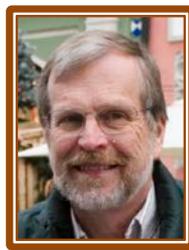




University of Wisconsin-Madison Space Science and Engineering Center

Cooperative Institute for  
Meteorological Satellite Studies



# IMPROVING VERY-SHORT-RANGE FORECASTS OF MOISTURE-DRIVEN WEATHER EVENTS OVER ALASKA USING SOUNDINGS FROM MULTIPLE POES SATELLITES

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Richard Dworak<sup>1</sup> and Bill Line<sup>1</sup>

<sup>1</sup> Cooperative Institute for Meteorological Satellite Studies (CIMSS), University of Wisconsin – Madison, Wisconsin

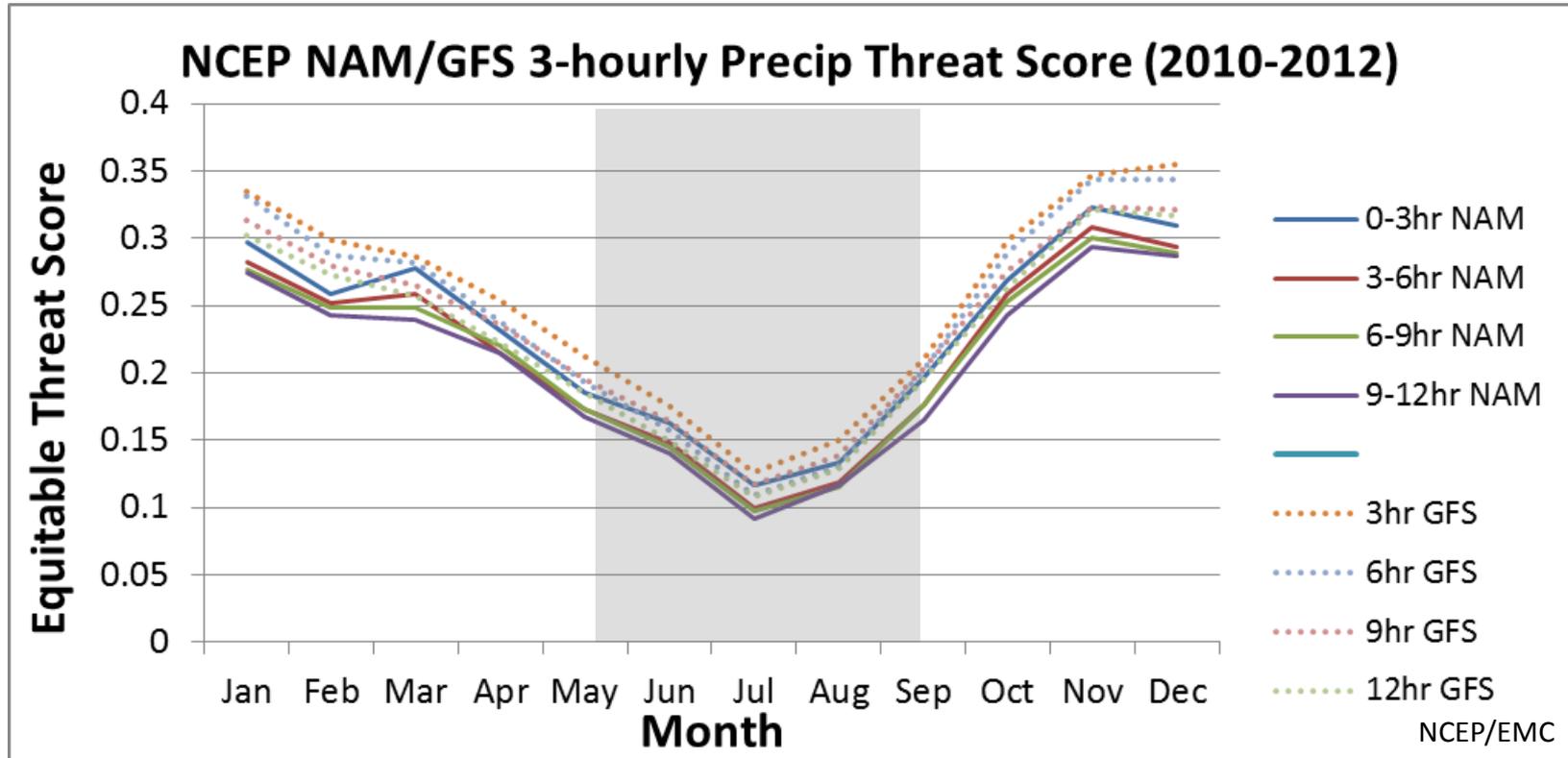
<sup>2</sup> NOAA/NESDIS/ORA, Advanced Satellite Products Team, Madison, Wisconsin

***□ Expanding the Utility / Value of real-time  
Satellite Sounder Products from Observations to Forecasts***

***□ A new project to Transition GOES Research to POES Data***

***□ Providing unprecedented understanding of the  
evolution of multi-Level Moisture fields***

# Motivation



- NWP performance in predicting the occurrence and non-occurrence of short-term precipitation and disruptive weather events in the warm season can be improved.
  - *Due in part to the inability to observe (and therefore predict) mesoscale moisture features*

# A Brief History of the CIMSS GOES NearCast Model

## *What are we trying to improve with NearCasts?*

*Short-range forecasts of timing and locations of severe thunderstorms  
- especially hard-to-forecast, isolated summer-time convection*

## *What are NearCasts?*

NearCasts are 1-9 hour, data-driven analyses and forecasts designed to identify areas where convection will (*or will not*) form

Use what GOES observes best – Upper and Mid-Level Moisture

NearCasts use all full-resolution, clear-air GOES observations of moisture and temperature made over land

*These data are not included in operational NWP systems*

NearCasts are intended to help forecasters:

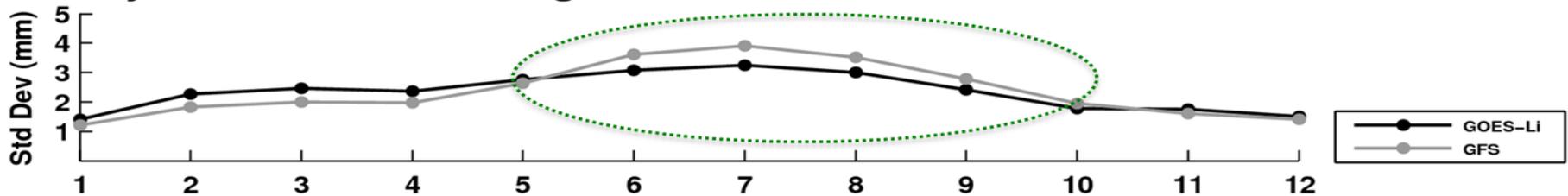
- Available within minutes of observation times,
- Frequently updated (hourly or sub-hourly), and
- Preserve observations better than traditional NWP products

# First, assure that the Satellite Soundings can add benefit

## Evaluation of GOES Precipitable Water Retrievals (Using NCEP GFS for First Guess)

- Comparisons against GPS TPW observations around the US show:
- GOES TPW (Li retrievals) data have a wet bias
  - Worst at time of day when GFS has highest precipitation bias
- GOES TPW data show greatest improvement over GFS First Guess:
  - 1) In warm months (*when NWP precipitation skill is worst*) and
  - 2) Using 06Z, **12Z** and 18Z GFS guess fields

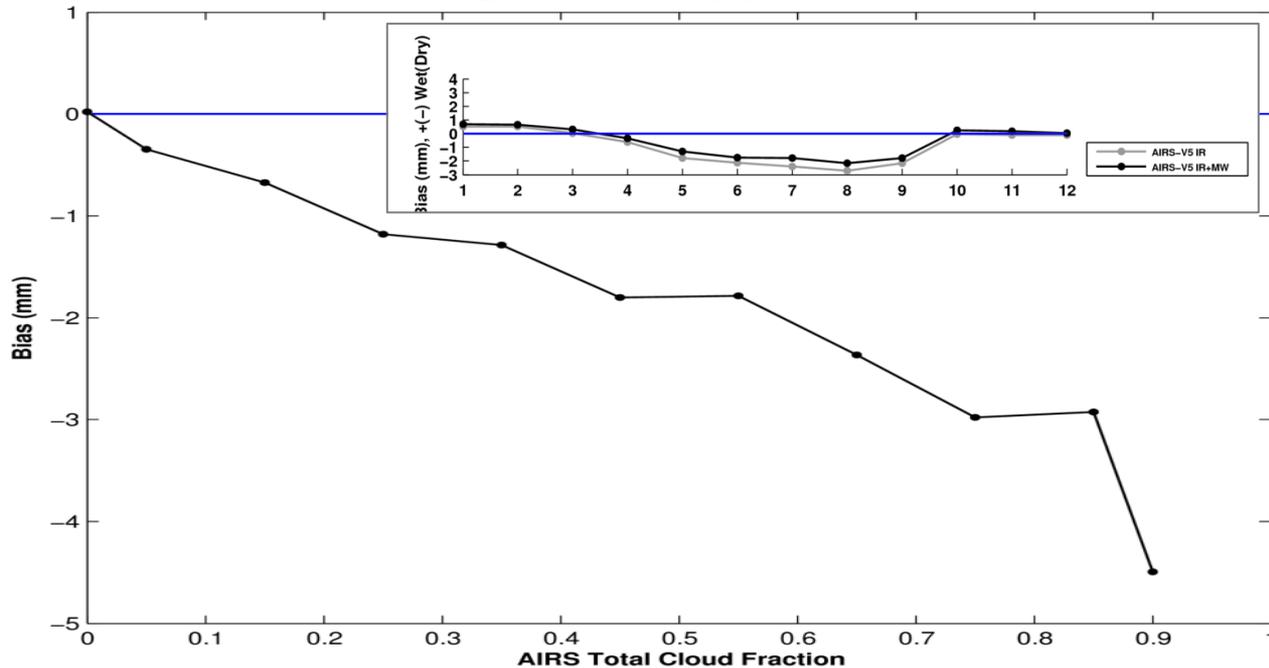
Monthly GOES–Li and Background GFS TPW Initialized @ 12Z v. GPS



We will perform similar evaluations of AIRS, CrIS and IASI moisture retrievals at AR GPS sites

# First, assure that the Satellite Soundings can add benefit

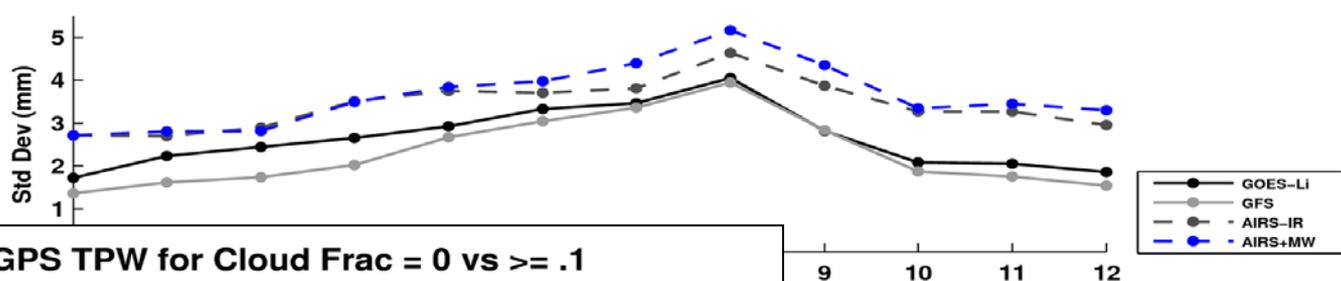
2011 All AIRS vs GPS TPW



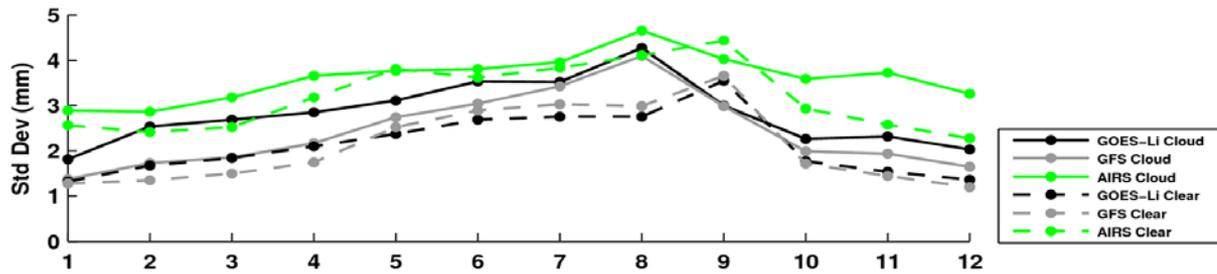
Total Precipitable Water (TPW) Validation tools are available from GOES-RRR activities over CONUS to assess performance of AIRS-V5 moisture data

-----  
 Showed Bias and Std.Dev. are affected by Cloud Amount

2011 Collocated AIRS with GOES-Li/GFS vs. GPS TPW



2011 AIRS GOES-Li/GFS vs GPS TPW for Cloud Frac = 0 vs >= .1



# The Fundamental Operational Forecasting Question:

**How can we preserve details in the moisture fields observed frequently by satellites in objective tools that can be available to forecasters immediately after the observations are made?**

- Why are we looking at alternative methods to NWP for providing objective guidance with these data?
  - *Fine model resolution is needed to preserve important features in data such as boundaries, max's and min's*
  - *Fine resolution, however, requires a small timestep*
    - => *Long run times*
    - => *And, the observations are Perishable*

# A Simple Alternative: CIMSS NearCasting Model

- A Lagrangian trajectory model that dynamically projects GOES temperature and moisture observations out to 9 hours in advance.
- Uses the under-utilized satellite moisture retrievals
  - *Evaluations have shown that NearCasts extend the use of GOES Legacy Moisture Soundings from observations to forecasts while preserving the full resolution of the satellite data*
- Goal: Provide information about the current state and near-term evolution of the moisture and stability structure of the pre-convective / heavy precipitation environment
  - *Helps determine where convection is most ( and least ) likely to occur and also where convection is ( is not ) likely to produce heavy precipitation*



# Advantages of Lagrangian framework

- Larger timestep (10-15 minutes)
  - => Quick turn-around times (~minutes) => little latency.
  - *Lagrangian equations of motion eliminate highly non-linear advection terms.*
- Model updates whenever new observations become available
  - *Hourly for GOES, after every overpass for POES*
- No smoothing of data => details in observations are preserved
  - *All Retrievals used / Preserved at full resolution*
- The system produces analyze and forecast of IR-based moisture and stability soundings even in regions that are or will become cloud covered.

# Explicit Trajectory Approach

( *Details* )

- Method uses an initial wind (obtained from NWP gridded velocity field) to start trajectories from each retrieval location.
- Trajectories are dynamically updated at every timestep using NWP forecasted pressure gradient fields.

At each time increment, the acceleration of every parcel is updated using the inviscid equations of motion, where M is the appropriate Geopotential parameter:

$$a_x^t = - \Delta M^t / \Delta x + f^t v^t \qquad a_y^t = - \Delta M^t / \Delta y + f^t u^t$$

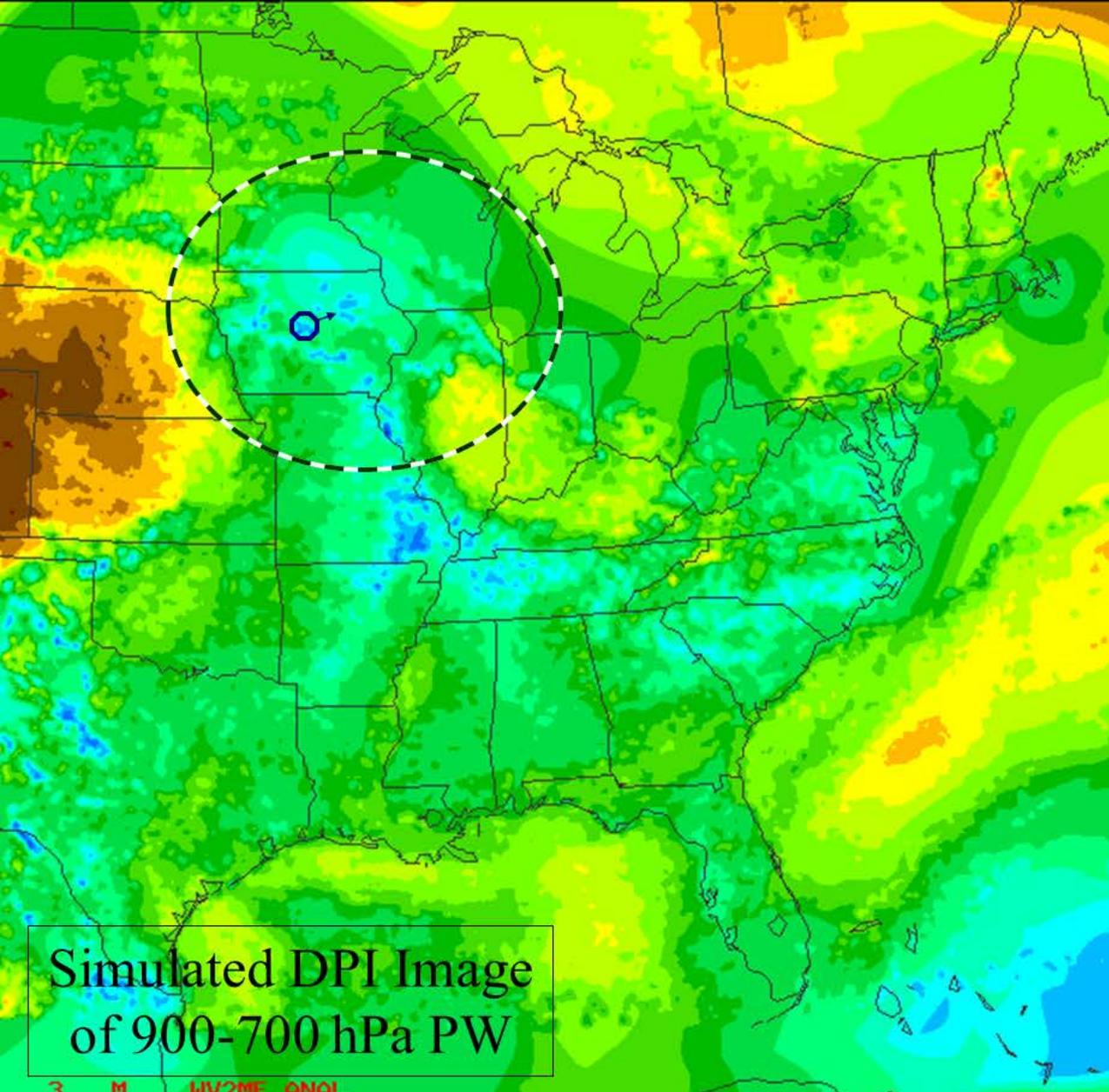
Then, parcel velocities and positions are updated, based on the discrete model formulation of Greenspan (1972, 1973):

$$\begin{aligned} u^{t+1} &= u^t + \Delta t ( 3/2 a_x^t - 1/2 a_x^{t-1} ) , & x^{t+1} &= x^t + 1/2 \Delta t ( u^t + u^{t+1} ) \\ v^{t+1} &= v^t + \Delta t ( 3/2 a_y^t - 1/2 a_y^{t-1} ) , & y^{t+1} &= y^t + 1/2 \Delta t ( v^t + v^{t+1} ) \end{aligned}$$

The initial timestep requires a special “startup” formula to update parcel velocities

$$u^t = u^0 + \Delta t a_x^0 \quad , \quad v^t = v^0 + \Delta t a_y^0$$

(*Petersen and Uccellini, 1979*)



# *Lagrangian NearCast*

## How it works:

- 1) Winds and height gradients from an NWP model are interpolated to full resolution retrieval locations at multiple levels

Simulated DPI Image  
of 900-700 hPa PW

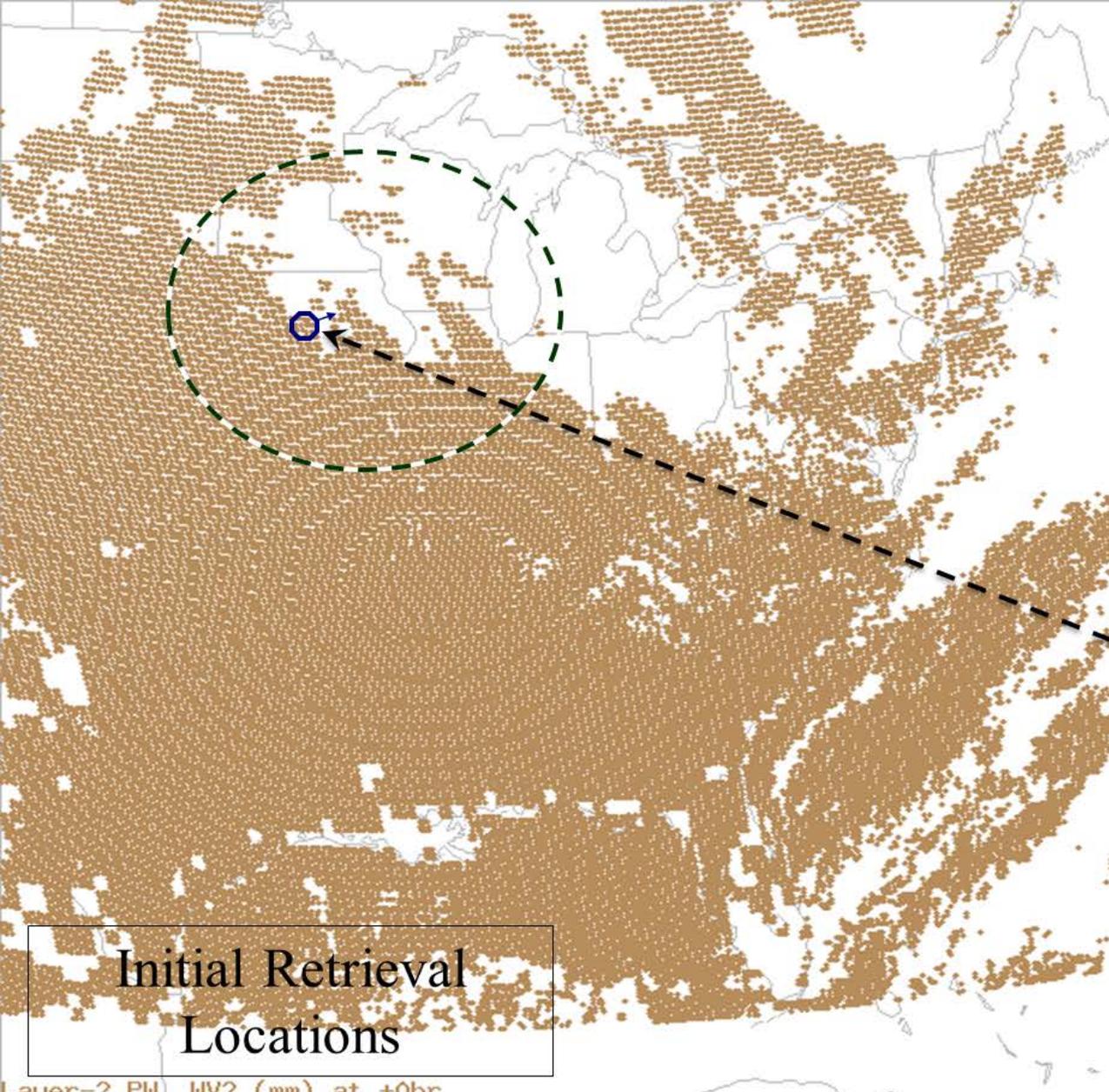
3 M WV2ME ANAL

13 April 2006 – 2100 UTC  
900-700 hPa GOES PW  
0 Hour NearCast

## *Lagrangian NearCast*

### How it works:

- 1) Winds and height gradients from an NWP model are interpolated to full resolution retrieval locations at multiple levels
- 2) Parcels are moved to new locations, using dynamically changing winds using 15 min. steps



Initial Retrieval  
Locations

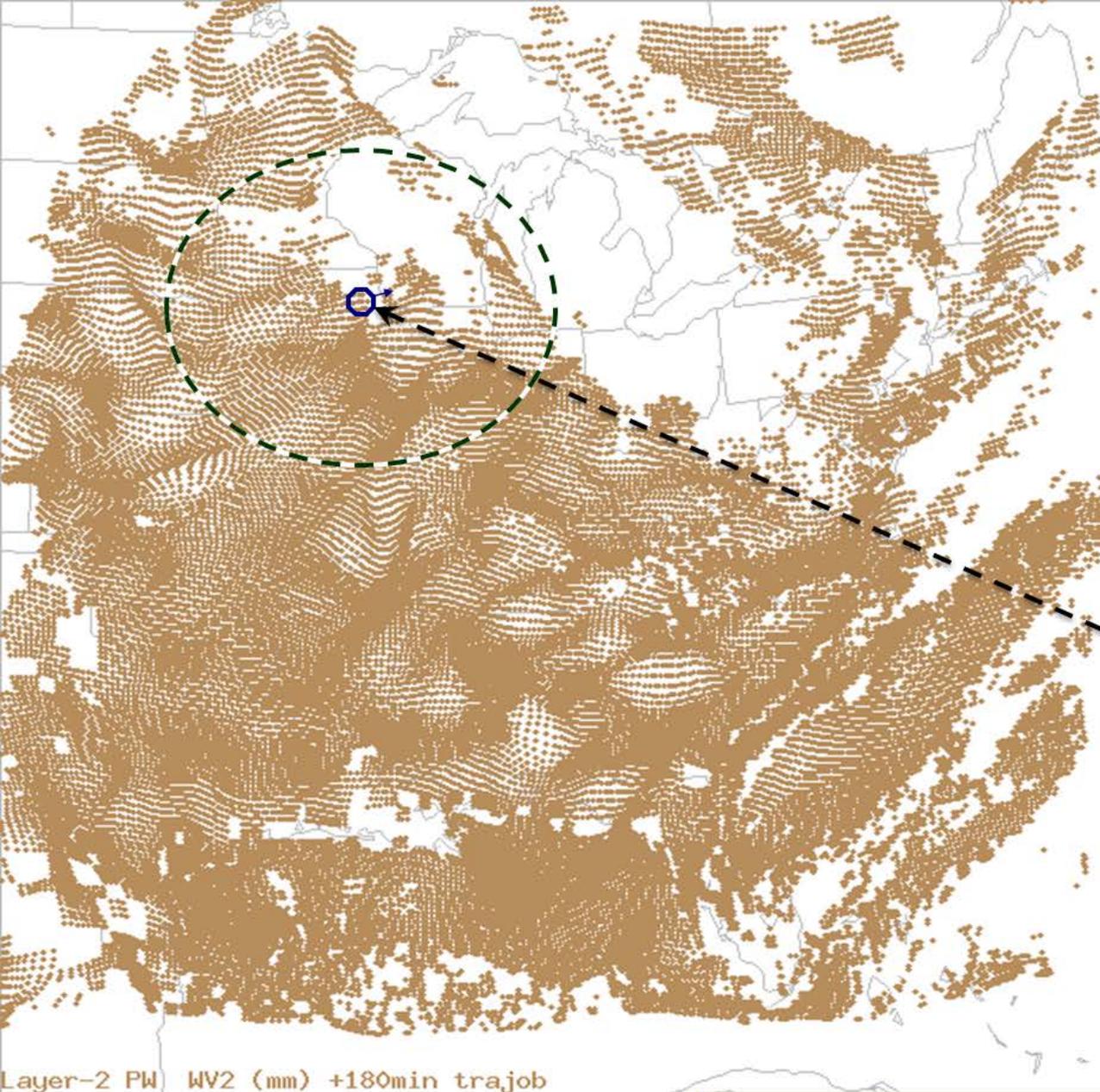
Layer-2 PW WV2 (mm) at +0hr

13 April 2006 – 2100 UTC  
900-700 hPa GOES PW  
0 Hour Ob Locations

## *Lagrangian NearCast*

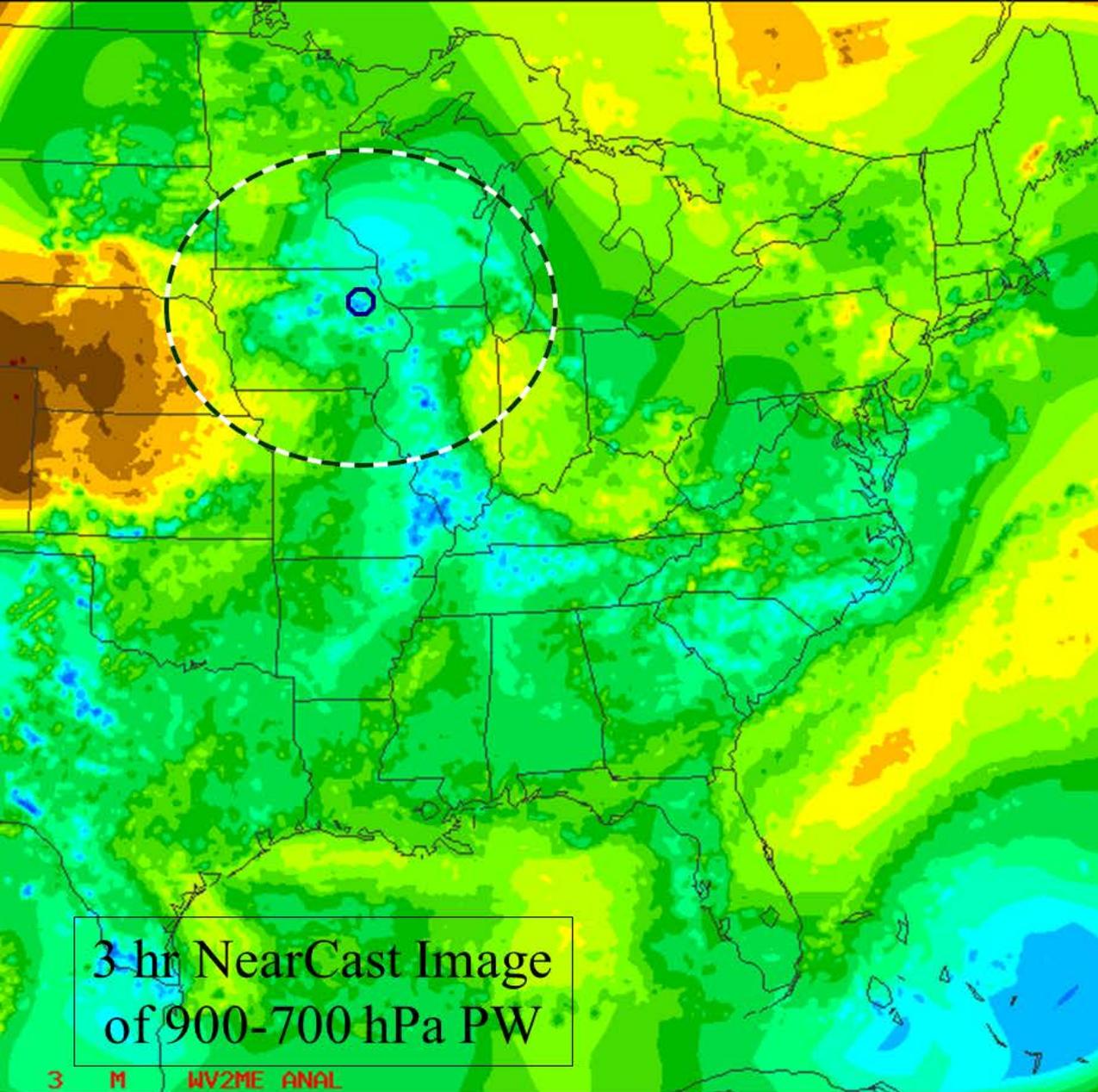
### How it works:

- 1) Winds and height gradients from an NWP model are interpolated to full resolution retrieval locations at multiple levels
- 2) Parcels are moved to new locations, using dynamically changing winds using 15 min. steps

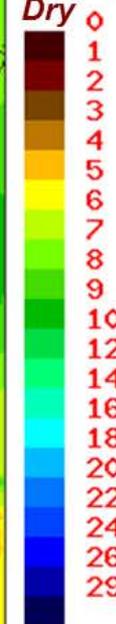


Layer-2 PW WV2 (mm) +180min trajob

13 April 2006 – 2100 UTC  
900-700 hPa GOES PW  
3 Hour NearCast Obs



CIMSS  
mm **Lagrangian NearCast**



**How it works:**

- 1) Winds and height gradients from an NWP model are interpolated to full resolution retrieval locations at multiple levels
- 2) Parcels are moved to new locations, using dynamically changing winds using 15 min. steps
- 3) The full set of “moved” moisture observations are then are combined with past NearCasts for the same time to produce an “image grid” for display

3 hr NearCast Image  
of 900-700 hPa PW

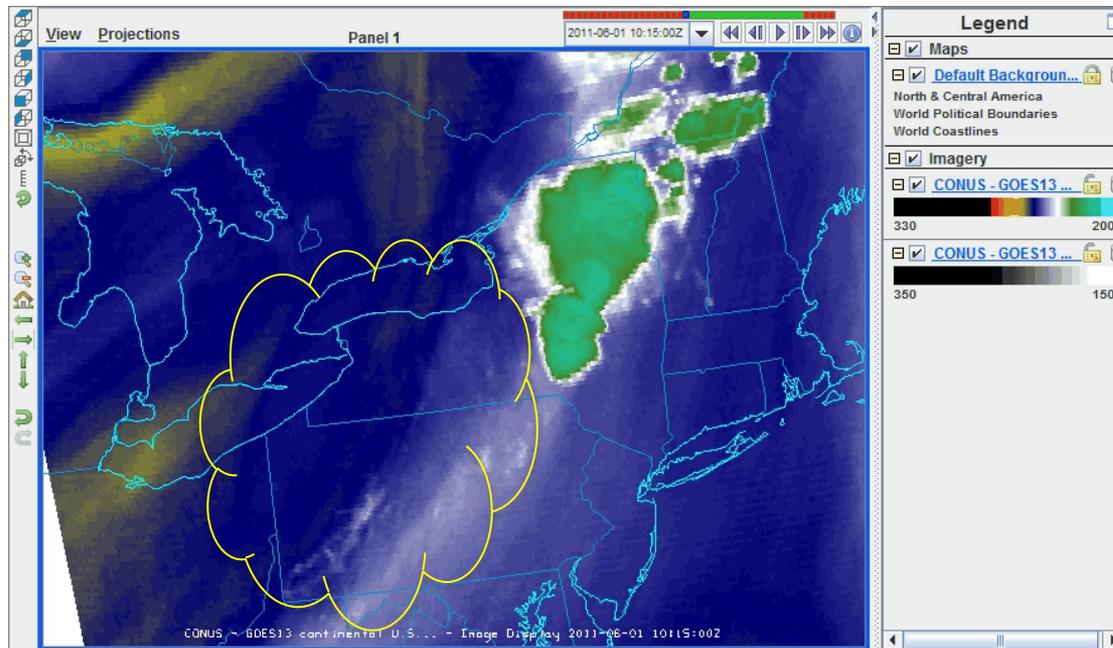
3 M WV2ME ANAL

10 km data, 10 minute time steps

13 April 2006 – 2100 UTC  
900-700 hPa GOES PW  
3 Hour NearCast Image

# How are the Satellite Observations Used to Gauge Atmospheric Stability?

- **Equivalent Potential Temperature (Theta-e)** contains information about the temperature and moisture content of air.



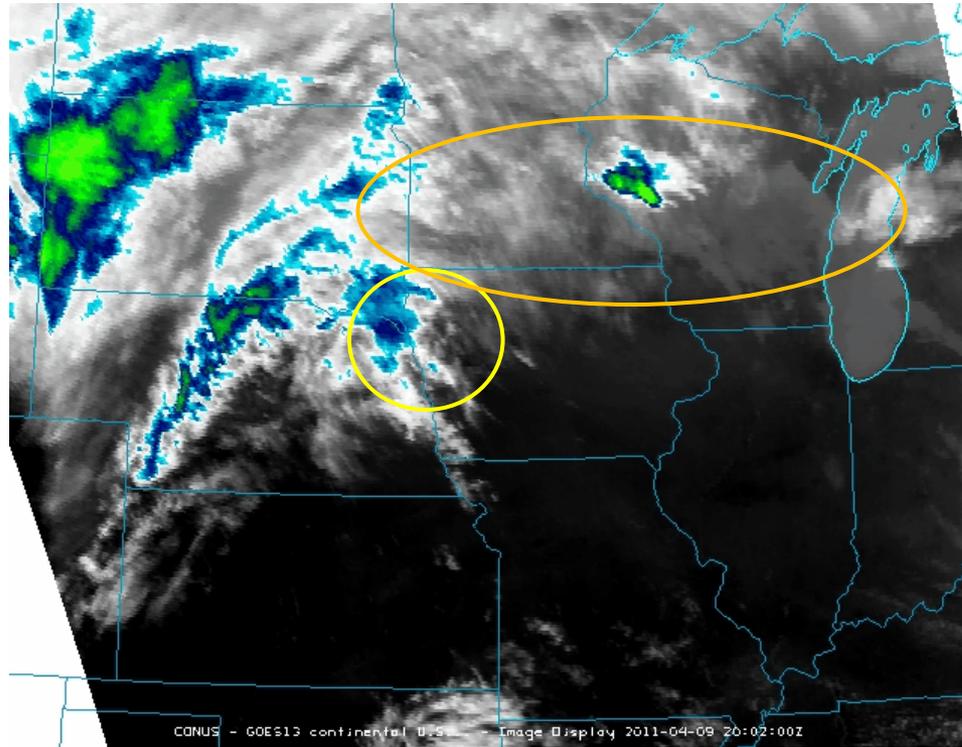
## Objective: To mimic what we've observed on WV imagery for years:

- *Convection develops where very dry air aloft is moving over moist air at the lower levels*
- *The diagnostic parameter Convective Instability captures this objectively as  $\Delta\theta_e / \Delta P$ ,*

Water Vapor Imagery: Warm colors = dry,  
Cool colors (*blues*) = wet

- Identify areas where  $\theta_e$  decreases with height

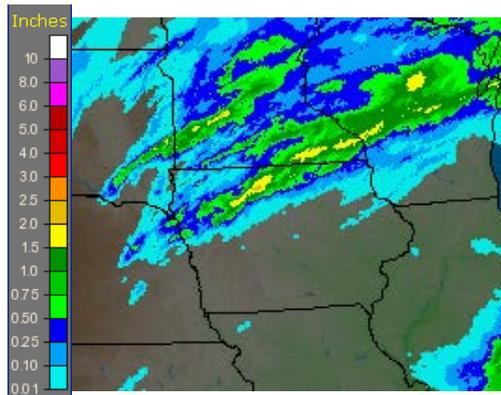
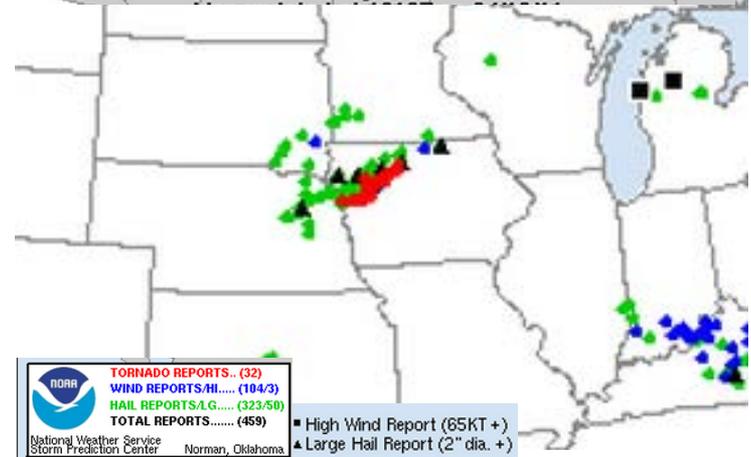
# April 09, 2011-Two Types of Convection



- **Initial severe convection** rapidly developed in E Nebraska around 22z and moved through NW Iowa before dissipating quickly in NC Iowa.



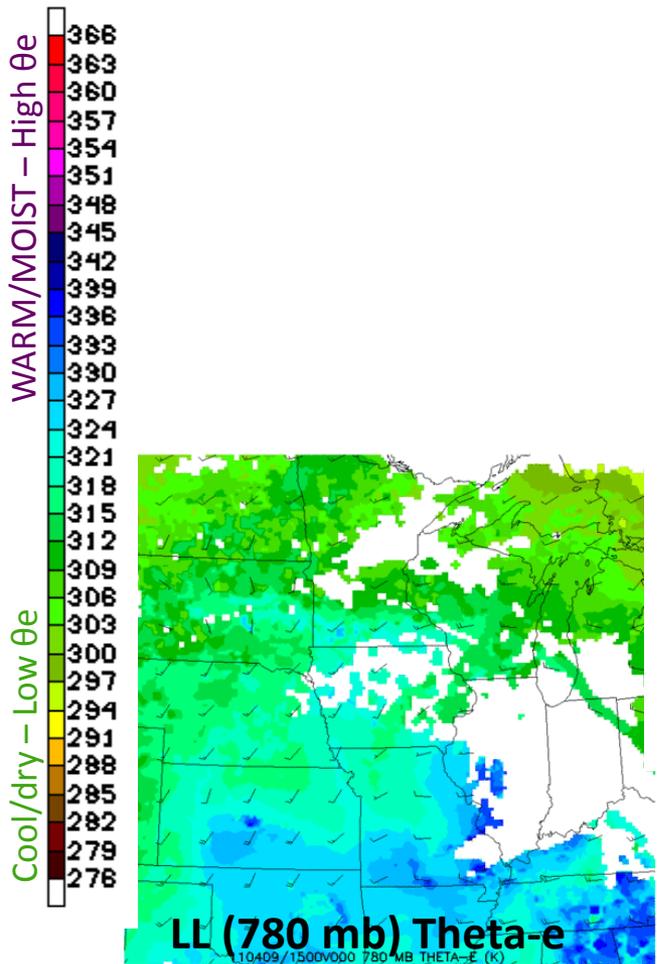
## SPC Storm Reports for 04/09/11



- Second round of non-severe convection developed in southern Minnesota around 02z and moved through central Wisconsin producing **widespread heavy rainfall**.

# 15z Isobaric NearCast Model Cycle

20110409-1500z NearCast - Valid: 20110409-1500z



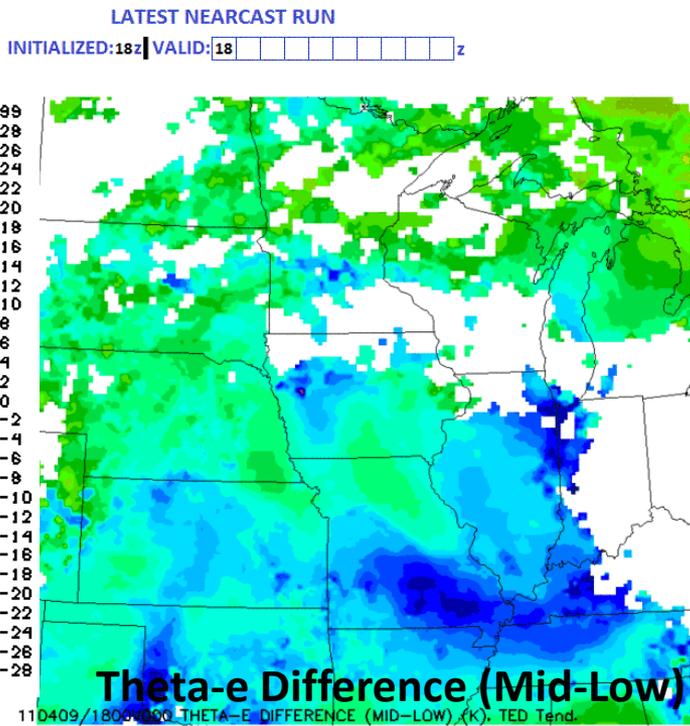
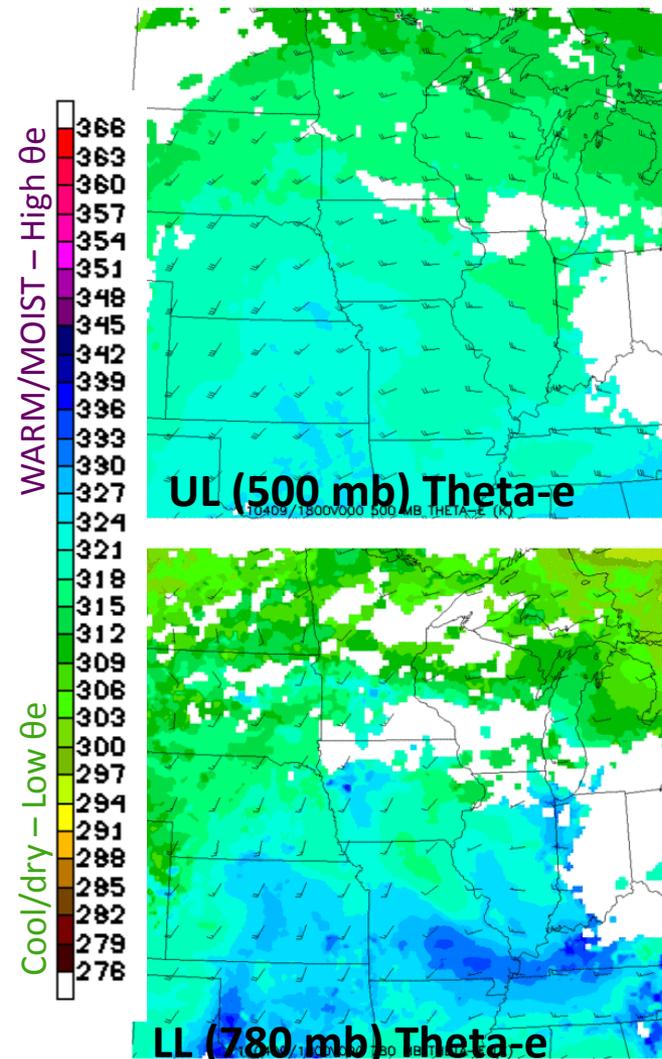
LATEST NEARCAST RUN  
INITIALIZED:15z | VALID:15z

- Low-Level Moisture Max + Mid-Level Dry air
- Focus on areas with:
  - Convective instability maximum and
  - Rapid destabilization tendencies.

**Significance of Display in Forecaster Training!** 16

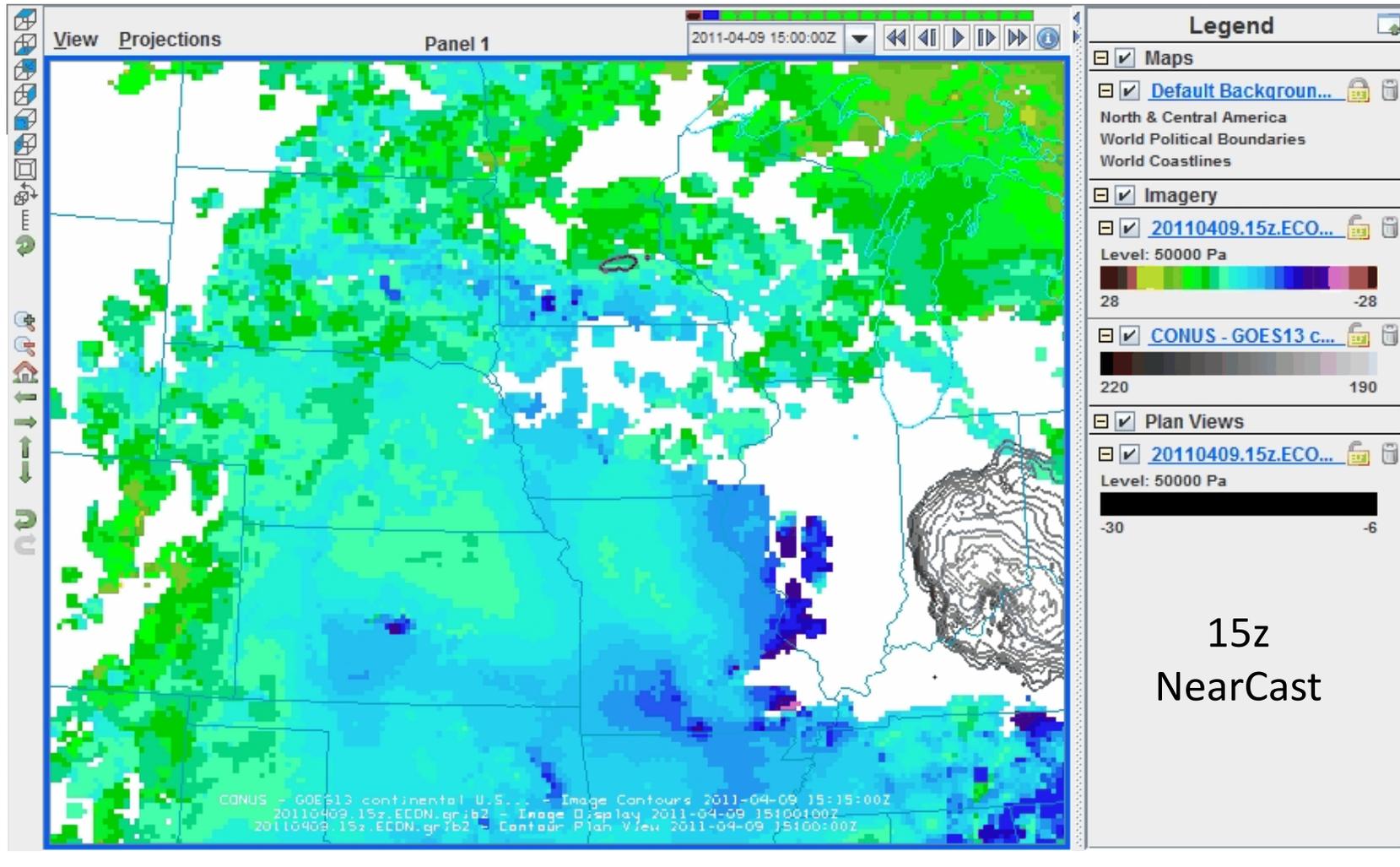
# 18z Isobaric NearCast Model Cycle

20110409-1800z NearCast - Valid: 20110409-1800z



- Good Continuity between successive model runs increases forecaster confidence
  - Continue to see stronger destabilization between 21z and 00z in NW Iowa
  - Destabilization tendencies weaken after 00Z as region ahead of instability max becoming unstable

# Validation

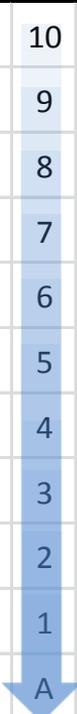


**Theta-E Difference (Convective Instability),  
Convective Instability Tendency, and  
Cloud-top Temperature**

# Preserving Previous Observations

NearCasts analyses and forecasts retain up to 10 hours of observations in its products by using previous model runs forecasts in producing its hourly updated displays.

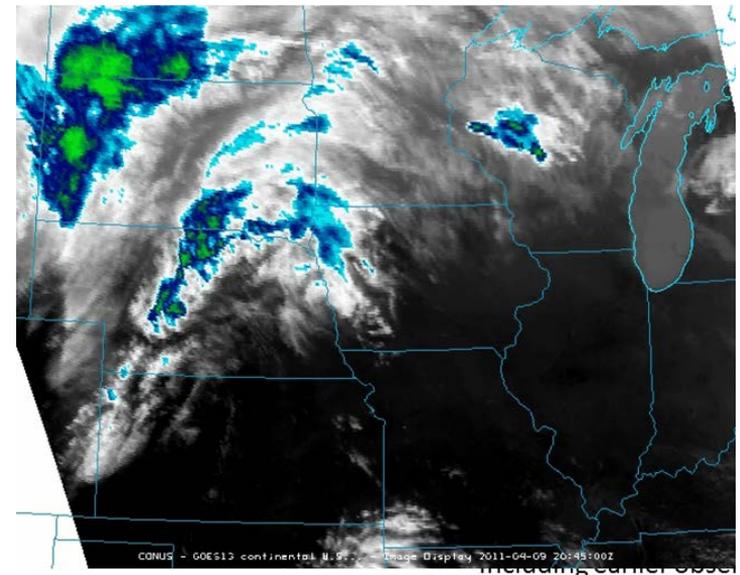
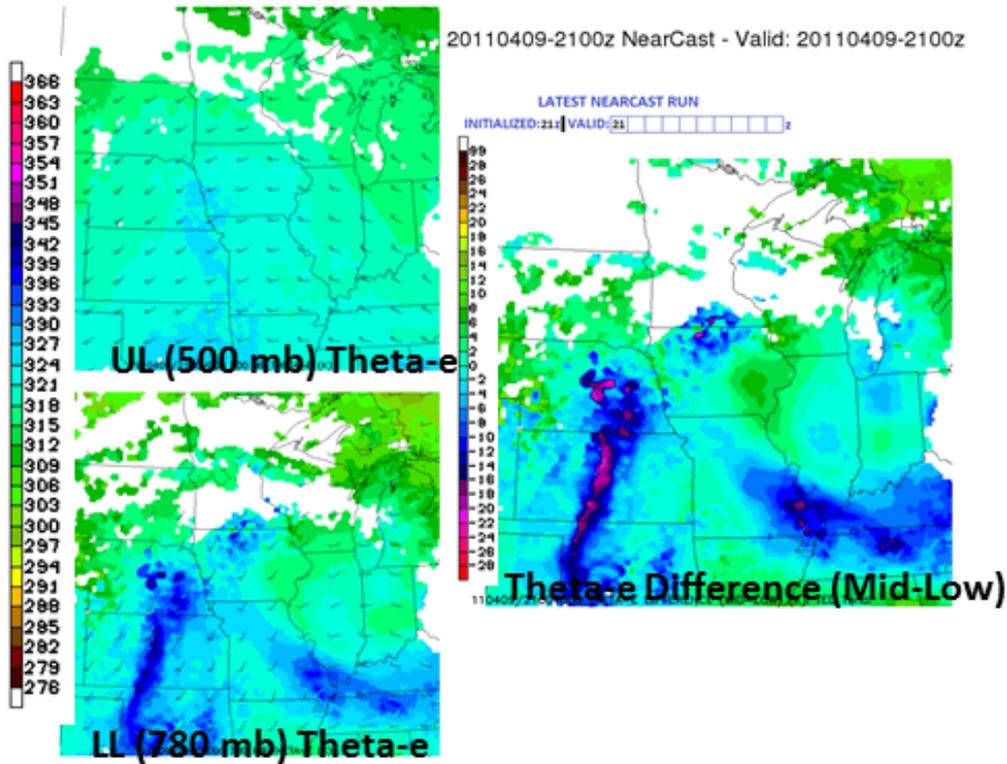
		Forecast Valid																					
		00z	01z	02z	03z	04z	05z	06z	07z	08z	09z	10z	11z	12z	13z	14z	15z	16z	17z	18z	19z	20z	
Forecast Initialization	00z	A	1	2	3	4	5	6	7	8	9	10											
	01z		A	1	2	3	4	5	6	7	8	9	10										
	02z			A	1	2	3	4	5	6	7	8	9	10									
	03z				A	1	2	3	4	5	6	7	8	9	10								
	04z					A	1	2	3	4	5	6	7	8	9	10							
	05z						A	1	2	3	4	5	6	7	8	9	10						
	06z							A	1	2	3	4	5	6	7	8	9	10					
	07z								A	1	2	3	4	5	6	7	8	9	10				
	08z									A	1	2	3	4	5	6	7	8	9	10			
	09z										A	1	2	3	4	5	6	7	8	9	10		
	10z											A	1	2	3	4	5	6	7	8	9	10	


← CURRENT CYCLE →
A
↓
6
↓

ANALYSIS
6HR FORECAST

# Including Earlier Observations Improves Analyses

## 21z Analysis

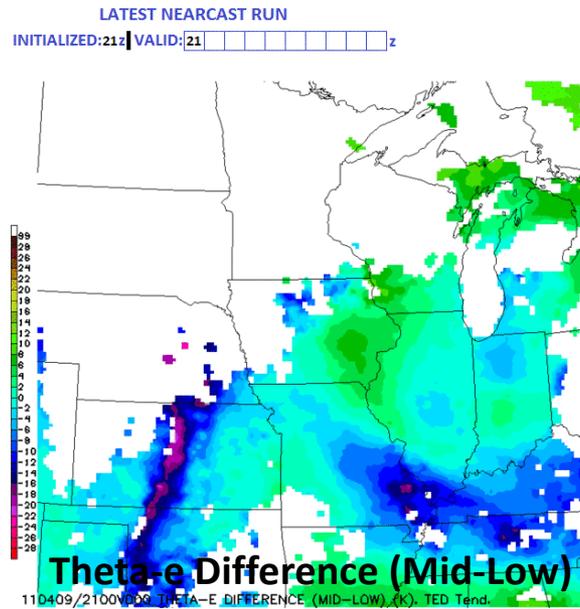


21z IR Imagery

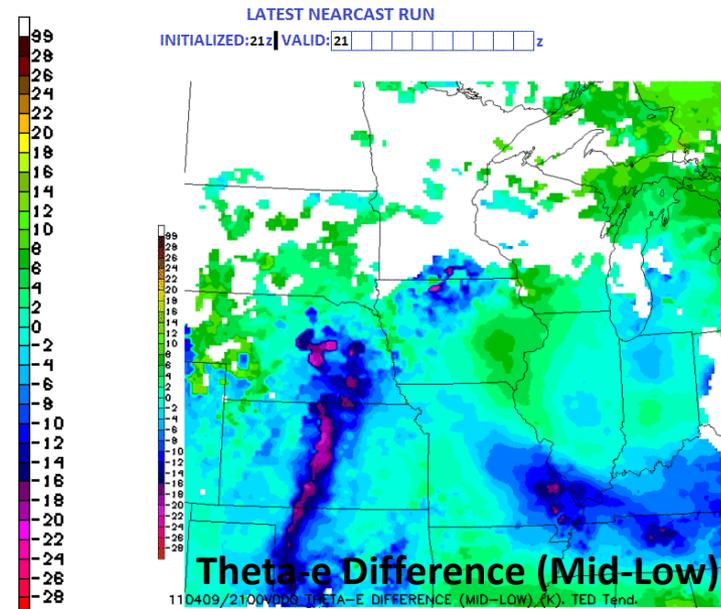
**Including Earlier Observations filled in gaps in analyses where clouds prevent IR obs**

# Including Earlier Observations Also Improves Forecast Coverage

20110409-2100z NearCast - Valid: 20110409-2100z



20110409-2100z NearCast - Valid: 20110409-2100z



Using 21z Obs only ↑



↑ Including Earlier Obs led to fewer gaps in forecasts, making GOES Legacy Soundings more useful

# Recapping

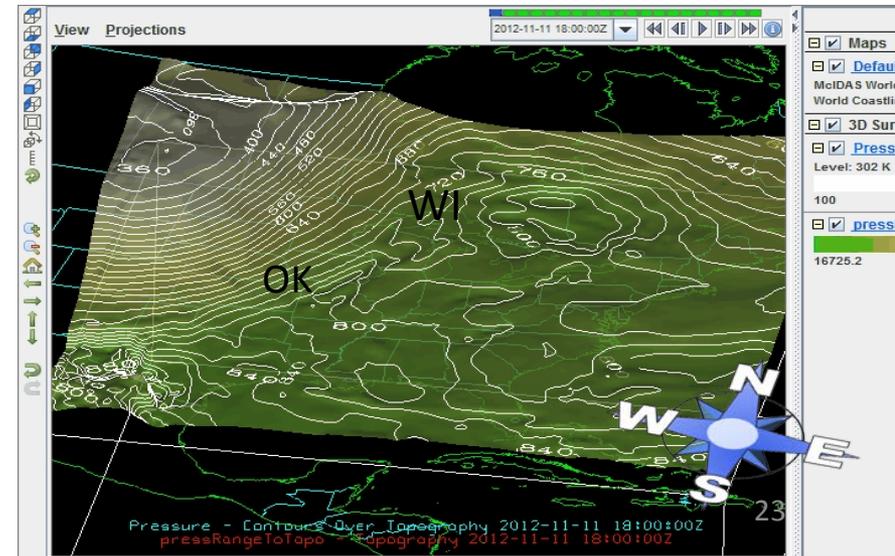
- ✓ This trajectory approach enhances the utility of GOES Legacy Moisture Soundings using pressure as the vertical coordinate.

Can we improve upon this?

- ✓ We know that these observations are made in the clear sky, where flow is primarily adiabatic.
  - ❖ *Therefore, test if predicting the movement of these observations in an isentropic framework will improve forecasts further.*

# Advantages of Isentropic Coordinates

- **Flow in adiabatic atmosphere is Isentropic**, so parcel trajectories in this framework are more appropriate.
- Isentropic surfaces act as **material surfaces** on synoptic spatial and time scales in the absence of diabatic processes.
- The horizontal component of flow implicitly includes the adiabatic component of **Vertical Motion**, since sloping isentropic surfaces vary in pressure and height
- **Moisture patterns** and flow are more coherent in space and time, since horizontal moisture transport on isentropic surfaces includes the vertical advection component (Oliver and Oliver, 1951).
- Vertical separation between isentropic levels gives a measure of **Static Stability**. When combined with with Mixing Ratio defines the **Total Amount of Moisture** being transported adiabatically to support sustained precipitation (Moore, 1987)



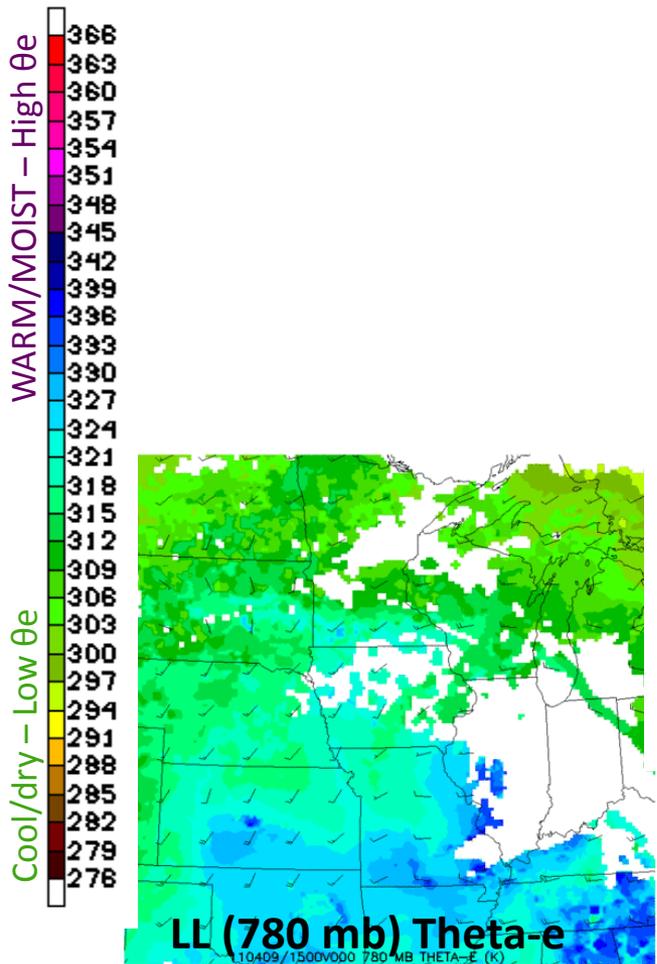
# 15z Isobaric NearCast Model Cycle

*For Reference*

20110409-1500z NearCast - Valid: 20110409-1500z

LATEST NEARCAST RUN

INITIALIZED:15z | VALID:15           z

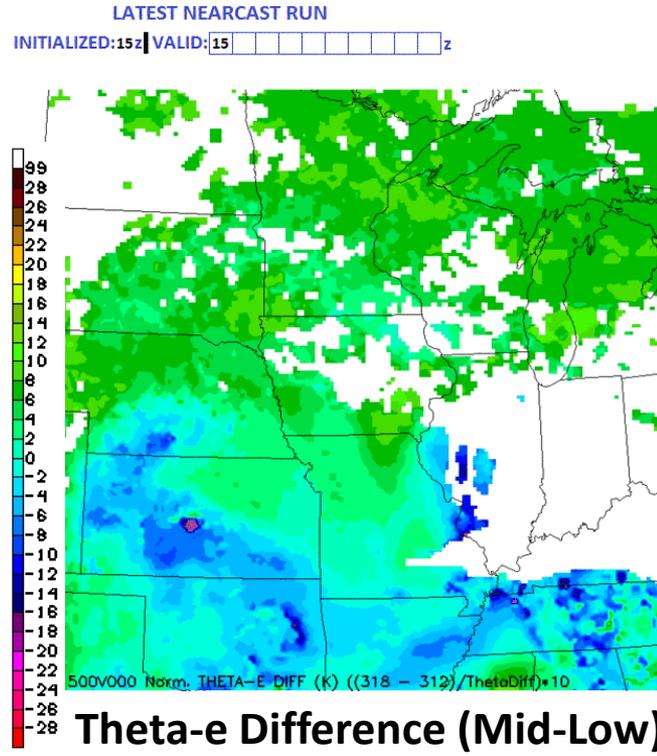
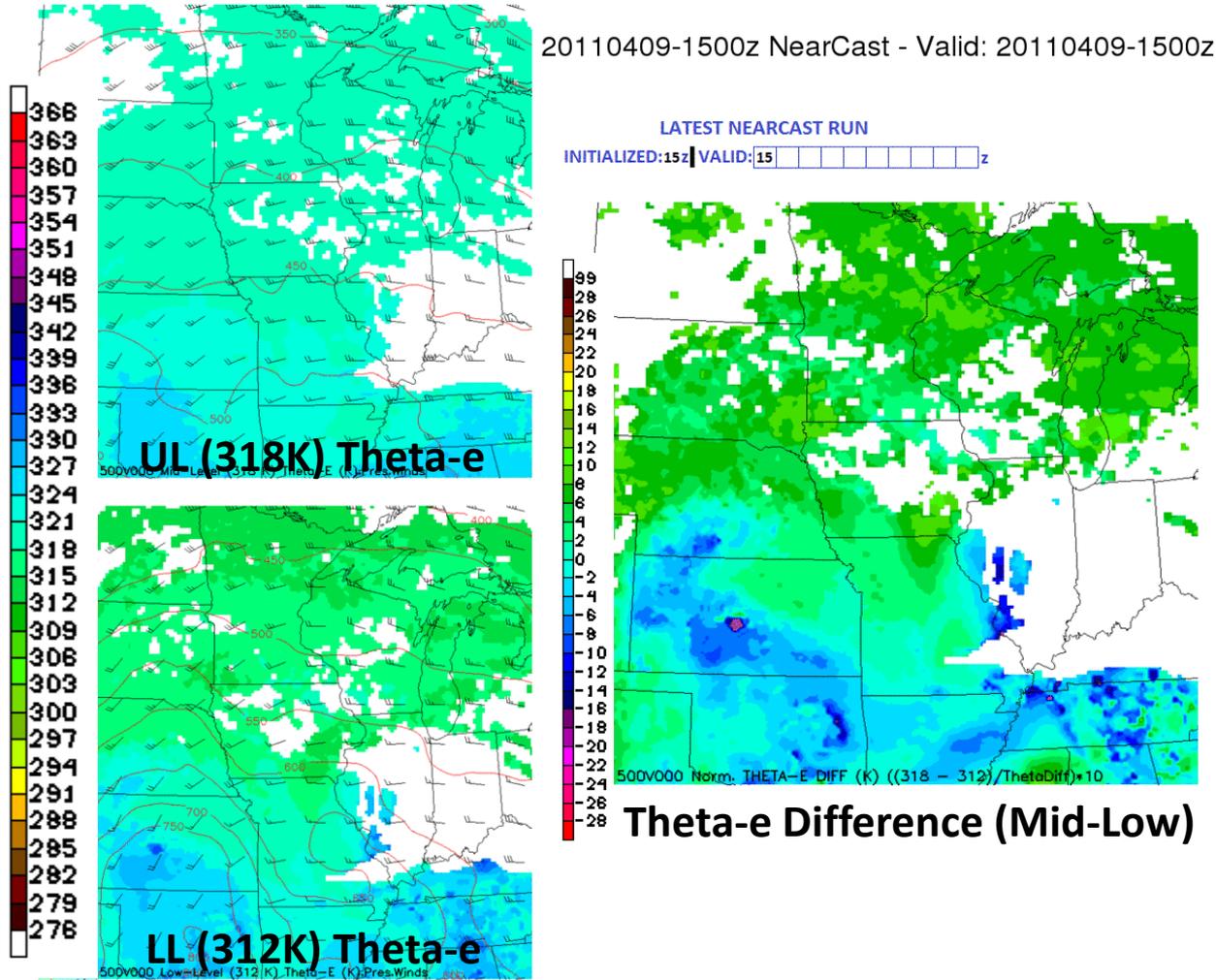


- Low-Level Moisture Max + Mid-Level Dry air = Convective instability maximum with rapid destabilization tendencies.  
=> Severe weather producing convection

# 15z Isentropic Nearcast Model Cycle

## Theta-e Products

- More Pronounced Upper-level dry air boundary



- Convective instability maximum enhanced,
  - Stronger destabilization tendencies
- Enhanced veering wind profile
  - Due to added acceleration of lower-level air parcels as they ascend

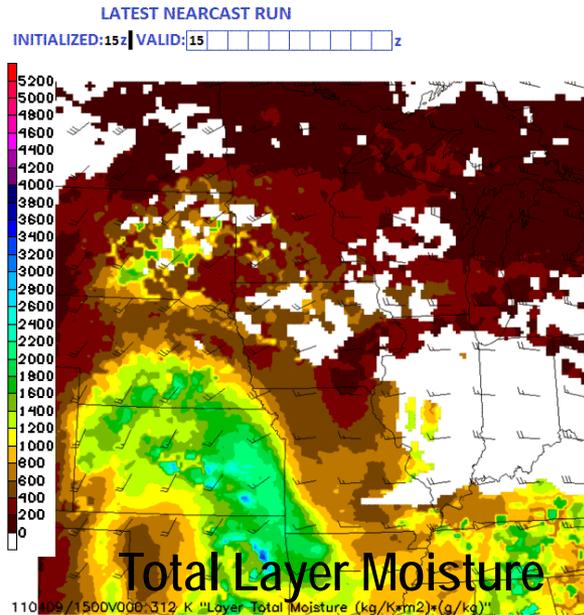
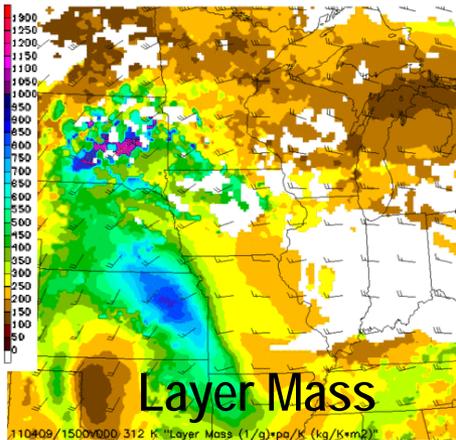
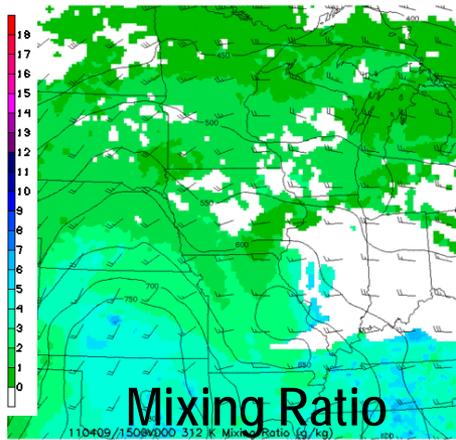
- More Continuous (and Ascending)  
Low-level  $\theta_e$  max

# 15z Isentropic Nearcast Model Cycle

## Total Moisture Availability

### Low (312K) Isentropic Layer

20110409-1500z NearCast - Valid: 20110409-1500z



**Product of Layer Average Mass and Mixing Ratio**

- Highest Total Moisture was located ahead (east) of the instability max and severe convection
- Supported heavier precipitation that occurred later in weaker storms that developed over MN and WI

# Summary of Event

What isentropic model told us

What Happened

## NW Iowa: 21z-00z

- Max in convective instability moving into previously stable region
- Strong destabilization tendencies
- Winds veering with height
- Strong ascent
- Low total moisture and weak TMFC



- Severe convection
- Short-lived, small-scale
- Only weak, local precip

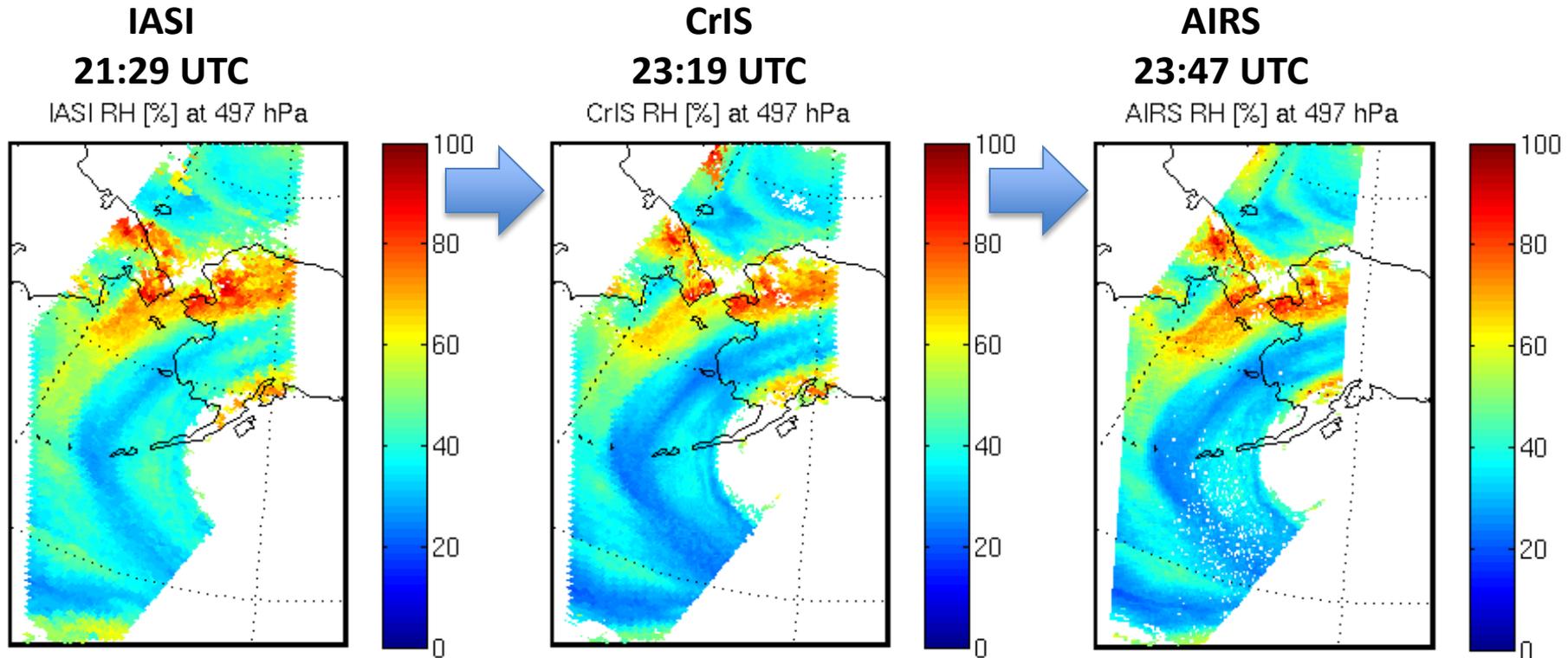
## SE Minnesota into Wisconsin: 02z-...z

- Max in convective instability moving into previously weakly unstable region
- Weaker destabilization tendencies
- Less veering of winds with height
- Strong to moderate ascent
- High total moisture and strong TMFC



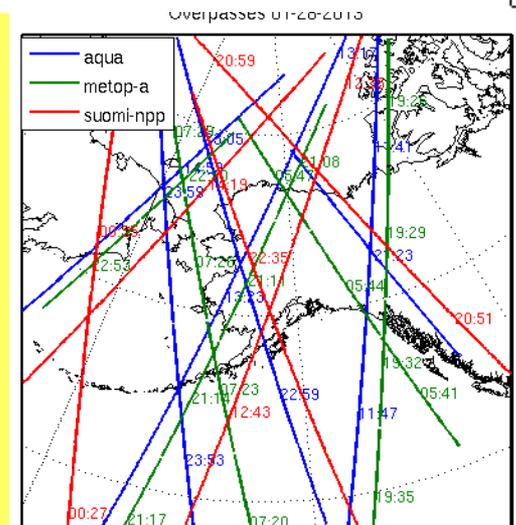
- Non-severe but strong convection
- Long-lived, large-scale
- Heavy and widespread precip.

# IASI, CrIS and AIRS 500hPa RH (01 Nov 2012)



**What Next? -- Availability of multiple overpasses from multiple new POES sounders provides opportunity to *adapt* these enhanced analysis and short-range forecast tools to Alaska using:**

- ***Improved IR Observations***
- ***Microwave Profiles***



# IASI, CrIS and AIRS 500 hPa RH (01 Nov 2012)

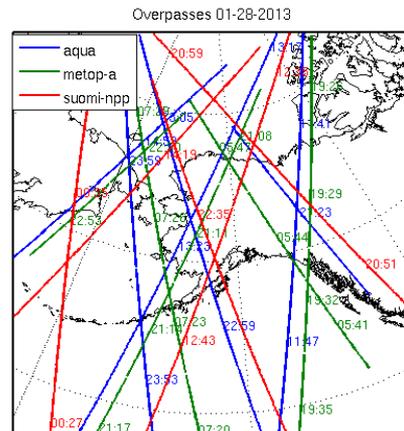
IASI  
21:29 UTC

CrIS  
23:19 UTC

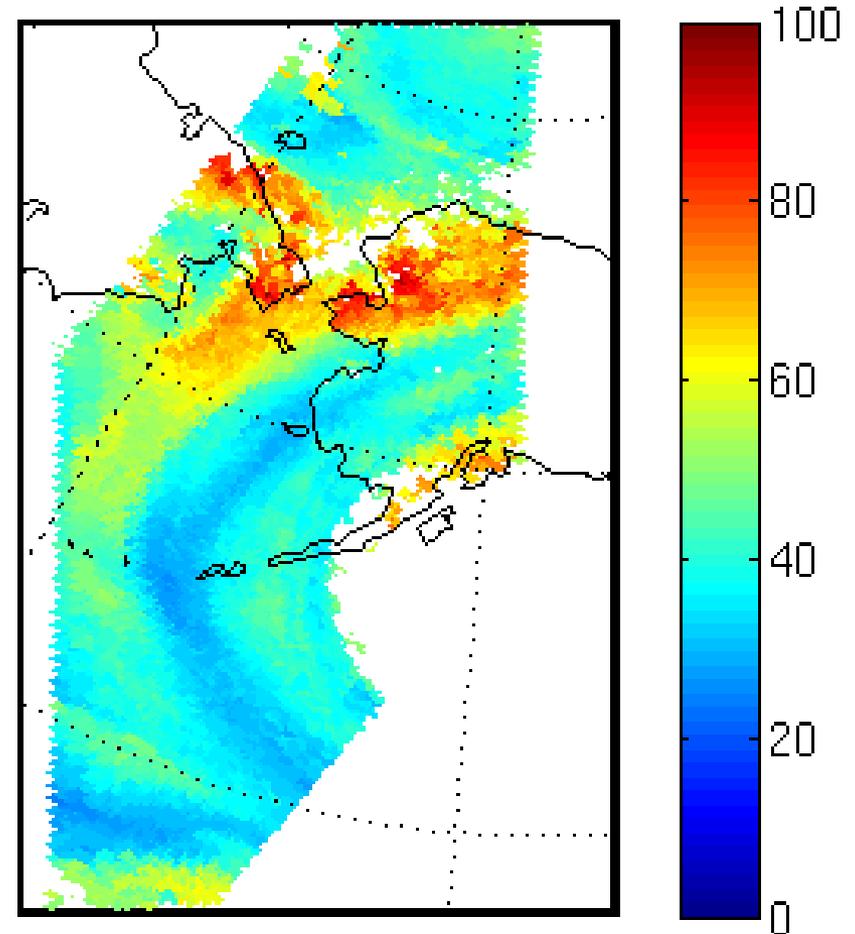
AIRS  
23:47 UTC

Instead of using hourly GOES IR soundings, we will take advantage of multiple overpasses from several hyperspectral POES sounders provides opportunity to adapt these NearCasting tools for forecasters in Alaska using:

- *High Vertical-Resolution IR Moisture/Temp Profiles*
- *Microwave Profiles*



IASI RH [%] at 497 hPa



# IASI, CrIS and AIRS 500 hPa RH (01 Nov 2012)

IASI  
21:29 UTC



CrIS  
23:19 UTC

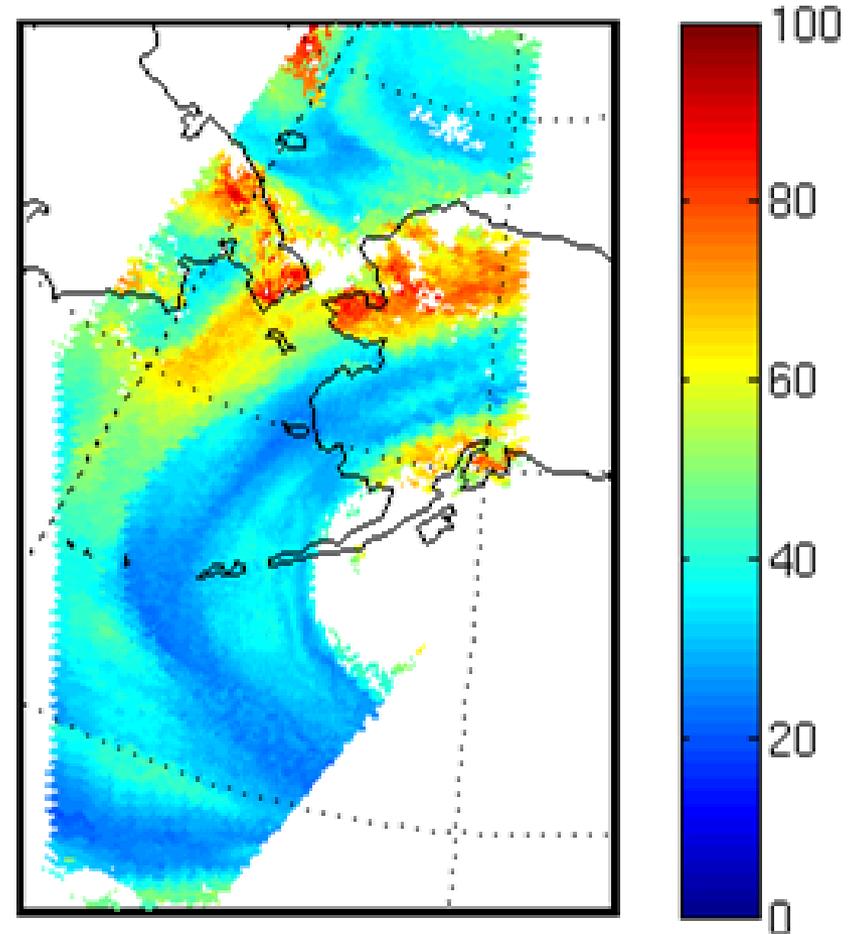
AIRS  
23:47 UTC

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- *Microwave Profiles*

Succession of images of retrievals from a series of overpasses reveals regular progression of large- and small-scale moisture features

CrIS RH [%] at 497 hPa



# IASI, CrIS and AIRS 500 hPa RH (01 Nov 2012)

IASI  
21:29 UTC

CrIS  
23:19 UTC

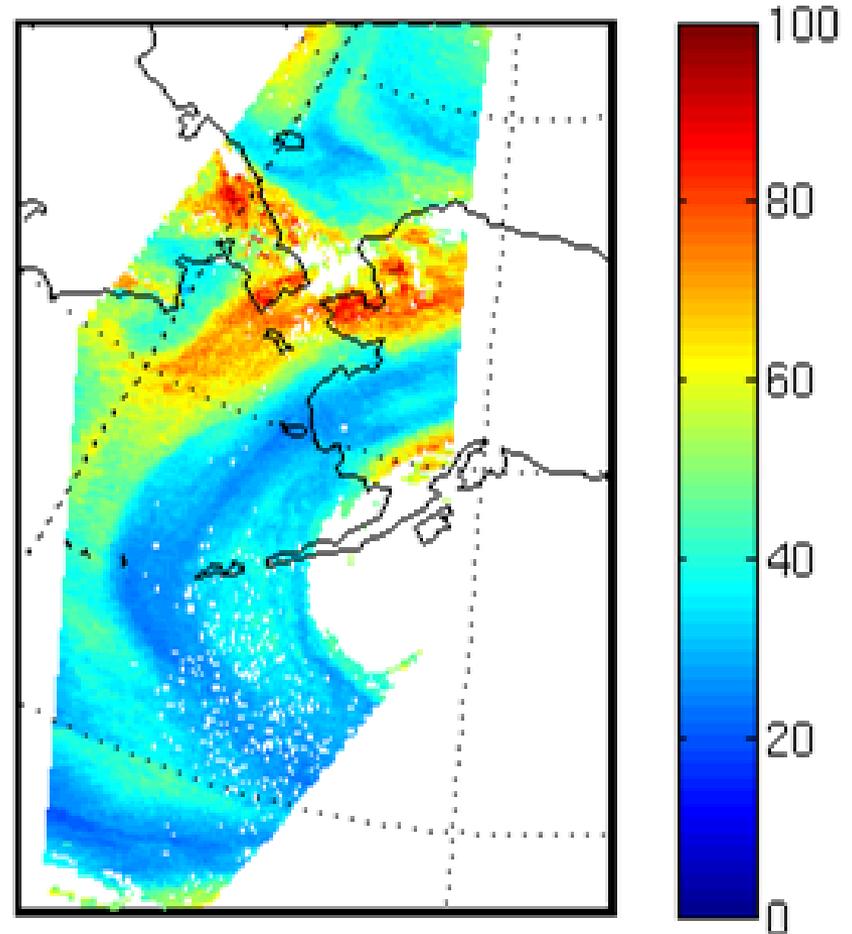
AIRS  
23:47 UTC



Instead of using hourly GOES IR soundings, we will take advantage of multiple overpasses from several hyperspectral POES sounders provides opportunity to adapt these NearCasting tools for forecasters in Alaska using:

- *High Vertical-Resolution IR Moisture/Temp Profiles*
- *Microwave Profiles*

AIRS RH [%] at 497 hPa



*New methods will be needed to:*

- *Recognize/remove Instrument Biases*
- *Account for different Instrument Noise levels in products*

# What are we planning – Project to begin in July 2013

## Basic goals:

- The long-term goal of this effort will focus on improving very-short-range moisture, stability and precipitation forecasts by identifying the 'best' JPSS/POES products and procedures to use in improving forecaster guidance for the AR.
- As the prerequisite step to this effort, we will first provide an independent assessment of the accuracy and test the applicability of JPSS/POES moisture data over land at high latitudes based on existing GPS TPW observation.

# What are we planning – Project to begin in July 2013

## Candidate Forecast Problems to be studied include:

- **Convective location, timing and sustainment:**
  - Though convection tends to be orographically forced, we will focus on identifying areas where convection can sustain over lower terrain.
  - Wildfires and resulting smoke - Diagnosing conditions with high-based thunderstorms with a deep dry sub-cloud layer though not so dry such that convective initiation is still a possibility
- **Mesoscale heavy snow events** – Small spatial scale snow events are very difficult to forecast, even after they are underway
- **Warm Season Heavy Rain events:**

Heavy rain events are difficult to accurately pinpoint spatially with the integration of larger scale vertical motion fields, complex terrain, and moisture plumes
- **Inland progression of Marine Stratus** – Weather and Aviation issues
- **Evolution of Turnagain Arm wind events:**
  - Hurricane force winds are a regular occurrence in Turnagain Arm can reach the Anchorage International Airport periodically and negatively impact air traffic operations.
  - There is a lack of understanding of the mountain wave response in the Anchorage vicinity that determines the winds and how the winds descend into the lower elevations

# What are we planning – Project to begin in July 2013

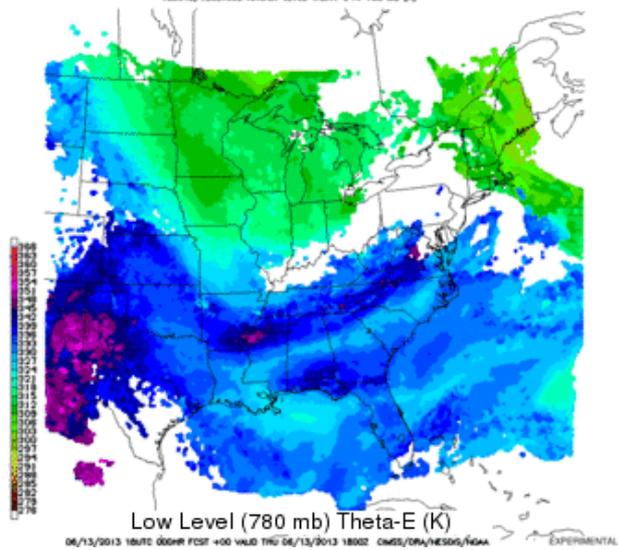
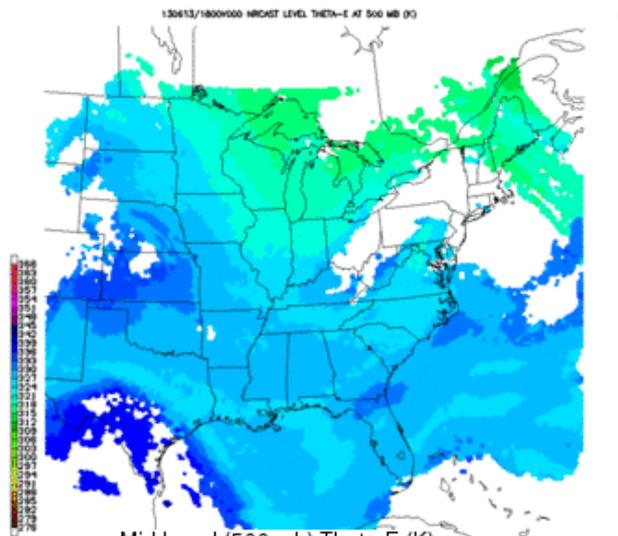
## The proposed sequence of tests to be conducted includes:

- Use deep-layer PW and  $\theta_e$  for LEOs to produce product equivalent to GOES-based NearCasts assuming horizontal flow.
- Use thinner-layer PW and  $\theta_e$  to produce product NearCasts assuming isobaric flow.
- Use thinner-layer PW and  $\theta_e$  to produce product NearCasts with isentropic version of NearCasting model to include the effects of orographic and frontal lifting.
- Use deep-layer PW and  $\theta_e$  from microwave sounders to produce NearCasts with both versions of the NearCast model in cloudy environments.
- If resources allow, consider development of a new, near-surface Lagrangian trajectory system to diagnose orographic uplift combining LEO retrievals with offshore satellite wind measurements.

## Testing methodologies will include:

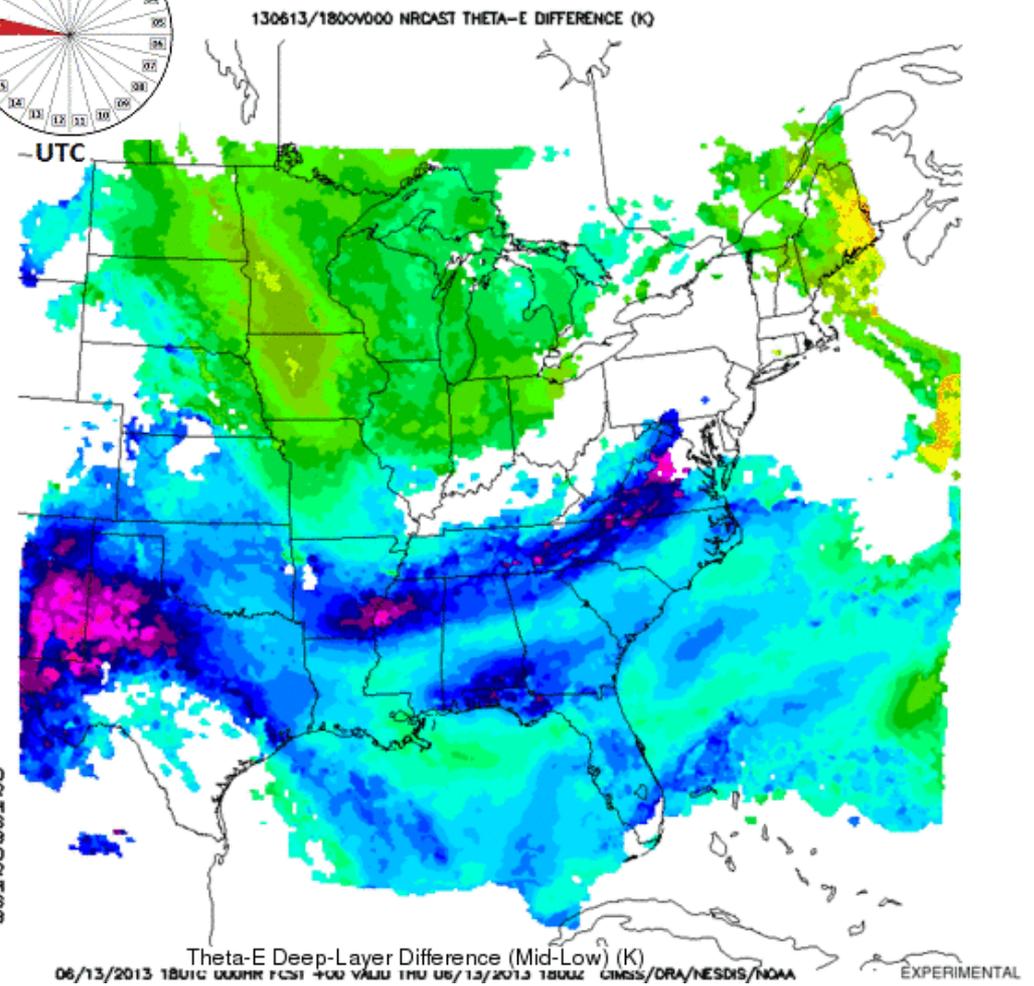
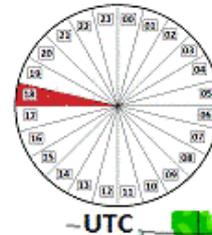
- Correlating NearCasts of moisture transports and time/space evolution of convective instability to observed convection and precipitation.
- Develop new diagnostic tools appropriate for high-base convection as needed.
- Use higher-vertical-resolution versions of NearCasts to develop LEO-based CAPE/CINE prediction products
- Add confidence information to output fields.

# Some “Eye Candy” during Questions?



00 Hr NearCast Analysis - Valid: 13Jun13-18z

DAYS AGO: 4



*Five-day loop of hourly multi-level moisture analyses and final NearCast*