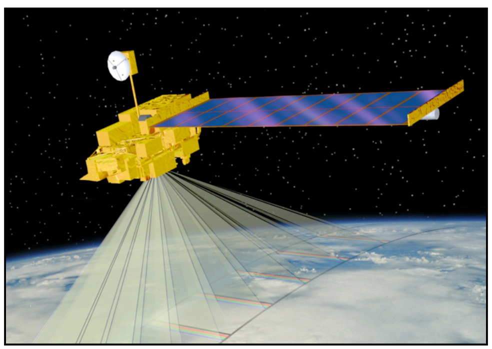
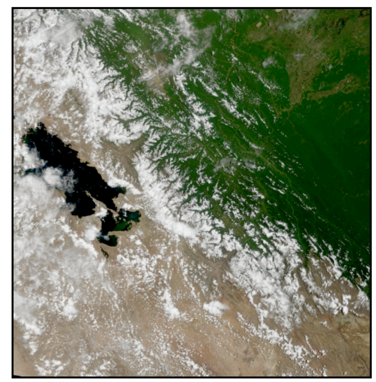
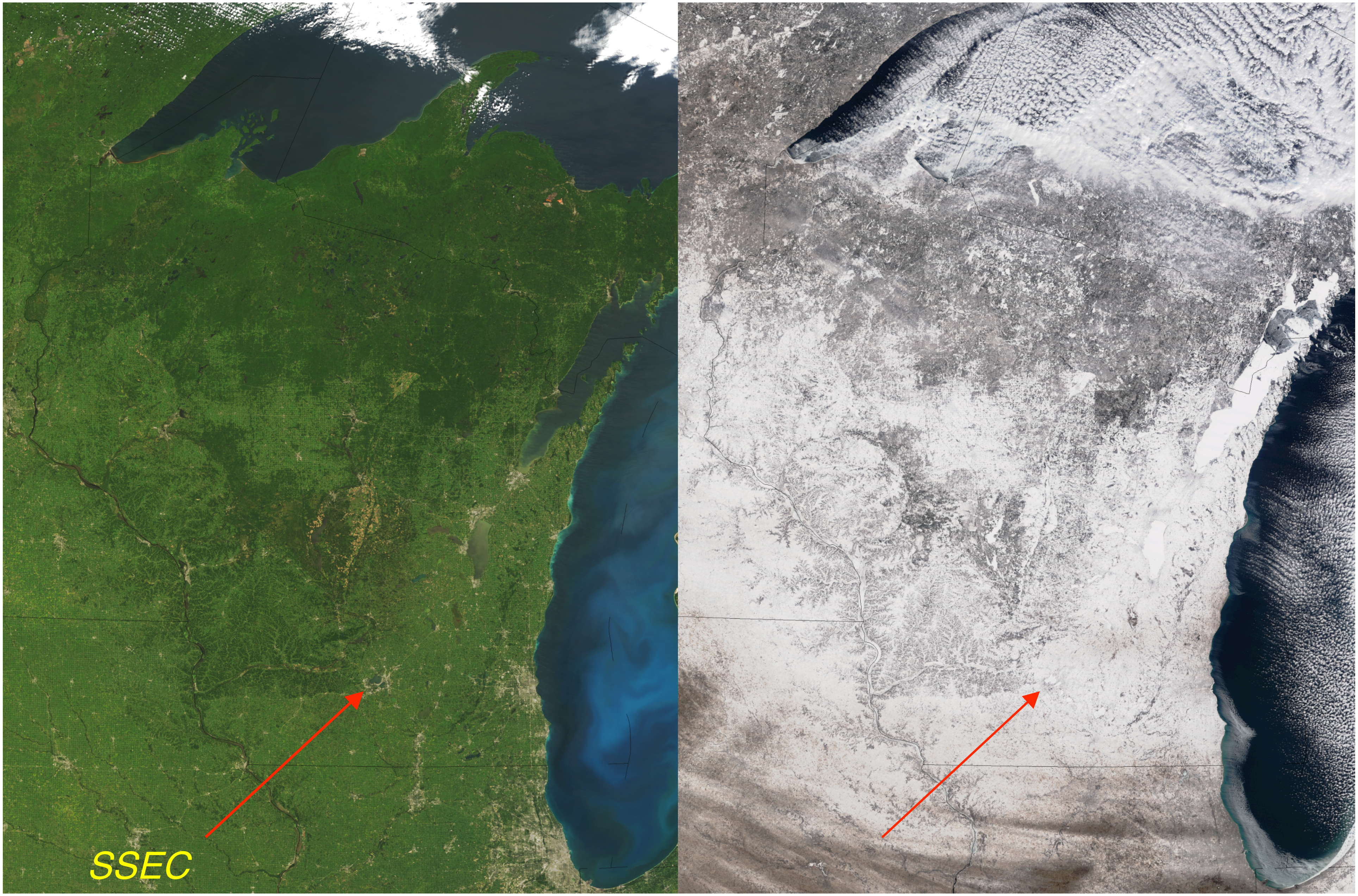
MODIS Sensor Characteristics

GEOSS/AMERICAS Remote Sensing Workshop
São Paulo, Brazil
26 November 2007





Kathleen Strabala
Cooperative Institute for Meteorological Satellite Studies
Space Science and Engineering Center
University of Wisconsin-Madison



Visit Wisconsin: Beautiful in Summer and Winter

Slide Credits

University of Wisconsin-Madison: Liam Gumley, Paul Menzel, Steve Ackerman, Paolo Antonelli, Chris Moeller, Kathy Strabala, Bryan Baum, Suzanne Seemann, Mat Gunshor

MODIS Science Team: Michael King, Steve Platnick, Eric Vermote, Robert Wolfe, Bob Evans, Jacques Descloitres, Jack Xiong.

Other colleagues: Wenjian Zhang, Stefan Maier, Jackie Marsden, Jamie Shutler, Tim Smyth, Roger De Abreu, Gerardo Lopez.

Introduction to MODIS

MODerate resolution Imaging Spectroradiometer (MODIS)

Type: Instrument that flies on 2 polar orbiting research satellites

Heritage: AVHRR (land), SeaWIFS (ocean), HIRS (atmosphere)

Spectral coverage: 36 bands from 0.4 to 14.2 microns

Spatial resolution: 2 bands @ 250 m; 5 @ 500 m; 29 @ 1000 m

Major differences:

- More spectral bands (490 detectors)
- Multiple samples along track on each earth scan
- Higher spatial resolution
- On-orbit radiometric, spatial, and spectral calibration
- Improved radiometric accuracy and precision (12-bit)
- Improved geolocation accuracy
- Higher data rate requiring X-band direct broadcast (10.6 Mbps day, 3.3 Mbps night)

Terra

Launched: Dec. 18, 1999

10:30 am descending

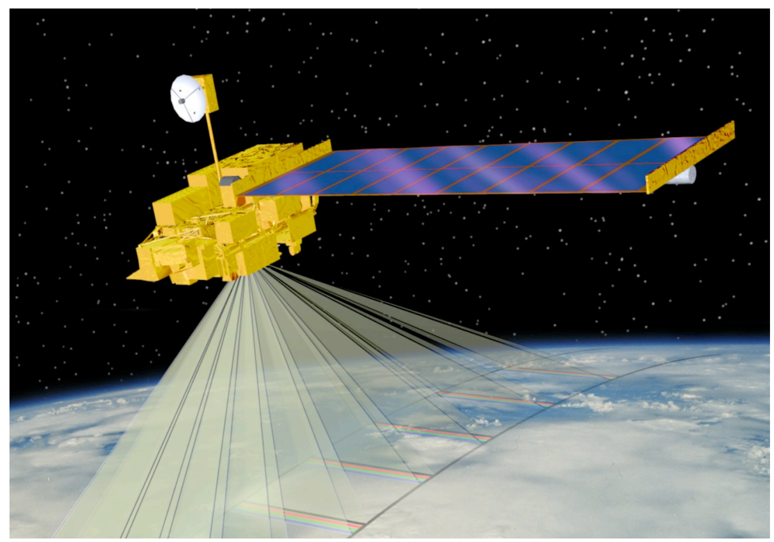
ASTER: Hi-res imager

CERES: Broadband scanner

MISR: Multi-view imager

MODIS: Multispectral imager

MOPITT: Limb sounder



Terra MODIS first light image, 24 Feb. 2000

Aqua

Launched: May 4, 2002

1:30 pm ascending

AIRS: Infrared sounder

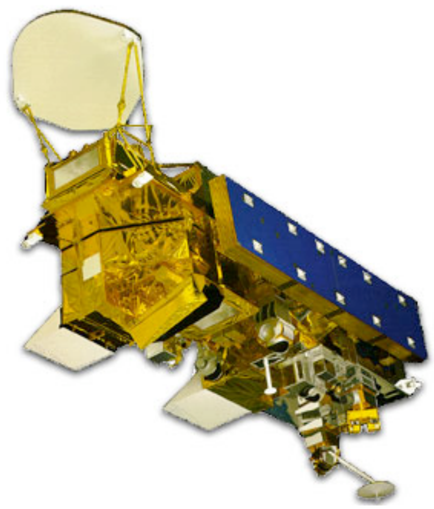
AMSR-E: Microwave scanner

AMSU: Microwave scanner

CERES: Broadband scanner

HSB: Microwave sounder

MODIS: Multispectral imager



Formation Flyers

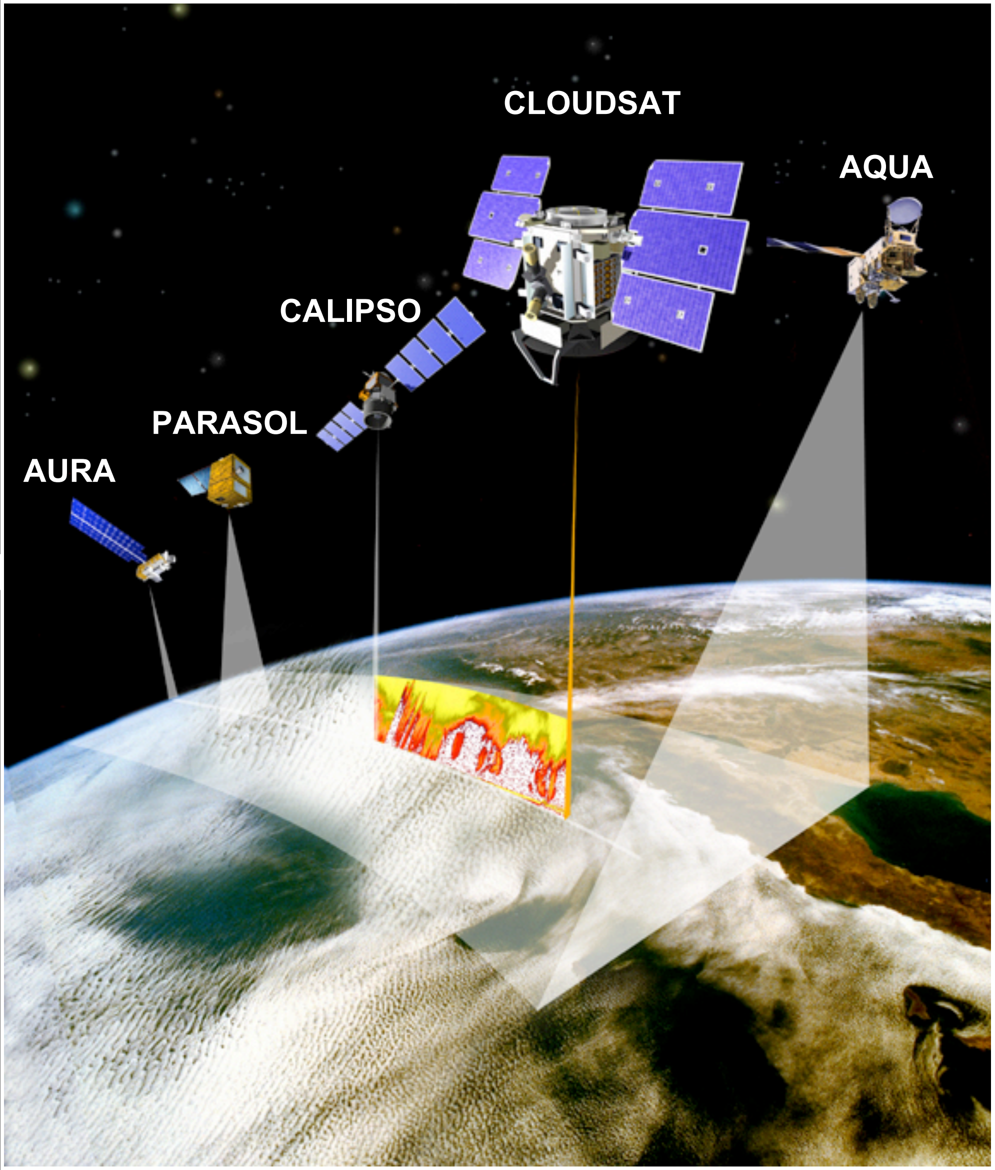
Coordinated observations by multiple sensors without the risk of one large platform

Morning Train (10:30 am)

- Terra (multidisciplinary)
- Landsat-7 (land)
- EO-1 (technology)
- SAC-C (GPS water vapor)
- NPP (EOS/NPOESS bridge)

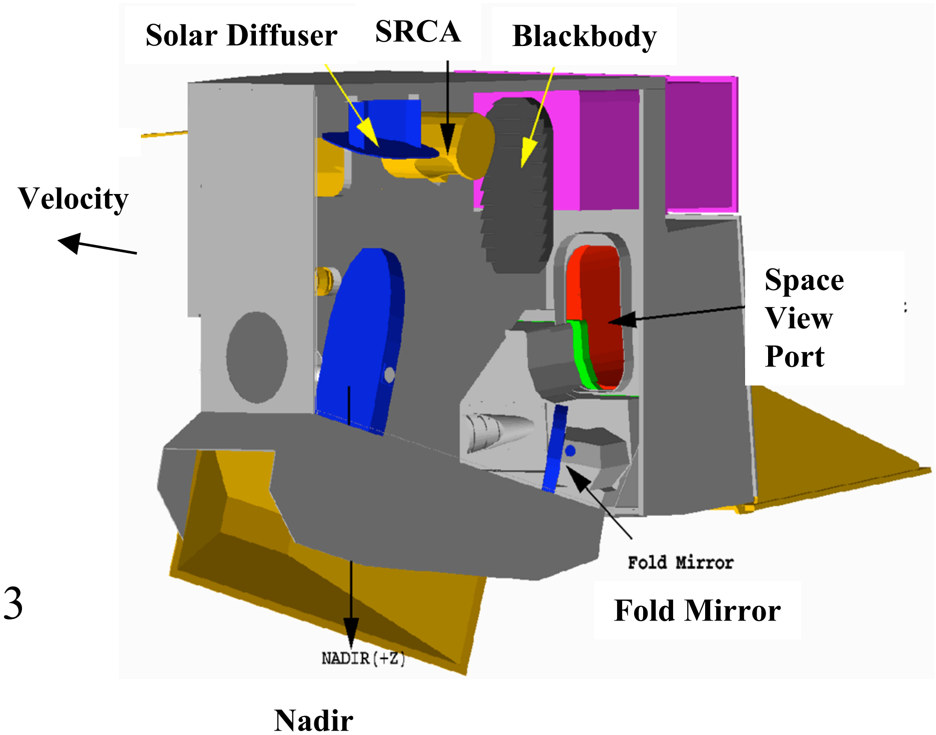
Afternoon Train (1:30 pm)

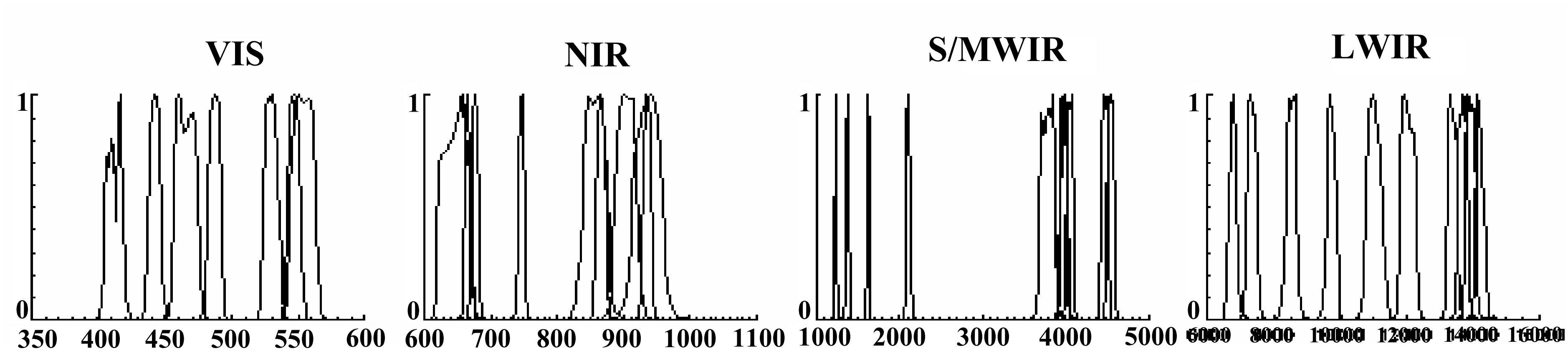
- Aqua (multidisciplinary)
- Aura (chemistry)
- Cloudsat (cloud radar)
- CALIPSO (cloud lidar)
- Parasol (polarimetry)
- NOAA-16 (weather)



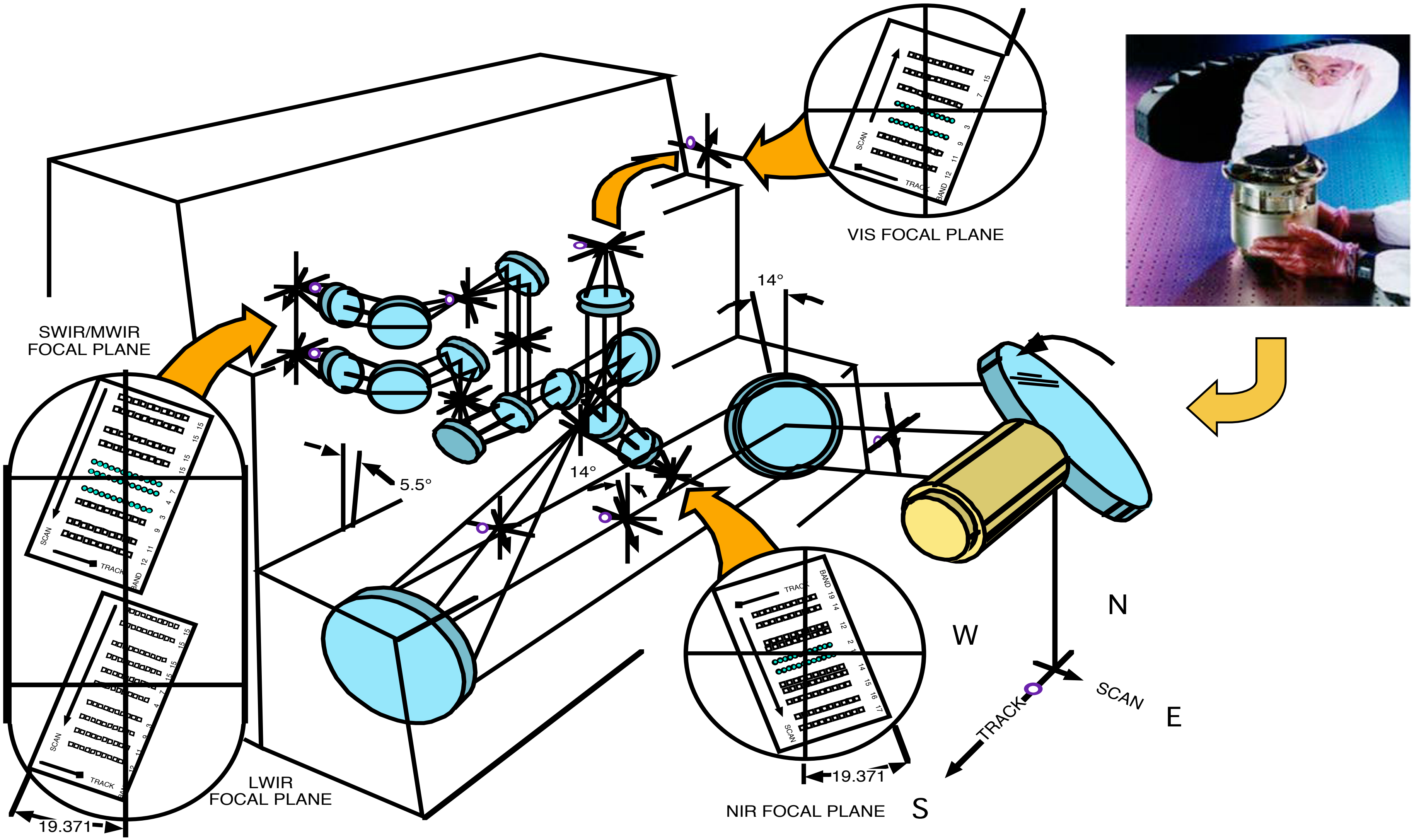
Instrument Overview

- 36 spectral bands (490 detectors) cover wavelength range from 0.4 to 14.5 μm
- Spatial resolution at nadir: 250m (2 bands), 500m (5 bands) and 1000m
- 4 Focal Plane Assemblies: VIS, NIR, SMIR, LWIR
- On-Board Calibrators: SD/SDSM, SRCA, and BB (plus space view)
- 12 bit (0-4095) dynamic range
- 2-sided Paddle Wheel Scan Mirror scans 2330 km swath in 1.47 sec
- Day data rate = 10.6 Mbps; night data rate = 3.3 Mbps





MODIS Optics System



On-board Calibrators

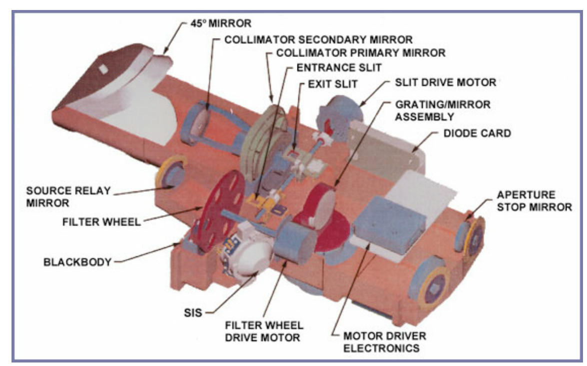
- **SD** – Solar Diffuser for RSB calibration, SD BRDF determined from pre-launch, referenced to a transfer standard calibrated at NIST
- **SDSM** – Solar Diffuser Stability Monitor for tracking SD degradation
- **BB** – Blackbody (12 thermistors reference to NIST standard) for TEB calibration. Emissivity determined from pre-launch calibration using a blackbody calibration source.
- **SRCA** – Spectroradiometric Calibration Assembly for spectral and spatial characterization

SD

SDSM

BB

SRCA



MODIS Challenges

Multiple detectors:

Detector differences are noticeable

Dead or out-of-family detectors must be handled

Multiple samples along track introduce bowtie distortion

Spectral information:

Many interdependent bands

How to utilize all the spectral information?

Data rate:

Orders of magnitude larger than heritage sensors

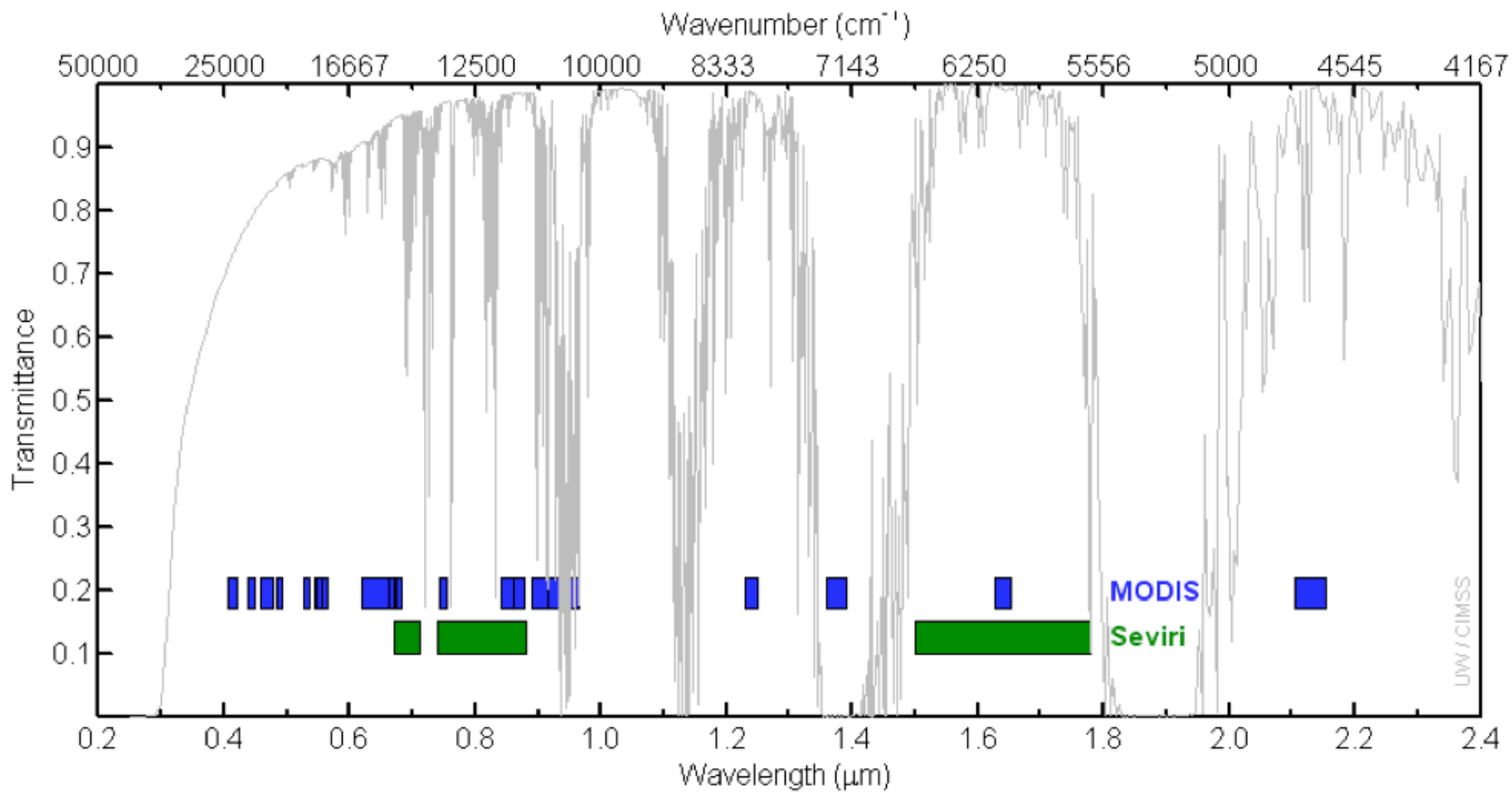
MODIS Reflected Solar Bands

Primary Use	Band	Bandwidth[1]	Spectral Radiance[2]	Required SNR[3]
Land/Cloud/Aerosols Boundaries	1	620 - 670	21.8	128
	2	841 - 876	24.7	201
Land/Cloud/Aerosols Properties	3	459 - 479	35.3	243
	4	545 - 565	29.0	228
	5	1230 - 1250	5.4	74
	6	1628 - 1652	7.3	275
	7	2105 - 2155	1.0	110
Ocean Color/ Phytoplankton/ Biogeochemistry	8	405 - 420	44.9	880
	9	438 - 448	41.9	838
	10	483 - 493	32.1	802
	11	526 - 536	27.9	754
	12	546 - 556	21.0	750
	13	662 - 672	9.5	910
	14	673 - 683	8.7	1087
	15	743 - 753	10.2	586
	16	862 - 877	6.2	516
Atmospheric Water Vapor	17	890 - 920	10.0	167
	18	931 - 941	3.6	57
	19	915 - 965	15.0	250

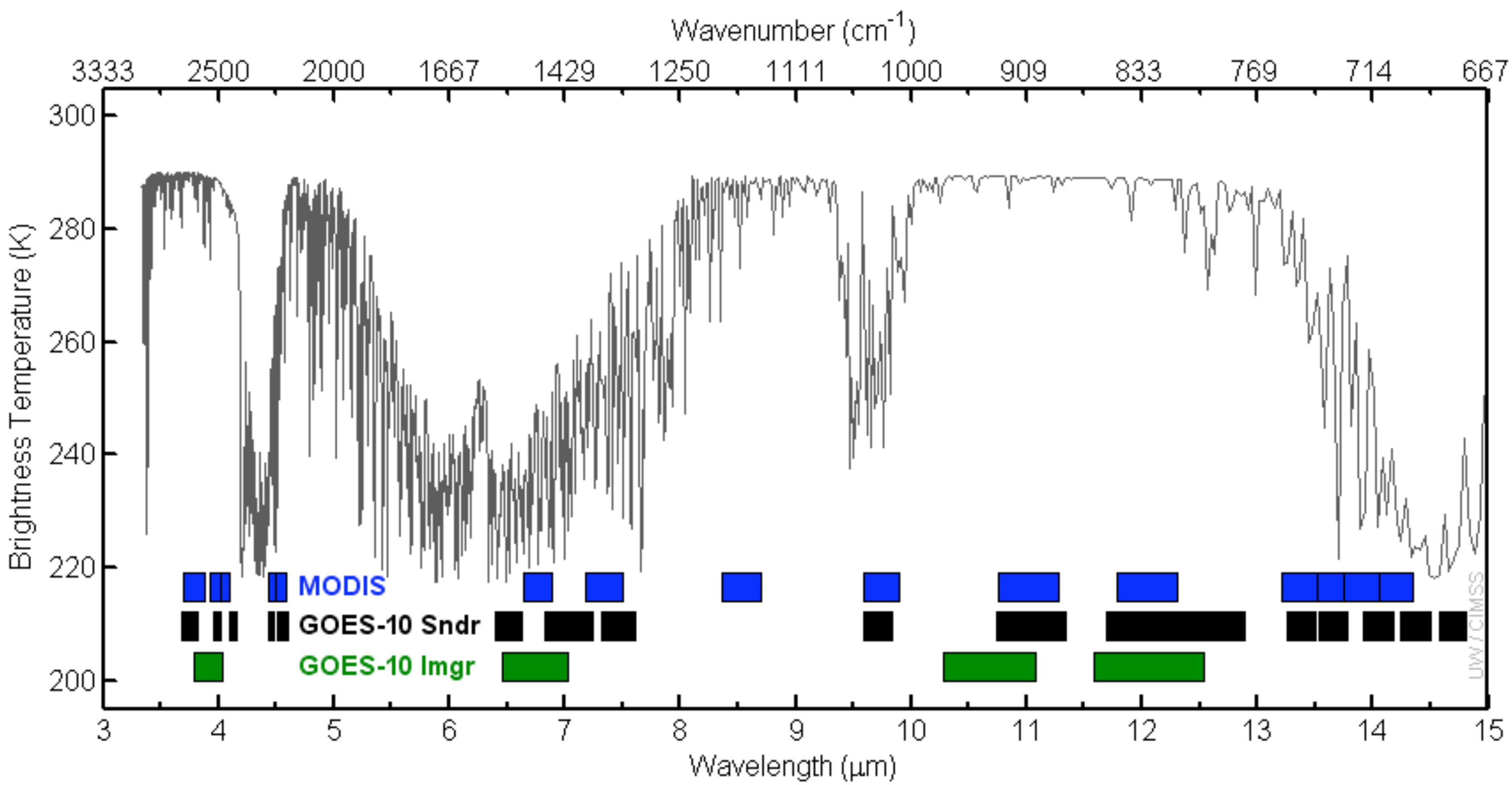
MODIS Thermal Emissive Bands

Primary Atmospheric Application	Band	Bandwidth[1]	$T_{typical}$ (K)	Radiance[2] at $T_{typical}$	NEΔT (K) Specification	NEΔT (K) Predicted
Surface Temperature	20	3.660-3.840	300	0.45	0.05	0.05
	22	3.929-3.989	300	0.67	0.07	0.05
	23	4.020-4.080	300	0.79	0.07	0.05
Temperature profile	24	4.433-4.498	250	0.17	0.25	0.15
	25	4.482-4.549	275	0.59	0.25	0.10
Moisture profile	27	6.535-6.895	240	1.16	0.25	0.05
	28	7.175-7.475	250	2.18	0.25	0.05
	29	8.400-8.700	300	9.58	0.05	0.05
Ozone	30	9.580-9.880	250	3.69	0.25	0.05
Surface Temperature	31	10.780-11.280	300	9.55	0.05	0.05
	32	11.770-12.270	300	8.94	0.05	0.05
Temperature profile	33	13.185-13.485	260	4.52	0.25	0.15
	34	13.485-13.785	250	3.76	0.25	0.20
	35	13.785-14.085	240	3.11	0.25	0.25
	36	14.085-14.385	220	2.08	0.35	0.35

MODIS Visible and Near-infrared Bands



MODIS Infrared Spectral Bands



Scanner Characteristics

MODIS Orbit and Scan Geometry

Terra: 10:30 am local descending

Aqua: 1:30 pm local ascending

Orbit period: 99 minutes

Repeat cycle: 16 days (same as Landsat)

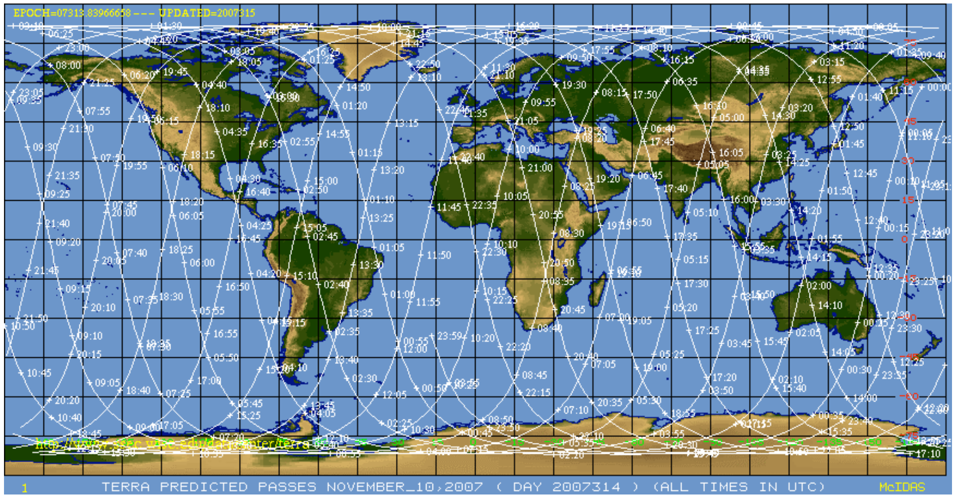
Scan mirror: Double sided, 20.3 revs/minute

Scan rate: 1.477 scans/sec

Scan angle: +/- 55 degrees

Swath width: 2330 km across track, 10 km along track

Example of Daily MODIS Orbits



Terra, MOD09, day 2007314, Collection 005

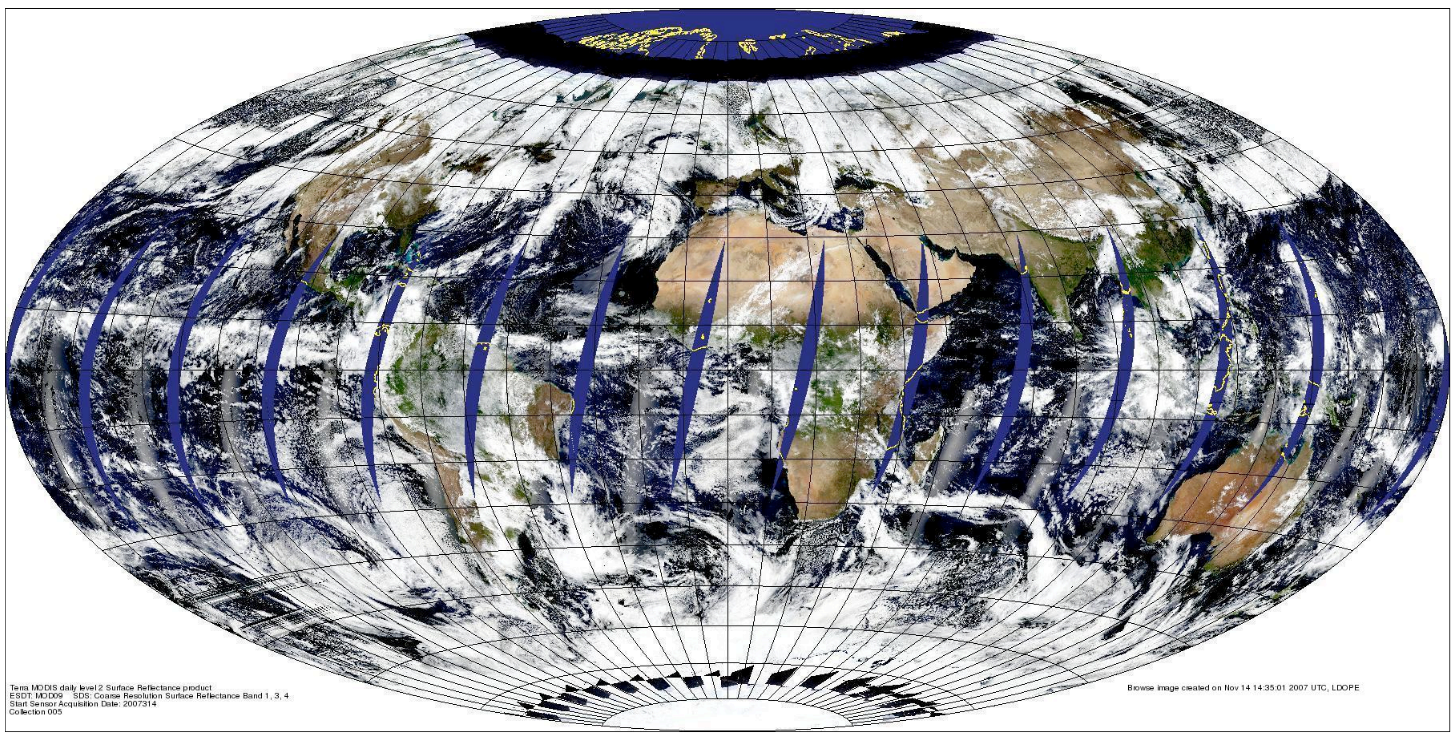
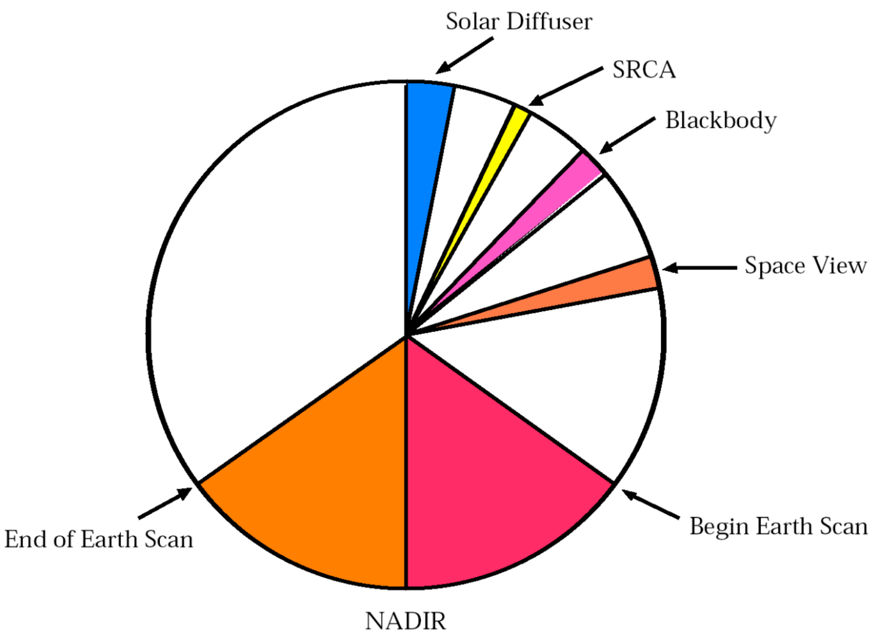
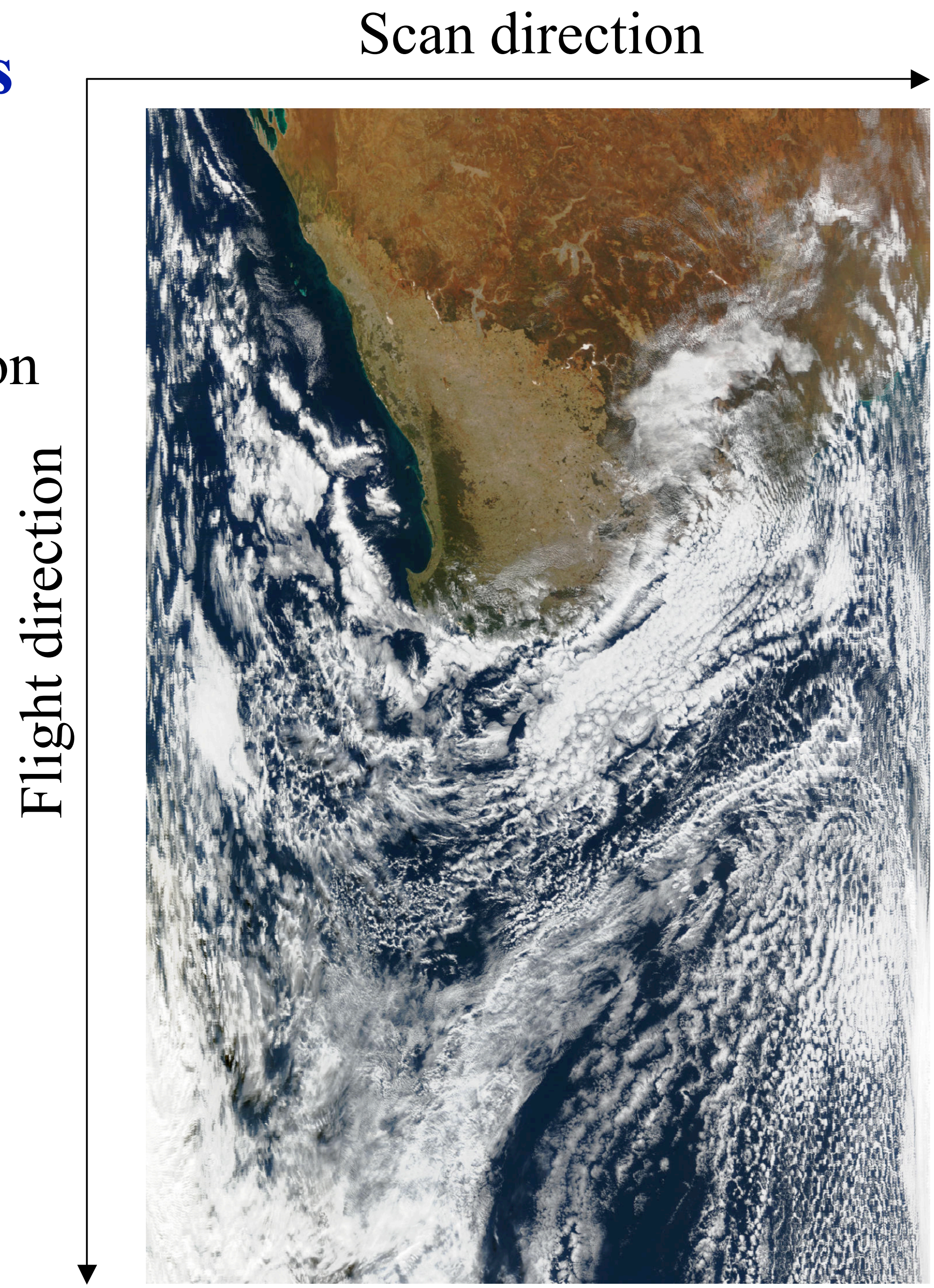


Image Acquisition Details

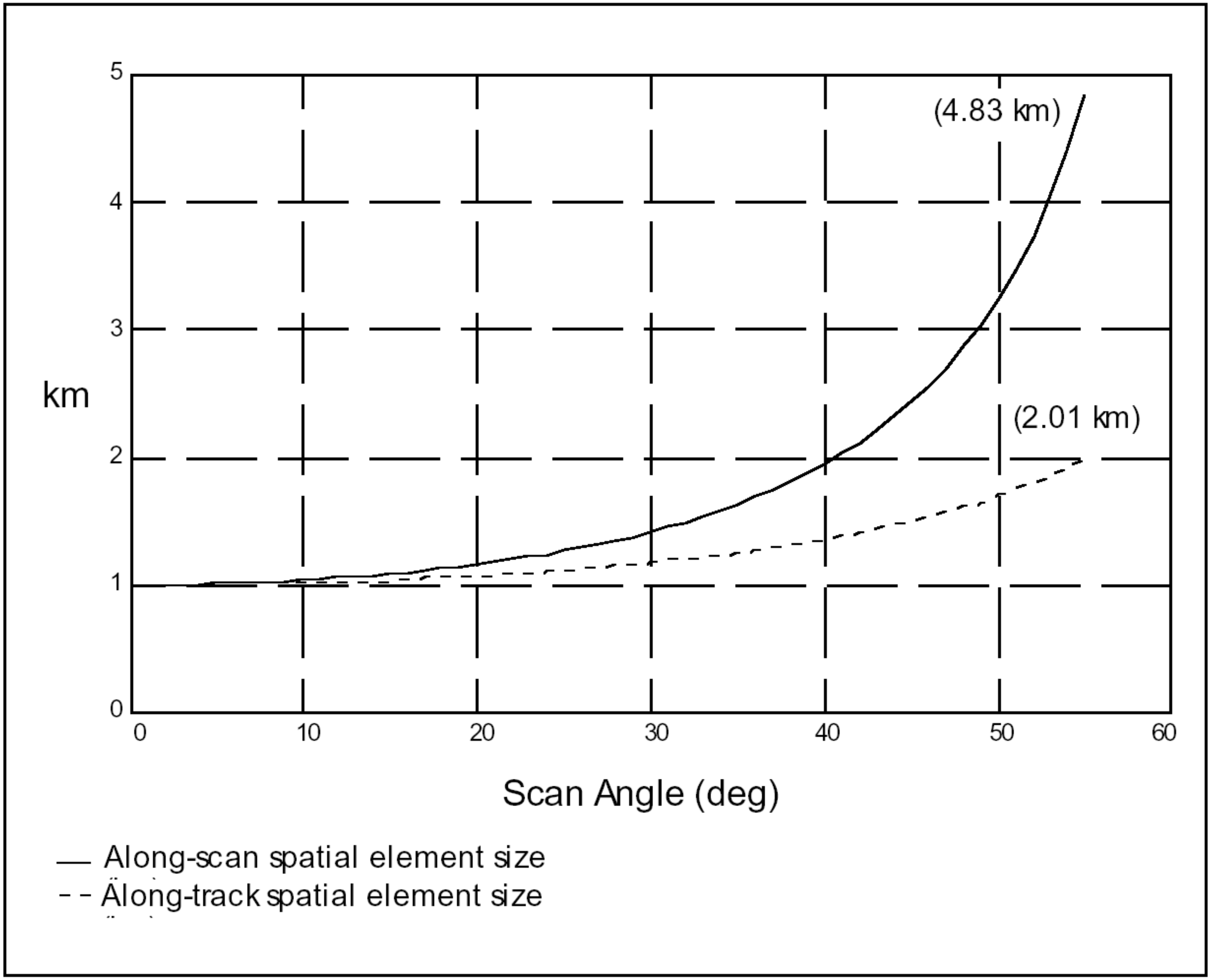
Scan sequence:

1. Solar diffuser
2. Spectroradiometric Calibration Assembly
3. Blackbody
4. Space View
5. Earth scan



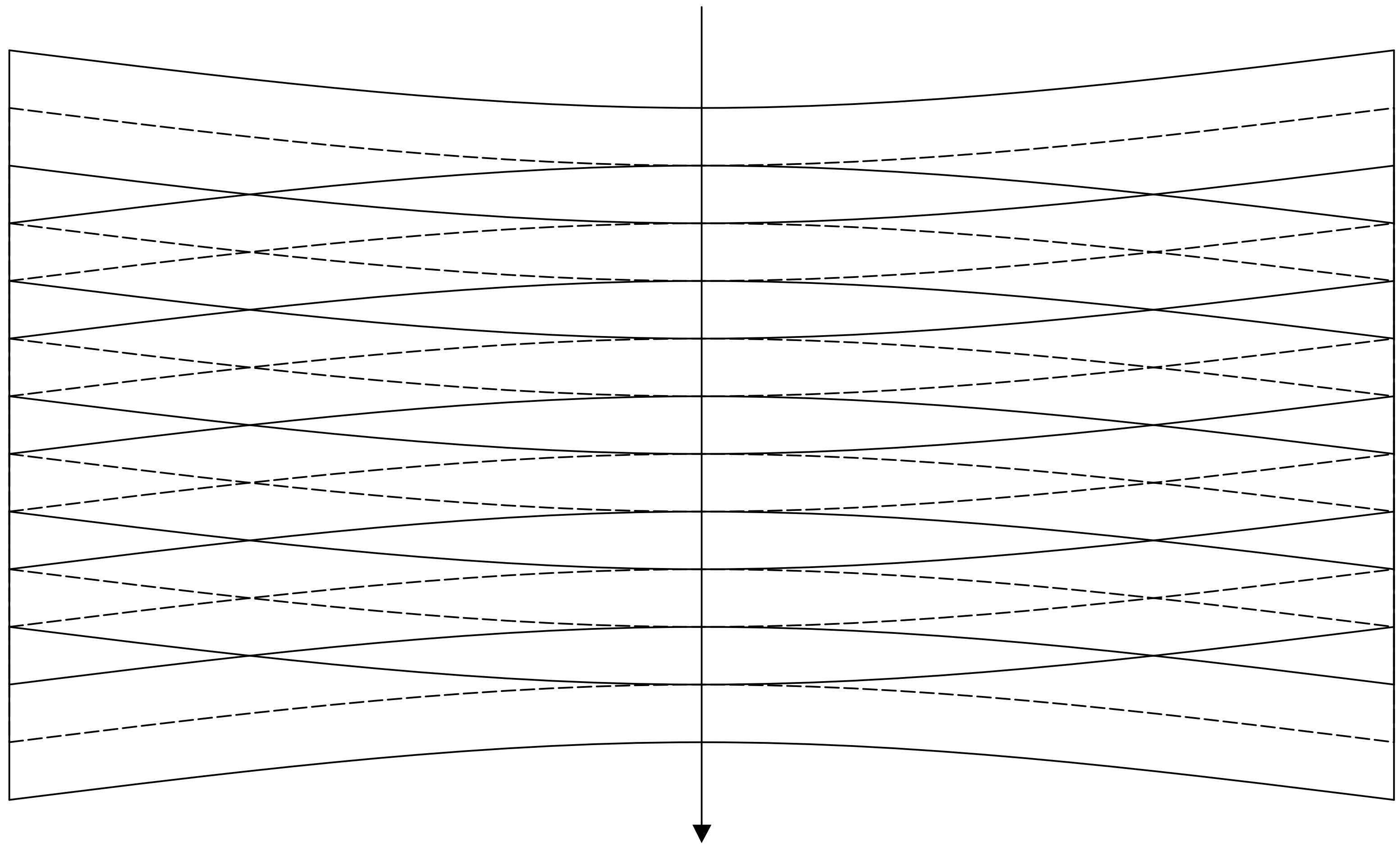


Growth of MODIS 1 km pixel with scan angle

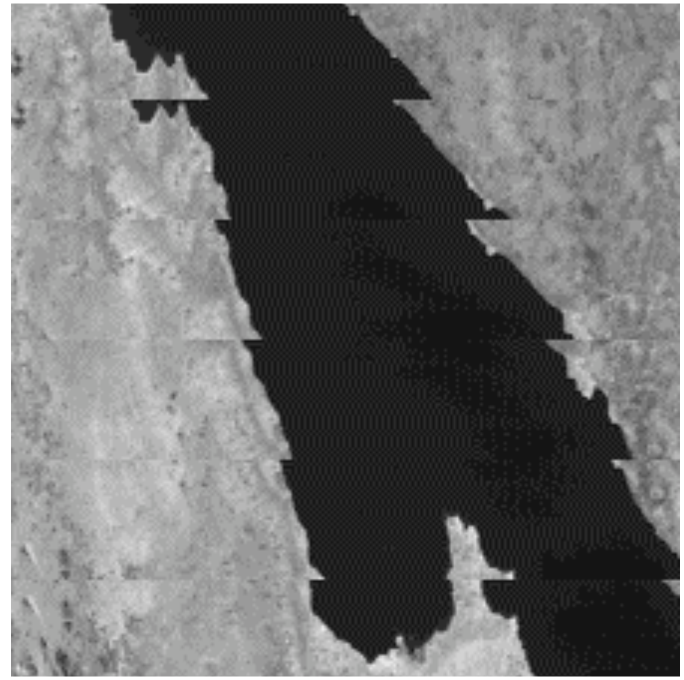


MODIS Bowtie Artifacts

Consecutive “bowtie” shaped scans are contiguous at nadir, and overlap as scan angle increases…



MODIS bowtie artifacts at edge of swath



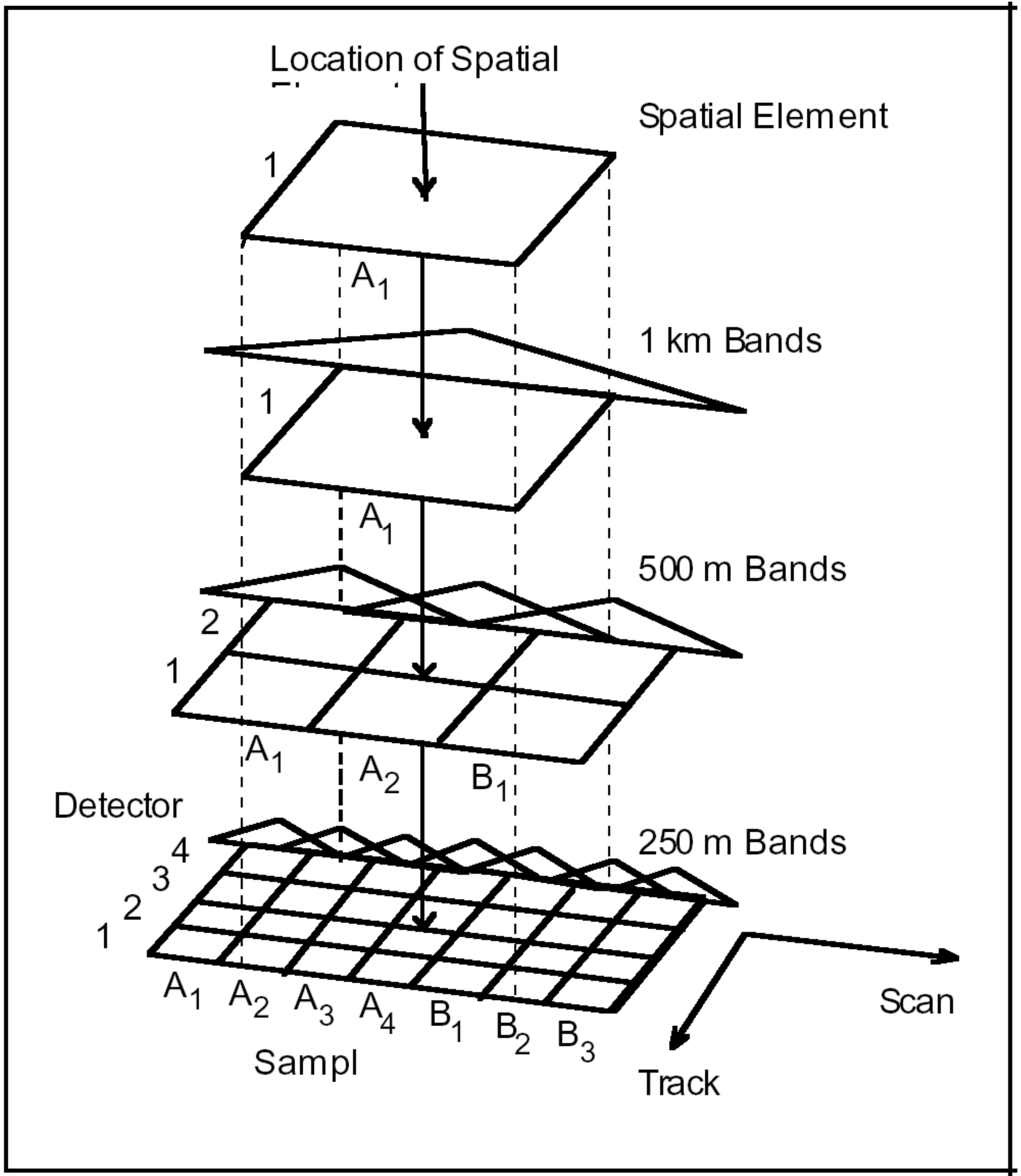
Band 2 (0.87 micron)

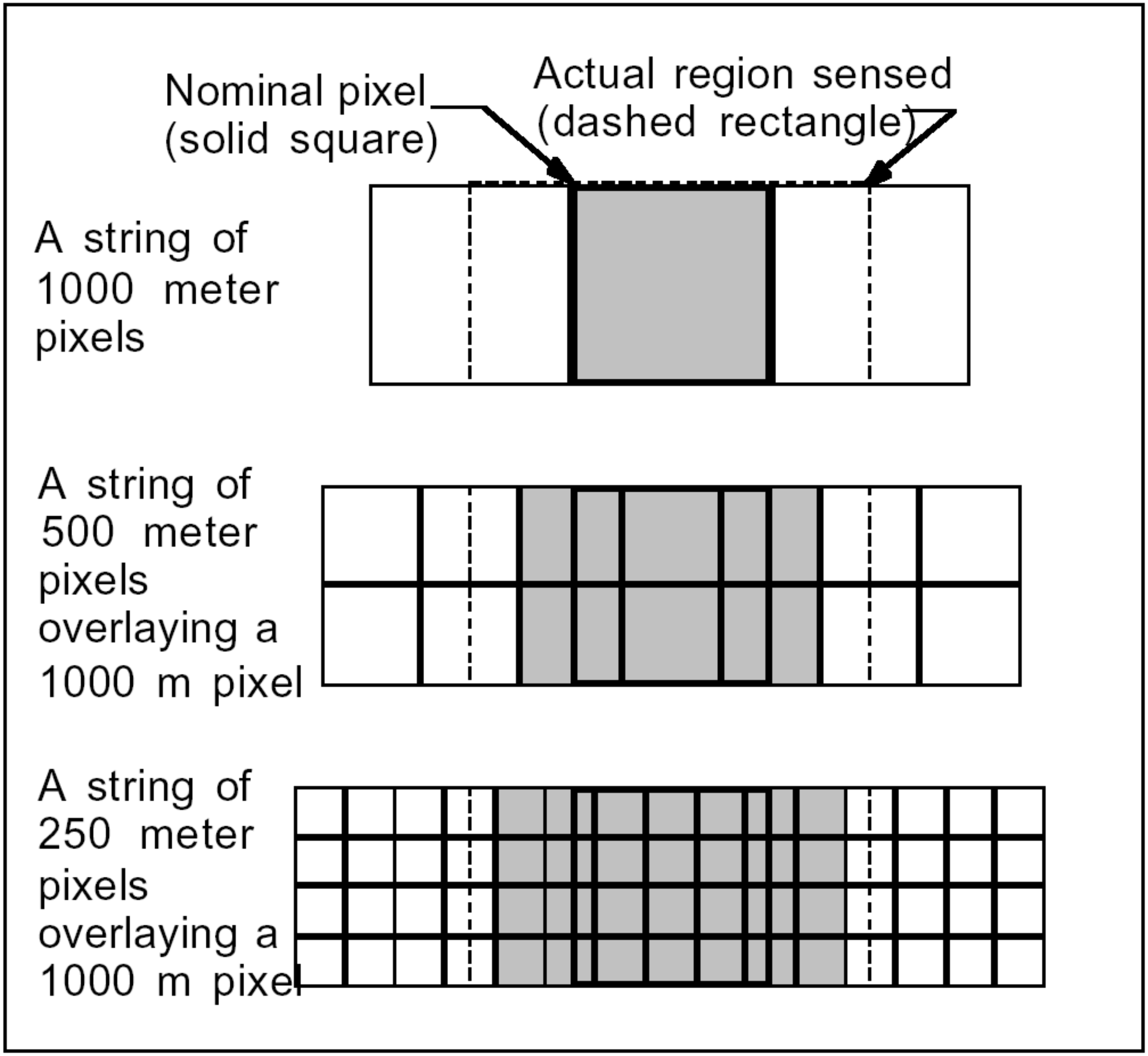
250 meter resolution

Bowtie Artifacts

1. Are not a ‘problem’: they are a consequence of the sensor design
2. Can be removed for visualization purposes by reprojecting the image onto a map
3. Do not affect science algorithms that run on a pixel-by-pixel basis or within one earth scan
4. Will be present on next generation of operational polar orbiting imagers (VIIRS on NPP/NPOESS)

Inter-band Registration



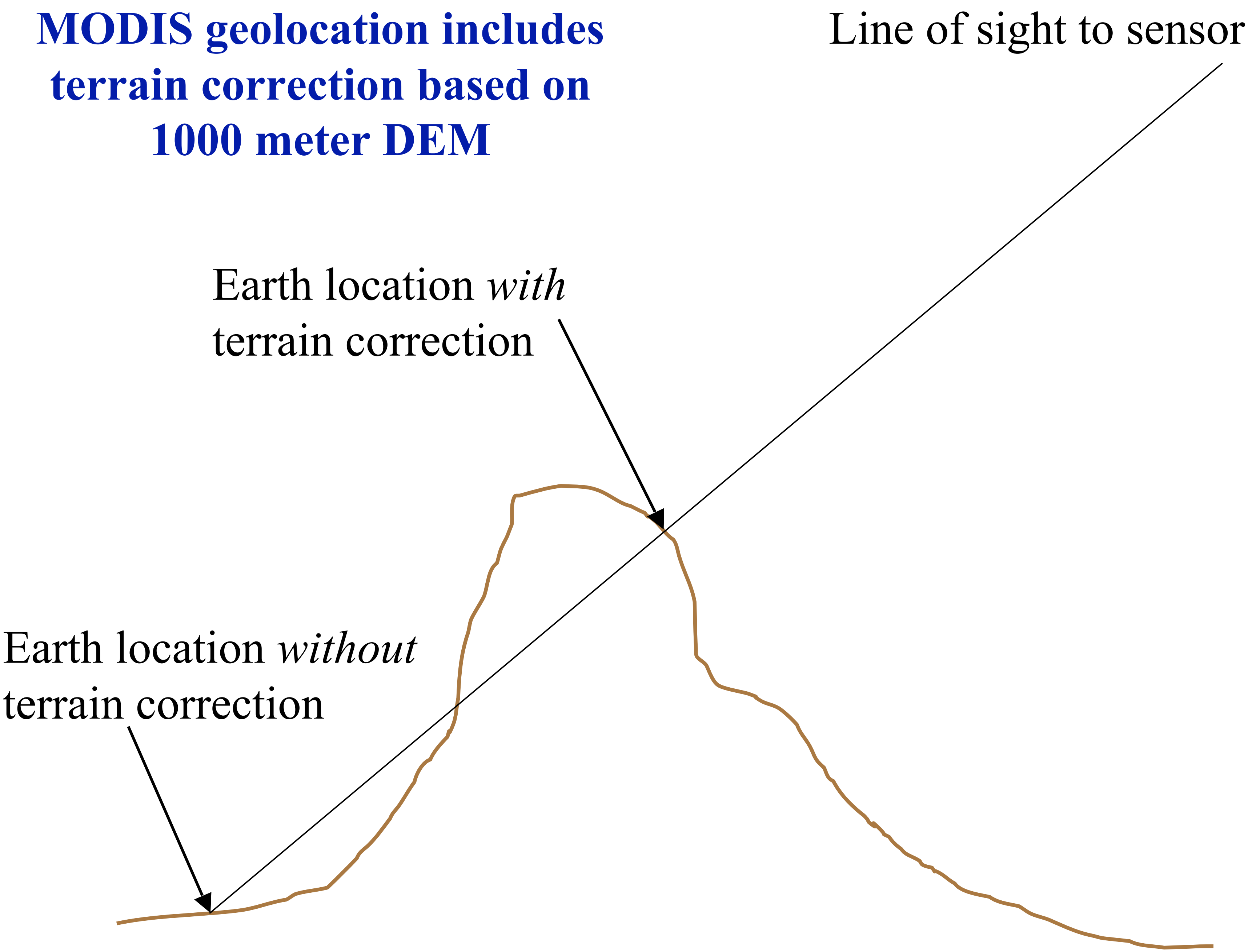

Nominal pixel
(solid square)
Actual region sensed
(dashed rectangle)
A string of
1000 meter
pixels
A string of
500 meter
pixels
overlaying a
1000 m pixel
A string of
250 meter
pixels
overlaying a
1000 m pixel

MODIS Geolocation

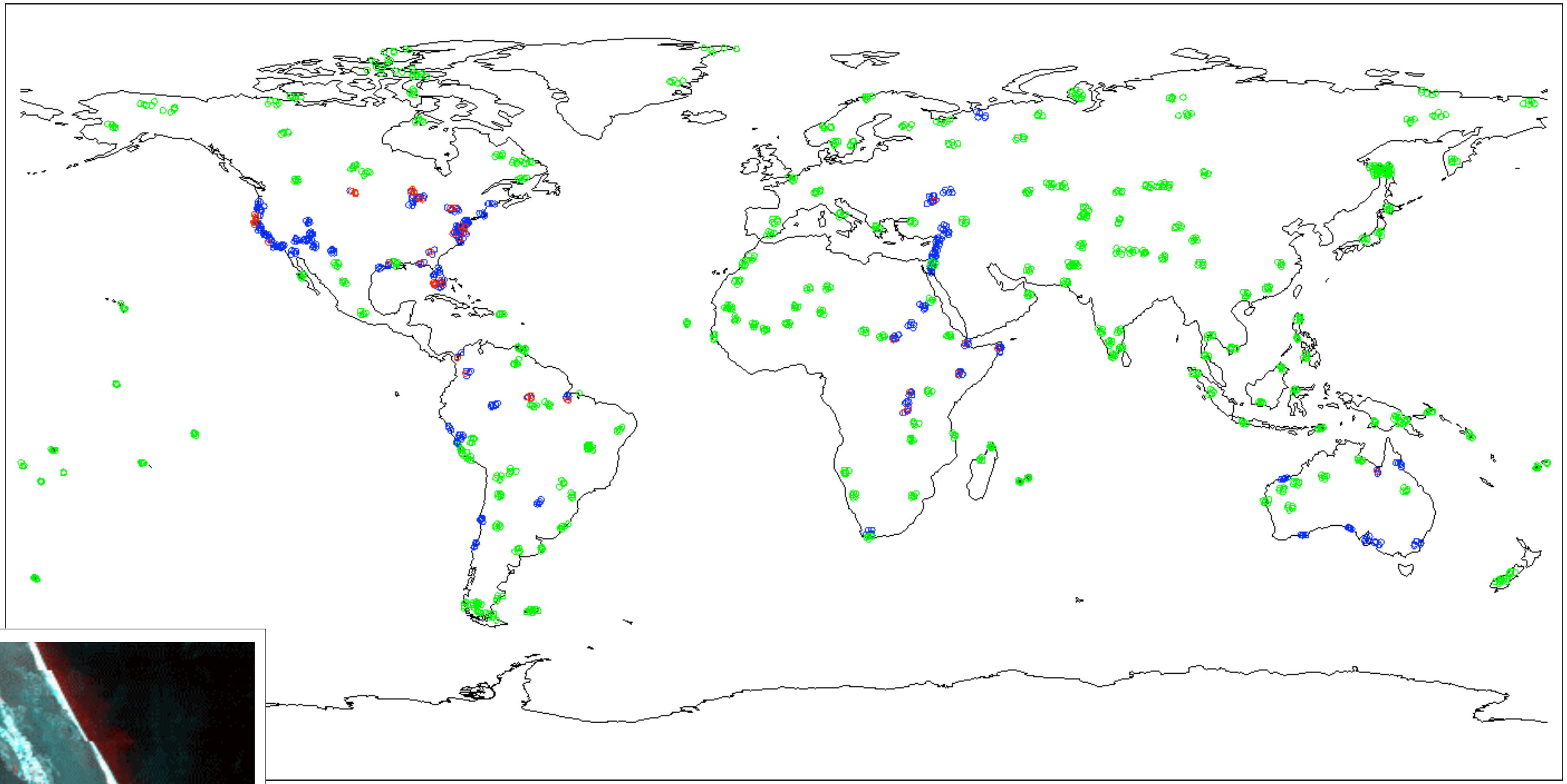
Earth locations computed for every 1000 meter pixel (WGS84):

- Geodetic latitude (degrees, -90S to +90N)
- Geodetic longitude (degrees, -180W to +180E)
- Sensor zenith and azimuth (degrees, pixel to sensor)
- Solar zenith and azimuth (degrees, pixel to sun)
- Terrain height above geoid (meters)
- Land/Sea mask
  - 0: Shallow Ocean
  - 1: Land
  - 2: Ocean Coastlines and Lake Shorelines
  - 3: Shallow Inland Water
  - 4: Ephemeral (intermittent) Water
  - 5: Deep Inland Water
  - 6: Moderate or Continental Ocean
  - 7: Deep Ocean

MODIS geolocation includes terrain correction based on 1000 meter DEM



Ground Control Points (GCPs)



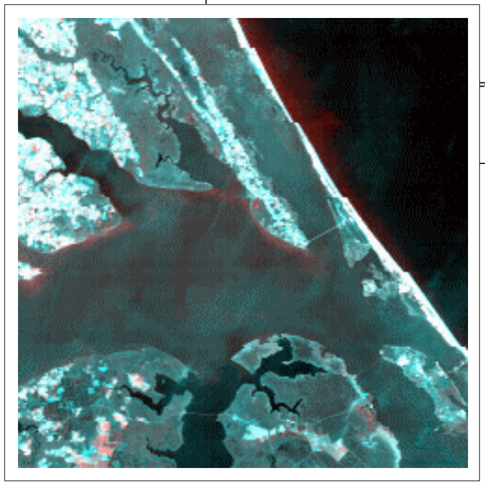


Image chips from Landsat TM/ETM scenes

366 old chips (blue)
51 chips removed (red)
990 new chips (green)

Geolocation Collection 4 (C4)

Terra

- Excellent results – Root Mean Square (RMS) error in nadir equivalent units is better than accuracy goal
- Small remaining northern/ southern hemisphere difference
- Large errors occur after orbit maneuvers (about 6 per year)
  - accuracy in following orbit suspect

Aqua

- Good results – RMS error is better than goal in track direction but slightly over goal in scan direction (but much better than specification – 150 m)
- Early post-launch coordinate system issue resolved before C4
- Definitive ephemeris is used for best results – causes up to 24 hr processing delay

	Terra	**Aqua**
Along-track RMS error (m)	38	43
Along-scan RMS error (m)	43	56
Years	4.0	1.6
Ground Control Point Match-ups/day	83	74

Realtime Geolocation

1. For realtime processing, ephemeris and attitude downlinked from spacecraft must be used.
2. Post-processed ephemeris and attitude from NASA GSFC Flight Dynamics may be used for non realtime processing (delay of at least 24 hours after data acquisition)
3. What is the impact on geolocation accuracy of realtime processing?

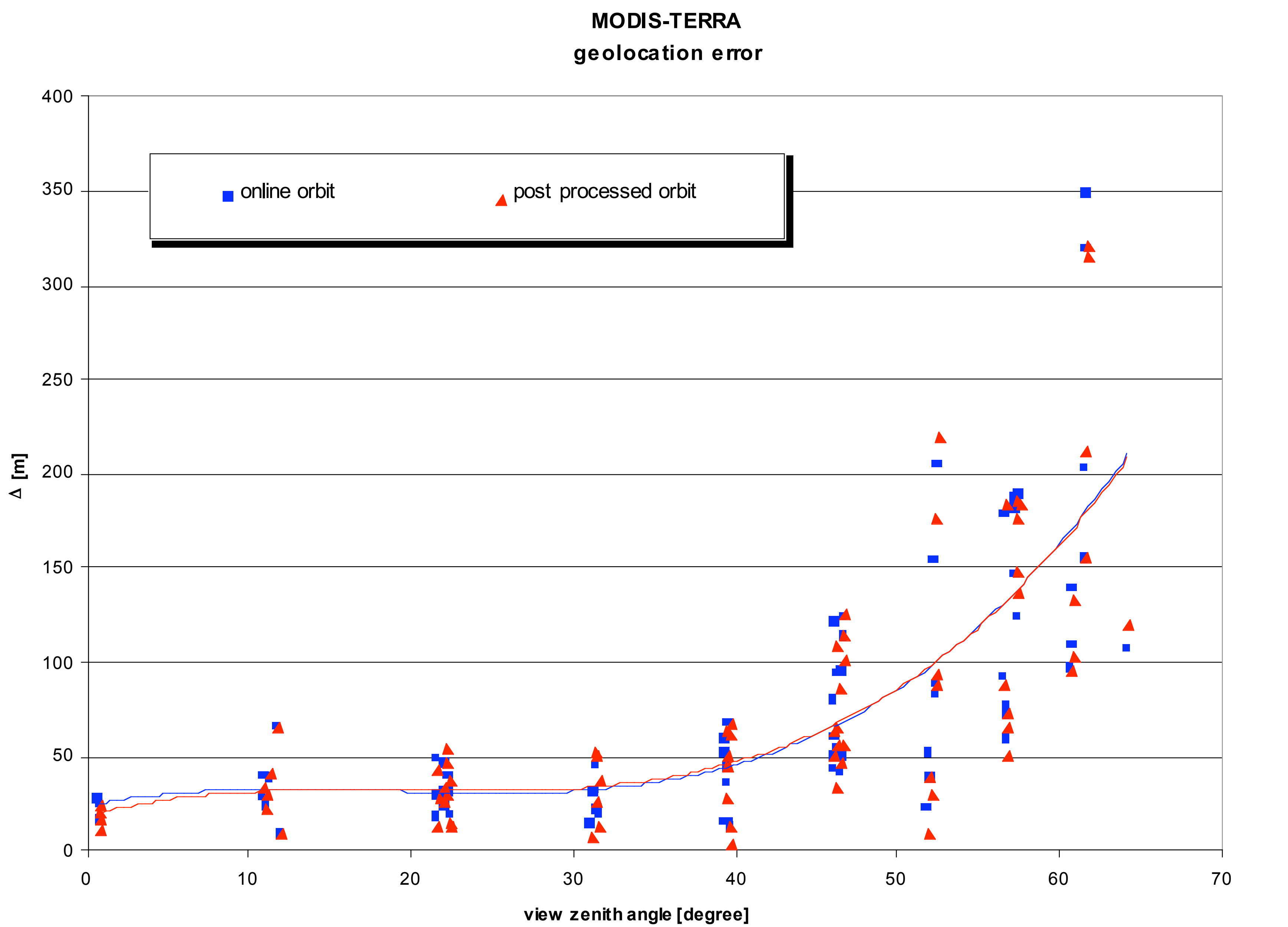
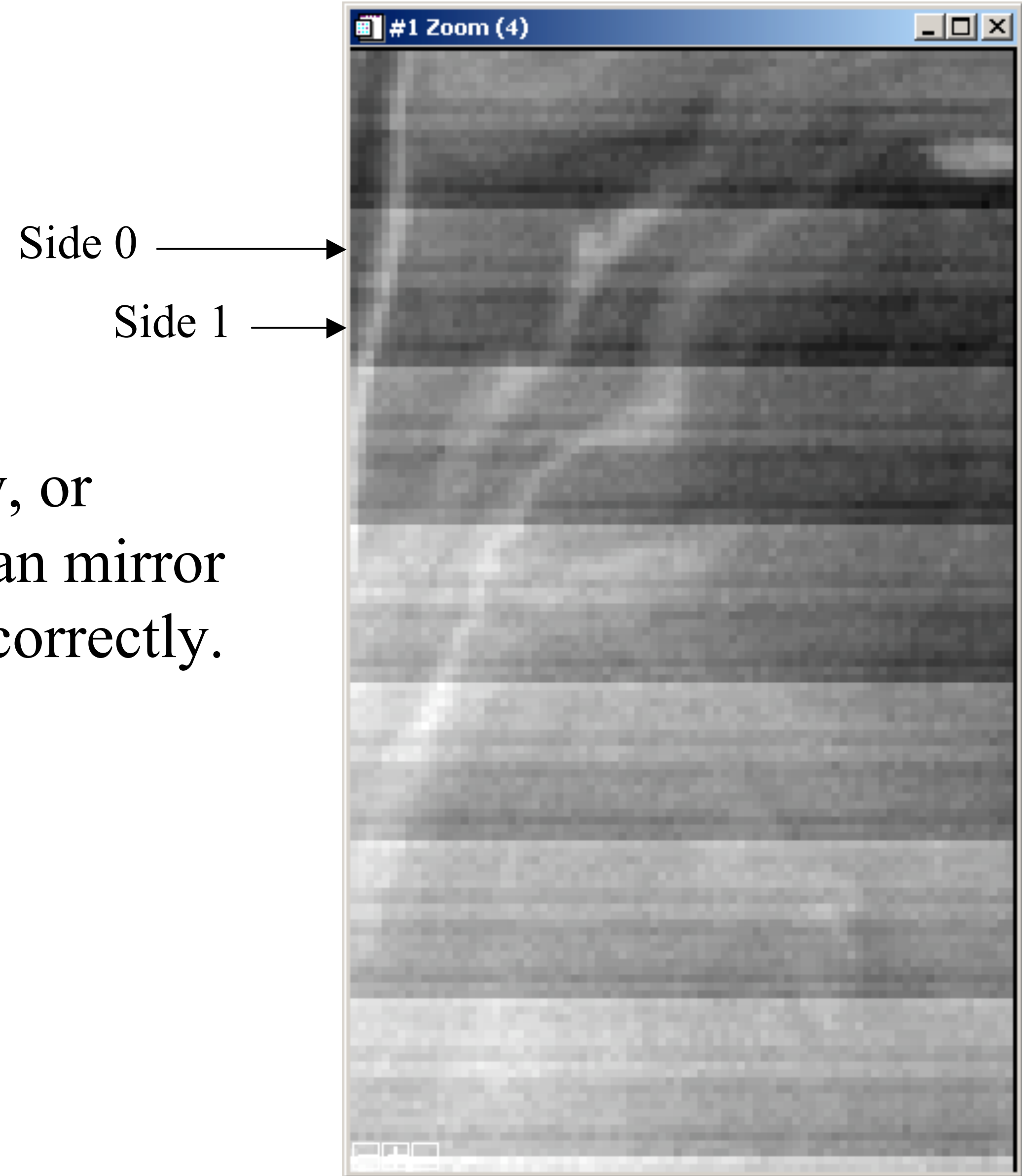


Figure courtesy of Stefan Maier, DOLA

Image Artifacts
(other than Bowtie)

Mirror Side Striping (Band 8, 0.41 μm)



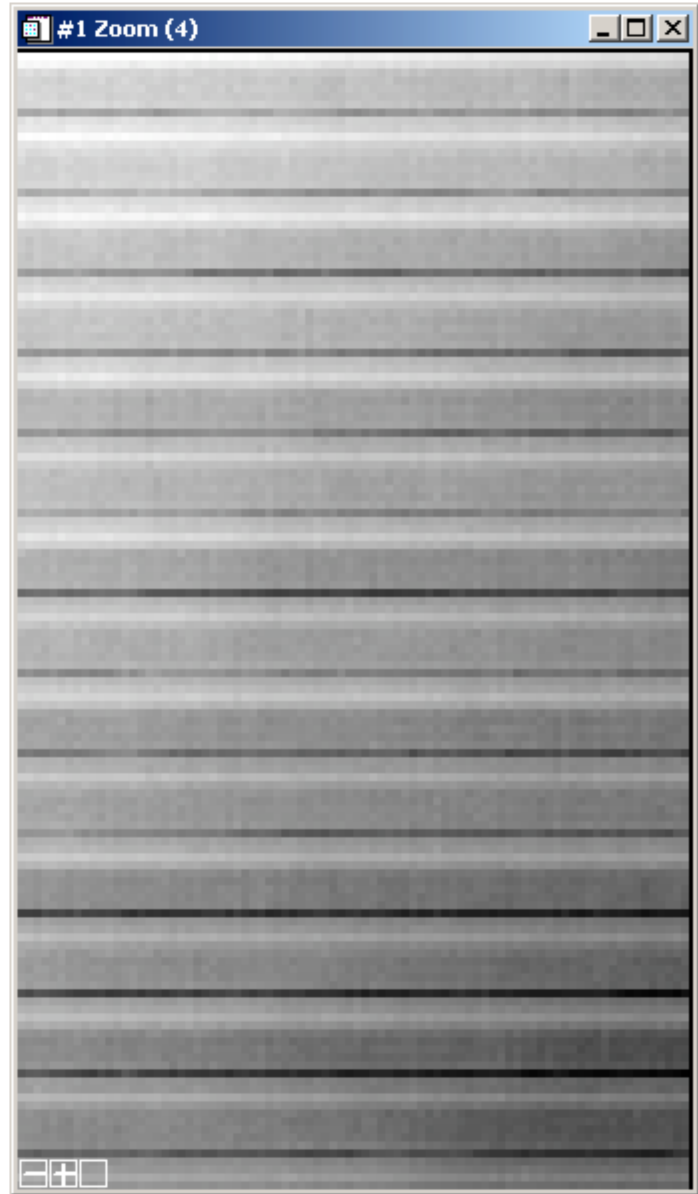
Reflectance, emissivity, or polarization of each scan mirror side not characterized correctly.

Can be corrected.

Detector Difference Striping (Band 27, 6.7 μm)

Responsivity of each detector not characterized correctly.

Can be corrected.



Noisy Detectors (Band 34, 13.6 μm)

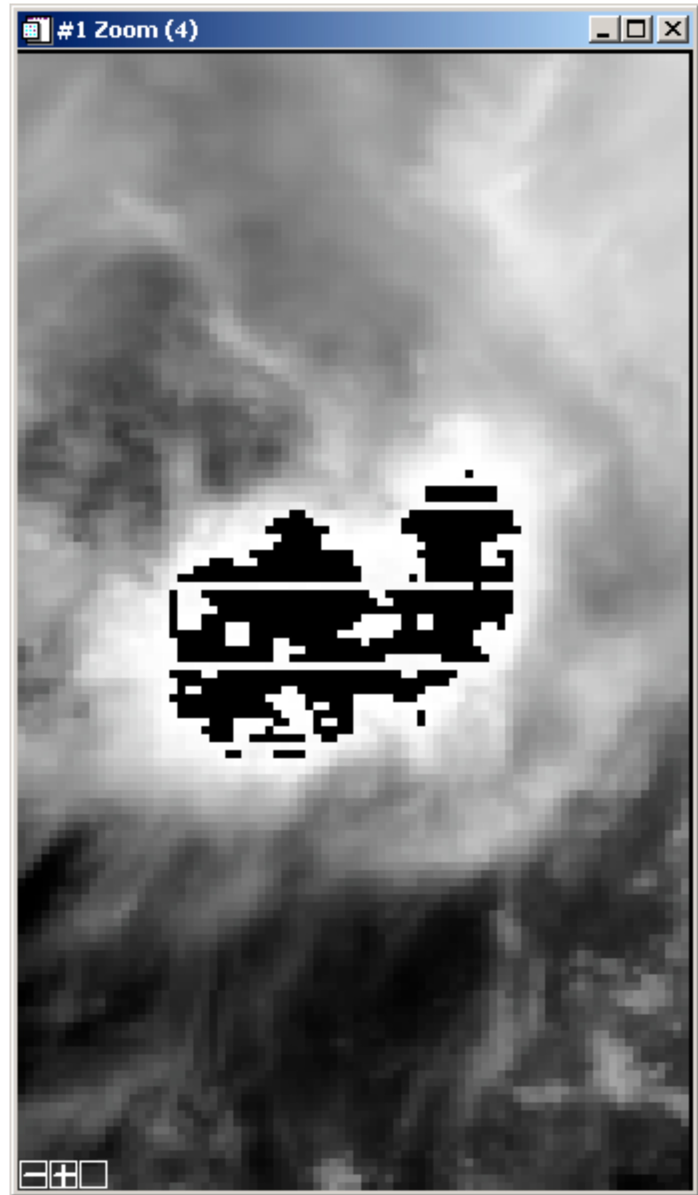
Detectors are noisy on a per frame basis and unpredictable from scan to scan.

Difficult to correct.

Saturation (Band 2, 0.87 μm)

Signal from earth scene is too large for 12 bit digitization with current gain settings.

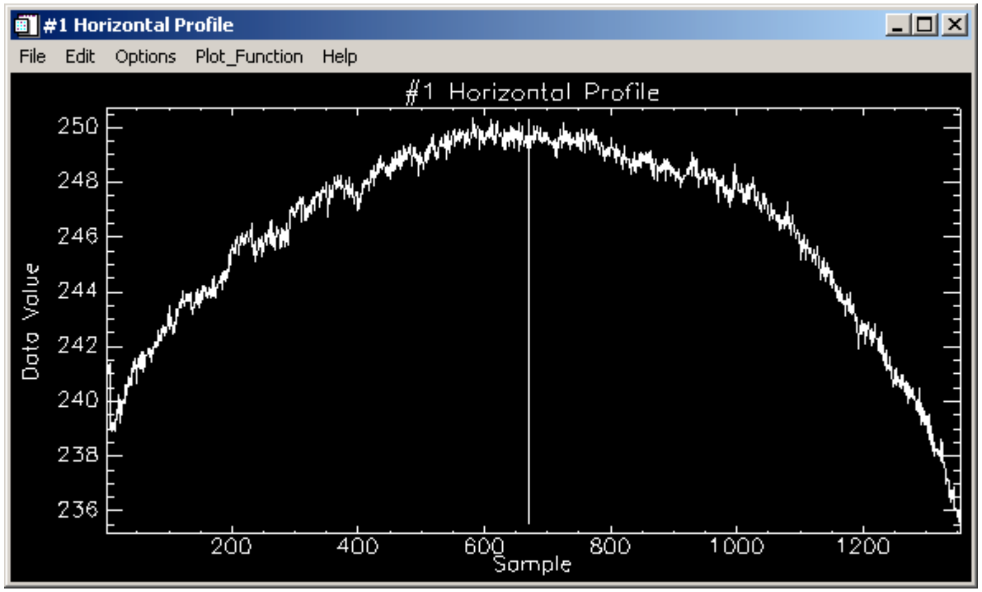
Workaround available.



Response vs. Scan Angle (Band 35, 13.9 µm)

Scan mirror reflectance, emissivity, or polarization not characterized correctly as a function of scan angle.

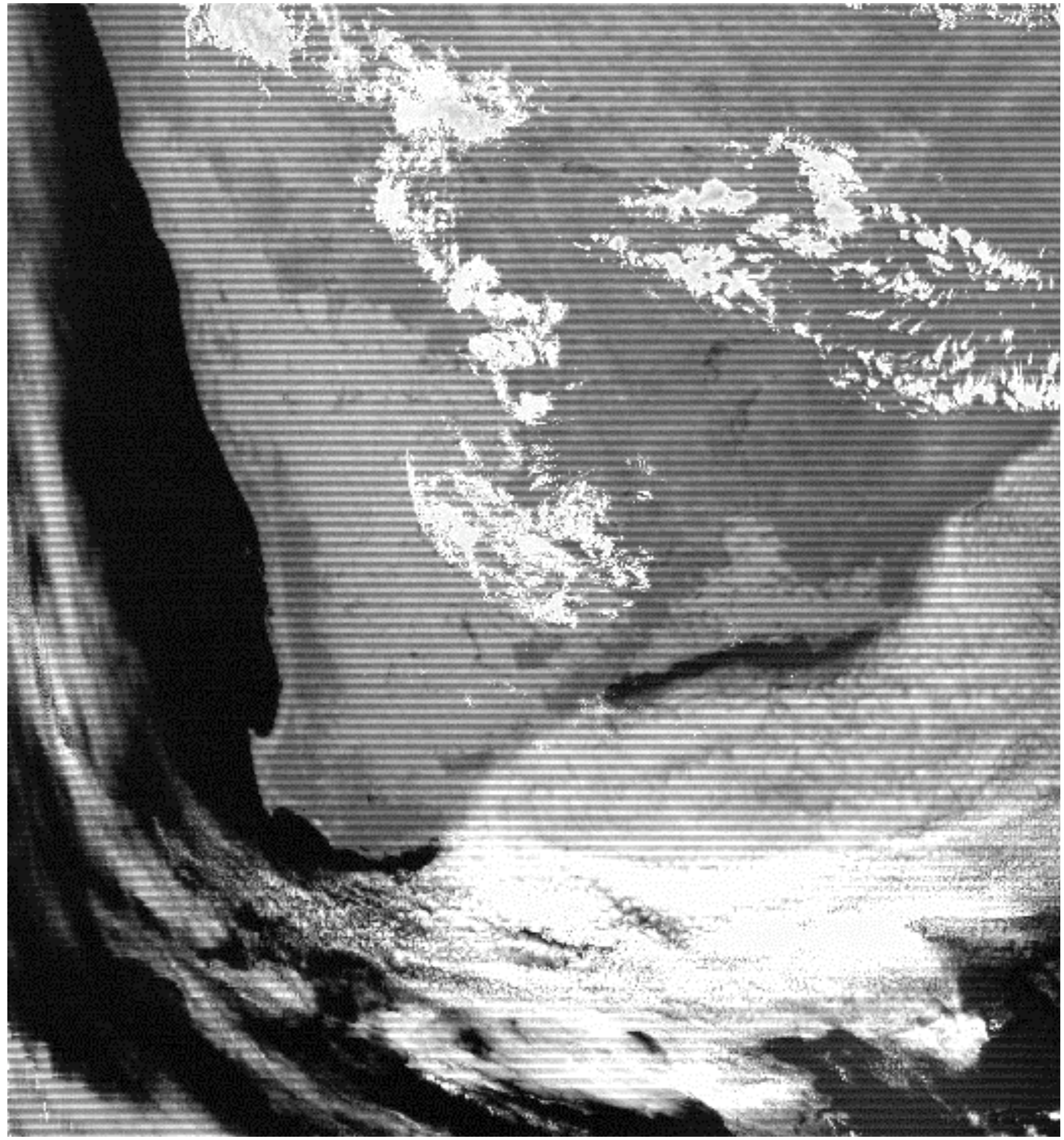
Deep Space Maneuver data on Terra incorporated for collection 5 processing.



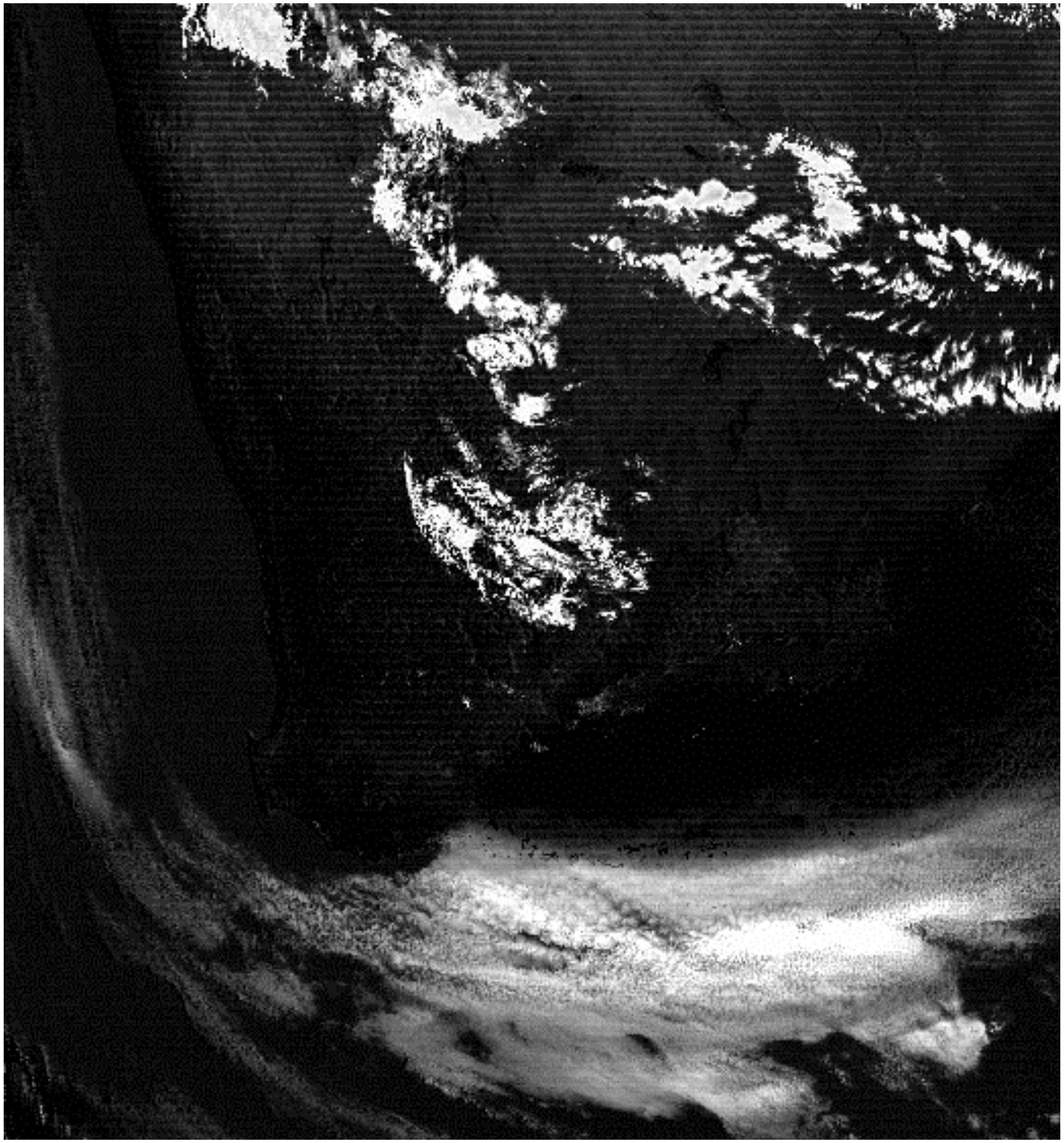
Band 26 Optical Leak

Photons intended for Band 5 detectors (1.24 μ m) leak into Band 26 (1.38 μm) detectors.

Correction is operational for collection 4 processing.



Band 26 Corrected

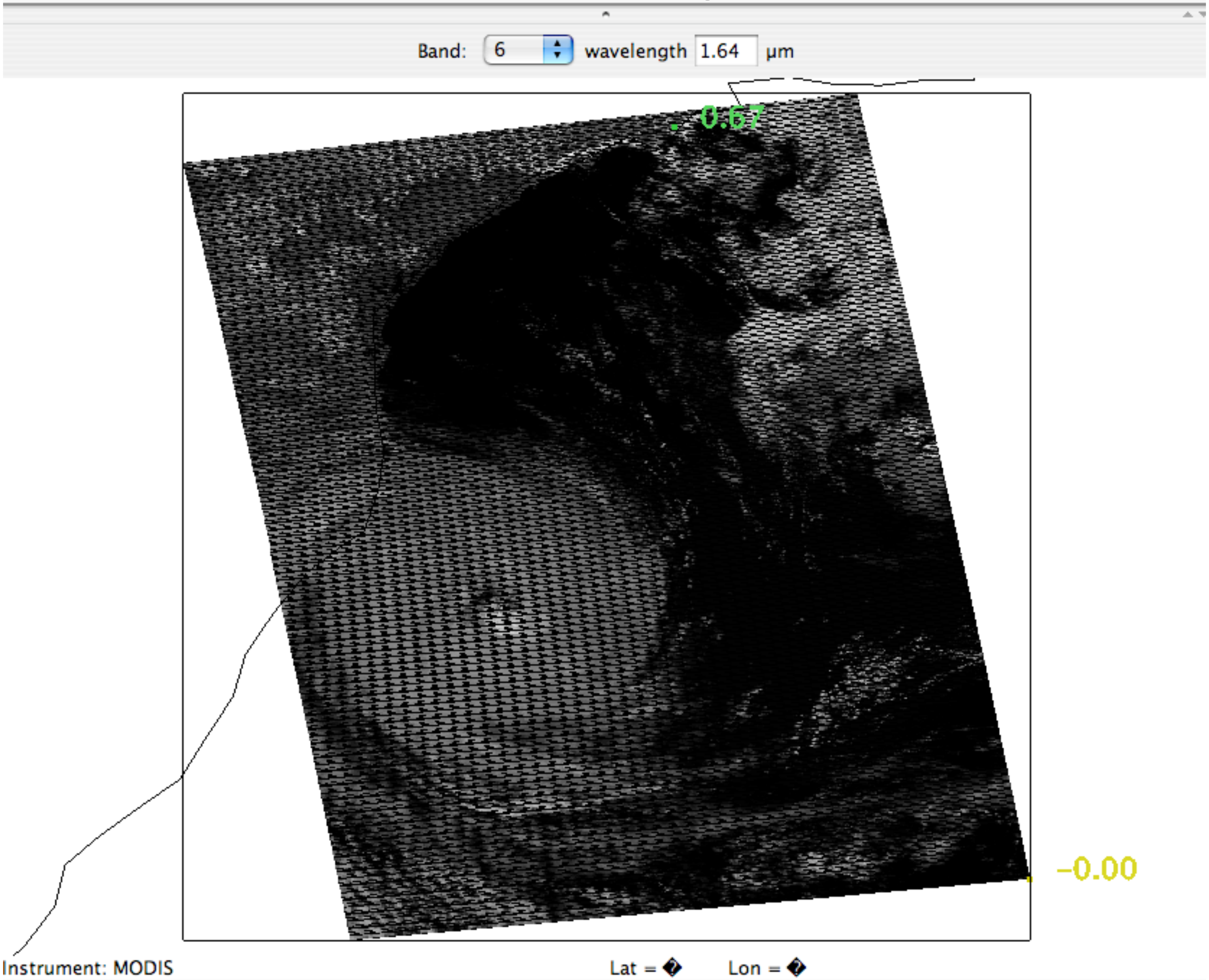


Detector dependent correction factors remove the land surface contribution and reduce striping.

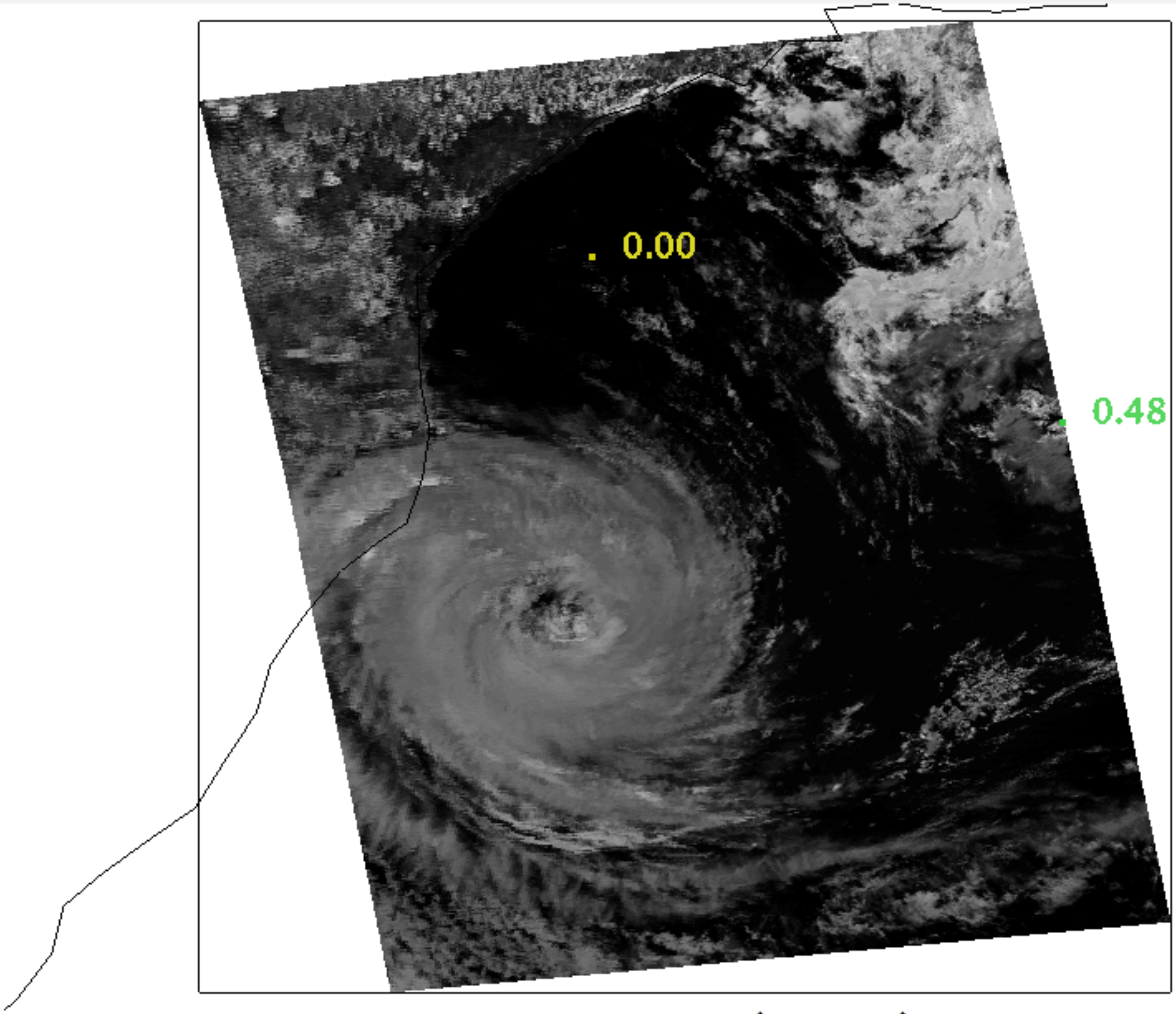
FIXED!

Band 6 Aqua numerous dead detectors

Solution - use band 7 as a surrogate. 1.6 versus 2.1 microns



Band: 7 wavelength 2.13 μm



nstrument: MODIS Lat = � Lon = �

Destriping

MODIS Destriping

Striping is a consequence of the calibration algorithm, where each detector is calibrated independently. If the instrument were characterized perfectly, there would be no striping.

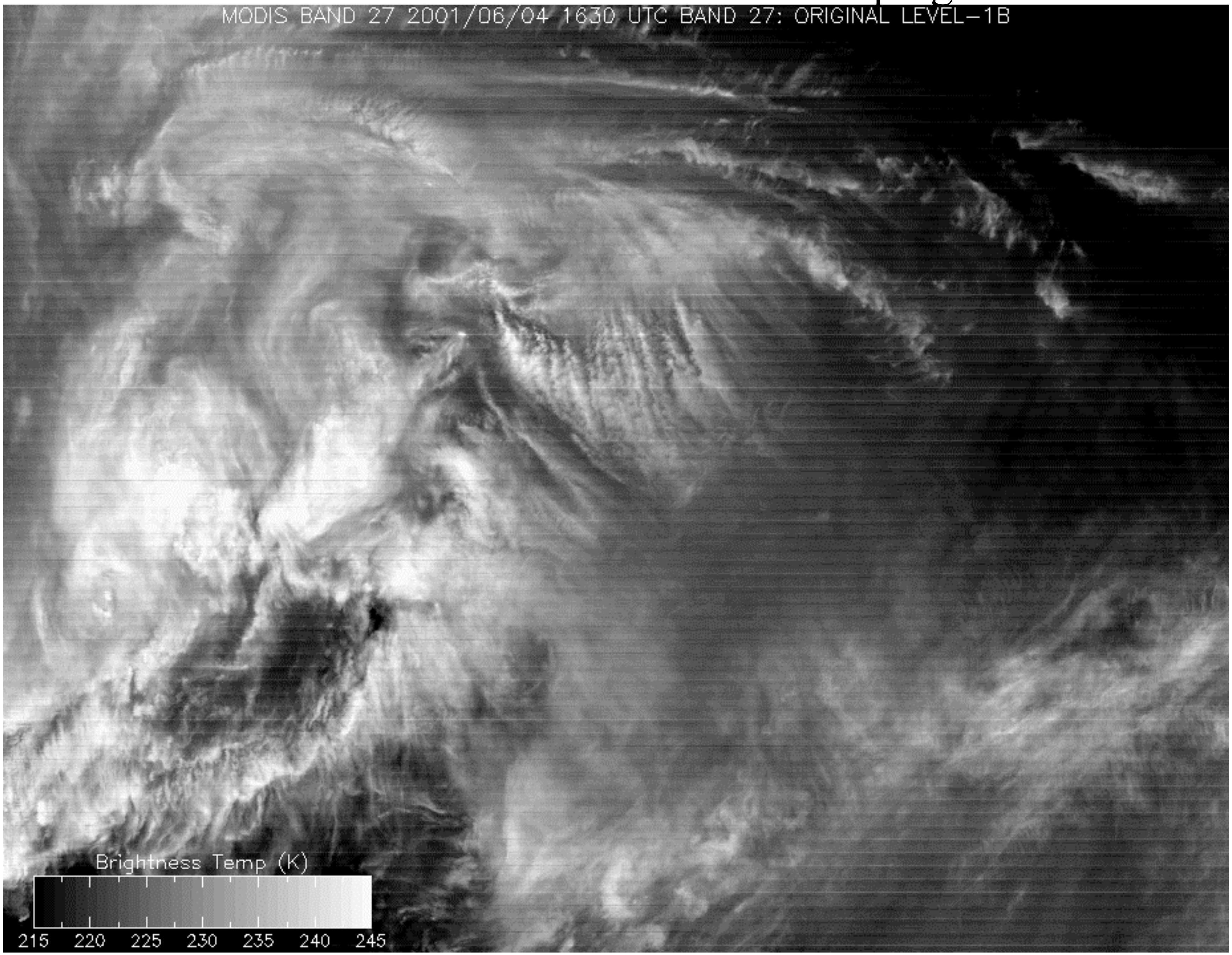
However, it is not possible to characterize the instrument perfectly because of time, cost, and schedule constraints.

As a result, striping artifacts are introduced by:

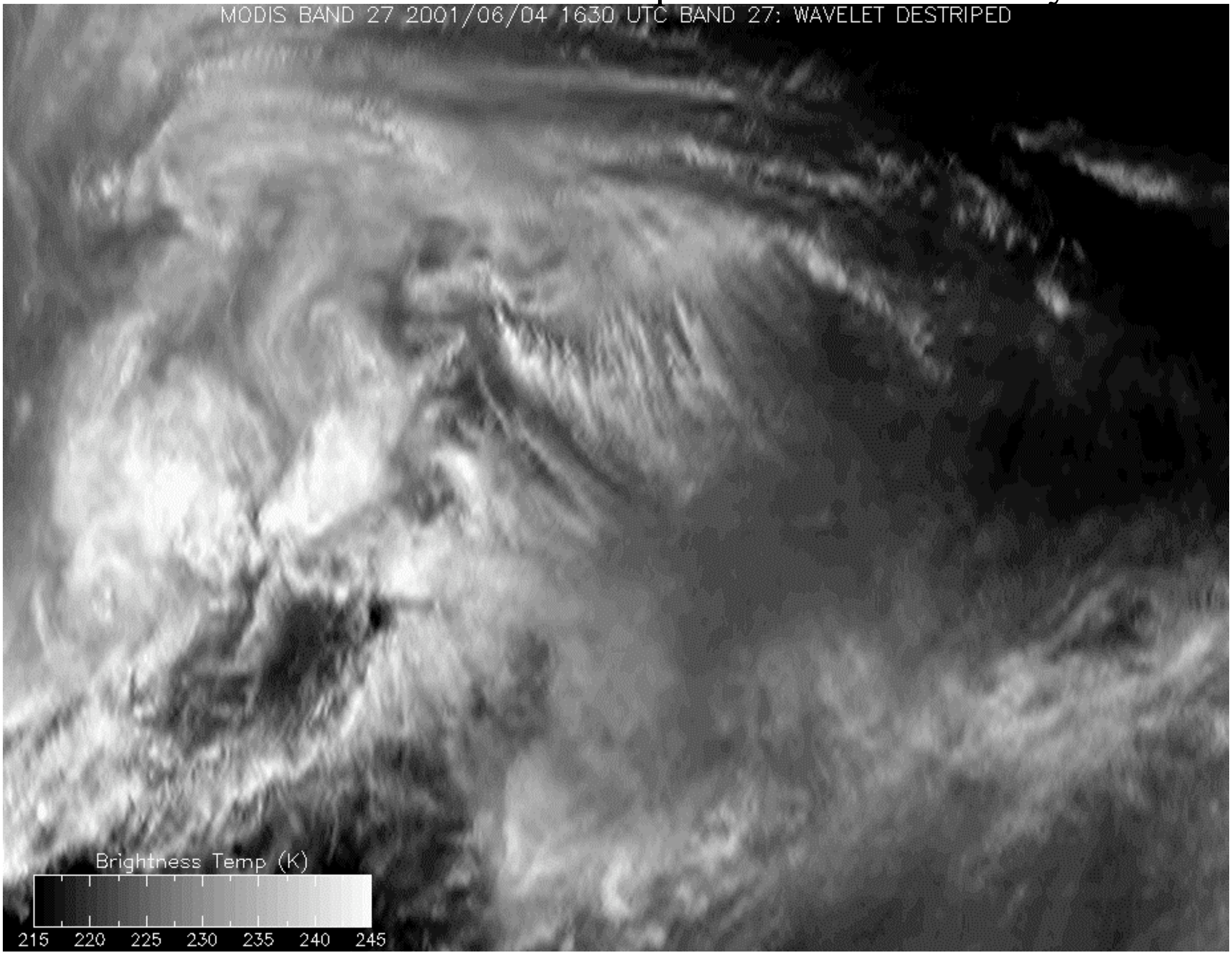
- Two-side scan mirror is not characterized perfectly
- Detectors behavior can change in orbit (bias, spectral response)
- Detectors may be noisy

The challenge is to design a destriping algorithm which is effective, fast, and insensitive to instrument changes.

Terra MODIS Band 27 With Striping



Terra MODIS Band 27 Destriped via Wavelet Analysis



Algorithm Details

Weinreb et al., 1989: "Destriping GOES Images by Matching Empirical Distribution Functions". Remote Sens. Environ., 29, 185-195.

• Accounts for both detector-to-detector and mirror side striping.

• MODIS is treated as a 20 detector instrument in the emissive bands (10 detectors on each mirror side).

• The empirical distribution function (EDF) is computed for each detector (cumulative histogram of relative frequency).

• The EDF for each detector is adjusted to match the EDF of a reference in-family detector.

• Algorithm operates on L1B scaled integers (0-32767).

Destriping Algorithm Implementation

- IDL, FORTRAN-90, and C code for Terra/Aqua L1B 1KM files in DAAC or IMAPP format.
- Requires about 60 seconds to run for each granule.
- Correction LUT is created for each individual granule.
- Uncorrected scaled integers are replaced with corrected scaled integers (could store the correction LUT instead).
- Bands 20, 22-25, 27-30, 33-36 are destriped.
- Impact on bands 31 and 32 is equivocal.
- For Terra MODIS, noisy detectors in some bands are replaced with neighbors (could use interpolation instead):

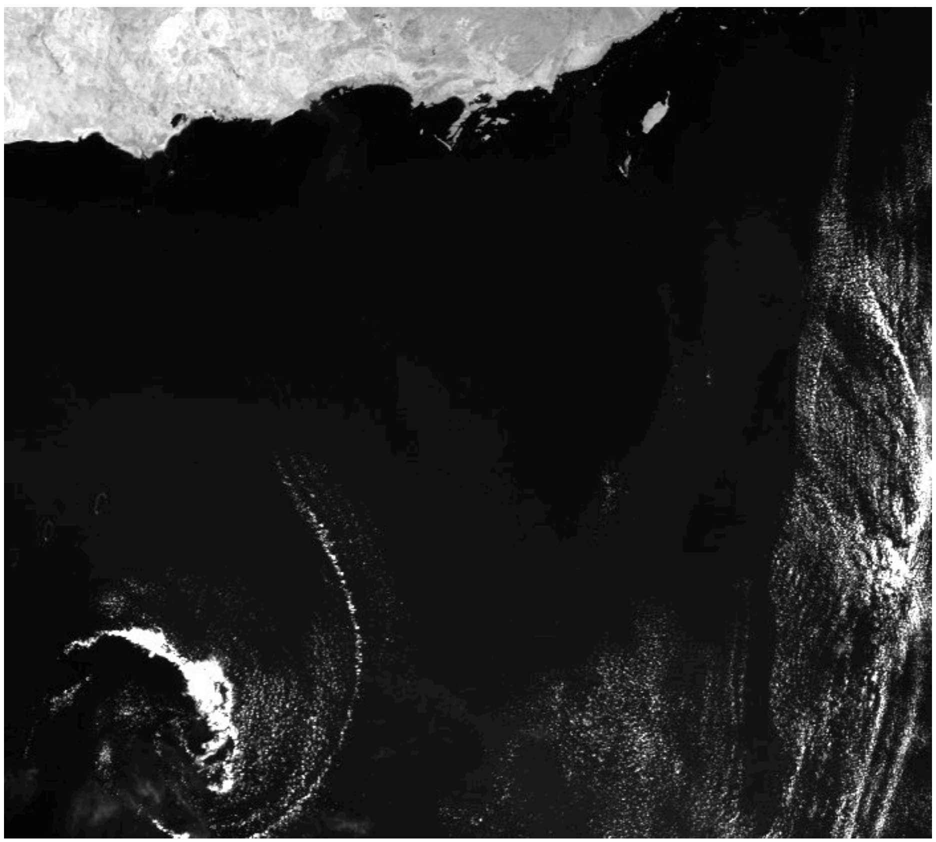
    27 (dets 0, 6); 28 (dets 0, 1); 33 (det 1); 34 (dets 6, 7, 8)

- For Aqua MODIS, no detectors are replaced.
- Applied to DAAC code but only for running algorithms.
- Code available from Liam Gumley@ssec.wisc.edu

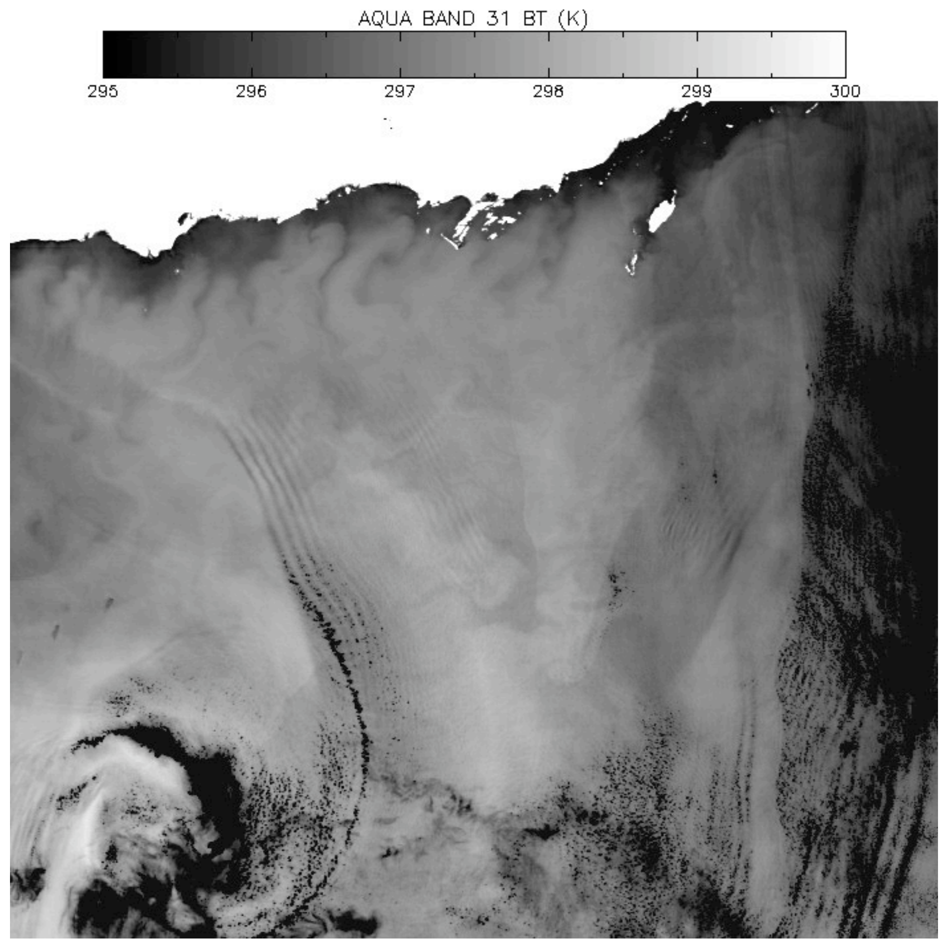
Aqua Example

MYD021KM.A2003147.0555.003.2003149154542.hdf (May 27)

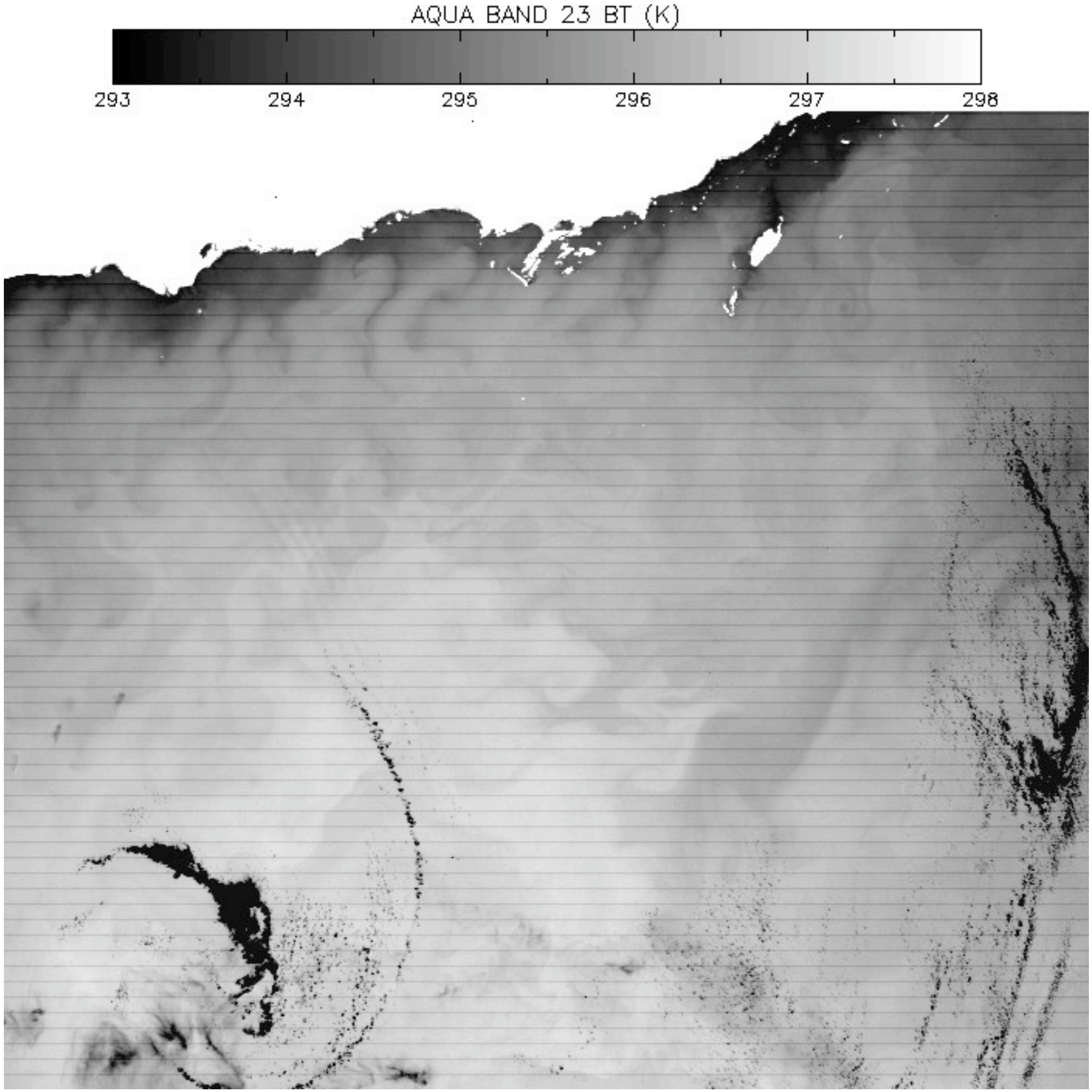
Northwest Shelf of Western Australia, 700 x 700 pixel subscene

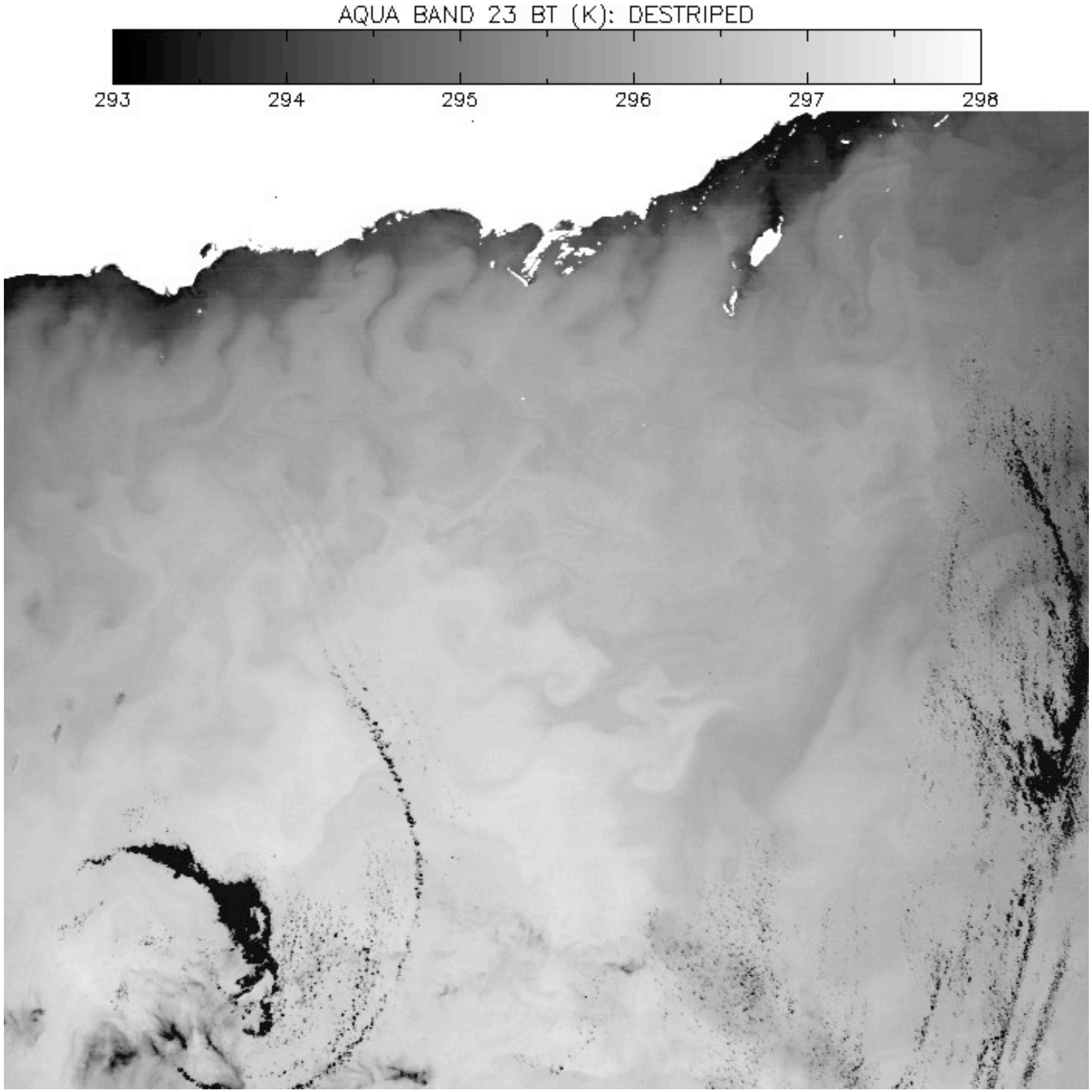


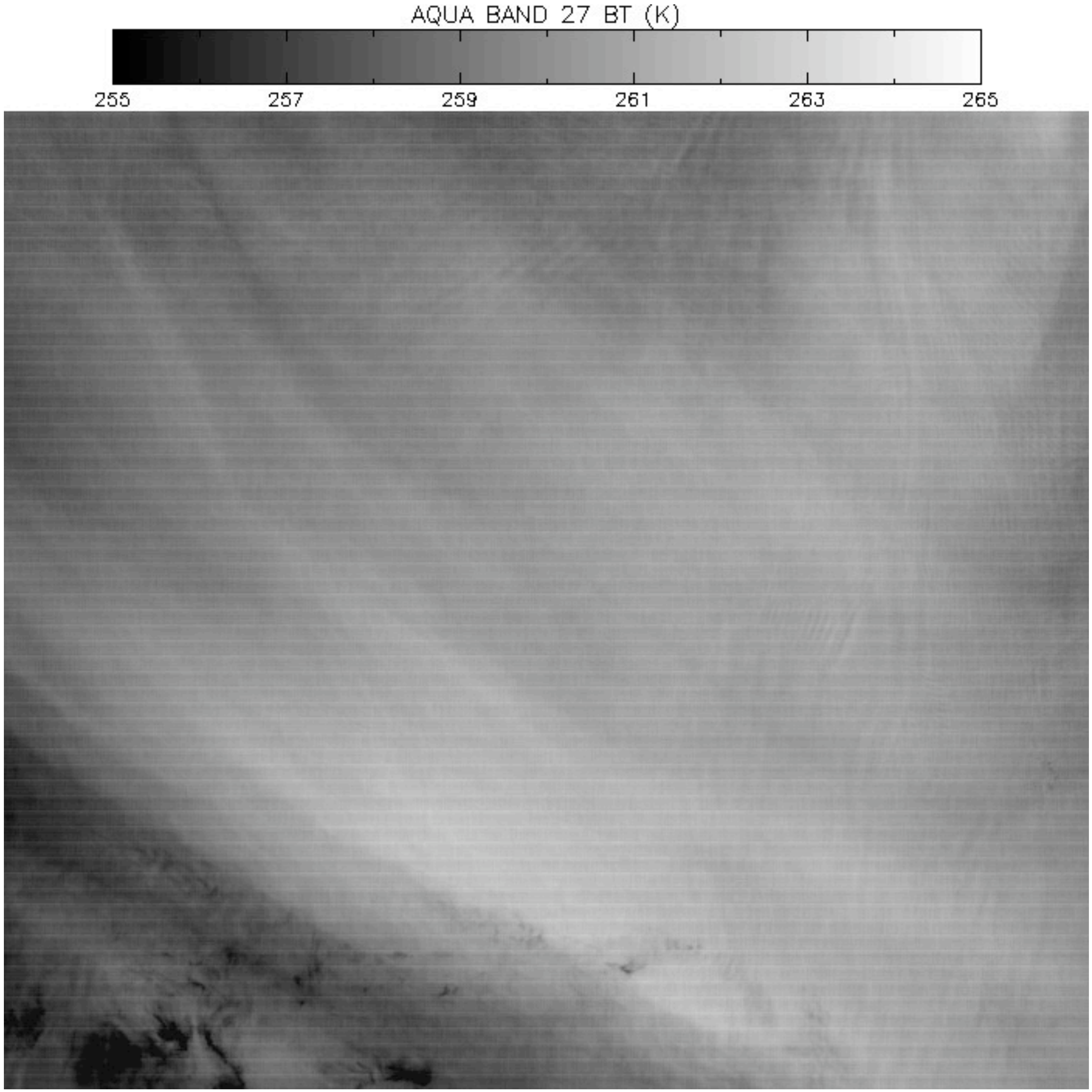
Band 2

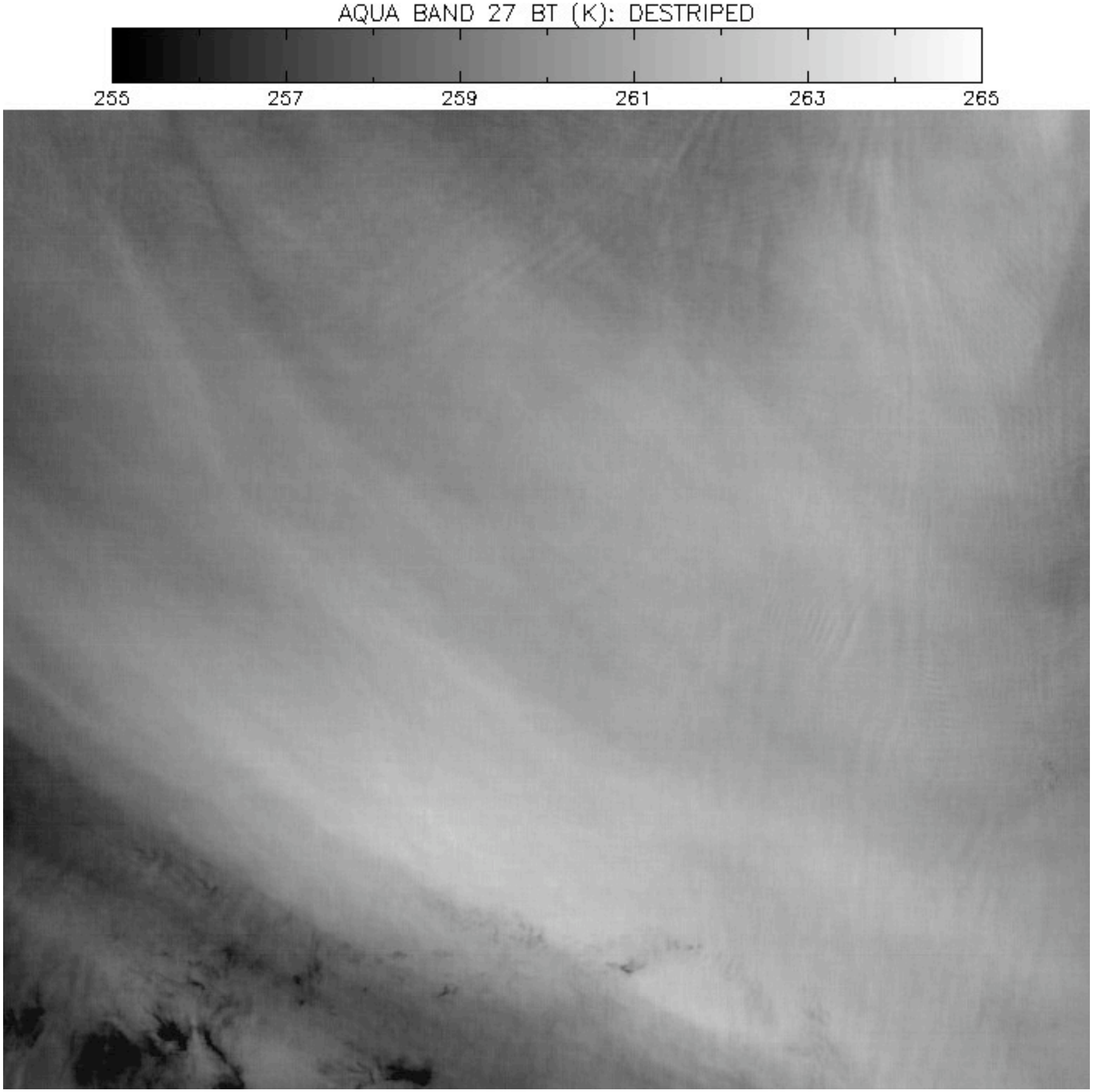


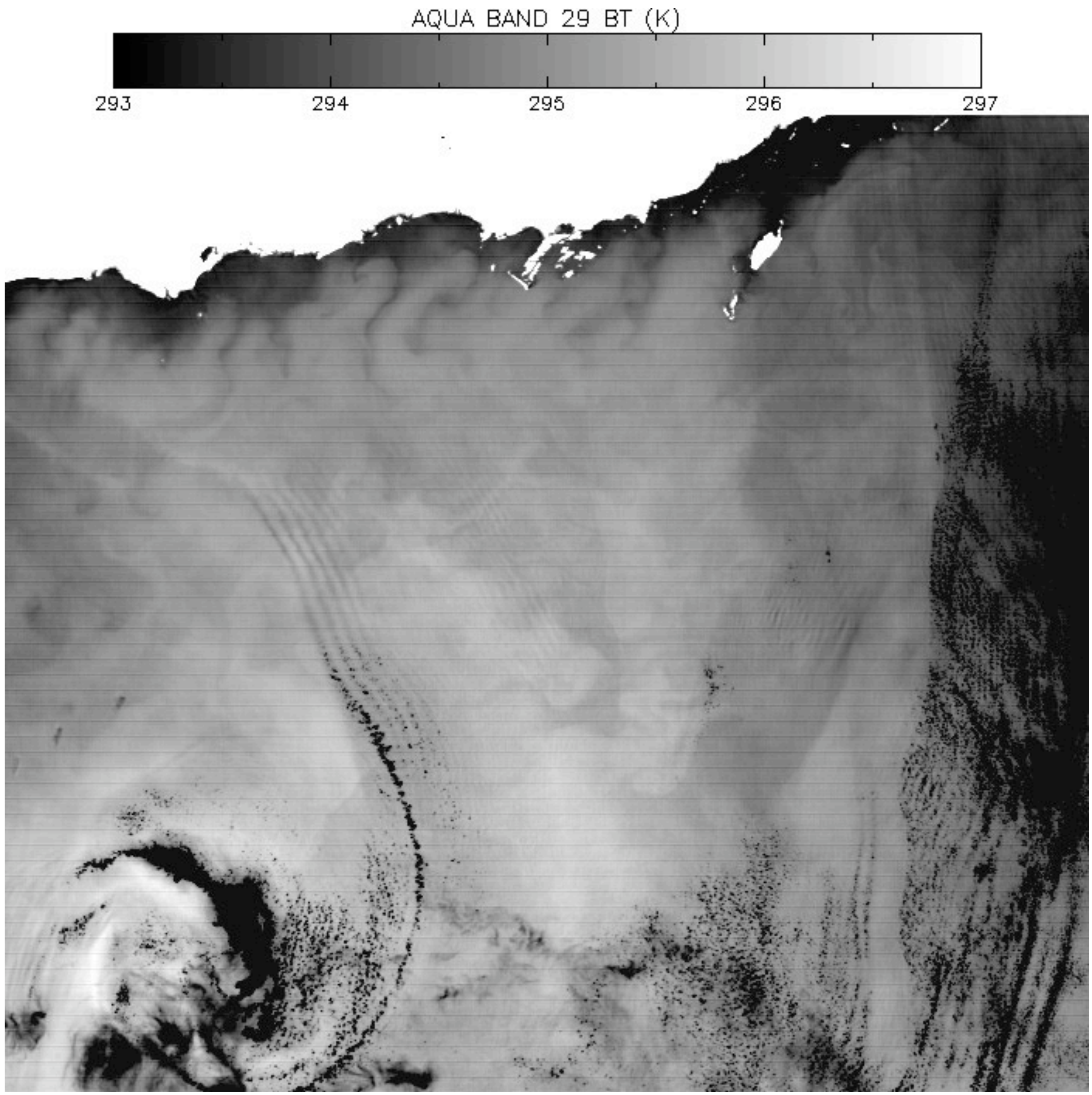
Band 31

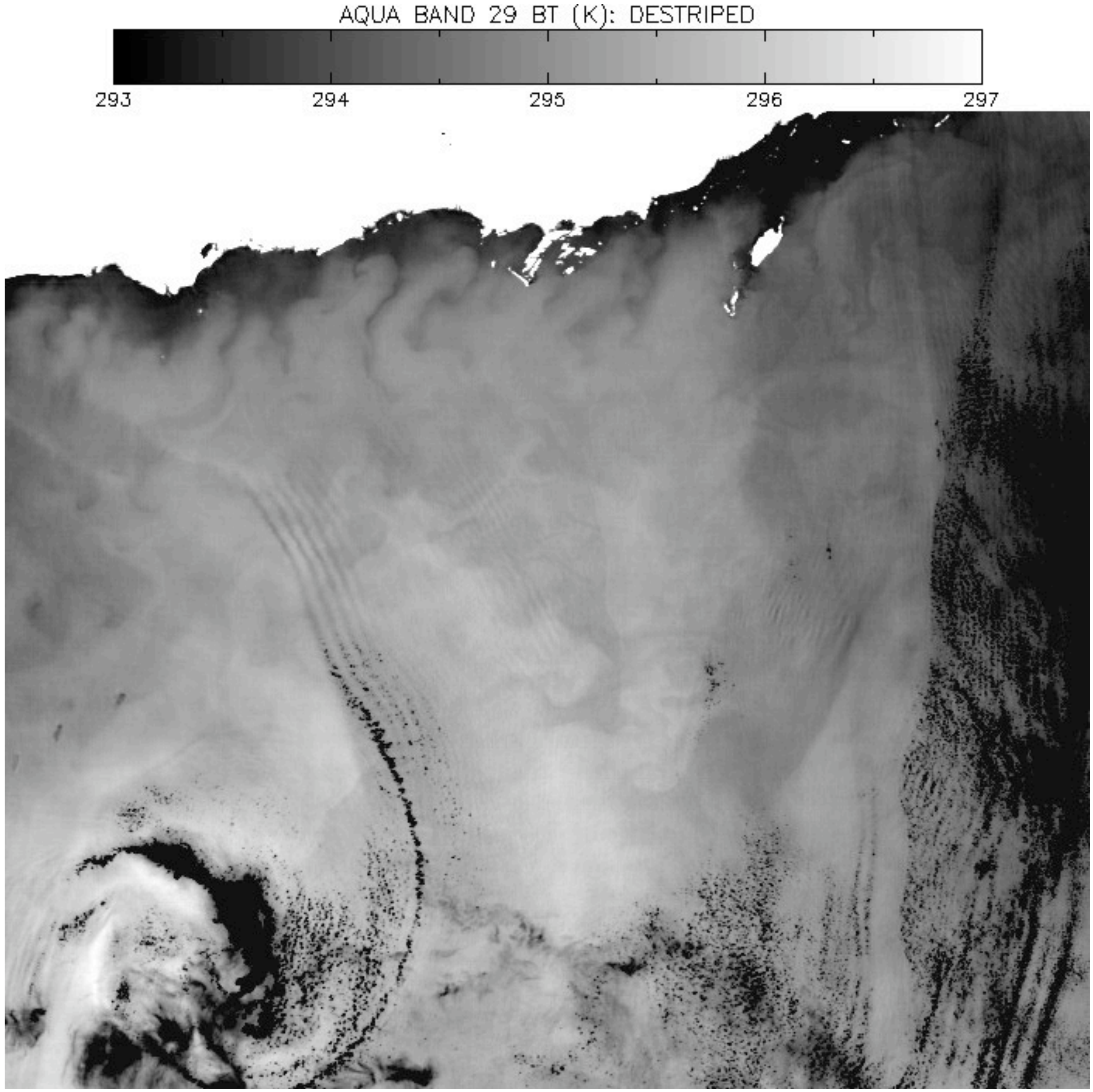

AQUA BAND 23 BT (K)
293
294
295
296
297
298


AQUA BAND 23 BT (K): DESTRIPED
293
294
295
296
297
298


AQUA BAND 27 BT (K)
255
257
259
261
263
265

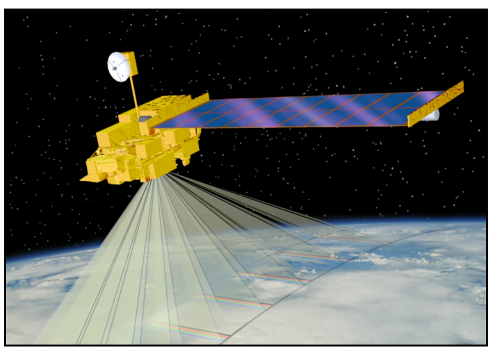

AQUA BAND 27 BT (K): DESTRIPED
255
257
259
261
263
265

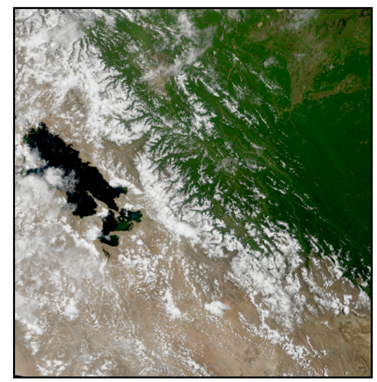

AQUA BAND 29 BT (K)
293
294
295
296
297


AQUA BAND 29 BT (K): DESTRIPED
293
294
295
296
297

Multi-spectral Cloud Detection (demonstrated with MODIS)

GEOSS/AMERICAS Remote Sensing Workshop
São Paulo, Brazil
26 November 2007





Kathleen Strabala
Cooperative Institute for Meteorological Satellite Studies
Space Science and Engineering Center
University of Wisconsin-Madison

Cloud Detection Techniques

- Take advantage of spectral properties of clouds, surface and atmosphere
- Majority of bands not chosen for cloud detection
- Used for other purposes but need to know where clouds are for all other algorithms to be created
- Multi-spectral techniques combine the information gained from individual spectral tests for final result
- MODIS multi-spectral instrument has 36 spectral bands - more tests can be applied

MODIS Cloud Mask

Ackerman, Frey, Strabala – CIMSS

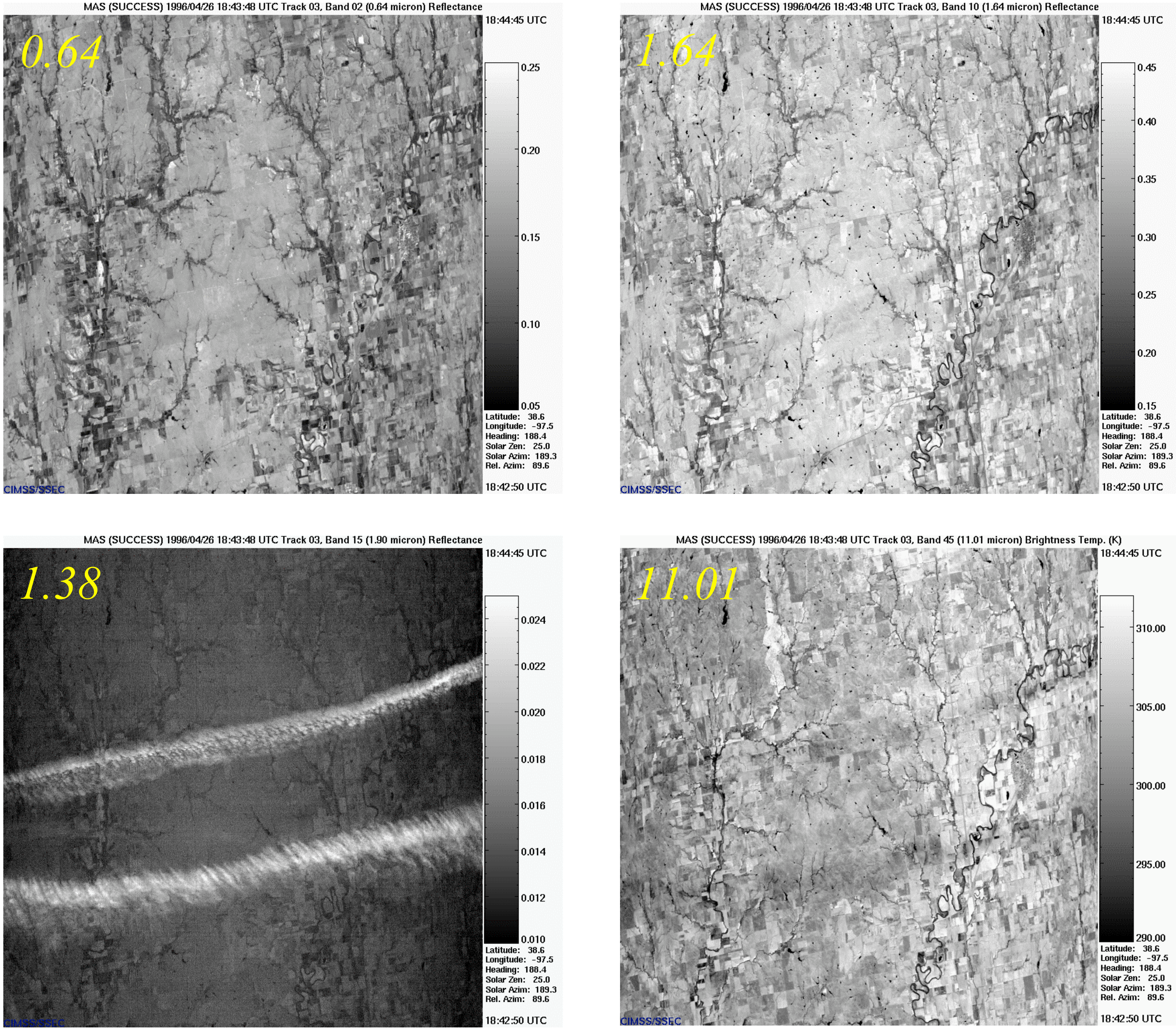
- **1 km** nadir spatial resolution **day & night**, (250 m day)
  - **19 spectral bands (0.55-13.93 µm, incl. 1.38 µm)**
    11 individual spectral tests (function of 5 processing paths) combined for initial pixel confidence of clear
  - spatial variability test over ocean
  - clear sky restoral tests applied at end (sanity checks)
- **48 bits per pixel** including individual test results and processing path
- **bits 1,2** give combined test results as: *confident clear, probably clear, undecided, obstructed/cloudy* (clear sky conservative)

MODIS Cloud Mask

- Created in 1990's with these constraints:
  - Has to be useful to all three MODIS teams
    - Land, Ocean and Atmosphere
  - CPU constraints – Must be efficient
    - Eliminated the use of neuro-networks, etc.
  - File size constraints – Must be a usable size
    - Information stored at bit level
  - Comprehension – Mask must be easily understood by users

Algorithm Development

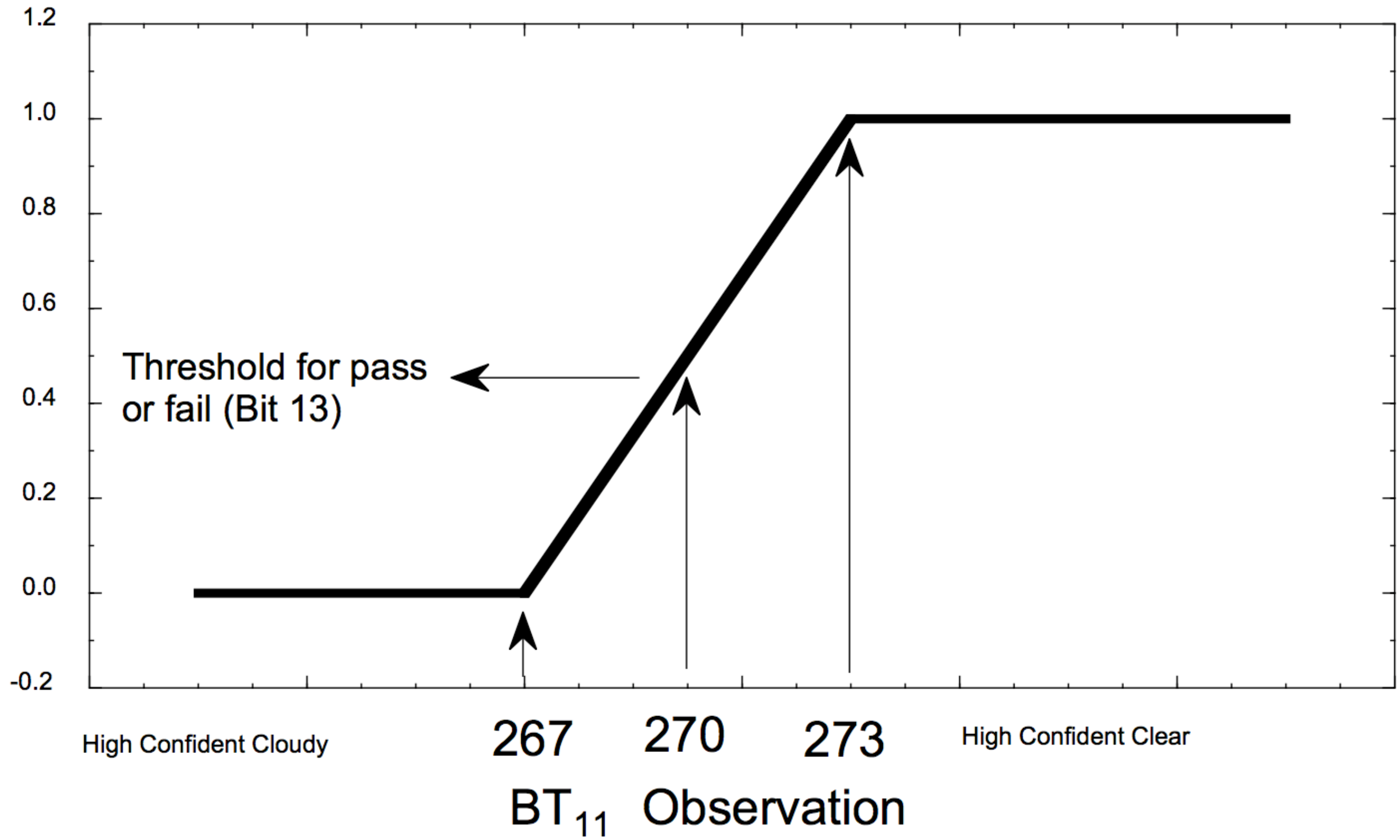
- Built upon work done by others:
  - ISCCP – Rossow and Garder 1993
  - CLAVR – Stowe et al. 1991
  - APOLLO – Saunders and Kriebel 1988
- New spectral channels – new tests
  - 1.38 micron high cloud reflectance test
- Many spectral channels
  - more tests go into final product
  - first platform with 8-11 (can use tri-spectral tests)


MAS (SUCCESS) 1996/04/26 18:43:48 UTC Track 03, Band 02 (0.64 micron) Reflectance
0.64
18:44:45 UTC
0.25
0.20
0.15
0.10
0.05
Latitude: 38.6
Longitude: -97.5
Heading: 188.4
Solar Zen: 25.0
Solar Azim: 189.3
Rel. Azim: 89.6
18:42:50 UTC
CIMSS/SSEC
MAS (SUCCESS) 1996/04/26 18:43:48 UTC Track 03, Band 10 (1.64 micron) Reflectance
1.64
18:44:45 UTC
0.45
0.40
0.35
0.30
0.25
0.20
0.15
Latitude: 38.6
Longitude: -97.5
Heading: 188.4
Solar Zen: 25.0
Solar Azim: 189.3
Rel. Azim: 89.6
18:42:50 UTC
CIMSS/SSEC
MAS (SUCCESS) 1996/04/26 18:43:48 UTC Track 03, Band 15 (1.90 micron) Reflectance
1.38
18:44:45 UTC
0.024
0.022
0.020
0.018
0.016
0.014
0.012
0.010
Latitude: 38.6
Longitude: -97.5
Heading: 188.4
Solar Zen: 25.0
Solar Azim: 189.3
Rel. Azim: 89.6
18:42:50 UTC
CIMSS/SSEC
MAS (SUCCESS) 1996/04/26 18:43:48 UTC Track 03, Band 45 (11.01 micron) Brightness Temp. (K)
11.01
18:44:45 UTC
310.00
305.00
300.00
295.00
290.00
Latitude: 38.6
Longitude: -97.5
Heading: 188.4
Solar Zen: 25.0
Solar Azim: 189.3
Rel. Azim: 89.6
18:42:50 UTC
CIMSS/SSEC

Algorithm Development

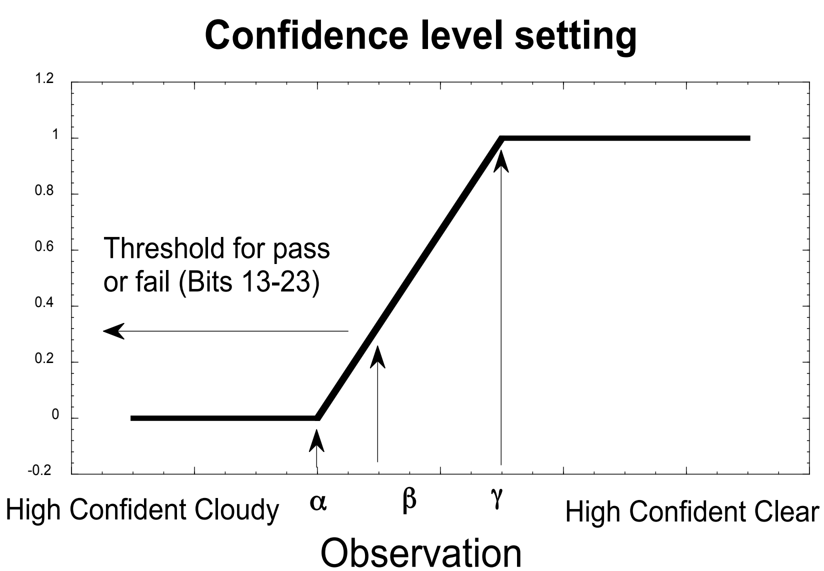
- Solution
  - Cloud mask based on combination of individual spectral tests.
  - Given constraints and building on previous work, best possible chance of an end product that would be useful to as many people as possible.

Confidence Level of Clear



Example thresholds for the simple IR window cold cloud test.

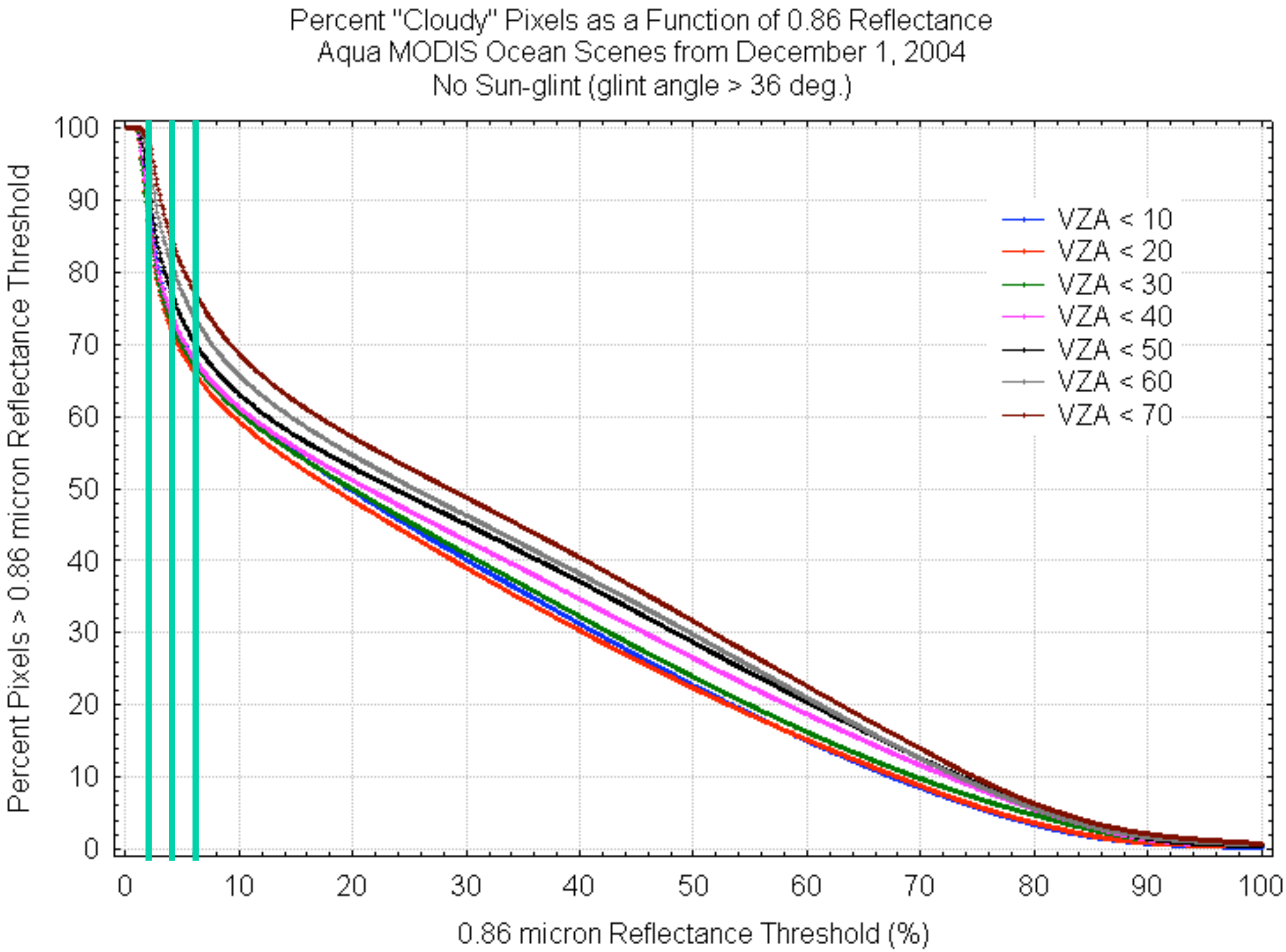
Quality Flags



- Each test returns a confidence (F) ranging from 0 to 1.
- Similar tests are grouped and minimum confidence selected [min (F_i)]
- Quality Flag is

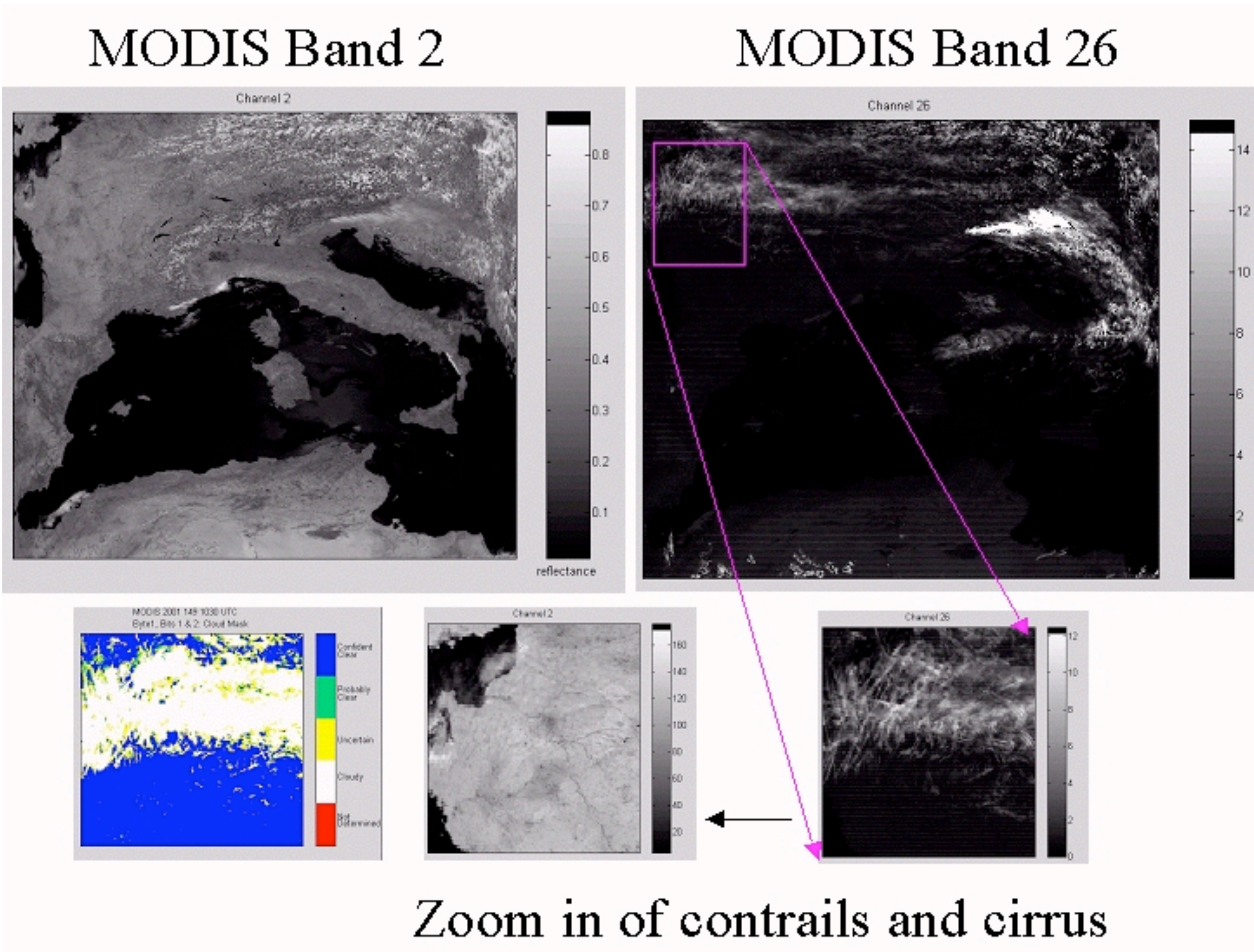
$$Q = \sqrt[N]{\prod_{i=1}^{N} \min(F_i)}$$

- Four values; 0, >.66, >.95 and >.99



Percent "Cloudy" Pixels as a Function of 0.86 Reflectance
Aqua MODIS Ocean Scenes from December 1, 2004
No Sun-glint (glint angle > 36 deg.)
Percent Pixels > 0.86 micron Reflectance Threshold
0.86 micron Reflectance Threshold (%)
VZA < 10
VZA < 20
VZA < 30
VZA < 40
VZA < 50
VZA < 60
VZA < 70

Some tests see cloud, some don't



Thresholds Domains

- Day/Night – Solar Zenith > 85 = night
- Land/Water – Based upon 1km USGS map
- Desert – Based upon USGS 1 km Olson Ecosystem map
- Polar Day/Night – Latitude greater than 60
- Coast – 2 pixels surrounding water bodies
- High Elevation - > 2000 m
- Sunglint – Intense point of solar reflection

"Mirror" reflection of sunlight off calm water.

Sun Glint

Simple example where your eye is the sensor

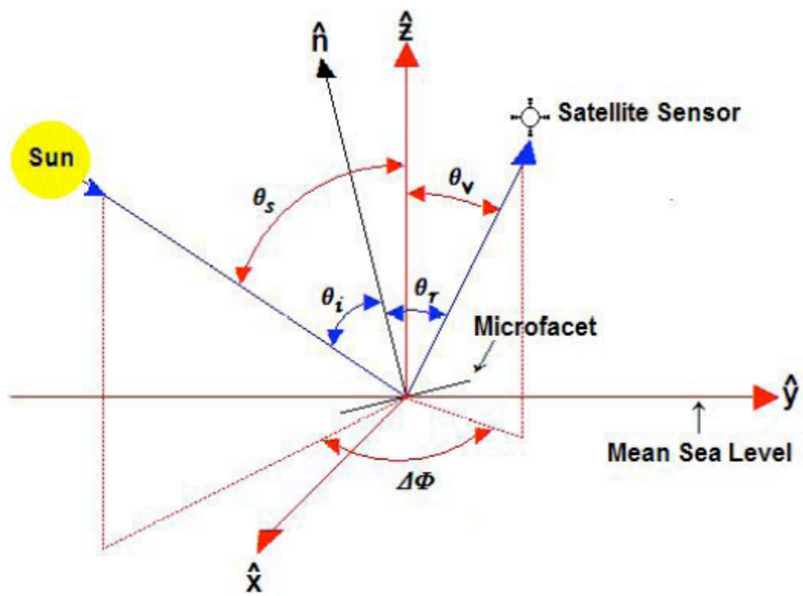
Sun Glint Ellipse Defined by: $\theta_r < 36$

$\cos \theta_r = \sin \theta_v \cos \theta_s \cos \Delta\Phi + \sin \theta_v \cos \theta_s$

Where θ_v = Viewing Zenith Angle

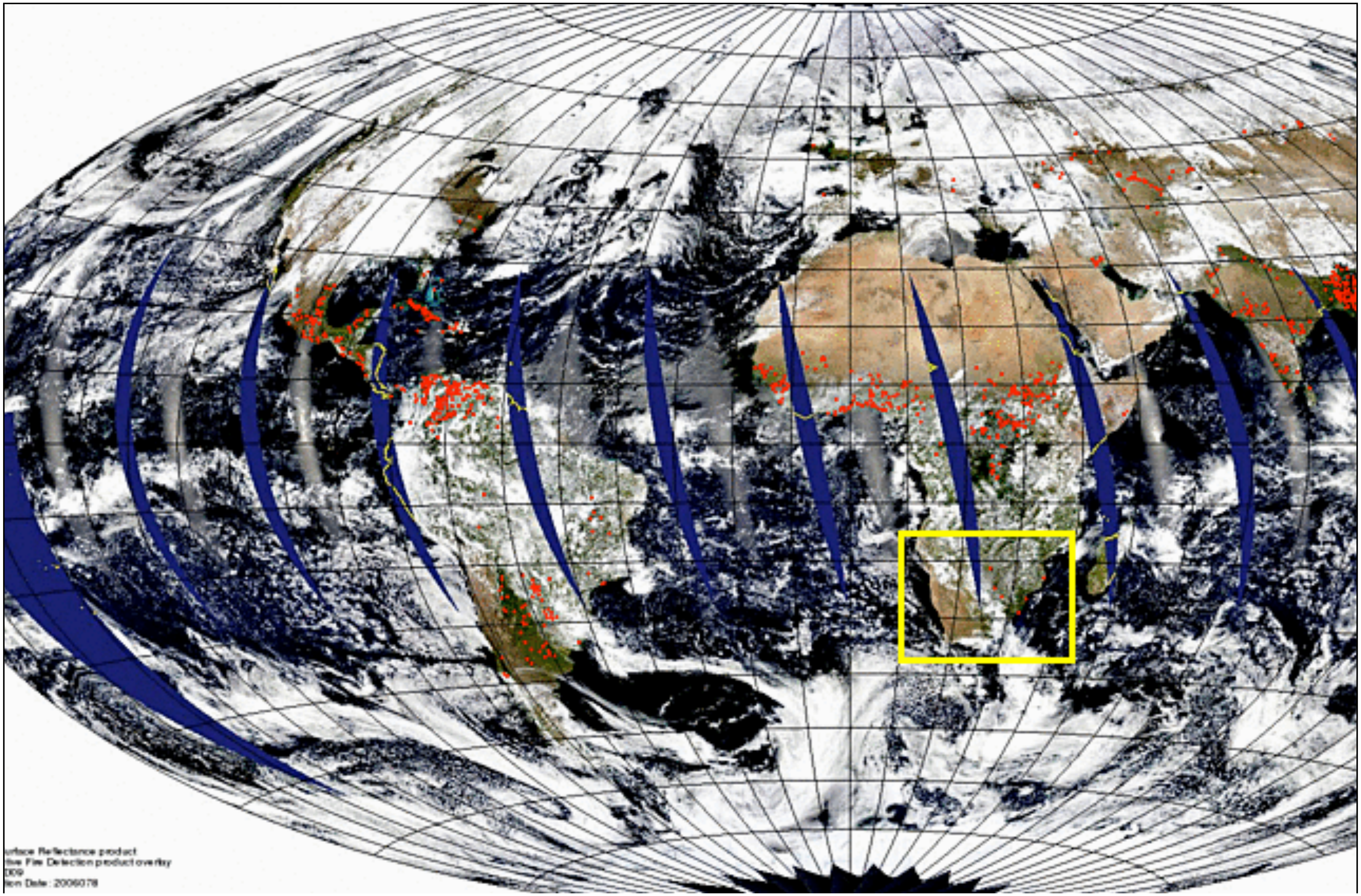
θ_s = Solar Zenith Angle

$\Delta\Phi$ = Relative Angle – difference between the Solar and Viewing azimuth angles.



Aqua MODIS Sun Glint Example

19 March 2006



Detecting Clouds (IR) **Thresholds vary based upon scene type**

IR Brightness Temperature Threshold Tests

IR tests sensitive to sfc emissivity and atm PW, dust, and aerosols

BT11 < SST- 6 K (Reynolds blended SST global 1 degree - oisst.20060215

Land - GDAS sfc temp global 1 degree -gdas1.PGrbF00.060220.18z)

BT6.7 < Threshold mid-level cloud

BT13.9 < Threshold cold high cloud (large viewing zenith angles cause problems)

IR Brightness Temperature Difference Tests

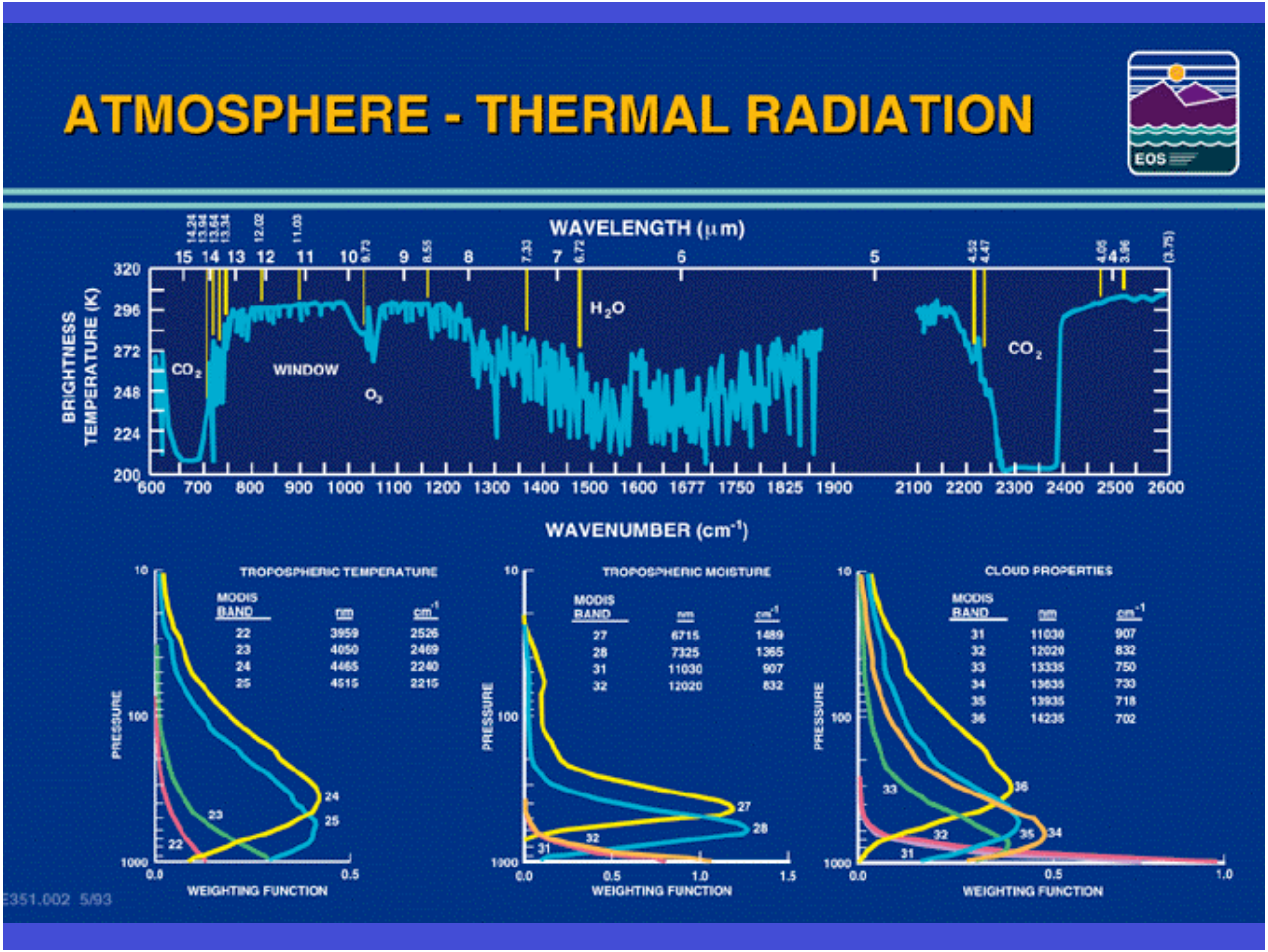
BT8 - BT11 > Threshold (High thin cloud)

BT11-BT12 > Threshold (High thin cloud)

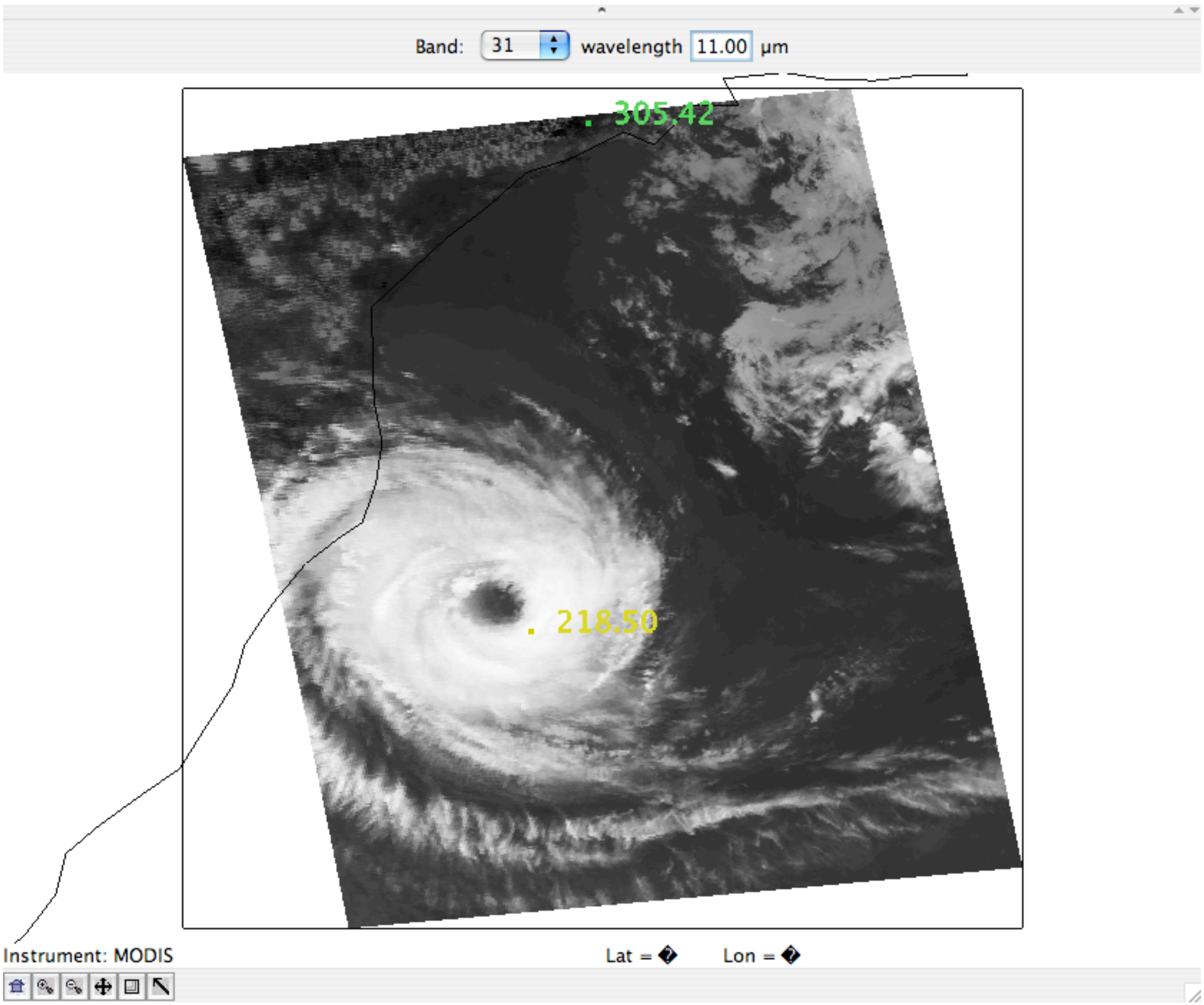
BT3.9 - BT11 > 12 K indicates daytime low cloud cover

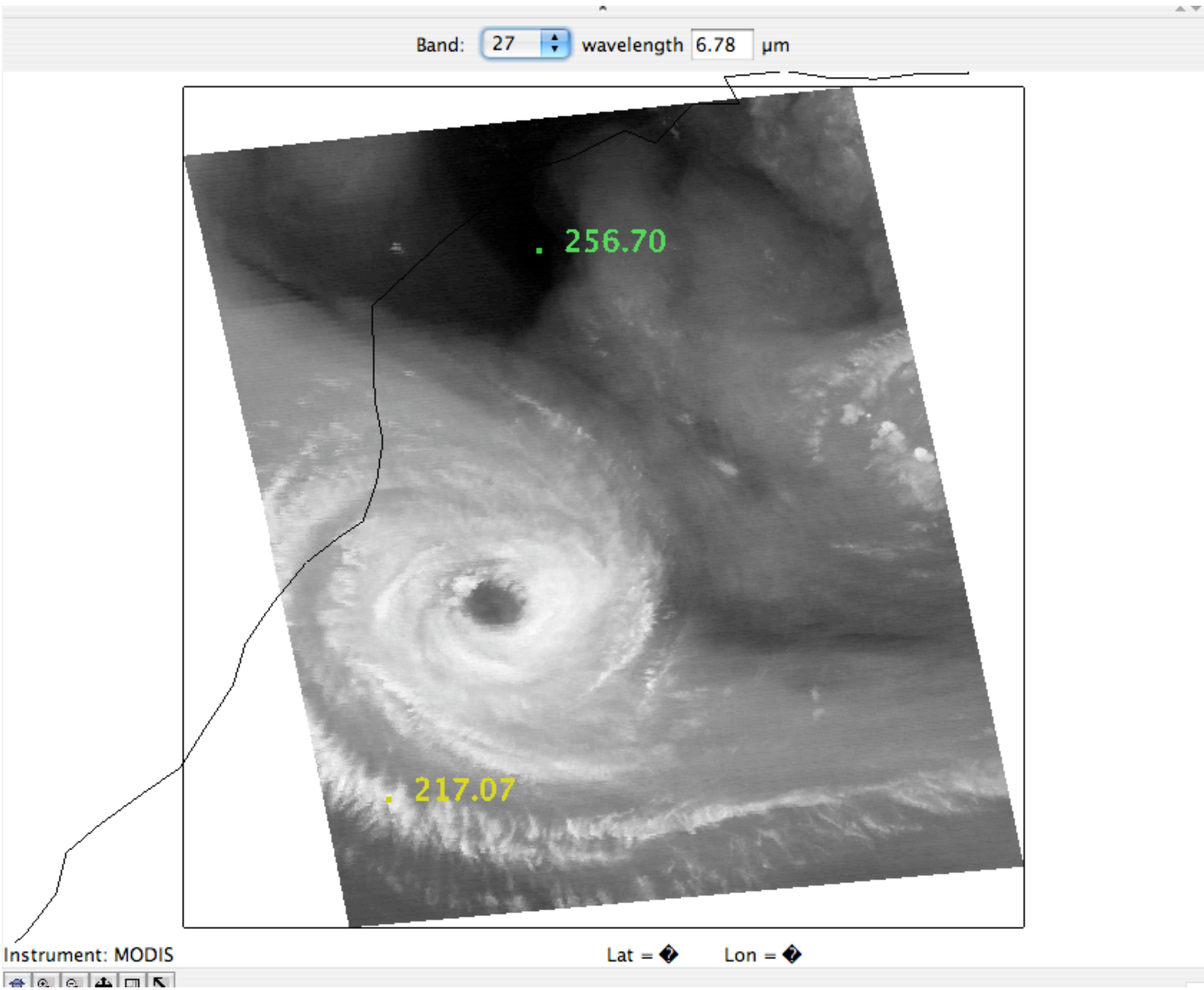
BT11 - BT6.7 large neg diff for clr sky over Antarctic Plateau winter

BT11 – BT7.3 Temperatures close in poles or snow/ice mean cloud

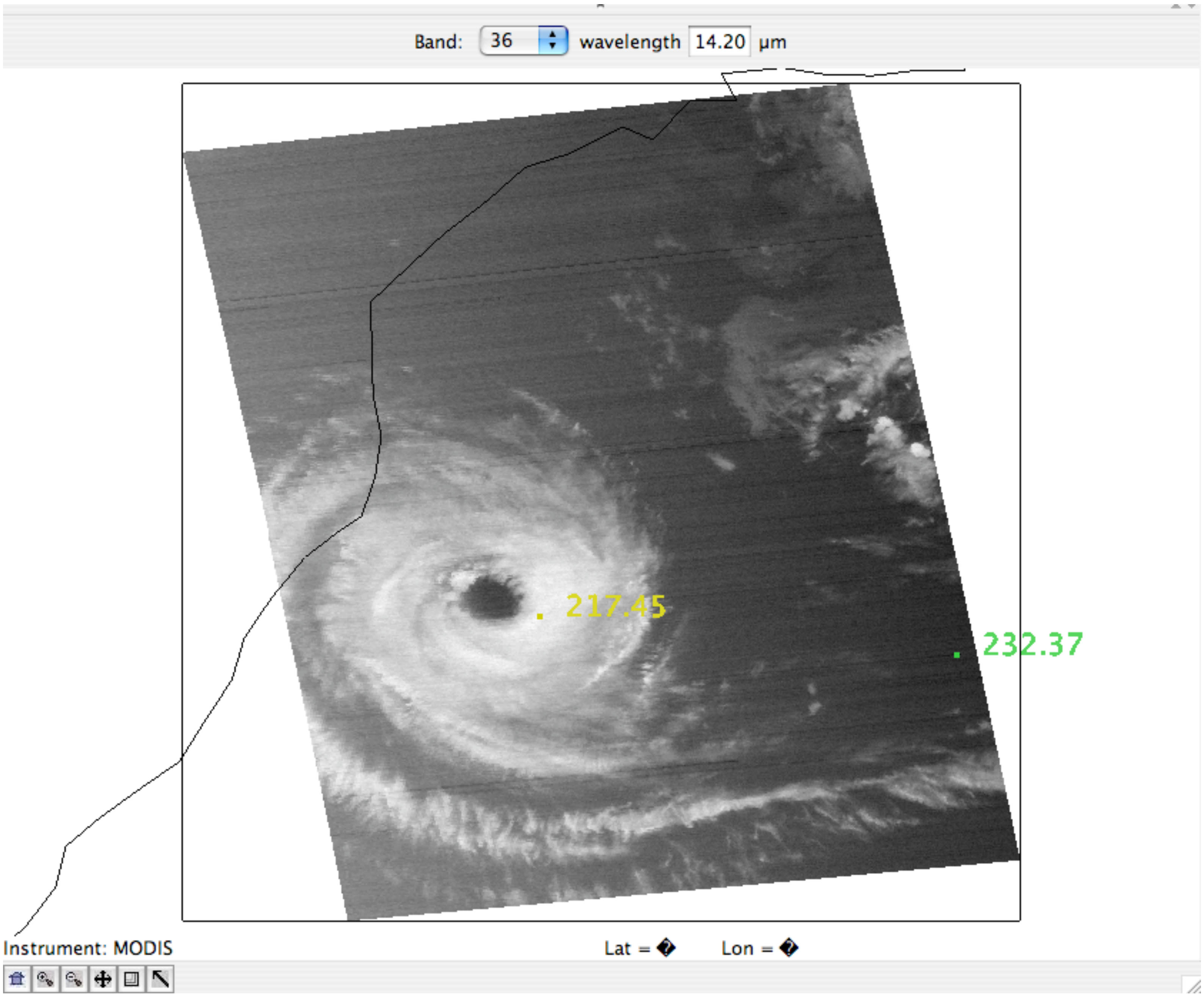


ATMOSPHERE - THERMAL RADIATION
EOS
WAVELENGTH (μm)
14.24 13.94 13.64 13.34 12.02 11.03 9.73 8.55 7.33 6.72 4.52 4.47 4.05 3.96 (3.75)
15 14 13 12 11 10 9 8 7 6 5 4
BRIGHTNESS TEMPERATURE (K)
320 296 272 248 224 200
CO2
WINDOW
O3
H2O
CO2
600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1677 1750 1825 1900 2100 2200 2300 2400 2500 2600
WAVENUMBER (cm-1)
TROPOSPHERIC TEMPERATURE
MODIS BAND nm cm-1
22 3959 2526
23 4050 2469
24 4465 2240
25 4515 2215
PRESSURE
10 100 1000
0.0 0.5
WEIGHTING FUNCTION
TROPOSPHERIC MOISTURE
MODIS BAND nm cm-1
27 6715 1489
28 7325 1365
31 11030 907
32 12020 832
0.0 0.5 1.0 1.5
CLOUD PROPERTIES
MODIS BAND nm cm-1
31 11030 907
32 12020 832
33 13335 750
34 13635 733
35 13935 718
36 14235 702
0.0 0.5 1.0
E351.002 5/93

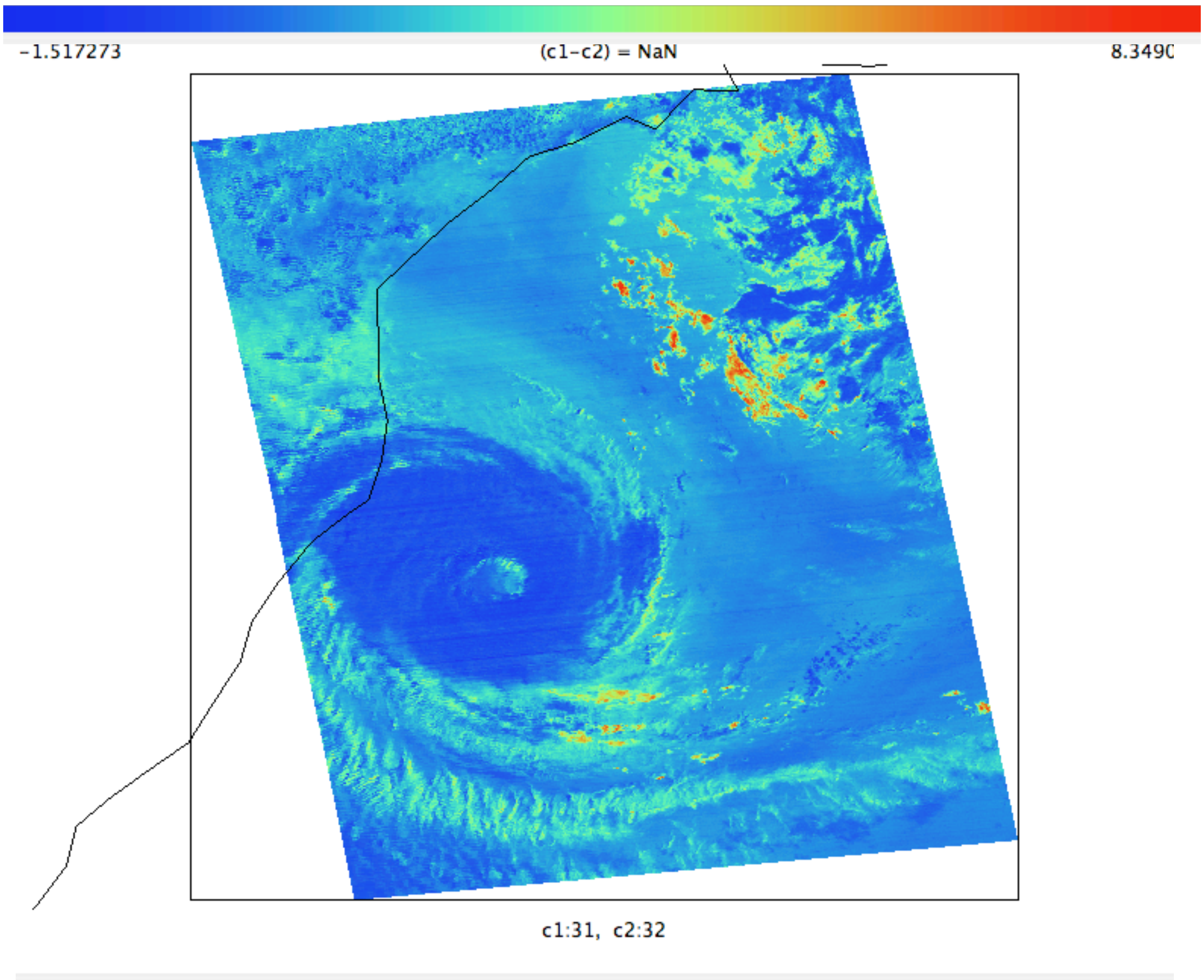

Band: 31 wavelength 11.00 µm
305.42
218.50
Instrument: MODIS
Lat = �
Lon = �



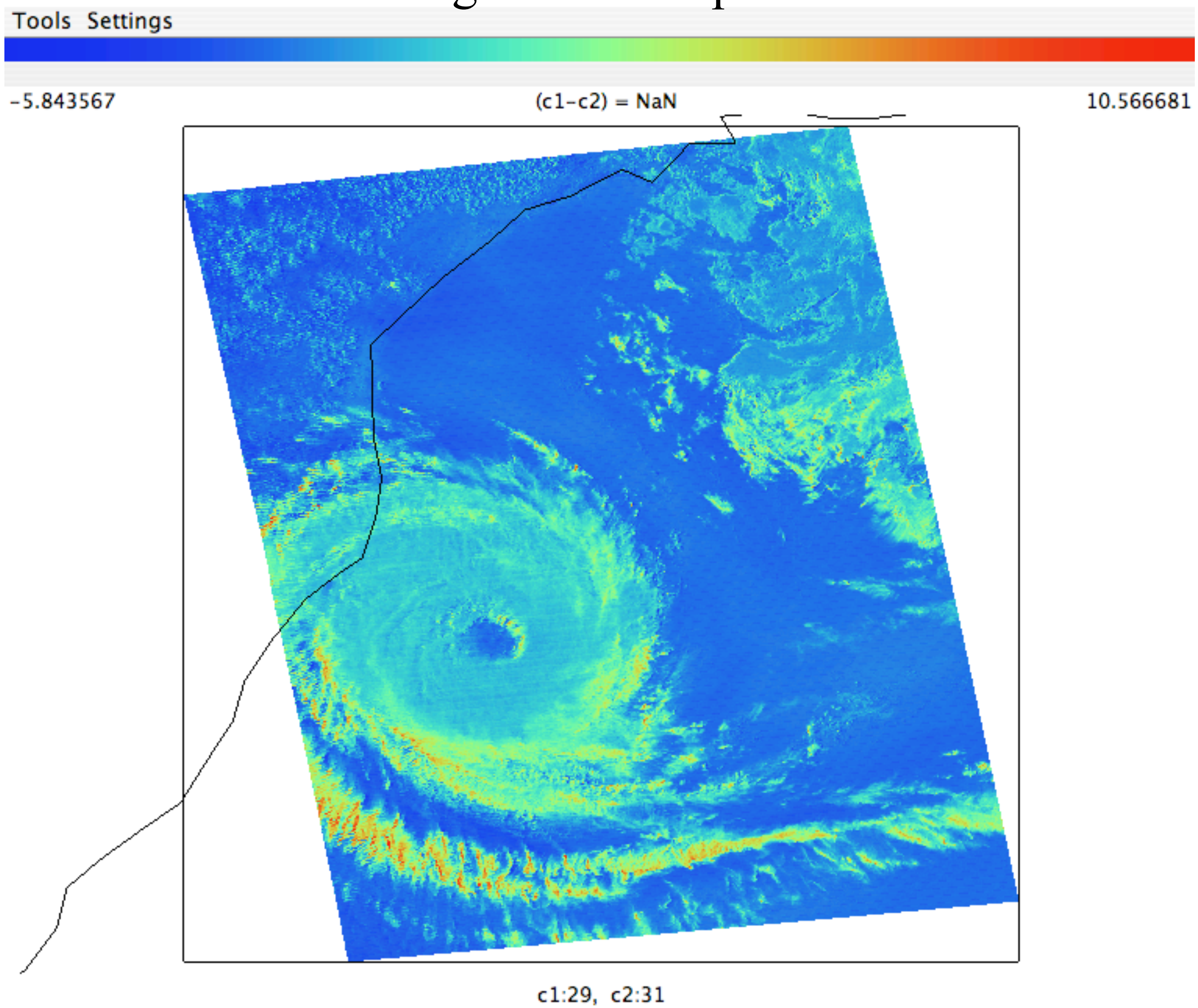
Band: 27 wavelength 6.78 µm
256.70
217.07
Instrument: MODIS
Lat = �
Lon = �

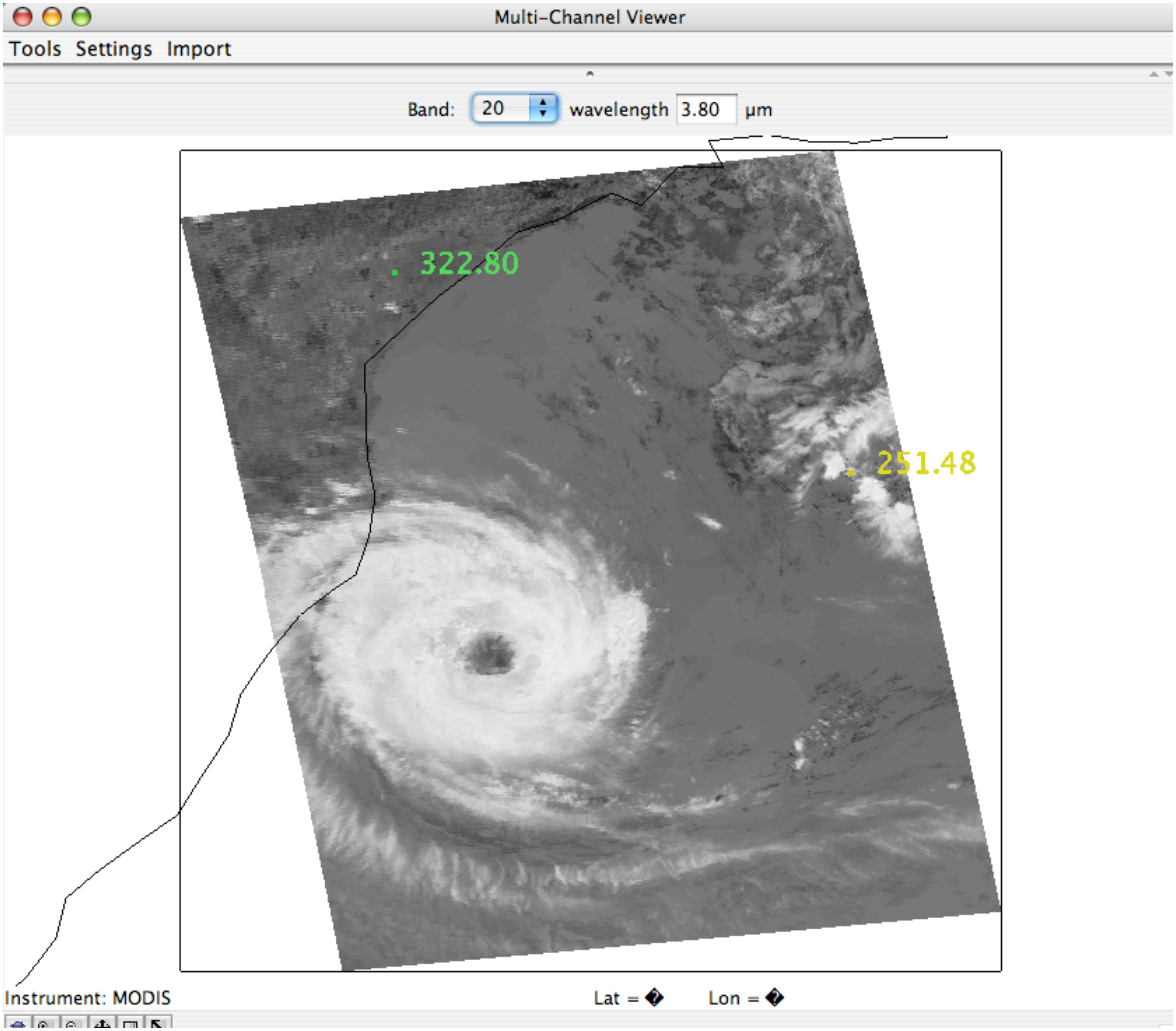

Band: 36 wavelength 14.20 μm
217.45
232.37
Instrument: MODIS
Lat = �
Lon = �

11-12 micron Brightness Temperature Difference



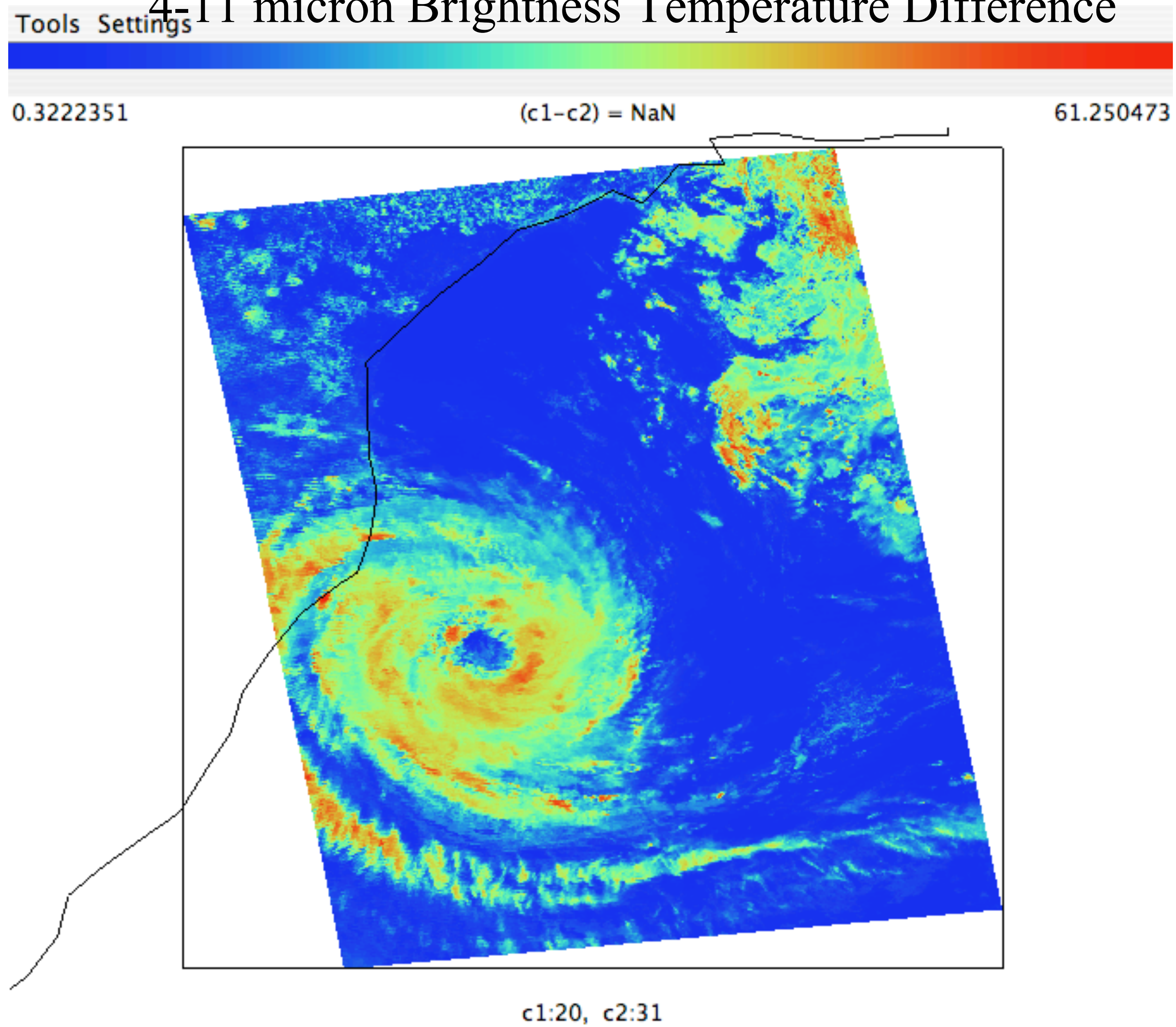
8-11 micron Brightness Temperature Difference





Multi-Channel Viewer
Tools Settings Import
Band: 20 wavelength 3.80 µm
322.80
251.48
Instrument: MODIS
Lat = �
Lon = �

4-11 micron Brightness Temperature Difference



Detecting Clouds (vis)

Reflectance Threshold Test

r.87 > 5.5% over ocean indicates cloud
r.66 > 18% over vegetated land indicates cloud

Near IR Thin Cirrus Test

r1.38 > threshold indicates presence of thin cirrus cloud
ambiguity of high thin versus low thick cloud (resolved with BT13.9)
problems in high terrain

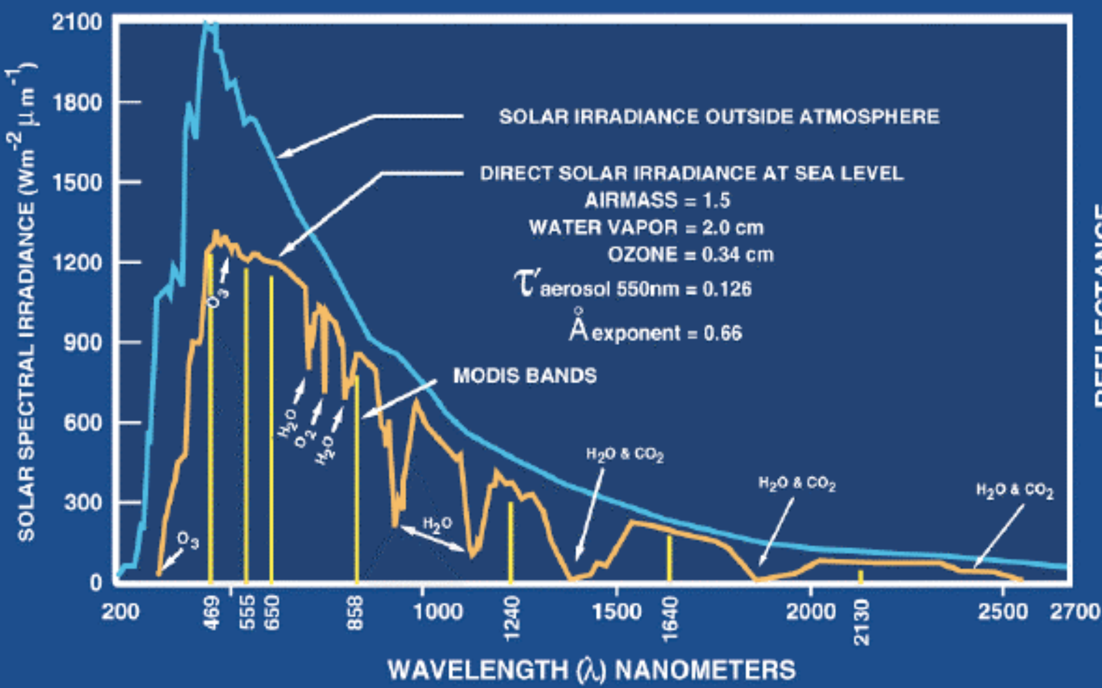
Reflectance Ratio Test

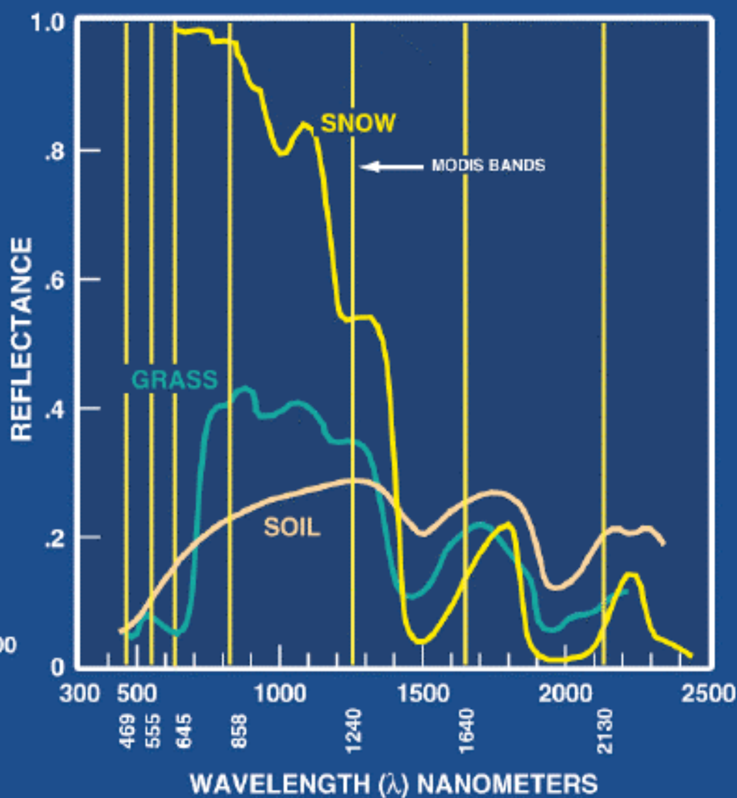
r.87/r.66 between 0.9 and 1.1 for cloudy regions
must be ecosystem specific – snow causes false signal

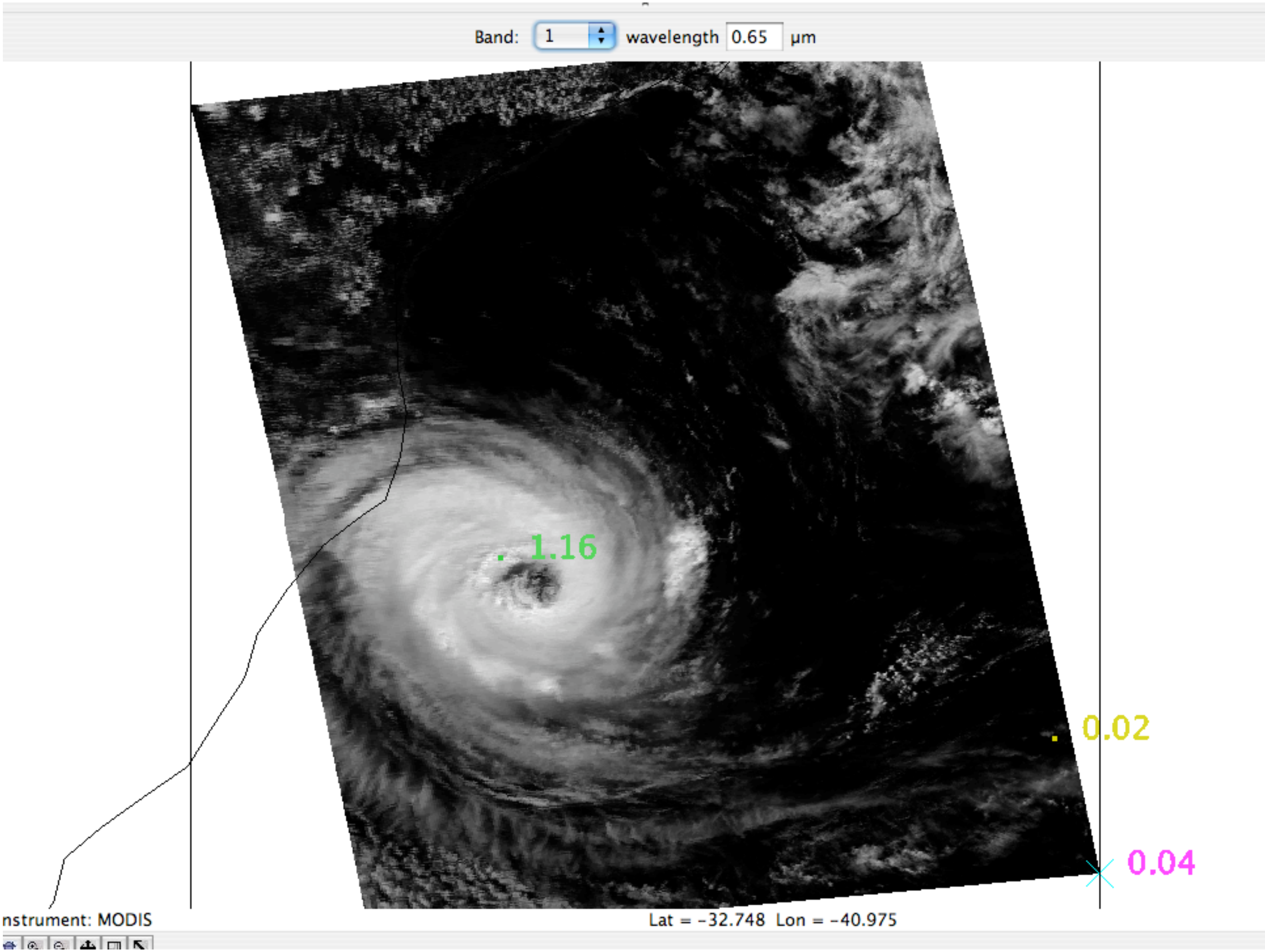
Snow Test

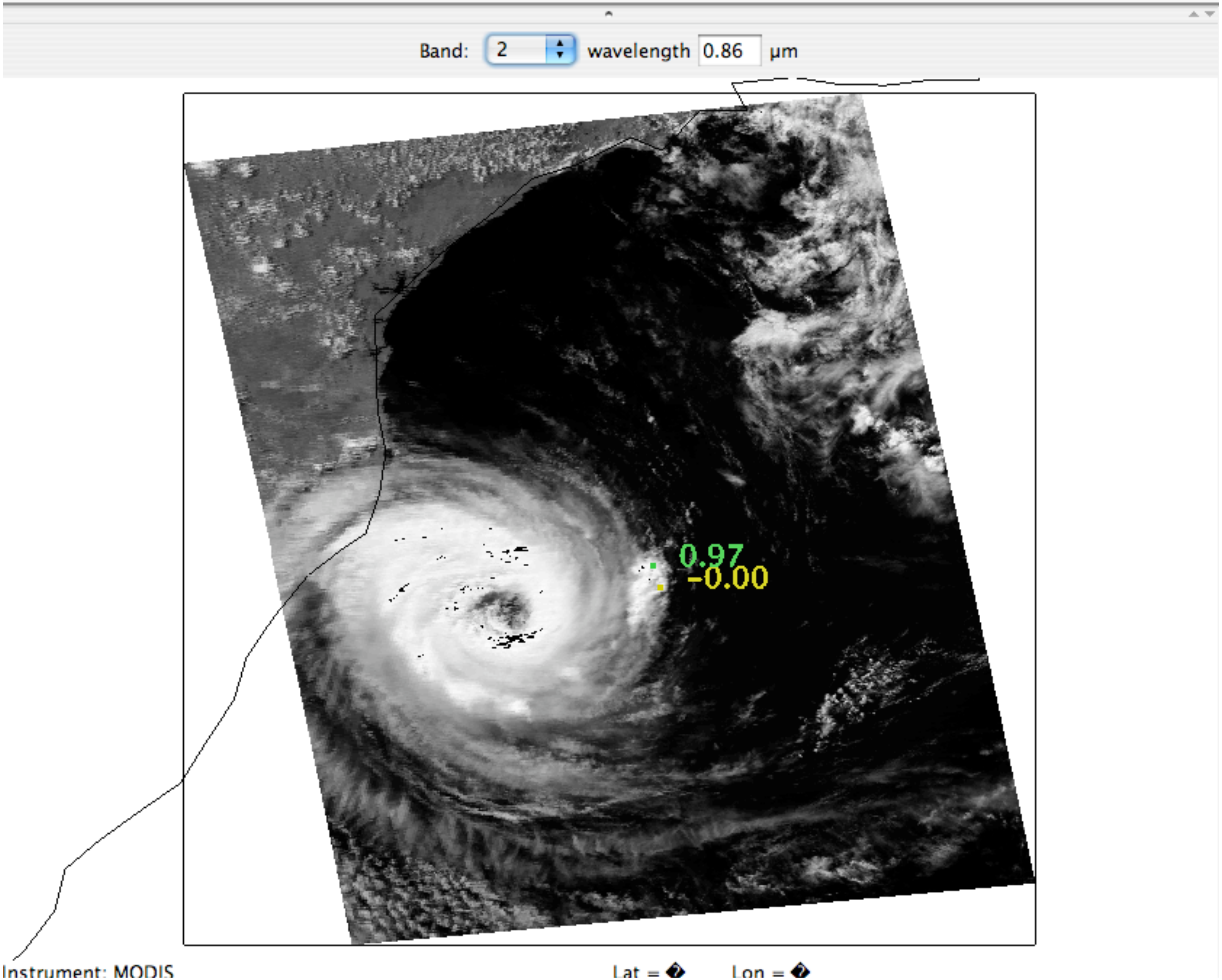
NDSI = [r.55-r1.6]/ [r.55+r1.6] > 0.4 and r.87 > 0.1 then snow

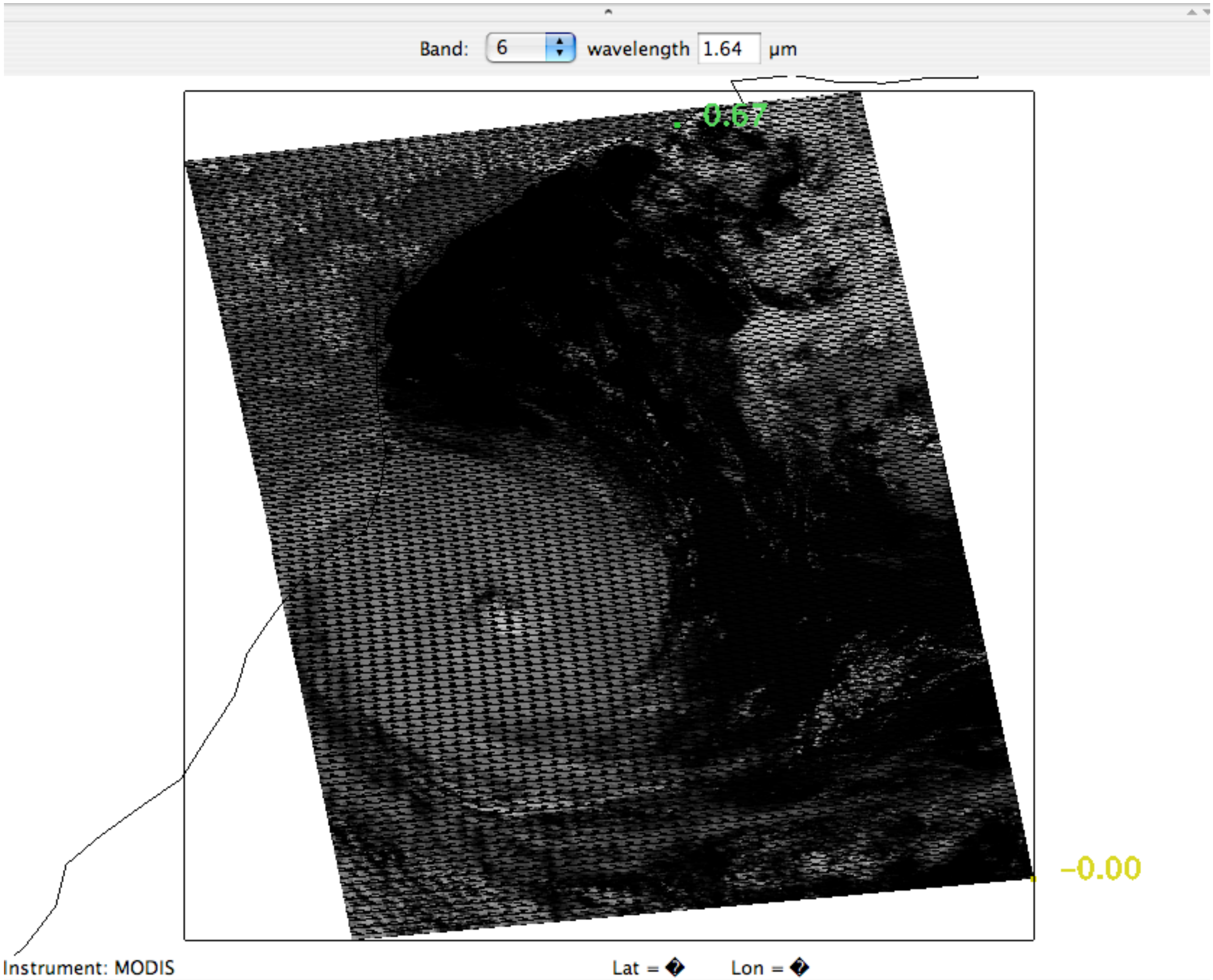
LAND-SOLAR RADIATION



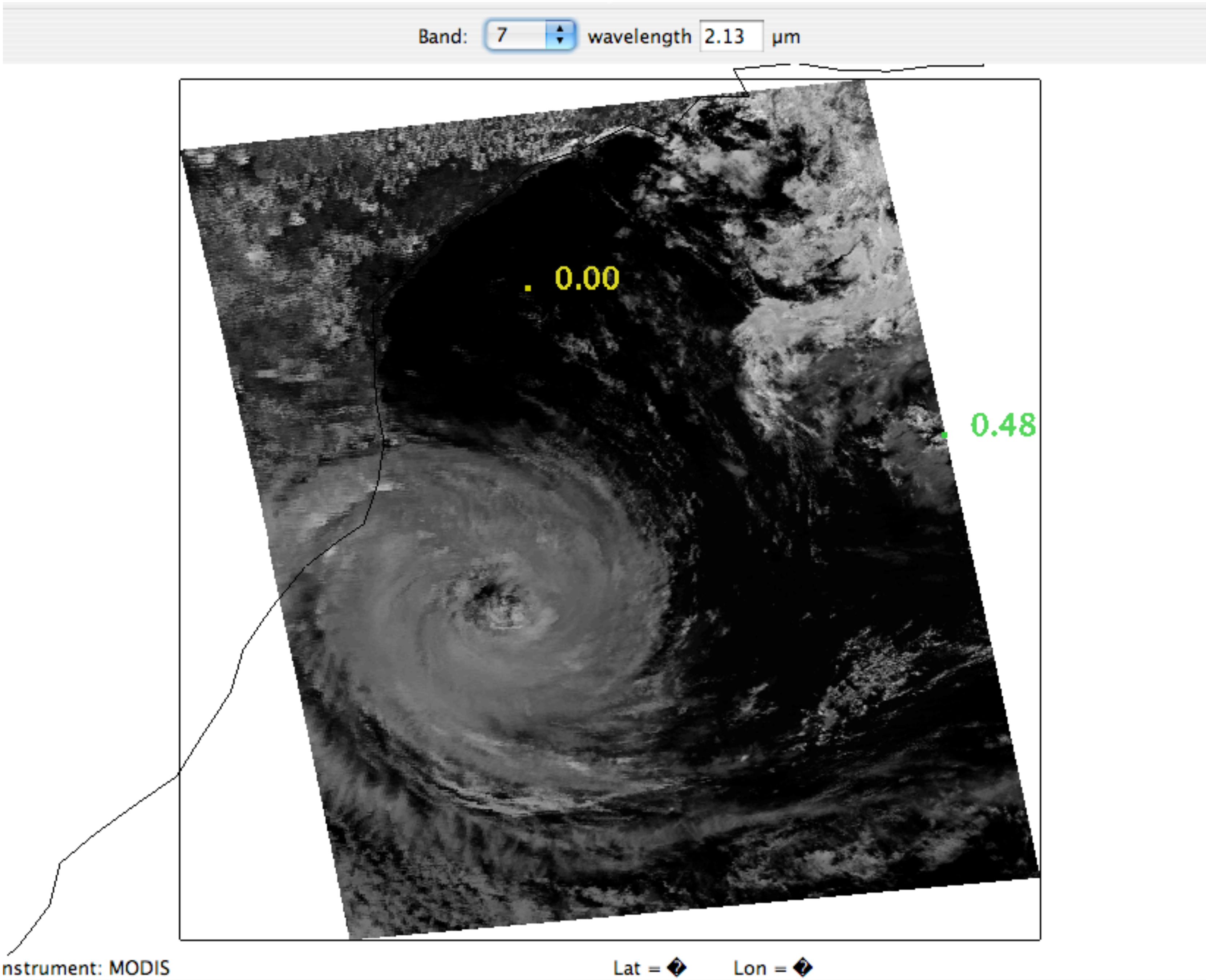


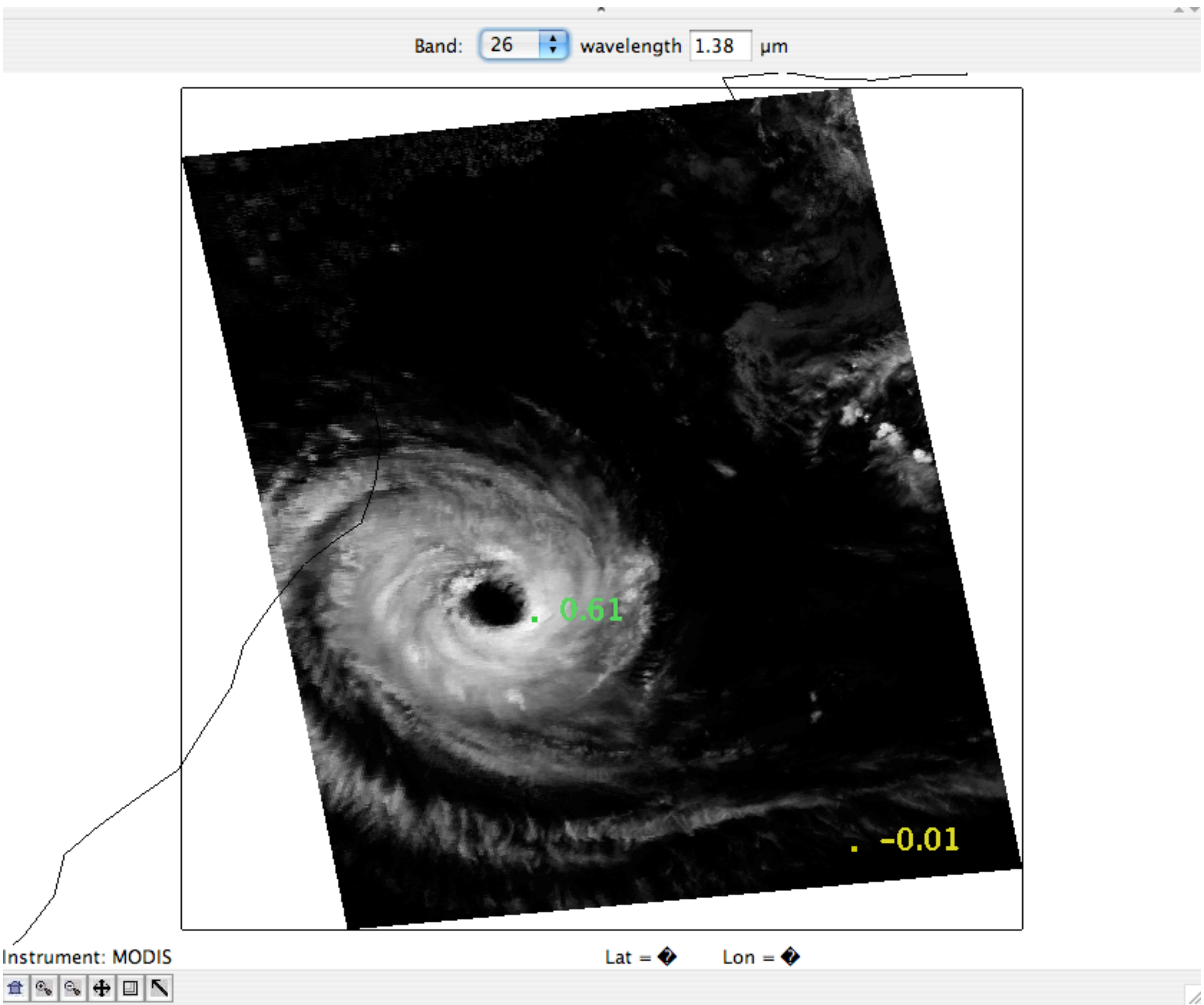

Band: 1 wavelength 0.65 µm
1.16
0.02
0.04
nstrument: MODIS
Lat = -32.748 Lon = -40.975


Band: 2 wavelength 0.86 µm
0.97
-0.00
Instrument: MODIS
Lat =
Lon =



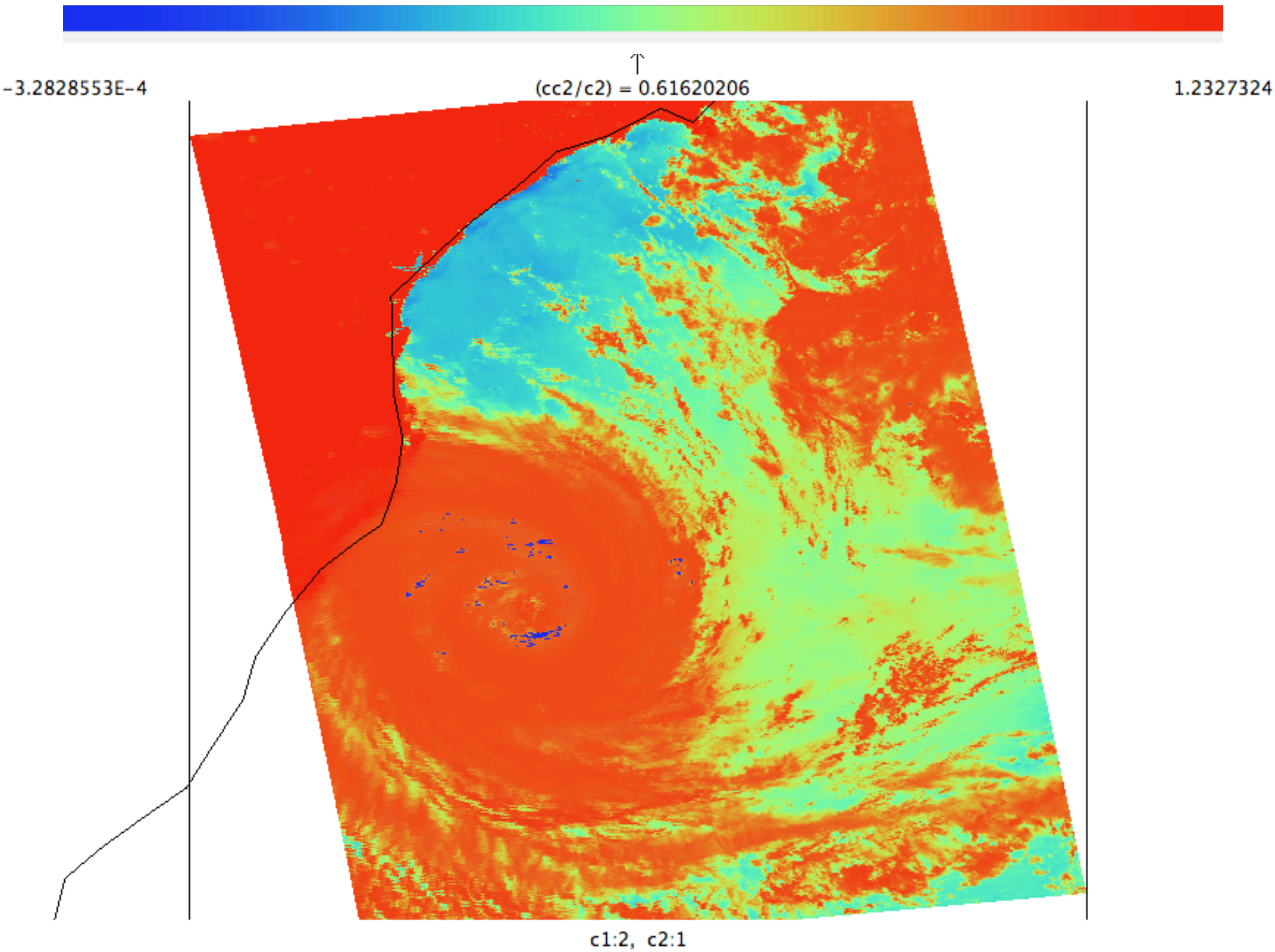
Band: 6
wavelength 1.64 µm
0.67
-0.00
Instrument: MODIS
Lat = �
Lon = �


Band: 7 wavelength 2.13 μm
0.00
0.48
nstrument: MODIS
Lat = �
Lon = �



Band: 26 wavelength 1.38 µm
0.61
-0.01
Instrument: MODIS
Lat = �
Lon = �

Band 2 / Band 1 reflectances



Other Tests

- BT11 Spatial variability test (3x3 pixels)
  - Cloud if > .50 K
- Clear Sky Restoral Tests (sanity checks)
  - Clear if land night BT11 > 292 K
  - Desert clear if BT11 > 300 K
- Ancillary data comparisons
  - Ocean windows BT compared to OISST
  - Nighttime land compared with GDAS sfc temperature
- Temporal Consistency Checks
  - Not currently used on MODIS

Use of Threshold File

Code section from Fortran Land_Day.f subroutine

```
c ********  START OF GROUP 3 TESTS
      ****************
c ... visible (channel 1) reflectance threshold test.
      if (visusd) then
        if (nint(masv66) .ne. nint(bad_data)) then
          nmtests = nmtests + 1
          call set_qa_bit(qa_bits,20)
          if (masv66.le.dlref1(2)) then
            call set_bit(testbits,20)
            nptests = nptests + 1
          end if
          call
        conf_test(masv66,dlref1(1),dlref1(3),dlref1(4),
     +                  dlref1(2),1,c5)
          cmin3 = min(cmin3,c5)
          ngtests(3) = ngtests(3) + 1
        end if
      end if
```

Daytime Land Thresholds from **thresholds.dat.Aqua** file

```
! Daytime land

dl11_12hi     : 3.0
dl11_4lo      : -14.0, -12.0, -10.0, 1.0
dlco2         : 222.0, 224.0, 226.0, 1.0
dlh20         : 215.0, 220.0, 225.0, 1.0
dlref1        : 0.22,  0.18,  0.14,  1.0
dlref3        : 0.04,  0.035, 0.03,  1.0
dlvrat        : 1.85,  1.90,  1.95,  1.0
dltci         : 0.035, 0.0125
```

Users can fine tune thresholds for a region of interest

- Thresholds file included in delivery
  - thresholds.dat.Aqua
  - thresholds.dat.Terra
  - Contain Cloud mask 0, 1 and inflection point thresholds values for each test
  - File can be updated and the scene rerun

Example for daytime land reflectance in band 1:

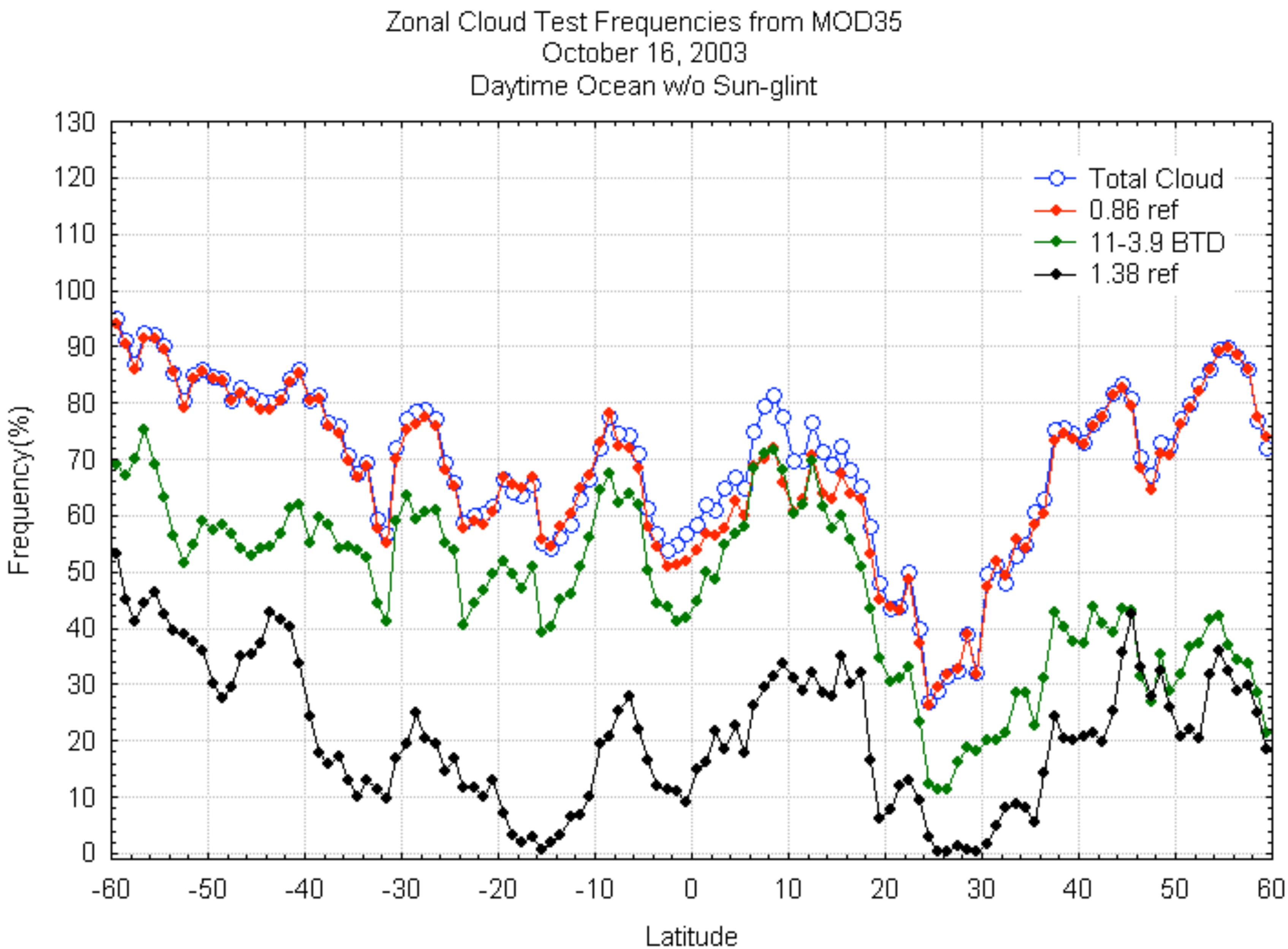
dlref1 : 0.22, 0.18, 0.14, 1.0

if too much cloud found, change to

dlref1 : 0.24, 0.20, 0.16, 1.0

Non-static Inputs

- MODIS L1B (MOD021KM, MOD02QKM) and geolocation file (MOD03)
- Daily Near Real-Time SSM/I EASE-Grid Daily Global Ice Concentration and Snow Extent (NISE) (Nighttime)
  ex: NISE_SSMIF13_20020430.HDFEOS
- Daily SSMI sea ice concentration from the National Centers for Environmental Predition (NCEP) (Nighttime)
  ex: eng.020430
- 6 hourly Global Data Assimilation System T126 resolution analysis from NCEP (Land Surface Temperature)
  ex: gdas1.PGrbF00.020430.00z
- Weekly Optimum Interpolation (OI) Sea Surface Temperature (SST) Analysis ex: oisst.20050608
- Latest 7 days ancillary data and documentation available from:
  ftp://ftp.ssec.wisc.edu/pub/eosdb/ancillary


Zonal Cloud Test Frequencies from MOD35
October 16, 2003
Daytime Ocean w/o Sun-glint
Total Cloud
0.86 ref
11-3.9 BTD
1.38 ref
Frequency(%)
Latitude
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-60
-50
-40
-30
-20
-10
0
10
20
30
40
50
60

Output Product Description

Product Resolution: 1 km and 250 m

bit field	Description Key	Result
0	Cloud Mask Flag	0 = not determined
		1 = determined
1-2	FOV Confidence Flag	00 = cloudy
		01 = uncertain
		10 = probably clear
		11 = confident clear
Processing Path Flags		
3	Day / Night Flag	0 = Night / 1 = Day
4	Sun glint Flag	0 = Yes / 1 = No
5	Snow / Ice Background Flag	0 = Yes/ 1 = No
6-7	Land / Water Flag	00 = Water
		01 = Coastal
		10 = Desert
		11 = Land

ADDITIONAL INFORMATION

bit field	Description Key	Result
8	Heavy Aerosol Flag	0 = Yes / 1 = No
9	Thin Cirrus Detected (solar)	0 = Yes / 1 = No
bit field	**Description Key**	**Result**
10	Shadow Found	0 = Yes / 1 = No
11	Thin Cirrus Detected (IR)	0 = Yes / 1 = No
12	Spare	

1-km Spectral Test Cloud Flags

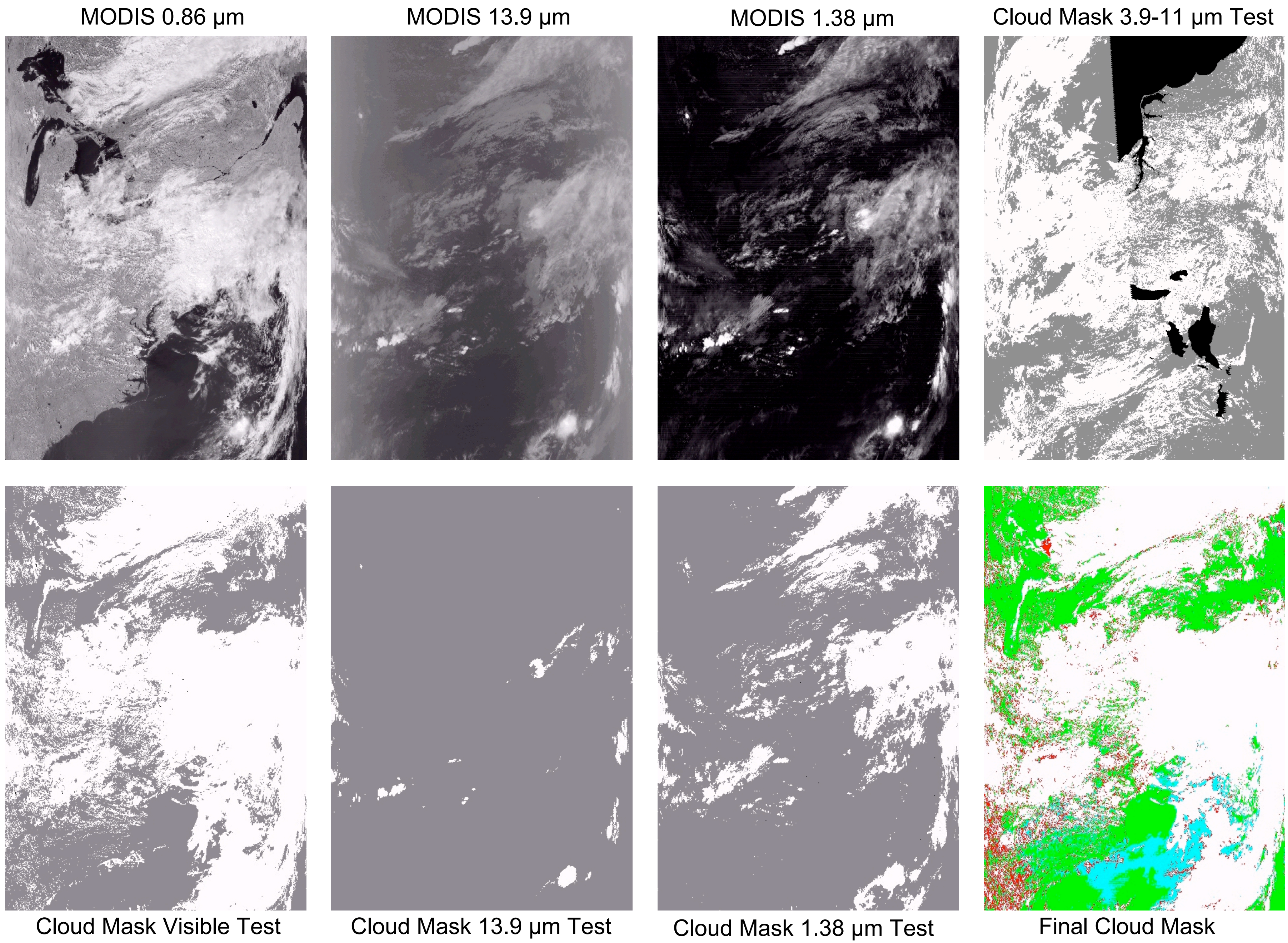
bit field	Description Key	Result
13	Cloud Flag - 11 µm IR Threshold	0 = Yes / 1 = No
14	High Cloud Flag - CO2 Threshold Test	0 = Yes / 1 = No
15	High Cloud Flag - 6.7 µm Test	0 = Yes / 1 = No
16	High Cloud Flag - 1.38 µm Test	0 = Yes / 1 = No
17	High Cloud Flag - 3.7-12 µm Test	0 = Yes / 1 = No
18	Cloud Flag - IR Temperature Difference	0 = Yes / 1 = No
19	Cloud Flag - 3.9-11 µm Test	0 = Yes / 1 = No
20	Cloud Flag - Visible Reflectance Test	0 = Yes / 1 = No
21	Cloud Flag - Visible Ratio Test	0 = Yes / 1 = No
22	Clear-sky Restoral Test	0 = Yes / 1 = No
23	Cloud Flag - 7.3-11 µm Test	0 = Yes / 1 = No

Additional Tests

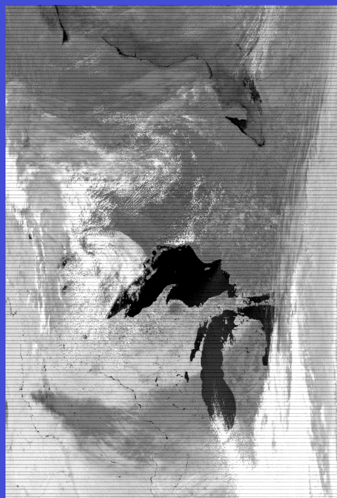
bit field	Description Key	Result
24	Cloud Flag - Temporal Consistency	0 = Yes / 1 = No
25	Cloud Flag - Spatial Consistency	0 = Yes / 1 = No
26	Clear-sky Restoral Tests	0 = Yes / 1 = No
27	Cloud Test – Surface Temp. Comparison	0 = Yes / 1 = No
28	Suspended Dust Flag	0 = Yes / 1 = No
29	Cloud Flag – 8.6-7.3 μm Test	0 = Yes / 1 = No
30	Cloud Flag – 11 μm Spatial Variability	0 = Yes / 1 = No
31	Spare	

250-m Cloud Flag - Visible Tests

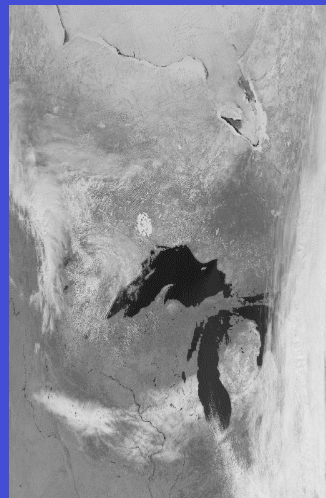
32-47	250 m visible reflectance test	0 = Yes / 1 = No


MODIS 0.86 µm
MODIS 13.9 µm
MODIS 1.38 µm
Cloud Mask 3.9-11 µm Test
Cloud Mask Visible Test
Cloud Mask 13.9 µm Test
Cloud Mask 1.38 µm Test
Final Cloud Mask

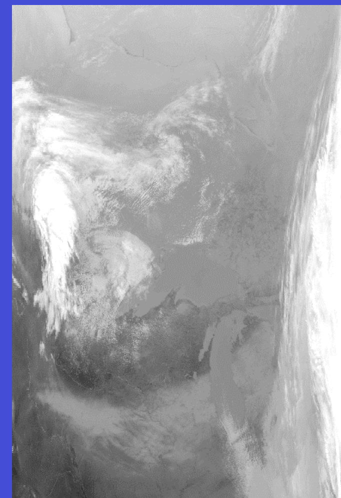
1.6 µm image



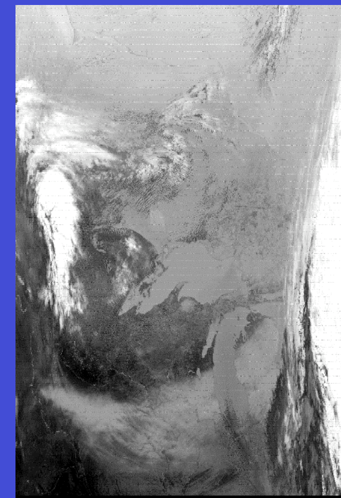
0.86 µm image



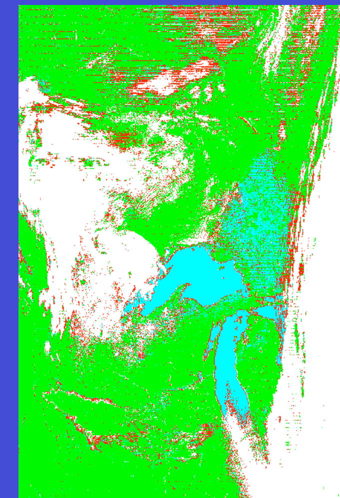
11 µm image



3.9 µm image

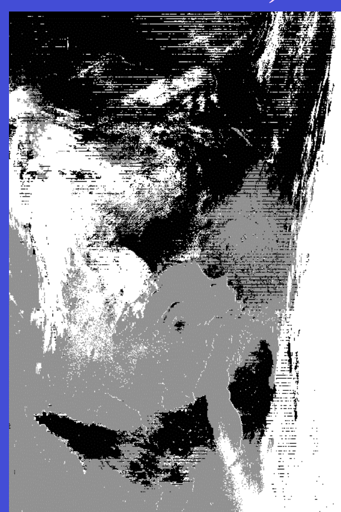


cloud mask

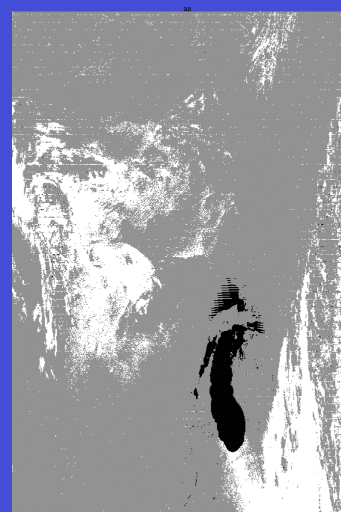


Snow test
(impacts choice of
tests/thresholds)

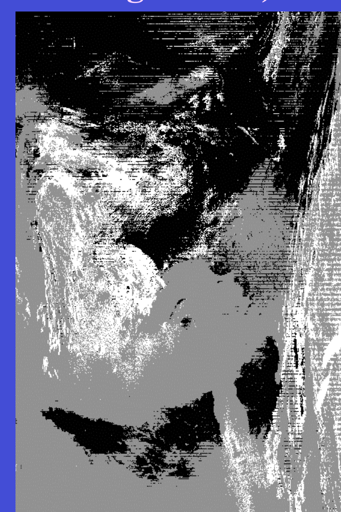
VIS test
(over non-snow
covered areas)



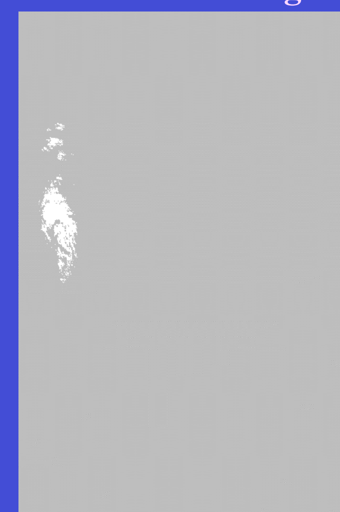
3.9 - 11 BT test
for low clouds



11 - 12 BT test
(primarily for
high cloud)

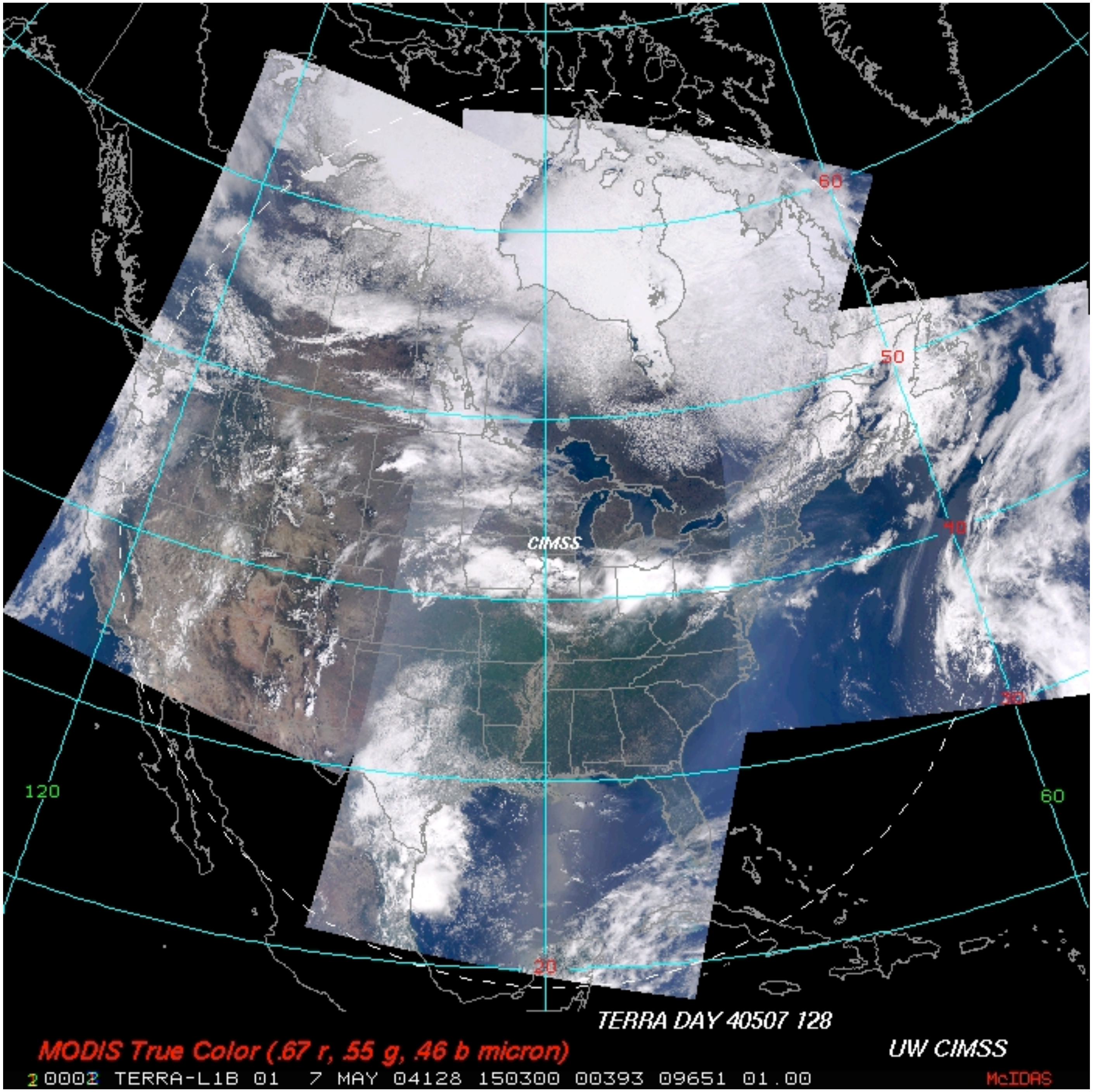


13.9 µm
high cloud test
(sensitive in cold regions)

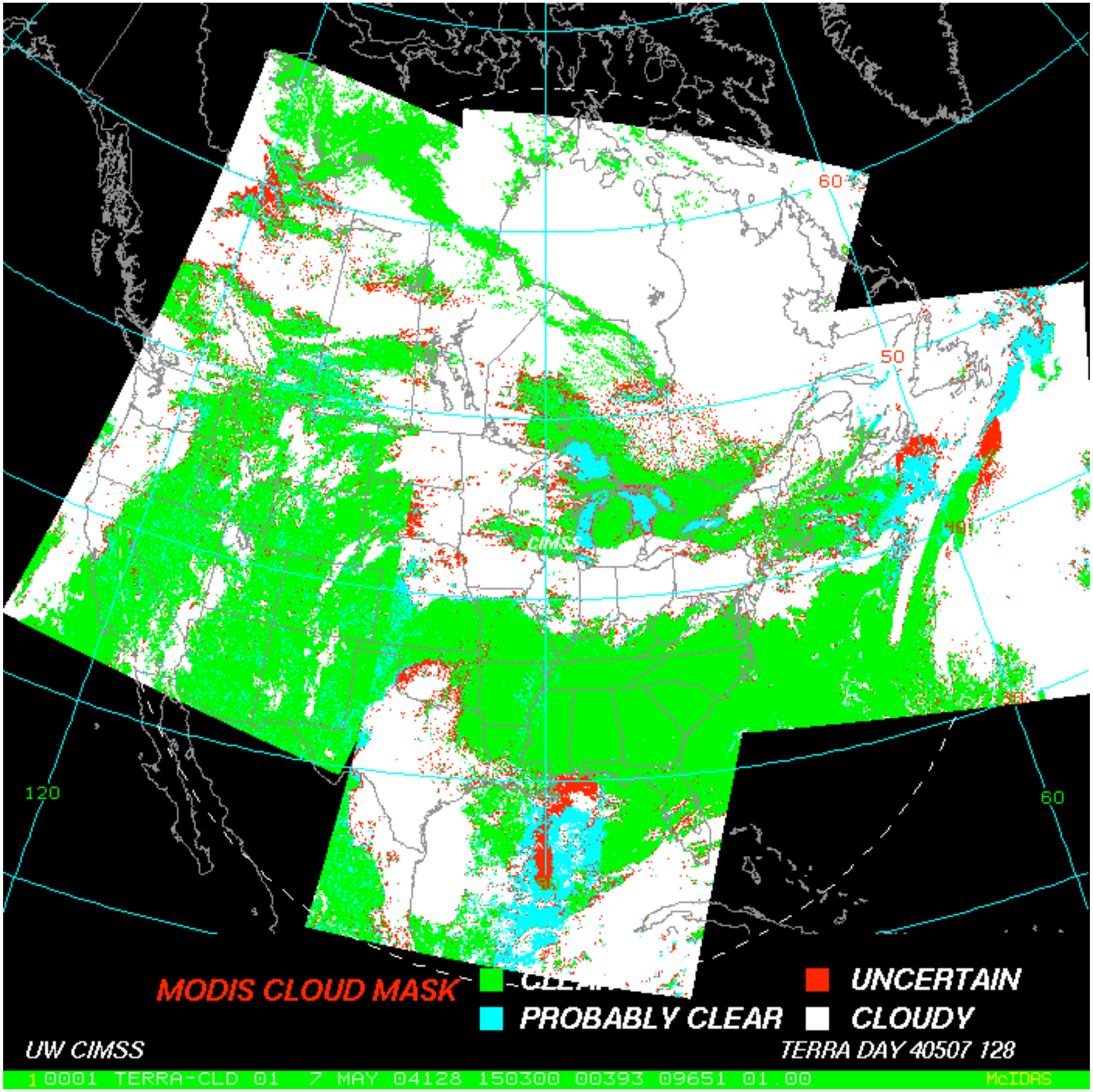


MODIS cloud mask example

(**confident clear** is green, **probably clear** is blue, **uncertain** is red, **cloud** is white)

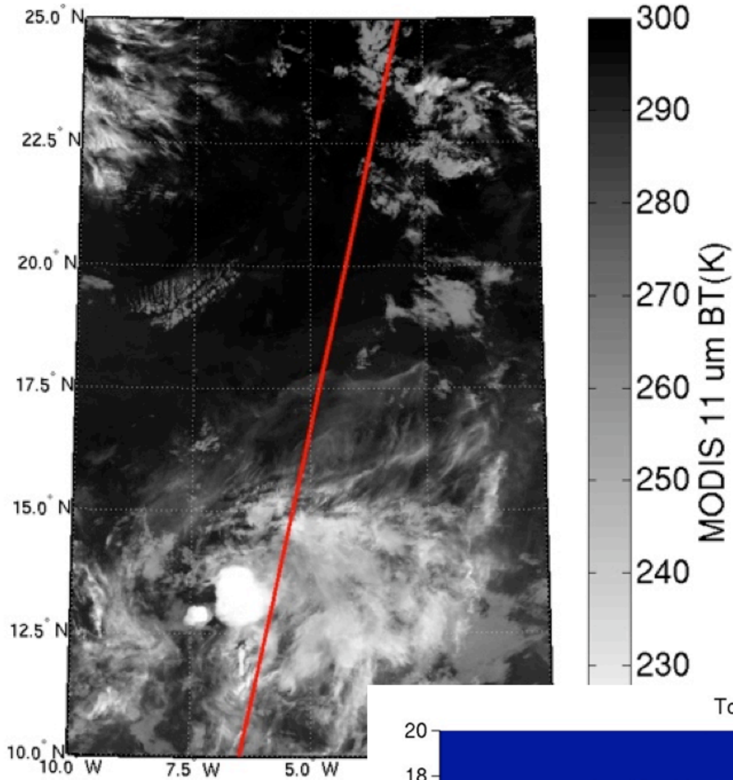


60
50
40
30
20
120
60
CIMSS
TERRA DAY 40507 128
MODIS True Color (.67 r, .55 g, .46 b micron)
UW CIMSS
20002 TERRA-L1B 01 7 MAY 04128 150300 00393 09651 01.00
McIDAS

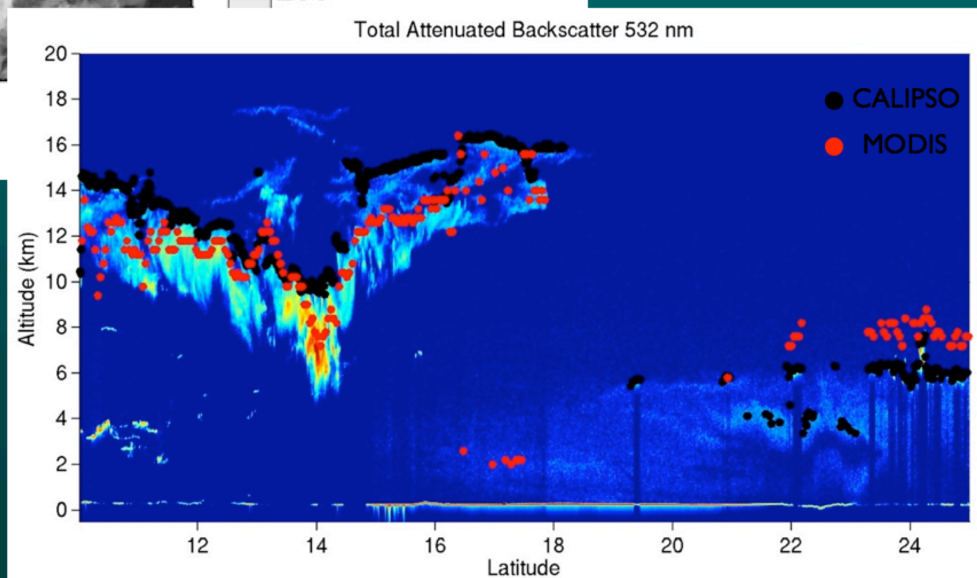


60
50
40
120
60
MODIS CLOUD MASK
UNCERTAIN
PROBABLY CLEAR
CLOUDY
UW CIMSS
TERRA DAY 40507 128
1 0001 TERRA-CLD 01 7 MAY 04128 150300 00393 09651 01.00
McIDAS

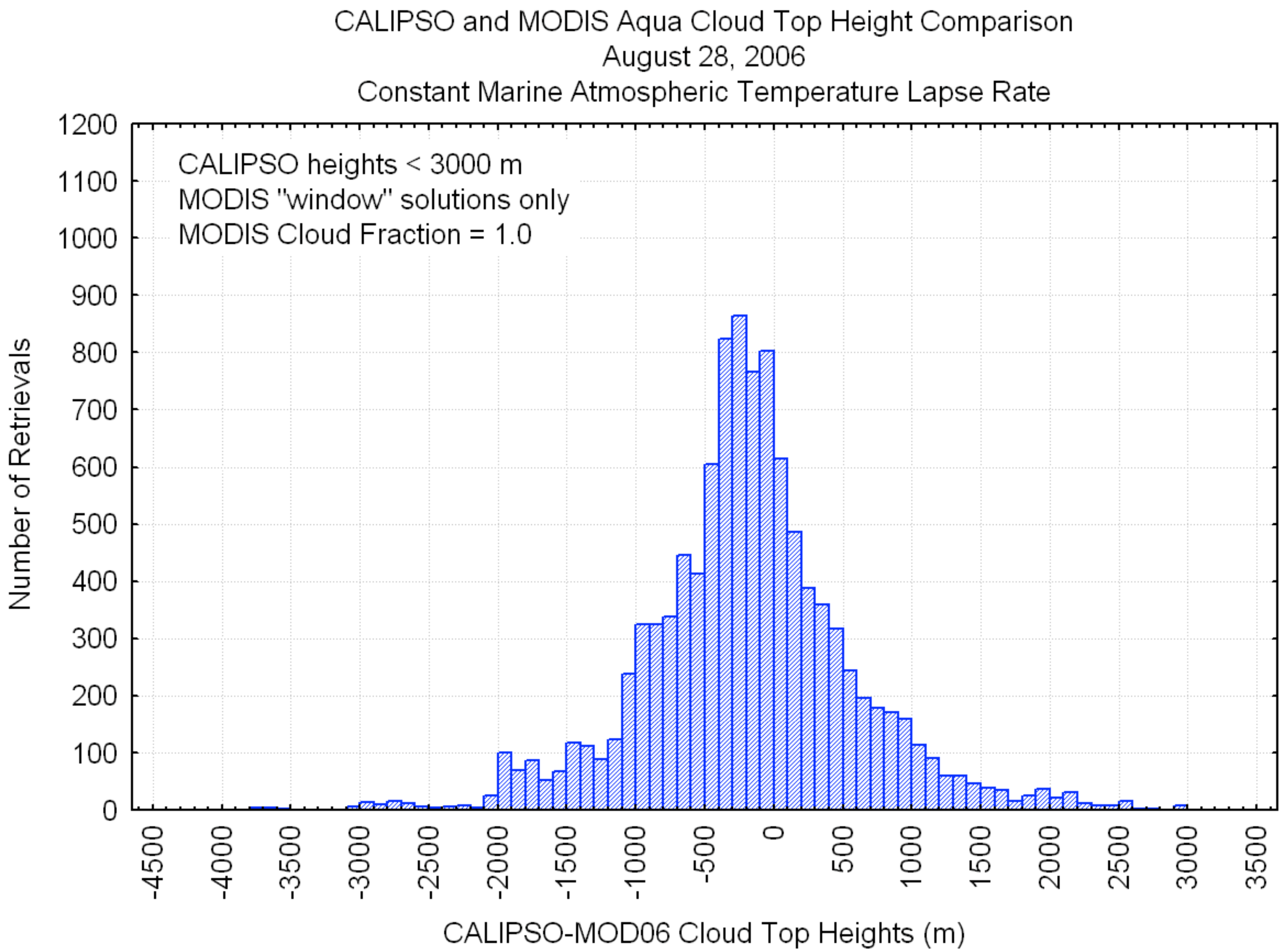
MODIS and CALIPSO Cloud Comparison



28 August 2007



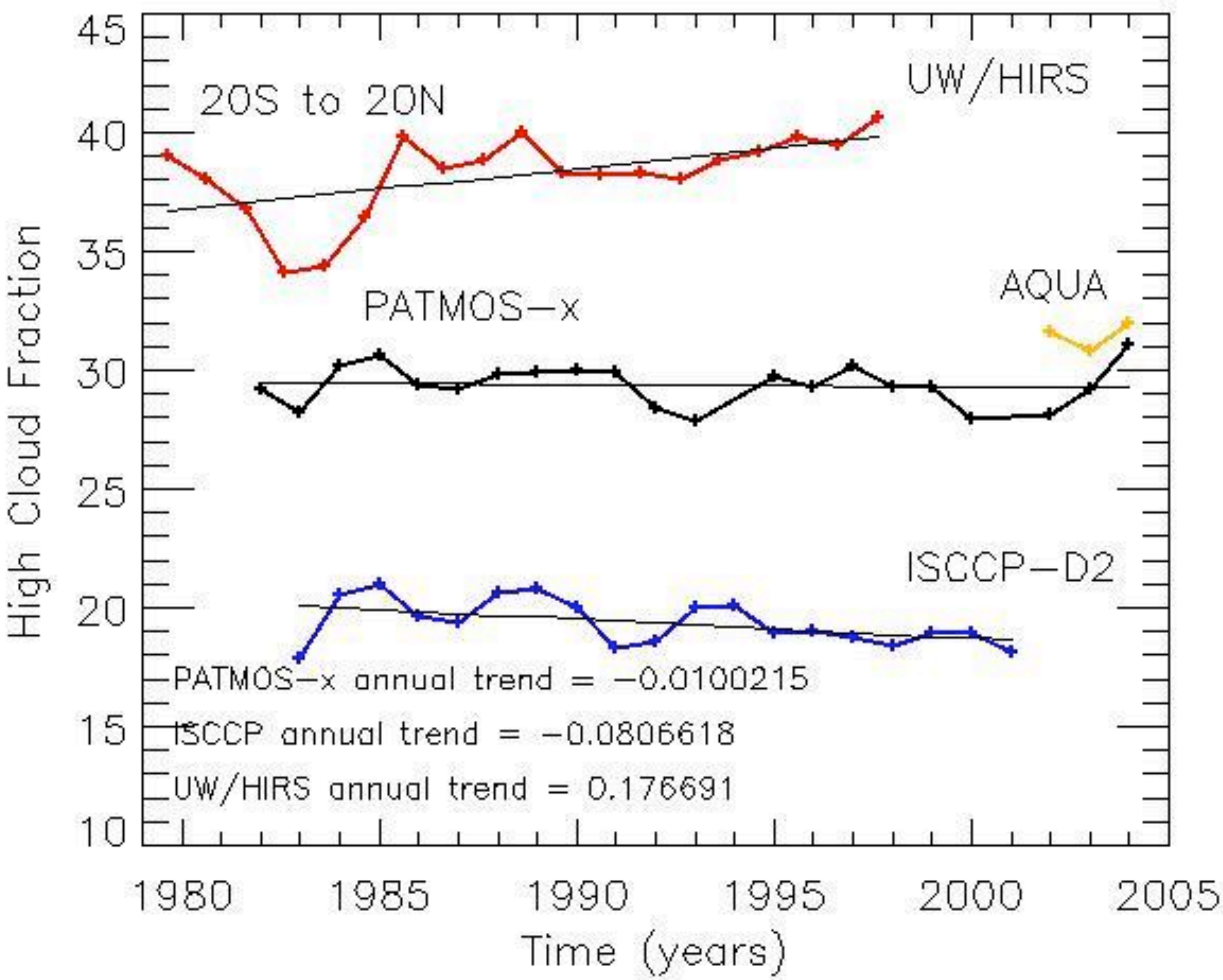
MODIS and CALIPSO Cloud Comparison

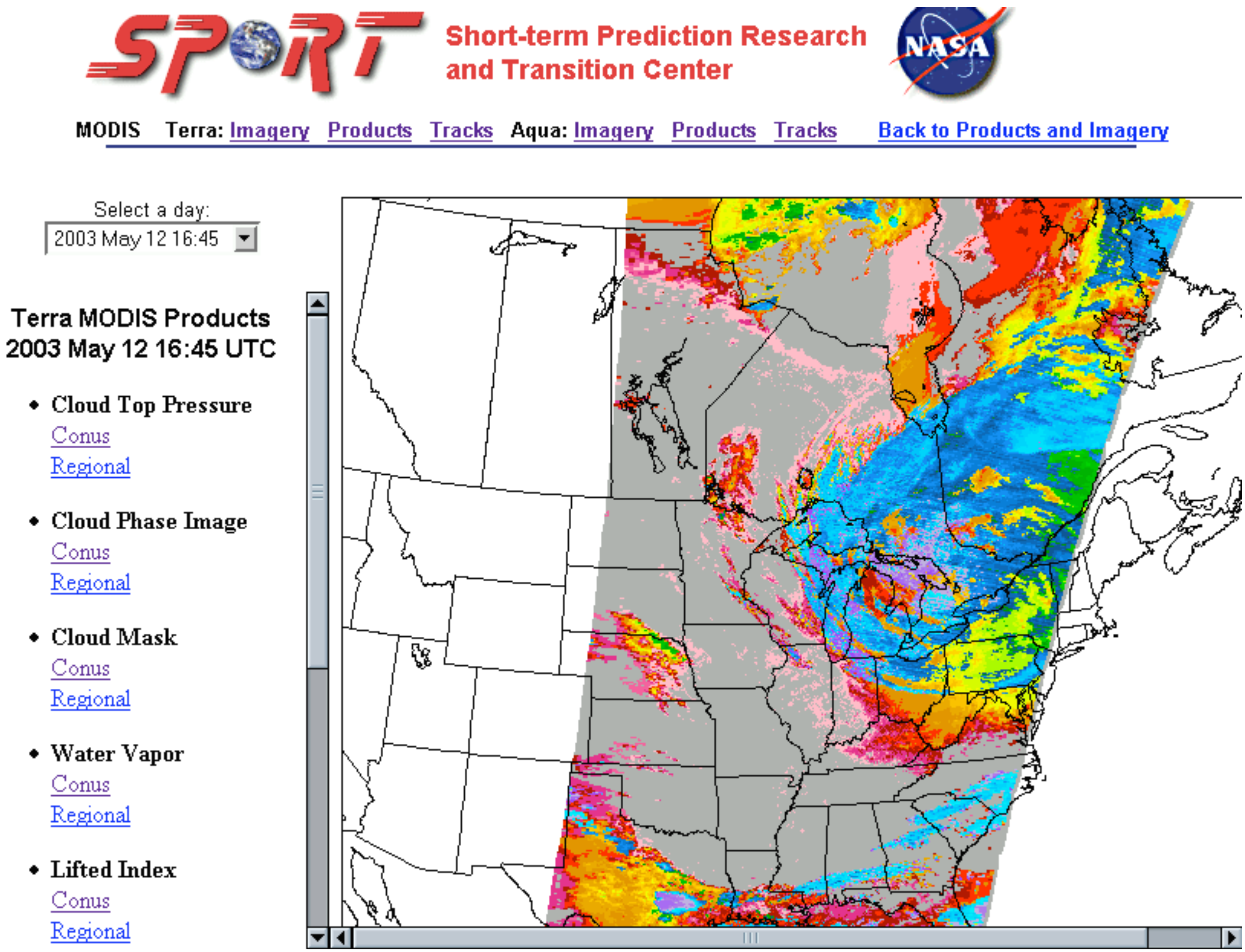


Applications

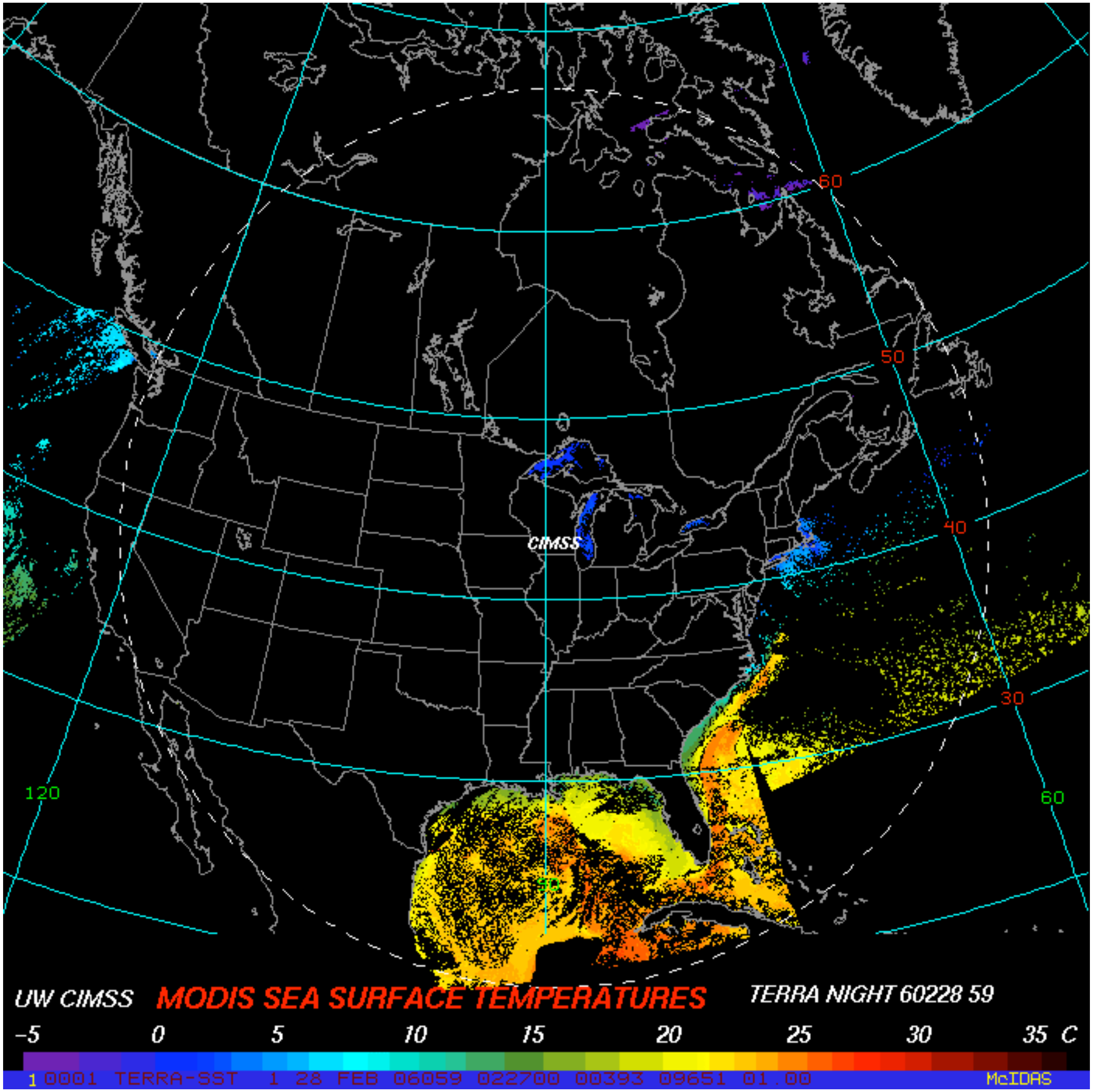
- Top of the Food Chain
  - Input to all other algorithms - regulates when retrievals are performed.
- Cloud Climatology
- Cloud Modeling, Climate Modeling
- Data Assimilation
- Meteorology
  - Forecasting Max/Min Temperatures
  - Precipitation
  - Etc.

Extending Cloud Climatologies

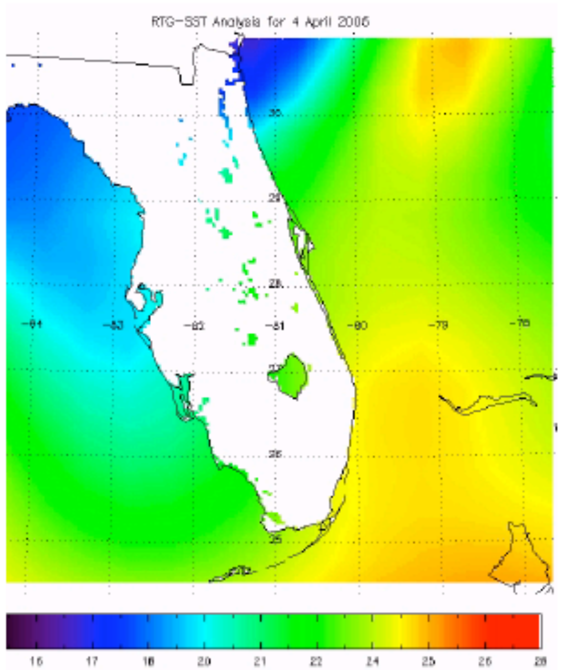


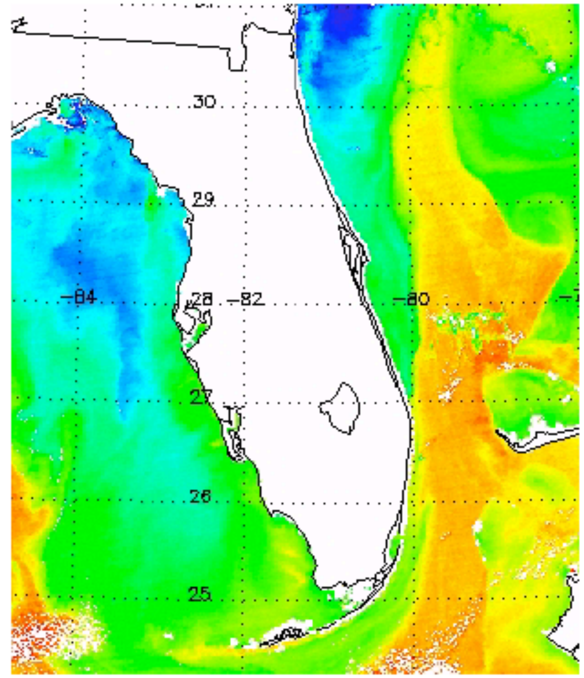


http://wwwghcc.msfc.nasa.gov/sport/sport_featured.html


60
50
40
30
120
60
CIMSS
UW CIMSS
MODIS SEA SURFACE TEMPERATURES
TERRA NIGHT 60228 59
-5 0 5 10 15 20 25 30 35 C
1 0001 TERRA-SST 1 28 FEB 06059 022700 00393 09651 01.00
McIDAS

Global .5 degree SST

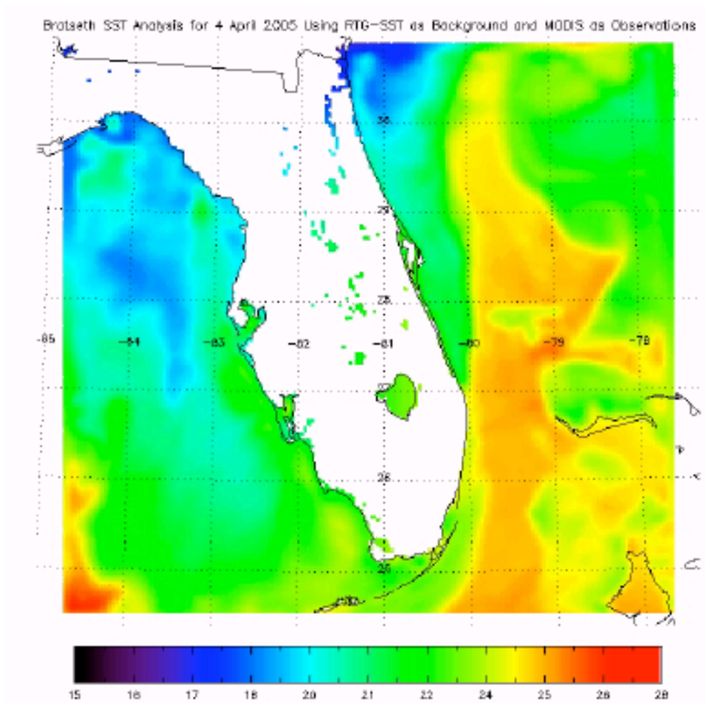




MODIS 1842 UTC SST

Sea Surface Temperatures

4 April 2005

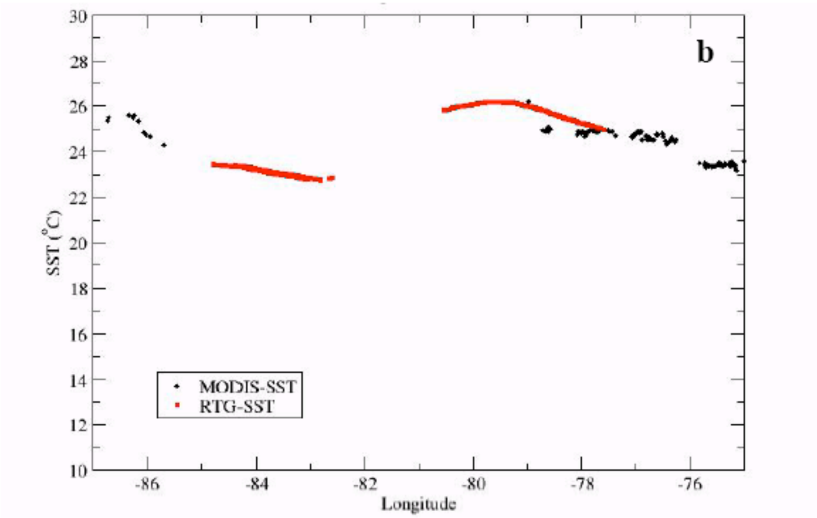


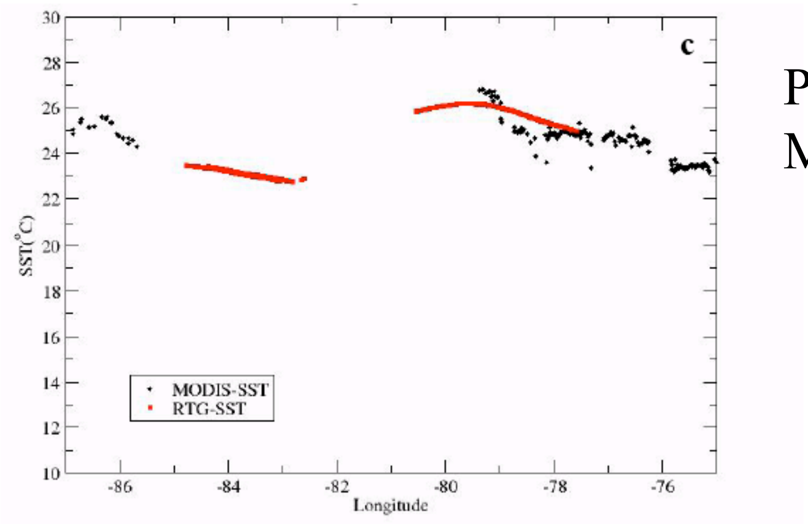
Bratseth analysis combining the RTG-SST and MODIS data.

SST Comparison – MODIS and Global Gridded

10 December 2005 - 28 N Latitude

Confident Clear Cloud
Mask Threshold





Probably Clear Cloud
Mask Threshold

IMAPP MODIS Product Page, Moscow, Russia

Use IMAPP MODIS cloud mask as a means of choosing scenes for users

EOStation.ScanEx.ru

- EOStation
- Schedules
- >MODIS data
  - Product calendar
  - MRDS
  - Search&Browse
  - Sample files
- Custom service
- Under the hood
- Software
- Image gallery
- Contact us

Login to your private area:

Password:

Login

MODIS Data >> Single Pass Browse [AM0409050814]

Pass ID:	AM0409050814
Satellite:	Terra
Start time:	2004-09-05 08:14 UTC

RGB: 1-4-3, 1:10

Band 32 (IR), 1:10

Product files currently available for this pass that may be downloaded or requested on CDs.
Use links on file names to download the files. If file names are not marked as a link then the file is missing or you have no permission to access corresponding data type.

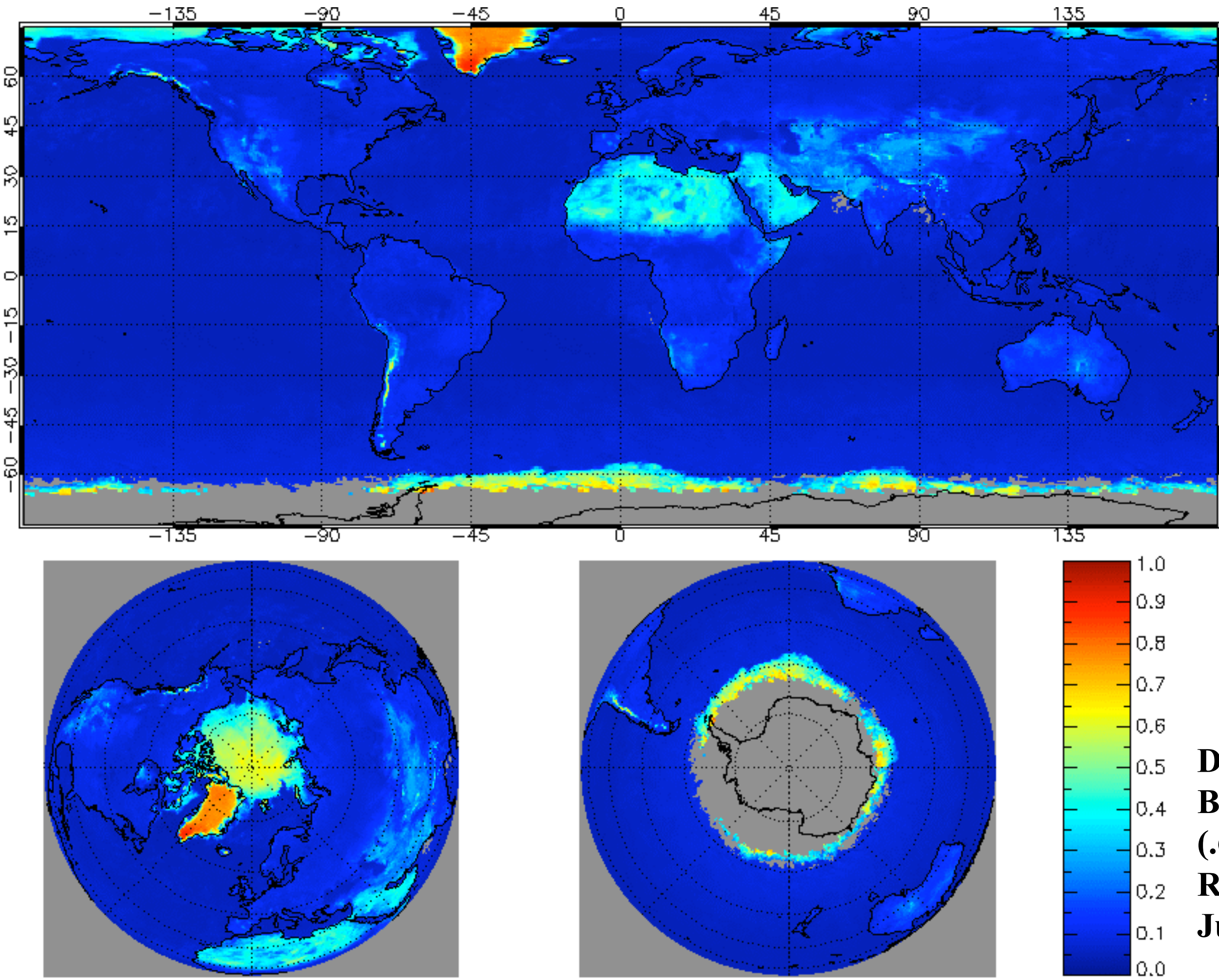
File	Size	Notes
TCB1.AM0409050814.ecw	1823 kB	True color (1-4-3) image, ECW compressed, 1km
-	-	MODIS Level-0(raw) data
-	-	MOD01, unpacked image data
-	-	MOD03, geolocation data
-	-	MOD021KM, geolocated calibrated radiances (1km)
-	-	MOD02HKM, geolocated calibrated radiances (500m)
-	-	MOD021KM, geolocated calibrated radiances (250m)
-	-	MOD021OBC, onboard calibrator data
MOD35.AM0409050814.cl.gif	623 kB	1km MODIS cloud mask. GIF image, levels of free sky confidence
MOD14_AM0409050814.zip	26 MB	MOD14, MODIS fire mask (ZIP compressed)
MOD14shp_AM0409050814.zip	13 kB	MODIS fire points vector map (ESRI SHP, ZIP compressed)

http://eostation.scanex.ru/data/cellquery.html

Known Problems

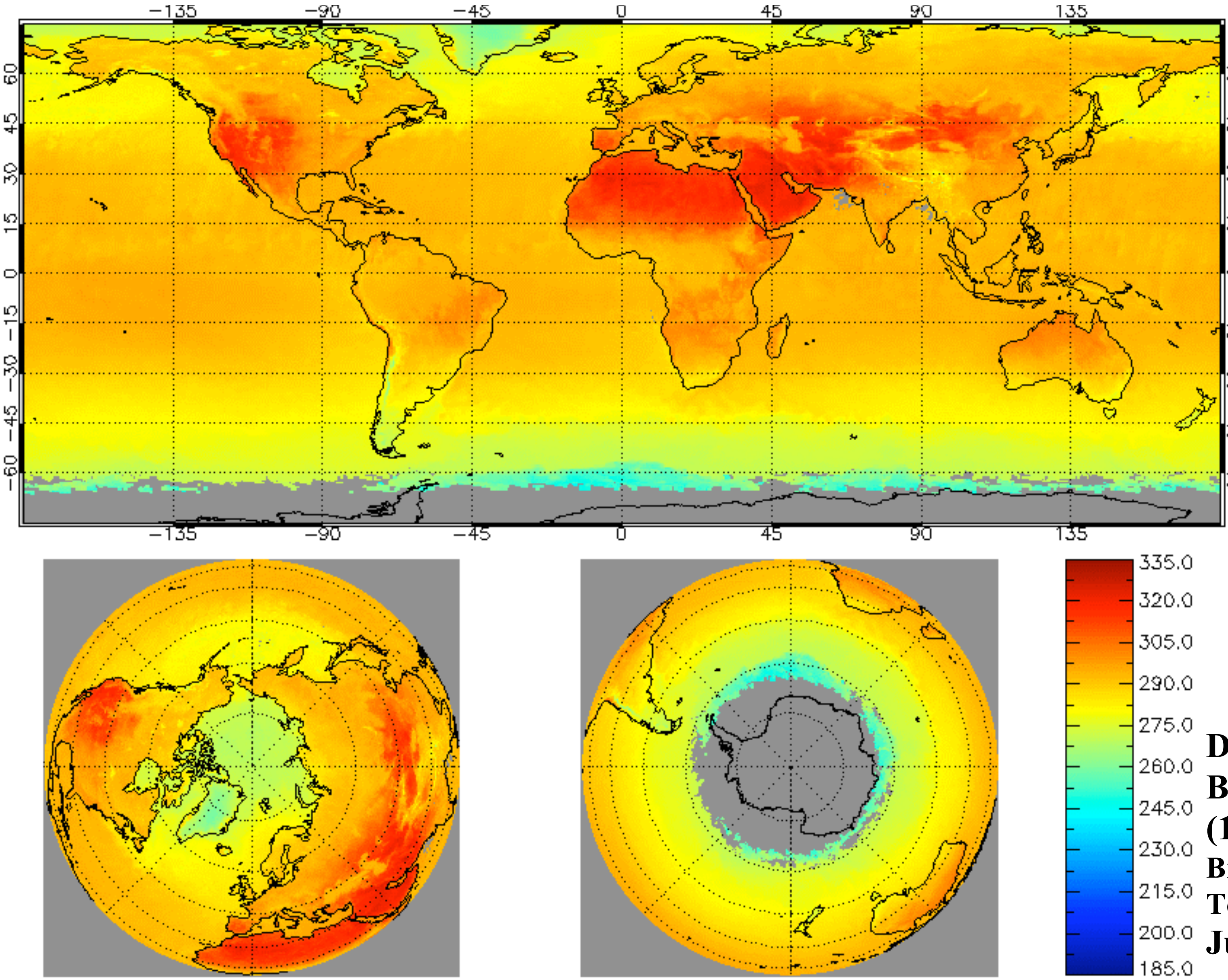
- MODIS algorithm is clear sky conservative
  - If there is a doubt, it is cloudy
- Nighttime algorithm is different –
  - 16 versus 36 channels available
- Transition regions
  - terminator, edges of desert regions, edges of snow regions, etc.
- Very specific regions
  - Certain surfaces, certain times of year, certain sun angles (bare soils over the midwest during the spring)

MODIS Clear Sky Product



Daytime
Band 1
(.65 μm)
Reflectance
July 2002

MODIS Clear Sky Product



Daytime
Band 31
(11 µm)
Brightness
Temperature
July 2002