism to initiate its release remains unidentified



(Schultz and Sienkiewicz 2013)

Maximum winds downstream of frontolysis

Rapid weakening of the bent-back front creates region of frontolysis, if the surface environment has near-neutral static stability, strong winds can reach the surface via descent

The Problem

- The link between subsiding upper-level air and high surface winds has not been fully established
- Many studies just hint at the "downward transfer of higher momentum air" (Kapela et al. 1995; Knox et al. 2011)
- Current research is still defining the Sting Jet structure and evolution (Schultz and Sienkiewicz 2013)
- Questions remain about the role of stratospheric intrusions in sting jet formation

- ***With the advent of the GOES-R and Suomi NPP missions do we have new tools to further establish this link and improve high wind forecasts through data assimilation?***

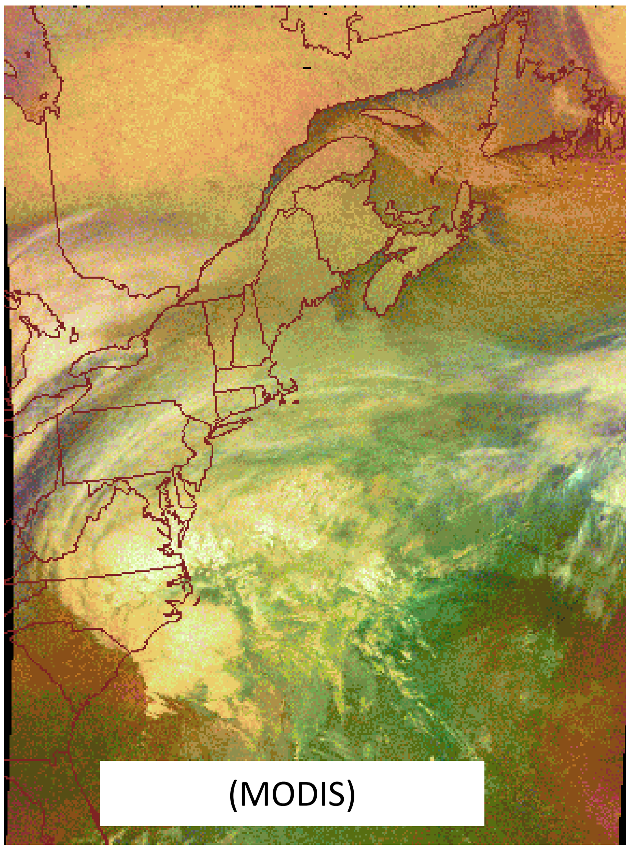
Goals, Expected Results, Significance, & Application

- **Current Activities:**
  - Diagnose the dynamical structure of non-convective high wind events
  - Greater understanding of the role of stratospheric intrusions in producing high impact non-convective wind events
  - Increased knowledge of how to interpret new RGB Air Mass Imagery for forecasting issues
- **Future Activities:**
  - Demonstrate the impact of assimilation of high resolution satellite data on WRF* Model Forecasts
  - Clarify the ability of numerical models to resolve stratospheric intrusions and associated high winds

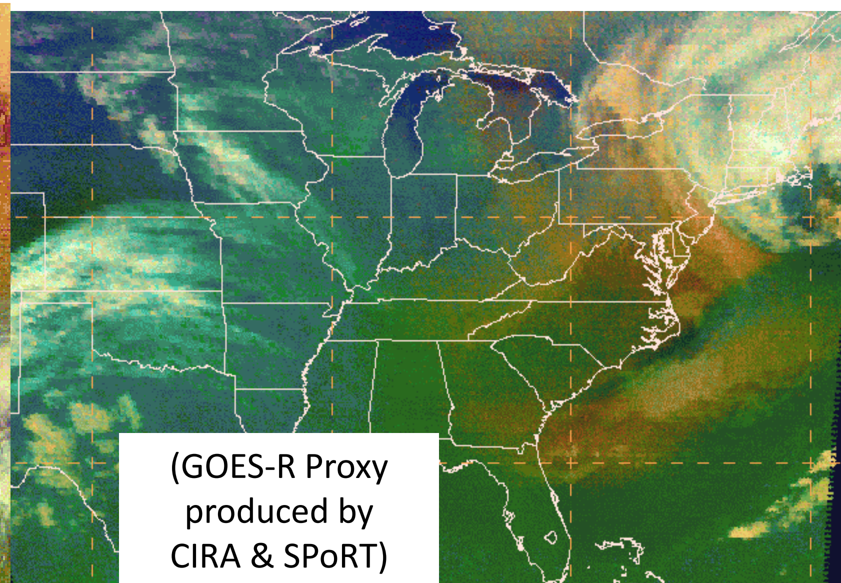
*Advanced Weather Research and Forecasting Model

Satellite Products

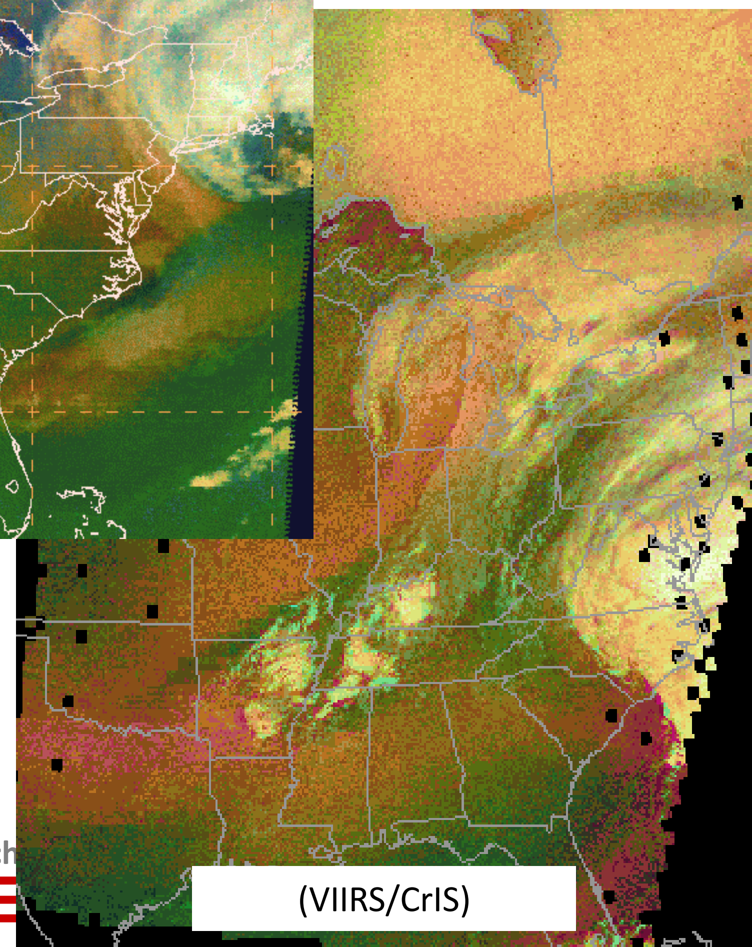
- RGB Air Mass Imagery
- Orange regions denote warm, dry, ozone-rich stratospheric air



(MODIS)

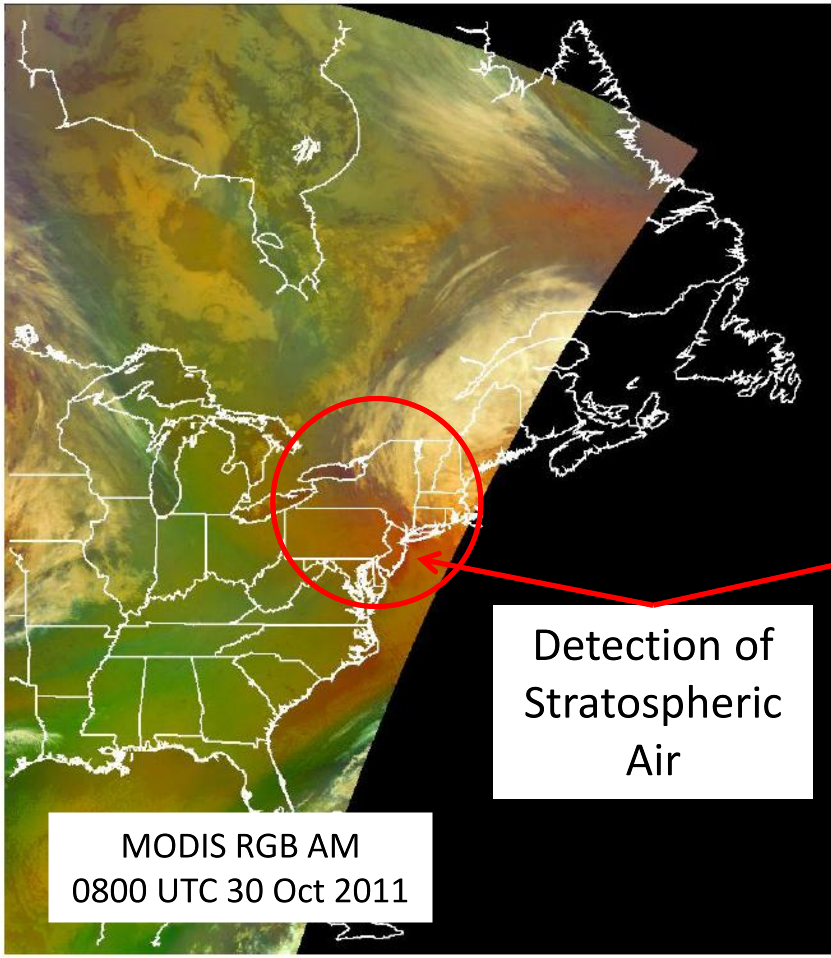


(GOES-R Proxy produced by CIRA & SPoRT)

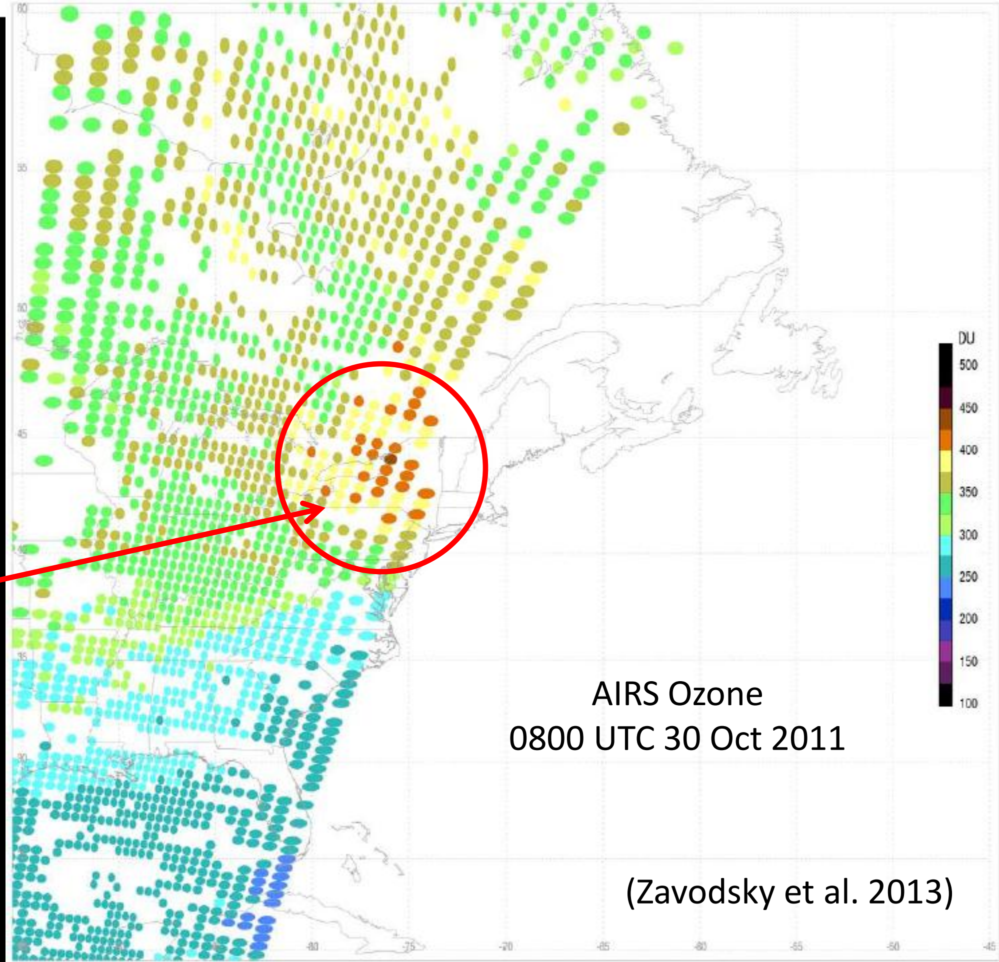


(VIIRS/CrIS)

Satellite Products

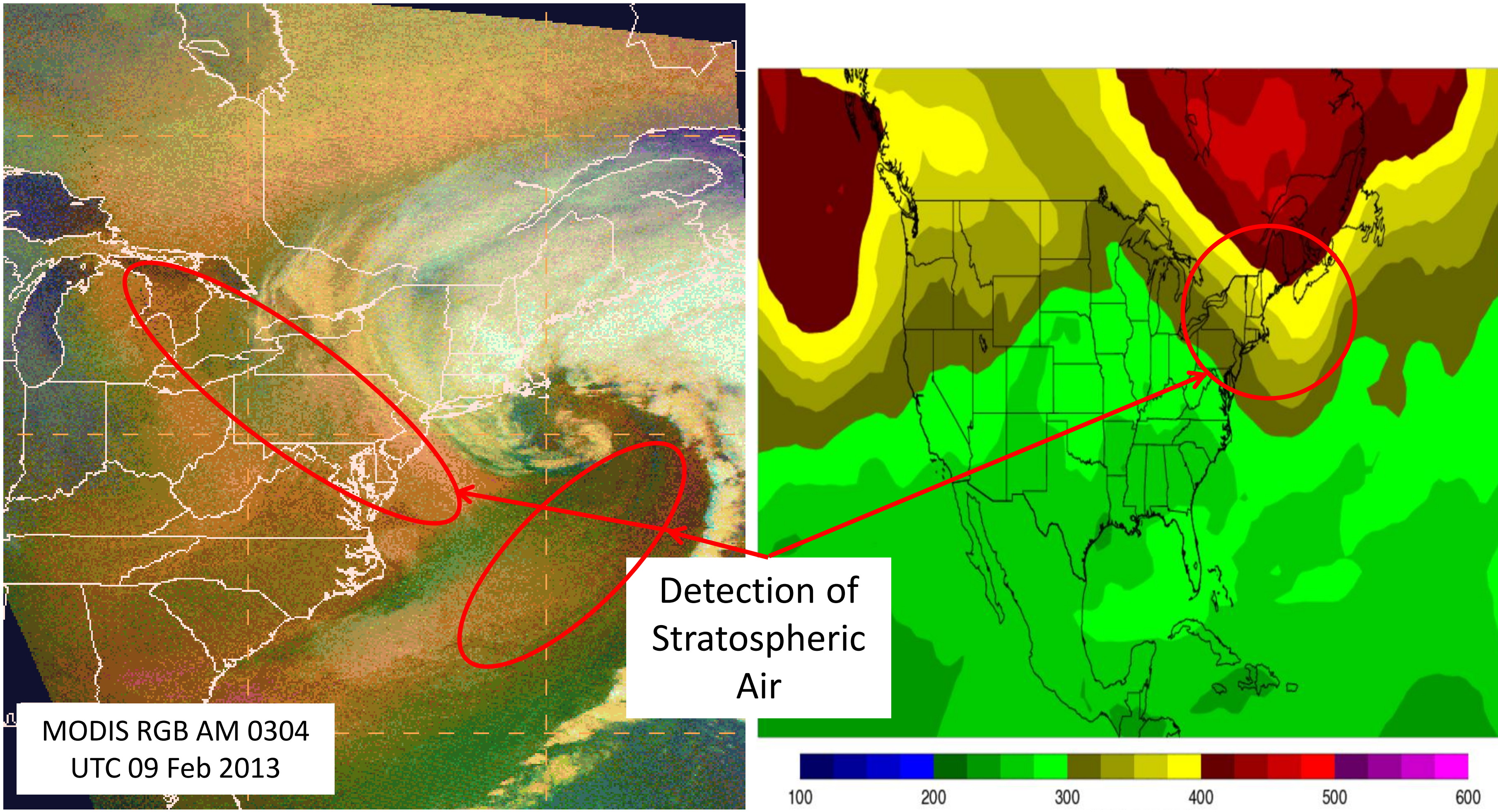


Detection of Stratospheric Air



Transitioning unique data and research technologies to operations

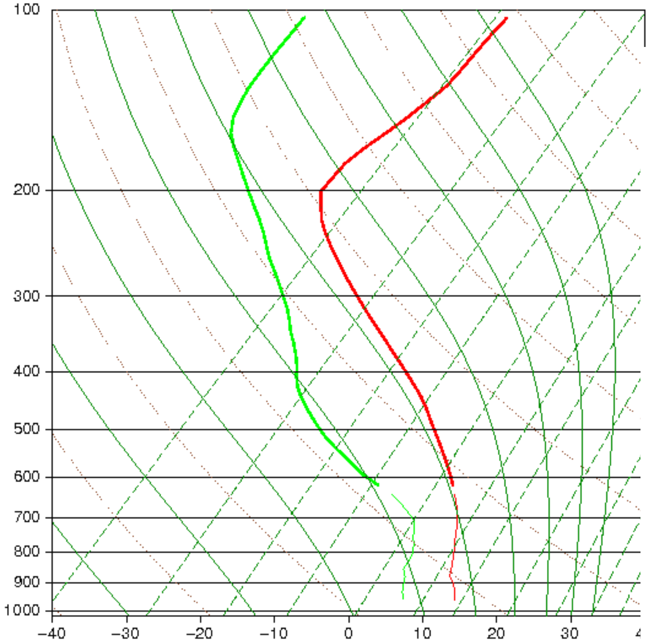
Satellite Products



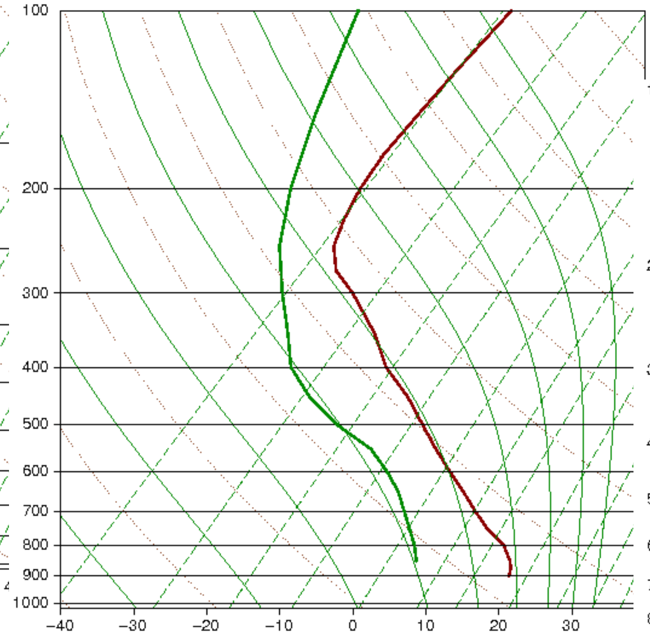
OMPS Daily Ozone 08 Feb 2013

Satellite Products

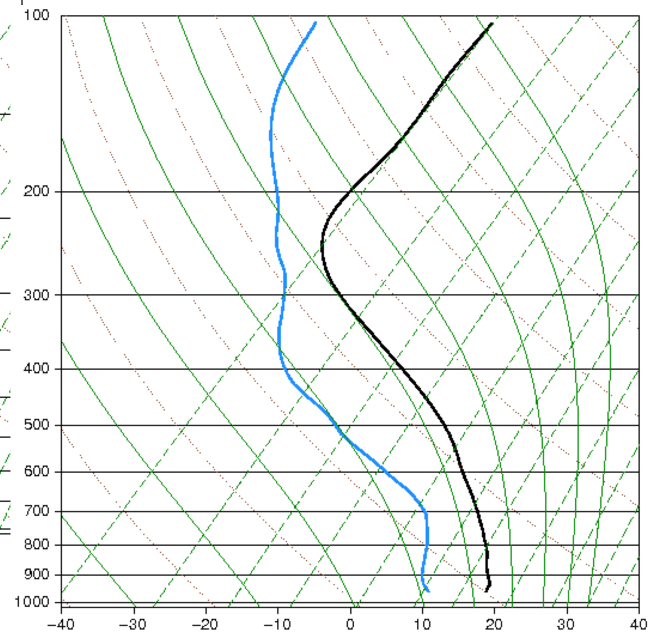
- Temperature and moisture profiles
- Profiles will verify RGB Air Mass Imagery and be assimilated into WRF Model runs



AIRS
Temperature (red)
Dew Point (green)



CrIMSS (CrIS/ATMS)
Temperature (red)
Dew Point (green)



IASI
Temperature (black)
Dew Point (blue)

Data & Analysis Tools

- Data
  - Archived surface and upper air **observations** from Unidata's IDD Network
  - 1.25° x 1.25° Modern-Era Retrospective Analysis for Research and Applications (**MERRA Reanalysis**)
  - 13 km **RUC/RAP** from ARM Climate Research Facility
- Analysis Tools

GrADS

COLA

Perl & IDL

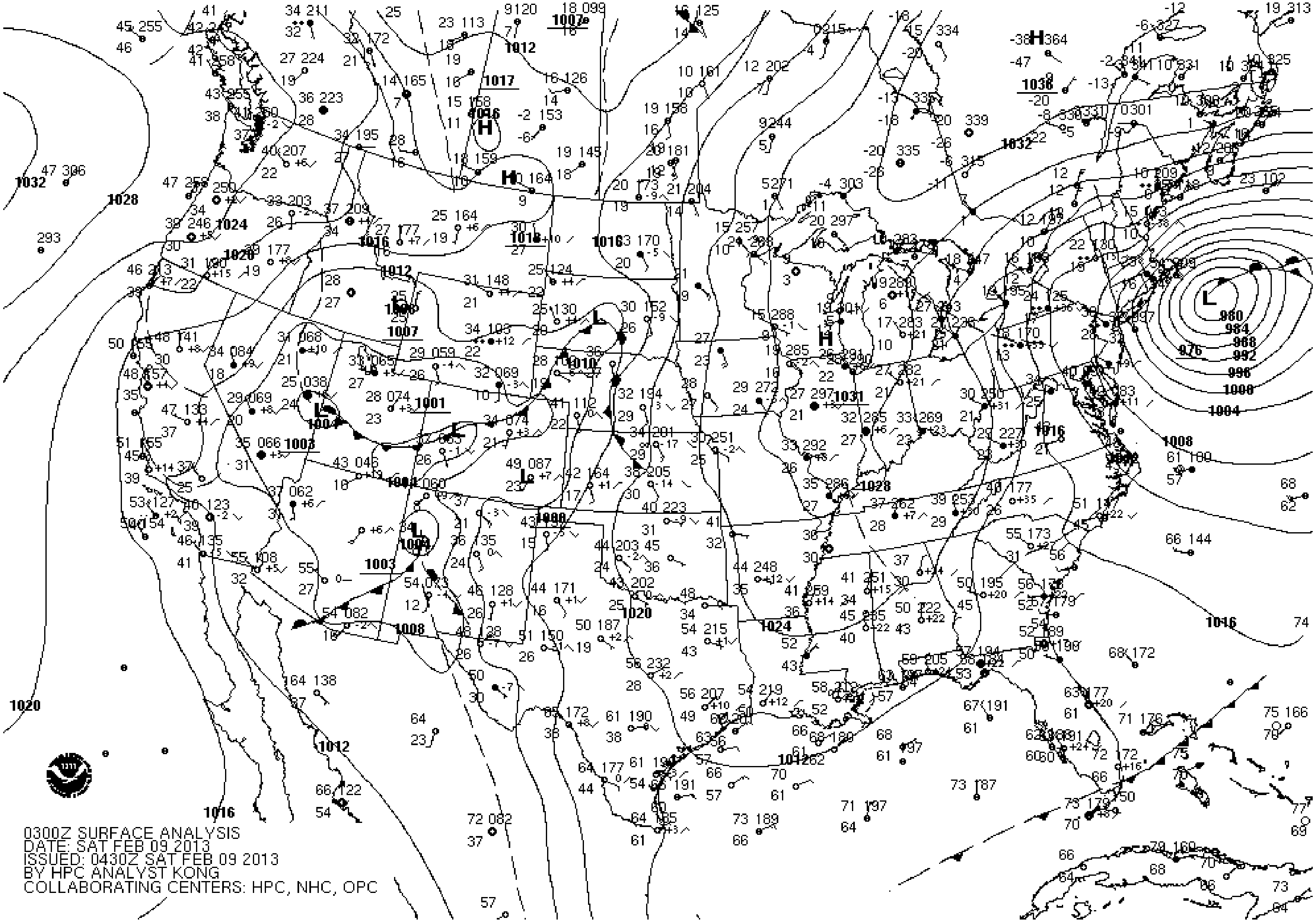
Methodology

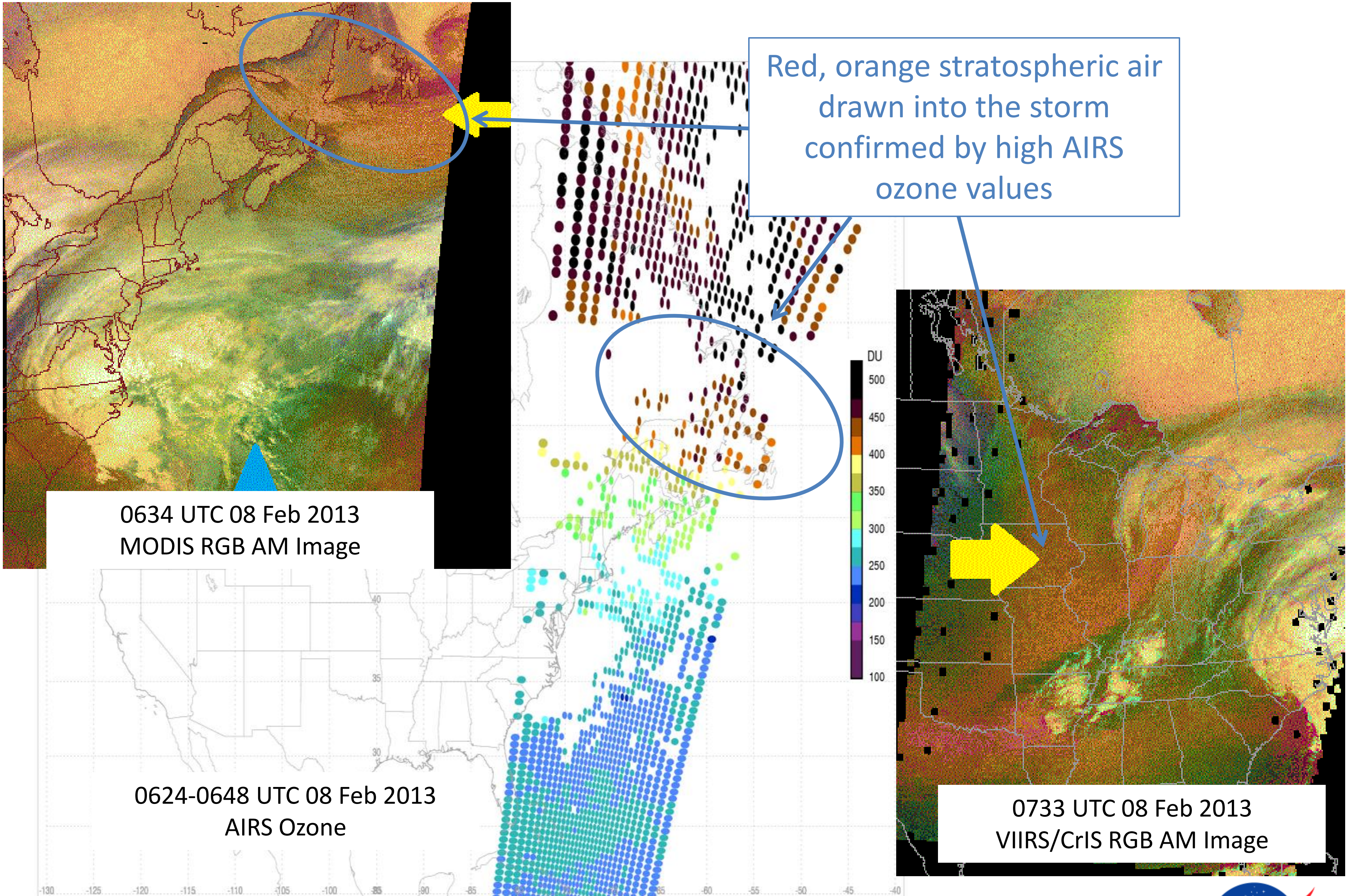
- Study High-Impact Events
  - 26 October 2010 (Mid West) – previous research
  - 30 October 2011 (Northeast) – previous research
  - 29 February 2012 (Mid West)
  - 9 February 2013 (Northeast)
  - 7 March 2013 (Northeast)

Methodology

- Current Activities
  - Diagnostic Analysis of Satellite Imagery
  - Determine the role of stratospheric intrusions in creating high surface winds
    - Compare RGB Air Mass imagery to
      - AIRS/OMPS Ozone
      - AIRS, CrIMSS (CrIS/ATMS), and IASI Temperature and Moisture Profiles
      - Observations, MERRA Reanalysis, and 13 km RUC/RAP data to assess storm characteristics such as gusts, wind, potential vorticity, omega, relative humidity, and frontogenesis
      - HYSPLIT Trajectories to assess conveyor belts

Northeast Event 09 February 2013





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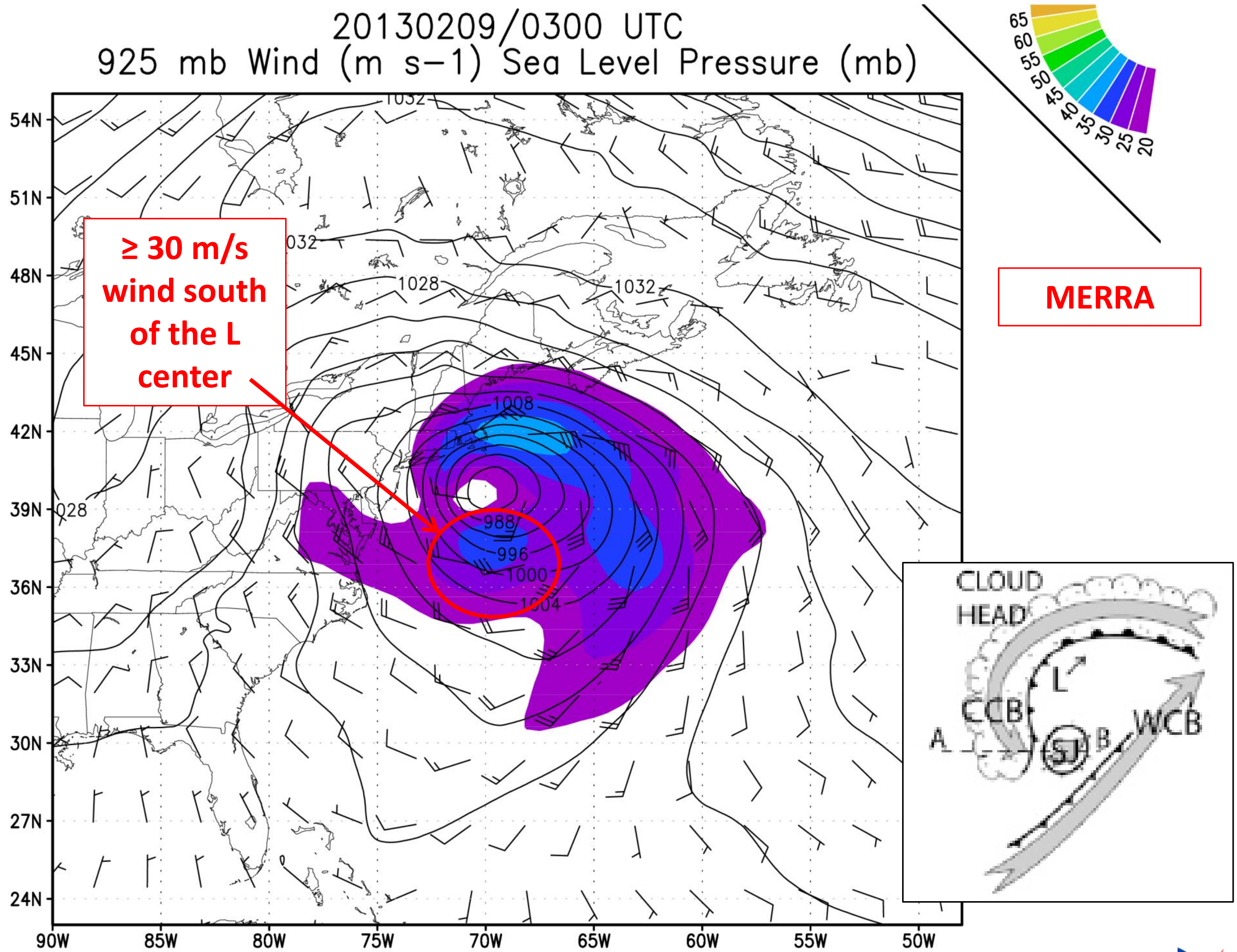

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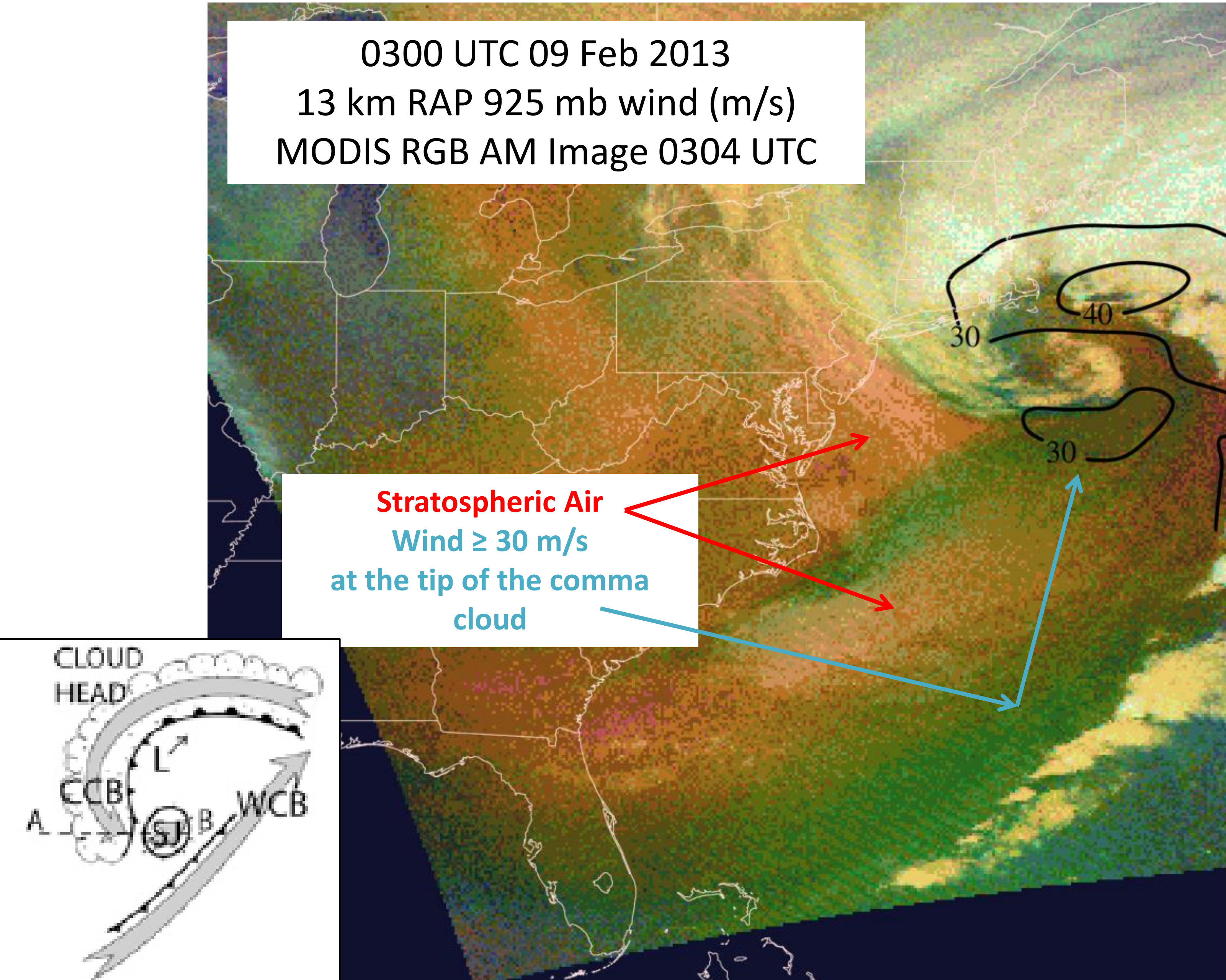
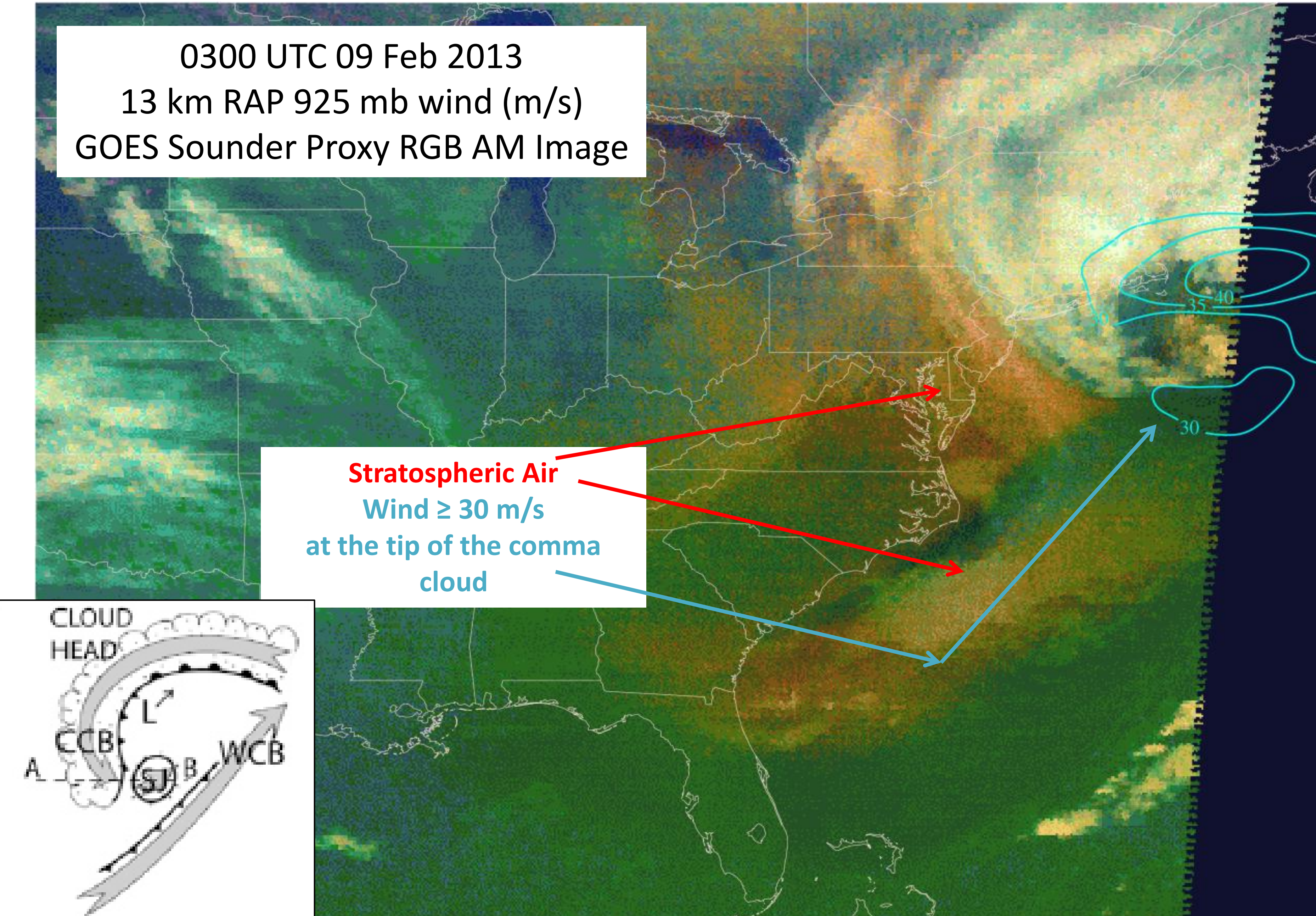
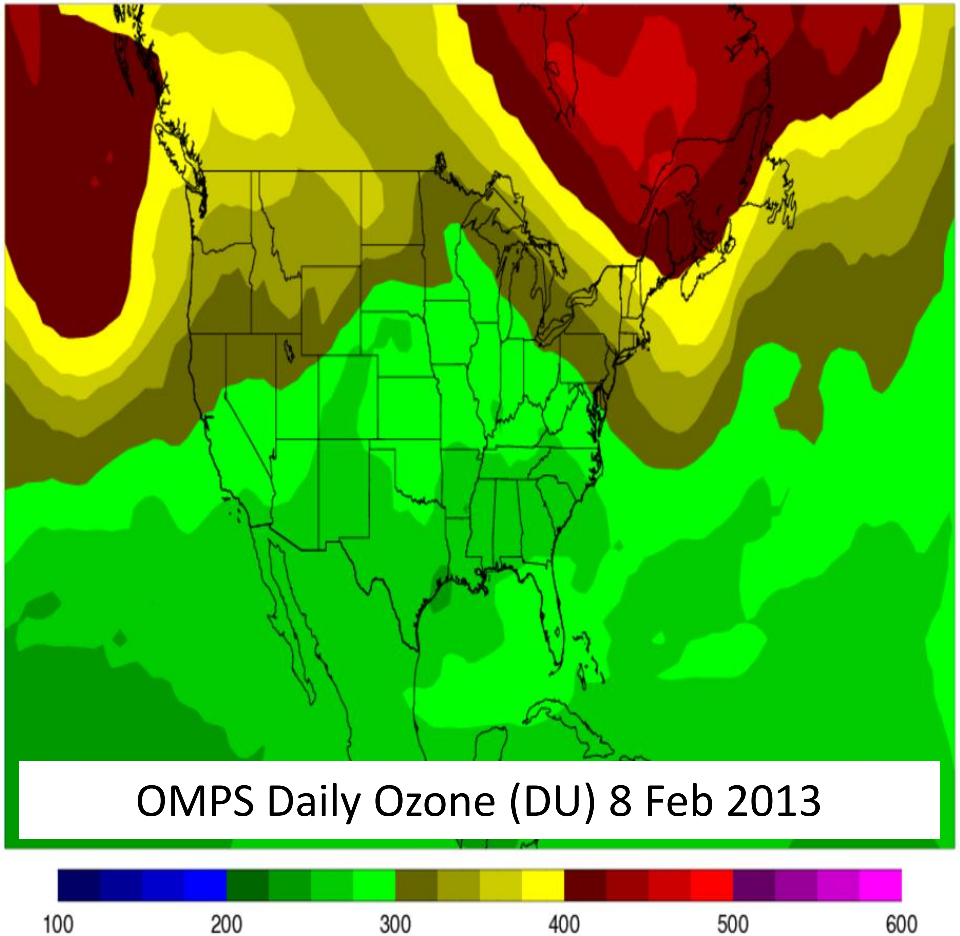
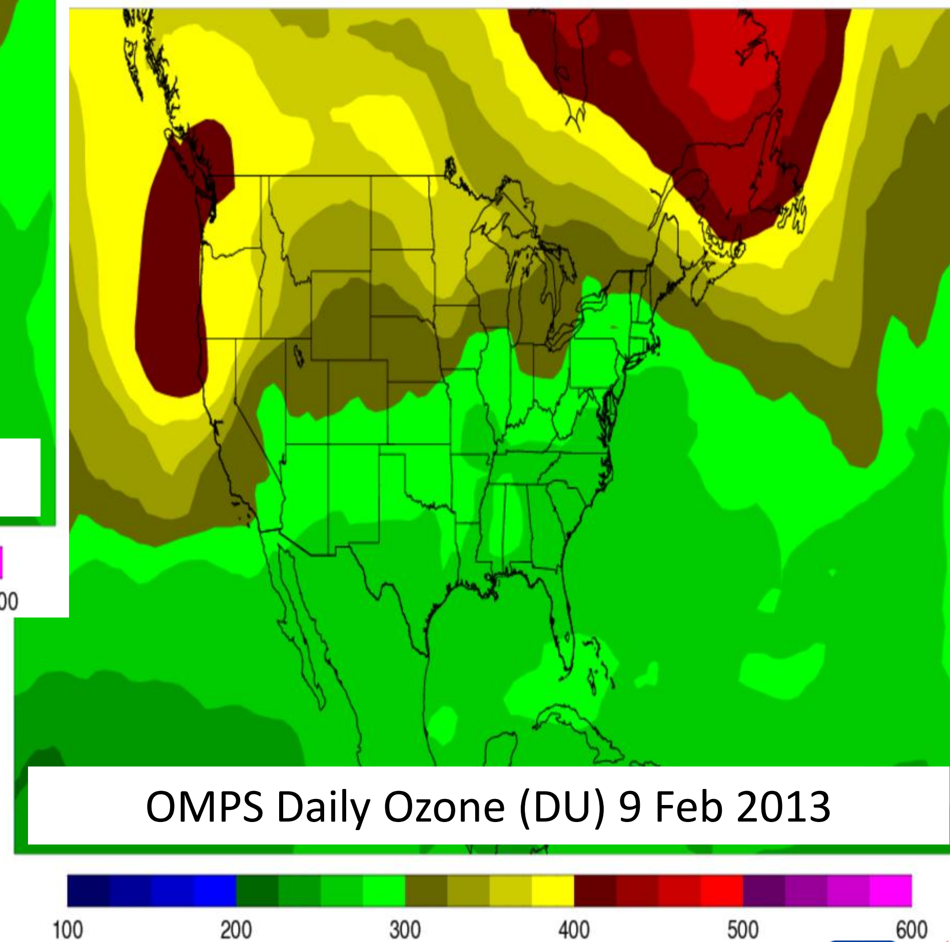

0300 UTC 09 Feb 2013
13 km RAP 925 mb wind (m/s)
MODIS RGB AM Image 0304 UTC
30
40
30
Stratospheric Air
Wind ≥ 30 m/s
at the tip of the comma
cloud
CLOUD
HEAD
L
CCB
A
SJ
B
WCB

0300 UTC 09 Feb 2013
13 km RAP 925 mb wind (m/s)
GOES Sounder Proxy RGB AM Image

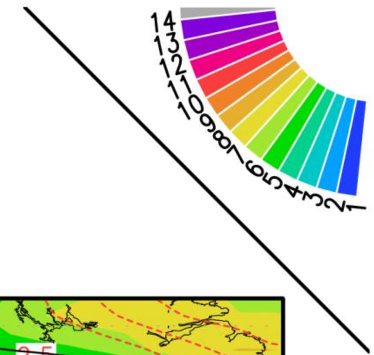


Stratospheric Air
Wind ≥ 30 m/s
at the tip of the comma cloud

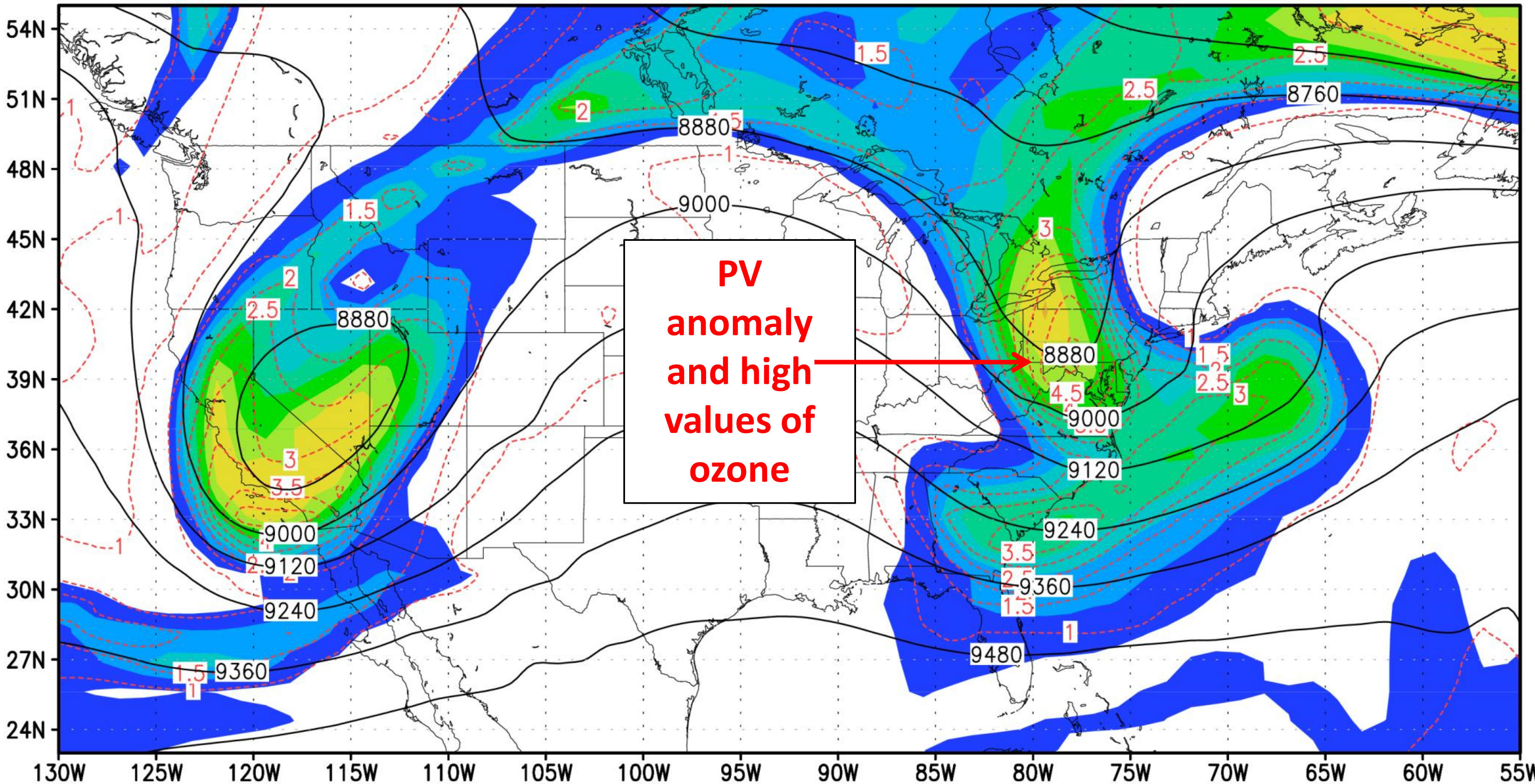

OMPS Daily Ozone (DU) 8 Feb 2013
100
200
300
400
500
600

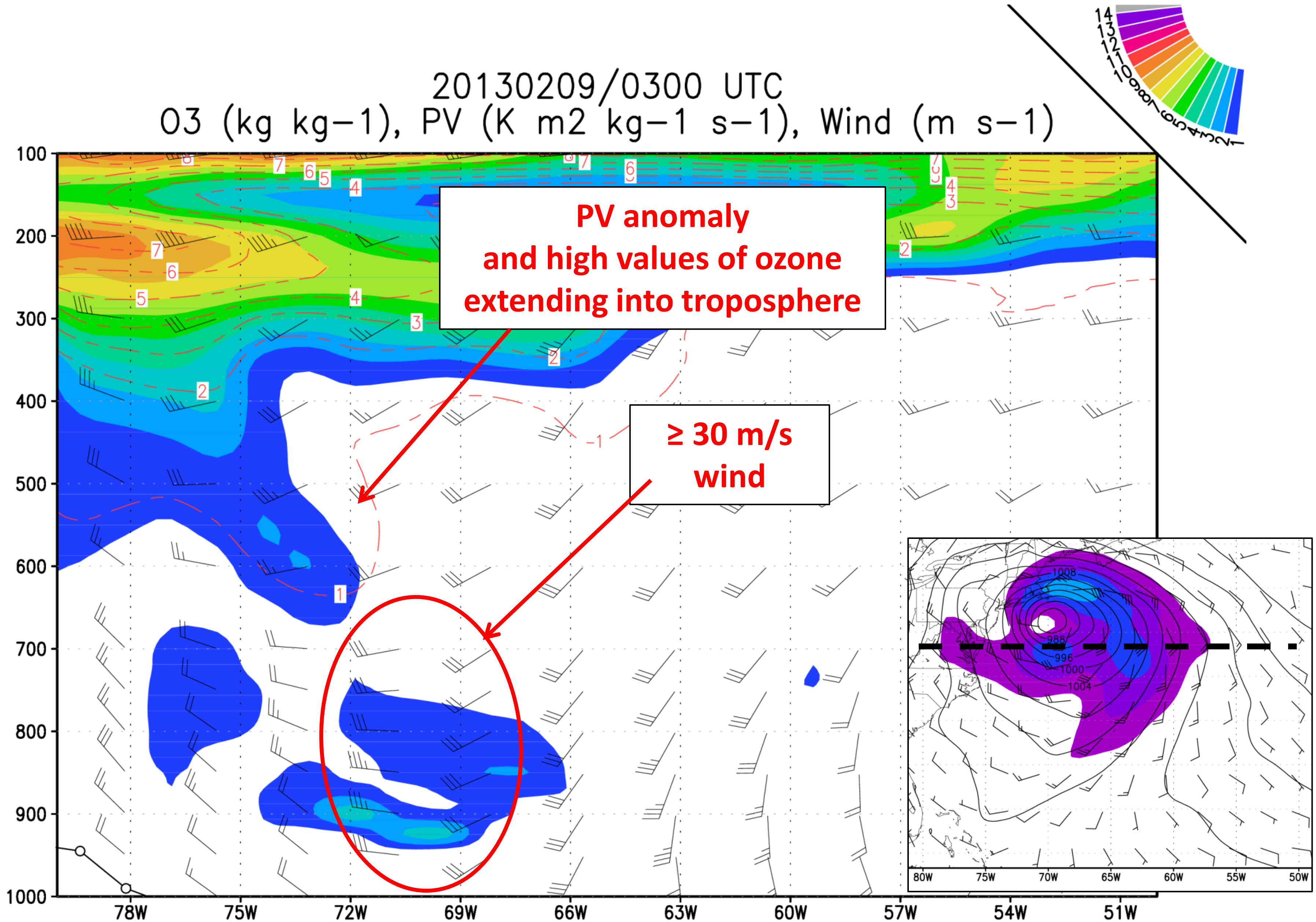

OMPS Daily Ozone (DU) 9 Feb 2013
100
200
300
400
500
600

MERRA

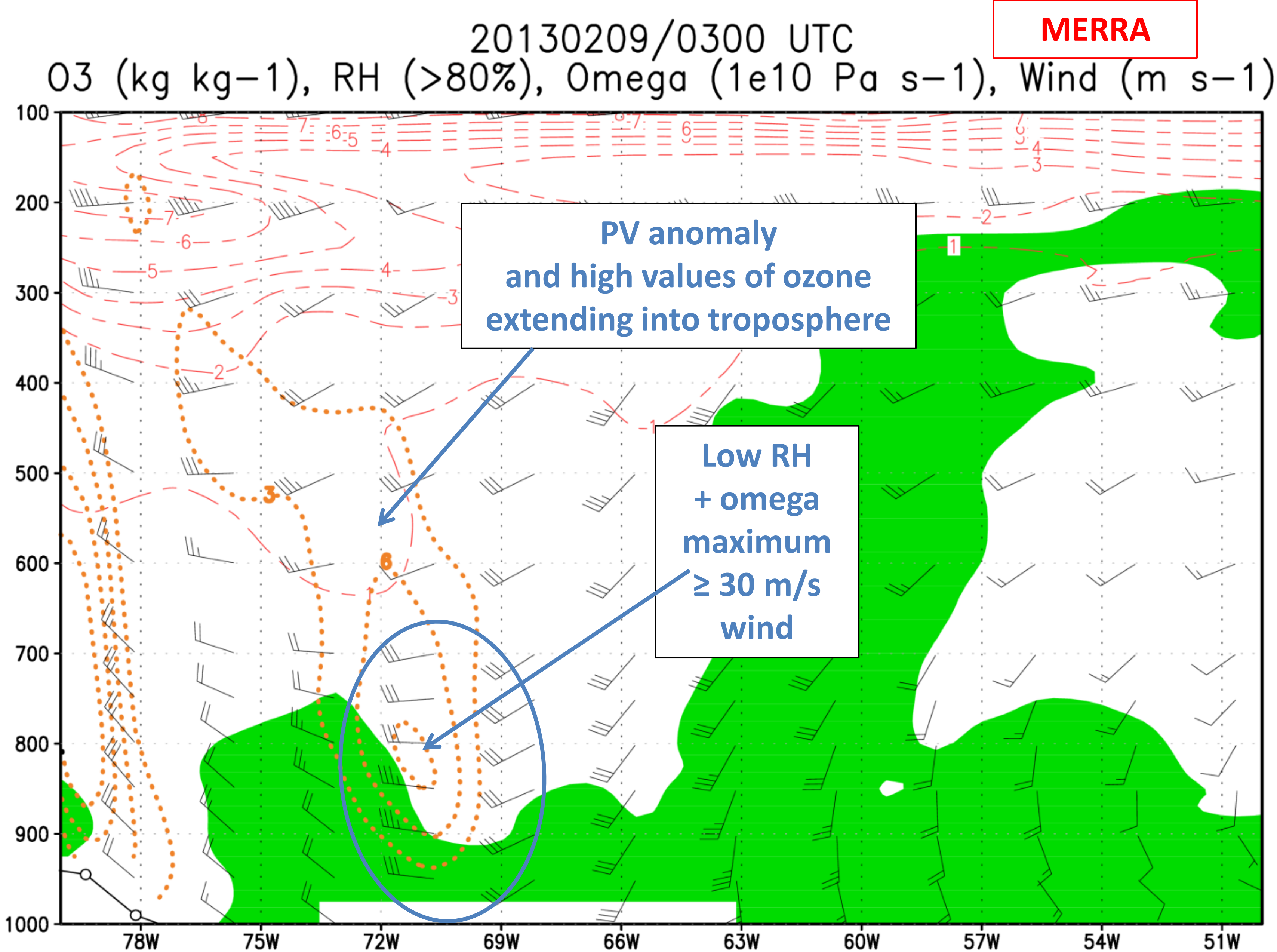


20130209/0300 300 mb O3 (kg kg−1), PV (K m2 kg−1 s−1) and Height (m)





20130209/0300 UTC
O3 (kg kg−1), PV (K m2 kg−1 s−1), Wind (m s−1)
PV anomaly
and high values of ozone
extending into troposphere
≥ 30 m/s
wind



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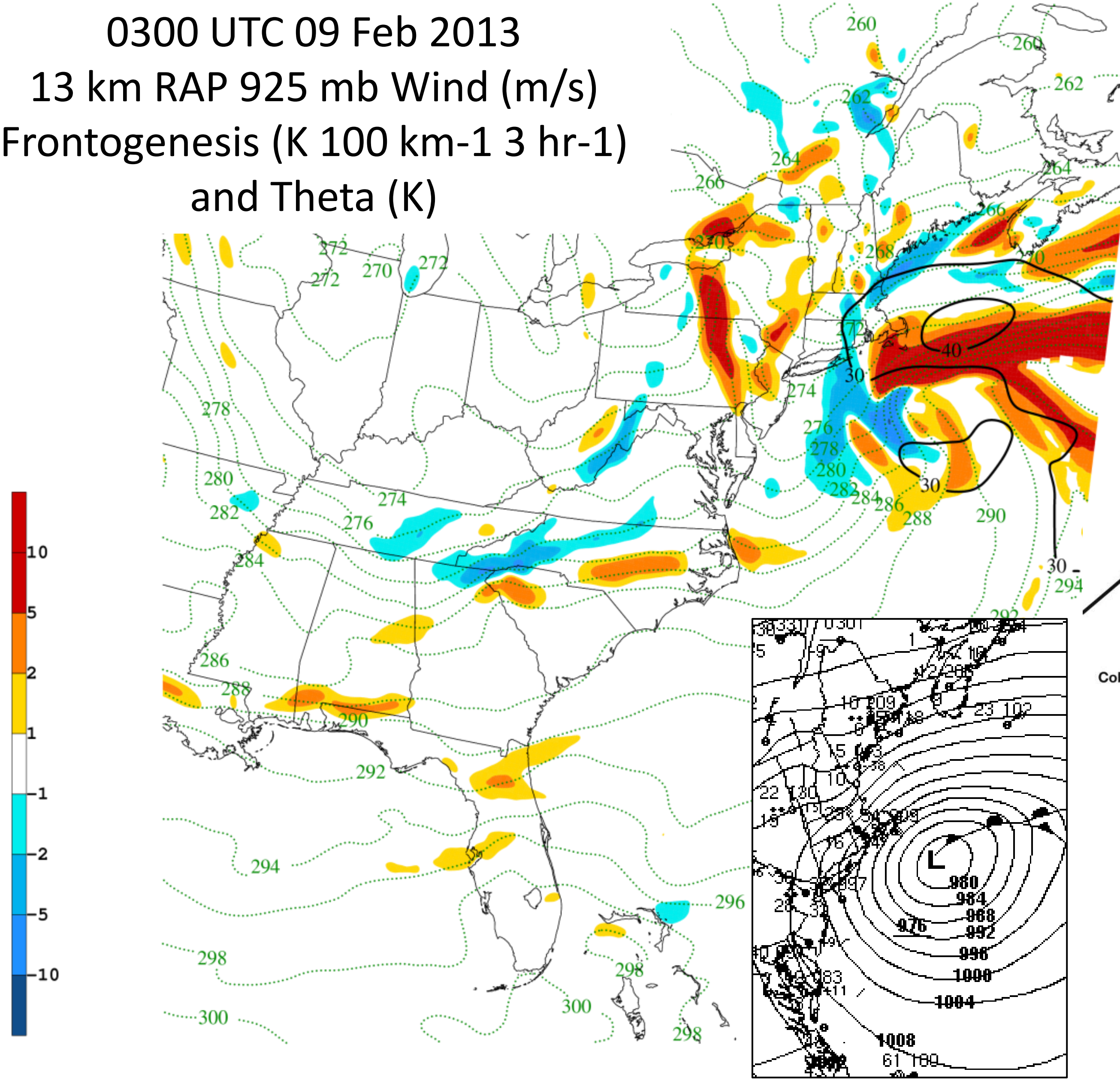
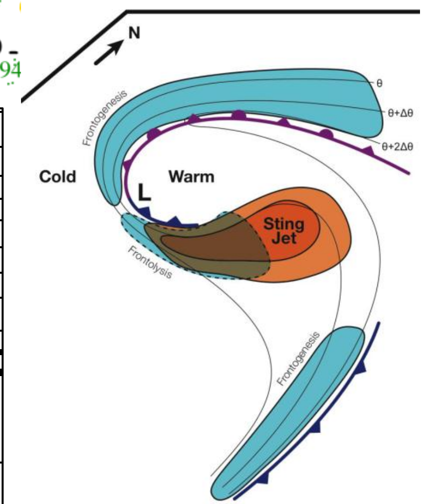
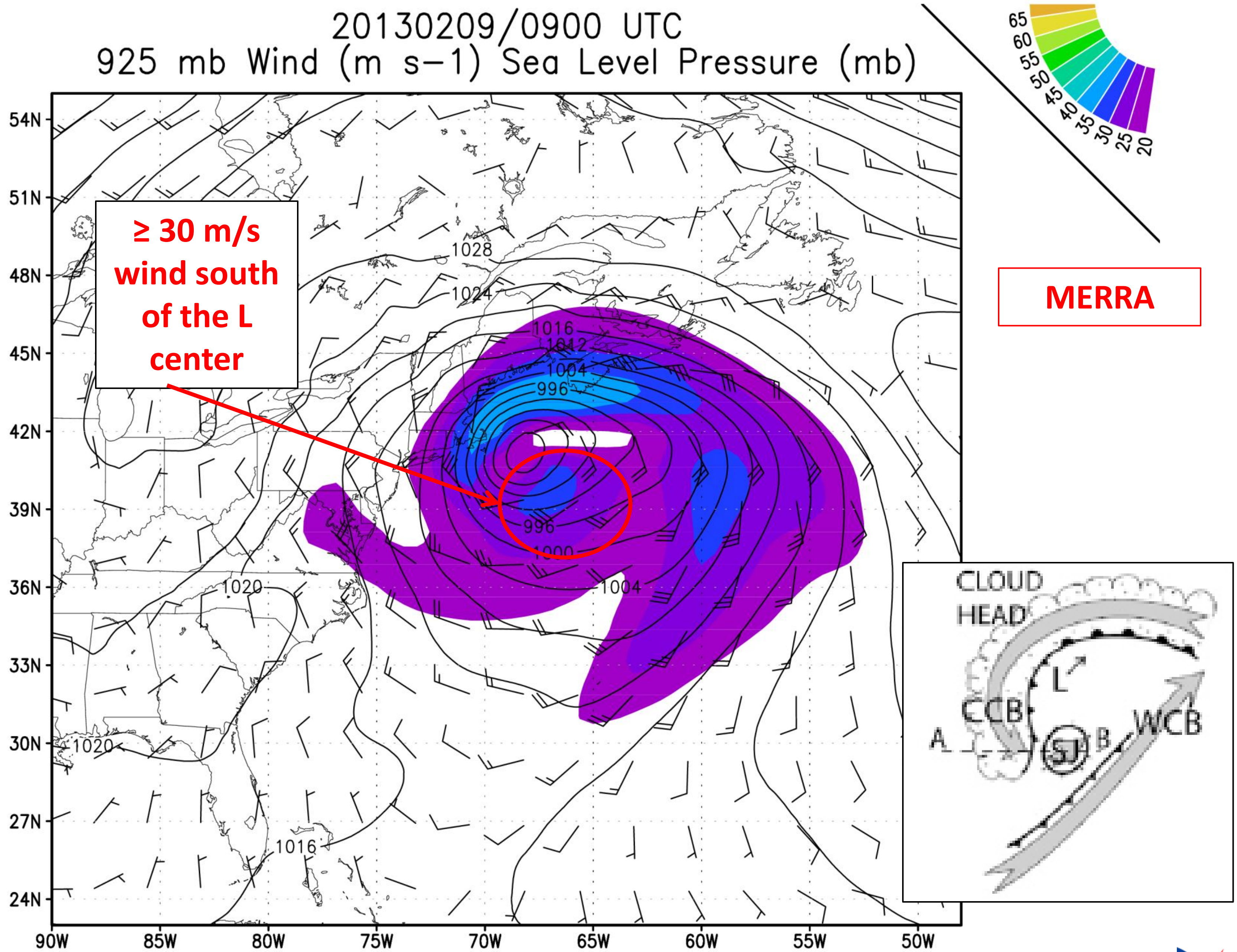
0300 UTC 09 Feb 2013
13 km RAP 925 mb Wind (m/s)
Frontogenesis (K 100 km-1 3 hr-1)
and Theta (K)






20130209/0900 UTC
925 mb Wind (m s−1) Sea Level Pressure (mb)
≥ 30 m/s wind south of the L center
MERRA
65
60
55
50
45
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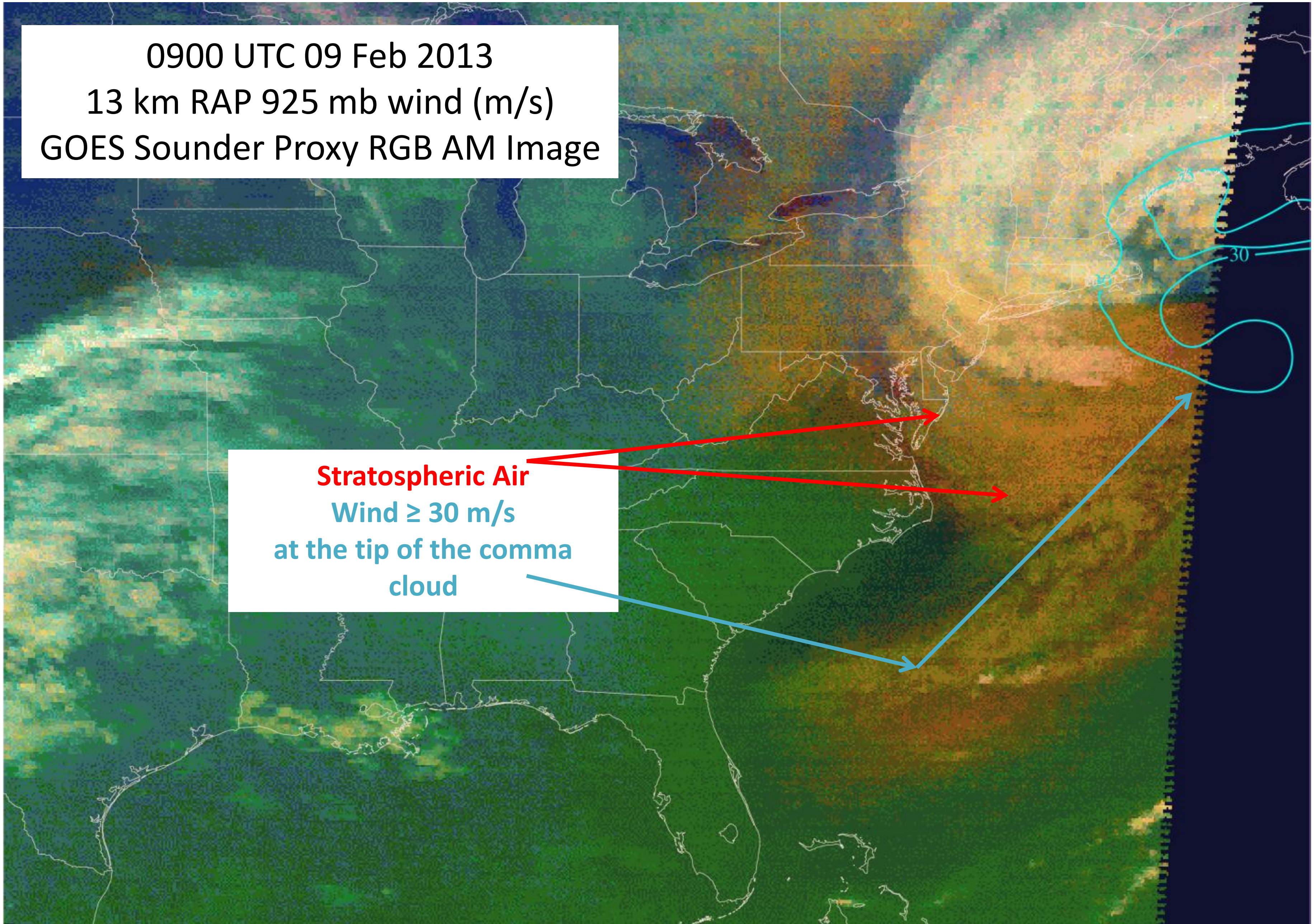
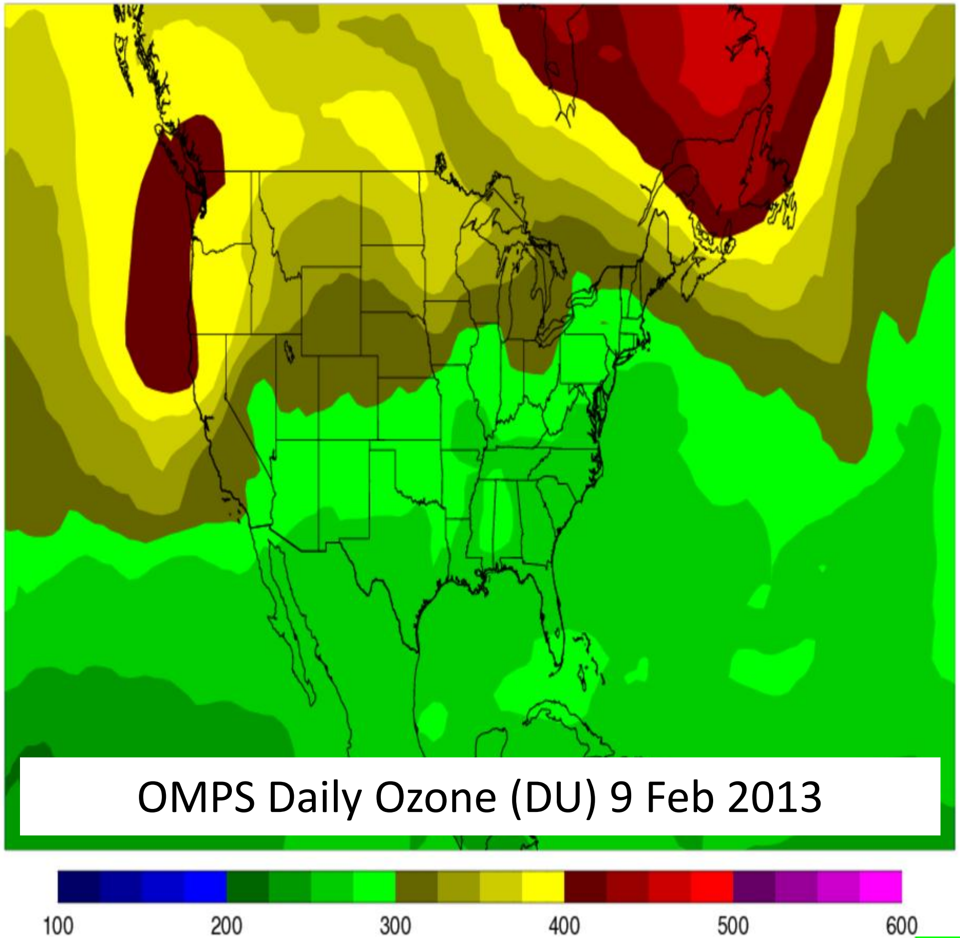
25
20
1028
1024
1016
1012
1004
996
1000
1020
1016
54N
51N
48N
45N
42N
39N
36N
33N
30N
27N
24N
90W
85W
80W
75W
70W
65W
60W
55W
50W
CLOUD HEAD
L
CCB
A
SJ
B
WCB


0900 UTC 09 Feb 2013
13 km RAP 925 mb wind (m/s)
GOES Sounder Proxy RGB AM Image
Stratospheric Air
Wind ≥ 30 m/s
at the tip of the comma
cloud
30


OMPS Daily Ozone (DU) 9 Feb 2013
100
200
300
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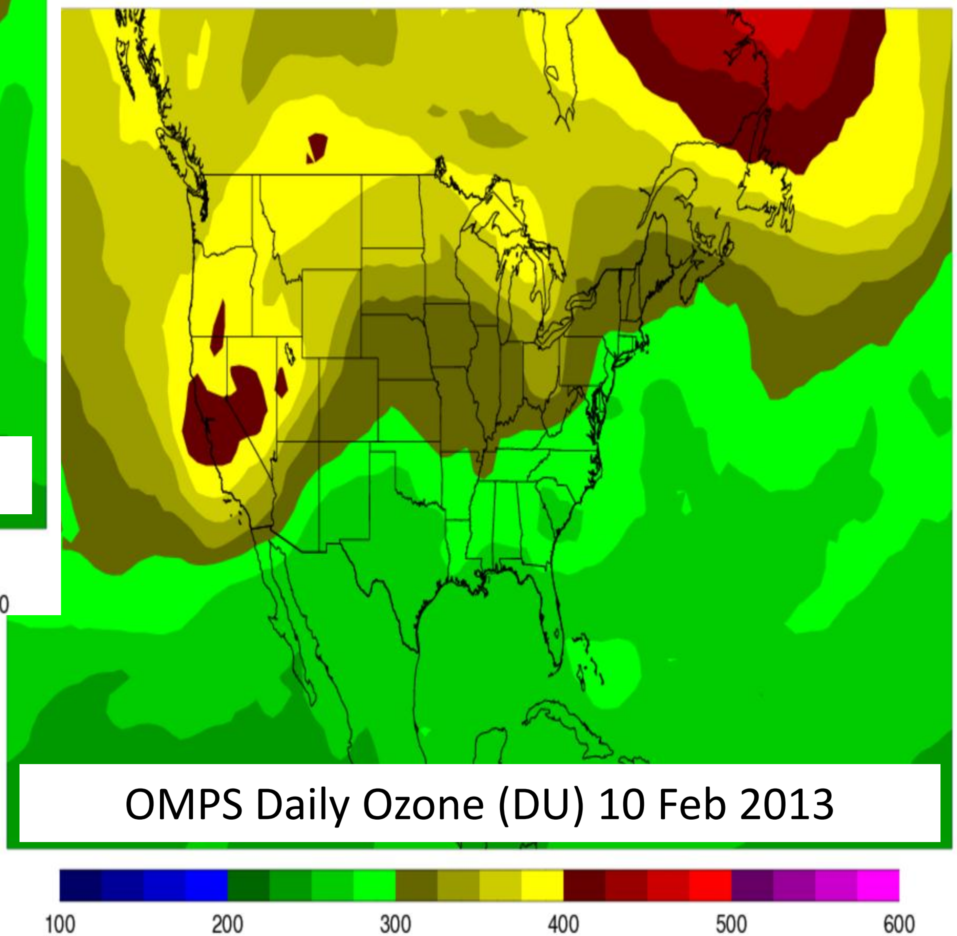
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100
200
300
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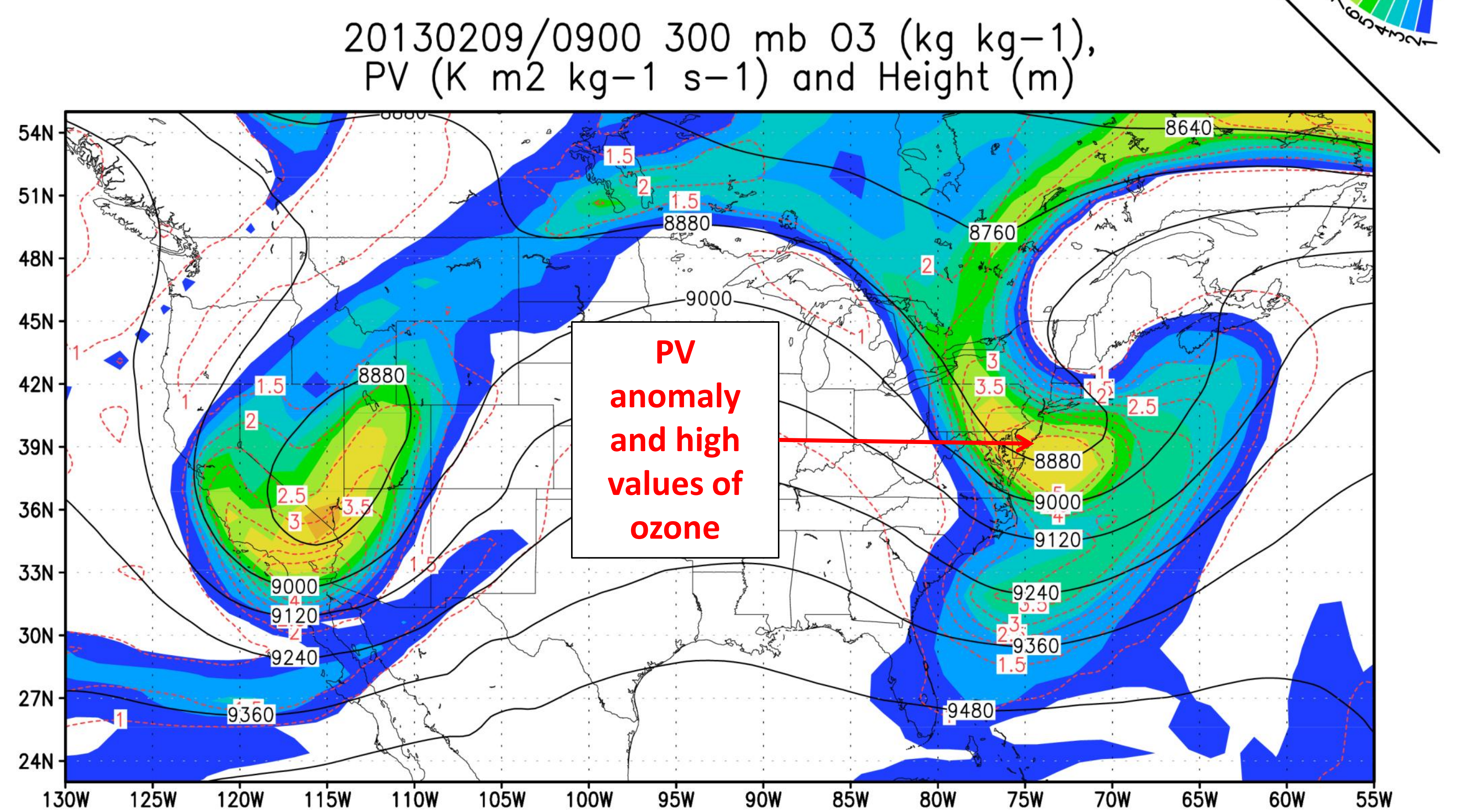
MERRA


20130209/0900 300 mb O3 (kg kg−1),
PV (K m2 kg−1 s−1) and Height (m)
PV anomaly and high values of ozone
8640
8760
8880
9000
9120
9240
9360
9480
54N
51N
48N
45N
42N
39N
36N
33N
30N
27N
24N
130W
125W
120W
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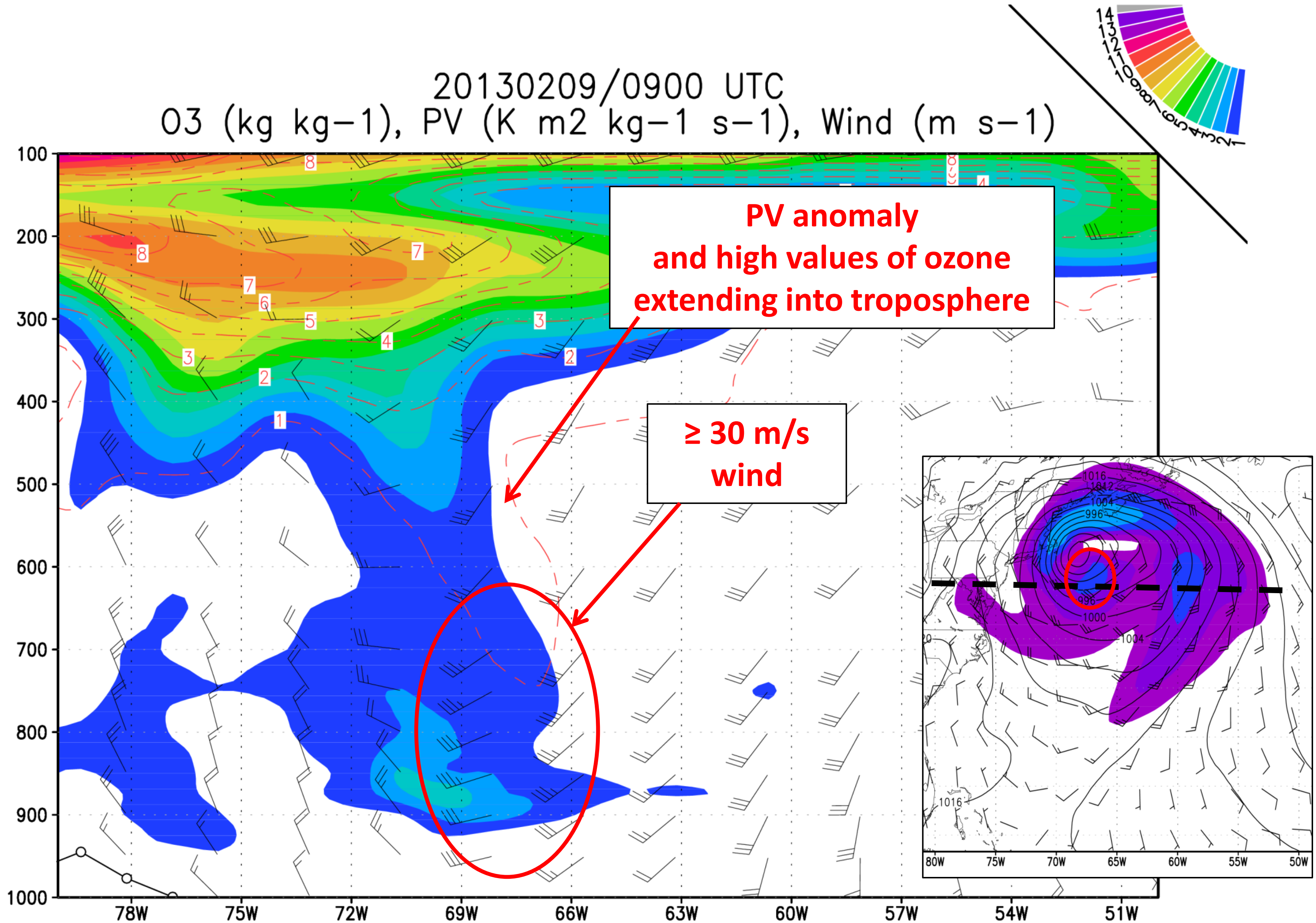
75W
70W
65W
60W
55W



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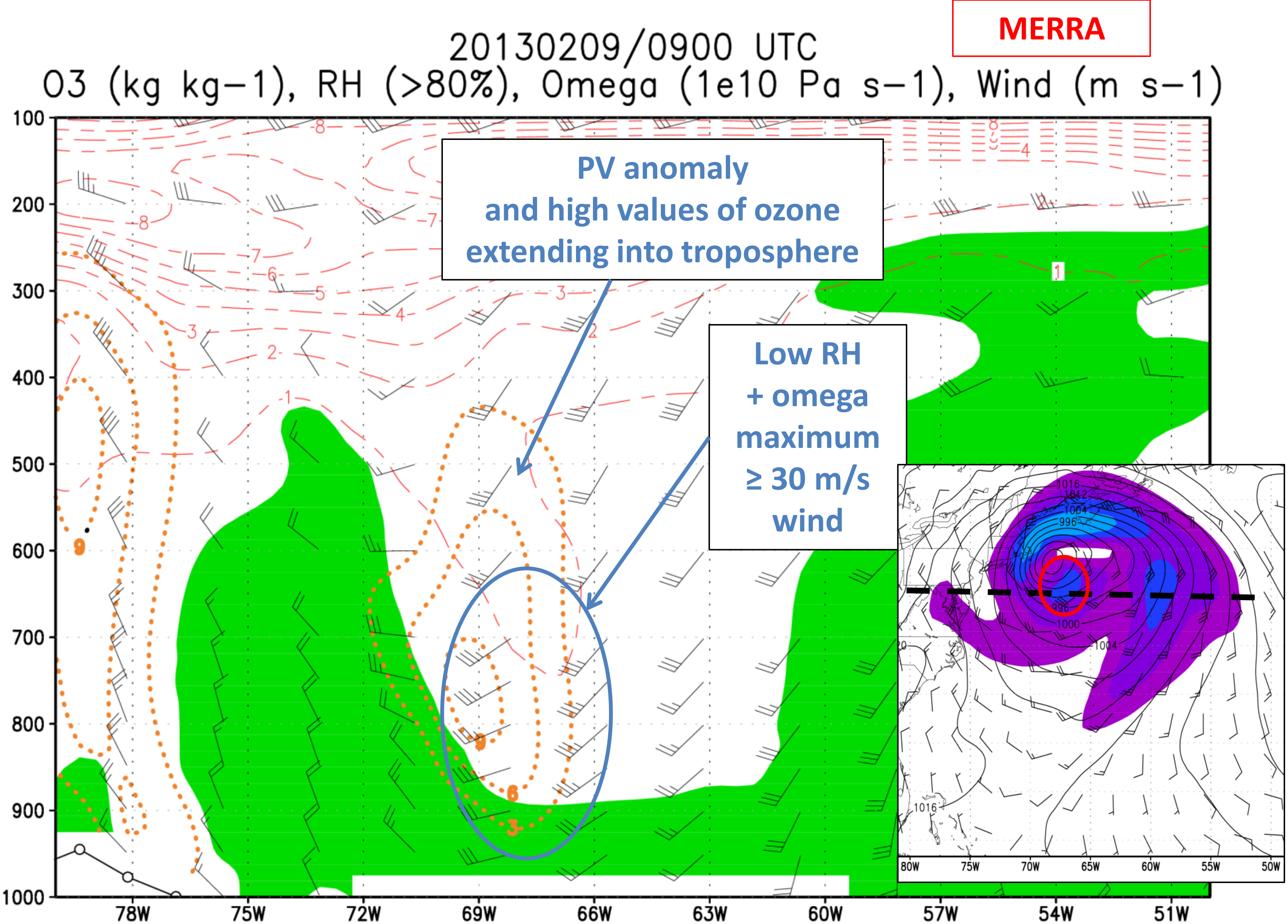

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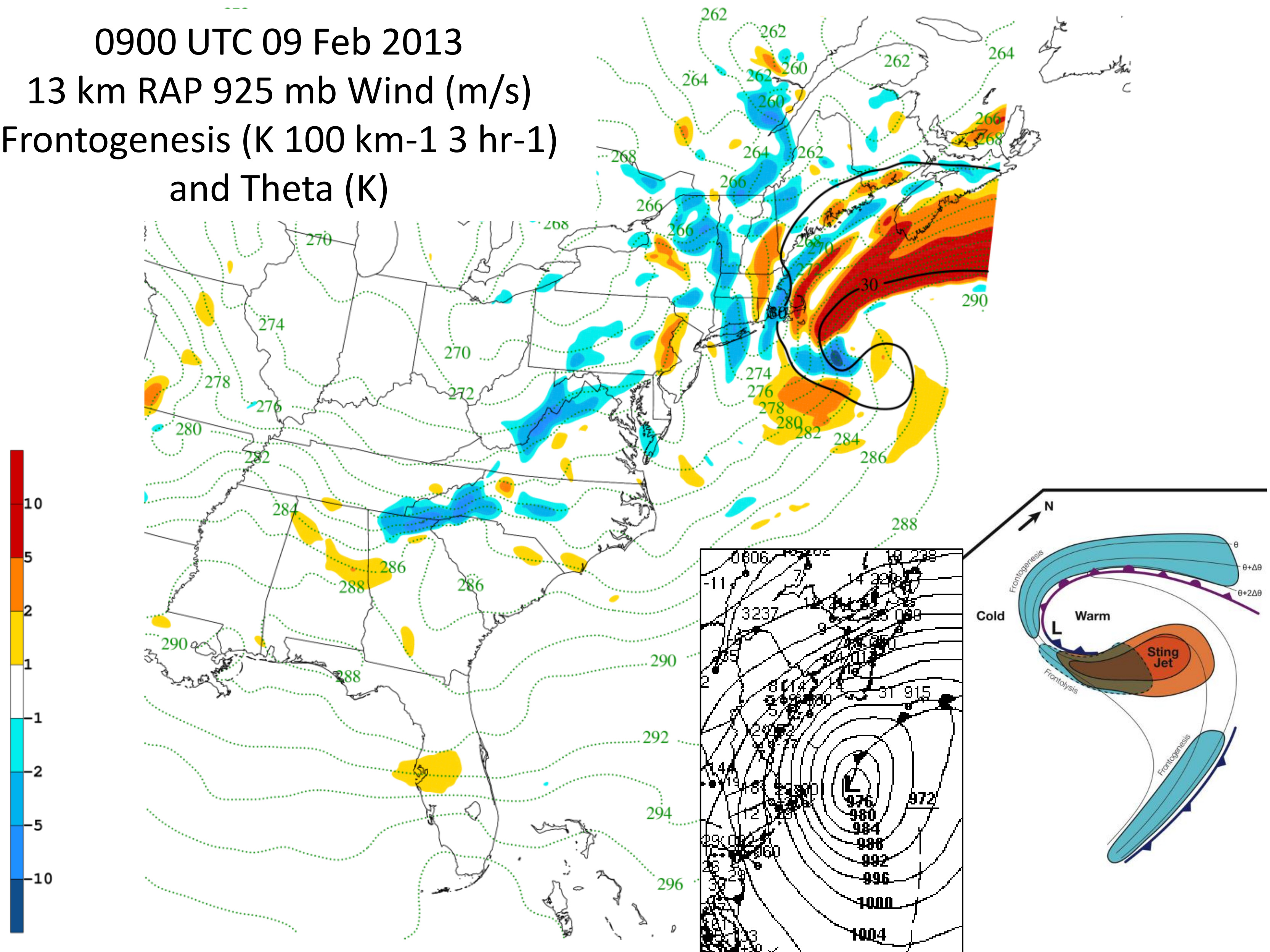
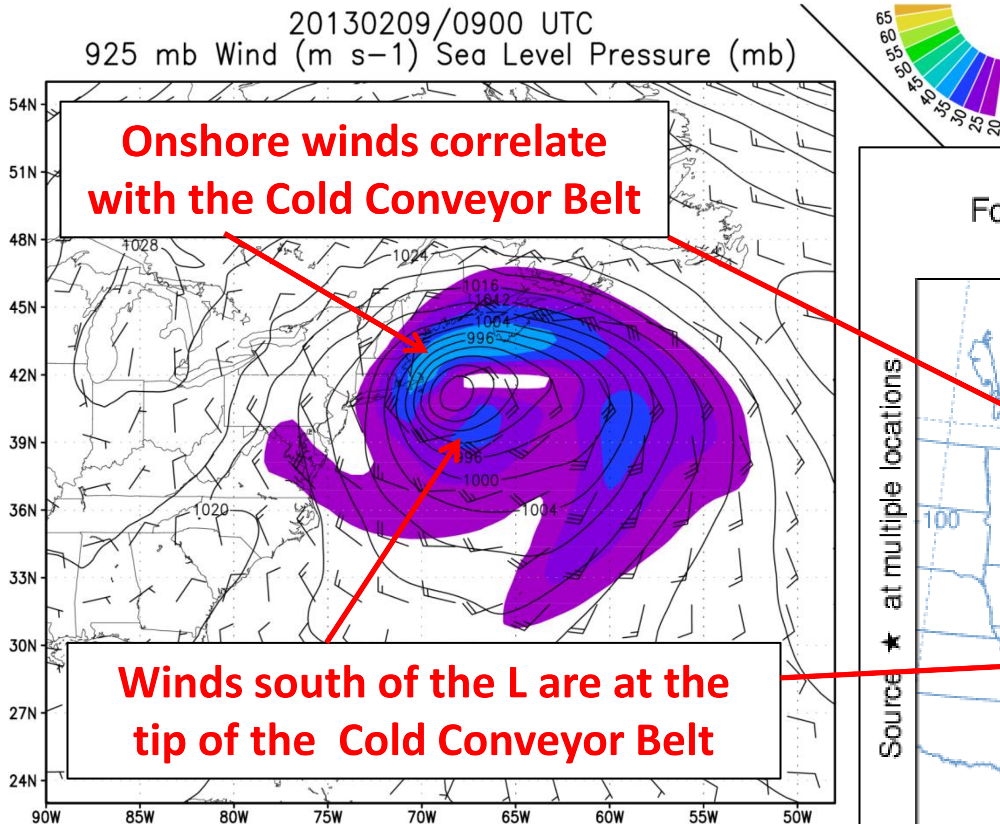
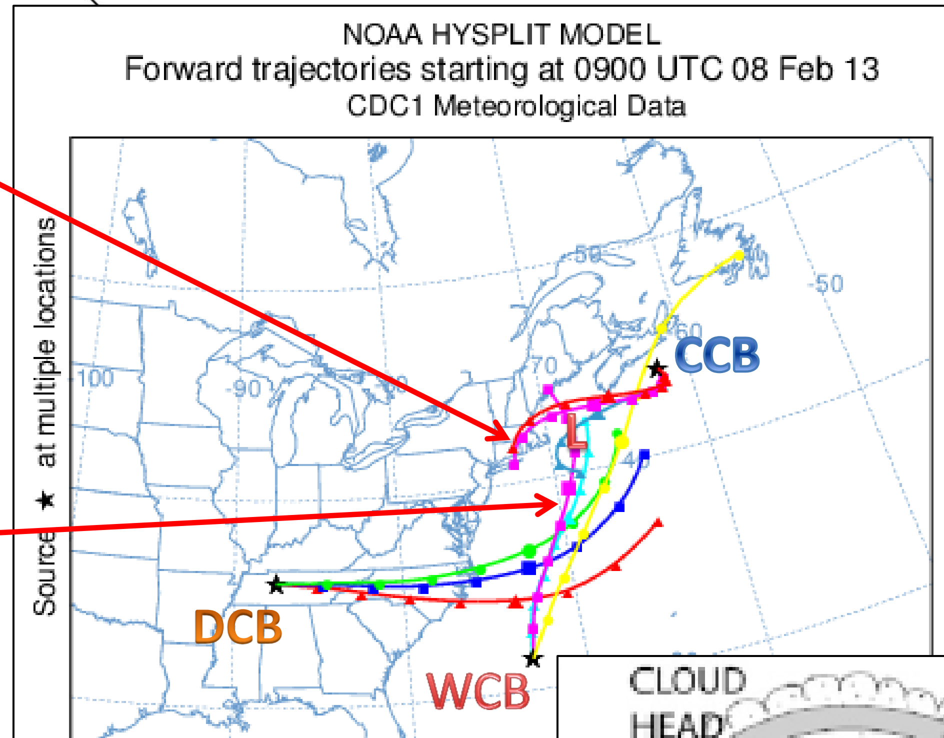
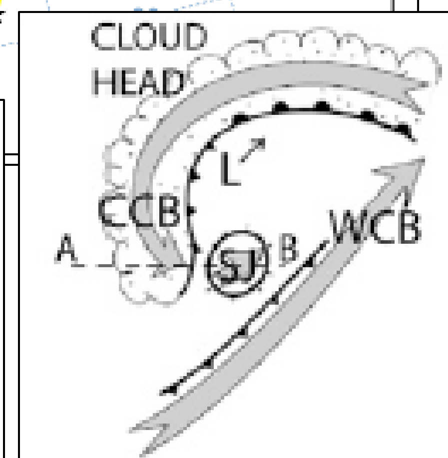




Onshore winds correlate with the Cold Conveyor Belt

Winds south of the L are at the tip of the Cold Conveyor Belt





More analysis is needed to confirm the presence of a sting jet:
DSCAPE
Low level static stability
Cross sections of frontolysis and omega
Backward trajectories from the surface

Schultz and Sienkiewicz (2013) argue the Sting Jet can only occur in Shapiro-Keyser Cyclones
However Norwegian cyclones have never been evaluated for the presence of the Sting Jet

Conclusions

- AIRS/OMPS ozone, MERRA PV and ozone **confirm** the presence of **stratospheric air** in **RGB Air Mass imagery.**
- **Vertical cross sections** of PV, omega, RH, and wind **show** a **connection** between the **stratospheric intrusion**, **downward vertical motion**, and **high surface winds**.
- **Characteristics** similar to a **sting jet** are **observed**, but **more analysis** is needed **to confirm** its presence.

Recent Blog Posts

Early February Northeast Blizzard

Early February Blizzard Part 2

Improved Ozone Monitoring with the release of AIRS Version 6 data

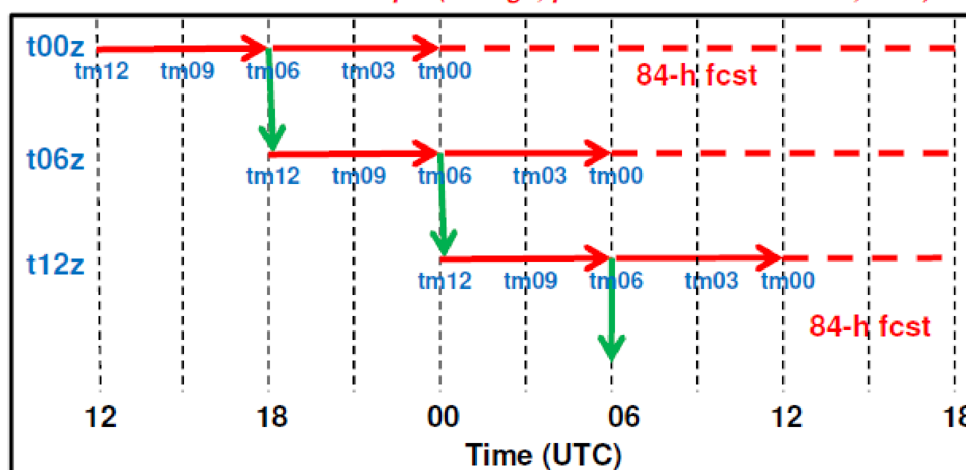
Future Activities

- Advanced Weather Research and Forecasting Model
  - Determine whether the assimilation of satellite profiles improves the model representation of stratospheric intrusions and high winds
    - Model configuration will follow NSSL Operational WRF
    - Model run will be initialized with GFS model data
    - Assimilate AIRS, CrIMSS (CrIS/ATMS), and IASI Temperature and Moisture Profiles
    - GSI will be used for assimilation of the profiles
    - Assimilated run will be compared to reanalysis and a control run with conventional assimilation

Future Activities

- Developmental Testbed Center (DTC) GSIv3.0 and WRF-ARW Version 3.3
- Forecast cycling mimics the operational NAM
- Initialized with GFS data
- Lateral boundary conditions every 3 hours
- 12 km Domain & 35 vertical levels*
- 5 m resolution geographic data
- Scheme choices follow operational NSSL WRF
  - MP scheme: WSM6
  - PBL Scheme: MYJ
  - LW Radiation: RRTM
  - SW Radiation: Dudhia
  - LSP: Noah Land-Surface

Schematic for GSI scripts (DiMego, personal communication, 2011)



Experiment Setup

- Control Run will assimilate:
  - Satellite: AMSU, HIRS, MHS, GOES Sounder, GPSRO, radar winds
  - Conventional: All observations used in EMC's Table 4
- Experimental Run will assimilate:
  - Satellite: AIRS, CrIMSS (CrIS/ATMS), IASI, AMSU, HIRS, MHS, GOES Sounder, GPSRO, radar winds
  - Conventional: All observations used in EMC's Table 4
- Compare Reanalysis, Control, and Experiment to determine if assimilation improved the model forecast

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