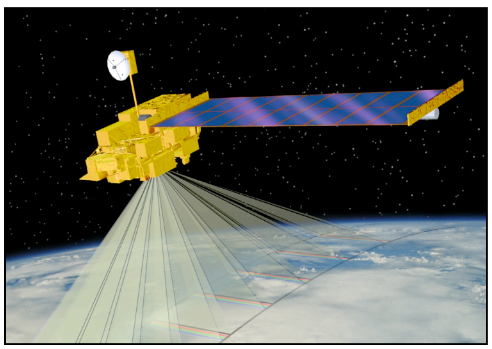
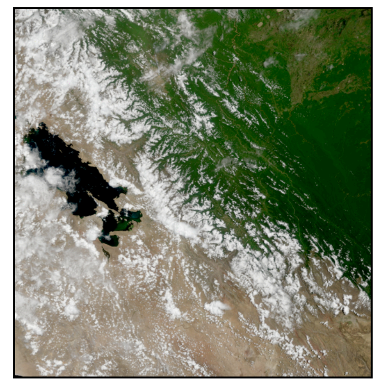
Multi-spectral Satellite Products (MODIS)

GEOSS/AMERICAS Remote Sensing Workshop

São Paulo, Brazil

27 November 2007





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Space Science and Engineering Center

University of Wisconsin-Madison

Lecture Outline

- Can research satellites be useful to operational forecasters?
- Review of MODIS Standard products
- How to order MODIS products
- MODIS Level 2 Atmosphere product theory and algorithms
  - MODIS Cloud Phase Product
- MODIS Level 2 Land product theory and algorithms
  - MODIS Fire Detection Product
  - MODIS Vegetation Indices
- MODIS Level 2 Ocean product theory and algorithms
  - Ocean Color
  - Sea Surface Temperatures

MODIS Science Team

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

MODIS Team Product Comparisons http://modis.gsfc.nasa.gov/

Group	Level 2	Level 3
Calibration	Satellite Projection	None
Atmospheres	Satellite Projection	Daily, Eight Day, Monthly 1 degree equal angle
Land	L2G - Gridded	Daily, 16 day 250m, 500m Sinusoidal Tiles*
Ocean	Satellite Projection	Daily, Weekly, Monthly, Yearly 1 km, 4 km, 36 km, 1 degree

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

Can MODIS Data and Products be of Use to Forecasters?

Can Research Satellites be Used in Operations?

What makes a product useful?

- Provide environmental products that are new and/or better

Given this criteria, what do MODIS products provide that is new or better?

1. Higher Spatial Resolution (data 1km, products 1km and 4km at nadir)
2. Unique spectral bands (36 bands including cirrus, snow and ice, bands that allow retrieval of phase both day and night)
3. New products (Cloud Phase, Cloud Top Temperature)
4. Preparation for GOES-R – many similar bands to MODIS

Usefulness must be weighed against

1. Limited bandwidth
2. Timeliness of products (overpass times + processing times)

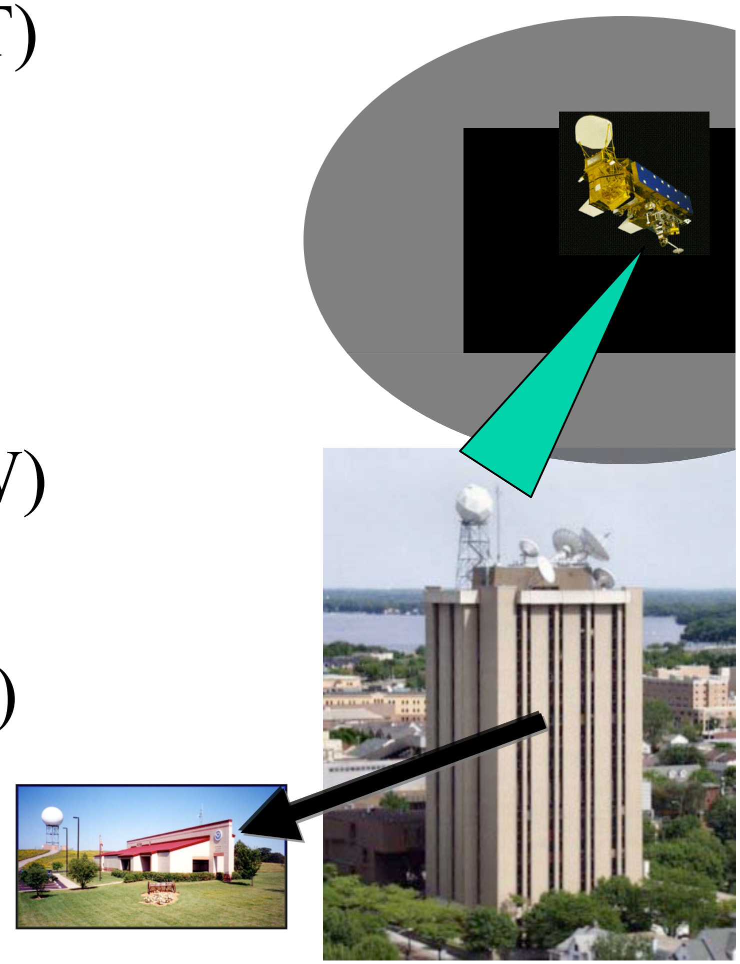
DB data processed within 1.5 hours.

Types of Imagery and Products

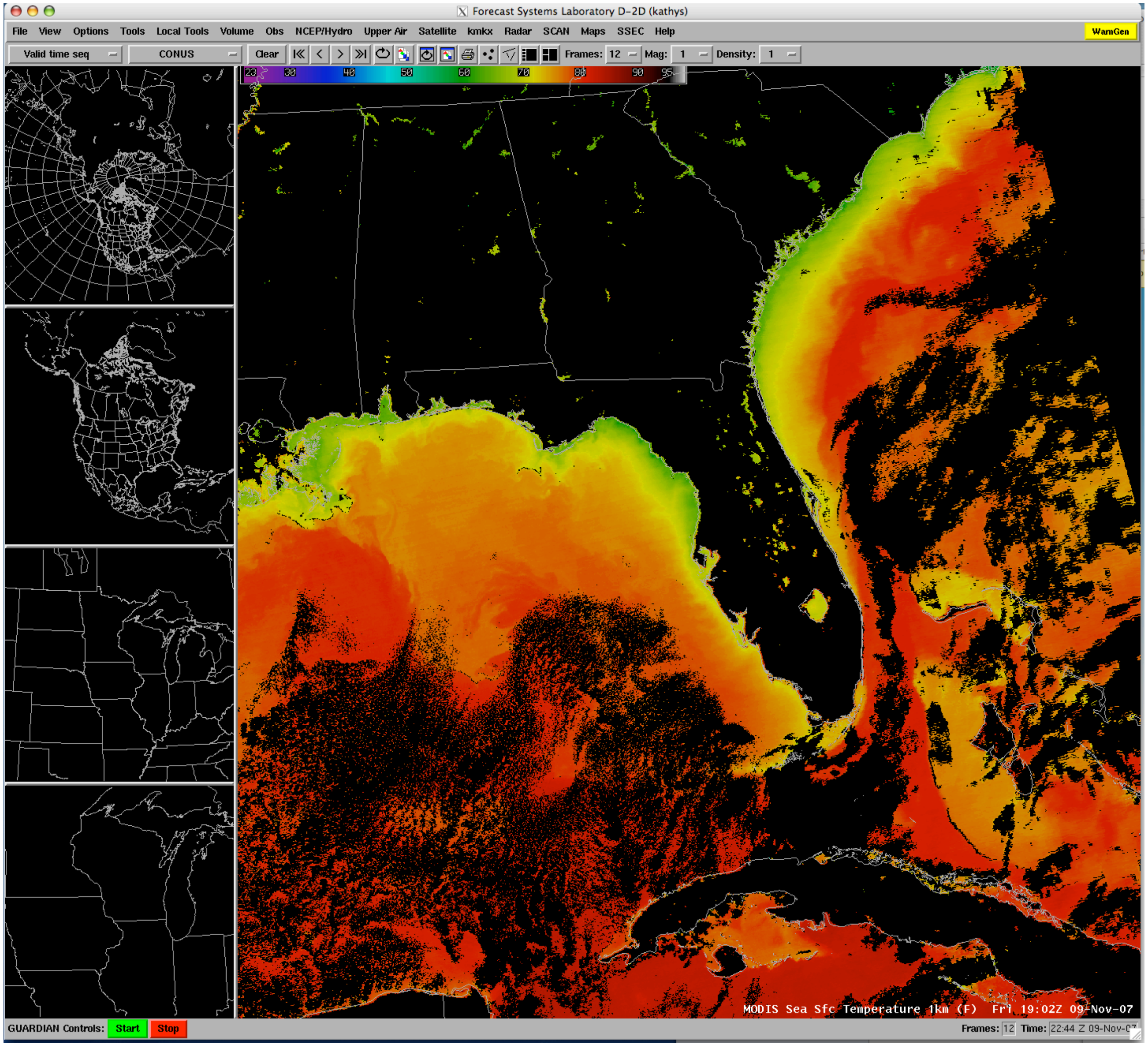
- 1 Kilometer Resolution
  - Visible (Band 1)
  - Snow/Ice (Band 7)
  - Cirrus (Band 26)
  - 3.7µm (Band 20)
  - Water Vapor (Band 27)
  - IR Window (Band 31)
  - 11µm – 3.7µm product (Fog Product)

Types of Imagery and Products

- Marine (1 Kilometer)
  - Sea Surface Temperature (SST)
  - NDVI
  - Land Surface Temperature
- Atmosphere (4 Kilometer)
  - Total Precipitable Water (TPW)
  - Cloud Phase (CTP)
  - Cloud Top Temperature (CTT)



MODIS Sea Surface Temperature viewed in AWIPS



MODIS Sea Surface Temperature used by Forecasters

FXUS63 KMKX 142114
AFDMKX

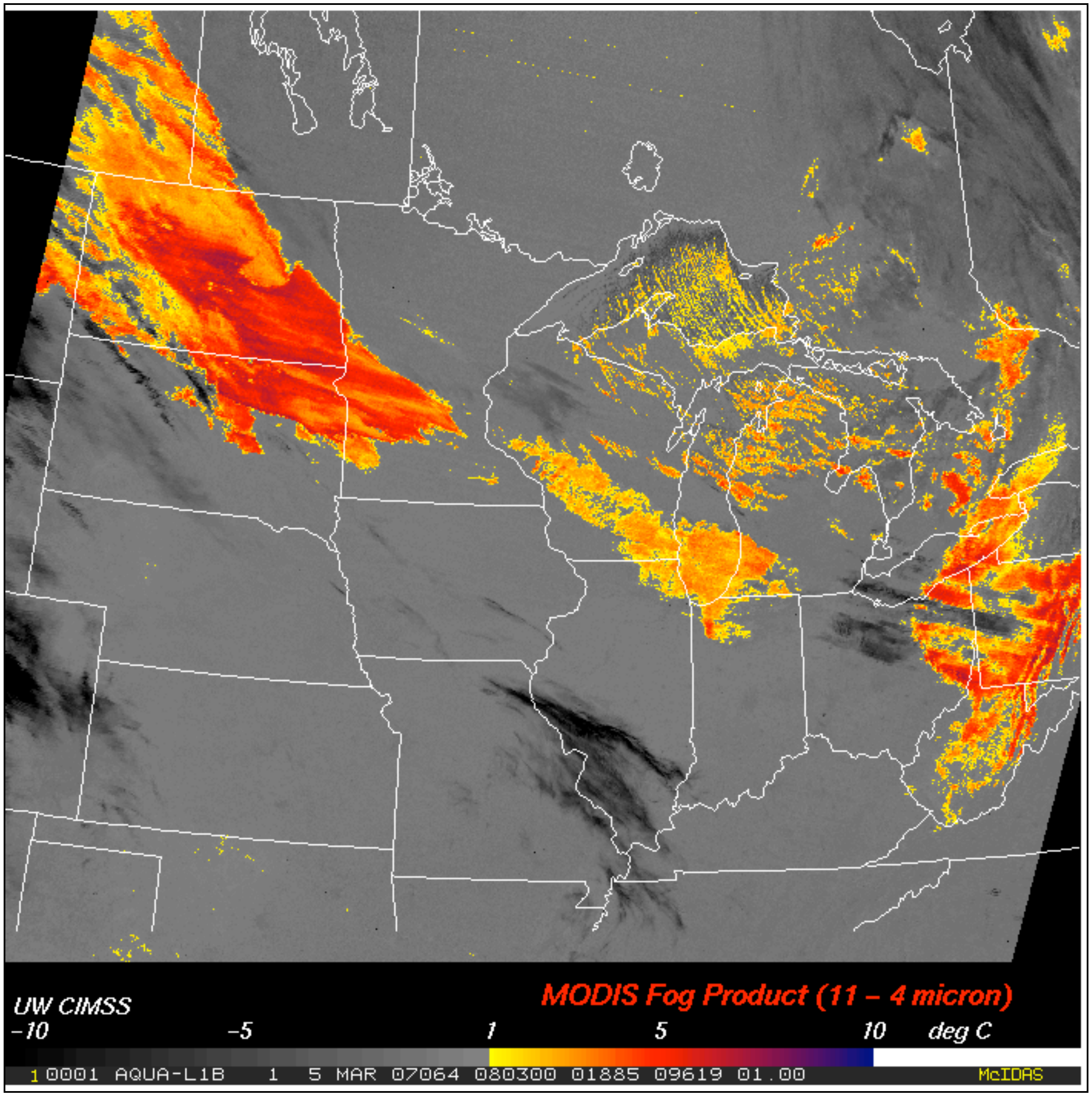
AREA FORECAST DISCUSSION
NATIONAL WEATHER SERVICE MILWAUKEE/SULLIVAN WI
313 PM CST WED NOV 14 2007

FORECAST FOCUS ON GUSTY WEST WINDS SPREADING COLDER AIR OVER SRN WI

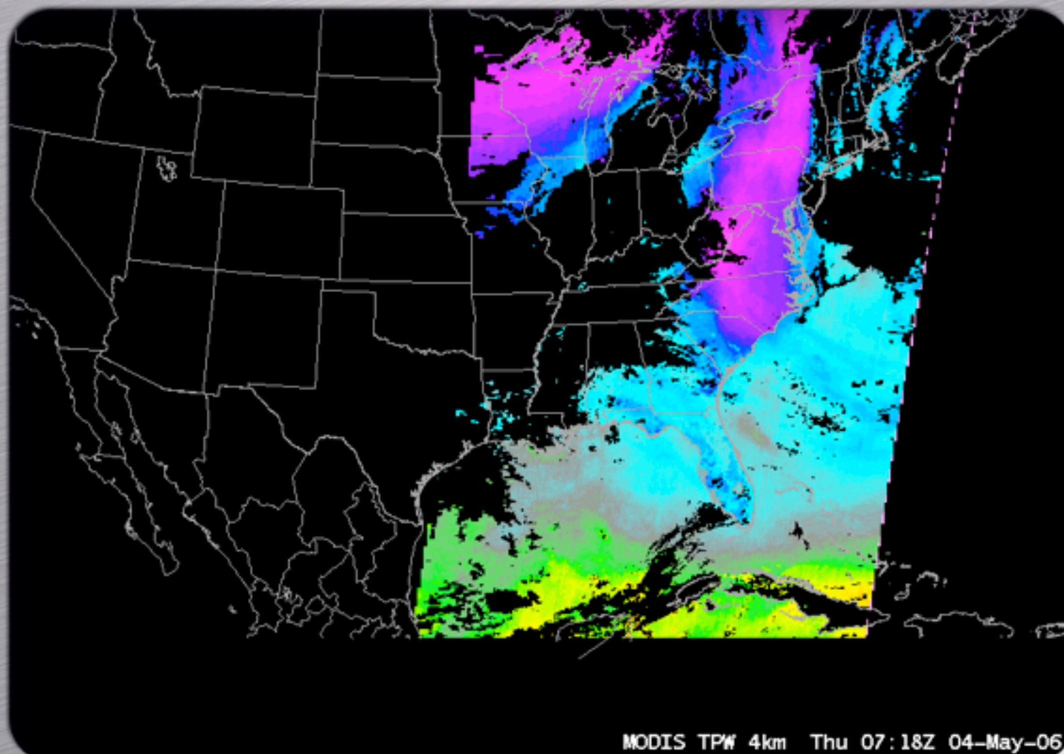
TONIGHT. …….

QUIET SUNDAY AS HIGH PRESSURE SETTLES OVER WRN GREAT LAKES…WITH TEMPS A BIT HIGHER THAN MEX GUIDANCE AS SRLY FLOW SETS UP IN THE AFTERNOON OVER THE CWA...AND SE FLOW OFF RELATIVELY WARMER WATERS OF LAKE MICHIGAN (MID 40S TO AROUND 50 PER LATEST MODIS SEA-SFC TEMPERATURE IMAGE) HOLD TEMPS UP IN LAKE SHORE COUNTIES.

Aqua MODIS KARX CIMSS Web Page
Fog Product   5 March 2007



MODIS Imagery in AWIPS



Total Precipitable Water

AREA FORECAST DISCUSSION
NATIONAL WEATHER SERVICE MILWAUKEE/SULLIVAN WI
409 AM CDT FRI JUL 6 2007

.DISCUSSION...FORECAST FOCUS ON POTENTIAL FOR ISOLATED TSTM ACTIVITY TODAY...THEN HOW HIGH WILL THE MERCURY SOAR THIS WEEKEND?

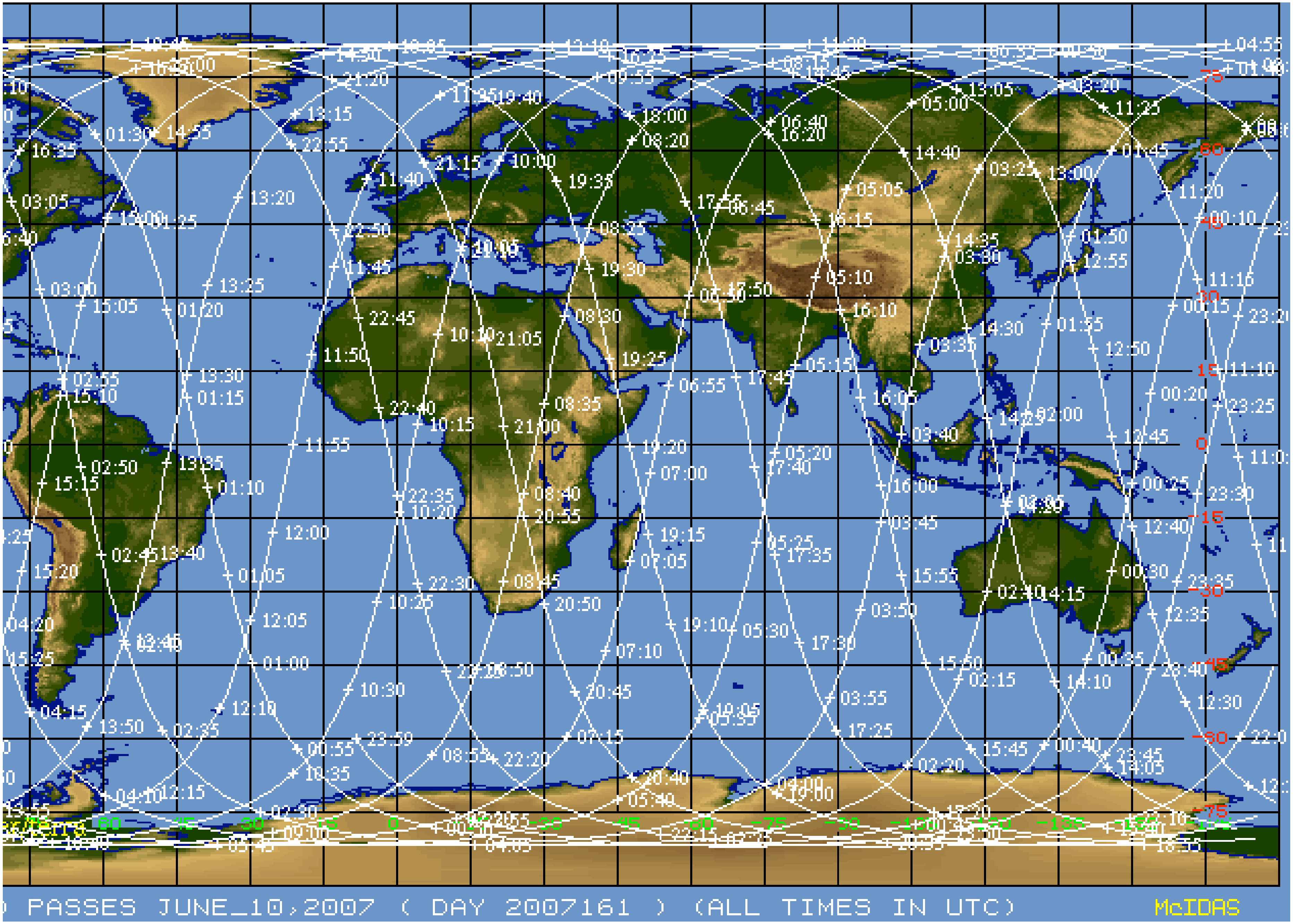
00Z 500/250MB ANALYSIS INDICATED UPPER TROUGHING OVER THE GREAT LAKES/ERN CONUS WITH IMPRESSIVE RIDGING OVER THE WRN CONUS. 500MB HEIGHTS IN THE 596-598DM RANGE FROM AZ NWD INTO WA/ID YIELDING BLISTERING TEMPS WELL INTO THE 100S IN MANY LOCALES ACROSS THE INTERMOUNTAIN WEST. THIS BLOB OF HEAT WILL GRADUALLY ADVECT EWD TOWARD INTO OUR AREA THIS WEEKEND...MORE ON THIS LATER. OTWR NWLY FLOW IN THE LOWER LEVELS OF THE AMS TRYING TO ADVECT SOME DRIER AIR INTO GREAT LAKES WITH GOES/MODIS TOTAL PRECIP WATER PRODUCTS SHOWING PWS DIPPING AOB 0.75 INCHES...WITH SFC TDS GNRLY IN THE 50S UPSTREAM. IR IMAGERY EARLY THIS MORNING SHOWING CLEAR SKIES OVER ALL OF SRN WI.

How to select a MODIS data set from the official NASA site

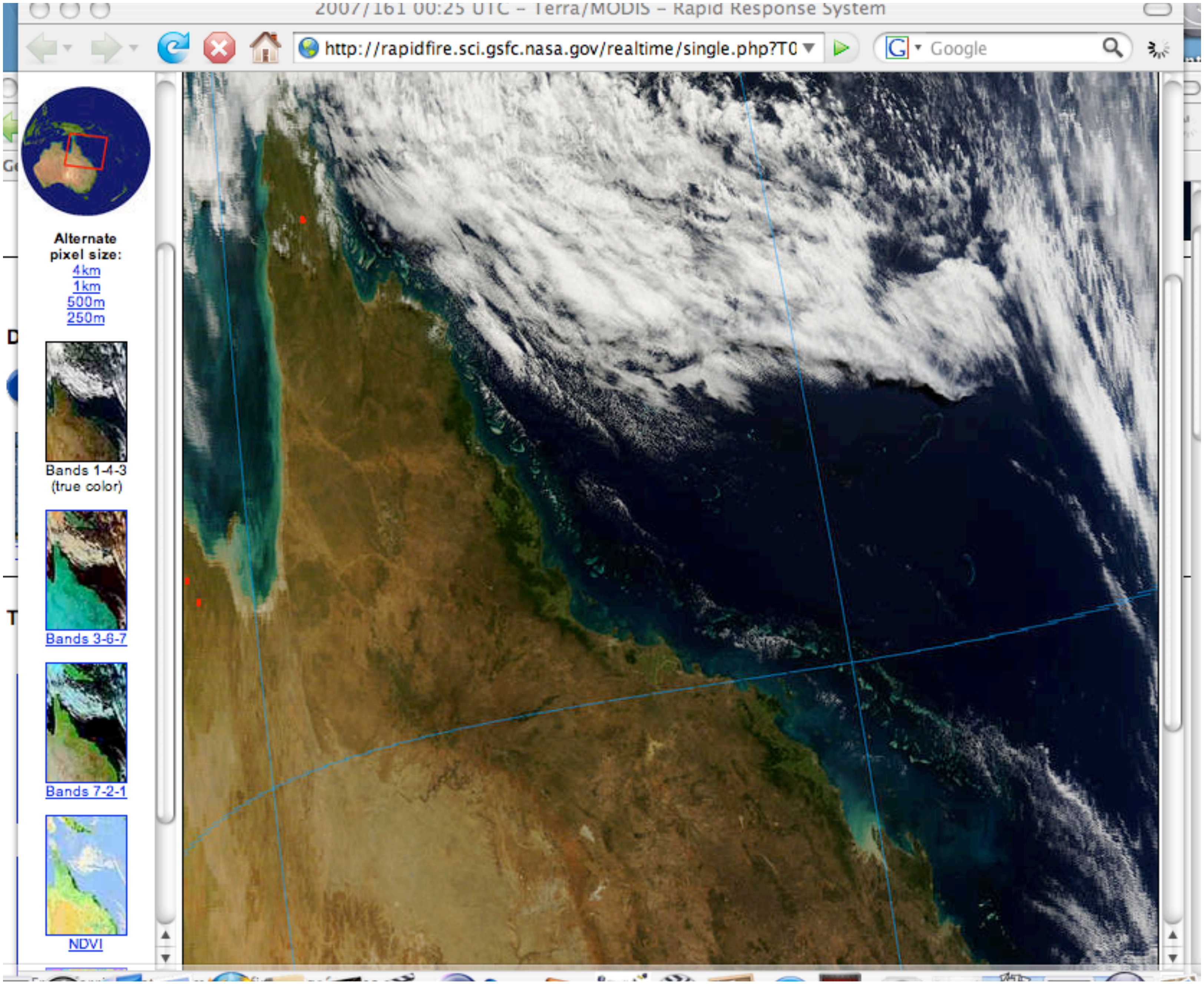
- L1B files - calibrated, geolocated files
- L2 products - science products created from L1B products
- 5 minute segments of data
- 2330 km cross track by 2030 km along track
- Direct broadcast data sets can be different sizes
- HDF format
- Example is for L1B and atmosphere products only
- Data availability lag for official products is ~ 2days
- Some products and images available within 2 hours

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

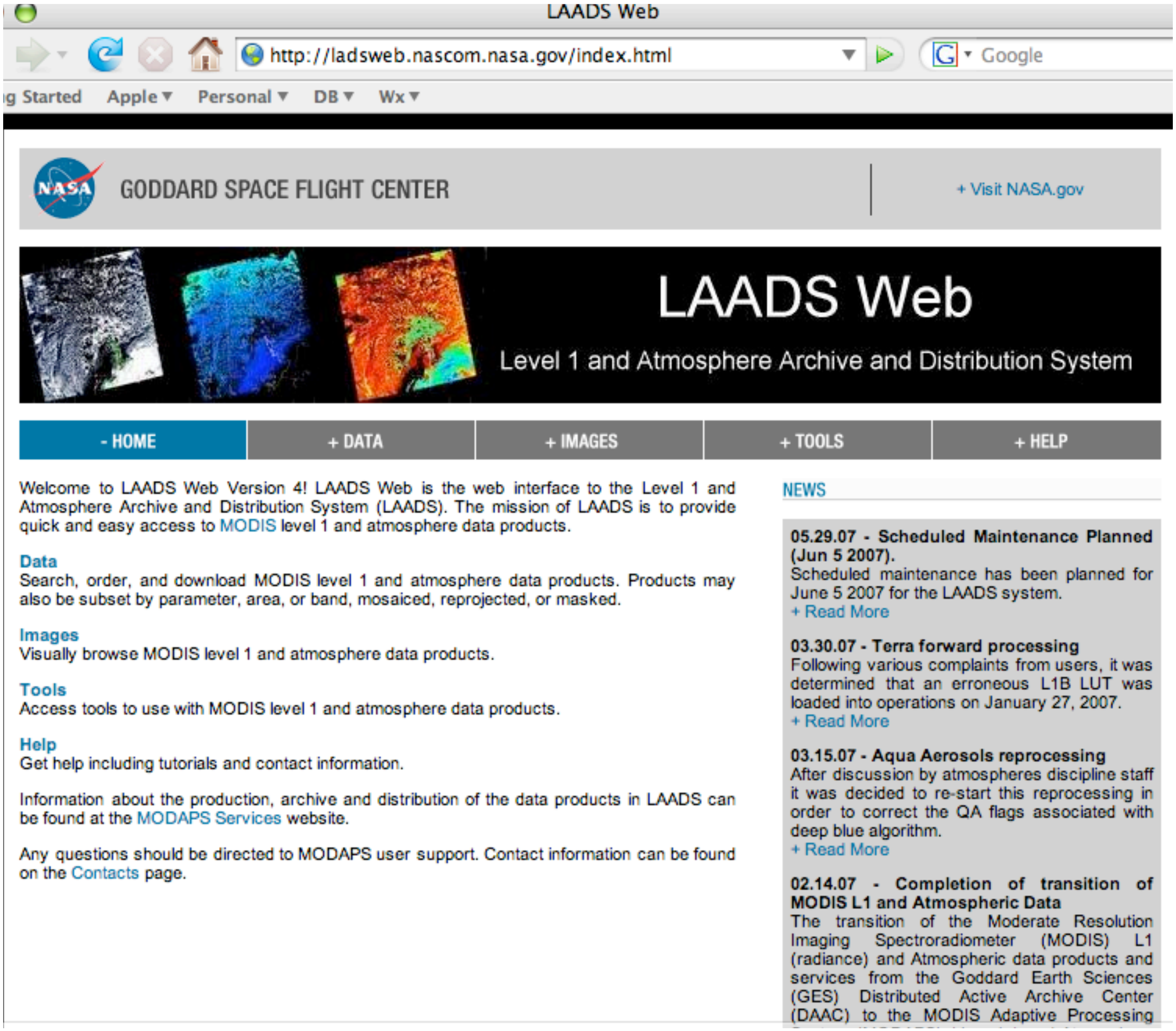
MODIS Orbit Tracks for 1 Day (10 June 2007)



MODIS true color browse image from 00:25 UTC 10 June 2007



MODIS Web site for L1B and Atmosphere Products



MODIS File names

- Naming conventions
  - Prefix.Ayyyyddd.hhmm.005.yyyydddhhmmss.hdf
  - where:
    - yyyy is year
    - ddd is day of the year
    - hh is hour
    - mm is minute
    - ss is seconds
  - The first date/time is the data observation time and the second is the time the file was created.
  - Example: MYD021KM.A2004087.1630.005.2007252102626.hdf is the MODIS 1km L1B file from Aqua. Terra starts with MOD.

MODIS Standard Products (1)

Prefix: MOD - Terra MYD - Aqua

Calibration

- MOD01 - Level-1A Radiance Counts
- MOD02 - Level-1B Calibrated Geolocated Radiances
  - MYD021KM.A2004087.1630.005.2007252102626.hdf – 36 BAND 1km
  - MOD02HKM.A2007302.1445.005.2007302233251.hdf – 7 BAND 500m
  - MOD02QKM.A2007302.1445.005.2007302233251.hdf – 2 BAND 250m
- MOD03 - Geolocation Data Set
  - MOD03.A2007302.1445.005.2007302223440.hdf

Atmosphere

- MOD04_L2 - Aerosol Product
  - MYD04_L2.A2003061.1130.004.2004097122504.hdf
- MOD05_L2 - Total Precipitable Water (Water Vapor)
- MOD06_L2 - Cloud Product
  - MYD06_L2.A2004087.1630.005.2006178160109.hdf
- MOD07_L2 - Atmospheric Profiles
  - MOD07_L2.A2006219.1110.005.2006220114735.hdf
- MOD 08 - Gridded Atmospheric Product
- MOD35_L2 - Cloud Mask
  - MYD35_L2.A2004087.1630.005.2007252104816.hdf

MODIS Standard Products (2)

Prefix: MOD - Terra MYD - Aqua

Land

- MOD 09 - Surface Reflectance
- MOD 10 - Snow Cover
- MOD 11 - Land Surface Temperature & Emissivity
- MOD 12 - Land Cover/Land Cover Change
- MOD 13 - Vegetation Indices (NDVI & EVI)
- MOD 14 - Thermal Anomalies (Fires)
  - MYD14.A2003232.1110.004.2004152085610.hdf
- 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)

Prefix: MOD - Terra MYD - Aqua

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

How to order MODIS data

L1B and Atmosphere Products

1) Go to http://ladsweb.nascom.nasa.gov/
and select data and then search. Make sure that cookies are accepted by your browser (most browsers are set this way already).

2) Under Satelllite/Instrument choose either Aqua or Terra

3) Under Group:
Choose Aqua Level 1 Products or Terra Level 1 Products (depends on what you chose in step 1).

3) Under Products:
Choose either 1km, 500m or 250m L1B Calibrated Radiances or you can choose all 3 if you want.

4) Under Start Date and Time:
Type in the start date of the search period
(example: 07/10/2006 00:00:00

5) Under End Date and Time:
Type in the end date of the search period
(example: 07/15/2006 23:59:59)

How to order MODIS data (2)

6) In the Spatial Selection section choose:
Latitude/Longitude

A map should pop up. You can either outline your area of interest by outlining a box on the map, or you can type in the North, South, East and West Limits in the boxes to the right of the images for your area of interest.

7) Under Coverage Selection Choose:
If you only want Day granules (will contain channels in the visible wavelengths), then make sure the Night and Both boxes are not checked.

8) Click on the Search button at the bottom. This might take a minute or two.

9) Eventually, you will receive a page that contains a list of granules that met your search criteria. Under the Browse column, you can click on the image to get a quick look view of the granule.

How to order MODIS data (3)

10) Click on the Order Files Now button at the bottom of the window.

11) A page will appear that asks for your email address.

12) Once you type that in you can choose FTP Pull to be notified when the data is ready via email and then click on the Order button.

13) A lot of data is already online. If the data that you ordered is online, It will tell you so right away. If not, the data will be staged and you will be told by email when it is ready.

How to order MODIS data (4)

14) Here is an example of an email that I received that tells me how I can get the data.

Your Order ID is: 500143562

The data you ordered has been staged, and you can retrieve the data through anonymous FTP using:

```
ftp    ladsweb.nascom.nasa.gov
  username: anonymous
  password: kathy.strabala@ssec.wisc.edu

cd    /orders/500143562
  binary
  prompt
  mget *
```

How to order MODIS data (5)

Subsetting Data

15) If you want to get a subset of data so that the files are not as big, when you are at step 10 select Add Files to Shopping Cart instead of Order Files Now at the bottom of the page. A page will then appear telling you that your files have been added to your shopping cart. From this page, click on the "view your shopping cart" link. This will bring back a list of the files that you found in your search. At the bottom of this web page, there is a section titled Post Processing Selection. Choose the "Post process and order data now" option and then click on the Order button. This will allow you to choose how you would like to subset the data and if you would like to convert the products to geoTIFF format. The "Subset by parameter" means to subset by an array in the file (such as Cloud Phase in the MOD06_L2 file). If you choose to subset by geographic area of interest, then you will be able to choose a small latitude and longitude region that you are interested in. The file size will then be smaller and will be only over your area of interest. Once you have selected a box, click on the Order button. It will take you to another page where you make subset selections. Then click on the Order button again. Then you will be back at step number11 above. ***** If you subset data, you will not be able to view the file in Hydra *******

Direct Broadcast

- Data acquired from the satellite directly as it passes overhead
- SeaDAS - Level 1B software + ocean product software
  - http://seadas.gsfc.nasa.gov/
- University of Wisconsin - Madison
  - Data product software (MODIS cloud mask (MOD35), cloud top properties and cloud phase, (MOD06), atmospheric profiles (MOD07), aerosol (MOD04), near infrared water vapor, sea surface temperatures, and software to create product images through funding for the International MODIS / AIRS Processing Package (IMAPP) http://cimss.ssec.wisc.edu/imapp/
  - Products freely distributed

    ftp://ftp.ssec.wisc.edu/pub/eosdb
- Direct Readout Lab (DB software for NDVI, Fires, LST)
  - http://directreadout.gsfc.nasa.gov/index.cfm?section=downloads&page=technology

MODIS Cloud Phase

Cloud Phase Detection

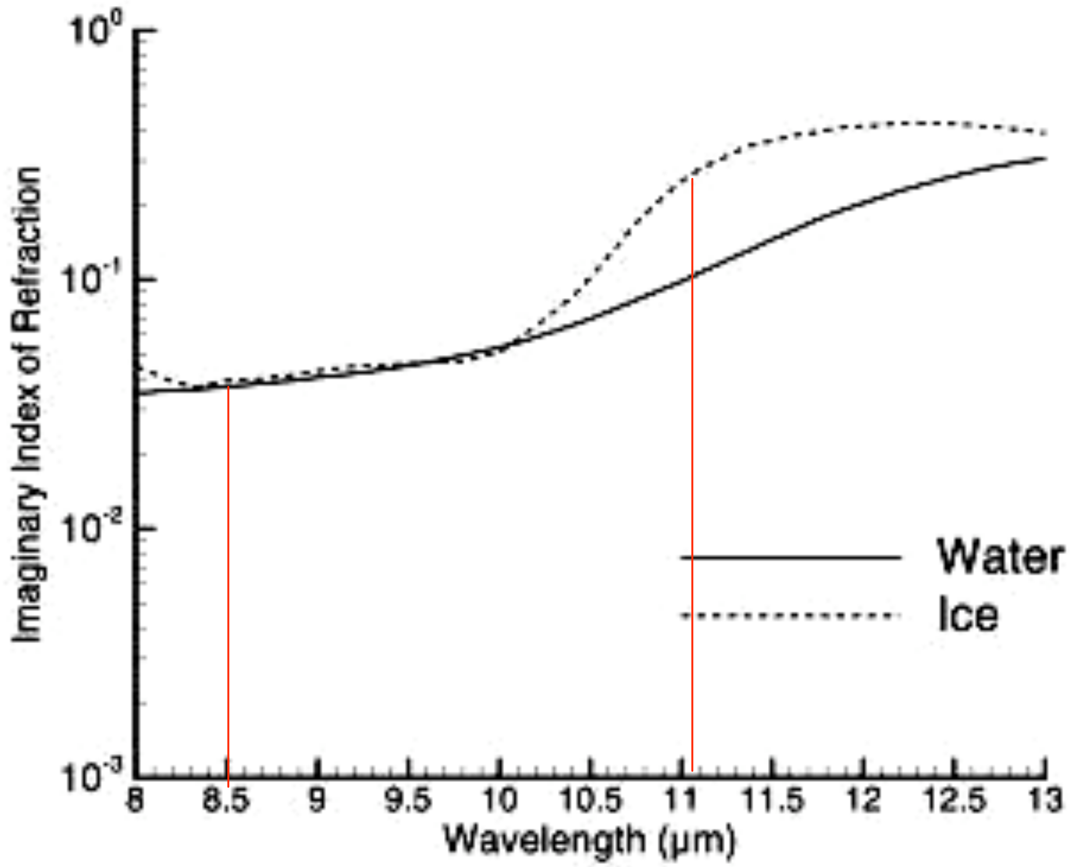
Atmosphere

- *MOD 04 - Aerosol Product*
- *MOD 05 - Total Precipitable Water (Water Vapor)*
- ***MOD06_L2 - Cloud Product***
- *MOD 07 - Atmospheric Profiles*
- MOD 08 - Gridded Atmospheric Product
- *MOD 35 - Cloud Mask*

Cloud Phase

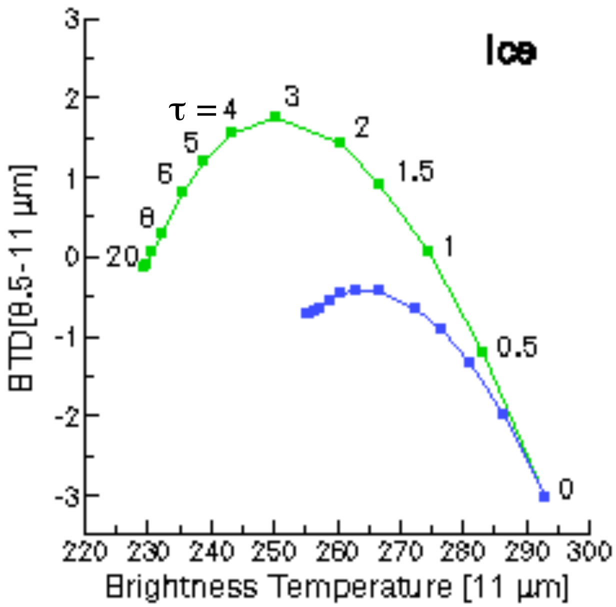
Dr. Bryan Baum CIMSS

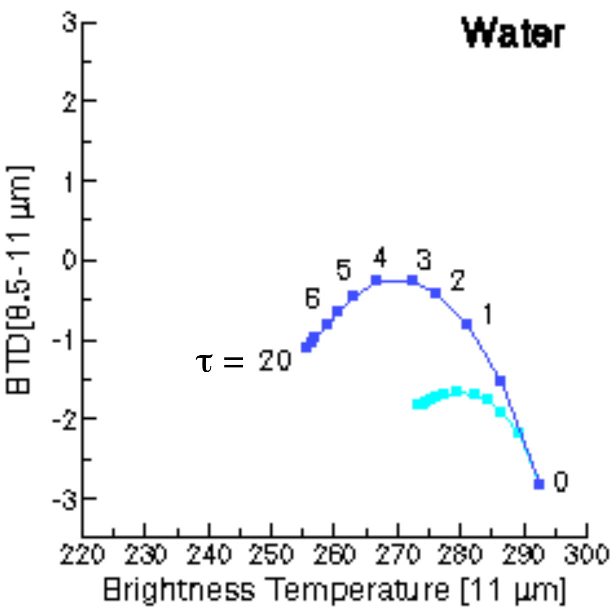
- Based upon the differential absorption of ice and water between 8 and 11 microns
- Simple brightness temperature difference (8-11 BTDIF) thresholding technique
- Included as part of the MOD06 product



Imaginary Index of Refraction of Ice and Water
8 – 13 microns

Simulations of Ice and Water Phase Clouds
8.5 - 11 μm BT Differences





High Ice clouds

• BTD[8.5-11] > 0 over a large range of optical thicknesses τ
•T_{cld} = 228 K

Midlevel clouds

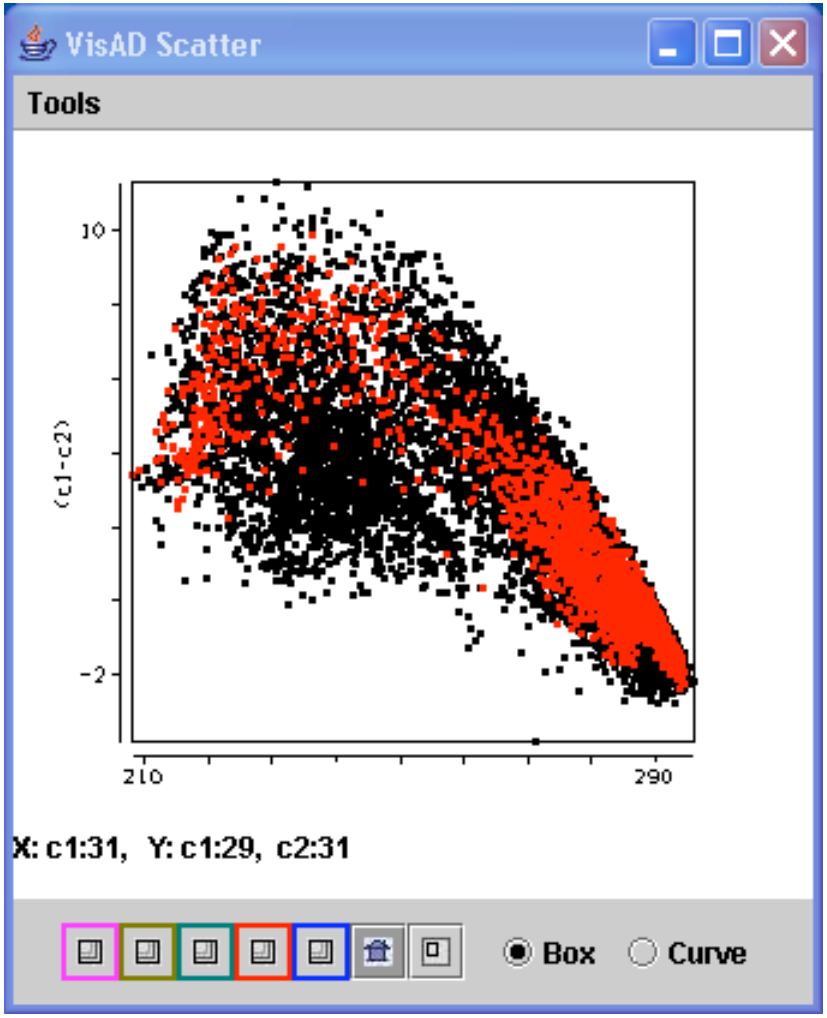
• BTD[8.5-11] values are similar (*i.e.*, negative) for both water and ice clouds
•T_{cld} = 253 K

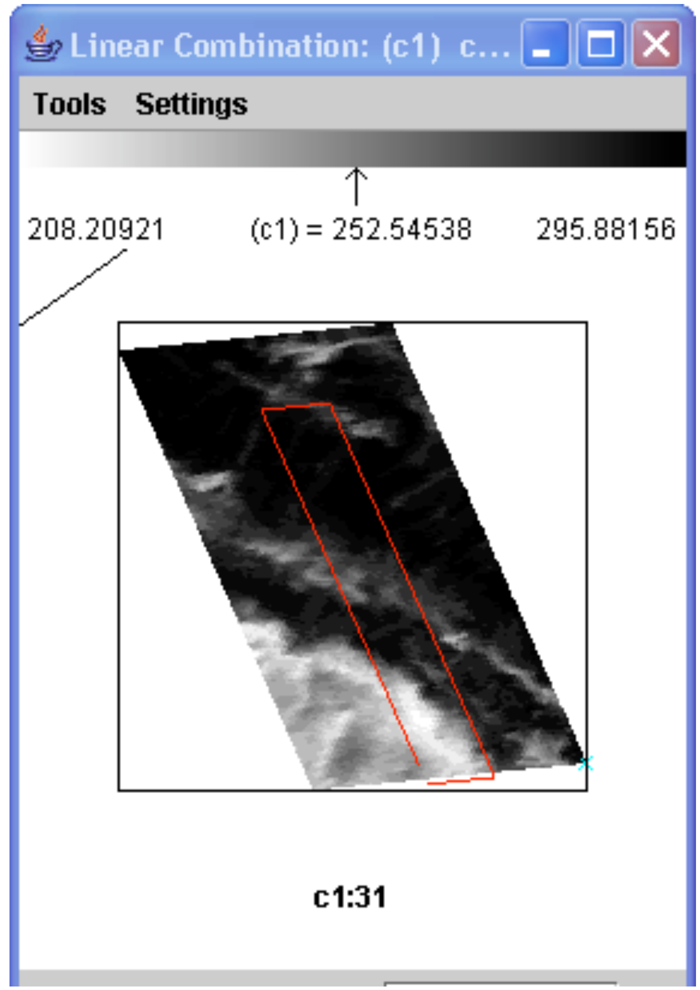
Low-level, warm clouds

• BTD[8.5-11] values always negative
•T_{cld} = 273 K

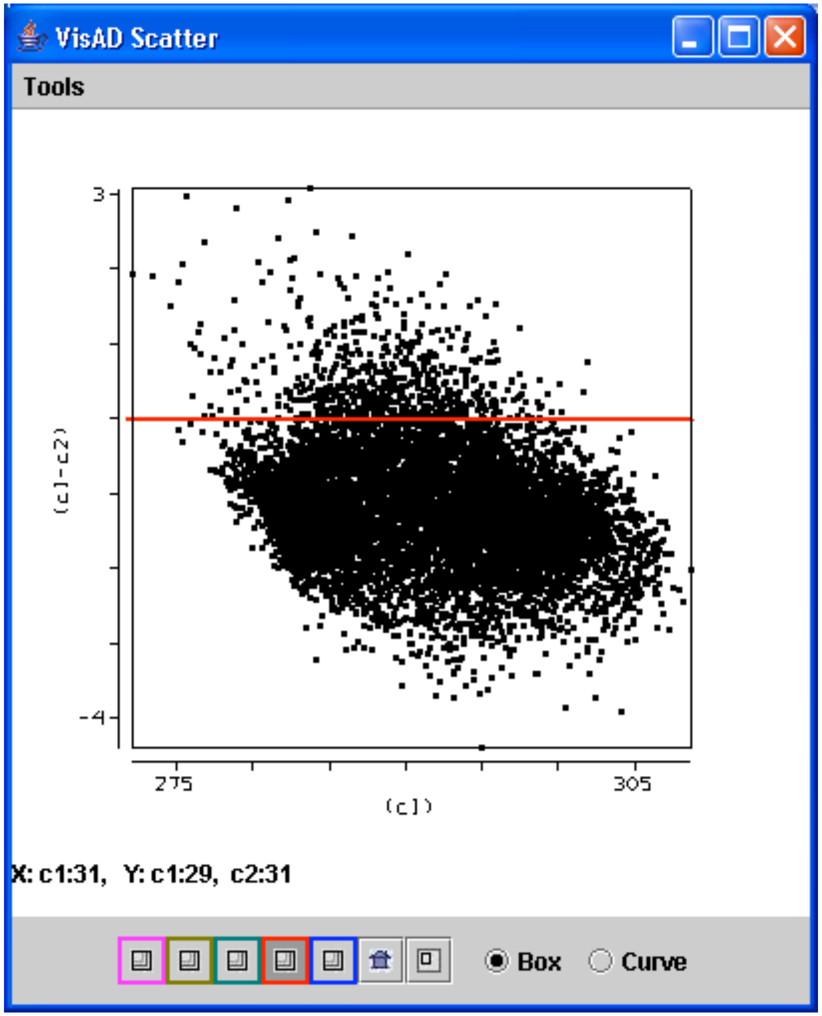
Ice: Cirrus model derived from FIRE-I in-situ data (Nasiri et al, 2002)
Water: r_e=10 μm
Angles: $\theta_o = 45^o$, $\theta = 20^o$, and $\phi = 40^o$
Profile: midlatitude summer

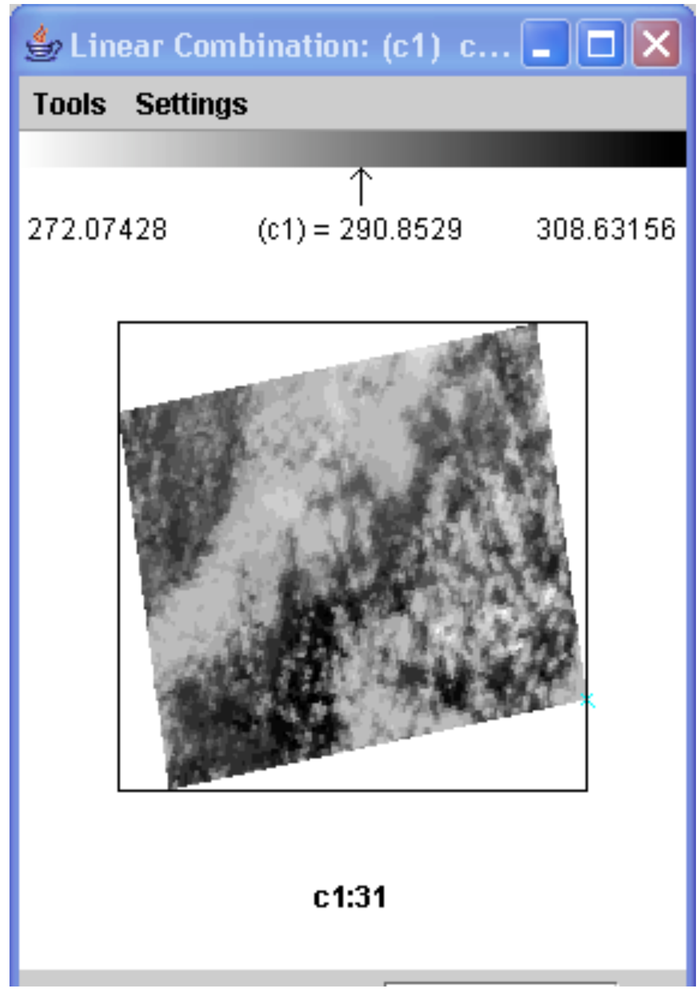
Ice Cloud Example





Water Cloud Example





IRPHASE Thresholds

- Ice Cloud
  - BT11 < 238 K or BTD8-11> 0.5 K
- Mixed Phase
  - BT11 between 238 and 268 K

    and
  - BTD8-11 between –0.25 and –1.0 K
- Water Cloud
  - BT11 > 238 K and BTD8-11 < -1.5 K

    or
  - BT11>285 and BTD8-11 < -0.5 K

Output Product Description

<u>4 categories</u>

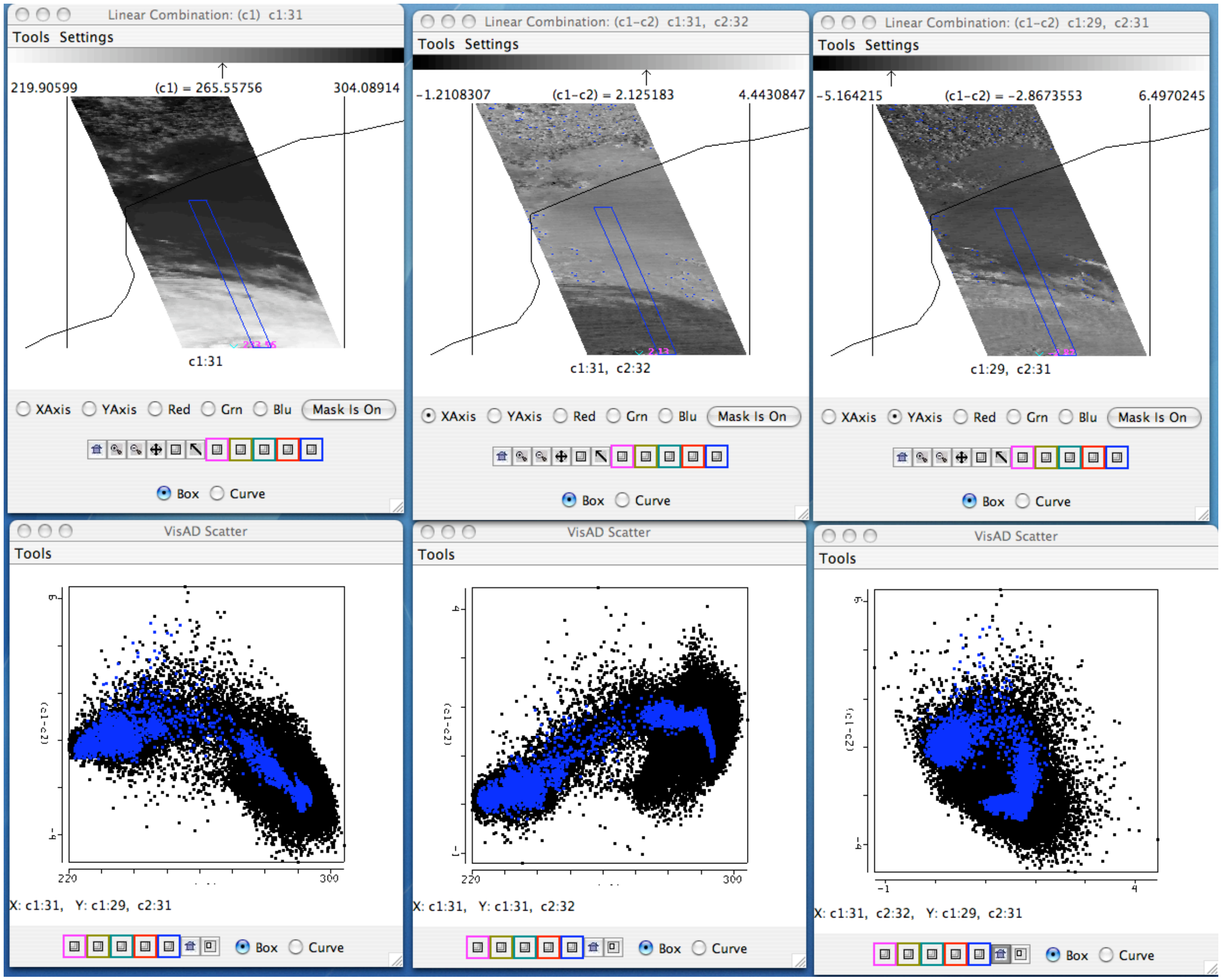
1 – Water Cloud

2 – Ice Cloud

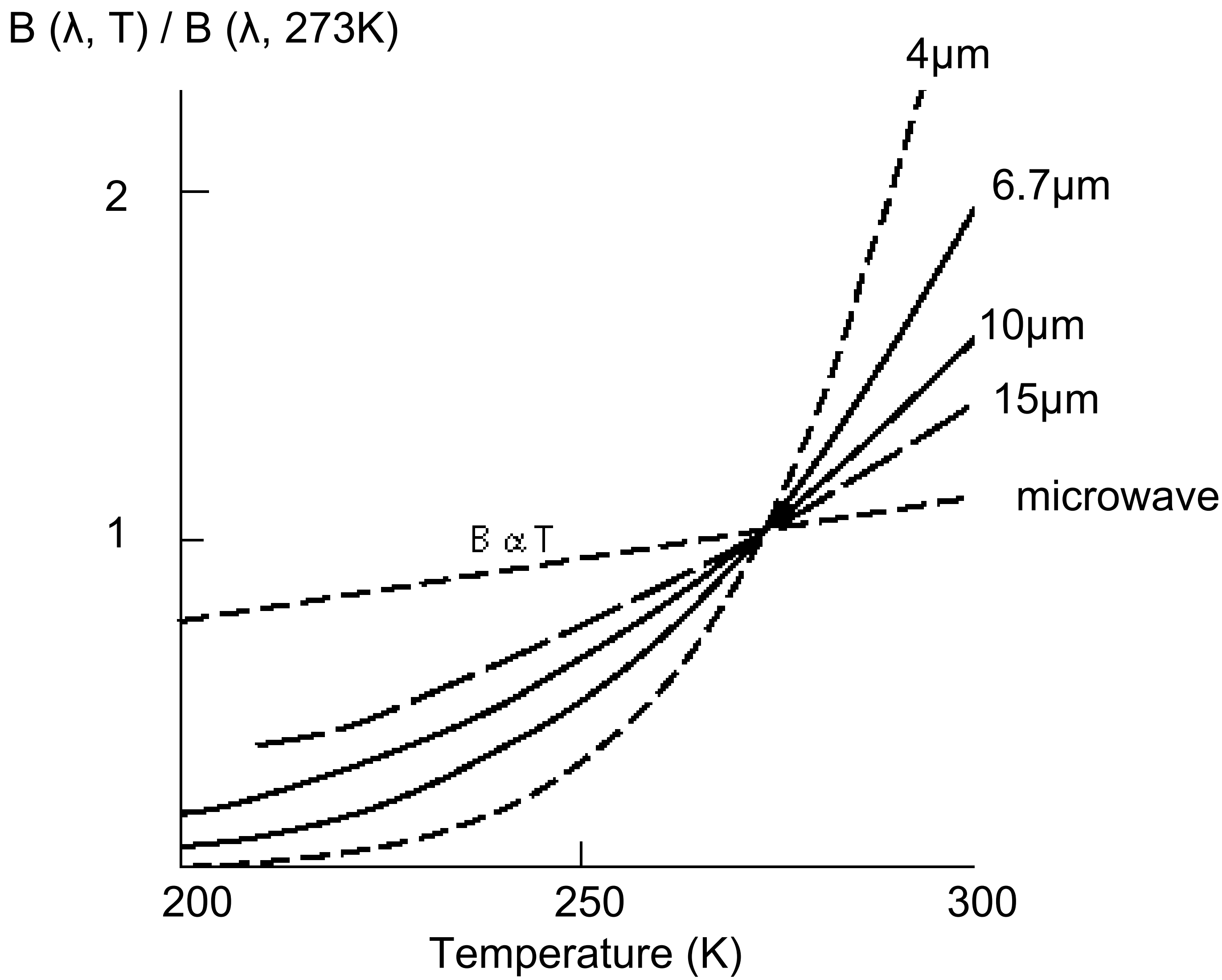
3 – Mixed Phase Cloud

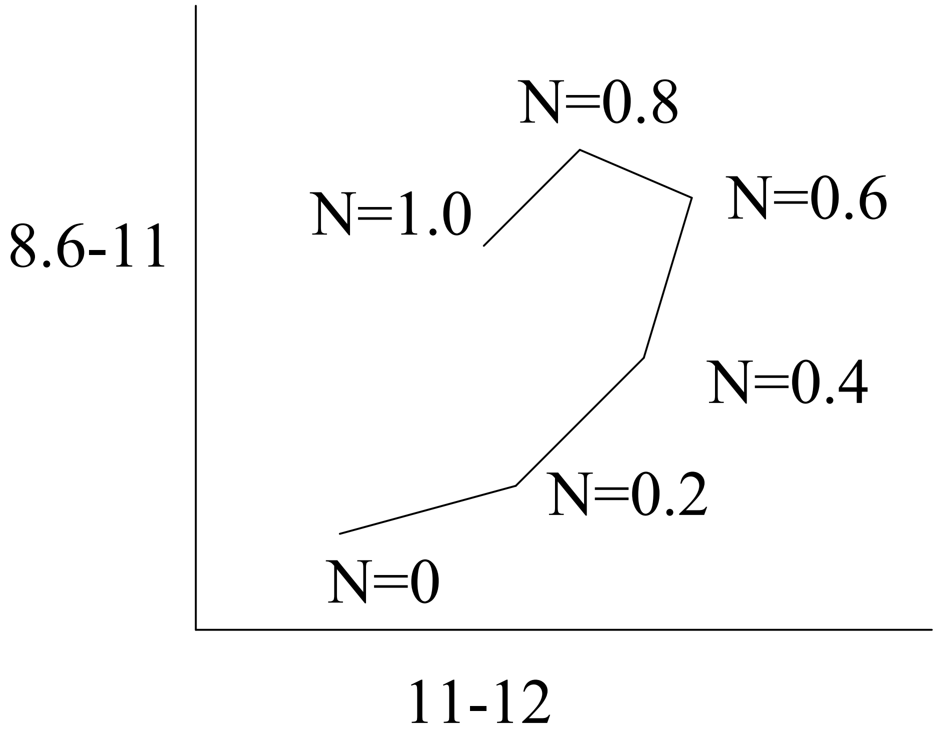
6 – Undecided

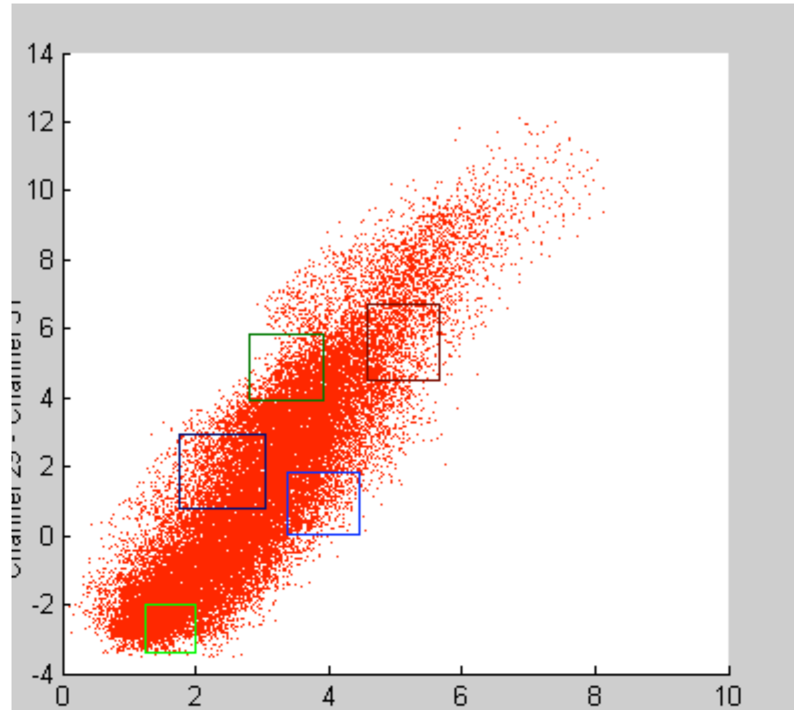
Ice Cloud Example



Temperature Sensitivity of B(λ,T) for typical earth scene temperatures







Broken clouds appear different in 8.6, 11 and 12 um images;
assume Tclr=300 and Tcld=230

$$T(11)-T(12)=[(1-N)*B11(Tclr)+N*B11(Tcld)]^{-1} - [(1-N)*B12(Tclr)+N*B12(Tcld)]^{-1}$$

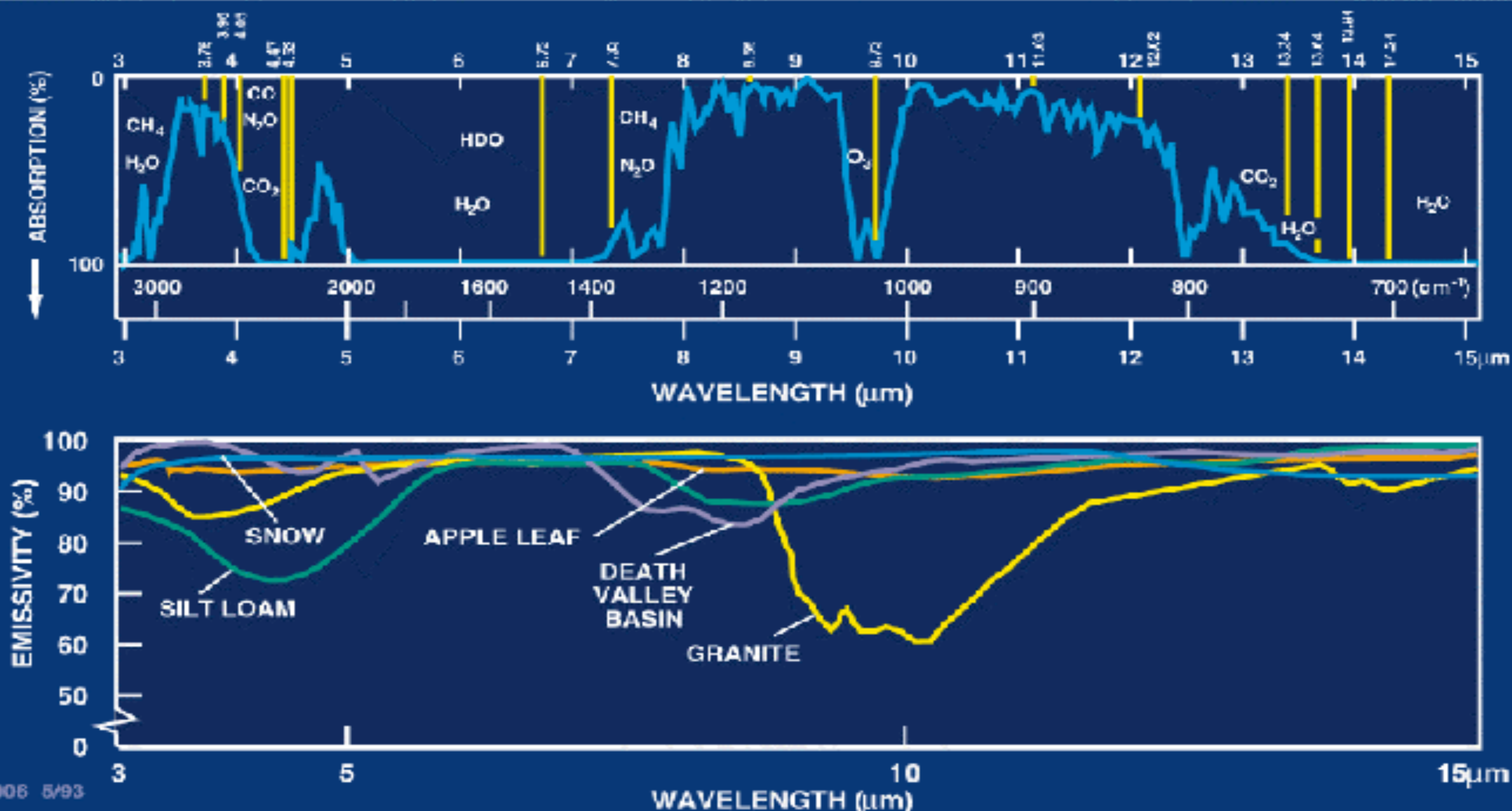
$$T(8.6)-T(11)=[(1-N)*B8.6(Tclr)+N*B8.6(Tcld)]^{-1} - [(1-N)*B11(Tclr)+N*B11(Tcld)]^{-1}$$

Warm part of pixel has more influence at shorter wavelengths

Known Problems

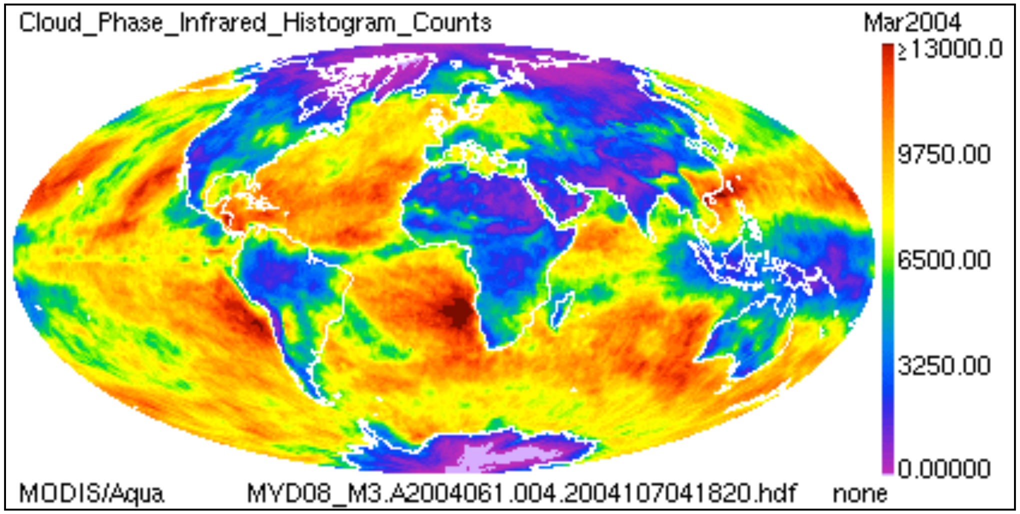
- Mid-level cloud (BT ~ 250 K)
  - Ambiguous solution
- Surface Emissivity Effects
  - Not always the same over the IR window (granite)
- Mixed phase cloud category
  - should be considered as undecided

LAND - THERMAL RADIATION

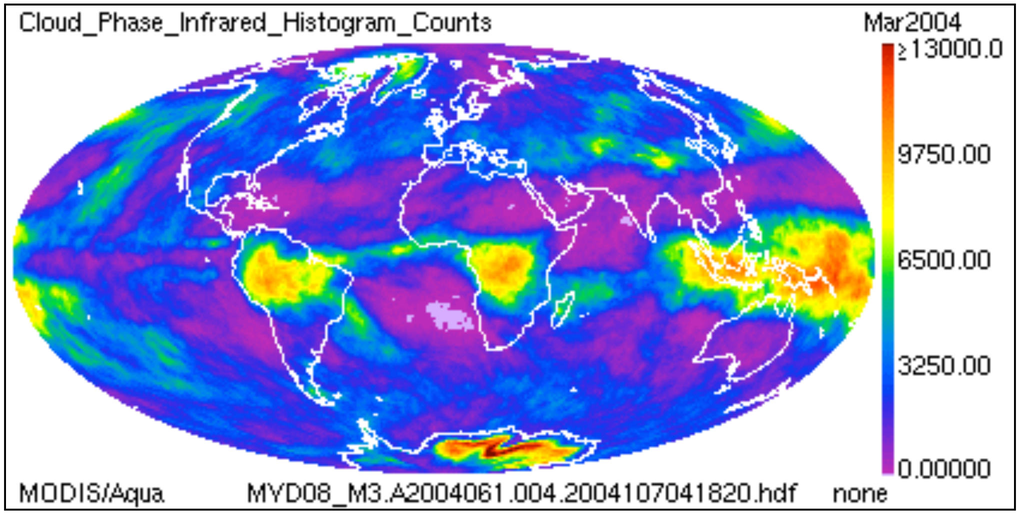


C351.006 5/93

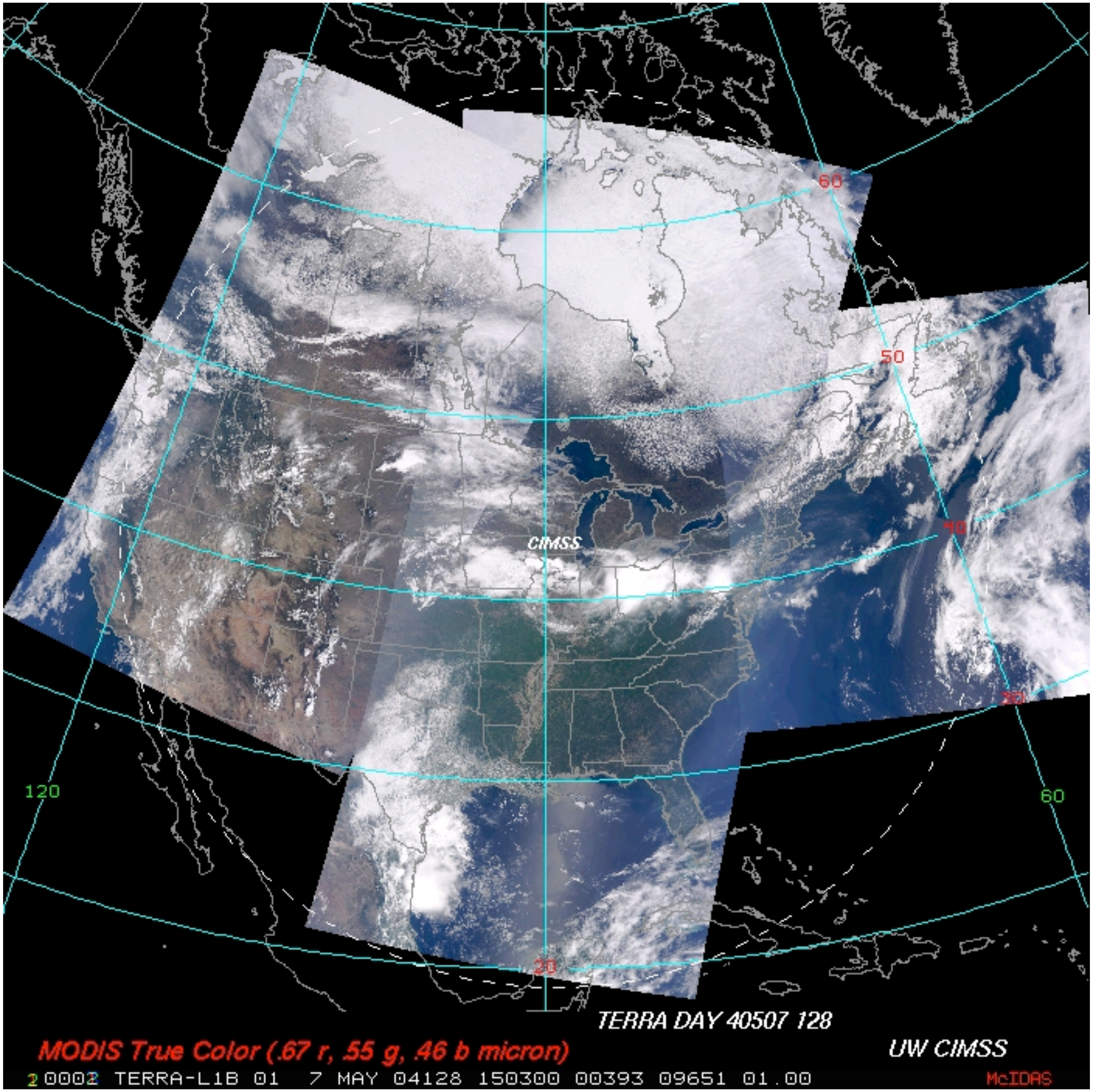
Cloud Phase Level 3 Product   March 2004



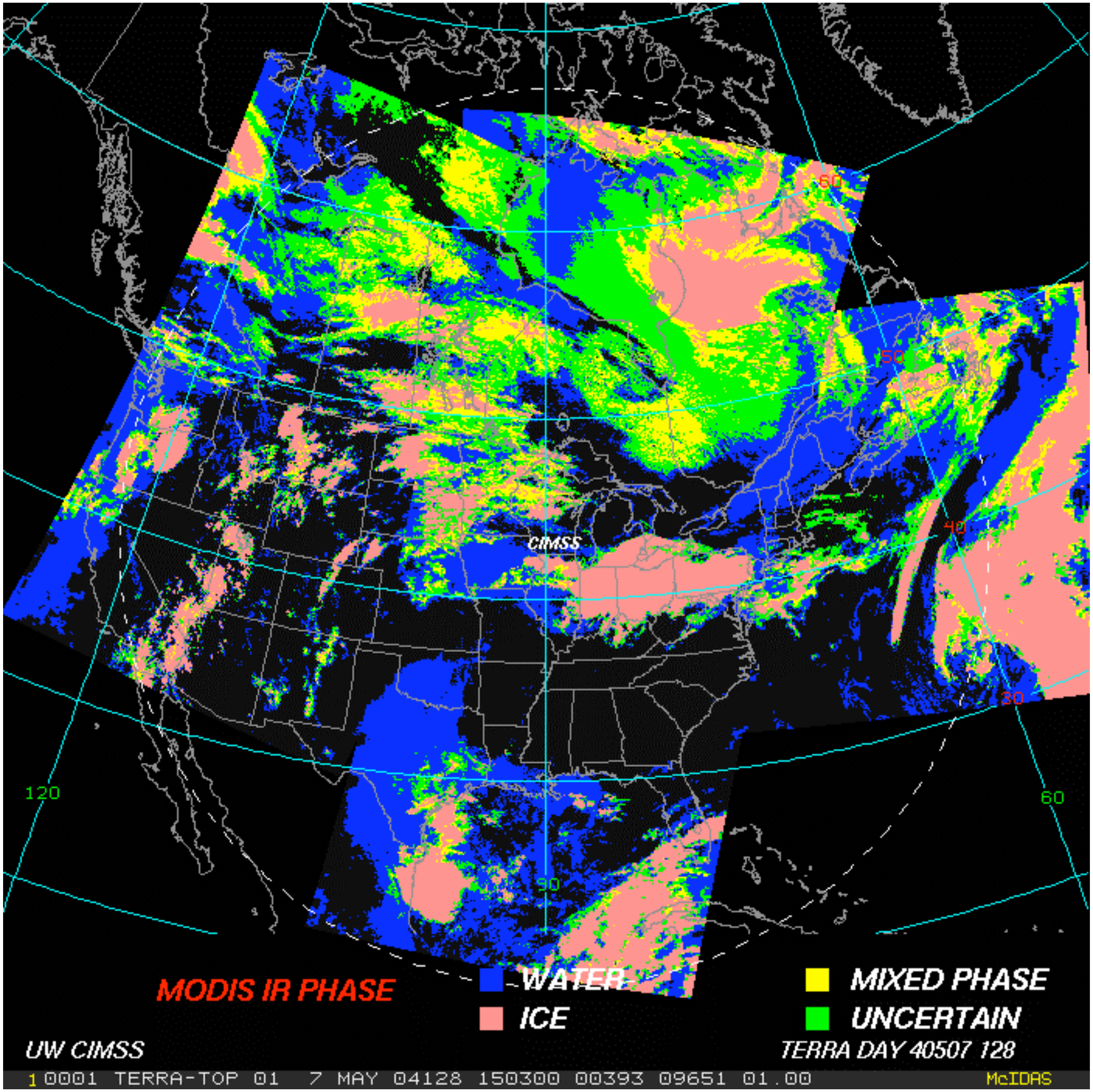
Water



Ice



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


MODIS IR PHASE
WATER
ICE
MIXED PHASE
UNCERTAIN
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TERRA DAY 40507 128
CIMSS
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McIDAS
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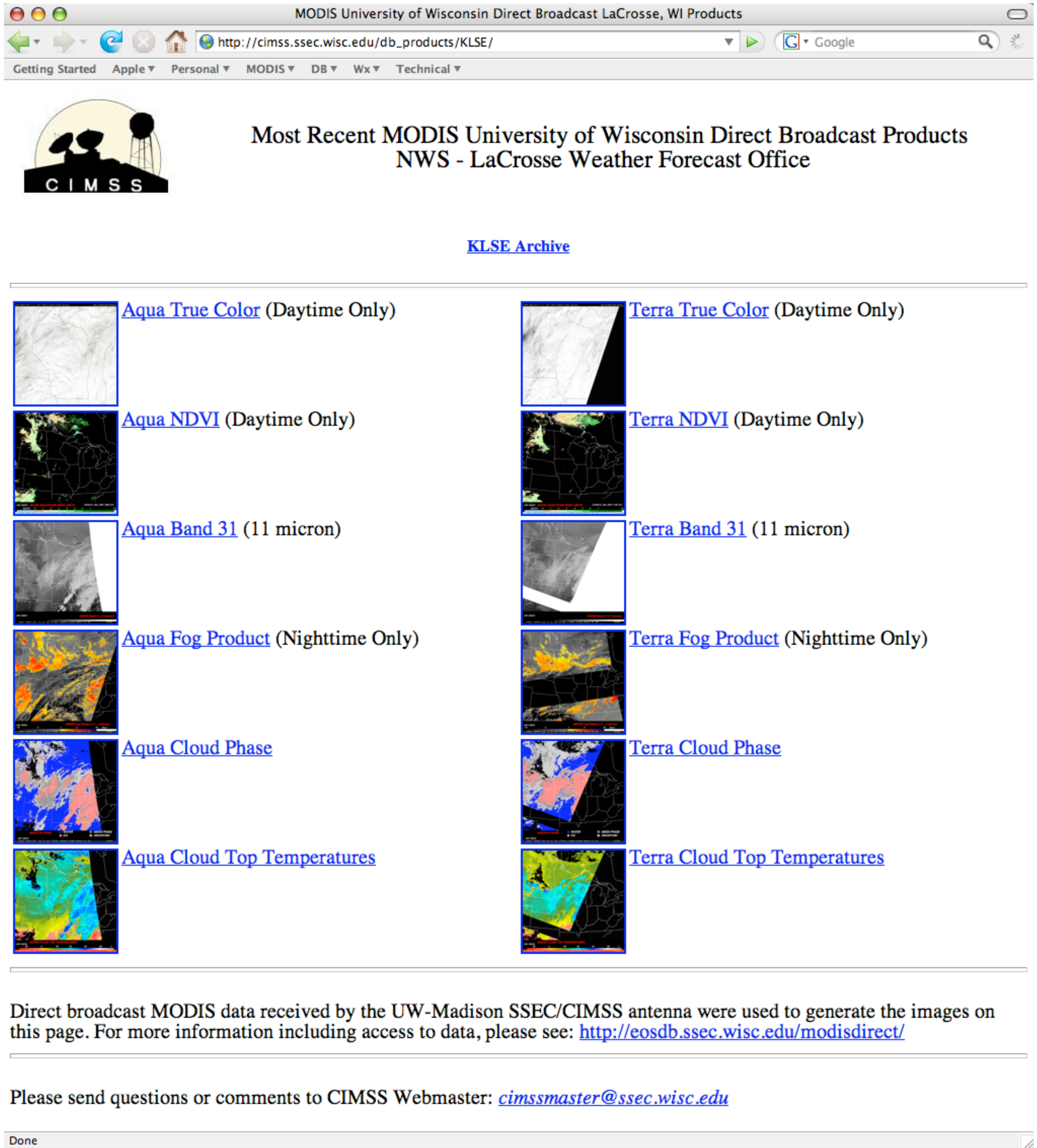
Applications

1. Meteorological
   - Aviation - icing
   - Thunderstorm maturity - glaciation
   - Freezing rain
   - Numerical Weather Prediction Models

2. Climatological
   - Global Cloud Modeling - Ice and water clouds absorb and reflect differently at different wavelengths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Getting Started
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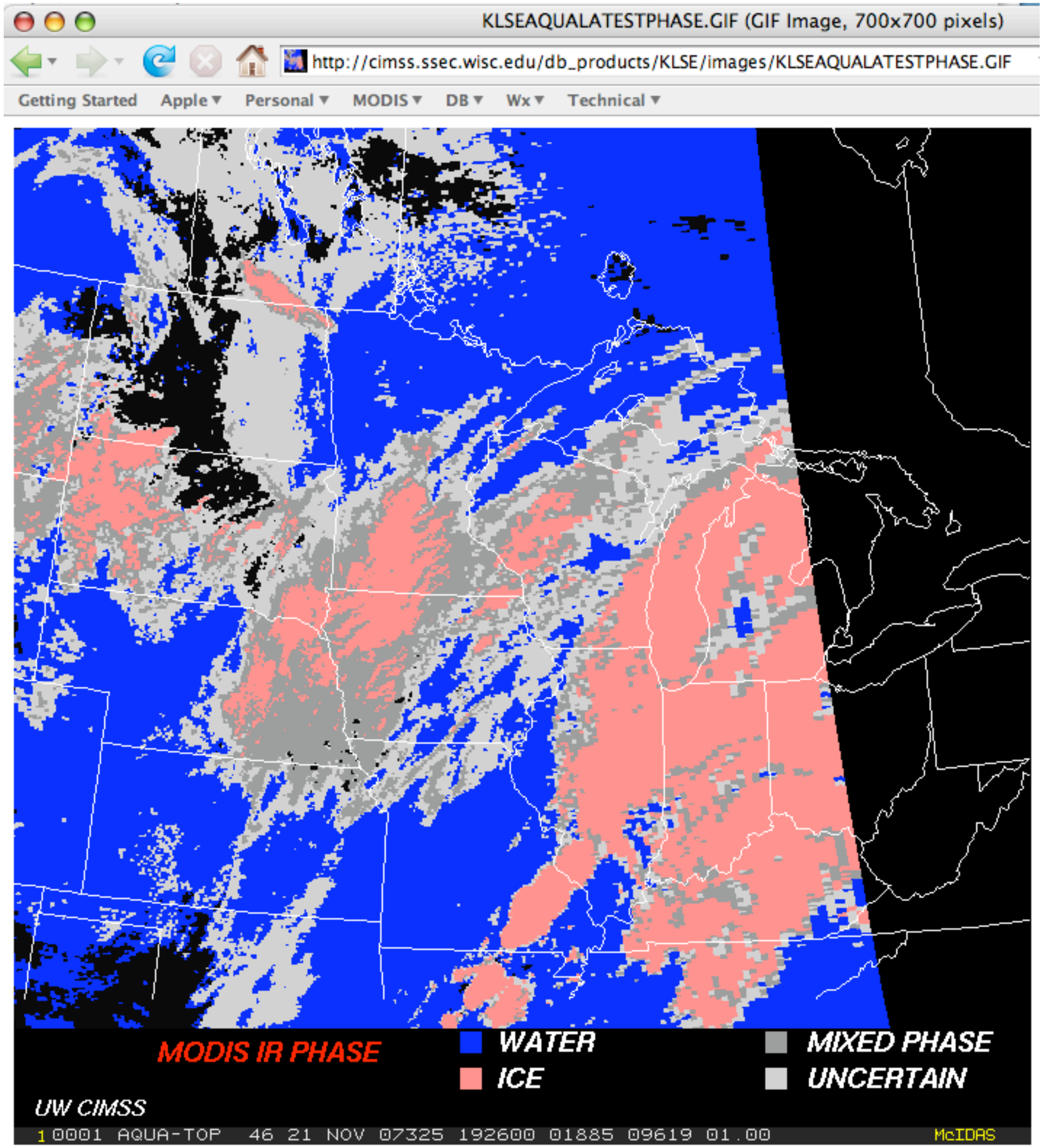
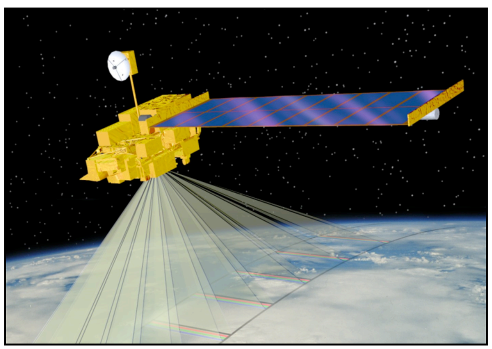
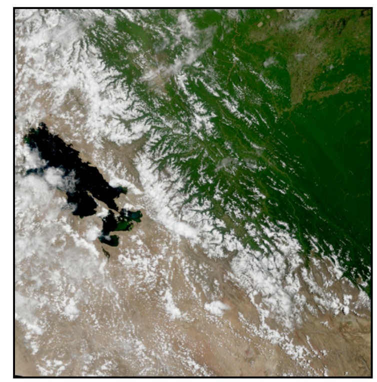
Personal
MODIS
DB
Wx
Technical
CIMSS
Most Recent MODIS University of Wisconsin Direct Broadcast Products
NWS - LaCrosse Weather Forecast Office
KLSE Archive
Aqua True Color (Daytime Only)
Terra True Color (Daytime Only)
Aqua NDVI (Daytime Only)
Terra NDVI (Daytime Only)
Aqua Band 31 (11 micron)
Terra Band 31 (11 micron)
Aqua Fog Product (Nighttime Only)
Terra Fog Product (Nighttime Only)
Aqua Cloud Phase
Terra Cloud Phase
Aqua Cloud Top Temperatures
Terra Cloud Top Temperatures
Direct broadcast MODIS data received by the UW-Madison SSEC/CIMSS antenna were used to generate the images on this page. For more information including access to data, please see: http://eosdb.ssec.wisc.edu/modisdirect/
Please send questions or comments to CIMSS Webmaster: cimssmaster@ssec.wisc.edu
Done


KLSEAQUALATESTPHASE.GIF (GIF Image, 700x700 pixels)
http://cimss.ssec.wisc.edu/db_products/KLSE/images/KLSEAQUALATESTPHASE.GIF
Getting Started
Apple
Personal
MODIS
DB
Wx
Technical
MODIS IR PHASE
WATER
ICE
MIXED PHASE
UNCERTAIN
UW CIMSS
1 0001 AQUA-TOP 46 21 NOV 07325 192600 01885 09619 01.00
McIDAS

MODIS Land Products

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





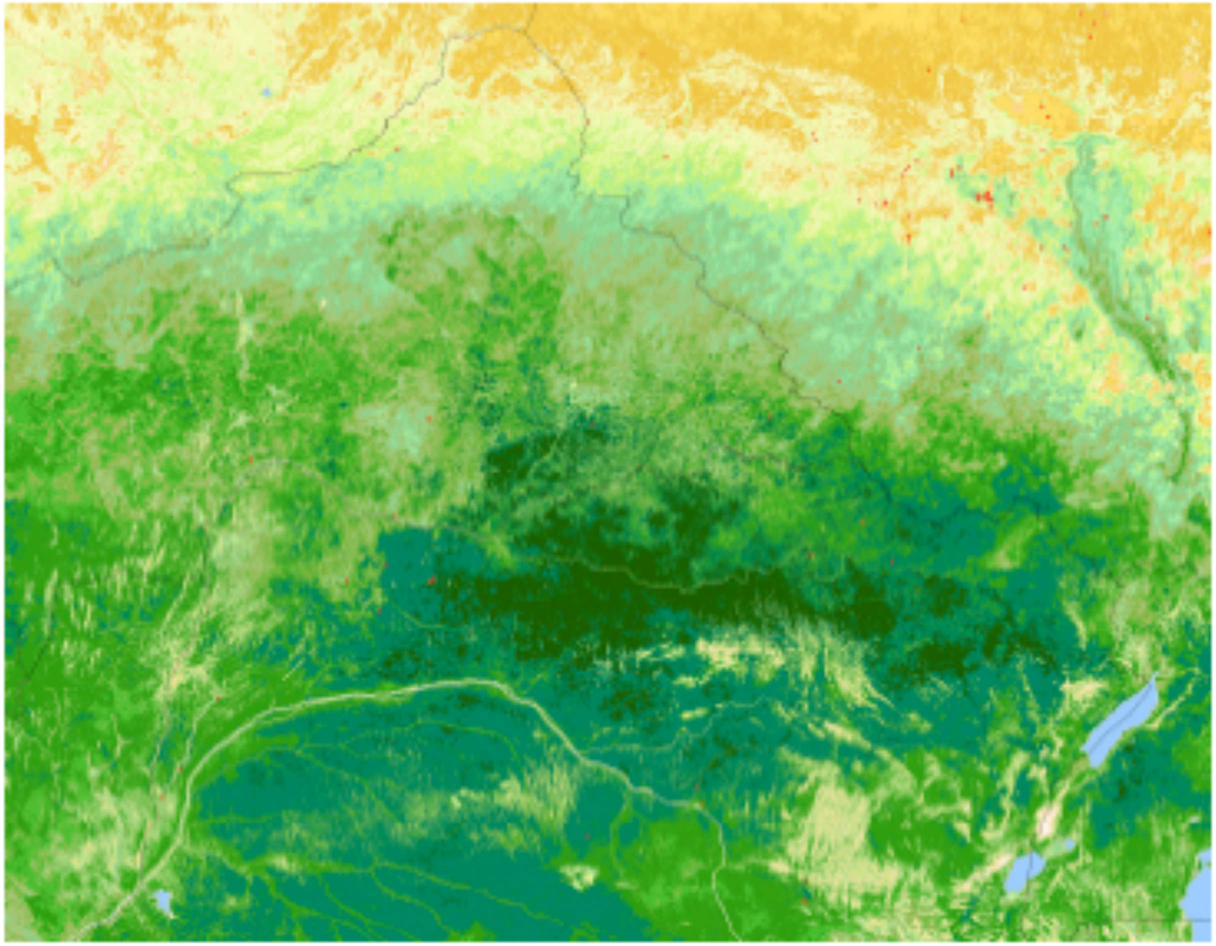
Kathleen Strabala
Cooperative Institute for Meteorological Satellite Studies
Space Science and Engineering Center
University of Wisconsin-Madison

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)***
- 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 in (drive) a chemical reaction. Example: Photosynthesis in plants

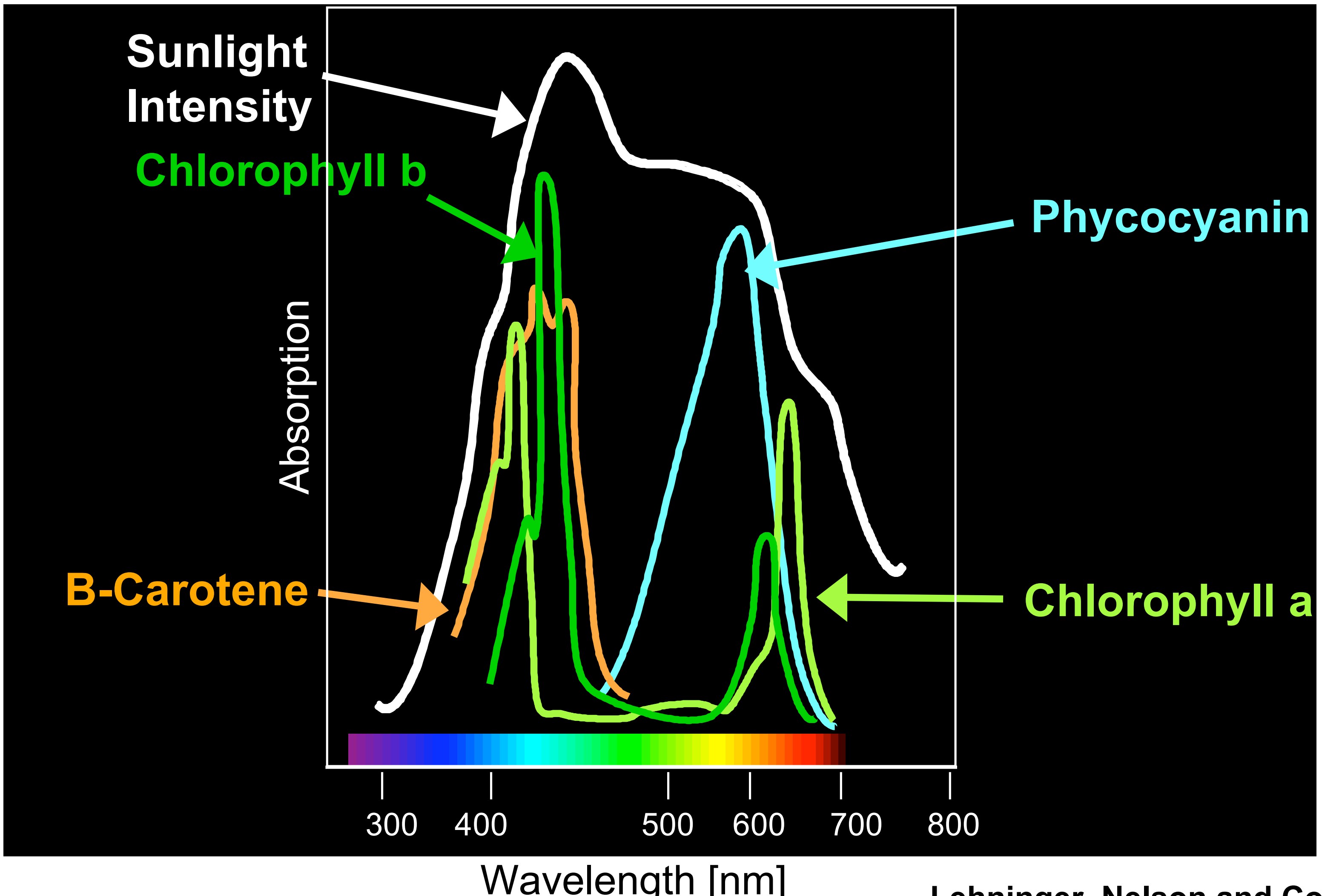
[illegible]

- 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

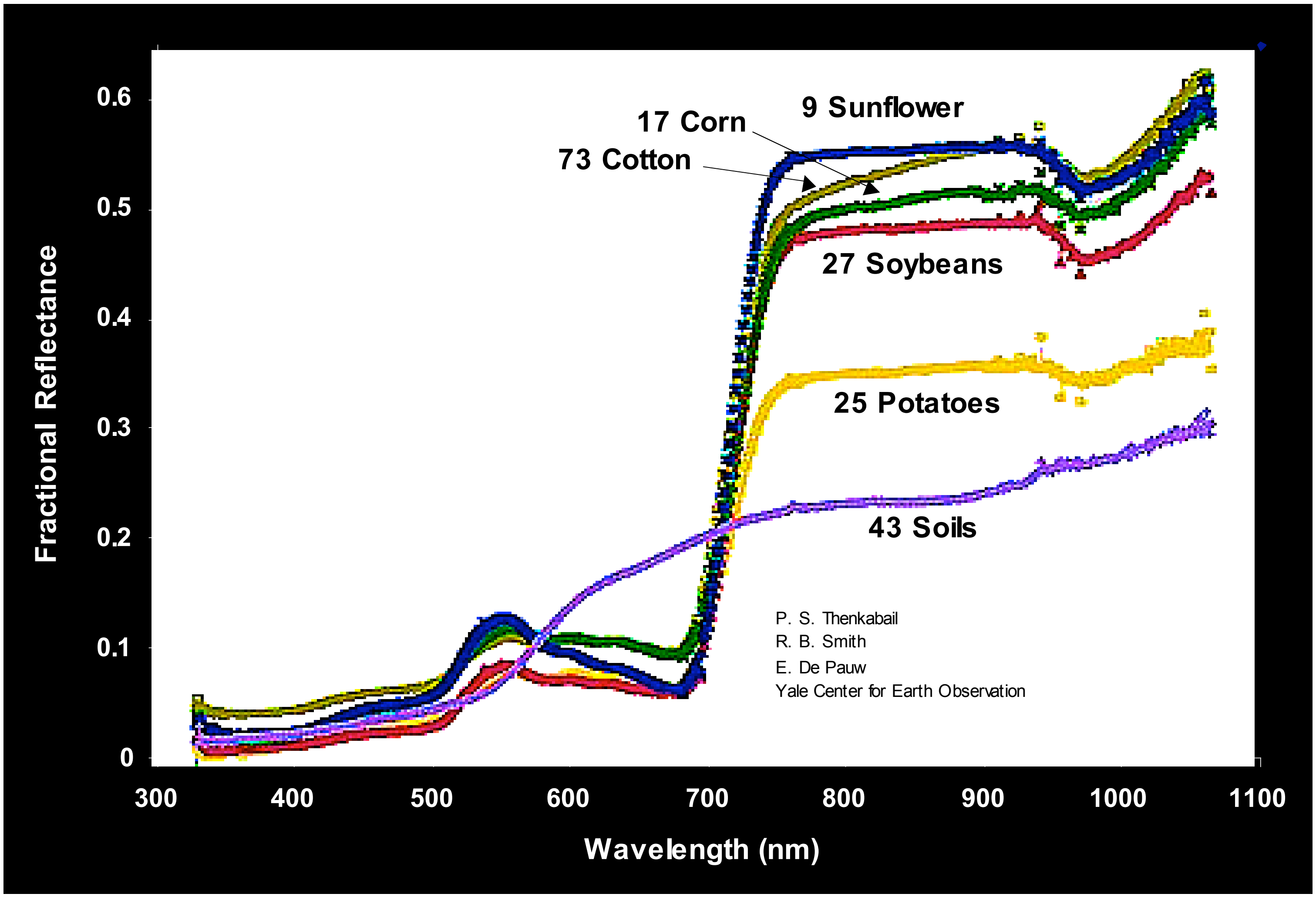
Theoretical description

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

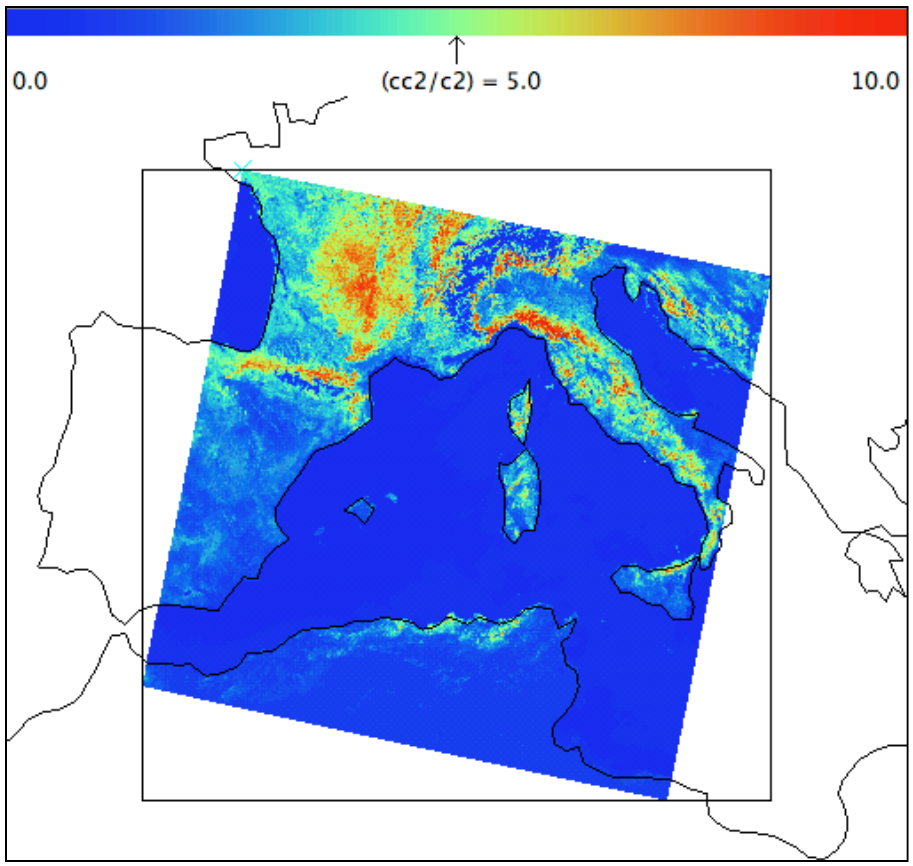
Contrast between RED and NIR responses is correlated to vegetation amount

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



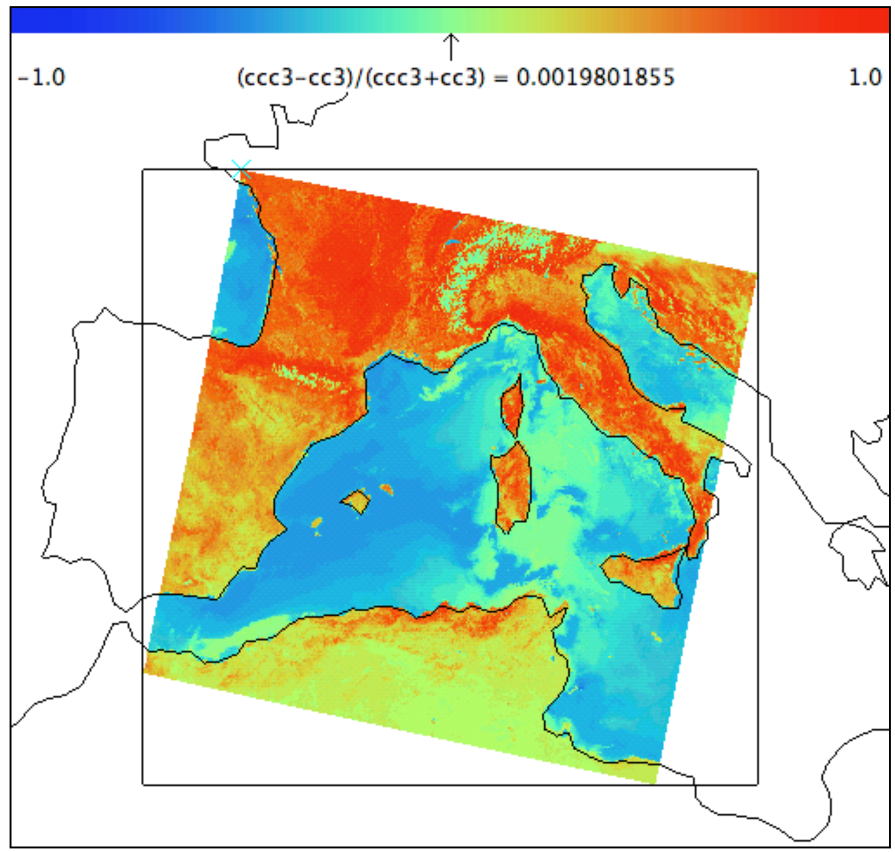
Normalized Difference Vegetation Index (NDVI)

Defined as the ratio

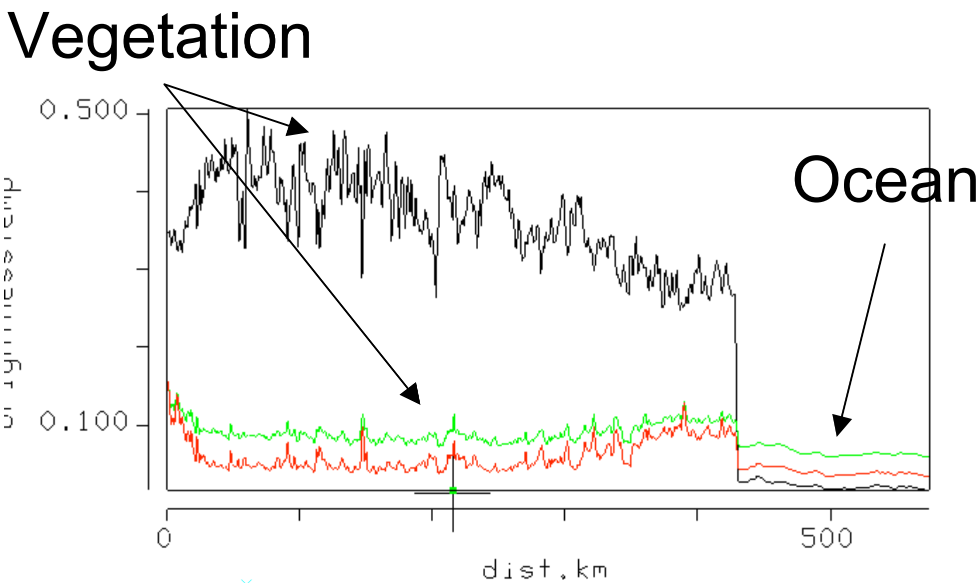
$$(r_{.86} - r_{.68})/(r_{.86} + r_{.68})$$

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

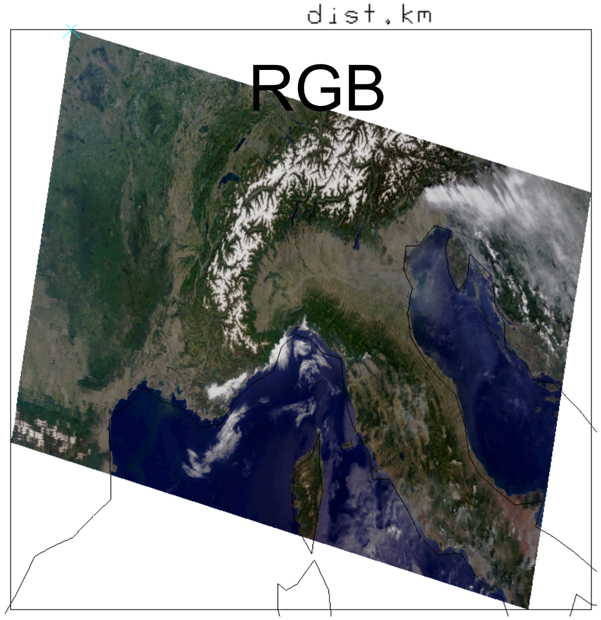
Applications:	
Vegetation Monitoring	Agricultural Activities
Drought studies	Landcover Change
Public Health Issues (mosquitos)	Climate Change Detection
Net Primary Production	Carbon Balance

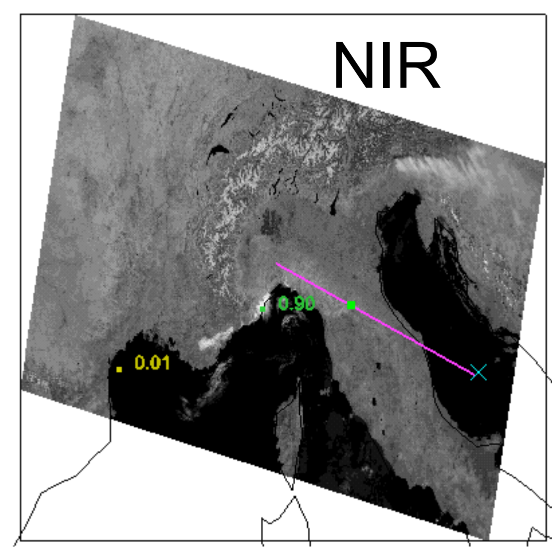


NIR and VIS over Vegetation and Ocean



NIR (.86 micron)
Green (.55 micron)
Red (0.68 micron)





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)

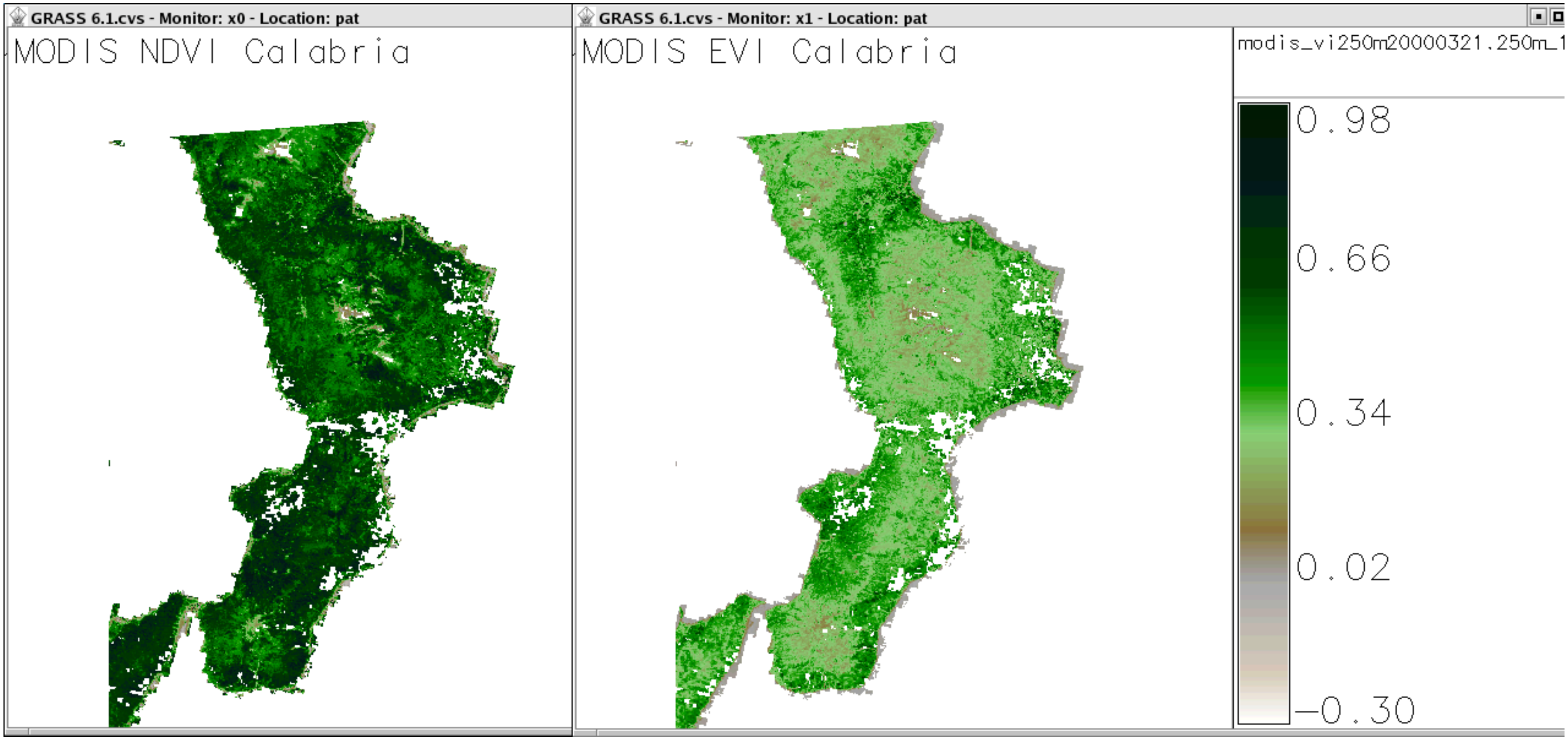
C_1 and C_2 are called aerosol resistance terms (Set to 6 and 7.5 respectively)
G is the gain factor (Set to 2.5)

- 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

  16-bit signed integer

  tiles ~1200x1200 km

* 250 m from 70 N to 70 S Latitude

Inputs and Processing Chain for MODIS VI Production

Level1B, Geolocation

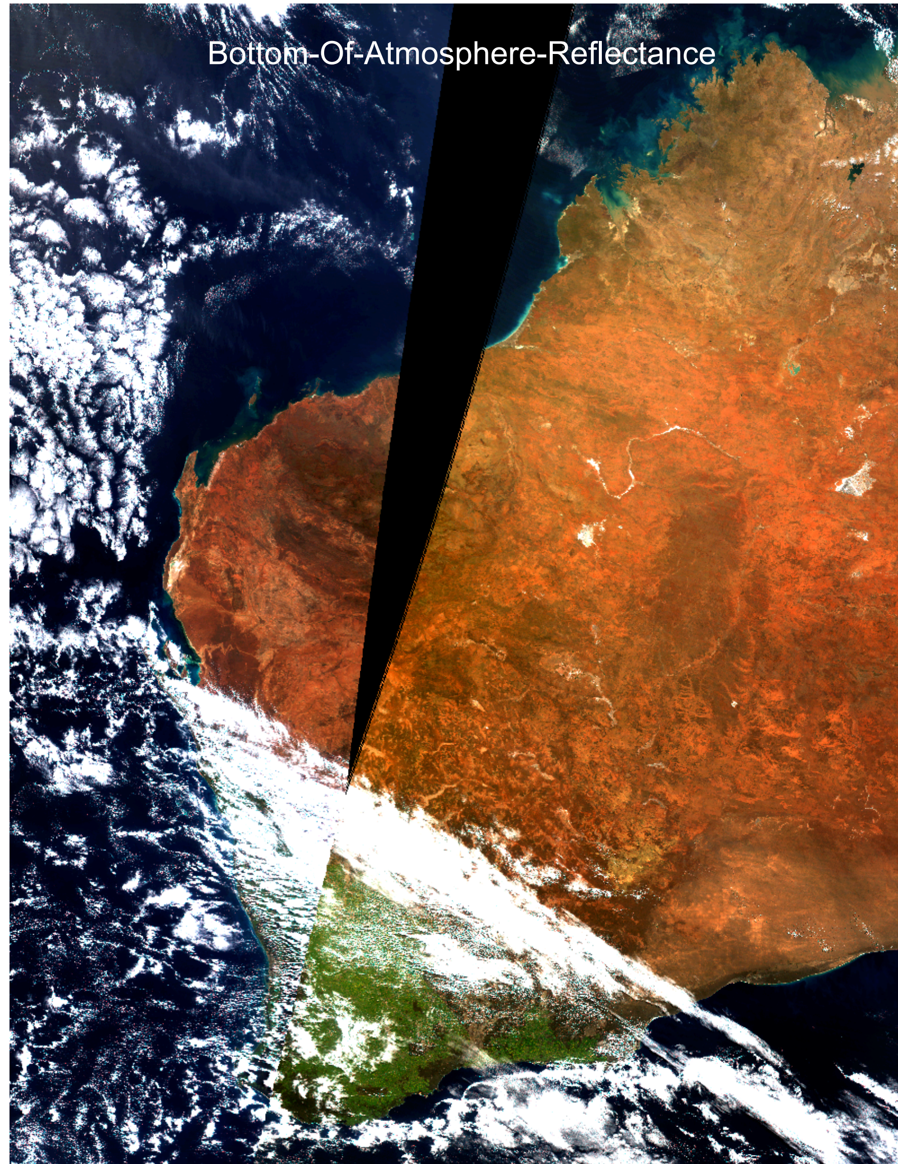
Cloud Masking

Atmospheric Correction

Selection of pixels to be included in 16 day composite

VI Equation

Atmospheric contribution is removed to retrieve surface properties



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

Global Compositing

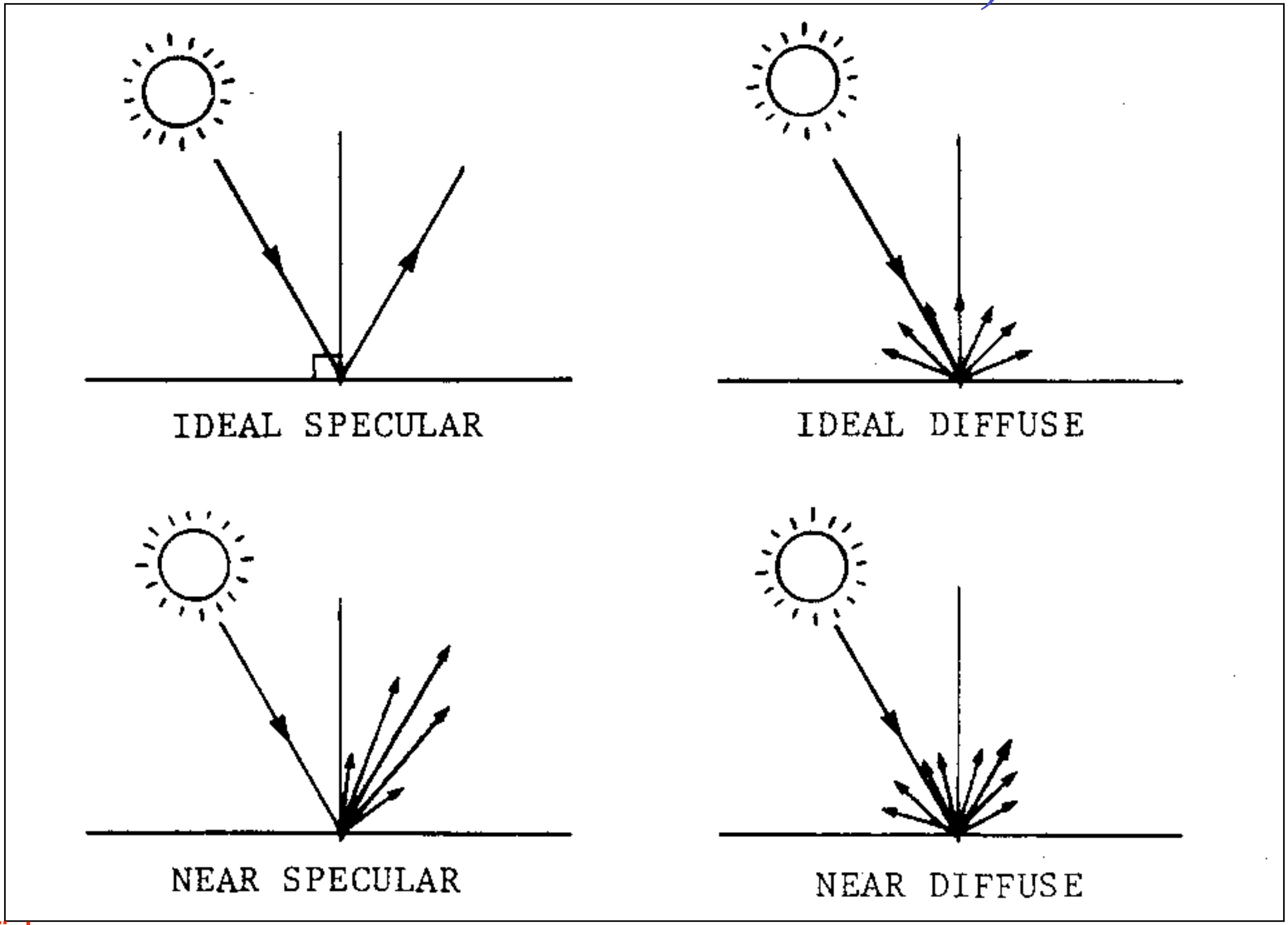
Multiple observations over same 250m or 500m scene over 16 day time period

- 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)

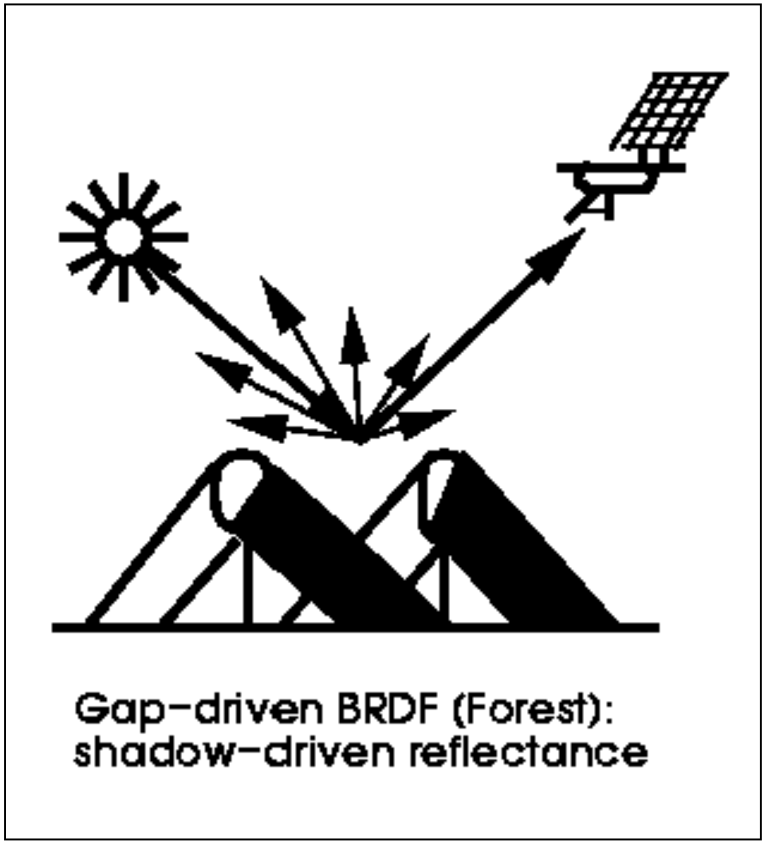
- If number of good pixels > 5
  - Bidirectional Reflectance Distribution Function (BRDF) selection
    - Good pixel values corrected for angular effects
- If number of good pixels $1 < n < 5$
  - Constrained-view angle-maximum value (CV-MVC) selection
    - Highest values closest to nadir
- If number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

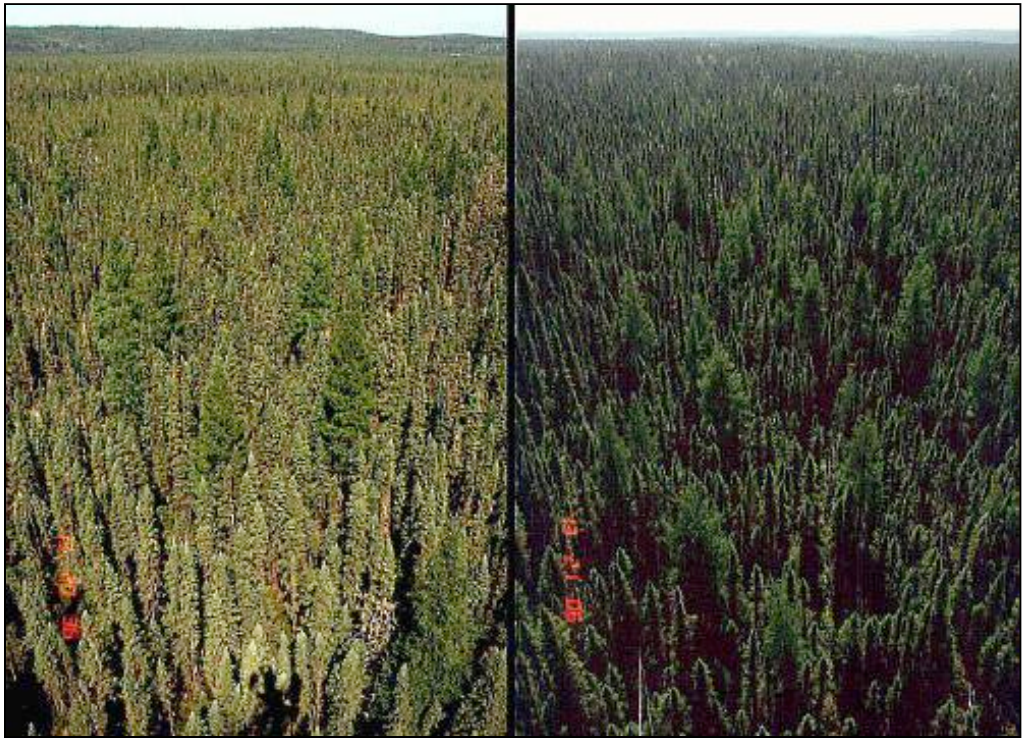
BRDF (Bi-directional Reflectance Distribution Function)



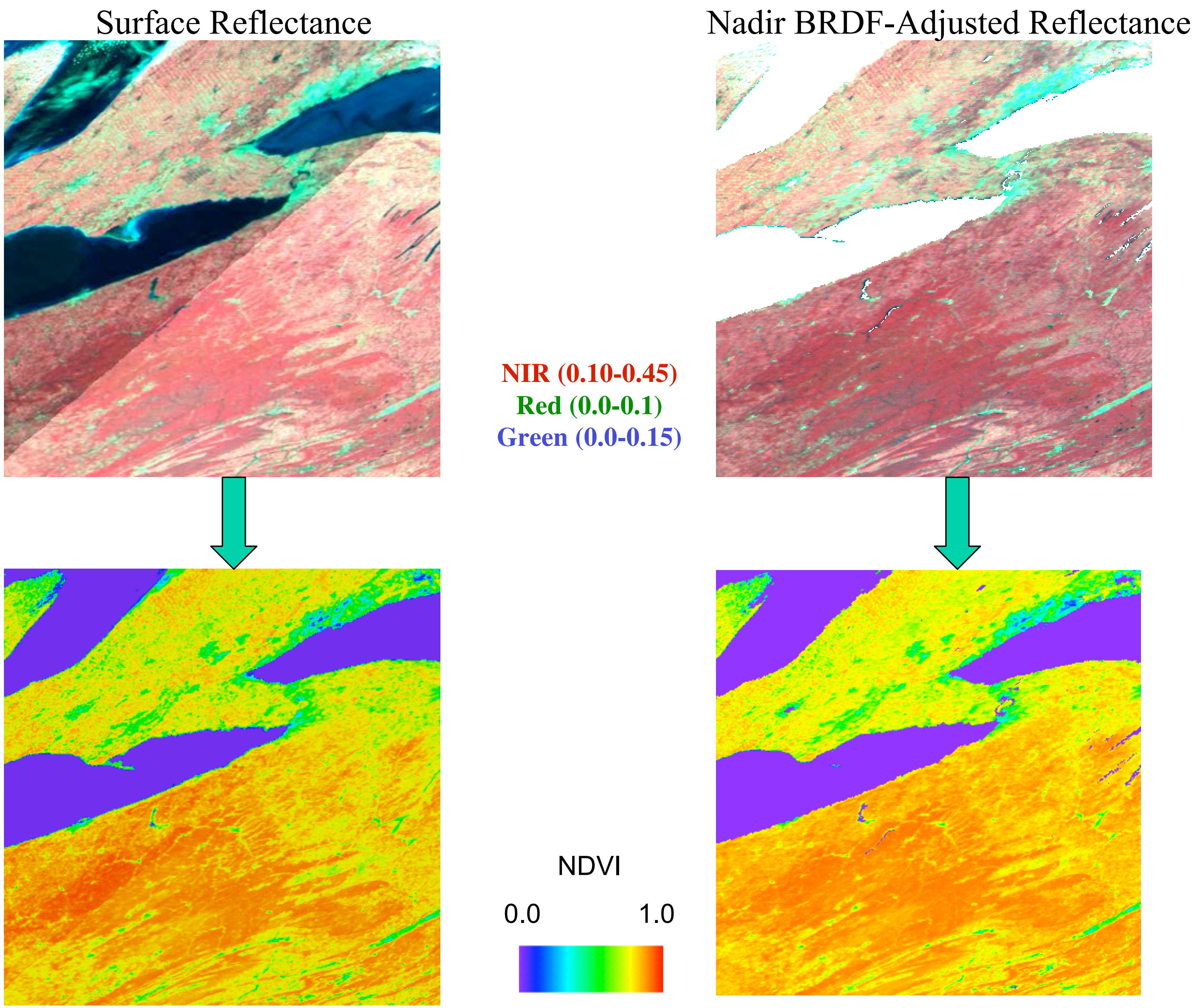
Wolfgang Lück

BRDF Example

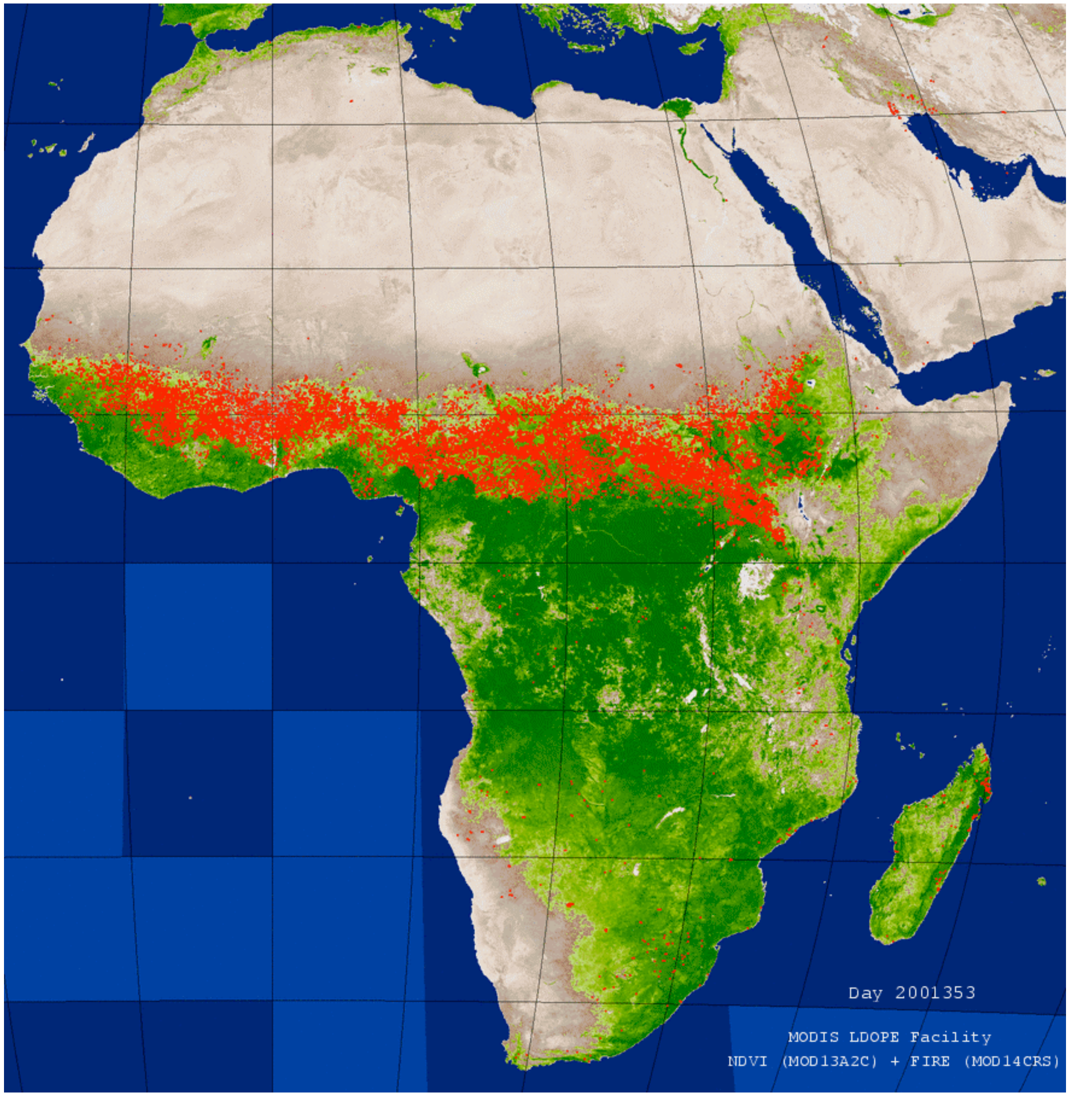




Black spruce forest in Canada.
Left, sun behind camera
Right, sun opposite


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
- Canopy background effects
- Angular effects

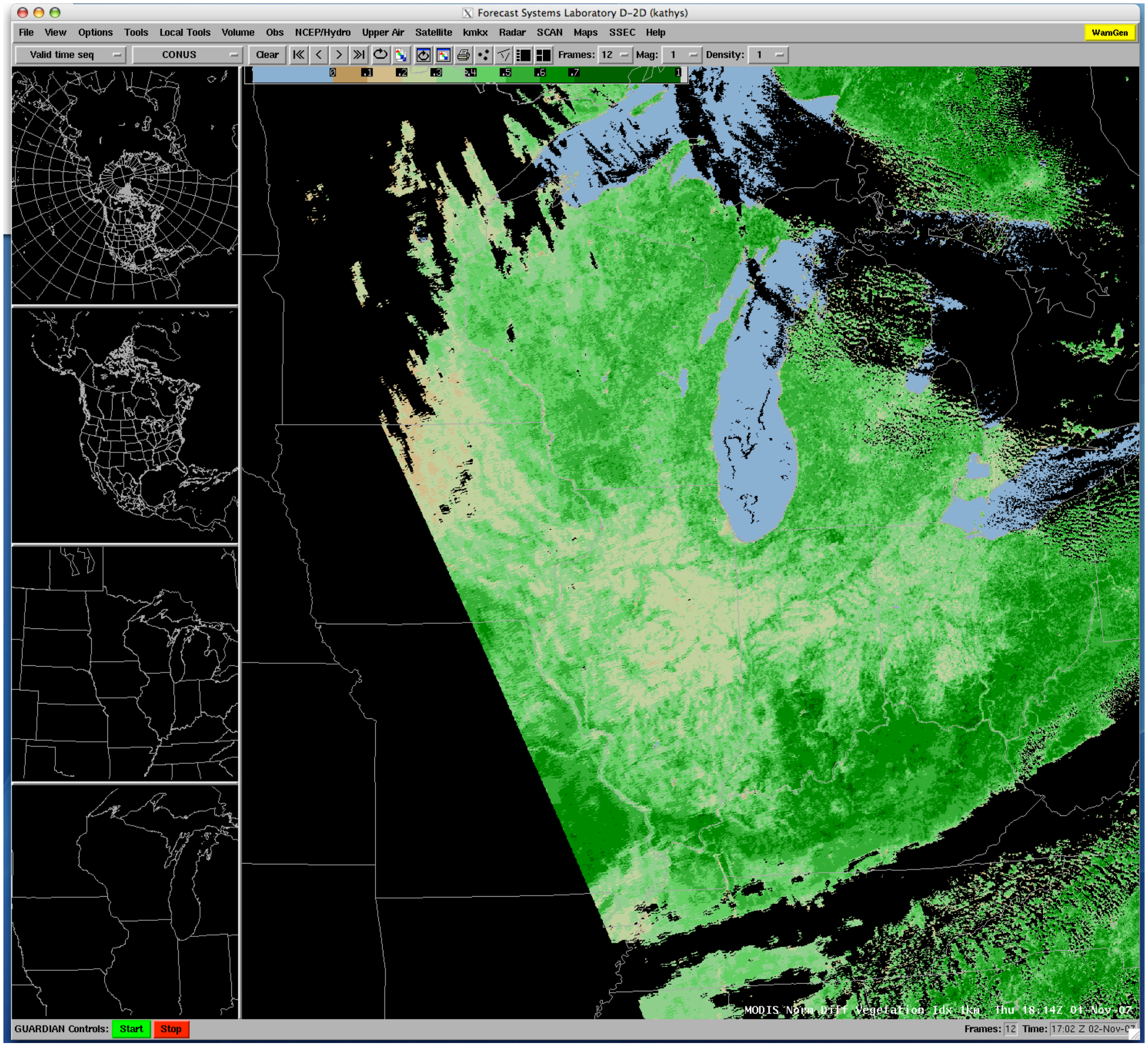
REFERENCES

- 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

Applications

- Monitoring of seasonal, inter-annual, and long term variations of vegetation structure and biophysical parameters
- Climate Studies - Model input
- Famine Early Warning - Drought
- Epidemiology
- Correlated with Net Primary Production
- Fire Potential - US National Weather Service Forecasters

Example of MODIS NDVI product viewed by US Operational Forecasters in AWIPS   1 November 2007



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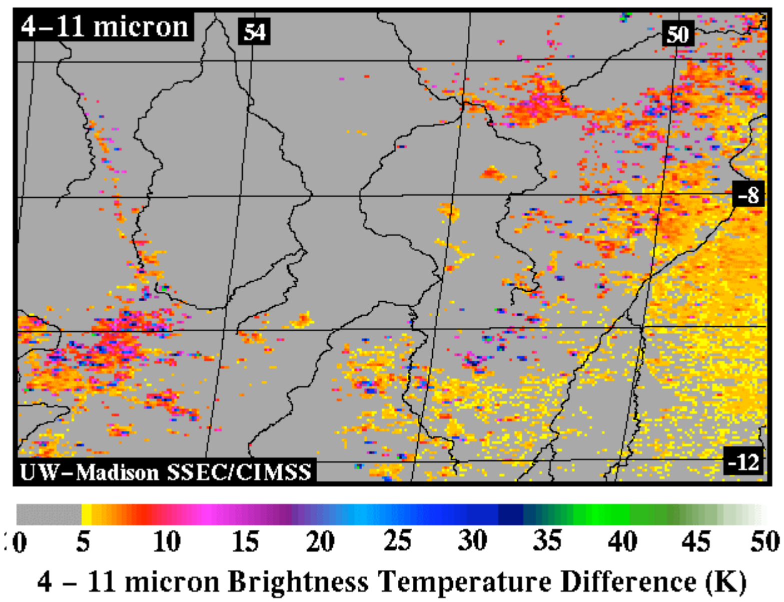
- MOD 44 - Vegetation Cover Conversion

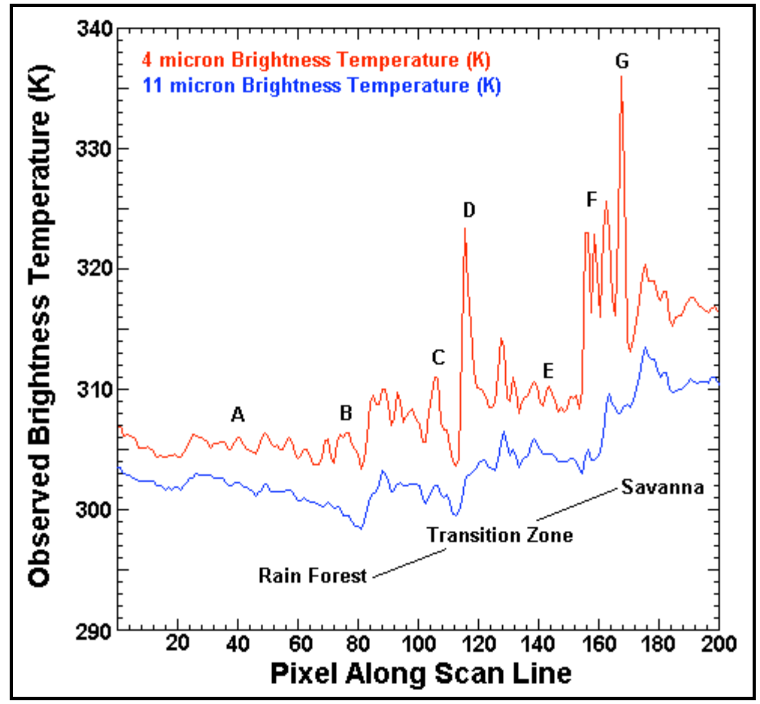
MODIS Fire Product

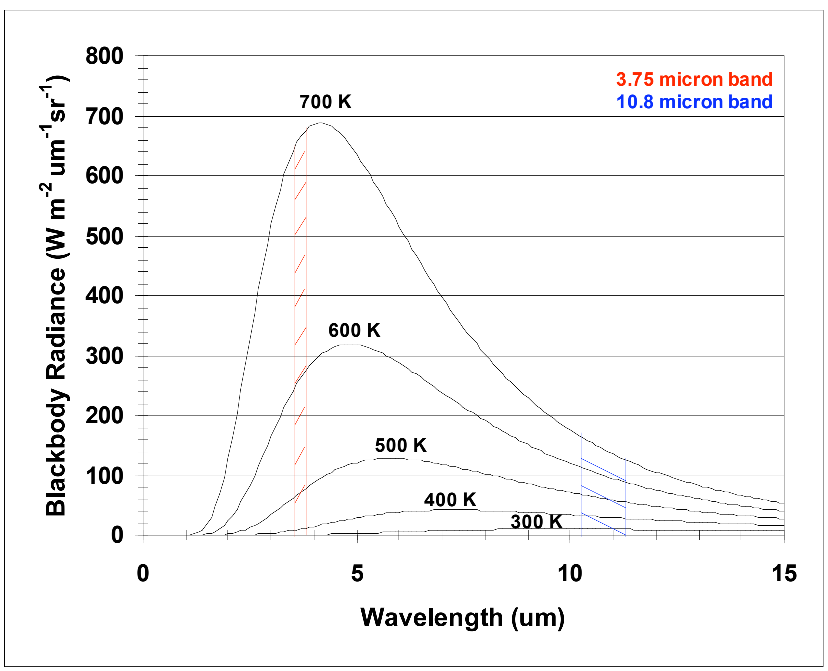
Louis Giglio   Chris Justice

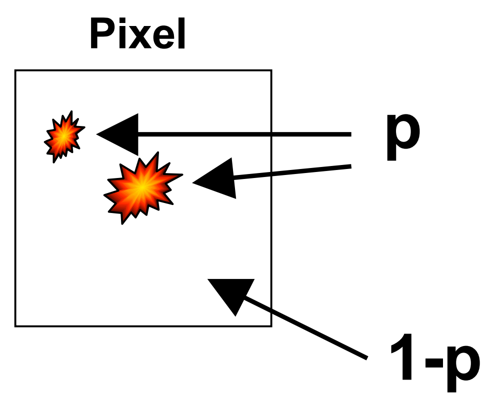
- Based upon the Temperature Sensitivity difference between 4 and 11 microns
- Contextual Fire Detection Algorithm
  - Infrared static Brightness Temperature thresholds
  - Dynamic thresholds compare pixel to surrounding background
- Variety of output product temporal and spatial resolutions

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

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

$\alpha = c_2/\lambda T$ B is proportional to T^α

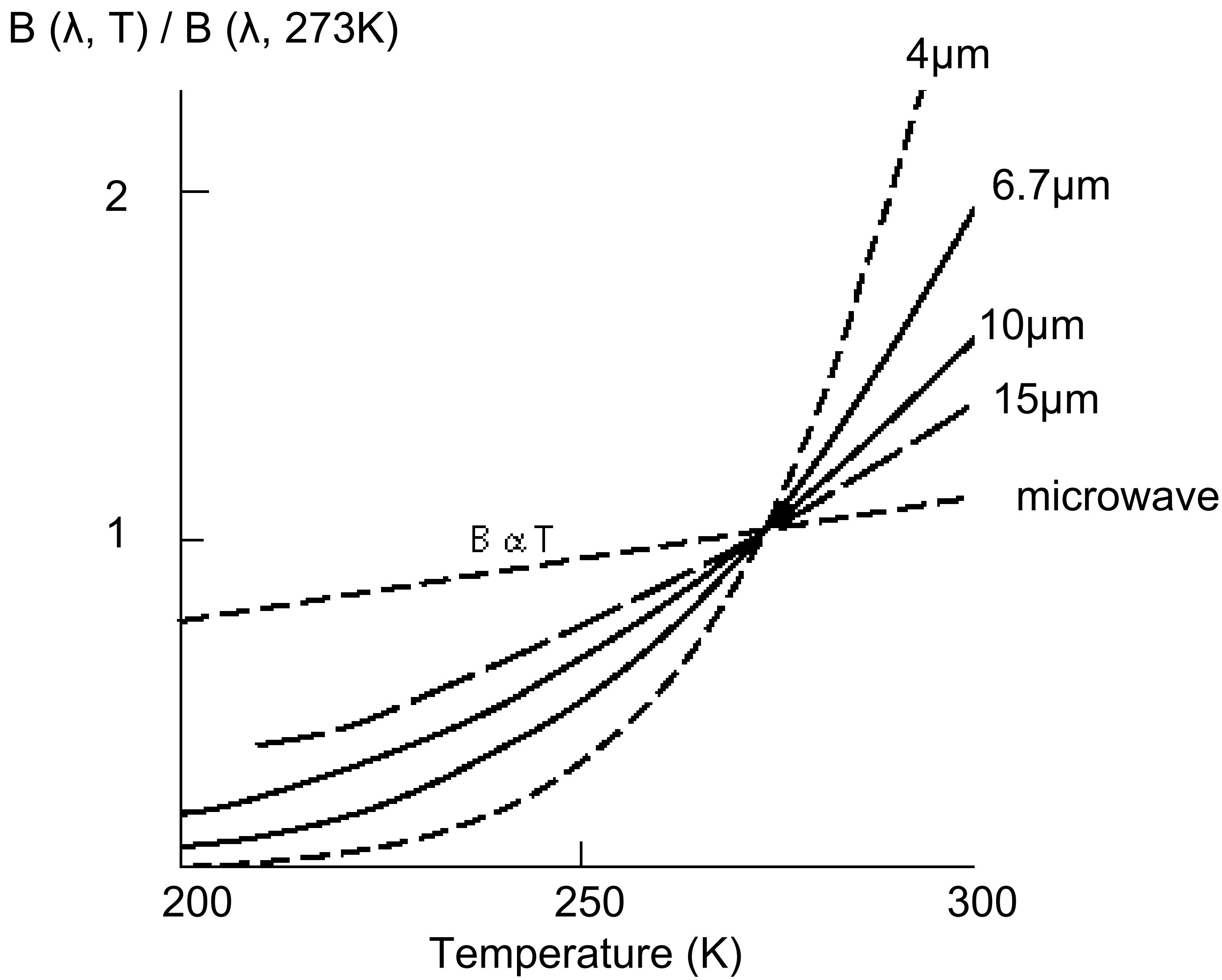
Wavelength	Typical Scene Temperature	Temperature Sensitivity
(4.0 μm)	300	11.99
(11 μm)	300	4.32

$T(4)^{**}12 = P^*T_{fire}{}^{**}12 + (1-P)^*T^{**}12 \sim P^*400^{**}12 + (1-P)^*300^{**}12$

$T(11)^{**}4 = P^*T^{**}4_{fire} + (1-P)^*T^{**}4 \sim P^*400^{**}4 + (1-P)^*300^{**}4$

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

Temperature Sensitivity of B(λ,T) for typical earth scene temperatures



B(10 um,T) / B(10 um,273) $\propto T^4$

B(10 um,273)= 6.1

B(10 um,200)= 0.9 → 0.15

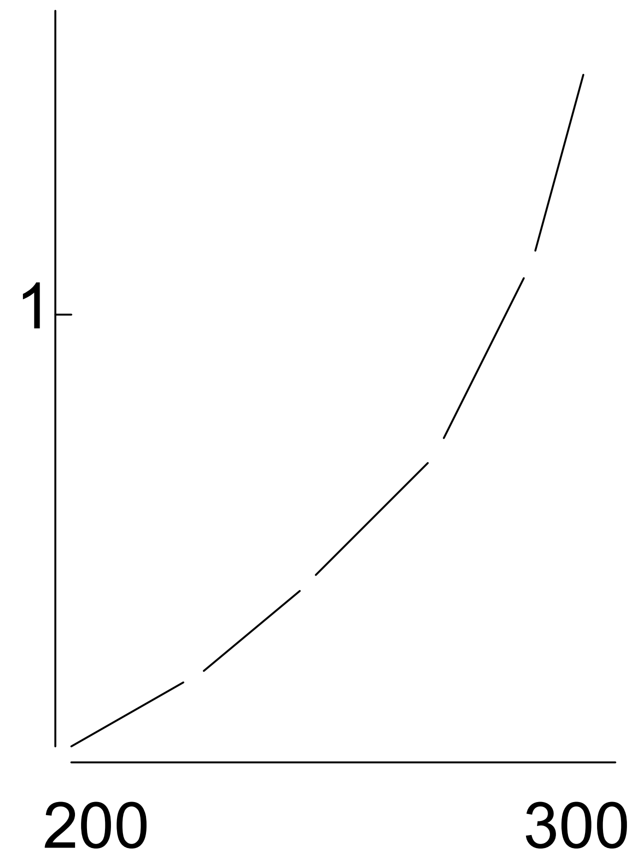
B(10 um,220)= 1.7 → 0.28

B(10 um,240)= 3.0 → 0.49

B(10 um,260)= 4.7 → 0.77

B(10 um,280)= 7.0 → 1.15

B(10 um,300)= 9.9 → 1.62



$B(4\ um,T) / B(4\ um,273) \propto T^{12}$

$B(4\ um,273) = 2.2 \times 10^{-1}$

$B(4\ um,200) = 1.8 \times 10^{-3} \rightarrow 0.0$

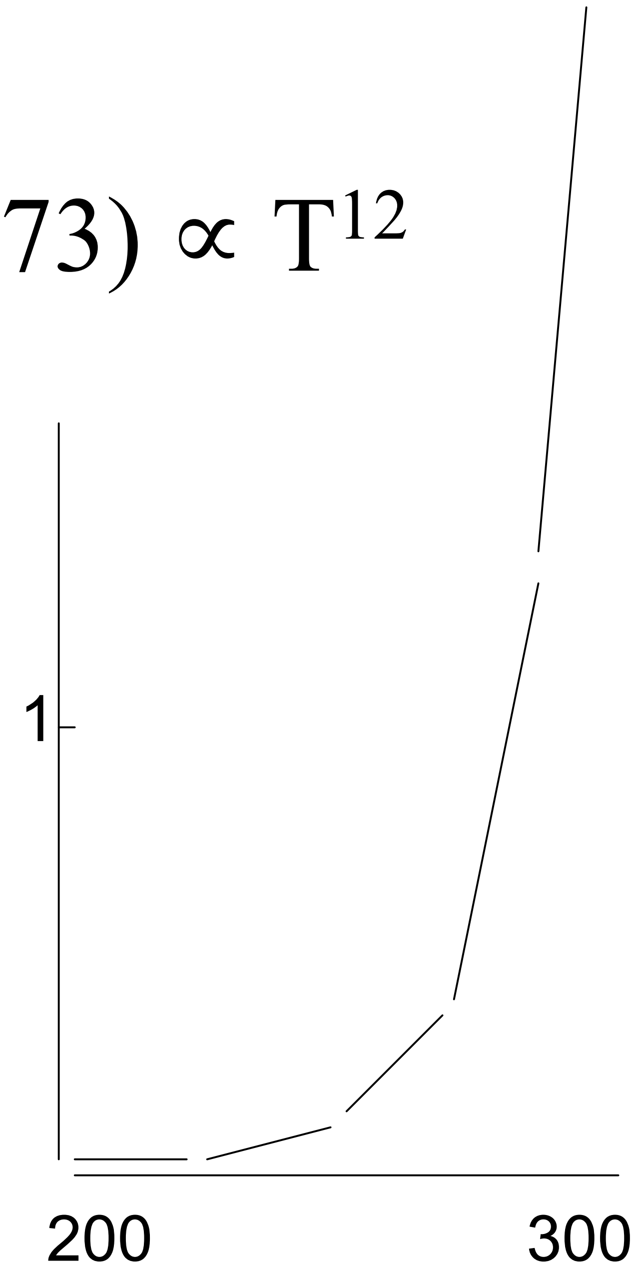
$B(4\ um,220) = 9.2 \times 10^{-3} \rightarrow 0.0$

$B(4\ um,240) = 3.6 \times 10^{-2} \rightarrow 0.2$

$B(4\ um,260) = 1.1 \times 10^{-1} \rightarrow 0.5$

$B(4\ um,280) = 3.0 \times 10^{-1} \rightarrow 1.4$

$B(4\ um,300) = 7.2 \times 10^{-1} \rightarrow 3.3$



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

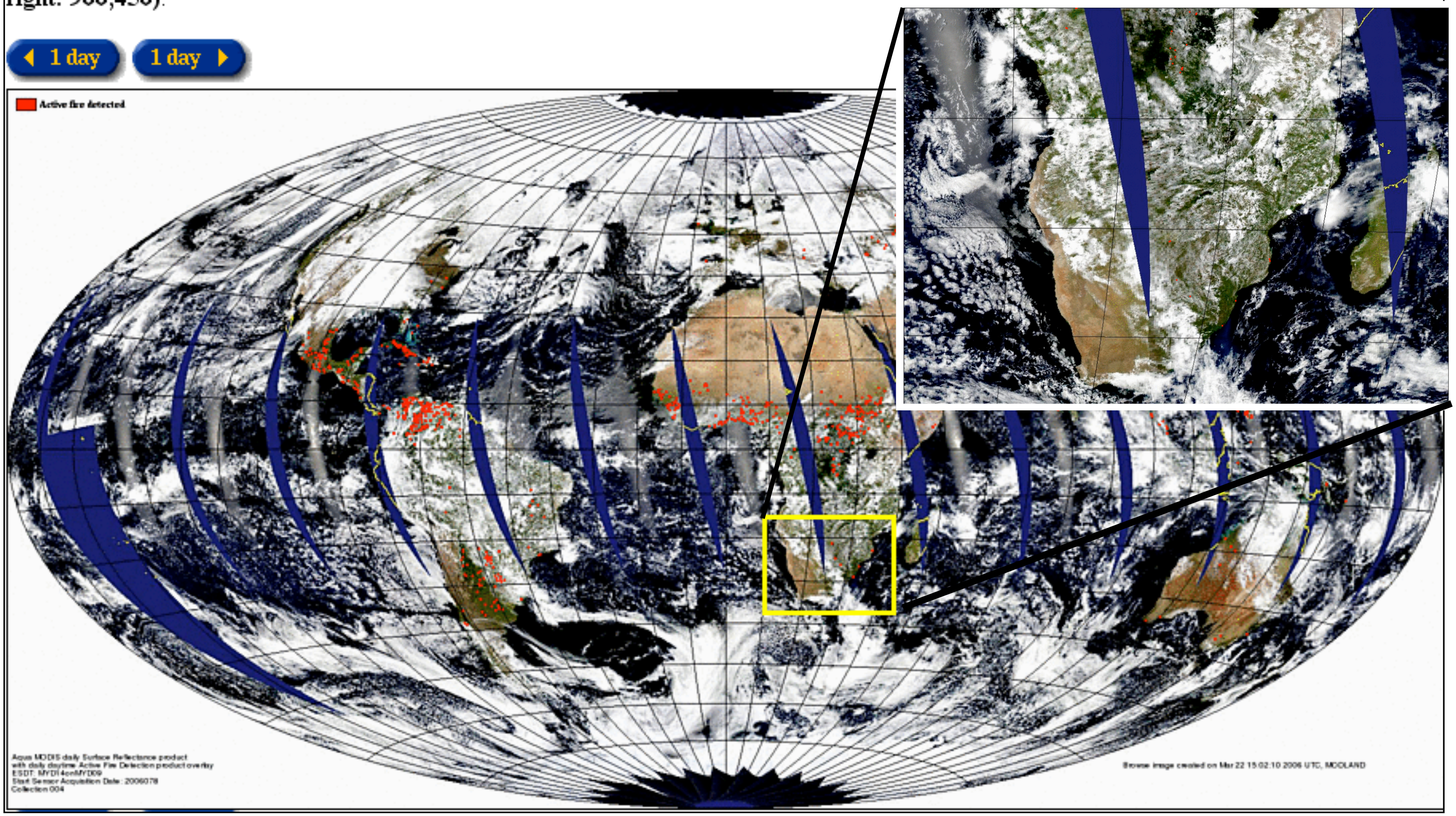
Global Daily Browse

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

Aqua, MYD14MYD09, day 2006078 (03/19/2006), Collection 004

Select a region you want zoom in:

Note: If you can not drag a box on the image, please enter the coordinates in the text boxes. **The image size is 900x450 (upper left: 0,0; lower right: 900,450)**.



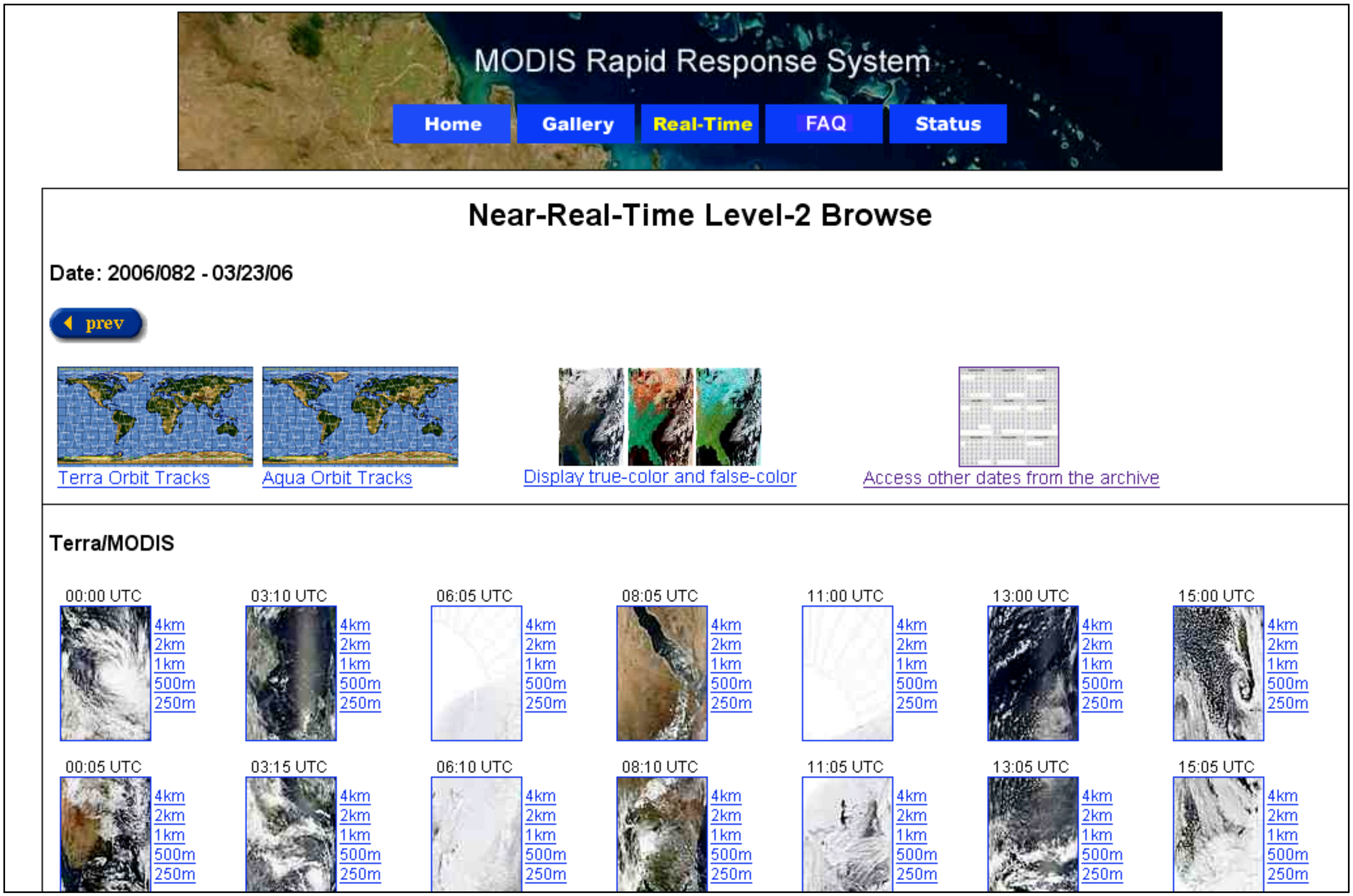
MOD14 Key Output Parameters

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/



Examples of Automated Fire Detection Algorithms

Single channel thresholds

e.g. AVHRR Instituto Nacional De Pesquisas Espaciais (INPE) fire product,
European Space Agency ERS Along Track Scanning Radiometer (ATSR) fire product

- Saturation in the 4 micron band
- Elevated brightness temperature in the 4 micron band (I.e. > 315K)

Multi-channel thresholds

e.g. Canada Centre for Remote Sensing (CCRS) Fire M3, CSU CIRA Fog/Reflectivity Product

- 3 steps

Use 4 micron band fixed thresholds to identify possible fires
Use 11 micron band fixed thresholds to eliminate clouds
Use 4 minus 11 micron band differences to distinguish fires from warm background

Contextual algorithms

e.g. AVHRR Joint Research Centre of the European Commission (JRC) World Fire Web,
Tropical Rainfall Mapping Mission (TRMM) Visible and Infrared Scanner (VIRS) GSFC fire product,
AVHRR NOAA Fire Identification, Mapping and Monitoring Algorithm (FIMMA) fire product
TERRA MODIS Fire Product

- Implement multi-channel variable thresholds based on the heterogeneity of the background

Contextual identification and sub-pixel characterization

e.g. UW-Madison GOES Automated Biomass Burning Algorithm(ABBA)

- Implement contextual algorithms and determine estimates of sub-pixel fire size and temperature. Include offsets for emissivity and atmospheric attenuation.

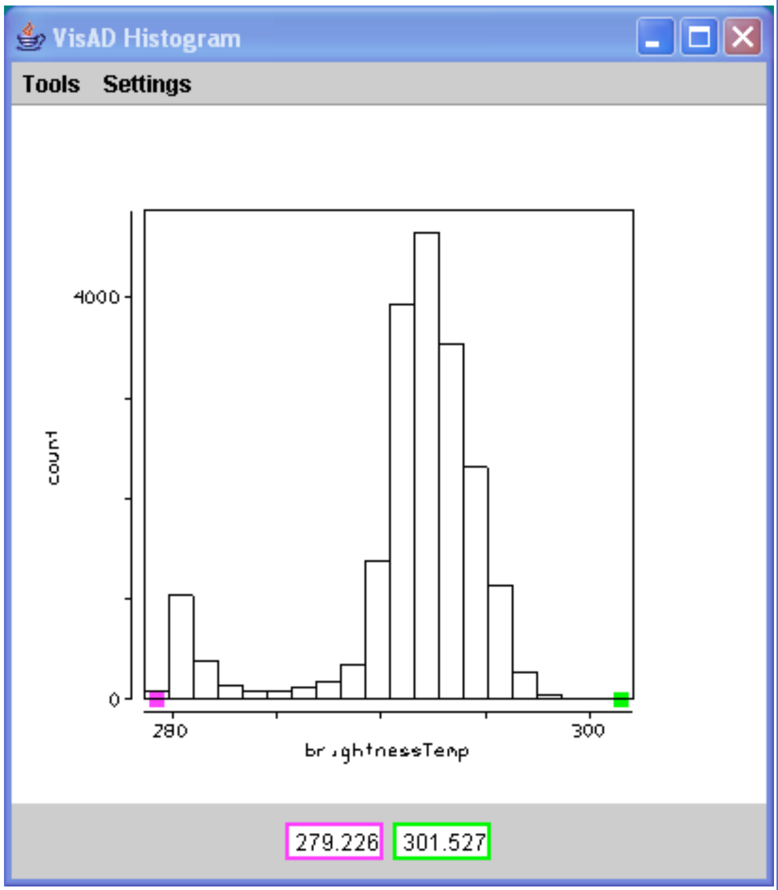
Algorithm Description

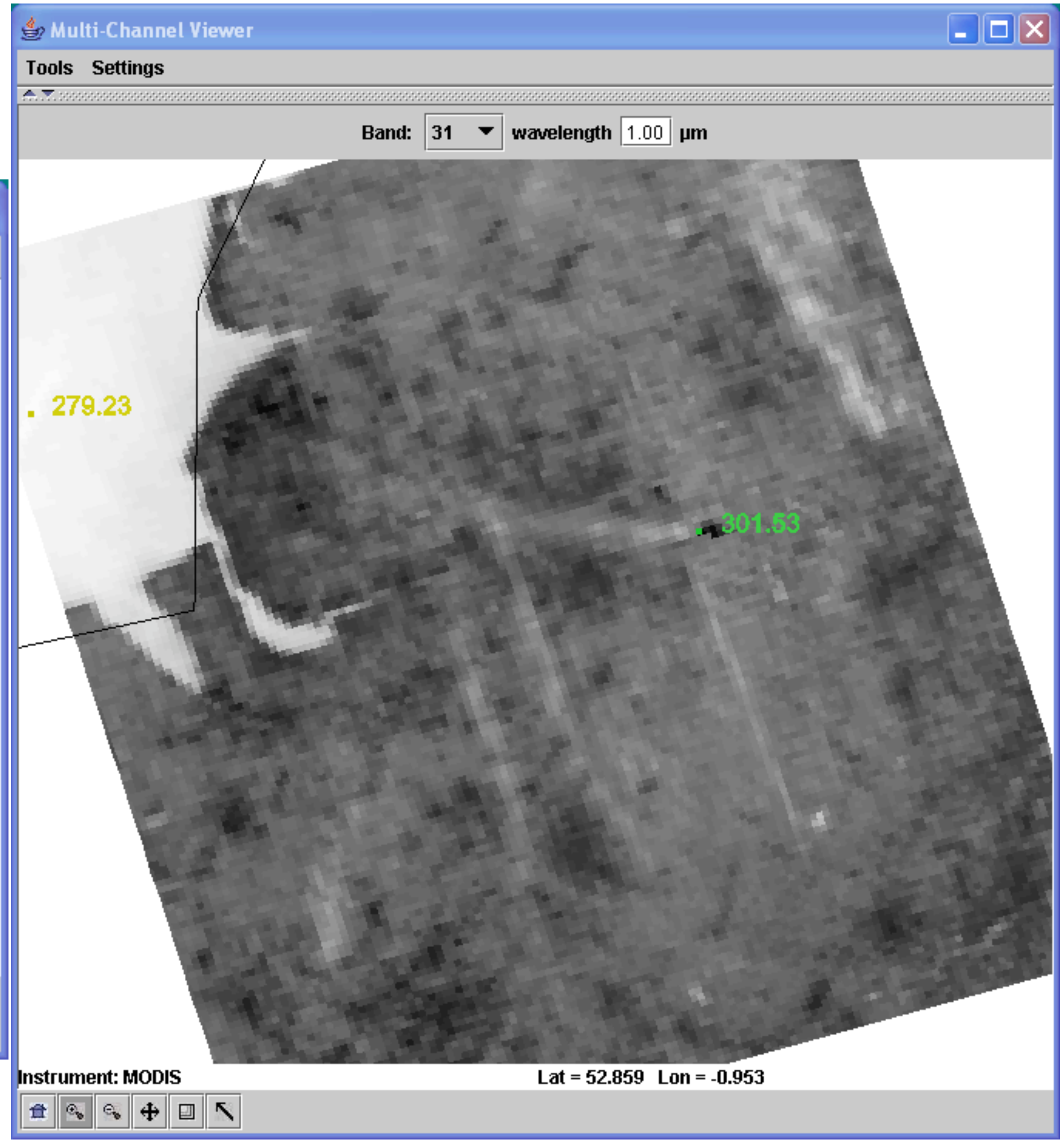
- MODIS bands 21 and 22 (3.99 micron)
  - Band 22 saturates at 331 K
  - Band 21 “fire channel” saturates at ~ 500 K
    - 12 bit range broader – less sensitive
    - The calibration of B21 uses fixed calibration coefficients and not using the scan-by-scan onboard black body (more noise)
    - So use 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.)

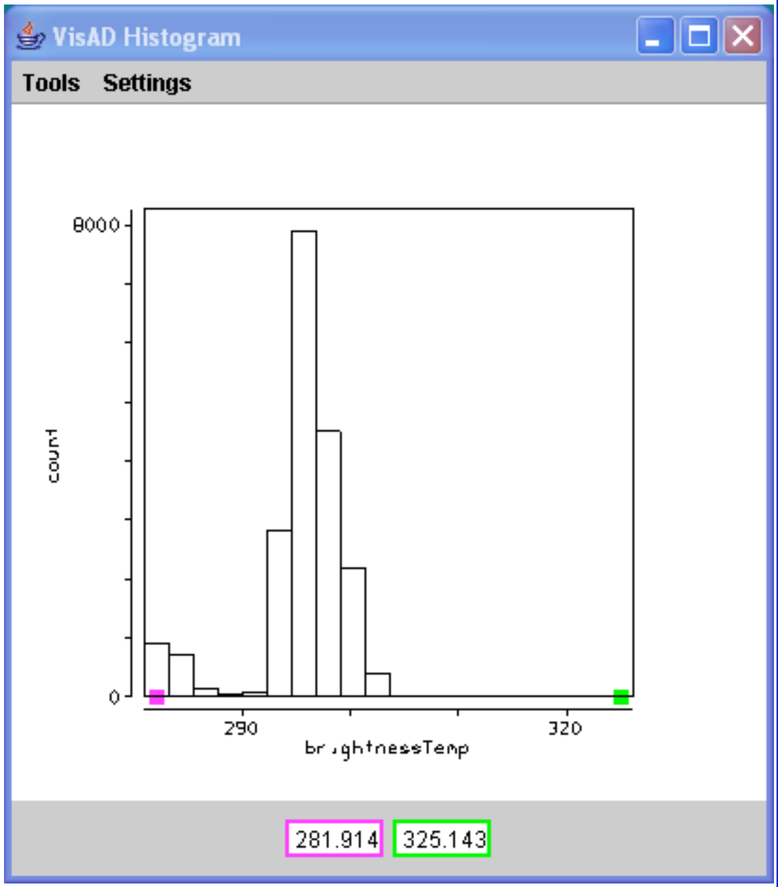
Aqua MODIS true color image 18 April 2003 12:45 UTC

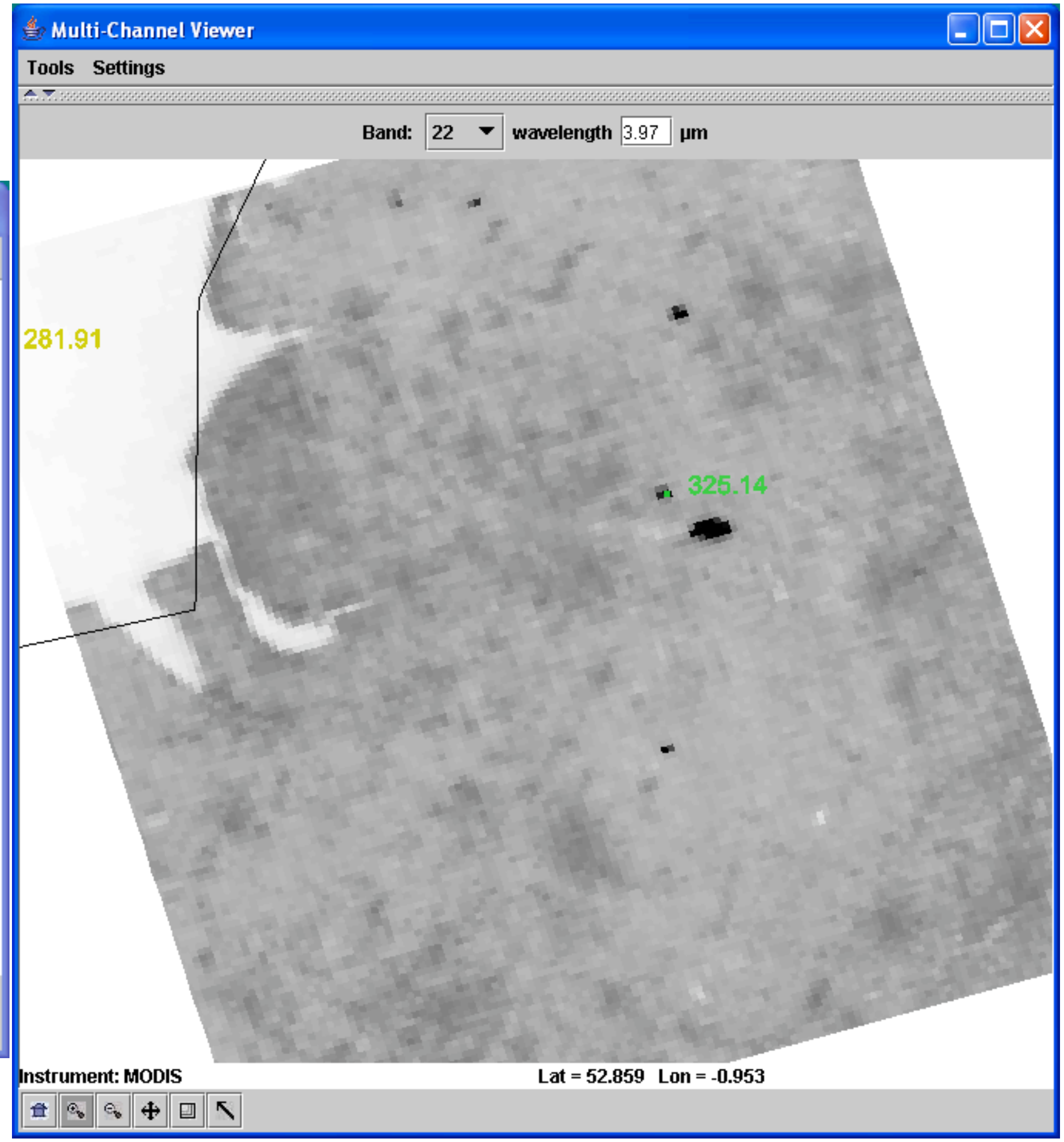
Band 31 Example



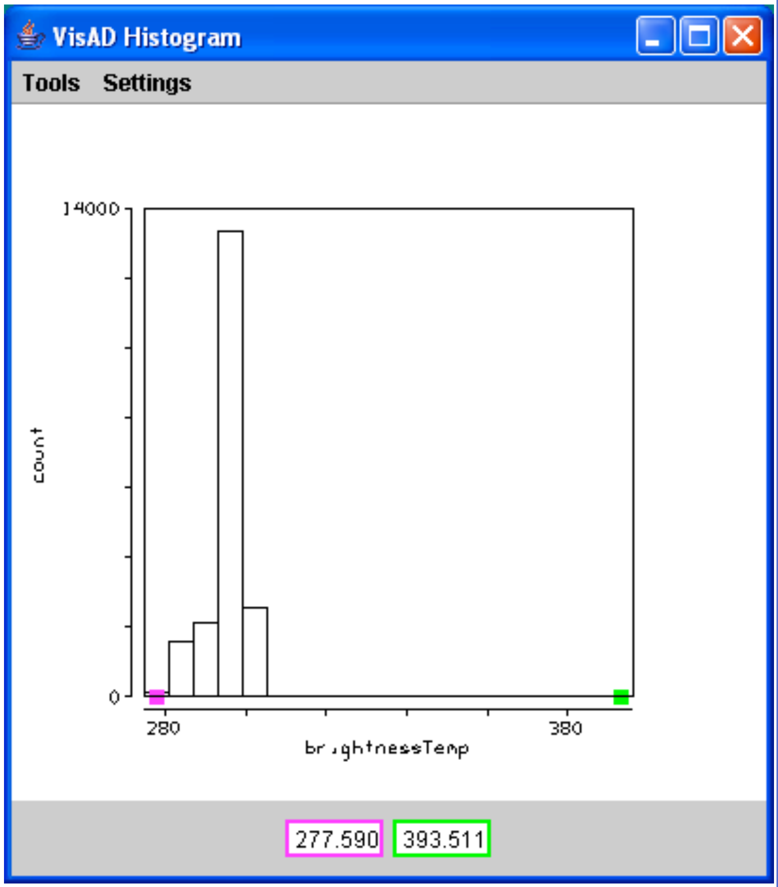


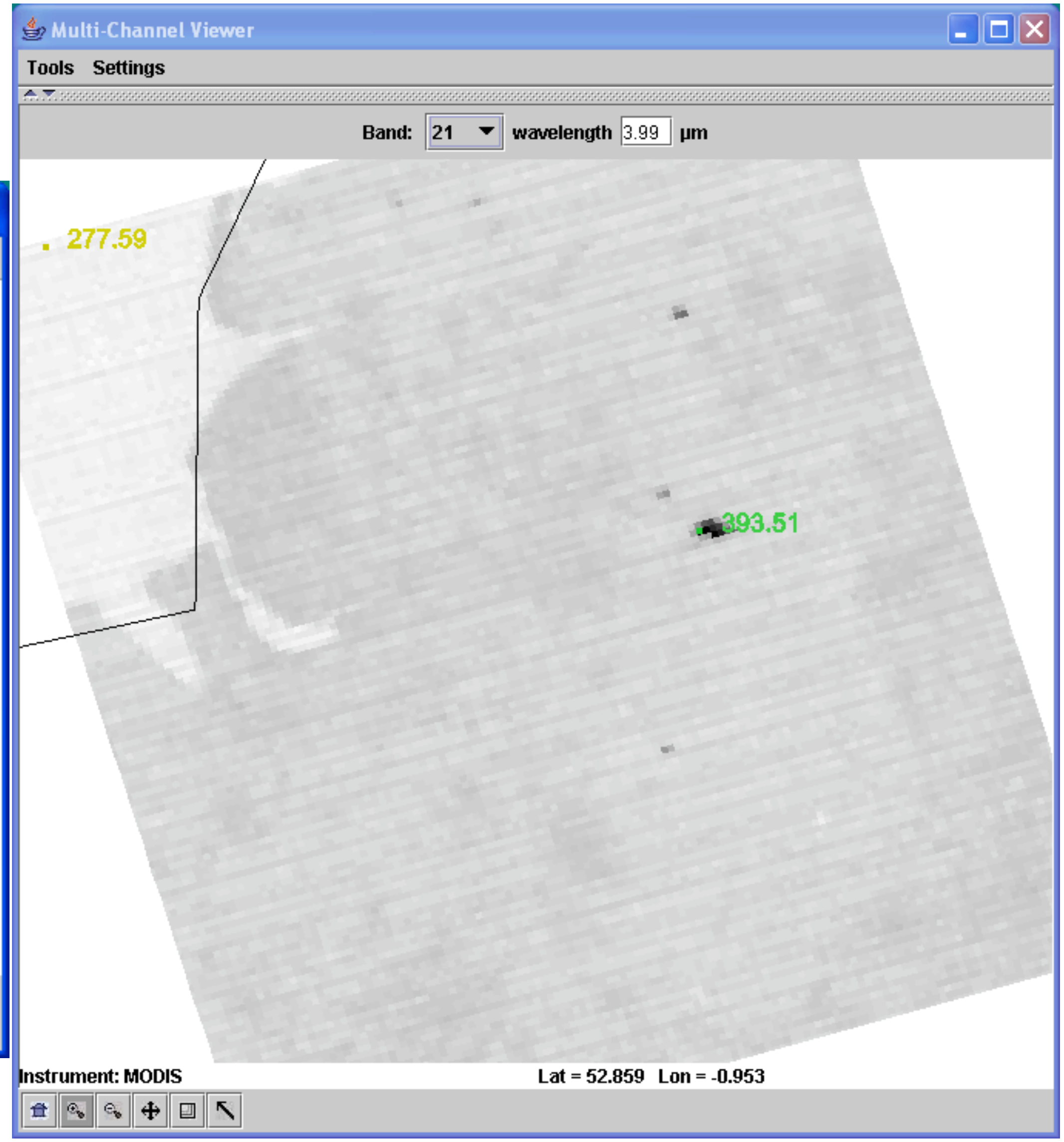
Band 22 Example



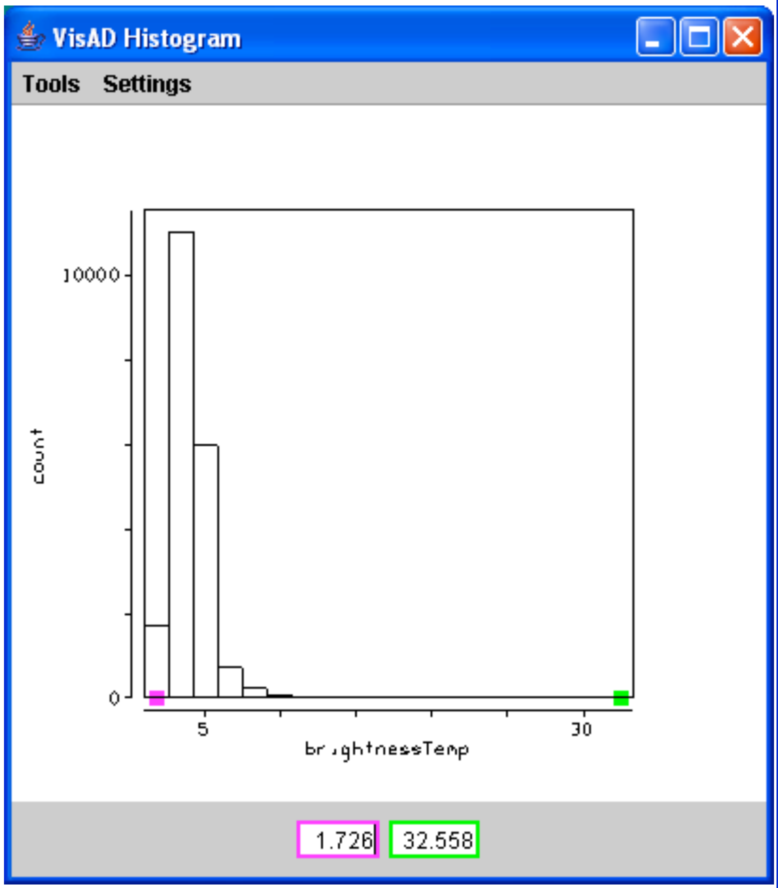


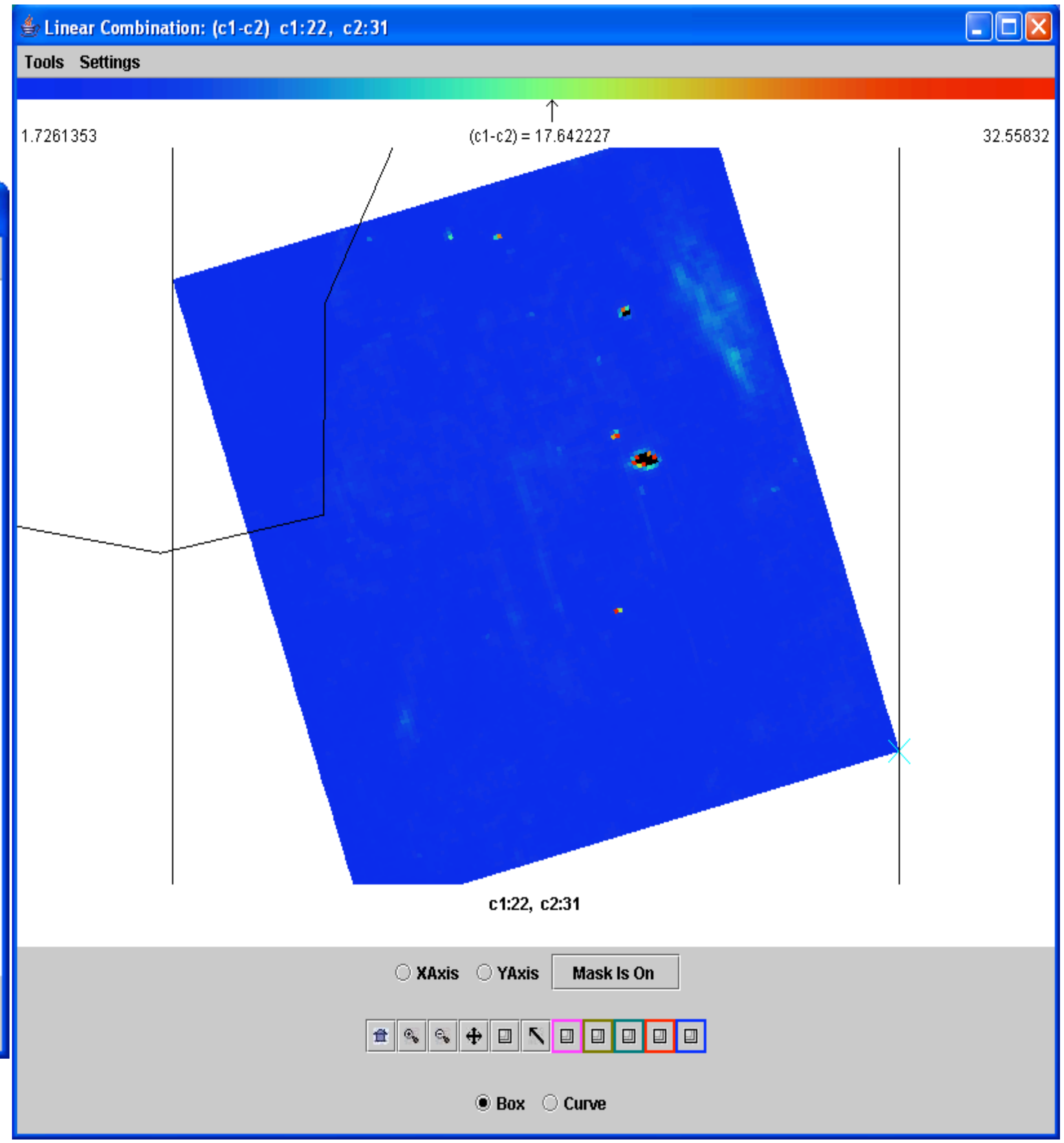
Band 21 Example



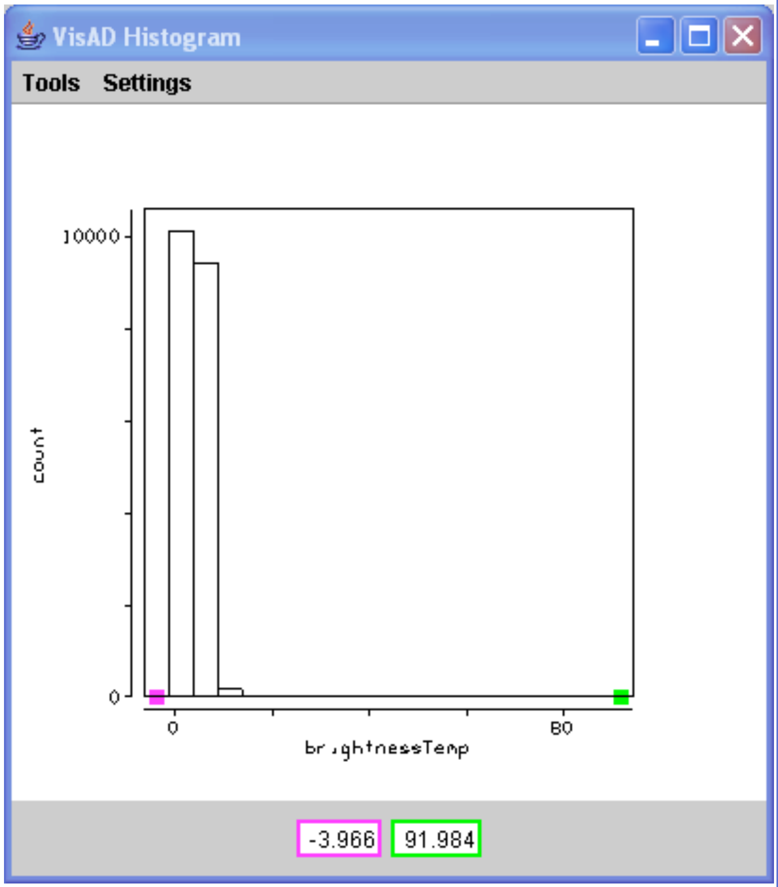


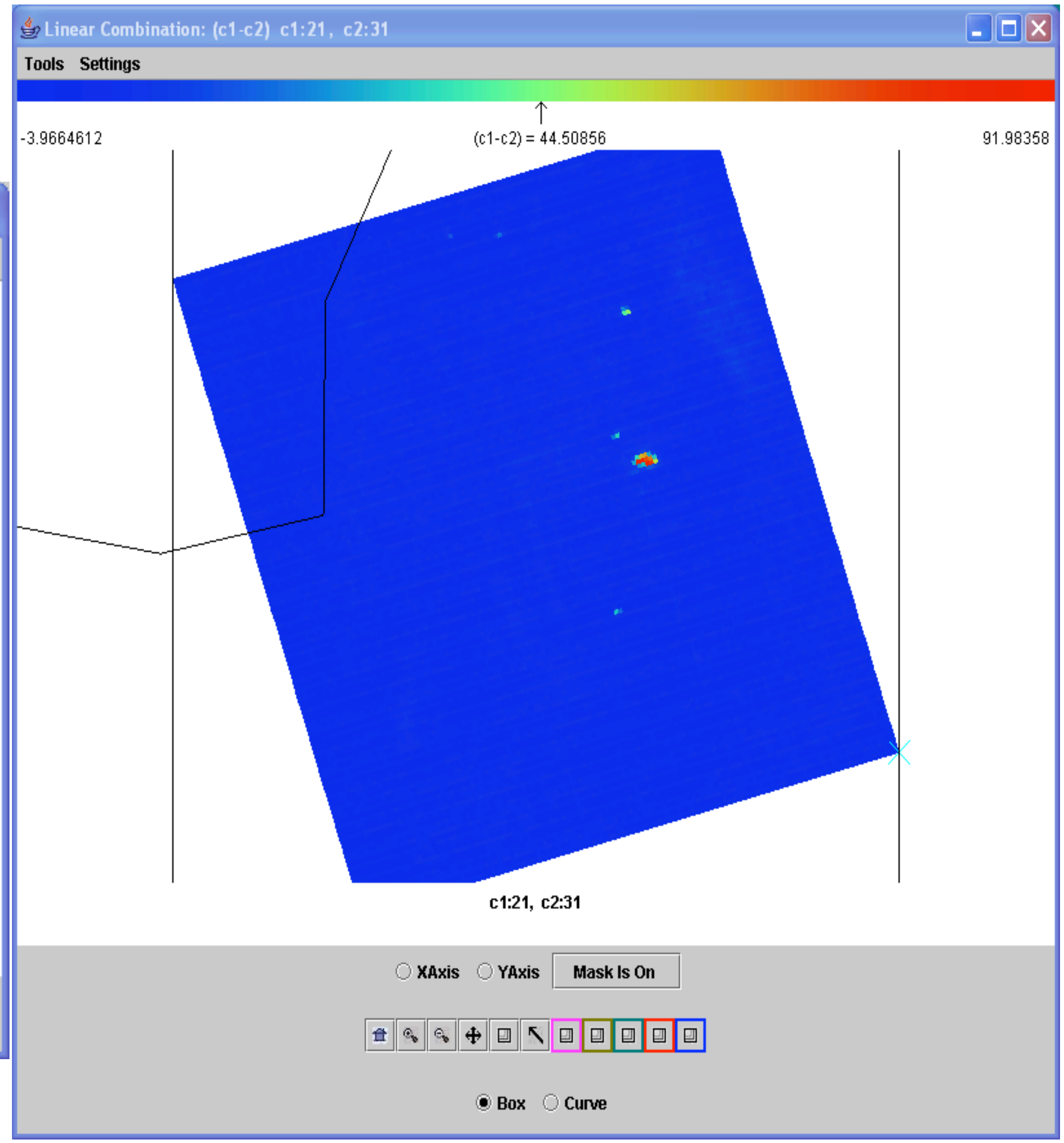
Band 22 – Band 31 Example



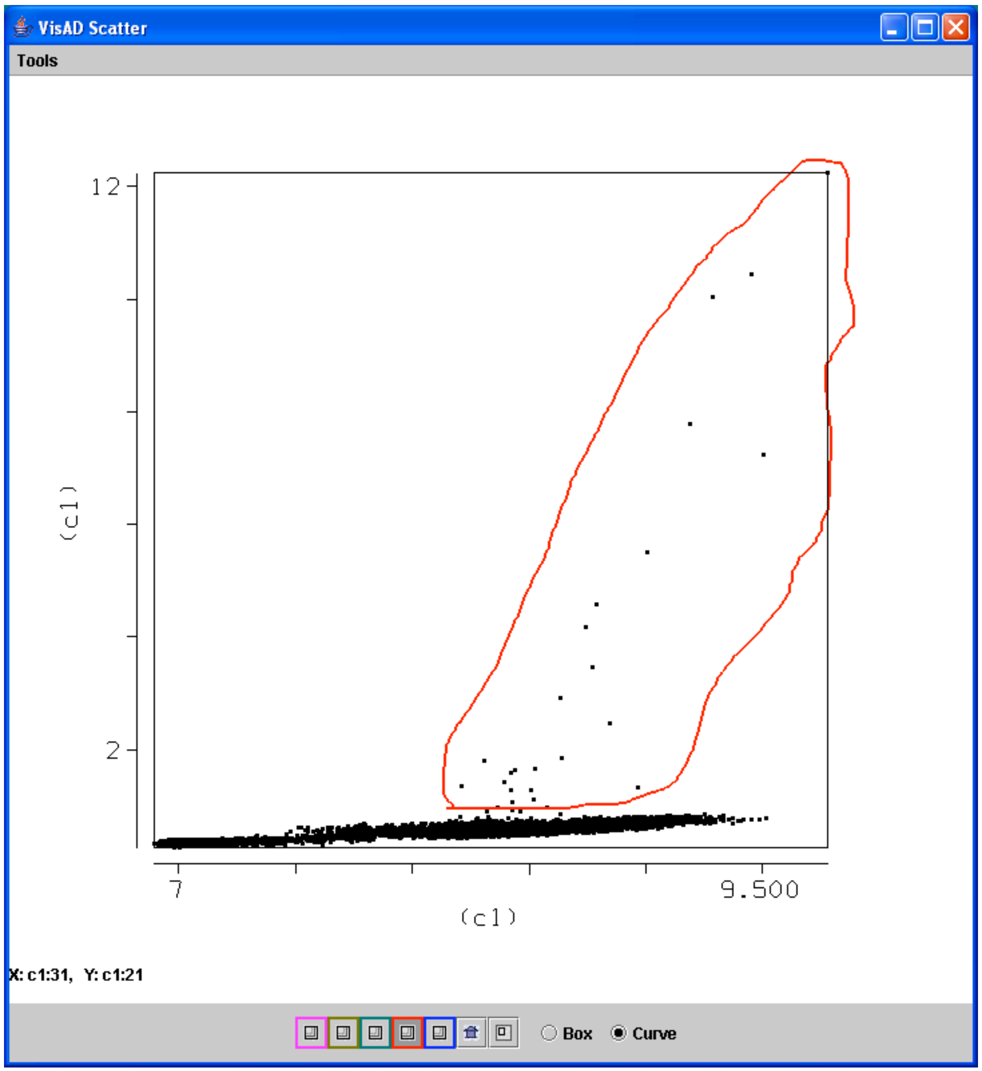


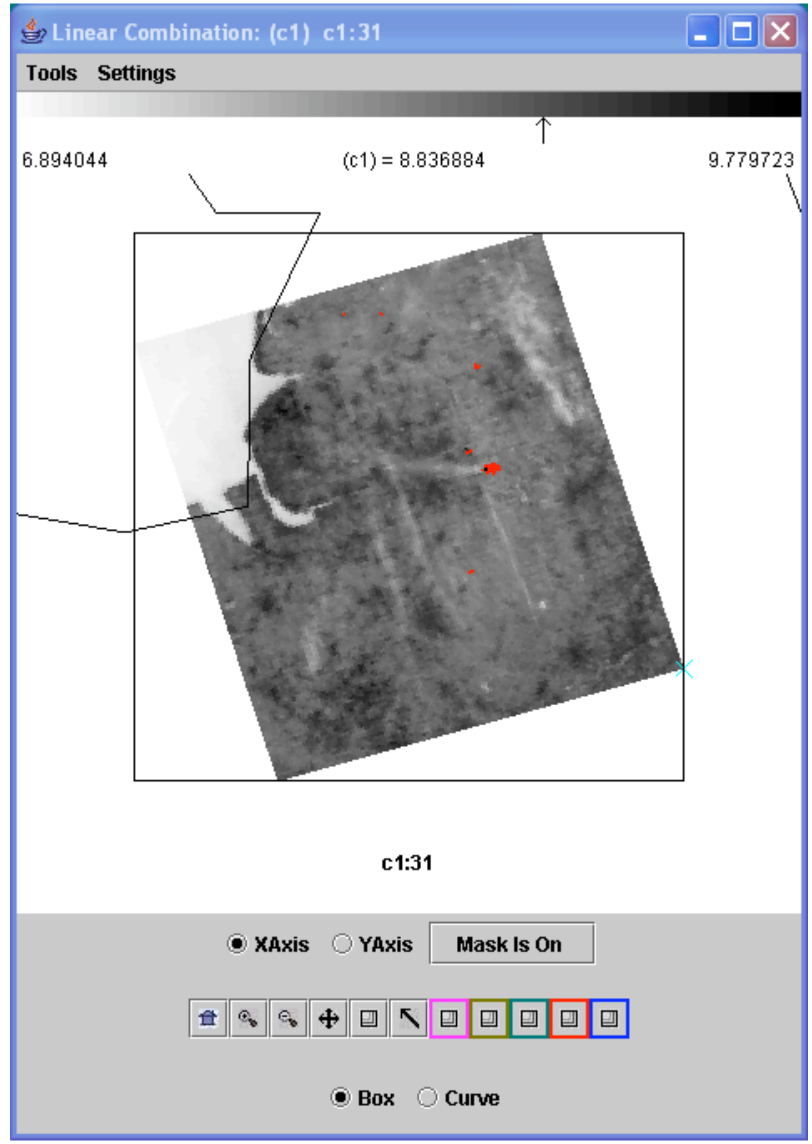
Band 21 – Band 31 Example





Example of Relationship between Planck Radiance of 4 and 11 microns





Algorithm Description (cont.)

- Potential Fire Pixel identified
  - BT4 > 310 K (~37 C)
  - BT4-11 > 10 K
  - .86 micron reflectance < .3
- Otherwise flagged as non-fire pixel

Screening Potential Fire Pixels

(1) BT4 > 360 K (~87 C)

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) $\partial'_4 > 5K$

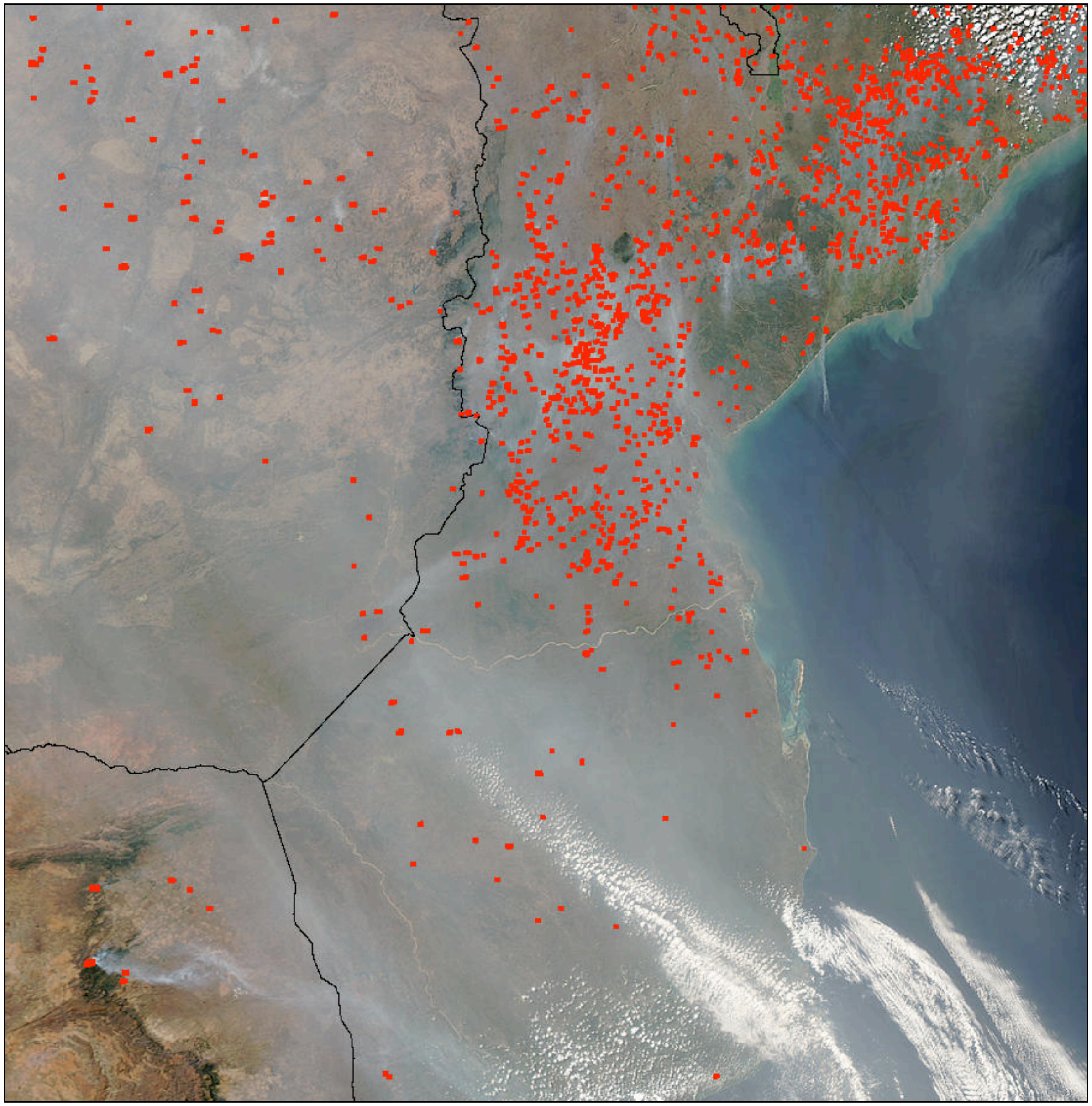
Where δ is the Mean Absolute Difference (MAD):

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

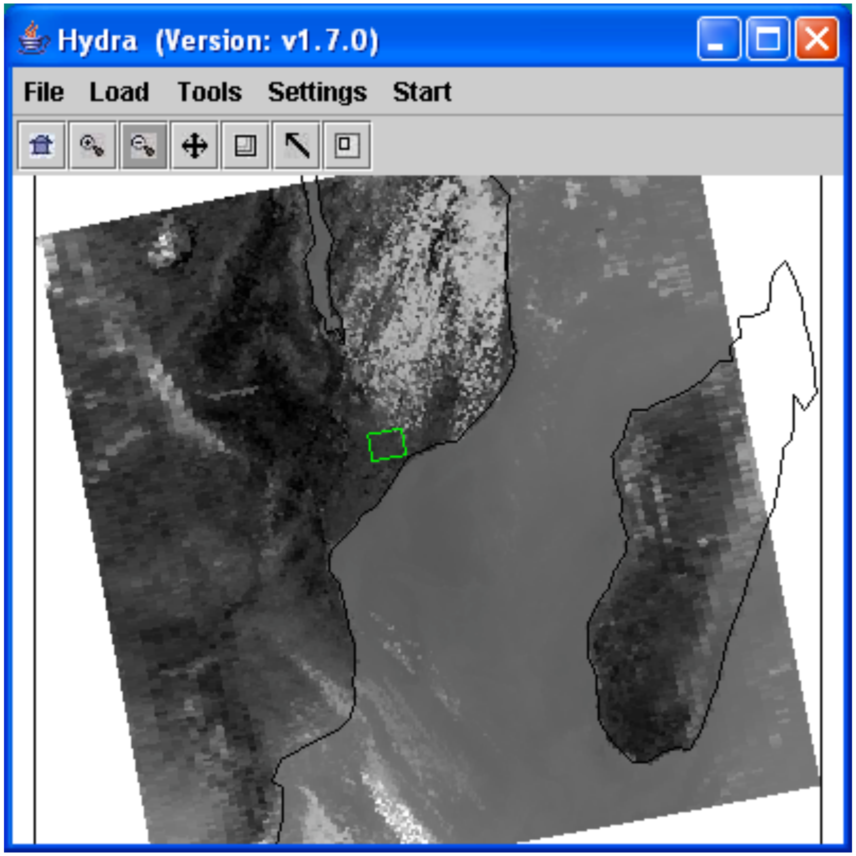
Problem Areas

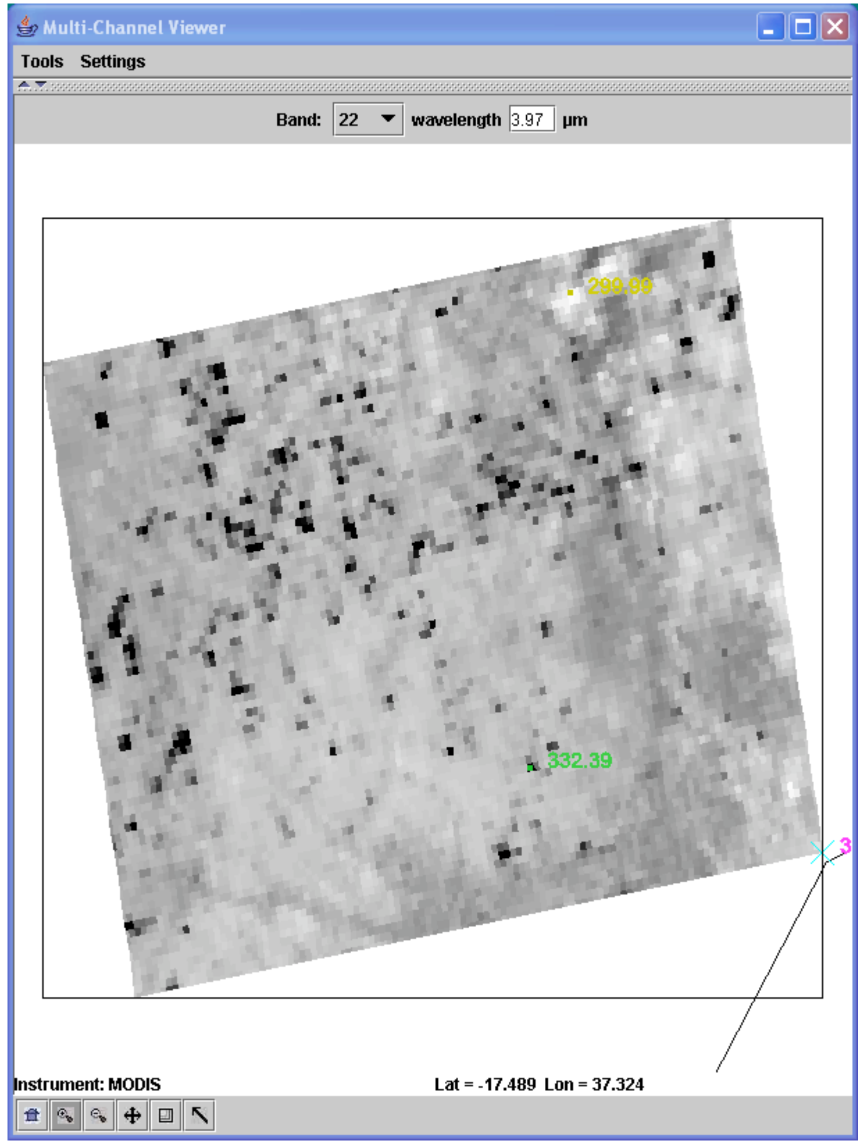
- If there are many fires – hard to get representative background temperature in max 21x21 pixel region
- Sunglint – Affects 4 micron band radiance
- Transition areas – contextual tests pick up boundaries
- Coastal areas – need really good geolocation so no mixed pixels are included
- Clouds – BT4-11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





REFERENCES

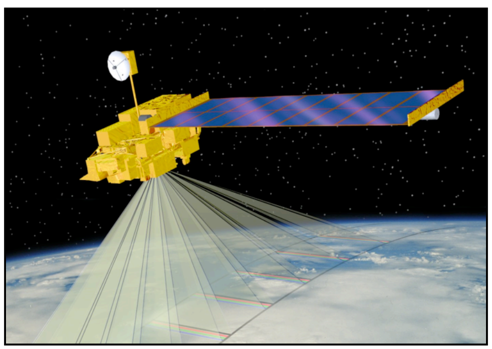
Csiszar, I., J. Morisette and L. Giglio, 2006: Validation of active fire detection from moderate resolution satellite sensors: the MODIS example in Northern Eurasia. *IEEE Transactions on Geoscience and Remote Sensing* , vol. 44, no. 7, 1757-1764.

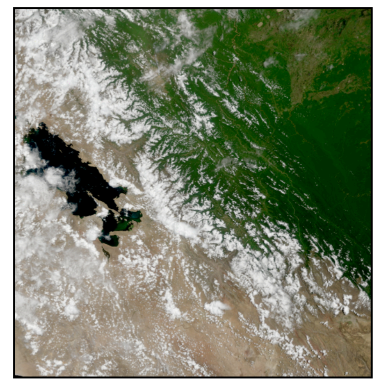
Giglio, L., Descloitres, J., Justice, C. O., and Kaufman, Y., 2003, An enhanced contextual fire detection algorithm for MODIS. *Remote Sensing of Environment*, 87:273-282.

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.

MODIS Ocean Products

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





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

MODIS Ocean Standard Products

Geophysical Parameter Name	Description
nLw_412	Normalized water-leaving radiance at 412 nm
nLw 443	Normalized water-leaving radiance at 443 nm
nLw_488	Normalized water-leaving radiance at 488 nm
nLw_531	Normalized water-leaving radiance at 531 nm
nLw_551	Normalized water-leaving radiance at 551 nm
nLw_667	Normalized water-leaving radiance at 667 nm
Tau_869	Aerosol optical thickness at 869 nm
Eps_78	Epsilon of aerosol correction at 748 and 869 nm
Chlor_a	OC3 Chlorophyll a concentration
K490	Diffuse attenuation coefficient at 490nm
Angstrom_531	Angstrom coefficient, 531-869 nm
SST	Sea Surface Temperature: 11 micron
SST4	Sea Surface Temperature: 4 micron (night only)

MODIS Atmospheric Correction for Ocean Bands

Statement of the problem:

• Total radiance observed by the satellite is composed of 5-10% ocean signal and 90-95% atmosphere signal.

• The atmospheric and ocean surface scattering effects must be accurately modelled and removed.

• Desired parameter is normalized water leaving radiance (nLw) for MODIS bands 8, 9, 10, 11, 12, 13 (0.412, 0.443, 0.488, 0.531, 0.551, 0.667 microns)

Aerosol model selection:

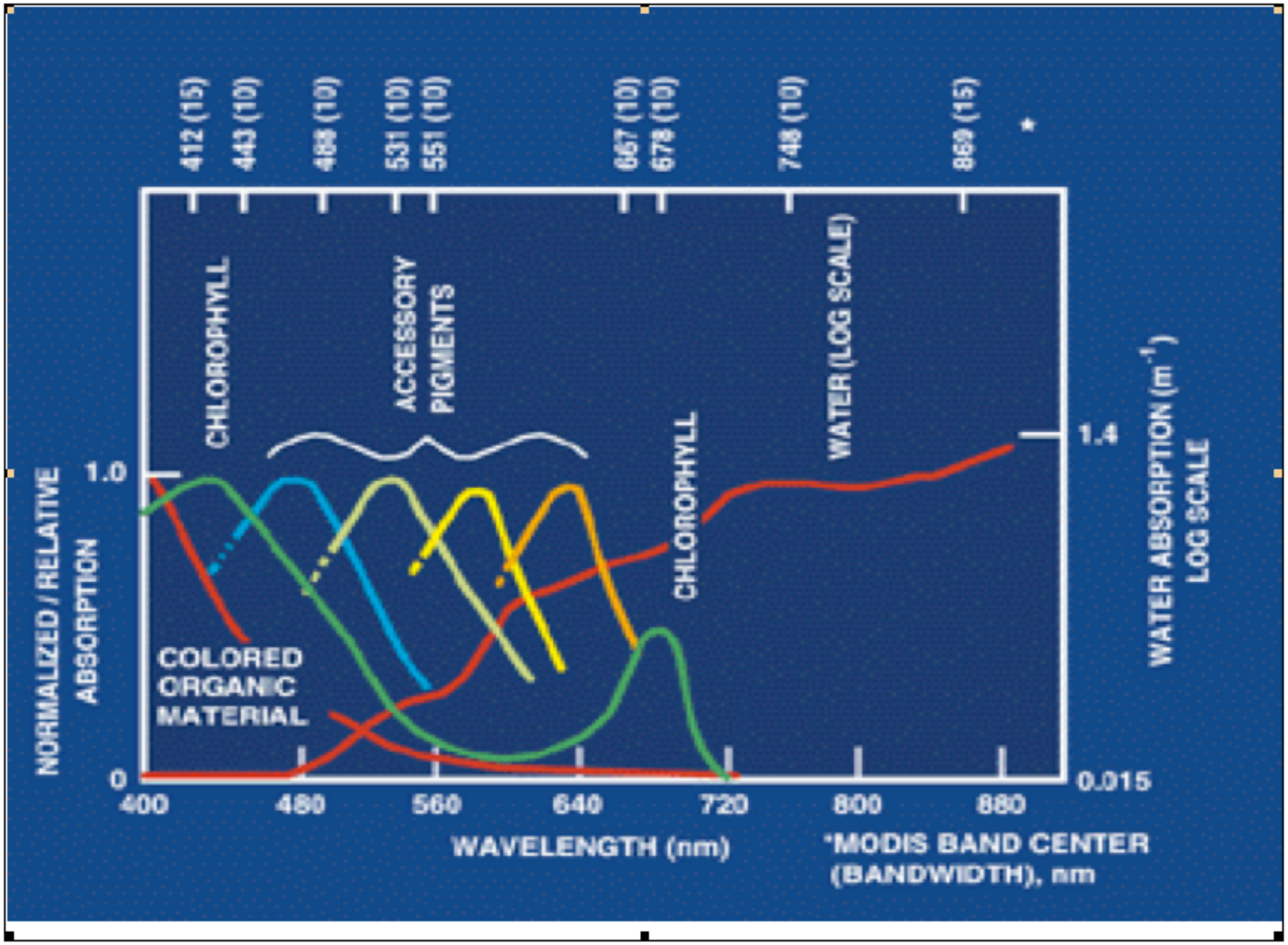
• Assume zero (or negligible) water leaving radiance in the NIR bands (15 and 16; 0.750 and 0.865 microns); remainder is from aerosols.

• This is extrapolated to visible wavelengths using aerosol models.

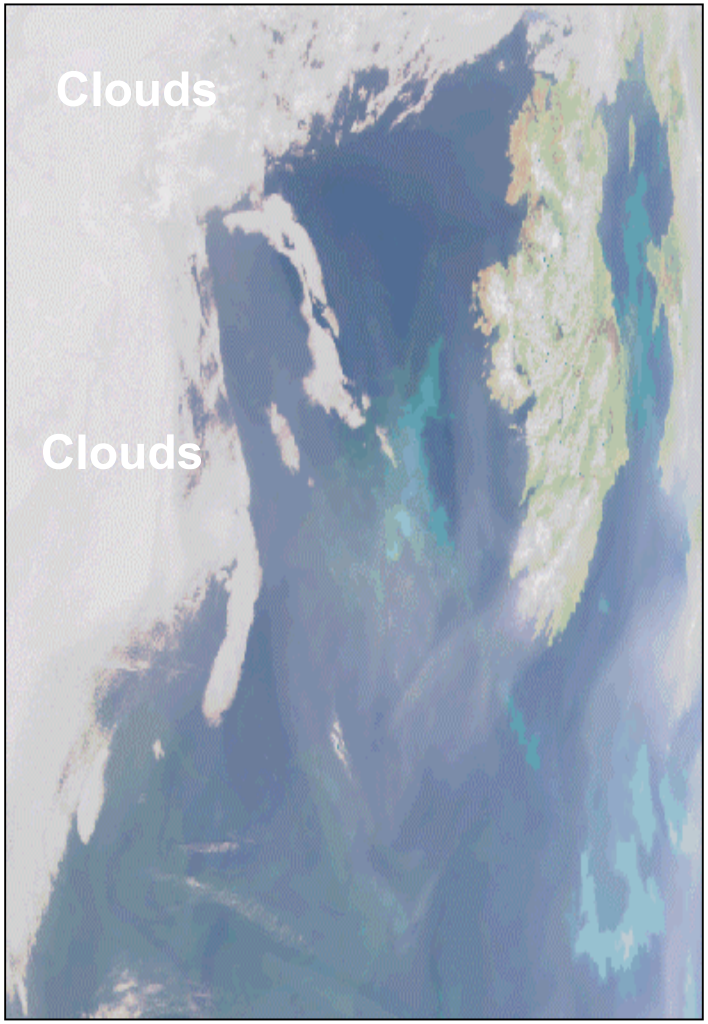
• For case 1 waters, NIR bands are used to select aerosol model.

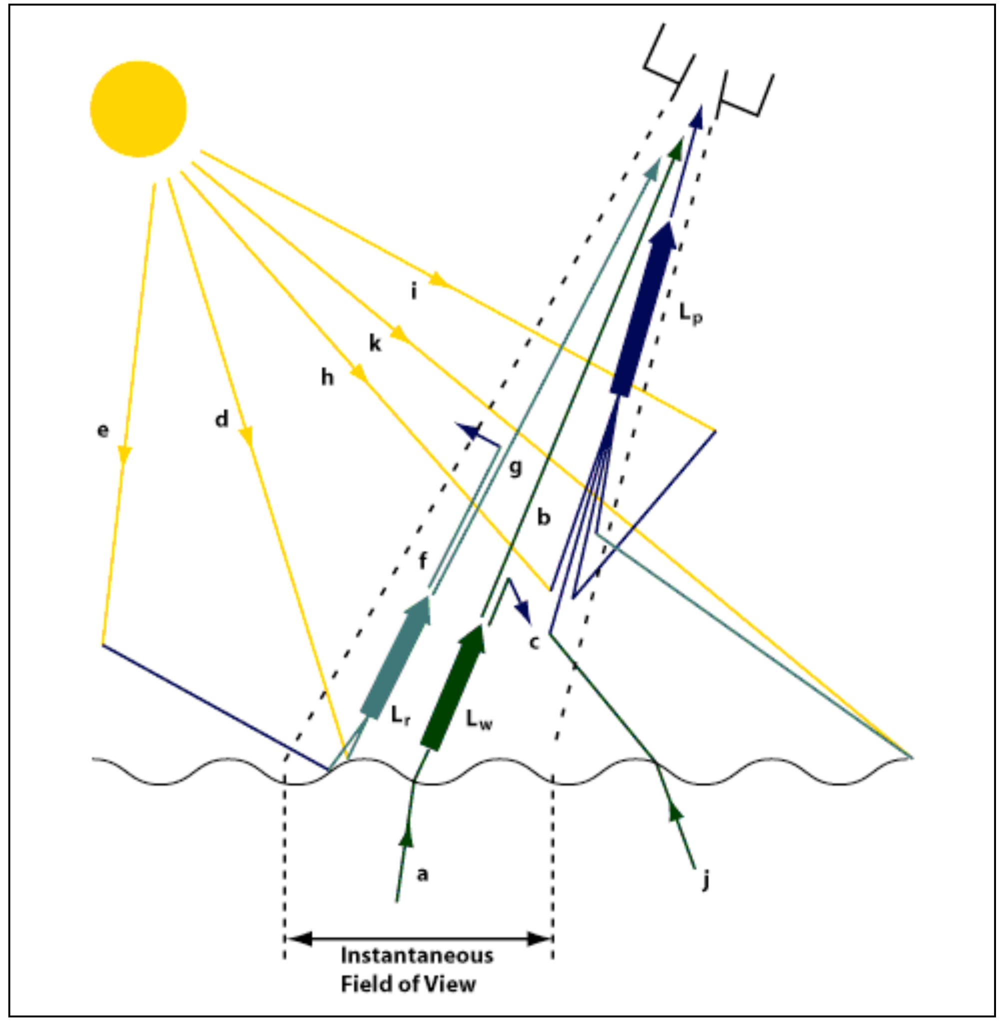
• Where this assumption is not valid, water-leaving radiance in NIR bands is estimated and removed prior to aerosol model selection.

Visible light absorption by water



Atmospheric correction is critical for ocean color retrievals





- L_w is only 5-10% of signal reaching satellite: rest due to L_p
- L_p components: molecular (Rayleigh) & aerosols

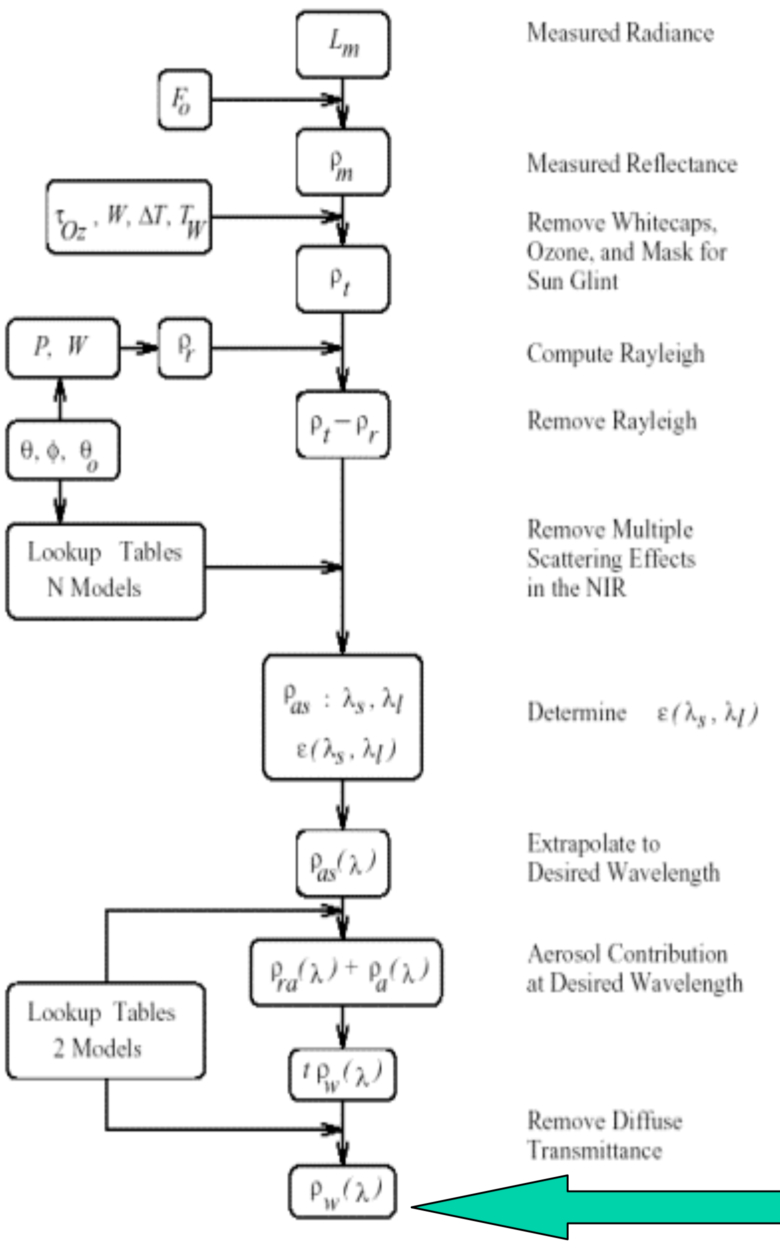


Figure 21. Annotated flow diagram of the algorithm.

Reflectance at water surface

$\rho_t = \rho_r + (\rho_a + \rho_{ra}) + t\rho_{wc} + t\rho_g + t\,\rho_w$

* ρ_w is the quantity we wish to retrieve at each wavelength.

* ρ_g is Sun glint, the direct + diffuse reflectance of the solar radiance from the sea surface. This effect for SeaWiFS is minimized by tilting the sensor. MODIS does not tilt and the sun glint must be removed, depends on vector winds and polarization.

* ρ_{wc} is the contribution due to "white"-capping, estimated from statistical relationship with wind speed.

* ρ_r is the contribution due to molecular (Rayleigh) scattering, which can be accurately modeled. MODIS requires accurate measurement of change in mirror reflectivity with angle of incidence, depends on polarization, winds, atmospheric pressure

* $\rho_a + \rho_{ra}$ is the contribution due to aerosol and Rayleigh-aerosol scattering, estimated in NIR from measured radiances and extrapolated to visible using aerosol models.

* ρ_t is the total reflectance measured at the satellite

MODIS Chlorophyll Algorithm (OC3)

Semi-analytical algorithm(1)

Chl_a = 10**(0.283 - 2.753*R + 1.457*R^2 + 0.659*R^3 - 1.403*R^4)

where:

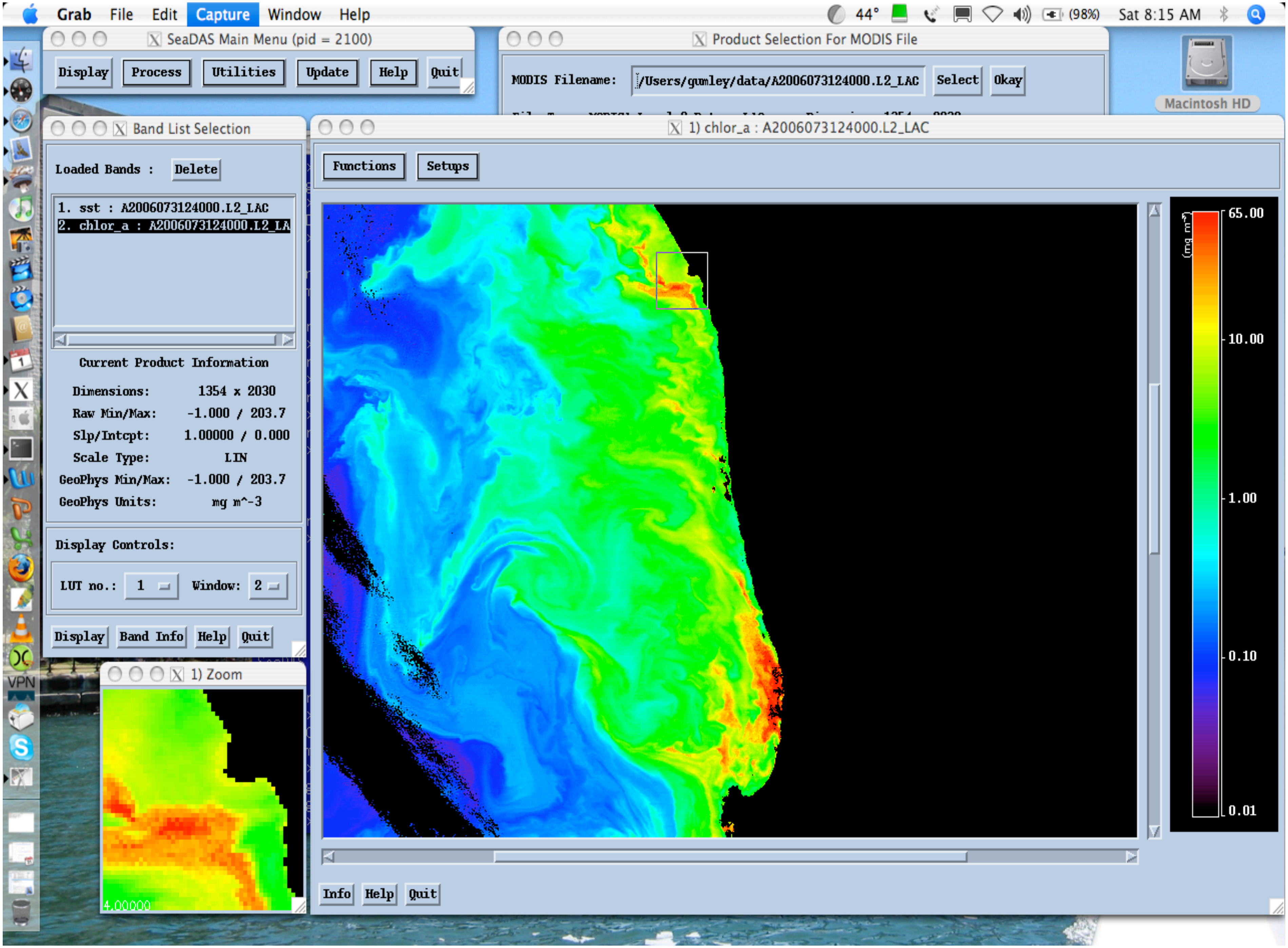
R = log10((Rrs443 > Rrs488) / Rrs551)

Rrs = nLw / F0; remote sensing reflectance

F0 = extraterrestrial solar irradiance

nLw = water leaving radiance at 443, 488, 551

(1) Performance of the MODIS Semi-analytical Ocean Color Algorithm for Chlorophyll-a Carder, K.L.; Chen, F.R.; Cannizzaro, J.P.; Campbell, J.W.; Mitchell, B.G. Advances in Space Research. Vol. 33, no. 7, pp. 1152-1159. 2004



Grab File Edit Capture Window Help
Sat 8:15 AM
SeaDAS Main Menu (pid = 2100)
Display
Process
Utilities
Update
Help
Quit
Product Selection For MODIS File
MODIS Filename:
/Users/gumley/data/A2006073124000.L2_LAC
Select
Okay
Macintosh HD
Band List Selection
Loaded Bands :
Delete
1. sst : A2006073124000.L2_LAC
2. chlor_a : A2006073124000.L2_LA
Current Product Information
Dimensions: 1354 x 2030
Raw Min/Max: -1.000 / 203.7
Slp/Intcpt: 1.00000 / 0.000
Scale Type: LIN
GeoPhys Min/Max: -1.000 / 203.7
GeoPhys Units: mg m^-3
Display Controls:
LUT no.: 1
Window: 2
Display
Band Info
Help
Quit
1) Zoom
4.00000
1) chlor_a : A2006073124000.L2_LAC
Functions
Setups
(mg m⁻³)
65.00
10.00
1.00
0.10
0.01
Info
Help
Quit

First Order Estimation of SST

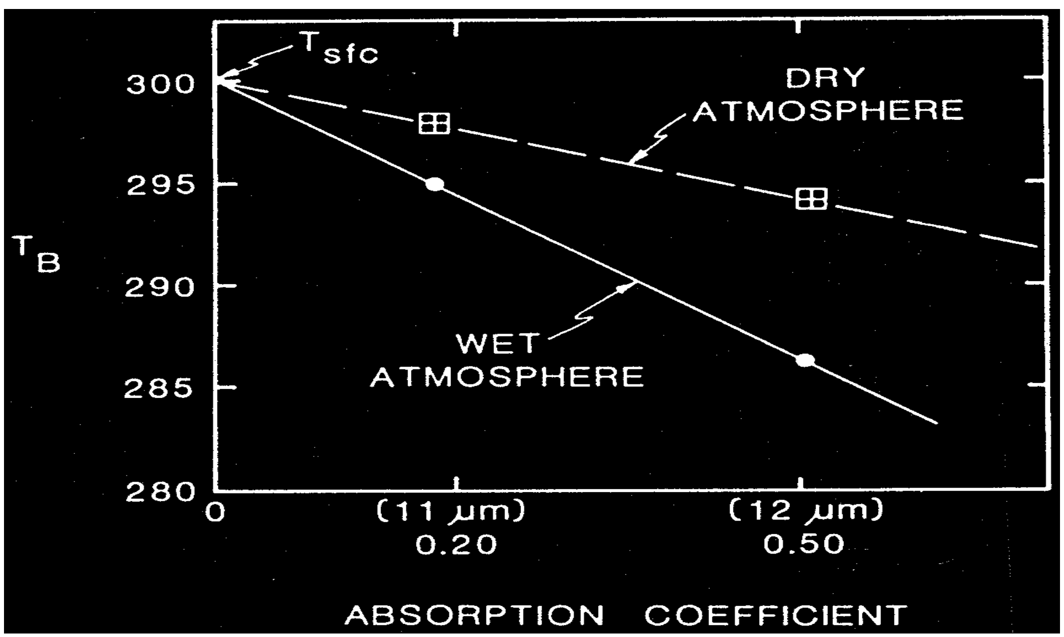
Moisture attenuation in atmospheric windows varies linearly with optical depth.

$$\tau_\lambda = e^{-k_\lambda u} = 1 - k_\lambda u$$

For same atmosphere, deviation of brightness temperature from surface temperature is a linear function of absorbing power. Thus moisture corrected SST can inferred by using split window measurements and extrapolating to zero k_λ

$$T_s = T_{bw1} + [\, k_{w1} / (k_{w2} - k_{w1}) \,] \, [T_{bw1} - T_{bw2}] \; .$$

Moisture content of atmosphere inferred from slope of linear relation.



MODIS Longwave Infrared Sea Surface Temperature (c5)

$$dBT <= 0.5$$

$$sst = a00 + a01*BT11 + a02*dBT*bsst + a03*dBT*(1.0/mu - 1.0)$$

$$dBT >= 0.9$$

$$sst = a10 + a11*BT11 + a12*dBT*bsst + a13*dBT*(1.0/mu - 1.0)$$

$$0.5 < dBt < 0.9$$

$$sstlo = a00 + a01*BT11 + a02*dBT*bsst + a03*dBT*(1.0/mu - 1.0)$$

$$ssthi = a10 + a11*BT11 + a12*dBT*bsst + a13*dBT*(1.0/mu - 1.0)$$

$$sst = sstlo + (dBT - 0.5)/(0.9 - 0.5)*(ssthi - sstlo)$$

where:

$dBT = BT11 - BT12$

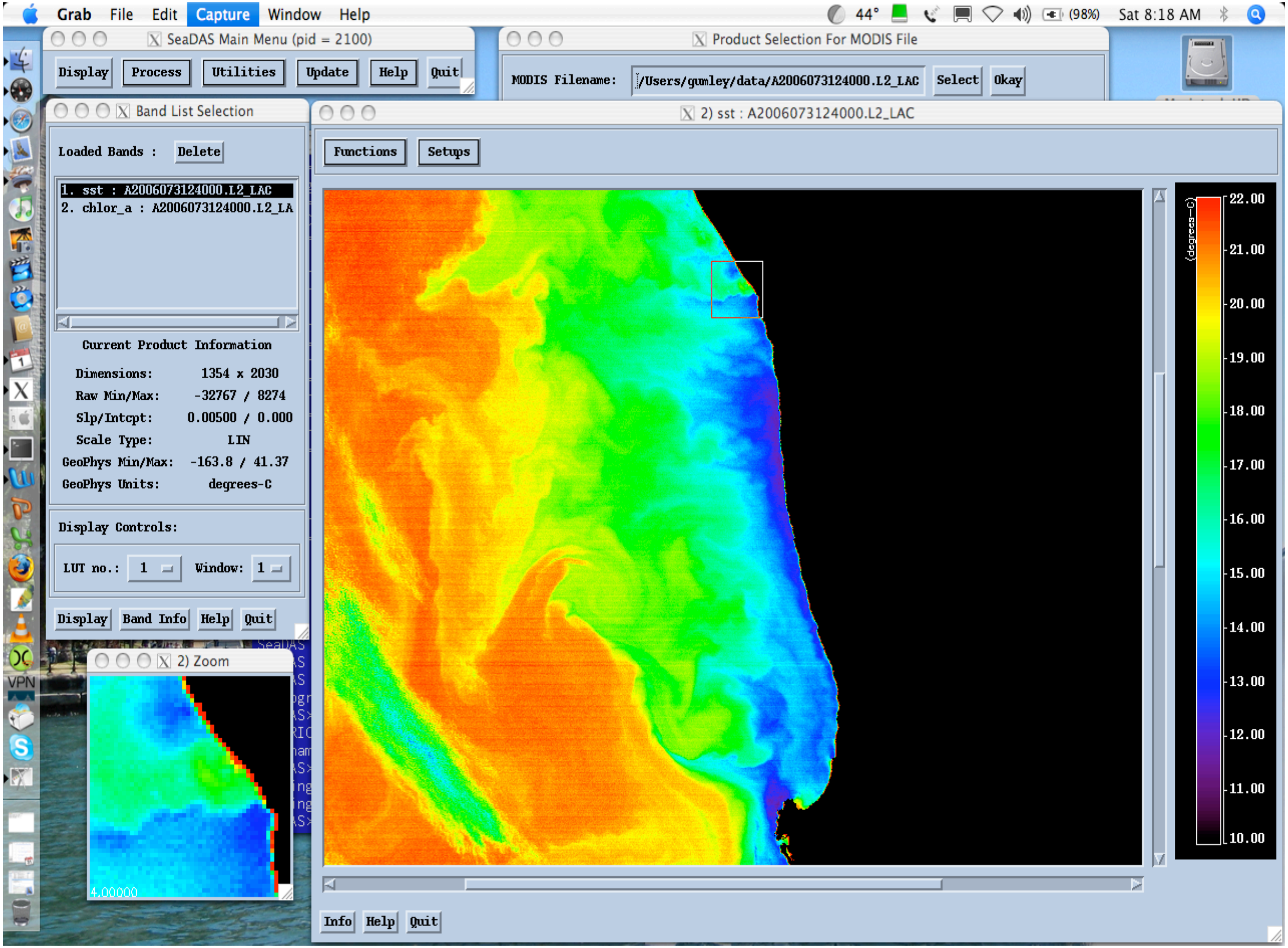
BT11 = brightness temperature at 11 um, in deg-C

BT12 = brightness temperature at 12 um, in deg-C

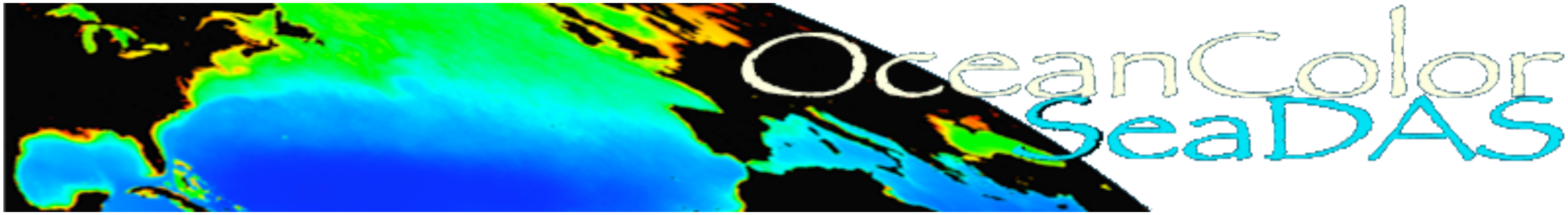
bsst = Either sst4 (if valid) or sstref (from Reynolds OISST)

mu = cosine of sensor zenith angle

a00, a01, a02, a03, a10, a11, a12, a13 derived from match-ups

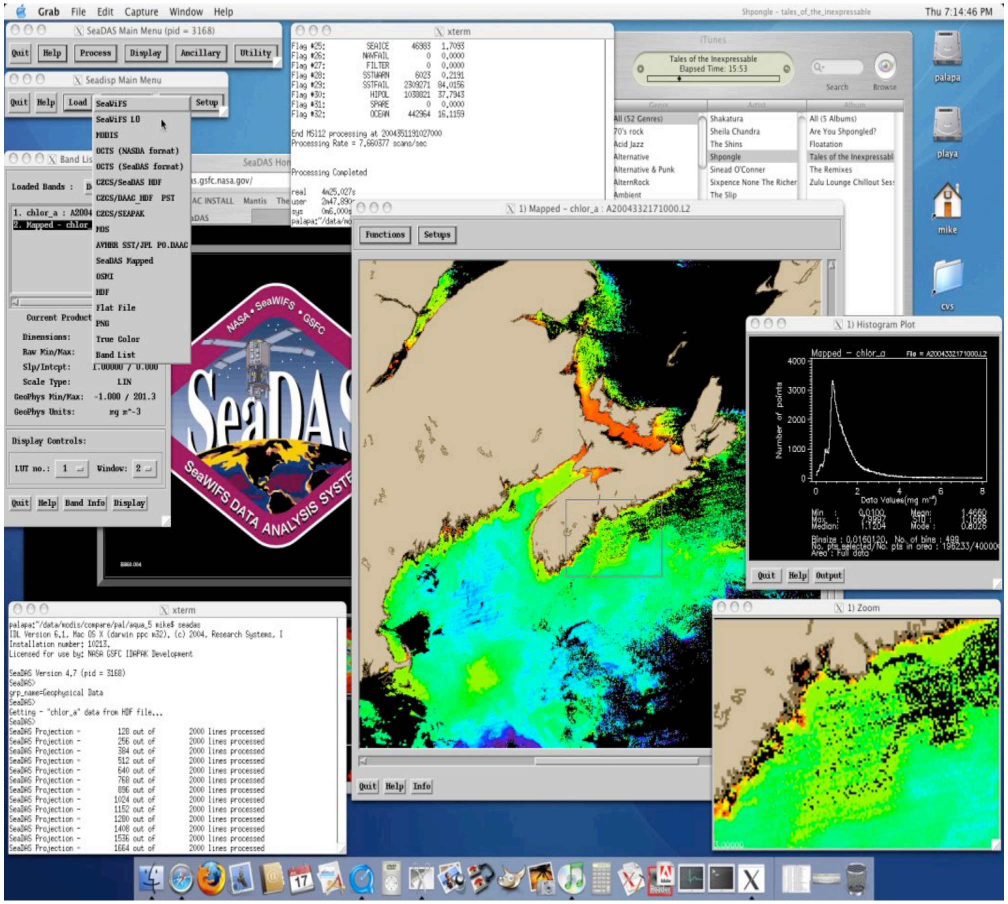


Grab File Edit Capture Window Help
Sat 8:18 AM
SeaDAS Main Menu (pid = 2100)
Display Process Utilities Update Help Quit
Product Selection For MODIS File
MODIS Filename: /Users/gumley/data/A2006073124000.L2_LAC
Select Okay
Band List Selection
Loaded Bands : Delete
1. sst : A2006073124000.L2_LAC
2. chlor_a : A2006073124000.L2_LA
Current Product Information
Dimensions: 1354 x 2030
Raw Min/Max: -32767 / 8274
Slp/Intcpt: 0.00500 / 0.000
Scale Type: LIN
GeoPhys Min/Max: -163.8 / 41.37
GeoPhys Units: degrees-C
Display Controls:
LUT no.: 1 Window: 1
Display Band Info Help Quit
2) Zoom
2) sst : A2006073124000.L2_LAC
Functions Setups
(degrees-C)
22.00
21.00
20.00
19.00
18.00
17.00
16.00
15.00
14.00
13.00
12.00
11.00
10.00
Info Help Quit



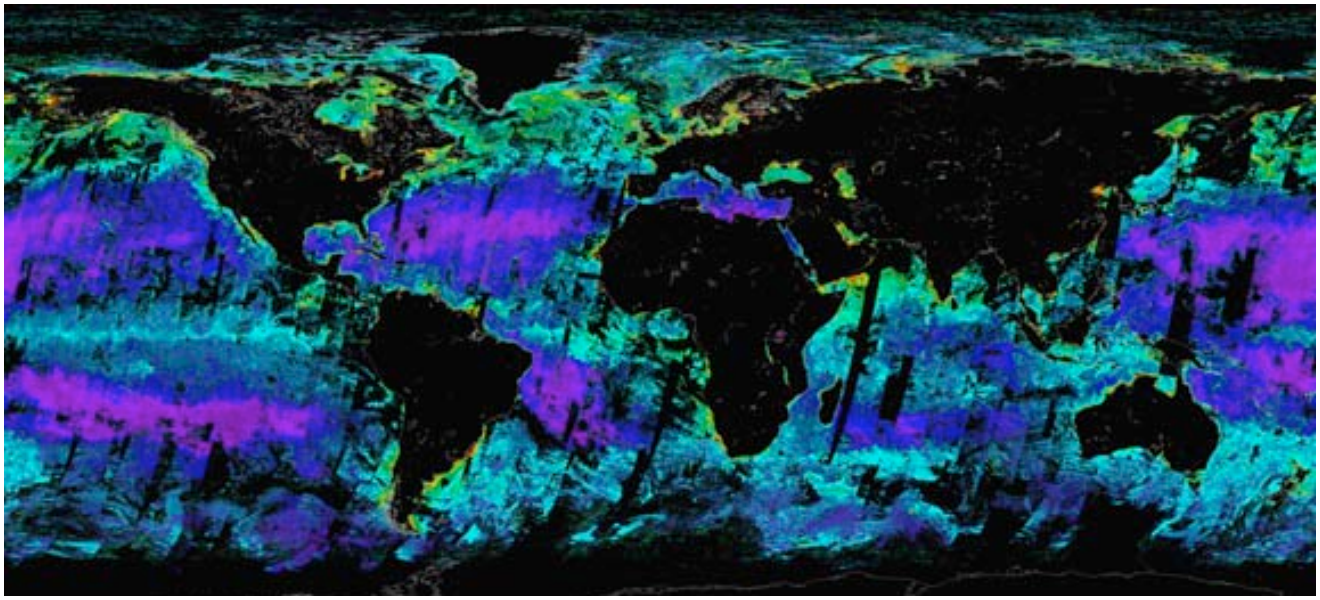
The official NASA MODIS ocean processing algorithms are implemented in the SeaWIFS Data Analysis System (SeaDAS).

SeaDAS is a comprehensive freely available software package for the processing, display, analysis, and quality control of ocean color and SST data.



http://oceancolor.gsfc.nasa.gov/seadas/

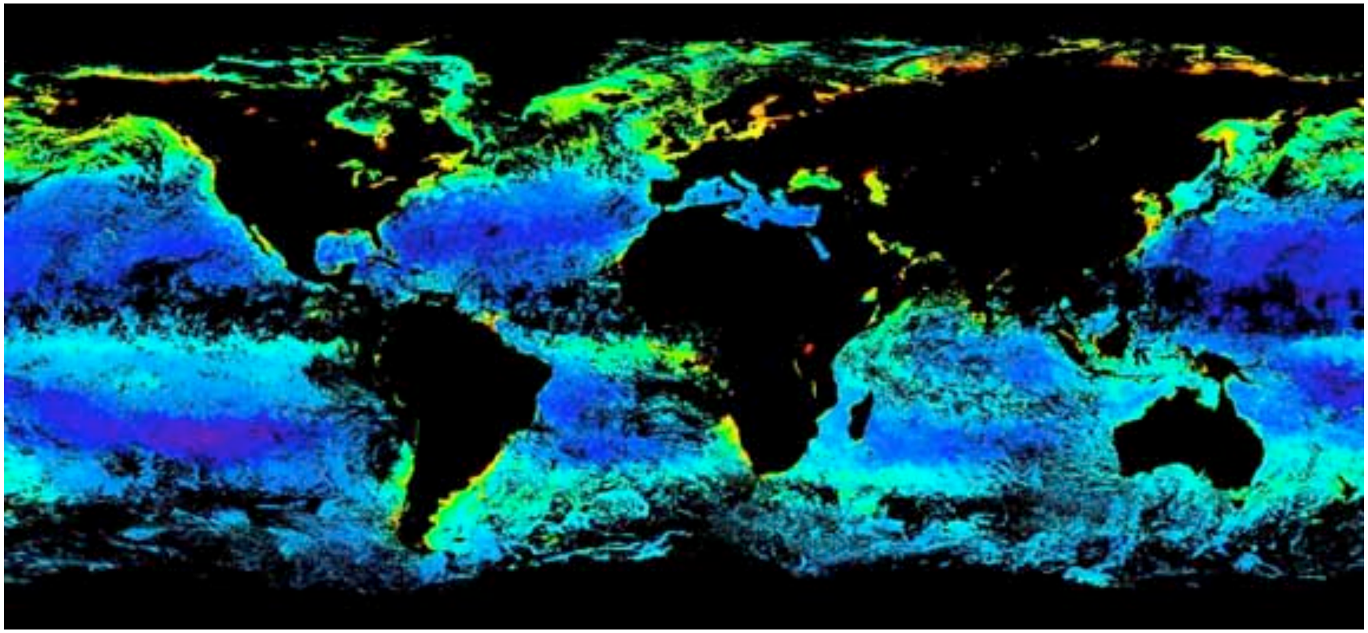
Chlorophyll - MODIS and SeaWiFS

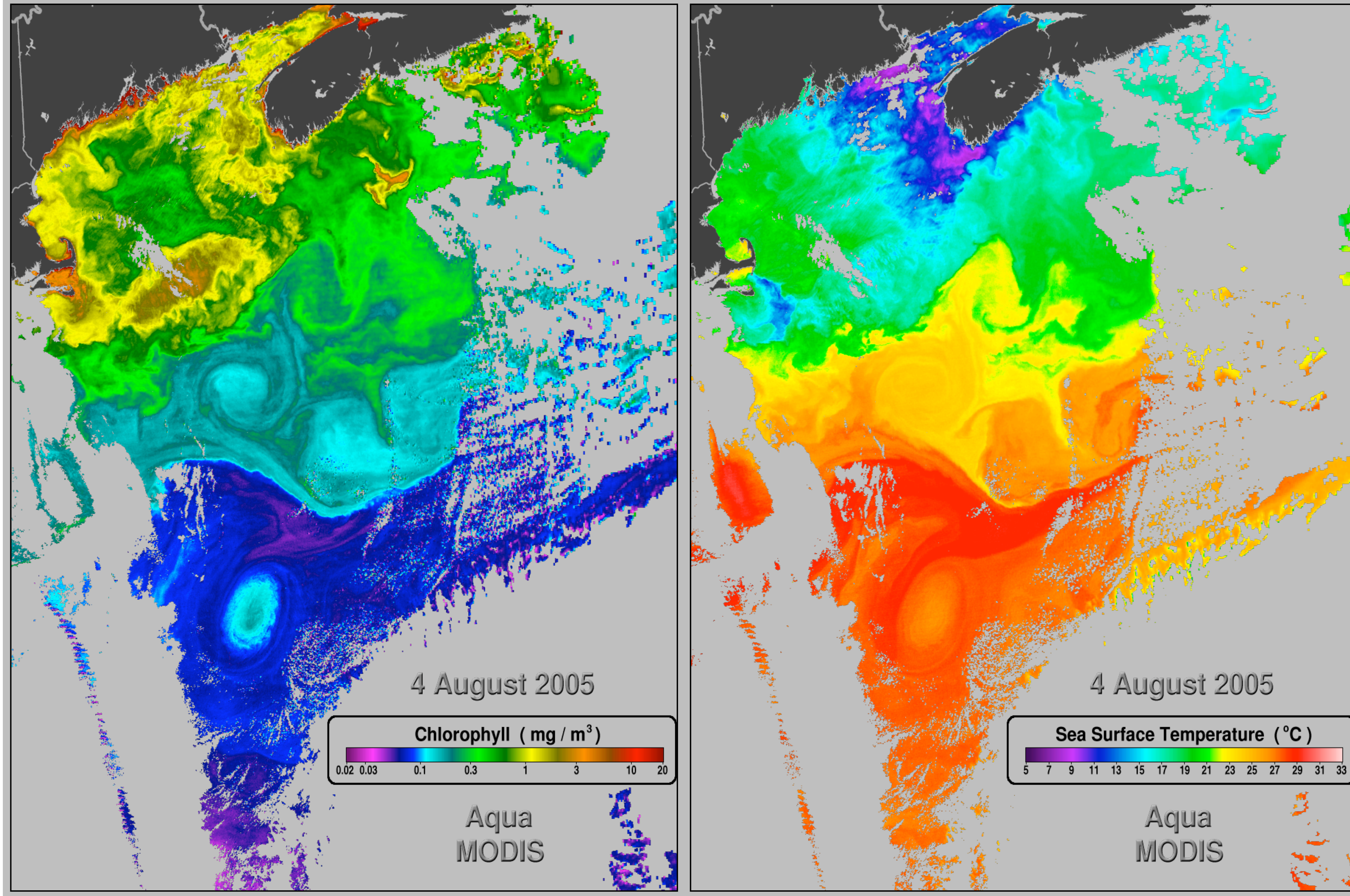


MODIS Chlor
243-250, 2000
U. Miami

MODIS tropics coverage is greater (time of day + no tilt loss). MODIS reveals global fine structure. Color scales not identical, cal not final.

SeaWiFS Chlor
241-248, 2000
SeaWIFS Project




4 August 2005
Chlorophyll (mg / m³)
0.02 0.03 0.1 0.3 1 3 10 20
Aqua
MODIS
4 August 2005
Sea Surface Temperature (°C)
5 7 9 11 13 15 17 19 21 23 25 27 29 31 33
Aqua
MODIS

Applications

- Climate Monitoring - Ocean Temps. Rising?
  - Strength and location of Tropical Cyclones
- Ocean is a Carbon Sink
- Climate Studies - Model input
- Fisheries
- Local forecasting - near-shore temperatures, lake shore fronts, etc.
- Ocean Productivity

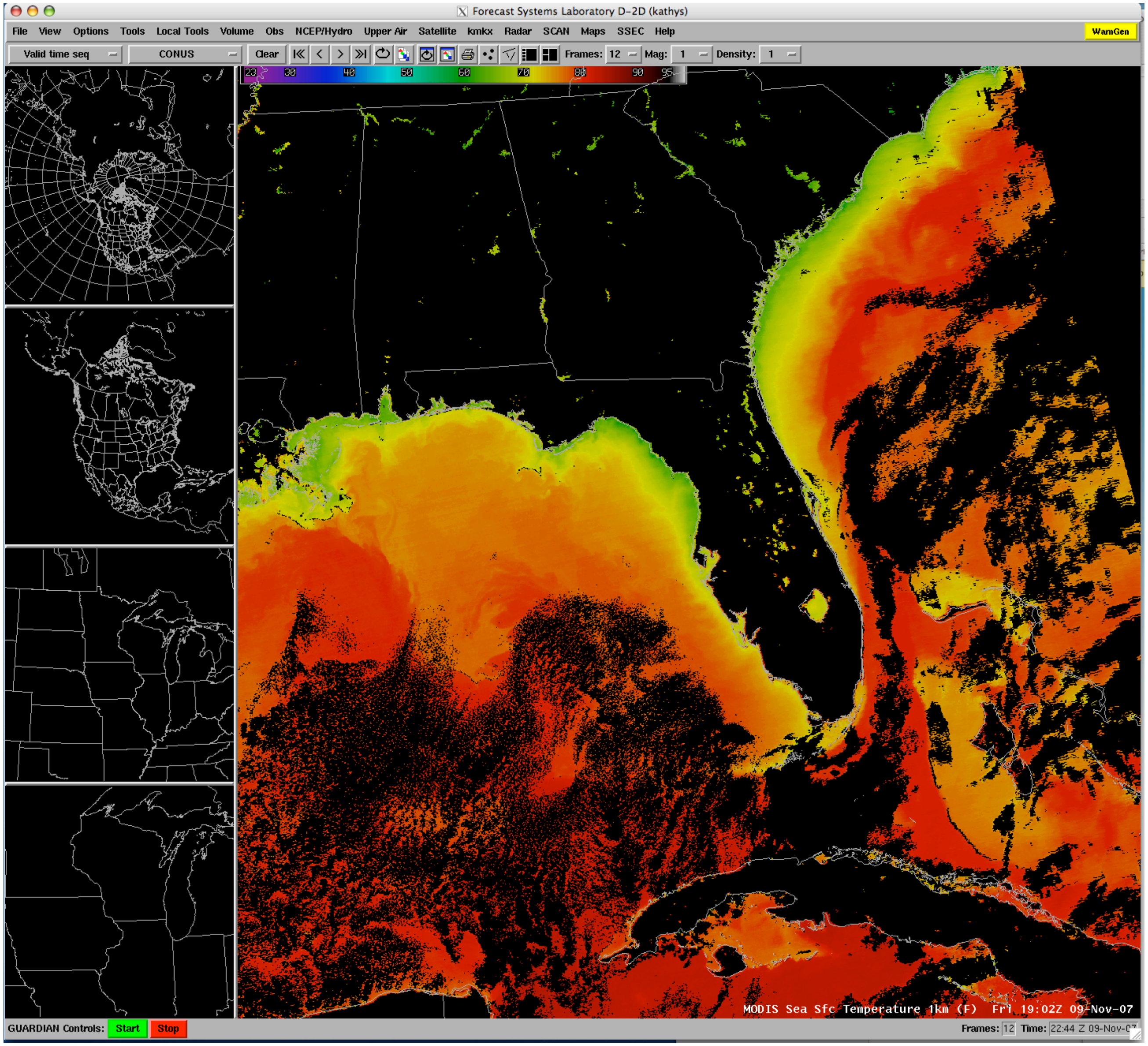
- Recent trends in global ocean chlorophyll

- Gregg, W. W., N. W. Casey, and C. R. McClain

- Geophysical Research Letters 32, 2005:

- A 6-year time series of remotely-sensed global ocean chlorophyll was evaluated using linear regression analysis to assess recent trends. Global ocean chlorophyll has increased 4.1% ($P < 0.05$). Most of the increase has occurred in coastal regions, defined as bottom depth < 200 m, where an increase of 10.4% was observed. The main contributors to the increase were the Patagonian Shelf, Bering Sea, and the eastern Pacific, southwest African, and Somalian coasts. Although the global open ocean exhibited no significant change, 4 of the 5 mid-ocean gyres (Atlantic and Pacific) showed declines in chlorophyll over the 6 years. In all but the North Atlantic gyre, these were associated with significant increases in sea surface temperature in at least one season. **These results suggest that changes are occurring in the biology of the global oceans.** Geophys. Res. Lett. 32: () 10.1029/2004GL021808 2005

MODIS Sea Surface Temperature viewed in AWIPS



MODIS Sea Surface Temperature used by Forecasters

FXUS63 KMKX 142114
AFDMKX

AREA FORECAST DISCUSSION
NATIONAL WEATHER SERVICE MILWAUKEE/SULLIVAN WI
313 PM CST WED NOV 14 2007

FORECAST FOCUS ON GUSTY WEST WINDS SPREADING COLDER AIR OVER SRN WI
TONIGHT. …….

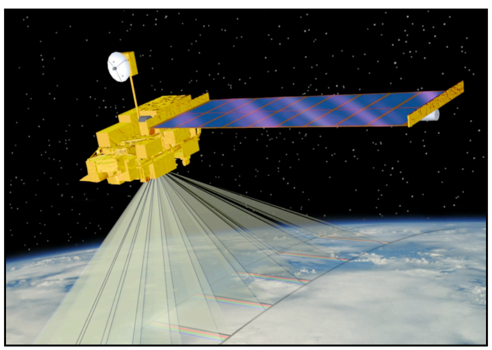
QUIET SUNDAY AS HIGH PRESSURE SETTLES OVER WRN GREAT LAKES…WITH TEMPS A BIT HIGHER THAN MEX GUIDANCE AS SRLY FLOW SETS UP IN THE AFTERNOON OVER THE CWA...AND SE FLOW OFF RELATIVELY WARMER WATERS OF LAKE MICHIGAN (MID 40S TO AROUND 50 PER LATEST MODIS SEA-SFC TEMPERATURE IMAGE) HOLD TEMPS UP IN LAKE SHORE COUNTIES.

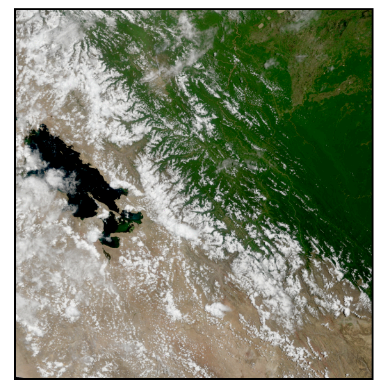
GOES-10/MODIS Fire Detection Comparison

Sensor	Spatial Resolution	Temporal Resolution	Saturation 4 micron	Saturation 11 micron
MODIS	1 km (nadir)	4 times daily	500 K	400 K (A) 340 K (T)
GOES-10 Imager	4 km	Every 15 minutes	321.5 K	K
GOES-10 Sounder	10 km	Every 4 hours	345 K	345 K

MODIS Atmospheric Profiles

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





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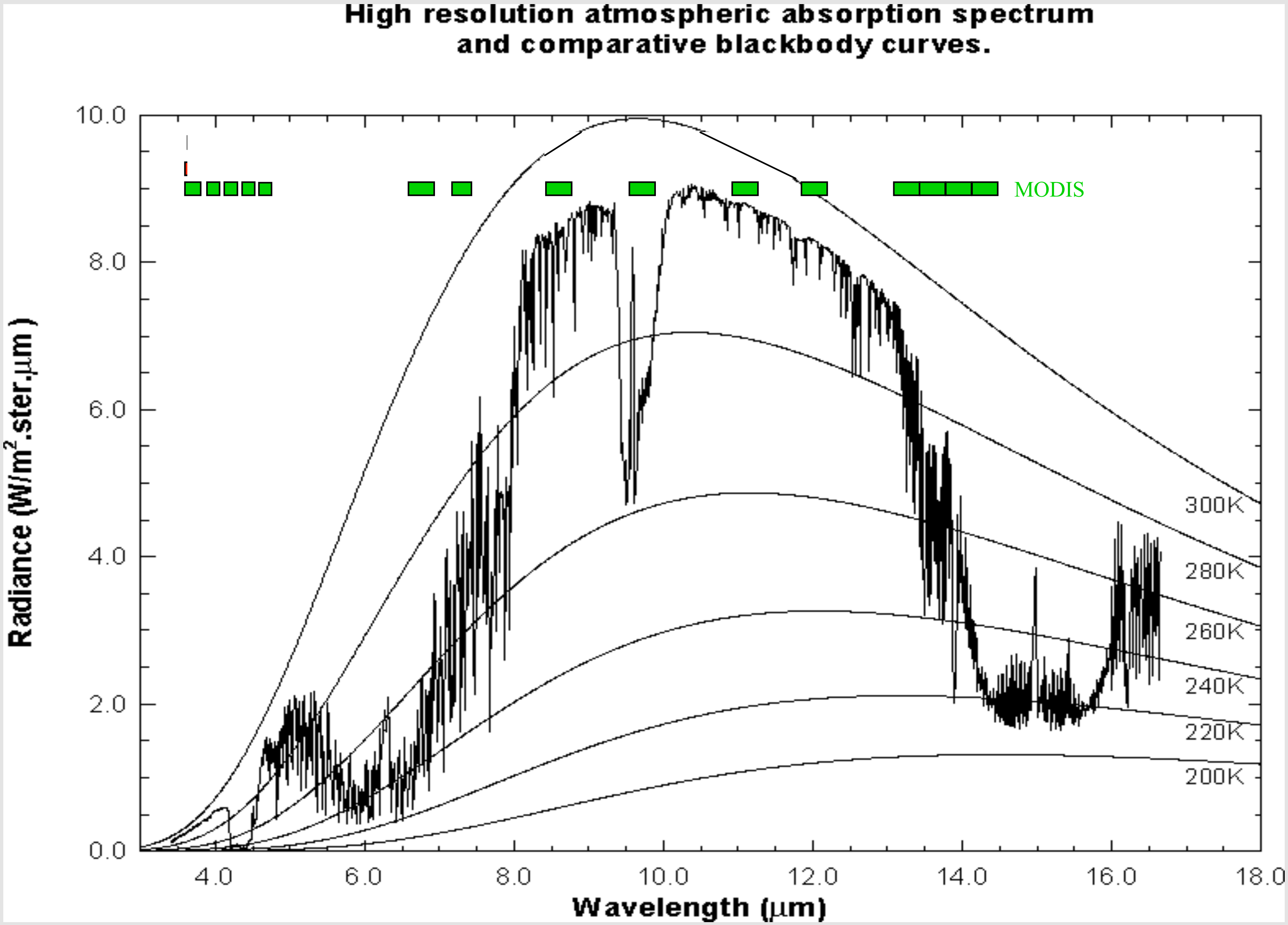
Cooperative Institute for Meteorological Satellite Studies
Space Science and Engineering Center
University of Wisconsin-Madison

MODIS Atmospheric Profiles

Suzanne Wetzel Seemann, Eva Borbas CIMSS

- Retrievals are performed in 5x5 FOV (approximately 5km resolution) clear-sky radiances over land and ocean for both day and night.
- Algorithm is a statistical regression and has the option for a subsequent nonlinear physical retrieval.
- Regression predictors include MODIS infrared radiances from bands 25, 27-36 (4.4 - 14.2mm).
- Clear sky determined by MODIS cloud mask (MOD35).

MODIS IR Spectral Bands



Atmospheric Profile Output

- Atmospheric precipitable water vapor (total, high, and low)
- Profiles of temperature and moisture (20 levels)
- Total column ozone
- Stability indices (lifted index, total totals)
- Surface Skin Temperature

Algorithm Discussion

Clear radiance exiting the atmosphere for a MODIS IR band with wavelength λ:

$$I_\lambda = \varepsilon_\lambda^{sfc} B_\lambda(T_{sfc})\, \tau_\lambda(p_{sfc}) - \int_o^{p_{sfc}} B_\lambda(T(p))\, [\, d\tau_\lambda(p) / dp \,]\; dp \,.$$

I_λ is measured by MODIS for λ = 4.4 - 14.2μm (I_{25}, I_{27}, … I_{36})

I_λ can be considered a nonlinear function of the atmospheric properties including T, q, ozone, surface pressure, skin temperature, and emissivity.

We can infer a statistical regression relationship using calculated radiances from a global set of radiosonde profiles and surface data.

Relationship is inverted to retrieve atmospheric properties from observed MODIS radiances.

Algorithm Discussion

Global radiosondes: data set drawn from NOAA-88, TIGR-3, ozonesondes, ECMWF, desert radiosondes containing 12000+ global radiosonde profiles of temperature, moisture, and ozone used for training data set.

RT model: Radiance calculations for each training profile are made using a 101 pressure layer transmittance model. MODIS instrument noise is added to calculated spectral band radiances.

- Radiosonde temperature-moisture-ozone profile / calculated MODIS radiance pairs are used to create the statistical regression relationship.

Bias corrections are applied to the observed MODIS radiances to account for forward model error, spectral response uncertainty, and calibration error.

Recent improvements to the algorithm:

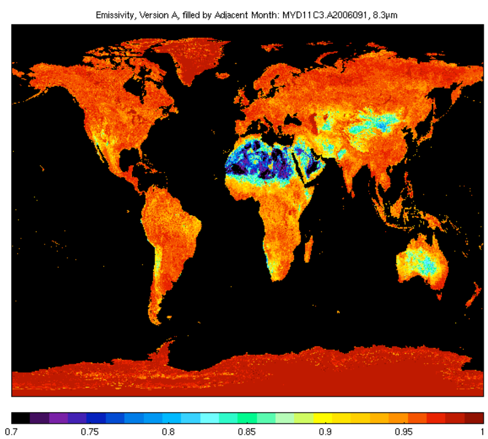
• Global database of infrared (IR) land surface emissivity

• Distributed for use in the retrieval of atmospheric temperature and moisture profiles is introduced.

• Emissivity is derived using input from the MODIS operational land surface emissivity product (called MYD11).

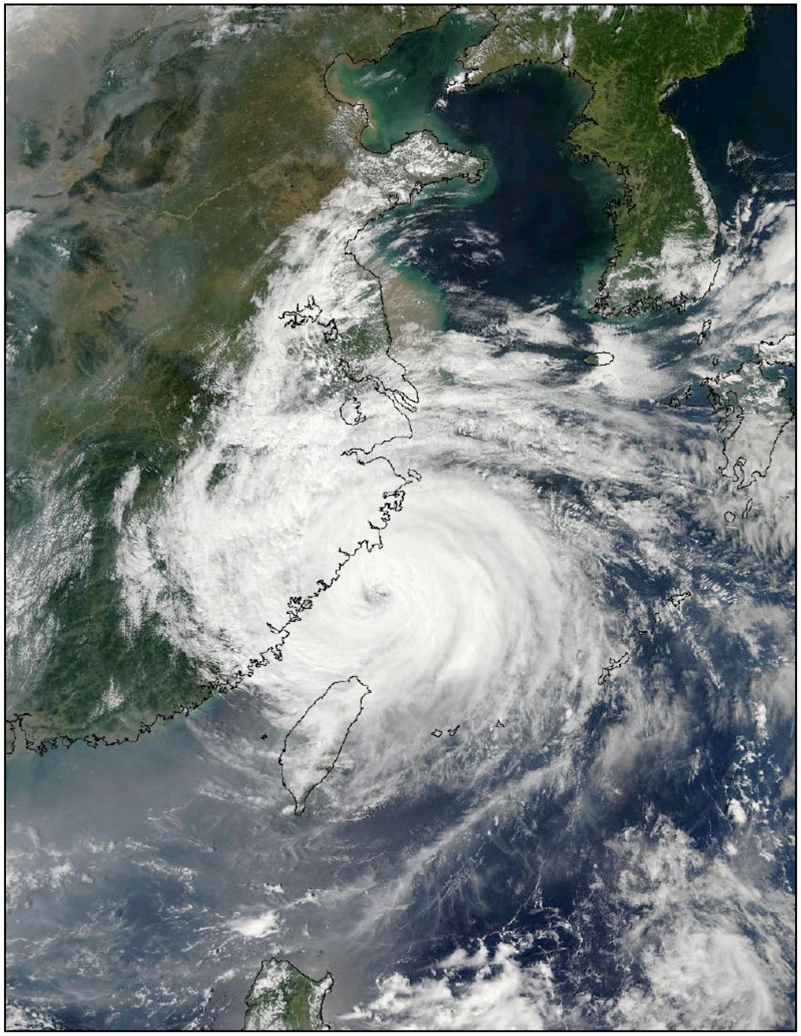
• MODIS MOD07 retrieval algorithm requires a surface emissivity value corresponding to each of the global training profiles

• Improvement is evident over retrievals made with a typical assumption of constant emissivity.



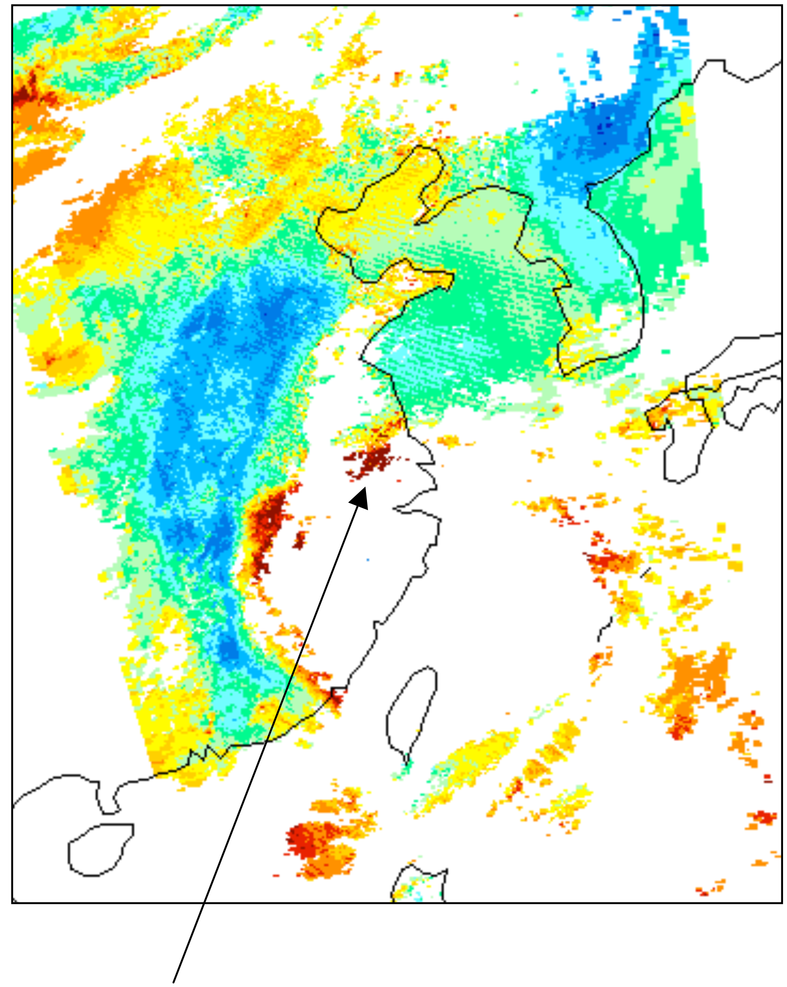
Database available from:
http://cimss.ssec.wisc.edu/iremis/

Typhoon Sinlaku, 7 September 2002
Aqua MODIS

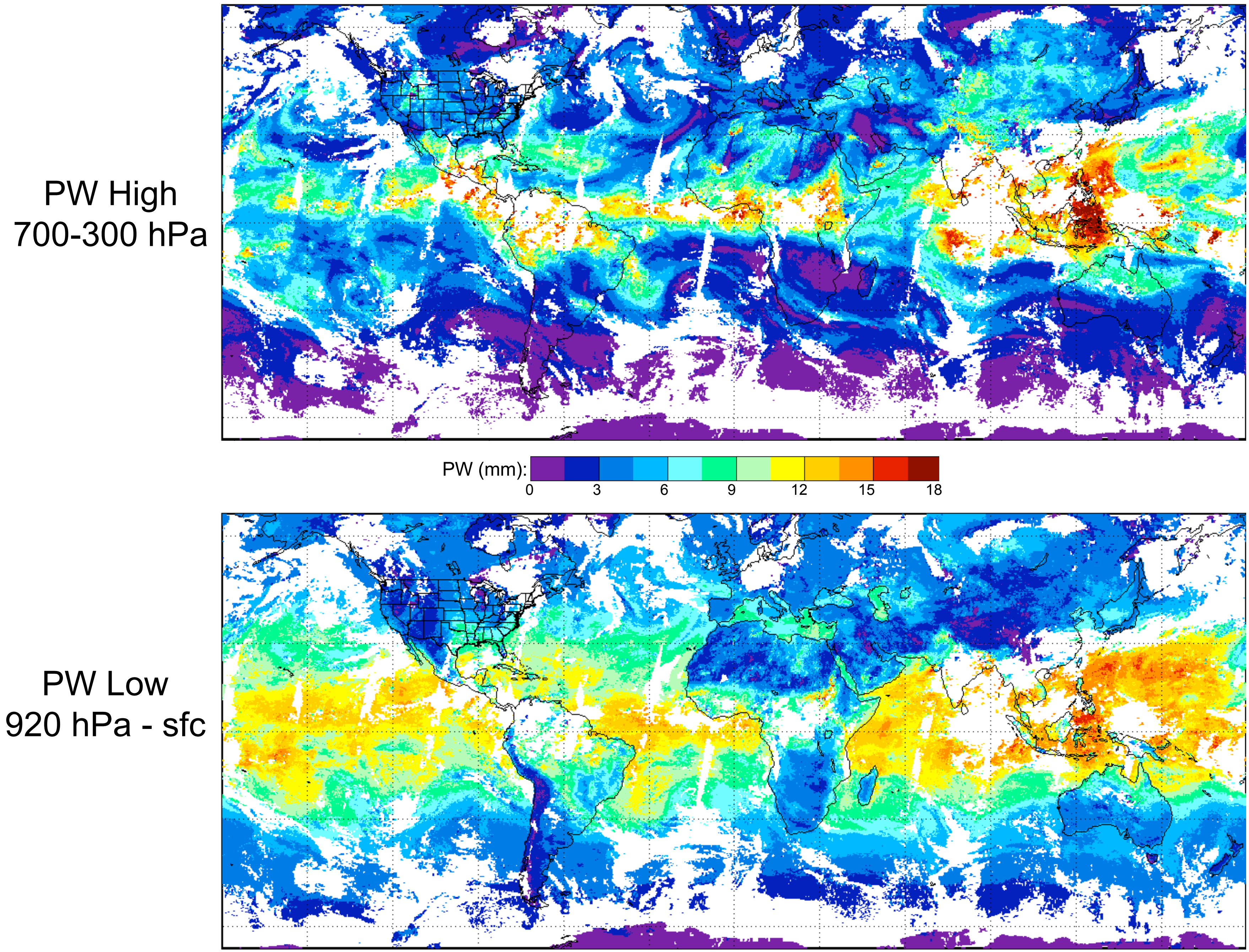


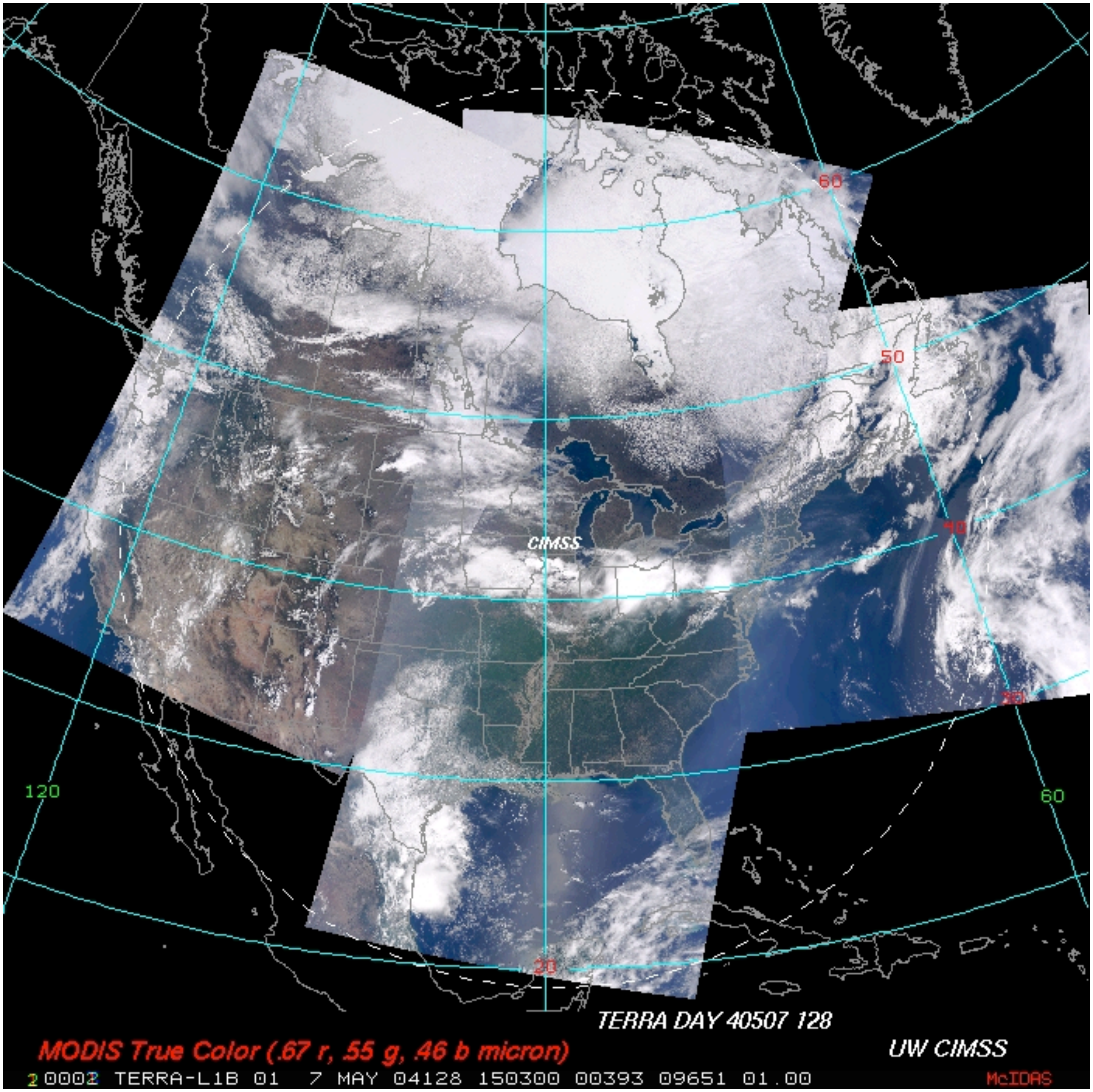
Aqua MODIS true color image

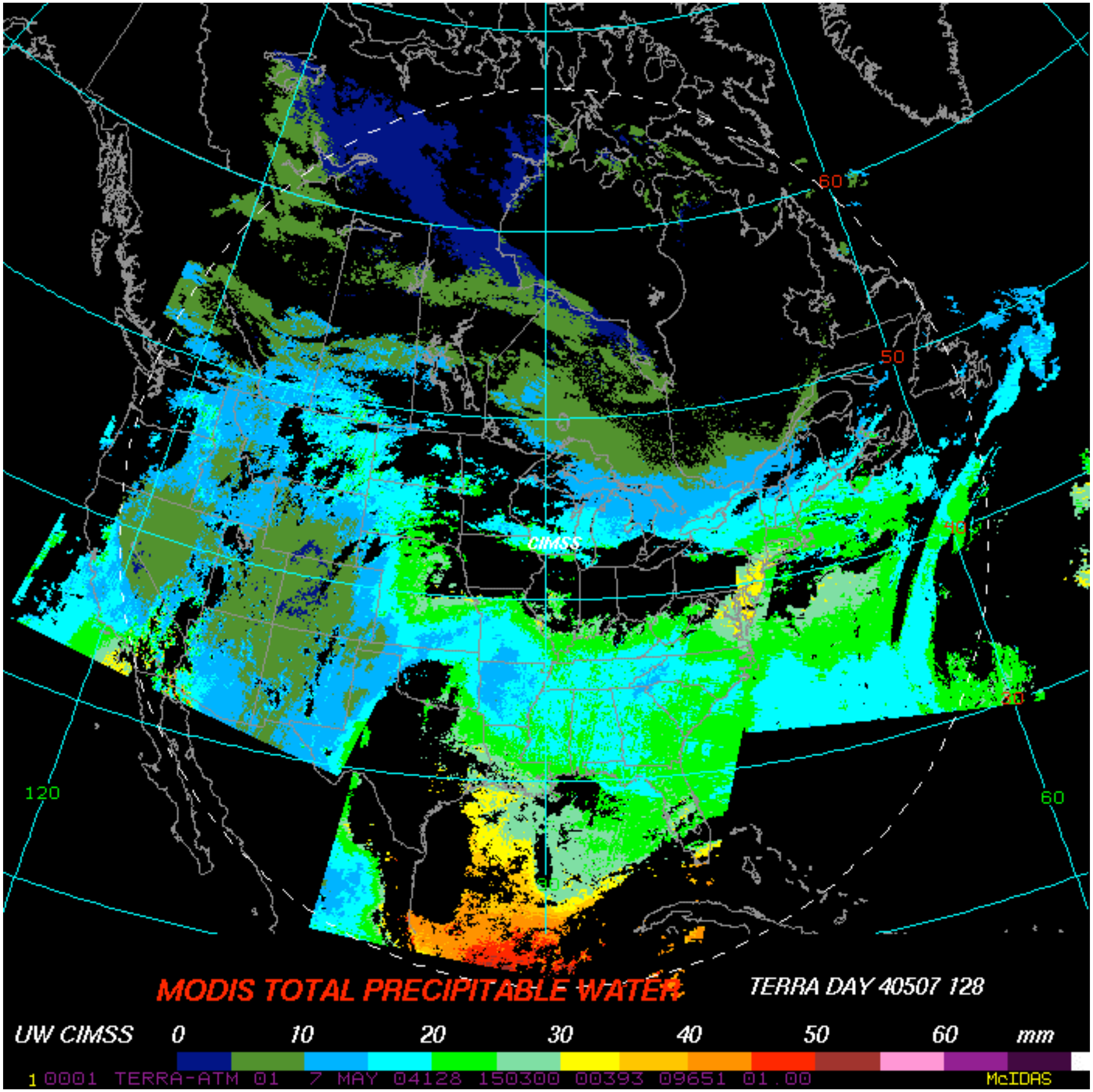
Total Precipitable Water Vapor



TPW = 72.5 mm

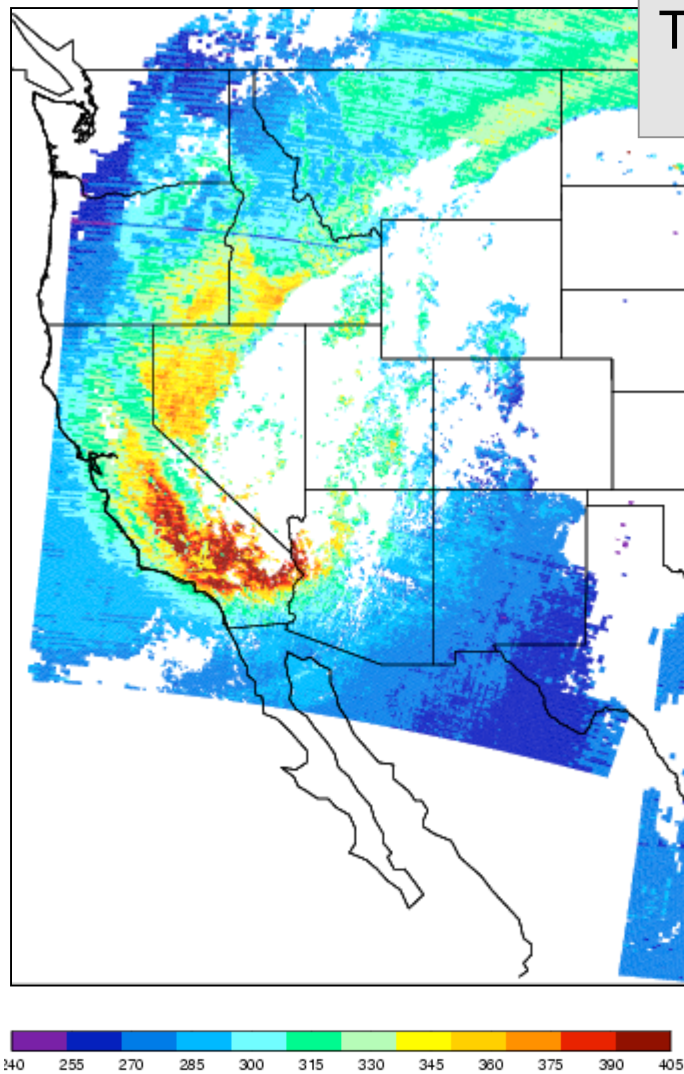

PW High
700-300 hPa
PW (mm):
0
3
6
9
12
15
18
PW Low
920 hPa - sfc

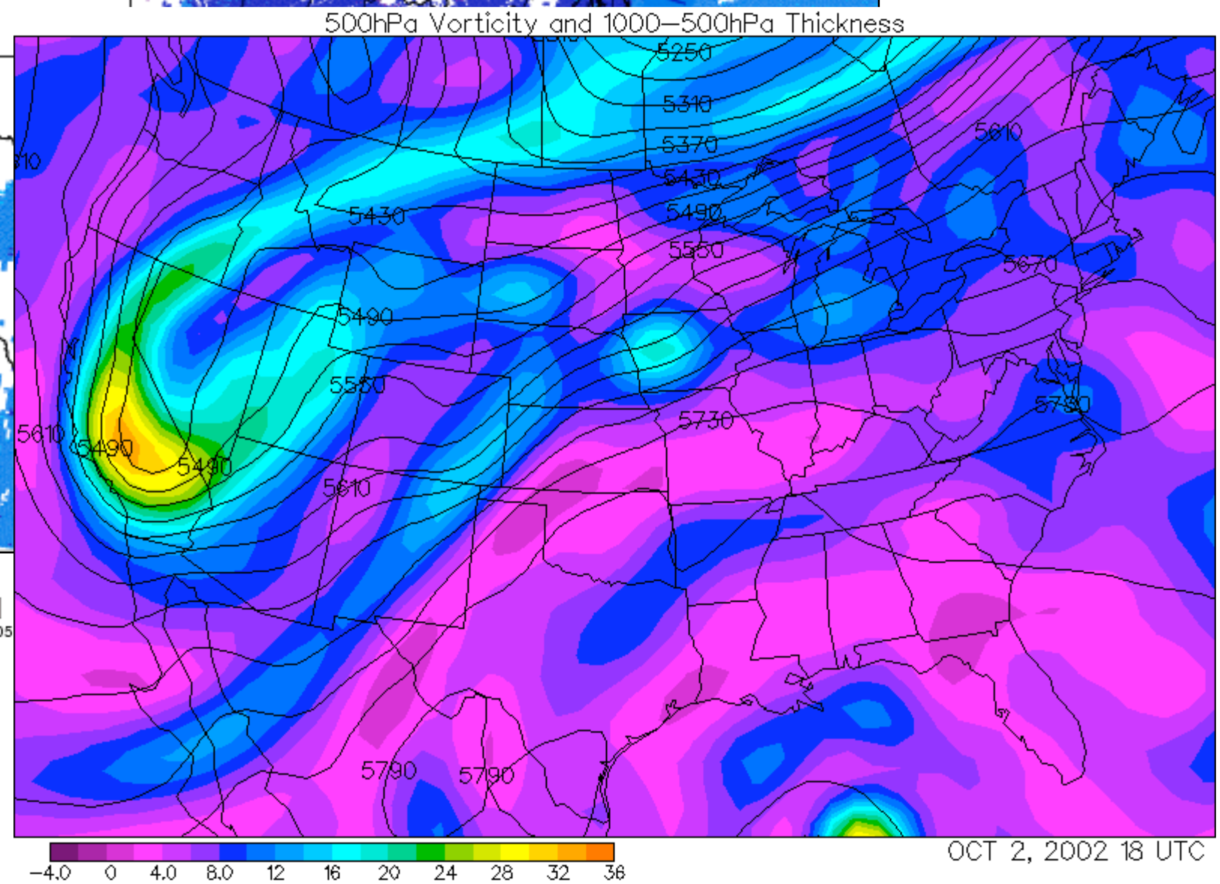

60
50
40
30
20
120
60
CIMSS
TERRA DAY 40507 128
MODIS True Color (.67 r, .55 g, .46 b micron)
UW CIMSS
2 0002 TERRA-L1B 01 7 MAY 04128 150300 00393 09651 01.00
McIDAS



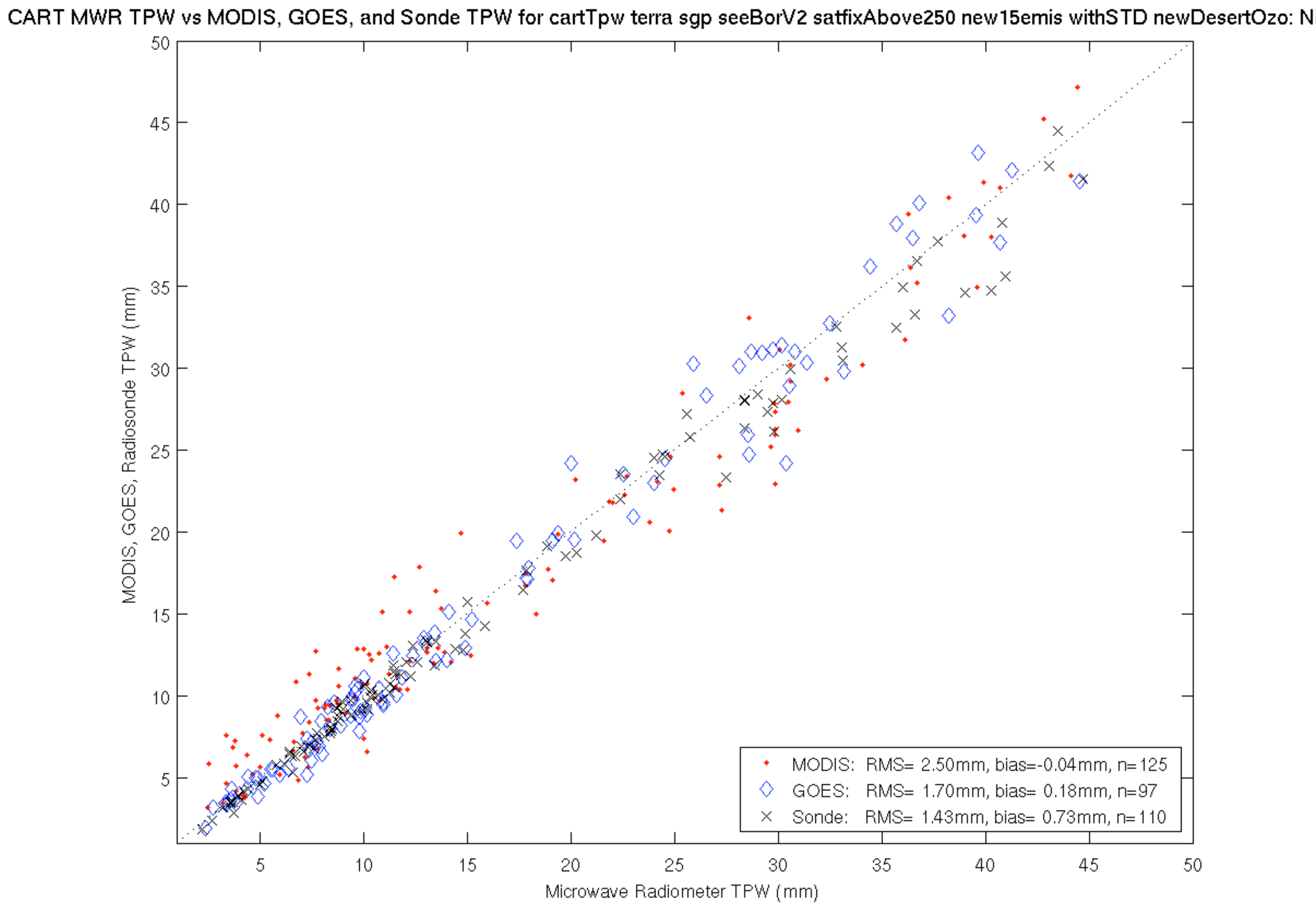
MODIS TOTAL PRECIPITABLE WATER
TERRA DAY 40507 128
UW CIMSS
0
10
20
30
40
50
60
mm
CIMSS
60
50
40
20
120
60
1 0001 TERRA-ATM 01 7 MAY 04128 150300 00393 09651 01.00
McIDAS

Total Column Ozone, 2 October 2002
Terra MODIS direct broadcast



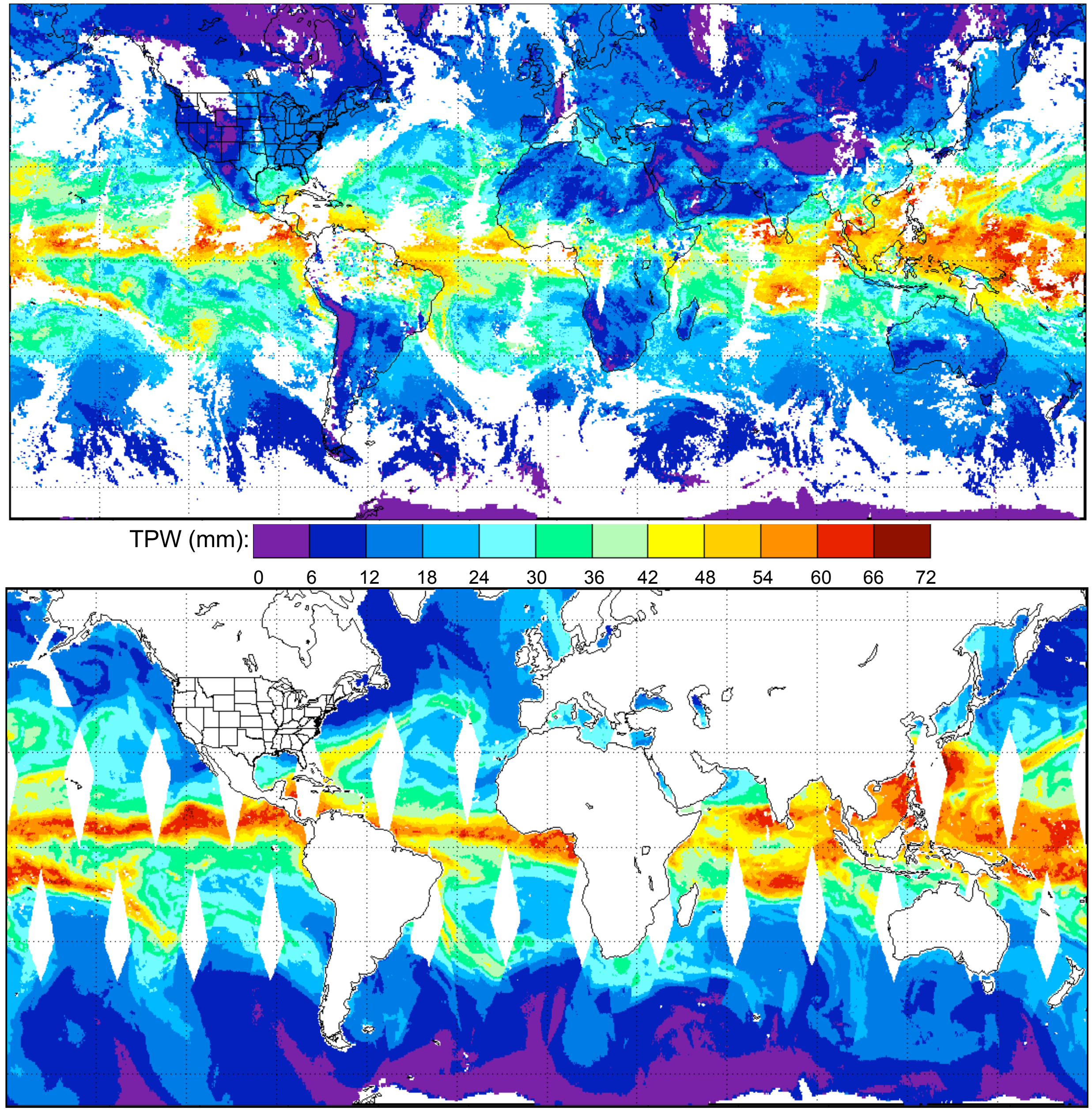


ARM CART Site Comparison



Global Total Precipitable Water Comparison 22 May 2002

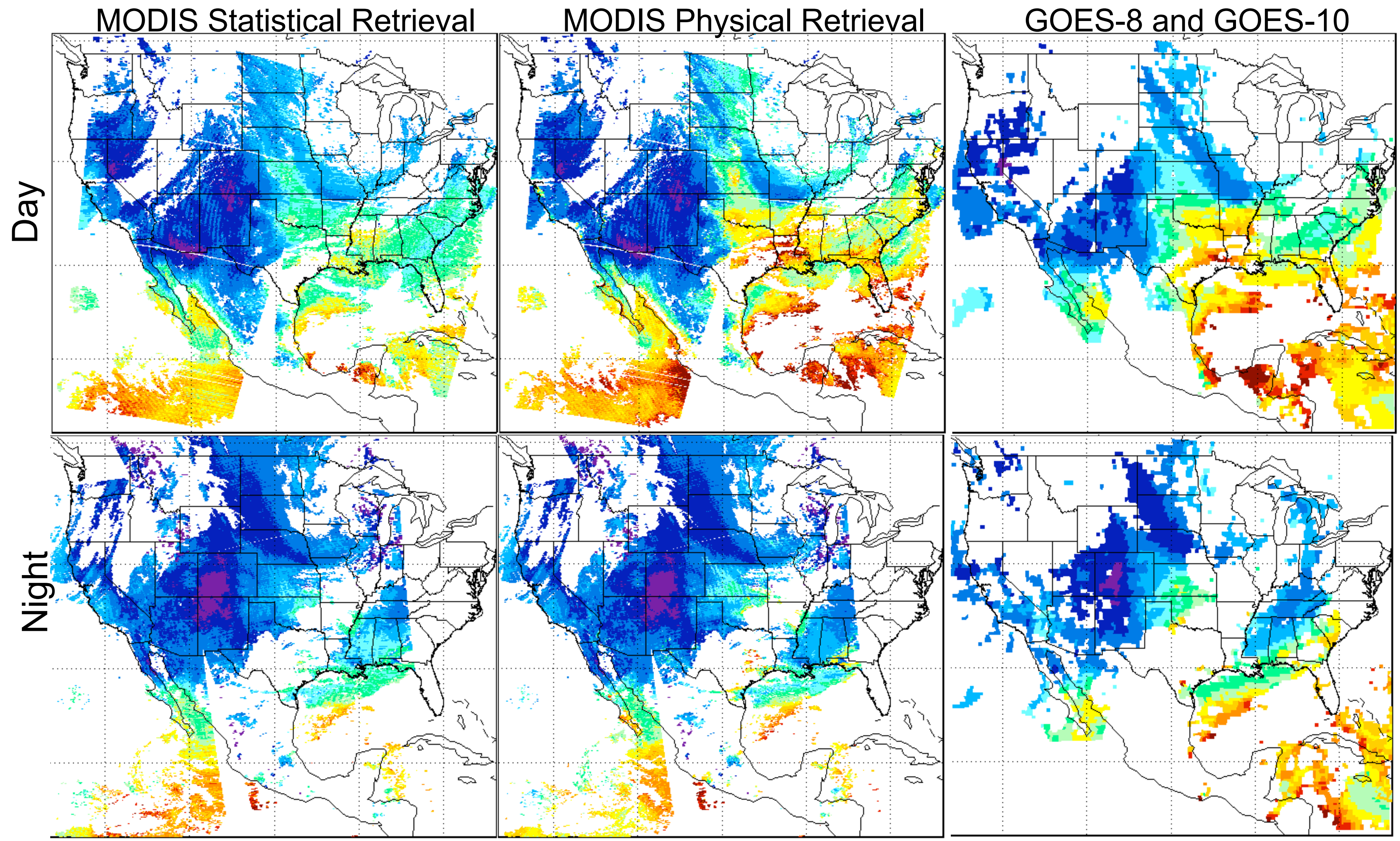
MODIS TPW



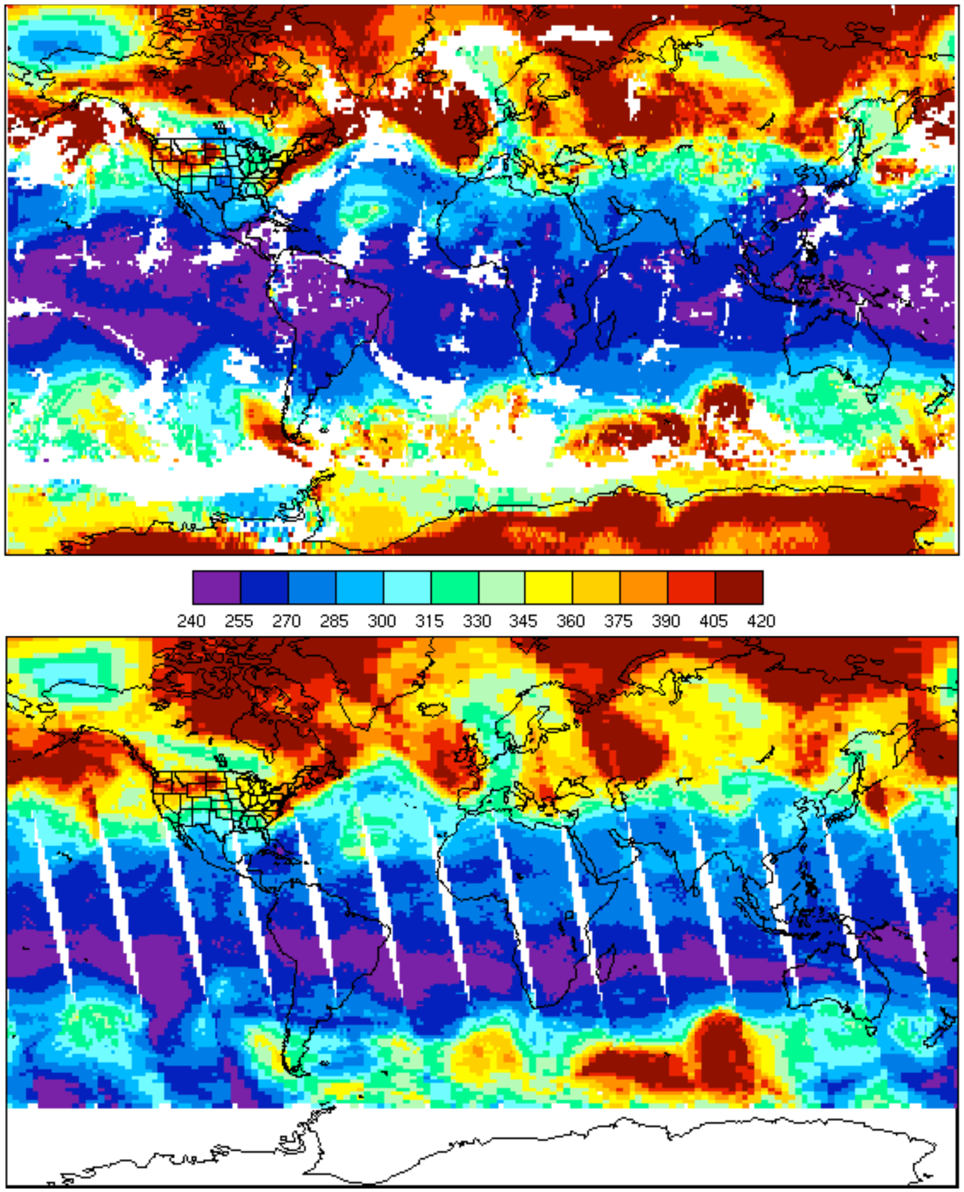
SSM/I f-14 TPW

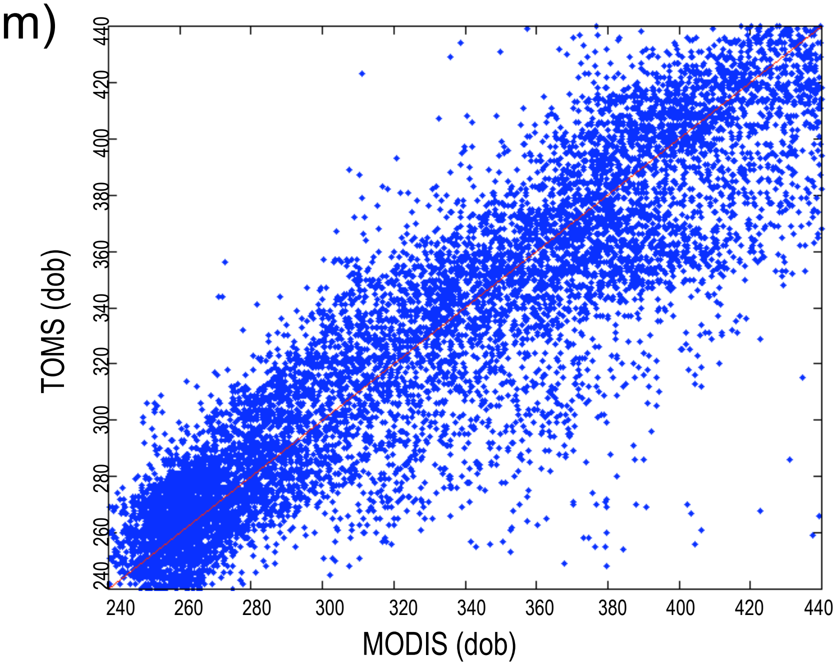
Ascending and descending passes were averaged

TPW (mm) for 2 June 2001 over North America

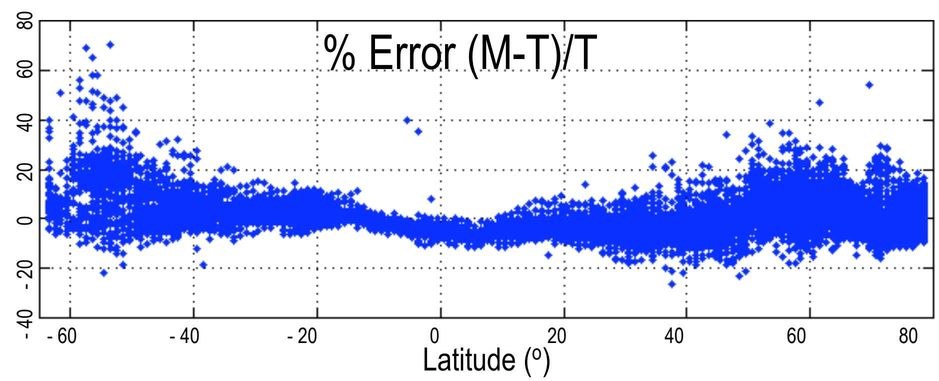


Total Ozone from MODIS (top) and TOMS (bottom)
May 22, 2002

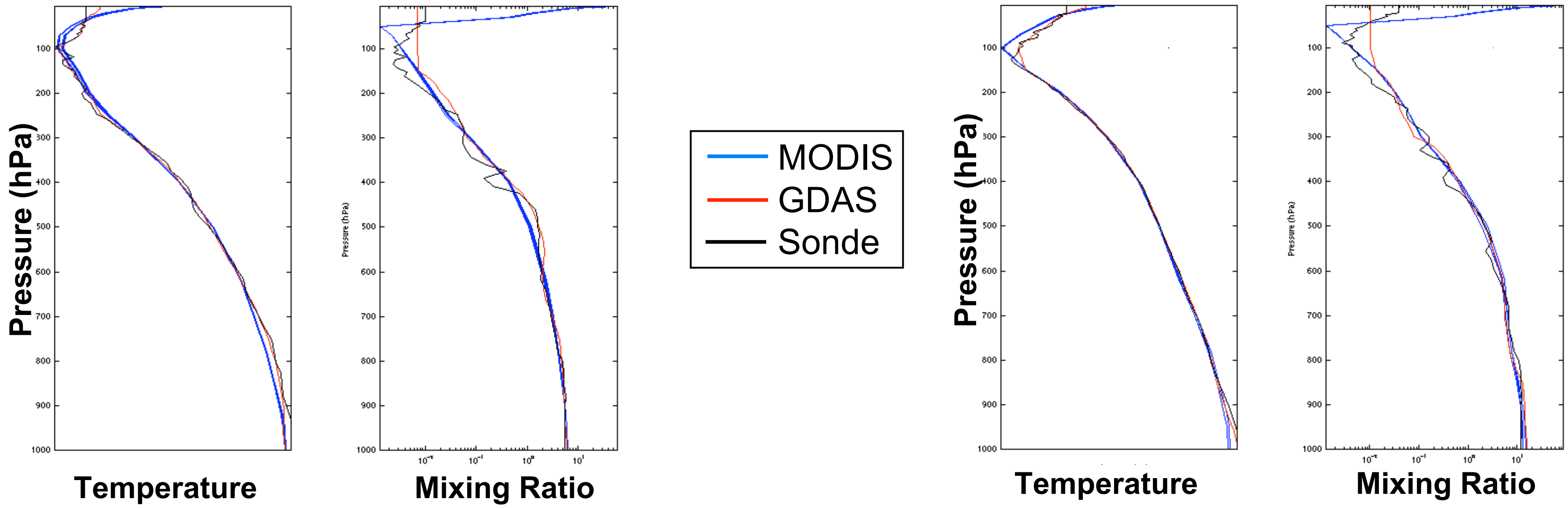




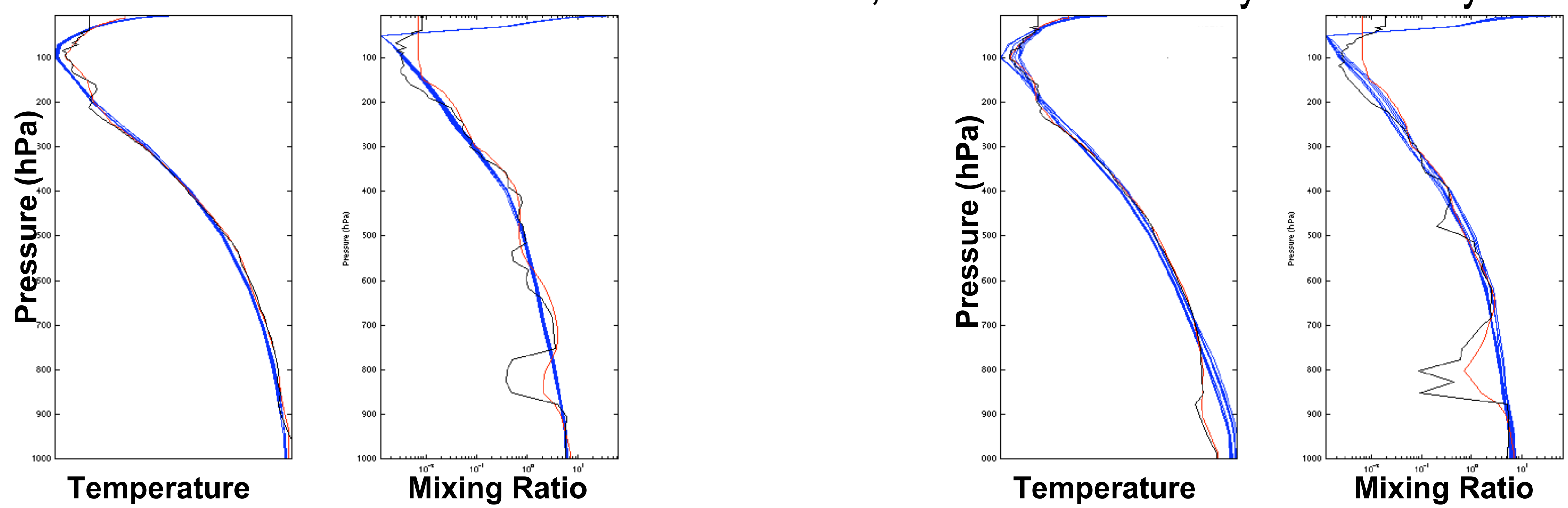
Mean difference MODIS - TOMS = 4.4 dob
RMS = 27.4 dob
mean abs % error: abs(M-T)/T = 5.9%
N = 10,614



MODIS profiles agree well with radiosondes and NCEP-GDAS when the atmospheric temperature and moisture is fairly smooth and monotonic:



But not so well with smaller-scale features, such as isolated dry or moist layers:



Applications

1. Meteorological
   - 3 dimensional view of atmosphere in clear sky
   - Dry Line
   - Humidity
   - Convection
   - Instability
   - Severe Weather
   - Precipitation Potential

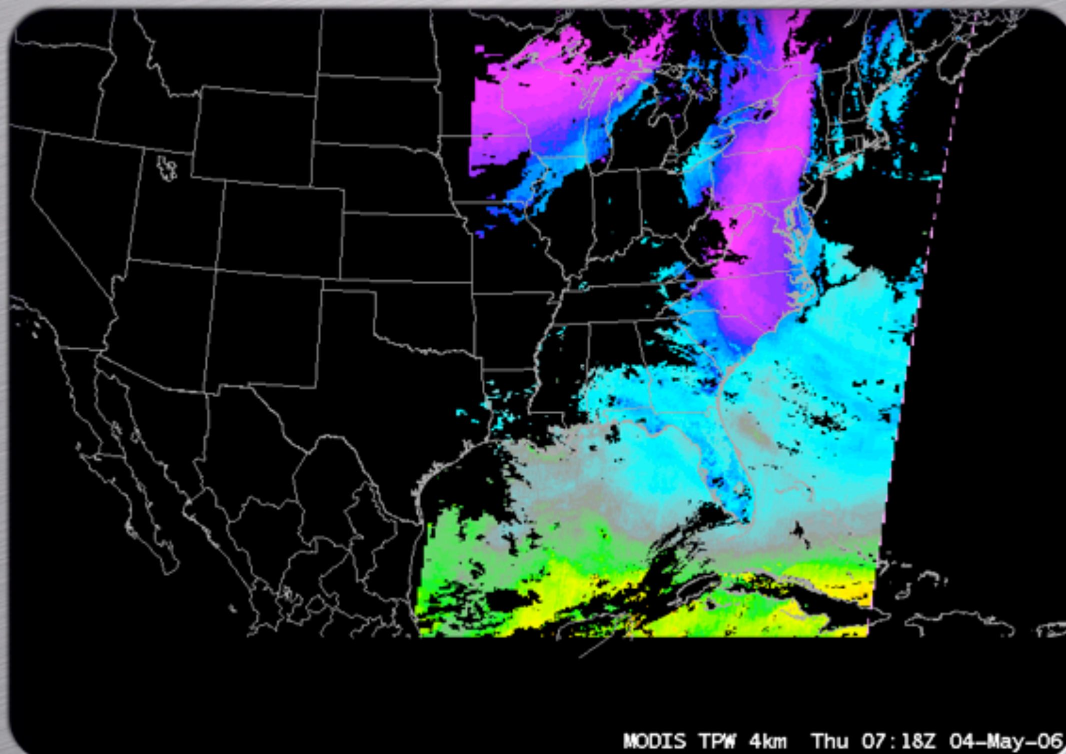
2. Climatological
   - Global Circulations Monitoring
   - Greenhouse Gas Measure

References

Seemann, S., J. Li, W. P. Menzel, and L. Gumley, 2003: Operational retrieval of atmospheric temperature, moisture, and ozone from MODIS infrared radiances. Journal of Applied Meteorology and Climatology, 42, 1072-1091.

Seemann, S.W., E. E. Borbas, R. O. Knuteson, G. R. Stephenson, H.-L. Huang, 2007: Development of a Global Infrared Land Surface Emissivity Database for Application to Clear Sky Sounding Retrievals from Multi-spectral Satellite Radiance Measurements. Journal of Applied Meteorology and Climatology, accepted April 2007

MODIS Imagery in AWIPS



Total Precipitable Water

AREA FORECAST DISCUSSION
NATIONAL WEATHER SERVICE MILWAUKEE/SULLIVAN WI
409 AM CDT FRI JUL 6 2007

.DISCUSSION...FORECAST FOCUS ON POTENTIAL FOR ISOLATED TSTM ACTIVITY TODAY...THEN HOW HIGH WILL THE MERCURY SOAR THIS WEEKEND?

00Z 500/250MB ANALYSIS INDICATED UPPER TROUGHING OVER THE GREAT LAKES/ERN CONUS WITH IMPRESSIVE RIDGING OVER THE WRN CONUS. 500MB HEIGHTS IN THE 596-598DM RANGE FROM AZ NWD INTO WA/ID YIELDING BLISTERING TEMPS WELL INTO THE 100S IN MANY LOCALES ACROSS THE INTERMOUNTAIN WEST. THIS BLOB OF HEAT WILL GRADUALLY ADVECT EWD TOWARD INTO OUR AREA THIS WEEKEND...MORE ON THIS LATER. OTWR NWLY FLOW IN THE LOWER LEVELS OF THE AMS TRYING TO ADVECT SOME DRIER AIR INTO GREAT LAKES WITH GOES/MODIS TOTAL PRECIP WATER PRODUCTS SHOWING PWS DIPPING AOB 0.75 INCHES...WITH SFC TDS GNRLY IN THE 50S UPSTREAM. IR IMAGERY EARLY THIS MORNING SHOWING CLEAR SKIES OVER ALL OF SRN WI.

INPE/CPTEC 700 hPa Temperatures from MODIS