GOES-R AWG Aviation Team: SO_2 Detection

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NOAA/NESDIS/STAR

With contributions from: Andrew Parker
UW-CIMSS

Outline

- Aviation Team
- Executive Summary
- Algorithm Description
- Examples of Product Output
- Validation Approach
- Validation Results
- Summary

Aviation Team

- **Co-Chairs:** Ken Pryor and Wayne Feltz
- **Aviation Team**
  - » K. Bedka, J. Brunner, W. MacKenzie
  - » J. Mecikalski, M. Pavolonis, B. Pierce
  - » W. Smith, Jr., A. Wimmers, J. Sieglaff
- Others
  - » Walter Wolf (AIT Lead)
  - » Shanna Sampson (Algorithm Integration)
  - » Zhaohui Zhang (Algorithm Integration)

Executive Summary

- This ABI SO_2 detection algorithm produces a yes/no SO_2 flag
- Software Version 3 was delivered in March. ATBD (80%) and test datasets are scheduled to be delivered in June 2010
- The SO_2 detection algorithm utilizes spectral and spatial information to identify SO_2 clouds. Only infrared measurements are used, so the algorithm methodology is day/night consistent.
- Validation Datasets: Hyperspectral ultra-violet based retrievals of SO_2 total column loading from the Ozone Monitoring Instrument (OMI).
- Validation studies indicate that the SO_2 loading algorithm is very close to meeting the 100% accuracy specification.

Requirements and Product Qualifiers SO_2 Detection

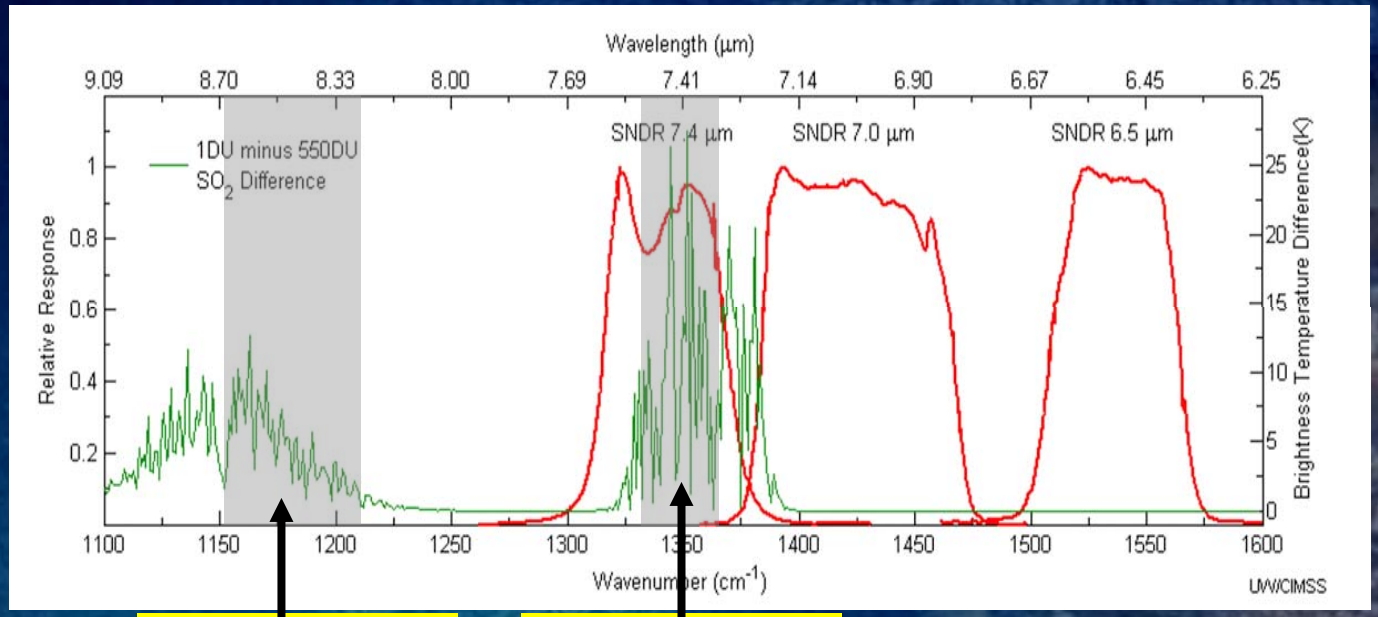
Name	User & Priority	Geographic Coverage (G, H, C, M)	Vertical Resolution	Horizontal Resolution	Mapping Accuracy	Measurement Range	Measurement Accuracy	Product Refresh Rate/Coverage Time (Mode 3)	Product Refresh Rate/Coverage Time (Mode 4)	Vendor Allocated Ground Latency	Product Measurement Precision
SO_2 Detection	GOES-R	Full Disk	Total Column	2 km	1 km	Binary yes/no detection from 10 to 700 Dobson Units (DU)	70% correct detection	Full disk: 60 min	Full disk: 5 min	806 sec	N/A

Name	User & Priority	Geographic Coverage (G, H, C, M)	Temporal Coverage Qualifiers	Product Extent Qualifier	Cloud Cover Conditions Qualifier	Product Statistics Qualifier
SO_2 Detection	GOES-R	Full Disk	Day and night	Quantitative out to at least 70 degrees LZA and qualitative at larger LZA	Clear conditions down to feature of interest associated with threshold accuracy	Over specified geographic area

Algorithm Description

Algorithm Channel Selection

The ABI algorithm utilizes SO_2 absorption lines located in the channel 10 (7.3 μm) and channel 11 (8.5 μm) bands in combination with the lack of SO_2 absorption in the 6.2, 11, and 12 μm bands to detect SO_2 induced spectral anomalies.



ABI channel 11 coverage

ABI channel 10 coverage

Spectral Information

- As in Pavolonis (2010), effective absorption optical depth ratios (β-ratios) are used to infer cloud microphysical information.
- Cloud microphysical anomalies (large deviations from theoretical values) are then used to identify potential SO_2 contaminated pixels.

$$\beta_{observed} = \frac{\ln(1.0 - \varepsilon_{\lambda 1})}{\ln(1.0 - \varepsilon_{\lambda 2})}$$

Spectral ratio of effective absorption optical depth

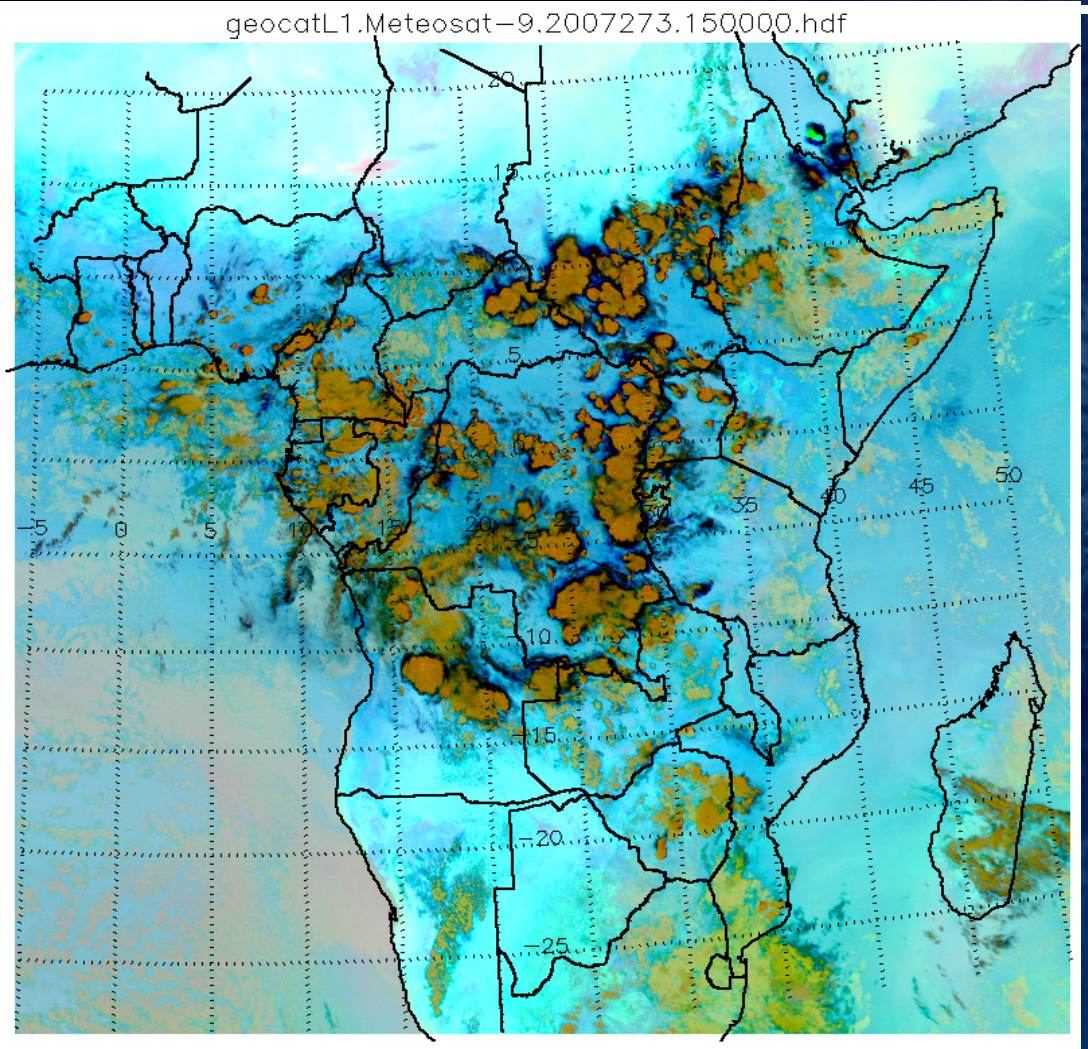
$$\beta_{theoretical} = \frac{(1.0 - \omega_{\lambda 1} g_{\lambda 1})\sigma_{ext\lambda 1}}{(1.0 - \omega_{\lambda 2} g_{\lambda 2})\sigma_{ext\lambda 2}}$$

Spectral ratio of scaled extinction coefficients

$$\beta_{theoretical} \approx \beta_{observed}$$

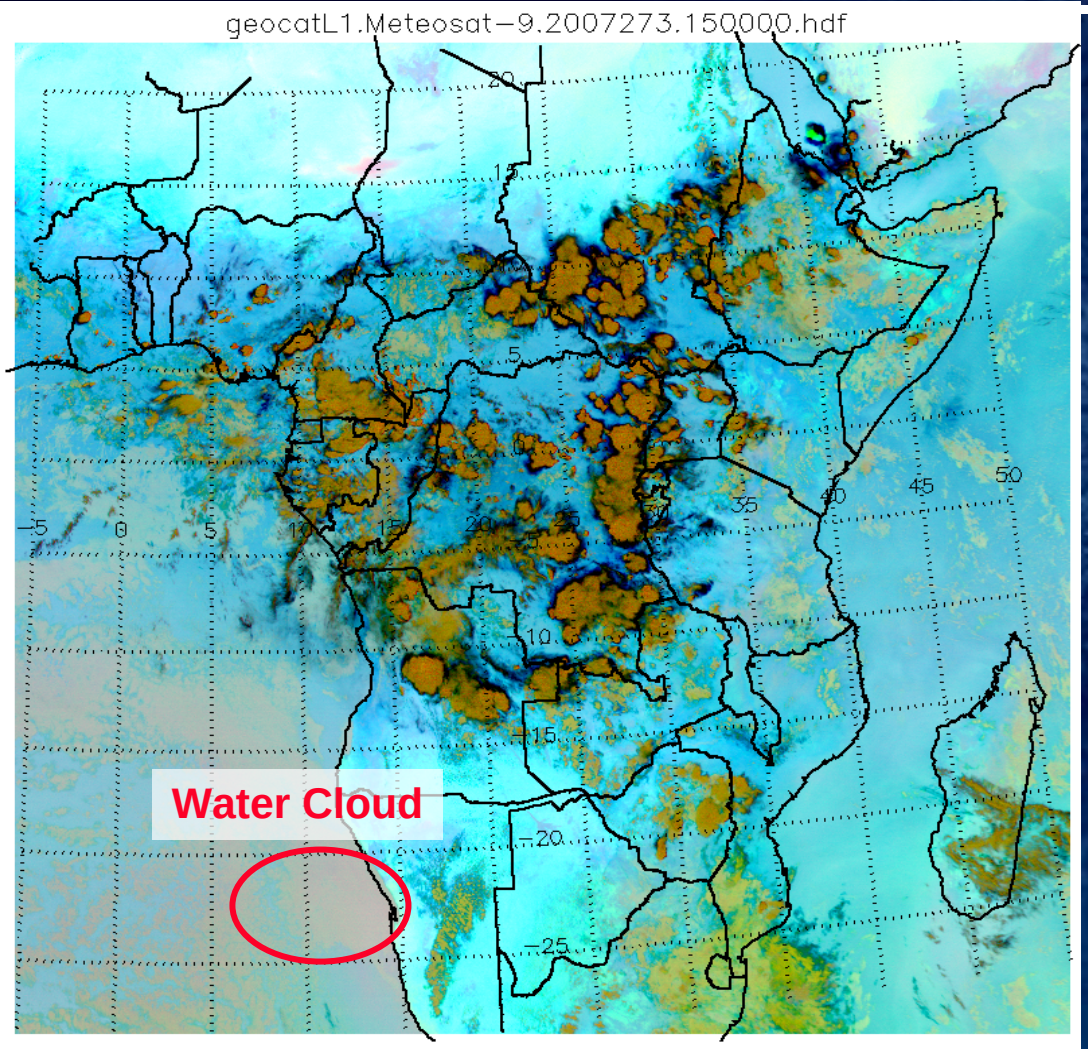
This relationship provides a direct link to theoretical size distributions from the measurements

Spectral Information



Compare the spectral signature of an SO_2 cloud, an ice cloud ,and a liquid water cloud.

Spectral Information



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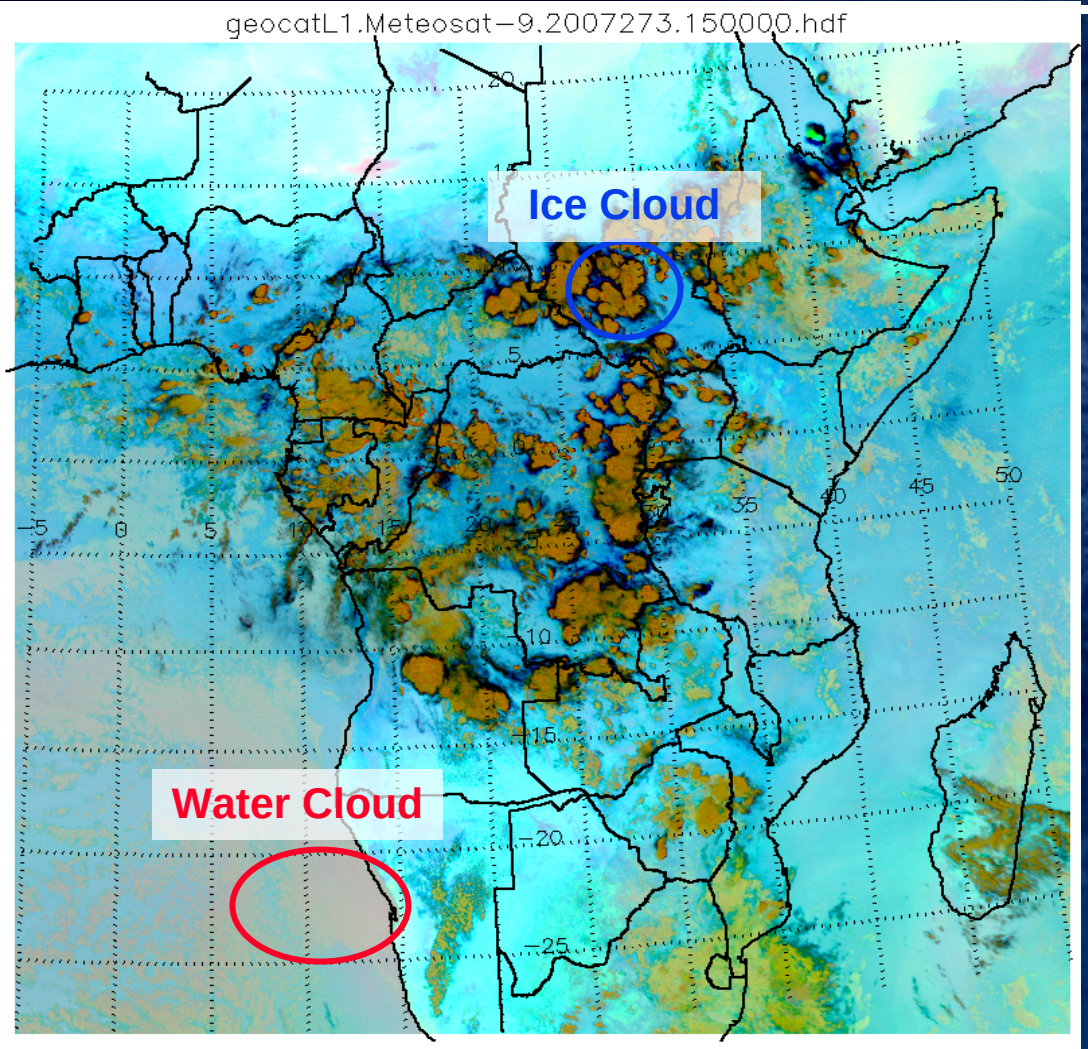

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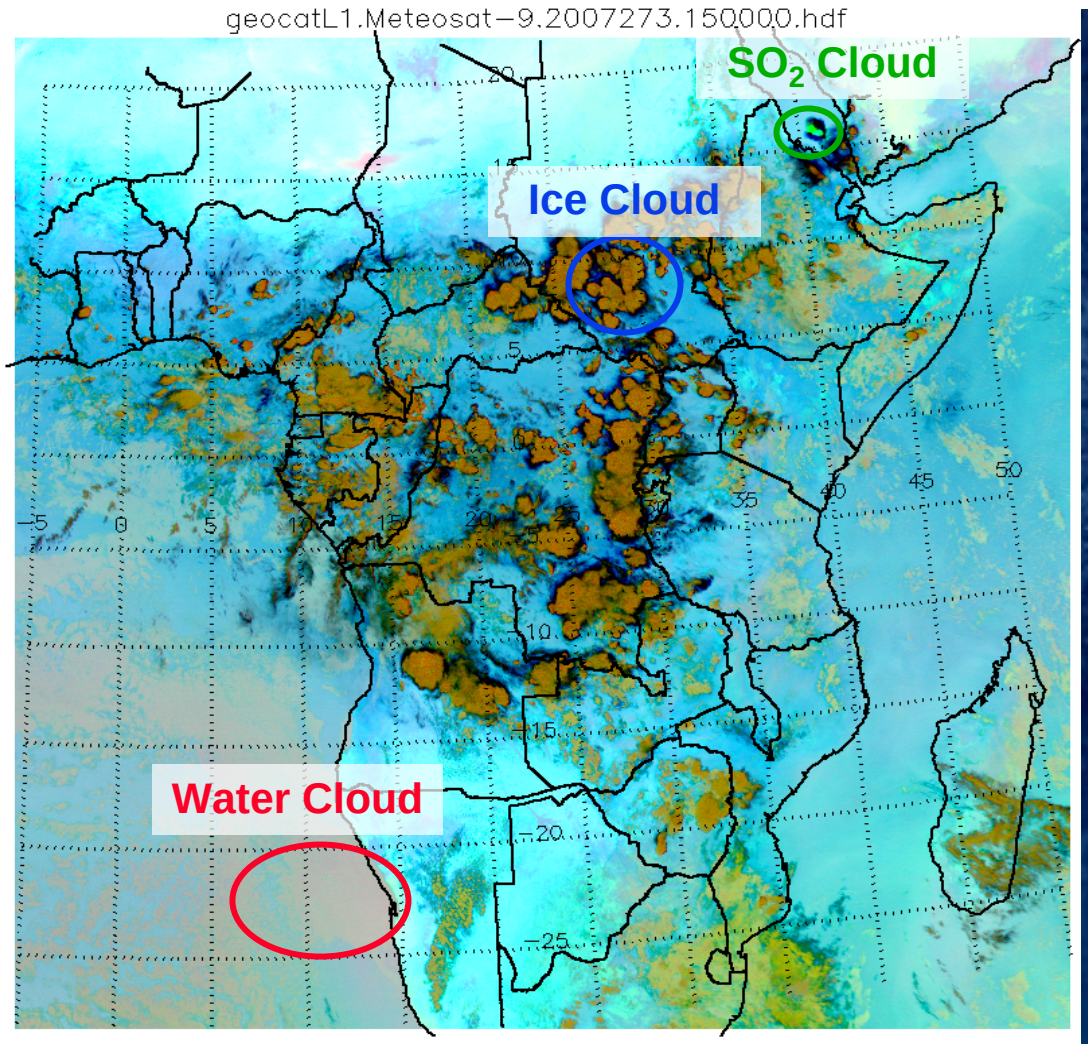
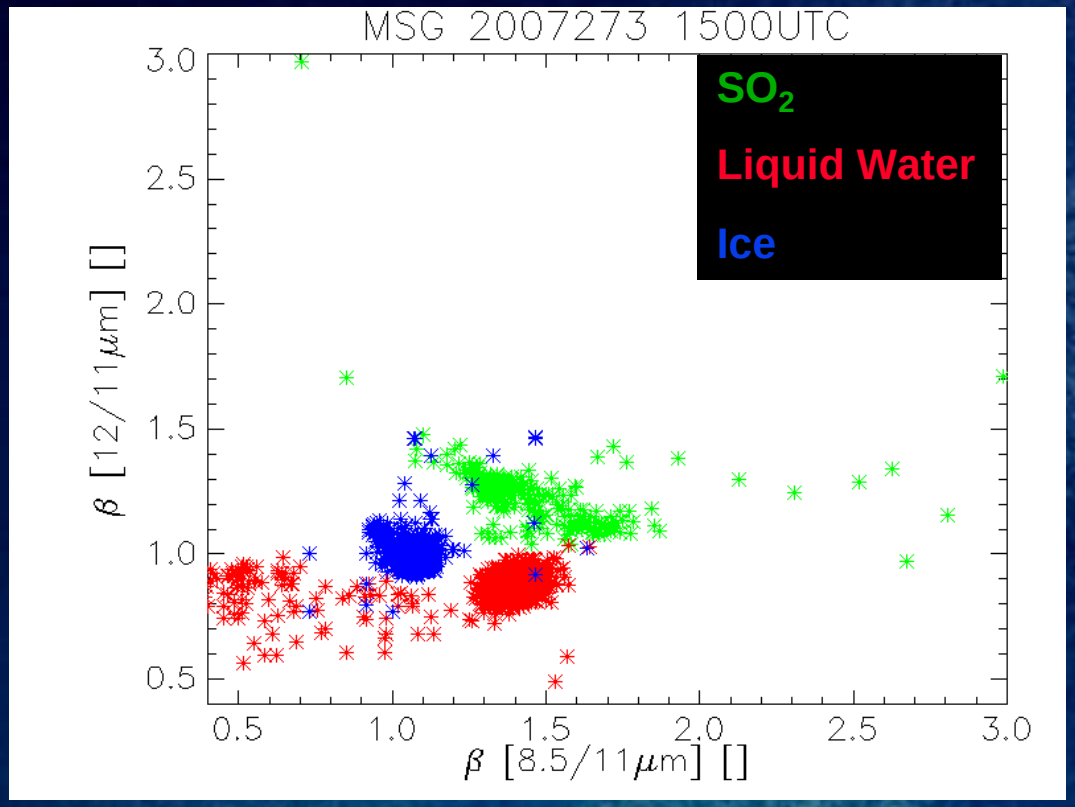


Compare the spectral signature of an SO_2 cloud, an ice cloud ,and a liquid water cloud.

Spectral Information

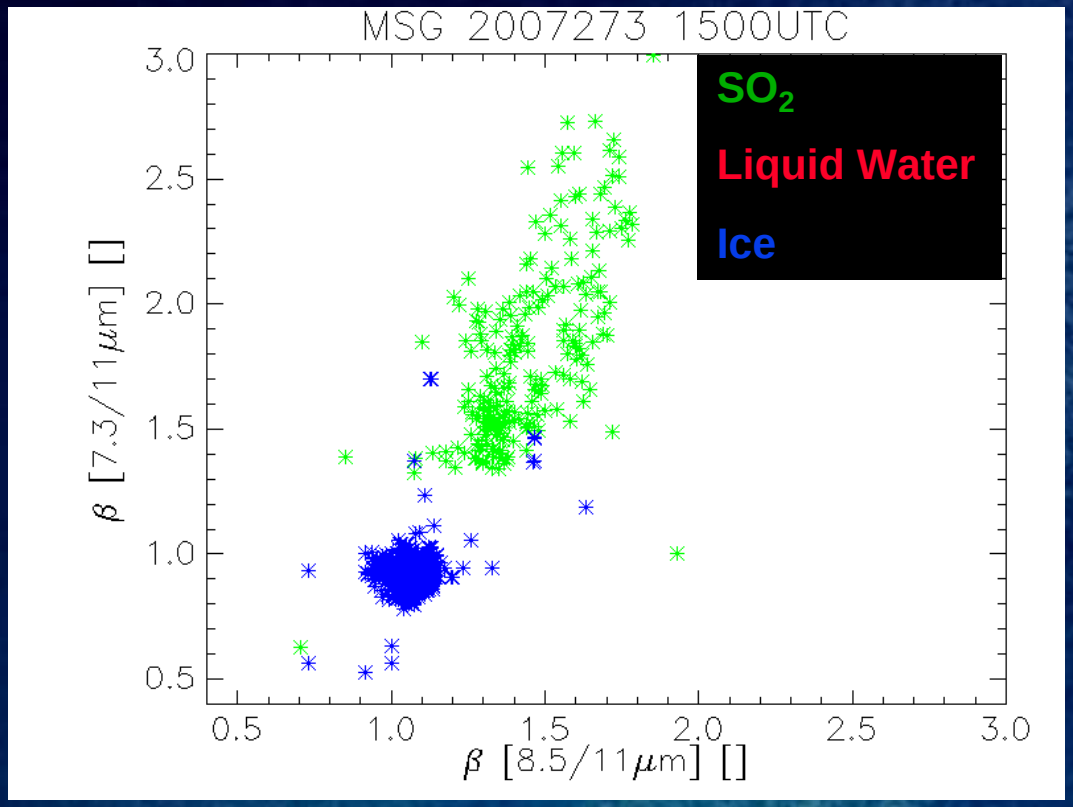
β(8.5, 11), β(12, 11) SO_2 spectral signature



- **The SO_2 cloud is characterized by the simultaneous occurrence of large β(12, 11) and large β(8.5, 11).**
- **Ice clouds tend to have smaller β(8.5, 11) relative to SO_2 clouds.**
- **SO_2 clouds tend to have larger β(12, 11) relative to liquid water clouds when hydrometeors are co-located with the SO_2.**

Spectral Information

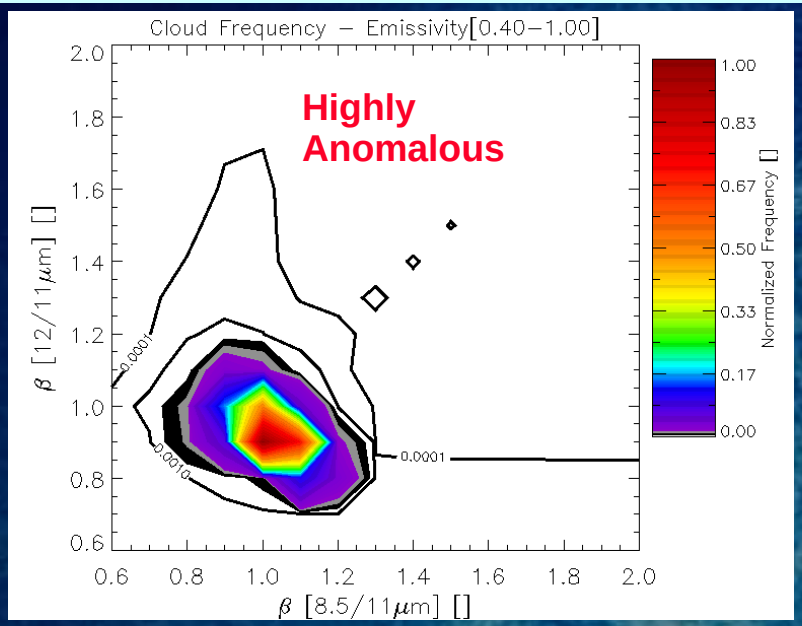
β(8.5, 11), β(7.3, 11) SO_2 spectral signature

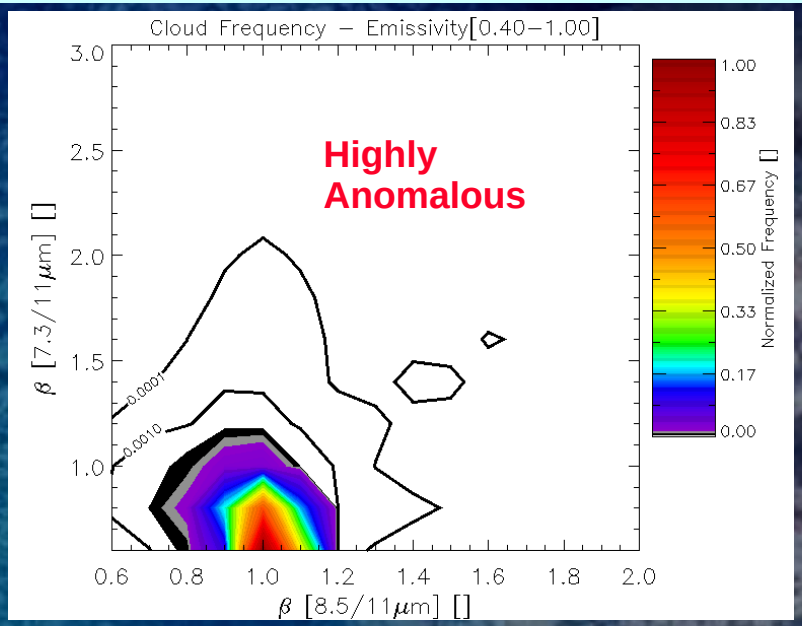


- The SO_2 cloud is characterized by the simultaneous occurrence of large β(7.3, 11) and large β(8.5, 11).
- Ice clouds tend to have smaller β(8.5, 11) and β(7.3, 11) relative to SO_2 clouds.
- Liquid water clouds are often present well below the peak of the 7.3 μm weighting function, and hence does not noticeably impact the 7.3 μm radiance.

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 SO_2 pixels will have a totally unique spectral signature).
- The methodology of Wielicki and Welch (1986) is used to construct cloud objects.
- In the SO_2 algorithm, cloud objects are constructed from pixels whose β-ratios have a low frequency of occurrence in a training data set that does not contain SO_2 clouds (pixels are spectrally anomalous, but not necessarily totally spectrally unique).





Cloud Object Illustration

- **In this simplified generic example, assume SO_2 *might* be present when pixel values exceed 6 (arbitrary units) and SO_2 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
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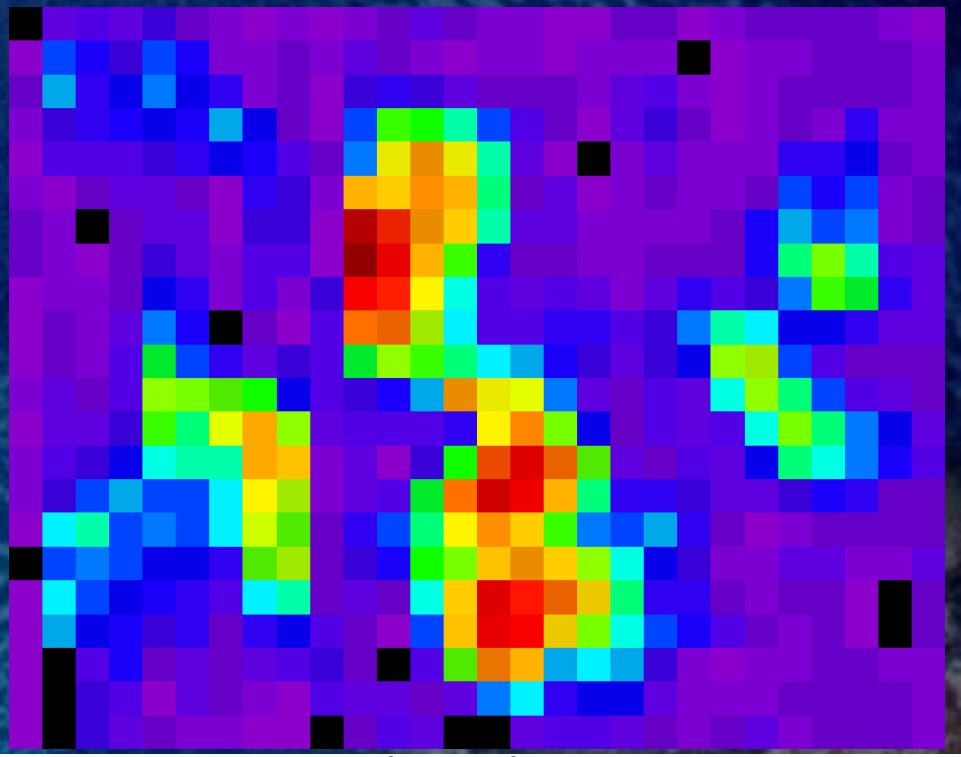

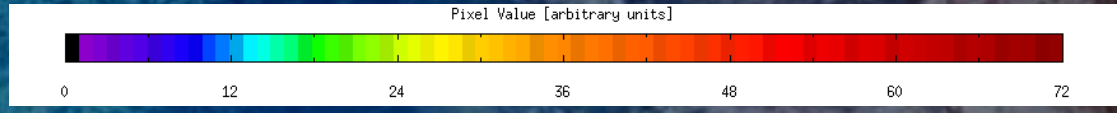

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1	0	6	5	1	4	3	2	1	5	4	4	3	4	11	13	7	9	9	4	2	2	2	3	3	3	3	2
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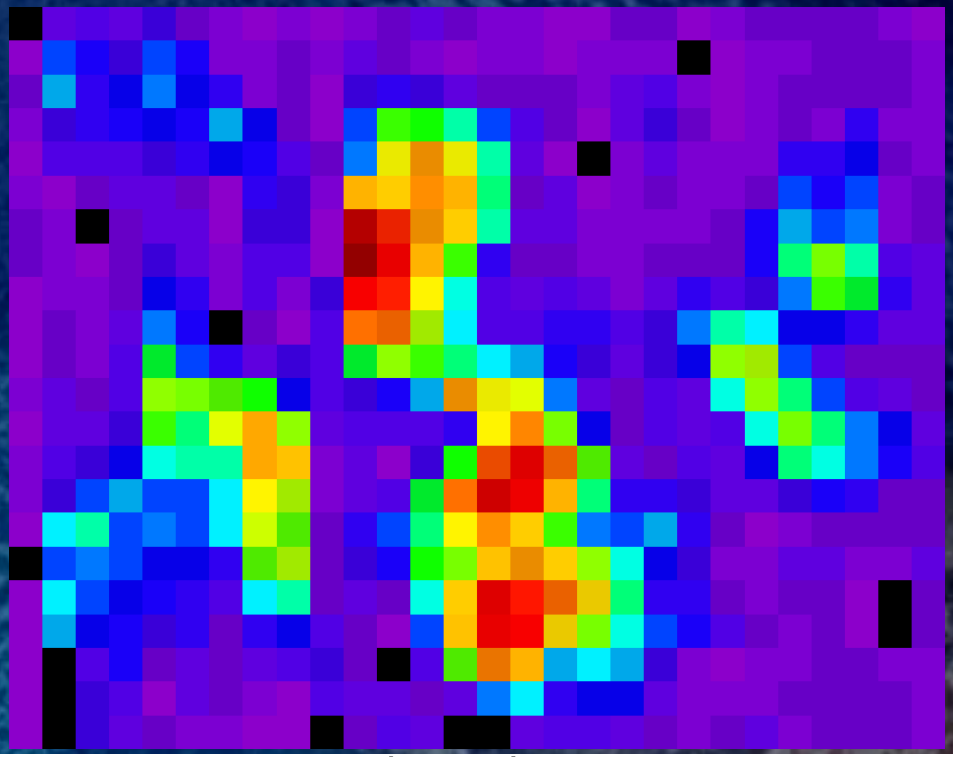
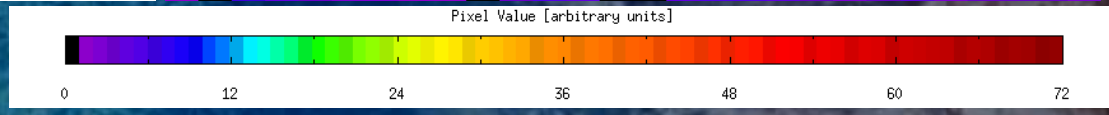
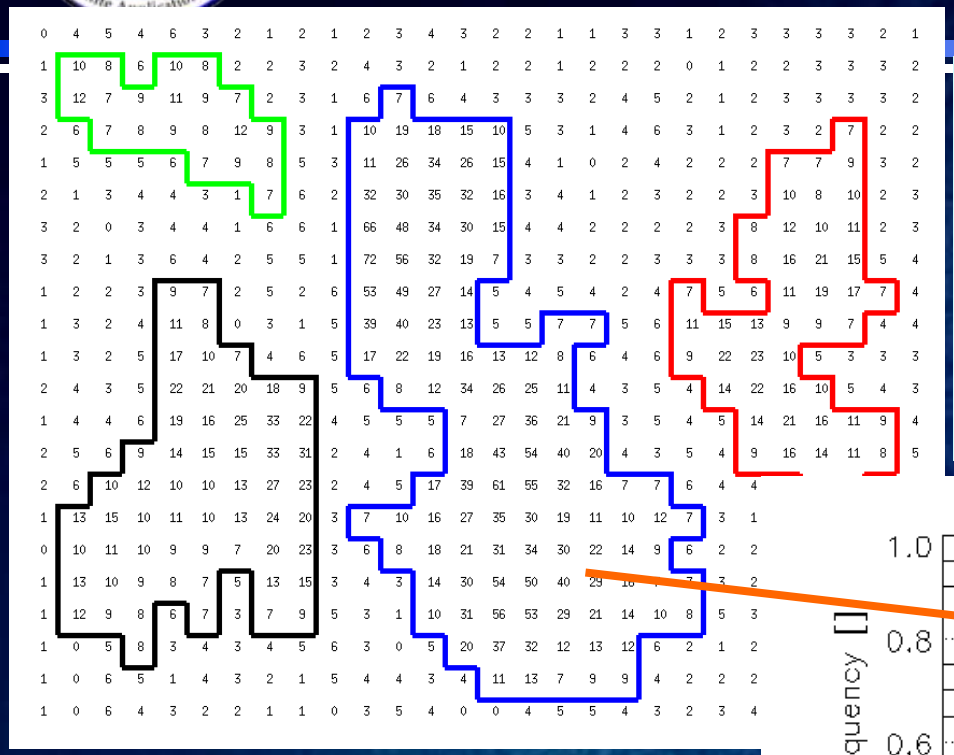
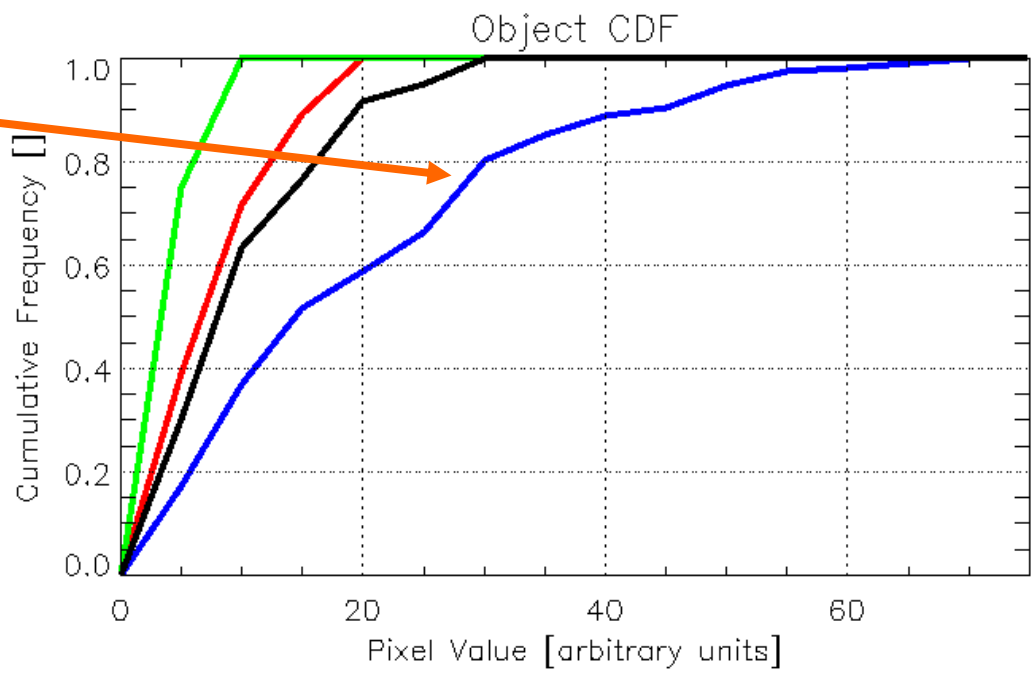




Cloud Object Illustration



- **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 SO_2 threshold.**
- ***As such, only the pixels that compose the "blue" object will be classified as SO_2.***



Cloud Object Based SO_2 Detection

- The previous simple example illustrates how the SO_2 detection algorithm works.
- Object membership is primarily determined by cloud frequency of occurrence.
- A set of spectral and spatial cloud object statistics are computed for each object (e.g. β-ratio CDF's, cloud emissvity CDF's, spatial uniformity metrics, etc…)
- For each object, all of the pixels that compose the object are either SO_2 or not SO_2 based on thresholds applied to the cloud object statistics.

SO_2 Detection Processing Schematic

INPUT: ABI and ancillary data

↓

Compute cloud emissivities and β-ratios

↓

Determine which pixels meet cloud object membership criteria

↓

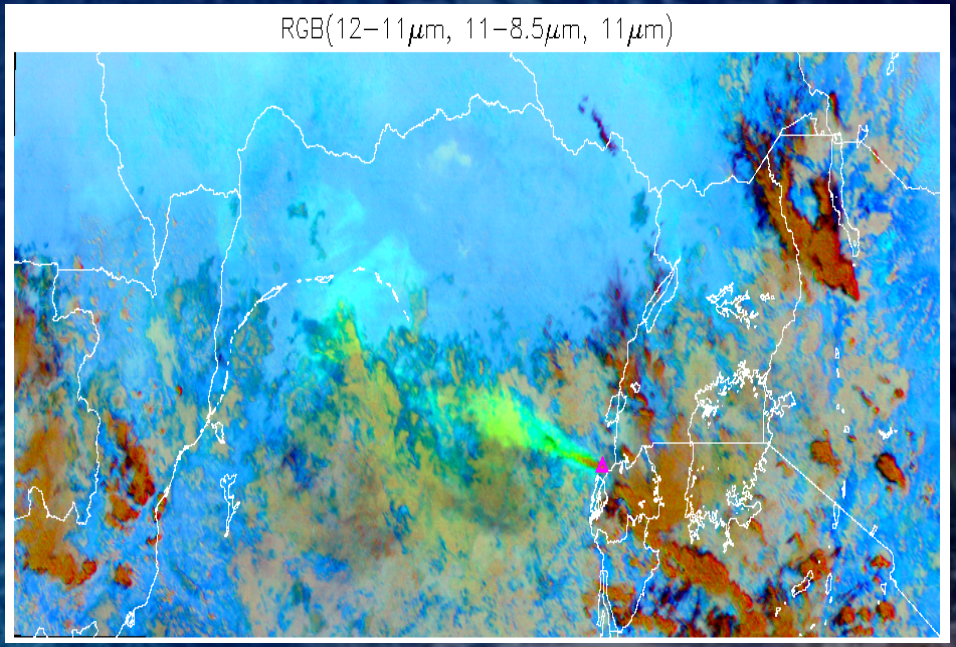
Construct cloud objects and compute cloud object statistics

↓

Determine which cloud objects are SO_2 clouds

↓

Output SO_2 mask



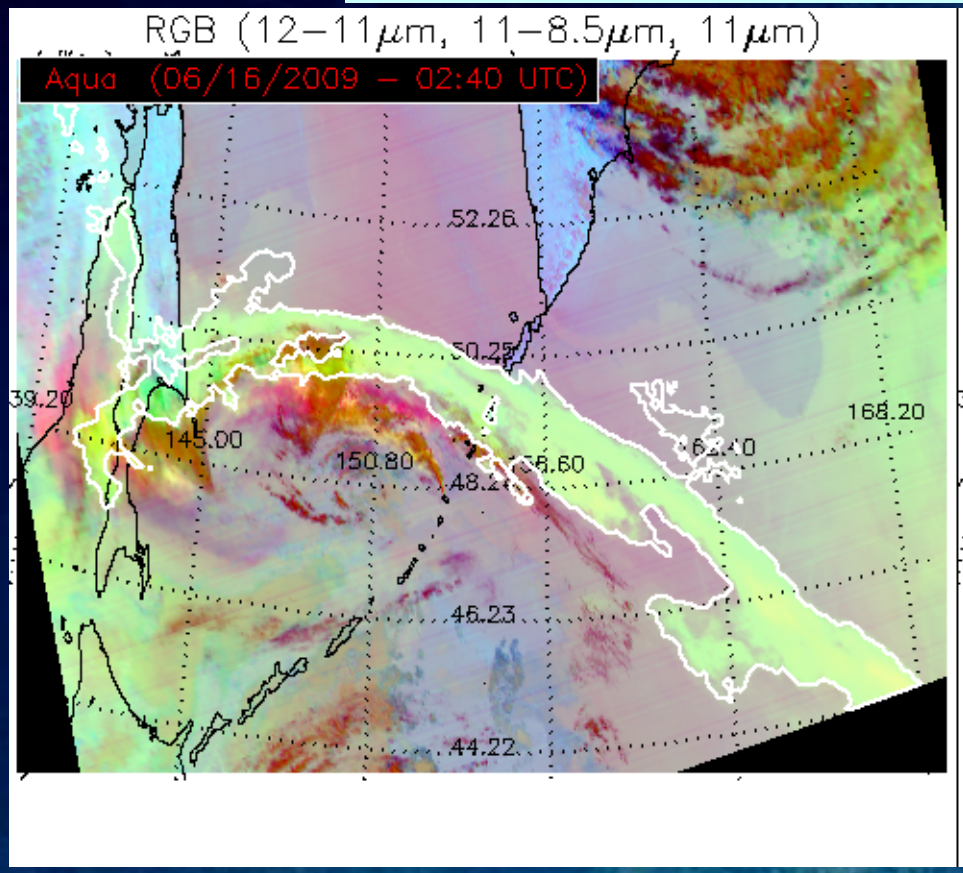
Algorithm Summary

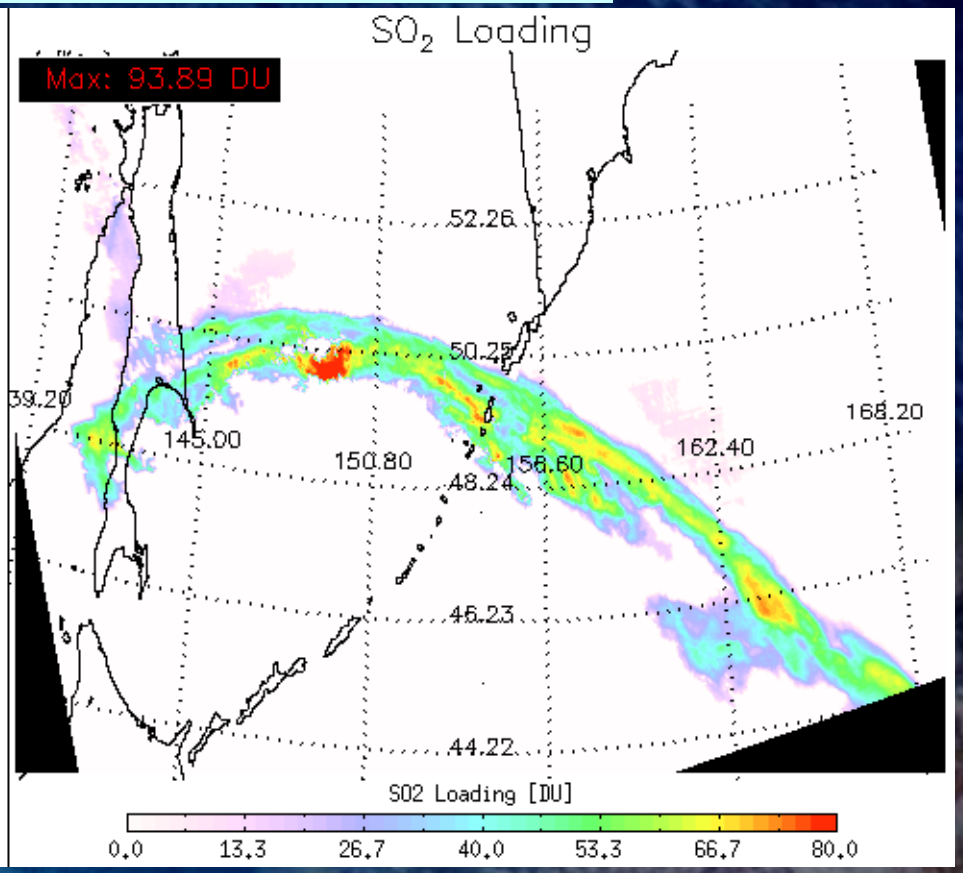
- Input Datasets: 1). ABI channels 8, 10, 11, 14, and 15, 2). Satellite viewing angle, 3). Clear sky radiances and transmittances, 4). Cloud frequency of occurrence LUT
- β-ratios are calculated to help identify cloud microphysical "anomalies" possibly associated with SO_2 absorption.
- Cloud objects are constructed from potential SO_2 pixels.
- Spectral and spatial cloud object statistics are used to determine if all of the pixels that compose a cloud object contain SO_2 or do not contain SO_2.
- A flag indicating the approximate SO_2 loading is also produced and stored in the quality flags.

Examples of Product Output

Aqua MODIS Example

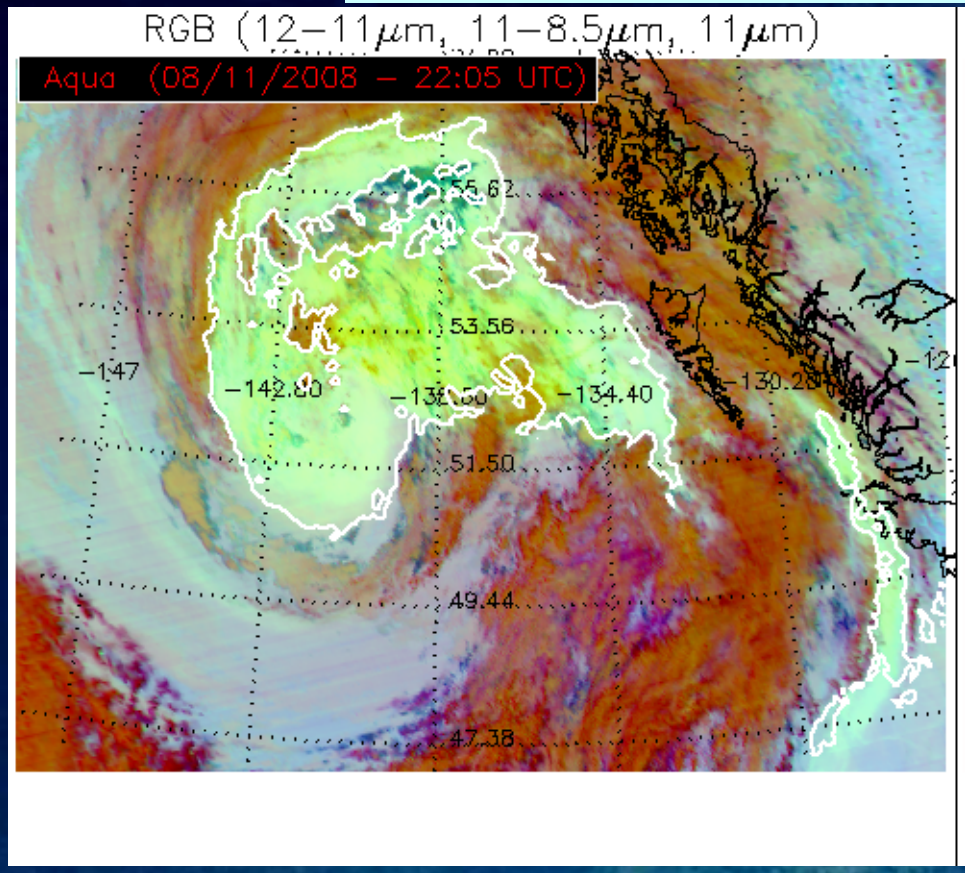
Sarychev, June 16, 2009 - 02:40

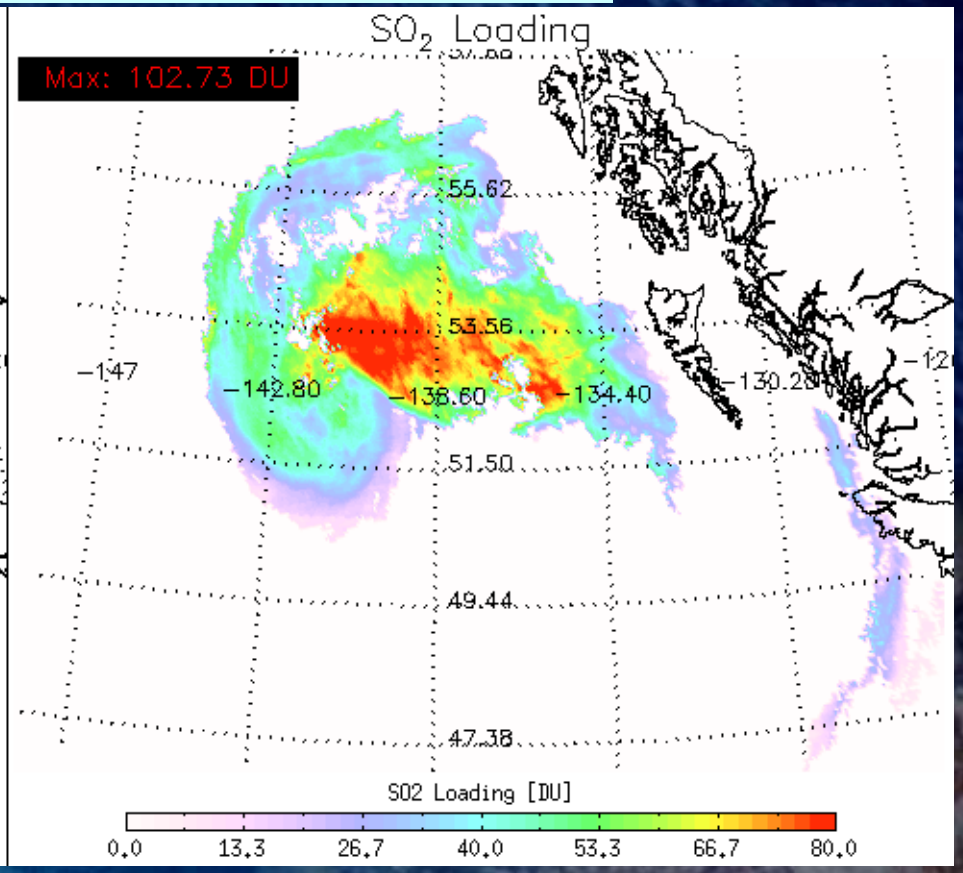




Aqua MODIS Example

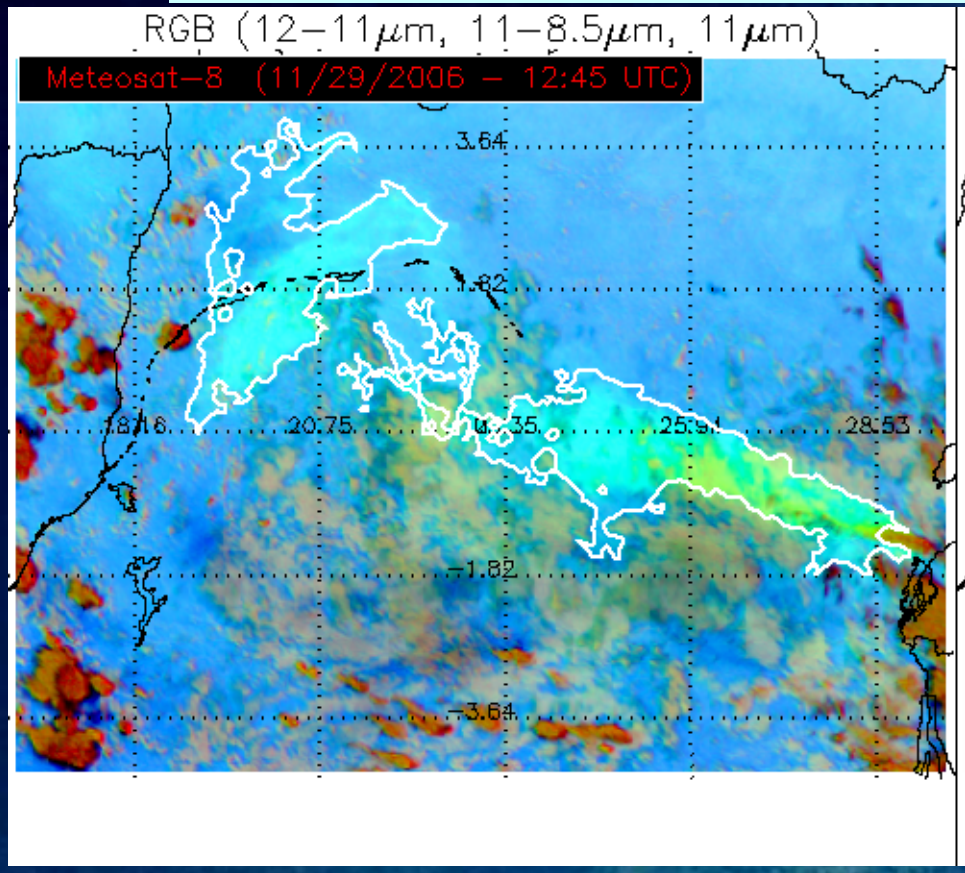
Kasatochi, August 11, 2008 - 22:05

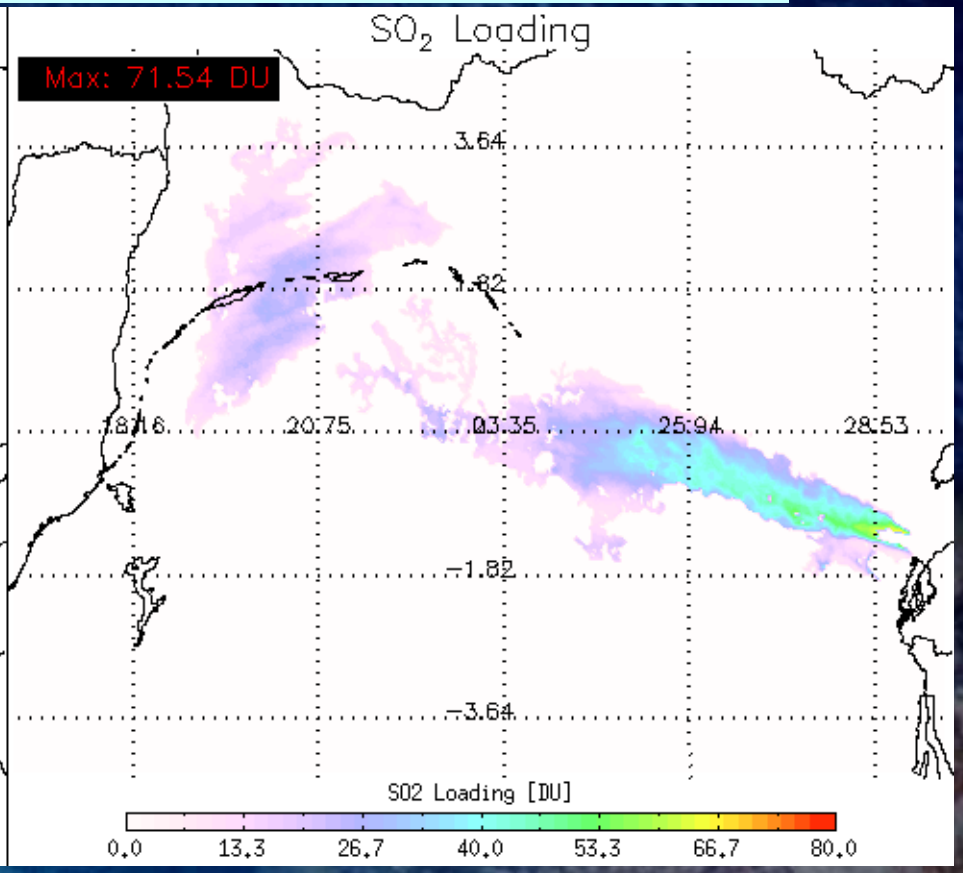




SEVIRI Example

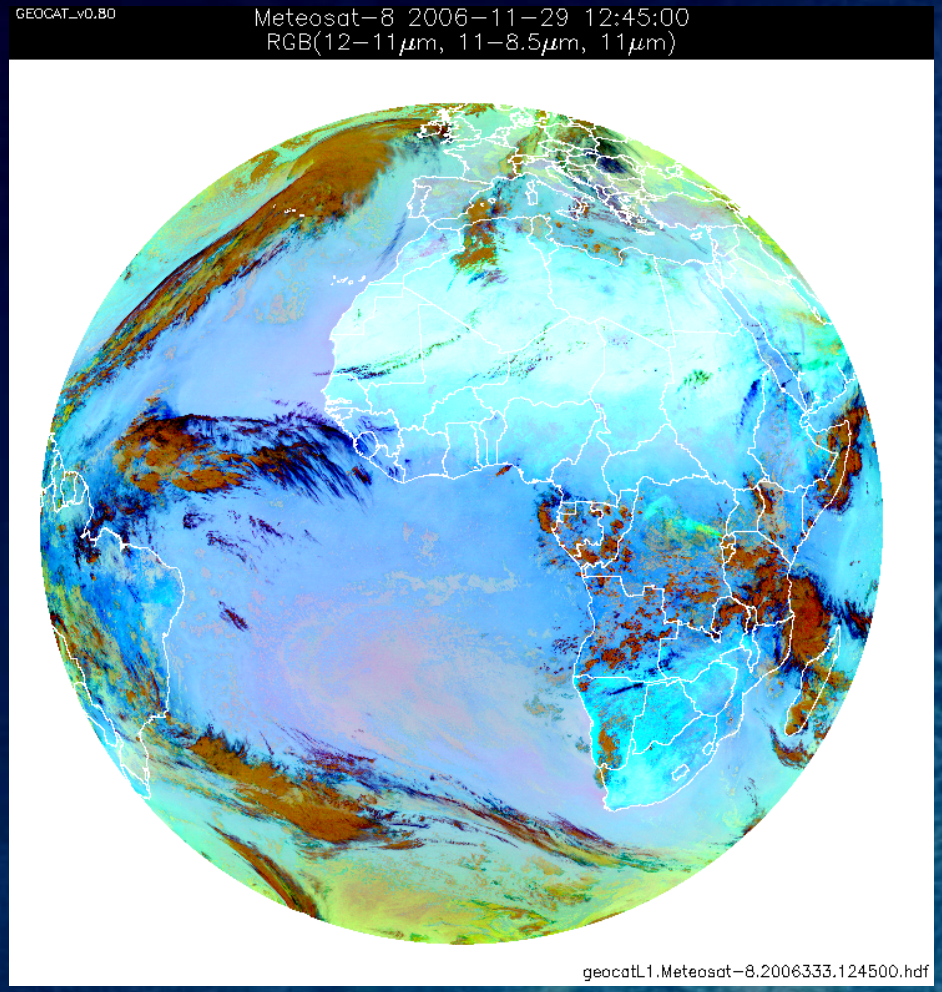
Nyamuragira, November 29, 2006 - 12:44

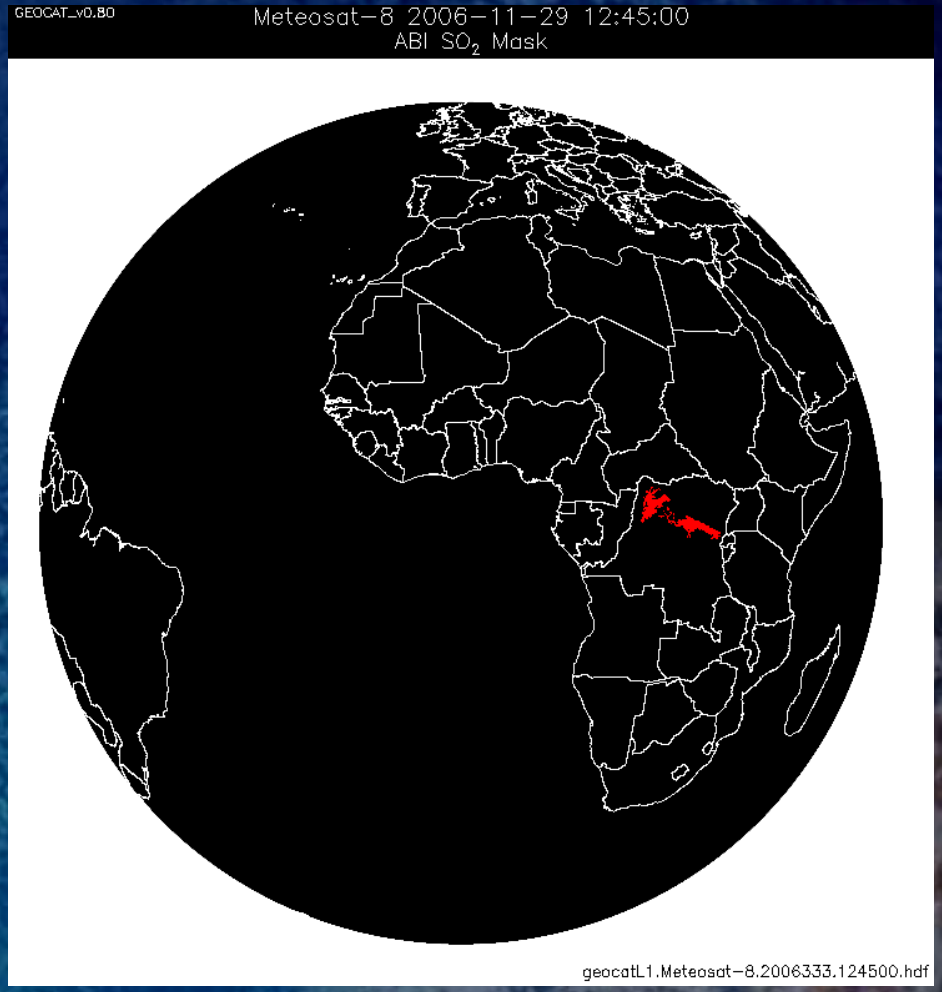




SEVIRI Example

Nyamuragira, November 29, 2006 - 12:44





Validation Approach

Validation Approach

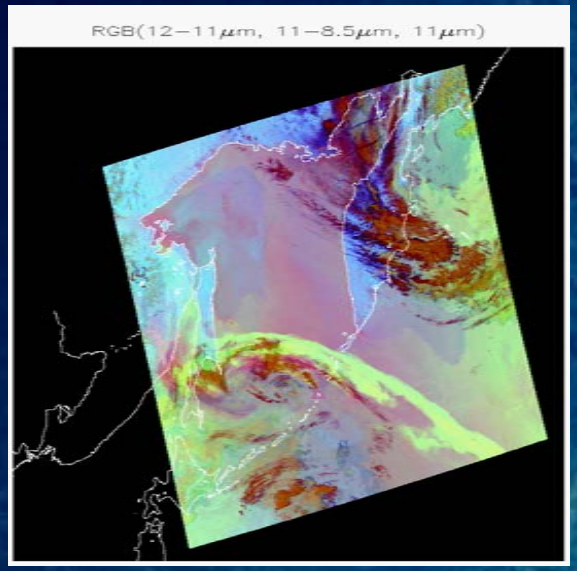
The Ozone Monitoring Instrument (OMI) is used as "truth"

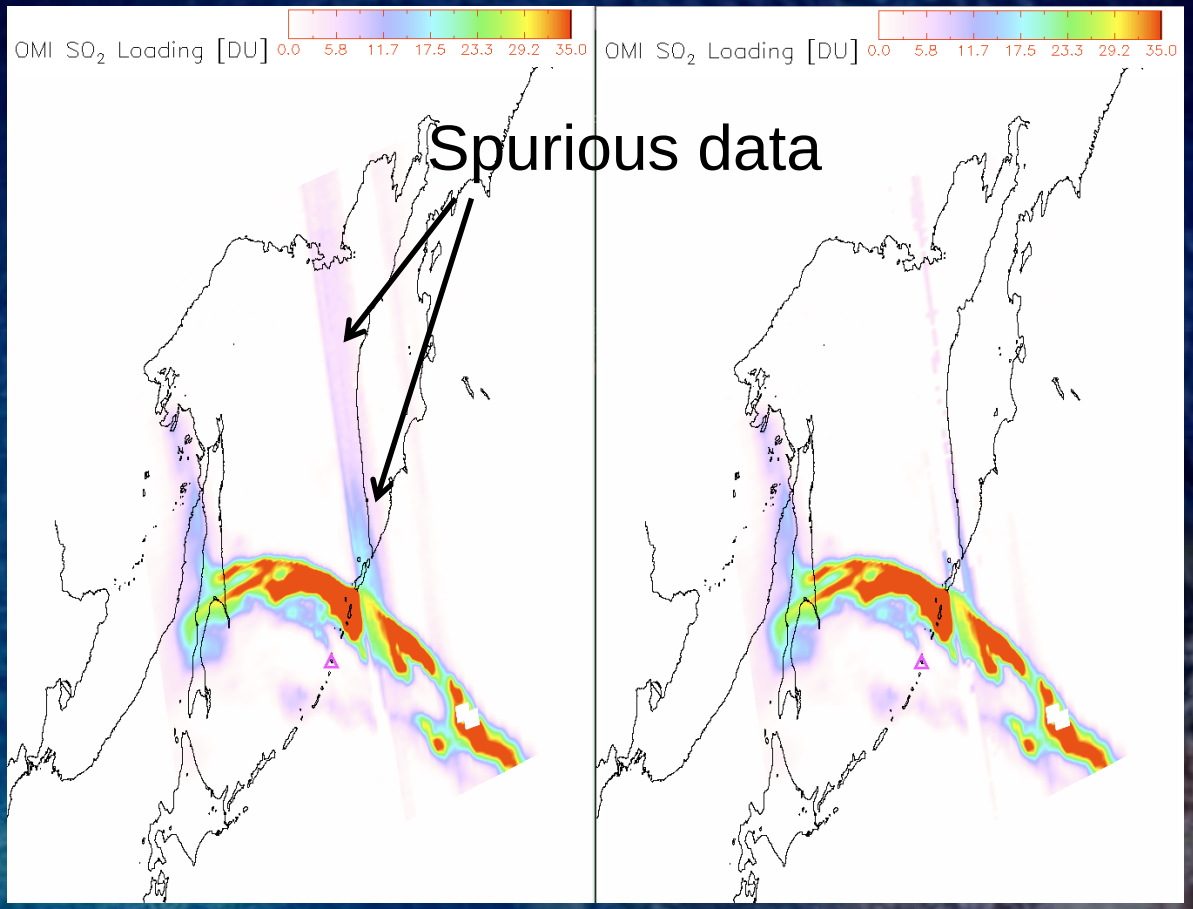
The ABI SO_2 mask is validated as a function of OMI SO_2 loading, using a skill score metric.

- OMI is a Dutch-Finnish instrument on board the Aura satellite in NASA's A-Train.
- OMI uses measurements of backscattered solar UV radiation to detect SO_2. OMI can detect SO_2 at levels less than 1 DU.
- Although OMI is very sensitive to SO_2, it only views a given area of earth once daily.
- The MODIS instrument on the Aqua satellite (also in the A-Train) observes the same area as OMI, which allows us to study any SO_2 clouds observed by OMI. This allows us to see clouds outside the SEVIRI domain.

Validation Approach

- OMI SO_2 Quality Flag (QF) from the OMI data set is used to filter out bad data.
- Pixels are flagged as bad data if UV spectral information is not consistent.





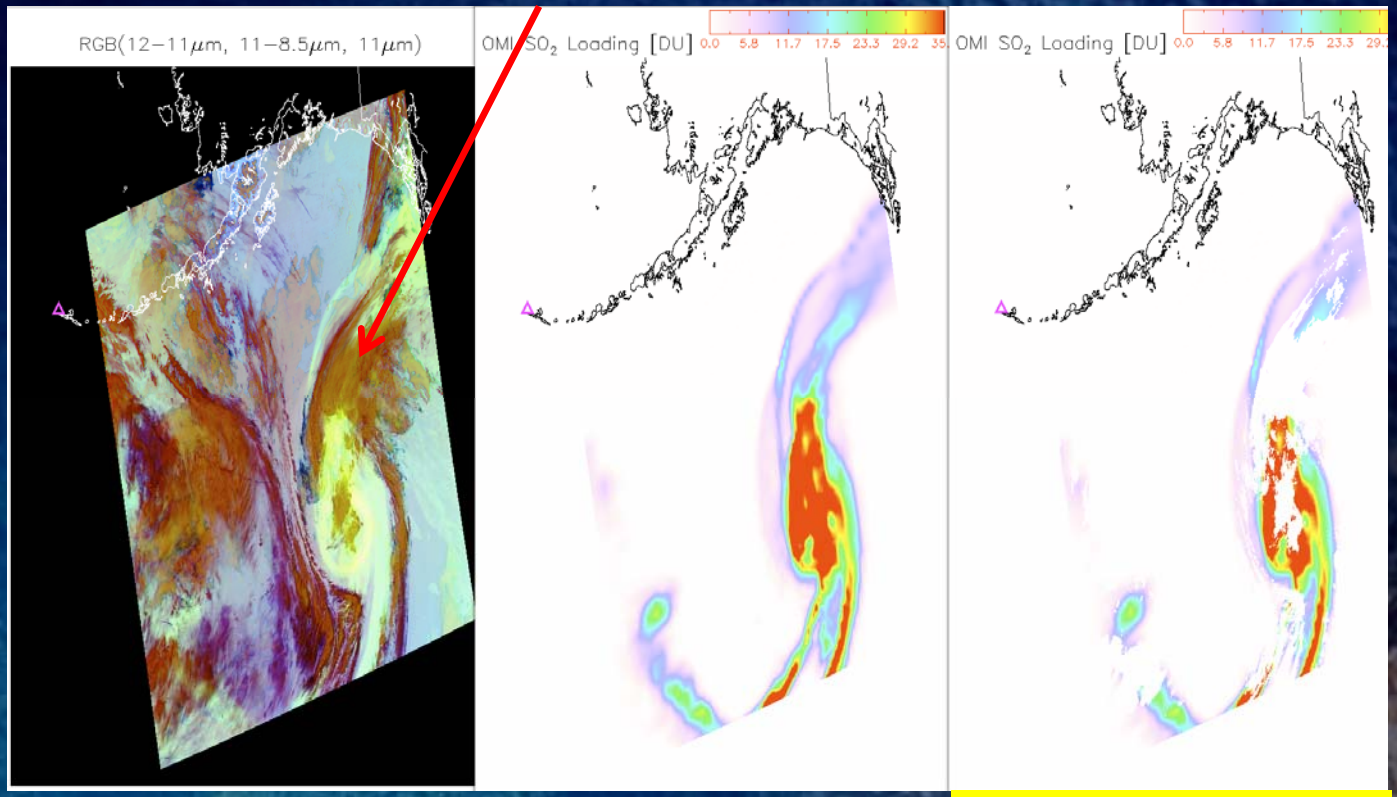
Before filtering

After filtering

Validation Approach

Meteorological (ice) cloud

Filter out OMI pixels in which meteorological cloud overlies SO_2. The specifications do not require us to detect these pixels.

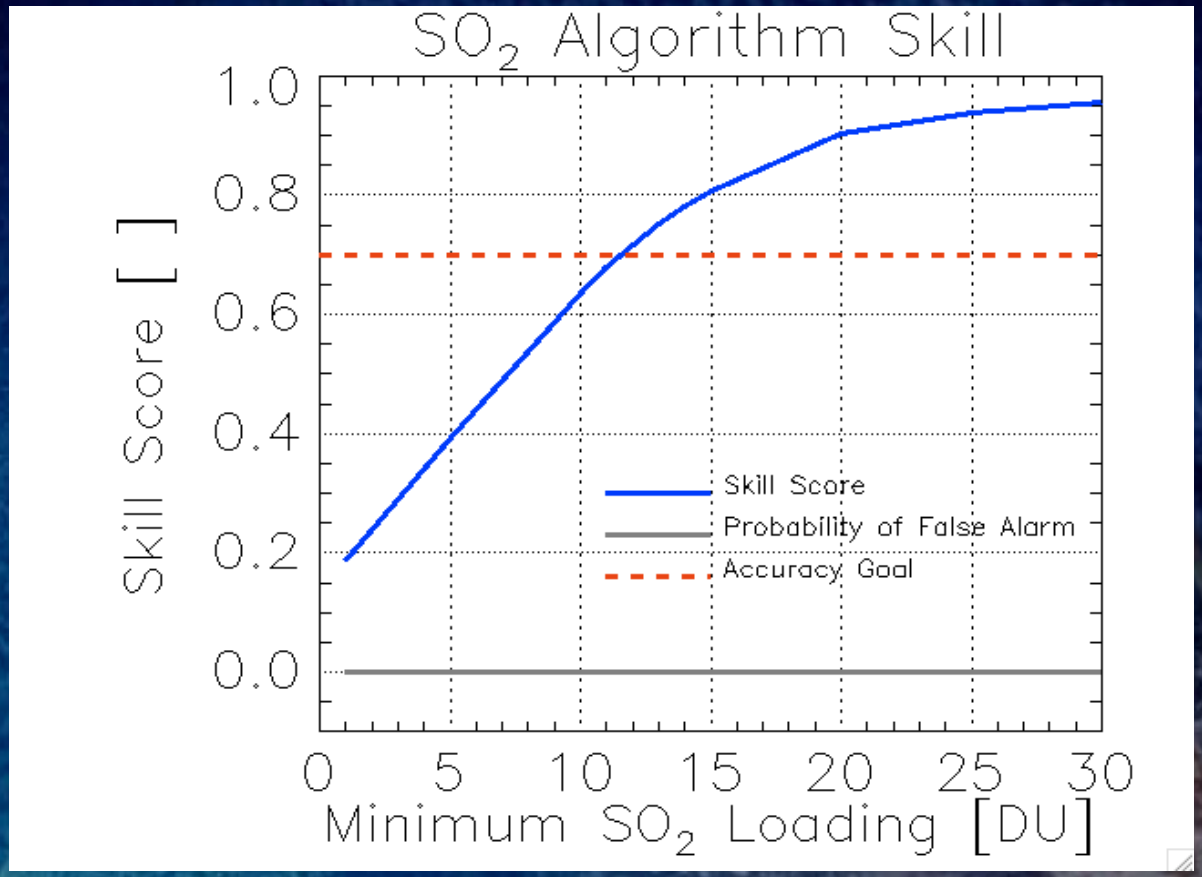


After filtering

Validation Results

SO_2 Validation

- *The ABI SO_2 mask is validated as a function of OMI SO_2 loading, using a skill score metric.*
- *A total of 35 MODIS SO_2 scenes were matched up in space and time with OMI (270,000 validation points).*
- *The skill score is 0.64 when the OMI SO_2 indicates 10 DU or more of SO_2.*



F&PS requirements – SO_2

F&PS requirement: Product Measurement Range	F&PS requirement: Product Measurement Accuracy	F&PS requirement:80 % of Product Measurement Accuracy	Validation results – using 35 MODIS scenes
Binary yes/no detection from 10 to 700 Dobson Units (DU)	70% correct detection	56% correct detection	64% of SO_2 in Product Measurement Range detected (70% detection level reached at approx. 11.5 DU)

Summary

- The ABI SO_2 Detection algorithm provides a new capability for objective detection of SO_2 clouds, which may be an aviation hazard and impact climate.
- The improved spatial and temporal resolution of the ABI, along with a 7.3 um band that is better suited for SO_2 detection, will likely lead to improved SO_2 detection capabilities (relative to SEVIRI and MODIS).
- The SO_2 algorithm meet all performance (within the error bar of the validation source) and latency requirements
- The SO_2 detection will be included in the Alaska Proving Ground Experiment