GOES-R AWG Aviation Team: Fog/Low Cloud Detection

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Outline

- Aviation Team
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- Validation Approach
- Validation Results
- Summary

Aviation Team

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- **Aviation Team**
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- Others
  - » Walter Wolf (AIT Lead)
  - » Shanna Sampson (Algorithm Integration)
  - » Zhaohui Zhang (Algorithm Integration)

Executive Summary

- This ABI Fog/Low Cloud detection algorithm generates two Option 2 products (fog/low cloud mask and depth)
- ABI channels 2, 7, and 14 are directly utilized in the algorithm. Many other channels (e.g. 10, 11, 15) are used indirectly through the cloud phase algorithm output.
- Software Version 3 was delivered in March. ATBD (80%) and test datasets are scheduled to be delivered in June 2010
- The algorithm uses spatial and spectral information to identify fog/low stratus clouds. The algorithm is capable of both day and night detection. Fog/low cloud depth is calculated for pixels positively identified by the fog mask
- Validation Datasets: Surface observations of ceiling over CONUS are used to validate the fog/low cloud mask. SODAR data from the San Francisco Bay area are used for the depth.
- Validation studies indicate that both products are in compliance with the 80% accuracy specification

Requirements and Product Qualifiers Low Cloud and Fog

Name	User & Priority	Geographic Coverage (G, H, C, M)	Temporal Coverage Qualifiers	Product Extent Qualifier	Cloud Cover Conditions Qualifier	Product Statistics Qualifier
Low Cloud and Fog	GOES-R	FD	Day and night	Quantitative out to at least 70 degrees LZA and qualitative beyond	Clear conditions down to feature of interest (no high clouds obscuring fog) associated with threshold accuracy	Over low cloud and fog cases with at least 42% occurrence in the region

Vertical Res.	Horiz. Res.	Mapping Accuracy	Msmnt. Range	Msmnt. Accuracy	Refresh Rate/Coverage Time Option (Mode 3)	Refresh Rate Option (Mode 4)	Data Latency	Long-Term Stability	Product Measurement Precision
0.5 km (depth)	2 km	1 km	Fog/No Fog	70% Correct Detection	15 min	5 min	159 sec	TBD	Undefined for binary mask

C – CONUS **FD** – Full Disk M - Mesoscale

Algorithm Description

What Is Fog?

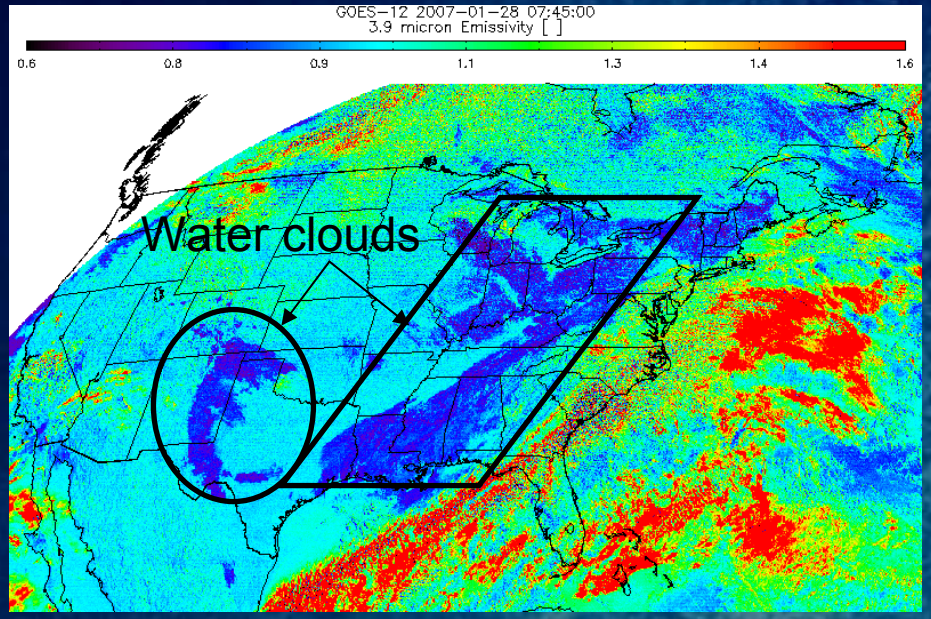
- **Aviation based fog/low cloud definition**
  - Visual flight rules - ceiling > 3000 ft (914 m)
  - Marginal visual flight rules 1000 ft (305 m) < ceiling < 3000 ft (914 m)
  - Instrument flight rules - 500 ft (152 m) < ceiling < 1000 ft (305 m)
  - Low instrument flight rules - ceiling < 500 ft (152 m)

Given the above definition, our aim is to identify clouds that have a ceiling lower than ~300 meters (instrument flight rules).

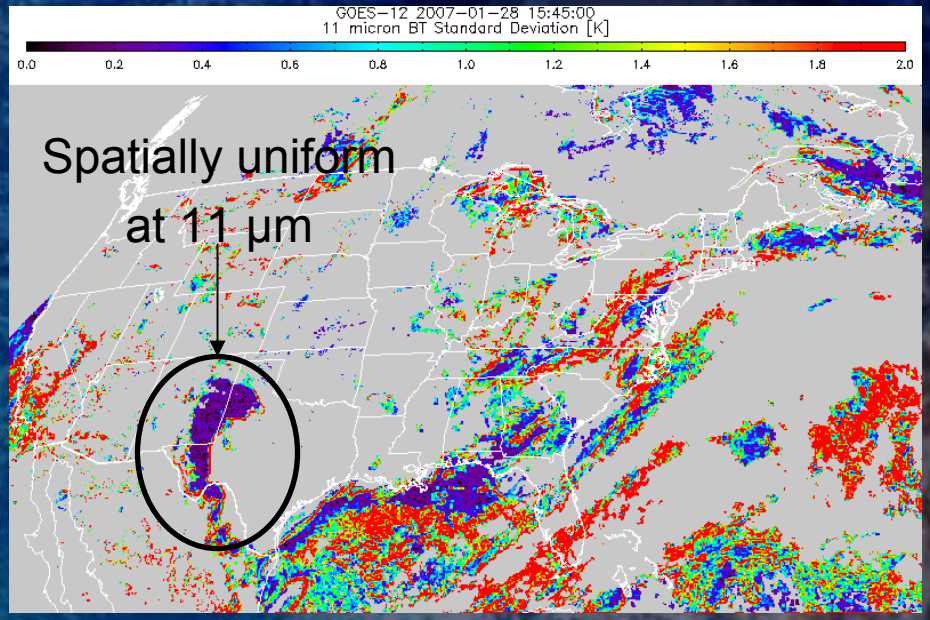
Fog/Low Cloud Detection

- **Characteristics of fog/low stratus cloud used for detection**
  - Low difference between the cloud temperature and modeled surface temperature (surface temperature bias)
  - Spatially uniform at 11µm and 0.65 µm
  - Low 3.9 µm pseudo-emissivity signal at night (akin to the traditional 3.9 -11 µm BTD)
  - Elevated 3.9 µm reflectance (small particles)

Nighttime 3.9 µm pseudo-emissivity



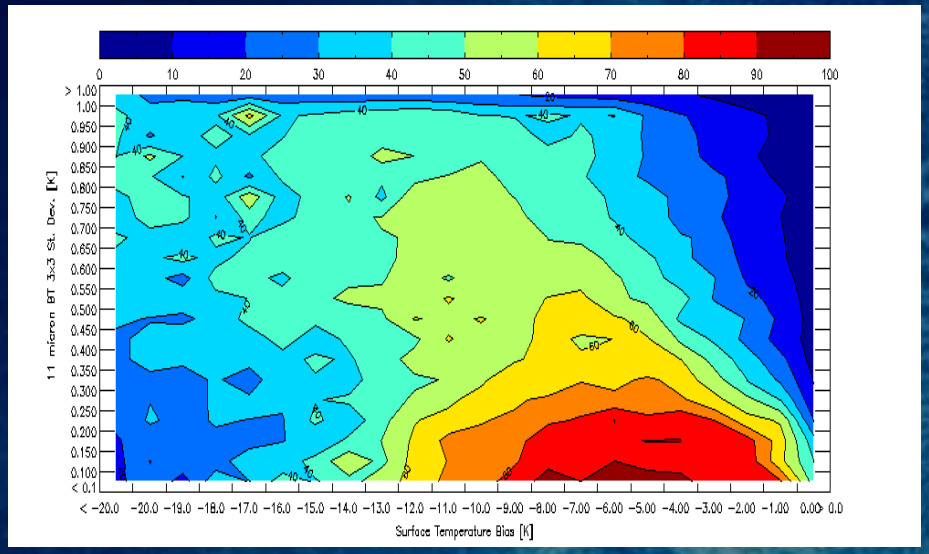
Daytime 11 µm spatial uniformity



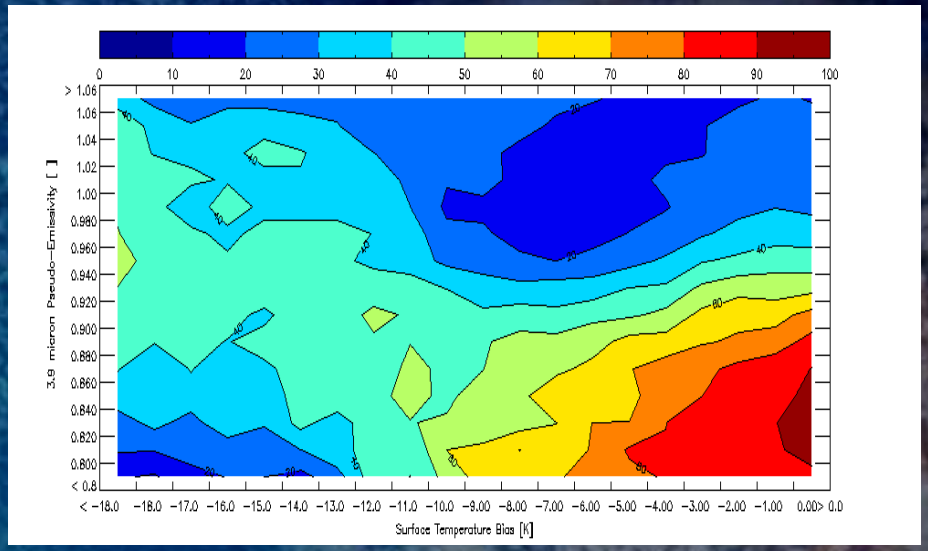
Fog/Low Cloud Detection

- First step is to use pre-determined LUT's to assign a probability that fog/low cloud is present at each pixel depending on the spectral and spatial characteristics
- During the day, the LUT is a function surface temperature bias and 11 μm spatial uniformity (within a 3 x 3 pixel array)
- At night, the LUT is a function of surface emissivity, surface temperature bias, and the 3.9 μm pseudo-emissivity

Daytime Fog Probability LUT



Nighttime Fog Probability LUT

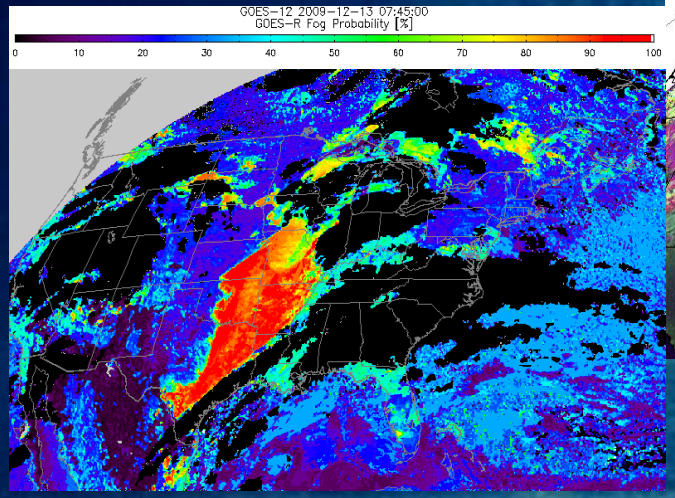


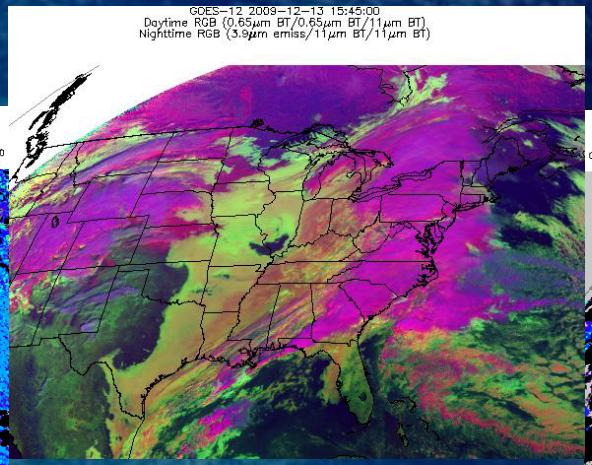
Fog/Low Cloud Detection

- At night, the fog probability LUT is applied to all pixels that are not flagged as multi-layered or ice clouds by the GOES-R cloud type algorithm (including clear pixels)

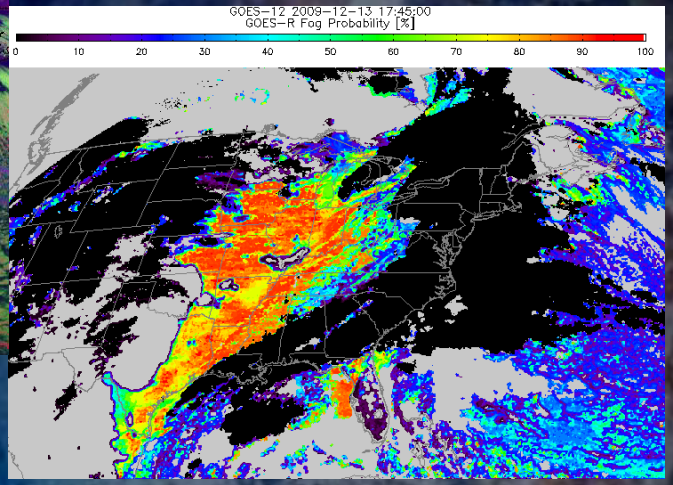
- During the day, the fog probability LUT is applied to all pixels that are flagged as liquid water, supercooled liquid water, or mixed phase by the GOES-R cloud typing

Nighttime Fog Probability from LUT





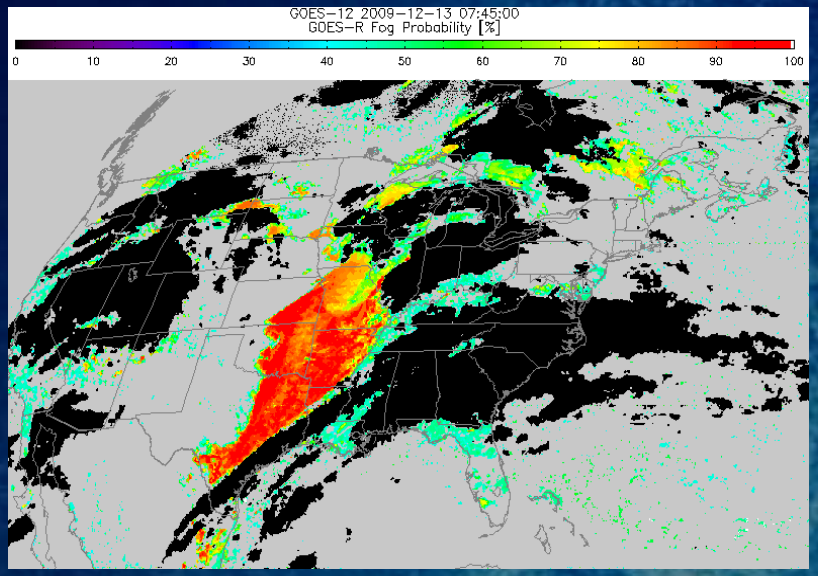
Daytime Fog Probability from LUT



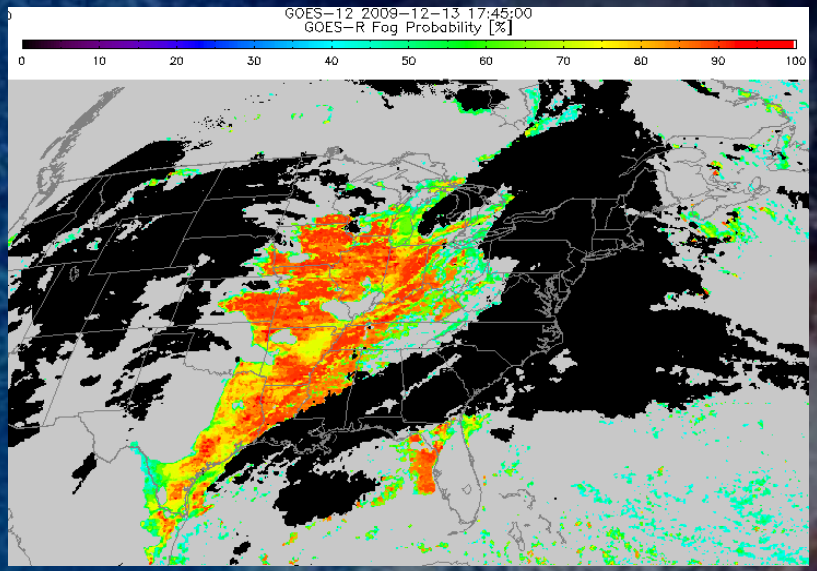
Use of Cloud Objects

- A cloud object is defined as spatially connected pixels that meet a certain set of criteria.
- Cloud objects are used to address the problem of spectral non-uniqueness (e.g. not all fog pixels will have a totally unique spectral signature).
- The methodology of Wielicki and Welch (1986) is used to construct cloud objects.
- In the fog algorithm, cloud objects are constructed from pixels whose fog probability from the LUT is greater than 40%.

Nighttime Fog Object Mask



Daytime Fog Object Mask



Cloud Object Illustration

- **In this simplified generic example, assume fog *might* be present when pixel values exceed 6 (arbitrary units) and fog is *very likely present* when pixel values exceed 40.**

0	4	5	4	6	3	2	1	2	1	2	3	4	3	2	2	1	1	3	3	1	2	3	3	3	3	2	1
1	10	8	6	10	8	2	2	3	2	4	3	2	1	2	2	1	2	2	2	0	1	2	2	3	3	3	2
3	12	7	9	11	9	7	2	3	1	6	7	6	4	3	3	3	2	4	5	2	1	2	3	3	3	3	2
2	6	7	8	9	8	12	9	3	1	10	19	18	15	10	5	3	1	4	6	3	1	2	3	2	7	2	2
1	5	5	5	6	7	9	8	5	3	11	26	34	26	15	4	1	0	2	4	2	2	2	7	7	9	3	2
2	1	3	4	4	3	1	7	6	2	32	30	35	32	16	3	4	1	2	3	2	2	3	10	8	10	2	3
3	2	0	3	4	4	1	6	6	1	66	48	34	30	15	4	4	2	2	2	2	3	8	12	10	11	2	3
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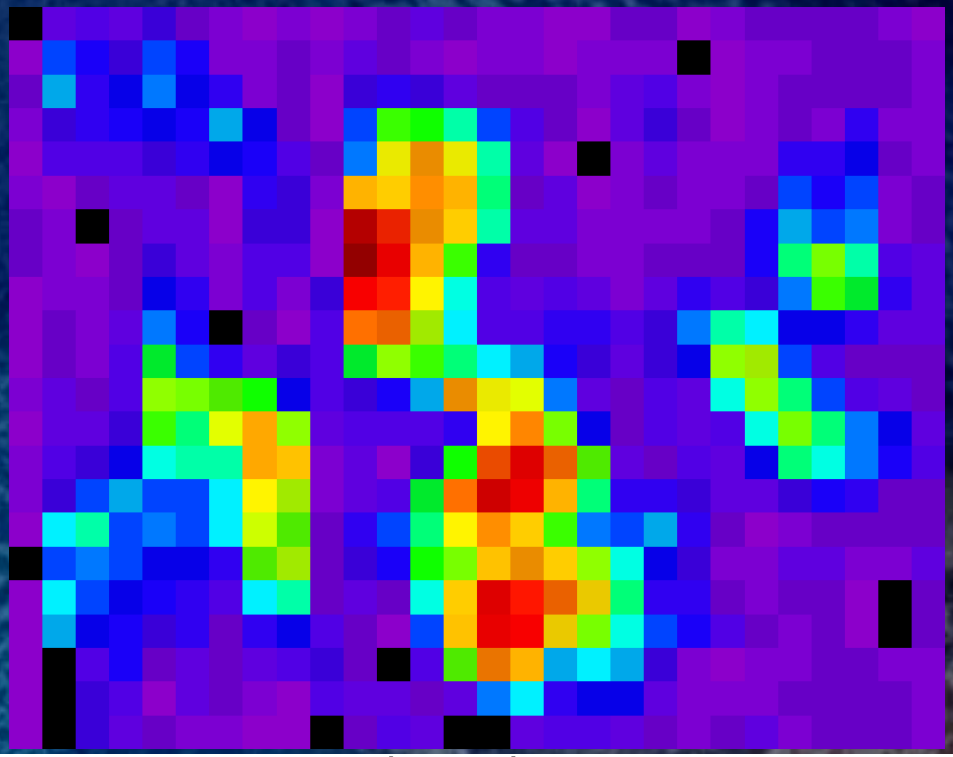

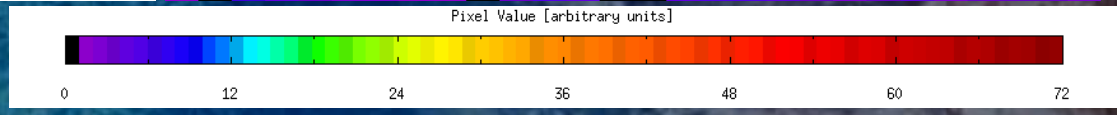

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1	10	8	6	10	8	2	2	3	2	4	3	2	1	2	2	1	2	2	2	0	1	2	2	3	3	3	2
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1	13	15	10	11	10	13	24	20	3	7	10	16	27	35	30	19	11	10	12	7	3	1	2	3	3	3	3
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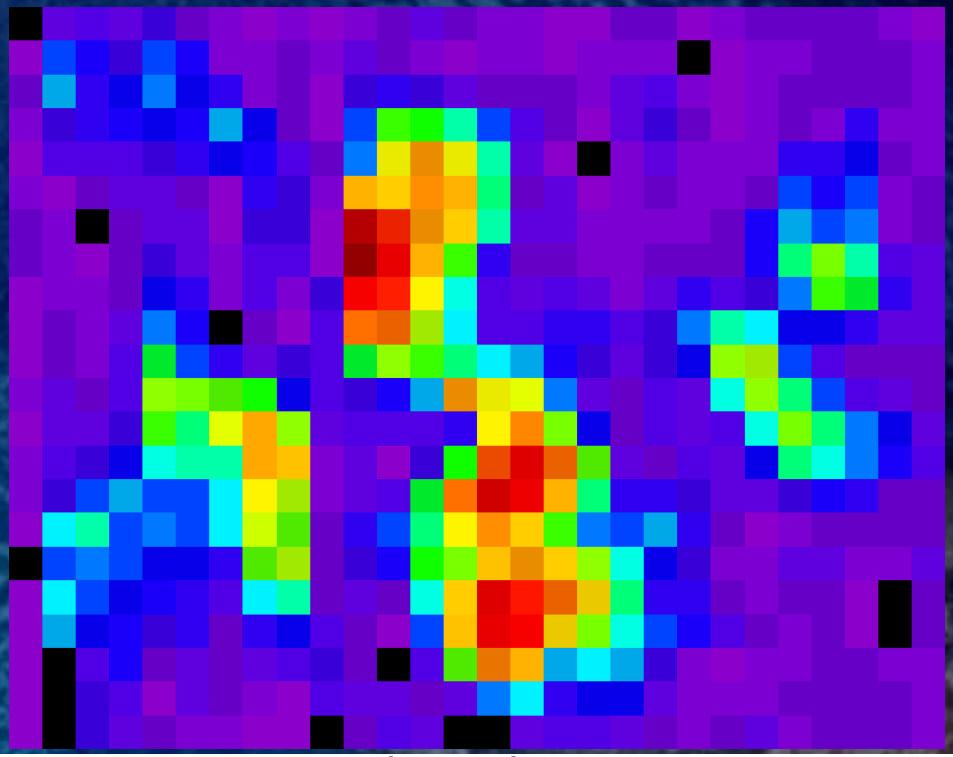
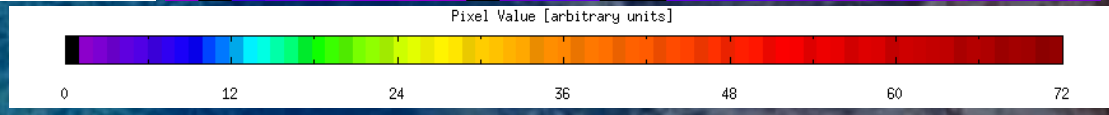
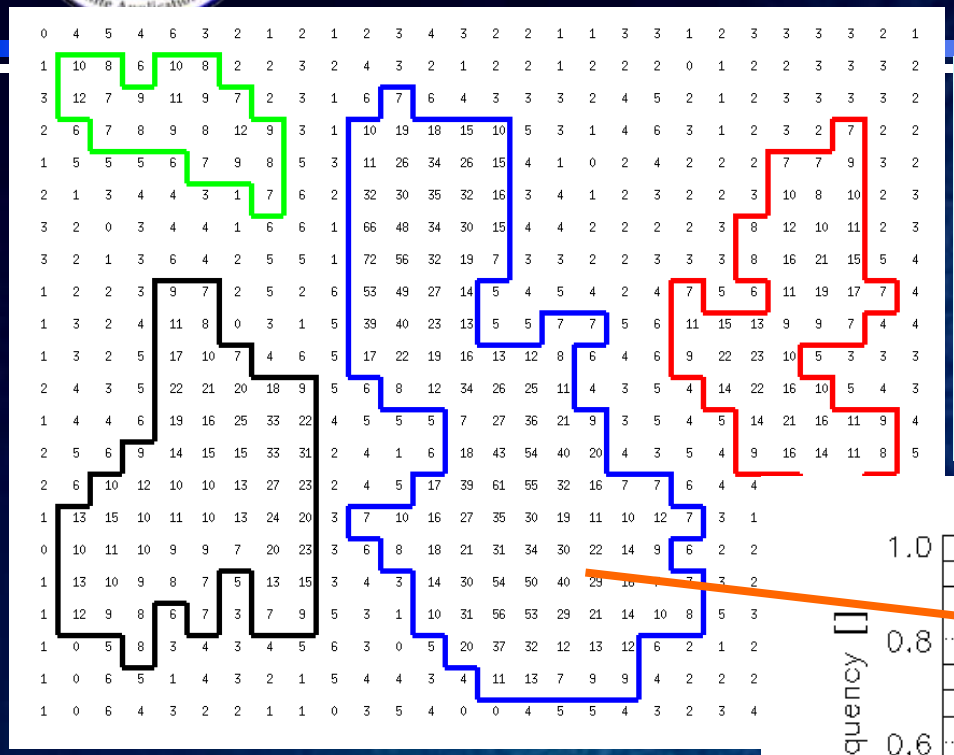
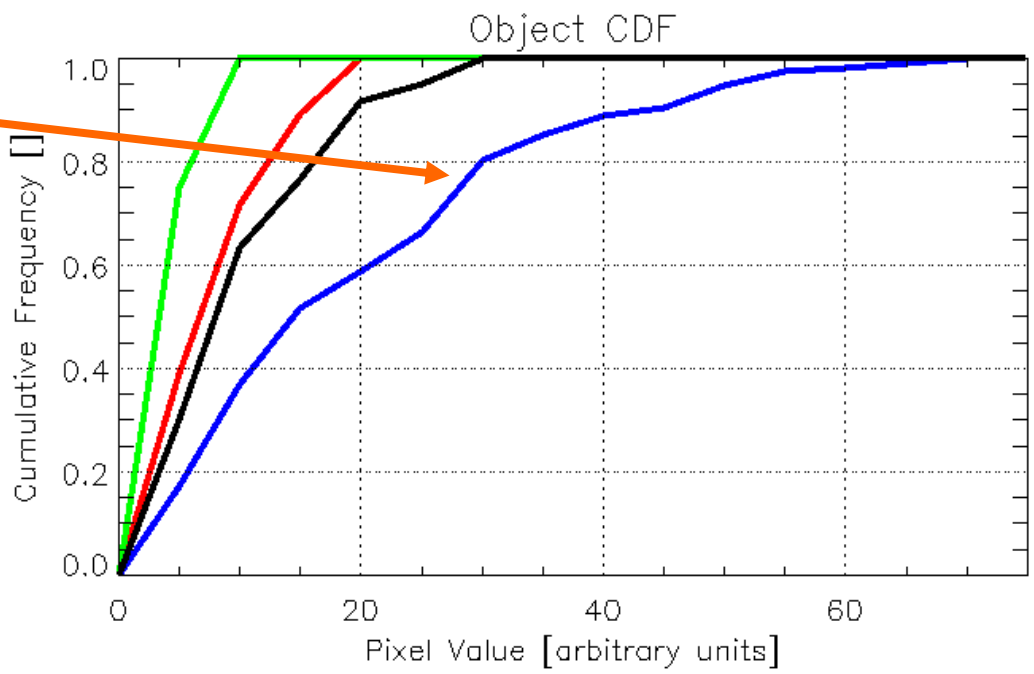




Cloud Object Illustration



- While each object has several pixel values that numerically overlap with all other objects, only the object outlined in blue contains pixel values that exceed our high confidence fog threshold.
- *As such, only the pixels that compose the "blue" object will be classified as fog.*



Cloud Object Based Fog/Low Cloud Detection

- The previous simple example illustrates how the fog detection algorithm works.
- Object membership is primarily determined by fog probability obtained from pre-determined LUT's and surface temperature bias.
- A set of spectral and spatial cloud object statistics are computed for each object (e.g. IR channel CDF's, reflective channel CDF's, spatial uniformity metrics, etc…)
- For each object, all of the pixels that compose the object are either fog or not fog based on thresholds applied to the cloud object statistics.

Retrieval Strategy for Fog Depth

- The fog depth retrieval is performed on pixels that have a discernable fog signal as determined by the fog detection algorithm.
- During the day, the fog depth is computed using the retrieved liquid water path and an assumed liquid water content consistent with in-situ measurements of fog.
- At night, a regression relationship, conceptually similar to the one developed by Ellrod, is used.
- Fog depth retrievals are not possible in the day/night terminator.

Retrieval Strategy for Fog Depth

Daytime approach: **Use the retrieved liquid water path (LWP) and an assumed liquid water content (LWC) to calculate the cloud geometrical thickness (e.g. fog depth).**

The fog depth (ΔZ) is given by:

$$\Delta Z = LWP / LWC$$

- **The LWP is produced by the cloud team.**
- **The LWC is assumed to be 0.06 g/m^3 (Hess et. al, 1998).**
- **The LWP is only available for solar zenith angles < 70°.**

Retrieval Strategy for Fog Depth

Nighttime approach: **Use a regression relationship between the $ems_{ac}(3.9\mu m)$ and fog depth determined from ground based instruments to estimate fog depth.**

The fog depth (ΔZ) is given by the following regression equation:

$$\Delta Z = A[ems_{ac}(3.9\mu m)] + B$$

A and B are regression constants.

- **This approach is analogous to the Ellrod method, except $ems_{ac}(3.9\mu m)$ is used in lieu of the 3.9 - 11 μm brightness temperature difference.**
- **The following analysis will illustrate the benefits of using ems_{ac} $(3.9\mu m)$.**

Fog/Low Cloud Detection Processing Schematic

INPUT: ABI data, cloud phase output, cloud optical properties output, and ancillary data

↓

Use LUTs to determine the probability that any given pixel contains fog/low cloud

↓

Determine which pixels meet cloud object membership criteria

↓

Construct cloud objects and compute cloud object statistics

↓

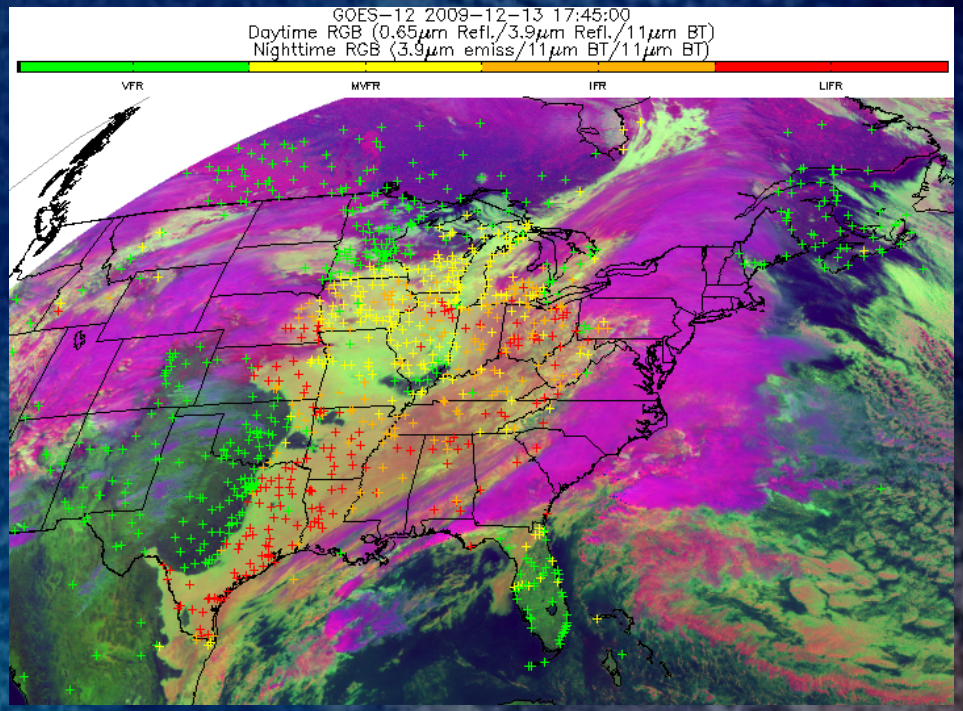
Use object statistics to determine which cloud objects are fog/low cloud

↓

Calculate fog/low cloud depth

↓

Output Fog/Low Cloud Mask

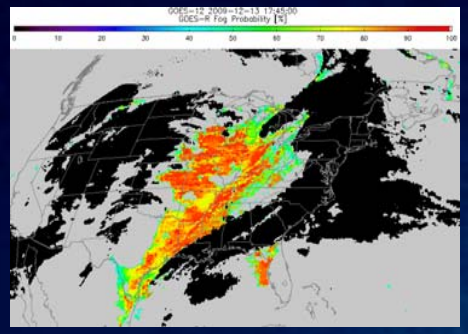


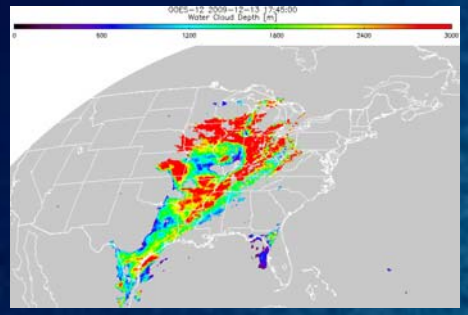
Algorithm Summary

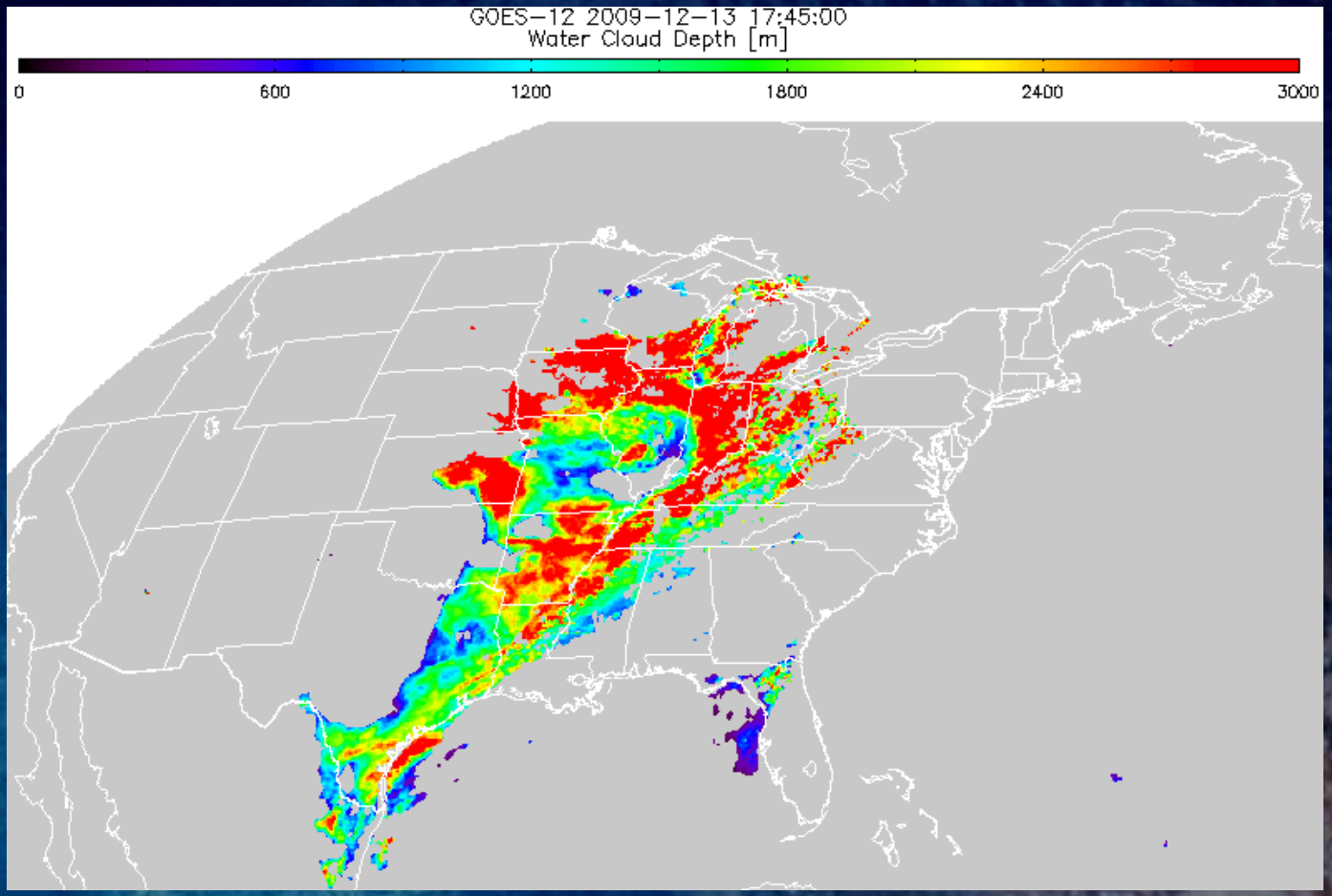
- Input Datasets: 1). ABI channels 2,7,14, 2). GOES-R cloud phase and daytime optical properties, 3). Solar zenith angle, 4). Clear sky radiances and transmittances, 5). NWP forecast data (GFS), 6). Fog/low cloud LUT's
- Cloud objects are constructed from potential fog/low cloud pixels.
- Spectral and spatial cloud object statistics are used to determine if all of the pixels that compose a cloud object contain fog or do not contain fog.
- The fog/low cloud depth is created for every pixel positively identified by the fog/low cloud mask

Examples of Product Output

Fog/Low Cloud Detection Product Output

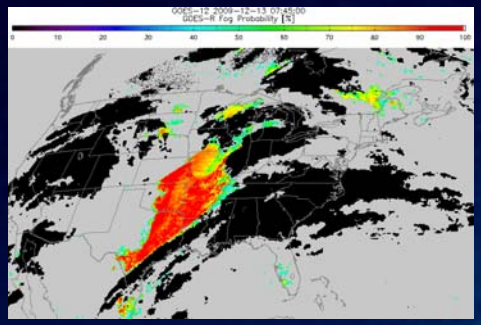


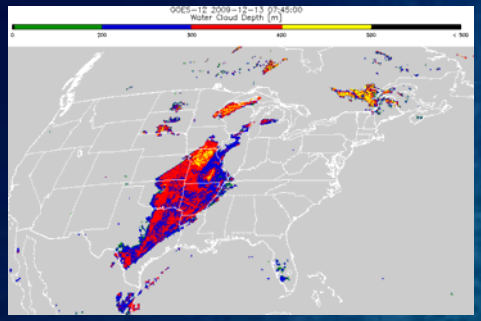


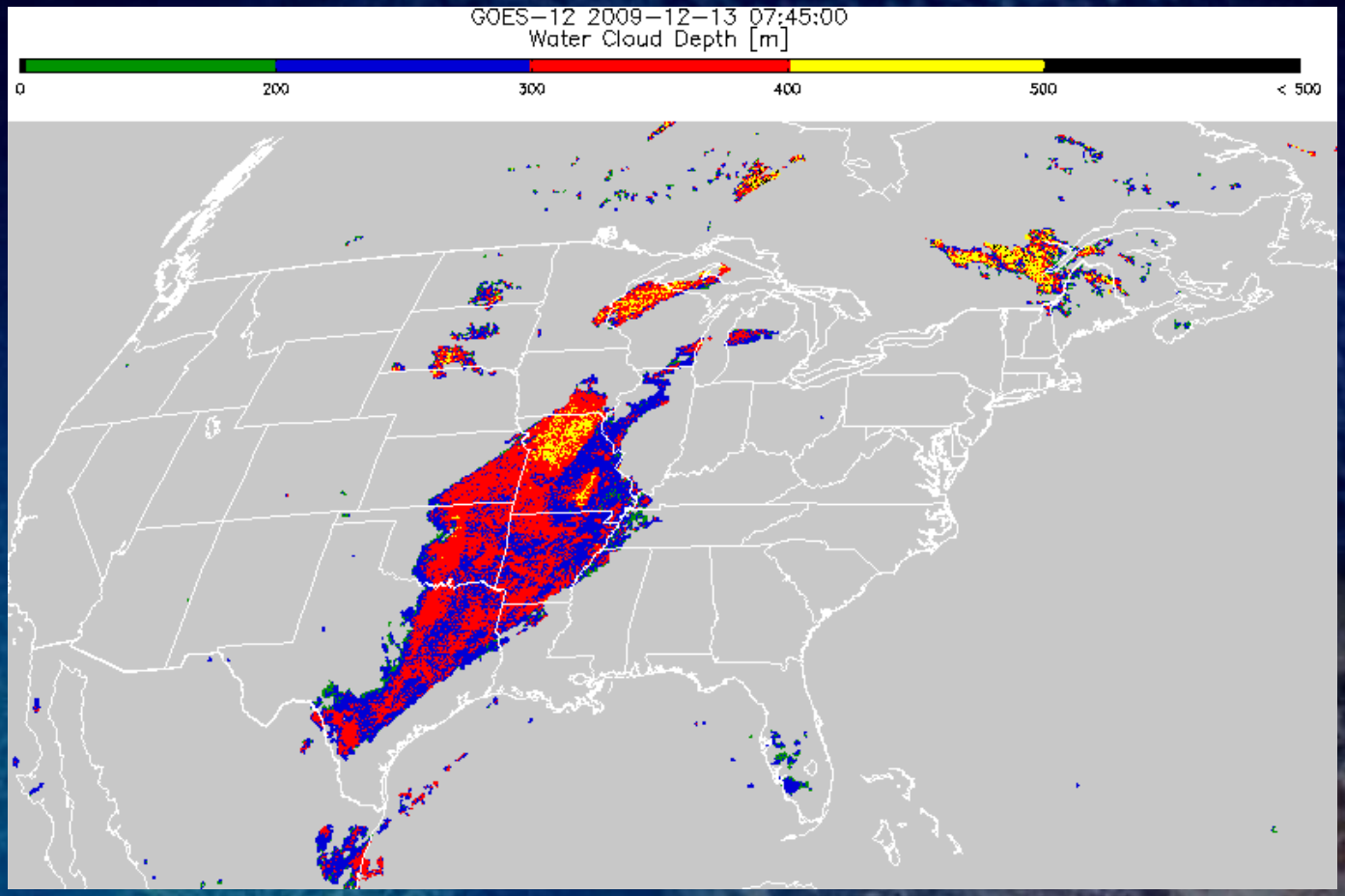


Daytime outputs

Fog/Low Cloud Detection Product Output

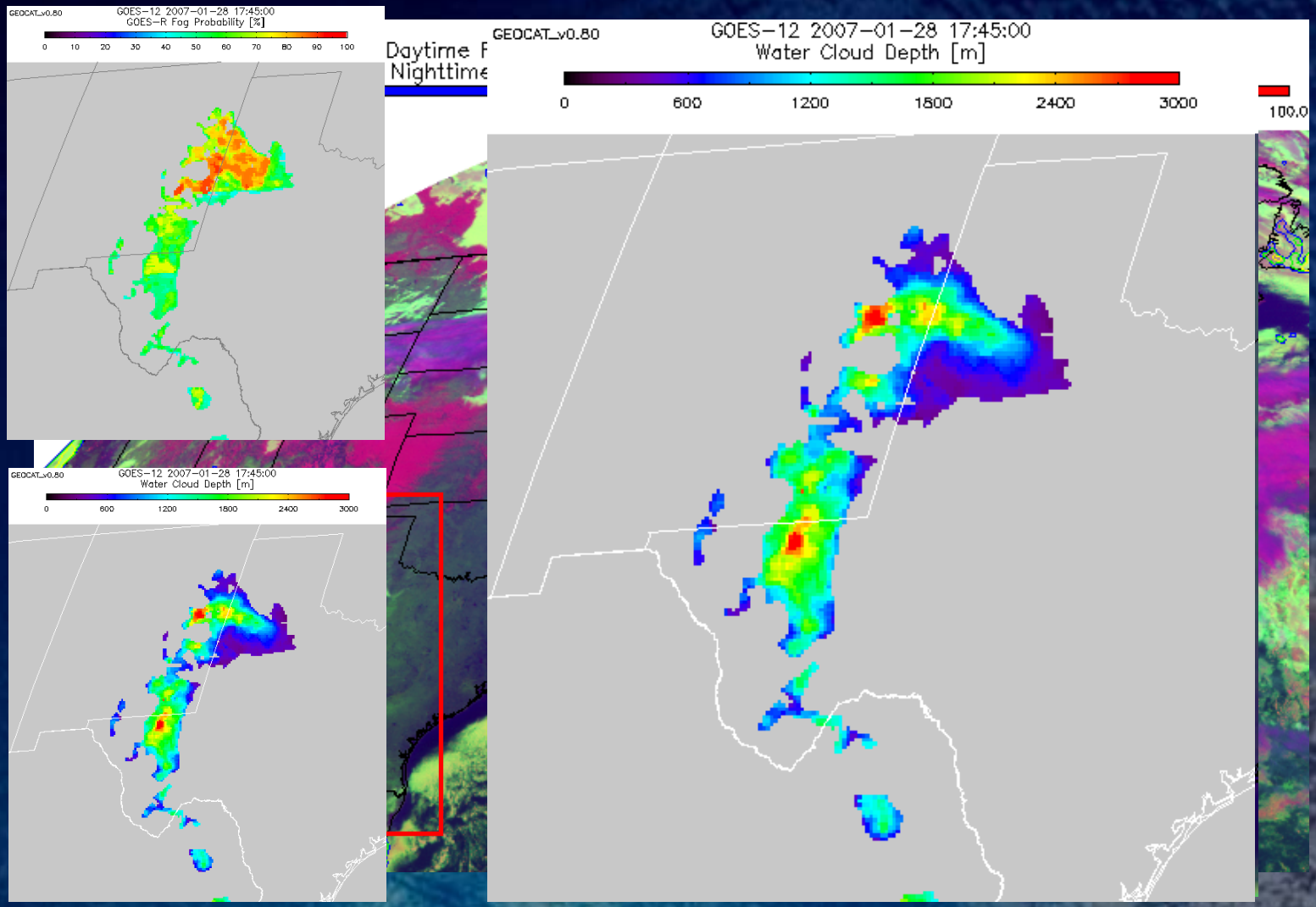




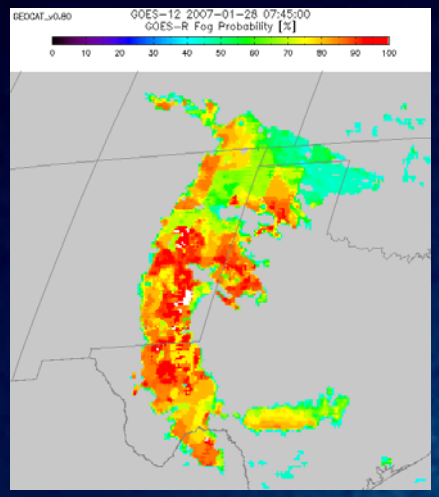


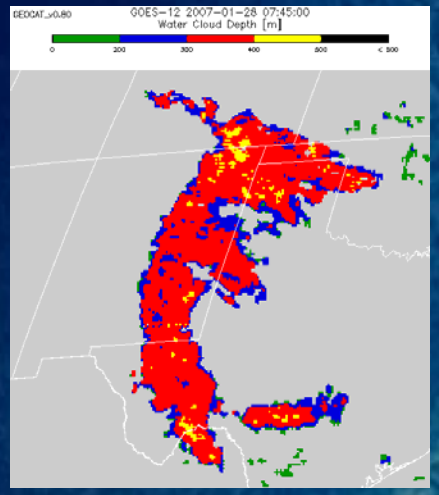
Nighttime outputs

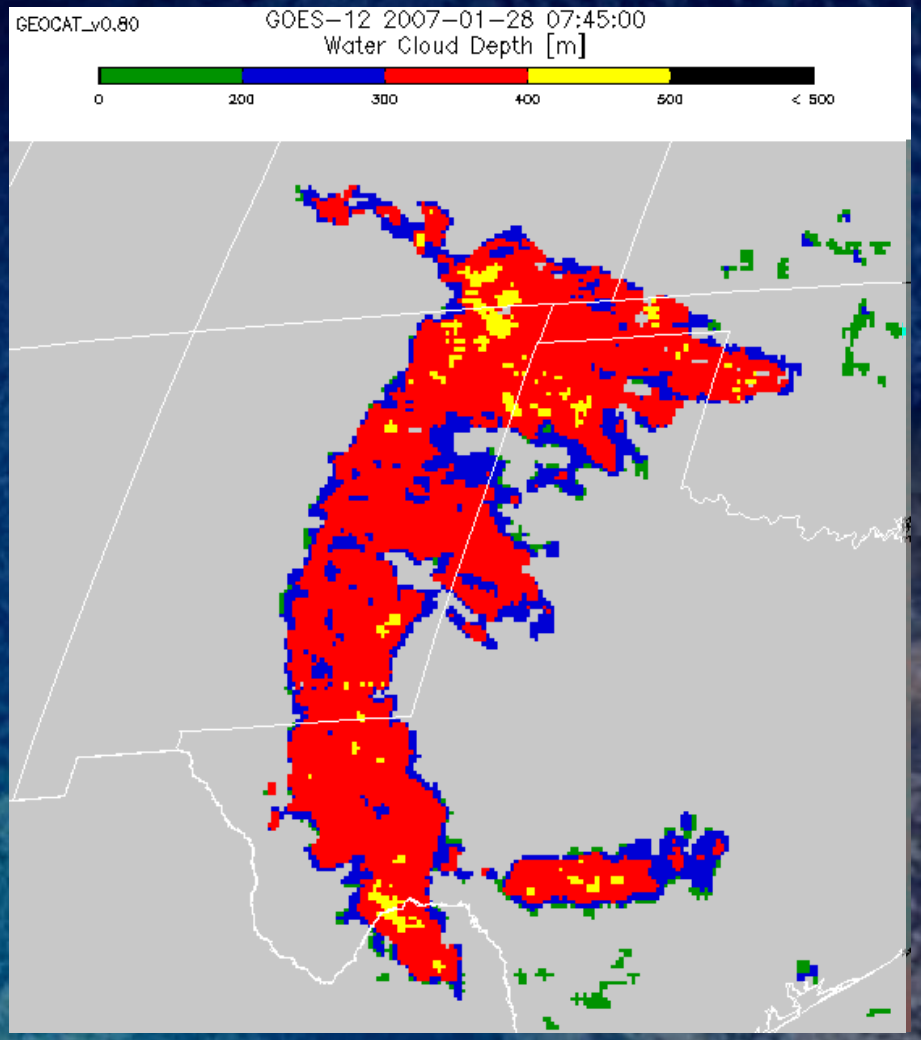
Fog/Low Cloud Detection Product Output



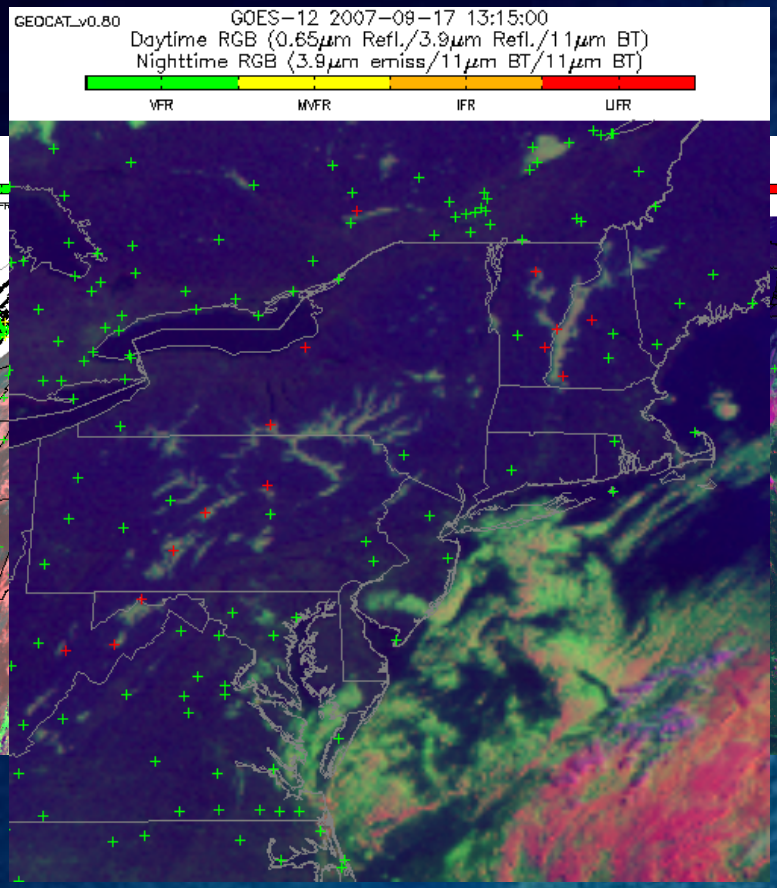
Fog/Low Cloud Detection Product Output

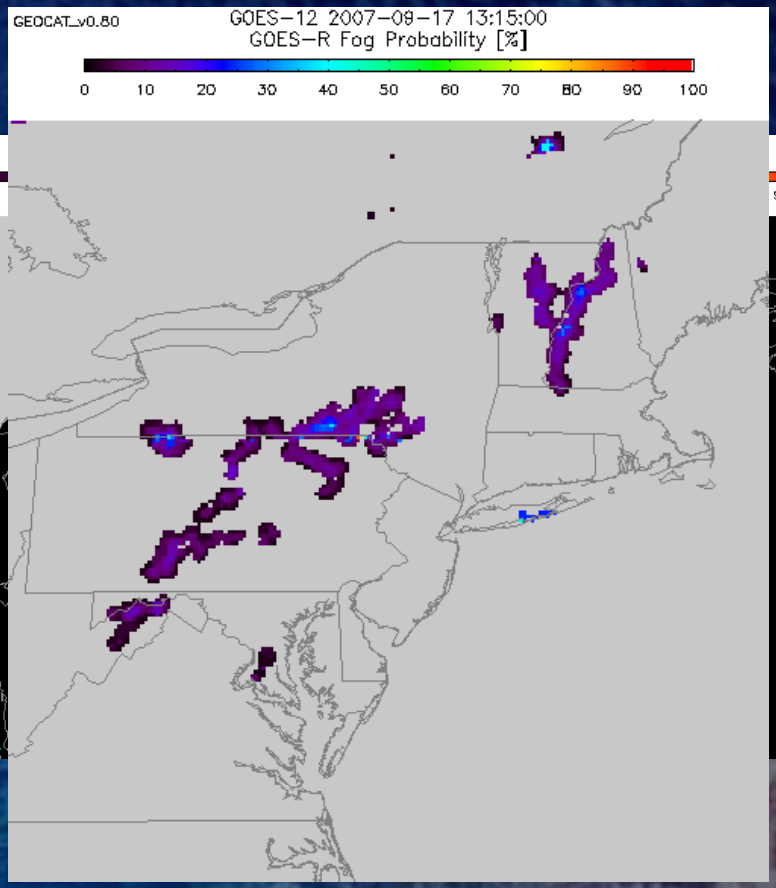






Fog/Low Cloud Detection Product Output





Validation Approach

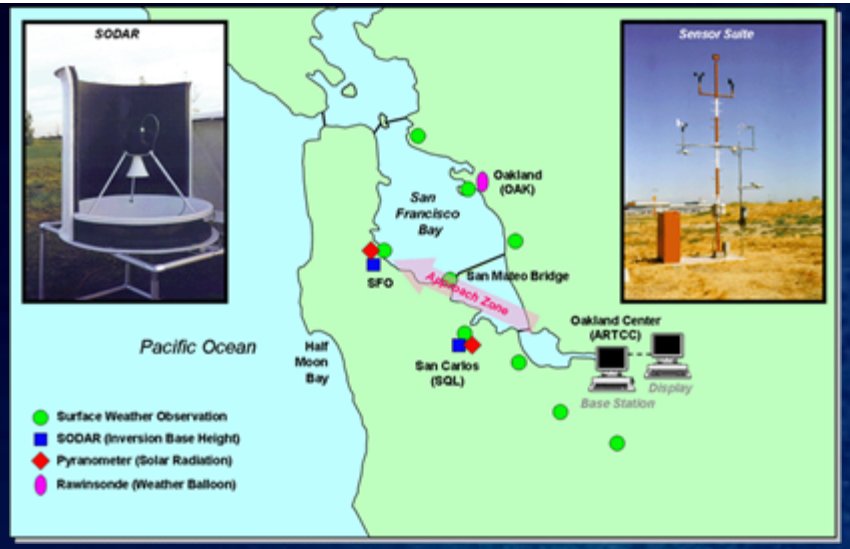
Validation Approach: Datasets

- Test data
  - » GOES-12 data over CONUS (greatest amount of surface observations)
- Truth data
  - » Surface observations of ceiling height
  - » SODAR data (for fog depth)
  - » CALIOP cloud layer product combined with surface observations (current focus of validation efforts, presented validation is based on surface observations alone)

Fog/Low Cloud Detection Validation Approach

- ***Fog/low cloud detection validation methodology***
  - » Assess fog detection as a function of surface observations of cloud ceiling
- ***Fog depth validation methodology***
  - » Cloud boundaries derived from a combination of ceilometer and SODAR measurements are used to determine fog depth

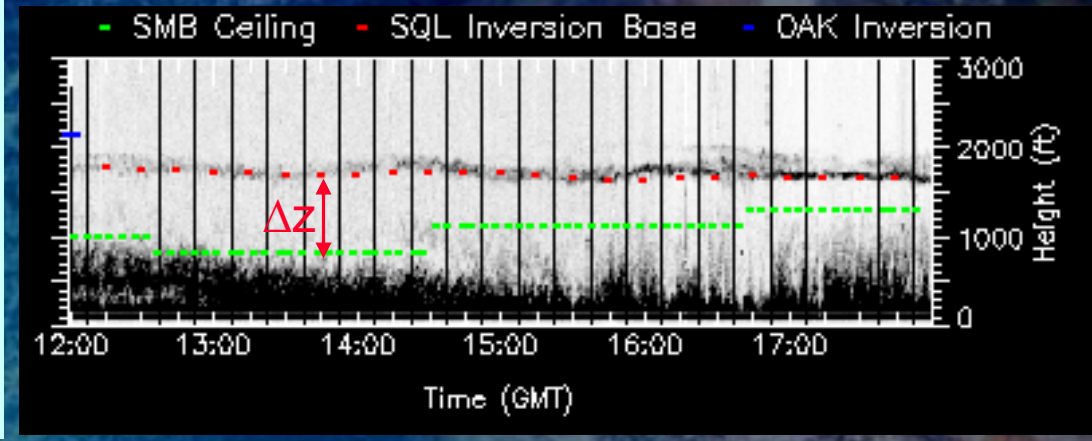
Fog/Low Cloud Depth Validation Approach



•The acoustic SODAR (Sonic Detection And Ranging) is an upwardly pointing parabolic antenna that emits an audible signal whose return signal is proportional to the vertical gradient of air density. As such, the SODAR is capable of detecting the base of the inversion, which defines the top of the stratus deck.

•A combination of ceilometer and SODAR measurements are used to infer the geometric boundaries of low clouds in the San Francisco Bay Area.

•This network of instruments is operated by the FAA and NWS.



Validation Results

Fog/Low Cloud Detection Validation Results

- Currently focusing on two large-scale fog events to test the validation strategy.
- Surface observations were gathered for a 24-hour period for each event.
  - » ~20,000 observations for each event
- Surface observations reporting ceilings < 300m were considered fog/low cloud
- The GOES-R cloud type algorithm was used to screen observations under multi-layered or ice clouds that would contaminate validation

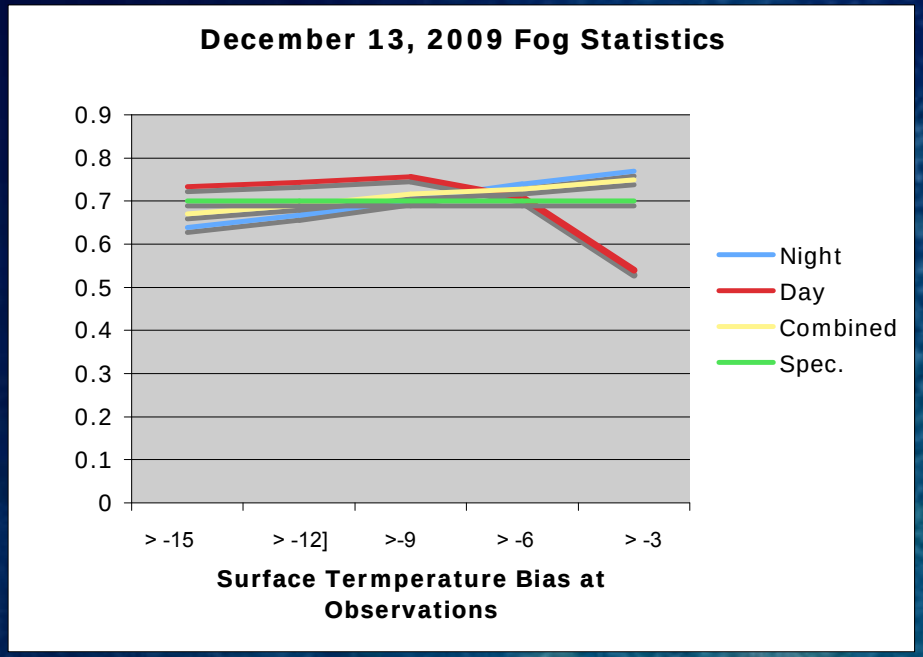
Fog / Low Cloud Detection Validation Results

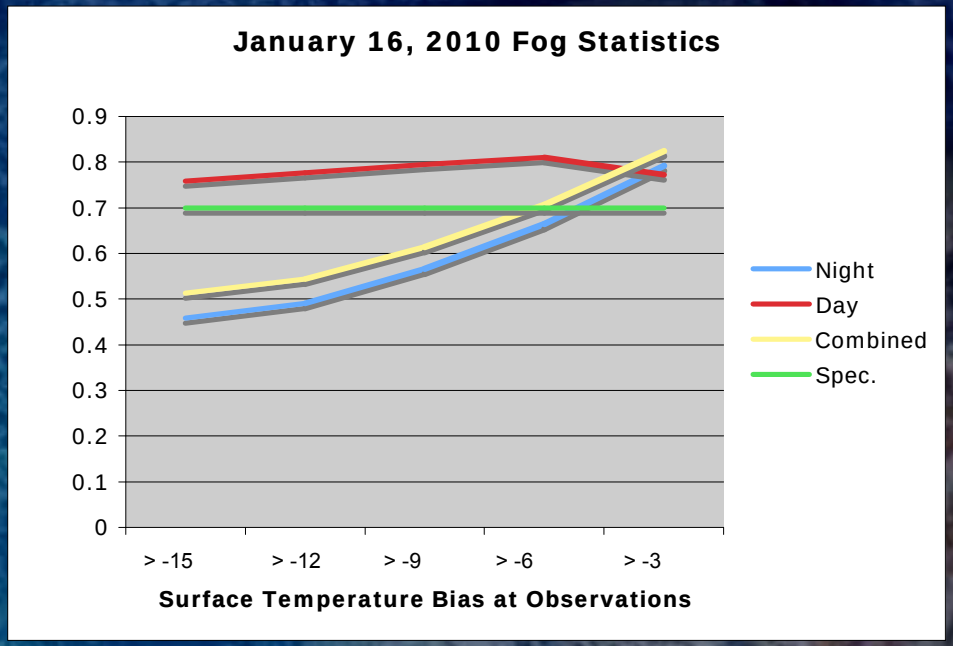
Date		# obs	POD	FAR	Skill
13-Dec-08	Day	7139	0.803	0.07	0.733
	Night	14926	0.764	0.125	0.639
	Both	22065	0.779	0.11	0.67
16-Jan-10	Day	5423	0.823	0.064	0.759
	Night	19952	0.637	0.178	0.458
	Both	25375	0.664	0.151	0.513

- The GOES-R fog/low cloud specification is 70%
- Initial calculated skill scores for the two events fall short
- Surface observations appear to be the issue
  - » Observations with thin cirrus overhead sometimes are missed by the cloud type multilayered ice cloud detection and the cloud type algorithm is not designed (or required) to detect multilayered liquid water clouds.
  - » Unlimited ceilings (clear sky) and unreported ceilings from surface observations are not differentiated
- Further screening of the surface observations can help remove reports that are considered poor for this method of validation

Fog / Low Cloud Detection Validation Results

- Observations with multiple cloud layers overhead that are missed by the cloud type algorithm are one problematic source of error
  - » By separating the results using the surface temperature bias (the difference between the IR inferred surface temperature and the NWP surface temperature) at the observation locations, the impact of contaminated ceiling reports can be seen
  - » When using obs with low surface temperature bias alone the fog detection specification can be reached

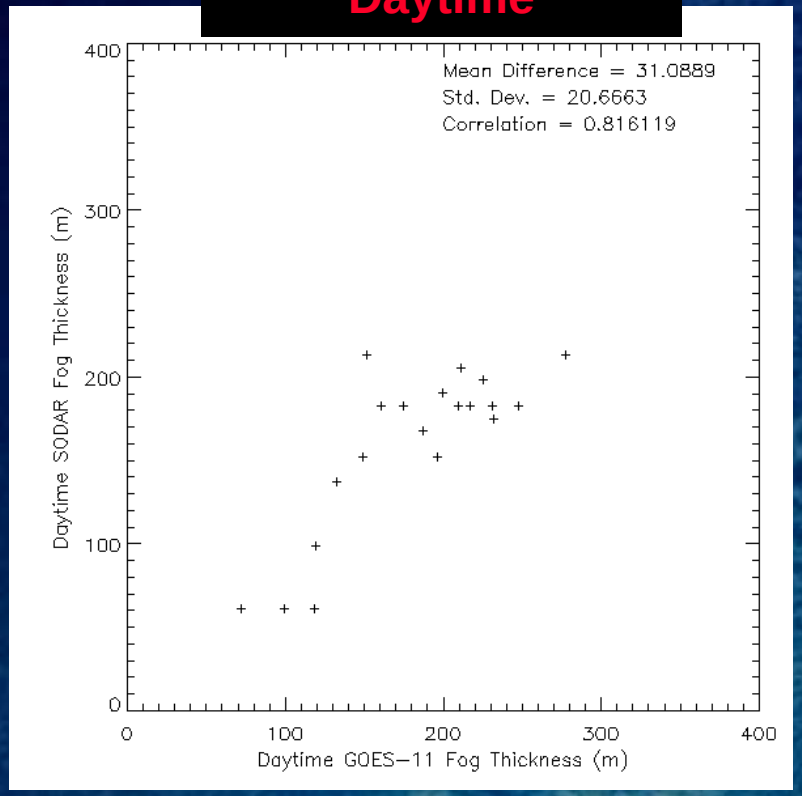




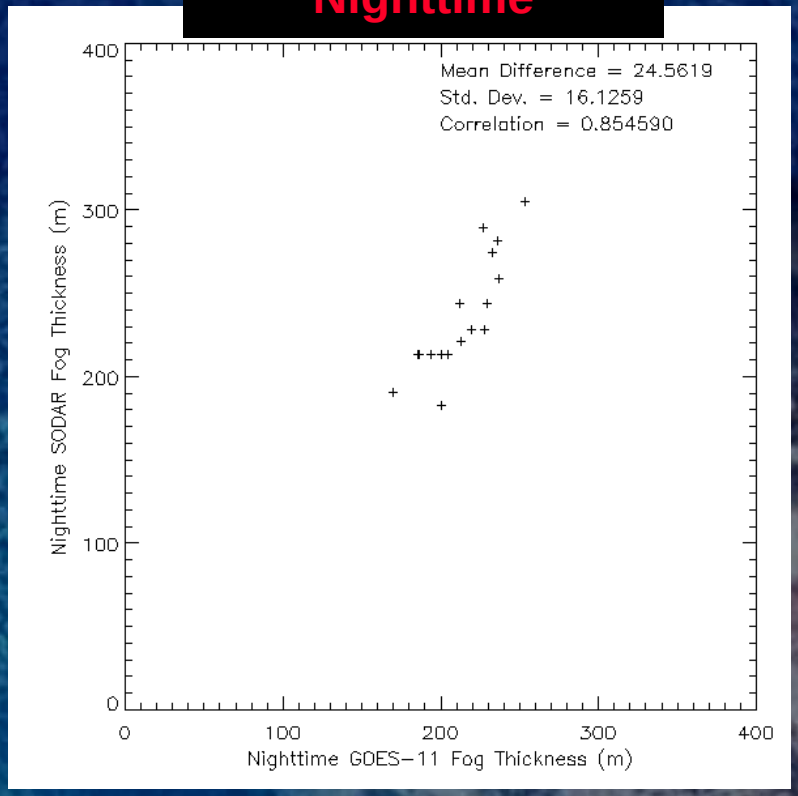
Fog / Low Cloud Depth Validation Results

Initial performance estimates indicate that the 500 m accuracy will be readily achieved (bias < 32 m). The strong correlations indicate that the spatial and temporal patterns are informative.

Daytime



Nighttime



Fog/Low Cloud F&PS Requirements and Validation

Product Measurement Range	Product Measurement Accuracy	Fog Detection Validation Using GOES-12 data over CONUS	Product Vertical Resolution	Fog Depth Validation using SODAR data
Binary Yes/No	56% correct detection (80% of spec.) 70% correct detection (100% of spec.)	59.7% (two cases combined, ~47,500 observations) *The skill score increases significantly when large T_{sfc} bias pixels are screened out.	0.5 km (fog depth)	31 m (day) 25 m (night)

Summary

- The GOES-R ABI fog/low cloud detection algorithm provides a new capability for objective detection of hazardous aviation conditions created by fog/low clouds
- Improved ABI spatial and temporal resolution will likely improve detection capabilities
- The GOES-R fog algorithm in on track to meet all performance and latency requirements
- These products are currently being evaluated using a real-time website (http://cimss.wisc.edu/geocat)