

Continuity Atmosphere Products QA Plan

for CLDMSK, CLDPROP, AERDB, AERDT, & WATVP



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1.0 Introduction

This document describes the QA Flag Scientific Data Sets (SDS's) for all Level 2 (L2) Continuity Atmosphere products. Also provided in this document are other key (non-QA related) BitFlag SDS's (Cloud_Mask, for example).

1.1 What are QA Flags?

It should be noted that within the Atmosphere Retrieval Group, the term "QA" is loosely defined to include a wide variety of Flags that detail (1) confidence or quality of the physical parameter retrieved, (2) retrieval processing path or retrieval algorithm logical path, (3) input data source, (4) retrieval spectral bands used, (5) retrieval status or outcome, (6) retrieval method, (7) data or scene characteristics, and (8) metadata or ancillary input source. Level 2 Runtime QA Flags are computed and stored for individual Level 2 parameters or semi-related groups of parameters within each L2 Continuity Atmosphere product.

1.2 Spatial Resolution of QA Flags

Each Level 2 atmospheric parameter and any associated QA is retrieved at a spatial resolution determined by the sensitivity of instrument retrieval. It often matches a single field of view (FOV) of key algorithm spectral bands in the source instrument data. Resolutions are typically at 750x750 (VIIRS) or 1000x1000 meters (MODIS) - varying from instrument to instrument (VIIRS vs. MODIS) -- and sometimes from product to product (e.g. Cloud vs. Aerosol).

It should be noted that Cloud Mask flags (which are not QA Flags, but are Bit Flags) may be recomputed at the spatial resolution of the retrieval (coarser resolution for Aerosol, for example) for the determination of cloudy and clear pixels, land surface type, sunglint, day/night, and snow/ice. However the spatial resolution of the Cloud_Mask Flags and the QA Flags always match within each general product file category (Cloud or Aerosol, for example).

1.3 Why are QA Flags important?

QA Flags are important to be able to perform more useful, more meaningful, and more powerful imaging -- as well as more finely-tuned scientific research on stand-alone Level 2 data. QA Flags are also an important element in the sequential data reduction or aggregation when moving from Level 2 (L2) orbital swath granule data to Level 3 (L3) global gridded data. In other words, these QA flags provide more detailed information surrounding and associated with specific parameters of the Level 2 granule input and thus provide better basis to produce Level 3 global gridded parameters.

1.4 The Continuity Atmosphere Products

Level 2 (L2) Continuity Atmosphere products, retrieved from various remote sensing instruments and other sources of ancillary data, are grouped into user-friendly NetCDF4 files based upon the general overview category of data (Cloud, Aerosol, etc.). Continuity Atmosphere products are grouped as follows (with the standard NetCDF4 filename prefix given in parentheses):

Level 2 Products

- Cloud Optical & Cloud Top Properties (CLDPROP_L2)
- Cloud Mask (CLDMSK_L2)
- Aerosol Deep Blue (AERDB_L2)

The Continuity Atmosphere Level 3 (L3) products are produced to include various statistical quantities created from Level 2 (L2) input. In order to properly aggregate a Level 2 parameter to Level 3, various Level 2 QA flags must be utilized. For example, L2 QA Flags provide a means to separate a Level 2 product by cloud phase (liquid water clouds vs. ice clouds), fully cloudy vs. partly cloudy (PCL) retrievals, day/night aggregation, etc. within the L3 product.

Level 3 Products

- Cloud Properties (CLDPROP_L3)
- Aerosol Deep Blue (AERDB_L3)

Note that the L3 syntax used in the bullet list, above, is further divided (when run operationally) into the acronym D3 for Daily and M3 for monthly. L3 was listed above, for ease of documentation, to refer to all temporal periods of L3 data.

1.5 Topics covered in this Document

Topics covered in this plan include -- in Section 2, a thorough breakdown of the type, structure, and content of Level 2 runtime QA Flags as well as other key (non QA related) Bit Flag SDS's (e.g. Cloud_Mask). Section 2 is the pivotal portion of this document and includes information on the type and structure of these flags to assist data users in finding and interpreting the appropriate Flag or Flags for their scientific and research needs.

In Section 3, at the end of this document, a primer on reading and decoding QA Flags and/or (non-QA) Bit Flags is provided. This is helpful to scientific data users that are new to working with QA and Bit Flags within their software & application programs.

2.0 QA & Bit Flags of Continuity Atmosphere Products

2.1 Cloud Mask Product (CLDMSK)

The Continuity Atmosphere Cloud Mask product (CLDMSK) consists of a 750x750 m (VIIRS) or 1000x1000 m (MODIS) set of parameters derived from solar reflectance and thermal emitted channels.

For completeness and to provide more useful documentation, outlined in this section is the a breakdown of the full *“Cloud_Mask”* array. Even though this array is not technically a QA array, it’s a vitally important array, and needs to be decoded by reading individual bit flags -- so outlining the format of this key array is prudent. Cloud Mask QA flags, which tie into the full *“Cloud_Mask”* array, are stored in a separate QA array (SDS) called *“Quality_Assurance”*.

Note the green shading in the tables that follow means the flags are in the same byte and bit location as in the MODIS Standard Products (MOD & MYD). Unshaded rows means those flags are new or moved from previous MODIS Standard Product locations.

CLDMSK Product: "Cloud_Mask" SDS (Complete)

Scientific Data Set (SDS): "Cloud_Mask"

Description: Cloud Mask Array

Resolution: 750x750 m or 1000x1000 m (depending on instrument)

Length: 6 bytes (48 bits)

First Byte (Byte 0)

Flag Name	Number of Bits	Bit Value	Bit Value Definitions
Cloud Mask Status Flag	1	0	Not Determined ^{n.f}
		1	Determined
Cloud Mask Cloudiness Flag (a.k.a Unobstructed FOV Confidence Flag)	2	0	Cloudy (or Fill, if Status Flag = 0)
		1	Probably Cloudy
		2	Probably Clear
		3	Confident Clear
Day / Night Flag	1	0	Night ^{n.f} (or Fill, if Status Flag = 0)
		1	Day
Sunglint Flag	1	0	Yes (or Fill, if Status Flag = 0)
		1	No
Snow / Ice Flag	1	0	Yes (or Fill, if Status Flag = 0)
		1	No
Surface Type Flag (a.k.a. Land / Water Flag)	2	0	Water: Ocean, Deep Lakes, or Deep Rivers (or Fill)
		1	Coast or Shallow Lakes or Shallow Rivers
		2	Desert
		3	Land

Second Byte (Byte 1)

Flag Name	Number of Bits	Bit Value	Bit Value Definitions
Spare	1		TBD
Thin Cirrus Detected (solar)	1	0	Yes
		1	No
Snow Cover from Ancillary Map	1	0	Yes
		1	No
Thin Cirrus Detected (infrared)	1	0	Yes
		1	No
Cloud Adjacency (cloudy, probably cloudy, plus one pixel adjacent)	1	0	Yes
		1	No
Cloud Flag, Ocean IR Threshold Test	1	0	Yes
		1	No
Spares	2		TBD

Third Byte (Byte 2)

Flag Name	Number of Bits	Bit Value	Bit Value Definitions
High Cloud Flag 1.38 μm Test Result	1	0 1	Yes No
High Cloud Flag 3.9-12 μm Test Result (night only)	1	0 1	Yes No
Cloud Flag IR Temperature Difference Test Result	1	0 1	Yes No
Cloud Flag 3.9-11 μm Test Result	1	0 1	Yes No
Cloud Flag Visible Reflectance Test Result	1	0 1	Yes No
Cloud Flag Visible Ratio Test Result	1	0 1	Yes No
Clear Sky Restoral Test (NDVI in coastal areas)	1	0 1	Yes No
Cloud Flag Water 1.6 or 2.1 μm Test Result	1	0 1	Yes No
<i>Fourth Byte (Byte 3)</i>			
Flag Name	Number of Bits	Bit Value	Bit Value Definitions
Cloud Flag Water 8.6-11 μm Test Result	1	0 1	Yes No
Clear Sky Restoral Test (spatial consistency, ocean)	1	0 1	Yes No
Clear Sky Restoral Tests (polar night, land, sunglint)	1	0 1	Yes No
Cloud Flag (surface temperature water, night, land) Test Result	1	0 1	Yes No
Spares	2		TBD
Cloud Flag (night, ocean) 11 μm Variability Test Result	1	0 1	Yes No
Cloud Flag (night, ocean, "low-emissivity") 3.9-11 μm Test Result	1	0 1	Yes No
<i>Fifth Byte (Byte 4)</i>			
Flag Name	Number of Bits	Bit Value	Bit Value Definitions
Spares (No 250 m tests)	8		TBD
<i>Sixth Byte (Byte 5)</i>			
Flag Name	Number of Bits	Bit Value	Bit Value Definitions
Spares (No 250 m tests)	8		TBD

Green Shading means the flags are in the same byte and bit locatoin as in the MODIS Standard Products

CLDMSK Product: "Quality_Assurance" QA Flags for CLDMSK*Scientific Data Set (SDS): "Quality_Assurance"**Description: Cloud Mask QA Array**Resolution: 750x750 m or 1000x1000 m (depending on instrument)**Length: 10 bytes (80 bits)****First Byte (Byte 0)***

Flag Name	Number of Bits	Bit Values	Bit Value Definitions
Cloud Mask (1 km) Usefulness Flag	1	0 1	Not useful Useful
Cloud Mask (1 km) Confidence Flag	3	0 1 2 3 4 5 6 7	Lowest Confidence Not Used Not Used Not Used Intermediate Confidence Not Used High Confidence Highest Confidence
Spares	4		TBD

Second Byte (Byte 1)

Flag Name	Number of Bits	Bit Values	Bit Value Definitions
Spares	1		TBD
Thin Cirrus (Solar) Test	1	0 1	Not Applied Applied
Snow Cover from Ancillary Data	1	0 1	Ancillary Data Not Tested Ancillary Data Tested
Thin Cirrus (IR) Test	1	0 1	Not Applied Applied
Cloud Adjacency Test (nearest neighbor pixels)	1	0 1	Not Applied Applied
IR Threshold Test	1	0 1	Not Applied Applied
Spares	1		TBD
Spares	1		TBD

Third Byte (Byte 2)

Flag Name	Number of Bits	Bit Values	Bit Value Definitions
High Cloud (1.38 μm) Test	1	0 1	Not Applied Applied
High Cloud (3.9-12 μm) Test	1	0 1	Not Applied Applied

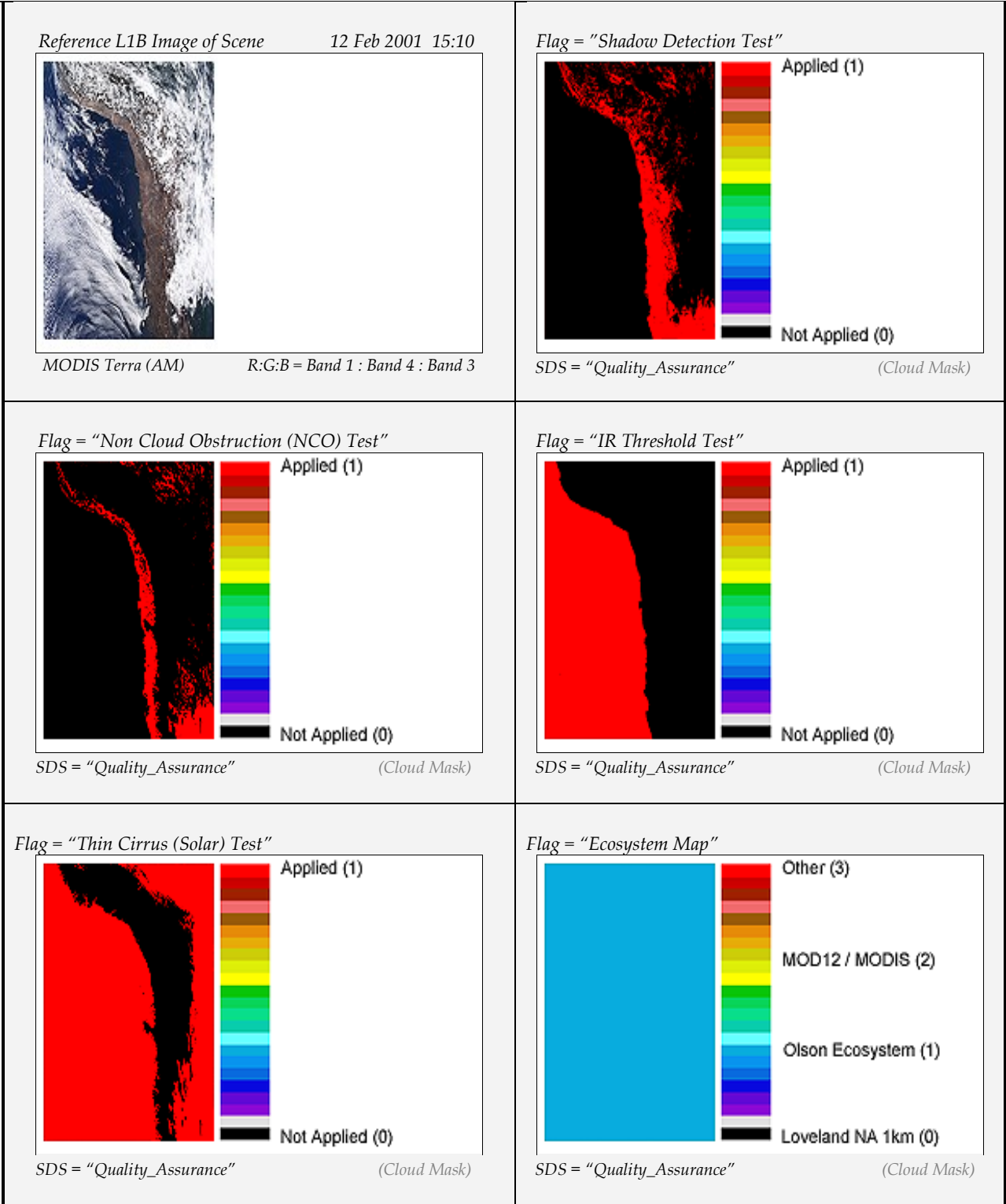
Transmissive High Cloud (11-12 μm) Test	1	0 1	Not Applied Applied
3.9-11 μm Test	1	0 1	Not Applied Applied
0.412/0.68/0.86 μm Reflectance Test	1	0 1	Not Applied Applied
0.86/0.68 Ratio Test	1	0 1	Not Applied Applied
Clear Sky Restoral Test (Coastal NDVI)	1	0 1	Not Applied Applied
Cloud Flag – Water 1.6 or 2.1 μm Test	1	0 1	Not Applied Applied
Fourth Byte (Byte 3)			
Flag Name	Number of Bits	Bit Values	Bit Value Definitions
Ocean 8.6-11 μm Test	1	0 1	Not Applied Applied
Clear Sky Restoral Test (Spatial variability, water)	1	0 1	Not Applied Applied
Clear Sky Restoral Tests (Polar night, land, sun-glint)	1	0 1	Not Applied Applied
Surface Temperature Test	1	0 1	Not Applied Applied
Spares	1		TBD
Night Ocean 8.6-7.3 μm Test	1	0 1	Not Applied Applied
Night Ocean 11 μm Spatial Variability Test	1	0 1	Not Applied Applied
Night Ocean Low Cloud Test (3.9-11 μm)	1	0 1	Not Applied Applied
Fifth Byte (Byte 4)			
Flag Name	Number of Bits	Bit Values	Bit Value Definitions
Spares (Previously 250 m Visible Tests, repeated 8 times)	1x8		TBD
Sisth Byte (Byte 5)			
Flag Name	Number of Bits	Bit Values	Bit Value Definitions
Spares (Previously 250 m Visible Tests, repeated 8 times)	1x8		TBD
Seventh Byte (Byte 6)			

Flag Name	Number of Bits	Bit Values	Bit Value Definitions
<i>input data information flags</i>			
Number of bands used to generate cloud mask	2	0 1 2 3	None 1-7 8-14 15-21
Number of spectral tests used to generate cloud mask	2	0 1 2 3	None 1-3 4-6 7-9
Spares	4		TBD
<i>Eighth Byte (Byte 7)</i>			
Flag Name	Number of Bits	Bit Values	Bit Value Definitions
<i>input data resource flags</i>			
Clear Radiance Origin	2	0 1 2	MOD35 (MODIS Cloud Mask) Forward calculation from NCEP GDAS model Other
Surface Temperature Over Land	2	0 1 2 3	NCEP GDAS GMAO MOD11 (MODIS Land Surface Temperature) Other
Surface Temperature Over Ocean	2	0 1 2 3	Reynolds blended GMAO MOD28 (Sea Surface Temperature) Other
Surface Winds	2	0 1 2	NCEP GDAS GMAO Other
<i>Ninth Byte (Byte 8)</i>			
Flag Name	Number of Bits	Bit Values	Bit Value Definitions
Ecosystem Map	2	0 1 2 3	Loveland NA 1 km Olson Ecosystem MOD12 MODIS Land Cover product Other
Snow Mask	2	0 1 2	MOD33 MODIS Snow Cover product SSMI product Other
Ice Cover	2	0 1 2	MOD42 MODIS Sea Ice Product SSMI product Other

Land/Sea Mask	2	0 1 2	USGS 1 km 6 level USGS 1 km binary Other
<i>Tenth Byte (Byte 9)</i>			
Flag Name	Number of Bits	Bit Values	Bit Value Definitions
Digital Elevation Model	1	0 1	EOS DEM Not used
Precipitable Water	2	0 1 2	NCEP GDAS GMAO MOD07 Atmospheric Profile
Spares	5		TBD

Green Shading means the flags are in the same byte and bit locatoin as in the MODIS Standard Products

Sample Runtime QA Flag Images
from the heritage MODIS Standard Cloud Mask Product (as samples)



Note: Images were created by "bitflag_visualizer", available at http://modis-atmos.gsfc.nasa.gov/tools_bitflag_visualizer.html.

2.2 Cloud Properties Product (CLDPROP)

The Continuity Atmosphere Cloud Properties product (CLDPROP) consists of a 750x750 m (VIIRS) or 1000x1000 m (MODIS) set of parameters derived from solar reflectance and thermal emitted channels. Cloud Property QA flags are stored in two separate QA arrays (SDS's).

The first Bit Flag SDS, *Cloud_Mask*, contains Cloud Mask Flags, which are copied from the Cloud Mask Product (CLDMSK). It should be noted that in the second byte of the *Cloud_Mask* SDS, shown on page 4, the flags were moved and reordered from the source *Cloud_Mask* SDS in the CLDMSK product -- detail follows starting on page 4.

Note the green shading in the tables that follow means the Flags are in the same byte and bit location as in the MODIS Standard Products (MOD & MYD). Unshaded rows means those flags are new or moved from previous MODIS Standard Product locations. Programmers using old MODIS Standard code beware!

CLDPROP Product: "Cloud_Mask" SDS (Abbreviated, Reordered)

Scientific Data Set (SDS): "Cloud_Mask"

Description: Cloud Mask QA flags

Resolution: 750x750 m or 1000x1000 m (depending on instrument)

Length: 2 bytes (16 bits)

First Byte (Byte 0)

Flag Name	Number of Bits	Bit Value	Bit Value Definitions
Cloud Mask Status Flag	1	0	Undetermined ^{n,f}
		1	Determined
Cloud Mask Cloudiness Flag	2	0	Confident Cloudy (or Fill, if Status Flag = 0)
		1	Probably Cloudy
		2	Probably Clear
		3	Confident Clear
Day / Night Flag	1	0	Night ^{n,f} (or Fill, if Status Flag = 0)
		1	Day
Sunglint Flag	1	0	Yes (or Fill, if Status Flag = 0)
		1	No
Snow / Ice Flag	1	0	Yes (or Fill, if Status Flag = 0)
		1	No
Surface Type Flag	2	0	Water: Ocean, Deep Lakes, or Deep Rivers (or Fill)
		1	Coast or Shallow Lakes or Shallow Rivers
		2	Desert
		3	Land

Second Byte (Byte 1) *

Flag Name	Number of Bits	Bit Value	Bit Value Definitions
High Cloud Test 1.38 μm : Result	1	0	No or Not Applied
		1	Might have Cloud
High Cloud Test 1.38 μm : Applied?	1	0	Not Applied
		1	Applied
Visible Reflectance Threshold Test: Result	1	0	No or Not Applied
		1	Might have Cloud
Visible Reflectance Threshold Test: Applied?	1	0	Not Applied
		1	Applied
R0.86 / R0.65 μm test: Result	1	0	No or Not Applied
		1	Might have Cloud
R0.86 / R0.65 μm test: Applied?	1	0	Not Applied
		1	Applied
Spares	2		TBD

* Note the second byte is reordered from the full Cloud_Mask SDS. (See pages 9-10 of this document).

The second BitFlag SDS (this time QA-related), is named *Quality_Assurance*, and contains information from the Cloud Optical and Cloud Top Properties Algorithms including product quality, retrieval processing information (retrieval logical path and retrieval outcome), and scene characteristic flags.

CLDPROP Product: "Quality_Assurance" QA Flag SDS for CLDPROP

Scientific Data Set (SDS): "Quality_Assurance"			
<i>Description: Cloud Optical Property product quality & retrieval processing QA flags</i>			
<i>Resolution: 750x750 m or 1000x1000 m (depending on instrument)</i>			
<i>Length: 4 bytes (32 bits)</i>			
First Byte (Byte 0)			
Flag Name	Number of Bits	Bit Value	Bit Value Definitions
Primary (VNSWIR - 2.1 μm) Cloud Retrieval Spectral Data Availability	1	0	Some or all spectral data not available
		1	All spectral data available
Primary (VNSWIR - 2.1 μm) Cloud Retrieval Confidence Flag	2	0	No Confidence or Fill (<i>Fill setting is used if both Cloudy and Partly Cloudy (PCL) Retrieval are fill</i>)
		1	Marginal Confidence
		2	Good Confidence
		3	Very Good Confidence
Primary (VNSWIR - 2.1 μm) Cloud Retrieval Outcome Flag	1	0	Retrieval not attempted or unsuccessful ^f
		1	Retrieval successful
1.6 μm - 2.1 μm Cloud Retrieval Spectral Data Availability	1	0	Some or all spectral data not available
		1	All spectral data available
1.6 μm - 2.1 μm Cloud Retrieval Confidence Flag	2	0	No Confidence or Fill (<i>Fill setting is used if both Cloudy and Partly Cloudy (PCL) Retrieval are fill</i>)
		1	Marginal Confidence
		2	Good Confidence
		3	Very Good Confidence
1.6 μm - 2.1 μm Cloud Retrieval Outcome Flag	1	0	Retrieval not attempted or unsuccessful ^f
		1	Retrieval successful
Second Byte (Byte 1)			
Flag Name	Number of Bits	Bit Value	Bit Value Definitions
Cloud Retrieval Phase Flag	3	0	Cloud Mask Undetermined ^{n,f}
		1	No Cloud ^f
		2	Liquid Water Cloud
		3	Ice Cloud
		4	Undetermined Phase Cloud
Rayleigh Correction	1	0	No Correction
		1	Yes, Correction was made

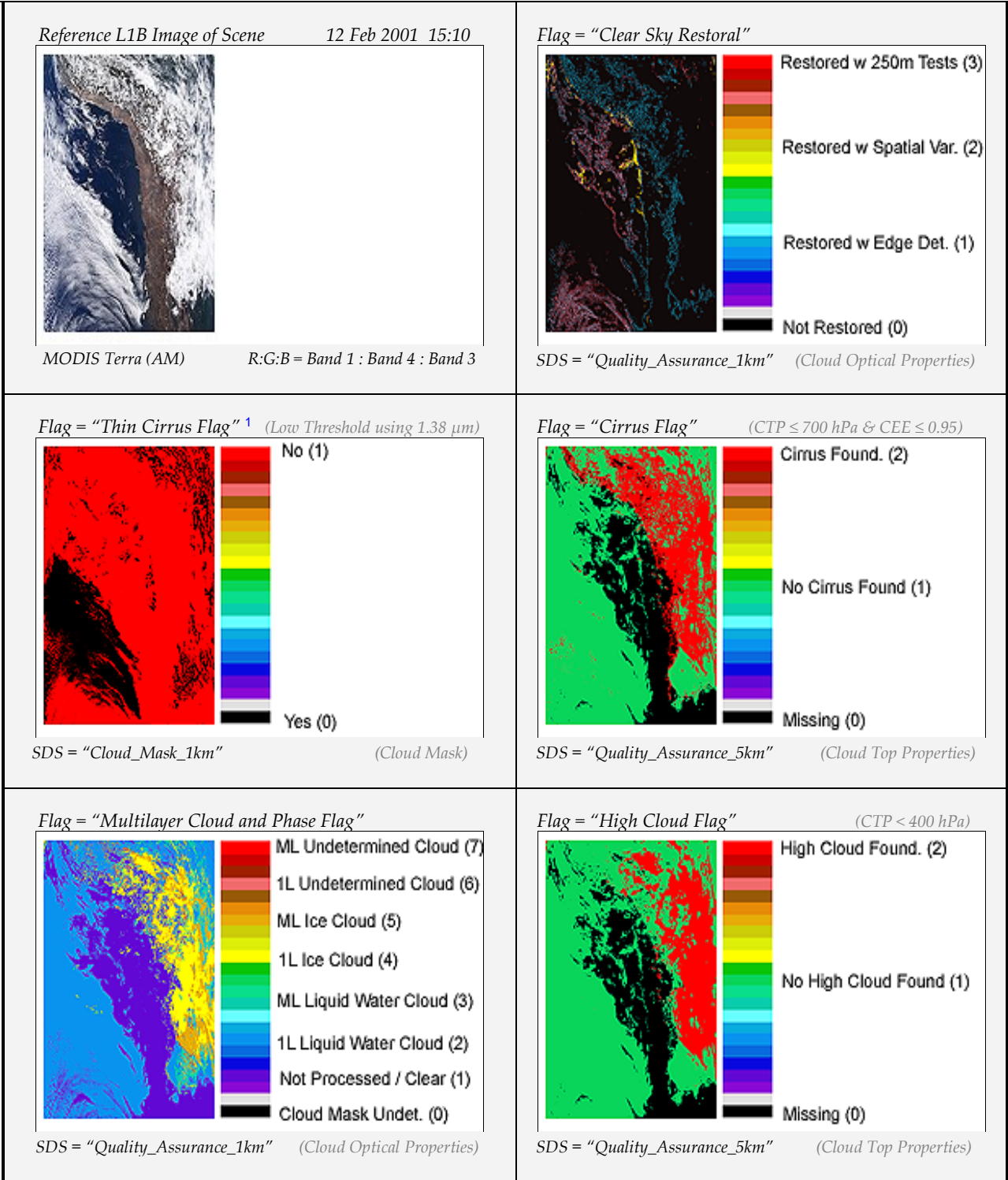
Band Used for Optical Thickness Retrieval	2	0 1 2 3	Retrieval not attempted ^f 0.645 μm (land) 0.858 μm (water) 1.24 μm (snow / ice)
Primary (VNSWIR - 2.1 μm) Optical Thickness Out-of-Bounds	1	0 1	No Yes
VIIRS Bow-Tie Pixel Indicator	1	0 1	Normal Pixel Bow-Tie Pixel
Third Byte (Byte 2)			
Flag Name	Number of Bits	Bit Value	Bit Value Definitions
Clear Sky Restoral Type Flag	2	0 1 2 3	Not Restored Tagged as "Partly Cloudy" (PCL) via Edge Detection Restored to Clear Sky via Spatial Variance Tagged as "Partly Cloudy" (PCL) via High Res Data
VNSWIR – 1.6 μm Retrieval Outcome Flag	1	0 1	Retrieval not attempted or failed ^f Retrieval successful
VNSWIR – 1.6 μm PCL Retrieval Outcome Flag	1	0 1	Retrieval not attempted or failed ^f Retrieval successful
VNSWIR – 3.7 μm Retrieval Outcome Flag	1	0 1	Retrieval not attempted or failed ^f Retrieval successful
VNSWIR – 3.7 μm PCL Retrieval Outcome Flag	1	0 1	Retrieval not attempted or failed ^f Retrieval successful
1.6 μm – 2.1 μm PCL Retrieval Outcome Flag	1	0 1	Retrieval not attempted or failed ^f Retrieval successful
VNSWIR – 2.1 μm PCL Retrieval Outcome Flag	1	0 1	Retrieval not attempted or failed ^f Retrieval successful
Fourth Byte (Byte 3)			
Flag Name	Number of Bits	Bit Value	Bit Value Definitions
Earth Surface Type used in Optical Thickness Retrieval	2	0 1 2 3	Ice Free Ocean Ice Covered Ocean Snow Free Land Snow Covered Land
VNSWIR - 1.6 μm Cloud Retrieval Spectral Data Availability	1	0 1	Some or all spectral data not available All spectral data available
VNSWIR – 3.7 μm Cloud Retrieval Spectral Data Availability	1	0 1	Some or all spectral data not available All spectral data available
Cloud Top Pressure Abnormal	1	0 1	No Yes
Spares	3		

Green Shading means the flags are in the same byte and bit locatoin as in the MODIS Standard Products

ⁿ Cloud Optical Property retrieval not attempted

^f fill values used for Cloud Optical Property retrieval

Sample Runtime QA Flag Images
from the heritage MODIS Standard Cloud Product (as samples)



¹ Note: "Thin Cirrus Flag" from Cloud Mask is suspect (due to 1.38 μ m test limitations) for portions of this granule.
Note: Images were created by "bitflag_visualizer", available at http://modis-atmos.gsfc.nasa.gov/tools_bitflag_visualizer.html.

2.3 Aerosol Deep Blue Product (AERDB)

The Aerosol Deep Blue (AERDB) QA flags are stored in a myriad of separate short integer (I*2) SDS's. Therefore it is not necessary to strip out bit flags from a byte SDS in the Aerosol (AERDB) Product. The individual I*2 QA Flags are documented below.

*AERDB Product: I*2 QA Flag SDS*

<i>Scientific Data Set (SDS): "Aerosol_Optical_Thickness_QA_Flag_Land"</i>			
<i>Description: Deep Blue AOT QA over Land flag</i>			
<i>Resolution: 8x8 pixels or 6x6 km</i>			
<i>Length: Integer*2</i>			
Flag Name	Int Length	Int Value	Int Value Definitions
Deep Blue AOT Quality Flag over Land	1	0	No Retrieval ^{n,f}
		1	Poor Quality
		2	Moderate Quality
		3	Good Quality

*AERDB Product: I*2 QA Flag SDS*

<i>Scientific Data Set (SDS): "Aerosol_Optical_Thickness_QA_Flag_Ocean"</i>			
<i>Description: SOAR QA over Ocean flag</i>			
<i>Resolution: 8x8 pixels or 6x6 km</i>			
<i>Length: Integer*2</i>			
Flag Name	Int Length	Int Value	Int Value Definitions
SOAR AOT Quality Flag over Ocean	1	0	No Retrieval ^{n,f}
		1	Poor Quality
		2	(Note: Setting of 2 is not used in Operational Code)
		3	Good Quality

AERDB Product: I*2 QA Flag SDS

Scientific Data Set (SDS): *"Aerosol_Type_Land"*

Description: *Aerosol Optical Model over Land flag*

Resolution: *8x8 pixels or 6x6 km*

Length: *Integer*2*

Flag Name	Int Length	Int Value	Int Value Definitions
Aerosol Type from Optical Model over Land	1	-999	No Retrieval, Fill
		0	Dust (land)
		1	Smoke (land)
		2	High Altitude Smoke (land)
		3	Pyroculonimbus Clouds (land)
		4	Non Smoke Fine Mode (land)
		5	Mixed Mode (land)
		6	Background (land)

AERDB Product: I*2 QA Flag SDS

Scientific Data Set (SDS): *"Aerosol_Type_Land_Ocean"*

Description: *Aerosol Optical Model over Land & Water flag*

Resolution: *8x8 pixels or 6x6 km*

Length: *Integer*2*

Flag Name	Int Length	Int Value	Int Value Definitions
Aerosol Type from Optical Model over Land, Ocean, & Water	1	-999	No Retrieval, Fill
		0	Dust (land & ocean)
		1	Smoke (land & ocean)
		2	High Altitude Smoke (land & ocean)
		3	Pyroculonimbus Clouds (land & ocean)
		4	Non Smoke Fine Mode (land & ocean)
		5	Mixed Mode (land & ocean)
		6	Background (land & ocean maritime)
		7	Fine Dominated (land & ocean)

AERDB Product: I*2 QA Flag SDS*Scientific Data Set (SDS): "Aerosol_Type_Ocean"**Description: SOAR retrieved Aerosol Optical Model over Ocean / Water flag**Resolution: 8x8 pixels or 6x6 km**Length: Integer*2*

Flag Name	Int Length	Int Value	Int Value Definitions
SOAR retrieved Aerosol Optical Model over Ocean & Water	1	-999	No Retrieval, Fill
		1	Dust (ocean)
		2	Fine Dominated (ocean)
		3	Maritime (ocean)
		4	Mixed Mode (ocean)

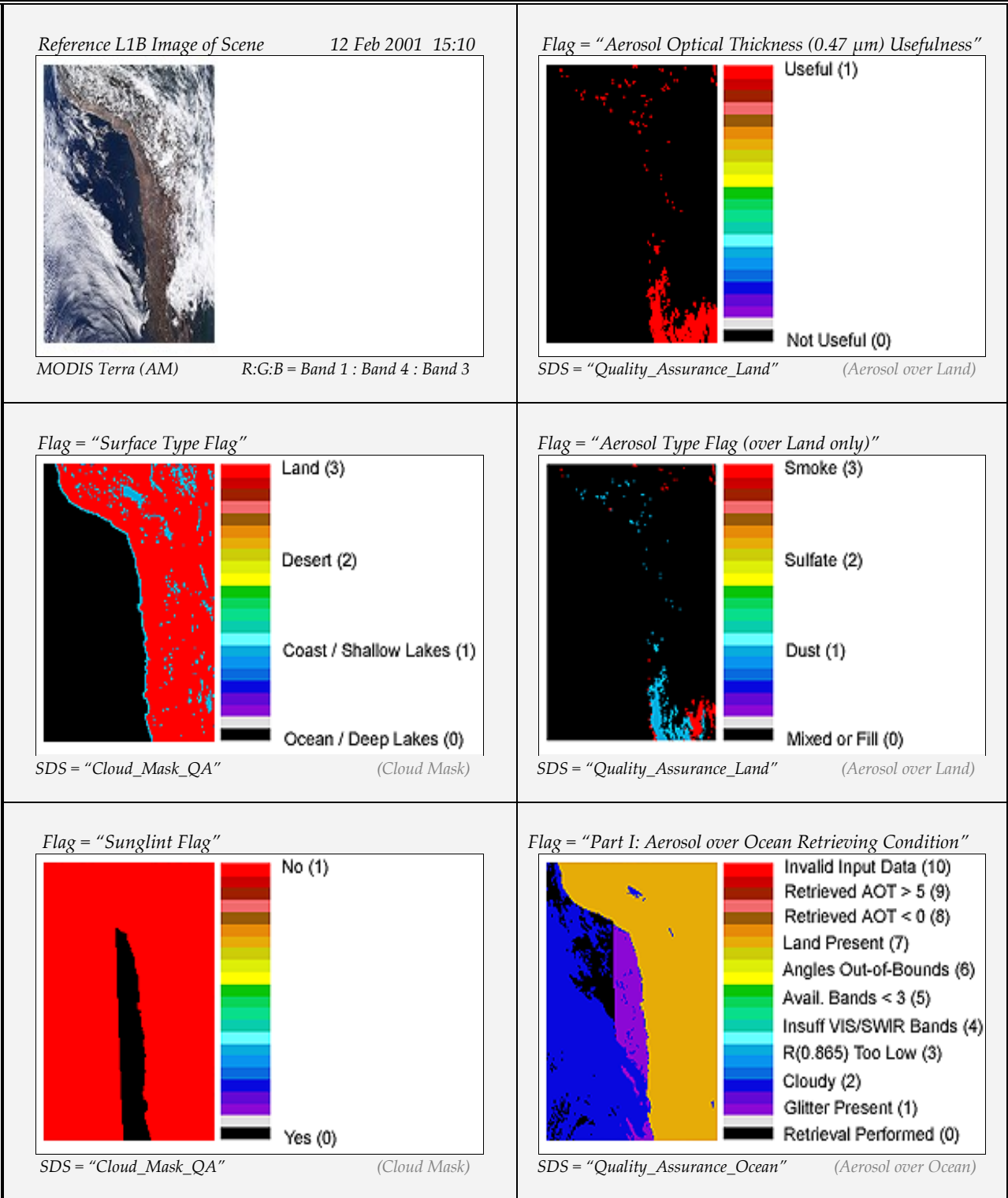
AERDB Product: I*2 QA Flag SDS*Scientific Data Set (SDS): "Algorithm_Flag_Land"**Description: Deep Blue Algorithm Surface Type over Land flag**Resolution: 8x8 pixels or 6x6 km**Length: Integer*2*

Flag Name	Int Length	Int Value	Int Value Definitions
Deep Blue Alrorithm Flag over Land	1	-999	No Retrieval
		0	Arid (Deep Blue)
		1	Vegitated
		2	Mixed

AERDB Product: I*2 QA Flag SDS*Scientific Data Set (SDS): "Algorithm_Flag_Ocean"**Description: SOAR Algorithm over Water flag**Resolution: 8x8 pixels or 6x6 km**Length: Integer*2*

Flag Name	Int Length	Int Value	Int Value Definitions
SOAR Alrorithm Flag over Ocean	1	-999	No Retrieval
		0	Full Retrieval
		1	Turbid / Shallow
		2	Mixed

Sample Runtime QA Flag Images
from the heritage MODIS Standard Aerosol Product (as samples)



Note: Images were created by "bitflag_visualizer", available at http://modis-atmos.gsfc.nasa.gov/tools_bitflag_visualizer.html.

2.4 Aerosol Dark Target Product (AERDT)

The Aerosol Dark Target(AERDT) QA flags are stored in a myriad of separate short integer (I*2) SDS's. Therefore it is not necessary to strip out bit flags from a byte SDS in the Aerosol Dark Target (AERDT) Product. The individual I*2 QA Flags are documented below.

*AERDT Product: I*2 QA Flag SDS*

<i>Scientific Data Set (SDS): "Aerosol_Cldmask_Land_Ocean"</i>			
<i>Description: Aerosol Cloud Mask 750m Resolution</i>			
<i>Resolution: 1x1 pixels or 750x750 m</i>			
<i>Length: Integer*2</i>			
Flag Name	Int Length	Int Value	Int Value Definitions
Aerosol Cloud Mask (750x750 m)	1	-9999	No Retrieval, Fill
		0	Cloud
		1	Clear

*AERDT Product: I*2 QA Flag SDS*

<i>Scientific Data Set (SDS): "Aerosol_Type_Land"</i>			
<i>Description: Dark Target Aerosol Type over Land</i>			
<i>Resolution: 8x8 pixels or 6x6 km</i>			
<i>Length: Integer*2</i>			
Flag Name	Int Length	Int Value	Int Value Definitions
Aerosol Type over Land	1	-9999	No Retrieval, Fill
		1	Continental
		2	Moderate Absorption Fine
		3	Strong Absorption Fine
		4	Weak Absorption Fine
		5	Dust

AERDT Product: I*2 QA Flag SDS

Scientific Data Set (SDS): **"Error_Flag_Land_And_Ocean"** (1st Dimension / Ocean)

Description: **Dark Target Aerosol Error Code (First Dimension, Ocean)**

Resolution: **8x8 pixels or 6x6 km**

Length: **Integer*2**

Dimensions: **2 (First index or position Ocean, Second index or position Land)**

Flag Name	Int Length	Int Value	Int Value Definitions	
Ocean and Land Aerosol Error Flag	1	-9999	No Retrieval, Fill	
First index position Ocean			<i>Success Flags</i>	
		0	Success: Number of pixels used > Threshold	
		1	Success: Number of pixels used < Threshold	
		2	N/A	
		3	Success: Reflectance at 0.86 μm < 1.5 Rayleigh	
		4	N/A	
		5	Success: Aerosol Content is variable (Threshold 1)	
		6	Success: Aerosol Content is variable (Threshold 2)	
		7	Success: Aerosol Type is variable	
		8	Success: Observations less than 3	
		9	Success: Optical depth (0.554 μm) between -0.1 & 0.0	
		10	Success: Glint Angle between 30 & 40 Degrees	
		11	Partial Success: Glint angle < 40 degrees (only glint, reflectance, & num pixels stored)	
		12	Success: Algorithm detects dust in glint area	
		13	Success: Cirrus may be present	
		14	Success: Algorithm detects dust off glint area	
		15	N/A	
		16	N/A	
		17	Success: Reflectance at 0.865 μm less than threshold	
		18	N/A	
		19	N/A	
				<i>Failure Flags</i>
			20	Fail: Data is not available for Wavelengths used
			21	Fail: Glint angle (reflectance, std dev, & num pixels stored)
			22	Fail: Not enough pixels to process
			23	N/A
			24	N/A
			25	N/A
			26	Fail: Angles are out of bounds
		27	N/A	
		28	Fail: Optical Depth (0.554 μm) < -0.10	
		29	Fail: Optical Depth (0.554 μm) > 5.00	

AERDT Product: I*2 QA Flag SDS

Scientific Data Set (SDS): **"Error_Flag_Land_And_Ocean"** (2nd Dimension / Land)

Description: **Dark Target Aerosol Error Code** (Second Dimension, Land)

Resolution: **8x8 pixels or 6x6 km**

Length: **Integer*2**

Dimensions: **2** (First index or position Ocean, Second index or position Land)

Flag Name	Int Length	Int Value	Int Value Definitions	
Ocean and Land Aerosol Error Flag	1	-9999	No Retrieval, Fill	
Second index position Land			<i>Success Flags</i>	
		1	Success: Procedure > 1 only Continental model	
		2	Success: Water Pixel may be present	
		3	Success: Cirrus clouds may be present	
		4	Success: Fitting error is greater than 0.25	
		5	Success: Mass Concentration & Fine Mode Optical Depth set to 0 when Opt. Depth (0.54 μm) is negative	
		6	Success: Number of pixels between 3% & 5%	
		7	Success: Number of pixels between 5% & 8%	
		8	Success: Number of pixels between 8% & 12%	
		9	Success: Optical Depth is negative	
		10	Success: Optical Depth (0.554 μm) < 0.2	
		11	N/A	
		12	N/A	
		13	N/A	
		14	N/A	
		15	N/A	
		16	N/A	
		17	N/A	
		18	N/A	
		19	N/A	
		20	N/A	
				<i>Failure Flags</i>
			21	Fail: Angles are out of bounds
			22	Fail: Data is not Available for wavelengths used
			23	Fail: Not enough pixels to process
			24	Fail: 2.13 μm Threshold is not met
		25	Fail: Optical Depth (0.554 μm) < -0.10	
		26	Fail: Optical Depth (0.554 μm) > 5.0	

AERDT Product: I*2 QA Flag SDS

Scientific Data Set (SDS): "Land_Ocean_Quality_Flag"

Description: Dark Target Quality Flag over Land and Ocean

Resolution: 8x8 pixels or 6x6 km

*Length: Integer*2*

Flag Name	Int Length	Int Value	Int Value Definitions
Aerosol Retrieval Quality Flag	1	-9999	No Retrieval, Fill
		0	Bad
		1	Marginal
		2	Good
		3	Very Good

AERDT Product: I*2 QA Flag SDS

Scientific Data Set (SDS): "Land_Sea_Flag"

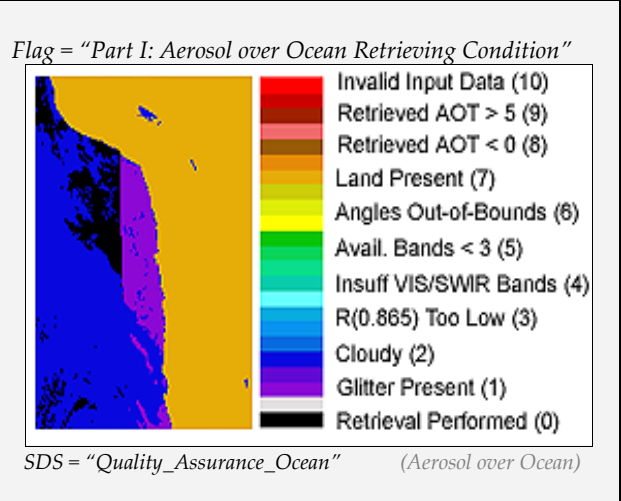
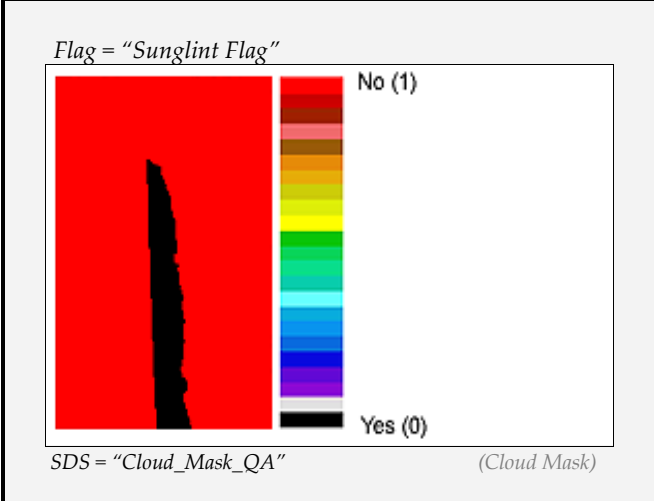
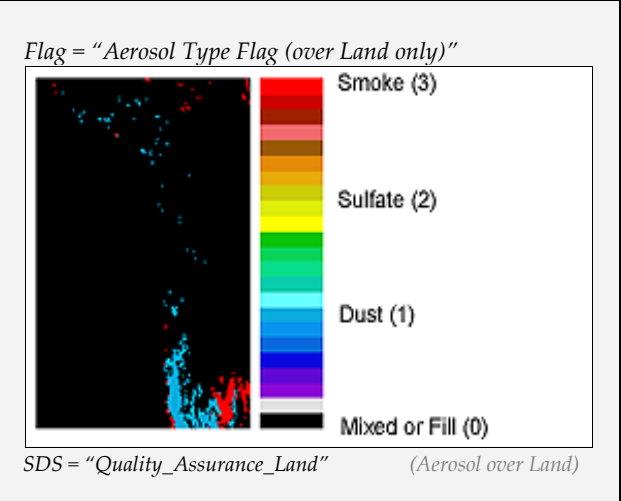
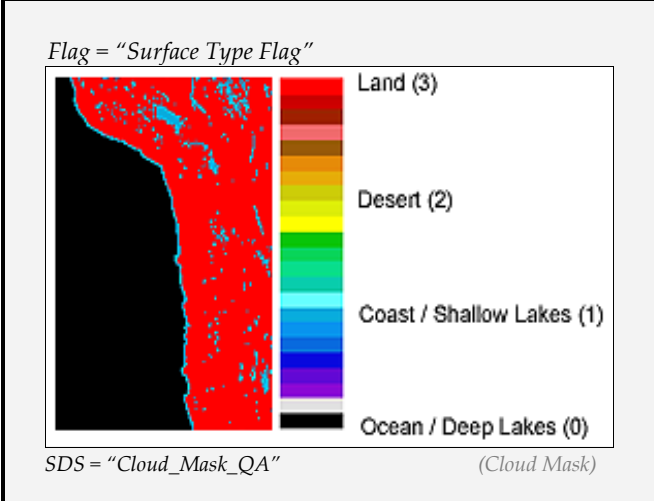
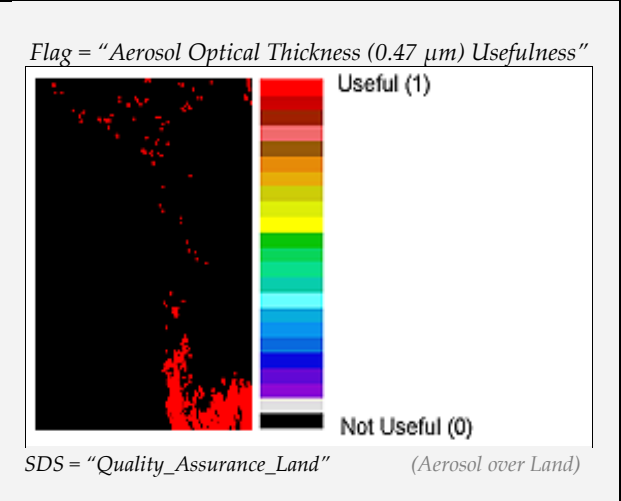
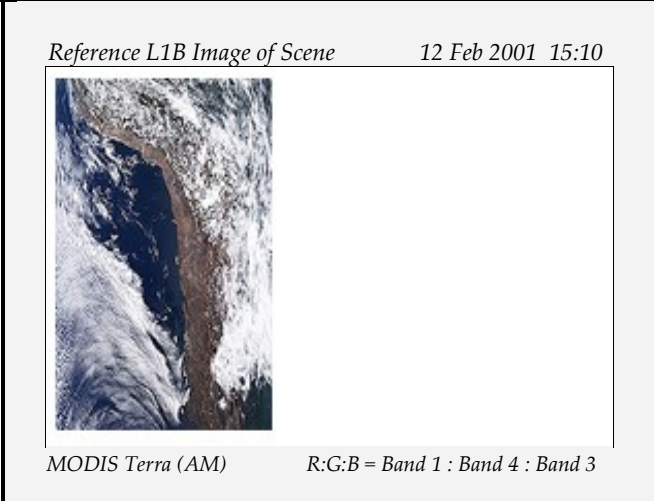
Description: Dark Target Retrieval Surface Type based on MOD03 Land Sea Mask

Resolution: 8x8 pixels or 6x6 km

*Length: Integer*2*

Flag Name	Int Length	Int Value	Int Value Definitions
Surface Type under Retrieval	1	-9999	No Retrieval, Fill
		0	Ocean
		1	Land and Ephemeral Water
		2	Coastal

Sample Runtime QA Flag Images
from the heritage MODIS Standard Aerosol Product (as samples)



Note: Images were created by "bitflag_visualizer", available at http://modis-atmos.gsfc.nasa.gov/tools_bitflag_visualizer.html.

2.4 Water Vapor Product (WATVP)

The Continuity Atmosphere Water Vapor product (WATVP) consists of a 750x750 m (VIIRS) set of parameters. The Water Vapor (WATVP) QA flags are stored in two SDS's documented below.

WATVP Product: QA Flag SDS

<i>Scientific Data Set (SDS): "Land_Sea_Mask"</i>			
<i>Description: Land and Sea Mask</i>			
<i>Resolution: 1x1 pixels or 750x750 m</i>			
<i>Length: Byte*1</i>			
Flag Name	Byte Length	Value	Byte Value Definitions
Land Sea Mask (750x750 m)	1	0	Ocean or Coastline
		1	Land

WATVP Product: I*2 QA Flag SDS

<i>Scientific Data Set (SDS): "Quality_Flag"</i>			
<i>Description: Dark Target Aerosol Type over Land</i>			
<i>Resolution: 8x8 pixels or 6x6 km</i>			
<i>Length: Integer*2</i>			
Flag Name	Int Length	Int Value	Int Value Definitions
Water Vapor Retrieval Quality Flag	2	-32768	Fill Value
		1	Good Retrieval for both VIIRS & NUCAPS
		2	Good Retrieval VIIRS only
		3	Good Retrieval NUCAPS only
		4	No VIIRS or NUCAPS retrieval or non-physical retrieval

3.0 A Primer on Reading & Interpreting Bit Flags

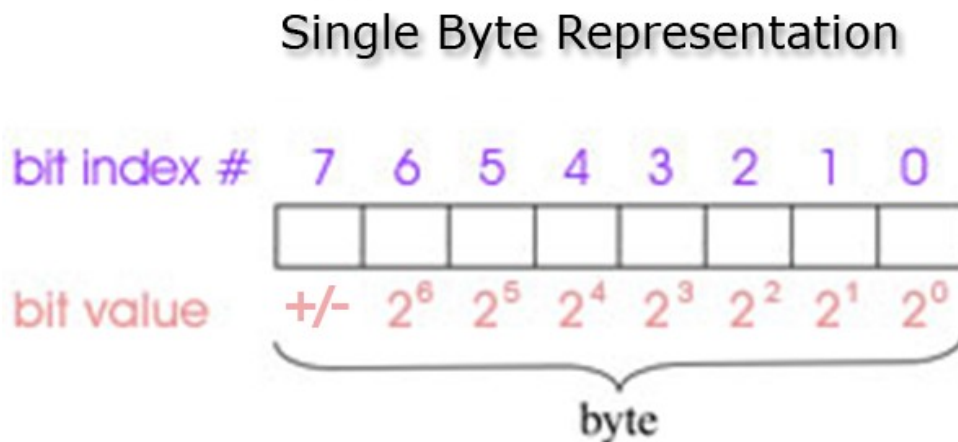
All Level-2 (L2) Continuity Atmosphere NetCDF4 data products contain one or more QA flag Scientific Data Set (SDS) arrays. QA flag SDS names may contain the string "Quality_Assurance" or may have a more descriptive name like "Cloud_Mask". However, they all have one common attribute – bit flag (or bit string) arrays containing one or more flags stored in particular (fixed) bit positions of the array.

Bit and Byte Array Indexing Convention: "Zero-based"

The convention for indexing arrays varies from language to language. Array indexing in FORTRAN typically starts at 1; and array indexing in C typically starts at 0. However, almost all tools used for bit extraction (in both FORTRAN and C) use an index start convention of 0 for both bits and bytes. In addition, the NetCDF4 interface is based in the C (0-based) language. Therefore a 0-based start convention for indexing (numbering) the bits and bytes is always used. In summary, the first byte is always called byte 0, and the first (lowest order) bit is always called bit 0.

NetCDF4 Bit Ordering Convention:

When reading bit flags from *bit string* SDSs (Quality Assurance or Cloud Mask arrays, for example), the bits will always be numbered from right (bit index #0) to left (bit index #7). That is, the least significant bit (2^0) is on the right and most significant bit (the sign bit) is on the left. A visual example of this format is offered below.



Numerical Whole-Byte Dumps

Users should note that if one uses the NetCDF4 utility, *ncdump*, or other tools to dump full-byte values as decimal numbers (that is, decimal numbers ranging from -128 to 127) from *bit flag* SDS arrays. One simply converts the numbers to 8 bit registers of 0 or 1, where the bit tagged as the first bit (bit index #0) is the lowest order (or least significant) bit (2^0); and the bit tagged as the last bit (bit index #7) is the highest order (or most significant) bit (the sign bit).

To decode individual flags, one queries groups of sequential bits (matching the length of each flag) in the proper bit order from 0 to 7 and interprets the value of those bits (using the same *least significant to most significant* convention) to obtain the correct flag value. An example of this *bit flag* decoding is detailed below.

For example, consider the second byte of the Cloud_Mask_5km SDS:

<i>Example QA Bit Flag Array (just a random sample layout)</i>			
Flag Name	Number of Bits	Bit Values	Bit Value Definitions
C6 Sunlint Flag	2	0	Fill <u>or</u> CTP retrieval fail
		1	No Sunlint & CTP retrieval success
		2	Sunlint & CTP retrieval success
C6 Snow / Ice Flag	2	0	Fill <u>or</u> CTP retrieval fail
		1	No Snow/Ice & CTP retrieval success
		2	Snow/Ice & CTP retrieval success
C6 Surface Type Flag	3	0	Fill <u>or</u> CTP retrieval fail
		1	Ocean, Deep Lakes and Rivers & CTP retr. success
		2	Coast, Shallow Lakes and Rivers & CTP retr. success
		3	Desert & CTP retrieval success
		4	Land & CTP retrieval success
Day / Night Flag	1	0	Night (or Fill, if Status Flag = 0)
		1	Day

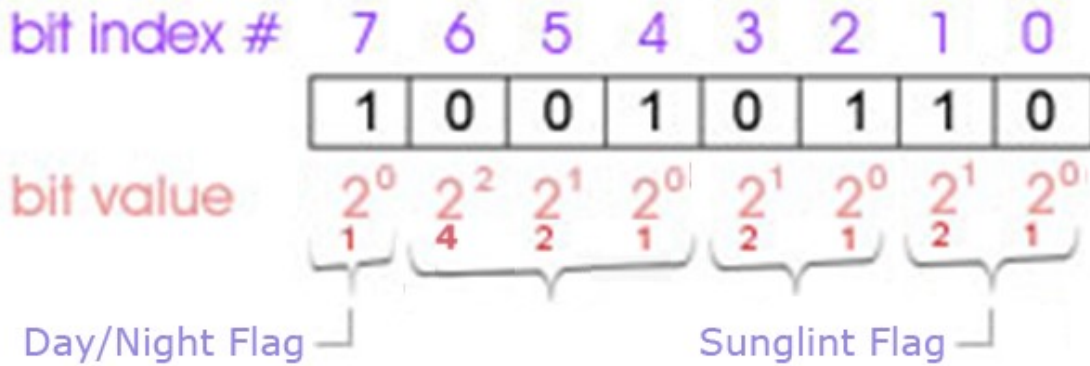
Suppose the following flags were set:

- Sunlint Flag = 2 (Sunlint & CTP Retrieval Success)
- Snow/Ice Flag = 1 (No Snow/Ice & CTP Retrieval Success)
- Surface Type Flag = 1 (Ocean & CTP Retrieval Success)
- Day/Night Flag = 1 (Day)

Bit-String Dump

The bits for the example case noted above are shown in the figure below. Flags are then positioned from the right; and least to most significant bits are ordered from right to left for each individual flag.

Sample Bit Flags



Evaluation of signed bit strings

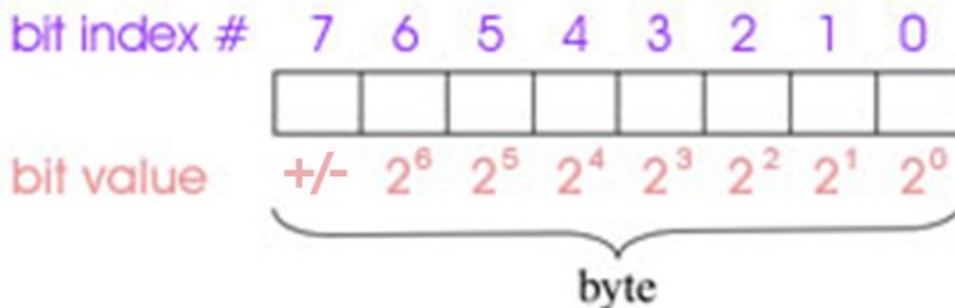
Case 1: Bit strings of length 7 bits or fewer

Evaluating signed bit strings is easy if you are looking at bit strings of length 7 or fewer. In this case, the decimal numbers are always positive (and will range from 0 to a maximum number which depends on the number of bits being read (for example, 3 bits allows for a maximum decimal number of 7)) and will follow the standard interpretation convention shown in the figure below.

Case 2: Bit strings of length 8 bits, but with the sign bit set to 0 (positive numbers)

Evaluating signed bit strings similarly easy if you are looking at bit strings of length 8 and with the most significant bit (the sign bit) set to 0. In this case the numbers are (still) always positive (and will range from 0 to 127) and will follow the standard interpretation convention shown in the figure below.

Single Byte Representation



Case 3: Bit strings of length 8 bits, but with the sign bit set to 1 (negative numbers)

Evaluating signed bit strings is more convoluted if you are looking at bit strings of length 8 but with the most significant bit (the sign bit) set to 1. In this case the numbers are always negative (and will range from -1 to -128) and follow the interpretation formula of outlined below:

Step 1: With the sign bit set to 1, the number will be given a negative sign.

Step 2: Flip all 8 bit registers. All 0's change to 1's; and all 1's change to 0's.

Step 3: Evaluate the bit registers using the Case 2 convention shown above (shown in the previous figure), however when you are done with that calculation, add 1 to the result. Note that the sign bit will always get flipped back to 0 in step 2.

So in the example shown above, with the bit registers showing 10010110. Step 1 says you will assign a negative (-) sign to the result. Step 2 says you flip all the bit registers, which yields 01101001. This "flipped" bit string is interpreted as:

$$1x2^6 + 1x2^5 + 1x2^3 + 1x2^0$$

Or

$$64 + 32 + 8 + 1$$

Or

$$105$$

Adding 1 (as specified in Step 3) we get,

$$106$$

Changing the sign to negative (as noted in Step 1) we get the final answer

$$-106$$

So the bit string of 10010110, will be read as -106.

Numerical Whole-Byte Dump

Sometimes, it's helpful to dump out the numeric values of byte arrays in order to see what values are being stored/read (as a sanity check) to see if you understand how these flags are being set and if they make sense given the sample granule you are studying. There are several ways to dump out the numeric value of a byte from a NetCDF4

bit flag array. One of the easiest ways is to use the NetCDF4 dump utility, *ncdump*. Here is example syntax of using *ncdump* to dump out the byte values of the SDS *Cloud_Mask* from a sample NetCDF4 file called *test.nc* to an output file called *dump.out* on a linux/irix command line:

```
ncdump -v Cloud_Mask test.nc > dump.out
```

Online Bit-String Conversion Tools

There are online tools (calculators) that can assist users to convert bit strings to decimal values (and visa-versa). Here is one example online tool, the link is below along with a screen capture:

http://www.binaryconvert.com/convert_signed_char.html

The screenshot shows a web interface for converting between decimal and binary representations of a signed character. At the top, there is a navigation bar with tabs for different data types: Unsigned char, Signed char, Unsigned short, Signed short, Unsigned int, Signed int, Float, and Double. The current selection is "Signed char (8-bit) Two's complement".

The main content area is divided into two sections. The top section is labeled "Decimal" and displays the value **-106**. Below this, it states "accurate representation = -106". To the right of this section is a large blue sphere icon and a button labeled "New conversion".

The bottom section is labeled "Binary" and displays the bit string **1 0 0 1 0 1 1 0**. Below the bit string, there are eight small squares representing individual bits: the first square is green, the second is grey, the third is green, the fourth is grey, the fifth is green, the sixth is green, the seventh is grey, and the eighth is grey.