GOES-R AWG Cloud Team: Cloud Top Phase and Cloud Type

Presented By: Mike Pavolonis
NOAA/NESDIS/STAR

Outline

- Executive Summary
- Algorithm Description
- ADEB and IV&V Response Summary
- Requirements Specification Evolution
- Validation Strategy
- Validation Results
- Summary

Executive Summary

- This ABI Cloud Phase Algorithm determines the cloud top (layer that the radiometer senses) thermodynamic phase of the highest cloud layer.
- The cloud phase output is a subset of a more detailed cloud classification produced by the GOES-R Cloud Type Algorithm
- A unique infrared cloud classification scheme is used to determine the cloud type
- CALIPSO validation tools have been developed and applied to a SEVIRI data set
- The CALIPSO based validation indicates that the cloud phase and cloud type algorithms comfortably meet the F&PS specification
- Version 5 and the 100% ATBD will be delivered in June

Algorithm Description

Algorithm Output (cloud type)

Category	Description	Value
Clear	Clear cloud mask output	0
Spare	Spare category	1
Liquid Water	Liquid water cloud with an 11 μm brightness temperature > 273 K	2
Supercooled Water	Liquid water cloud with an 11 μm brightness temperature < 273 K	3
Mixed Phase	High probability of containing both ice and liquid water near cloud top	4
Optically Thick Ice	Ice topped cloud that is opaque/near-opaque in the infrared (infrared optical depth greater than about 1.0)	5
Optically Thin Ice	Ice clouds that are optically thin in the infrared (infrared optical depth of about 1.0 or less)	6
Multilayered Ice	Semi-transparent ice cloud overlapping a lower, opaque cloud layer	7

Algorithm Output (cloud phase)

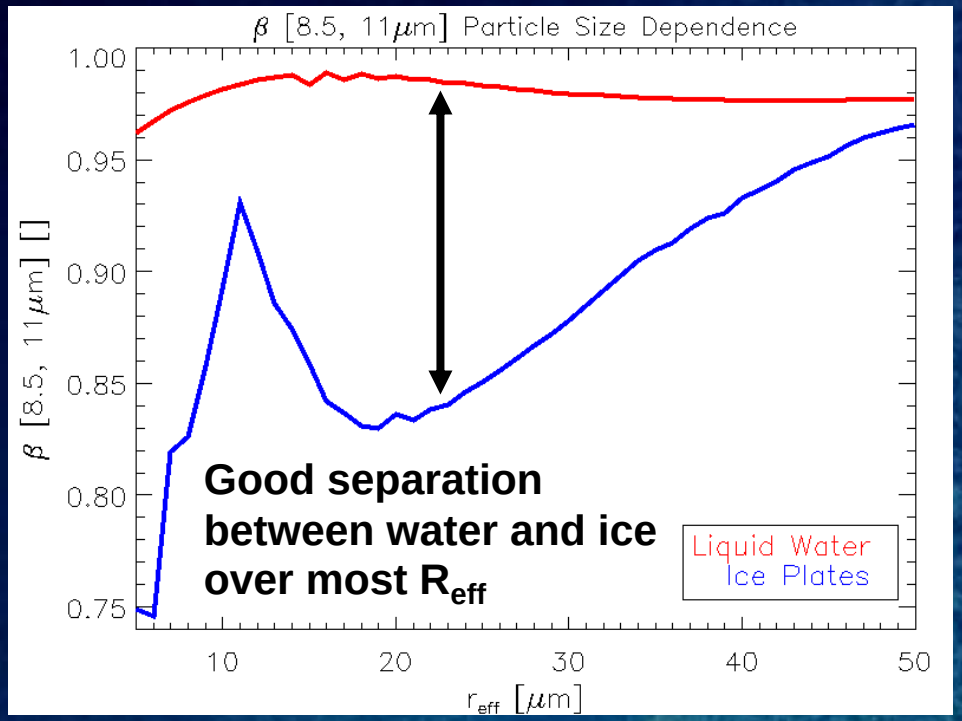
Category	Description	Value
Clear	Clear cloud mask output	0
Liquid Water	Liquid water cloud with an 11 μm brightness temperature > 273 K	1
Supercooled Water	Liquid water cloud with an 11 μm brightness temperature < 273 K	2
Mixed Phase	High probability of containing both ice and liquid water near cloud top	3
Ice	All ice topped clouds	4

Algorithm Summary

- ABI channels used: 10, 11, 14, and 15
- Effective absorption optical depth ratios (β-ratios) are used to determine cloud type (liquid water, supercooled liquid water, mixed phase, opaque ice, semi-transparent ice, and multilayered clouds).
- The cloud phase (liquid water, supercooled liquid water, mixed phase, and ice) is determined from the cloud type output (ice = opaque ice, semi-transparent ice, and multilayered clouds).

Use of Spectral Information

- As in Pavolonis (2010), effective absorption optical depth ratios (β-ratios) are used to infer cloud microphysical information.



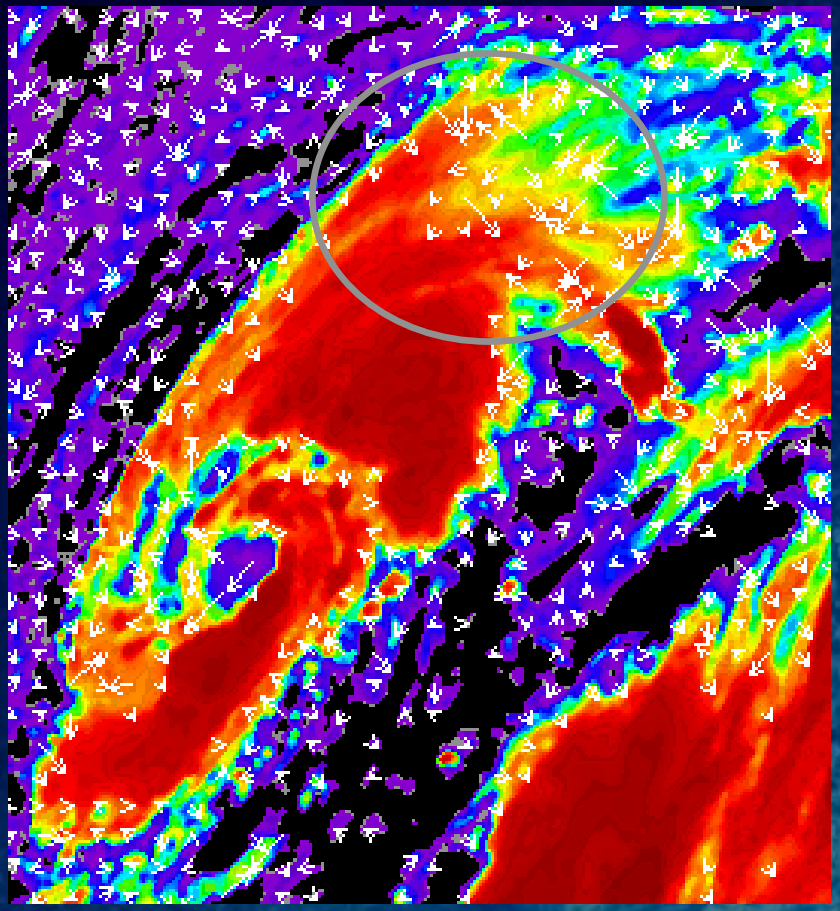
$$\beta_{observed} = \frac{\ln(1.0 - \varepsilon_{\lambda 1})}{\ln(1.0 - \varepsilon_{\lambda 2})}$$

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

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

Cloud phase relationship derived from single scatter properties

Use of Spatial Information



- The pixel Local Radiative Center (LRC) is used to avoid cloud edge artifacts.
- A median filter is used to eliminate product "noise."

Cloud Type/Phase Processing Schematic

INPUT: ABI and ancillary data

↓

Compute cloud emissivities and β-ratios

↓

Compute gradient filter

↓

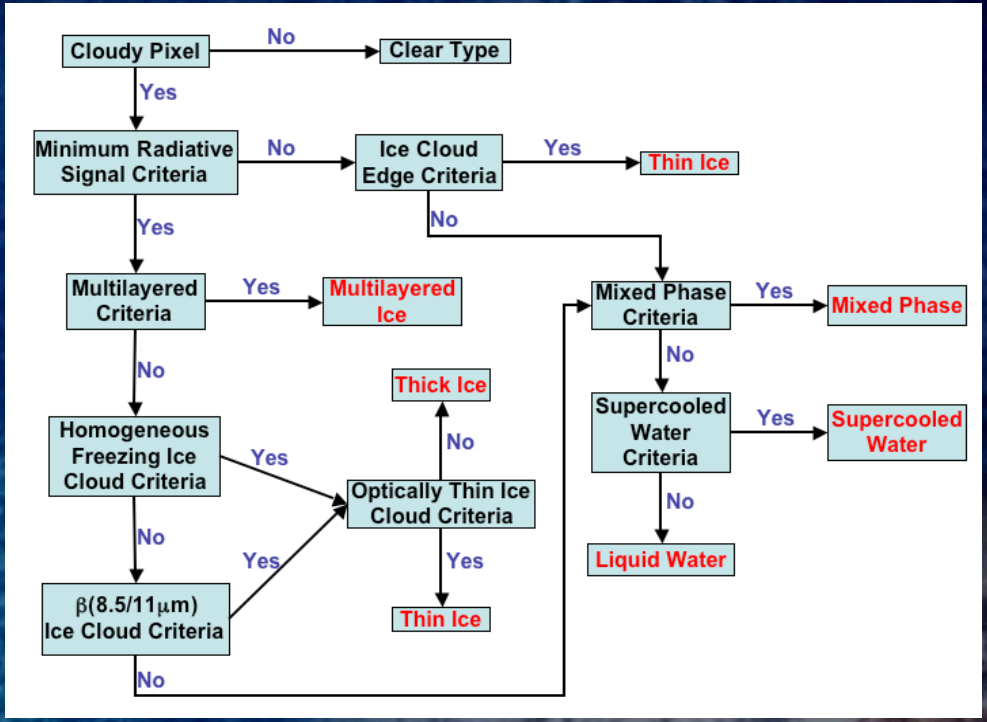
Apply logical tests to determine cloud type

↓

Apply median filter to cloud type

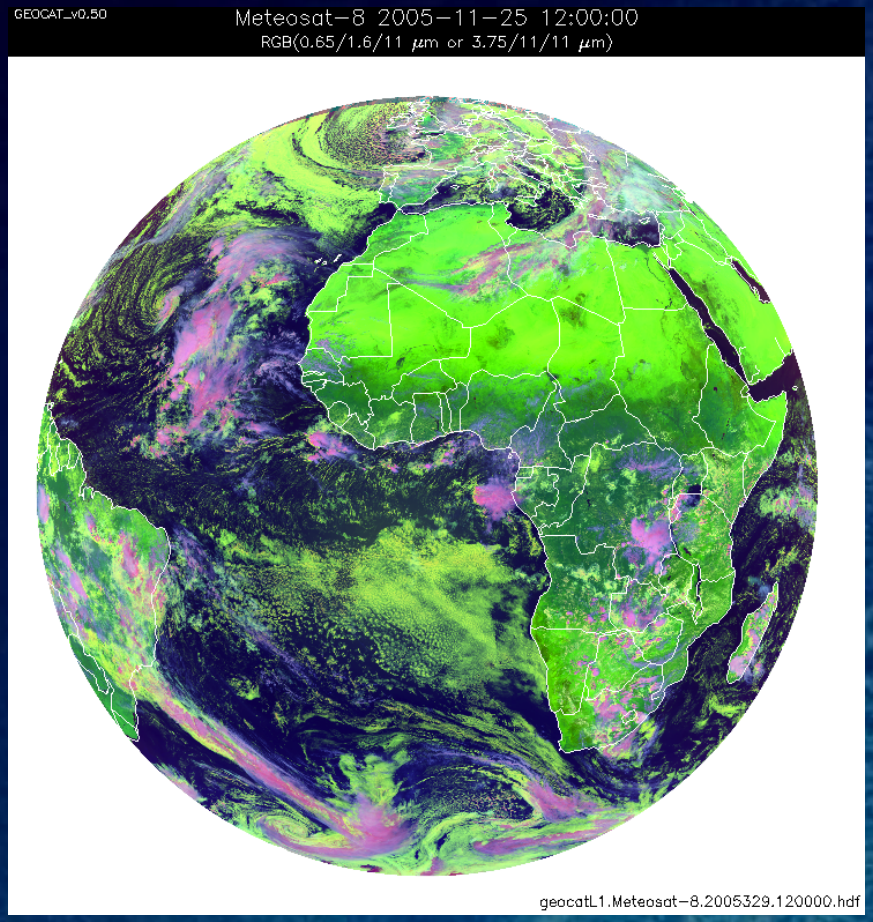
↓

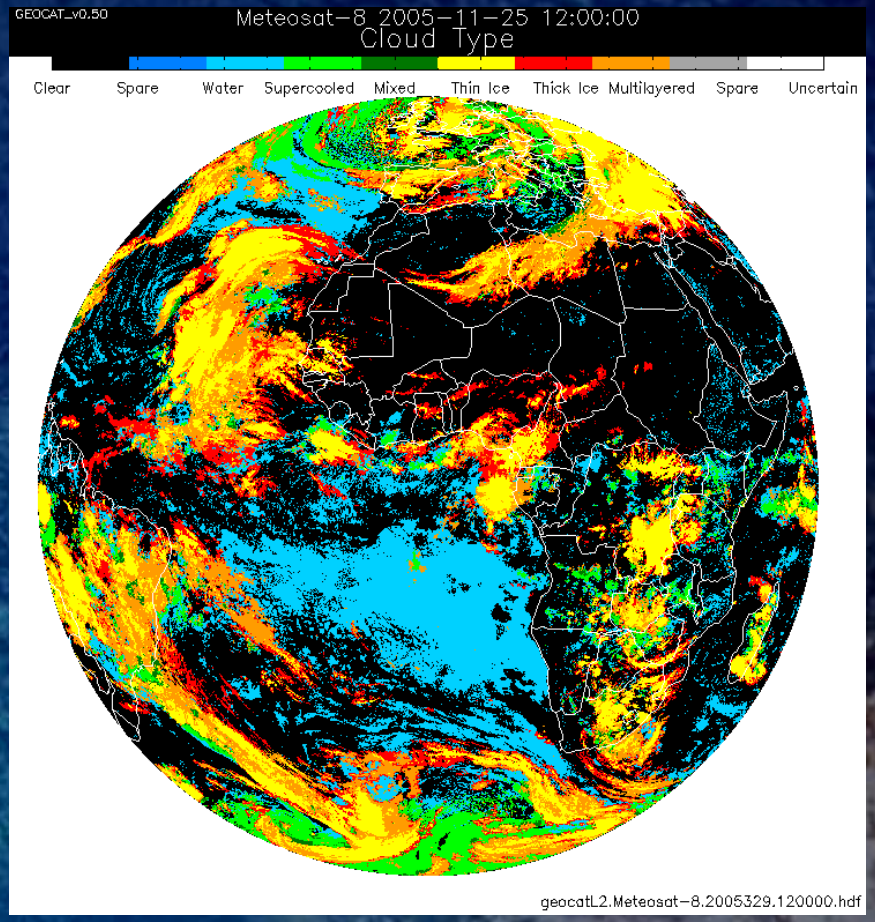
Determine cloud phase from cloud type and output both



Algorithm Results

Full disk cloud type results

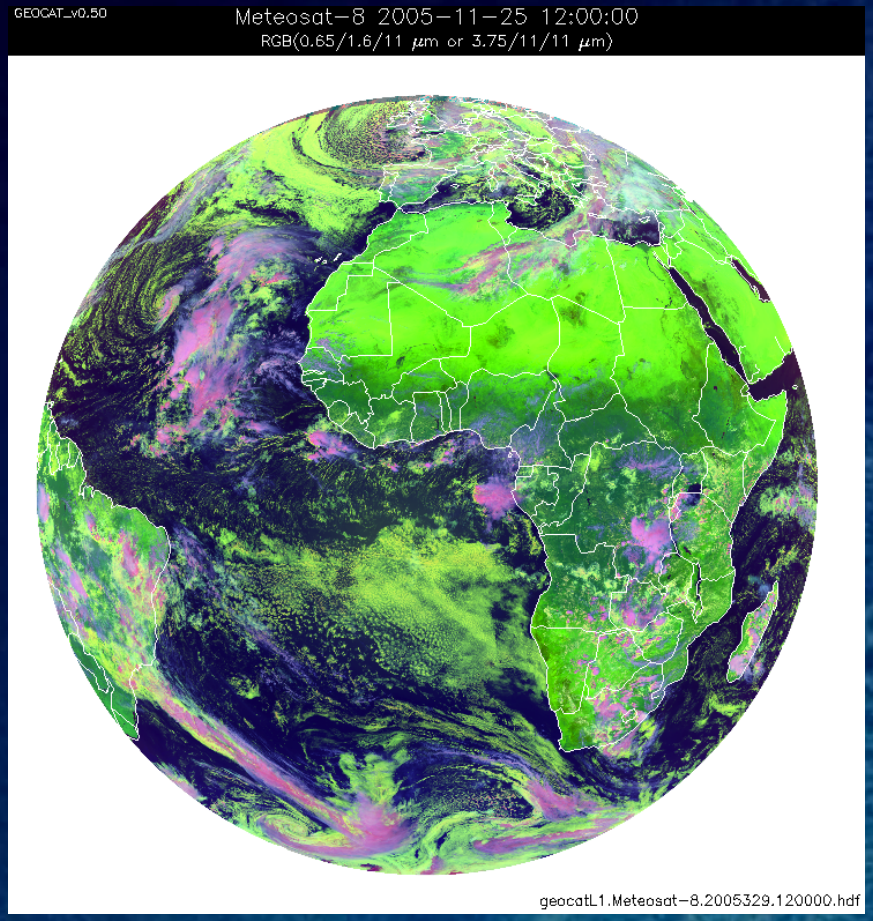


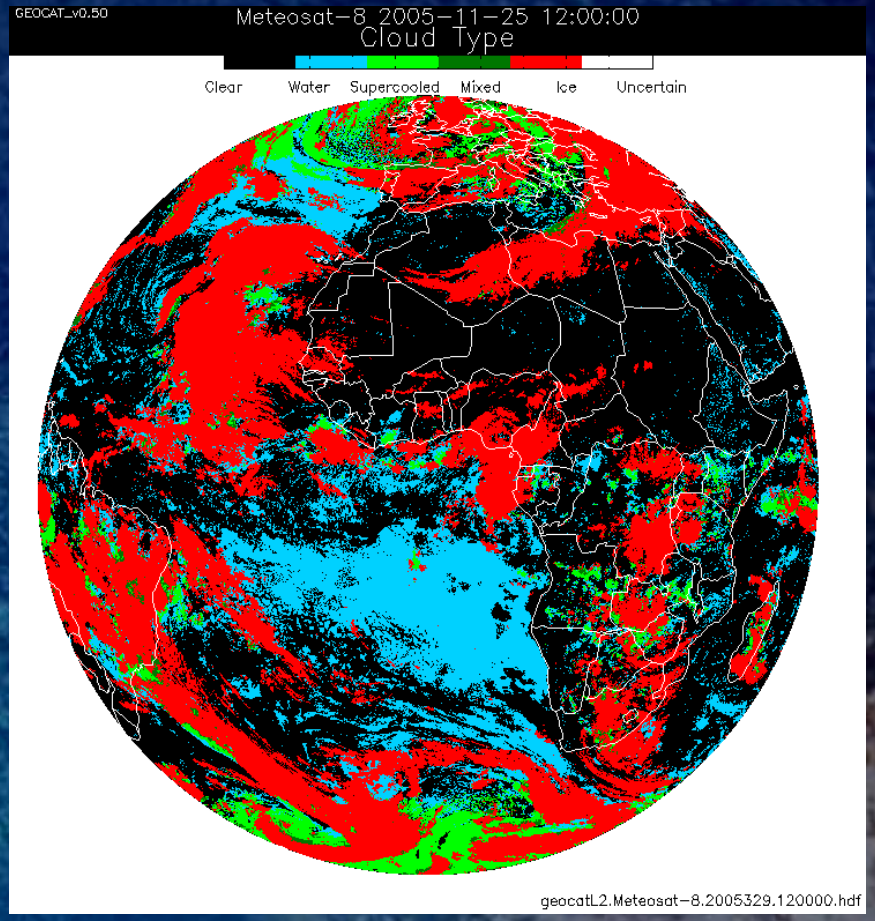


Water, Supercooled Water, Mixed Phase, Thick Ice, Thin Ice, Multilayered

Algorithm Results

Full disk cloud phase results





Water, Supercooled Water, Mixed Phase, Ice

Algorithm Changes from 80% to 100%

- Adjusted 7.3 μm thresholds based on clear sky weighting function (MODIS testing revealed the need for this).
- Other small threshold adjustments.
- Metadata output added.
- Quality flags standardized.

ADEB and IV&V Response Summary

- All ATBD errors and clarification requests have been addressed.
- No feedback required substantive modifications to the approach.

Requirements
Cloud Top Phase

Name	User & Priority	Geographic Coverage (G, H, C, M)	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
Cloud Top Phase	GOES-R	C	Cloud Top	2 km	1 km	Liquid/solid/ super cooled/mixed	20% Classification error	5 min	5 min	50 sec	TBD	20%
Cloud Top Phase	GOES-R	FD	Cloud Top	2 km	1 km	Liquid/solid/ super cooled/mixed	20% Classification error	15 min	5 min	159 sec	TBD	20%
Cloud Top Phase	GOES-R	M	Cloud Top	2 km	1 km	Liquid/solid/ super cooled/mixed	20% Classification error	5 min		50 sec	TBD	20%

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

Requirements
Cloud Top Phase

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Requirements
Cloud Top Phase

Name	User & Priority	Geographic Coverage (G, H, C, M)	Temporal Coverage Qualifiers	Product Extent Qualifier	Cloud Cover Conditions Qualifier	Product Statistics Qualifier
Cloud Top Phase	GOES-R	C	Day and night	Quantitative out to at least 65 degrees LZA and qualitative beyond	In presence of clouds with optical depth >1. Clear conditions down to cloud top associated with threshold accuracy	Over specified geographic area
Cloud Top Phase	GOES-R	FD	Day and night	Quantitative out to at least 65 degrees LZA and qualitative beyond	In presence of clouds with optical depth >1. Clear conditions down to cloud top associated with threshold accuracy	Over specified geographic area
Cloud Top Phase	GOES-R	M	Day and night	Quantitative out to at least 65 degrees LZA and qualitative beyond	In presence of clouds with optical depth >1. Clear conditions down to cloud top associated with threshold accuracy	Over specified geographic area

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Cloud Top Phase	GOES-R	FD	Day and night	Quantitative out to at least 65 degrees LZA and qualitative beyond	In presence of clouds with optical depth >1. Clear conditions down to cloud top associated with threshold accuracy	Over specified geographic area
Cloud Top Phase	GOES-R	M	Day and night	Quantitative out to at least 65 degrees LZA and qualitative beyond	In presence of clouds with optical depth >1. Clear conditions down to cloud top associated with threshold accuracy	Over specified geographic area

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Requirements
Cloud Type

Name	User & Priority	Geographic Coverage (G, H, C, M)	Vertical Res.	Horiz. Res.	Mapping Accuracy	Msmnt. Rang	Msmnt. Accuracy	Refresh Rate/Coverage Time Option (Mode 3)	Refresh Rate Option (Mode 4)	Data Latency	Long-Term Stability	Product Measurement Precision
Cloud Type	GOES-R	C	N/A	10 km	5 km	7 types	Probability of correct typing of 60%	15 min	5 min	536 sec	TBD	20%
Cloud Type	GOES-R	FD	N/A	2 km	1 km	7 types	Probability of correct typing of 60%	15 min	5 min	159 sec	TBD	20%
Cloud Type	GOES-R	M	N/A	2 km	1 km	7 types	Probability of correct typing of 60%	15 min		266 sec	TBD	20%

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Requirements
Cloud Type

Name	User & Priority	Geographic Coverage (G, H, C, M)	Vertical Res.	Horiz. Res.	Mapping Accuracy	Msmnt. Rang	Msmnt. Accuracy	Refresh Rate/Coverage Time Option (Mode 3)	Refresh Rate Option (Mode 4)	Data Latency	Long-Term Stability	Product Measurement Precision
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Requirements
Cloud Type

Name	User & Priority	Geographic Coverage (G, H, C, M)	Temporal Coverage Qualifiers	Product Extent Qualifier	Cloud Cover Conditions Qualifier	Product Statistics Qualifier
Cloud Type	GOES-R	C	Day and night	Quantitative out to at least 65 degrees LZA and qualitative beyond	In presence of limited clouds with optical depths between 2.0 and 60 (day)	Over specified geographic area
Cloud Type	GOES-R	FD	Day and night	Quantitative out to at least 65 degrees LZA and qualitative beyond	In presence of limited clouds with optical depth between 2.0 and 60 (day)	Over specified geographic area
Cloud Type	GOES-R	M	Day and night	Quantitative out to at least 65 degrees LZA and qualitative beyond	In presence of limited clouds with optical depth between 2.0 and 60 (day)	Over specified geographic area

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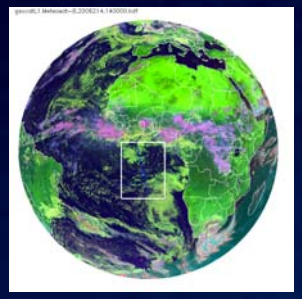
Validation Approach

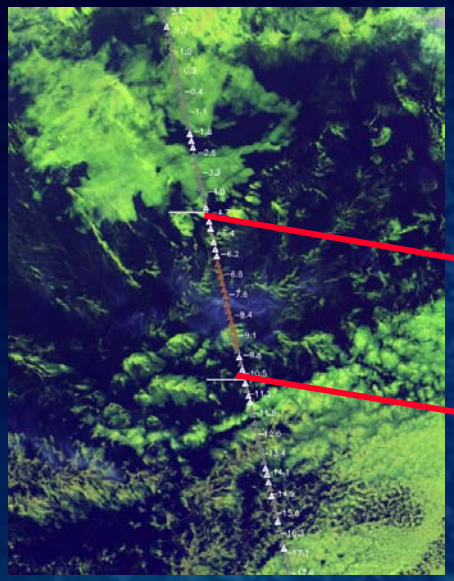
Validation Approach

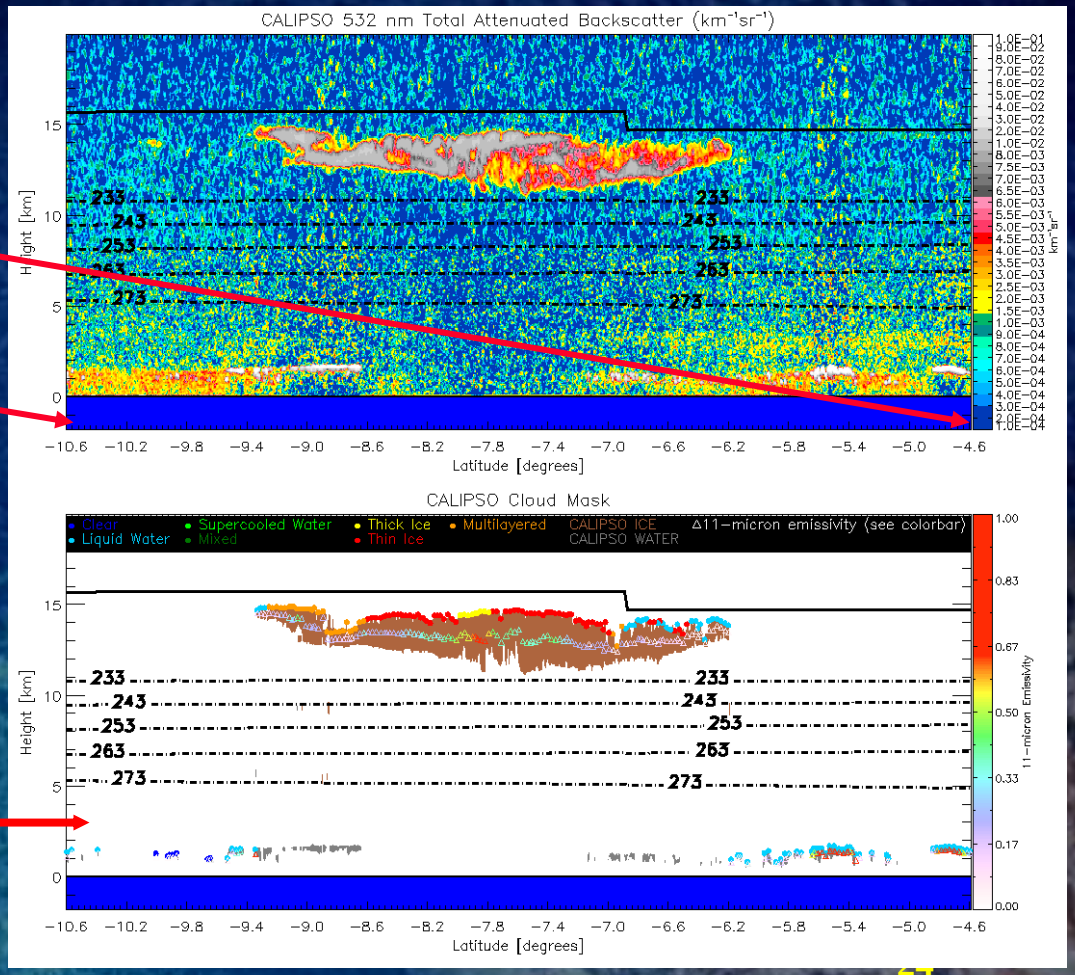
- While CALIOP provides an unprecedented view of clouds, it does not provide a direct measurement of cloud phase. Cloud phase must be retrieved.
- Thus, we decided to focus on using the CALIOP cloud boundaries along with NWP temperature profiles to identify clouds which have a cloud top temperature less than 233 K (definite ice clouds) and clouds which have a cloud top temperature greater than 273 K (definite water clouds).
- Fundamental thermodynamic and cloud physics theory dictates that liquid water is exceedingly unlikely at temperatures less than 233 K and ice is not possible at temperatures greater than 273 K.
- In addition, aircraft measurements have shown that liquid water dominates at temperatures of 268 K and higher, while ice dominates at temperatures of 238 K and smaller (Korolev et al., 2003), so our “definite” liquid water and ice cloud categories can be expanded.
- The mixed phase category has been eliminated from the CALIPSO cloud phase product, thus it cannot be used to validate potentially mixed phase clouds. A new version of the CALIPSO cloud products will be available for our validation period soon. When it is we will re-generate the validation.
- *****In our validation analysis, we do NOT invoke the minimum cloud optical depth qualifier.**

Performance Estimates

August 2, 2006 14:00 (day)







CALIPSO phase mask and GOES-R cloud typing results

Performance Estimates

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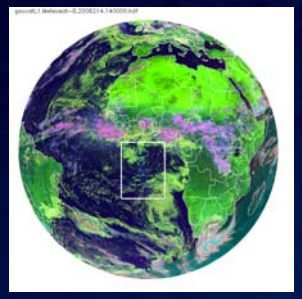
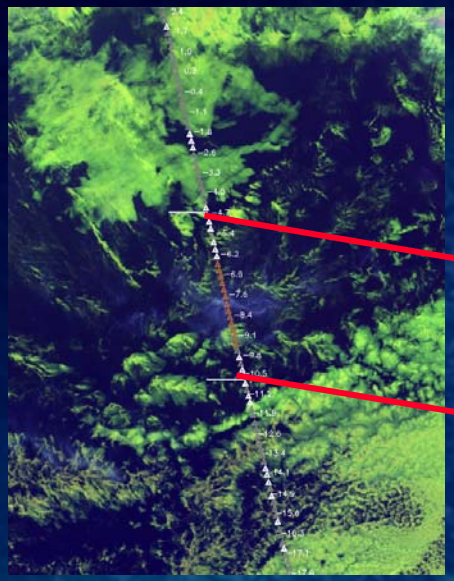
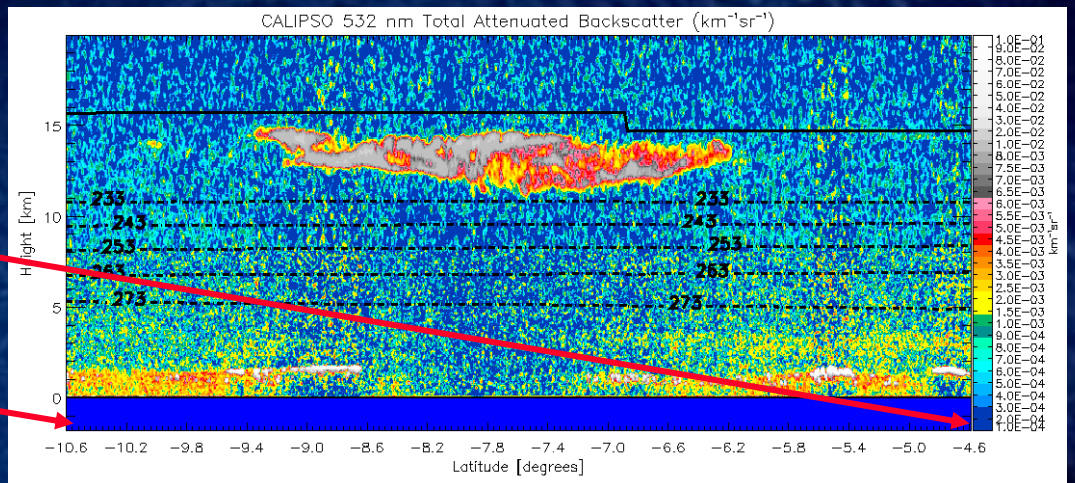
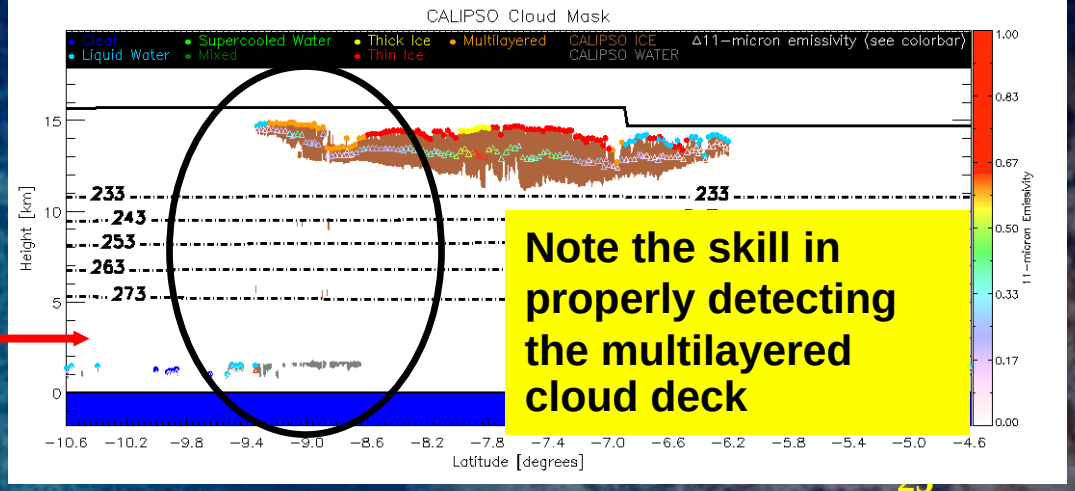






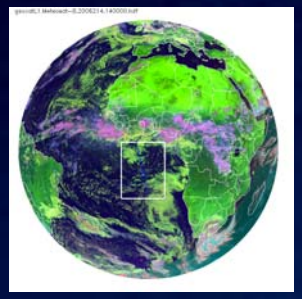


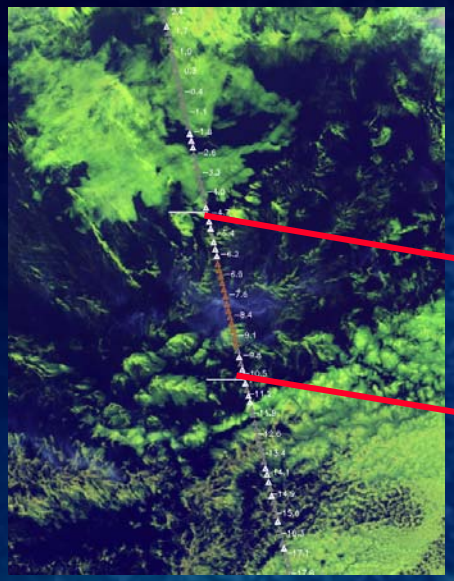
CALIPSO phase mask and GOES-R cloud typing results

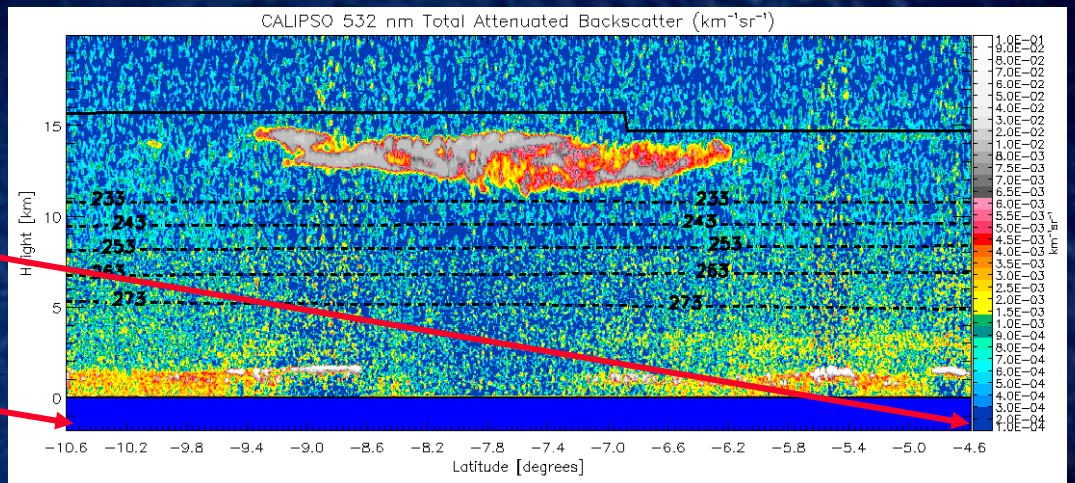
Note the skill in properly detecting the multilayered cloud deck

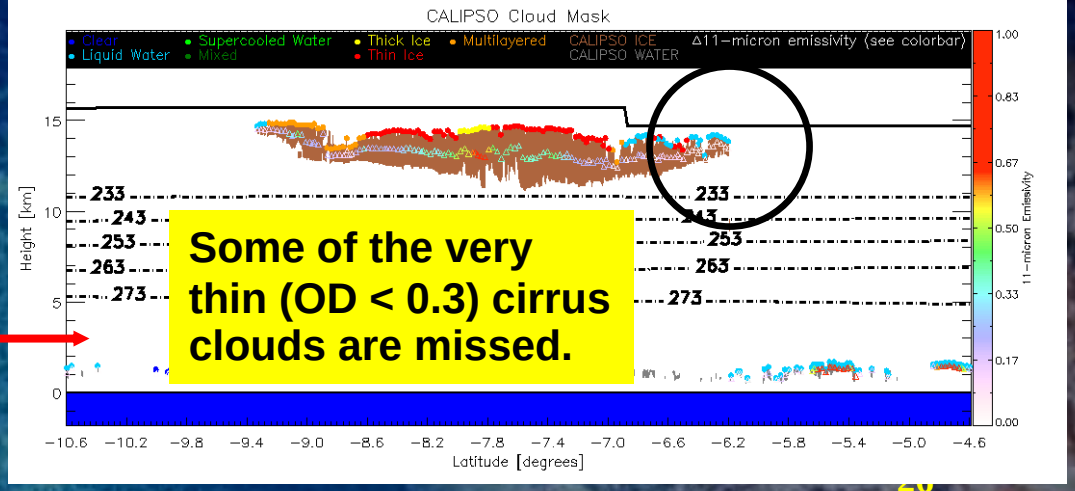
Performance Estimates

August 2, 2006 14:00 (day)









Some of the very thin (OD < 0.3) cirrus clouds are missed.

CALIPSO phase mask and GOES-R cloud typing results

Validation Results

Error Budget (Cloud Phase)

January

Category	CALIPSO Count	ABI Phase Count	Percent Agree	Percent Disagree
Liquid Water/ Supercooled water	4870	4711	96.74%	3.45%
Potentially Mixed Phase	1570	?	?%	?%
Ice Phase	5449	4520	82.95%	17.05%
Total	10,319	9231	89.46%	10.54%

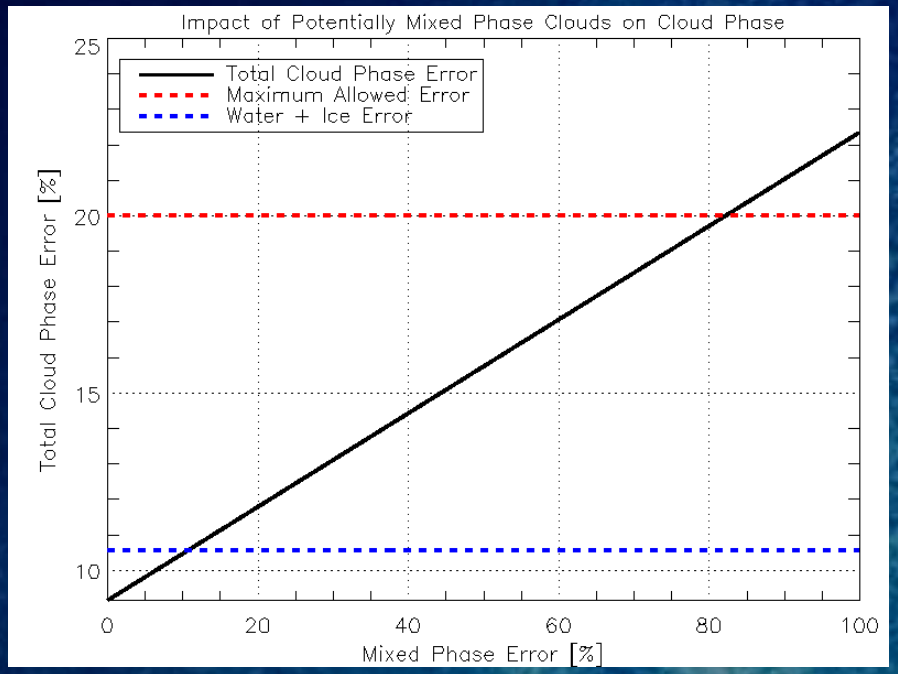
August

Category	CALIPSO Count	ABI Phase Count	Percent Agree	Percent Disagree
Liquid Water/ Supercooled water	6556	6365	97.09%	2.91%
Potentially Mixed Phase	2753	?	?%	?%
Ice Phase	5661	4881	86.22%	13.78%
Total	12,217	11,246	92.05%	7.95%

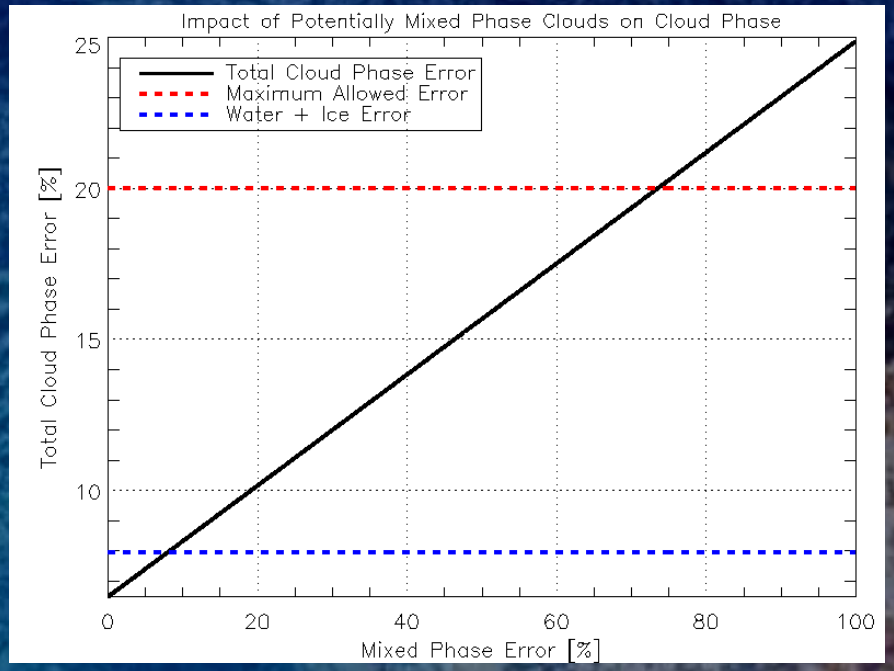
Error Budget (Cloud Phase)

The error in classifying potentially mixed phase clouds can be as large as 72% and the cloud phase algorithm will still meet the 20% error specification.

January



August



Error Budget (Cloud Type)

January

Category	CALIPSO Count	ABI Phase Count	Percent Agree	Percent Disagree
Liquid Water/ Supercooled water	4870	4711	96.74%	3.45%
Potentially Mixed Phase	1570	?	?%	?%
Optically Thick Ice	1261	1190	94.37%	5.63%
Optically Thin Ice	1601	988	61.71%	38.29%
Multilayered Ice	2587	865	33.44%	66.56%
Total	10,319	9231	75.14%	24.86%

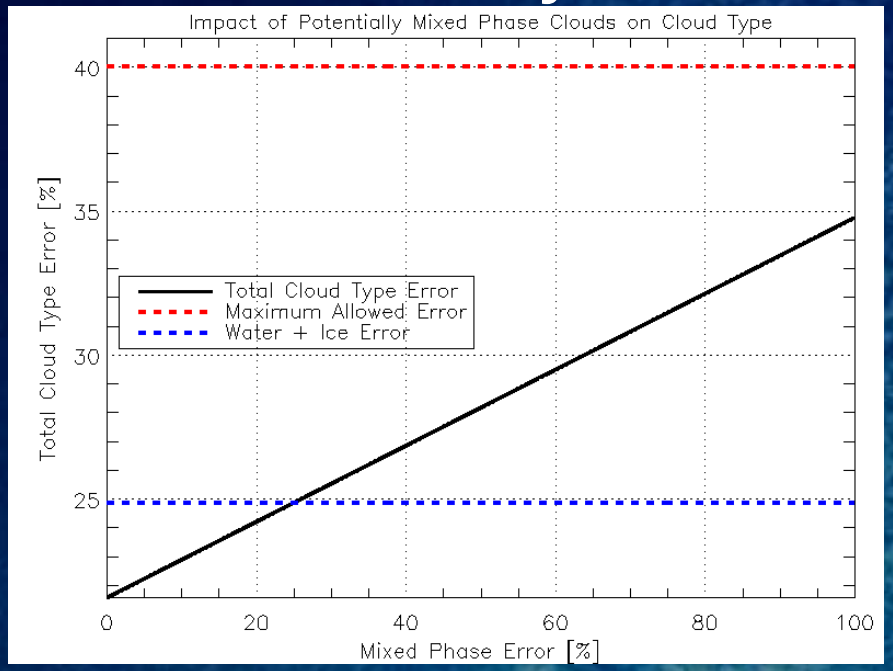
August

Category	CALIPSO Count	ABI Phase Count	Percent Agree	Percent Disagree
Liquid Water/ Supercooled water	6556	6365	97.09%	2.91%
Potentially Mixed Phase	2753	?	?%	?%
Optically Thick Ice	1447	1390	96.06%	3.94%
Optically Thin Ice	1573	1095	69.61%	30.39%
Multilayered Ice	2641	692	26.20%	73.80%
Total	12,217	9642	78.10%	21.90%

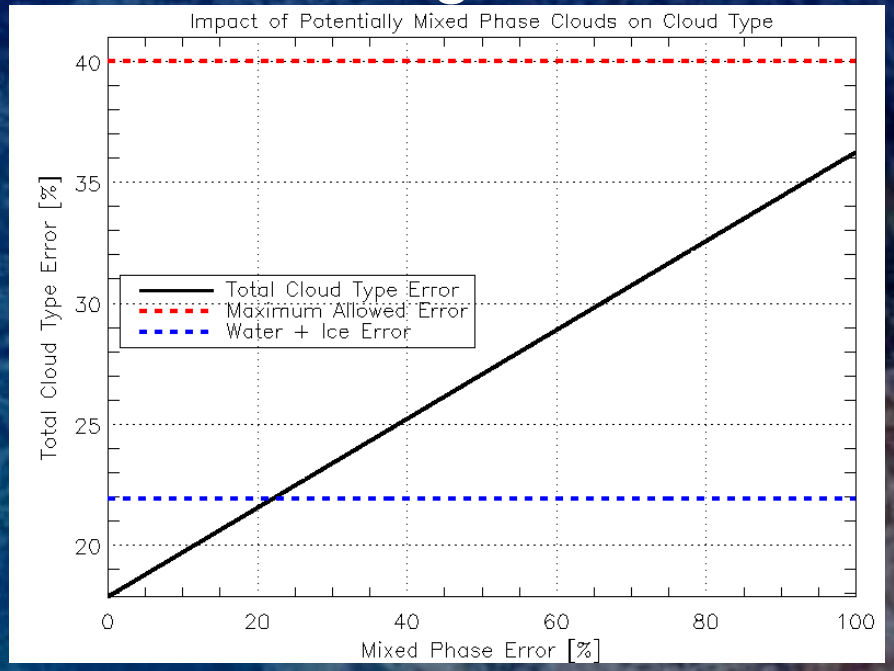
Error Budget (Cloud Type)

The error in classifying potentially mixed phase clouds can be as large as 100% and the cloud type algorithm will still meet the 40% error specification.

January

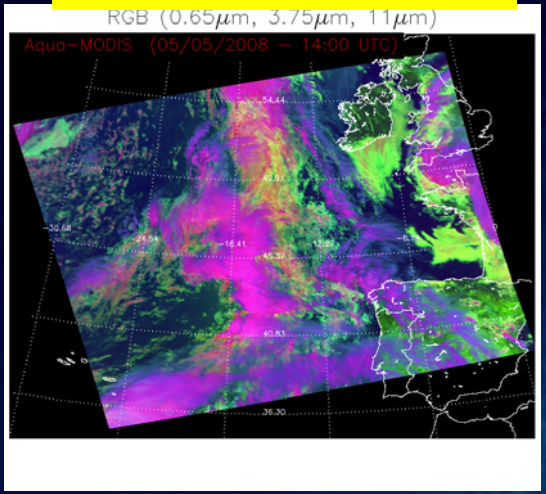


August

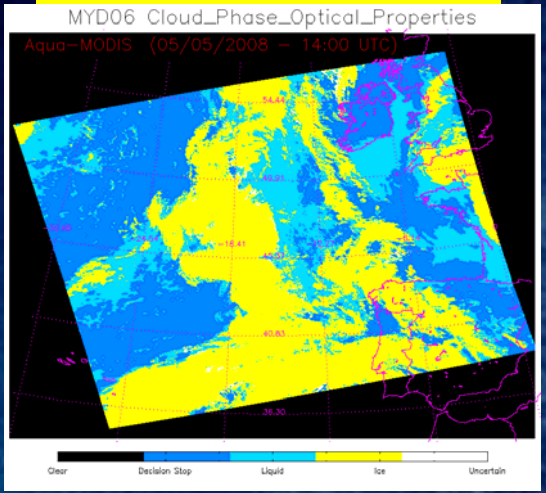


Cloud Phase/Type Inter-comparisons

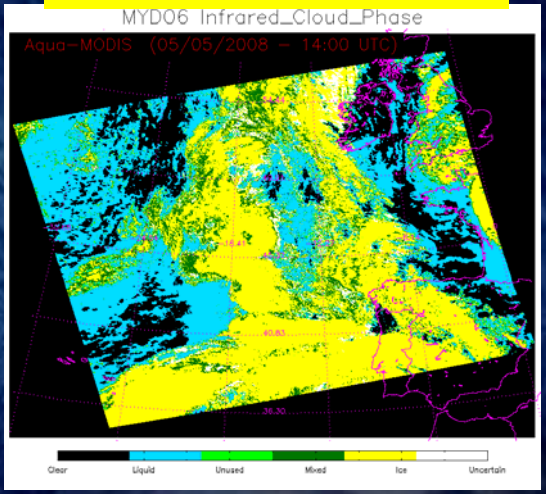
False Color



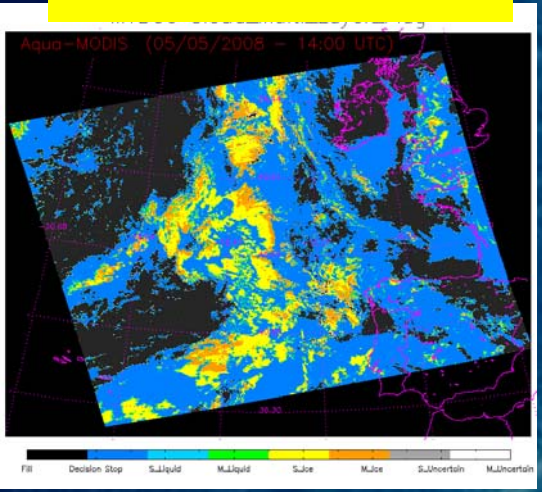
MYD06 NIR



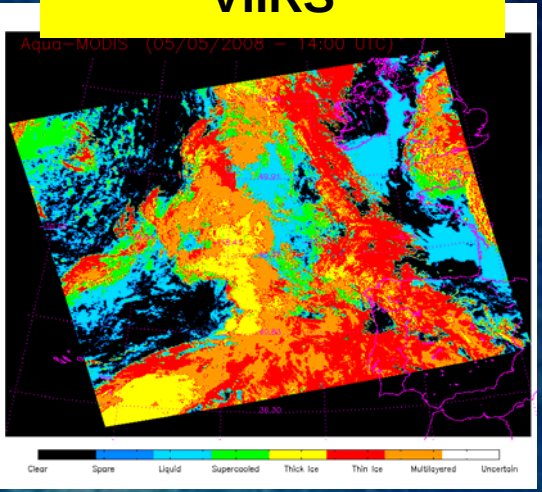
MYD06 IR



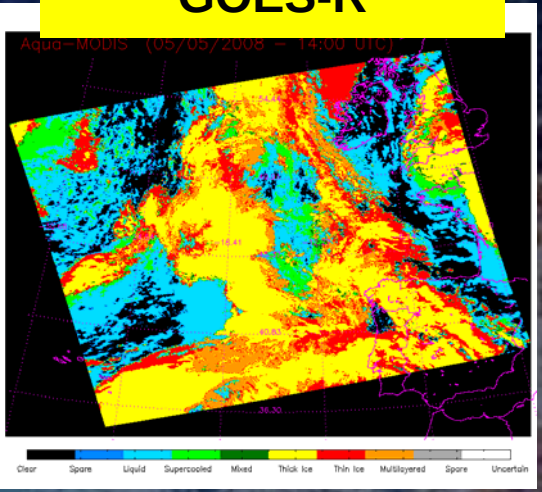
MYD06 NIR Multi



VIIRS



GOES-R



Cloud Phase/Type Inter-comparisons

Cloud Phase Comparison

Phase	Beta	MYD06 NIR	MYD06 IR	PH05
Liquid	384,897 (18.99%)	578,969 (28.57%)	400,834 (19.78%)	512,162 (25.27%)
Mixed	15,304 (0.76%)	0 (0.00%)	154,485 (7.62%)	0 (0.00%)
Ice	1,626,616 (80.25%)	1,362,649 (67.23%)	1,212,086 (59.80%)	1,514,655 (74.73%)
Uncertain	0 (0.00%)	85,199 (4.20%)	259,412 (12.80%)	0 (0.00%)

Multilayered Cloud Detection Comparison

	Beta	MYD06 NIR	PH05
Multilayer Count	386,508 (19.07%)	258,768 (12.77%)	701,027 (34.59%)

Summary

- The ABI Cloud Phase/Type Algorithm provides a unique IR-only solution that utilizes the new capabilities offered by the ABI
- Version 5 and the 100% ATBD will be delivered soon.
- These products meet the specifications and are proving useful to downstream applications (cloud height, fog, cloud optical properties, icing)
- We will now focus on developing deep dive validation tools.