Analysis of Convectively Sourced Water Vapor in the Overworld Stratosphere at Northern Midlatitudes: A Detailed Case Study of the August 27th Plume Encounter during SEAC4RS

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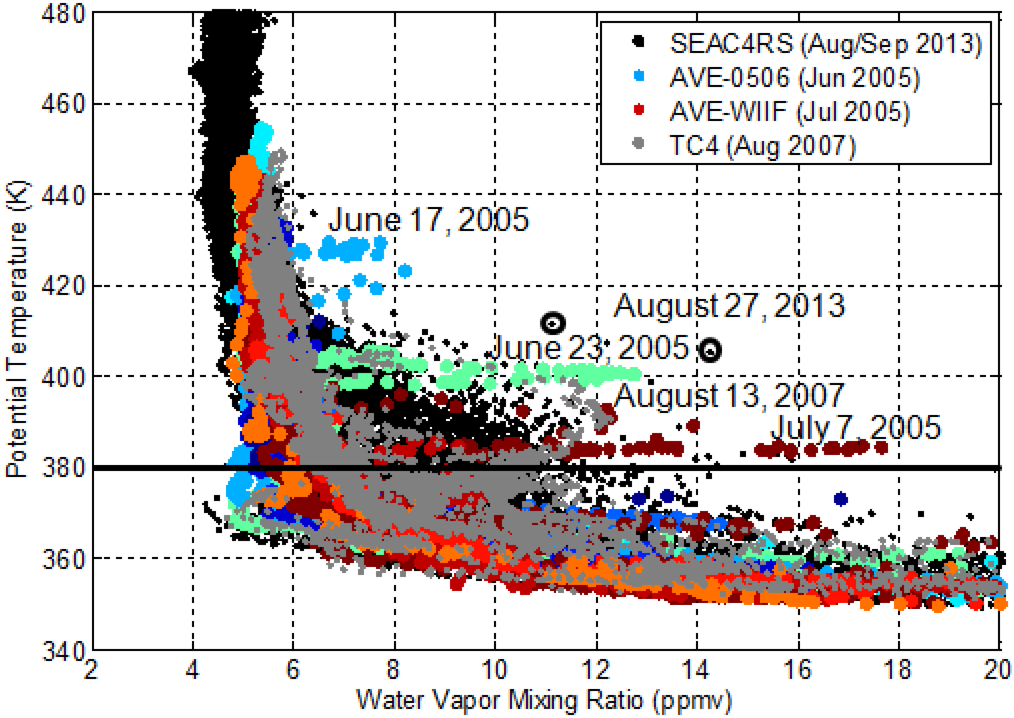
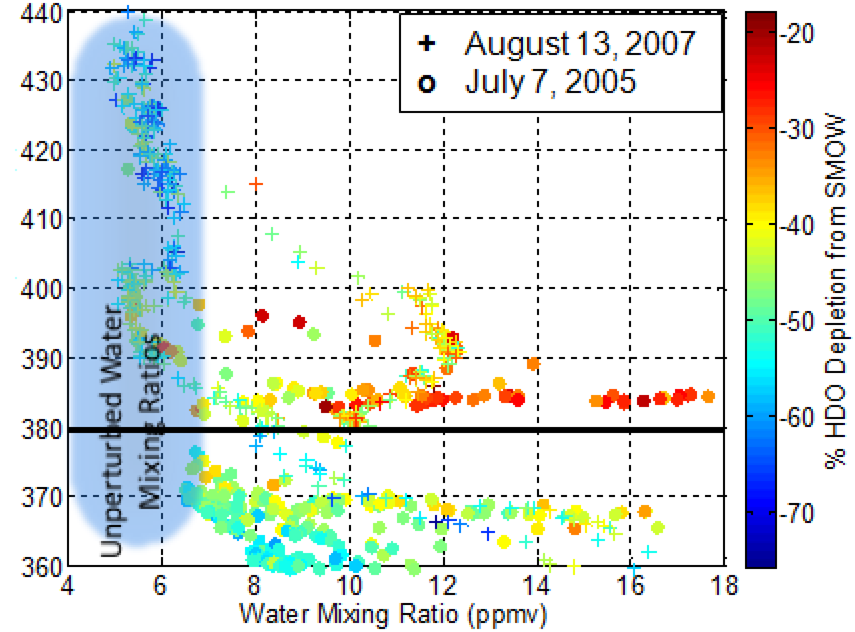
In Situ Evidence of Convective Injection of H_2O

Harvard Water Vapor & Isotopologue Data

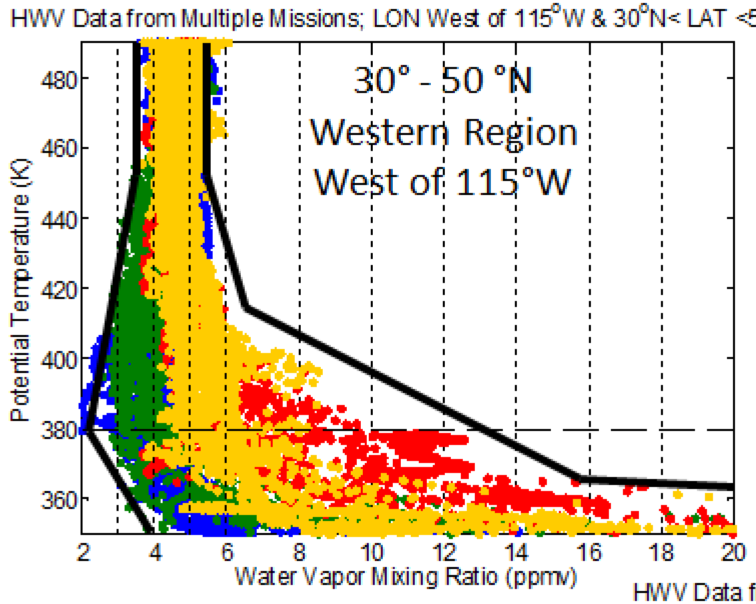


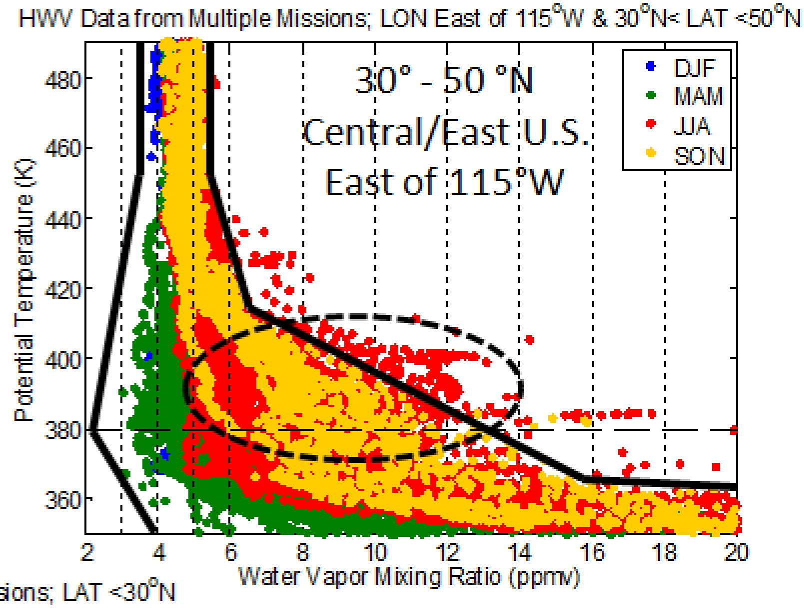


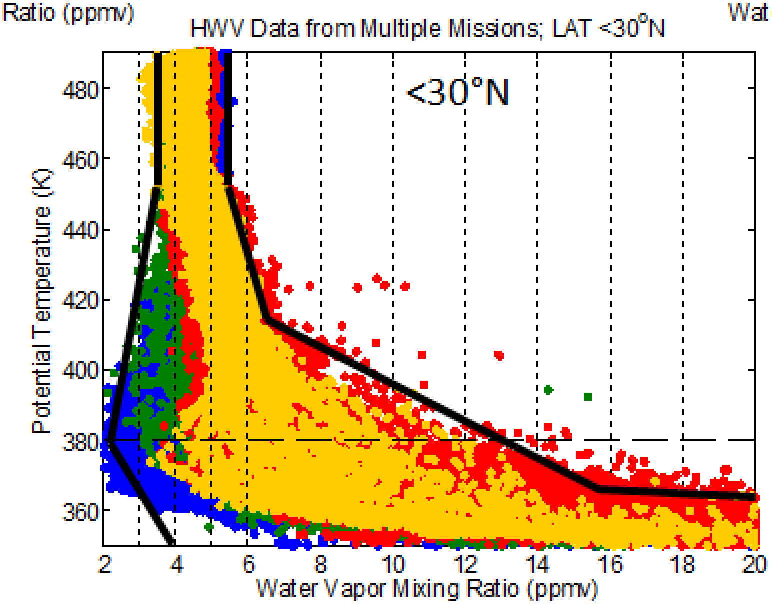
- ❖ Summertime convective plumes observed over Continental U.S.
- ❖ Hydration plumes observed to add up to ~10 ppmv above 400 K
- ❖ Hydration plumes evident up to ~430 K
- ❖ **These events circumvent temperature control of tropopause**

HWV In Situ Data by Season & Region

Seasonal & Regional Differences, Summer Plumes over U.S.

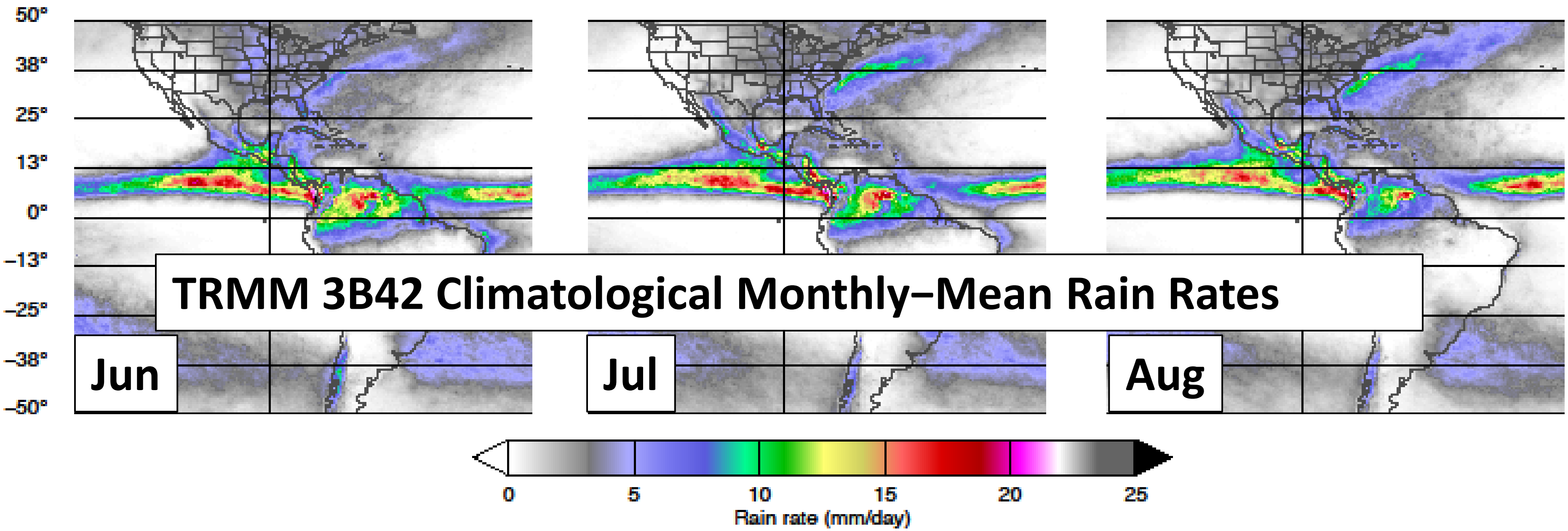


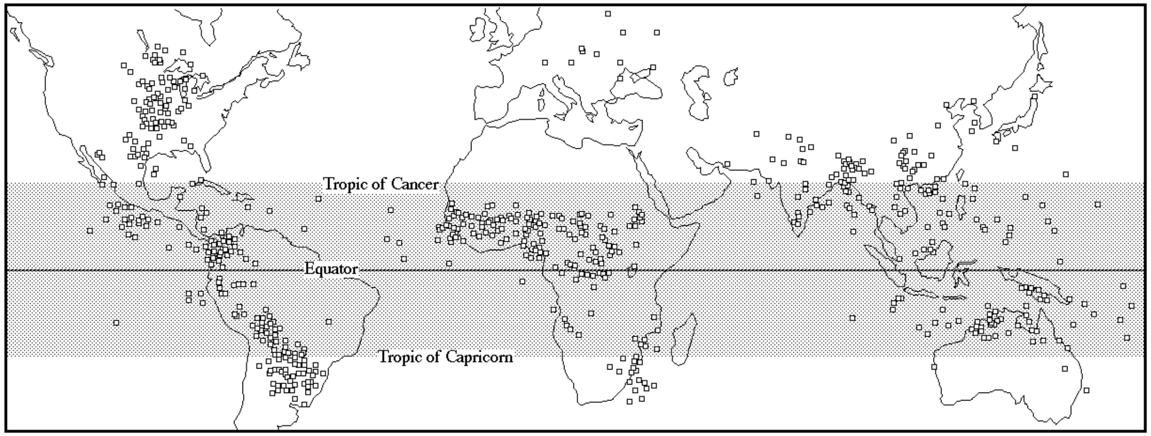




Convection – Two Sources: 1) NAM & 2) MCCs

NAM Over Central America & SW U.S.; MCCs Over Great Plains



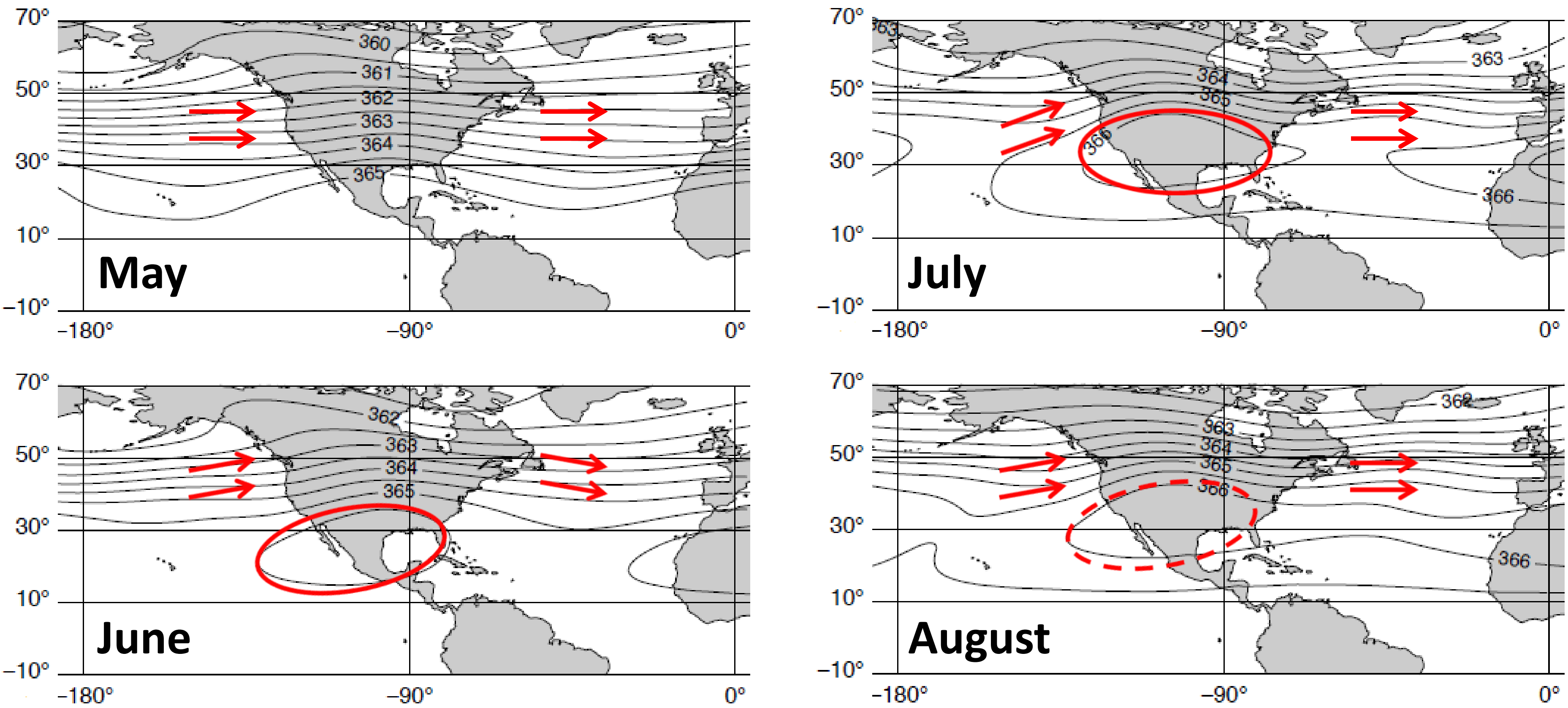


The global distribution MCCS based on satellite imagery as described in Laing and Fritsch (1997). Figure 5 from "Extratropical Synoptic-Scale Processes and Severe Convection" by Charles A. Doswell III, in *Severe Convective Storms* A Meteorological Monograph to be published by The American Meteorological Society

Dynamics – Development of NAM Anti-Cyclone

Seasonal Development of North American Monsoon at 390 K

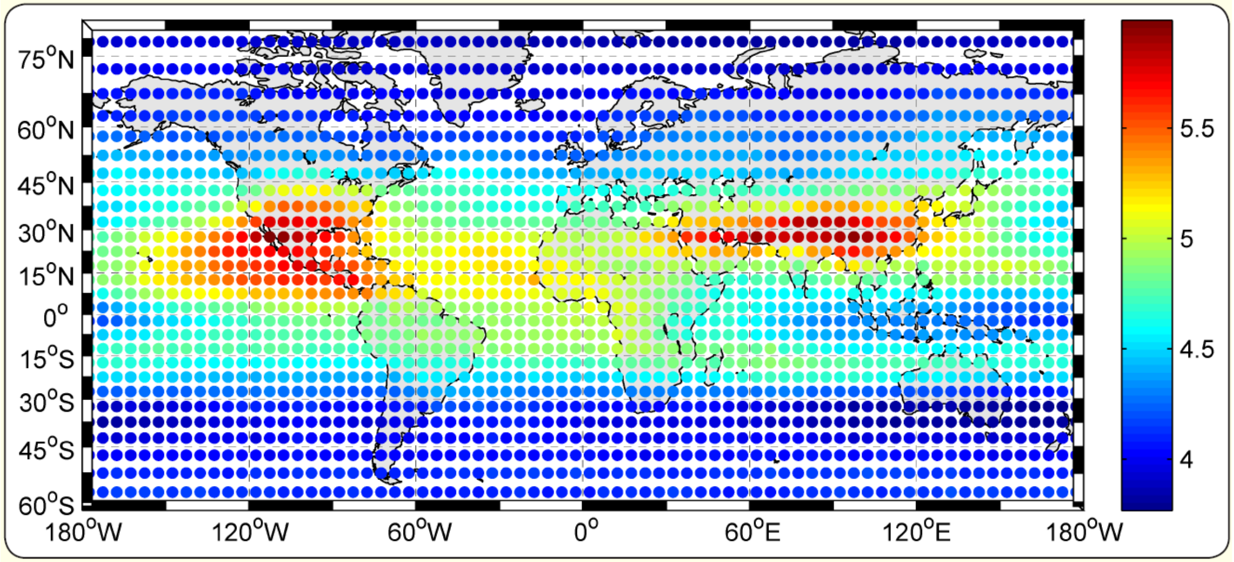
Climatological Montgomery Streamfunction (m^2/s^{-2} x 10^3)
at 390 K (1998-2013) from Ken Bowman



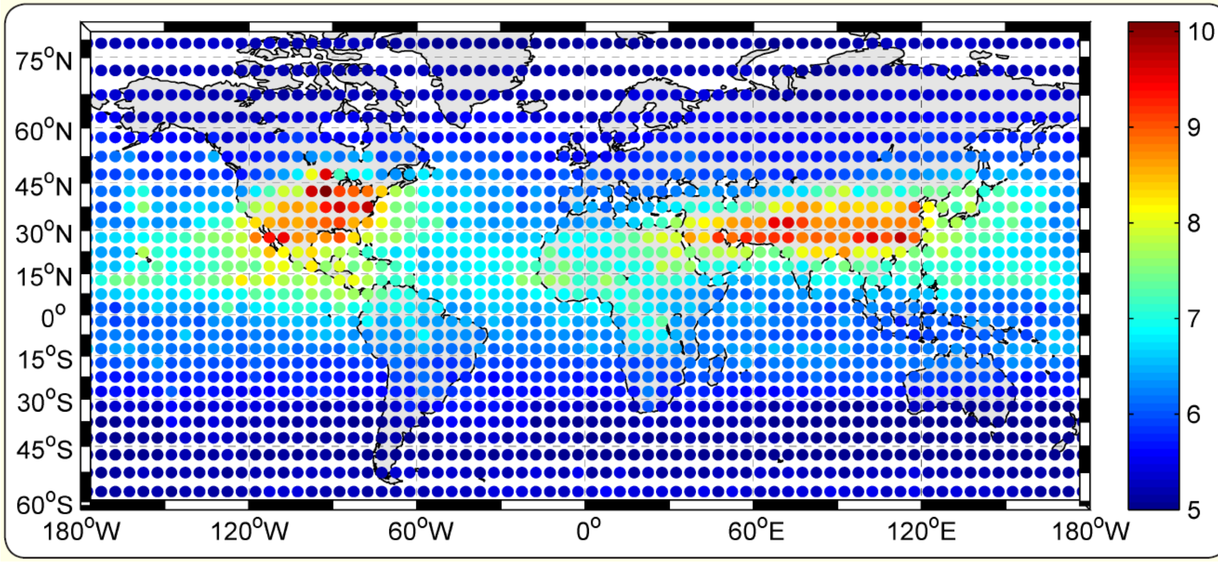
Satellite Evidence of Convective Injection of H_2O

MLS Measurements of H2O at 100 hPa, Jul-Aug 2005-2013

Mean



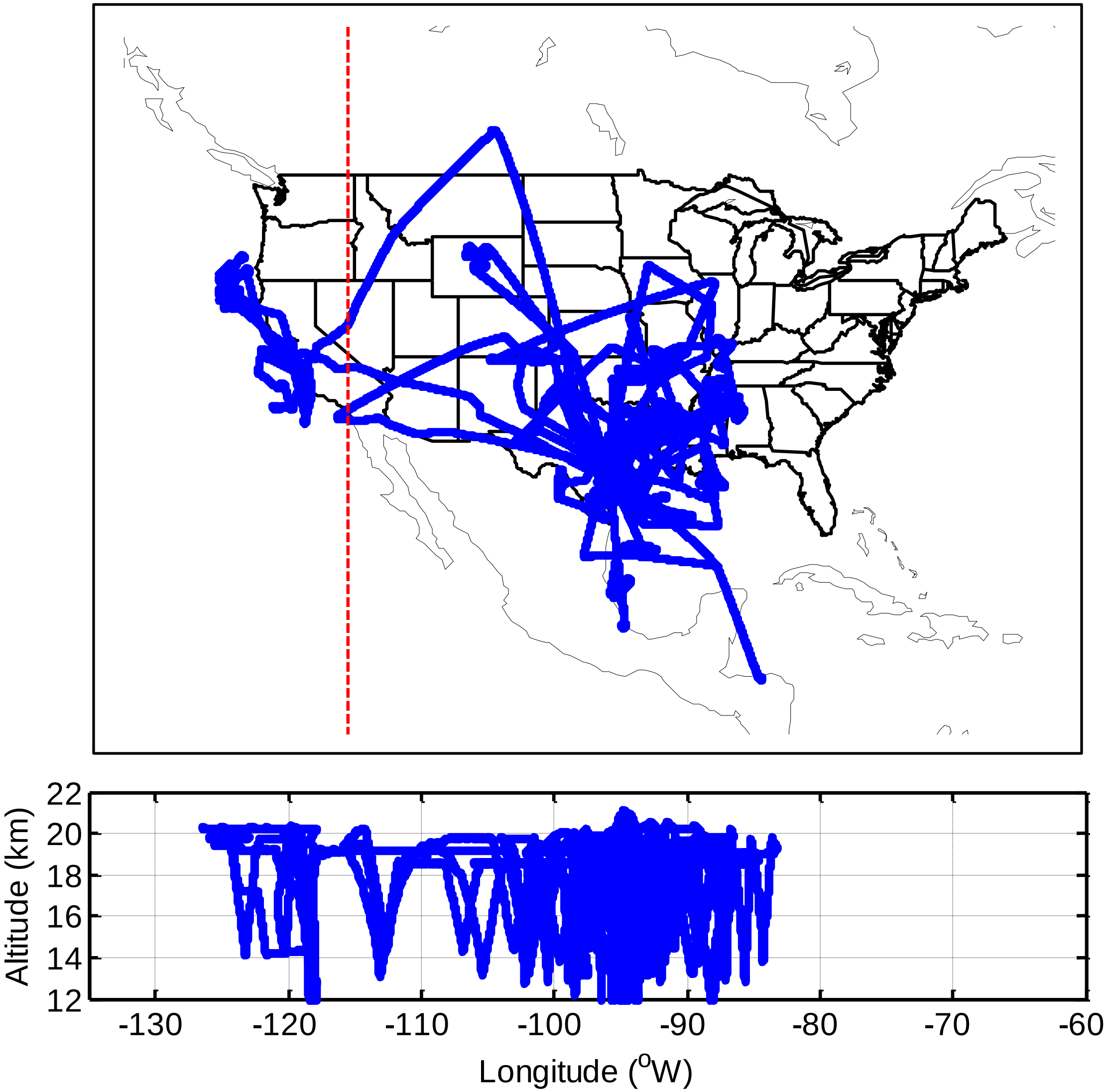
Max



from David Wilmouth

SEAC4RS – Aug. & Sep. 2013, Houston TX

ER-2 Flight Tracks & Vertical Profiles



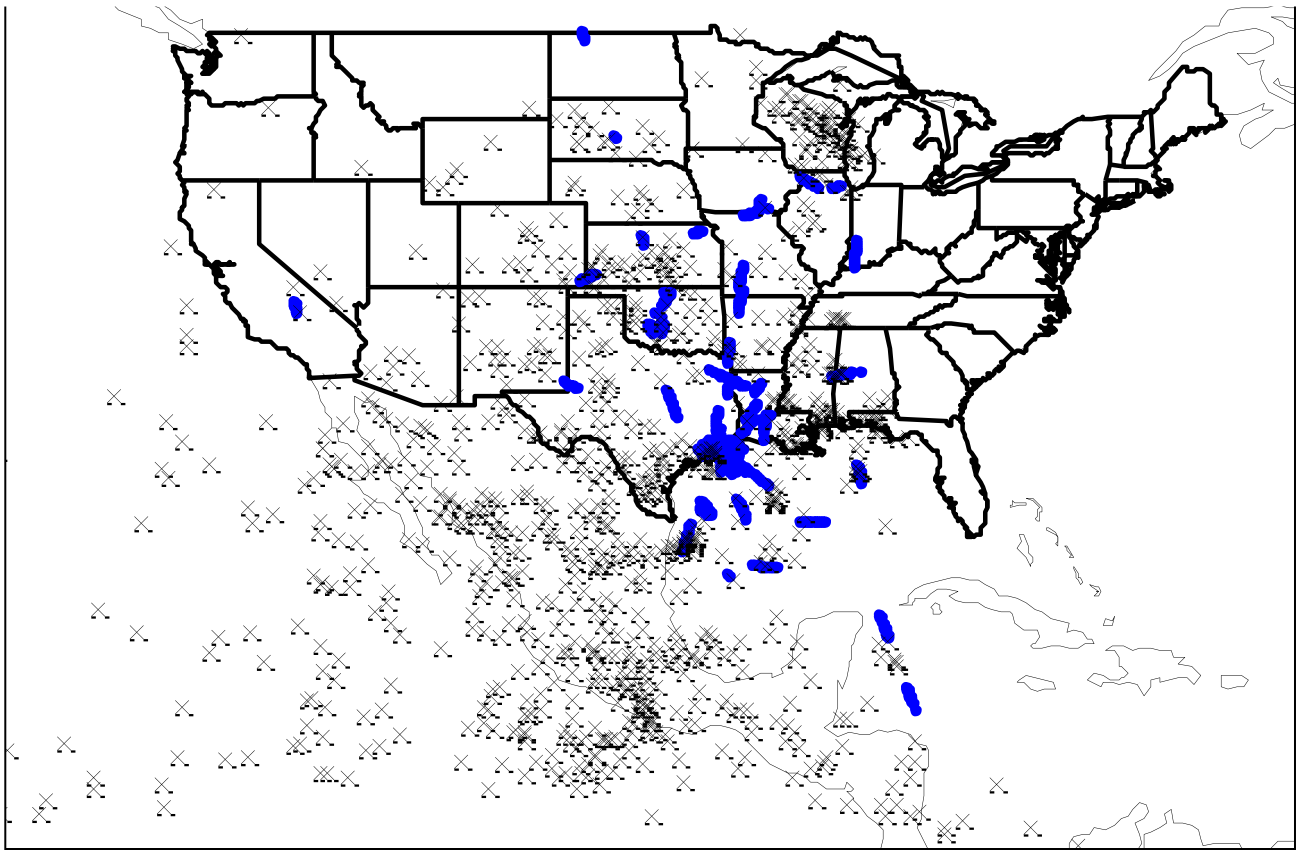
SEAC4RS – Source Regions of Convective Influence

Convective Clusters in Mexico, Gulf Coast & Central U.S.

- ● Locations of Convective Influence Along Flight Track From Lenny's Analysis

  NOTE: Convective Influence Predominantly Below Flight Level

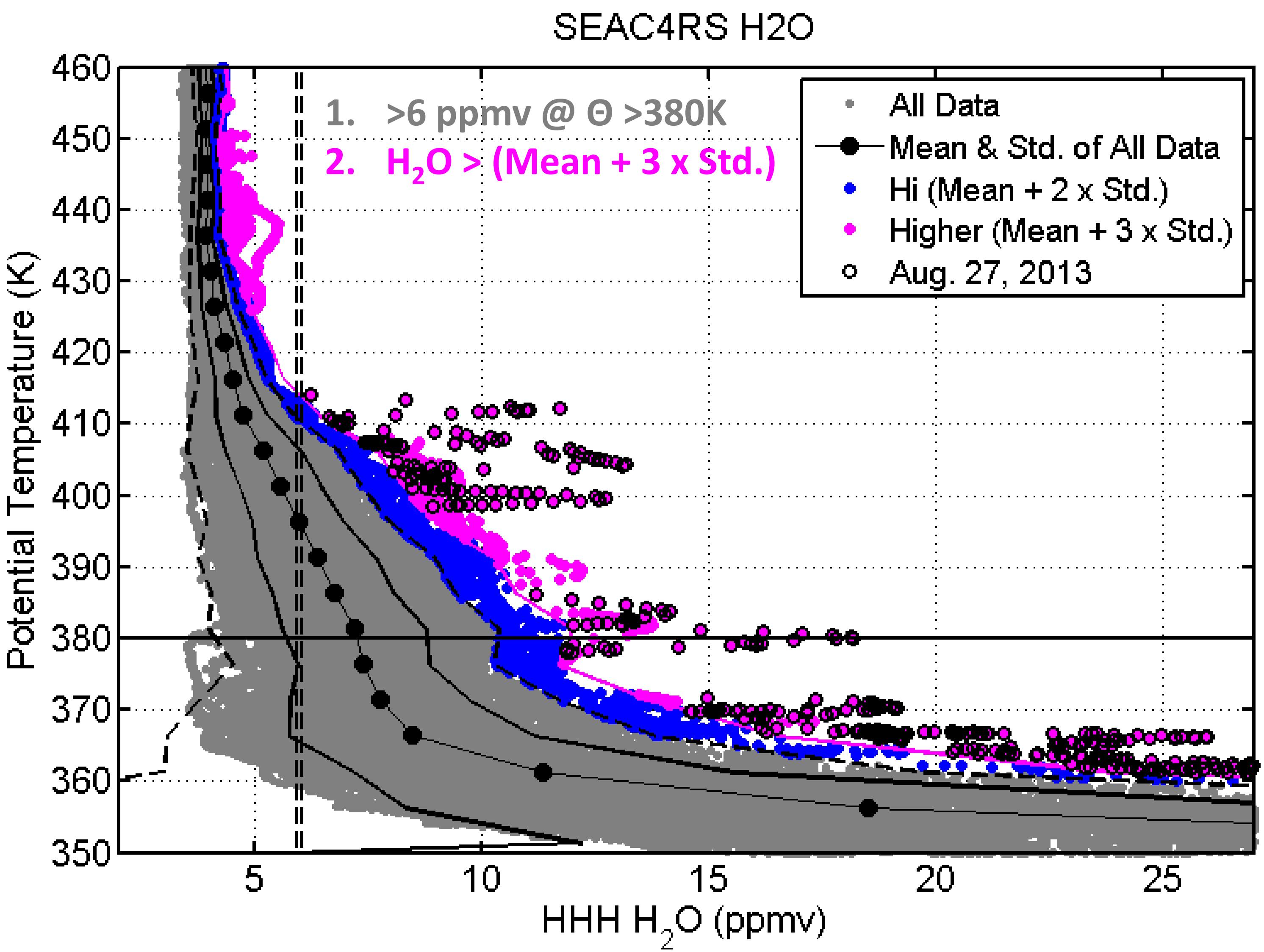
- ✖ Location of Convective Storm Source Clusters



Lenny Pfister's Convective Influence Analysis

SEAC4RS – In Situ H_2O Data

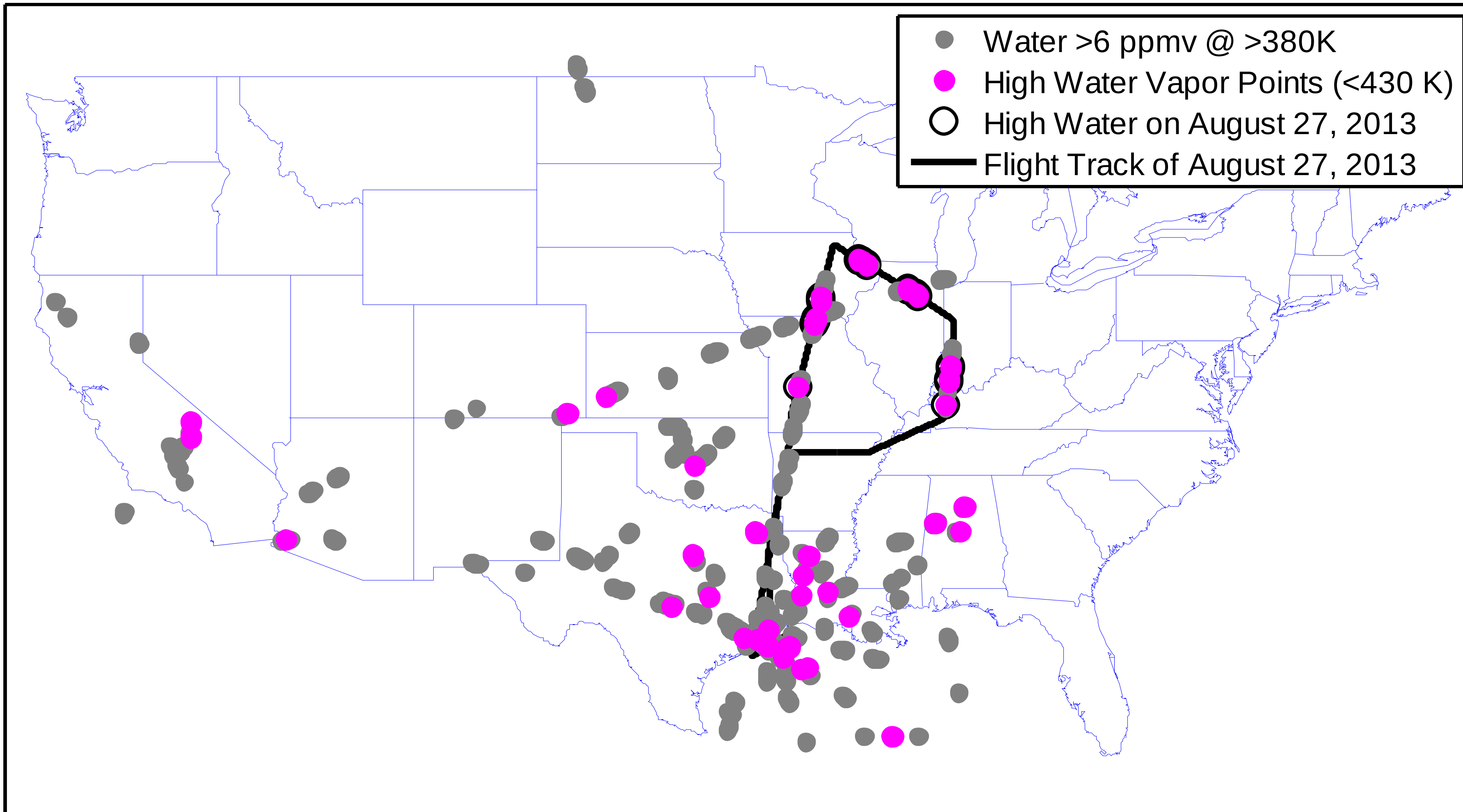
Two Criteria for High Water in Overworld: “Bump” & Extrema



SEAC4RS – High Water in Overworld Stratosphere

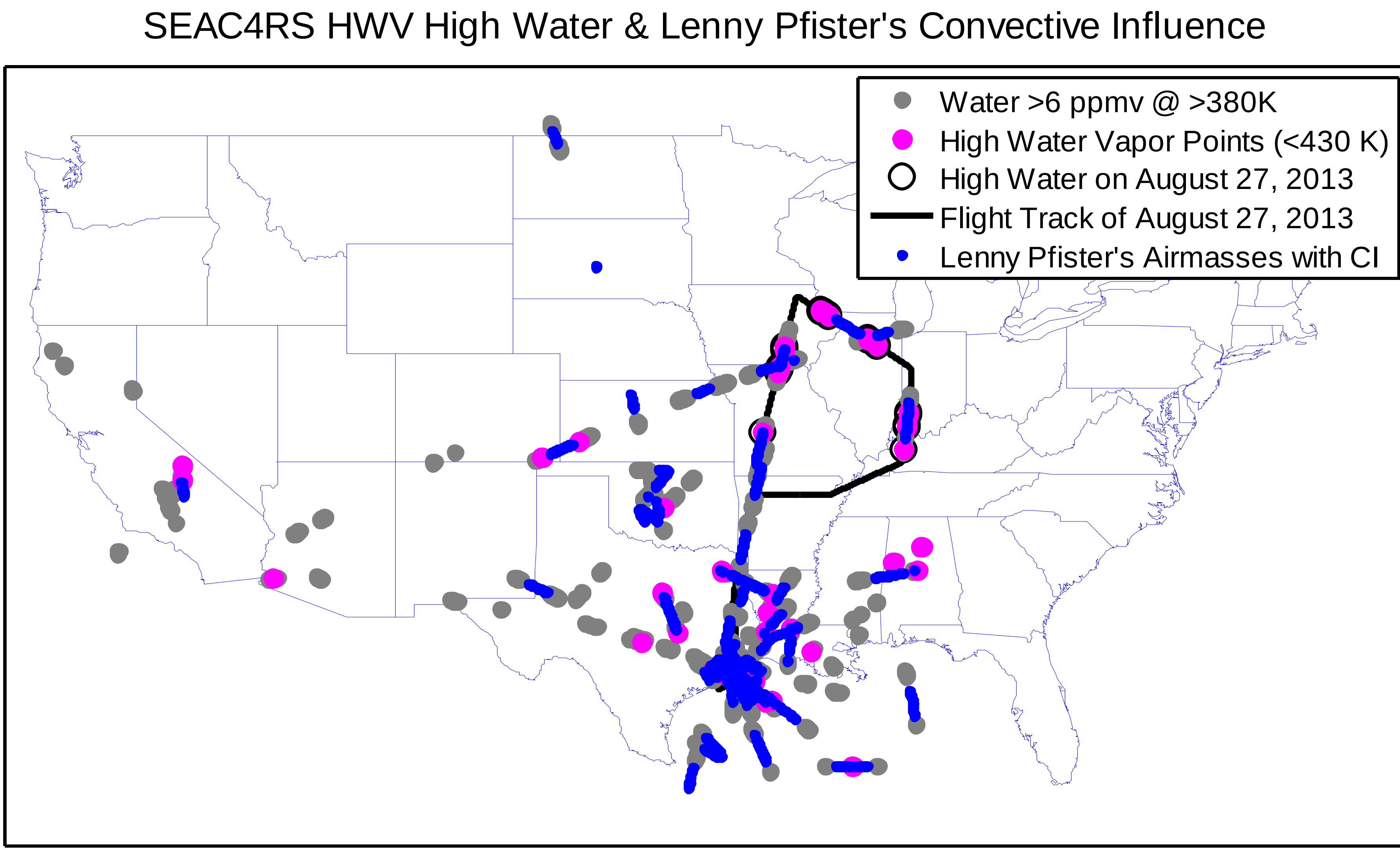
In Situ Observations of High Water

SEAC4RS HWV High Water



SEAC4RS – High Water & Convective Influence

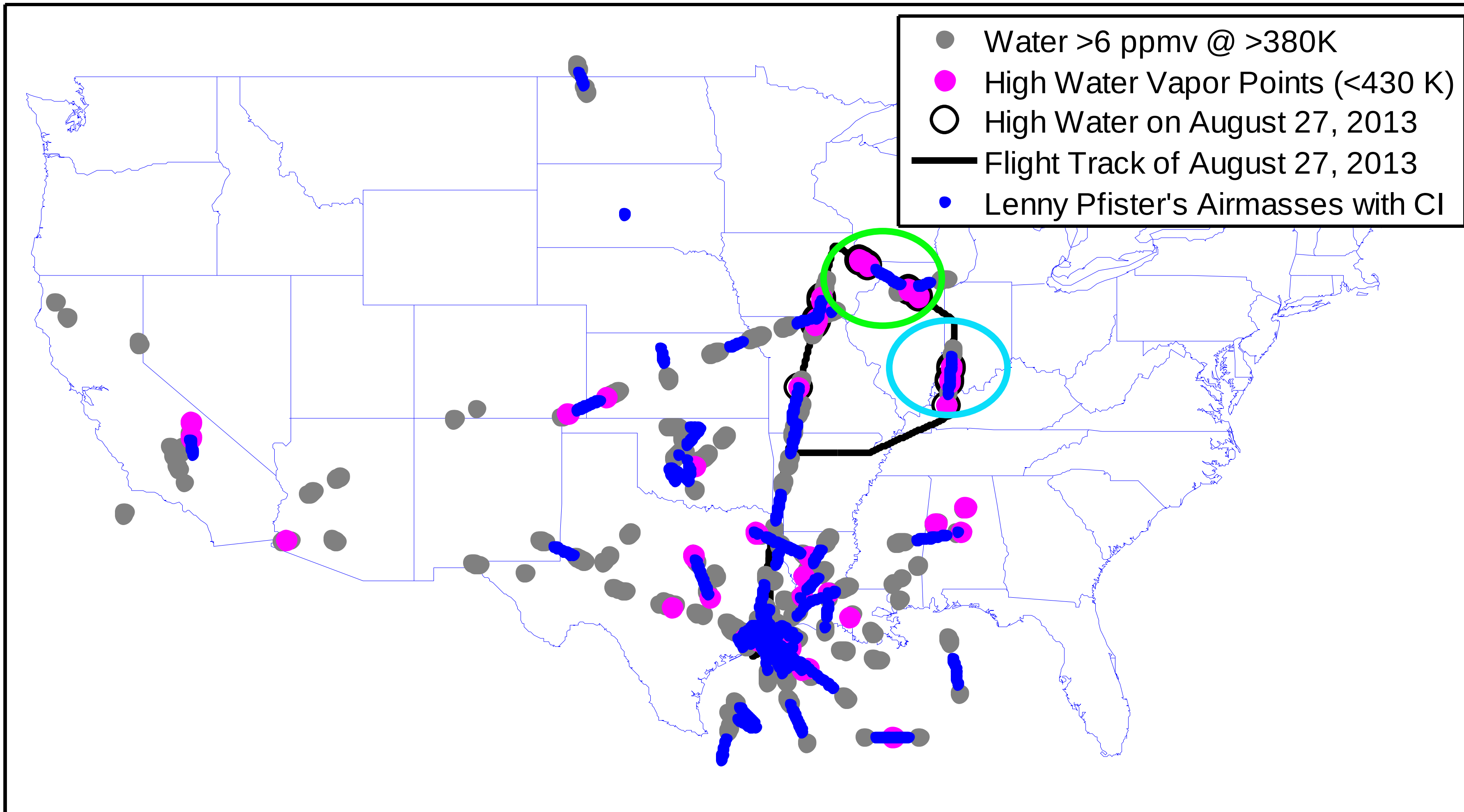
Good Correspondence Between Regions with High H_2O & C.I.



SEAC4RS – High Water & Convective Influence

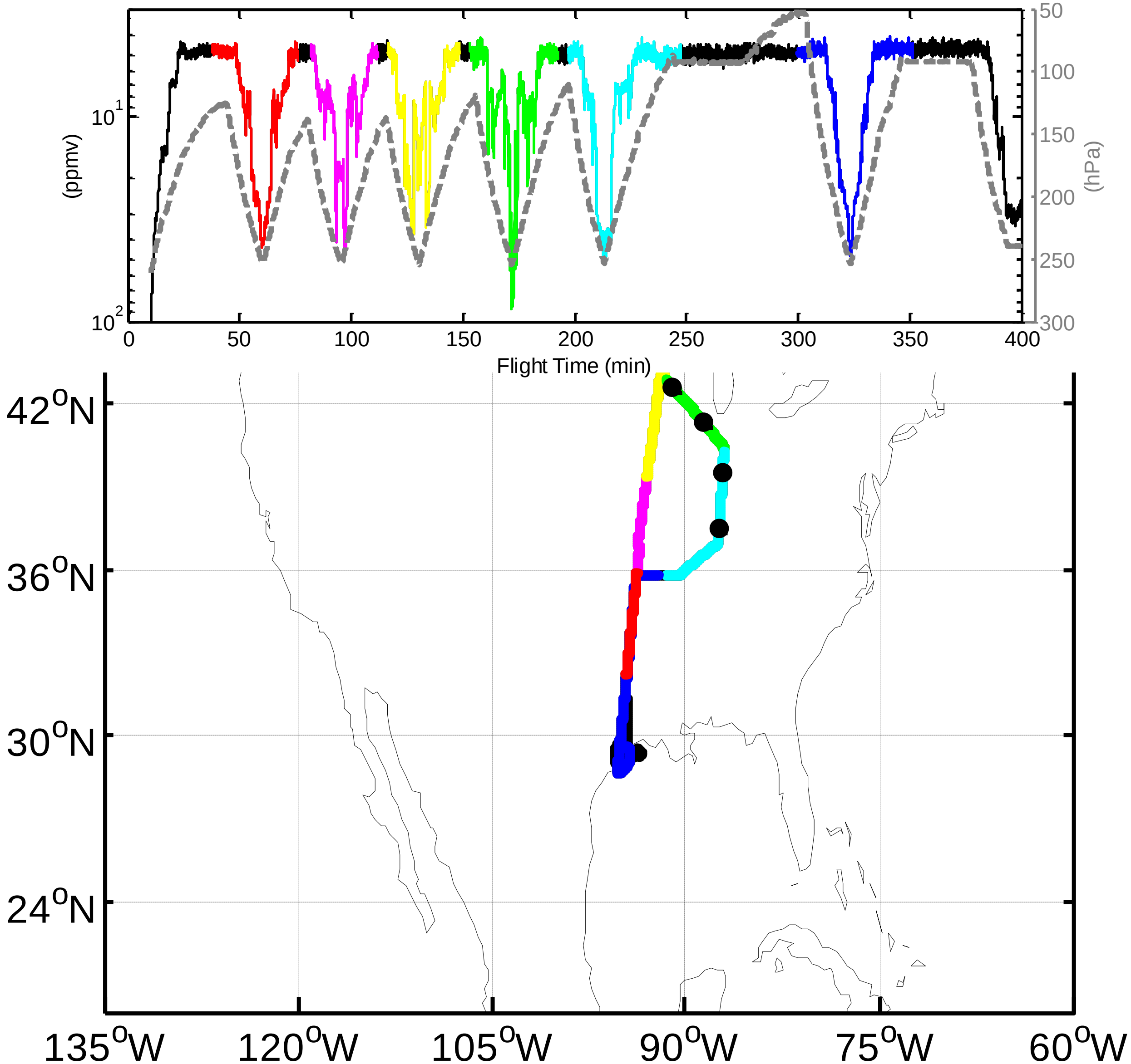
Good Correspondence Between Regions with High H_2O & CI

SEAC4RS HWV High Water & Lenny Pfister's Convective Influence



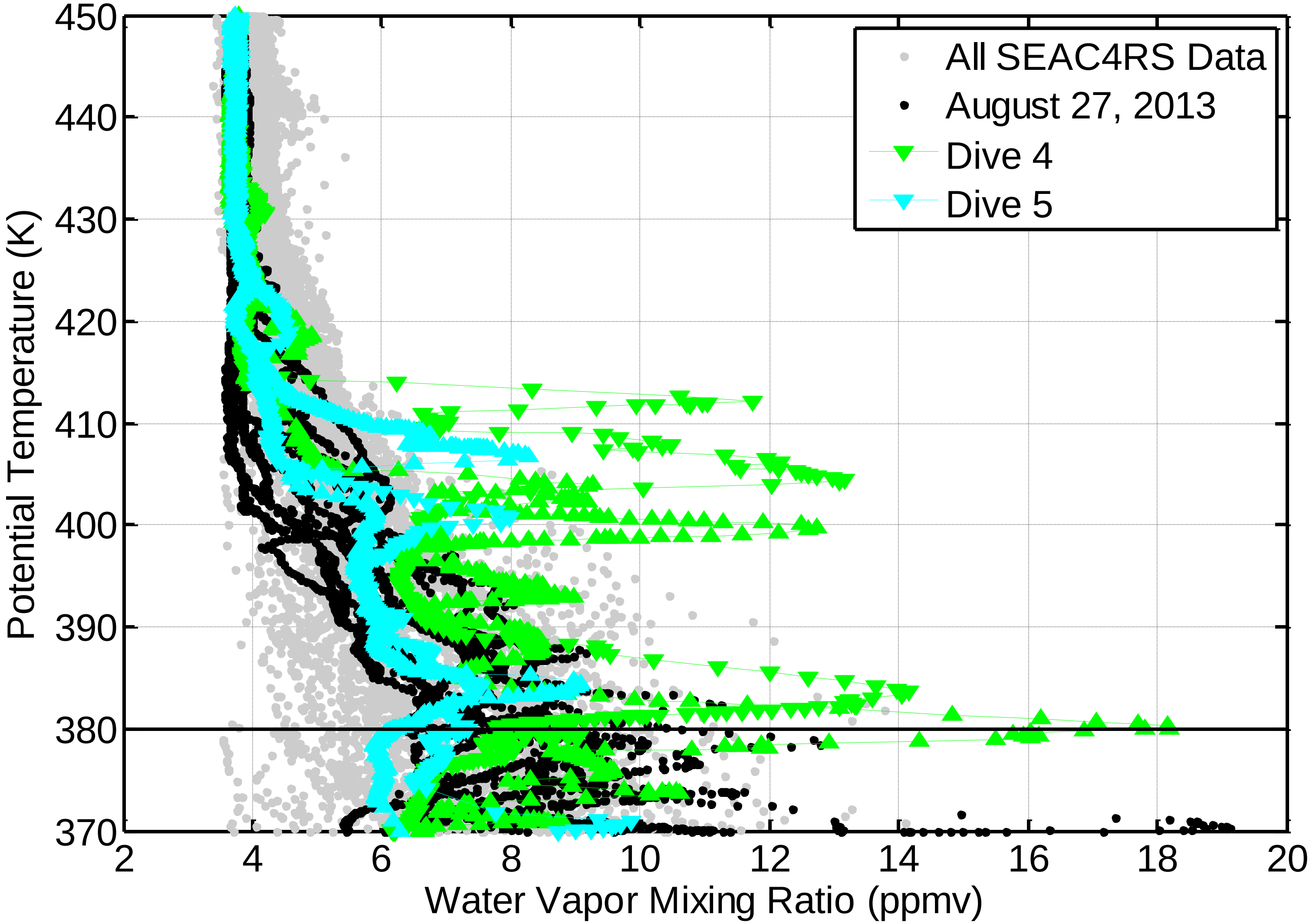
Flight of August 27, 2013

Sample MCS Outflow over Great Lakes Region



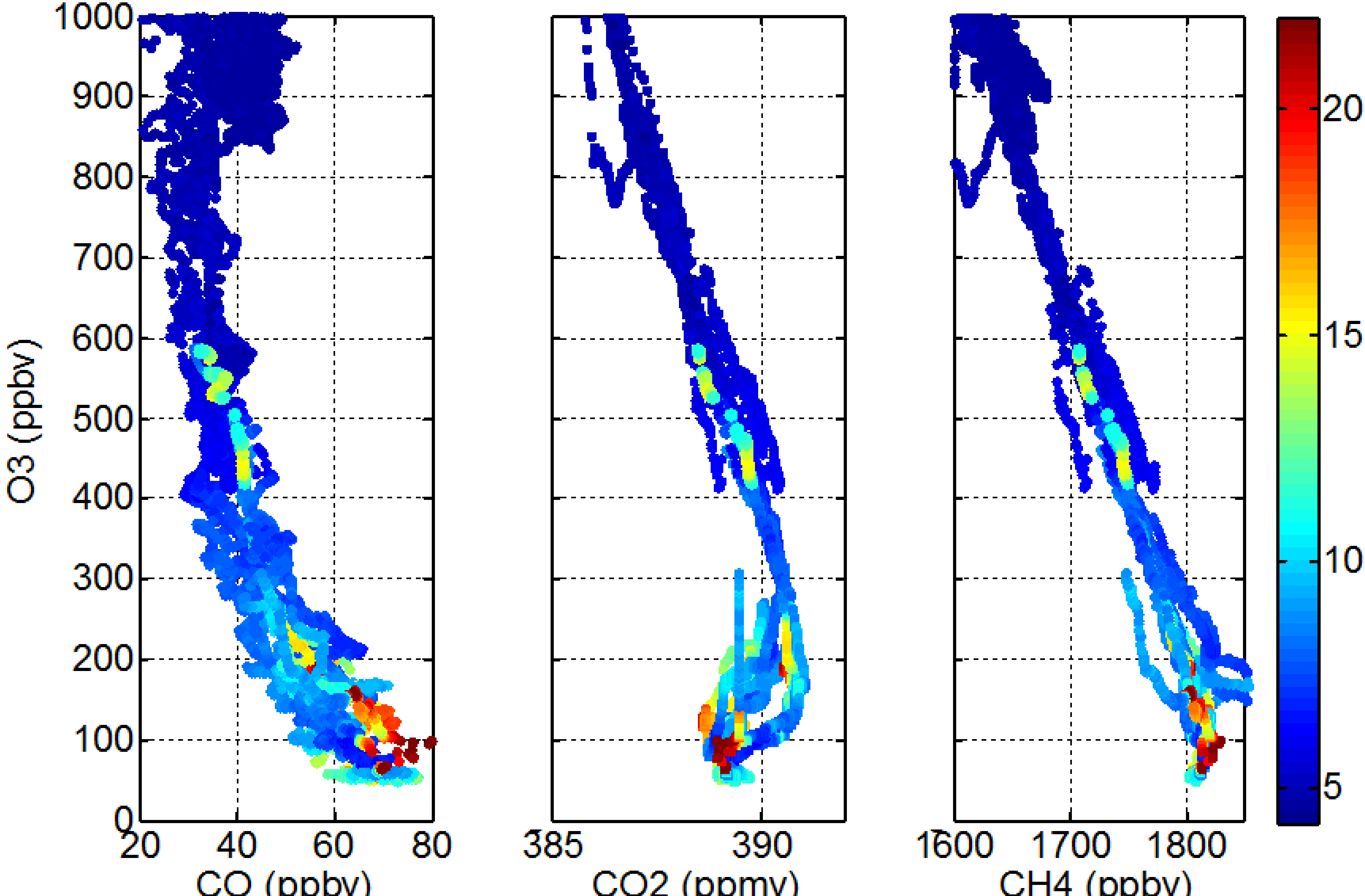
Convectively Sourced Plume in SEAC4RS

Plume in Overworld Stratosphere Observed on Aug. 27, 2013



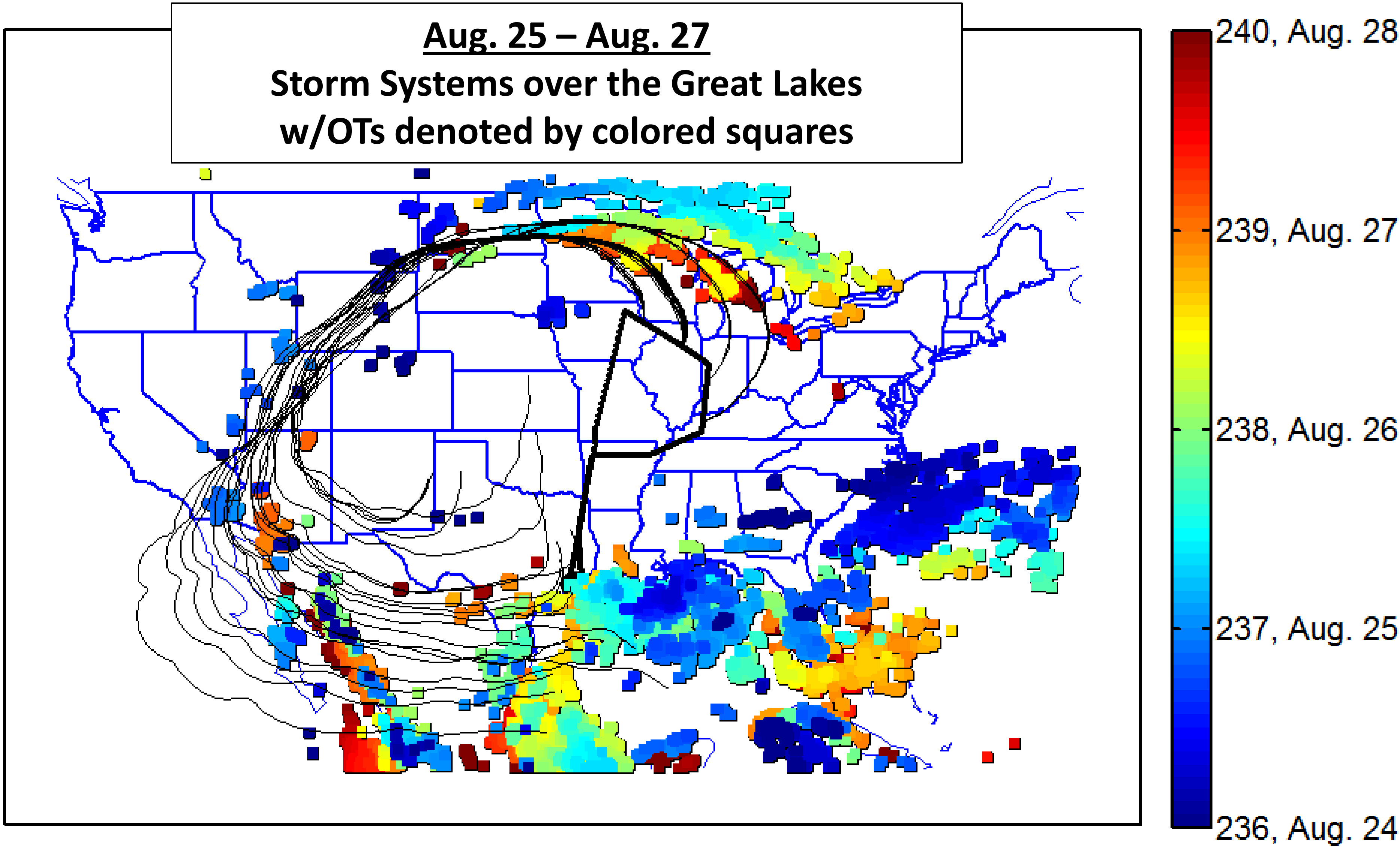
Minimal Impact on Other Trace Species

Tracers Plotted vs. O_3 & Color-coded by Water VMR



Overshooting Top Detections Using GOES-IR

All OT Detections in 4 Days Prior to Aug. 27, 2013



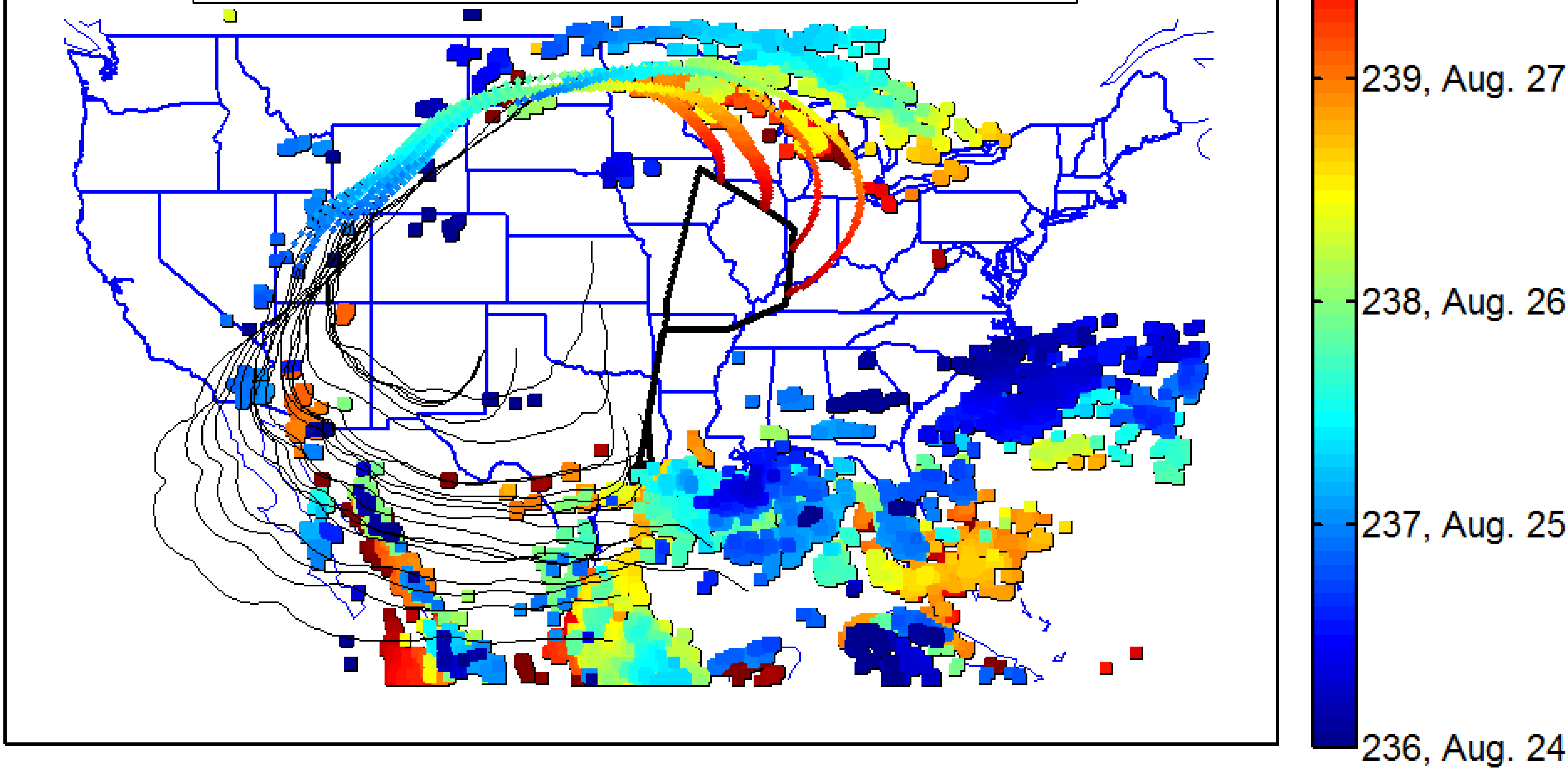
Trajectory Model by Ken Bowman **OT Analysis by K. Bedka**

Linking Aug. 27, 2013 Plumes to Storm Systems

Flight Track, OT Detections & Back-trajectories

Aug. 25 – Aug. 27

Back-trjectories from Aircraft Plume Encounters Link to OTs & Storm Systems



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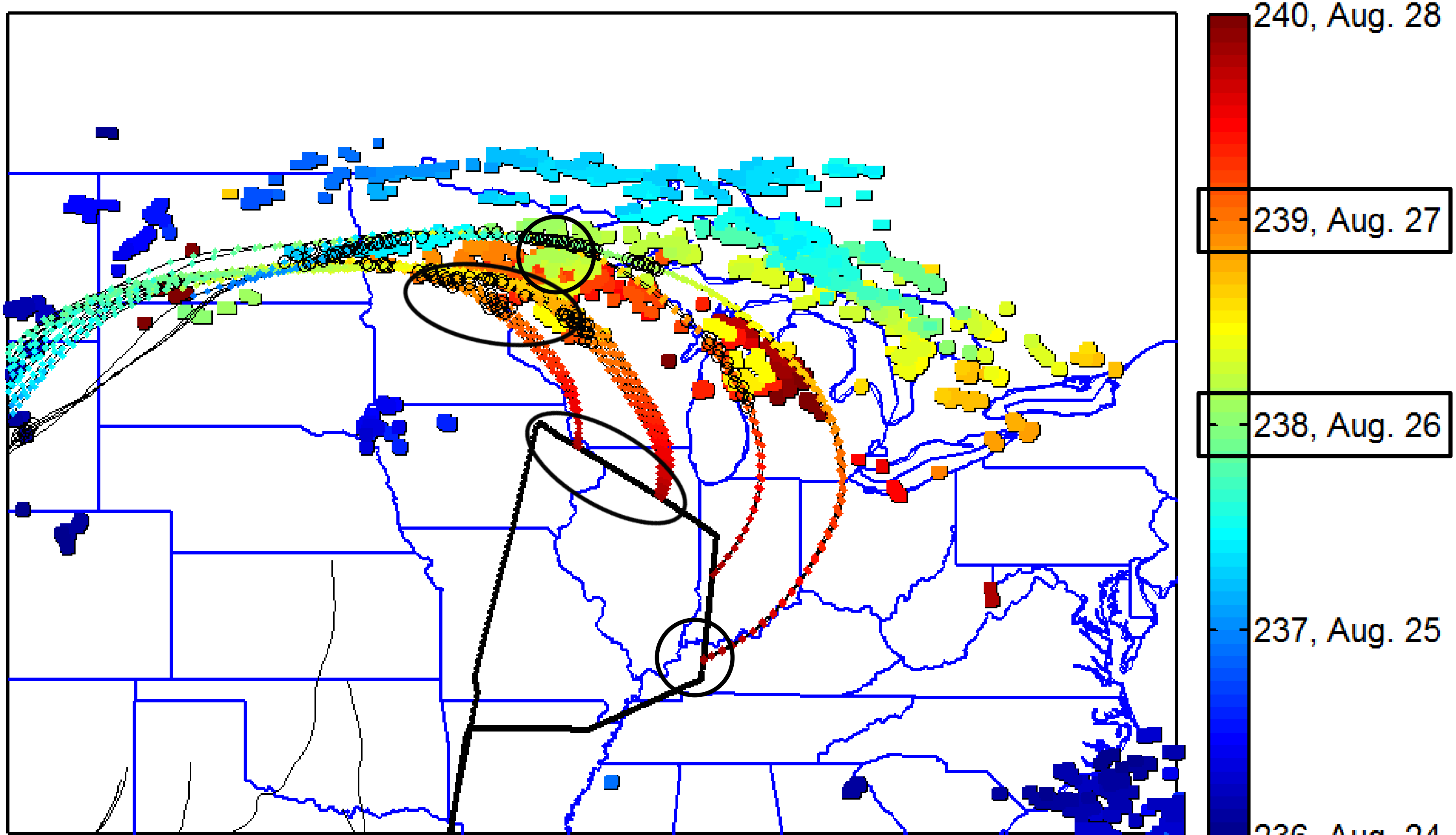
OT Analysis by K. Bedka

Linking Aug. 27, 2013 Plumes to Storm Systems

Flight Track, OT Detections & Back-trajectories

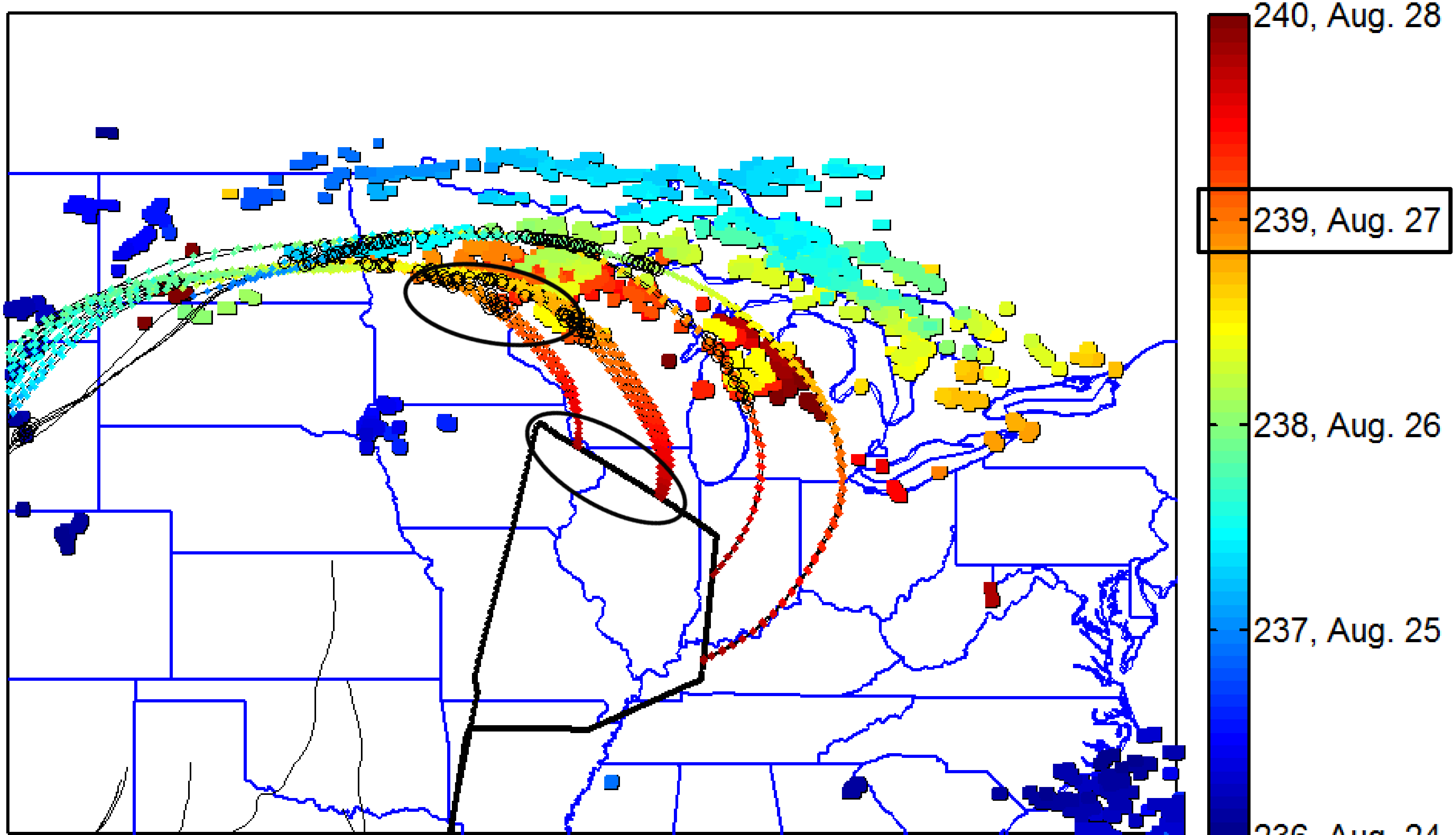


Trajectory Model by Ken Bowman

OT Analysis by K. Bedka

Linking Aug. 27, 2013 Plumes to Storm Systems

Flight Track, OT Detections & Back-trajectories

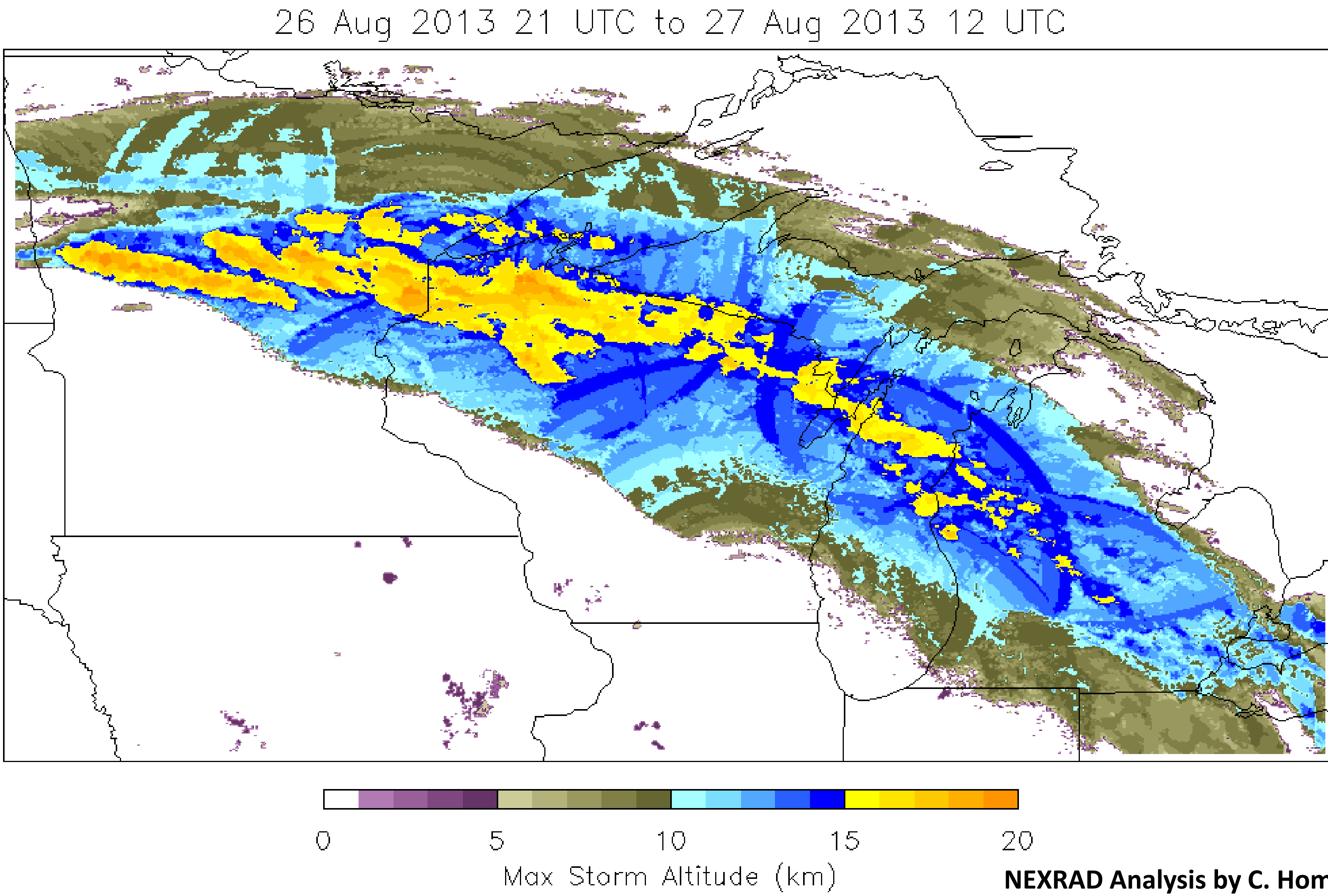


Trajectory Model by Ken Bowman

OT Analysis by K. Bedka

Max Storm Altitude Determined with NEXRAD

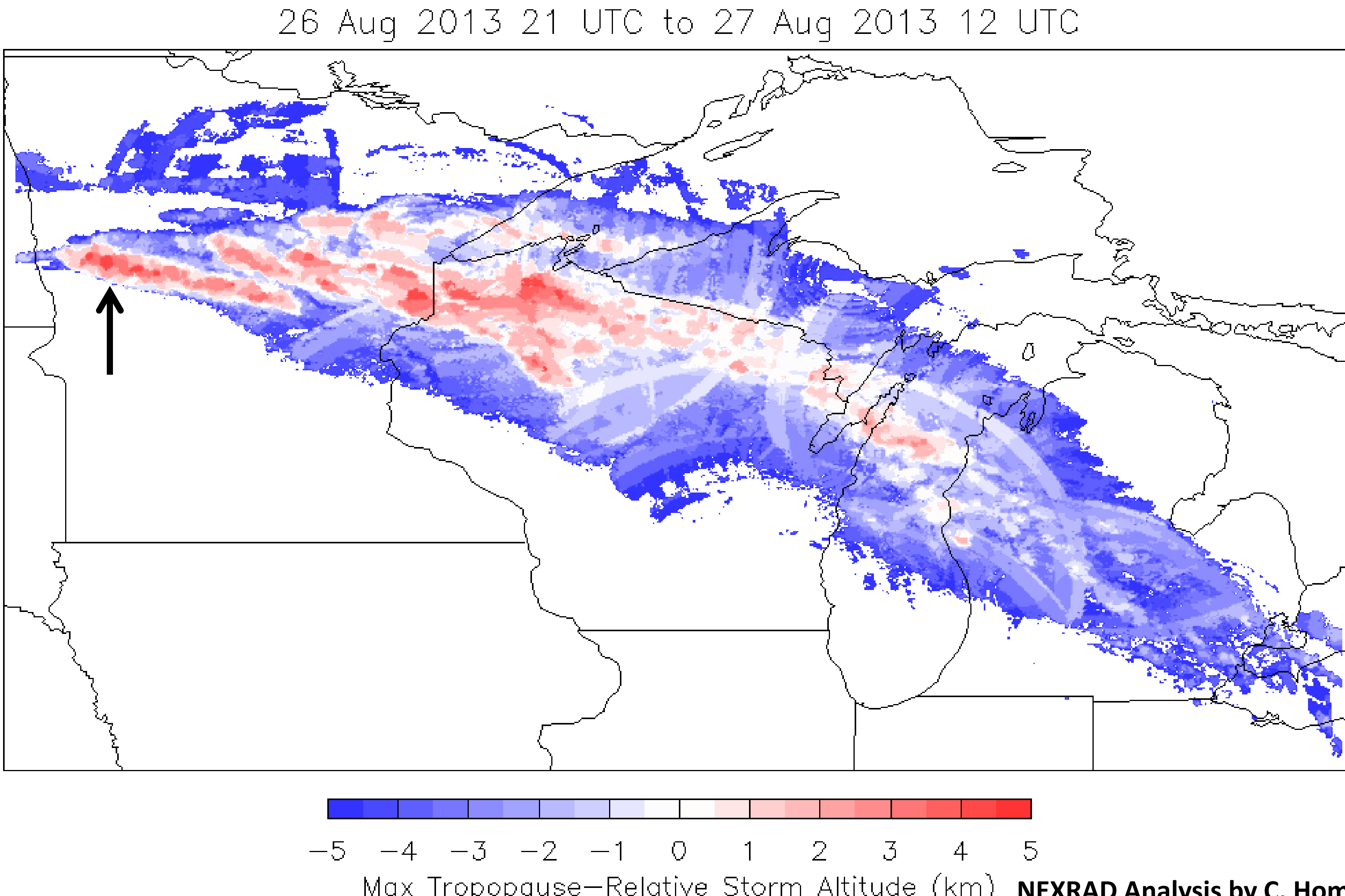
Storm Evolution Over a 15 hour Period, Aug 26 – 27, 2013



NEXRAD Analysis by C. Homeyer

Depth of Penetration Above Trop. NEXRAD

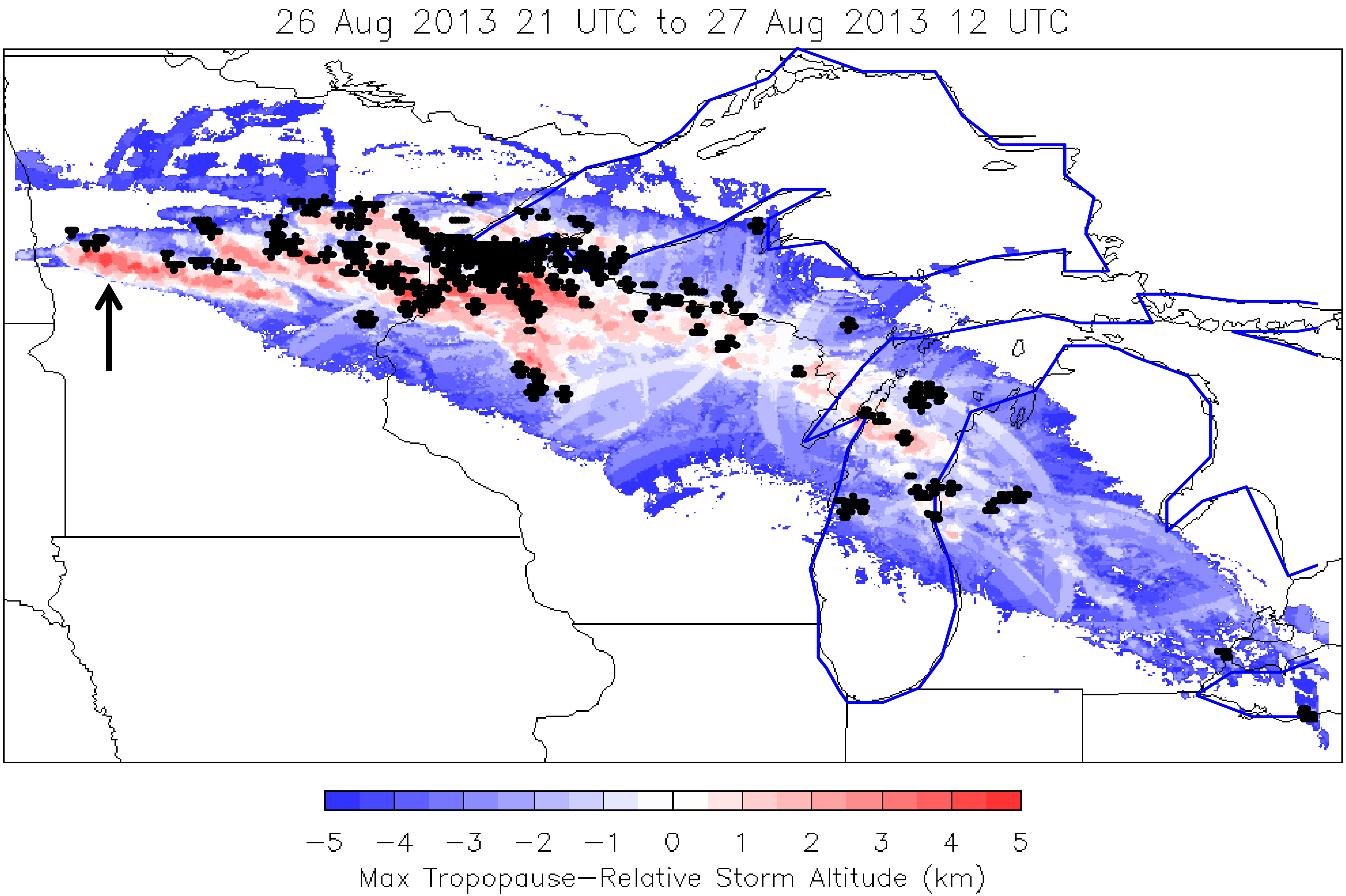
Storm Evolution Over a 15 hour Period, Aug 26 – 27, 2013



NEXRAD Analysis by C. Homeyer

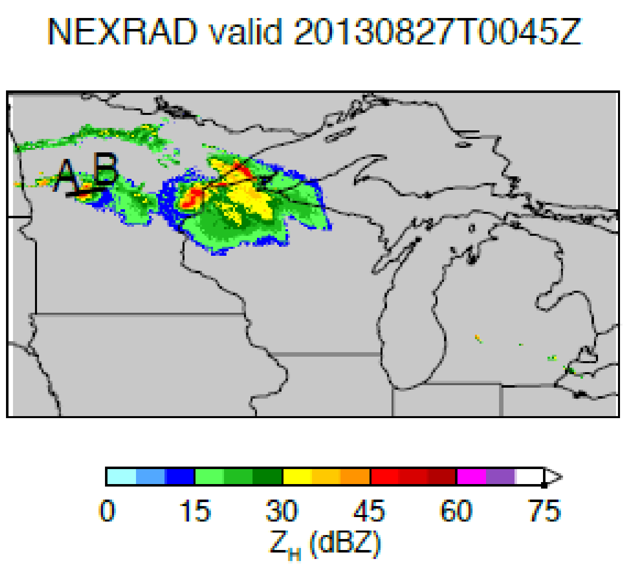
NEXRAD and OT Detection Comparison

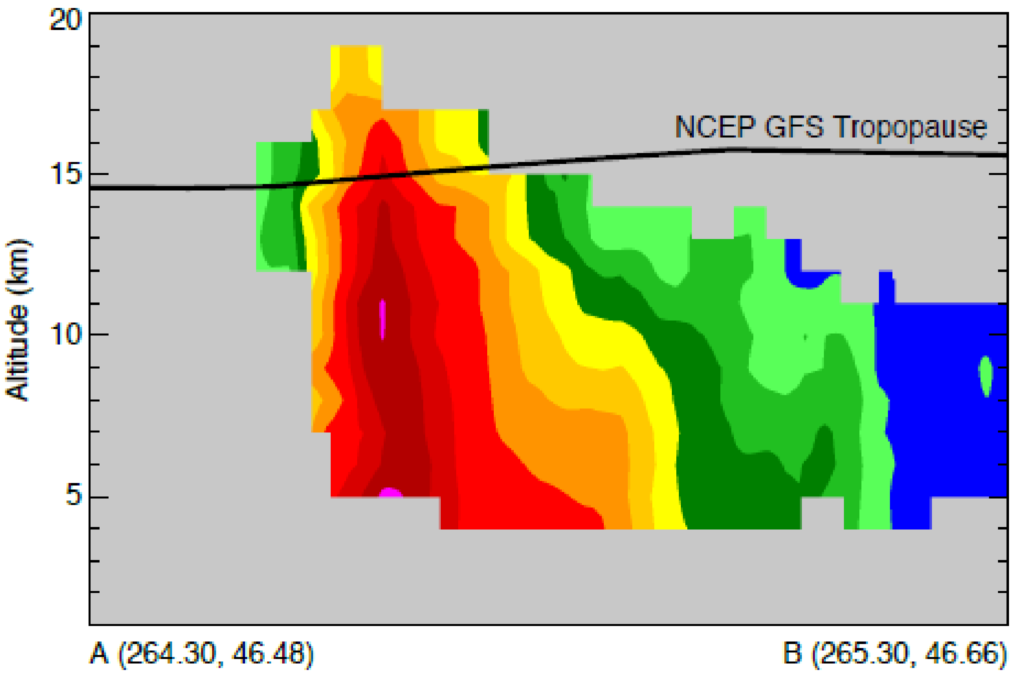
Storm Evolution Over a 15 hour Period, Aug 26 – 27, 2013



Depth of Penetration Above Trop. NEXRAD

Snapshot of Candidate Storm System in Radar Data



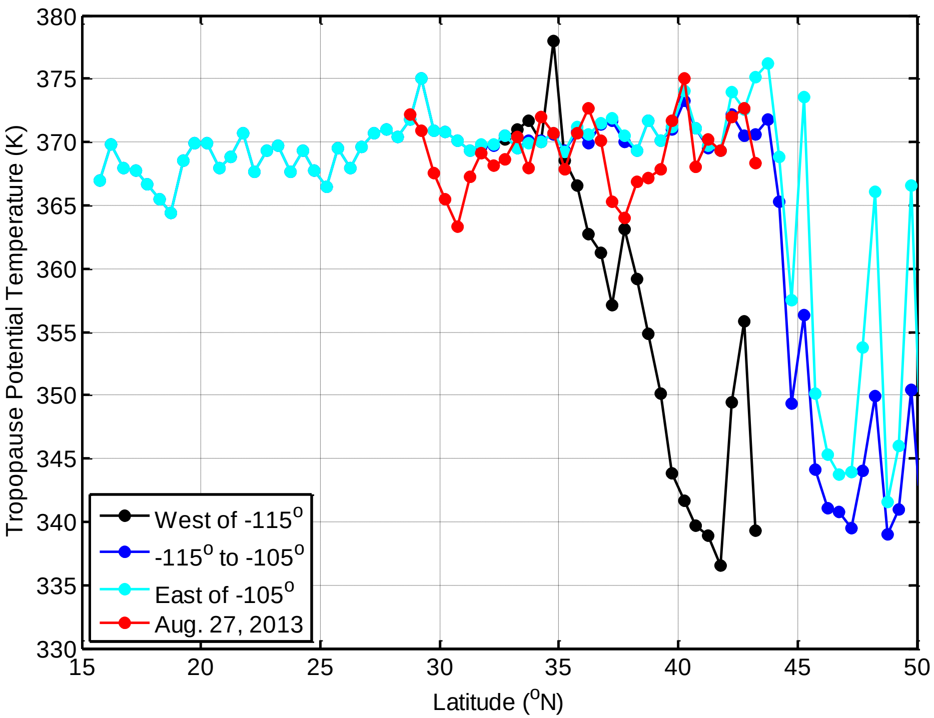


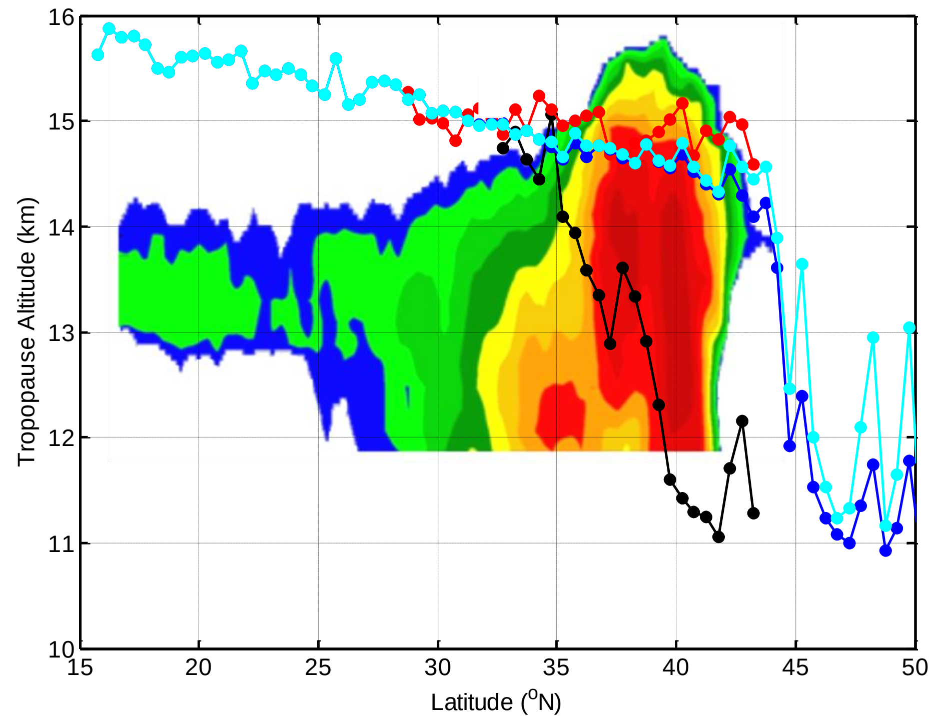
- Transect of Storm at 0045Z on Aug. 27 (Location of Arrow on Previous Slide)
- NEXRAD Data Show Storm Structure
- **Core Penetrates Local Tropopause Level by Several Kilometers**

NEXRAD Analysis by C. Homeyer

Deep Convection Relative to Tropopause

High Tropopause Sloping Down with Latitude; Break at ~45°N

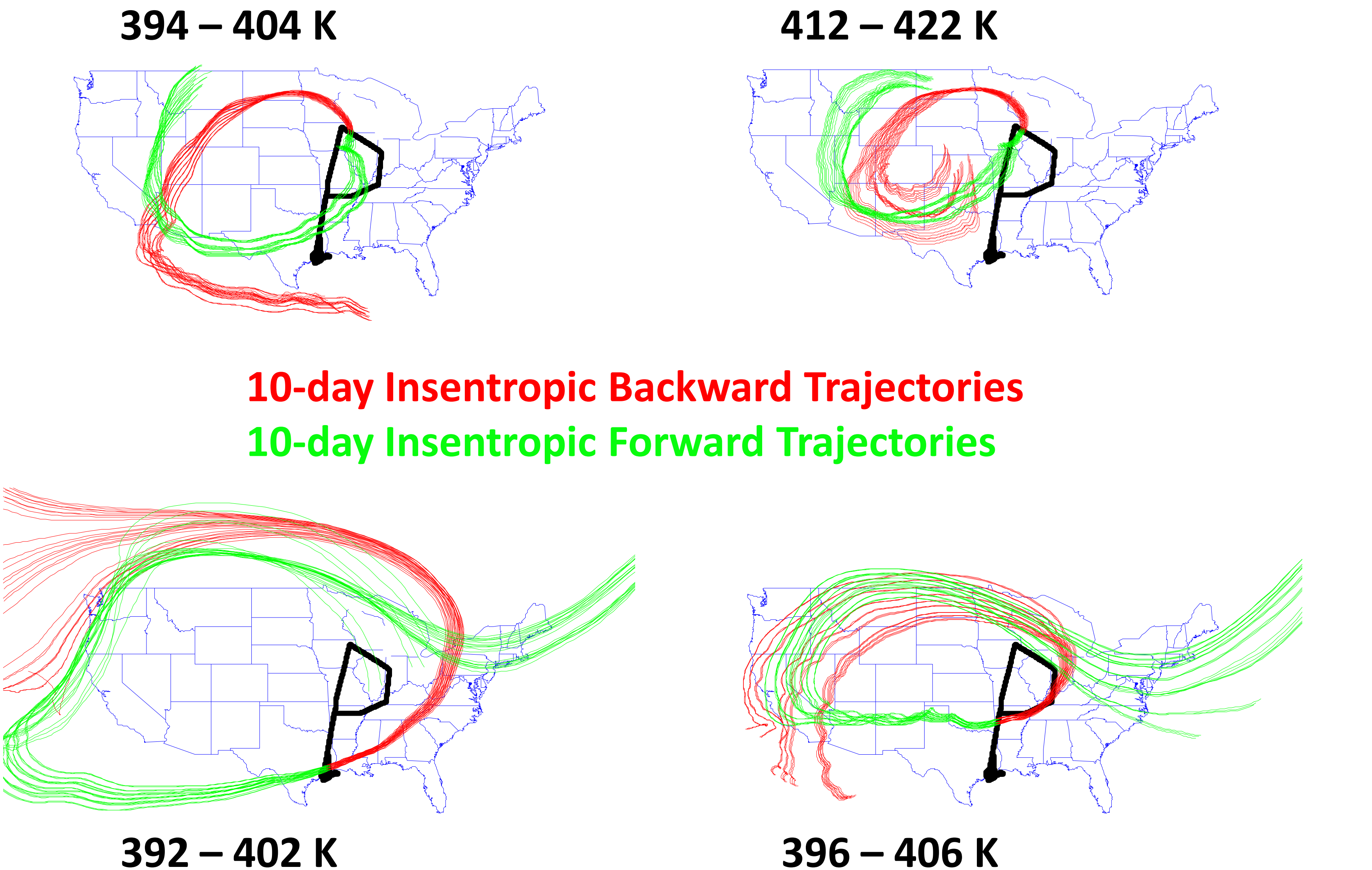




- ❖ High (Tropical) Tropopause over Much of U.S. During SEAC4RS Period
- ❖ Nearly Constant Potential Temperature, but Lower Altitude at High Lats.
- ❖ **Deep Convection More Likely to Penetrate Tropopause at Higher Latitudes**

Dynamics – NAM Anti-Cyclone on Aug. 27, 2013

Variability in NAM Structure with Altitude & Latitude

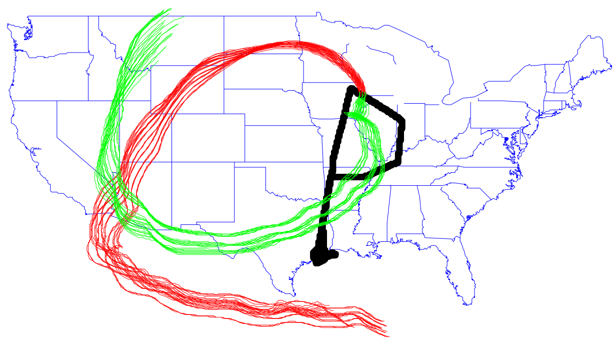


Trajectory Model by Ken Bowman

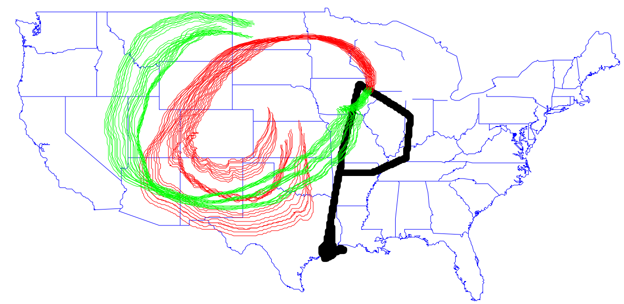
Dynamics – NAM Anti-Cyclone on Aug. 27, 2013

Variability in NAM Structure with Altitude & Latitude

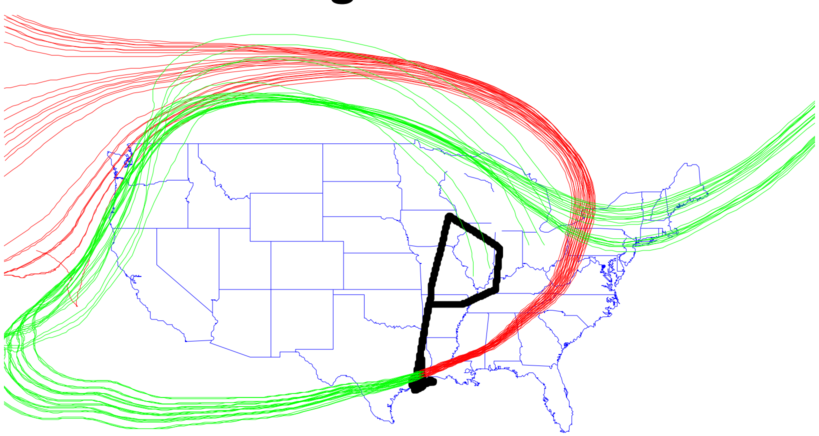
394 – 404 K



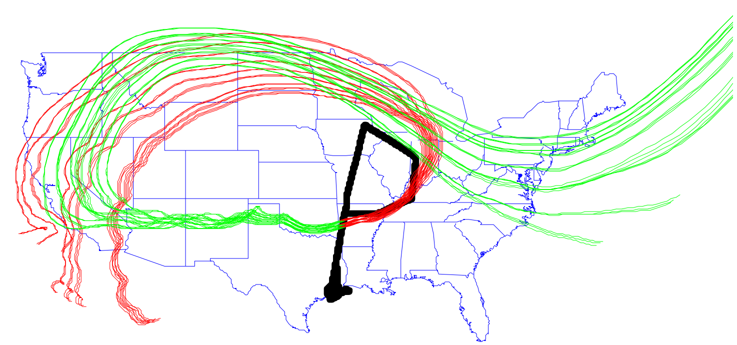
412 – 422 K



- Tighter Circulation at Higher Latitudes ↑
- Tighter Circulation at Higher Theta Levels →
- **Long Residence Time for Covectively Influenced Air at 410 K**



392 – 402 K

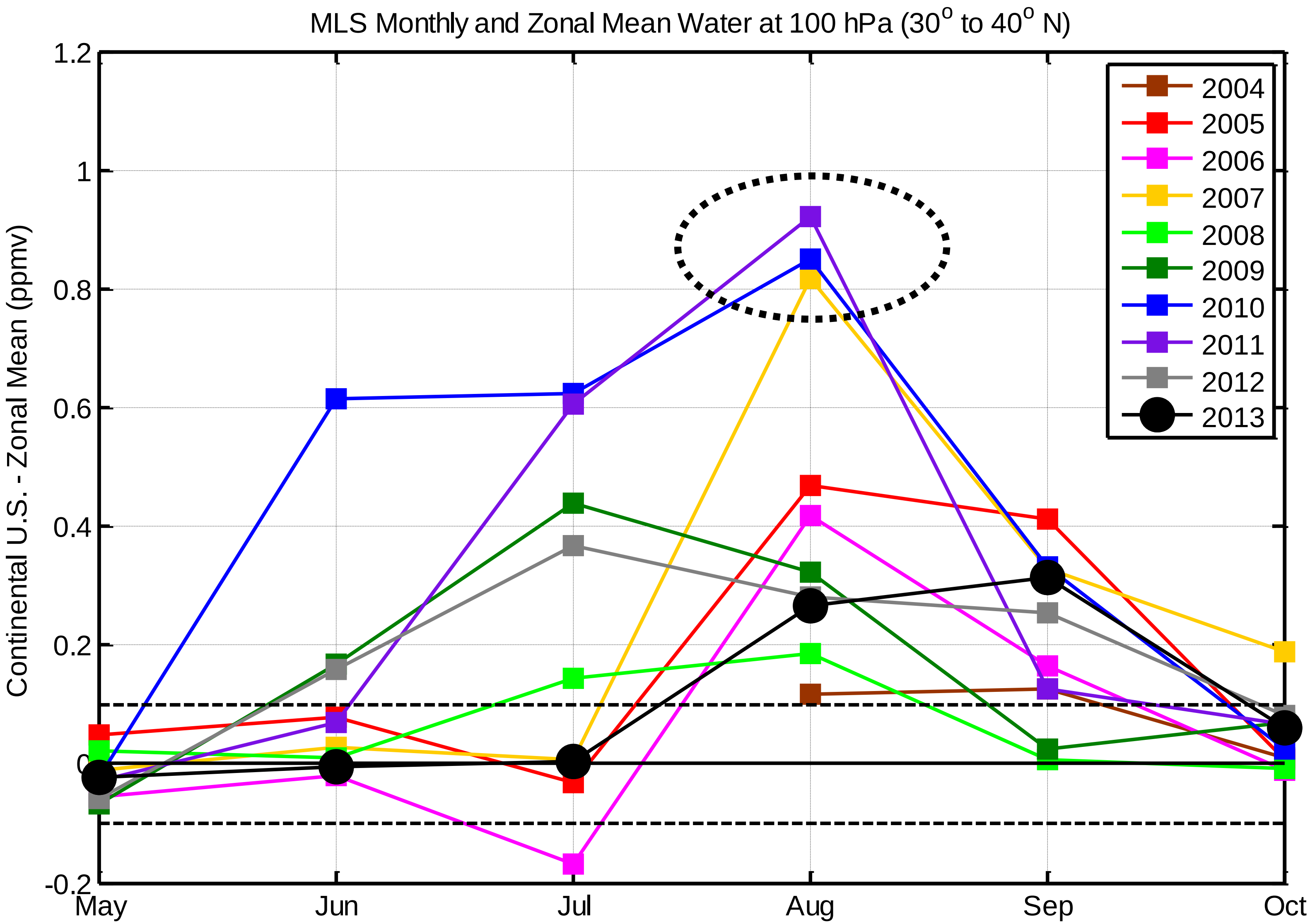


396 – 406 K

Trajectory Model by Ken Bowman

MLS Satellite Monthly Mean Measurements

ΔH_2O = Con. U.S. – Zonal Mean at 100 hPa



Summary

Complementary Data Sets – Aircraft, Satellite, Radar

- Convection can deliver large quantities of water directly to the lowermost and overworld stratosphere (up to ~440 K)
- This mechanism bypasses the thermal control of the tropopause
- Plumes are evident in both high-resolution aircraft and global satellite data
- GOES IR imagery is useful for identifying potential storm candidates
- OT algorithm and back trajectories can be used to confirm storm source
- NEXRAD radar data (at 5 min data rate) provide a wealth of precise information about the exact storm location, storm evolution, and a robust estimate of penetration depth relative to the tropopause
- Trajectories in late August, 2013 show that there was a persistent anti-cyclonic circulation over the U.S. providing a means of containing the convectively influence air

Ongoing Work

Complementary Data Sets & Case-study Comparison

- Analysis of tracer from SEAC4RS data may provide more information on the amount of near surface boundary layer air that is transported via this mechanism – not available for Aug 27

- Further analysis of this and of other similar plume case studies will provide insight into the details of the convective source term

- Model analysis of this and of other similar plume case studies will provide insight into chemical impacts of convection

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- The frequency and intensity of these events may increase in response to climate forcing, specifically warmer surface temperatures and higher low-level moisture