Marco Fulle - www.stromboli.net

The GOES-R volcanic ash, SO_2, and fog/low cloud products: Current status and future development

Mike Pavolonis
(NOAA/NESDIS)
Corey Calvert and Justin Sieglaff
(UW-CIMSS)

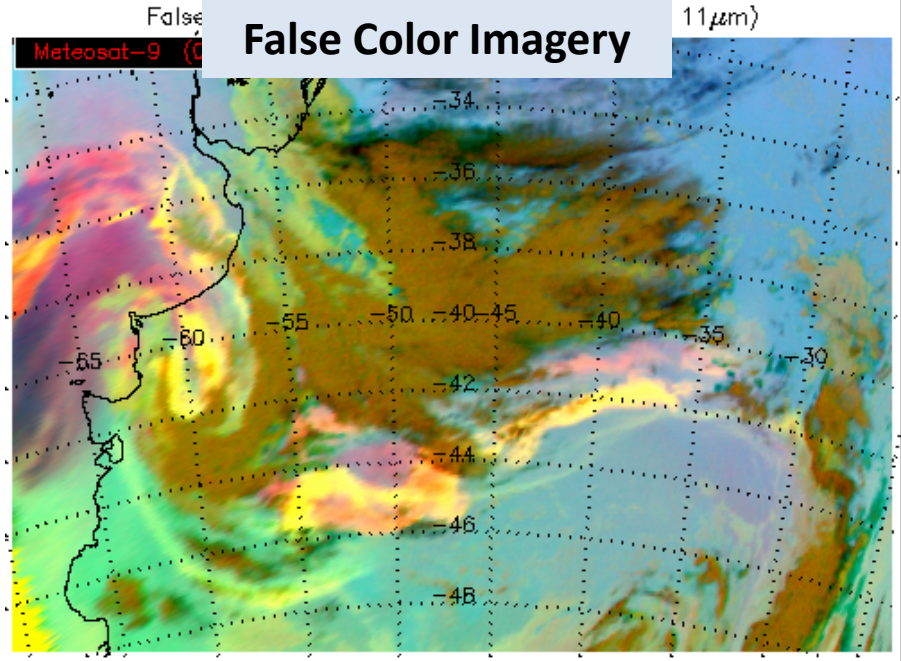
GOES-R Volcanic Ash Products

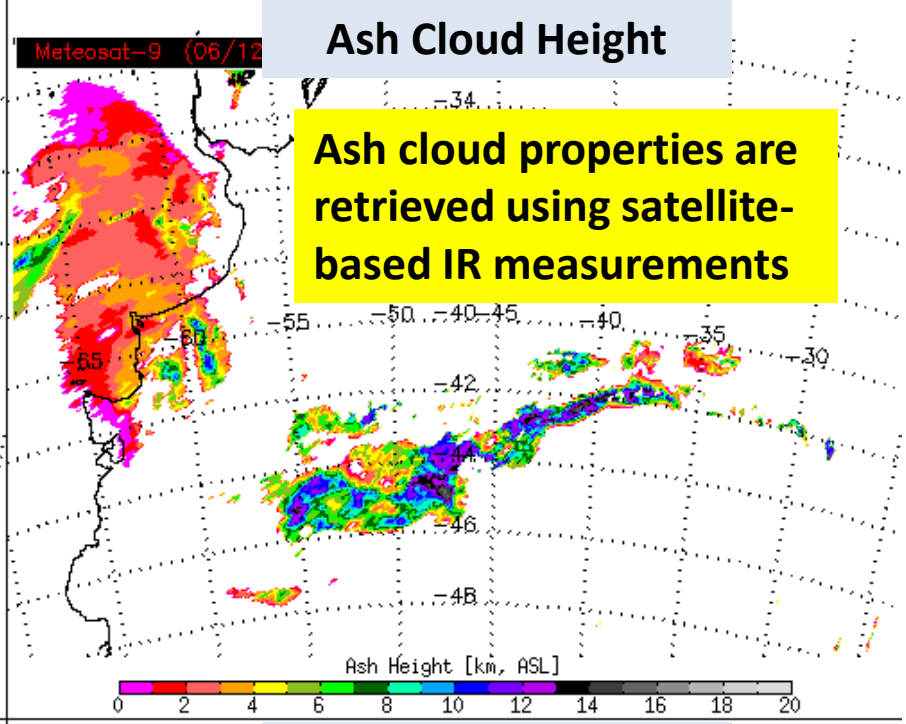
Products

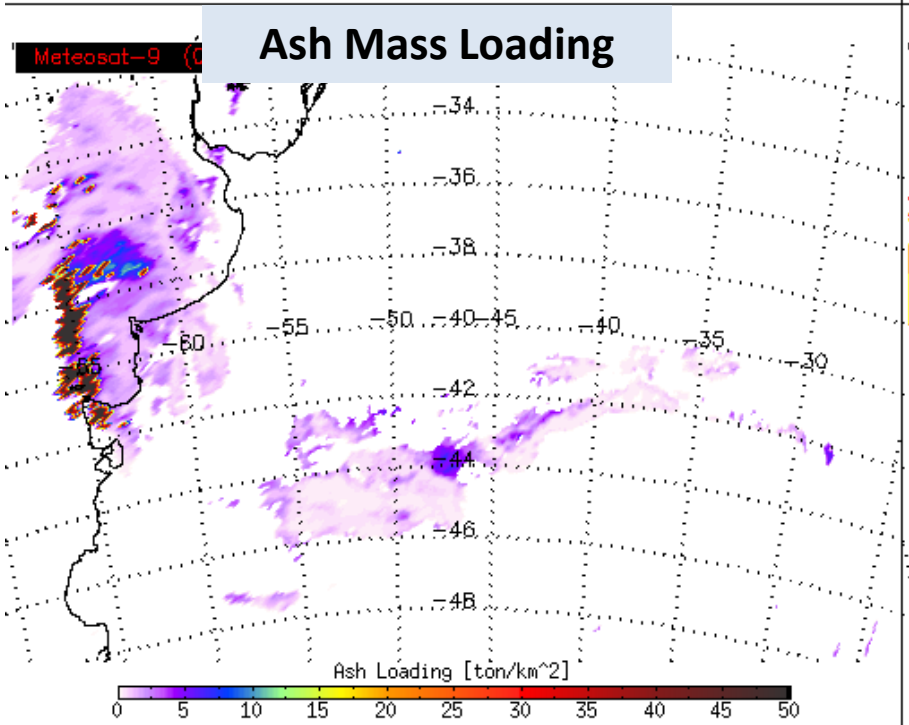
Volcanic Ash Requirements

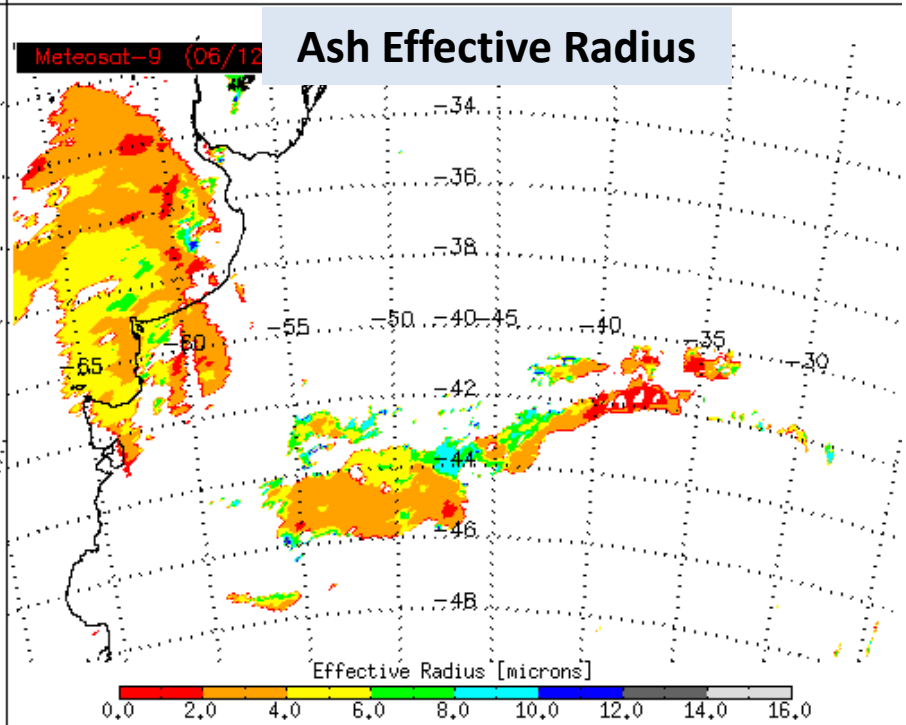
Name	User & Priority	Geographic Coverage (G, H, C, M)	Vertical Resolution	Horizontal Resolution	Mapping Accuracy	Measurement Range	Measurement Accuracy	Product Refresh Rate/Coverage Time (Mode 3)	Product Refresh Rate/Coverage Time (Mode 4)	Vendor Allocated Ground Latency	Product Measurement Precision
Volcanic Ash: Detection and Height	GOES-R	Full Disk	3 km (top height)	2 km	1 km	0 - 50 tons/km^2	2 tons/km^2	Full disk: 15 min	Full disk: 15 min	430 sec	2.5 tons/km^2

Name	User & Priority	Geographic Coverage (G, H, C, M)	Temporal Coverage Qualifiers	Product Extent Qualifier	Cloud Cover Conditions Qualifier	Product Statistics Qualifier
Volcanic Ash: Detection and Height	GOES-R	Full Disk	Day and night	Quantitative out to at least 60 degrees LZA and qualitative at larger LZA	Clear conditions down to feature of interest associated with threshold accuracy	Over volcanic ash cases


False Color Imagery
Meteosat-9
11μm)
-34
-36
-38
-55
-50
-40
-45
-40
-35
-60
-65
-30
-42
-44
-46
-48


Ash Cloud Height
Meteosat-9
Ash cloud properties are retrieved using satellite-based IR measurements
-34
-55
-50
-40
-45
-40
-35
-60
-65
-30
-42
-44
-46
-48
Ash Height [km, ASL]
0
2
4
6
8
10
12
14
16
18
20

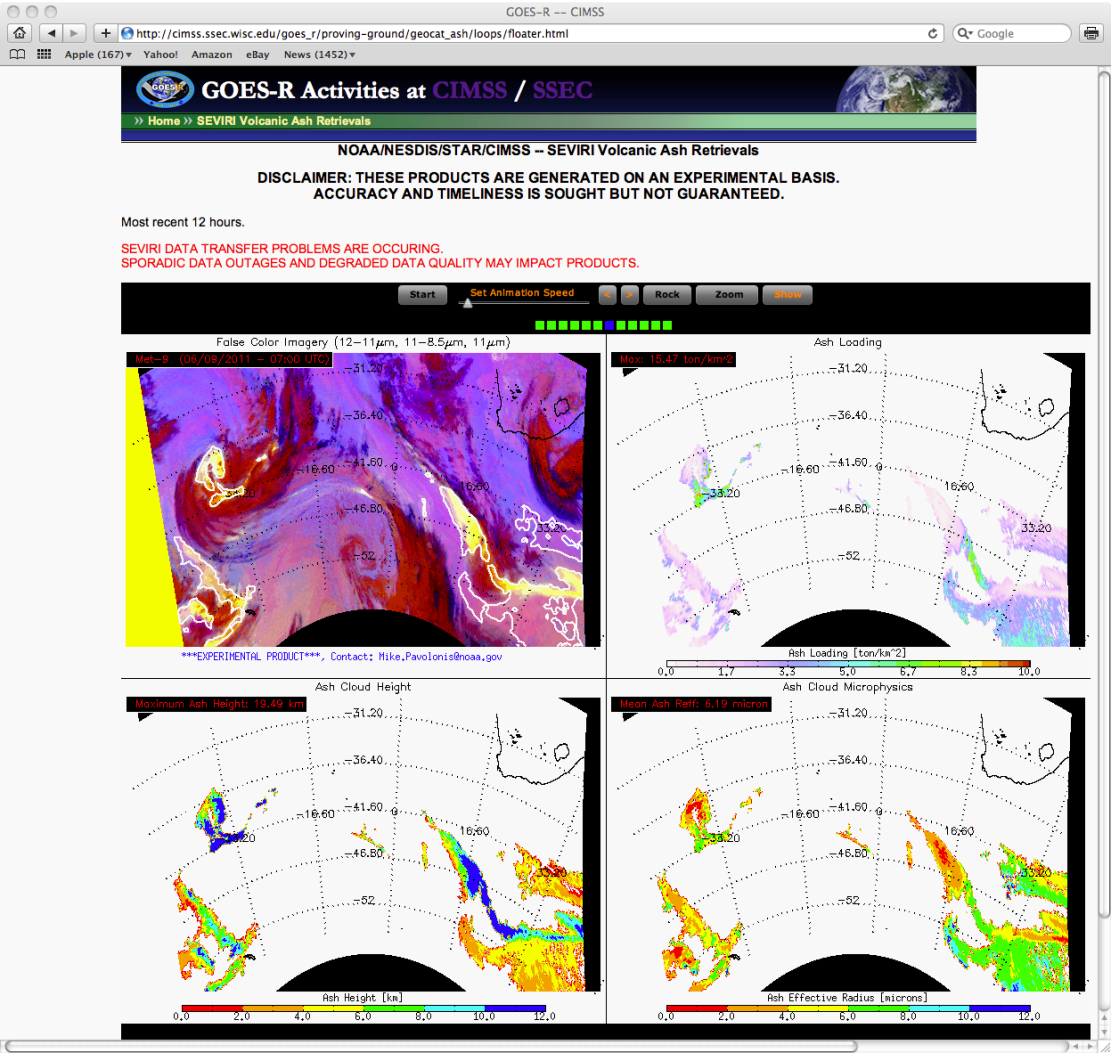

Ash Mass Loading
Meteosat-9
-34
-36
-38
-55
-50
-40
-45
-40
-35
-60
-65
-30
-42
-44
-46
-48
Ash Loading [ton/km^2]
0
5
10
15
20
25
30
35
40
45
50


Ash Effective Radius
Meteosat-9
-34
-36
-38
-55
-50
-40
-45
-40
-35
-60
-65
-30
-42
-44
-46
-48
Effective Radius [microns]
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0

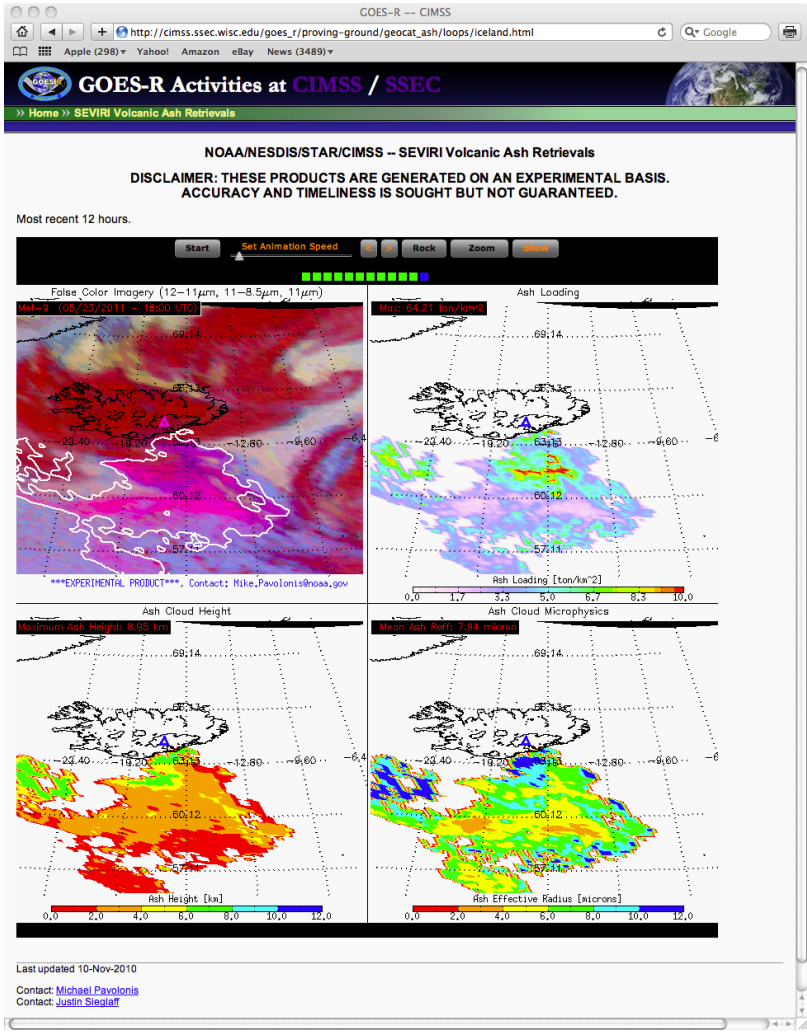
Products are displayed on the web in near-realtime

http://cimss.ssec.wisc.edu/goesr/proving-ground/geocat_ash

Cordon Caulle



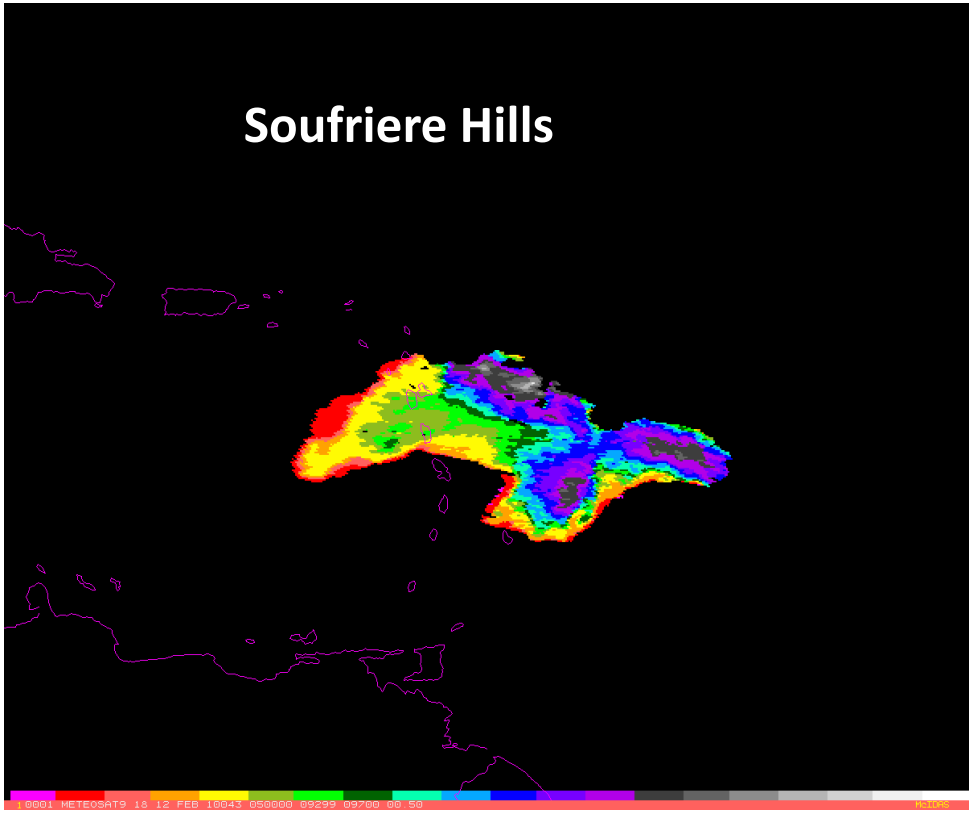
Grimsvotn

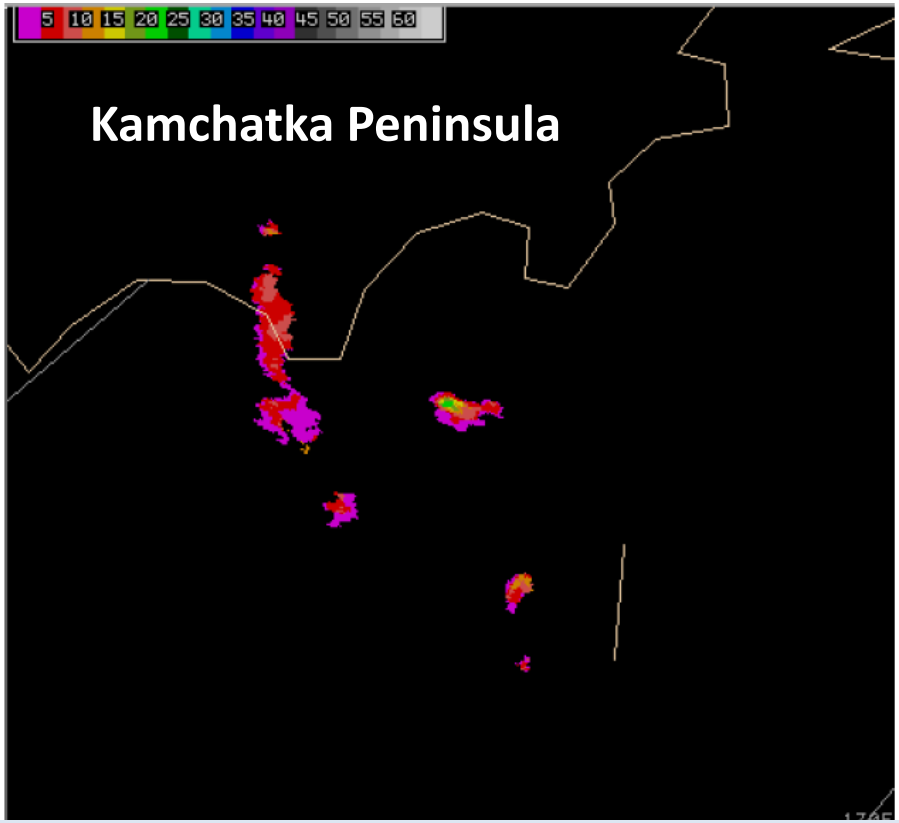


Distribution of Products to VAAC's

SEVIRI products are now available to W-VAAC via McIDAS server

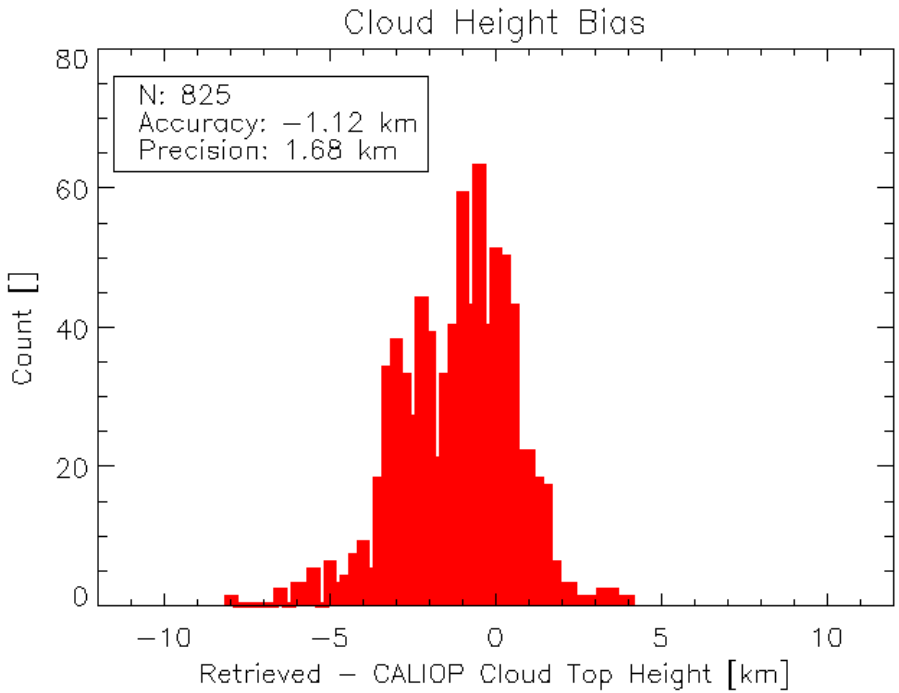
MODIS products have been provided to A-VAAC since January 2011 via AWIPS server





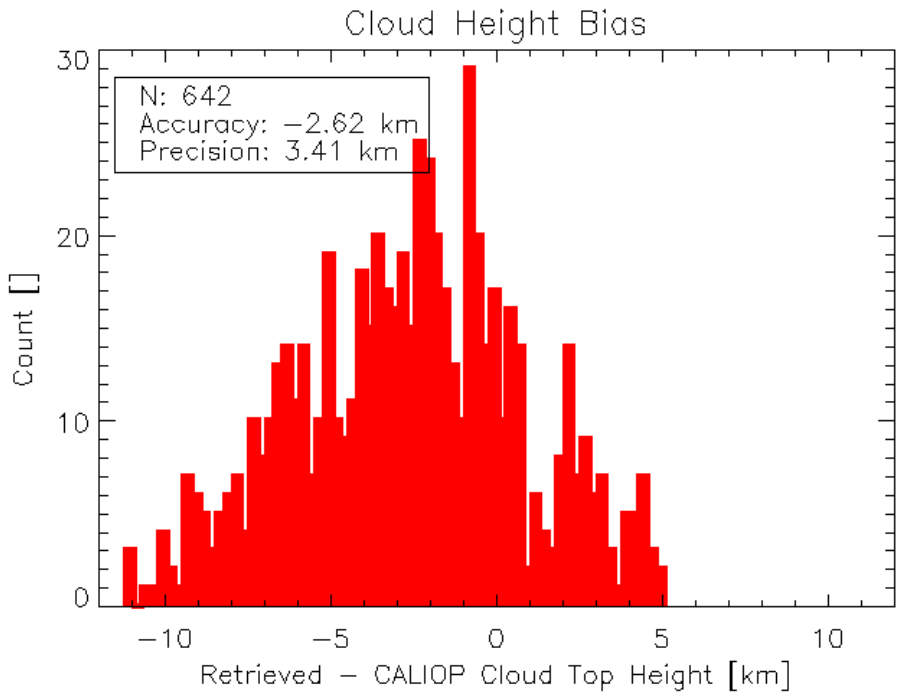
Volcanic ash cloud property retrieval code has also been installed at Australian Bureau of Meteorology (Darwin VAAC); Montreal, Toulouse, and Wellington VAAC's also plan to evaluate the products (London, Buenos Aires, and Tokyo VAAC's regularly access online products)

Eyjafjallajökull



Nearly all of these observations are of the distal volcanic ash cloud

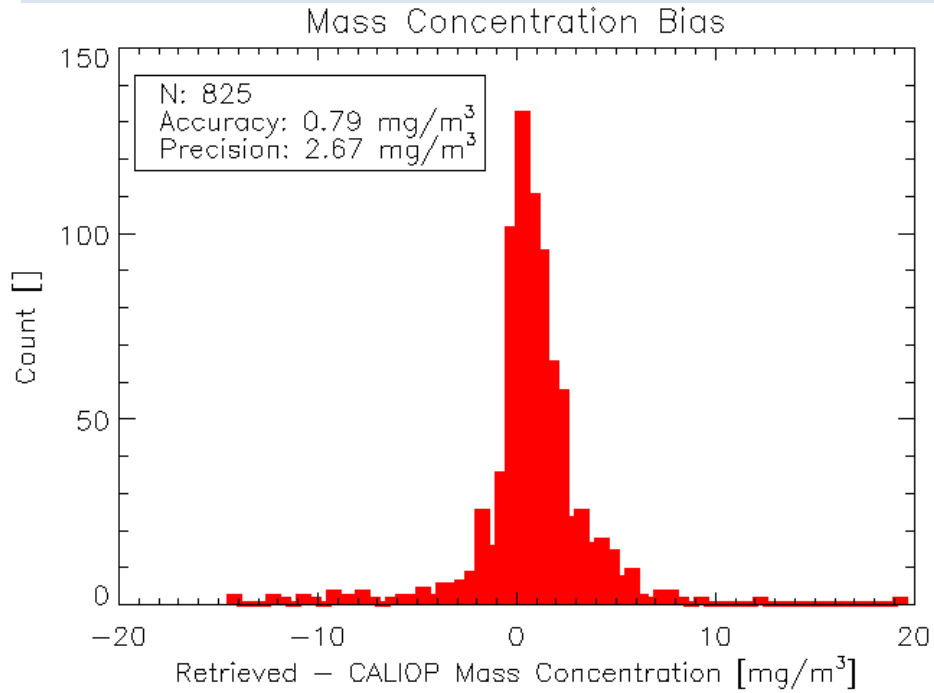
Grimsvotn and Cordon Caulle



- **Comparisons to CALIOP indicate that the ash cloud top height estimates are biased low, as expected.**

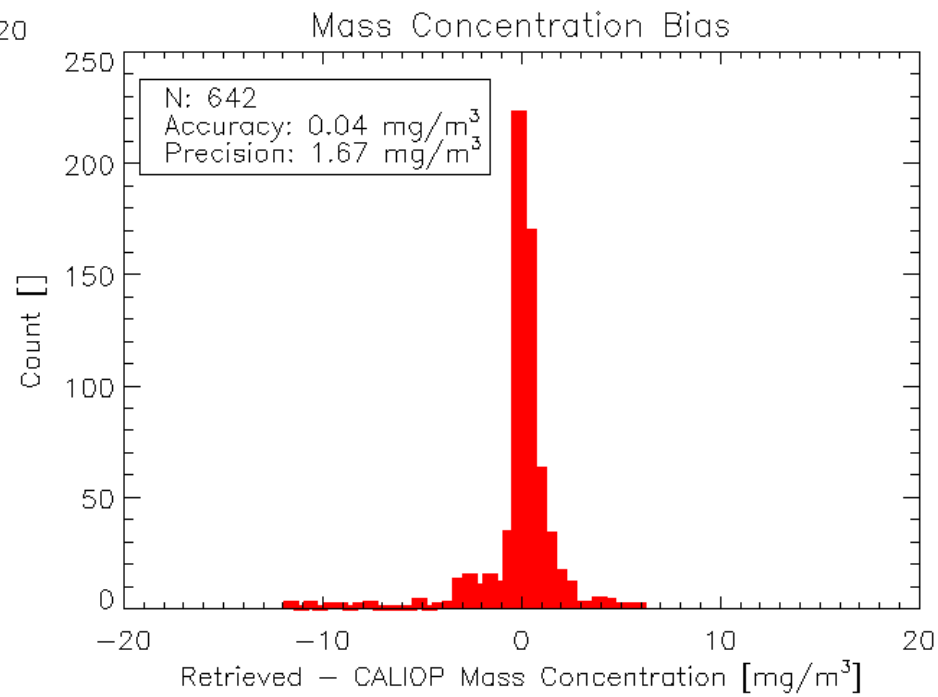
- **Aged stratospheric Cordon Caulle cloud accounts for most of the observations in figure on right**

Eyjafjallajökull



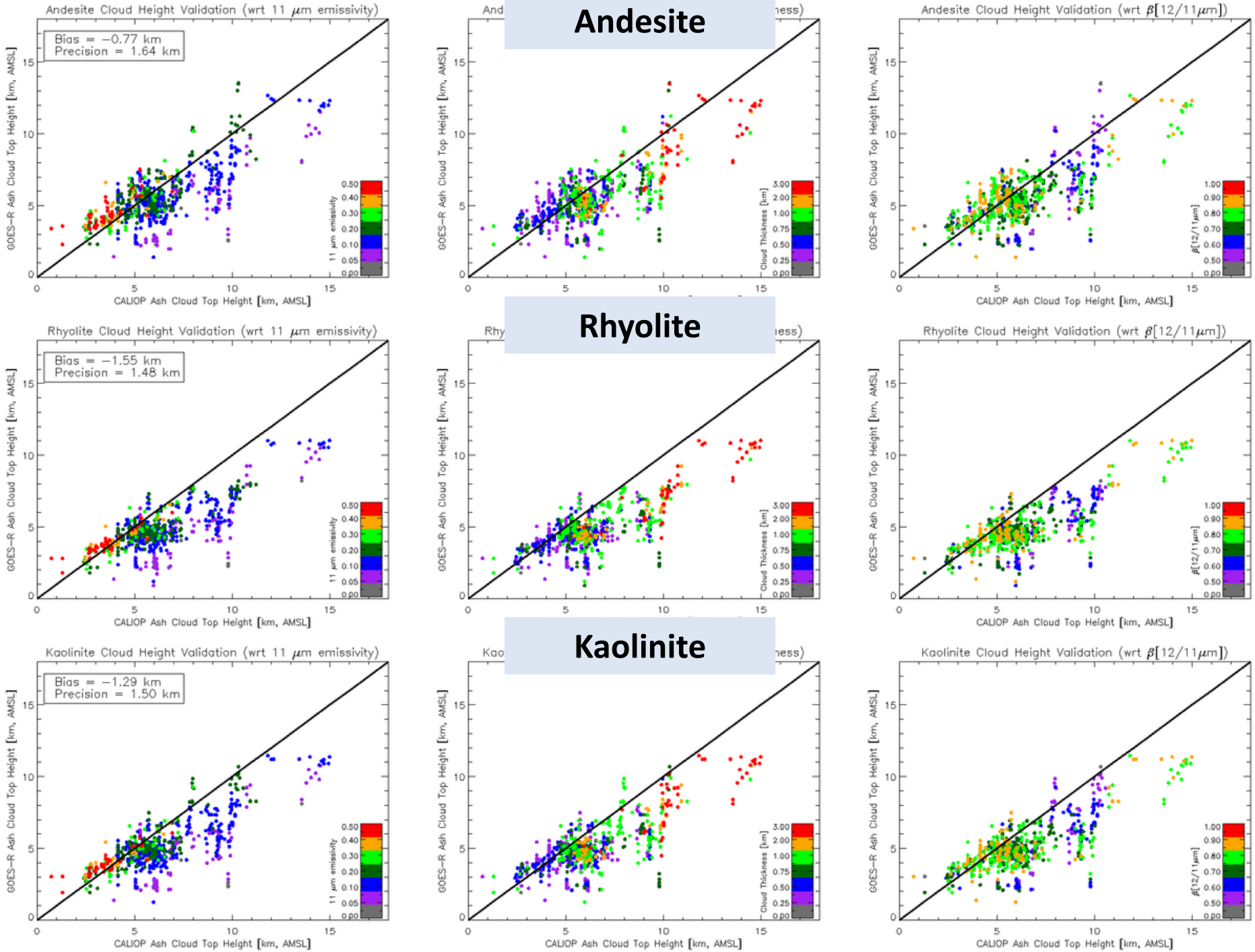
- **Mean relative difference: ~40 – 50%**
- **Differences are due solely to cloud height differences**

Grimsvotn and Cordon Caulle



$$MC = \frac{4\pi\rho_{ash}\tau(\lambda)}{3(\Delta z)\sigma_{ext}(\lambda)} \int_{r1}^{r2} r^3 n(r)\,dr$$

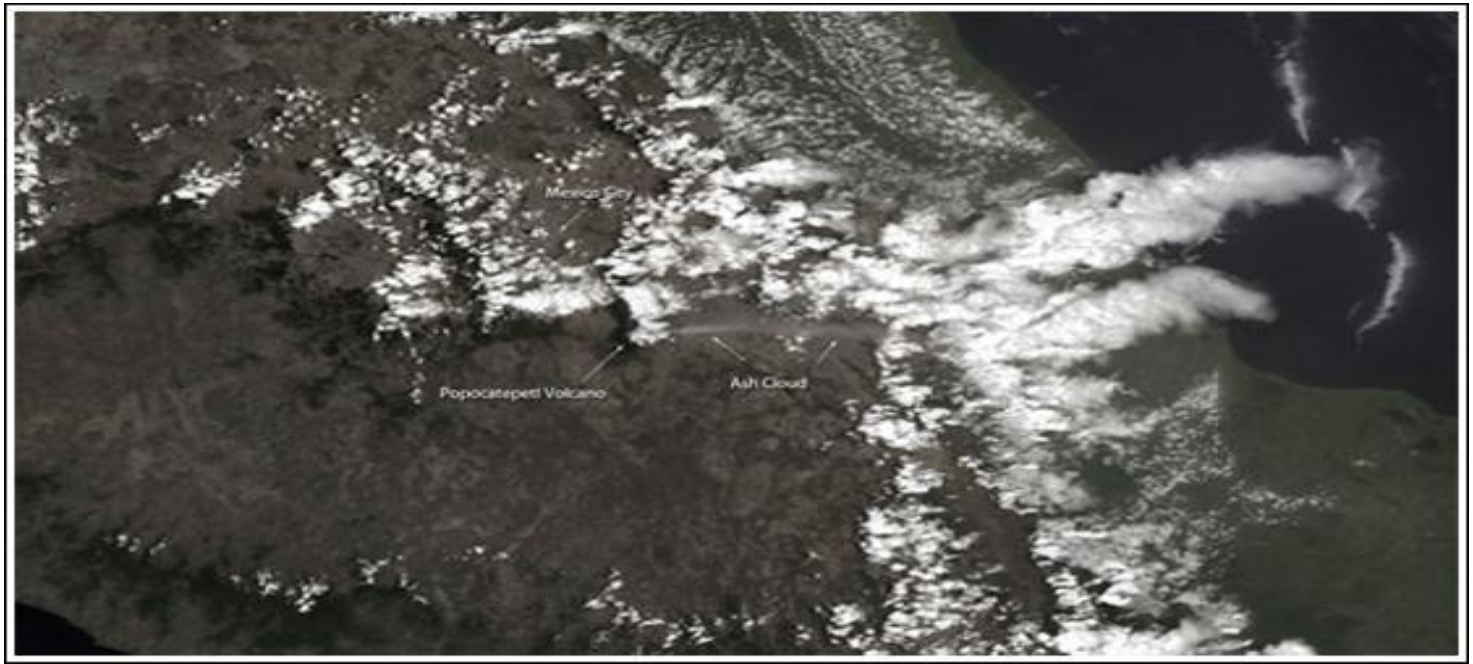
The LIDAR cloud boundary constrained estimate is used as "truth"


Andesite
Rhyolite
Kaolinite
Andesite Cloud Height Validation (wrt 11 μm emissivity)
Bias = −0.77 km
Precision = 1.64 km
Andesite Cloud Height Validation (wrt β[12/11μm])
Rhyolite Cloud Height Validation (wrt 11 μm emissivity)
Bias = −1.55 km
Precision = 1.48 km
Rhyolite Cloud Height Validation (wrt β[12/11μm])
Kaolinite Cloud Height Validation (wrt 11 μm emissivity)
Bias = −1.29 km
Precision = 1.50 km
Kaolinite Cloud Height Validation (wrt β[12/11μm])
GOES−R Ash Cloud Top Height [km, AMSL]
CALIOP Ash Cloud Top Height [km, AMSL]
11 μm emissivity
Cloud Thickness [km]
β[12/11μm]

JPSS Activities

- We are funded to apply the GOES-R volcanic ash algorithm to VIIRS and transition code to NESDIS operations
- VIIRS is lacking a key channel (13.3 µm) needed to perform the full GOES-R retrieval, so a "scaled-down" two channel version of the GOES-R retrieval algorithm will be implemented
- However, in order to take full advantage of the JPSS a combined VIIRS/CrIS GOES-R like algorithm should be developed (currently there is no funding available for this activity)

Suomi NPP VIIRS image of Popocatepetl ash plume



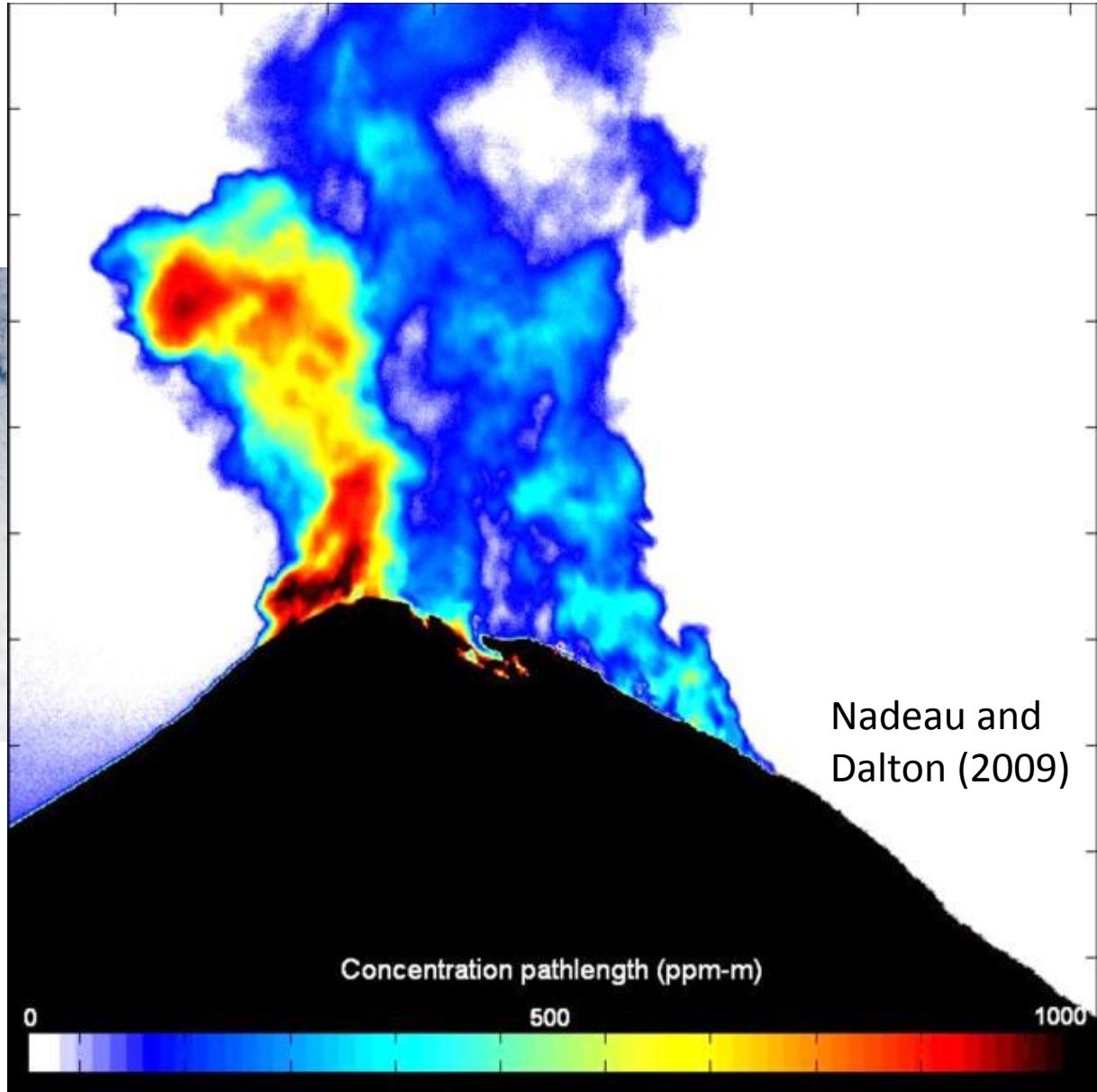
Future Direction

- **Near-term product improvements planned:**
  - **Continue to validate and characterize product performance**
  - **Compare GOES-R products to aircraft based measurements**
  - **Continue to integrate the GOES-R ash retrievals into the automated volcanic cloud alert system (GOES-R3)**
- **Possible long-term improvements (if funding allows):**
  - **Blend LEO and GEO products by using the results from a hyperspectral infrared (e.g. AIRS, IASI, and CrIS) retrieval of ash cloud properties as a first guess to a narrowband imager retrieval (e.g. ABI, SEVIRI, etc…)**

References

- Denlinger, R., M.J. Pavolonis, and J. Sieglaff, 2012: A robust method to forecast volcanic ash plumes., *J. Geophysical Research*, Submitted February 2012.
- Heidinger, A. K. and M. J. Pavolonis, 2009: Nearly 30 years of gazing at cirrus clouds through a split-window. Part I: Methodology. *J.Appl.Meteorol. and Climatology*, **48(6)**, 110-1116.
- Heidinger, A. K., M. J. Pavolonis, R. E. Holz, B. A. Baum, and S. Berthier, 2010: Using CALIPSO to explore the sensitivity to cirrus height in the infrared observations from NPOESS/VIIRS and GOES-R/ABI. *Journal of Geophysical Research-Atmospheres,* **115**, doi:10.1029/2009JD012152 ER.
- Pavolonis, M. J., W. F. Feltz, A. K. Heidinger, and G. M. Gallina, 2006: A daytime complement to the reverse absorption technique for improved automated detection of volcanic ash. *J.Atmos.Ocean.Technol.,* **23**, 1422-1444.
- Pavolonis, M. J. and J. Sieglaff, 2010b: GOES-R Advanced Baseline Imager (ABI) Algorithm Theoretical Basis Document for Volcanic Ash Detection and Height, Version 3.0., 86 pp.
- Pavolonis, M. J., 2010a: Advances in extracting cloud composition information from spaceborne infrared radiances: A robust alternative to brightness temperatures Part I: Theory, *J. Applied Meteorol. And Climatology*, 49(9), 1992-2012.
- Pavolonis, M. J., 2012: Advances in extracting cloud composition information from spaceborne infrared radiances: A robust alternative to brightness temperatures. Part II: Proof of concept. *J. Applied Meteorology and Climatology*, In Prep.
- Pavolonis, M.J. and A.K. Heidinger, 2012: Automated retrievals of volcanic ash and dust cloud properties from upwelling infrared measurements. In Prep.
- Schmehl, K. J., S.E. Haupt, and M.J. Pavolonis, 2011: A genetic algorithm variational approach to data assimilation and application to volcanic emissions, *Pure and Applied Geophysics*, DOI: 10.1007/s00024-011-0385-0.
- Webley, P.W., T. Steensen, M. Stuefer, G. Grell, S. Freitas, and M. J. Pavolonis, 2012: Analyzing the Eyjafjallajokull 2010 eruption using satellite remote sensing, lidar, and WRF-Chem dispersion and tracking model., *J. Geophysical Research*, Revised version submitted February 2012.

GOES-R SO_2



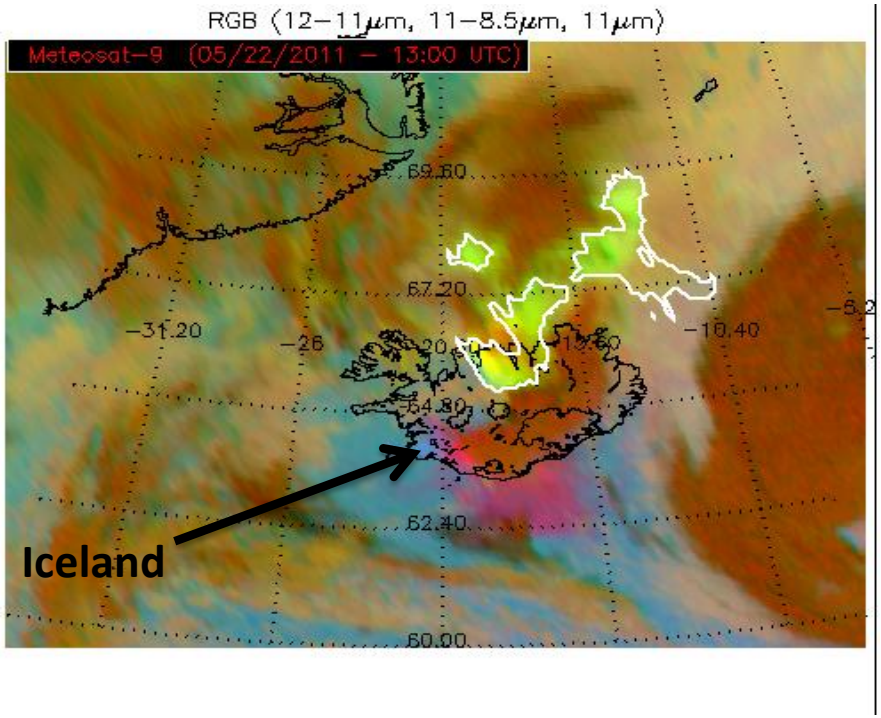
Nadeau and Dalton (2009)

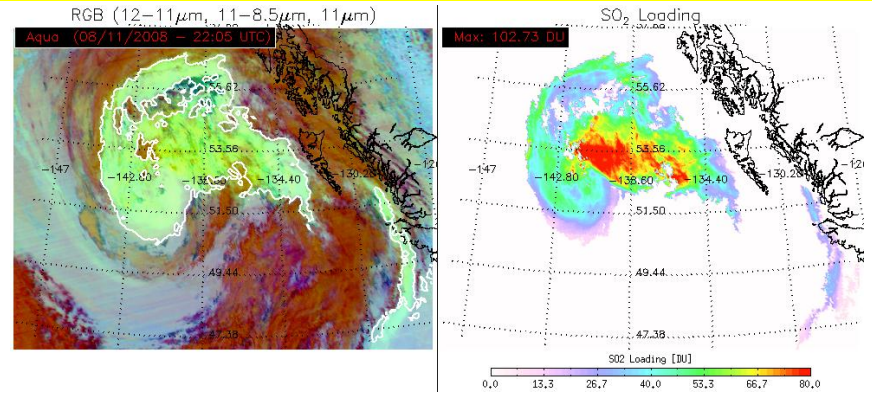
GOES-R SO_2 Product

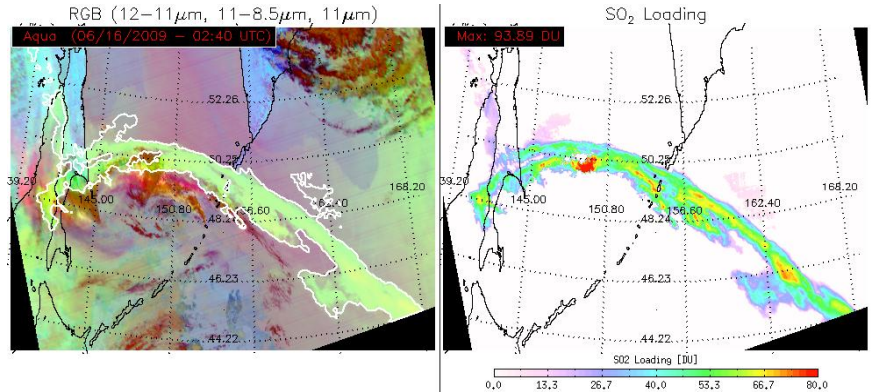
- **The GOES-R requirements called for a yes/no SO_2 flag**

- **As of April 1, 2012, AWG funding for the development of the SO_2 product will expire.**

- **While the continued development of the SO_2 product will NOT be directly supported (at least in FY12), an existing GOES-R Risk Reduction project aimed at developing a fully automated volcanic cloud alert system will be leveraged to continue development (at least in FY12)**



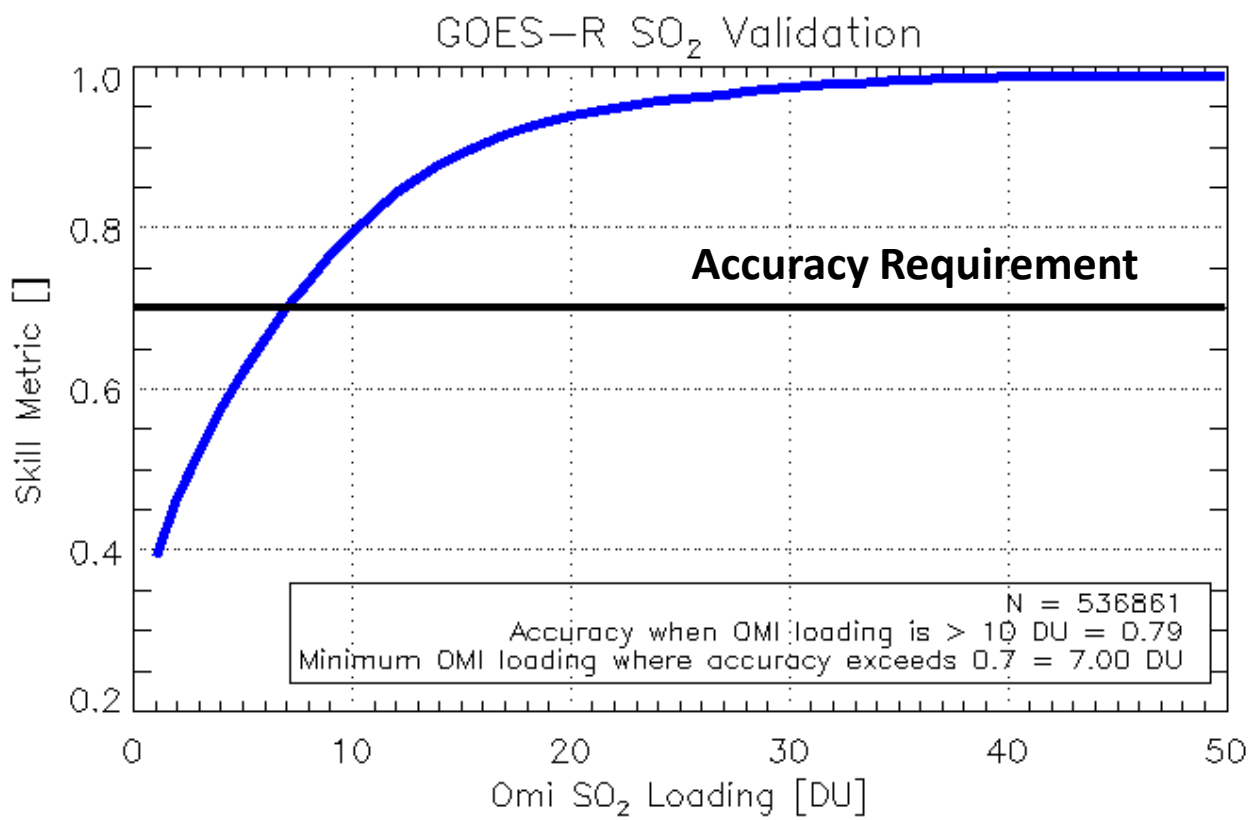




SO_2 Product Validation

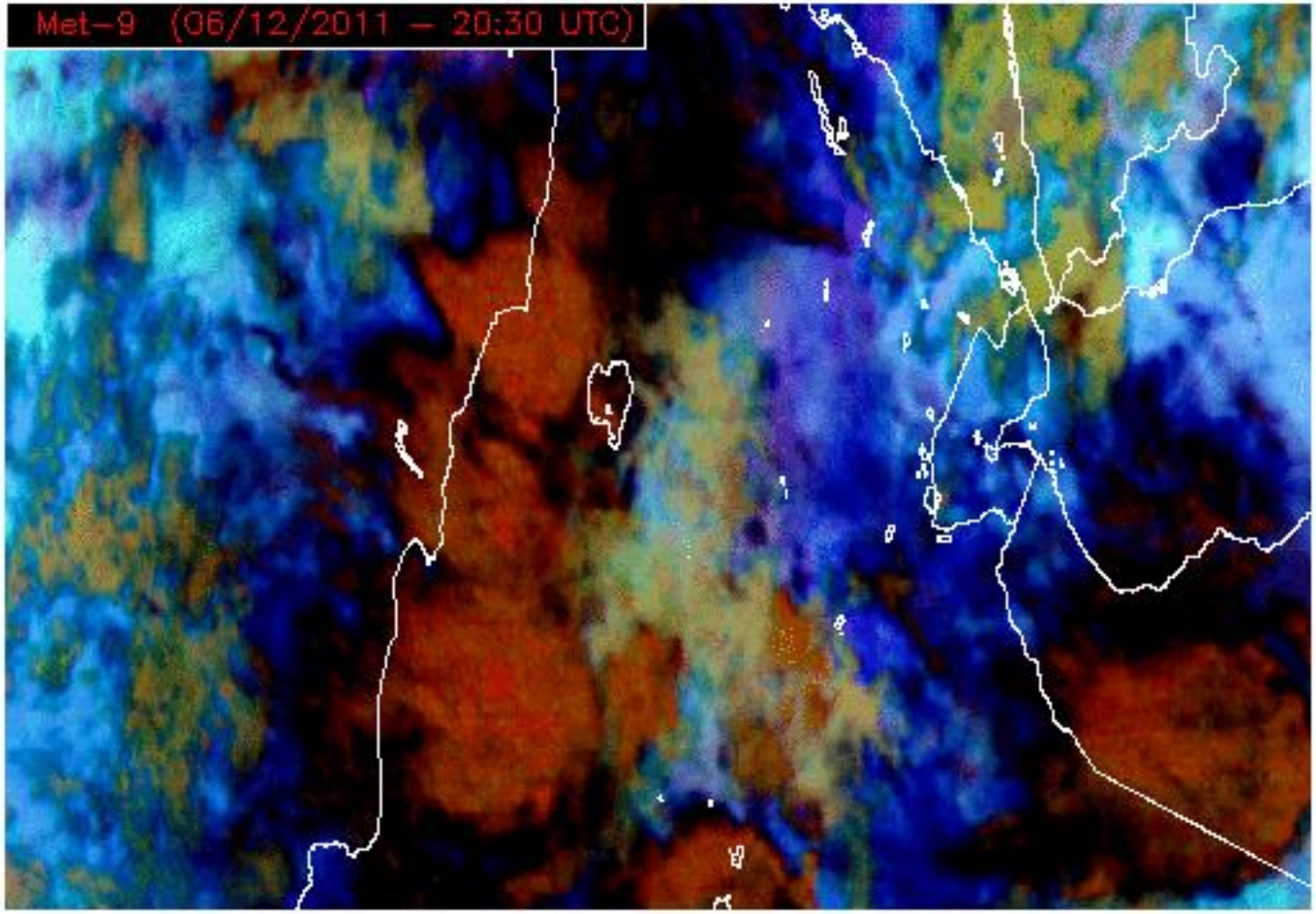
- *The ABI SO_2 mask is validated as a function of OMI SO_2 loading.*
- *Only scenes that contained SO_2 clouds were used so this analysis reflects how the algorithm will perform in relevant situations*
- *The accuracy is 79% when the OMI SO_2 indicates 10 DU or more of SO_2.*

Accuracy



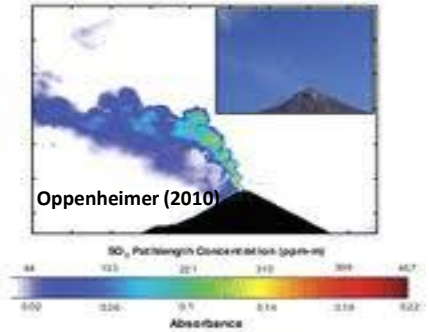
1. **ABI channel 10 (7.3 µm) was specifically designed to be sensitive to SO_2**
2. **Volcanic ash can occur in-between LEO overpasses**
3. **SO_2 can be present in deadly concentrations in the hours following an eruption**

False Color Imagery (12–11 µm, 11–8.5 µm, 11µm)



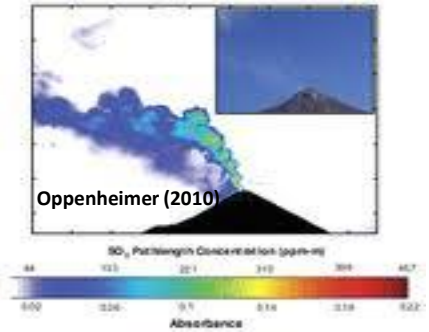
Future Direction

- **Near-term product improvements planned:**
  - **Convert binary SO_2 detection to probabilistic SO_2 detection**
  - **Add SO_2 alert capability to volcanic cloud alert system being developed under GOES-R Risk Reduction**



Future Direction

- **Long-term improvements planned:**
  - **Increase detection sensitivity by correcting for non-SO_2 clouds**
  - **Expand methodology to include estimate of SO_2 height**
  - **While the GOES-R SO_2 was required and designed to detect larger SO_2 gas loadings in the mid troposphere and higher associated with significant volcanic activity, we are working on determining if approach can be used to detect and characterize significant BL sulfate aerosol events like Hawaiian vog**
  - **Continue to work with modeling groups (ARL, ESRL, NCEP, USGS, academia, etc…) on using GOES-R volcanic ash and SO_2 products in model validation, inverse modeling, and data assimilation studies**



References

- Pavolonis, M. J., 2011: GOES-R Advanced Baseline Imager (ABI) Algorithm Theoretical Basis Document for SO_2 Detection, Version 2.0., 52 pp.

- Pavolonis, M. J., 2010: Advances in extracting cloud composition information from spaceborne infrared radiances: A robust alternative to brightness temperatures Part I: Theory, *J. Applied Meteorol. And Climatology*, 49(9), 1992-2012.

GOES-R Fog/Low Cloud Products

GOES-R Fog/Low Cloud Products

- ***The primary goal of the GOES-R fog/low cloud detection algorithm is to identify hazardous IFR/LIFR conditions.***

- **Products produced: probability of IFR (including LIFR conditions), probability of LIFR, and thickness of highest cloud layer (valid for liquid water clouds only)**

- **The original GOES-R requirements were for an ill-defined fog/low cloud (yes/no) mask and fog/low cloud thickness (of highest liquid water cloud layer)**

- **VFR - Visual flight rules**
  ceiling > 3000 ft and vis > 5 mi
- **MVFR - Marginal visual flight rules**
  1000 ft < ceiling < 3000 ft or 3 mi < vis < 5 mi
- ***IFR - Instrument flight rules***
  ***500 ft < ceiling < 1000 ft* or 1 mi < vis < 3 mi**
- ***LIFR - Low instrument flight rules***
  ceiling < 500 ft or vis < 1 mi

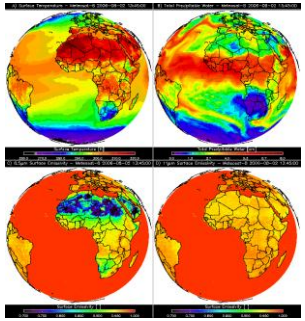
Fused Fog/Low Cloud Detection Approach

Satellite Data

-Minimum channel requirement: 0.65, 3.9, 6.7/7.3 and 11/13.3 µm
-Previous image for temporal continuity (GEO only)
-Cloud Phase

+

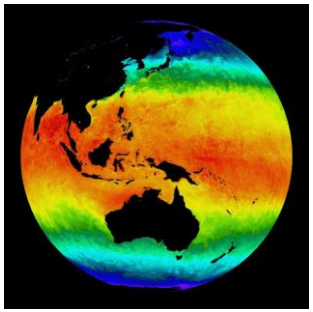
Static Ancillary Data



-DEM
-Surface Type
-Surface Emissivity

+

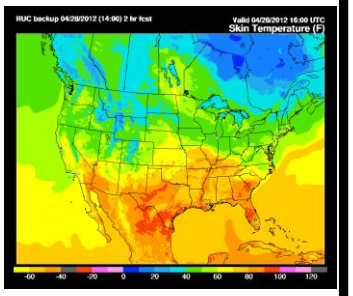
Daily SST Data



0.25 degree OISST

+

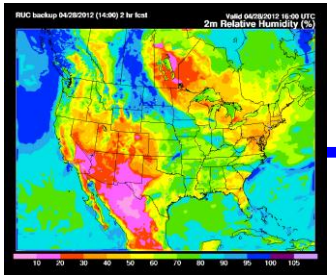
NWP



-Surface Temperature
-Profiles of T and q
-RUC/RAP (2-3 hr forecast) or GFS (12 hr forecast)

Clear Sky RTM

NWP RH Profiles

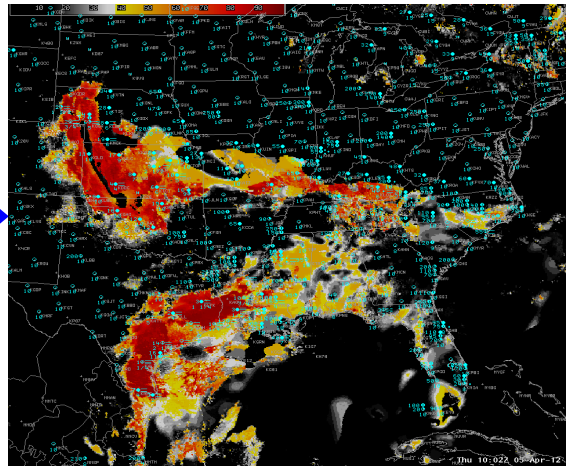


-RUC/RAP (2-3 hr forecast) or GFS (12 hr forecast)

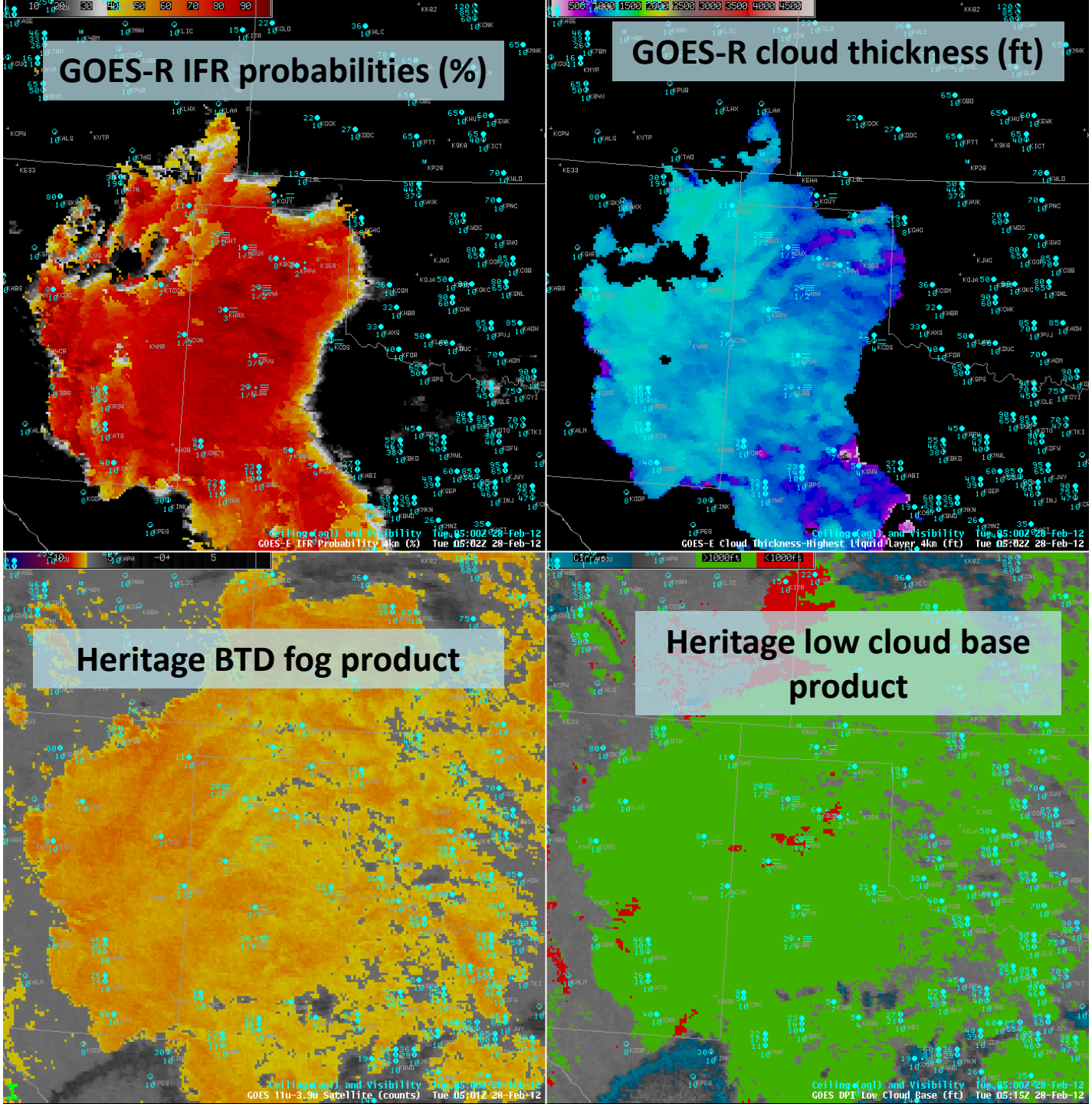
Naïve Bayesian Model

Total run time:
2 - 3 minutes

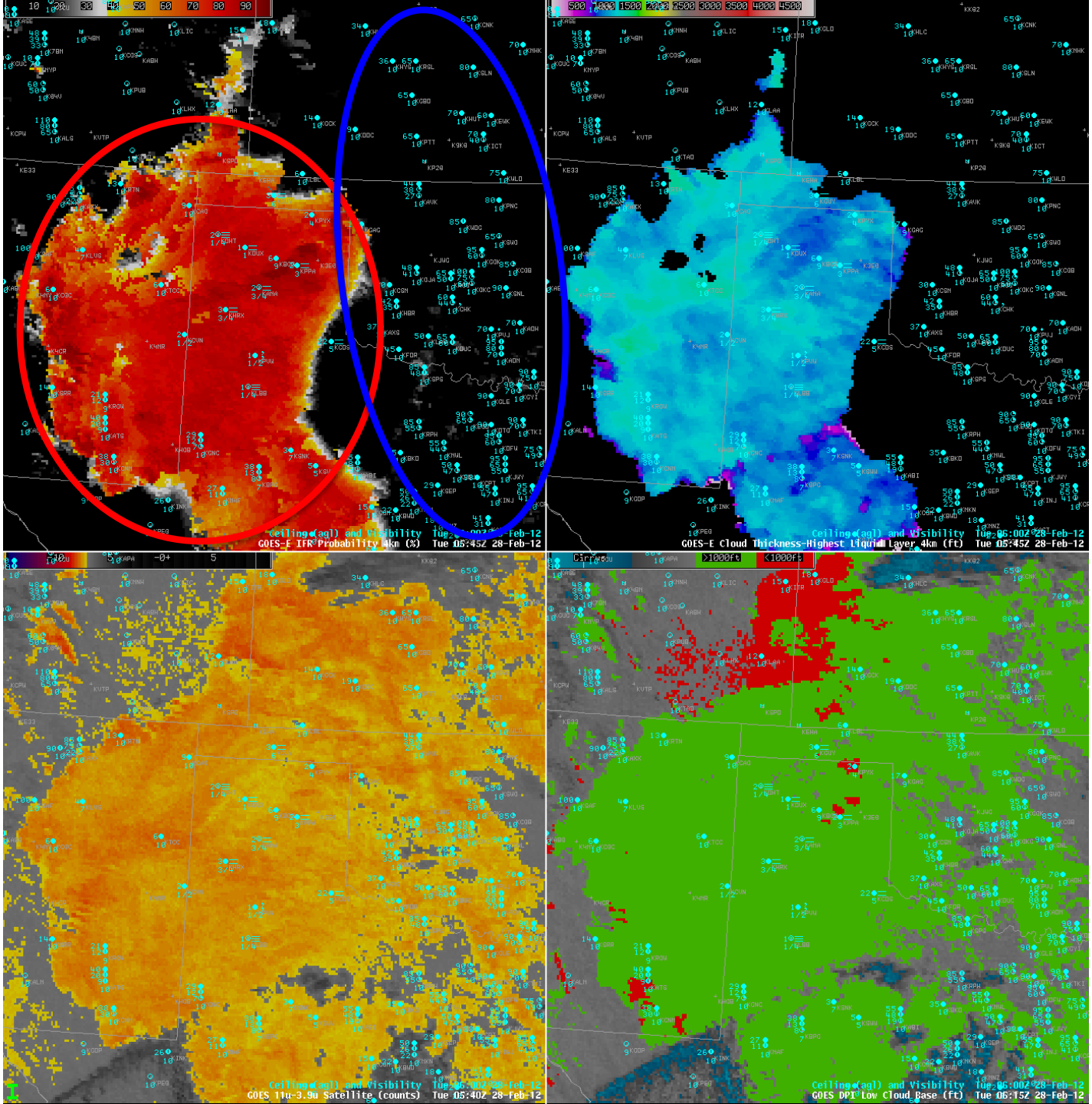
IFR and LIFR Probability



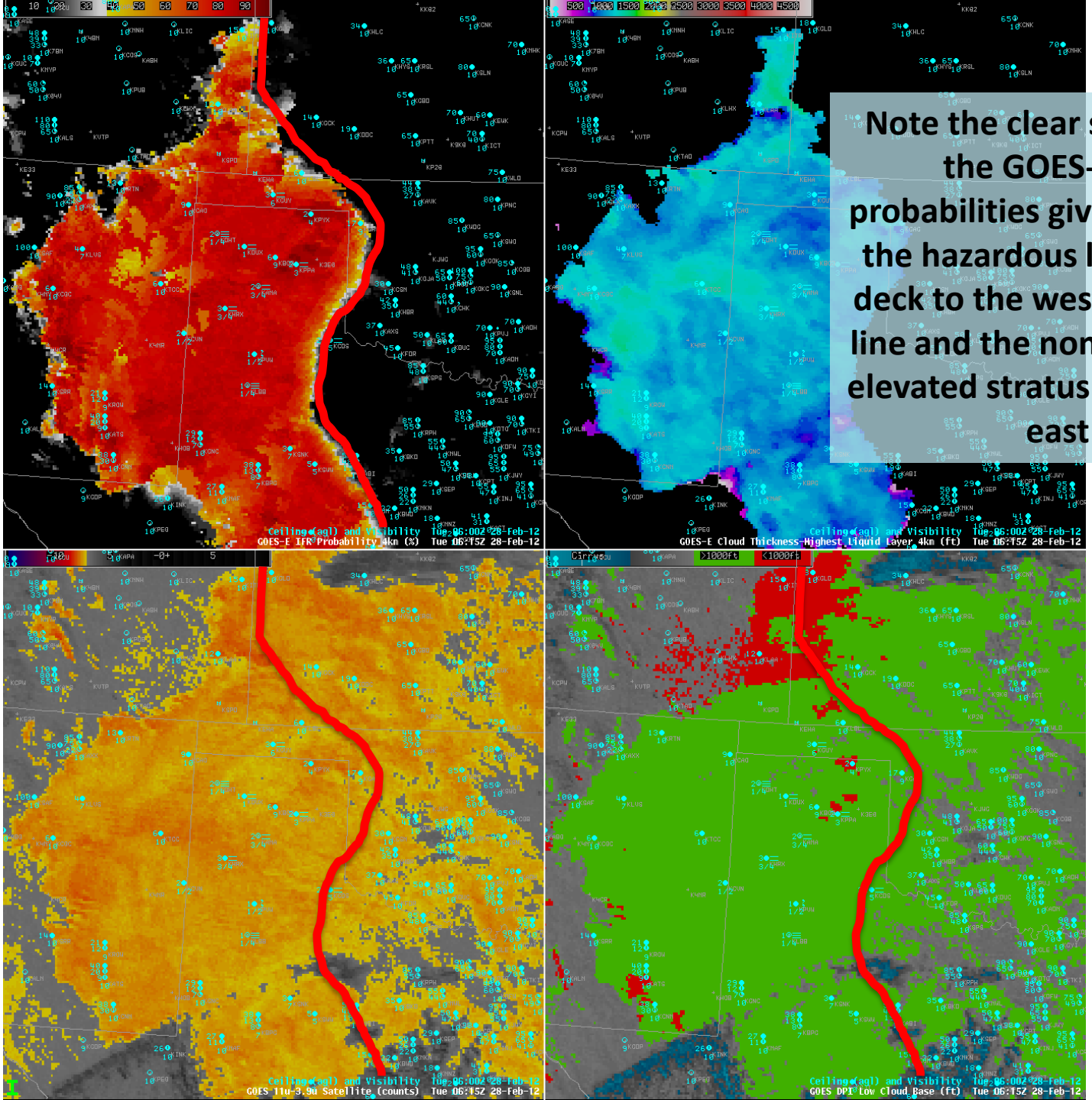
IMPORTANT: Other sources of relevant data (e.g. sfc obs) influence results through the model fields



2/28/2012
05:02 UTC

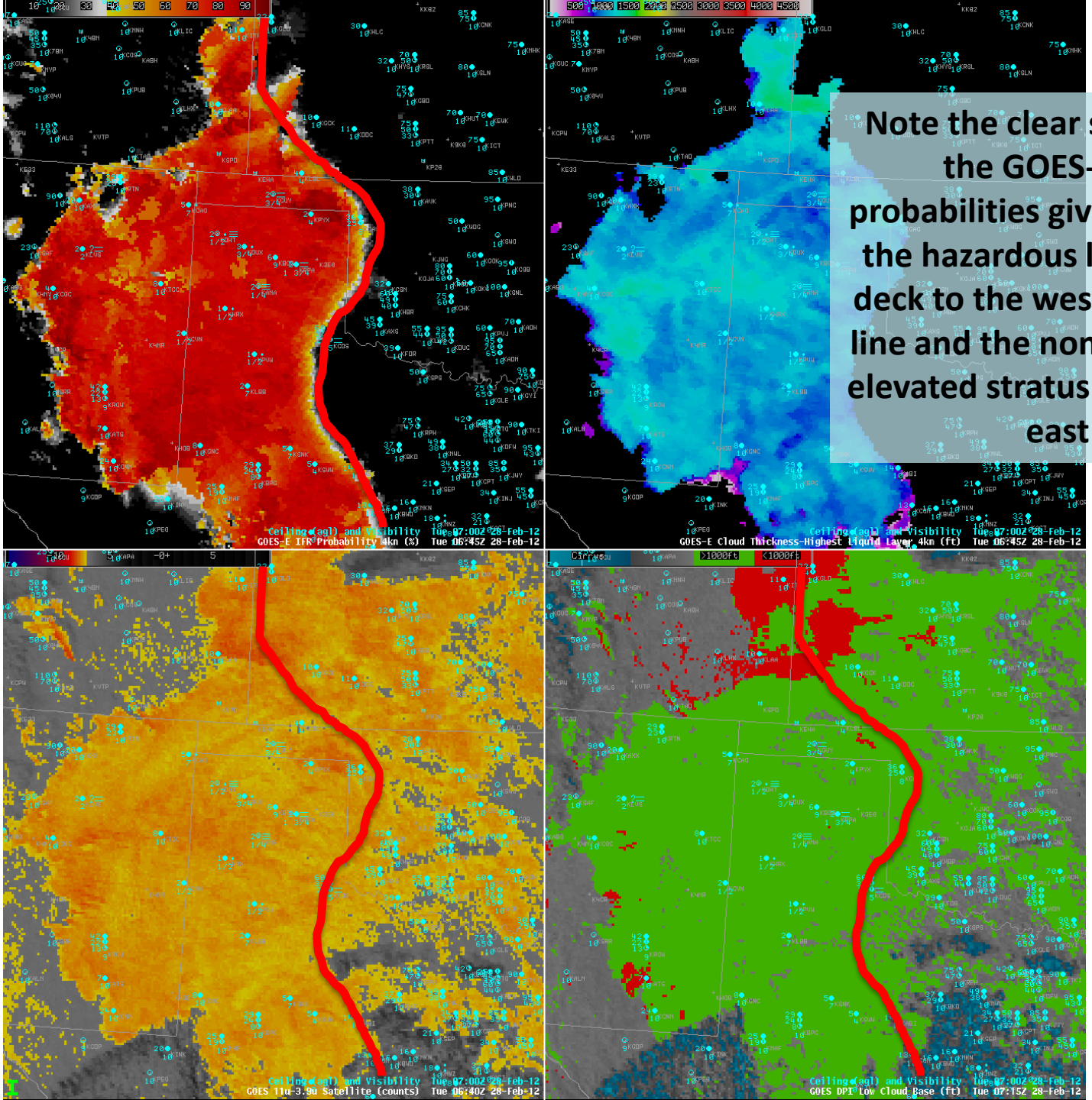


2/28/2012
05:45 UTC



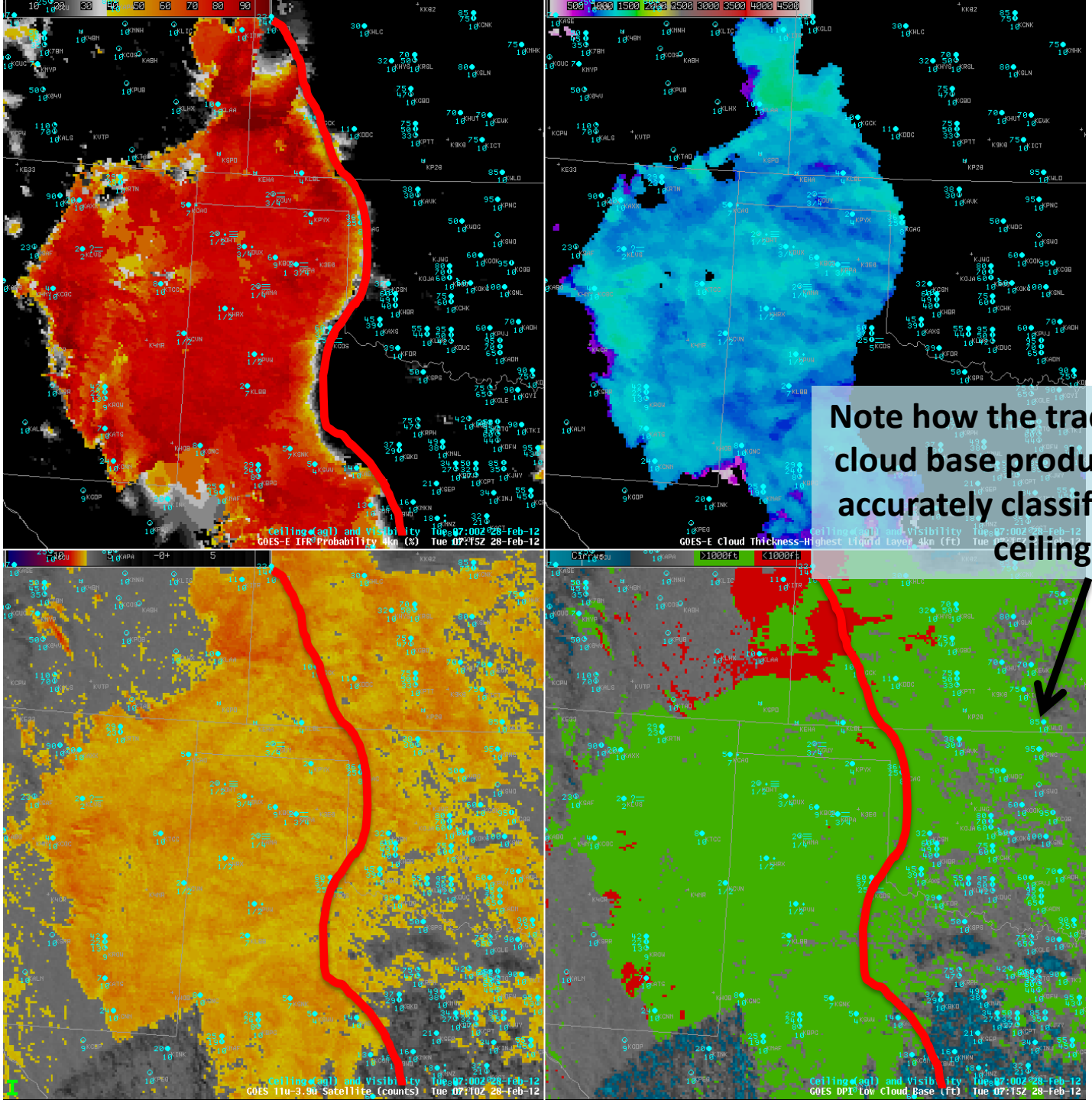
Note the clear separation the GOES-R IFR probabilities gives between the hazardous low stratus deck to the west of the red line and the non-hazardous elevated stratus deck to the east

2/28/2012
06:15 UTC



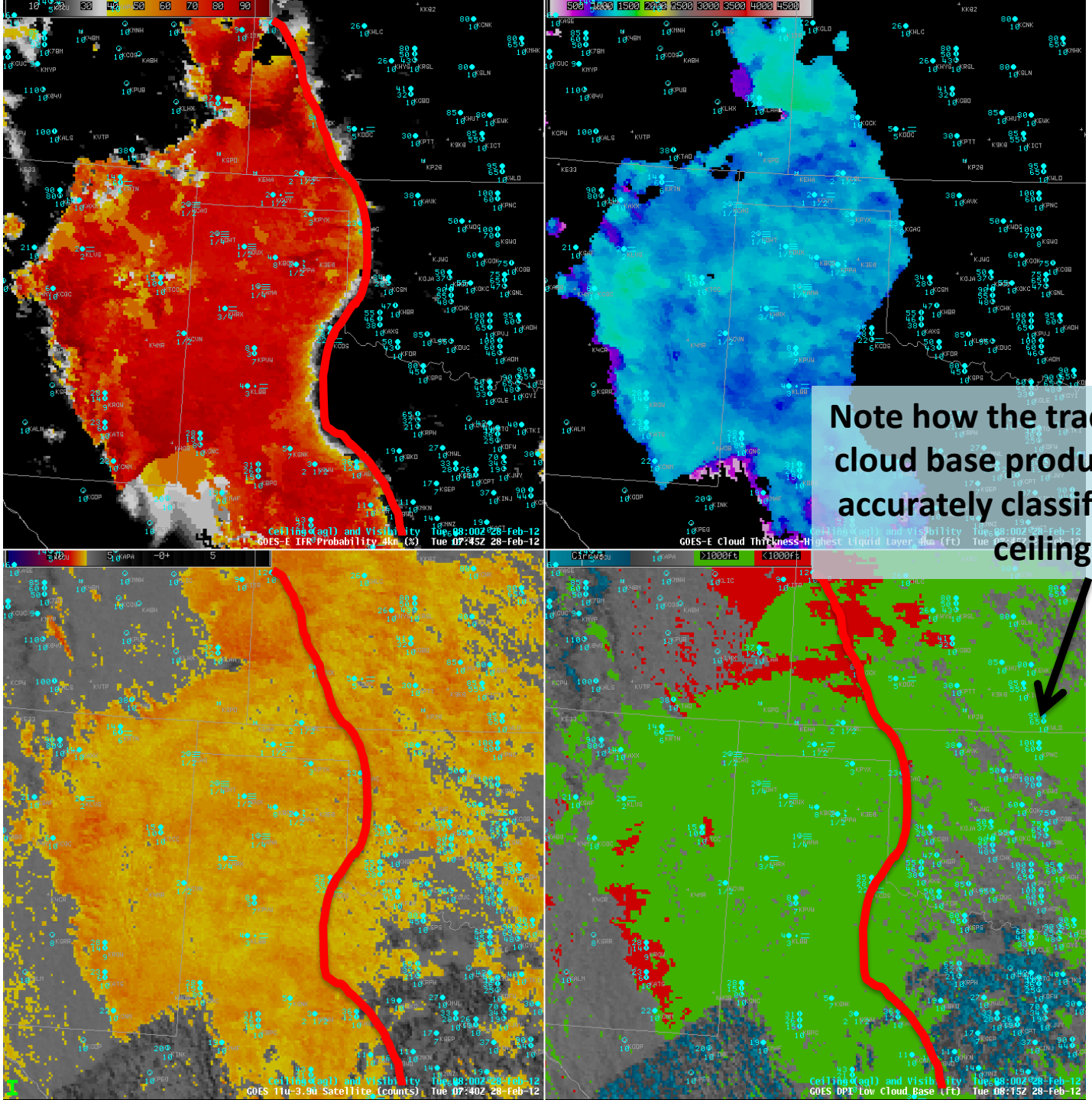
Note the clear separation the GOES-R IFR probabilities gives between the hazardous low stratus deck to the west of the red line and the non-hazardous elevated stratus deck to the east

2/28/2012
06:45 UTC



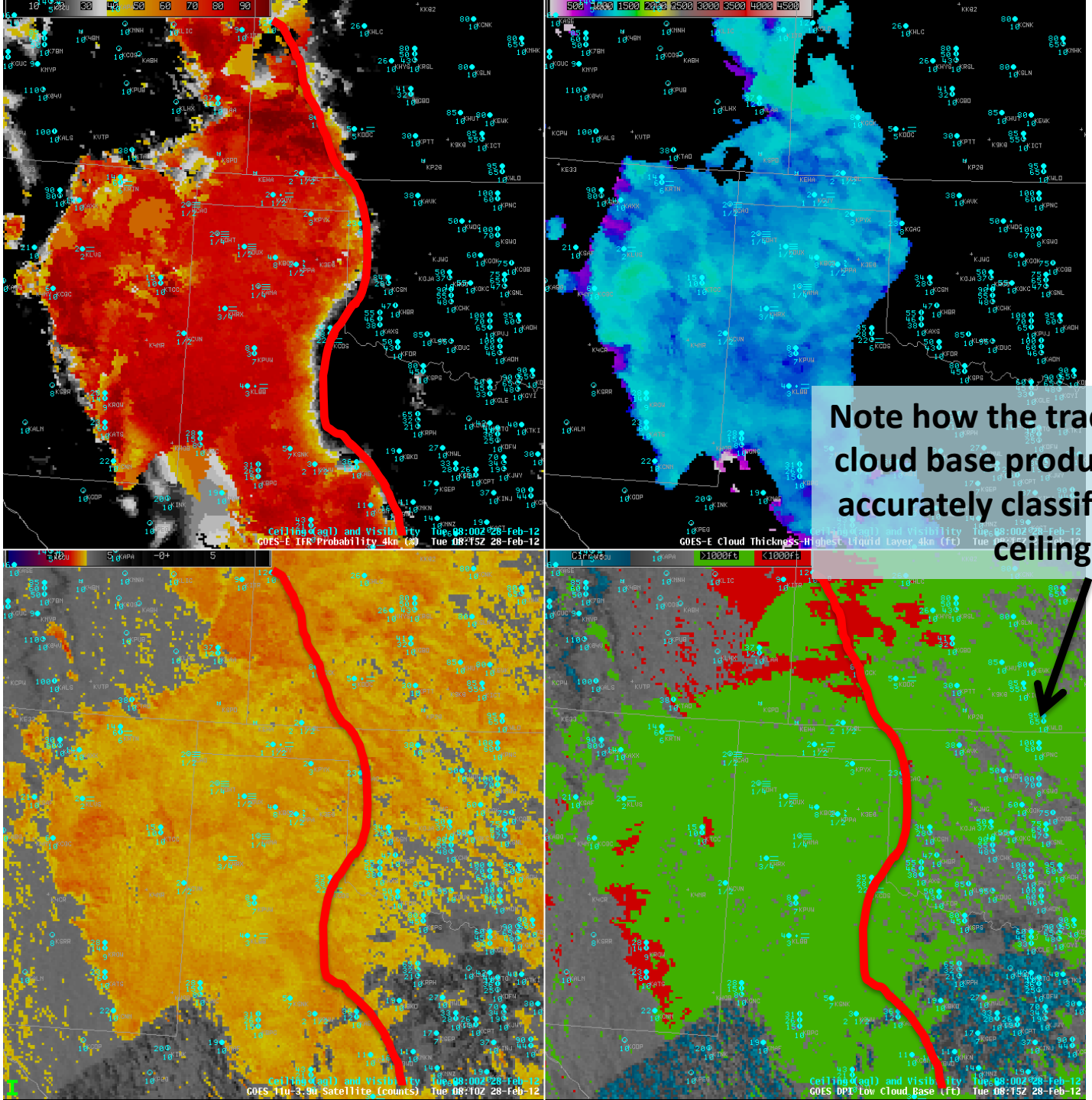
Note how the traditional low cloud base product does not accurately classify the cloud ceilings

2/28/2012
07:15 UTC



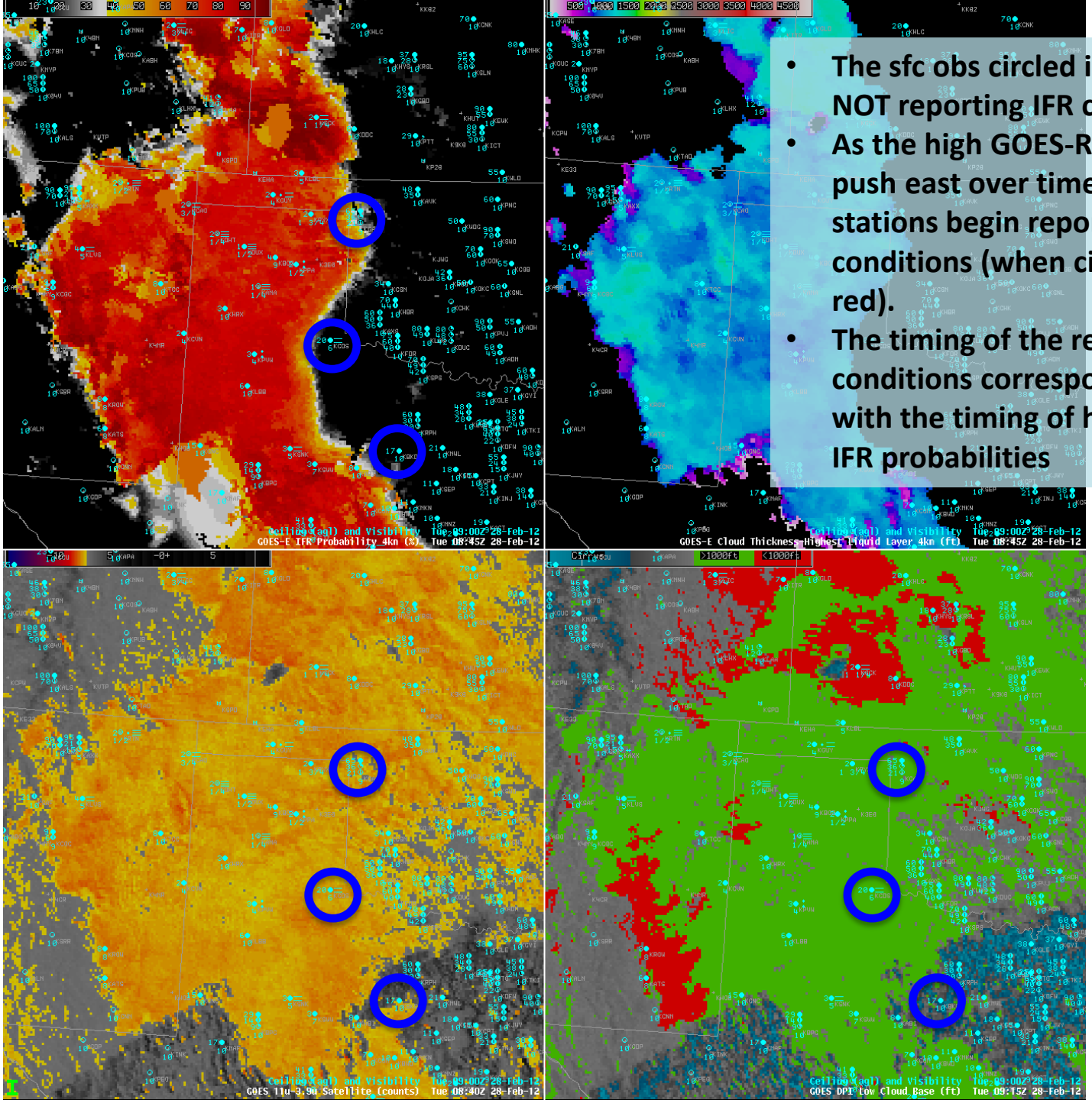
Note how the traditional low cloud base product does not accurately classify the cloud ceilings

2/28/2012
07:45 UTC



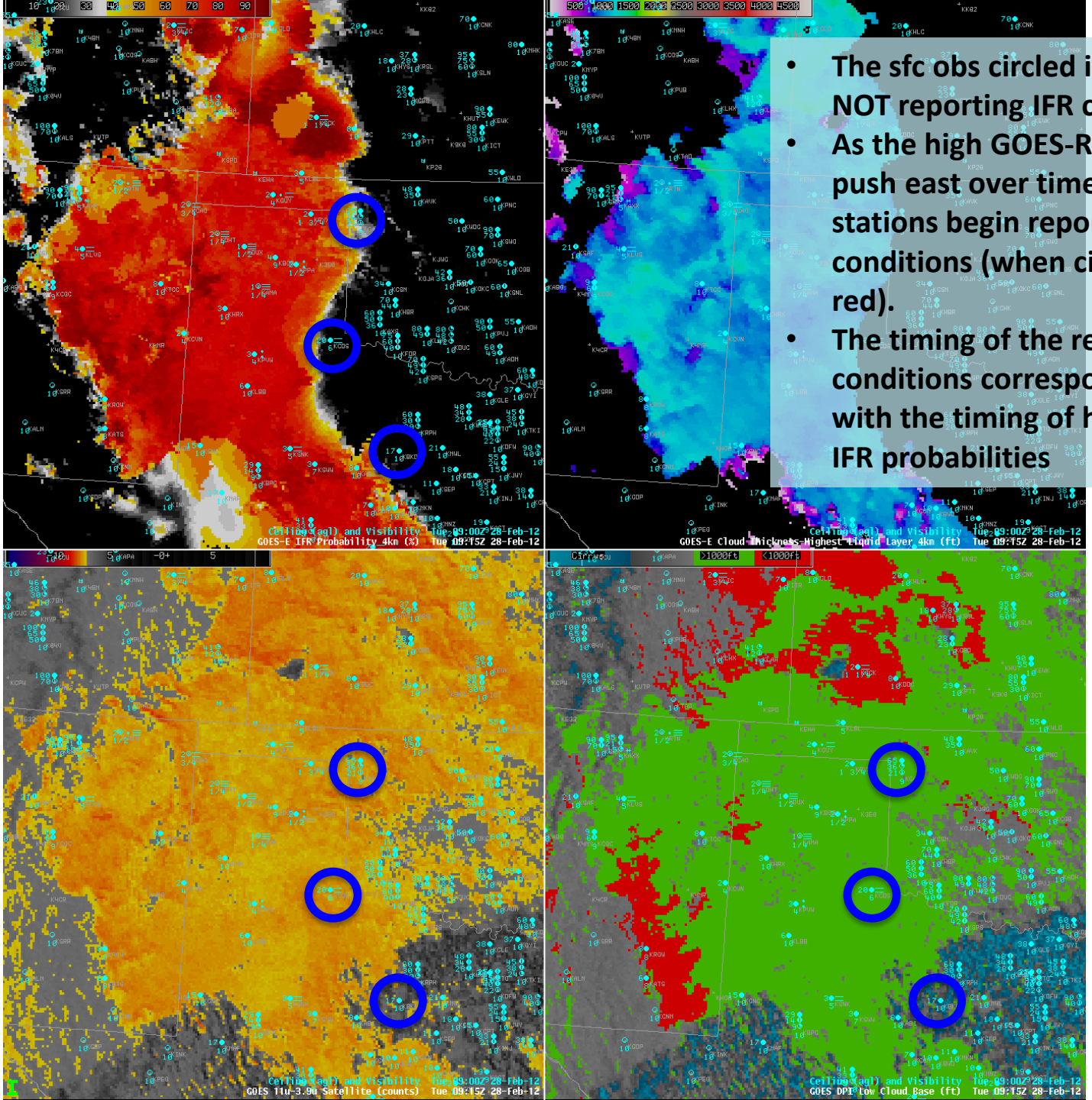
Note how the traditional low cloud base product does not accurately classify the cloud ceilings

2/28/2012
08:15 UTC



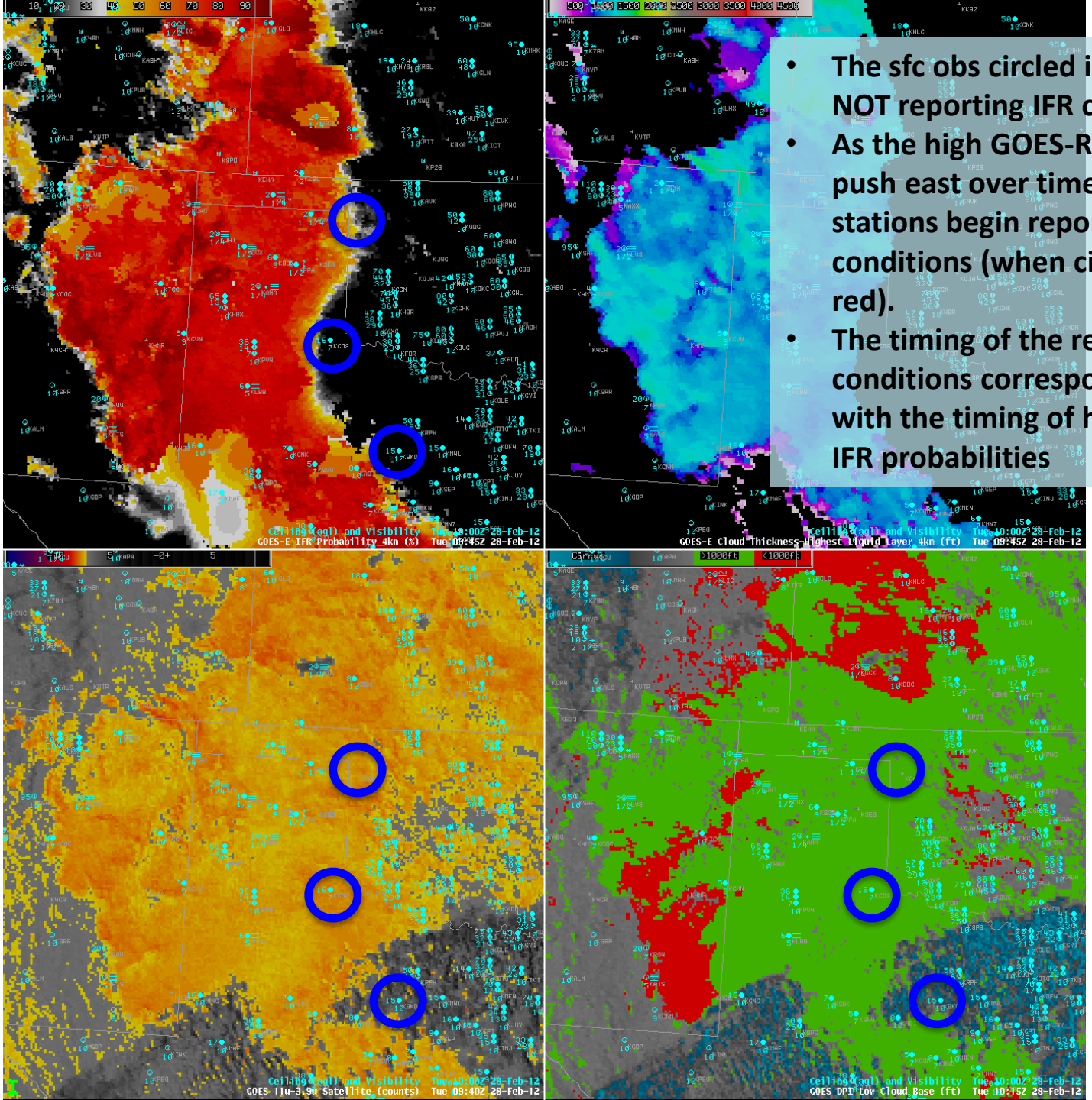
- The sfc obs circled in blue are NOT reporting IFR conditions.
- As the high GOES-R IFR probs push east over time those stations begin reporting IFR conditions (when circles turn red).
- The timing of the reported IFR conditions corresponds well with the timing of high GOES-R IFR probabilities

2/28/2012
08:45 UTC



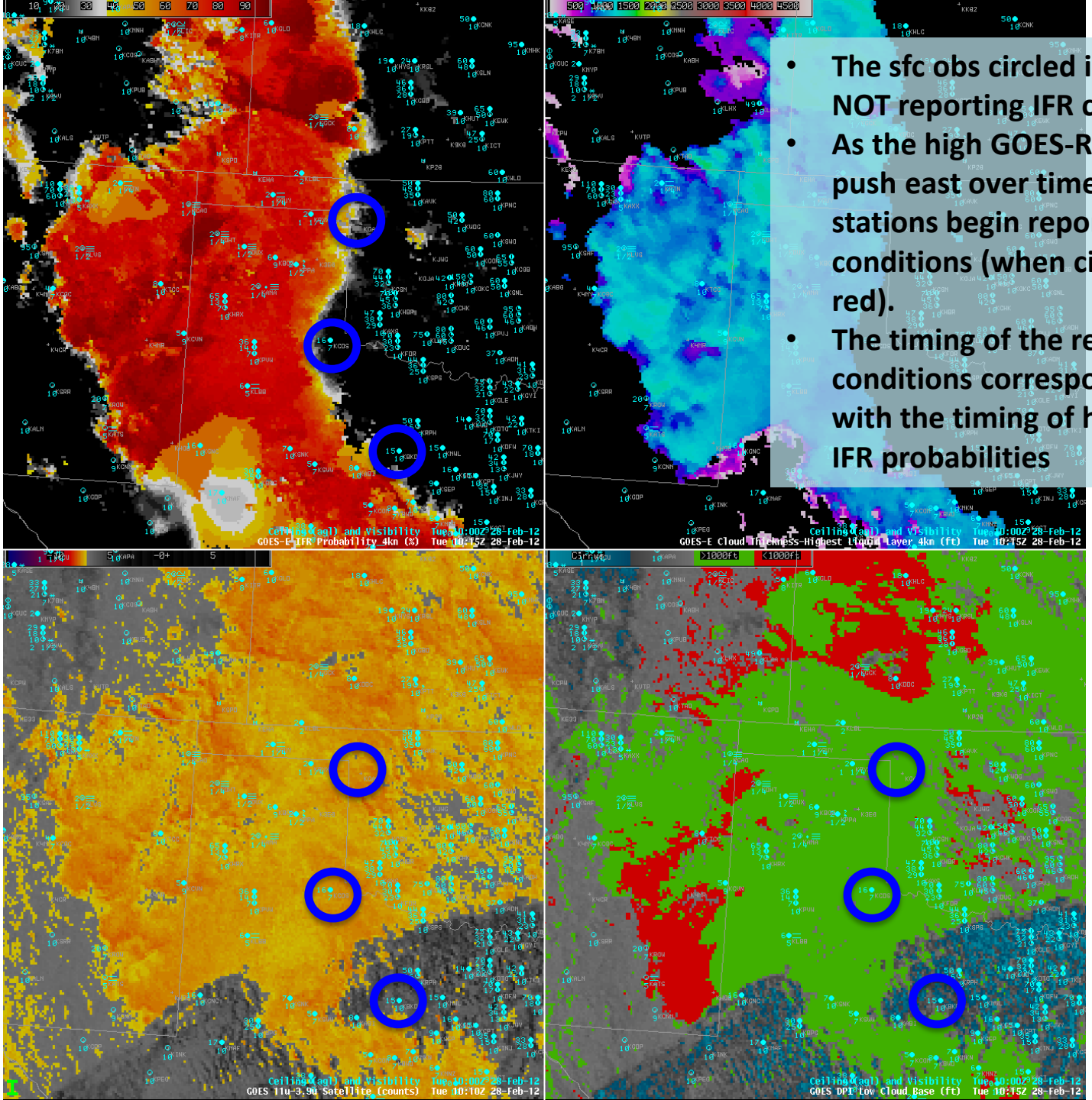
- The sfc obs circled in blue are NOT reporting IFR conditions.
- As the high GOES-R IFR probs push east over time those stations begin reporting IFR conditions (when circles turn red).
- The timing of the reported IFR conditions corresponds well with the timing of high GOES-R IFR probabilities

2/28/2012
09:15 UTC



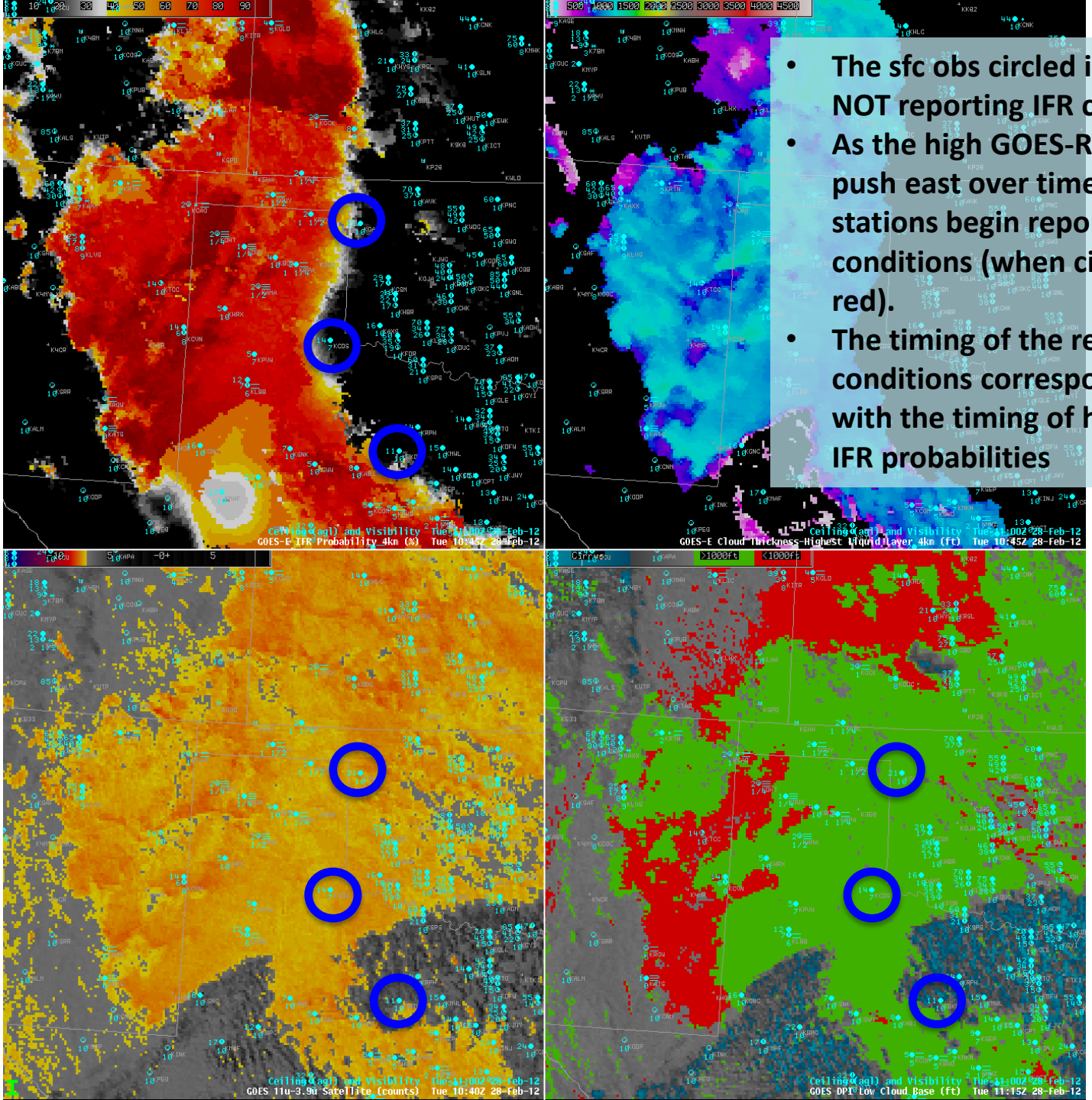
- The sfc obs circled in blue are NOT reporting IFR conditions.
- As the high GOES-R IFR probs push east over time those stations begin reporting IFR conditions (when circles turn red).
- The timing of the reported IFR conditions corresponds well with the timing of high GOES-R IFR probabilities

2/28/2012
09:45 UTC



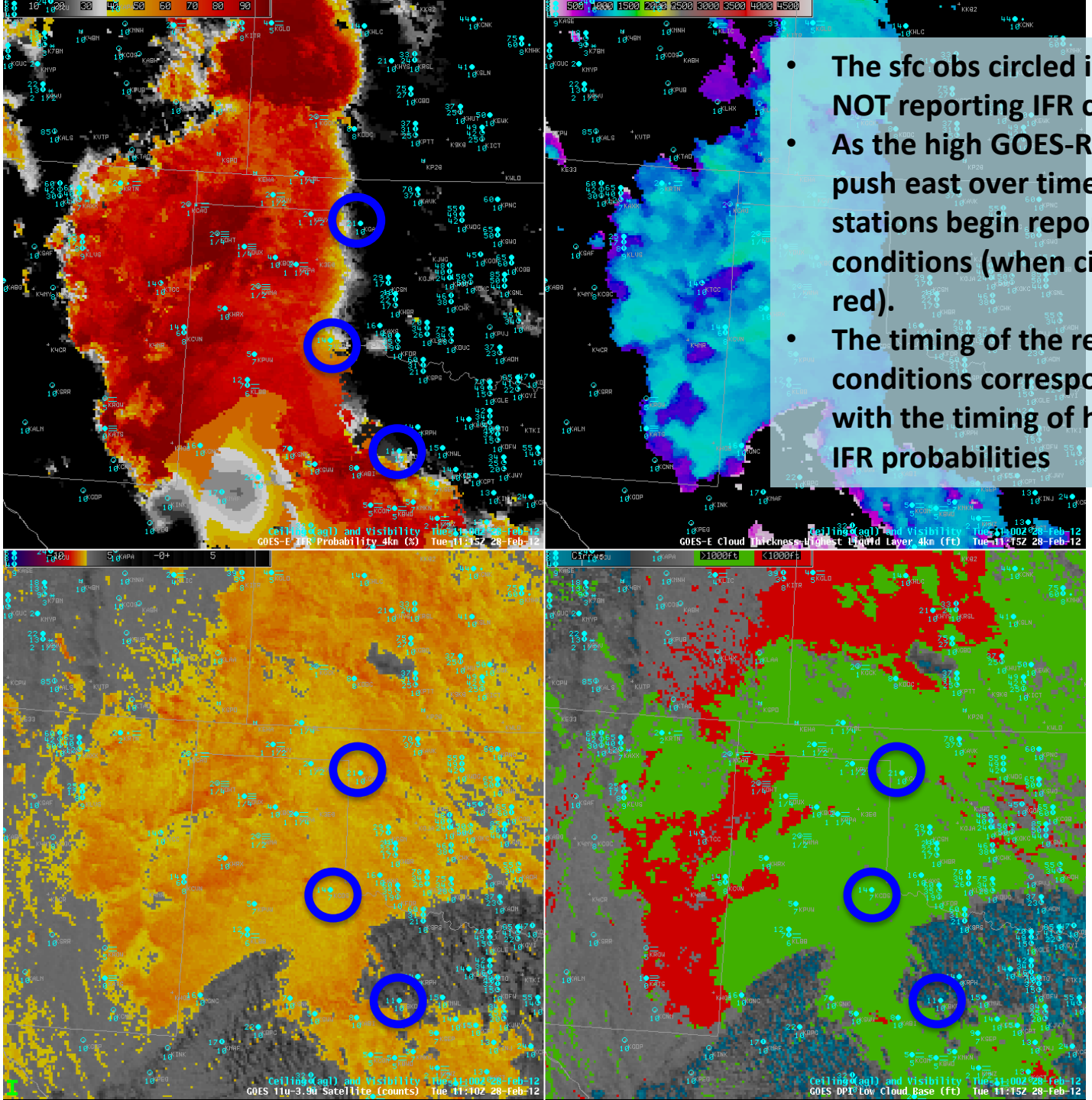
- The sfc obs circled in blue are NOT reporting IFR conditions.
- As the high GOES-R IFR probs push east over time those stations begin reporting IFR conditions (when circles turn red).
- The timing of the reported IFR conditions corresponds well with the timing of high GOES-R IFR probabilities

2/28/2012
10:15 UTC



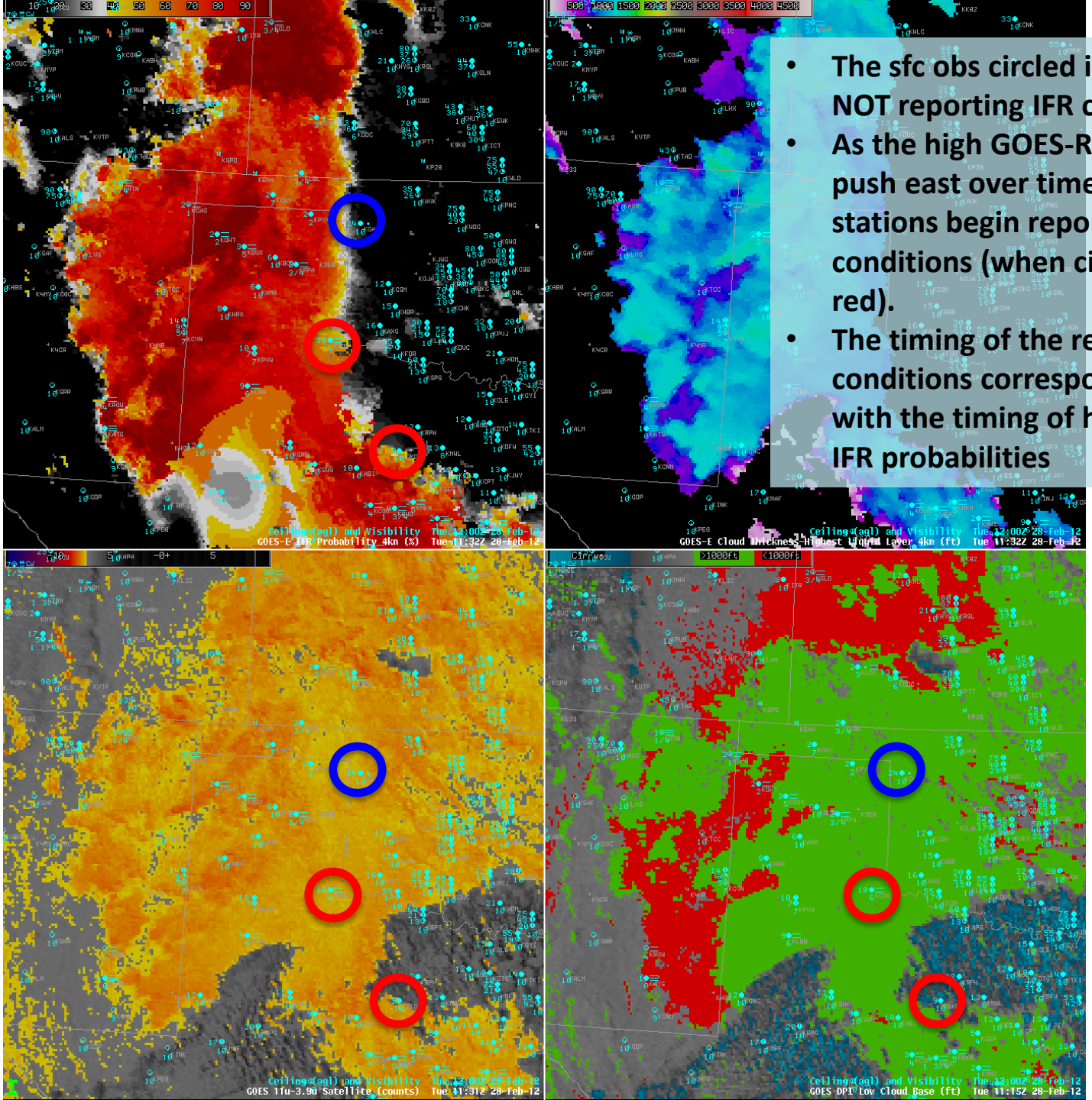
- The sfc obs circled in blue are NOT reporting IFR conditions.
- As the high GOES-R IFR probs push east over time those stations begin reporting IFR conditions (when circles turn red).
- The timing of the reported IFR conditions corresponds well with the timing of high GOES-R IFR probabilities

2/28/2012
10:45 UTC



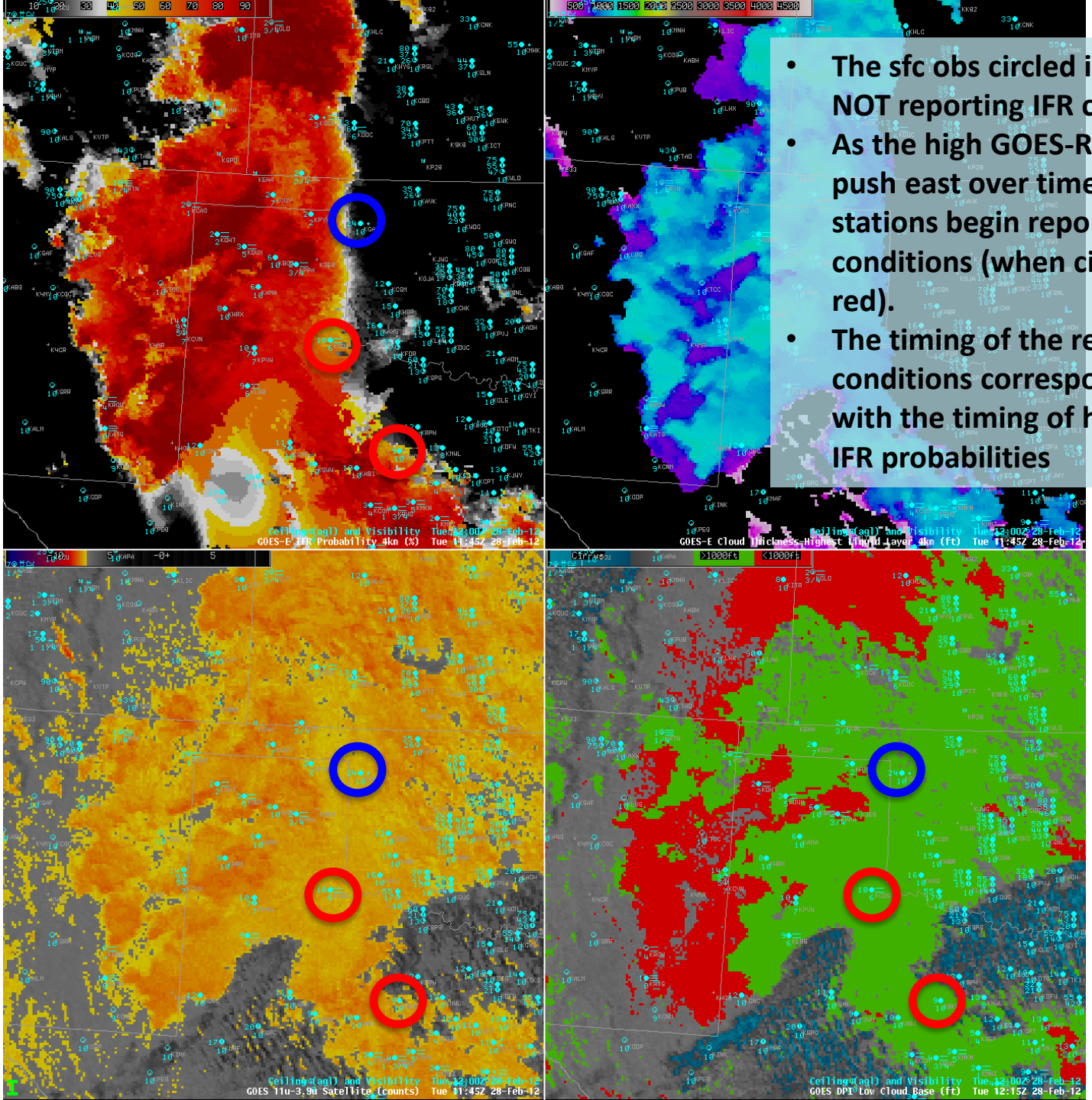
- The sfc obs circled in blue are NOT reporting IFR conditions.
- As the high GOES-R IFR probs push east over time those stations begin reporting IFR conditions (when circles turn red).
- The timing of the reported IFR conditions corresponds well with the timing of high GOES-R IFR probabilities

2/28/2012
11:15 UTC



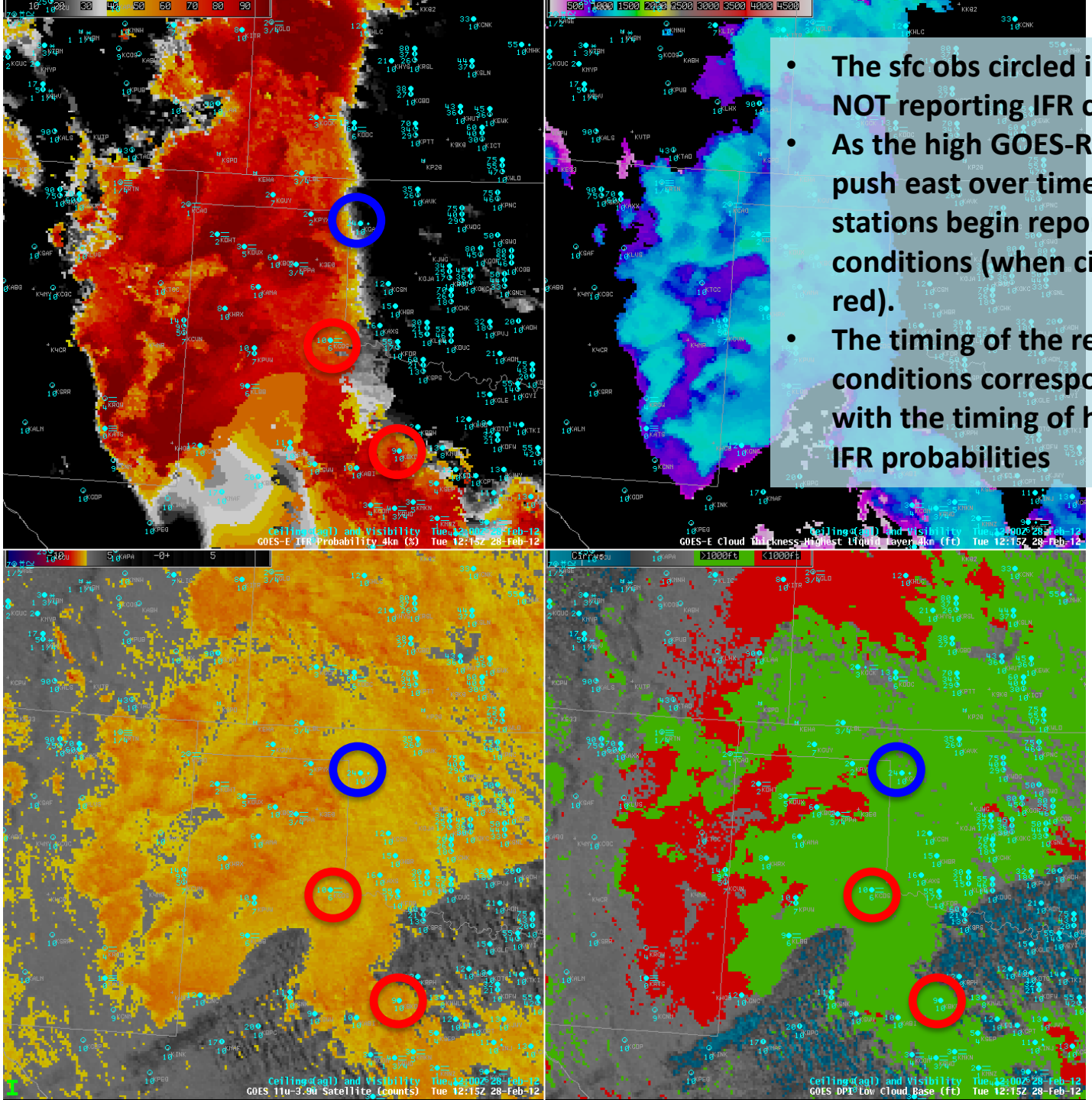
- The sfc obs circled in blue are NOT reporting IFR conditions.
- As the high GOES-R IFR probs push east over time those stations begin reporting IFR conditions (when circles turn red).
- The timing of the reported IFR conditions corresponds well with the timing of high GOES-R IFR probabilities

2/28/2012
11:32 UTC



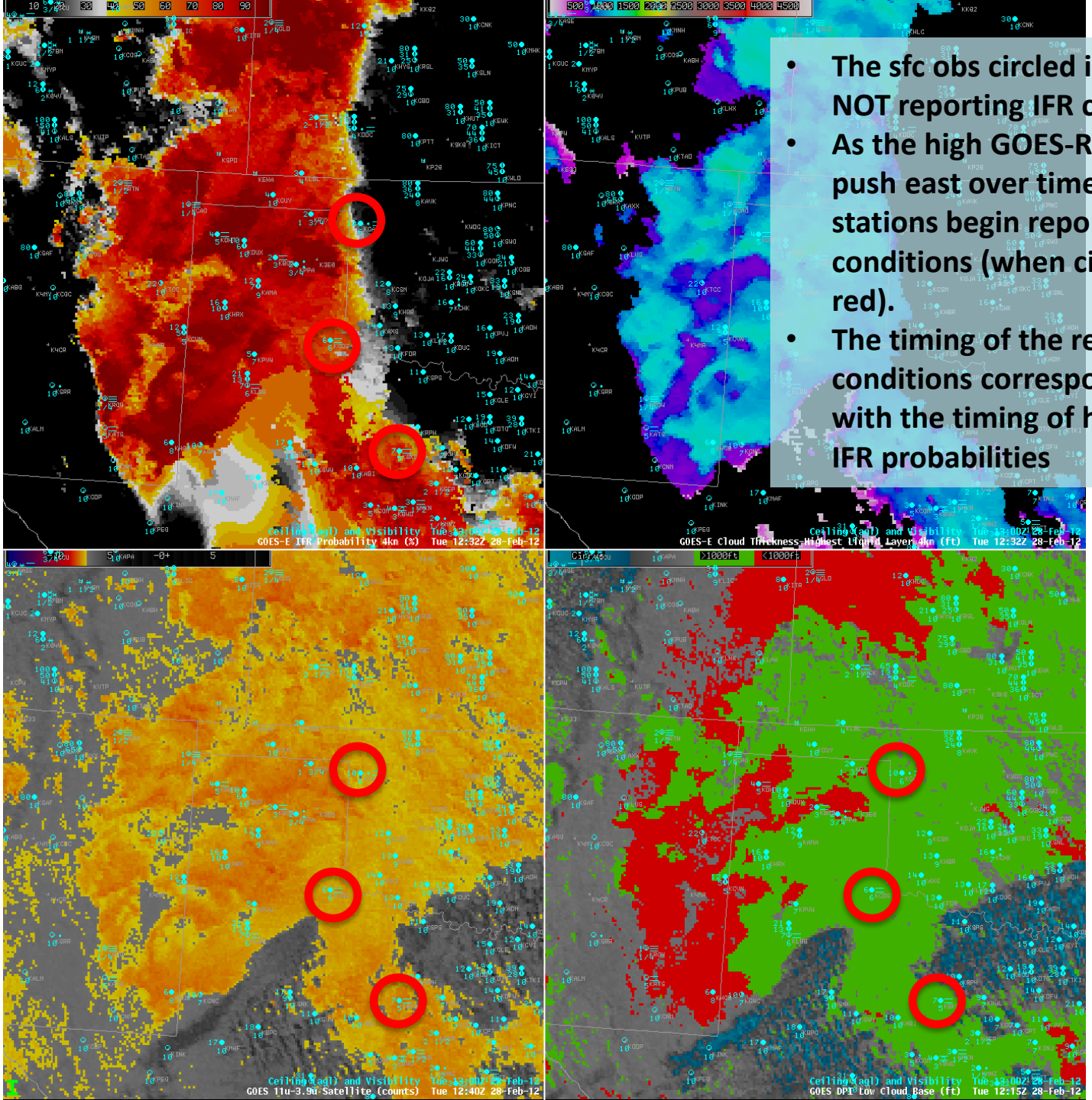
- The sfc obs circled in blue are NOT reporting IFR conditions.
- As the high GOES-R IFR probs push east over time those stations begin reporting IFR conditions (when circles turn red).
- The timing of the reported IFR conditions corresponds well with the timing of high GOES-R IFR probabilities

2/28/2012
11:45 UTC



- The sfc obs circled in blue are NOT reporting IFR conditions.
- As the high GOES-R IFR probs push east over time those stations begin reporting IFR conditions (when circles turn red).
- The timing of the reported IFR conditions corresponds well with the timing of high GOES-R IFR probabilities

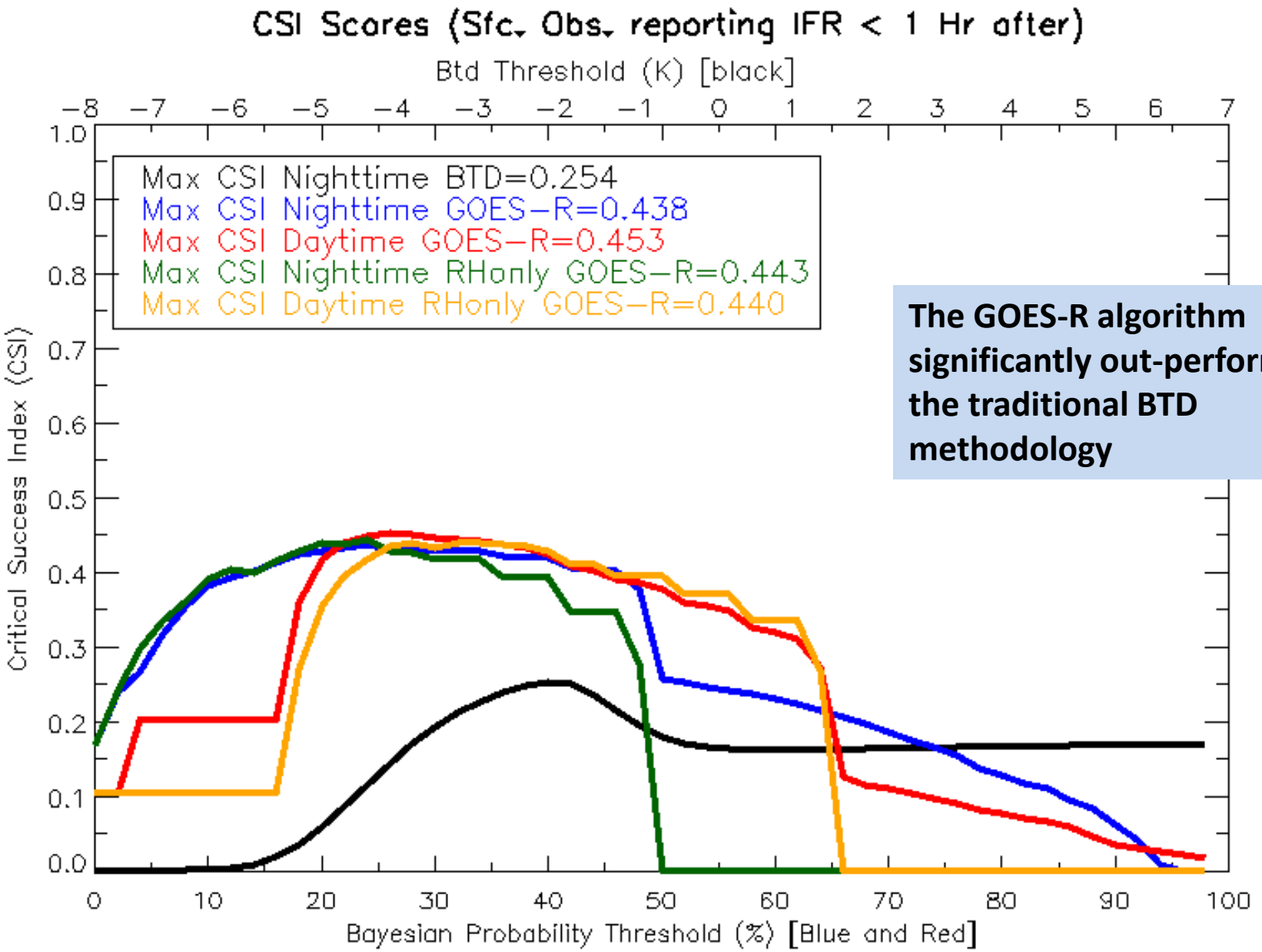
2/28/2012
12:15 UTC



- The sfc obs circled in blue are NOT reporting IFR conditions.
- As the high GOES-R IFR probs push east over time those stations begin reporting IFR conditions (when circles turn red).
- The timing of the reported IFR conditions corresponds well with the timing of high GOES-R IFR probabilities

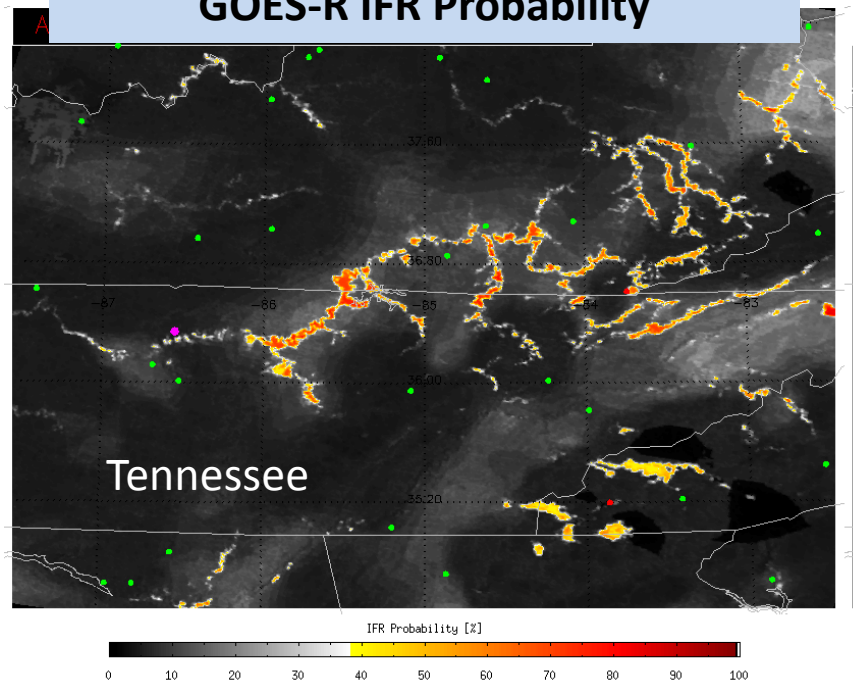
2/28/2012
12:32 UTC

Validation

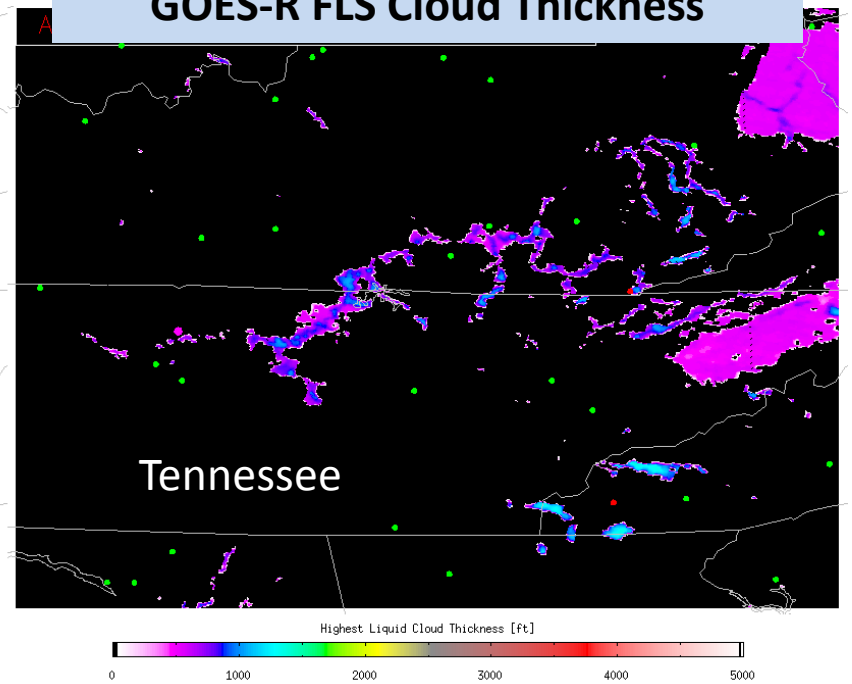


The GOES-R algorithm significantly out-performs the traditional BTD methodology

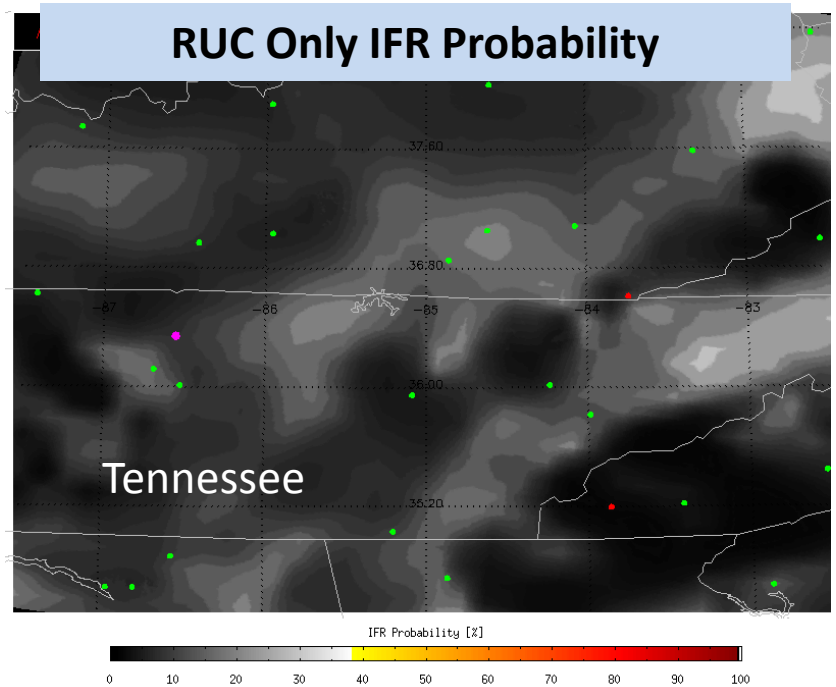
GOES-R IFR Probability



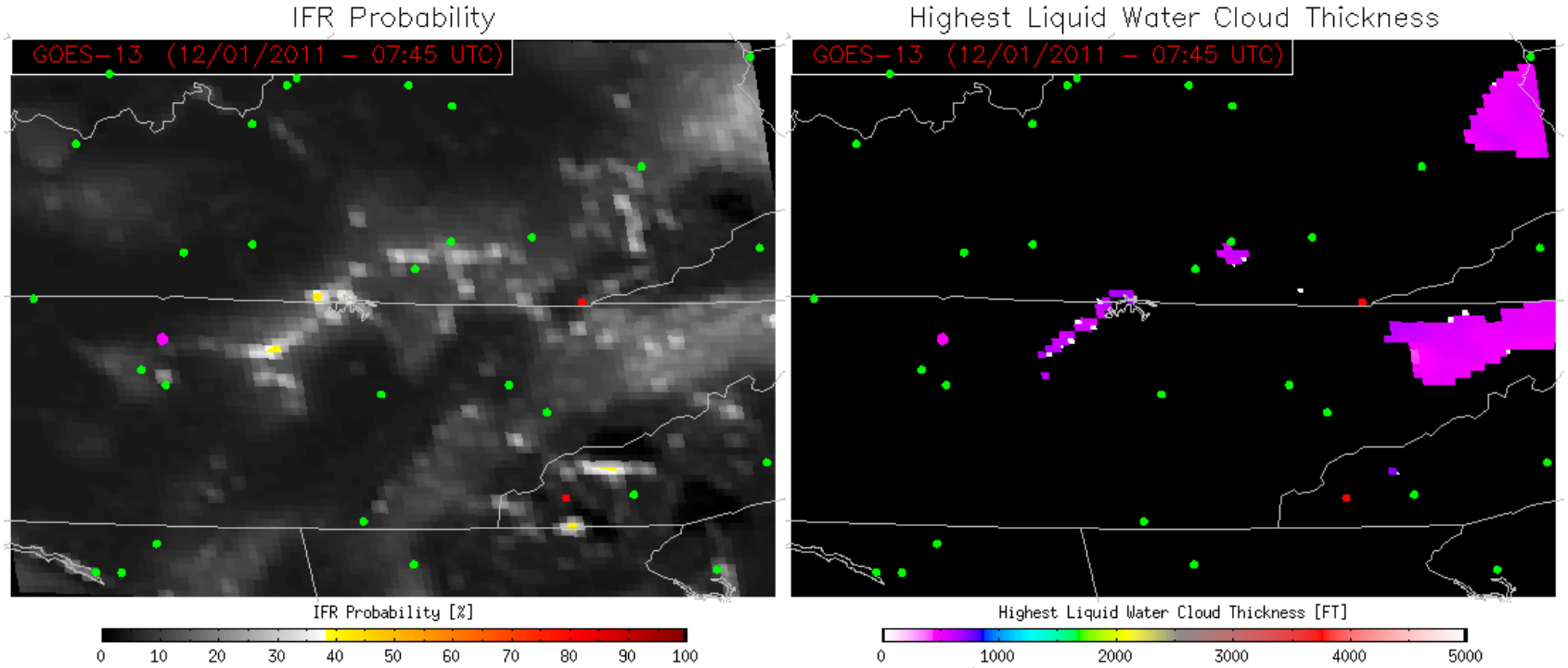
GOES-R FLS Cloud Thickness



RUC Only IFR Probability



Overnight on December 1, 2011, freezing fog formed near lakes and rivers in Northern Tennessee. This event was not forecasted and led to several traffic accidents that included a fatality. Localized events like this one are generally not captured by models, so satellite data are critical and dominate the information content of the GOES-R IFR probability.



GOES-R fog/low cloud algorithm applied to GOES-13

Clearly higher spatial resolution measurements are important for identifying localized, but operationally significant, areas of fog/low cloud!

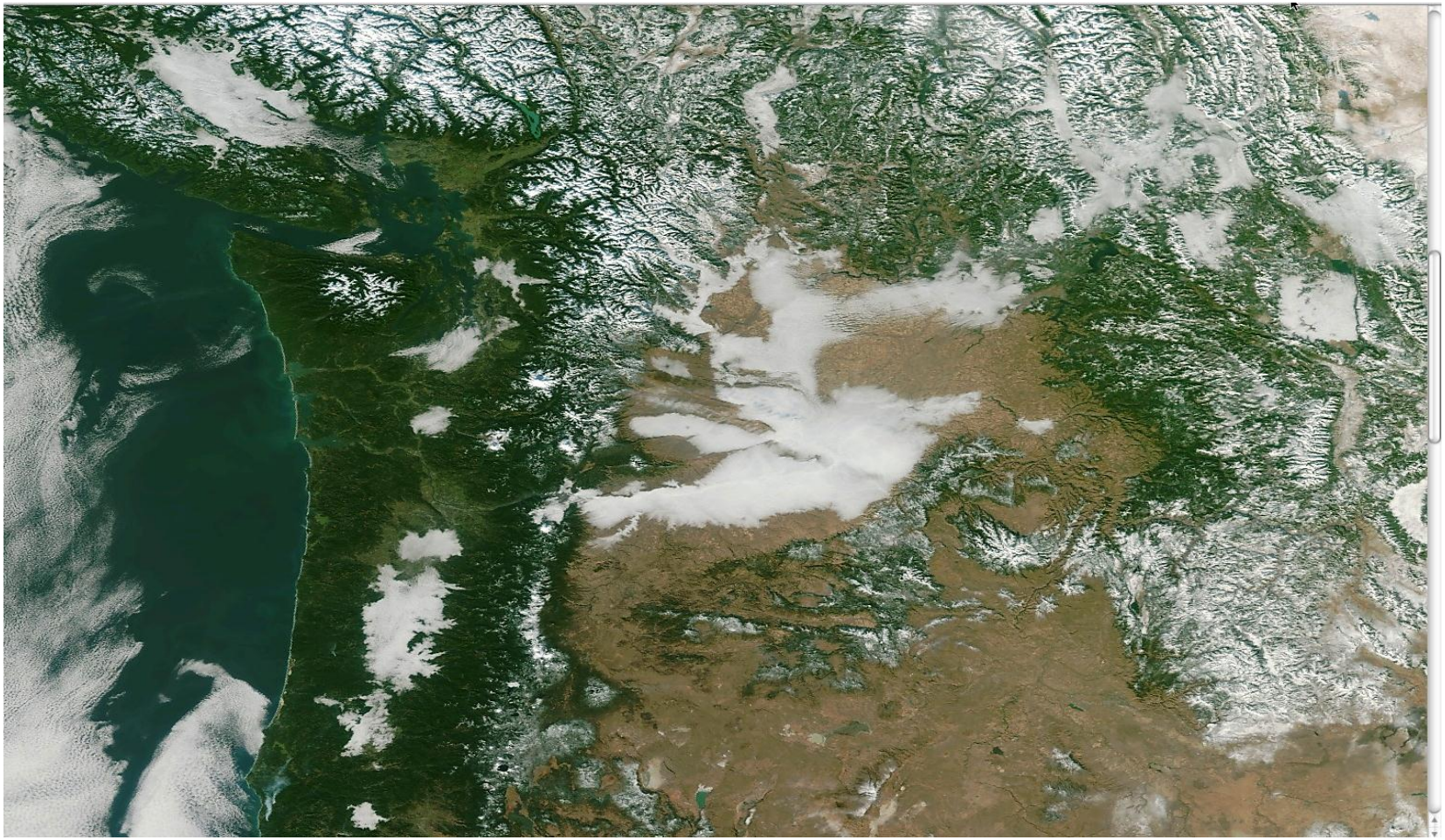
Proving Ground Activities

- The NWS Alaska Region and the MKX WFO have a completed a first round of fog/low cloud product evaluations (forecaster comments were generally positive)
- An updated version of the products was recently made available via LDM servers and an updated training module was developed (we are awaiting feedback on training module)
- Another round of product evaluations will start soon (AK, Eastern, Central, Western Regions and AWC will participate)

Mount Holly, NJ AFD (3/20/2012): IN ANY EVENT...PERHAPS THE MOST IMPORTANT SENSIBLE WEATHER ELEMENTOVER THE COASTAL WATERS FOR THE NEXT 24 HOURS OR SO MAY BE THE FOG.THE LOW CLOUD IMAGES AND **GEOCAT IMAGES** SHOW THAT THE FOG ISEXPANDING THIS MORNING...

JPSS Activities

- There are no specific requirements to quantitative generate fog/low cloud products from JPSS (the high spatial resolution of VIIRS, would allow for improved detection of localized, but operationally significant, fog events)
- The GOES-R approach can be applied to VIIRS data but this task is not funded
- VIIRS also has a day/night visible band that may aid in fog detection



Future Direction

- **Near-term product improvements planned:**
  - **Start using expanded domain Rapid Refresh model (in lieu of RUC)**
  - **Distribute new training module and schedule live training sessions**
  - **Continue to validate and characterize product performance**
- **Long-term improvements planned:**
  - **Use high spatial resolution visible data during the day**
  - **Merge LEO and GEO capabilities (e.g. use high spatial resolution VIIRS FLS probability as *a priori* probability in GOES classifier)**
  - **Incorporate morphometric characterization of landforms into classifier (this should allow for more accurate and detailed depiction of smaller scale valley fogs and local variability in cloud base)**
  - **Develop 1 - 3 hour *prognostic* IFR and LIFR probability products**
  - **Develop valley fog alert capability and integrate results with GPS applications**

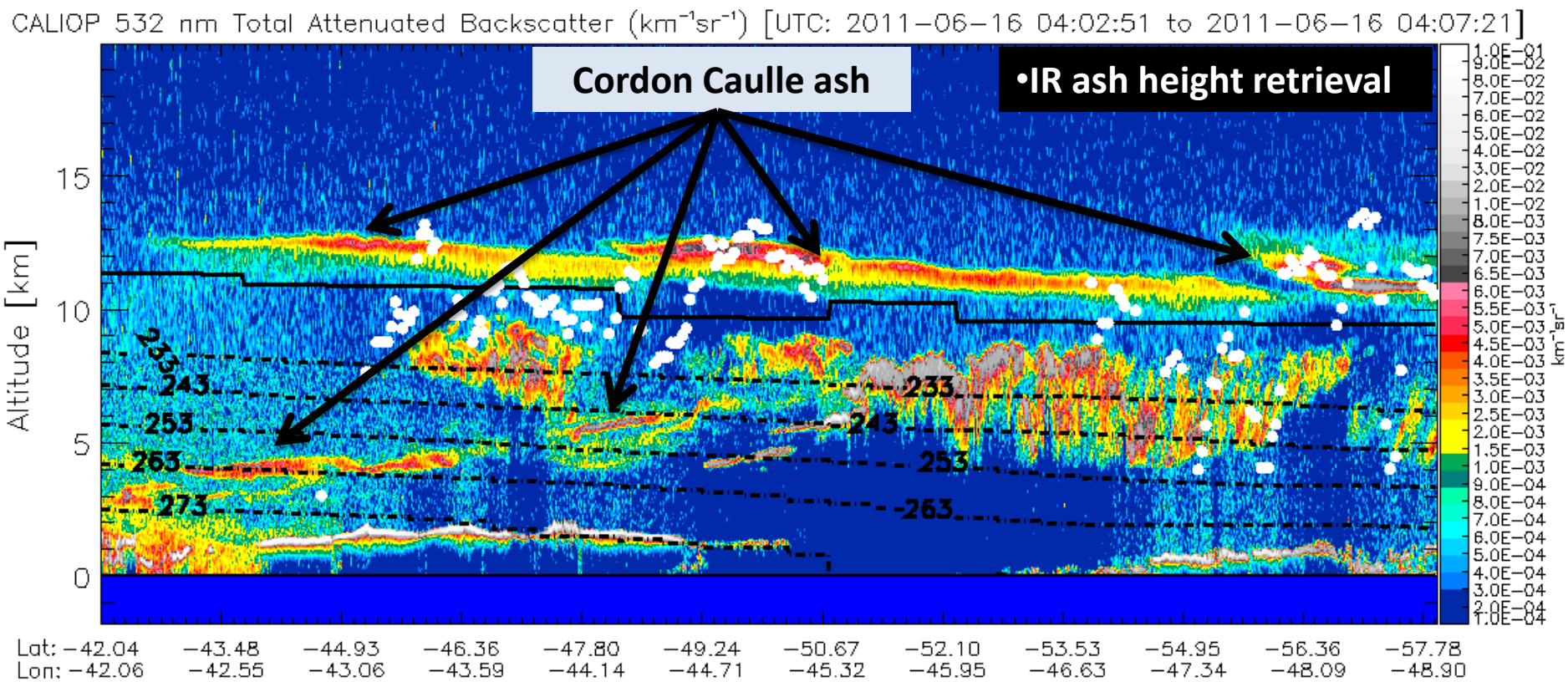
Fake example – not a real product, yet!

References

- Calvert, C. and Pavolonis, M. J., 2011: GOES-R Advanced Baseline Imager (ABI) Algorithm Theoretical Basis Document for Fog and Low Cloud Detection, Version 2.0., 67 pp.
- Calvert, C. and Pavolonis, M.J., 2012: Probabilistic identification of low cloud ceilings., In preparation.
- Gultepe, I., T. Kuhn, M.J. Pavolonis, C. Calvert, J. Gurka, A.J. Heymsfield, P.S.K Liu, B. Zhou, R. Ware, B. Ferrier, J. Milbrandt, B. Hansen, and B. Berstein, 2012: Ice fog in the Arctic during the FRAM-IF project: Aviation and nowcasting applications., *Bull. Amer. Meteor. Soc.*, Submitted February 2012.
- Pavolonis, M. J., 2010a: Advances in extracting cloud composition information from spaceborne infrared radiances: A robust alternative to brightness temperatures Part I: Theory, *J. Applied Meteorol. And Climatology*, 49(9), 1992-2012.
- Pavolonis, M. J., 2010b: GOES-R Advanced Baseline Imager (ABI) Algorithm Theoretical Basis Document for Cloud Type and Cloud Phase, Version 3.0., 86 pp.
- Walther, A. and A. K. Heidinger, 2010: GOES-R Advanced Baseline Imager (ABI) Algorithm Theoretical Basis Document for Daytime Cloud Optical Properties, Version 3.0.
- Walther, A., A. K. Heidinger and M.J. Foster, 2011: Implementation of the Daytime Cloud Optical and Microphysical Properties Algorithm (DCOMP) in PATMOS-x, In press.

Back-up Slides

- The majority of CALIOP overpasses of Cordon Caulle volcanic ash used in this analysis occurred after June 15, when the stratospheric ash cloud from the early stage of the eruption was on its second circuit around the world
- While some of the infrared retrieved heights were over-estimated (relative to CALIOP), stratospheric heights were only retrieved in regions where CALIOP indicated that the cloud was actually in the stratosphere
- The accuracy of the infrared based ash cloud heights generally decreased as the cloud geometric thickness decreased



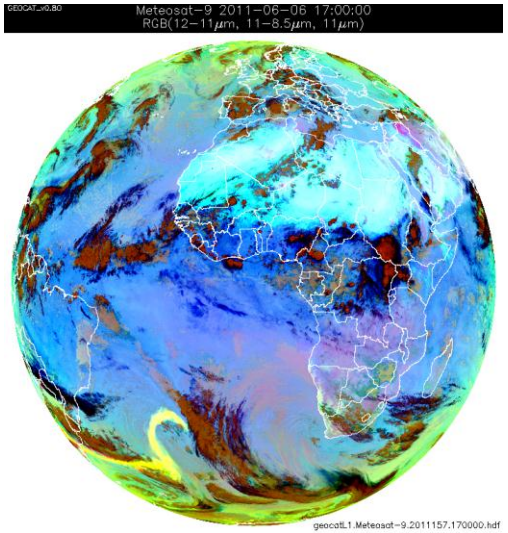
GOES-R SO_2 Product

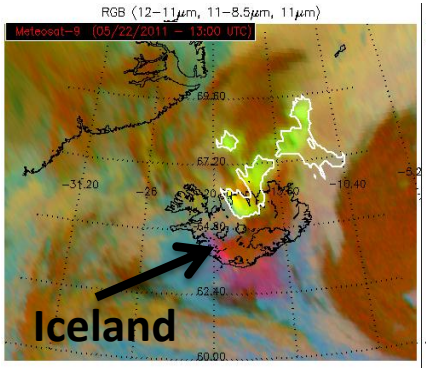
- The GOES-R requirements call for a yes/no SO_2 mask

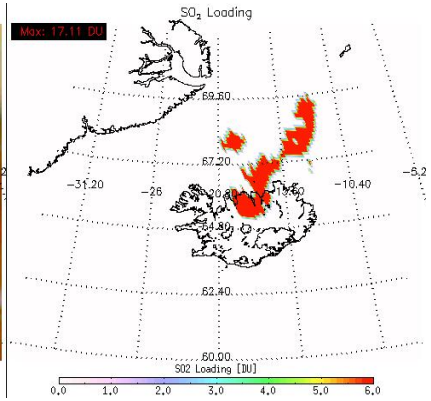
- The GOES-R SO_2 algorithm utilizes the 6.2, 7.3, 8.5, 11, and 12 µm channels (these channels are available not only on the GOES-R ABI, but also current imagers MODIS and SEVIRI)

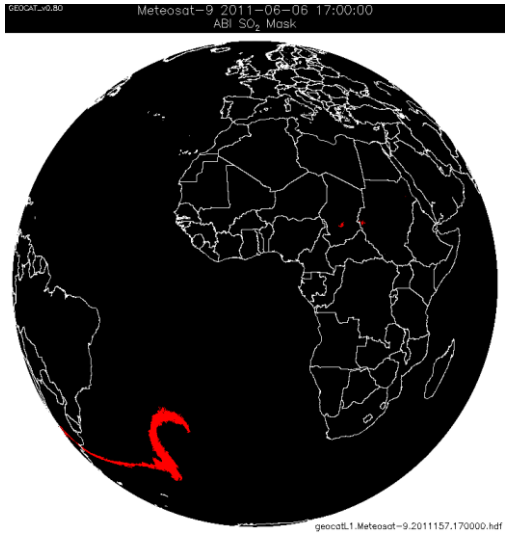
- Various non-satellite data sets (including NWP fields) are used to correct for emission of radiation by the surface and major IR-active atmospheric gases (H_2O, O_3, and CO_2) (see Pavolonis, 2010)

- SO_2 clouds are detected by identifying cloud microphysical anomalies that are only likely to arise because of SO_2 absorption (see Pavolonis 2011 and Pavolonis 2010 for details)



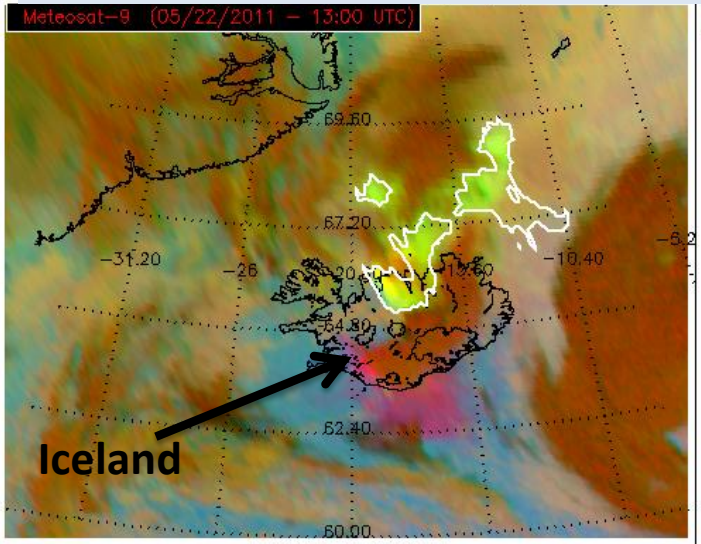


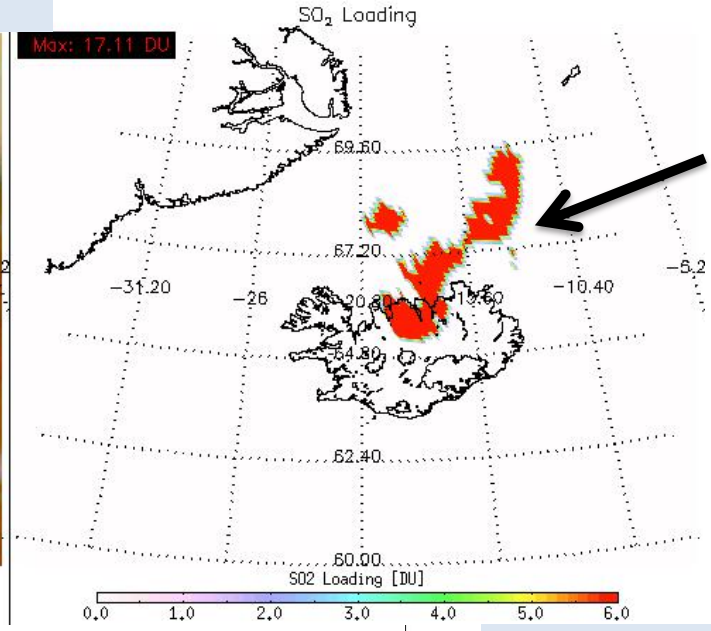




Grimsvotn, May 22, 2010 - 13:00 UTC

GOES-R SO_2 Product

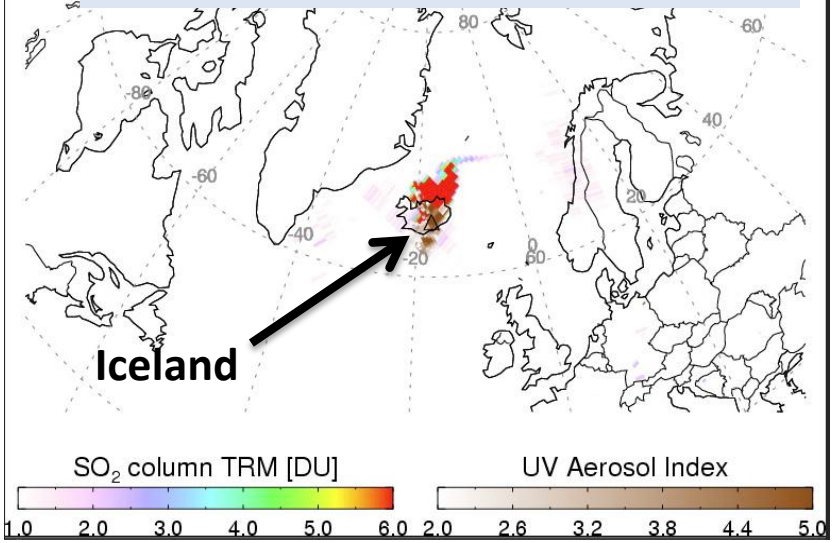




SO_2 loading estimate using GOES-R algorithm

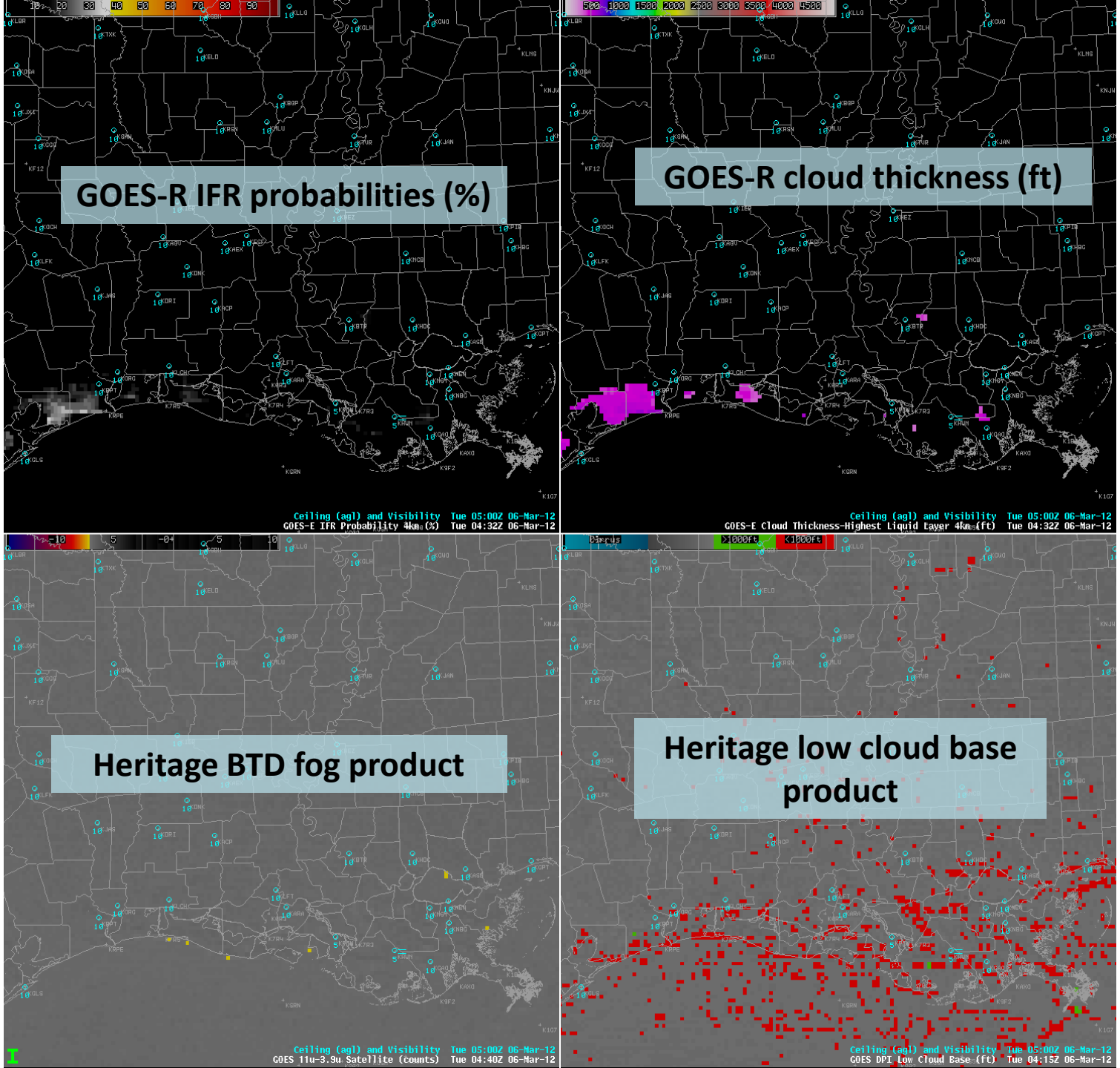
- **To add value to the GOES-R products an estimate of the SO_2 loading is also provided**
- **The GOES-R and Ozone Monitoring Instrument (OMI) products are in good agreement**
- **OMI, which is in LEO, is much more sensitive to SO_2 than any GEO sensor**

OMI SO_2 Product



Southern Louisiana Radiation Fog

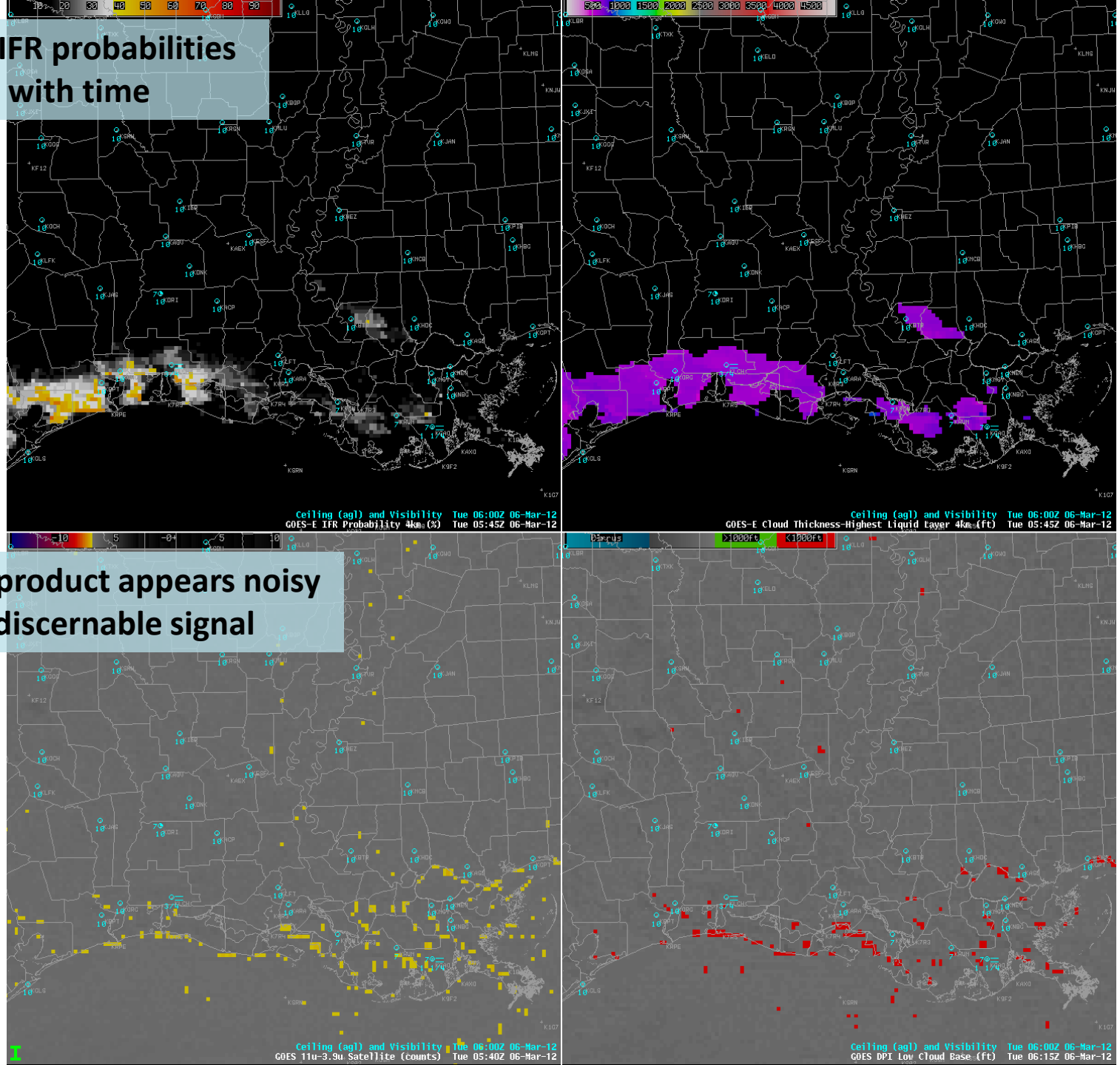
- **Shallow fog formed across southern Louisiana on March 6, 2012.**
- **AFD was posted by NWS in St. Charles at 4:31 AM CST (10:31 UTC) with mention of shallow fog formation**
- **Updated AFD was posted at 5:33AM (11:33 UTC) with mention of fog as an aviation hazard**
- **GOES-R IFR probabilities steadily increase hours before AFD was posted indicating the possible formation of shallow fog**
- **The traditional BTD product has difficulty discerning areas of fog throughout entire event**



3/6/2012
04:32 UTC

GOES-R IFR probabilities increase with time

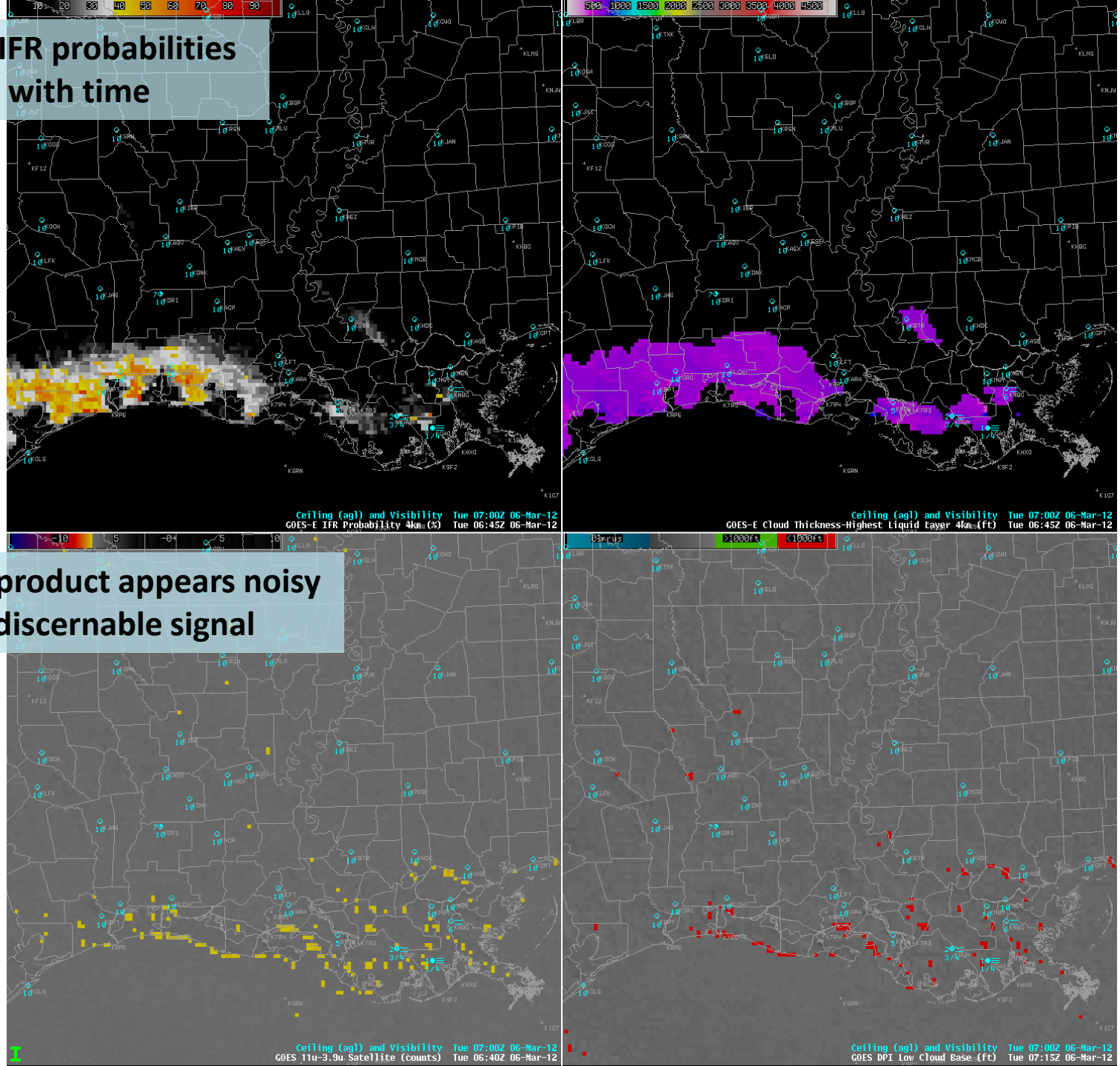
BTD fog product appears noisy with no discernable signal



3/6/2012
05:45 UTC

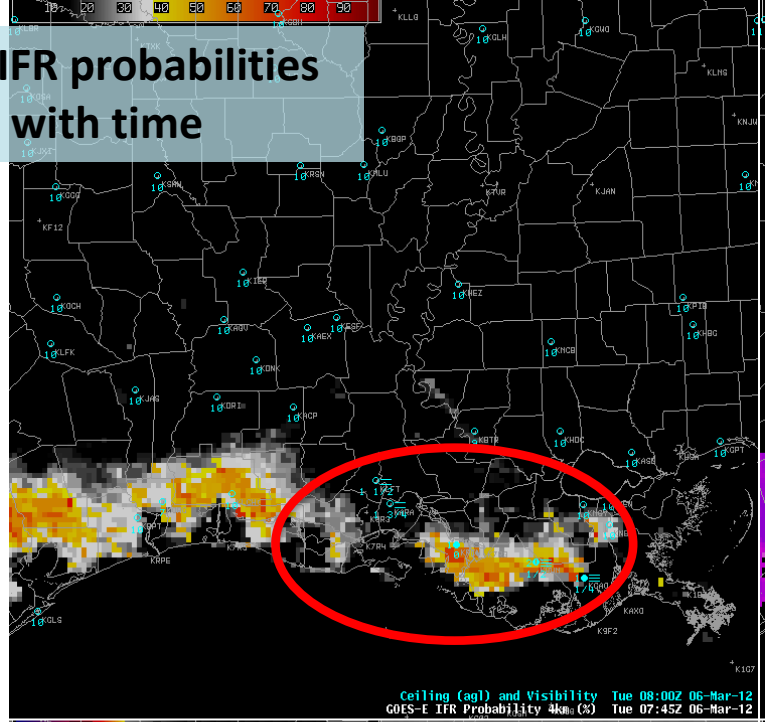
GOES-R IFR probabilities increase with time

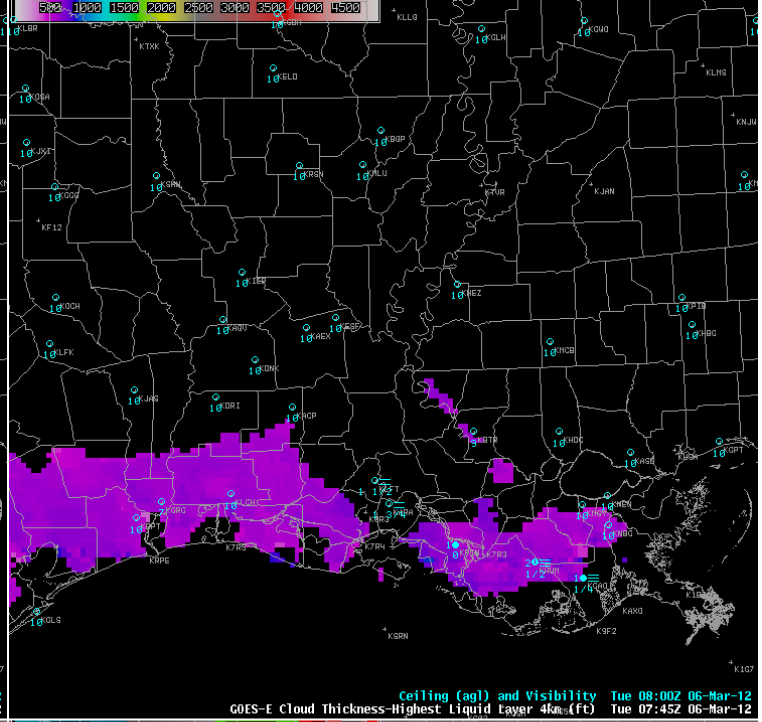
BTD fog product appears noisy with no discernable signal



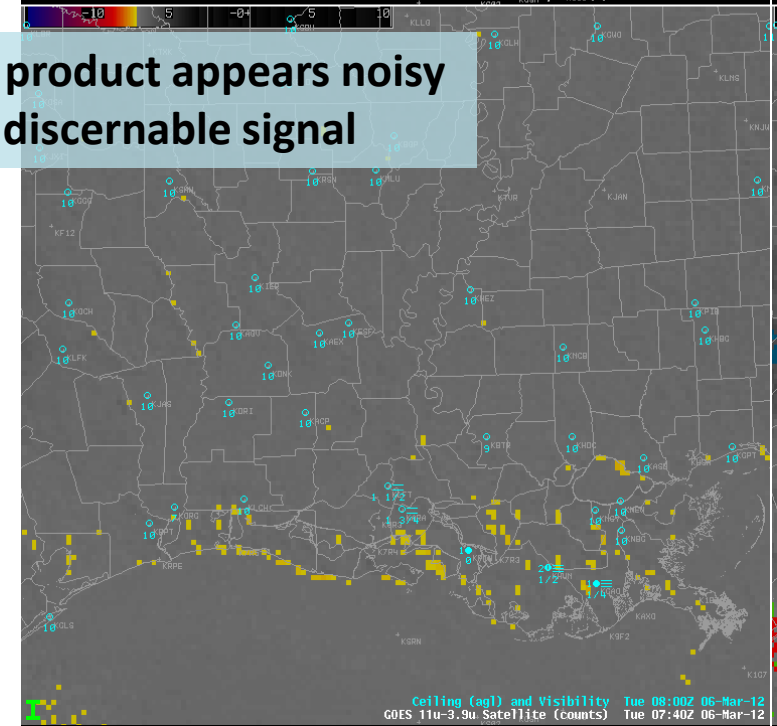
3/6/2012
06:45 UTC

GOES-R IFR probabilities increase with time

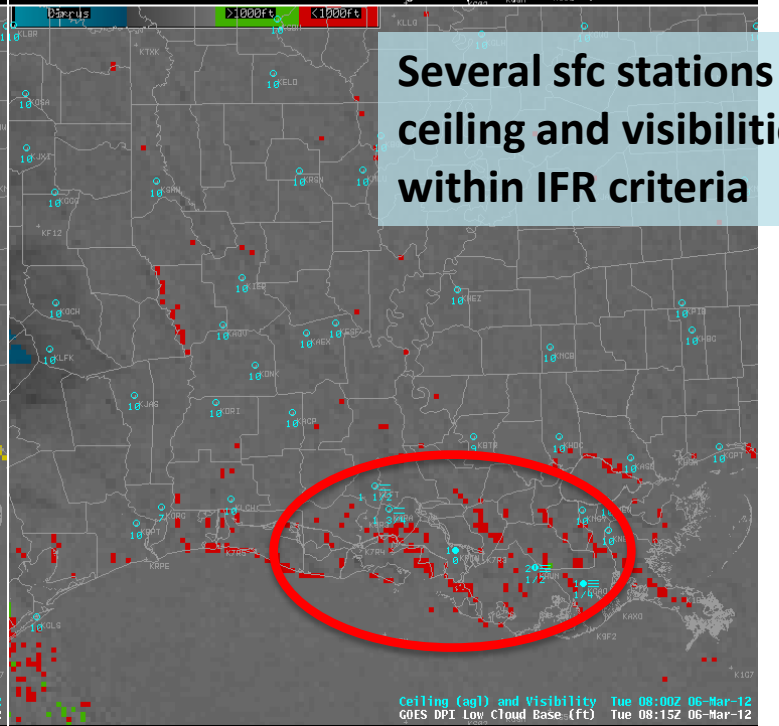




BTD fog product appears noisy with no discernable signal

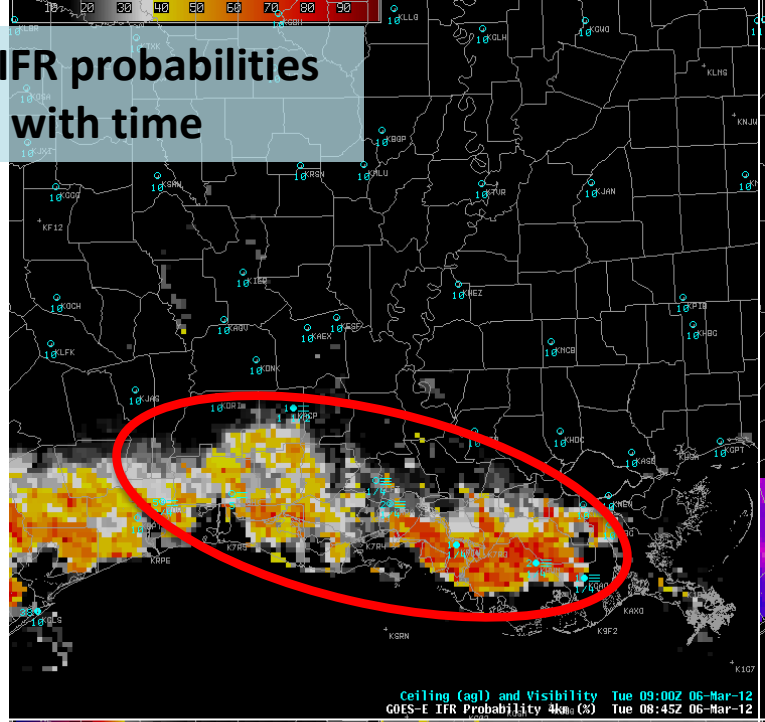


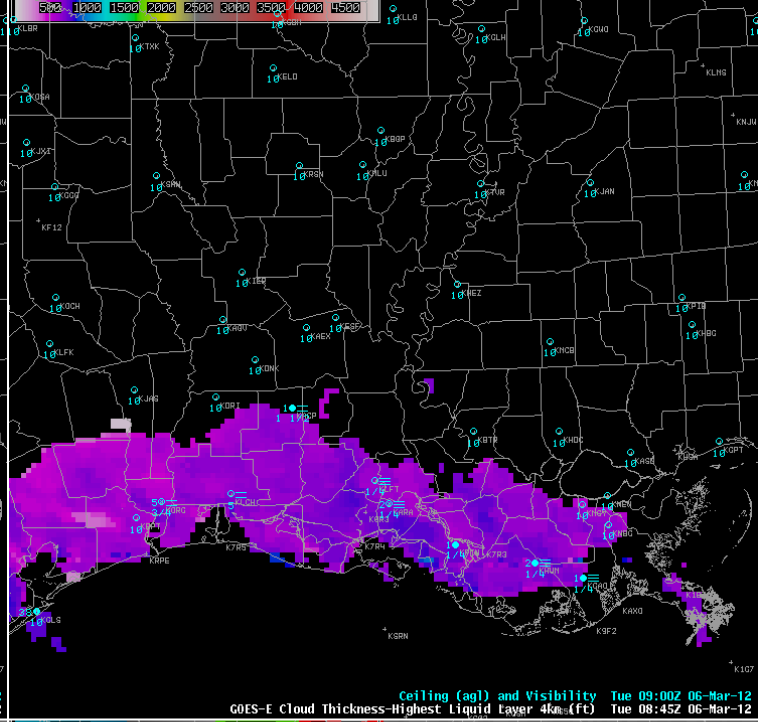
Several sfc stations indicate ceiling and visibilities well within IFR criteria



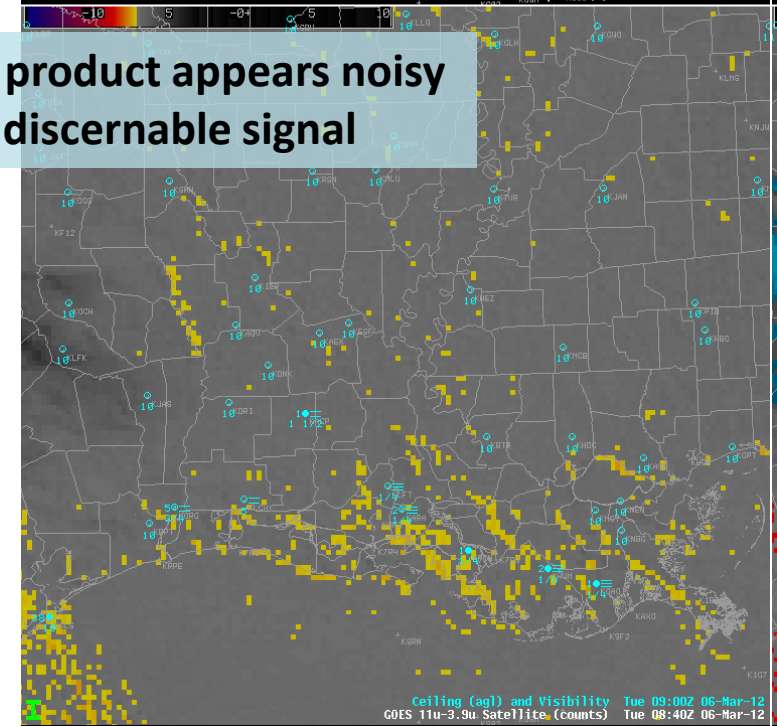
3/6/2012
07:45 UTC

GOES-R IFR probabilities increase with time

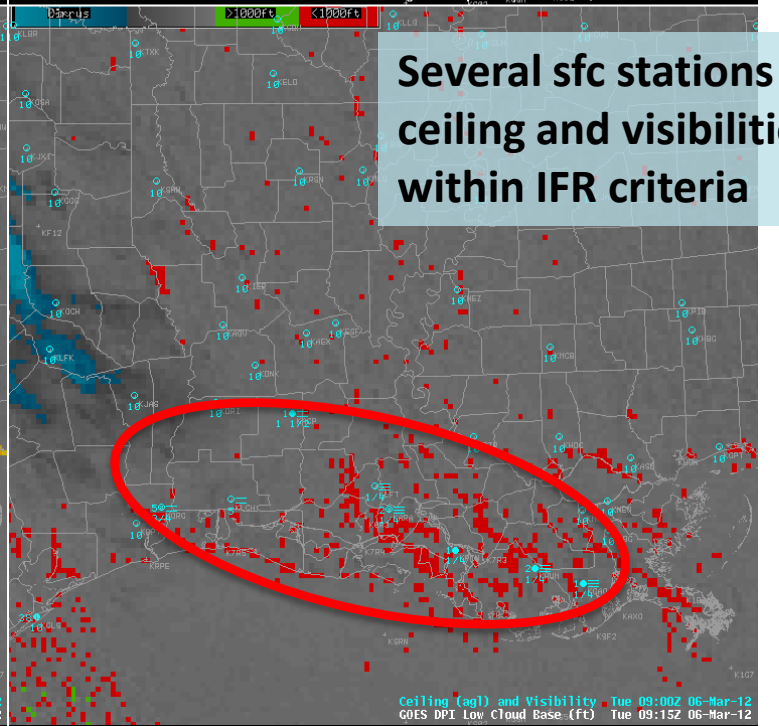




BTD fog product appears noisy with no discernable signal

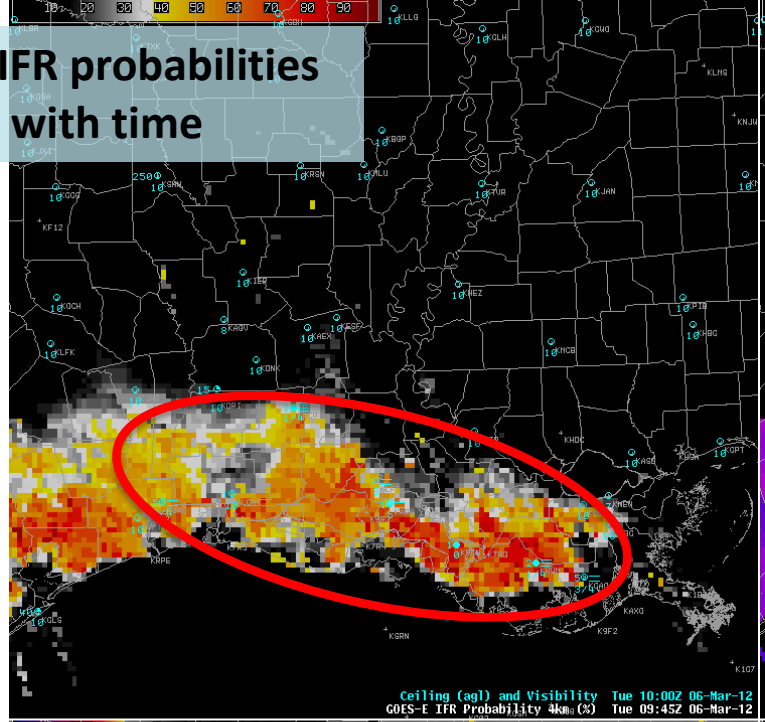


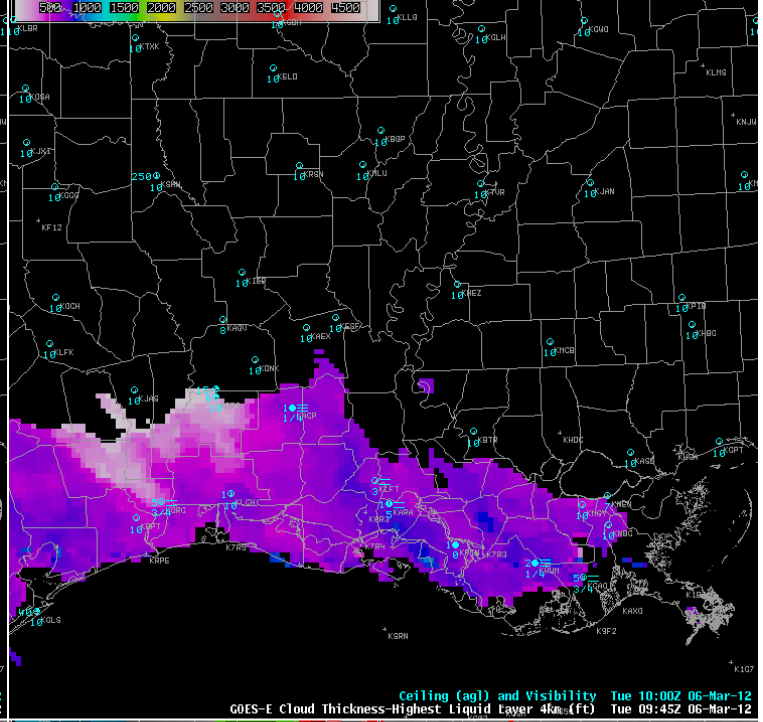
Several sfc stations indicate ceiling and visibilities well within IFR criteria



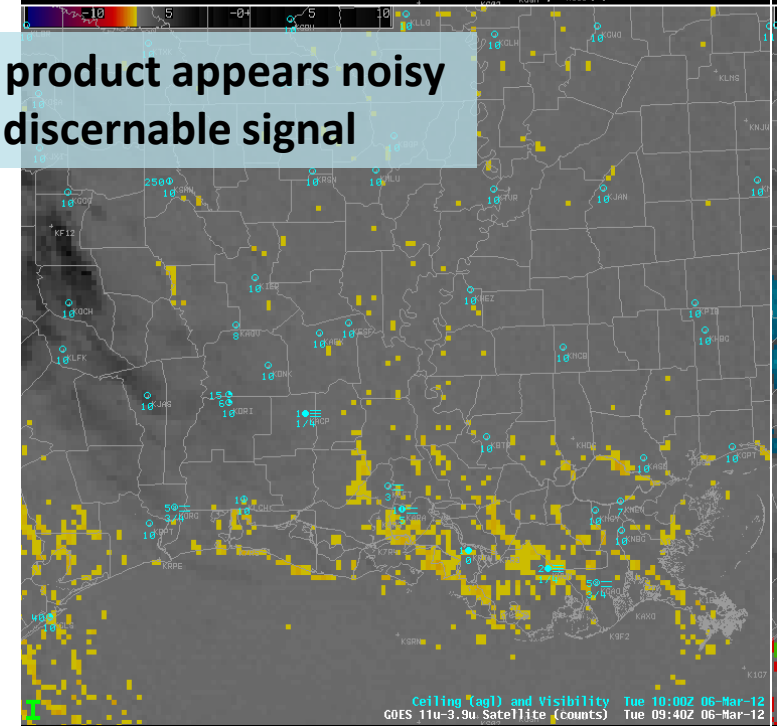
3/6/2012
08:45 UTC

GOES-R IFR probabilities increase with time

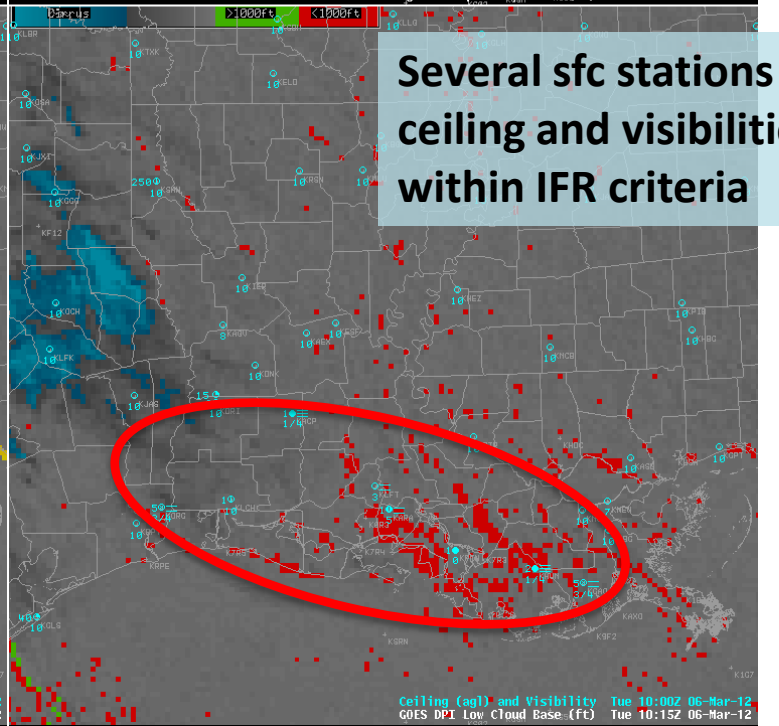




BTD fog product appears noisy with no discernable signal

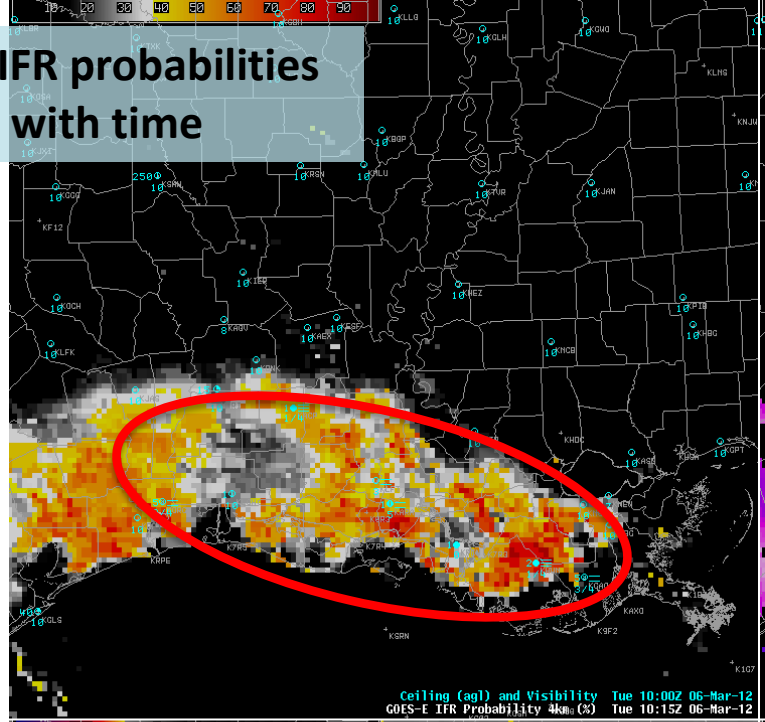


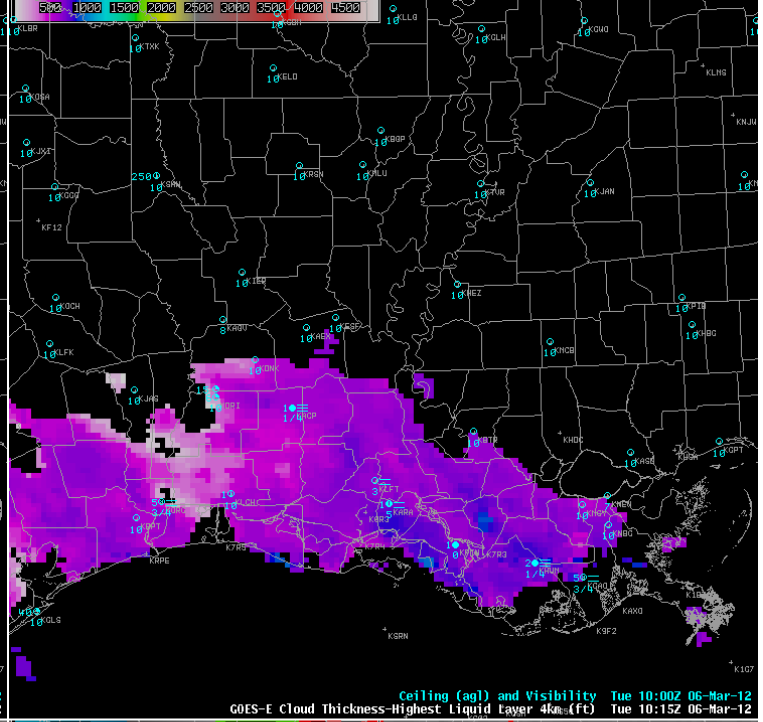
Several sfc stations indicate ceiling and visibilities well within IFR criteria



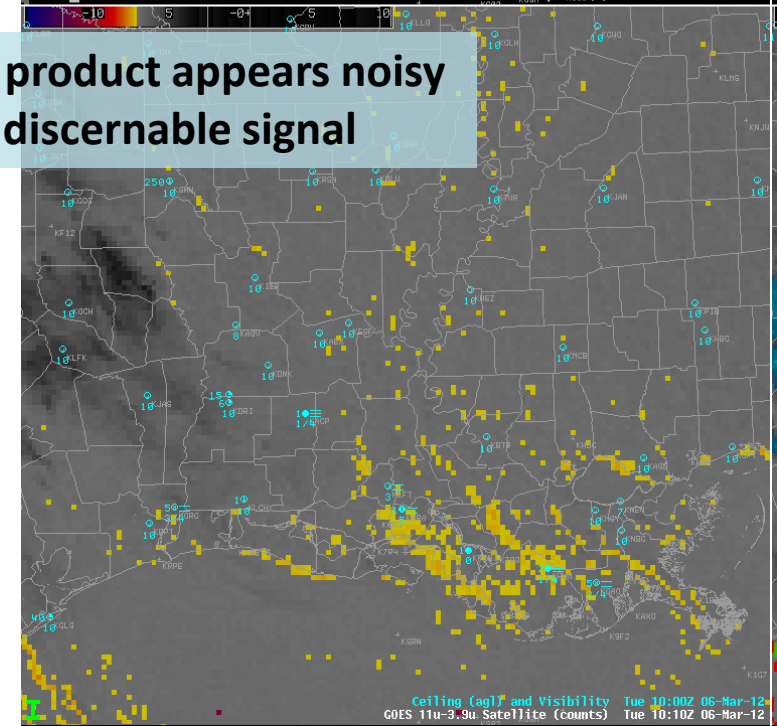
3/6/2012
09:45 UTC

GOES-R IFR probabilities increase with time

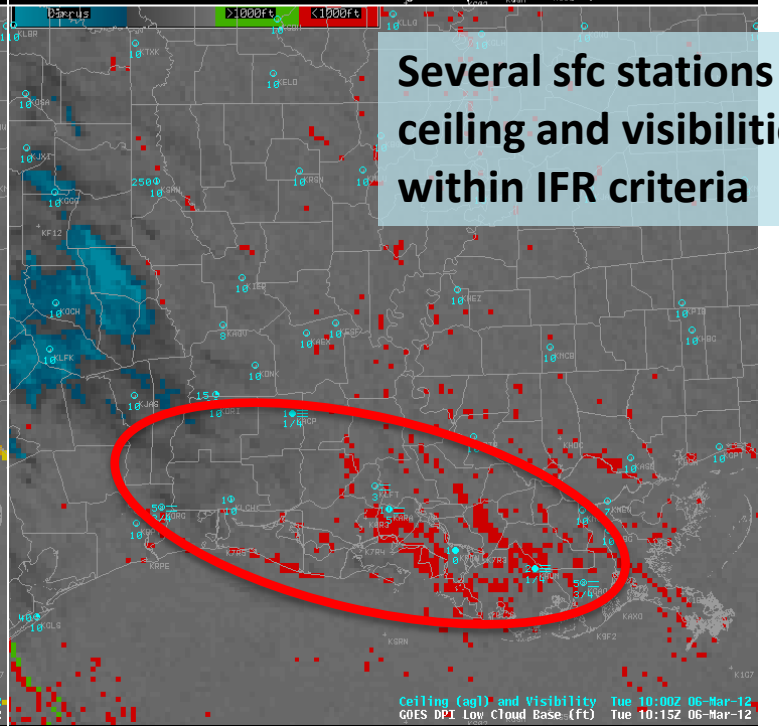




BTD fog product appears noisy with no discernable signal



Several sfc stations indicate ceiling and visibilities well within IFR criteria



3/6/2012
10:15 UTC

AFD from Lake Charles, LA NWS initially posted at 4:31AM CST (10:31 UTC) on March 6, 2012, several hours after the GOES-R IFR probabilities indicated fog in the area was likely

000
FXUS64 KLCH 061133
AFDLCH

AREA FORECAST DISCUSSION
NATIONAL WEATHER SERVICE LAKE CHARLES LA
431 AM CST TUE MAR 6 2012

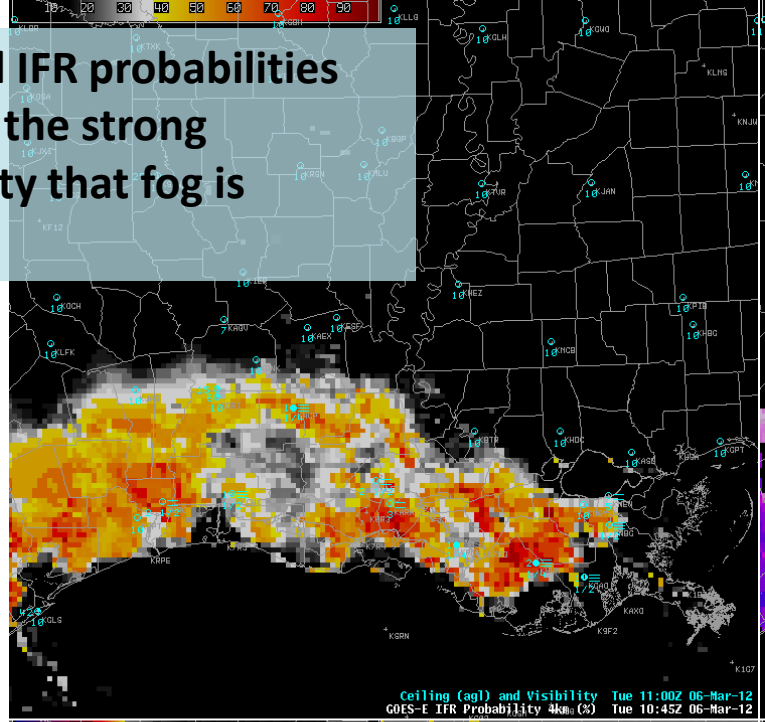
DISCUSSION...
THE CLEAR SKIES AND LIGHT WINDS HAVE ALLOWED SOME SHALLOW RADIATIONAL FOG TO FORM ACROSS PORTIONS OF THE I-10 CORRIDOR...AS AIR TEMPERATURES MEET UP WITH THE DEW POINT. SOME LOCATIONS HAVE REPORTED VISIBILITIES BELOW 1/2 MILE. HOWEVER...THE NATURE OF THE FOG SEEMS TO BE PATCHY...AND NOT ANTICIPATING A DENSE FOG ADVISORY. WILL MENTION THE PATCHY FOG IN THE ZONES...LIFTING QUICKLY BY MID-MORNING...AS SOLAR HEATING TAKES HOLD.

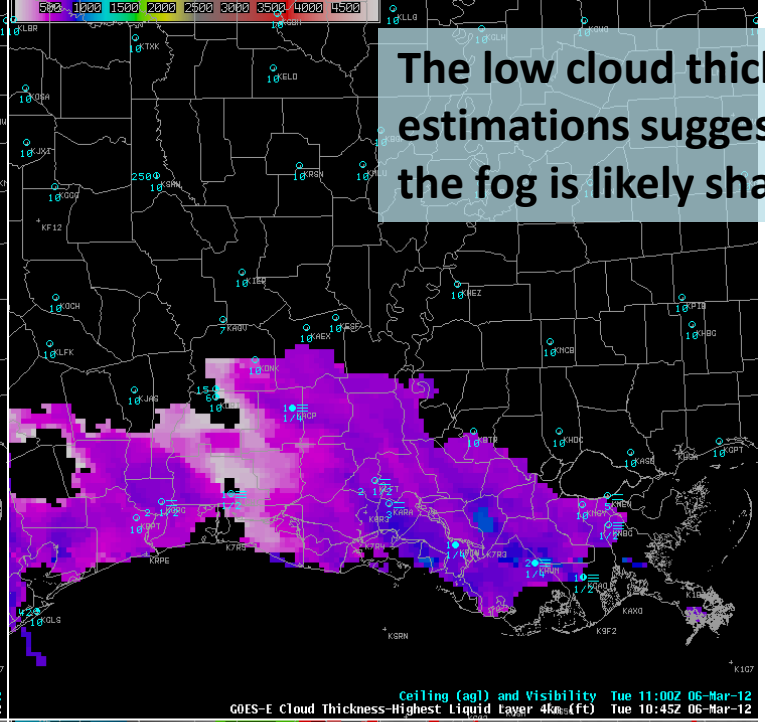
3/6/2012
10:15 UTC

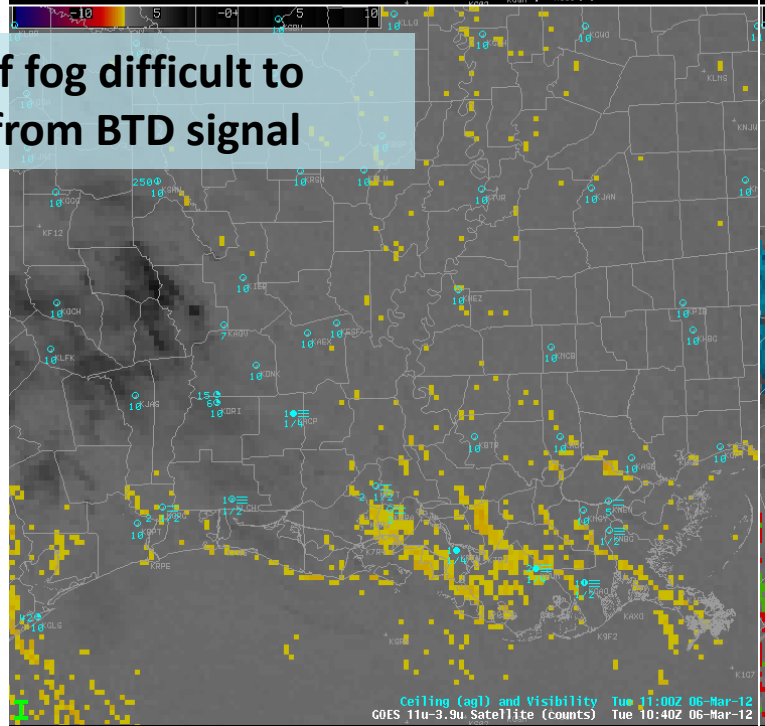
Elevated IFR probabilities indicate the strong possibility that fog is present

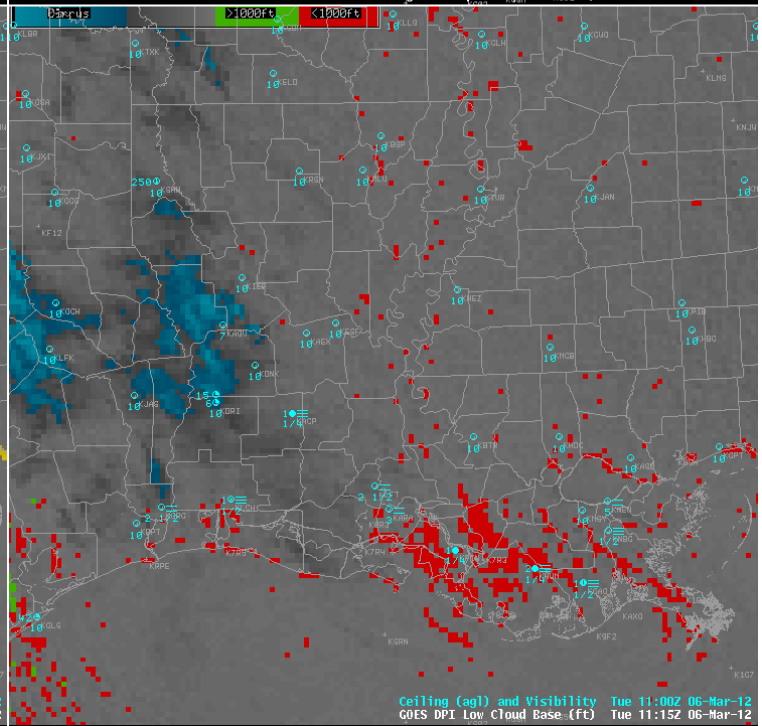
The low cloud thickness estimations suggest that the fog is likely shallow

Extent of fog difficult to discern from BTD signal







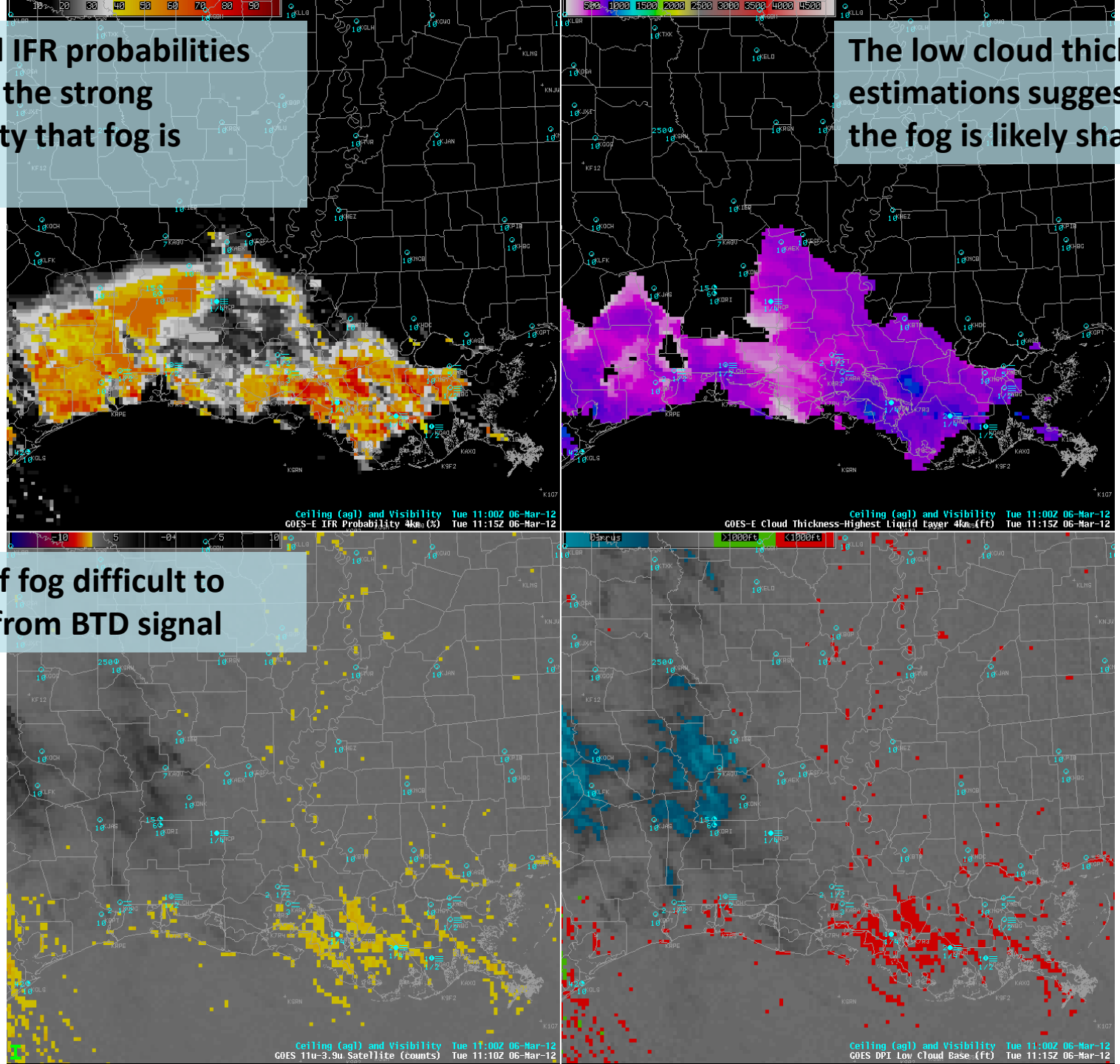


3/6/2012
10:45 UTC

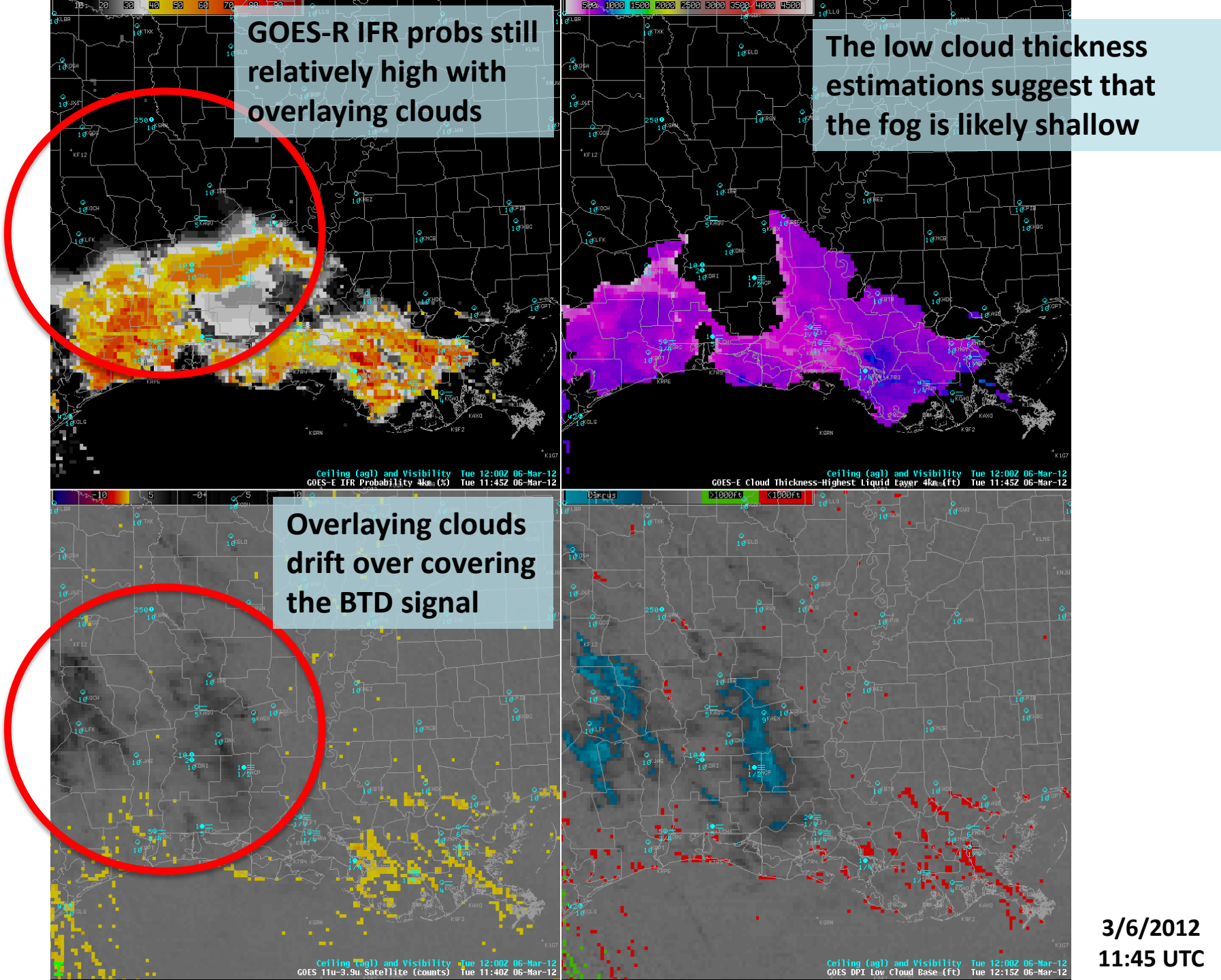
Elevated IFR probabilities indicate the strong possibility that fog is present

The low cloud thickness estimations suggest that the fog is likely shallow

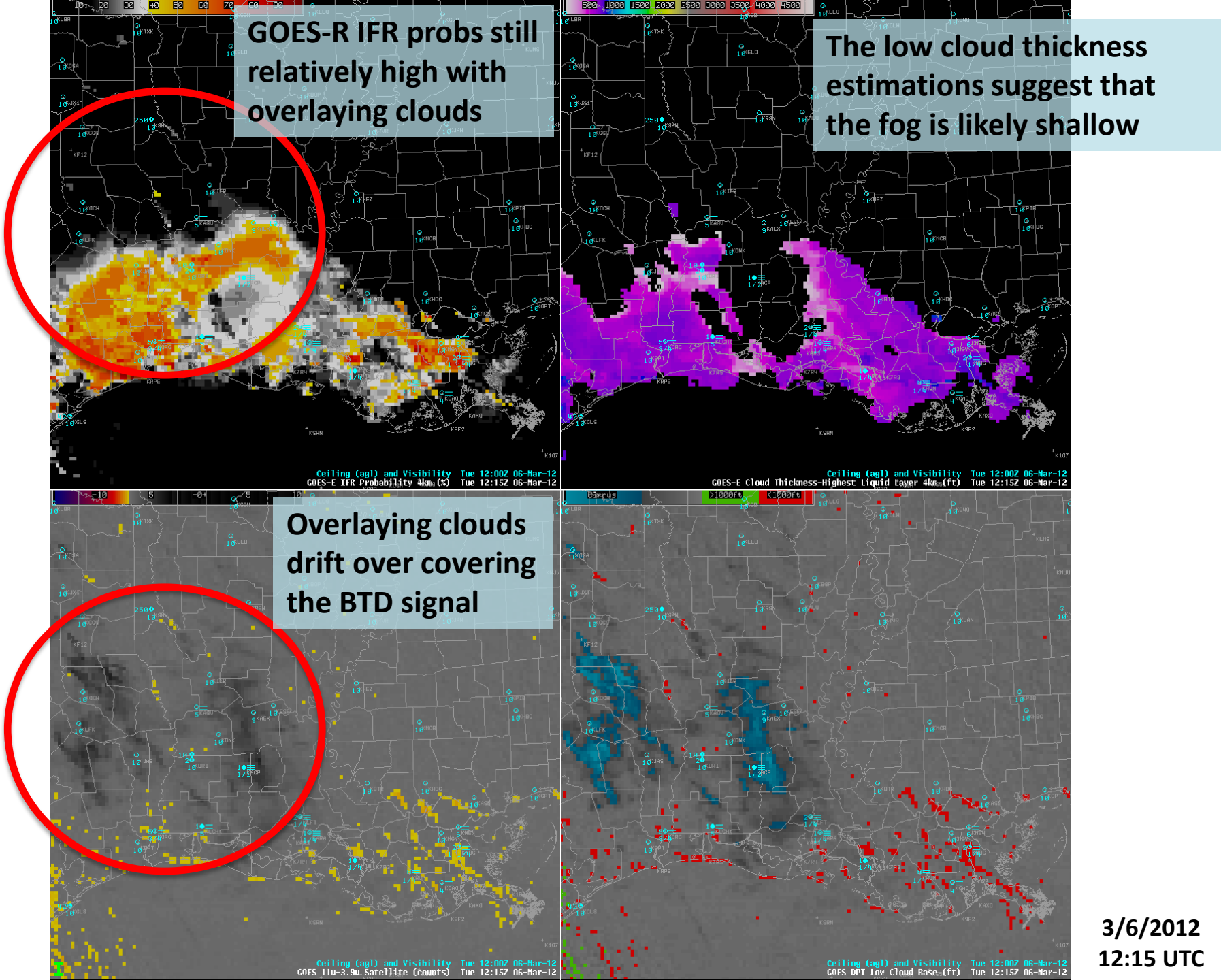
Extent of fog difficult to discern from BTD signal



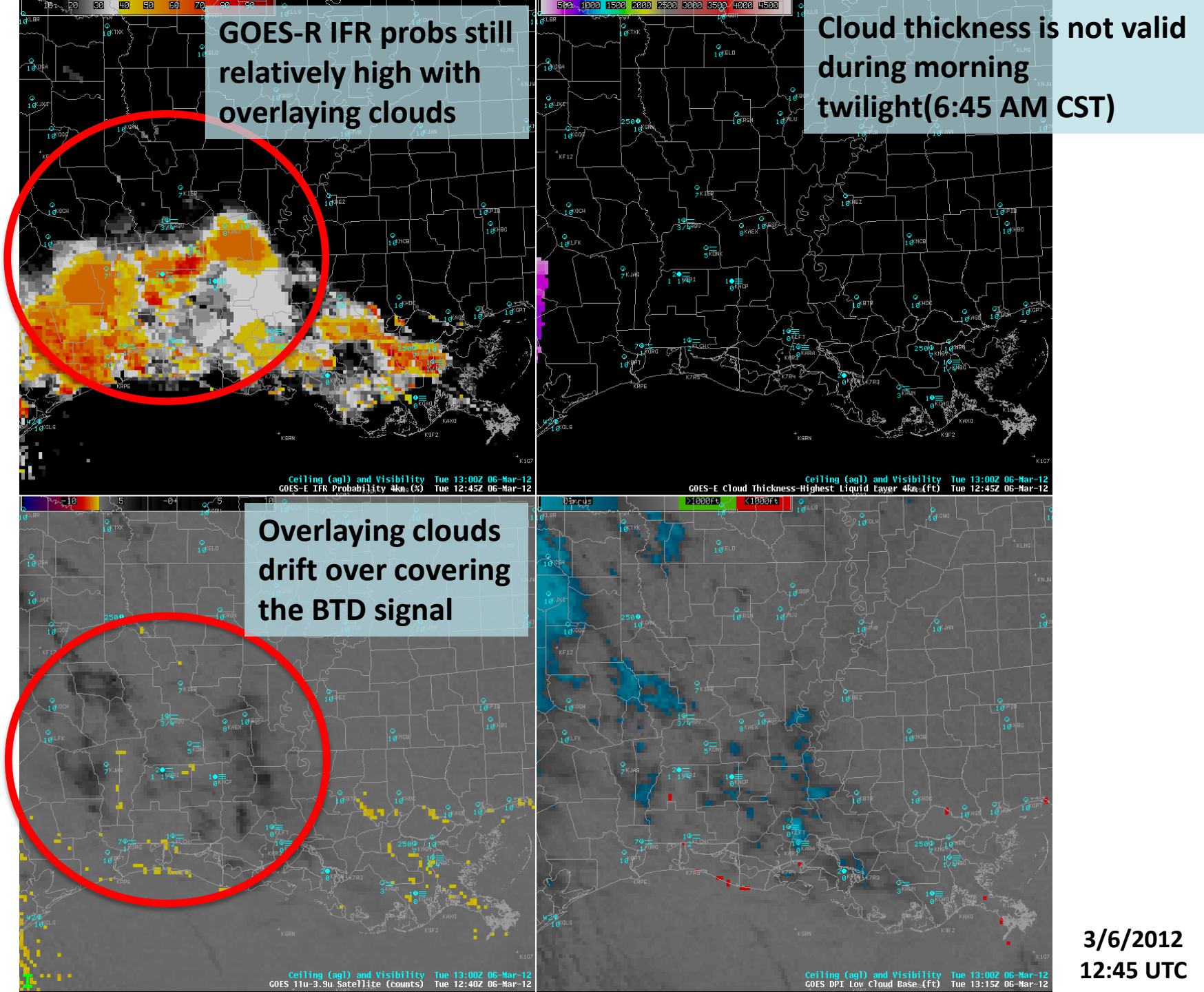
3/6/2012
11:15 UTC



3/6/2012
11:45 UTC



3/6/2012
12:15 UTC

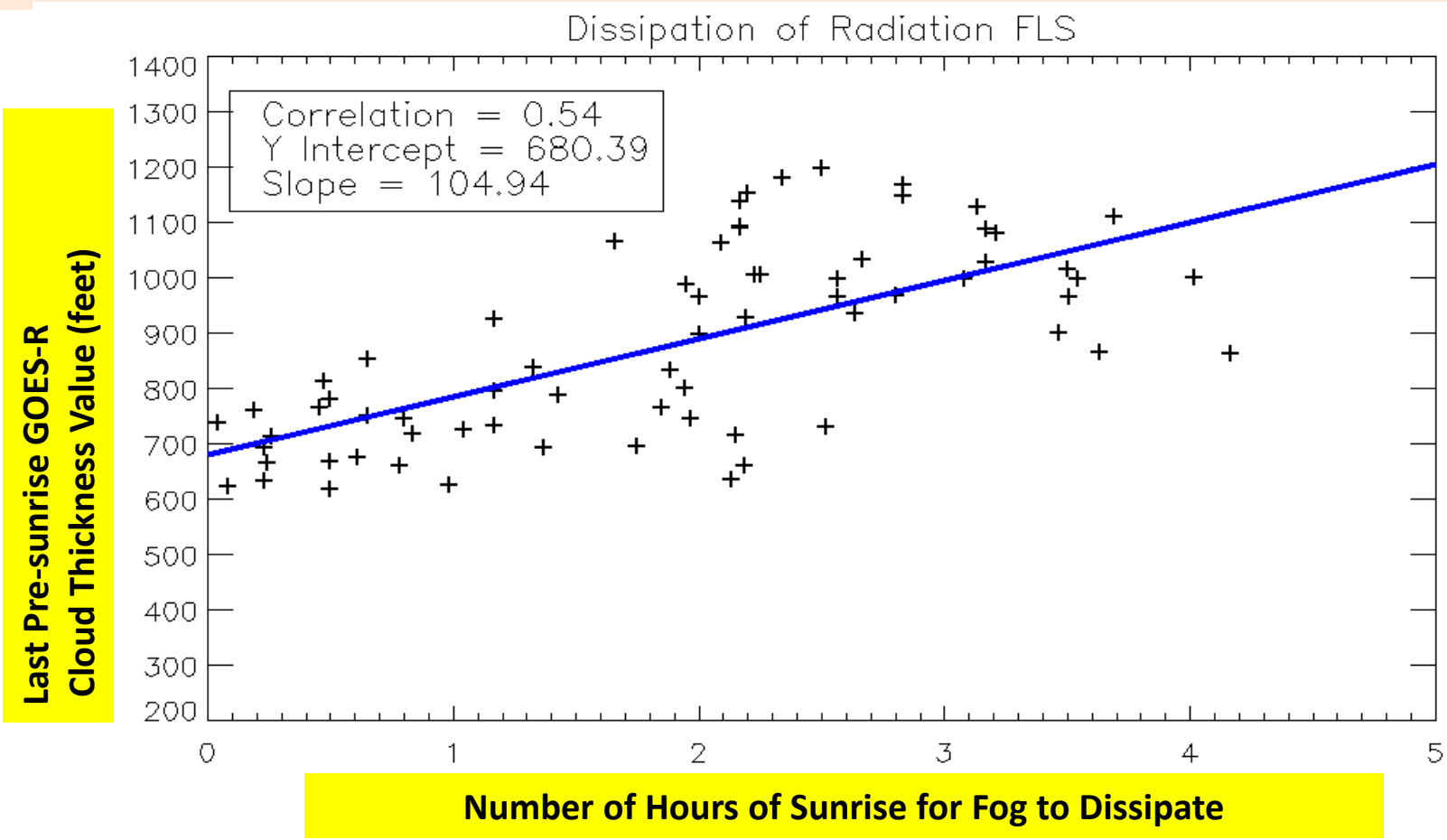


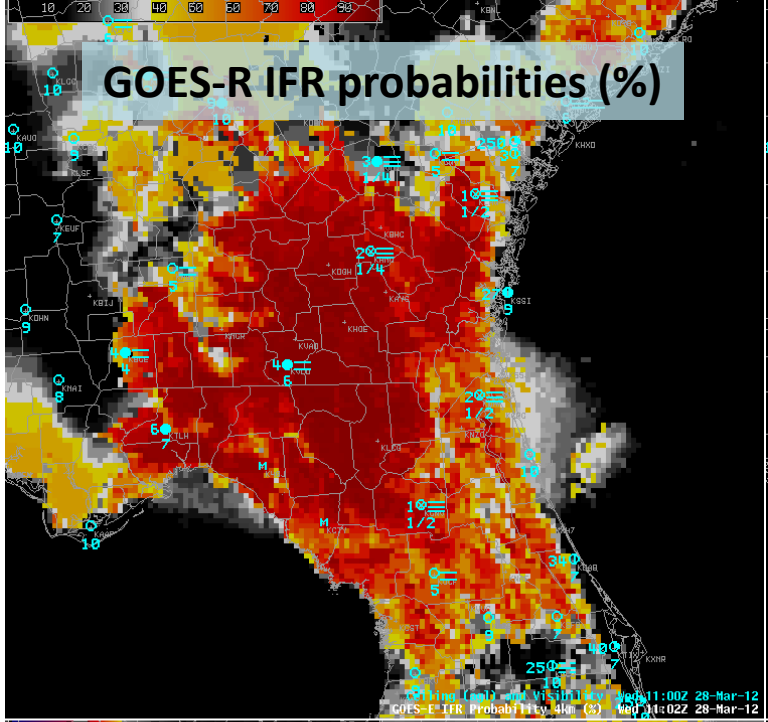
3/6/2012
12:45 UTC

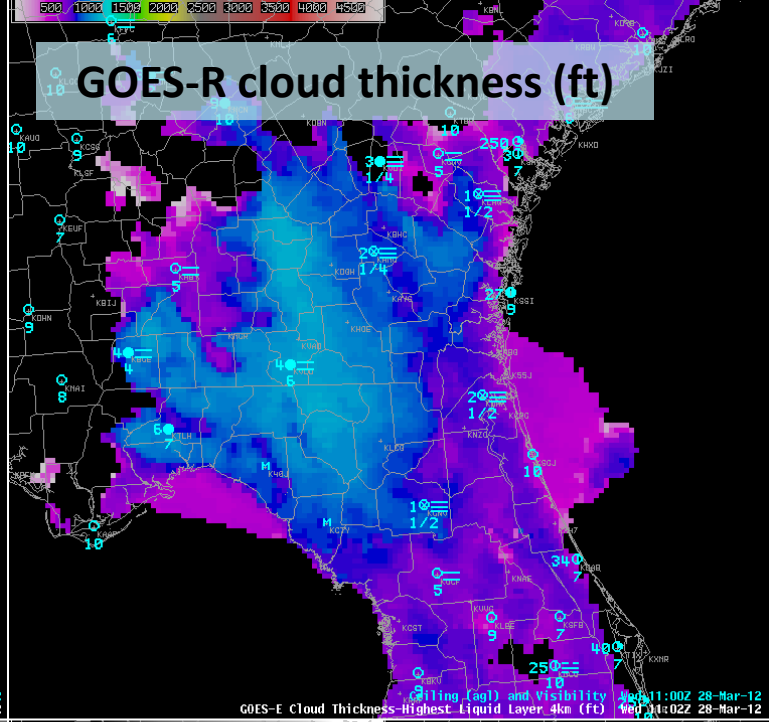
Using the GOES-R Cloud Thickness Product to Estimate Fog Dissipation Time

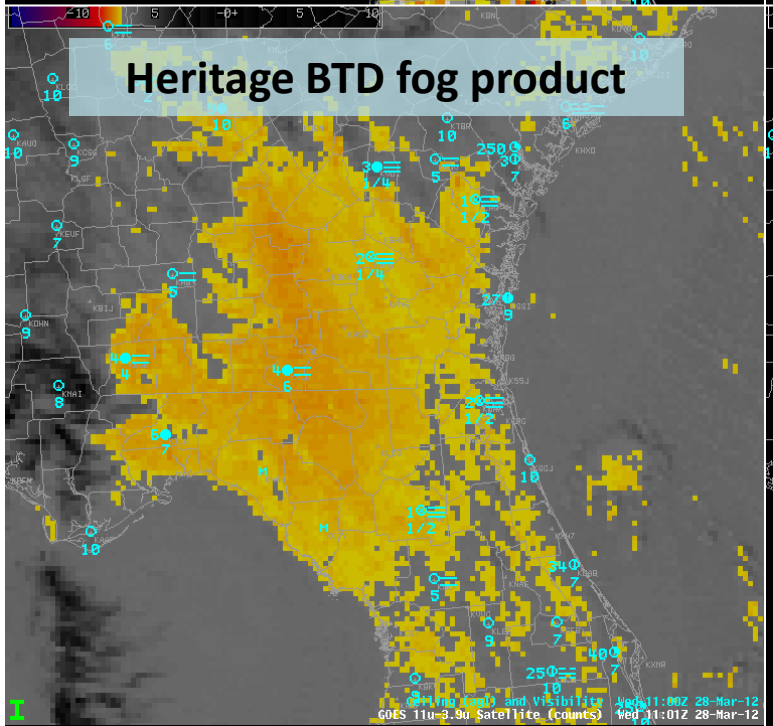
(Applies to Radiation Fog Only)

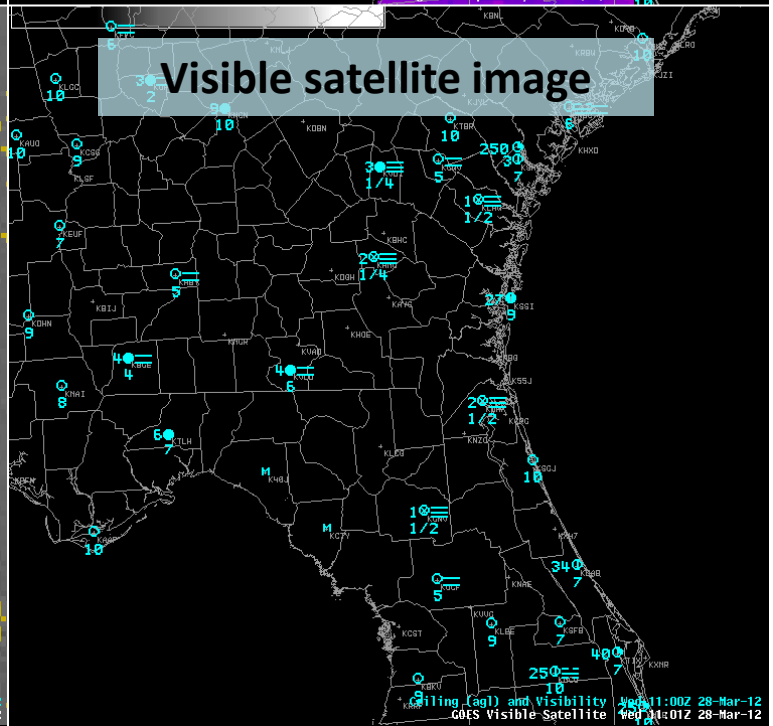
- **A relationship between the last pre-sunrise GOES-R cloud thickness estimation and the time it takes radiation fog to dissipate was developed**



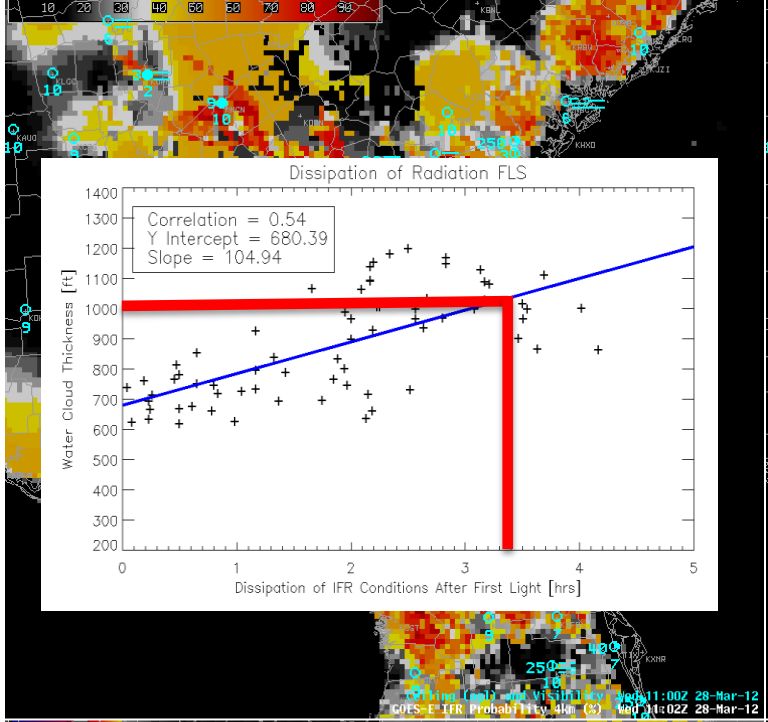


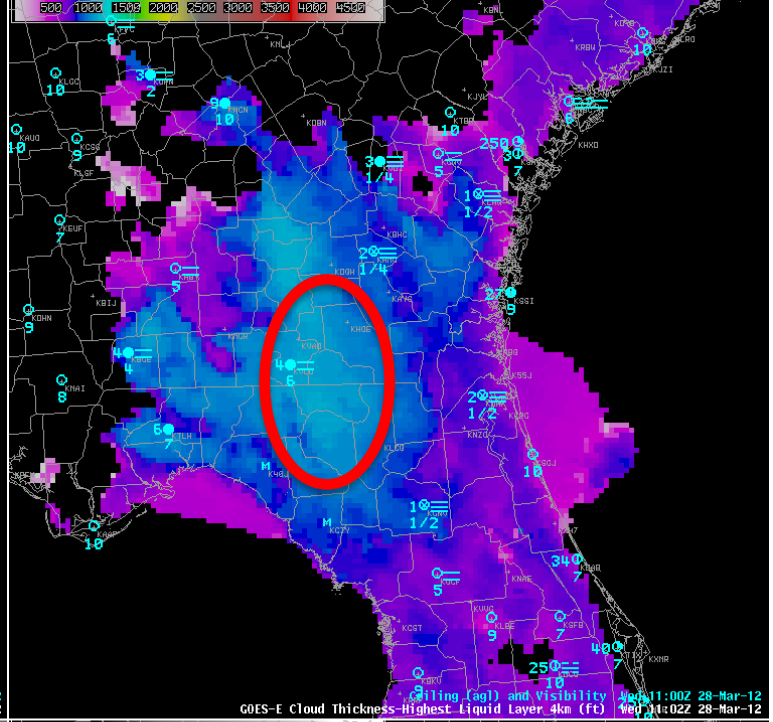


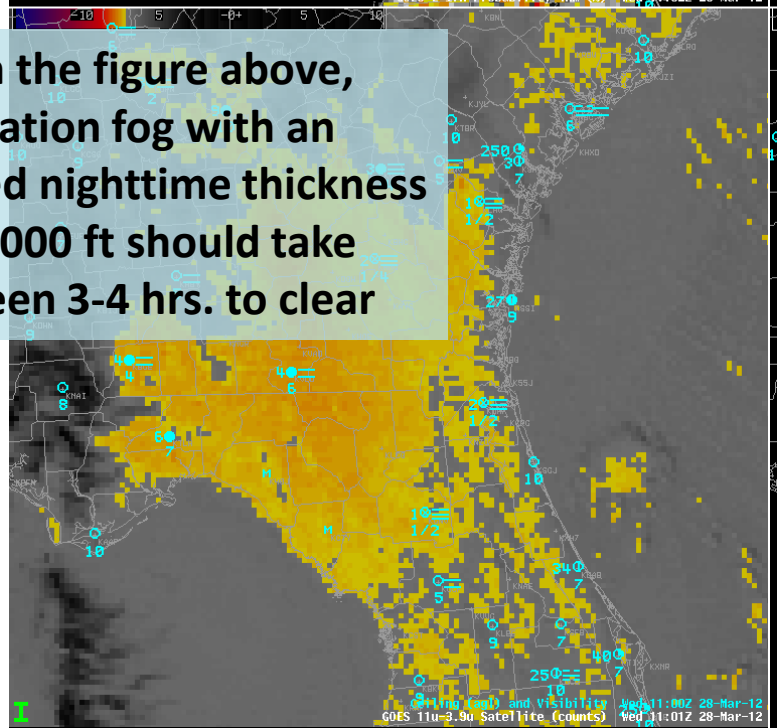


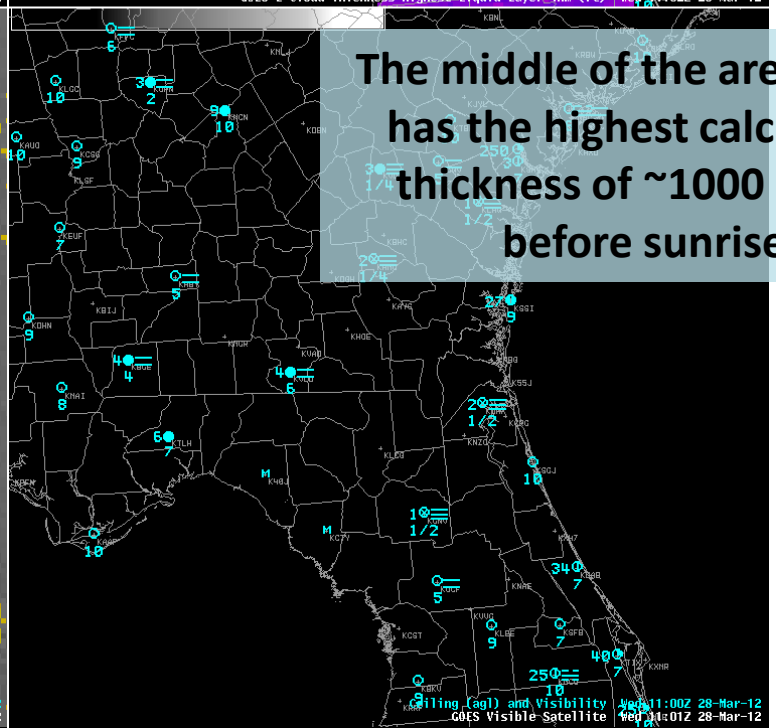


3/28/2012
11:02 UTC





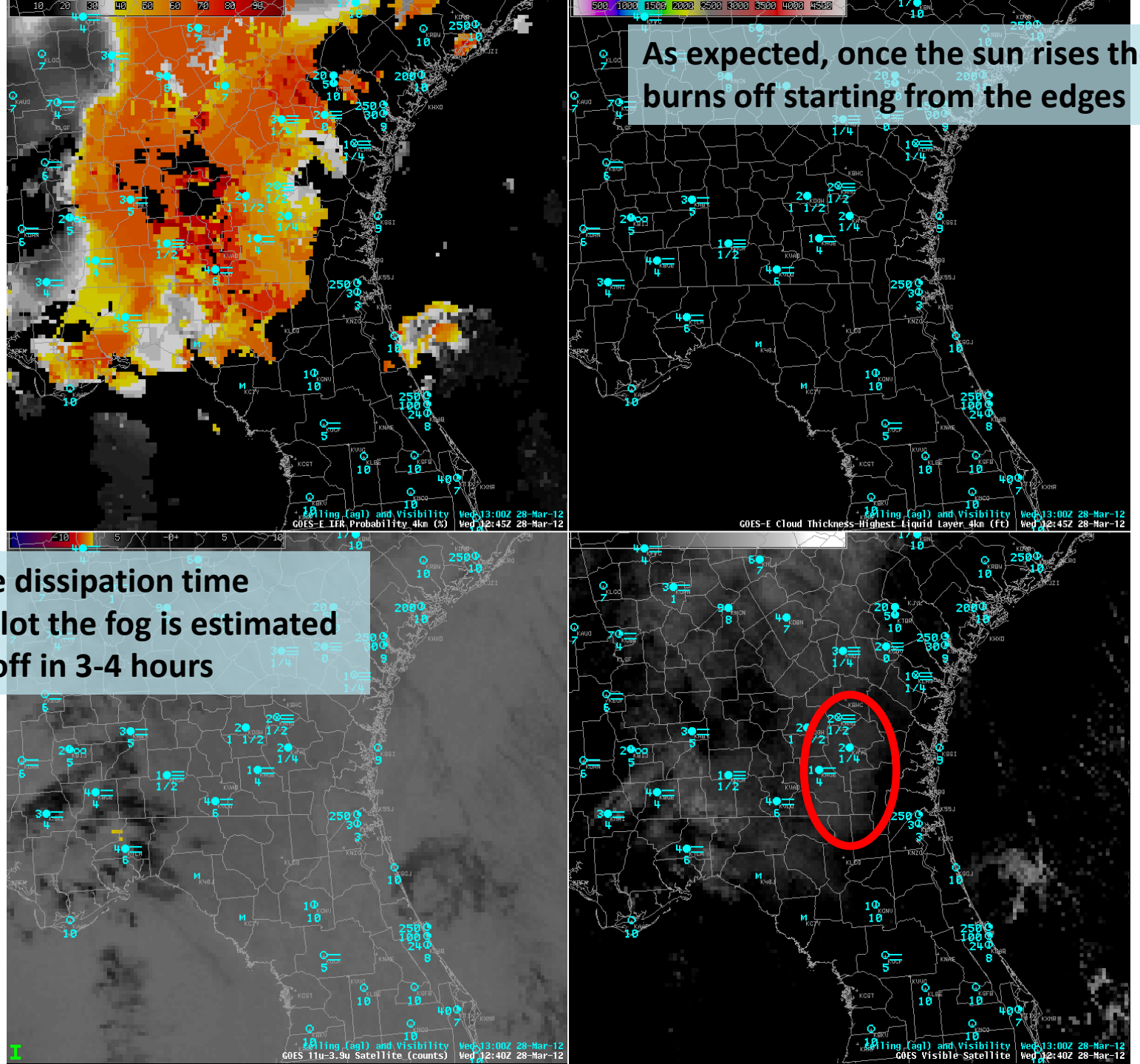




From the figure above, radiation fog with an estimated nighttime thickness of ~1000 ft should take between 3-4 hrs. to clear

The middle of the area of fog has the highest calculated thickness of ~1000 ft just before sunrise

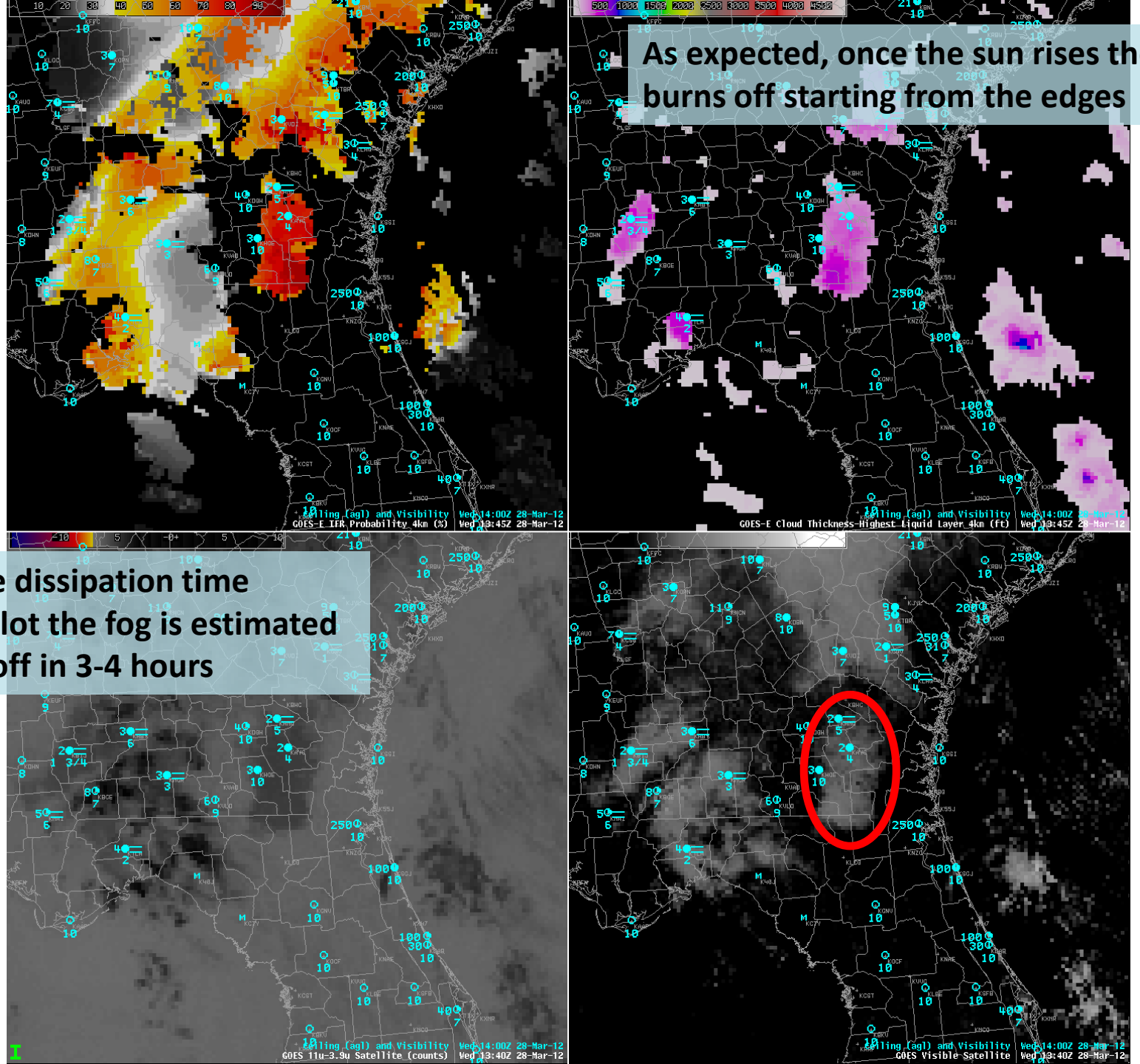
3/28/2012
11:02 UTC



As expected, once the sun rises the fog burns off starting from the edges

From the dissipation time scatter plot the fog is estimated to burn off in 3-4 hours

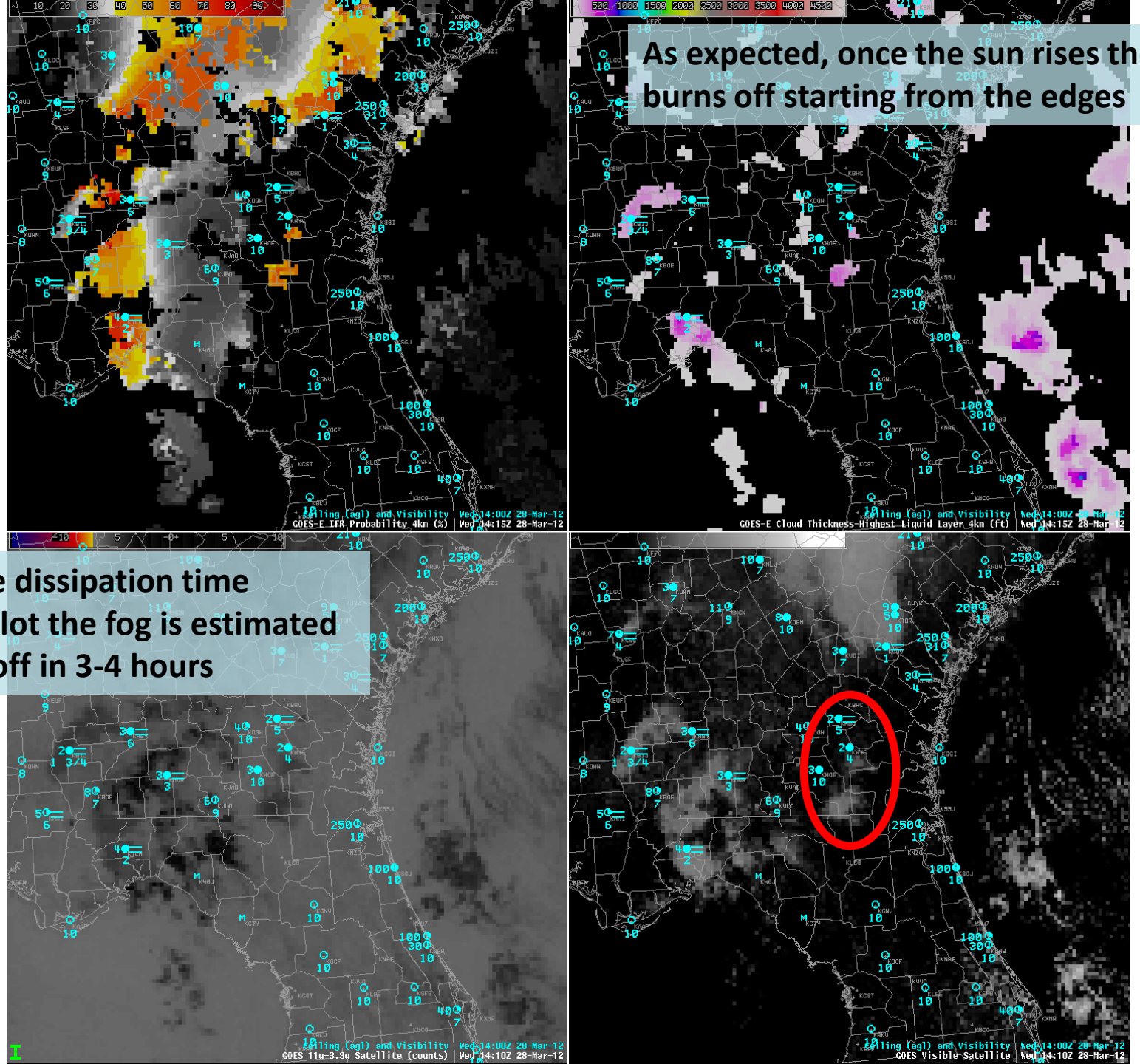
3/28/2012
12:45 UTC



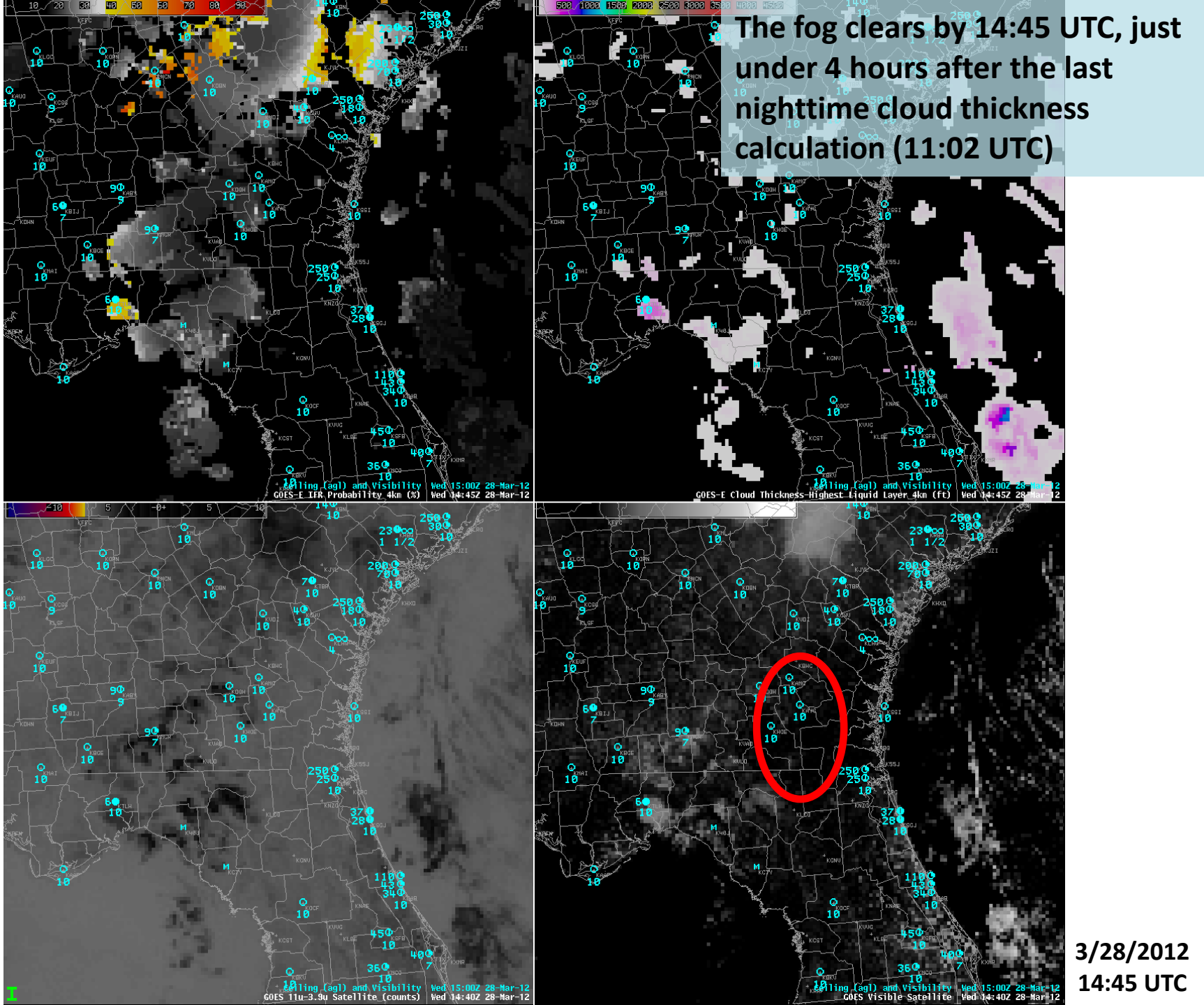
As expected, once the sun rises the fog burns off starting from the edges

From the dissipation time scatter plot the fog is estimated to burn off in 3-4 hours

3/28/2012
13:45 UTC



3/28/2012
14:15 UTC



The fog clears by 14:45 UTC, just under 4 hours after the last nighttime cloud thickness calculation (11:02 UTC)

3/28/2012
14:45 UTC