Expanding the Utility of Satellite Moisture Products from Observations to Nowcasts

Ralph Petersen and Lee Cronce

- University of Wisconsin – Madison
- Space Science and Engineering Center
- Cooperative Institute for Meteorological Satellite Studies
- Madison, WI

A Fundamental Question for Operational Forecasting :

Can we preserve details in the multi-level moisture fields observed frequently by Geostationary Satellites in objective Nowcasting tools that can be available to forecasters *immediately* after the observations are made?

- ✓ *Ultimately, the optimal way to use SEVIRI clear-air moisture data will be in improved, very-frequently updated NWP systems.*
  - ✓ *These will not be available for many years*
  - ✓ *Model output will always lag observations by an hour of more*
  - ✓ *Until then, a simple, fast means of providing objective short-range Nowcasts of detailed horizontal moisture structures immediately after the SEVIRI observations are made is useful*
    - ✓ *It also provides an excellent means to monitor model performance and moisture forecasts*

What are we been trying to improve?

Short-range forecasts of timing and locations of severe thunderstorms

- especially hard-to-forecast, isolated summer-time convection

What are NearCasts?

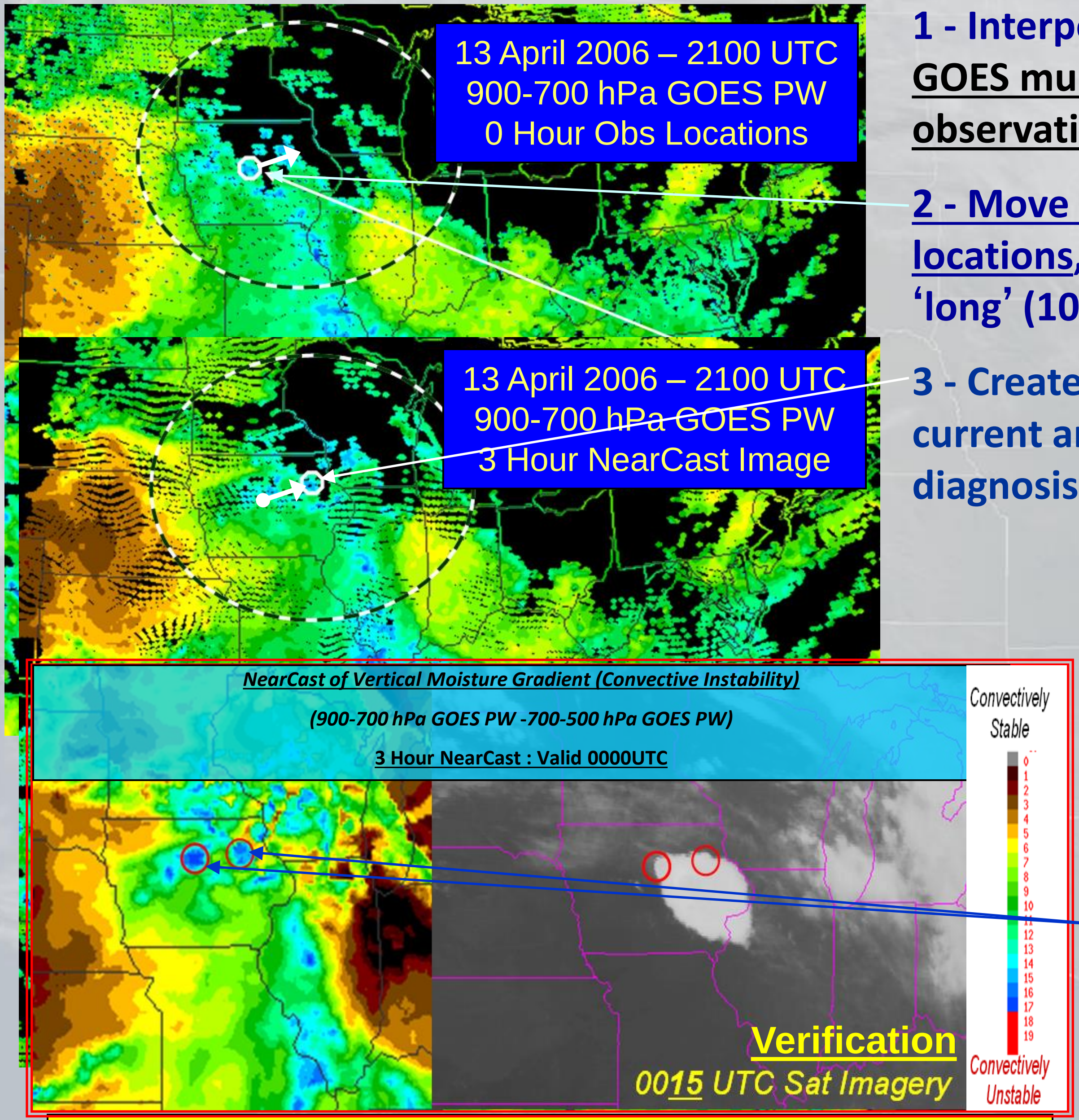
- ✓ ***Data-driven*** ***analyses and 1-9 hour projections designed to help forecasters monitor where/when convection is/isn't likely to develop.***
- ✓ ***Use all high-density observations of moisture and humidity made over land from GOES and SEVIRI.***

---- These data are not fully included in operational NWP systems ----

NearCasts are designed to:

- *Be available within minutes of observation times,*
- *Be frequently updated (hourly or sub-hourly), and*
- *Retain observations more fully than traditional NWP products*
- *Provide information about the convective environment even after convection has begun*

How the Lagrangian NearCasts work:



Updated Hourly - Full-resolution 10 km data - 10 minute time steps

1 - Interpolate wind data to locations of full resolution GOES multi-layer moisture & temperature observations, including Maxima/Minima

2 - Move these high-definition data to future locations, using dynamically changing winds with 'long' (10 min.) time steps.

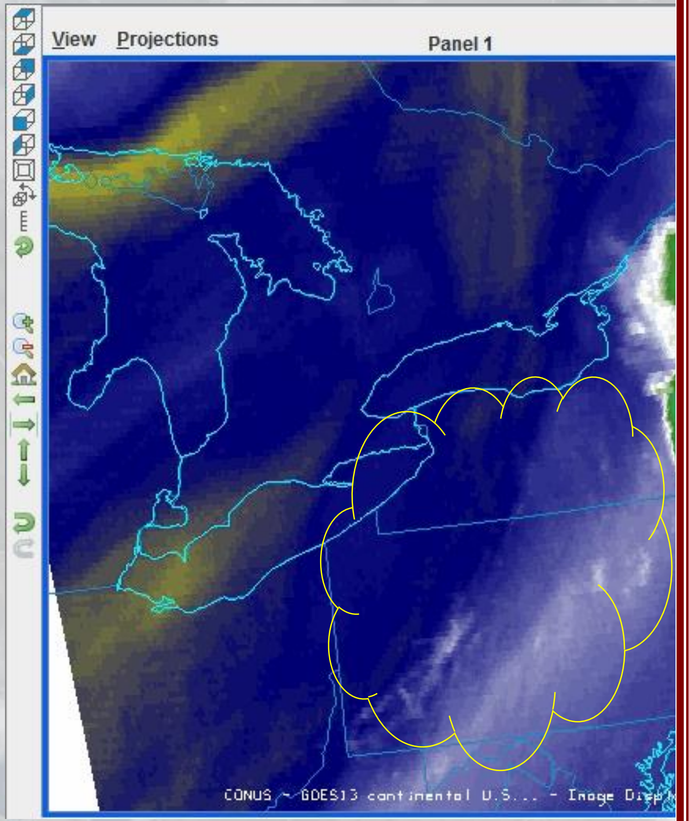
3 - Create grids from these 'projected parcels' from current and recent earlier observations for display and diagnosis

a) Combine outputs to produce a variety of derived parameters, including vertically integrated products and indicators to help identify mesoscale areas where severe convective is likely to/or not to develop

c) NearCasts *transform GOES IR Sounding from observations into forecasts*, adding forecaster utility - even after convection initiates.

Initial tests used used 2 layers of data between 900-700 and 700-300 hPa.

An early example of how NearCasts of SEVIRI Observations can help Nowcast Convective Potential



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

Objective #1: Determine sources of lower-level moisture/heat

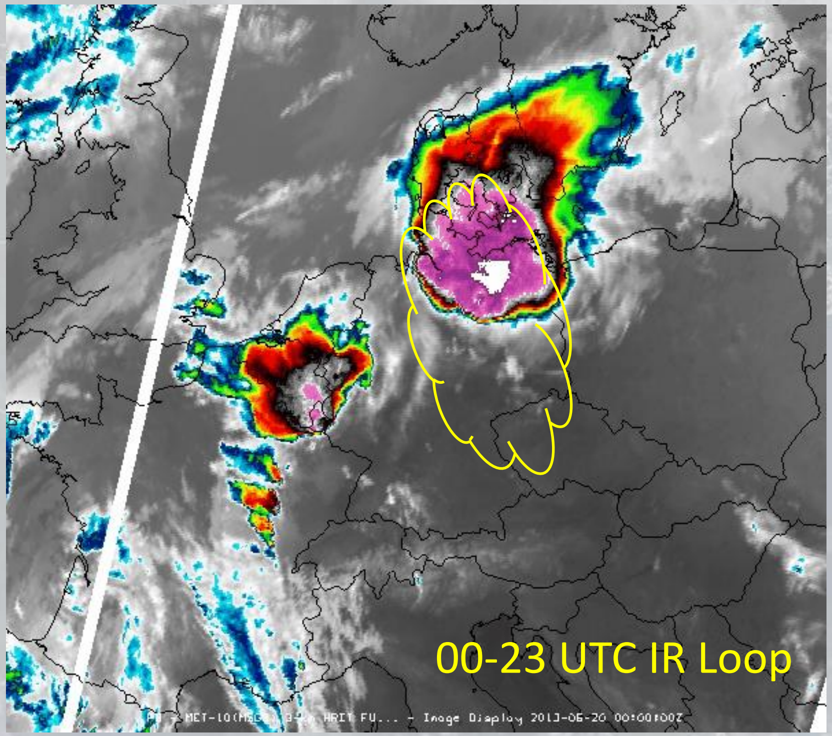
- *Equivalent Potential Temperature (Theta-e) combines information about the temperature and moisture content (total thermal energy)*

Objective #2: Mimic what we've observed on WV imagery for years:

- *Convection often along areas where upper-level dry streaks overtake warm air at lower levels*
- *This process could include a number of different factors influencing the development of convections, including:*
  - *Convective Instability,*
  - *IPV forcing, (Deformation/Frontogenesis)*
  - *Slantwise Convective Instability,*
  - *Wet Downburst Potential, . . .*
- ***Initial Tactic:*** **Identify areas where θe decreases with height**

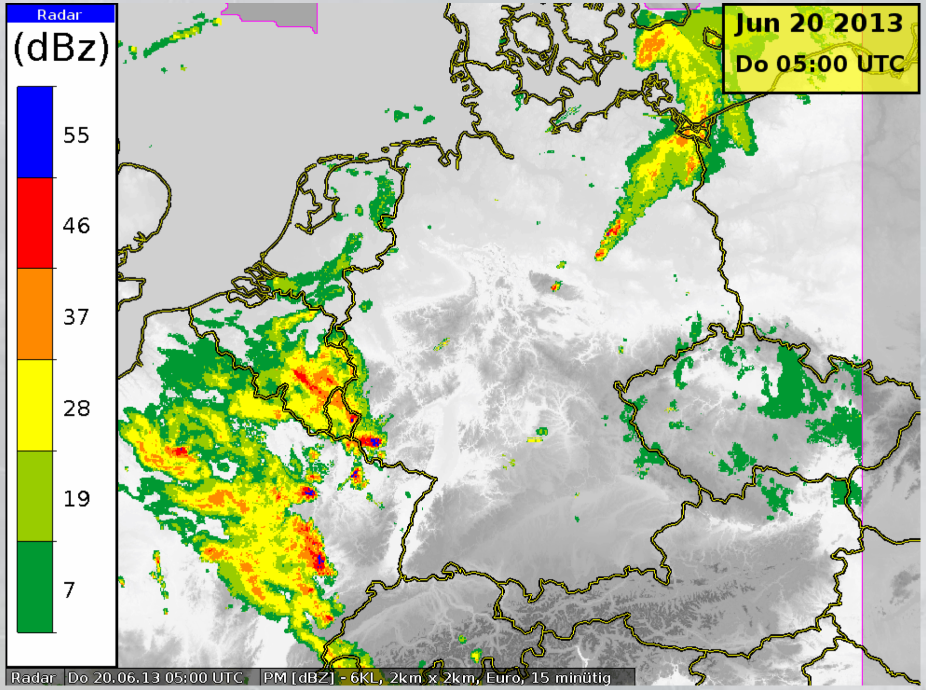
Example: 20 June 2013 – Convection over Eastern Germany

- What Occurred: Although COSMO-DE and COSMO-EU picked up the MCS which reached western Germany in the morning hours, the MCS was predicted a little bit too far in the west in the 00 UTC runs but better in the 03 UTC runs
- ***The development of new cells at the southern edge of the outflow boundary was missing in all of local models and in the COSMO-DE EPS.***
- ***The new squall line which spread out into eastern Germany was missed in all of the model prediction.***
- ***The southern MCS was also absent, with no convection predicted for Bavaria***
- ***The strong convection over eastern parts of Germany was totally absent in the model predictions from 00 to 09 UTC.***
- Only the COSMO-DE EPS 12 UTC run showed the northern part of the squall line
  - Probably due to latent heat nudging.
- Even then, the model squall line weakened too quickly and dissolved around 18 UTC
  - Possibly a sign of too little moisture.



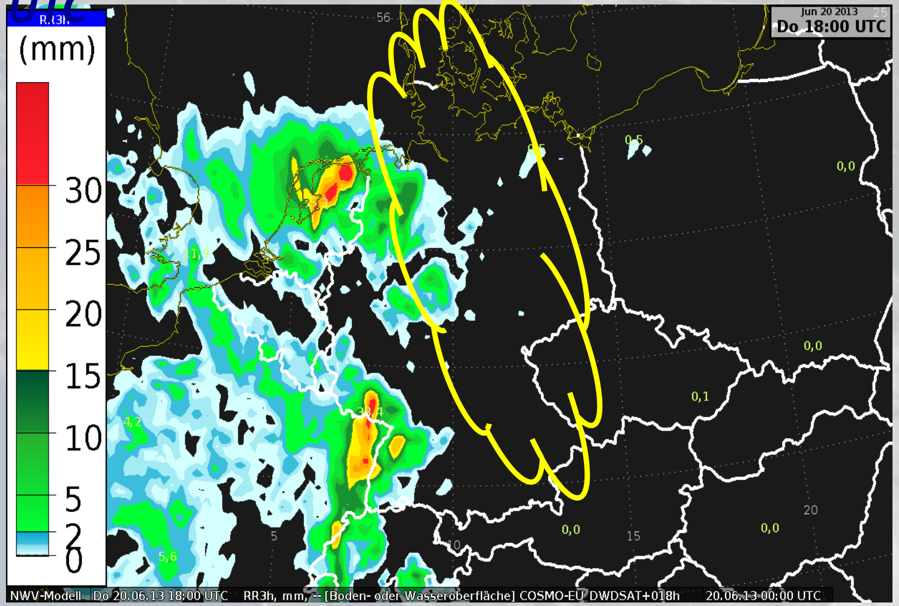
June 20, 2013
Convection over Eastern Germany missed by NWP guidance

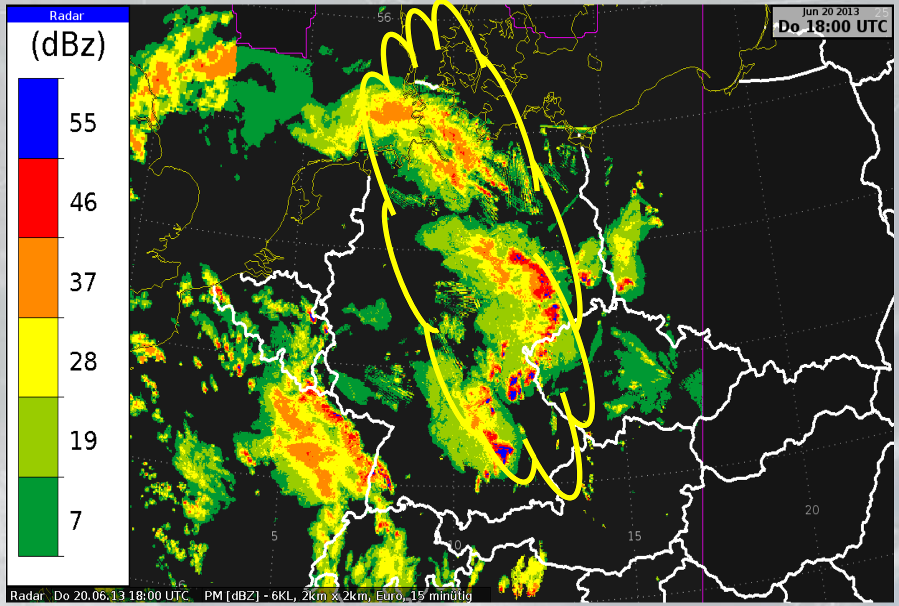
05 to 21 UTC Radar



COSMO_EU 00Z forecast valid 1800UTC

Radar Observation from 1800 UTC

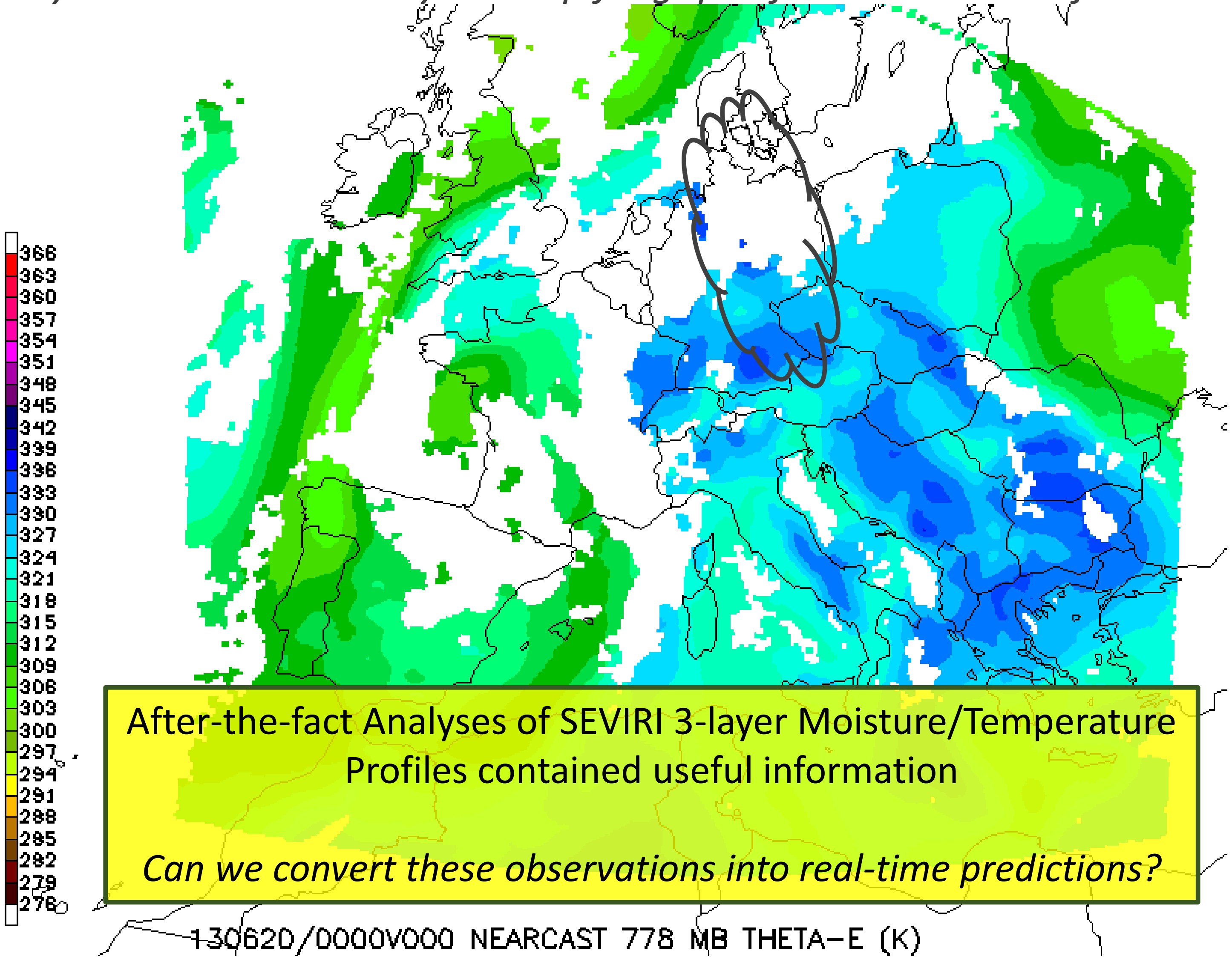




Full day loop of hourly NearCast Analyses Lower-Level (*~795 mb*) Theta-E Observations

(Enhancements over 'single-time' GEO observations alone)

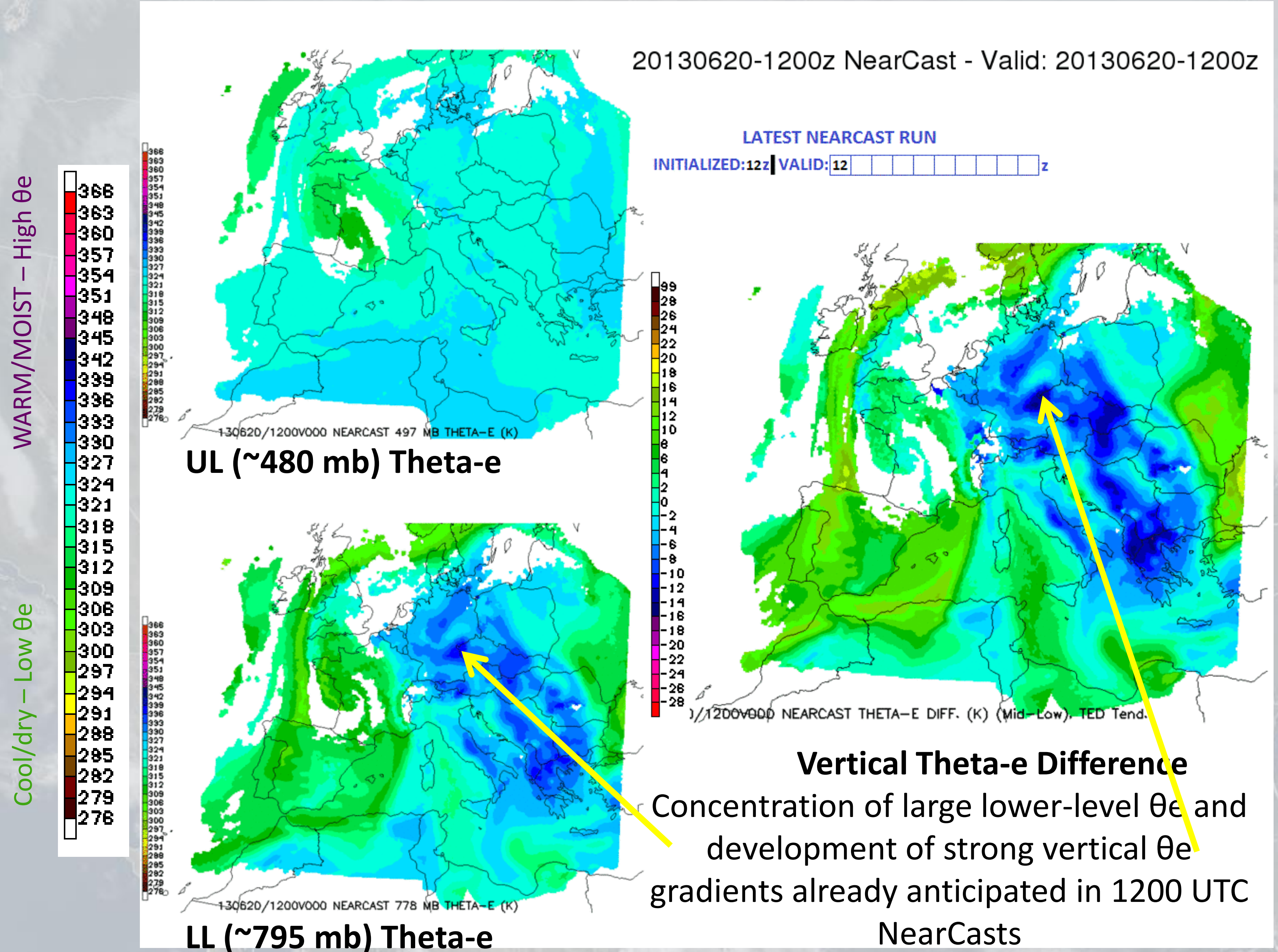
Cycled NearCast Analyses help fill gaps after clouds have formed



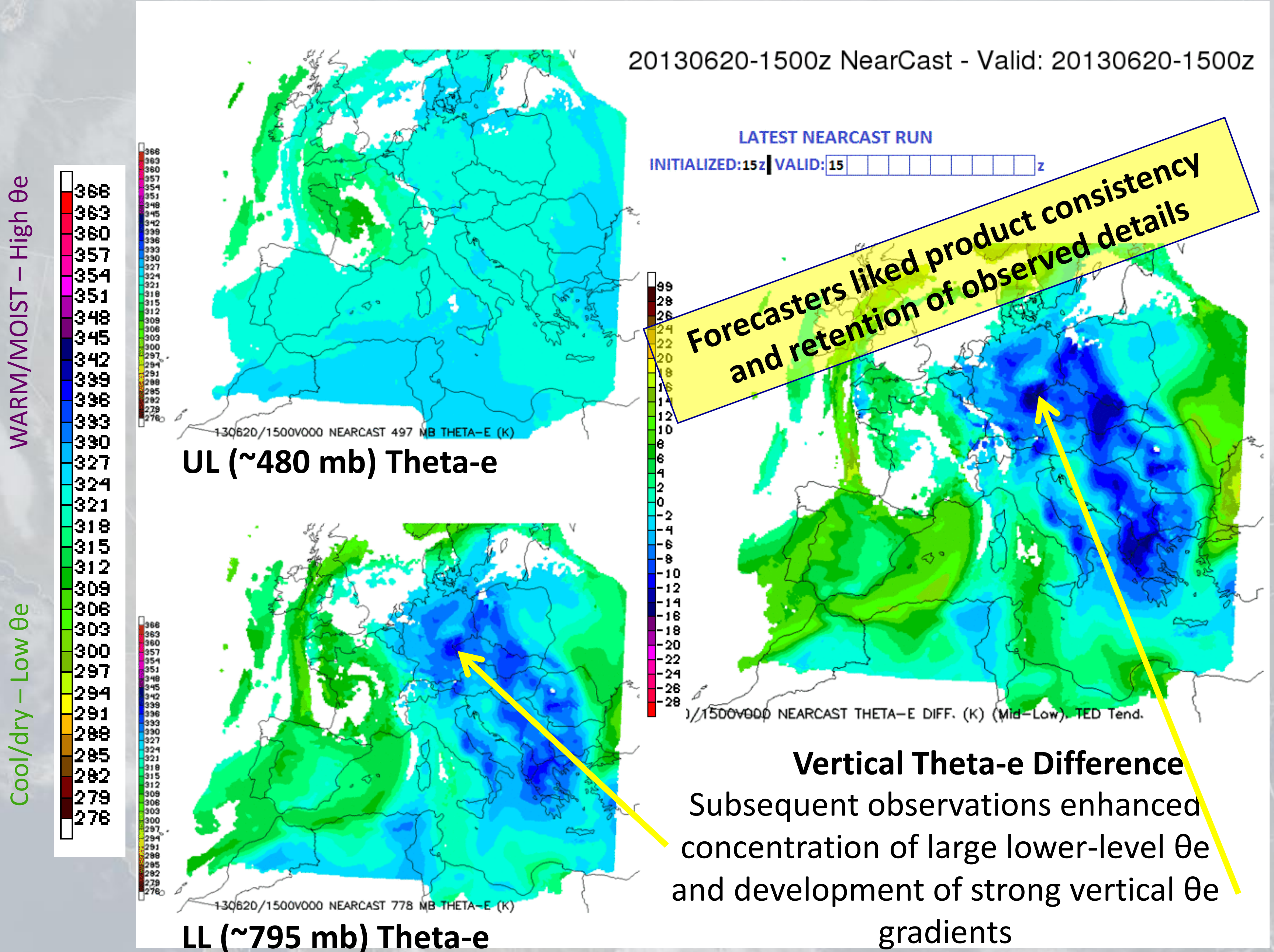
After-the-fact Analyses of SEVIRI 3-layer Moisture/Temperature Profiles contained useful information

Can we convert these observations into real-time predictions?

1200 UTC NearCasts using EUMETSAT Retrievals from 0400-1200 UTC



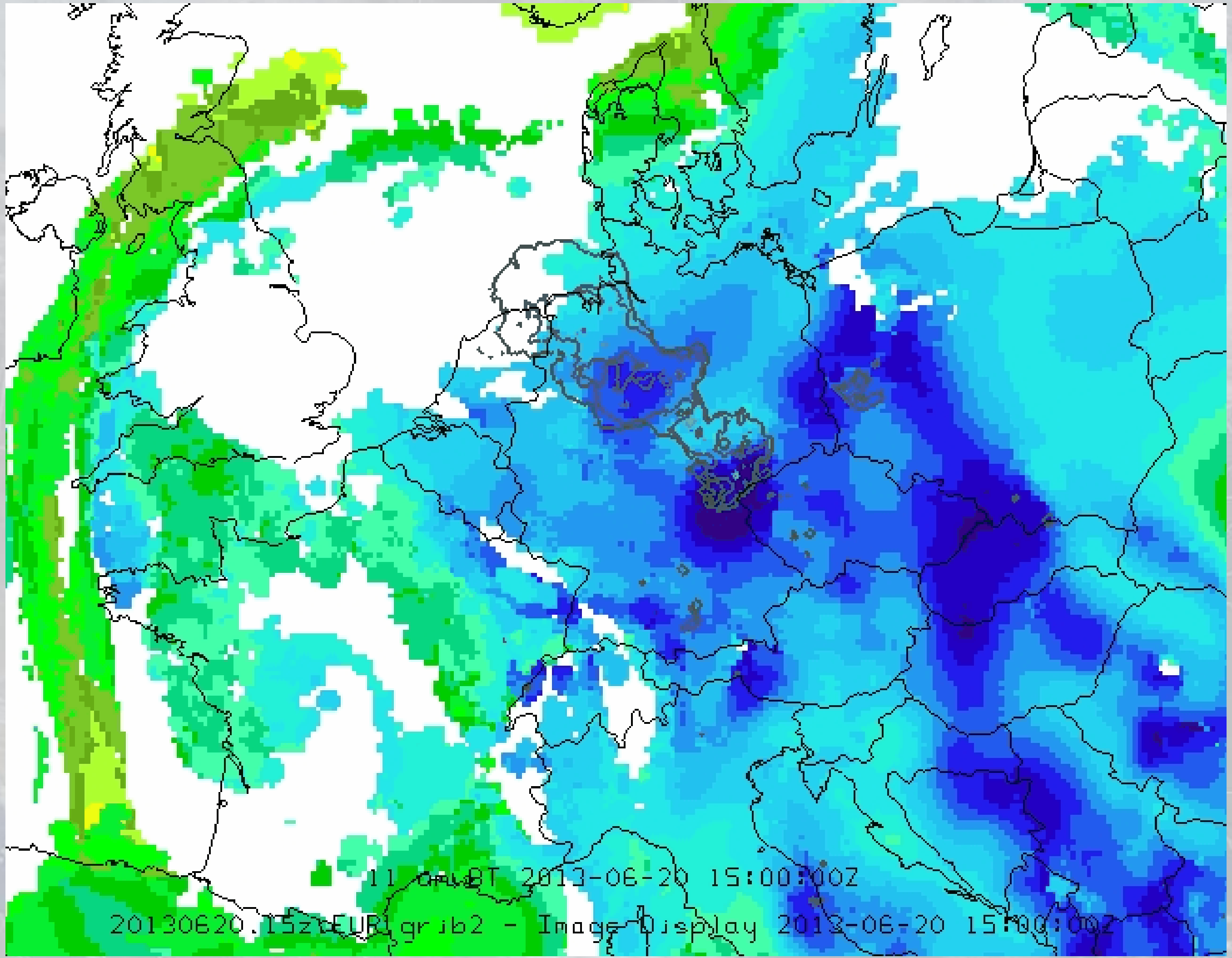
1500 UTC NearCasts using EUMETSAT Retrievals from 0700-1500 UTC



Verification of EUMETSAT 1500 UTC NearCast shows:

✓ Run-to-Run Consistency

✓ Value of including updated observations in later runs



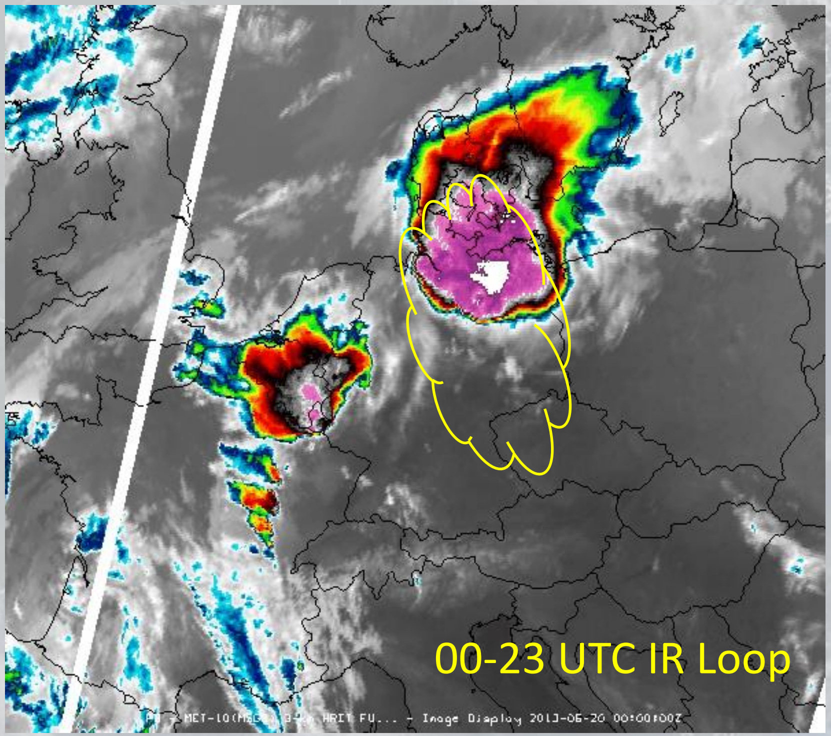
Vertical Theta-E Difference (shaded) with Cloud-Top Temperatures <220K Contoured

20 June 2013 – Eastern Germany Convection

- Forecaster Comments:
- “The NearCast gave a very good indication of where convection was started.
- It’s really impressive to see that the convection was initiated at the northern edge of the ThetaE maximum over northeaster Bavaria and at another smaller ThetaE maximum located at the alpine foothills in the southwest of Bavaria.
  - *There are some hills around 600 - 1000 m high which possibly could have helped to trigger convection.*
  - *Out of these cells the MCS over eastern Germany developed.*

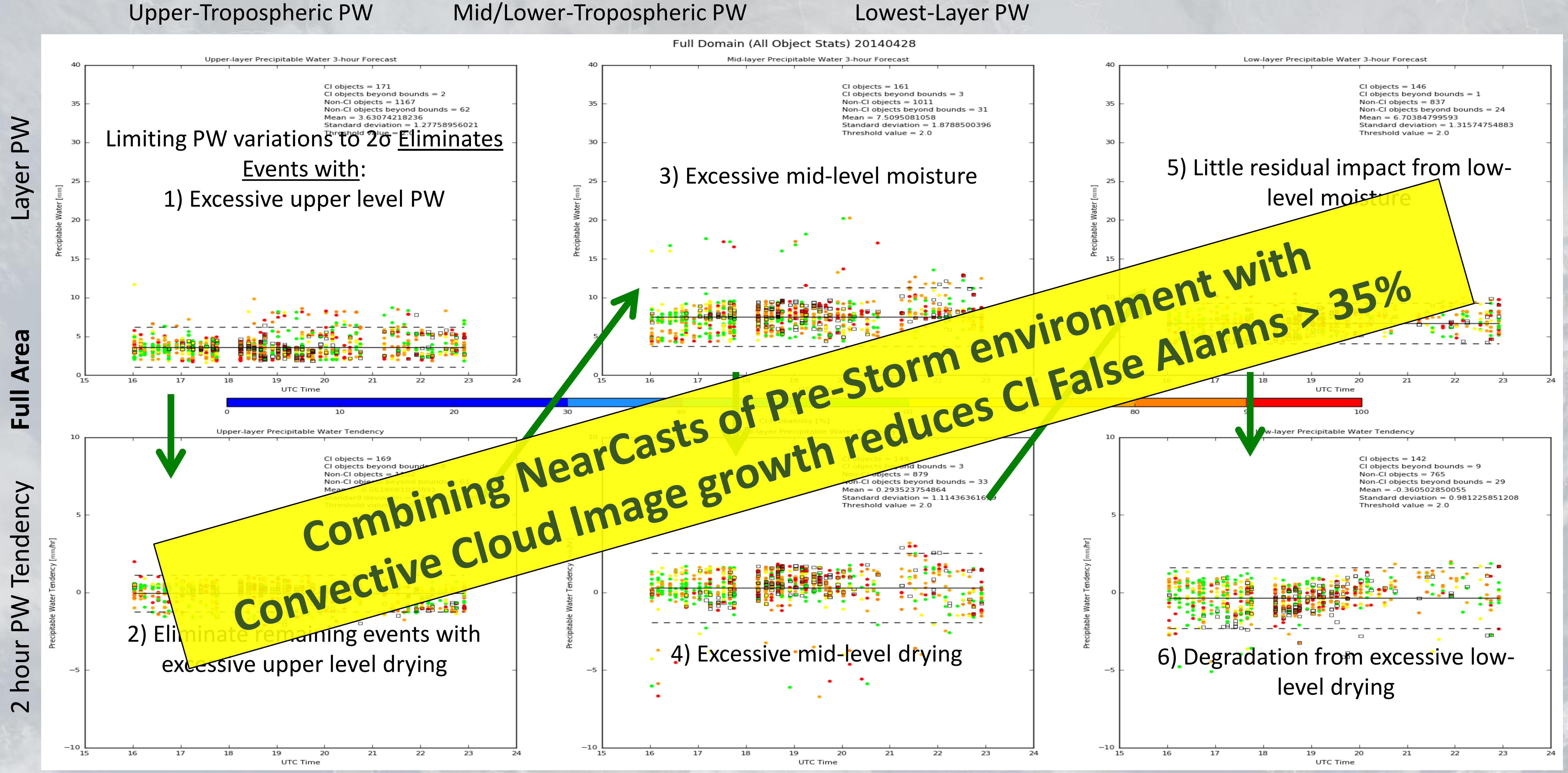
- Because the operational models missed this convective initiation there, they also missed the development of the MCS.
- *If we had had NearCast, we would have been able to make a first estimation of the position where the convection would be most probably initiated.*
- *The NearCast would (have) improved the forecast of this day.”*

Christian Herald, DWD

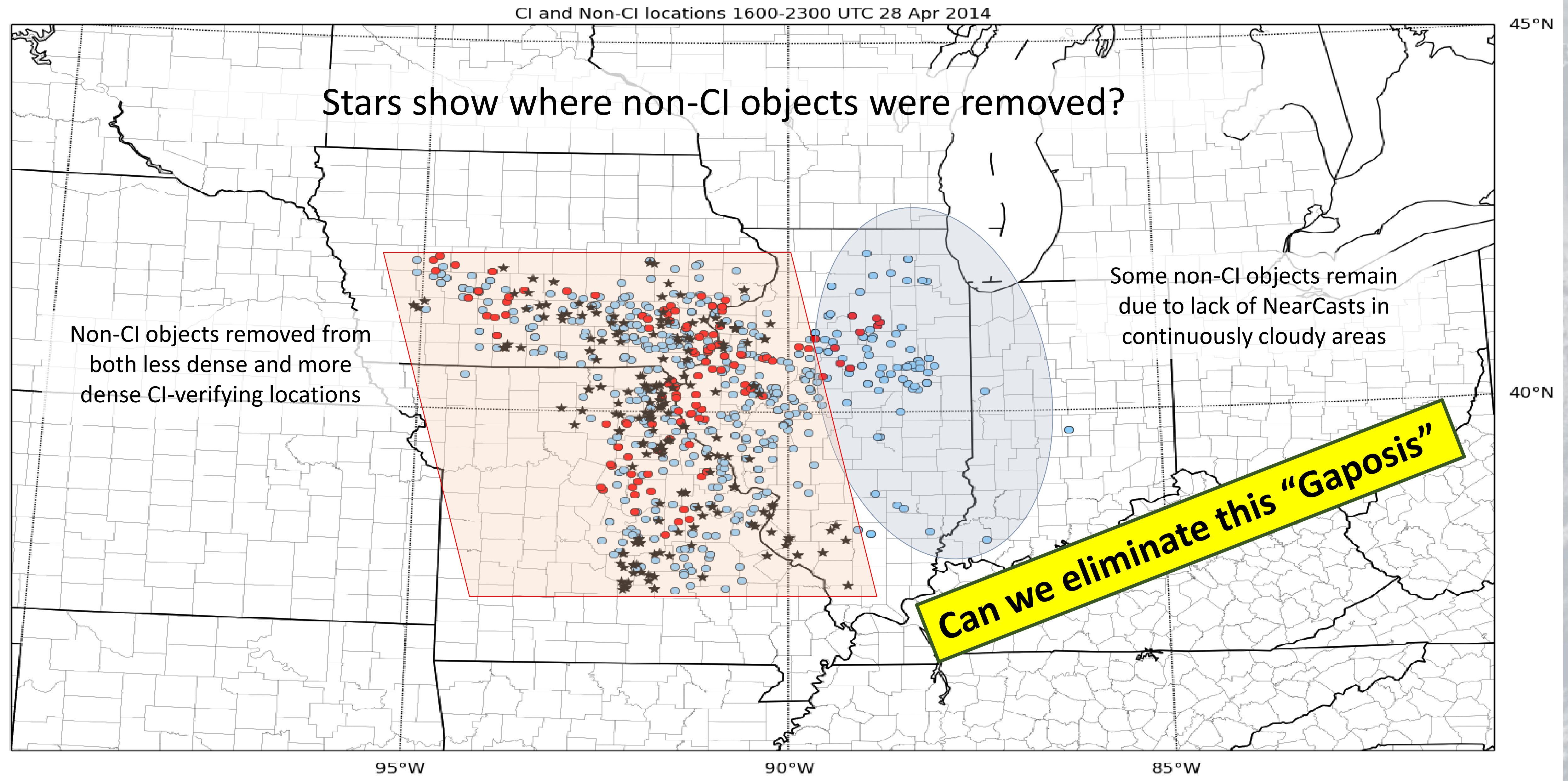


CI False Alarms Reducted by adding NearCasts

Using predicted NearCast 3-Layer Precipitable Water Values and Tendencies



CI False Alarm Mitigation Example: 28 Apr 2014

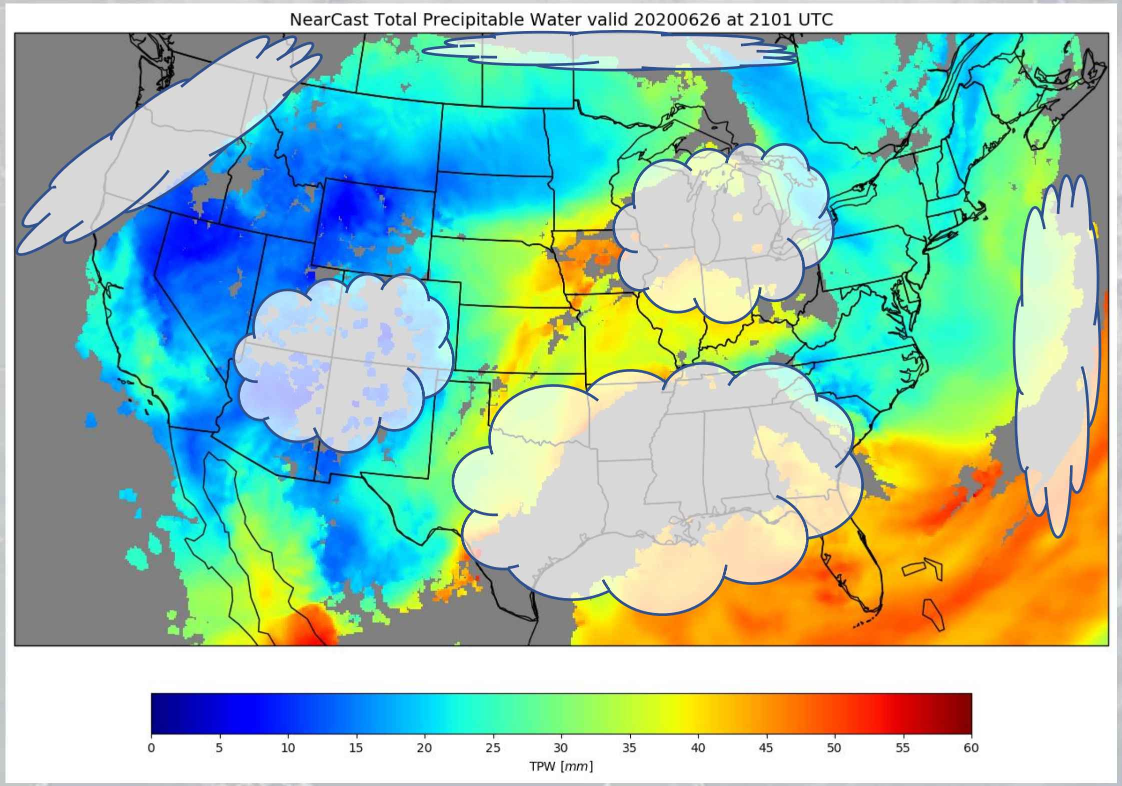


NearCast's Geostationary Roots and Issues

- NearCasts were originally developed to work with GEO-based data sets
- Favorably evaluated, but two issues have been voiced often in feedback:
    1. *Desire for more information near the earth's surface, and*
    2. *The GEO-only NearCast provide NO information available in cloudy areas*

  - *Including NearCast forward projection of earlier GEO data reduces gaps by ~20%, but that alone is not sufficient*

✓A new approach was needed to mitigate data-voids in cloudy regions and provide more consistent coverage

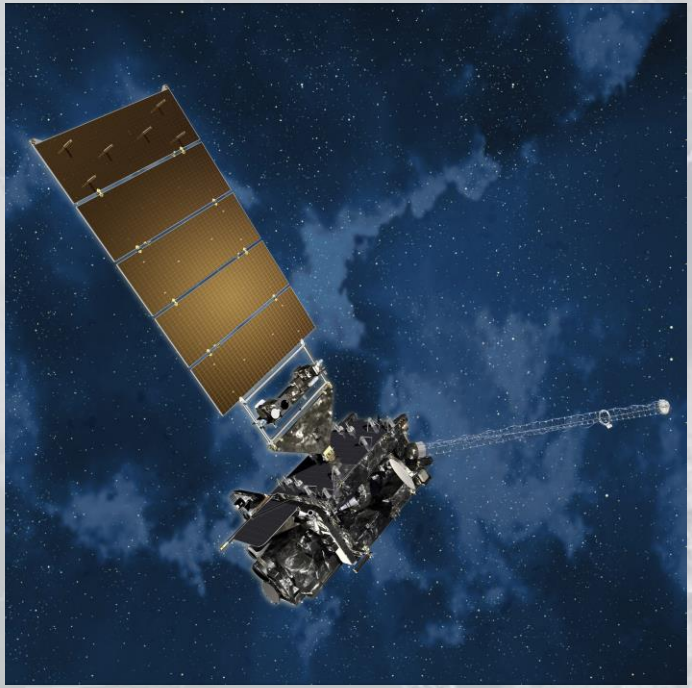


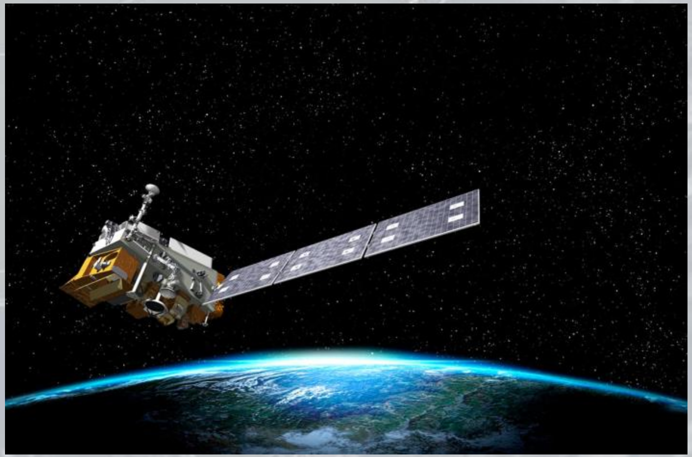
What's new in CIMSS NearCasts

- NearCasts increase the utility and benefit of satellite-based observations in operational forecasting
  - Allow forecasters to see and use *real-time* predictions of satellite-derived products directly
    - Not only 'hidden' through D/A
  - Extremely fast
    - Forecast refreshes are available within minutes of satellite retrieval updates

- Forecasters use Real-time GEO data much more than POES
  - *More continuous snapshot of changing atmosphere*
  - *High spatial resolution*
  - *But not available in cloudy areas*

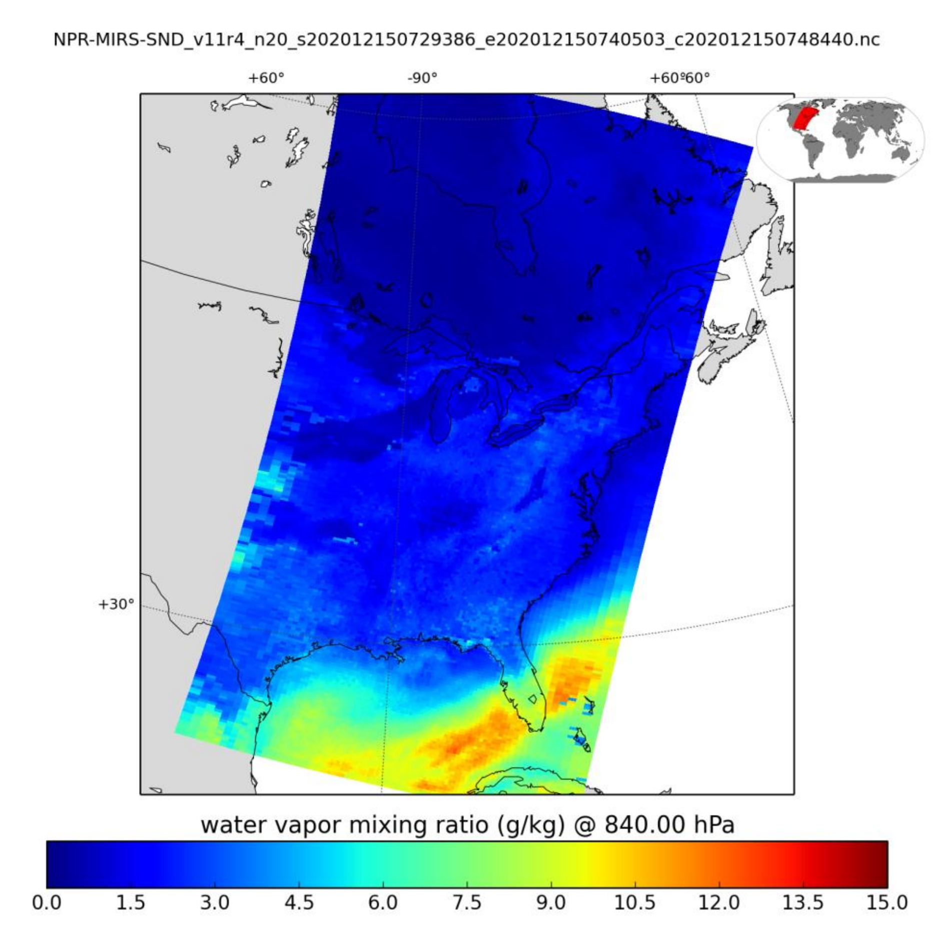
- ***NEW:*** Total Precipitable Water and Equivalent Potential Temperature NearCasts are available for 3 sigma layers 1.0-0.9, 0.9-0.7 and 0.7-0.3
  - Corresponds to peaks in moisture weighting function from GOES, MSG and MTG Imager
  - \+ Accounts for topography using a 'stepwise' approach
- The quantities can then be used to predict fundamental stability and moisture parameters, such as TPW, LI, CAPE, etc.
- *Fosters validations using off-time observations of integrated variables (e.g., TPW)*





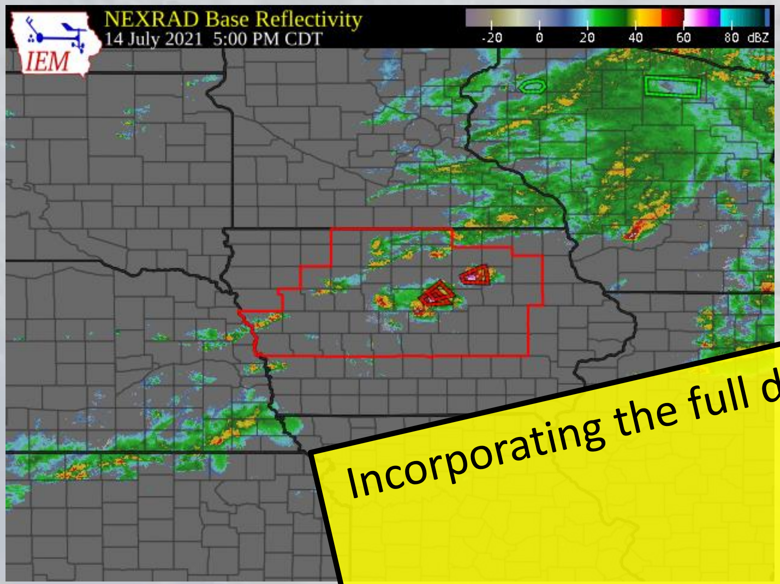
Adding Microwave Observations from Polar Orbiters

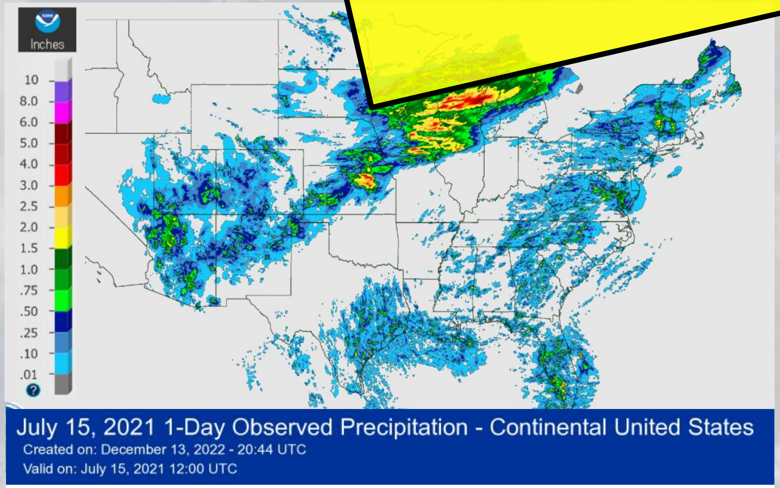
- Microwave (MW) observations can 'see' through clouds and have the potential to fill in cloudy gaps, but *only available from low-earth orbit (LEO) platforms*
  - <u>Real-time</u> data limited to areas with Direct Broadcast (DB) antennae
    - Data latency can range from several minutes to over an hour
      - Always arrive later than most recent GEO data
  - Lower temporal/spatial resolution than GEO-based measurements
  - Coarser spatial resolution
- ***<u>But, something is much better than nothing!</u>***
- MiRS chosen as our MW profile data source
  - ***<u>Lowest product latency and easily accessible</u>***
  - Highest spatial resolution
  - Contains multiple LEO platforms with consistent QC
    - Suomi-NPP, NOAA-19/20, Metop-A/B/C, etc.
  - *MiRS observations are assembled into valid-time files corresponding with half-hourly GEO-NearCast run times and combined with existing GEO trajectories*



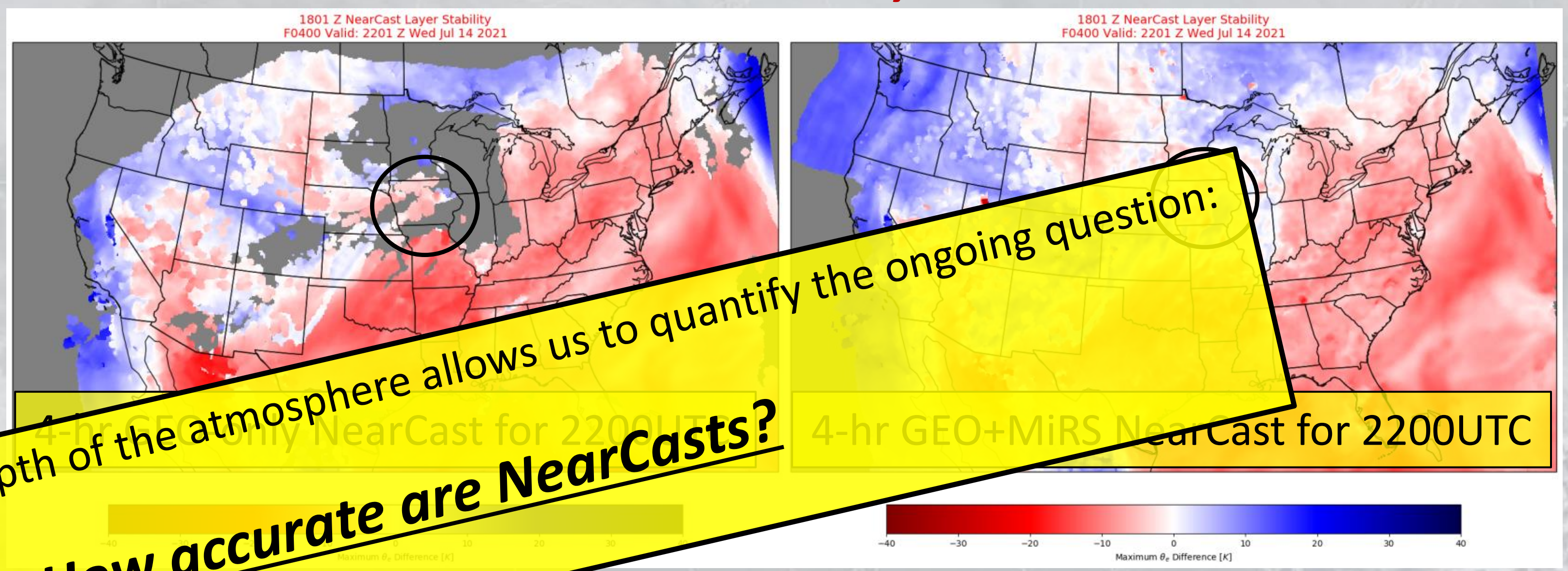
Early Hazardous Weather Case Combining GEO-LEO : 14 July 2021 Iowa Severe Weather

2200 UTC Observations





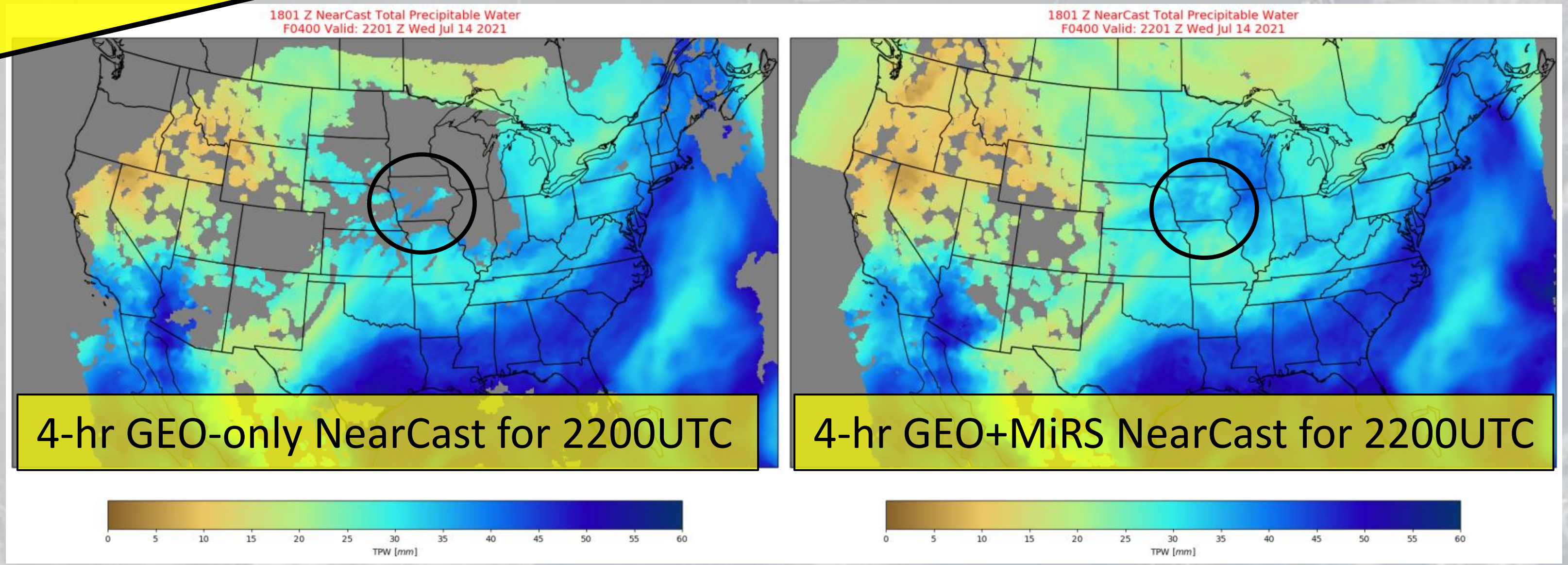
Pseudo-Stability



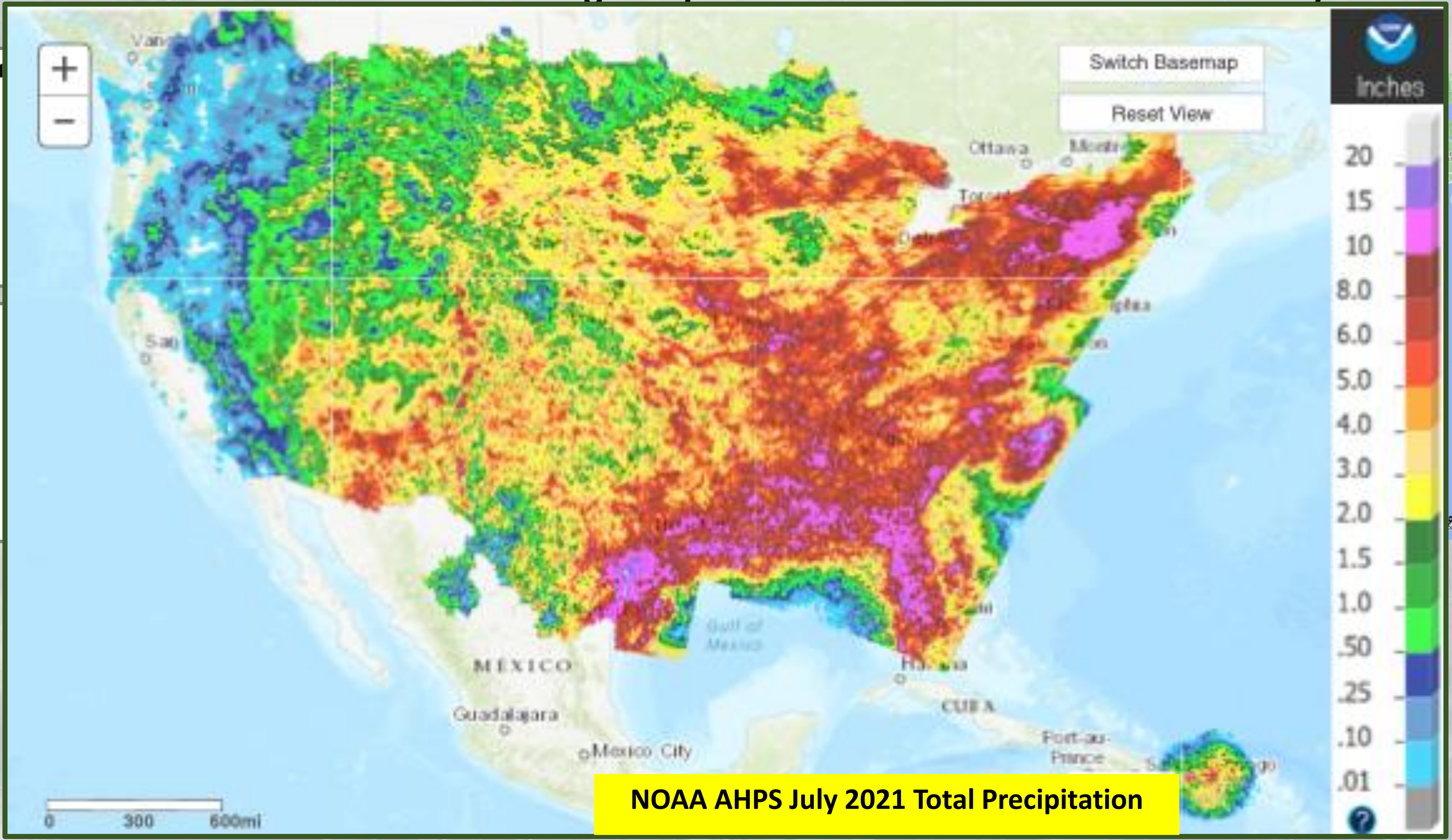
Incorporating the full depth of the atmosphere allows us to quantify the ongoing question:

<u>How accurate are NearCasts?</u>

Total Precipitable Water



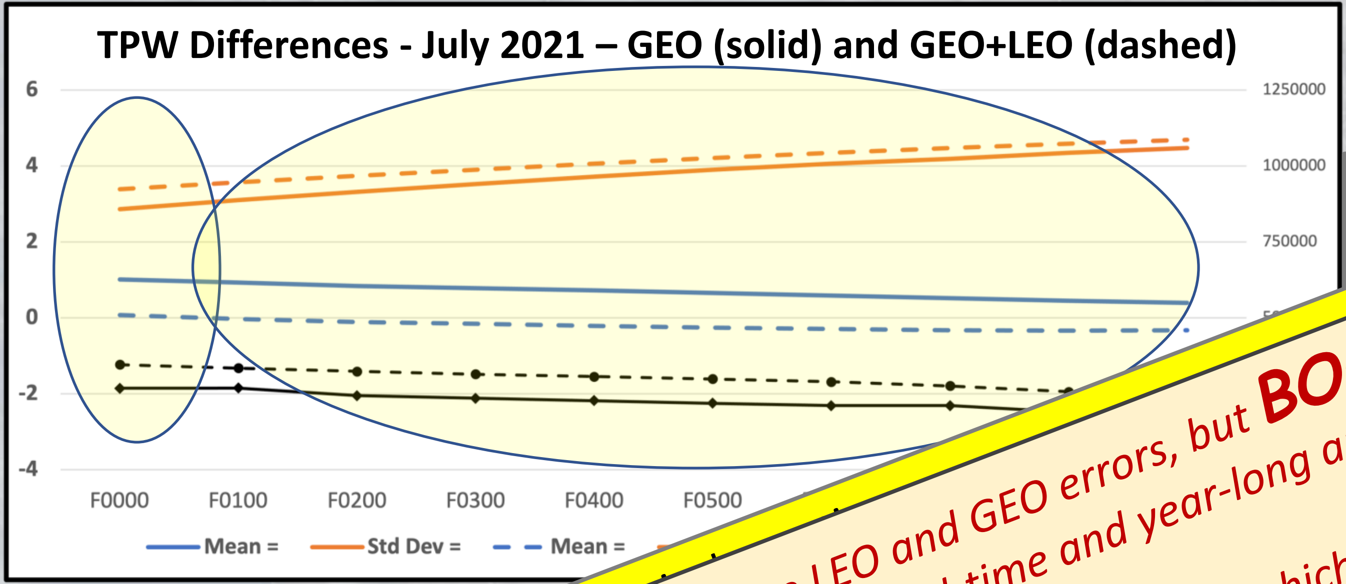
NearCast TPW Validation using *independent* Suominet surface-based GPS/TPW



NearCast TPW Forecast Validation using independent Suominet surface-based GPS/TPW

01 – 30 July 2021

Total Error (*mm*)



- GEO-only … TPW
- … onditions
- … (and larger Std
- … impact of small, sub-FOV clouds
- … IR soundings in merger process
- … is consistent with systematic differences seen between platforms

… shows:

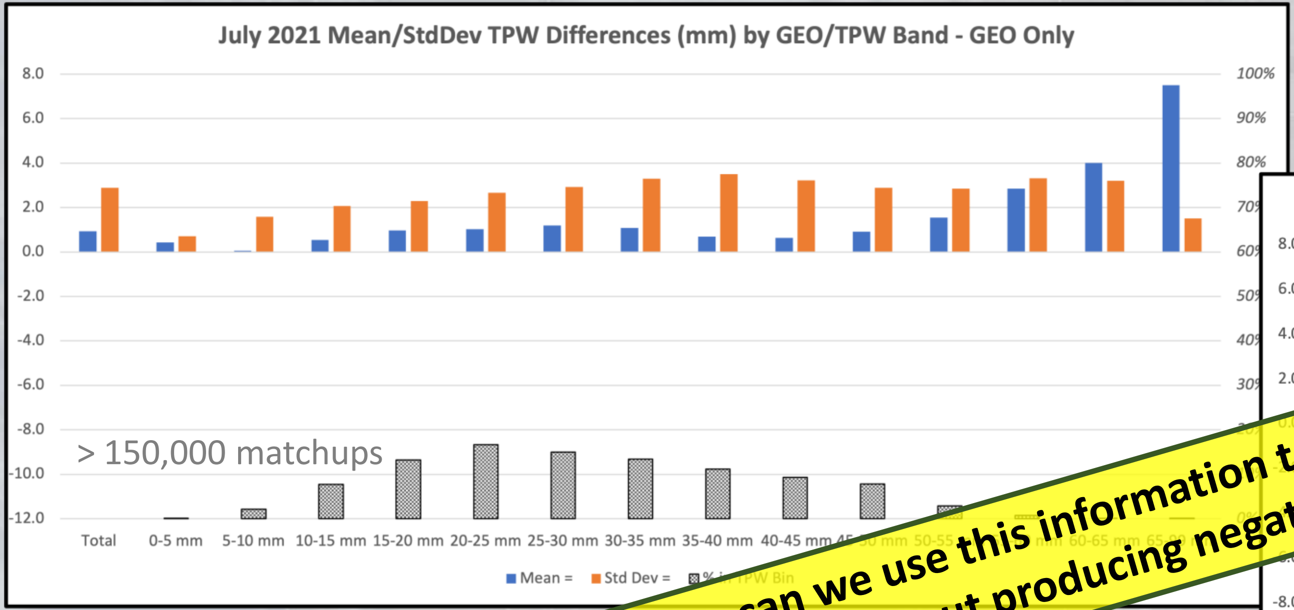
- … thought 9-hr valid periods
- … sing Biases (*possibly due to loss of high moisture IR retrievals post convection*)
- Random Error increase steadily at ~3% per hour
  - *Error levels and trends comparable to later-arriving sophisticated models*
- No major initial computational shocks present
- Adding MiRS maintains differences similar to those for initial analyses

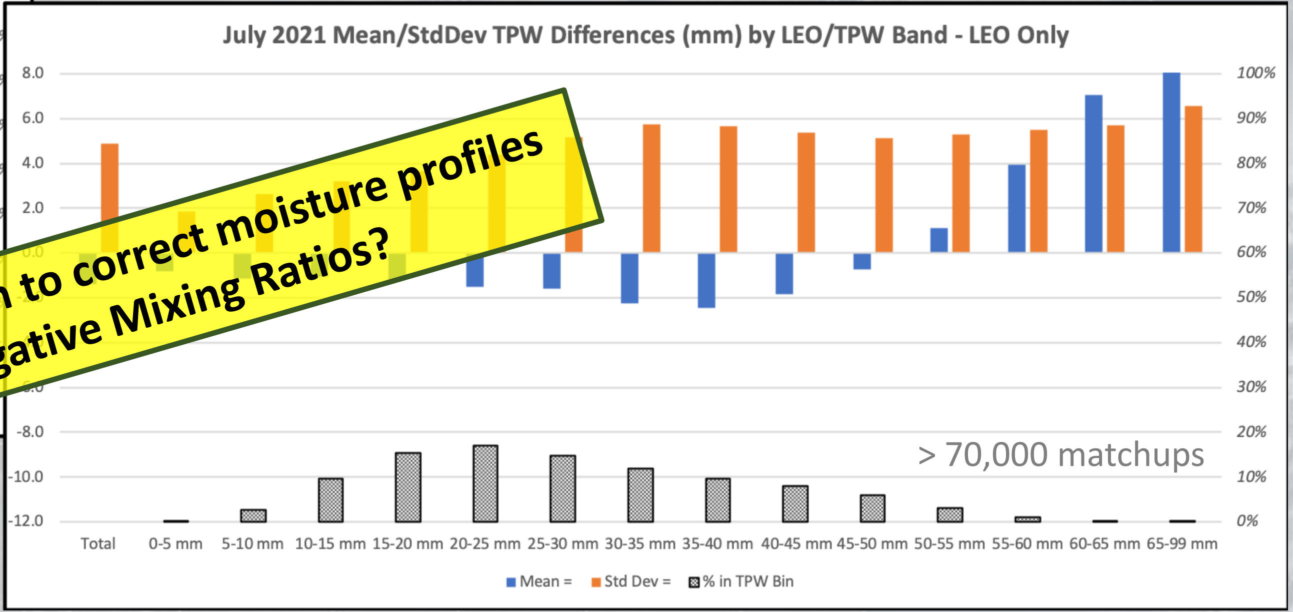
Next step was to separate LEO and GEO errors, but **BOOM!** *- **major** computer failure this summer – CPU, real-time and year-long archives completely lost –*

But we've recovered enough to move Forward (which is, after all, the motto of the State of Wisconsin)

Comparing overall Bias and Std Dev structures for different moisture environments

Separate by GEO-only and LEO-only data - Values in mm TPW



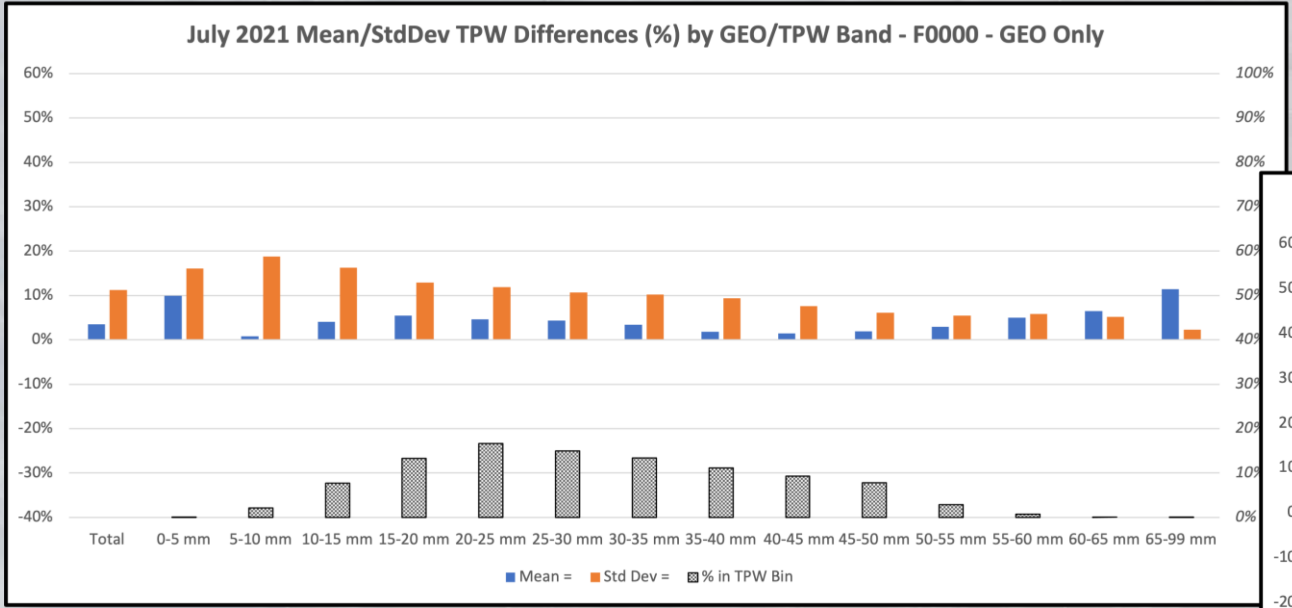


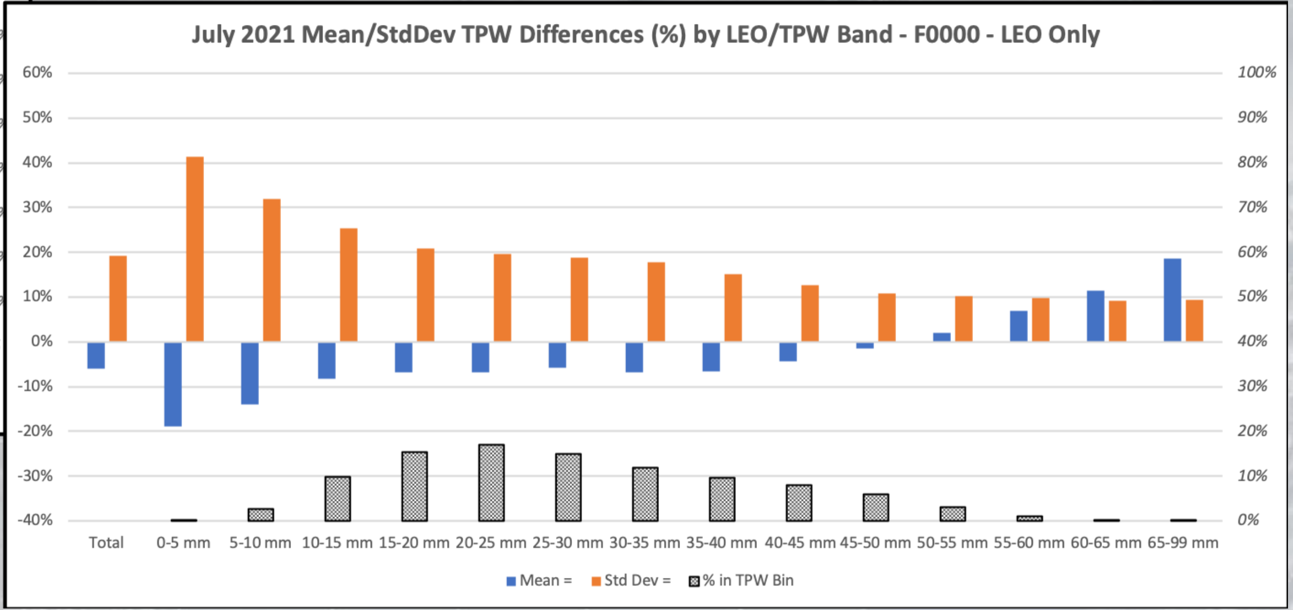
How can we use this information to correct moisture profiles without producing negative Mixing Ratios?

- For GEO, all bands show positive biases
  - *Many bands have systematic (bias) and random (Std Dev) that differ from overall values*
- For LEO, systematic errors shift from dry biases before 50mm TPW to substantially moist biases at higher TPWs
  - *Systematic (bias) and random (Std Dev) for individual bands have have larger differences from overall values*
  - *Random Errors of LEO are consistently at least 2x larger than for GEO across the full range of TPW.*

Comparing overall Bias and Std Dev structures for different moisture environments

Separate by GEO-only and LEO-only data - Values in ***<u>% TPW</u>***

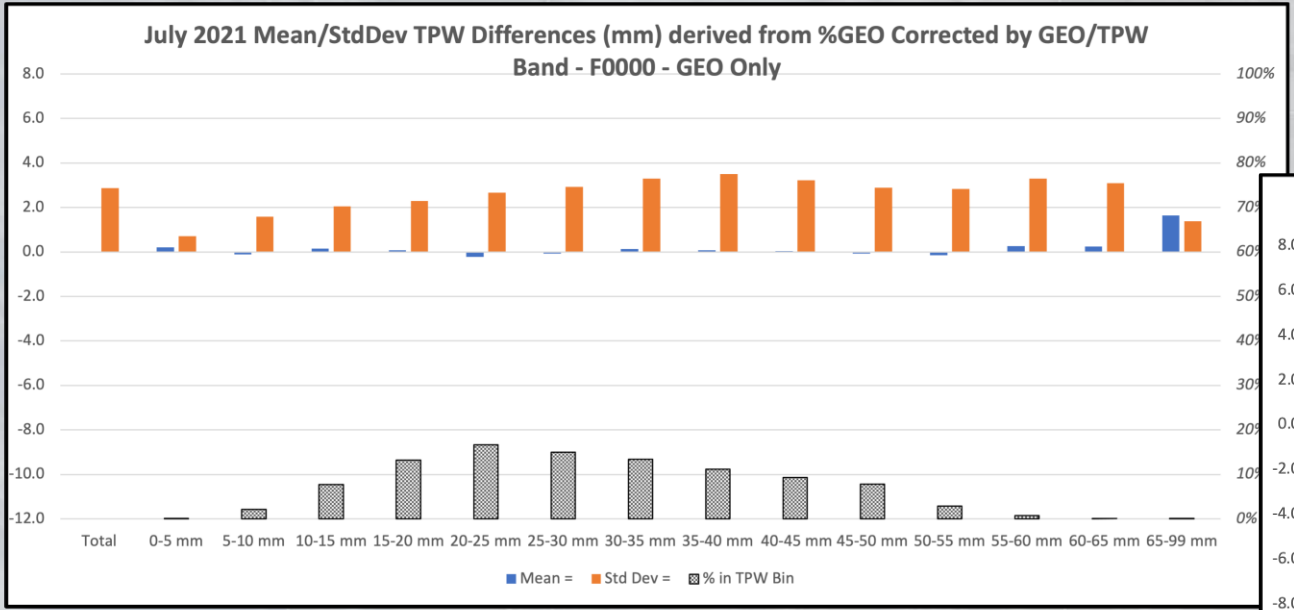


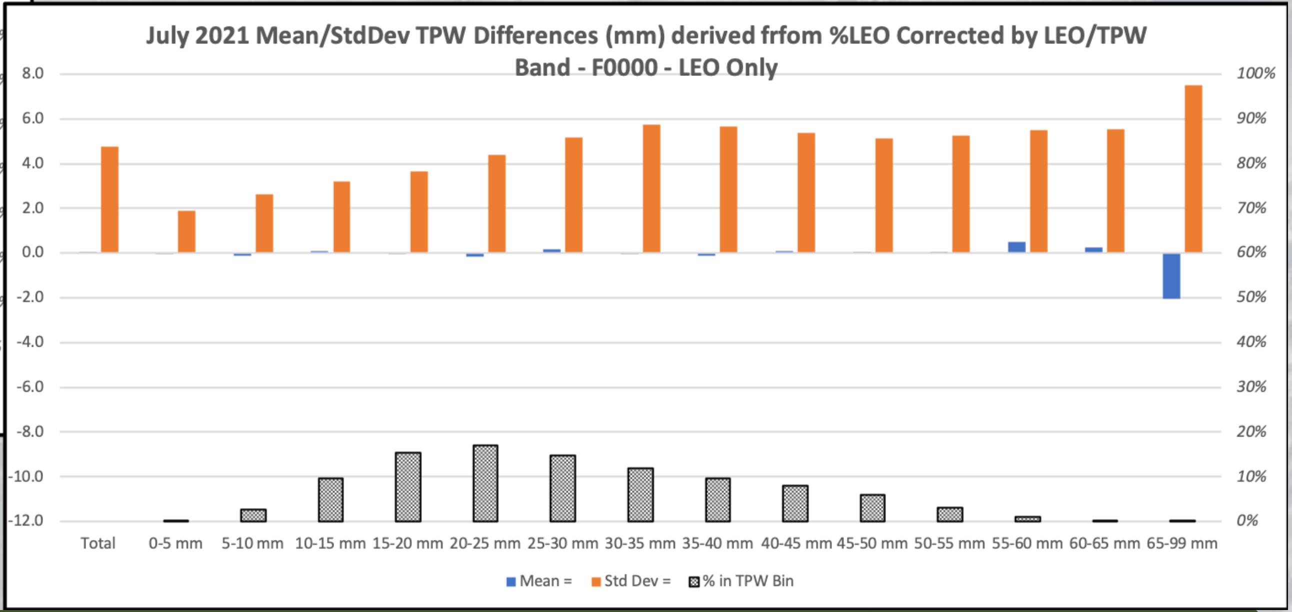


- For GEO, all bands show positive % biases
  - *Peaks in upper TPW ranges are reduced*
- For LEO, systematic% errors still shift from dry biases before 50mm TPW to moist biases at higher TPWs
  - *Biases at low ranges are exaggerated and at high ranges somewhat more reduced*
  - *Random Errors of LEO are consistently at least 2x larger than for GEO across the full range of TPW.*
  - *Allows bias correction that prevent negative humidity (and limit supersaturation)*

Results after Non-Uniform % Bias Corrections

Separate by GEO-only and LEO-only data - mm TPW - After % Bias Corrections





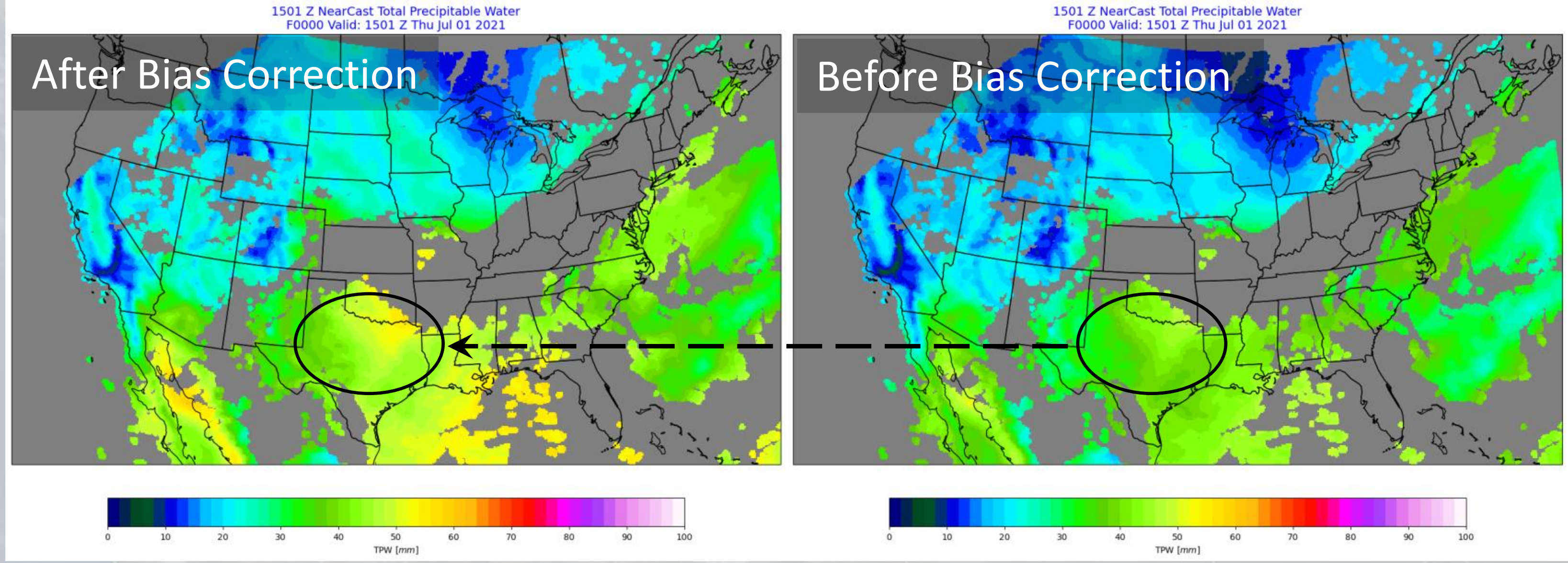
Although applying a uniform Bias Correction had very little impact,

Using Non-Uniform Corrections nearly eliminated all Biases for both absolute and relative errors

- TPW bias correction methods also reduced some Std Devs slightly
  - *LEO Std Dev still >05% larger than GEO – Weighted less when producing GEO-LEO Graphics*
- TPW % correction probably more useful across seasons - Update correction coefficients frequently (e.g., daily, weekly)
- Vertical Moisture Error Structure can also be assessed using AMDAR WV observations (*already under test for IASI*)

Results after % vertical Bias Correction by different moisture environments

Separate by GEO-only and LEO-only data - <u>mm TPW</u> - After % Bias Corrections



<< GEO

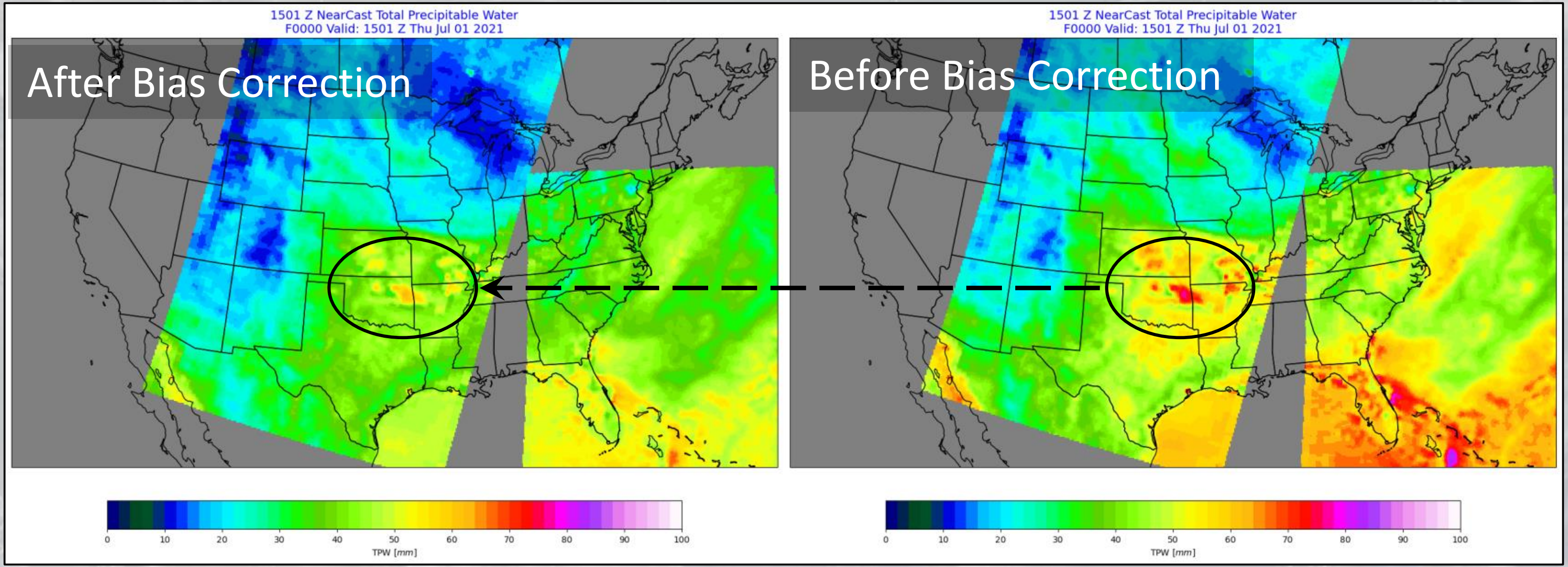
TPW dried slightly for all values

Largest reductions for highest moisture ranges

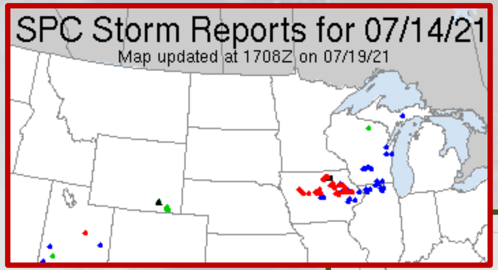
LEO (MIRS) >>

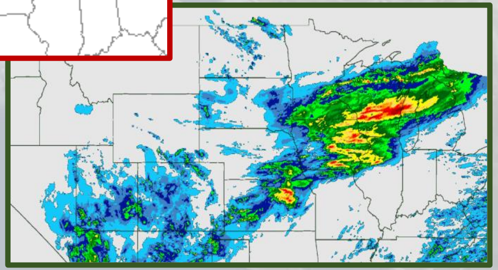
TPW moistened slightly for low/mid-range TPWs

Larger reductions for higher moisture ranges

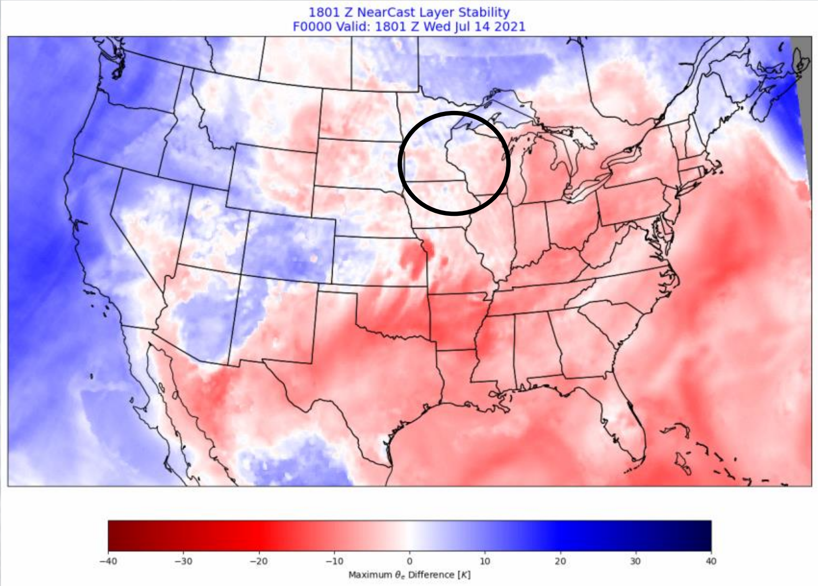


Hazardous Weather Example: 14 July 2021 Iowa Severe Weather

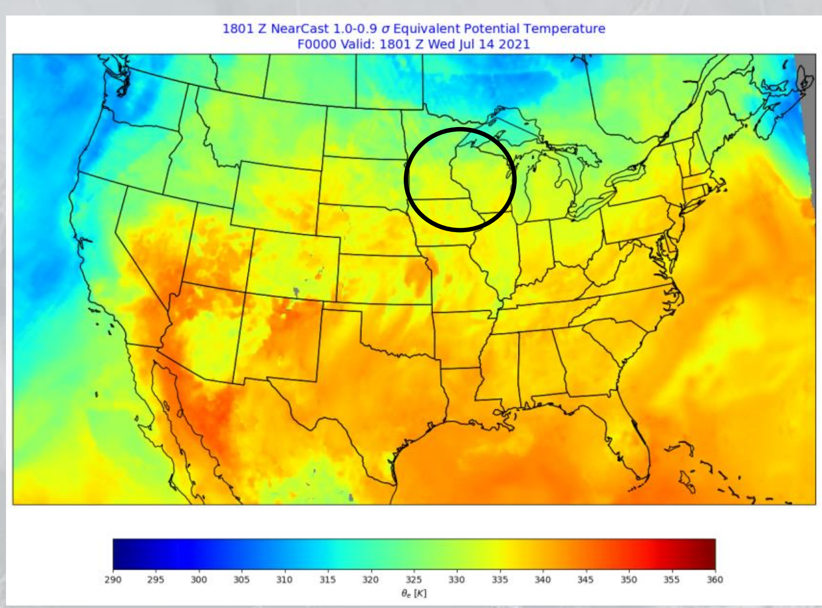




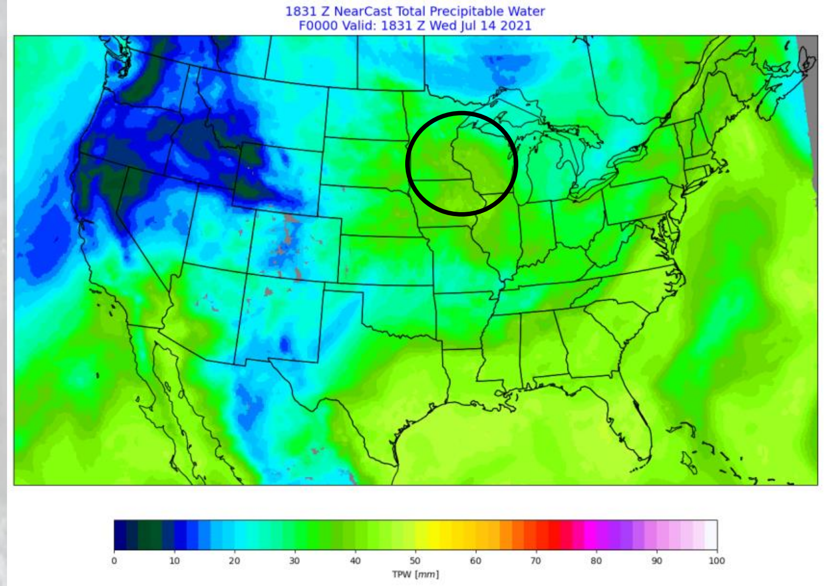
Pseudo-Stability



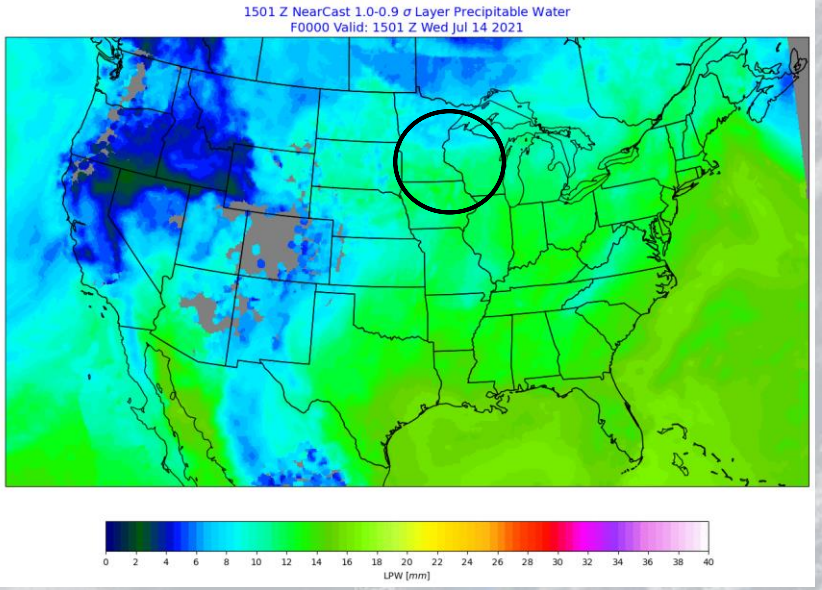
Low-level Theta-E (100 hPa Layer)

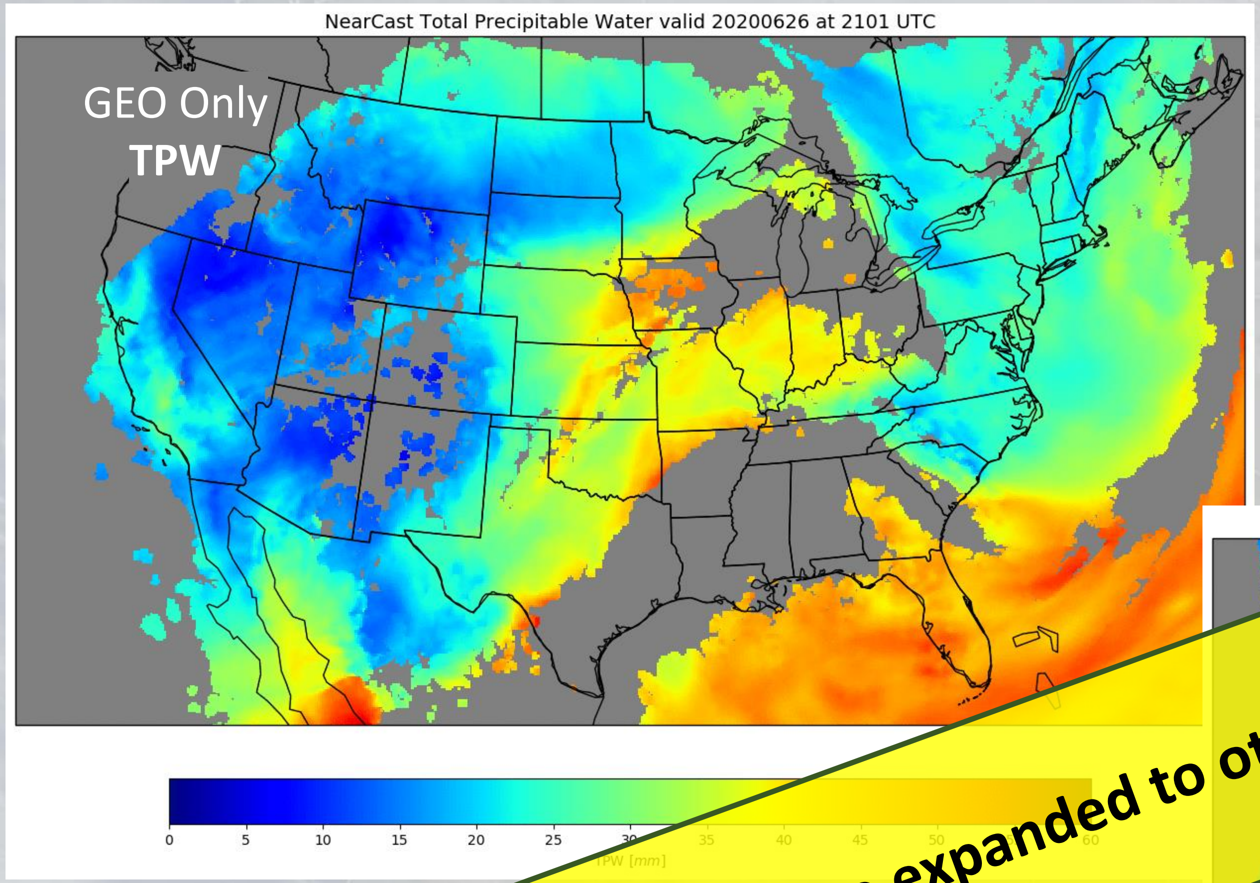


Total Precipitable Water



Low-level Precipitable Water (100 hPa Layer)





LEO Microwave Observations are useful for Nowcasting!

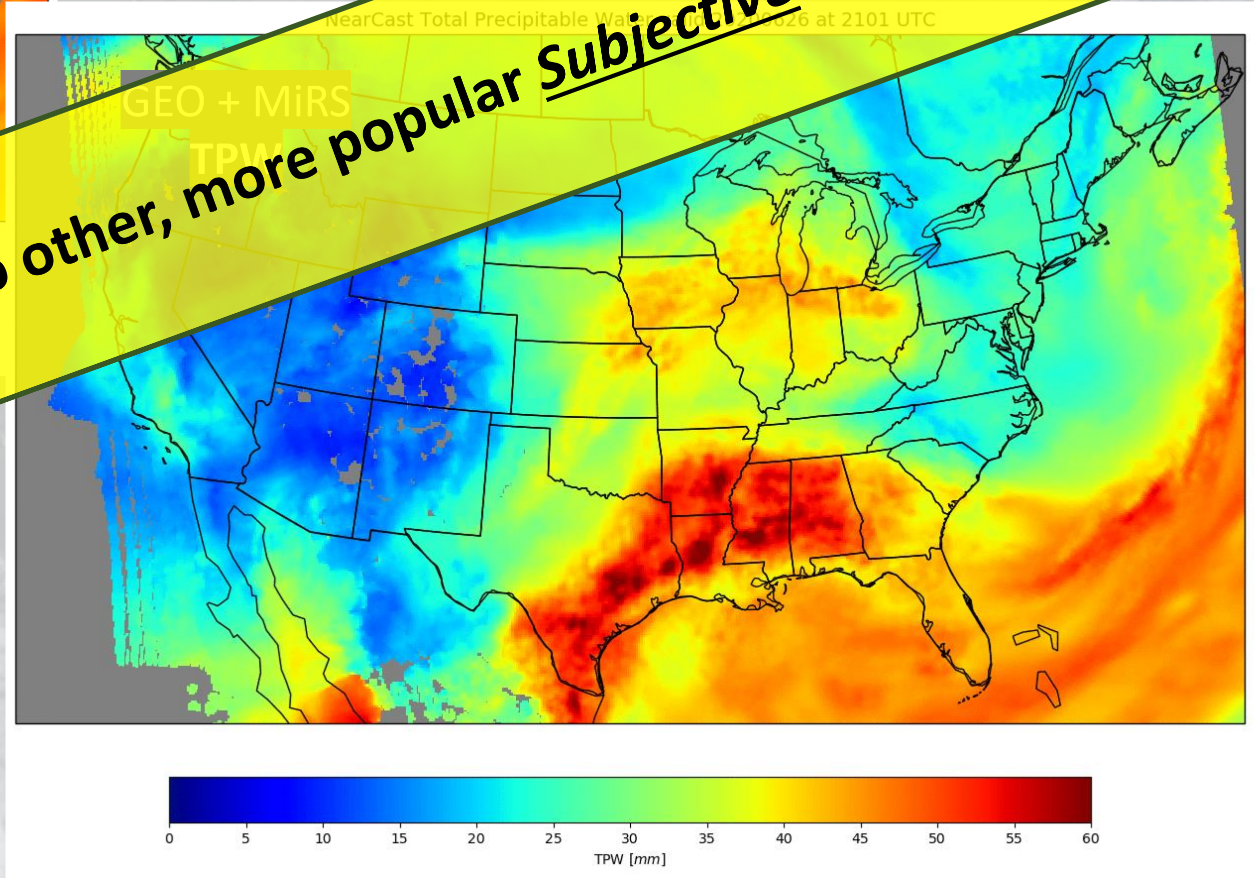
- **MiRS fills in cloud gaps**
  - **New Bias Corrections harmonise GEO and LEO**
- New visualization tool improves integration of different data sources and reduces GOES random errors
- Products are more Forecaster Friendly

New NearCast Formulation

✓ Sigma Coordinate

- *Improves flow in areas of steep terrain and along coasts*
  - *Allows Projections of Near-Surface Observations*
- σ-coordinate model reduces noise, adds lowest level obs and TPW

Can NearCasting method be expanded to other, more popular *Subjective* Nowcasting tools?



Allows calculation of Parameters Integrated through Entire Troposphere:

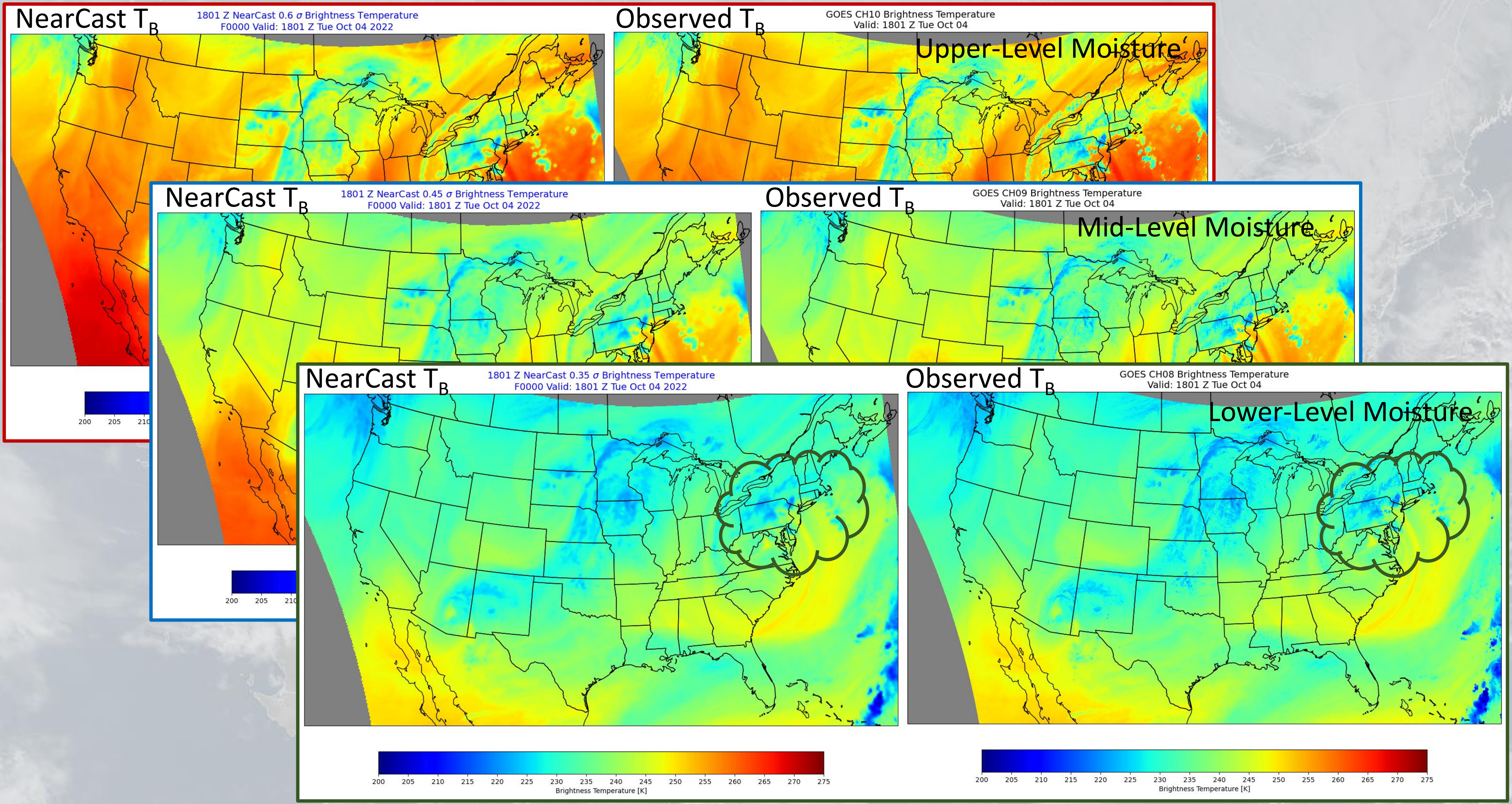
✓ **Total Precipitable Water**

✓ Conventional Stability Indices

New tools comparing GPS-TPW observations permit real-time bias-corrections

Subjective NearCasts – WV Radiance Projections – 3 WV Channels

10 km Resolution NearCasts vs. Full Resolution Observations



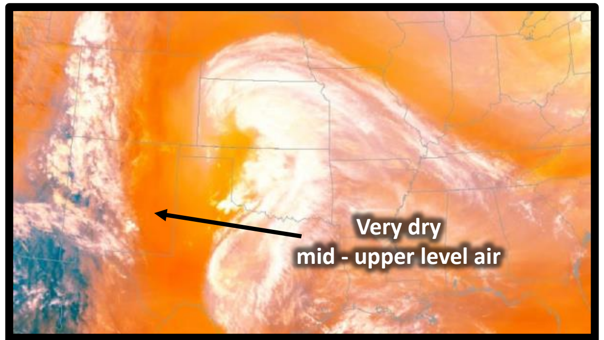
Subjective NearCasts – 9 hr Projections of WV RGB Projection – Our VERY FIRST (UGLY) ATTEMPT ! ! !

Differential Water Vapor RGB

Quick Guide

Why is the Differential Water Vapor RGB Imagery Important?

The Differential Water Vapor RGB was designed to analyze water vapor distribution. It can be used to identify upper level moisture boundaries, trough/ridge patterns, potential vorticity (PV) anomalies, and the influences of PV anomalies and stratospheric air on rapid cyclogenesis and tropopause fold-driven high-impact wind events. Analysis of moist/dry layers is also important for predicting changes in hurricane intensity and extratropical transition.



Differential Water Vapor RGB from GOES-16 ABI at 2022 UTC, 13 April 2017

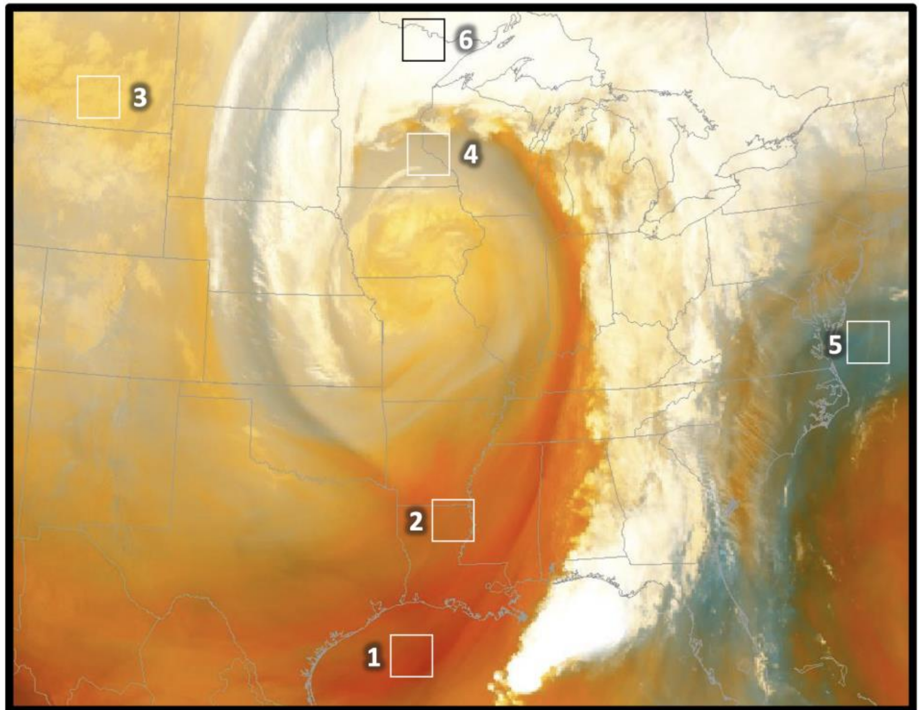
Differential Water Vapor RGB Recipe

**when cloud free*

Color	Band / Band Diff. (µm)	Min – Max Gamma	Physically Relates to…	*Small contribution to pixel indicates…	*Large Contribution to pixel indicates…
Red	7.3 – 6.2 (inv)	30 to -3 C 0.2587	Vertical water vapor difference	Moist upper levels	Dry upper levels
Green	7.3 (inv)	5 to -60 C 0.4	Low level water vapor	Dry low levels	Moist lower levels
Blue	6.2 (inv)	-29.25 to -64.65 C 0.4	Upper level water vapor	Dry upper levels	Moist upper levels

RGB Interpretation

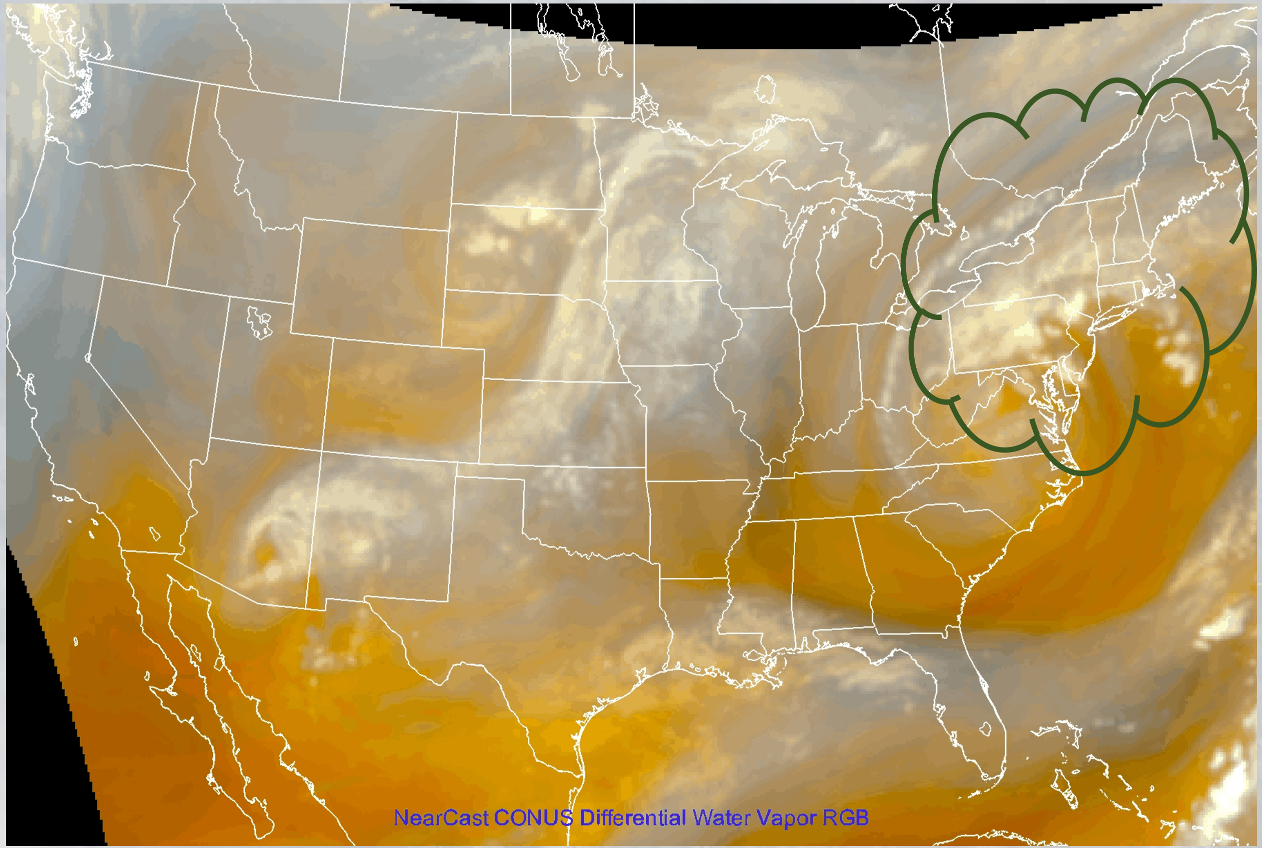
1. **Very dry mid-upper level** *(bright orange)*
2. **Dry mid-upper level** *(orange)*
3. **Dry upper level, Moist mid level; Mid level cloud** *(gold)*
4. **Moderate moisture mid-upper level** *(gray)*
5. **Moist upper level** *(light teal)*
6. **Thick, high clouds** *(white)*



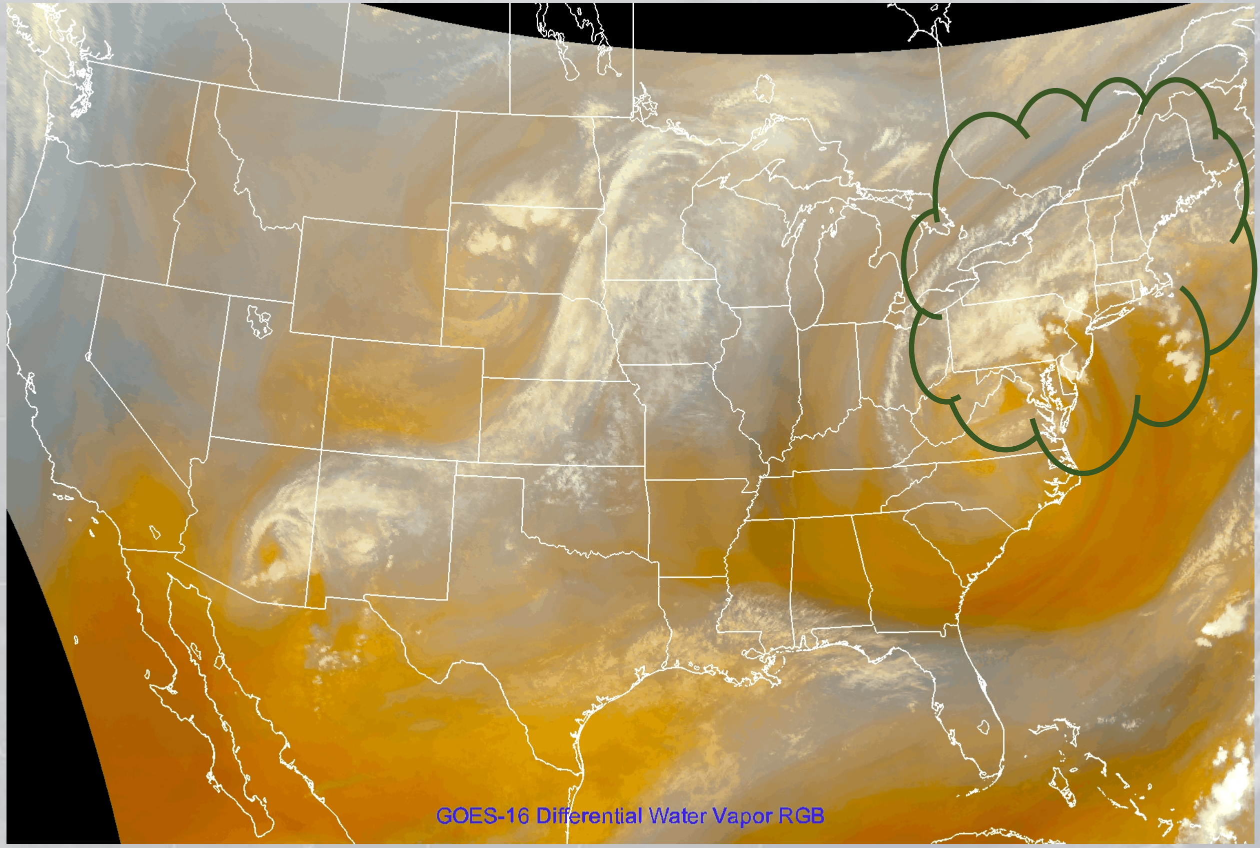
Differential Water Vapor RGB from GOES-16 ABI at 1002 UTC, 01 May 2017.

Subjective NearCasts – 9 hr Projections of WV RGB Projection – Our VERY FIRST (UGLY) Low Resolution ATTEMPT ! ! !

0 hr 10 km Resolution NearCast



Verifying full resolution Observations



- How useful can this be for NowCasting?
  - Appears especially robust in first 4-6 hour
  - Portrays progression/leading edge of moist/dry streams even after convection begins

Subjective NearCasts – 9 hr Projections of WV RGB Projection – Our VERY FIRST (UGLY) Low Resolution ATTEMPT ! ! !

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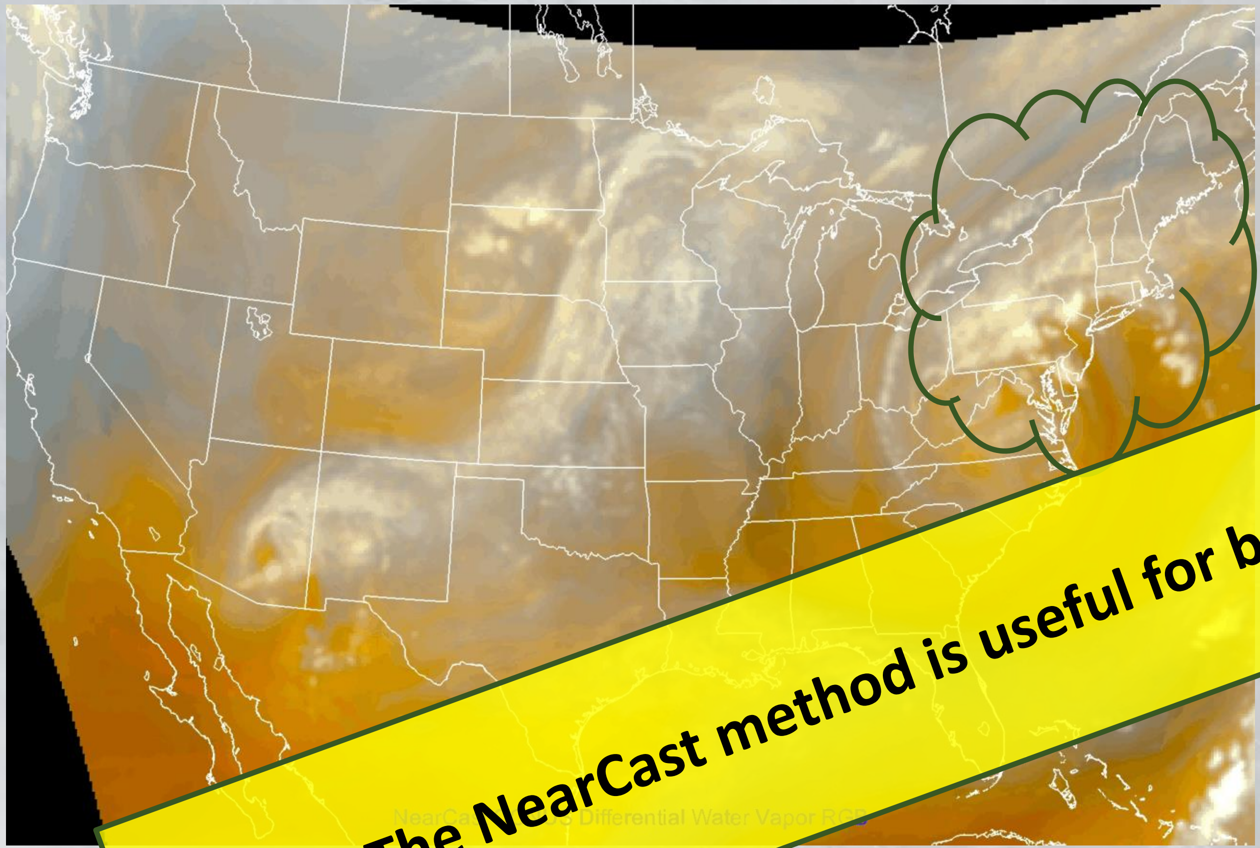
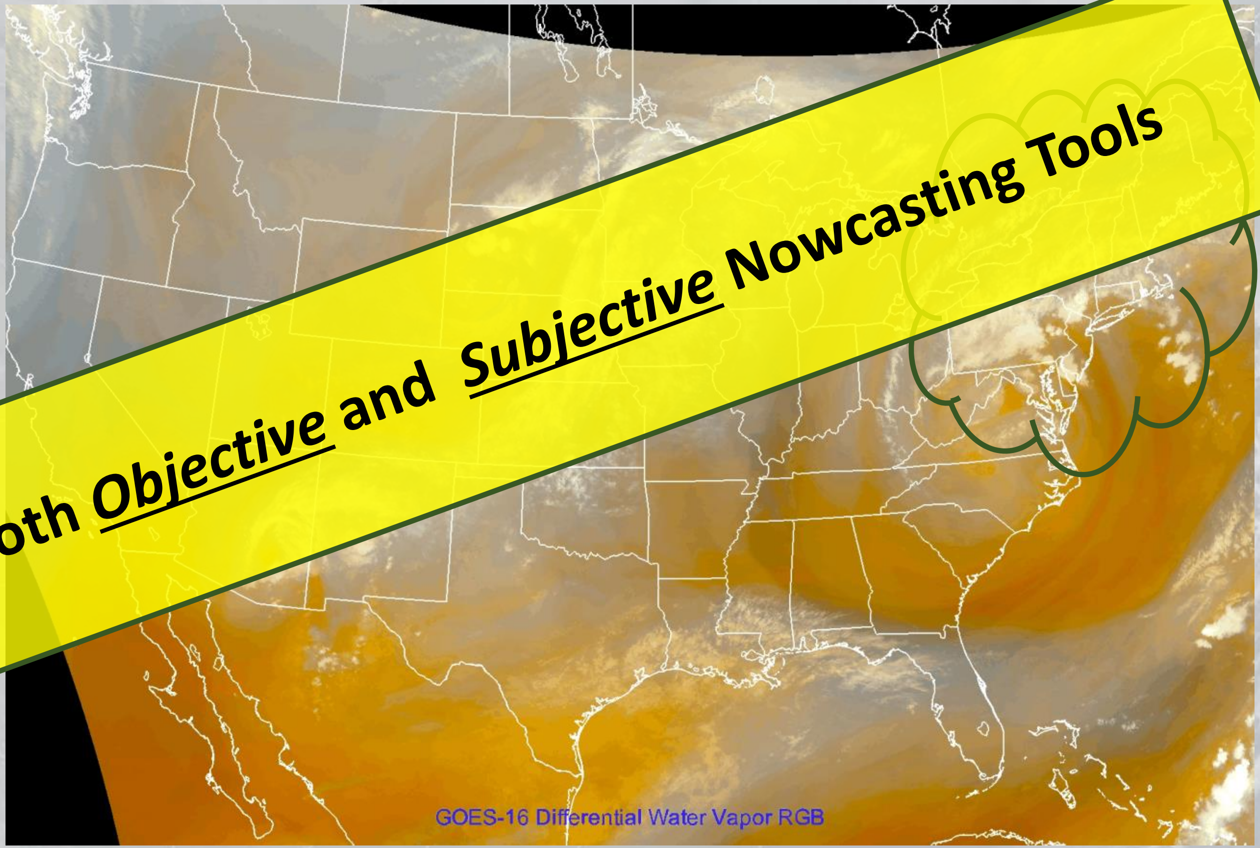


Verifying full resolution Observations



YES! The NearCast method is useful for both *Objective* and *Subjective* Nowcasting Tools

- How useful can this be for NowCasting?
  - Appears especially robust in first 4-6 hour
  - Portrays progression/leading edge of moist/dry streams even after convection begins
    - Will benefit from higher resolution output grid

What more might we do with MTG to improve Pre-Storm Nowcasts?

First, a request:

- Please, retain and disseminate operationally produced soundings from both MTG-IRS and –FCI *and* make them easily available to the users and research/development communities!
  - *This was not done during MSG Sounder product like GII, etc.*
- Make *real-time* microwave products (e.g., MiRS) operational for NOAA and MetOp satellites for use in Nowcasting over Europe

A Shopping list of Potential Additional NearCast Applications:

Remember: Although retrievals from FCI will not be as accurate as IRS, they will be very important to describe horizontal moisture variations prior to storm development.

Might forecasters benefit from transforming other MTG/LEO 'clear air' observations/products into forecasts?

☛ Forecast 'Clear-air' RGBs by expanding NearCasts of GEO radiances?

Evaluating vertical structures for IRS over Europe will be hampered by lack of off-time AMDAR WV observations. Consider using Metop products generated with IRS algorithm over US as a transfer mechanism for updating bias over MTG domains

Thanks for your attention over the years. I wish I could have been with you more recently!