JPSS Risk Reduction: Uniform Multi-Sensor Cloud Algorithms for Consistent Products Critical Design Review

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Products Covered in this CDR

- Cloud Mask
- Cloud Top Phase
- Cloud Type
- Cloud Top Height
- Cloud Cover Layers
- Cloud Top Temperature
- Cloud Top Pressure
- Nighttime Cloud Optical Depth
- Nighttime Cloud Particle Size Distribution
- Nighttime Cloud Liquid Water
- Nighttime Cloud Ice Water Path

Review Agenda

• Introduction	1:00 pm – 1:10 pm	Wolf
• Requirements	1:10 pm – 1:20 pm	Wolf
• Operations Concept	-------------------------	
• ATB – Cloud Mask	1:20 pm – 2:05 pm	Heidinger
• Cloud Phase	2:05 pm – 2:50 pm	Pavolonis
• Break	2:50 pm – 3:00 pm	
• Cloud Height	3:00 pm – 3:45 pm	Heidinger
• NCOMP	3:45 pm – 4:30 pm	Heck
• Software Architecture & Interfaces	4:30 pm – 4:40 pm	Wolf
• Detailed Design	4:40 pm – 4:50 pm	Wolf
• Quality Assurance	-------------------------	
• Algorithm Package	-------------------------	
• Risks & Actions	4:50 pm – 4:55 pm	Wolf
• Summary and Conclusions	4:55 pm – 5:00 pm	Wolf

Outline

- Introduction
- Requirements
- Operations Concept
- Volcanic Ash
- Cloud Phase
- NCOMP
- Software Architecture and Interfaces
- Design Overview and System Description
- Algorithm Package
- Quality Assurance
- Risks and Actions Summary
- Summary and Conclusions

Introduction

Presented by

Walter Wolf

Contents

- Project Objectives
- Stakeholders
- Teams
- Project Plan
- Entry and Exit Criteria

Project Background

- NWS requests continuity of NOAA products between current and future NOAA operational satellites
- Demonstration of cost effective processing for NOAA JPSS products
- Demonstration of NOAA's goal of enterprise solutions by employing same algorithms for "POES" and "GOES"
- Supports NWS OS&T implementation strategy of multi-sensor algorithms and products

Project Background – NDE

- Disseminate NPOESS Data Records to customers.
- Generate and disseminate tailored NPOESS Data Records (versions of NPOESS Data Records in previously agreed alternative formats and views).
- Generate and disseminate NOAA-unique products (augmented environmental products constructed from NPOESS Data Records).
- Deliver NOAA-unique products, product processing elements, and associated metadata to CLASS for long-term archiving.
- Provide services to customers, including NDE product training, product enhancement, and *implementation support across NOAA.*
- Provide software for NPOESS Data Record format translation and other data manipulations.

Project Objectives

- Modification of the NOAA Heritage Cloud, Cryosphere, Volcanic Ash, and Aerosol algorithms to work on VIIRS data
- This will bring scientific consistency between the current operational products, GOES-R products and VIIRS products
- Run the product system within NDE

Products Objectives
Cloud Products

- Cloud Mask
- Cloud Top Phase
- Cloud Type
- Cloud Top Height
- Cloud Cover Layers
- Cloud Top Temperature
- Cloud Top Pressure
- Cloud Optical Depth
- Cloud Particle Size Distribution
- Cloud Liquid Water
- Cloud Ice Water Path

Products Objectives
Aerosol Products

- Aerosol Detection
- Aerosol Optical Depth
- Aerosol Particle Size
- Volcanic Ash Mass Loading
- Volcanic Ash Height

Products Objectives
Cryosphere Products

- Snow Cover
- Ice Concentration and Cover
- Ice Surface Temperature
- Ice Thickness/Age

JPSS Risk Reduction Integrated Product Team

- IPT Lead: Walter Wolf (STAR)
- IPT Backup Lead: AK Sharma (OSPO)
- NESDIS team:
  - » STAR: Andy Heidinger, Jeff Key, Shobha Kondragunta, Istvan Laszlo, Mike Pavolonis
  - » OSPO: Gilberto Vicente, Hanjun Ding, Zhaohui Cheng
  - » OSD: Tom Schott, Jim Silva, Geof Goodrum
  - » NOAA JPSS: Mitch Goldberg
  - » NIC: Sean Helfrich, Pablo Clemente
  - » Data Center: Lei Shi (NCDC)
  - » Others: Shanna Sampson, Peter Romanov, Xingpin Liu, William Straka III, Ray Garcia
- User team
  - » Lead: Kevin Schrab (NWS) Mike Johnson(NWS), John Derber (NWS/NCEP/EMC), Jeff Ator (NWS/NCEP/NCO), Lars Peter-Riishojgaard (JCSDA), Gary Hufford (NWS), VAACs
  - » Others: International NWP users, NWP FOs, Climate Users
- Sounding Product Oversight Panel
- Other POPs involved: EPOP, ICAPOP, CAL/NAVPOP, ACPOP, SURPOP

Project Stakeholders

- OSPO
- STAR
- OSD
- JPSS
- NOAA National Weather Service
- National Ice Center
- Department of Defense
- Global NWP

Project Plan

- Year 1 – Design and Development (2012 – 2013)
  - » Develop Requirements Document
  - » Product leads to identify updates to the algorithms to work with VIIRS data
  - » Identify ancillary data for the algorithms
  - » Conduct CDR
  - » Algorithm development
  - » Implement algorithms within the Framework
  - » Conduct TRR

Project Timeline
Year 1

Timeline: Qtr 3, Qtr 4 | 2013: Qtr 1, Qtr 2, Qtr 3, Qtr 4 | 2014: Qtr 1, Qtr 2, Qtr 3, Qtr 4

ID	Task Name	Start	Finish
1	**JPSS Risk Reduction**		
2	**Development Phase**		
3	**IPT Lead informed to begin product development**		10/1
4	**Algorithm Evaluation/Preliminary Development**	10/1	12/31
5	Initial Archive Requirements identified	10/1	10/30
6	Quality Monitoring Concept Defined	10/1	10/30
7	Long-term Maintenance Concept Defined	10/1	10/30
8	Development processing system defined	10/1	10/30
9	Evaluate the modifications required to create VIIRS products from the GOES-R alg	10/1	10/30
10	Initial Information Technology (IT) Security concept defined	10/1	10/30
11	**Requirements Review**		10/31
12	Preliminary development Aerosol, Cloud, Cryosphere and Volcanic Ash algorithm d	10/1	12/28
13	Identify ancillary data inputs for all the algorithms	11/1	12/28
14	Preliminary development of infrastructure to implement the NetCDF4 readers and w	11/1	12/28
15	**Critical Design Reviews for Aerosol, Cloud, Cryosphere, and Volcanic Ash alg**		12/31
16	**Algorithm Developmen**	1/2	2/28
17	Development of Aerosol, Cloud, Cryosphere and Volcanic Ash algorithms	1/2	2/28
18	Define Aerosol, Cloud, Cryosphere and Volcanic Ash output files	1/2	2/28
19	Development of infrastructure to implement the NetCDF4 readers and writers for th	2/1	2/28
20	**Algorithm Implement/Testing/Demonstratio**	3/1	10/31
21	Begin documentation of the framework	3/1	3/1
22	Implement Cloud Mask, Height, and Phase algorithms into the framework	3/1	5/30
23	Cloud Mask, Height, and Phase test cases processed	4/1	5/30
24	**Test Readiness Review for Cloud Mask, Height, and Phase**		5/31
25	**Deliver preliminary Cloud DAP to NDE**		5/31
26	Implement Aerosol Detection, Aerosol Optical Depth and Volcanic Ash algorithms i	6/3	8/29
27	Aerosol Detection, Aerosol Optical Depth and Volcanic Ash test case processed	7/1	8/29
28	**Test Readiness Review for Aerosol Detection, Aerosol Optical Depth and Volc**		8/30
29	**Deliver preliminary Aerosol and Volcanic Ash DAP to NDE**		8/30
30	Implement Cryosphere algorithms into the framework	8/1	10/30
31	Cryosphere algorithm test case processed	9/2	10/30
32	**Test Readiness Review for Cryosphere algorithms**		10/31
33	**Deliver preliminary Cryosphere DAP to NDE**		10/31
34	**Pre-operational Phase**		
56	**Operational Phase**		

Project Plan

- Year 2 –Transition to Pre-Operations (2013 – 2014)
  - » Deliver initial DAP (Framework with pre-operational algorithms) to NDE
  - » Conduct Software Review
  - » Update algorithms
  - » Transition and test system within the NDE environment
  - » Perform test data flows
  - » Conduct System Readiness Review
  - » Deliver final DAP to NDE

Project Timeline
Year 2

2013: Qtr 3, Qtr 4, Qtr 1, Qtr 2, Qtr 3, Qtr 4 — 2014: Qtr 1, Qtr 2, Qtr 3, Qtr 4

ID	Task Name		
1	**JPSS Risk Reduction**		
2	**Development Phase**		
34	**Pre-operational Phase**		
35	Transition Framework to the pre-operational system on the NDE hardware	11/1	11/29
36	NDE/OSPO Contractor Staff Training for the Framework	11/1	11/29
37	Pre-operational product output evaluated & tested within the NDE environment	12/2	12/31
38	Aerosol, Cloud, Cryosphere, and Volcanic Ash algorithms are upgraded	12/2	2/27
39	**Software Review for Aerosol, Cloud, Cryosphere, and Volcanic Ash algorithms**		2/28
40	Provide test products to the end users	2/3	2/28
41	Prepare Documentation	12/2	2/28
42	Developed Operational Products Implementation Plan	12/2	2/28
43	Baseline products system	2/3	2/28
44	Evaluated and Modify Operational Documentation	3/3	5/29
45	Validation and Verification of Operational Quality Assurance for Products	3/3	5/29
46	Validation and Verification of Monitoring capability for Products	3/3	5/29
47	**All documentation is complete**		5/30
48	**Final DAP delivered to NDE**		5/30
49	Prepare for Transition to Operations	5/1	5/30
50	**Conduct System Readiness Review for Aerosol, Cloud, Cryosphere, and Volcanic**		5/30
51	Operational and backup processing capabilities in place	6/2	6/30
52	Final IT Security Concept Defined	6/2	6/30
53	Transition DAP to operations	6/2	7/31
54	Brief SPSRB Oversight Panel(s) on product status	8/1	8/15
55	Brief SPSRB capability is ready to operational	8/1	8/15
56	**Operational Phase**		
57	**SPSRB manager and secretaries notified JPSS Risk Reduction NOAA Unique Pro**		8/29
58	SPSRB Secretaries/manager update the SPSRB product metrics web page	8/18	8/29

Project Plan
Cloud Product Schedule

- **Schedule (Milestones)**
  - » Project begins – 10/05/12
  - » Requirements Review – 12/27/12 (10/31/12)
  - » Critical Design Review – 04/05/13 (12/31/12)
  - » Test Readiness Review – (05/31/13, 08/30/13, 10/31/13)
    - – Cloud Mask – 05/31/13
    - – Cloud Phase, Cloud Height, NCOMP – 08/30/13
  - » Software Review – 02/28/14 (02/28/14)
  - » System Readiness Review – 05/30/14 (05/30/14)

CDR Entry Criteria

- Reviewed Requirements Document
- Review of JPSS RRPS Project:
  - » Requirements
  - » Operations Concept
  - » Algorithm Theoretical Basis
  - » Software Architecture & Interfaces
  - » Detailed Design
  - » Algorithm Package
  - » Quality Assurance
  - » Risks and Actions

CDR Exit Criteria

- Critical Design Review Report
  - » The CDR Report (CDRR), a standard artifact of the SPSRB Process Lifecycle, will be compiled before the TRR
  - » The report will contain:
    - – Actions
    - – Comments
    - – CDR presentation

Outline

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- Cloud Phase
- Cloud Height
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Requirements for JPSS Risk Reduction: Uniform Multi-Sensor Algorithms for Consistent Products

Presented by
Walter Wolf

JPSS Risk Reduction System Requirements

- All JPSS Risk Reduction System Project requirements are present in this section
- All JPSS Risk Reduction System Project requirements are documented in a single RAD and are part of the CDR documentation suite
- Basic requirements are shown in all yellow text on a single slide

JPSS Risk Reduction Requirements Information

- The JPSS Risk Reduction Products are addressing SPSRB requirements
- The Products created from this project will at least meet the associated product requirements within the L1RD Supplement
- The version of the RAD that is released with the CDR report will trace the Risk Reduction products to the L1RD Supplement requirements

Basic Requirement 0.0

- **JPSS-PS-R 0.0:** *The JPSS Risk Reduction Product System (JPSS RRPS) development project shall adopt the standard practices of the Satellite Product and Services Review Board (SPRB).*

  » **Driver:** *STAR Enterprise Product Lifecycle (EPL)*. The SPSRB process has been updated by incorporating aspects of the STAR EPL Process.

Basic Requirement 0.0

- **GOES-PS-R 0.1:** *The JPSS RRPS development project practices shall be tailored from the SPSRB process.*

  » This requirement should be met by following the SPSRB process, as long as the tailoring does not introduce an incompatibility.

Basic Requirement 1.0

- **JPSS-PS-R 1.0:** *The JPSS RRPS shall generate Global Cloud products.*

- **Driver:** **SPSRB requirements:**
  - » 1107-0011: Gridded Cloud Products for NWP Verification
  - » 0909-0018: CLAVR-x and GSIP cloud product composites over Alaska

Basic Requirement 1.0

- **JPSS-PS-R 1.1:** *The Cloud products shall include Cloud Mask, Cloud Phase, Cloud Type, Cloud Top Height, Cloud Cover Layers, Cloud Top Temperature, Cloud Top Pressure, Cloud Optical Depth, Cloud Particle Size Distribution, Cloud Ice Water Path, Cloud Liquid Water.*
  - » Current operational products, with upgraded capabilities.

Basic Requirement 1.0

- **JPSS-PS-R 1.1.1:** *The Cloud Mask Product shall have accuracy of 90% correct detection.*

- **JPSS-PS-R 1.1.2:** *The Cloud Phase Product shall have accuracy of 80% Correct Classification (5 phases).*

- **JPSS-PS-R 1.1.3:** *The Cloud Type Product shall have accuracy of 60% correct classification (7 categories).*

  » Current operational products, with upgraded capabilities.

Basic Requirement 1.0

- **JPSS-PS-R 1.1.4:** *The Cloud Top Height Product shall have accuracy of 500 m for clouds with emissivity > 0.8.*

- **JPSS-PS-R 1.1.5:** *The Cloud Cover Layers Product shall have accuracy of 80% Correct Classification (Low, Mid, High).*

- **JPSS-PS-R 1.1.6:** *The Cloud Top Temperature Product shall have accuracy of 3 K for clouds with emissivity > 0.8.*

  » Current operational products, with upgraded capabilities.

Basic Requirement 1.0

- **JPSS-PS-R 1.1.7:** *The Cloud Top Pressure Product shall have accuracy of 50 mb for clouds with emissivity > 0.8.*

- **JPSS-PS-R 1.1.8:** *The Cloud Optical Depth Product shall have accuracy of better than:*
  - *Liquid phase:*
  - *20% error (Day), 20% (Night);*
  - *Ice phase:*
  - *20% (Day), 30% (Night)*

  - Current operational products, with upgraded capabilities.

Basic Requirement 1.0

- **JPSS-PS-R 1.1.9:** *The Cloud Particle Size Distribution Product shall have accuracy of:*
  - » *4 µm for liquid phase*
  - » *10 µm for ice phase*

- **JPSS-PS-R 1.1.10:** *The Cloud Ice Water Path Product shall have accuracy of greater of 25g/m2 or 30% error.*

- **JPSS-PS-R 1.1.11:** *The Cloud Liquid Water Product shall have accuracy of greater of 25g/m2 or 15% error.*

  - » Current operational products, with upgraded capabilities.

Basic Requirement 1.0

- **JPSS-PS-R 1.1.12:** *The Cloud Mask Product shall have horizontal resolution of 0.75 km.*
- **JPSS-PS-R 1.1.13:** *The Cloud Phase Product shall have horizontal resolution of 0.75 km.*
- **JPSS-PS-R 1.1.14:** *The Cloud Type Product shall have horizontal resolution of 0.75 km.*

  » Current operational products, with upgraded capabilities.

Basic Requirement 1.0

- **JPSS-PS-R 1.1.15:** *The Cloud Top Height Product shall have horizontal resolution of 0.75 km.*
- **JPSS-PS-R 1.1.16:** *The Cloud Cover Layers Product shall have horizontal resolution of 0.75 km.*
- **JPSS-PS-R 1.1.17:** *The Cloud Top Temperature Product shall have horizontal resolution of 0.75 km.*

  » Current operational products, with upgraded capabilities.

Basic Requirement 1.0

- **JPSS-PS-R 1.1.18:** *The Cloud Top Pressure Product shall have horizontal resolution of 0.75 km.*

- **JPSS-PS-R 1.1.19:** *The Cloud Optical Depth Product shall have horizontal resolution of 0.75 km.*

- **JPSS-PS-R 1.1.20:** *The Cloud Particle Size Distribution Product shall have horizontal resolution of 0.75 km.*

  » Current operational products, with upgraded capabilities.

Basic Requirement 1.0

- **JPSS-PS-R 1.1.21:** *The Cloud Ice Water Phase Product shall have horizontal resolution of 0.75 km.*

- **JPSS-PS-R 1.1.22:** *The Cloud Liquid Water Product shall have horizontal resolution of 0.75 km.*

  » Current operational products, with upgraded capabilities.

Basic Requirement 1.0

- **JPSS-PS-R 1.2:** *The Cloud Products shall have global coverage.*
  - Current operational products, with upgraded capabilities.
- **JPSS-PS-R 1.2.1:** *The Cloud Products shall have latency of 30 minutes after granule data is available.*
  - Latency is defined as the interval from the last observation to when the product is available to users. Current capability is 60 minutes.

Basic Requirement 1.0

- **JPSS-PS-R 1.2.2:** *The Cloud Products shall have at least 90% coverage of the globe every 12 hours (monthly average).*

- **JPSS-PS-R 1.2.3:** *The Cloud Products shall have timeliness of ≤ 3 hours.*

  » Current operational products, with upgraded capabilities.

Basic Requirement 1.0

- **JPSS-PS-R 1.3:** *The Cloud Products shall include quality information.*
  - » QC flags will be specified in the External Users Manual.

- **JPSS-PS-R 1.4:** *The JPSS RRPS shall write Cloud Products files in NetCDF4 formats.*
  - » SPSRB requirement

Basic Requirement 1.0

- **JPSS-PS-R 1.5:** *The JPSS RRPS developers shall perform validation and verification of the Cloud Products.*
  - » Validation tools will be based upon the GOES-R validation tools and/or the heritage validation tools
- **JPSS-PS-R 1.5.1:** *The JPSS RRPS developers shall plot datasets for verification of the Cloud Products.*

Basic Requirement 1.0

- **JPSS-PS-R 1.5.2:** *The JPSS RRPS developers shall verify that Cloud Products files are generated correctly.*
  - » Will be included in the unit tests described in the UTR and the system test described in the SRR.

- **JPSS-PS-R 1.5.3:** *The JPSS RRPS system shall perform routine data range checks to flag anomalous values in the input data.*
  - » Anomalous values will be flagged. These checks will be included in the code and described in the SRR.

Basic Requirement 1.0

- **JPSS-PS-R 1.5.4:** *The JPSS RRPS system shall perform routine data range checks to flag anomalous values in the Cloud Products.*
  - » Out-of-range values will be flagged. These checks will be included in the code. UTR will address.
- **JPSS-PS-R 1.5.5:** *The JPSS RRPS developers shall generate matchup datasets between Cloud Products retrievals and in situ measurements.*
  - » In situ data obtained from NCEP & ECMWF analysis, SURFRAD measurements, and CALIPSO data.

Basic Requirement 2.0

- **JPSS-PS-R 2.0:** *The JPSS RRPS shall generate Aerosol Products.*

Driver: **SPSRB requirements:**

» *1009-0016: Dust Aerosol Concentration Product*

» *0707-0014: Support satellite-based verification of the National Air Quality Forecast Capability*

Basic Requirement 2.0

- **JPSS-PS-R 2.1:** *The Aerosol Products shall include Aerosol Optical Depth and Aerosol Detection.*

- **JPSS-PS-R 2.1.1:** *The Aerosol Optical Depth Product shall have accuracy based on Aerosol Optical Depth ranges:*
  - *Over land:*
  - *< 0.04: 0.06*
  - *0.04 – 0.80: 0.04*
  - *> 0.80: 0.12*
  - *Over water:*
  - *< 0.40: 0.02*
  - *> 0.40: 0.10*

  - Current operational product, with upgraded capabilities.

Basic Requirement 2.0

- **JPSS-PS-R 2.1.2:** *The Aerosol Detection Product shall have accuracy:*
  - » *Dust: 80% correct detection over land and ocean*
  - » *Smoke: 80% Correct detection over land; 70% correct detection over ocean*

- **JPSS-PS-R 2.1.3:** *The Aerosol Optical Depth Product shall have horizontal resolution of 0.75 km (nadir).*

- **JPSS-PS-R 2.1.4:** *The Aerosol Detection Product shall have horizontal resolution of 0.75 km.*

  - » Current operational products, with upgraded capabilities.

Basic Requirement 2.0

- **JPSS-PS-R 2.2:** *The Aerosol Products shall have global coverage.*
  - » Current operational products, with upgraded capabilities.
- **JPSS-PS-R 2.2.1:** *The Aerosol Products shall have latency of 30 minutes after granule data is available.*
  - » Latency is defined as the interval from the last observation to when the product is available to users. Current capability is 60 minutes.

Basic Requirement 2.0

- **JPSS-PS-R 2.2.2:** *The Aerosol Products shall have at least 90% coverage of the globe every 12 hours (monthly average).*

- **JPSS-PS-R 2.2.3:** *The Aerosol Products shall have timeliness of ≤ 3 hours.*

  - » Current operational products, with upgraded capabilities.

Basic Requirement 2.0

- **JPSS-PS-R 2.3:** *The Aerosol Products shall include quality information.*
  - » QC flags will be specified in the External Users Manual.

- **JPSS-PS-R 2.4:** *The JPSS RRPS shall write Aerosol Products files in NetCDF4 formats.*
  - » SPSRB requirement

Basic Requirement 2.0

- **JPSS-PS-R 2.5:** *The JPSS RRPS developers shall perform validation and verification of the Aerosol Products.*

  » Validation tools will be based upon the GOES-R validation tools

- **JPSS-PS-R 2.5.1:** *The JPSS RRPS developers shall plot datasets for verification of the Aerosol Products.*

Basic Requirement 2.0

- **JPSS-PS-R 2.5.2:** *The JPSS RRPS developers shall verify that Aerosol Products files are generated correctly.*
  - » Will be included in the unit tests described in the UTR and the system test described in the SRR.
- **JPSS-PS-R 2.5.3:** *The JPSS RRPS system shall perform routine data range checks to flag anomalous values in the input data.*
  - » Anomalous values will be flagged. These checks will be included in the codeand described in the SRR.

Basic Requirement 2.0

- **JPSS-PS-R 2.5.4:** *The JPSS RRPS system shall perform routine data range checks to flag anomalous values in the Aerosol Products.*
  - » Out-of-range values will be flagged. These checks will be included in the code. UTR will address.
- **JPSS-PS-R 2.5.5:** *The JPSS RRPS developers shall generate matchup datasets between Aerosol Products retrievals and in situ measurements.*
  - » In situ data obtained from AERONET Measurements

Basic Requirement 3.0

- **JPSS-PS-R 3.0:** *The JPSS RRPS shall generate Volcanic Ash Products.*

- **Driver:** **SPSRB requirements:**

  0507-05: Polar/Geostationary Volcanic Ash Detection and Height on CLAVR-X

Basic Requirement 3.0

- **JPSS-PS-R 3.1:** *The Volcanic Ash Products shall include Volcanic Ash Detection (Mass Loading) and Height.*

- **JPSS-PS-R 3.1.1:** *The Volcanic Ash Detection (Mass Loading) and Height Product shall have accuracy:*
  - » *2 tons/km2, 3 km height.*

JPSS-PS-R 3.1.2: *The Volcanic Ash Detection (Mass Loading) and*

Height Product shall have horizontal resolution of 0.75 km (nadir).

- » Current operational product, with upgraded capabilities.

Basic Requirement 3.0

- **JPSS-PS-R 3.2:** *The Volcanic Ash Detection (Mass Loading) and Height Products shall have global coverage.*
  - » Current operational products, with upgraded capabilities.
- **JPSS-PS-R 3.2.1:** *The Volcanic Ash Detection (Mass Loading) and Height Product shall have latency of 30 minutes after granule data is available.*
  - » Latency is defined as the interval from the last observation to when the product is available to users. Current capability is 60 minutes.

Basic Requirement 3.0

- **JPSS-PS-R 3.2.2:** *The Volcanic Ash Detection (Mass Loading) and Height Product shall have at least 90% coverage of the globe every 12 hours (monthly average).*

  Current operational product, with upgraded capabilities.

- **JPSS-PS-R 3.2.3:** *The Volcanic Ash Detection (Mass Loading) and Height Product shall have timeliness of ≤ 3 hours.*

  » Current operational product, with upgraded capabilities.

Basic Requirement 3.0

- **JPSS-PS-R 3.3:** *The Volcanic Ash Detection (Mass Loading) and Height Product shall include quality information.*
  - » QC flags will be specified in the External Users Manual.
- **JPSS-PS-R 3.4:** *The JPSS RRPS shall write Volcanic Ash Detection (Mass Loading) and Height Product files in NetCDF4 formats.*
  - » SPSRB requirement.

Basic Requirement 3.0

- **JPSS-PS-R 3.5:** *The JPSS RRPS developers shall perform validation and verification of the Volcanic Ash Detection (Mass Loading) and Height Product.*
  - » Validation tools will be based upon the GOES-R validation tools

- **JPSS-PS-R 3.5.1:** *The JPSS RRPS developers shall plot datasets for verification of the Volcanic Ash Detection (Mass Loading) and Height Products.*

Basic Requirement 3.0

- **JPSS-PS-R 3.5.2:** *The JPSS RRPS developers shall verify that Volcanic Ash Detection (Mass Loading) and Height Products files are generated correctly.*
  - » Will be included in the unit tests described in the UTR and the system test described in the SRR.
- **JPSS-PS-R 3.5.3:** *The JPSS RRPS system shall perform routine data range checks to flag anomalous values in the input data.*
  - » Anomalous values will be flagged. These checks will be included in the code And described in the SRR.

Basic Requirement 3.0

- **JPSS-PS-R 3.5.4:** *The JPSS RRPS system shall perform routine data range checks to flag anomalous values in the Volcanic Ash Detection (Mass Loading) and Height Products.*

  » Out-of-range values will be flagged. These checks will be included in the code. UTR will address.

- **JPSS-PS-R 3.5.5:** *The JPSS RRPS developers shall generate matchup datasets between Volcanic Ash Detection (Mass Loading) and Height Products retrievals and in situ measurements.*

  » In situ data obtained from CALIPSO data.

Basic Requirement 4.0

- **JPSS-PS-R 4.0:** *The JPSS RRPS shall generate Cryosphere Products.*

  » **<u>Driver:</u> SPSRB requirements:**

Basic Requirement 4.0

- **JPSS-RRPS-R 4.1:** *The Cryosphere Products shall include Ice Concentration, Ice Age, Ice Surface Temperature, and Snow Cover.*
  - » Continuity with GOES-R product, upgraded VIIRS capability
- **JPSS-RRPS-R 4.1.1:** *The Ice Concentration Product shall have accuracy of 10% Uncertainty.*
  - » Continuity with GOES-R product, upgraded VIIRS capability

Basic Requirement 4.0

- **JPSS-RRPS-R 4.1.2:** *The Ice Age Product shall have accuracy:*
  - » *80% correct classification (Ice free areas, First year ice, Older ice)*
  - » Continuity with GOES-R product, upgraded VIIRS capability
- **JPSS-RRPS-R 4.1.3:** *The Ice Surface Temperature Product shall have accuracy of 1K.*
  - » Continuity with GOES-R product, upgraded VIIRS capability

Basic Requirement 4.0

- **JPSS-RRPS-R 4.1.4:** *The Ice Snow Cover Product shall have accuracy of 90% correct classification.*

.

  - » Continuity with GOES-R product, upgraded VIIRS capability

- **JPSS-RRPS-R 4.1.5:** *The Ice Concentration Product shall have horizontal resolution of 0.75 km.*

  - » Continuity with GOES-R product, upgraded VIIRS capability

Basic Requirement 4.0

- **JPSS-RRPS-R 4.1.6:** *The Ice Age Product shall have horizontal resolution of 0.75 km.*
  - » Continuity with GOES-R product, upgraded VIIRS capability
- **JPSS-RRPS-R 4.1.7:** *The Ice Surface Temperature Product shall have horizontal resolution of 0.75 km.*
  - » Continuity with GOES-R product, upgraded VIIRS capability
- **JPSS-RRPS-R 4.1.8:** *The Snow Cover Product shall have horizontal resolution of 0.375 km.*
  - » Current operational product, with upgraded capabilities.

Basic Requirement 4.0

- **JPSS-RRPS-R 4.2:** *The Cryosphere Products shall have global coverage.*
  - » Current operational products, with upgraded capabilities.

- **JPSS-RRPS-R 4.2.1:** *The Cryosphere Products shall have latency of 30 minutes after granule data is available.*
  - » Latency is defined as the interval from the last observation to when the product is available to users. Current capability is 60 minutes.

Basic Requirement 4.0

- **JPSS-RRPS-R 4.2.2:** *The Cryosphere Products shall have at least 90% coverage of the globe every 12 hours (monthly average).*
  - » Current operational products, with upgraded capabilities.
- **JPSS-RRPS-R 4.2.3:** *The Cryosphere Product shall have timeliness of ≤ 3 hours.*
  - » Current operational product, with upgraded capabilities.

Basic Requirement 4.0

- **JPSS-RRPS-R 4.3:** *The Cryosphere Products shall include quality information.*
  - » QC flags will be specified in the External Users Manual.
- **JPSS-RRPS-R 4.4:** *The JPSS RRPS shall write Cryosphere Products files in NetCDF4 formats.*
  - » SPSRB requirement.

Basic Requirement 4.0

- **JPSS-RRPS-R 4.5:** *The JPSS RRPS developers shall perform validation and verification of the Cryosphere Products.*
  - Validation tools will be based upon the GOES-R validation tools
- **JPSS-RRPS-R 4.5.1:** *The JPSS RRPS developers shall plot datasets for verification of the Cryosphere Products.*

Basic Requirement 4.0

- **JPSS-RRPS-R 4.5.2:** *The JPSS RRPS developers shall verify that Cryosphere Products files are generated correctly.*
  - » Will be included in the unit tests described in the UTR and the system test described in the SRR
- **JPSS-RRPS-R 4.5.3:** *The JPSS RRPS system shall perform routine data range checks to flag anomalous values in the input data.*
  - » Anomalous values will be flagged. These checks will be included in the codeand described in the SRR.

Basic Requirement 4.0

- **JPSS-RRPS-R 4.5.5:** *The JPSS PS developers shall generate matchup datasets between Cryosphere Products retrievals and in situ measurements.*
  - » In situ data obtained from NCEP & ECMWF analysis, AMSR-E products, Upward Looking Sonar data, Canadian Ice Service measurements and Buoy data.

Basic Requirement 5.0

- **JPSS-RRPS-R 5.0:** *The JPSS PS system shall have a data ingest capability.*
  - **<u>Driver:</u>** This basic requirement is traced to algorithm input needs, as documented in the Algorithm Theoretical Basis Documents (ATBDs).

Basic Requirement 5.0

- **JPSS-RRPS-R 5.1:** *The JPSS PS system shall ingest NPP VIIRS L1 data.*
    - » Required algorithm input. Ingest from the IDPS. Data link for development is established by NDE.

Basic Requirement 6.0

- **JPSS-RRPS-R 6.0:** *The JPSS RRPS developers shall modify the GOES-R algorithms to generate a retrieval of Cloud Products, Aerosol Products, Volcanic Ash Products, and Cryosphere Products.*

  » **Driver:** This basic requirement is traced to user needs for Cloud Mask products.

Basic Requirement 6.0

- **JPSS-RRPS-R 6.1:** *The JPSS RRPS Algorithms shall be implemented by processing codes written in C, C++ and Fortran 90.*
  - » Adaptation of current algorithm/framework code.

- **JPSS-RRPS-R 6.1.1:** *The JPSS RRPS processing code shall be able to run in the Development Environment (Linux with 12 dual core 2.33 GHz CPUs.*
  - » *S/W: Intel Compiler (C/C++/Fortran) and IDL for Validation*
  - » *Storage: 100 TB)*

  - » C code, C++ code, and Fortran code can run in this environment

Basic Requirement 6.0

- **JPSS-RRPS-R 6.1.2:** *The JPSS RRPS processing code shall be able to run in the NDE Test Environment (Linux machine with 6 quad core 3.2 GHz CPUs*
  - » *S/W: Intel Compiler (C/C++/Fortran) and IDL for Validation*
  - » *Storage: 30 TB)*
  - » C code, C++ code, and Fortran code can run in this environment
- **JPSS-RRPS-R 6.1.3:** *The JPSS RRPS processing code shall be able to run in the OSPO Operations Environment: (Linux machine with 6 quad core 3.2 GHz CPUs*
  - » *S/W: Intel Compiler (C/C++/Fortran) and IDL for Validation*
  - » *Storage: 30 TB)*
  - » C code, C++ code, and Fortran code can run in this environment

Basic Requirement 7.0

- **JPSS-RRPS-R 7.0:** *The JPSS RRPS system shall generate metadata for each retrieved product.*

  » ***Driver:*** *Metadata will be used by the Product Monitoring Project*

Basic Requirement 7.0

- **JPSS-RRPS-R 7.1:** *The JPSS RRPS system shall write a metadata text files associated with the retrieved products.*

  » Coordinate with the Product Monitoring Project.

- **JPSS-RRPS-R 7.1.1:** *The metadata shall include overall quality and summary level metadata.*

  » Coordinate with the Product Monitoring Project.

Basic Requirement 7.0

- **JPSS-RRPS-R 7.1.2:** *The metadata shall include Granule metadata.*
  - » Coordinate with the Product Monitoring Project.
- **JPSS-RRPS-R 7.1.3:** *The metadata shall include product specific metadata.*
  - » Coordinate with the Product Monitoring Project.

Basic Requirement 8.0

- **JPSS-RRPS-R 8.0:** *The JPSS RRPS system shall have QC monitoring capability.*

- **Driver:** This basic requirement is traced to an OSPO need for QC monitoring.

Basic Requirement 8.0

- **JPSS-RRPS-R 8.1:** *The JPSS RRPS Product files shall include overall quality control flags and quality summary level metadata.*
  - » Needed for distribution, quality control and post-processing. JPSS PS code will generate metadata for this purpose.
- **JPSS-RRPS-R 8.2:** *The JPSS RRPS system shall be capable of monitoring input data latency and overall quality.*
  - » Need to import metadata from input file and create code for generating metadata.

Basic Requirement 8.0

- **JPSS-RRPS-R 8.3:** *The JPSS RRPS system shall be capable of monitoring product latency.*
  - » Run status file will include processing time.

- **JPSS-RRPS-R 8.4:** *The JPSS RRPS system shall produce real-time imagery for visual inspection of output files.*
  - » Will be done with IDL.

Basic Requirement 8.0

- **JPSS-RRPS-R 8.5:** *The JPSS RRPS system shall be capable of monitoring product distribution status to ensure that the data/products are successfully available for transfer to the user community.*
  - » A run status file will be produced. Work with OSPO to determine needs.
- **JPSS-RRPS-R 8.5.1:** *Each run status file shall include all runtime error messages.*
  - » Error messages will include system messages and error conditions written by the code.

Basic Requirement 8.0

- **JPSS-RRPS-R 8.5.2:** *Each run status file shall indicate whether or not the run was completed without error.*
  - » Code will write this message. This indication will be the last message in the file, so that operators can find it easily.
- **JPSS-RRPS-R 8.6:** *The JPSS PS system shall write a log file for each production run.*
  - » Used by OSPO for QC monitoring and troubleshooting.

Basic Requirement 8.0

- **JPSS-RRPS-R 8.6.x:** *Placeholder for TBD requirements for the log file.*
    - » Log file requirements will be specified at the UTR.

Basic Requirement 9.0

- **JPSS-RRPS-R 9.0:** *The JPSS PS developers shall produce a fully functional pre-operational system in the STAR Development Environment.*

  » **Driver:** This basic requirement is traced to an NDE need for a unit-tested, fully functional system delivered to its Test Environment.

Basic Requirement 9.0

- **JPSS-RRPS-R 9.1:** *The Development Environment shall be capable of hosting the conversion of JPSS RRPS science code to JPSS RRPS pre-operational code.*
  - » See derived requirements 9.1.x.
- **JPSS-RRPS-R 9.1.1:** *The Development Environment shall include the INTEL FORTRAN 90/95 compiler.*
  - » Needed for the Framework FORTRAN code. Development Environment servers have this.

Basic Requirement 9.0

- **JPSS-RRPS-R 9.1:** *The Development Environment shall be capable of hosting the conversion of JPSS RRPS science code to JPSS RRPS pre-operational code.*
  - » See derived requirements 9.1.x.
- **JPSS-RRPS-R 9.1.1:** *The Development Environment shall include the INTEL FORTRAN 90/95 compiler.*
  - » Needed for the Framework FORTRAN code. Development Environment servers have this.

Basic Requirement 9.0

- **JPSS-RRPS-R 9.1.2:** *The Development Environment shall include the INTEL C compiler.*
  - » Needed for the Framework C code. Development Environment servers have this.
- **JPSS-RRPS-R 9.1.3:** *The Development Environment shall include the INTEL C++ compiler.*
  - » Needed for the Framework C++ code. Development Environment servers have this.

Basic Requirement 9.0

- **JPSS-RRPS-R 9.1.4:** *The Development Environment shall include Linux machine with 100TB of disk storage.*
  - » Development Environment servers have this.
- **JPSS-RRPS-R 9.2:** *The Development Environment shall be capable of hosting unit tests and a system test.*
  - » Unit tests and system test required prior to delivery of pre-operational system to OSPO.

Basic Requirement 9.0

- **JPSS-RRPS-R 9.2.1:** *The Development Environment shall have access to the OSPO DDS.*
  - » For ingest of VIIRS data and GFS data.
- **JPSS-RRPS-R 9.2.2:** *The Development Environment shall have access to the OSPO DDS server.*
  - » For ingest of IMS daily snow cover data.

Basic Requirement 9.0

- **JPSS-RRPS-R 9.3:** *The Development Environment shall host the pre-operational system.*
  - For development and unit testing. Complete unit test of the pre-operational system is expected before delivery to NDE.
- **JPSS-RRPS-R 9.3.1:** *The pre-operational system shall include all processing code and ancillary files needed to conduct unit tests.*
  - Complete unit test of the pre-operational system is expected before delivery to NDE. The UTR will provide a detailed description of the source code units and ancillary files.

Basic Requirement 9.0

- **JPSS-RRPS-R 9.3.2:** *The pre-operational system shall include all input test data needed to conduct unit tests.*
  - » Complete unit test of the pre-operational system is expected before delivery to NDE. The UTR will provide a detailed description of the unit test data.
- **JPSS-RRPS-R 9.3.3:** *The JPSS RRPS pre-operational system baseline shall be established and maintained with the Clear Case CM tool.*
  - » CM of the pre-operational system is expected throughout its development.

Basic Requirement 10.0

- **JPSS-RRPS-R 10.0:** *The JPSS RRPS integrated pre-operational system shall be transitioned from the STAR Development Environment to the NDE Test Environment.*

  » **Driver:** This basic requirement is traced to an NDE need for a system-tested, integrated pre-operational system delivered to its Test Environment.

Basic Requirement 10.0

- **JPSS-RRPS-R 10.1:** *The Development Environment shall host the JPSS RRPS integrated pre-operational system.*
  - » For system testing. A complete system test of the integrated pre-operational system is expected before delivery to NDE.

- **JPSS-RRPS-R 10.1.1:** *The integrated pre-operational system shall include all processing code and ancillary files needed to conduct the system test.*

  Complete system test of the integrated pre-operational system is expected. The SRR will provide a description of the processing software system and ancillary files.

Basic Requirement 10.0

- **JPSS-RRPS-R 10.1.2:** *The integrated pre-operational system shall include all input data needed to conduct a system test.*
  - » Complete system test of the integrated pre-operational system is expected. The SRR will provide a description of the system test data.
- **JPSS-RRPS-R 10.1.3:** *The integrated pre-operational system shall include all output data produced by the system test.*
  - » Needed by NDE to verify the system test in its Test Environment. Comparison of outputs from system test in STAR and NDE environments will be part of the NDE system test. Specific items will be listed in the SRR.

Basic Requirement 10.0

- **JPSS-RRPS-R 10.1.4:** *The JPSS RRPS integrated pre-operational system baseline shall be established and maintained with the Clear Case CM tool.*

  » CM of the integrated pre-operational system is expected throughout its development.

Basic Requirement 10.0

- **JPSS-RRPS-R 10.2:** *The JPSS RRPS development team shall set up an internal FTP site for transferring the integrated pre-operational system to NDE as a Delivered Algorithm Package (DAP).*
  - » NDE needs to reproduce the system test in its Test Environment. ftp.star.nesdis.noaa.gov is a currently functioning site that will be used.

- **JPSS-RRPS-R 10.2.1:** *The JPSS RRPS development team shall ensure that the NDE PAL has the information needed to acquire the JPSS RRPS DAP from the internal FTP site.*
  - » Use of ftp.star.nesdis.noaa.gov ensures this.

Basic Requirement 11.0

- **JPSS-RRPS-R 11.0:** *STAR shall deliver a JPSS RRPS document package to OSPO.*

  » **Driver:** This basic requirement is traced to an OSPO need for documentation to support operations, maintenance, and distribution.

Basic Requirement 11.0

- **JPSS-RRPS-R 11.1:** *The JPSS RRPS document package shall include a README text file.*

- **JPSS-RRPS-R 11.1.1:** *The README file shall list each item in the final pre-operational system baseline, including code, test data, and documentation.*

  » All required deliverable items must be correctly identified

Basic Requirement 11.0

- **JPSS-RRPS-R 11.2:** *The JPSS RRPS document package shall include a Review Item Disposition (RID) document.*

- **JPSS-RRPS-R 11.2.1:** *The RID shall describe the final status of all development project tasks, work products, and risks.*

  » Supports the final System Readiness Review Report (SRRR)

Basic Requirement 11.0

- **JPSS-RRPS-R 11.3:** *The JPSS RRPS document package shall include an Algorithm Theoretical Basis Document (ATBD).*
  - » The ATBD will follow SPSRB Version 2 document standards
- **JPSS-RRPS-R 11.4:** *The JPSS RRPS document package include a Requirements Allocation Document (RAD).*
  - » The RAD will follow document standards stated in EPL v3 process asset DG-6.2

Basic Requirement 11.0

- **JPSS-RRPS-R 11.5:** *The JPSS RRPS document package shall include a System Maintenance Manual (SMM).*

  » The SMM will follow SPSRB Version 2 document standards.

- **JPSS-RRPS-R 11.6:** *The JPSS RRPS document package shall include an External Users Manual (EUM).*

  » The EUM will follow SPSRB Version 2 document standards.

Basic Requirement 11.0

- **JPSS-RRPS-R 11.7:** *The JPSS RRPS document package shall include an Internal Users Manual (IUM).*
  - » The IUM will follow SPSRB Version 2 document standards.
- **JPSS-RRPS-R 11.8:** *The JPSS RRPS document package shall include a Critical Design Document (CDD).*
  - » The CDD will follow STAR EPL document standards in DG-8.2 and DG-8.2.A.

Basic Requirement 11.0

- **JPSS-RRPS-R 11.9:** *The JPSS RRPS document package shall include a Code Test Document (CTD).*
  - » The CTD will follow STAR EPL document standards in DG-10.3 and DG-10.3.A.
- **JPSS-RRPS-R 11.10:** *The JPSS RRPS document package shall include a System Readiness Document (SRD).*
  - » The SRD will follow STAR EPL document standards in DG-11.5 and DG-11.5.A.

Basic Requirement 11.0

- **JPSS-RRPS-R 11.11:** *The JPSS RRPS document package shall include a System Readiness Review Report (SRRR).*
  - » The SRRR will follow document standards stated in EPL v3 process asset DG-11.6
- **JPSS-RRPS-R 11.11.1:** *The SRRR shall document the approved readiness of the JPSS RRPS system for transition to operations.*
  - » This is an SRR exit criteria item

Basic Requirement 12.0

- **JPSS-RRPS-R 12.0:** *The JPSS RRPS system shall undergo an OSPO Code Review Security for security compliance*

    » **Driver:** OSPO Security

Basic Requirement 12.0

- **JPSS-RRPS-R 12.1:** *The JPSS RRPS system shall comply with OSPO data integrity check list.*

  » OSPO data integrity check list is part of the OSPO Code Review Security check lists.

- **JPSS-RRPS-R 12.2:** *The JPSS RRPS system shall comply with OSPO development security check list.*

  » OSPO development security check list is part of the OSPO Code Review Security check lists.

Basic Requirement 12.0

- **JPSS-RRPS-R 12.3:** *The JPSS RRPS system shall comply with OSPO code check list.*

  » OSPO code check list is part of the OSPO Code Review Security check lists.

Basic Requirement 13.0

- **JPSS-RRPS-R 13.0:** *The JPSS RRPS developers shall specify IT resource needs for operations.*

  » **Driver:** OSPO IT Capacity Planning

Basic Requirement 13.0

- **JPSS-RRPS-R 13.1:** *The JPSS RRPS system shall run on Redhat Linux.*
  - » Servers are available.
- **JPSS-RRPS-R 10.2:** *Operational server shall have 30 TB of disk space.*
  - » Available servers have this capability.
- **JPSS-RRPS-R 13.3:** *Each operational server shall have 8 GB of RAM for each core.*
  - » Available servers have this capability.

JPSS RR Requirements shown with the JPSS L1RD Supplement Requirements

Cloud Mask

	JPSS L1RD	JPSS RRPS
Name	Cloud Mask	Cloud Mask
User & Priority	JPSS 3	JPSS 3
Geographic Coverage		Global coverage
Vertical Reporting Interval	N/A	N/A
Horizontal Cell Size	0.8 km at Nadir	0.75 km.
Mapping Uncertainty, 3 Sigma	4 km threshold; 1 km objective	4 km threshold; 1 km objective
Measurement Range	Cloudy/Not Cloudy	Cloudy/Not Cloudy
Measurement Accuracy	1. Ocean, Day, COT>1.0 – 94%; 2. Day, Land, COT>1.0 – 90%; 3. Ocean, Night, COT>1.0 – 85%; 4. Land, Night, COT>1.0- 88%;	90%
Product Refresh Rate	Threshold - At least 90% coverage of the globe every 12 hours (monthly average); Objective – 4 hrs;	Threshold - At least 90% coverage of the globe every 12 hours (monthly average); Objective – 4 hrs;
Cloud Leakage Rate	1. Ocean, Day, COT>1.0, outside Sun Glint region – 1%; 2. Day, Land, COT>1.0 – 3%; 3. Land, Ocean, Night, COT>1.0 – 5%	1. Ocean, Day, COT>1.0, outside Sun Glint region – 1%; 2. Day, Land, COT>1.0 – 3%; 3. Land, Ocean, Night, COT>1.0 – 5%
False Alarm Rate	1. Ocean, Day, COT>1.0- 5%; 2. Land, Day, ToC NDVI < 0.2 or ToC NDVI > 0.4, or Desert, COT > 1.0 – 7%; 3. Land, Ocean, Night, COT>1.0 – 8%;	1. Ocean, Day, COT>1.0- 5%; 2. Land, Day, ToC NDVI < 0.2 or ToC NDVI > 0.4, or Desert, COT > 1.0 – 7%; 3. Land, Ocean, Night, COT>1.0 – 8%;
Latency	96 min	30 minutes after granule data is available
Timeliness		≤ 3hours

Cloud Mask

Cloud Mask Applicable Conditions:

- 1. Requirements apply whenever detectable clouds are present.
- 2. Cloud Mask shall be computed and reported for the total cloud cover.

Cloud Top Phase

	JPSS L1RD	JPSS RRPS
Name	Cloud Phase	
User & Priority		
Geographic Coverage		Global coverage
Vertical Reporting Interval		
Horizontal Cell Size		0.75 km.
Mapping Uncertainty, 3 Sigma		
Measurement Range		
Measurement Accuracy		80% Correct Classification (7 phases)
Product Refresh Rate		Threshold - At least 90% coverage of the globe every 12 hours (monthly average); Objective – 4 hrs;
Latency		30 minutes after granule data is available
Timeliness		≤ 3hours

Cloud Type

	JPSS L1RD	JPSS RRPS
Name	Cloud Type	
User & Priority		
Geographic Coverage		Global coverage
Vertical Reporting Interval		
Horizontal Cell Size		0.75 km.
Mapping Uncertainty, 3 Sigma		
Measurement Range		
Measurement Accuracy		60%
Product Refresh Rate		Threshold - At least 90% coverage of the globe every 12 hours (monthly average); Objective – 4 hrs;
Latency		30 minutes after granule data is available
Timeliness		≤ 3hours

Cloud Top Height

	JPSS L1RD	JPSS RRPS
Name	Cloud Top Height	Cloud Top Height
User & Priority	JPSS 3	JPSS 3
Geographic Coverage		Global coverage
Vertical Reporting Interval	Threshold - Tops of up to four cloud layers (1); Objective - Tops of all distinct cloud layers	Threshold - Tops of up to four cloud layers (1); Objective - Tops of all distinct cloud layers
Horizontal Cell Size	Threshold – 7 km; Objective – 1 km;	0.75 km.
Mapping Uncertainty, 3 Sigma	Threshold 4 km; Objective 1 km;	Threshold 4 km; Objective 1 km;
Measurement Range		
Measurement Accuracy	Threshold – 1. COT ≥1 – 1.0 km; 2. COT < 1 – 2.0 km; Objective – 1. COT ≥ 1 – 0.3 km; 2. COT < 1 – 035 km;	500 m for Clouds with emissivity > 0.8
Product Refresh Rate	Threshold - At least 90% coverage of the globe every 12 hours (monthly average); Objective – 4 hrs;	Threshold - At least 90% coverage of the globe every 12 hours (monthly average); Objective – 4 hrs;
Latency	96 min	30 minutes after granule data is available
Timeliness		≤ 3hours
Product Measurement Precision	Threshold – 1. COT ≥1 – 1.0 km; 2. COT < 1 – 2.0 km; Objective – 1. COT ≥ 1 – 0.15 km; 2. COT < 1 – 0.15 km;	Threshold – 1. COT ≥1 – 1.0 km; 2. COT < 1 – 2.0 km; Objective – 1. COT ≥ 1 – 0.15 km; 2. COT < 1 – 0.15 km;

Cloud Top Height (CTH)

CTH Applicable Conditions:

- 1. Requirements apply whenever detectable clouds are present.

Cloud Cover/Layers

	JPSS L1RD	JPSS RRPS
Name	Cloud Cover/Layers	Cloud Cover Layers
User & Priority	JPSS 3	JPSS 3
Geographic Coverage		Global
Vertical Reporting Interval	Threshold -Up to four cloud layers; Objective – 0.1 km;	Threshold -Up to four cloud layers; Objective – 0.1 km;
Horizontal Cell Size	Threshold – 7 km; Objective – 1 km;	0.75 km
Mapping Uncertainty, 3 Sigma	Threshold - 4 km; Objective - 1 km	Threshold - 4 km; Objective - 1 km
Measurement Range(Applies only to total cloud cover; Not applicable to layers)	Threshold - 0 to 1.0 HCS Area; Objective – 0 to 1.0;	Threshold - 0 to 1.0 HCS Area; Objective – 0 to 1.0;
Measurement Accuracy	0.1 + 0.3(TBR-7) sin (SZA) of HCS Area	80% Correct Classification (Low, Mid, High)
Product Refresh Rate	Threshold - At least 90% coverage of the globe every 12 hours (monthly average); Objective – 4 hrs;	Threshold - At least 90% coverage of the globe every 12 hours (monthly average); Objective – 4 hrs;
Latency	96 min	30 minutes after granule is available
Timeliness		≤ 3hours

Cloud Cover/Layers

CC/L Applicable Conditions:

- 1. Requirements apply whenever detectable clouds are present.
- 2. Cloud Cover shall be computed and reported at each separate, distinct layer,
- as well as for the total cloud cover.

Cloud Top Temperature

	JPSS L1RD	JPSS RRPS
Name	Cloud Top Temperature	Cloud Top Temperature
User & Priority	JPSS 4	JPSS 4
Geographic Coverage		Global coverage
Vertical Reporting Interval	Threshold – Tops of up to four cloud layers; Objective – Tops of all distinct cloud layers	Threshold – Tops of up to four cloud layers; Objective – Tops of all distinct cloud layers
Horizontal Cell Size	Threshold – 7 km; Objective – 1 km;	0.75 km.
Mapping Uncertainty, 3 Sigma	4 km threshold; 1 km objective	4 km threshold; 1 km objective
Measurement Range		
Measurement Accuracy	Threshold – 1. Optical thickness ≥ 1 – 3K; 2. Optical Thickness < 1 – 6K; Objective - 1. Optical thickness ≥ 1 – 1.5K; 2. Optical Thickness < 1 – 2K;	3 K for clouds with emissivity > 0.8
Product Refresh Rate	Threshold - At least 90% coverage of the globe every 12 hours (monthly average); Objective – 4 hrs;	Threshold - At least 90% coverage of the globe every 12 hours (monthly average); Objective – 4 hrs;
Latency	96 min	30 minutes after granule data is available
Timeliness		≤ 3hours
Product Measurement Precision	Threshold – 1. Optical thickness ≥ 1 – 3K; 2. Optical Thickness < 1 – 6K; Objective – N/A	Threshold – 1. Optical thickness ≥ 1 – 3K; 2. Optical Thickness < 1 – 6K; Objective – N/A

Cloud Top Temperature (CTT)

CTT Applicable Conditions:

- 1. Requirements apply whenever detectable clouds are present.

Cloud Top Pressure

	JPSS L1RD	JPSS RRPS
Name	Cloud Top Pressure	Cloud Top Pressure
User & Priority	JPSS 4	JPSS 4
Geographic Coverage		Global coverage
Vertical Reporting Interval	Threshold – Tops of up to four cloud layers	Threshold – Tops of up to four cloud layers
Horizontal Cell Size	Threshold – 7 km; Objective – 1 km;	0.75 km.
Mapping Uncertainty, 3 Sigma	4 km threshold; 1 km objective	4 km threshold; 1 km objective
Measurement Range	Cloudy/Not Cloudy	Cloudy/Not Cloudy
Measurement Accuracy	Threshold – COT ≥ 1 1. Surface to 3 km – 100 mb; 2. 3 to 7 – 75 mb; 3. > 7 km – 50 mb; Objective – 1. Surface to 3 km – 30 mb; 2. 3 to 7 – 22 mb; 3. > 7 km – 15 mb;	50 mb for clouds with emissivity > 0.8
Product Refresh Rate	Threshold - At least 90% coverage of the globe every 12 hours (monthly average); Objective – 4 hrs;	Threshold - At least 90% coverage of the globe every 12 hours (monthly average); Objective – 4 hrs;
Latency	96 min	30 minutes after granule data is available
Timeliness		≤ 3hours
Product Measurement Precision	Threshold – COT ≥ 1 1. Surface to 3 km – 100 mb; 2. 3 to 7 – 75 mb; 3. > 7 km – 50 mb; Objective – 1. Surface to 3 km – 10 mb; 2. 3 to 7 – 7 mb; 3. > 7 km – 5mb;	Threshold – COT ≥ 1 1. Surface to 3 km – 100 mb; 2. 3 to 7 – 75 mb; 3. > 7 km – 50 mb; Objective – 1. Surface to 3 km – 10 mb; 2. 3 to 7 – 7 mb; 3. > 7 km – 5mb;

Cloud Top Pressure (CTP)

CTP Applicable Conditions:

- 1. Requirements apply whenever detectable clouds are present.

Cloud Optical Thickness

	JPSS L1RD	JPSS RRPS
Name	Cloud Optical Thickness	Cloud Optical Thickness
User & Priority	JPSS 3	JPSS 3
Geographic Coverage		Global coverage
Vertical Reporting Interval	Threshold – up to four cloud layers; Objective – 4 layers;	Threshold – up to four cloud layers; Objective – 4 layers;
Horizontal Cell Size	Threshold – 7 km; Objective – N/S;	1 km.
Mapping Uncertainty, 3 Sigma	Threshold - 4 km; Objective - 1 km;	Threshold - 4 km; Objective - 1 km;
Measurement Range	Cloudy/Not Cloudy	Cloudy/Not Cloudy
Measurement Accuracy	Threshold – Greater of 24 % or 1 Tau Objective – 5%;	Liquid phase: 20% error (Day), 20% (Night); Ice phase: 20% Day), 30% (Night)
Product Refresh Rate	Threshold - At least 90% coverage of the globe every 12 hours (monthly average); Objective – 4 hrs;	Threshold - At least 90% coverage of the globe every 12 hours (monthly average); Objective – 4 hrs;
Latency	96 min	30 minutes after granule data is available
Timeliness		≤ 3hours
Product Measurement Precision	Threshold – Greater of 33 % or 1 Tau Objective – 2%;	Threshold – Greater of 33 % or 1 Tau Objective – 2%;

Cloud Optical Thickness (COT)

COT Applicable Conditions:

- 1. Requirements apply whenever detectable clouds are present.

Cloud Effective Particle Size

	JPSS L1RD	JPSS RRPS
Name	Cloud Effective Particle Size	Cloud Effective Particle Size
User & Priority	JPSS 3	JPSS 3
Geographic Coverage		Global coverage
Vertical Reporting Interval	Threshold – up to four cloud layers; Objective – 0.3 km;	Threshold – up to four cloud layers; Objective – 0.3 km;
Horizontal Cell Size	Threshold – 7 km; Objective – 1 km;	1 km.
Mapping Uncertainty, 3 Sigma	4 km threshold; 1 km objective	4 km threshold; 1 km objective
Measurement Range	Threshold - 0 to 50 µm; Objective – N/S	Threshold - 0 to 50 µm; Objective – N/S
Measurement Accuracy	Threshold – Greater of 22% or 1 µm for water; Greater of 28% or 1 µm for ice; Objective – 5%;	4 µm for liquid phase 10 µm for ice phase
Product Refresh Rate	Threshold - At least 90% coverage of the globe every 12 hours (monthly average); Objective – 4 hrs;	Threshold - At least 90% coverage of the globe every 12 hours (monthly average); Objective – 4 hrs;
Latency	96 min	30 minutes after granule data is available
Timeliness		≤ 3hours
Product Measurement Precision	Threshold – Greater of 22% or 1 µm for water; Greater of 28% or 1 µm for ice; Objective – 2%;	Threshold – Greater of 22% or 1 µm for water; Greater of 28% or 1 µm for ice; Objective – 2%;

Cloud Effective Particle Size (CEPS)

CEPS Applicable Conditions:

- 1. Requirements apply both day and night and whenever detectable clouds are present.

Cloud Liquid Water

	JPSS L1RD	JPSS RRPS
Name	Cloud Liquid Water	Cloud Liquid Water
User & Priority	JPSS 3	JPSS 3
Geographic Coverage		Global coverage
Vertical Reporting Interval	N/S	N/S
Horizontal Cell Size	Threshold m- 15 km @ nadir;	1 km.
Mapping Uncertainty, 3 Sigma	N/S	N/S
Measurement Range		
Measurement Accuracy	Threshold – Sea: 0.03 mm; Objective – Sea: 0.02 mm;	Greater of 25 g/m2 or 15% error
Product Refresh Rate	Threshold - At least 90% coverage of the globe every 12 hours (monthly average); Objective – N/S;	Threshold - At least 90% coverage of the globe every 12 hours (monthly average); Objective – N/S hrs;
Latency	96/130 min	30 minutes after granule data is available
Timeliness		≤ 3hours
Product Measurement Precision	Threshold –Sea: 0.08 mm; Objective – Sea: 0.06 mm;	Threshold –Sea: 0.08 mm; Objective – Sea: 0.06 mm;

Cloud Ice Water Path

	JPSS L1RD	JPSS RRPS
Name		Cloud Ice Water Path
User & Priority		
Geographic Coverage		Global coverage
Vertical Reporting Interval		
Horizontal Cell Size		1.0 km.
Mapping Uncertainty, 3 Sigma		
Measurement Range		
Measurement Accuracy		Greater of 25g/m2 or 30% error
Product Refresh Rate		Threshold - At least 90% coverage of the globe every 12 hours (monthly average); Objective – 4 hrs;
Latency		30 minutes after granule data is available
Timeliness		$\leq$ 3hours

Aerosol Detection

	JPSS L1RD	JPSS RRPS
Name	Suspended Matter	Aerosol Detection
User & Priority	JPSS 2	JPSS 2
Geographic Coverage		Global coverage
Vertical Reporting Interval	Threshold: Total Column Objective: 0.2 km	Threshold: Total Column Objective: 0.2 km
Horizontal Cell Size	Theshold: 3 km Objective: 1 km	0.75 km.
Mapping Uncertainty, 3 Sigma	Threshold: 3 km Objective: 0.1 km	Threshold: 3 km Objective: 0.1 km
Measurement Range	Radioactive Smoke Plumes: 0 to 150 microg/m3	Smoke: 0 to 200 microg/m3
Measurement Accuracy	Threshold: Suspended Matter: 80% Dust: 80% Smoke: 70% Volcanic Ash: 60% Objective: Suspended Matter, Dust, Smoke, Volcanic Ash: 100% Mixed Aerosol: 80%	Dust: 80% correct detection over land and ocean Smoke: 80% Correct detection over land 70% correct detection over ocean
Product Refresh Rate	Threshold - At least 90% coverage of the globe every 24 hours (monthly average); Objective – 4 hrs;	Threshold - At least 90% coverage of the globe every 12 hours (monthly average); Objective – 4 hrs;
Latency	Threshold: 96 min Objective: 30 min	30 minutes after granule data is available
Timeliness		≤ 3hours

Aerosol Optical Thickness

	JPSS L1RD	JPSS RRPS
Name	Aerosol Optical Thickness	Aerosol Optical Depth
User & Priority	JPSS 4	JPSS 4
Geographic Coverage		Global coverage
Vertical Reporting Interval	Threshold - Total column; Objective - Total column	Threshold - Total column; Objective - Total column
Horizontal Cell Size	Threshold - 6 km (nadir); 12.8 km (Edge Of Scan); Objective – 1 km;	0.75 km (nadir)
Mapping Uncertainty, 3 Sigma	Threshold – 4 km; Objective – 1 km;	Threshold – 4 km; Objective – 1 km;
Measurement Range	Threshold – 0 to 2; Objective – 0 to 10;	Threshold – 0 to 2; Objective – 0 to 10;
Measurement Accuracy	Threshold – 1. Over Ocean - 0.08 (Tau < 0.3) 0.15 (Tau ≥ 0.3) (1,2,4); 2. Over Land – 0.06 (Tau < 0.1); 0.05 (0.1 ≤ Tau ≤ 0.8); 0.2 (Tau > 0.8) (1,2,4); Objective – 1. Over Ocean – 1%; 2. Over Land – 1%;	Based on Aerosol Optical Depth ranges: Over land: < 0.04: 0.06 0.04 – 0.80: 0.04 > 0.80: 0.12 Over water: < 0.40: 0.02 > 0.40: 0.10
Product Refresh Rate	Threshold - At least 90% coverage of the globe every 24 hours (monthly average); Objective – 4 hrs;	Threshold - At least 90% coverage of the globe every 12 hours (monthly average); Objective – 4 hrs;
Latency	96 min	30 minutes after granule data is available
Timeliness		≤ 3hours

Aerosol Optical Thickness (AOT)

AOT Applicable Conditions:

- 1. Clear, daytime only
- 2. Zenith angles less than or equal to 80 degrees. (3)

Aerosol Particle Size Parameter

	JPSS L1RD	JPSS RRPS
Name	Aerosol Particle Size Parameter	Aerosol Particle Size
User & Priority	JPSS 4	JPSS 4
Geographic Coverage		Global coverage
Vertical Coverage	Threshold - Surface to 30 km; Objective - Surface to 50 km;	Threshold - Surface to 30 km; Objective - Surface to 50 km;
Vertical Cell Size	Threshold – Total Column; Objective – 0.25 km;	Threshold – Total Column; Objective – 0.25 km;
Horizontal Cell Size	Threshold - 6 km (nadir); 12.8 km (Edge Of Scan); Objective – 1 km;	0.75 km.
Mapping Uncertainty, 3 Sigma	Threshold – 4 km; Objective – 1 km;	Threshold – 4 km; Objective – 1 km;
Measurement Range	Threshold Operational -1 to +3 alpha units; Objective -2 to +4 alpha units;	Threshold Operational -1 to +3 alpha units; Objective -2 to +4 alpha units;
Measurement Accuracy	Operational over Ocean Threshold – 0.3 alpha units; Objective – 0.1 alpha units;	Fine/Coarse Angstrom exponent: 0.3 over ocean and land
Product Refresh Rate	Threshold - At least 90% coverage of the globe every 24 hours (monthly average); Objective – 4 hrs;	Threshold - At least 90% coverage of the globe every 12 hours (monthly average); Objective – 4 hrs;
Latency	96 min	30 minutes after granule data is available
Timeliness		≤ 3hours
Product Measurement Precision	Operational over Ocean Threshold – 0.3 alpha units; Objective – 0.1 alpha units;	Operational over Ocean Threshold – 0.3 alpha units; Objective – 0.1 alpha units;

Aerosol Particle Size Parameter (APSP)

APSP Applicable Conditions:

- 1. Clear, daytime only

Volcanic Ash and Height

	JPSS L1RD	JPSS RRPS
Name	Volcanic Ash	Volcanic Ash Detection (Mass Loading) and Height
User & Priority	JPSS 3	JPSS 3
Geographic Coverage		Global coverage
Vertical Cell Size	Threshold – Total Column; Objective – 0.2 km;	Threshold – Total Column; Objective – 0.2 km;
Horizontal Cell Size	Threshold - 3 km Objective – 1 km;	0.75 km.
Mapping Uncertainty, 3 Sigma	Threshold – 3 km; Objective – 0.1 km;	Threshold – 3 km; Objective – 0.1 km;
Measurement Range	N/S	N/S
Measurement Accuracy	Threshold –50%; Objective – 100%	2 tons/km2, 3 km height
Product Refresh Rate	Threshold - At least 90% coverage (product retrieval is attempted regardless of sky condition) of the globe ovr 24 hours (monthly average).Objective – 3 hrs;	Threshold - At least 90% coverage of the globe every 12 hours (monthly average); Objective – 3 hrs;
Latency	96 min	30 minutes after granule data is available
Timeliness		≤ 3hours

Volcanic Ash

Applicable Conditions:

- 1. Clear, for AOT greater than 0.15, daytime only.

Snow Cover

	JPSS L1RD	JPSS RRPS
Name	Snow Cover	Snow Cover
User & Priority	JPSS 3	JPSS 3
Geographic Coverage		Global coverage
Sensing Depth	Threshold – N/S; Objective – 1.0 m;	Threshold – N/S; Objective – 1.0 m;
Horizontal Cell Size	Threshold 1. Clear - 1.6 km EOS; 2. Cloudy and/or nighttime – H/S Objective – 1. Clear - 1.0 km; 2. Cloudy and/or nighttime – 1.0 km	0.75 km.
Mapping Uncertainty, 3 Sigma	Threshold 1. clear – 3km; 2. Cloudy – N/S Objective 1. Clear – 1 km; 2. Cloudy – 1km;	Threshold 1. clear – 3km; 2. Cloudy – N/S Objective 1. clear – 1 km; 2. Cloudy – 1km;
Measurement Range	0 - 100% HSC area fraction; 0 or 1 BSC mask	0 - 100% HSC area fraction; 0 or 1 BSC mask
Measurement Accuracy	Threshold 1. Clear: 10% of FSC area; 90% probability of correct snow/no-snow classification (2,3); 2. Cloudy – N/S Objective 1. Clear: 10% for snow depth (microwave instrument); 90% probability of correct BSC snow/no snow classification (VIIRS); 2. Cloudy: 10% for snow depth	90% correct classification
Product Refresh Rate	Threshold - At least 90% coverage of the globe every 24 hours (monthly average).Objective – 4 hrs;	Threshold - At least 90% coverage of the globe every 12 hours (monthly average); Objective – 4 hrs;
Latency	96/130 min	30 minutes after granule data is available
Timeliness		≤ 3hours

Snow Cover

Snow Cover Applicable Conditions:

- 1. Clear Daytime, only

Sea Ice Concentration

	JPSS L1RD	JPSS RRPS
Name	Sea Ice Concentration	Ice Concentration
User & Priority	JPSS 3	JPSS 3
Geographic Coverage	All ice-covered regions of the global ocean	Global coverage
Vertical Coverage	Ice surface	Ice Surface
Horizontal Cell Size	Threshold 1. Clear - 1km 2. All weather – No capability Objective 1. Clear – 0.5 km 2. All weather - 1 km	0.75 km.
Mapping Uncertainty, 3 Sigma	Threshold 1. Clear - 1km @ nadir 2. Cloudy -No capability Objective 1. Clear – 0.5 km 2. Cloudy - 1 km	Threshold 1. Clear - 1km @ nadir 2. Cloudy -No capability Objective 1. Clear – 0.5 km 2. Cloudy - 1 km
Measurement Range	0/10 to 10/10	0/10 to 10/10
Measurement Uncertainty	Threshold Note 1 Objective 5%	10%
Product Refresh Rate	Threshold - At least 90% coverage of the globe every 24 hours (monthly average). Objective 6 hrs	Threshold - At least 90% coverage of the globe every 12 hours (monthly average); Objective – 6 hrs;
Cloud Leakage Rate	1. Ocean, Day, COT>1.0, outside Sun Glint region – 1%; 2. Day, Land, COT>1.0 – 3%; 3. Land, Ocean, Night, COT>1.0 – 5%	1. Ocean, Day, COT>1.0, outside Sun Glint region – 1%; 2. Day, Land, COT>1.0 – 3%; 3. Land, Ocean, Night, COT>1.0 – 5%
Latency	96 / 130 min	30 minutes after granule data is available
Timeliness		≤ 3hours

Ice Age

	JPSS L1RD	JPSS RRPS
Name	Ice Age	Ice Age
User & Priority	JPSS 3	JPSS 3
Geographic Coverage	All ice-covered regions of the global ocean	Global coverage
Vertical Coverage	Ice surface	Ice Surface
Horizontal Cell Size	Threshold 1. Clear - 1km 2. All weather – No capability Objective 1. Clear – 0.5 km 2. All weather -1 km	0.75 km.
Mapping Uncertainty, 3 Sigma	Threshold 1. Clear - 1km @ nadir 2. Cloudy -No capability Objective 1. Clear – 0.5 km 2. Cloudy - 1 km	Threshold 1. Clear - 1km @ nadir 2. Cloudy -No capability Objective 1. Clear – 0.5 km 2. Cloudy - 1 km
Measurement Range	Threshold- Ice free, New/Young Ice, all other ice; Objective- Ice Free, Nilas, Grey White, Grey, White, First Year Medium, First Year Thick, Second Year, and Multiyear; Smooth and Deformed Ice	Threshold- Ice free, New/Young Ice, all other ice; Objective- Ice Free, Nilas, Grey White, Grey, White, First Year Medium, First Year Thick, Second Year, and Multiyear; Smooth and Deformed Ice
Measurement Uncertainty	Threshold -70% Objective - 90%	80% correct classification (Ice free areas, First year ice, Older ice)
Product Refresh Rate	Threshold - At least 90% coverage of the globe every 24 hours (monthly average). Objective - 6 hrs	Threshold - At least 90% coverage of the globe every 12 hours (monthly average); Objective – 6 hrs;
Latency	96/130 min	30 minutes after granule data is available
Timeliness		≤ 3hours

Ice Surface Temperature

	JPSS L1RD	JPSS RRPS
Name	Ice Surface Temperature	Ice Surface Temperature
User & Priority	JPSS 4	JPSS 4
Geographic Coverage	Threshold - Ice-covered oceans (1) Objective - All ice-covered waters.	Global coverage
Sensing Depth	Ice Surface	Ice Surface
Horizontal Cell Size	Threshold 1. Nadir - 1km 2. Worst Case –1.6 km Objective 1. Nadir - 0.1km 2. Worst Case – 0.1 km	0.75 km.
Mapping Uncertainty, 3 Sigma	Threshold 1. Nadir - 1km 2. Worst Case – 1.6 km Objective 1. Nadir - 0.1km 2. Worst Case – 0.1 km	Threshold 1. Nadir - 1km 2. Worst Case – 1.6 km Objective 1. Nadir - 0.1km 2. Worst Case – 0.1 km
Measurement Range	Threshold- 213 - 275 K Objective- 213 - 293 K (2 m above ice)	Threshold- 213 - 275 K Objective- 213 - 293 K (2 m above ice)
Measurement Uncertainty	Threshold - 1K Objective - N/S	1K
Product Refresh Rate	Threshold - At least 90% coverage of the globe every 24 hours (monthly average). Objective 12 hrs	Threshold - At least 90% coverage of the globe every 12 hours (monthly average); Objective – 12 hrs;
Latency	96 min	30 minutes after granule data is available
Timeliness		≤ 3hours

JPSS RRPS System Requirements – Summary

- The JPSS Risk Reduction System Requirements have been established.
- The Requirements have been documented in the Requirements Allocation Document (RAD).
- The Requirements are traceable to drivers (customer needs or expectations) and other requirements.

Outline

- Introduction
- Requirements
- Operations Concept
- Cloud Mask
- Cloud Phase
- Cloud Height
- NCOMP
- Software Architecture and Interfaces
- Detailed Design
- Algorithm Package
- Quality Assurance
- Risks and Actions Summary
- Summary and Conclusions

Operations Concept

Presented by

A. K. Sharma

Operations Concept - Overview

- Identify intentions of the customers/users of the products
  - » Identify the SPSRB user requests
    - – 1107-0011: Gridded Cloud Products for NWP Verification
    - – 0909-0018: CLAVR-x and GSIP cloud product composites over Alaska
    - – 0507-05: Polar/Geostationary Volcanic Ash Detection and Height on CLAVR-X
    - – 1009-0016: Dust Aerosol Concentration Product
    - – 0707-0014: Support satellite-based verification of the National Air Quality Forecast Capability
    - – 0403-1: CrIS/ATMS Products for NWS
  - » Interact with the customers/users to produce an initial algorithm/system design that is consistent with their concept of operations

Operations Concept - Overview

- Review the answers to the following questions based on customer/user needs and expectations and production constraints
  - » What is the product?
  - » Why is this product being produced?
  - » How will this product be used?
  - » How should this product be produced (operational scenario)?

- The operations concept will be refined by the JPSS Risk Reduction Product Team (IPT), in consultation with customers/users, as the product solution and design are matured through the design development phase.

What is the Product?

- Cloud Mask
- Cloud Top Phase
- Cloud Type
- Cloud Top Height
- Cloud Cover Layers
- Cloud Top Temperature
- Cloud Top Pressure
- Cloud Optical Depth
- Cloud Particle Size Distribution
- Cloud Liquid Water
- Cloud Ice Water Path

What is the Product?

- Aerosol Detection
- Aerosol Optical Depth
- Aerosol Particle Size
- Volcanic Ash Mass Loading
- Volcanic Ash Height

What is the Product?

- Snow Fraction
- Ice Concentration
- Ice Age
- Ice Surface Temperature

What is the Product - Cont.

					Product Type and Number					
Fiscal Year (FY)	Product Delivery/Tracking Name	Environmental Observational Parameters	Satellites	Sensors	N #	E #	R #	T #	O #	Tailoring Options or Comments
FY15	JPSS Risk Reduction	Cloud Mask	NPP	VIIRS	1					Formats: NetCDF4, Coverage: Granule Update Cycle: 87 seconds
FY15	JPSS Risk Reduction	Cloud Phase	NPP	VIIRS	1					Formats: NetCDF4, Coverage: Granule Update Cycle: 87 seconds
FY15	JPSS Risk Reduction	Cloud Cover Layers	NPP	VIIRS	1					Formats: NetCDF4, Coverage: Granule Update Cycle: 87 seconds
FY15	JPSS Risk Reduction	Cloud Height	NPP	VIIRS	1					Formats: NetCDF4, Coverage: Granule Update Cycle: 87 seconds
FY15	JPSS Risk Reduction	Cloud Top Pressure	NPP	VIIRS	1					Formats: NetCDF4, Coverage: Granule Update Cycle: 87 seconds
FY15	JPSS Risk Reduction	Cloud Top Temperature	NPP	VIIRS	1					Formats: NetCDF4, Coverage: Granule Update Cycle: 87 seconds
FY15	JPSS Risk Reduction	Cloud Type	NPP	VIIRS	1					Formats: NetCDF4, Coverage: Granule Update Cycle: 87 seconds

What is the Product - Cont.

					Product Type and Number					
Fiscal Year (FY)	Product Delivery/Tracking Name	Environmental Observational Parameters	Satellites	Sensors	N #	E #	R #	T #	O #	Tailoring Options or Comments
FY15	JPSS Risk Reduction	Cloud Optical Depth	NPP	VIIRS	1					Formats: NetCDF4, Coverage: Granule Update Cycle: 87 seconds
FY15	JPSS Risk Reduction	Cloud Particle Size Distribution	NPP	VIIRS	1					Formats: NetCDF4, Coverage: Granule Update Cycle: 87 seconds
FY15	JPSS Risk Reduction	Cloud Ice Water Path	NPP	VIIRS	1					Formats: NetCDF4, Coverage: Granule Update Cycle: 87 seconds
FY15	JPSS Risk Reduction	Cloud Liquid Water Path	NPP	VIIRS	1					Formats: NetCDF4, Coverage: Granule Update Cycle: 87 seconds
FY15	JPSS Risk Reduction	Aerosol Detection	NPP	VIIRS	1					Formats: NetCDF4, Coverage: Granule Update Cycle: 87 seconds
FY15	JPSS Risk Reduction	Aerosol Optical Depth	NPP	VIIRS	1					Formats: NetCDF4, Coverage: Granule Update Cycle: 87 seconds
FY15	JPSS Risk Reduction	Aerosol Particle Size	NPP	VIIRS	1					Formats: NetCDF4, Coverage: Granule Update Cycle: 87 seconds
FY15	JPSS Risk Reduction	Volcanic Ash Detection & Height	NPP	VIIRS	1					Formats: NetCDF4, Coverage: Granule Update Cycle: 87 seconds

What is the Product - Cont.

					Product Type and Number					
Fiscal Year (FY)	Product Delivery/Tracking Name	Environmental Observational Parameters	Satellites	Sensors	N #	E #	R #	T #	O #	Tailoring Options or Comments
FY15	JPSS Risk Reduction	Snow Mask	NPP	VIIRS	1					Formats: NetCDF4, Coverage: Granule Update Cycle: 87 seconds
FY15	JPSS Risk Reduction	Ice Concentration	NPP	VIIRS	1					Formats: NetCDF4, Coverage: Granule Update Cycle: 87 seconds
FY15	JPSS Risk Reduction	Ice Age/Thickness	NPP	VIIRS	1					Formats: NetCDF4, Coverage: Granule Update Cycle: 87 seconds
FY15	JPSS Risk Reduction	Ice Surface Temperature	NPP	VIIRS	1					Formats: NetCDF4, Coverage: Granule Update Cycle: 87 seconds

N=New E=Enhanced R=Replacement T=Tailored O=Other

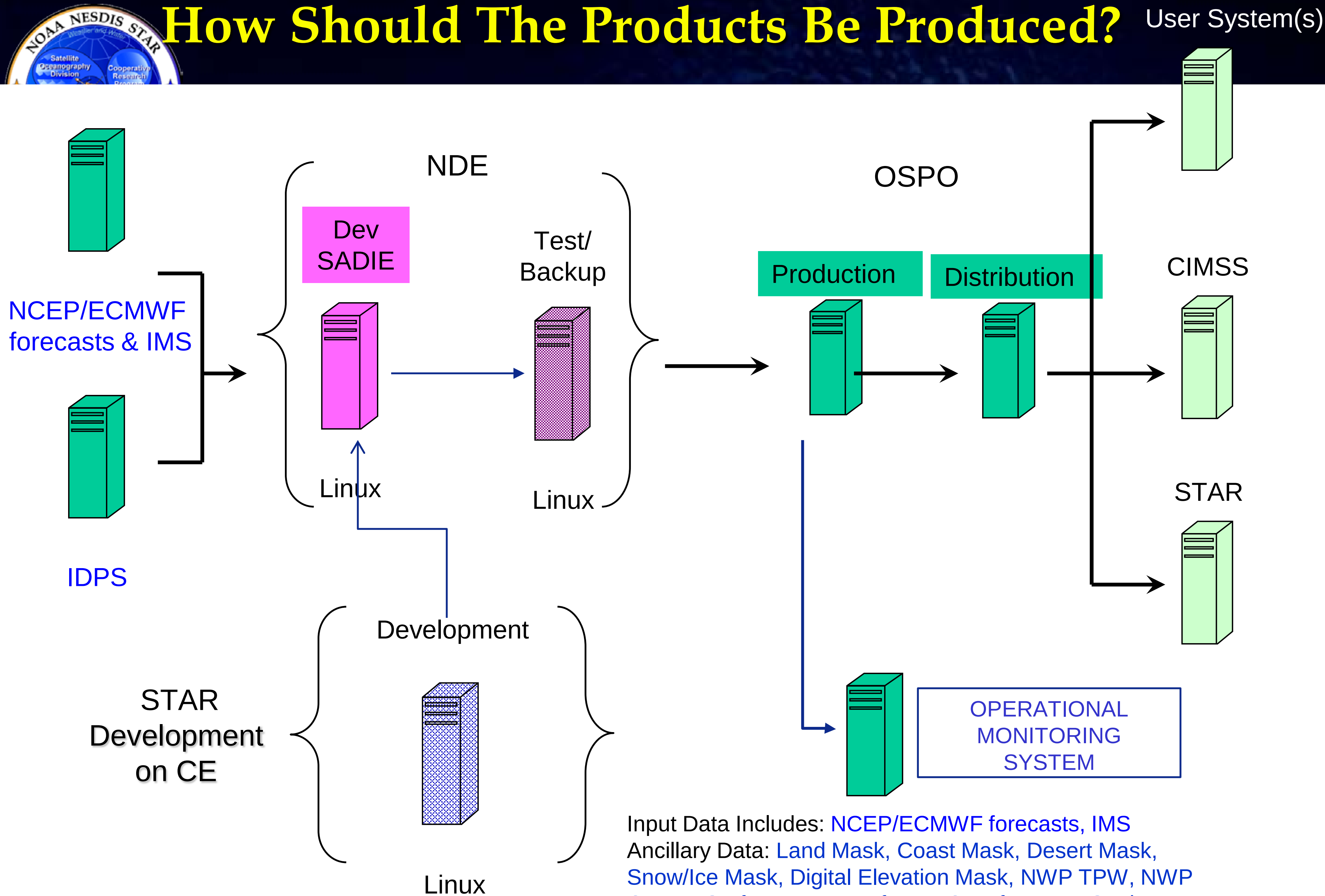
Why Are The Products Being Produced?

- NWS requests continuity of NOAA products between current and future NOAA operational satellites
- Demonstration of cost effective processing for NOAA JPSS products
- Demonstration of NOAA's goal of enterprise solutions by employing same algorithms for "POES" and "GOES"
- Supports NWS OS&T implementation strategy of multi-sensor algorithms and products

How Will The Products Be Used?

- Gridded Cloud Products for NWP Verification
- CLAVR-x and GSIP cloud product composites over Alaska
- Polar/Geostationary Volcanic Ash Detection and Height on CLAVR-X
- Dust Aerosol Concentration Product
- Support satellite-based verification of the National Air Quality Forecast Capability
- CrIS/ATMS Products for NWS

How Should The Products Be Produced?



Input Data Includes: NCEP/ECMWF forecasts, IMS
Ancillary Data: Land Mask, Coast Mask, Desert Mask, Snow/Ice Mask, Digital Elevation Mask, NWP TPW, NWP Ozone, Surface pressure from NCEP forecast, Seebor Surface Emissivity, Surface Type, Surface Reflectance

How Should The Products Be Produced? Cont.

- There will be three distinct environments
  - » Development Environment (STAR)
    - Development and testing of pre-operational codes on Redhat Linux OS
  - » Test environment (NDE)
    - Pre-operational codes and documents (DAP) received from STAR will be implemented and tested on the designated Red Hat Linux machine at NDE and modified as needed before it is promoted to operation
  - » Operation Environment (OSPO)
    - Operational DAP will be run on the designated Redhat Linux machine at ESPC and the products monitoring GUI will be posted on the intranet web server and accessed under ESPC VPN by the operators, PALS and maintenance programmers. Products will be distributed via DDS/PDA and OSPO ftp/http servers.

How Should The Products Be Produced? Cont.

- Production and Delivery Scenarios
  - » The ESPC Ingest Systems will handle all input satellite data and ancillary data
  - » The JPSS RR product system will collect the satellite inputs and required ancillary data to run the OMPS LP algorithms
  - » The product will be generated in NetCDF4
  - » The JPSS RR metadata will be available for the Product Monitoring Tool system to use
  - » The product users will be granted access to the ESPC distribution system through the data access request submission process.
  - » ESPC will handle the distribution of JPSS RR products

Development and Operational System Environments

Project Name:	JPSS Risk Reduction	
IT Item	Research	Production
Agency	STAR	OSPO (ESPC)
Platform(s) and need dates	Linux (RHEL OS on x86-64 platform) with 12 CPUs (dual core) and 48 GB of memory. Dates: August 2013.	Linux (RHEL OS on x86-64 platform) with 6 CPUs (quad core) and 48 GB of memory. Dates: August 2013. (Purchased by NDE)
Operating Systems	Linux (RHEL OS on x86-64 platform)	Linux (RHEL OS on x86-64 platform)
Programming languages/compilers ***	Intel Compiler (C/C++/Fortran)	Intel Compiler (C/C++/Fortran) libraries
Scripting languages	Perl (version 5.8 or higher)	Perl (version 5.8 or higher)
Graphical/Imaging programs, COTS S/W, other tools, libraries, etc	IDL (version 7.0 or higher)	IDL (version 7.0 or higher)
Helpdesk Monitoring Tool (standardized tool or customized tool?)	None	NPP Product Monitorinig Tool (PSDI project)
Other platforms needed for monitoring/imaging/graphics (specify platform & operating system)	None	None
Other (tools, shareware, libraries, critical non-static ancillary data, etc)	Libraries: netCDF 4.0, HDF5, and BUFR Utilities: wgrib2	Libraries: netCDF 4.0, HDF5, and BUFR Utilities: wgrib2

Development and Operational System Environments – cont.

Project Name:	JPSS Risk Reduction			
IT Item	Development	Production	Back-up Operations	
			On-Site	Off-Site
Agency	OSPO (ESPC)	OSPO (ESPC)	OSD (ESPC)	CIP
Platform(s) and need dates (include secondary platforms for monitoring, imagery or graphics, if necessary)	Linux with 6 CPUs (quad core, 3.2 GHz), 8 GB/CPU Dates: June 2012 – June 2017.	Linux with 6 CPUs (quad core, 3.2 GHz), 8 GB/CPU memory. Dates: August 2013. This is to be purchased by NDE.	Linux with 6 CPUs (quad core, 3.2 GHz), 8 GB/CPU memory. Dates: August 2013. This is to be purchased by NDE.	Linux with 6 CPUs (quad core, 3.2 GHz), 8 GB/CPU memory. Dates: August 2013. This is to be purchased by NDE.
Storage required on systems	30 TB	30 TB	30 TB	30 TB
How often does system run (granule time, orbital, daily); event or schedule driven?	87 seconds (Event)	87 seconds (Event)	87 seconds (Event)	87 seconds (Event)
Memory used at run time	4 GB for nominal processing	4 GB for nominal processing	4 GB for nominal processing	4 GB for nominal processing
Input data volume and input data sources	CLASS: 2 TB/day NCEP ftp server: 0.6 GB/day	IDPS: 2 TB/day TBD: 0.6 GB/day	IDPS: 2 TB/day TBD: 0.6 GB/day	IDPS: 2 TB/day TBD: 0.6 GB/day
Data volume for distribution; planned distribution server; specific push users & volumes	N/A	NDE DS: 100 GB/day	NDE DS: 100 GB/day	NDE DS: 100 GB/day
Communication Requirements/Protocol	DDS: ftp NCEP ftp server: ftp	ftp-s (managed by NDE)	ftp-s (managed by NDE)	ftp-s (managed by NDE)
Days to retain input and output data	96 hours	96 hours	96 hours	96 hours

Development and Operational System Maintenance Resources

- Walter Wolf, Andy Heidinger, Jeff Key, Shobha Kondragunta, Istvan Laszlo, Mike Pavolonis (STAR) and Peter Romanov (CREST) – Development Readiness and Quality Control support
- Shanna Sampson, Xingpin Liu (STAR), William Straka III, Ray Garcia (CIMSS) – Development support
- A. K. Sharma, Gilberto Vicente, Hanjun Ding, Zhaohui Cheng(OSPO) – Operational Readiness and Quality control support

Distribution Environment – Capabilities and Resources

- NDE Data Distribution System
- Personnel
  - » NDE Personnel
  - » STAR Personnel
  - » OSPO Personnel

Production Scenarios – Monitoring and Maintenance

- NDE will provide the system monitoring capability
- OSPO will provide the routine validation capability
- OSPO PAL and STAR will perform routine validation of the VIIRS Risk Reduction products

Production Scenarios – Monitoring and Maintenance – cont.

- Production Monitoring and Maintenance Scenarios
  - » The PAL and maintenance personnel at OSPO will monitor the system's function and resolve the issues.
  - » The maintenance personnel at OSPO will maintain and back up the database
  - » STAR personnel are available for operational science issues
  - » The JPSS Risk Reduction product files will have variables available for product monitoring

VIIRS Risk Reduction System Requirements

- The VIIRS Risk Reduction System Requirements have been established.
- The Requirements have been documented in the Requirements Allocation Document (RAD).
- The Requirements are traceable to drivers (customer needs or expectations) and other requirements.

Production Scenarios – Archive Product

- The VIIRS Risk Reduction products will not be archived to CLASS / NCDC archive

User Interaction

- The ESPC help desk will serve as the operational point of contact to provide 24/7 service support for users
  - » Provides information about the VIIRS RR data products to the user community
  - » Resolves user issues through coordination with the associated PALs
- The PALs will coordinate further with the STAR scientists for any product quality issue when identified and communicate with users.

Summary

- The OSPO Ingest Systems will handle all input satellite data and ancillary data
- OSPO will run the VIIRS RR system
- OPSO PAL and STAR team will perform product validation
- NCEP will use the associated products within their models and will provide the support for products testing and validation
- VIIRS RR products will be available to be sent the to Reformatting Toolkit project, the Product Monitoring project and CLASS

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Algorithm Theoretical Basis
VIIRS Clear Sky Mask

Presented by

Andrew Heidinger
STAR

Algorithm Theoretical Basis

- Purpose: Provide product developers, reviewers and users with a theoretical description (scientific and mathematical) of the NOAA VIIRS Cloud Mask (NVCM) algorithm, which will work on VIIRS data

- Will be documented in the ATBD of NOAA VIIRS Cloud Mask.

CDR Requirements
Clear Sky Masks

Name	User & Priority	Geographic Coverage (Global)	Vertical Resolution	Horizontal Resolution	Mapping Accuracy	Measurement Range	Measurement Accuracy	Refresh Rate/Coverage Time	Allocated Ground Latency	Product Measurement Precision
Clear Sky Masks	JPSS	Global	N/A	0.75 km	0.75 km	0 – 1 Binary	90% probability of correct detection	90 min	30 min from receipt	10%

CDR Requirements
Clear Sky Masks

Name	User & Priority	Geographic Coverage (Global)	Temporal Coverage Qualifiers	Product Extent Qualifier	Cloud Cover Conditions Qualifier	Product Statistics Qualifier
Clear Sky Masks	JPSS	Global	Day and night	Quantitative out to at least 70 degrees LZA and qualitative beyond	Clear conditions associated with threshold accuracy	Over specified geographic area

Algorithm Changes from ABI

- ABI mask provided a 4-level mask with a vector of yes/no decisions for each test.
- Based on our experience since then, we propose the following changes.
  - Add additional surface classifications (i.e. Arctic, Antarctic)
  - Add additional test to exploit VIIRS channels
  - Expand 1bit decisions for each test to 2 bit flags
  - Provide an overall cloud probability in addition to the 4-level mask.

CDR Algorithm

Preferred Solution:

- A *hybrid* approach that uses a naïve Bayesian logic to generate a cloud probability and a discrete 4-level cloud mask with results from each test.

- This improves the overall performance and maintains flexibility.

CDR Algorithm

- Benefits:
  - » Provide users an extra flexibility to determine what they consider clear or cloudy.
  - » Provide users who read the test results more information on strongly a test was passed.
  - » Replaces empirical thresholds with a more rigorous probablistic framework.
- Disadvantage
  - » Discrete thresholds replaced with continuous curves(more complex – but designed to avoid interpolation – so very quick).

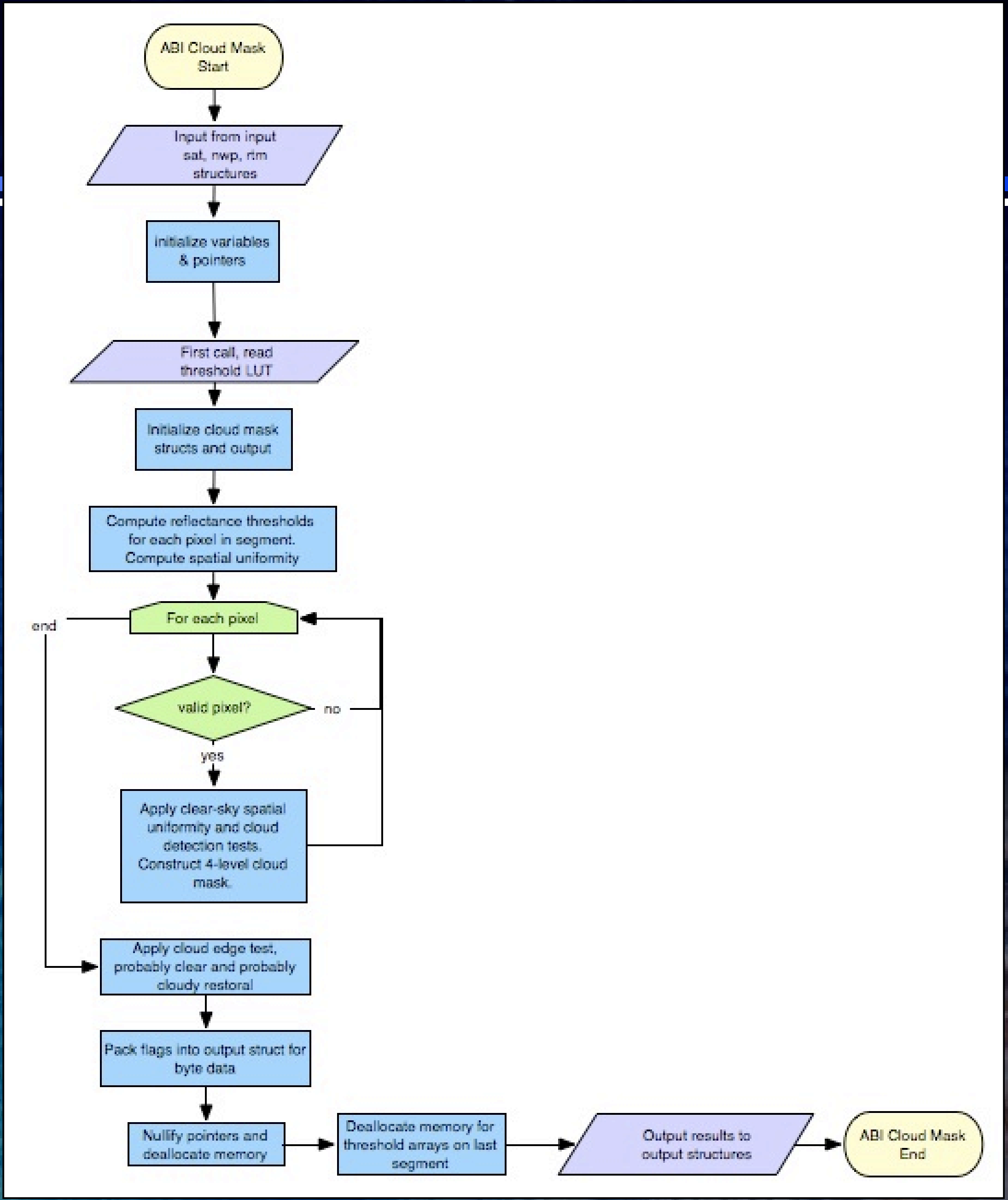
CDR Algorithm

- **Philosophy of the CDR VIIRS Cloud Mask**
  - » We recognize that cloud detection is an important part of each algorithm and each team must have influence of the cloud detection they use.
  - » The NVCM therefore attempts to do no harm and to minimize false detection of clouds.
  - » We will output the results of each test and this should allow each team to pick and choose which tests provide value to their application.
  - » As stated before, the 4-level mask also provides additional flexibility and optimization potential to each application.
  - » A cloud probability provides even more.

Algorithm Objectives

- Meet the requirements for clear radiance detection.
- Provide the needed information on the presence of cloud to the other AWG algorithms that need it.
- Performance should be insensitive to solar/sensor viewing geometry to provide information relative to climate studies.

Processing Outline



VIIRS Cloud Mask Processing

- Begin VIIRS Cloud Mask subroutine
- Input data from satellite, rtm and nwp structures
- Initialize local variables and pointers
- On first call, read in threshold lut
- Initialize output structures
- Compute thresholds for each pixel and spatial uniformity
- Apply cloud detection and clear-sky spatial uniformity tests for each pixel
- Apply cloud edge tests and probably clear/cloudy restoral tests
- Pack flags into byte output
- Nullify local pointers and deallocate memory
- Deallocate lut arrays on last processed segment
- Output results to output structure
- End VIIRS Cloud Mask subroutine

Cloud Mask Sensor Inputs

VIIRS Band	Nominal Wavelength Range (µm)	Nominal Central Wavelength (µm)	Nominal Central Wavenumber (cm-1)	Nominal sub-satellite IGFOV (km)	Sample Use
M1	0.402-0.422	0.412	21277	0.75	
M2	0.436-0.454	0.445	15625	0.75	
M3	0.478-0.498	0.488	11561	0.75	
M4	0.545-0.565	0.555	7257	0.75	
M5	0.662-0.682	0.672	6211	0.75	RGCT, RVCT, RUT
M6	0.739-0.754	0.746	4444	0.75	
M7	0.846-0.885	0.865	2564	0.75	RRCT
M8	1.23-1.25	1.24	1616	0.75	
M9	1.371-1.386	1.378	1439	0.75	CIRREF
M10	1.58-1.64	1.61	1362	0.75	NIRREF
M11	2.225-2.275	2.25	1176	0.75	
M12	3.66-3.84	3.7	1041	0.75	EMISS4 Day/Night
M13	3.973-4.128	4.05	966	0.75	
M14	8.4-8.7	8.55	893	0.75	
M15	10.263-11.263	10.763	813	0.75	TGCT, ETROP, TVCT.TUT
M16	11.538-12.488	12.013	752	0.75	FMFT

Current Input   Expected Added Input   Possible Added Input

Cloud Mask Input
Sensor Input Details

Cloud Mask requires for each pixel:

- Calibrated/Navigated ABI brightness temperatures/radiances/reflectances
- Spectral response information
- Solar-view geometry (satellite zenith, relative azimuth, solar zenith)
- Geolocation (latitude, longitude)

Name	Type	Description	Dimension
M5 (0.65 µm) Visible brightness/Albedo	input	Calibrated VIIRS level 1b brightness /Albedo	Scan grid (xsize, ysize)
M7 (0.86 µm) Visible brightness/Albedo	input	Calibrated VIIRS level 1b brightness /Albedo	Scan grid (xsize, ysize)
M9 (1.38 µm) Visible brightness/Albedo	input	Calibrated VIIRS level 1b brightness /Albedo	Scan grid (xsize, ysize)
M10 (1.61 µm) Visible brightness/Albedo	input	Calibrated VIIRS level 1b brightness /Albedo	Scan grid (xsize, ysize)
M12 (3.7 µm) radiances/emissivities	input	Calibrated VIIRS level 1b radiances and emissivities	Scan grid (xsize, ysize)
M14 (8.5 mm) brightness temperature	Input	Calibrated VIIRS level 1b brightness temperatures	Scan grid (xsize, ysize)
M15 (11 µm) brightness temp/radiances	input	Calibrated VIIRS level 1b brightness temperatures	Scan grid (xsize, ysize)
M16 (12 µm) brightness temp/radiances	input	Calibrated VIIRS level 1b brightness temperatures	Scan grid (xsize, ysize)

Cloud Mask Input
Sensor Input Details

Name	Type	Description	Dimension
Latitude	Input	VIIRS Latitude	Scan grid (xsize, ysize)
Longitude	Input	VIIRS Longitude	Scan grid (xsize, ysize)
Time	Input	Time of image	Scan grid (xsize, ysize)
Sun Earth Distance	Input	Sun earth distance factor	real4
Glint angle	Input	Glint Zenith angle	Scan grid (xsize, ysize)
Solar geometry	input	VIIRS solar zenith angle	Scan grid (xsize, ysize)
View angles	input	VIIRS view zenith and relative azimuth angles	Scan grid (xsize, ysize)
QC flags	input	VIIRS quality control flags with level 1b data	Scan grid (xsize, ysize)

Algorithm Input: Ancillary data

- Two types of ancillary data needed:
  - Static Non-VIIRS Data: Global Land Cover, Land Mask, Desert Mask, Coast Mask, Digital elevation, Global Emissivity
  - Dynamic Non-VIIRS Data: Clear-sky radiances, Clear-sky brightness temperatures, Black body radiances, Atmospheric transmittances, Surface temperature uniformity, NWP Cell number, NWP surface and troposphere levels, and Snow Mask

Cloud Mask Input Ancillary Input Details

- Non-VIIRS Static Data

Name	Type	Description	Dimension
Global Land Cover	input	Global land cover classification collection created by UMD (Hansen et al., 1998). 14 land cover classes, created from AVHRR data collected from 1981-1994	1 km resolution
Land Mask	input	Derived from global land cover land types	Scan grid (xsize, ysize)
Desert Mask	input	Derived from global land cover land types	Scan grid (xsize, ysize)
Coast Mask	input	Created from global 1-km land/water mask used for collection 5. Differentiates coast at distances from 1 km – 10 km.	1 km resolution
Digital elevation	input	NGDC-GLOBE global digital elevation model with a horizontal resolution of 1km	1 km resolution
Global Emissivity	input	MODIS monthly mean IR land surface emissivity for M12	0.05 deg resolution

Cloud Mask Algorithm Input Ancillary Input Details

- Non-VIIRS Dynamic Data

Name	Type	Description	Dimension
Clear-sky radiances	Input	Clear sky radiances for VIIRS channels M12, M14, M15 and M16, derived from CRTM	NWP grid (xsize, ysize)
Clear-sky brightness temperatures	Input	Clear sky brightness temperatures for VIIRS channel M12,M14,M15, and M16 derived from CRTM	NWP grid (xsize, ysize)
Black body radiances	Input	Black body radiances for VIIRS channel M15, derived from CRTM	NWP grid (xsize, ysize)
Atmospheric transmittances	Input	Atmospheric transmittance profiles for VIIRS M12, M14, M15 and M16	NWP grid (xsize, ysize)
Surface temperature uniformity	Input	3x3 standard deviation of NWP surface temperature from GFS model	NWP grid (xsize, ysize)
NWP Cell number	Input	X and Y cell number for each latitude and longitude	Scan grid (xsize, ysize)
Snow Mask	Input	Daily global snow and ice mask available at a horizontal resolution of 4km in the northern hemisphere (IMS) and 25km in the southern (SSMI)	4 km resolution
NWP surface and troposphere levels	Input	NWP level for surface and troposphere for each pixel.	NWP grid (xsize, ysize)

Cloud Mask Algorithm Output

- Metadata in header of the HDF files
  - » Processing date stamp
  - » Others
- Output Datasets

Name	Type	Description	Dimension
cloud_mask	output	Cloud Mask product: 4 level cloud mask. 0 = cloudy, 1 = probably cloudy, 2 = probably clear, 3 = clear	grid (xsize, ysize)
Cloud probability	outpiut	Cloud probabilty floating point value 0 – 1.	grid (xsize,ysize)
clear_sky_mask	output	Binary Clear sky Mask product: 2 level clear sky mask. 0 = clear, 1 = cloud	grid (xsize, ysize)
cloud_mask_packed	output	Packed Cloud Mask product: 4 byte array containing the individual test and flag output bits. Byte 0 is empty. Byte 1 contains the ancillary data flags. Byte 2 contains the uniformity and cloud detection tests. Byte 3 contains the near IR and restoral tests.	grid (8, xsize, ysize)

Algorithm Output

4-level cloud mask output values

Value	Description
Clear	Pixels that passed no test for cloud and failed a test for spatial heterogeneity
Probably Clear	Pixels that passed no test for cloud but passed tests for spatial heterogeneity
Probably Cloudy	Pixels that passed a test for cloud and passed a test for cloud edges
Cloudy	Pixels that passed a test for cloud and failed a test for cloud edges

Binary cloud mask output values

Value	Description
Clear	Pixel is clear
Cloudy	Pixel is cloudy

4-level cloud mask test output values

Value	Description
Clear	Test was failed strongly
Probably Clear	Test was failed weakly
Probably Cloudy	Test was passed weakly
Cloudy	Test was passed strongly.

Algorithm Output

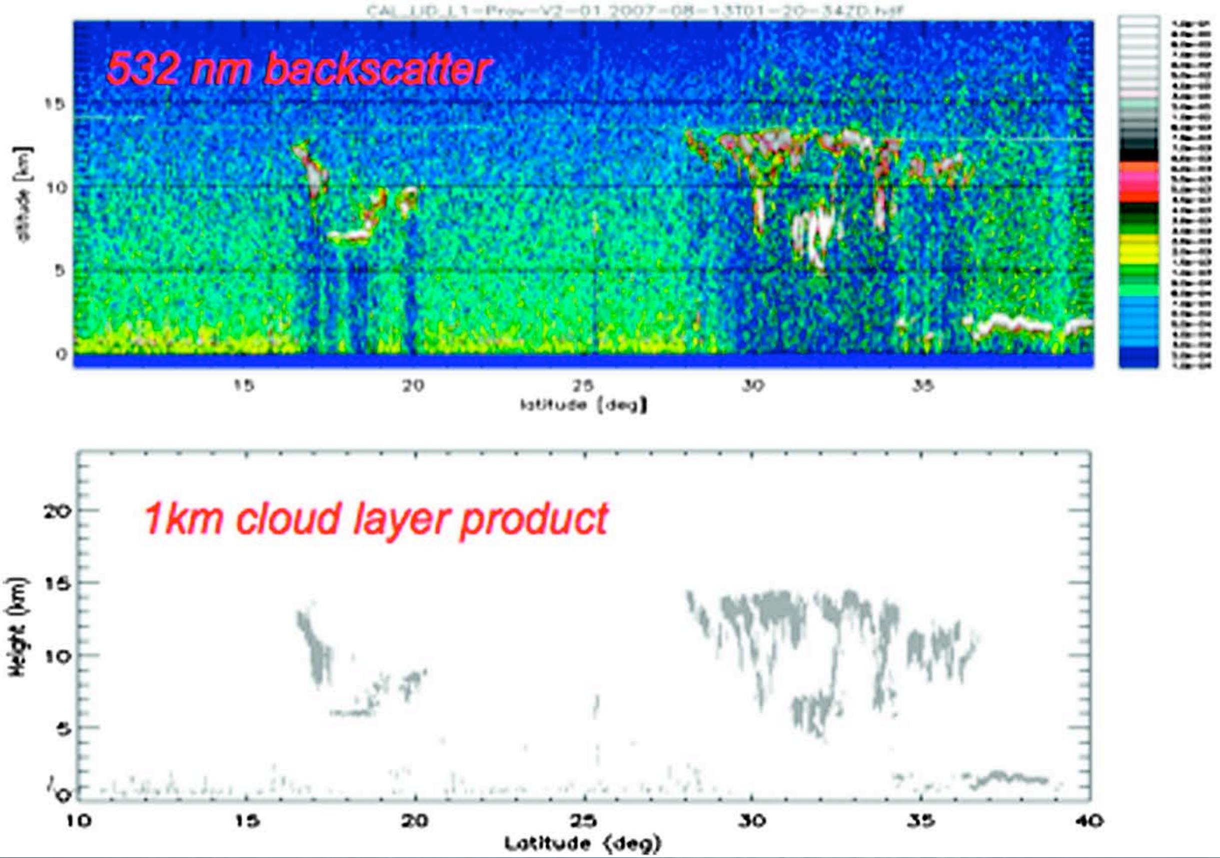
Individual test and flag output bits

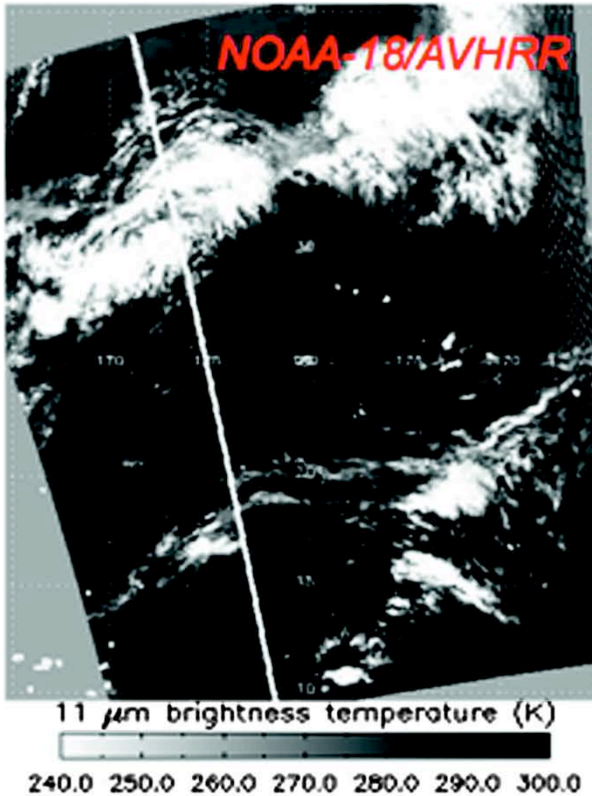
Byte	Bit	Description
Ancillary Data Flags		
1	1	Cloud mask attempted flag
1	2	Daytime visible tests attempted
1	3	Daytime spatial uniformity tests attempted
1	4	4 µm day time tests attempted
1	5	4 µm night time tests attempted
1	6	Solar contamination
1	7	Coast / No Coast Flag
1	8	Mountain / No Mountain Flag
Meta Data Flags		
2	1	Smoke contaminated Flag (not currently filled)
2	2	Dust contaminated Flag (not currently filled)
2	3	Shadow contaminated Flag (not currently filled)
2	4	Fire contaminated Flag (not currently filled)
2	5-8	Surface type used for thresholds
11 µm Tests		
3	1-2	TGCT – Thermal Gross Contrast Test
3	3-4	RTCT – Relative Thermal Contrast Test
3	5-6	TUT – Thermal (11µm BT) Uniformity Test
3	7-8	ETROP – Emissivity at Tropopause Test
4	1-2	FMFT – (11µm-12µm) test
4	3-4	(11µm-6.7µm) test
4	5-6	(11µm-6.7µm) covariance test
4	7-8	(11µm-8.5µm) covariance test
Remaining Detection Tests		
5	1-2	EMISS4 – 4 µm emissivity test
5	3-4	EMISS4 Day– 4 µm emissivity test
5	5-6	EMISS4 Night– 4 µm emissivity test
5	7-8	(11µm-4µm) night test
0.65 µm Tests		
6	1-2	RGCT – Reflectance Gross Contrast Test
6	3-4	RUT – Reflectance (0.63 mm) Uniformity Test
6	5-6	RVCT – Relative Visible Contrast Test
6	7-8	RRCT – Reflectance Ratio Test
7	1-2	NIRREF – Near-IR Snow Test (1.6 µm)
7	3-4	CIRREF- Near IR Cirrus Test (1.38 µm)

Retrieval Strategy

- Employ a 4-level mask for maximal utility
- Provide all test results in output for maximum flexibility (this allows an application to remove cloud tests that are problematic and to rederive the cloud mask)
- We are using tests taken from heritage and fully intend to modify to suit the needs of the downstream applications.

Training the Mask with Calipso/CALIOP





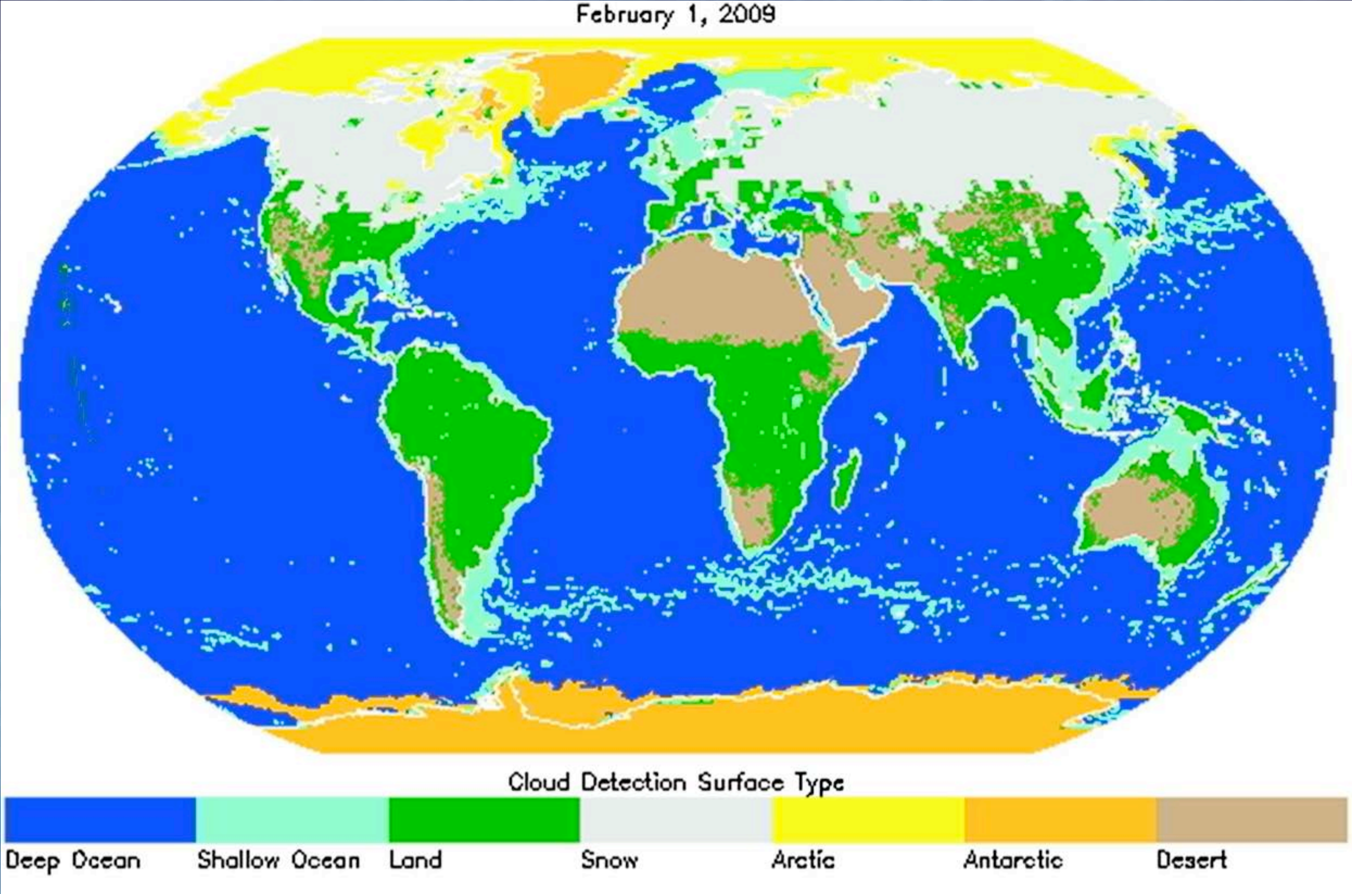
Same colocation tools used in GOES-R applied here to VIIRS Cloud Mask for CALIPSO based Cloud Layer Products.

Cloud Mask Threshold Regions

- The GOES-R Cloud Mask had 4 regions
- Deep Ocean
- Land
- Snow/Sea Ice
- Desert

- For the Global JPSS we have expanded to be
- Deep Ocean
- Shallow Water
- Land
- Snow
- Arctic
- Antarctic + Greenland
- Desert

Example cloud mask threshold regions for a NH winter Day.



Mathematical Description I

- In the ABI mask, we chose a threshold directly for each of the 12 tests.
- In this mask, we let the naïve Bayesian logic do this for us.
- We can use the same tests (this is the naïve part) without large multi-dimensional array that is common in traditional Bayesian techniques.

Mathematical Description II

- We use the CALIPSO training as we used in the ABI mask but now compute for each test the probability that a given value was cloudy.
- We store these as equally spaced threshold curves so no interpolation is needed.
- The values for each test are combined together for final probability value – which is used for the mask output.
- The values for each test are discretized into a 4-level flag that is also an output.

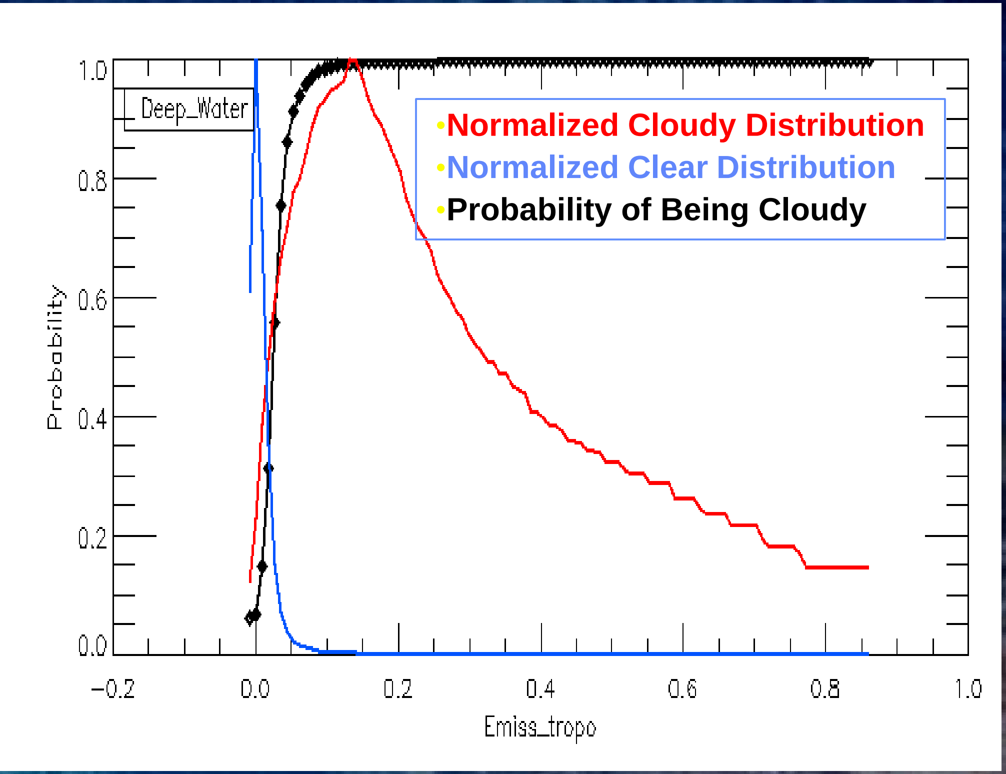
Mathematical Description III

In the ABI mask, we used one number for a clear/cloudy threshold. We used the value close to the 0.90 probability.

In this mask, we replace this single number with the black curve shown below.

The black curve is computed from cloudy (red) and clear (blue) results given to us from the colocated CALISP/VIIRS analysis.

A benefit of this approach is that tests work together and a test can "vote" for clear and cloudy – we get much more confident clear that previously.



Physical Description: Overview

- The cloud mask is really comprised of multiple mini-algorithms each trying to exploit some signature that can used to detect the presence of cloud.

- The cloud mask has the following types of tests
  - » Spatial tests for cloudy pixels
  - » Spectral tests for cloudy pixels
  - » Spatial tests for filtering clear pixels
  - » Temporal tests used in ABI are missing

- The remainder of this section illustrates the main physical basis of each test.

Cloud Mask Test Summary

- All Tests from GOES-R expect the 11-6.7 μm BTD and 11&6.7 μm Covariance are used.

- New Tests are
  - Brightness temperature difference 11 and 8.5 micron (Btd_11_85)
    - Test is useful for water cloud detection at all times of day

  - Reflectance Ratio Test (RRCT)
    - Test is useful to over most surfaces

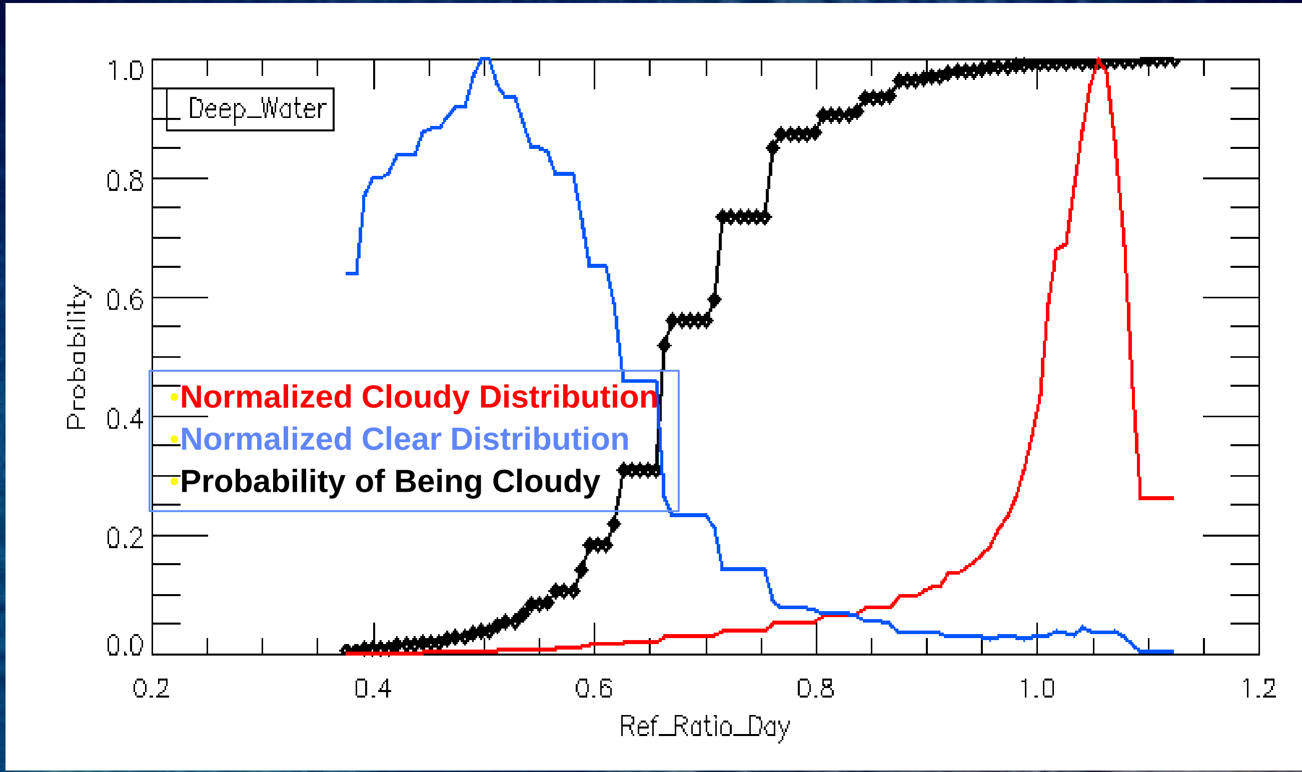
- Following slides demonstrate the tests proposed for the JPSS Cloud Mask.

- These will only be shown for the DEEP OCEAN region.

Cloud Mask Test: Reflectance Ratio (RRCT)

- The ratio of the 0.86 to 0.65 mm reflectances is a common test.
- Clear-skies have values less than one (over ocean).
- Cloudy skies have values near one.
- This test is only applied during day.
- Oceanic glint is avoided.
- Very sensitive to dust.

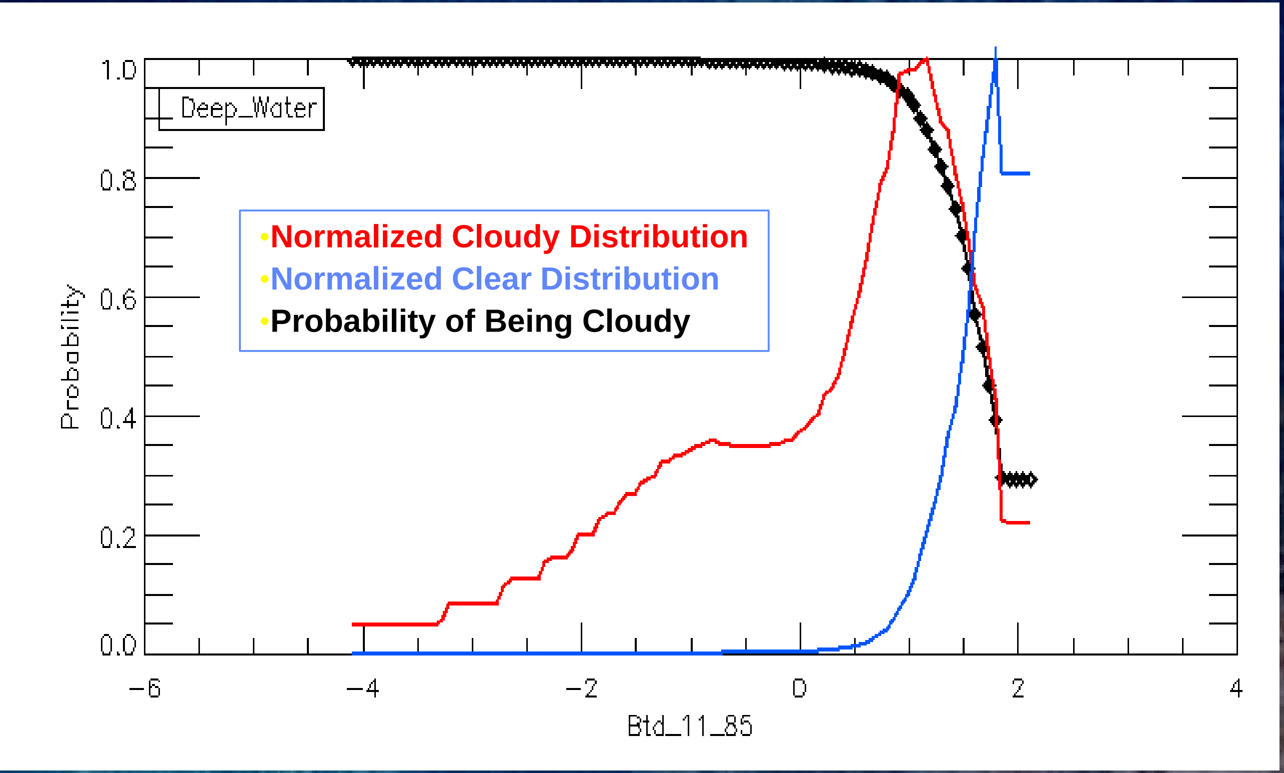
Example distributions computed from VIIRS for this test



Cloud Mask Test: Btd_11_85

- The BTD_11_85 test works on the brightness temperature difference between 11 and 8.5 µm.
- At 8.5 µm, clouds have different emissivities than 11 µm depending on the phase.
- Ice cloud have positive BTD values
- Water clouds have negative BTD values.
- The clear value is positive due to water vapor effects.

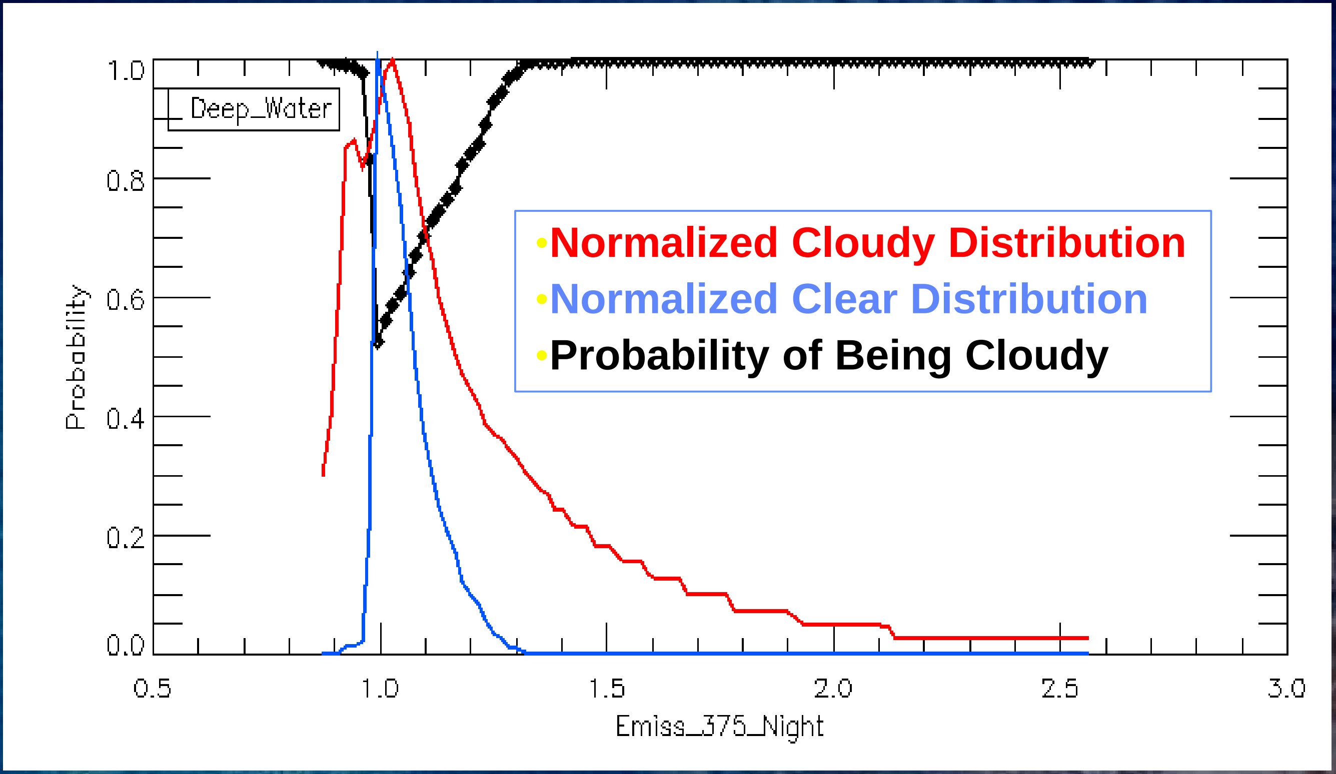
Example distributions computed from VIIRS for this test



Cloud Mask Test: EMISS4 Night

- Emiss_375_Night uses the fact that clouds have a different pseudo emissivity at 3.75 microns than most surfaces.
- Water clouds have emissivities less than one
- Ice cloud have emissivities larger than one.
- This test is only applied at night.
- Similar to ULST in GOES-R Mask.

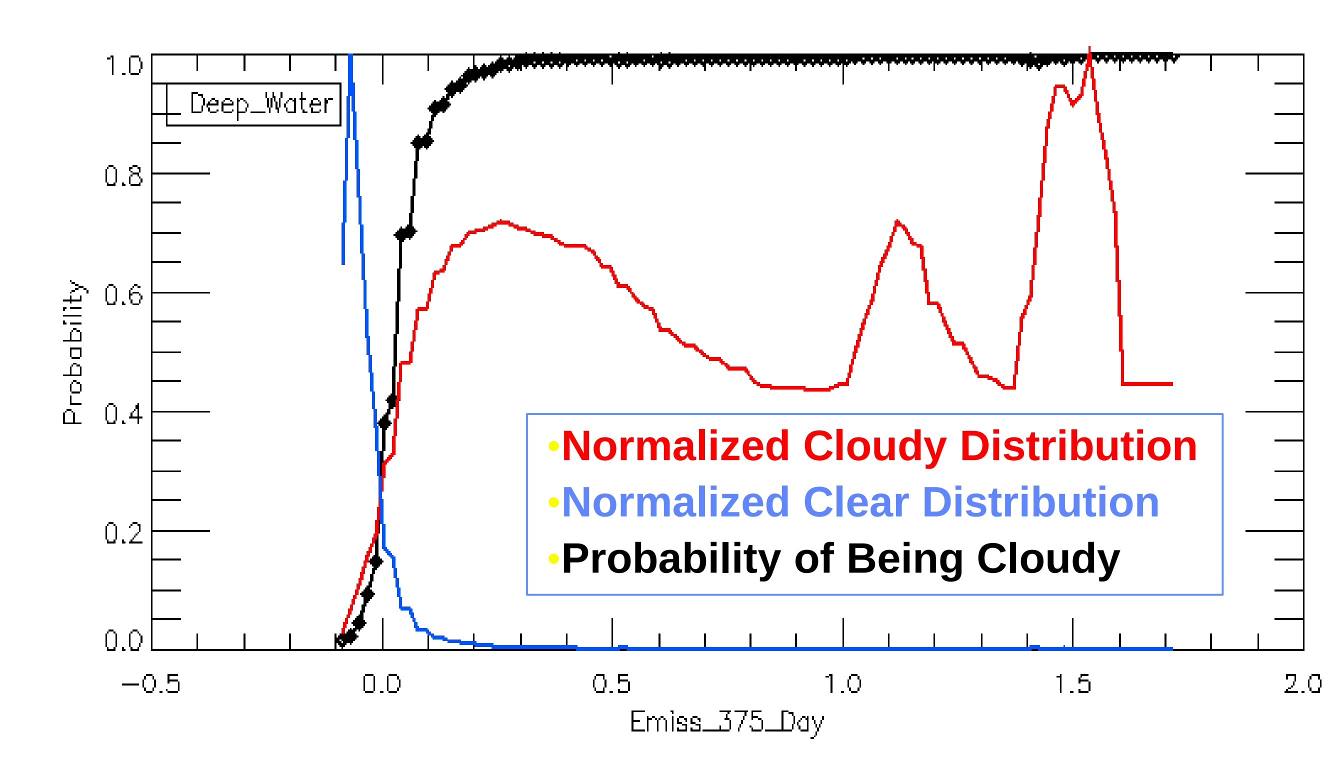
Example distributions computed from VIIRS for this test



Cloud Mask Test: EMISS4 Day

- Emiss_375_Day uses the fact that clouds have a different pseudo emissivity at 3.75 microns larger most surfaces during the day.
- Water and ice cloud both exhibit large emissivities during the day.
- This test is only applied during day.
- Oceanic glint is avoided

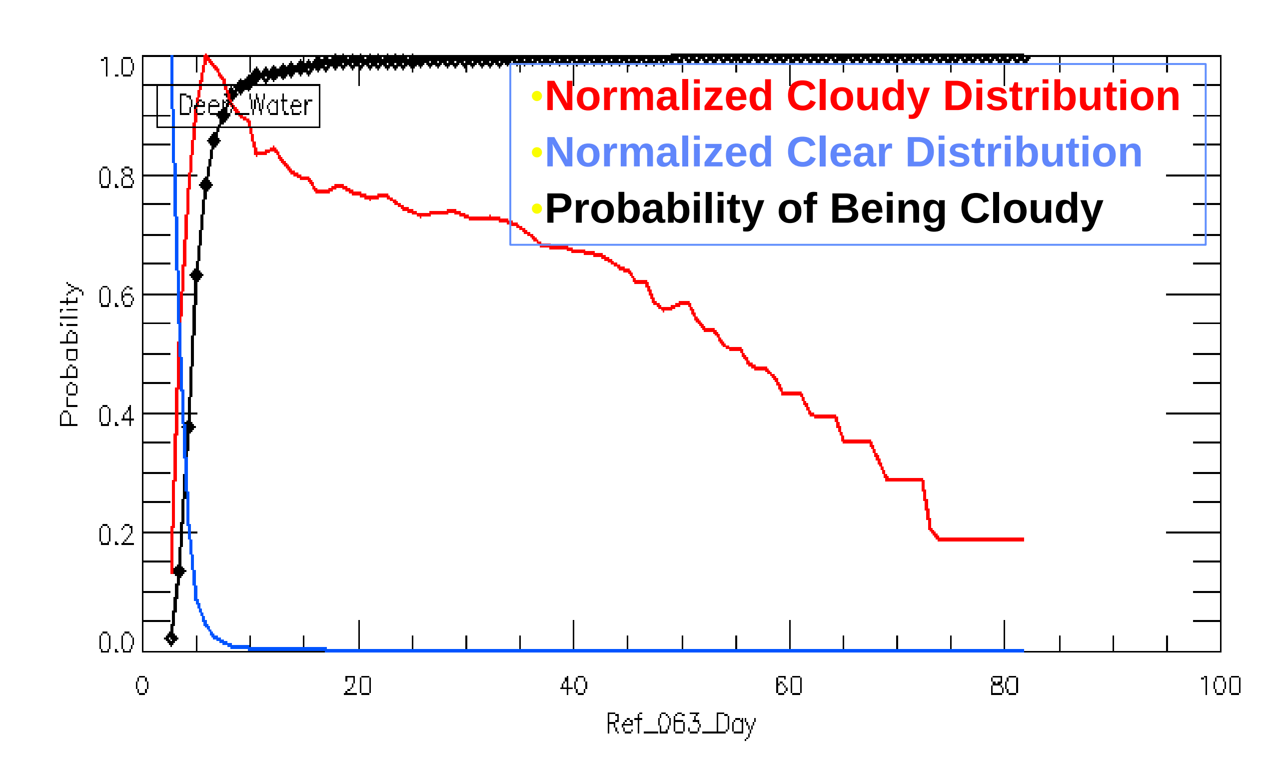
Example distributions computed from VIIRS for this test



Cloud Mask Test: RGCT

- The Reflectance Gross Contrast Test (RGCT) is taken from GOES-R AWG.
- All clouds are brighter than the surface.
- This test is based on the observed TOA reflectance minus a clear-sky estimate.
- This test is only applied during day.
- Oceanic glint is avoided

Example distributions computed from VIIRS for this test



Cloud Mask Test: 1.38 µm Reflectance (CIRREF)

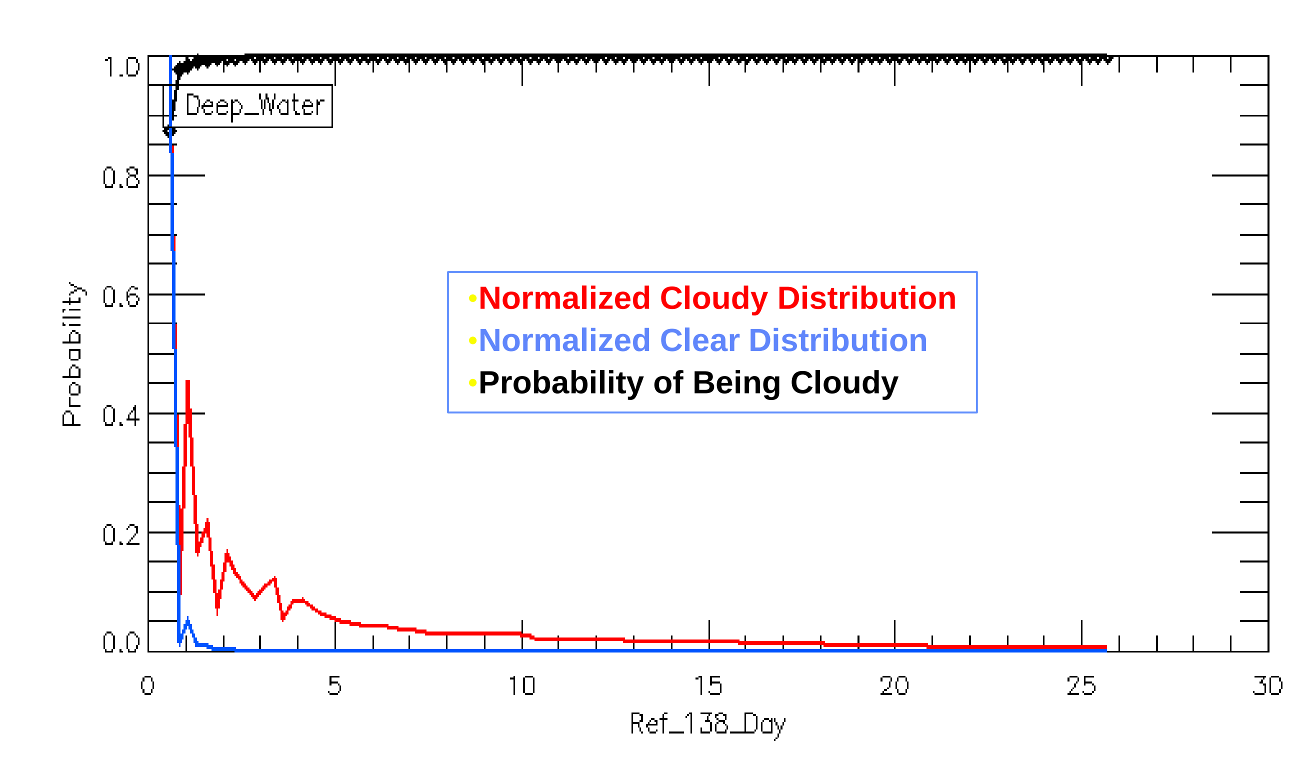
- The 1.38 micron observation is very sensitive to cirrus and does not sense the surface under most conditions.

- This test was used in GOES-R AWG and appears in the VCM.

- This test is only applied during day.

- A GOES-R AWG Test

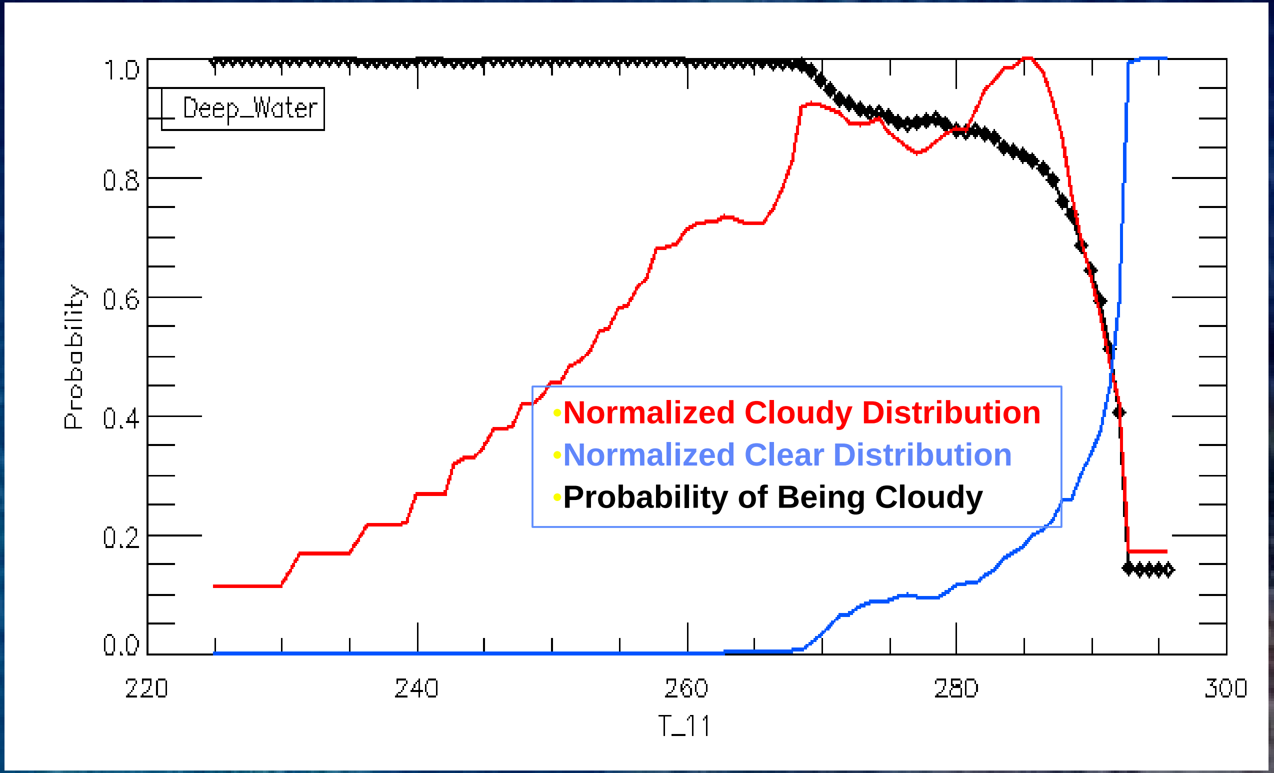
Example distributions computed from VIIRS for this test



Cloud Mask Test: 11 µm BT (TGCT)

- The 11 µm brightness temperature was not used in the GOES-R AWG.
- Found to add skill in the Naïve Bayesian Formulation.
- Useful in preventing false cloud detection when NWP data is uncertain.
- GOES-R AWG

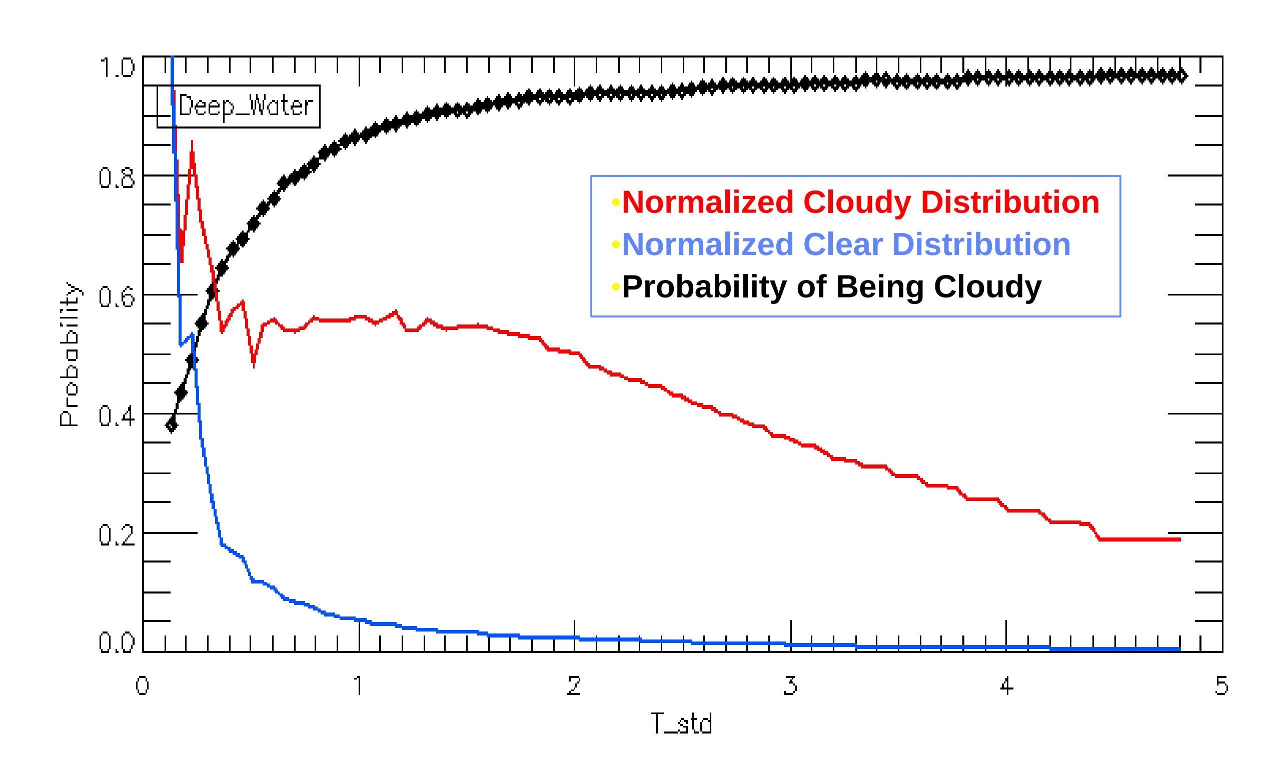
Example distributions computed from VIIRS for this test



Cloud Mask Test: TUT

- TUT is the Thermal Uniformity Test.
- Based on 3x3 pixel standard deviation of 11 µm BT.
- This test is not a guarantee of cloud but clouds tend to be more heterogeneous than the surface.
- This test is also useful in preventing false detection over uniform surfaces (Antarctica)
- GOES-R AWG Test

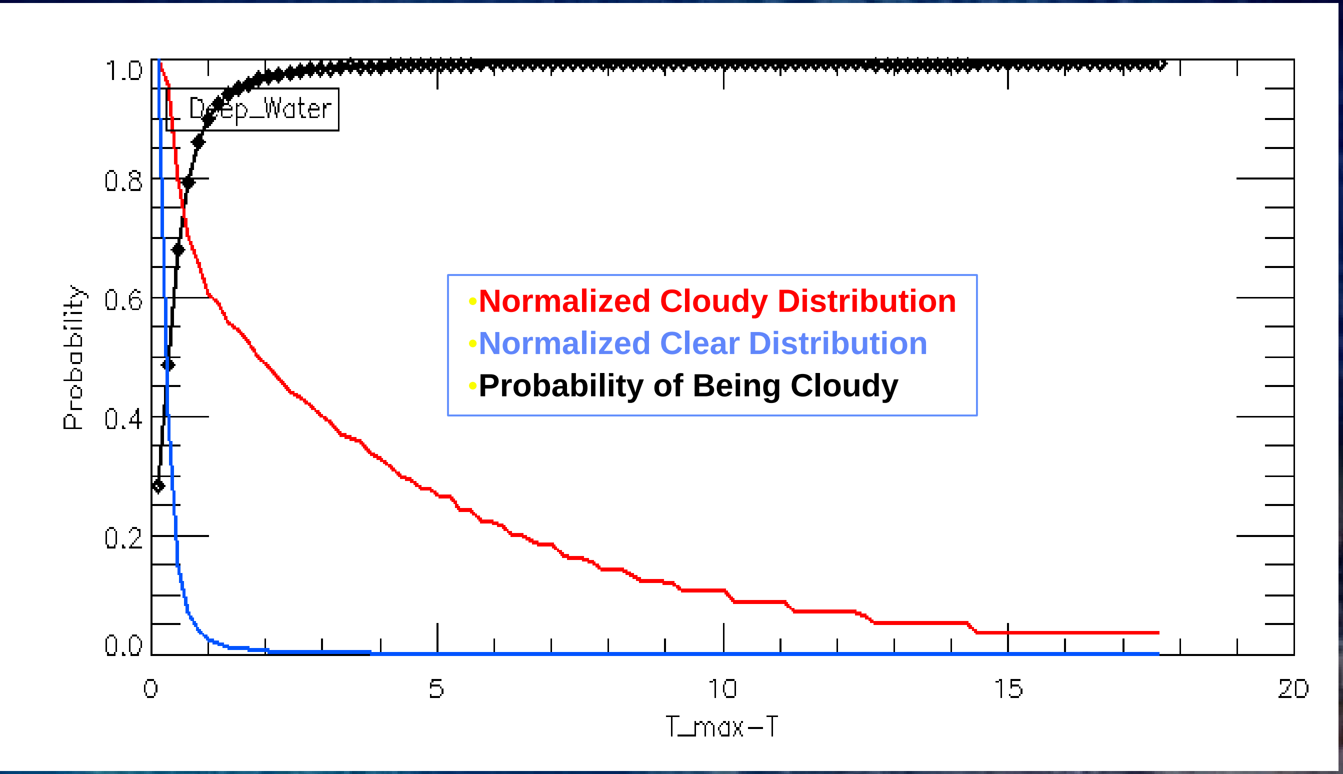
Example distributions computed from VIIRS for this test



Cloud Mask Test: TVCT

- The T_max –T test looks at the difference in the maximum T11 over a 3x3 array minus the center pixels' value.
- Physical basis is that clouds are colder than the clear ocean.
- Good at detecting edges.
- A GOES-R AWG test.
- Coasts and mountains are avoided.

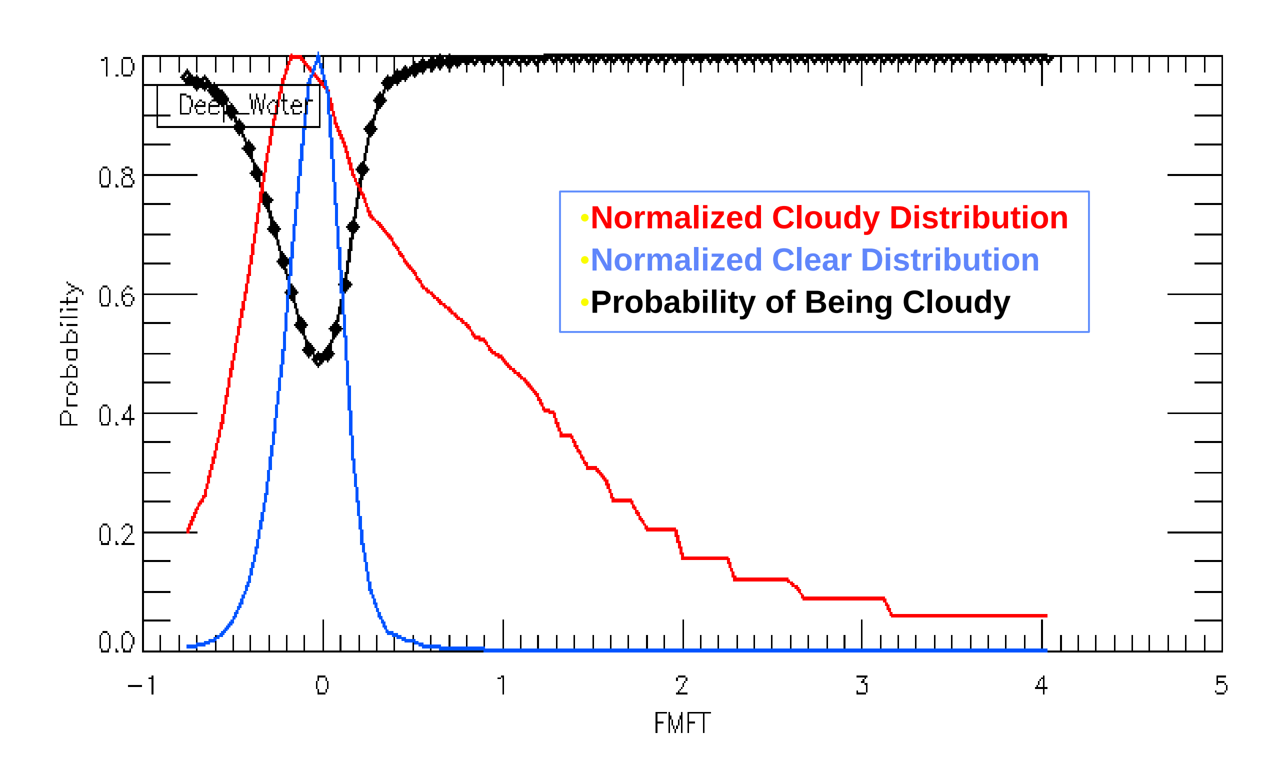
Example distributions computed from VIIRS for this test



Cloud Mask Test: FMFT

- FMFT is the four-five test from the CLAVR-1 heritage.
- FMFT works on the split-window (11-12 micron BTD).
- Cirrus exhibit large BTD.
- Low clouds exhibit negative values.
- A GOES-R AWG test.

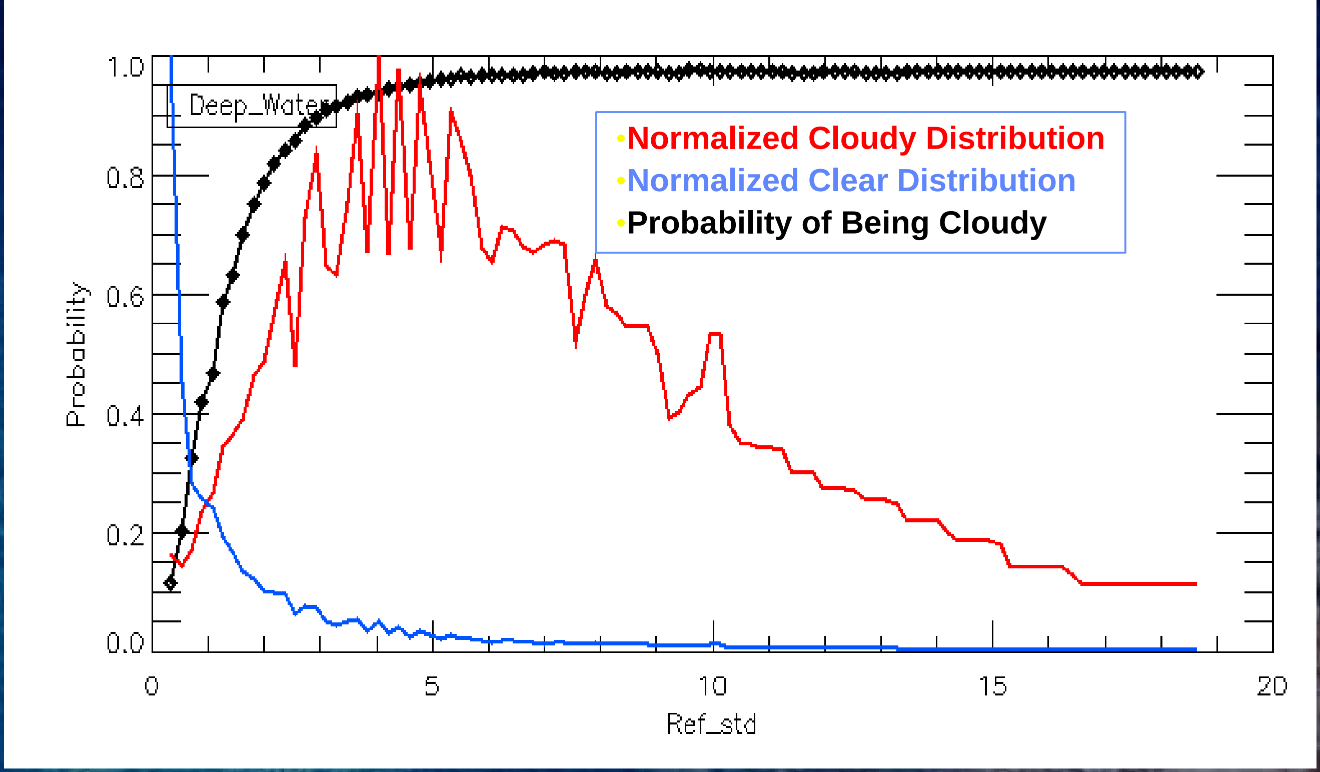
Example distributions computed from VIIRS for this test



Cloud Mask Test: RUT

- The Reflectance Uniformity Test (RUT) operates on the standard deviation of the 3x3 0.65 μm reflectance array.
- Clouds tend to be more heterogenous than the surface (most of the time).
- This test is only applied during day.

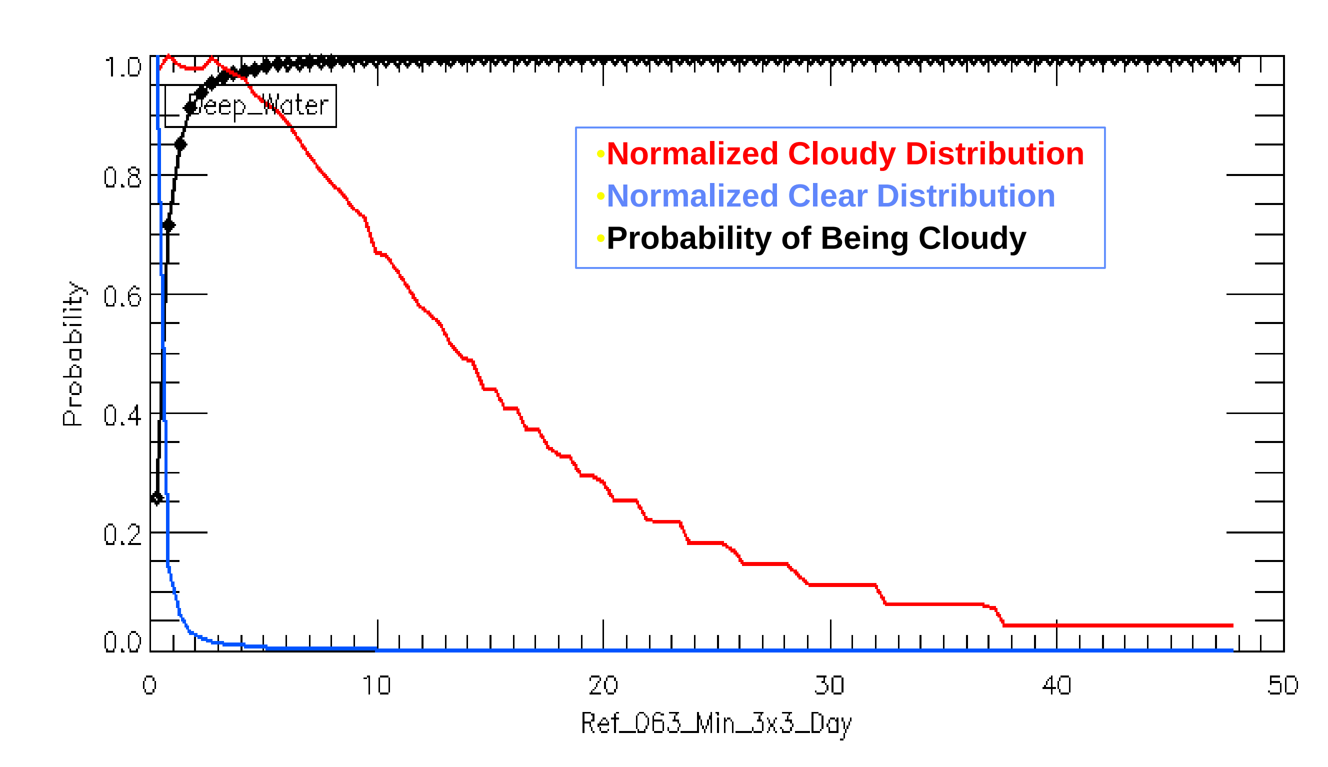
Example distributions computed from VIIRS for this test



Cloud Mask Test: Ref – Ref_Min (RVCT)

- Ref – Ref_Min is a test that compares a pixel's 0.65 µm reflectance to the minimum value in a 3x3 pixel array.
- Most surfaces are more homogeneous than clouds.
- Similar to TUT.
- From GOES-R AWG.
- This test is only applied during day.

Example distributions computed from VIIRS for this test



Cloud Mask Test: Tropopause Emissivity (ETROP)

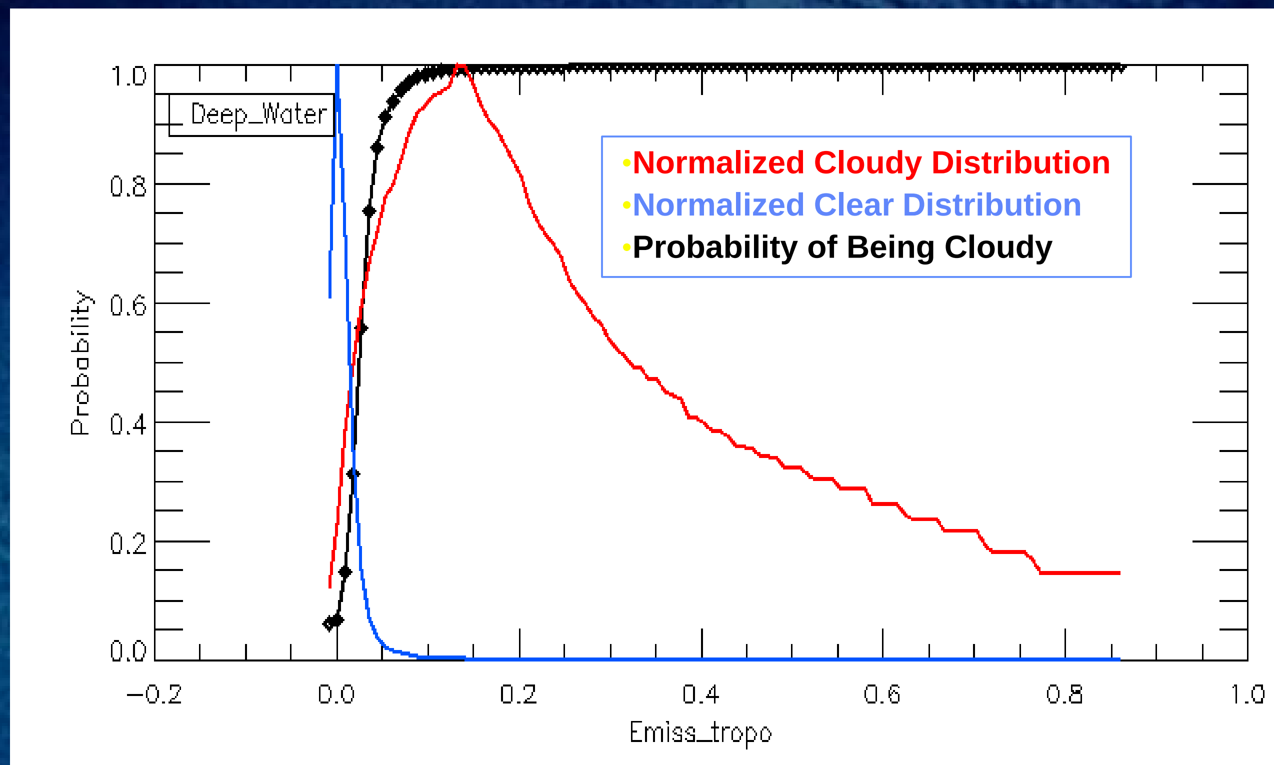
- The 11 mm Tropopause Emissivity test operates on the 11 micron emissivity computed using the tropopause level as the reference temperature..

- Test accounts for variation in sensitivity due to surface and atmospheric conditions.

- Very sensitive test but also sensitive to clear-sky RTM accuracy.

- GOES-R AWG Test

Example distributions computed from VIIRS for this test



Algorithm Output

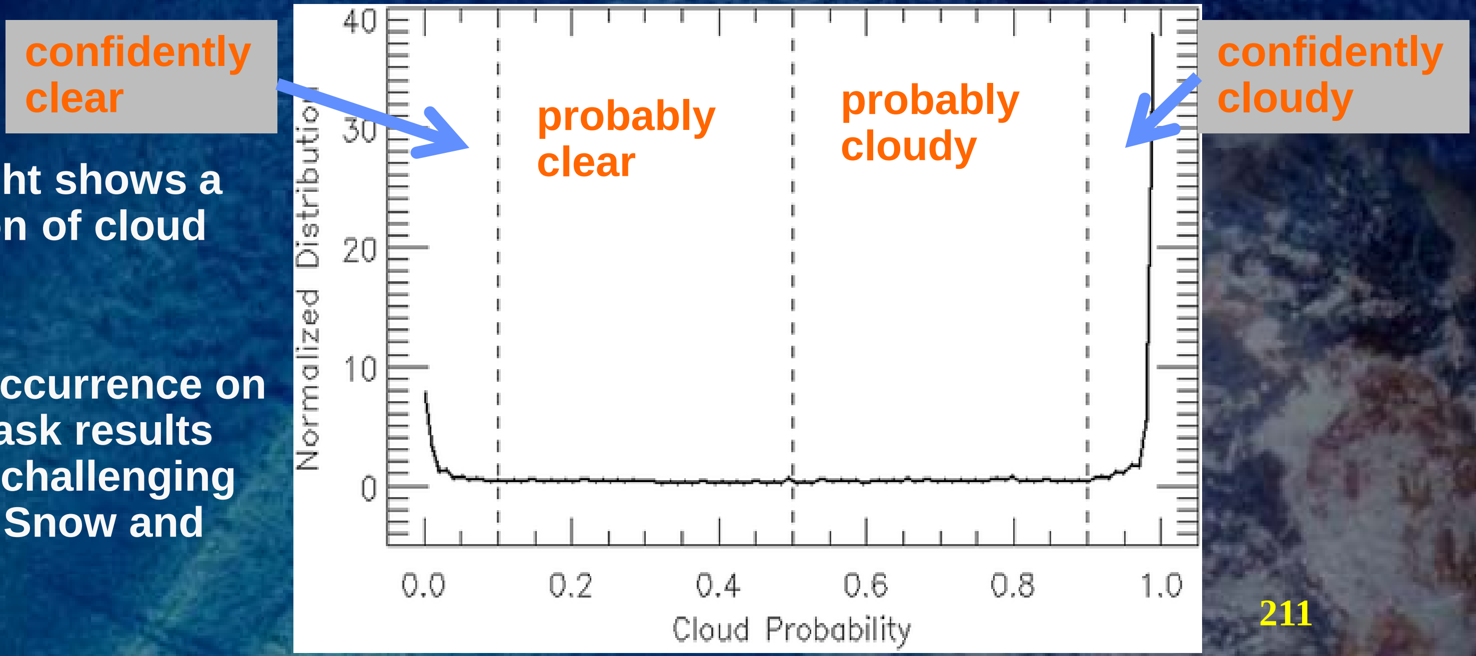
- Processing currently limited to viewing angles < 70 degrees.
- Algorithm will output the 4-level cloud mask, the binary cloud mask, the cloud probability and the cloud test flags.

Generation of a 4-Level Mask

- The Pixel's cloud probability is used to assign the final 4-level mask
- If the probability < 0.10, the mask = confident clear
- If the probability > 0.10 but < 0.50, the most = probabilty clear
- If the probability > 0.50 and probability< 0.90, the mask = probably cloudy
- If the probability > 0.90, the mask = confident cloudy.

- Image on the right shows a global distribution of cloud probability.

- Most common occurrence on non-confident mask results occurrence over challenging surfaces (Arctic, Snow and Antarctica)



Generation of a Binary Mask

- The Pixel's cloud probability is used to assign the final binary mask

- If the probability < 0.50, the mask = clear

- If the probability > 0.50, the mask = cloudy.

Generation of a 4-level Test Value

- Same logic is applied to that used in making 4-level cloud mask

- Each test has a cloud probability curve of its own.

- Same 0.0-0.1, 0.1-0.5, 0.5-0.9, 0.9-1.0 thresholds can be used to make the 4-level confidences for each test.

- If space becomes an issue, we can fall back to binary test results using 0.5 as the threshold as we did in the ABI mask.

Example Application of A Test

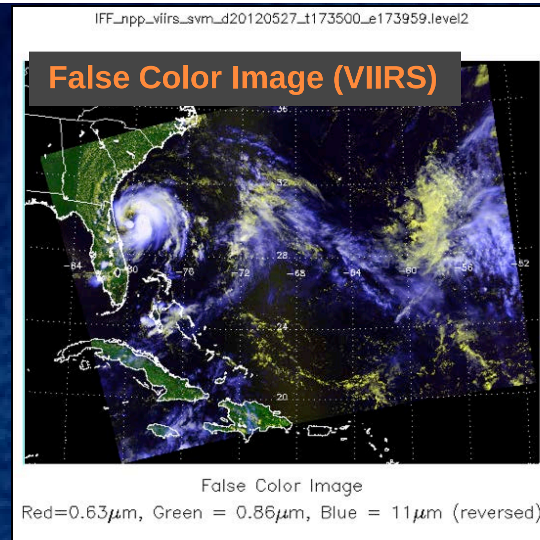
11 mm Emissivity Test (ETROP)

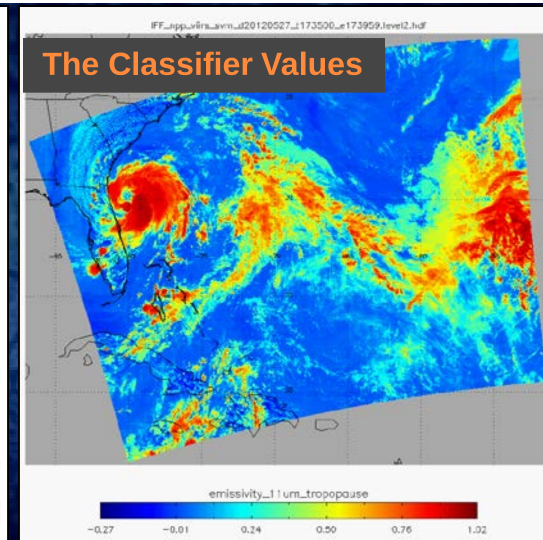
Upper left image shows a false color image for reference.

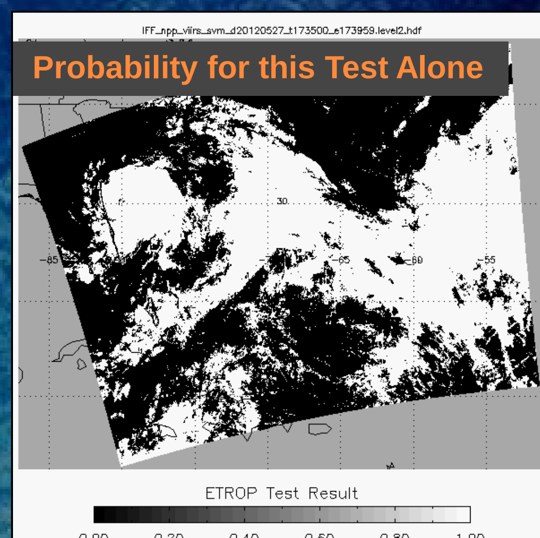
Upper right image shows the observed 11 μm emissivity at Tropopause values.

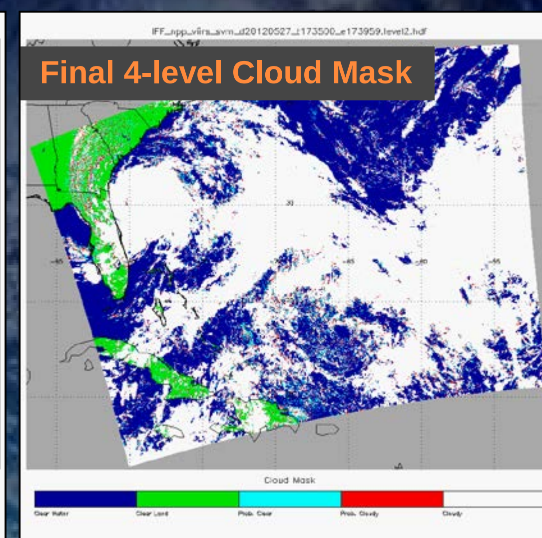
Lower left image shows mask for this test alone (using 0.5 threshold)

Lower right image shows the final mask for all tests.









Practical Considerations

- Algorithm performance demands accurate NWP and computationally efficient and accurate clear-sky RTM calculations.

- Current NWP and implementation of fast clear-sky RTM performance is adequate and we expect improvements.

Practical Considerations: Exception Handling

- Each cloud mask check the available flags to see if the needed channels are available.
- A cloud mask will be produced if at least the 11 micron channel is available.
- A quality flag is included in the output to notify users if any or all channels were missing.
- If a cloud mask can not be produced, the quality flag indicates a non-valid cloud mask.

Performance Estimates: Calculation of Metrics

- The Probability of Incorrect Detection (POID) in the F&PS is 13% (threshold) and 5%(objective)

- POD = (number of correcty identified clear pixels + number of correctly identified cloudy pixels) / (number of cloudy CALIPSO pixels and number of clear CALIPSO pixels)

- Leakage or Missed Cloud = number of pixels with cloud mask = CLEAR or PROBABLY CLEAR when colocated CALIPSO views within a VIIRS pixel were cloudy.

- False Alarm = number of pixels with cloud mask = CLOUDY or PROBABLY CLOUDY when no colcoated CALIPSO views within VIIRS pixel were cloudy.

- For this computation, the 4-level mask was converted to a binary mask

Performance Estimates

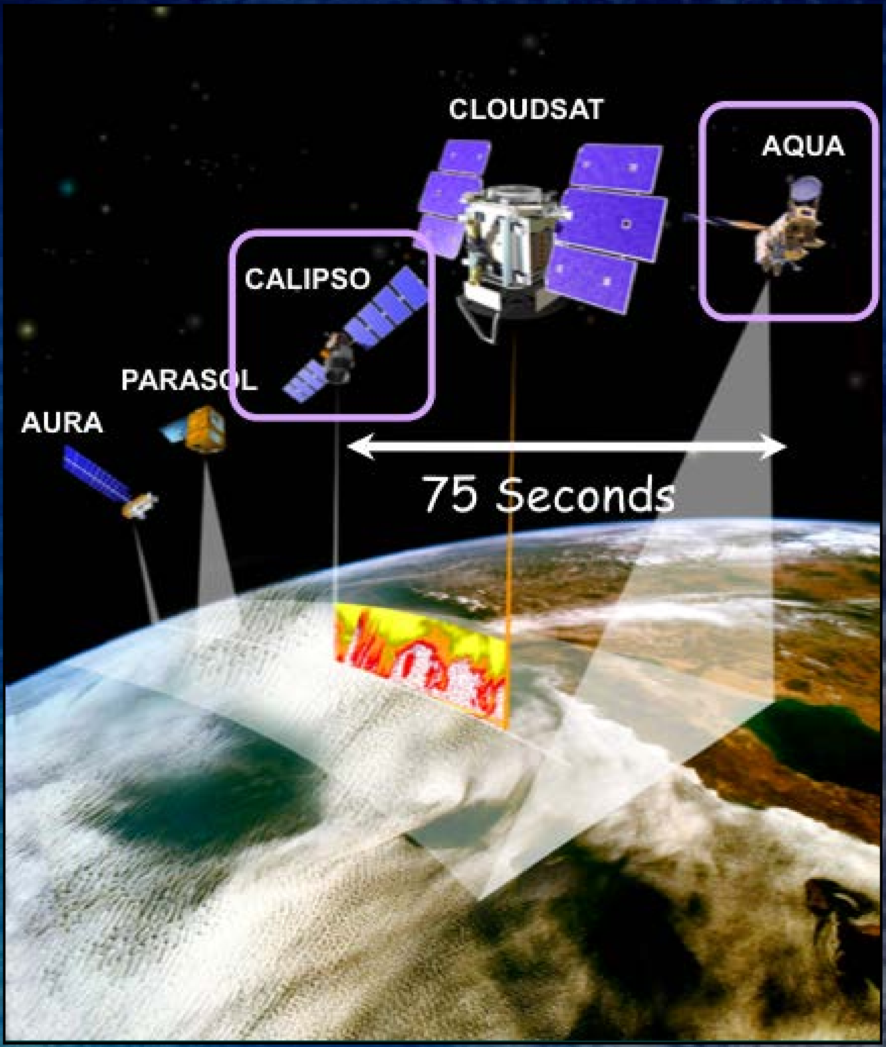
•With the launch of CALIPSO (a lidar) and CLOUDSAT (a radar) into the EOS A-train, we now unprecedented information on the vertical structure of clouds.

• CALIPSO is very sensitive to the presence of any cloud in the column and therefore is our first choice in cloud height validation.

•The weaknesses of CALIPSO are low snr during the day and difficulty distinguishing cloud from aerosol.

•Even with these weaknesses, CALIPSO is the best we have.

•Similar data should exist in the GOES-R era (Earth-Care…)



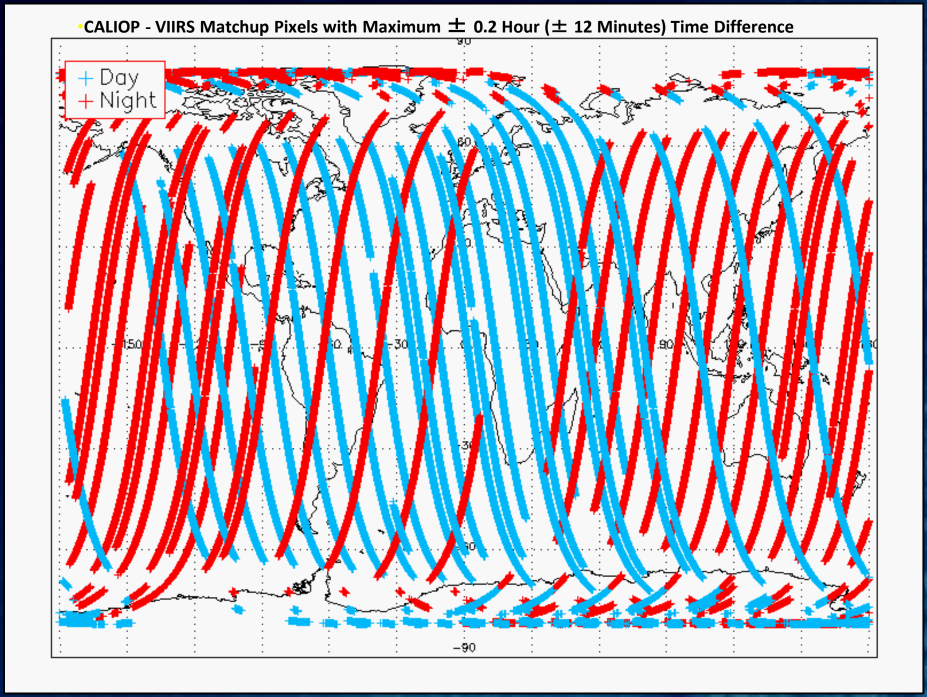
CALIPSO As A Validation Source

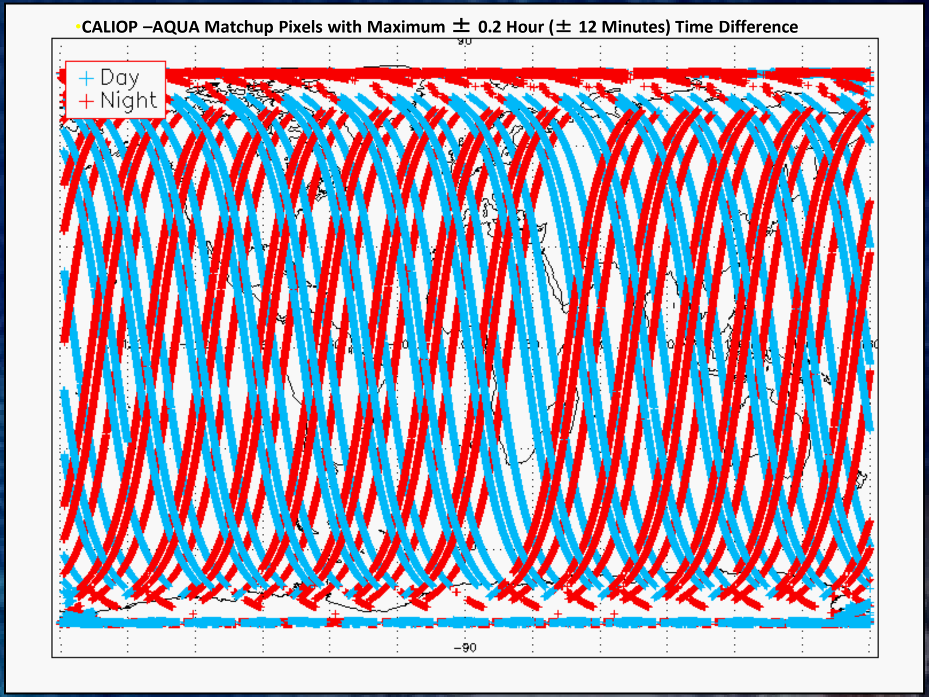
CALIPSO TRACK

CALIOP lidar	
Laser wavelengths	532, 1064 nm
Repetition Rate	20.16 Hz
Pulse length	20 nsec
Beam divergence	100 urad
Telescope IFOV	130 μrad
Surfaces GIFOV diameter	70 m

CALIOP Vertical and Horizontal Averaging		
Altitude (km)	Horizontal Resolution (km)	Vertical Resolution (m)
31.0 - 40.0	5.0	300
20.2 – 30.1	1.67	180
8.2-20.2	1.0	60
0.5 – 8.2	0.33	30

CALIPSO Collocation Pixels





3 day collocation (08/14/2012, 11/10/2012 and 02/09/2013)

CALIPSO Collocation Stats with other masks (VCM, MODIS C6)

3 day collocation (08/14/2012, 11/10/2012 and 02/09/2013)

90N – 90S, Ocean/Land, Day/Night, No Snow/Snow/Ice

Cloud Mask Algorithm	Sample Size	Cloud fraction				Probability of		
		Active	Passive	Pr. Clear	Pr. Cloudy	Detection	False D.	Leakage
NOAA VIIRS	901051	0.715	0.697	0.054	0.060	0.909	0.037	0.054
VCM IDPS	860046	0.716	0.641	0.071	0.031	0.878	0.024	0.099
NOAA MODIS	1222722	0.727	0.698	0.060	0.050	0.927	0.022	0.051
MODIS C6	1222722	0.727	0.707	0.061	0.044	0.926	0.027	0.047

60N – 60S, Ocean/Land, Day/Night, No Snow/No Ice

Cloud Mask Algorithm	Sample Size	Cloud fraction				Probability of		
		Active	Passive	Pr. Clear	Pr. Cloudy	Detection	False D.	Leakage
NOAA VIIRS	729886	0.713	0.684	0.035	0.033	0.928	0.022	0.051
VCM IDPS	690211	0.715	0.659	0.069	0.030	0.911	0.017	0.072
NOAA MODIS	876514	0.715	0.689	0.028	0.025	0.954	0.010	0.036
MODIS C6	878574	0.716	0.707	0.074	0.035	0.950	0.021	0.029

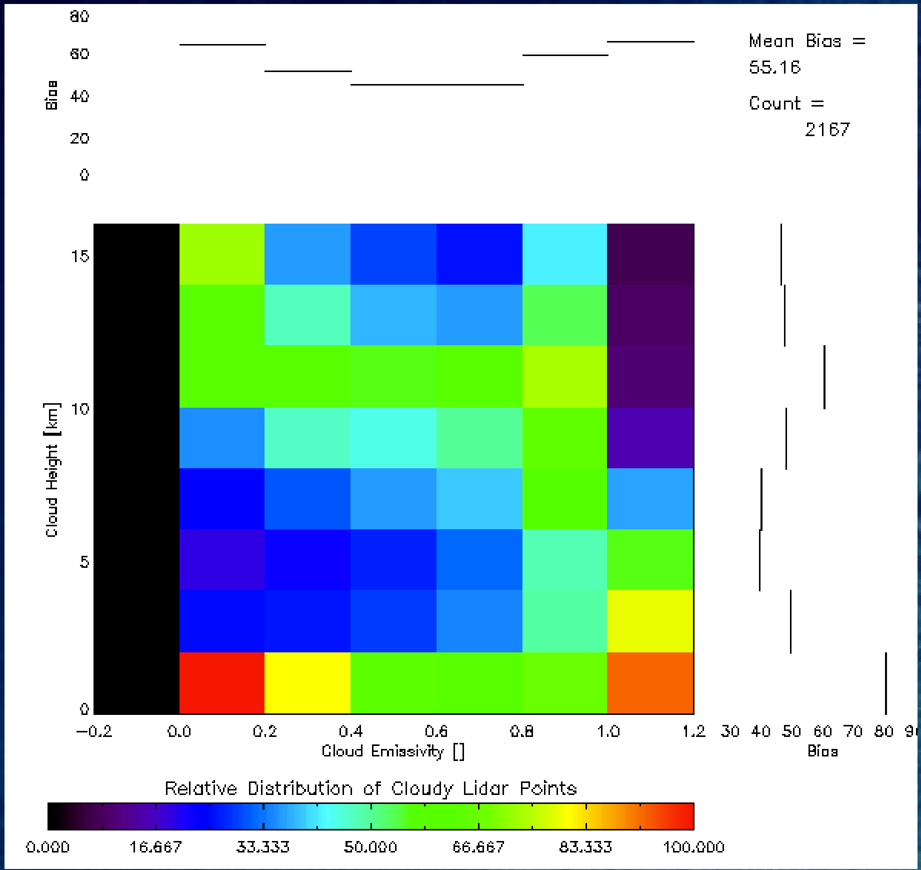
NOAA Cloud Masks compares well for this data.

We are trained against CALIPSO so these numbers maybe inflated for the NOAA Cloud Mask.

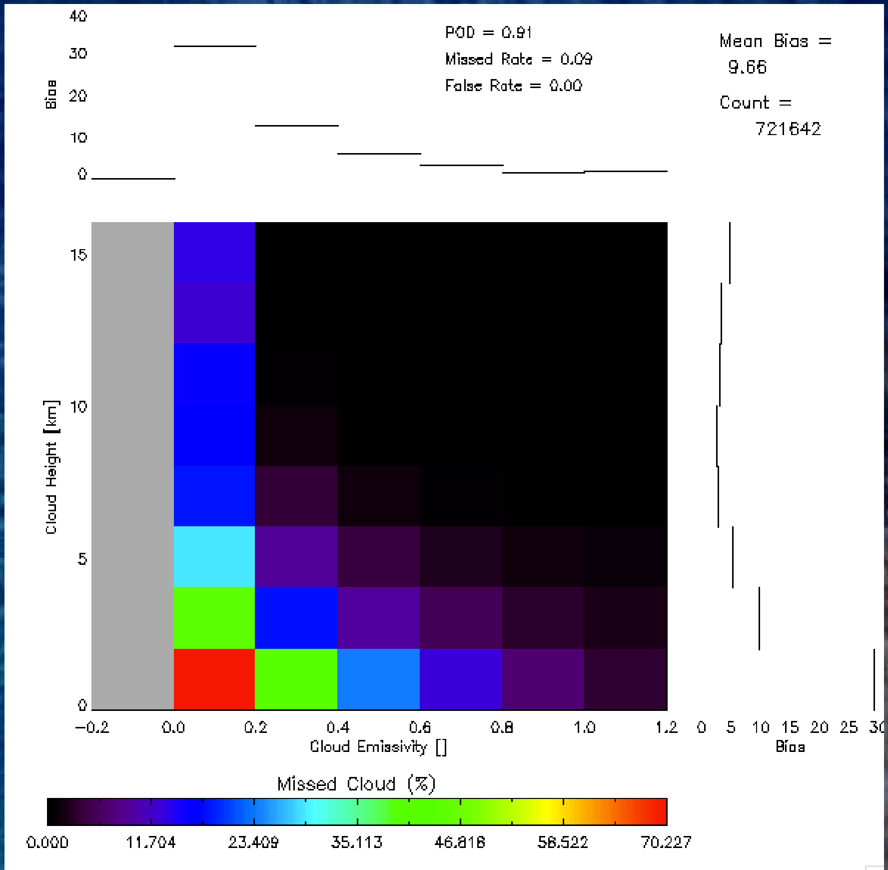
CALIPSO Analysis of MODIS run like VIIRS

Given the quantity of MODIS/CALIPSO matchups relative to those from VIIRS/CALIPSO, we still find use in running the VIIRS algorithms on MODIS. Here are results for 2010 for all regions.

Height/emissivity distribution of Cloudy Calipso values



height/emissivity distribution of missed pixels



CALIPSO Analysis of MODIS run like VIIRS

Results here for NOAA mask applied to AQUA/MODIS and broken out by the threshold regions

	Deep Ocean	Shallow Water	Land	Snow	Arctic	Antarctic + Greenland	Desert
CALIPSO Cloud Frac	0.817	0.725	0.654	0.726	0.681	0.716	0.343
Cloud Frac	0.793	0.697	0.586	0.662	0.640	0.681	0.307
POD	0.961	0.944	0.915	0.852	0.869	0.795	0.943
Skill Score	0.920	0.892	0.859	0.702	0.733	0.532	0.848
False Alarm	0.008	0.014	0.008	0.042	0.045	0.085	0.011
Missed Cloud	0.031	0.042	0.076	0.106	0.086	0.120	0.047

POD exceeds 87% threshold for all but Snow Covered Land. NIRREF test not included in the above analysis (dead on AQUA/MODIS). Overall global POD = 91%.

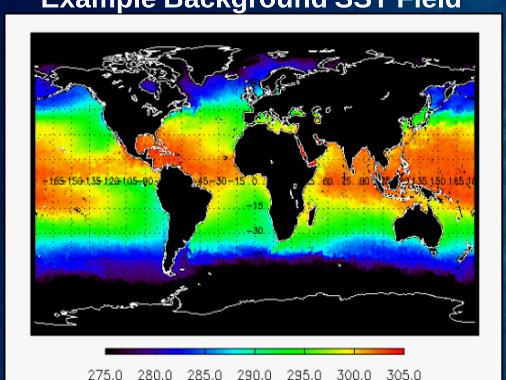
Performance Estimates: SST Bias Monitoring

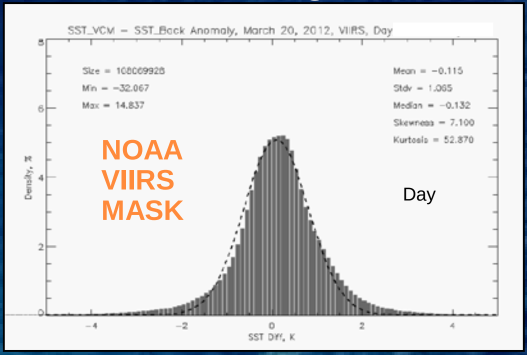
- We have worked closely with STAR SST Team on the GOES-R AWG and JPSS CAL/VAL programs.

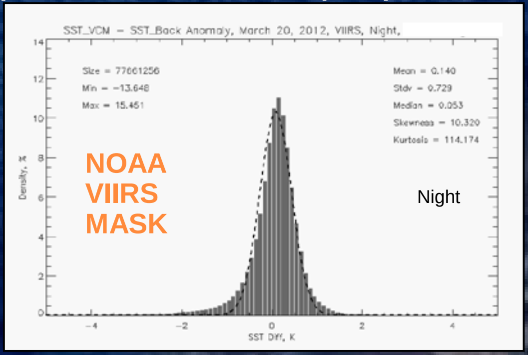
- We have developed tools to match the SQUAM (SST Quality Monitoring Analysis) results and will use these to monitor our cloud mask's performance.

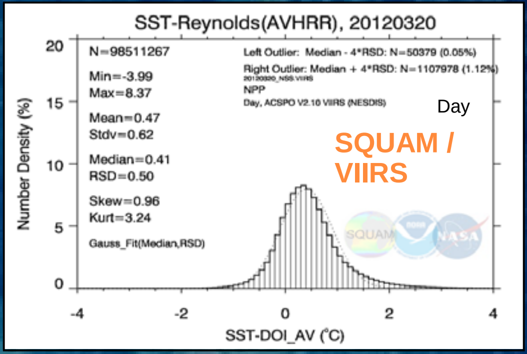
- SST Team will always do additional filtering that is not appropriate for a multi-purpose cloud mask.

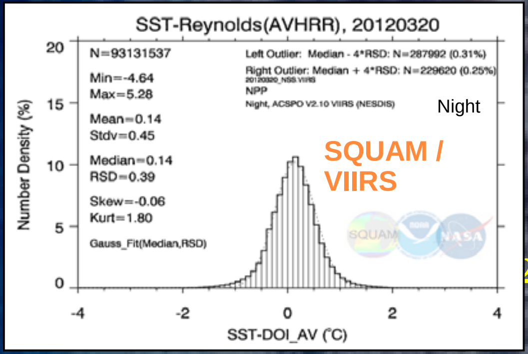
Example Background SST Field











Pre-Planned Improvements

- Use CrIS information.
- Use VIIRS DNB (JPSS RR funded)
- Employ selected two-dimensional classifiers

Clear Sky Mask Risks and Actions

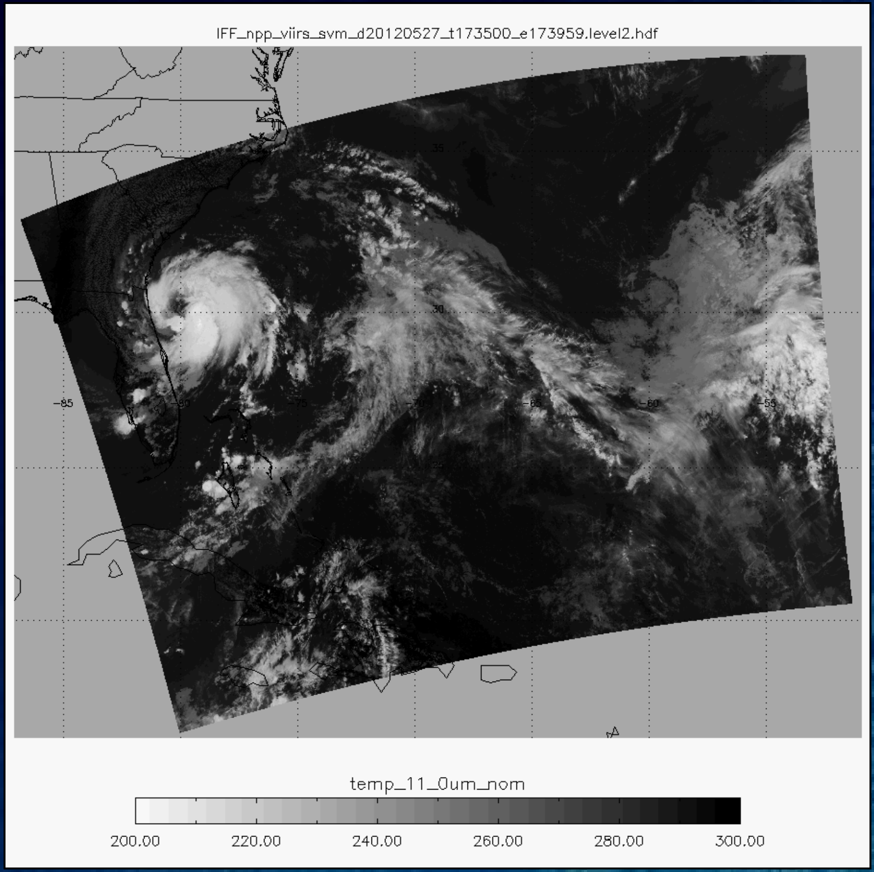
- None

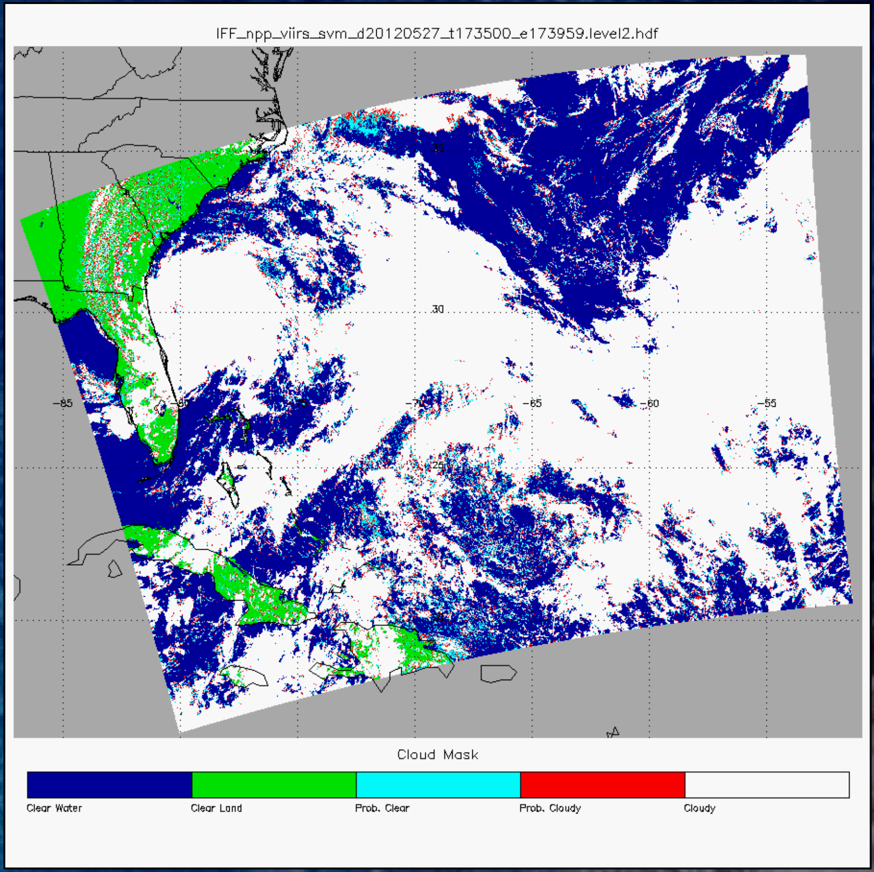
References

- Heidinger, Andrew K.; Evan, Amato T.; Foster, Michael J. and Walther, Andi. **A naive Bayesian cloud-detection scheme derived from CALIPSO and applied within PATMOS-x.** Journal of Applied Meteorology and Climatology, Volume 51, Issue 6, 2012, 1129–1144
- Schreiner, Anthony J.; Ackerman, Steven A.; Baum, Bryan A. and Heidinger, Andrew K.. **A multispectral technique for detecting low-level cloudiness near sunrise**. Journal of Atmospheric and Oceanic Technology, Volume 24, Issue 10, 2007, pp.1800-1810.
- Thomas, Sarah M.; Heidinger, Andrew K. and Pavolonis, Michael J.. **Comparison of NOAA's operational AVHRR-derived cloud amount to other satellite-derived cloud climatologies**. Journal of Climate, Volume 17, Issue 24, 2004, pp.4805-4822.
- Heidinger, Andrew K.; Frey, Richard and Pavolonis, Michael. **Relative merits of the 1.6 and 3.75 micron channels of the AVHRR/3 for cloud detection**. Canadian Journal of Remote Sensing, Volume 30, Issue 2, 2004, pp.182-194.

Algorithm Output: Example 4-level Mask

Example Output of the Cloud Mask (right) with accompanying 11 micron Image (left)
TC Beryl, May 27, 2012





Outline

- Introduction
- Requirements
- Operations Concept
- Cloud Mask
- Cloud Phase
- Cloud Height
- NCOMP
- Software Architecture and Interfaces
- Detailed Design
- Algorithm Package
- Quality Assurance
- Risks and Actions Summary
- Summary and Conclusions

Algorithm Theoretical Basis
Cloud Type and Cloud-top Phase

Presented by

Michael Pavolonis
Cloud Application Team
STAR

Algorithm Theoretical Basis

- Purpose: Provide product developers, reviewers and users with a theoretical description (scientific and mathematical) of the JPSS Cloud Top Phase and Cloud Type algorithm

- Will be documented in the ATBD of the JPSS Cloud Top Phase and Cloud Type products

CDR Requirements
Cloud Top Phase

Name	User & Priority	Geographic Coverage	Vertical Res.	Horiz. Res.	Msmnt. Range	Msmnt. Accuracy	Data Latency	Refresh Rate	Timeliness
Cloud Top Phase	JPSS	Global	Cloud Top	0.75 km	Liquid/solid/ super cooled/mixed (5 categories)	80% correct classification	30 minutes after granule is available	at least 90% coverage of the globe every 12 hours (monthly average)	≤ 3 hours

CDR Requirements Cloud Type

Name	User & Priority	Geographic Coverage	Vertical Res.	Horiz. Res.	Msmnt. Range	Msmnt. Accuracy	Data Latency	Refresh Rate	Timeliness
Cloud Type	JPSS	Global	Cloud Top	0.75 km	7 categories	60% correct classification	30 minutes after granule is available	at least 90% coverage of the globe every 12 hours (monthly average)	≤ 3 hours

Algorithm Theoretical Basis

- First, lets define the cloud top phase and cloud type categories (per the Requirements Allocation Document)…

Algorithm Output (cloud type)

Category	Description	Value
Clear	Clear cloud mask output	0
Spare	Spare category	1
Liquid Water	Liquid water with cloud top temperature > 273 K	2
Supercooled Water	Liquid water with cloud top temperature < 273 K	3
Mixed Phase	Mainly a water signal, but may contain some ice	4
Thick Ice	Ice cloud that is opaque in the infrared	5
Thin Ice	An approximate optical depth threshold is used to distinguish between thin and thick ice clouds	6
Multilayered Ice	Mainly ice cloud overlapping a lower, distinct, cloud layer	7

Algorithm Output (cloud phase)

Category	Description	Value
Clear	Clear cloud mask output	0
Liquid Water	Cloud top temperature > 273 K	1
Supercooled Water	Cloud top temperature < 273 K	2
Mixed Phase	Mainly a water signal, but may contain some ice	3
Ice	All ice phased clouds (cloud top)	4

CDR Algorithm

- The cloud phase/type algorithm developed for GOES-R will be slightly modified to accommodate the VIIRS.
- More specifically, the algorithm will have to function without infrared absorption channels (water vapor channels) and certain thresholds will need to be tuned to the VIIRS instrument.
- In addition, the software will be modified so that the approach can be applied to nearly any sensor (using the same code), while still taking full advantage of each sensor's capabilities.

Algorithm Objectives

- Meet the requirements for cloud-top phase and cloud type.
- Provide the cloud phase and multi-layered cloud flag needed by the cloud top height and optical properties algorithms.
- The cloud phase product is derived from the cloud type output. Thus, regardless of product priorities, the cloud type product will always be produced.
- Provide needed performance information to allow for proper use of our products.

Cloud Phase/Type Sensor Inputs

VIIRS Band	Nominal Wavelength Range (µm)	Nominal Central Wavelength (µm)	Nominal sub-satellite IGFOV (km)	Sample Use
M1	0.402-0.422	0.412	0.75	
M2	0.436-0.454	0.445	0.75	
M3	0.478-0.498	0.488	0.75	
M4	0.545-0.565	0.55	0.75	
I1	0.600-0.680	0.64	0.375	
M5	0.662-0.682	0.672	0.75	
M6	0.739-0.754	0.746	0.75	
I2	0.846-0.885	0.865	0.375	
M7	0.846-0.885	0.865	0.75	
M8	1.230-1.250	1.240	0.75	
M9	1.371-1.386	1.378	0.75	
I3	1.580-1.640	1.61	0.375	
M10	1.580-1.640	1.61	0.75	
M11	2.225-2.275	2.25	0.75	
I4	3.550-3.930	3.74	0.375	
M12	3.660-3.840	3.7	0.75	
M13	3.973-4.128	4.05	0.75	
M14	8.400-8.700	8.55	0.75	Cloud Type/Phase
M15	10.263-11.263	10.763	0.75	Cloud Type/Phase
I5	10.500-12.400	11.45	0.375	
M16	11.538-12.488	12.013	0.75	Cloud Type/Phase
DNB	0.5–0.9	0.7	0.75	

Current Input   Expected Added Input   Possible Added Input

Cloud Phase/Type Input Sensor Input Details

JPSS VIIRS Cloud Phase/Type requires for each pixel:

- Calibrated/Navigated VIIRS brightness temperatures/radiances/reflectances
- Spectral response information
- Solar-view geometry (satellite zenith, relative azimuth, solar zenith)
- Geolocation (latitude, longitude)

Possible Added Input

Name	Type	Description	Dimension
M5 reflectance	input	Calibrated VIIRS level 1b reflectance for M5	Scan grid (xsize, ysize)
M12 reflectance	input	Calibrated VIIRS level 1b reflectance for M12	Scan grid (xsize, ysize)
M12 brightness temp/radiance	input	Calibrated VIIRS level 1b brightness temperature and radiance for M12	Scan grid (xsize, ysize)
M14 brightness temp/ radiance	input	Calibrated VIIRS level 1b brightness temperature and radiance for M14	Scan grid (xsize, ysize)
M15 brightness temp/ radiance	input	Calibrated VIIRS level 1b brightness temperature and radiance for M15	Scan grid (xsize, ysize)
M16 brightness temp/ radiance	input	Calibrated VIIRS level 1b brightness temperature and radiance for M16	Scan grid (xsize, ysize)

Cloud Phase/Type Input
Sensor Input Details

Name	Type	Description	Dimension
Latitude	Input	VIIRS Latitude	Scan grid (xsize, ysize)
Longitude	Input	VIIRS Longitude	Scan grid (xsize, ysize)
Glint angle	Input	Glint Zenith angle	Scan grid (xsize, ysize)
Solar geometry	input	VIIRS solar zenith angle	Scan grid (xsize, ysize)
View angles	input	VIIRS view zenith and relative azimuth angles	Scan grid (xsize, ysize)
QC flags	input	VIIRS quality control flags with level 1b data	Scan grid (xsize, ysize)

Cloud Phase/Type Input Ancillary Input Details

- Non-VIIRS Static Data

Name	Type	Description	Dimension
Snow Mask	input	Daily global snow and ice mask available at a horizontal resolution of 4km in the northern hemisphere (IMS) and 25km in the southern (SSMI)	4 km resolution
Land Mask	input	Derived from global land cover land types	Scan grid (xsize, ysize)
Coast Mask	input	Created from global 1-km land/water mask used for collection 5. Differentiates coast at distances from 1 km – 10 km.	1 km resolution
Digital elevation	input	NGDC-GLOBE global digital elevation model with a horizontal resolution of 1km	1 km resolution

Cloud Phase/Type Algorithm Input Ancillary Input Details

- Non-VIIRS Dynamic Data

Name	Type	Description	Dimension
Clear-sky TOA radiances	Input	TOA clear sky radiances for VIIRS channels M14, M15, and M16 derived from CRTM	Scan grid (xsize, ysize)
Clear-sky radiance profiles	Input	Clear sky radiance profiles for VIIRS channels M14, M15, and M16 derived from CRTM	NWP grid (xsize, ysize, ivza, nprof)
Atmospheric transmittance profiles	Input	Atmospheric transmittance profiles for VIIRS channels M14, M15, and M16 derived from CRTM	NWP grid (xsize, ysize, ivza, nprof)
NWP pressure, temperature, and height profiles	Input	Profiles of NWP temperature, pressure and height for each cell.	NWP grid (xsize, ysize)
NWP/imager co-location	Input	X and Y cell number for each latitude and longitude	Scan grid (xsize, ysize)
NWP surface and troposphere levels	Input	NWP level for surface and troposphere for each pixel.	NWP grid (xsize, ysize)

Cloud Phase/Type Algorithm Input Ancillary Input Details

- Non-VIIRS Dynamic Data

Name	Type	Description	Dimension
NWP surface temperature	Input	Temperature of surface from NWP for each cell.	NWP grid (xsize, ysize)

Cloud Phase/Type Algorithm Product Precedence Details

- Products required to run algorithm

Name	Type	Description	Dimension
Cloud Mask	Input	VIIRS Cloud Mask	Scan grid (xsize, ysize)

Algorithm Output (cloud type)

Category	Description	Value
Clear	Clear cloud mask output	0
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Algorithm Output (cloud phase)

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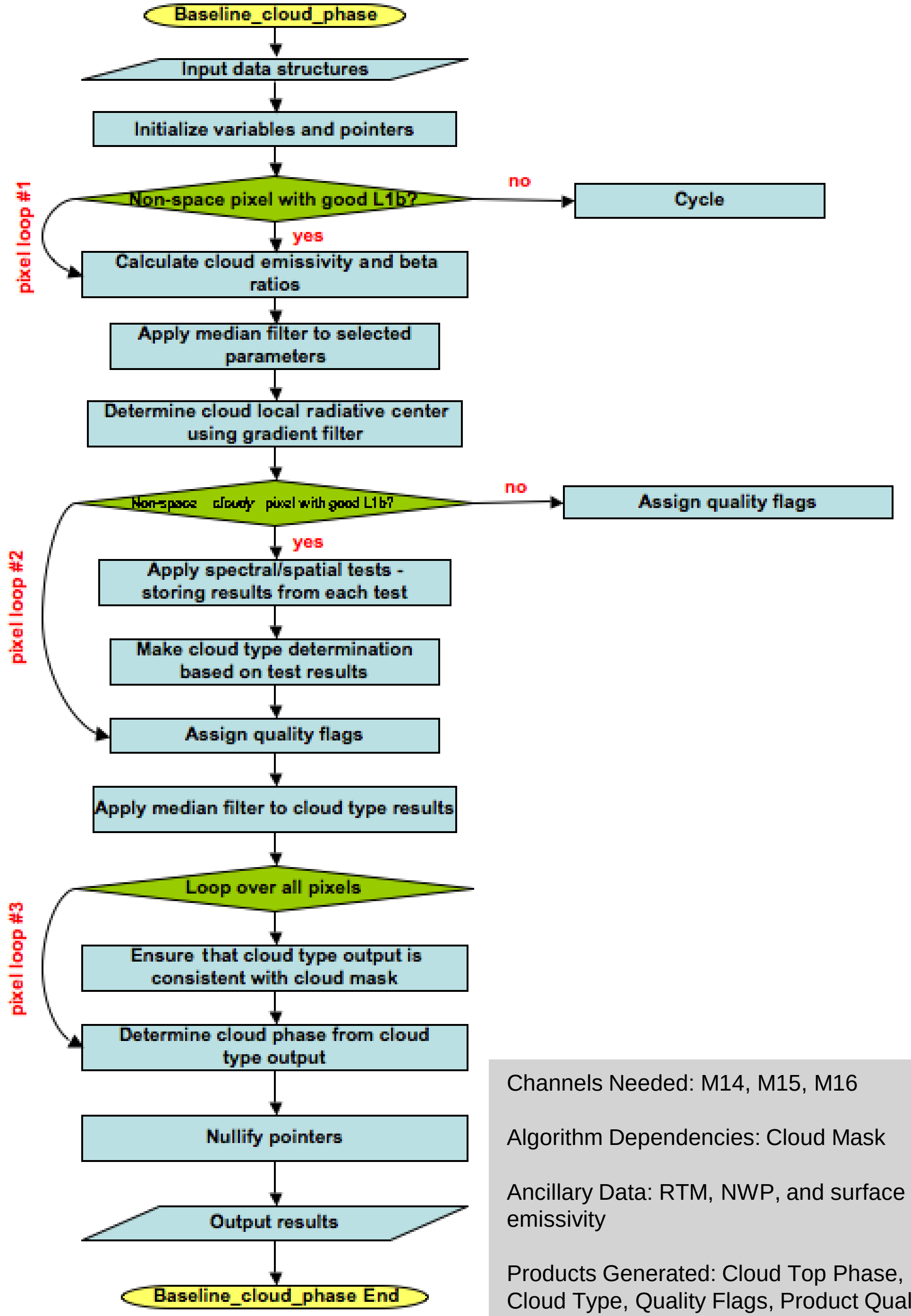
High-level Algorithm Flowchart

1). Compute radiative parameters relevant to cloud type

2). Utilize spectral tests to determine cloud type

3). Remove “noise” and determine cloud phase from cloud type



Channels Needed: M14, M15, M16

Algorithm Dependencies: Cloud Mask

Ancillary Data: RTM, NWP, and surface emissivity

Products Generated: Cloud Top Phase, Cloud Type, Quality Flags, Product Quality Information, and Meta Data

High-level Algorithm Flowchart

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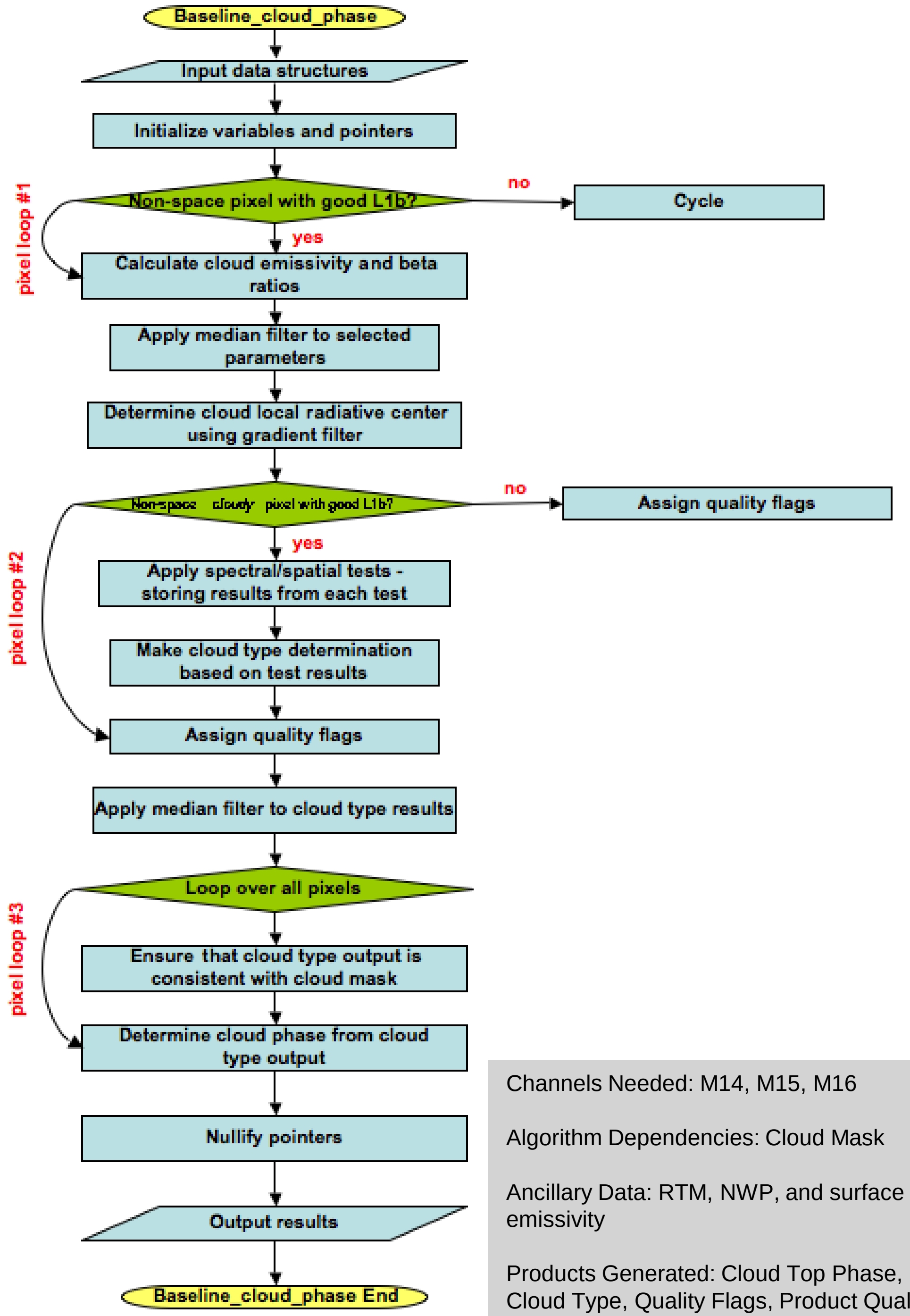


Channels Needed: M14, M15, M16

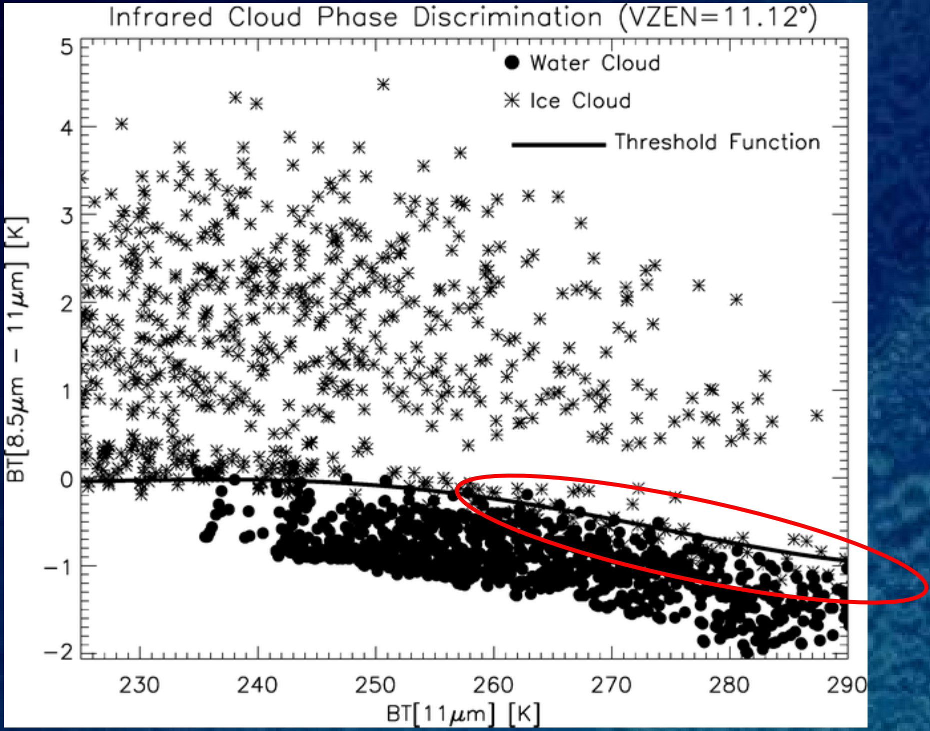
Algorithm Dependencies: Cloud Mask

Ancillary Data: RTM, NWP, and surface emissivity

Products Generated: Cloud Top Phase, Cloud Type, Quality Flags, Product Quality Information, and Meta Data

Physical Description

Traditional BT Methods



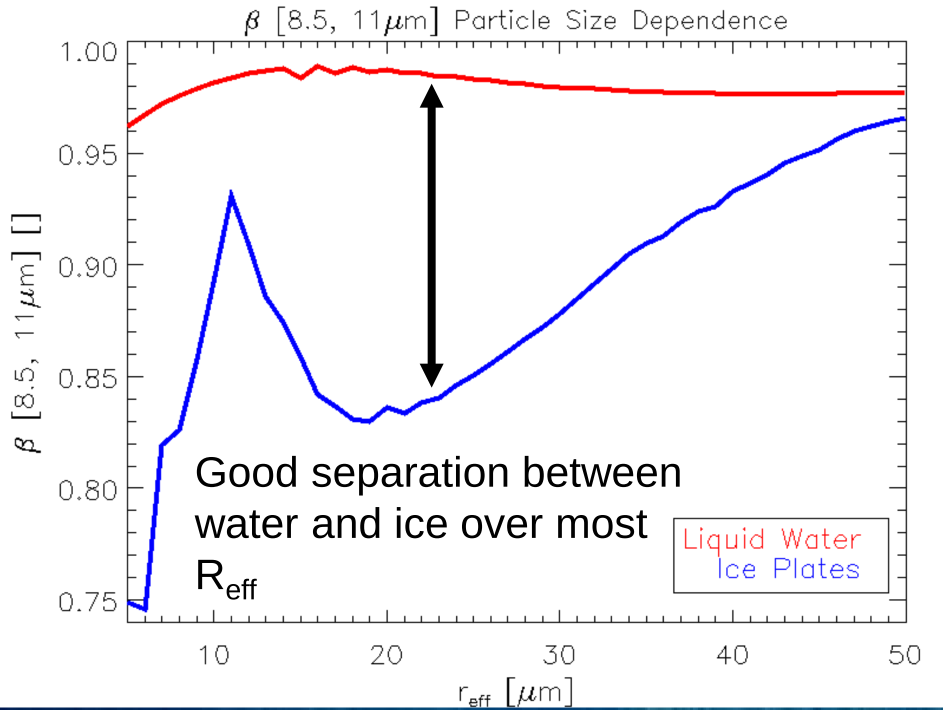
Sensitive to:

1. *Composition*
2. *Particle size*
3. *Particle shape*
4. *Optical depth*
5. *Cloud height*
6. *Surface leaving radiance*
7. *Atmospheric water vapor and temperature*

From Pavolonis et al., 2005, JAM

Physical Description

The goal is to isolate the cloud microphysical signal in the measured radiances such that it can be directly related to particle distributions via the single scatter properties.



Cloud phase relationship derived from single scatter properties

Sensitive to:

1. *Composition*
2. *Particle size*
3. *Particle shape*

See Pavolonis, 2010, JAMC

Physical Description

The advent of more accurate fast RT models, higher quality NWP data, surface emissivity databases, and faster computers allows us to calculate a reasonable estimate of the clear sky radiance and transmittance for each pixel. Thus, a given measured IR radiance can be converted to an effective emissivity as follows:

$$\varepsilon(\lambda) = \frac{R_{obs}(\lambda) - R_{clr}(\lambda)}{[R_{ac}(\lambda) + T_{ac}(\lambda)B(\lambda, T_{eff})] - R_{clr}(\lambda)}$$

- *No attempt is made to separate the effects of cloud scattering and emission, hence this is an effective emissivity.*
- *Assumes a completely cloudy FOV*
- *Dependence on T_{eff} will be revisited later*

Physical Description

After Van de Hulst (1980) and Parol et al. (1991)…

$$\beta_{observed} = \frac{\ln[1.0 - \varepsilon(\lambda_1)]}{\ln[1.0 - \varepsilon(\lambda_2)]}$$

Spectral ratio of effective absorption optical depth

Physical Description

After Van de Hulst (1980) and Parol et al. (1991)…

$$\beta_{observed} = \frac{\ln[1.0 - \varepsilon(\lambda_1)]}{\ln[1.0 - \varepsilon(\lambda_2)]}$$

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

Physical Description

After Van de Hulst (1980) and Parol et al. (1991)…

$$\beta_{observed} = \frac{\ln[1.0 - \varepsilon(\lambda_1)]}{\ln[1.0 - \varepsilon(\lambda_2)]}$$

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

Physical Description

$$\varepsilon(\lambda) = \frac{R_{obs}(\lambda) - R_{clr}(\lambda)}{[R_{ac}(\lambda) + T_{ac}(\lambda)B(\lambda, T_{eff})] - R_{clr}(\lambda)}$$

$$\beta_{observed} = \frac{\ln[1.0 - \varepsilon(\lambda_1)]}{\ln[1.0 - \varepsilon(\lambda_2)]}$$

•In the absence of high quality independent cloud height information (e.g. lidar), T_{eff} and the above cloud terms are considered to be unknown (cloud type information is needed to determine cloud top height from VIIRS).

•Pavolonis (2010) showed that even in the absence of cloud height information robust information on cloud type can be extracted from $\beta_{observed}$ when infrared window channels are used in the ratio

Physical Description

As described in Pavolonis (2010) and the GOES-R Cloud Phase ATBD, four different cloud vertical boundary assumptions are employed by the cloud type/phase algorithm when computing the cloud emissivity:

1). Single layer tropopause

$$\varepsilon(\lambda) = \frac{R_{obs}(\lambda) - R_{clr}(\lambda)}{[R_{ac}(\lambda) + T_{ac}(\lambda)B(\lambda, T_{eff})] - R_{clr}(\lambda)}$$

T_{eff} and the above cloud (ac) terms are chosen consistent with a cloud at the tropopause

Physical Description

As described in Pavolonis (2010) and the GOES-R Cloud Phase ATBD, four different cloud vertical boundary assumptions are employed by the cloud type/phase algorithm when computing the cloud emissivity:

1). Single layer tropopause

2). Multilayer tropopause

$$\varepsilon(\lambda) = \frac{R_{obs}(\lambda) - R_{clr}(\lambda)}{[R_{ac}(\lambda) + T_{ac}(\lambda)B(\lambda, T_{eff})] - R_{clr}(\lambda)}$$

T_{eff} and the above cloud (ac) terms are chosen consistent with a cloud at the tropopause

The clear sky radiance is replaced with the radiance originating from an elevated "black" surface, with the aim of simulating the impact of an underlying low cloud layer

Physical Description

As described in Pavolonis (2010) and the GOES-R Cloud Phase ATBD, four different cloud vertical boundary assumptions are employed by the cloud type/phase algorithm when computing the cloud emissivity:

1). Single layer tropopause

2). Multilayer tropopause

3). Single layer opaque cloud

$$\varepsilon(\lambda) = \frac{R_{obs}(\lambda) - R_{clr}(\lambda)}{[R_{ac}(\lambda) + T_{ac}(\lambda)B(\lambda, T_{eff})] - R_{clr}(\lambda)}$$

T_{eff} and the above cloud (ac) terms are chosen in such a way that the resulting cloud emissvities are large (> 0.95)

Physical Description

As described in Pavolonis (2010) and the GOES-R Cloud Phase ATBD, four different cloud vertical boundary assumptions are employed by the cloud type/phase algorithm when computing the cloud emissivity:

1). Single layer tropopause

2). Multilayer tropopause

3). Single layer opaque cloud

4). Multilayer opaque cloud

$$\varepsilon(\lambda) = \frac{R_{obs}(\lambda) - R_{clr}(\lambda)}{[R_{ac}(\lambda) + T_{ac}(\lambda)B(\lambda, T_{eff})] - R_{clr}(\lambda)}$$

T_{eff} and the above cloud (ac) terms are chosen in such a way that the resulting cloud emissvities are large (> 0.95)

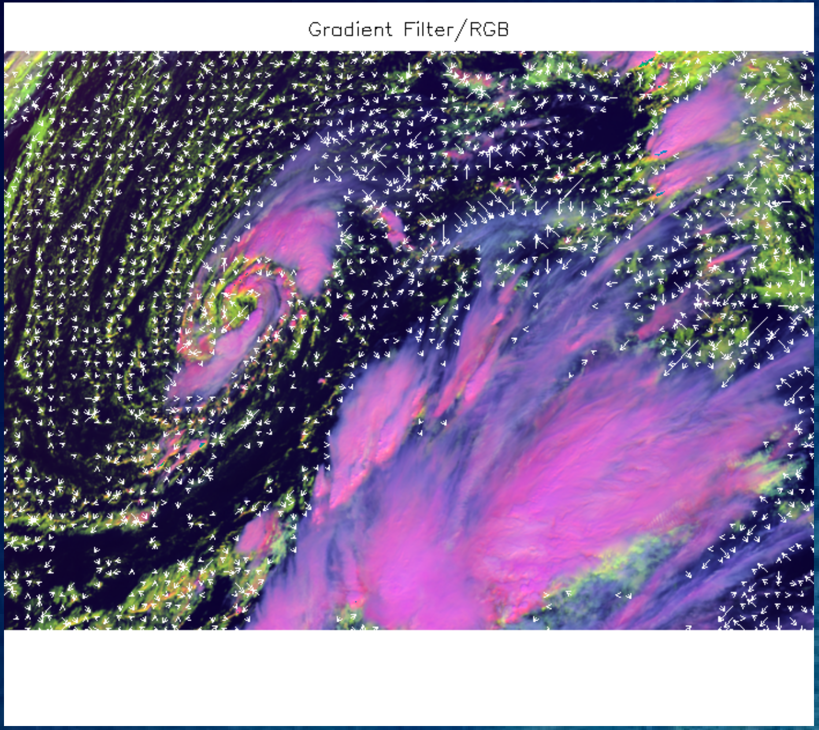
The clear sky radiance is replaced with the radiance originating from an elevated "black" surface, with the aim of simulating the impact of an underlying low cloud layer

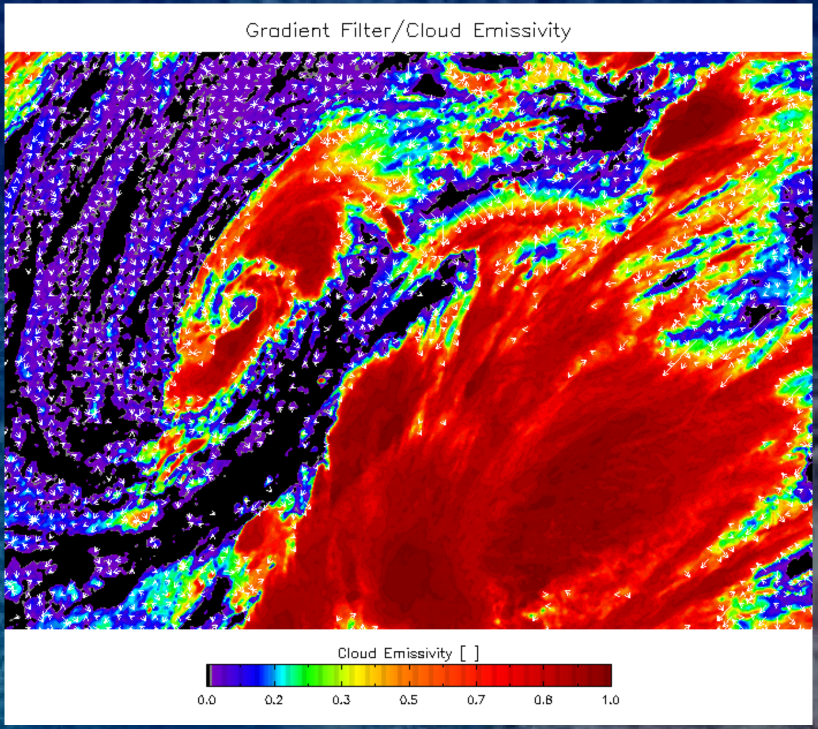
Mathematical Description

- A tool that we call the "gradient filter" is used to identify each pixel's "local radiative center (LRC)"
- Given a cloud emissivity image, the LRC for a given pixel is defined as the location in the direction of the gradient vector upon which the gradient reverses or when an emissivity value greater than some threshold is found.
- By definition, the gradient vector points from low to high values.
- This concept is illustrated graphically on the next few slides.

Mathematical Description

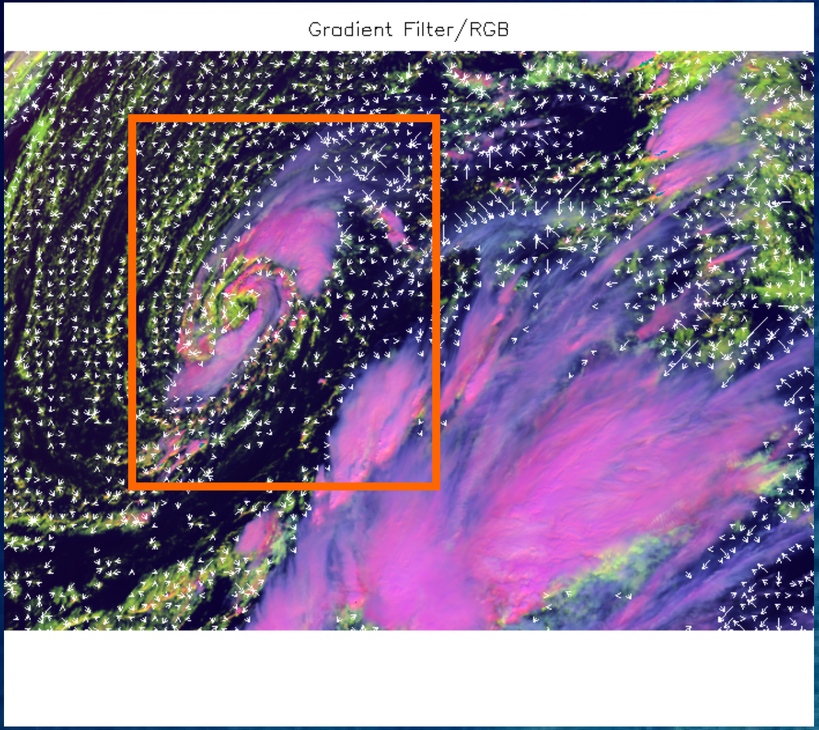
- The tail of each vector represents the pixel of interest.
- The head of each vector represents the LRC of the pixel of interest.

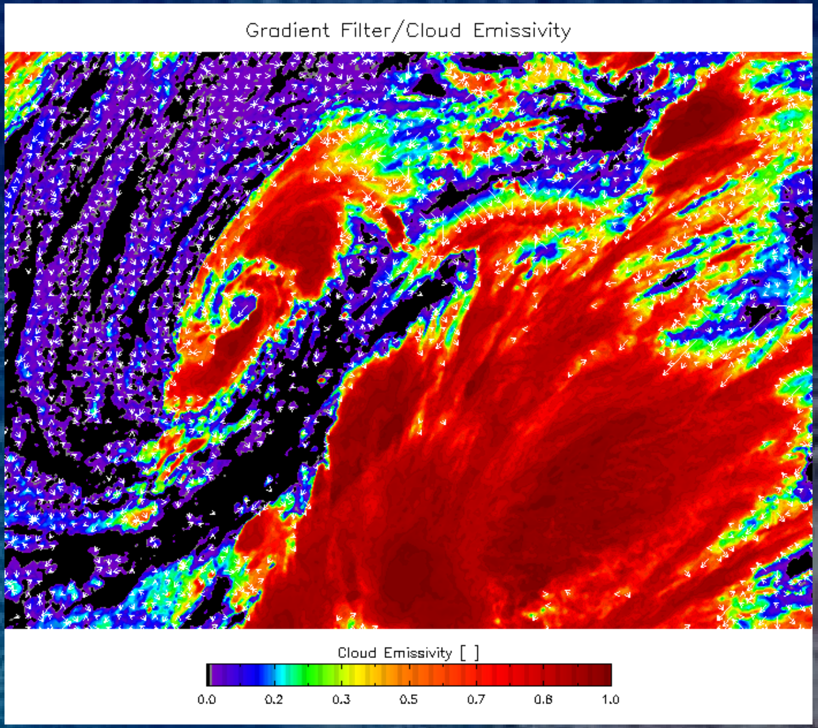




Mathematical Description

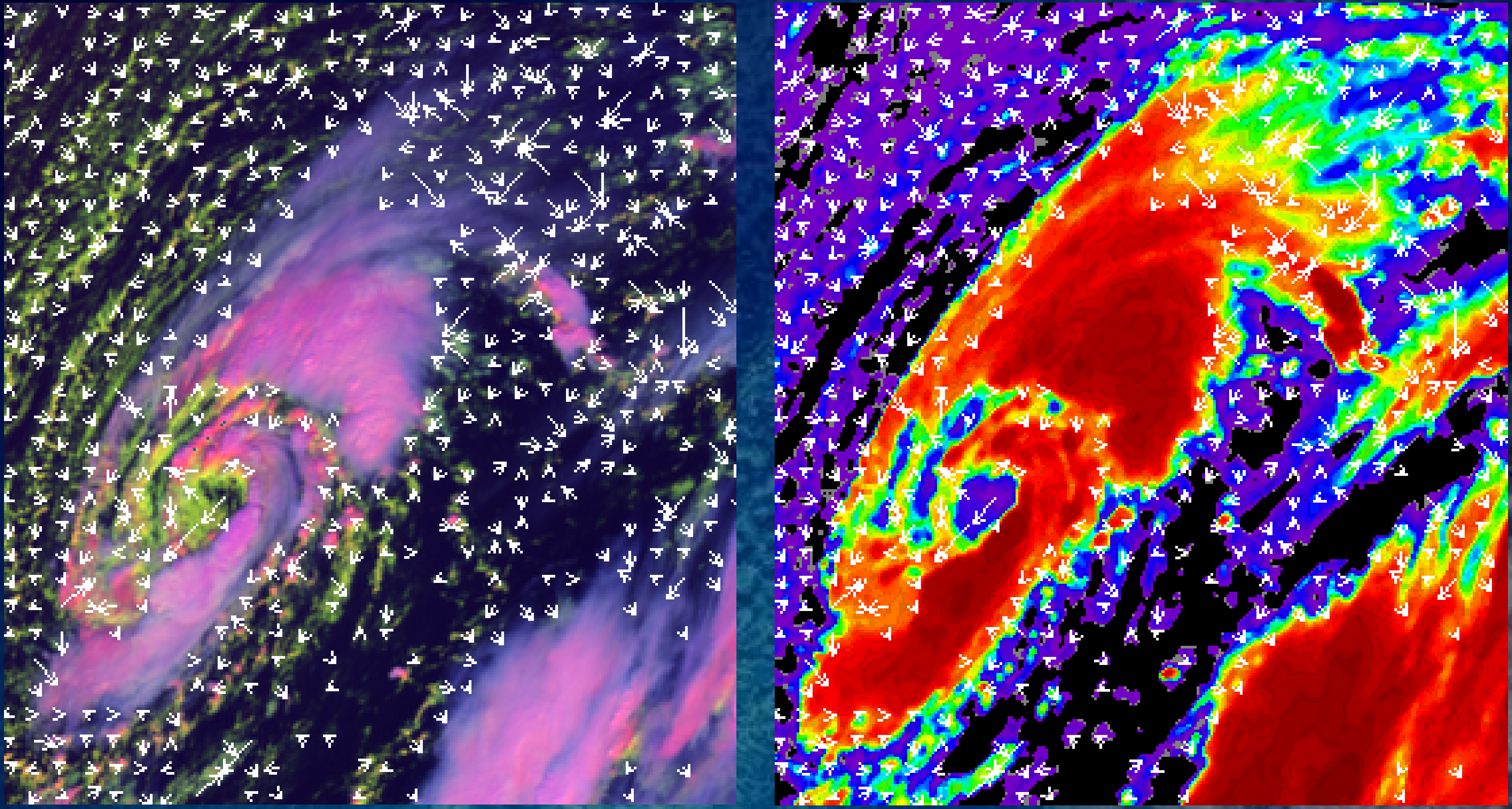
- The tail of each vector represents the pixel of interest.
- The head of each vector represents the LRC of the pixel of interest.





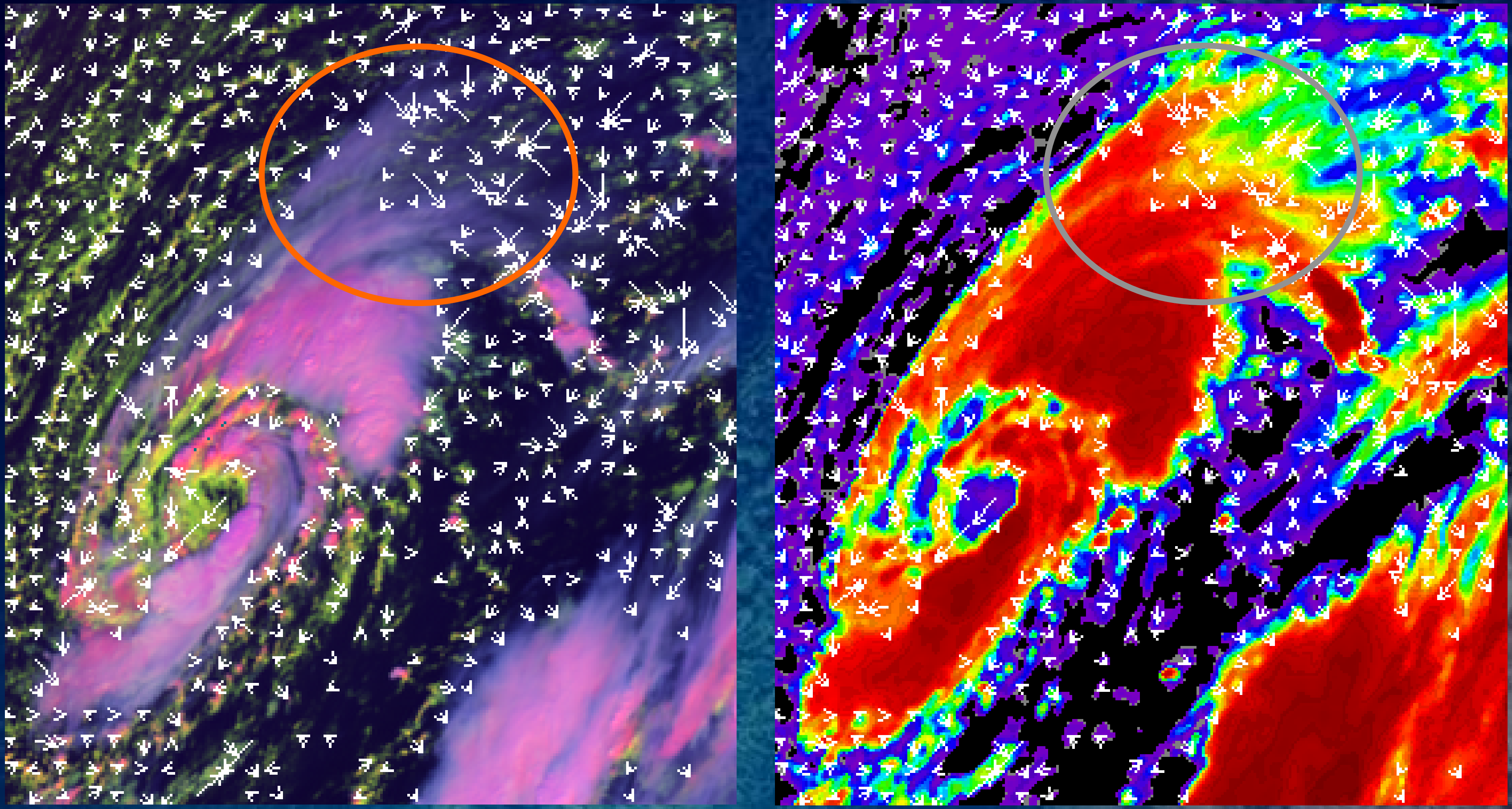
Mathematical Description

Zoomed in view of gradient vectors



Mathematical Description

Zoomed in view of gradient vectors

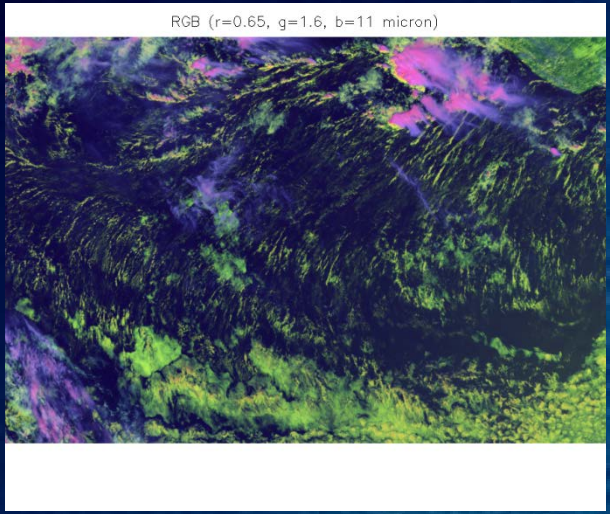


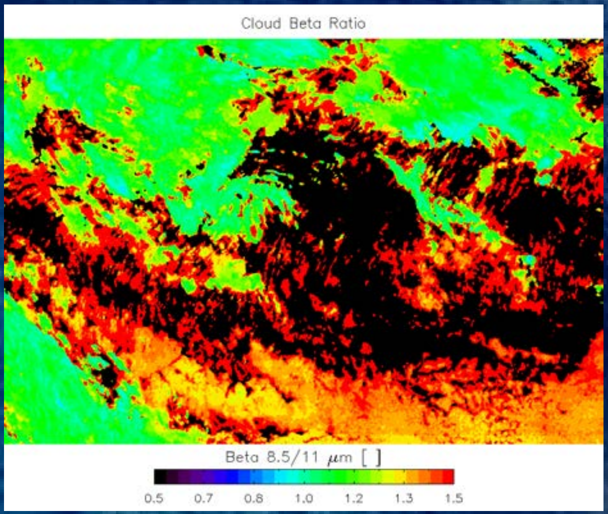
Mathematical Description

- The LRC is used to provide a second source of spectral information for each pixel.
- This second source of spectral information is most needed at cloud edges and in broken cloud decks where the cloud fraction is less than 1, but otherwise unknown.
- This second source is also needed to more accurately classify optically thin clouds, where the difference between the observed and calculated clear sky radiance is small.
- At least 200 scan lines are needed in memory in order to accurately determine the LRC.
- An upcoming figure illustrates the benefit of using LRC information.

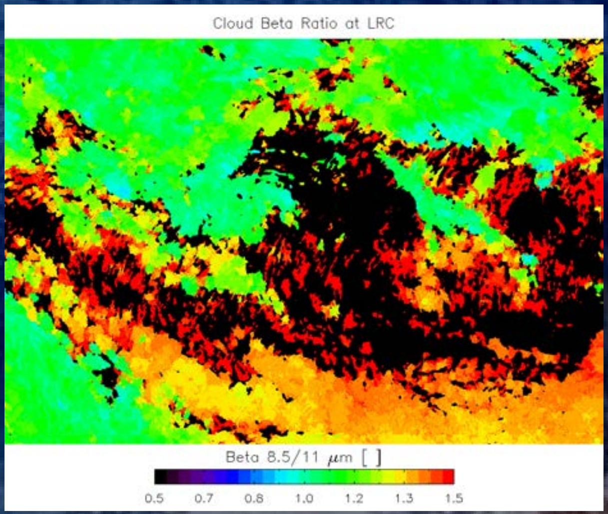
Physical Description

The β-ratio at the LRC is also examined in order to prevent misclassification when the observed minus clear sky radiance difference is small.





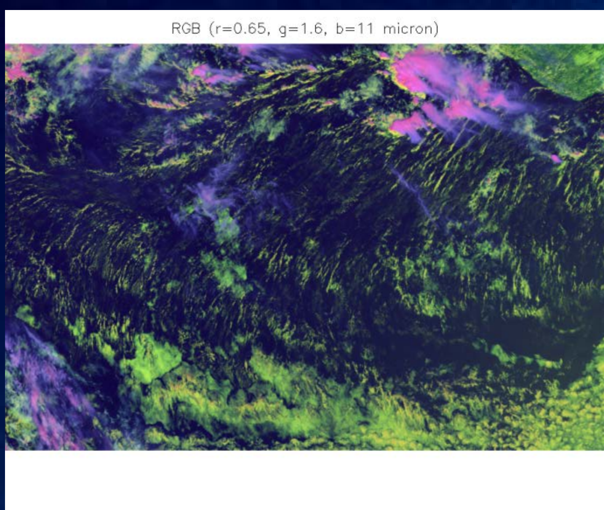
β(8.5,11)

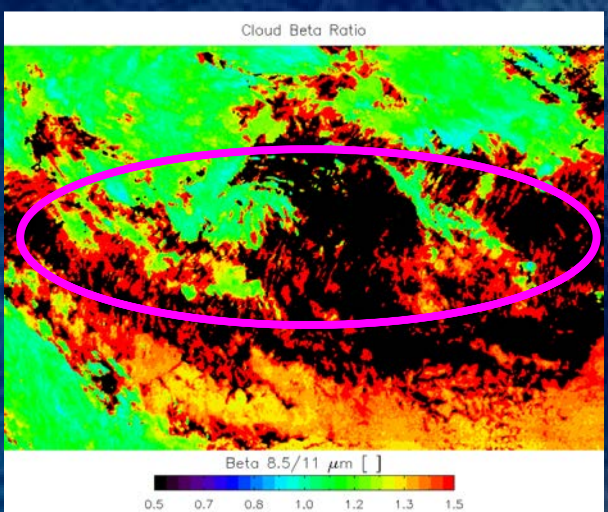


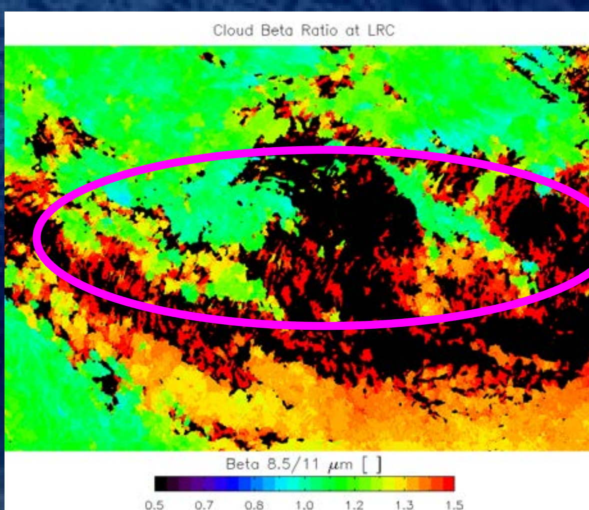
β(8.5,11) at LRC

Physical Description

The β-ratio at the LRC is also examined in order to prevent misclassification when the observed minus clear sky radiance difference is small.







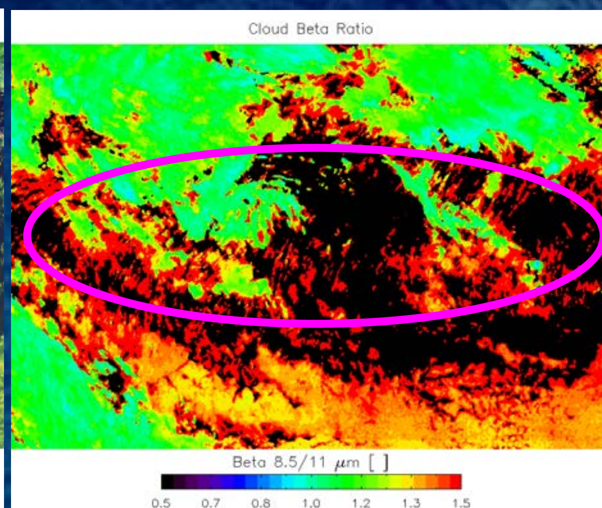
β(8.5,11)

β(8.5,11) at LRC

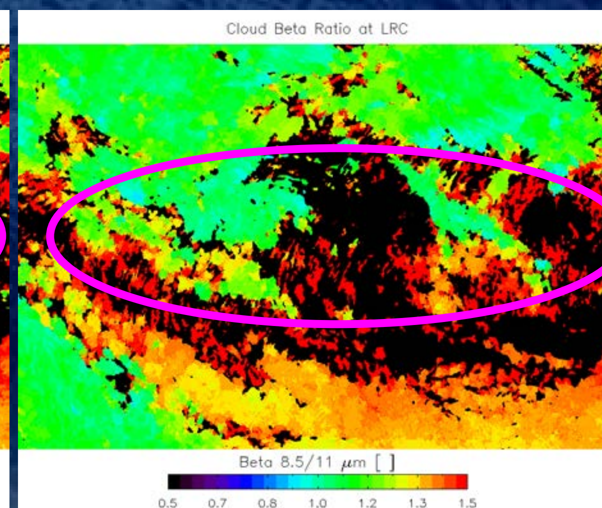
Physical Description

The β-ratio at the LRC is also examined in order to prevent misclassification when the observed minus clear sky radiance difference is small.

Note how the anomalously large β(8.5,11) at the cloud edges is eliminated when the β(8.5,11) at each pixel is replaced by the β(8.5,11) at the LRC



β(8.5,11)



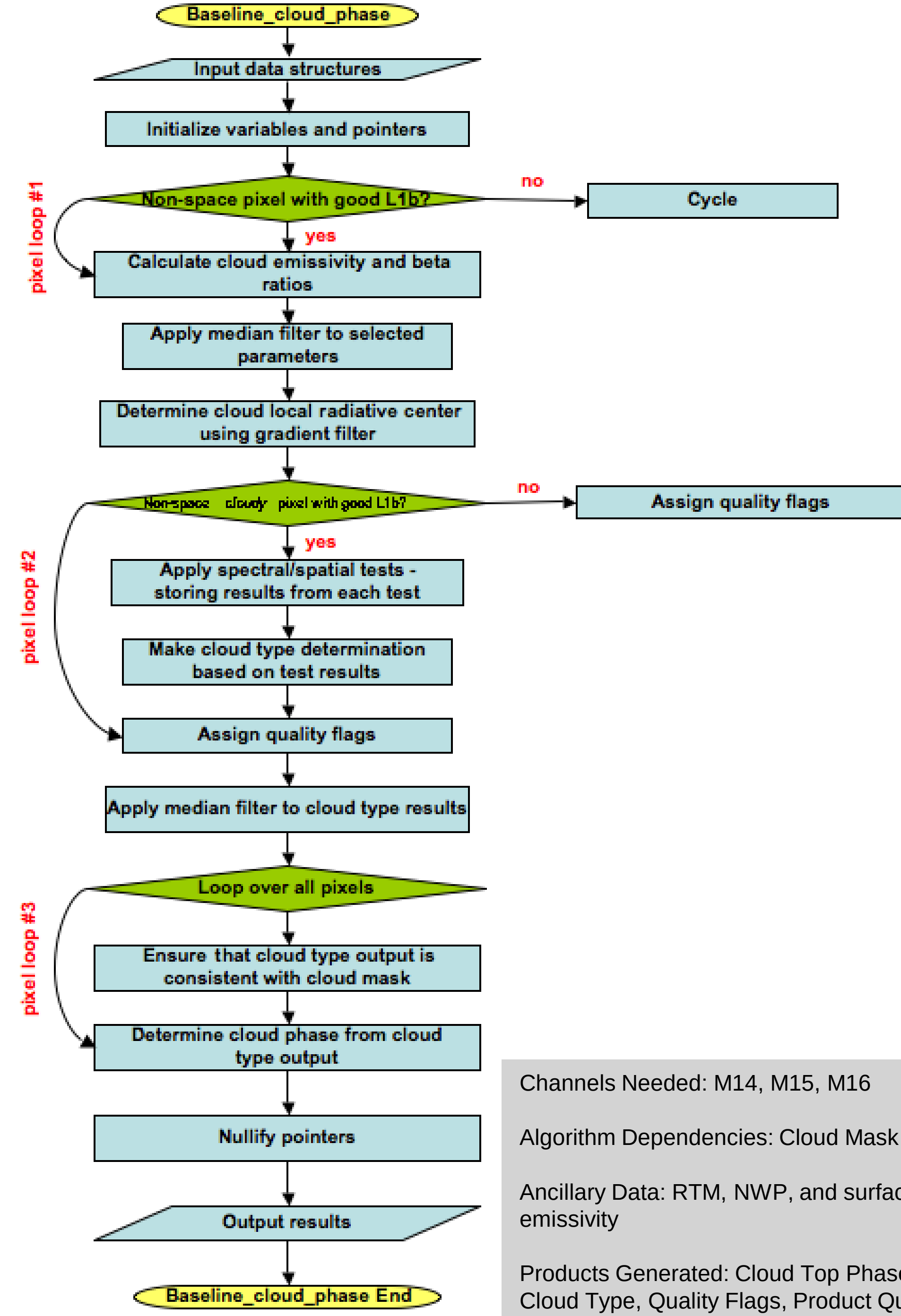
β(8.5,11) at LRC

High-level Algorithm Flowchart

1). Compute radiative parameters relevant to cloud type

2). Utilize spectral tests to determine cloud type

3). Remove "noise" and determine cloud phase from cloud type

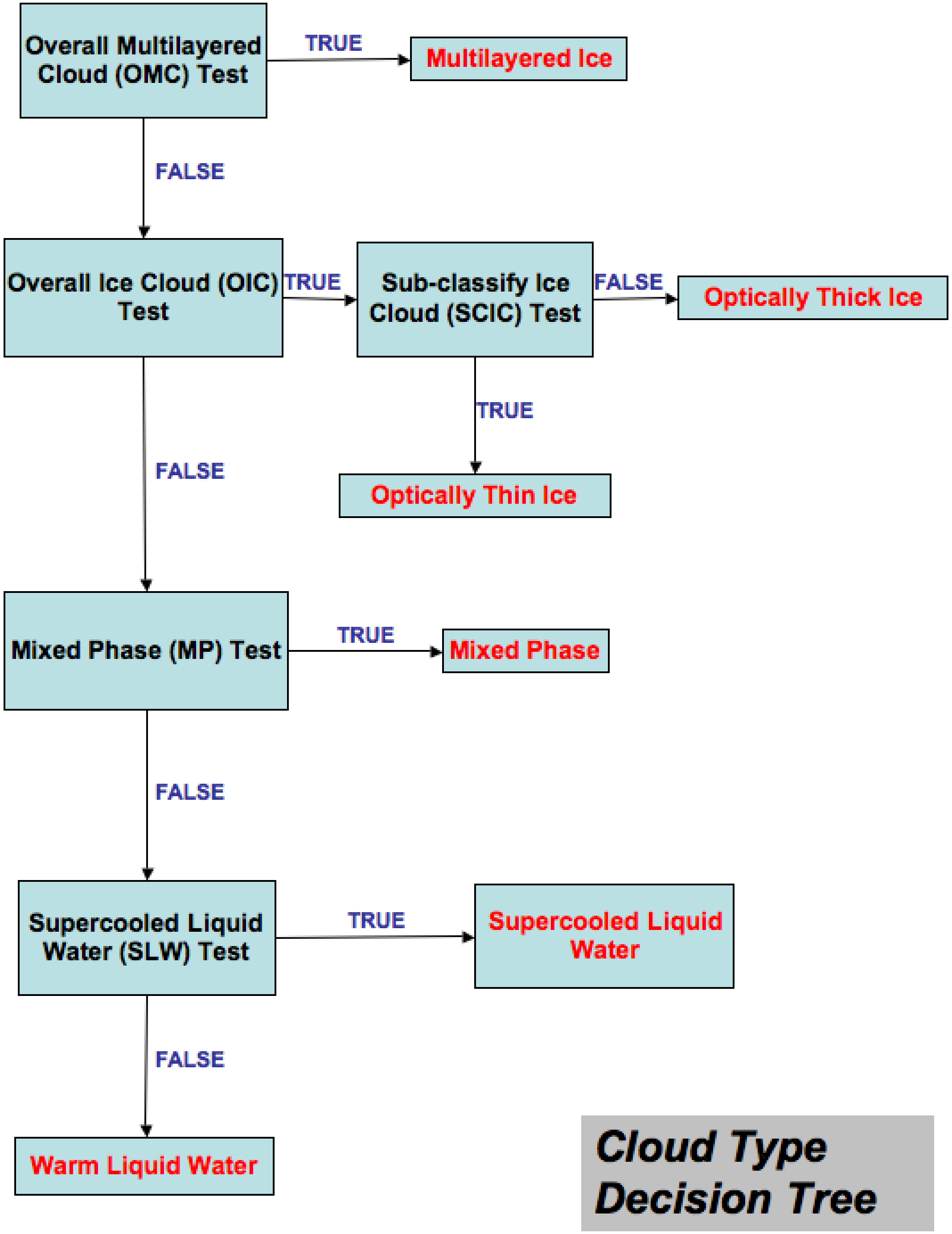


Channels Needed: M14, M15, M16

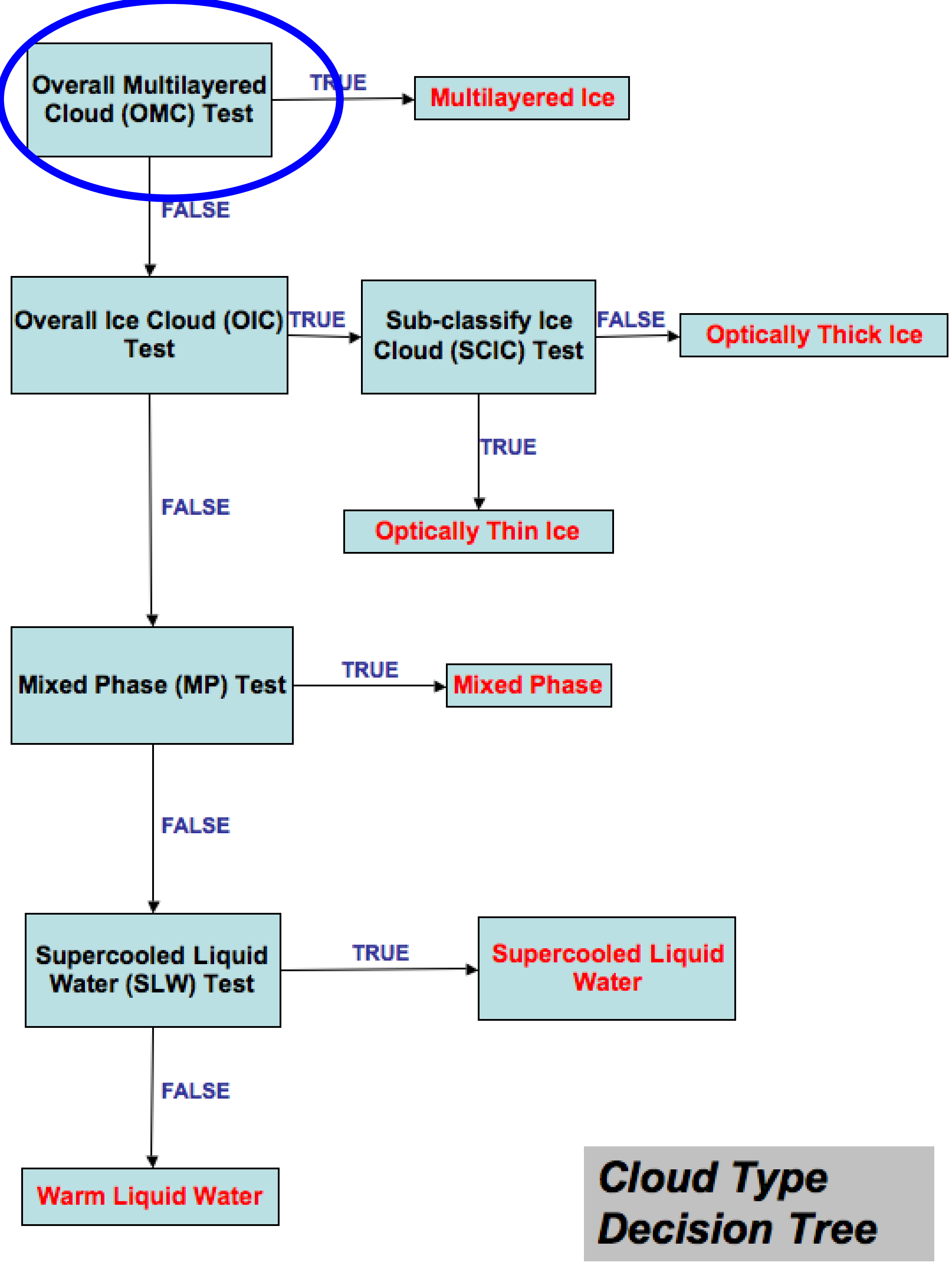
Algorithm Dependencies: Cloud Mask

Ancillary Data: RTM, NWP, and surface emissivity

Products Generated: Cloud Top Phase, Cloud Type, Quality Flags, Product Quality Information, and Meta Data



Physical Description

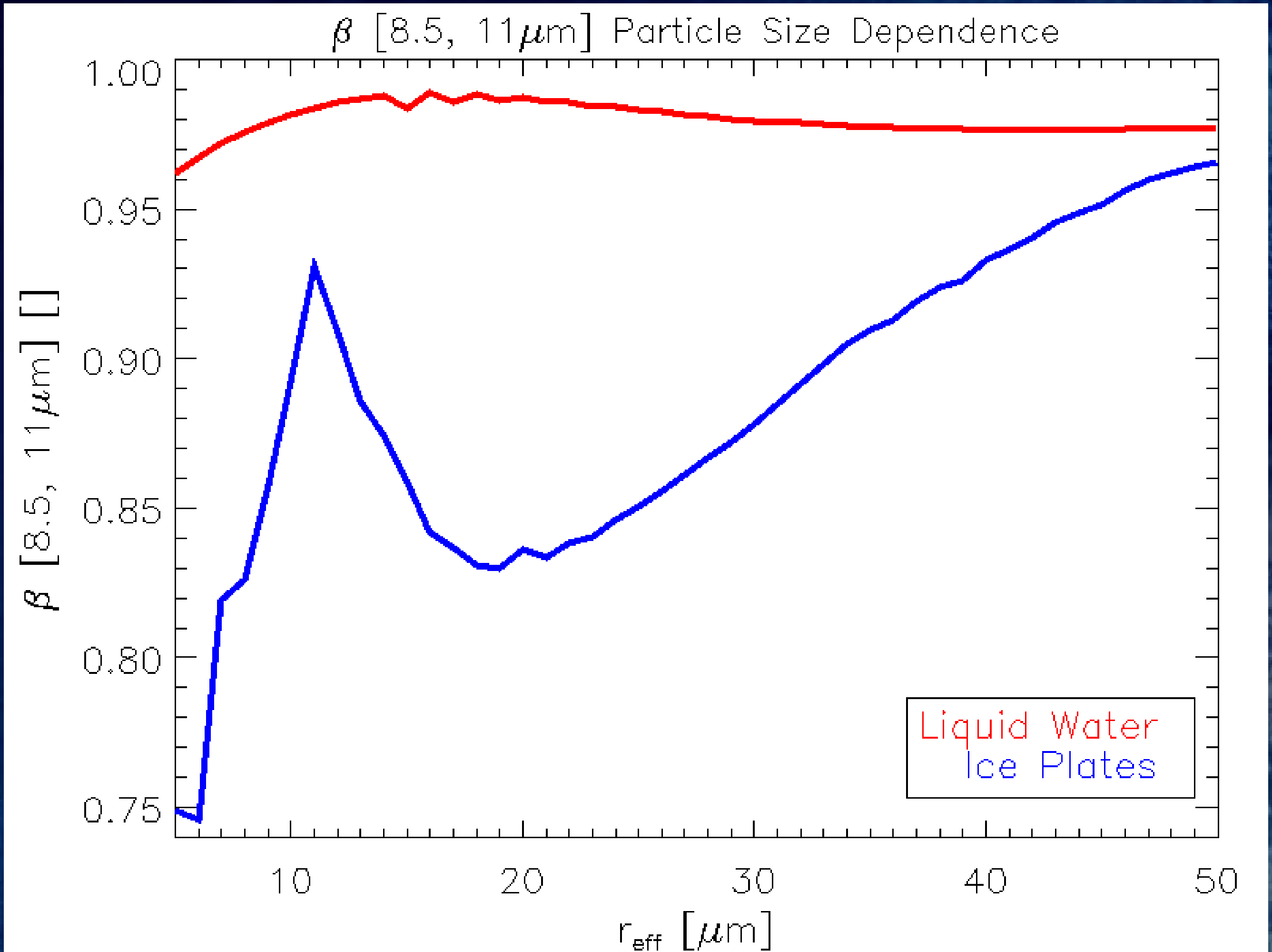


Physical Description

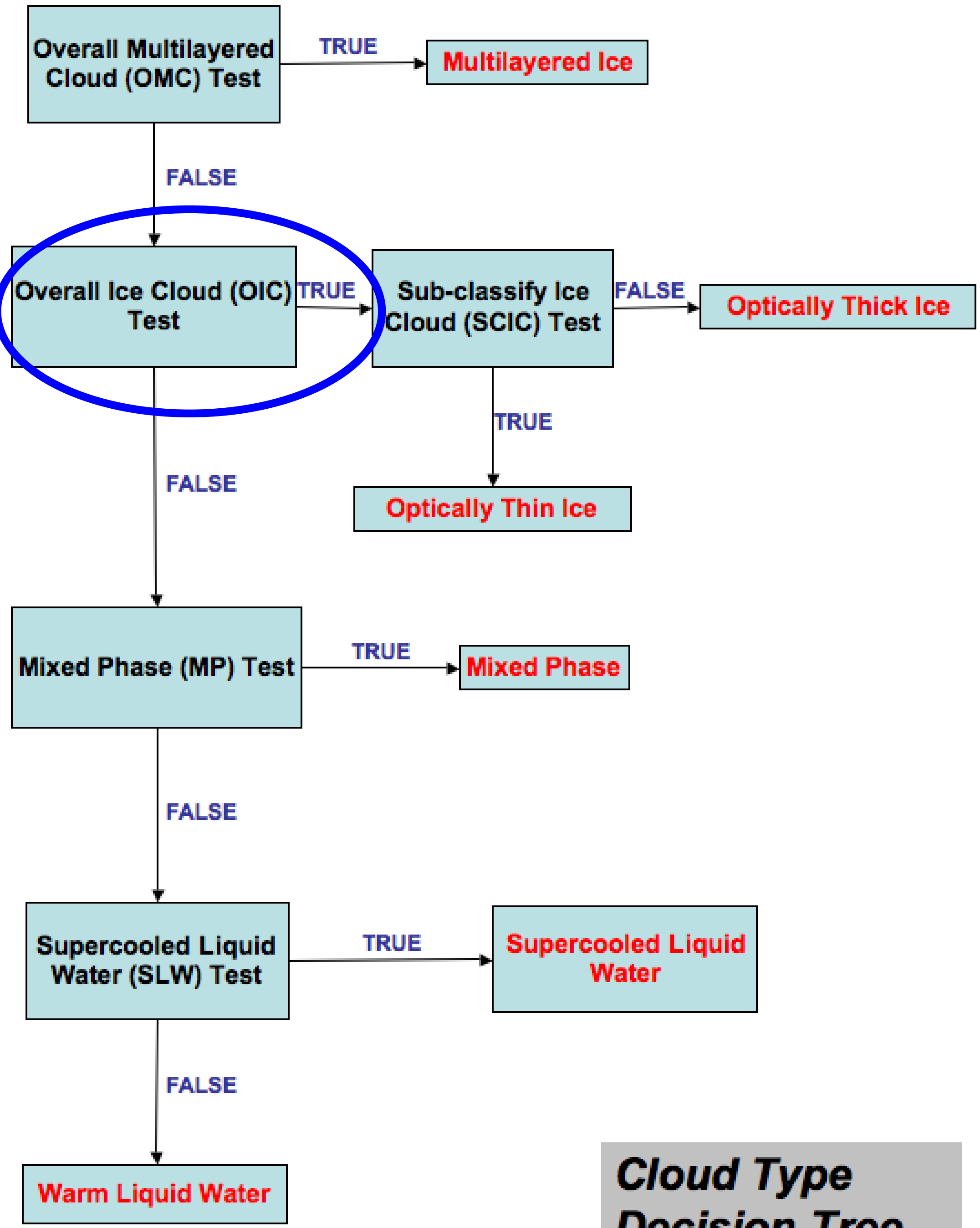
Goal: Determine when a semi-transparent ice cloud overlaps a lower cloud layer by identifying deviations from expected single layer cloud behavior in various β-ratios *(same logic as GOES-R, except tests that rely on infrared water vapor absorption channels are not used)*

Input:
ε_{mtropo}(11µm),
β_{stropo}(12/11µm),
β_{mtropo}(12/11µm),
$\beta_{mopaque}$(12/11µm),
β_{stropo}(8.5/11µm),
β_{mtropo}(8.5/11µm),
$\beta_{mopaque}$(8.5/11µm) at LRC,
$\beta_{sopaque}$(8.5/11µm)

Physical Description



Semi-transparent multilayered ice clouds will resemble liquid water with single layer β assumption and resemble ice with multilayer β assumption



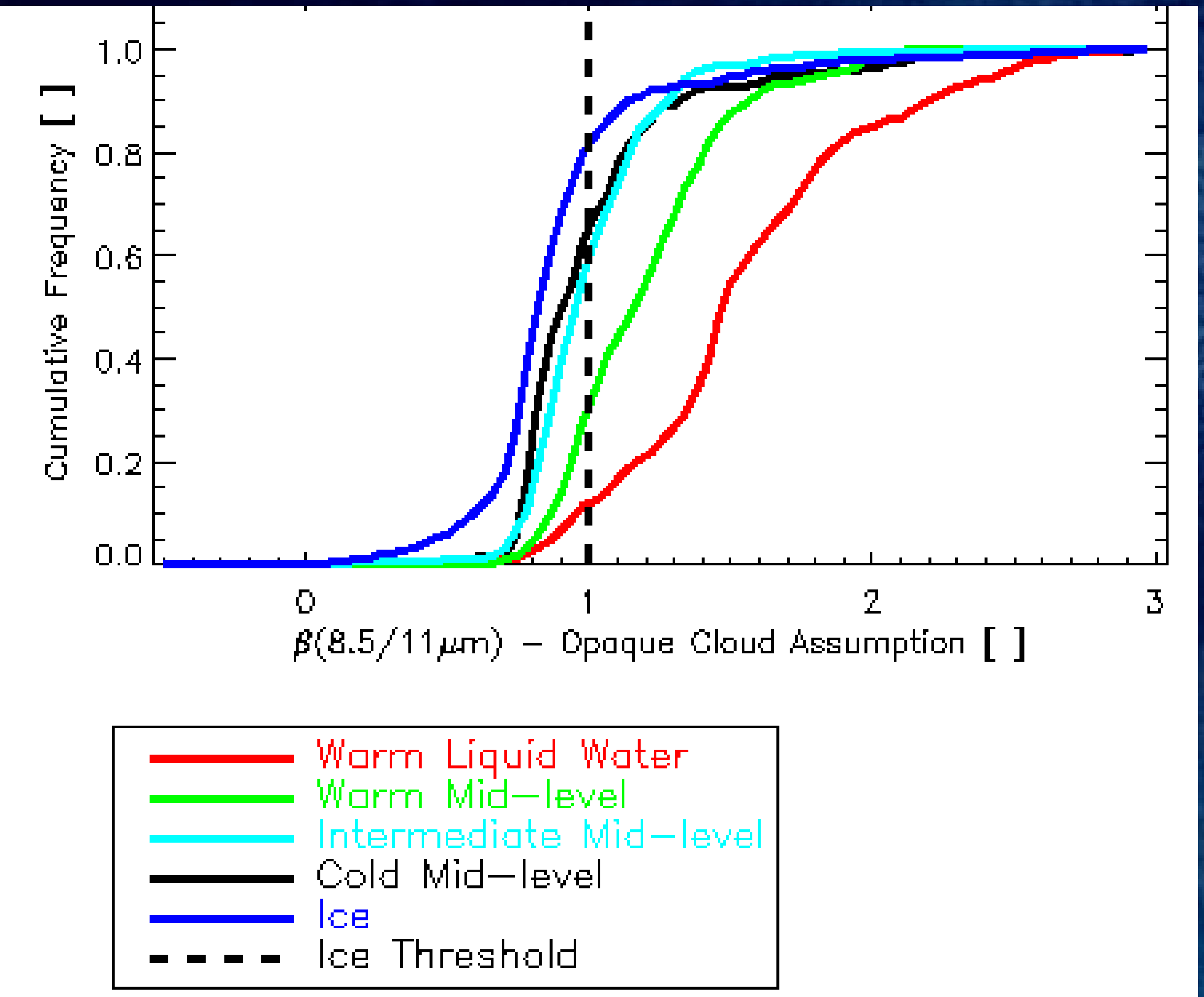
Cloud Type Decision Tree

Physical Description

Goal: Determine if cloudy pixel is solely composed of ice crystals (e.g. cirrus) or is glaciated at cloud top *(same logic as GOES-R, except certain thresholds no longer rely on information from infrared water vapor absorption channels)*

Input:
T_{opaque}(11μm),
T_{opaque}(11μm) at LRC,
β_{stropo}(12/11μm),
$\beta_{sopaque}$(12/11μm),
β_{stropo}(8.5/11μm),
$\beta_{sopaque}$(8.5/11μm),
$\beta_{sopaque}$(8.5/11μm) at LRC

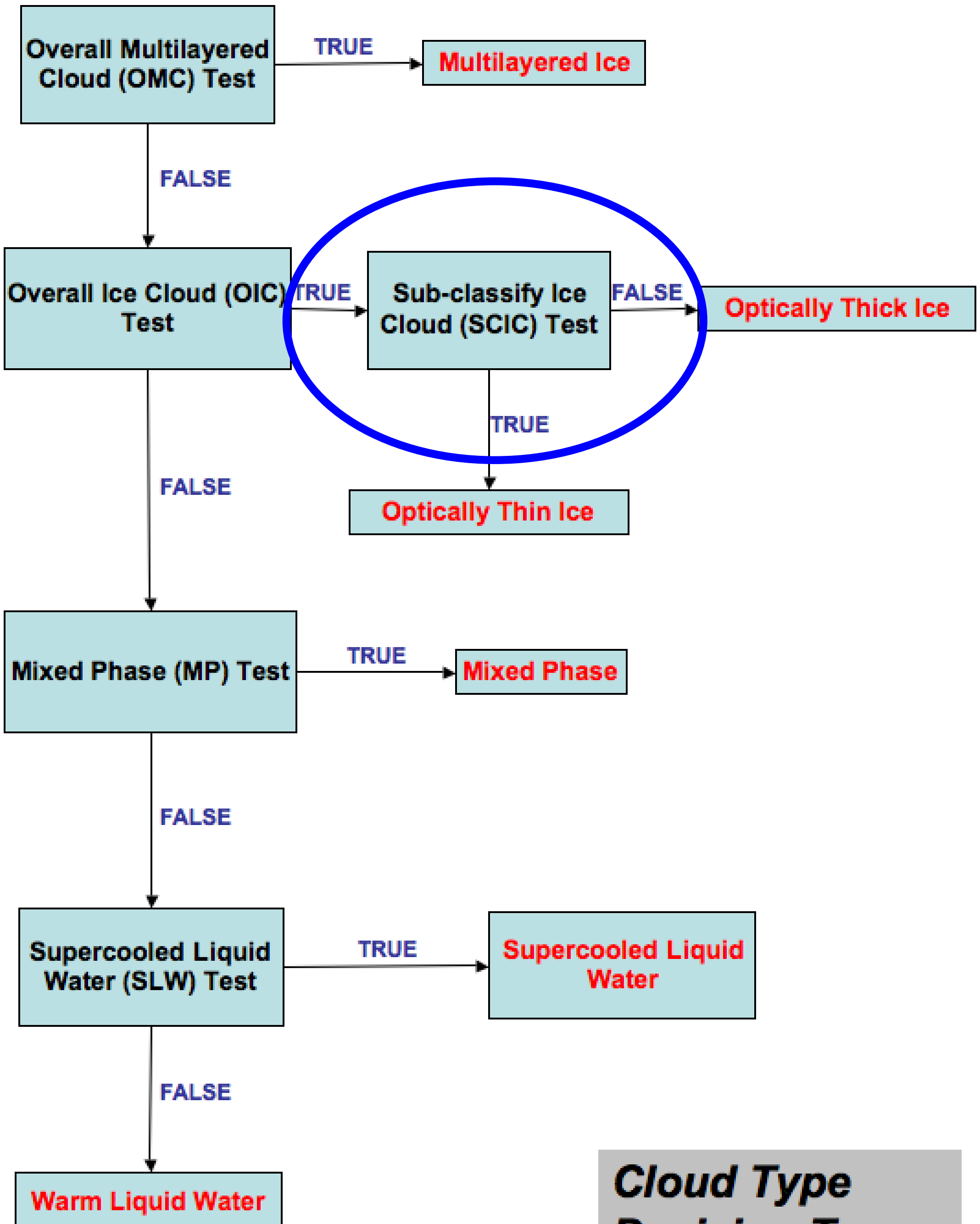
Physical Description



CALIOP and theoretical relationships were used to determine the thresholds used to identify ice clouds.

Some of these thresholds will need to be tuned slightly in order to optimize the performance for VIIRS.

Physical Description



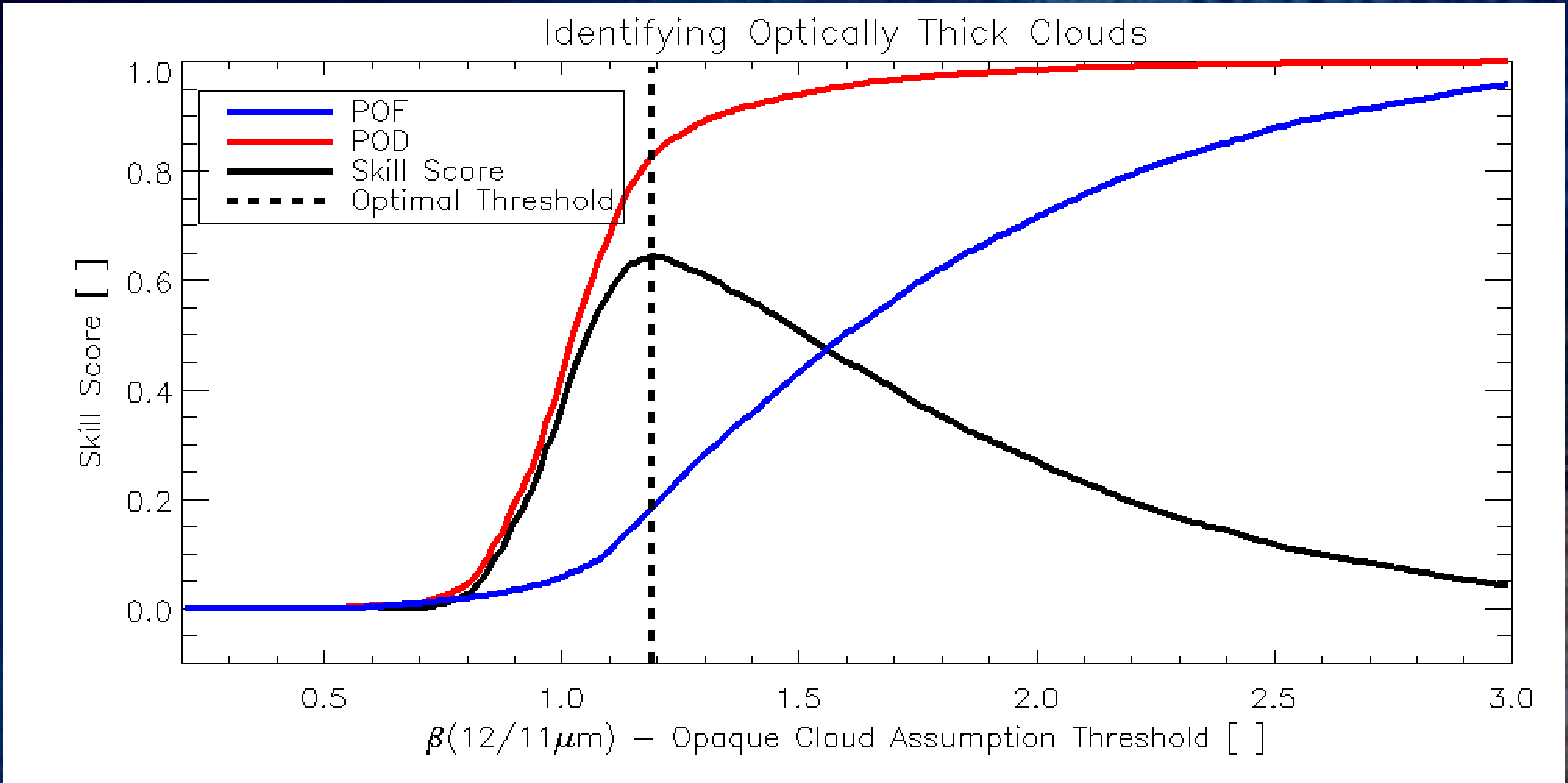
Cloud Type Decision Tree

Goal: Determine if ice cloud is optically thick (optical depth > ~5) or thin *(exact same logic as GOES-R)*

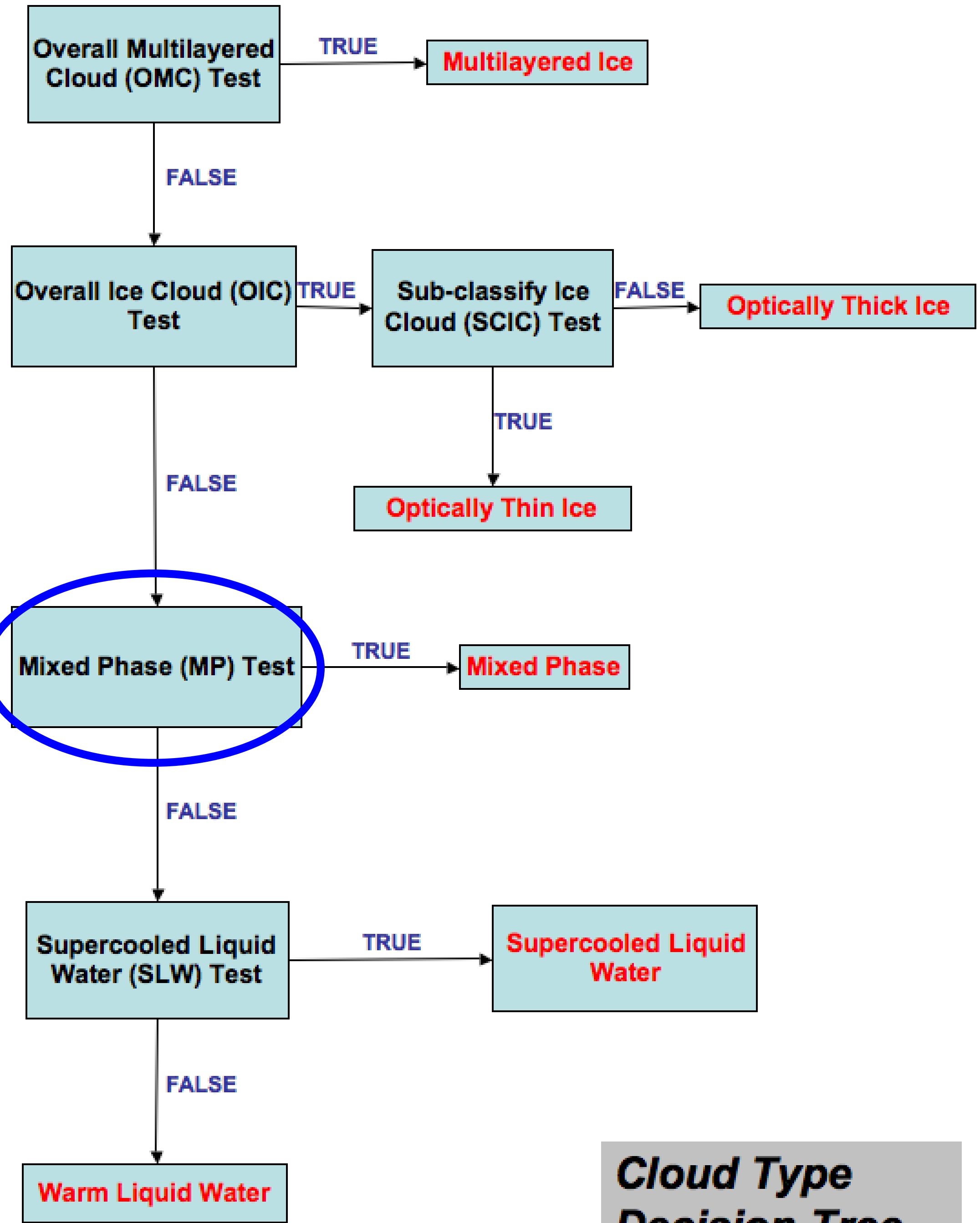
Input:
ε_{stropo}(11μm),
$\beta_{sopaque}$(12/11μm)

Physical Description

$\beta_{sopaque}$(12/11μm) will exceed a theoretical maximum value if the cloud is semi-transparent to infrared radiation. A CALIOP based analysis was used to verify that actual measurements behave as expected and to select an optimal threshold



Physical Description



Cloud Type Decision Tree

Goal: Identify optically thick clouds that are potentially mixed phase near cloud top *(exact same logic as GOES-R)*

Input:

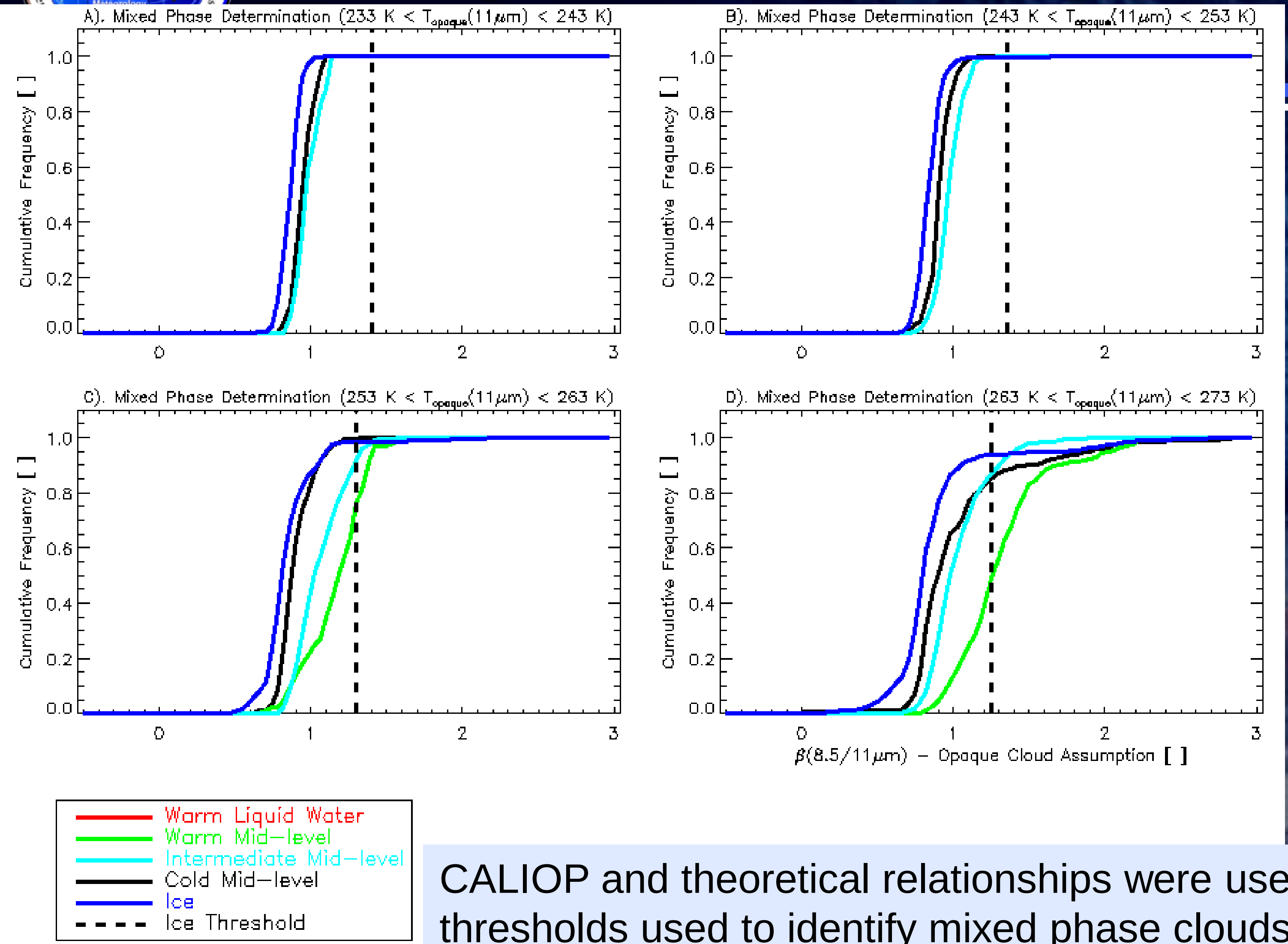
T_{opaque}(11μm),

T_{opaque}(11μm) at LRC,

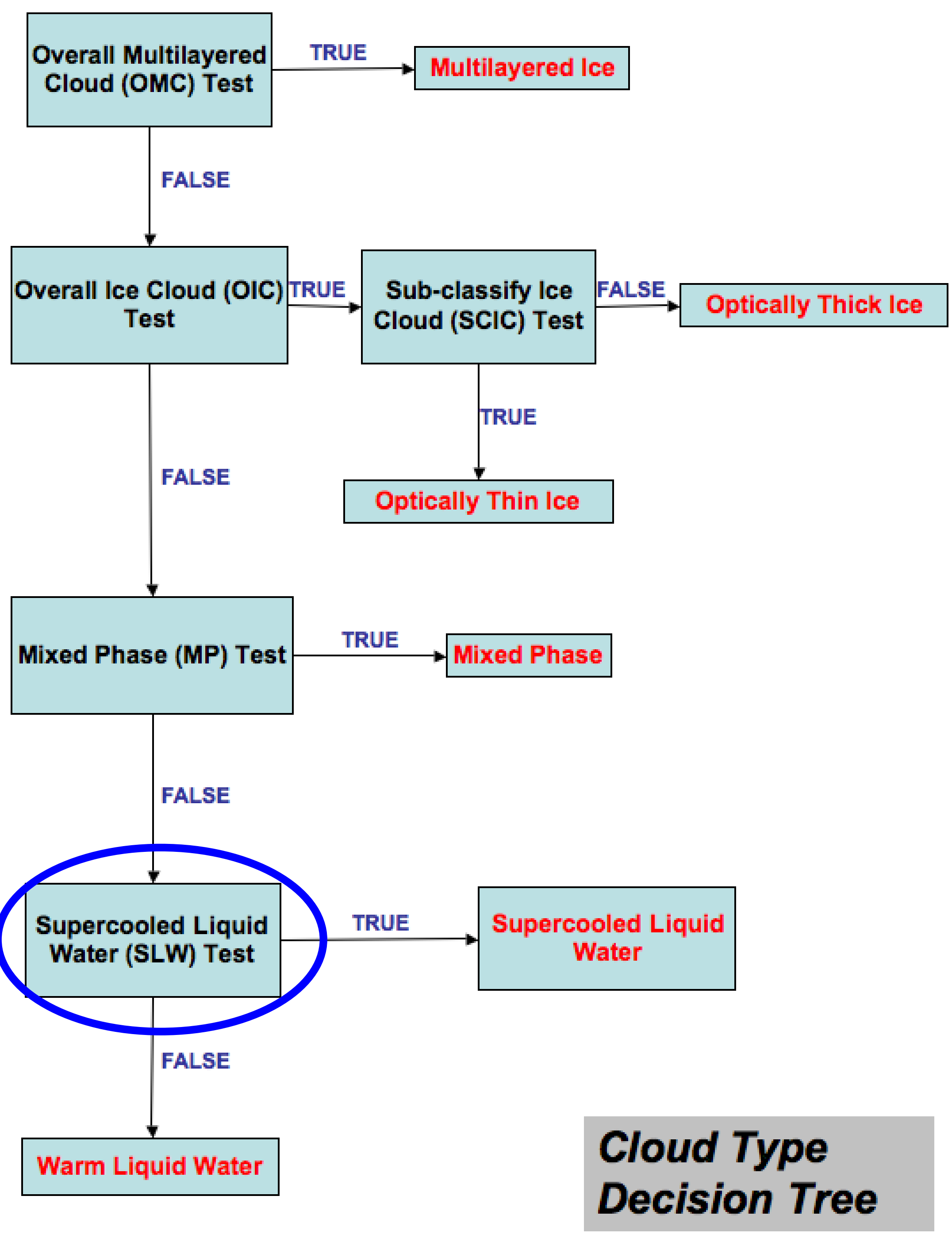
$\beta_{sopaque}$(8.5/11μm),

$\beta_{sopaque}$(8.5/11μm) at LRC

Physical Description



CALIOP and theoretical relationships were used to determine the thresholds used to identify mixed phase clouds. Some of these thresholds will need to be tuned slightly in order to optimize the performance for VIIRS.



Physical Description

Goal: Identify supercooled liquid water clouds *(exact same logic as GOES-R)*

Input:

T_{opaque}(11µm)

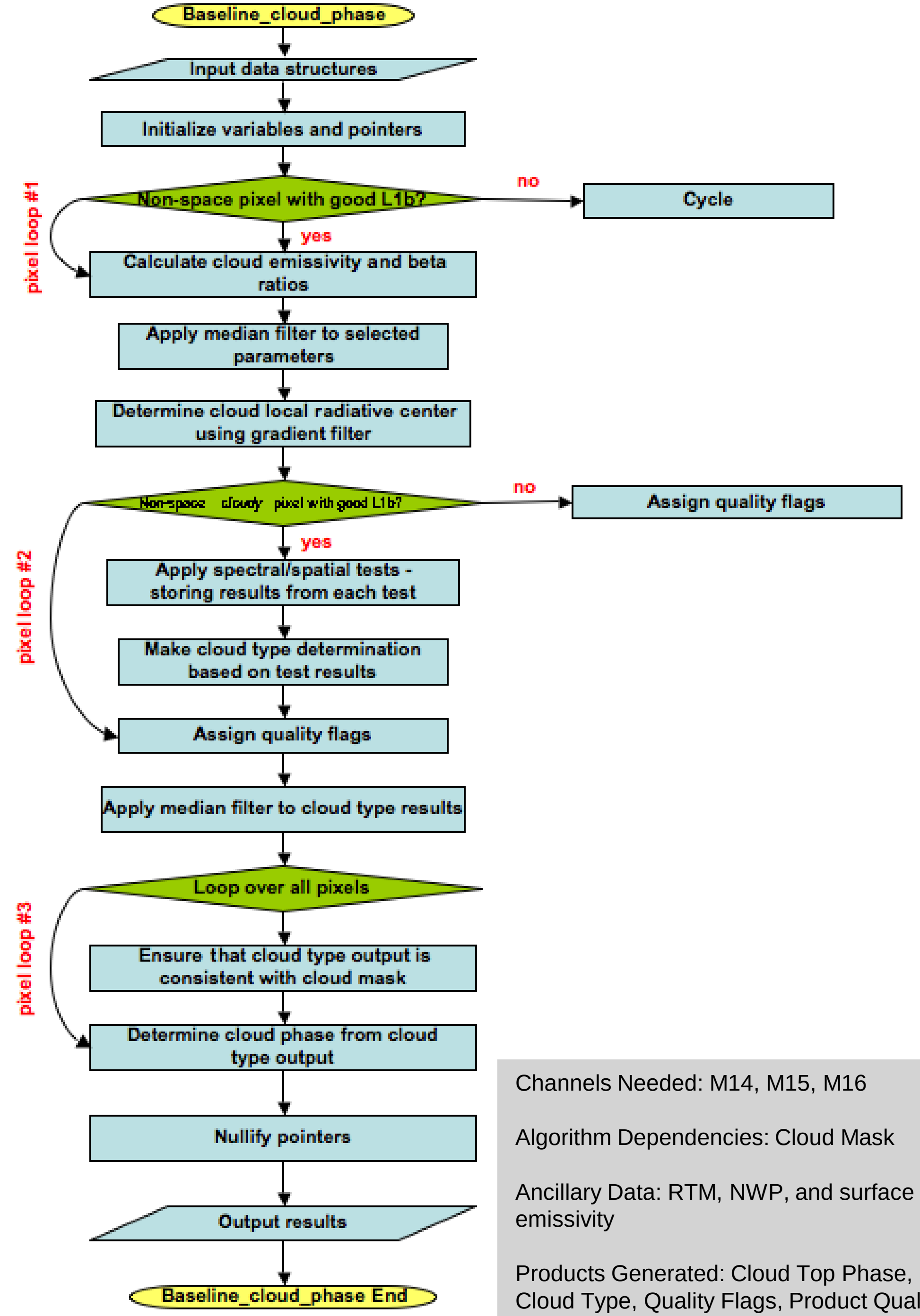
If T_{opaque}(11µm) < 273.16 K then the cloud is classified as supercooled liquid water

High-level Algorithm Flowchart

1). Compute radiative parameters relevant to cloud type

2). Utilize spectral tests to determine cloud type

3). Remove “noise” and determine cloud phase from cloud type



Channels Needed: M14, M15, M16

Algorithm Dependencies: Cloud Mask

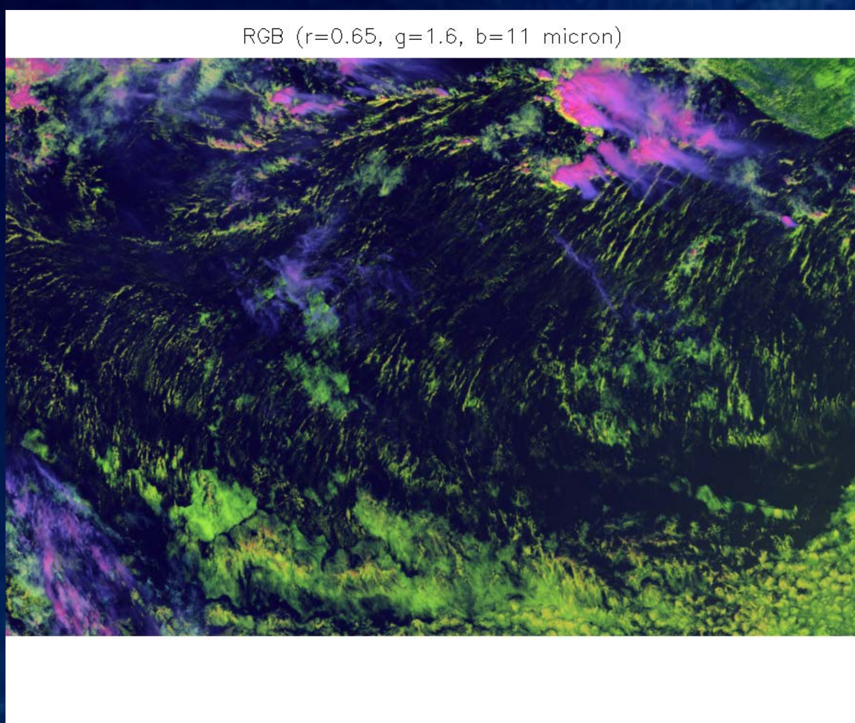
Ancillary Data: RTM, NWP, and surface emissivity

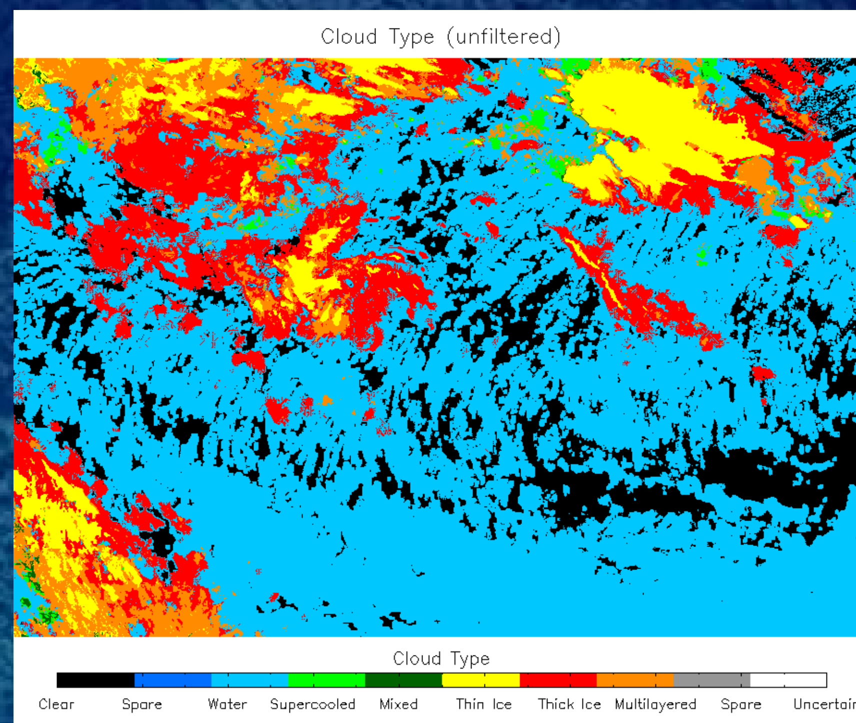
Products Generated: Cloud Top Phase, Cloud Type, Quality Flags, Product Quality Information, and Meta Data

Retrieval Strategy

Cloud type results prior to using median filter

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

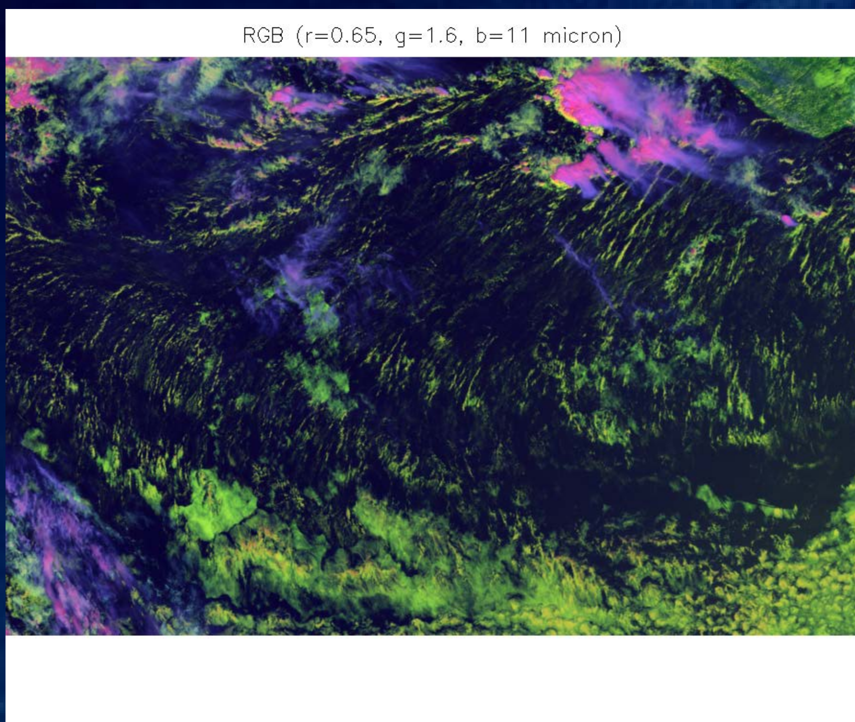


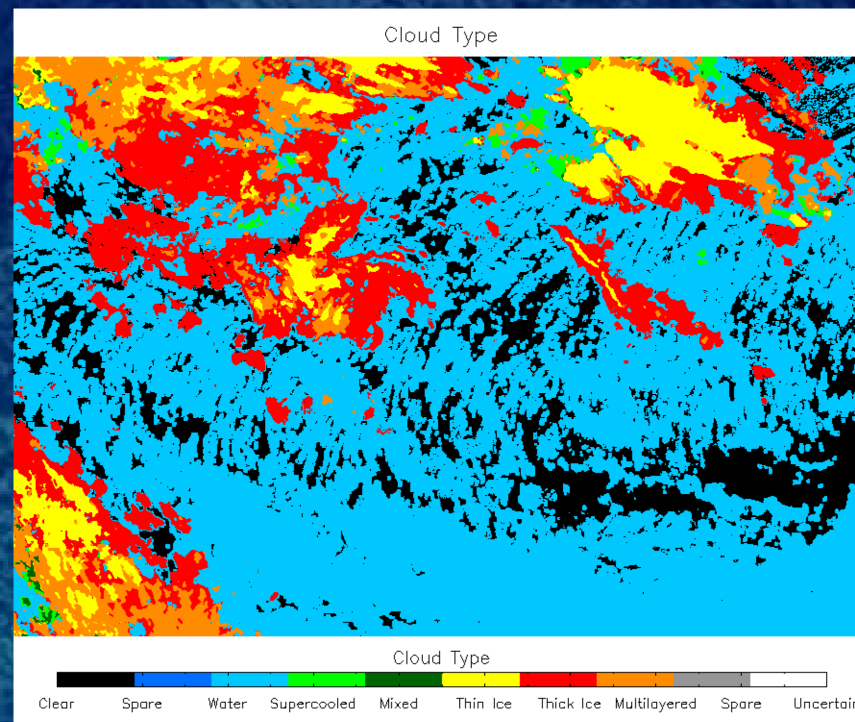


Retrieval Strategy

Cloud type results after using median filter

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

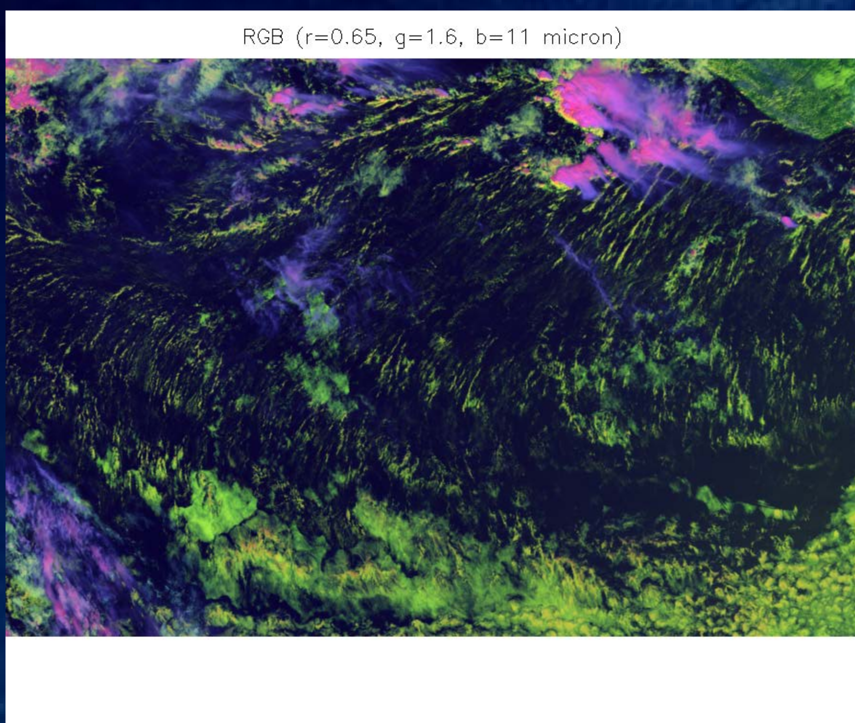


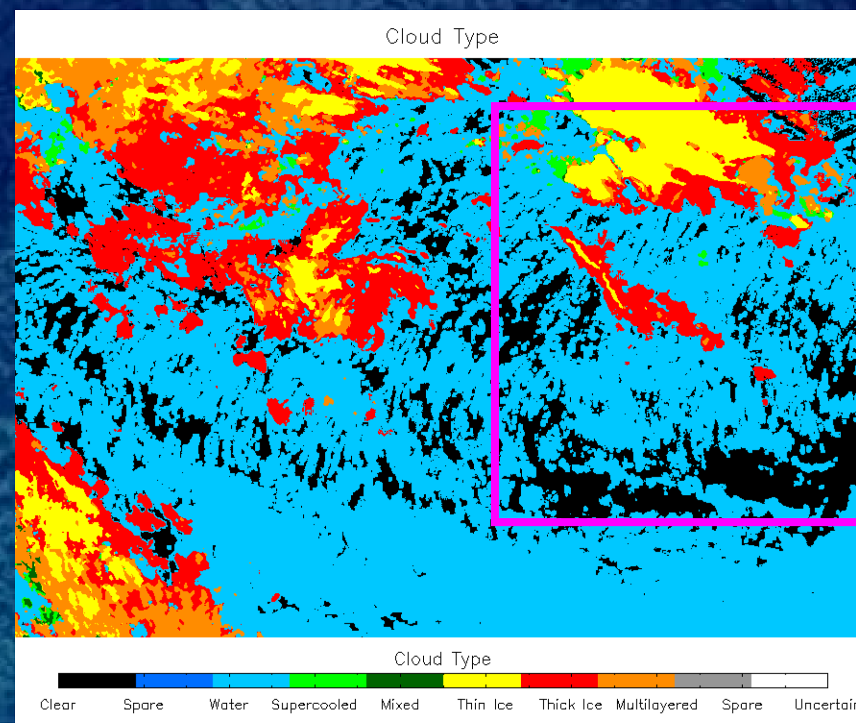


Retrieval Strategy

Cloud type results after using median filter

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

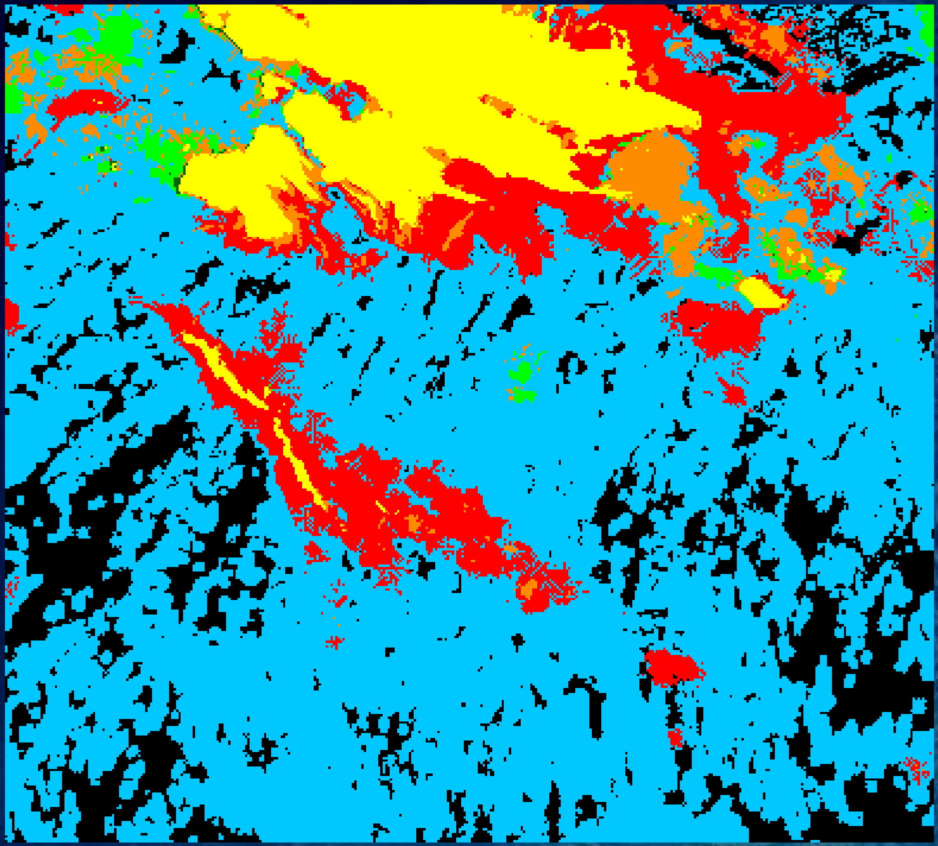




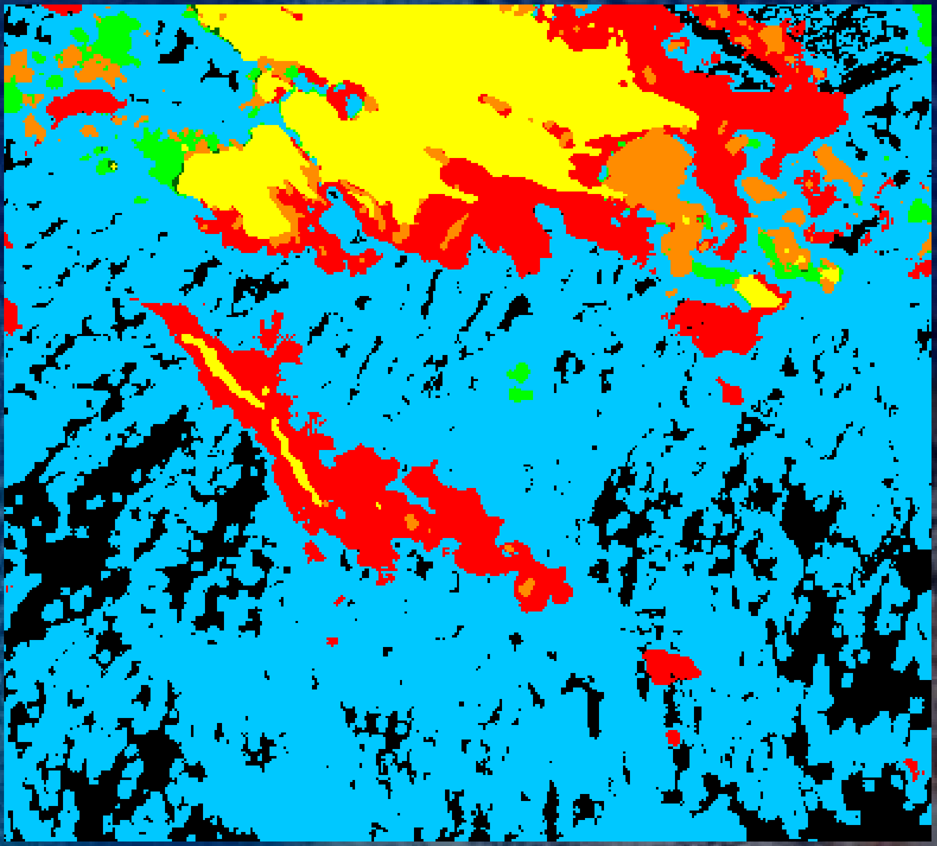
Retrieval Strategy

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

Pre-median Filter



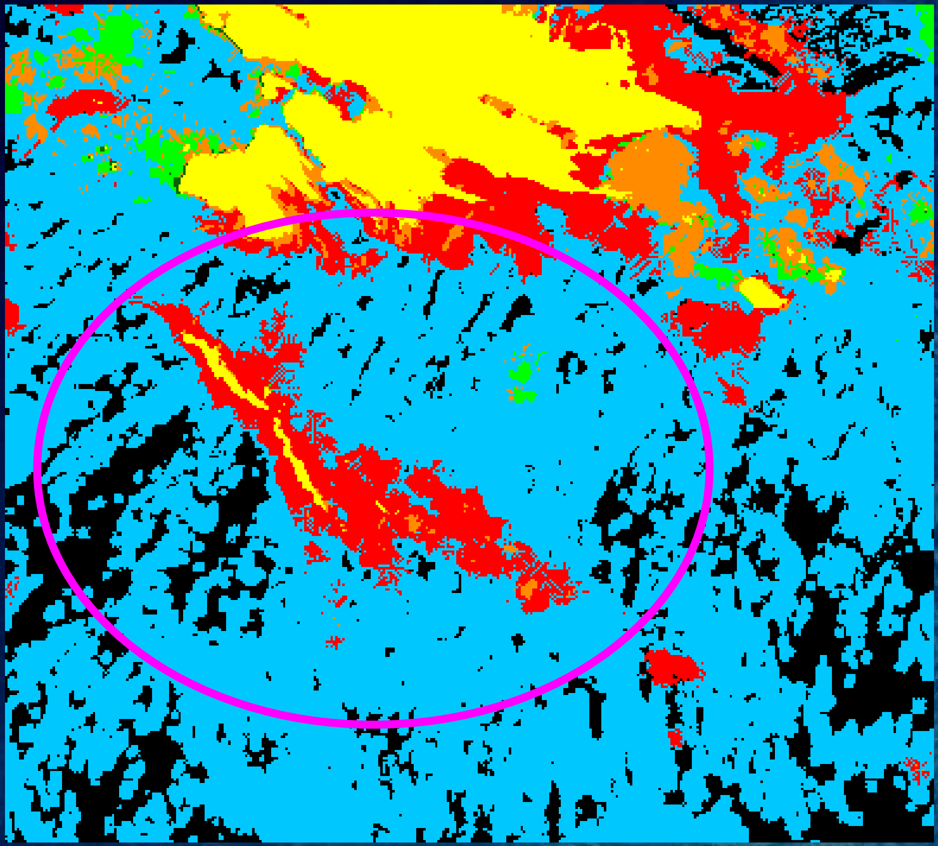
Post-median Filter



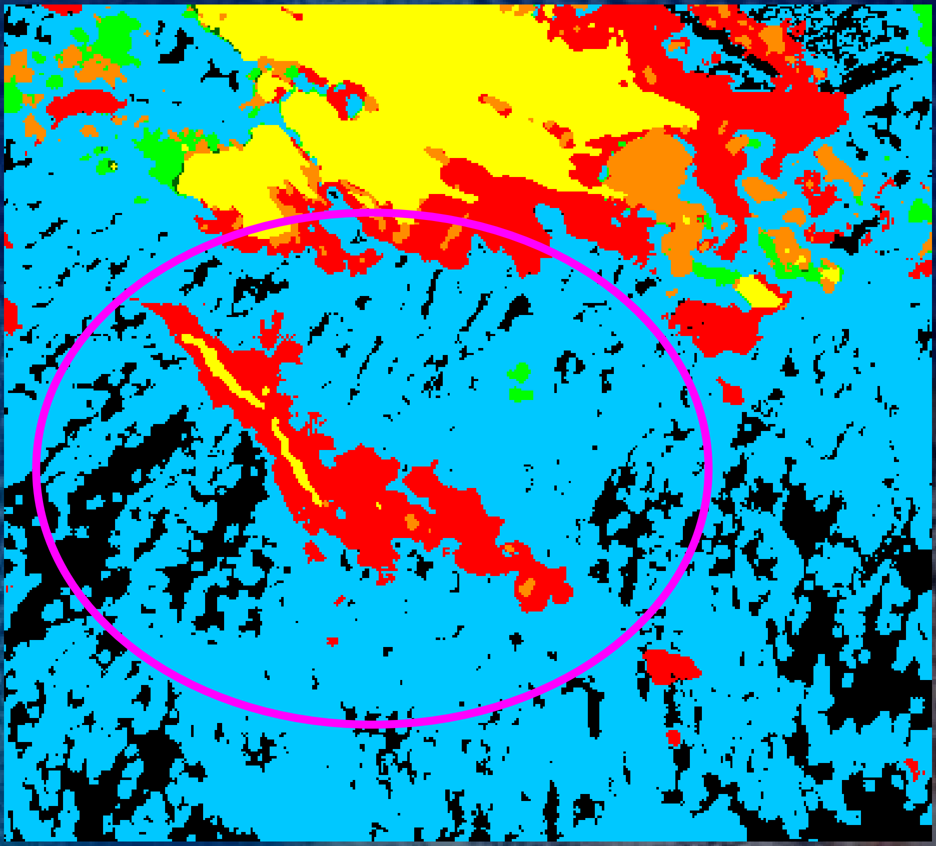
Retrieval Strategy

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

Pre-median Filter

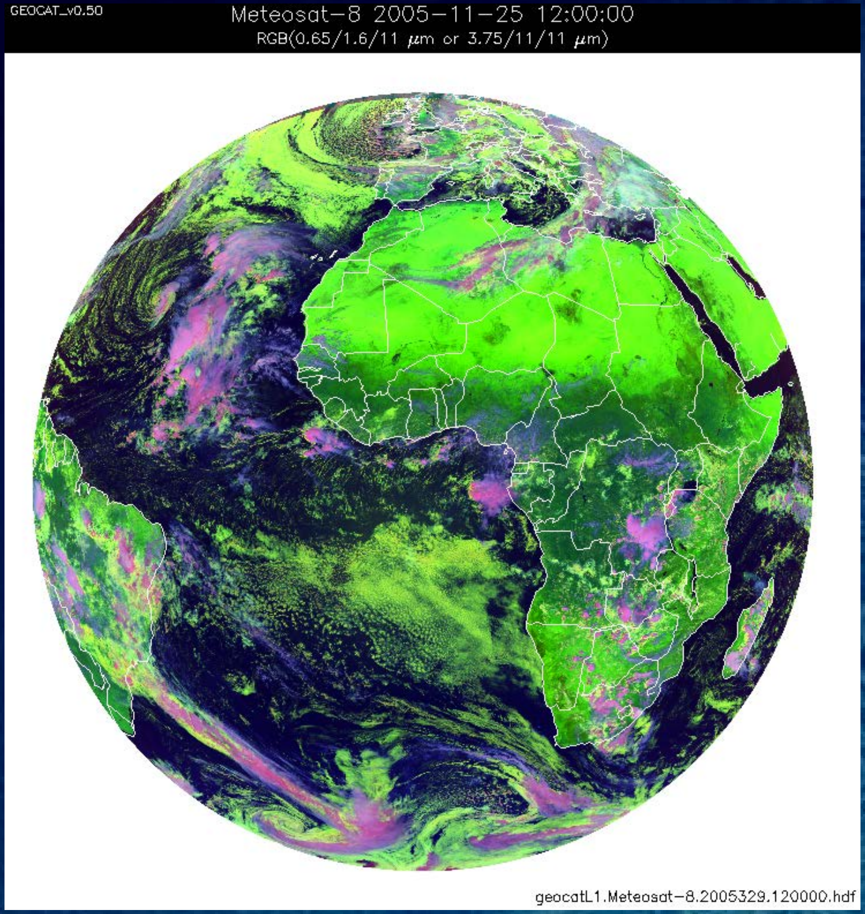


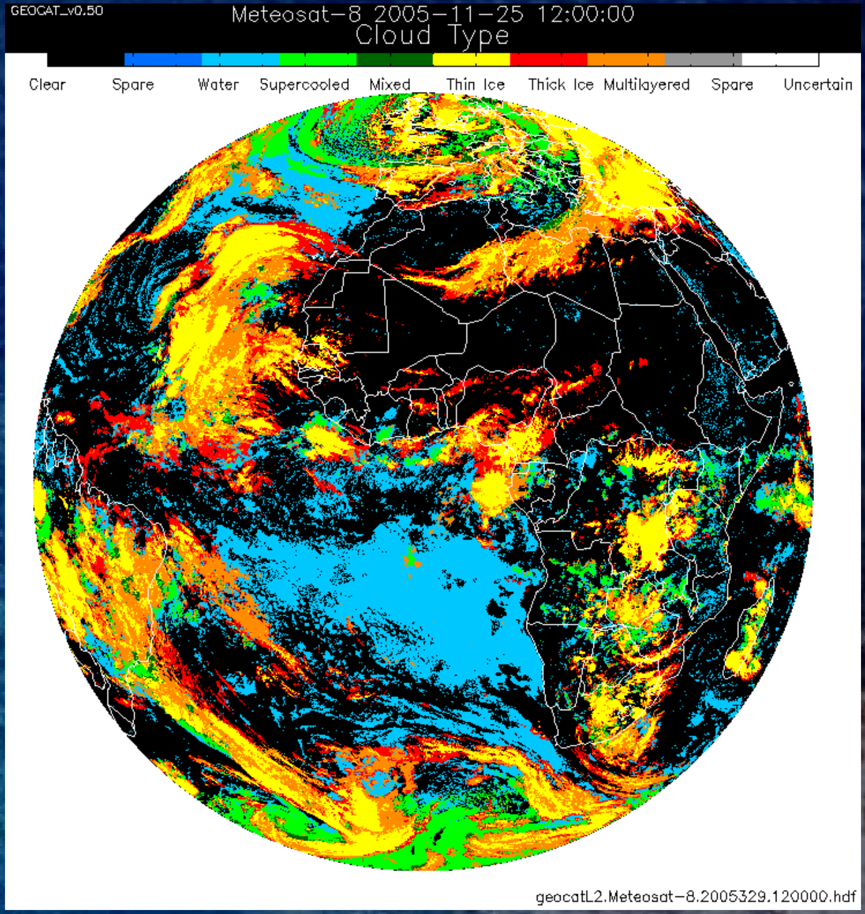
Post-median Filter



Retrieval Strategy

SEVIRI cloud type results

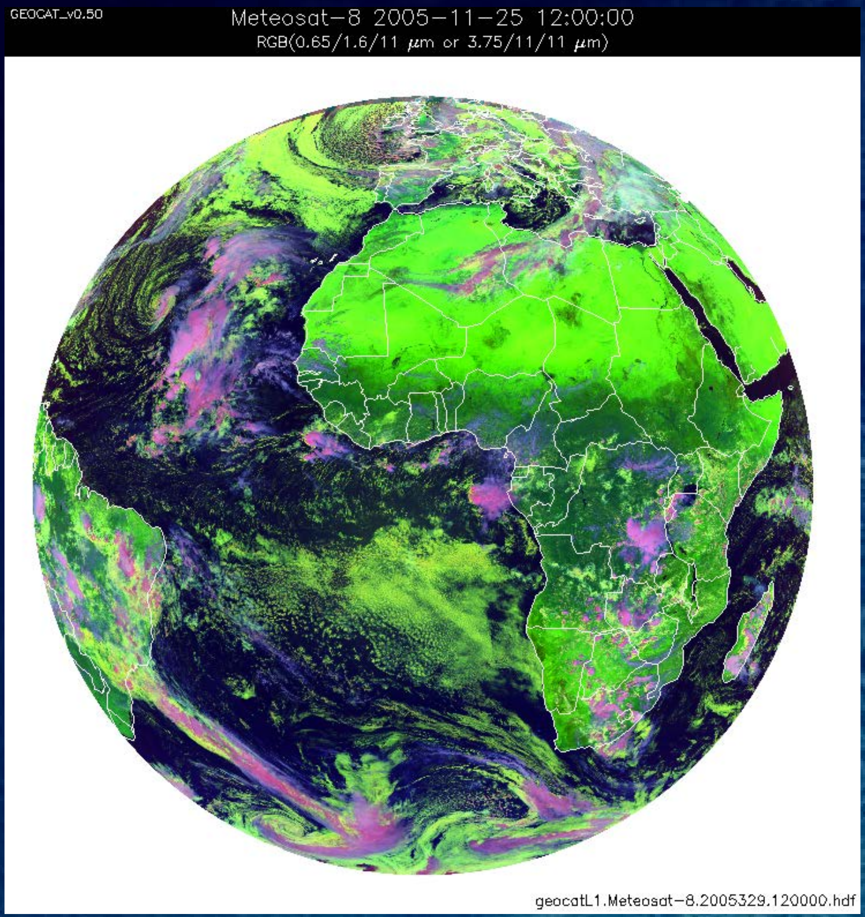


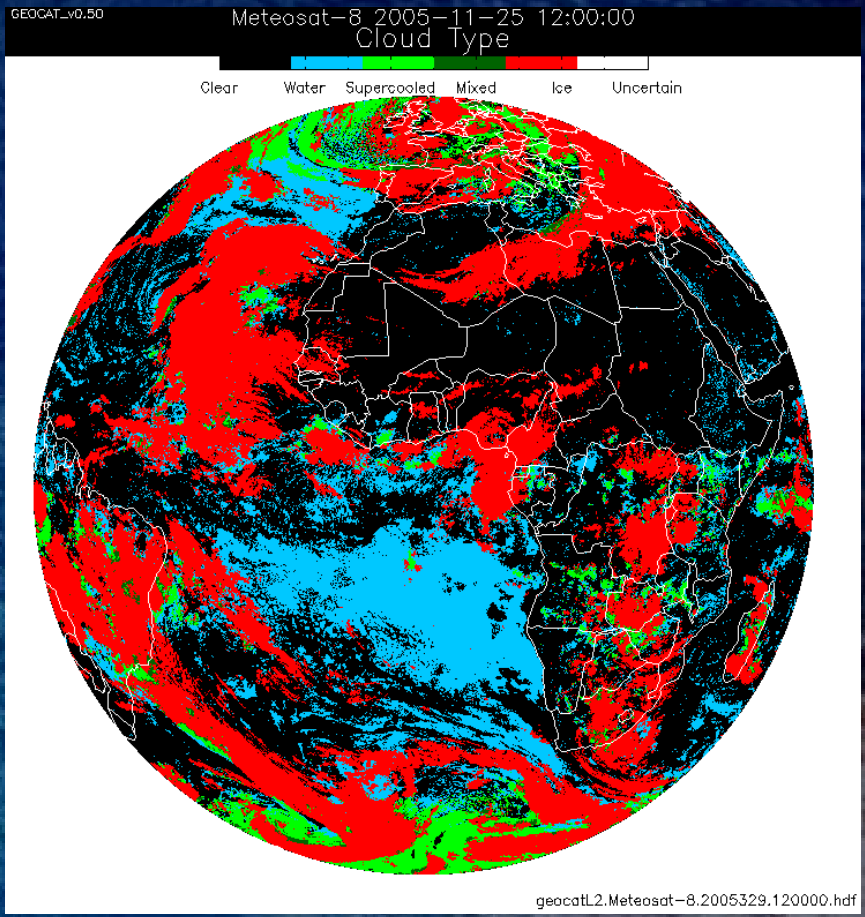


Water, Supercooled Water, Mixed Phase, Thick Ice, Thin Ice, Multilayered

Retrieval Strategy

SEVIRI cloud phase results

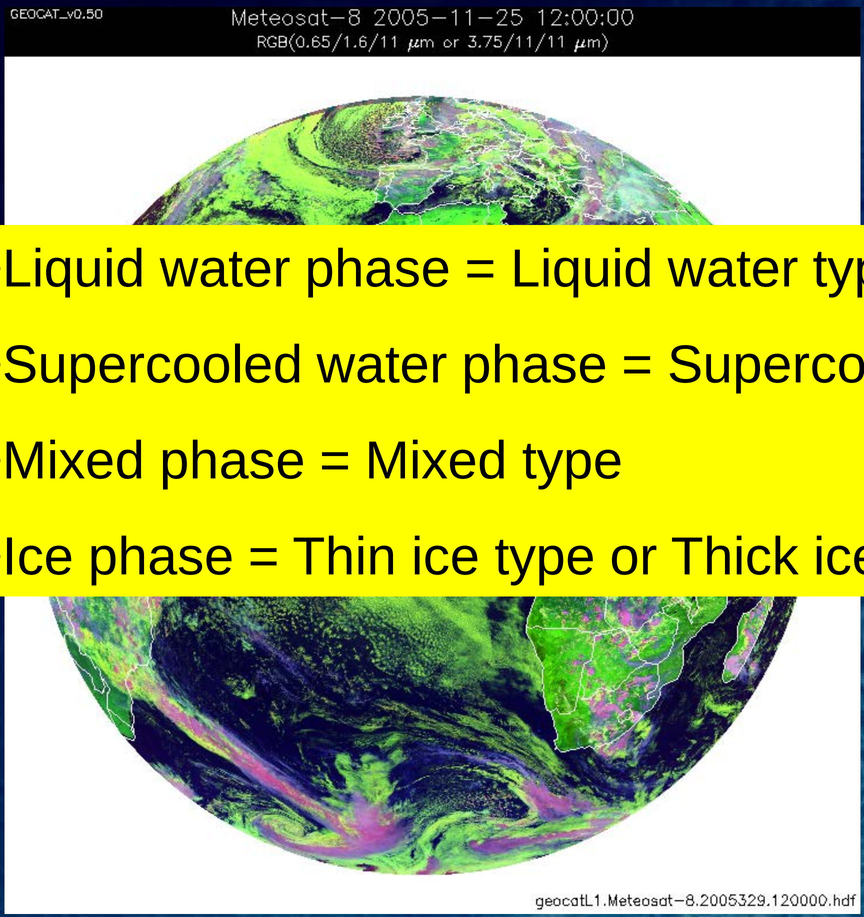


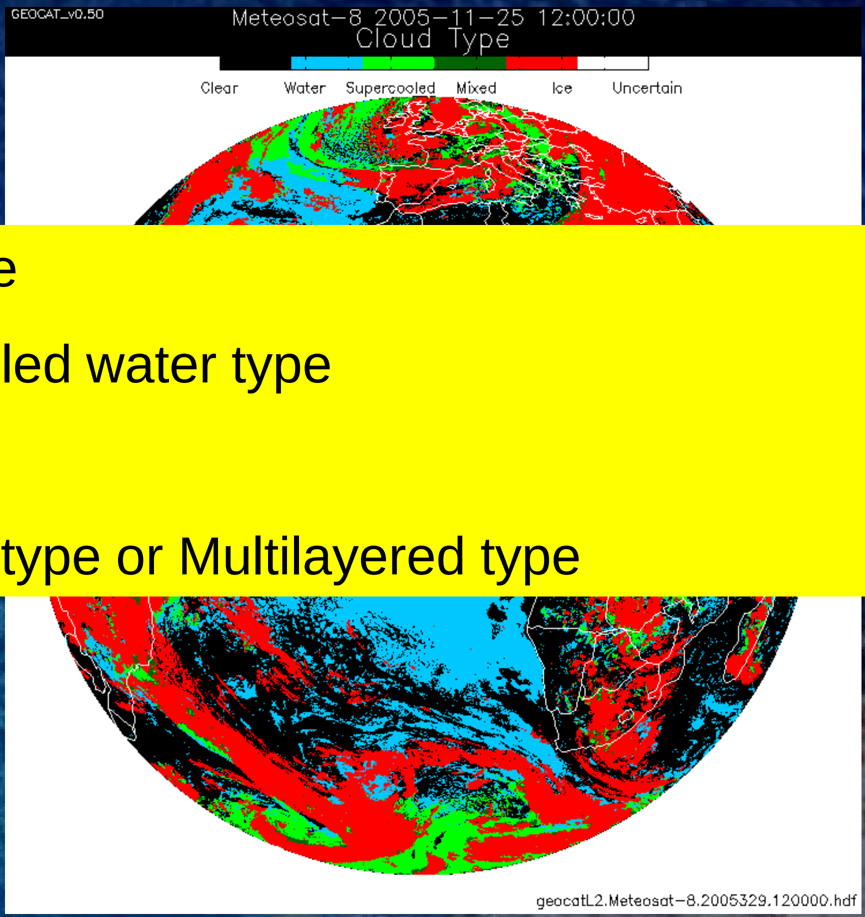


Water, Supercooled Water, Mixed Phase, Ice

Retrieval Strategy

Derivation of cloud phase from cloud type





- Liquid water phase = Liquid water type
- Supercooled water phase = Supercooled water type
- Mixed phase = Mixed type
- Ice phase = Thin ice type or Thick ice type or Multilayered type

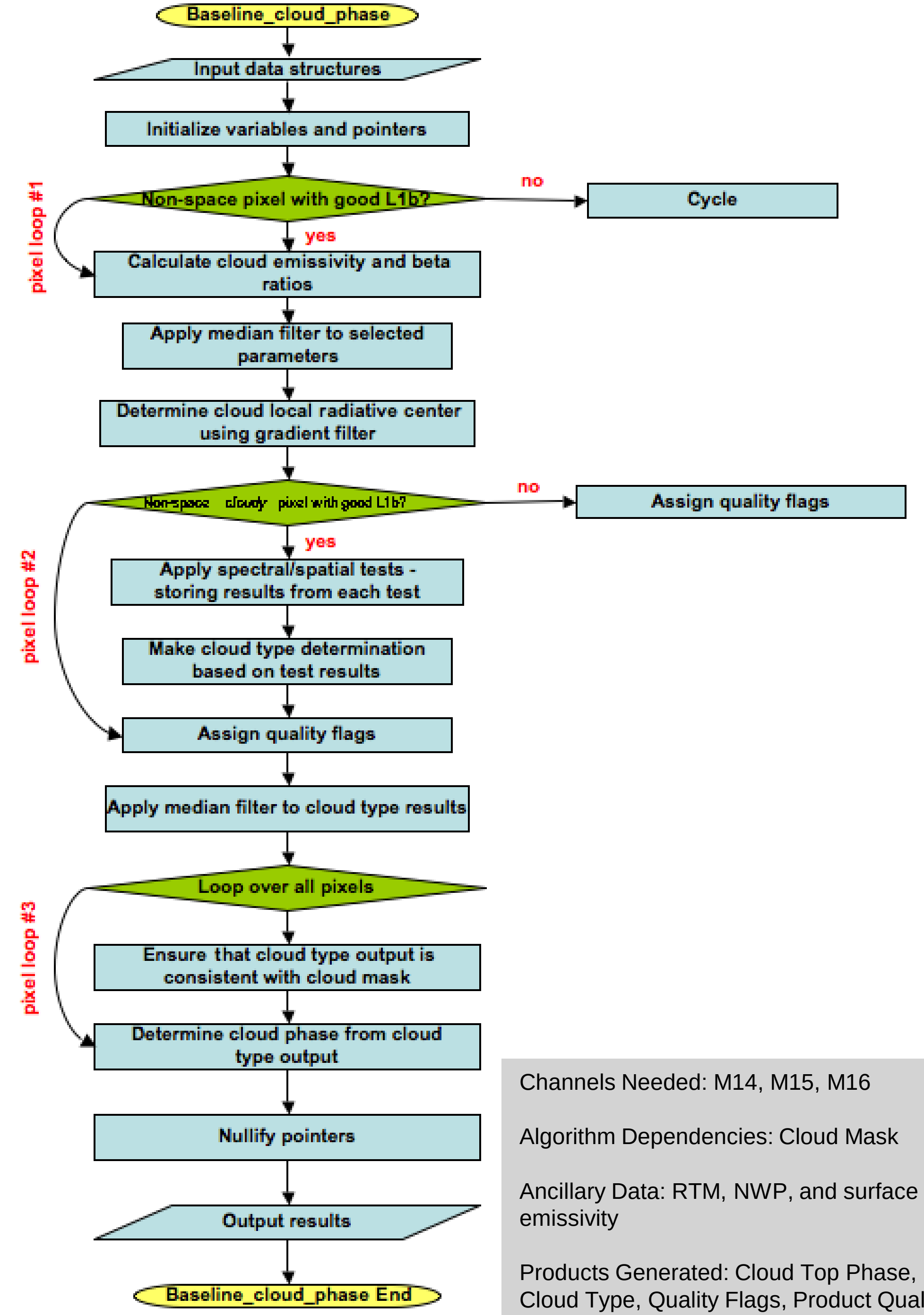
Water, Supercooled Water, Mixed Phase, Ice

High-level Algorithm Flowchart

1). Compute radiative parameters relevant to cloud type

2). Utilize spectral tests to determine cloud type

3). Remove “noise” and determine cloud phase from cloud type



Channels Needed: M14, M15, M16

Algorithm Dependencies: Cloud Mask

Ancillary Data: RTM, NWP, and surface emissivity

Products Generated: Cloud Top Phase, Cloud Type, Quality Flags, Product Quality Information, and Meta Data

Algorithm Output

- Algorithm is only designed to be applied to the VIIRS M-bands with “bow-tie” deleted pixels restored.
- Algorithm will output the cloud type and cloud phase and associated quality information.

Practical Considerations: Exception Handling

- The algorithm performs best when the 8.5, 11, and 12 μm channels provide valid data.
- However, the algorithm will run and produce degraded results if either of the following channel combinations are available: (8.5,11μm), (11,12 μm). The extent of the degradation has yet to be quantified.
- If none of the above channel combinations are available, each pixel will be set to a flag that indicates that the phase/type is unknown.
- If clear sky radiance calculations (based on NWP data) are unavailable, the algorithm output will also be set to unknown.

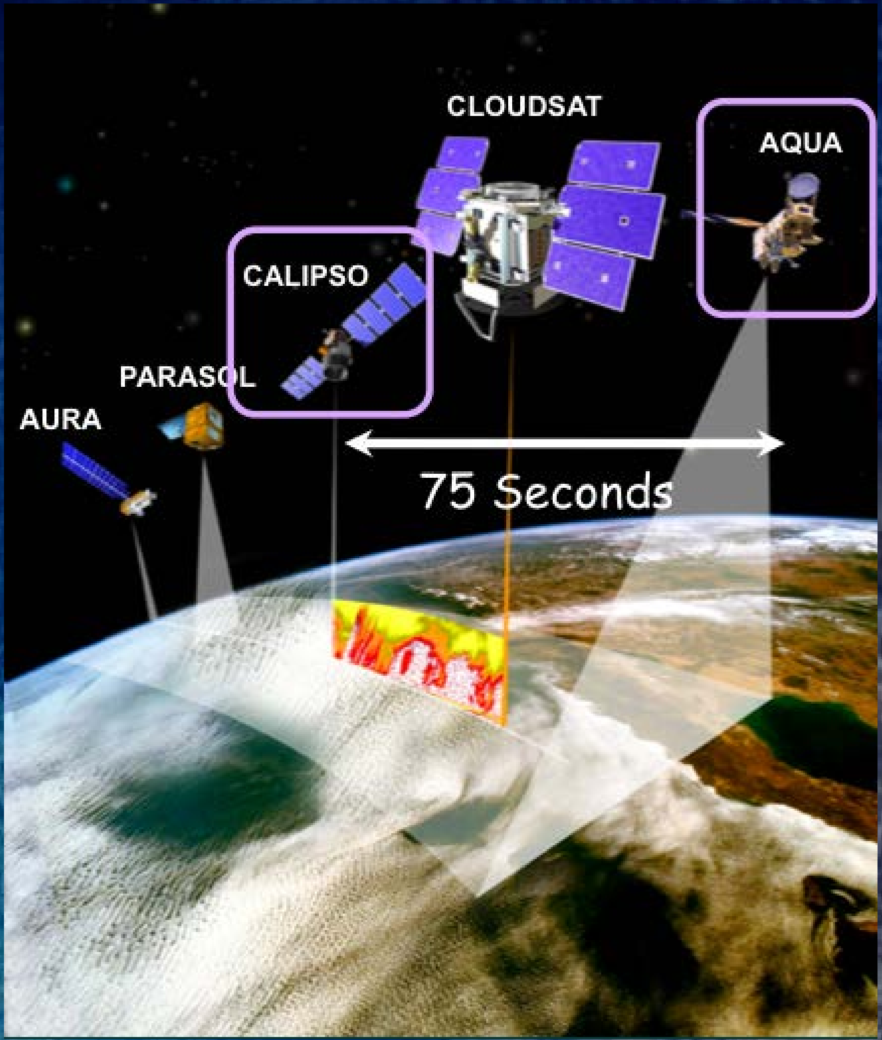
Performance Estimates

•With the launch of CALIPSO (a lidar) and CLOUDSAT (a radar) into the EOS A-train, we now unprecedented information on the vertical structure of clouds.

• CALIPSO is very sensitive to the presence of any cloud in the column and therefore is our first choice in cloud height validation.

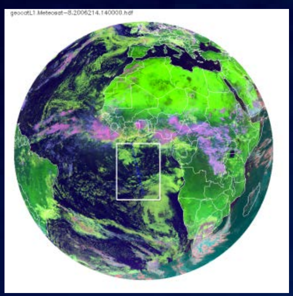
•The weaknesses of CALIPSO are low snr during the day and difficulty distinguishing cloud from thick aerosol.

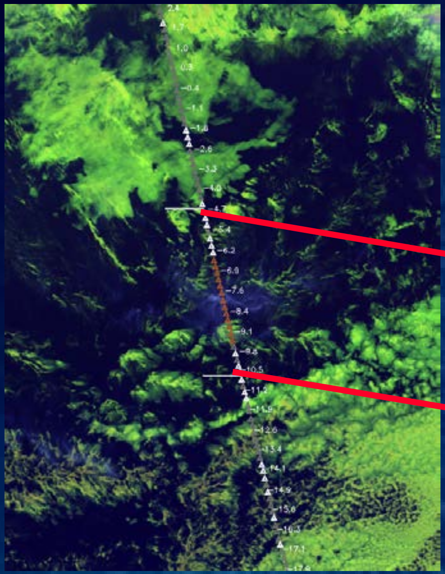
•Even with these weaknesses, CALIPSO is the best we have.

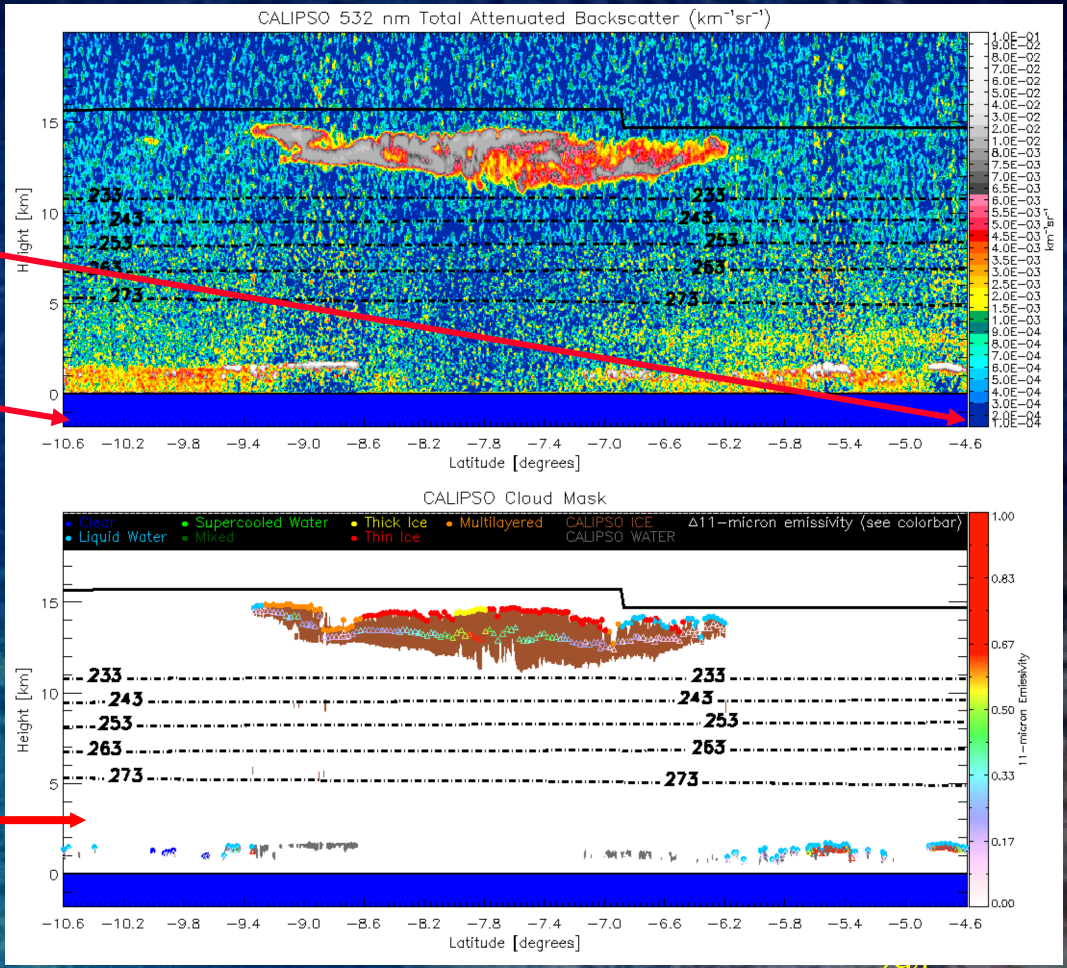


Performance Estimates

August 2, 2006 14:00 (day)



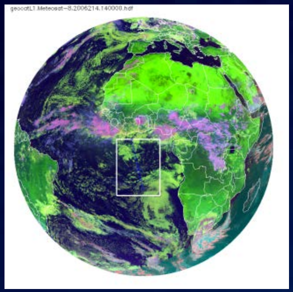


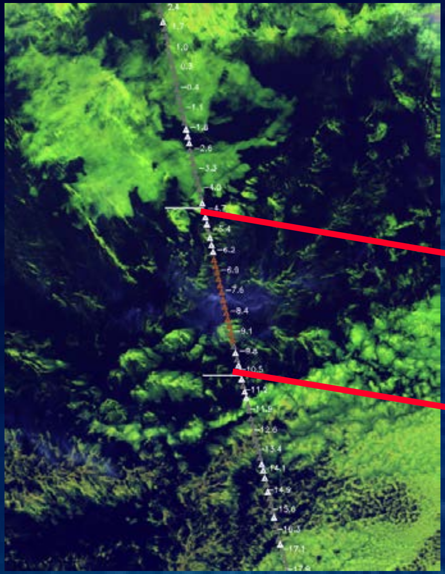


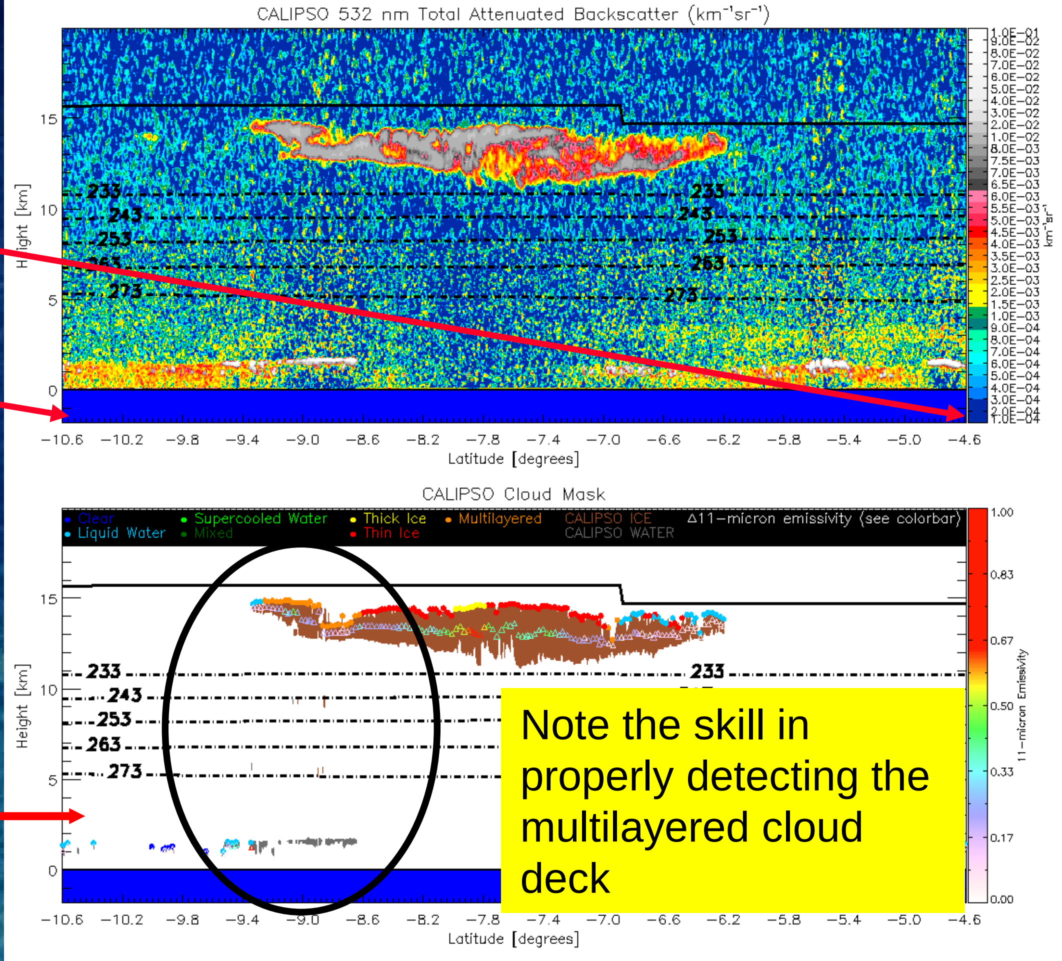
CALIPSO phase mask and GOES-R cloud typing results

Performance Estimates

August 2, 2006 14:00 (day)





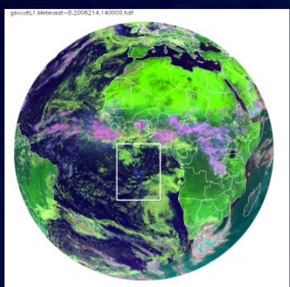


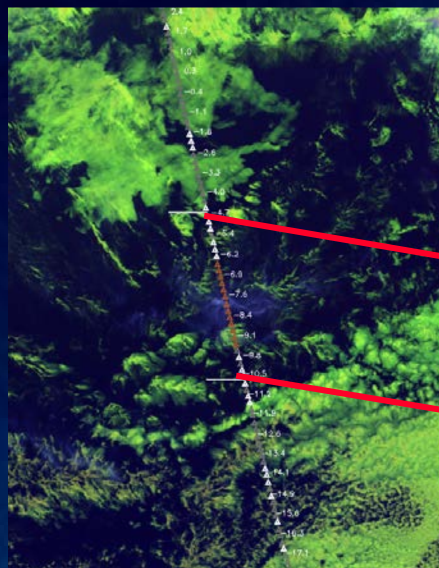
Note the skill in properly detecting the multilayered cloud deck

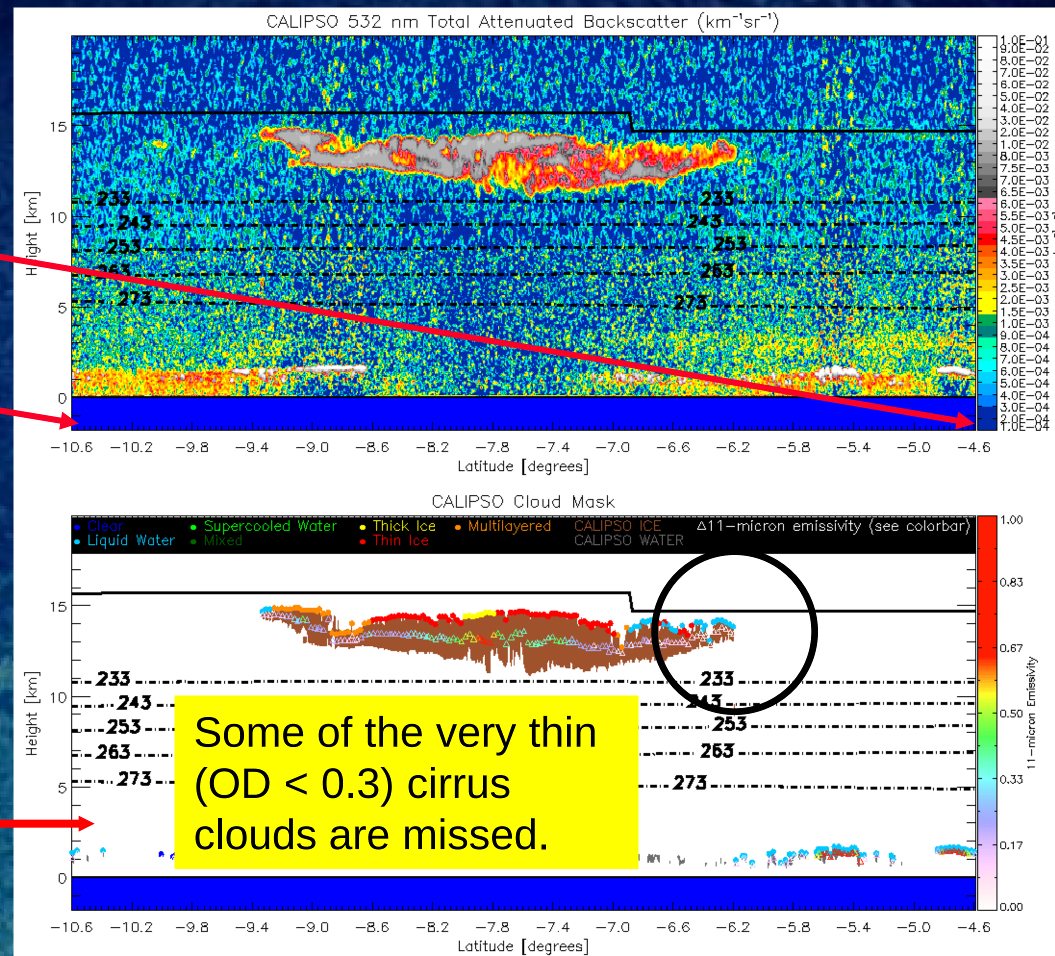
CALIPSO phase mask and GOES-R cloud typing results

Performance Estimates

August 2, 2006 14:00 (day)







CALIPSO phase mask and GOES-R cloud typing results

Validation Results

Error Budget (Cloud Phase)

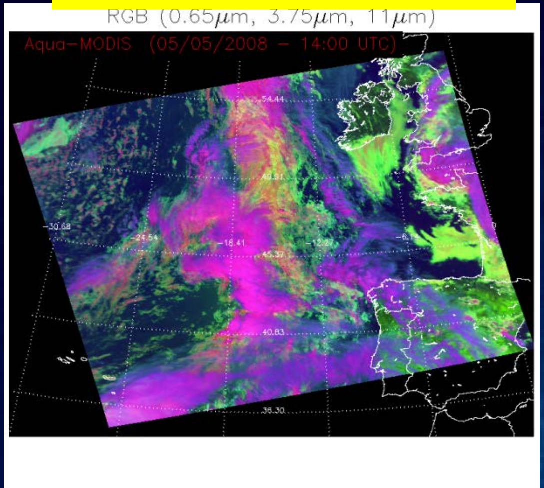
Category	CALIPSO Count	ABI Phase Count	Percent Agree	Percent Disagree
Liquid Water/ Supercooled water	49,642	44,915	90.48%	9.52%
Potentially Mixed Phase	21,434 (not included in total)	?	?%	?%
Ice Phase	45,607	38,693	84.84%	15.16%
Total	95,249	83,608	87.78%	12.22%

Error Budget (Cloud Phase)

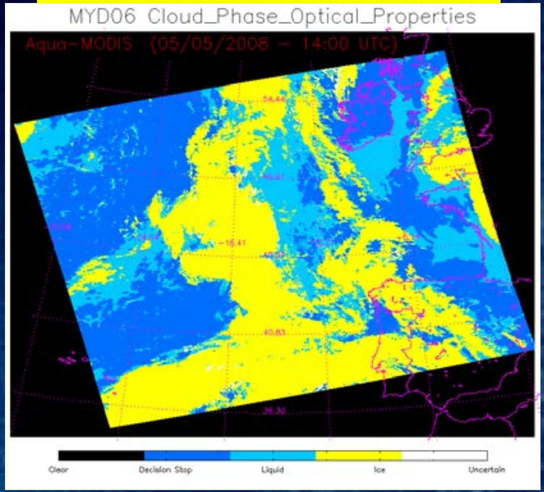
Category	CALIPSO Count	ABI Phase Count	Percent Agree	Percent Disagree
Liquid Water/ Supercooled water	49,642	44,915	90.48%	9.52%
Potentially Mixed Phase	21,434 (not included in total)	?	?%	?%
Optically Thick Ice	5763	4975	86.33%	13.67%
Optically Thin Ice	15,689	9183	58.53%	41.47%
Multilayered Ice	24,155	9570	39.62%	60.38%
Total	95,249	68,643	72.07%	27.93%

Cloud Phase/Type Inter-comparisons

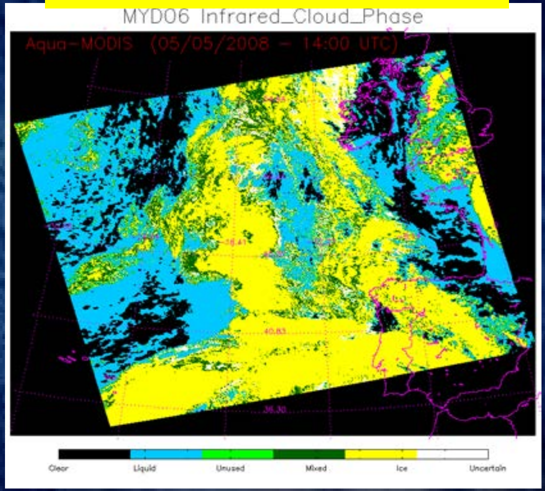
False Color



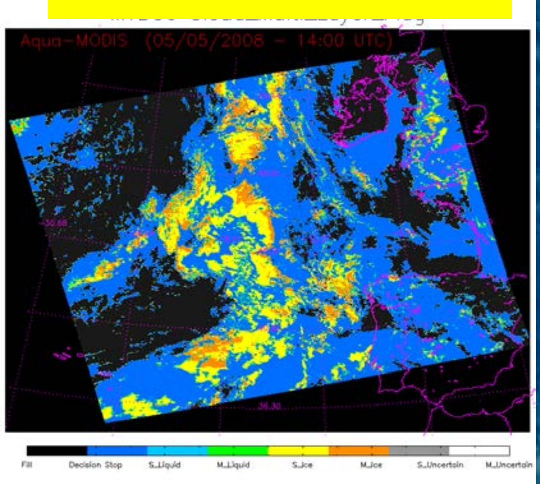
MYD06 NIR



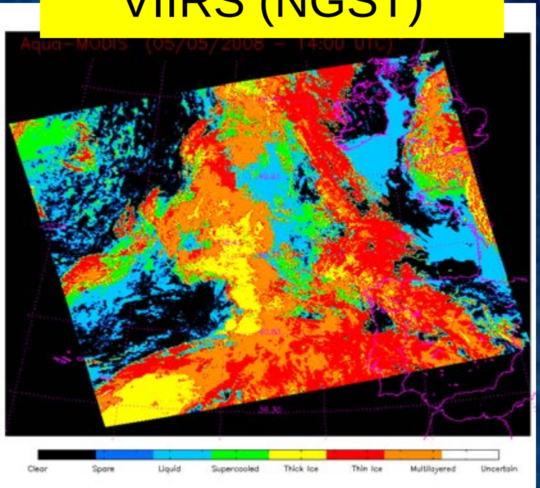
MYD06 IR



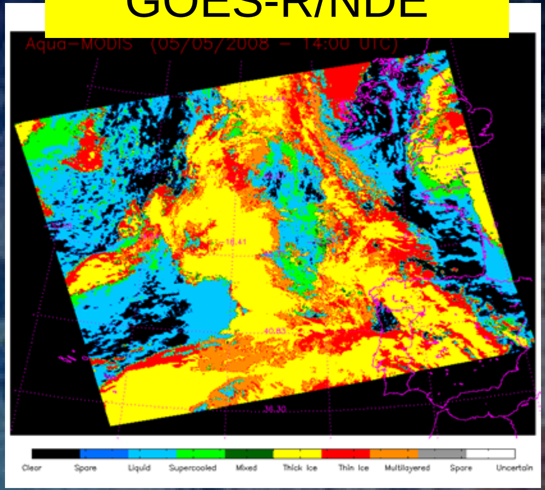
MYD06 NIR Multi



VIIRS (NGST)



GOES-R/NDE



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%)

Performance Estimates: Summary

- Our cloud phase results agree with CALIOP ~88% of the time.
- Our ~12% misclassification rate is well under the 20% threshold specified for cloud top phase in the requirement document.
- Our cloud type results agree with CALIOP ~72% of the time.
- Our ~28% misclassification rate is well under the 40% threshold specified for cloud type in the requirements document.
- This analysis includes all detected clouds with an IR optical depth > 0.
- The lack of infrared water vapor absorption channels on VIIRS will likely degrade the multilayered cloud detection capabilities, but the impact on the cloud phase results is expected to be very small
- The algorithm will soon be tested and validated on VIIRS “golden days”
- The new CALIOP cloud phase product will be used in the validation analysis

References

- Pavolonis, Michael J.; Heidinger, Andrew K. and Uttal, Taneil. **Daytime global cloud typing from AVHRR and VIIRS: Algorithm description, validation, and comparisons**. Journal of Applied Meteorology, Volume 44, Issue 6, 2005, pp.804-826.
- Pavolonis, Michael J. and Heidinger, Andrew K.. **Daytime cloud overlap detection from AVHRR and VIIRS**. Journal of Applied Meteorology, Volume 43, Issue 5, 2004, pp.762-778.
- Heidinger, Andrew K. and Pavolonis, Michael J.. **Global daytime distribution of overlapping cirrus cloud from NOAA's Advanced Very High Resolution Radiometer**. Journal of Climate, Volume 18, Issue 22, 2005, pp.4772-4784.
- 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
- Pavolonis, M.J., 2011: GOES-R Advanced Baseline Imager (ABI) Algorithm Theoretical Basis Document for Cloud Type and Cloud Phase, Version 2.0, 86 pp.

Outline

- Introduction
- Requirements
- Operations Concept
- Cloud Mask
- Cloud Phase
- Cloud Height
- NCOMP
- Software Architecture and Interfaces
- Detailed Design
- Algorithm Package
- Quality Assurance
- Risks and Actions Summary
- Summary and Conclusions

Algorithm Theoretical Basis: VIIRS Cloud-top Height, Temperature and Pressure

Presented by

Andrew Heidinger
Cloud Height Algorithm Lead
STAR

Algorithm Theoretical Basis

- Purpose: Provide product developers, reviewers and users with a theoretical description (scientific and mathematical) of the JPSS-RR VIIRS Cloud Top Height, Cloud Top Temperature, Cloud Top Pressure and Cloud base height algorithms

- Will be documented in the ATBD of JPSS-RR VIIRS Cloud Top physical products

CDR Requirements Cloud Top Height

Name	User & Priority	Geographic Coverage (Global)	Vertical Res.	Horiz. Res.	Mapping Accuracy	Msmnt. Range	Msmnt. Accuracy	Refresh Rate/Coverage Time	Allocated Ground Latency	Product Measurement Precision
Cloud Top Height	VIIRS	Global	Cloud Top	0.75 km	0.75 km	100 – 1000 mb	500 m (for low level clouds with emissivity > 0.8)	90 min	30 minutes from receipt	1.3 km

CDR Requirements
Cloud Top Height

Name	User & Priority	Geographic Coverage (Global)	Temporal Coverage Qualifiers	Product Extent Qualifier	Cloud Cover Conditions Qualifier	Product Statistics Qualifier
Cloud Top Height	VIIRS	Global	Day and night	Quantitative out to at least 70 degrees LZA and qualitative beyond	Clear conditions associated with threshold accuracy	Over specified geographic area

CDR Requirements
Cloud Top Pressure

Name	User & Priority	Geographic Coverage (Global)	Vertical Resolution	Horizontal Resolution	Mapping Accuracy	Measurement Range	Measurement Accuracy	Refresh Rate/Coverage Time	Allocated Ground Latency	Product Measurement Precision
Cloud Top Pressure	VIIRS	Global	Cloud Top	0.75 km	0.75 km	100 – 1000 mb	50 mb (for low level clouds with emissivity > 0.8)	at least 90% coverage of the globe every 12 hours (monthly average)	30 minutes from receipt	10 mb

CDR Requirements
Cloud Top Pressure

Name	User & Priority	Geographic Coverage (Global)	Temporal Coverage Qualifiers	Product Extent Qualifier	Cloud Cover Conditions Qualifier	Product Statistics Qualifier
Cloud Top Pressure	VIIRS	Global	Day and night	Quantitative out to at least 70 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

CDR Requirements
Cloud Top Temperature

Name	User & Priority	Geographic Coverage (Global)	Vertical Res.	Horiz. Res.	Mapping Accuracy	Msmnt. Range	Msmnt. Accuracy	Refresh Rate/Coverage Time	Allocated Ground Latency	Product Measurement Precision
Cloud Top Temperature	VIIRS	Global	At Cloud Tops	0.75 km	0.75 km	180 – 300 K	1.0 K for known emissivity = 1.0 and known atmosphere and low clouds; 3 K for low level cloud emissivity > 0.8	at least 90% coverage of the globe every 12 hours (monthly average)	30 minutes from receipt	1 K

CDR Requirements
Cloud Top Temperature

Name	User & Priority	Geographic Coverage (G,lobal)	Temporal Coverage Qualifiers	Product Extent Qualifier	Cloud Cover Conditions Qualifier	Product Statistics Qualifier
Cloud Top Temperature	VIIRS	Global	Day and night	Quantitative out to at least 70 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

CDR Requirements
Cloud Layers/Heights & Thickness

Name	User & Priority	Geographic Coverage (Global)	Vertical Res.	Horiz. Res.	Mapping Accuracy	Msmnt. Range	Msmnt. Accuracy	Refresh Rate/Coverage Time	Allocated Ground Latency	Product Measurement Precision
Cloud Layers/ Heights &Thickness	VIIRS	Global	1 cloud layer	0.75 km	0.75 km	Thickness: only by general cloud type. Heights of up to 1 layers	Thickness: 80% corrected typing. Height: By general cloud type	90 min	30 min from receipt	Thickness: 50% in thickness; Heights: 30% in height

CDR Requirements
Cloud Layers/Heights & Thickness

Name	User & Priority	Geographic Coverage (Global)	Temporal Coverage Qualifiers	Product Extent Qualifier	Cloud Cover Conditions Qualifier	Product Statistics Qualifier
Cloud Layers/ Heights &Thickness	VIIRS	Global	Day and night	Quantitative out to at least 70 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

Differences with GOES-R Algorithm

The GOES-R AWG Cloud Height Algorithm (ACHA) is the basis of the JPSS-RR algorithm. The differences are summarized as:

- **Channel set is 8.5, 11 and 12 μm.**
- **OE covariance matrices are reformulated to include off-diagonal elements**
- **Multi-layer solution expanded in complexity**
- **Determination of *a priori* modified**
- **Incorporates latest ice scattering models**
- **Improved estimation of optical depth.**
- **Optical depth used to estimate cloud base height.**

CDR Algorithm

- Modification of the GOES-R AWG solution (ACHA) for the longwave IR channels on VIIRS (8.5,11 and 12 μm)
  - Uses 11, 12 and 8.5 μm observations to estimate cloud temperature, emissivity and a μ-physical index (β).
  - Use an optimal estimation framework to allow each piece of information to contribute appropriately to the final solution.
  - Temperature coupled with NWP profiles used to estimate height and pressure
  - Optical depth and particle size derived for emissivity and β using assumed scattering models. Used to derive cloud base height.

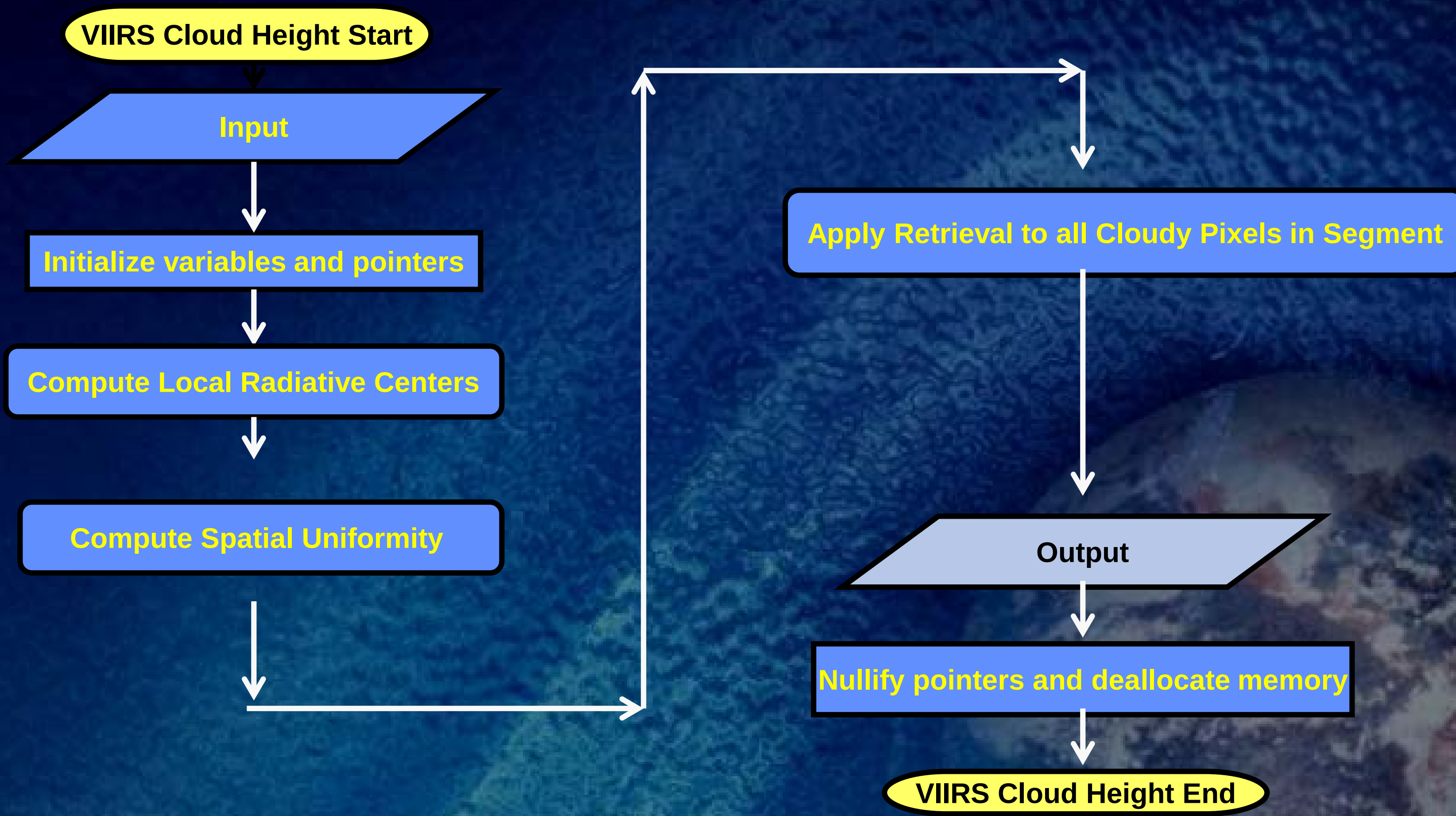
CDR Algorithm

- **Rationale for selection**
  - » The VIIRS is lacking the 13.3 μm channel available on ABI.
  - » In addition, no IR absorption bands are available unless CrIS data is available (assumed not in short-term).
  - » The AVHRR algorithm is applicable to VIIRS but performance is improved with the 8.5 μm channel.
  - » The IDPS nighttime algorithm uses the 3.75 μm channel. This algorithm is currently not performing well and we feel the day/night consistency of a totally longwave IR approach is the best.

Algorithm Objectives

- Meet the NOAA GOES-R requirements for cloud-top height, pressure and temperature.
- Provide additional products of cloud emissivity and microphysical index. These products are derived automatically in the cloud height algorithm and offer value to our customers.
- Provide needed performance information to allow for proper use of our products.
- Provide information quick enough for use by the AMV algorithm.

Processing Outline



Cloud Height Sensor Inputs

VIIRS Band	Central Wavelength (µm)	Sub-satellite IGFOV (km)	Sample Use (in current algorithm)
M1	0.412	0.75	
M2	0.445	0.75	
M3	0.488	0.75	
M4	0.555	0.75	
M5	0.672	0.75	
M6	0.746	0.75	
M7	0.865	0.75	
M8	1.240	0.75	
M9	1.378	0.75	
M10	1.610	0.75	
M11	2.250	0.75	
M12	3.700	0.75	
M13	4.050	0.75	
M14	8.550	0.75	Core ACHA for VIIRS
M15	10.763	0.75	Core ACHA for VIIRS
M16	12.013	0.75	Core ACHA for VIIRS
CrIS	13.3	tbd	CrIS convolved Channel

Current Input Expected Added Input Possible Added Input

Cloud Height Input
Sensor Input Details

JPSS-RR VIIRS Cloud Height requires for each pixel:

- Calibrated/Navigated VIIRS brightness temperatures/radiances/reflectances
- Spectral response information
- Solar-view geometry (satellite zenith, relative azimuth, solar zenith)
- Geolocation (latitude, longitude)

Possible Added Input

Name	Type	Description	Dimension
M14 brightness temp/radiances	input	Calibrated VIIRS level 1b brightness temperatures for channel M14	Scan grid (xsize, ysize)
M15 brightness temp/radiances	input	Calibrated VIIRS level 1b brightness temperatures for channel M15	Scan grid (xsize, ysize)
M16 brightness temp/radiances	input	Calibrated VIIRS level 1b brightness temperatures for channel M16	Scan grid (xsize, ysize)
Pseudo ABI Channel 16 from CrIS	input	Calibrated brightness temperatures from CrIS convolved with the GOES-R ABI Channel 16 SRF.	Scan grid (xsize, ysize)

Cloud Height Input Sensor Input Details

Name	Type	Description	Dimension
Latitude	Input	VIIRS Latitude	Scan grid (xsize, ysize)
Longitude	Input	VIIRS Longitude	Scan grid (xsize, ysize)
Time	Input	Time of image	Scan grid (xsize, ysize)
View angles	input	VIIRS view zenith angle	Scan grid (xsize, ysize)
QC flags	input	VIIRS quality control flags with level 1b data	Scan grid (xsize, ysize)

Algorithm Input: Ancillary Data

- Three types of ancillary data needed:
  - » Static Non-VIIRS Data: M14, M15 and M16 surface emissivities. Land/sea mask, Surface elevation
  - » Dynamic Non-VIIRS Data: RTM clear-sky radiances, RTM cloudy radiance profiles, RTM transmittances, NWP troposphere temperatures, NWP profiles, NWP cell numbers, NWP surface and troposphere levels, Snow Mask
  - » VIIRS Derived Data: Cloud Type, Cloud Mask

Cloud Height Input
Ancillary Input Details

- Non-VIIRS Static Data

Name	Type	Description	Dimension
Surface Emissivity	input	SEEBOR (or equivalent) surface emissivity for channels M14,M15 and M16	5 km resolution
Land Mask	input	Derived from global land cover land types	Scan grid (xsize, ysize)
Digital elevation	input	NGDC-GLOBE global digital elevation model with a horizontal resolution of 1km	1 km resolution

Cloud Height Algorithm Input Ancillary Input Details

- Non-VIIRS Dynamic Data

Name	Type	Description	Dimension
Clear-sky radiances	Input	Clear sky radiances for VIIRS channels M14, M15 and M16 derived from CRTM	NWP grid (xsize, ysize)
Cloudy radiance profiles	Input	Cloudy sky radiance profiles for VIIRS channels M14, M15 and M16 derived from CRTM	NWP grid (xsize, ysize)
Atmospheric transmittances	Input	Atmospheric transmittance profiles for VIIRS channels M14, M15, M16 derived from CRTM	NWP grid (xsize, ysize)
NWP troposphere temperature	Input	Temperature of troposphere from NWP for each cell.	NWP grid (xsize, ysize)
NWP pressure, temperature and height profiles	Input	Profiles of NWP temperature, pressure and height for each cell.	NWP grid (xsize, ysize)
NWP Cell number	Input	X and Y cell number for each latitude and longitude	Scan grid (xsize, ysize)
NWP surface and troposphere levels	Input	NWP level for surface and troposphere for each pixel.	NWP grid (xsize, ysize)
Snow Mask	input	Daily global snow and ice mask available at a horizontal resolution of 4km in the northern hemisphere (IMS) and 25km in the southern (SSMI)	4 km resolution

Cloud Height Algorithm Product Precedence Details

- VIIRS products required to run algorithm

Name	Type	Description	Dimension
Cloud Type	Input	Derived VIIRS Cloud Type	Scan grid (xsize, ysize)
Cloud Mask	Input	Derived VIIRS Cloud Mask	Scan grid (xsize, ysize)

Cloud Height Algorithm Output

Name	Type	Description	Dimension
cloud_top_temperature	output	cloud top temperature product: Cloud top temperature in Kelvin	grid (xsize, ysize)
cloud_top_pressure	output	cloud top pressure product: Cloud top pressure in hPa	grid (xsize, ysize)
cloud_top_height	output	cloud top height product: Cloud top height in meters	grid (xsize, ysize)
cloud_emissivity	output	cloud top emissivity product: Cloud top emissivity	grid (xsize, ysize)
Cloud_base_height	output	Cloud base height	Grid (xsize,ysize)
Cloud_water path	output	Integrated ice/water path	grid (xsize,ysize)
quality_flags*	output	cloud top product quality flags	grid (xsize, ysize)
meta_data	output	Meta data (processing path decision)	grid (xsize, ysize)

Retrieval Strategy

As stated before, we are producing cloud-top height, temperature and pressure. Our strategy is:

- Use a physical-model based approach to take advantage of advancements in radiative transfer modeling, knowledge of surface radiative properties and NWP quality.
- In recognition that other algorithms (AMV) are relying on us, we are emphasizing computational efficiency.
- In recognition that cloud top pressure is being used in NWP assimilation, we prefer a solution that provides estimates of its own error. Therefore, we use an *optimal estimation* framework to perform the retrieval because it is efficient, stable and well-accepted in the community and provides errors estimates.

Physical Description: General Overview

BT_{14} = Channel M14 Brightness Temperature

BT_{15} = Channel M15 Brightness Temperature

BT_{16} = Channel M16 Brightness Temperature

T_{cld} = Cloud-top Temperature

e_{cld} = Channel M15 Cloud Emissivity

®$_{15,16}$ = Cloud Emissivity Ratio (15,16)

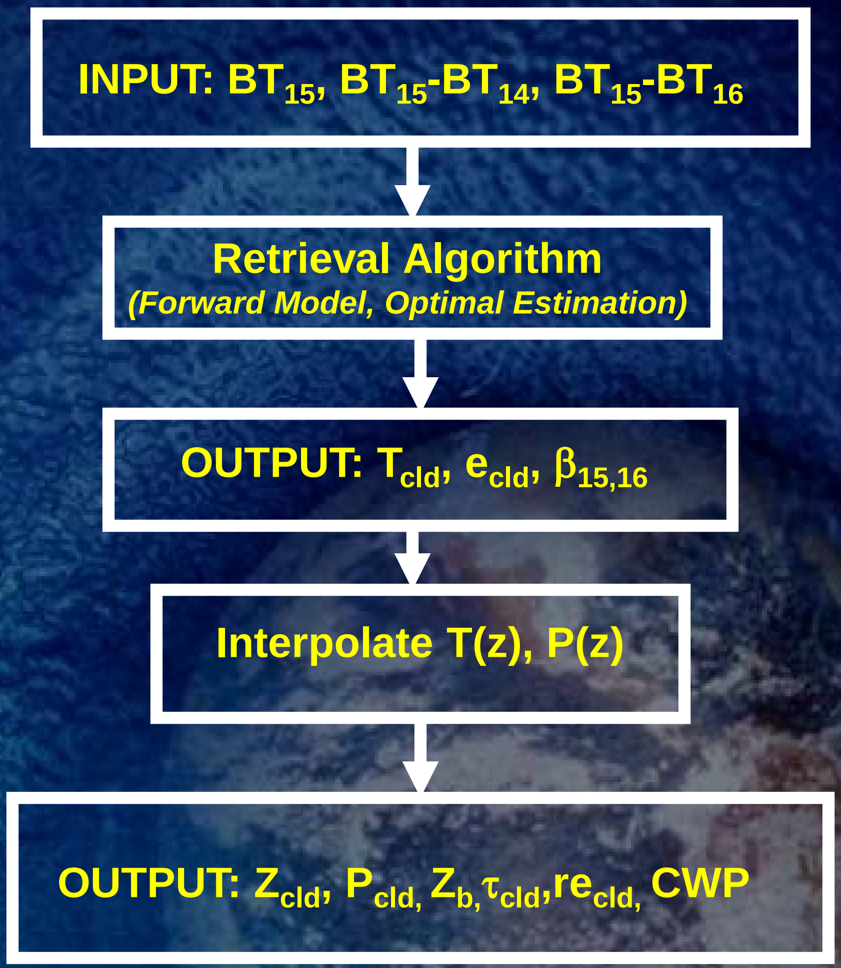
P_{cld} = Cloud-top Pressure

Z_{cld} = Cloud-top Height

Z_b = cloud-base height

T(z) = Temperature Profile

P(z) = Pressure Profile



Note, e_{cld} and β are not products in F&PS but are necessary for estimation of other products.

Physical Description; Rationale for Channel Selection

- As stated before, we are employing a three-channel algorithm (Channels M14,M15 and M16) to retrieve the cloud height products:
  - It replaces the CO_2 channel of ABI (16) with the 8.5 micron channel (M14). This hurts the sensitivity to cirrus due to lack of sensitivity to height provided by a window-only solution.
  - It uses the multiple window channels to gain sensitivity to cloud microphysics to help account for them in the estimation of cloud height.
  - It uses the 11 micron window (channel M15) for overall sensitivity to emissivity and cloud-top temperature. (ISCCP)
  - We see this as a sensible choice for VIIRS using the ABI heritage algorithm. Fusion with CrIS offers additional benefits.

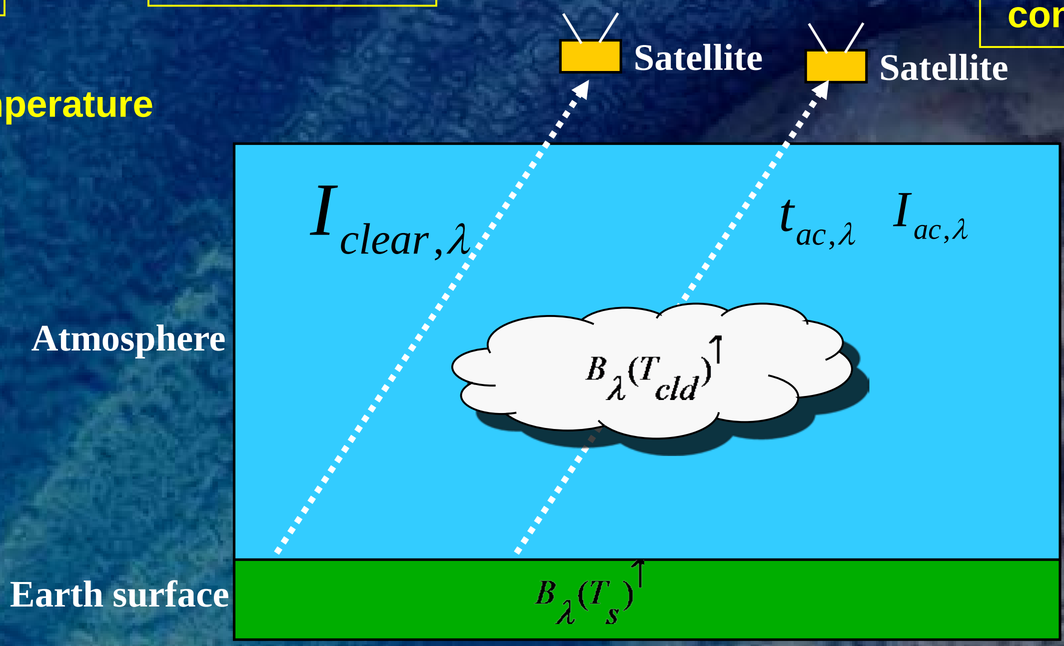
Physical Description
Forward Model I

Equation for the TOA Radiance for a Single Channel (i.e. M15)

$$I_{15} = \underbrace{I_{ac,15}\ +}_{\text{Atmospheric Contribution above the cloud}}\ \underbrace{t_{ac,15}\, e_{cld,15}\, B_{15}(T_{cld})}_{\text{Cloud Contribution}}\ +\ \underbrace{I_{clear,15}(1-e_{cld,15})}_{\text{Surface and atmosphere below cloud contribution}}$$

Conversion to Brightness Temperature

$$BT_{15} = B^{-1}_{15}(I_{15})$$



Legend

- B = Planck Function
- B^{-1} = Inverse Planck Function
- I = radiance
- BT = Brightness Temperature
- t_{ac} = above cloud transmission
- I_{ac} = above cloud emission
- e_{cld} = cloud emissivity
- T_{cld} = Cloud Temperature

Physical Description: Forward Model 2

- The previous forward model predicts a radiance in a single channel.
- Our retrieval requires us to predict and relate multiple observations to each other.
- Channel observations are related to each other via the microphysical parameter, β, defined as

$$\beta = \ln(1-e_{cld,y}) / \ln(1-e_{cld,x})$$

$e_{cld,x}$ = cloud emissivity for channel x
$e_{cld,y}$ = cloud emissivity for channel y
ln() = natural logarithm function

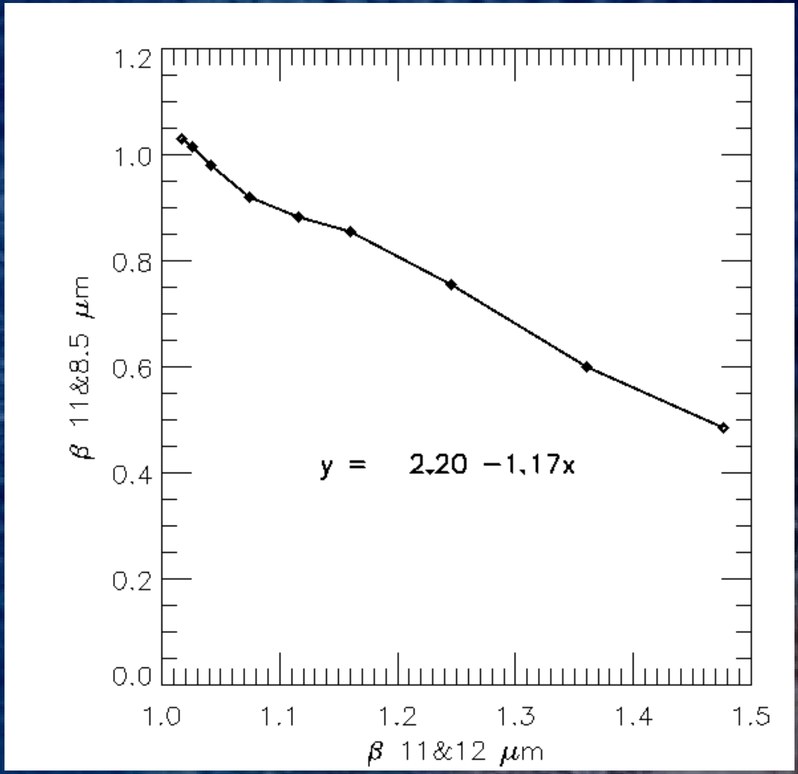
β is related directly to particle size and is therefore a direct measure of cloud microphysics and was described in detail in the cloud typing presentation.

This allows us to write the single channel RT equation for channels M14 and M16 in terms of the cloud emissivity in channel M15 and β values relative to channel M15. (It ties them all together)

Physical Description: Microphysical Assumptions

- The retrieval needs to relate the β values computed at 11 and 12 μm to those computed at 11 and 8.5 μm.
- To accomplish this, we needed to pre-compute their variation and fit it as a polynomial.
- Water clouds were simulated with Mie theory for spherical droplets.
- Ice clouds were simulated using one of the habits in the data-base provided by Professor Ping Yang of Texas A&M. For the current version, we have chosen aggregates as the preferred habit. Our validation studies have supported this choice.

Example linear relationship computed for $\beta_{15,16}$ and $\beta_{15,14}$ for ice aggregates



Physical Description: Derivation of Cloud-top Pressure and Temperature

- The retrieval fundamentally estimates the cloud temperature (T_{cld}).
- Knowing, T_{cld} we use the available atmospheric profile information to find the pressure and height level that corresponds to T_{cld}
- We linearly interpolate within the profile to compute exact P_{cld} and Z_{cld} values.
- Our current source of atmospheric profile information is the NCEP Global Forecast System (GFS).
- For low clouds in the presence of inversions, we employ a different technique (2 slides forward)

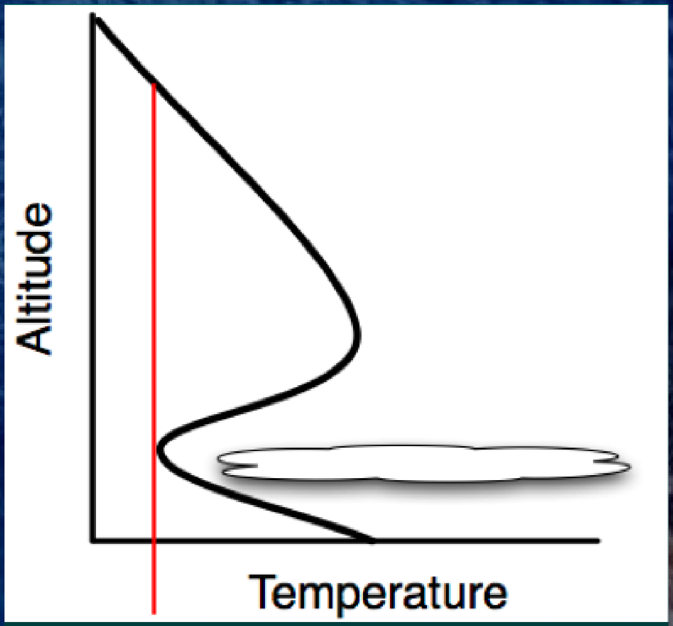
Physical Description: Derivation of Cloud-base Height

- Knowing, emissivity and β, we can estimate optical depth and particle size from scattering parameterizations.
- Knowledge of phase, optical depth and particle size allows us to predict extinction of cloud.
- From the optical depth and extinction, we can estimate geometrical thickness of cloud.
- We can also predict the geometrical depth into the cloud corresponding to the retrieved cloud height.
- From this information, we estimate the true physical top and base height of the cloud. True top is not reported.

Physical Description: Low Level Inversions

- When atmospheric inversions are present, a value of T_{cld} can correspond to multiple values of P_{cld} and Z_{cld}.
- Low level inversions are very common in many regions (marine stratus).
- We search the NWP profile, if a low-level inversion is found, the lowest cloud height that corresponds to T_{cld} is taken as the final value.
- This methodology has a large impact on the meeting of the specification and has little to do with the VIIRS instrument performance.
- Note the performance for low-level clouds in inversions is not a function of the instrument. It is a function of our knowledge of the profiles within inversions.

Illustration of a cloud in an inversion



Physical Description: Cloud Layer

- Based on the value of P_{cld}, each pixel is determined to be either a high, middle or low level cloud.
- This information is needed for the generation of the cloud cover layers product (the fraction coverage over a larger region of high, middle and low level clouds).
- The high clouds are those with $P_{cld} < 440$ hPa.
- The low clouds are those with $P_{cld} > 680$ hPa.
- These pressure bounds are taken from the ISCCP project and are commonly used in the definition of cloud layers.

Mathematical Description

We have chosen to use an optimal estimation to control the retrieval process.

- Why Optimal Estimation?
  - » Its very flexible. We can add / subtract observations (y) or retrieved parameters (x) without having to develop a retrieval scheme. (ie. We can add the 13.3 channel from CrIS easily in the future).
  - » It is numerically stable. In situations where we have little confidence in our results (*i.e.. very thin cirrus in a coastal region*), the retrieval gracefully falls back to the a priori values (*no erratic behavior*)
  - » It provides diagnostic measures of the performance. If our estimates of the forward model and *a priori* covariances are correct, the error estimates of the retrieved parameters (x) should also be correct.

Mathematical Description: Optimal Estimation Requirements

- The mathematics of optimal estimation are well developed and have been applied to many satellite retrieval problems.

- It requires the following

  » An appropriate forward model.

  » *A priori* estimates or first guesses for each parameter

  » Uncertainty estimates for the *a priori* and the forward model.

  » Ability to efficiently estimate the Kernel matrix where each element is the derivative of each observation to each retrieved parameter.

Mathematical Description
Optimal Estimation Description

- In optimal estimation, each iteration is controlled by the following equation

$$\delta x = S_x K^T \mathbf{S_y}^{-1}[\mathbf{y} - \mathbf{f}(\mathbf{x})] + S_a^{-1}(x_a - x)$$

x = retrieved vector = T_{cld}, e_{cld}, β

δx = increments to x ($x_{i+1} = x_i + \delta x$)

x_a = *a priori* values of x (ie the first guess)

S_a = error covariance of x_a

y = observed vector = BT_{15}, BT_{15}-BT_{14},BT_{15}-BT_{16}

f() = forward model

S_y = error covariance of forward model K = Kernel Matrix (df / dx)

S_x = error covariance of x (derived from K, S_a and S_y)

K = Kernel Matrix or Jacobian

Mathematical Description: The Kernel Matric

- The most computationally intensive calculations are used to compute the Kernel Matrix (K) where each element of K is the partial derivate of each modeled observation (f) to each retrieved parameter (x).

$$K_{i,j} = \partial f_i / \partial x_j$$

• For example, the first row of K has the terms like: dBT_{14} / dT_{cld}, dBT_{14} / de_{cld}, $dBT_{14} / d\beta$

•Our forward model was designed to make the computation of K easy. We don't have to run the forward model twice to compute the derivatives.

Mathematical Description: Convergence

- Convergence
  - » We use a standard metric for the checking the convergence of optimal estimation.

$$CONV = \sum \partial x S_x^{-1} \partial x$$

  - » When CONV << the rank of x (the number of retrieved parameter = 3), convergence is achieved. In practice, when CONV < 0.1, we stop.
  - » We also stop when the T_{cld} increments fall below 0.1 K.
  - » Typically, convergence is achieved in 3-4 iterations.
  - » It is stopped after 10 iterations

Mathematical Description: Diagnostics

- One major benefit of optimal estimation is that it can automatically diagnose its own performance.

- The error covariance matrix of the retrieved parameters, x is defined as:

$$S_x^{-1} = S_a^{-1} + K^T S_y^{-1} K$$

- We use the diagonal elements to S_x to estimate the uncertainty of each retrieved parameter.

- Of course, the values of S_x are only meaningful if our estimates of the *a priori* and forward model errors are realistic - this is the biggest challenge in using the optimal estimation approach for cloud remote sensing.

- The AMV teams has asked for us to make these diagnostic available to them and we will do this.

Mathematical Description: *a priori* estimates and uncertainties

- Specification of *a priori* (first guess) and its uncertainty.
  - **We analyzed CALIPSO global distributions of T_{cld}, e_{cld} and β separated for each cloud type.**
  - The mean of these distributions were used for the *a priori* value (first guess)
  - The standard deviation of the distribution were used for the *a priori* covariance matrix, S_a.
  - Currently, *a priori* covariance matrix is diagonal
  - For opaque cloud types, the 11 μm brightness temperature is used as first guess for T_c.
  - For cirrus, the *a priori* value of T_c is defined relative to the tropopause.

Mathematical Description: Forward Model Uncertainty

- Specification of the forward model uncertainty.
  - » We have assumed realistic calibration and noise levels (instrument performance is not a driver).
  - » Analysis of clear-sky observations and predicted clear-sky values provided measurements of bias and its variation for land and water surfaces as a function of local time.
  - » The 3x3 spatial deviation of observations are also used to compute the error covariance matrix of the forward model. Our plane parallel model is less accurate in highly heterogeneous scenes.
  - » Forward model error covariance matrix is also assumed to be diagonal.
  - » Improved specification of the forward model error covariance matrix is a goal.

Mathematical Description How to get P and Z from T

- For profiles without an inversion, a binomial search on the profiles of T, Z and P is performed from the surface to the Tropopause.
- The final value is linearly interpolated between the values from the temperature levels that surround the cloud temperature.
- When a low level inversion is present, the profiles are searched upward starting at the surface.

Algorithm Summary

- We chose an approach using Channels M14, M15 and M16 to make a logical step forward based on our GOES and POES heritage
- We retrieve T_{cld}, e_{cld} and $\beta_{14,15}$ directly. We have to retrieve e_{cld} and $\beta_{15,16}$ in order to retrieve T_{cld}.
- We use an optimal estimation approach for its stability, flexibility and for the performance diagnostics it provides.
- We derive P_{cld} and Z_{cld} from T_{cld} and the atmospheric profiles from NWP.
- We plan to extend the algorithm using Channels from CrIS (13.3 μm & 6.7 μm)

Practical Considerations

- Algorithm performance demands accurate NWP and computationally efficient and accurate clear-sky RTM calculations.
- Current NWP and fast clear-sky RTM performance is adequate and we expect improvements.
- Given that the GOES and AVHRR algorithms are already implemented into NESDIS OPS, we believe we have sufficiently solved any issues relating to operational implementation.

Practical Considerations: Exception Handling

- The algorithm checks the sensor data flags to see if each channel is valid.
- If any of the three channels is not valid, the retrieval is not performed.
- If the retrieval is not performed, the retrieved parameters are set to a missing value and the quality flags are set to the lowest quality value.

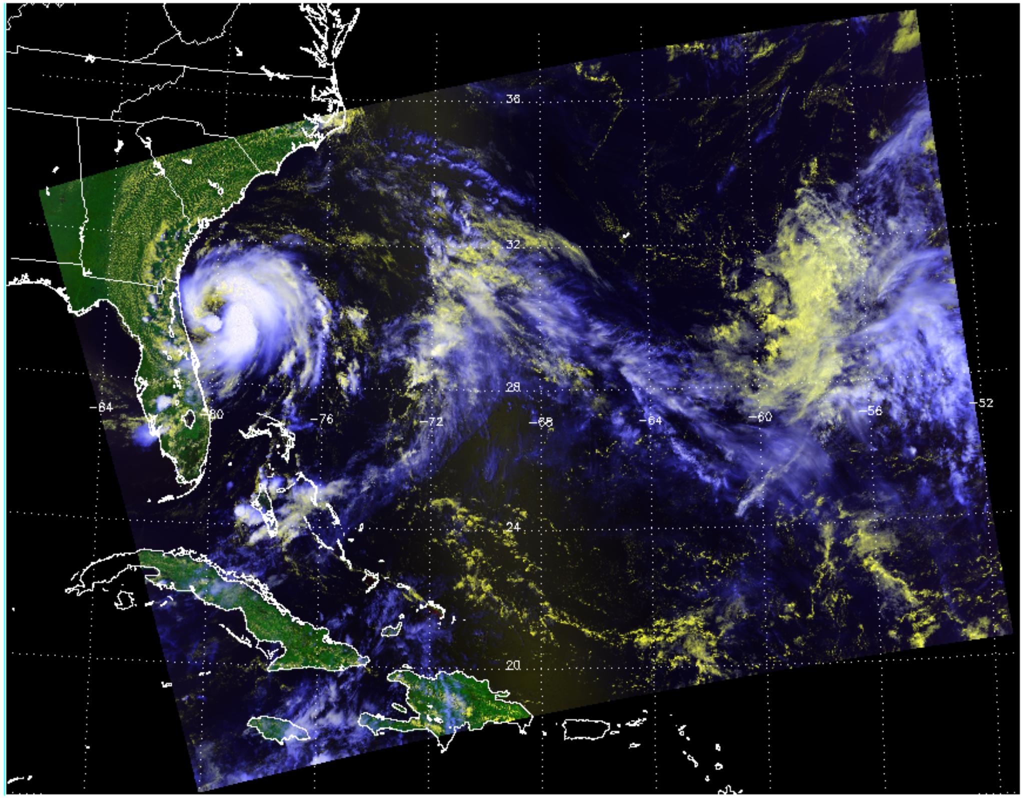
Algorithm Output

The following images show sample output of the VIIRS cloud height algorithm run on a VIIRS scene containing Tropical Storm Beryl (May 27, 2012 17:35 UTC).

The image on the right shows a false color image constructed from channels M5, M7 and M15.

High thick clouds are white while low clouds are yellow.

IFF_npp_viirs_svm_d20120527_t173500_e173959.level2



False Color Image

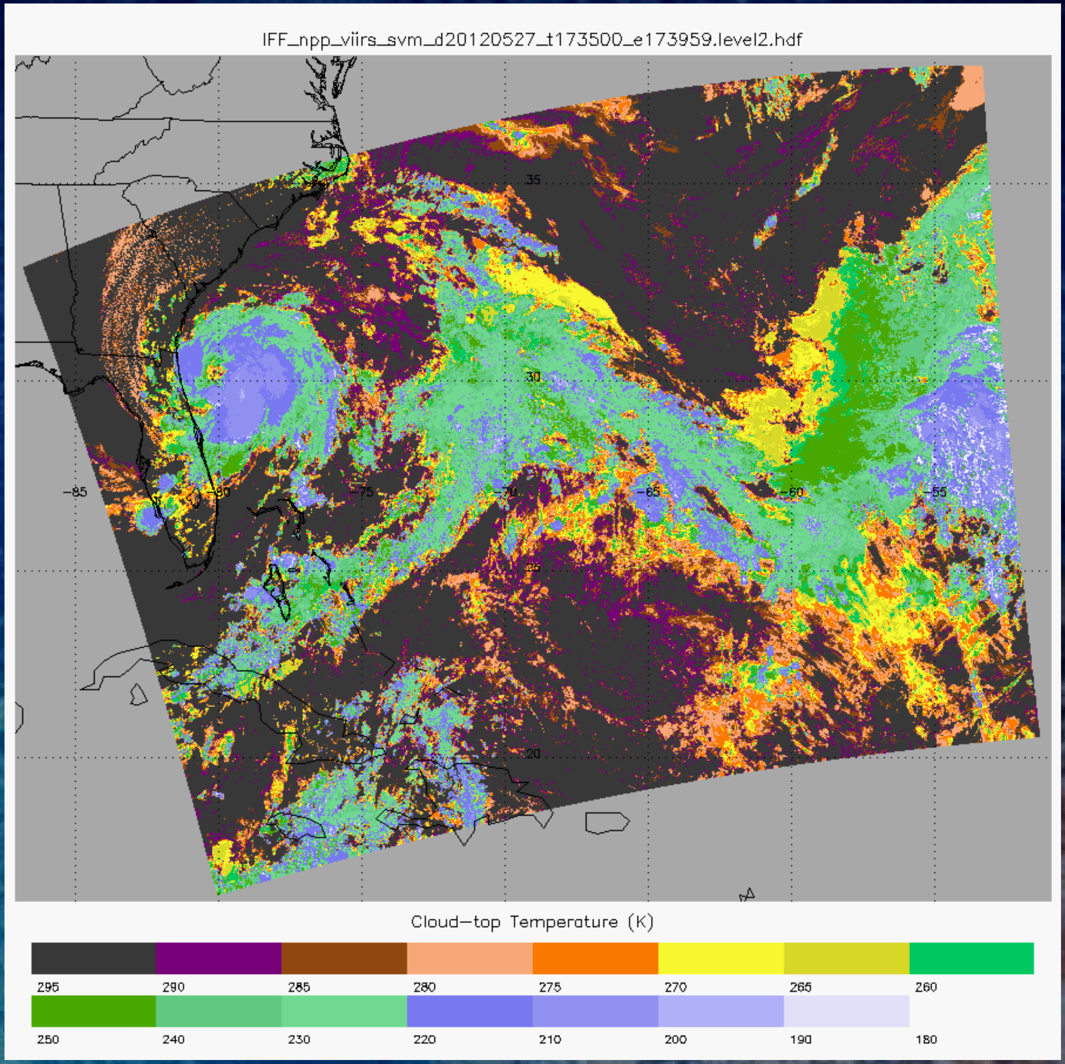
Red=0.63μm, Green = 0.86μm, Blue = 11μm (reversed)

Algorithm Output

Image of the cloud-top temperature.

Light grey regions represent data voids

Dark grey regions represent pixels where no retrieval was performed (i.e. clear-sky)

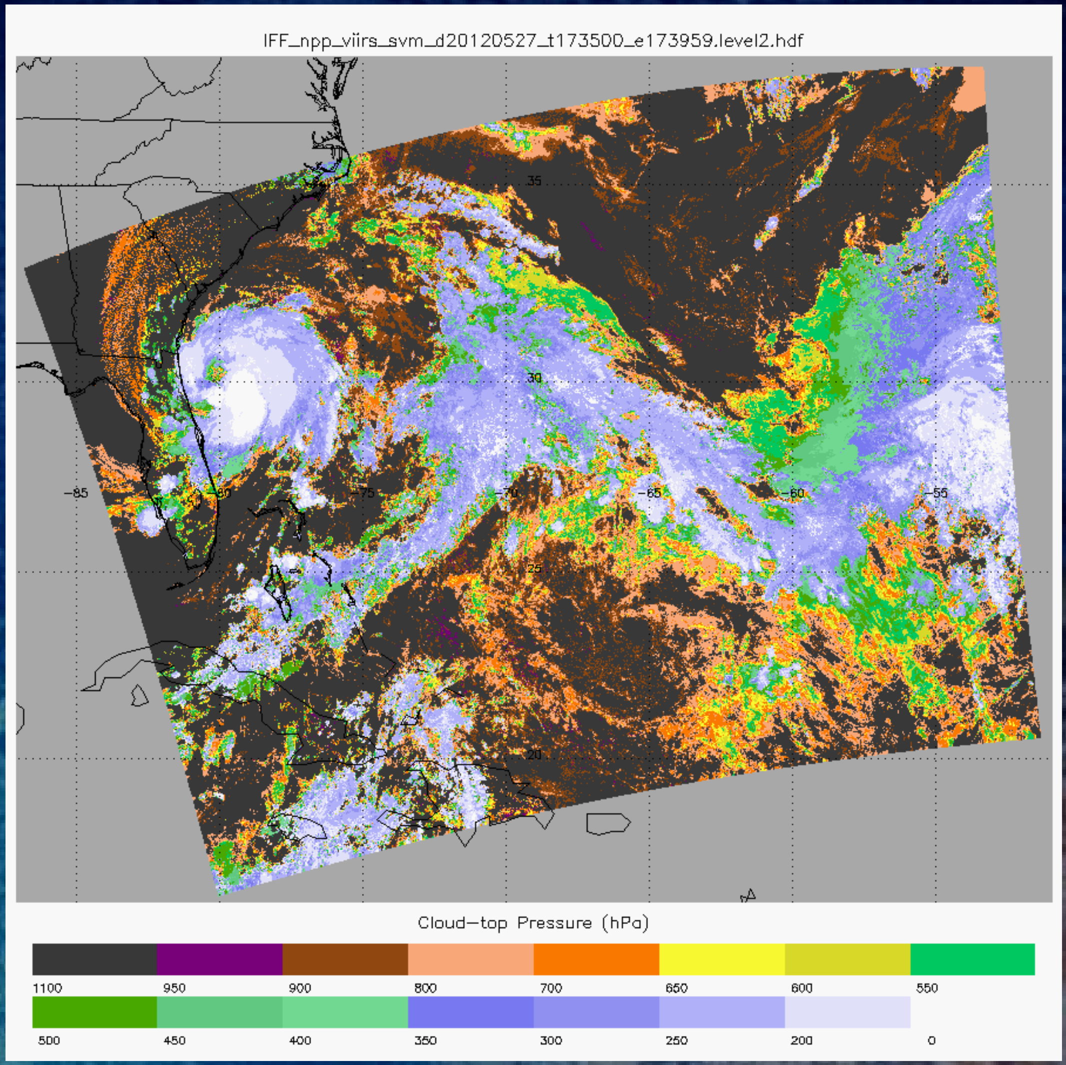


Algorithm Output

Image of the cloud-top pressure.

Light grey regions represent data voids

Dark grey regions represent pixels where no retrieval was performed (i.e. clear-sky)

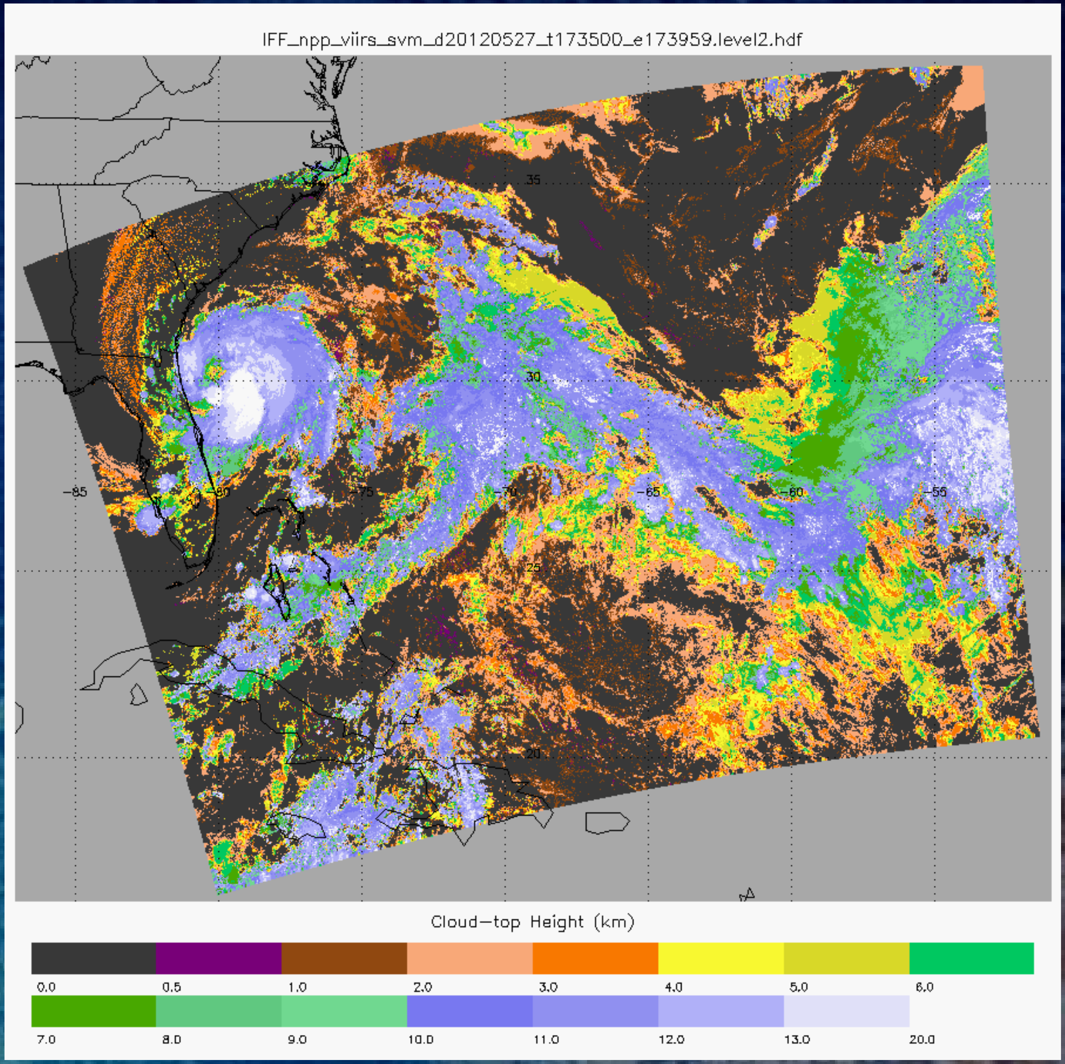


Algorithm Output

Image of the cloud-top height.

Light grey regions represent data voids

Dark grey regions represent pixels where no retrieval was performed (i.e. clear-sky)

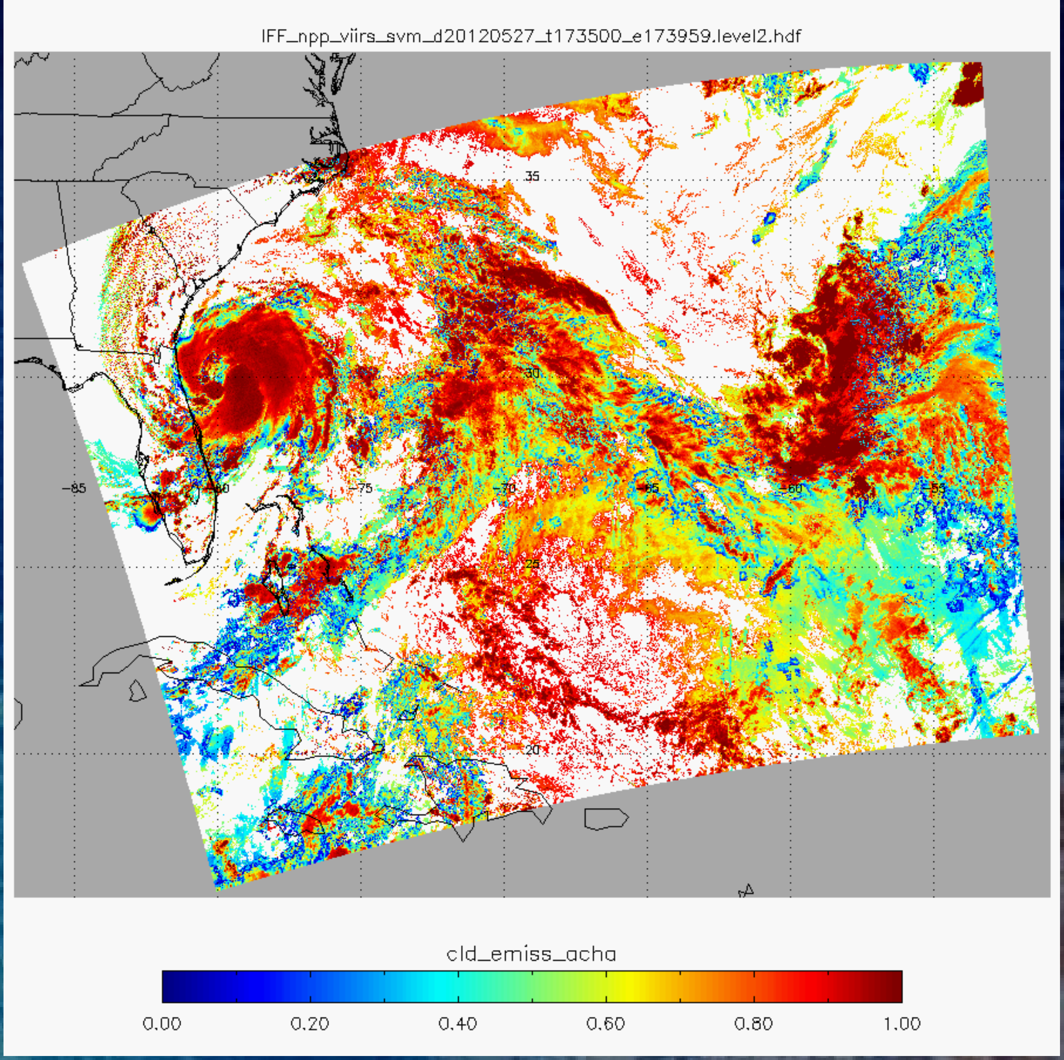


Algorithm Output

Image of the cloud emissivity in channel M15 (11 microns).

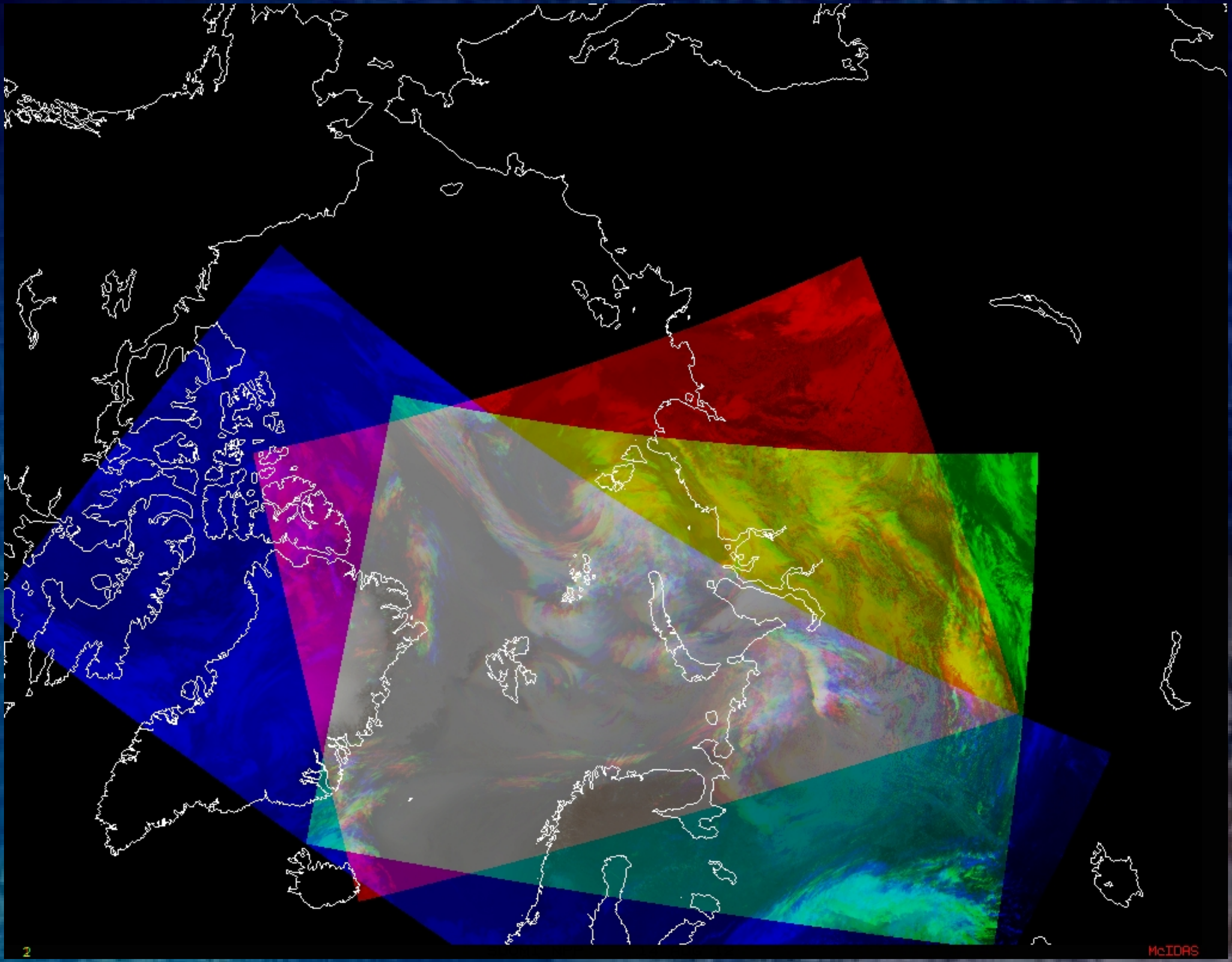
Light grey regions represent data voids

White regions represent pixels where no retrieval was performed (i.e. clear-sky)



Algorithm Output

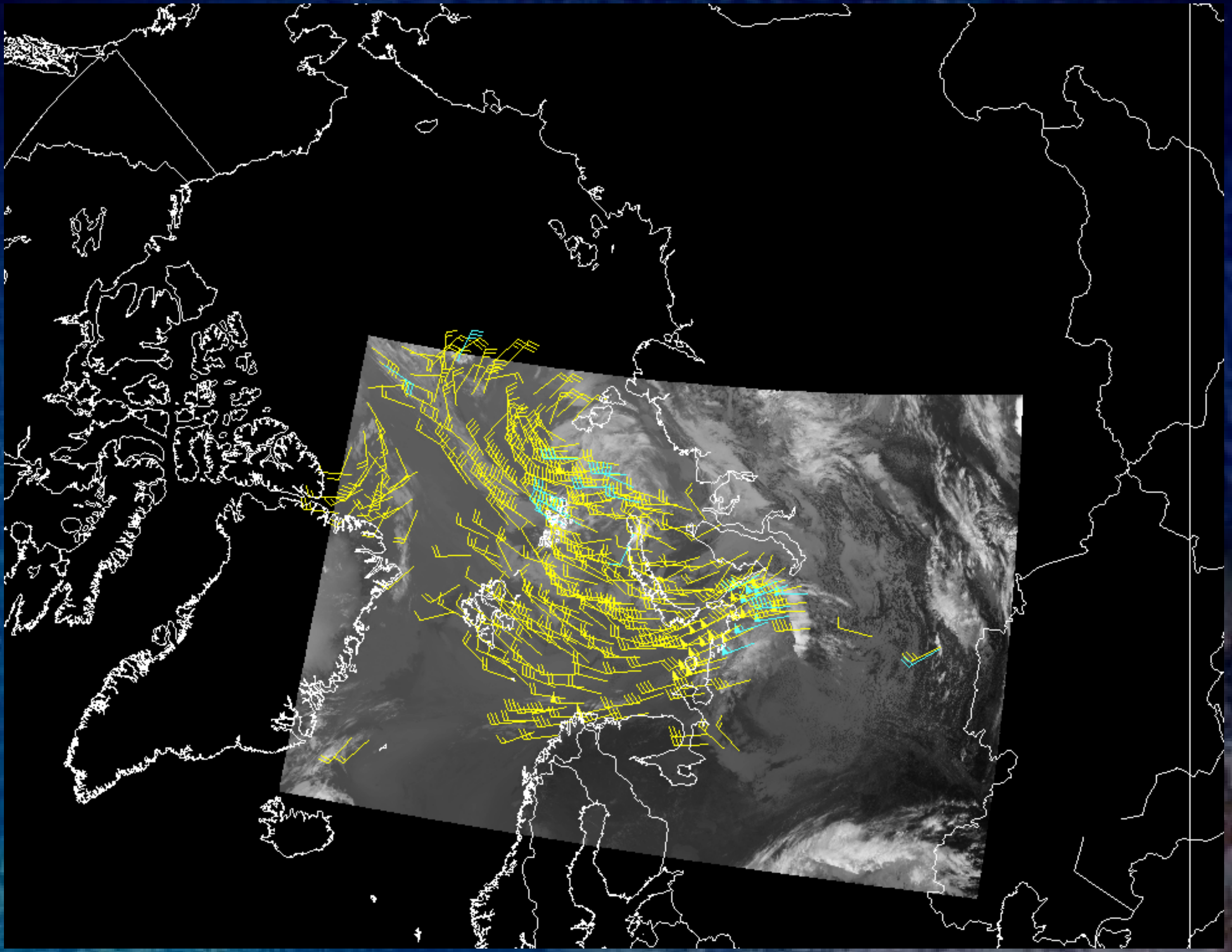
Three orbits of VIIRS data needed for AMV derivation. The grey region represents the overlap of the 3 orbits.



Algorithm Output

Example of VIIRS AMVs over the Arctic. Cyan vectors range from 100-400 hPa. Yellow AMVs are below 400 hPa.

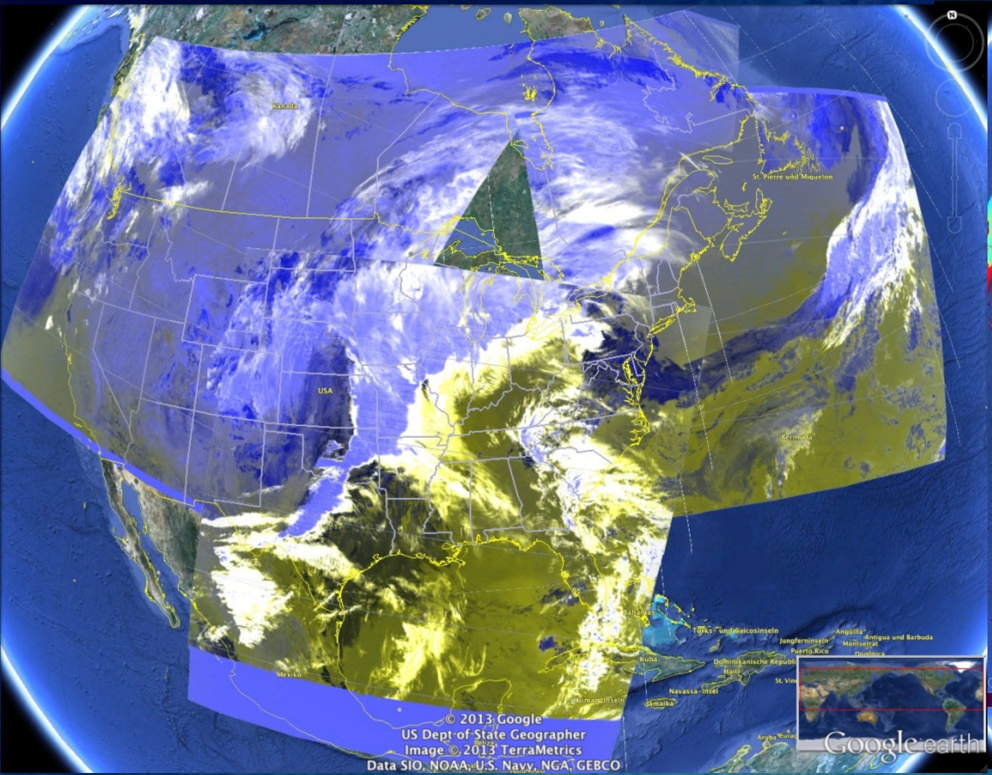
VIIRS cloud mask and cloud pressure are derived for the middle image time and used in the height assignment of each AMV.

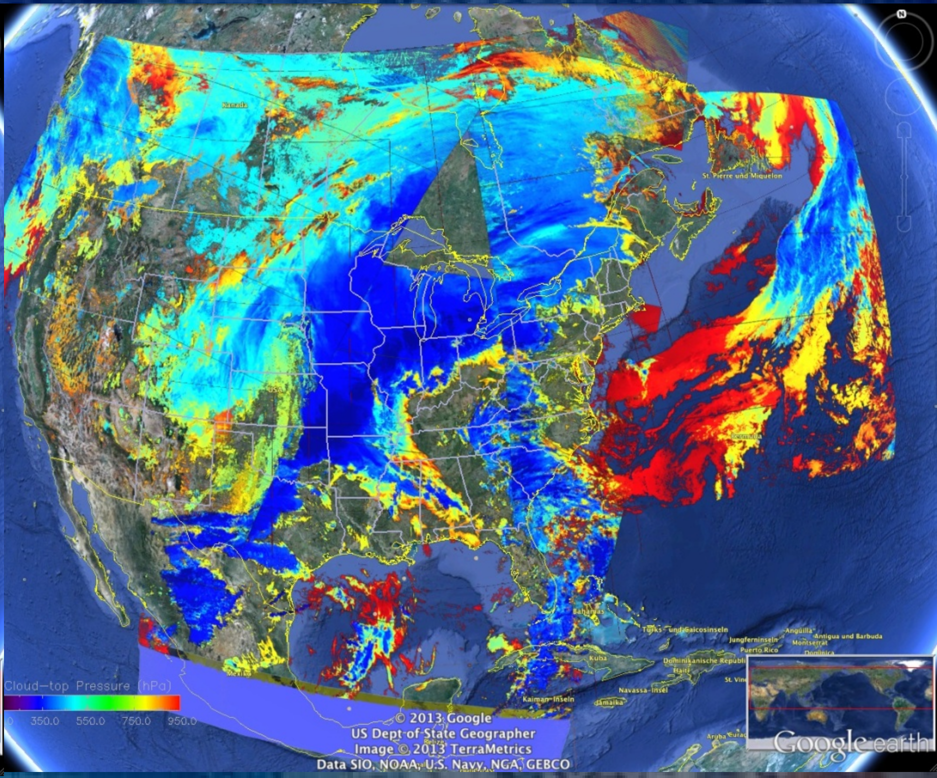


Algorithm Output: Real-Time CTP from UW/SSEC DB

Example of VIIRS Cloud Top Pressure (Right) and a Nighttime False Color (Left).

Data generated automatically in near real-time from UW/SSEC Direct Broadcast





Performance Estimates

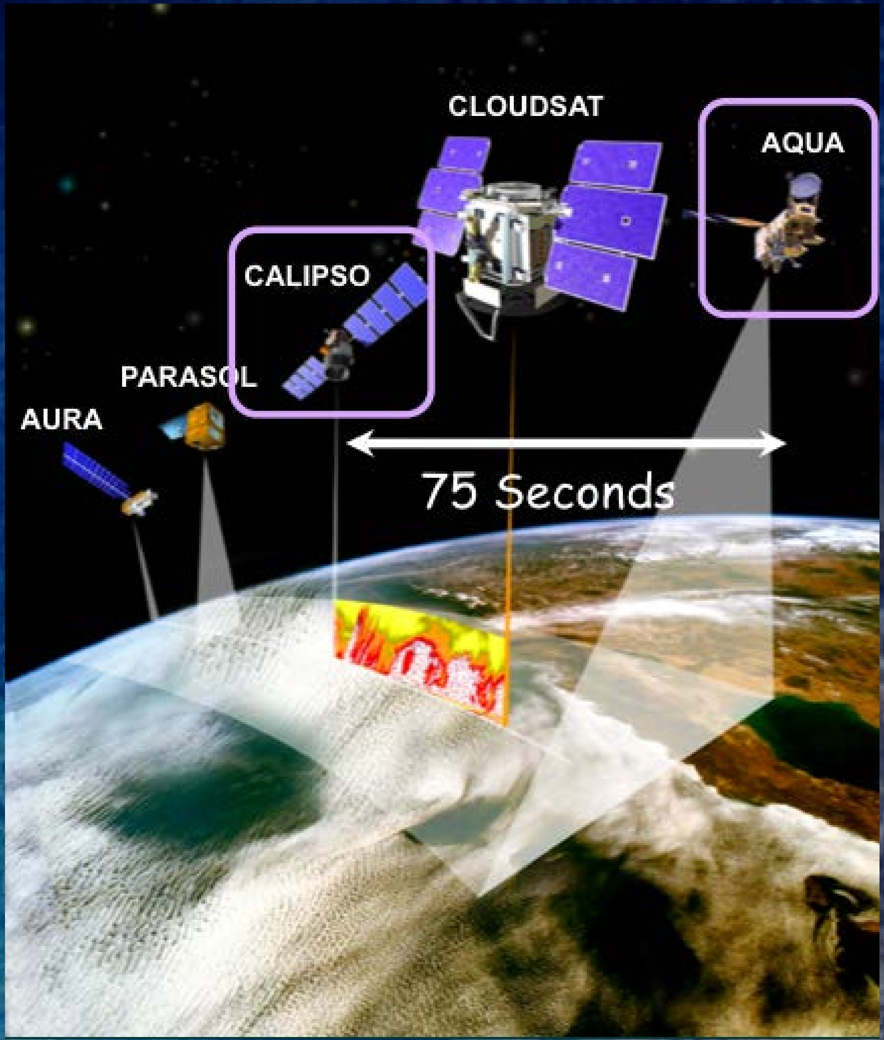
- With the launch of CALIPSO (a lidar) and CLOUDSAT (a radar) into the EOS A-train, we now have unprecedented information on the vertical structure of clouds.

- CALIPSO is very sensitive to the presence of any cloud in the column and therefore is our first choice in cloud height validation.

- The weaknesses of CALIPSO are low snr during the day and difficulty distinguishing cloud from aerosol.

- Even with these weaknesses, CALIPSO is the best we have.

- VIIRS joins the A-Train periodically



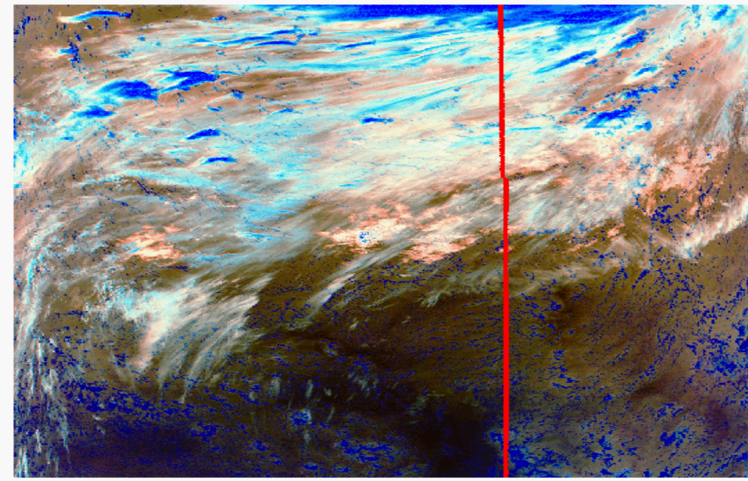
Performance Estimates from CALIPSO

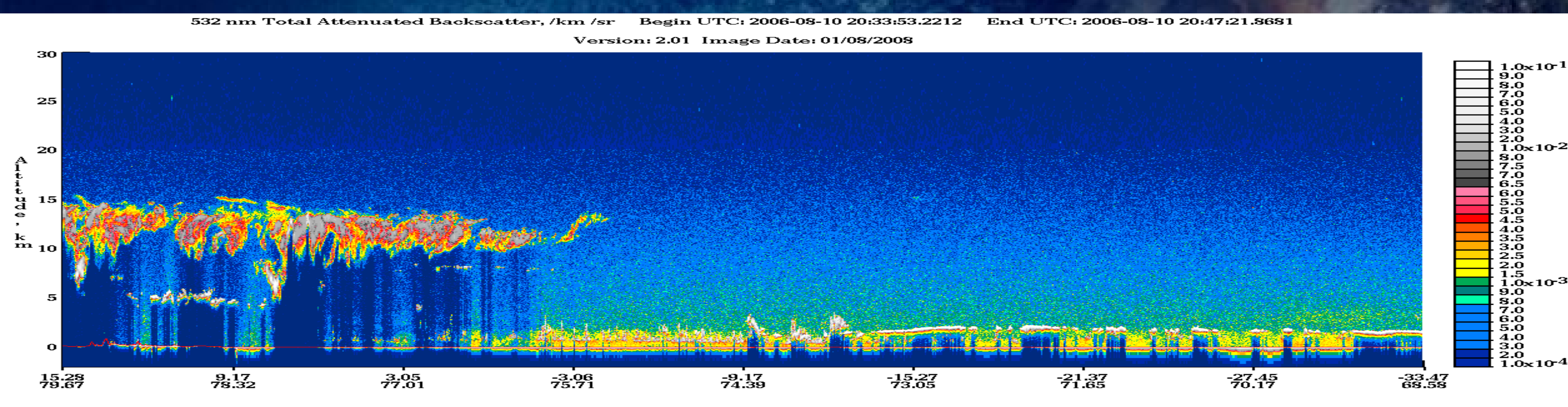
•The images on this page provide an illustration of the information provided by CALIPSO

•CALIPSO provides the height boundaries and mid-layer temperatures for up to 10 layers of cloud in each field of view.

•CALIPSO products are improving and will be able to provide phase and optical thickness.

•CloudSat validation tools are being developed too.





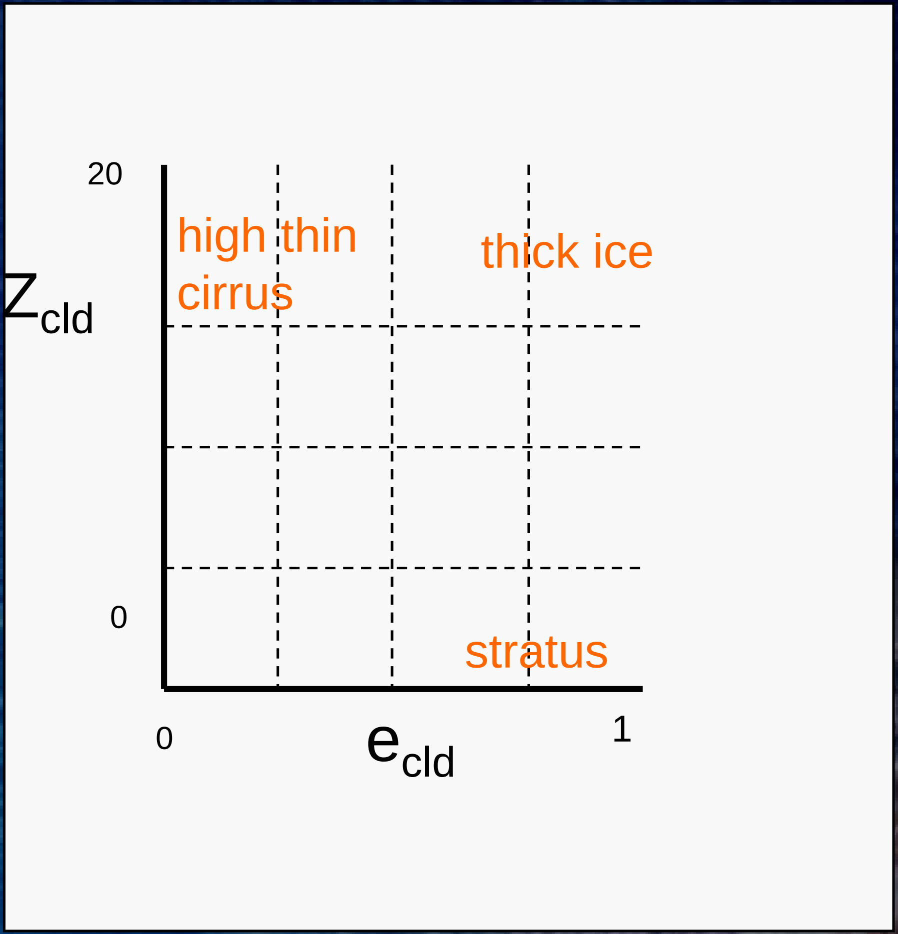
Performance Estimates: Stratifying Performance by Height and Emissivity

- It allows us to globally characterize the performance of several algorithms with respect to cloud height and emissivity – parameters used to stratify specifications in the F&PS.

- CALIPSO data provides cloud height and cloud temperature as standard products.

- Cloud emissivity can be estimated from the cloud temperature (T_c), the observed 11 μm radiance (I) and the computed clear-sky 11 μm radiance (I_{clr}).

$$e_{cld} = (I - I_{clear}) / (B(T_{cld}) - I_{clear})$$

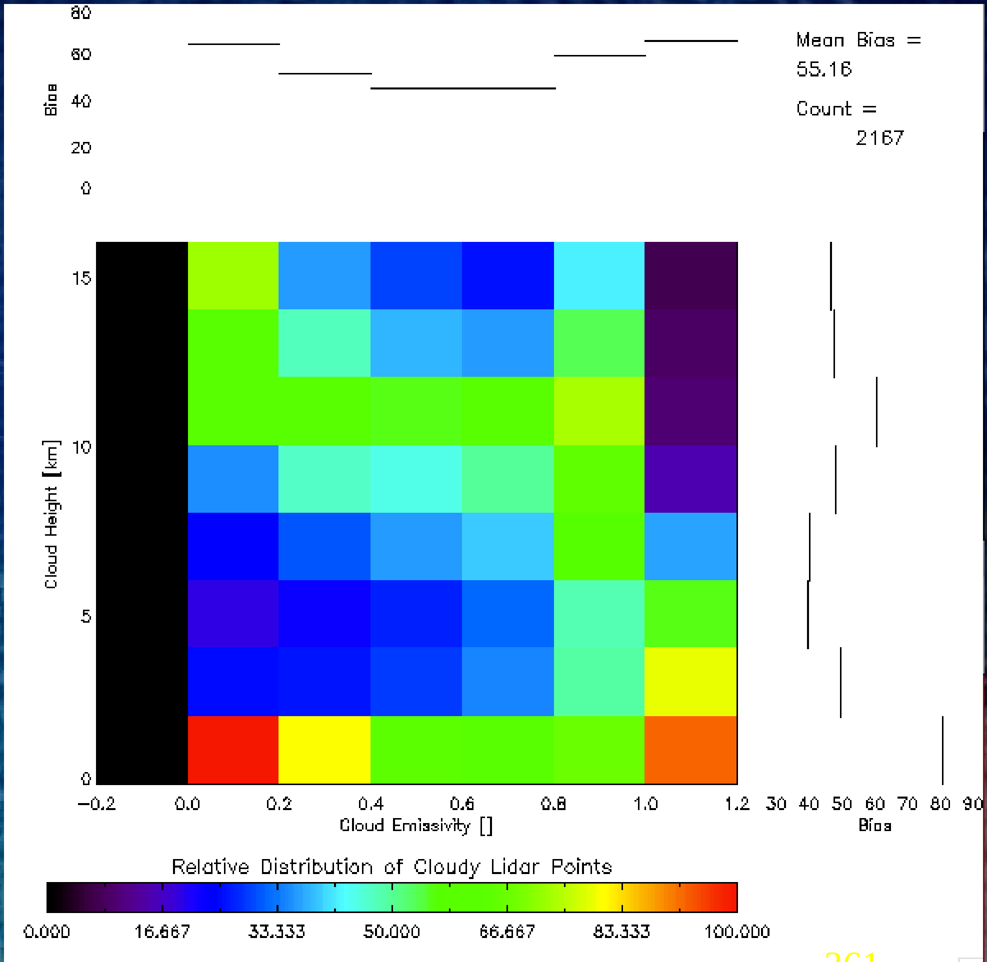


Performance Estimates/ Distribution of Validation Points

- The image on the right shows the distribution in the height / emissivity diagram of all of the CALIPSO cloudy pixels.

- Data set is MODIS for 2010 (x10 days)

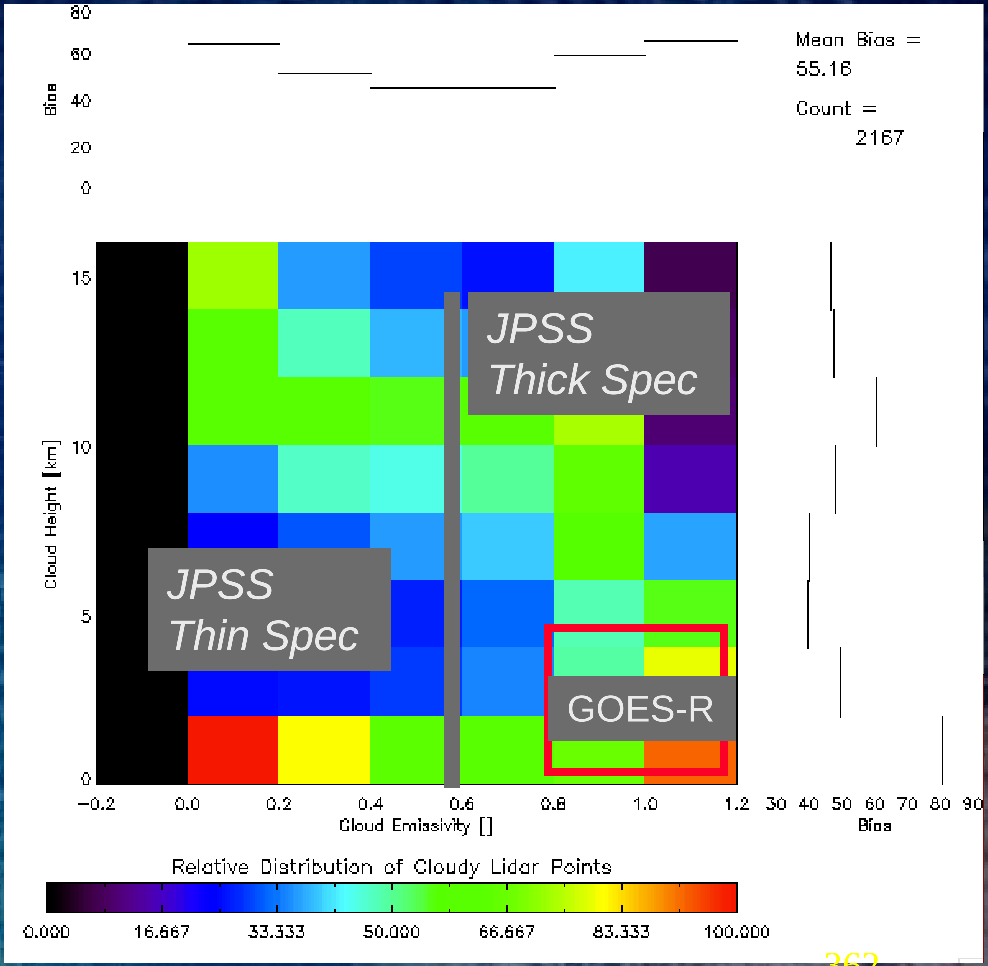
- Largest cluster of points very thin and low (a problem area for CALIPSO)



Performance Estimates/ Distribution of Validation Points

- This image is the same as that on the previous slide.

- The Specification Compliance Regions for GOES-R and JPSS are added.



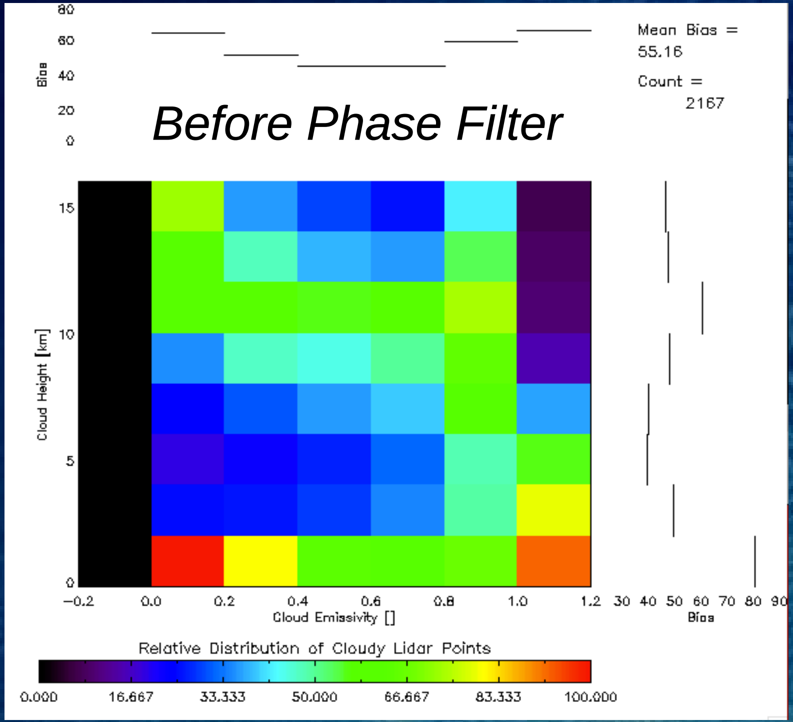
Performance Estimates/ Impact of Mask & Phase Filtering

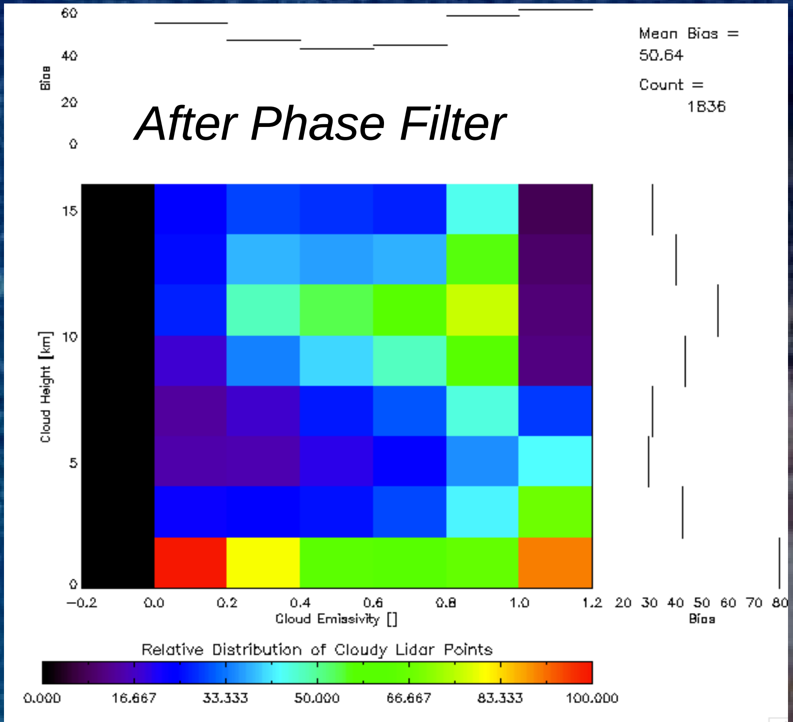
In this analysis, we exclude pixels where the phase is obviously inconsistent with CALIPSO

This has the impact of reducing the weight of very thin cirrus in this analysis.

This legitimately throws out some sampling errors but also does lead to an overestimate in the JPSS-Thin Region.

Impact of cloud mask errors also not included.



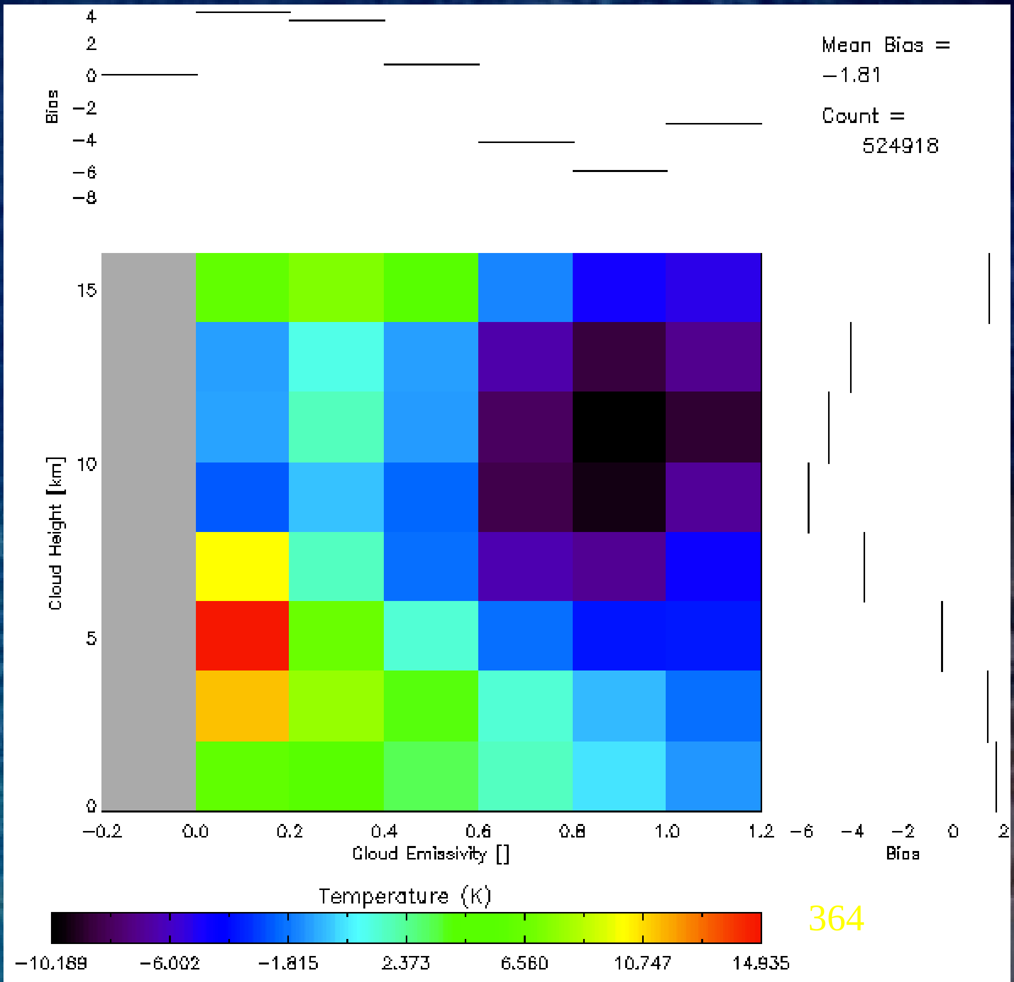


Performance Estimates: T_{cld}

Cloud Temperature – Land, Ocean and Polar 2010 MODIS

Accuracy Specs are in ()

- ALL = -1.8 K (N/A)
- GOER-R = -1K (2K)
- JPSS Thin: 2.4 K (3 K)
- JPSS Thick : -4K (6 K)

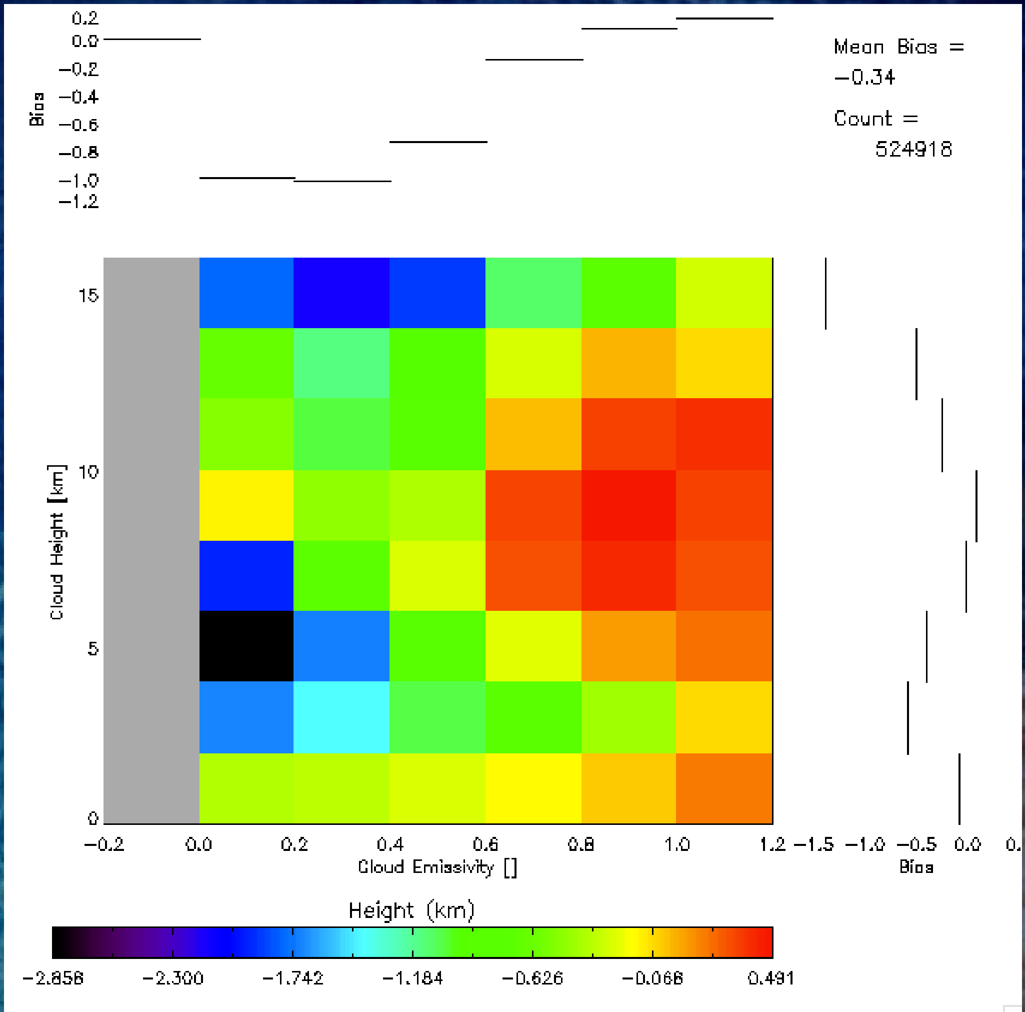


Performance Estimates: Z_{cld}

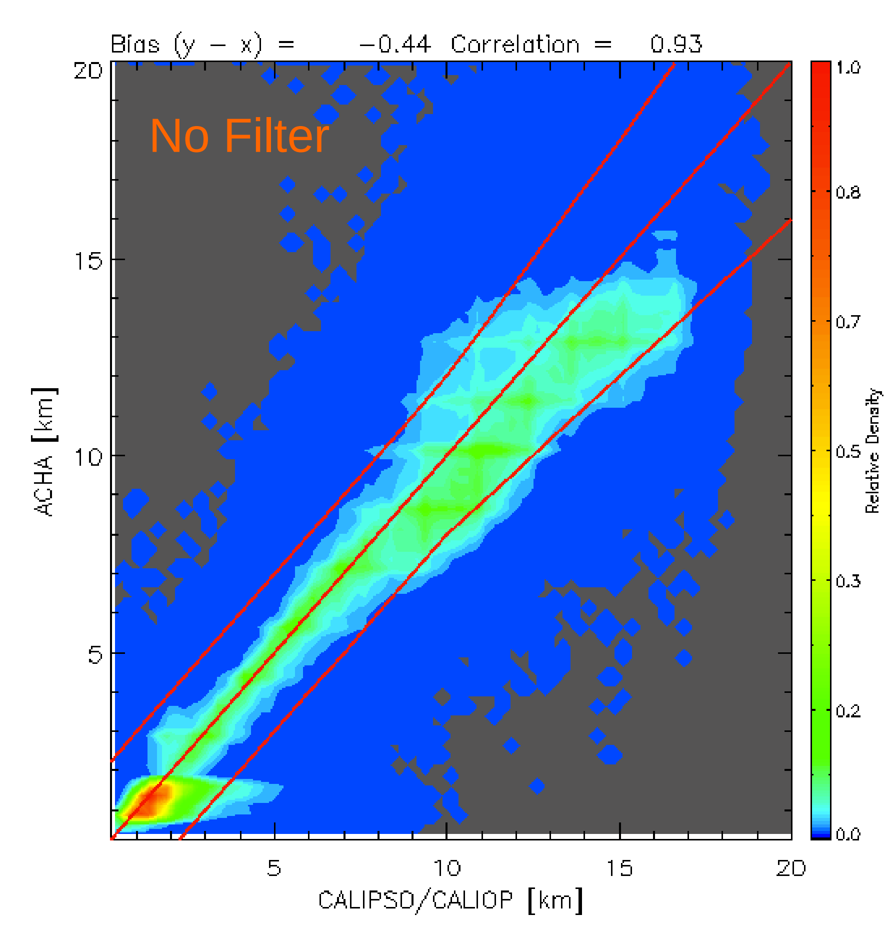
Cloud Height – Land, Ocean and Polar 2010 MODIS

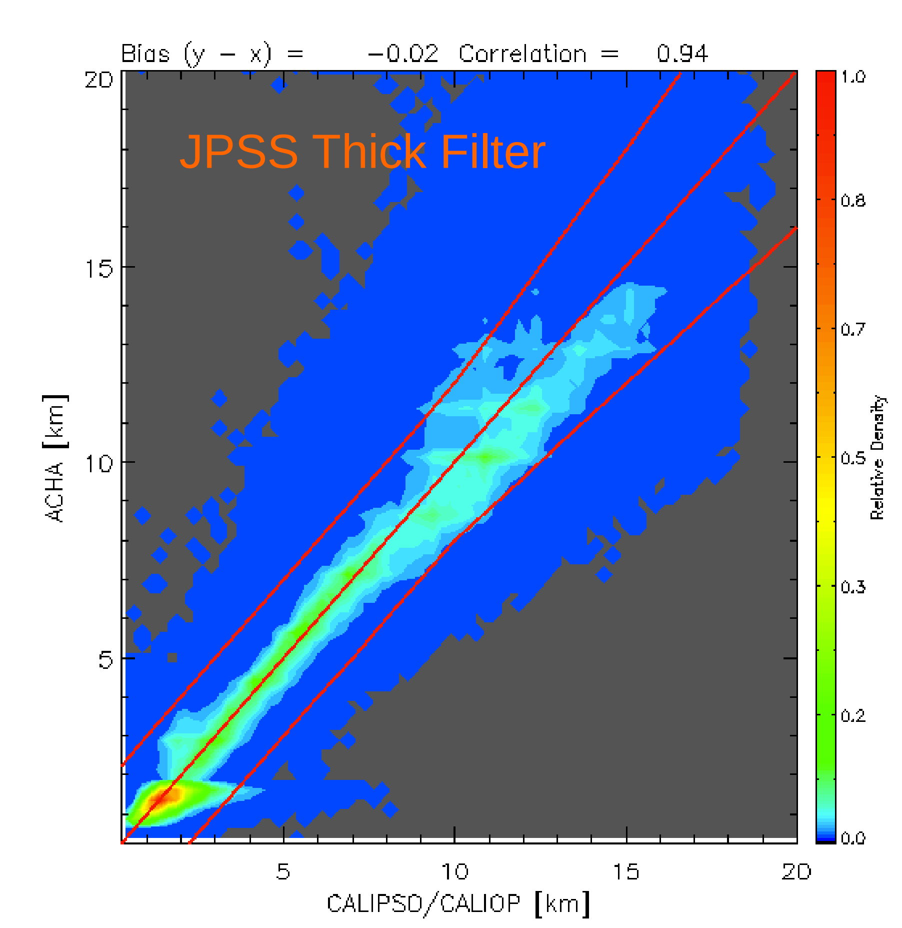
Accuracy Specs are in ()

- ALL = -340m (N/A)
- GOER-R = +10m (500m)
- JPSS Thin = -890 m (1000 m)
- JPSS Thick : +30m (2000 m)



Scatterplots of ACHA vs CALIPSO





Cloud Layer Performance

Name	Definition	Probability of Correct Typing All / JPSS Thick
High	7-20 km	97 % / 96%
Middle	3-7 km	77 % / 83 %
Low	0-3 km	87% / 92 %

Performance Estimates: Summary

- The VIIRS channel set does not provide any H_2O or CO_2 absorbing channels and we expect ACHA on GOES-R to be slightly better than ACHA on VIIRS and these numbers confirm this.

- We are faring well against the GOES-R and JPSS Accuracy specifications for cloud height and temperature. We infer that cloud pressure is also good. (Consistent with GOES-R CDR)

- Cloud Layer spec is met for High and Low. Middle layer clouds are much fewer and performance issues with thin high clouds are driving this error. When JPSS Thick filter applied, all are met.

- Cloud base height validation is yet to be done. Our technique is similar to that in IDPS.

Pre-Planned Improvements

- Add in a 13.3 or 6.7 micron channel from convolved CrIS data.
- Continue to improve covariance matrices.
- Explore NWP information for cloud base improvement.
- NWP and RTM performance is critical to this application and we will stay in tune with advances in these areas. (Better surface temperature and emissivity data sources are important)

References

- Heidinger, A. K.; Pavolonis, M. J.; Holz, R. E.; Baum, Bryan A. and Berthier, S. Using CALIPSO to explore the sensitivity to cirrus height in the infrared observations from NPOESS/VIIRS and GOES-R/ABI. Journal of Geophysical Research, Volume 115, 2010, doi:10.1029/2009JD012152.

- Heidinger, Andrew K. and Pavolonis, Michael J. Gazing at cirrus clouds for 25 years through a split window, part 1: Methodology. Journal of Applied Meteorology and Climatology, Volume 48, Issue 6, 2009, pp.1100-1116.

- Schreiner, Anthony J.; Schmit, Timothy J. and Aune, Robert M.. Maritime inversions and the GOES Sounder Cloud Product. National Weather Digest, Volume 26, Issue 1, 2002, pp.27-38.

Outline

- Introduction
- Requirements
- Operations Concept
- Cloud Mask
- Cloud Phase
- Cloud Height
- NCOMP
- Software Architecture and Interfaces
- Detailed Design
- Algorithm Package
- Quality Assurance
- Risks and Actions Summary
- Summary and Conclusions

Algorithm Theoretical Basis

Nighttime Cloud Optical and Microphysical Properties

Patrick Heck
CIMSS/UW-Madison

Patrick Minnis
NASA Langley Research Center

Algorithm Theoretical Basis

- The purpose: provide a theoretical description (scientific and mathematical) of the VIIRS Nighttime Cloud Optical and Microphysical Properties (cloud optical depth, cloud effective radius, liquid water path, ice water path) for the product developers, reviewers and users.
- Documented in the GOES-R ABI NCOMP ATBD

CDR Requirements (Night)
Cloud Optical Depth

Name	User & Priority	Geographic Coverage (G, H, C, M)	Vertical Res.	Horiz. Res.	Mapping Accuracy	Msmnt. Range	Msmnt. Accuracy	Refresh Rate	Data Latency	Product Measurement Precision
Cloud Optical Depth	JPSS	Global	Total Column	0.75 km	1 km	1.0 – 5.0	20% liquid; 30% ice	90 min	30 min from receipt	Max of 0.8 or 30%

CDR Requirements (Night) Cloud Optical Depth

Name	User & Priority	Geographic Coverage (G, H, C, M)	Temporal Coverage Qualifiers	Product Extent Qualifier	Cloud Cover Conditions Qualifier	Product Statistics Qualifier
Cloud Optical Depth	JPSS	Global	night	Quantitative out to at least 65 degrees LZA and qualitative beyond	In presence of clouds with optical depth > 1	Over specified geographic area

CDR Requirements (Night)
Cloud Particle Size Distribution

Name	User & Priority	Geographic Coverage (G, H, C, M)	Vertical Res.	Horiz. Res.	Mapping Accuracy	Msmnt. Range	Msmnt. Accuracy	Refresh Rate	Data Latency	Product Measurement Precision
Cloud Particle Size Distribution	JPSS	Global	Cloud Top	0.75 km	1 km	2 – 32 µm Liquid 2-50 µm Ice	Max of 4 µm or 30% for liquid phase, 10 µm for ice phase	90 min	30 min from receipt	Max of 4 µm or 25% for liquid phase, 10 µm or 25% for ice phase

CDR Requirements (Night) Cloud Particle Size Distribution

Name	User & Priority	Geographic Coverage (G, H, C, M)	Temporal Coverage Qualifiers	Product Extent Qualifier	Cloud Cover Conditions Qualifier	Product Statistics Qualifier
Cloud Particle Size Distribution	JPSS	Global	night	Night; quantitative out to at least 65 degrees LZA and qualitative beyond	In presence of clouds with 1 < COD < 5	Over specified geographic area

CDR Requirements (Night) Cloud Ice Water Path

Name	User & Priority	Geographic Coverage (G, H, C, M)	Vertical Res.	Horiz. Res.	Mapping Accuracy	Msmnt. Range	Msmnt. Accuracy	Refresh Rate	Data Latency	Product Measurement Precision
Cloud Ice Water Path	JPSS	Global	SFC – 20 km	0.75 km	1 km	Night: 25 – 175 g/m2	Greater of 25 g/m2 or 30%	90 min	30 min from receipt	Greater of 25 g/m2 or 40%

CDR Requirements(Night) Cloud Ice Water Path

Name	User & Priority	Geographic Coverage (G, H, C, M)	Temporal Coverage Qualifiers	Product Extent Qualifier	Cloud Cover Conditions Qualifier	Product Statistics Qualifier
Cloud Ice Water Path	JPSS	Global	Day and night	Quantitative out to at least 65 degrees LZA and qualitative beyond	In presence of clouds with 1 < COD < 5	Over specified geographic area

CDR Requirements (Night) Cloud Liquid Water

Name	User & Priority	Geographic Coverage (G, H, C, M)	Vertical Res.	Horiz. Res.	Mapping Accuracy	Msmnt. Range	Msmnt. Accuracy	Refresh Rate	Data Latency	Product Measurement Precision
Cloud Liquid Water	JPSS	Global	Total Column	0.75 km	1 km	Night: 25 – 100 g/m2	Greater of 25 g/m2 or 15%	90 min	30 min from receipt	Greater of 25 g/m2 or 15%

CDR Requirements (Night) Cloud Liquid Water

Name	User & Priority	Geographic Coverage (G, H, C, M)	Temporal Coverage Qualifiers	Product Extent Qualifier	Cloud Cover Conditions Qualifier	Product Statistics Qualifier
Cloud Liquid Water	JPSS	Global	Day and night	Quantitative out to at least 65 degrees LZA and qualitative beyond	In presence of clouds with 1 < COD < 5	Over specified geographic area

Algorithm Theoretical Basis

- The purpose:

  Provide a scientific and mathematical description of the VIIRS nighttime cloud optical and microphysical retrieval algorithm for product developers, reviewers and users.

- As documented in the GOES-R ABI Cloud Team Algorithm Theoretical Basis Document (ATBD).

- The only change from GOES-R to VIIRS is input LUT.

NCOMP Algorithm

- Just as with ABI, the Solar-infrared Infrared Split-Window Technique (SIST) from NASA Langley has been chosen for NCOMP.
  - » SIST was modified to work in a GOES-R framework and streamlined to accept ABI products as input.
  - » NCOMP is ready to run on VIIRS data in geocat.
- No other approaches were considered because
  - » The algorithm is considered state-of-the-art.
  - » No other algorithm currently retrieves nighttime optical properties and microphysics.
- See GOES-R NCOMP ATBD and *Minnis et al.* references

NCOMP Algorithm (2)

- Rationale for selection
  - » The chosen approach is well-tested on a variety of satellite instruments, including
    - GOES and GOES-R ABI
    - MODIS (as part of the CERES project)
    - SEVIRI
    - MTSAT
    - AVHRR
  - » The chosen approach has been and is operationally processing data from all of these instruments in real-time.
  - » The algorithm is ready to be tested on simulated ABI data and VIIRS data from Suomi NPP.

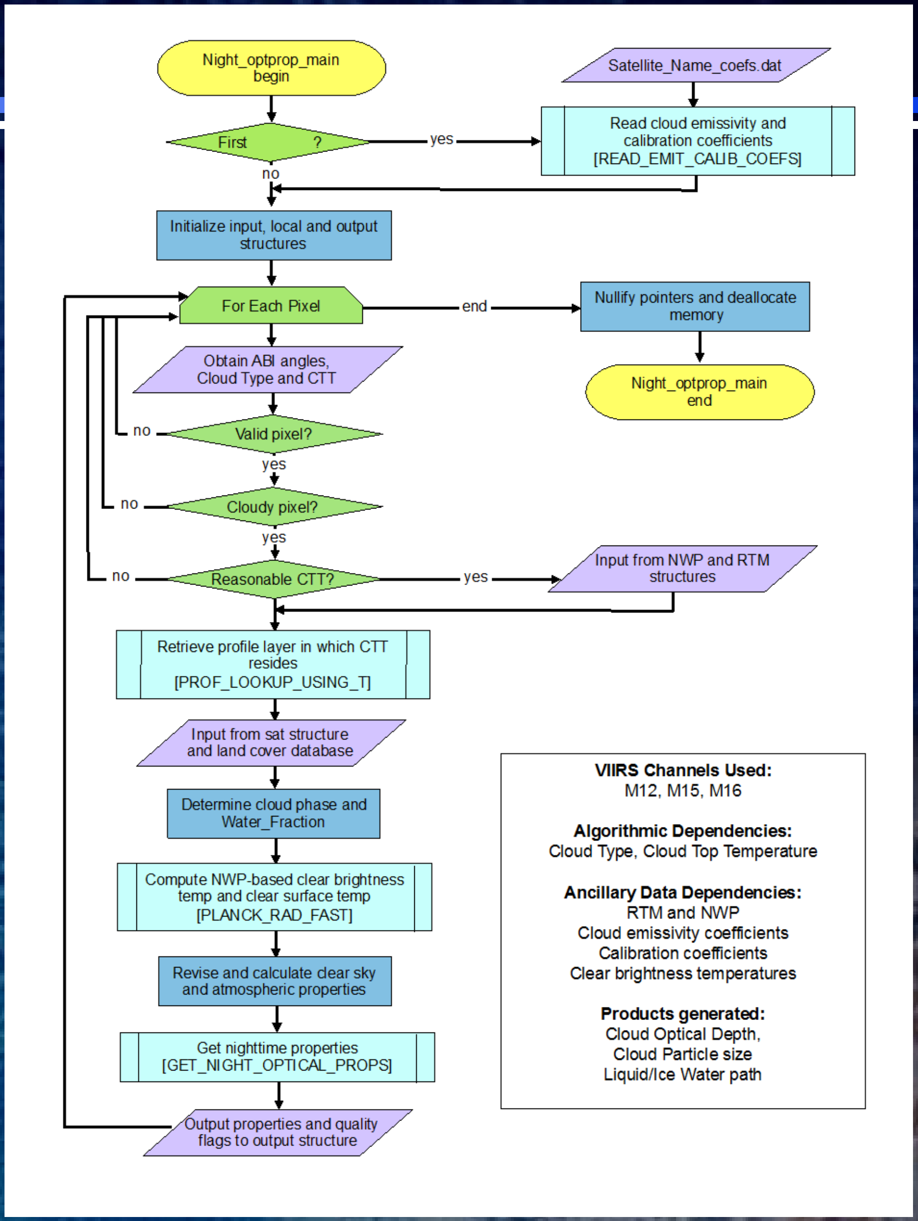
NCOMP Algorithm Objectives

- Meet the L1RD requirements specified for cloud optical properties and microphysical quantities
- To produce cloud optical thickness, cloud particle size, liquid water path (LWP) and ice water path (IWP) for each VIIRS pixel
- Provide needed performance information to allow for proper use of our products
- Based on well-tested algorithms
- Simple to implement and operationally robust
- Has improvement potential

NCOMP Processing Outline

VIIRS Nighttime Cloud Optical Properties Processing

- Begin VIIRS Nighttime Cloud Optical Properties subroutine
- On first call, read in lookup tables
- Initialize output structures and local pointers
- For each valid pixel with valid input, initialize NWP and RTM data. Then determine if it is cloudy and has a reasonable CTT, first determine cloud phase. Then compute surface emissivity, revise and calculate clear sky and atmospheric properties. Next calculate nighttime cloud optical depth and effective radius using NCOMP method described in Mathematical Description section. Finally, calculate LWP and IWP based on phase and optical properties.
- Output data to output structures.
- At end of scan line loop, nullify all local pointers and deallocate local memory
- Deallocate LUT arrays on last processed segment
- End Nighttime Cloud Optical Properties subroutine



NCOMP VIIRS Algorithm Input
Sensor Input

VIIRS Band	Wavelength Range (µm)	Central Wavelength (µm)	Central Wavenumber (cm-1)	sub-satellite IGFOV (km)	Sample Use
M12	3.660 – 3.840	3.74	2674	0.750	NCOMP
M14	8.4 – 8.7	8.55	1170	0.750	NCOMP
M15	10.263 – 11.263	10.763	929	0.750	NCOMP
M16	11.538 – 12.488	12.013	832	0.750	NCOMP

Current Input

Possible Added Input

NCOMP Algorithm Input Sensor Input Details

- For each pixel:
  - VIIRS brightness temperatures
  - Satellite zenith angle
  - Solar zenith and relative azimuth (for future twilight usage)
  - Spectral response information for conversion to radiance

Name	Type	Description	Dimension
M12 brightness temperature	input	Calibrated VIIRS level 1b radiance at channel M12	grid (xsize, ysize)
M15 brightness temperature	input	Calibrated VIIRS level 1b radiance at channel M15	grid (xsize, ysize)
M16 brightness temperature	input	Calibrated VIIRS level 1b radiance at channel M16	grid (xsize, ysize)
Satellite zenith angle	input	VIIRS view zenith angle	grid (xsize, ysize)
Solar geometry	input	VIIRS solar zenith and azimuth angles	grid (xsize, ysize)

NCOMP Algorithm Input
Ancillary Input

- Three types of ancillary data needed:
  - » **VIIRS-derived Data:** Cloud type, Cloud Top Temperature
  - » **Non-VIIRS Ancilliary Data:** Surface Type, Surface Emissivities for Channels M12, M15 and M16, Clear-sky IR Radiative Transfer Model Calculations, All-sky Temperature, Height and Pressure profiles and Skin Temperatures.
  - » Calibration and Cloud Emittance Parameterization Coefficients from LUT

NCOMP Algorithm Input Ancillary Input Details

- **VIIRS Data:** Cloud Type and Cloud Temperature

For each pixel:

Name	Type	Description	Dimension
Cloud Type	input	VIIRS level 2 cloud type data	grid (xsize, ysize)
Cloud Temperature	input	VIIRS level 2 cloud top temperature data	grid (xsize, ysize)

NCOMP Algorithm Input Ancillary Input Details (2)

- **Non-VIIRS Data:** Surface Type, Surface Emissivity, Clear-sky IR Radiative Transfer Model Calculations, All-sky Temperature, Height and Pressure Profiles

Name	Type	Description	Size	Dimension
Surface Type	input	Background surface information	1-km	grid (xsize, ysize)
Surface Emissivity	input	Surface emissivities for channels M12, M15 and M16	5-km	grid (xsize, ysize)
Clear-sky IR Radiative Transfer Model Calculations	input	RTM data for channels M12, M15 and M16	101 levels	grid (xsize, ysize)
All-sky T, Z and P profiles and T_{Skin}	input	Temperature profile from NWP data	0.5 deg 26 levels	grid (xsize, ysize)

NCOMP Algorithm Input Ancillary Input Details (3)

- **Additional Non-VIIRS Coefficient Input:** Calibration Coefficients and Cloud Emittance Parameterization Coefficients

Name	Type	Description	Dimension
Calibration Coefficients	input	Algorithm coefficients	For each necessary channel, a set of 2 Real*4 coefficients
Cloud Emittance Parameterization Coefficients	input	Algorithm coefficients	3 sets of 3840 Real*4 coefficients: 1 set each for channels M12, M15 and M16

NCOMP Algorithm Product Precedence Details

- **Products required to run algorithm**

Name	Type	Description	Dimension
Cloud Type	input	VIIRS level 2 cloud type data	grid (xsize, ysize)
Cloud Top Temperature	input	VIIRS level 2 cloud top temperature data	grid (xsize, ysize)

NCOMP Algorithm Output

- Cloud optical thickness
- Cloud particle size
- Liquid water path (for water clouds)
- Ice water path (for ice clouds)

For each pixel:

Name	Type	Description	Dimension
Cloud Optical Thickness value	output	Retrieved COT value for each cloudy pixel	grid (xsize, ysize)
Cloud Particle Size value	output	Retrieved CPS value for each cloudy pixel	grid (xsize, ysize)
Cloud Liquid Water Path value	output	Retrieved LWP value for each water pixel	grid (xsize, ysize)
Cloud Ice Water Path value	output	Retrieved IWP value for each ice pixel	grid (xsize, ysize)

NCOMP Algorithm Output(2)

- Product Processing Flags
- Product Quality Flags

For each pixel:

Name	Type	Description	Dimension
Data Quality Flag	output	8 possible values for each pixel	grid (xsize, ysize)
Processing Flag	output	14 possible values for each pixel for which NCOMP retrieval was valid	grid (xsize, ysize)

NCOMP Retrieval Strategy

- Strategy
  - » Use parameterizations that relate effective cloud emittance to optical depth and to differences between clear sky temperature and cloud temperature.
  - » In an iterative step, compute optical depth for a set of particle size models
  - » Choose the model with smallest brightness temperature difference (BTD) errors between observed and computed T_{M12}, T_{M15} and T_{M16}
  - » Use iterative interpolation scheme to adjust optical depth and effective particle size to find a solution between model two solutions

NCOMP Retrieval Strategy (2)

- **Cloud typing and cloud temperature determination methods**
  - » Type - Using VIIRS cloud type (determines phase)
  - » Temperature - Using VIIRS cloud top temperature

- **NCOMP retrieval will be performed for**
  - » Night (quantitatively) and Twilight (qualitatively)
  - » Cloudy pixels only
  - » Pixels with a valid VIIRS cloud temperature
  - » Pixels with a valid VIIRS cloud type

- **Solar Zenith Angle limits**

Night: $SZA \geq 90$

Twilight: $82 \leq SZA < 90$

NCOMP Retrieval Strategy (3)

- Utilize pre-calculated atmospheric profiles of
  - » Clear-sky temperatures and transmissivities to move cloud temperature to TOA and to account for contributions of atmosphere and clear sky temperature (RTM)
  - » All-sky temperatures for placing cloud temperature in appropriate layer (NWP)

- Efficiency measures
  - » Phase - retrieval performed only for appropriate phase
  - » Iterations limited to physically realistic situations
  - » No forward calculations used
  - » No large Look-Up Tables used

NCOMP Physical Description

Infrared Emittance in Thermal Wavelengths

Usual method of describing observed radiance at wavelength λ and a cloud with optical depth τ is

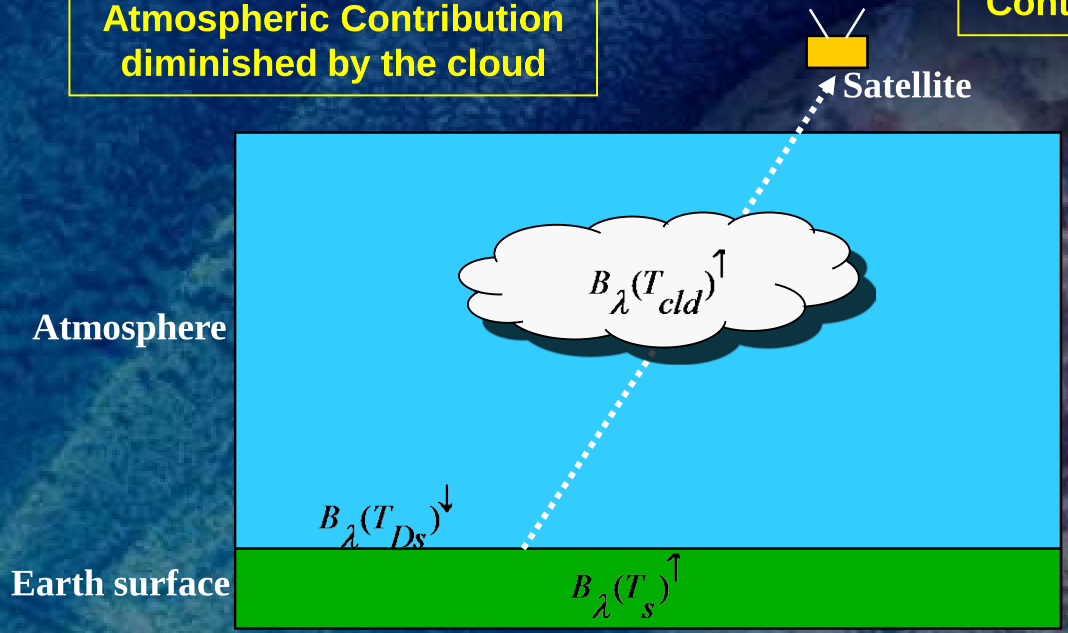
$$B\left(T\right) = L_{u\uparrow}(\mu) + t_u(\mu)\left\{\left[t_l \varepsilon_s B\left(T_s\right) + L_{l\uparrow}\right]\left(1-\varepsilon(\mu,\tau)\right) + \varepsilon(\mu,\tau) B\left(T_{cld}\right)\right\}$$

Above Cloud Atmospheric Contribution

Surface and Below Cloud Atmospheric Contribution diminished by the cloud

Cloud Contribution

Cloud, below cloud atmospheric and surface contributions are diminished by the above cloud atmospheric transmittance



NCOMP Physical Description

Infrared Emittance in Thermal Wavelengths (2)

Each term is attributed to the cloud, surface and atmosphere and their respective ε and/or t

$$B(T) = L_{u\uparrow}(\mu) + t_u(\mu)\left\{\left[t_l \varepsilon_s B(T_s) + L_{l\uparrow}\right](1-\varepsilon(\mu,\tau)) + \varepsilon(\mu,\tau) B(T_{cld})\right\}$$

- B = Planck function
- T = equivalent blackbody temperature
- $L_{u\uparrow}$ = upwelling atmospheric radiance above cloud
- μ = cosine of satellite viewing angle
- ε = effective cloud emittance
- t_u = atmospheric transmittance above the cloud
- t_l = atmospheric transmittance below the cloud
- ε_s = surface emittance
- T_s = surface skin temperature
- T = equivalent blackbody temperature
- $L_{l\uparrow}$ = upwelling atmospheric radiance below cloud
- τ_λ = optical depth

NCOMP Physical Description
Infrared Emittance in Thermal Wavelengths (3)

Each term can be measured and/or computed by combining TOA satellite measurements with ancillary and model data.

$$B(T) = L_{u\uparrow}(\mu) + t_u(\mu)\left\{\left[t_l \varepsilon_s B(T_s) + L_{l\uparrow}\right](1-\varepsilon(\mu,\tau)) + \varepsilon(\mu,\tau) B(T_{cld})\right\}$$

- $L_{u\uparrow}$: RTM
- μ : satellite
- t_u : RTM
- ε_λ: LUT

- t_l : RTM
- ε_s: ancillary
- T_s : NWP
- $L_{l\uparrow}$: RTM

- ε: LUT
- μ: satellite
- τ: cloud model
- T_{cld}: satellite

Each term’s source is noted in yellow.

NCOMP Physical Description
Infrared Emittance in Thermal Wavelengths (4)

- For semi-transparent clouds, ε_λ and T_{cld} can be estimated from simultaneous measurements at two different wavelengths, λ_1 and λ_2 (assuming a hydrometeor absorbs differently at λ_1 and λ_2).
- If scattering is neglected then

$$\varepsilon_\lambda = 1 - \exp(-\tau_{a\lambda} / \mu)$$

where $\tau_{a\lambda}$, absorption optical depth, is a function of effective particle size, r_e.

- If ε_λ is known, then τ_λ can be determined from the equation above.
- If T_{cld} is know from another source, e.g., VIIRS algorithms, then τ_λ and r_e can be estimated by using two or three different wavelengths.
- This technique uses three wavelengths: VIIRS channels M12, M15 and M16.

NCOMP Mathematical Description Retrieval Schematic

For each pixel:

For each phase-appropriate model, assume $\tau = 1.0$ and compute $T'_{10.8}$ using T_{cs}, T_{cld} and $\varepsilon_{10.8}$ parameterization

↓

Iterate to obtain actual τ

↓

Using τ from above, T_{cs} and T_{cld}, compute $T'_{3.7}$ utilizing $\varepsilon_{3.7}$ parameterizations

↓

Similarly, using τ from above, T_{cs} and T_{cld}, compute $T'_{12.0}$ utilizing $\varepsilon_{12.0}$ parameterizations

--> Contains iteration

NCOMP Mathematical Description Approach

- For each pixel the algorithm employs a cloud emittance parameterization.
- This parameterization allows the computation of an 10.8-μm effective cloud emittance, $\varepsilon_{10.8}$, hence an 10.8-μm temperature, $T'_{10.8}$, by using the previously mentioned relationship between temperature, $B_\lambda(T_\lambda)$ and effective cloud emittance, ε_λ, in thermal wavelengths.
- The algorithm use this emittance parameterization to compute $T'_{10.8}$ and iterates in optical depth using the VIIRS T_{cld} and T_{cs} to compute optical depth for a given set of phase-appropriate effective particle size, r_e.
- When this iteration is complete, optical depth has been determined, but only for assumed r_e.
- The emittance parameterization is then used to obtain $\varepsilon_{3.7}$ and $\varepsilon_{12.0}$, as well as $T'_{3.7}$ and $T'_{12.0}$ for the same r_e.

NCOMP Mathematical Description
Emittance Parameterizations

The cloud emittance parameterization was developed from adding-doubling calculations and is described by the following equation:

$$\varepsilon(\lambda,r_e) = a_0 + a_1\{1/\ln(\Delta T)\} + a_2\{1/\ln(\Delta T)\}^2$$

where $\Delta T = T_{cs} - T_{cld}$, $a_i = \Sigma\, b_j \{1/\ln(T_{cs})\}$, and $b_j = \Sigma\, c_k\, \mu^k$

($i = 0, 2$; $j = 0, 1$ and $k = 0, 4$)

- ε = effective cloud emittance
- λ = wavelength
- r_e = effective particle size
- a_i, b_j, c_k = coefficients
- T_{cs} = clear sky temperature
- T_{cld} = effective cloud temperature
- μ = cosine (viewing zenith angle)

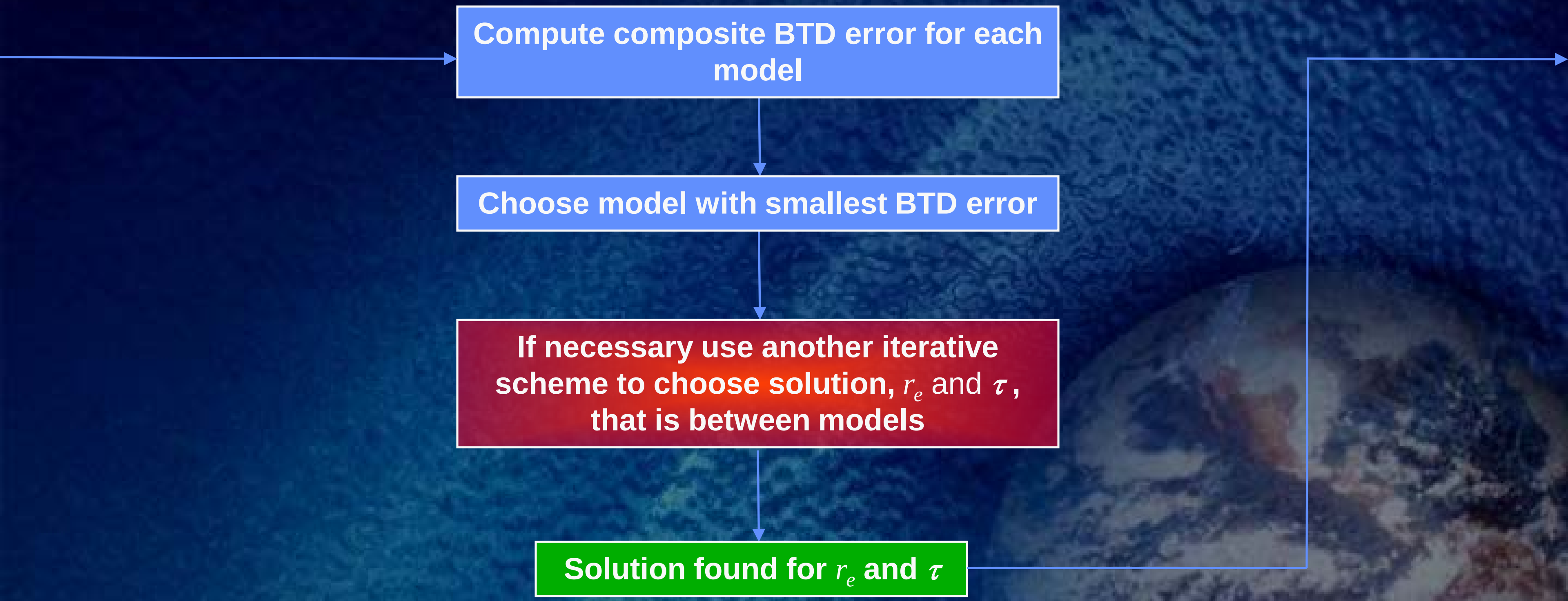
For a set of water droplet and ice crystal models, an $\varepsilon(\lambda,r_e)$ was computed for 9 nodes of τ. The parameterization for each λ was created from those results.

NCOMP Mathematical Description Adding-Doubling Calculations

The adding-doubling calculations from which the parameterizations of ε were derived are described below:

- Plane-parallel theory, i.e., horizontal scattering and absorption are invariant for both the clouds and the atmosphere
- Water clouds
  - » 7 models: r_e = 2, 4, 6, 8, 12, 16, and 32 μm
  - » Optical properties from Mie Theory
- Ice clouds
  - » 9 models: r_e = 1.8, 5.7, 7.6, 9.8, 15.0, 23.3, 38.6, 46.7 and 52.2 μm)
  - » Optical properties from ray tracing results (Takano and Liou, 1989), randomly oriented hexagonal crystals
- τ nodes = 0.25, 0.5, 1, 2, 3, 4, 8, 16 and 32
- T_{cs} nodes = 240, 260, 280, 300, 320 K
- T_{cld}(water) nodes = 240, 255, 265, …, 295 K
- T_{cld}(ice) nodes = 195, 210, …, 270 K

NCOMP Mathematical Description Retrieval Schematic (2)



--> Contains iteration

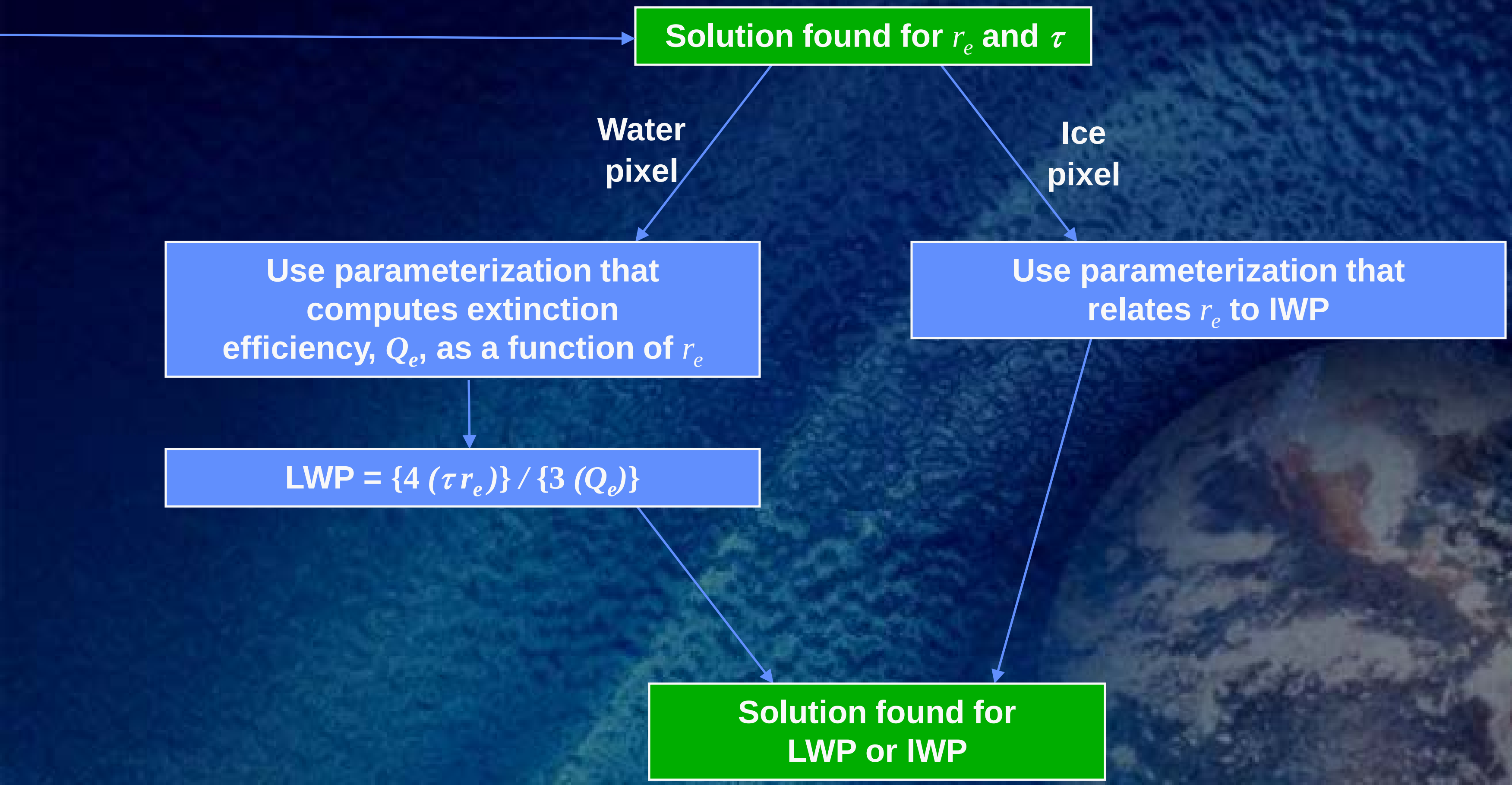
NCOMP Mathematical Description Approach (2)

- A solution is found for each r_e model of the appropriate phase (same 7 water models and 9 ice models).
- For each model, the solution has:
  - » a computed $T'_{3.9}$, $T'_{10.8}$ and $T'_{12.0}$
  - ≈ a computed τ and ε
  - » r_e (fixed for each particle size model)
  - » an error computed from BTDs:

$$[(T'_{3.7} - T'_{10.8}) - (T_{3.7} - T_{10.8})]^2 + [(T'_{10.8} - T'_{12.0}) - (T_{10.8} - T_{12.0})]^2$$

- The particle size model with the smallest error is chosen as the first guess (including the appropriate τ, as well as the model's associated r_e).
- An iterative scheme is used to interpolate between particle size models and to adjust τ and r_e accordingly.

NCOMP Mathematical Description Retrieval Schematic (3)



Algorithm Description Summary

- As with ABI, NCOMP for VIIRS utilizes already developed, instrument-specific cloud emittance parameterizations.
  - » In an iterative scheme NCOMP determines cloud optical depth and particle size by minimizing BTD errors between observed and computed VIIRS temperatures.
  - » The computed temperatures used in the BTD error calculation are constructed for a range of phase-appropriate particle size models using the coinciding emittance parameterizations.
  - » Once the minimum error model is identified, a separate iterative scheme interpolates between adjacent particle size models to obtain the actual retrieved COD and CPS.
  - » LWP and IWP are then computed using standard methods.

NCOMP Practical Considerations

- Numerical computational considerations
  - » Several iterative steps are involved, but are well-tested in an operational setting.
  - » No forward calculations or large Look-Up Tables are required.

- Programming and procedural considerations
  - » NCOMP is a pixel by pixel algorithm with no requirements that larger amounts of imagery be processed.
  - » Results will not vary if larger or smaller amounts of imagery are processed, assuming that the scale of the ancillary data remains the same.
  - » Several aforementioned ancillary data sets must be available before NCOMP retrieval.
  - » VIIRS cloud type and cloud temperature must be available before the NCOMP retrieval.

NCOMP Practical Considerations

- Configuration of the retrieval
  - » The following data should be configurable for possible post-launch justification
    - – Algorithm coefficients (LUT)
    - – RTM profiles (possible resource change)
    - – NWP profiles (possible resource change)
    - – Surface emissivity dataset (possible resource change)

- Quality assessment and diagnostics
  - » Quality flags will be produced for
    - – Missing/No data (VIIRS radiance problem)
    - – Retrieval performed
    - – No retrieval performed due to retrieval inconsistencies
    - – No retrieval required (daytime, off earth, etc.)
    - – No retrieval performed due to ancillary data problem

NCOMP Exceptions

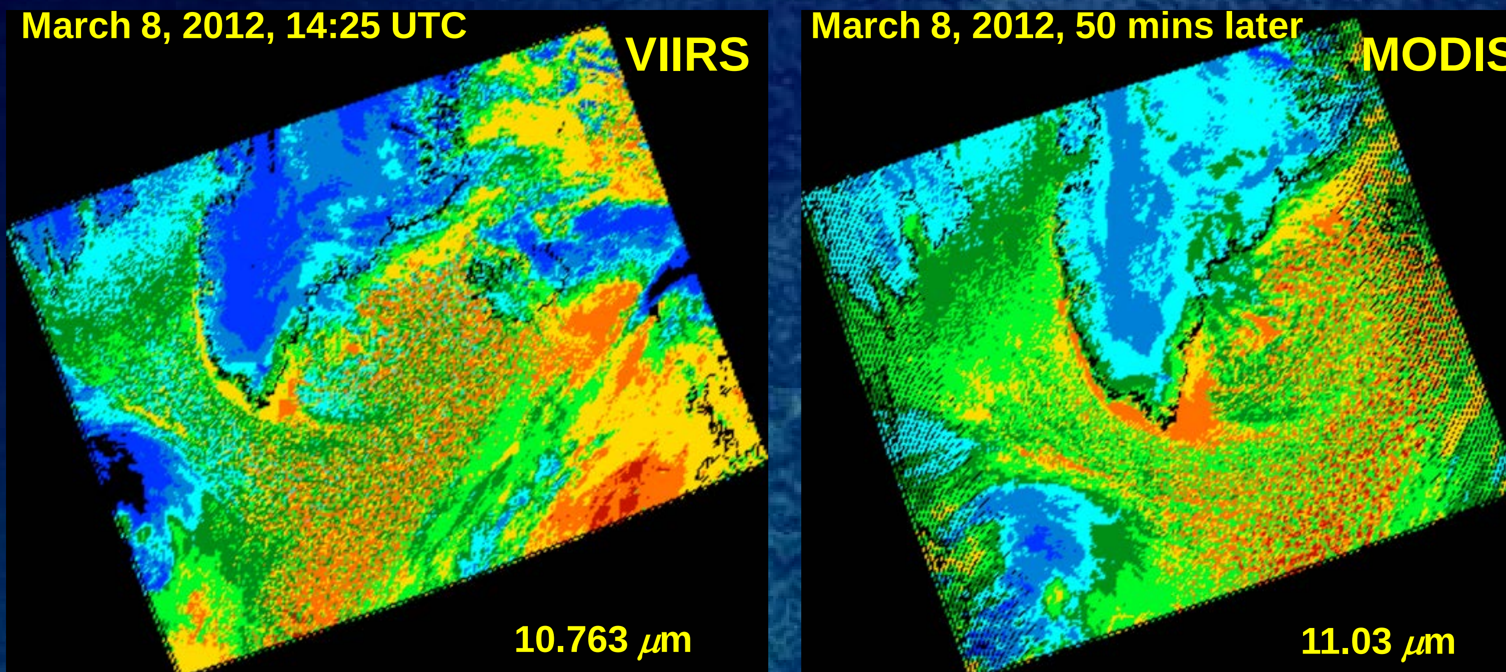
- Exception Handling
  - The retrieval is not performed if there are invalid inputs or if the criteria for performing NCOMP are not met, e.g., if it is daytime or not a cloudy pixel.
  - Product Quality Flags identical to the GOES-R PQF indicate these occurrences.

NCOMP Algorithm Testing VIIRS Data

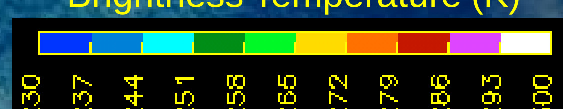
Algorithm Input

» **Sensor Input**: VIIRS channel M15 (10.763 μm) compared to MODIS 11.03 μm

» Sensitivity of NCOMP retrievals to calibration or degradation issues required first exploring differences between VIIRS and MODIS with its well understood response



Brightness Temperature (K)

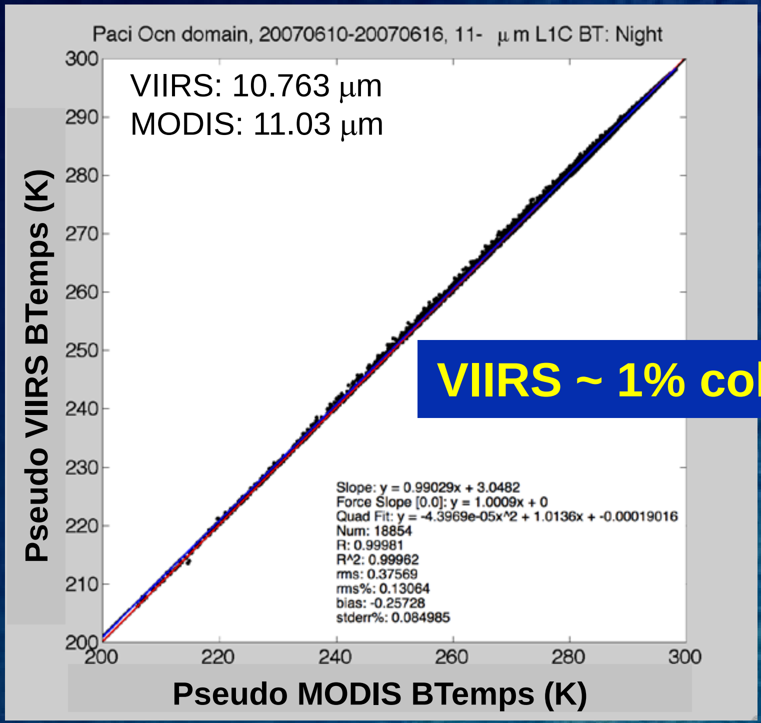


NCOMP Algorithm Testing VIIRS Data (2)

Algorithm Input

» **Sensor Input**: VIIRS channel M15 (10.763 *µ*m) compared to MODIS 11.03 *µ*m using IASI-derived Pseudo Brightness Temperatures at night

IASI from June 10 – 16, 2007



VIIRS ~ 1% colder

- **Both VIIRS and MODIS constructed from IASI observations**
- **This exhibits a not unexpected results of VIIRS being about 1% colder than MODIS**
- **This difference is solely due to channel differences between the two instruments.**

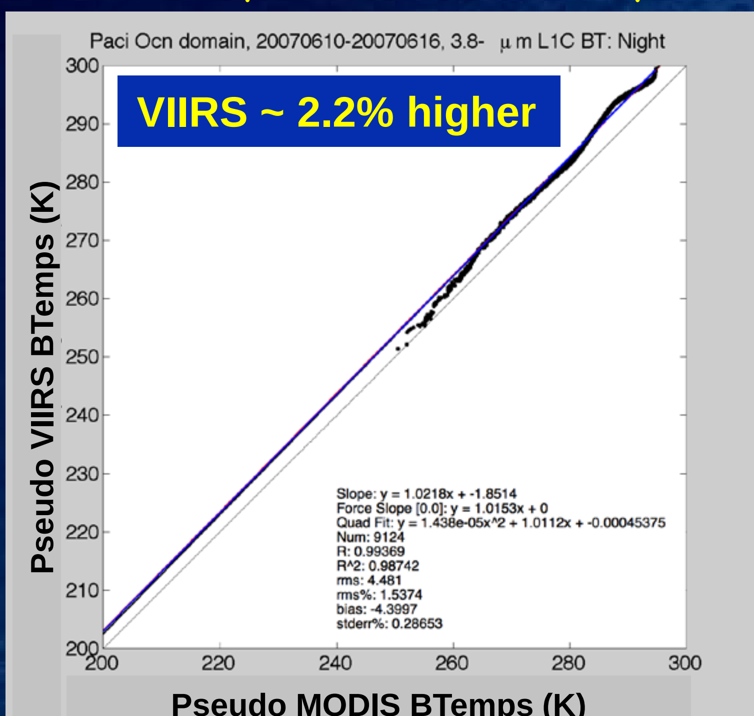
NCOMP Algorithm Testing VIIRS Data (3)

Algorithm Input

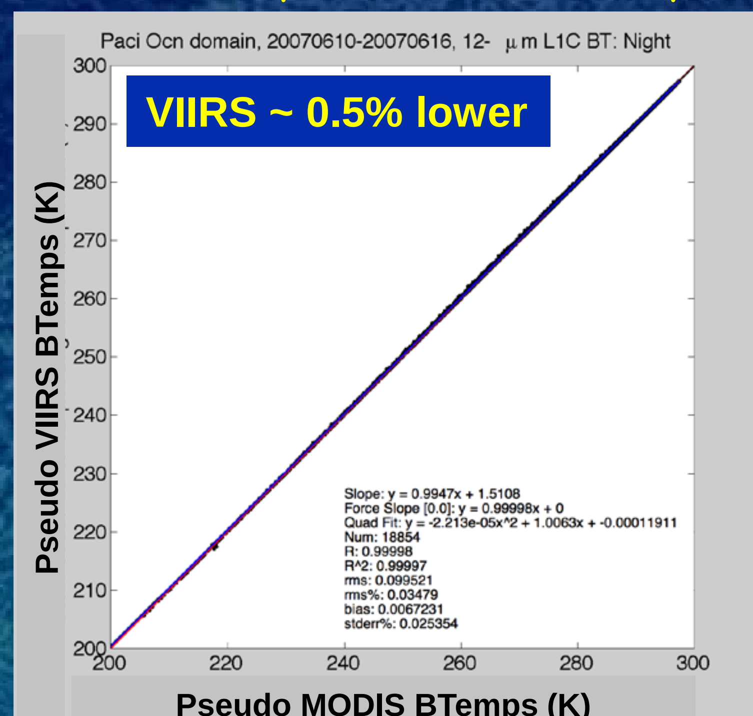
» **Sensor Input**: VIIRS channels M12 (3.74 *μ*m) and M16 (12.013 *μ*m) compared to MODIS channels using IASI-based Pseudo Brightness Temperatures.

IASI from June 10 – 16, 2007

VIIRS: 3.74 μm and MODIS: 3.793 μm

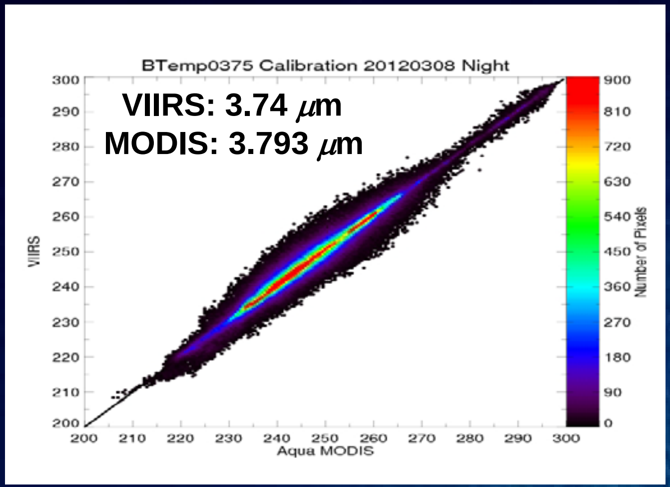


VIIRS: 12.013 μm and MODIS: 12.02 μm

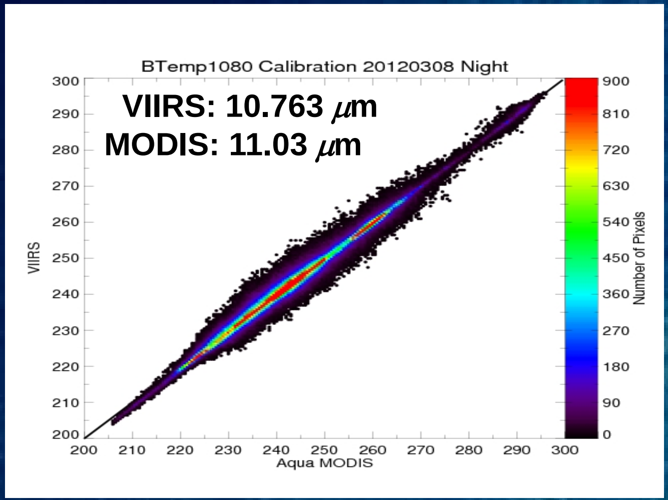


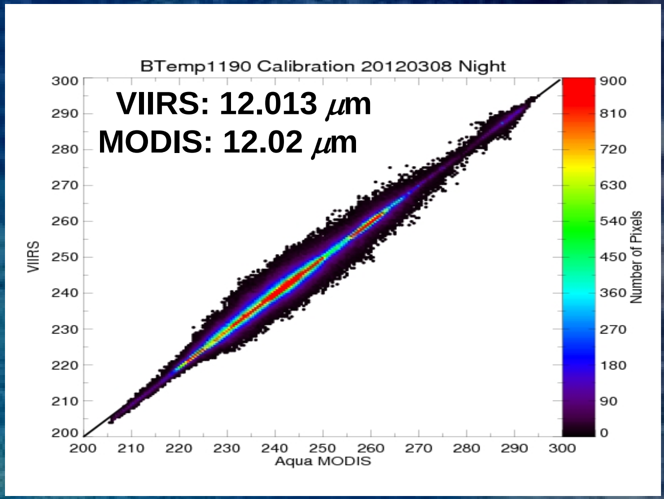
NCOMP Algorithm Testing VIIRS Data (4)

Frequency



- Comparisons of matched VIIRS and MODIS data
- A conversion has been applied to the Aqua MODIS data based on the IASI fits, so any differences are due to temporal and spatial matching or potentially VIIRS degradation or calibration issues.
- Fortunately, differences are minor indicating that all 3 VIIRS channels appear to be well characterized, hence will perform well in NCOMP





NCOMP Algorithm Testing VIIRS Data (5)

Frequency

- VIIRS data compares well to Aqua MODIS, so appears to be ready for input to NCOMP. Comparisons will continue.
- No indication that retrievals will exhibit differences from NCOMP as applied to SEVIRI data since SEVIRI data was also referenced to MODIS within NCOMP
- NCOMP will be applied to VIIRS data within GEOCAT and the Framework.

NCOMP Algorithm Performance Estimates

- NCOMP Cloud Optical Depth, Cloud Effective Particle Size, LWP and IWP can be validated with coincident data from several different sources
  - » **Satellite-based remote retrievals**
  - » **Surface-based remote retrievals**
  - » **Aircraft-based *in situ* retrievals**

- As with any property retrieved from satellite instruments, direct comparison is difficult due to time and space matching issues, differences in algorithm assumptions and spectral variations.

- Due there being no algorithm changes from GOES-R to VIIRS, other than small variations in the cloud emittance parameterization and instrument differences, it is expected that NCOMP validation results will be similar to the GOES-R ABI validation.

NCOMP Algorithm Performance Estimates (2)

Satellite-based Remote Retrievals for Comparison

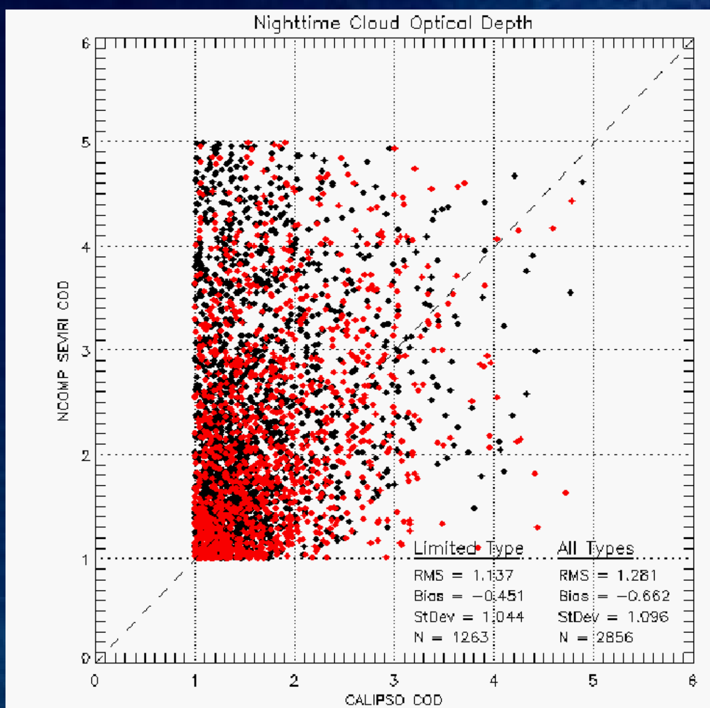
Two types of satellite-based retrievals are used:

- **Products obtained with a similar algorithm to check consistency:**
  - **MODIS CERES project (SIST applied to MODIS data)**
  - **SEVIRI (SIST applied to SEVIRI data)**
  - **Any other satellite with ABI-like wavelengths**
- **Products obtained with different algorithms (and possibly different instruments) to check consistency and infer accuracy:**
  - **MODIS**
  - **CALIPSO/CLOUDSAT**
  - **AMSR-E or other microwave instruments**

NCOMP Algorithm Performance Estimates (3)

Satellite-based: Comparison of Matched GOES-R NCOMP Retrievals and CALIPSO: Cloud Optical Depth

ABI NCOMP Results using SEVIRI as proxy



10-week Period Sampled from 4 Seasons

Red points are for ABI Cloud Type water, supercooled water and cirrus, hence likely to have a single phase

Black points are the remaining Cloud Types, i.e., more likely to by multi-phase, hence are excluded from the statistical comparisons.

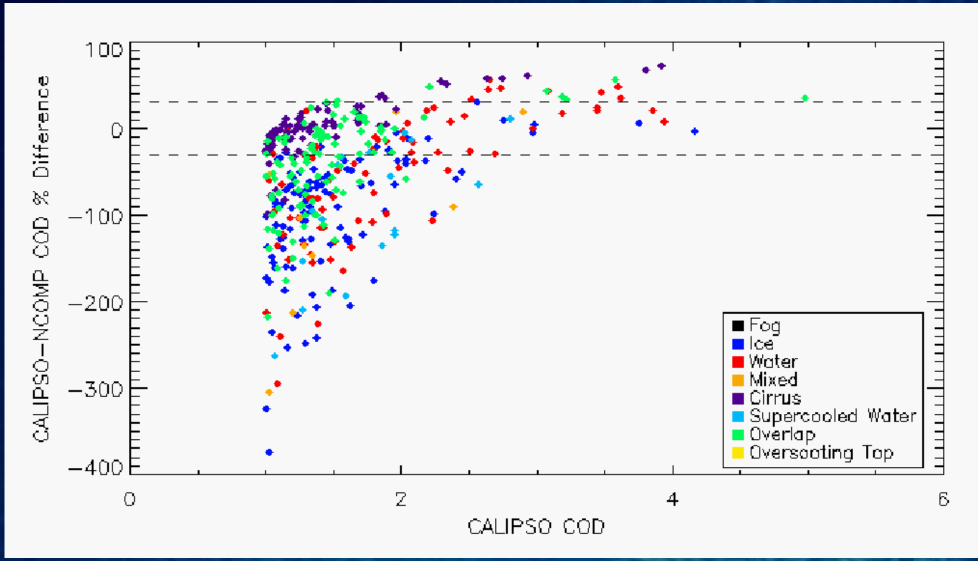
Accuracy = -0.451 or 35.2%

This does not meet the F&PS requirements of 30%, so further examination was required.

NCOMP Algorithm Performance Estimates (4)

Satellite Based: Comparison of Matched GOES-R NCOMP Retrievals and CALIPSO: Cloud Optical Depth

ABI NCOMP Results using SEVIRI as proxy



10-week Period Sampled from 4 Seasons

Using only the those ABI retrievals for which CALIPSO is also most reliable, i.e., cirrus, the percentage differences are reduced.

Accuracy = +0.084 or 1.32%, well under the F&PS requirement of 30%.

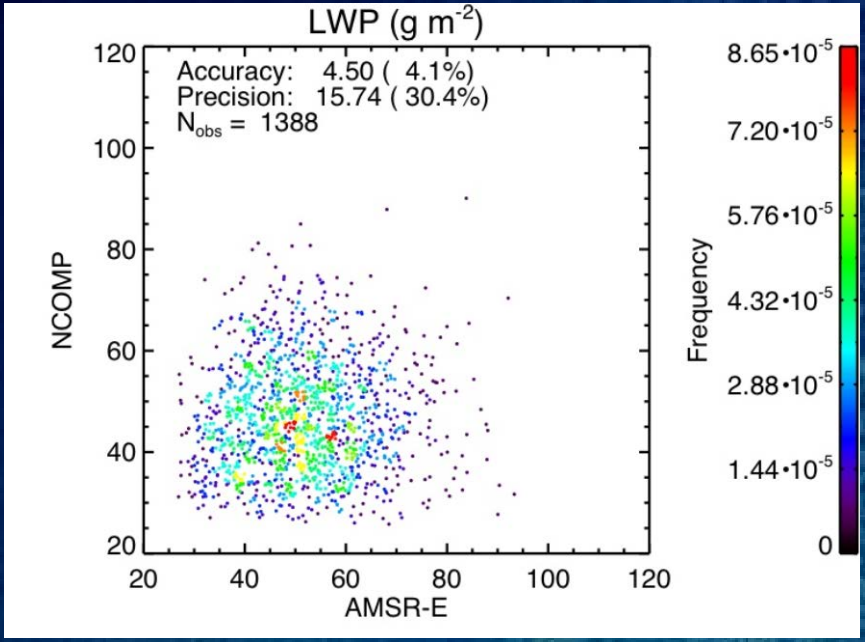
Precision = 0.49 or 30%, also within the F&PS requirement of 0.8 or 30%.

Given that the range of COD is from 1 to 5 in the NCOMP F&PS, it is expected that cirrus clouds will continue to be our best COD validation option.

NCOMP Algorithm Performance Estimates (5)

Satellite Based: Comparison of Matched NCOMP and AMSR-E: Liquid Water Path

ABI NCOMP Results using SEVIRI as proxy



10-week Period Sampled from 4 Seasons

Limited again to 1 < COD < 5.

Additionally limited to those aggregate ABI phase retrievals where at least 75% were water.

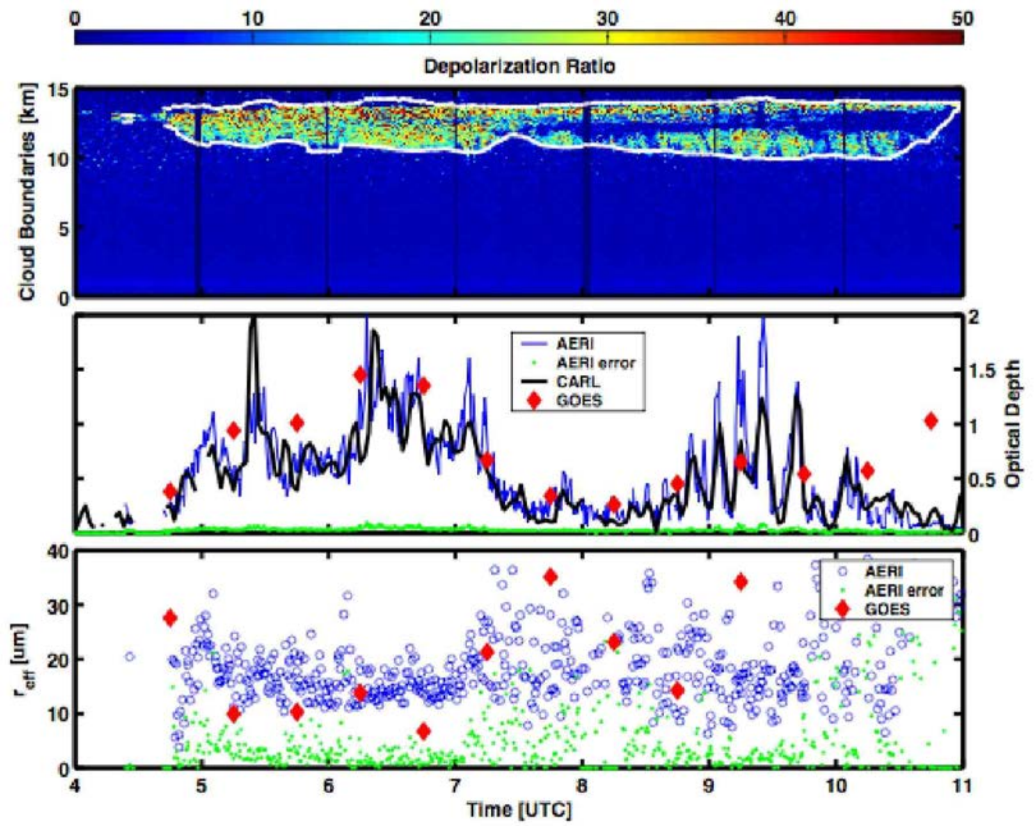
Accuracy = +4.5 g/m^2, meeting the requirement of 25.0 g/m^2.

Precision = 15.7 g/m^2, also within the requirement of 25.0 g/m^2.

NCOMP Algorithm Performance Estimates (6)

Surface-Based: Remote Retrievals compared to LaRC NCOMP (SIST) applied to GOES data: τ and r_e

From TX2002 field campaign: 0400 to 1100 UTC on 29 November 2002



These semi-transparent ice clouds indicate excellent agreement in optical depth and good agreement in effective particle size. Note that sampling issues and extinction depth in the cloud are important for r_e

From surface lidar:

- Cloud vertical boundaries

Cloud Optical Depth from surface lidar, surface interferometer and SIST

- AERI =surface interferometer
- CARL = surface raman lidar
- GOES = GOES satellite using SIST

Cloud Effective Particle Size from surface interferometer and SIST

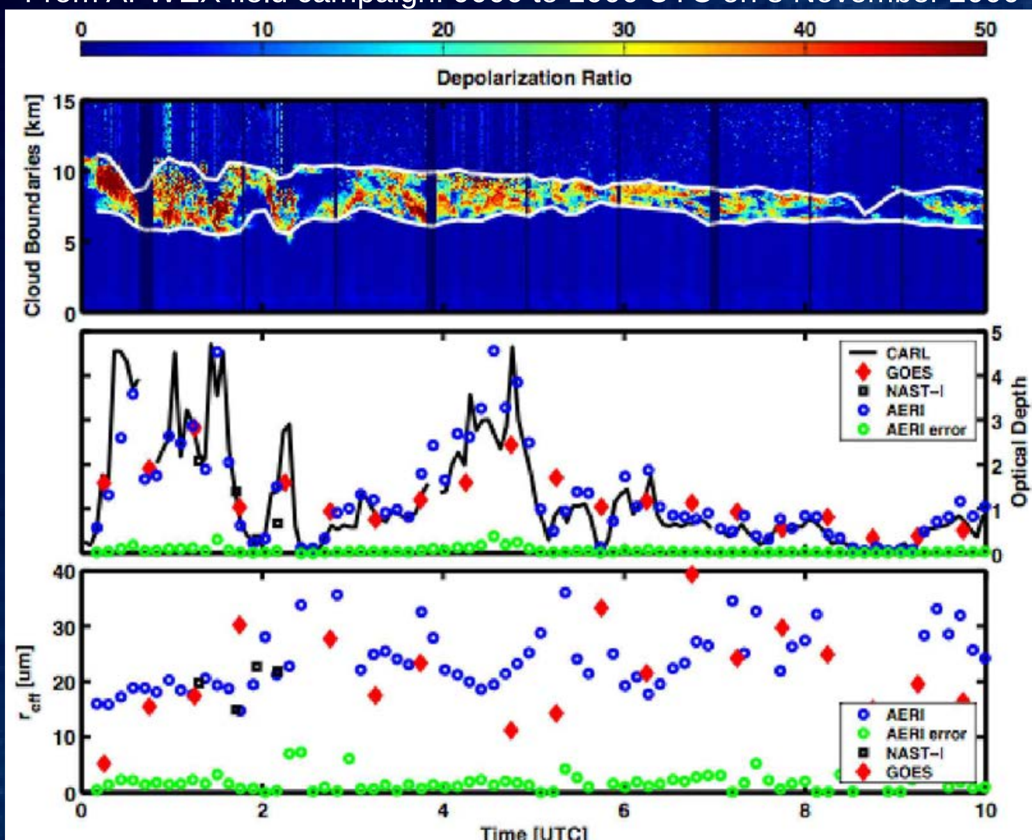
- AERI =surface interferometer
- GOES = GOES satellite using SIST

From D. Deslover, personal communication

NCOMP Algorithm Performance Estimates (7)

Surface-based: Remote Retrievals with Aircraft *in situ* Retrievals Added (still LaRC SIST applied to GOES): τ and r_e

From AFWEX field campaign: 0000 to 1000 UTC on 8 November 2000



These semi-transparent ice clouds indicate excellent agreement in optical depth and good agreement in effective particle size. Surface and aircraft retrievals have been time averaged here.

From surface lidar:

- Cloud vertical boundaries

Cloud Optical Depth from surface lidar, SIST and aircraft and surface interferometers

- CARL = surface raman lidar
- GOES = GOES satellite using SIST
- NAST-I = aircraft interferometer
- AERI = surface interferometer

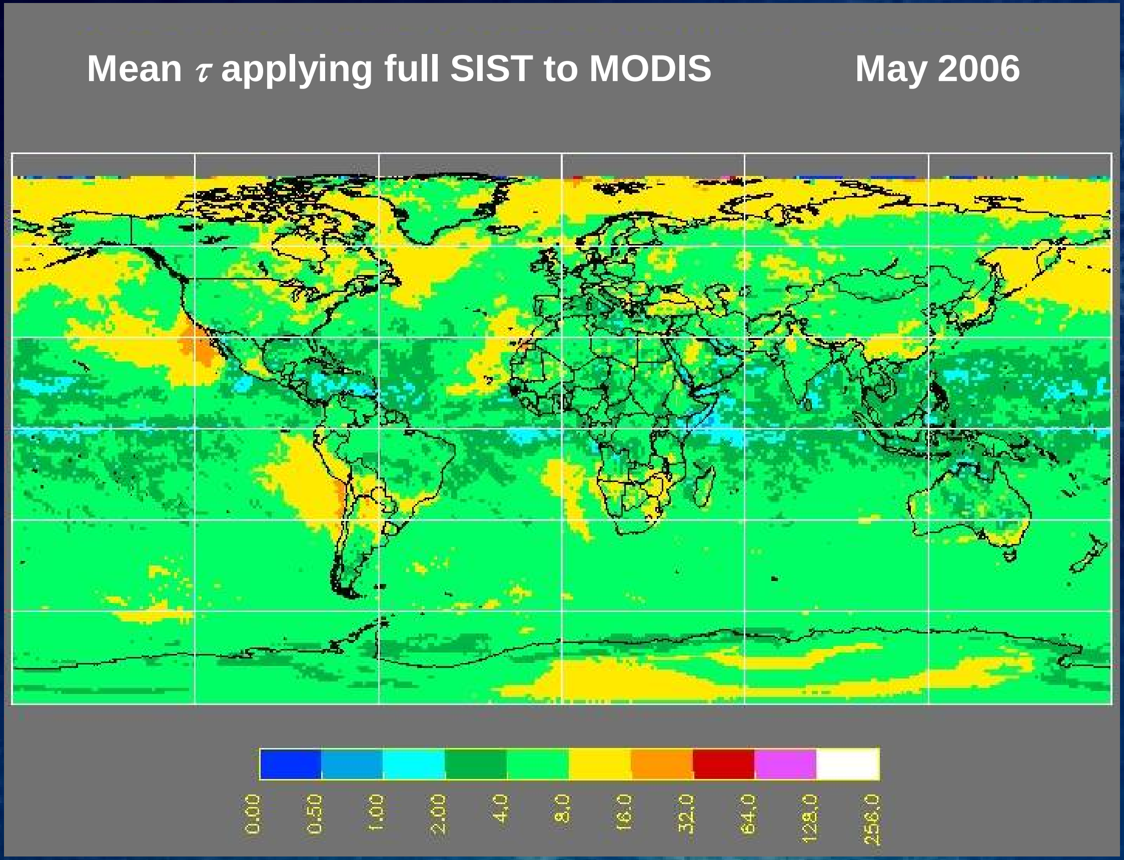
Cloud Effective Particle Size from surface and aircraft interferometers and SIST

- AERI =surface interferometer
- NAST-I = aircraft interferometer
- GOES = GOES satellite using SIST

From D. Deslover, personal communication

NCOMP Algorithm Performance Estimates (9)

Satellite-based Retrievals with a Similar Algorithm and Different Instrument/Platform: τ



Many years of MODIS data have been processed with the CERES version of the SIST and validated.

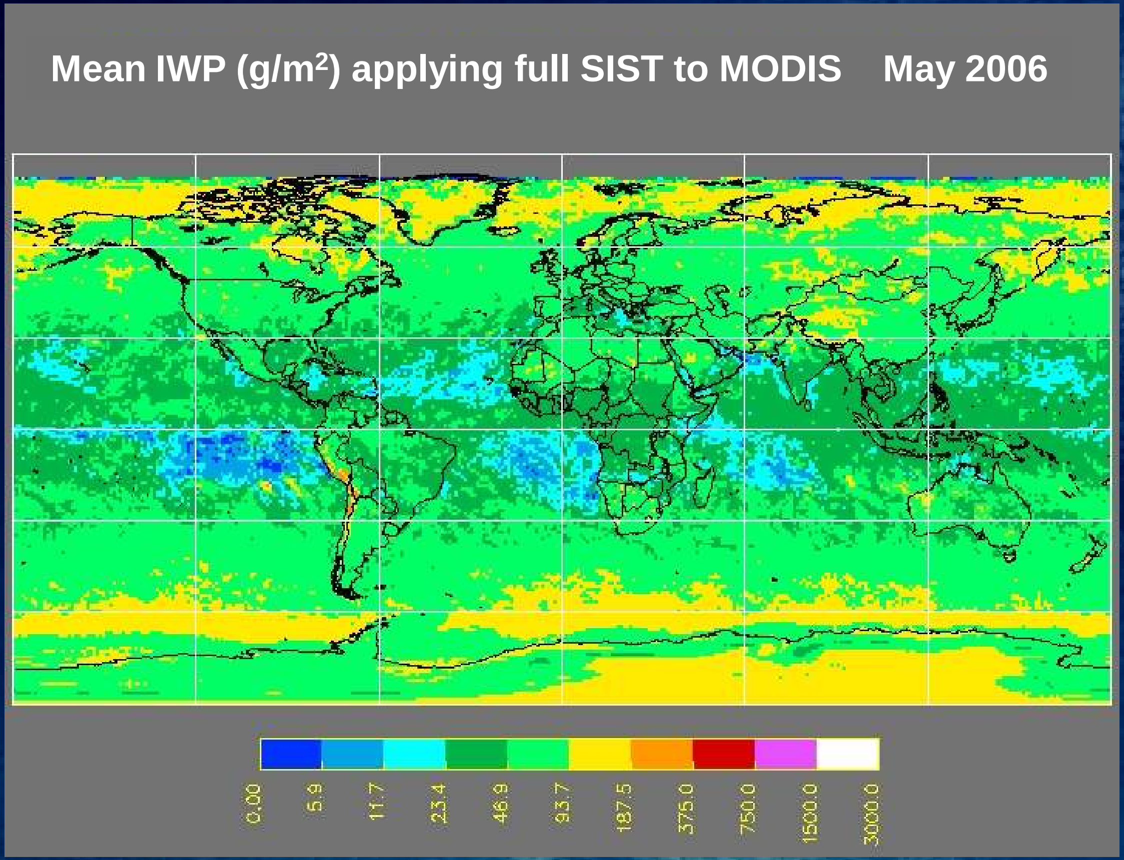
This plot shows the mean nighttime cloud optical depth for water and ice clouds for the entire month of May 2006.

All individual MODIS pixels are available for comparison to simulated ABI data.

Direct comparisons with VIIRS NCOMP are forthcoming.

NCOMP Algorithm Performance Estimates (10)

Satellite-based Retrievals with a Similar Algorithm and Different Instrument/Platform: IWP



This plot shows the mean nighttime Ice Water Path for the entire month of May 2006.

Again, all individual MODIS pixels are available for comparison to simulated ABI data.

Direct comparisons with VIIRS NCOMP are forthcoming.

NCOMP Algorithm Performance Estimates (11)

Future Planned Validation

For Cloud Optical Depth, Cloud Particle Size, LWP and IWP, additional validation will be performed using:

- Surface Data and/or Aircraft Data from field programs (All)
- Additional CALIPSO/CloudSat (primarily COD)
- Microwave-based Satellite Retrievals (LWP)
- MODIS Retrievals (All)

NCOMP Algorithm Performance Estimates (12)

Summary of NCOMP Performance from Application to SEVIRI Data as GOES-R Proxy

Product	*Measurement Range*	*Measurement Accuracy*	*Measurement Precision*
COD	1.0 – 5.0 1.0 – 5.0	30% 6.3%	max of 0.8 or 30% 0.54 or 29.9%
CPS	**liquid**: 2 < CPS < 32μm 2 < CPS < 32μm **ice**: 2 < CPS < 50μm 2 < CPS < 50μm	**liquid**: max of 4μm or 30% *no direct comparison **ice**: 10μm 1.8 μm	**liquid**: max of 4μm or 25% *no direct comparison **ice**: max of 10μm or 25% *9.1 μm or 19.6%
LWP	25 < LWP < 100 gm^{-2} 25 < LWP < 100 gm^{-2}	greater of 25 gm^{-2} or 15% 5.7 gm^{-2} or 11.5%	greater of 25 gm^{-2} or 40% 14.7 gm^{-2} or 29.5%
IWP	25 < IWP < 175 gm^{-2} 25 < IWP < 175 gm^{-2}	greater of 25 gm^{-2} or 30% *no direct comparison	greater of 25 gm^{-2} or 40% *no direct comparison

Black entries are the VIIRS L1RD requirements
Red entries are NCOMP performance results

VIIRS NCOMP expected to be similar

NCOMP Algorithm Assumptions and Limitations

- **Assumptions:**
  - Input VIIRS temperatures are available and well-calibrated
  - Internal NCOMP calibration coeffients are available (in LUT)
  - Input VIIRS products are available (Cloud Top Temperature and Cloud Type)
  - All ancillary datasets are available
  - Satellite angles and other satellite input are available

- **Limitations:**
  - Quantitive retrievals for solar zenith angle ≥ 90
  - Qualitative retrievals for 82 ≤ solar zenith angle < 90
  - Qualitative retrievals for VZA > 65
  - All products for clouds with 1 < COD < 5
  - All products assume single-layer clouds

NCOMP Algorithm Error Sources

- Primary sources of error in NCOMP retrievals are uncertainties in:
  - » Ancillary datasets
    - – errors in RTM or NWP profiles
    - – clear sky quantities
    - – spatial or temporal resolution differences with observations
  - » Heterogeneity of clouds
    - – Multi-layer
    - – 3-D effects
  - » Twilight conditions or when SZA is very close to 90 degrees, hence 3.9-μm channel could impacted.
  - » Accuracy of cloud emittance parameterizations
  - » Occasions when the iterative scheme does not perform well
- All of these can impact COD, CPS and LWP/IWP.

NCOMP Summary of Algorithm Development

- A heritage algorithm (SIST) was adapted and streamlined to work in the GOES-R ABI framework and then in the VIIIRS framework.
- The algorithm is ready to be applied to VIIRS data.
- The analyses and validation NCOMP SEVIRI results indicate that the selected algorithm will meet the VIIRS mission accuracy requirement for NCOMP.
- After VIIRS NCOMP is fully implemented, further validations will be performed.

NCOMP Future Algorithm Development

- The inclusion of additional VIIRS channels will be explored, but options are limited due to the channel selection on VIIRS (no CO2 channel).
  - The 8.5-µm channel (M14) can be useful in mid-range ice cloud optical depth retrieval and in multilayer situations.
- A new parameterization that allows for retrieval of COD > 8 will be tested and evaluated for inclusion in future NCOMP versions.
- Streamlined and improved iteration techniques within the NCOMP will continue to be studied for
  - Increased computation speed
  - More accurate r_e in situations where defaults are currently used, including situations where nearest model nodes are used due to nonconvergence of iteration schemes.

NCOMP References (1)

- Chepfer, H., V. Noel, P. Minnis, D. Baumgardner, L. Nguyen, G. Raga, M. J. McGill, and P. Yang, 2005: Particle habit in tropical ice clouds during CRYSTAL-FACE: Comparison of two remote sensing techniques with in situ observations. J. Geophys. Res., 110.
- Chiriaco, M., H. Chepfer, P. Minnis, M. Haeffelin, S. Platnick, D. Baumgardner, P. Dubuisson, M. McGill, V. Noel, J. Pelon, D. Spangenberg, S. Sun-Mack, and G. Wind, 2006: Comparison of CALIPSO-like, LaRC, and MODIS retrievals of ice cloud properties over SIRTA in France and Florida during CRYSTAL-FACE. *J. Appl. Meteorol. Climatol*., 43.
- Comstock, J. M., R. dEntremont, D. DeSlover, G. G. Mace, S. Y. Matrosov, S. A. McFarlane, P. Minnis, D. Mitchell, K. Sassen, M. D. Shupe, D. D. Turner, and Z. Wang, 2007: An intercomparison of microphysical retrieval algorithms for upper tropospheric ice clouds. Bull. Am. Meteorol. Soc., 88, 191-204.
- Dong, X., P. Minnis, B. Xi, S. Sun-Mack, and Y. Chen, 2008: Validation of CERES-MODIS stratus cloud properties using ground-based measurements at the DOE ARM SGP site. *J. Geophys. Res.* 113.
- Dong, X., B. Xi, and P. Minnis, 2006: Observational evidence of changes in water vapor, clouds, and radiation at the ARM SGP site. Geophys. Res. Lett., 33, L19818, 10.1029/2006GL027132.
- Dong, X., P. Minnis, and B. Xi, 2005: A climatology of midlatitude continental clouds from the ARM SGP Central Facility: Part I: Low-level cloud macrophysical, microphysical and radiative properties. J. Climate, 18, 1391-1410.
- Dong, X., B. Xi, P. Minnis, and C. N. Long, 2006: A climatology of midlatitude continental clouds from the ARM SGP Central Facility: Part II: Cloud fraction and radiative forcing. J. Climate, 19, 1765-1783.
- Dong, X., P. Minnis, G. G. Mace, W. L. Smith, Jr., M. Poellot, R. T. Marchand, and A. D. Rapp, 2002: Comparison of stratus cloud properties deduced from surface, GOES, and aircraft data during the March 2000 ARM Cloud IOP. J. Atmos. Sci., 59, 3256-3284.
- Mace, G. G., Y. Zhang, S. Platnick, M. D. King, P. Minnis, and P. Yang, 2005: Evaluation of cirrus cloud properties from MODIS radiances using cloud properties derived from ground-based data collected at the ARM SGP site. J. Appl. Meteorol., 44,221-240.

NCOMP References (2)

- Min, Q, P. Minnis, and M. M. Khaiyer, 2004: Comparison of cirrus optical depths from GOES-8 and surface measurements. J. Geophys. Res., 109, No. D15, D15207 10.1029/2003JD004390, August 12.
- Minnis, P.; Garber, D. P.; Young, D. F.; Arduini, R. F.; and Takano, Y.: Parameterization of Reflectance and Effective Emittance for Satellite Remote Sensing of Cloud Properties. Journal of Atmospheric Sciences, Vol. 55, 3313-3339, 1998.
- Minnis, P.; Kratz, D. P.; Coakley, J. A., Jr.; King, M. D.; Garber, D.; Heck, P.; Mayor, S.; Young, D. F. and Arduini, R.: Cloud Optical Property Retrieval (Subsystem 4.3). "Clouds and the Earth's Radiant Energy System (CERES) Algorithm Theoretical Basis Document, Volume III: Cloud Analyses and Radiance Inversions (Subsystem 4)", NASA RP 1376 Vol. 3,edited by CERES Science Team, December, 1995, pp. 135-176.
- Minnis, P., K. N. Liou, and Y. Takano, 1993b: Inference of cirrus cloud properties using satellite-observed visible and infrared radiances. Part I: Parameterization of radiance fields. *J. Atmos. Sci.*, 50, 1279-1304.
- Minnis, P., P. W. Heck, and D. F. Young, 1993a: Inference of cirrus cloud properties from satellite-observed visible and infrared radiances. Part II: Verification of theoretical radiative properties. *J. Atmos. Sci.*, 50, 1305-1322.
- Takano, Y. and K. N. Liou, 1989: Radiative transfer in cirrus clouds I. Single scattering and optical properties of oriented hexagonal ice crystals. *J. Atmos. Sci.*, 46, 3-20.
- Takano, Y., Liou, K. N. and P. Minnis, 1992: The effects of small ice crystals on cirrus infrared properties. *J. Atmos. Sci.*, 49, 1487-1493.
- Turner, D. D., A. M. Vogelmann, R. Austin, J. C. Barnerd, K. Cady-Pereira, C. Chiu, S. A. Clough, C. Flynn, M. M. Khaiyer, J. Liljegren, K. Johnson, B. Lin, C. Long, A. Marshak, S. Y. Matrosov, S. McFarlane, M. Miller, Q. Min, P. Minnis, W. OHirok, Z. Wang, and W. Wiscombe, 2007: Optically thin liquid water clouds: Their importance and our challenge. Bull. Am.Meteorol. Soc., 88, 177-190.
- Young, D. F.; Minnis, P.; Baumgardner, D.; and Gerber, H.: Comparison of In Situ and Satellite-Derived Cloud Properties During SUCCESS.Geophys. Res. Ltrs., 25, April 15, 1998, pp.1125-1128.

Outline

- Introduction
- Requirements
- Operations Concept
- Volcanic Ash
- Cloud Phase
- NCOMP
- Software Architecture and Interfaces
- Detailed Design
- Algorithm Package
- Quality Assurance
- Risks and Actions Summary
- Summary and Conclusions

Software Architecture and Interfaces

Presented by

Walter Wolf

Software Architecture

- **Purpose:** Demonstrate that the algorithm process flow provides for an implementation that is consistent with the theoretical basis and meets requirements.

CDR Software Architecture

- A preferred solution has been selected for the Aerosol, Cloud and Cryosphere Products

- The software system is an integrated collection of software elements, or code, that implements the preferred solution, producing well-defined output products from a well-defined set of input data.

- The software architecture describes the structure of the system software elements and the external and internal data flows between software elements.

Software Architecture Levels

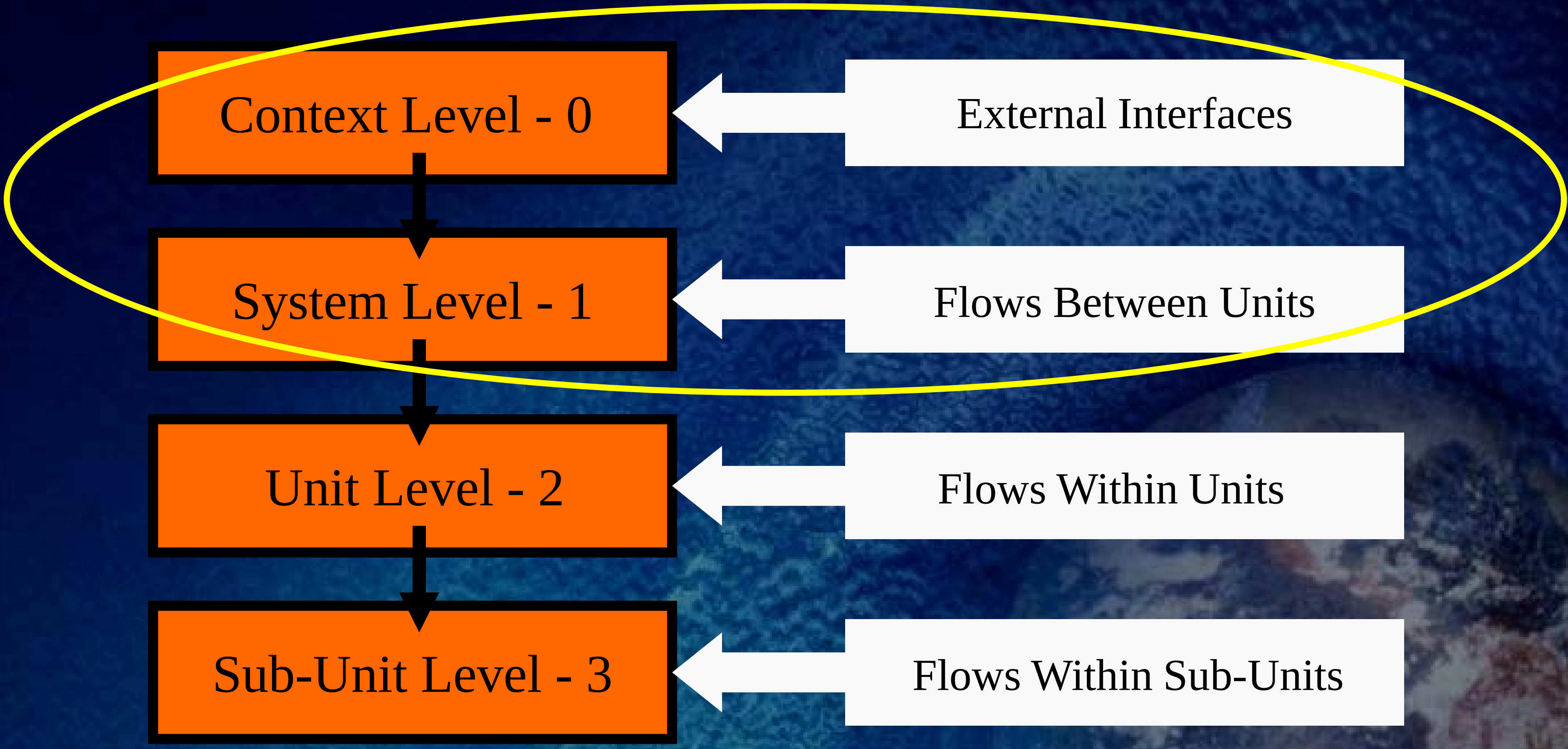
Context Level - 0 ← External Interfaces

System Level - 1 ← Flows Between Units

Unit Level - 2 ← Flows Within Units

Sub-Unit Level - 3 ← Flows Within Sub-Units

Software Architecture Levels



External Interfaces -- Definition

- **An external input is defined as a data source needed by the system that is produced or made available by a process external to the system**

- **An external output is defined as a product that is created by the system for an external user**

External Interfaces - Criteria

- Most input/output data files for the Aerosol, Cloud and Cryosphere algorithms will be in NetCDF4 format.
  - » Exceptions:
    - – NCEP model forecast data
    - – CRTM coefficients
    - – PCF file
    - – Log file

- The data passed to the units and sub-units will be stored in arrays.

External Interface Design at CDR

AIT Framework

Purpose

- **Purpose: Demonstrate that the AIT Framework provides an infrastructure that will enable the implementation of the Aerosol, Cloud and Cryosphere algorithms that meet the requirements.**

STAR AIT Framework Overview

- The STAR AIT Framework is a main program designed to run any scientific algorithm
- The Framwork is a C++ program that interfaces with C++/C/Fortran 90/95 algorithms
- The Framework is run by perl scripts
- Production Control Files (PCF) determine what algorithms are run when the framework is executed

STAR AIT Framework Details

- Common ancillary data is used across algorithms (where possible)
- Forward model is run once for all algorithms
- Satellite data and ancillary data is stored in memory for use by the algorithms
- Algorithms may be run in any order – determined by the PCF file

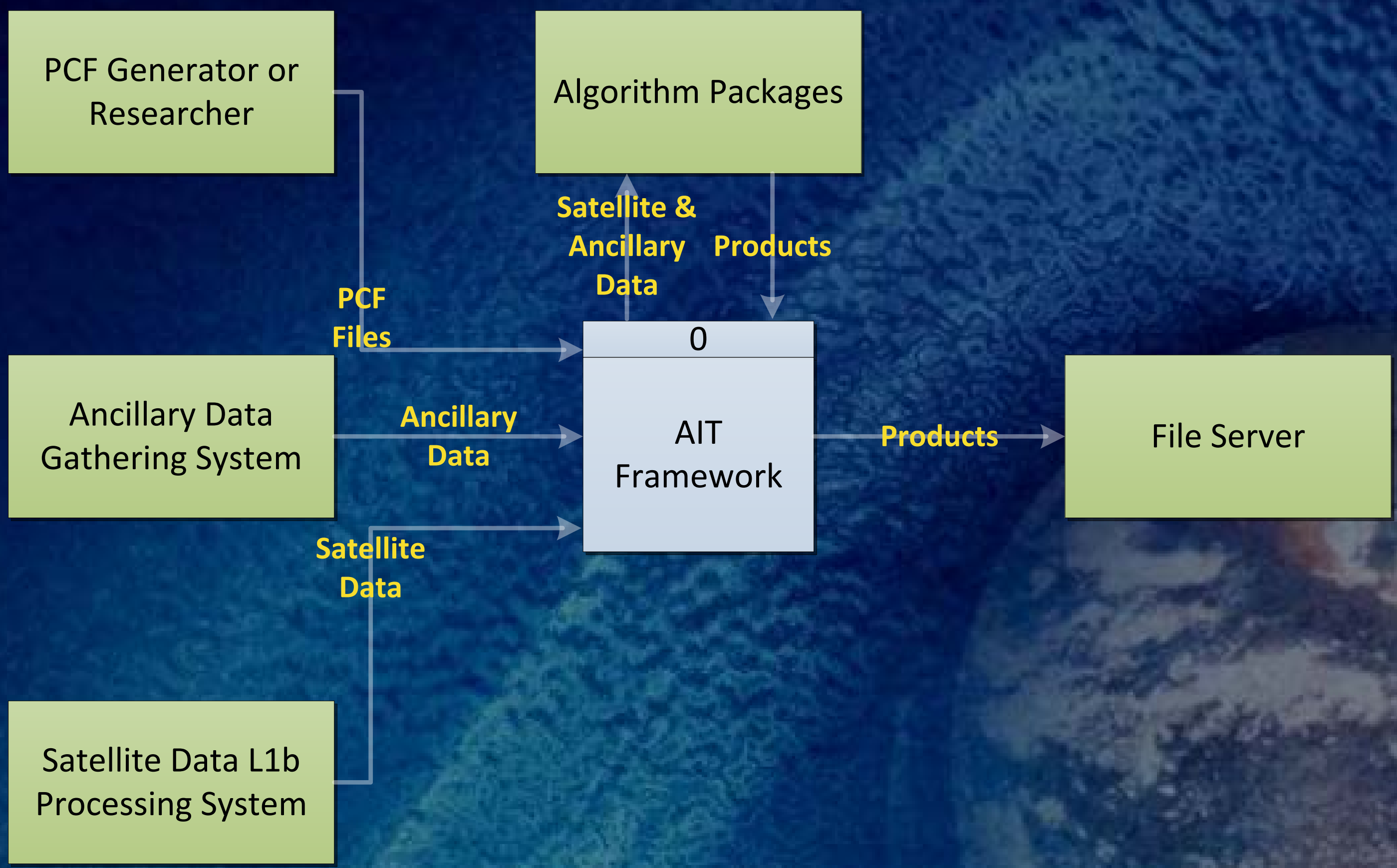
STAR AIT Framework Algorithms

- Algorithms plugged into the framework are subroutine calls
- Data is not read within the algorithm, all input data is either passed into the algorithm or is read via a function call
- Readers and writers of all types of input and output data are treated as algorithms

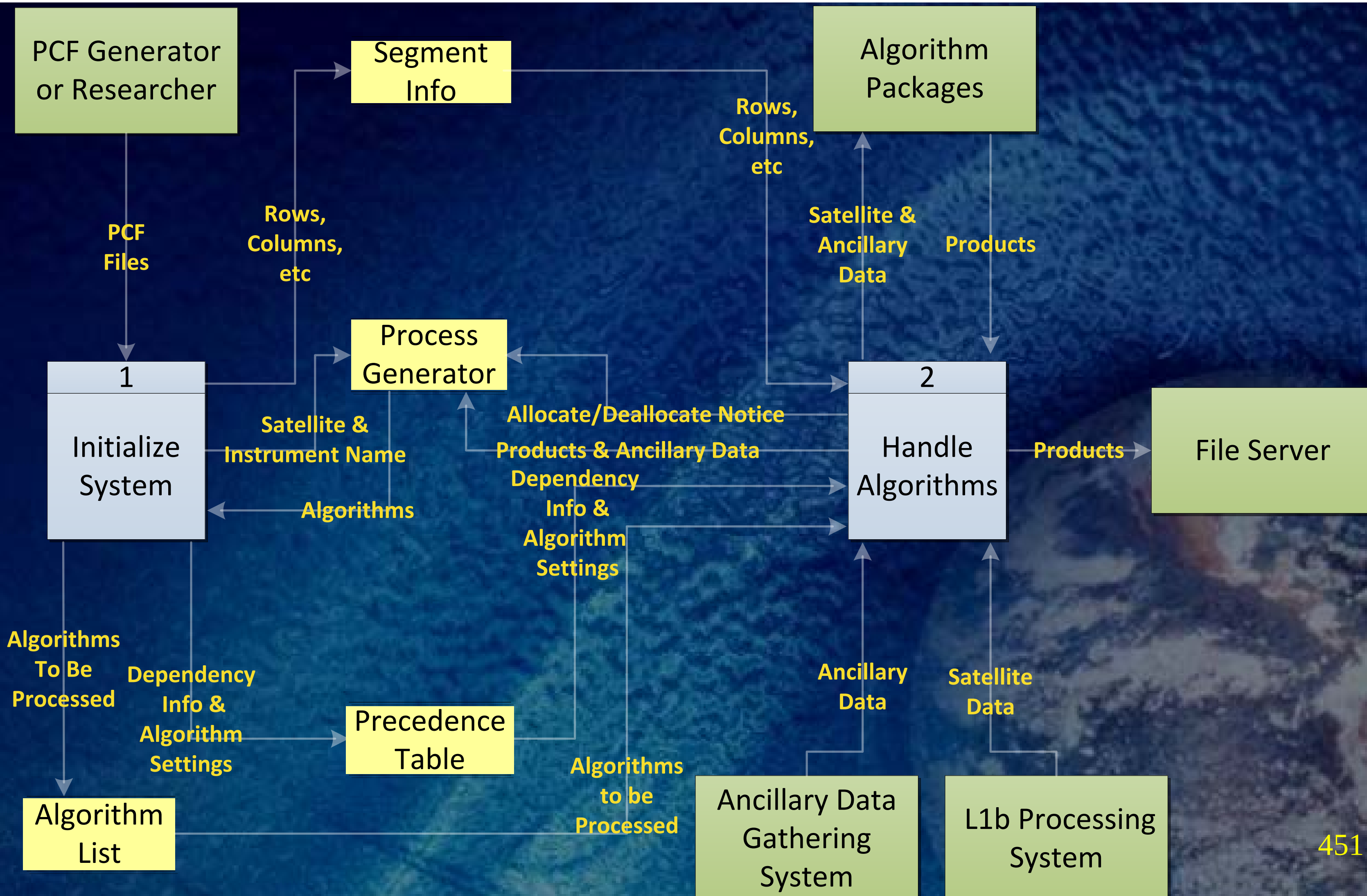
Framework Data Flow and Interfaces

- The following slides show the data flow and interfaces in the framework.

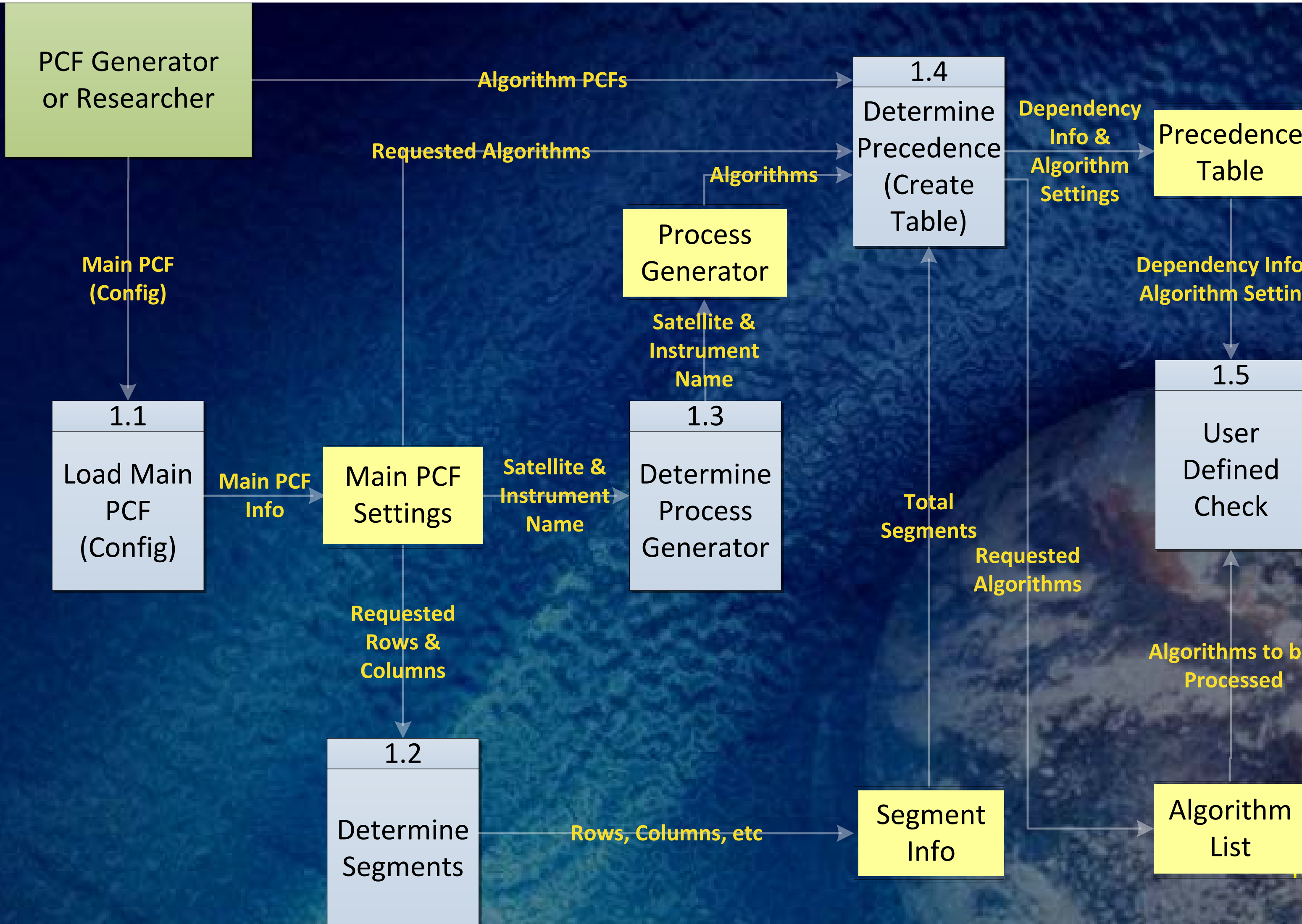
Framework Context Diagram



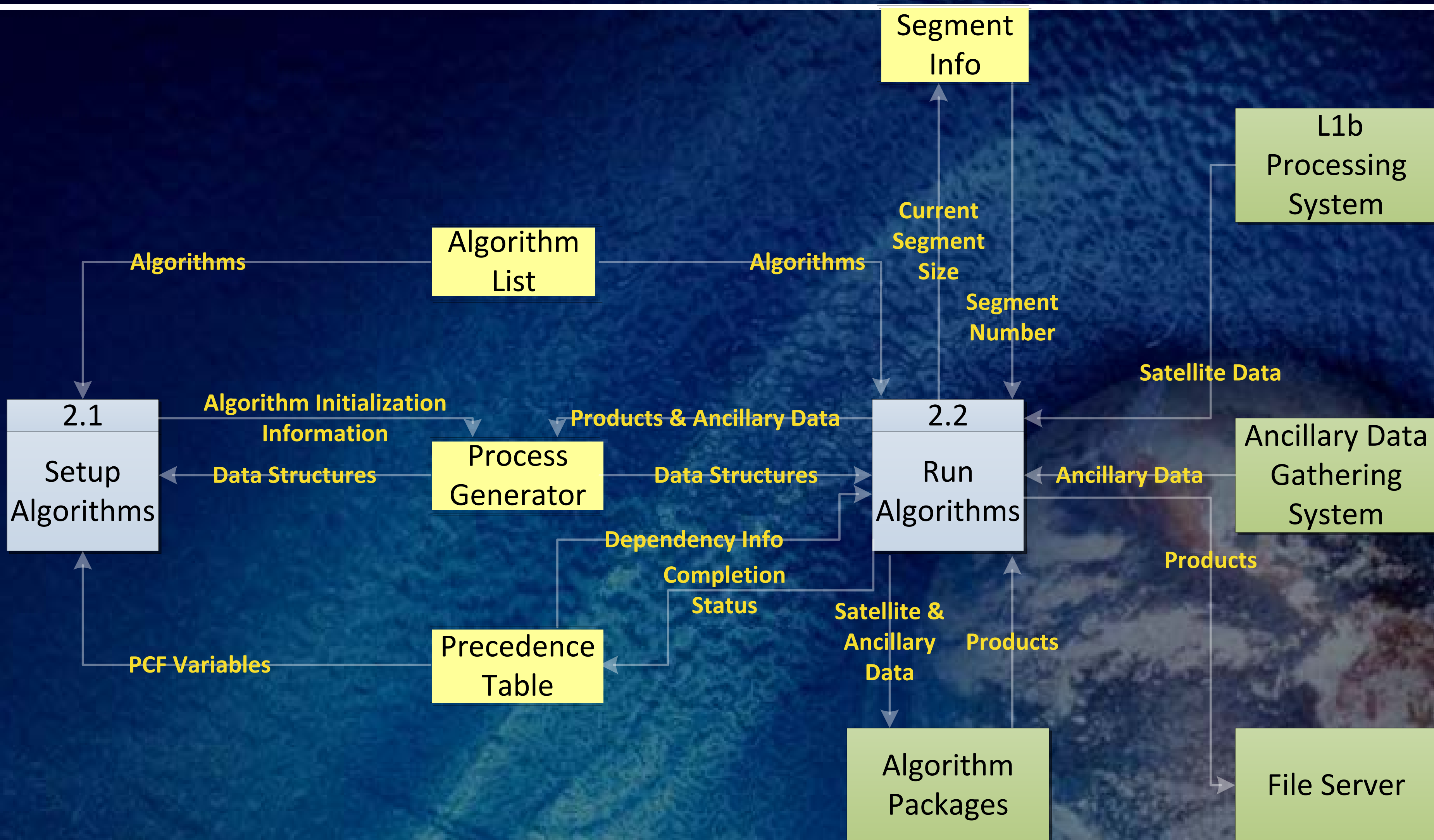
Framework System Level



Framework Unit Level 1
Initialize System



Framework Unit Level 2
Handle Algorithms



Inputs

- PCF files
- Data
  - » Common ancillary data
  - » Radiance data
  - » Specific algorithm data

PCF Files

- Production Control Files (PCF) contain the information required to run an algorithm
  - » Algorithm dependencies to determine product precedence
  - » Algorithm specific variables such as flags and thresholds
  - » Framework loads the contents of the PCF file when the algorithm has been flagged to run in the configuration file or if it is needed by something that has been flagged to run in the configuration file.

PCF File:
3 Main Sections

- DEPENDENCIES
  - » List the Type and PCF ID for each dependency the algorithm requires
- OTHER
  - » This section contains algorithm specific variables such as thresholds, flags, etc that are flexible and can be changed at run time.
- TEMPORAL
  - » This section dictates temporal needs for the algorithm if requested.

PCF Layout Example

(Default_PCF/MSG8/SEVIRI/AWG_Cloud_Mask.pcf)

```
#
# AWG_CLOUD_MASK
#
AWG_CLOUD_MASK
```

PCF ID indicates beginning of entry.

```
PRODUCT
```

PRODUCT or ANCILLARY

```
#
# Set flag for output
#
OUTPUT_TO_FILE: Y
```

Output result to file (Y/N)

```
#
# Dependencies
#
DEPENDENCIES:
```

"DEPENDENCIES" keyword indicates dependency section of the PCF.

```
SATELLITE_DATA:
```

SATELLITE_DATA dependency type doesn't have a dependency below. The framework will look for what satellite data to use in the config file. This avoids tedious modification to each PCF.

```
LAND_MASK:
```

Dependency Type

```
LAND_MASK
```

Dependency PCF ID

PCF Layout (cont 1)

```
COAST_MASK:
COAST_MASK_NASA_1KM

DESERT_MASK:
DESERT_MASK

SNOW_MASK:

SNOW_MASK_IMS_SSMI
```

1^{st} Dependency

```
SNOW_MASK_NWP
```

Backup Dependency

```
PSEUDO_EMISSIVITY:
GOESR_ABI_CHN7_EMISS

SURFACE_ELEVATION:
SFC_ELEV_GLOBE_1KM

SURFACE_EMISSIVITY:
SFC_EMISS_SEEBOR
SFC_EMISS_CONSTANT

NWP_DATA:
NWP_GFS
```

PCF Layout (cont 2)

```
RTM:
CRTM

TEMPORAL_DATA:
TEMPORAL_DATA_FIXED
```

Temporal data is special – has it's own section that needs to be filled out if it is specified to run.

```
#
# Create this section only if Temporal Data part of dependencies
#
TEMPORAL:
```

"TEMPORAL" keyword indicates temporal section. Only required for algorithms needing temporal data.

```
Timestep_Type: MSG_SEVIRI
```

Each satellite/instrument has a different time increment. Informs system what to expect.

```
Timestep: -1
```

-1 = most recent previous time step

```
Actual_Time: -900.0
```

Actual time difference in seconds. (-15 min)

```
Load:
```

Load keyword tells system the following list needs to be loaded into the system as temporal data.

```
AWG_CLOUD_MASK = /need/to/create/file
```

PCF ID & Filename

PCF Layout (cont 3)

```
#
# Settings
#
OTHER:
```

Keyword “OTHER” indicates algorithm variables/settings section.

```
CldMask_Packed_Constant: 4
Flag_Constant: 24
Ancillary_Path: cloud_team_delivery_0/data_algorithms/
Ancillary_SubDir: baseline_cloud_mask/
```

AWG_CLOUD_MASK specific variables.

```
END AWG_CLOUD_MASK
```

End of algorithm entry

Specific Algorithm Data

- Each algorithm currently reads its own specific ancillary data (such as coefficient files, look up tables, etc)
- See algorithm section for details

Product Precedence

- The following 6 slides show the ancillary data product precedence information:
  - » VIIRS SDR data
  - » Static Ancillary data
  - » Dynamic Ancillary data
  - » Radiative Transfer Model (RTM)

- The full product precedence chart for the Aerosol, Cloud and Cryosphere algorithms is shown later in this section.

Product Precedence
S-NPP VIIRS

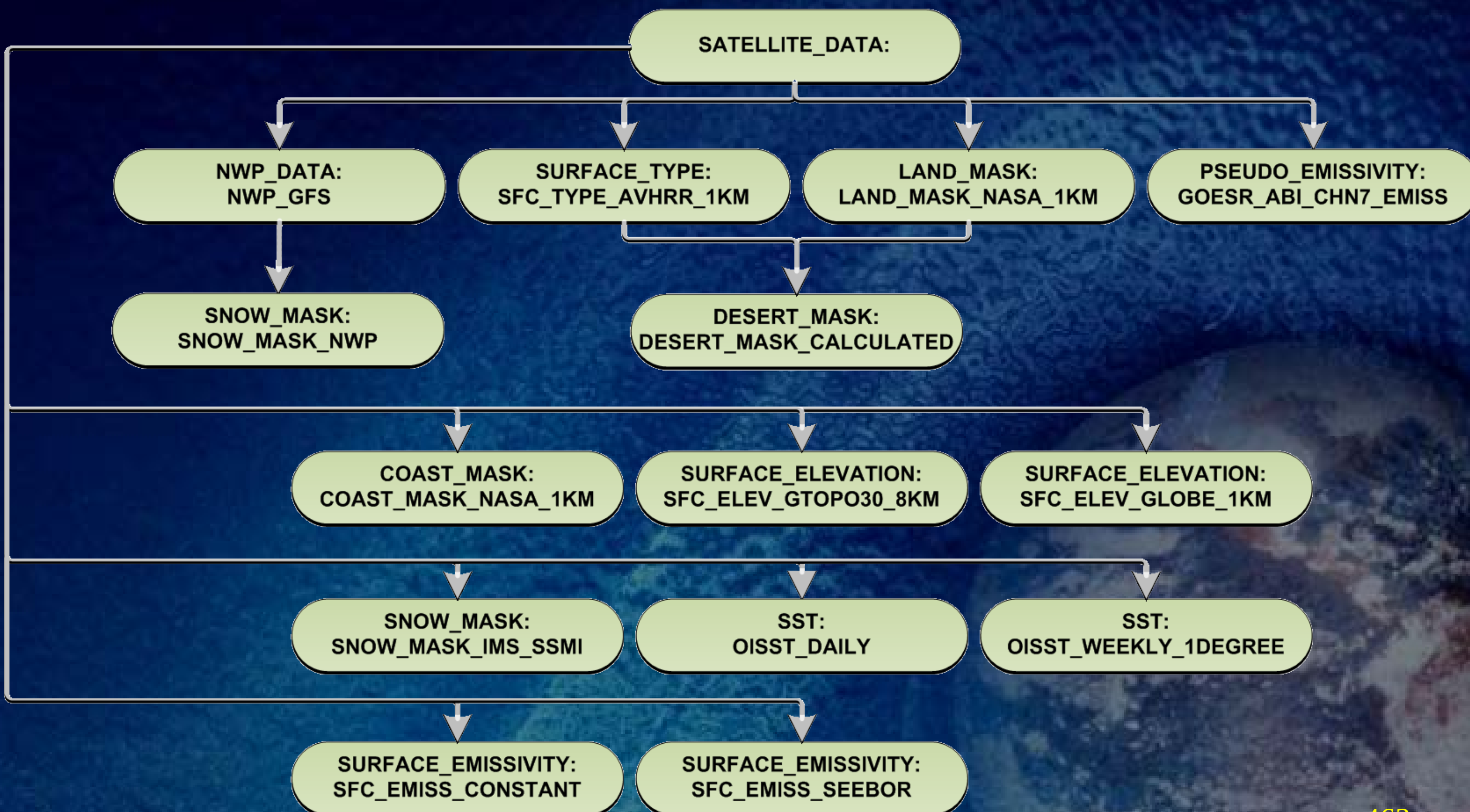


Table of DynamicAncillary Data

Ancillary Data	Description	Filename	Size
CRTM	Community Radiative Transfer Model	N/A	N/A
NWP_GFS	NCEP GFS model data in grib format – 1 x 1 degree (360x181), 26 levels	gfs.tHHz.pgrbfhh	26MB
OISST_WEEKLY_1DEGREE	NCEP EMC Reynolds OISST weekly analysis, 1 degree resolution	oisst.YYYYMMDD.nc	778704 bytes
SNOW_MASK_IMS_SSMI	Snow/Ice mask, IMS – Northern Hemisphere, SSM/I – Southern Hemisphere 4km resolution – the 25 km SSM/I has been oversampled to 4km	snow_map_4km_YYMMDD.nc	39mb
SNOW_MASK_NWP	Snow/Ice mask, calculated from snow surface variable in the GFS grib file	N/A	N/A

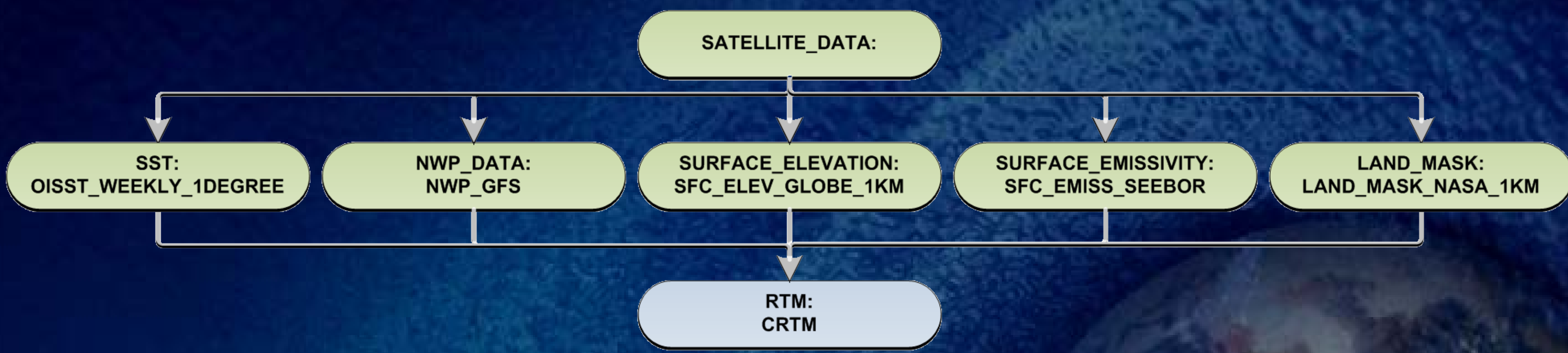
Table of Static Ancillary Data

Ancillary Data	Description	Filename	Size
COAST_MASK_NASA_1KM	Global 1km land/water used for MODIS collection 5	coast_mask_1km.nc	890 MB
DESERT_MASK_CALCLTED	Desert mask calculated using LAND_MASK_NASA_1KM and SFC_TYPE_AVHRR_1KM	N/A	N/A
LAND_MASK_NASA_1KM	Global 1km land/water used for MODIS collection 5	lw_geo_2001001_v03m.nc	890 MB
SFC_ALBEDO	MODIS White Sky Surface albedo	AlbMap.WS.c004.v2.0.YYYY.DDD.0.659_x4.nc AlbMap.WS.c004.v2.0.YYYY.DDD.1.64_x4.nc	28 MB x 2
SFC_ELEV_GLOBE_1KM	Digital surface elevation at 1km resolution	GLOBE_1km_digelev.nc	1843.2 MB
SFC_ELEV_GTOPO30_8KM	Digital surface elevation at 8km resolution	digelev_hires_le.map	32 MB

Table of Static Ancillary Data

Ancillary Data	Description	Filename	Size
SFC_EMISS_CONSTANT	Surface emissivity, constant value -- The emissivity is read in from the PCF file and is set to 0.98 (it's default value)	N/A	N/A
SFC_EMISS_SEEBOR	Surface emissivity at 5km resolution, climatology monthly	global_emiss_intABI_2005DDD.nc	693 MB x 12
SFC_TYPE_AVHRR_1KM	Surface type mask based on AVHRR at 1km resolution	gl-latlong-1km-landcover.nc	890 MB
VOLCANO_SMITH_1KM	Volcano mask	volcano_mask_1km.nc	890 MB
NEEDLELEAF MASK	Needle-leaf forest cover fraction data reader	gl-latlong-1km-needleleaf.nc	933120444 bytes
TREECOVER MASK	tree cover fraction data reader	gl-latlong-1km-treecover.nc	933120420 bytes
EEZ MASK	Exclusive Economic Zone mask	eez_global.nc	933120440 bytes

Product Precedence
RTM



Key:

- Required Precedence
- Algorithm

CRTM Inputs and Outputs

Filename	Size
viirs-m_npp.SpcCoeff.bin	928 bytes
viirs-m_npp.TauCoeff.bin	6.3 kb

Output Files

- Output files are in NetCDF format
- See individual algorithms for details on the contents

STAR Hardware

- Rack of Linux Dell Processors (72 CPUS) for product development.

- 20 TB of disk space on the SAN for all simulated data, proxy data and products.

Software/Compilers

- Framework uses netCDF libraries
  - » NetCDF 4
  - » HDF 5 (required by NetCDF 4)
- Framework uses wgrib commands
- Perl scripts
  - » Code generation
  - » Standards checking
- Currently runs on Intel 12+ compilers
- ClearCase and ClearQuest used for version control
- Valgrind used to check for memory leaks

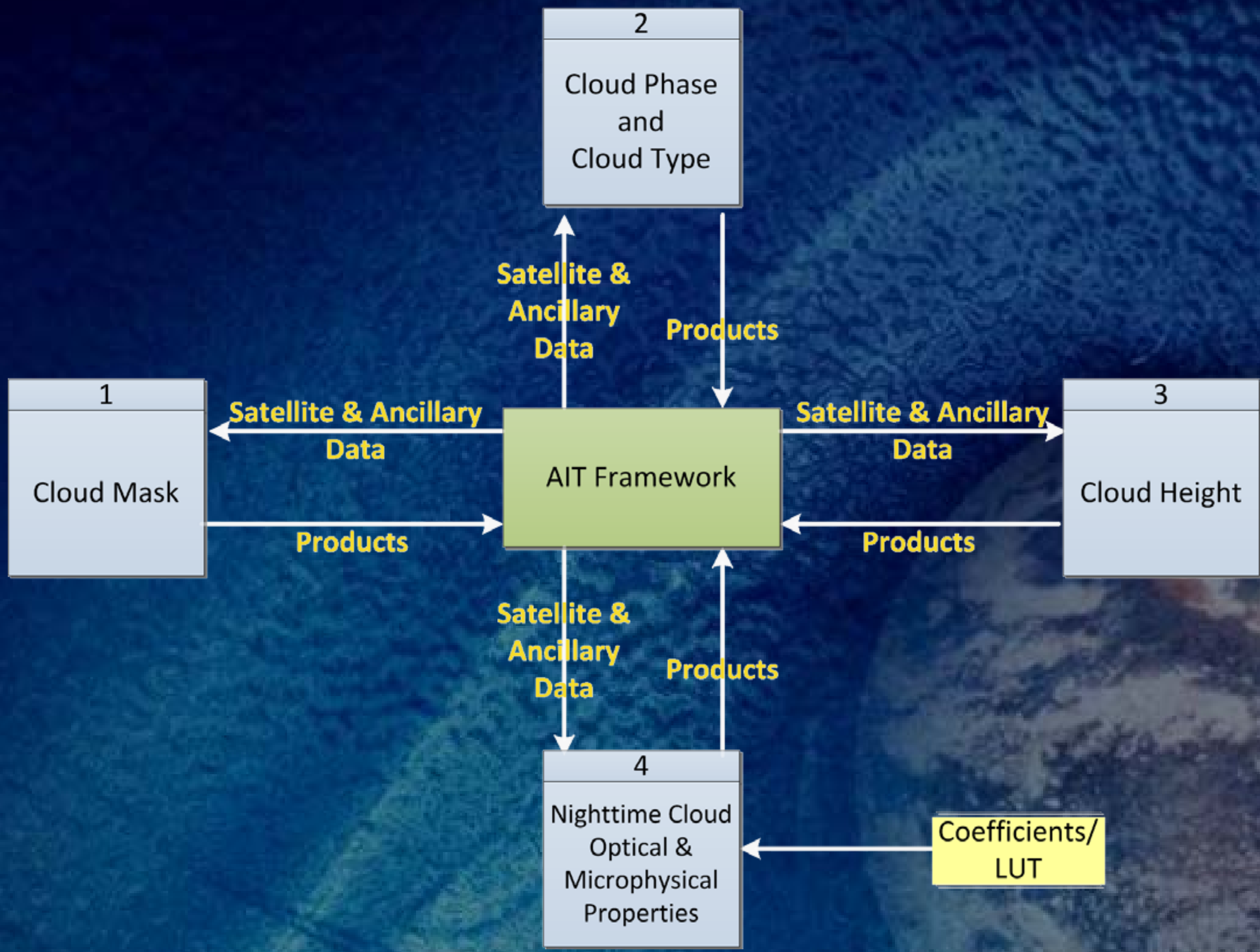
External Interface Design at CDR

System Level

Product Precedence

- All VIIRS products listed within the Software Architecture and Detailed Design sections that are used as product precedence are products created within the NDE JPSS Risk Reduction project

Cloud Mask, Cloud Phase/Type, Cloud Height and NCOMP System Level Data Flow-Diagram



System Level Data Flow – Table

Cloud Mask
Input, Internal, and Output Data Flows at the System Level

Interface Item	Interface Type	Source	Description
Coefficients	Input	UW/CIMSS	Clear sky oceanic reflectance
VIIRS SDR	Input	VIIRS	VIIRS calibrated and navigated brightness temperature and radiances in bands M12, M13, M14, M15, M16 and reflectance in bands M5, M7, M9, M10 with solar and satellite view angles.
Land Mask	Input	NASA	Global 1 km land/water mask used for MODIS collection 5
Surface Elevation	Input	NGDC	Digital surface elevation at 1km resolution
IMS Snow and Ice Mask	Input	IMS	Snow mask by the Interactive Multisensor Snow and Ice Mapping System
Desert Mask	Input	Calculated	Calculated desert mask based on the land mask
Coast Mask	Input	Calculated	Calculated coast mask based on the land mask
Surface Emissivity	Input	UW Baseline Fit	MODIS monthly mean IR land surface emissivity for channel M7
RTM	Input	RTM	CRTM Clear sky radiance/BT for bands M7, M14 and blackbody radiance for channel M14 and atmospheric transittance profiles for channel M7
NWP	Input	GFS model	Surface, Tropopause Level, Surface Temperature
Cloud Mask	Output	Cloud Mask	Cloud mask, clear sky binary mask, and cloud mask packed produced by cloud mask algorithm

System Level Data Flow – Table

Cloud Type/Phase
Input, Internal, and Output Data Flows at the System Level

Interface Item	Interface Type	Source	Description
VIIRS SDR	Input	VIIRS	VIIRS calibrated and navigated brightness temperature in bands M14, M15, M16
Land Mask	Input	NASA	Global 1 km land/water mask used for MODIS collection 5
Surface Elevation	Input	NGDC	Digital surface elevation at 1km resolution
IMS Snow and Ice Mask	Input	IMS	Snow mask by the Interactive Multisensor Snow and Ice Mapping System
Coast Mask	Input	Calculated	Calculated coast mask based on the land mask
RTM	Input	CRTM	Clear sky radiance and transmittance for bands 14, 15, 16 TOA radiance bands 14, 15, 16
NWP	Input	GFS model	Temperature, Pressure, Height profiles, Surface Level, Tropopause Level, Surface Temperature
VIIRS Cloud Mask	Input	VIIRS Cloud Mask	Cloud mask produced by VIIRS cloud mask algorithm
VIIRS Cloud Type/Phase	Output	VIIRS Cloud Type	Cloud phase produced by VIIRS cloud type algorithm

System Level Data Flow – Table

Cloud Height
Input, Internal, and Output Data Flows at the System Level

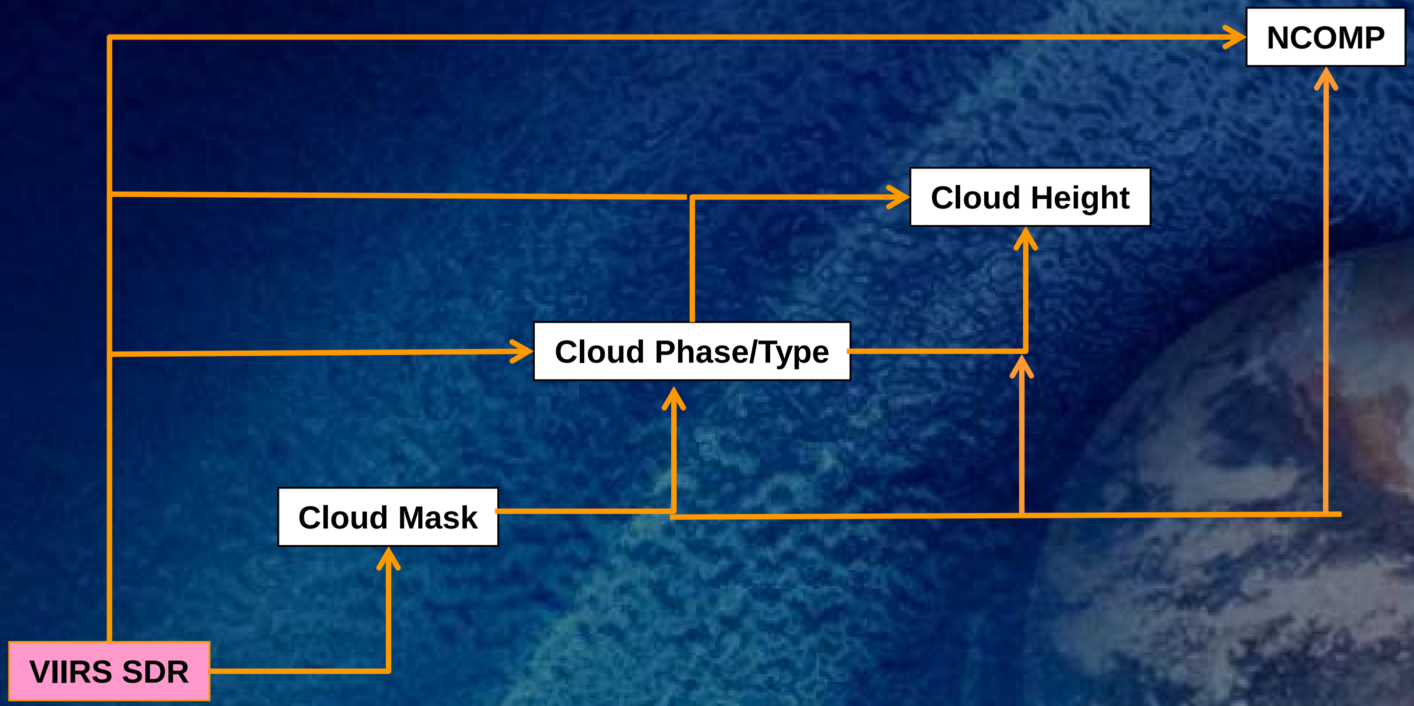
Interface Item	Interface Type	Source	Description
VIIRS SDR	Input	VIIRS	VIIRS calibrated and navigated brightness temperatures and radiances in bands M14, M15, M16 with solar and satellite view angles.
Surface Elevation	Input	NGDC	Digital surface elevation at 1km resolution
Land Mask	Input	NASA	Global 1 km land/water mask used for MODIS collection 5
Surface Emissivity	Input	UW Baseline Fit	MODIS monthly mean IR land surface emissivity for channel M14, M15, M16
IMS Snow and Ice Mask	Input	IMS	Snow mask by the Interactive Multisensor Snow and Ice Mapping System
RTM	Input	RTM	CRTM Clear sky radiance and transmittances for bands M14, M15, M16 and radiance profiles for channels M14, M15, M16
NWP	Input	GFS model	Temperature, Pressure, Height profiles, Surface Level Tropopause Temperature
Cloud Mask	Input	Cloud Mask	Cloud mask produced by VIIRS cloud mask algorithm
Cloud Type/Phase	Input	Cloud Type	Cloud type produced by VIIRS cloud type algorithm
Cloud Height, Top Temperature, Top Pressure, Cloud Cover Layers	Output	Cloud Height	Cloud Height, Cloud Top Temperature, Cloud Top Pressure, Cloud Cover Layers produced by VIIRS cloud height algorithm

System Level Data Flow – Table

Nighttime Cloud Optical Properties
Input, Internal, and Output Data Flows at the System Level

Interface Item	Interface Type	Source	Description
Coefficients	Input	UW/CIMSS	Emittance parameterization
VIIRS SDR	Input	VIIRS	VIIRS calibrated and navigated brightness temperature in bands M12, M15, M16 with solar and satellite view angles.
Land & Coast Mask	Input	NASA	Global 1 km land/water & coast mask used for MODIS collection 5
Surface Emissivity	Input	UW Baseline Fit	UW Baseline Fit Emissivity band 7
RTM	Input	CRTM	Clear sky radiance and transmittance for bands 12, 15, 16 TOA radiance for a black cloud bands 12, 15, 16
NWP	Input	GFS model	Temperature, Pressure, Height profiles
VIIRS Cloud Mask	Input	VIIRS Cloud Mask	Cloud mask produced by VIIRS cloud mask algorithm
VIIRS Cloud Optical Prop.	Output	VIIRS Cloud Optical Prop.	Cloud optical prop. produced by VIIIRS cloud nighttime opt. prop. algorithm

System Level Data Flow – Precedence



System Level Data Flow – Sequence(1)

- The framework reads in common datasets such as VIIRS SDR and ancillary data for all products. The following apply to Cryosphere products:
  - » VIIRS SDR
  - » Land/Coast Mask
  - » Surface Elevation
  - » Surface Emissivity
  - » Desert Mask
  - » Coast Mask
  - » NWP
  - » CRTM

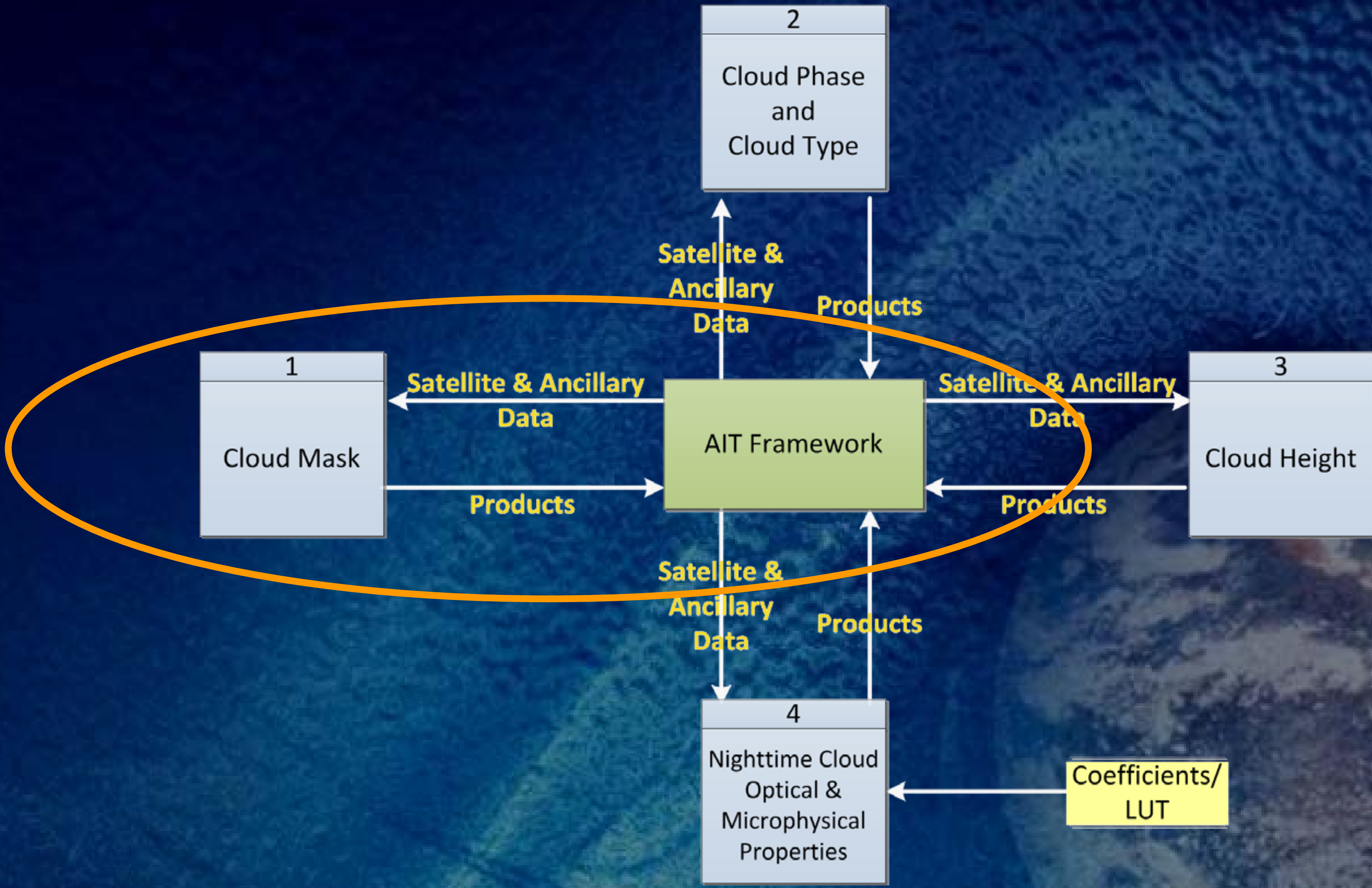
System Level Data Flow – Sequence(2)

- The framework checks the precedence to produce cryosphere products. It will run the following products upstream:
  - » VIIRS Cloud Mask
  - » VIIRS Cloud Type
  - » VIIRS Cloud Height
- All the ancillary data including VIIRS SDR will be passed to the cryosphere algorithms through data structures.
- Cloud algorithms read in their product specific inputs such as look up table and coefficient files.
- Cloud product outputs will be sent back to the framework through data structures.

External Interface Design at CDR

Unit Levels

Cloud Mask, Cloud Phase/Type, Cloud Height and NCOMP System Level Data Flow-Diagram



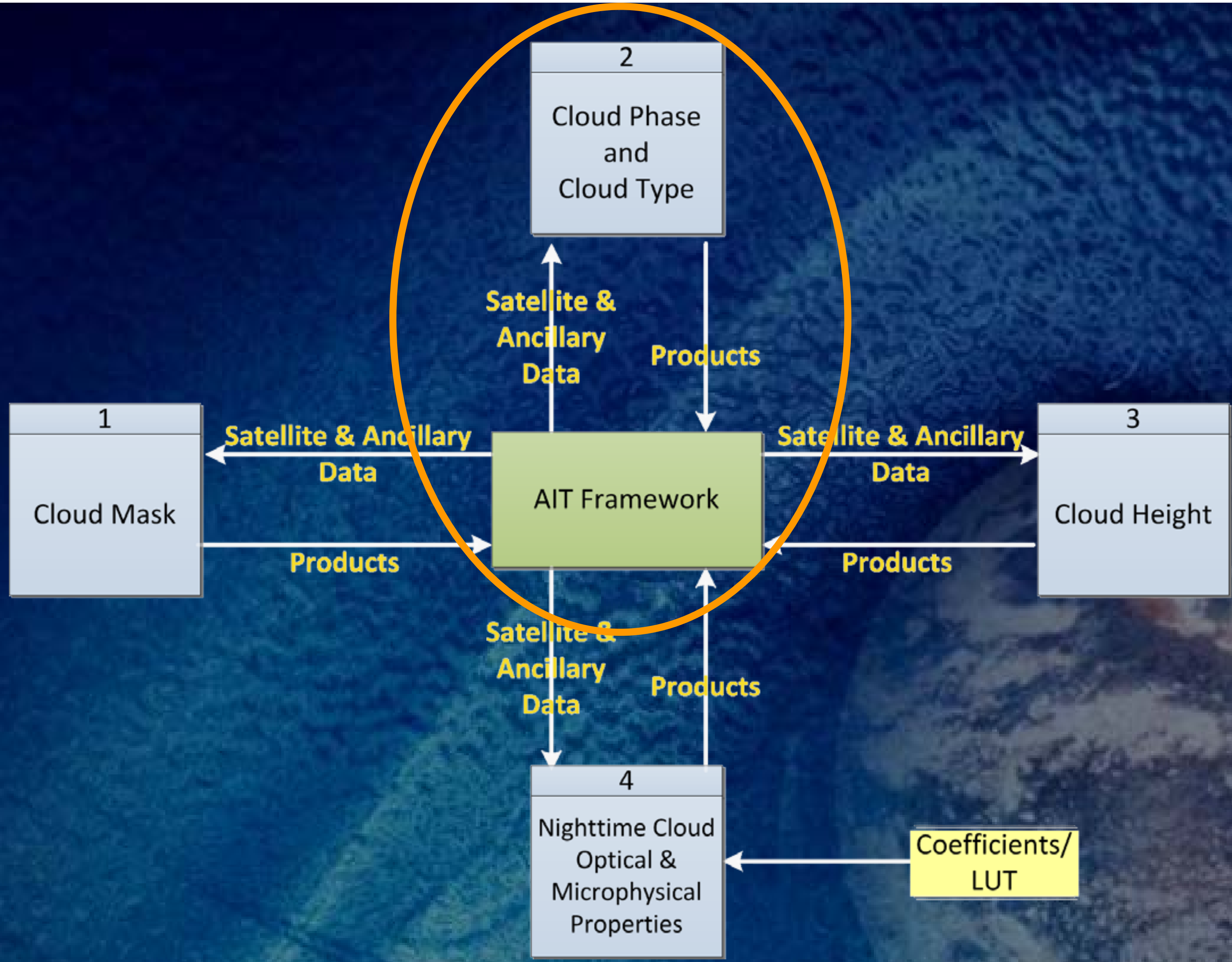
Unit Level Data Flow – Table

Cloud Mask

Input, Internal, and Output Data Flows at the System Level

Interface Item	Interface Type	Source	Description
Coefficients	Input	UW/CIMSS	Clear sky oceanic reflectance
VIIRS SDR	Input	VIIRS	VIIRS calibrated and navigated brightness temperature and radiances in bands M12, M13, M14, M15, M16 and reflectance in bands M5, M7, M9, M10 with solar and satellite view angles.
Land Mask	Input	NASA	Global 1 km land/water mask used for MODIS collection 5
Surface Elevation	Input	NGDC	Digital surface elevation at 1km resolution
IMS Snow and Ice Mask	Input	IMS	Snow mask by the Interactive Multisensor Snow and Ice Mapping System
Desert Mask	Input	Calculated	Calculated desert mask based on the land mask
Coast Mask	Input	Calculated	Calculated coast mask based on the land mask
Surface Emissivity	Input	UW Baseline Fit	MODIS monthly mean IR land surface emissivity for channel M7
RTM	Input	RTM	CRTM Clear sky radiance/BT for bands M7, M14 and blackbody radiance for channel M14 and atmospheric transittance profiles for channel M7
NWP	Input	GFS model	Surface, Tropopause Level, Surface Temperature
Cloud Mask	Output	Cloud Mask	Cloud mask, clear sky binary mask, and cloud mask packed produced by cloud mask algorithm

Cloud Mask, Cloud Phase/Type, Cloud Height and NCOMP System Level Data Flow-Diagram

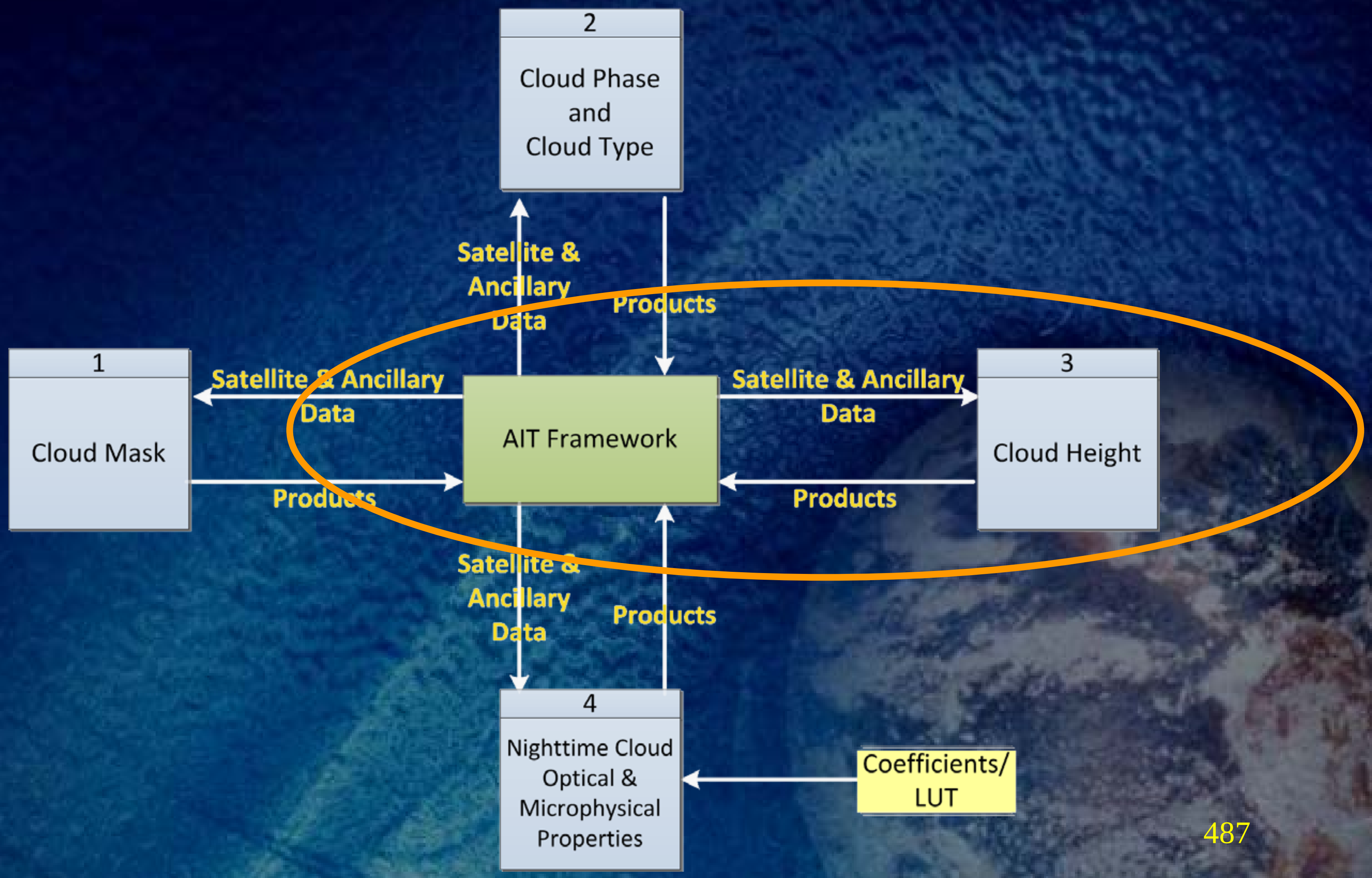


Unit Level Data Flow – Table

Cloud Type/Phase
Input, Internal, and Output Data Flows at the System Level

Interface Item	Interface Type	Source	Description
VIIRS SDR	Input	VIIRS	VIIRS calibrated and navigated brightness temperature in bands M14, M15, M16
Land Mask	Input	NASA	Global 1 km land/water mask used for MODIS collection 5
Surface Elevation	Input	NGDC	Digital surface elevation at 1km resolution
IMS Snow and Ice Mask	Input	IMS	Snow mask by the Interactive Multisensor Snow and Ice Mapping System
Coast Mask	Input	Calculated	Calculated coast mask based on the land mask
RTM	Input	CRTM	Clear sky radiance and transmittance for bands 14, 15, 16 TOA radiance bands 14, 15, 16
NWP	Input	GFS model	Temperature, Pressure, Height profiles, Surface Level, Tropopause Level, Surface Temperature
VIIRS Cloud Mask	Input	VIIRS Cloud Mask	Cloud mask produced by VIIRS cloud mask algorithm
VIIRS Cloud Type/Phase	Output	VIIRS Cloud Type	Cloud phase produced by VIIRS cloud type algorithm

Cloud Mask, Cloud Phase/Type, Cloud Height and NCOMP System Level Data Flow-Diagram

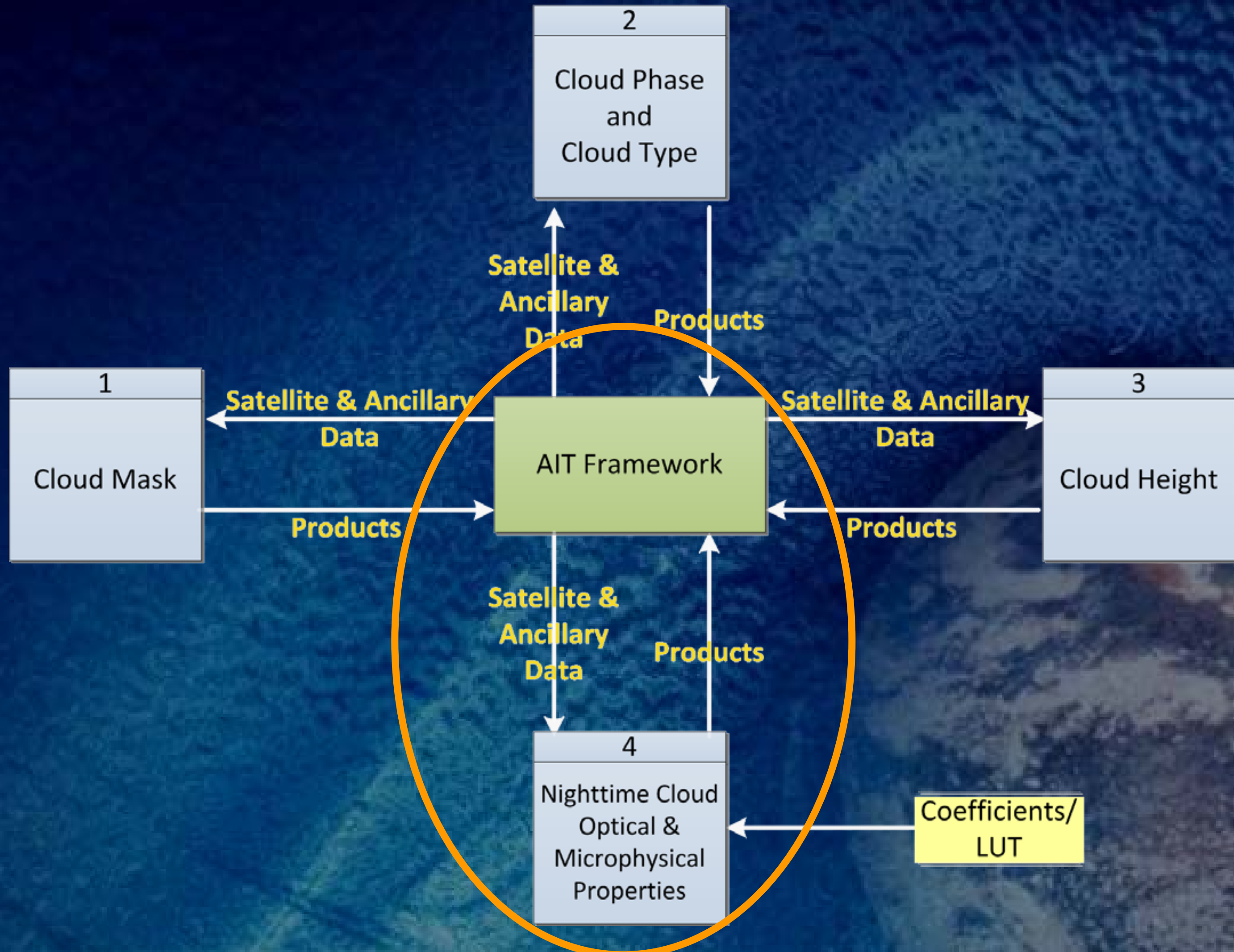


Unit Level Data Flow – Table

Cloud Height
Input, Internal, and Output Data Flows at the System Level

Interface Item	Interface Type	Source	Description
VIIRS SDR	Input	VIIRS	VIIRS calibrated and navigated brightness temperatures and radiances in bands M14, M15, M16 with solar and satellite view angles.
Surface Elevation	Input	NGDC	Digital surface elevation at 1km resolution
Land Mask	Input	NASA	Global 1 km land/water mask used for MODIS collection 5
Surface Emissivity	Input	UW Baseline Fit	MODIS monthly mean IR land surface emissivity for channel M14, M15, M16
IMS Snow and Ice Mask	Input	IMS	Snow mask by the Interactive Multisensor Snow and Ice Mapping System
RTM	Input	RTM	CRTM Clear sky radiance and transmittances for bands M14, M15, M16 and radiance profiles for channels M14, M15, M16
NWP	Input	GFS model	Temperature, Pressure, Height profiles, Surface Level Tropopause Temperature
Cloud Mask	Input	Cloud Mask	Cloud mask produced by VIIRS cloud mask algorithm
Cloud Type/Phase	Input	Cloud Type	Cloud type produced by VIIRS cloud type algorithm
Cloud Height, Top Temperature, Top Pressure, Cloud Cover Layers	Output	Cloud Height	Cloud Height, Cloud Top Temperature, Cloud Top Pressure, Cloud Cover Layers produced by VIIRS cloud height algorithm

Cloud Mask, Cloud Phase/Type, Cloud Height and NCOMP System Level Data Flow-Diagram



Unit Level Data Flow – Table

Nighttime Cloud Optical Properties
Input, Internal, and Output Data Flows at the System Level

Interface Item	Interface Type	Source	Description
Coefficients	Input	UW/CIMSS	Emittance parameterization
VIIRS SDR	Input	VIIRS	VIIRS calibrated and navigated brightness temperature in bands M12, M15, M16 with solar and satellite view angles.
Land & Coast Mask	Input	NASA	Global 1 km land/water & coast mask used for MODIS collection 5
Surface Emissivity	Input	UW Baseline Fit	UW Baseline Fit Emissivity band 7
RTM	Input	CRTM	Clear sky radiance and transmittance for bands 12, 15, 16 TOA radiance for a black cloud bands 12, 15, 16
NWP	Input	GFS model	Temperature, Pressure, Height profiles
VIIRS Cloud Mask	Input	VIIRS Cloud Mask	Cloud mask produced by VIIRS cloud mask algorithm
VIIRS Cloud Optical Prop.	Output	VIIRS Cloud Optical Prop.	Cloud optical prop. produced by VIIIRS cloud nighttime opt. prop. algorithm

NCOMP Input Ancillary Data

Name	Type	Description	Dimension
Calibration Coefficients	input	Algorithm coefficients	For each necessary channel, a set of 2 Real*4 coefficients
Cloud Emittance Parameterization Coefficients	input	Algorithm coefficients	3 sets of 3840 Real*4 coefficients: 1 set each for channels M12, M15 and M16

Outline

- Introduction
- Requirements
- Operations Concept
- Aerosol Detection
- AOD and Aerosol Particle Size
- Cloud Mask
- Cloud Height
- Software Architecture and Interfaces
- Detailed Design
- Algorithm Package
- Quality Assurance
- Risks and Actions Summary
- Summary and Conclusions

Detailed Design

Presented by

Walter Wolf

Design Overview Description

- The design overview builds on the software architecture by providing a high level description of each system element that is defined in the software architecture.
- The design overview describes the project system's functionality and design characteristics at a high level that covers, for each system elements:
  - » Its purpose
  - » External interfaces
  - » Decomposition into sub-elements
  - » Functional sequence
  - » Design Language
  - » Input and Output File Descriptions

Design Overview

- Fully defines the structure and capabilities of the software product components.
  - » Software architecture details are finalized
  - » Software components are completely defined
  - » Interfaces to software components are fully characterized
  - » Connects the design to the allocated product-component requirements, architecture, and higher level designs

Metadata Design

- Metadata design should respond to metadata requirements
- There is no archive requirement for this project, so the only metadata with be product level metadata for OSPO trending
- From our experience, the Cloud Teams can populate the metadata from Cloud Mask, Cloud Phase, Cloud Type, Cloud Height, Cloud Layers, Cloud Top Temperature & Pressure, and NCOMP products

Cloud Mask Unit Description (1)

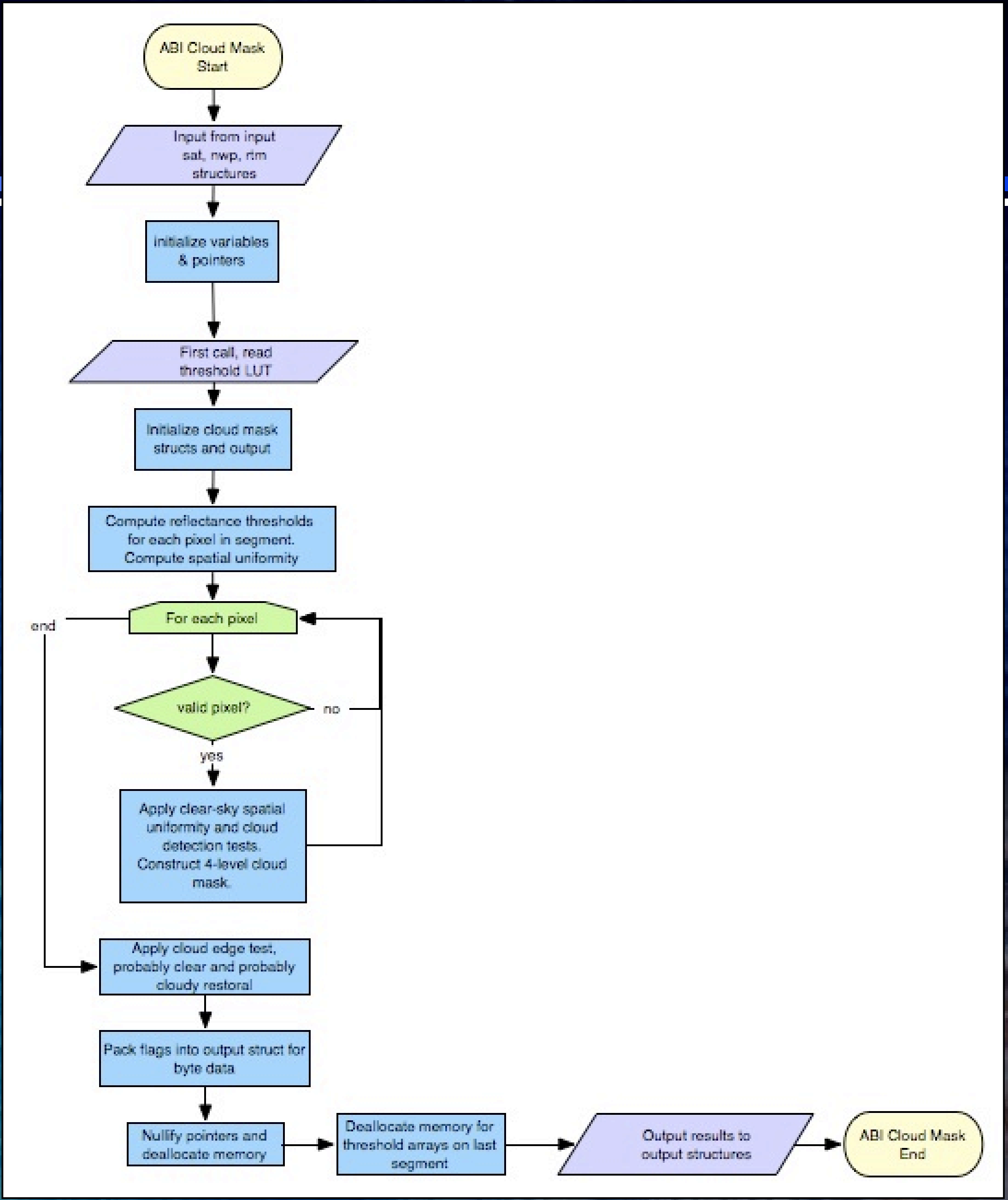
- **Produce cloud mask with associated quality flags. Provide the needed information on the presence of cloud to the other JPSS RR VIIRS algorithms that need it.**

- **Interfaces**
  - » **VIIRS calibrated and navigated brightness temperature and radiances in bands M12, M13, M14, M15, M16 and reflectance in bands M5, M7, M9, M10 with solar and satellite view angles.**
  - » **Land Mask**
  - » **Surface Elevation**
  - » **IMS Snow and Ice Mask**
  - » **Desert Mask**
  - » **Coast Mask**
  - » **Surface Emissivity**
  - » **RTM**
  - » **NWP: Surface & Tropopause Level, Surface Temperature**

Processing Outline

VIIRS Cloud Mask Processing

- Begin VIIRS Cloud Mask subroutine
- Input data from satellite, rtm and nwp structures
- Initialize local variables and pointers
- On first call, read in threshold lut
- Initialize output structures
- Compute thresholds for each pixel and spatial uniformity
- Apply cloud detection and clear-sky spatial uniformity tests for each pixel
- Apply cloud edge tests and probably clear/cloudy restoral tests
- Pack flags into byte output
- Nullify local pointers and deallocate memory
- Deallocate lut arrays on last processed segment
- Output results to output structure
- End VIIRS Cloud Mask subroutine



Cloud Mask Unit Description (3)

- Design Language – FORTRAN 90/95
- Assumptions that apply to the unit design
  - » VIIRS radiance data are within specs.
  - » NWP data is available
  - » All ancillary data is available at the pixel level
- Limitations that apply to the unit design
  - » None

Cloud Phase/Type Unit Description (1)

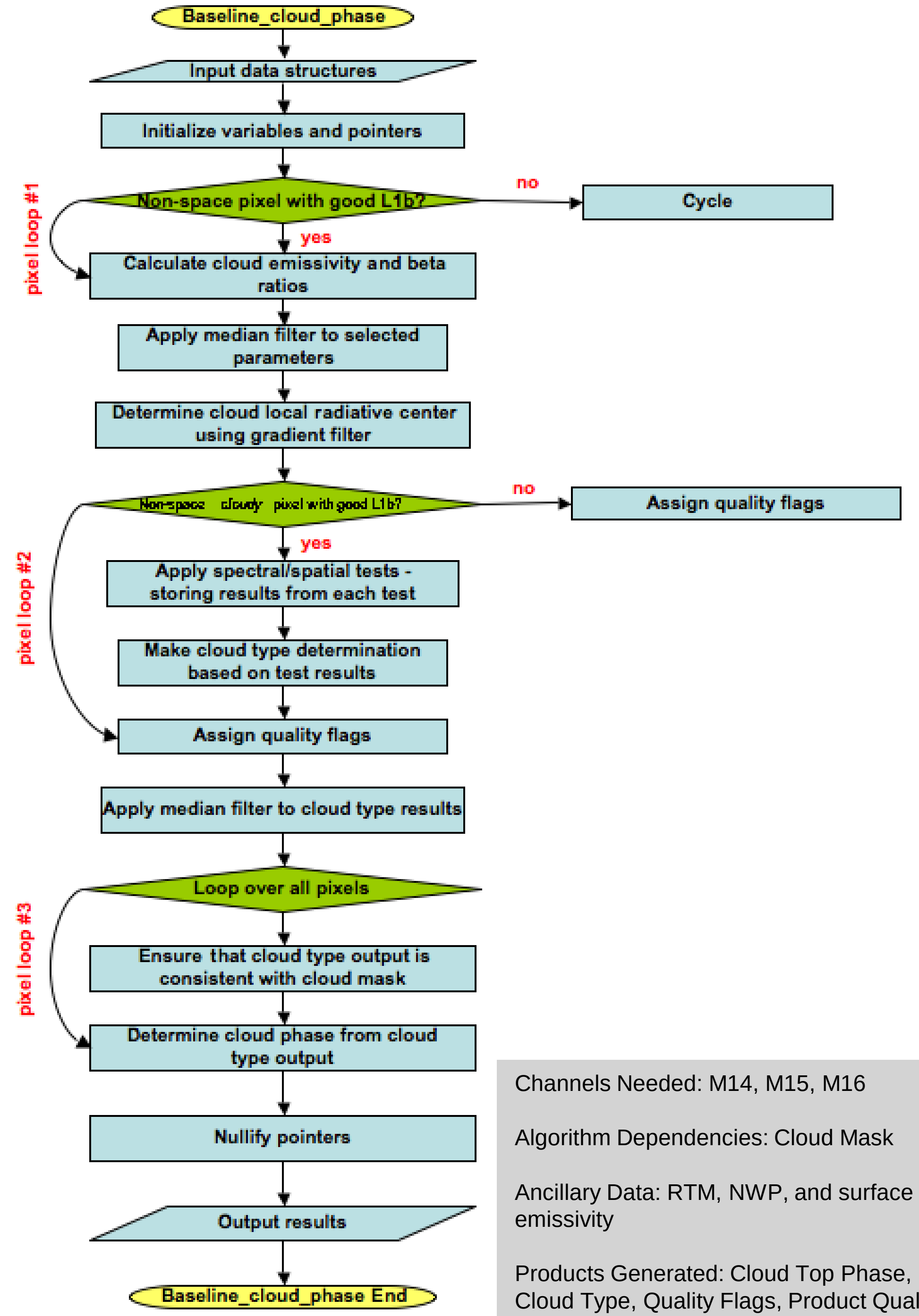
- **Produces Cloud Phase and Cloud Type with associated quality flags.**
- **Interfaces**
  - » **VIIRS calibrated and navigated brightness temperatures for channels M14, M15 and M16 along with solar and satellite view angles**
  - » **Land Mask**
  - » **Coast Mask**
  - » **VIIRS Snow/Ice Mask/IMS Snow and Ice Mask**
  - » **Surface Elevation**
  - » **CRTM**
  - » **NWP**
  - » **VIIRS Cloud Mask**

Cloud Phase/Type High-level Algorithm Flowchart

1). Compute radiative parameters relevant to cloud type

2). Utilize spectral tests to determine cloud type

3). Remove "noise" and determine cloud phase from cloud type



Channels Needed: M14, M15, M16

Algorithm Dependencies: Cloud Mask

Ancillary Data: RTM, NWP, and surface emissivity

Products Generated: Cloud Top Phase, Cloud Type, Quality Flags, Product Quality Information, and Meta Data

Cloud Phase/Type Unit Description (3)

- Design Language – FORTRAN 90/95

- Assumptions apply to the unit design:
  - » Cloud Mask is available
  - » Algorithm is only designed to be applied to the VIIRS M-bands with “bow-tie” deleted pixels restored

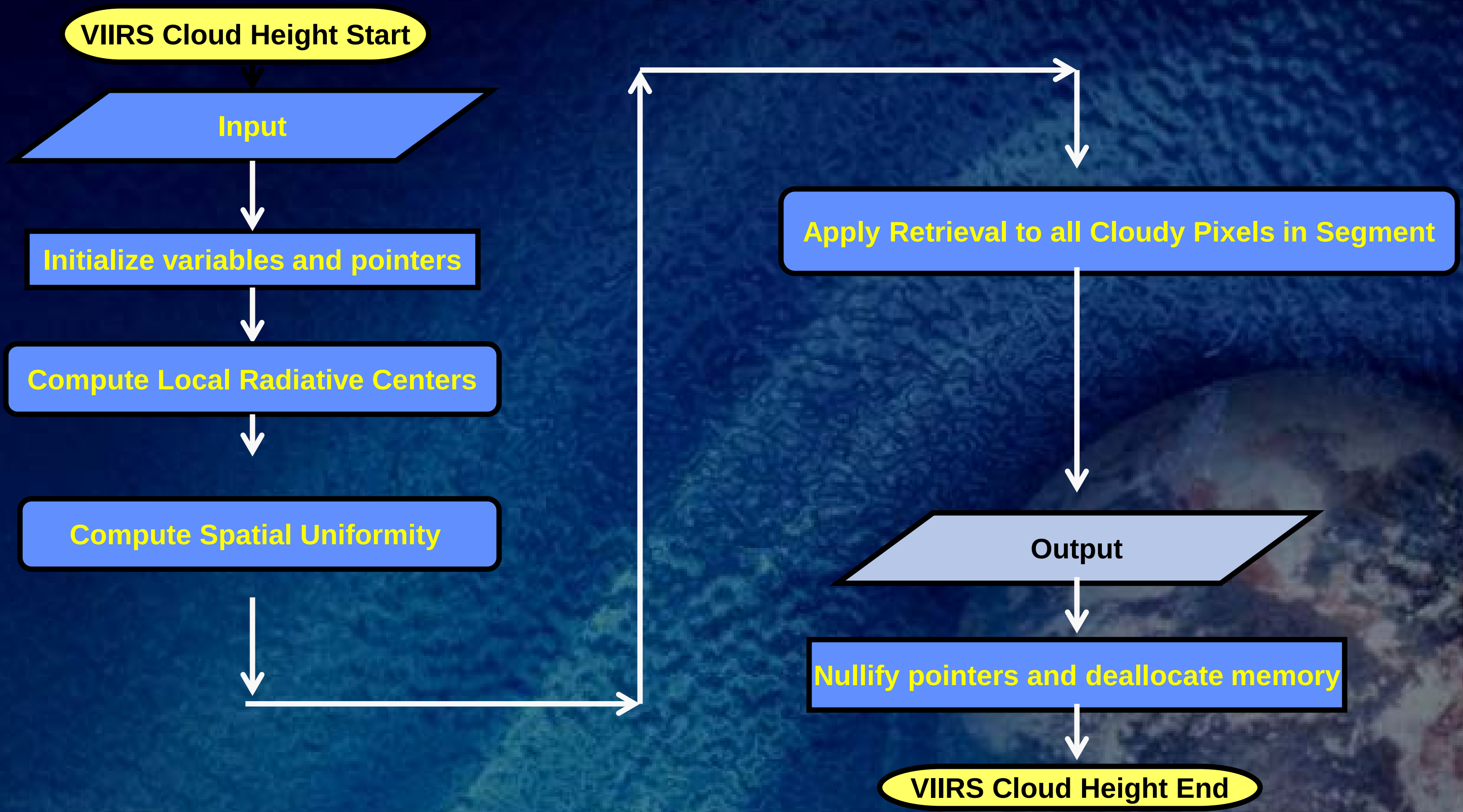
- Limitations apply to the unit design:
  - » If clear sky radiance calculations (based on NWP data) are unavailable, the algorithm output will also be set to unknown

Cloud Height Unit Description (1)

- Produce cloud-top height, pressure and temperature with associated quality flags.

- Interfaces
  - VIIRS calibrated and navigated brightness temperatures and radiances in bands M14, M15, M16 with solar and satellite view angles
  - Surface Elevation
  - Land Mask
  - Surface Emissivity
  - IMS Snow and Ice Mask
  - RTM
  - NWP: Temperature, Pressure & Height profiles, Surface Level & Tropopause Temperature
  - Cloud Mask
  - Cloud Type/Phase

Cloud Height Processing Outline



Cloud Height Unit Description (3)

- Design Language – FORTRAN 90/95
- Assumptions that apply to the unit design
  - » VIIRS radiance data are within specs.
  - » All ancillary data is available at the pixel level
- Limitations that apply to the unit design
  - » None

NCOMP Unit Description (1)

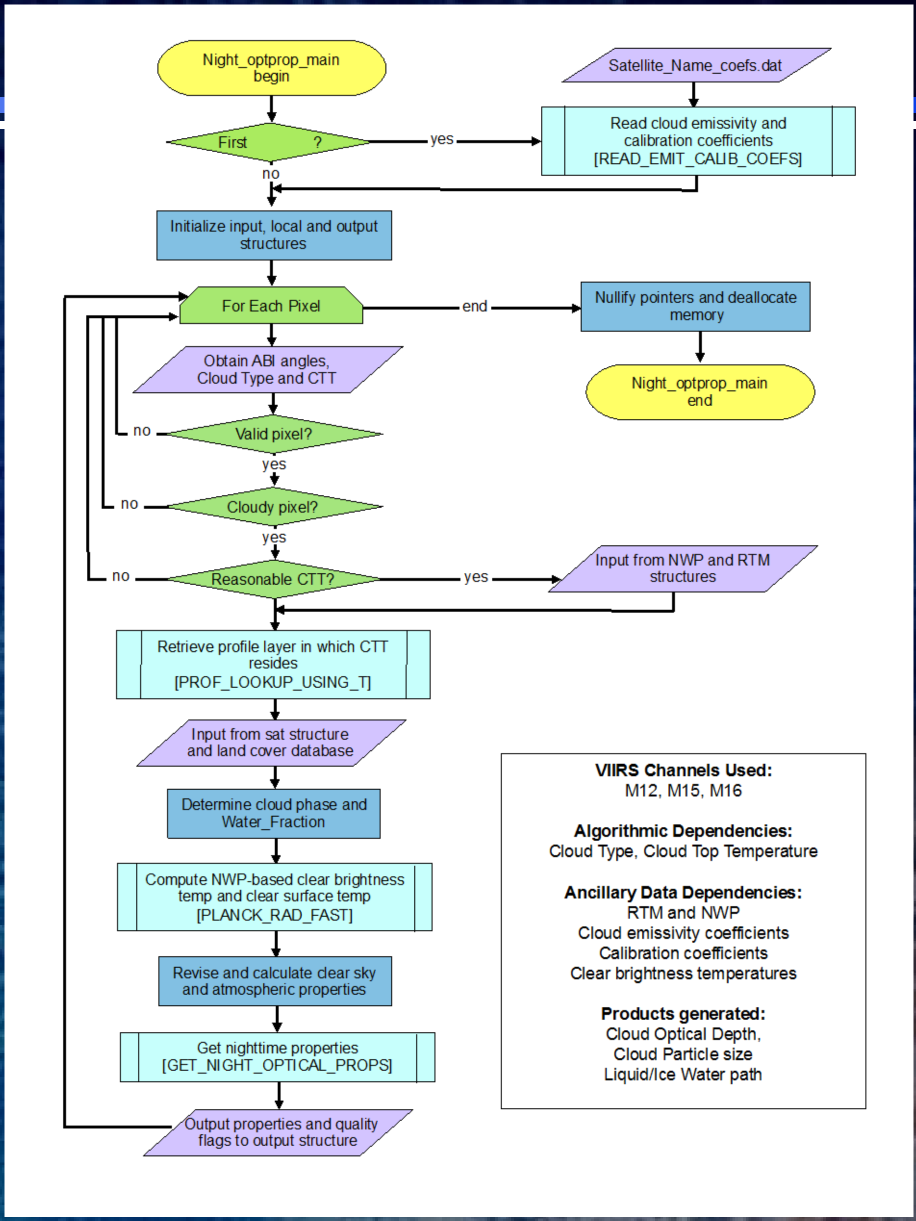
- **Produce Nighttime Cloud Optical and Microphysical products with associated quality flags**

- **Interfaces**
  - » **VIIRS calibrated and navigated Brightness Temperature in Channels M12, M15 and M16 with solar and satellite view angles**
  - » **Coefficients**
  - » **Land & Coast Mask**
  - » **Surface Emissivity**
  - » **RTM**
  - » **NWP**
  - » **VIIRS Cloud Type**
  - » **VIIRS Cloud Top Temperature**

NCOMP Processing Outline

VIIRS Nighttime Cloud Optical Properties Processing

- Begin VIIRS Nighttime Cloud Optical Properties subroutine
- On first call, read in lookup tables
- Initialize output structures and local pointers
- For each valid pixel with valid input, initialize NWP and RTM data. Then determine if it is cloudy and has a reasonable CTT, first determine cloud phase. Then compute surface emissivity, revise and calculate clear sky and atmospheric properties. Next calculate nighttime cloud optical depth and effective radius using NCOMP method described in Mathematical Description section. Finally, calculate LWP and IWP based on phase and optical properties.
- Output data to output structures.
- At end of scan line loop, nullify all local pointers and deallocate local memory
- Deallocate LUT arrays on last processed segment
- End Nighttime Cloud Optical Properties subroutine



NCOMP
Unit Description (3)

- Design Language – FORTRAN 90/95

- Assumptions apply to the unit design:
  - » VIIRS radiance data are within specs
  - » All ancillary data are available

- Limitations apply to the unit design:
  - » Quantitive retrievals for solar zenith angle ≥ 90
  - » Qualitative retrievals for 82 ≤ solar zenith angle < 90
  - » Qualitative retrievals for VZA > 65
  - » All products for clouds with 1 < COD < 5
  - » All products assume single-layer clouds

System Description

Output

Input

Unit/Sub-Unit	Cloud Mask	Cloud Phase/Type	Cloud Height	NCOMP
VIIRS SDR	√	√	√	√
Land Mask	√	√	√	√
Surface Elevation	√	√	√	
NWP - GFS	√	√	√	√
VIIRS Cloud Mask		√	√	
VIIRS Snow Cover/IMS	√	√	√	
VIIRS Cloud Phase/Type			√	√
Surface Emissivity	√		√	√
CRTM	√	√	√	√
Desert Mask	√			
Coast Mask	√			
Cloud Height, Layers, Top Temp & Press				√
Coefficient File				√

Outline

- Introduction
- Requirements
- Operations Concept
- Volcanic Ash
- Cloud Phase
- NCOMP
- Software Architecture and Interfaces
- Detailed Design
- Algorithm Package
- Quality Assurance
- Risks and Actions Summary
- Summary and Conclusions

Algorithm Package

Presented by

Walter Wolf

VPW DAP

- The DAP shall contain:
  - » Science algorithm source code, including make files and scripts.
  - » Test plans, test description, test procedures, and detailed performance testing results.
  - » Test input data, temporary files, and expected output data.
  - » Coefficient files and/or look-up tables.
  - » Quality monitoring information (quality flags, quality flag values).
  - » Production rule-set definitions.
  - » Product file specifications – layout, content, and size.
  - » Data flow diagrams.
  - » List of exit codes and their associated messages.
  - » List of expected compiler warnings (see bullet 5 below).
  - » Estimates of resources required for execution.
  - » Algorithm Theoretical Basis Documents (ATBDs) or reference to where the ATBDs can be obtained.
  - » Delivery Memo.
  - » README text file.

VPW DAP

- Delivery memo will contain:
  - » Point(s) of contact for questions specific to the algorithm (include name, telephone, e-mail address).
  - » List of delivery contents.
  - » Purpose of the delivery, e.g. an initial release, modification, etc.
  - » Description of problem(s) resolved, if any, and method of resolution.
  - » Description of significant changes from previous version, if any.
  - » List of documents updated/added/superseded, if any.
  - » List of known remaining defects.

- The README text file in the DAP must contain:
  - » Location of all required DAP contents.
  - » DAP version number.
  - » Supporting COTS/Open Source software package requirements.
  - » Target configuration for setup (directories and files after setup scripts have been executed). This is understood to be a list of where everything is located once the DAP has been unpacked.
  - » Other pertinent information as judged by the algorithm developer(s) (e.g. compiler settings, etc.).

Outline

- Introduction
- Requirements
- Operations Concept
- Cloud Mask
- Cloud Height
- DCOMP
- NCOMP
- Software Architecture and Interfaces
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Quality Assurance

Presented by

Walter Wolf

Quality Assurance Background

- STAR has used the Capability Maturity Model Integrated (CMMI) to improve processes and practices for development and the transfer of research to operations.

- The JPSS Risk Reduction Project will follow the updated SPSRB process that has been influenced by the STAR EPL process.

Quality Assurance – Project

- The Requirements Review (December 2012)
  - » Will present the initial draft of the requirements and a Requirements Allocation Document (RAD) has been made available to the project stakeholders. It will be updated throughout the lifecycle of the project.
- The Critical Design Review (April 2013)
  - » To finalize requirements and to verify that the chosen design is able to meet those requirements.
- A Test Readiness Review (May 2013, Aug 2013)
  - » Will present the unit tests to demonstrate that the system is ready to be run in the Test Environment.
- A Software Review (February 2014)
  - » Will be conducted to ensure that the Product Monitoring software is able to fulfill the functional software requirements.
- The System Readiness Review (May 2014)
  - » Will show that the Product Monitoring System is ready to be transitioned to operations.

Configuration Management (CM)

- STAR CM Tool (IBM Rational ClearCase, Version 7.0)
  - » Has been purchased and implemented in the Collaborative Environment.
- OSPO CM Tool – Subversion
  - » Open source
- CM personnel have been identified.
- CM training:
  - » Administrator training completed.
  - » If required, developers will be trained by the CM administrator.

SPSRB Coding Standards

- Coding standards guidelines and quick references are available.
- Provide a common list of abbreviations.
- Adhere to the standards throughout the development life cycle.
- Have checklists available for developers to keep track of the delivery status of the code.
- Code is checked for compiance during the software review.

Quality Assurance – Software

- The JPSS Risk Reduction software will be delivered incrementally as part of the series of algorithm package deliveries.

- This will allow system testing of the code within NDE.

Quality Assurance – Software

- All code development is being conducted on a platform that is nearly identical to the test and production target platforms using the same compilers and operating system.
- STAR code checking tools will be used to minimize coding bugs and to ensure that software meets the coding standards.
- The status of all system calls and intrinsic functions are checked.
- Unit tests will be conducted for each product individually.
  - » The PALs will have access to test data products to verify that values appear reasonable.

Quality Assurance – Software

- An official algorithm package will be delivered:
  - » All Product Monitoring code and system files
  - » Test plans
  - » Test data sets
  - » Error messaging/handling
  - » Configuration files
  - » Production rules
  - » Database specifications
  - » Data flow diagrams
  - » Estimates of resource usage
  - » Delivery memo

Quality Assurance – Products

- JPSS Risk Reduction developers will work with:
  - » The algorithm developers to ensure that the implemented algorithms are producing the correct results
  - » The PALs to ensure that the system has been implemented correctly
  - » The users to ensure that the products are what the users require

Quality Assurance – Archive and Maintenance

- Archive Plan
  - » Currently no plan to archive any of the products
- Long Term Maintenance Plan
  - » The Product Monitoring System will be maintained by the OSPO staff
  - » STAR system developers will be available

Quality Assurance – Documentation and Metadata

- Documentation/Metadata Plan
  - » The Documentation will include the SPRSB documents with the RAD and RID
  - » Metadata associated with these products are the variables that may be used for product monitoring

Quality Assurance Summary

- Quality assurance plan will consist of:
  - » Project reviews at which stakeholders are encouraged to participate.
  - » Ongoing interaction with algorithm developers, NDE and OSPO PALs.
  - » Adhering to SPSRB software standards and use of standard libraries only.
  - » Software unit tests shall be presented in the TRR.
  - » Documentation of the code operation, production rules, and software tests will be in the algorithm package.
  - » Documentation of requirements will be in the RAD.
  - » Early release of software will allow for early system implementation.

Outline

- Introduction
- Requirements
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- Cloud Mask
- Cloud Height
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- NCOMP
- Software Architecture and Interfaces
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- Quality Assurance
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Risks and Actions

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Walter Wolf

Risk and Actions Summary

- There are currently 0 risks identified from this CDR

Outline

- Introduction
- Requirements
- Operations Concept
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Summary and Conclusions

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Review Objectives Have Been Addressed

- **The following have been reviewed**
  - » **Requirements**
  - » **Operations Concept**
  - » **Algorithm Theoretical Basis**
    - – Cloud Mask
    - – Cloud Phase/Type
    - – Cloud Height, Cloud Layers, Cloud Top Temperature & Pressure
    - – NCOMP
  - » **The Software System Architecture**
  - » **The Detailed Design**
  - » **The Quality Assurance Plan**

Next Steps

- Begin preparing the documentation
- Code Development phase
  - » Develop and implement algorithms
  - » Begin software deliveries to the AIT
- Test Readiness Reviews are the next major review for the Cloud products.

Open Discussion

- The review is now open for free discussion