JPSS Risk Reduction: Uniform Multi-Sensor Aerosol, Volcanic Ash, and Daytime Cloud Optical and Microphysical Properies Algorithms for Consistent Products
Critical Design Review

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Products Covered in this CDR

- Aerosol Detection
- Aerosol Optical Depth
- Aerosol Particle Size
- Volcanic Ash Mass Loading
- Volcanic Ash Height
- Daytime Cloud Optical Depth
- Daytime Cloud Particle Size Distribution
- Daytime Cloud Liquid Water
- Daytime 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 – Aerosol Detection	1:20 pm – 2:05 pm	Kondragunta
AOD and Aerosol Particle Size	2:05 pm – 2:50 pm	Laszlo
Break	2:50 pm – 3:00 pm	
Volcanic Ash	3:00 pm – 3:45 pm	Pavolonis
DCOMP	3:45 pm – 4:30 pm	Walther
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
- Aerosol Detection
- AOD and Aerosol Particle Size
- Volcanic Ash
- DCOMP
- 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 JPSS/S-NPP Data Records to customers.
- Generate and disseminate tailored JPSS/S-NPP 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 JPSS/S-NPP 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 JPSS/S-NPP 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

2013 | 2014

Qtr 3 | Qtr 4 | Qtr 1 | Qtr 2 | Qtr 3 | Qtr 4 | Qtr 1 | Qtr 2 | Qtr 3 | Qtr 4

ID	Task Name		
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

ID	Task Name	Start	Finish
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)
    - – Aerosol Detection, AOD, APS, Volcanic Ash, DCOMP – 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

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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 Path 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*

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.*

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  - » 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.*

  » **Driver:** 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/PDA.*
  - » For ingest of VIIRS data and GFS data.
- **JPSS-RRPS-R 9.2.2:** *The Development Environment shall have access to the OSPO DDS/PDA 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		≤ 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
- Aerosol Detection
- AOD and Aerosol Particle Size
- Volcanic Ash
- DCOMP
- 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.

Fiscal Year (FY)	Product Delivery/Tracking Name	Environmental Observational Parameters	Satellites	Sensors	Product Type and Number 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

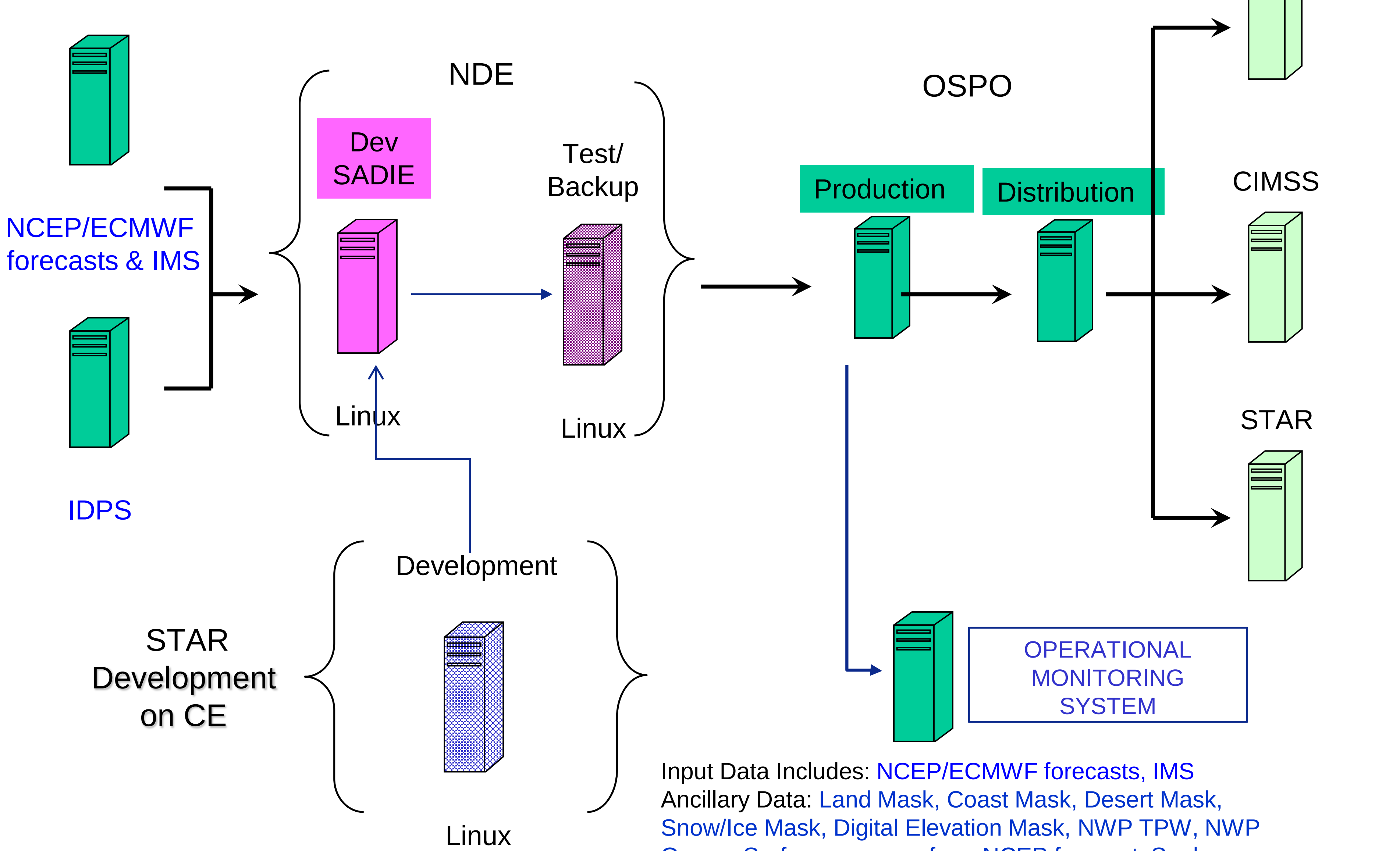
Why Are The Products Being Produced?

- 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			
			Back-up Operations	
IT Item	Development	Production	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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- Summary and Conclusions

Algorithm Theoretical Basis

Aerosol Detection
Smoke & Dust

Presented by

Shobha Kondragunta
VIIRS Aerosol Team Co-lead
NOAA/NESDIS/STAR

Aerosol Detection Algorithm Theoretical Basis

- Purpose: Provide product developers, reviewers and users with a theoretical description (scientific and mathematical) of the VIIRS Aerosol Detection algorithm

- Will be documented in the ATBD

Aerosol Detection Algorithm

- **Dust and smoke detection/imagery algorithm is based on heritage from NESDIS algorithm developed for MODIS and GOES-R**

- **Advantages:**
  - » Algorithm uses spectral threshold methods, with some texture tests for uniformity, for dust and smoke detection.
  - » Algorithm is fast and designed to run in near real-time.
  - » Algorithm for dust detection uses VIIRS deep blue channels (412 nm and 445nm) that GOES-R ABI will not have.

- **Disadvantages:**
  - » Like any algorithm based on thresholds, tuning of thresholds will be needed for changes associated with calibration etc.

Aerosol Detection CDR Algorithm

- **Shortfalls:**
  - » Current algorithm requires prior knowledge of the presence of ice or thin clouds .
  - » Nighttime detection remains a difficulty.
  - » Current algorithm provides a yes/no decision with no confidence level.
  - » Algorithm performs better over water and dark vegetated surfaces compared to bright surfaces (dry arid lands etc.)
  - » Smoke/dust over cloud or below cloud or mixed in with cloud cannot be detected.
  - » No detection will be performed over snow/ice (both land and water) and sunglint over water

Aerosol Detection CDR Algorithm: Selection Rationale

- Selection rationale:
  - Initial approach was to adapt GOES-R ABI aerosol detection algorithm as is. However, a new algorithm for dust that uses deep blue channels (412 nm and 440nm) was developed using MODIS as a proxy. For smoke, the same algorithm as GOES-R ABI will be used. The new algorithm using deep blue channel was originally developed for MODIS at the request of NWS for dust forecast verification applications. As an alternative algorithm, smoke detection with deep-blue channel is explored.

Aerosol Detection CDR Algorithm

- Adaptation of the current MODIS type algorithm to VIIRS with appropriate modifications in response to requests from the user community (NWS)
- Similarities with current MODIS offers smooth transition as well as an opportunity.

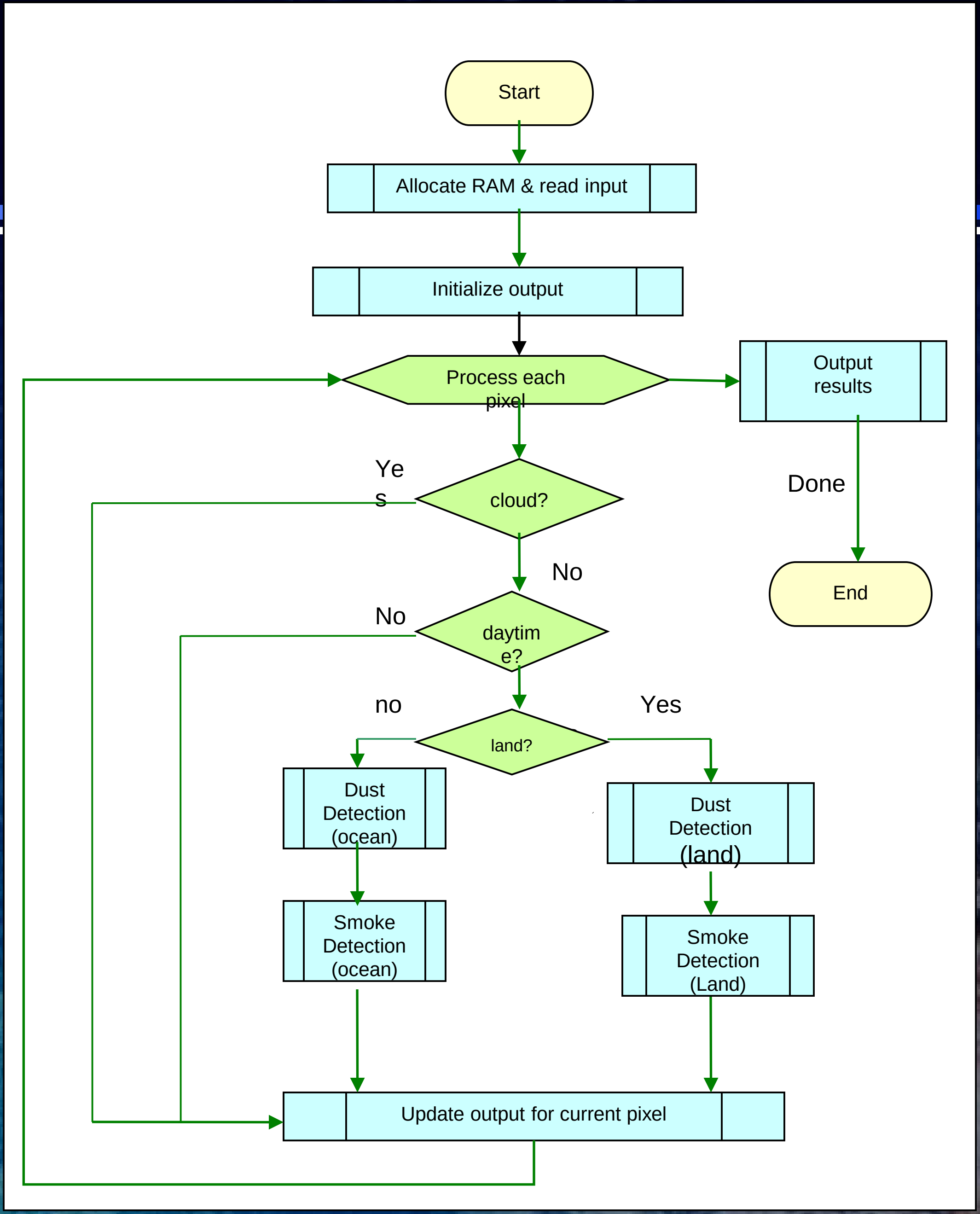
Capabilities Assessment Aerosol Detection

	Current Legacy Capabilities	NPP IDPS Capabilities	Proposed Operational Capabilities
Satellite Source (s)	Aqua MODIS	NPP VIIRS	NPP VIIRS
Product Name	Aerosol Detection	Aerosol Detection	Aerosol Detection
Accuracy	MODIS – Dust mask: 70% Dust concentration: 5 ug/m^3	Suspended Matter: 80% Dust/Sand: 80% Smoke: 70% Volcanic Ash: 60% Sea Salt: 80%	Dust: 80% correct detection over land and ocean Smoke: 80% Correct detection over land 70% correct detection over ocean
Latency	1 Day	90 minutes (threshold: 15 minutes)	30 minutes after granule data is available
Refresh	90 minutes (MODIS)	at least 90% coverage of the globe every 12 hours (monthly average)	at least 90% coverage of the globe every 12 hours (monthly average)
Timeliness	24 hours	See Latency	≤ 3 hours
Coverage	CONUS	Global	Global
Horizontal Resolution	1 km	0.75 km	0.75 km
Other attributes	MODIS – Dust concentration scaled from MODIS AOD product (ABI modified algorithm)	Dust, sand, volcanic ash, SO2, smoke	VIIRS algorithm maintains continuity with MODIS, GOES, and GOES-R algorithms

Aerosol Detection CDR Algorithm Objectives

- Provides aerosol detection over the whole globe although NWS is interested only over CONUS, Alaska, and Hawaii.
- Although difficult to quantify due to lack of validation datasets, products are expected to meet the requirement specified for aerosol detection.
- Maintains MODIS/ABI heritage
- Simple to implement and operationally robust.
- Has improvement potential.

Processing Outline



The Basics of Aerosol Detection Algorithm

- For dust detection
  - » Threshold test is first applied to DBDI (Deep Blue Dust Index), which is calculated from the contrast between 412nm (M1) and 445nm (M2), to determine a pixel potentially covered by dust. Different threshold is used for over land and ocean.
  - » Threshold test is then applied to NDI (Non-Dust index), which is based on spectral contrast between 440nm (M1) and 2250nm (M11) to further determine a pixel covered by dust by removing pixels contaminated by other absorbing aerosol.

- For smoke detection
  - » Over land, fire detection based on brightness temperatures and thick smoke detection based on dark land surface test and spectral threshold test are used to identify the pixels covered by smoke
  - » Over ocean, thick smoke detection based on blue channel test and spectral threshold test are used to identify the pixels covered by smoke
  - » As an alternate algorithm, smoke is detected with deep-blue channels through threshold tests to NDI and DBDI for pixels identified as other absorbing aerosols in deep-blue dust detection.

Aerosol Detection Sensor Inputs

Band Name	Wavelength (m)	Bandwidth (m)
M1	0.412	0.0200
M2	0.445	0.0180
M3	0.488	0.0200
M4	0.555	0.0200
M5	0.672	0.0200
M6	0.746	0.0150
M7	0.865	0.0390
M8	1.240	0.0200
M9	1.378	0.0150
M10	1.610	0.0600
M11	2.250	0.0500
M12	3.700	0.1800
M13	4.050	0.1550
M14	8.550	0.3000
M15	10.7625	1.0000
M16	12.0125	0.9500

Dust

Smoke

Smoke

Smoke

Dust/Smoke

Smoke

Smoke

Several other bands are used in various internal tests to identify clouds, bright pixels, fires, and snow/ice

Aerosol Detection Input Sensor Input Details (1)

- For each pixel
  - » Calibrated/Navigated VIIRS reflectances and brightness temperatures
  - » Geo-location (Latitude/longitude)
  - » Illuminating and Viewing Geometry (Solar Zenith Angle, Satellite zenith angle, Solar Azimuth Angle and Satellite Azimuth Angle)
  - » VIIRS sensor quality flags
  - » Bright pixel flag – internally computed

Aerosol Detection Input
Sensor Input Details (2)

Name	Type	Description	Dimension
M1 reflectance	input	Calibrated VIIRS level 1b reflectance at M1	grid (xsize, ysize)
M2 reflectance	input	Calibrated VIIRS level 1b reflectance at M2	grid (xsize, ysize)
M5 reflectance	input	Calibrated VIIRS level 1b reflectance at M5	grid (xsize, ysize)
M7 reflectance	input	Calibrated VIIRS level 1b reflectance at M7	grid (xsize, ysize)
M10 reflectance	input	Calibrated VIIRS level 1b reflectance at M10	grid (xsize, ysize)
M11 reflectance	input	Calibrated VIIRS level 1b reflectance at M11	grid (xsize, ysize)
M12 brightness temperature	input	Calibrated VIIRS level 1b brightness temperature at M12	grid (xsize, ysize)
M15 brightness temperature	input	Calibrated VIIRS level 1b brightness temperature at M15	grid (xsize, ysize)
Latitude	input	Pixel latitude	grid (xsize, ysize)
Longitude	input	Pixel longitude	grid (xsize, ysize)
Solar Zenith Angle	input	Pixel Solar Zenith Angle	grid (xsize, ysize)
Solar Azimuth Angle	input	Pixel Solar Azimuth Angle	grid (xsize, ysize)
Satellite Zenith Angle	input	Pixel Satellite Zenith Angle	grid (xsize, ysize)
Satellite Azimuth Angle	input	Pixel Satellite Azimuth Angle	grid (xsize, ysize)
QC flags	input	VIIRS quality control flags with level 1b data	grid (xsize, ysize)

Aerosol Detection Input
Ancillary Input

- **Ancillary data needed:**
  - » **VIIRS Dynamic Data:** Cloud mask, snow/ice mask, sunglint mask, day/night flag
  - » **Non-VIIRS Static Data:** Land/water mask, Surface Elevation

Aerosol Detection Input Ancillary Input Details (1)

- VIIRS Dynamic Data:

Name	Type	Description	Dimension
Cloud mask[a]	input	VIIRS level 2 cloud mask data	granule (xsize, ysize)
Snow/Ice mask[b]	input	VIIRS level 2 Snow/Ice mask data	granule(xsize, ysize)
Sunglint mask[c]	input	VIIRS level 2 sunglint mask	granule(xsize, ysize)
Day/night flag	input	Come from VIIRS data	granule(xsize, ysize)

Aerosol Detection Input Ancillary Input Details (2)

- Non-VIIRS Static Data

Name	Type	Description	Resolution
Land/water Mask	input	Global land/water mask	750 m
Surface Elevation	input	Global surface elevation above sea-level	750 m

Aerosol Detection Output

- Metadata
  - » Processing date stamp
  - » Others

- Scientific Datasets

Name	Type	Description	Dimension
Smoke Flag	output	Detected smoke binary flag (1/0 - yes/no)	granule (xsize, ysize)
Dust Flag	output	Detected dust binary flag (1/0 – yes/no)	granule (xsize, ysize)

Aerosol Detection Physical Description

- Clear sky Top of the Atmosphere (TOA) reflectance and brightness temperature measured by VIIRS has both atmospheric and surface contributions.
- Spectral (wavelength dependent) characteristics of surface, clouds, and aerosols are exploited. For example:
  - » Rayleigh scattering decreases with wavelength
  - » Surface reflectance increases with wavelength
  - » Dust absorption increases with decreasing wavelength
  - » Small particles (smoke) scatter more at 0.63 µm than at 0.83 µm
  - » Spectral contrasts are different for land and water

Aerosol Detection Physical Description

Aerosol Detection

- Aerosol and surface signals are separated through analysis of spectral differences in brightness temperatures in ‘atmospheric windows’ and differences in spectral reflectance.
- Thresholds based on simulations and observations from existing satellite instruments.

Dust Detection Physical Description

In deep-blue wavelength region:

» Dust absorption increases with the decreasing wavelength length (reducing spectral contrast)

» Rayleigh scattering increases with the decreasing wavelength length (increasing the spectral contrast)

» Surface is relatively dark

DBDI: Deep Blue Dust Index. It is defined as:

$$DBDI = -100[\log_{10}(R_{412nm} / R_{445nm}) - \log_{10}(R'_{412nm} / R'_{445nm})]$$

Where R is TOA reflectance, R' is the reflectance from Rayleigh scattering.

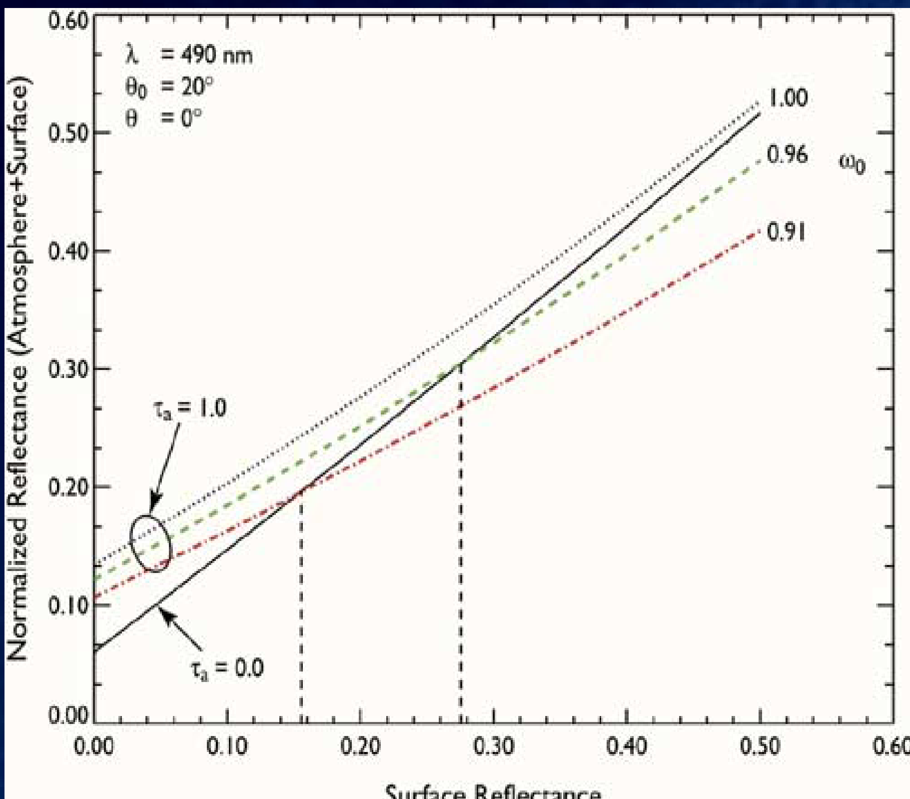
Small particles (smoke) scatter more at 0.412 µm than at 2.25 µm

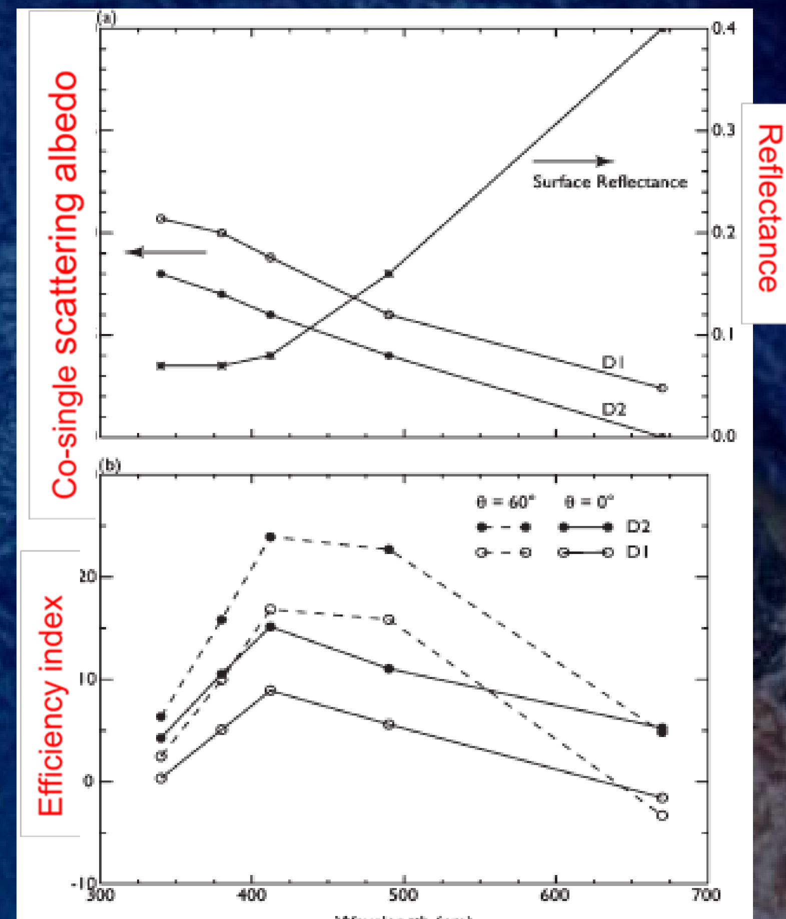
NDI: Non-dust Aerosol Index. It is defined as:

$$NDAI = -10[\log_{10}(R_{412nm} / R_{2250nm})]$$

Dust Detection Physical Description

Normalized TOA reflectance Vs. Surface reflectance



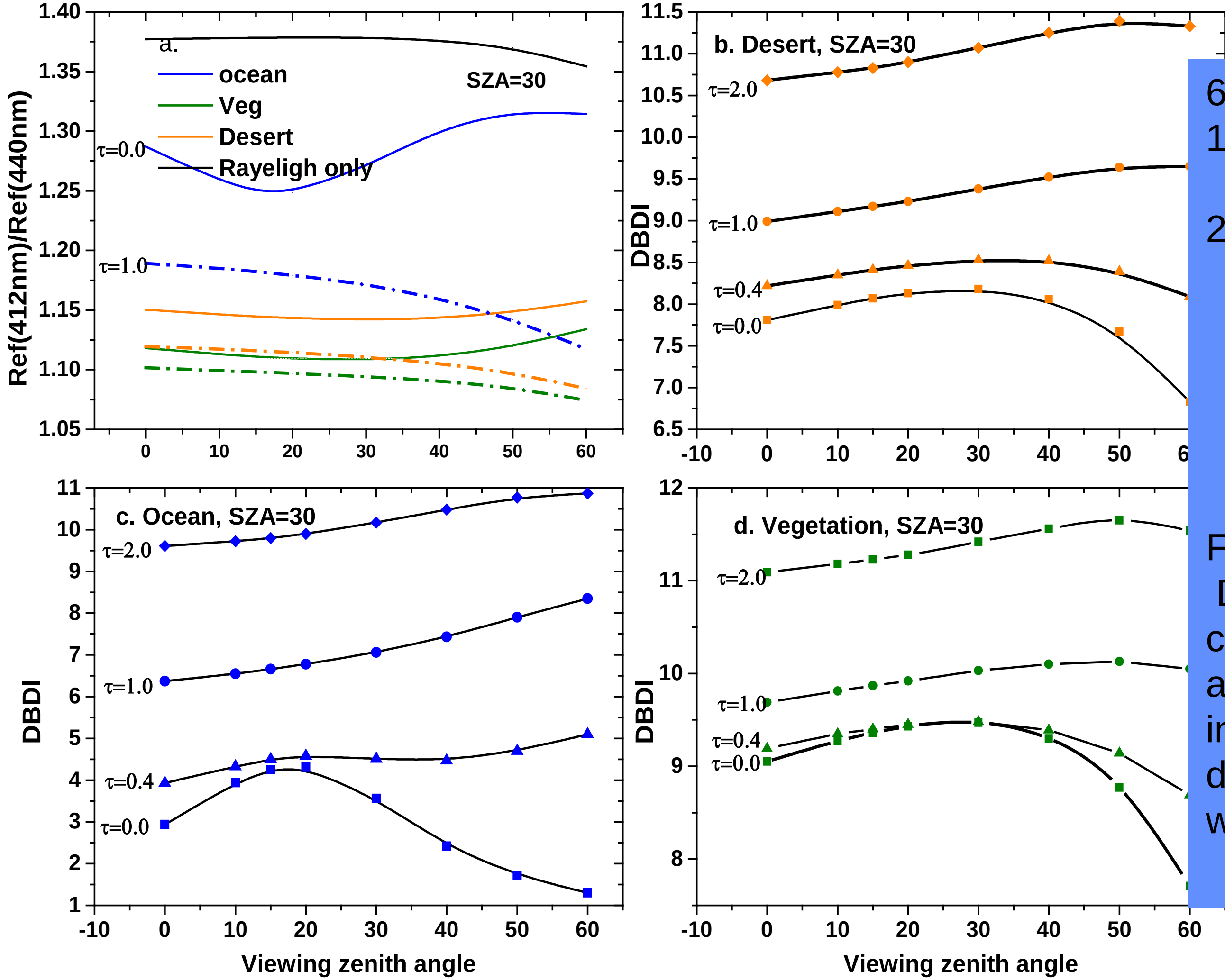


Dust brightens a scene with dark background

Hsu et al. (2003, 2004)

D1- Dust model 1 D2- Dust model 2

6S Radiative Transfer Model Simulations



6S Simulations:

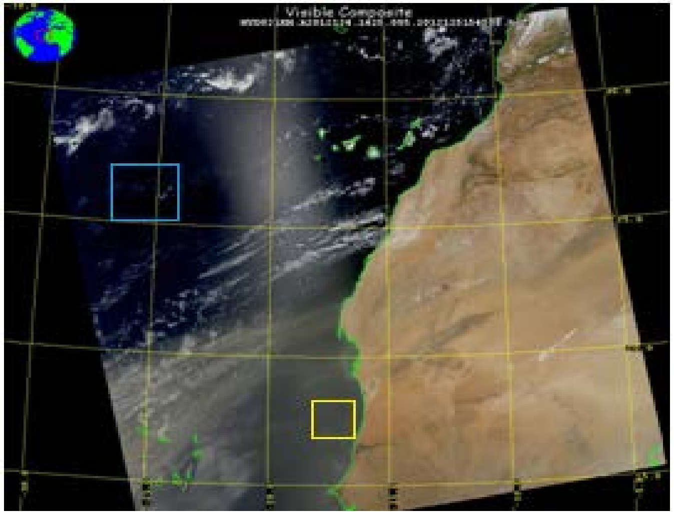
1. MODIS C5 dust aerosol model used
2. Desert, vegetation, ocean BRDF with easterly wind speed of 6 m/s are used to represent surfaces in 6S

Finding:

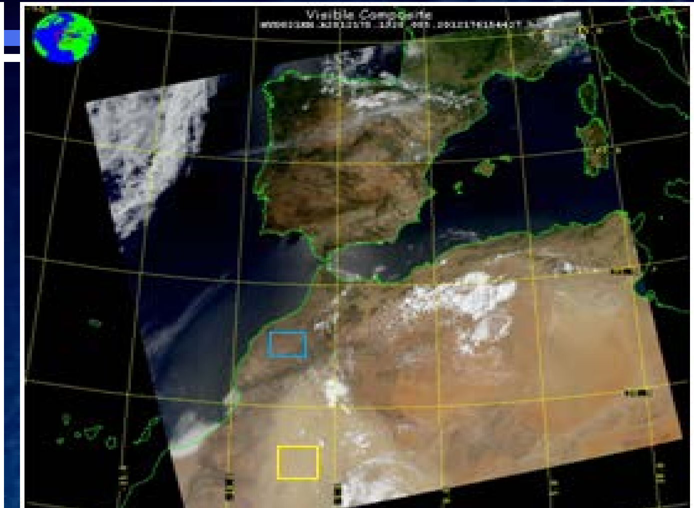
DUST reduces the contrast between 412nm and 440 nm as a result of increasing absorption by dust with decreasing wavelength

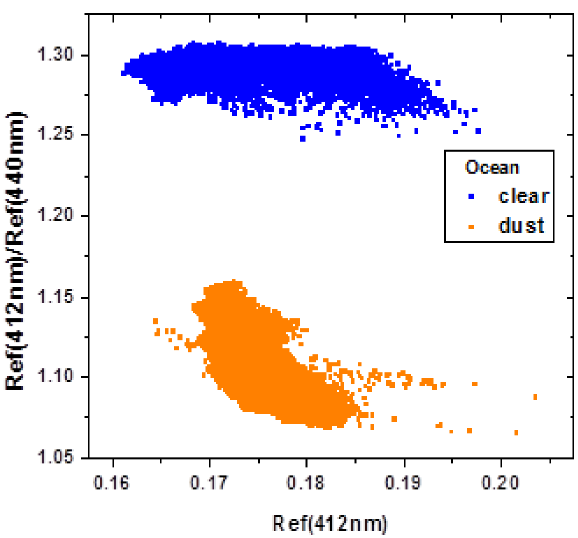
From Observations

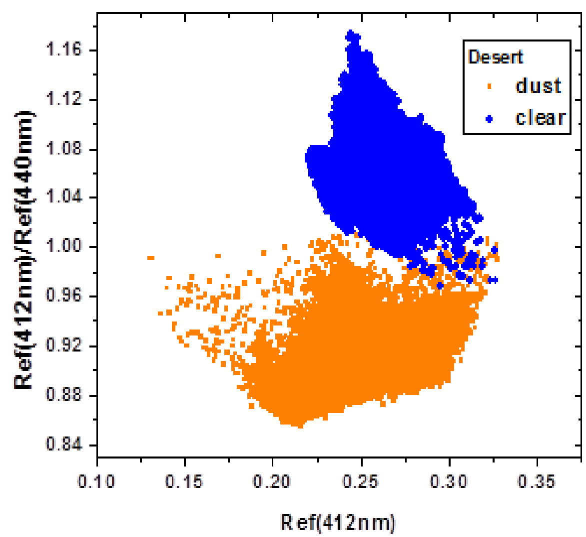
Water



Land

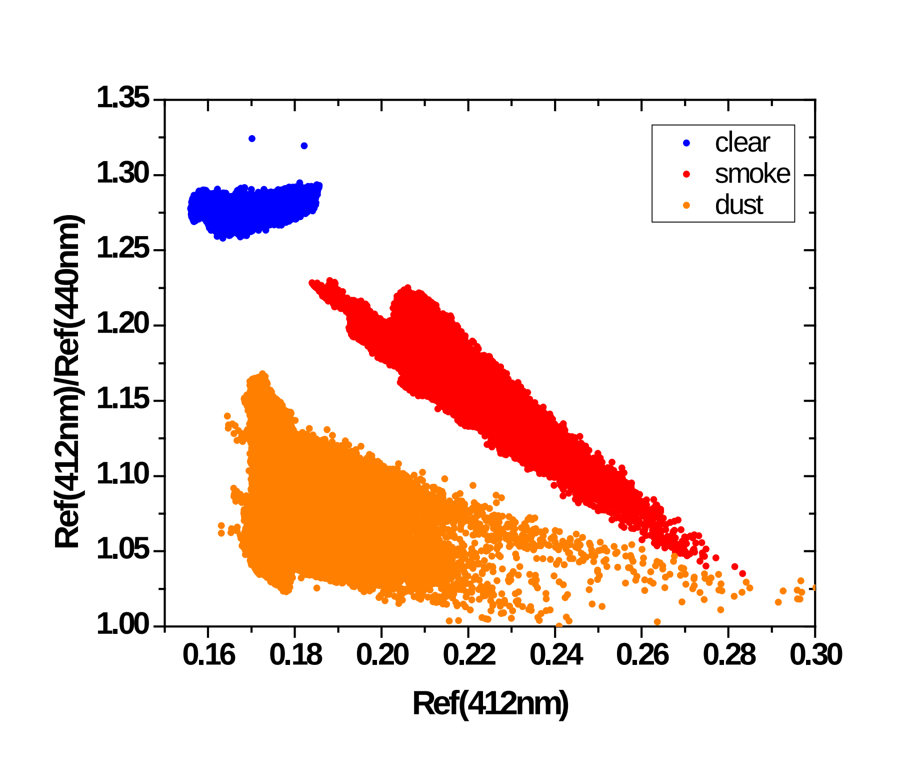


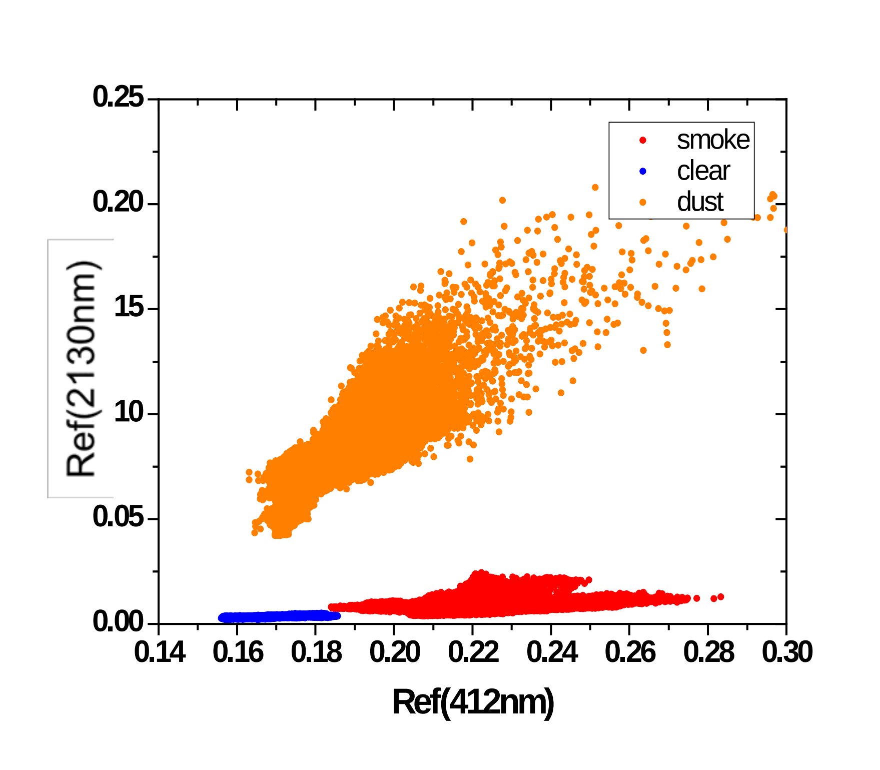




1. Dust reduces the contrast of 412nm to 440nm
2. The reduction in contrast is stronger over water than over land.

Dust v. Smoke





What does the Smoke do ?

- Having the same effect as dust in terms of the reduction in the contrast of 412nm to 440nm
- Difference in particle size enables us to pick-out the smoke by introducing short-wave IR channel, such as 2.25 µm

Determination of thresholds and sensitivity

Truth data:

- » only Aqua granules with dominant dust were selected
- » From 2002 to 2012, about 50 granules

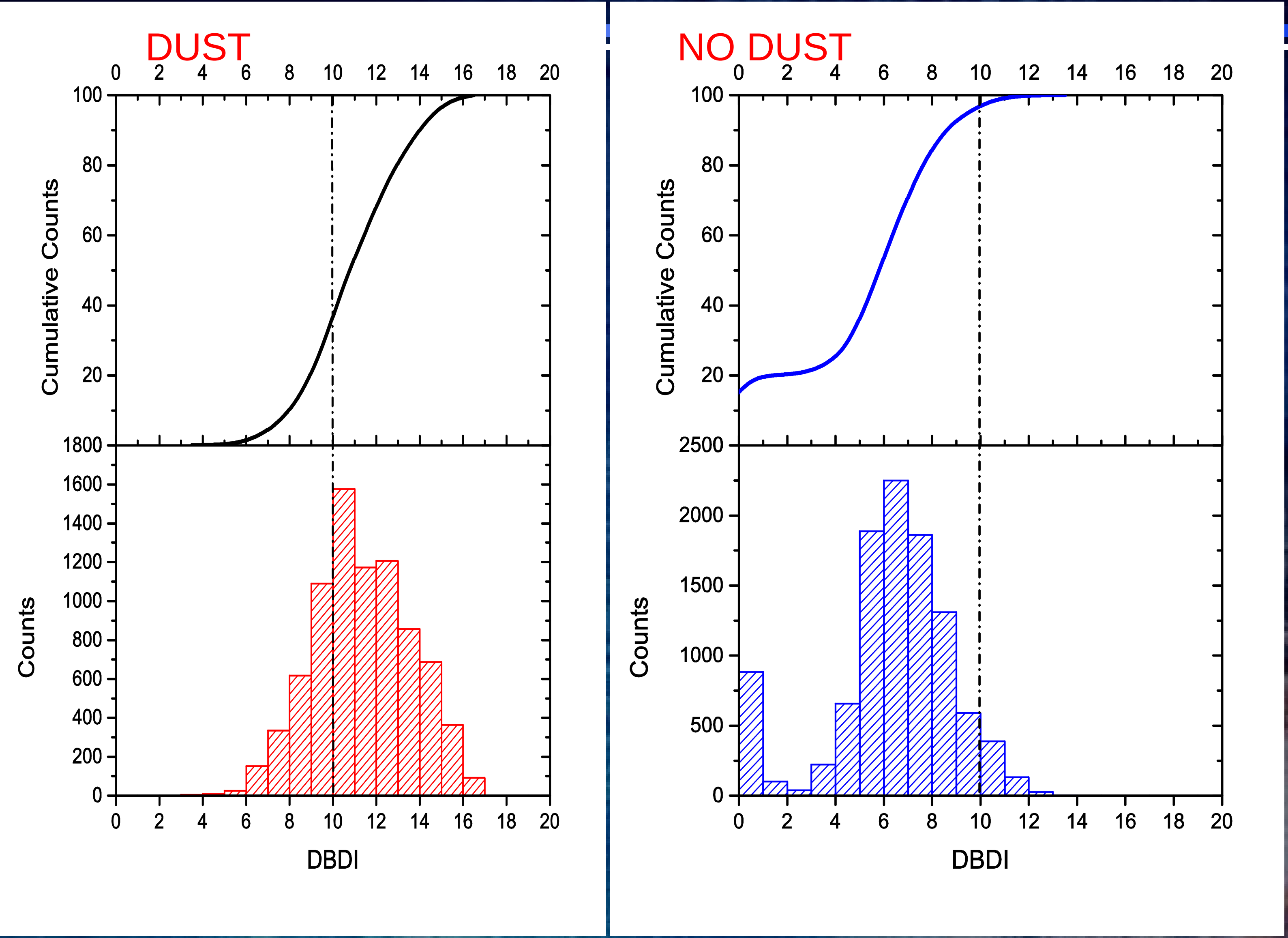
Over land: Deep blue AOD product

Over water: MODIS C5 AOD product

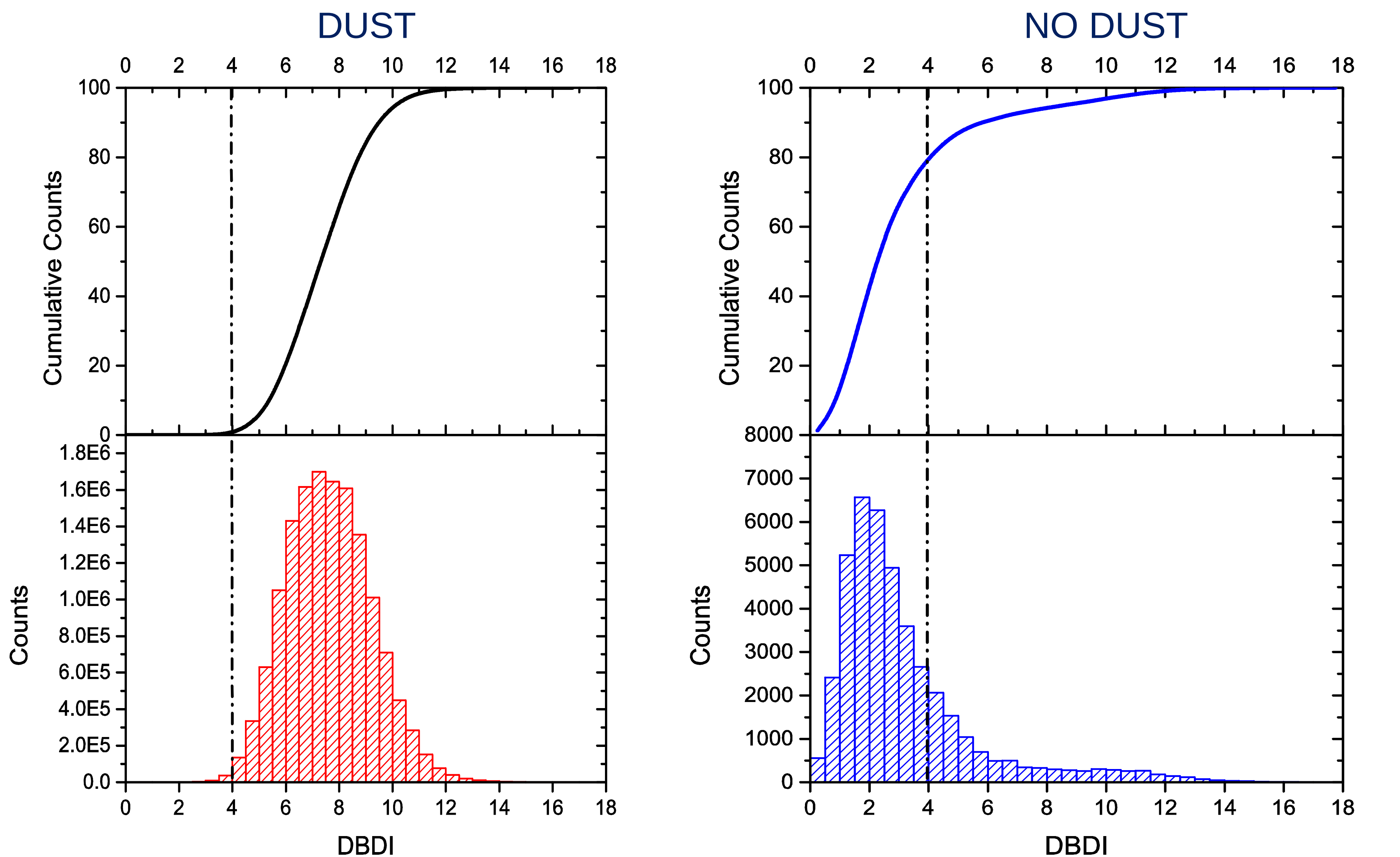
*represents AOD and AE(Angstrom exponent) from MODIS deep-blue retrievals

	DUST		*SMOKE*	
	present	**absent**	**present**	**absent**
Land	**AOD*>0.5 AE*<0.5**	**0.0<AOD*<0.2 AE*>=1.0**	**AOD>0.5 AE>1.0**	**0.0<AOD<0.2**
water	**AOD>0.5 AE<0.9 FMW<0.3**	**0.0<AOD<0.2 FMW>0.7**	**AOD>0.5 AE>=1.0 FMW>0.7**	**0.0<AOD<0.2 FMW<0.3**

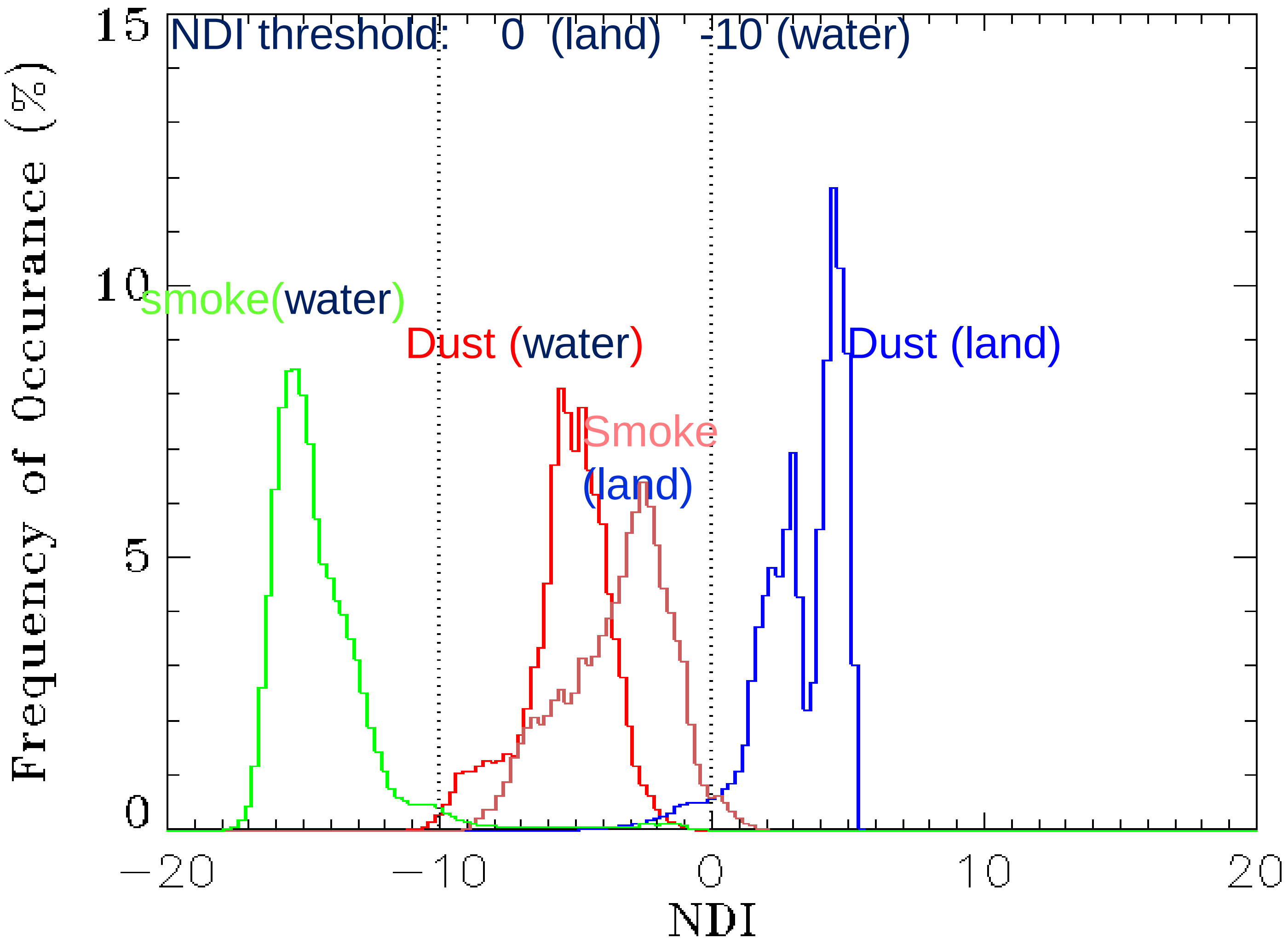
DBDI: Over Land



DBDI: Over Water



NDI: Over Land and Water



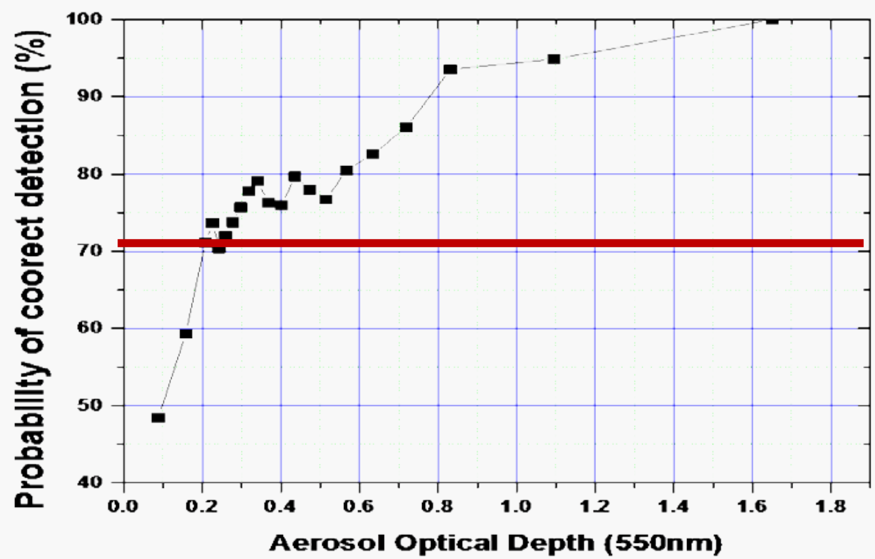
Sensitivity Studies (1)

Data used in the analysis to determine DBDI and NDI thresholds and Probability of Correct Detection and Accuracy:

• MODIS Deep-Blue product for 2010 over US

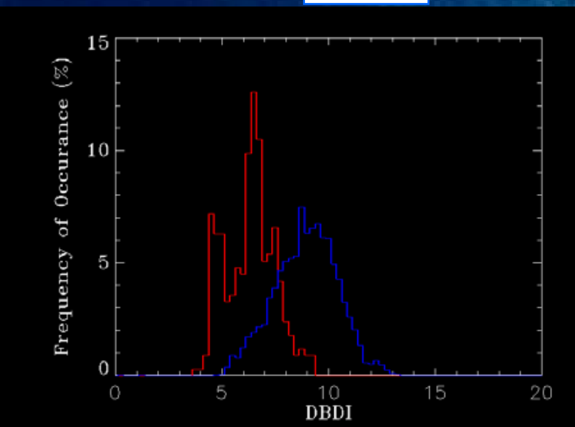
• Dust in a pixels if Angstrom Exponent < 0.9. All other AOD pixels are identified as non-dust.

Threshold: DBDI:7.5 NDI:1.3



non-dust

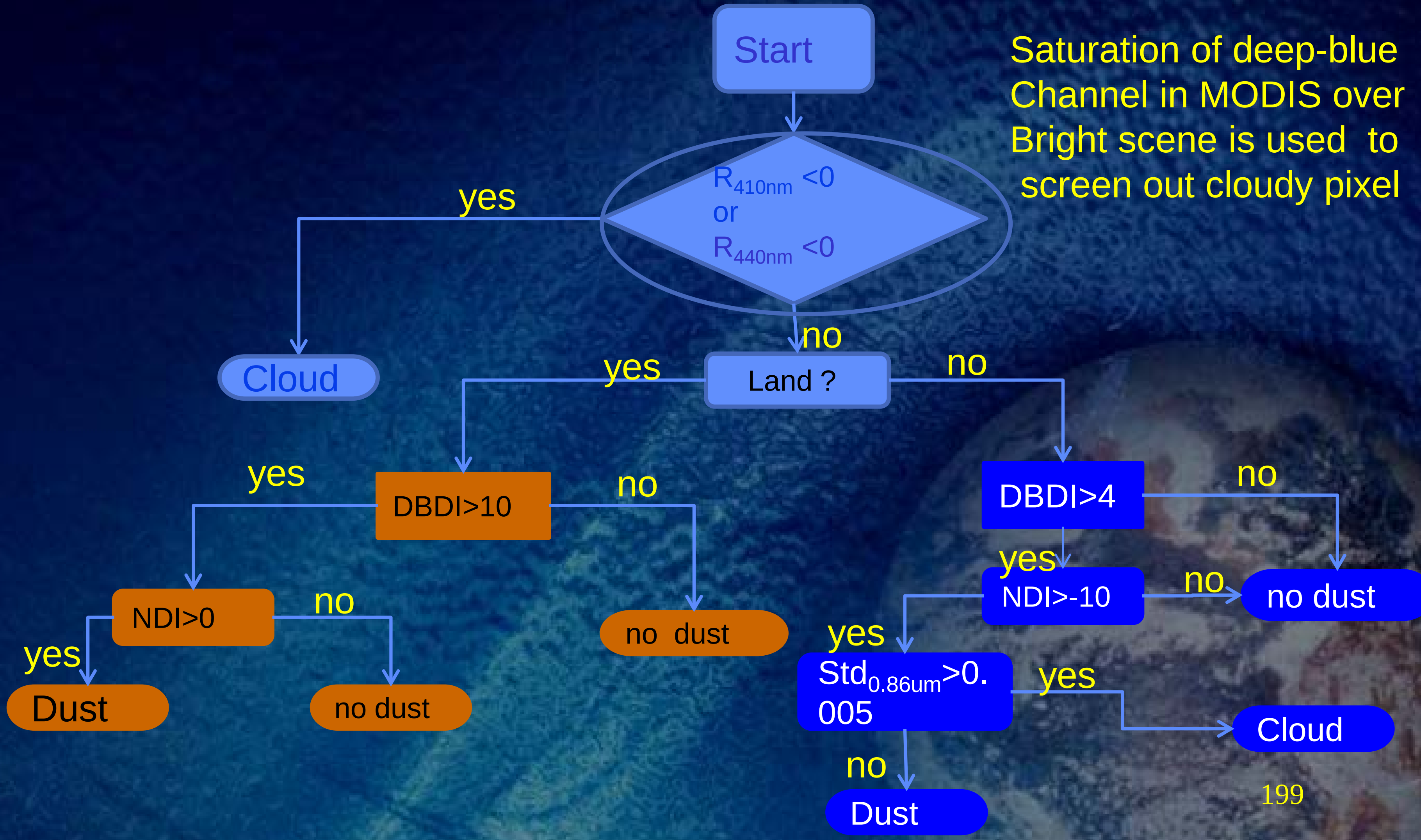
dust



Using probability of correct detection of 70% as a bench mark, detection limit for identifying dust from MODIS data is about 0.2 in AOD units.

AOD range	0.08±0.03	0.15±0.02	0.20±0.008	0.23±0.004
Accuracy (%)	48.5	59.3	71.1	73.7

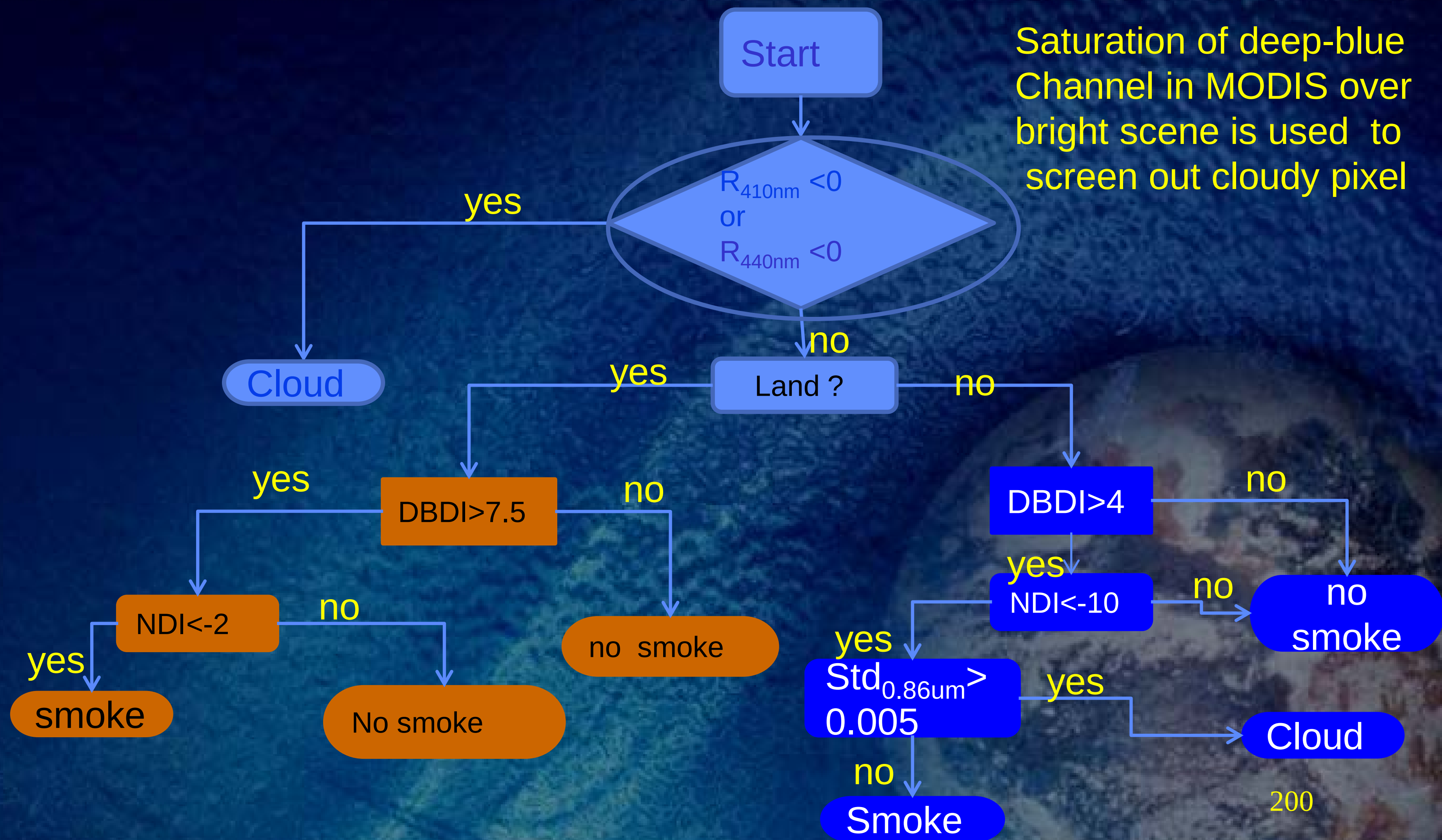
Flow chart (dust)



Saturation of deep-blue Channel in MODIS over Bright scene is used to screen out cloudy pixel

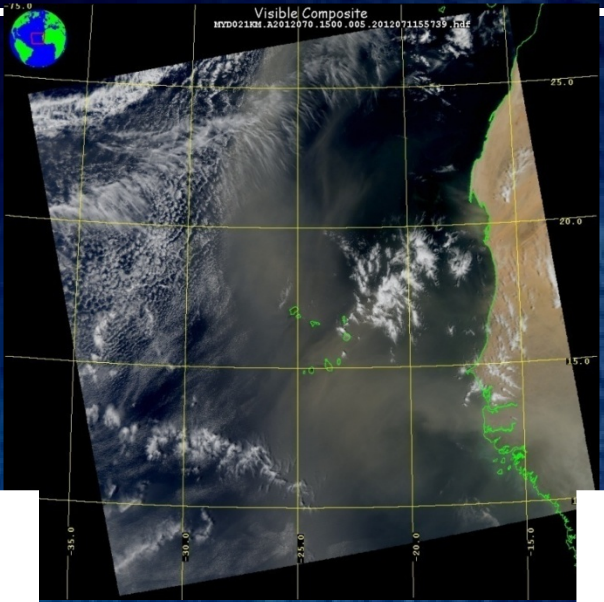
Flow chart (Smoke)

Saturation of deep-blue Channel in MODIS over bright scene is used to screen out cloudy pixel

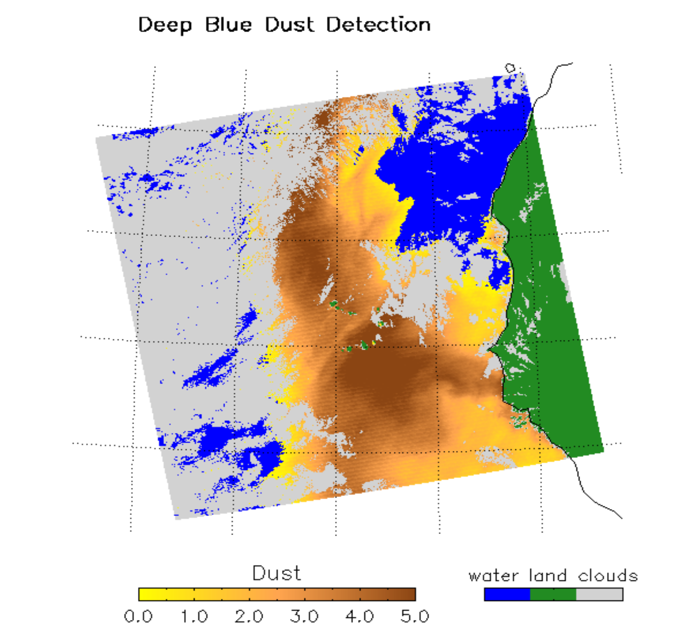


Example 1: Dust over west coast of Africa

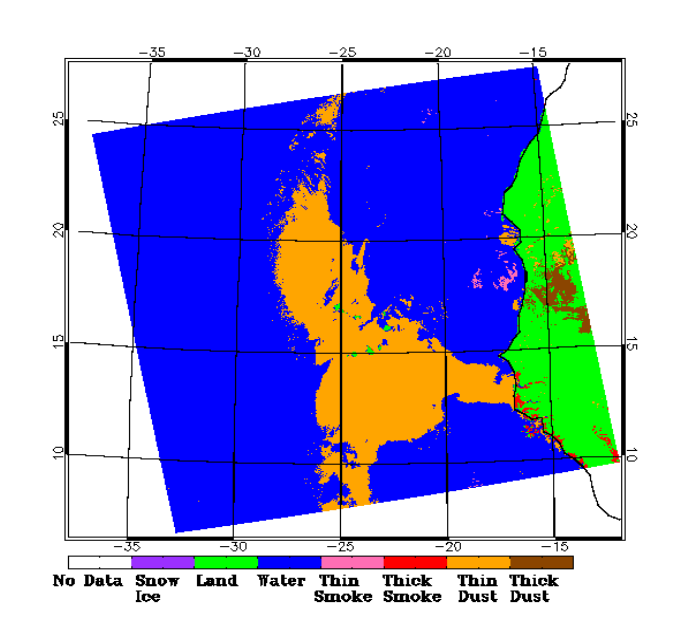
Date:03/10/2012, Aqua



Deep-blue dust mask



ABI ADP product

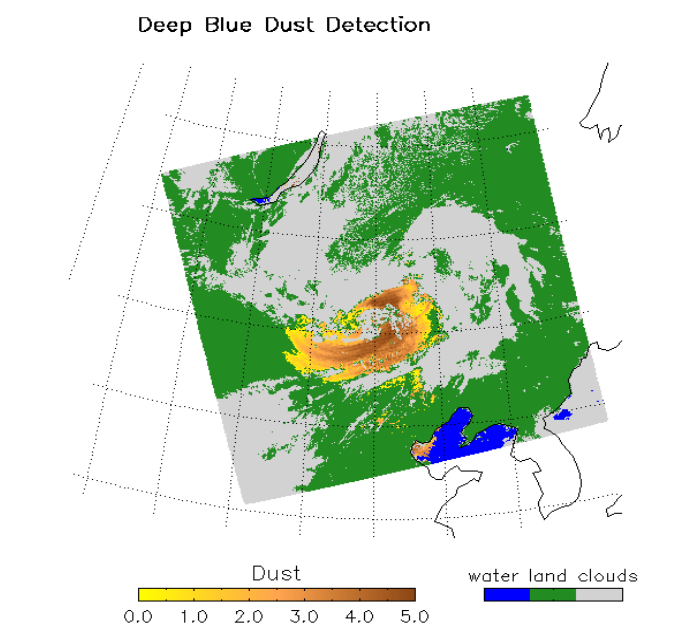


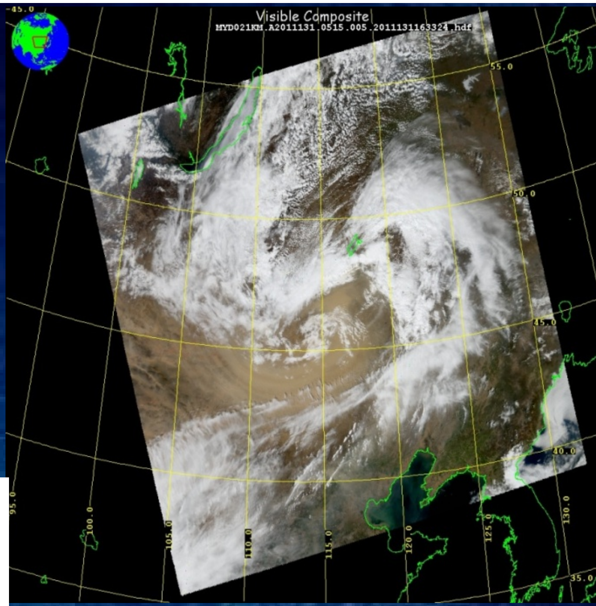
Example 2: Dust over central China

Date: 05/10/2011, UTC:0515

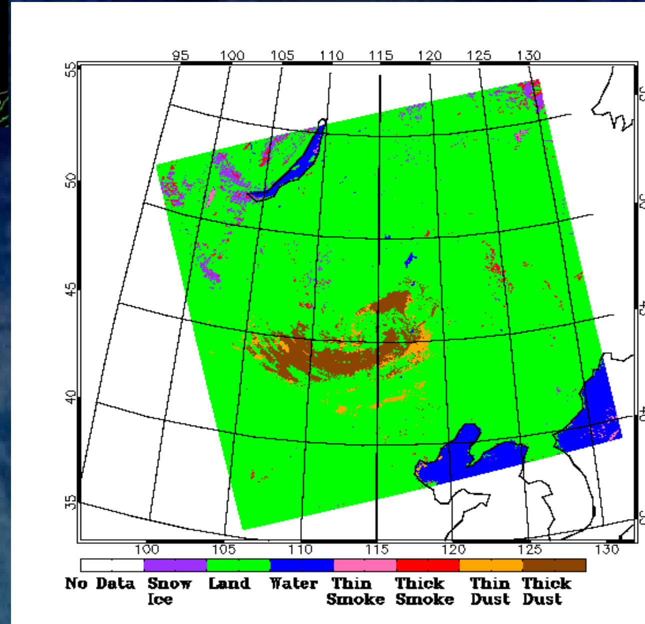
Aqua

Deep-blue dust mask



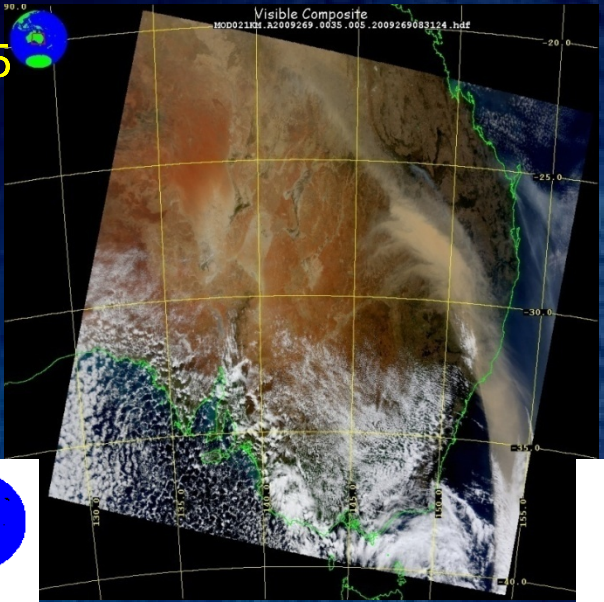


ABI ADP product

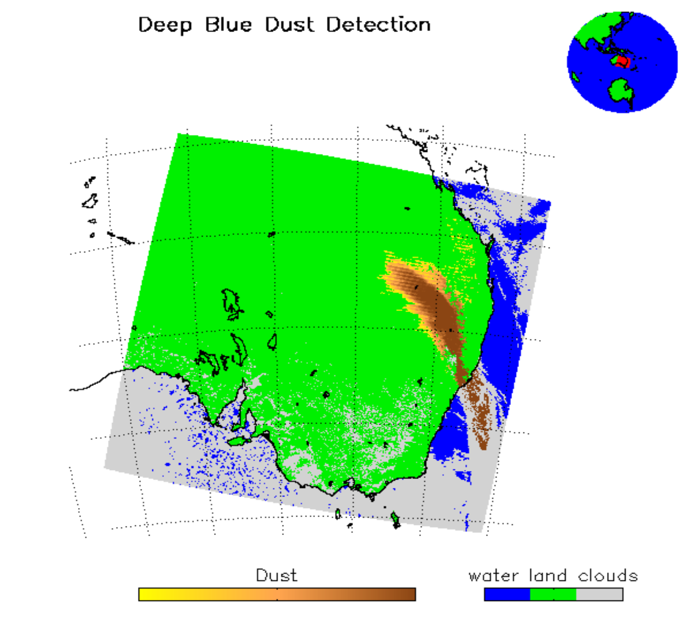


Example 3: Dust over coast of Australia

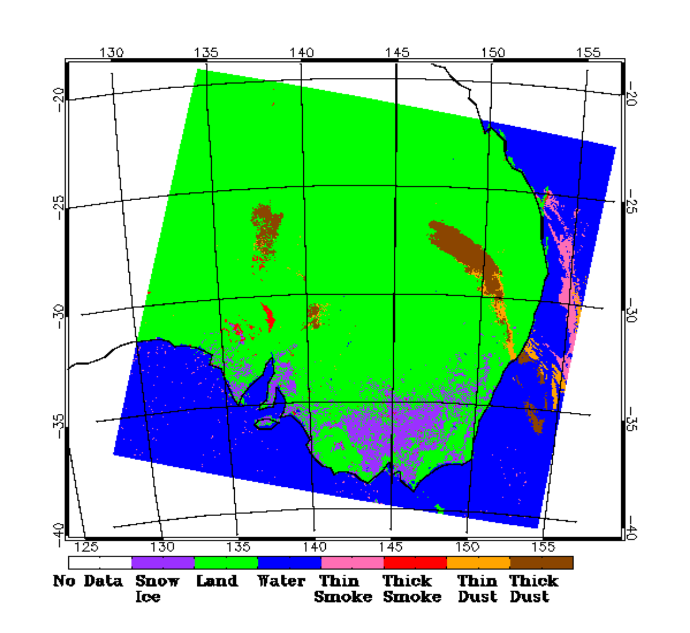
Date: 09/26/2009, UTC:0035
Aqua



Deep-blue dust mask

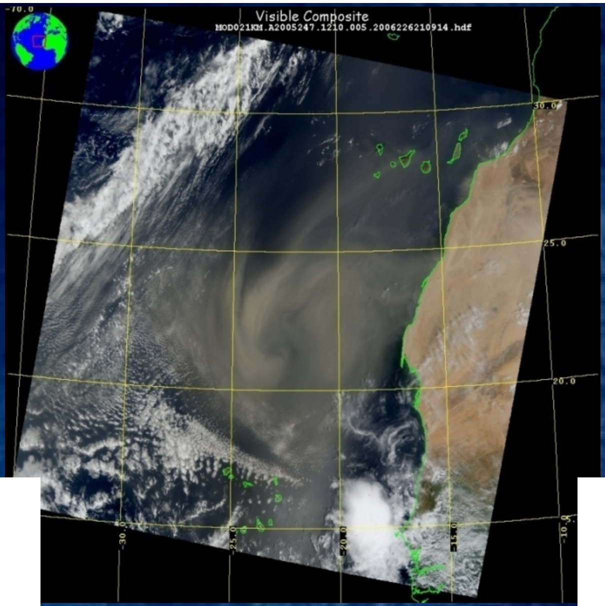


ABI ADP product

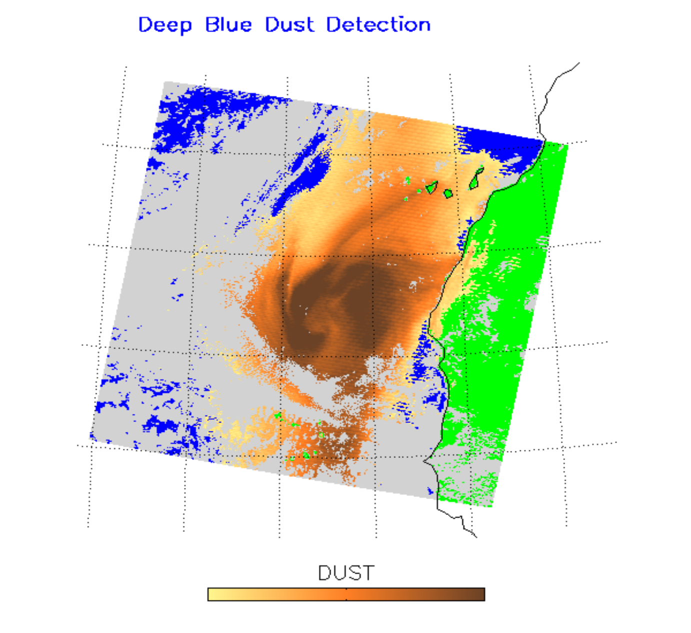


Example 4: Dust over west coast of Africa

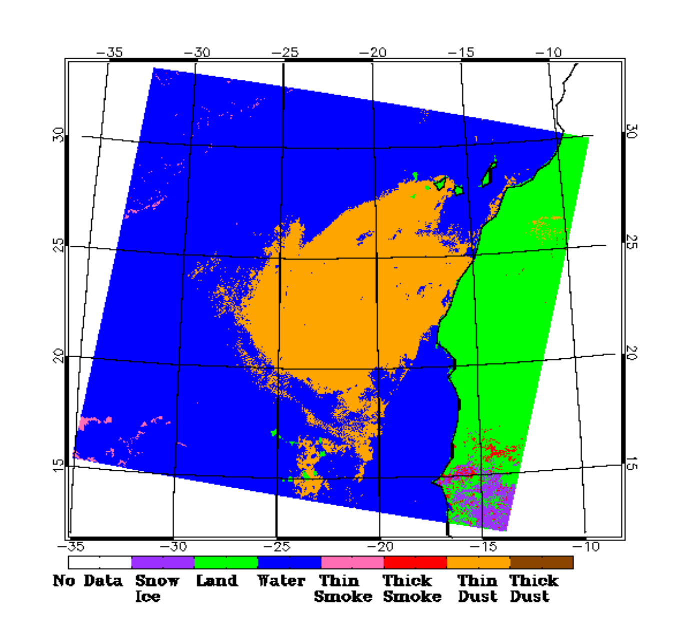
Date:09/04/2005 UTC:1210
Terra



Deep-blue dust mask

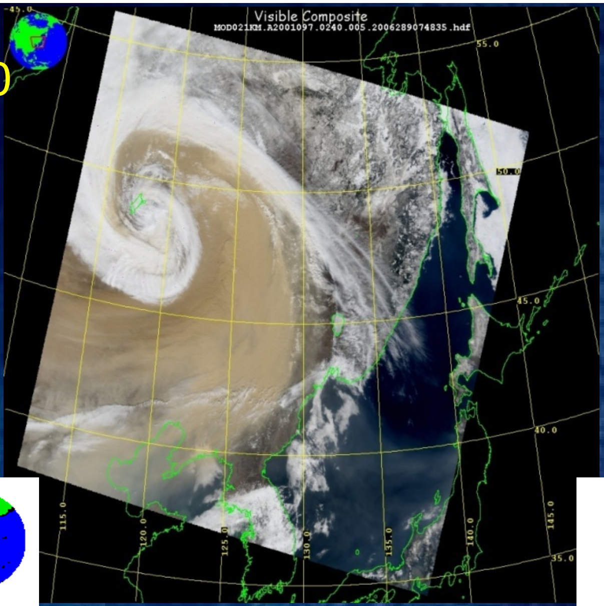


ABI ADP product

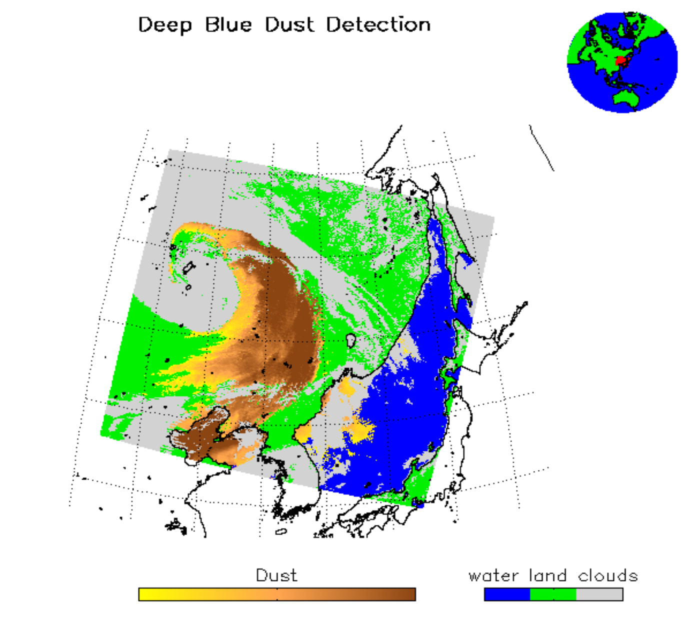


Example 5:   Dust over central china

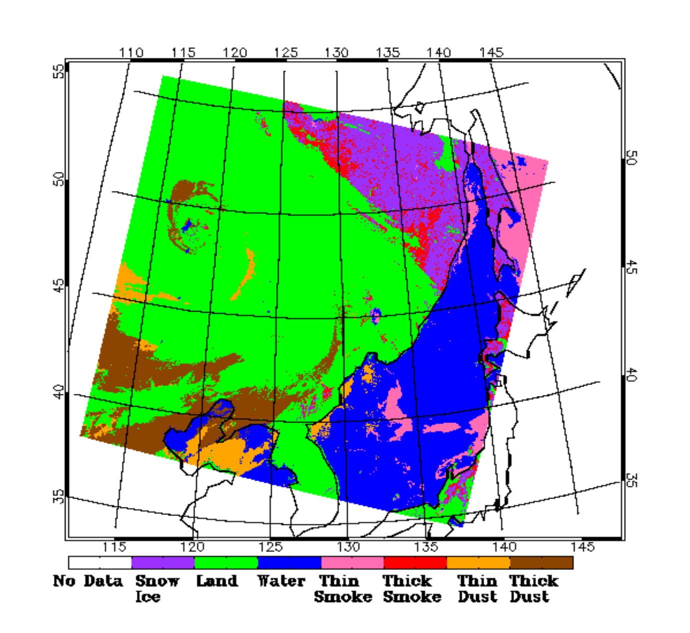
Date: 04/07/2001 UTC:0240
Terra



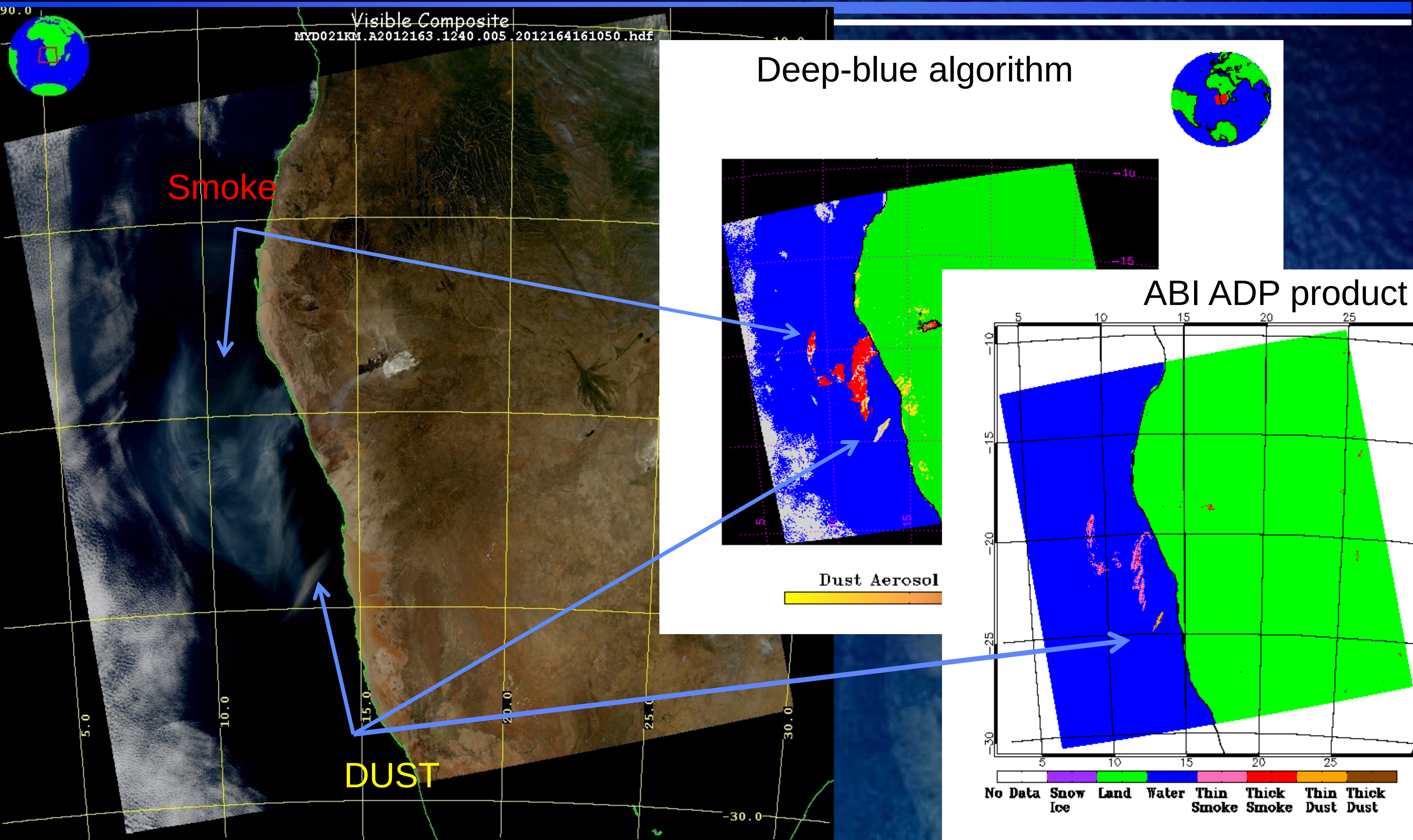
Deep-blue dust mask



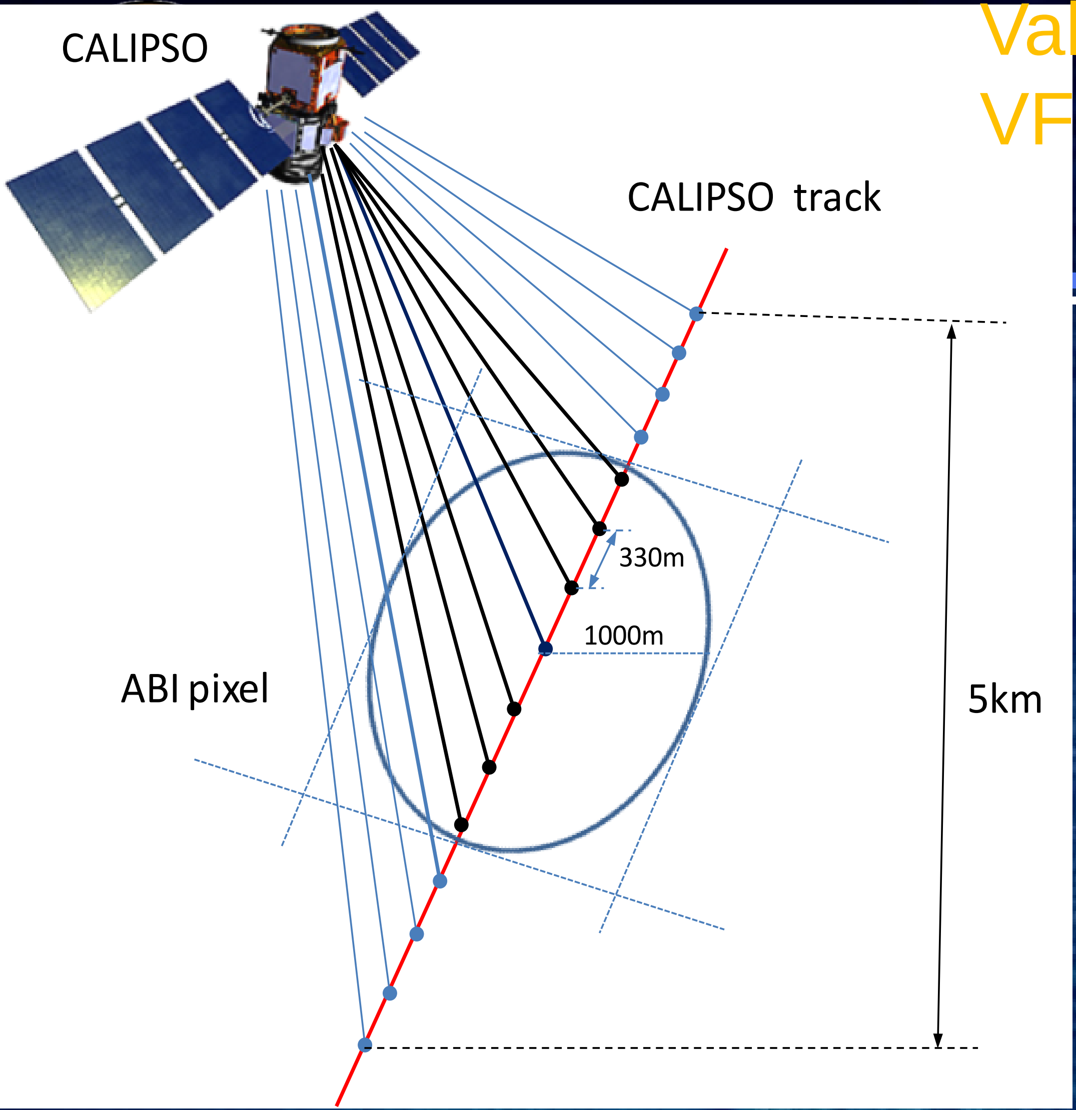
ABI ADP product



Example 6: Dust and smoke over west coast 06/11/2012



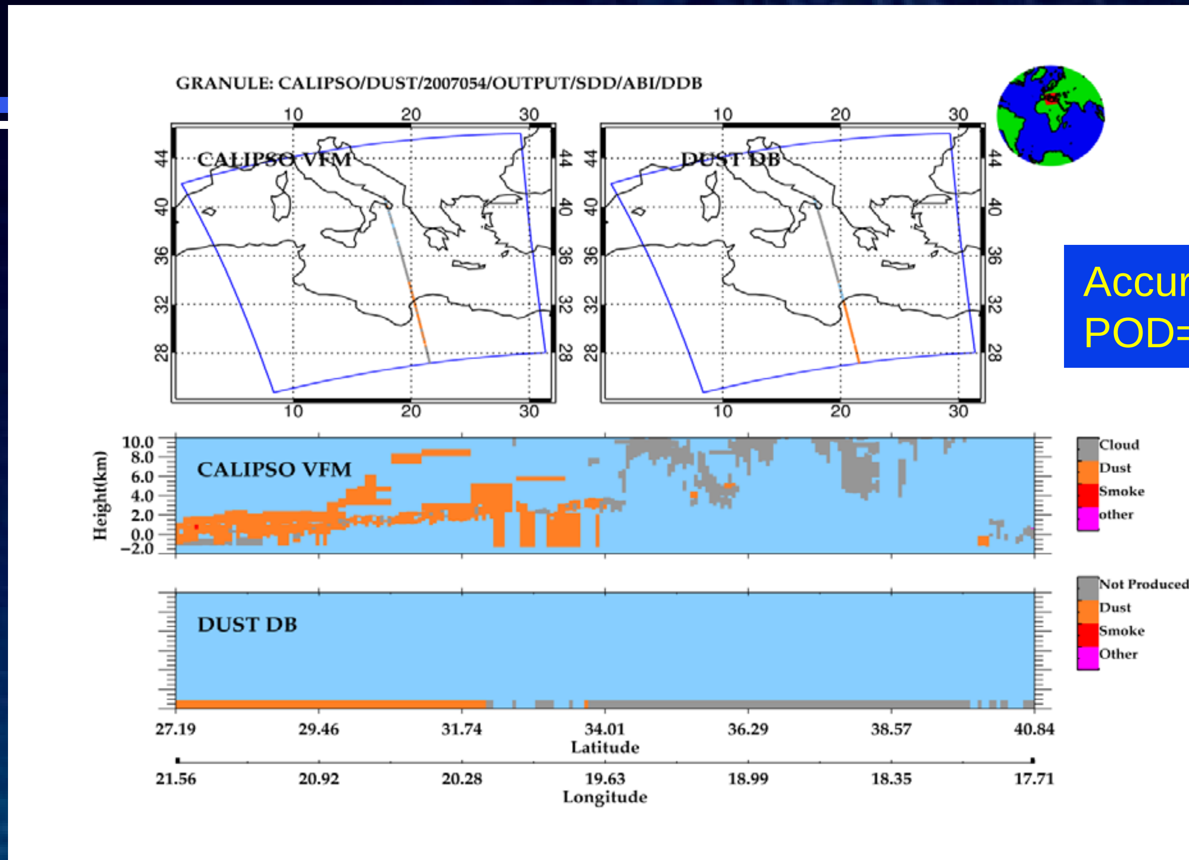
Validation with CALIPSO VFM: match-up strategy



- Time difference: ±2 minutes
- Spatially , VIIRS pixels within ± 375m of
  the middle CALIPSO profile was selected.
- Middle three profiles are used to determine aerosol type in the column
  - All three profiles need to be cloud-free;
  - Dominant aerosol type is determined through the calculation of dust (or smoke) fraction (i.e., no of dust (or smoke) layers divided by the no. of aerosol layers from surface to 12km.
- VIIRS SM data are filtered for high quality.

True Positive (TP): VIIRS and CALIPSO say dust
True Negative(TN): VIIRS and CALIPSO say no dust
False Negative(FN): VIIRS says no dust but CALIPSO says dust
False Positive(FP): VIIRS says dust when CALIPSO says no dust

POD = TP/(TP+FN)
Accuracy = (TP+TN)/(TP+TN+FP+FN)
FAR = FP/(FP+TP)

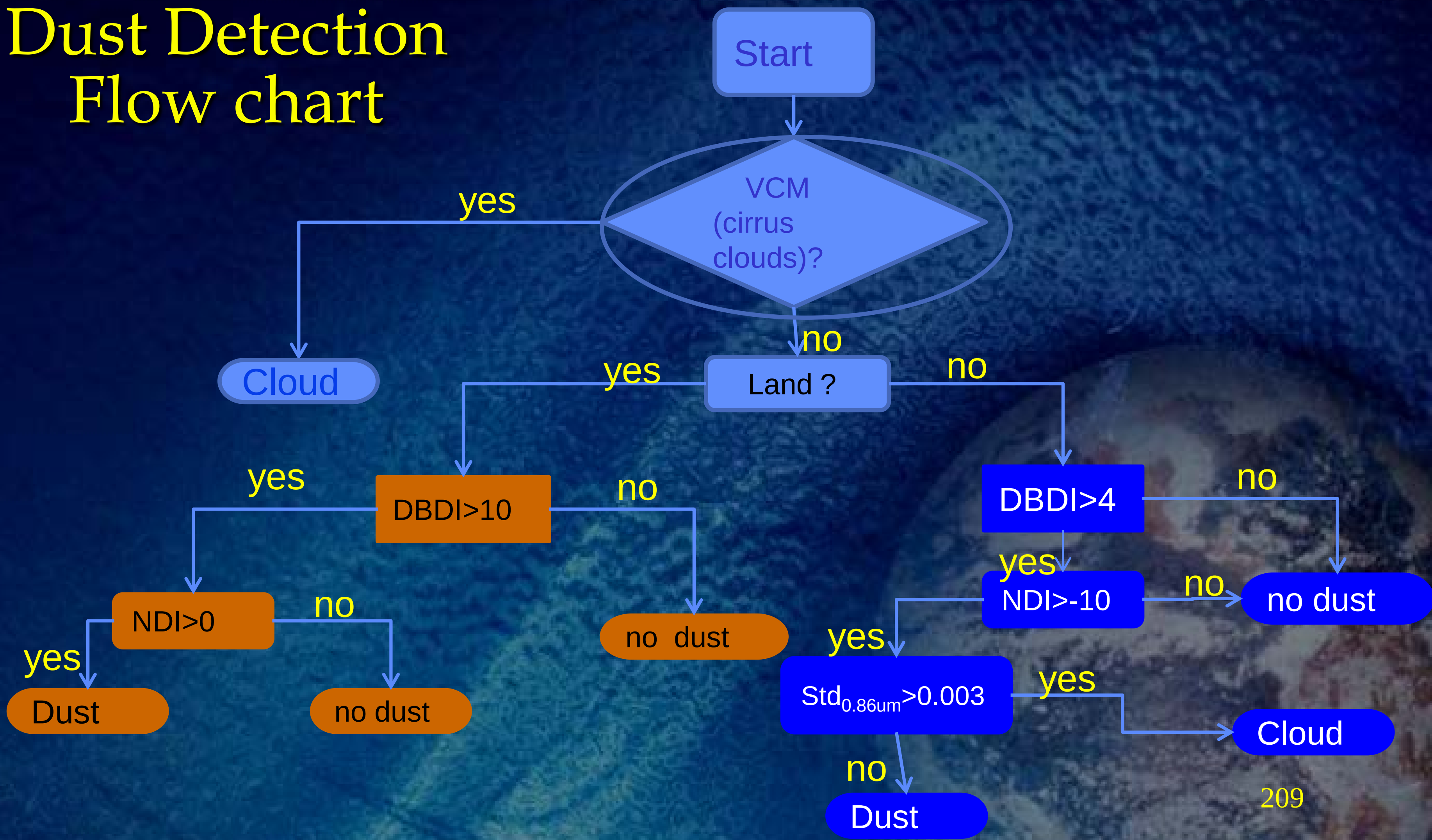


Accuracy=75%
POD= 67%

Cases	True Positive	False Negative	True Negative	False Positive	Accuracy (%)	POD (%)
172	4770	4903	21813	5228	72.4	50.0

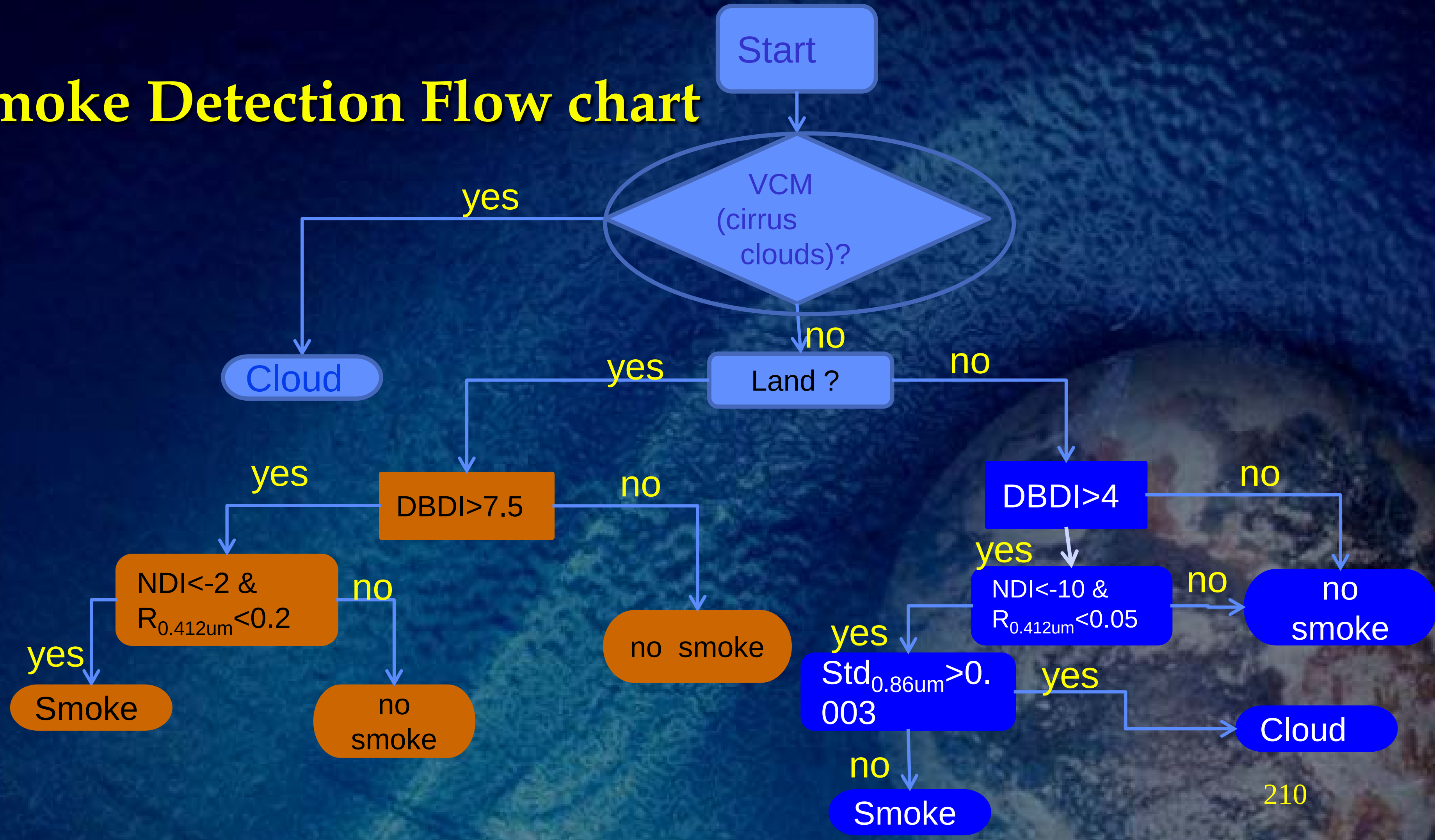
Application to NPP VIIRS

Dust Detection Flow chart



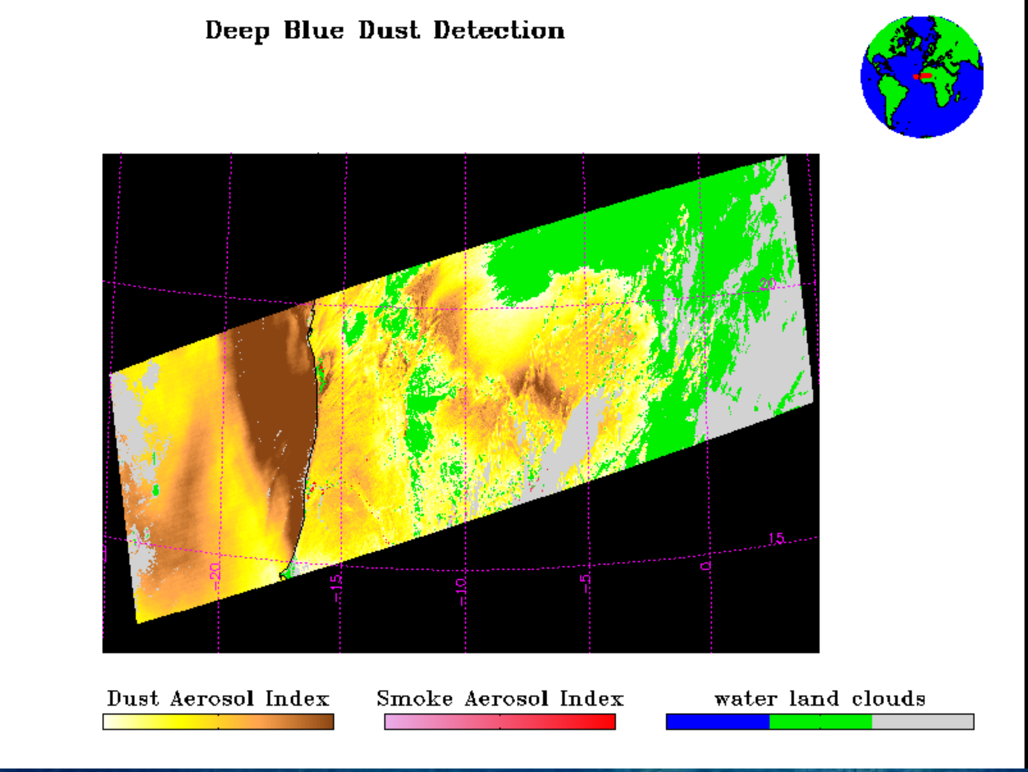
Application to NPP VIIRS

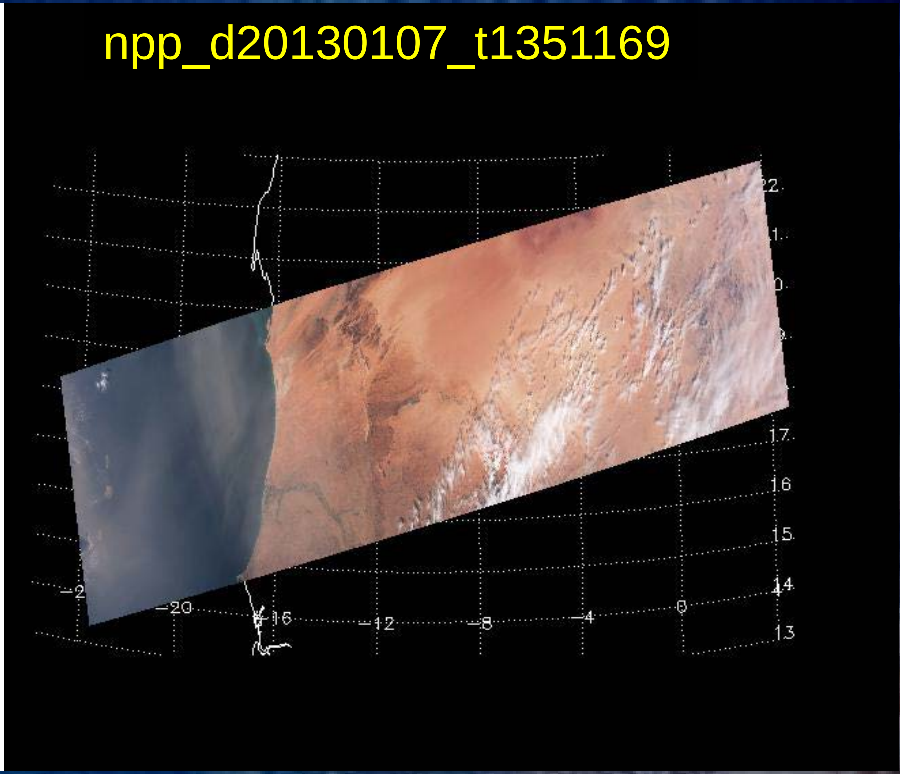
Smoke Detection Flow chart



Application to NPP VIIRS: example 1

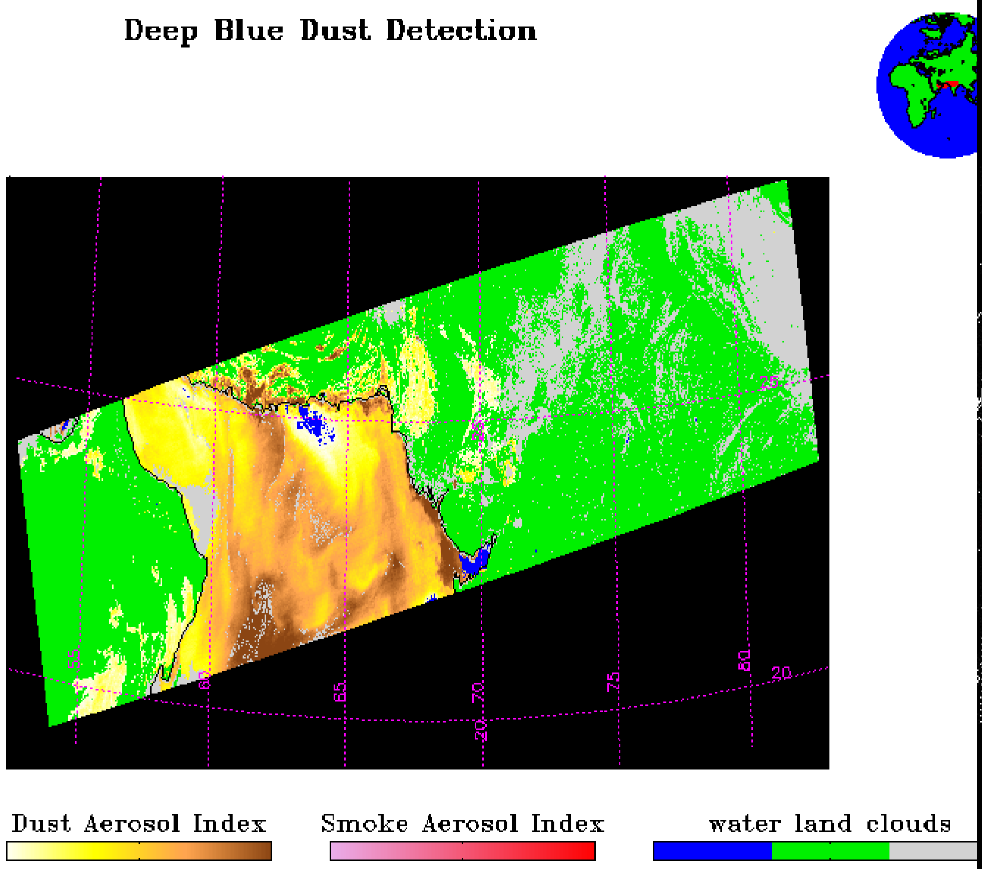
Dust over Sahara and west coast of Africa (01/07/2013)

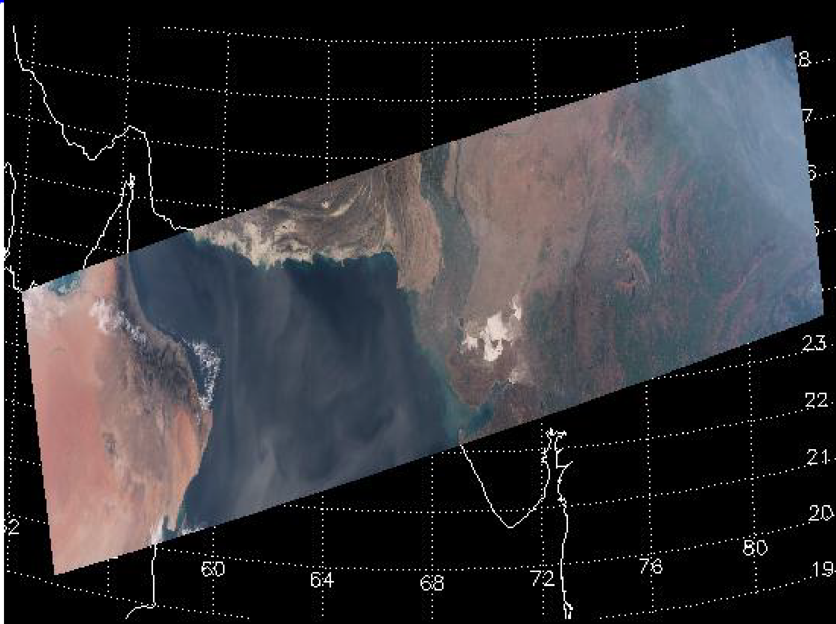




Application to NPP VIIRS: example 2

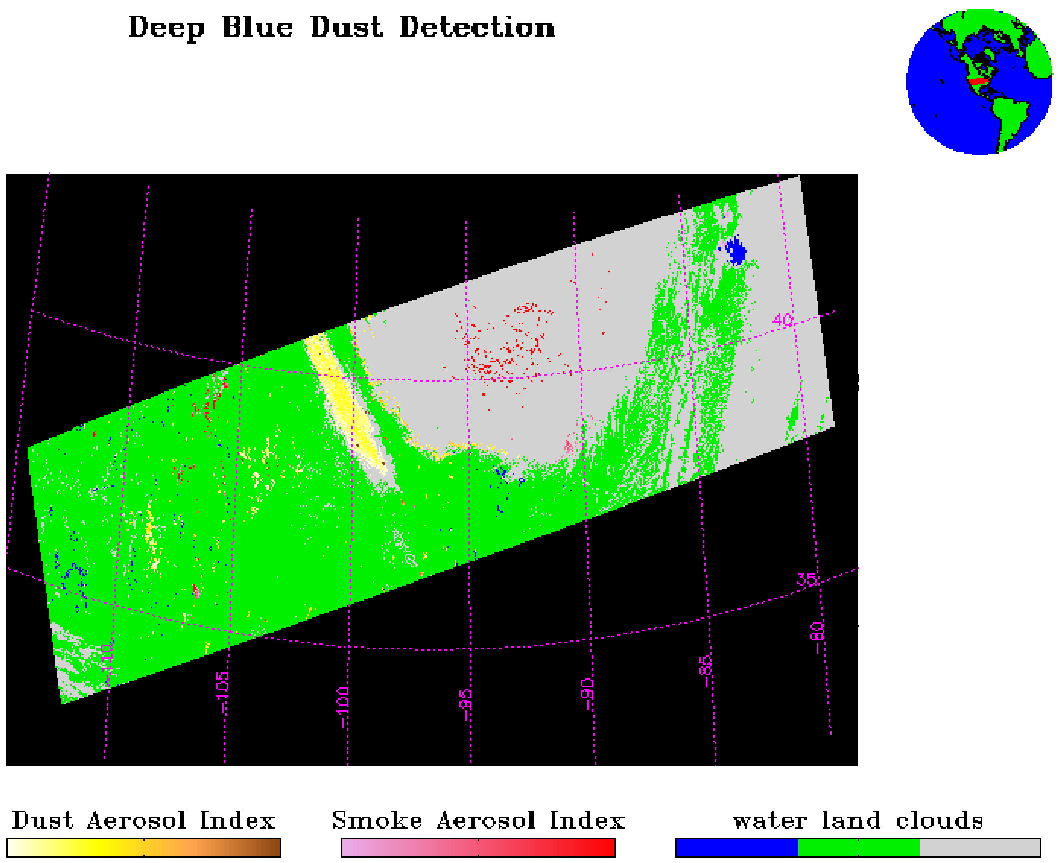
Dust over Arabian Sea (01/13/2013)

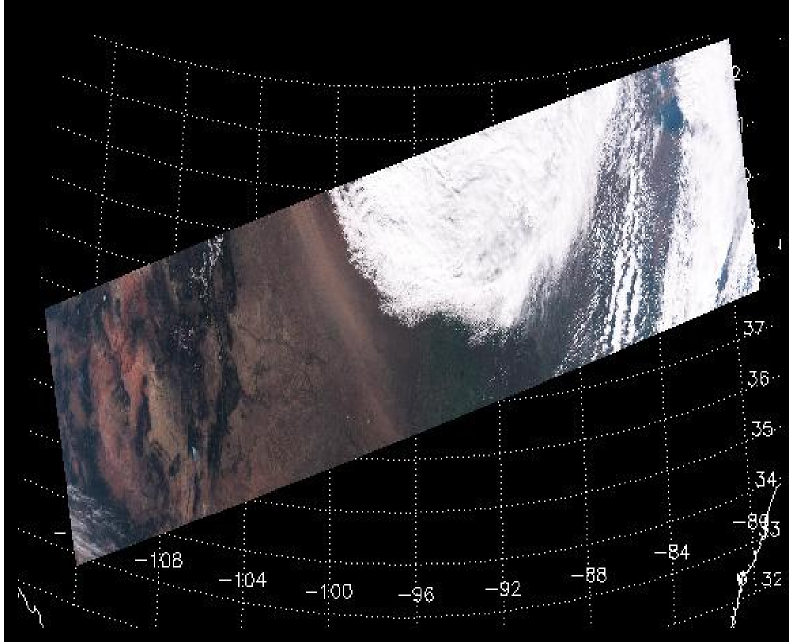




Application to NPP VIIRS: example 3

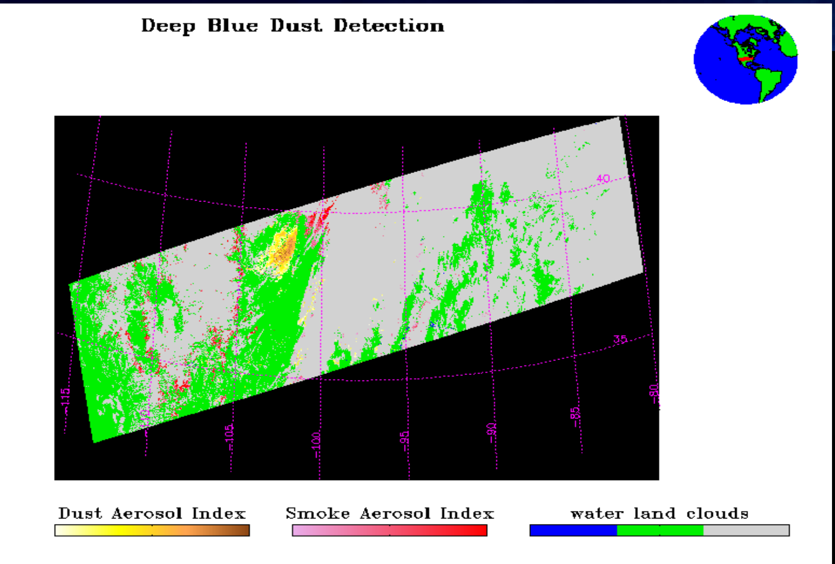
Blowing dust over U.S. (10/18/2012)

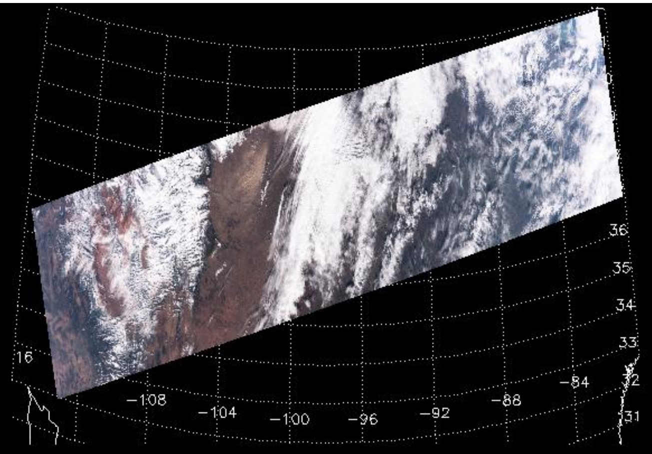


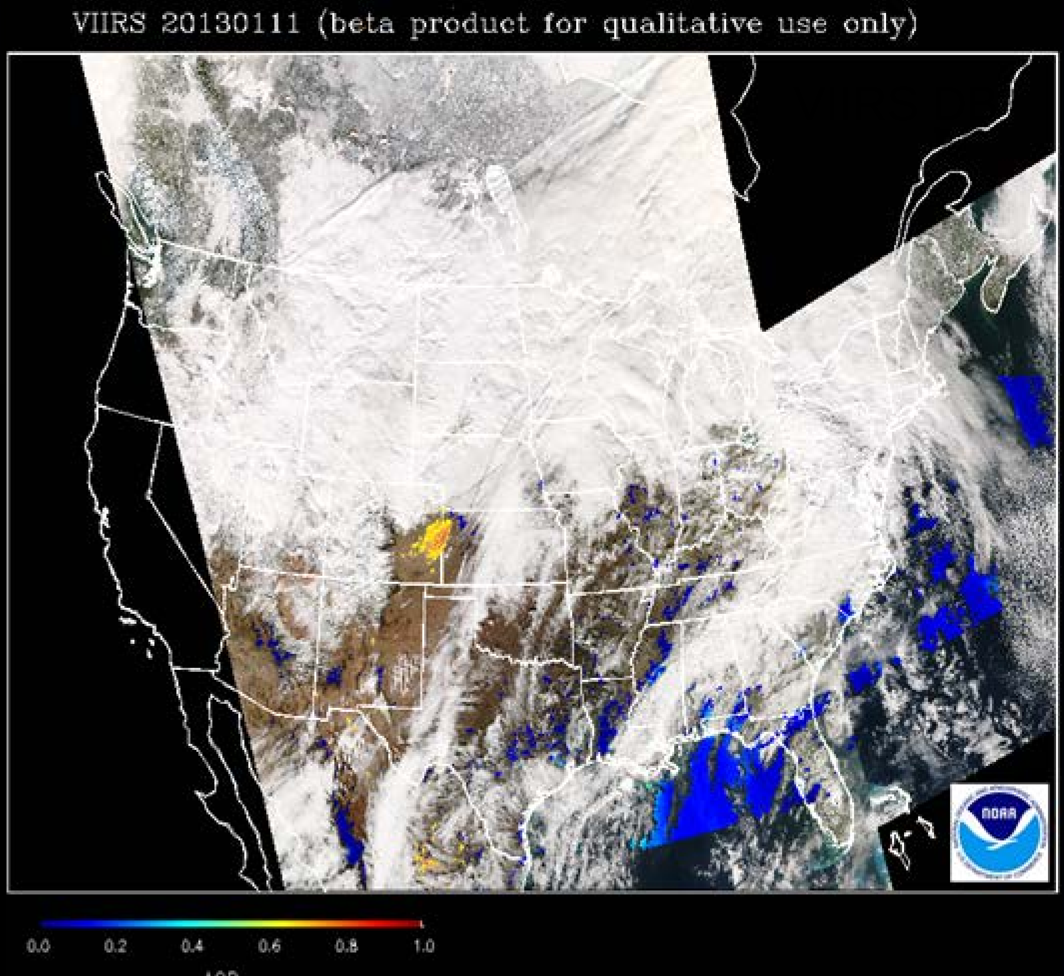


Application to NPP VIIRS: Example 4

Blowing dust in central U.S.

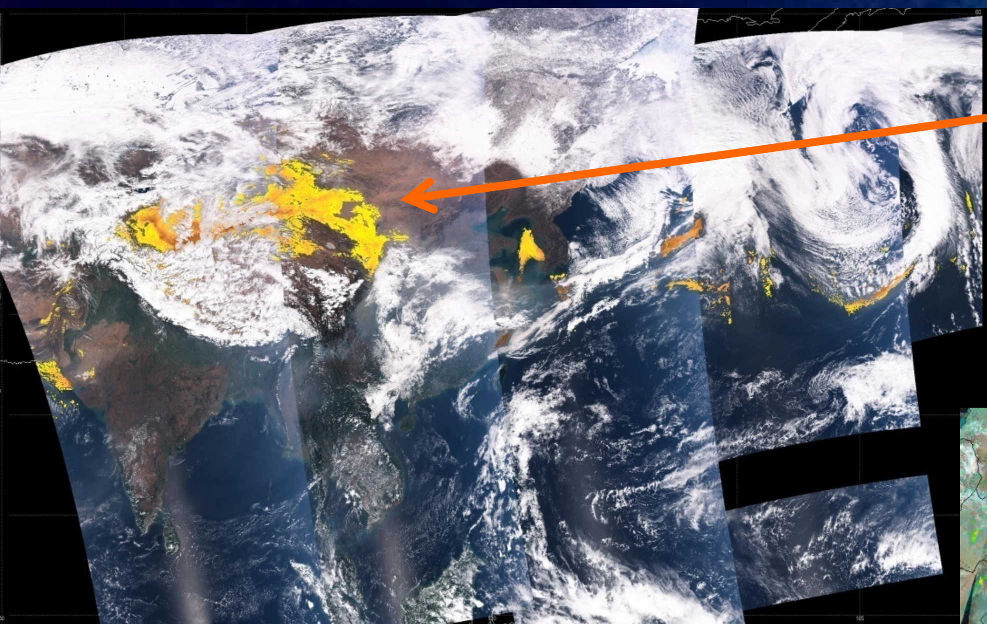






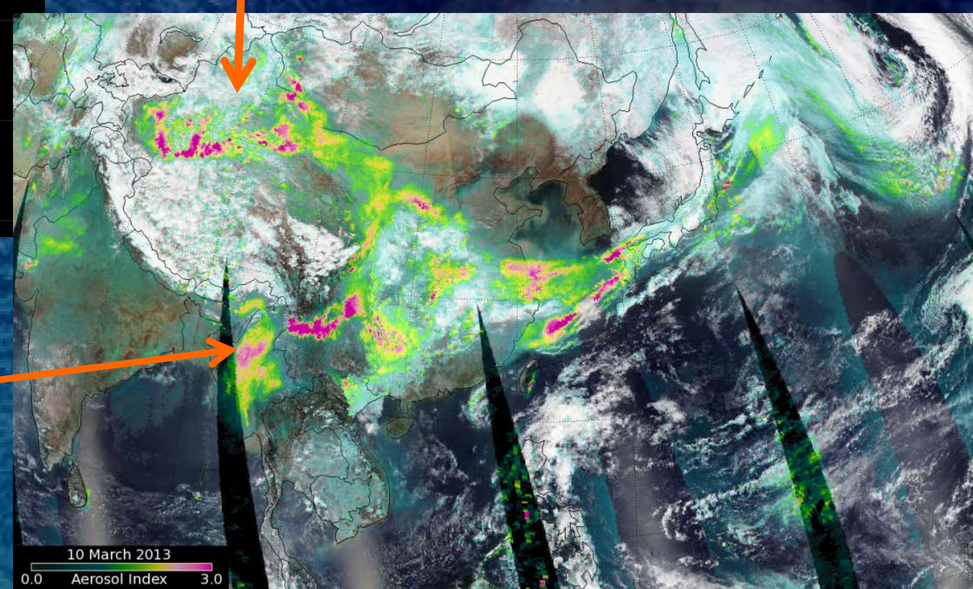
Application to NPP VIIRS: Example 5

Asian dust on 03/10/2013



dust

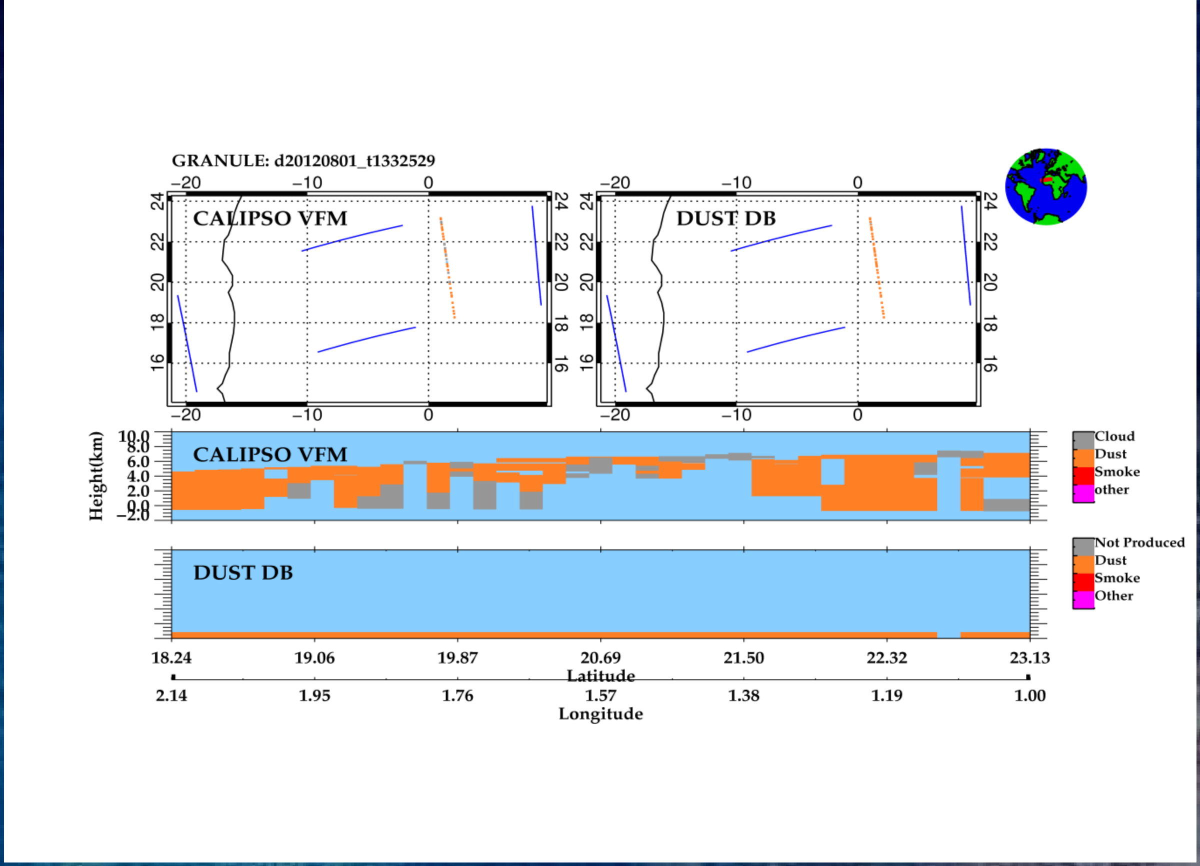
OMPS Aerosol Index



Haze

VIIRS DBDI Dust vs. CALIPSO Vertical Feature Mask

Accuracy=75%
POD = 100%
FAR = 25%

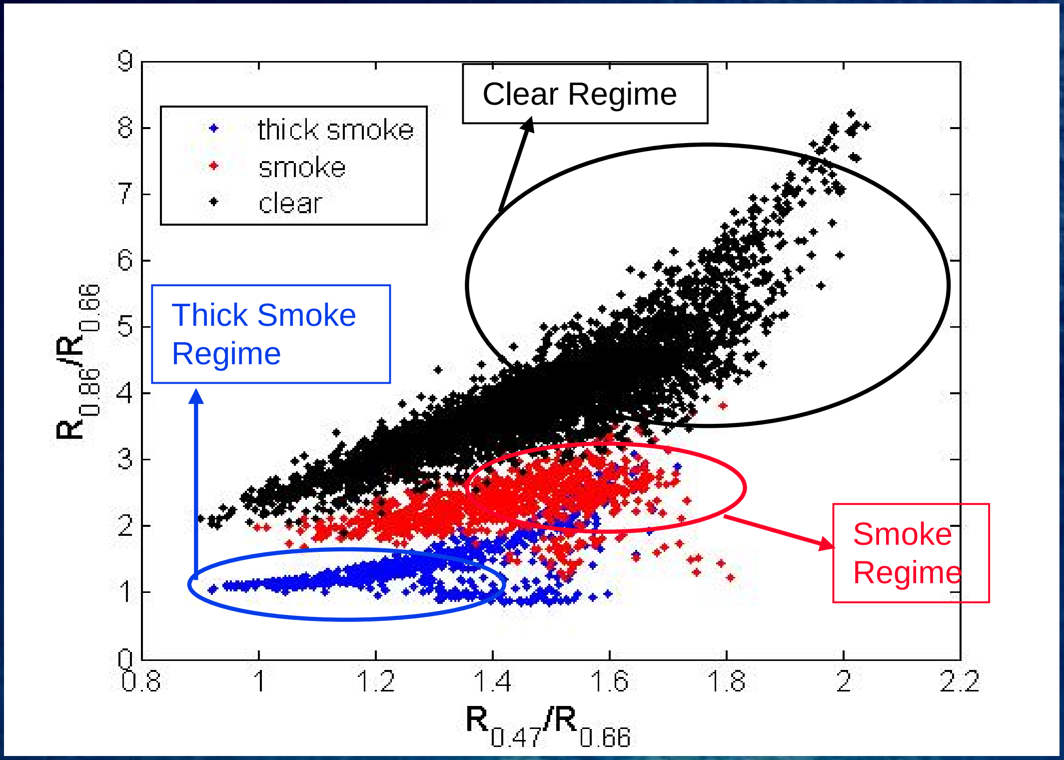


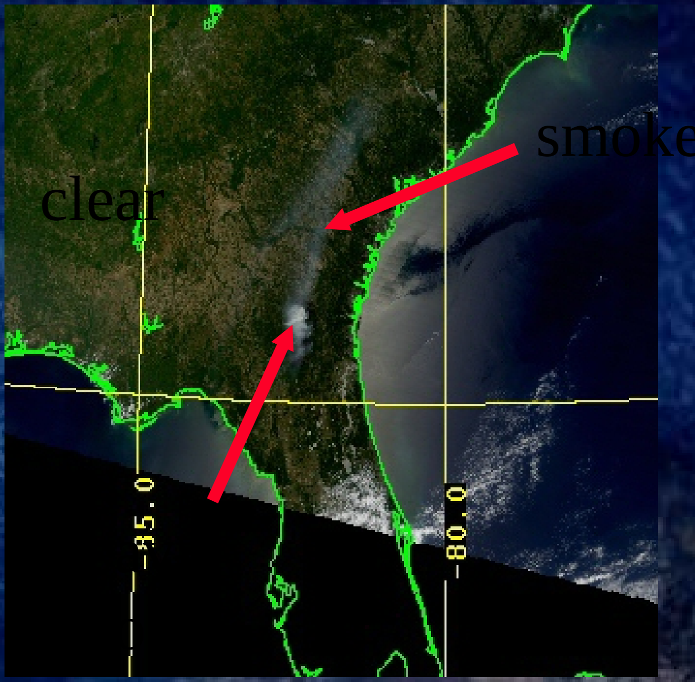
VIIRS DBDI Dust vs. CALIPSO Vertical Feature Mask

Land Granules		Accuracy	POD	FAR
d20120801_t1332529	DBDI	78.4	100.0	22.2
	VSUMO	24.3	0.0	N/A
d20130108_t1010226	DBDI	96.7	96.7	0.0
	VSUMO	0.0	0.0	N/A
d20130115_t1122460	DBDI	78.3	84	10.6
	VSUMO	16.7	0.0	N/A
d20130222_t1110420	DBDI	93.3	96.0	4
	VSUMO	16.7	0.0	N/A
Water Granules		**Accuracy**	**POD**	**FAR**
d20120801_t1324204	DBDI	89.1	44.4	0.0
	VSUMO	80.4	0.0	N/A
d20130108_t1511560	DBDI	93.0	100.0	6.98
	VSUMO	6.9	0.0	N/A
d20130131_t1443344	DBDI	82.7	84.7	2.7
	VSUMO	2.3	0.0	N/A
d20130131_t1444598	DBDI	79.8	82.2	6.3
	VSUMO	13.1	0.0	N/A
d20130222_t1110420	DBDI	90.9	80.0	0
	VSUMO	45.0	0.7	14.3

Aerosol Detection Physical Description (ABI Smoke Detection Algorithm as Heritage)

- Spectral (wavelength dependent) thresholds can separate thick smoke, light smoke, and clear sky conditions





Smoke Detection Algorithm Mathematical Description

Definitions:

BT – Brightness Temperature

R – Reflectance

BTD – Brightness Temperature Difference

MeanR – Mean of reflectance (3 X 3 pixels)

StdR – Standard deviation of reflectance (3 X 3 pixels)

Formulae:

$$R_1 = \frac{R_{0.48\,\mu m}}{R_{0.67\,\mu m}}$$

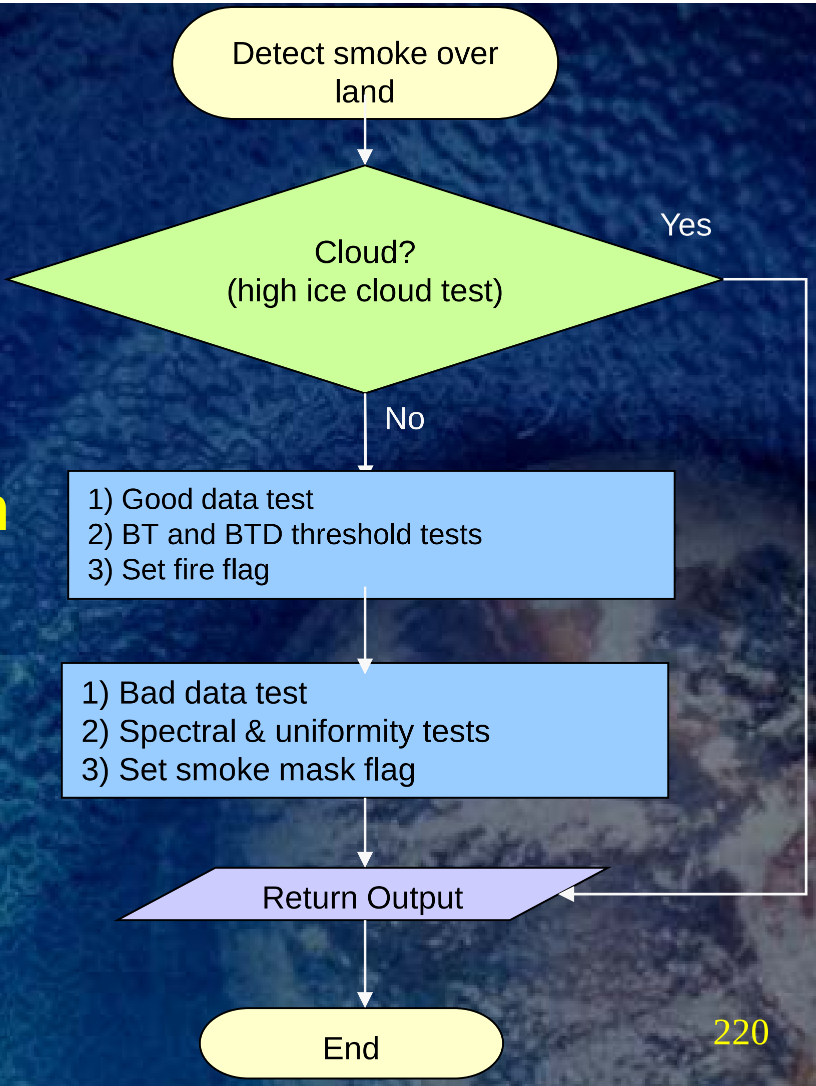
$$R_2 = \frac{R_{0.86\,\mu m}}{R_{0.67\,\mu m}}$$

$$R_3 = \frac{R_{0.48\,\mu m}}{R_{1.61\,\mu m}}$$

$$R_4 = \frac{R_{2.25\,\mu m}}{R_{1.61\,\mu m}}$$

Mathematical Description of Smoke Detection - Land

1. **High ice cloud test**
2. **Fire detection**
3. **Thick smoke detection**
4. **Return output**



Mathematical Description of Smoke Detection - Land

1. Test for the quality of the input radiance data

   $R_{0.488\mu m}$, $R_{0.67\mu m}$, $R_{0.86\mu m}$, $R_{2.25\mu m} > 0$ &
   $BT_{3.7\mu m}$, $BT_{10.7\mu m}$, $> 0K$
   Quality flags for above channels equal to zero, indicating quality of the data is assured.

If above conditions are satisfied, then proceeds to next test, otherwise to next pixel.

2. Fire detection (hot spot)

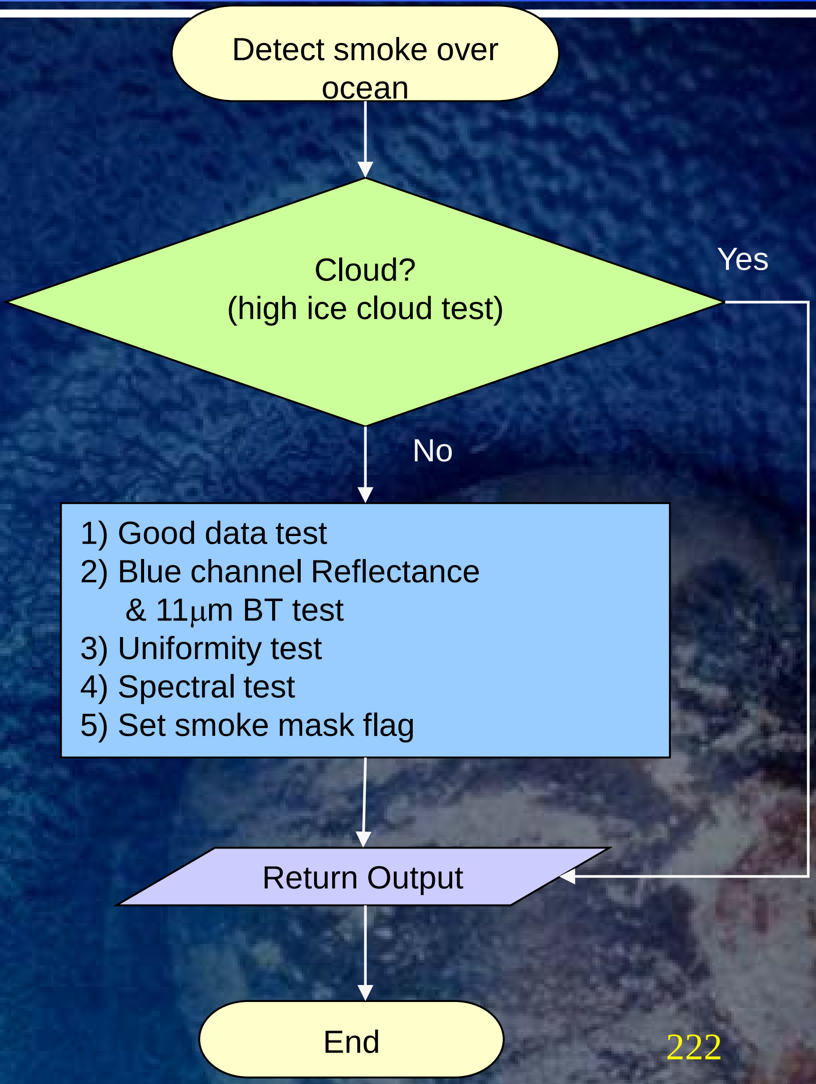
   If $BT_{3.7\mu m} > 350K$ and $BT_{3.7\mu m} - BT_{10.7\mu m} > 10K$
   then fire and thick smoke

3. Spectral and uniformity tests for thick smoke

   If $R_{2.25\mu m} < 0.2$ and $R_{0.67\mu m} > (0.06 + R_{2.25\mu m})$ and
   $R_1 \geq 0.85$ and $R_2 \geq 1.0$ and
   $StdR_{0.67\mu m} \leq 0.04$ (in 3x3 pixels box)
   then thick smoke

Mathematical Description of Smoke Detection - Ocean

1. **High ice cloud test**
2. **Smoke detection**
3. **Return output**



Mathematical Description of Smoke Detection - Ocean

1. Test for the quality of the input radiance data

$R_{0.48\mu m}$, $R_{0.86\mu m}$, $R_{1.61\mu m}$ and $R_{2.25\mu m} > 0$
If above conditions are satisfied, then proceeds to next test, otherwise to next pixel.

2. Uniformity test

If $StdR_{0.86\mu m} <= 0.003$ then
thick smoke determination test
else
thin smoke determination test

2.1) Thick smoke determination test
If $R_3 \geq 10.0$ and $R_{0.48\mu m} \geq 0.12$ and $0.02 =< R_{1.61um} < 0.045$ and $R_4 < 1.0$
then thick smoke
else
if $R_{0.86\mu m} > 0.055$ and $R_3 \geq 5.0$ then thin smoke (1)

2.2). thin smoke determination test

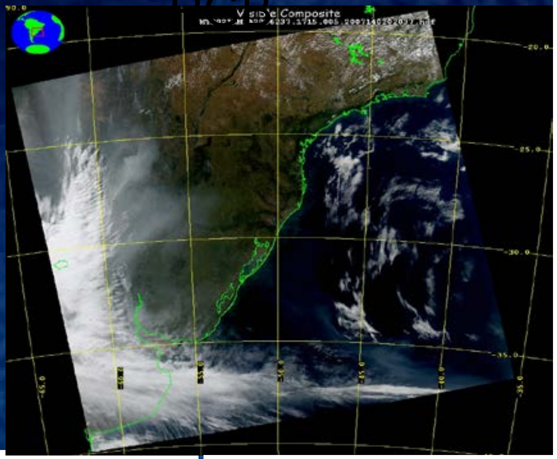
If $R_{0.86\mu m} > 0.055$ and $R_3 \geq 5.0$ and $R_4 < 0.6$ then thin smoke (2)

Example 1: Smoke over South America

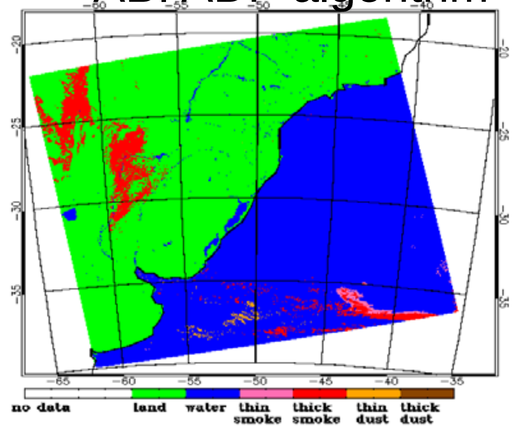
Date: 08/25/2006, UTC:1715
Aqua

Red - Smoke

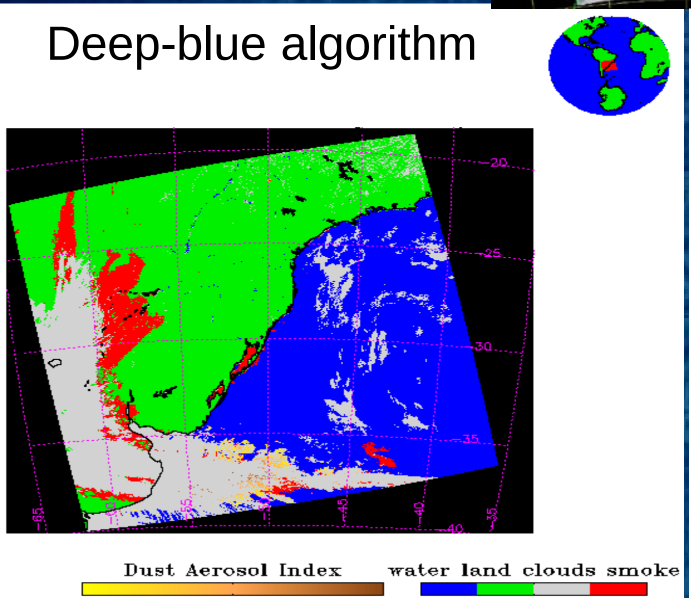
RGB



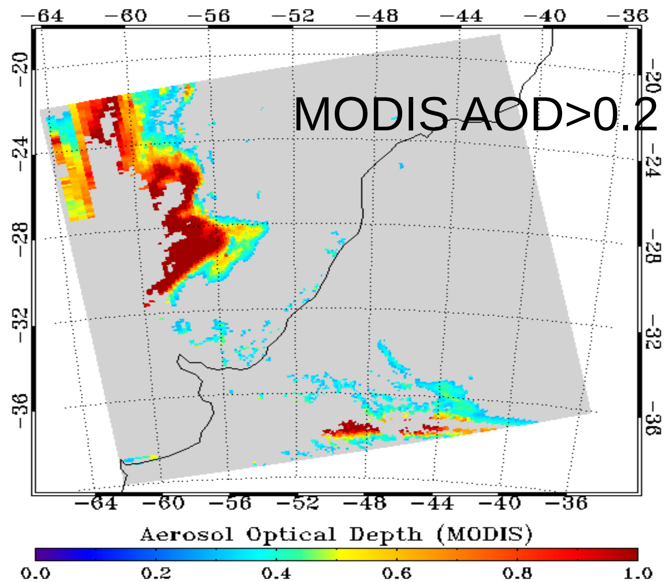
ABI ADP algorithm



Deep-blue algorithm

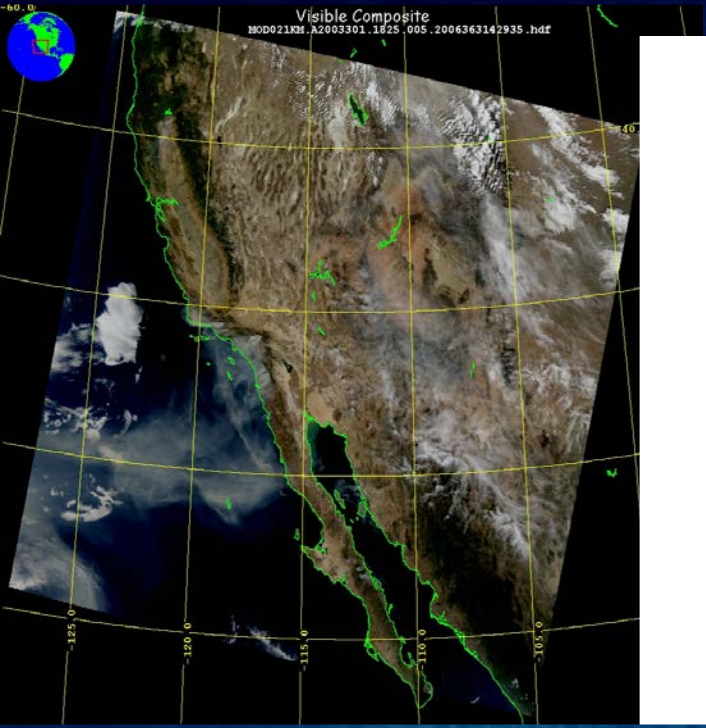


MODIS AOD>0.2

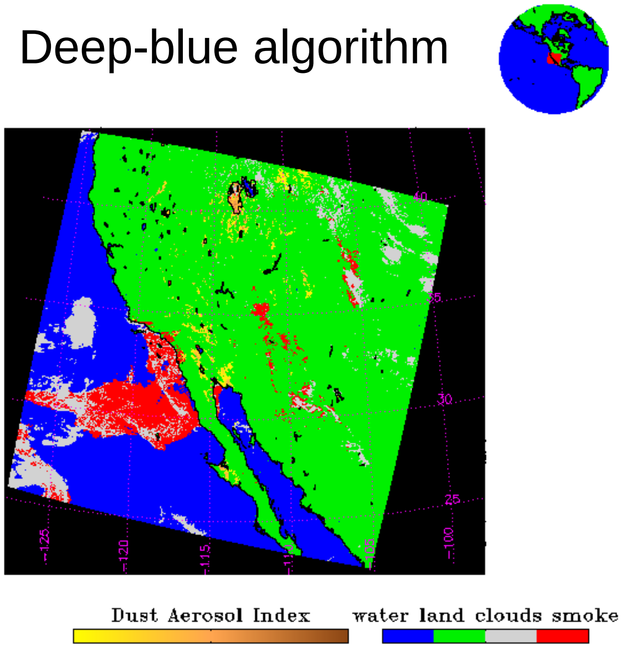


Example 2: Smoke over west coast of U.S

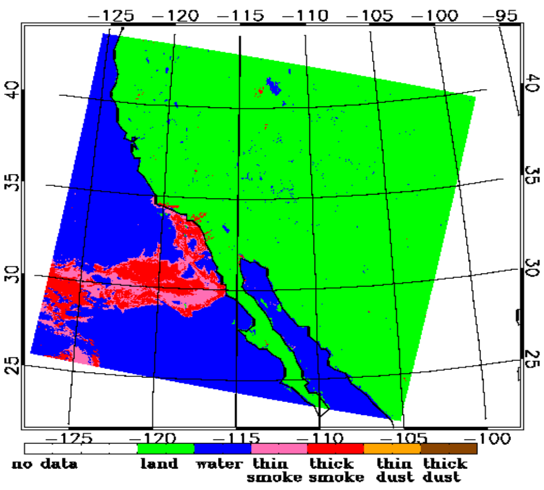
Date: 10/28/2003, UTC:1825 Terra



Deep-blue algorithm

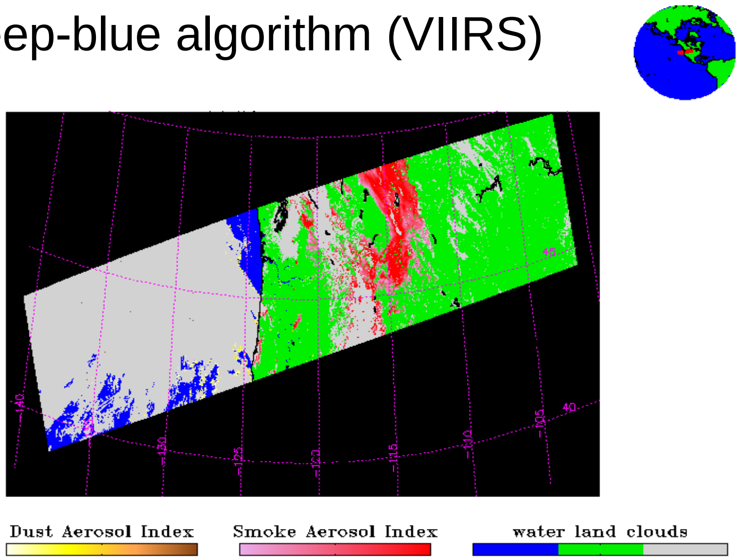


ABI ADP algorithm

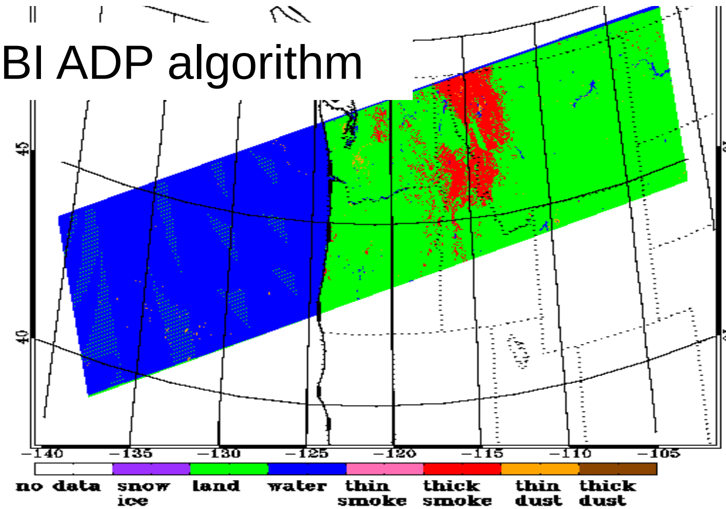


Application to NPP VIIRS: Example 1

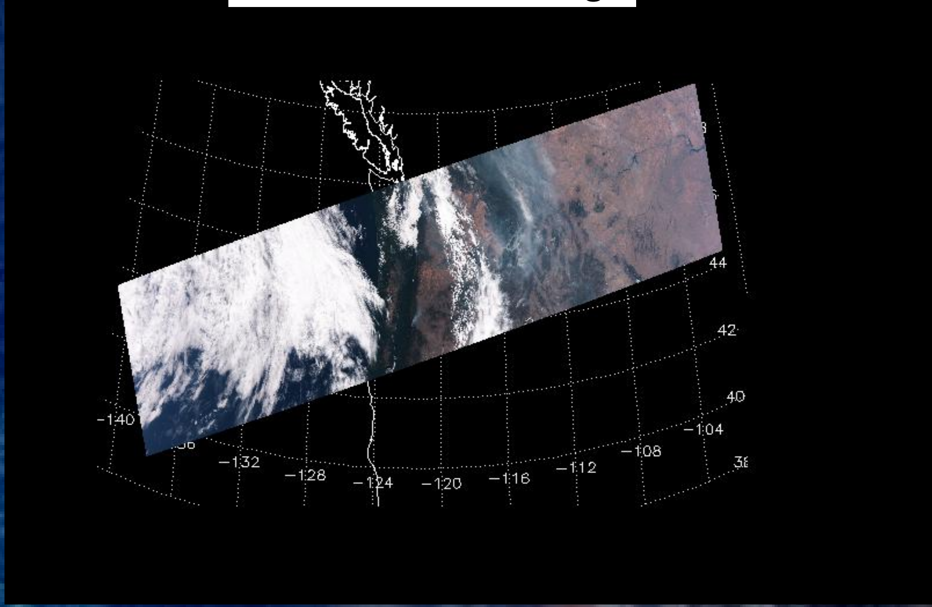
Deep-blue algorithm (VIIRS)



ABI ADP algorithm



VIIRS RGB image

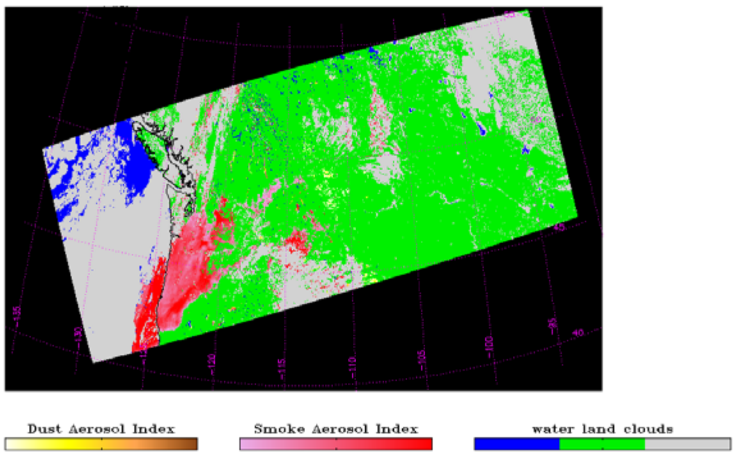


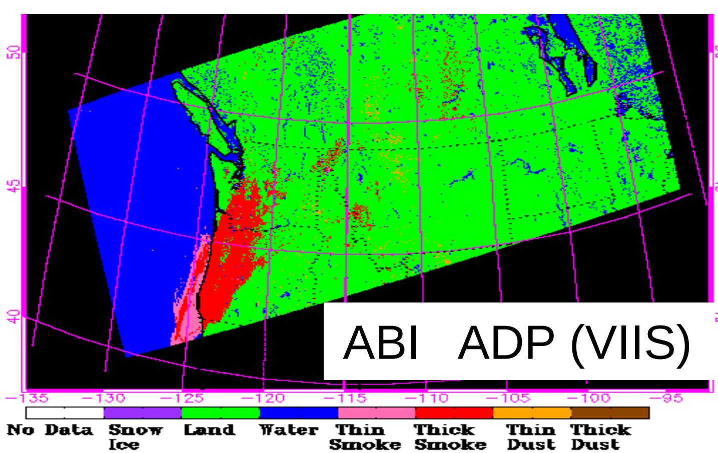
Smoke over west coast of US (09/22/2012)

Application to NPP VIIRS: Example 2

09/24/2012 U.S. west coast

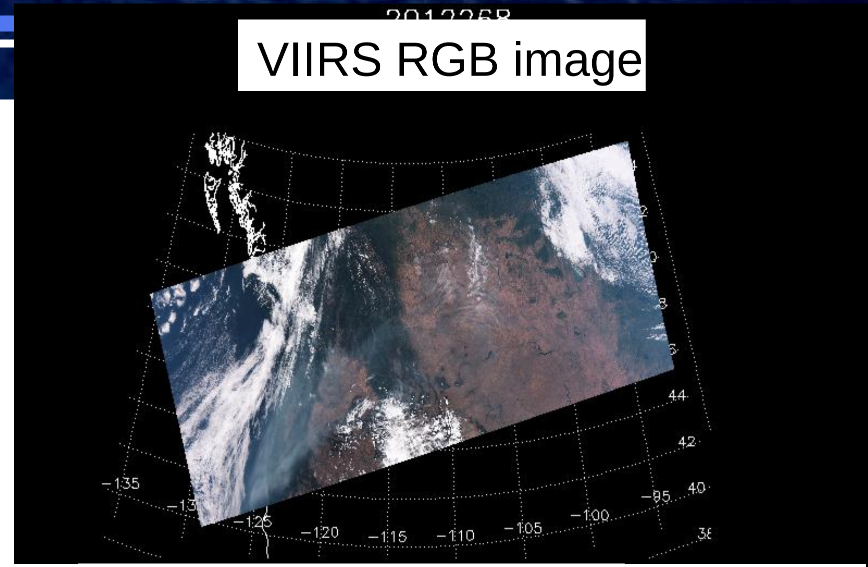
Deep-blue algorithm (VIIRS)



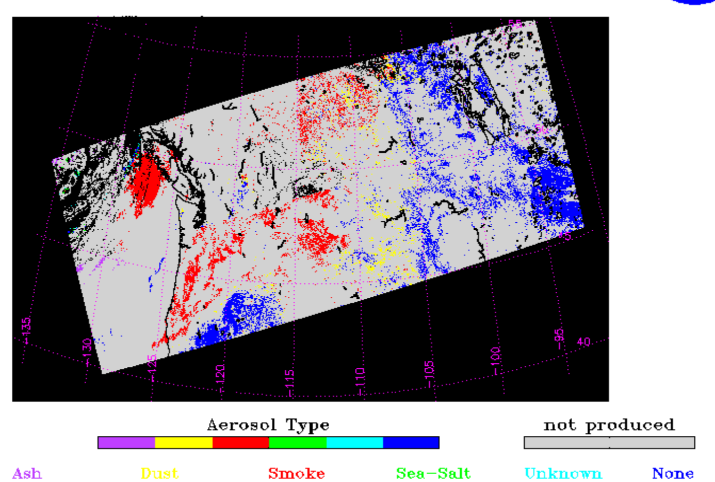


ABI ADP (VIIS)

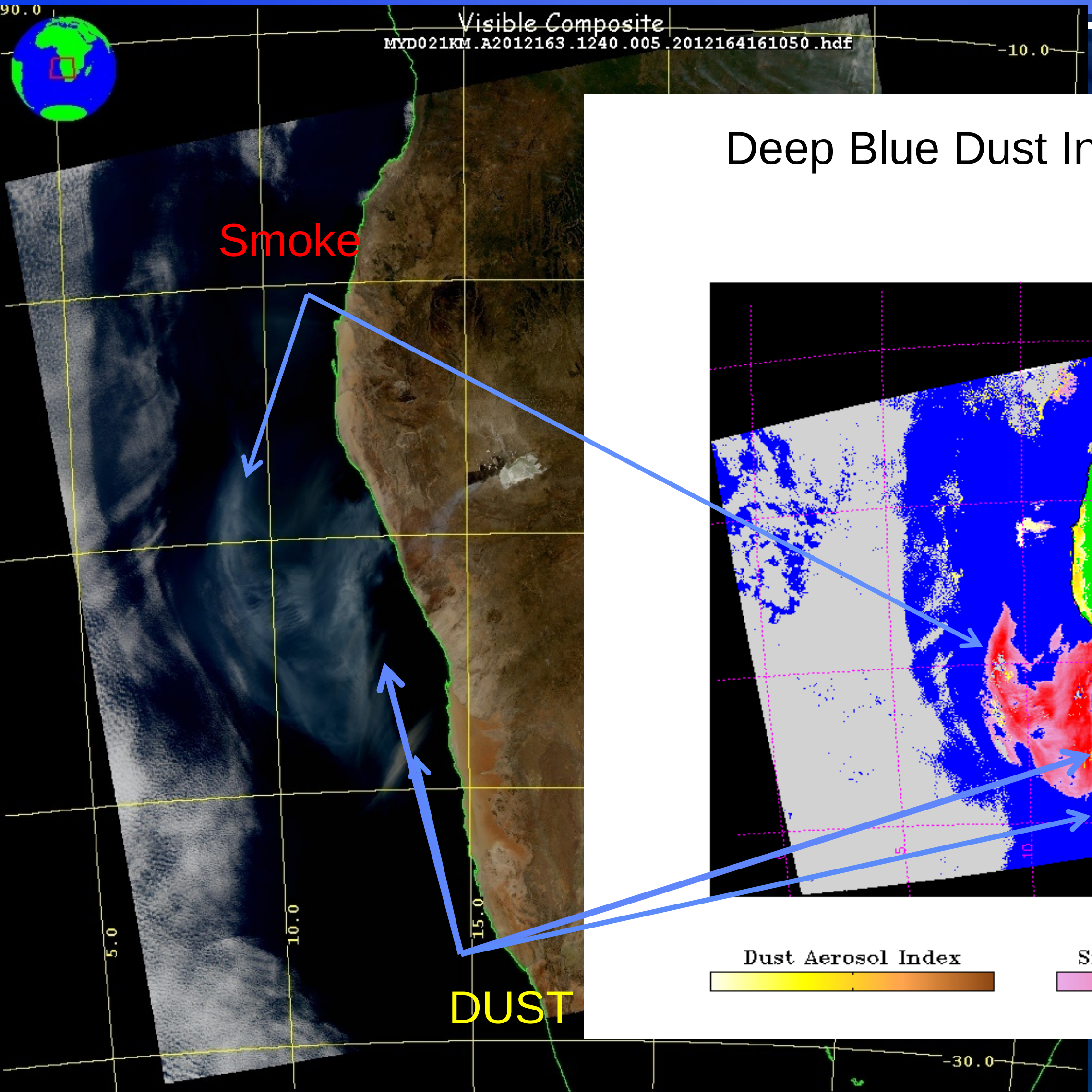
VIIRS RGB image

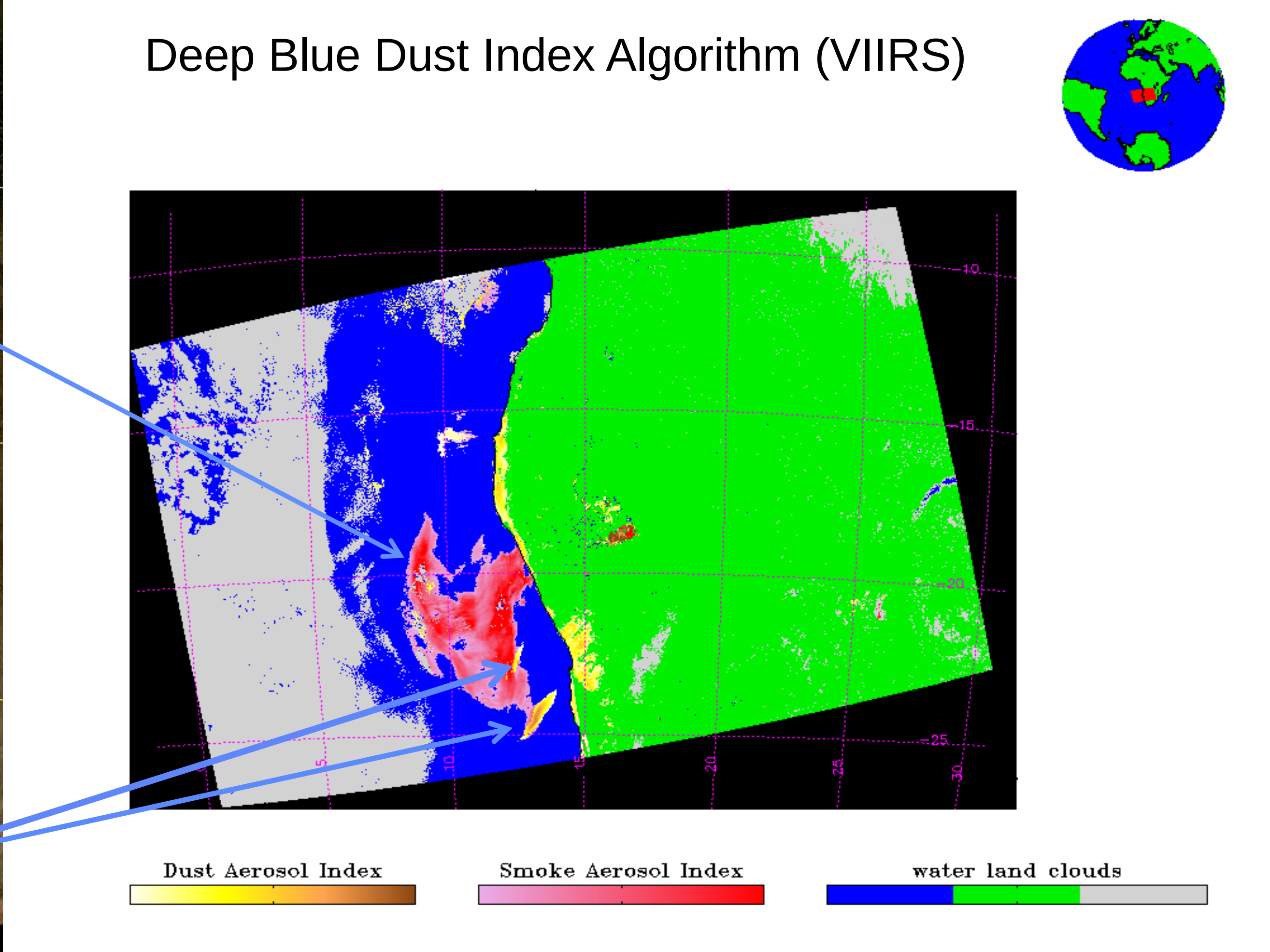


VIIRS SM/Aerosol Type



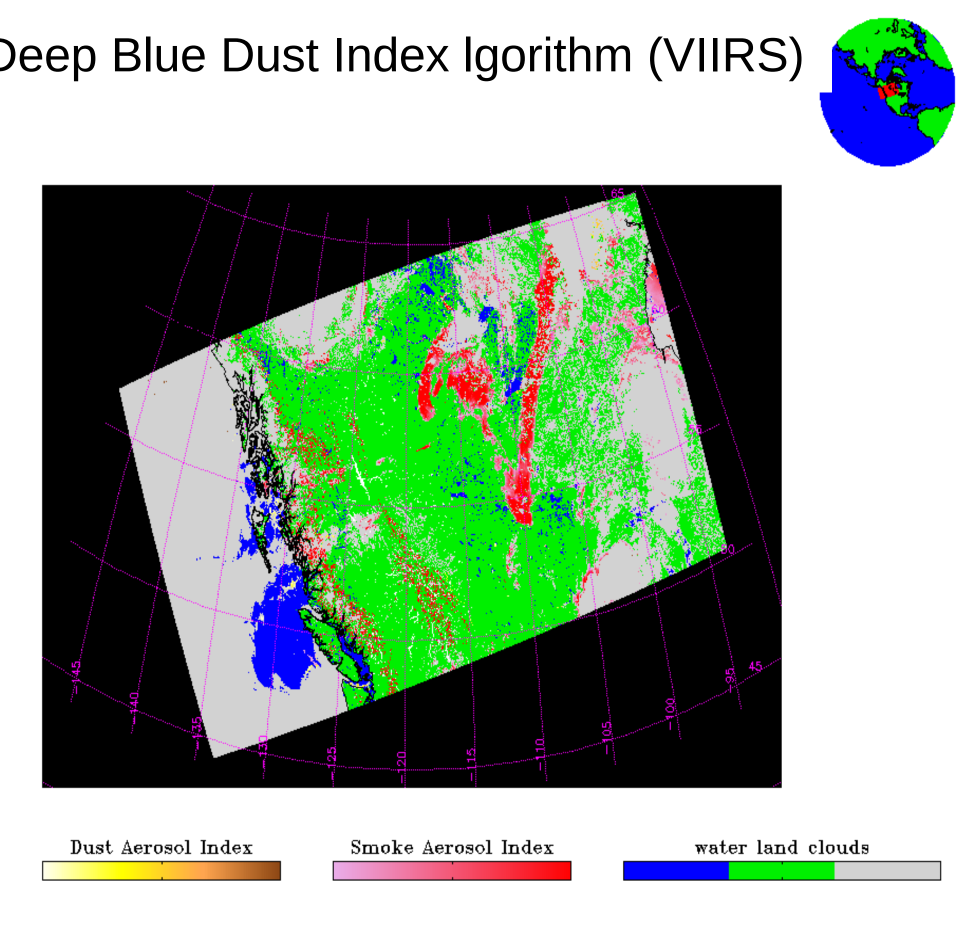
Example 3: Dust and smoke over west coast Of Africa (06/11/2012)

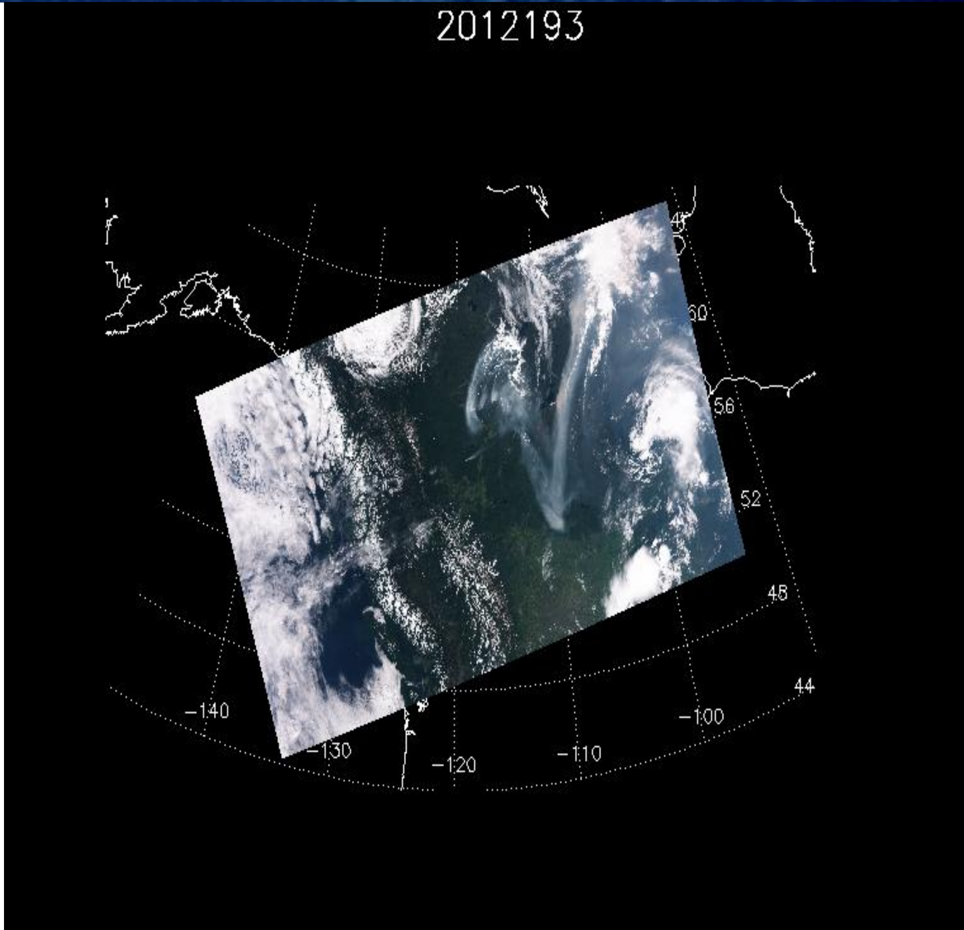




Application to NPP VIIRS: Example 4

Smoke plume over Canada 07/11/2012

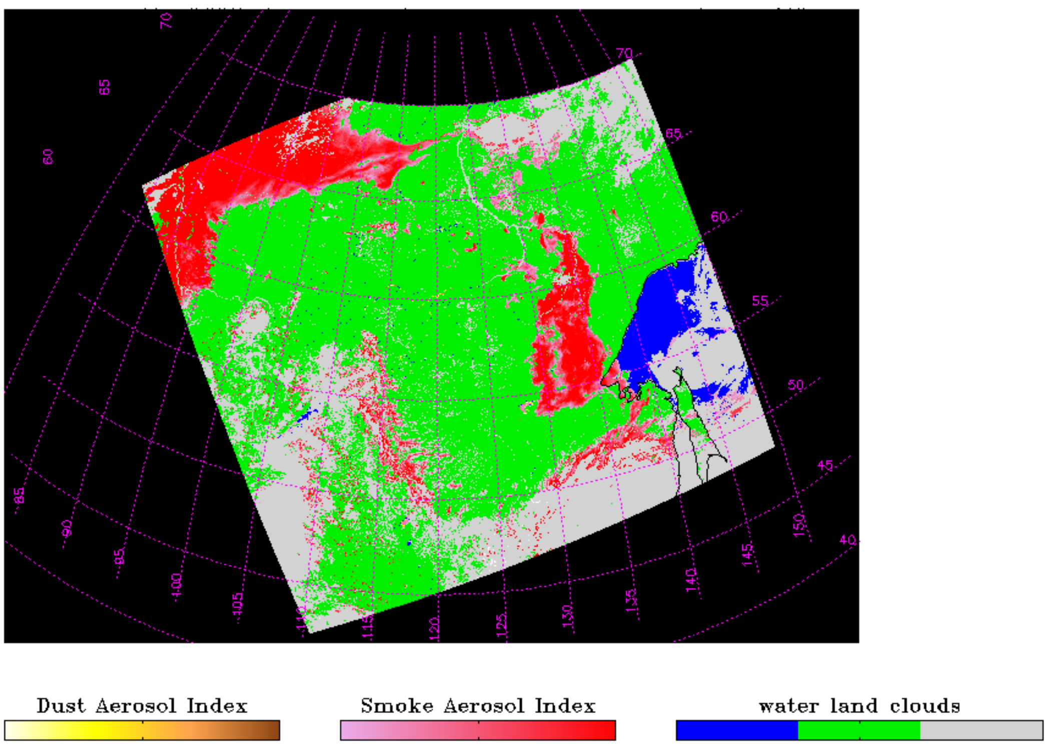


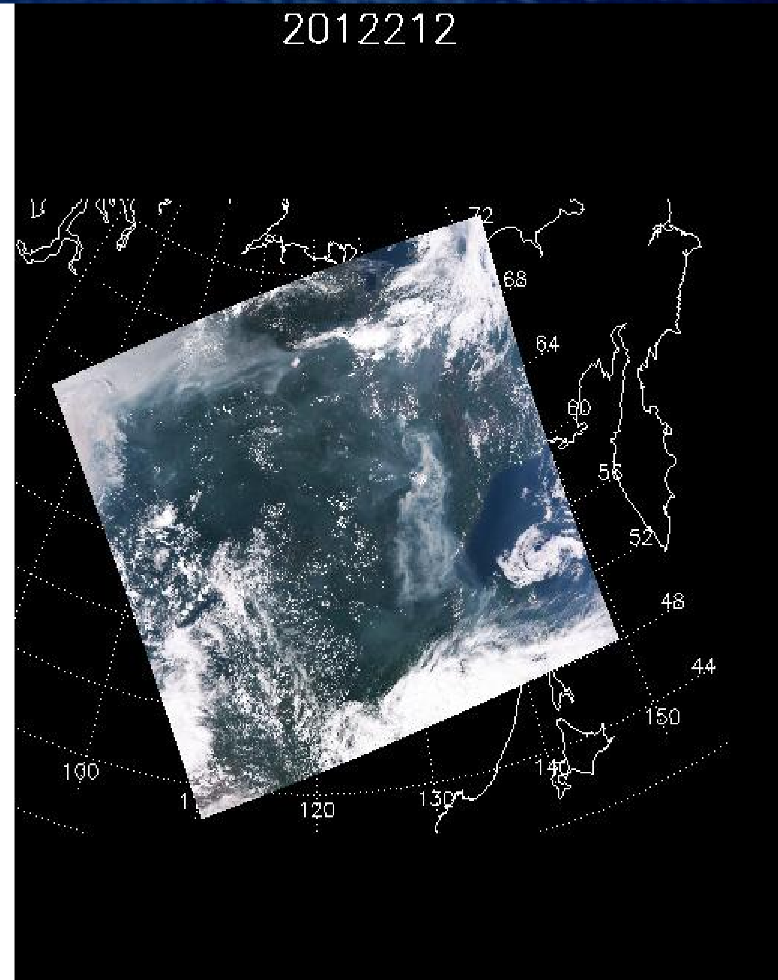


Application to NPP VIIRS: Example 5

Smoke plume over Russia 07/30/2012

Deep Blue Dust Index Algorithm (VIIRS)





Validation of smoke detection results

Table 1. Accuracy, Probability of Detection, and False Alarm Ratio of ABI smoke detection

	No. of Matchups	Accuracy	POD	FAR
	CALIPSO VFM			
Smoke	5192 (22)	80.5%	71.9%	28.1%
	Supervised MODIS AOD product			
Smoke over land	639637 (60)	80.1%	77.3%	22.7%
Smoke over water	459803 (57)	82.2%	86.4 %	13.5%

Aerosol Detection Algorithm Output

- The algorithm output is a netCDF file for both smoke and dust flags with values:
  - » 0 (no dust/smoke) and 1 (dust/smoke)
- If necessary DBDI value will be written to the output as well to show the intensity.
- If necessary, the algorithm also produces two bytes of quality control output which includes
  - » Day / Night flag
  - » Land / Ocean flag
  - » Sunglint flag
  - » Cloud flags

Aerosol Detection: Practical Considerations

- **Programming and Procedural Considerations**
  - » Aerosol detection is a pixel by pixel algorithm
  - » Detection is performed separately for land and ocean
  - » Some ancillary data flags (day/night, snow/ice, sunglint, cloud/clear) need to be applied to identify valid pixels before the detection of aerosols

- **Numerical Computation Considerations**
  - » To balance the efficiency and memory requirement for the full disk processing, a block of scanning pixels are read into a RAM buffer together instead of reading data pixel by pixel

Exception Handling

- If cloud mask/products is not sufficient for aerosol detection, internal cloud mask will be used
- Bad data test will be used to flag pixels with fill values

Future Development Plan

- **Further Algorithm Validation**
  - » **HMS smoke product**
  - » **VIIRS/GOES Automatic Smoke Detection and Tracking Algorithm**
- Develop real-time validation and monitoring tools.
- **Algorithm Improvement**
  - » **For dust detection, rescue dust detection over sunglint.**
  - » **For dust detection, reducing false alarm rate over bright surfaces and developing NDVI based thresholds for DBDI**.

Aerosol Detection Summary of Algorithm Development

- Applicability of heritage ABI smoke detection algorithm and MODIS deep blue dust detection algorithm.
- Using MODIS data, individual tests were developed for dust and smoke detection over land and ocean
- The algorithm was run on MODIS data for smoke detection and both MODIS and VIIRS data for dust events
- Qualitative comparisons of dust/smoke detection showed a good agreement with RGB imagery
- Preliminary comparisons with CALIPSO VFM product indicated a high accuracy and POD.

Assumptions and Limitations

- **Assumptions:**
  - » **All channels on VIIRS are available and functional**
- **Limitations:**
  - » **Only daytime;**
  - » **Needs accurate clear-sky reflectances;**
  - » **Tests are optimized for dark surface, i.e., over ocean is normally better than over land;**
  - » **Algorithm tuning might be needed when instrument calibration changes**

Aerosol Detection: Other Considerations

- If the VIIRS standard cloud mask is not sufficient, a cloud screening suitable for aerosol detection has to be developed.
- Detection thresholds need to be finalized based on more VIIRS observations.

CDR Aerosol Detection Risk

- **Risk 1:** Smoke detection over bright surface not optimized
- **Risk Assessment:** Medium
- **Impact:** Aerosol detection algorithm accuracy
- **Mitigation:**
  - » Conduct additional testing and fine tune the algorithm as needed to smoke over land
- **Status:** Open

CDR Aerosol Detection Risk

- **Risk 2:** Dust detection over bright surface not optimized
- **Risk Assessment:** Medium
- **Impact:** Aerosol detection algorithm accuracy over land
- **Mitigation:**
  - » Conduct additional testing and fine tune the algorithm as needed to smoke over land
  - » Conduct additional testing and fine tune the algorithm as needed to rescue detection of thick dust or smoke over sunglint region
- **Status:** Open

References

Hsu, N.C., S.-C. Tsay, M. D. King, and J. R. Herman (2004) *Aerosol properties over bright reflecting source regions*. IEEE Trans. Geosci. Remote Sens., 42 (3), 557-569, doi: 10.1109/TGRS.2004.824067.

Hsu, N.C., S.-C. Tsay, M. D. King, and J. R. Herman (2006), *Deep Blue retrievals of Asian aerosol properties during ACE-Asia*, IEEE Trans. Geosci. Remote Sens., 44 (11), 3180-3195, doi: 10.1109/TGRS.2006.879540.

Herman, J. R., P. K. Bhartia, O. Torres, N. C. Hsu, C. J. Seftor, and E. Celarier, Global distribution of UV-absorbing aerosols from Nimbus 7/TOMS data, J. Geophys. Res., 102, 16,911-16,921, 1997.

Ackerman, S. A., Remote sensing aerosols using satellite infrared observations, J. Geophys. Res., 102, 17,069– 17,079, 1997.

Pubu Ciren, H. Liu, S. Kondragunta, and I. Laszlo , Adapting MODIS Dust Mask Algorithm to Suomi NPP VIIRS for Air Quality Applications, AGU fall meeting, San Francisco, Dec 11-16, 2012

Outline

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

Algorithm Theoretical Basis

Aerosol Optical Depth and Aerosol Particle Size

Presented by

Istvan Laszlo
NOAA/NESDIS/STAR

Algorithm Theoretical Basis

- **Purpose: Provide a physical and mathematical description of the JPSS RRPS VIIRS aerosol retrieval algorithm for product developers, reviewers and users.**
- **Will be documented in the JPSS RRPS VIIRS Aerosol Algorithm Theoretical Basis Document (ATBD)**

Aerosol optical depth (AOD) is the extinction (scattering + absorption) vertical optical thickness of aerosols.

Requirements
Aerosol Optical Depth

Satellite Source	**NPP VIIRS**	
Product Name	Aerosol Optical Depth	
Accuracy	Over land: AOD < 0.1: 0.06 0.1 ≤ AOD ≤ 0.8: 0.05 AOD > 0.8: 0.20	Over water: AOD < 0.3: 0.08 AOD ≥ 0.3: 0.15
Latency	30 minutes after granule data is available	
Refresh	at least 90% coverage of the globe every 12 hours (monthly average)	
Timeliness	≤ 3 hours	
Coverage	Global	
Horizontal Resolution	0.75 km (nadir)	

Requirements
Aerosol Particle Size (APSP)

Satellite Source	NPP VIIRS	
Product Name	Aerosol Particle Size	
Accuracy	Over land: 0.3	Over water: 0.3
Latency	30 minutes after granule data is available	
Refresh	at least 90% coverage of the globe every 12 hours (monthly average)	
Timeliness	≤ 3 hours	
Coverage	Global	
Horizontal Resolution	0.75 km (nadir)	

JPSS/RRPS Aerosol Algorithm

Features of the AOD algorithm:

- Based on the MODIS/VIIRS/ABI heritages
- Uses multiple channels to simultaneously estimate AOD and aerosol type
- Advantages
  - » A lot of ground work has already been done with MODIS, VIIRS, ABI AOD algorithms
  - » MODIS and NPP/VIIRS have been tested in an operational environment
  - » Potential synergy with GOES-R/ABI aerosol product
- Disadvantages
  - » Sensitive to radiometric error (multi-channel retrieval)
  - » No retrievals over bright surface (sun-glint, bare soil, desert)
  - » Dependence on aerosol model assumptions
  - » Over land, uses Lambertian surface model and spectral regression with large variance for surface albedo, which can lead to AOD error

AOD Algorithm Objectives

- Meet the mission requirement specified for the AOD product.
- Maintain heritage with MODIS/VIIRS/ABI.
- Modular in design to support enhancements.
- Simple to implement and robust for operational use.

Features of NPP/IDPS and JPSS/RRPS algorithms

Water		
	NPP/IDPS	**JPSS/RRPS**
Surface pressure	Rayleigh optical functions are corrected to actual surface pressure.	Same as IDPS
Aerosol models	4 small-mode models, 5 large-mode models with 101 different fractional amounts	4 fine modes, 5 coarse modes. (Same as MODIS C5)
Channels used	0.672, 0.746, 0.865, 1.240, 1.610, 2.250 µm	0.672, 0.865, 1.610, 2.250 µm (ABI heritage)
Reference channel	0.865µm	Same as IDPS
RTM	6sV1.1	Same as IDPS
Surface reflectance contribution	Explicit calculation of the direct and diffuse water reflection given ancillary wind speed and direction.	Same as IDPS
Searching for fine mode weigth	Brute force. (discrete 101 fractions with interval of 0.01)	Interval halving (Same as MODIS C5)

Features of NPP/IDPS and JPSS/RRPS algorithms

Land		
	NPP/IDPS	**JPSS/RRPS**
Surface pressure	Elevation and synoptic variation of surface pressure.	Same as IDPS
	Molecular optical depth is calculated at local pressure.	Same as IDPS
Channels used	0.412, 0.445, 0.488, 0.672, 2.250 μm	0.488, 0.672, 2.250 μm (ABI heritage)
Reference channel	0.488 μm	0.488 μm
Aerosol models	Five typical land aerosol models from AERONET.	Four aerosol models: dust, smoke, urban, generic (MODIS C5)

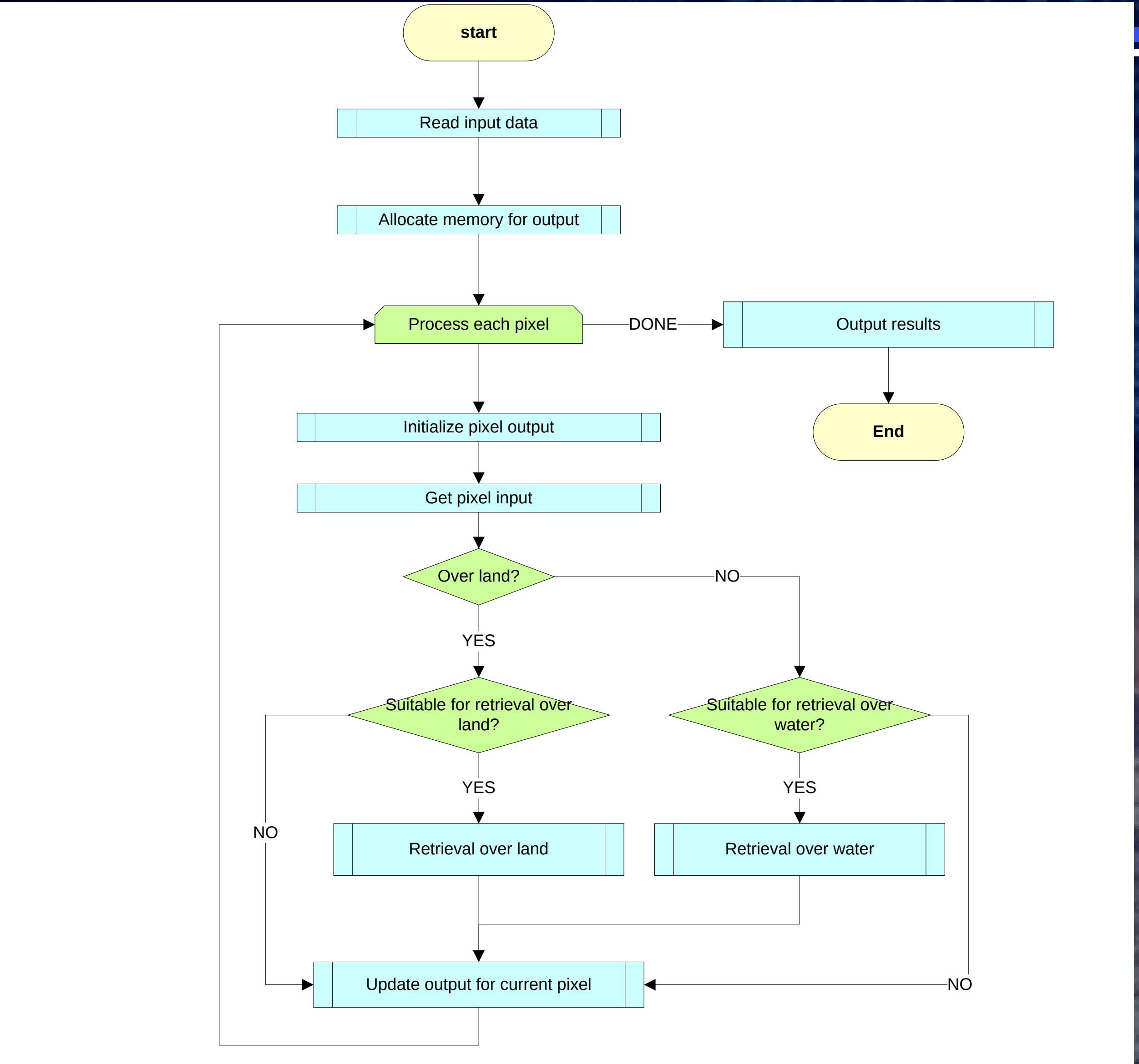
Features of NPP/IDPS and JPSS/RRPS algorithms

Land		
	NPP/IDPS	**JPSS/RRPS**
Surface reflectance	Based on the expected spectral albedo shape of vegetated surfaces derived from atmospheric correction using AERONET data and a limited set of 5 static aerosol models. Derived simultaneously with AOD and aerosol model.	Similar to MODIS, but surface reflectance at SWIR is determined in conjunction with AOD and aerosol model retrieval. Updated linear relationship between VIS and SWIR for dark surface.
Retrieval	Simultaneous retrieval of AOD, surface reflectance, and aerosol model. Based on the expected spectral albedo shape of vegetated surfaces	Similar to MODIS, but simultaneous retrieval of AOD, surface reflectance, and aerosol model.
RTM	6sV1.1	Same as IDPS

Tasks for Adopting ABI Algorithm to VIIRS Reflectances

- **Update LUTs**
  - » Generate aerosol and sunglint lookup tables for VIIRS channels.
- **Update surface reflectance relationship**
  - » Derive land surface reflectance relationships for VIIRS channels based on collocated VIIRS and AERONET data.
- Update gas absorption coeffs
  - » Derive coefficients for parameterization of gas (H_2O, O_3, other) absorption in VIIRS channels

AOD Processing Outline



AOD Algorithm Input
Sensor Input

VIIRS Band	Central Wavelength (µm)	Sub-satellite IGFOV (km)	Use for AOD in NPP/IDPS algorithm	Use for AOD in JPSS/RRPS algorithm
M1	0.412	0.75	Land	
M2	0.445	0.75	Land	
M3	0.488	0.75	Land	Land
M4	0.555	0.75		
M5	0.672	0.75	Land and Ocean	Land and Ocean
M6	0.746	0.75	Ocean	
M7	0.865	0.75	Ocean	Ocean
M8	1.240	0.75	Ocean	
M9	1.378	0.75		
M10	1.610	0.75	Ocean	Ocean
M11	2.250	0.75	Land and Ocean	Land and Ocean
M12	3.700	0.75		
M13	4.050	0.75		
M14	8.550	0.75		
M15	10.763	0.75		
M16	12.013	0.75		

land only   both land and ocean   ocean only   potential channel

Only channels used for AOD retrievals are listed.

AOD Algorithm Input
Sensor Input Details

- For each pixel
  - Calibrated/Navigated VIIRS reflectances
  - Solar-view geometry (satellite and solar zenith and azimuth angles)
  - Surface elevation
  - VIIRS sensor quality flags

Name	Type	Description	Dimension
M3 reflectance	input	Calibrated VIIRS level 1b reflectance in band M3	granule(xsize, ysize)
M5 reflectance	input	Calibrated VIIRS level 1b reflectance in band M5	granule (xsize, ysize)
M7 reflectance	input	Calibrated VIIRS level 1b reflectance in band M7	granule (xsize, ysize)
M10 reflectance	input	Calibrated VIIRS level 1b reflectance in band M10	granule (xsize, ysize)
M11 reflectance	input	Calibrated VIIRS level 1b reflectance in band M11	granule (xsize, ysize)
Latitude	input	Pixel latitude	granule (xsize, ysize)
Longitude	input	Pixel longitude	granule (xsize, ysize)
Solar geometry	input	VIIRS solar zenith and azimuth angles	granule (xsize, ysize)
View geometry	input	VIIRS view zenith and azimuth angles	granule (xsize, ysize)
Elevation	input	Pixel surface elevation	granule (xsize, ysize)
QC flags	input	VIIRS quality control flags with level 1b data	granule (xsize, ysize)

AOD Algorithm Input
Ancillary Input

- Ancillary data needed:
  - » VIIRS Dynamic Data: Cloud mask (including Snow/Ice mask, Fire mask, Heavy aerosol, Land/water mask)
  - » Non-VIIRS Dynamic Data: Ocean surface wind speed & direction, Surface pressure, Surface height, Water vapor amount, Ozone amount
  - » VIIRS-specific Static Data: Aerosol LUT, Sunglint LUT

AOD Algorithm Input Ancillary Input Details (1)

- VIIRS Dynamic Data

Name	Type	Description	Dimension
Cloud mask	input	VIIRS level 2 cloud mask data	granule (xsize, ysize)
Snow/Ice mask*	input	VIIRS level 2 snow/ice	granule(xsize, ysize)
Fire mask	input	VIIRS level fire mask	granule(xsize, ysize)
Heavy aerosol	input	VIIRS level 2 heavy aerosol mask	granule(xsize, ysize)
Land/water	input	VIIRS level 2 land/water mask	granule(xsize, ysize)

Data are from JPSS RR project. For development VCM from IDPS is used.

*May use Interactive Multisensor Snow and Ice Mapping System (IMS) Snow/ice mask if the VIIRS mask is not available

AOD Algorithm Input
Ancillary Input Details (2)

- Non-VIIRS Dynamic Data

Name	Type	Description	Dimension
Ocean surface wind speed & direction	input	NCEP wind speed data	0.5 deg
Surface pressure	input	NCEP surface pressure data	0.5 deg
Surface height	input	NCEP surface height data	0.5 deg
TPW	input	NCEP total precipitable water	0.5 deg
Ozone	input	NCEP ozone data	0.5 deg

AOD Algorithm Input Ancillary Input Details (3)

- VIIRS Static Data

Name	Type	Description	Dimension
Atmosphere LUT	Input	normalized aerosol extinction coefficient as function of aerosol model, aerosol optical depth (land only) and VIIRS channel	(4 x 20 x 11)* (9 x 11)**
		atmospheric reflectance as function of aerosol model, aerosol optical depth, VIIRS channel and scattering angle	(4 x 20 x 3 x 5527)* (9 x 20 x 4 x 5527)**
		atmospheric transmittance as function of aerosol model, aerosol optical depth, VIIRS channel and zenith angle	(4 x 20 x 3 x 21)* (9 x 20 x 4 x 21)**
		atmospheric spherical albedo as function of aerosol model, aerosol optical depth, and VIIRS channel	(4 x 20 x 3)* (9 x 20 x 4)**
Sunglint LUT	Input	water sunglint direct-hemispheric reflectance as function of aerosol model, aerosol optical depth, VIIRS channel, solar zenith angle, viewing zenith angle, relative azimuth angle, and surface wind speed	(9 x 20 x 4 x 21 x 21 x 21 x 4)
		water spherical albedo as function of VIIRS channel and aerosol model	(4 x 9)

*over land **over ocean

AOD Algorithm Output

- Metadata
  - » Processing date stamp & Others
- Scientific Datasets

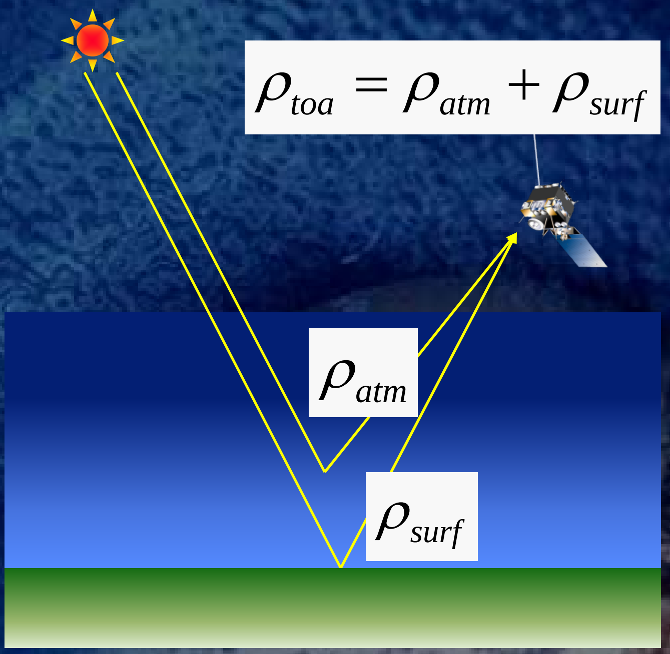
Name	Type	Description	Dimension
AOD at 550nm	output	Retrieved aerosol optical depth at 550 nm	granule (xsize, ysize)
AOD in VIIRS channels	output	Retrieved aerosol optical depth in VIIRS bands M1-M11	granule (xsize, ysize)
Aerosol type ID	output	Aerosol model selected from prescribed models during the retrieval; one for land and two (fine-mode and coarse mode) for ocean	granule (xsize, ysize)
Fine-mode weight (ocean only)	output	Fraction of fine-mode particle AOD to total AOD retrieved at 550nm over ocean	granule (xsize, ysize)
Aerosol Particle size	output	Ångström Exponents (proxy for particle size) calculated from AOD at two pairs of wavelengths (0.48,0.86 µm and 0.86, 2.25 µm)	granule (xsize, ysize)
QC flags	output	Quality control flags for each pixel: Valid/invalid retrieval; cloudy/clear.	granule (xsize, ysize)

AOD Retrieval Strategy

- AOD retrieval
  - uses VIIRS cloud mask for selecting only “clear” and “probably clear” pixels
  - performed for daytime only
- Radiative transfer
  - Look-up table (LUT) approach
    - Atmospheric LUT for land and ocean, respectively
    - LUT for ocean surface sunglint BRDF calculation
  - Atmospheric absorption
    - Uses parameterization of gaseous absorption for VIIRS channels
  - Surface reflectance
    - Land: Lambertian
    - Ocean: Lambertian (water leaving + whitecap) + BRDF (sunglint)
- Separate algorithms for land and ocean
- Determines “best” solution of AOD and aerosol model by matching calculated TOA reflectance with observed values in multiple channels

AOD Retrieval: Physical Basis (1)

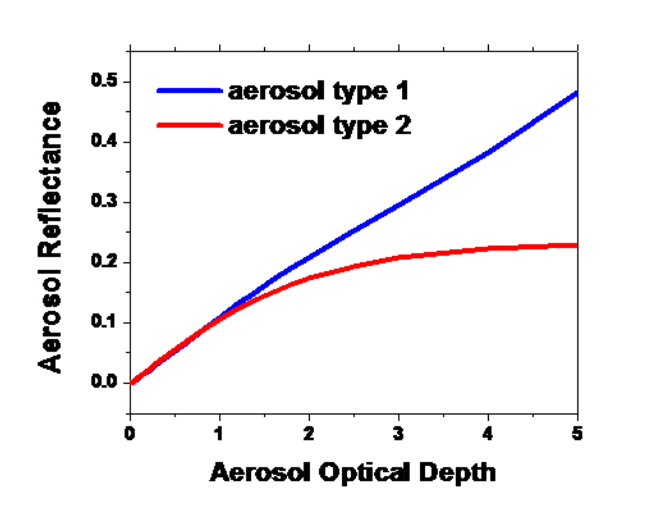
- The satellite-observed reflectance (ρ_{toa}) is the sum of atmospheric (ρ_{atm}) and surface components (ρ_{surf}) .
- These components are the result of reflection, scattering by molecules and aerosols and absorption by aerosols and gases.
- The atmospheric component carries information about aerosol.
- The aerosol portion of the atmospheric component (*aerosol reflectance*) is determined by the amount and type (size, shape and chemical composition) of aerosol.

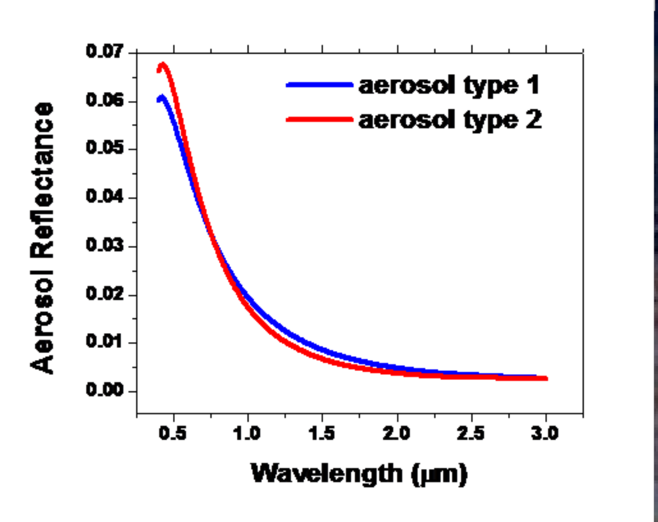


AOD Retrieval: Physical Basis (2)

- Aerosol reflectance (ρ_A) increases with increasing amount of aerosol (as measured by AOD) over dark surface
  → Used for estimating AOD

- The spectral dependence of aerosol reflectance is a function of aerosol type.
  → Used for estimating aerosol type (model)





The above facts are illustrated in the figures: the top figure is for 0.64 μm, AOD=0.4; model 1: urban; model 2: smoke;
solar zenith angle = 40°; view zenith angle = 40°; relative azimuth = 180°

AOD Mathematical Description
Calculation of TOA Reflectance

The satellite-observed reflectance (ρ_{toa}) is approximated as the sum of atmospheric (ρ_{atm}) and surface components (ρ_{surf})

$$\rho_{toa} = \rho_{atm} + \rho_{surf}$$

TOA reflectance

atmospheric contribution

surface contribution

- Calculated reflectances must account for transmission and absorption of radiation in the atmosphere and reflection at the surface.
- Atmospheric reflectances and transmittances are pre-calculated using the 6S RTM (*Vermote et al*., 1997) and stored in LUT for speed.
- Surface reflectance of ocean is calculated; that over land is retrieved. → Separate algorithms for aerosol retrieval over ocean and land.

AOD Mathematical Description Atmospheric Contribution

Calculation of atmospheric reflectance term

$$\rho_{atm} = T^{O_3} T^{og} \left[\left(\rho_{R+A} - \rho_R(P_0) \right) T^{\frac{1}{2}H_2O} + \rho_R(P) \right]$$

gas transmittance

atmosphere LUT

top of atmosphere

O_3, O_2, CO_2, N_2O, CH_4

molecules, aerosol, H_2O

bottom of atmosphere

ρ_{R+A} : reflectance due to molecules (R) and aerosol (A) together – calculated with 6S RTM and stored in LUT

ρ_R : reflectance due to molecules – calculated in the code following 6S; P_0 and P are standard and actual pressures, respectively

T : gas transmittance – described later

AOD Mathematical Description Look-Up Tables

- Lookup tables store pre-calculated atmospheric reflectance, transmittance, spherical albedo and surface BRDF as functions of AOD at 550 nm, aerosol models, geometries and ocean surface wind speeds.

Argument	Dimension	Bins
550-nm AOD	20	0.00, 0.01, 0.05, 0.10, 0.15, 0.20, 0.30, 0.40, 0.60, 0.80, 1.00, 1.20, 1.40, 1.60, 1.80, 2.00, 2.50, 3.00, 4.00, 5.00
VIIRS Channel	5	0.488, 0.672, 0.865, 1.610, 2.250 µm
Aerosol Model	13	4 for land 4 fine + 5 coarse modes for ocean
Solar Zenith Angle	21	0°, 4°, 8°, 12°, 16°, 20°, 24°, 28°, 32°, 36°, 40°, 44°, 48°, 52°, 56°, 60°, 64°, 68°, 72°, 76°, 80°
Satellite Zenith Angle	20	00.00, 02.84, 06.52, 10.22, 13.93, 17.64, 21.35, 25.06, 28.77, 32.48, 36.19, 39.90, 43.61, 47.32, 51.03, 54.74, 58.46, 62.17, 65.88, 69.59
Relative Azimuth Angle	21	0°, 9°, 18°, 27°, 36°, 45°, 54°, 63°, 72°, 81°, 90°, 99°, 108°, 117°, 126°, 135°, 144°, 153°, 162°, 171°, 180°
Scattering Angle	5527	0 to 5526 in step of 1
Wind Speed	4	1.00, 4.00, 6.00, 12.00

Aerosol Model - Land

Four aerosol models: dust, smoke, urban, generic (MODIS C5, *Levy et al*., 2007)

Physical parameters of aerosol models over land

Aerosol Model	Mode	Volume median radius r_V	Standard Deviation σ	Volume C_V ($\mu m^3/\mu m^2$)	Complex Refractive Index
Generic	Fine	$0.145+0.0203*\tau_{550}$	$0.3738+0.1365*\tau_{550}$	$0.1642*\tau_{550}^{0.7747}$	$(1.43+0.05*\tau_{550})$ - $(0.008+0.002*\tau_{550})i$
	Coarse	$3.1007+0.3364*\tau_{550}$	$0.7292+0.098*\tau_{550}$	$0.1482*\tau_{550}^{0.6846}$	
Urban	Fine	$0.1604+0.434*\tau_{550}$	$0.3642+0.1529*\tau_{550}$	$0.1718*\tau_{550}^{0.8213}$	1.42 – $(0.0072-0.0015*\tau_{550})i$
	Coarse	$3.3252+0.1411*\tau_{550}$	$0.7595+0.1638*\tau_{550}$	$0.0934*\tau_{550}^{0.6394}$	
Smoke	Fine	$0.1335+0.0096*\tau_{550}$	$0.3834+0.0794*\tau_{550}$	$0.1748*\tau_{550}^{0.8914}$	1.51-0.02i
	Coarse	$3.4479+0.9489*\tau_{550}$	$0.7433+0.0409*\tau_{550}$	$0.1043*\tau_{550}^{0.6824}$	
Dust	Fine	0.14	0.49	$0.01+0.08*\tau_{550}$	1.47-0.03i (<=0.47μm) 1.5-0.01i (>= 0.55μm)
	Coarse	2.30	0.60	$0.02+0.77*\tau_{550}$	

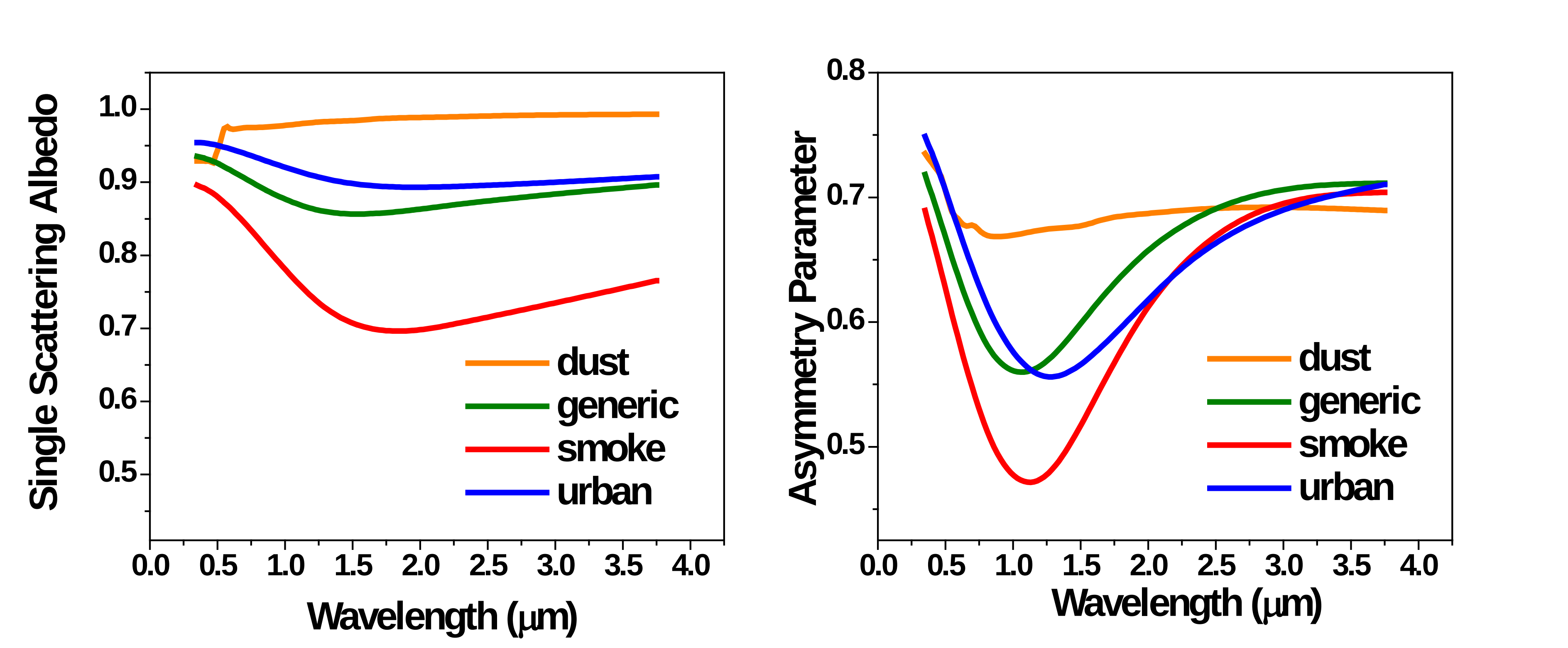
aerosol volume size distribution:

$$\frac{dV(r)}{d\ln r} = \sum_{i=1}^{2} \frac{C_{V,i}}{\sqrt{2\pi}\sigma_i} \exp\left[-\frac{(\ln r - \ln r_{V,i})^2}{2\sigma_i^2}\right]$$

V: volume [μm^3]; r_V: volume median radius [μm]; C_V: volume concentration [$\mu m^3/\mu m^2$]; σ_g: standard deviation of volume distribution

AOD Mathematical Description Aerosol Models (Land)

Four aerosol models: dust, smoke, urban, generic (MODIS C5, *Levy et al*., 2007)



Single scattering albedo and asymmetry parameter as a function of wavelength for the four land aerosol models

Aerosol Models - Ocean

Physical parameters of aerosol models over ocean (MODIS C5)

Aerosol model	Refractive index wavelength(μm)						r_g	σ_g	r_{eff}
	0.47	0.64	0.86	1.38	1.61	2.26			
Fine Mode									
F1	1.45-0.0035i	1.45-0.0035i	1.45-0.0035i	1.44-0.005i	1.43-0.01i	1.40-0.005i	0.07	1.49182	0.10
F2	1.45-0.0035i	1.45-0.0035i	1.45-0.0035i	1.45-0.005i	1.43-0.01i	1.40-0.0050i	0.06	1.82212	0.15
F3	1.40-0.002i	1.40-0.002i	1.40-0.002i	1.40-0.0035i	1.39-0.005i	1.36-0.003i	0.08	1.82212	0.20
F4	1.40-0.002i	1.40-0.002i	1.40-0.002i	1.40-0.0035i	1.39-0.005i	1.36-0.003i	0.10	1.82212	0.25
Coarse Mode									
C1	1.35-0.001i	1.35-0.001i	1.35-0.001i	1.35-0.001i	1.35-0.001i	1.35-0.001i	0.40	1.82212	0.98
C2	1.35-0.001i	1.35-0.001i	1.35-0.001i	1.35-0.001i	1.35-0.001i	1.35-0.001i	0.60	1.82212	1.48
C3	1.35-0.001i	1.35-0.001i	1.35-0.001i	1.35-0.001i	1.35-0.001i	1.35-0.001i	0.80	1.82212	1.98
C4	1.53-0.003i	1.53-0.0i	1.53-0.0i	1.46-0.0i	1.46-0.0i	1.46-0.0i	0.60	1.82212	1.48
C5	1.53-0.003i	1.53-0.0i	1.53-0.0i	1.46-0.0i	1.46-0.0i	1.46-0.0i	0.50	2.2255	2.50

aerosol number size distribution:

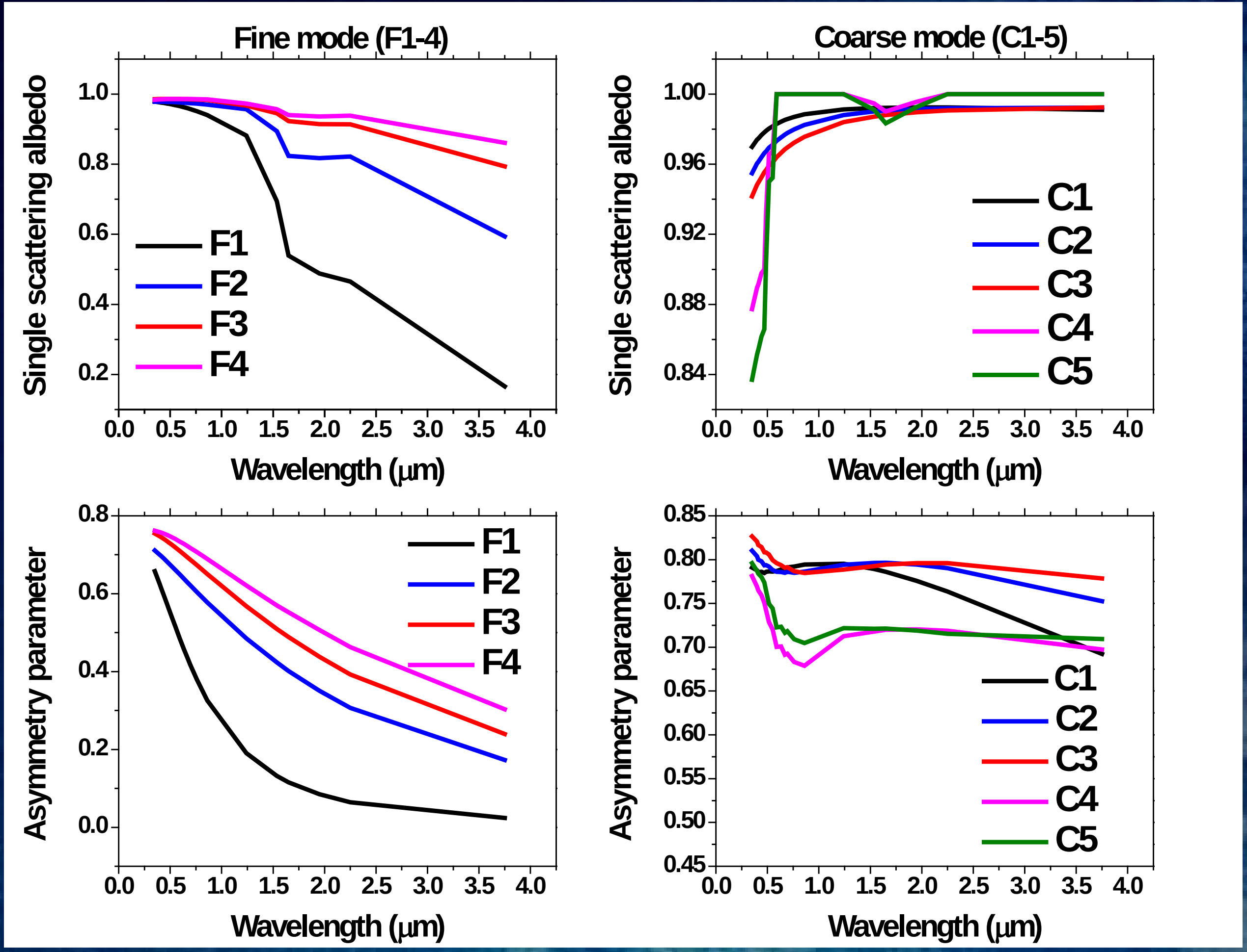
$$\frac{dN(r)}{d\ln r} = \sum_{i=1}^{2} \frac{N_0}{\sqrt{2\pi}\ln\sigma_{g,i}} \exp\left[-\frac{(\ln r - \ln r_{g,i})^2}{2\ln\sigma_{g,i}^2} \right]$$

r: radius [μ m]; N_0: concentration; r_g: geometric mean radius [μm]; σ_g: standard deviation of radius; r_{eff}: effective radius [μm]

F1-2: water soluble; F3-4: water soluble with humidity; C1-3: wet sea salt; C4-5: dust-like

AOD Mathematical Description
Aerosol Models (Ocean)

Four fine mode and five coarse mode aerosol models (MODIS C5)



Single scattering albedo and asymmetry parameter as a function of wavelength for the fine (left) and coarse mode (right) models over ocean.

Range of absorption and anisotropic scattering is much larger for fine mode.

AOD Mathematical Description Surface Contribution

Calculation of surface reflectance term

gas transmittance

atmosphere LUT

$$\rho_{surf} = T^{O_3} T^{og} T^{H_2O} \left[T^{\downarrow}_{R+A} T^{\uparrow}_{R+A} \frac{\rho_{lambertian}}{1 - S_{R+A}\rho_{lambertian}} + \rho_{brdf} \right]$$

land and ocean reflectances

Total (direct+diffuse) downward and upward transmittance T_{R+A} and spherical albedo S_{R+A} of molecular and aerosol atmosphere are calculated with 6S RTM and stored in LUT

Calculation of Lambertian ($\rho_{lambertian}$) and bi-directional (ρ_{brdf}) surface reflectances are shown later

Calculation of transmittances of ozone, water vapor and other gases T^{O3}, T^{H2O}, T^{og} are shown next

AOD Mathematical Description Gas Transmittance Parameterization (Water Vapor)

gas transmittance

- analytical functions guided by VIIRS ATBD
- non-linear least square fit
- calculated VIIRS channel transmittances from 6S RTM with spectral resolution of 0.0025 µm for mid-latitude summer temperature and pressure profile

water vapor

$$T_\lambda^{H_2O} = \exp[u_{H_2O} C_{1,\lambda}^{H_2O} + \ln(u_{H_2O}) C_{2,\lambda}^{H_2O} + u_{H_2O} \ln(u_{H_2O}) C_{3,\lambda}^{H_2O}]$$

transmittance

absorber amount

band dependent coefficients

= air mass × content

$$M = \frac{1}{\cos(\theta_s)} + \frac{1}{\cos(\theta_v)}$$

(where θ_s and θ_v are solar and view zenith angles)

AOD Mathematical Description Gas Transmittance Parameterization (Ozone and other gases)

gas transmittance

ozone

$$T_\lambda^{O_3} = \exp(-u_{O_3} C_\lambda^{O_3})$$

transmittance

absorber amount

band dependent coefficients

other constant gases (O_2, CO_2, N_2O, CH_4)

$$T_\lambda^{Og} = \exp\{M[C_{1,\lambda}^{Og} P + C_{2,\lambda}^{Og} \ln(P)] + \ln(M)[C_{3,\lambda}^{Og} P + C_{4,\lambda}^{Og} \ln(P)] + M\ln(M)[C_{5,\lambda}^{Og} P + C_{6,\lambda}^{Og} \ln(P)]\}$$

air mass

local surface pressure / standard surface pressure

AOD Mathematical Description Gas Transmittance Parameterization (2)

Fitted gas absorption coefficients:

VIIRS Channel (wavelength in μm)	$C_{1,\lambda}^{H_2O}$	$C_{2,\lambda}^{H_2O}$	$C_{3,\lambda}^{H_2O}$	$C_{\lambda}^{O_3}$	$C_{1,\lambda}^{Og}$	$C_{2,\lambda}^{Og}$	$C_{3,\lambda}^{Og}$	$C_{4,\lambda}^{Og}$	$C_{5,\lambda}^{Og}$	$C_{6,\lambda}^{Og}$
M3 (0.488)	6.78E-6	-3.73E-4	-1.23E-6	0.0180	-1.18E-4	3.66E-4	1.21E-4	-3.75E-4	3.13E-5	-9.67E-5
M5 (0.672)	-5.17E-4	-3.06E-5	7.73E-5	0.0433	-1.99E-3	8.46E-3	1.78E-3	-9.55E-3	5.19E-4	-2.32E-3
M7 (0.865)	-2.51E-3	7.13E-4	3.81E-4	1.53E-8	-2.76E-5	1.12E-3	8.44E-6	2.02E-4	2.69E-6	-9.67E-6
M10 (1.610)	-1.15E-3	8.63E-4	1.38E-4	0.0	-0.0209	3.94E-3	3.02E-3	0.0404	4.25E-3	4.55E-3
M11 (2.250)	-1.62E-3	1.01E-3	2.65E-4	0.0	-0.0471	0.0398	-0.0127	-0.0423	7.72E-3	-0.0137

AOD Mathematical Description

Ocean Surface Reflectance

$$T_{R+A}^{\downarrow} T_{R+A}^{\uparrow} \frac{\rho_{lambertian}}{1 - S_{R+A}\rho_{lambertian}} + \rho_{brdf}$$

Water reflection includes three components:

- Water-leaving radiance (Lambertian)
- Whitecap (Lambertian)
- Sunglint (bi-directional)

AOD Mathematical Description Ocean Surface Reflectance (2)

$\rho_{lambertian}$

water leaving (ρ_w) + whitecap (ρ_{wc})

$$\rho_{lambertian} = \rho_w + \rho_{wc}$$

$$\rho_{wc} = \rho_{wc-eff} \cdot 2.95 \times 10^{-6} [wsp]^{3.52}$$

ρ_{wc-eff}: Whitecap effective reflectance

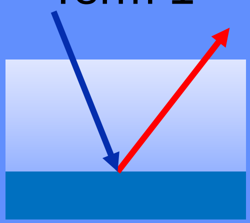
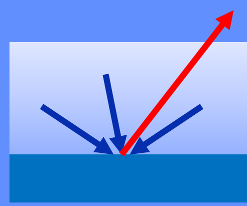
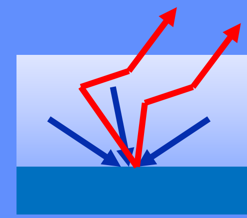
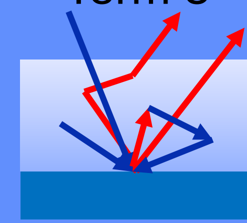
wsp: Wind speed (m/s)

VIIRS Channel (wavelength in µm)	ρ_{wc-eff}	ρ_w
M5 (0.672)	0.22	0.001
M7 (0.865)	0.22	0.0
M10 (1.610)	0.22	0.0
M11 (2.250)	0.22	0.0

ρ_w corresponds to constant chlorophyll concentration (0.4 mg m^{-3})

AOD Mathematical Description Ocean Surface Reflectance (3)

ρ_{brdf} Ocean BRDF follows 6S – modeled as the sum of five components

Term 1		Term 2		Term 3		Term 4		Term 5
	+		+		+		+	
direct in direct out		diffuse in direct out		direct in diffuse out		diffuse in diffuse out		≥2 interactions
$t_{R+A}^{dir\downarrow}\,\rho_{sgt}\,t_{R+A}^{dir\uparrow}$		$t_{R+A}^{dif\downarrow}\,\overline{\rho_{sgt}}\,t_{R+A}^{dir\uparrow}$		$t_{R+A}^{dir\downarrow}\,\overline{\rho_{sgt}^{'}}\,t_{R+A}^{dif\uparrow}$		$t_{R+A}^{dif\downarrow}\,\overline{\overline{\rho_{sgt}}}\,t_{R+A}^{dif\uparrow}$		$T_{R+A}^{\downarrow}T_{R+A}^{\uparrow}\dfrac{S_{R+A}\left(\overline{\overline{\rho_{sgt}}}\right)^2}{1-S_{R+A}\overline{\overline{\rho_{sgt}}}}$

$t_{R+A}^{dir\downarrow}, t_{R+A}^{dir\uparrow}$: transmittance of downward and upward direct radiation for aerosol and molecule

$t_{R+A}^{dif\downarrow}, t_{R+A}^{dir\uparrow}$: transmittance of downward and upward diffuse radiation for aerosol and molecule

$\rho_{sgt}, \overline{\rho_{sgt}}, \overline{\rho_{sgt}^{'}}, \overline{\overline{\rho_{sgt}}}$: sunglint reflectance and its various angular integrals

S_{R+A} : spherical albedo of aerosol and molecular atmosphere

AOD Mathematical Description Ocean Surface Reflectance (4)

ρ_{brdf}

Sunglint

Term 1 Term 2

$$\rho_{brdf} = t_{R+A}^{dir\downarrow}\rho_{sgt}t_{R+A}^{dir\uparrow} + t_{R+A}^{dif\downarrow}\overline{\rho_{sgt}}t_{R+A}^{dir\uparrow} + t_{R+A}^{dir\downarrow}\overline{\rho_{sgt}^{'}}t_{R+A}^{dif\uparrow} + t_{R+A}^{dif\downarrow}\overline{\overline{\rho_{sgt}}}t_{R+A}^{dif\uparrow} + T_{R+A}^{\downarrow}T_{R+A}^{\uparrow}\frac{S_{R+A}\left(\overline{\overline{\rho_{sgt}}}\right)^{2}}{1-S_{R+A}\overline{\overline{\rho_{sgt}}}}$$

calculated

Term 3 Term 4 Term 5

Sunglint LUT

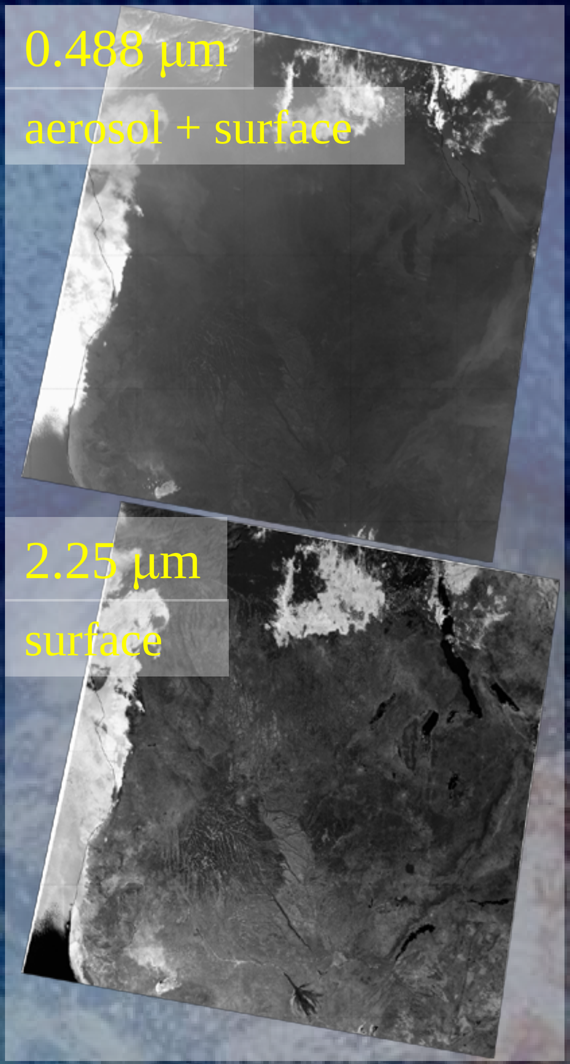
- Formulation follows 6S RTM
- Cox and Munk (1954) ocean model
- Constant salinity (34.3 ppt)
- Fixed westerly wind direction

All t , T , and S_{R+A} from atmosphere LUT

AOD Mathematical Description Land Surface Reflectance (1)

Physical basis (*King et al*., 1999, *Kaufman et al*. 1997):

- AOD at 2.25 µm is generally small; allows seeing the surface.
- Over dark targets and dense dark vegetation surface reflectance across the solar spectrum is well correlated.
- Parallel processes affect the surface reflectance at 0.488 and 0.672 µm and at 2.25 µm.
- Vegetation has low reflectivity in the visible (0.488 and 0.672 µm) region due to chlorophyll absorption and in the 2.25 µm region due to absorption by liquid water.



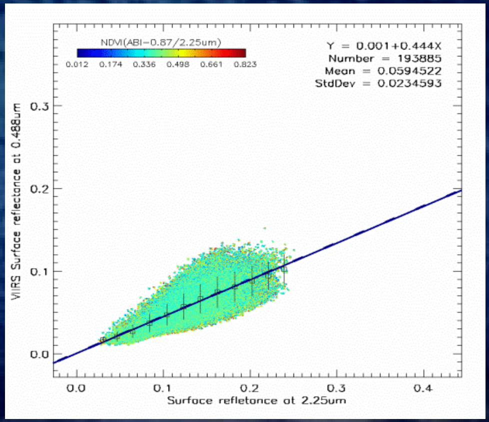
AOD Mathematical Description Land Surface Reflectance (2)

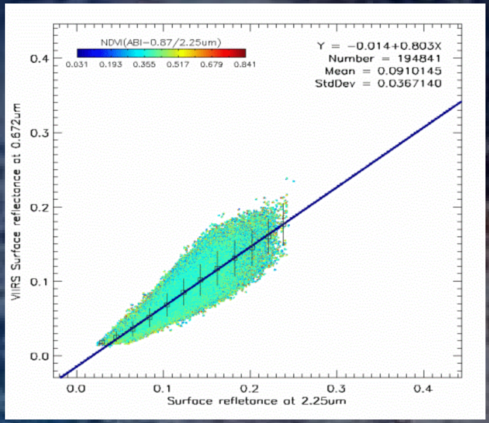
$\rho_{lambertian}$ Surface reflectances in the visible VIIRS channels

- Lambertian reflection is assumed.
- Surface reflectance at 2.25 µm ($\rho_{2.25}$) is derived from atmospheric correction of VIIRS measurement.
- Surface reflectances at 0.488 ($\rho_{0.488}$) and 0.672 µm ($\rho_{0.672}$) are estimated from that at 2.25 µm ($\rho_{2.25}$).
- The relationships were derived from linear fit of surface reflectances after atmospheric correction of collocated VIIRS and AERONET data:

$$\rho_{0.47\,\mu m} = 0.001 + 0.444\rho_{2.25\,\mu m}$$

$$\rho_{0.64\,\mu m} = -0.014 + 0.803\rho_{2.25\,\mu m}$$





AOD Mathematical Description Land Surface Reflectance (3)

Surface reflectance in the VIIRS 2.25µm channel ($\rho_{2.25\mu m}$) is derived for a given tabulated aerosol optical depth at 0.55 µm (τ)

$$\Delta\rho = \frac{\rho^{obs}_{2.25\mu m}}{T^{og}_{2.25\mu m} T^{O_3}_{2.25\mu m}} - \left\{ T^{H_2O/2}_{2.25\mu m} \left[\rho^{LUT}_{2.25\mu m}(\tau) - \rho^{Ray}_{P_0} \right] + \rho^{Ray}_{P} \right\}$$

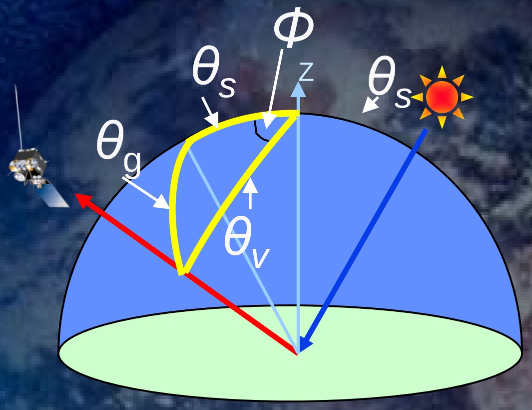
$$\rho_{2.25\mu m} = \frac{\Delta\rho}{\Delta\rho * \tilde{\rho}^{LUT}_{2.25\mu m}(\tau) + T^{H_2O}_{2.25\mu m} * T^{LUT,\downarrow}_{2.25\mu m}(\tau) * T^{LUT,\uparrow}_{2.25\mu m}(\tau)}$$

- Lambertian reflection is assumed.
- $\rho^{obs}_{2.25\mu m}$ is the TOA reflectance measured at 2.25µm; $\rho^{Ray}_{P_0}$ and ρ^{Ray}_{P} are the Rayleigh reflectance at standard and local pressure; $\rho^{LUT}_{2.25\mu m}(\tau)$, $\tilde{\rho}^{LUT}_{2.25\mu m}(\tau)$, $T^{LUT,\downarrow}_{2.25\mu m}(\tau)$ and $T^{LUT,\uparrow}_{2.25\mu m}(\tau)$ are the LUT TOA atmosphere reflectance, spherical albedo, downward and upward transmittance, respectively.

AOD Mathematical Description
Selection of Dark Pixel

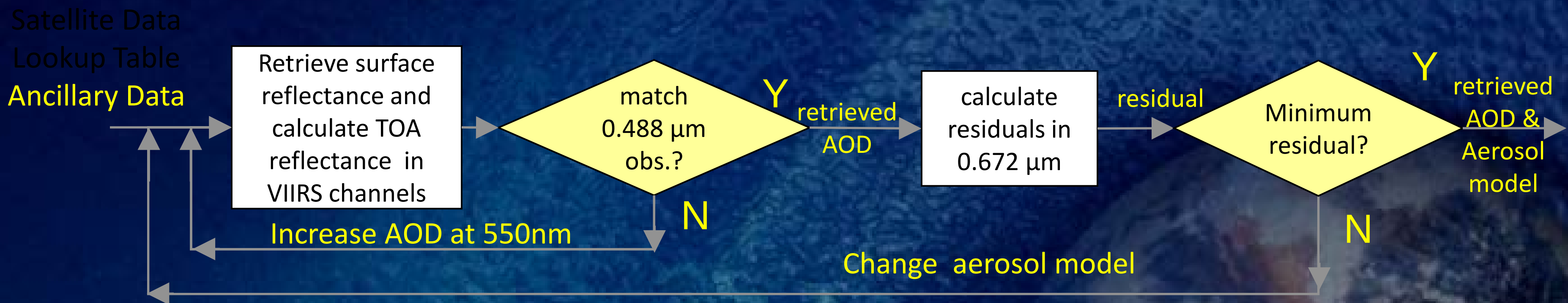
- Land – select pixels with low SWIR (M11: 2.25 µm) reflectance:
  - » $0.01 \leq \rho_{2.25\ \mu m} \leq 0.25$
- Ocean – avoid areas effected by glint:
  - » glint angle $\theta_g > 40^o$
    - – θ_g is the angle between the viewing direction θ_v and the direction of specular reflection θ_s:

      $\theta_g = \cos^{-1}(\cos\theta_s \cos\theta_v + \sin\theta_s \sin\theta_v \cos\Phi)$



AOD Mathematical Description
AOD Retrieval over Land

- Retrieve AOD for each of the four aerosol models by matching the observed TOA reflectance in reference channel 0.488 μm and calculate the corresponding residuals at 0.672 μm



where residual is calculated as: $$residual = (\rho^{cal}_{0.672\,\mu m} - \rho^{obs}_{0.672\,\mu m})^2$$

- Select the aerosol model and AOD with the minimum residual as the “best” solution

AOD Mathematical Description
AOD Retrieval over Ocean

- Assume TOA reflectance can be approximated by a linear combination of contributions from two aerosol modes corresponding to the fine and coarse parts of size distribution with a fine-mode weight

$$\rho_\lambda^t(\tau_{550}) = \eta\rho_\lambda^f(\tau_{550}) + (1-\eta)\rho_\lambda^c(\tau_{550})$$

where ρ_λ^t is total aerosol reflectance;

ρ_λ^f is the reflectance from fine mode aerosol;

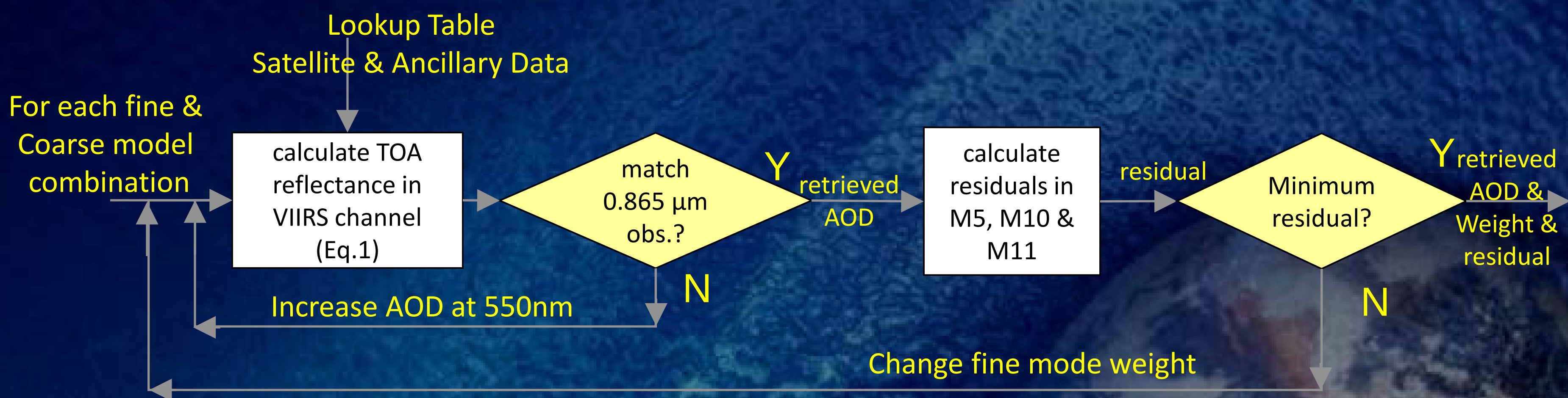
ρ_λ^c is the reflectance from coarse mode aerosol;

η is the fine mode weight

τ_{550} is the aerosol optical depth at 0.55 μm

AOD Mathematical Description
AOD Retrieval over Ocean (2)

- Retrieve AOD and fine mode weight for each combination of candidate fine and coarse aerosol models.



where residual is calculated as: $$residual = \sum_{i=1}^{3}(\rho_{\lambda}^{t} - \rho_{\lambda}^{obs})^2$$

- Select the AOD and combination of fine and coarse modes with minimum residual as the "best" solution.

Size Parameter

- The Ångström exponent is used as proxy for particle size:
  - Large/small values of Ångström exponent indicate small/large particles, respectively.
- The Ångström exponent (α) describes the wavelength (λ) dependence of aerosol optical depth (τ): $\tau \propto \lambda^{-\alpha}$
- The Ångström exponent is calculated from AODs and two pairs of wavelengths (MODIS heritage):

$$\alpha_{0.488\,\mu m,\,0.865\,\mu m} = -\frac{\ln \tau_{0.488\,\mu m} - \ln \tau_{0.865\,\mu m}}{\ln 0.488 - \ln 0.865}$$

$$\alpha_{0.865\,\mu m,\,2.250\,\mu m} = -\frac{\ln \tau_{0.865\,\mu m} - \ln \tau_{2.250\,\mu m}}{\ln 0.865 - \ln 2.250}$$

Summary of AOD Retrieval

- The algorithm uses the MODIS , VIIRS and ABI methods.
- Retrieval is from clear-sky (confidently clear and probably clear) VIIRS reflectances during daytime.
- In the retrieval, pre-calculated TOA reflectances are compared with multi-channel observations.
    - » The retrieved AOD and aerosol model are the ones that provide the best agreement of TOA reflectances with the observed ones.
- Separate algorithms for land and ocean.
    - » Land reflectance is estimated using the MODIS C5 approach; this different from NPP/IDPS.
    - » Ocean reflectance is calculated from wind-speed and direction dependent models.

Practical Considerations

- **Numerical computational considerations**
  - » LUT is used for increased speed.
  - » The LUT uses scattering angle; speed of search and accuracy is increased.
  - » Linear interpolation of LUT values.
  - » Interval halving method is used in LUT for searching for the "best" combination of fine and coarse mode ocean aerosol models; increases efficiency.
- **Programming and procedure considerations**
  - » Pixel by pixel retrieval
  - » Calibrated and geo-located reflectances, cloud mask must be available before aerosol retrieval
  - » Program modules are used to ease upgrades

Practical Considerations (2)

- **Configuration of the retrieval**
  - » The following data are configurable:
    - – Algorithm coefficients (LUT and land surface reflectance relationship)
    - – Criterion values (e.g., selecting atmospheric/surface conditions)
    - – Water vapor and ozone dataset (possible resource change)
    - – Metadata setting
- **Quality assessment and diagnostics**
  - » Quality flags will be produced for
    - – Missing/No data
    - – Coast, Snow/Ice, Cloud proximity
    - – Cloud (retrieval from "possibly clear" reflectance category)
    - – Pixel with large view angle (> 60 degrees)
    - – Less than maximum number of channels used for retrieval
    - – Residuals are greater than threshold

Practical Considerations (3)

- **Exception handling**
  - Quality control flags will be checked and inherited from the sensor input data for handling these exceptions
    - **Bad sensor input data (depending on what input QC available)**
    - **Missing sensor input data**
    - **Algorithm can not be run if all of the aerosol channel data are bad or missing**
  - Quality control flags will be checked and inherited from VIIRS cloud mask for handling the following exceptions
    - **Clear, possibly clear, cloudy, possibly cloudy pixel**
  - Quality control flags will be generated for handling these exceptions
    - snow/ice pixel
    - bright surface
    - nearby cloud
    - costal pixel

AOD Algorithm Verification

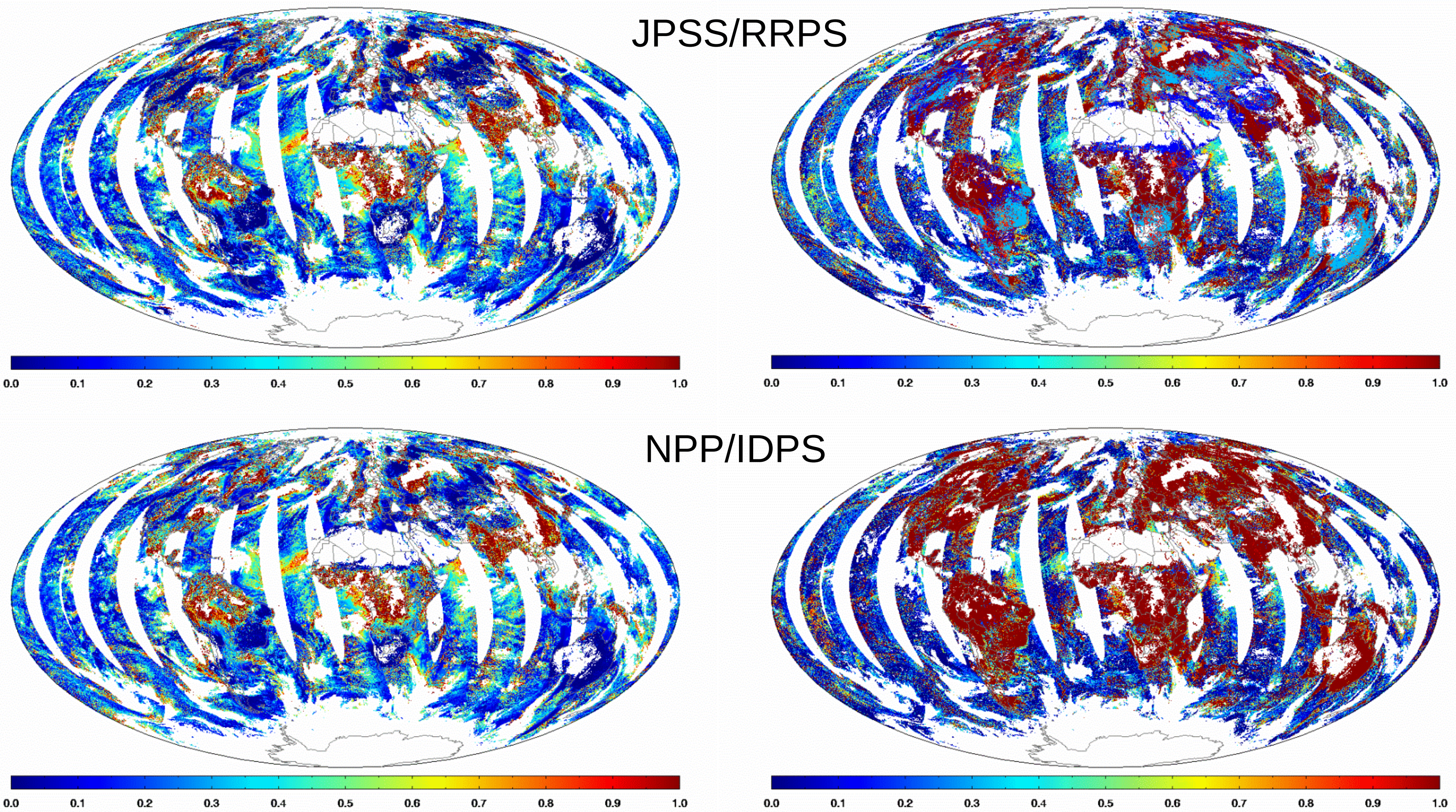
- Comparison with independent satellite-derived products
  - » EOS/MODIS
  - » NPP/VIIRS
- Comparison with ground-based aerosol measurements
  - » AERONET

Retrieval Example

NPP/VIIRS input for 09/01/2012 is used

Aerosol Optical Depth at 550nm

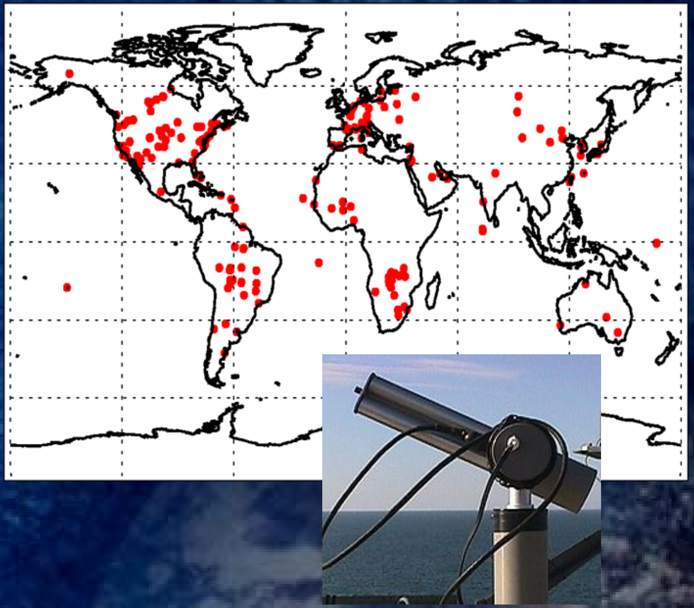
Aerosol Angstrom Exponent



AOD Algorithm Verification Comparison with AERONET

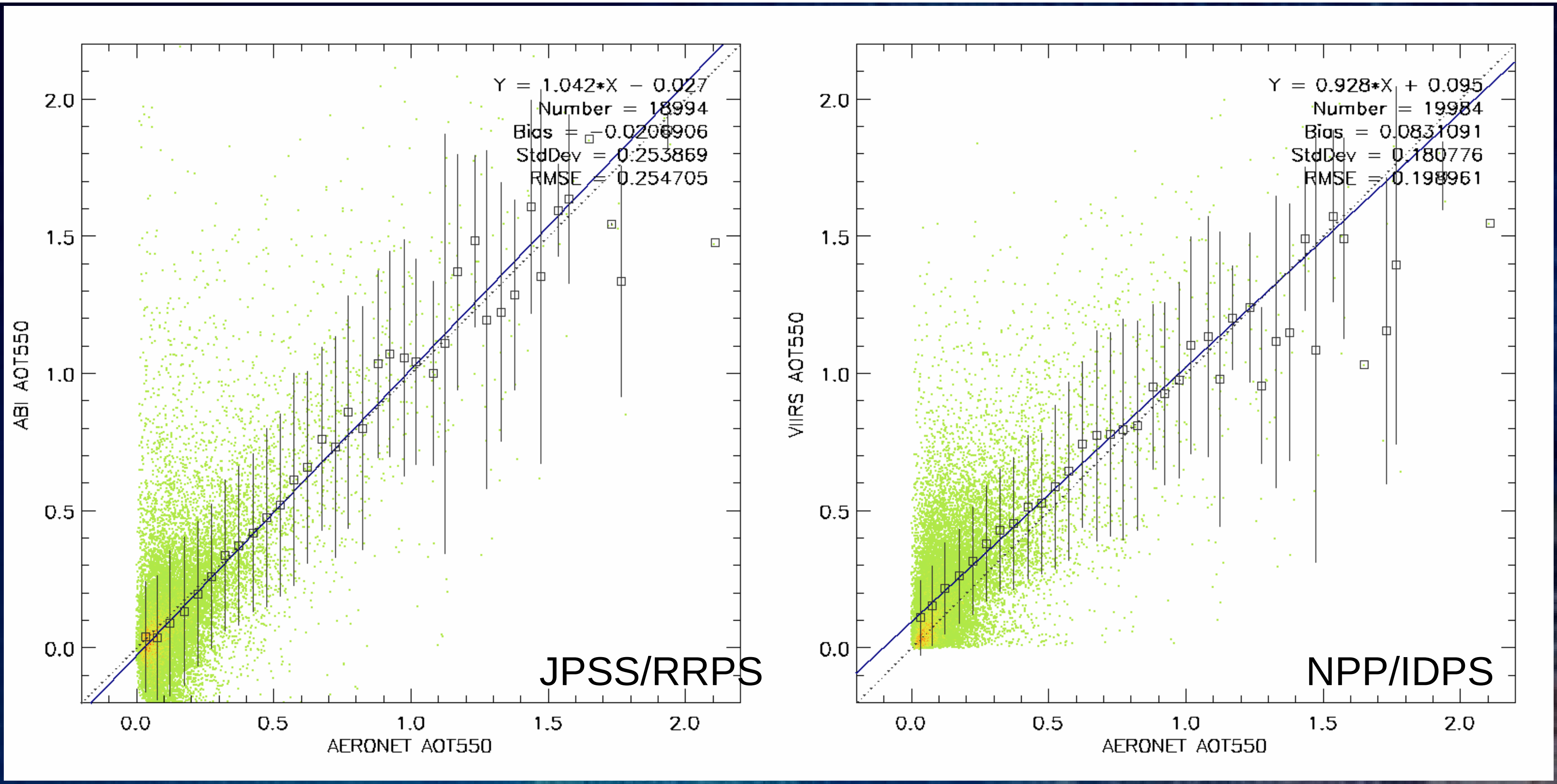
- AERONET: ground-based measurements over 100 stations worldwide for more than 10 years; quality assured aerosol optical properties (*Holben et al*., 1998).
- Collocated AERONET and JPSS/RRPS* dataset
  - Spatial average: JPSS/RRPS high quality retrievals within a circle of 10-km radius centered on AERONET stations.
  - Temporal average: AERONET measurements within one-hour window centered on the NPP overpass time, at least three measurements are available.
  - Time period for examples on next slides: 05/02/2012 – 01/31/2013

AERONET Stations



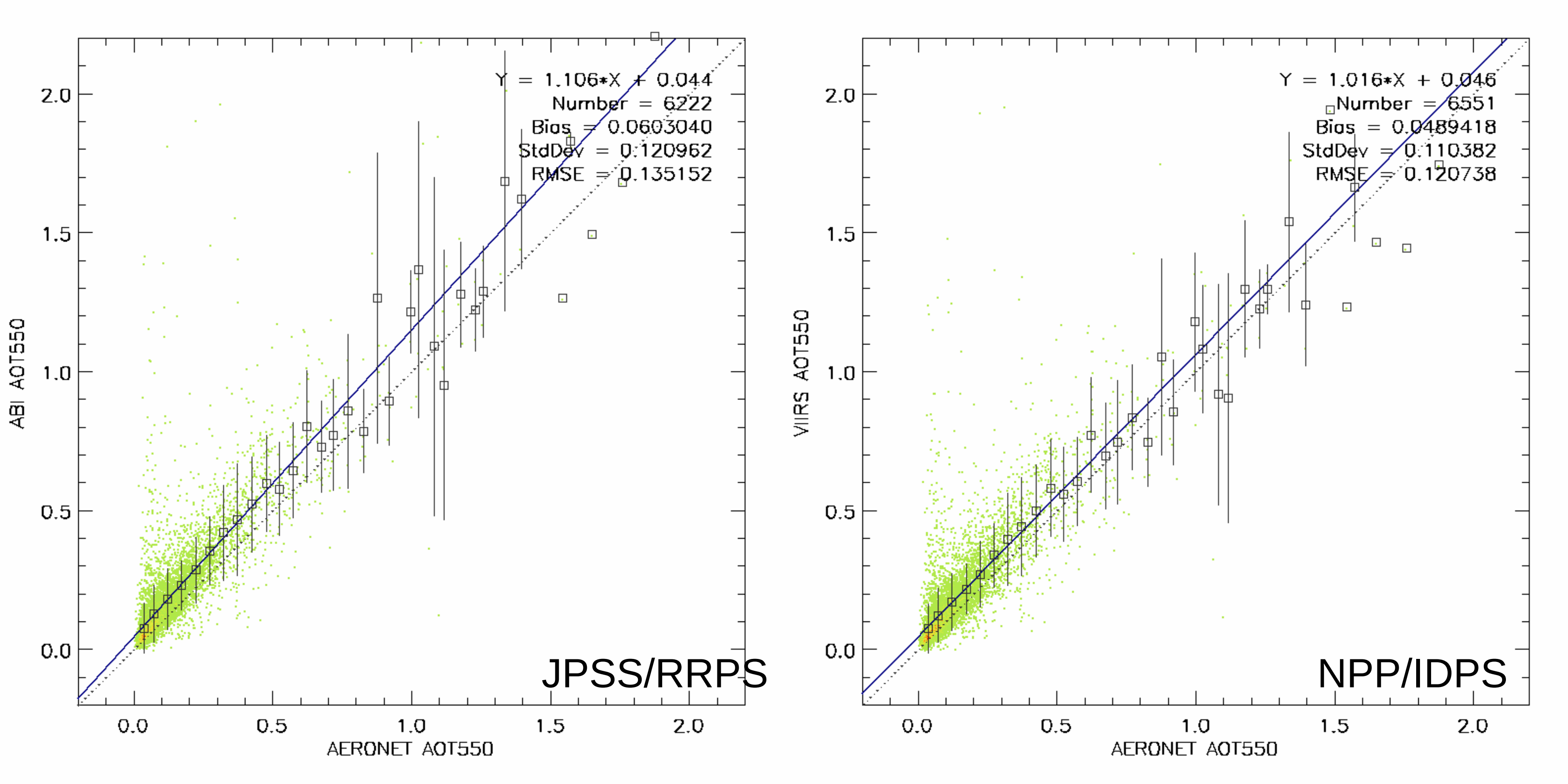
*JPSS/RRPS is the aerosol product derived from VIIRS data using the JPSS RRPS ABI-like algorithm

Validation - Aerosol Optical Depth at 550 nm over Land



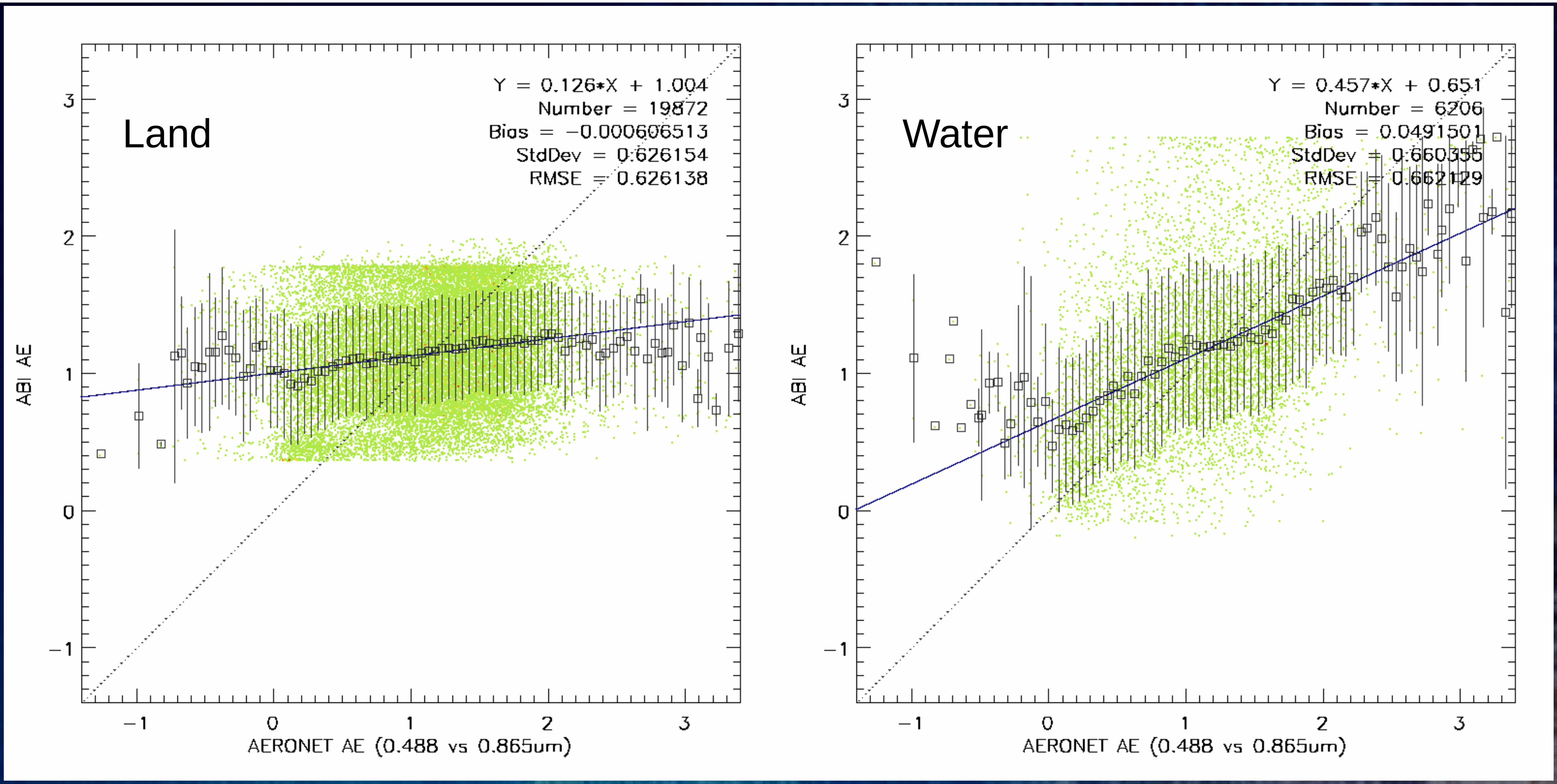
JPSS/RRPS accuracy is higher than that from NPP/IDPS, but precision is lower.

Validation - Aerosol Optical Depth at 550 nm over Water



JPSS/RRPS accuracy and precision are slightly lower than that from NPP/IDPS

Validation
Aerosol Ångström Exponent (AE)



JPSS/RRPS AE has no skill over land and limited skill over water. NPP/IDPS results are similar (not shown).

Future Development Plan

- **Further Algorithm Validation**
  - » Satellite data/retrievals: MODIS, CALIPSO, MISR, VIIRS , MODIS-like VIIRS
  - » Ground: AERONET, field campaigns
- **Algorithm Improvement**
  - » Derive NDVI-dependent surface reflectance relationship
  - » Utilize "new" channels (0.412, 0.445, 0.746, 1.240 µm) not available on ABI
  - » Revise internal tests using information in "new" channels
  - » Help identification of aerosol type by utilizing VIIRS channels 0.412 and 0.445µm (deep-blue channels)
  - » Extend aerosol retrievals for bright surface by utilizing VIIRS deep-blue channels.

AOD Summary of Algorithm Development

- Preliminary LUTs for VIIRS spectral bands were calculated.
- Calculated gas absorption coefficients for VIIRS channels
- Preliminary relationships between land surface reflectances in VIIRS SWIR and visible channels were established.
- Implemented algorithm and run with NPP/VIIRS reflectance for one day globally.

AOD Performance Estimates

- **Algorithm performance based on limited data (**05/02/2012 – 01/31/2013**) over AERONET sites**

Mean accuracy and precision values

	AOD		APSP	
	Land	Water	Land	Water
Accuracy	-0.02	0.06	meaningless	0.05
Precision	0.25	0.12	0.63	0.66

» **Note:**

– **Evaluation over ocean is limited due to sparseness of AEONET stations**

Assumptions and Limitations

- **Assumptions:**
  - » aerosols are spherical, and vertically well-mixed;
  - » surface is dark and Lambertian over land;
  - » reflectance of ocean can be calculated and that of land can be estimated with sufficient accuracy;
  - » calibrated VIIRS radiances are available;
  - » VIIRS cloud mask is available;
  - » ancillary data are available.
- **Limitations:**
  - » only daytime;
  - » needs accurate clear-sky reflectance;
  - » only over dark surface;
  - » does not account for bidirectional reflectance over land

Error Sources

- Primary sources of error in AOD are uncertainties in:
  - input VIIRS reflectances, due to
    - errors in calibration and stability
  - input cloud mask, causing
    - cloud contamination
  - surface reflectance, due to
    - contamination by snow/ice and inland water over land
    - contamination by sunglint, whitecap over ocean
  - aerosol models in LUT
  - ancillary data

CDR AOD Risks

- **Risk 3: Gaps in coverage**
- **Risk Assessment: Medium**
- **Impact: AOD retrieval is not available over highly reflective surfaces such as deserts, dry arid land, ground covered with snow/ice**
- **Mitigation:**
  - » Using the VIIRS deep-blue channels 0.412 and 0.445 µm and deep-blue algorithm may permit retrievals over bright snow/ice-free land surface
- **Status: Open**

CDR AOD Risks

- **Risk 4:** Loss of 2.25 μm channel or any other channel used in the multi-channel retrieval
- **Risk Assessment:** High for land, Low for ocean
- **Impact:**
  - » Current algorithm cannot retrieve AOD over land without 2.25 μm channel; cannot estimate aerosol type from only one channel; accuracy of AOD retrieval will decrease
- **Mitigation:**
  - » None. Development of single channel retrieval as a backup is possible, but it is unlikely to meet accuracy and precision requirements, especially over land
- **Status:** Closed

CDR AOD Risks

- **Risk 5:** Aerosol model selection may be inadequate for episodic events
- **Risk Assessment:** Medium
- **Impact:**
  - » Incorrect aerosol model retrieval
  - » Decreased accuracy of AOD retrieval
- **Mitigation:**
  - » Identify episodic dust events using deep-blue channels, or input from dust detection, and force algorithm to use dust model
- **Status:** Open

CDR AOD Risks

- **Risk 6:** Cloud, snow/ice, etc. contamination of pixel used for AOD retrieval
- **Risk Assessment:** Low
- **Impact:**
  - » Error in AOD retrieval 5% over water and 14% over land assuming a 3% error in clear reflectance
- **Mitigation:**
  - » Update/Implement internal tests using VIIRS channels (0.412, 0.445, 0.746, 1.240 µm) not available on ABI
- **Status:** Open

CDR AOD Risks

- **Risk 7:** Uncertainty in surface reflectance retrieval
- **Risk Assessment:** Low
- **Impact:**
  - » Increased error in AOD retrieval
- **Mitigation:**
  - – Develop and use NDVI-dependent surface reflectance relationships (coefficients of blue/red vs swir surface reflectances are function of NDVI)
- **Status:** Open

AOD References

- Cox, C., and W. Munk (1954). Statistics of the sea surface derived from sun glitter. *J. Mar. Res., 13, 198-208.*
- Holben, B.N., T.F. Eck, I. Slutsker, D. Tanré, J.P. Buis, A. Setzer, E.F. Vermote, J.A. Reagan, Y.J. Kaufman, T. Nakajima, F. Lavenue, I. Jankowiak, and A. Smirnov (1998). AeroNet – A federated instrument network and data archive for aerosol characterization, *Remote Sensing of the Environment, 66:(1) 1-16.*
- Kaufman, Y. J., D. Tanre, L. A. Remer, E. F. Vermote, A. Chu, and B. N. Holben (1997), Operational remote sensing of tropospheric aerosol over land from EOS moderate resolution imaging spectroradiometer, *J. Geophys. Res., 102(D14), 17051-17067.*
- King, M. D., Y. J. Kaufman, D. Tanre, and T. Nakajima (1999), Remote sensing of tropospheric aerosols from space: Past, present, and future, *Bull. Am. Meteorol. Soc., 80(11), 2229-2259.*

AOD References

- Levy, R.C., L.A. Remer, and O. Dubovik, Global aerosol optical properties and application to Moderate Resolution Imaging Spectroradiometer aerosol retrieval over land, J. Geophys. Res., 112(D13210), doi: 10.102, 2007
- Remer, L. A., Y. J. Kaufman, D. Tanre, S. Mattoo, D. A. Chu, J. V. Martins, R. R. Li, C. Ichoku, R. C. Levy, R. G. Kleidman, T. F. Eck, E. Vermote, and B. N. Holben (2005), The MODIS aerosol algorithm, products, and validation, *J. Atmos. Sci.,* 62(4), 947-973.
- Vermote, E. F., D. Tanre, J. L. Deuze, M. Herman, and J. J. Morcrette (1997), Second Simulation of the Satellite Signal in the Solar Spectrum, 6S: An overview, *IEEE Trans. Geosci. Remote Sens., 35(3), 675-686.*
- Vermote, E. F., R. Slonaker, S. Vibert, B. Petrenko (2006), National Polar-orbiting Operational Environmental Satellite System (NPOESS) VIIRS Aerosol Optical Thickness and Particle Size Parameter Algorithm Theoretical Basis Document, Version 5, Revision 8: June 2006, Document #: Y2388

Outline

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

Algorithm Theoretical Basis Volcanic Ash: Detection and Height

Presented by

Michael Pavolonis
Aviation Application Team
STAR

Algorithm Theoretical Basis

- Purpose: Provide product developers, reviewers and users with a theoretical description (scientific and mathematical) of the JPSS Volcanic Ash: Detection and Height algorithm

- Will be documented in the ATBD of the JPSS Volcanic Ash: Detection and Height products

CDR Requirements
Volcanic Ash

Name	User & Priority	Geographic Coverage	Vertical Res.	Horiz. Res.	Msmnt. Range	Msmnt. Accuracy	Data Latency	Refresh Rate	Timeliness
Volcanic Ash: Detection and Height	JPSS	Global	3 km (top height)	0.75 km	0 - 50 tons/km^2	2 tons/km^2	30 minutes after granule is available	at least 90% coverage of the globe every 12 hours (monthly average)	≤ 3 hours

CDR Algorithm

- Like all baseline GOES-R products, the official GOES-R volcanic ash algorithm software has been essentially “frozen” since 2011.
- Since 2011, however, research conducted under GOES-R Risk Reduction has resulted in several significant improvements to the science and software.
  - The ash detection approach has evolved such that its accuracy is now comparable to a manual analysis generated by a knowledgeable human
  - The same software can now be applied to any sensor (and even combinations of sensors), while taking full advantage of each sensor’s capabilities
- The improved GOES-R approach (not the “frozen” GOES-R approach) will be adopted for JPSS

CDR Algorithm

- Most of the underlying algorithm physics developed by the GOES-R AWG remains unchanged. It is the application of the physics that has changed.

- The volcanic ash algorithm consists of two main components:
  1. Identification of pixels that contain volcanic ash
  2. Retrieval of ash cloud properties

- Many more changes/improvements were made to the ash identification component than the ash cloud property retrieval component

Algorithm Objectives

- Meet the volcanic ash product requirements.
- Provide needed performance information to allow for proper use of our products.

Volcanic Ash 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	Ash Detection
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	Ash Detection
M13	3.973-4.128	4.05	0.75	
M14	8.400-8.700	8.55	0.75	Ash Detection
M15	10.263-11.263	10.763	0.75	Ash Detection and Retrieval
I5	10.500-12.400	11.45	0.375	
M16	11.538-12.488	12.013	0.75	Ash Detection and Retrieval
DNB	0.5–0.9	0.7	0.75	

Current Input

Expected Added Input

Possible Added Input

Volcanic Ash Input
Sensor Input Details

JPSS VIIRS volcanic ash algorithm 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)

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)

Volcanic Ash 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)

Volcanic Ash Input
Ancillary Input Details

- Non-ABI 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

Volcanic Ash Algorithm Input
Ancillary Input Details

- Non-ABI 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)

Volcanic Ash Algorithm Input Ancillary Input Details

- Non-ABI Dynamic Data

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

Volcanic Ash Algorithm Product Precedence Details

- No upstream JPSS products are required

Algorithm Output

- Ash detection mask (expressed as a probability)
- Ash top height (km)
- Ash mass loading (ton/km^2 or g/m^2)
- Product quality flags and information




Marco Fulle - www.stromboli.net

Volcanic Ash Detection

The ash cloud property retrieval procedure requires a priori knowledge on which pixels likely contain volcanic ash in order to constrain the retrieval and prevent false alarms

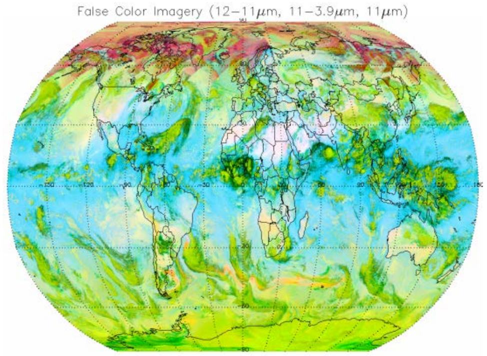


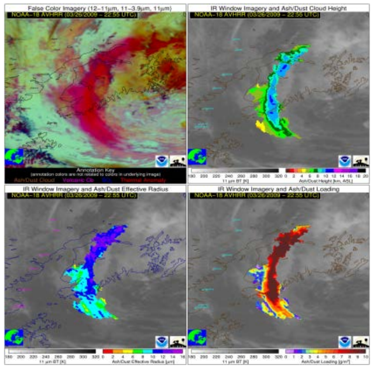
Automated Ash Detection Overview

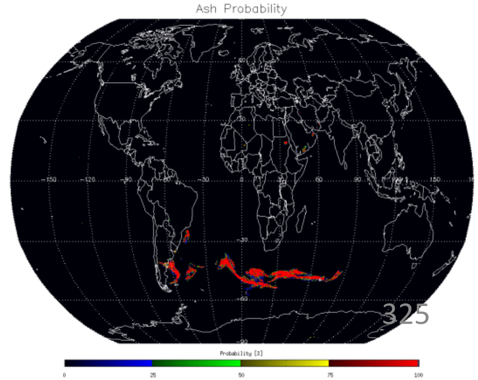
- The combination of radiative transfer theory (Pavolonis et al., 2006, Pavolonis, 2010), a naïve Bayesian statistical model, and image processing techniques (cloud object analysis) are used to detect volcanic ash clouds with skill comparable to that of a trained human analyst.

- The end results can actually be used to automatically issue ash cloud alerts to users (the alert criteria are highly configurable) and to construct a very accurate and objective depiction of ash cloud location that is critical for real-time model validation and data assimilation applications.

- The algorithm can be applied to a large number of sensors while taking full advantage of each sensor's capabilities.





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Volcanic Ash Detection

Radiative Transfer Theory

Channels Used in NOAA Ash Detection Algorithm

A temporal history of detected ash clouds is used to help ensure good consistency from image to image regardless of the sensor

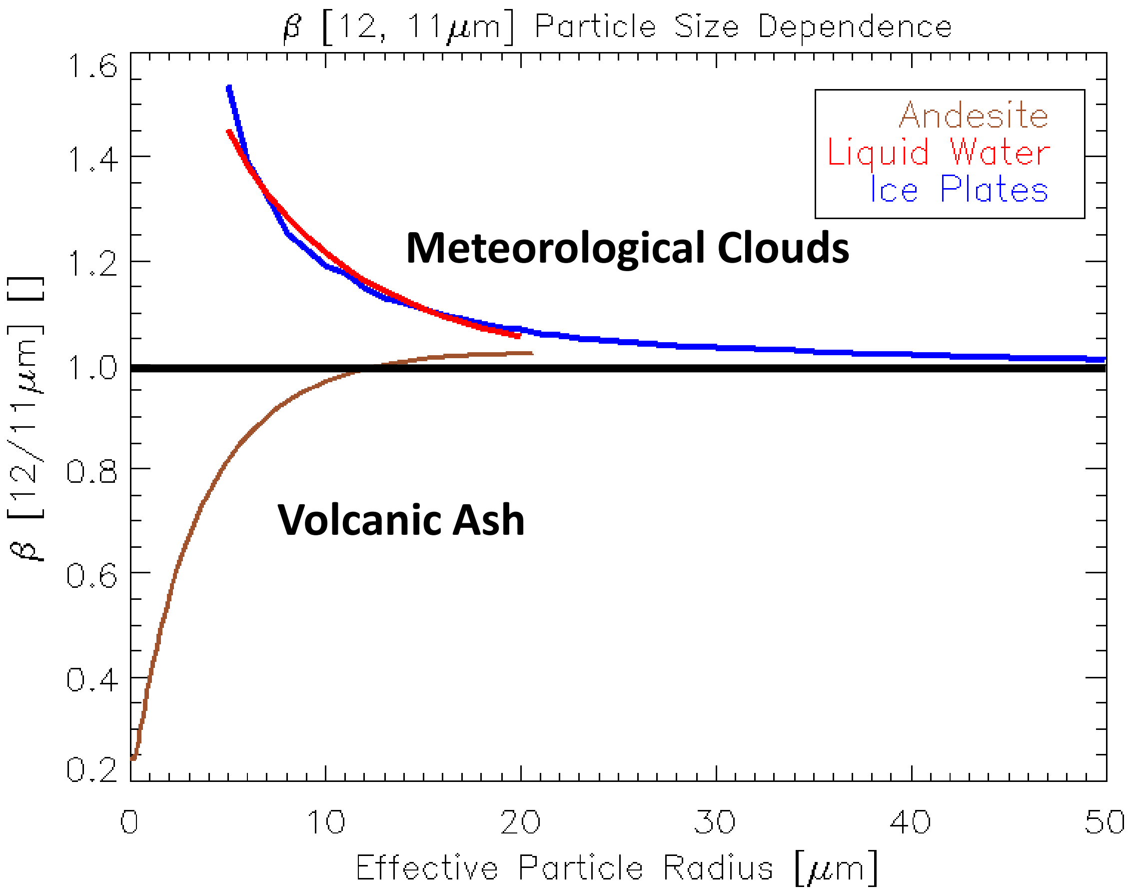
Sensor	Channels used
AVHRR	0.65, 3.75, 11, and 12 μm
COMS	0.65, 3.9, 11, and 12 μm
FY2	0.65, 3.9, 11, and 12 μm
GOES	0.65, 3.9, 11, and 13.3 μm
GOES-R ABI	0.65, 3.9, 7.3, 8.5, 11, and 12 μm
Himawari-8/9	0.65, 3.9, 7.3, 8.5, 11, and 12 μm
MODIS	0.65, 3.75, 7.3, 8.5, 11, and 12 μm
MTSAT	0.65, 3.9, 11, and 12 μm
SEVIRI	0.65, 3.9, 7.3, 8.5, 11, and 12 μm
VIIRS	0.65, 3.75, 8.5, 11, and 12 μm

***The same software is used for all sensors.

Radiative Transfer Theory

The spectral variation in cloud optical depth is related to cloud microphysics (including cloud composition). The spectral variation can be captured by taking the ratio of optical depth at two relevant wavelengths

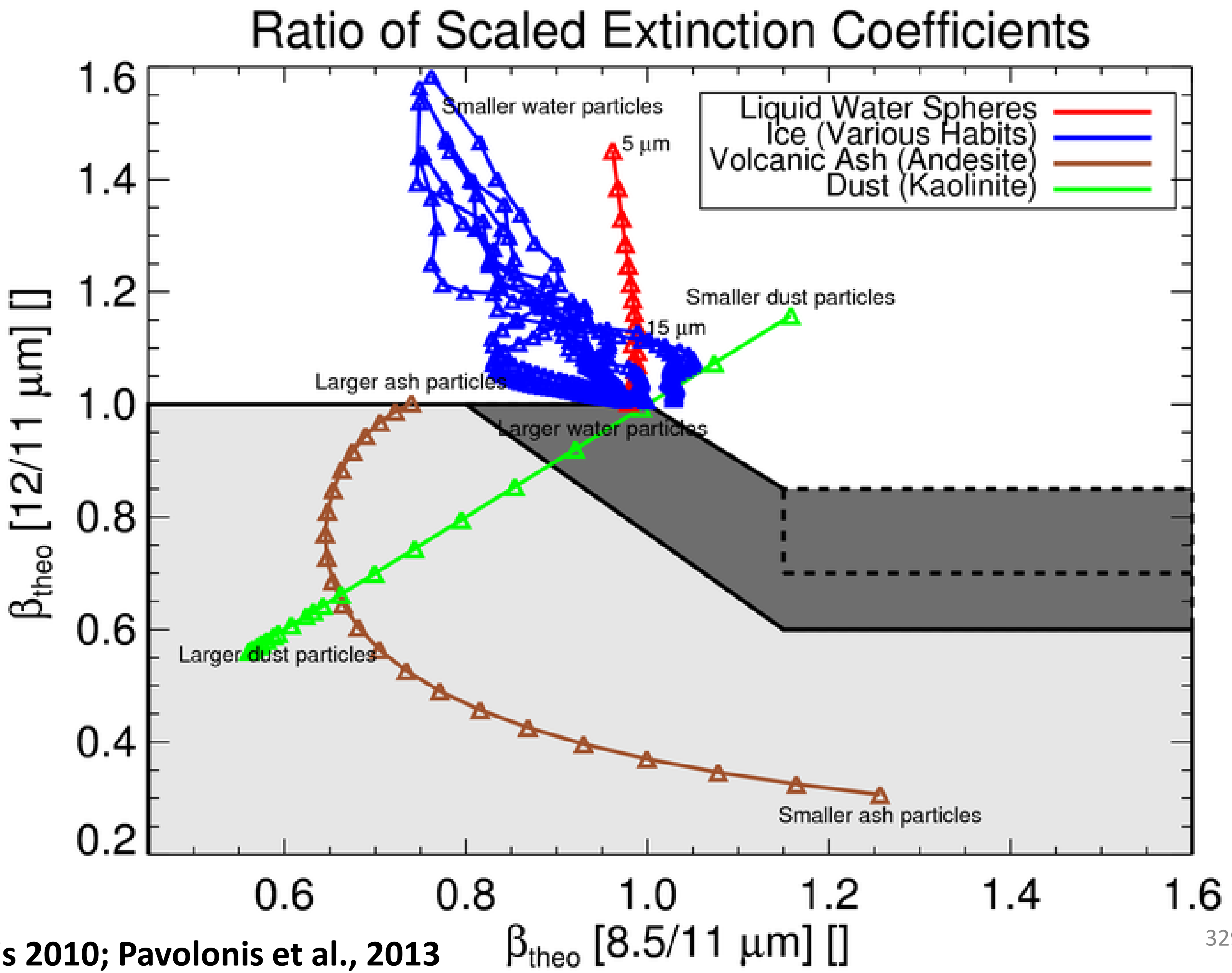
$$\beta_{observed} = \frac{\ln(1.0 - \varepsilon_{\lambda 1})}{\ln(1.0 - \varepsilon_{\lambda 2})}$$



Unlike the 11 – 12 μm BTD, β(12/11 μm) accounts for absorption by atmospheric gases, surface emissivity variations, and underlying cloud layers.

Globally applicable thresholds can be applied to β(12/11 μm)

Radiative Transfer Theory



Pavolonis 2010; Pavolonis et al., 2013

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

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

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

- **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.**
- **Pavolonis (2010) showed that even in the absence of cloud height information robust information on cloud microphysics 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 Volcanic Ash ATBD, three different cloud vertical boundary assumptions are employed by the volcanic ash algorithm when computing the cloud emissivity:

1). Single layer tropopause

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

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 Volcanic Ash ATBD, three different cloud vertical boundary assumptions are employed by the volcanic ash algorithm when computing the cloud emissivity:

1). Single layer tropopause

2). Multilayer tropopause

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

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 Volcanic Ash ATBD, three different cloud vertical boundary assumptions are employed by the volcanic ash algorithm when computing the cloud emissivity:

1). Single layer tropopause

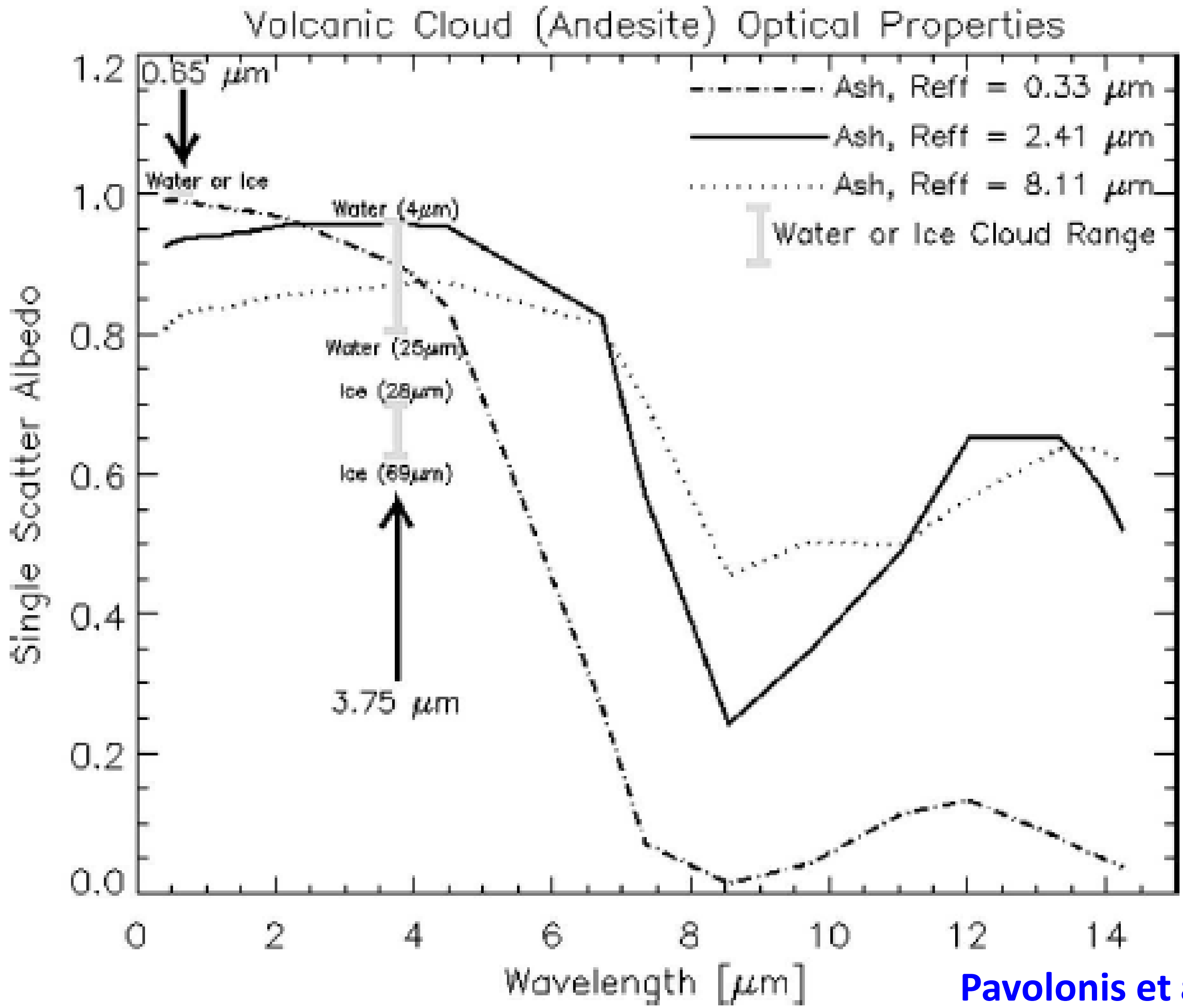
2). Multilayer tropopause

3). Single layer opaque cloud

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

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

Volcanic ash is a stronger absorber (weaker reflector) of radiation at visible wavelengths (0.65 µm) than liquid water and ice. Ash scatters radiation similar to liquid water clouds in the near-infrared (3.8 µm). Thus the ratio of the 3.8/0.65 µm reflectance is a useful ash detection metric.



Pavolonis et al. (2006)

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Volcanic Ash Detection

Naïve Bayesian Classifier

The probability that ash is present given the values of the satellite-based predictors (F) is:

$$P(C_{ash} \mid \mathbf{F}) = \frac{P(C_{ash})\prod_{i=1}^{N} P(F_i \mid C_{ash})}{P(C_{ash})\prod_{i=1}^{N} P(F_i \mid C_{ash}) + P(C_{other})\prod_{i=1}^{N} P(F_i \mid C_{other})}$$

The Naïve Bayes classifier allows one to assume that all predictors are independent, even if they are not

A large training data set has been compiled for AVHRR and MODIS, where the bounds of ash clouds were manually analyzed. Classifier training for all other sensors is simply derived from the robust AVHRR and MODIS training data sets.

The *a priori* values are assumed to be: $P(C_{ash}) = 0.0001$, $P(C_{other}) = 0.99990$

Predictors used in Naïve Bayesian Classifier

Predictor	Application Criteria
$\varepsilon_{tot}(11\mu m)$, $\beta_{tot}(12/11\mu m)$, Rat(3.8/0.65 µm)	Solzen < 85° and no glint
$\varepsilon_{tot}(11\mu m)$, $\beta_{opaque}(12/11\mu m)$, Rat(3.8/0.65 µm)	Solzen < 85° and no glint
$\varepsilon_{tot}(11\mu m)$, $\beta_{tot\_multi1}(12/11\mu m)$, Rat(3.8/0.65 µm)	Solzen < 85° and no glint
$\varepsilon_{tot}(11\mu m)$, $\beta_{tot\_multi2}(12/11\mu m)$, Rat(3.8/0.65 µm)	Solzen < 85° and no glint
$\varepsilon_{tot}(11\mu m)$, $\beta_{tot}(12/11\mu m)$, Ems(3.8 µm)	Solzen > 91° and no stray light
$\varepsilon_{tot}(11\mu m)$, $\beta_{opaque}(12/11\mu m)$, Ems(3.8 µm)	Solzen > 91° and no stray light
$\varepsilon_{tot}(11\mu m)$, $\beta_{tot\_multi1}(12/11\mu m)$, Ems(3.8 µm)	Solzen > 91° and no stray light
$\varepsilon_{tot}(11\mu m)$, $\beta_{tot\_multi2}(12/11\mu m)$, Ems(3.8 µm)	Solzen > 91° and no stray light
$\varepsilon_{tot}(11\mu m)$, $\beta_{tot}(12/11\mu m)$	85° < Solzen < 91° or in glint
$\varepsilon_{tot}(11\mu m)$, $\beta_{opaque}(12/11\mu m)$	85° < Solzen < 91° or in glint
$\varepsilon_{tot}(11\mu m)$, $\beta_{tot\_multi1}(12/11\mu m)$	85° < Solzen < 91° or in glint
$\varepsilon_{tot}(11\mu m)$, $\beta_{tot\_multi2}(12/11\mu m)$	85° < Solzen < 91° or in glint
$\varepsilon_{tot}(11\mu m)$, Ref(0.65 µm)	Solzen < 85°
$\varepsilon_{tot}(11\mu m)$, $\beta_{tot}(12/11\mu m)$, $\beta_{tot}(8.5/11\mu m)$	Always
$\varepsilon_{tot}(11\mu m)$, $\beta_{opaque}(12/11\mu m)$, $\beta_{opaque}(8.5/11\mu m)$	Always

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Volcanic Ash Detection

Image Processing Technique

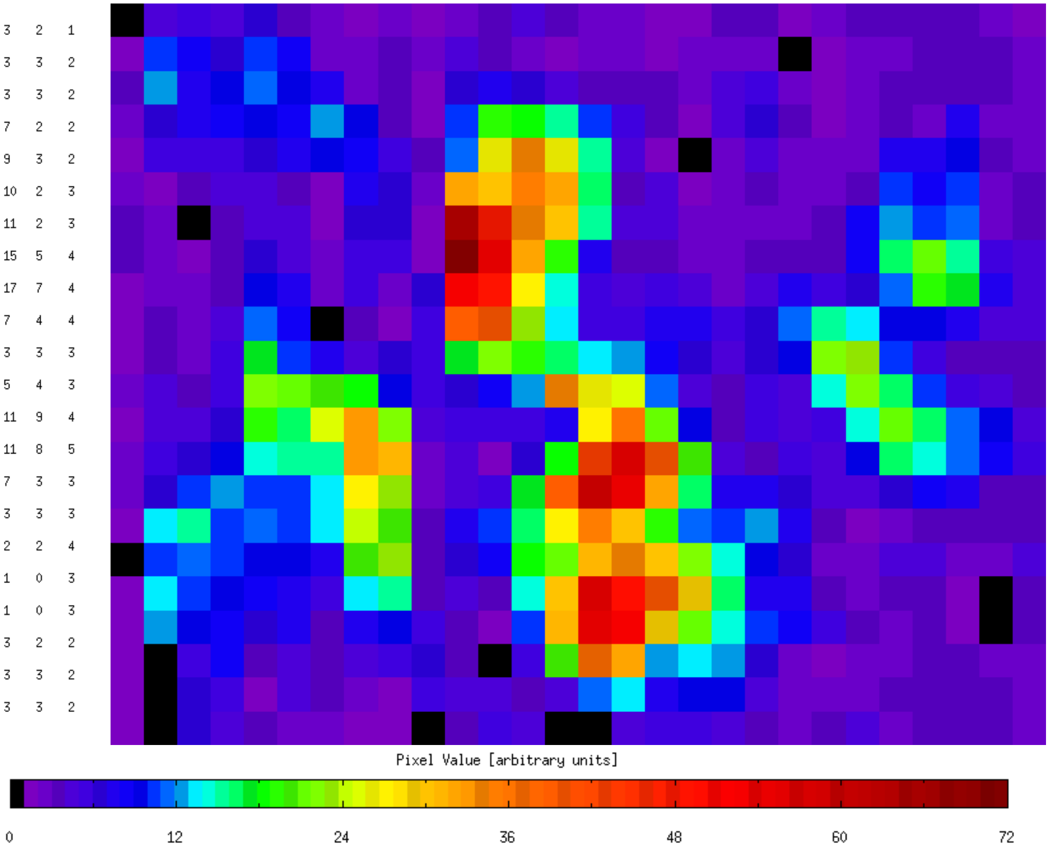
Use of Cloud Objects

- **Nearly all ash clouds (as viewed from space) are composed of a mixture of pixels that fall into 2 categories:**
  1. **Unambiguous volcanic ash spectral signature (generally the minority of pixels)**
  2. **Weak to moderate volcanic ash spectral signature and, as such, can be similar to other non-ash features or instrument noise (generally the majority of pixels)**
- **All spatially connected pixels that have an ash probability that exceeds a dynamic threshold are grouped into cloud objects.**
- **Cloud objects that contain at least a few spectrally unambiguous pixels are classified as “ash.” All other objects are classified as “not ash.”**

Cloud Object Illustration

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

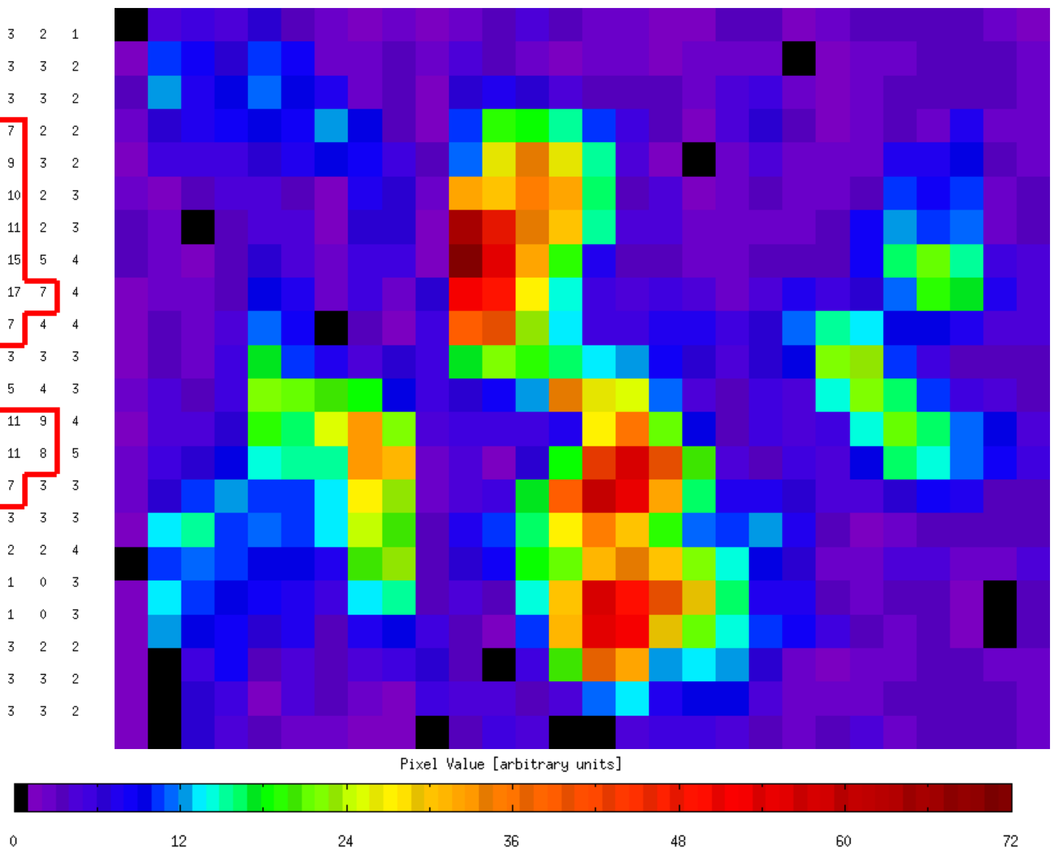
0	4	5	4	6	3	2	1	2	1	2	3	4	3	2	2	1	1	3	3	1	2	3	3	3	3	2	1
1	10	8	6	10	8	2	2	3	2	4	3	2	1	2	2	1	2	2	2	0	1	2	2	3	3	3	2
3	12	7	9	11	9	7	2	3	1	6	7	6	4	3	3	3	2	4	5	2	1	2	3	3	3	3	2
2	6	7	8	9	8	12	9	3	1	10	19	18	15	10	5	3	1	4	6	3	1	2	3	2	7	2	2
1	5	5	5	6	7	9	8	5	3	11	26	34	26	15	4	1	0	2	4	2	2	2	7	7	9	3	2
2	1	3	4	4	3	1	7	6	2	32	30	35	32	16	3	4	1	2	3	2	2	3	10	8	10	2	3
3	2	0	3	4	4	1	6	6	1	66	48	34	30	15	4	4	2	2	2	2	3	8	12	10	11	2	3
3	2	1	3	6	4	2	5	5	1	72	56	32	19	7	3	3	2	2	3	3	3	8	16	21	15	5	4
1	2	2	3	9	7	2	5	2	6	53	49	27	14	5	4	5	4	2	4	7	5	6	11	19	17	7	4
1	3	2	4	11	8	0	3	1	5	39	40	23	13	5	5	7	7	5	6	11	15	13	9	9	7	4	4
1	3	2	5	17	10	7	4	6	5	17	22	19	16	13	12	8	6	4	6	9	22	23	10	5	3	3	3
2	4	3	5	22	21	20	18	9	5	6	8	12	34	26	25	11	4	3	5	4	14	22	16	10	5	4	3
1	4	4	6	19	16	25	33	22	4	5	5	5	7	27	36	21	9	3	5	4	5	14	21	16	11	9	4
2	5	6	9	14	15	15	33	31	2	4	1	6	18	43	54	40	20	4	3	5	4	9	16	14	11	8	5
2	6	10	12	10	10	13	27	23	2	4	5	17	39	61	55	32	16	7	7	6	4	4	6	8	7	3	3
1	13	15	10	11	10	13	24	20	3	7	10	16	27	35	30	19	11	10	12	7	3	1	2	3	3	3	3
0	10	11	10	9	9	7	20	23	3	6	8	18	21	31	34	30	22	14	9	6	2	2	4	4	2	2	4
1	13	10	9	8	7	5	13	15	3	4	3	14	30	54	50	40	29	16	7	7	3	2	3	3	1	0	3
1	12	9	8	6	7	3	7	9	5	3	1	10	31	56	53	29	21	14	10	8	5	3	2	3	1	0	3
1	0	5	8	3	4	3	4	5	6	3	0	5	20	37	32	12	13	12	6	2	1	2	2	3	3	2	2
1	0	6	5	1	4	3	2	1	5	4	4	3	4	11	13	7	9	9	4	2	2	2	3	3	3	3	2
1	0	6	4	3	2	2	1	1	0	3	5	4	0	0	4	5	5	4	3	2	3	4	2	3	3	3	2



Cloud Object Illustration

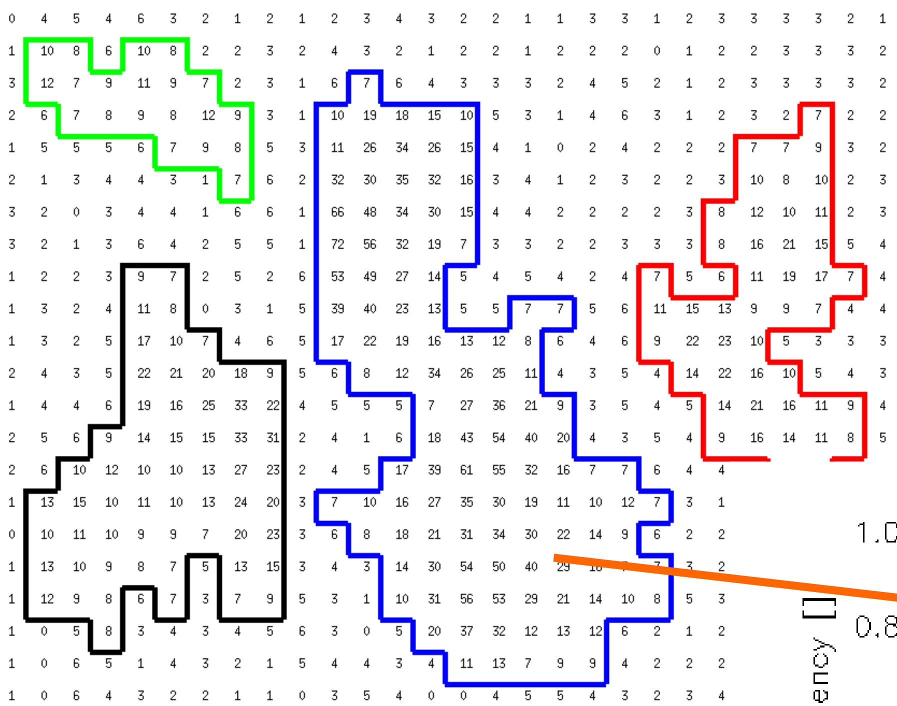
- In this simplified generic example, assume ash ***might*** be present when pixel values exceed 6 (arbitrary units) and ash is ***very likely present*** when pixel values exceed 40.

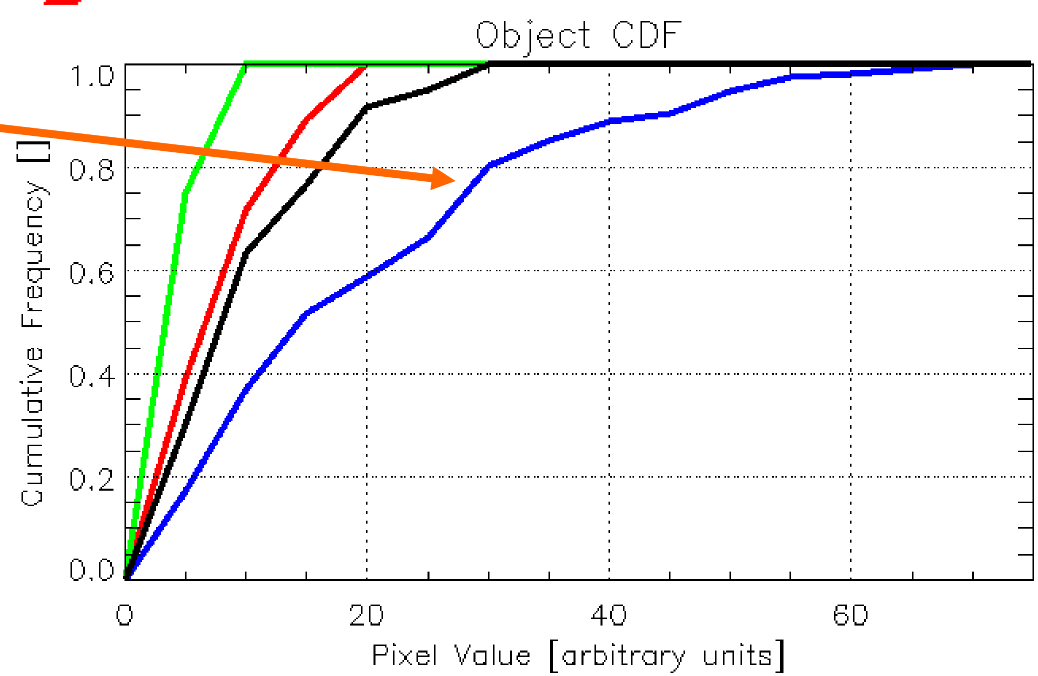
0	4	5	4	6	3	2	1	2	1	2	3	4	3	2	2	1	1	3	3	1	2	3	3	3	3	2	1
1	10	8	6	10	8	2	2	3	2	4	3	2	1	2	2	1	2	2	2	0	1	2	2	3	3	3	2
3	12	7	9	11	9	7	2	3	1	6	7	6	4	3	3	3	2	4	5	2	1	2	3	3	3	3	2
2	6	7	8	9	8	12	9	3	1	10	19	18	15	10	5	3	1	4	6	3	1	2	3	2	7	2	2
1	5	5	5	6	7	9	8	5	3	11	26	34	26	15	4	1	0	2	4	2	2	2	7	7	9	3	2
2	1	3	4	4	3	1	7	6	2	32	30	35	32	16	3	4	1	2	3	2	2	3	10	8	10	2	3
3	2	0	3	4	4	1	6	6	1	66	48	34	30	15	4	4	2	2	2	2	3	8	12	10	11	2	3
3	2	1	3	6	4	2	5	5	1	72	56	32	19	7	3	3	2	2	3	3	3	8	16	21	15	5	4
1	2	2	3	9	7	2	5	2	6	53	49	27	14	5	4	5	4	2	4	7	5	6	11	19	17	7	4
1	3	2	4	11	8	0	3	1	5	39	40	23	13	5	5	7	7	5	6	11	15	13	9	9	7	4	4
1	3	2	5	17	10	7	4	6	5	17	22	19	16	13	12	8	6	4	6	9	22	23	10	5	3	3	3
2	4	3	5	22	21	20	18	9	5	6	8	12	34	26	25	11	4	3	5	4	14	22	16	10	5	4	3
1	4	4	6	19	16	25	33	22	4	5	5	5	7	27	36	21	9	3	5	4	5	14	21	16	11	9	4
2	5	6	9	14	15	15	33	31	2	4	1	6	18	43	54	40	20	4	3	5	4	9	16	14	11	8	5
2	6	10	12	10	10	13	27	23	2	4	5	17	39	61	55	32	16	7	7	6	4	4	6	8	7	3	3
1	13	15	10	11	10	13	24	20	3	7	10	16	27	35	30	19	11	10	12	7	3	1	2	3	3	3	3
0	10	11	10	9	9	7	20	23	3	6	8	18	21	31	34	30	22	14	9	6	2	2	4	4	2	2	4
1	13	10	9	8	7	5	13	15	3	4	3	14	30	54	50	40	29	16	7	7	3	2	3	3	1	0	3
1	12	9	8	6	7	3	7	9	5	3	1	10	31	56	53	29	21	14	10	8	5	3	2	3	1	0	3
1	0	5	8	3	4	3	4	5	6	3	0	5	20	37	32	12	13	12	6	2	1	2	2	3	3	2	2
1	0	6	5	1	4	3	2	1	5	4	4	3	4	11	13	7	9	9	4	2	2	2	3	3	3	3	2
1	0	6	4	3	2	2	1	1	0	3	5	4	0	0	4	5	5	4	3	2	3	4	2	3	3	3	2



Cloud Object Illustration

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



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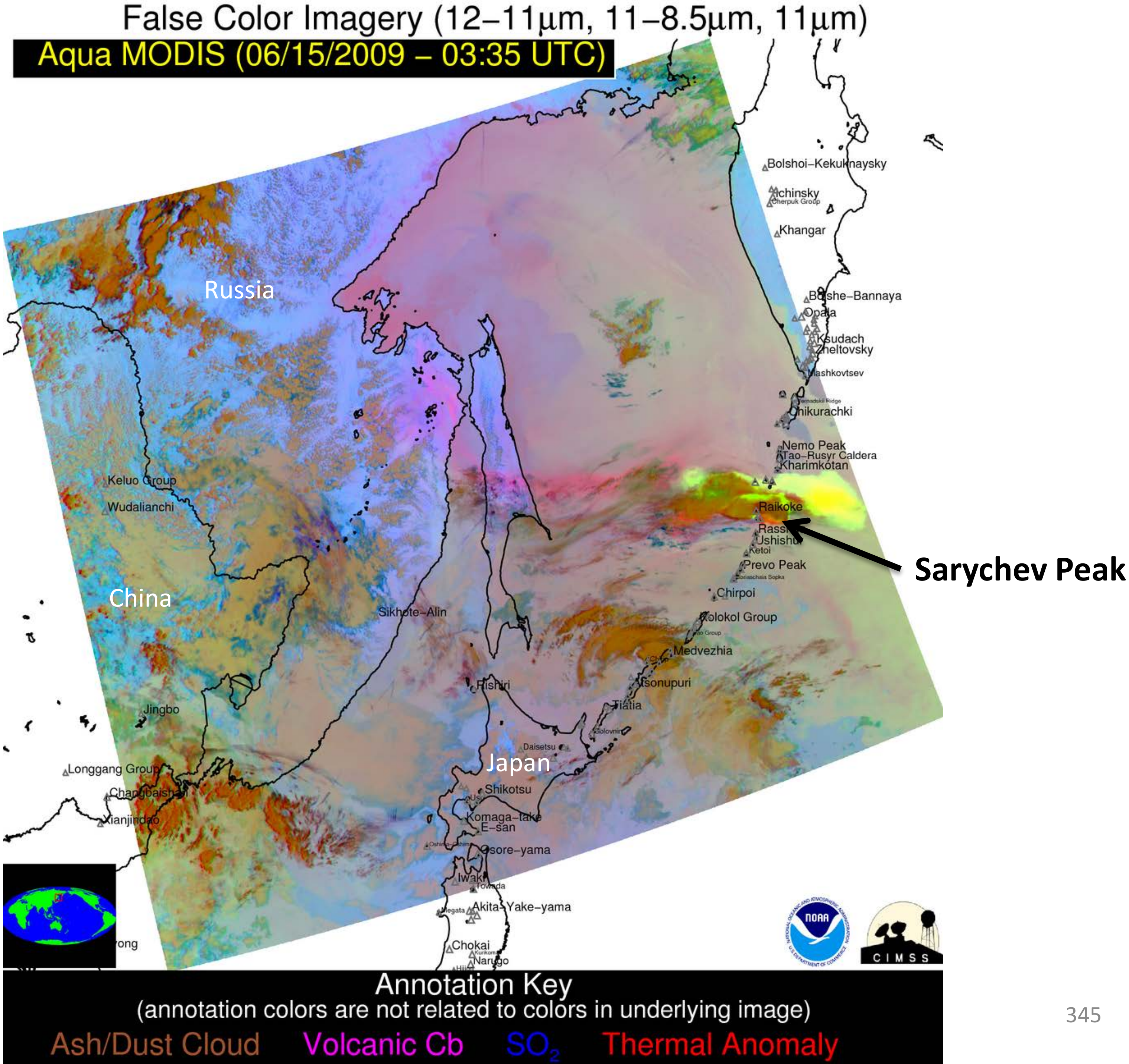
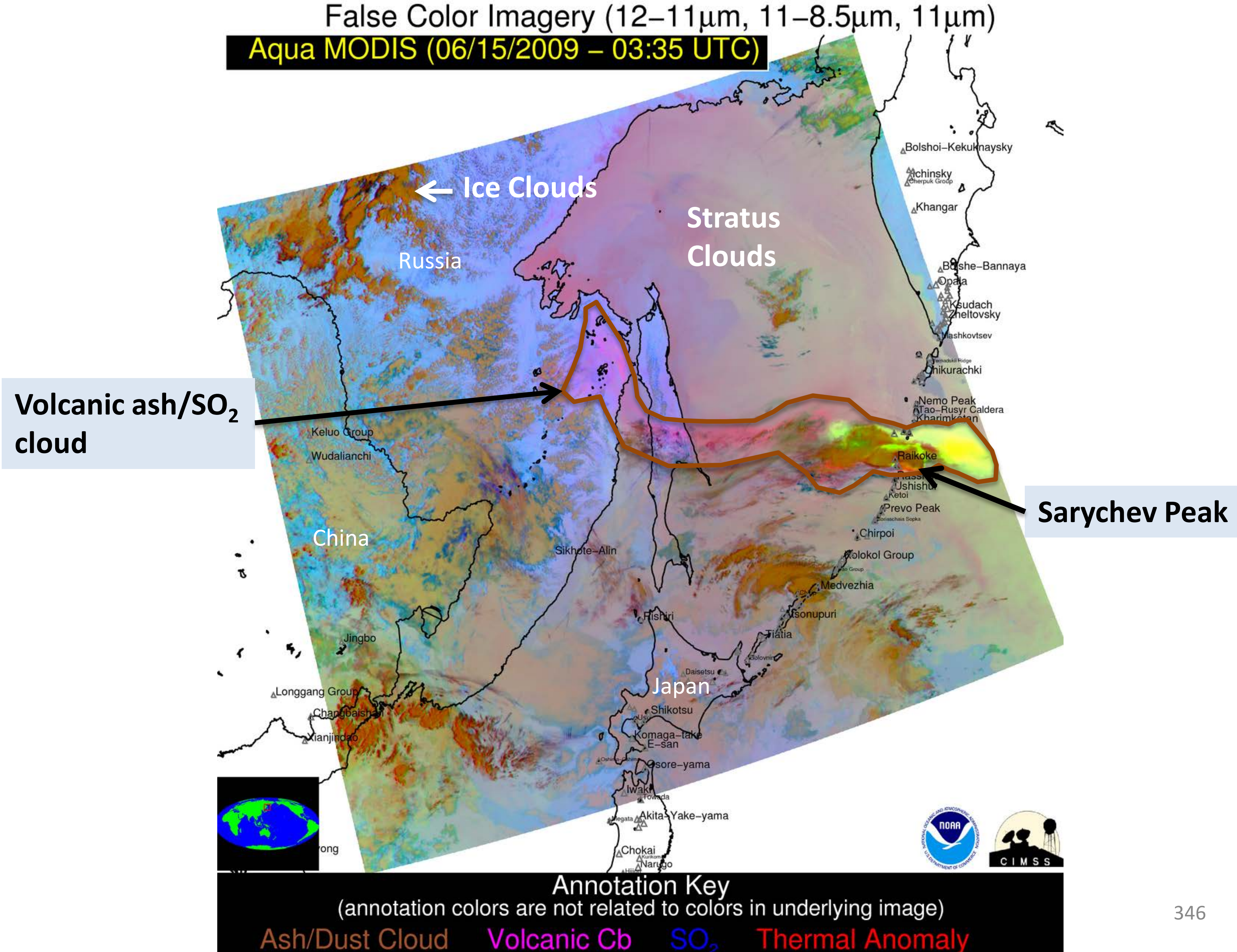
Volcanic Ash Detection

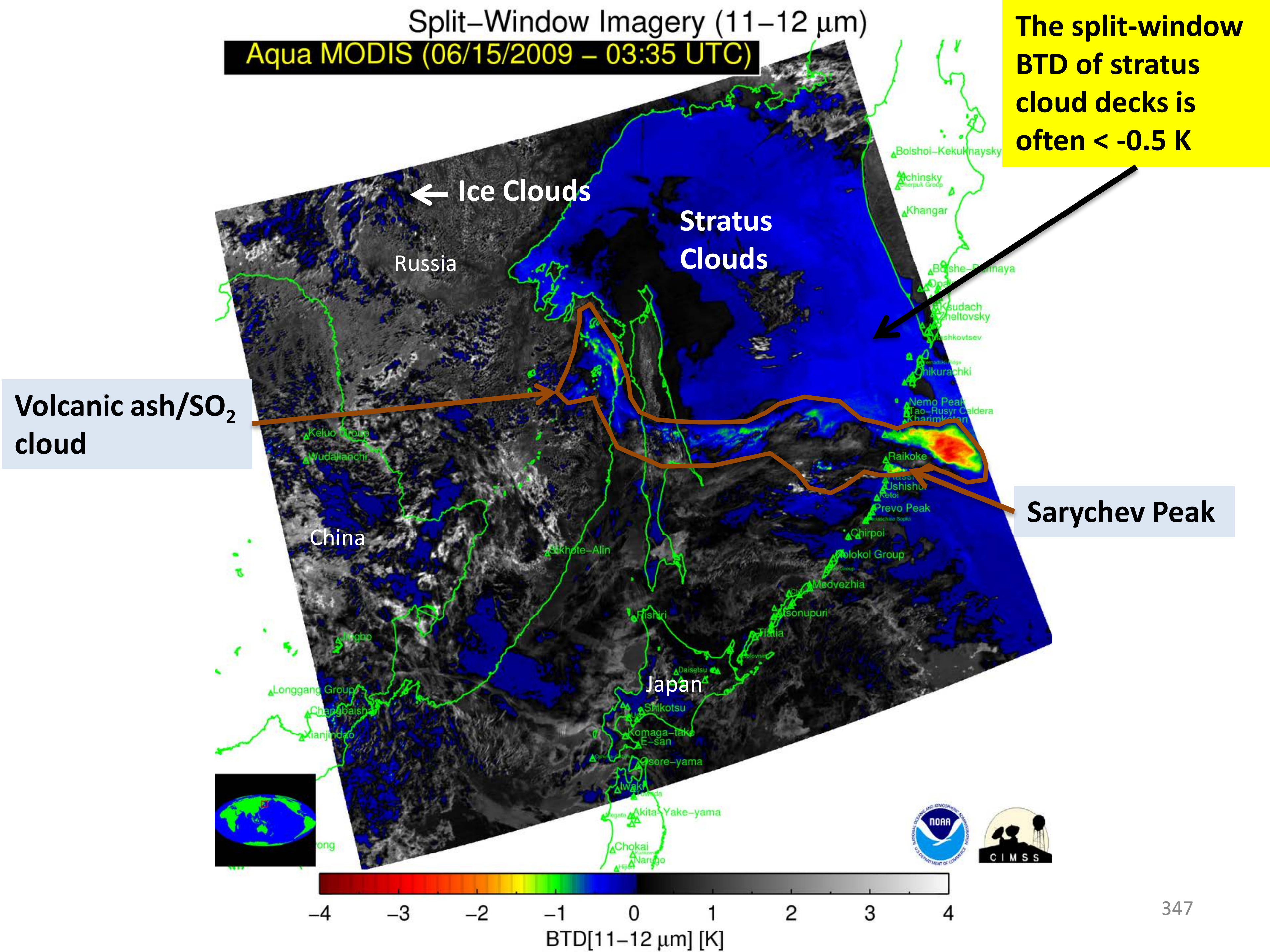
Application of Technique

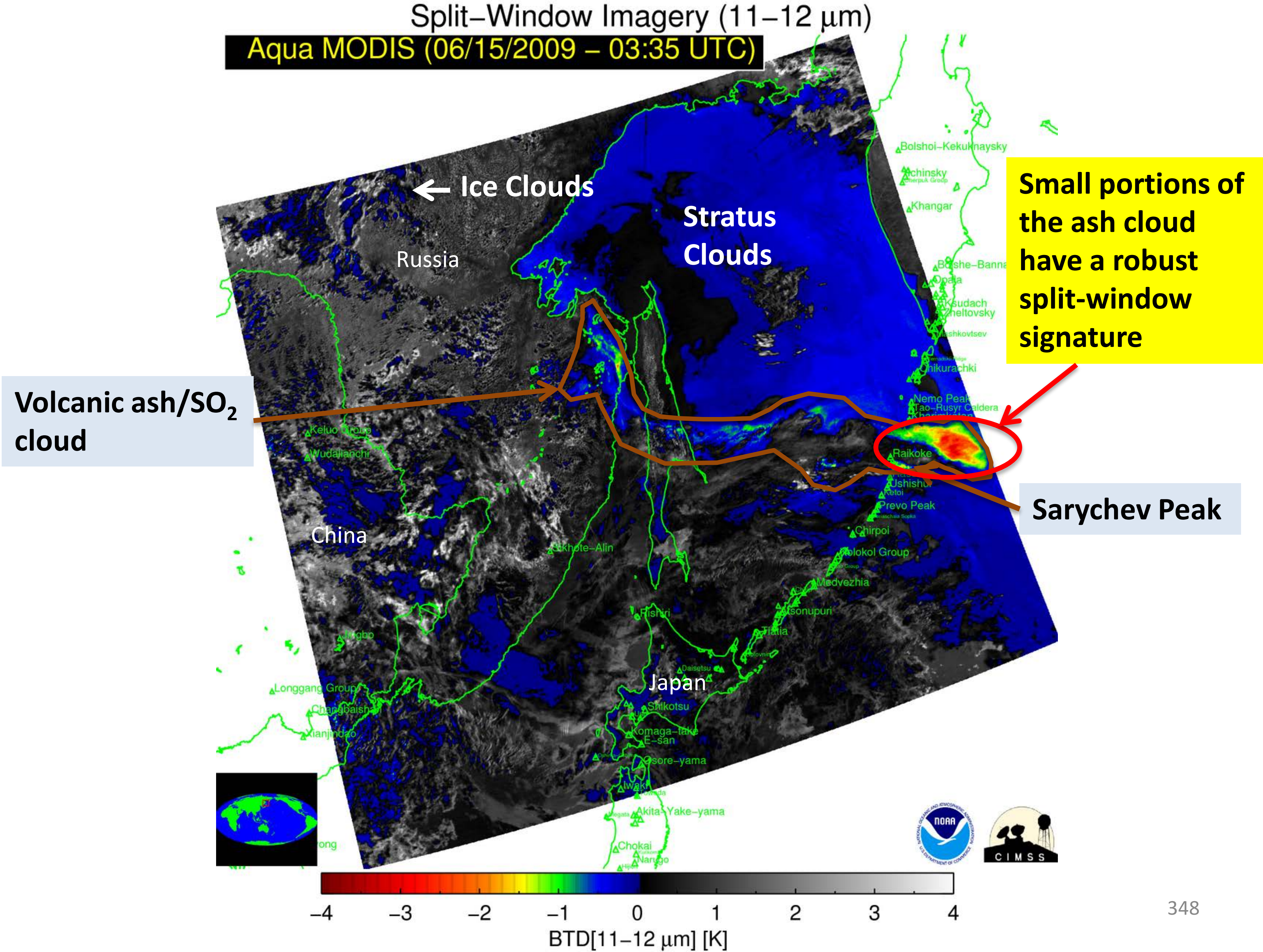



False Color Imagery (12–11µm, 11–8.5µm, 11µm)
Aqua MODIS (06/15/2009 – 03:35 UTC)
Russia
China
Japan
Sarychev Peak
Bolshoi–Kekuknaysky
Khangar
Opala
Ksudach
Zheltovsky
Nemo Peak
Tao–Rusyr Caldera
Kharimkotan
Raikoke
Ushishur
Ketoi
Prevo Peak
Chirpoi
Kolokol Group
Medvezhia
Tiatia
Keluo Group
Wudalianchi
Sikhote–Alin
Rishiri
Jingbo
Longgang Group
Changbaishan
Xianjindao
Daisetsu
Shikotsu
Komaga–take
E–san
Osore–yama
Iwaki
Towada
Akita–Yake–yama
Chokai
Narugo
CIMSS
Annotation Key
(annotation colors are not related to colors in underlying image)
Ash/Dust Cloud
Volcanic Cb
SO2
Thermal Anomaly

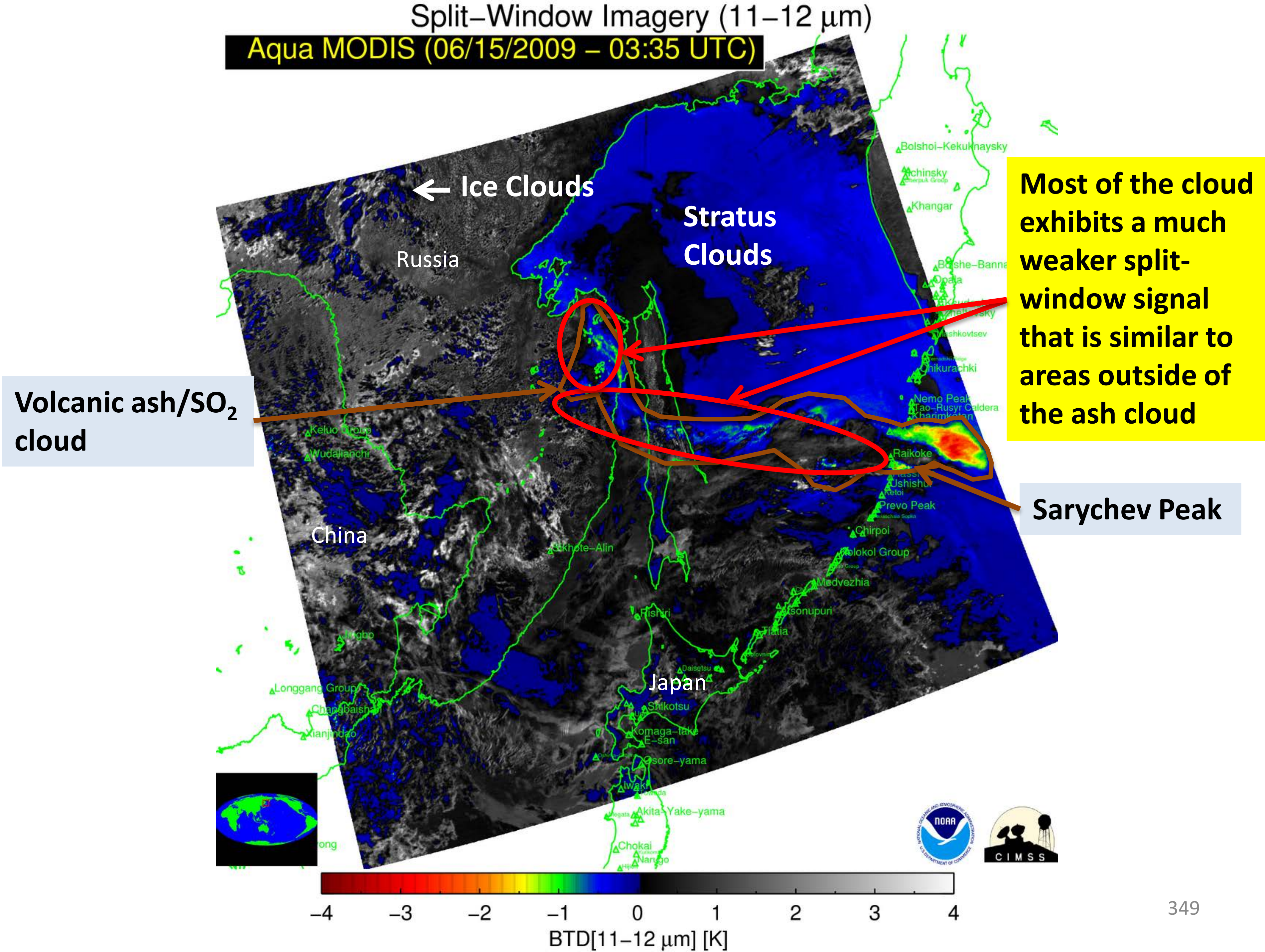


False Color Imagery (12–11µm, 11–8.5µm, 11µm)
Aqua MODIS (06/15/2009 – 03:35 UTC)
Ice Clouds
Stratus Clouds
Russia
China
Japan
Volcanic ash/SO_2 cloud
Sarychev Peak
Bolshoi–Kekuknaysky
Ichinsky
Khangar
Bolshe–Bannaya
Opala
Ksudach
Zheltovsky
Chikurachki
Nemo Peak
Tao–Rusyr Caldera
Raikoke
Ushishur
Ketoi
Prevo Peak
Chirpoi
Kolokol Group
Medvezhia
Tiatia
Keluo Group
Wudalianchi
Sikhote–Alin
Jingbo
Longgang Group
Changbaishan
Xianjindao
Rishiri
Daisetsu
Shikotsu
Komaga–take
E–san
Osore–yama
Iwaki
Towada
Akita–Yake–yama
Chokai
Narugo
CIMSS
Annotation Key
(annotation colors are not related to colors in underlying image)
Ash/Dust Cloud
Volcanic Cb
SO_2
Thermal Anomaly


Split–Window Imagery (11–12 µm)
Aqua MODIS (06/15/2009 – 03:35 UTC)
The split-window BTD of stratus cloud decks is often < -0.5 K
Ice Clouds
Stratus Clouds
Russia
China
Japan
Volcanic ash/SO_2 cloud
Sarychev Peak
Raikoke
Sikhote-Alin
Rishiri
Chirpoi
Medvezhia
Prevo Peak
Nemo Peak
Tao-Rusyr Caldera
Khangar
Bolshoi-Kekuknaysky
Ksudach
Zheltovsky
Keluo Group
Wudalianchi
Longgang Group
Changbaishan
Shikotsu
Komaga-take
E-san
Osore-yama
Iwaki
Akita-Yake-yama
Chokai
Tiatia
Daisetsu
BTD[11–12 µm] [K]
–4 –3 –2 –1 0 1 2 3 4
CIMSS



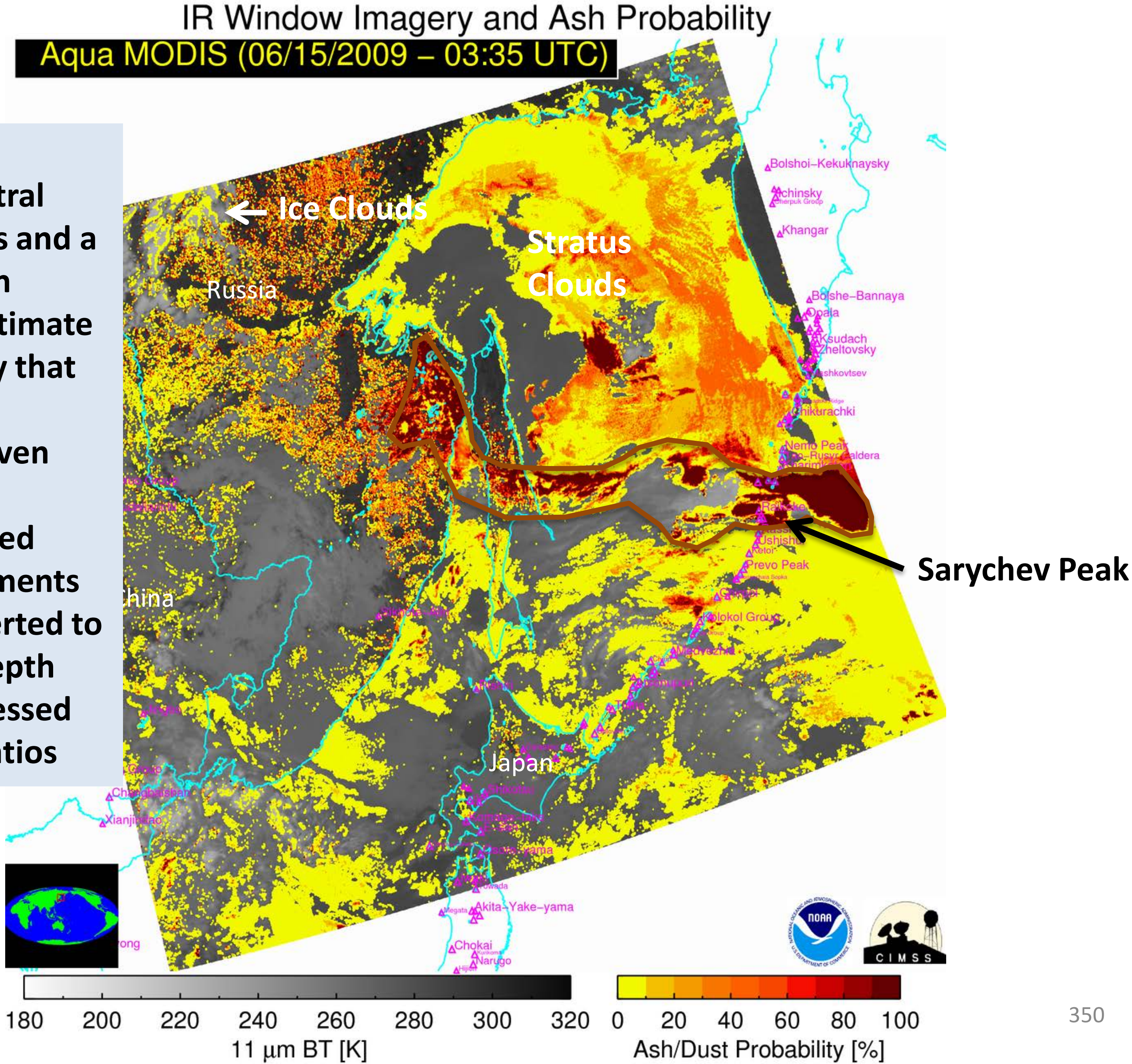
Split–Window Imagery (11–12 μm)
Aqua MODIS (06/15/2009 – 03:35 UTC)
Ice Clouds
Stratus Clouds
Russia
China
Japan
Small portions of the ash cloud have a robust split-window signature
Volcanic ash/SO_2 cloud
Sarychev Peak
Raikoke
Bolshoi–Kekuknaysky
Khangar
Nemo Peak
Tao–Rusyr Caldera
Prevo Peak
Chirpoi
Medvezhia
Sikhote–Alin
Rishiri
Tiatia
Shikotsu
Komaga–take
E–san
Osore–yama
Iwaki
Akita–Yake–yama
Chokai
Longgang Group
Changbaishan
Keluo Group
Wudalianchi
−4
−3
−2
−1
0
1
2
3
4
BTD[11–12 μm] [K]
CIMSS



Split–Window Imagery (11–12 μm)
Aqua MODIS (06/15/2009 – 03:35 UTC)
Ice Clouds
Russia
Stratus Clouds
Most of the cloud exhibits a much weaker split-window signal that is similar to areas outside of the ash cloud
Volcanic ash/SO_2 cloud
Sarychev Peak
China
Japan
Bolshoi–Kekuknaysky
Khangar
Nemo Peak
Tao–Rusyr Caldera
Raikoke
Ushishur
Ketoi
Prevo Peak
Chirpoi
Medvezhia
Tsonupuri
Tiatia
Sikhote–Alin
Keluo Group
Wudalianchi
Longgang Group
Changbaishan
Xianjindao
Rishiri
Daisetsu
Shikotsu
Komaga–take
E–san
Osore–yama
Iwaki
Akita–Yake–yama
Chokai
Narugo
–4
–3
–2
–1
0
1
2
3
4
BTD[11–12 μm] [K]

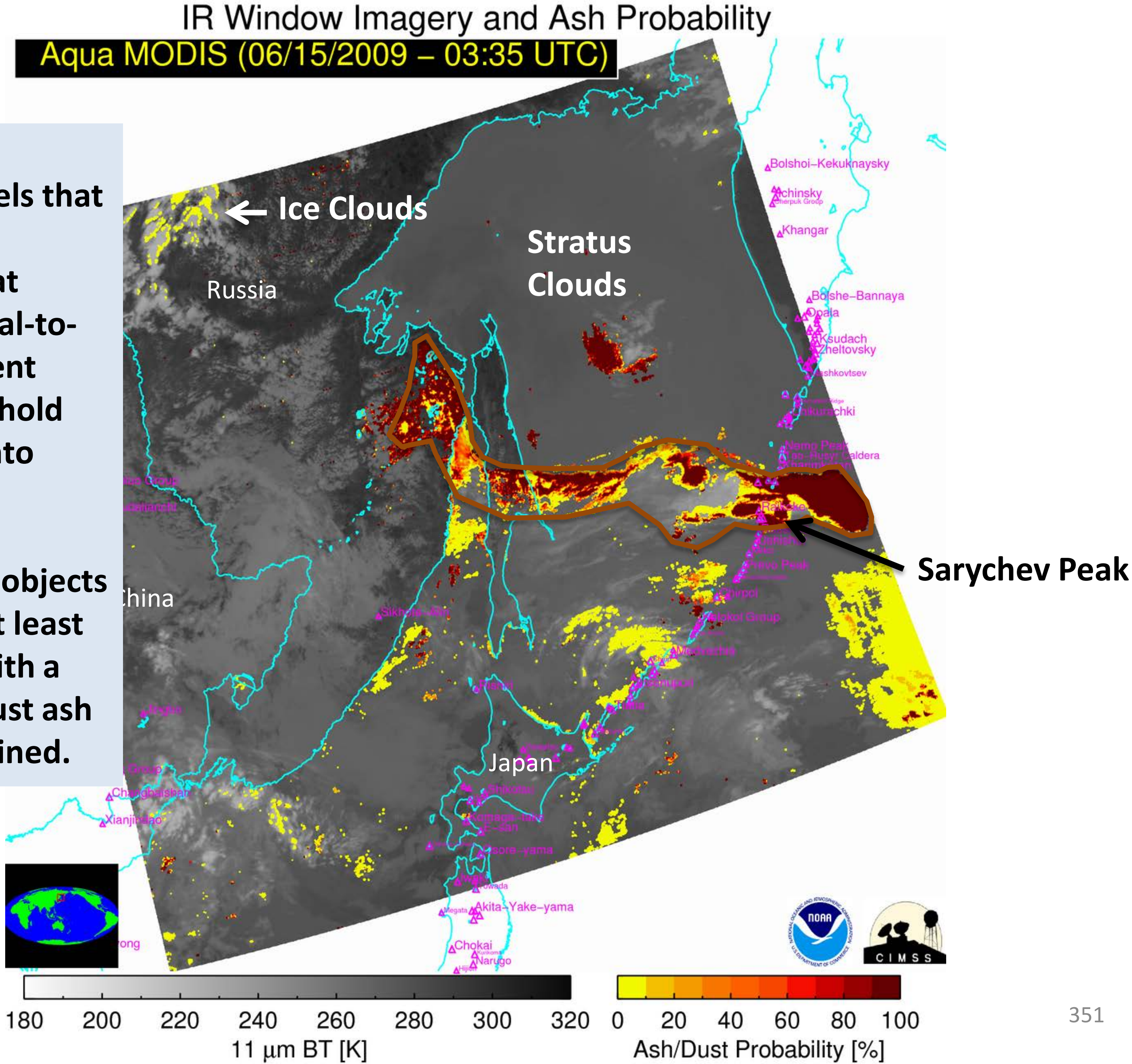
1). Utilize best available spectral measurements and a Naïve Bayesian classifier to estimate the probability that volcanic ash is present in a given pixel

- **-All infrared measurements are converted to optical depth and expressed as beta ratios**

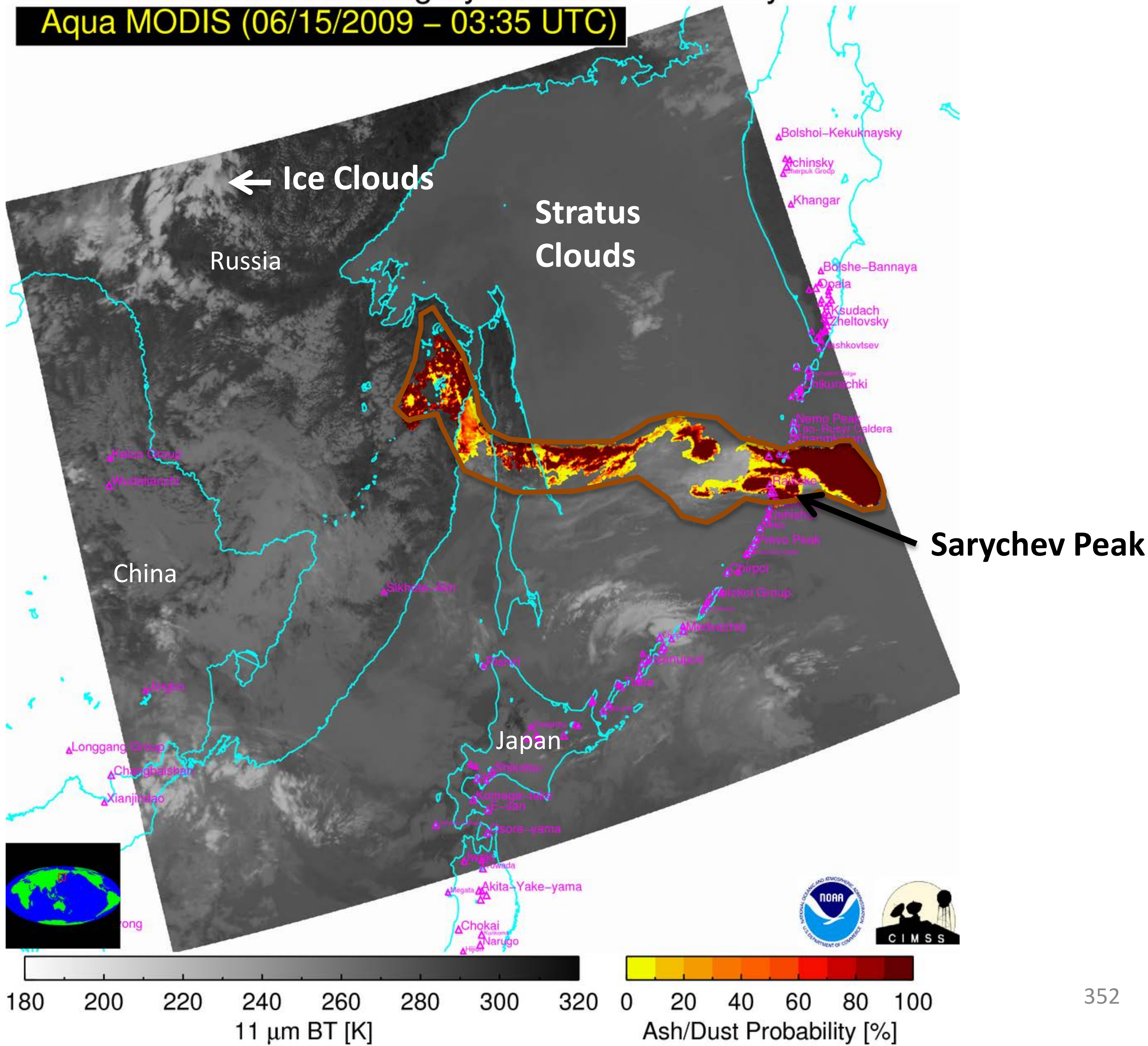


2). Spatially connected pixels that have an ash probability that exceeds a signal-to-noise dependent dynamic threshold are grouped into cloud objects.

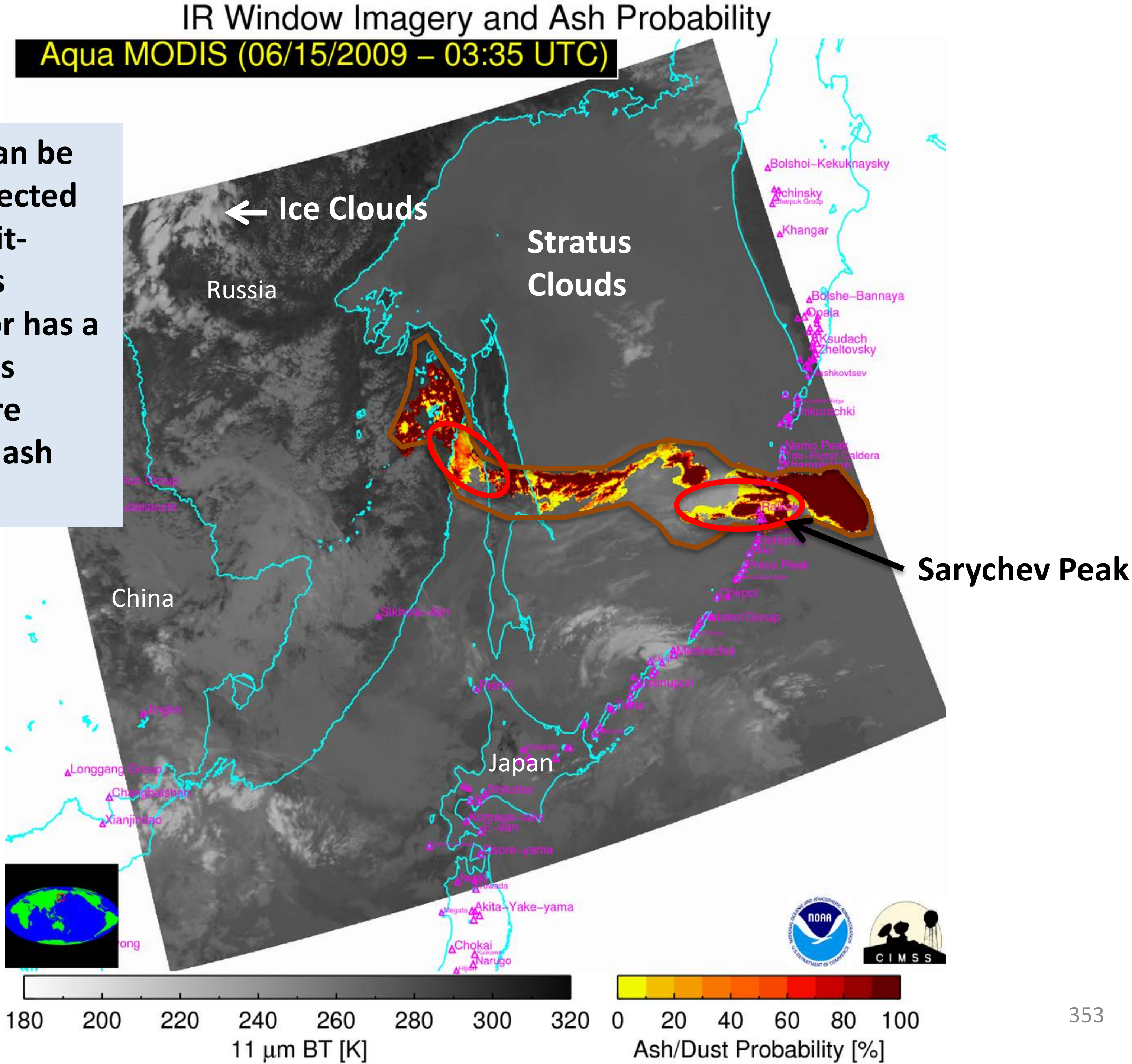
3). Only cloud objects that contain at least some pixels with a spectrally robust ash signal are retained.



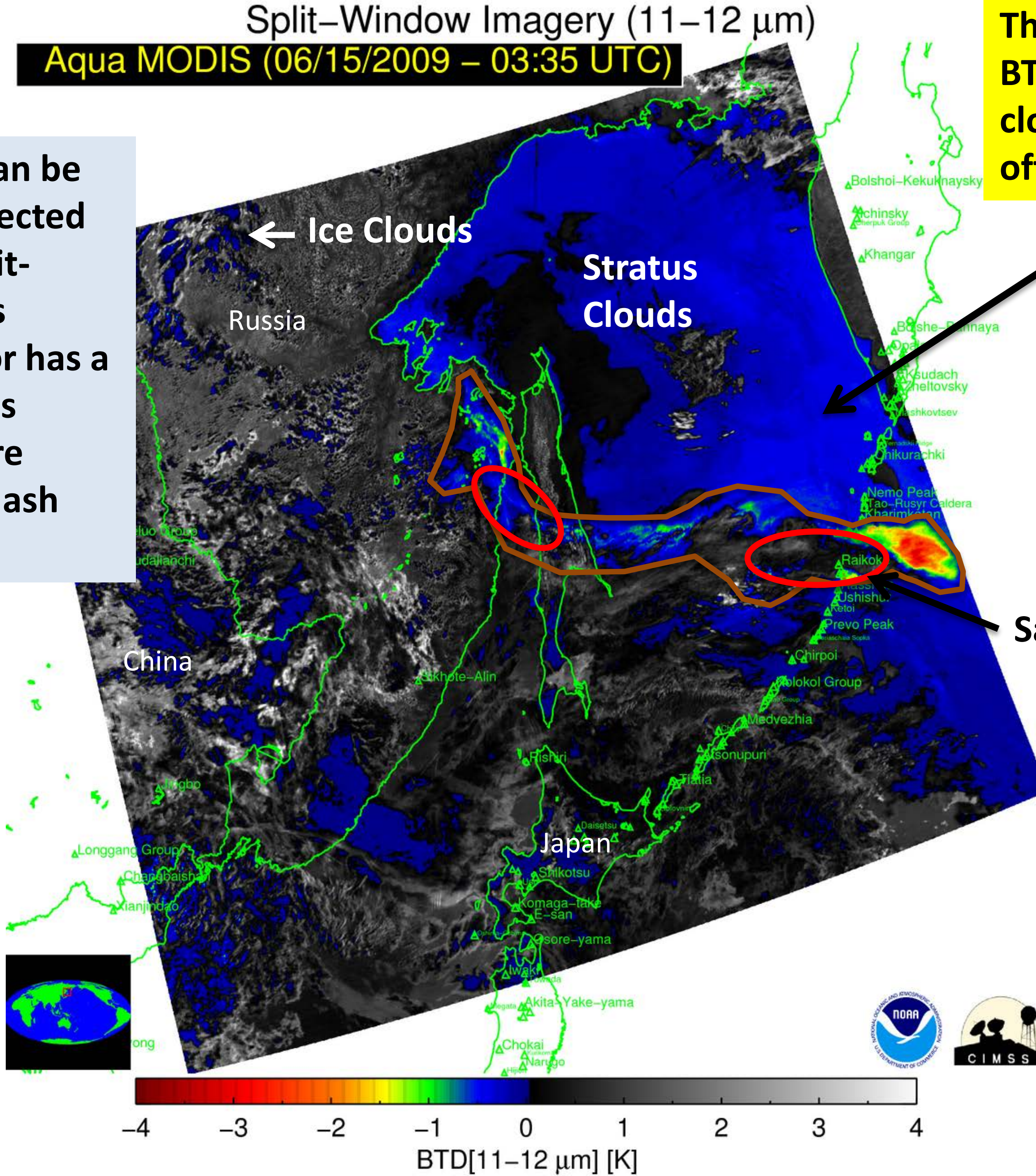
IR Window Imagery and Ash Probability



Volcanic ash can be accurately detected even if the split-window BTD is positive and/or has a similar value as another feature outside of the ash cloud

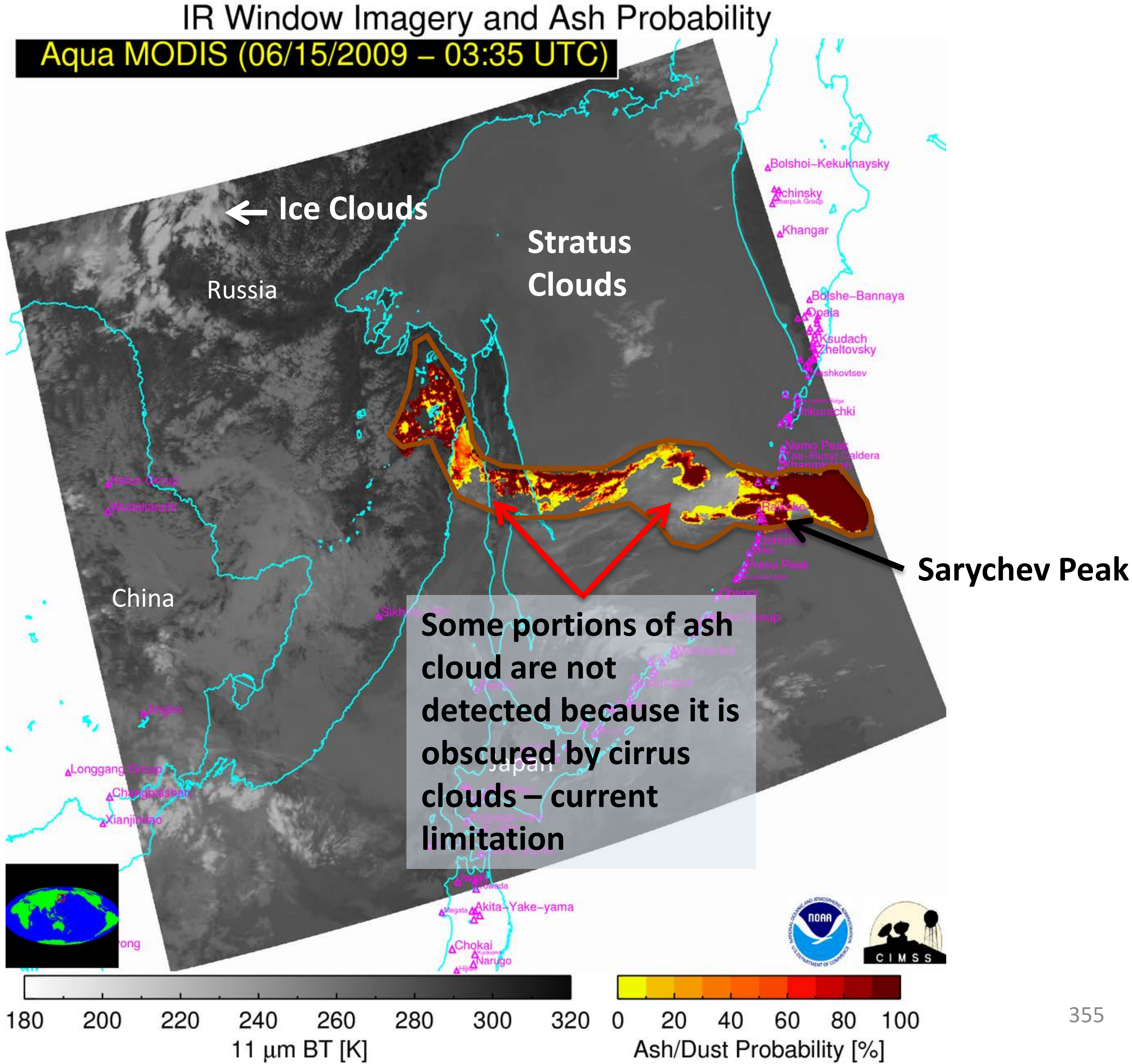


Volcanic ash can be accurately detected even if the split-window BTD is positive and/or has a similar value as another feature outside of the ash cloud

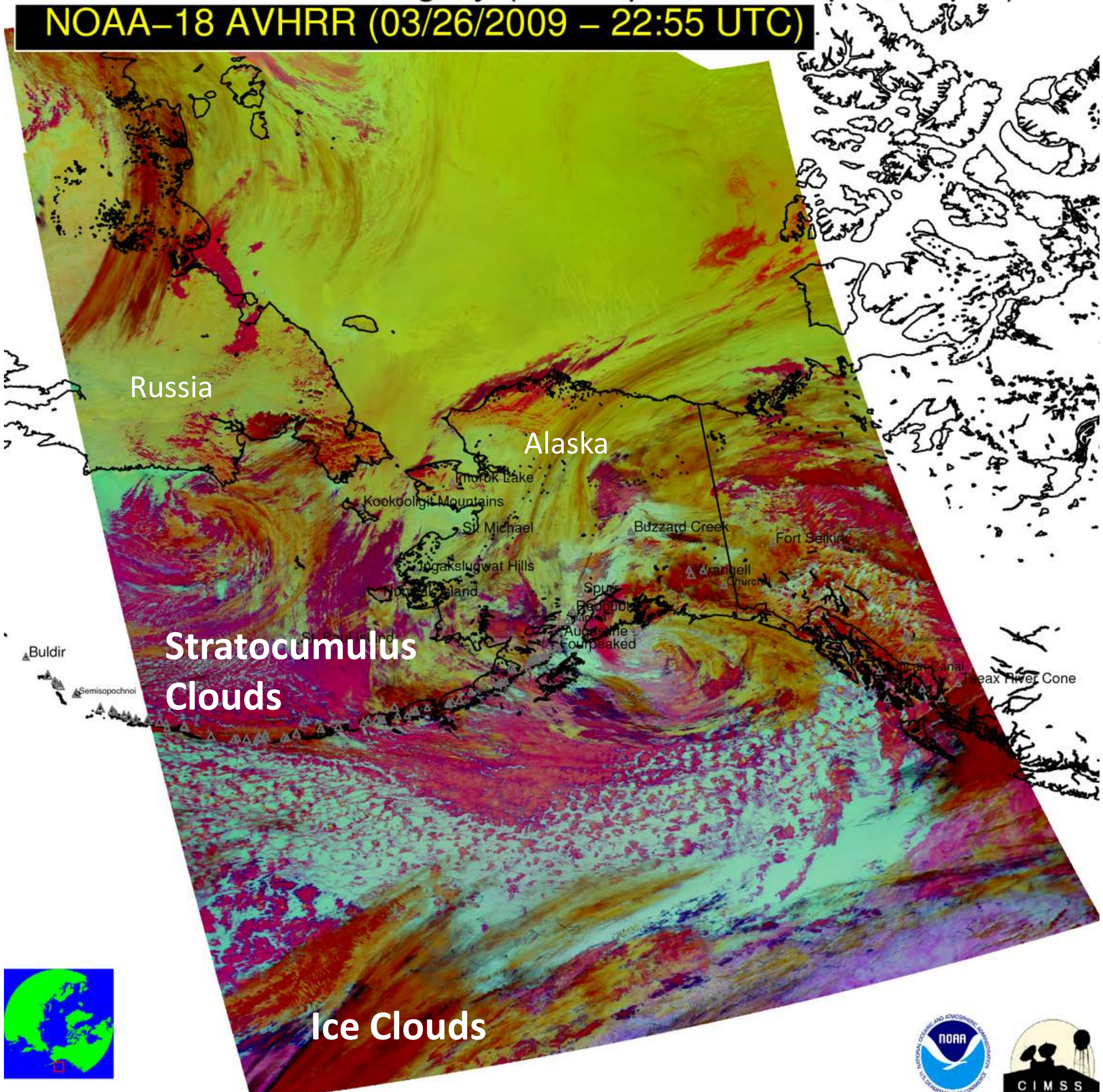


The split-window BTD of stratus cloud decks is often < -0.5 K

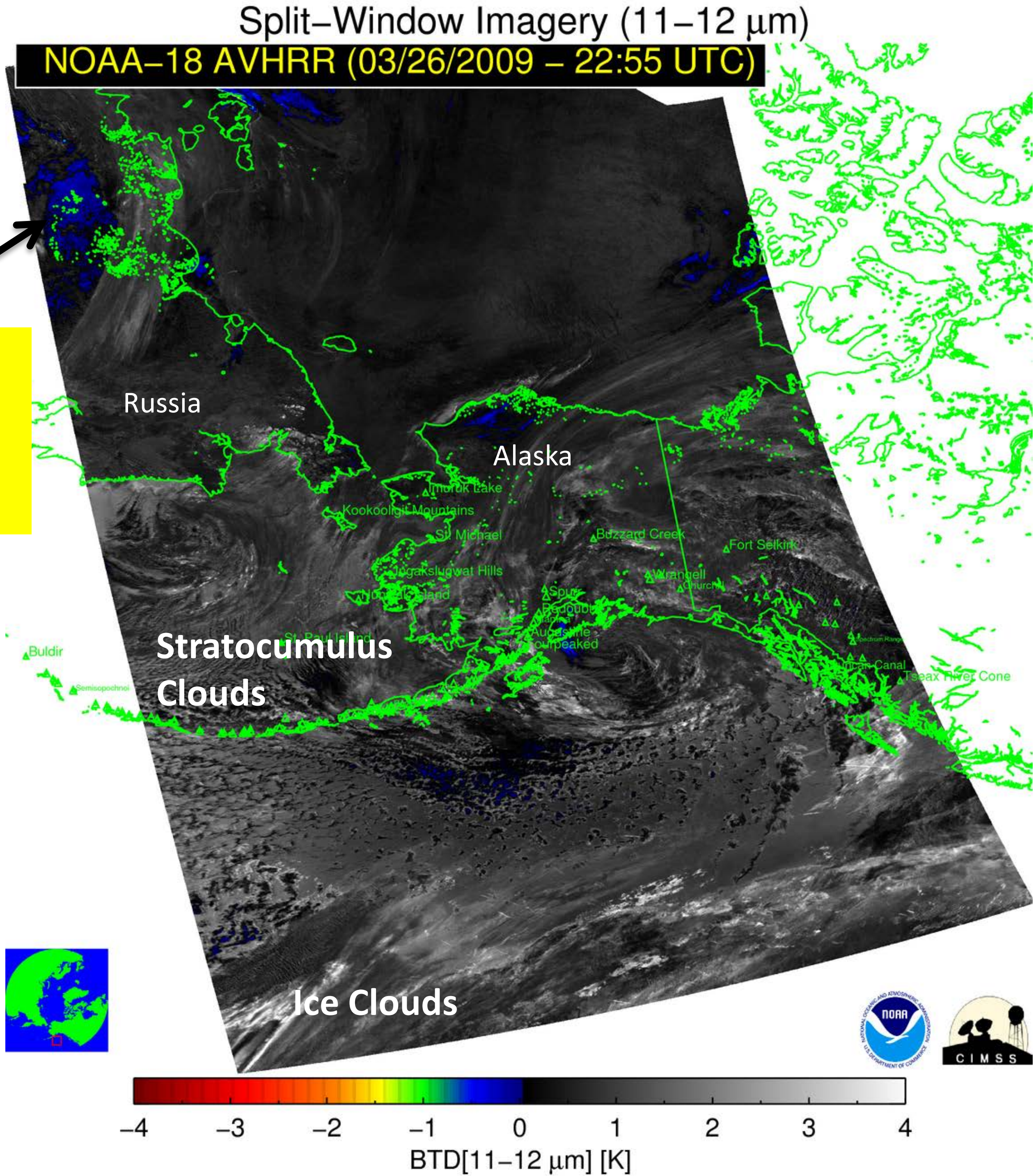
Sarychev Peak


IR Window Imagery and Ash Probability
Aqua MODIS (06/15/2009 – 03:35 UTC)
Ice Clouds
Stratus Clouds
Russia
China
Sarychev Peak
Some portions of ash cloud are not detected because it is obscured by cirrus clouds – current limitation
Bolshoi-Kekuknaysky
Khangar
Bolshe-Bannaya
Opala
Ksudach
Zheltovsky
Longgang Group
Changbaishan
Xianjindao
Akita-Yake-yama
Chokai
Narugo
180 200 220 240 260 280 300 320
11 µm BT [K]
0 20 40 60 80 100
Ash/Dust Probability [%]
CIMSS

False Color Imagery (12–11µm, 11–3.9µm, 11µm)

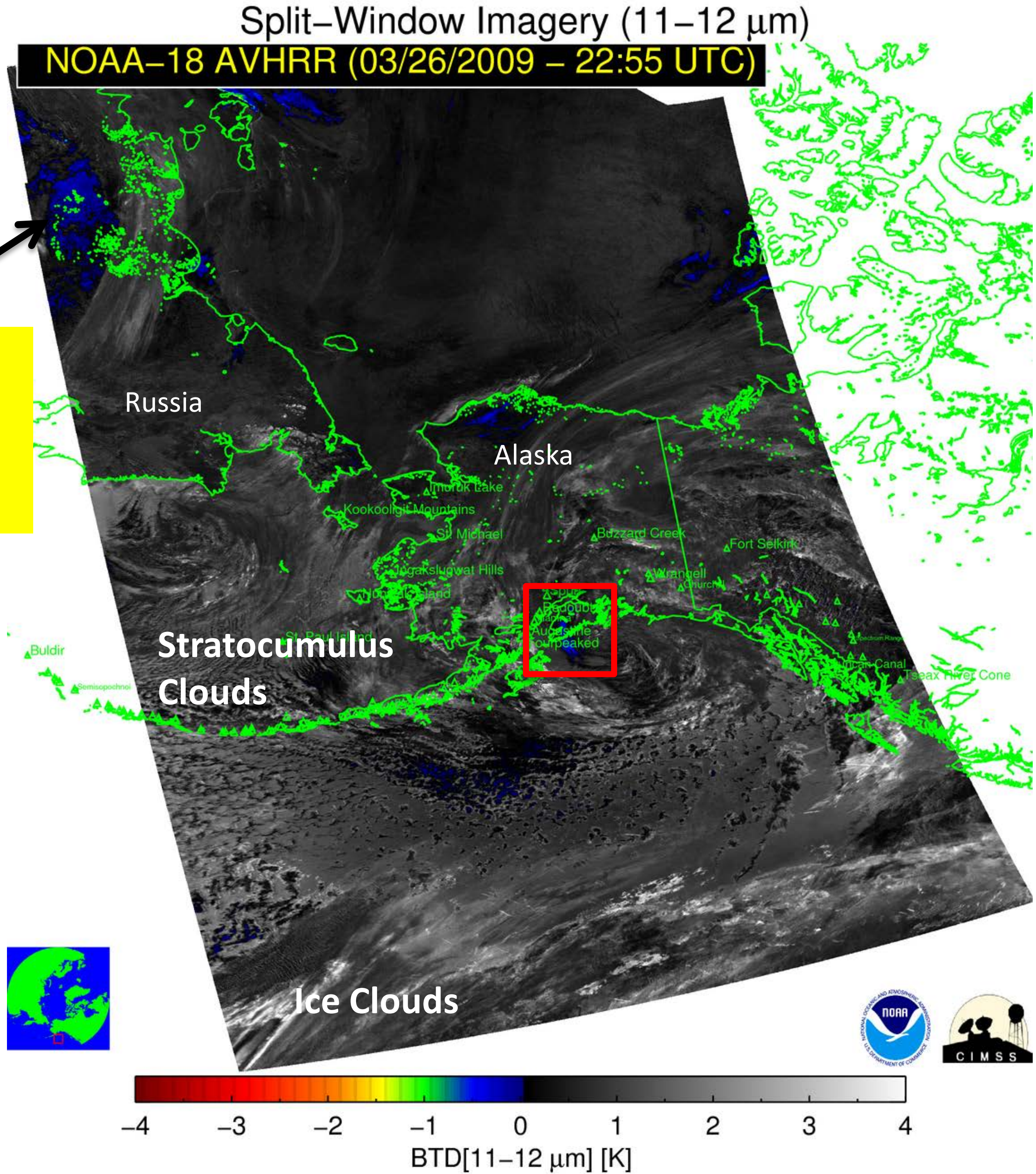


Annotation Key
(annotation colors are not related to colors in underlying image)
Ash/Dust Cloud Volcanic Cb SO_2 Thermal Anomaly

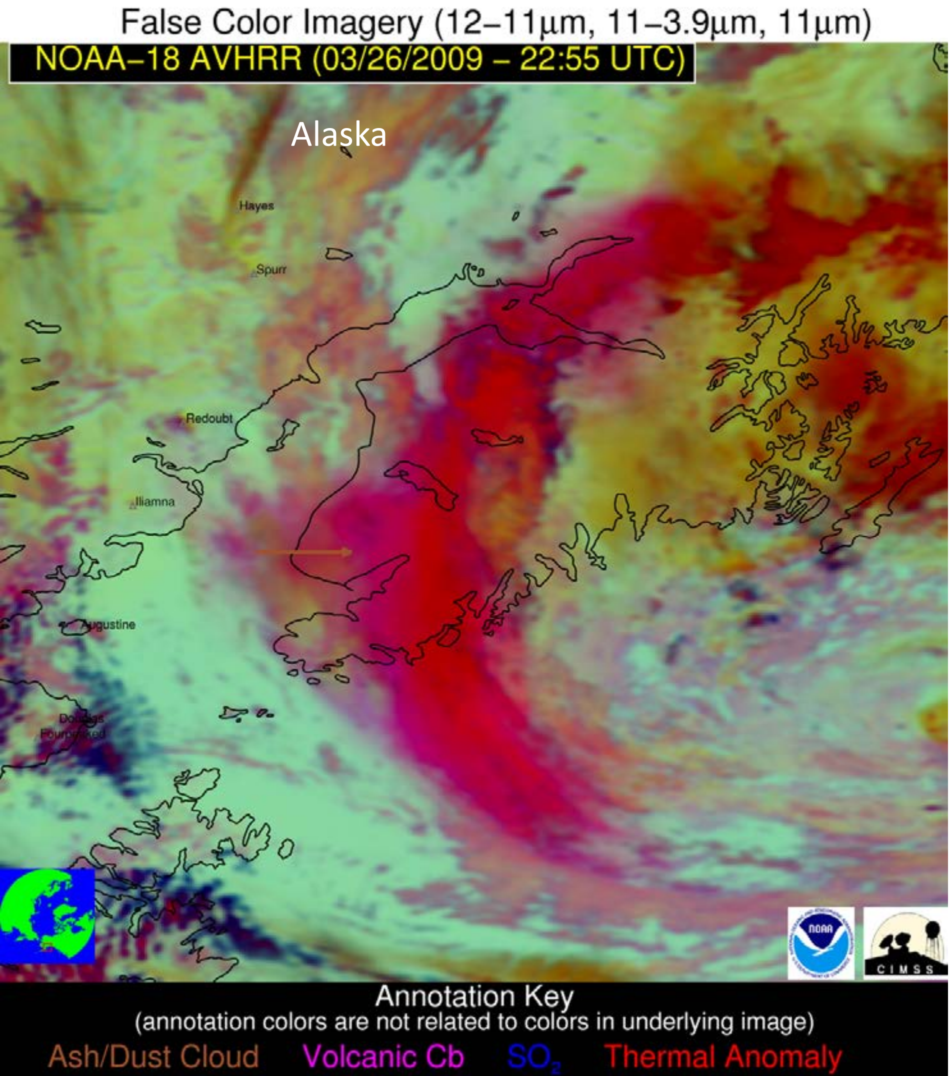


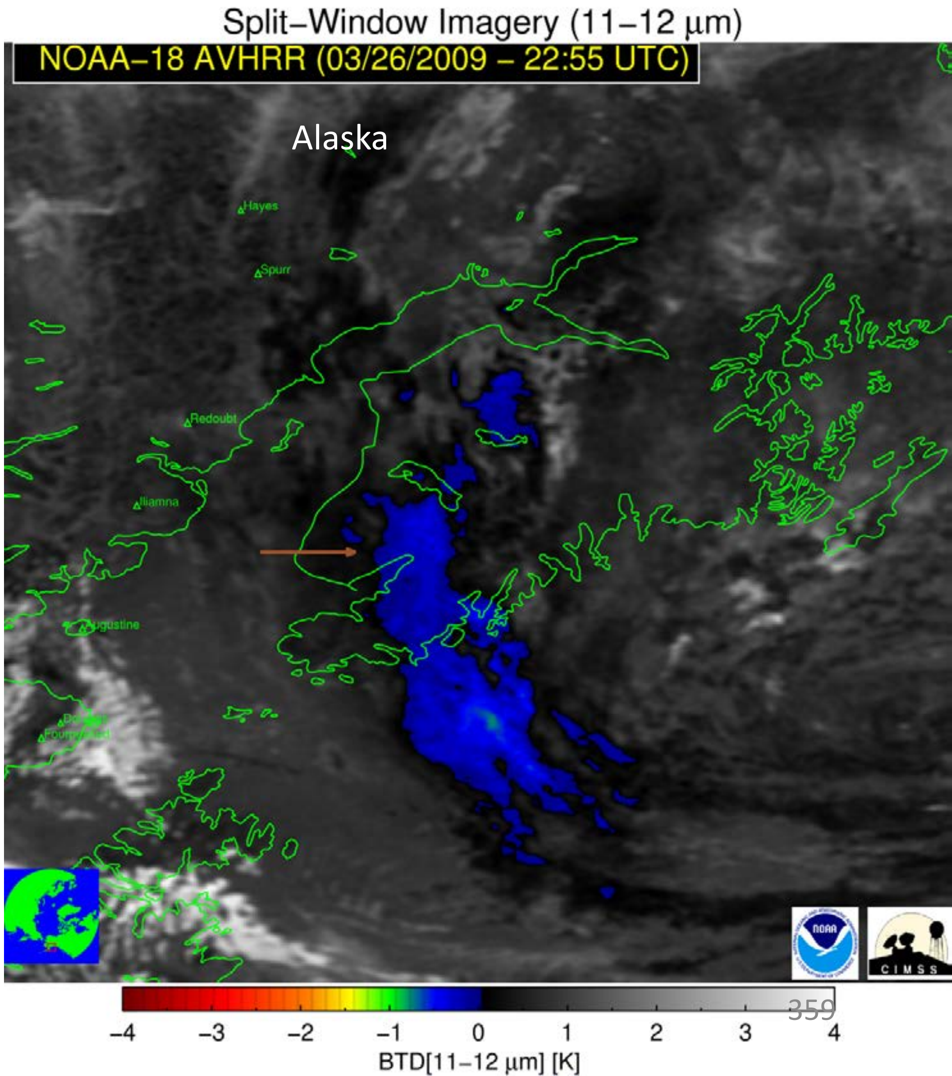
The split-window BTD of clear sky is often < -0.5 K

The split-window BTD of clear sky is often < -0.5 K

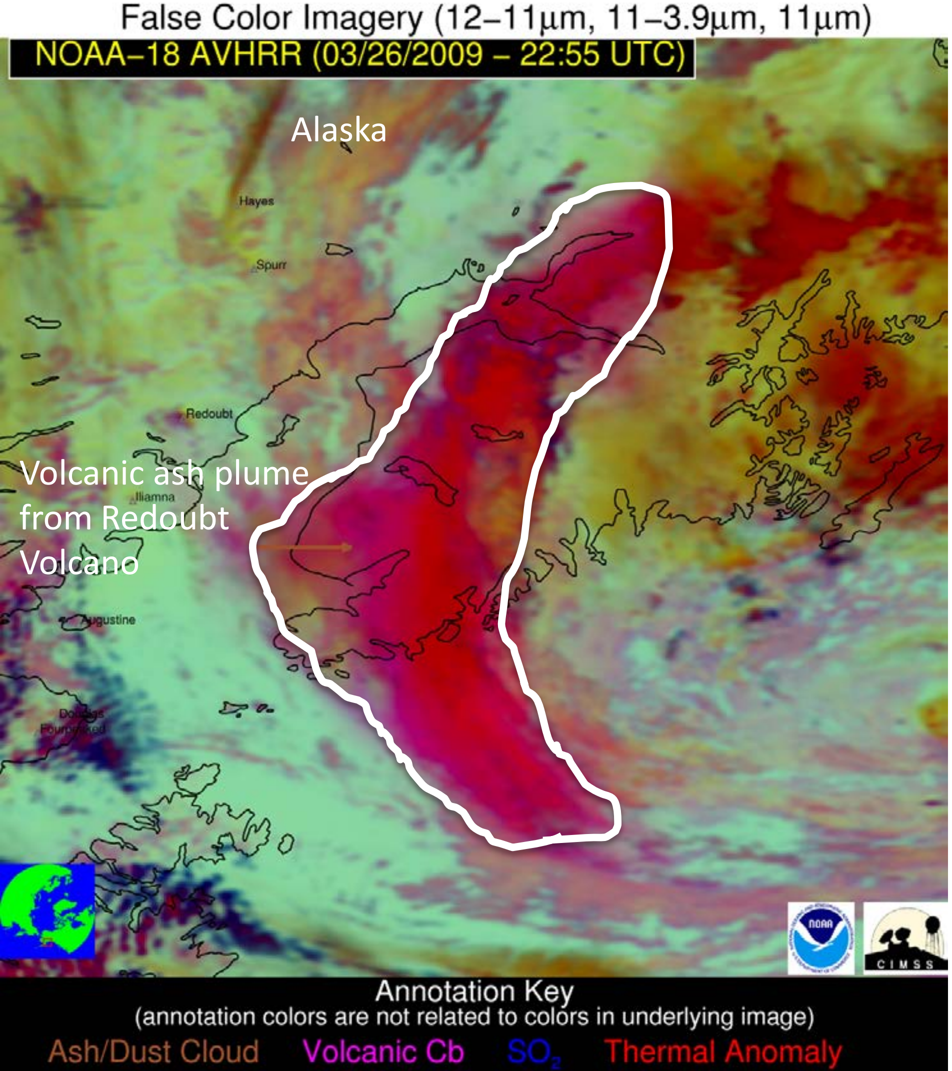


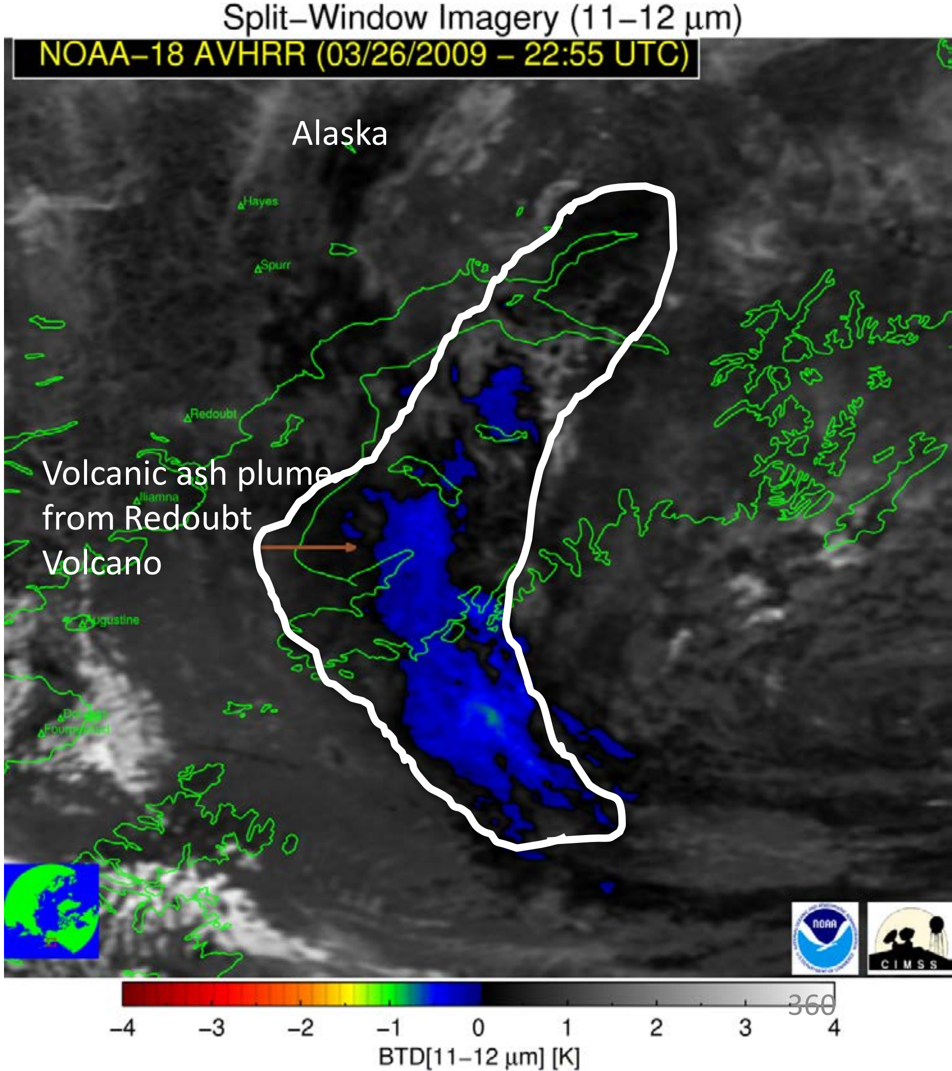
The split-window BTD of this ash plume is generally > -0.5 K. Using the split-window alone, this cloud cannot be quantitatively detected without introducing a massive number of false alarms.



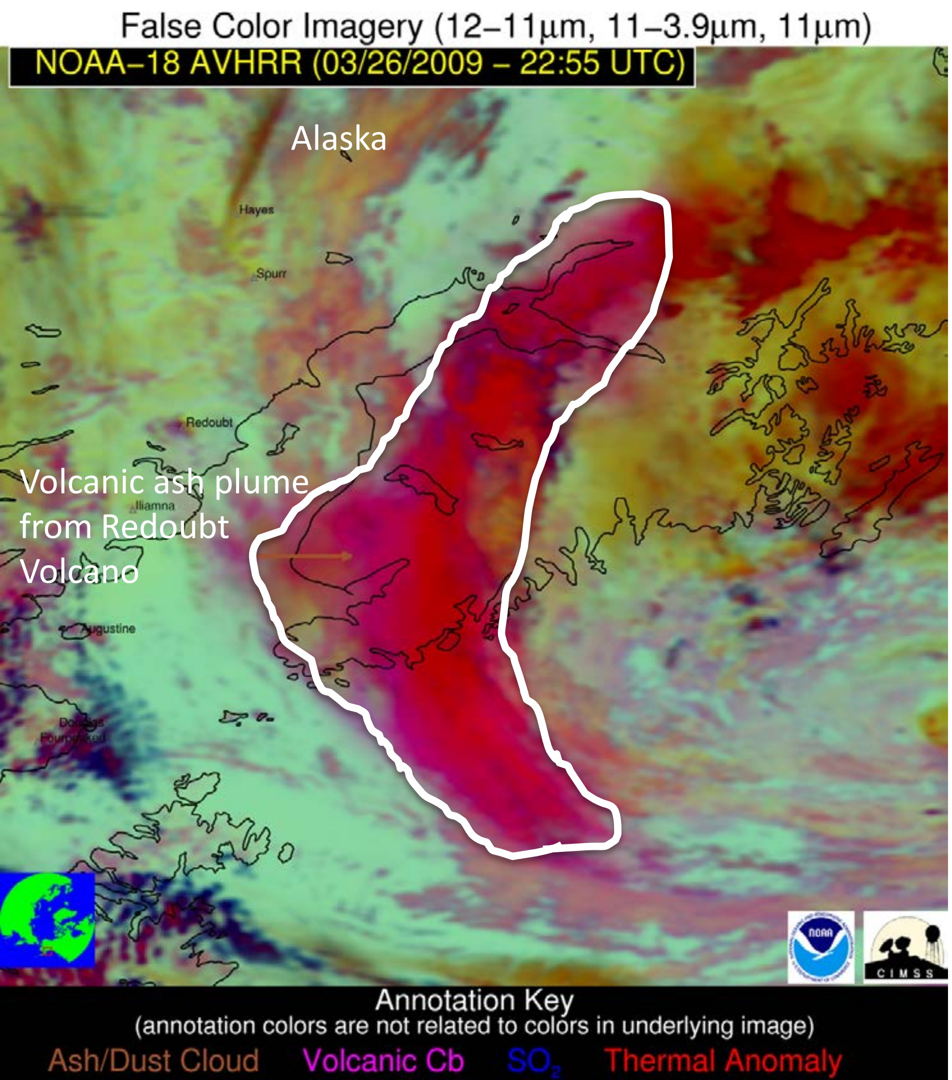


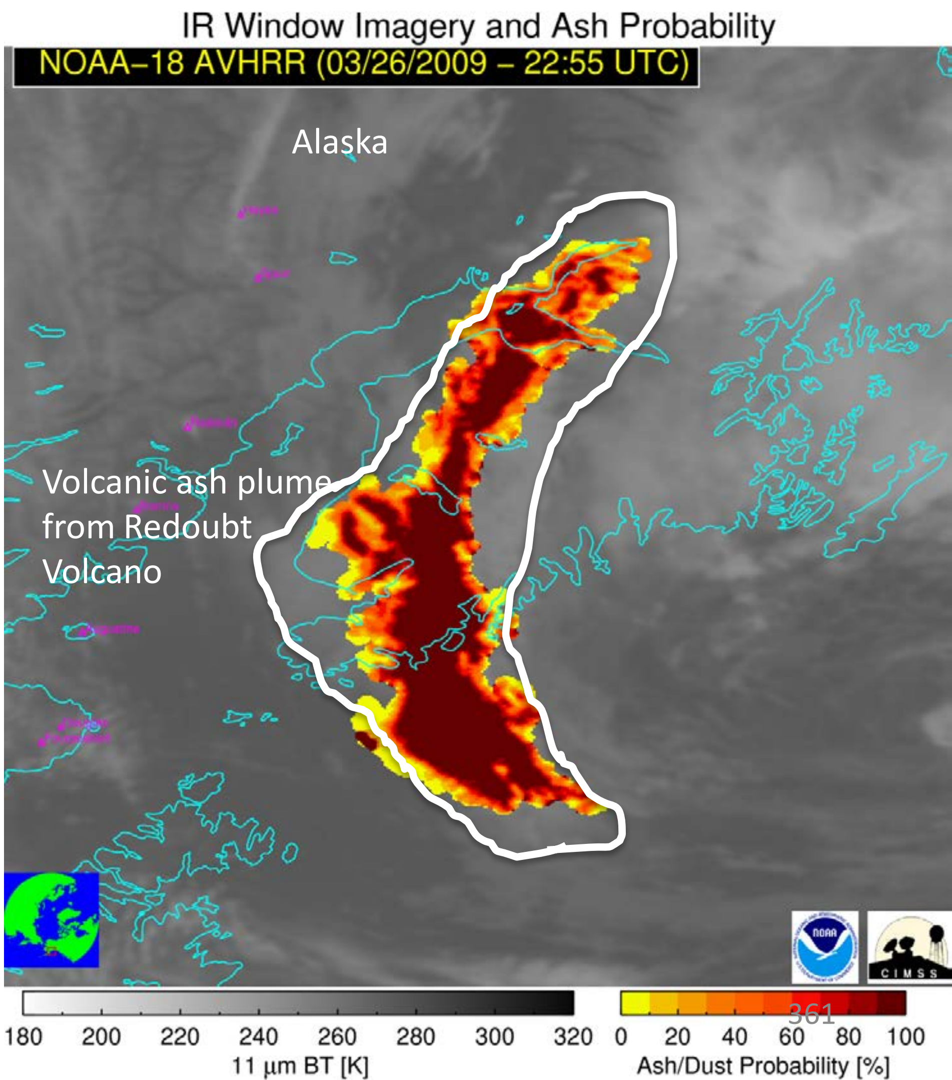
The split-window BTD of this ash plume is generally > -0.5 K. Using the split-window alone, this cloud cannot be quantitatively detected without introducing a massive number of false alarms.



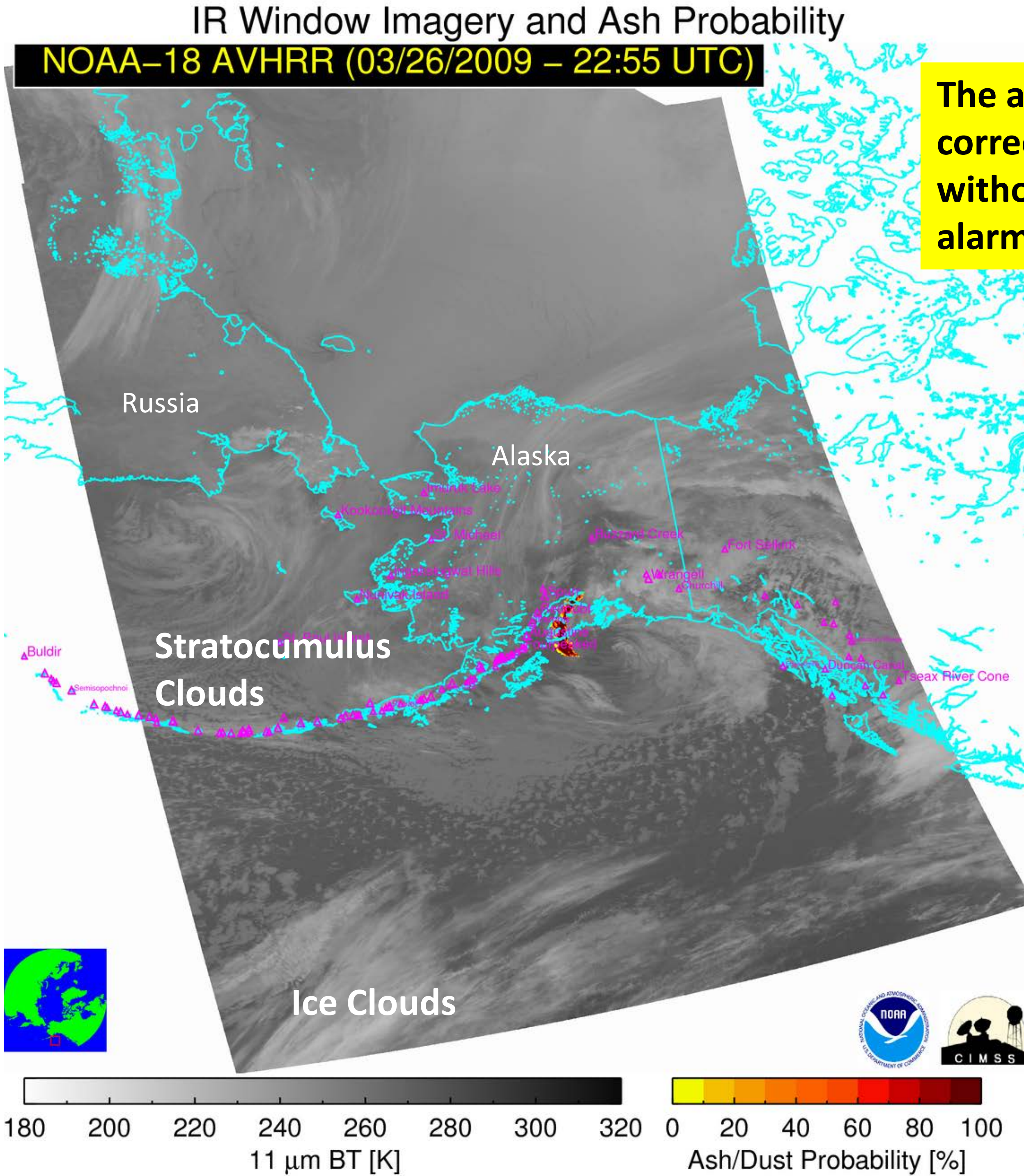


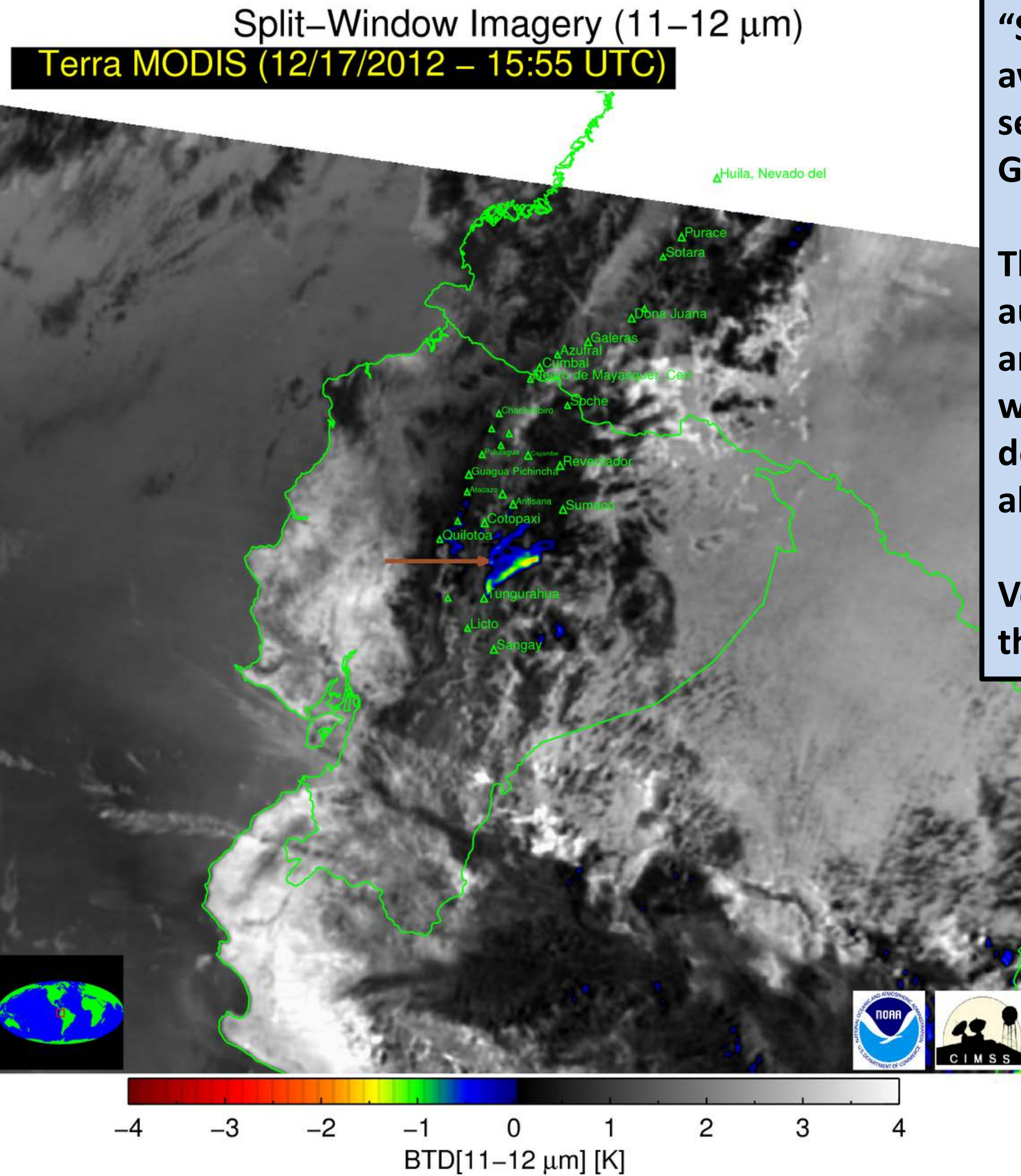
The ash detection method developed by NOAA is able to detect the majority of this cloud without introducing any false alarms.





The ash plume is correctly detected without any false alarms

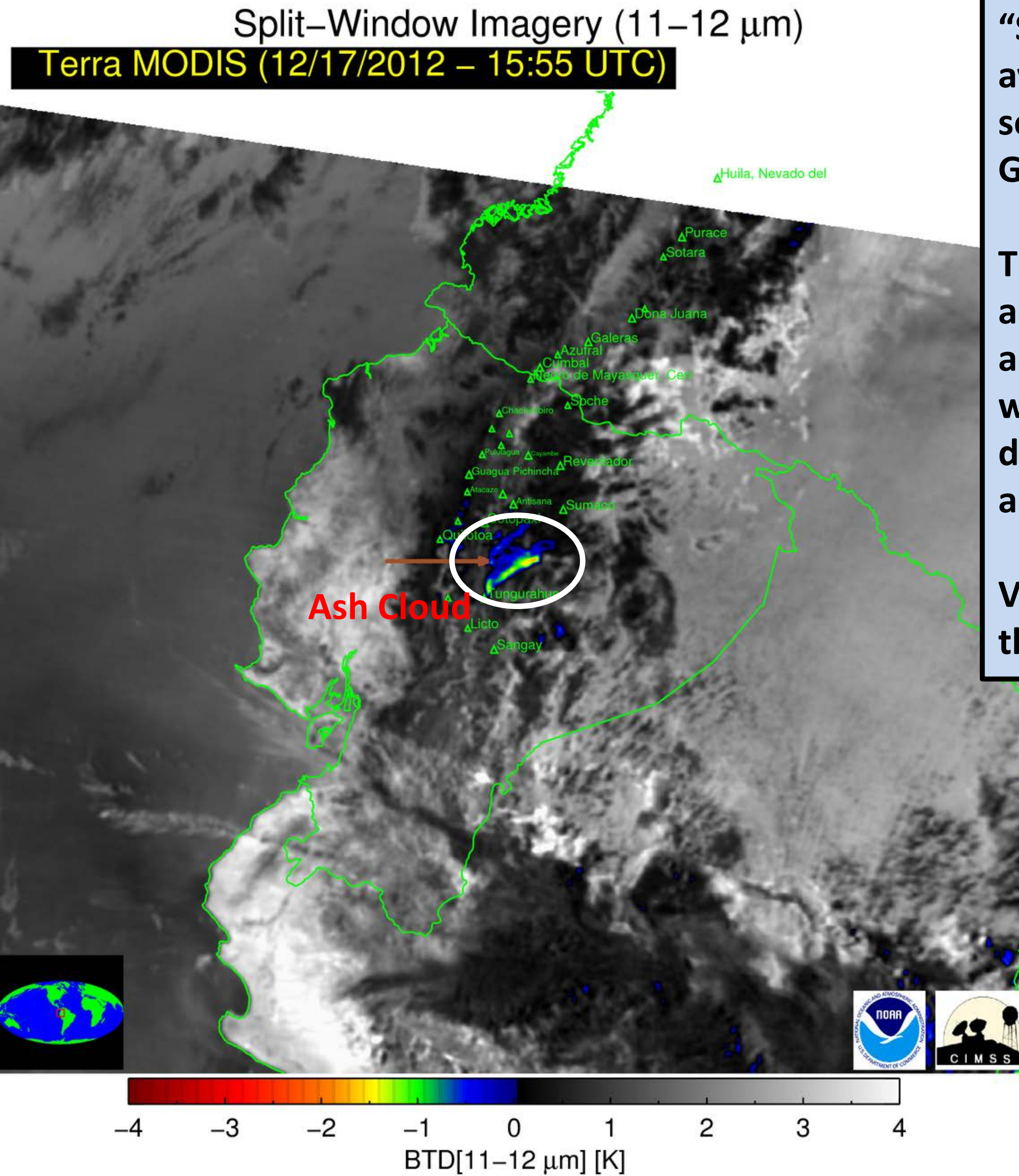




"Split-window" imagery is available on the web site for all sensors except GOES-12, GOES-13, GOES-14, and GOES-15.

The "split-window" imagery is automatically annotated (with arrows or contours) to show where a volcanic cloud was detected by our automated algorithm.

Volcano locations are denoted on the imagery



"Split-window" imagery is available on the web site for all sensors except GOES-12, GOES-13, GOES-14, and GOES-15.

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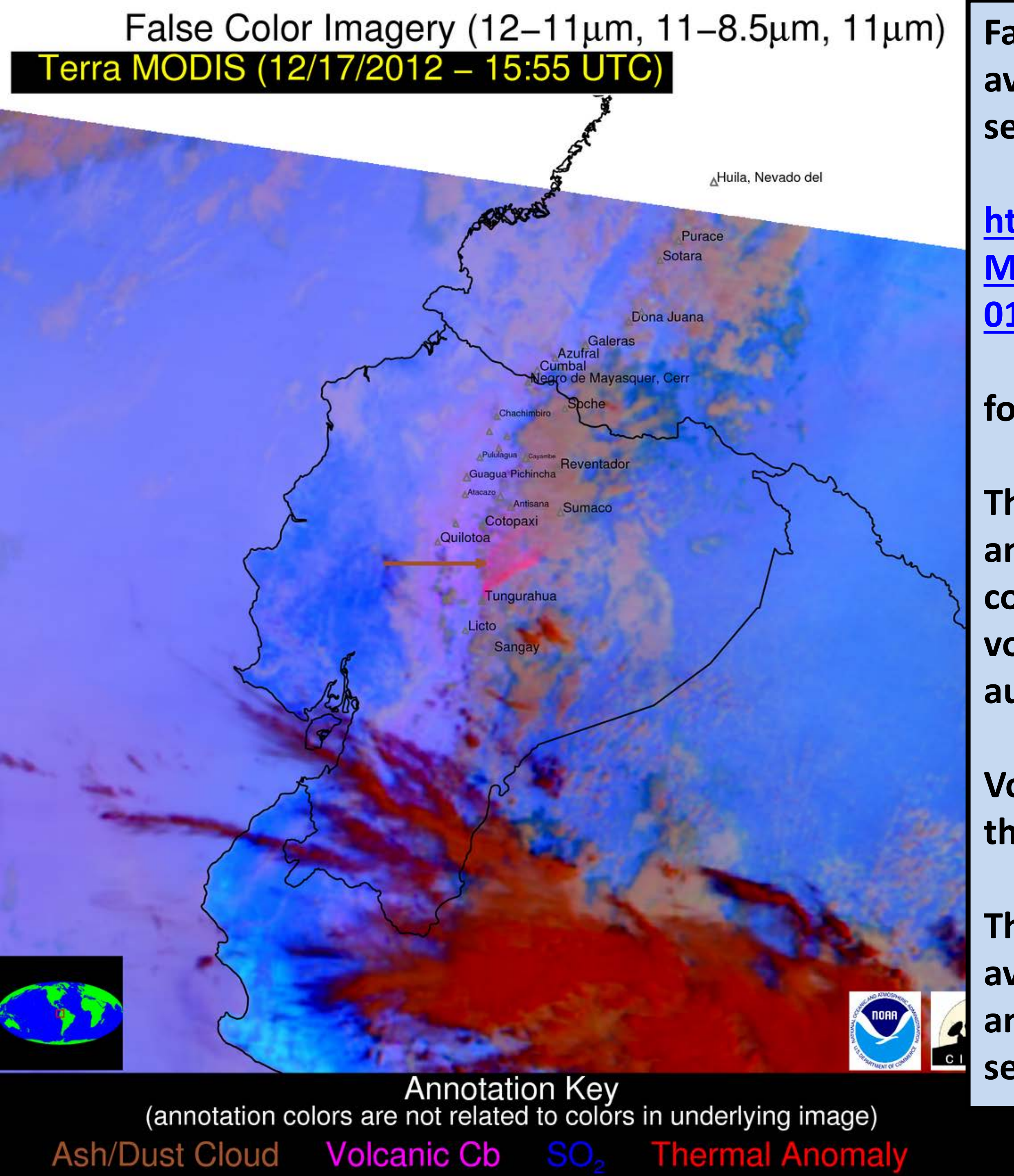


False color (RGB) imagery is also available on the web site. Please see:

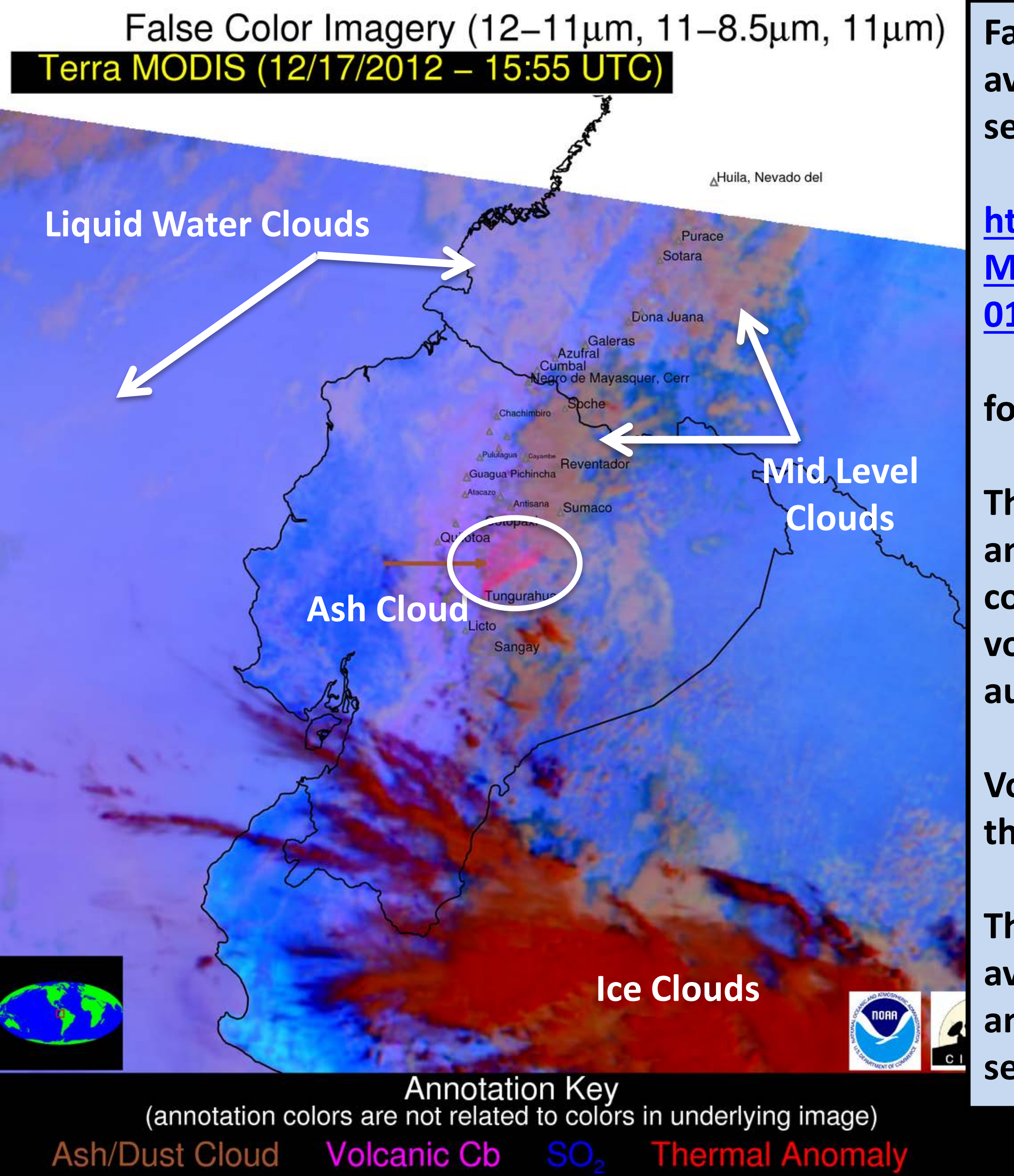
http://www.eumetsat.int/Home/Main/DataProducts/Training/SP_2012105102052215?l=en

for detailed RGB training material.

The RGB imagery is automatically annotated (with arrows or contours) to show where a volcanic cloud was detected by our automated algorithm.

Volcano locations are denoted on the imagery

This channel combination is available on MODIS, SEVIRI, VIIRS, and the GOES-R ABI (future sensor)



False color (RGB) imagery is also available on the web site. Please see:

http://www.eumetsat.int/Home/Main/DataProducts/Training/SP_201210510205221 5?l=en

for detailed RGB training material.

The RGB imagery is automatically annotated (with arrows or contours) to show where a volcanic cloud was detected by our automated algorithm.

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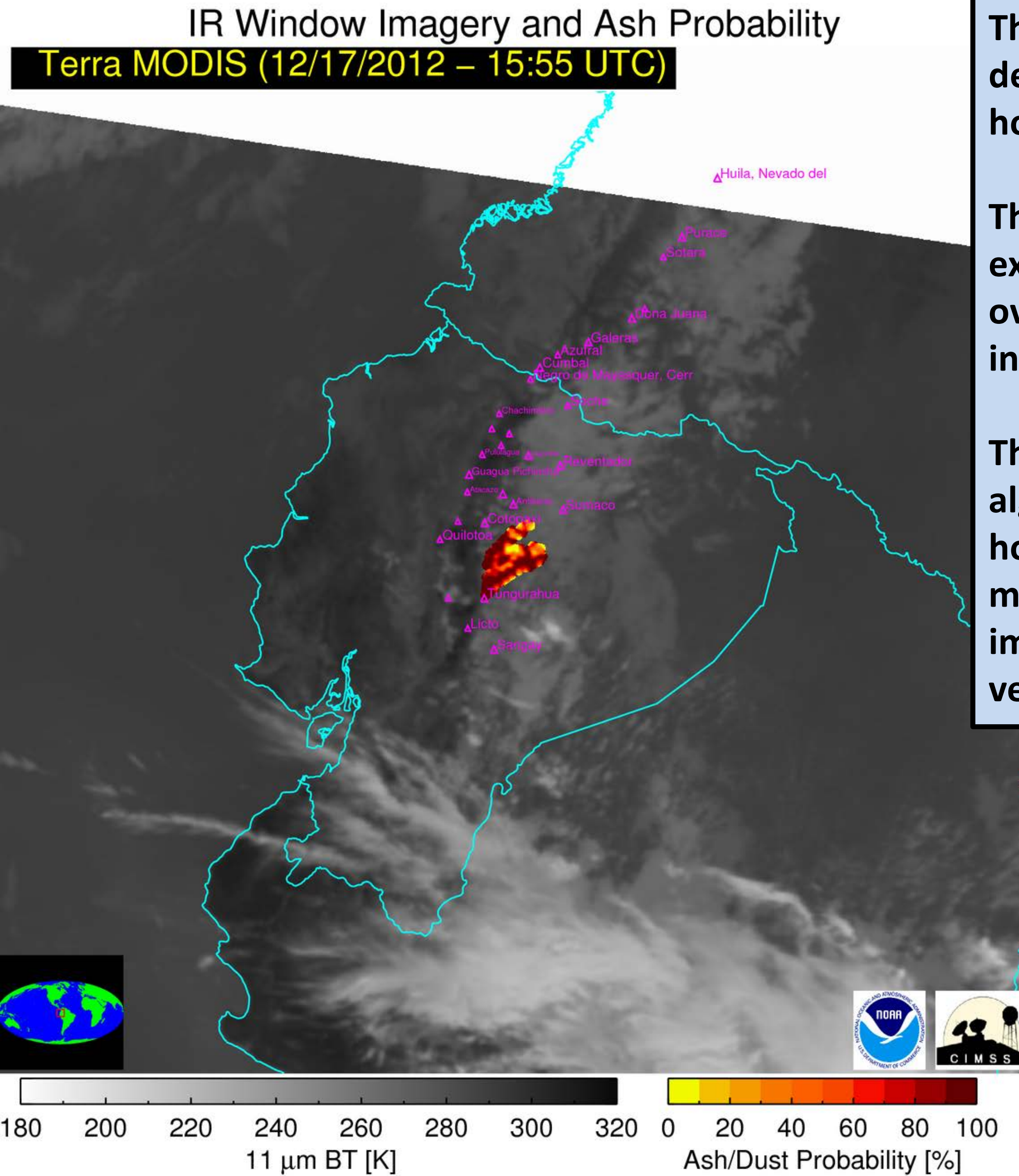
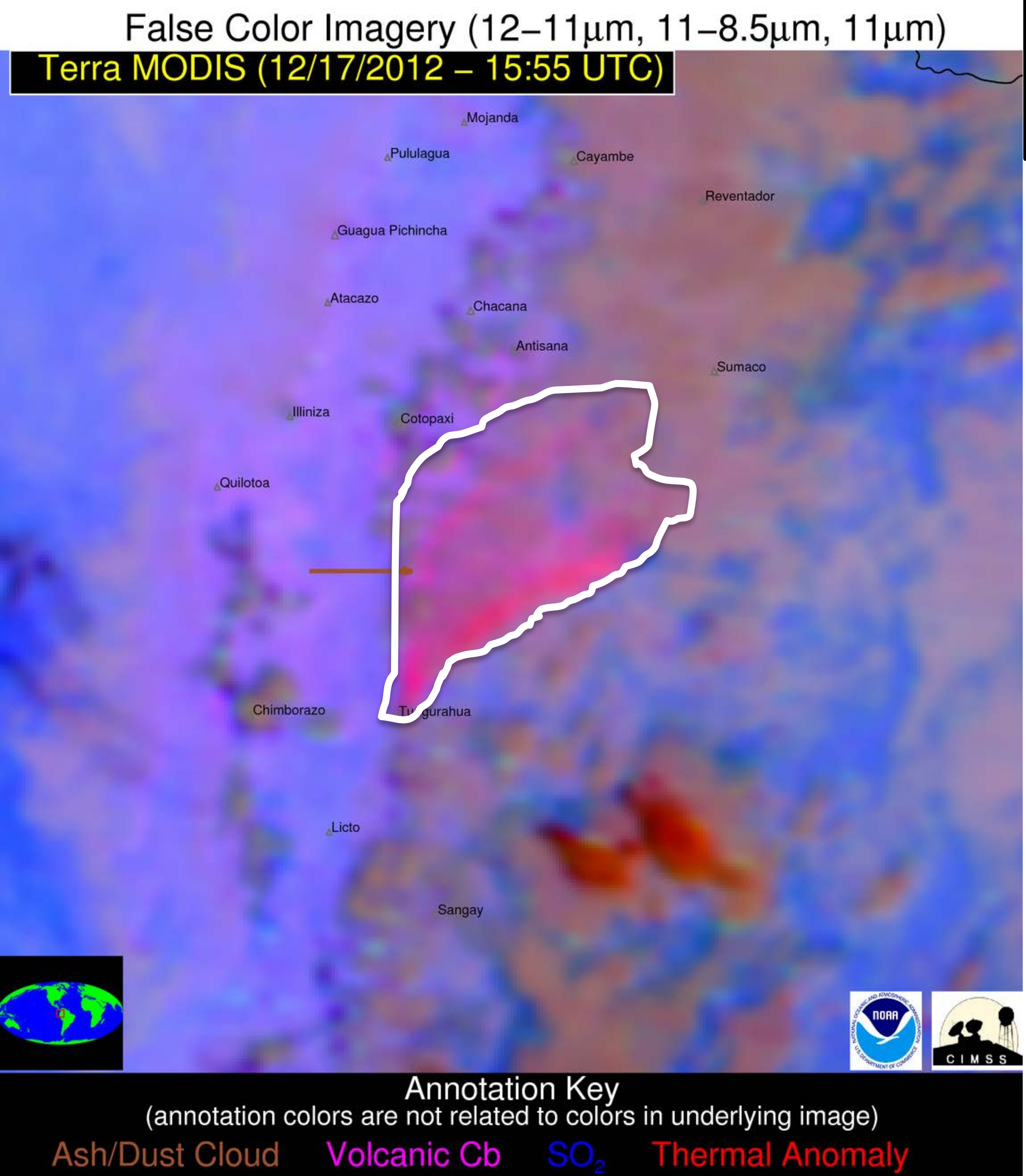


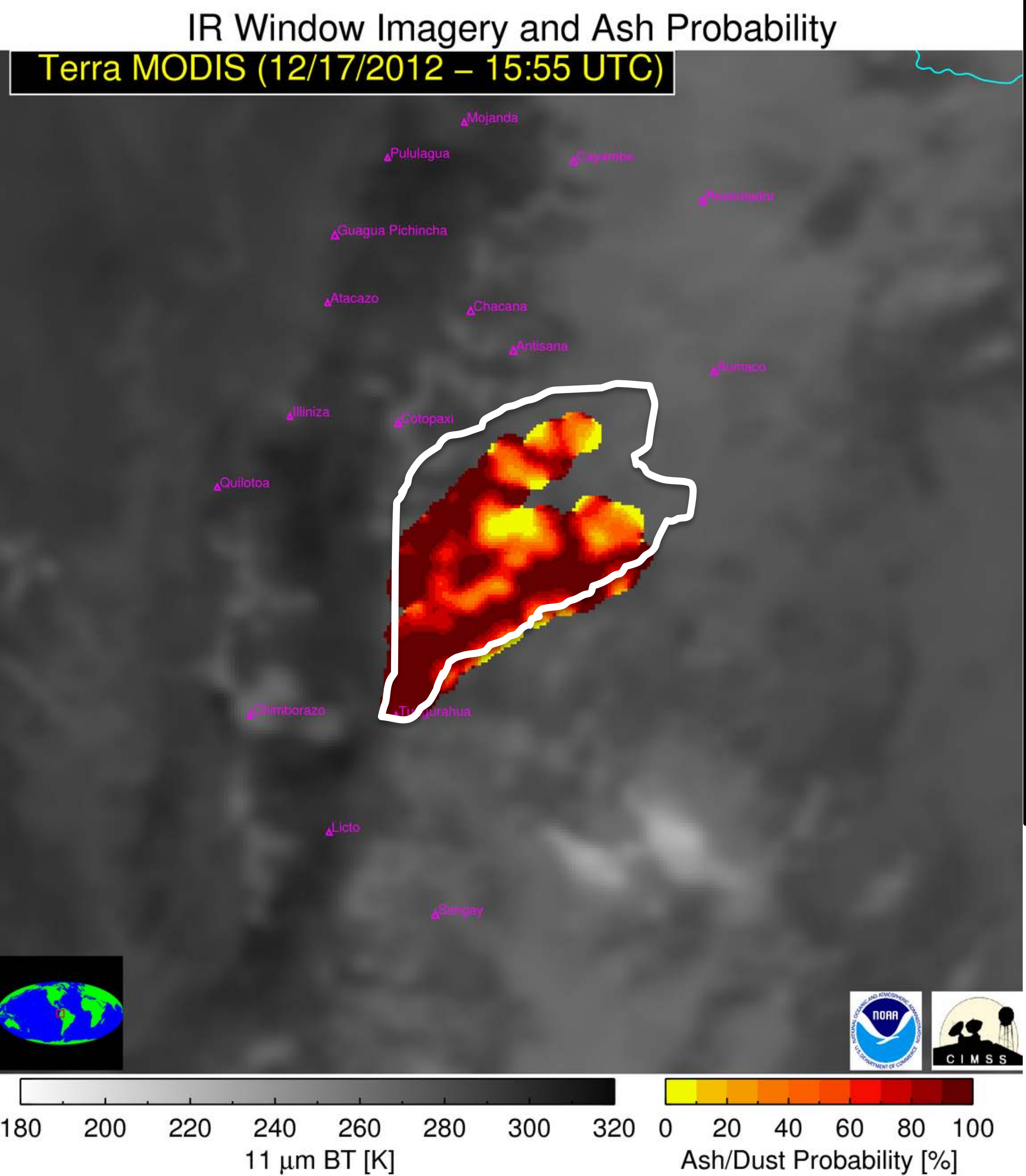
The automated volcanic ash detection results quantify the horizontal extent of volcanic ash

The ash detection, which is expressed as a probability, is overlaid on standard 11 µm infrared imagery

The automated ash detection algorithm is designed to mimic how a well trained human would manually analyze a multi-spectral image (high detection rate and a very low false alarm rate)



A manual analysis of this image suggests the horizontal boundary depicted in white

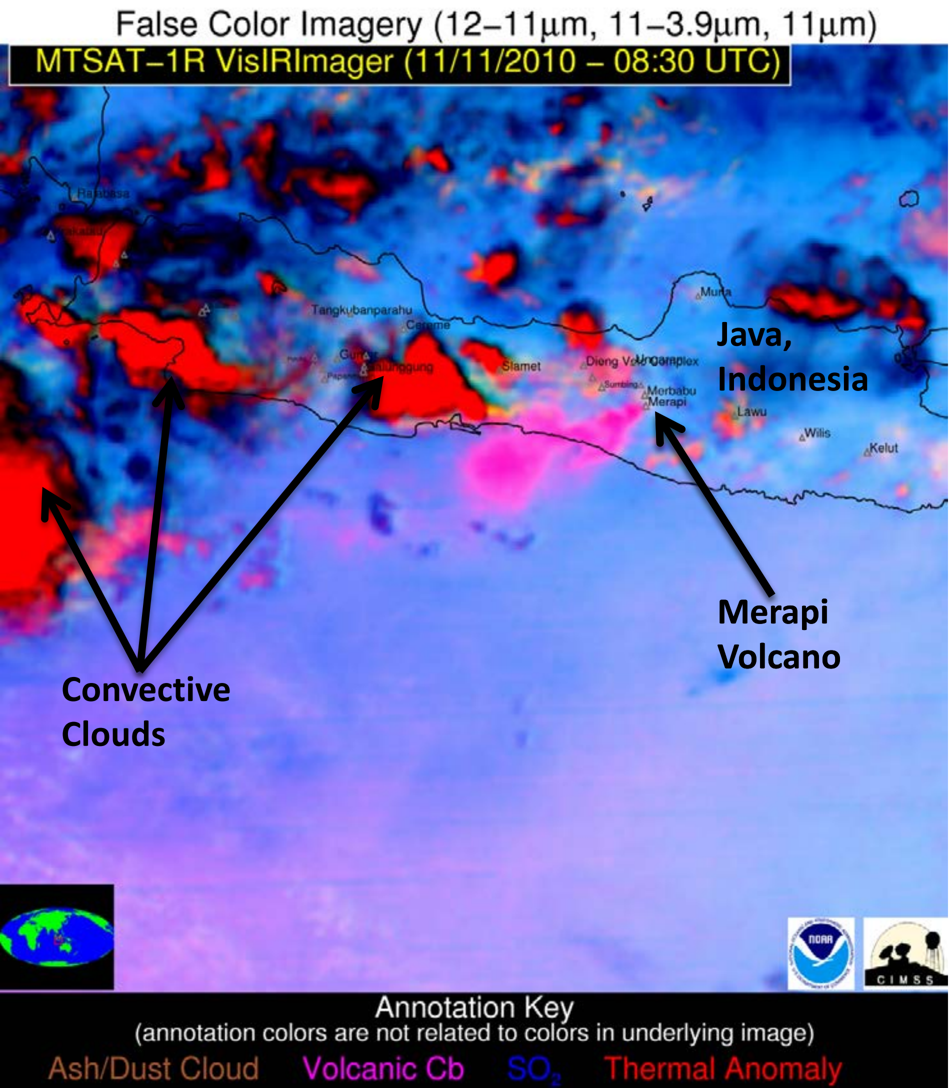


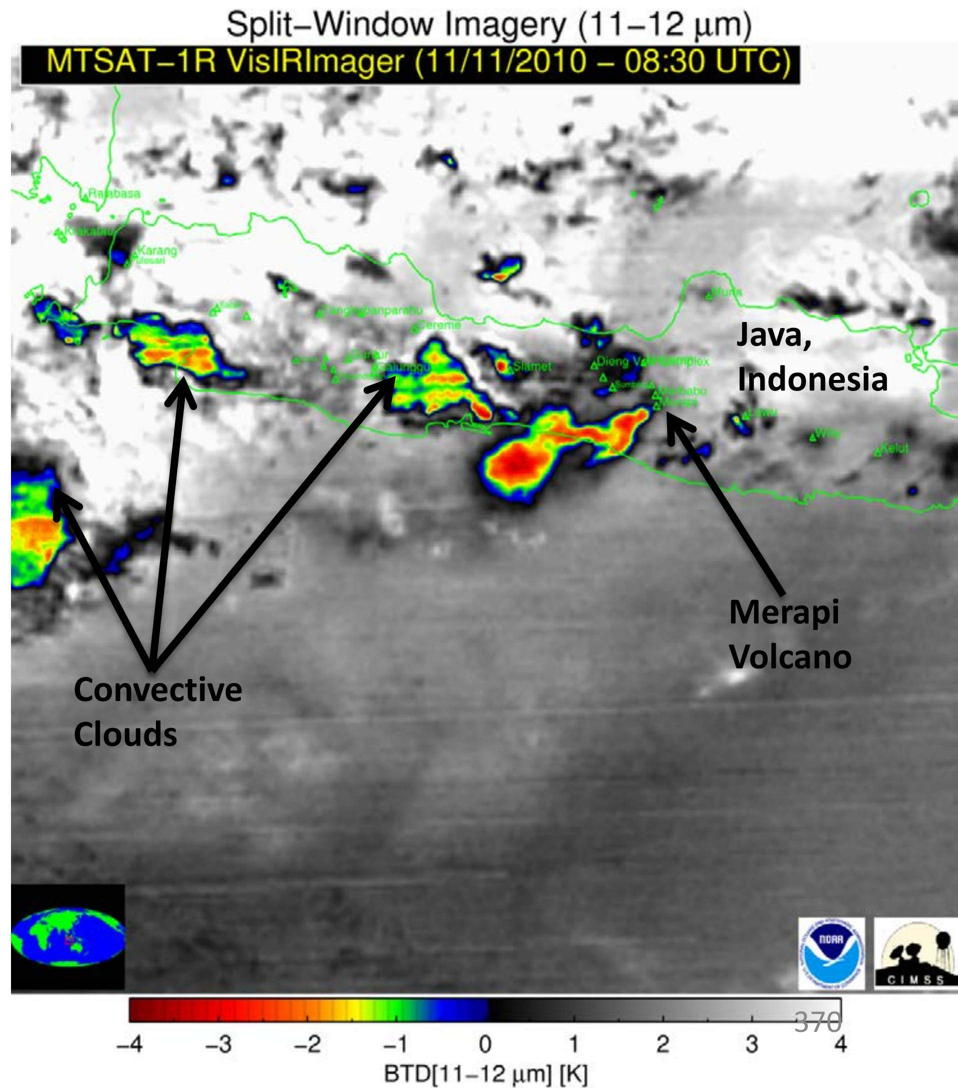
The horizontal extend of the ash cloud determined by our automated computer algorithm agrees very well with the bounds derived from manual analysis of multi-spectral imagery

While a very well trained human will most often slightly out-perform the computer algorithm, the automated detection results are accurate enough to be used to issue alerts when an ash cloud is found (and eventually initialize dispersion models)

Application of NOAA Ash Detection Technique to MTSAT-1R

Convective clouds often exhibit a significant negative split-window BTD in MTSAT-1R images





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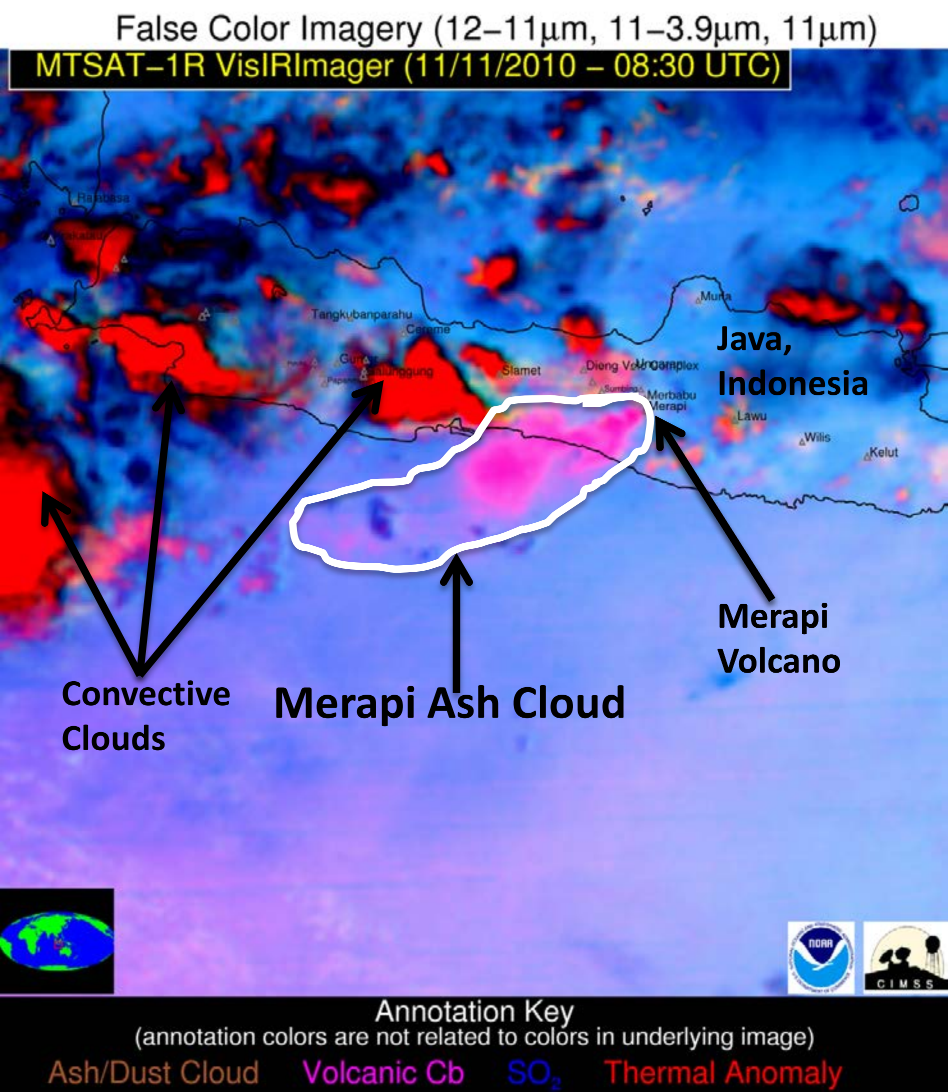
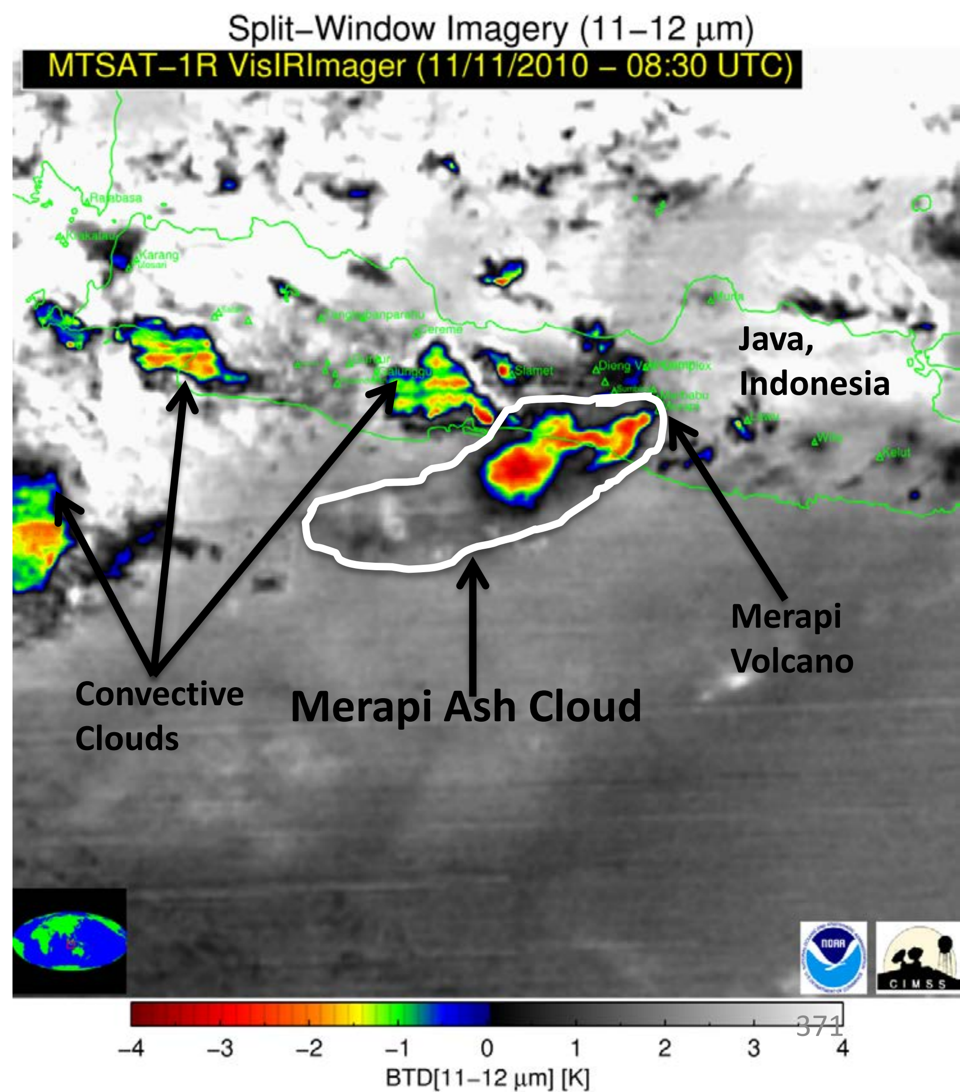
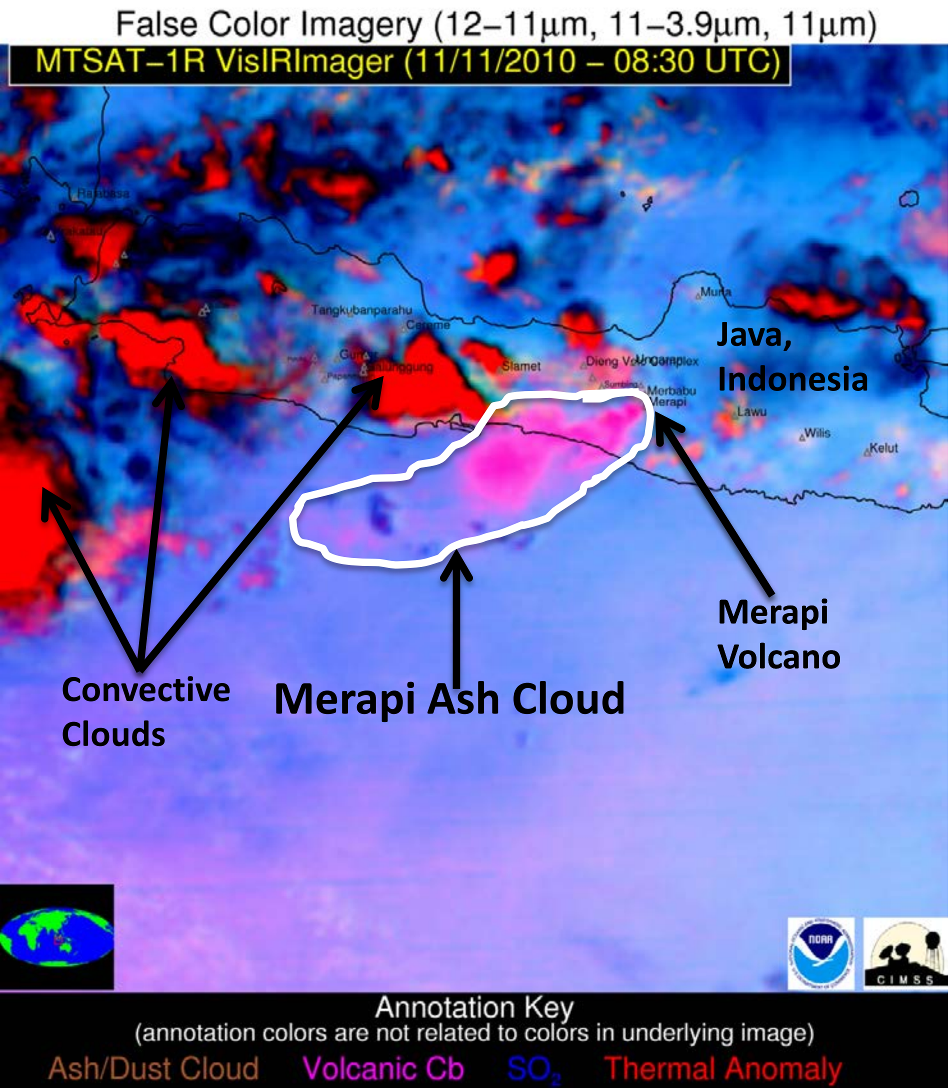
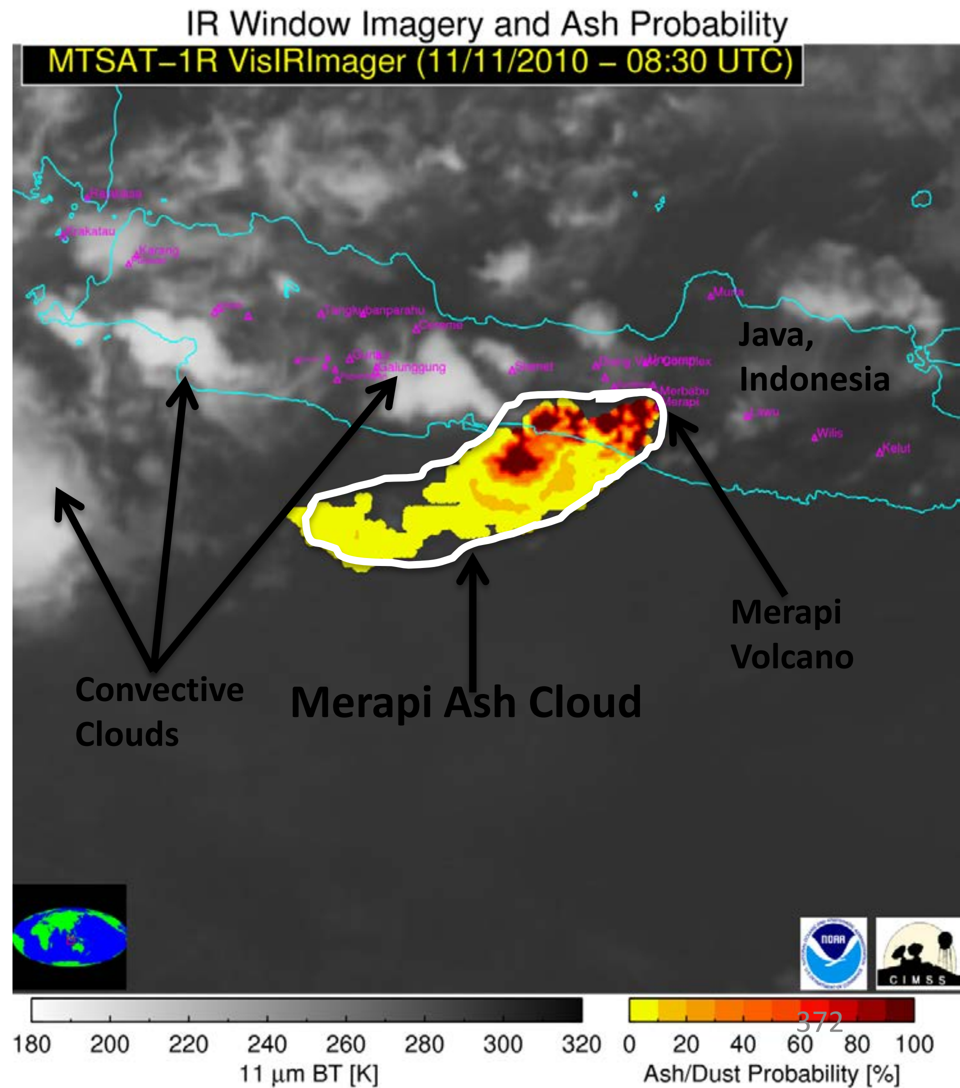




Application of NOAA Ash Detection Technique to MTSAT-1R

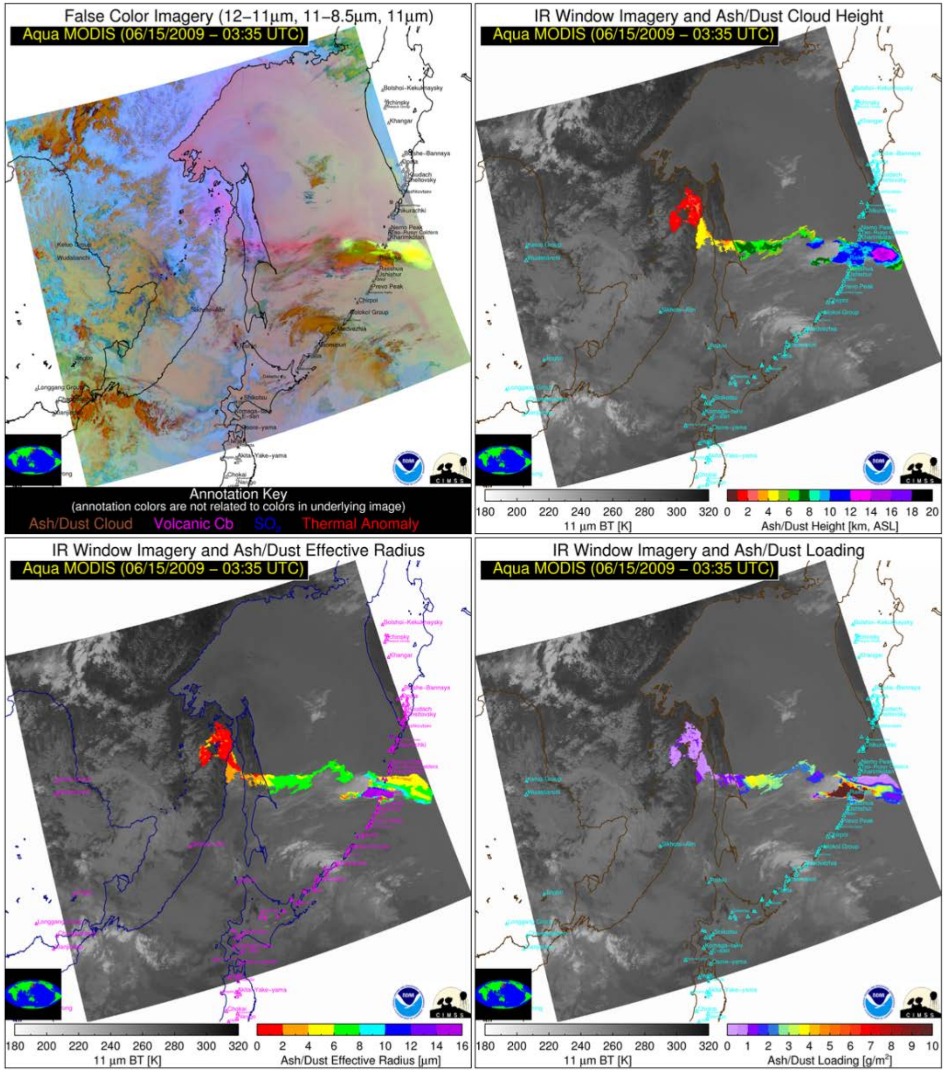
The NOAA algorithm is able accurately detect the ash cloud without introducing false alarms






Marco Fulle - www.stromboli.net

Volcanic Cloud Property Retrieval



- **An optimal estimation approach is used to retrieve the ash cloud temperature, 11 µm emissivity, and β(12/11 µm)**

- **The ash cloud height can be estimated from the cloud temperature using an atmospheric profile and the mass loading and effective particle radius can be estimated from the 11 µm emissivity and β(12/11 µm)**

- **A negative split-window BTD need not be present. See Pavolonis et al. (2013) for details.**

The retrieval solution is determined from a weighted combination of the difference between the measurements and forward model and the first guess

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

Channels Used in NOAA Ash Retrieval Algorithm

A temporal history of detected ash clouds is used to help ensure good consistency from image to image regardless of the sensor

Sensor	Channels used
AVHRR	11 and 12 µm
COMS	11 and 12 µm
FY2	11 and 12 µm
GOES	11 and 13.3 µm
GOES-R ABI	11, 12, and 13.3 µm
Himawari-8/9	11, 12, and 13.3 µm
MODIS	11, 12, and 13.3 µm
MTSAT	11 and 12 µm
SEVIRI	11, 12, and 13.3 µm
VIIRS	11 and 12 µm

***The same software is used for all sensors.

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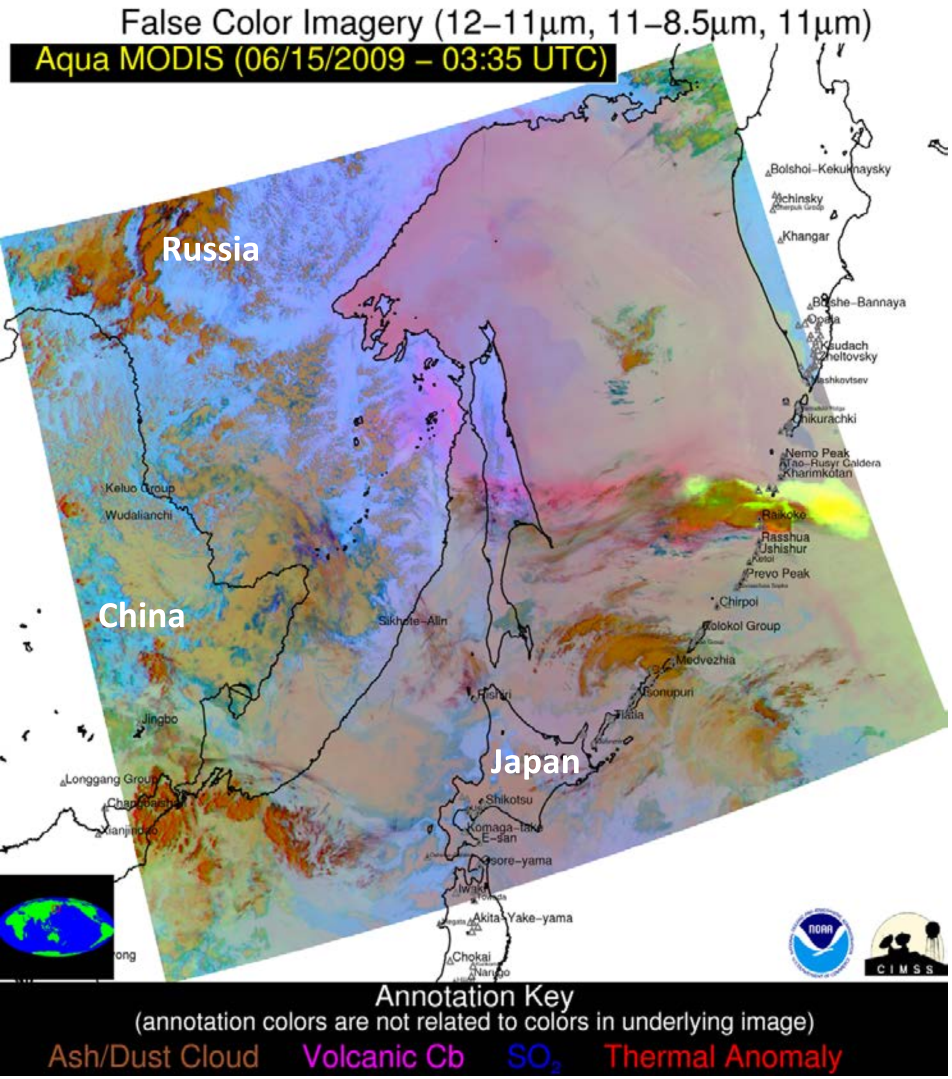
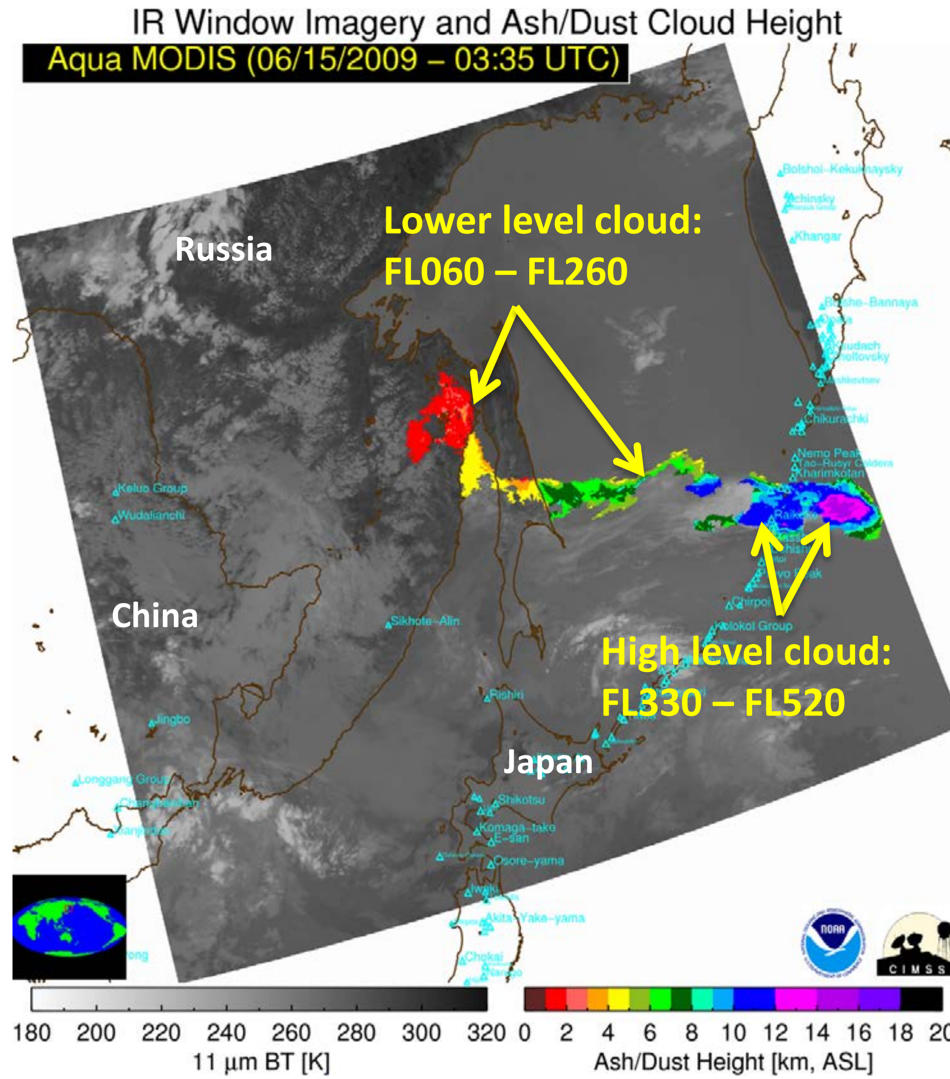
MODIS	11, 12, and 13.3 µm
MTSAT	11 and 12 µm
SEVIRI	11, 12, and 13.3 µm
VIIRS	11 and 12 µm

The VIIRS product can be improved if utilized in tandem with CrIS

***The same software is used for all sensors.

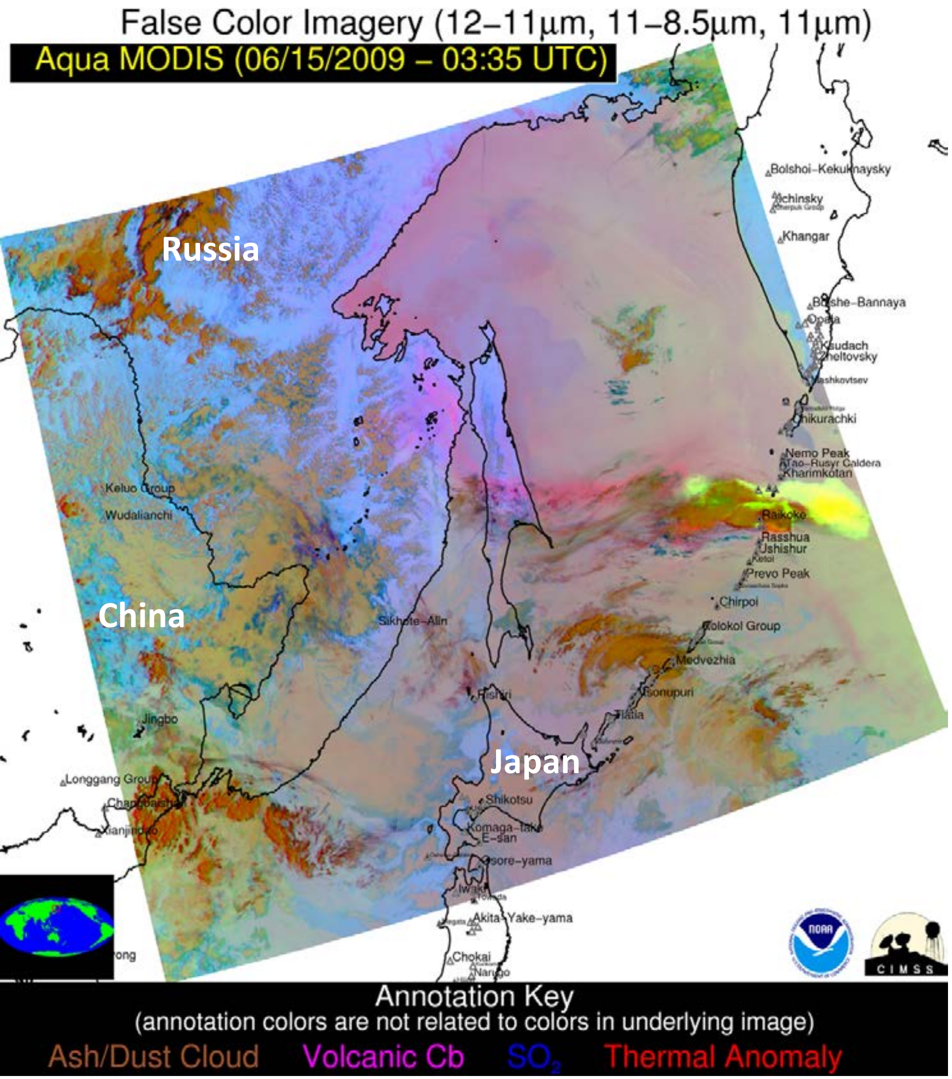
Ash Cloud Top Height

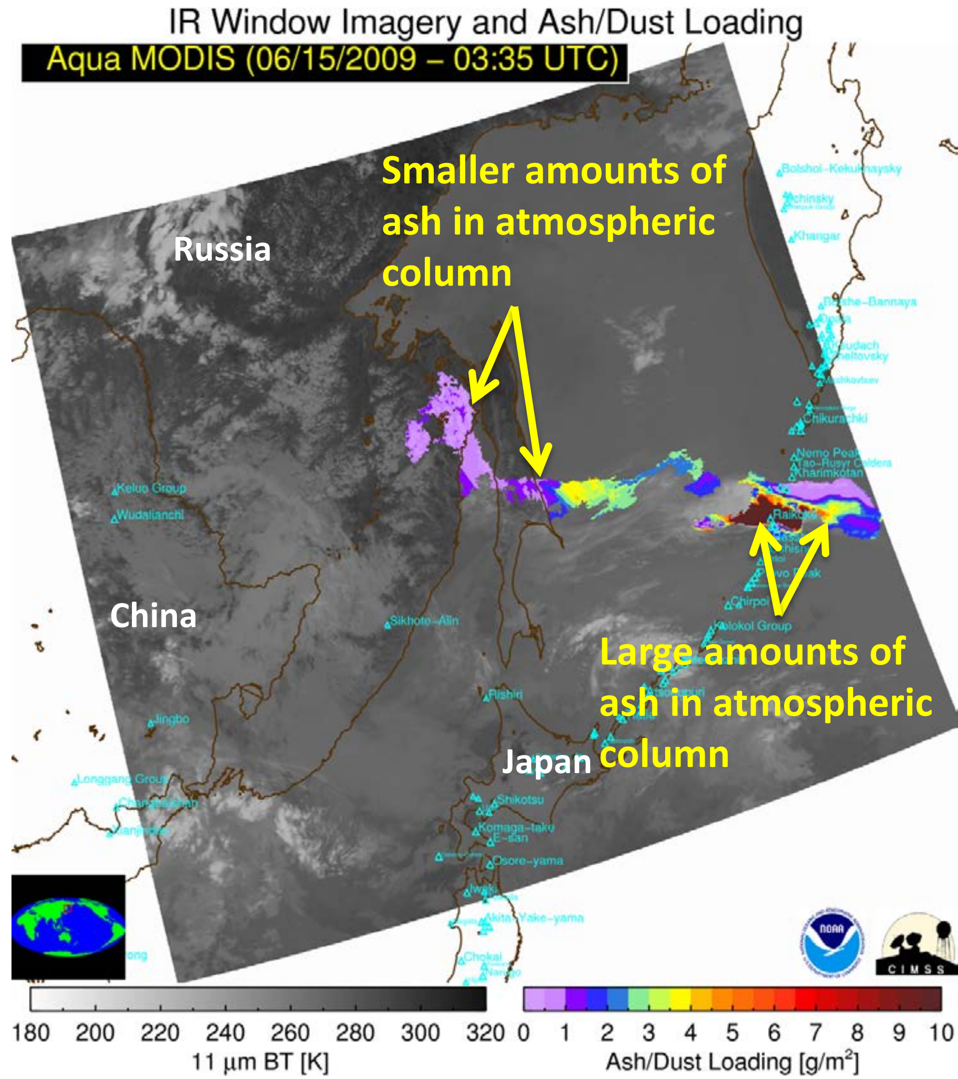




The ash cloud height retrieved by the NOAA algorithm agrees well with the height estimated by the Tokyo VAAC

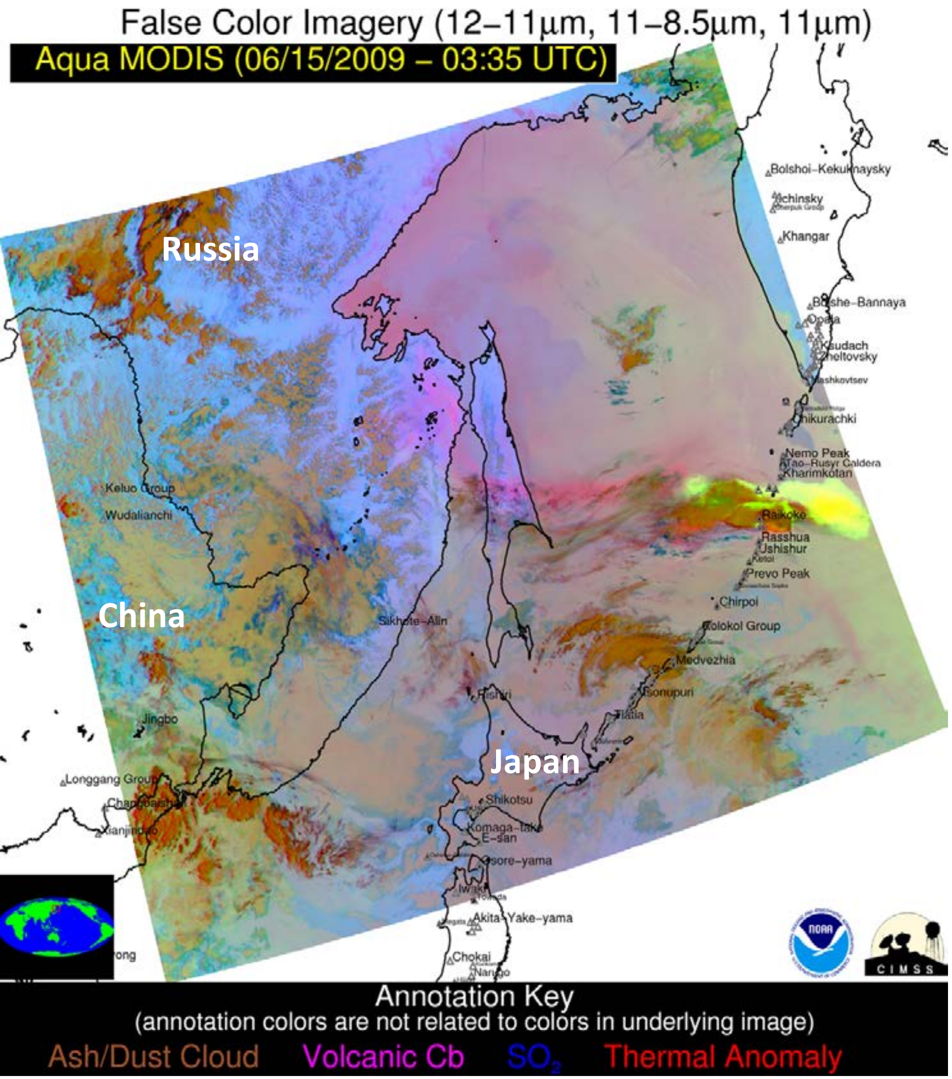
Ash Mass Loading (mass of ash per unit area)

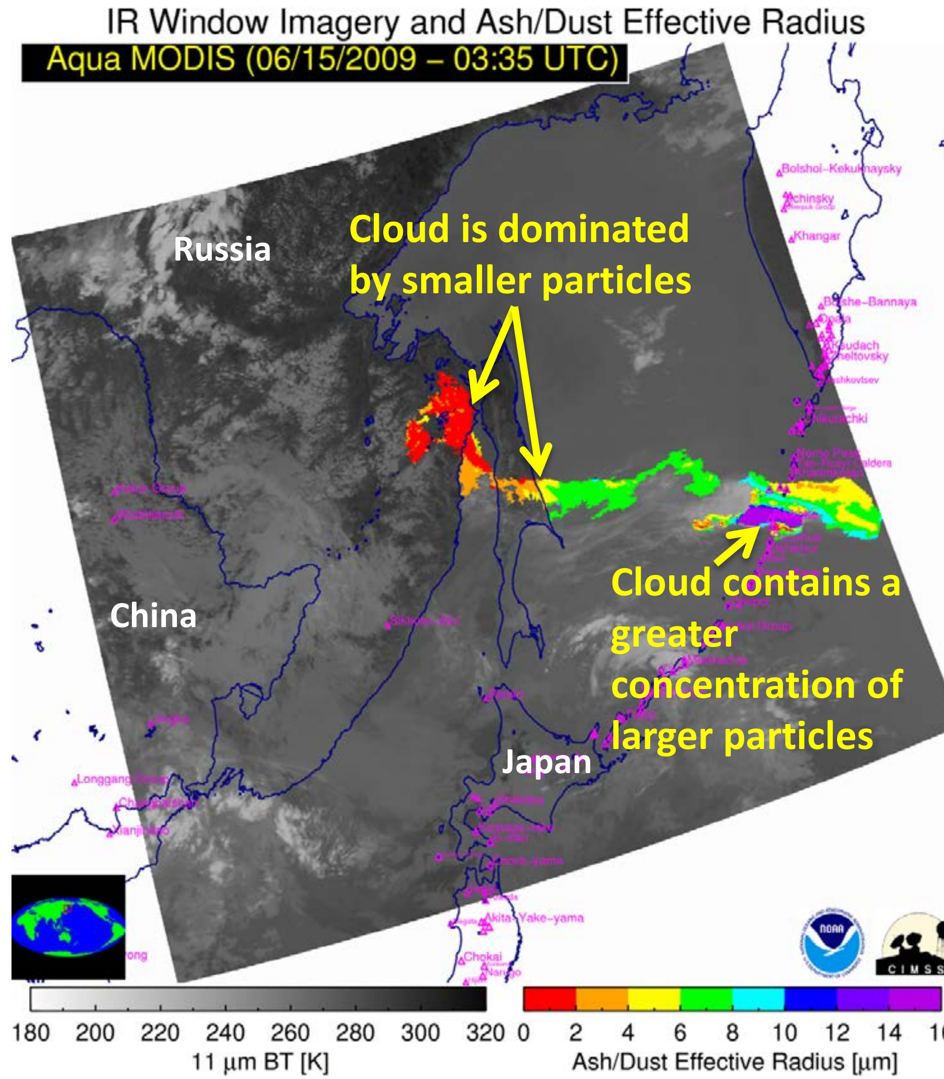




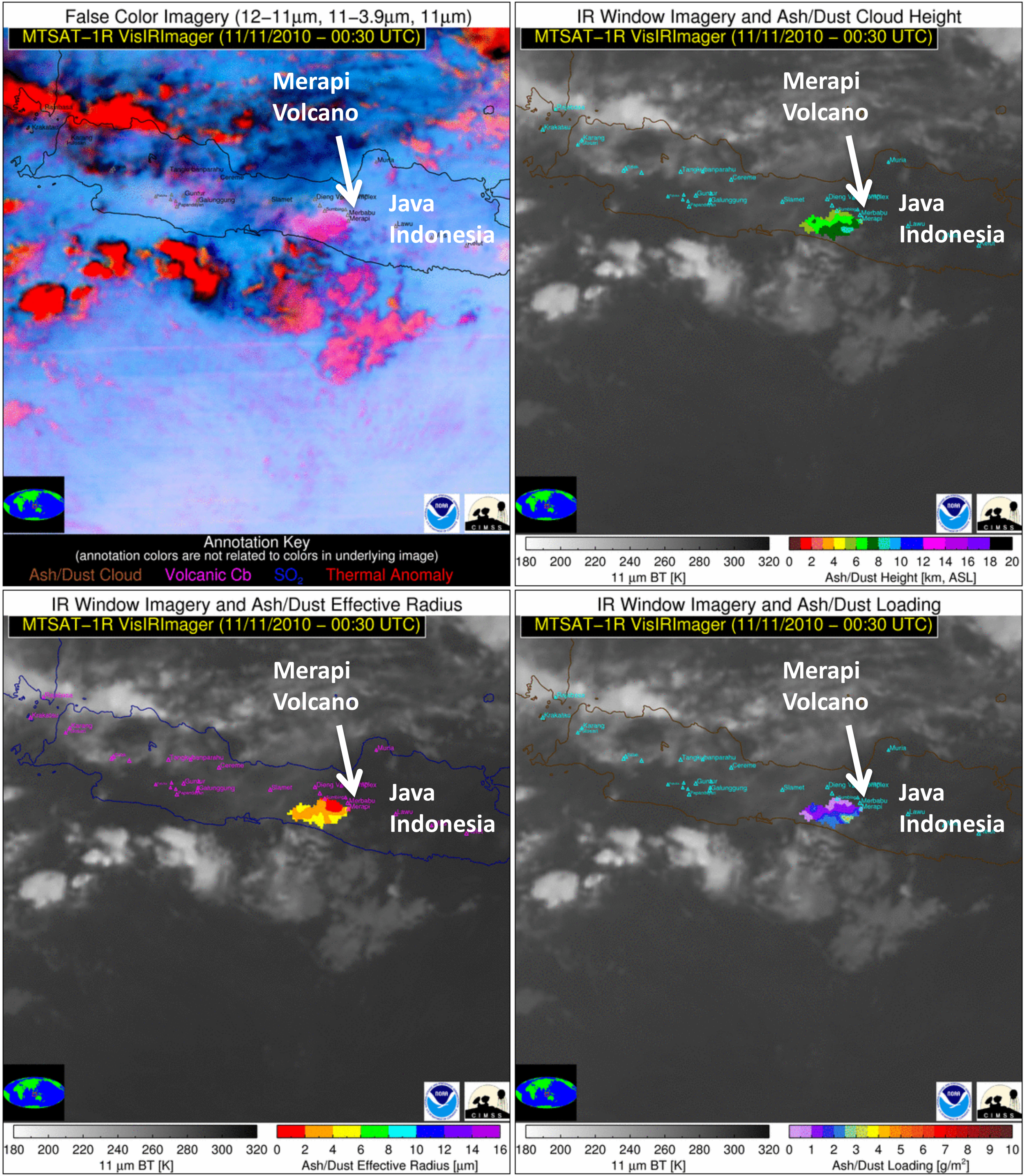
The ash mass loading product can be useful for assessing the accuracy of dispersion model forecasts. It also can be used to locate where the greatest amount of ash is likely present.

Ash Effective Particle Radius





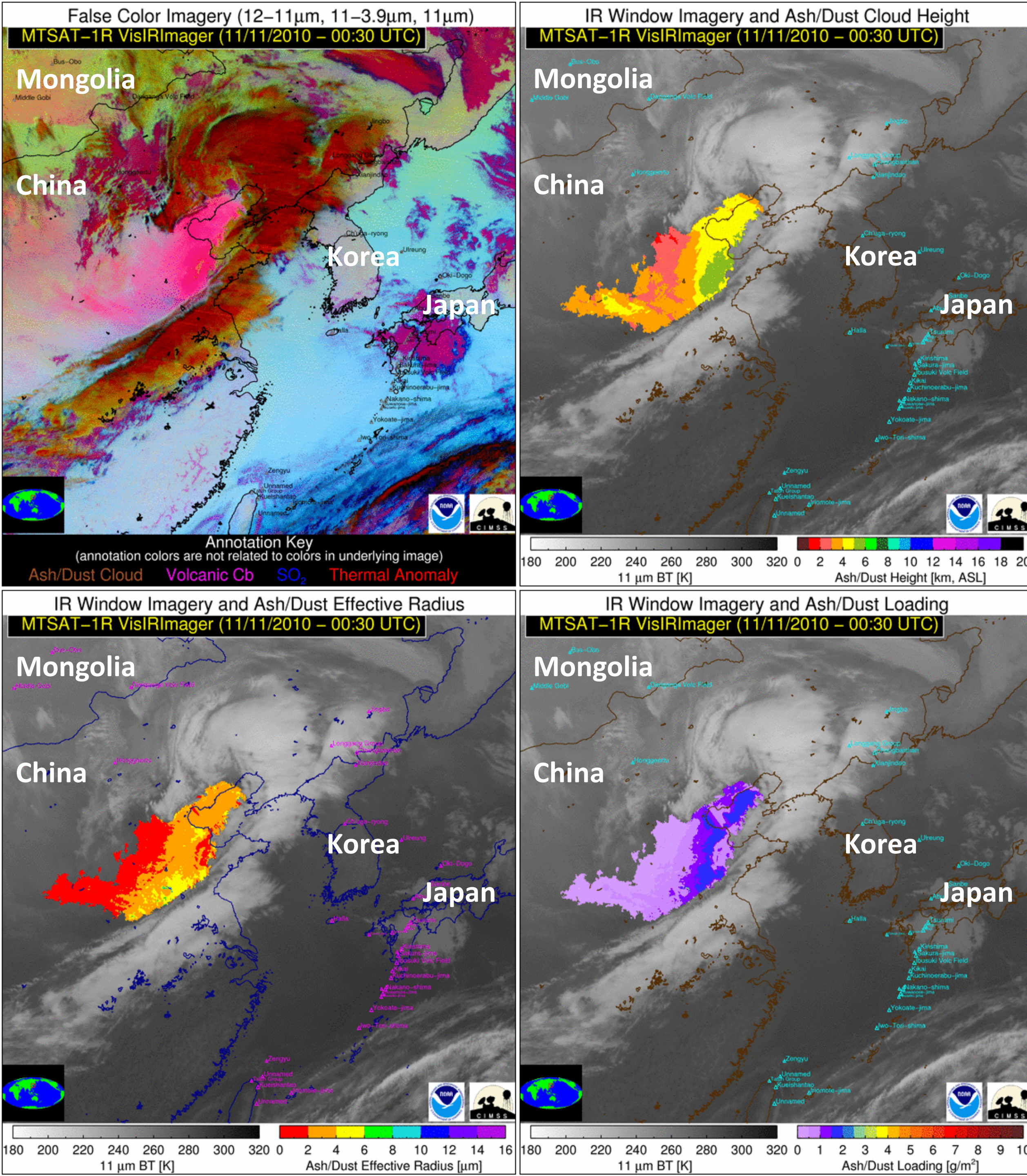
Cloud dominated by smaller particles will generally have a longer atmospheric residence time



MTSAT-1R 24 hour animation of November 11, 2010 Merapi (Indonesia) ash cloud

This example shows that the NOAA ash cloud property retrieval algorithm:

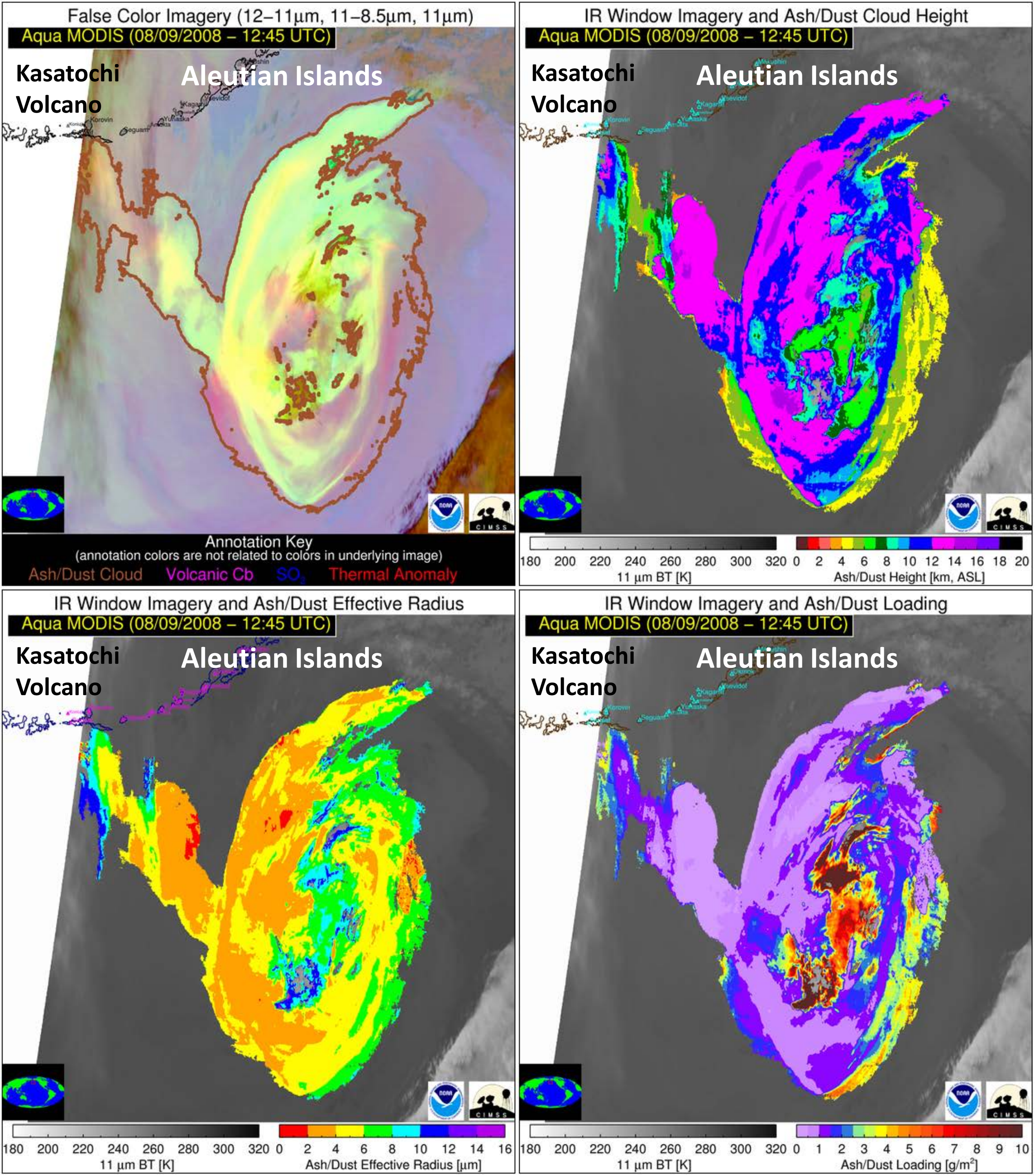
1. Is applicable to MTSAT
2. Works even in moist environments
3. Works at all times of the day



MTSAT-1R 24 hour animation of November 11, 2010 Gobia Desert dust cloud

This example shows that the NOAA ash cloud property retrieval algorithm:

1. **Is applicable to MTSAT**
2. **Is also applicable to dust clouds**
3. **Works at all times of the day**



August 9, 2008 (12:45 UTC): Kasatochi volcanic cloud

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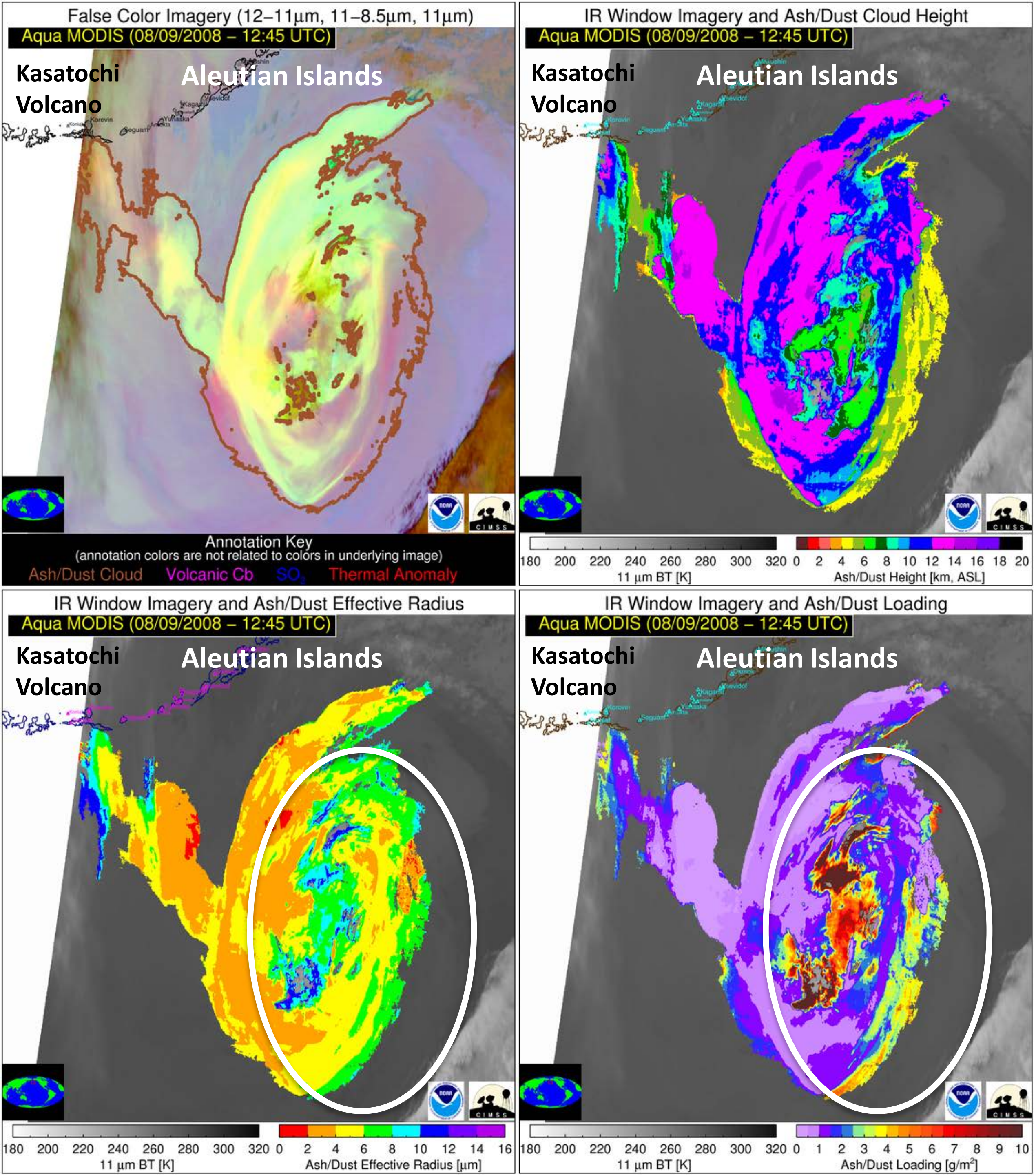
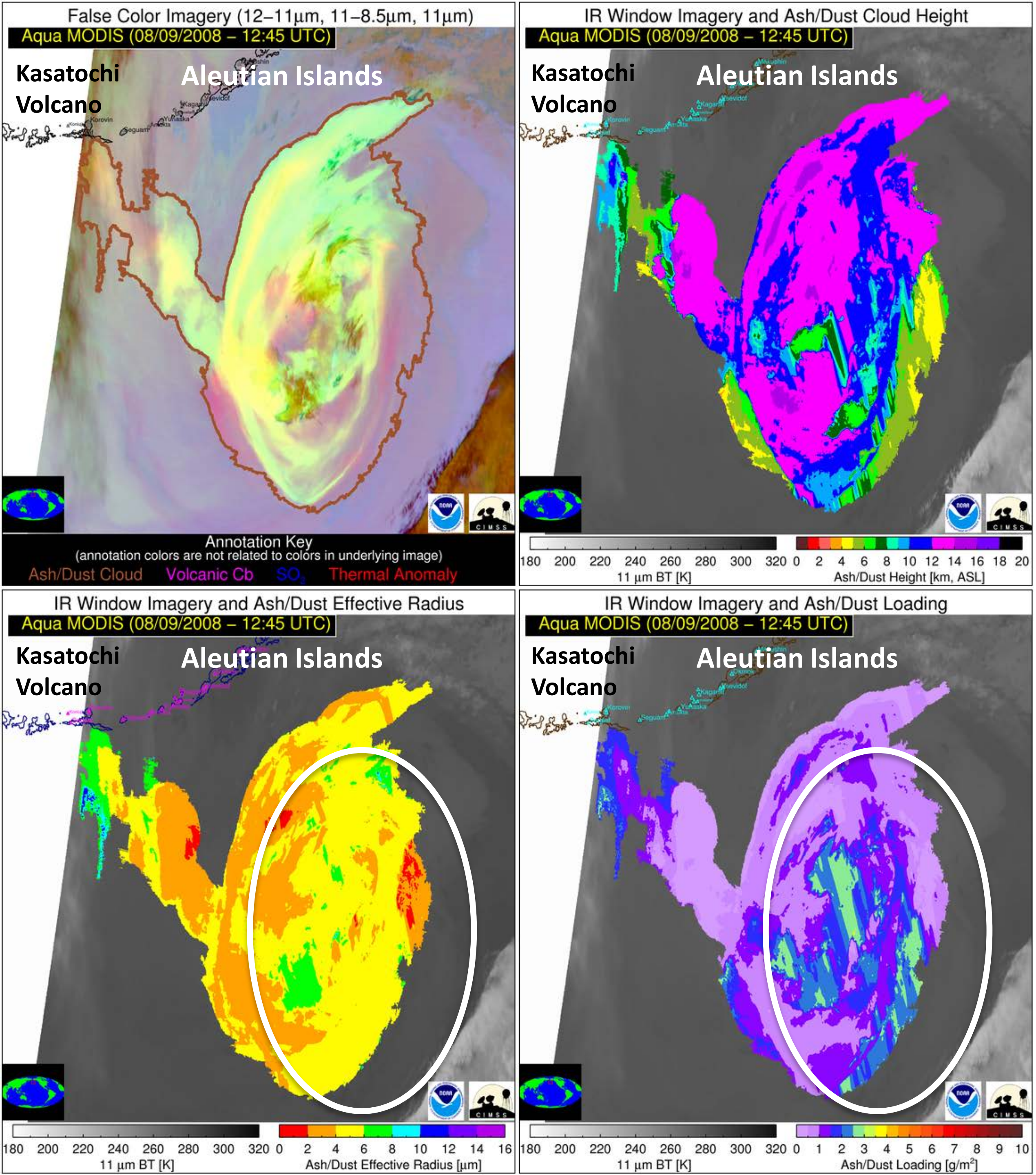


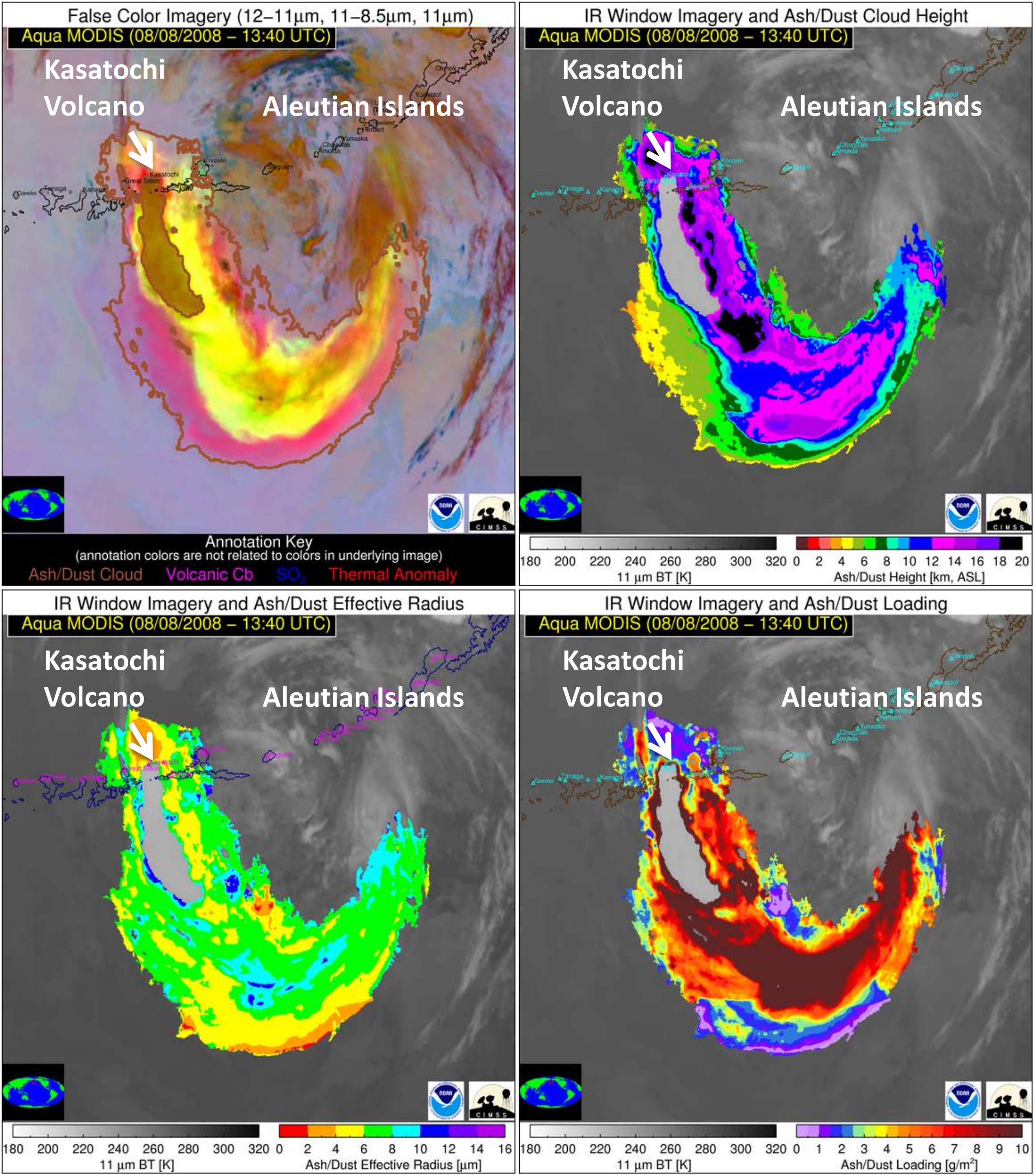
The ash mass loading and effective particle radius are greatly over-estimated in parts of this cloud due to underlying mid and high level meteorological clouds, which are very difficult to account for in the retrieval.



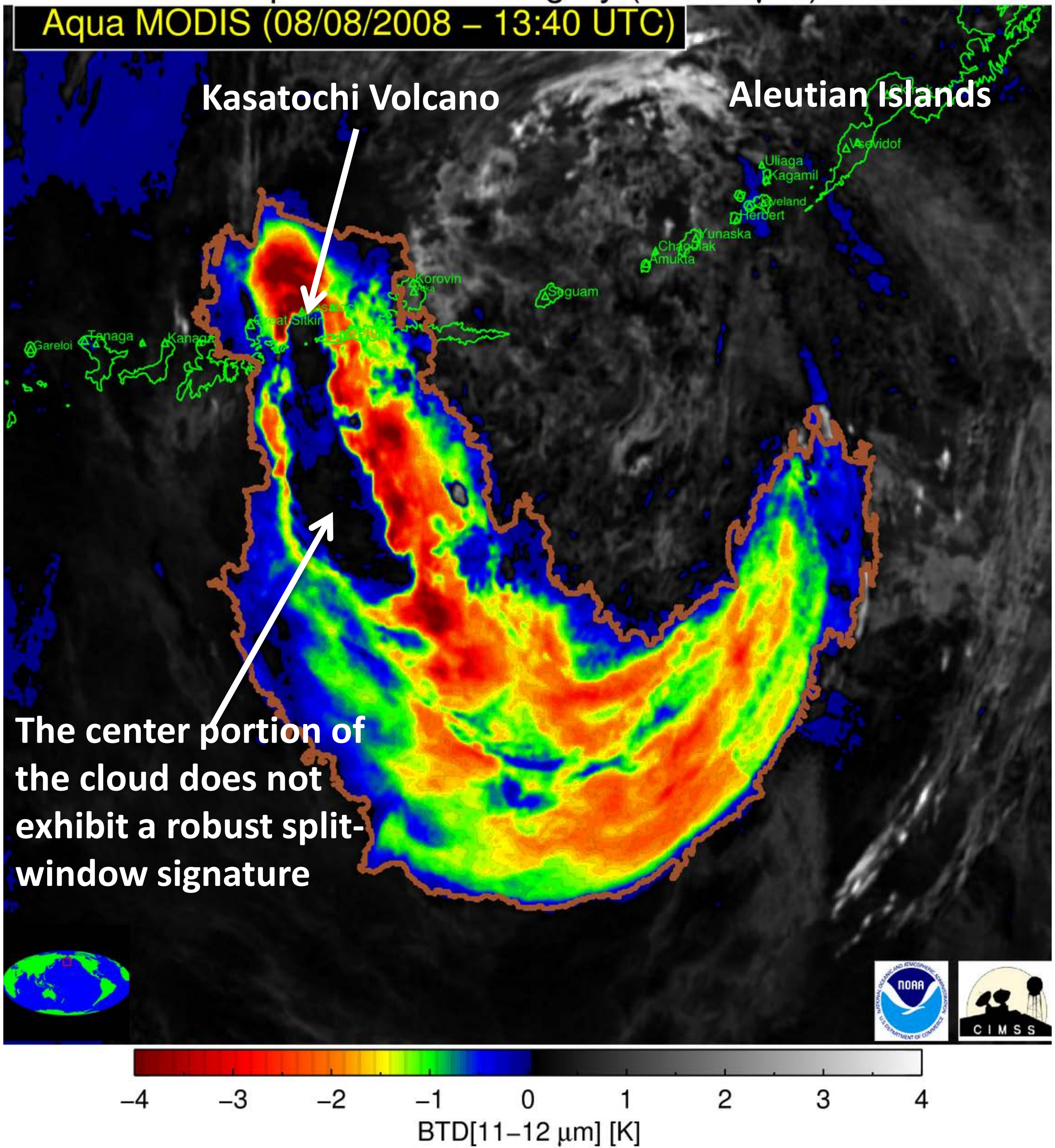
August 9, 2008 (12:45 UTC): Kasatochi volcanic cloud

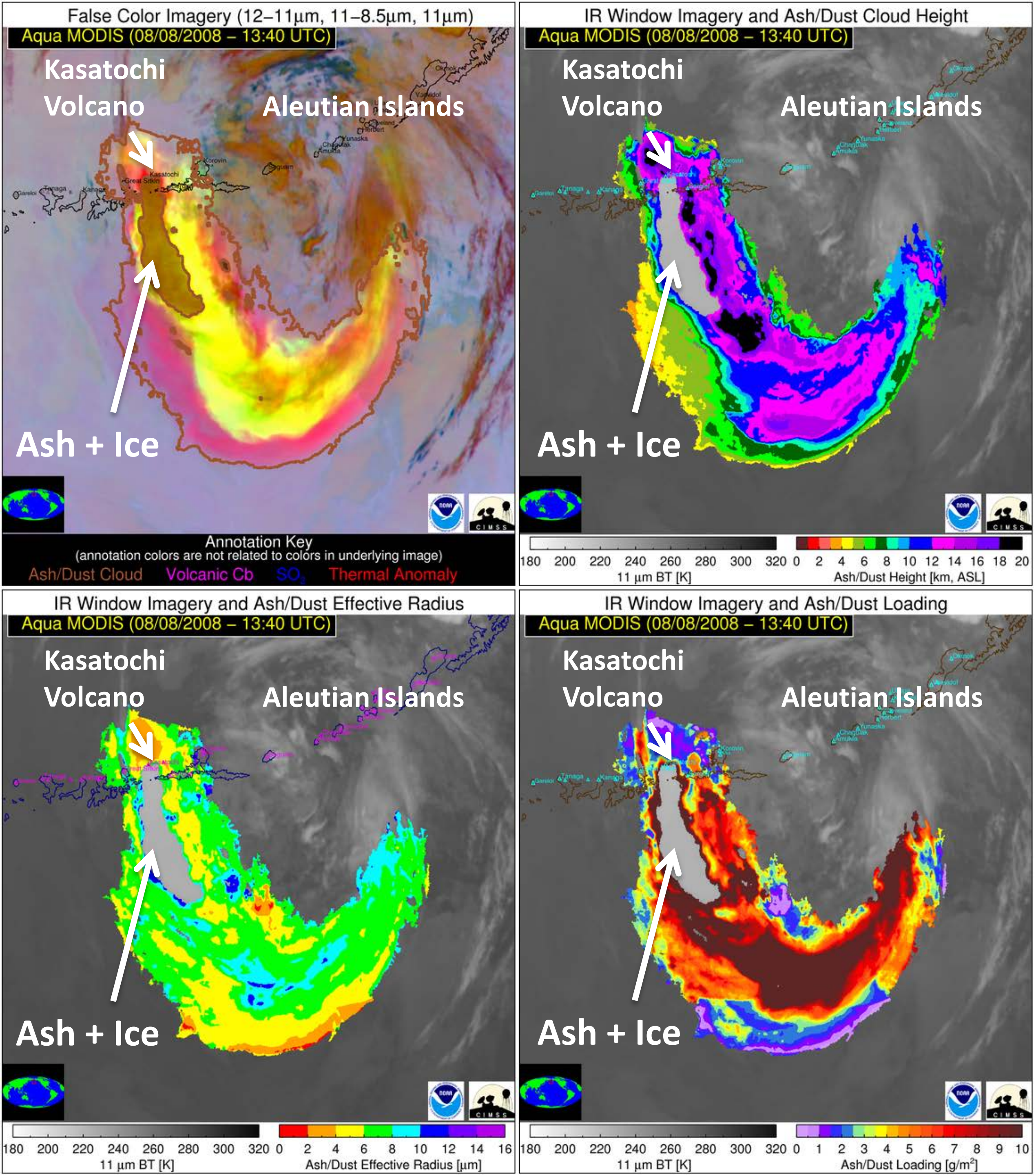
Any retrieved parameter that differs greatly from the median value within the cloud object is automatically identified and re-computed using a Cressman interpolation scheme.

August 8, 2008 (13:40 UTC): Kasatochi volcanic cloud



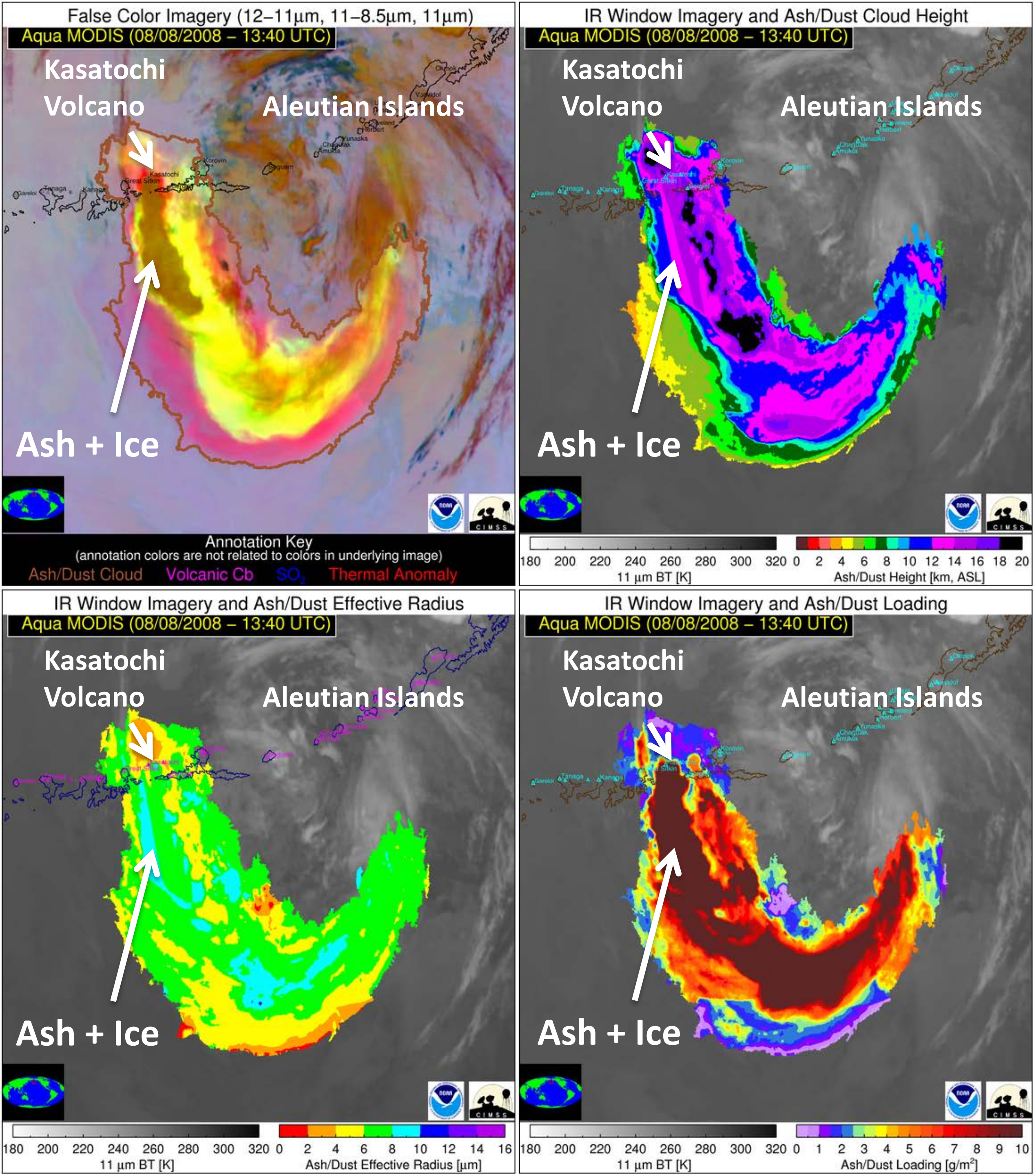
Split–Window Imagery (11–12 μm)





August 8, 2008 (13:40 UTC): Kasatochi volcanic cloud

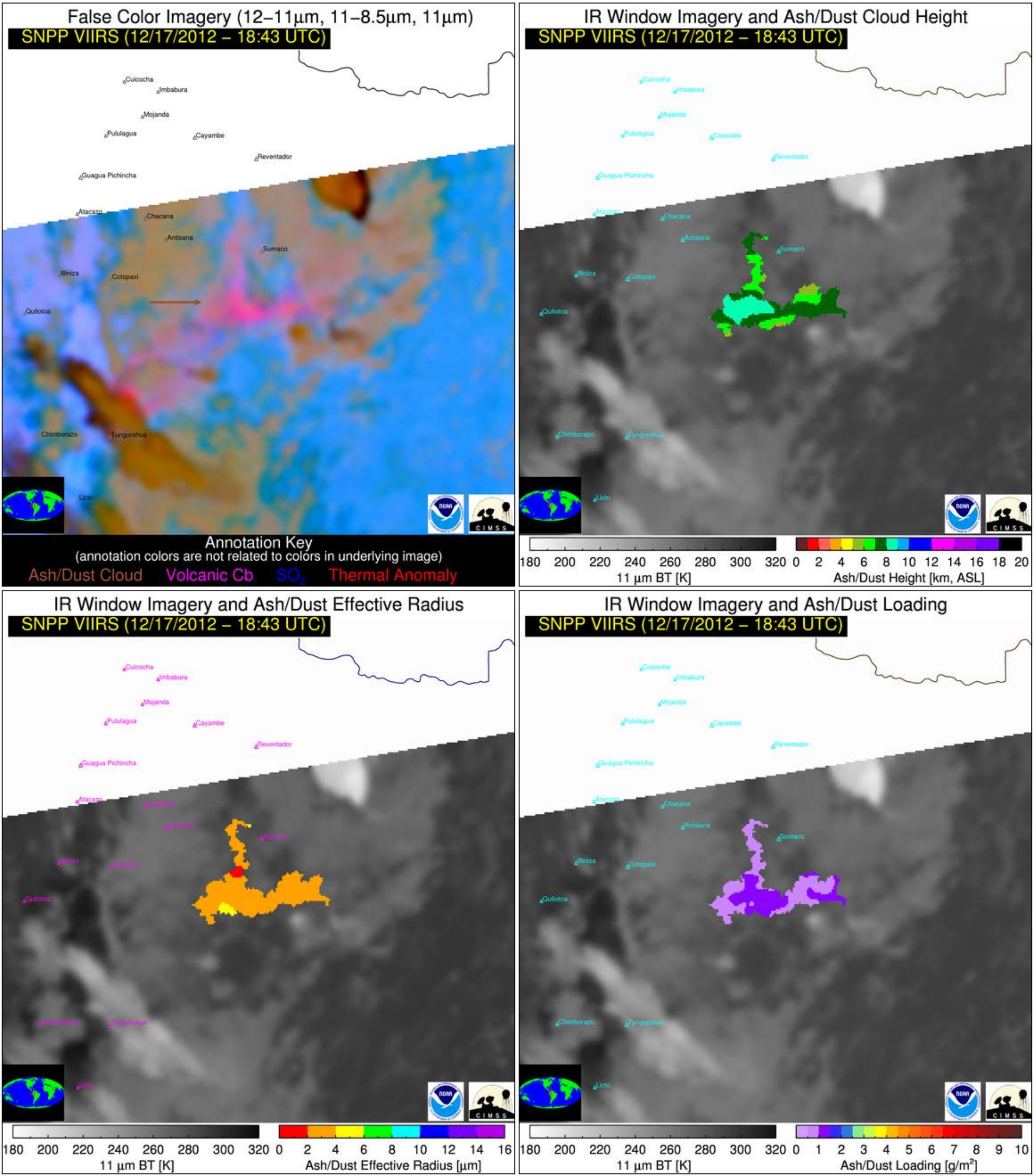
The optically thick center of the Kasatochi cloud contains ice particles in addition to volcanic ash and thus it cannot be distinguished from meteorological clouds and the ash cloud properties are not estimated.



August 8, 2008 (13:40 UTC): Kasatochi volcanic cloud

Artificial holes in volcanic clouds are automatically identified and a Cressman interpolation scheme is used to fill them.

December 17, 2012 (18:43 UTC): Tungurahua

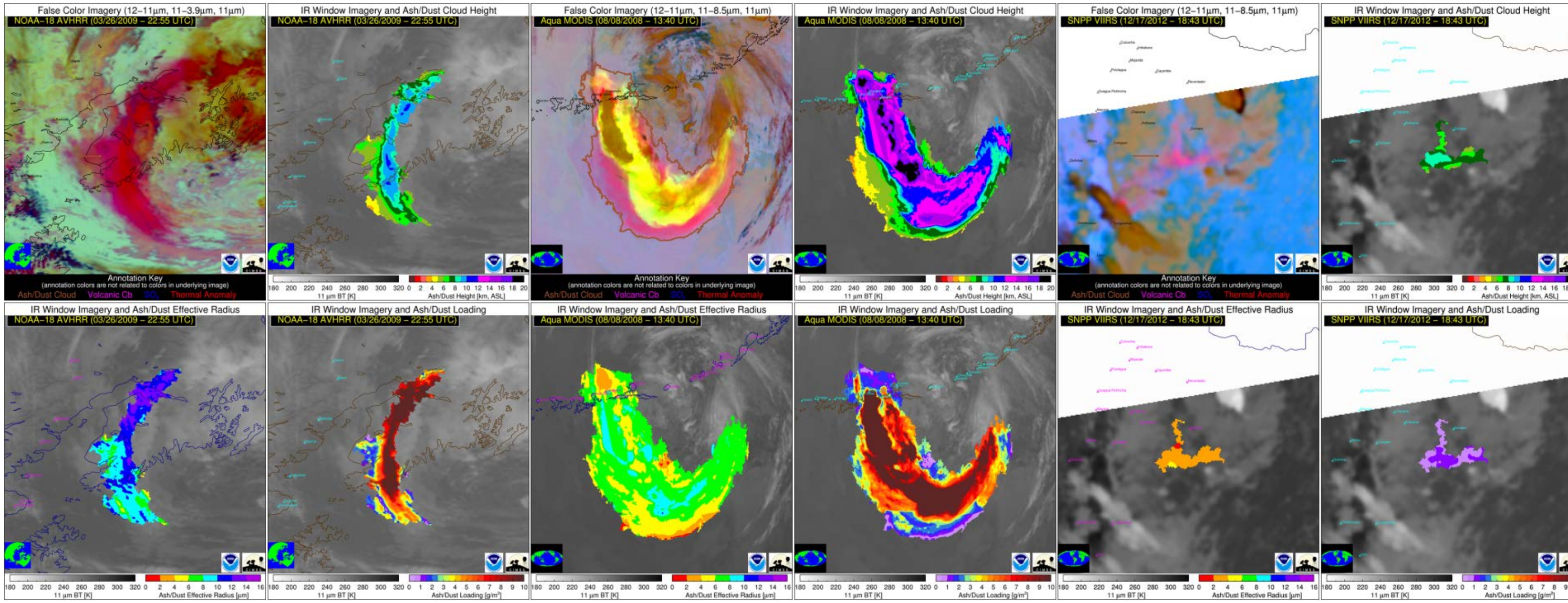


The algorithm runs on VIIRS, but we are still working on optimizing the conditional probability LUT's used in the ash detection component of the algorithm.

Making Full Use of the Space-based Observing System for Volcanic Cloud Monitoring

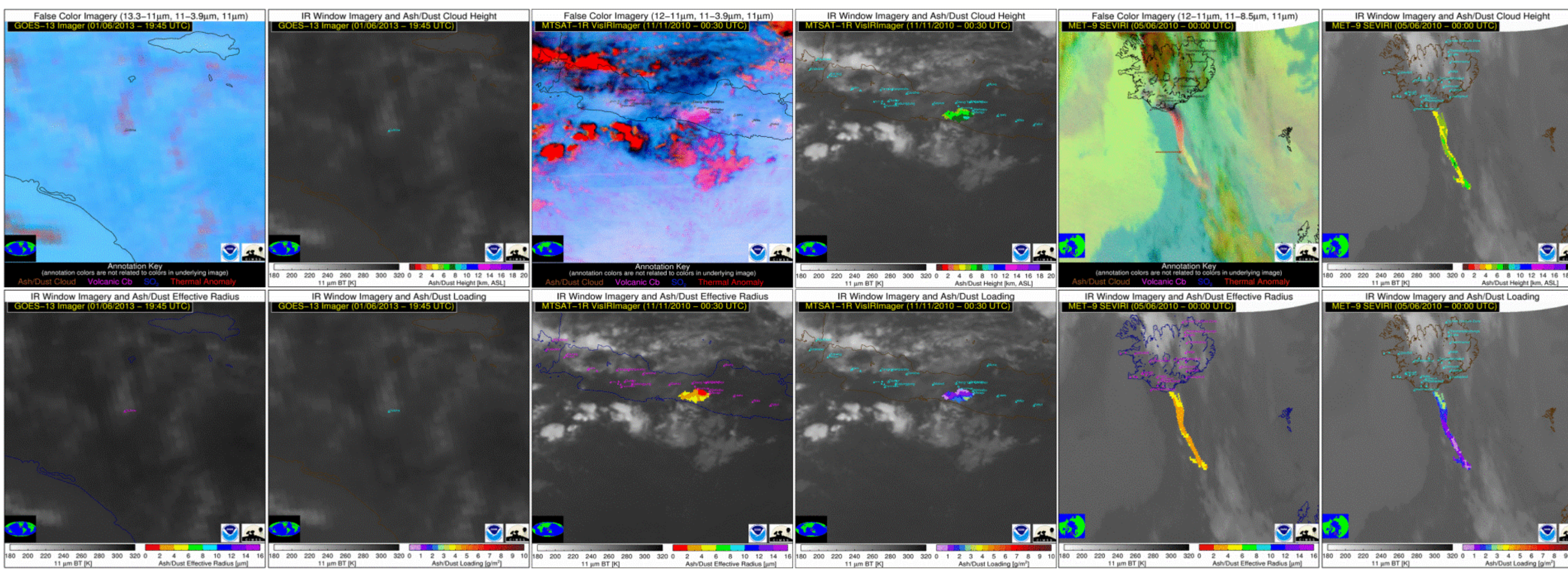
LEO

NOAA and MetOp AVHRR | Terra and Aqua MODIS | SNPP-VIIRS



GEO

GOES-12-15 | MTSAT-(1r and 2) | Met-(8,9,10) SEVIRI



Algorithm Output

- Algorithm is only designed to be applied to the VIIRS M-bands with “bow-tie” deleted pixels restored.
- Algorithm will output ash probability, ash top height, ash mass loading, and associated quality information.

Practical Considerations: Exception Handling

- While the ash detection component of the algorithm performs best when the 0.65, 3.75, 8.5, 11, and 12 μm channels provide valid data, it can produce useful output as long as the 11 and 12 μm channels are available.
- The ash retrieval component of the algorithm can only be applied if the 11 and 12 μm channels are both available.
- If the 11 and 12 μm channels are unavailable, each pixel will be set to a flag that indicates that the ash products could not be generated.
- None of the algorithms can function without the clear sky radiance calculations (based on NWP data).

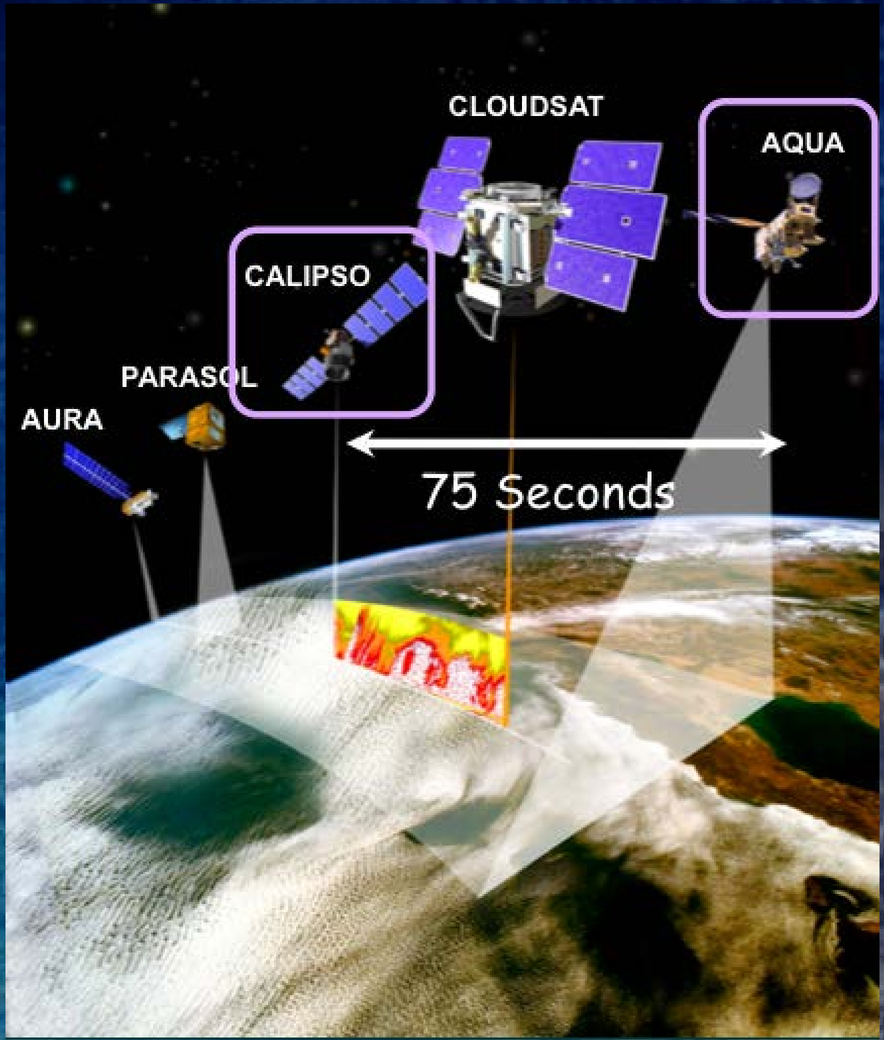
Performance Estimates

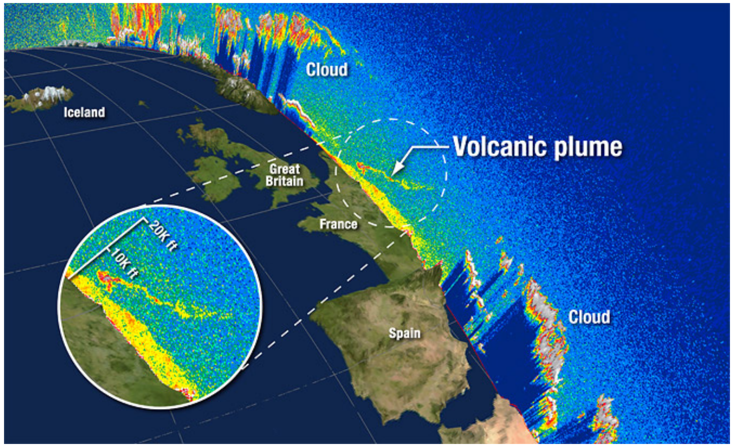
•With the launch of CALIPSO (a lidar) and CLOUDSAT (a radar) into the EOS A-train, we now unprecedented information on the vertical structure of clouds.

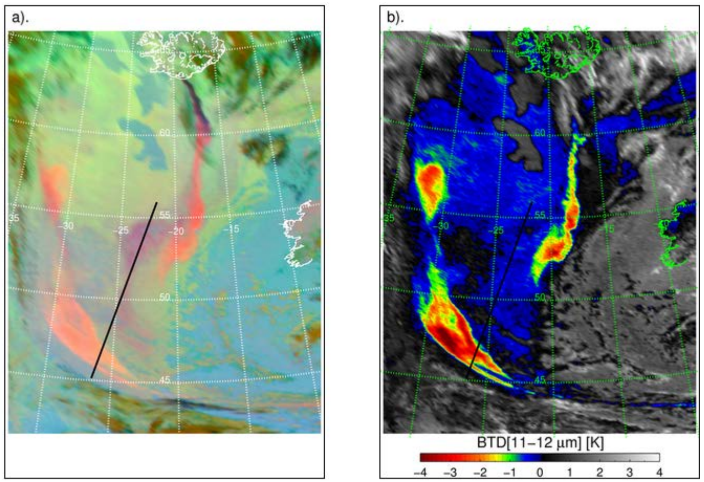
• CALIPSO is very sensitive to the presence of any cloud in the column and therefore is our first choice in cloud height validation.

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

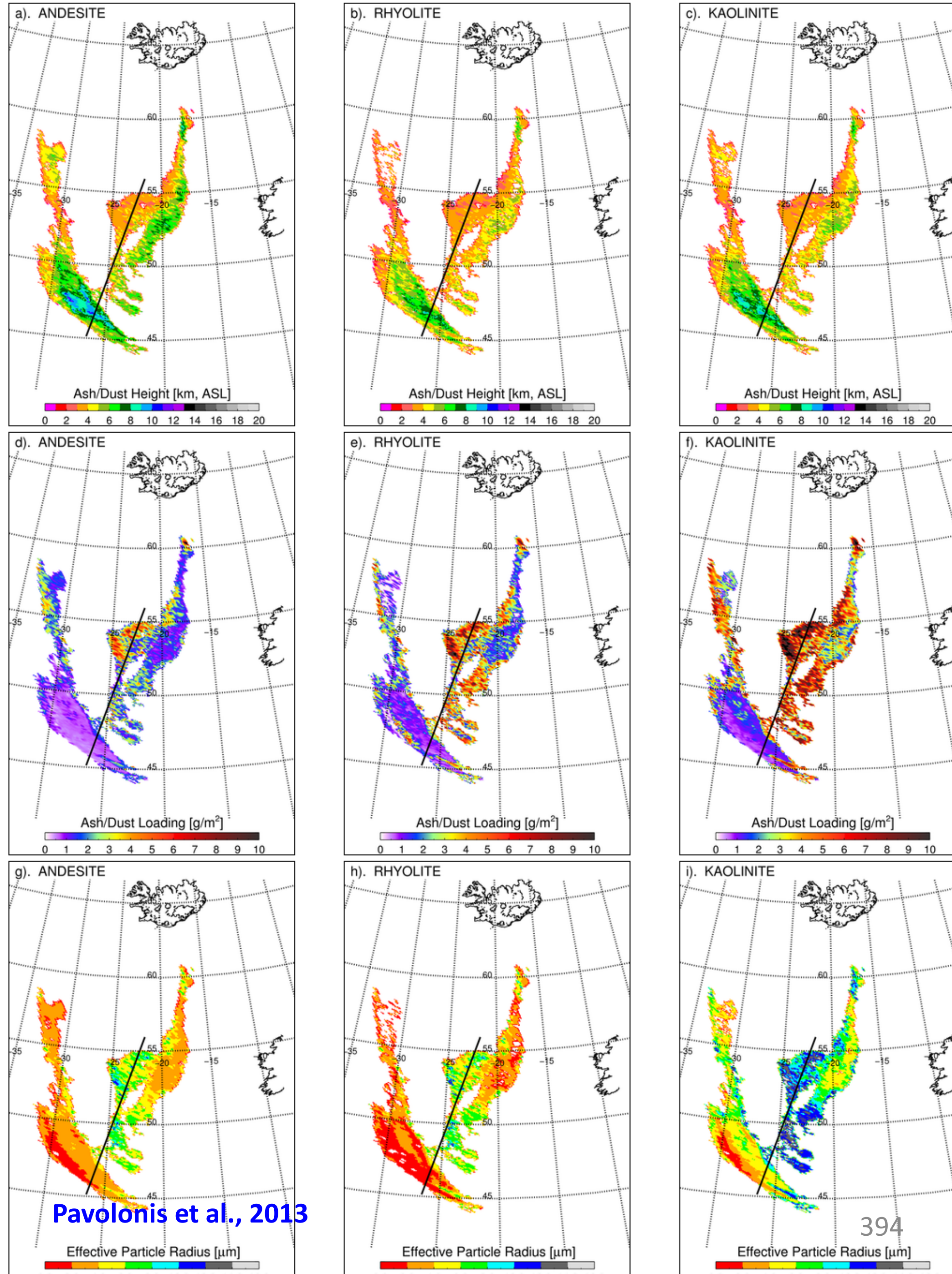
•The CALIPSO based validation will be supplemented with aircraft measurements and other ash relevant unique data sets.



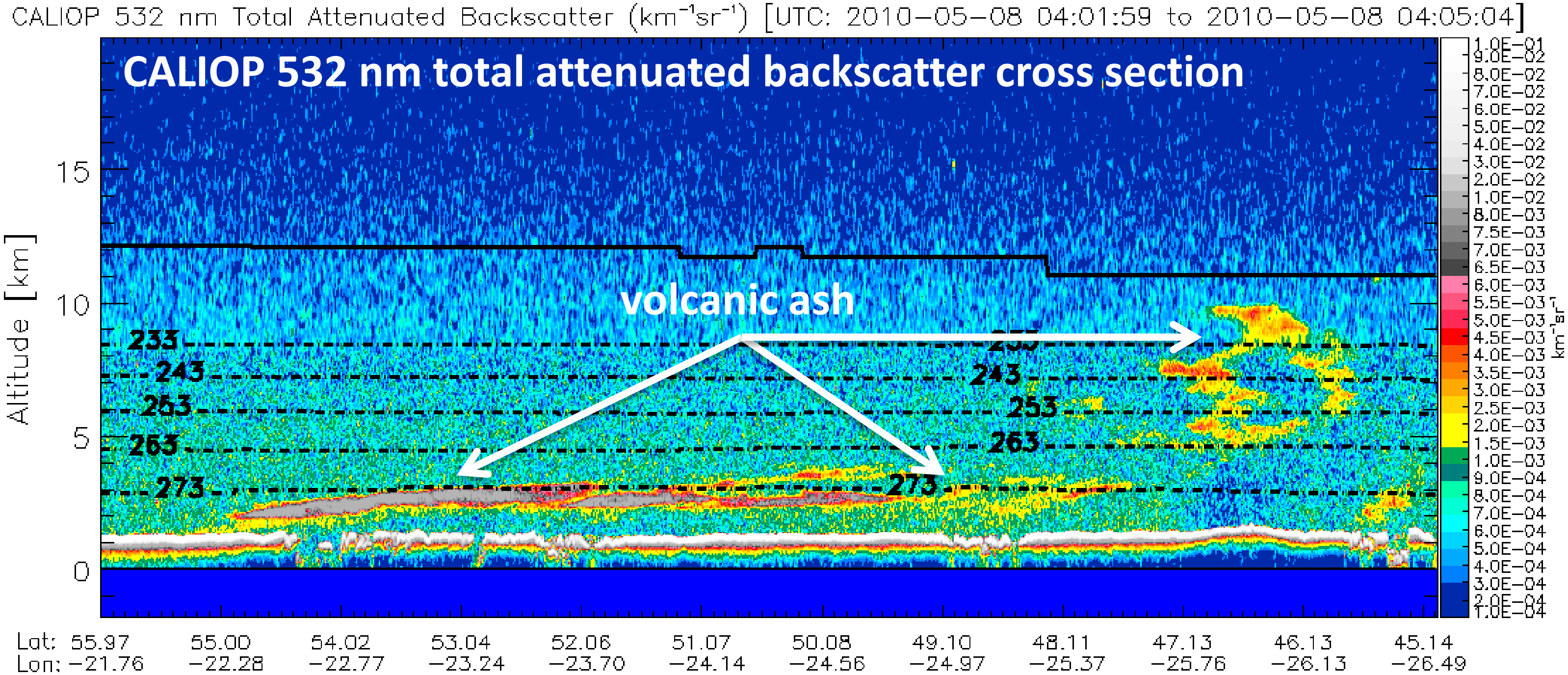


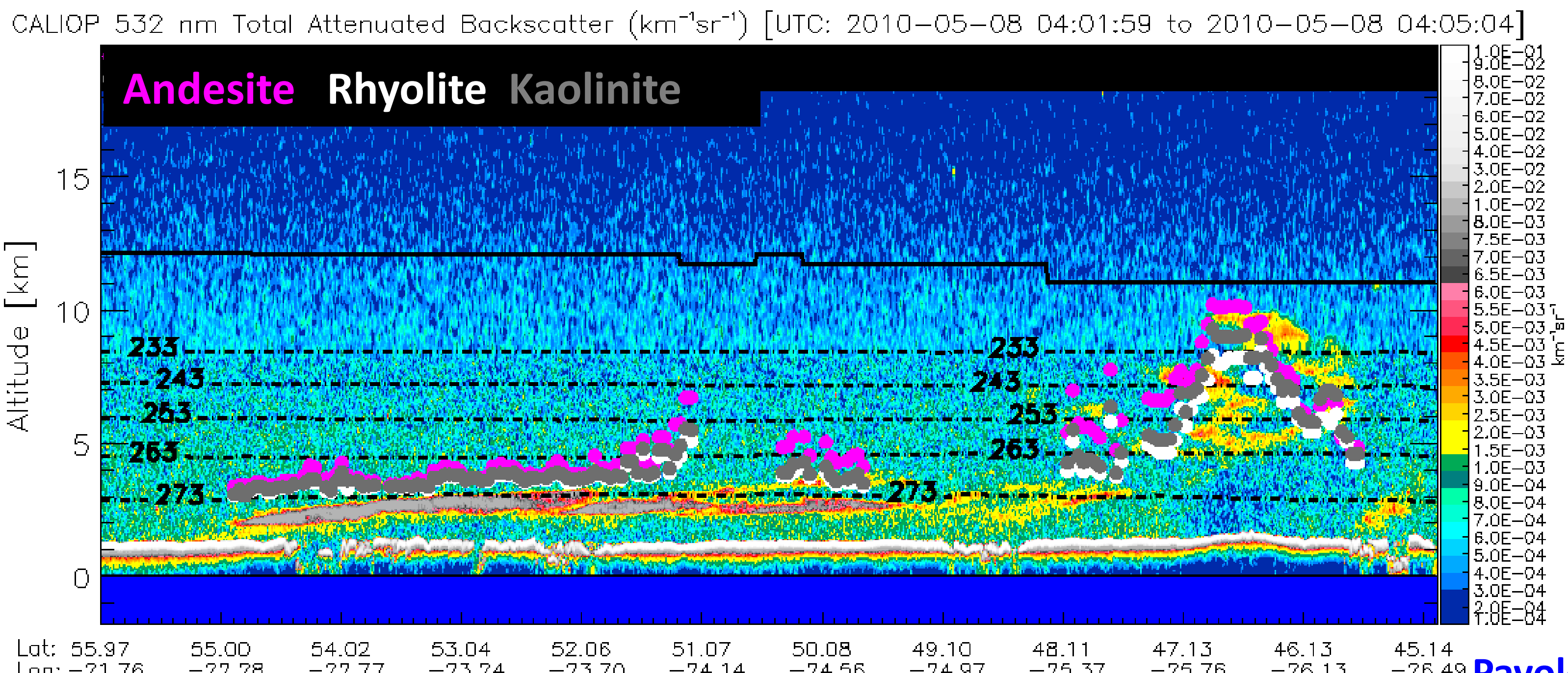


Spaceborne LIDAR measurements from CALIPSO were used to validate the NOAA volcanic ash retrieval algorithm as a function of the mineral composition chosen for the cloud.

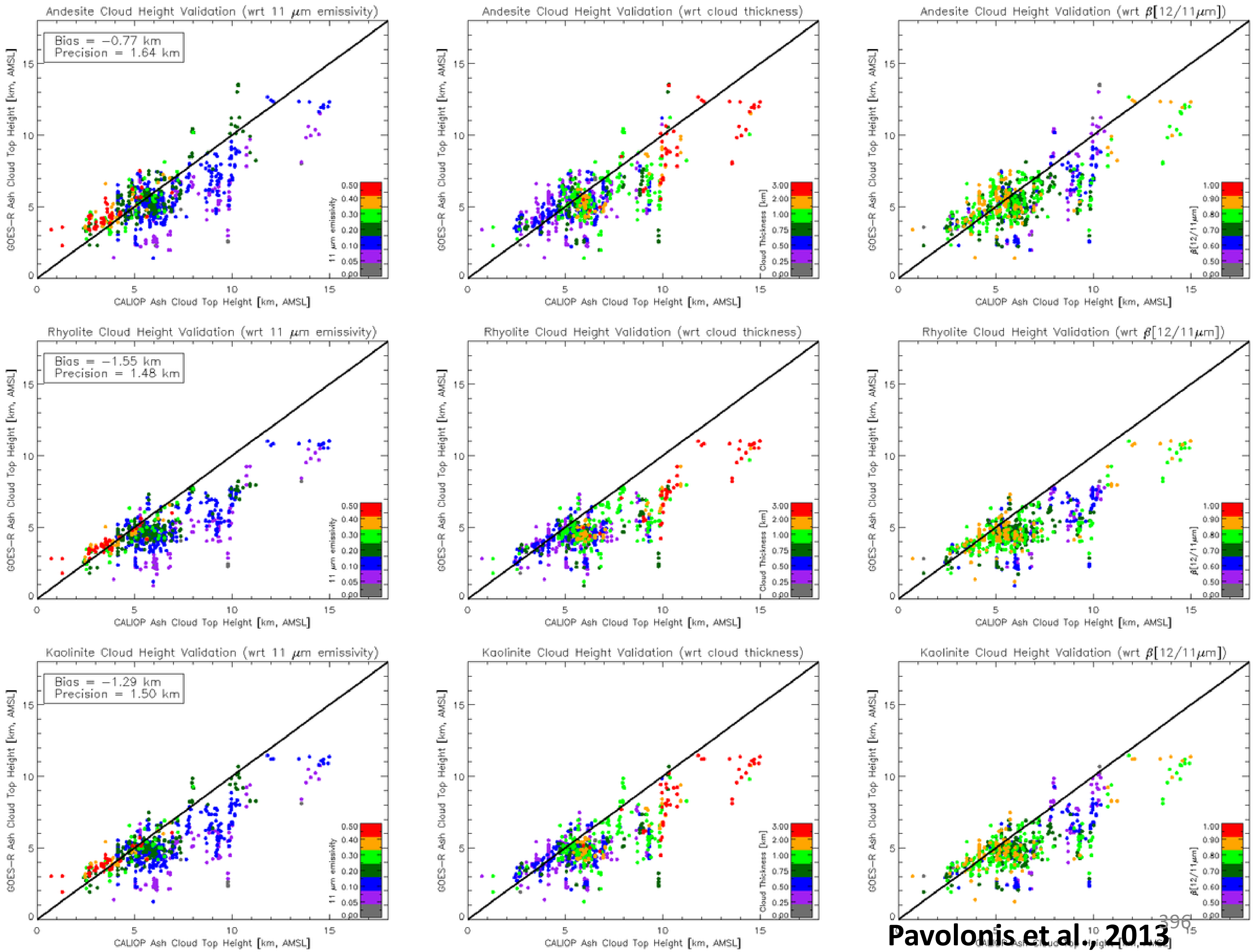


Pavolonis et al., 2013

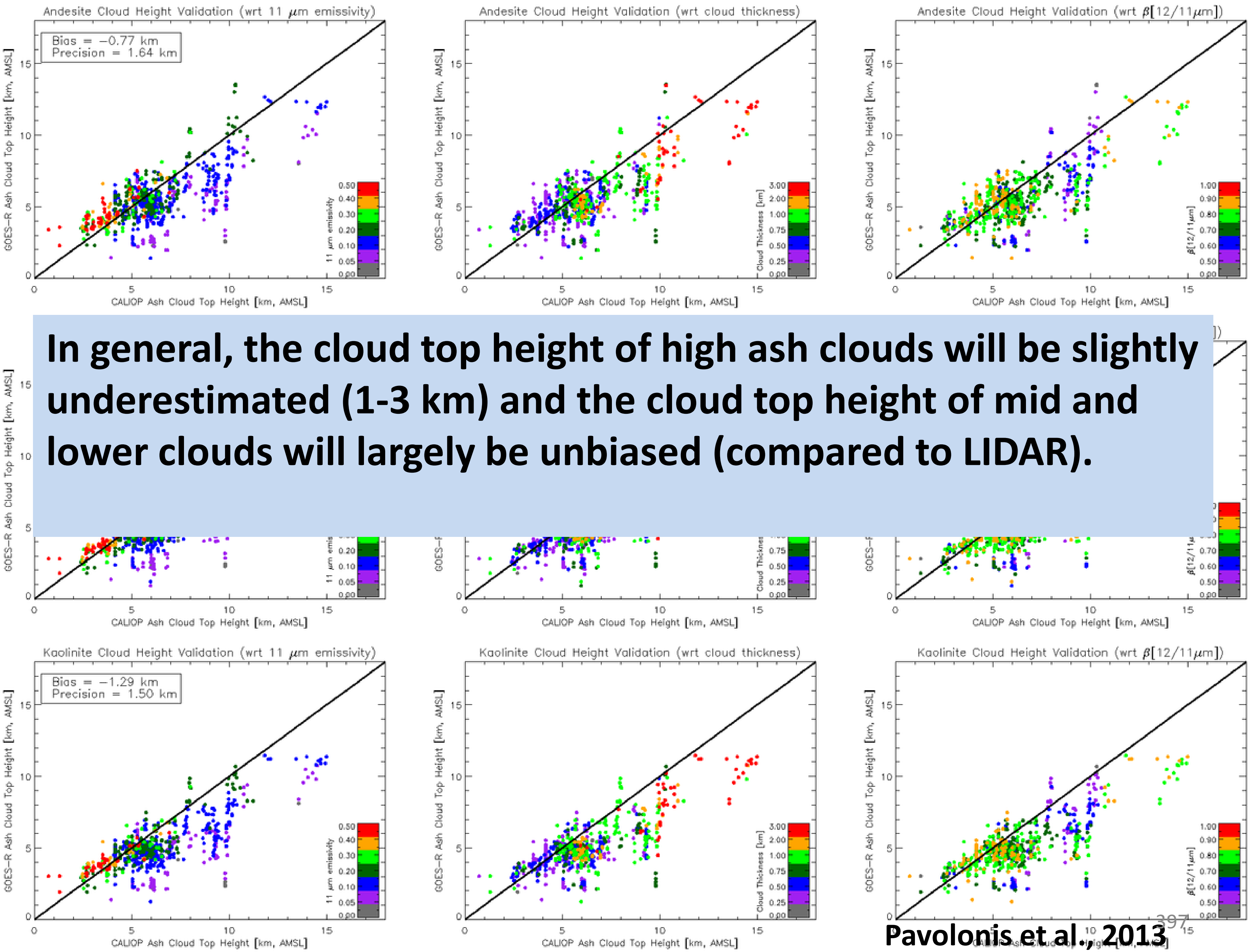




Pavolonis et al., 2013

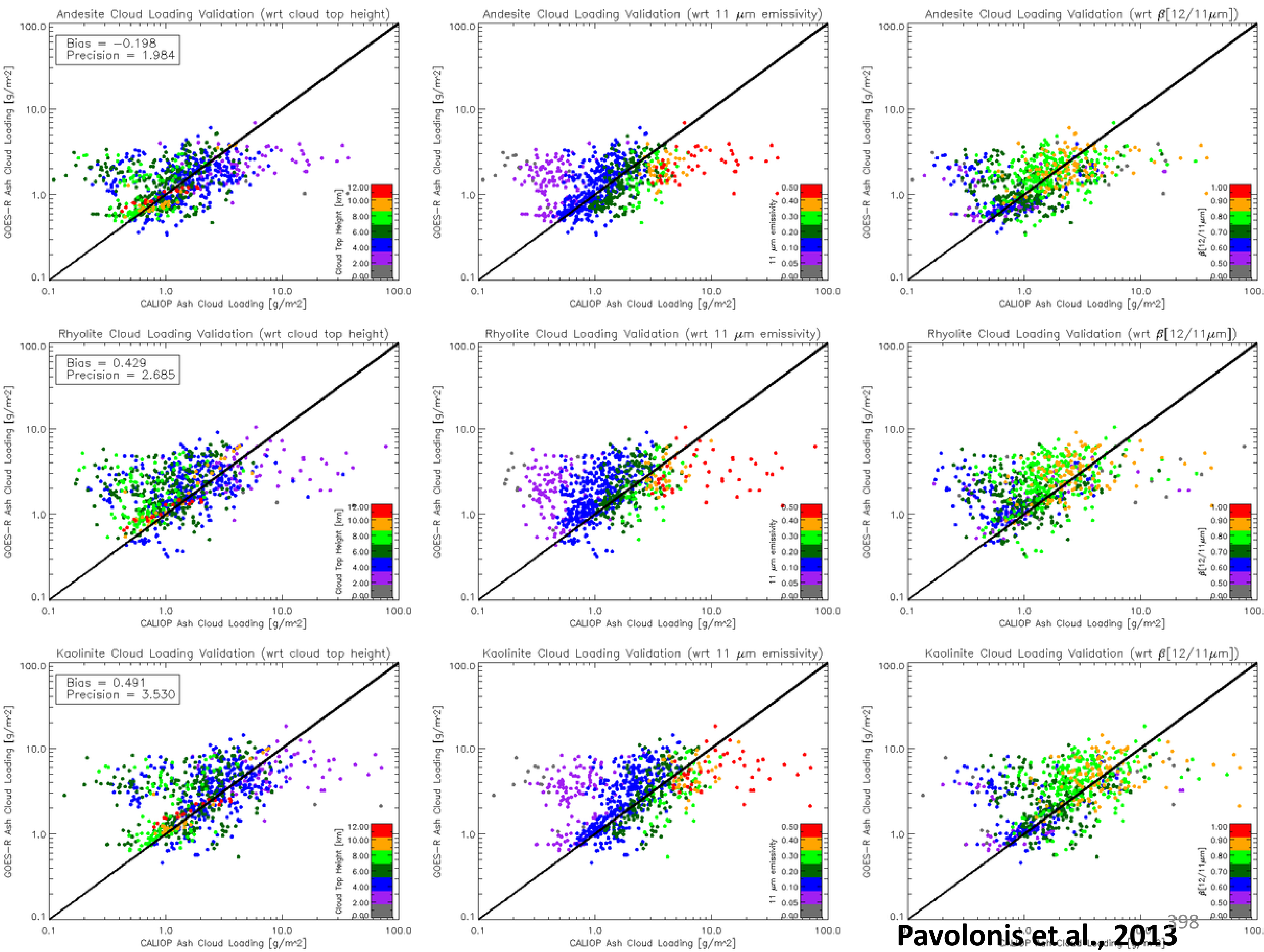


Pavolonis et al., 2013

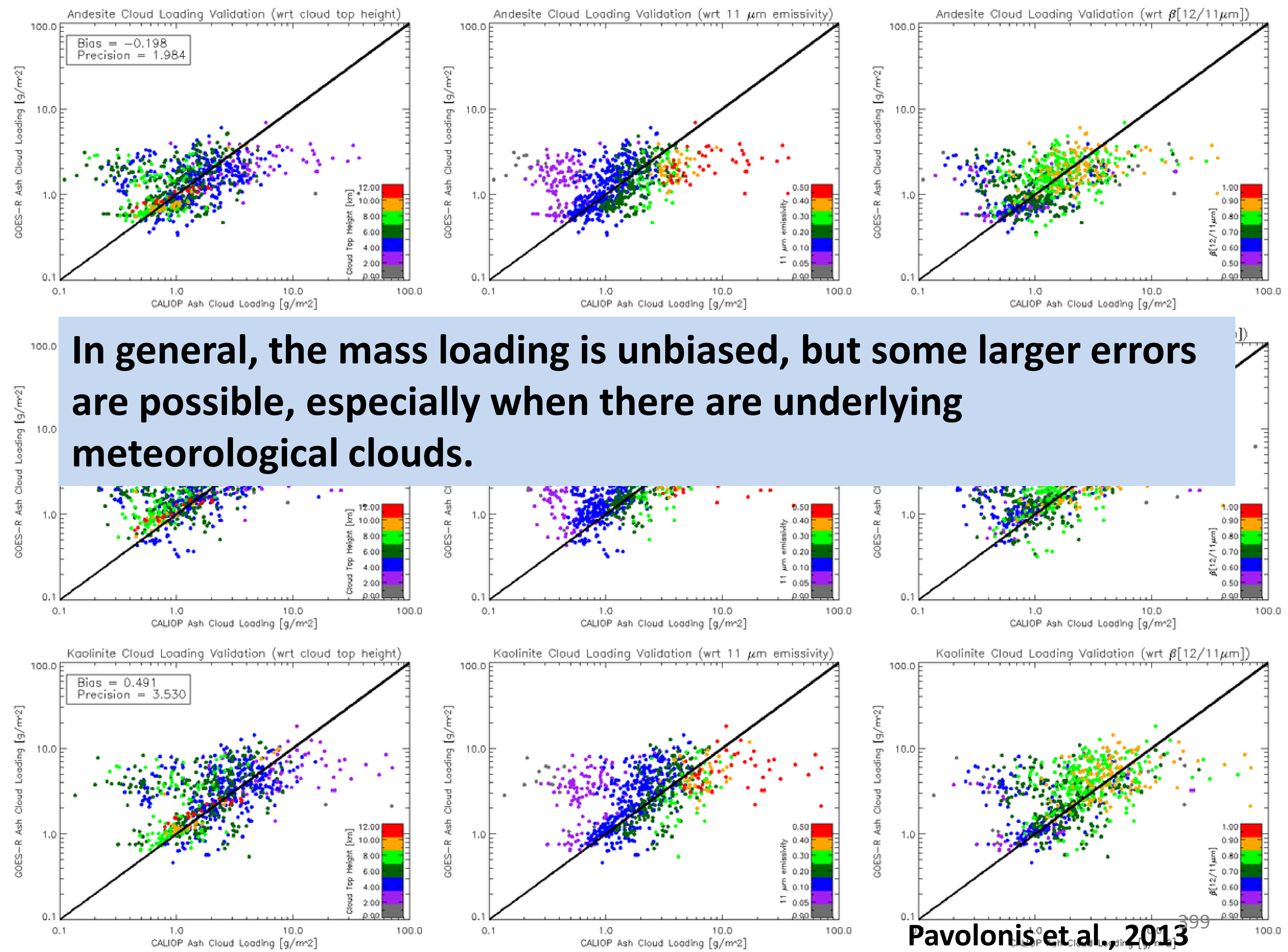


In general, the cloud top height of high ash clouds will be slightly underestimated (1-3 km) and the cloud top height of mid and lower clouds will largely be unbiased (compared to LIDAR).

Pavolonis et al., 2013



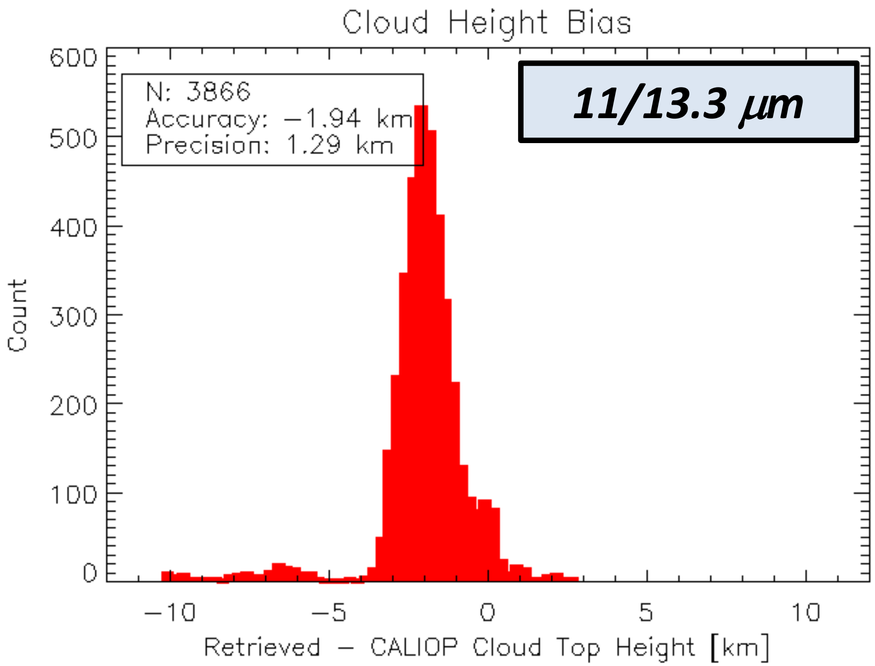
Pavolonis et al., 2013

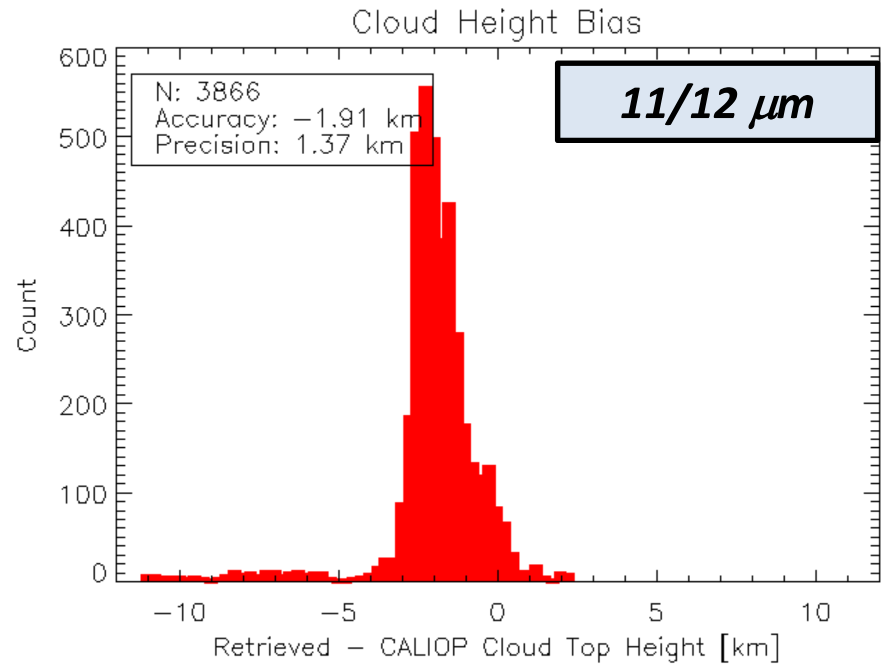


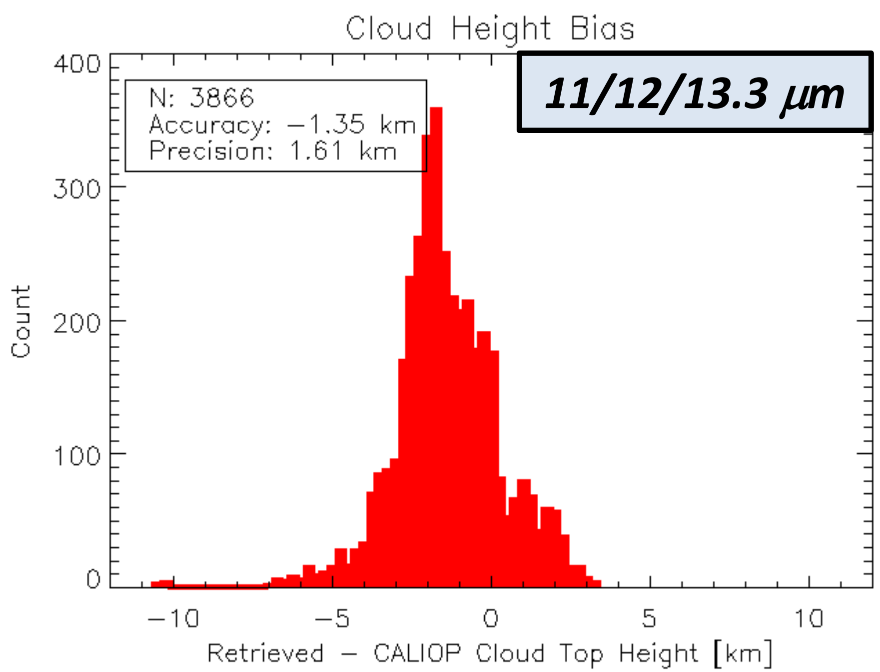
In general, the mass loading is unbiased, but some larger errors are possible, especially when there are underlying meteorological clouds.

Pavolonis et al., 2013

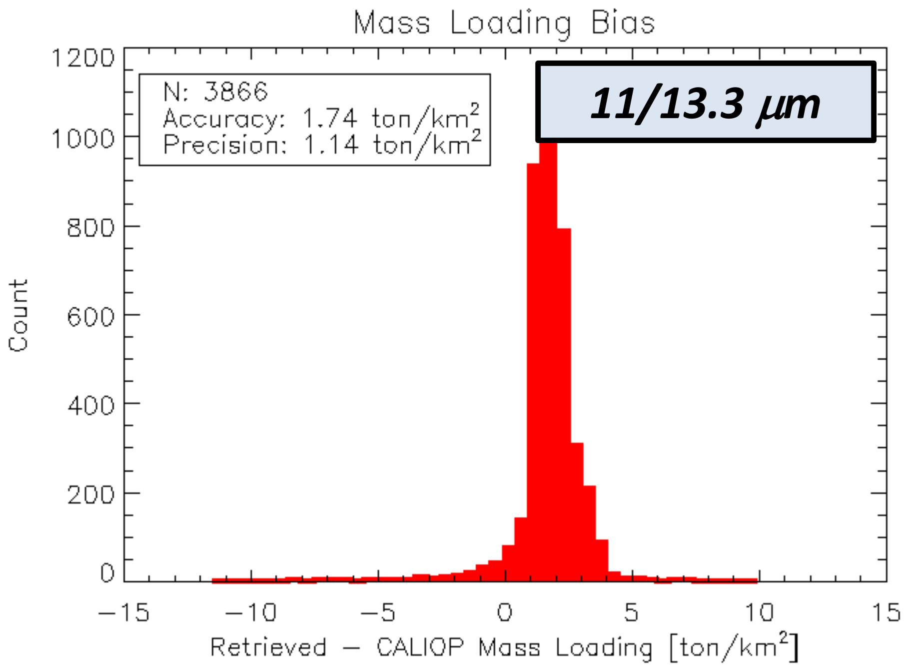
Ash Cloud Height Validation

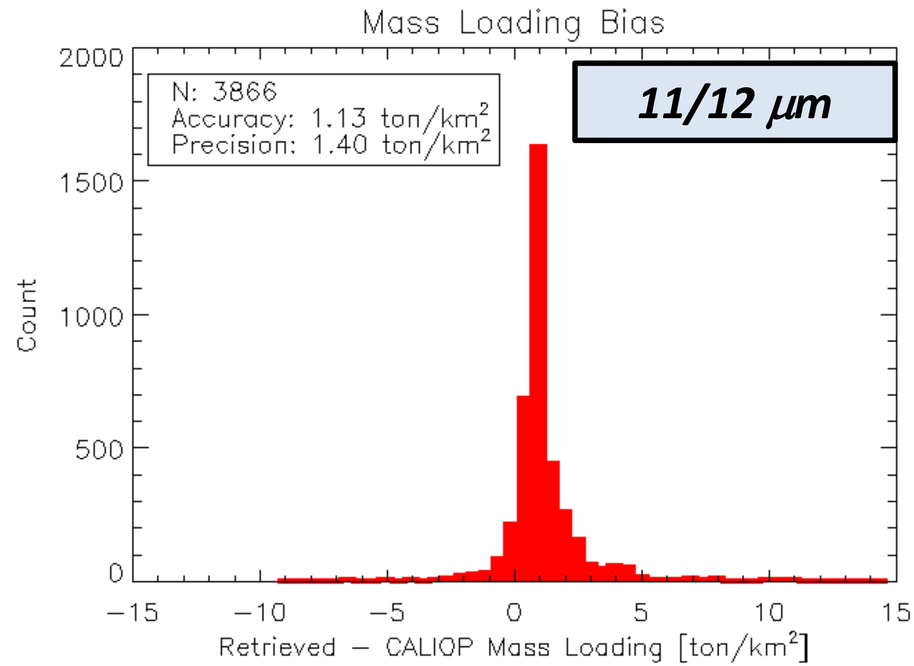


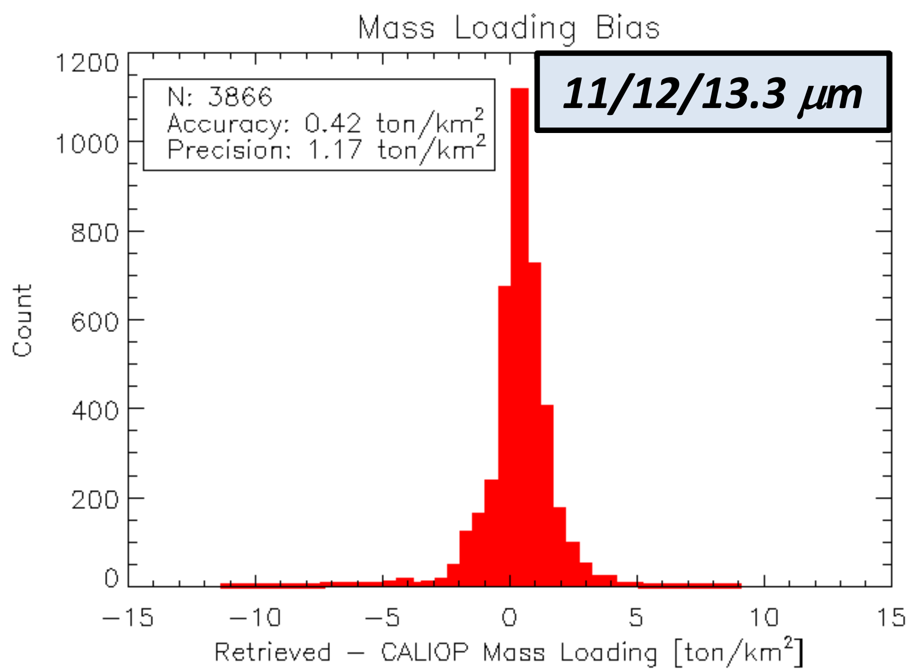




Ash Mass Loading Validation







Performance Estimates: Summary

- The GOES-R approach for estimating ash cloud height and mass loading has been shown to readily meet the accuracy specifications.
- An additional analysis aimed at quantifying the impact of using the GOES-R retrieval approach without the 13.3 μm channel reveals that the products will still meet the accuracy specifications.
- Nonetheless, we should aim to utilize VIIRS and CrIS in tandem in order to generate better (more accurate) products.
- The new and improved ash detection approach has a skill comparable to an experienced human analyst, which is a truly unique capability.

References

- **Pavolonis, M. J., W.F. Feltz, A.K. Heidinger, G. Gallina, 2006: A daytime complement to the reverse absorption technique for improved automated detection of volcanic ash. *J. Oceanic and Atmos. Tech*., 23, 1422-1444.**
- **Pavolonis, M., A. Heidinger, and J. Sieglaff, 2013: Automated retrievals of volcanic ash and dust cloud properties from upwelling infrared measurements, *J. Geophysical Research,* 118(3), 1436-1458.**
- 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 Volcanic Ash Detection and Height, Version 2.0, 71 pp.

Outline

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

VIIRS Daytime Cloud Optical and Microphysical Properties Algorithm Theoretical Basis

Presented by

Andi Walther
CIMSS, University of Wisconsin-Madison

Algorithm Theoretical Basis

- The purpose: provide a theoretical description (scientific and mathematical) of the VIIRS Daytime Cloud Optical and Microphysical Properties (cloud optical depth, cloud particle size, cloud liquid water path, ice water path) for the product developers, reviewers and users.

- Will be documented in the VIIRS Daytime Cloud Optical and Microphysical Properties ATBD

CDR Requirements Cloud Optical Depth

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 Optical Depth	JPSS	for optical depth > 1	Total Column	0.75 km	1 km	0.5 - 50	20%	12 hours	30 min from receipt	10%

CDR Requirements
Cloud Optical Depth

Name	User & Priority	Geographic Coverage (Global)	Temporal Coverage Qualifiers	Product Extent Qualifier	Cloud Cover Conditions Qualifier	Product Statistics Qualifier
Cloud Optical Depth	JPSS	for optical depth > 1	Day	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
Cloud Particle Size Distribution

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 Particle Size Distribution	JPSS	Global	Cloud Top	0.75 km	1 km	0 – 50 µm	4 µm for liquid phase, 10 µm for ice phase	12 hours	30 min from receipt	2 um

CDR Requirements
Cloud Particle Size Distribution

Name	User & Priority	Geographic Coverage (Global)	Temporal Coverage Qualifiers	Product Extent Qualifier	Cloud Cover Conditions Qualifier	Product Statistics Qualifier
Cloud Particle Size Distribution	JPSS	Global	Day	Day; quantitative out to at least 65 degrees LZA and qualitative beyond	In presence of clouds > 2 and < 60	Over specified geographic area

CDR Requirements
Cloud Ice Water Path

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 Ice Water Path	JPSS	for limited cloudiness	SFC – 20 km	0.75 km	1 km	0-1 mm (Day)	Greater of 0.1 mm or 30% during the day	12 hours	30 min from receipt	30%

CDR Requirements
Cloud Ice Water Path

Name	User & Priority	Geographic Coverage (Global)	Temporal Coverage Qualifiers	Product Extent Qualifier	Cloud Cover Conditions Qualifier	Product Statistics Qualifier
Cloud Ice Water Path	JPSS	for limited cloudiness	Day	Quantitative out to at least 65 degrees LZA and qualitative beyond	In presence of limited clouds with optical depth between 1.0 and 60 (day)	Over specified geographic area

CDR Requirements Cloud Liquid Water

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 Liquid Water	JPSS	Global	Total Column	0.75 km	1 km	0-1 mm	Greater of 0.1 mm or 30% during the day	12 hours	30 min from receipt	30%

CDR Requirements Cloud Liquid Water

Name	User & Priority	Geographic Coverage (Global)	Temporal Coverage Qualifiers	Product Extent Qualifier	Cloud Cover Conditions Qualifier	Product Statistics Qualifier
Cloud Liquid Water	JPSS	Global	Day	Quantitative out to at least 65 degrees LZA and qualitative beyond	In presence of limited clouds with optical depths between 2.0 and 60 (day)	Over specified geographic area

DCOMP Algorithm

- Approach is identical to GOES-ABI approach: Use of Bi-spectral measurements in the visible and near-infrared range to determine cloud optical depth (COD) and cloud particle size radius (CPS), also called cloud effective radius.
- Use of simple assumptions to determine liquid and ice water path
- Use of 1D-Var Optimal estimation technique (Rogers 1976).
- Use of pre-computed bidirectional reflectance and transmission look-up-tables.

DCOMP Algorithm General Scheme

- Pre-calculated reflectance tables (Approach by Nakajima King 1990)
  - » Makes use of more efficient computer resources by using analytic inversion and interpolation methods.
  - » Makes use of high spatial resolution land surface reflectance fields generated for MODIS MOD06 products.
  - » Fast forward computation due to pre-calculated LUTs

DCOMP Algorithm Channel Set

- The retrieval requires simultaneous measurements in one visible and in one near-infrared channel:
  - » Visible
    - – Channel M5 at 0.6 µm
      - Adequate for measurements over land
    - – Channel M7 at 0.8 µm
      - Is an alternative for ocean surface
  - » Near-infrared channel
    - – Channel M10 at 1.6 µm
      - Good noise/signal relation, not good for small liquid due to weak absorption, large influence of surface effects
    - – Channel M11 at 2.1 µm
      - Proposed baseline channel setting. Has stronger absorption, less surface influence. Use for snow retrieval.
    - – Channel M12 at 3.9 µm
      - Measures mainly cloud top- suitable for quality check
      - Requires consideration of thermal emission

DCOMP Algorithm Inversion Technique

- Optimal estimation technique (1D-Var)
  - » Iterative descent method for minimization of cost functions.
  - » Fast, flexible
  - » Finds optimal solutions with consideration of prior knowledge
  - » Propagates input and model uncertainty in solution uncertainty. Uncertainty can be provided in physical units.

DCOMP Algorithm Information

- Pre-calculations of reflectance tables
- Channel settings M5/M11 as the main retrieval approach. Additional channel settings will be possible via configuration file.
- Use of Optimal Estimation technique (1D-var)
- Radiative transfer model: *Doubling-Adding*
- Ice Scattering Model by Baum/Yang

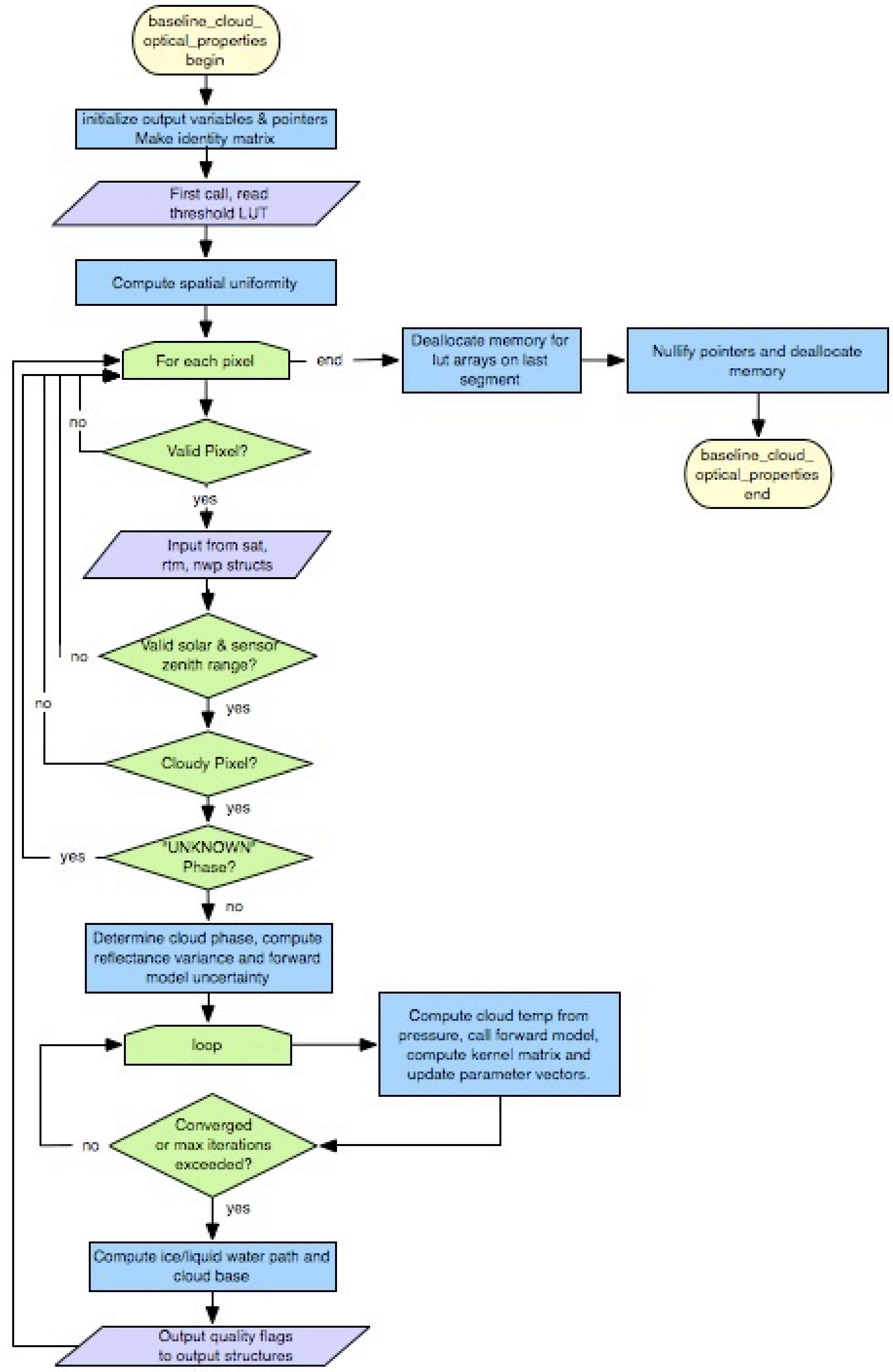
Algorithm Objectives

- Provide daytime microphysical products (cloud effective radius, cloud optical depth, ice water and liquid water content) over the VIIRS observation region
- Provide quality flags for all products.
- Provide physically-based uncertainty measures.
- Provide an algorithm, that will be able to run in an operationally working environment.
- The products may meet the VIIRS mission requirement.

Processing Outline

ABI Daytime Cloud Optical Properties Processing

- Begin ABI Daytime Cloud Optical Properties subroutine
- Initialize output structures and make indentity matrix
- Input data from satellite, rtm and nwp structures
- Initialize local variables and pointers
- On first call, read in threshold lut
- Compute spatial uniformity
- For each valid pixel intialize satellite, rtm and nwp data. Then determine if it is cloudy, in the correct sensor and solar zenith angle range. Using it's phase, compute forward model to get optical properties. Then 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 Daytime Cloud Optical Properties subroutine



Algorithm Input
Sensor Input(I)

VIIRS Band	Wavelength Range (µm)	Central Wavelength (µm)	Sample Use
M5	0.662-0.682	0.672	DCOMP Visible channel for mode 1-3 over land
M7	0.846-0.885	0.865	DCOMP Visible channel for mode 1-3 over sea
M10	1.371-1.386	1.61	DCOMP NIR channel for mode 1,4 (snow)
M11	2.23-2.28	2.25	DCOMP NIR channel for mode 2,4
M12	3.61-3.79	3.7	DCOMP NIR channel for mode 3,4

Sensor Input(II)

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

Algorithm Input: Ancillary data

- Three types of ancillary data needed:
  - » VIIRS Dynamic Data: Cloud mask, Cloud Type, Cloud Phase, Cloud Top Height
  - » Non-VIIRS Static Data: Surface Albedo, surface emissivity, Land/Sea Mask, Pre-computed Look-up-tables of cloud reflectance, transmission and spherical albedo
  - » Non-VIIRS Dynamic Data: NWP-based profiles of Air temperature and Water vapor, NWP-based stratospheric Ozone maps

Ancillary Inputs to the Algorithm

- **VIIRS Dynamic Data:**

Name	Type	Description	Dimension
Cloud height	input	VIIRS level 2 cloud height data	grid (xsize, ysize)
Cloud mask	input	VIIRS level 2 cloud mask data	grid (xsize, ysize)
Cloud phase	input	VIIRS level 2 cloud phase data	grid (xsize, ysize)
Cloud type	input	VIIRS level 2 cloud type data	grid (xsize, ysize)

Ancillary Inputs to the Algorithm

- **Non-ABI Static Data:**

Name	Type	Description	
LUT for water phase	input	Pre-calculated reflectivity/transmission values	
LUT for ice phase	input	Pre-calculated reflectivity/transmission values	
Surface Albedo	input	MODIS 16-data composites	1-km
Land/Sea mask	input	Land/Sea mask data	grid (xsize, ysize)

Ancillary Inputs to the Algorithm

- **Non-VIIRS Dynamic Data:**

Name	Type	Description	Dimension
Water vapor profile	input	NCEP 6-hour forecast data	0.25 deg resolution
Temperature profile	input	NCEP 6-hour forecast data	0.25 deg resolution

Algorithm Output

Name	Type	Description	Dimension
CPS values	output	Retrieved cloud particle size values for each pixel of the scanning mode	grid(xsize,ysize)
CPS uncertainty	output	CPS uncertainty in physical units from Optimal estimation solution. (propagated input and forward model uncertainty)	grid(xsize,ysize)
COD values	output	Retrieved cloud optical depth for each pixel of the scanning mode	grid(xsize,ysize)
COD uncertainty	output	COD uncertainty in COD units from Optimal estimation solution.	grid(xsize,ysize)
IWP values	output	Retrieved ice water path for each pixel of the scanning mode	grid(xsize,ysize)
LWP values	output	Retrieved liquid water path for each pixel of the scanning mode	grid(xsize,ysize)
QF	output	Quality Flags for each pixel of the scanning mode	grid(xsize,ysize)
Processing flag	output	Describes processing deceisons	grid(xsize,ysize)

Output: Quality Flag

DCOMP Quality Flag specification

QF1	Bit	F_i	Description	When to apply
DCOMP_PRCS_FLAG	0	1	0 - not processed 1- processed	
DCOMP_QF_COD_VALID	1	2	0 –Valid retrieval 1- not valid	If Q1/B0 EQ '1'
DCOMP_QF_REF_VALID	2	4	0 –Valid retrieval 1- not valid	If Q1/B0 EQ '1'
DCOMP_QF_COD_DEGRADED[1]	3	8	0 –no 1- degraded	If Q1/B0 EQ '1'
DCOMP_QF_REF_DEGRADED[2]	4	16	0 –no 1- degraded	If Q1/B0 EQ '1'
DCOMP_QF_CONVERGENCY	5	32	0 – convergent 1 - not	If Q1/B0 EQ '1'
DCOMP_QF_GLINT	6	64	0 – no glint 1- glint	If Q1/B0 EQ '1'

[1]Reasons for COD degradation are set in DCOMP_INFO flag. Possible reasons for COD are snow, sea-ice, twilight and thick cloud saturation.
[2]Reasons for REF degradation are set in DCOMP_INFO flag. Possible reasons for REF degradation are snow, sea-ice, twilight.

Output: Processing flag

DCOMP Processing Flag specification

QF1	Bit	F_i	Description	When to apply
DCOMP_INFO_PRCS_FLAG	0	1	0 - not processed 1- processed	
DCOMP_INFO_LAND_SEA	0	1	0 –Land 1- Ocean	
DCOMP_INFO_DAY_NIGHT	1	2	0 –Day 1-Night	
DCOMP_INFO_TWILIGHT	2	4	0- no 1- solar angle between 65 and 82	
DCOMP_INFO_SNOW	3	8	0 – no snow 1 -snow	
DCOMP_INFO_SEA_ICE	4	16	0 – no sea ice 1- sea ice	
DCOMP_INFO_PHASE	5	32	0- water 1- ice	If Q1/B0 EQ '1'
DCOMP_INFO_THICK_CLOUD[1]	6	64	0 – not 1 – yes	If Q1/B0 EQ '1'
DCOMP_INFO_THIN_CLOUD[2]	7	128	0-not 1-yes	If Q1/B0 EQ '1'

[1] Thick cloud retrieval set COD to upper bound (160). The COD Quality is degraded. REF quality is good.
[2] Thin cloud retrieval set REF to a-priori value. The REF retrieval output is not valid. COD quality is good.

Retrieval Strategy

- Algorithm will be performed
  - » for day scenes only (threshold sun zenith = 65 degrees)
  - » for cloudy pixels only (Use of VIIRS cloud mask)
- Atmospheric corrections:
  - » Rayleigh scattering, ozone
  - » Use of vertical profiles from NWP forecasts to correct water vapor extinction as given by ABI cloud height measurements
- Forward model
  - » Pre-computed by Radiative transfer model and stored in look-up-tables in advance
- Inversion technique
  - » Optimal estimation framework. Provides propagation from input and forward model uncertainty to solution uncertainty.
- Quality control flags
  - » Generate algorithm QC flags in addition to scientific products

Physical Description

- Definition of Cloud Effective Radius (Hansen and Travis 1974):

$$r_e = \int_0^\infty r^3 n(r)\,dr \Big/ \int_0^\infty r^2 n(r)\,dr$$

r = Particle radius

$n(r)$ = Particle size distribution

Cloud effective radius is defined as the total of all droplet volumes divided by the total of surface areas.

Physical Description

- Definition of Cloud Optical Depth:

$$\tau_c = \int_{cth}^{cbh} \beta_e(z)\mathrm{dz}$$

β_e	= extinction coefficient
z	= Height
cth	= Cloud Top Height
cbh	= Cloud Bottom Height

Cloud optical depth describes the extinction of radiation in an air column.

Physical Description

- Liquid and Ice water path is is a measure of the total amount of liquid or solid water present in an air column.

$$W_{I,L} = \int_{ctb}^{cth} w_{I,L} \mathrm{dz}$$

Physical Description

- Liquid and Ice water path are the only macro-physical parameter that can be linked to micro-physical properties within a cloud
- We use an estimate of LWP and IWP from optical thickness and cloud effective radius (Stephens 1978):

$$W_{L,I} \approx \frac{2}{3}\tau_c r_{eff}$$

Physical Description

- Normalization of reflected intensity defines reflectivity R_λ as

$$R_\lambda(\tau_c, r_e, \mu, \mu_0, \phi) = \frac{\pi I_\lambda(0, -\mu, \phi)}{\mu_0 F_0(\lambda)}$$

where I_λ is the measured radiance at the sensor, F_0 is the incoming solar Flux, μ_0 the cosine of the solar zenith angle ,and ϕ the relative azimuth angle between sensor and sun.

Physical Description

- Radiative Transfer Equation in the absence of thermal emission:

$$\mu \frac{\mathrm{d}I(\mu,\varphi)}{\mathrm{d}\tau} = I(\mu,\varphi) - \frac{\tilde{\omega}}{4\pi}\int_0^{2\pi}\int_{-1}^{1} p(\mu,\varphi,\mu',\varphi')I(\mu',\varphi')\mathrm{d}\mu'\mathrm{d}\varphi'$$

Measured attenuation of solar radiance is a function of single scattering albedo $\tilde{\omega}$, the scattering phase function *p* and the incoming solar radiation *I*.

Physical Description

- The reflected solar radiance at wavelength with no thermal emissions is almost exclusively a result of absorption and scattering processes within clouds and at surface.

- Extinction in the visible wavelength is caused by scattering ("conservative scattering") with single scattering albedo equals 1. Scattering is direct proportional to scattering cross area.

- Size of cloud particle determine the shape of scattering phase function and is needed to retrieve scattered radiance to a certain direction.

Physical Description

- The amount of absorption is direct proportional to absorber volume. Extinction in Near-IR is influenced by water absorption and is, thus, a function of cloud particle size.
- Simultaneous retrieval from optical depth and particle size is required since scattering and absorption can otherwise not be separated

Physical Description

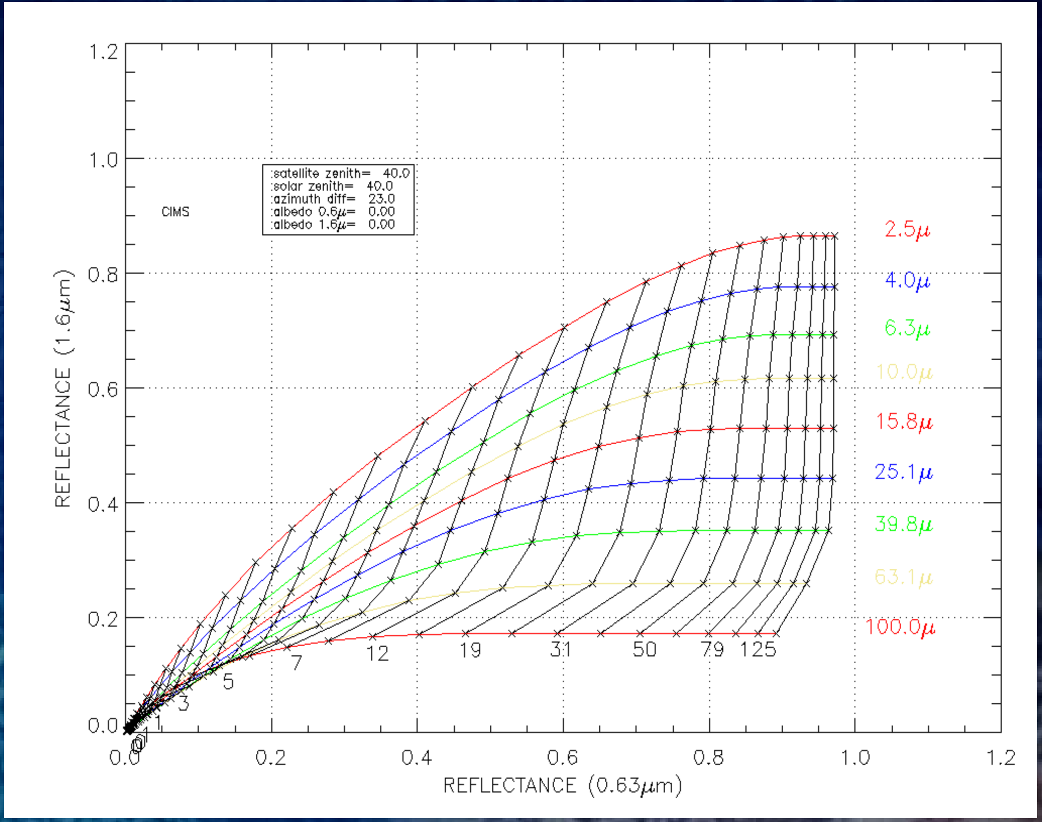
- Values of cloud reflection, transmission and spherical albedo functions are computed and stored at three geometrical angles, M optical thicknesses and N prescribed effective particle radii. This forms a look-up-table for direct reflection by clouds.

- Determination of effective radius and optical depth from this look-up-table constitutes an *inverse problem*. The principle of the solution is an iterative comparing of the measurements with the LUT entrees.

Physical Description

This image shows theoretical computed isolines of effective radius (colored lines running almost parallel to x-axis) and of cloud optical depth (black lines running almost parallel to y-axis) as a function of a visible channel (x-axis) and a near-infrared channel (y-axis) for a arbitrary geometrical constellation.

The image illustrates that we can expect definite solutions for clouds thicker than optical depth of around 5.



Optical parameters as a function of reflectance of two channels

Physical Description

- The reflected sunlight received at the satellite is a sum of several partitions:
  - » Radiation scattered at cloud
  - » Radiation that has transmitted through the cloud and was reflected at the surface and transmitted again through the cloud.
  - » Radiation that comes from multiple reflection processes between cloud and surface

Physical Description
Effect of Surface Reflection

Cloud Reflection

$R_C = f(\tau, r, \mu_0, \mu, \phi)$

Transmission from μ0

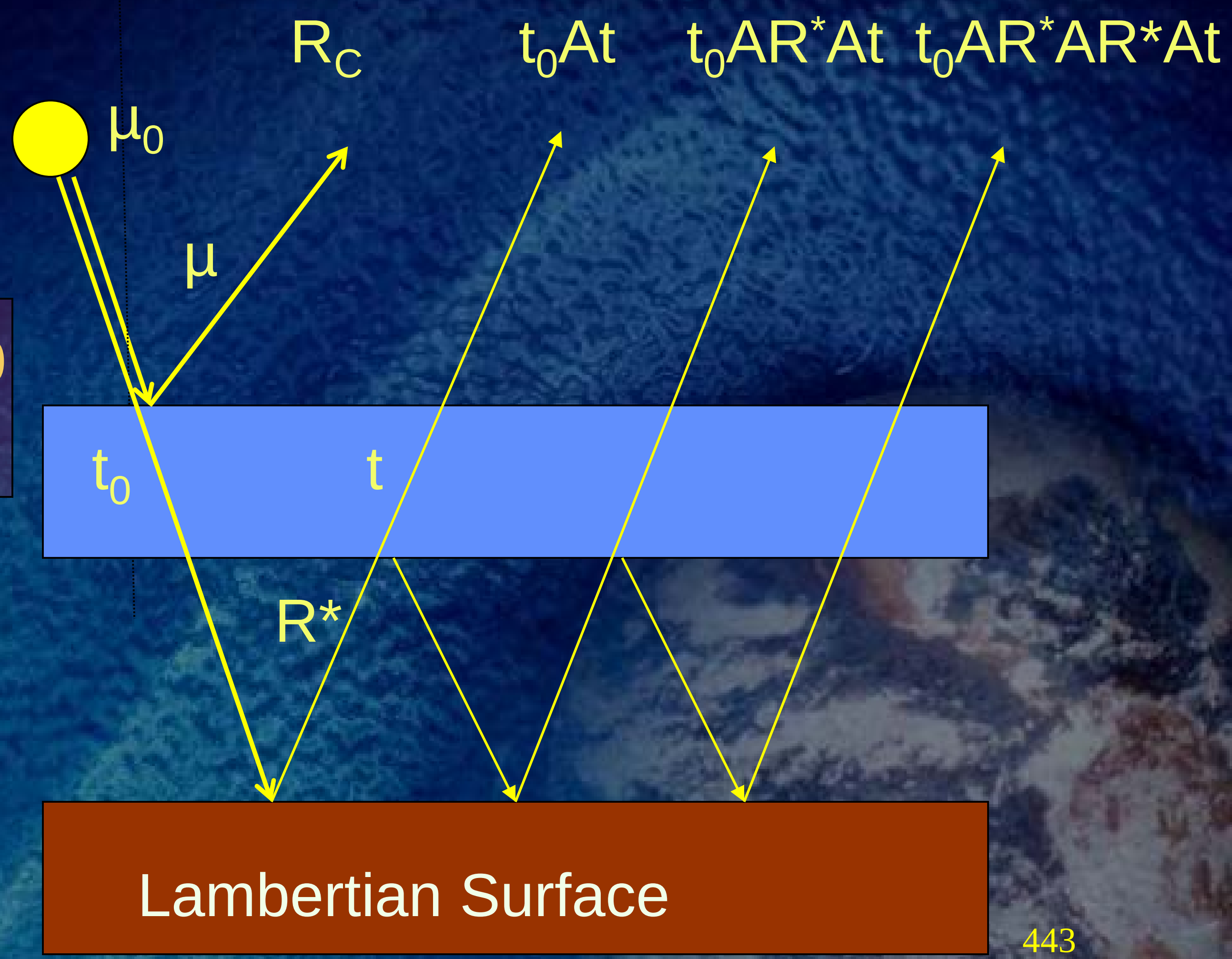
$t_0 = f(\tau, r, \mu_0)$

Transmission from μ

$t = f(\tau, r, \mu)$

Spherical Albedo

$R^* = f(\tau, r)$



Physical Description
Effect of Surface Reflection

- Last two slides demonstrated the contribution of backscattered radiances from Lambertian surface below the cloud.
- Due to geometrical reasons transmission t can seen as identical to t_0
- Reflectance with consideration of surface albedo are summarized as:

$$R = R_C + \frac{At^2}{(1 - AR^*)}$$

Full forward model

Radiance at top of cloud computed from clear-sky radiance profiles from NWP and cloud top temperature Planck function

$$I_{\mathrm{TOC}} = \varepsilon_c(\tau, r_e) B(T_c) + t_c(\tau, r_e)\,[I_{\mathrm{clr}} - I_a(H)],$$

Adequate reflectance value of terrestrial emission

$$R_{e,\mathrm{TOC}} = \frac{\pi d^2}{\mu_0 F_0} I_{\mathrm{TOC}},$$

Set of full forward model for each channel:

$$R_{\mathrm{TOC}} = R_c(\tau, r_e) + \frac{A_v t_{c,0}(\tau, r_e) t_c(\tau, r_e)}{1 - A_v S(\tau, r_e)} + R_{e,\mathrm{TOC}}(\tau, r_e).$$

Task of inversion is to find the pair of tau and ref, which satisfies the two equations

Mathematical Description Overview

- Mathematical methods have to deal with:
  - » Solving the Radiative Transfer Equation with Doubling-Adding method
  - » Fast inversion technique to retrieve atmospheric properties in an efficient way

Mathematical Description RTM Simulations

- Radiative transfer equation is solved using the method of Adding- Doubling.
- The model is run with 64 streams, 128 Legendre expansion coefficients and 12 azimuthal modes.
- Clouds are assumed to be plane-parallel, vertically homogeneous.

Mathematical Description RTM Simulations

- The effects of water vapor, ozone and Rayleigh scattering are included. Eventually the CRTM will be used when the CRTM is able to simulate visible and near-infrared channels. Currently, MODTRAN based regressions are used (expect for the 3.9 micron channel where the PFAAST model used).
- Profiles of water vapor are provided by the NCEP GFS model.
- Water cloud scattering is modeled using Mie Theory.
- Ice cloud scattering is modeled using the Baum/Yang models.

Mathematical Description Forward method

- Pre-computed Look-up-tables: Store cloud reflectance values R_c separated in ice and water with the following entrees for water:
  - » 45 Solar zenith angles: 0 to 88 degree in steps of 2 degree
  - » 45 Observation (sensor) zenith angles: 0 to 88 degree in steps of 2 degrees
  - » 45 Azimuth angle difference: 0 to 170 degree in steps of 5 degrees: 170 to 180 degree in steps of 1 degree.
  - » 9 Effective Cloud particle size defined in log10 space: From 0.4 to 2.0 in steps of 0.2.
  - » 29 Cloud optical depth defined in log10 space from -0.6 to 2.2 in steps of 0.1.

Mathematical Description

Pre-computed Look-up-tables:

- The set-up for ice clouds:
  - » 45 Solar zenith angles: 0 to 88 degree in steps of 2 degree
  - » 45 Observation (sensor) zenith angles: 0 to 88 degree in steps of 2 degrees
  - » 45 Azimuth angle difference: 0 to 170 degree in steps of 5 degrees: 170 to 180 degree in steps of 1 degree.
  - » 11 Effective Cloud particle size defined in micron space: [5, 10,15,20,30,40,50,70,90,110,130]
  - » 29 Cloud optical depth defined in log10 space from -0.6 to 2.2 in steps of 0.1.

Mathematical Description

Pre-computed Look-up-tables:

- LUTs additionally store
  - » Spherical Albedo for the same entrée points of effective radius and optical depth (Two-dimensional with (9 (11 for ice) ,29) entrees)
  - » Total transmission function similar to the entrees of effective radius, optical depth and solar zenith angle. (Three-dimensional with (9 (11),29,45) entrees)
- LUTs are stored in NetCDF4 format.

Mathematical Description Retrieval

$$R = R_C + \frac{At^2}{(1 - AR^*)}$$

- R is the measured normalized reflectivity at the sensor
- R_c, t, R^* are stored in the LUTs as functions of τ, r_{eff}
- Albedo A is specific for each observation point and time slot and will be determined by MODIS surface product MOD34.

Task on hand is to find these values of τ, r_{eff} , that the equation above is fulfilled.

This kind of a problem is called *optimization problem*.

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 3.9 channel easily in the future).
  - It is numerically stable. It 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

- The mathematics of optimal estimation are well developed and have 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 estimate the Kernel matrix where each element is the derivative of each observation to each retrieved parameter.

Mathematical Description: Optimal Estimation Definitions 1

- We employ an optimal estimation approach which minimizes a cost function (ϕ) of the form:

$$\Phi = (x - \mathbf{x}_a)^T \mathbf{S}_a^{-1} (x - \mathbf{x}_a) + [\mathbf{y} - \mathbf{f}(x)]^T \mathbf{S}_y^{-1} [\mathbf{y} - \mathbf{f}(\mathbf{x})]$$

x = retrieved vector = τ , r_{eff}

x_a = *a priori* values of x

S_a = error covariance of xa

y = observed vector = R_2 , R_5

f() = forward model

S_y = error covariance of forward model

Mathematical Description

- Each iteration is controlled by the following equation

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

K = Kernel Matrix (df / dx)

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

- Convergence
  - » We use a standard metric for the checking the convergence of the 1DVAR.
  - » Typically, convergence is achieved in 3-4 iterations.
  - » It is stopped after 10 iterations

Mathematical Description: The Kernel Matric

- The most computationally intensive calculations are used to compute the Kernel Matrix (K) (also known as the Jacobian) 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: $dR_2 / d\tau$, dR_5 / dr_{eff}
- 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.
  - Typically, convergence is achieved in 3-4 iterations.
  - It is stopped after 10 iterations

Mathematical Description: Diagnostics

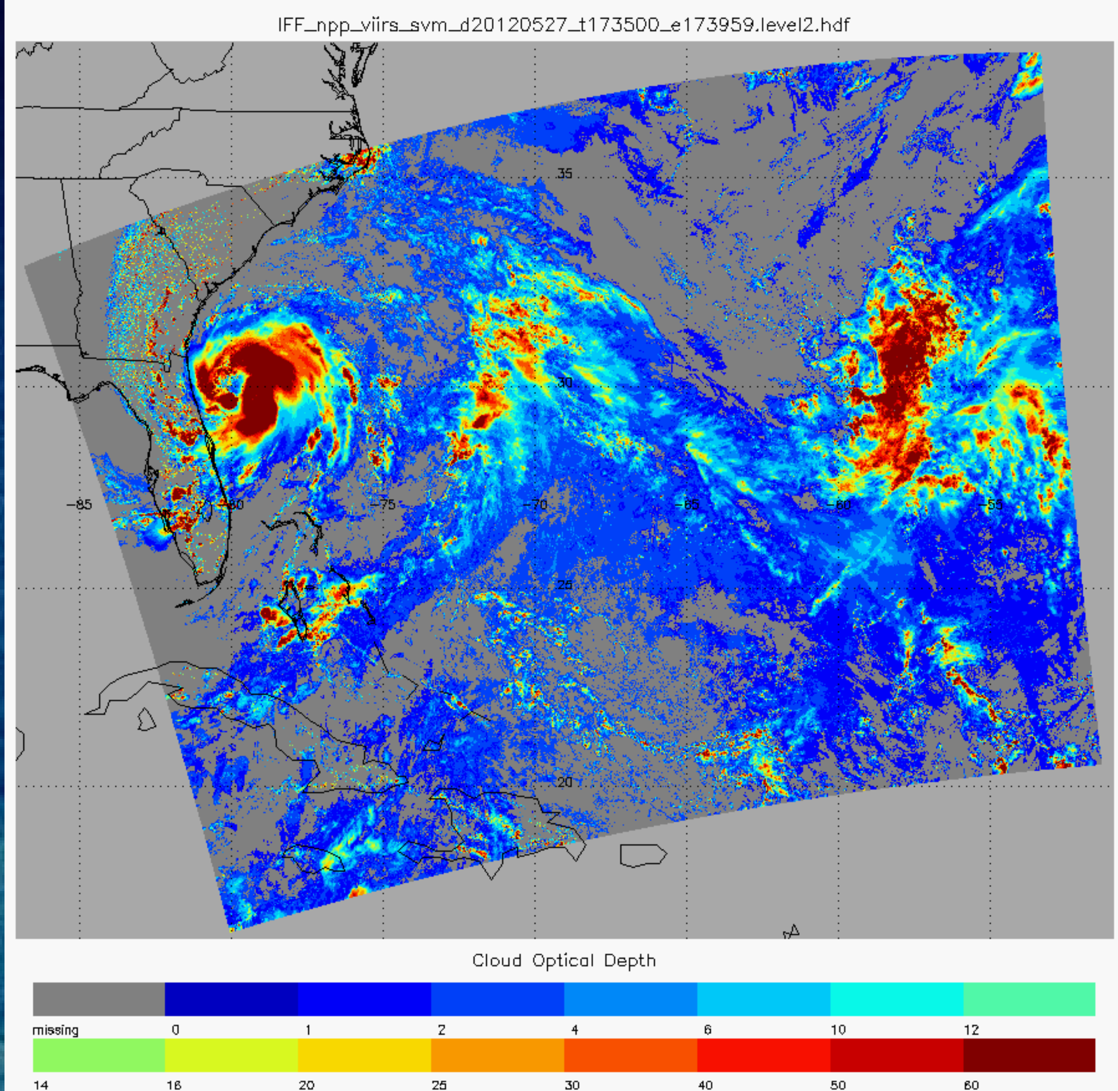
- One major benefit of optimal estimation is that it can automatically diagnose its own performance.
- The error covariance matrix of the retrieved parameters, x is defined as:

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

- 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.

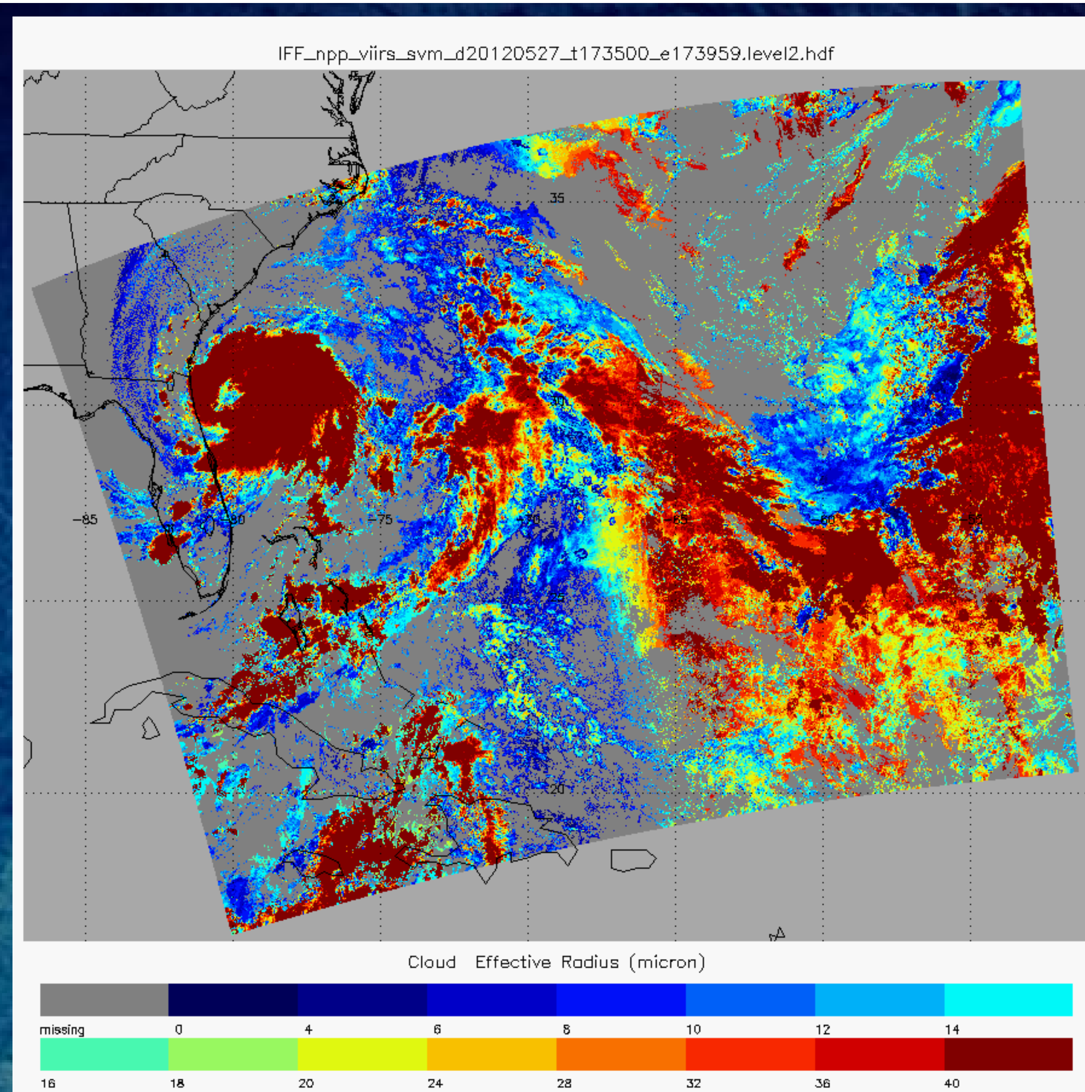
Algorithm Output

The following images show sample output of VIIRS daytime microphysical products (May 27, 2012 12 UTC).



Algorithm Output

Image of the Cloud effective radius.



Error Budget Estimates

Product	specs	KNMI	MODIS
COD	20%	met for 95% (100% of thin and medium clouds)	met for 90%
CPS	4 microns	met for 100%	met for 95 %
LWP	30% or 0.1mm	No comparison	met (combined comparison with IWP)
IWP	30% or 0.1mm	No comparison	met (combined comparison with IWP)

Challenges of retrieval over Snow surface

- **For a polar-orbiting satellite, the snow surface problem is more present as for geo satellites as GOES-ABI**
- **Choice of snow mask is crucial.** Wrong snow/non-snow discrimination is a potential high risk. There are dynamic snow masks with high temporal resolution and others with high spatial resolution.
- **Surface albedo** of snow surface is highly **uncertain**. (fresh snow, snow in forests or urban areas, etc.)
- High surface albedo, even if known accurately, leads to higher retrieval uncertainty from the theory.
- Pre-retrieved VIIRS products cloud mask, cloud phase and cloud height have also a higher risk of bad results.

Snow surface retrieval approach

- Combining multiple snow-masks and adjacent cloud-free pixels for a better snow/non-snow discrimination.
- Albedo over snow in NIR is smaller and less variable than in VIS channels. If snow is detected we will apply a two-channel method exclusively in NIR (channels M10, M11, M12).
- Estimating potential error by running DCOMP in snow and in non-snow mode during development.
- Modifying albedo input uncertainty will propagated to higher solution uncertainty values for COD and CPS.
- Extending processing flag to provide more information to the users
- Similar approach for sea-ice planned.

References

- Nakajima, King 1990: Determination of the optical thickness and effective particle radius of clouds from reflected solar radiation measurements. *J. Atmos. Sci*. 47, 1878-1893
- King 1987: Determination of the scaled optical thickness of clouds from reflected solar radiation measurements. *J. Atmos. Sci*. 44 ,1734-1751
- Baum, Heymsfield, Yang, Bedka, 2005: Bulk scattering properties for the remote sensing of ice clouds. Part I: Microphysical Data and Models. *J. Applied. Met.* 44, 1885-1895
- Heidinger, Andrew K.. "Rapid daytime estimation of cloud properties over a large area from radiance distributions". Journal of Atmospheric and Oceanic Technology, Volume 20, Issue 9, 2003, pp.1237-1250
- Platnick, S, Li, JY, King, MD, Gerber, H, Hobbs, PV (2001). A solar reflectance method for retrieving the optical thickness and droplet size of liquid water clouds over snow and ice surfaces. *JOURNAL OF GEOPHYSICAL RESEARCH-ATMOSPHERES*, 106(D14), 15185-15199.
- Walther, Andi, Andrew K. Heidinger, 2012: Implementation of the Daytime Cloud Optical and Microphysical Properties Algorithm (DCOMP) in PATMOS-x. *J. Appl. Meteor. Climatol.*, 51, 1371–1390.

Outline

- Introduction
- Requirements
- Operations Concept
- Aerosol Detection
- AOD and Aerosol Particle Size
- Volcanic Ash
- DCOMP
- 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

Level	
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

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

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

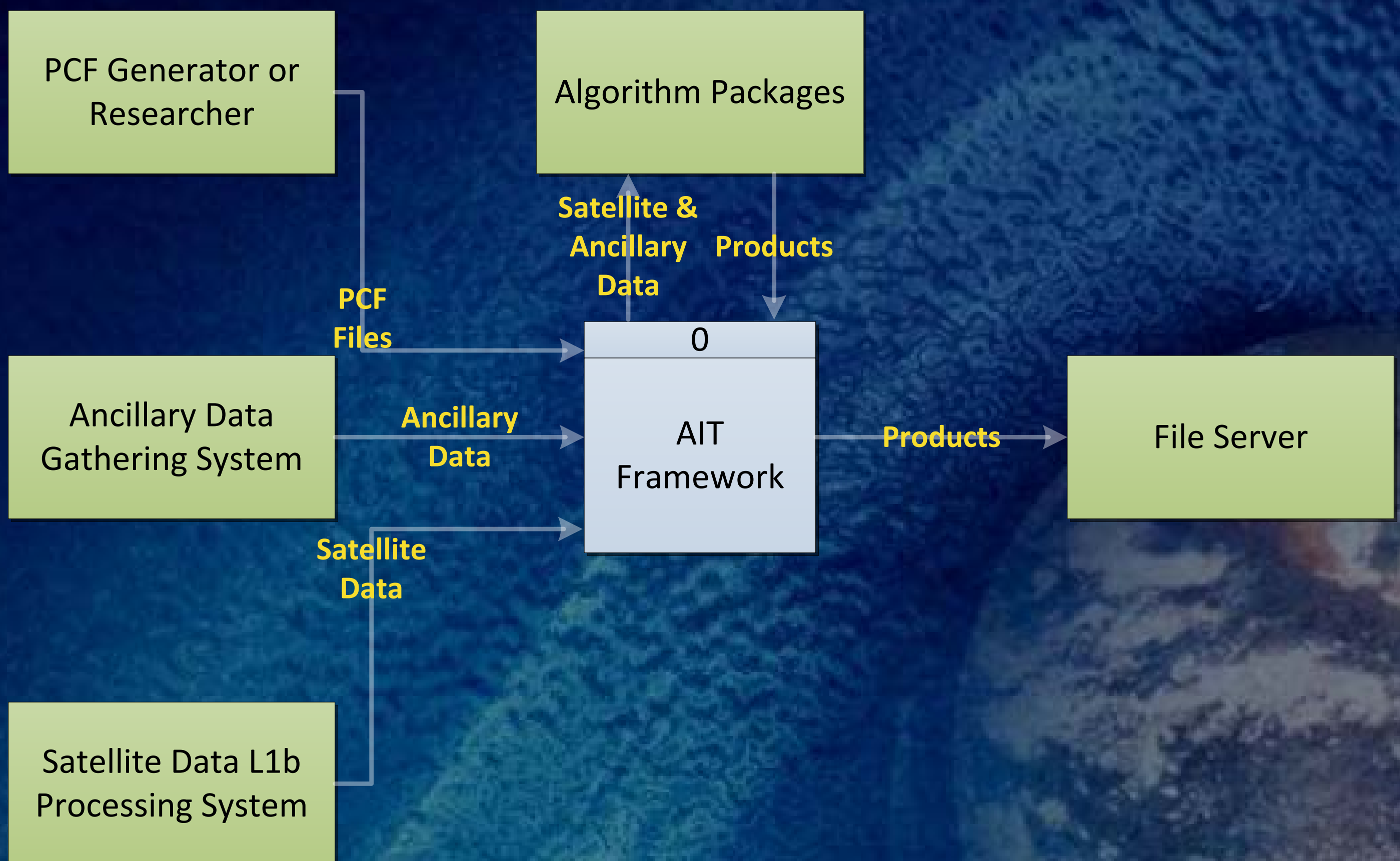
STAR AIT Framework Algorithms

- 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

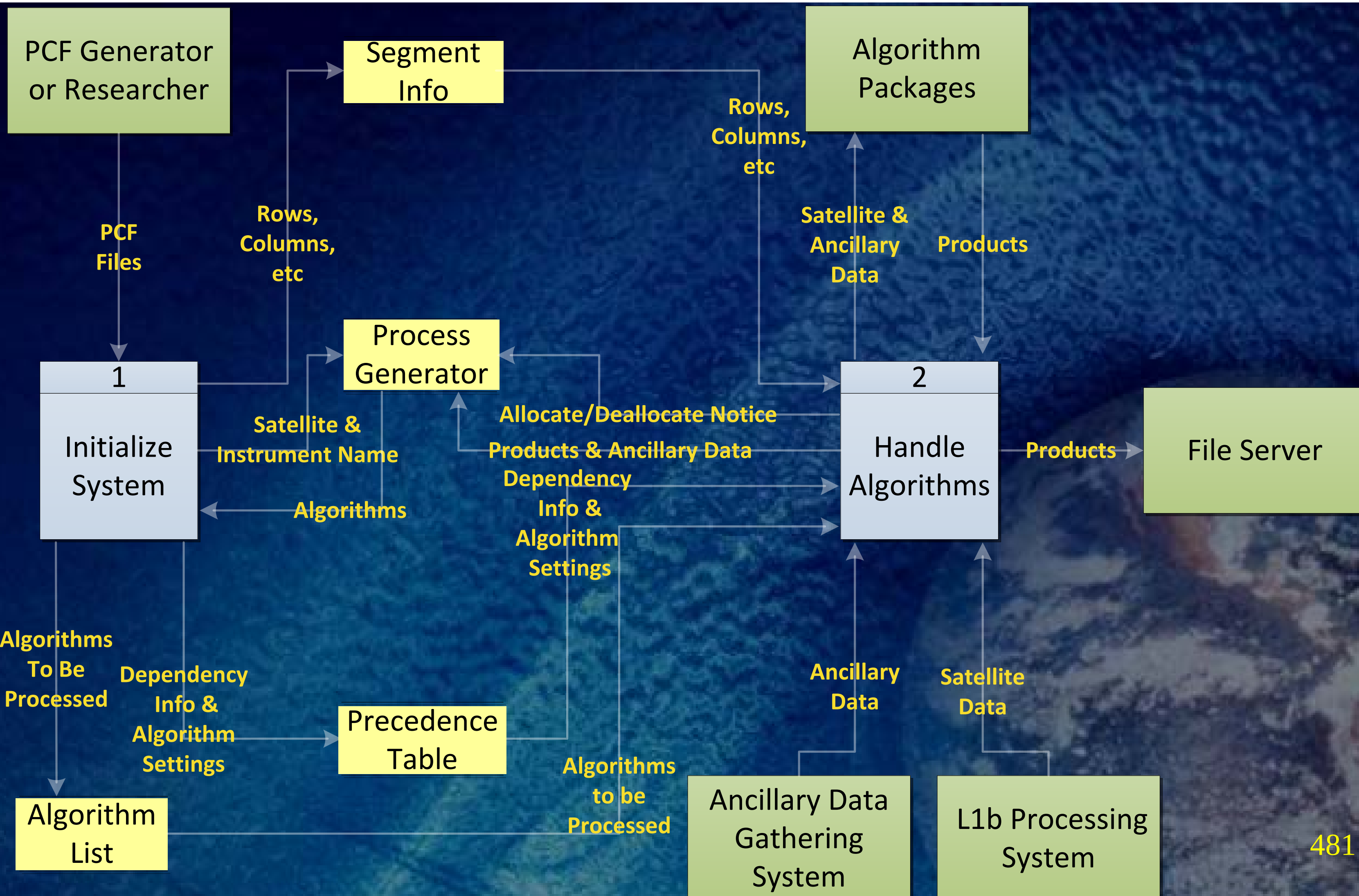
Framework Data Flow and Interfaces

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

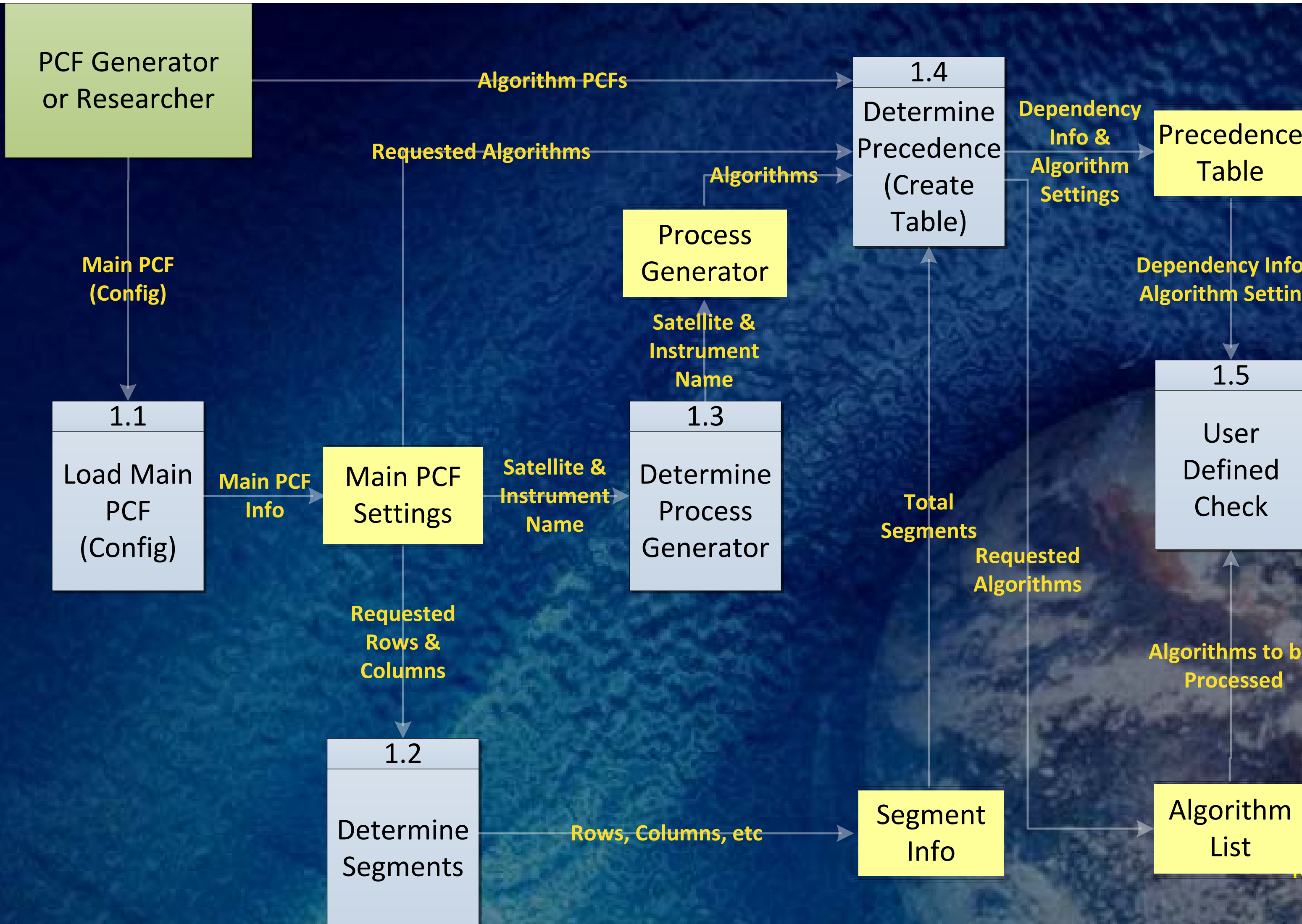
Framework Context Diagram



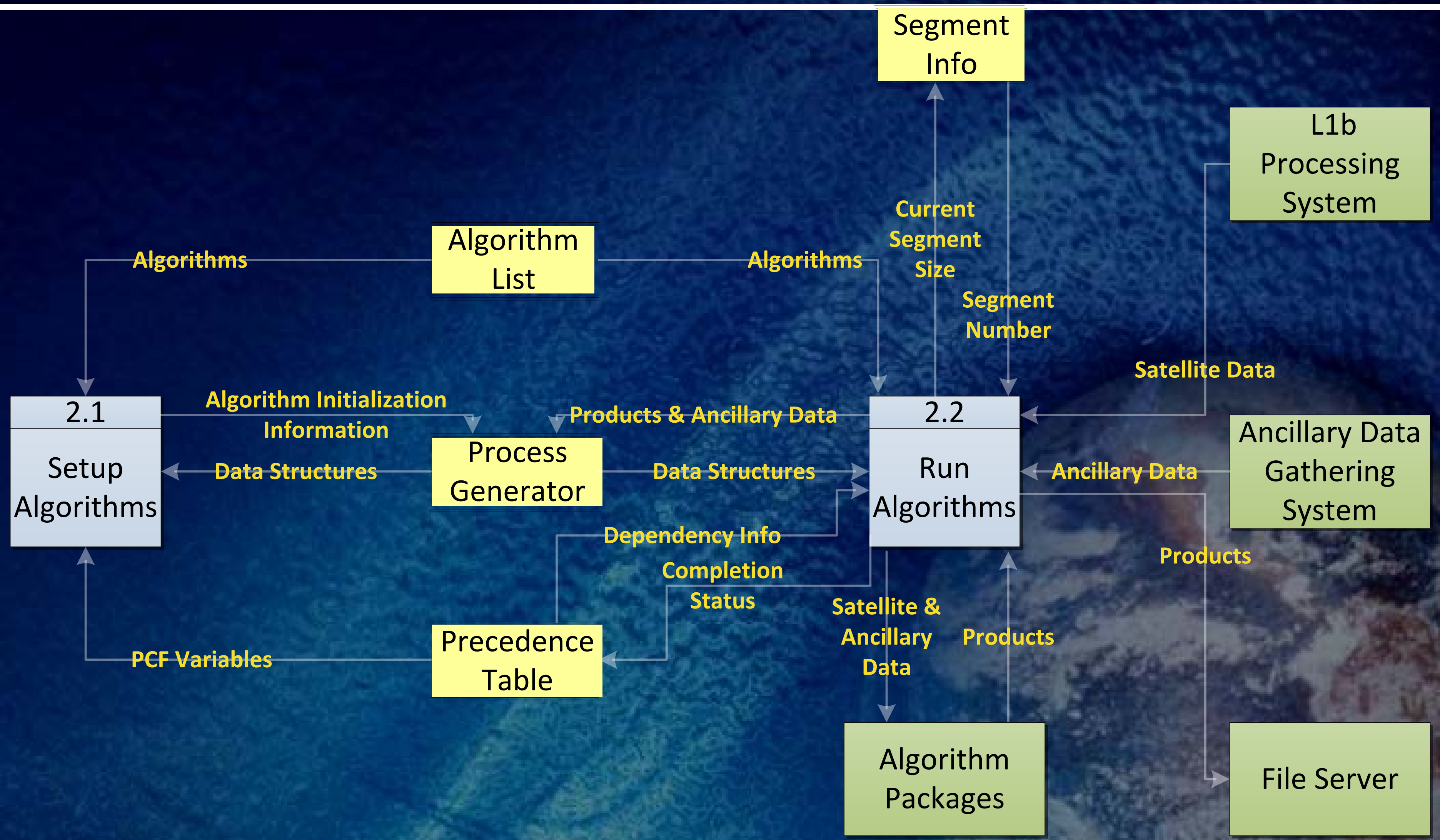
Framework System Level



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
```

1st 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

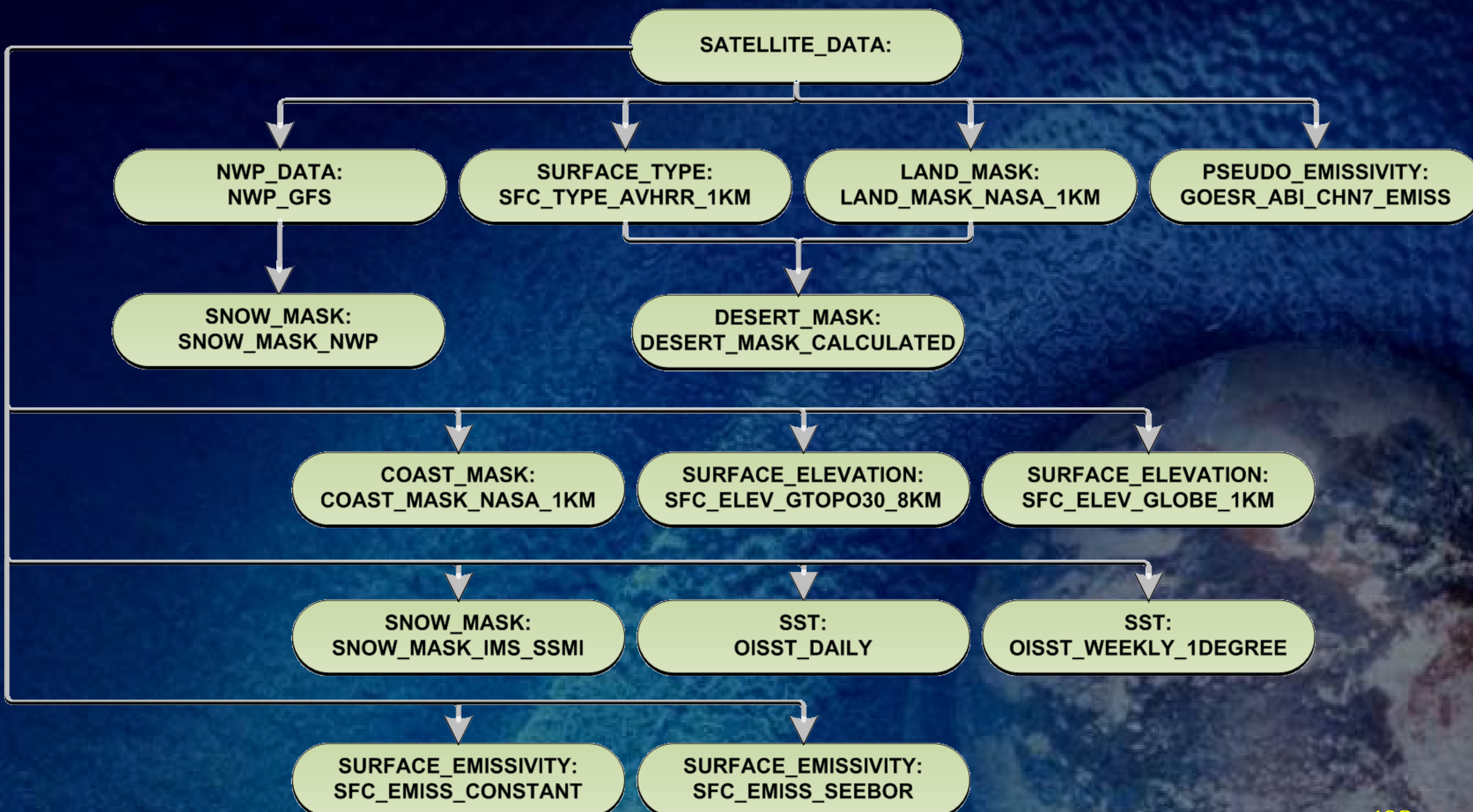


Table of DynamicAncillary Data

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

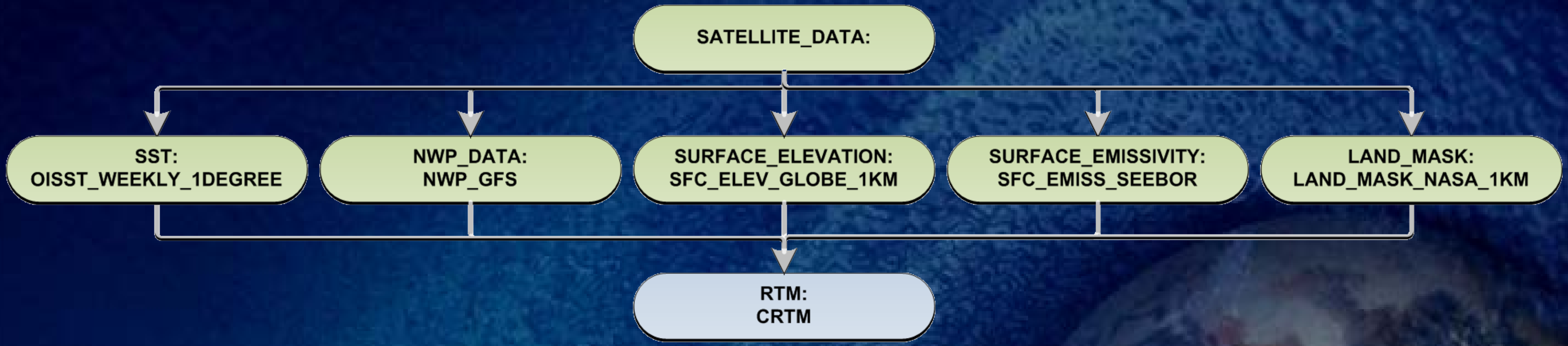
Table of Static Ancillary Data

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

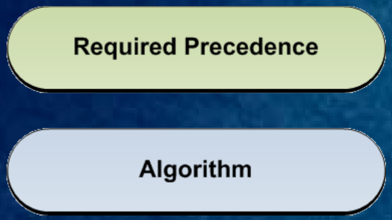
Table of Static Ancillary Data

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:



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

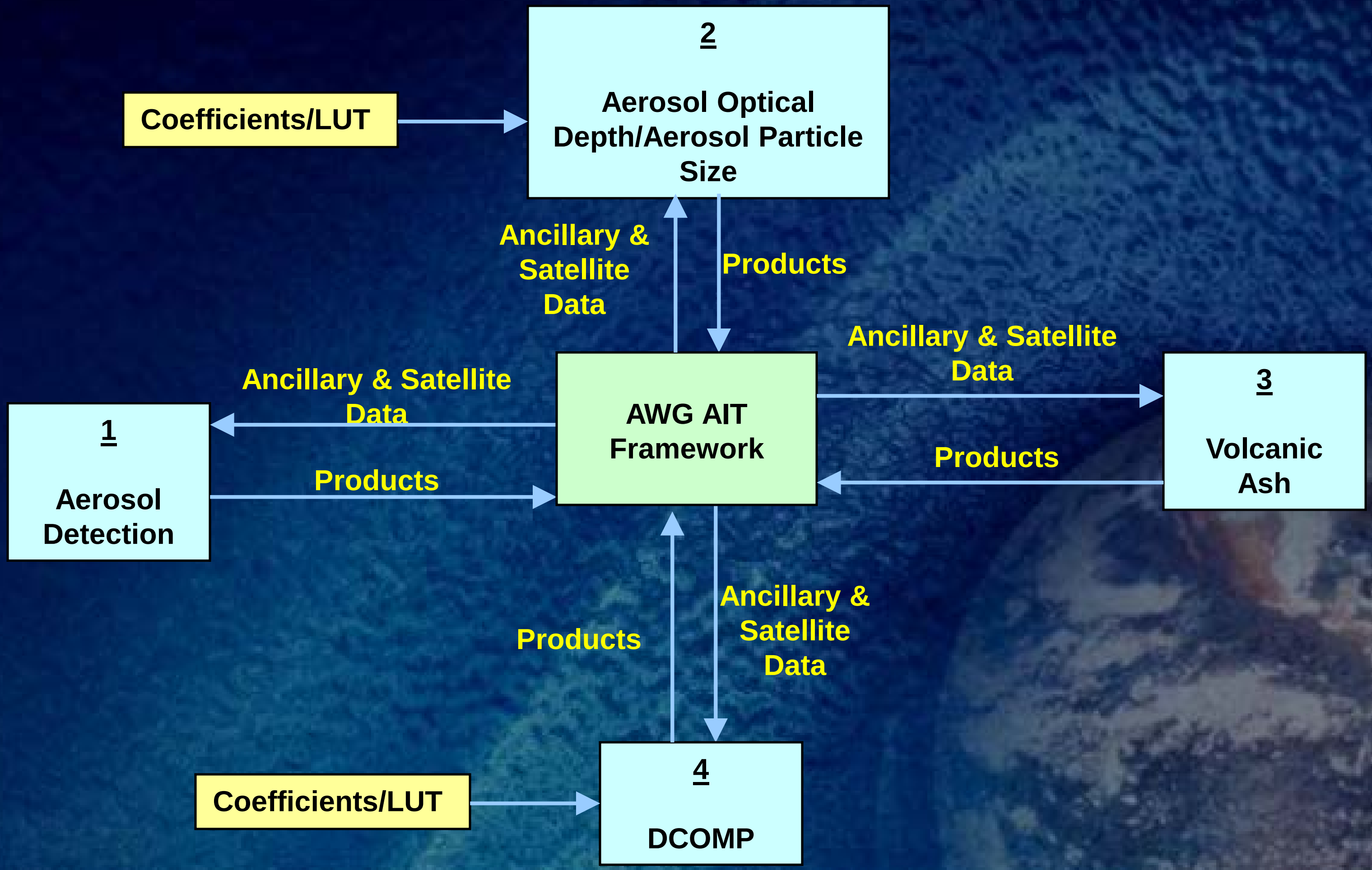
External Interface Design at CDR

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

Aerosol, Volcanic Ash, and DCOMP System Level Data Flow-Diagram



System Level Data Flows – Table

Aerosol Smoke/Dust Detection
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 M10, M11 reflectance in band M1, M2, M5, M7 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
Cloud Mask	Input	JPSSRR Cloud Mask	Cloud mask produced by cloud mask algorithm
Snow/Ice Mask	Input	JPSSRR/IMS	Location of areas covered by snow or ice
Sun Glint Mask	Input	Calculated	Location of areas covered by sun glint
Day/Night Mask	Input	Calculated	Defined by VIIRS pixel observation time
Smoke Mask, Dust Mask	Output	Smoke/dust Detection	Smoke/dust mask is given for each pixels as flag (0,1)

Yellow = Static White = Dynamic

System Level Data Flows – Table

SM/AOD and Particle Size

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

Interface Item	Interface Type	Source	Description
VIIRS SDR	Input	VIIRS	VIIRS calibrated and navigated reflectance in bands M3, M5, M11 over land and M5, M7, M10, M11 over Water 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
Cloud Mask	Input	JPSSRR	Cloud mask produced by ABI cloud mask algorithm
Snow/Ice Mask	Input	JPSSRR/IMS	Location of areas covered by snow or ice
Fire mask	Input	VIIRS fire mask	Fire Mask
Heavy aerosol	Input	VIIRS heavy aerosol mask	Heavy Aerosol Mask
Atmosphere LUT	Input	LUT	Lookup tables of atmospheric optical functions (reflectance, transmittance, and spherical albedo) calculated from 6S radiative transfer model
Sunglint LUT	Input	LUT	Water surface sunglint directional-hemispherical reflectance calculated from 6S radiative transfer model

System Level Data Flows – Table

VIIRS SM/AOD and Particle Size
Input, Internal, and Output Data Flows at the System Level

Interface Item	Interface Type	Source	Description
Wind speed/direction	Input	NCEP	Surface wind speed and direction (clockwise from local north)
Surface pressure, height	Input	NCEP	NCEP model predicted surface pressure and corresponding surface height
Total Precipitable Water	Input	NCEP	NCEP total precipitable water grids that bracket the satellite data
Surface height	Input	NCEP	NCEP surface height grids
Ozone	Input	NCEP	NCEP Ozone data
Aerosol Optical Depth	Output	AOD	Aerosol optical depths at VIIRS channels and 550nm
Particle Size	Output	Particle Size	Ångström Exponents (proxy for particle size) calculated from AOD at two pairs of wavelengths (0.47,0.86 µm and 0.86,2.25 µm)

System Level Data Flows – Table

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

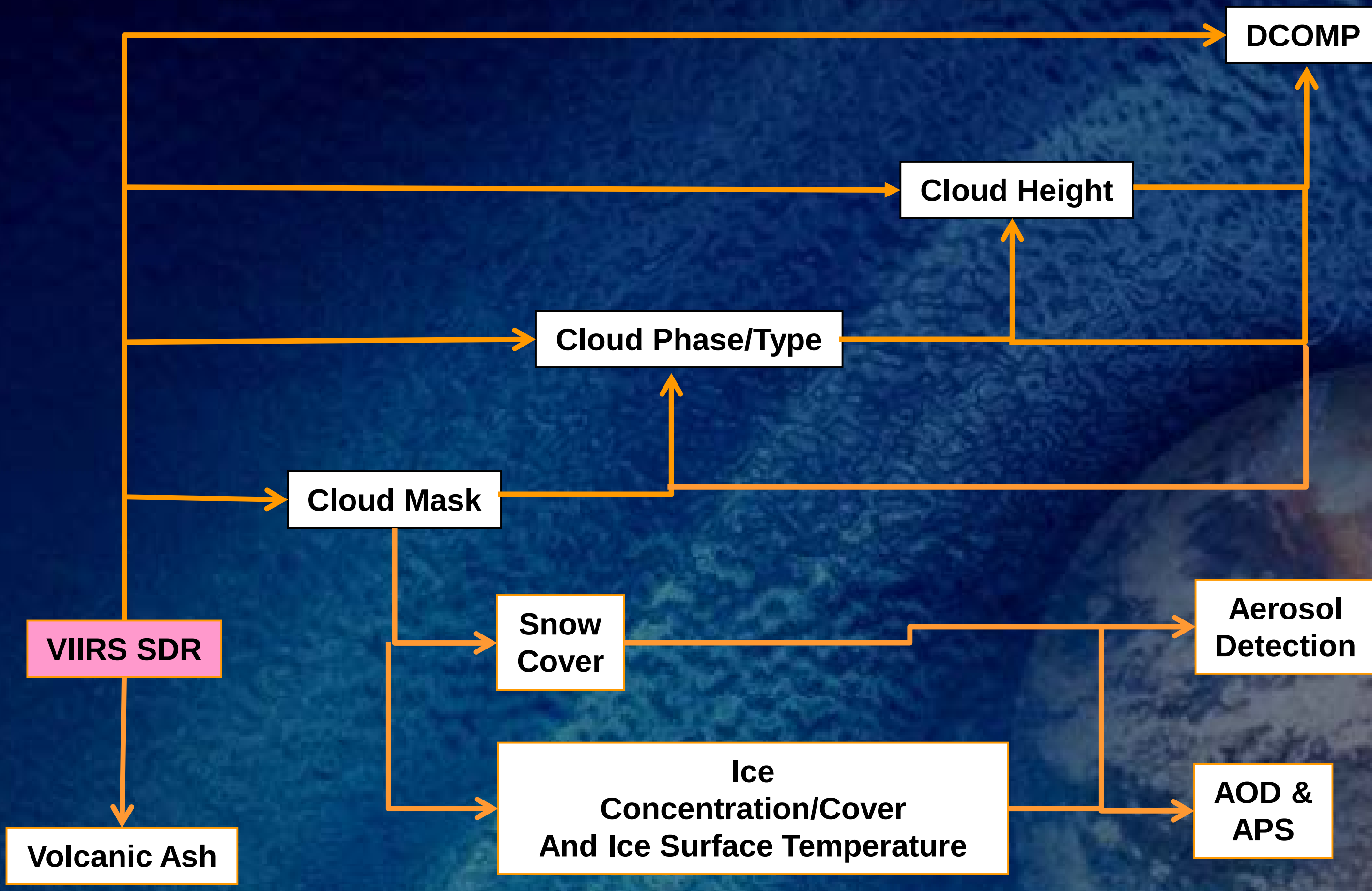
Interface Item	Interface Type	Source	Description
VIIRS SDR	Input	VIIRS	VIIRS calibrated and navigated reflectance in bands M5 & M12 brightness temperature & radiances in bands 12, 14, 15 and 16 with solar & satellite view angles
Land & Coast Mask	Input	NASA	Global 1 km land/water & coast mask used for MODIS collection 5
Surface Elevation	Input	NGDC	NGDC-GLOBE global digital elevation model with a horizontal resolution of 1km
NWP	Input	GFS model	Temperature, Pressure, Height profiles, Surface Temperature Level Tropopause Level, and Surface Temperature
RTM	Input	CRTM	Clear sky radiance and transmittance for bands 14, 15 and 16 TOA radiance for a black cloud bands 14, 15 and 16
IMS Snow and Ice Mask	Input	IMS	Snow mask by the Interactive Multisensor Snow and Ice Mapping System
VIIRS Volcanic Ash Products	Output	VIIRS Volcanic Ash	Volcanic Ash Height and Mass Loading produced from the VIIRS Volcanic Ash algorithm

System Level Data Flow – Table

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

Interface Item	Interface Type	Source	Description
Coefficients	Input	UW/CIMSS	Cloud reflectance and emissivity
VIIRS SDR	Input	VIIRS	VIIRS calibrated and navigated brightness temperature in bands 10, 11, 12 and reflectance in bands 5 and 7 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
NWP	Input	GFS model	Temperature and Water Vapor profiles
ABI Cloud Mask	Input	ABI Cloud Mask	Cloud mask produced by ABI cloud mask algorithm
ABI Cloud Height	Input	ABI Cloud Height	Cloud height produced by ABI cloud height algorithm
ABI Cloud Type/Phase	Input	ABI Cloud Type	Cloud type produced by ABI cloud type algorithm
ABI Cloud Optical Prop.	Output	ABI Cloud Opt. Prop	Cloud optical prop. produced by ABI cloud daytime 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 Aerosol, Volcanic Ash, and DCOMP products:
  - » VIIRS SDR
  - » Land/Coast Mask
  - » Surface Elevation
  - » Surface Emissivity
  - » Surface Albedo
  - » IMS
  - » NWP
  - » CRTM

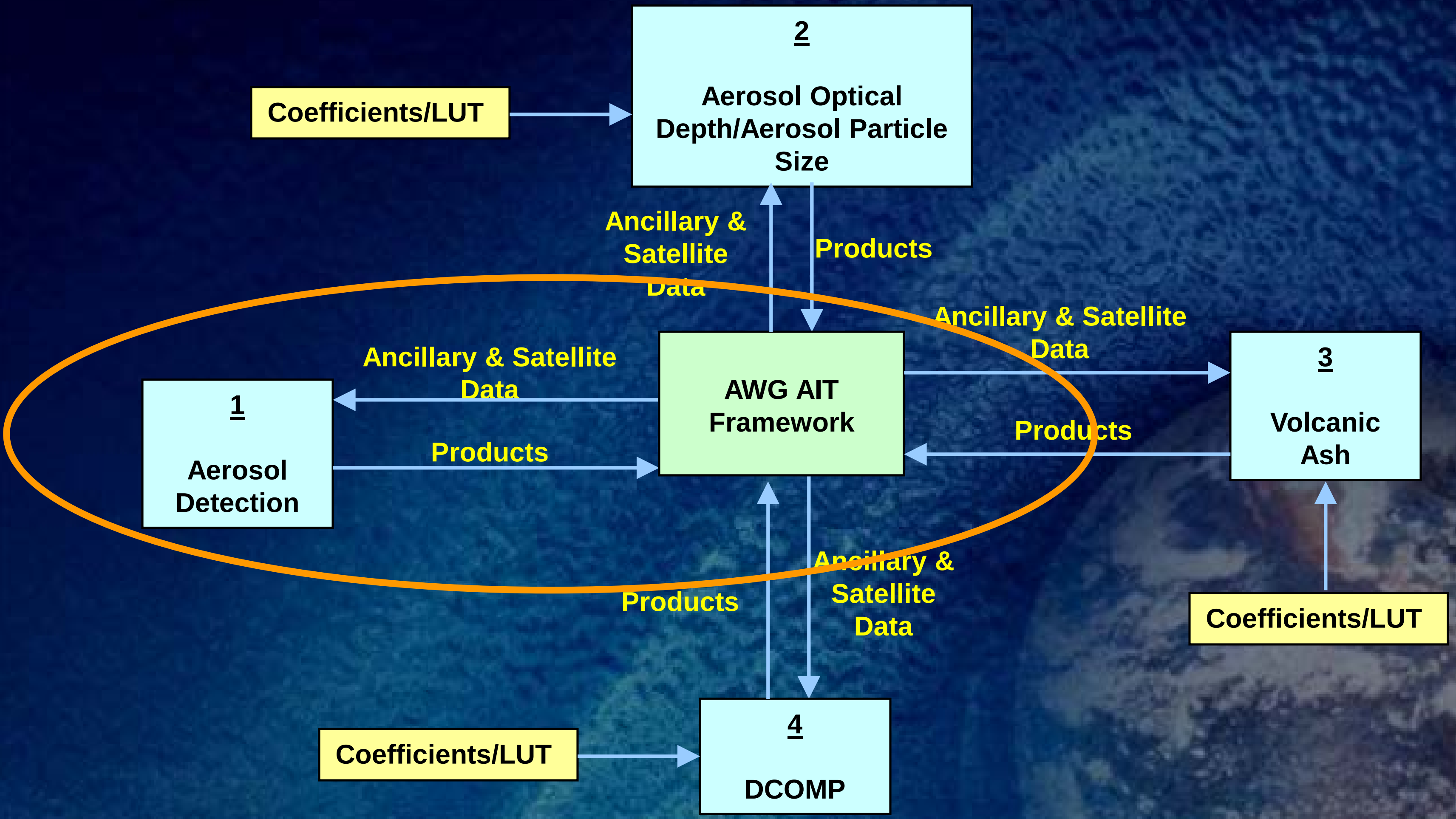
System Level Data Flow – Sequence(2)

- The framework checks the precedence to produce cryosphere products. It will run the following products upstream:
  - VIIRS Cloud Mask
  - VIIRS Cloud Type/Phase
  - VIIRS Cloud Height
  - Snow Cover
  - Ice Concentation & Ice Cover
- All the ancillary data including VIIRS SDR will be passed to the Aerosol, Volcanic Ash and DCOMP algorithms through data structures.
- Aerosol, Volcanic Ash and DCOMP algorithms read in their product specific inputs such as look up table and coefficient files.
- Aerosol, Volcanic Ash and DCOMP product outputs will be sent back to the framework through data structures

External Interface Design at CDR

Unit Levels

Aerosol, Volcanic Ash, and DCOMP System Level Data Flow-Diagram



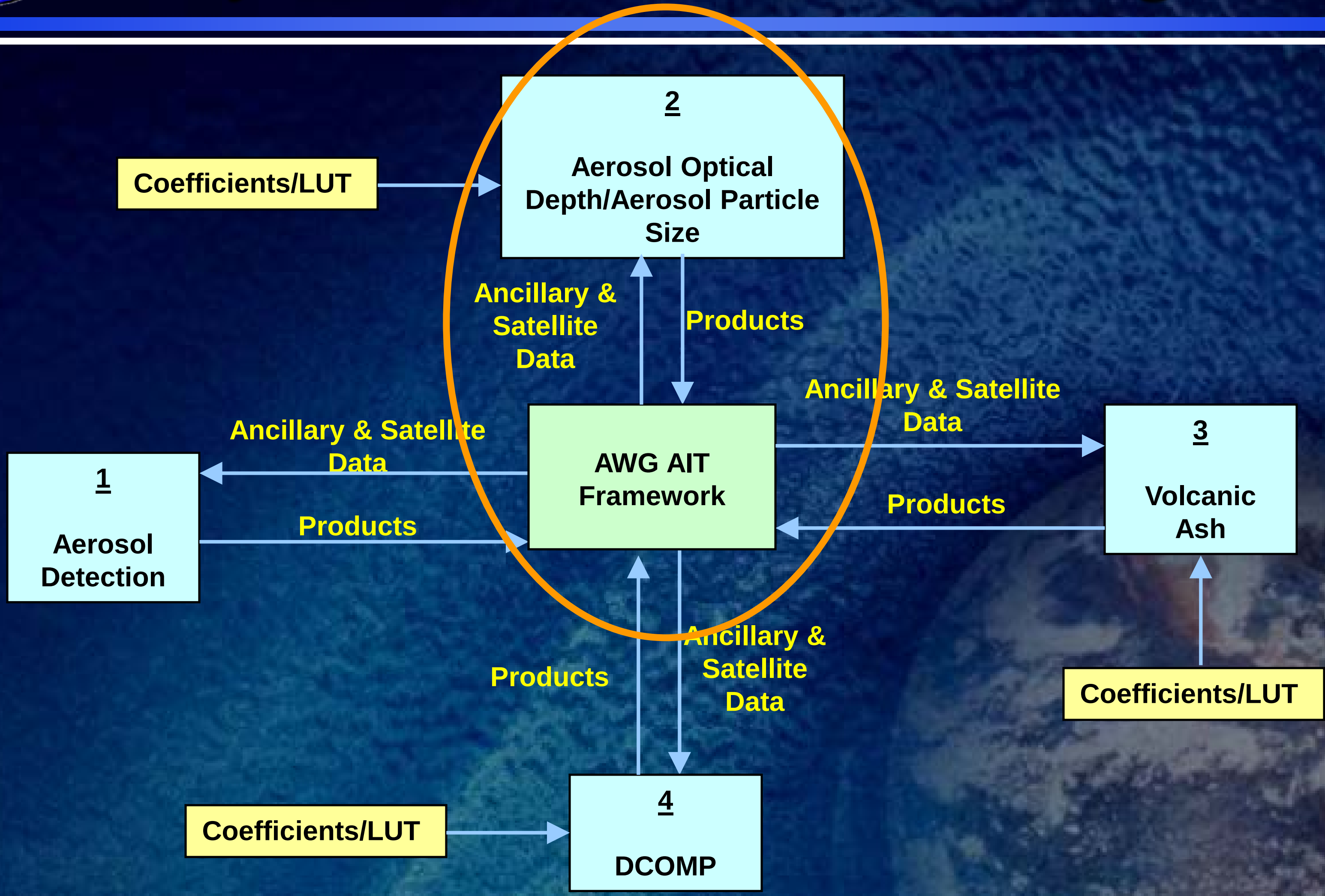
Unit Level Data Flows – Table

Aerosol Smoke/Dust Detection
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 M10, M11 reflectance in band M1, M2, M5, M7 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
Cloud Mask	Input	JPSSRR Cloud Mask	Cloud mask produced by cloud mask algorithm
Snow/Ice Mask	Input	JPSSRR/IMS	Location of areas covered by snow or ice
Sun Glint Mask	Input	Calculated	Location of areas covered by sun glint
Day/Night Mask	Input	Calculated	Defined by VIIRS pixel observation time
Smoke Mask, Dust Mask	Output	Smoke/dust Detection	Smoke/dust mask is given for each pixels as flag (0,1)

Yellow = Static White = Dynamic

Aerosol, Volcanic Ash, and DCOMP System Level Data Flow-Diagram



Unit Level Data Flows – Table

SM/AOD and Particle Size
Input, Internal, and Output Data Flows at the System Level

Interface Item	Interface Type	Source	Description
VIIRS SDR	Input	V IIRS	VIIRS calibrated and navigated reflectance in bands M3, M5, M11 over land and M5, M7, M10, M11 over Water 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
Cloud Mask	Input	JPSSRR	Cloud mask produced by ABI cloud mask algorithm
Snow/Ice Mask	Input	JPSSRR/IMS	Location of areas covered by snow or ice
Fire mask	Input	VIIRS fire mask	Fire Mask
Heavy aerosol	Input	VIIRS heavy aerosol mask	Heavy Aerosol Mask
Atmosphere LUT	Input	LUT	Lookup tables of atmospheric optical functions (reflectance, transmittance, and spherical albedo) calculated from 6S radiative transfer model
Sunglint LUT	Input	LUT	Water surface sunglint directional-hemispherical reflectance calculated from 6S radiative transfer model

Unit Level Data Flows – Table

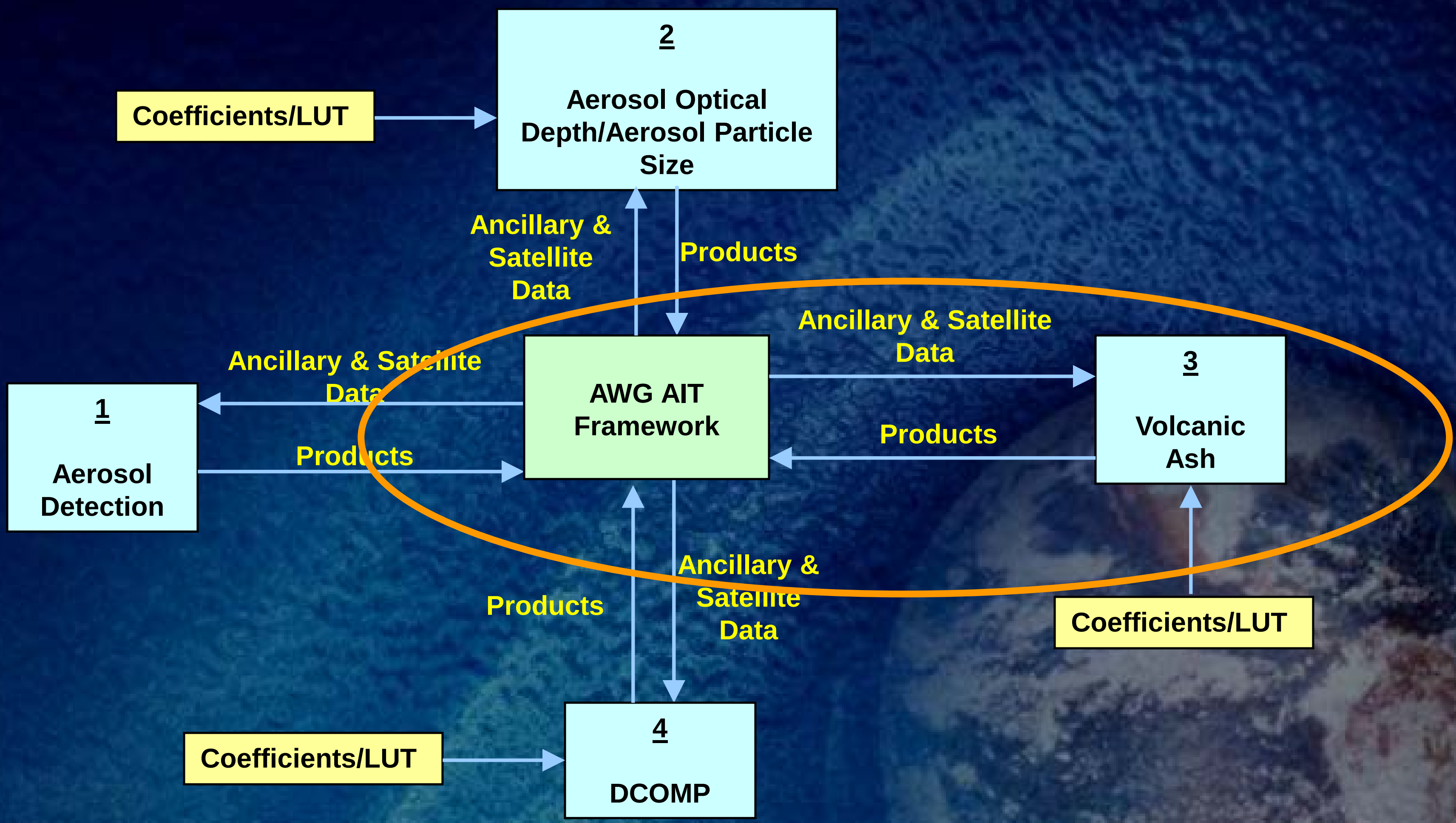
VIIRS SM/AOD and Particle Size
Input, Internal, and Output Data Flows at the System Level

Interface Item	Interface Type	Source	Description
Wind speed/direction	Input	NCEP	Surface wind speed and direction (clockwise from local north)
Surface pressure, height	Input	NCEP	NCEP model predicted surface pressure and corresponding surface height
Total Precipitable Water	Input	NCEP	NCEP total precipitable water grids that bracket the satellite data
Surface height	Input	NCEP	NCEP surface height grids
Ozone	Input	NCEP	NCEP Ozone data
Aerosol Optical Depth	Output	AOD	Aerosol optical depths at VIIRS channels and 550nm
Particle Size	Output	Particle Size	Ångström Exponents (proxy for particle size) calculated from AOD at two pairs of wavelengths (0.47,0.86 µm and 0.86,2.25 µm)

Aerosol Optical Depth and Aerosol Particle Size Input Ancillary Data

Name	Type	Description	Dimension
Atmosphere LUT	Input	normalized aerosol extinction coefficient as function of aerosol model, aerosol optical depth (land only) and VIIRS channel	(4 x 20 x 11)* (9 x 11)**
		atmospheric reflectance as function of aerosol model, aerosol optical depth, VIIRS channel and scattering angle	(4 x 20 x 3 x 5527)* (9 x 20 x 4 x 5527)**
		atmospheric transmittance as function of aerosol model, aerosol optical depth, VIIRS channel and zenith angle	(4 x 20 x 3 x 21)* (9 x 20 x 4 x 21)**
		atmospheric spherical albedo as function of aerosol model, aerosol optical depth, and VIIRS channel	(4 x 20 x 3)* (9 x 20 x 4)**
Sunglint LUT	Input	water sunglint direct-hemispheric reflectance as function of aerosol model, aerosol optical depth, VIIRS channel, solar zenith angle, viewing zenith angle, relative azimuth angle, and surface wind speed	(9 x 20 x 4 x 21 x 21 x 21 x 4)
		water spherical albedo as function of VIIRS channel and aerosol model	(4 x 9)

Aerosol, Volcanic Ash, and DCOMP System Level Data Flow-Diagram

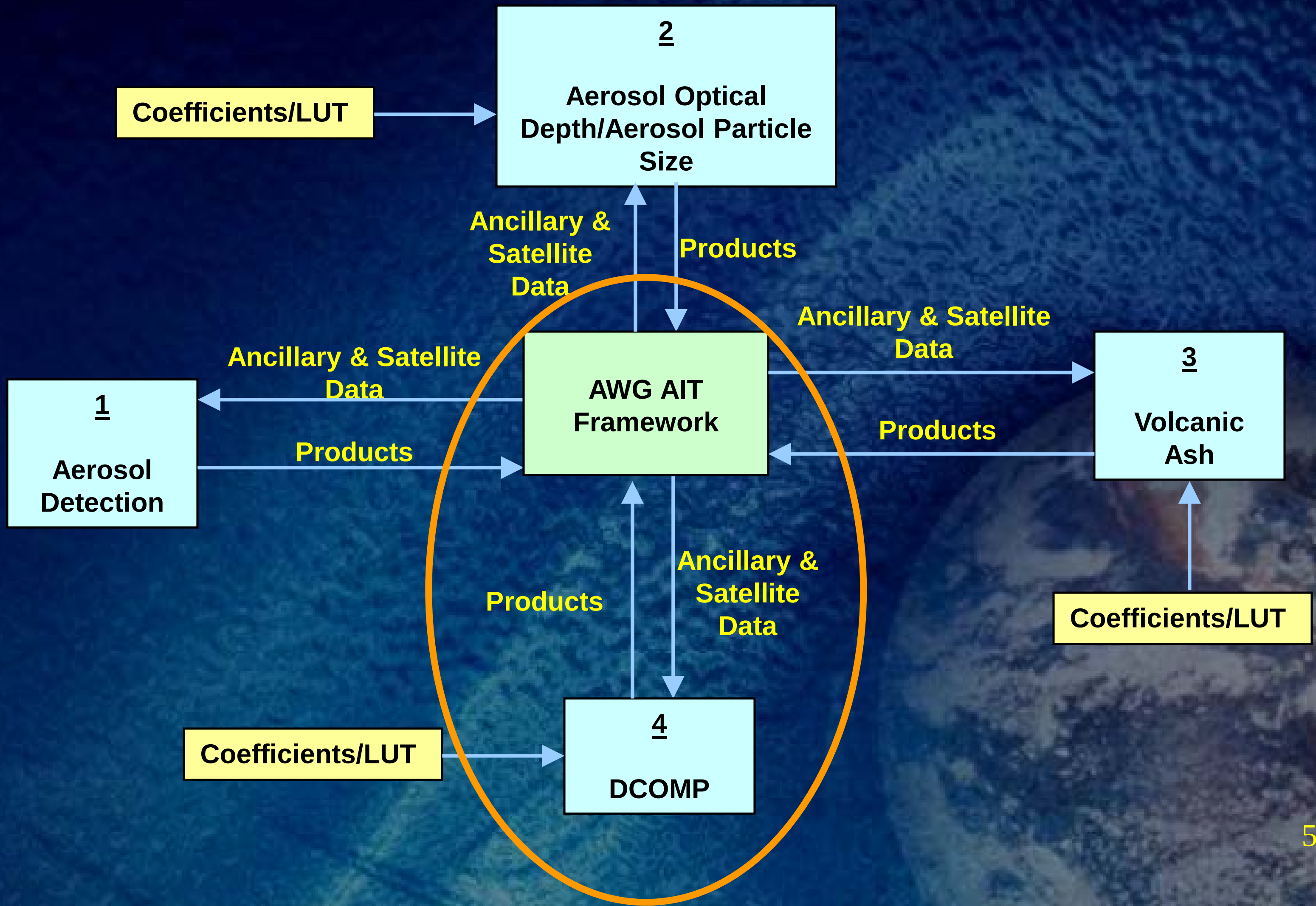


System Level Data Flows – Table

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

Interface Item	Interface Type	Source	Description
VIIRS SDR	Input	VIIRS	VIIRS calibrated and navigated reflectance in bands M5 & M12 brightness temperature & radiances in bands 12, 14, 15 and 16 with solar & satellite view angles
Land & Coast Mask	Input	NASA	Global 1 km land/water & coast mask used for MODIS collection 5
Surface Elevation	Input	NGDC	NGDC-GLOBE global digital elevation model with a horizontal resolution of 1km
NWP	Input	GFS model	Temperature, Pressure, Height profiles, Surface Temperature Level Tropopause Level, and Surface Temperature
RTM	Input	CRTM	Clear sky radiance and transmittance for bands 14, 15 and 16 TOA radiance for a black cloud bands 14, 15 and 16
IMS Snow and Ice Mask	Input	IMS	Snow mask by the Interactive Multisensor Snow and Ice Mapping System
VIIRS Volcanic Ash Products	Output	VIIRS Volcanic Ash	Volcanic Ash Height and Mass Loading produced from the VIIRS Volcanic Ash algorithm

Aerosol, Volcanic Ash, and DCOMP System Level Data Flow-Diagram



System Level Data Flow – Table

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

Interface Item	Interface Type	Source	Description
Coefficients	Input	UW/CIMSS	Cloud reflectance and emissivity
VIIRS SDR	Input	VIIRS	VIIRS calibrated and navigated brightness temperature in bands 10, 11, 12 and reflectance in bands 5 and 7 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
NWP	Input	GFS model	Temperature and Water Vapor profiles
ABI Cloud Mask	Input	ABI Cloud Mask	Cloud mask produced by ABI cloud mask algorithm
ABI Cloud Height	Input	ABI Cloud Height	Cloud height produced by ABI cloud height algorithm
ABI Cloud Type/Phase	Input	ABI Cloud Type	Cloud type produced by ABI cloud type algorithm
ABI Cloud Optical Prop.	Output	ABI Cloud Opt. Prop	Cloud optical prop. produced by ABI cloud daytime opt. prop. algorithm

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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

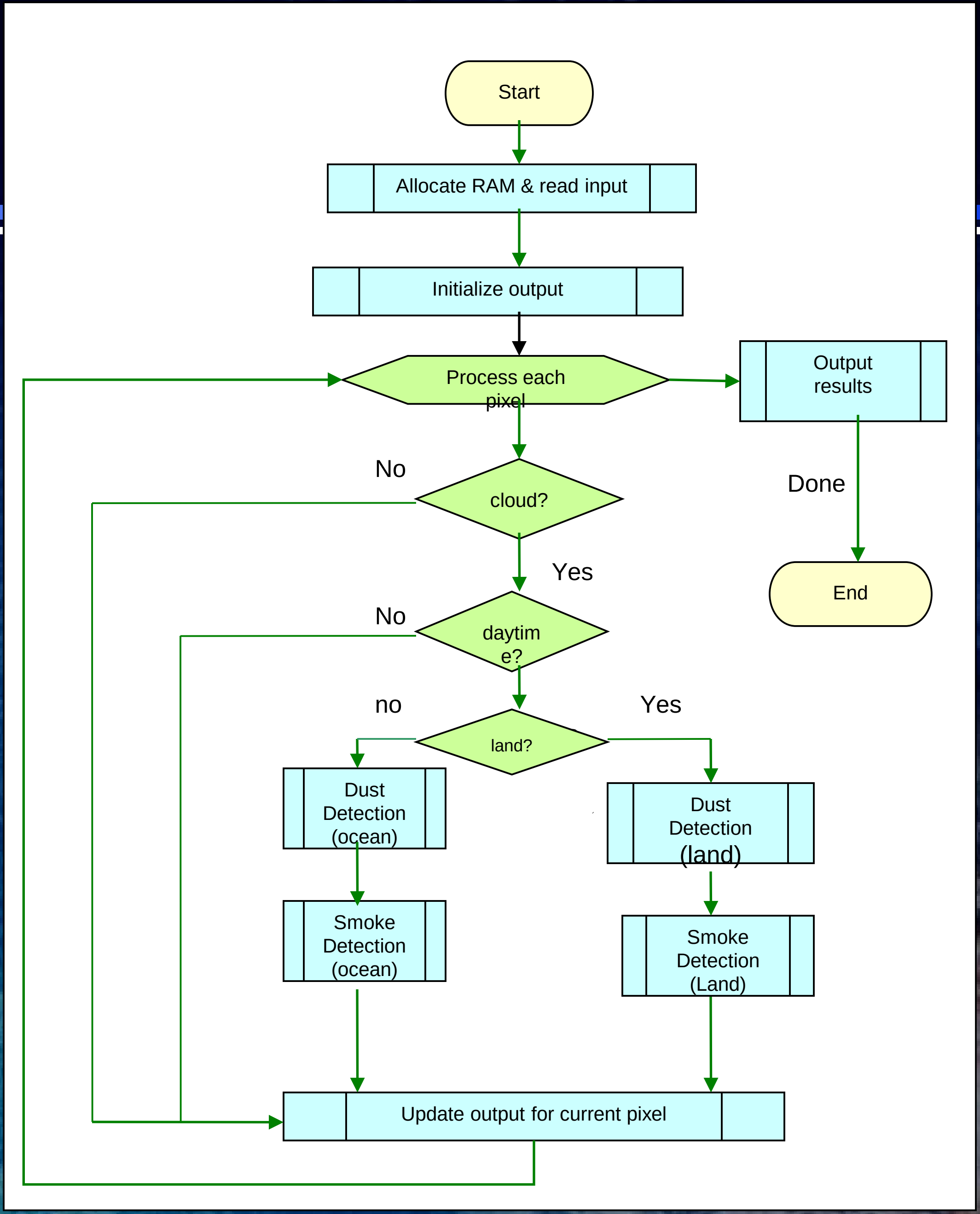
- Metadata design should respond to metadata requirements
- There is no archive requirement for this project, so the only metadata with be product level metadata for OSPO trending
- From our experience, the Aerosol and Cloud Teams can populate the metadata from Aerosol Detection, Aerosol Optical Depth, Aerosol Particle Size, Volcanic Ash, and DCOMP products

Aerosol Detection Unit Description (1)

- Produce aerosol detection products over the whole globe with associated quality flags.

- Interfaces
  - VIIRS calibrated and navigated brightness temperature in bands M10, M11 reflectance in band M1, M2, M5, M7 with solar and satellite view angles
  - Land/water mask
  - Surface elevation
  - Cloud Mask
  - Snow/Ice Mask
  - Sun Glint Mask
  - Day/Night Mask

Aerosol Detection Processing Outline



Aerosol Detection Unit Description (3)

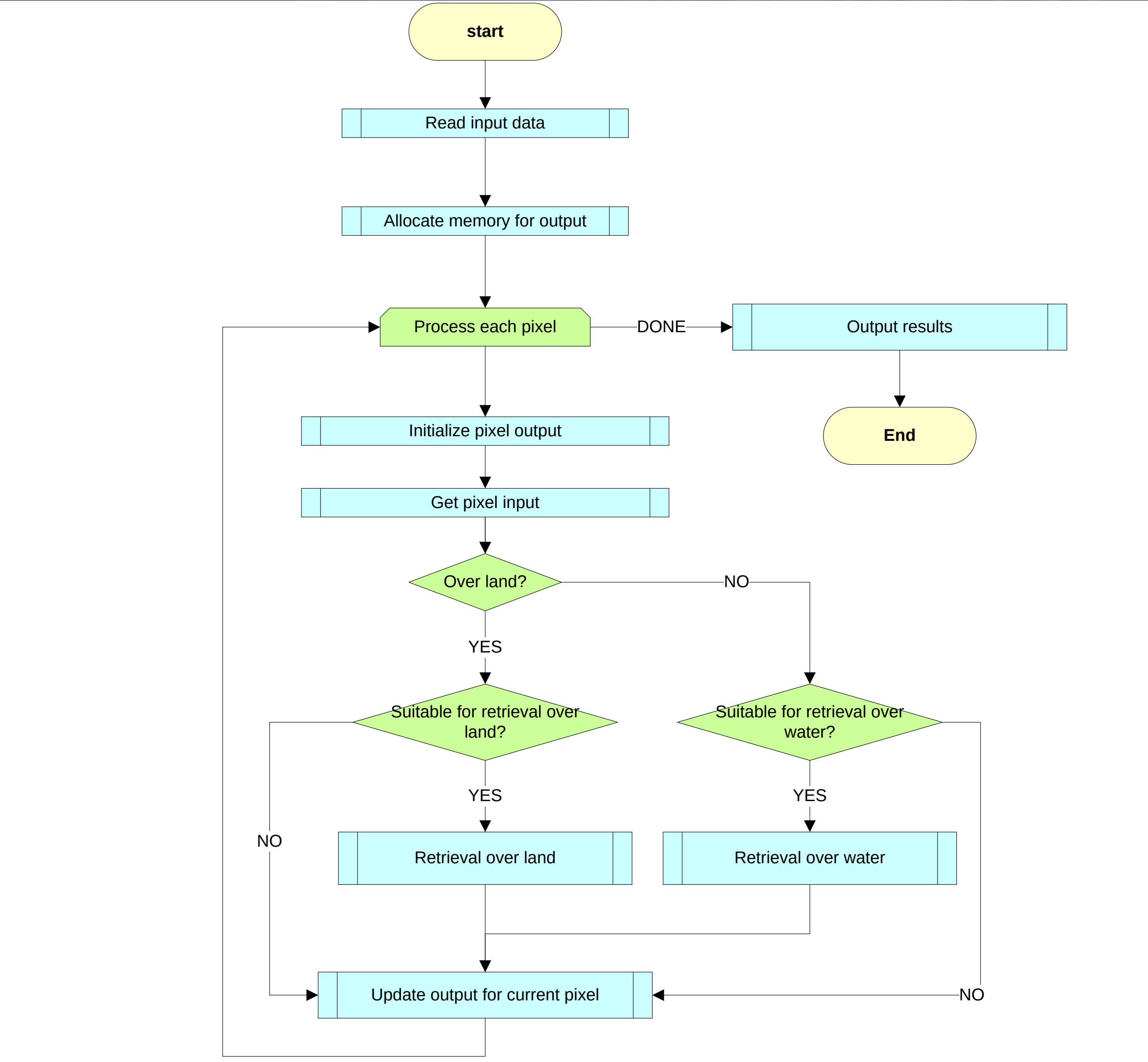
- Design Language – C++
- Assumptions applied to the unit design:
  - » VIIRS observation data are within specifications
- Limitations applied to the unit design:
  - » Only daytime;
  - » Algorithm tuning might be needed when instrument calibration changes

AOD & APS
Unit Description (1)

- **Produces aerosol optical depth and aerosol particle size with associated quality flags.**

- **Interfaces**
  - » **VIIRS calibrated and navigated reflectance in bands M3, M5, M11 over land and M5, M7, M10, M11 over Water with solar and satellite view angles**
  - » **Land Mask**
  - » **Surface Elevation**
  - » **Cloud Mask**
  - » **Snow/Ice Mask**
  - » **Fire mask**
  - » **Heavy aerosol**
  - » **Atmosphere LUT**
  - » **Sunglint LUT**
  - » **NCEP: Wind speed/direction, Surface pressure & height, Total Precipitable Water, Surface height, Ozone**

AOD & APS Processing Outline



AOD and APS Unit Description (3)

- Design Language – C++
- Assumptions apply to the unit design:
  - VIIRS reflectance and brightness temperature data are within specs.
  - Cloud mask eliminates all possible cloud contamination
  - Ancillary data are available
- Limitations apply to the unit design:
  - only daytime

Volcanic Ash Unit Description (1)

- Produce Volcanic Ash Loading and Height products with associated quality flags.

- Interfaces
  - VIIRS calibrated and navigated reflectance in bands M5 & M12 and brightness temperature and radiances in bands M12, M14, M15, and M16 along with solar and satellite view angles
  - Land & Coast Mask
  - Surface Elevation
  - NWP
  - RTM
  - IMS Snow and Ice Mask

Volcanic Ash Unit Description (2)

- **Design Language – F90/95**

- **Assumptions applied to the unit design:**
  - » VIIRS observation data are within specifications
  - » Algorithm is only designed to be applied to the VIIRS M-bands with "bow-tie" deleted pixels restored
  - » Clear sky radiance calculations are available

- **Limitations applied to the unit design:**
  - » While the ash detection component of the algorithm performs best when the 0.65, 3.75, 8.5, 11, and 12 μm channels provide valid data, it can produce useful output as long as the 11 and 12 μm channels are available
  - » The ash retrieval component of the algorithm can only be applied if the 11 and 12 μm channels are both available
  - » If the 11 and 12 μm channels are unavailable, each pixel will be set to a flag that indicates that the ash products could not be generated

DCOMP Unit Description (1)

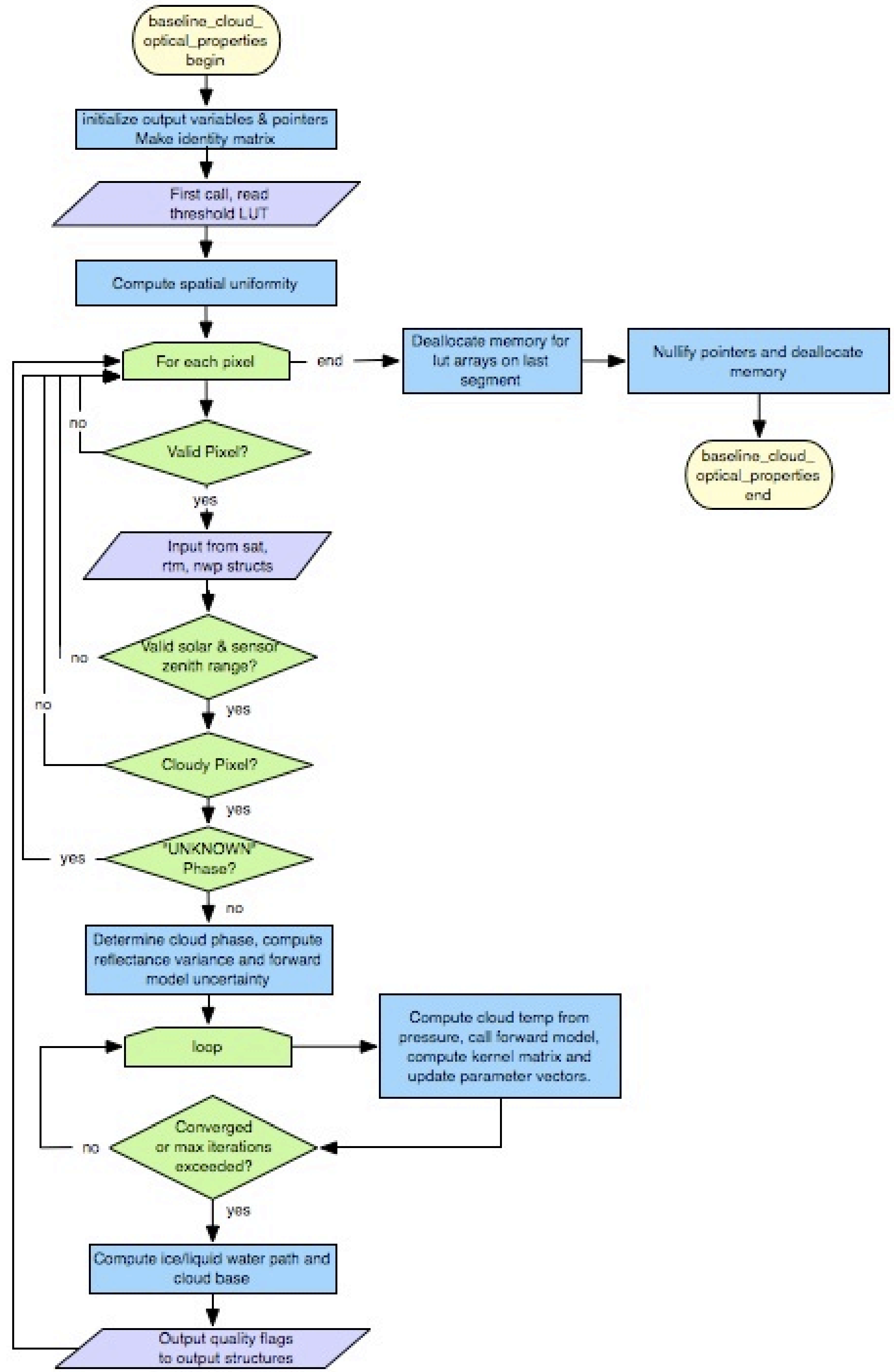
- **Produce Daytime Cloud Optical and Microphysical products with associated quality flags**

- **Interfaces**
  - » **VIIRS calibrated and navigated brightness temperature in bands 10, 11, 12 and reflectance in bands 5 and 7 with solar and satellite view angles**
  - » **Coefficients**
  - » **Land & Coast Mask**
  - » **Surface Emissivity**
  - » **NWP**
  - » **ABI Cloud Mask**
  - » **ABI Cloud Height**
  - » **ABI Cloud Type/Phase**
  - » **ABI Cloud Optical Prop.**

Processing Outline

ABI Daytime Cloud Optical Properties Processing

- Begin ABI Daytime Cloud Optical Properties subroutine
- Initialize output structures and make indentity matrix
- Input data from satellite, rtm and nwp structures
- Initialize local variables and pointers
- On first call, read in threshold lut
- Compute spatial uniformity
- For each valid pixel intialize satellite, rtm and nwp data. Then determine if it is cloudy, in the correct sensor and solar zenith angle range. Using it's phase, compute forward model to get optical properties. Then 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 Daytime Cloud Optical Properties subroutine



DCOMP
Unit Description (3)

- Design Language – FORTRAN 90/95

- Assumptions apply to the unit design:
  - » VIIRS radiance data are within specs.
  - » NWP data and CRTM calculations are available
  - » Cloud mask, cloud height, cloud phase and cloud type are available

- Limitations apply to the unit design:
  - » Daytime scenes only

System Description

Output

Input

Unit/Sub-Unit	Aerosol Detection	AOD & ASP	Volcanic Ash	DCOMP
VIIRS L1B	√	√	√	√
Land & Coast Mask	√	√	√	√
Surface Elevation	√	√	√	
NWP		√	√	√
VIIRS Cloud Mask	√	√		√
IMS Snow Cover	√	√	√	√
Sun Glint Mask	√			
Day/Night Mask	√			
Heavy Aerosol		√		
Fire Mask		√		
VIIRS Cloud Type				√
CRTM			√	√
Surface Emissivity & Surface Albedo				√
Cloud Height				√
Coefficient File		√		√

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Algorithm Package

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Walter Wolf

JPSS RR 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.
  - SPSRB Documentation or reference to where the documentation may be obtained.
  - Delivery Memo.
  - README text file.

JPSS RR 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.).

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Quality Assurance

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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 Product Monitoring 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 (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 operations, production rules, and software tests will be in the algorithm package.
  - » Documentation of requirements will be in the Product Monitoring RAD.
  - » Early release of software will allow for early system implementation.

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Risks and Actions

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CDR Aerosol Detection Risk

- **Risk 1:** Smoke detection over bright surface not optimized
  - » **Mitigation:**
    - – Conduct additional testing and fine tune the algorithm as needed to smoke over land

- **Risk 2:** Dust detection over bright surface not optimized
  - » **Mitigation:**
    - – Conduct additional testing and fine tune the algorithm as needed to smoke over land
    - – Conduct additional testing and fine tune the algorithm as needed to rescue detection of thick dust or smoke over sunglint region

CDR AOD Risks

- **Risk 3:** Gaps in coverage
  - » **Mitigation:**
    - – Using the VIIRS deep-blue channels 0.412 and 0.445 µm and deep-blue algorithm may permit retrievals over bright snow/ice-free land surface

- **Risk 5:** Aerosol model selection may be inadequate for episodic events
  - » **Mitigation:**
    - – Identify episodic dust events using deep-blue channels, or input from dust detection, and force algorithm to use dust model

CDR AOD Risks

- **Risk 6:** Cloud, snow/ice, etc. contamination of pixel used for AOD retrieval
  - » **Mitigation:**
    - – Update/Implement internal tests using VIIRS channels (0.412, 0.445, 0.746, 1.240 µm) not available on ABI

- **Risk 7:** Uncertainty in surface reflectance retrieval
  - » **Mitigation:**
    - – Develop and use NDVI-dependent surface reflectance relationships (coefficients of blue/red vs swir surface reflectances are function of NDVI)

Risk and Actions Summary

- There are currently 7 risks identified from the CDR
- 6 risks remain open and 1 is closed
  - » 4 open with a severity of Medium
  - » 2 open with a severity of Low

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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
    - – Aerosol Detection
    - – AOD and Aerosol Particle Size
    - – Volcanic Ash Height and Mass Loading
    - – DCOMP
  - » 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 Review is the next major review for the Aerosol, Volcanic Ash, and DCOMP products.

Open Discussion

- The review is now open for free discussion