MODIS/AIRS Workshop
MODIS Level 2 Products

Pretoria, South Africa

5 April 2006

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Cooperative Institute for Meteorological Satellite Studies

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Day 2 Lecture Outline

- Overview of MODIS level 2 products
- MODIS direct broadcast level 2 software
- MODIS Level 2 product theory and algorithms
  - MODIS cloud mask

  MODIS land product review
  - MODIS NDVI
  - MODIS fire product

MODIS Science Team

- Land, Ocean, Atmosphere, Calibration Teams
  - http://modis.gsfc.nasa.gov/
- Data Distribution Sites
  - Land
    - http://edcdaac.usgs.gov/dataproducts.asp
    - Snow/Ice data sets - http://nsidc.org/daac/modis/index.html
  - Atmosphere
    - http://daac.gsfc.nasa.gov/MODIS/products.shtml
  - Ocean
    - Ocean Color - http://oceancolor.gsfc.nasa.gov/
    - SST - http://daac.gsfc.nasa.gov/MODIS/products.shtml
  - L1B (Calibrated, Geolocated)
    - http://daac.gsfc.nasa.gov/MODIS/products.shtml

MODIS Standard Products (1)

Calibration

- ***MOD 01 - Level-1A Radiance Counts***
- ***MOD 02 - Level-1B Calibrated Geolocated Radiances***
- ***MOD 03 - Geolocation Data Set***

Atmosphere

- ***MOD 04 - Aerosol Product***
- ***MOD 05 - Total Precipitable Water (Water Vapor)***
- ***MOD 06 - Cloud Product***
- ***MOD 07 - Atmospheric Profiles***
- MOD 08 - Gridded Atmospheric Product
- ***MOD 35 - Cloud Mask***

MODIS Standard Products (2)

Land

- MOD 09 - Surface Reflectance
- MOD 10 - Snow Cover
- MOD 11 - Land Surface Temperature & Emissivity
- MOD 12 - Land Cover/Land Cover Change
- ***MOD 13 - Gridded Vegetation Indices (NDVI & EVI)***
- ***MOD 14 - Thermal Anomalies (Fires)***
- MOD 15 - Leaf Area Index & FPAR
- MOD 16 - Evapotranspiration
- MOD 17 - Net Photosynthesis and Primary Productivity
- MOD 29 - Sea Ice Cover
- MOD 43 - Bidirectional Reflectance Distribution Function (BRDF)
- MOD 44 - Vegetation Cover Conversion

MODIS Standard Products (3)

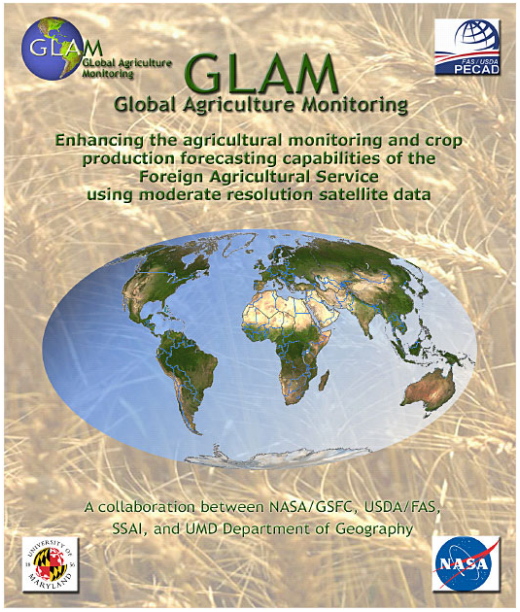
Ocean

- MOD 18 - Normalized Water-leaving Radiance
- MOD 19 - Pigment Concentration
- ***MOD 20 - Chlorophyll Fluorescence***
- MOD 21 - Chlorophyll_a Pigment Concentration
- MOD 22 - Photosynthetically Available Radiation (PAR)
- MOD 23 - Suspended-Solids Concentration
- MOD 24 - Organic Matter Concentration
- MOD 25 - Coccolith Concentration
- MOD 26 - Ocean Water Attenuation Coefficient
- MOD 27 - Ocean Primary Productivity
- ***MOD 28 - Sea Surface Temperature***
- MOD 36 - Total Absorption Coefficient
- MOD 37 - Ocean Aerosol Properties
- MOD 39 - Clear Water Epsilon

Key Areas of Uncertainty in Understanding Climate & Global Change

- Earth's radiation balance and the influence of clouds on radiation and the hydrologic cycle
- Oceanic productivity, circulation and air-sea exchange
- Transformation of greenhouse gases in the lower atmosphere, with emphasis on the carbon cycle
- Changes in land use, land cover and primary productivity, including deforestation
- Sea level variability and impacts of ice sheet volume
- Chemistry of the middle and upper stratosphere, including sources and sinks of stratospheric ozone
- Volcanic eruptions and their role in climate change

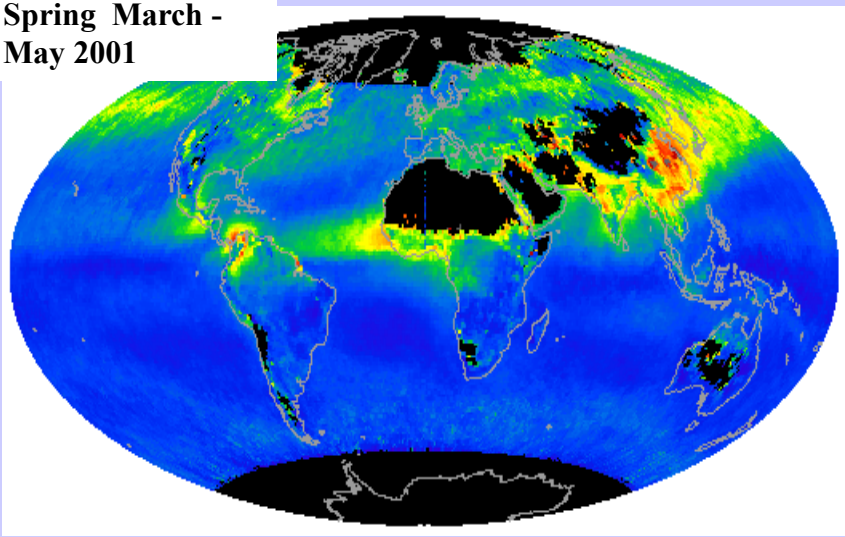
GLobal Agricultural Monitoring (GLAM)



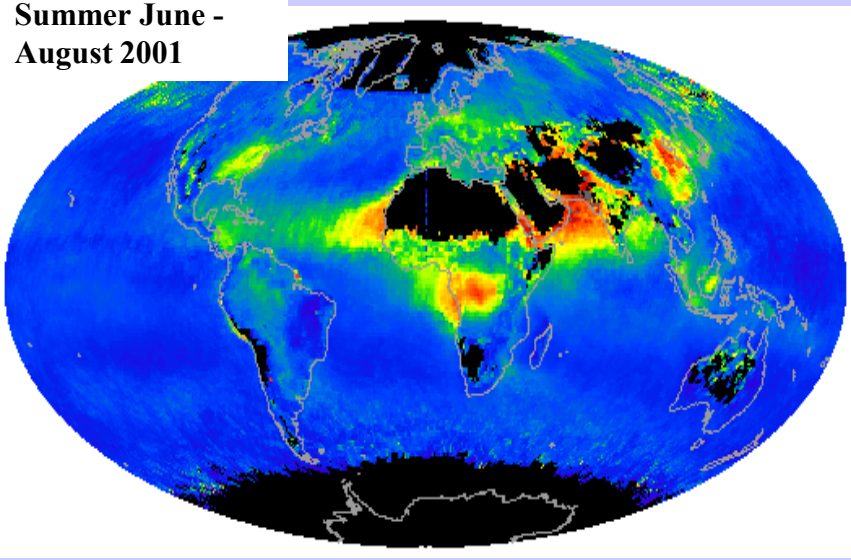
- **Upgrade from AVHRR 8km to MODIS**
  - **Establish Data Continuity**
- **NRT MODIS Rapid Response Data**
  - **Customized products**
- **MODIS Crop Mask / Type Mapping**
- **MODIS/AVHRR Time-series Data Base**
- **Improved GUI for Information Extraction**
- **Develop an Operational FAS Prototype based at GSFC**
- **Prepare for use of NPP VIIRS**

Project website: http://tripwire.geog.umd.edu/usda/index.asp

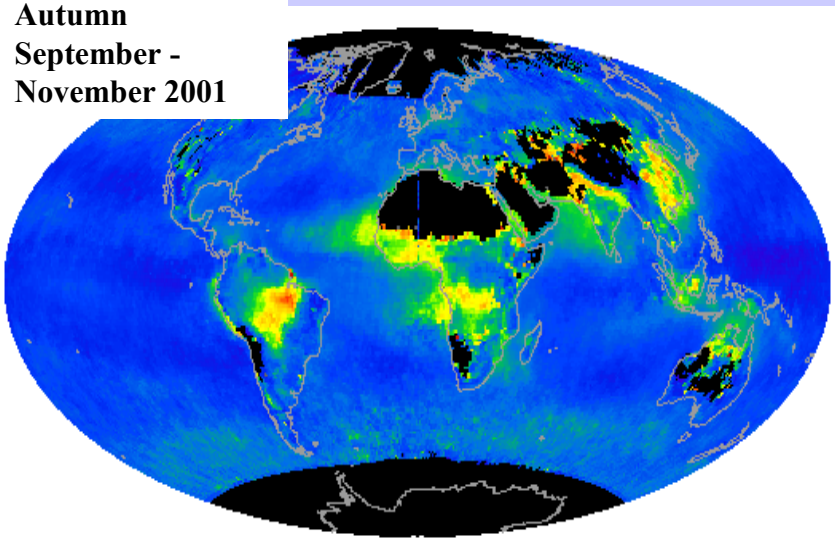
Spring March - May 2001



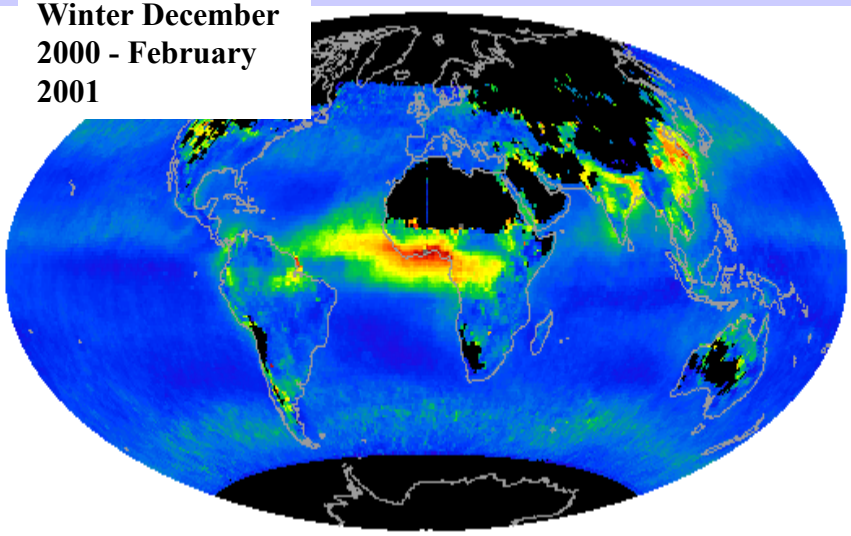
Summer June - August 2001

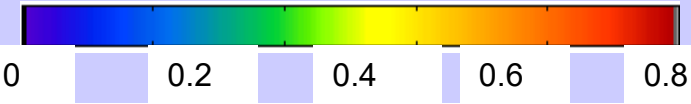


Autumn September - November 2001



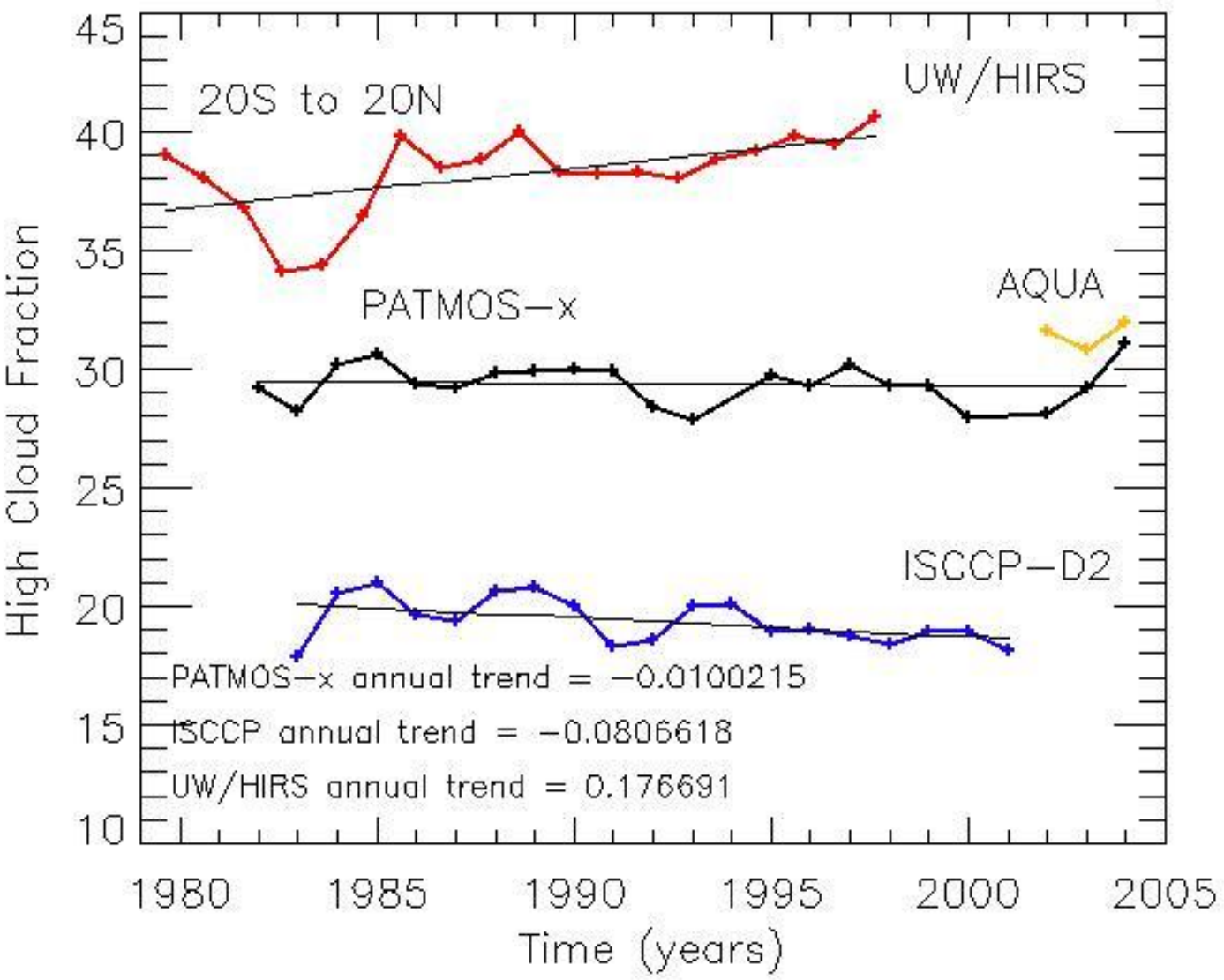
Winter December 2000 - February 2001





Average aerosol optical thickness

Extending Cloud Climatologies



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Direct Broadcast

- Many local, short time scale applications from climate research satellite
- Funding for the International MODIS / AIRS Processing Package (IMAPP)
- Direct Readout Lab (NDVI, Fires)
  - http://directreadout.gsfc.nasa.gov/index.cfm?section=downloads&page=technology
- SeaDAS
- Examples of IMAPP applications
  - Polar wind and MODIS products in Antarctica
  - Cloud and water vapor MODIS products used by forecasters in Argentina
  - MODIS cloud products used as part of CLOUDMAP2 European Union numerical weather prediction study

IMAPP Level 2 Products

- Attempt was made to match DAAC products as closely as possible
- Requires no outside toolkits besides HDF libraries
- All required ancillary data is gathered and distributed from our ftp site (see http site below)
- Tested on 5 different PC/Unix platforms (including Linux, Sun, IRIX, AIX and HP)
- Code is efficient – All current IMAPP products running and producing products ~ 1.5-2 hours after data collection ends

- *Available from:*
  http://cimss.ssec.wisc.edu/~gumley/IMAPP/

Current IMAPP Status

MODIS products – Level 1B and Geolocation

- cloud mask, cloud properties - height, temperature, emissivity, phase ***(Collect 5)***
- atmospheric profiles (T, q, tpw, total ozone, stability) ***(Collect 5)***
- aerosol optical depth
- sea surface temperatures
- near-infrared water vapor

MODIS utilities

- de-striping band 26 (correction for band 5 spectral leak)
- creating true color images tutorial

IMAPP Output L2 Product Format

- Binary flat file with accompanying text header file
- Band interleaved
  - cloud mask is exception – byte sequential
- IDL code included in release to turn products into HDF near –DAAC format if desired by user

Available from:

http://cimss.ssec.wisc.edu/~gumley/IMAPP/

MODIS Cloud Products

- IMAPP products only:
  - Cloud Mask (48 bit product)
  - Cloud Top Properties (Pressure, Temperature, Emissivity, Fraction)
  - Cloud Phase (Infrared Technique)

MODIS/AIRS Workshop
MODIS Level 2 Cloud Mask Product

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MODIS Cloud Mask

Ackerman, Frey, Strabala – CIMSS

http://modis-atmos.gsfc.nasa.gov/MOD35_L2/index.html

- **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

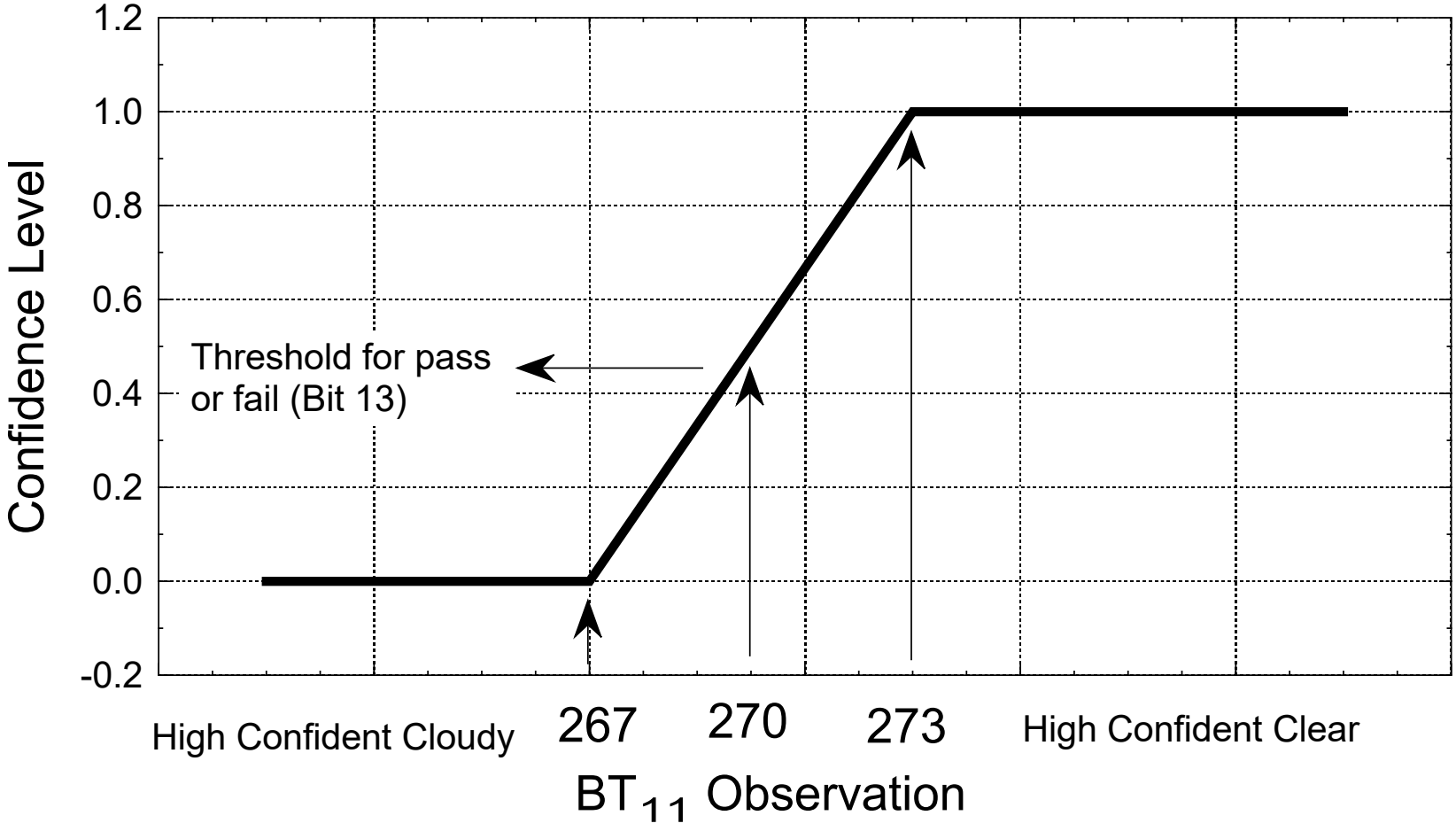
Algorithm Development

- 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)

Algorithm Development

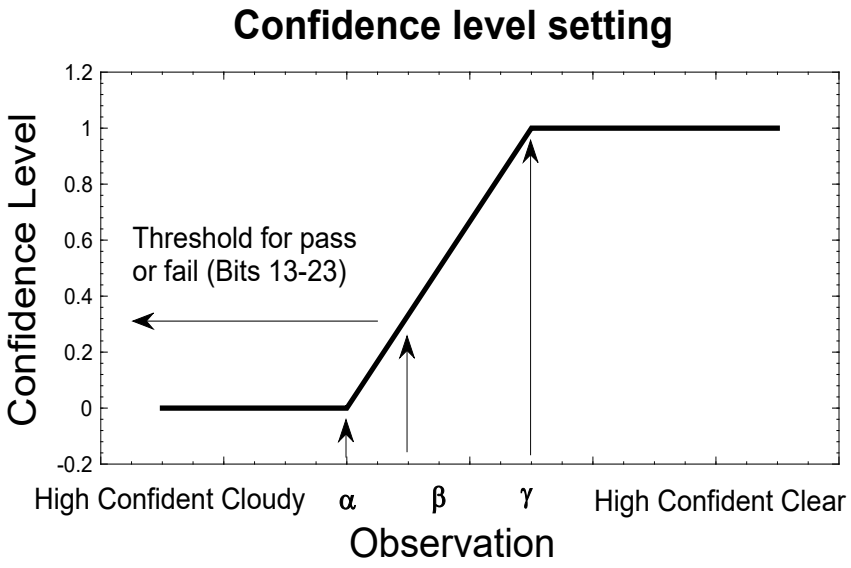
- Solution
  - Cloud mask based on combination of individual spectral tests.
  - Given constraints and building on previous work, best possible chance of an end product that would be useful to as many people as possible.

Confidence Level of Clear



Example thresholds for the simple IR window cold cloud test.

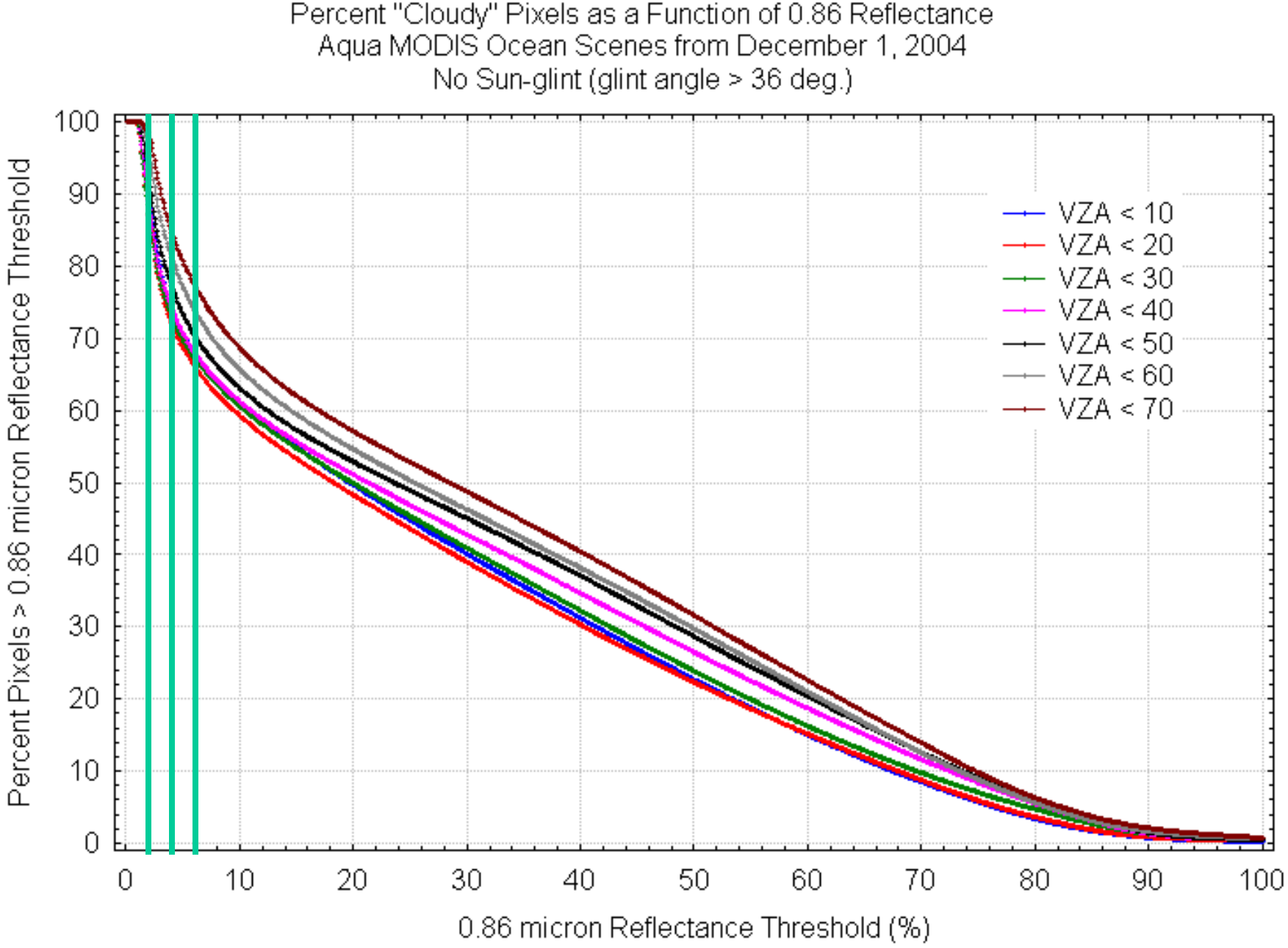
Quality Flags



- 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
0
10
20
30
40
50
60
70
80
90
100

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

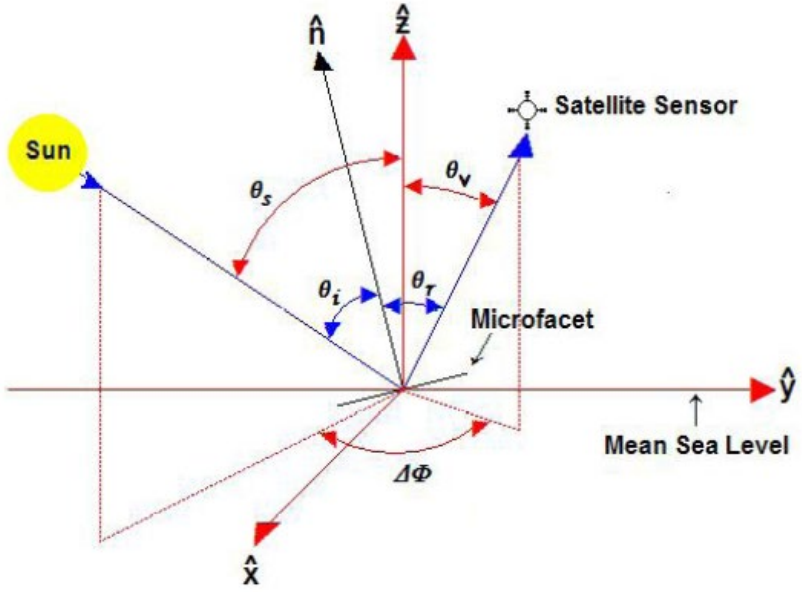
Sun Glint Ellipse Defined by: $\theta_r < 36$

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

Where θ_v = Viewing Zenith Angle

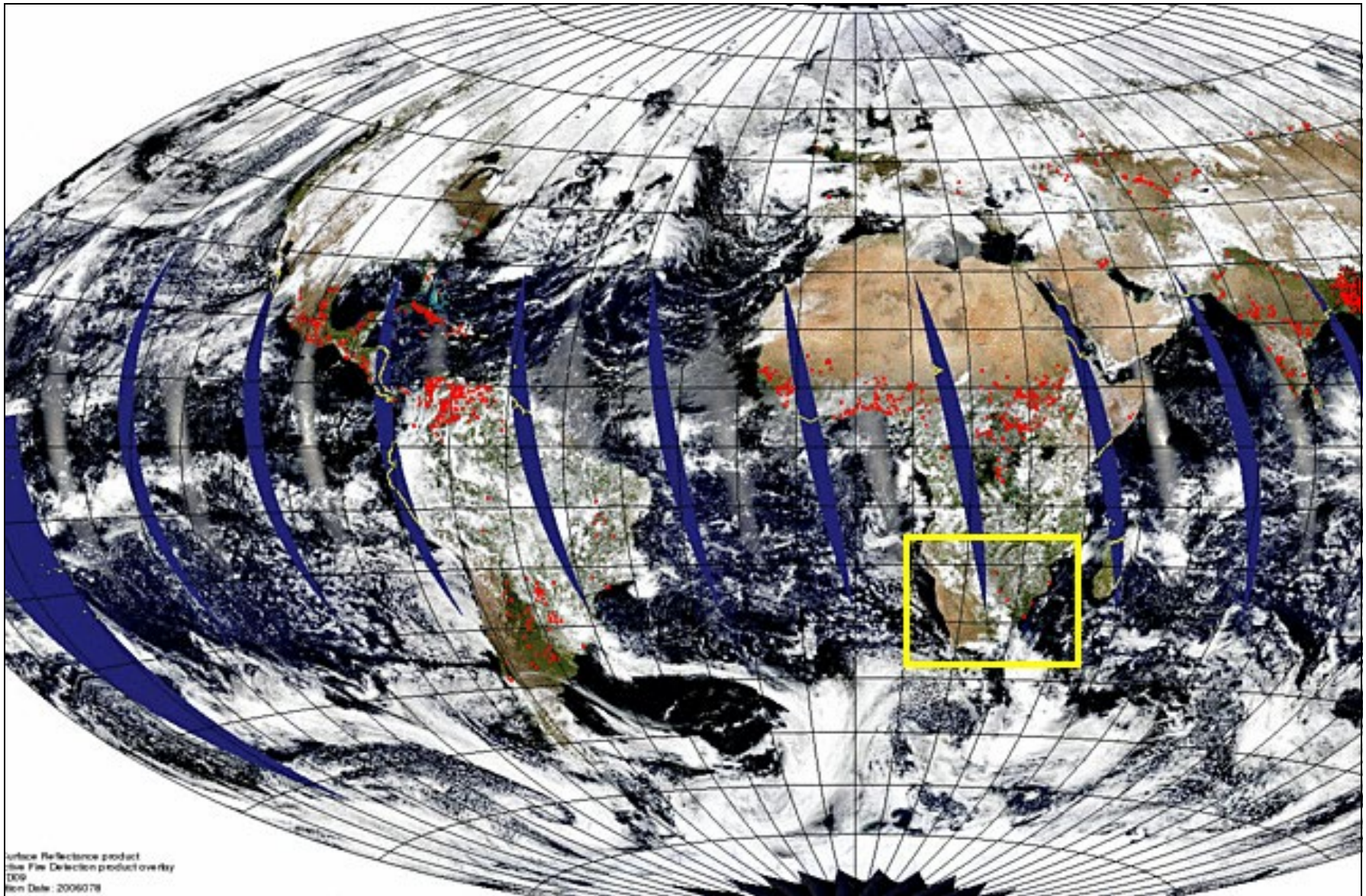
θ_s = Solar Zenith Angle

$\Delta\Phi$ = 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)

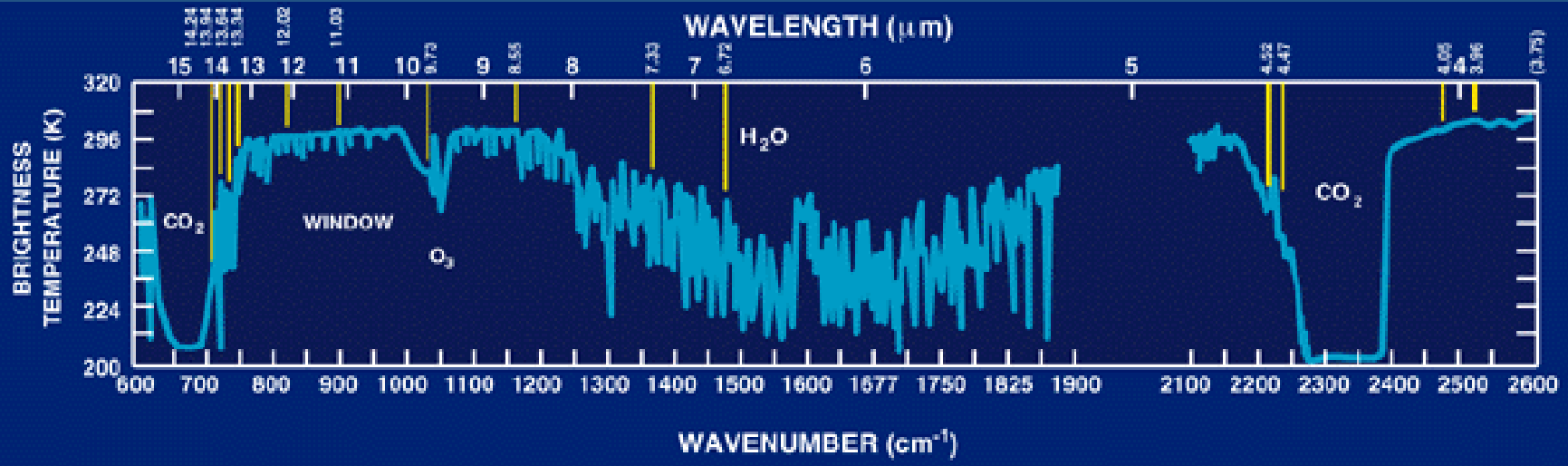
BT11-BT12 > Threshold (High thin cloud)

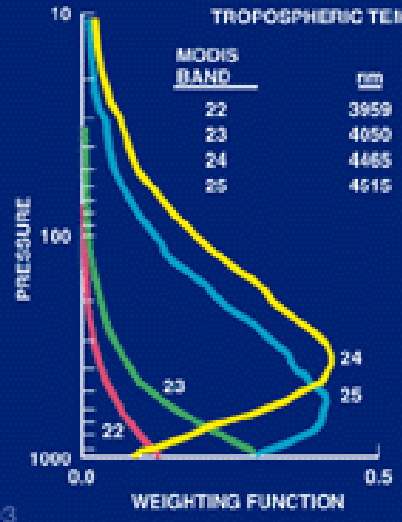
BT3.9 - BT11 > 12 K indicates daytime low cloud cover

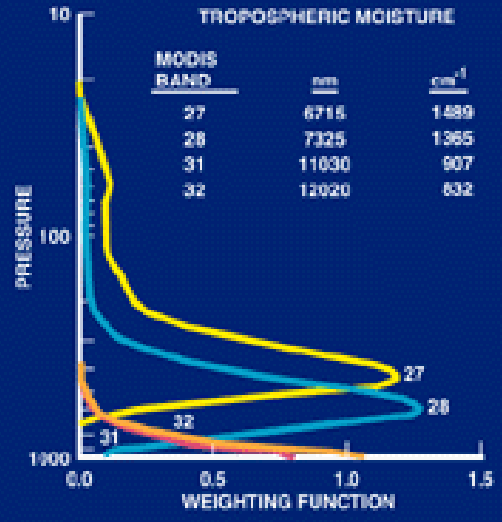
BT11 - BT6.7 large neg diff for clr sky over Antarctic Plateau winter

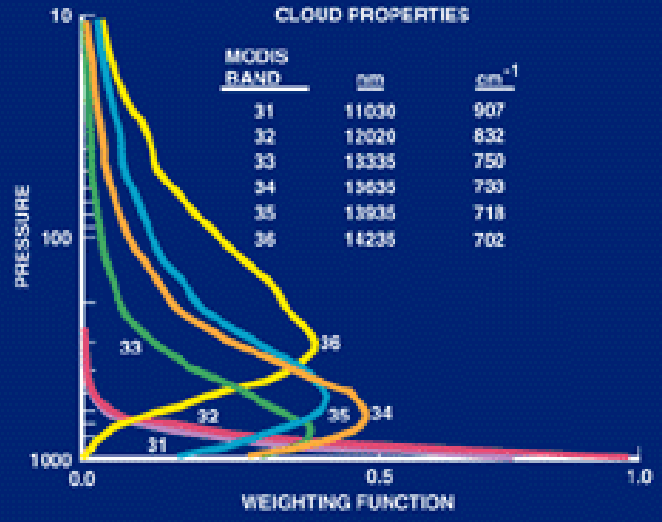
BT11 – BT7.3 Temperatures close in poles or snow/ice mean cloud

ATMOSPHERE - THERMAL RADIATION









E351.002 5/93

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

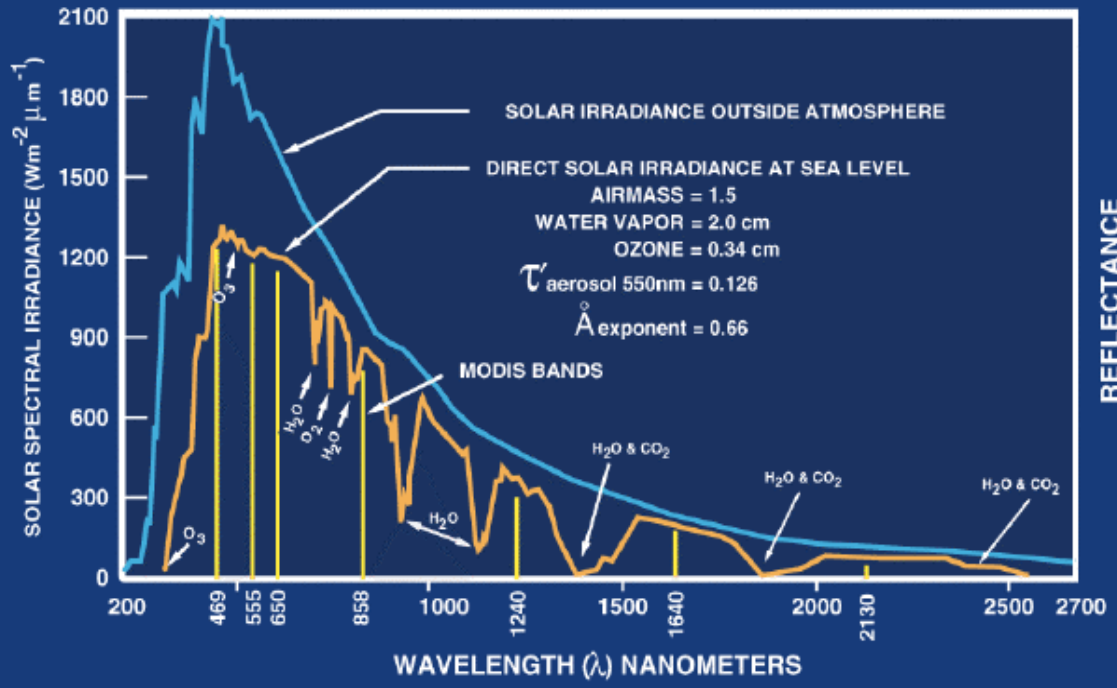
Reflectance Ratio Test

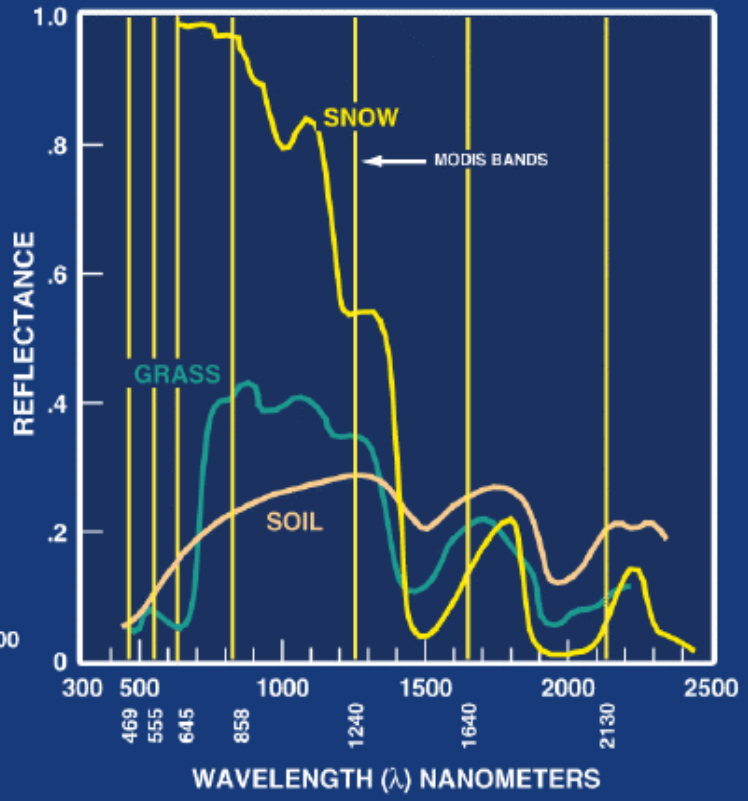
r.87/r.66 between 0.9 and 1.1 for cloudy regions
must be ecosystem specific – snow causes false signal

Snow Test

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

LAND-SOLAR RADIATION





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

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://aqua.ssec.wisc.edu/pub/terra/ancillary

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

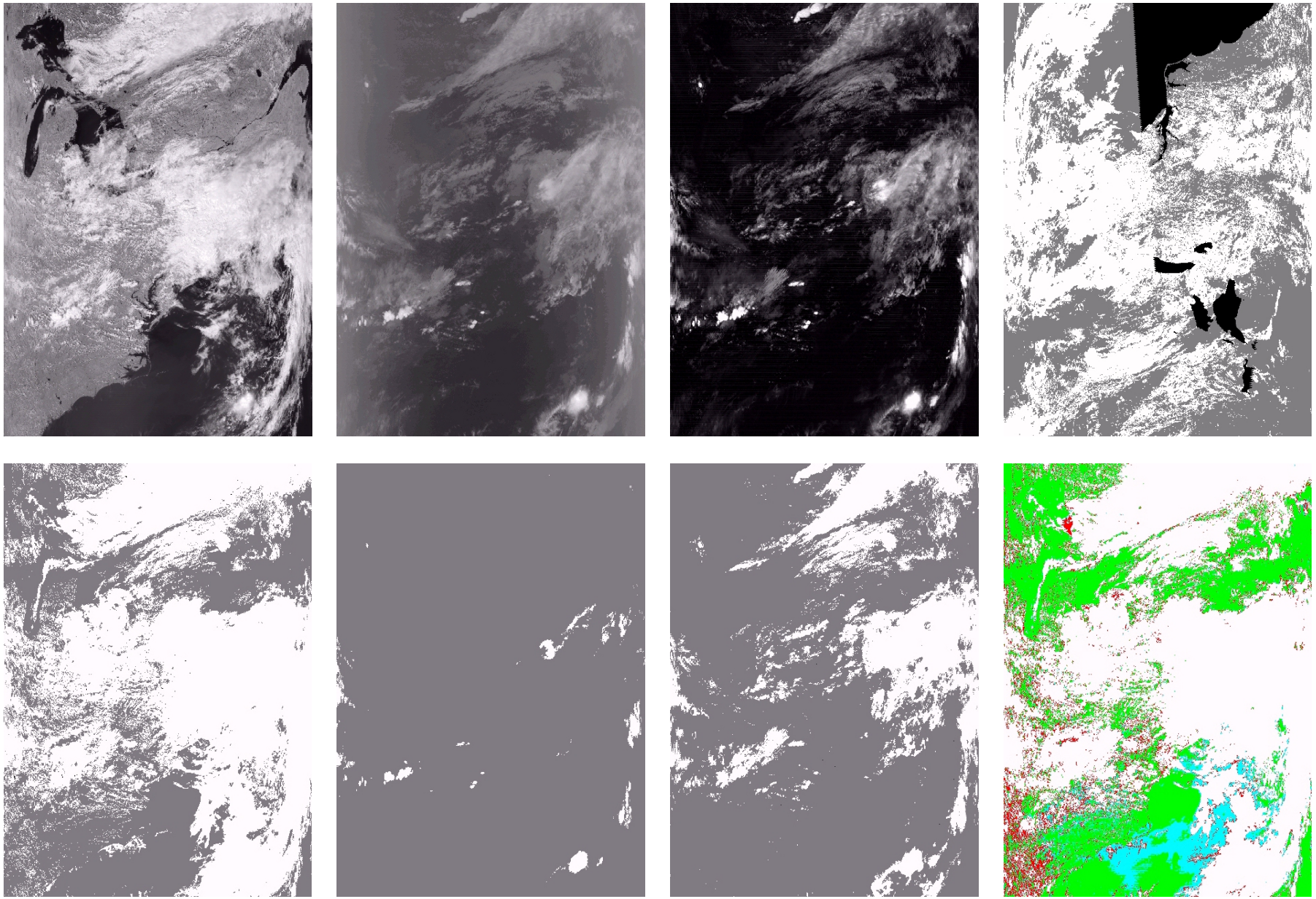
bit field	Description Key	Result
13	Cloud Flag - 11 μm IR Threshold	0 = Yes / 1 = No
14	High Cloud Flag - CO2 Threshold Test	0 = Yes / 1 = No
15	High Cloud Flag - 6.7 μm Test	0 = Yes / 1 = No
16	High Cloud Flag - 1.38 μm Test	0 = Yes / 1 = No
17	High Cloud Flag - 3.7-12 μm Test	0 = Yes / 1 = No
18	Cloud 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

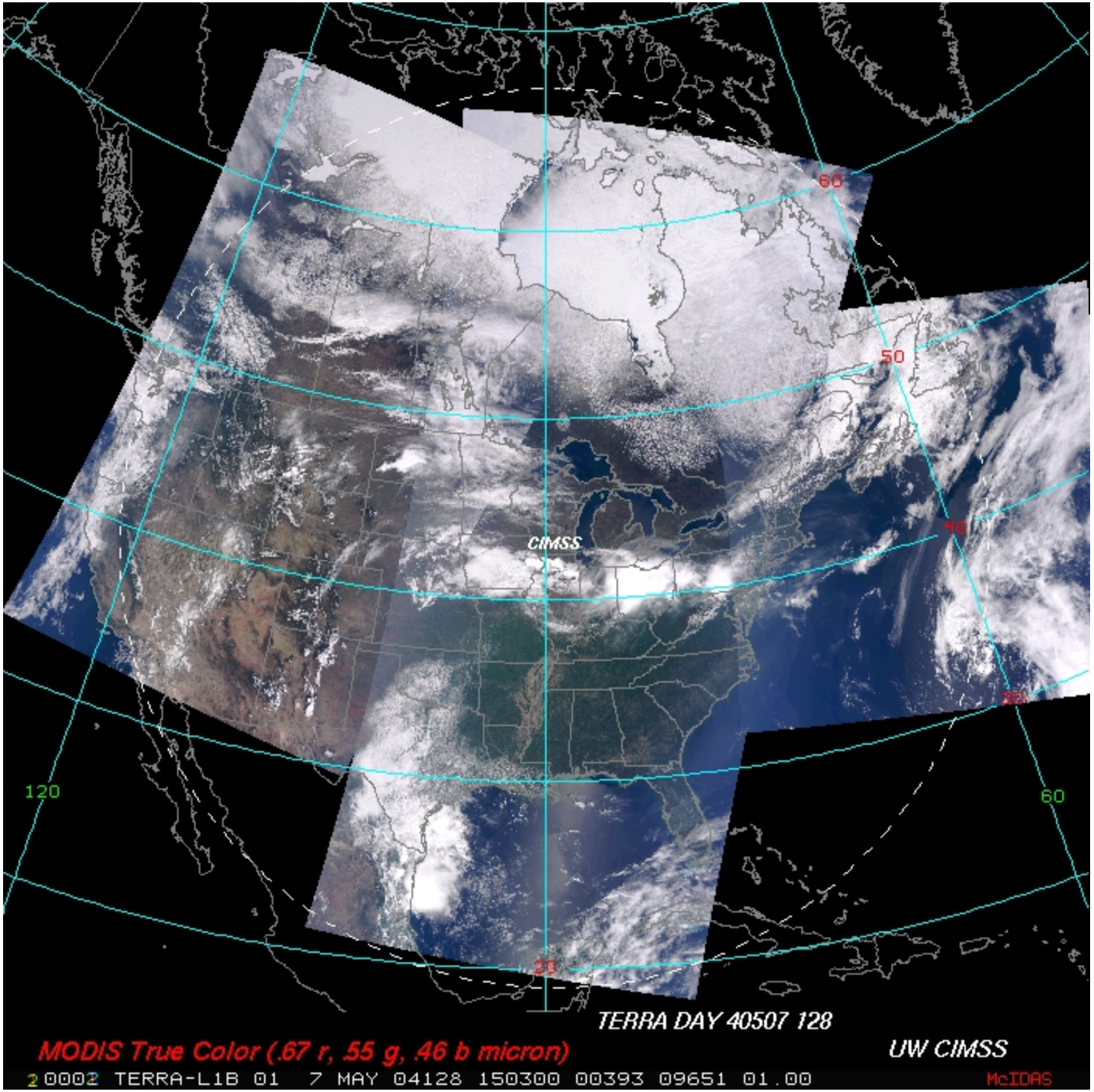
Additional Tests

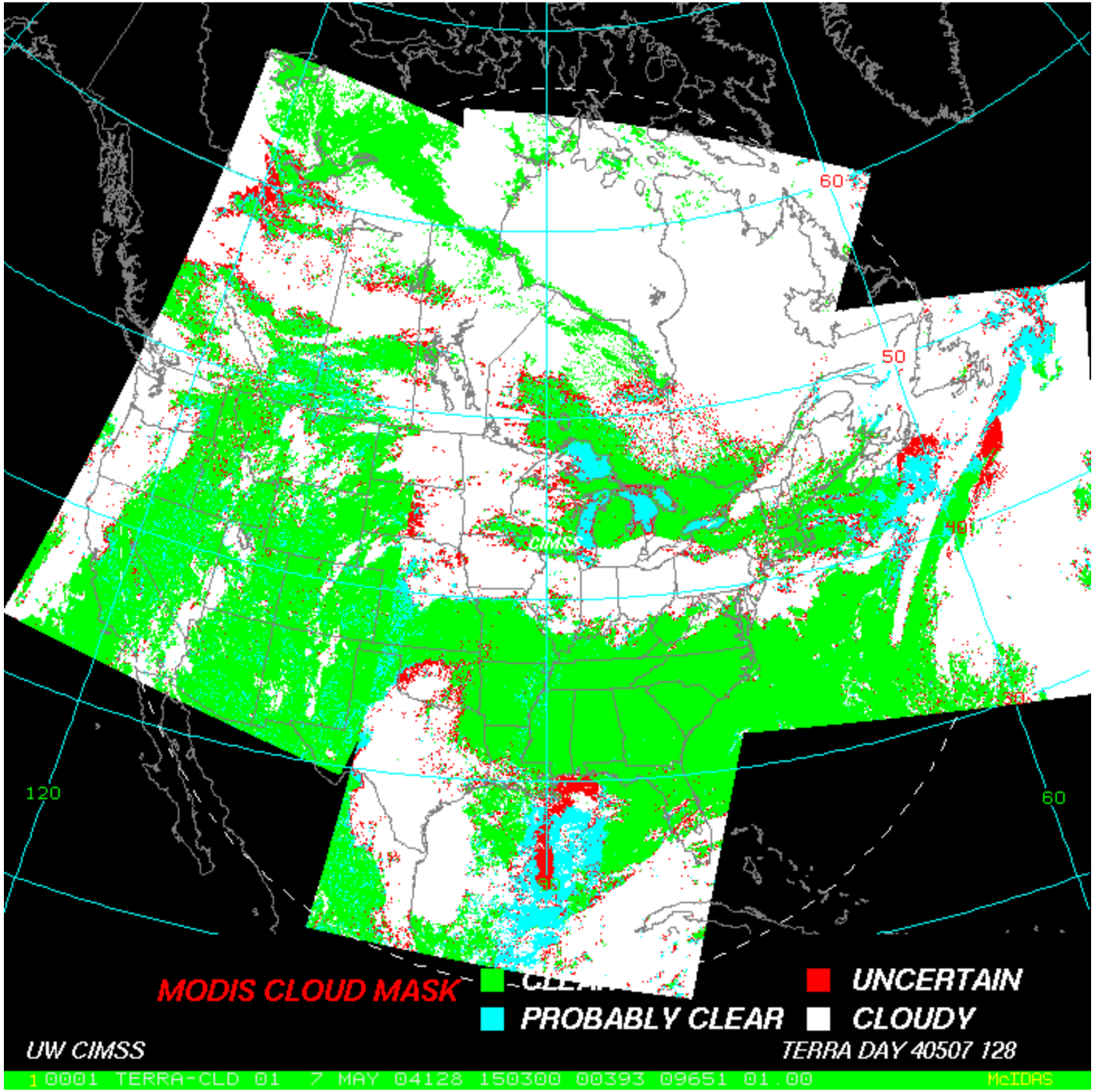
bit field	Description Key	Result
24	Cloud Flag - Temporal Consistency	0 = Yes / 1 = No
25	Cloud Flag - Spatial Consistency	0 = Yes / 1 = No
26	Clear-sky Restoral Tests	0 = Yes / 1 = No
27	Cloud Test – Surface Temp. Comparison	0 = Yes / 1 = No
28	Suspended Dust Flag	0 = Yes / 1 = No
29	Cloud Flag – 8.6-7.3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


60
50
40
30
20
120
60
CIMSS
TERRA DAY 40507 128
MODIS True Color (.67 r, .55 g, .46 b micron)
UW CIMSS
2 0002 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

SPoRT Short-term Prediction Research and Transition Center

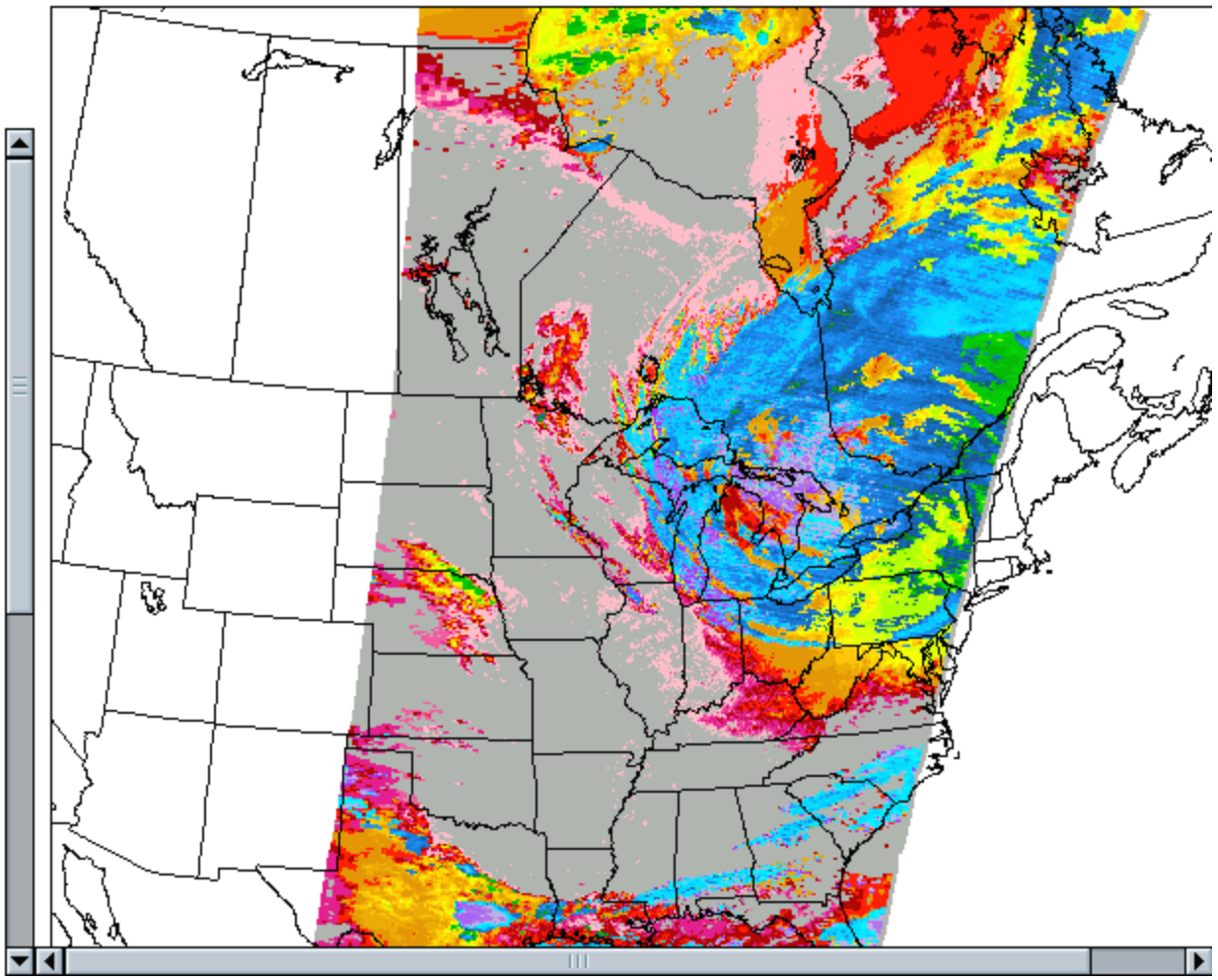
NASA

MODIS Terra: Imagery Products Tracks Aqua: Imagery Products Tracks Back to Products and Imagery

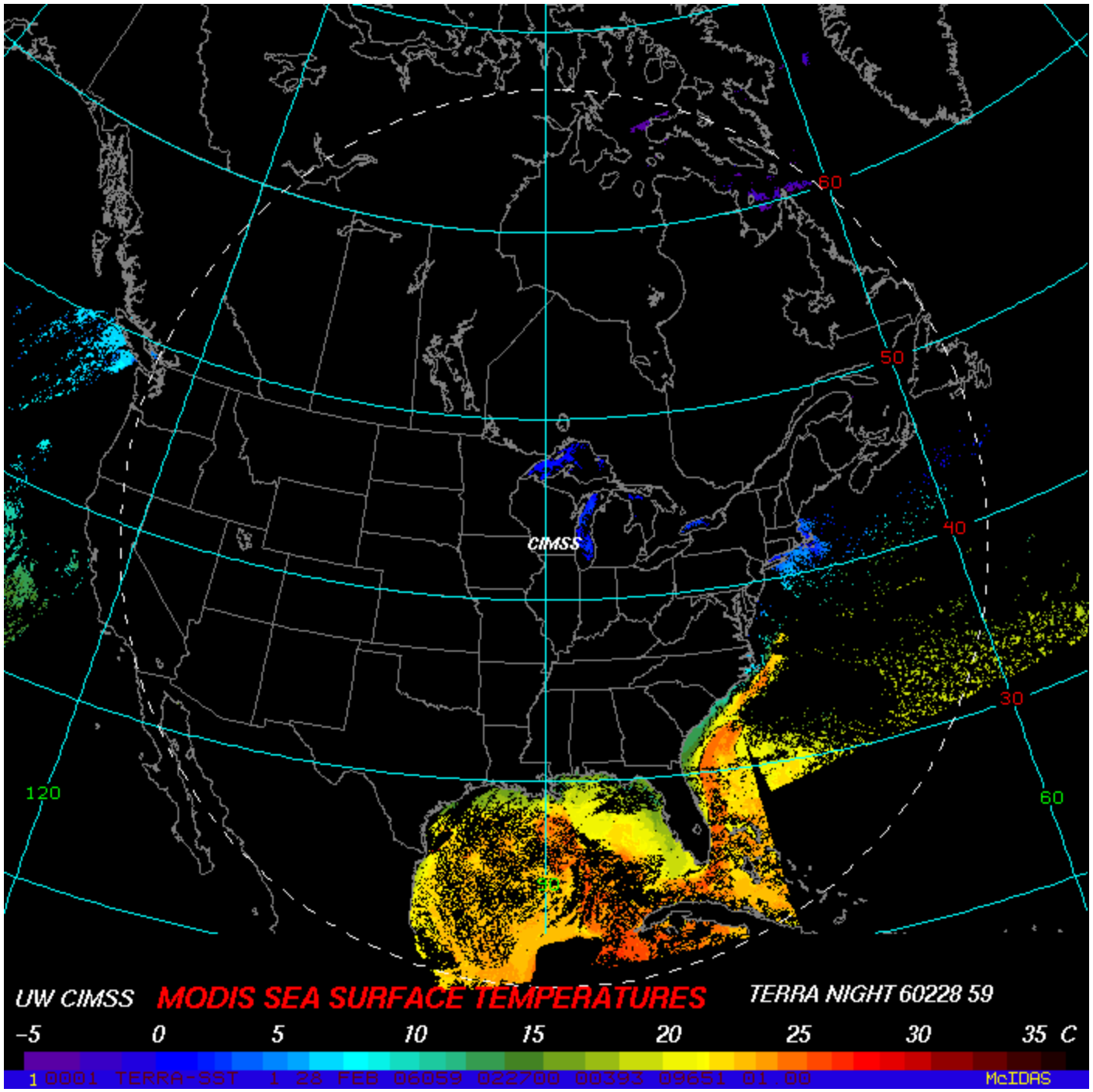
Select a day:
2003 May 12 16:45

Terra MODIS Products
2003 May 12 16:45 UTC

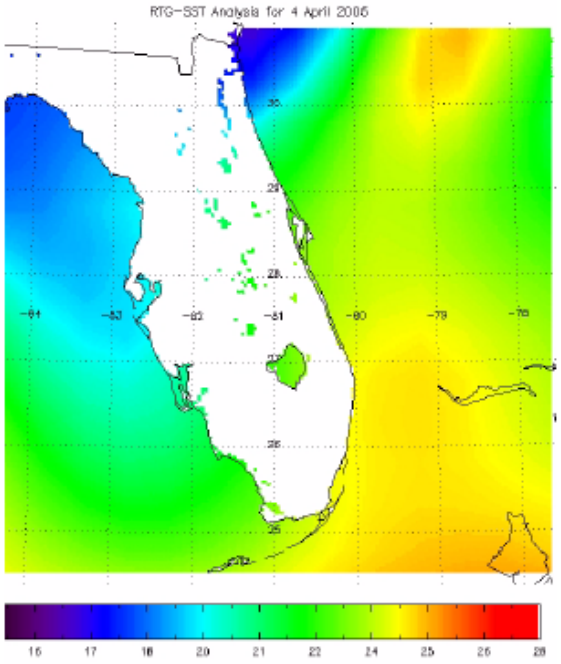
- **Cloud Top Pressure**
  Conus
  Regional
- **Cloud Phase Image**
  Conus
  Regional
- **Cloud Mask**
  Conus
  Regional
- **Water Vapor**
  Conus
  Regional
- **Lifted Index**
  Conus
  Regional

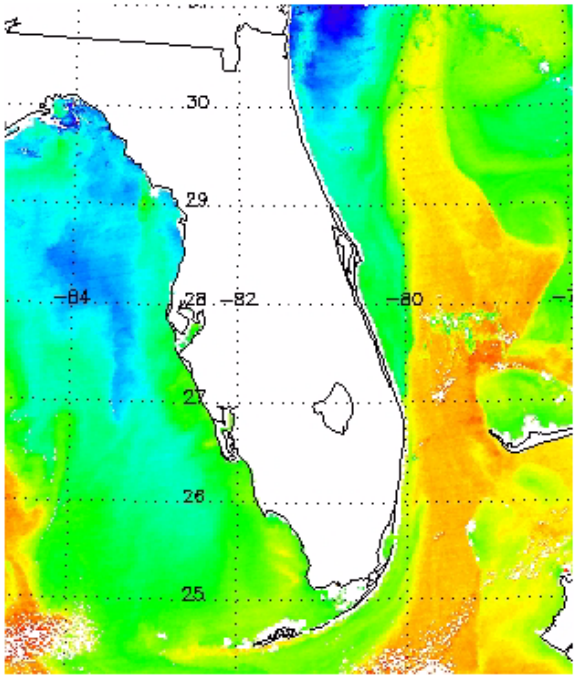


http://wwwghcc.msfc.nasa.gov/sport/sport_featured.html


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 060059 022700 003913 096511 01 00
McIDAS

Global .5 degree SST

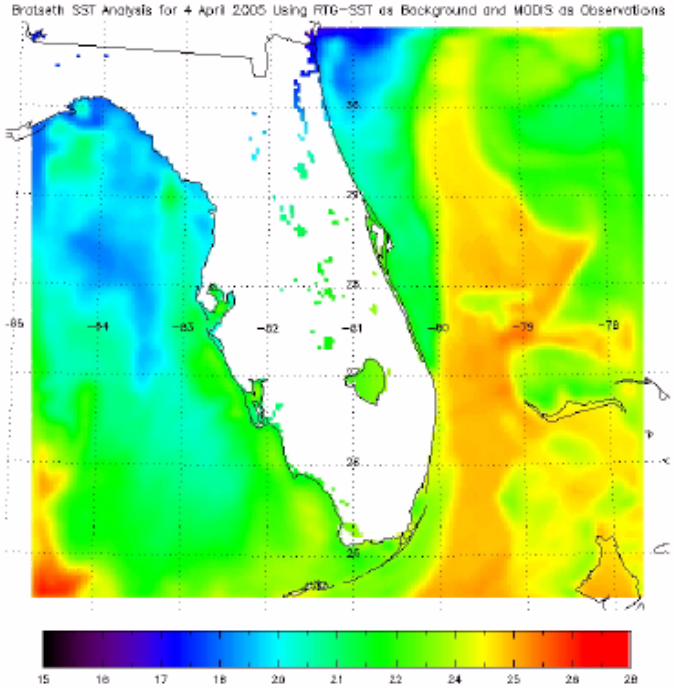




MODIS 1842 UTC SST

Sea Surface Temperatures

4 April 2005

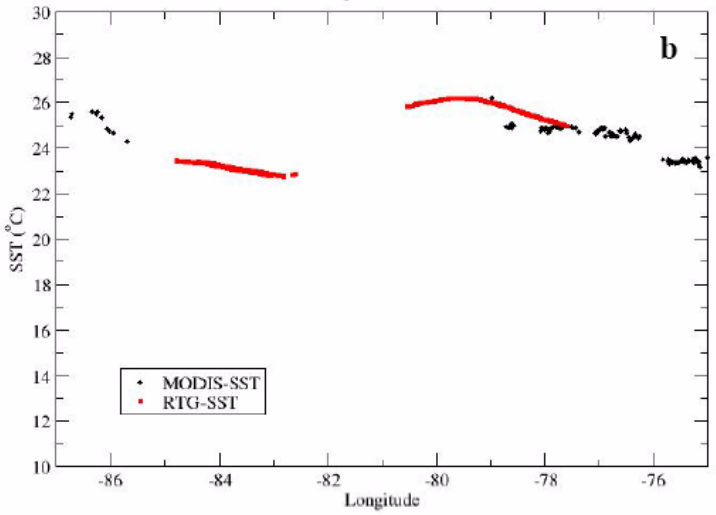


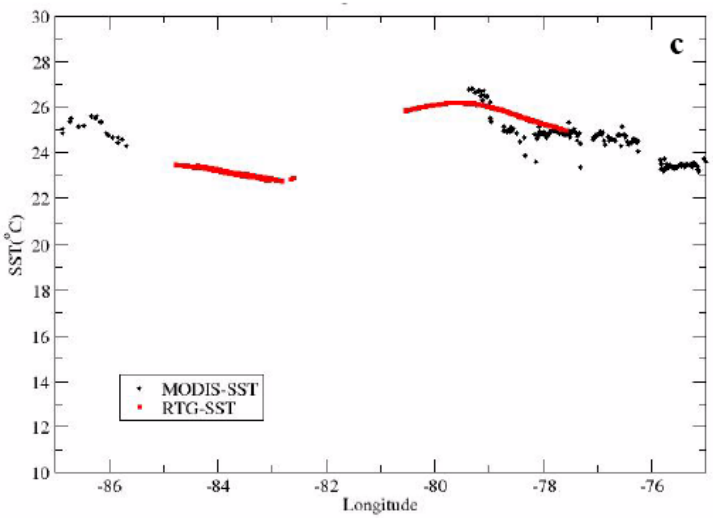
Bratseth analysis combining the RTG-SST and MODIS data.

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

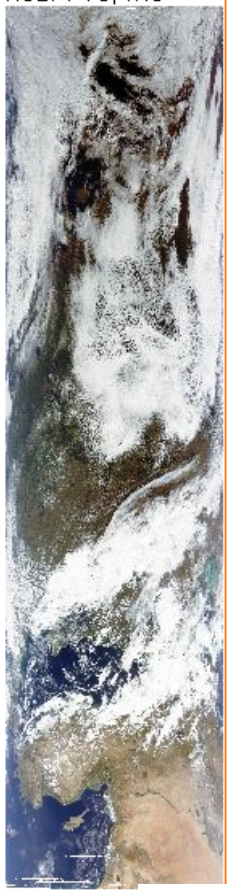
EOStation
Schedules
>MODIS data
Product calendar
MRDS
Search&Browse
Sample files
Custom service
Under the hood
Software
Image gallery
Contact us

Login to your private area:
Password:
Login

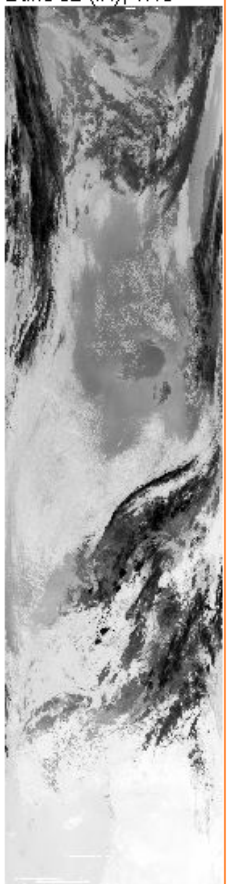
MODIS Data >> Single Pass Browse [AM0409050814]

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.

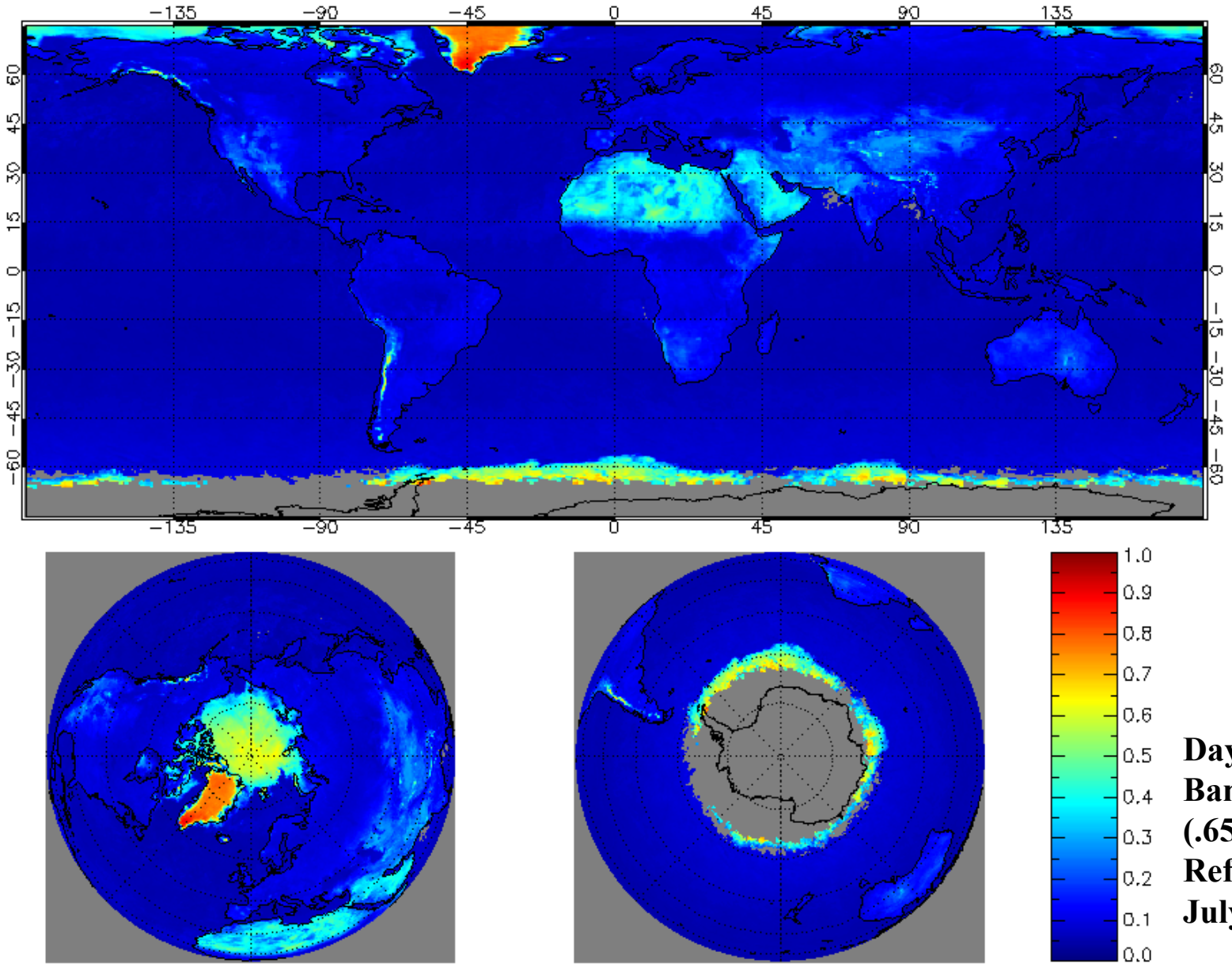
File	Size	Notes
TCB1.AM0409050814.ecw	1823 kB	True color (1-4-3) image, ECW compressed, 1km
-	-	MODIS Level-0(raw) data
-	-	MOD01, unpacked image data
-	-	MOD03, geolocation data
-	-	MOD021KM, geolocated calibrated radiances (1km)
-	-	MOD02HKM, geolocated calibrated radiances (500m)
-	-	MOD021KM, geolocated 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

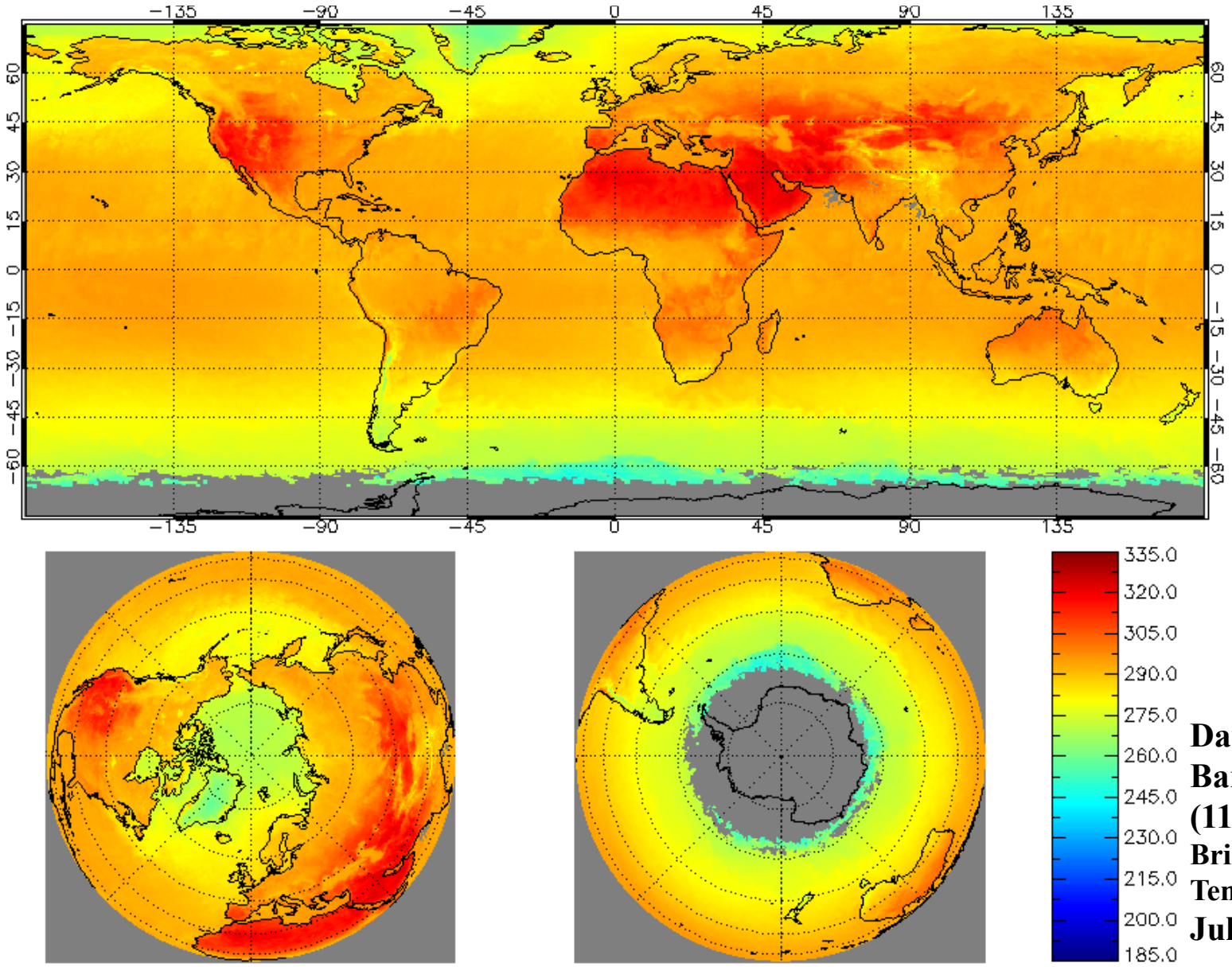
- MODIS algorithm is clear sky conservative
  - If there is a doubt, it is cloudy
- Nighttime algorithm is different –
  - 16 versus 36 channels available
- Transition regions
  - terminator, edges of desert regions, edges of snow regions, etc.
- Very specific regions
  - Certain surfaces, certain times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

MODIS Clear Sky Product

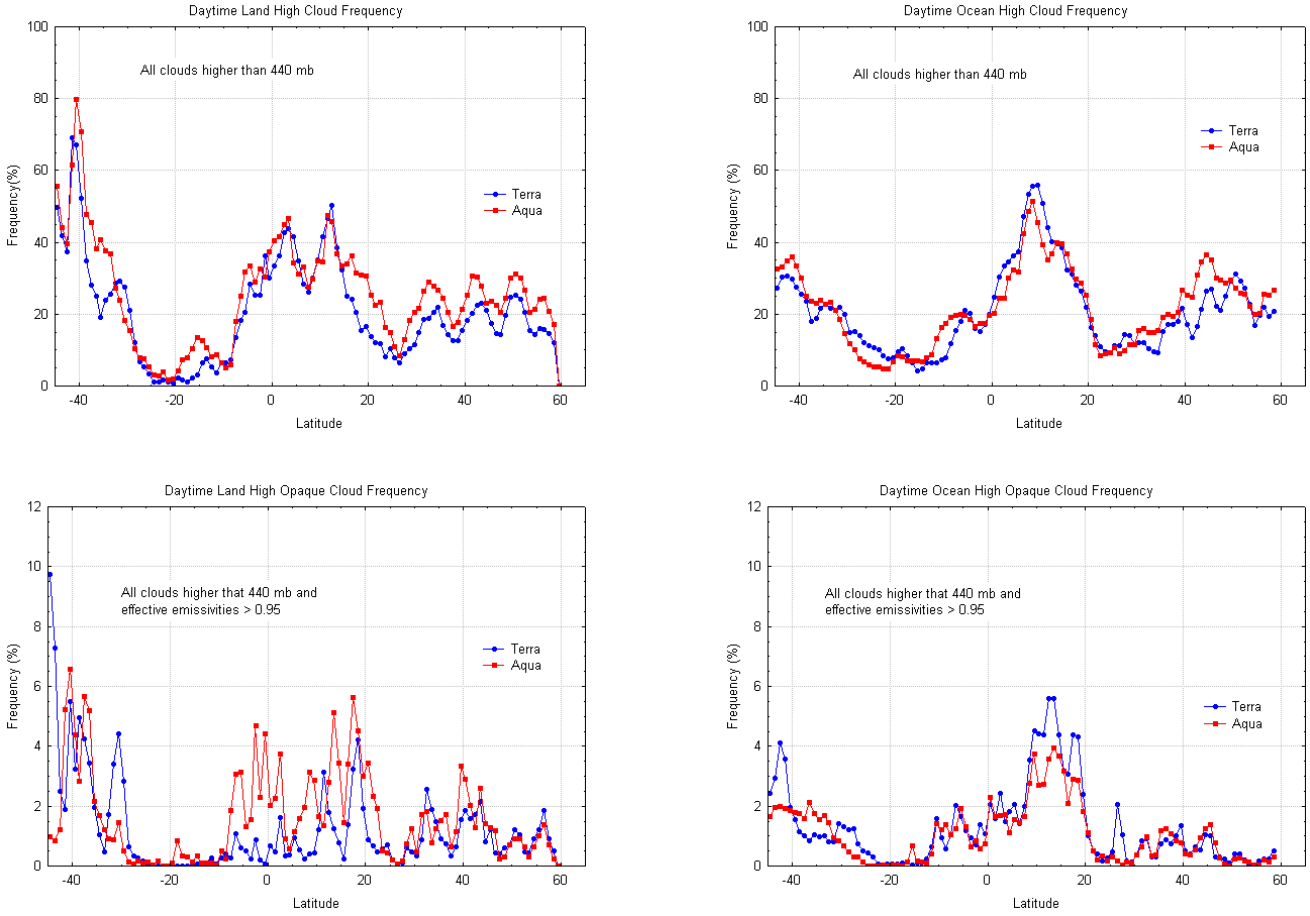


Daytime Band 1 (.65 μm) Reflectance July 2002

MODIS Clear Sky Product



3-Hourly Cloud Changes Measured by Terra and Aqua



Shown at left are zonal values of daytime land Terra and Aqua total high cloud frequency (top), and high, opaque cloud frequency (bottom) from August 24, 2002. The latter are mostly cold convective towers. With a local observing time of about 1:30 pm, roughly three hours later than Terra, we expect the Aqua measurements to indicate more convective activity and hence more thick, high clouds and more high clouds in general. This is clearly seen in the tropics and northern hemisphere where solar heating is greatest. For reference, the same data is plotted for ocean surfaces (right) where we would not expect to see changes in high clouds due to solar heating. Differences between Terra and Aqua are small as we expect, especially for high, opaque clouds

MODIS/AIRS Workshop
MODIS Level 2 Vegetation Indices (VI) Product

Pretoria, South Africa

5 April 2006

Kathleen Strabala

Cooperative Institute for Meteorological Satellite Studies

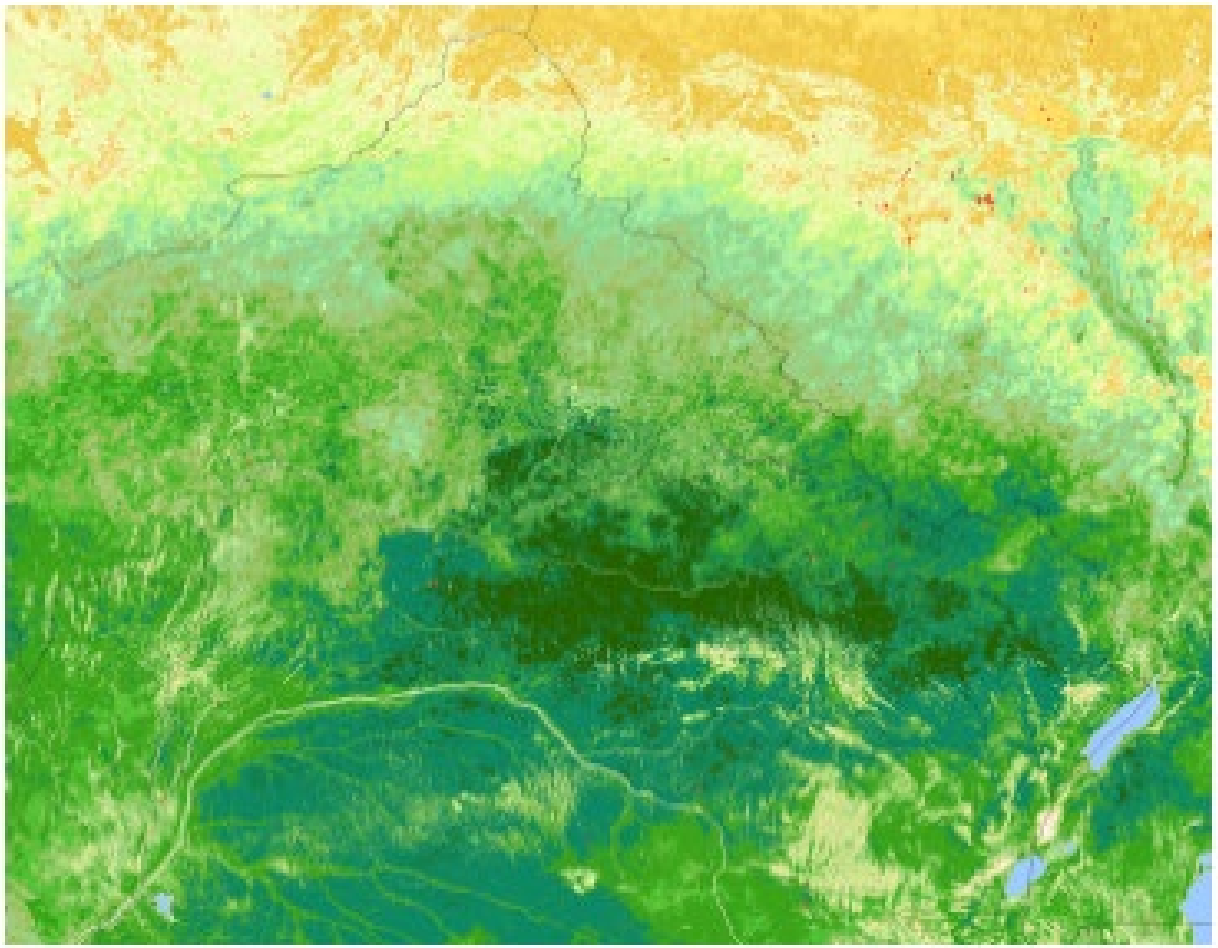
University of Wisconsin-Madison USA

MODIS Standard Products

Land

- MOD 09 - Surface Reflectance
- MOD 10 - Snow Cover
- MOD 11 - Land Surface Temperature & Emissivity
- MOD 12 - Land Cover/Land Cover Change
- ***MOD 13 - Gridded Vegetation Indices (NDVI & EVI)***
- MOD 14 - Thermal Anomalies (Fires)
- MOD 15 - Leaf Area Index & FPAR
- MOD 16 - Evapotranspiration
- MOD 17 - Net Photosynthesis and Primary Productivity
- MOD 29 - Sea Ice Cover
- MOD 43 - Bidirectional Reflectance Distribution Function (BRDF)
- MOD 44 - Vegetation Cover Conversion

Vegetation Index



Normalized Difference Vegetation Index (NDVI) image of Central Africa
http://rapidfire.sci.gsfc.nasa.gov/

Photo-Chemistry

- Light may be absorbed and participate (drive) a chemical reaction. Example: Photosynthesis in plants

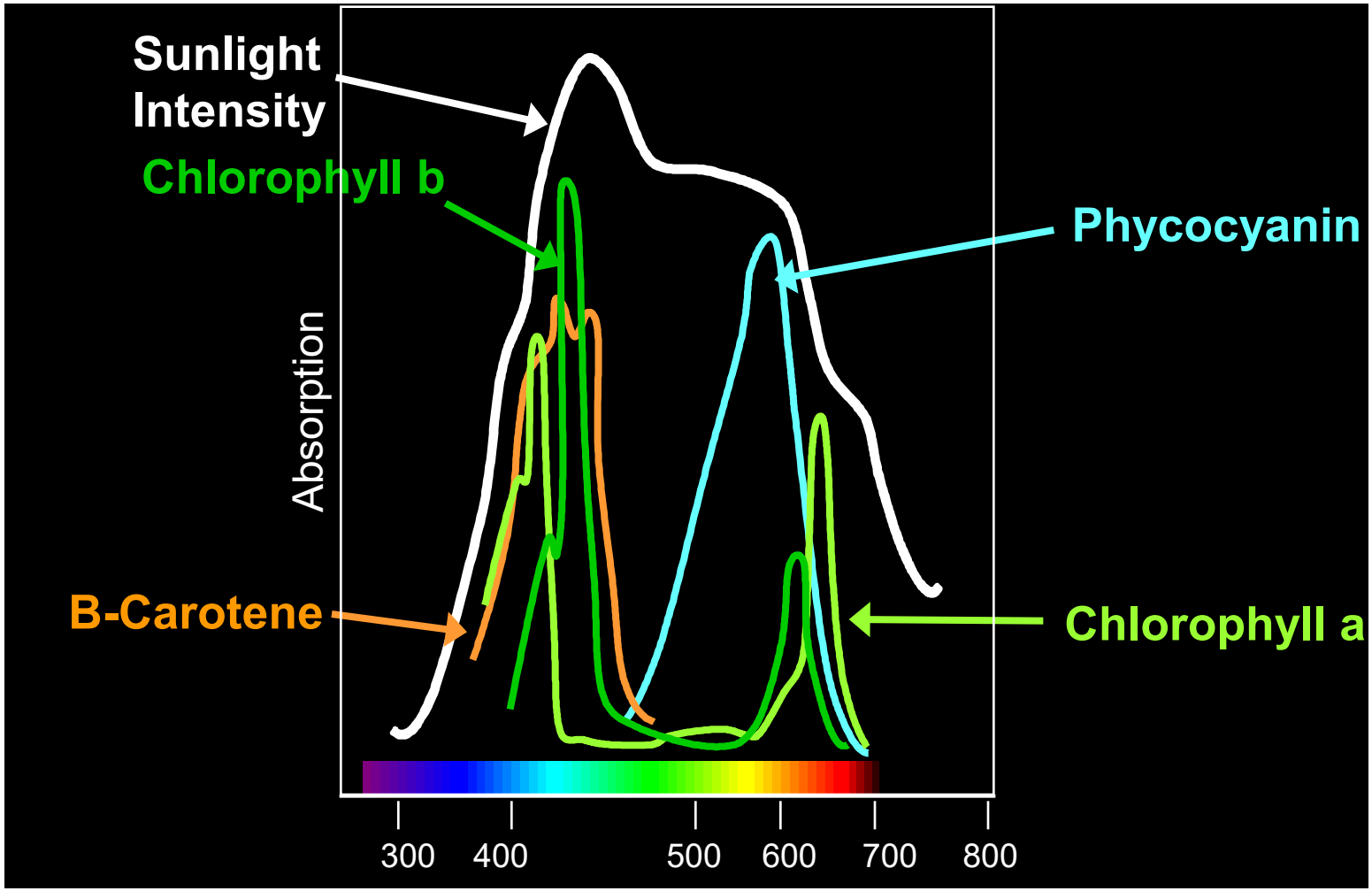
$$6CO_2 + 6H_2O + h\nu \rightarrow C_6H_{12}O_6 + 6O_2$$

- Only certain wavelengths are absorbed by some participant(s) in the reaction
- Some structure must be present to allow the reaction to occur – Chlorophyll
- Combination of chemical and structural properties of plants

Primary and secondary absorbers in plants

- Primary
  - Chlorophyll-a
  - Chlorophyll-b
- Secondary
  - Carotenoids
  - Phycobilins
  - Anthocyanins

Absorption of Visible Light by Photo-pigments



Lehninger, Nelson and Cox

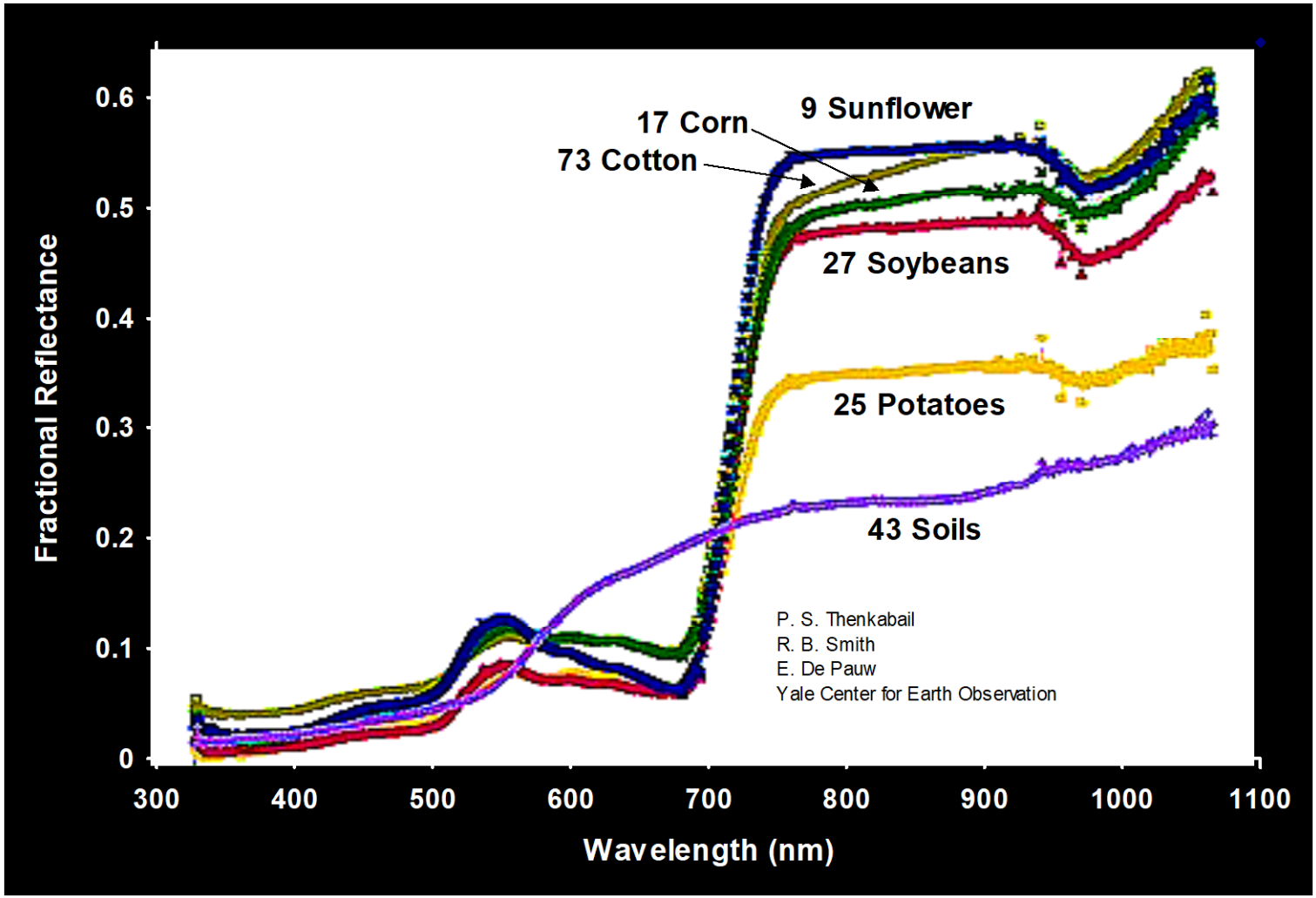
Theoretical description

VISIBLE radiation is highly absorbed by vegetation in the red (0.68 micron) and in the blue (0.47 micron). The absorption is mainly due to photosynthetically active pigments

NIR radiation is reflected and transmitted with very little absorption by vegetation

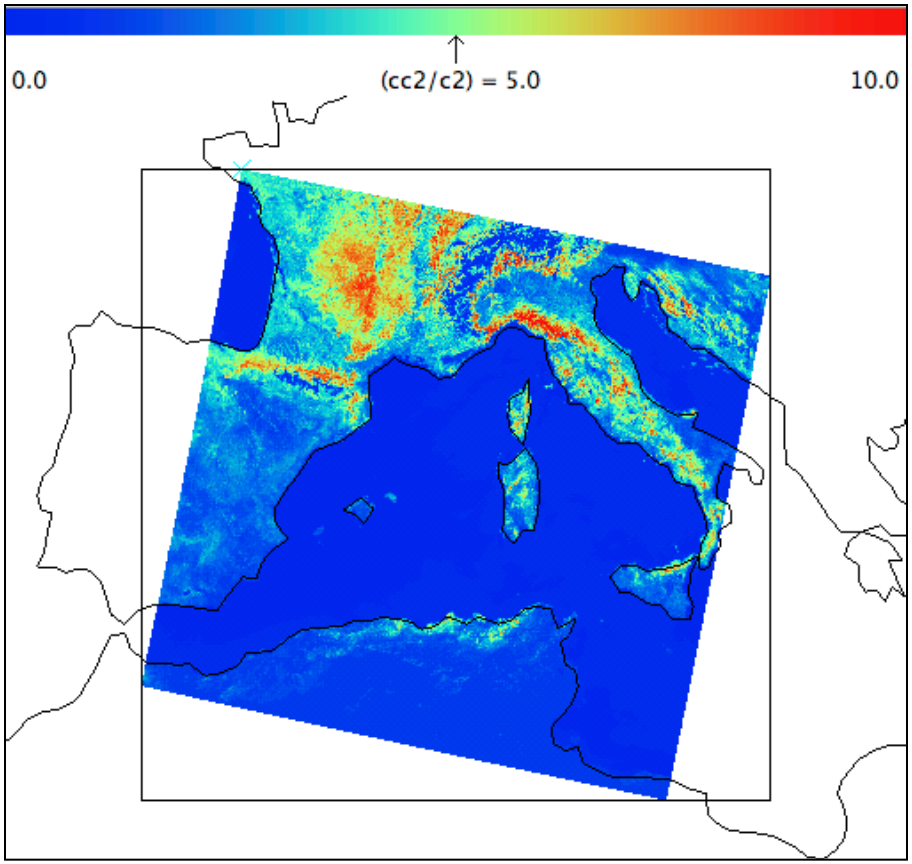
Contrast between RED and NIR responses is correlated to vegetation amount

Soil and crop reflectance



Simple Ratio (SR)

- It was the first index to be used (Jordan, 1969)
- Defined as the ratio X_{nir}/X_{red}
- For densely vegetated areas X_{red} tends to 0 and SR increases without bounds



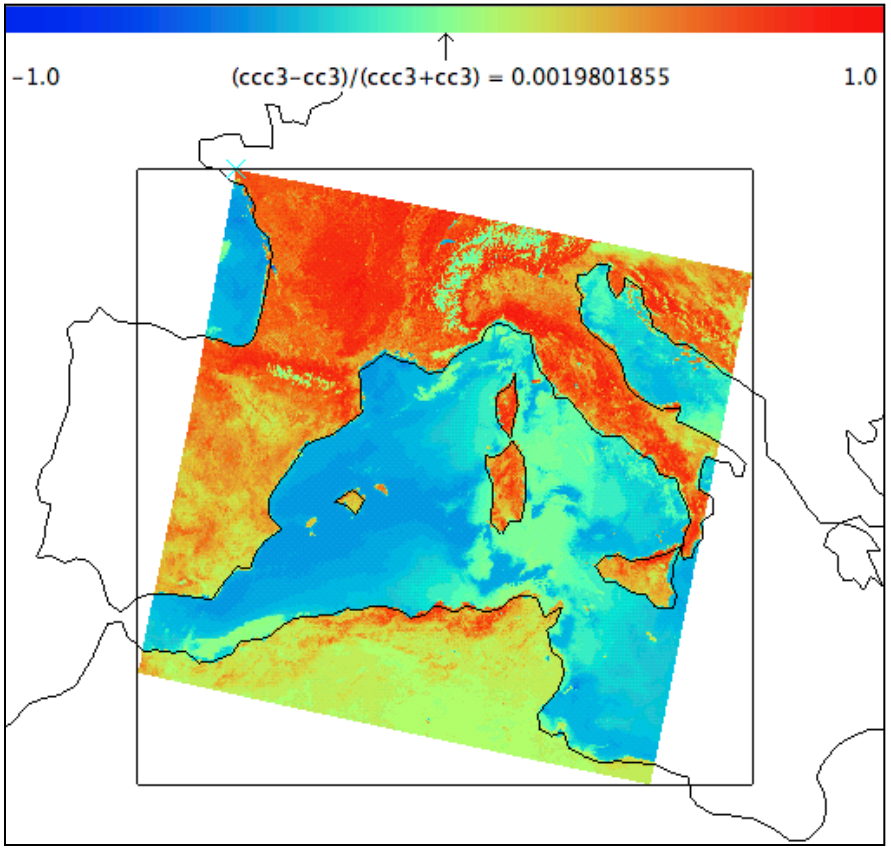
Normalized Difference Vegetation Index (NDVI)

Defined as the ratio

$$(X_{nir} - X_{red})/(X_{nir} + X_{red})$$

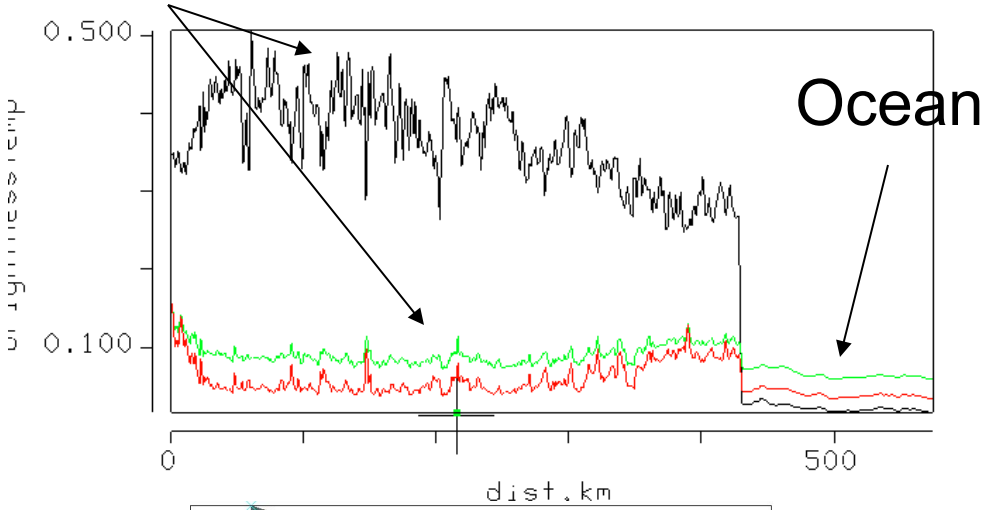
Correlated with:	
Plant Biomass	Crop Yield
Plant Nitrogen	Plant Dhlorophyll
Water Stress	Plant Diseases
Insect Damage	

Applications:	
Vegetation Monitoring	Agricultural Activities
Drought studies	Landcover Change
Public Health Issues (mosquitos)	Climate Change Detection
Net Primary Production	Carbon Balance



NIR and VIS over Vegetation and Ocean

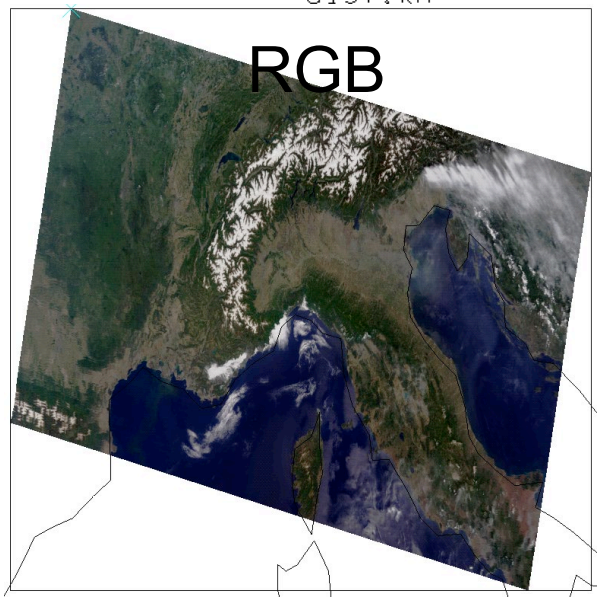
Vegetation

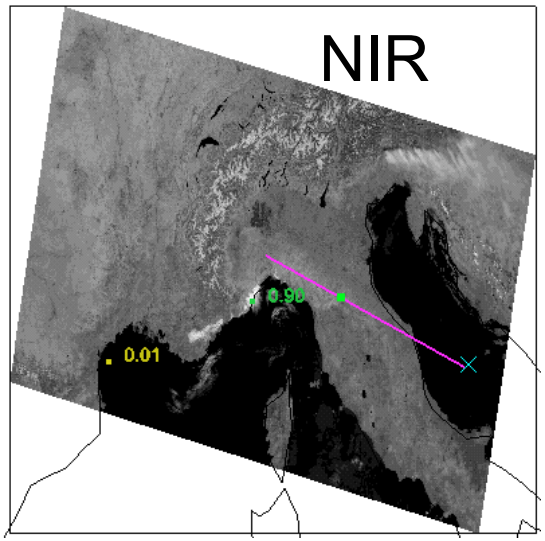


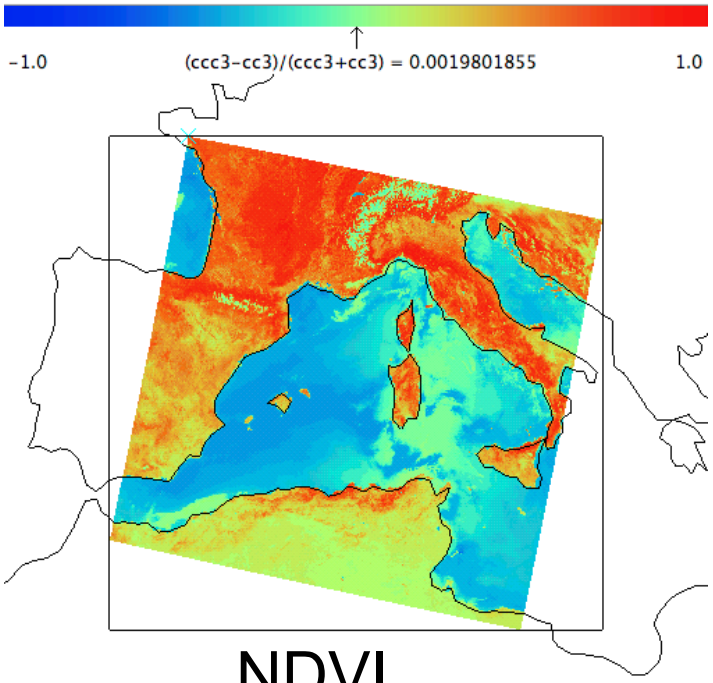
NIR (.86 micron)

Green (.55 micron)

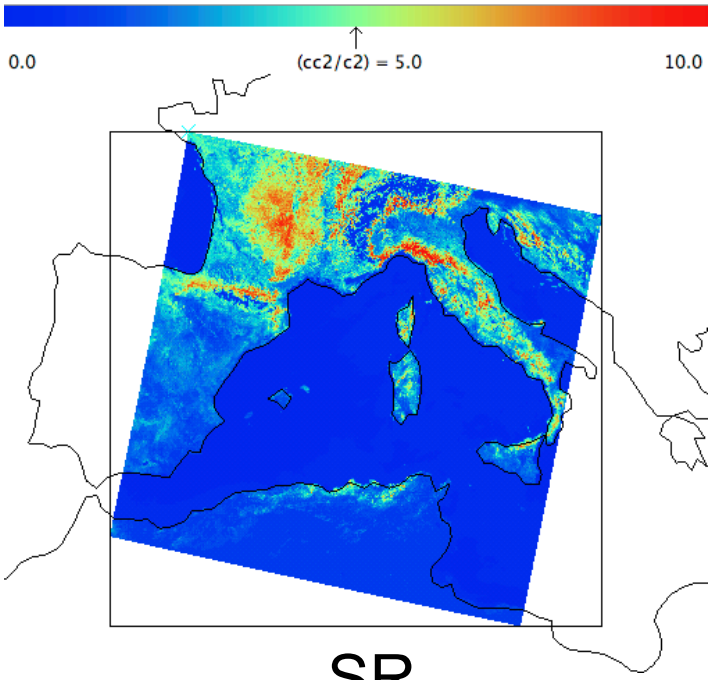
Red (0.68 micron)



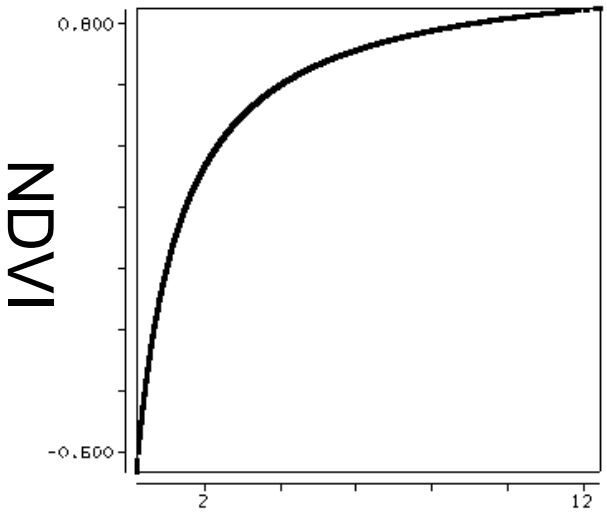




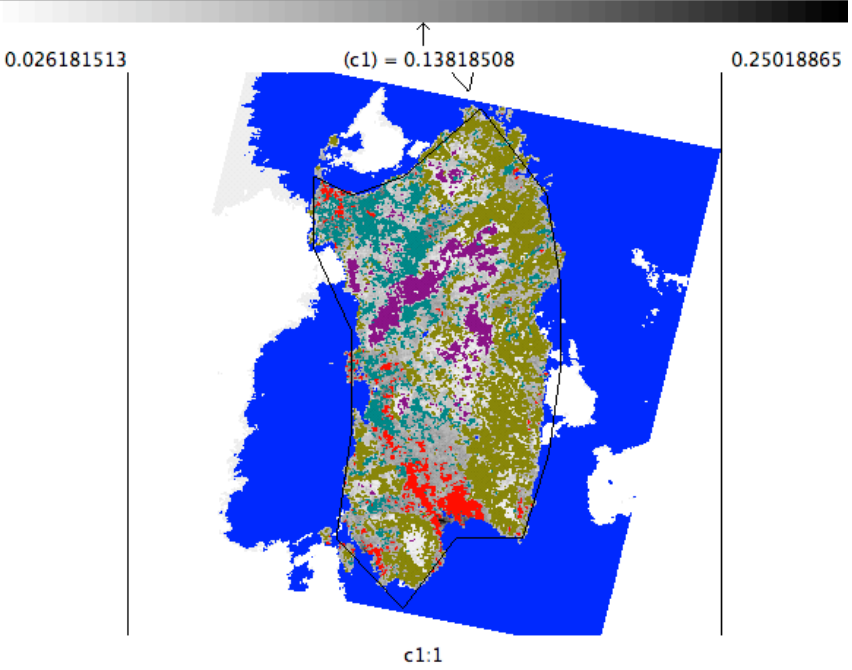
NDVI



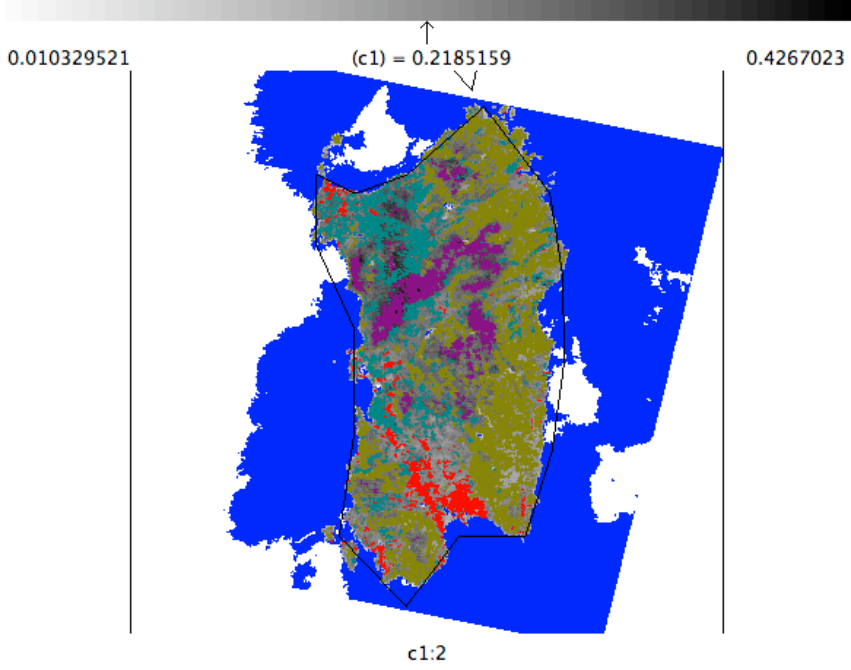
SR



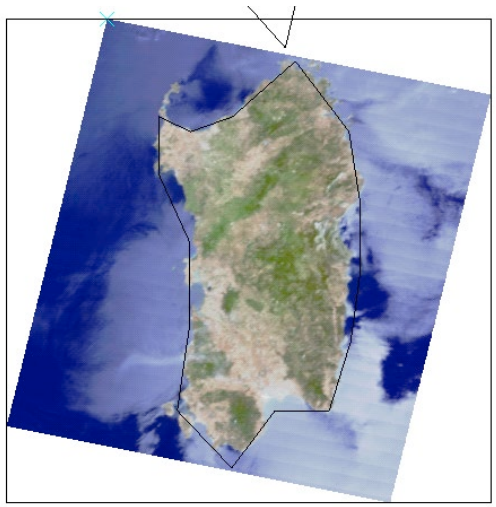
Correlation between NDVI and SR



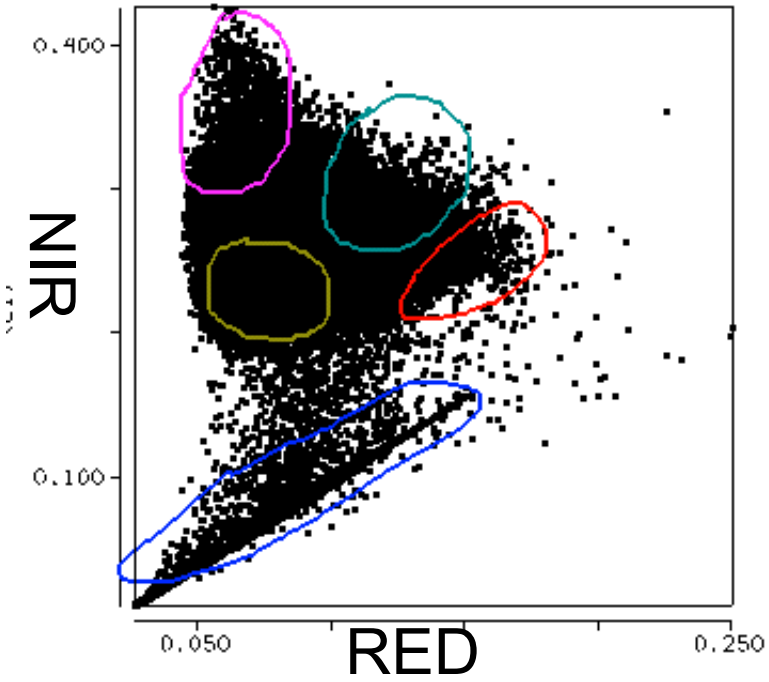
RED



NIR



True Color



Dense Vegetation

Less Vegetation

Less Vegetation

Barren Soil

Ocean

Enhanced Vegetation Index (EVI)

$$EVI = G * \frac{r_{NIR} - r_{red}}{L + r_{NIR} + C_1 r_{red} - C_2 r_{blue}}$$

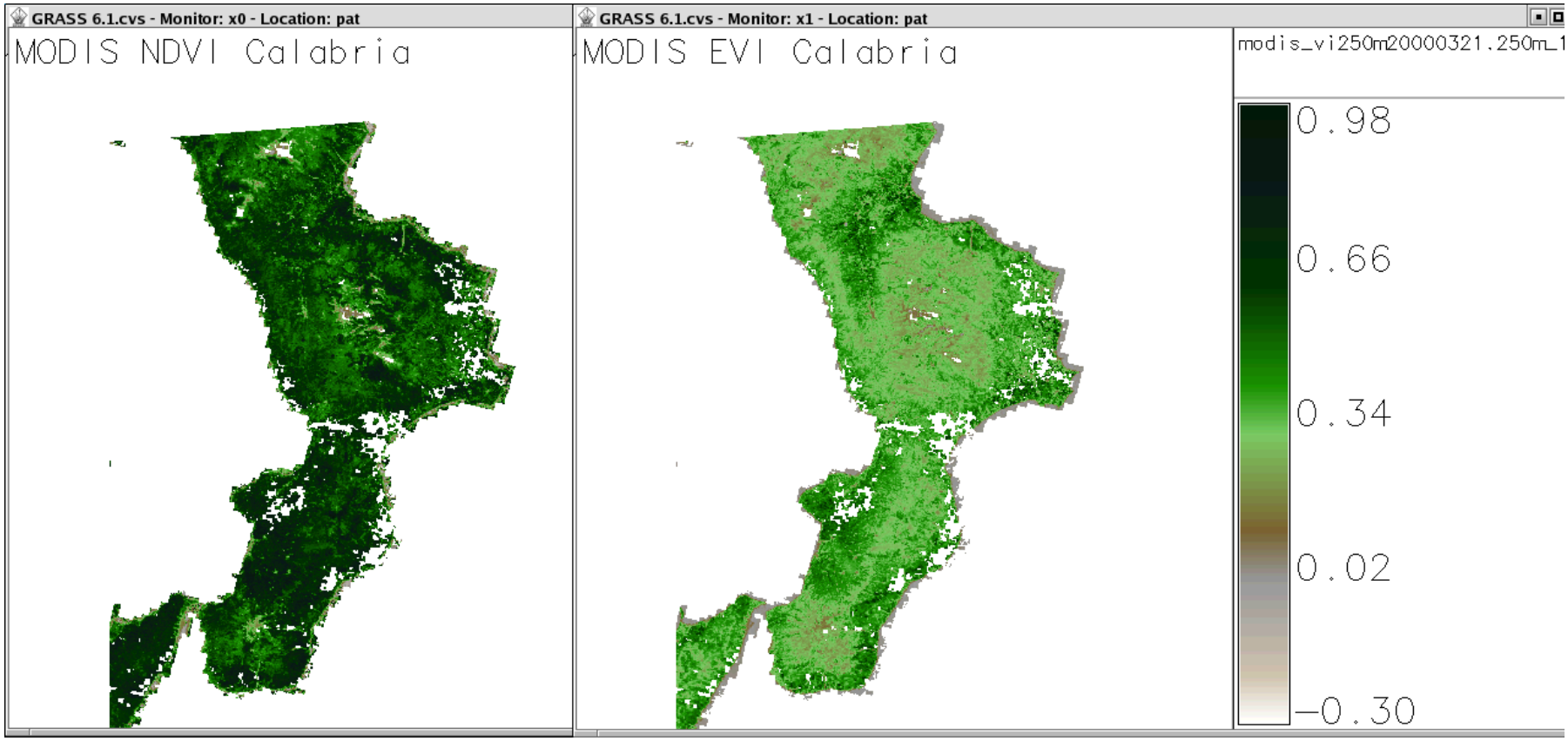
Where L is a canopy background adjustment term (Set to 1)

C_1 and C_2 are called aerosol resistance terms (Set to 6 and 7.5 respectively)

G is the gain factor (Set to 2.5)

- Improved sensitivity in high biomass regions (de-coupling of canopy background signal)
- Improved results in areas of high aerosol concentrations (uses blue band to correct for aerosols in red band)
  - Based on knowledge of wavelength dependency of aerosol effects

Comparison of NDVI and EVI



Both NDVI and EVI maps are colored with identical color table
(MODIS/Terra scene MOD13, composite of 21 March - 5 April 2000, Calabria, Southern Italy).
EVI is less prone to atmospheric distortion (from http://mpa.itc.it/rs/modis_ndvi_evi/)

Key Output Parameters

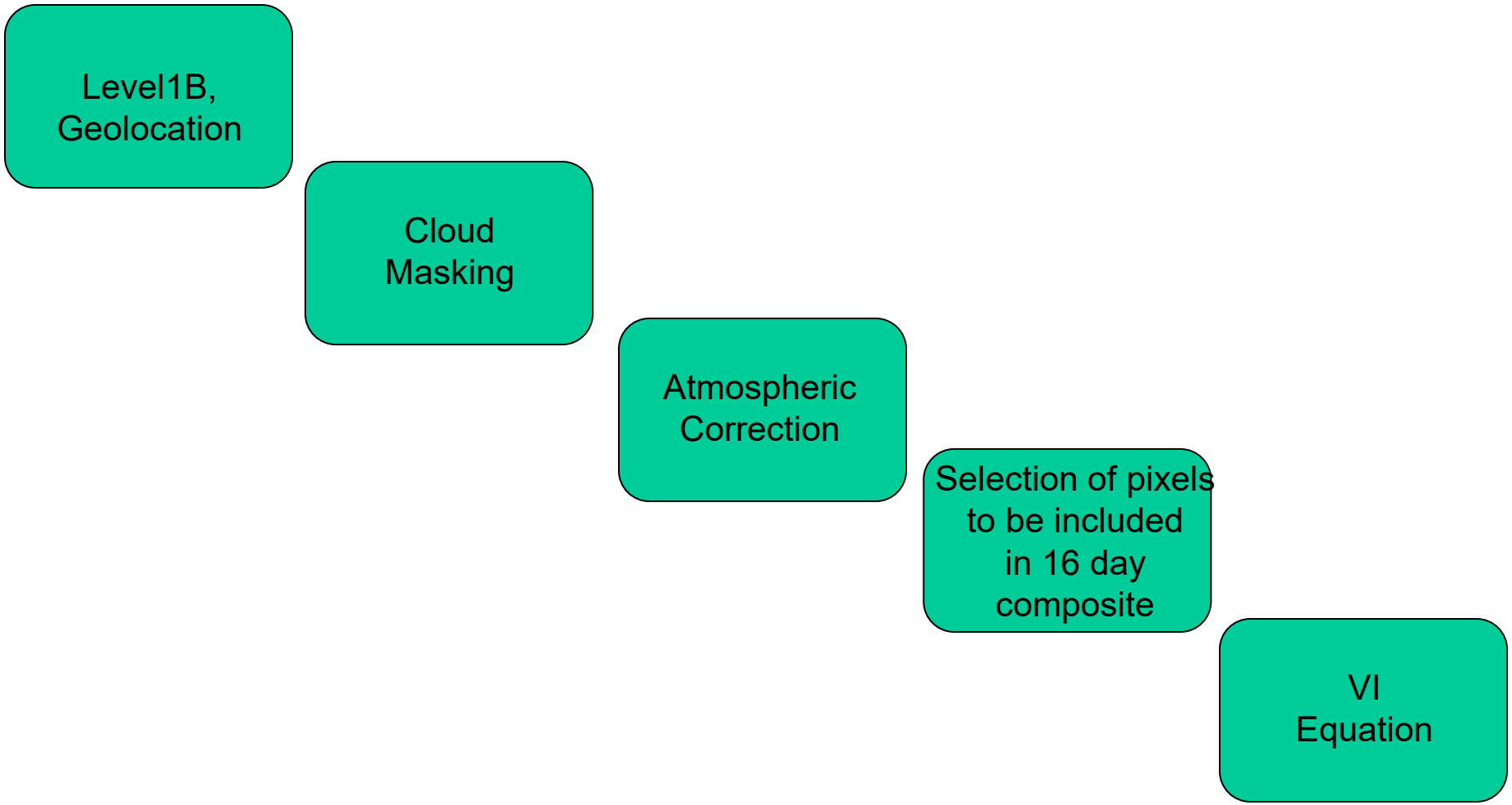
- NDVI at 250*, 500 m, 1 km 16 days
  - 1 km monthly
- EVI at 250*, 500 m, 1 km 16 days
  - 1 km monthly
- 16-bit signed integer

  tiles ~1200x1200 km

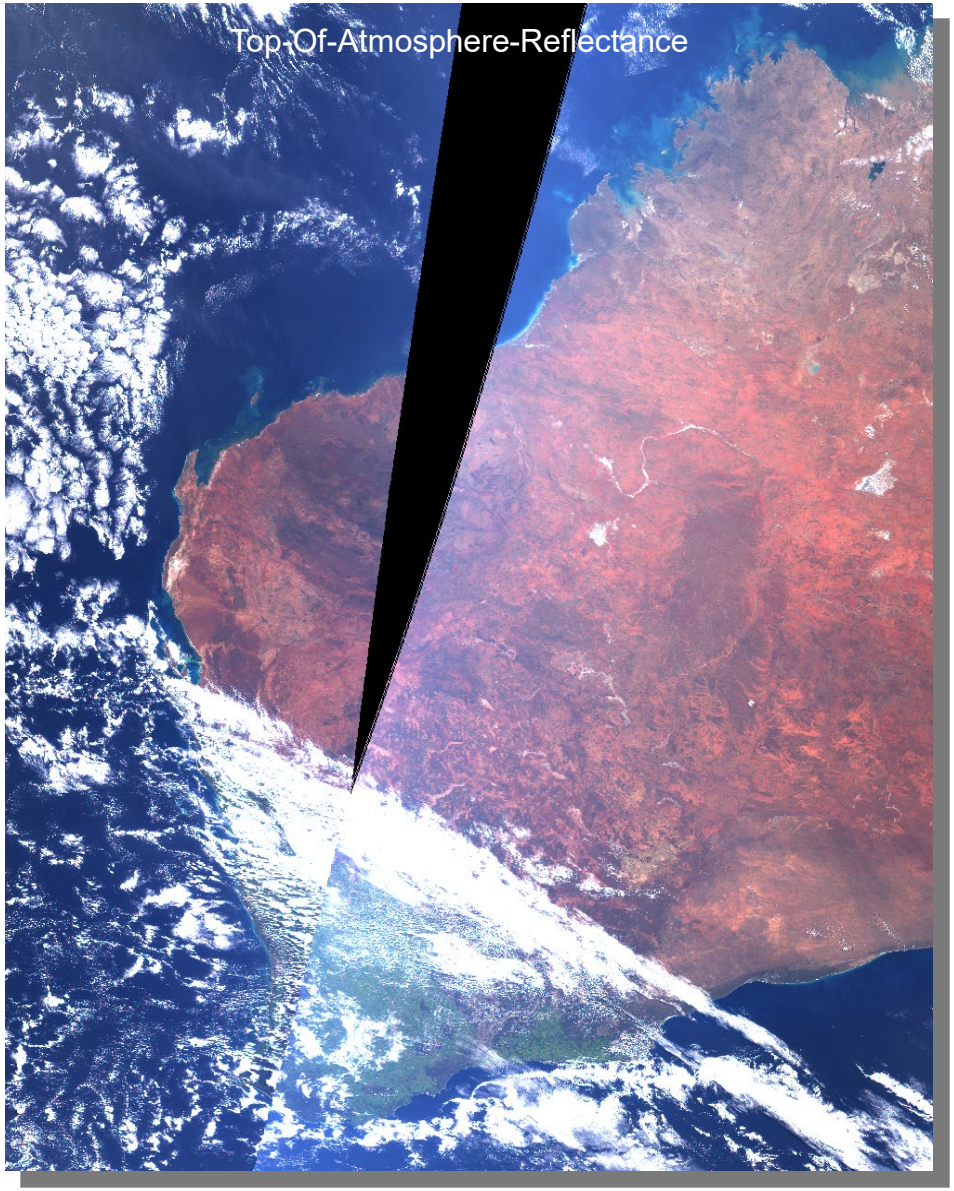
  Level 3 sinusoidal grid projection

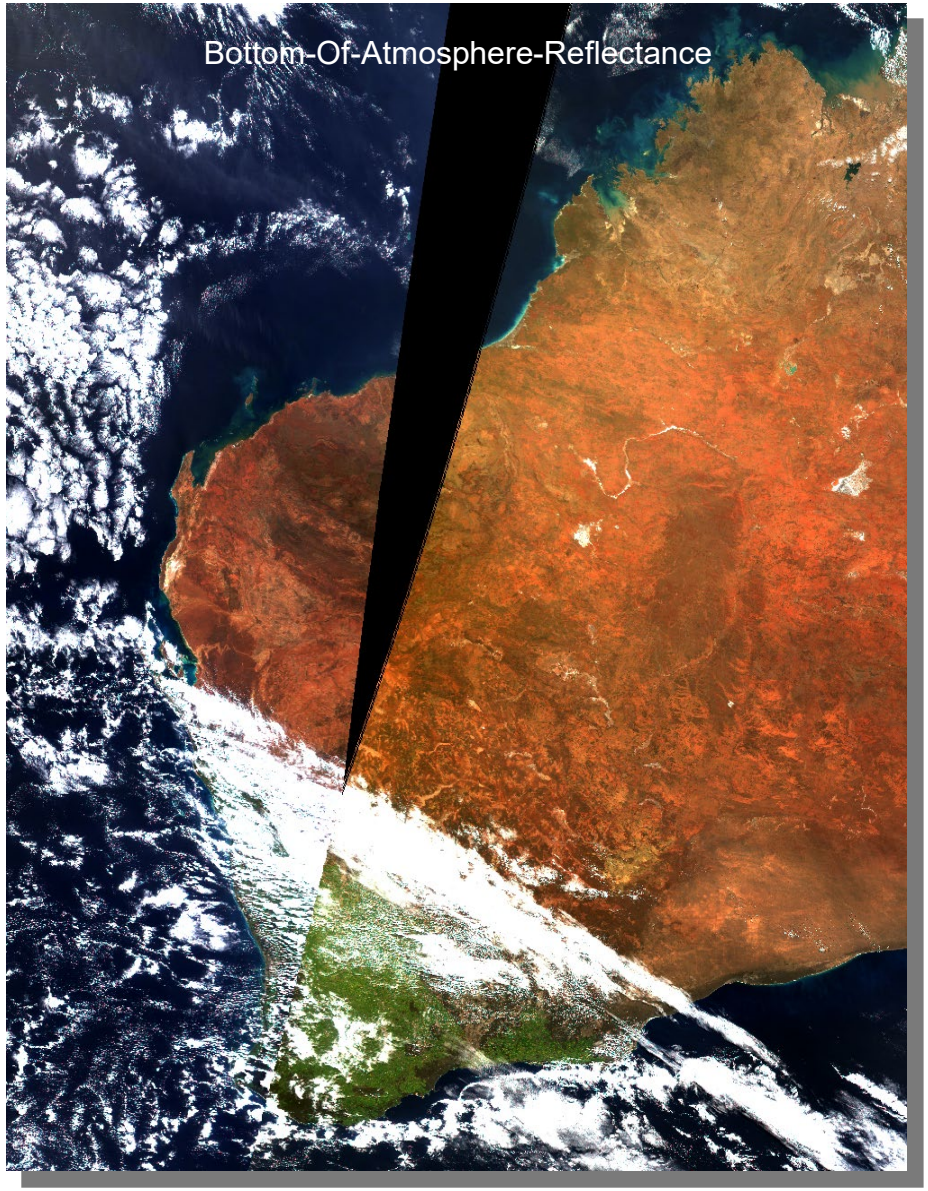
* 250 m from 70 N to 70 S Latitude

Inputs and Processing Chain for MODIS VI Production



Atmospheric contribution is removed to retrieve surface properties





Terra MODIS 09/09/2003 01:27UTC 03:04UTC

Global Compositing

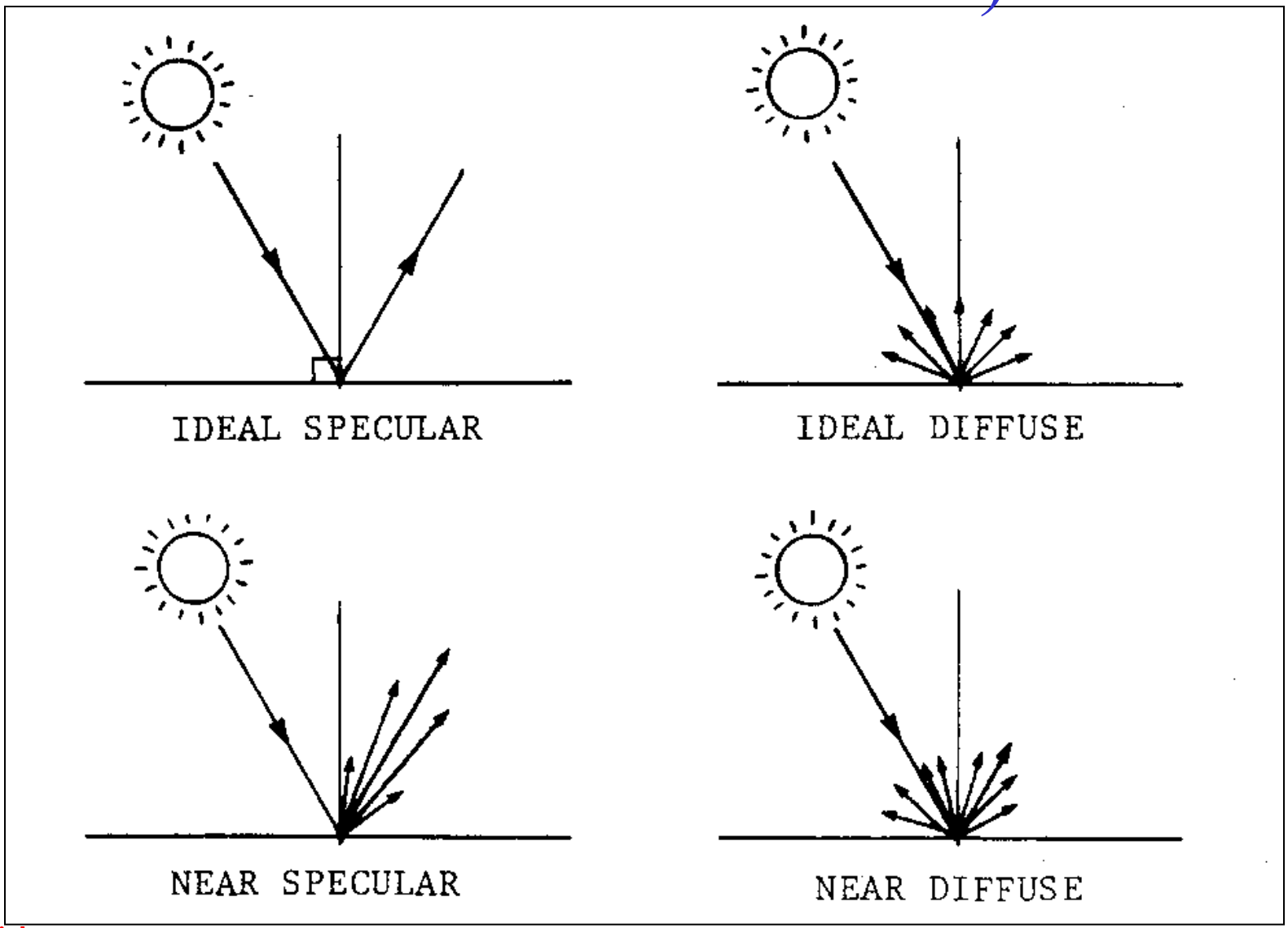
Multiple observations over same 250 or 500m scene over 16 day time period

- Selection of Representative Observation
- Uses surface reflectance as input
  - Corrects for molecular scattering, aerosol scattering and ozone absorption in observations
- Screening of reflectances to use in compositing
  - Cloud free, view angles < 45 degrees, low aerosol contamination pixels labeled as "good"

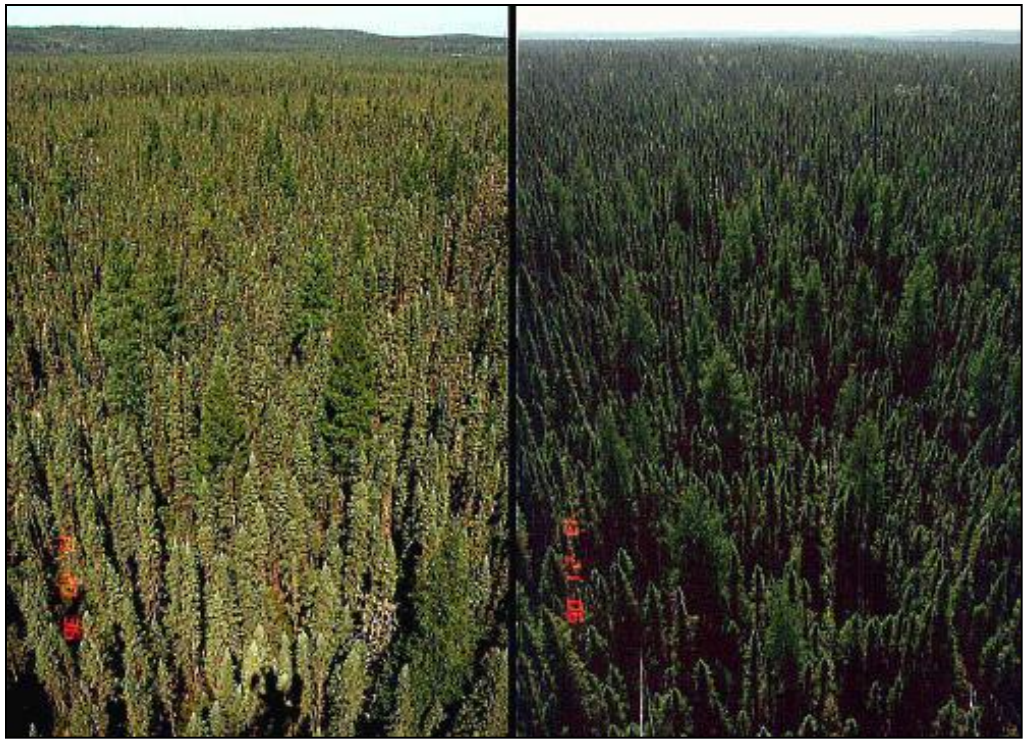
Global Compositing (continued)

- If number of good pixels > 5
  - Bidirectional Reflectance Distribution Function (BRDF) selection
    - Good pixel values corrected for angular effects
- If number of good pixels 1< n < 5
  - Constrained-view angle-maximum value (CV-MVC) selection
    - Highest values closest to nadir
- If number of good pixels = 0
  - Maximum value composite out of all “non-good” non-cloudy pixels
  - MVC can bias values to the high side

BRDF (Bi-directional Reflectance Distribution Function)



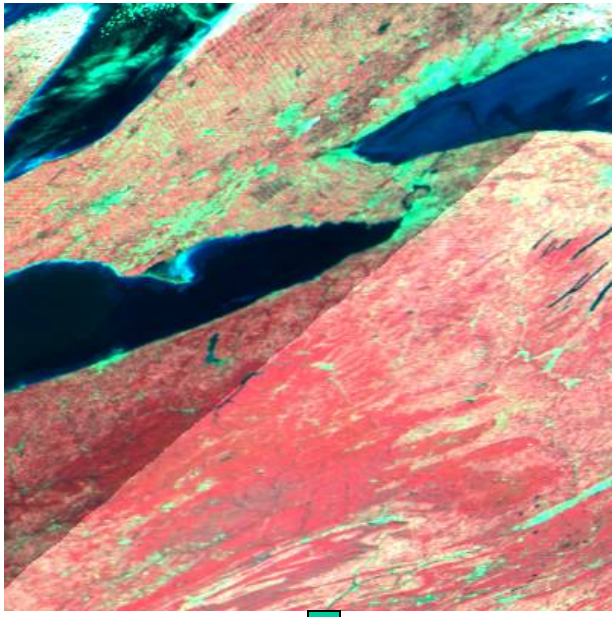
BRDF Example

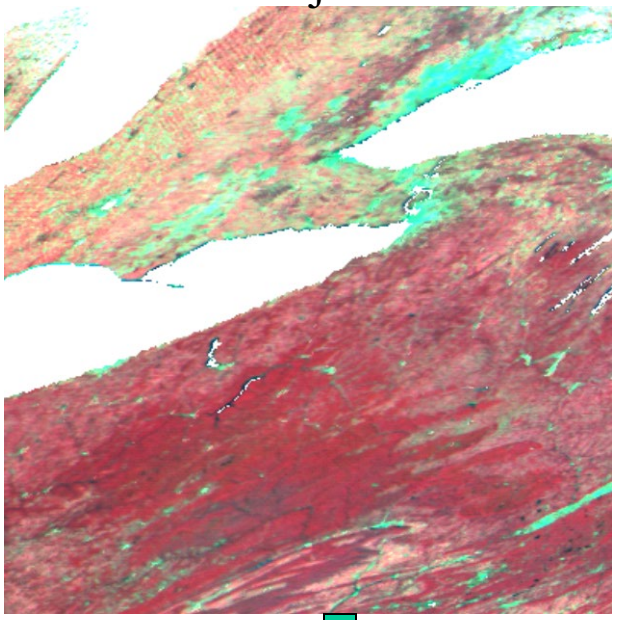


Black spruce forest in Canada.
Left, sun behind camera
Right, sun opposite

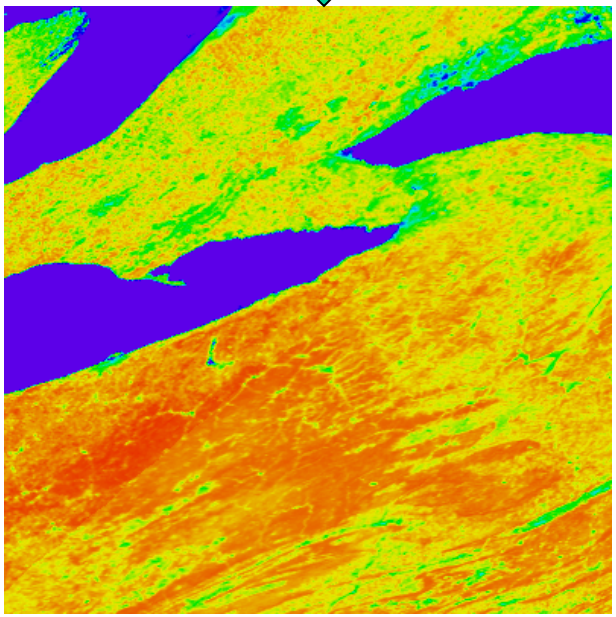
Surface Reflectance

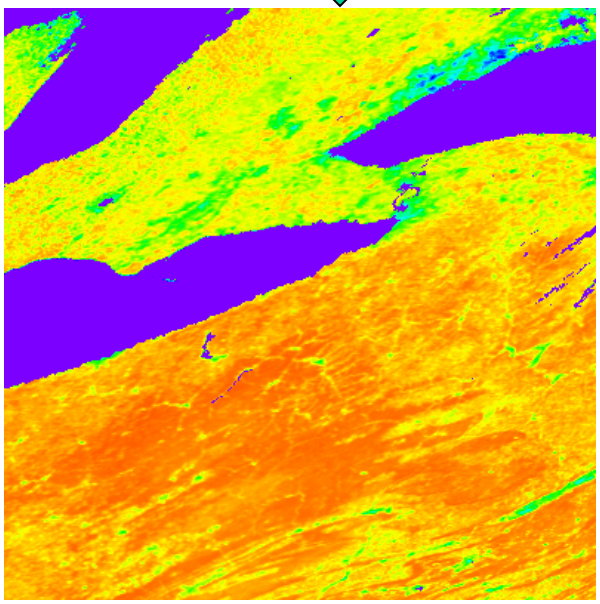
Nadir BRDF-Adjusted Reflectance





NIR (0.10-0.45)
Red (0.0-0.1)
Green (0.0-0.15)

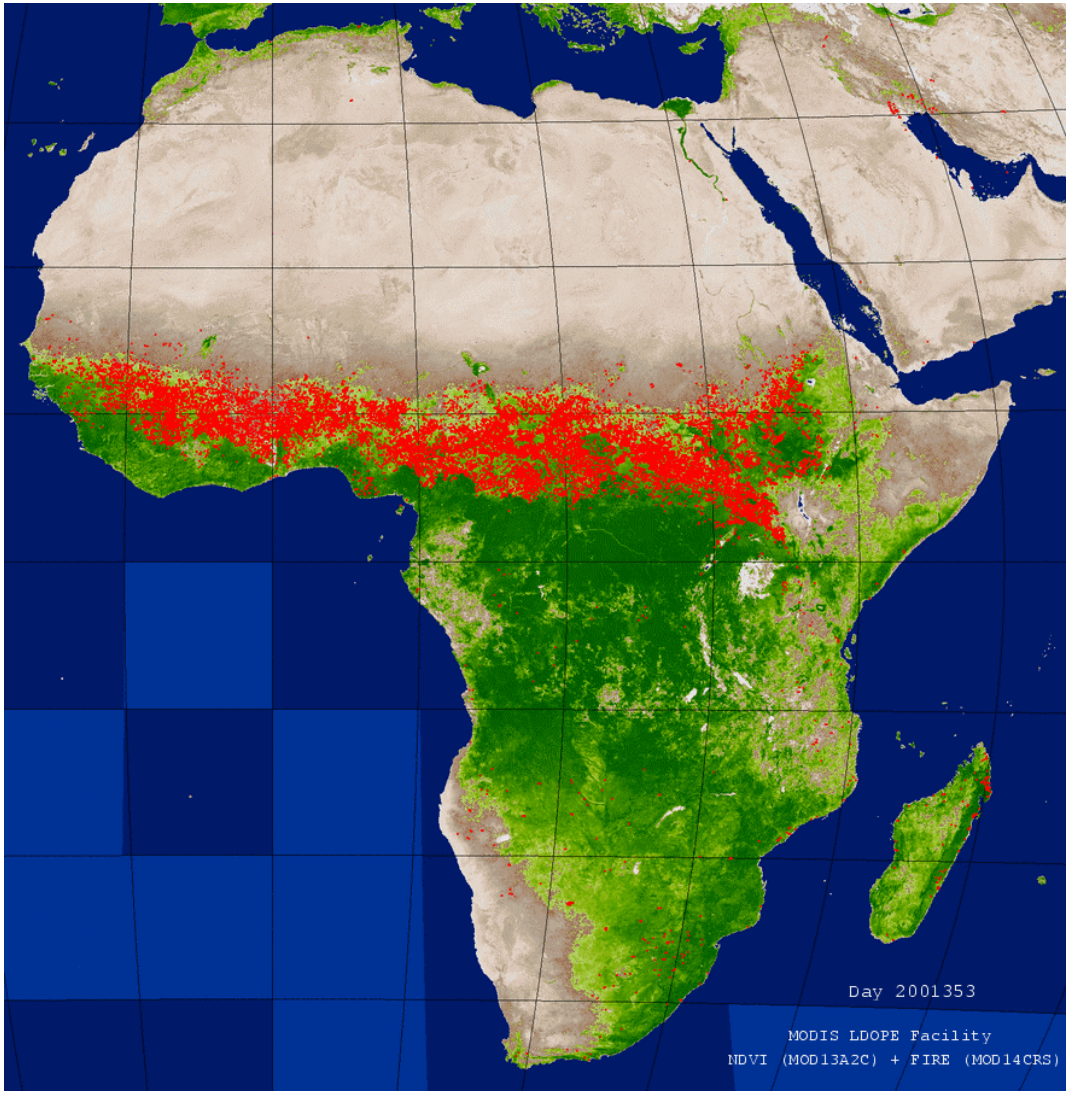




NDVI

0.0 1.0

Relevance of NDVI: FIRES



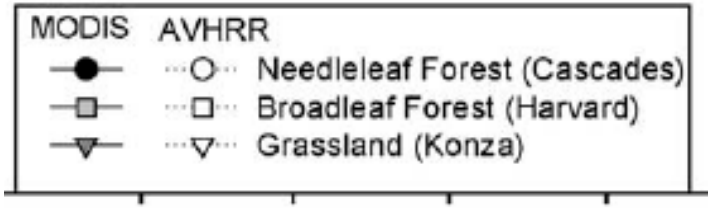
http://landweb.nascom.nasa.gov/animation/area.html

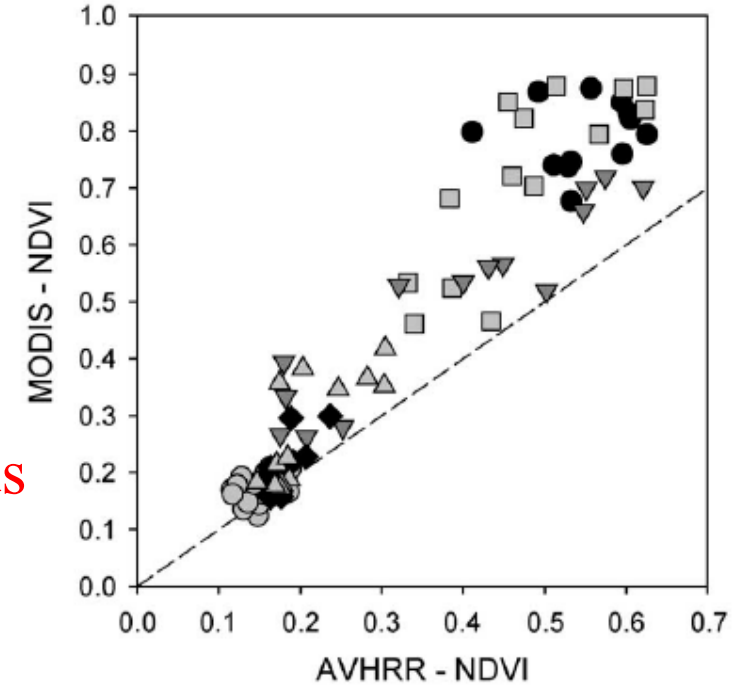
Challenges

- Red band saturation in high biomass regions
  - Chlorophyll-a maximum absorption is at .68
  - Non-linear stretch of NDVI enhances low ratio values – less sensitive as NDVI increases
- Clouds and aerosols
- Canopy structural effect
- Canopy background effects
- Angular effects

Validation

- AVHRR Comparisons (extend 20 year climate record)
- Airborne Sensor Comparisons
- Comparisons with Global Ground Truth Sites





Example of MODIS NDVI versus AVHRR NDVI for the 2000 growing season.

REFERENCES

- Beautiful example of how the NDVI works:

  http://www.uswcl.ars.ag.gov/epd/remsen/Vi/sorghumVI_files/v3_document.htm
- MOD13 Web Page:
  http://edcdaac.usgs.gov/modis/mod13q1v4.asp
- Citation:
  - Huete, A., K. Didam, T. Miura, E.P. Rodiguez, X. Gao and L.G. Ferreira: 2002. Overview of the radiometric and biophysical performance of the MODIS vegetation indices: 2002. *Remote Sensing of the Environment*, **83**, 195-213.
- Algorithm Theoretical Basis Document (ATBD)

  http://modis.gsfc.nasa.gov/data/atbd/atbd_mod13.pdf
- Direct Broadcast VI Product Software is available through the NASA Direct Readout Site:
  http://directreadout.gsfc.nasa.gov/index.cfm?section=downloads&page=technology

MODIS/AIRS Workshop
MODIS Level 2 Fire Product

Pretoria, South Africa

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MODIS Standard Products

Land

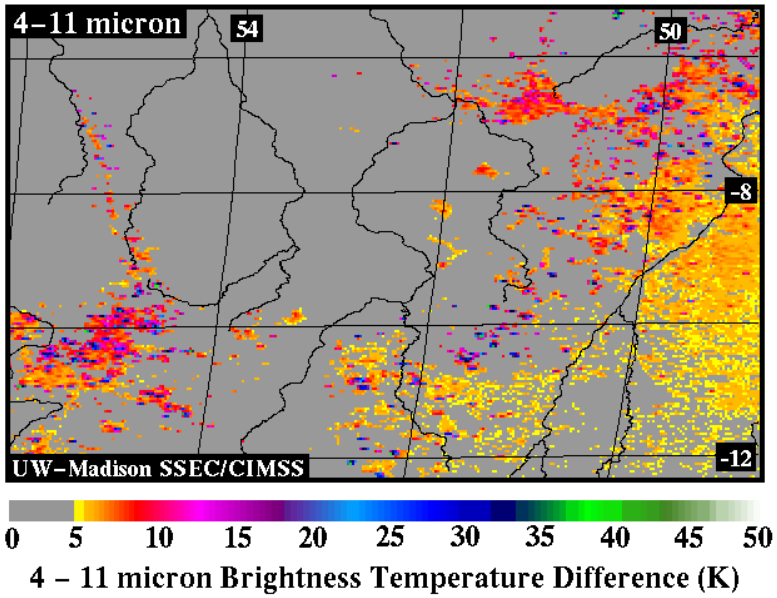
- MOD 09 - Surface Reflectance
- MOD 10 - Snow Cover
- MOD 11 - Land Surface Temperature & Emissivity
- MOD 12 - Land Cover/Land Cover Change
- MOD 13 - Gridded Vegetation Indices (NDVI & EVI)
- ***MOD 14 - Thermal Anomalies (Fires)***
- MOD 15 - Leaf Area Index & FPAR
- MOD 16 - Evapotranspiration
- MOD 17 - Net Photosynthesis and Primary Productivity
- MOD 29 - Sea Ice Cover
- MOD 43 - Bidirectional Reflectance Distribution Function (BRDF)
- MOD 44 - Vegetation Cover Conversion

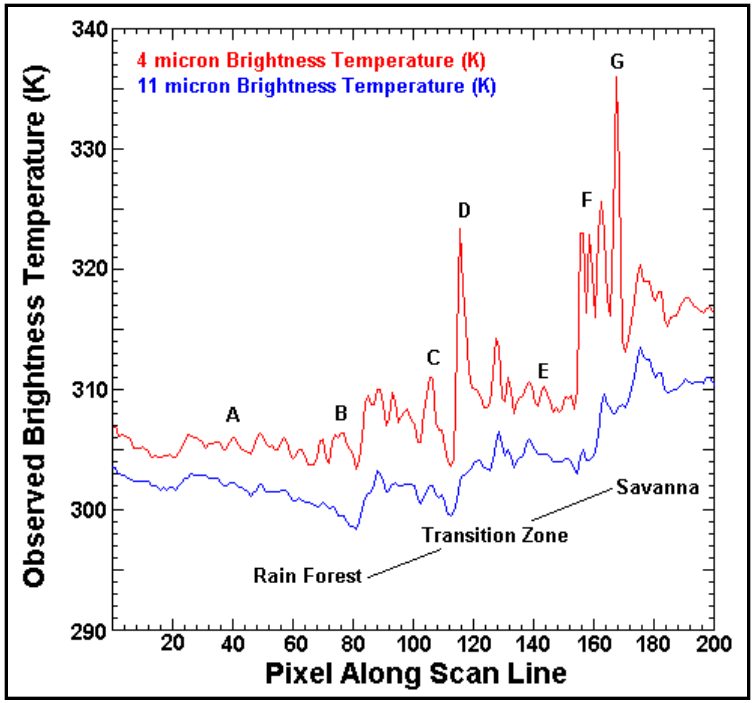
MODIS Fire Product

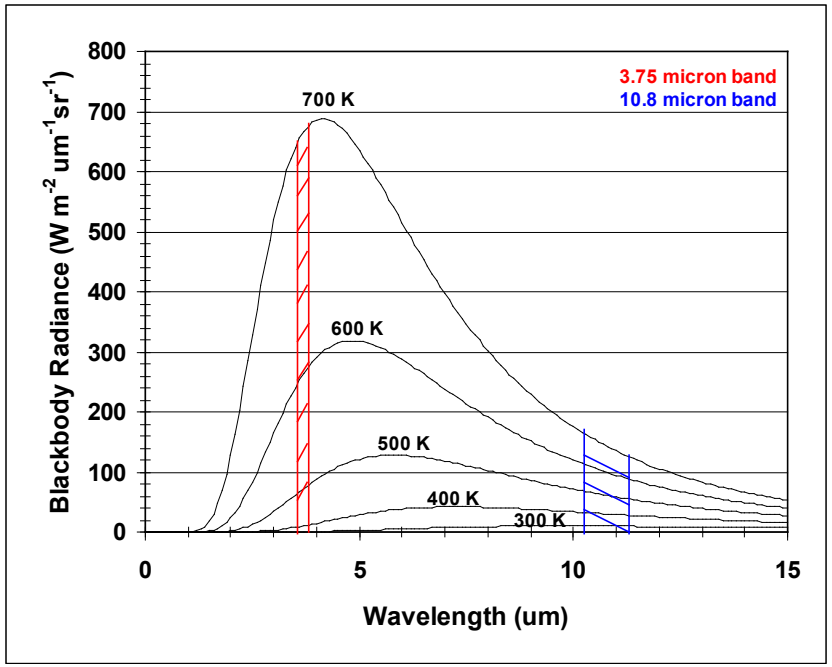
Louis Giglio Chris Justice

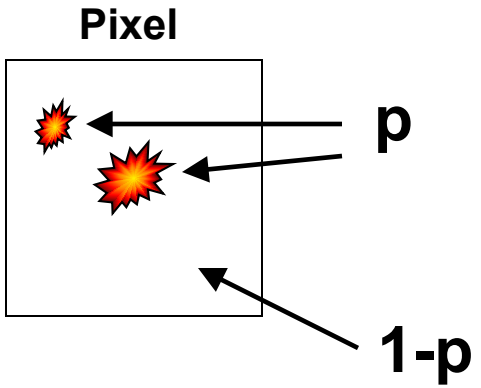
- Based upon the Temperature Sensitivity difference between 4 and 11 microns
- Contextual Fire Detection Algorithm
  - Infrared static Brightness Temperature thresholds
  - Dynamic thresholds compare pixel to surrounding background
- Variety of output product temporal and spatial resolutions

How are Meteorological Satellites Used to Monitor Fires?









$$B_4(T_4) = pB_4(T_{fire}) + (1-p)B_4(T_{bg})$$

$$B_{11}(T_{11}) = pB_{11}(T_{fire}) + (1-p)B_{11}(T_{bg})$$

Temperature Sensitivity

$$dB/B = \alpha\, dT/T$$

$$\alpha = c_2/\lambda T \qquad B \text{ is proportional to } T^{\alpha}$$

Wavelength	Typical Scene Temperature	Temperature Sensitivity
(4.0 μm)	300	11.99
(11 μm)	300	4.32

T(4)**12=P*T_{fire}**12+(1-P)*T**12 ~ P*400**12+(1-P)*300**12

T(11)**4=P*T**4_{fire}+(1-P)*T**4 ~ P*400**4+(1-P)*300**4

Warm part of pixel has more influence for B(4) than B(11)

MOD14 Inputs

- MOD021KM
  - Bands 1,2,7,21,22,31,32
- MOD03 (geolocation)

Direct Broadcast Version Available from:

- http://directreadout.gsfc.nasa.gov/index.cfm?section=downloads&page=technology

Output Products

Product	Level	Temporal Resolution	Spatial Resolution
MOD14	2	5 minute granules	1 km
MOD14GD MOD14GN	2G	5 minute grids	1 km
MOD14A1	3	Daily	1 km Sinusoidal Grid
MOD14A2	3	8 Day	1 km Sinusoidal Grid

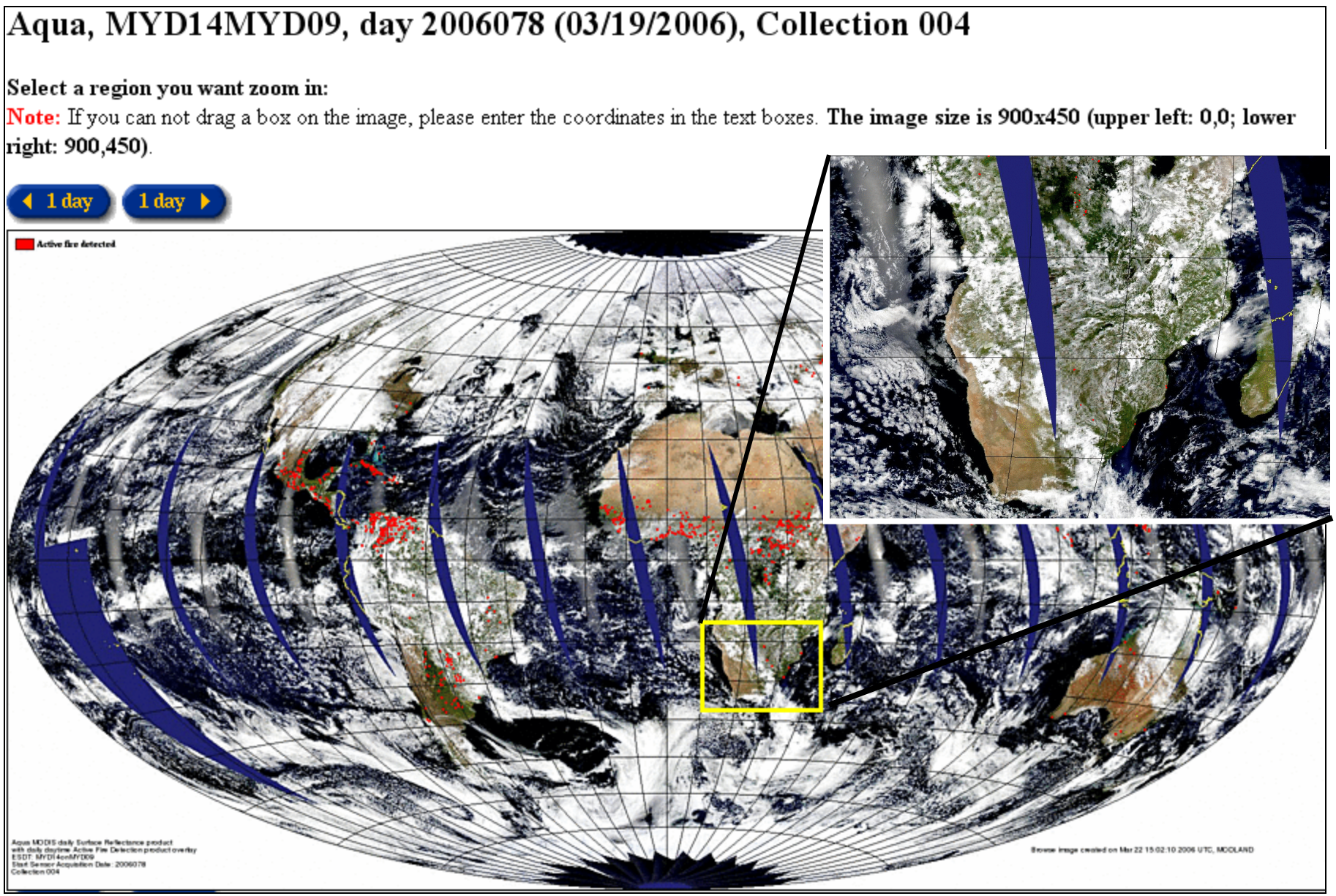
Global Daily Browse Product

Rapid Response Product ~ 4 hours behind real time

Goal: To provide rapid access to MODIS data globally

Global Daily Browse

http://landweb.nascom.nasa.gov/cgi-bin/browse/browse.cgi



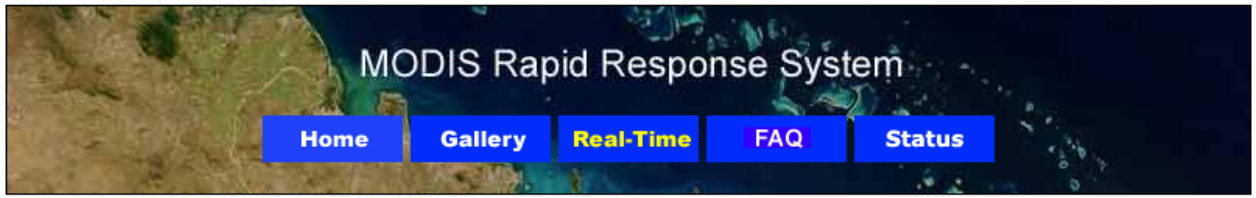
MOD14 Key Output Parameters

1km resolution

- fire_mask 8 bit unsigned integer
  - 0 missing input data
  - 3 water
  - 4 cloud
  - 5 non-fire
  - 6 unknown
  - 7 fire (low confidence)
  - 8 fire (nominal confidence)
  - 9 fire (high confidence)
- Line and element of fire pixel
- Latitude and longitude of fire pixel
- Fire pixel confidence (one value for each fire detected per scene)

Rapid Response Page

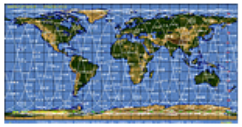
http://rapidfire.sci.gsfc.nasa.gov/

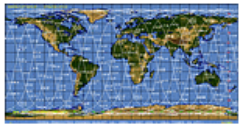


Near-Real-Time Level-2 Browse

Date: 2006/082 - 03/23/06

prev

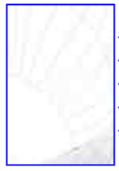
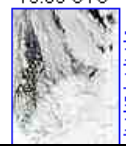

Terra Orbit Tracks


Aqua Orbit Tracks


Display true-color and false-color

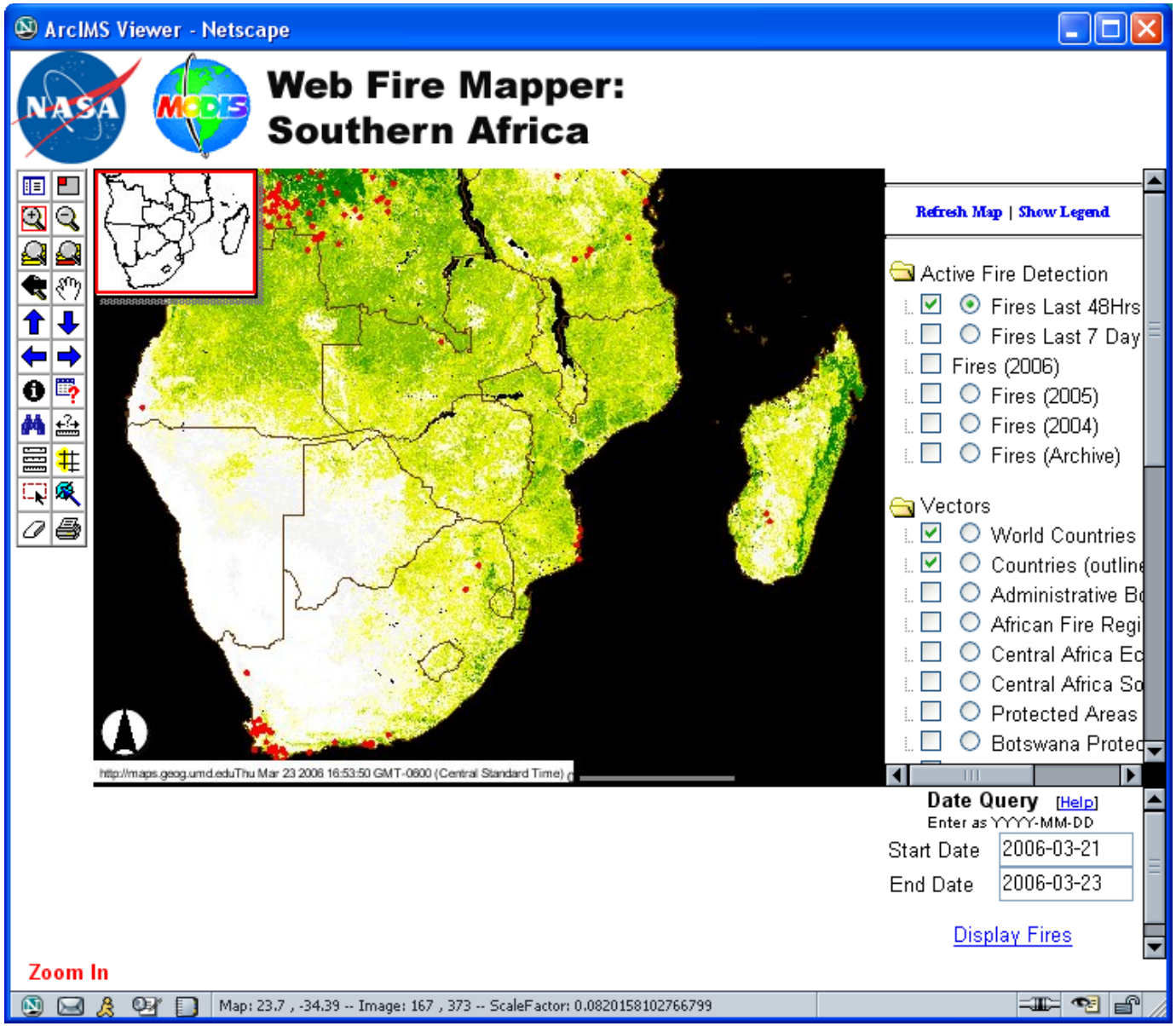

Access other dates from the archive

Terra/MODIS

00:00 UTC	03:10 UTC	06:05 UTC	08:05 UTC	11:00 UTC	13:00 UTC	15:00 UTC
 4km 2km 1km 500m 250m	 4km 2km 1km 500m 250m	 4km 2km 1km 500m 250m	 4km 2km 1km 500m 250m	 4km 2km 1km 500m 250m	 4km 2km 1km 500m 250m	 4km 2km 1km 500m 250m
00:05 UTC	03:15 UTC	06:10 UTC	08:10 UTC	11:05 UTC	13:05 UTC	15:05 UTC
 4km 2km 1km 500m 250m	 4km 2km 1km 500m 250m	 4km 2km 1km 500m 250m	 4km 2km 1km 500m 250m	 4km 2km 1km 500m 250m	 4km 2km 1km 500m 250m	 4km 2km 1km 500m 250m

Web Fire Mapper

http://maps.geog.umd.edu/



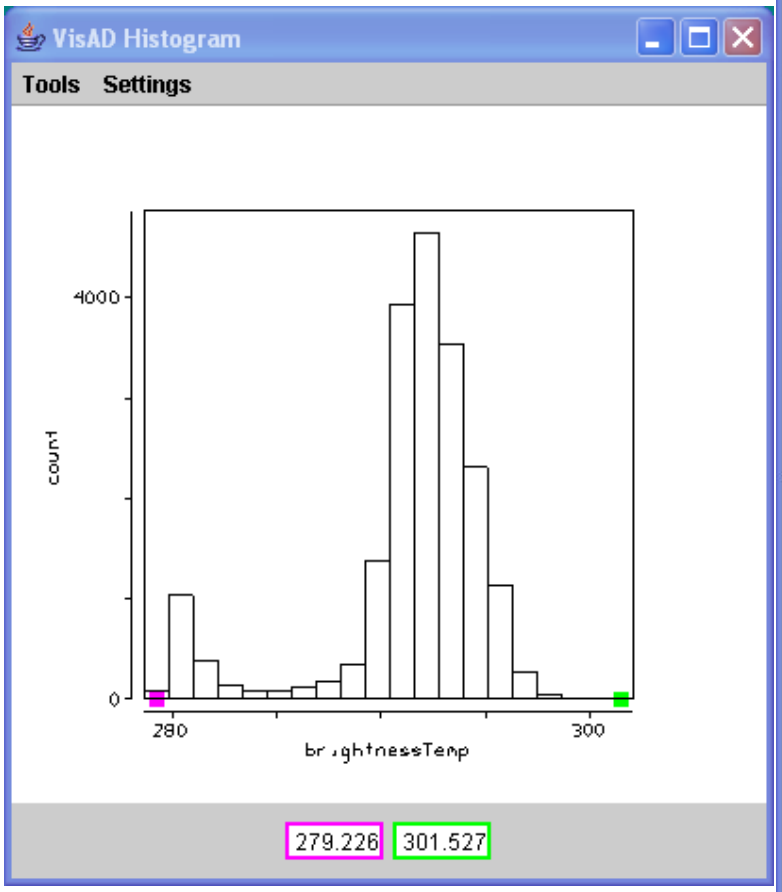
Algorithm Description

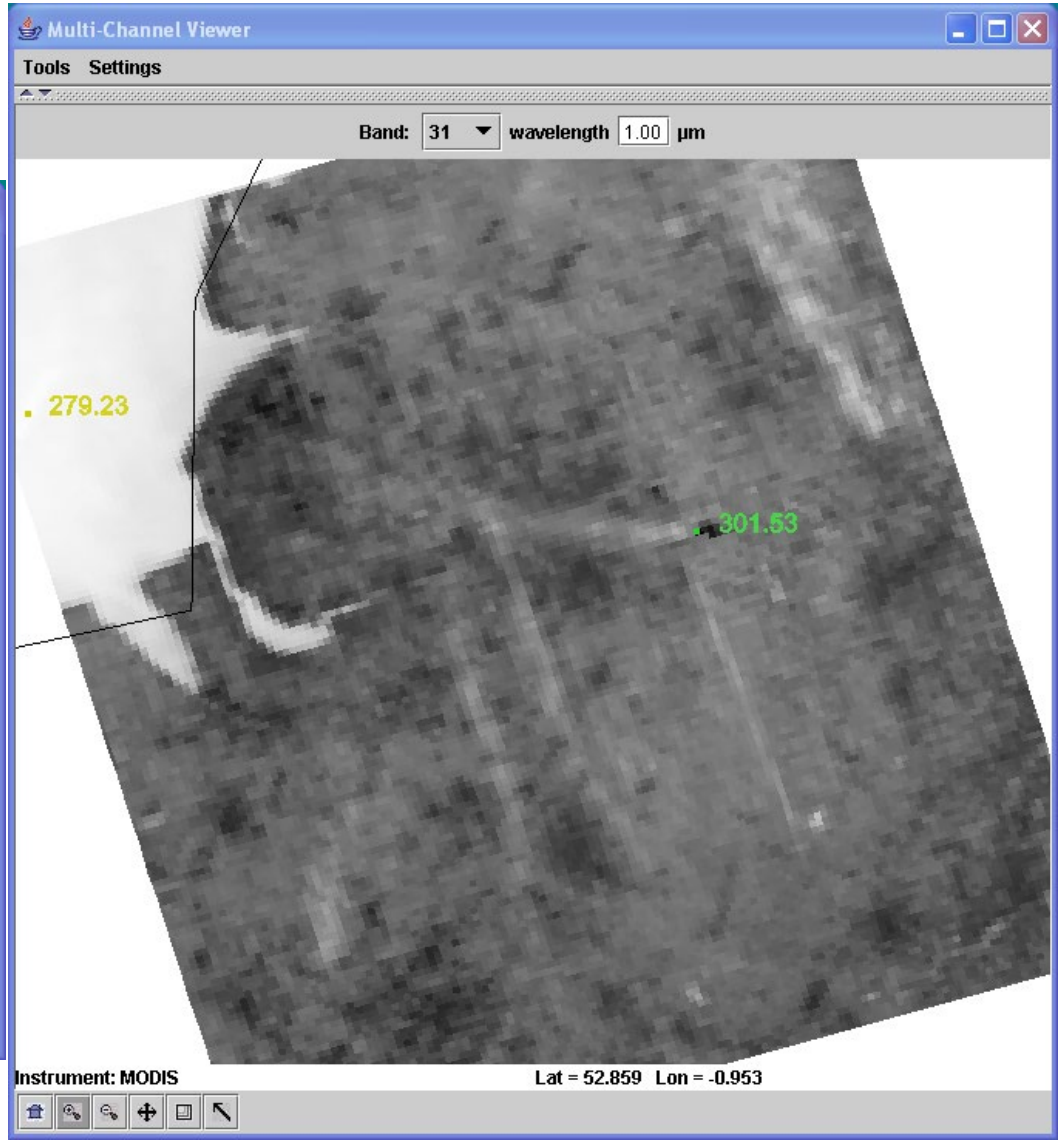
- MODIS bands 21 and 22 (3.99 micron)
  - Band 22 saturates at 331 K
  - Band 21 “fire channel” saturates at ~ 500 K
    - 12 bit range broader – less sensitive
    - The calibration of B21 uses fixed calibration coefficients and not using the scan-by-scan onboard black body (more noise)
    - So use Band 22 unless it is saturated
- MODIS band 31 (11 micron)
  - Saturates at ~ 400 K for Terra
  - Saturates at ~ 340 K for Aqua

Algorithm Description (cont.)

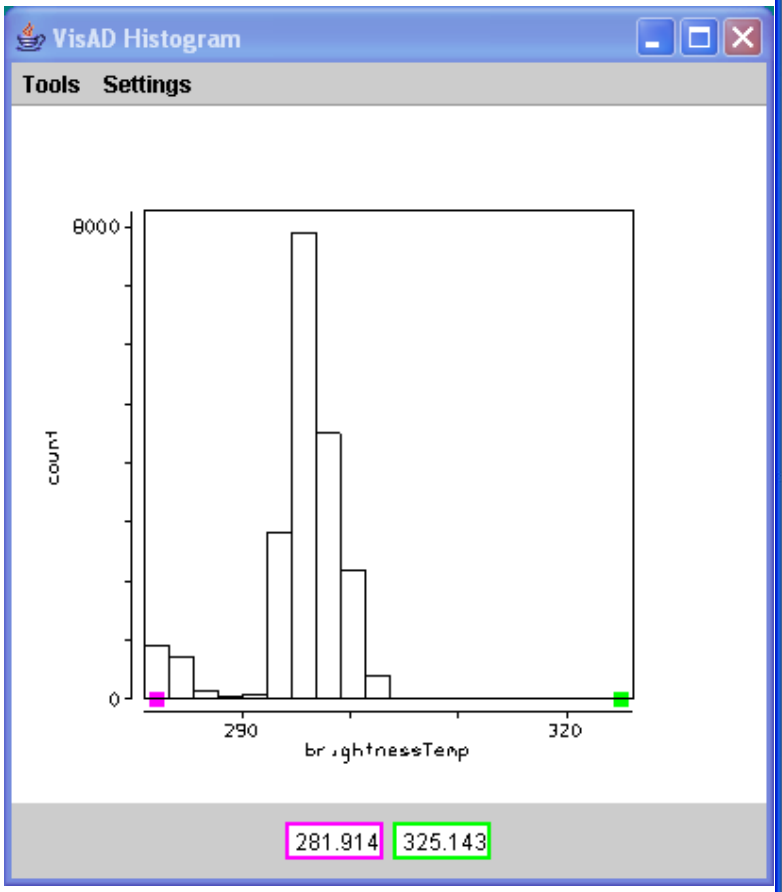
Aqua MODIS true color image 18 April 2003 12:45 UTC

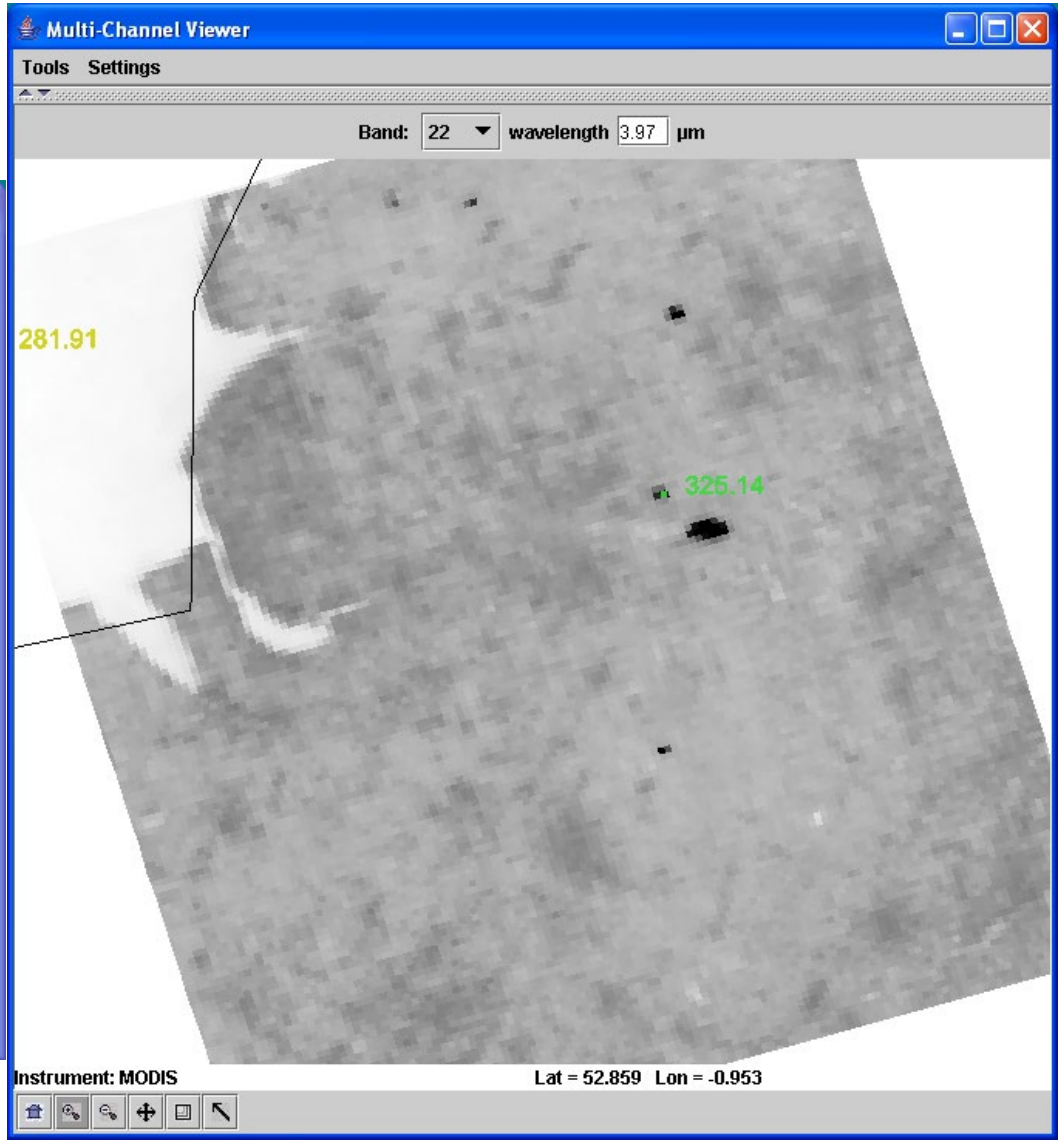
Band 31 Example



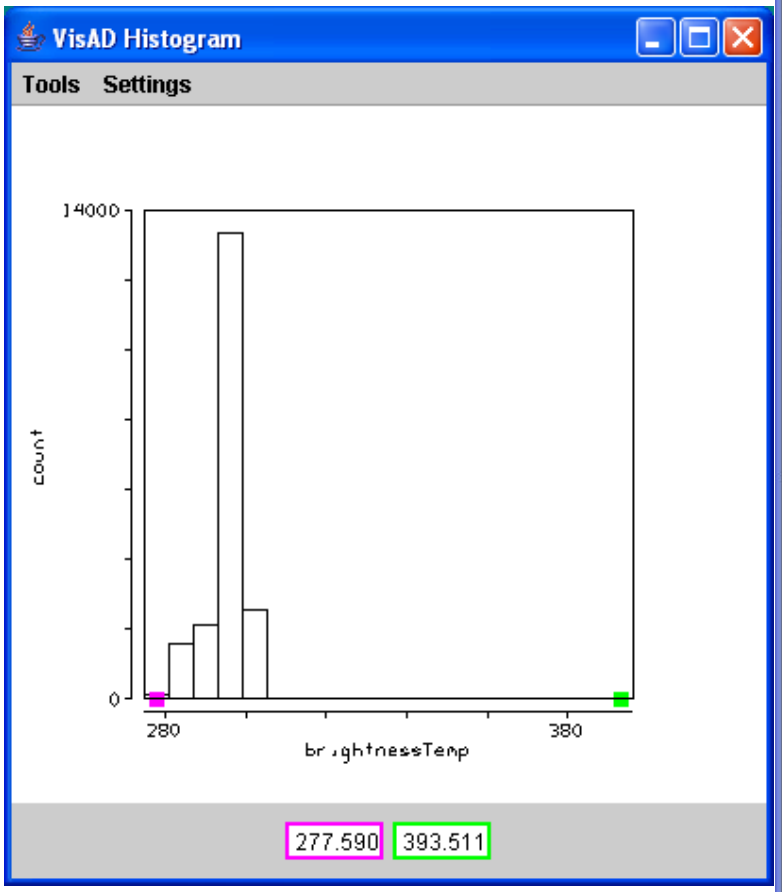


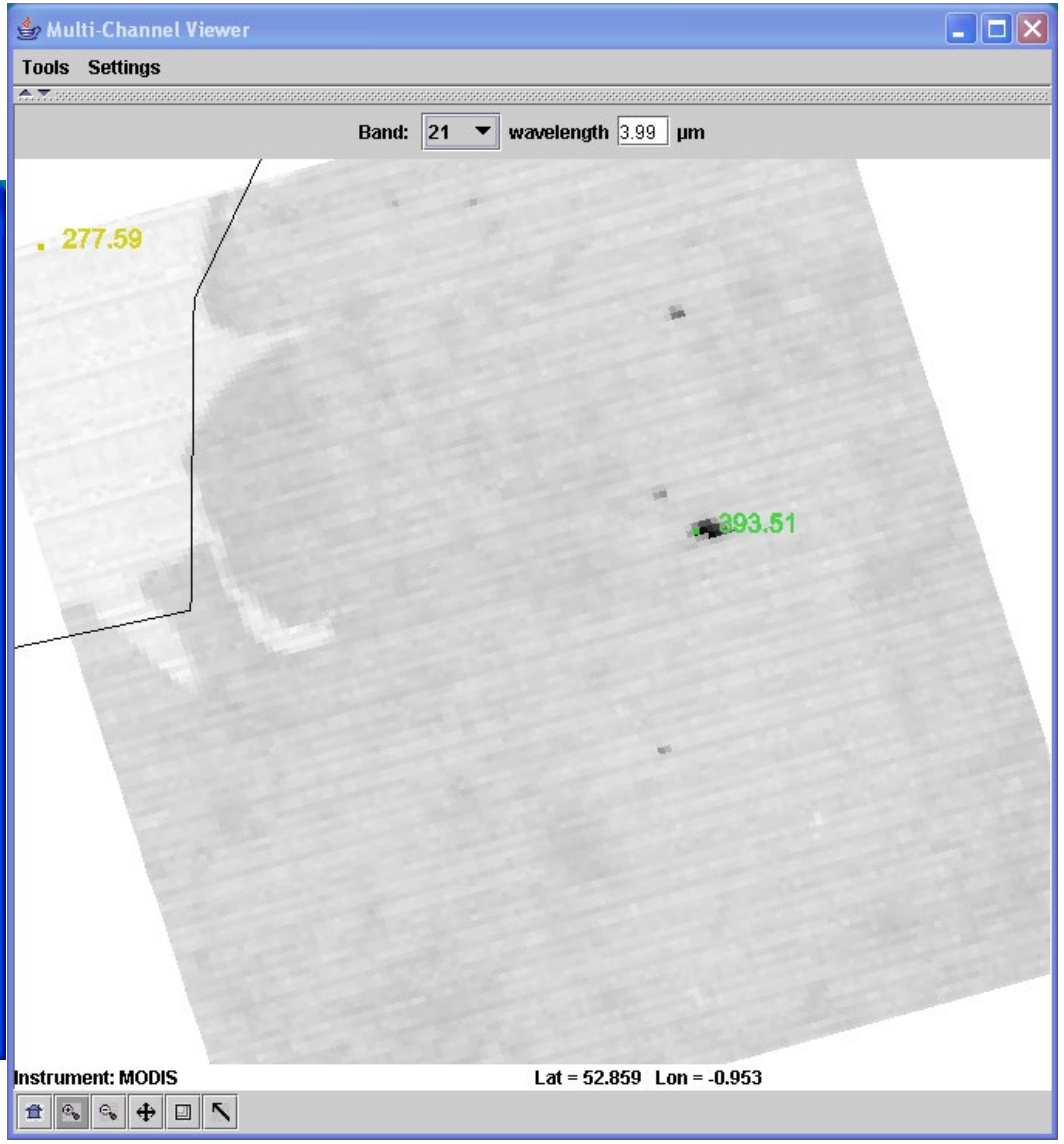
Band 22 Example



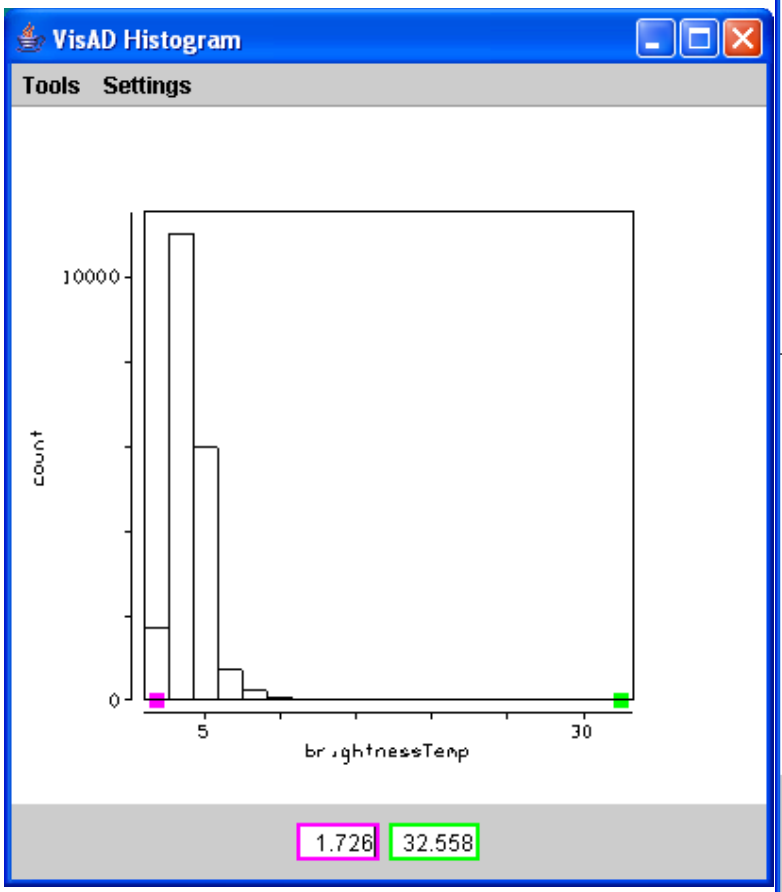


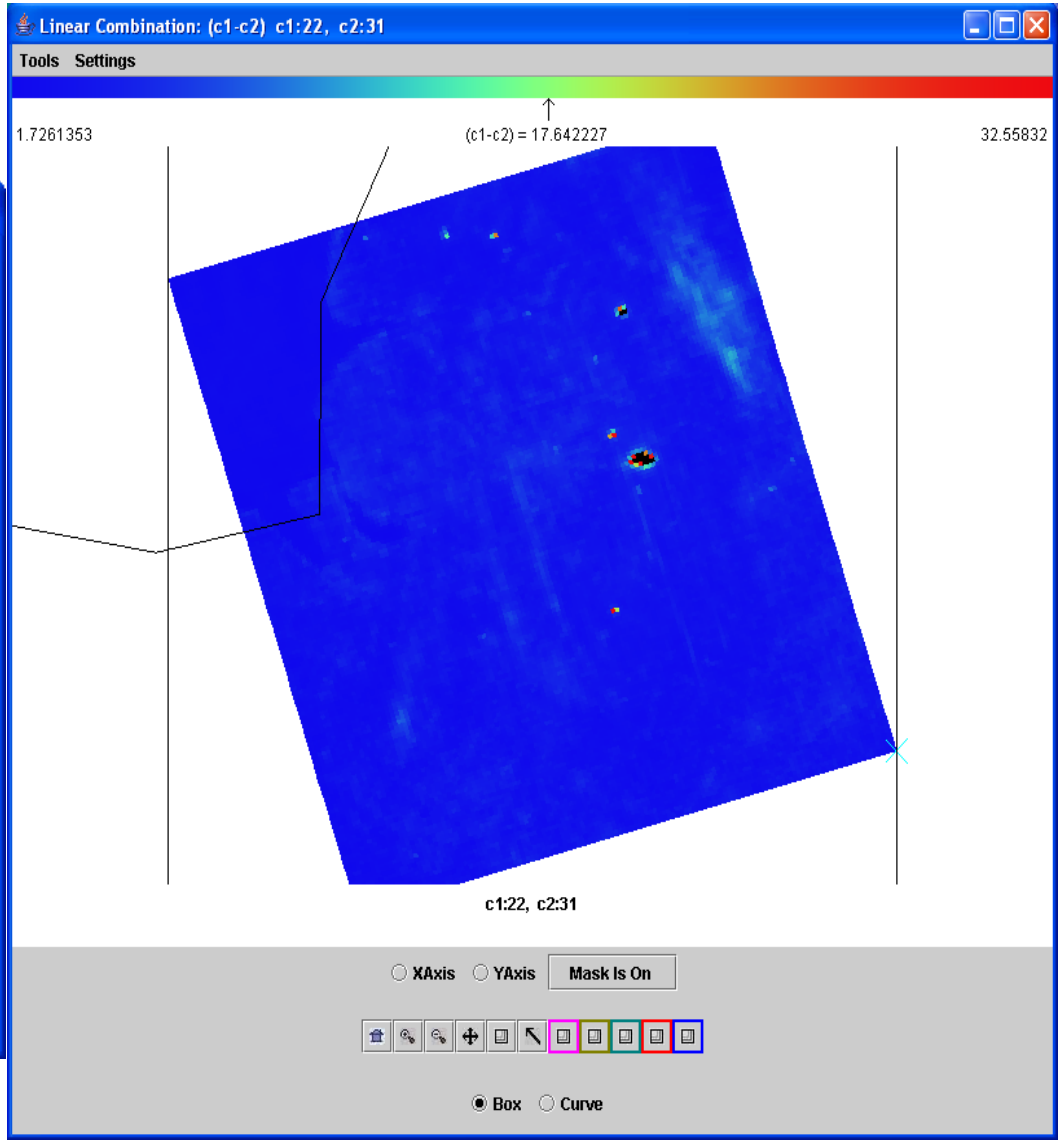
Band 21 Example



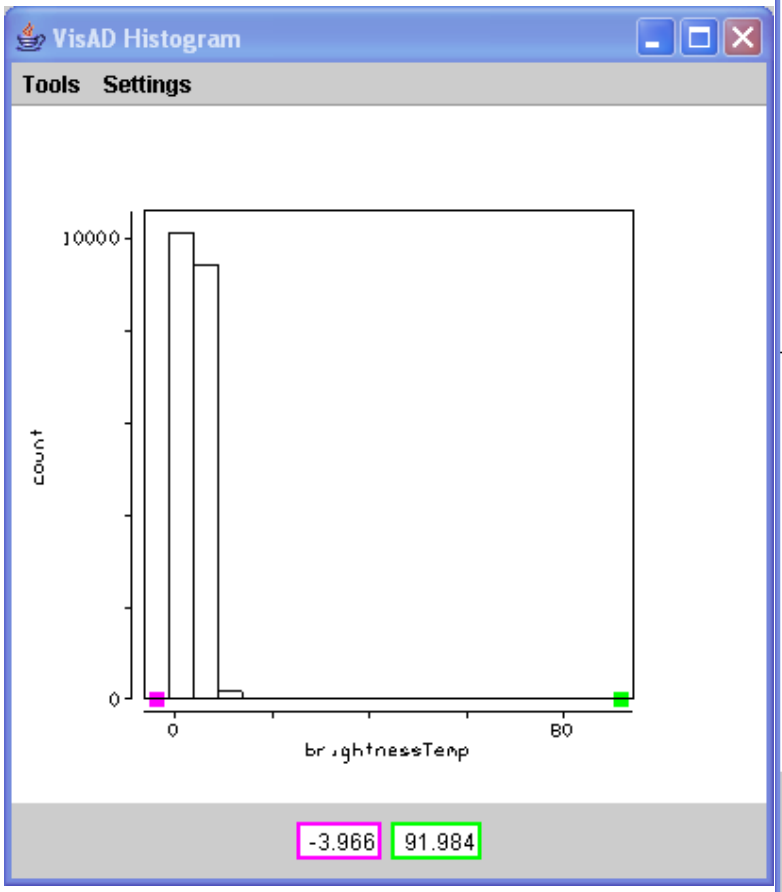


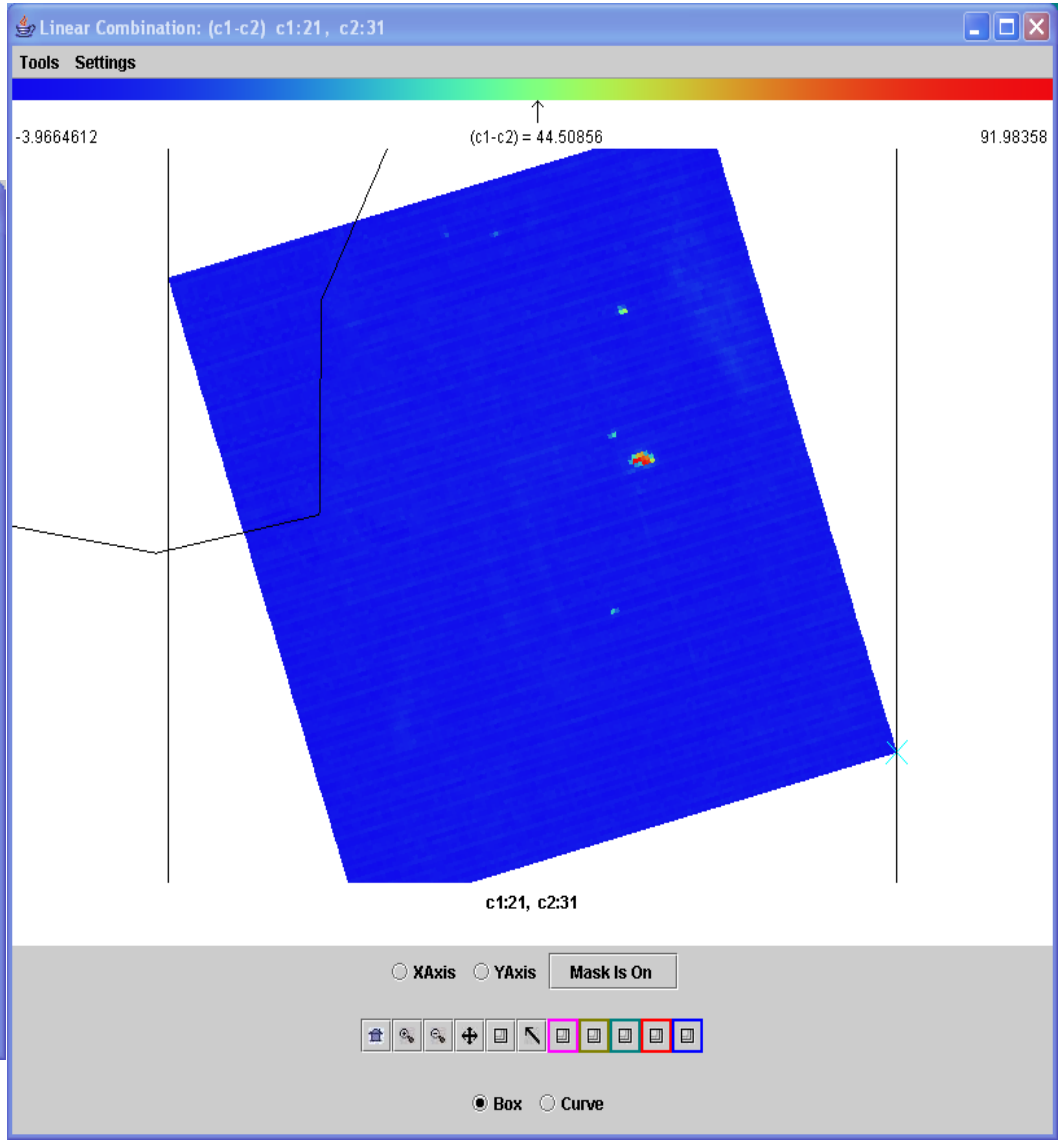
Band 22 – Band 31 Example



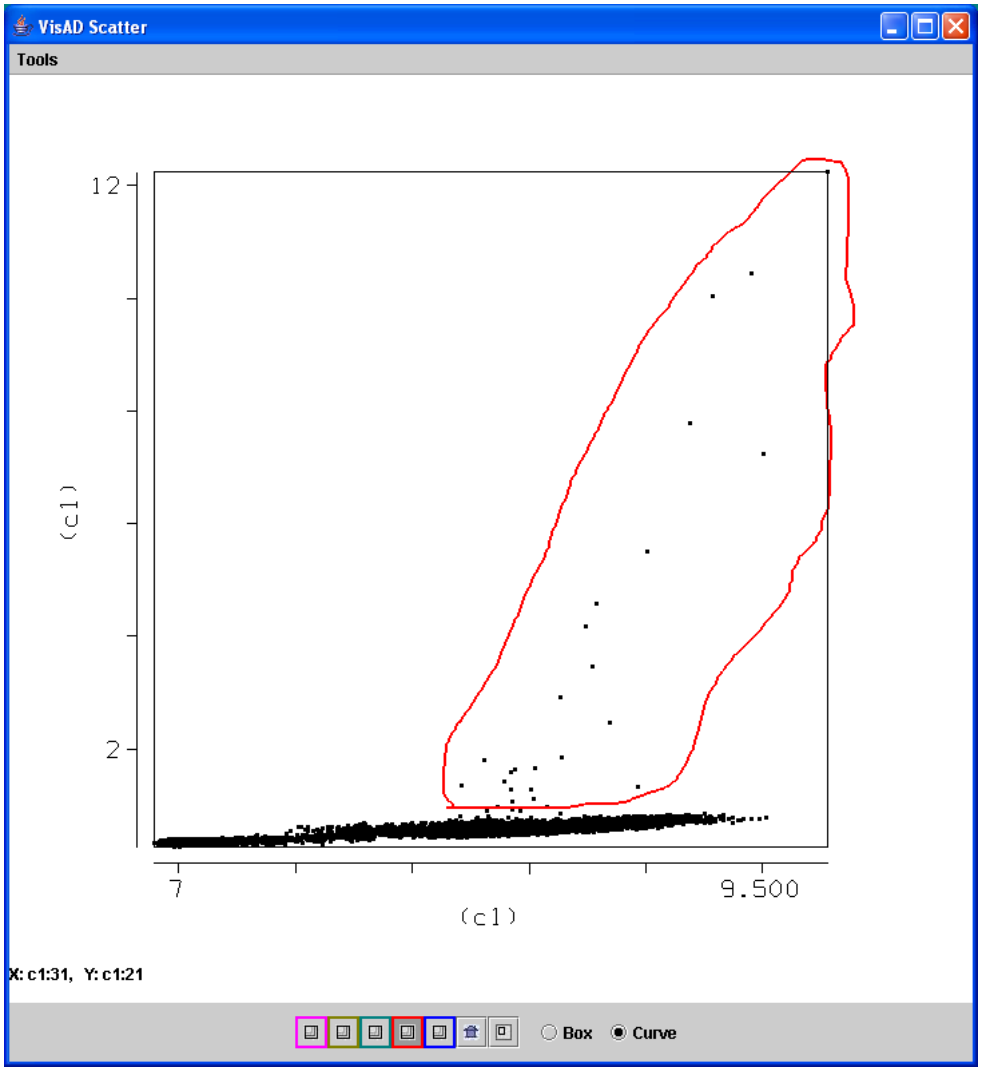


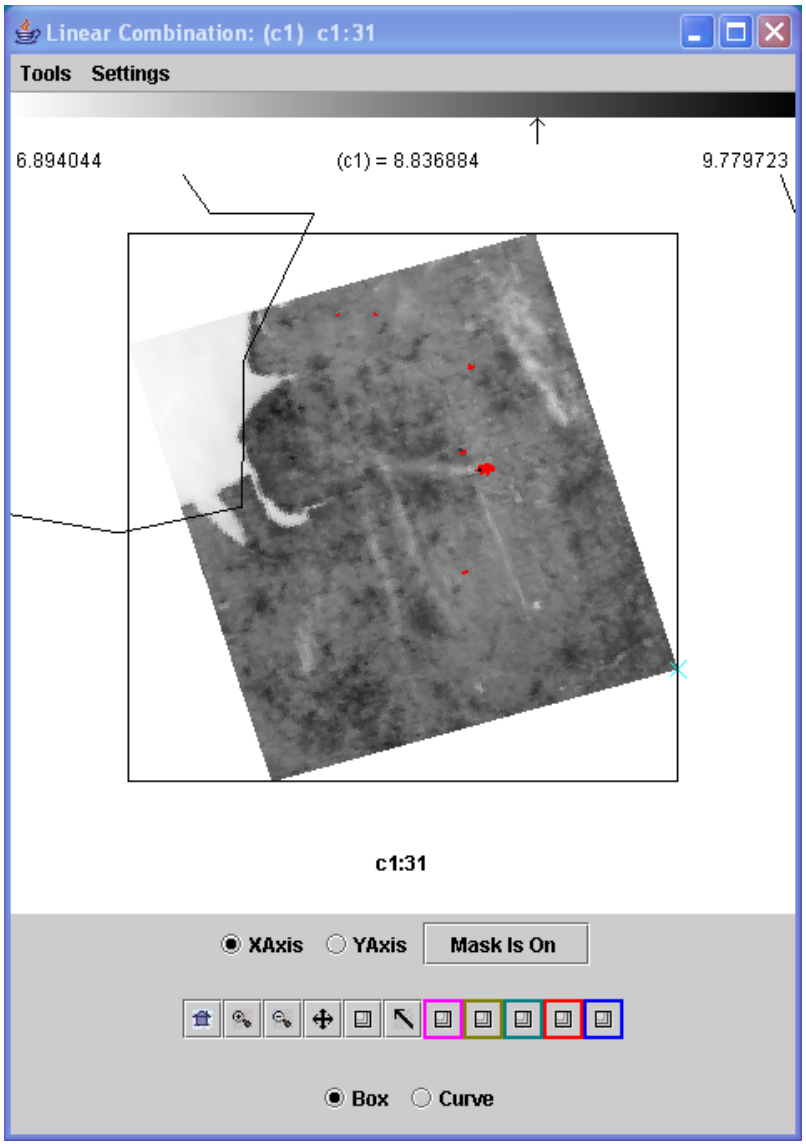
Band 21 – Band 31 Example





Example of Relationship between Planck Radiance of 4 and 11 microns





Algorithm Description (cont.)

- Potential Fire Pixel identified
  - BT4 > 310 K
  - BT4-11 > 10 K
  - .86 micron reflectance < .3
- Otherwise flagged as non-fire pixel

Screening Potential Fire Pixels

(1) BT4 > 360 K

Contextual Tests: Performed on as many as 21 x 21 box surrounding potential fire pixel to separate out from background

(2) $BT4-11 > \overline{BT4-11} + 3.5\partial_{BT4-11}$

(3) $BT4-11 > \overline{BT4-11} + 6K$

(4) $BT4 > \overline{BT4} + 3\partial_{BT4}$

(5) $BT11 > \overline{BT11} + \partial_{BT11} - 4K$

(6) $\partial'_4 > 5K$

Where δ is the Mean Absolute Difference (MAD):

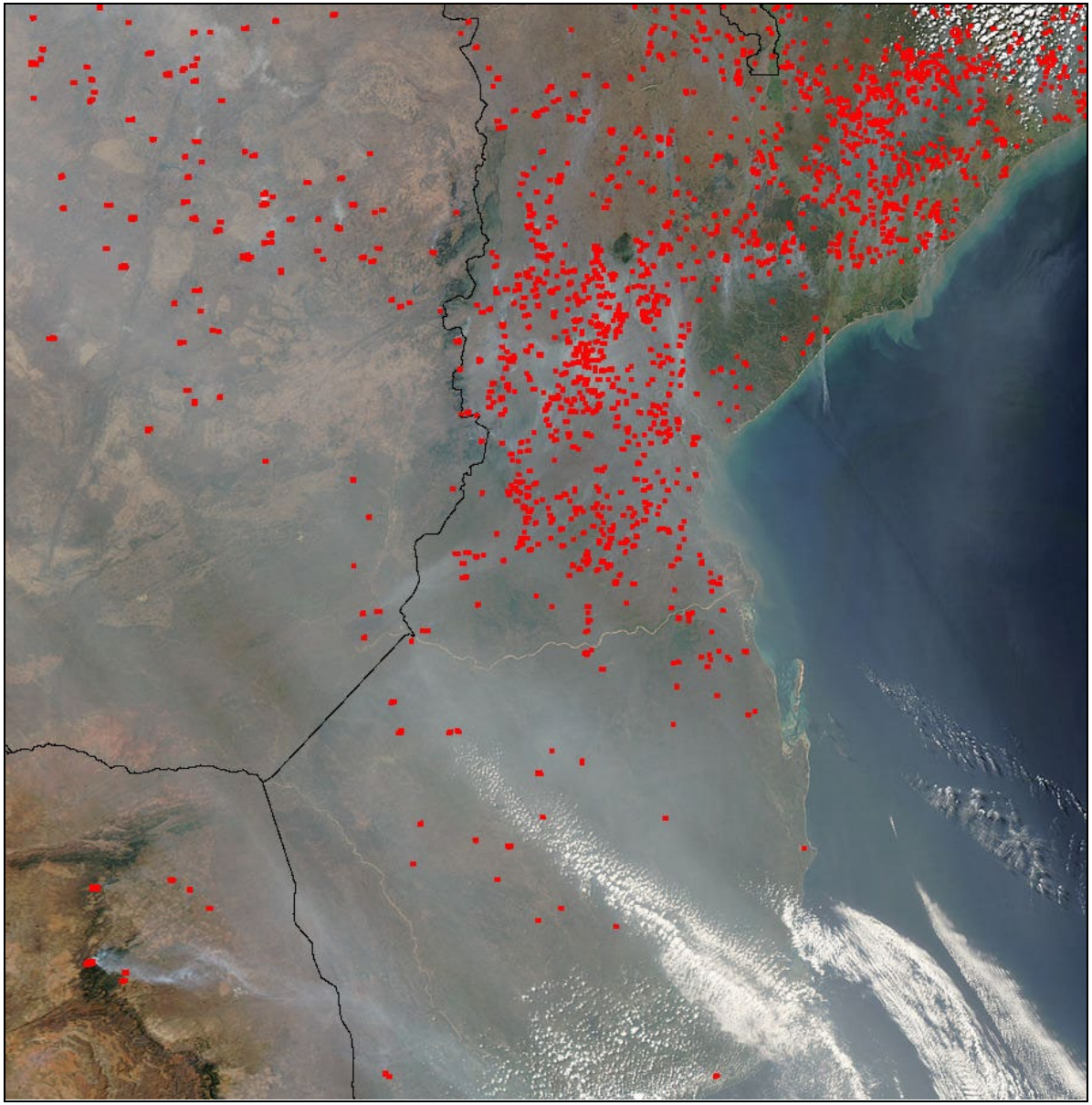
$$\text{MAD} = \frac{1}{N}\sum_i |x_i - \bar{x}|$$

Problem Areas

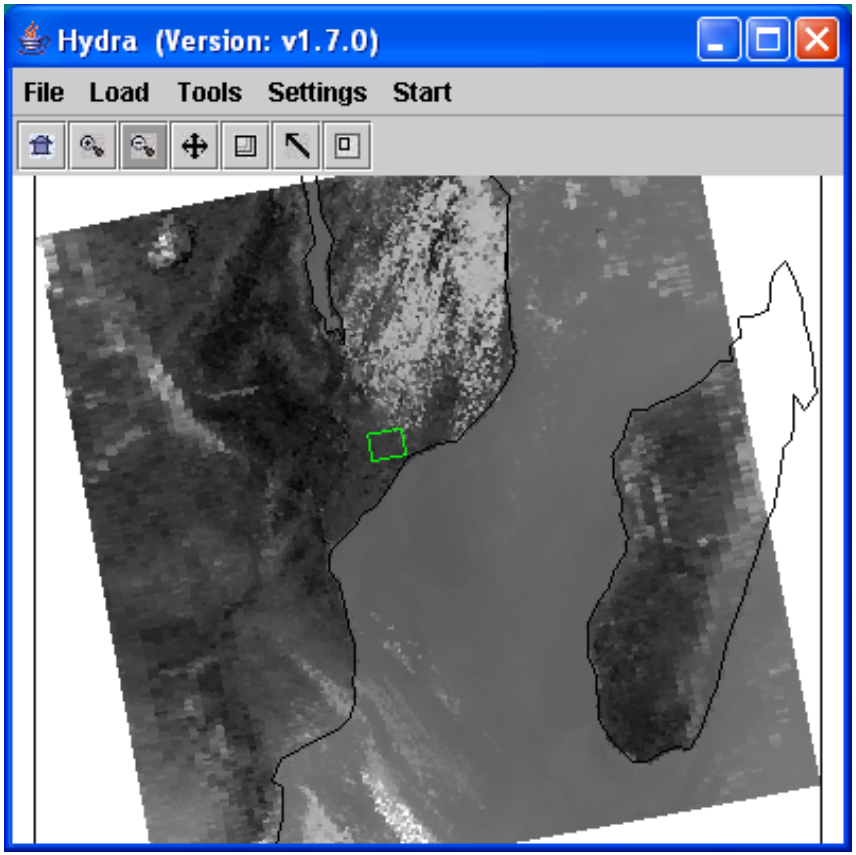
- If there are many fires – hard to get representative background temperature in max 21x21 pixel region
- Sunglint – Affects 4 micron band radiance
- Transition areas – contextual tests pick up boundaries
- Coastal areas – need really good geolocation so no mixed pixels are included
- Clouds – BT4-11 large over water and thick ice cloud

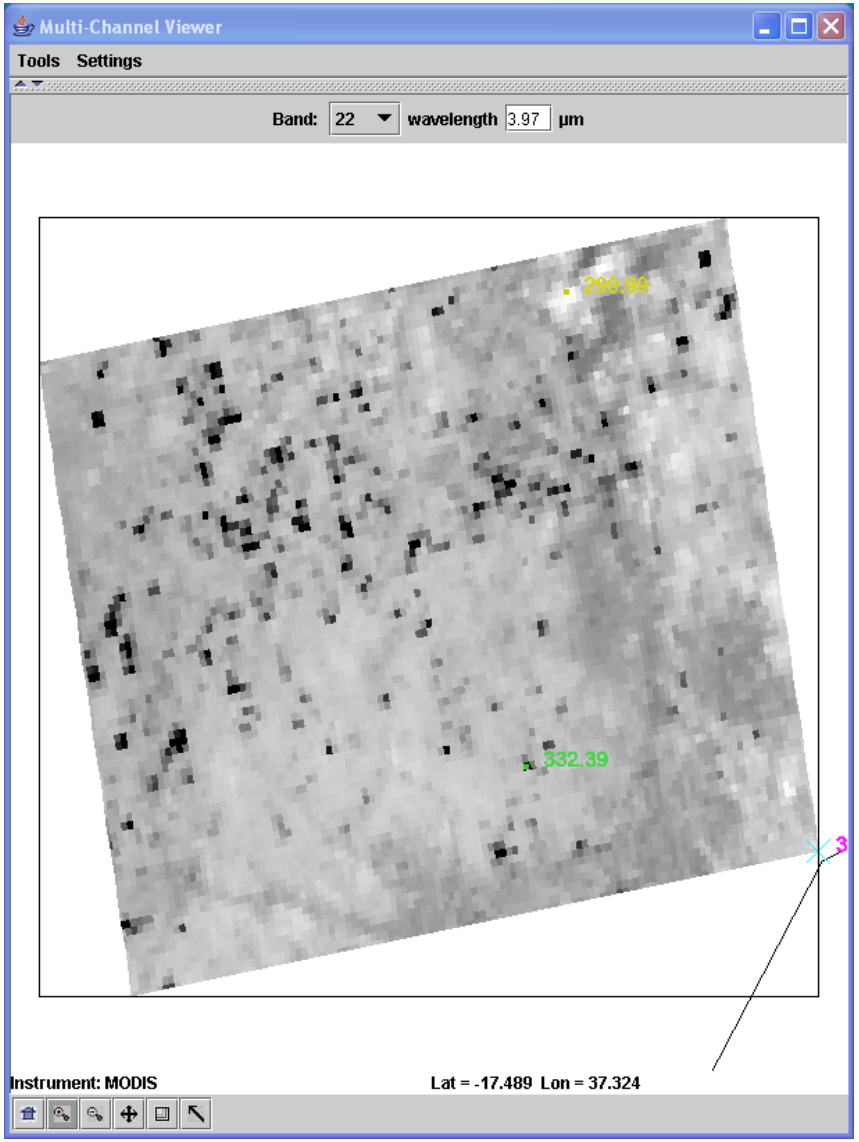
MODIS True Color IMAGE over South Eastern Africa

Aqua 11:10 UTC 20 August 2003



MODIS Band 22
Aqua MODIS 20 August 2003

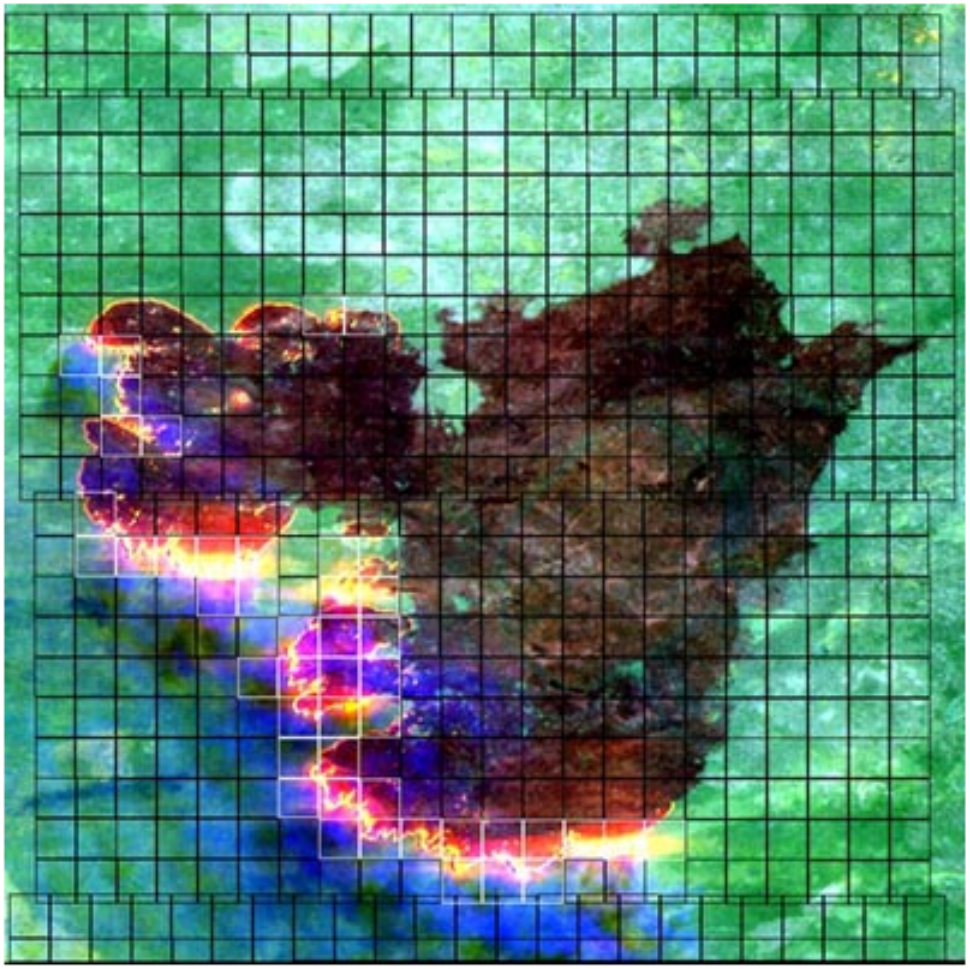




Validation

- Terra collocations with ASTER
  - 30 m footprint
- US Forest Service in situ observations
- Visual comparisons
- For more information, see:

  http://modis-fire.umd.edu/validation.asp



Red (2.4 μm; channel 9) - green (1.6 μm;, channel 4) - blue (0.5 μm; channel 1) false color ASTER image of a large fire complex from Aug 17 2001 9:08 UTC, centered at 18.8S 19.9 E. The gridded overlay denotes the nominal footprints of the MODIS pixels. The white cells are pixels flagged as fire by the MODIS version 3 algorithm.

REFERENCES

Direct Broadcast Fire Product Software is available through the NASA Direct Readout Site: http://directreadout.gsfc.nasa.gov/index.cfm?section=downloads&page=technology

Giglio, L., Descloitres, J., Justice, C. O., and Kaufman, Y., 2003, An enhanced contextual fire detection algorithm for MODIS. *Remote Sensing of Environment*, 87:273-282.

Justice, C. O, Giglio, L., Korontzi, S., Owens, J., Morisette, J. T., Roy, D., Descloitres, J., Alleaume, S., Petitcolin, F., and Kaufman, Y., 2002, The MODIS fire products. *Remote Sensing of Environment*, 83:244-262.