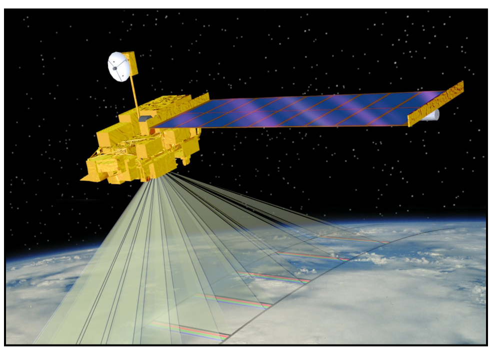
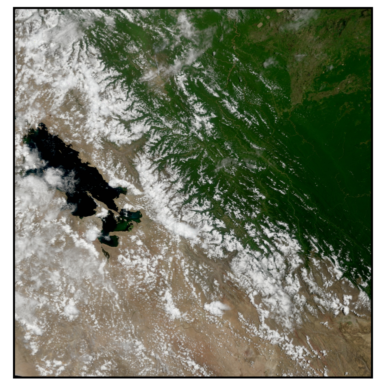
MODIS Products

2011 IMAPP Training Workshop: Satellite Direct Broadcast for Real-Time Environmental Applications
ECNU, China
2 June 2011
Part 2





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

MODIS Standard Land 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 Vegetation Indices

Photo-Chemistry

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

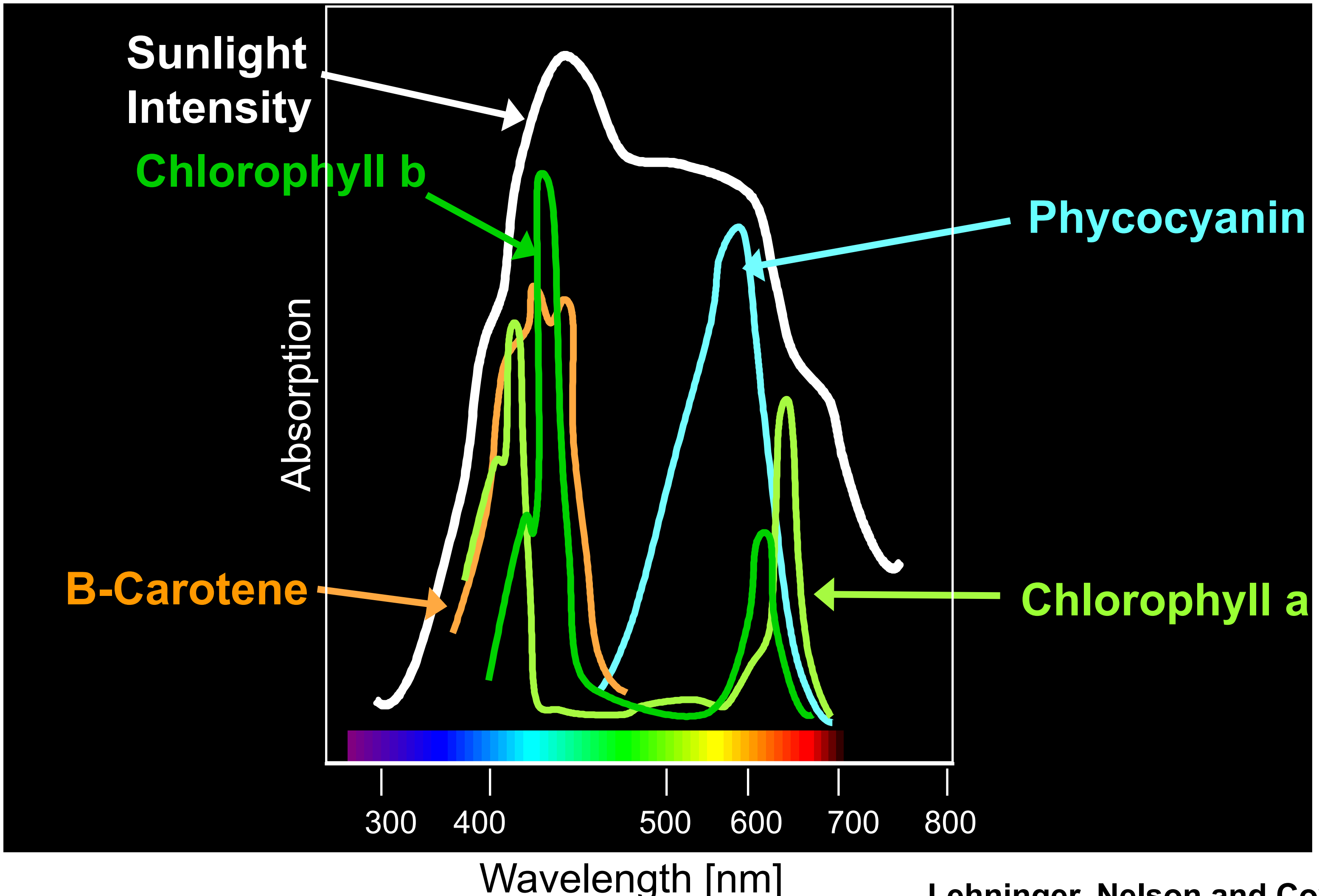
$$6CO_2 + 6H_2O + h\nu \rightarrow C_6H_{12}O_6 + 6O_2$$

- 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

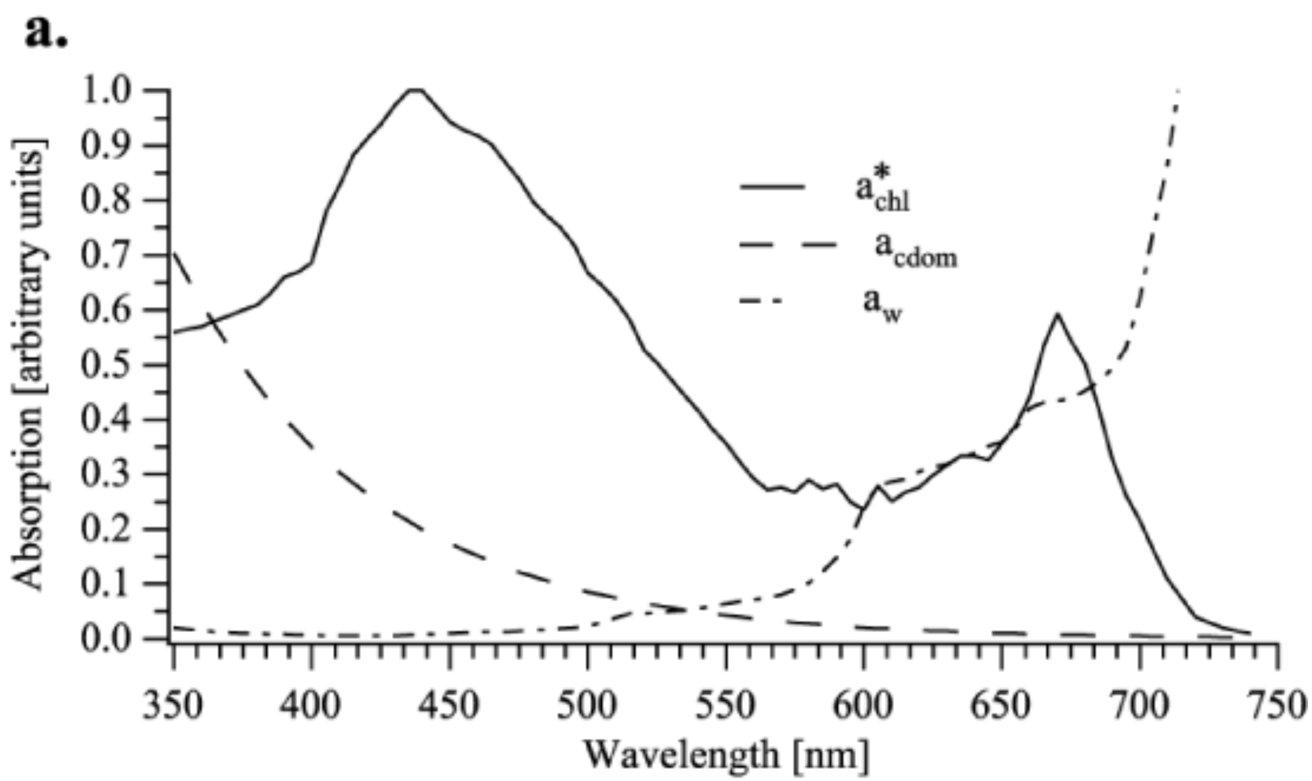


Fig. 1.1: Spectral variations of absorption in seawater. a: Qualitative comparison of the shapes of absorption spectra of pure water (Table 1.1), specific absorption by Chl (Prieur and Sathyendranath 1981), and CDOM as implemented in the HYDROLIGHT radiative transfer model (Mobley and Sundman 2000) described further by Morel and Maritorena (2001).

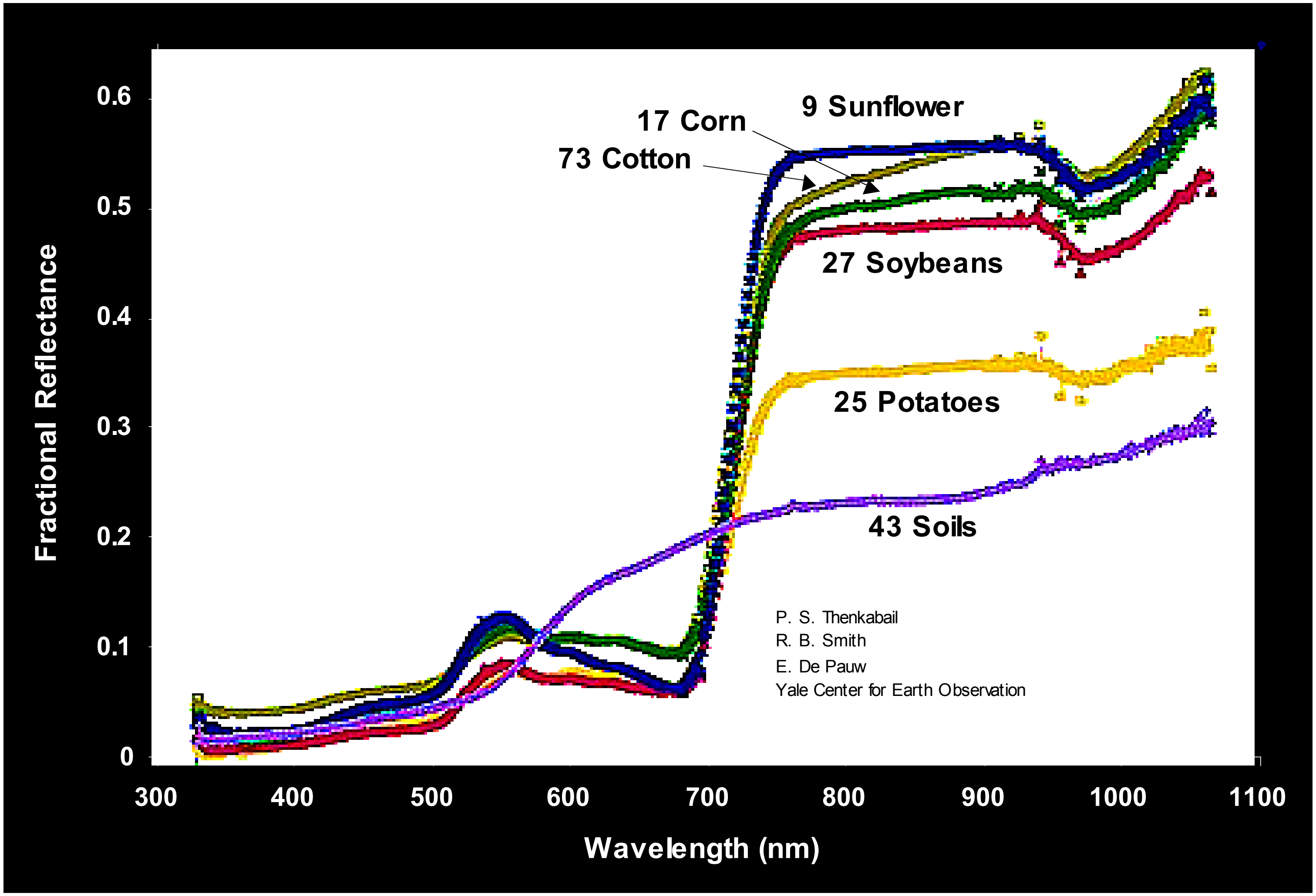
Theoretical description

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



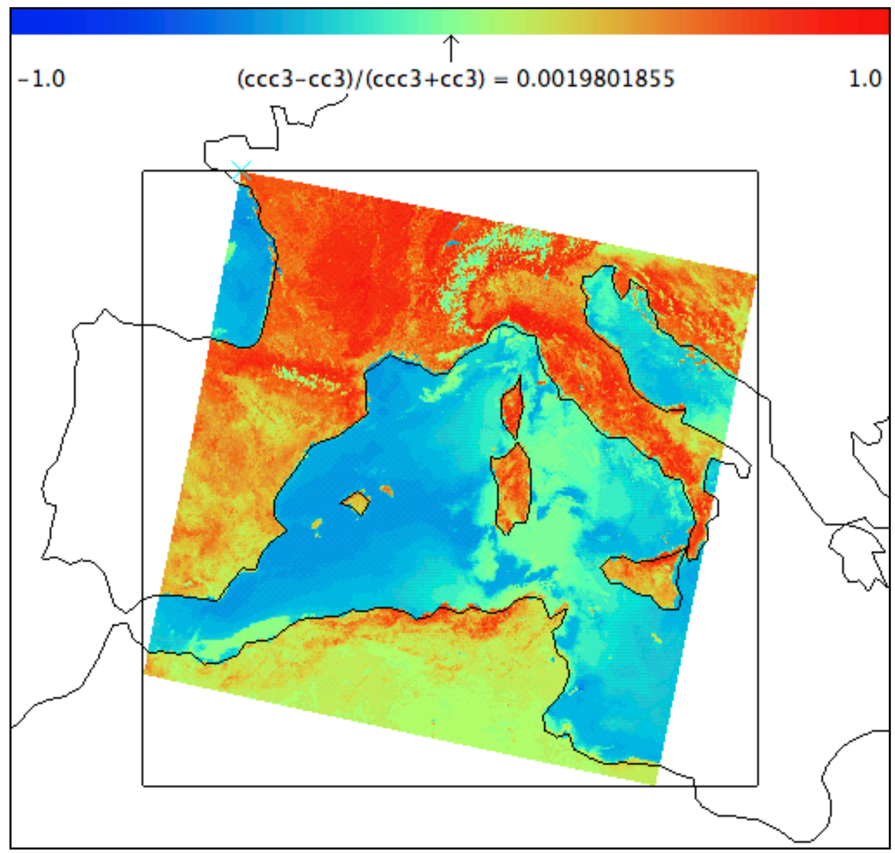
Normalized Difference Vegetation Index (NDVI)

Defined as the ratio

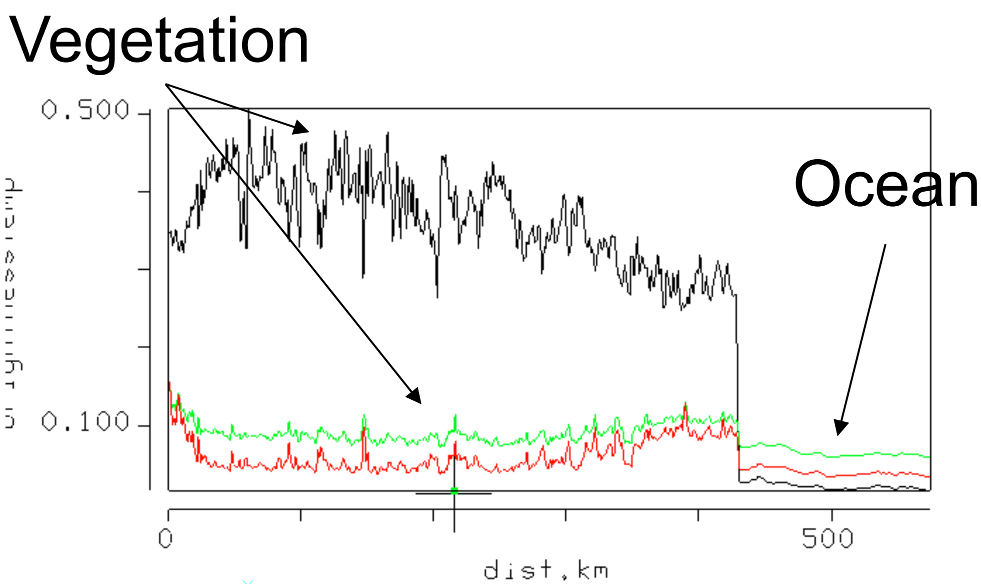
$$(r_{.86} - r_{.68})/(r_{.86} + r_{.68})$$

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

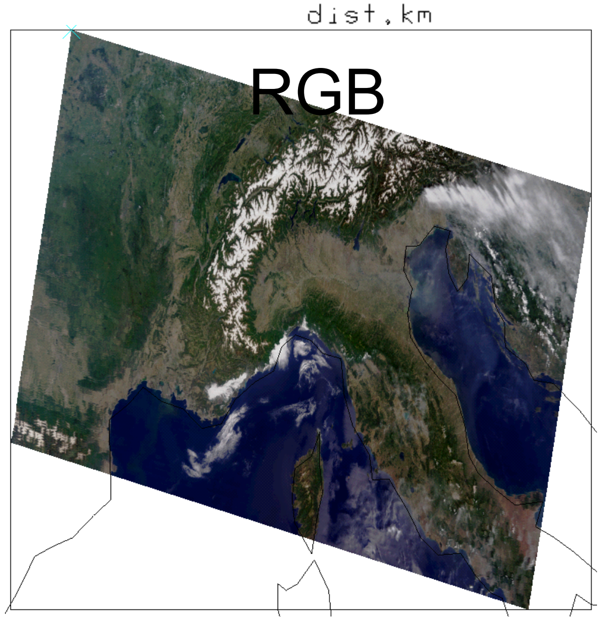
Applications:	
Vegetation Monitoring	Agricultural Activities
Drought studies	Landcover Change
Public Health Issues (mosquitos)	Climate Change Detection
Net Primary Production	Carbon Balance

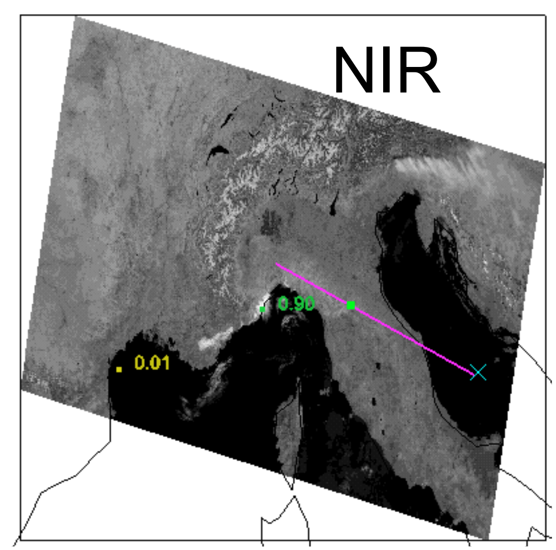


NIR and VIS over Vegetation and Ocean



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





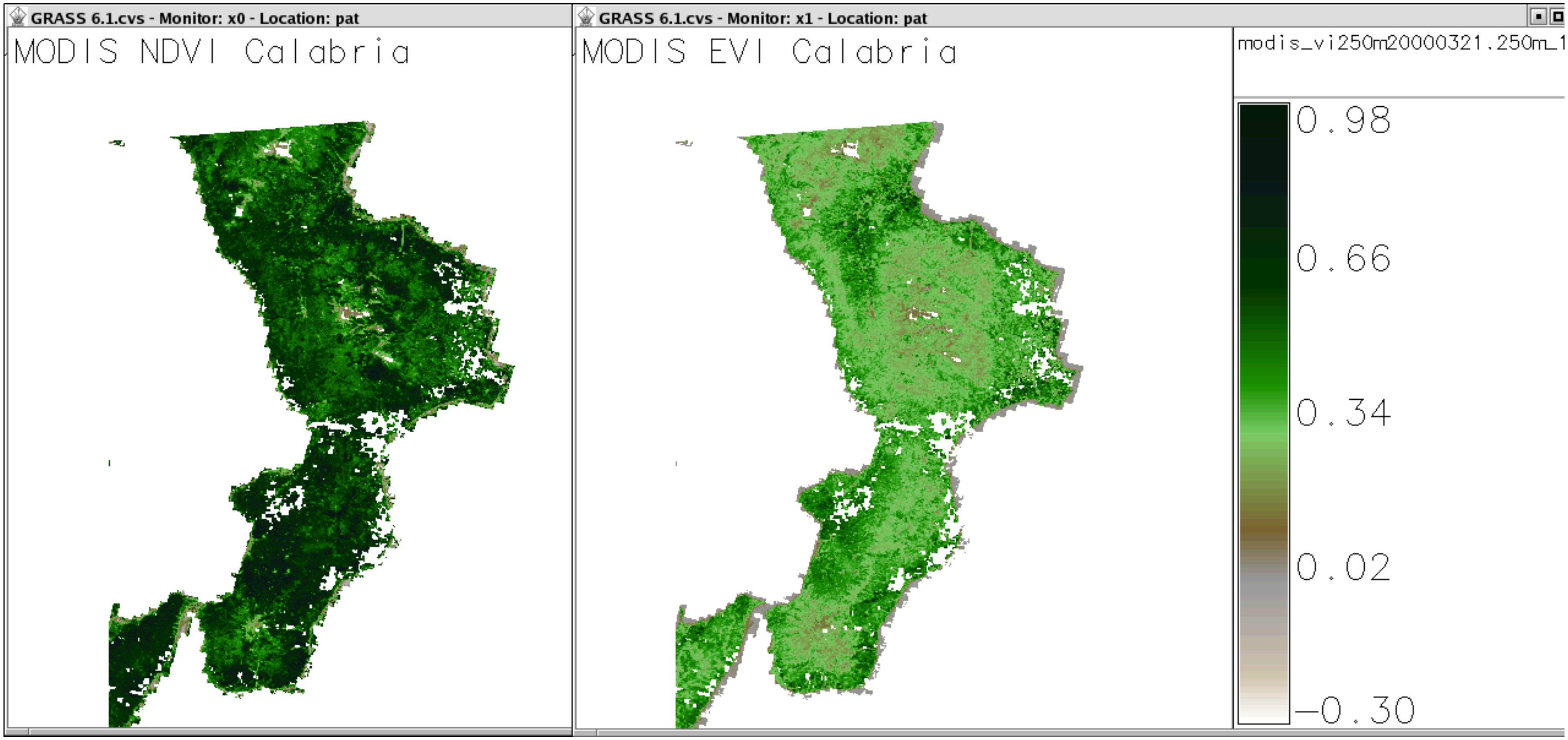
Enhanced Vegetation Index (EVI)

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

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/)

How does DB VI version differ from the MOD13 product?

- DB VI product uses the corrected reflectance, but not the MODIS surface reflectance MOD09 product
  - Corrected reflectance product removes the effects of the small particle scattering (Rayleigh scattering), but not the Mie scattering (includes aerosols)
  - NASA VI product (MOD13) uses the BRDF (Bidirectional Reflectance Distribution Function) product as input

Surface Reflectance (MOD09)

The surface reflectance product is defined as the reflectance that would be measured at the land surface if there were no atmosphere.

Surface Reflectance

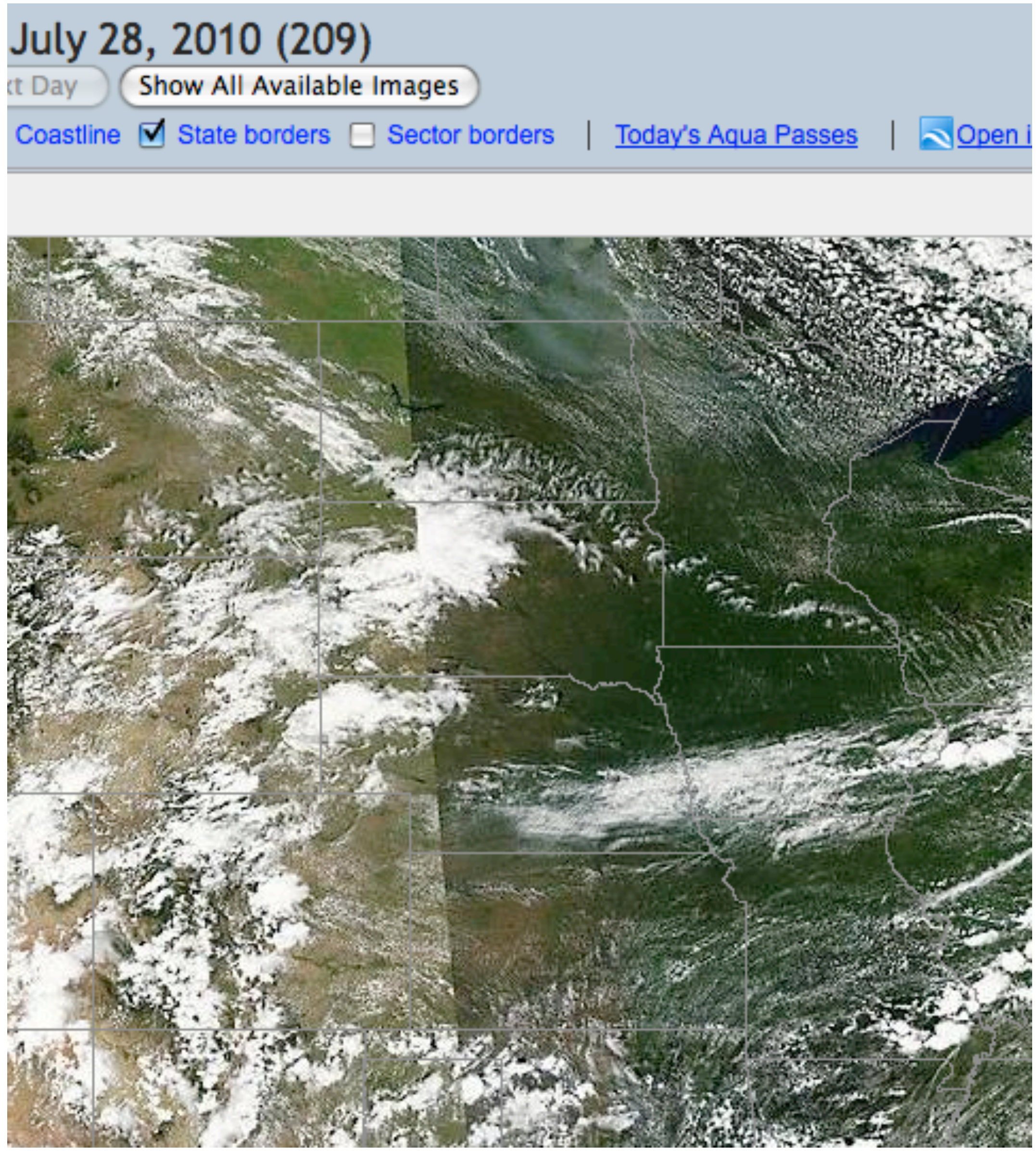
$$\rho_{TOA} = Tg(O_3, O_2, CO_2)\left[\rho_R + (\rho_{R+A} - \rho_R)Tg(U_{H_2O}/2) + T_{R+A}\frac{\rho_s}{1 - \rho_s S_{R+A}}Tg(U_{H_2O})\right] \quad ($$

ρ_{TOA} is the reflectance observed at the top of the atmosphere,
T_g refers to gaseous transmission,
ρ_R is the molecular scattering intrinsic reflectance,
ρ_{R+A} is the intrinsic reflectance of the molecules and aerosols,
T_{R+A} is the transmission of the molecules and aerosols and
S_{R+A} is the spherical albedo.

Example from MODIS Today web site

The effects of atmospheric and surface reflection are not uniform across a scan

This will affect your retrievals



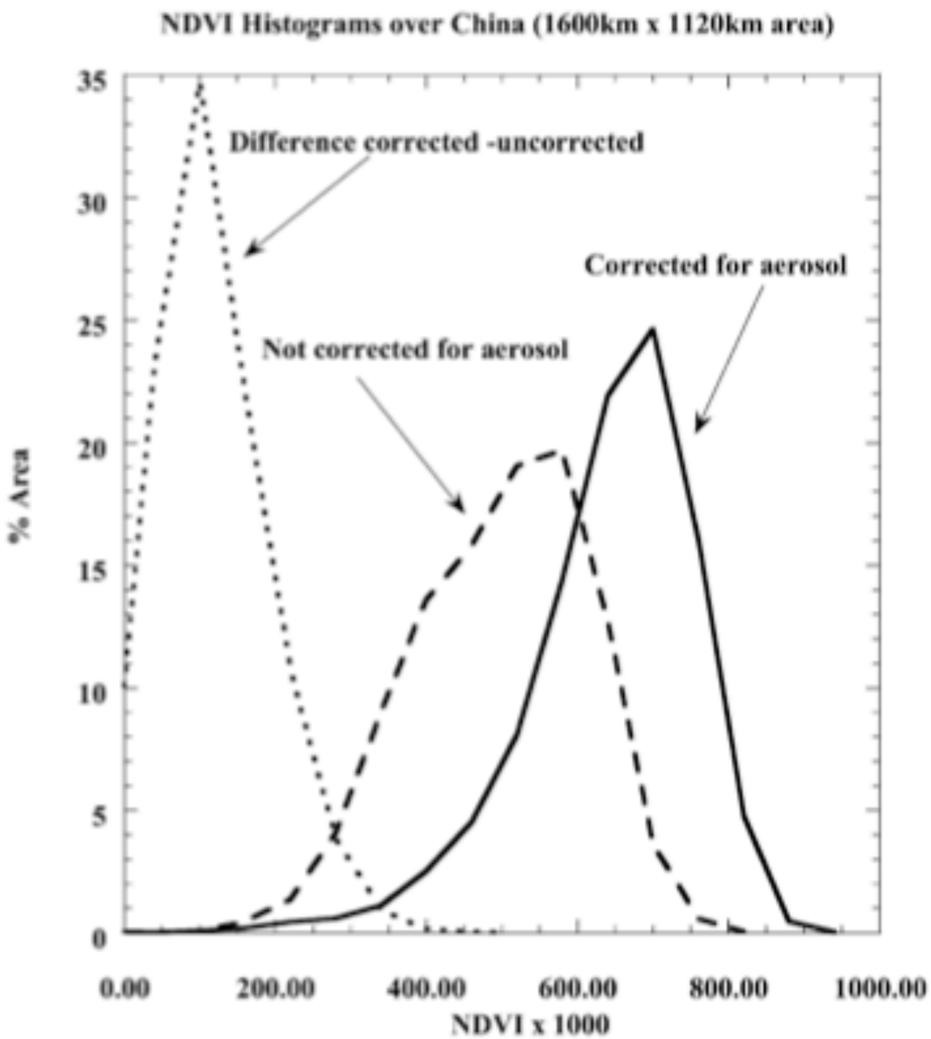


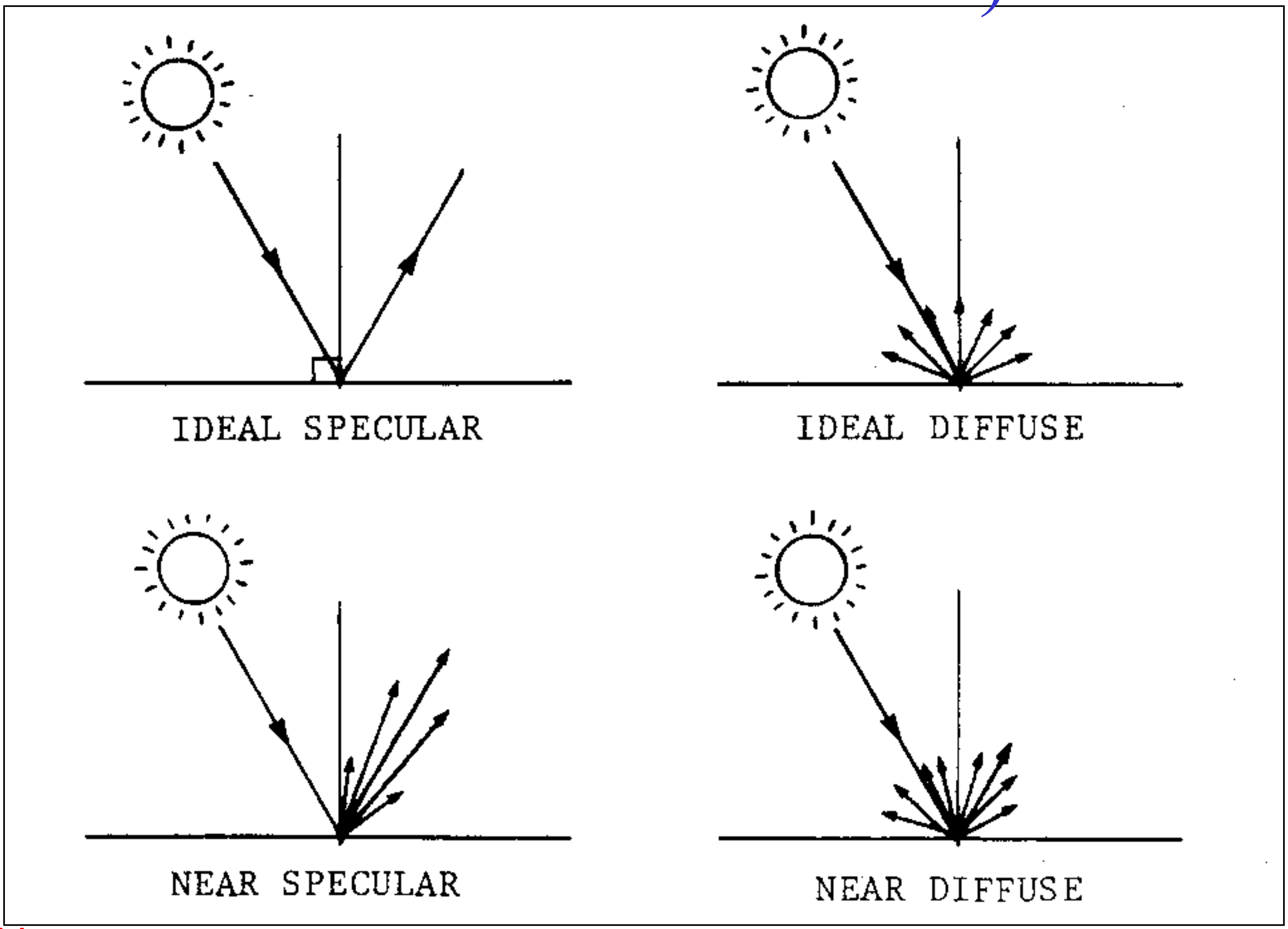
Fig. 4. Comparison of histograms of NDVI (corrected for aerosol and uncorrected for aerosol) observed over China (area of 1600 × 1120 km), the solid curve corresponds to the aerosol corrected data, the dashed one to the uncorrected and the small dash to the difference between uncorrected and corrected NDVI.

Importance of aerosol correction when Retrieving NDVI over China

Reference

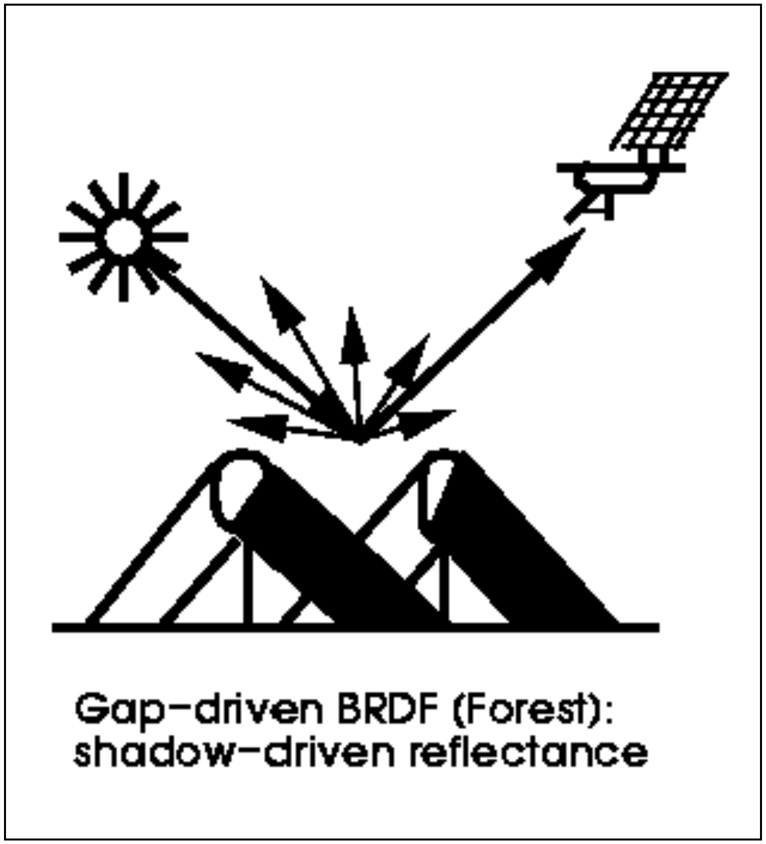
- E.F. Vermote, Nazmi Z. El Saleous, Christopher O. Justice, “Atmospheric correction of MODIS data in the visible to middle infrared: first results”. Remote Sensing of the Environment 83. (2002), 97–111.

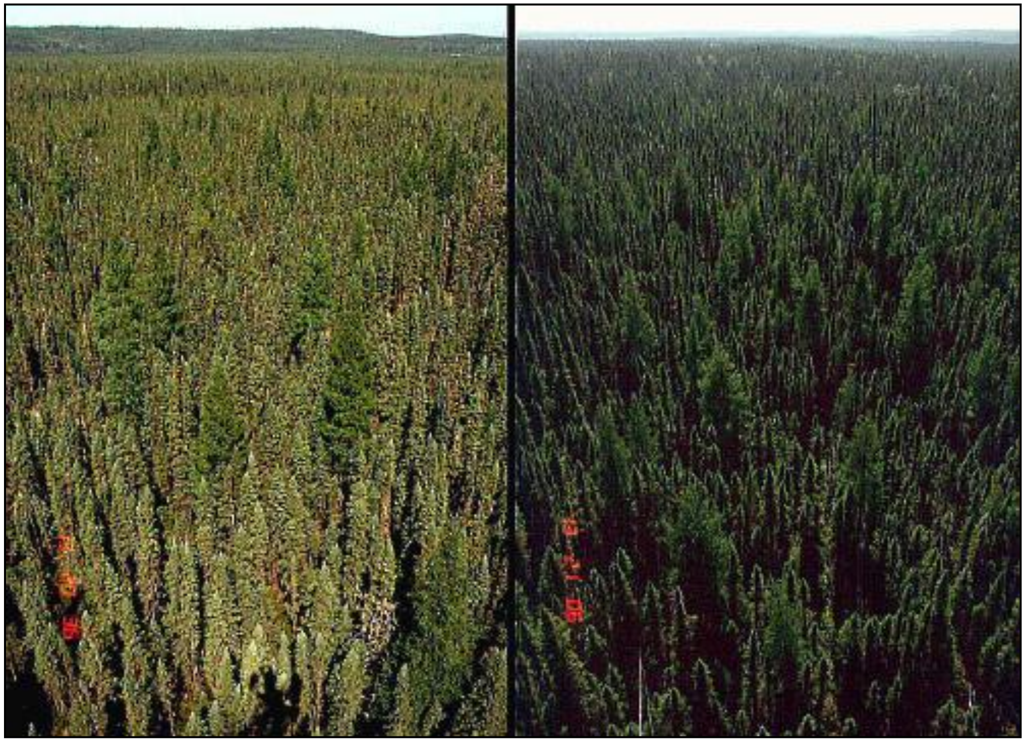
BRDF (Bi-directional Reflectance Distribution Function)



Wolfgang Lück

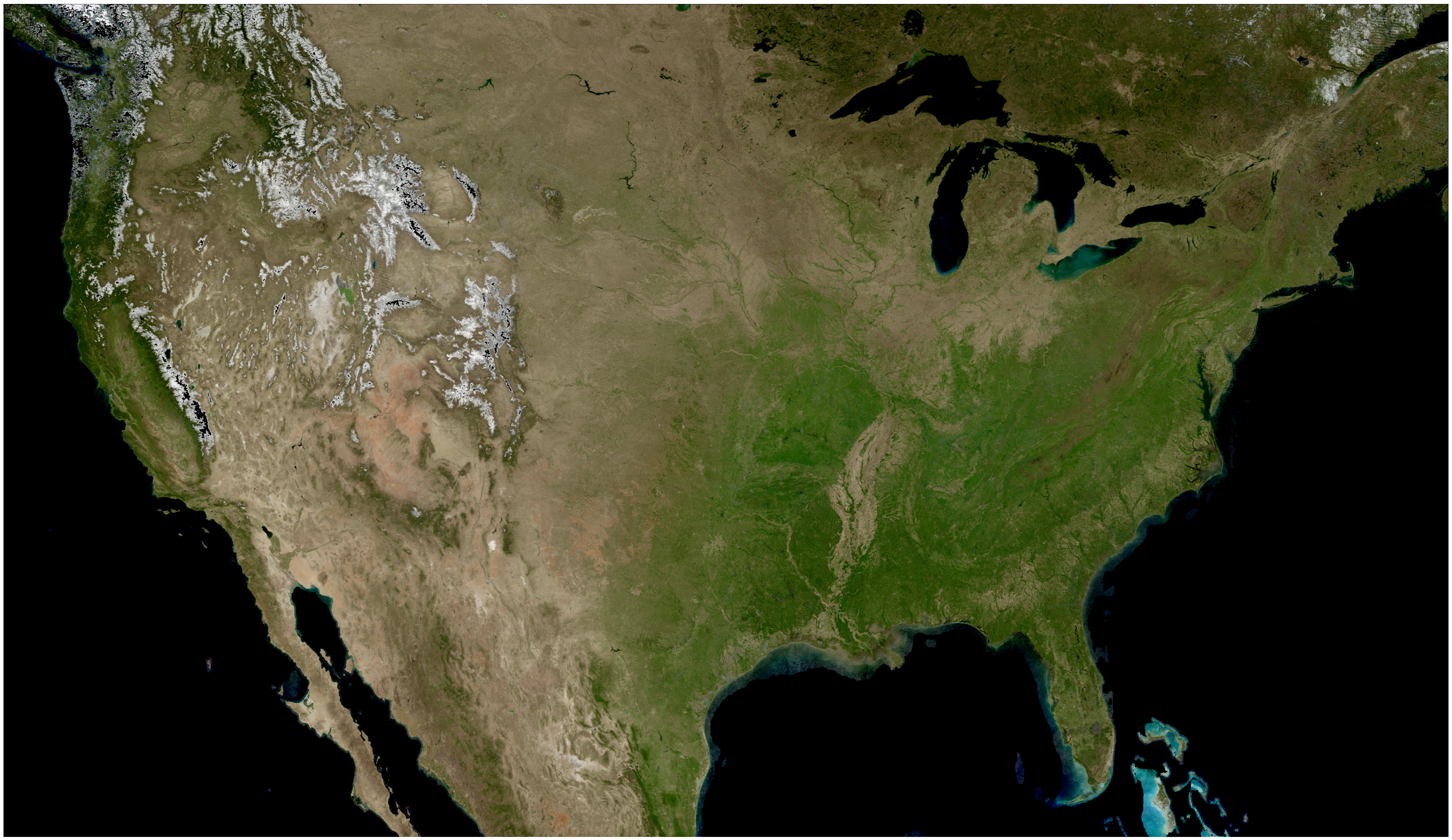
BRDF Example





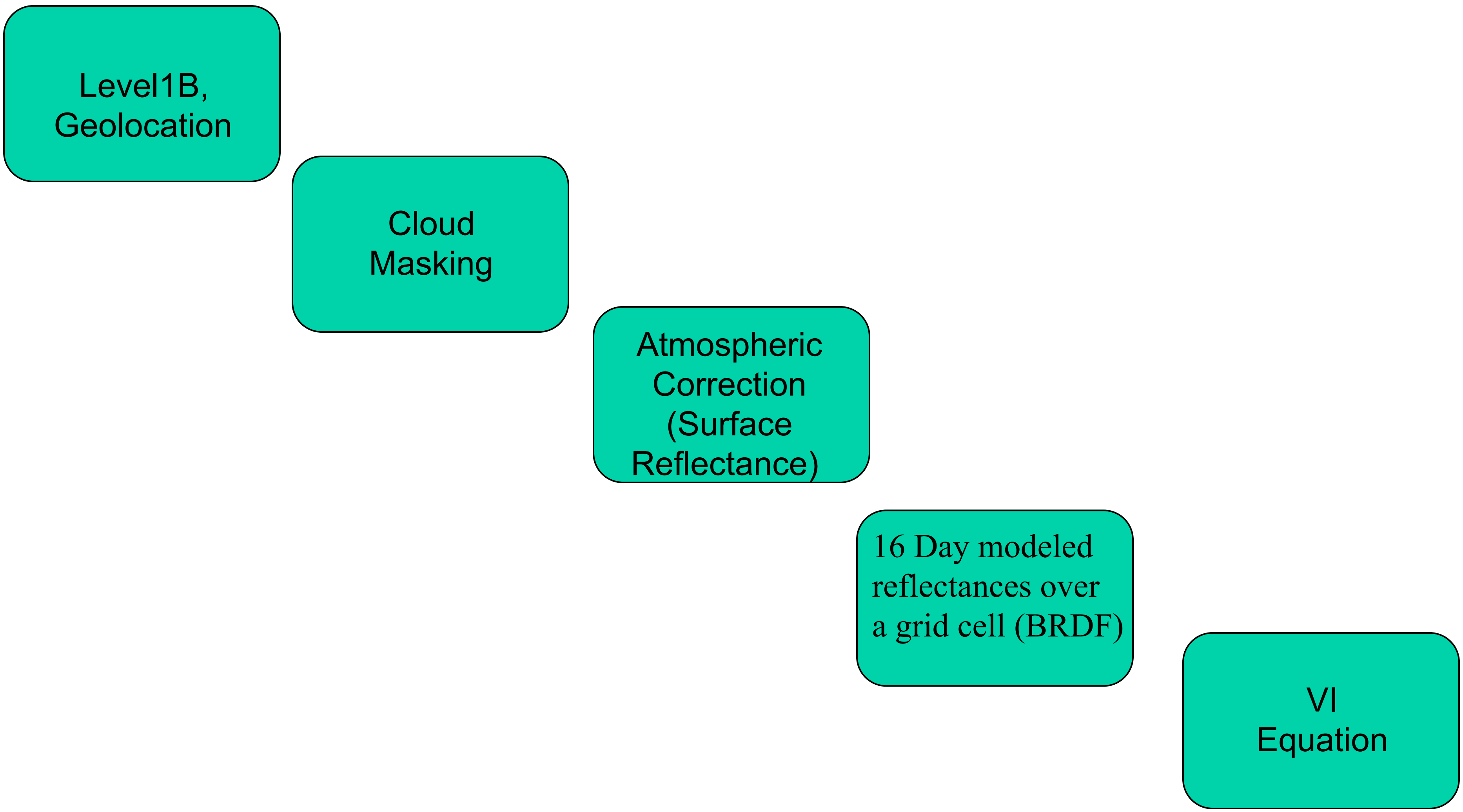
Black spruce forest in Canada.
Left, sun behind camera
Right, sun opposite

BRDF modeled refectances
16 days of UW MODIS DB data



18 April 2010

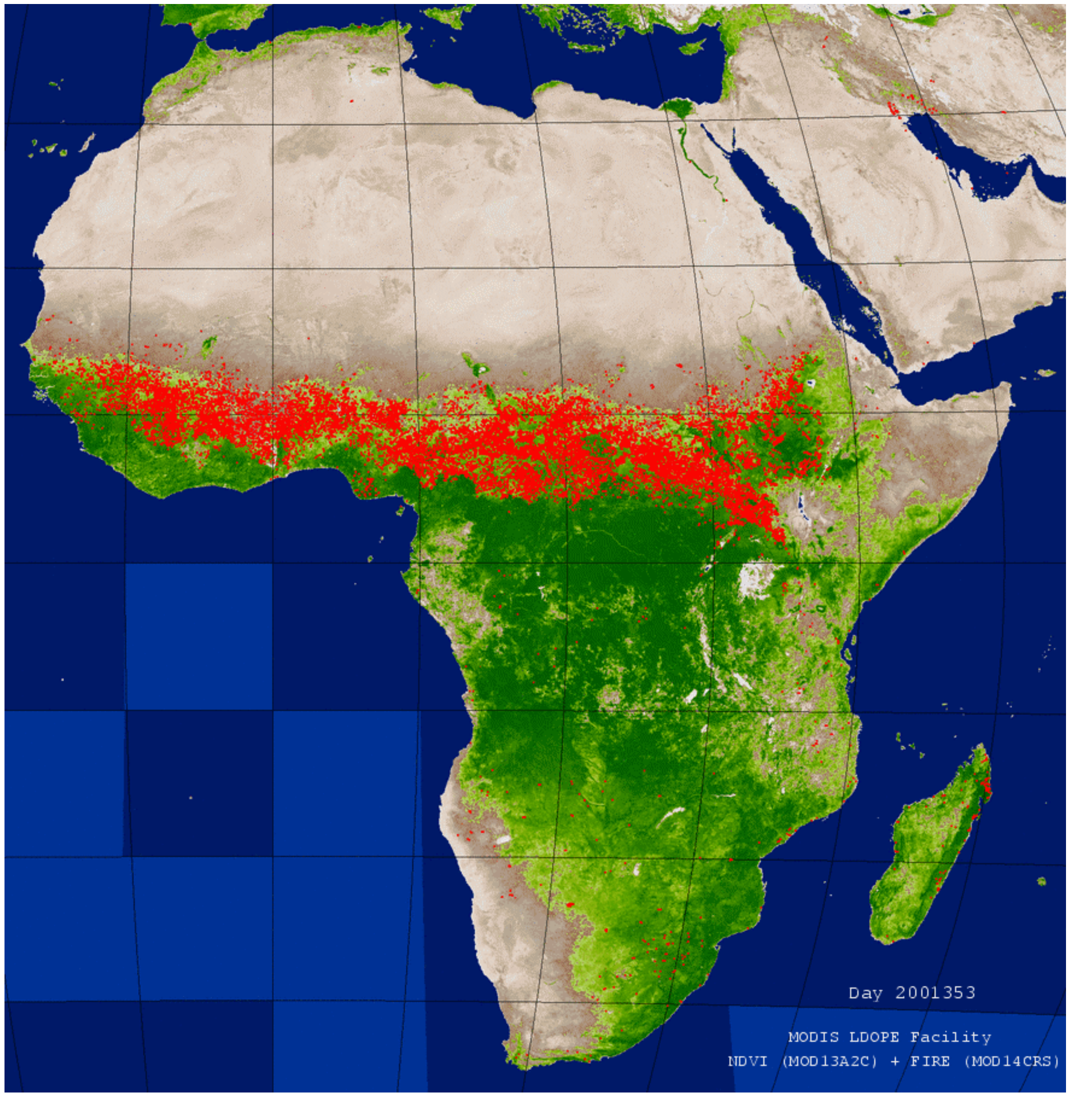
Inputs and Processing Chain for MODIS VI Production



BRDF References

- Shuai,Y., C. B. Schaaf, A. H. Strahler, J. Liu, Z. Jiao, Quality assessment of BRDF/albedo retrievals in MODIS operational system, Geophys. Res. Lett., 35, L05407, doi: 10.1029/2007GL032568,2008.
- Schaaf, C. B., F. Gao, A. H. Strahler, W. Lucht, X. Li, T. Tsang, N. C. Strugnell, X. Zhang, Y. Jin, J.-P. Muller, P. Lewis, M. Barnsley, P. Hobson, M. Disney, G. Roberts, M. Dunderdale, C. Doll, R. d'Entremont, B. Hu, S. Liang, and J. L. Privette, and D. P. Roy,First Operational BRDF, Albedo and Nadir Reflectance Products from MODIS, Remote Sens. Environ., 83, 135-148, 2002.

Relevance of NDVI: FIRES



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

REFERENCES

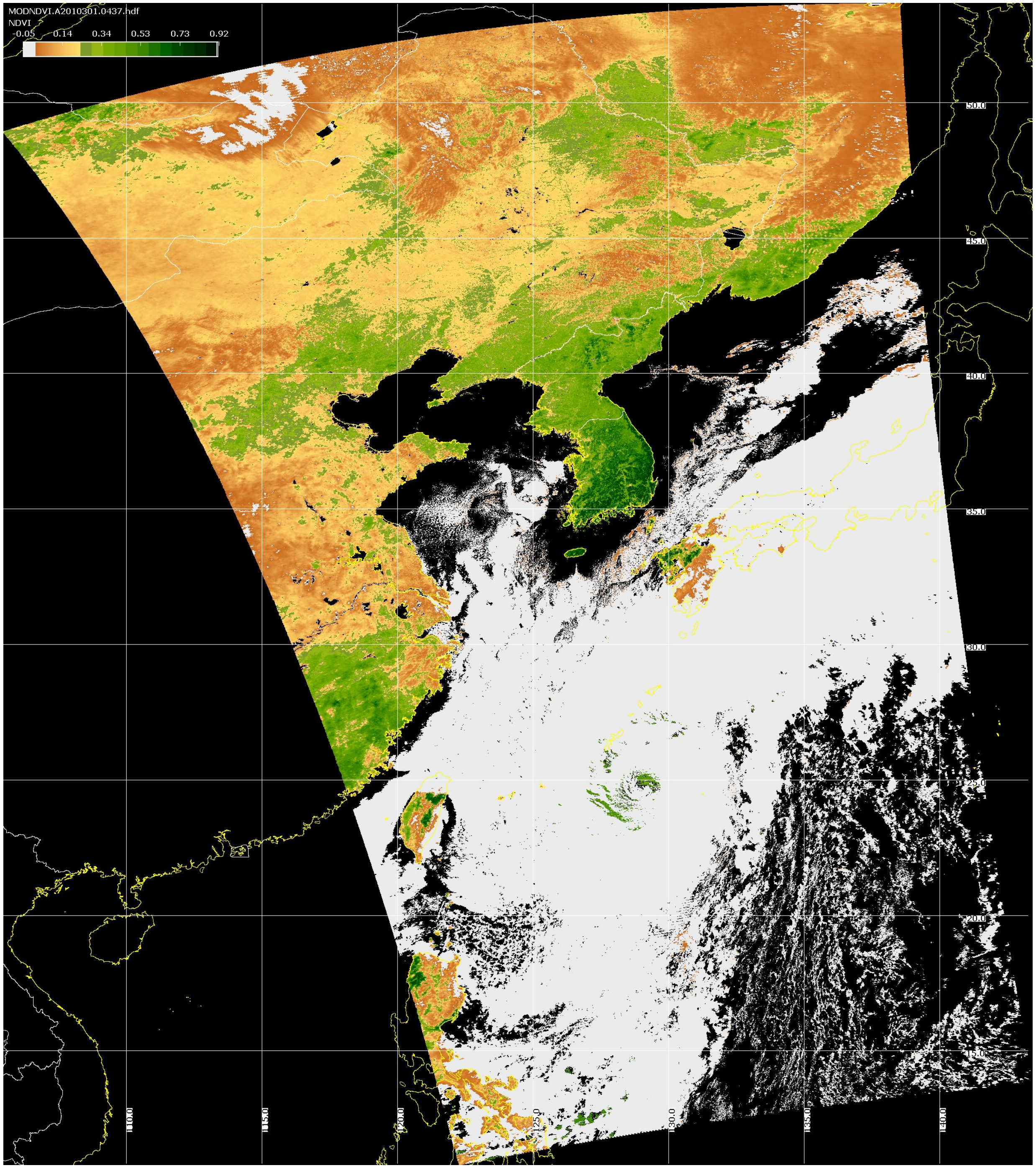
- MOD13 Web Page:

- Citation:
  - Ramachandran, Bhaskar, Justice, Christopher O., Abrams, Michael J., Huete, Alfredo, Didan, Kamel, Leeuwen, Willem, Miura, Tomoaki and Ed Glenn. MODIS Vegetation Indices, Land Remote Sensing and Global Environmental Change, Remote Sensing and Digital Image Processing: 2011. Springer New York, 978-1-4419-6749-7, Physics, 579-602.
  - 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

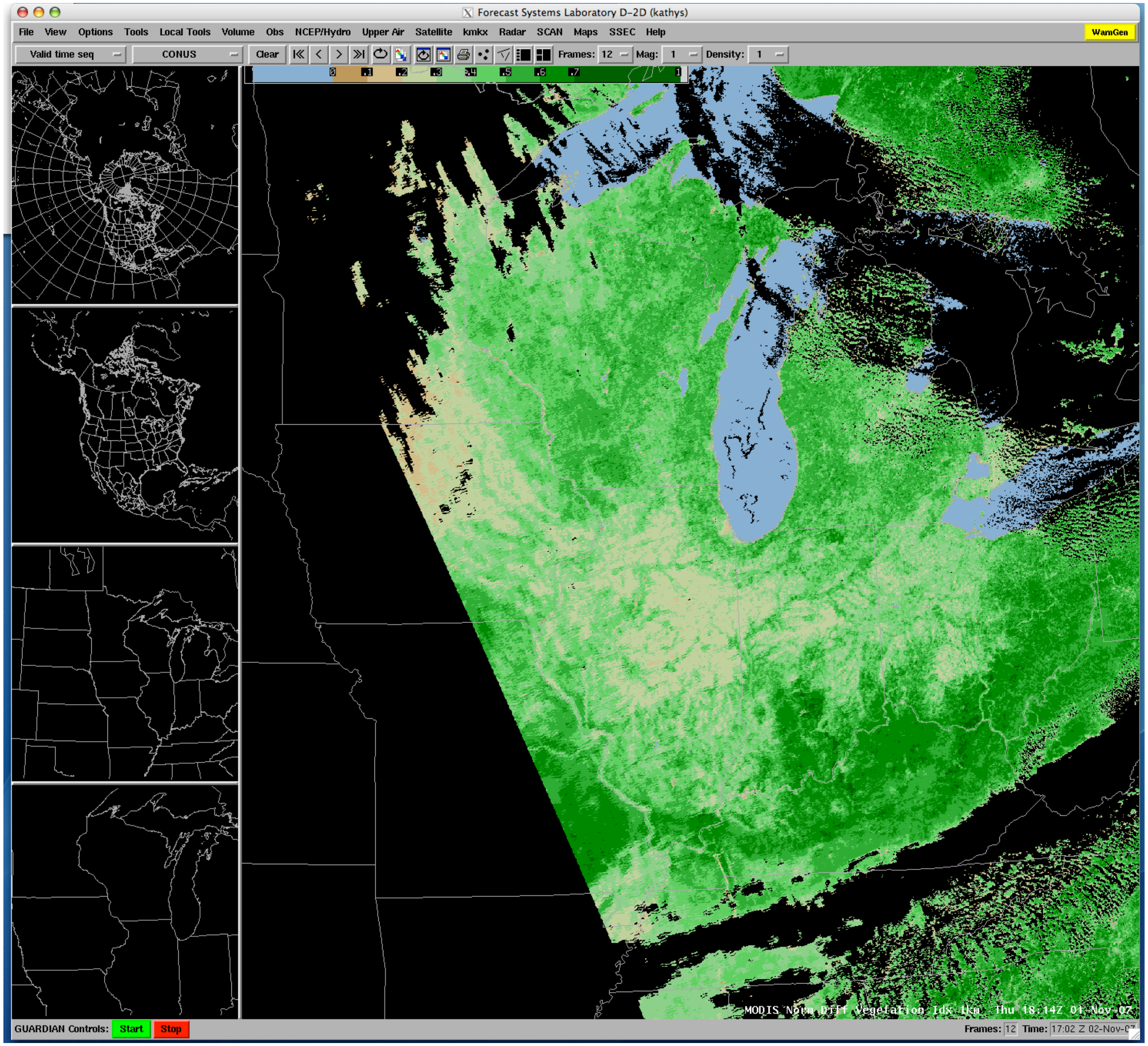
Applications

- 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

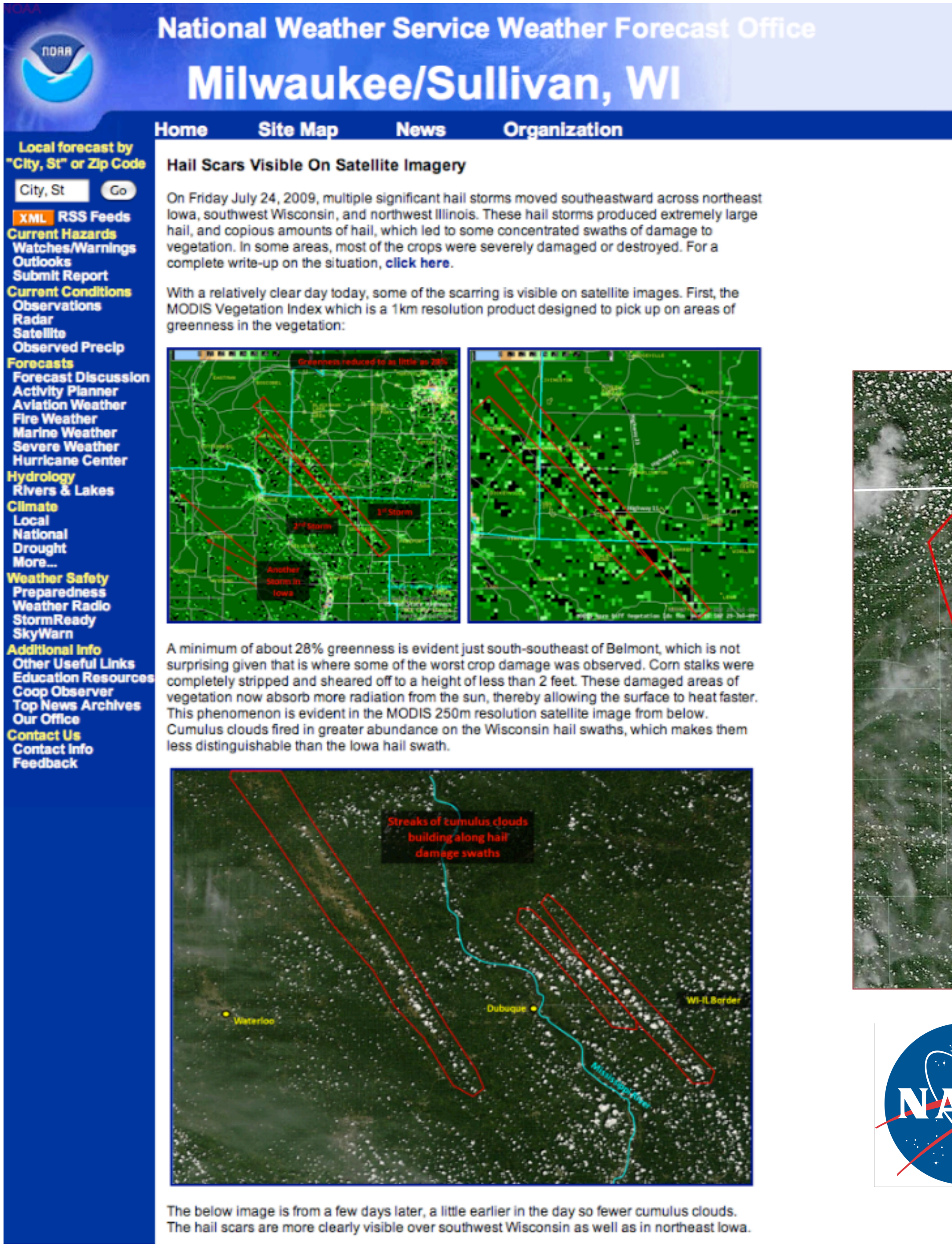


MODIS NDVI
Product from
ECNU
28 October 2010

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



MODIS NDVI product used to determine extent of hail damage July 2008



National Weather Service Weather Forecast Office

Milwaukee/Sullivan, WI

Home Site Map News Organization

Local forecast by "City, St" or Zip Code
City, St Go
XML RSS Feeds
Current Hazards
Watches/Warnings
Outlooks
Submit Report
Current Conditions
Observations
Radar
Satellite
Observed Precip
Forecasts
Forecast Discussion
Activity Planner
Aviation Weather
Fire Weather
Marine Weather
Severe Weather
Hurricane Center
Hydrology
Rivers & Lakes
Climate
Local
National
Drought
More...
Weather Safety
Preparedness
Weather Radio
StormReady
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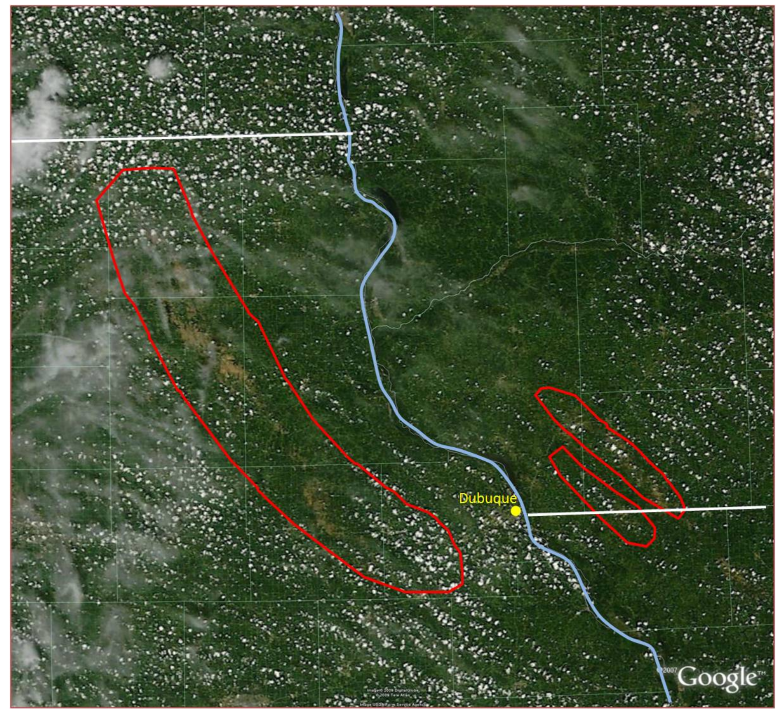
Hail Scars Visible On Satellite Imagery

On Friday July 24, 2009, multiple significant hail storms moved southeastward across northeast Iowa, southwest Wisconsin, and northwest Illinois. These hail storms produced extremely large hail, and copious amounts of hail, which led to some concentrated swaths of damage to vegetation. In some areas, most of the crops were severely damaged or destroyed. For a complete write-up on the situation, click here.

With a relatively clear day today, some of the scarring is visible on satellite images. First, the MODIS Vegetation Index which is a 1km resolution product designed to pick up on areas of greenness in the vegetation:

A minimum of about 28% greenness is evident just south-southeast of Belmont, which is not surprising given that is where some of the worst crop damage was observed. Corn stalks were completely stripped and sheared off to a height of less than 2 feet. These damaged areas of vegetation now absorb more radiation from the sun, thereby allowing the surface to heat faster. This phenomenon is evident in the MODIS 250m resolution satellite image from below. Cumulus clouds fired in greater abundance on the Wisconsin hail swaths, which makes them less distinguishable than the Iowa hail swath.

The below image is from a few days later, a little earlier in the day so fewer cumulus clouds. The hail scars are more clearly visible over southwest Wisconsin as well as in northeast Iowa.



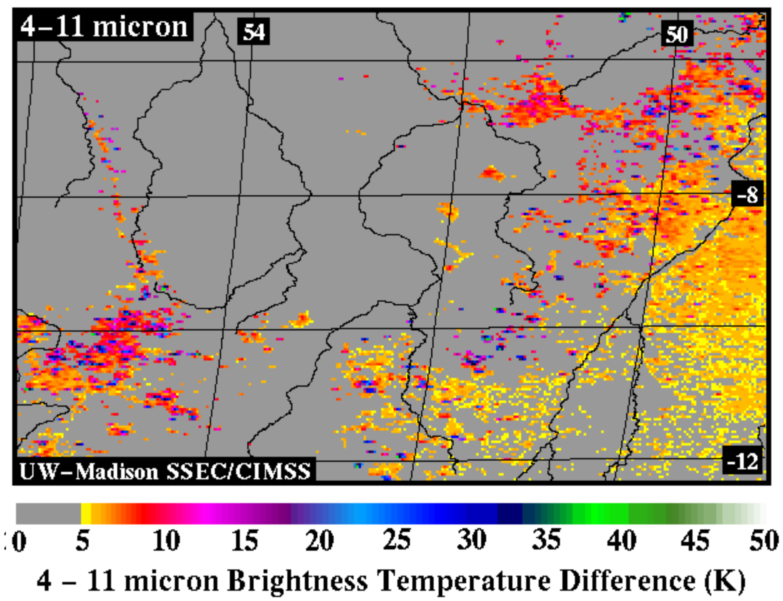
MODIS Fire Product (MOD14)

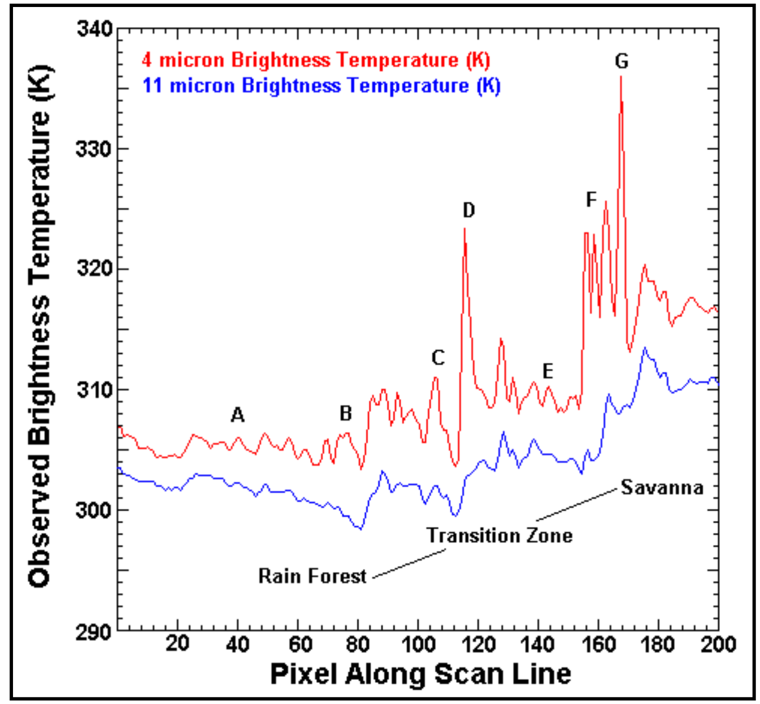
MODIS Fire Product

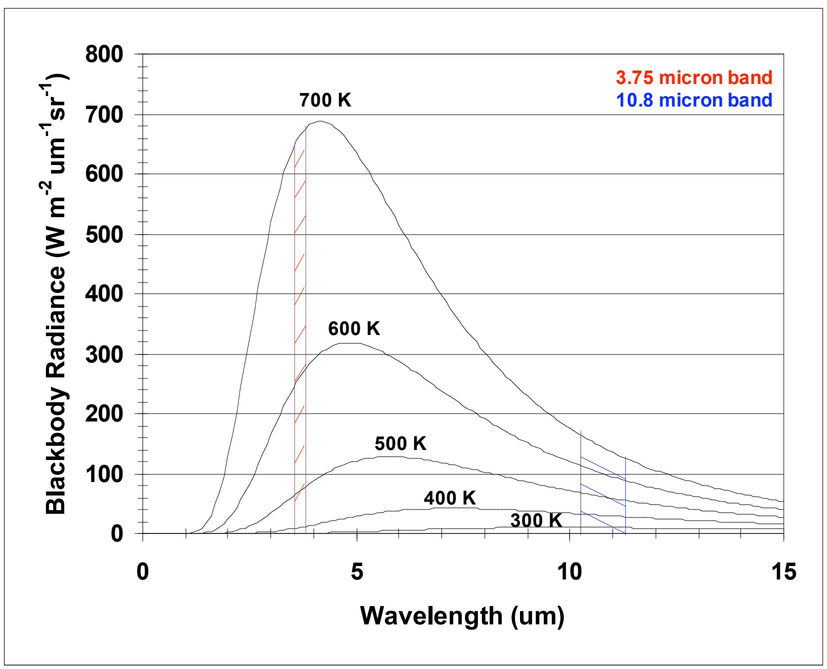
Louis Giglio   Chris Justice

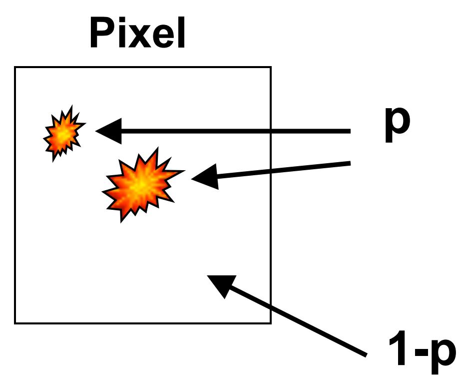
- Based upon the Temperature Sensitivity difference between 4 and 11 microns
- Contextual Fire Detection Algorithm
  - Infrared static Brightness Temperature thresholds
  - Dynamic thresholds compare pixel to surrounding background
- Swath based

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}

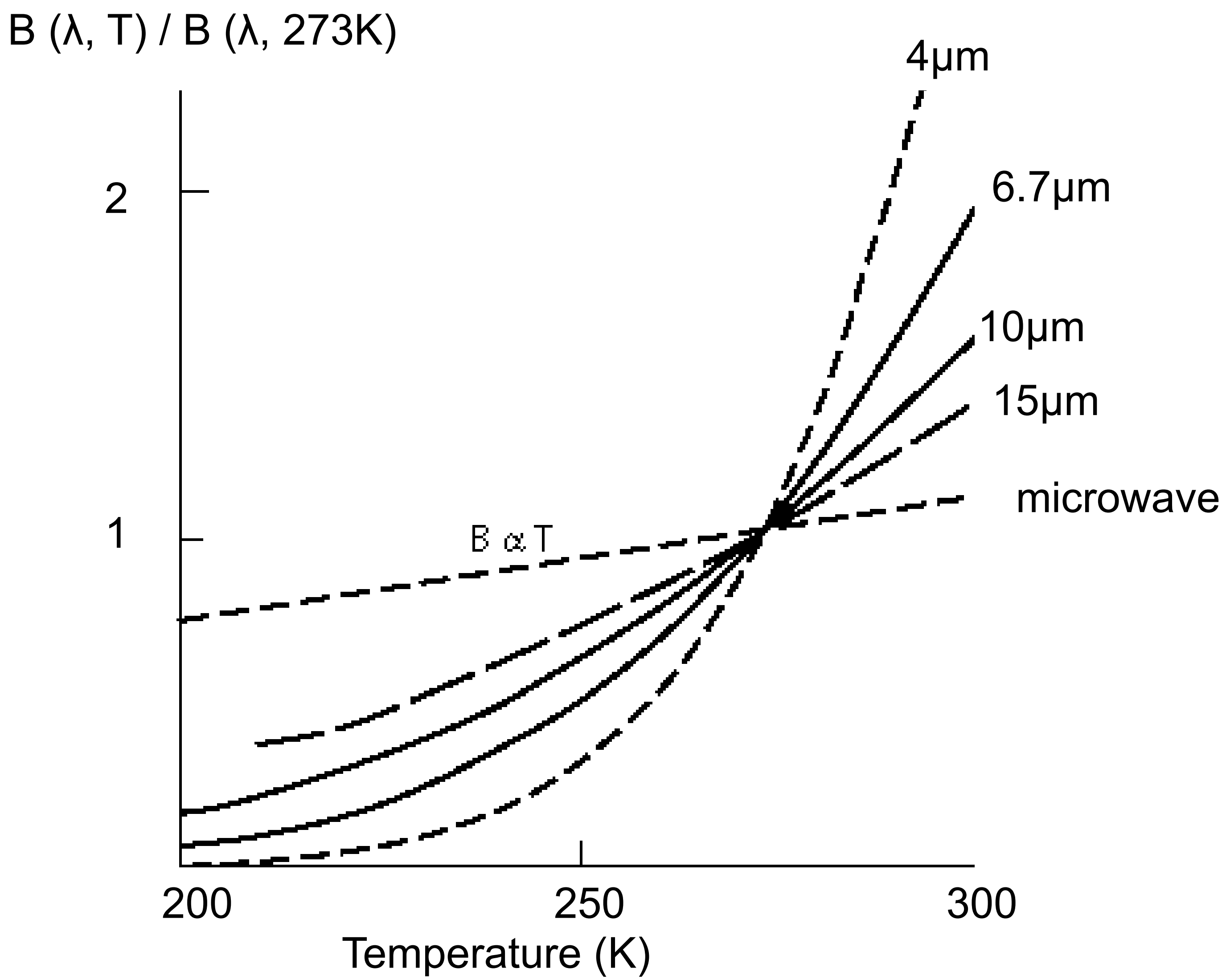
Wavelength	Typical Scene Temperature	Temperature Sensitivity
(4.0 μm)	300	11.99
(11 μm)	300	4.32

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

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

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 $\rightarrow$ 0.15

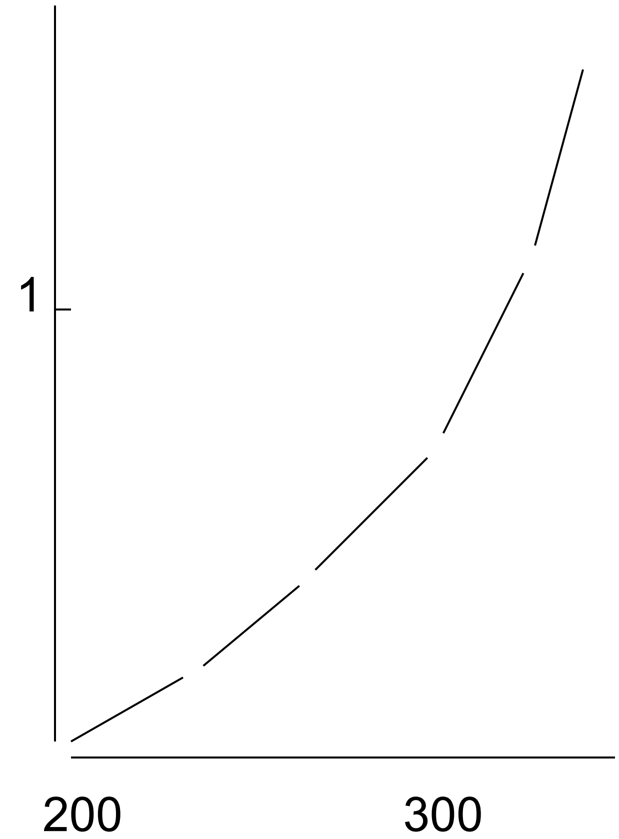
B(10 um,220)= 1.7 $\rightarrow$ 0.28

B(10 um,240)= 3.0 $\rightarrow$ 0.49

B(10 um,260)= 4.7 $\rightarrow$ 0.77

B(10 um,280)= 7.0 $\rightarrow$ 1.15

B(10 um,300)= 9.9 $\rightarrow$ 1.62



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

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

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

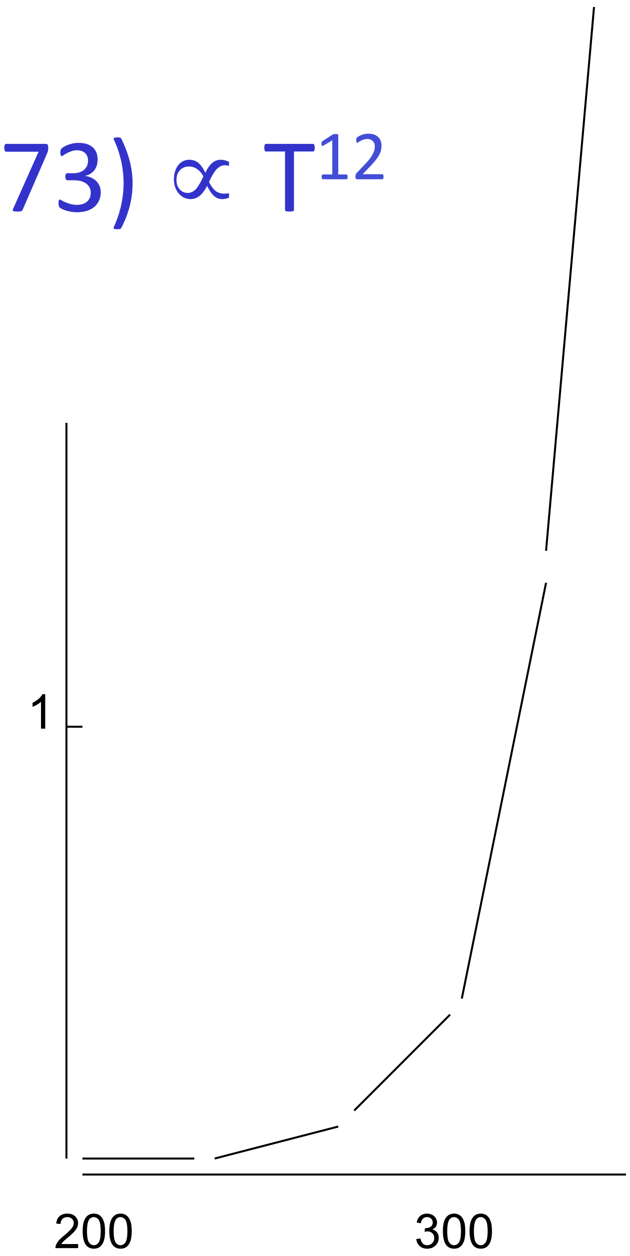
$B(4\ um,220) = 9.2 \times 10^{-3} \rightarrow 0.0$

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

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

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

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



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)

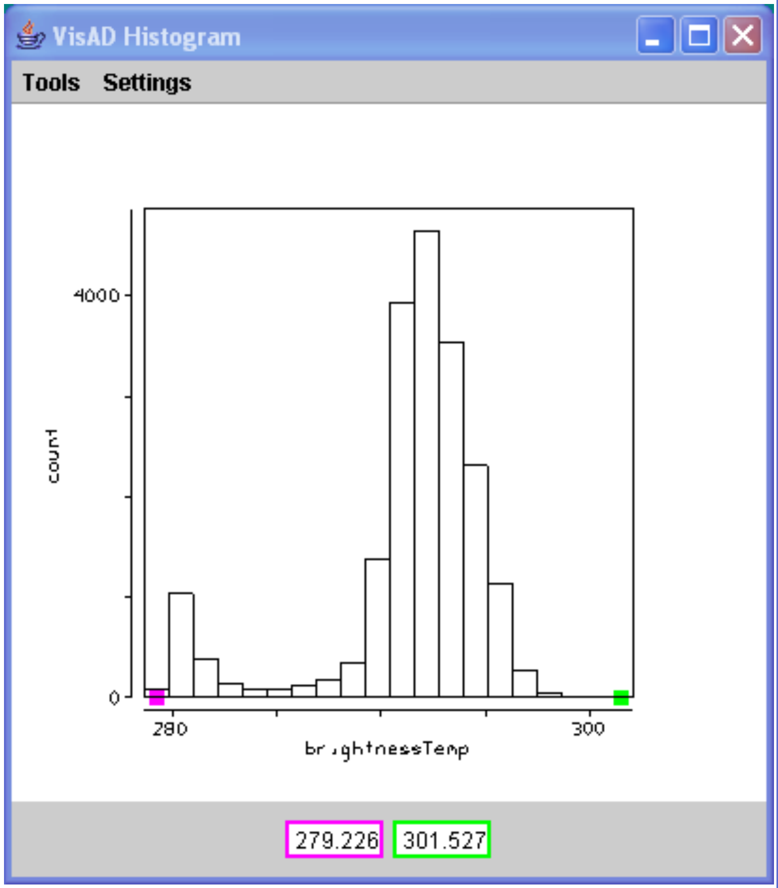
Algorithm Description

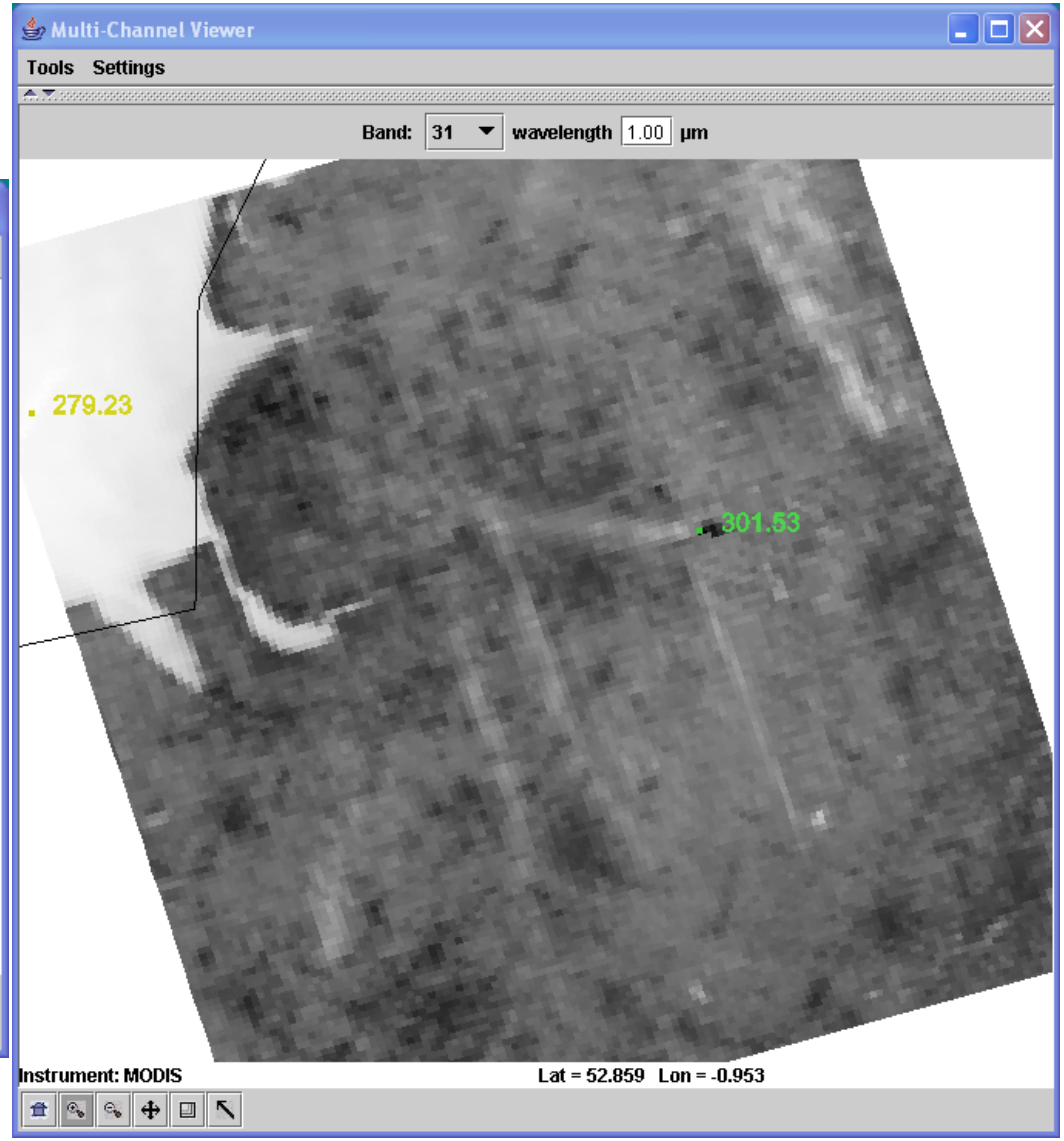
- MODIS bands 21 and 22 (3.99 micron)
  - Band 22 saturates at 331 K
  - Band 21 “fire channel” saturates at ~ 500 K
    - 12 bit range broader – less sensitive
    - The calibration of B21 uses fixed calibration coefficients and not using the scan-by-scan onboard black body (more noise)
    - So use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

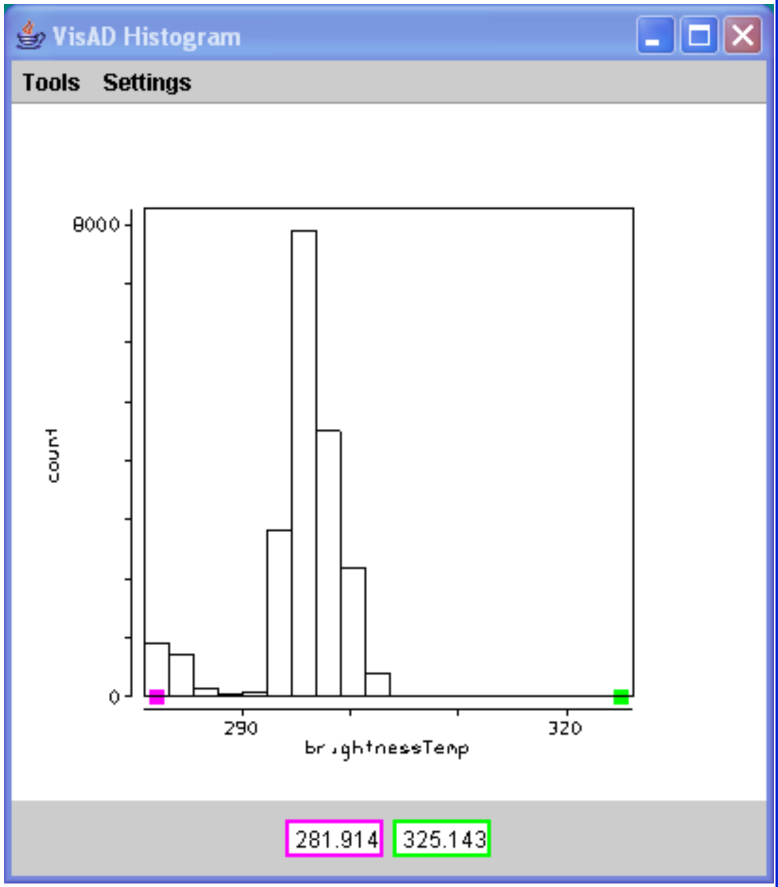
Aqua MODIS true color image 18 April 2003 12:45 UTC

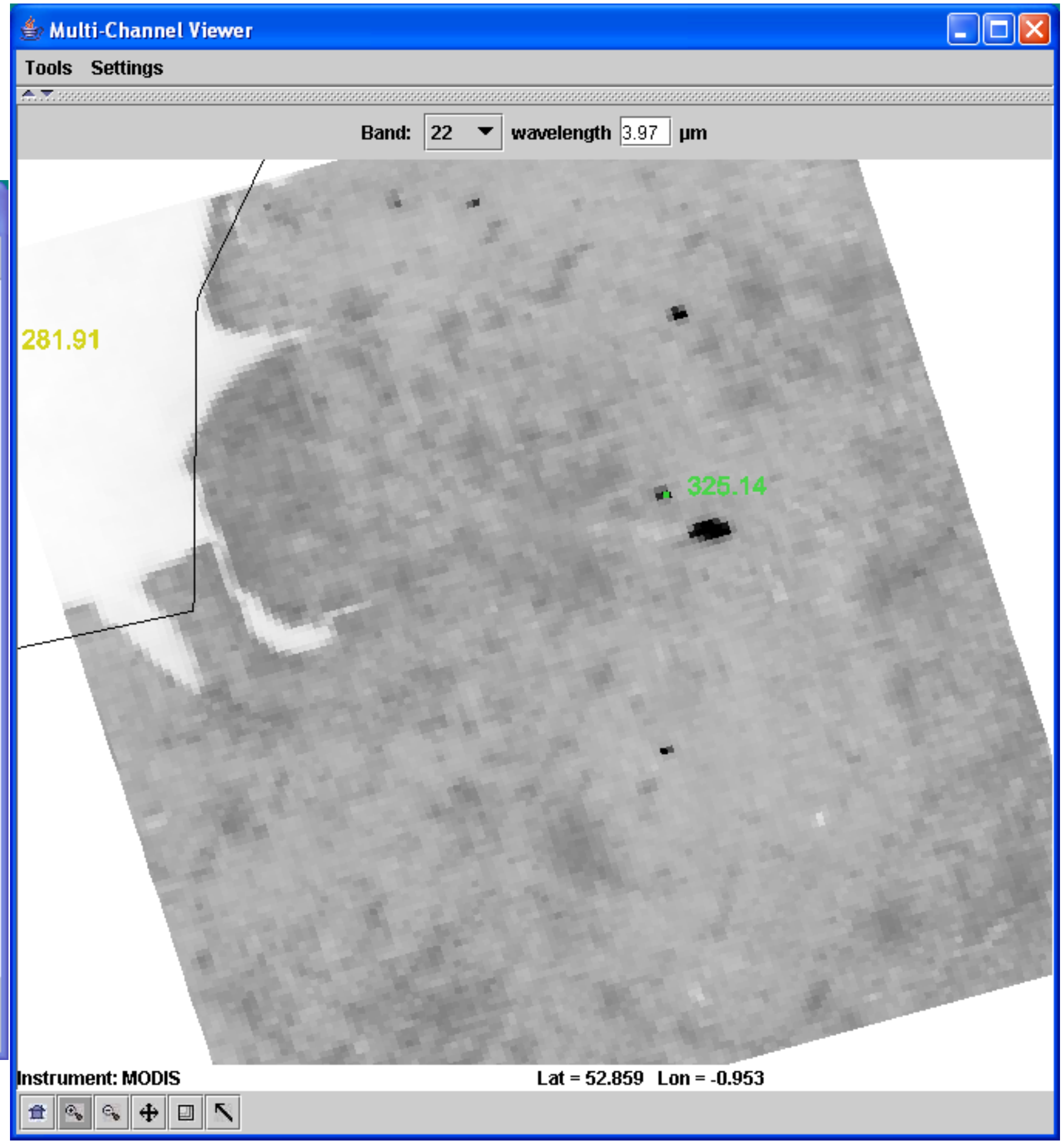
Band 31 Example



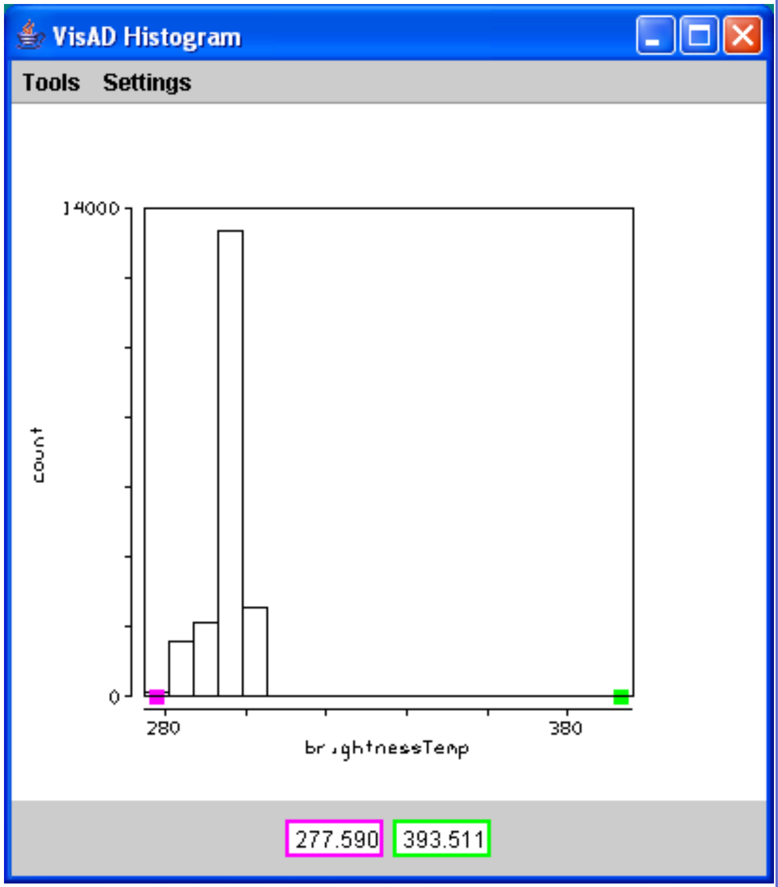


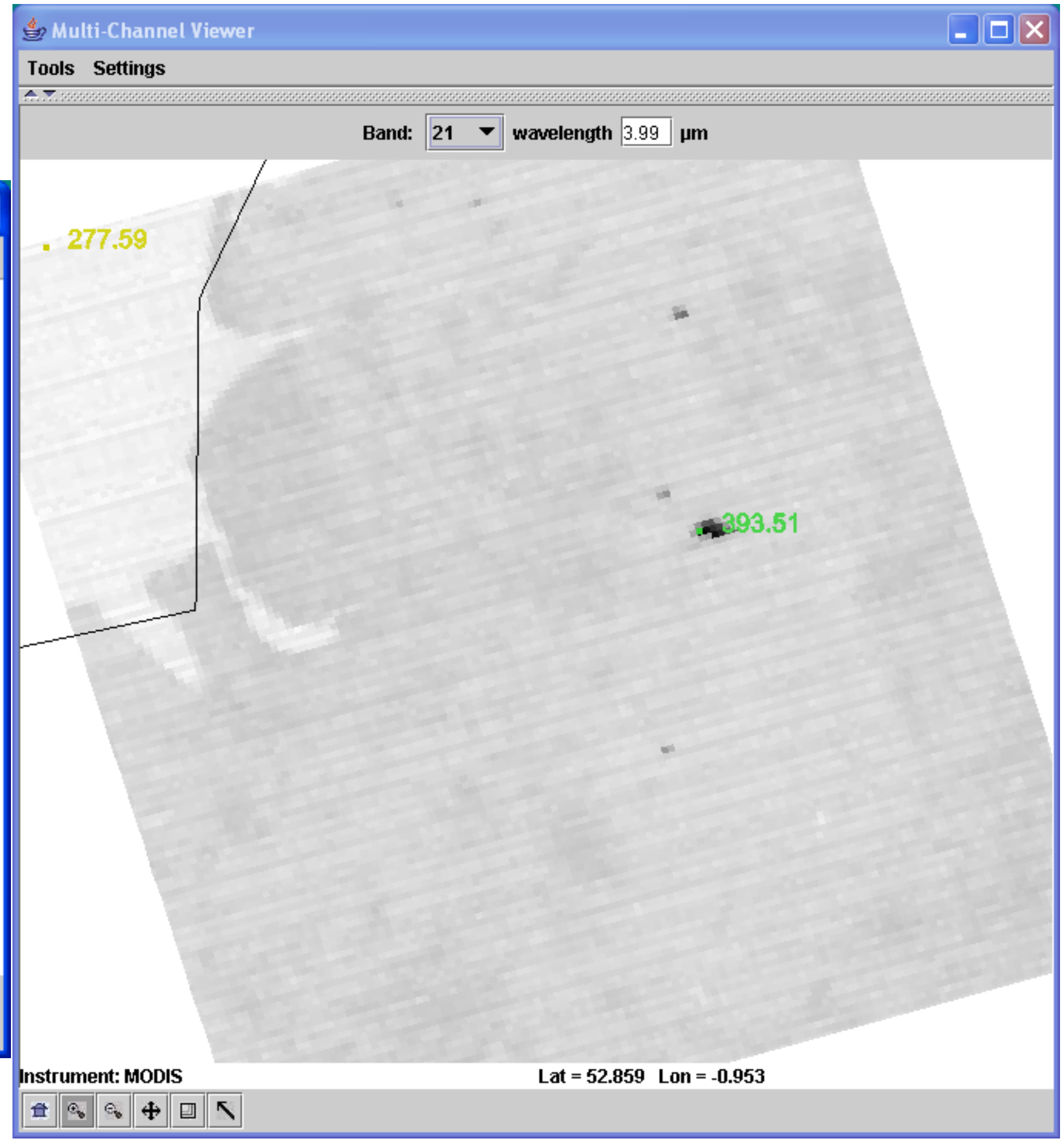
Band 22 Example



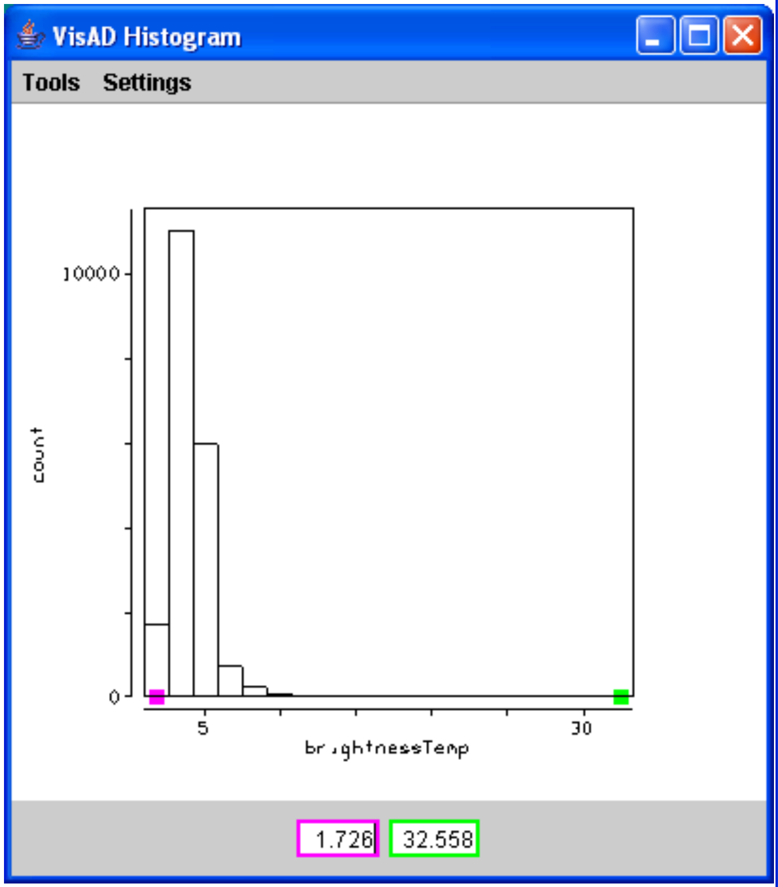


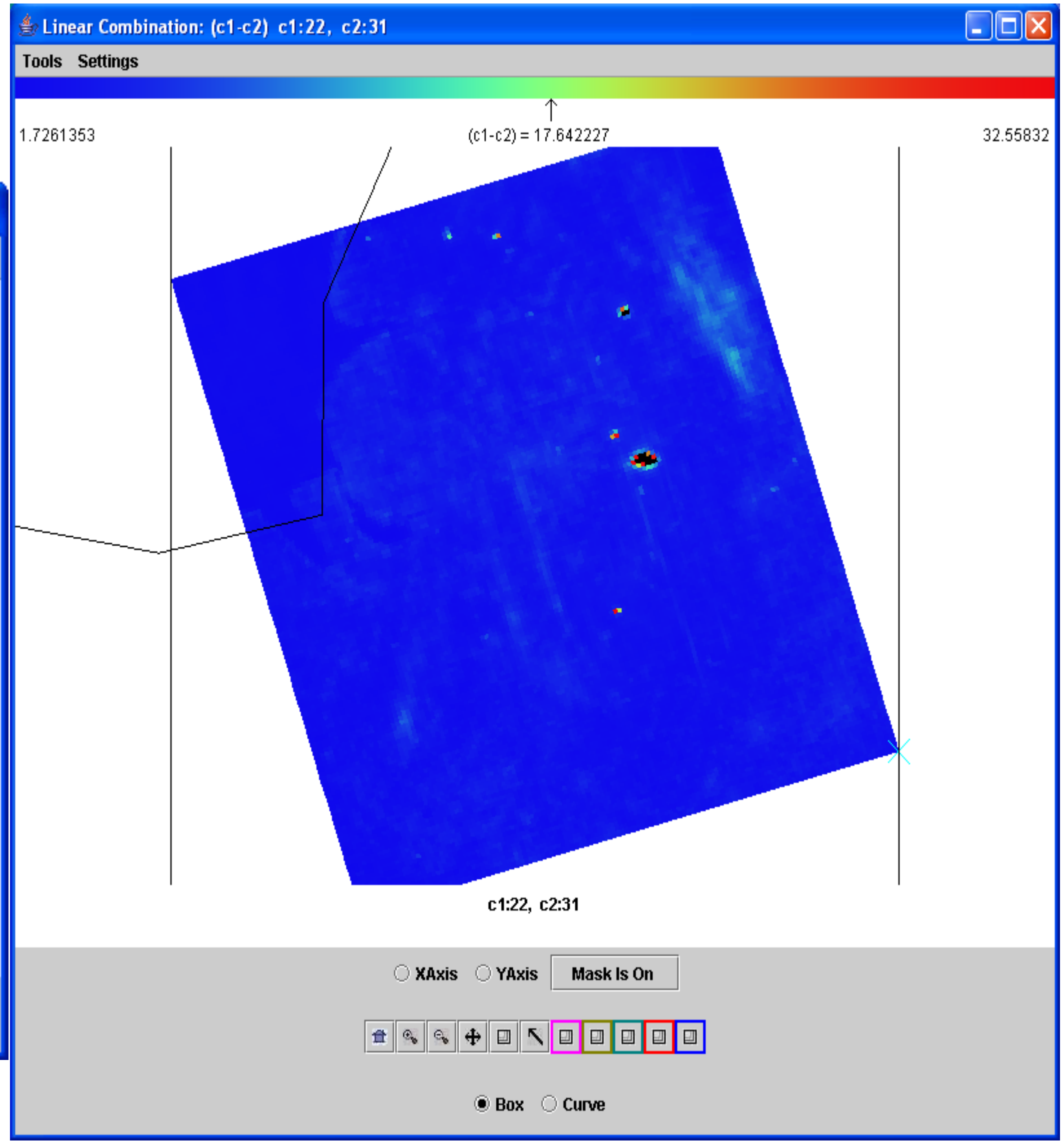
Band 21 Example



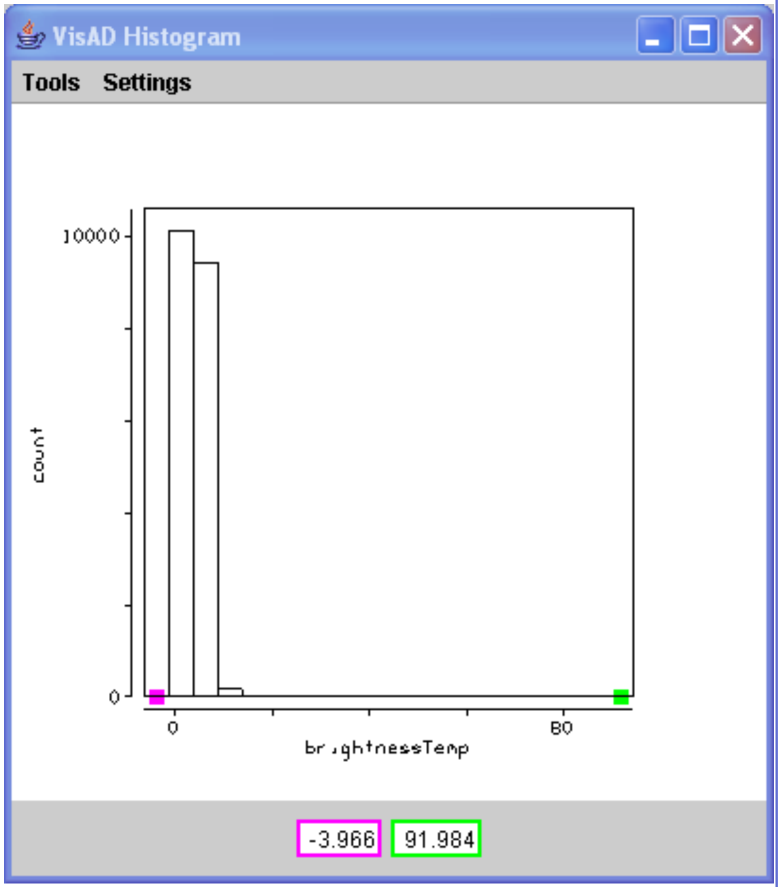


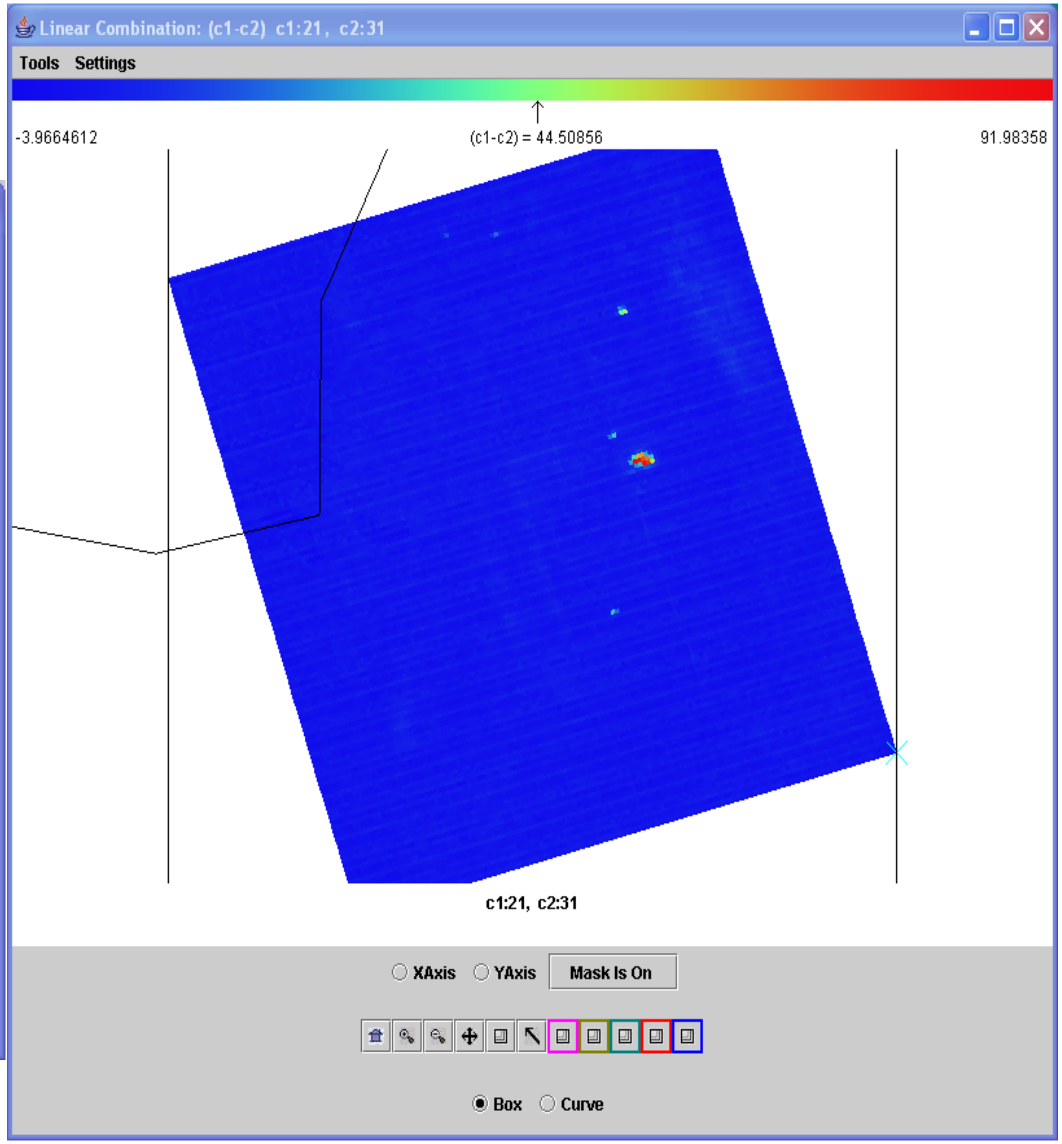
Band 22 – Band 31 Example



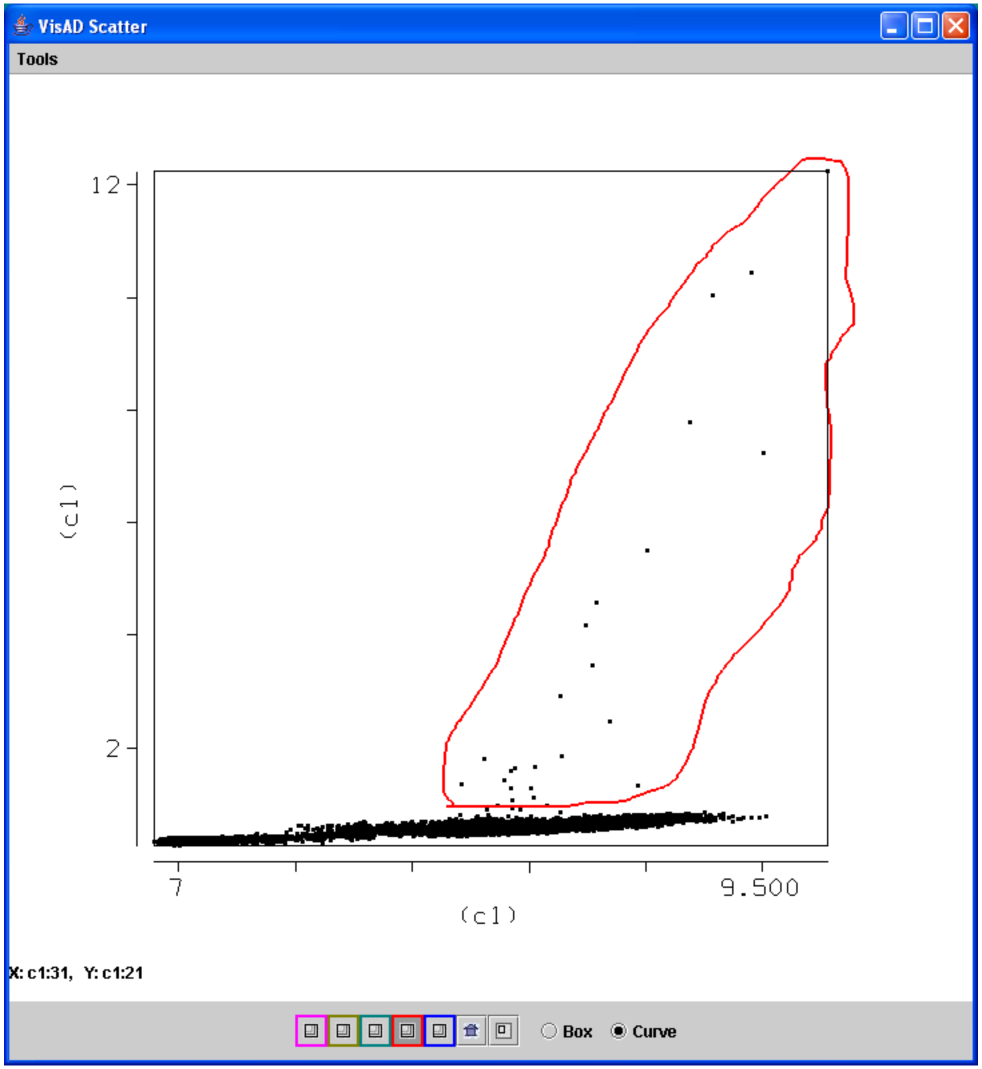


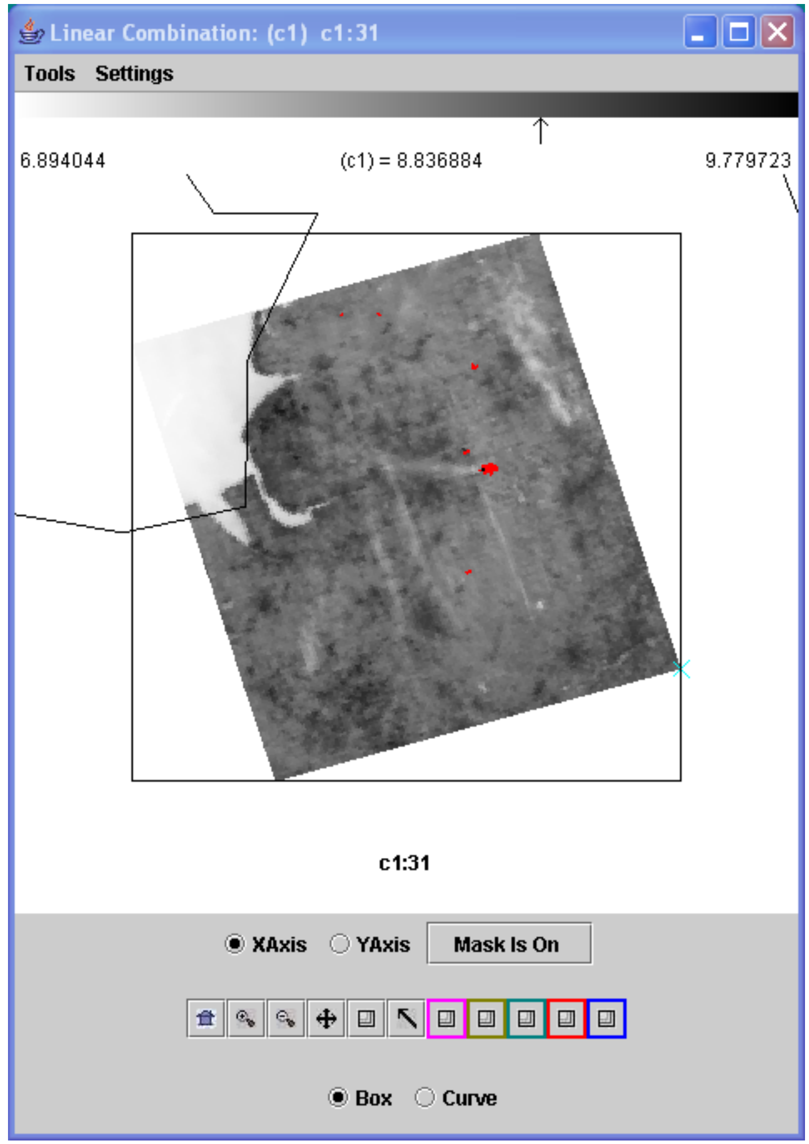
Band 21 – Band 31 Example





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

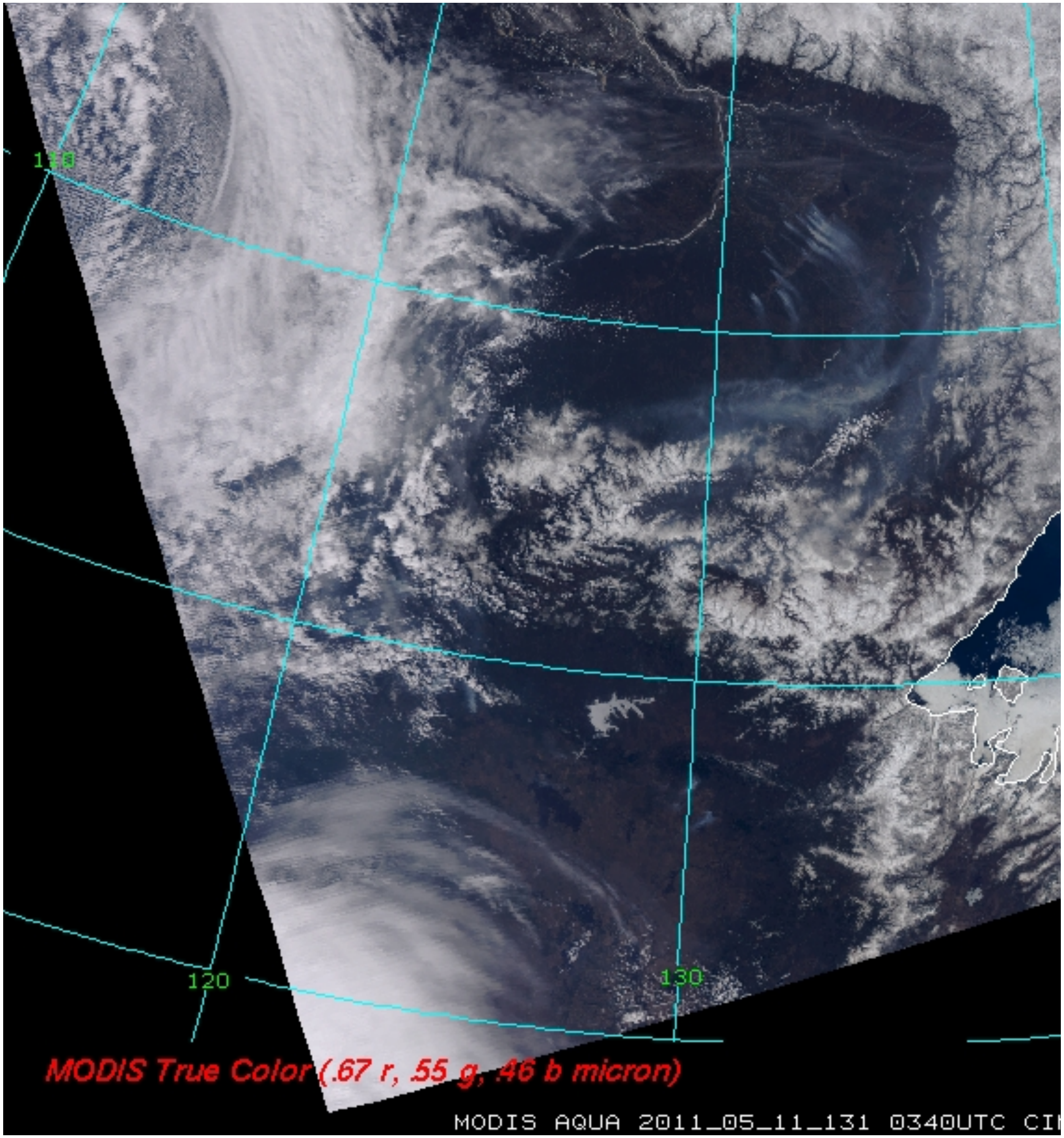
(6) $\partial_4' > 5K$

Where δ is the Mean Absolute Difference (MAD):

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

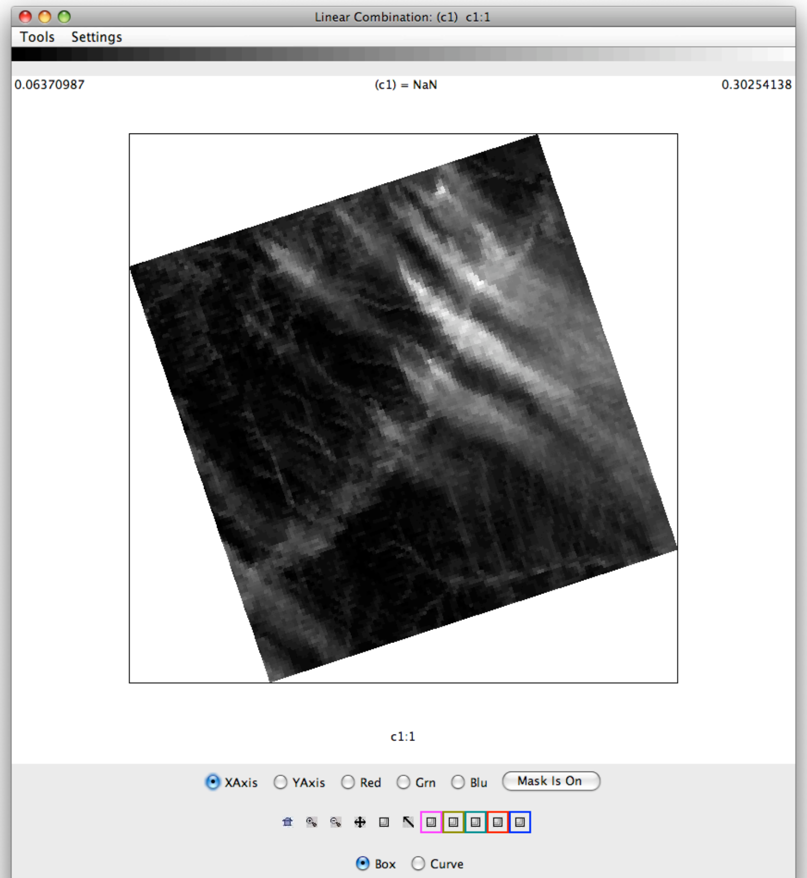
Problem Areas

- 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



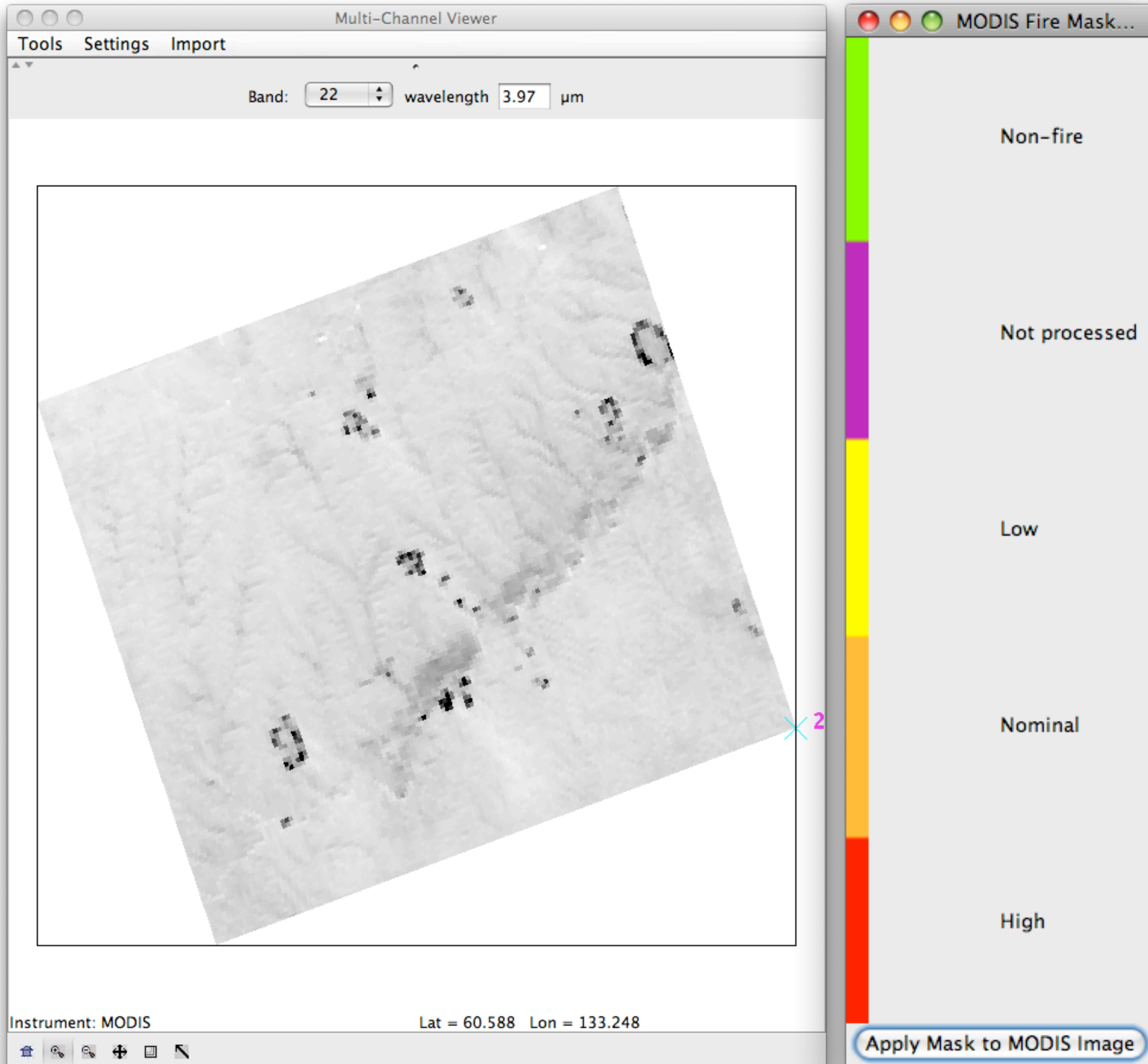
110
120
130
MODIS True Color (.67 r, .55 g, .46 b micron)
MODIS AQUA 2011_05_11_131 0340UTC CI

Aqua MODIS Aerosol/Fire Case Study
11 May 2011 03:40 UTC



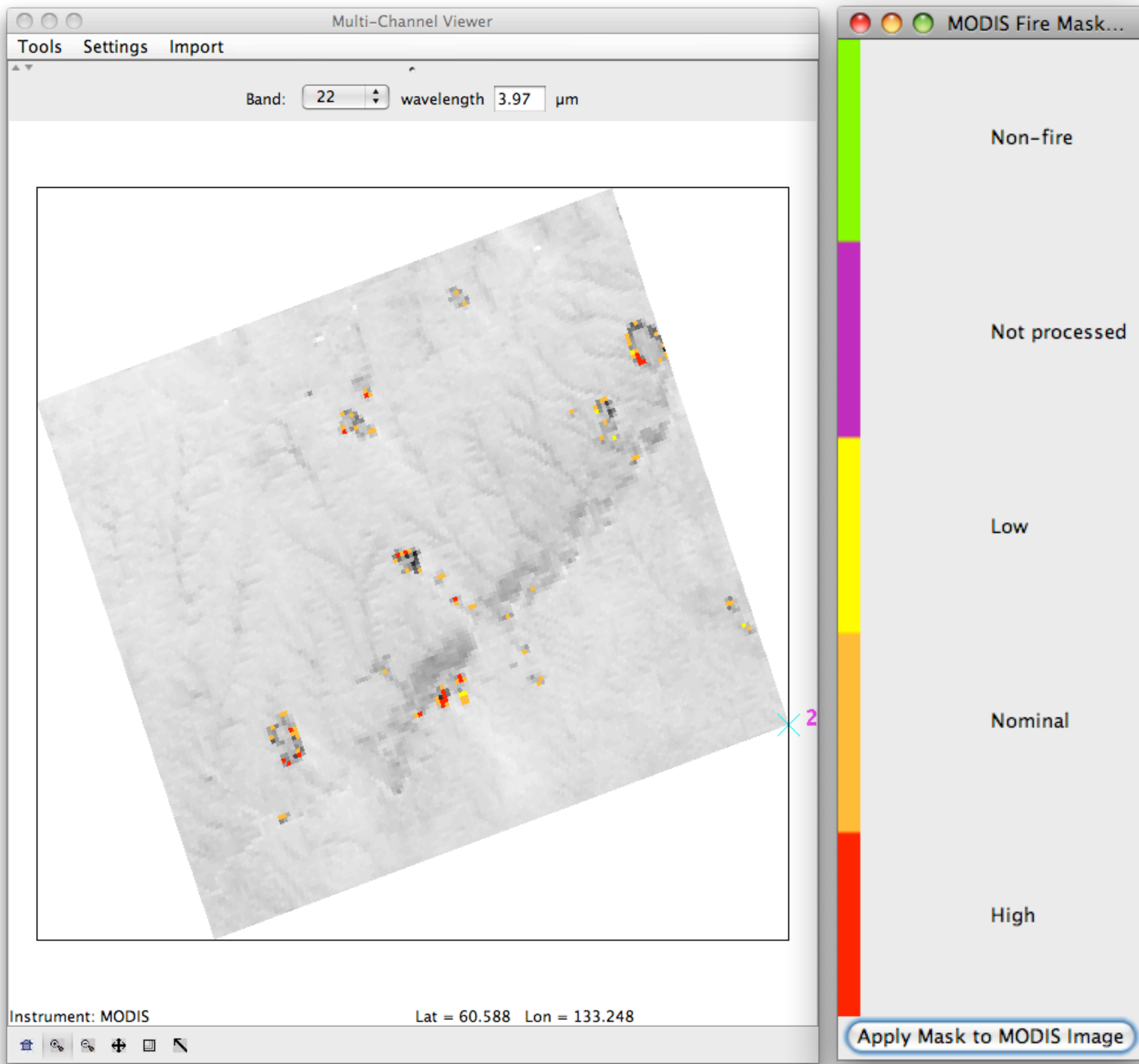
MODIS Fire Product

11 May 2011
03:40 UTC
Aqua MODIS



MODIS Fire Product

11 May 2011
03:40 UTC
Aqua MODIS



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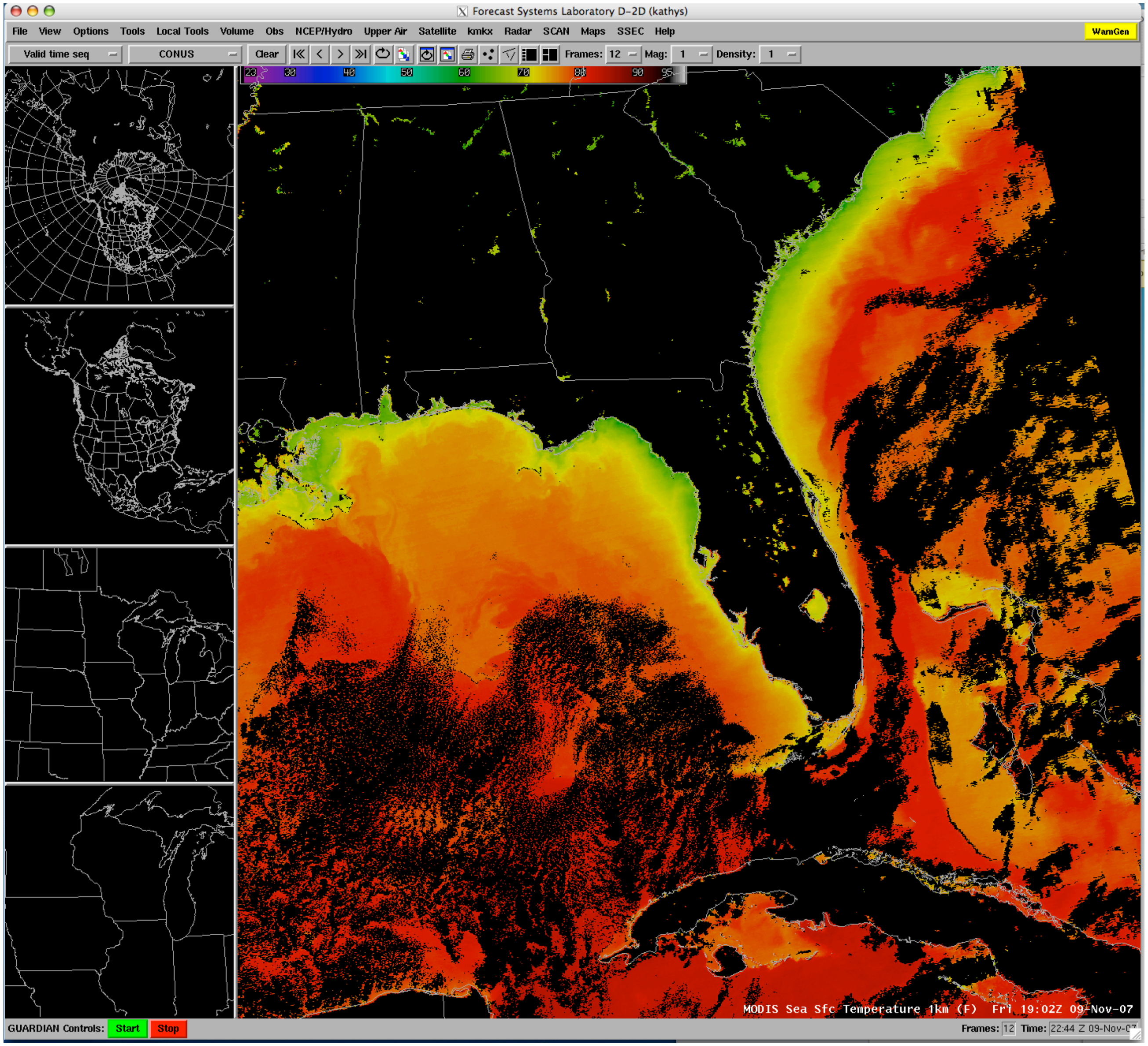
MODIS Ocean Products

MODIS Sea Surface Temperature viewed in AWIPS



MODIS Sea Surface Temperature used by Forecasters

AREA FORECAST DISCUSSION...UPDATED
NATIONAL WEATHER SERVICE MILWAUKEE/SULLIVAN WI
338 AM CDT TUE MAY 31 2011

UPDATED TO ADD TODAY/TONIGHT AND AVIATION/MARINE SECTIONS

.MARINE...CLEAR MODIS IMAGE FROM MONDAY EARLY AFTN SHOWED SHALLOWER NEAR SHORE WATERS HAD WARMED INTO THE LOWER 50S...WHILE MID LAKE TEMPS REMAINED IN THE MID 40S DUE TO OVERTURNING. TIGHTENING PRESS GRADIENT THIS MORNING AND SUNSHINE WILL RESULT IN STRONG MIXING EARLY THIS MRNG. HENCE WL BUMP UP START OF SMALL CRAFT ADVY SEVERAL HOURS...AND RUN INTO THE EVE. FEW GUSTS NEAR THE SHORE MAY REACH 30-35 KNOTS LATER THIS MRNG/ EARLY AFTN.

MODIS Sea Surface Temperature