# MODIS and VIIRS Data Environmental Applications: Part 2

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Hawaii Direct Broadcast Polar Orbiter Workshop

University of Hawaii Manoa

21 August 2013

# Aviation Applications

Turbulence, Clouds

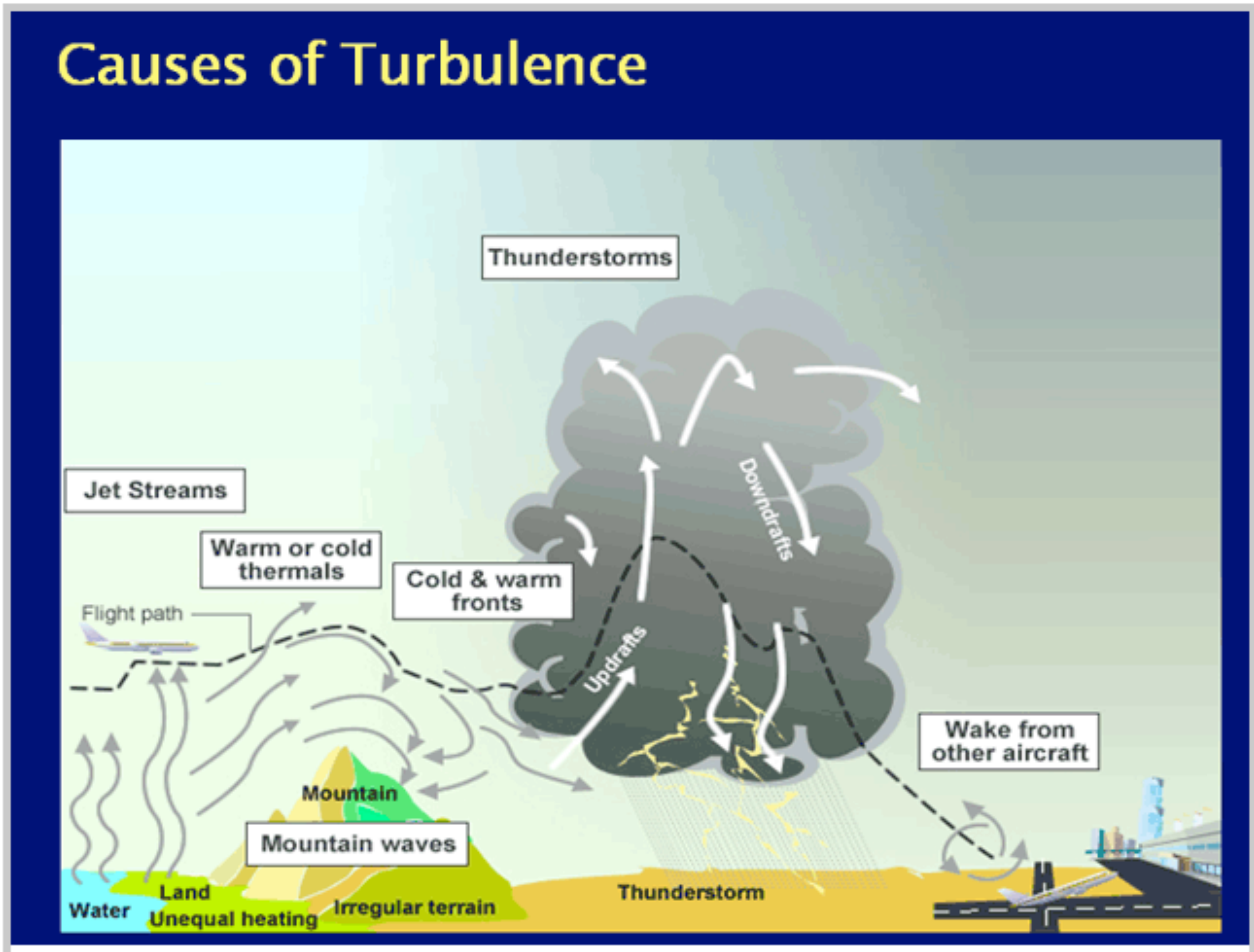
# Atmospheric Turbulence

## What is Turbulence?

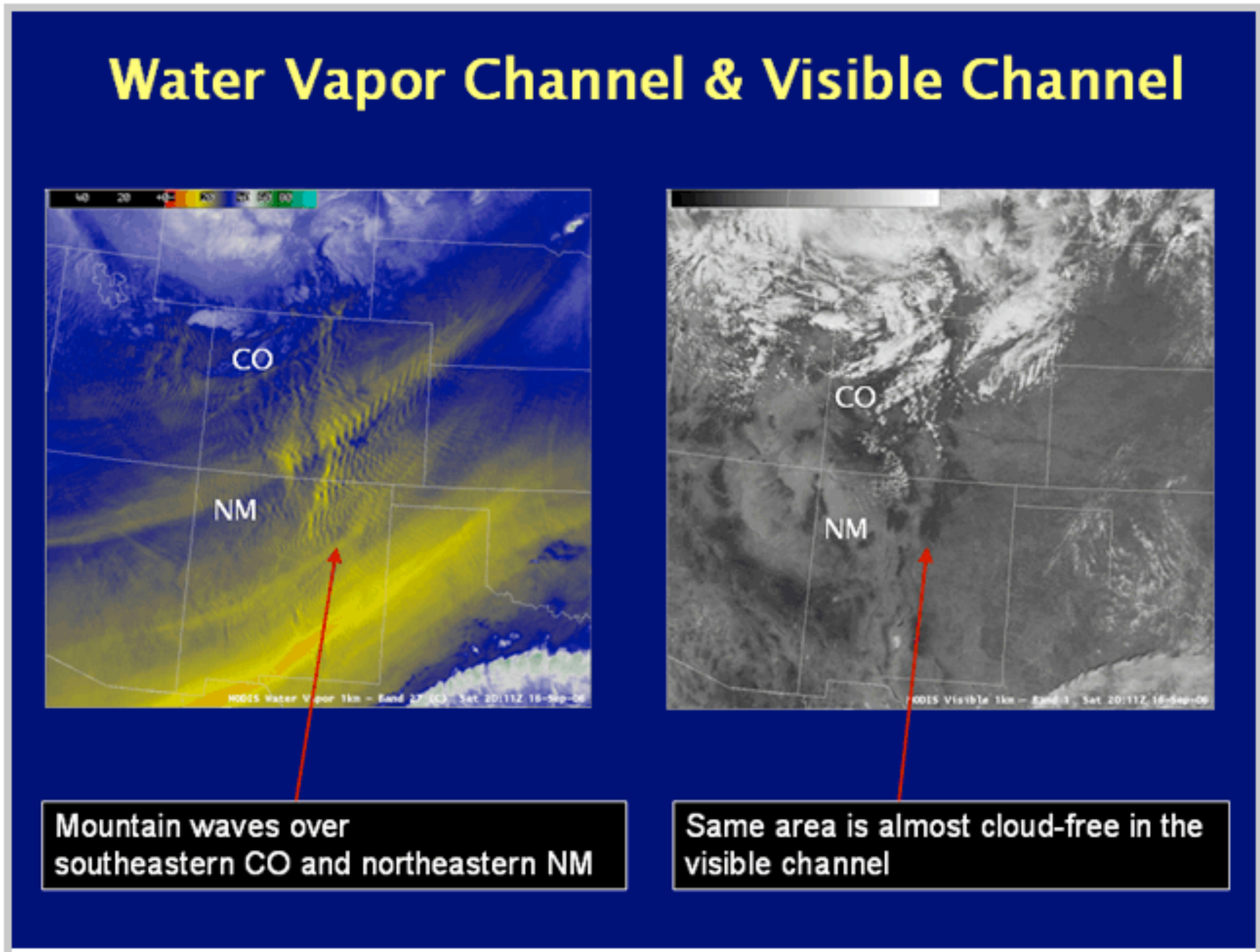
This smoke pattern shows turbulence as rapid, abrupt and chaotic changes in the speed and direction of air flow.

Colored smoke is used to show "wake turbulence" generated by an aircraft upon take-off or landing.

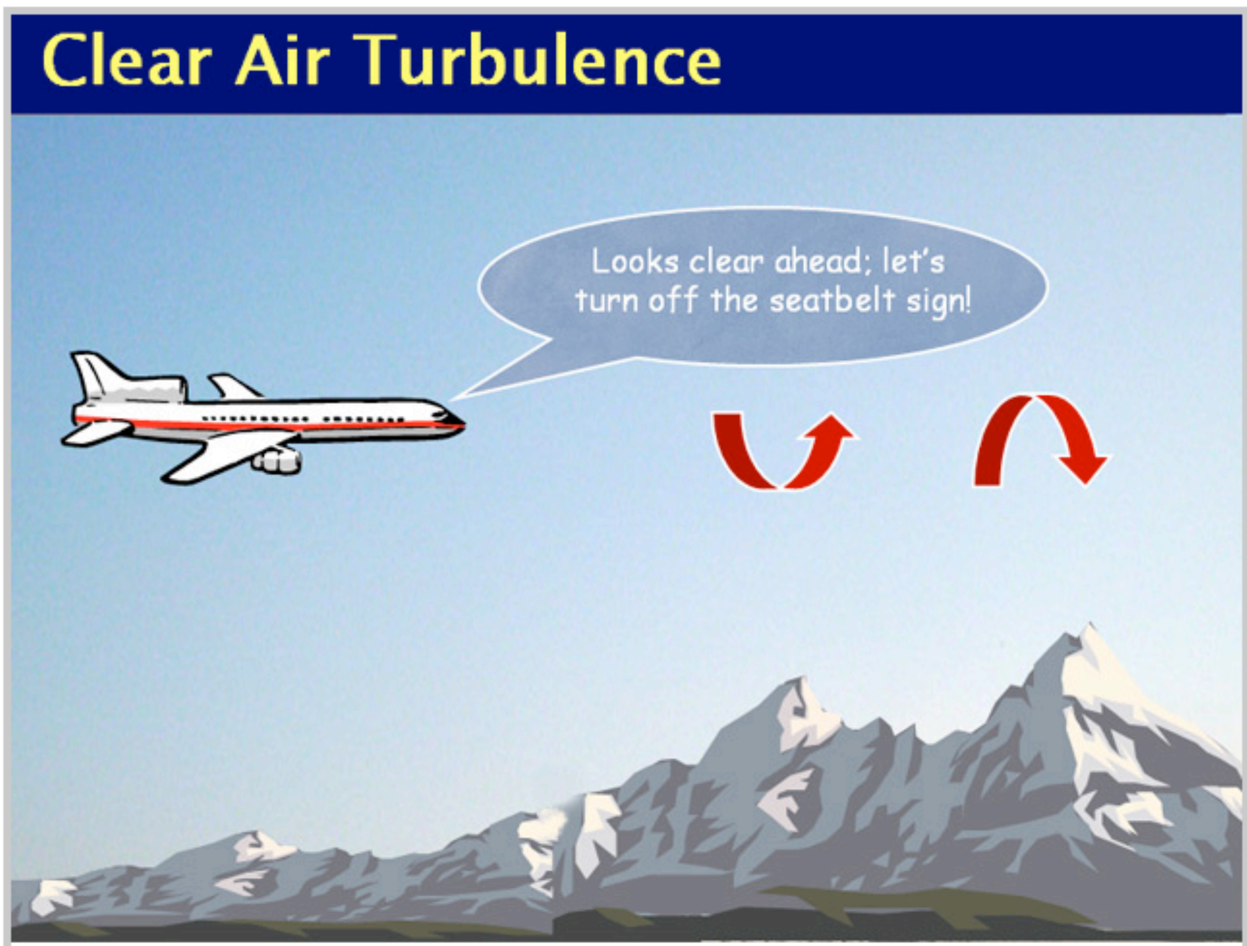
# Atmospheric Turbulence



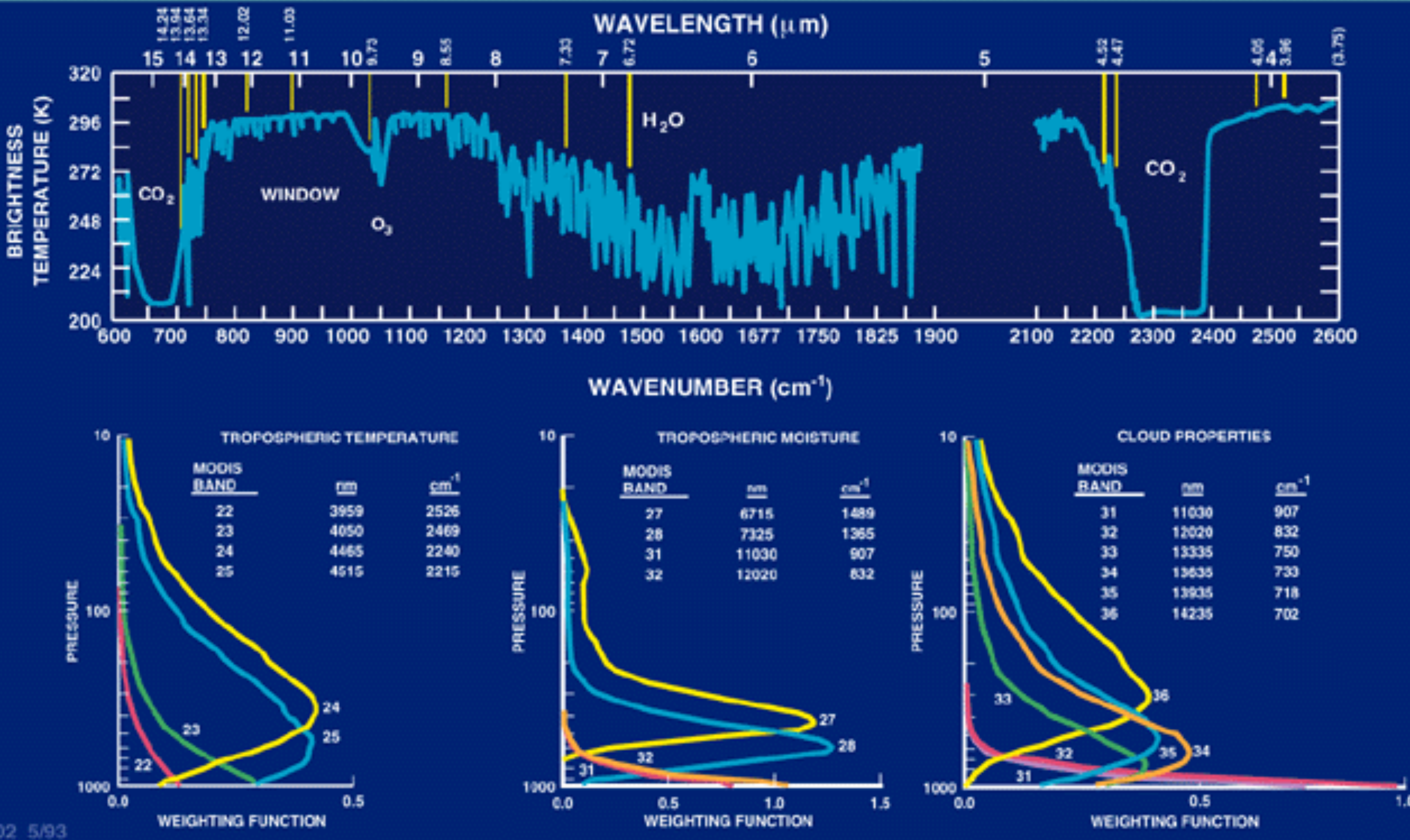
# Why is 6.7 μm Important for the Detection of Turbulence?



# Why is This Important?



# ATMOSPHERE - THERMAL RADIATION

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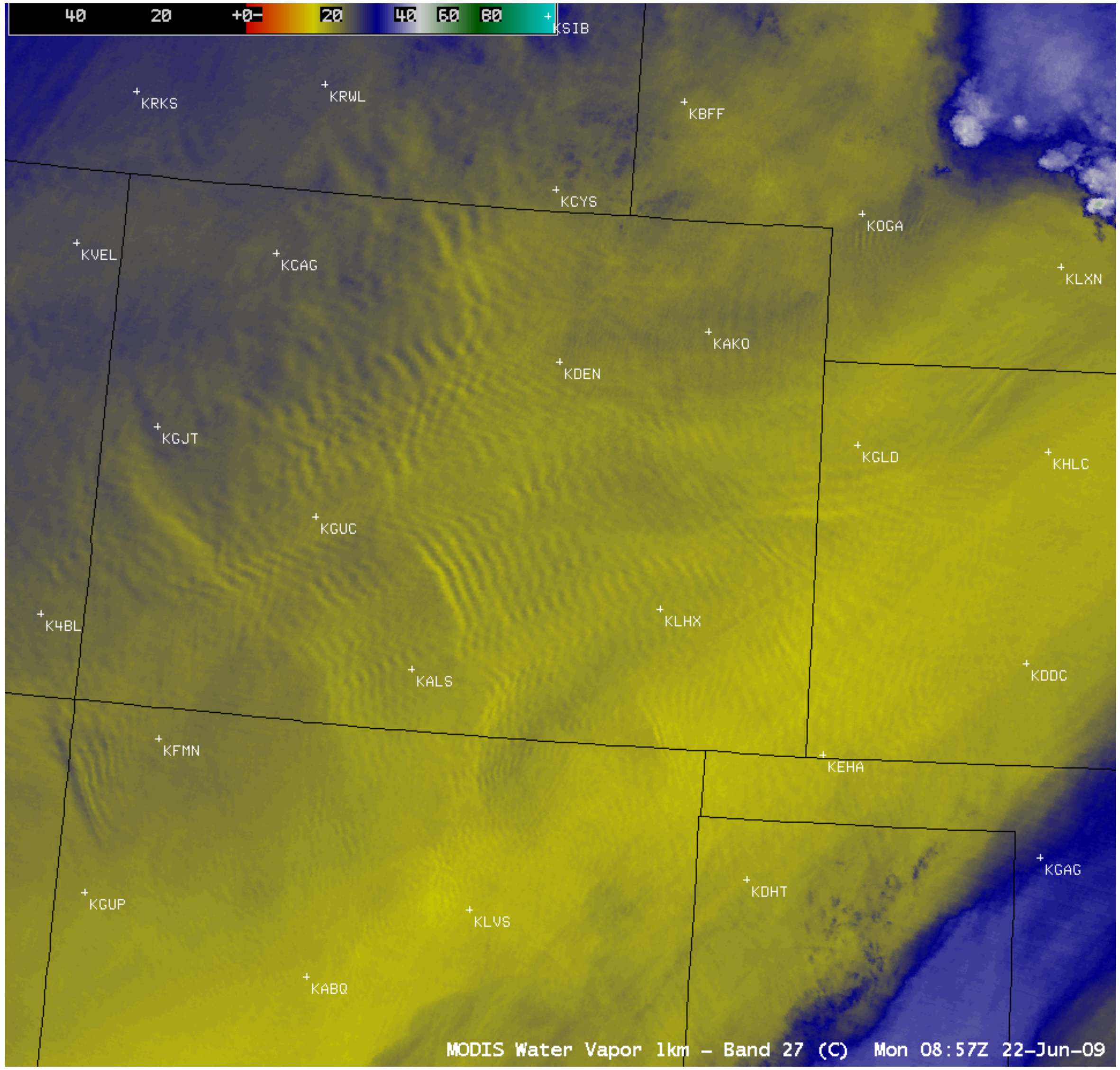
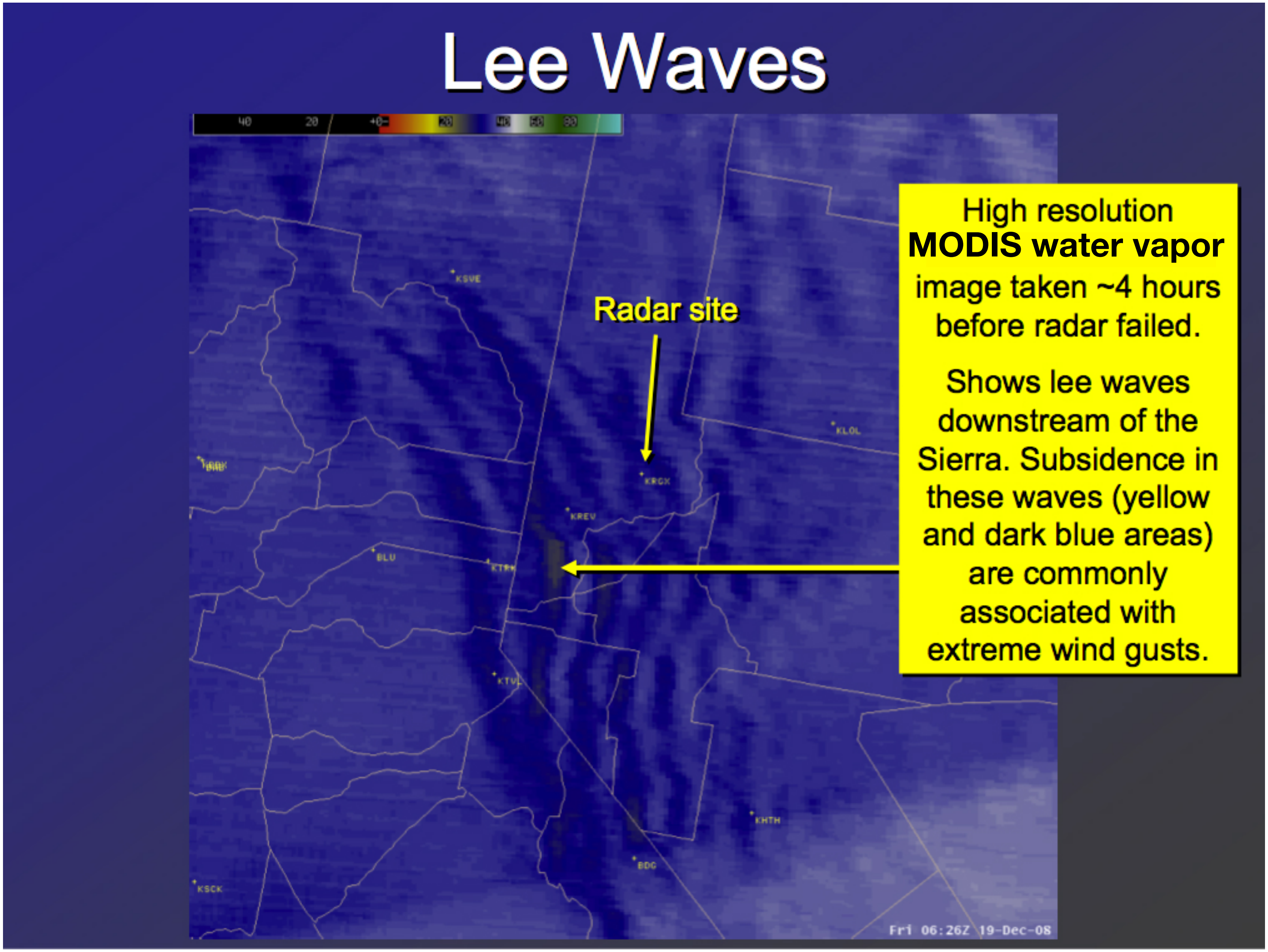
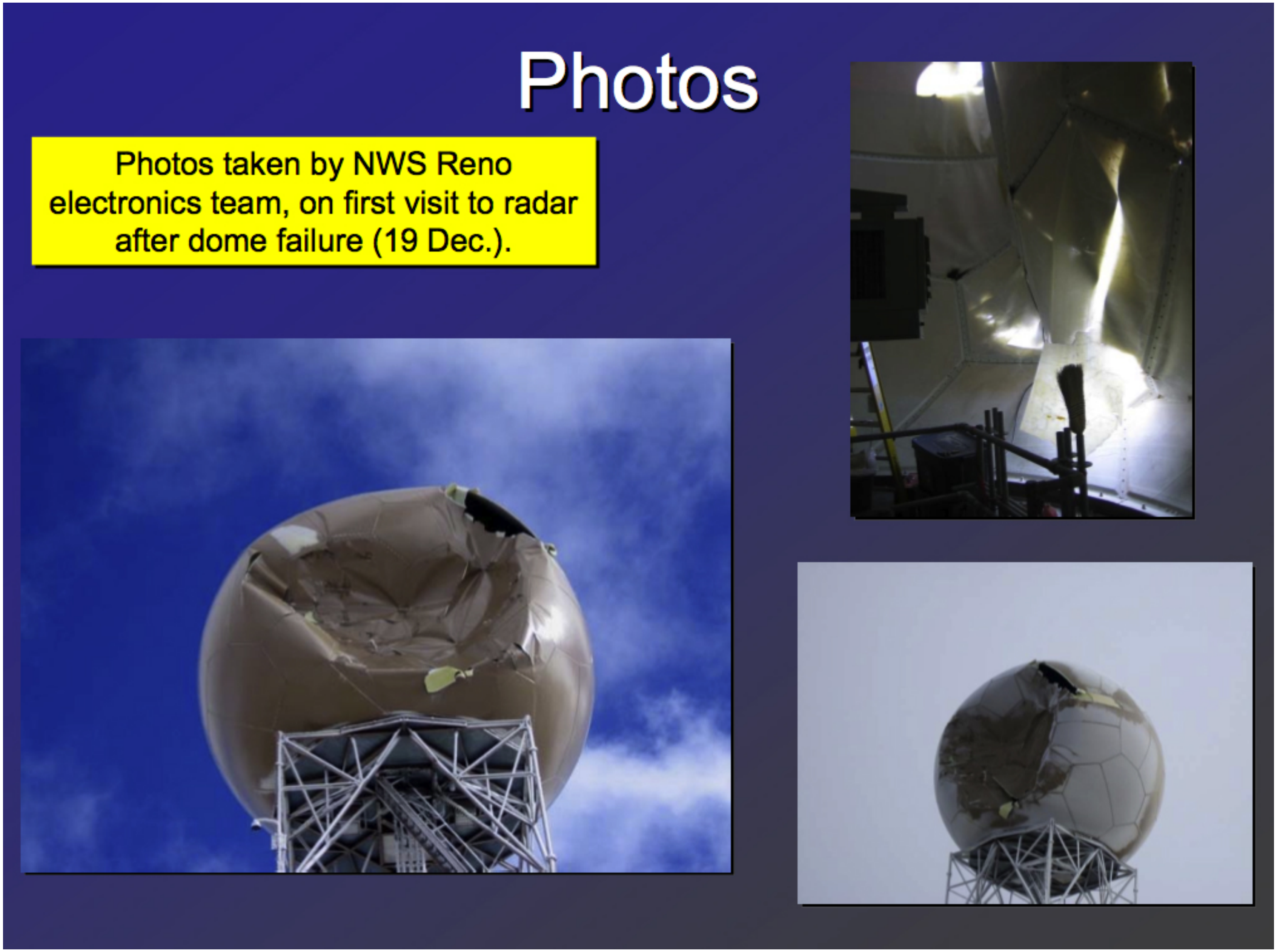
# Mountain Wave Clouds in Clear Air




MODIS and GOES
08:57 UTC
22 June 2009

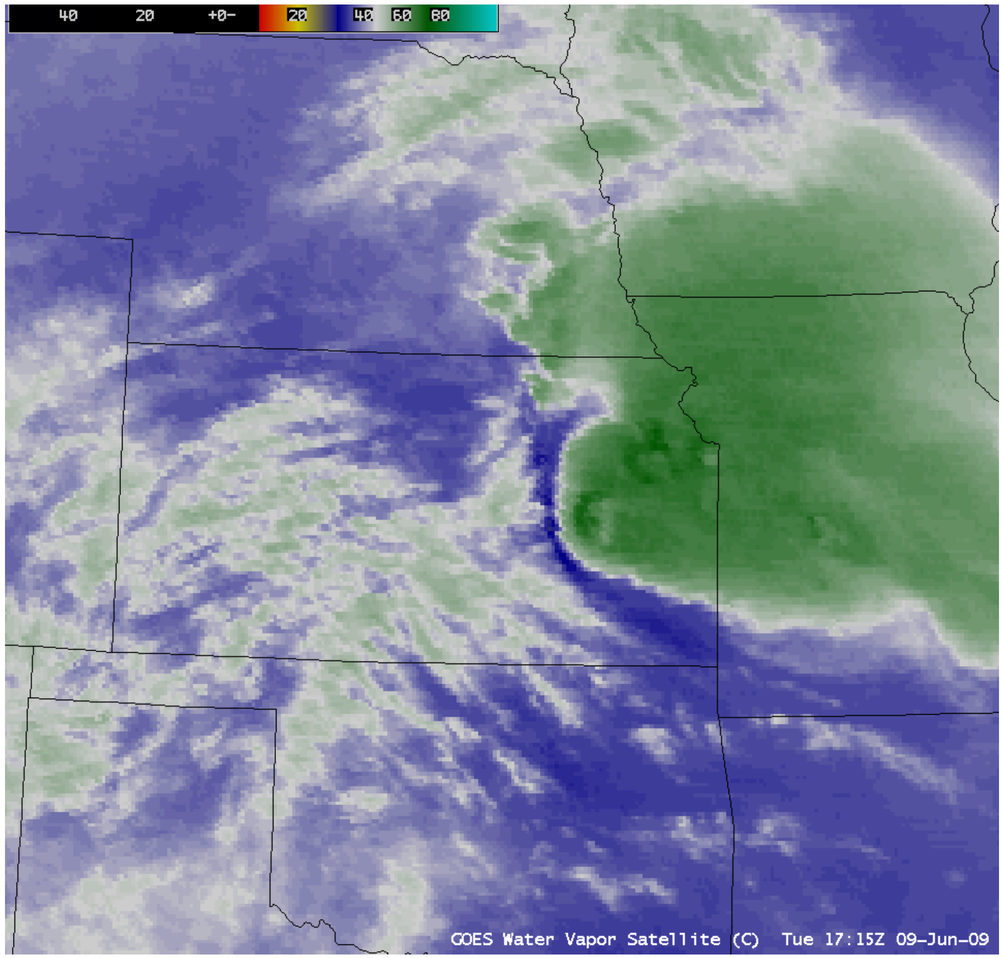



*(credit: NWS forecast office, Reno NV)*



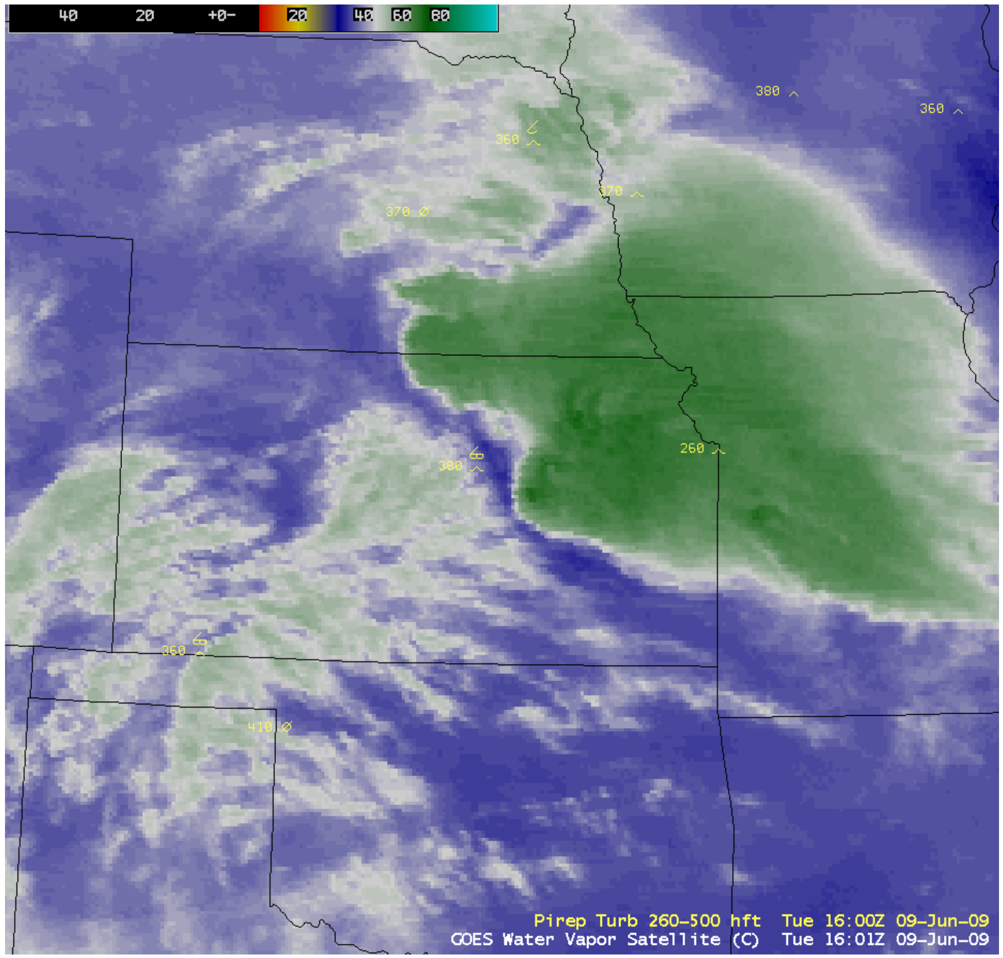

*(credit: NWS forecast office, Reno NV)*

# Turbulence Not Just from Orography



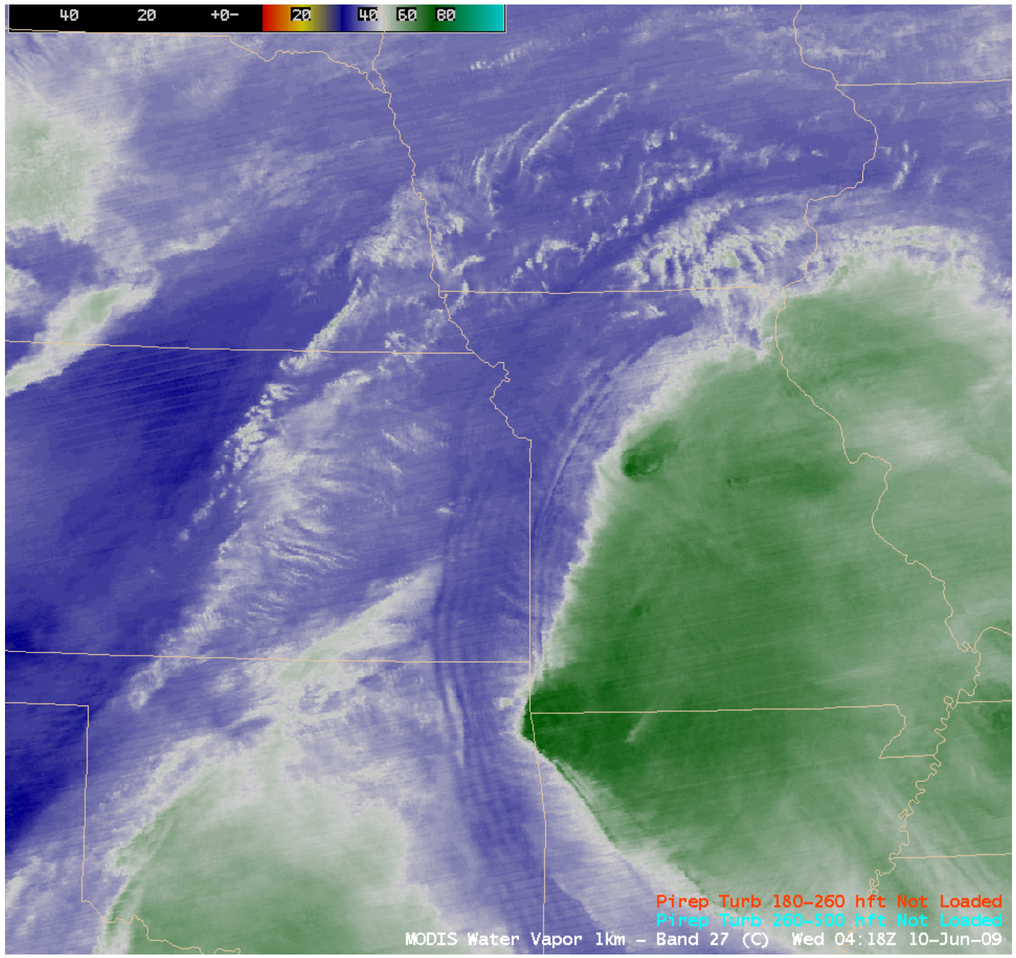

MODIS 6.7μm
Water Vapor
Band
17:15 UTC
9 June 2009

# Pilot Reports of Turbulence




GOES 6.5μm Water Vapor Band 16:00 UTC 9 June 2009

# Turbulence Not Just from Orography




MODIS 6.7 µm Water Vapor Band
04:18 UTC
10 June 2009

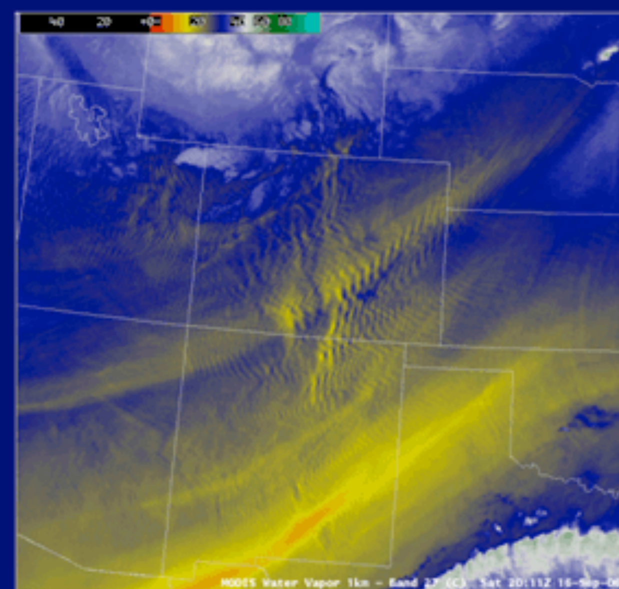
# Why is 6.7 µm Important for the Detection of Turbulence?

## Summary

Turbulence is a significant hazard to aviation, and satellite imagery can sometimes be a helpful tool in turbulence detection.

Mountain waves are one common cause of turbulence, and water vapor channel imagery has the ability to detect areas where this type of turbulence may be present.

The typical "herringbone" signature of mountain waves often occurs in clear (cloud-free) air, making the water vapor channel the only tool for accurate turbulence detection in those cases.



# Cloud Applications Continued

- Clouds
  - Composition
  - Cloud Top Properties
  - Cloud Phase

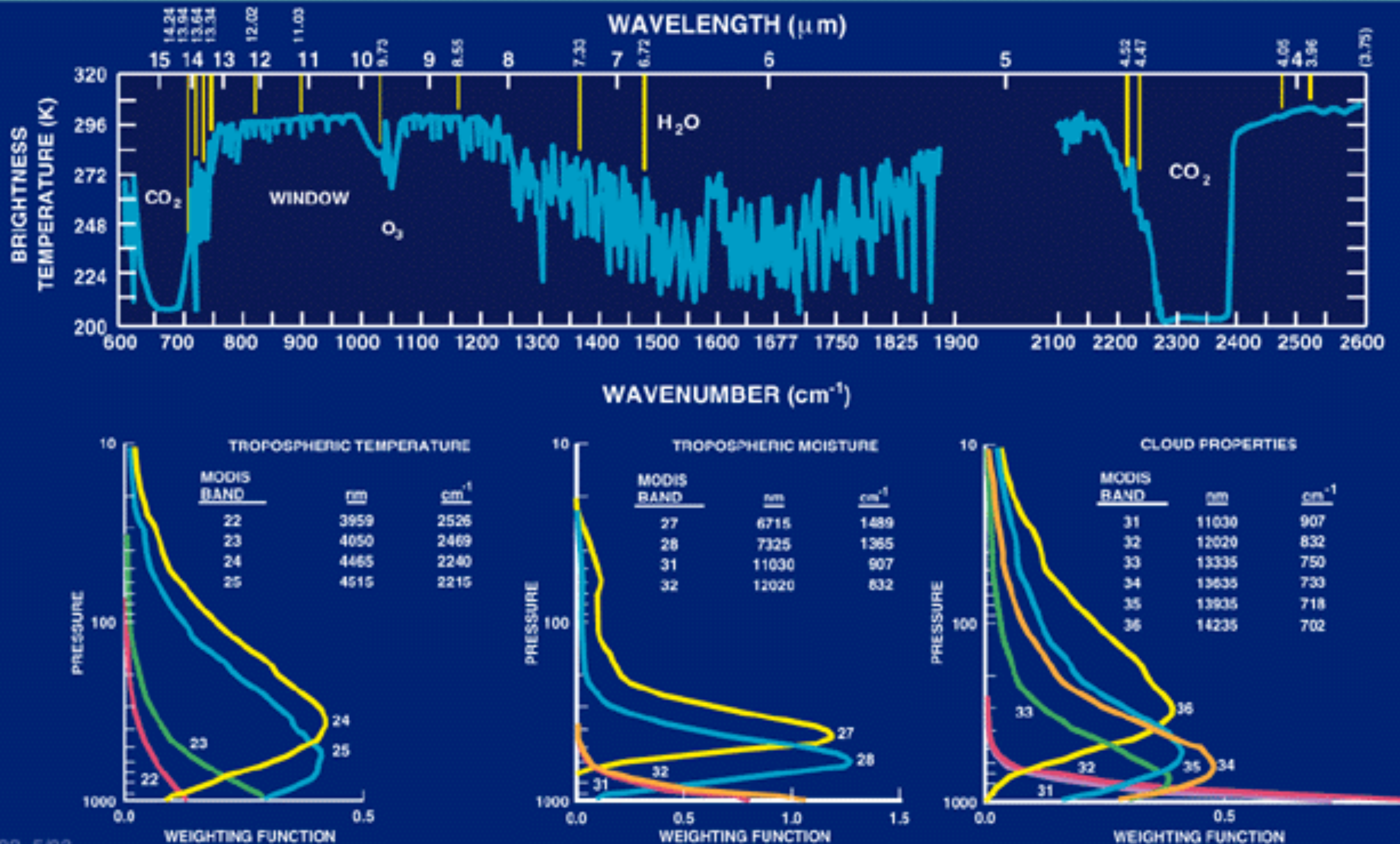
# Clouds

- MOD06 Cloud Product
  Example filename: a1.13214.2325.mod06ct.hdf
  - Cloud Top Properties at 5km
    - Cloud Top Pressure, Cloud Top Temperature, Cloud Fraction, Cloud Emissivity
  - Cloud Phase at 5 km
  - Cloud Optical Properties at 1 km (Daytime only)
    - Cloud Effective Radius
    - Cloud Optical Thickness

# Cloud Top Property Algorithm

- Cloud Top Pressure, Temperature, Emissivity derived using $CO_2$ "slicing"
- MODIS product utilizes 4 spectral channels in the 13 – 14 μm region.
- 5x5 1 km pixel retrievals where at least 5 of the 1 km pixels are cloudy as determined by the cloud mask
- Cloud properties retrieved both day and night

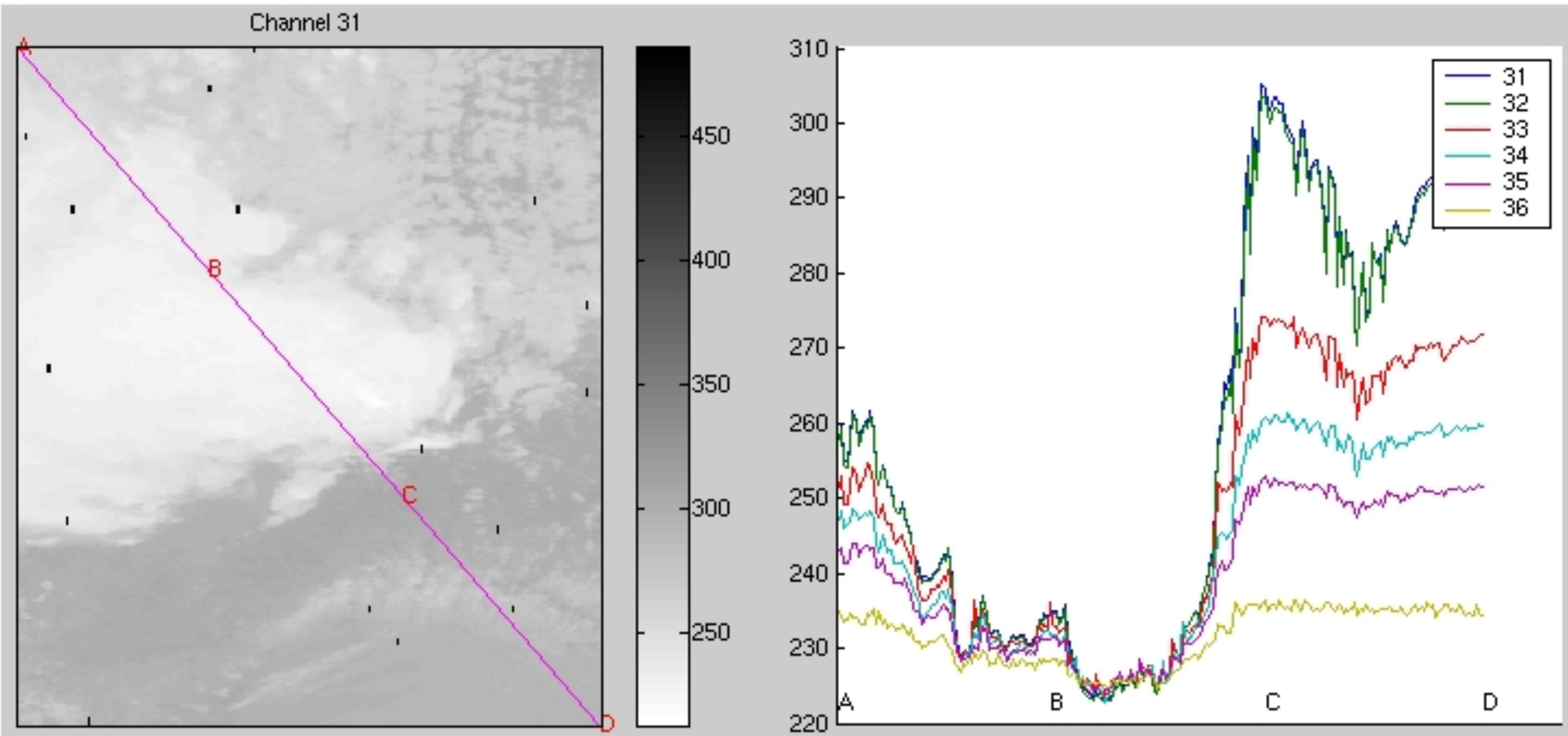
# ATMOSPHERE - THERMAL RADIATION




E351.002 5/93

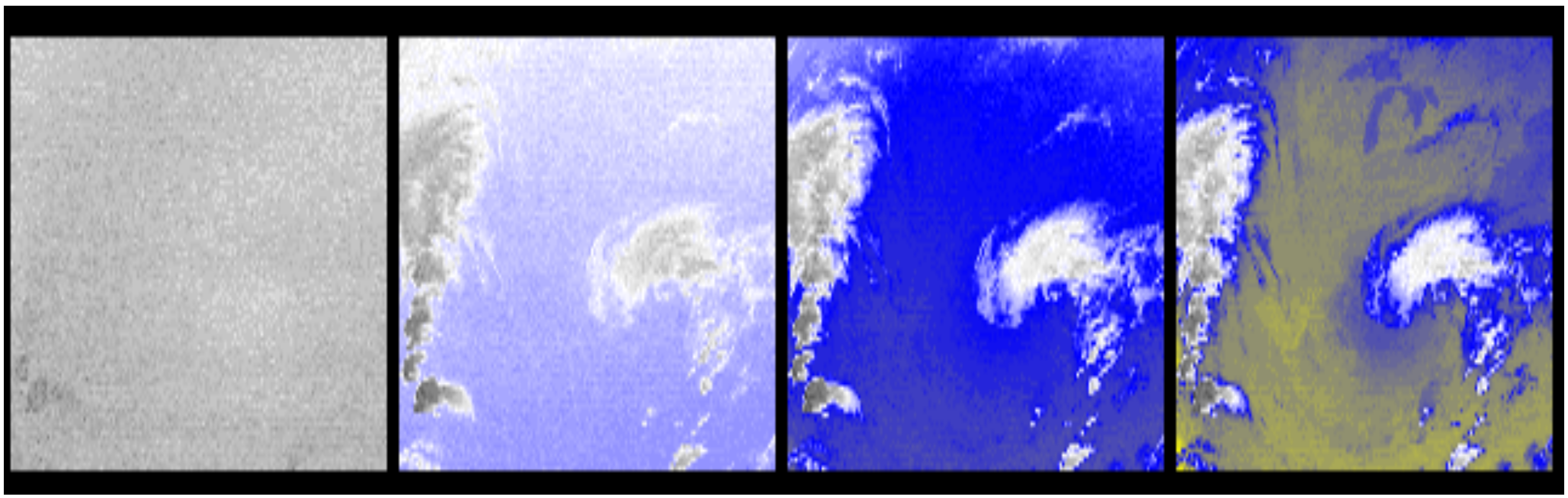
BT in and out of clouds for MODIS $CO_2$ bands

- demonstrate weighting functions and cloud top algorithm



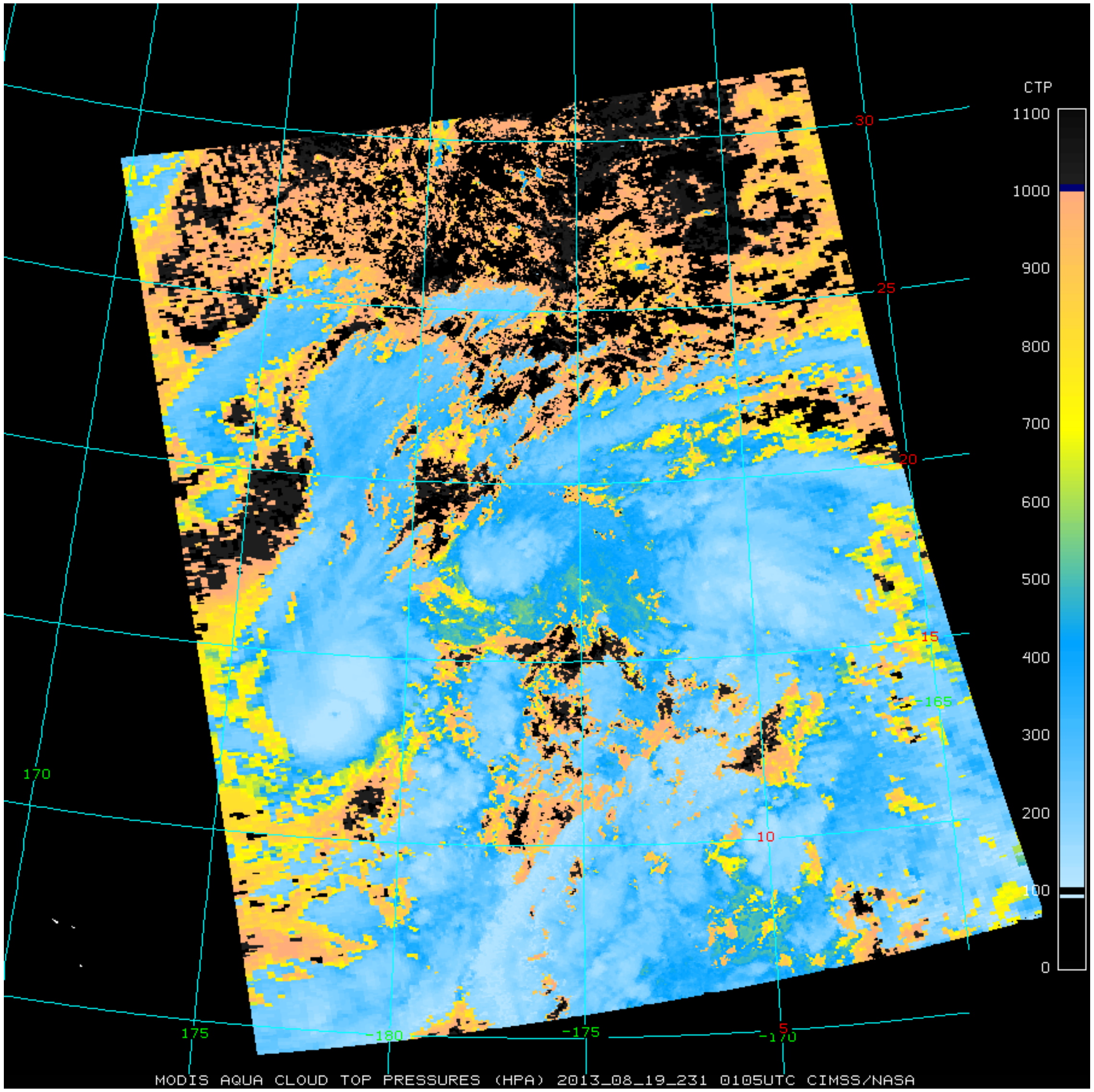

S. Platnick, ISSAOS '02

**CO2 channels see to different levels in the atmosphere**

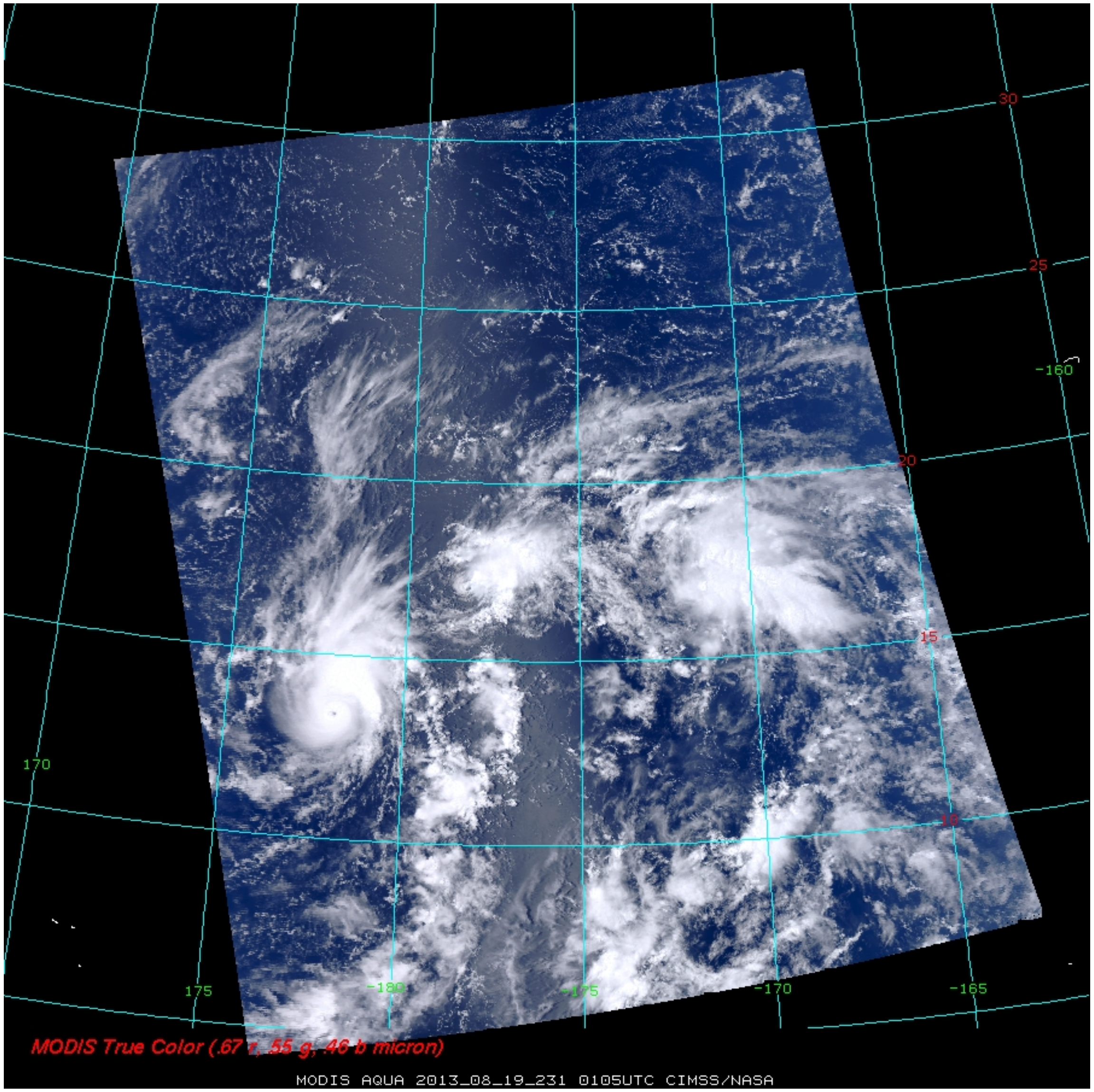


14.2 um 13.9 um 13.6 um 13.3 um

# Example Cloud Top Pressure Product

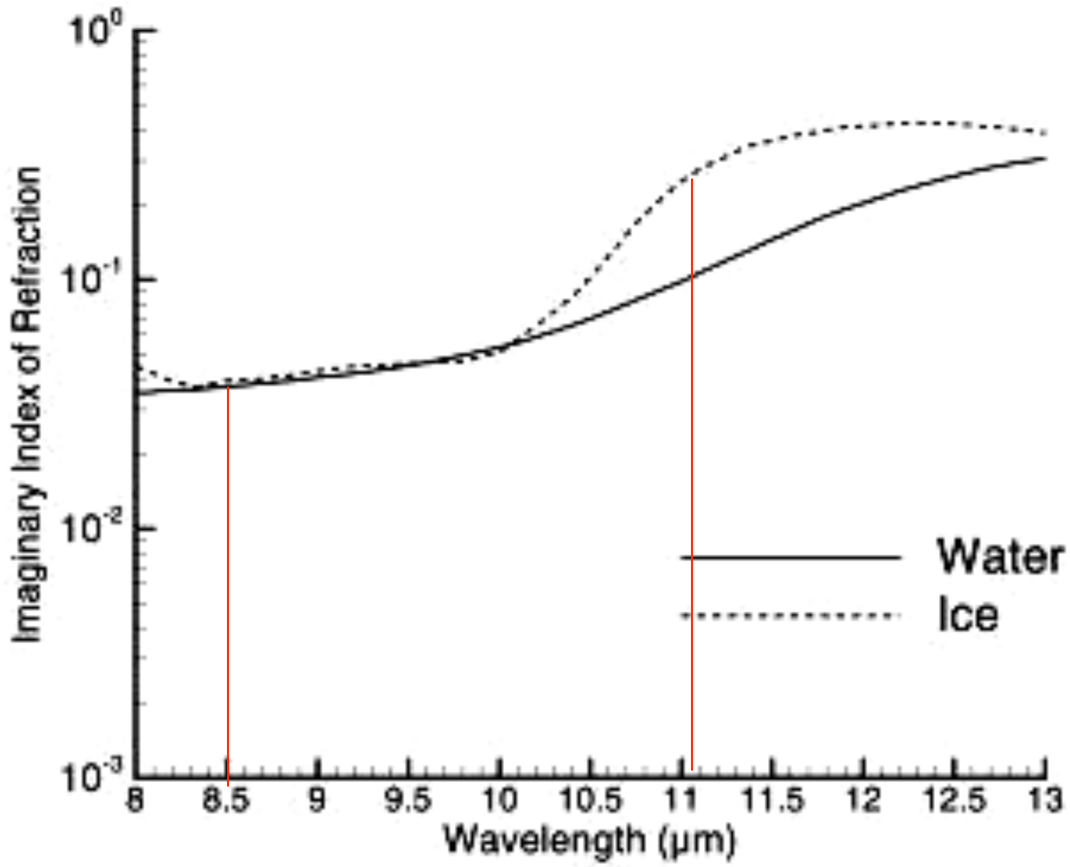


# Example Cloud Top Pressure Product



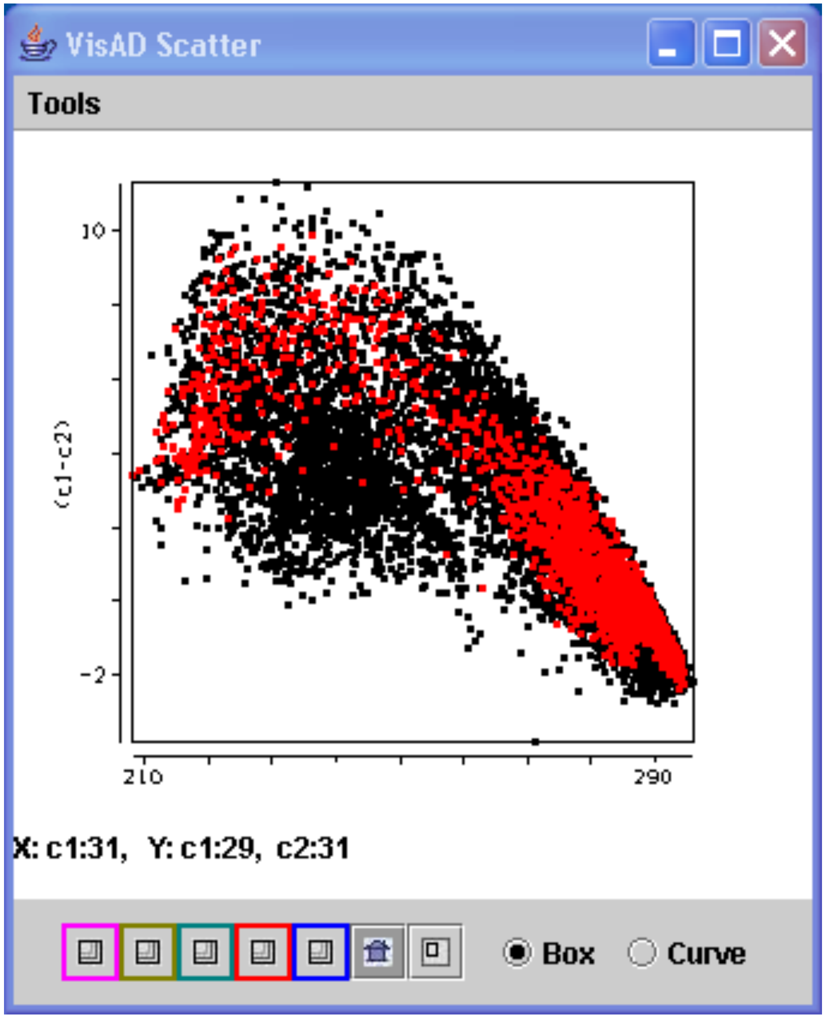
# Cloud Phase

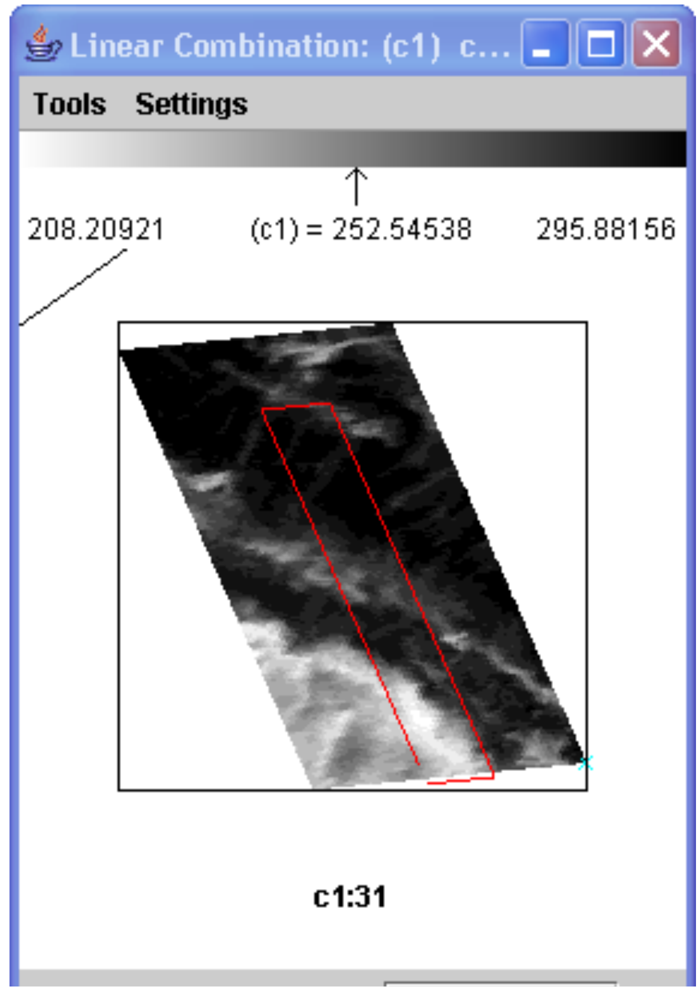
- IR Brightness Temperature Difference Product
  - Band 29 (8.6 μm) – Band 31 (11 μm)
  - Takes advantage of difference in water/ice cloud absorption in this spectral region
- Near Infrared Bands (1.6 and 2.1 μm)
- Short Wave Infrared Bands (4 μm region)



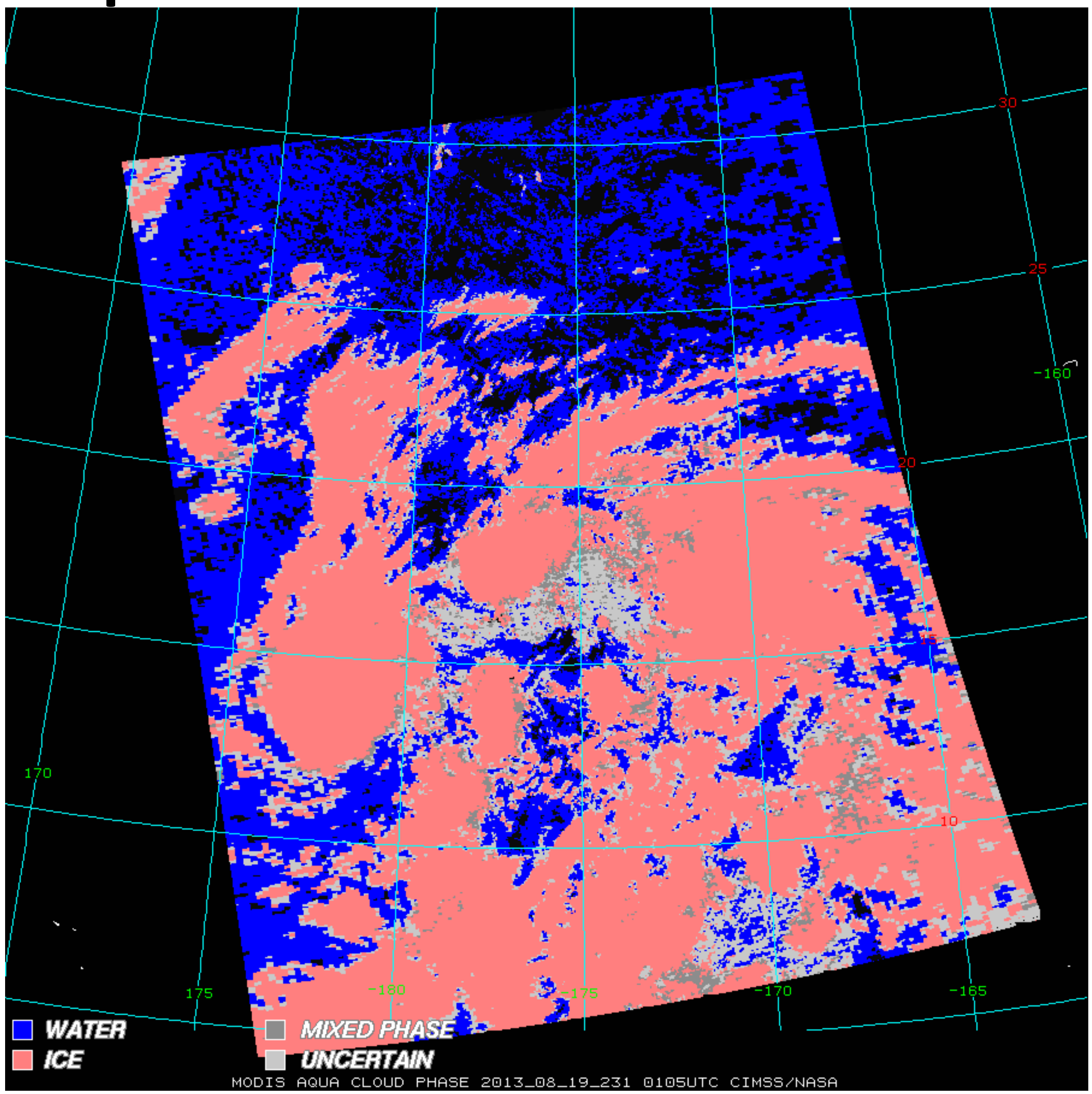

Imaginary Index of Refraction of Ice and Water 8 – 13 microns

# Ice Cloud Example

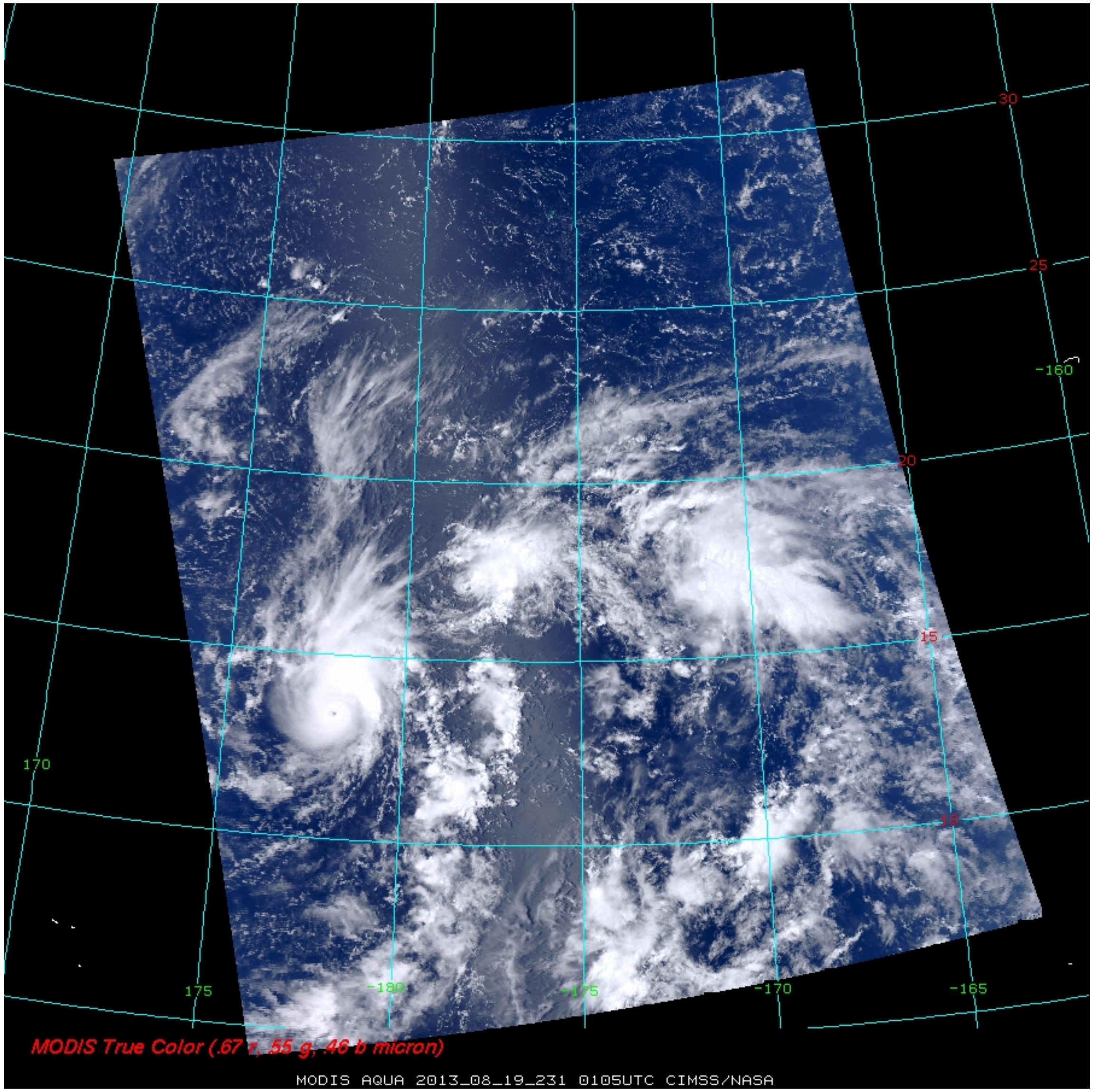


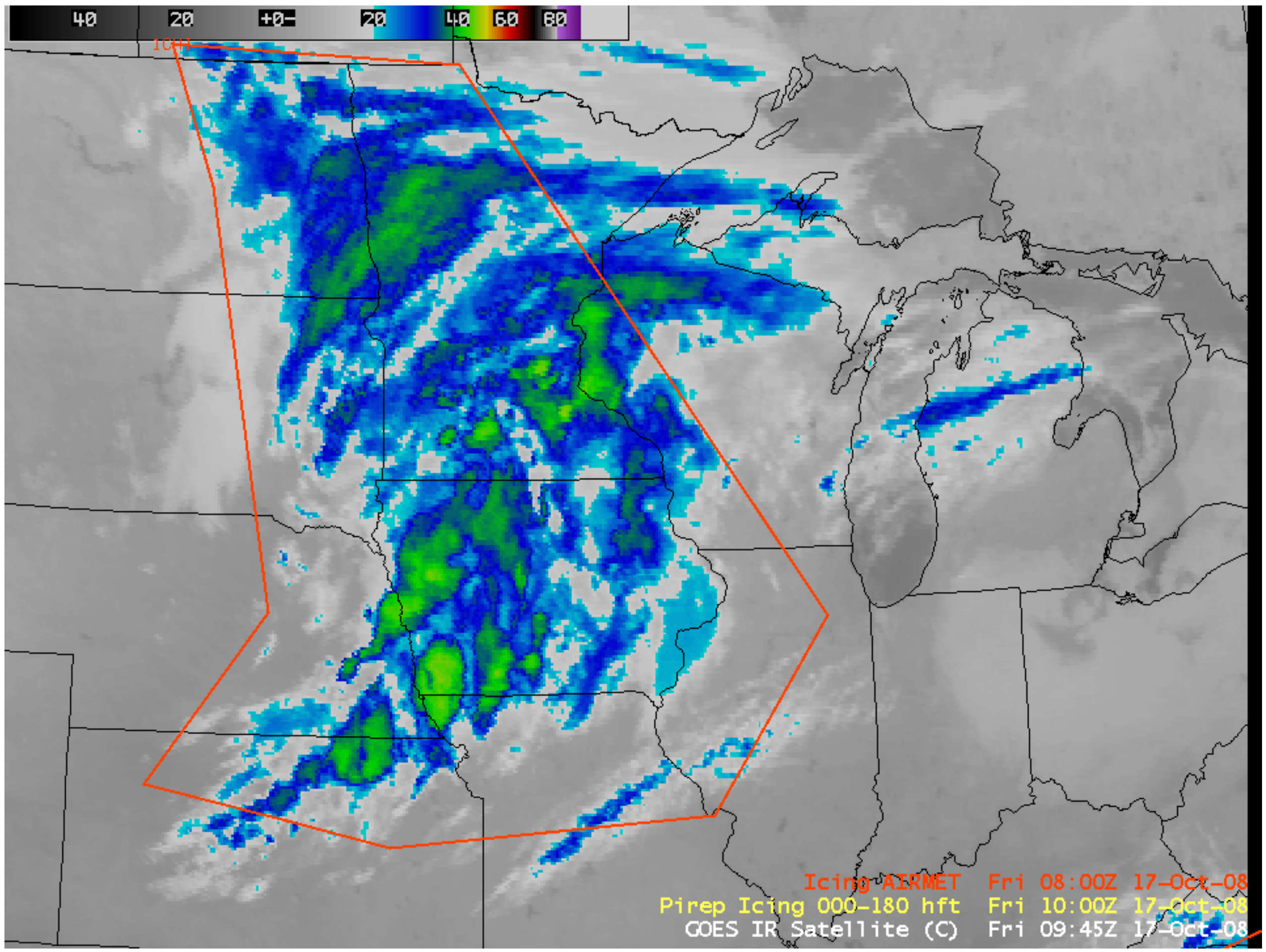
# Example Cloud Phase Product



# Example Cloud Top Pressure Product



# Using Satellite Imagery to Help Diagnose Areas of Aircraft Icing Potential



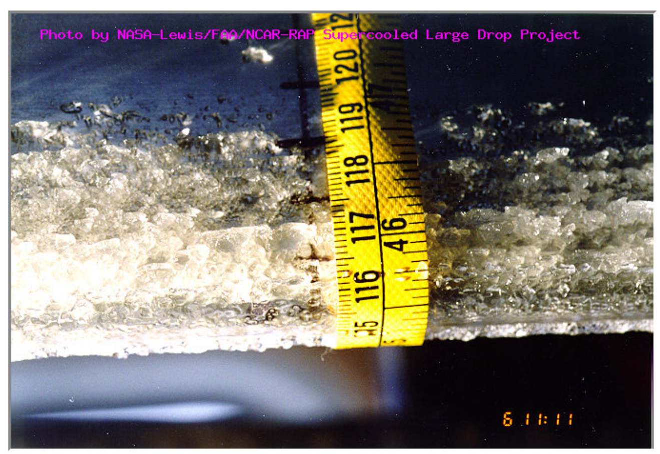

GOES IR window animation     17 October 2008

# Icing

- Freezing Level
  - Altitude at which the temperature is 0 degrees C
  - Above this level the temperature is < 0 C
- Water Can Exist at Temperatures Well Below Freezing
  - Supercooled Water
- An airplane whose temperature is < freezing in this environment can accrue ice

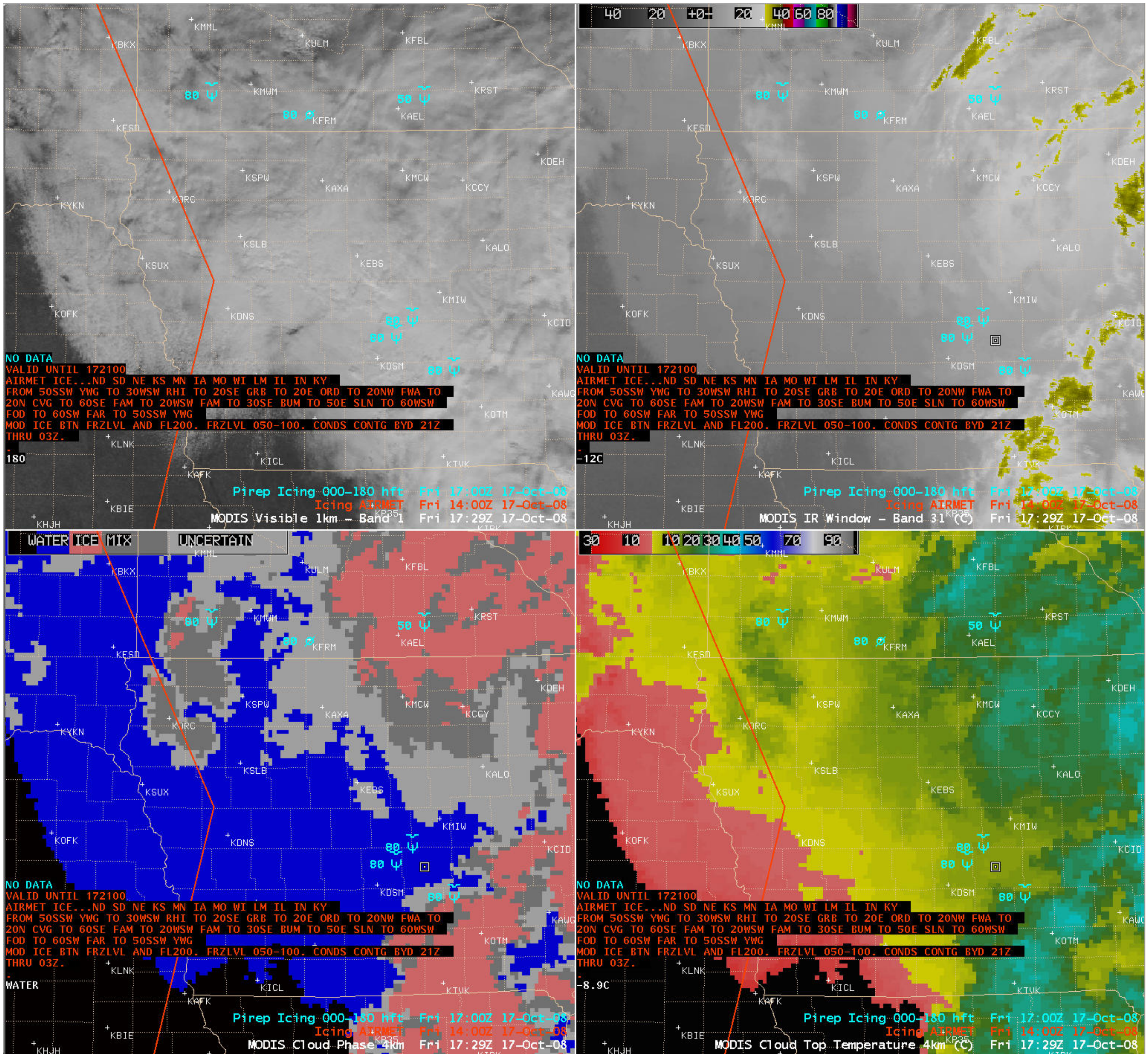
# Why is This  Important?

- We worry about icing because it can adversely affect the flight characteristics of an aircraft. Icing can increase drag, decrease lift, and cause control problems. The added weight of the accreted ice is generally only a factor in light aircraft.




Ice Accumulation On
The Wing of a Small Aircraft
NASA

- A closer view using AWIPS images of the MODIS visible channel, 11.0 µm "IR window" channel, Cloud Top Temperature (CTT) product, and Cloud Phase product at 17:29 UTC (below) indicated that much of the cloud shield along the trailing (western) edge of the shortwave over Minnesota and Iowa exhibited cloud top temperatures that were below freezing (generally in the -5 to -12º C range), but the MODIS Cloud Phase product designated those trailing edge clouds as "Water droplet" clouds (blue enhancement). Within this area of supercooled water droplet clouds were several pilot reports of icing at the 8000-foot altitude  across southern Minnesota and western/central Iowa.


NO DATA
VALID UNTIL 172100
AIRMET ICE...ND SD NE KS MN IA MO WI LM IL IN KY
FROM 50SSW YWG TO 30WSW RHI TO 20SE GRB TO 20E ORD TO 20NW FWA TO
20N CVG TO 60SE FAM TO 20WSW FAM TO 30SE BUM TO 50E SLN TO 60WSW
FOD TO 60SW FAR TO 50SSW YWG
MOD ICE BTN FRZLVL AND FL200. FRZLVL 050-100. CONDS CONTG BYD 21Z
THRU 03Z.
Pirep Icing 000-180 hft Fri 17:00Z 17-Oct-08
Icing AIRMET Fri 14:00Z 17-Oct-08
MODIS Visible 1km - Band 1 Fri 17:29Z 17-Oct-08
MODIS IR Window - Band 31 (C) Fri 17:29Z 17-Oct-08
WATER ICE MIX UNCERTAIN
MODIS Cloud Phase 4km Fri 17:29Z 17-Oct-08
MODIS Cloud Top Temperature 4km (C) Fri 17:29Z 17-Oct-08

# Other Cloud Applications Too

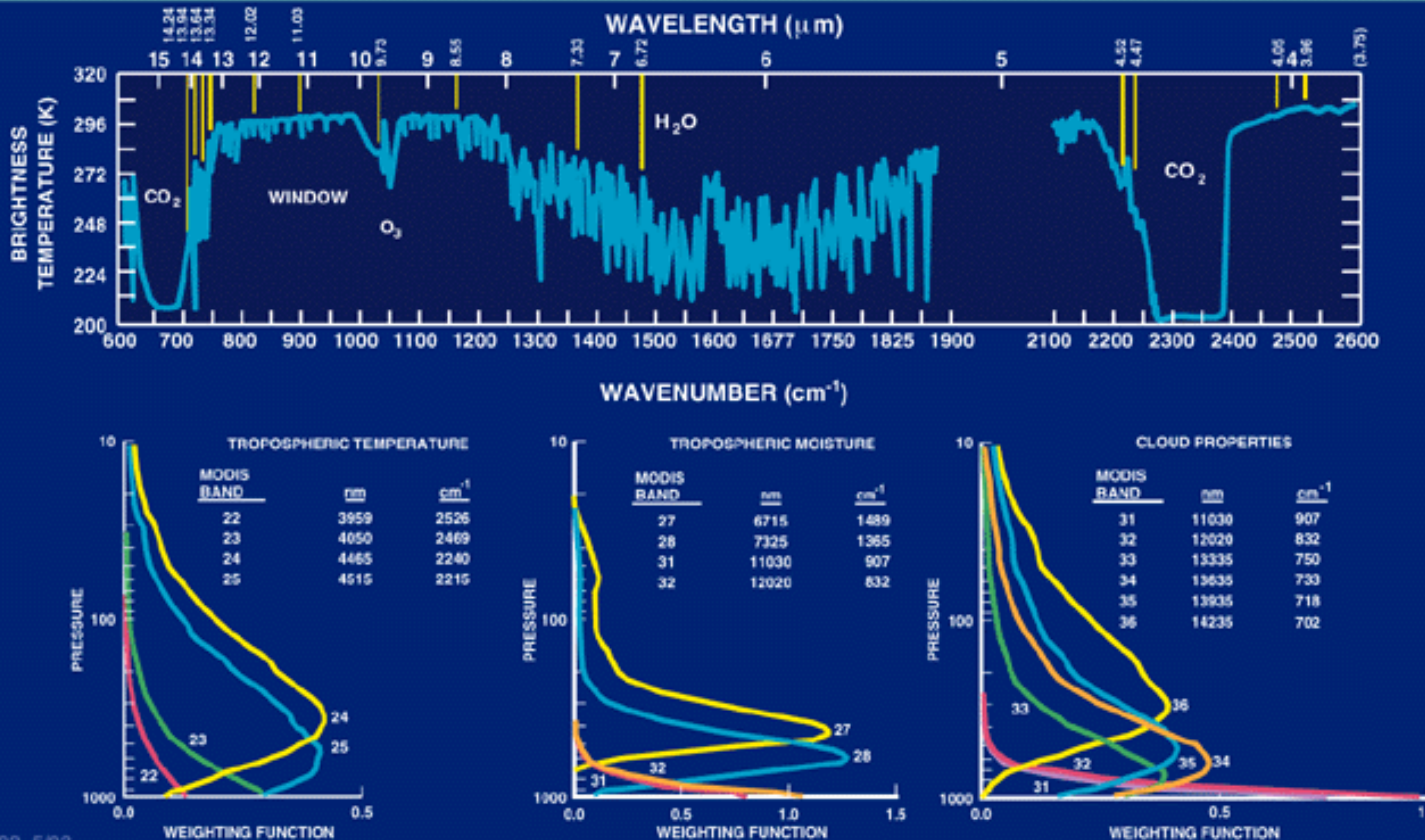
- Identification of mature T-storms
  - Must glaciate, meaning tops of cell must be ice
- Accurate height of "thin" high clouds
  - Energy transmitted from below the cloud in the IR window. Can't get accurate level from window BT.
  - Important for pilots. Clouds mean more moisture, dry entrainment and potential for turbulence.

# Other Applications

# Sea Surface Temperatures

- Simple Brightness Temperature Difference Algorithm
- "Split Window" technique
- Regression between
  - 11-12 µm BTDIF (MODIS bands 31 and 32)
  - 4 – 11 µm BTDIF (MODIS bands 22 and 31)
    - Must be careful in sunglint regions because of solar contamination
  - In essence, you are trying to correct for the lowering of the observed brightness temperatures by water vapor using the BTDIF between these two window channels

# ATMOSPHERE - THERMAL RADIATION

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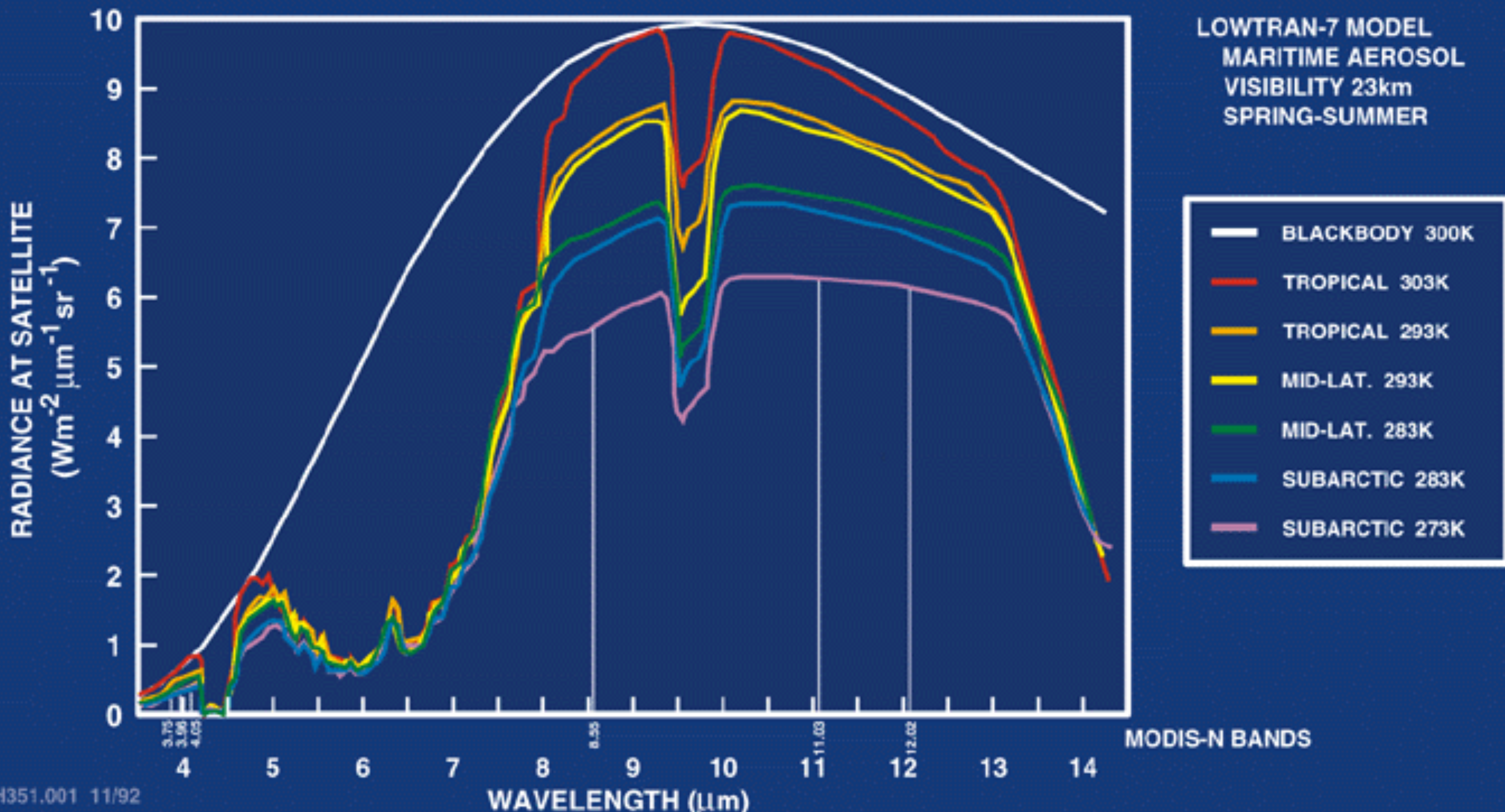
# MODIS SEA SURFACE TEMPERATURE




H351.001 11/92

# MODIS Longwave Infrared Sea Surface Temperature (c5)

$dBT \le 0.5$

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

$dBT \ge 0.9$

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

$0.5 < dBt < 0.9$

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

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

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

where:

$dBT = BT11 - BT12$

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

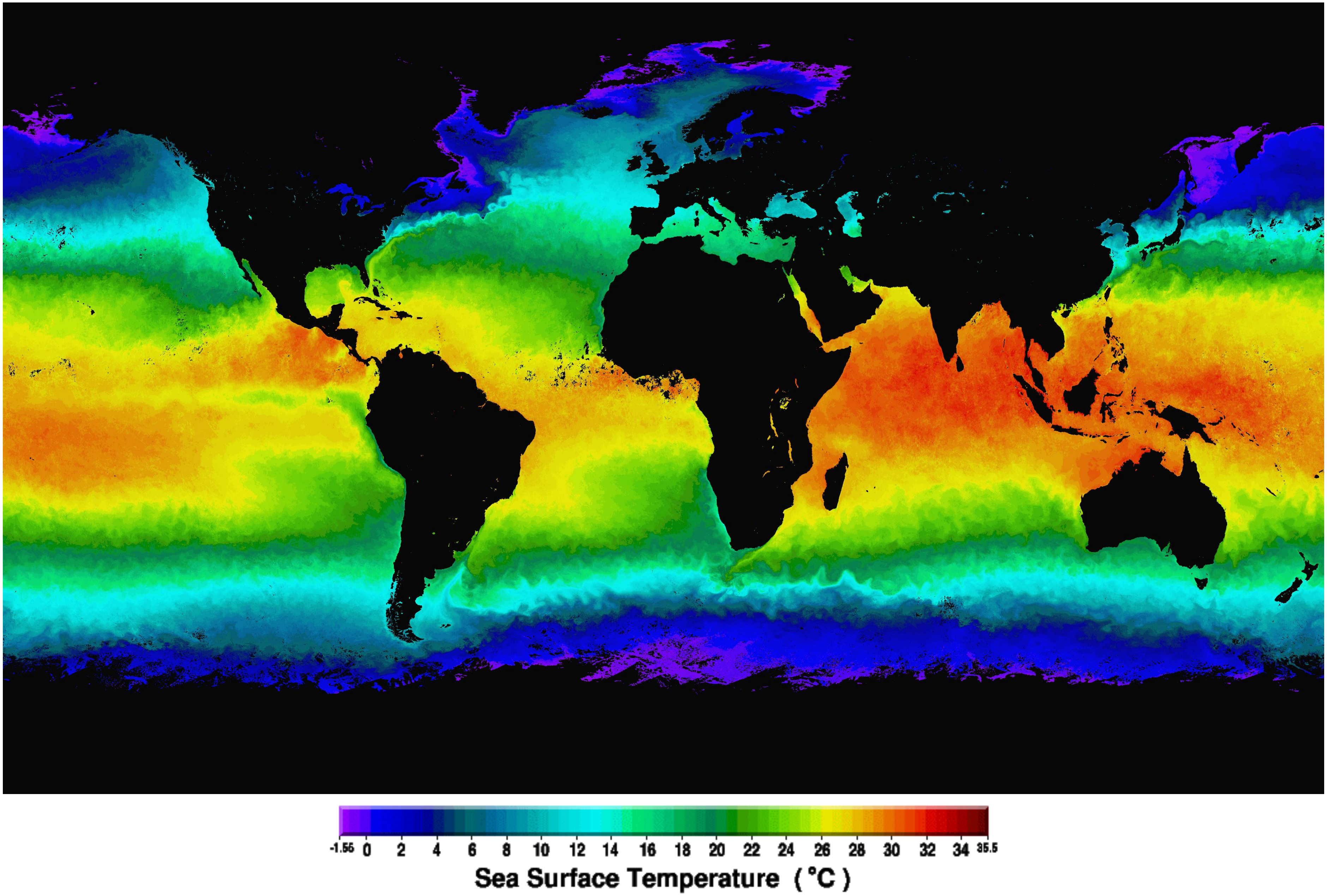
BT12 = brightness temperature at 12 um, in deg-C

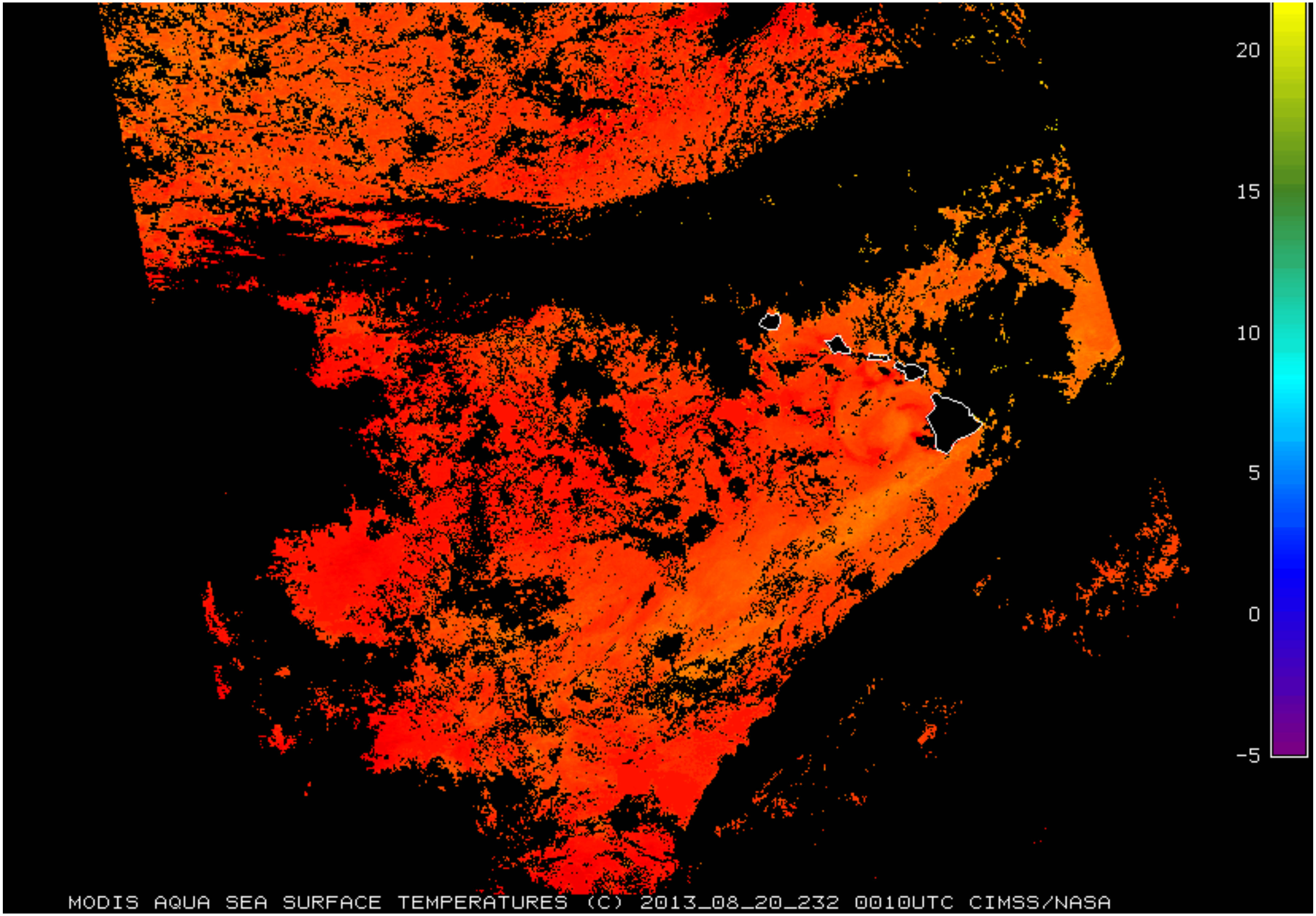
bsst = Either sst4 (if valid) or sstref (from Reynolds OISST)

mu = cosine of sensor zenith angle

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

# Aqua MODIS Sea Surface Temperature, April 2004




20
15
10
5
0
-5
MODIS AQUA SEA SURFACE TEMPERATURES (C) 2013_08_20_232 0010UTC CIMSS/NASA

# 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 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) |

# Ocean Color - SeaDAS

# MODIS Atmospheric Correction for Ocean Bands

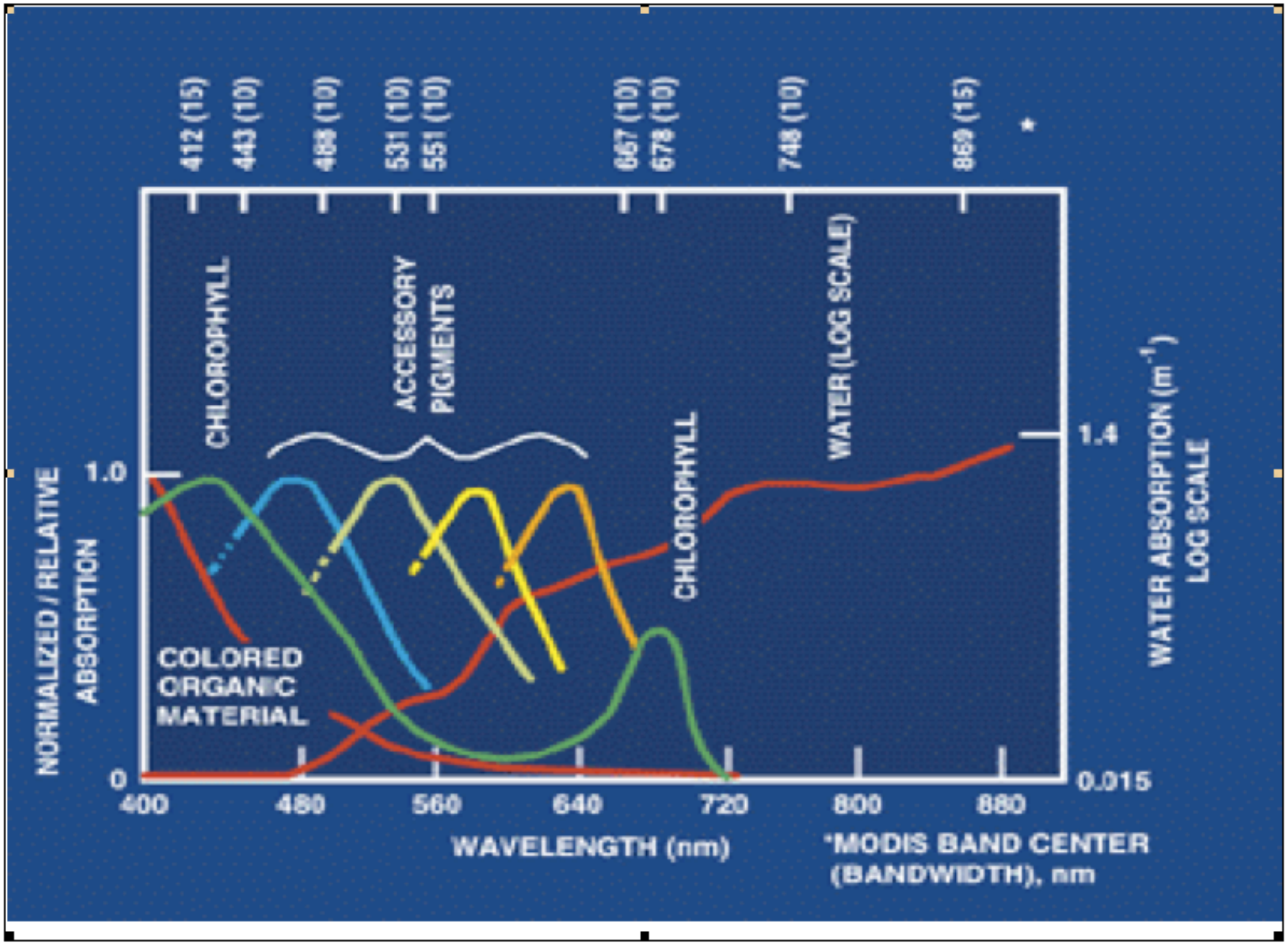
Statement of the problem:

- 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)

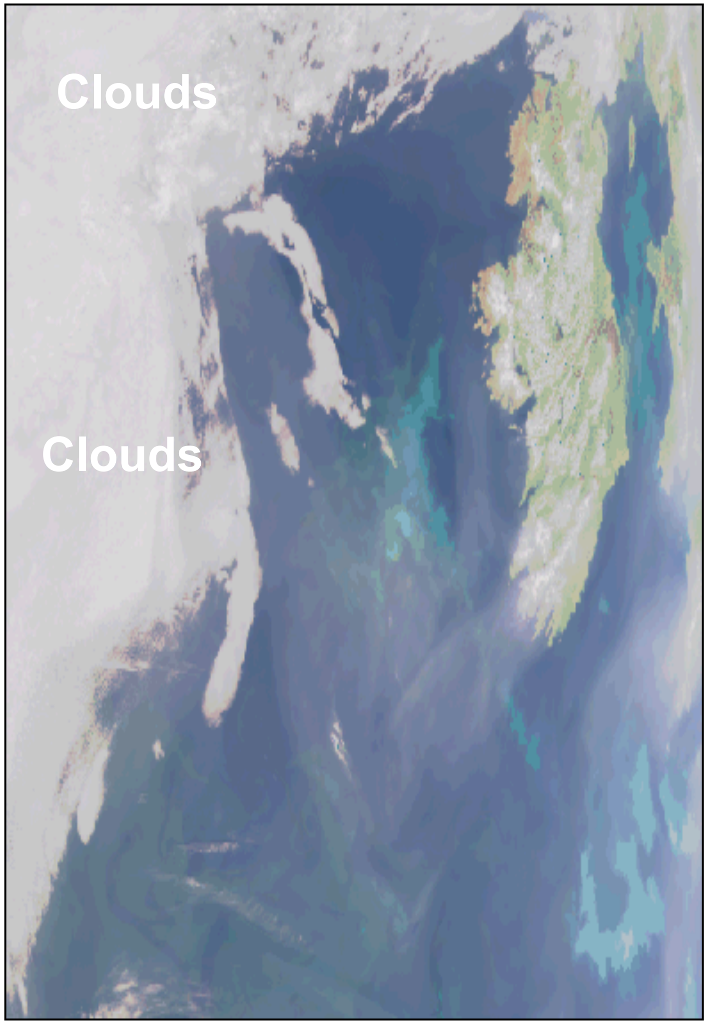
Aerosol model selection:

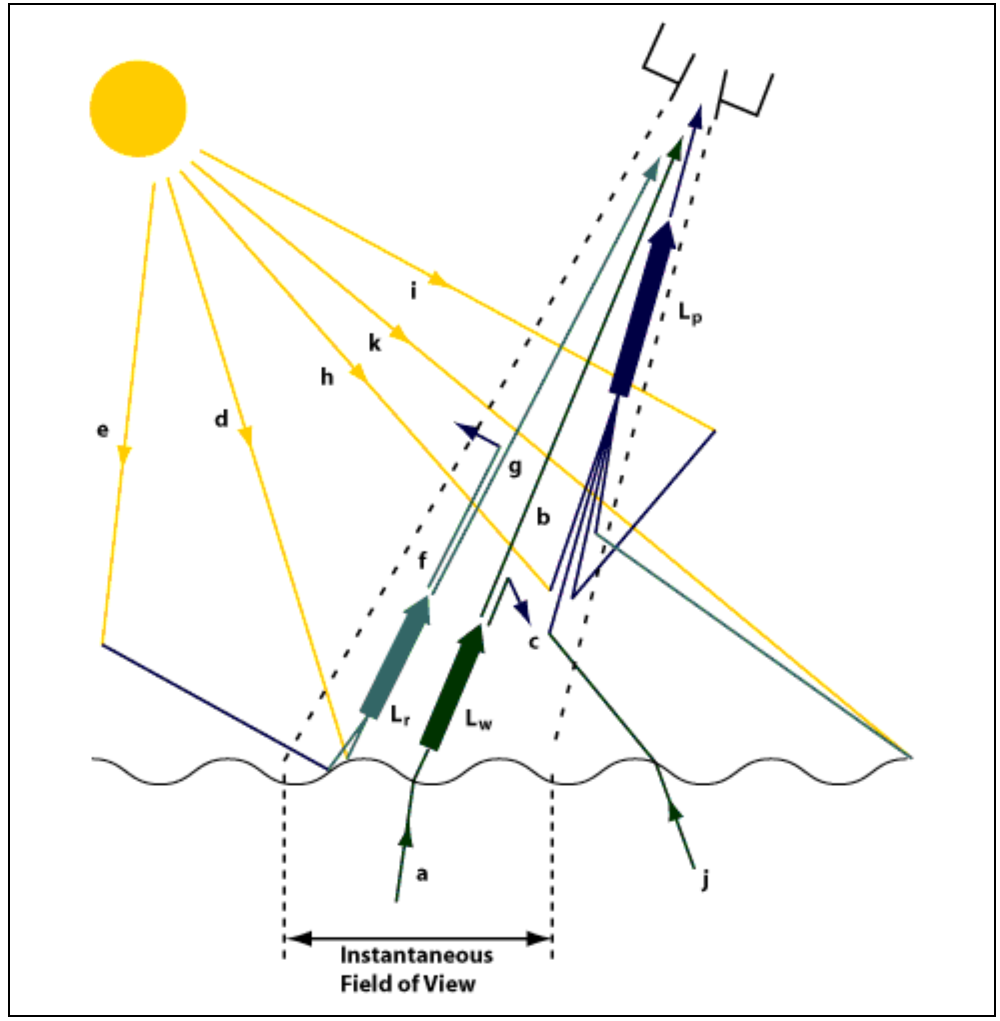
- Assume zero (or negligible) water leaving radiance in the NIR bands (15 and 16; 0.750 and 0.865 microns); remainder is from aerosols.
- This is extrapolated to visible wavelengths using aerosol models.
- For case 1 waters, NIR bands are used to select aerosol model.
- Where this assumption is not valid, 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

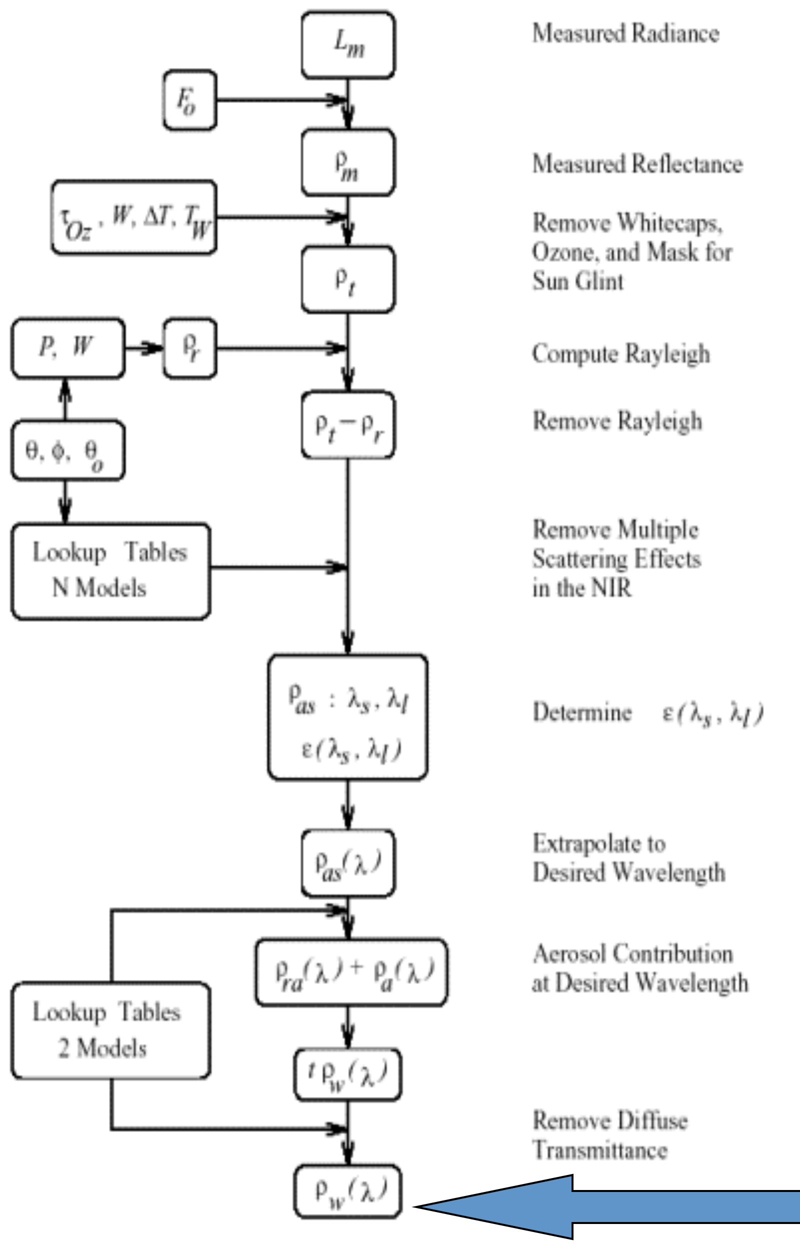



Figure 21. Annotated flow diagram of the algorithm.

Reflectance at water surface

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

* $\rho_w$ **is the quantity we wish to retrieve at each wavelength.**

* $\rho_g$ **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.**

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

* $\rho_r$ **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.**

* $\rho_t$ **is the total reflectance measured at the satellite**

# MODIS Chlorophyll Algorithm (OC3)

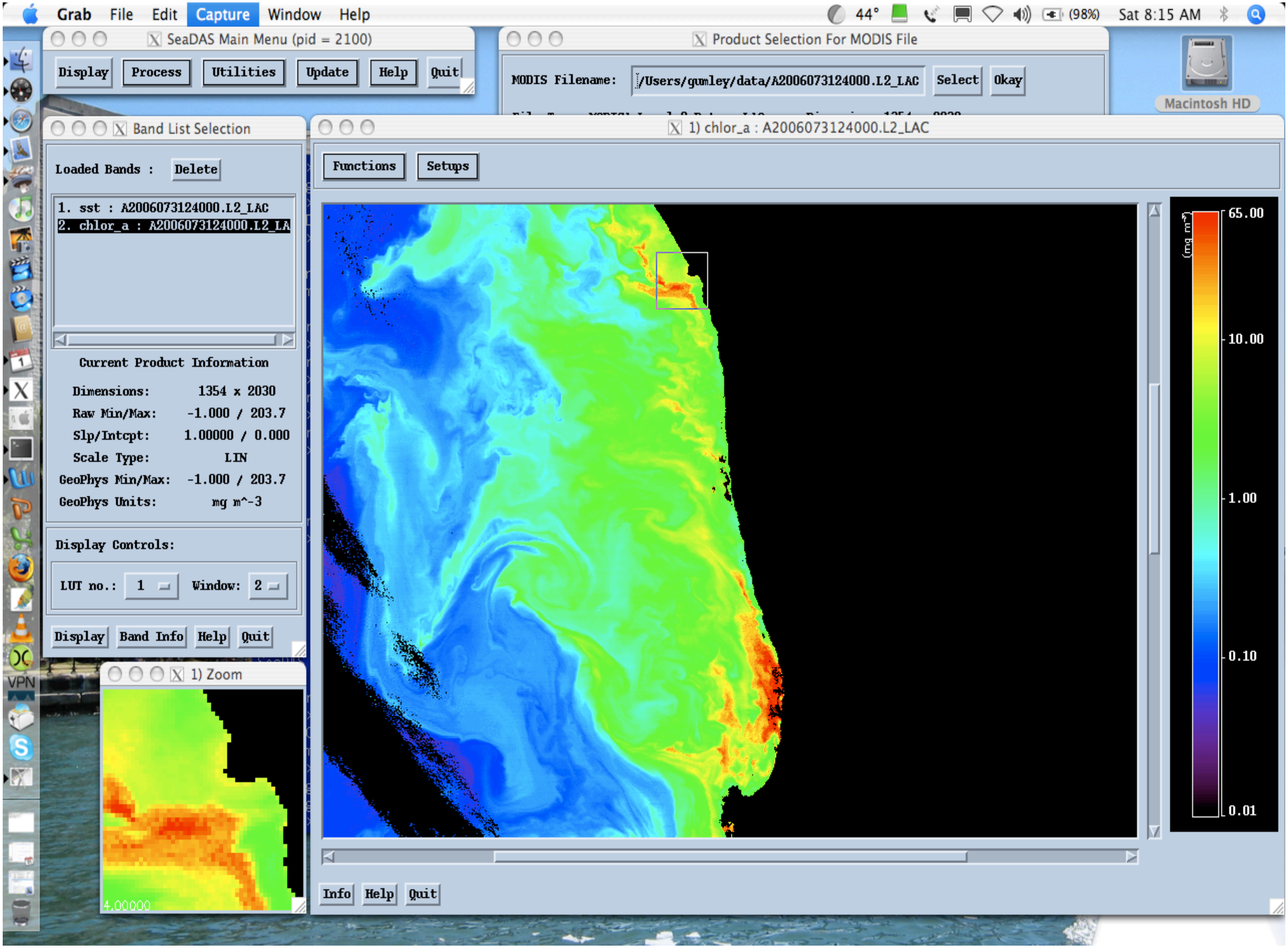
Semi-analytical algorithm[1]

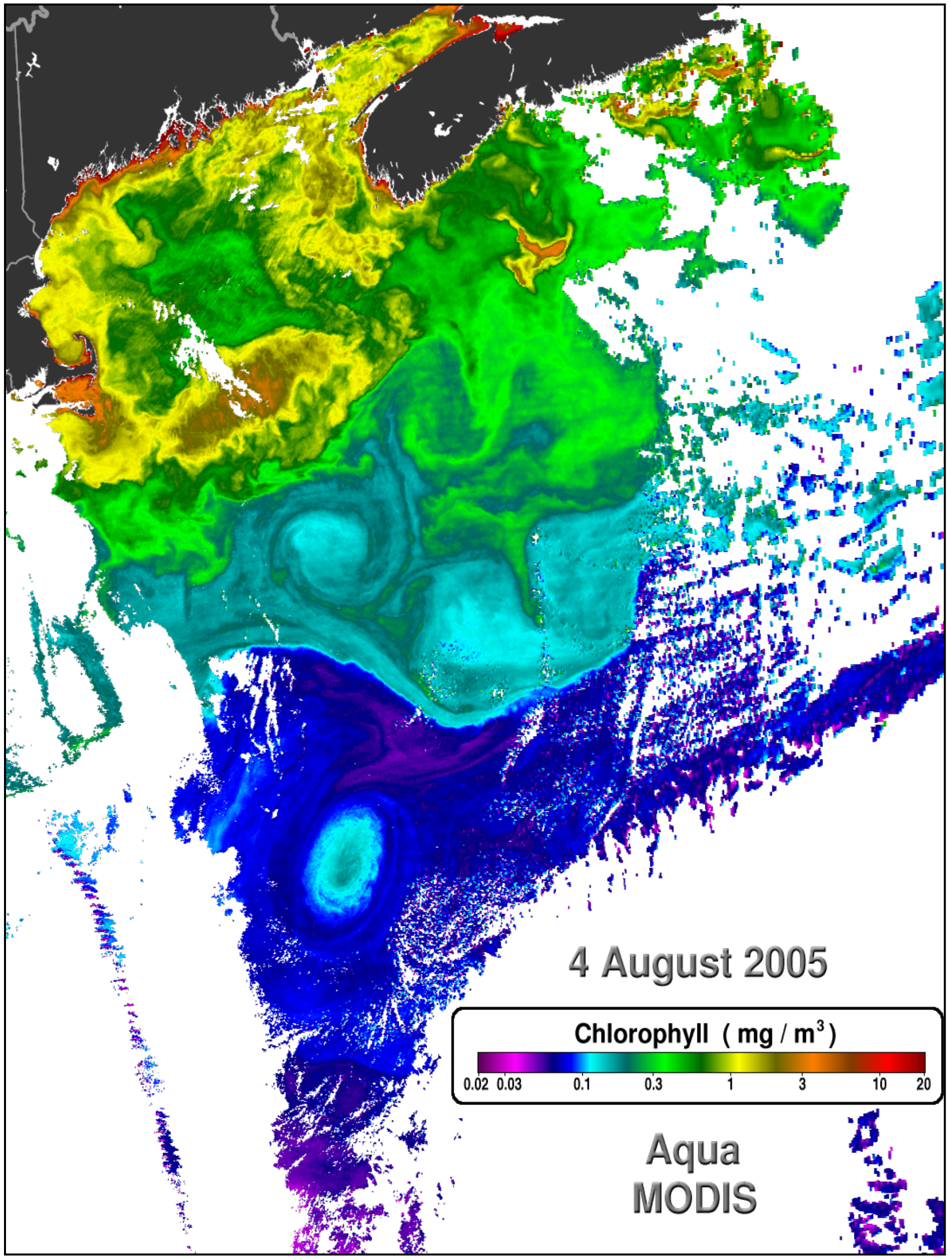
Chl_a = 10**(0.283 - 2.753*R + 1.457*$R^2$ + 0.659*$R^3$ - 1.403*$R^4$)

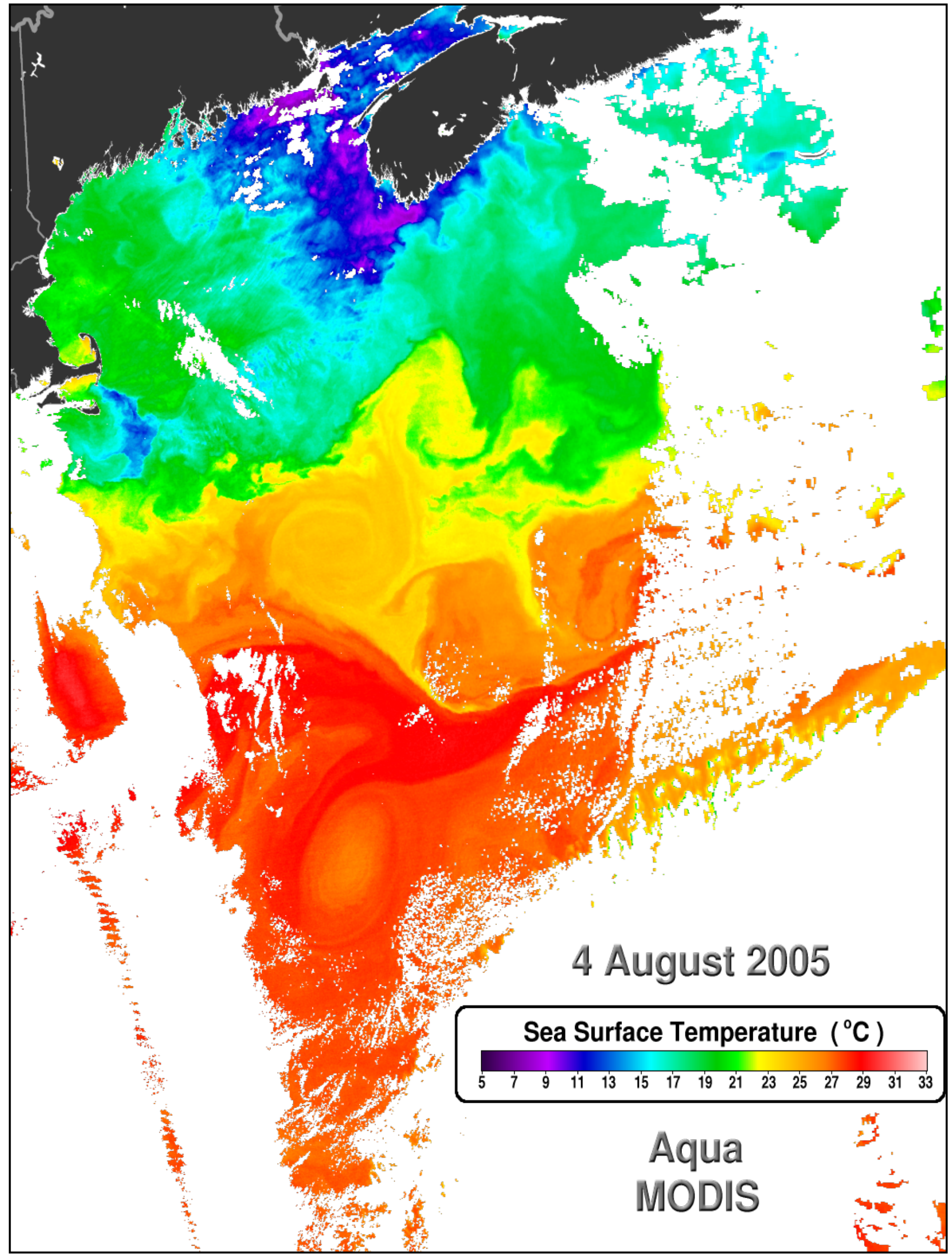
where:

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
65.00
10.00
1.00
0.10
0.01
Info Help Quit

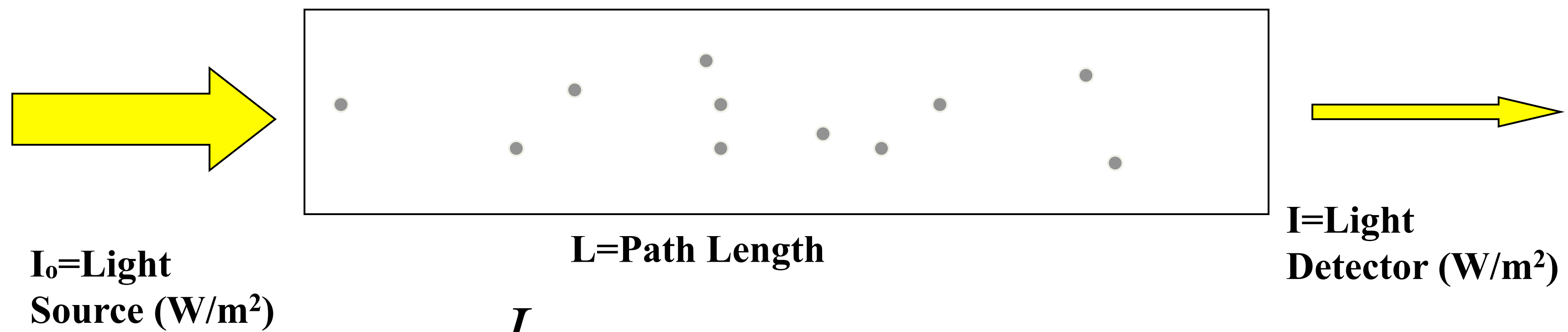

4 August 2005
Chlorophyll ( mg / m3 )
0.02 0.03 0.1 0.3 1 3 10 20
Aqua
MODIS


4 August 2005
Sea Surface Temperature ( °C )
5 7 9 11 13 15 17 19 21 23 25 27 29 31 33
Aqua
MODIS

# Air Quality Applications

## Aerosol Detection

# Scattering and Absorption of Light by Aerosols




$$\frac{I}{I_0} = e^{-\sigma_{ext} L} = e^{-(\sigma_{sp} + \sigma_{ap}) L}$$

$$\tau = (\sigma_{sp} + \sigma_{ap}) * L \qquad \varpi = \sigma_{sp} / (\sigma_{sp} + \sigma_{ap})$$

The quantity L is called the density weighted path length. $\sigma_{ext(\lambda)}$ L is a measure of the cumulative depletion that the beam of radiation has experienced as a result of its passage through the layer and is often called the optical depth $\tau_{\lambda}$.

# Wide Spectral Range makes land retrieval possible

- **Mid-IR is used to observe the surface brightness**
- **Then aerosol is derived from estimated surface reflectance in the visible and actual reflectance**

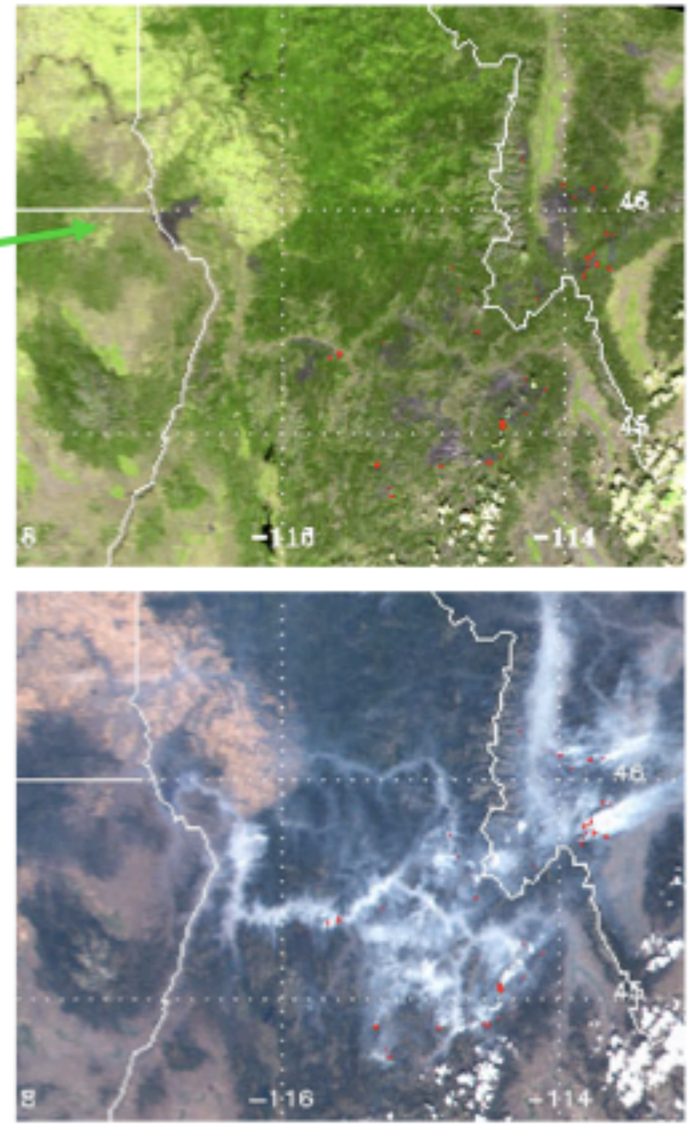
$t_{0.66} \sim [r^*_{0.66} - 0.5r^*_{2.1}]$

$t_{0.47} \sim [r^*_{0.47} - 0.25r^*_{2.1}]$

λ(μm)

1.2
1.6
2.1

0.47
0.55
0.66

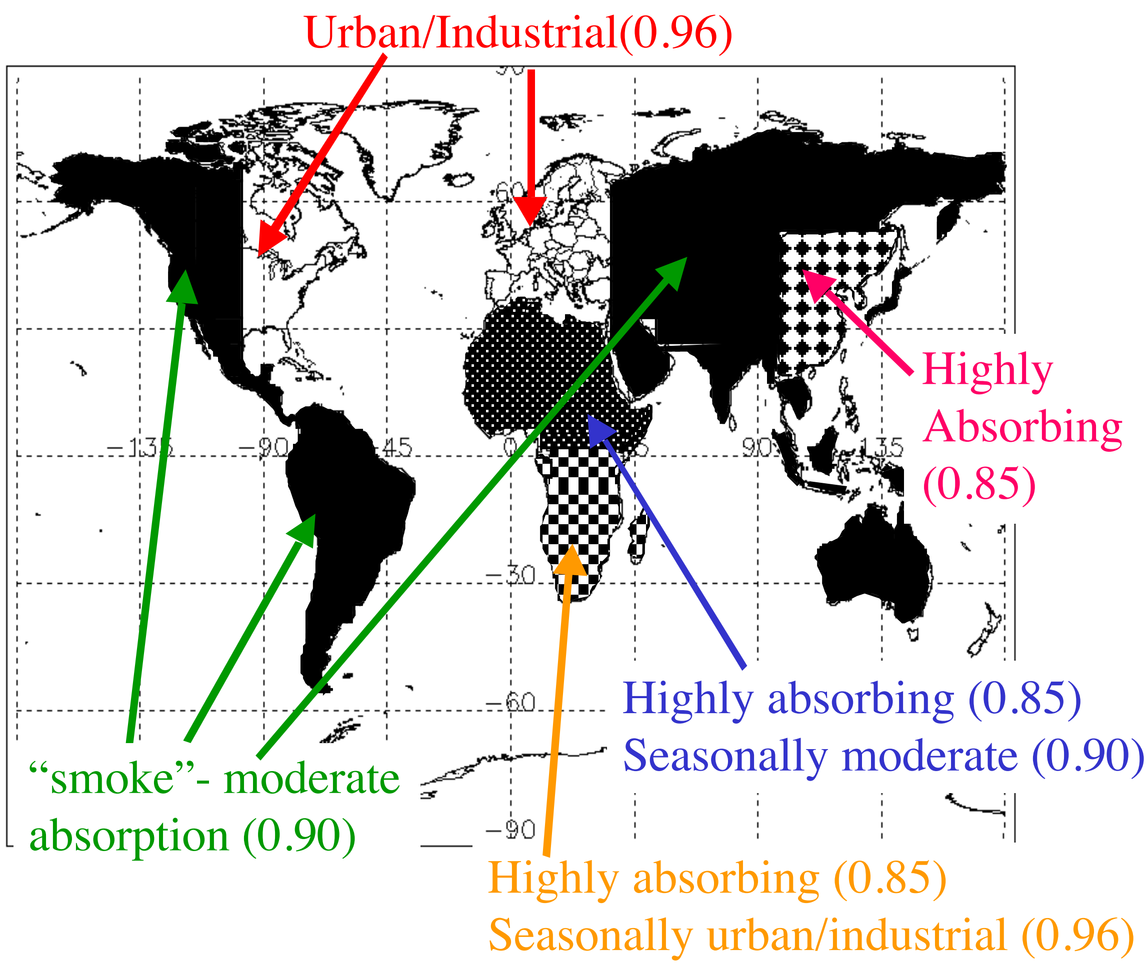



Yoram Kaufman

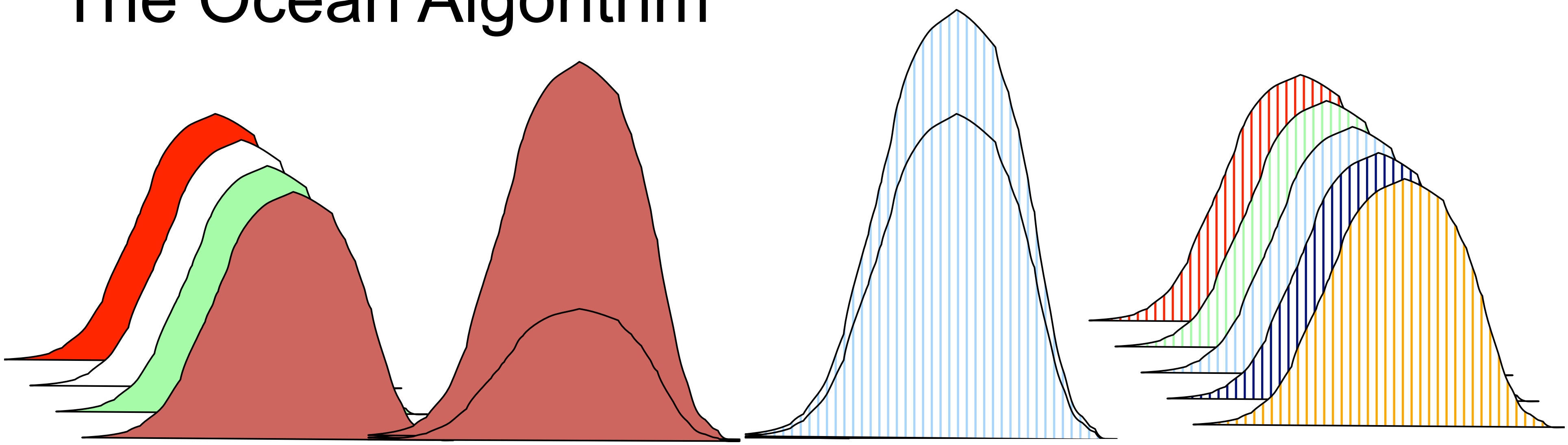
3 non-dust models plus dust

Set by geography and season

# Models are dynamic f(τ)

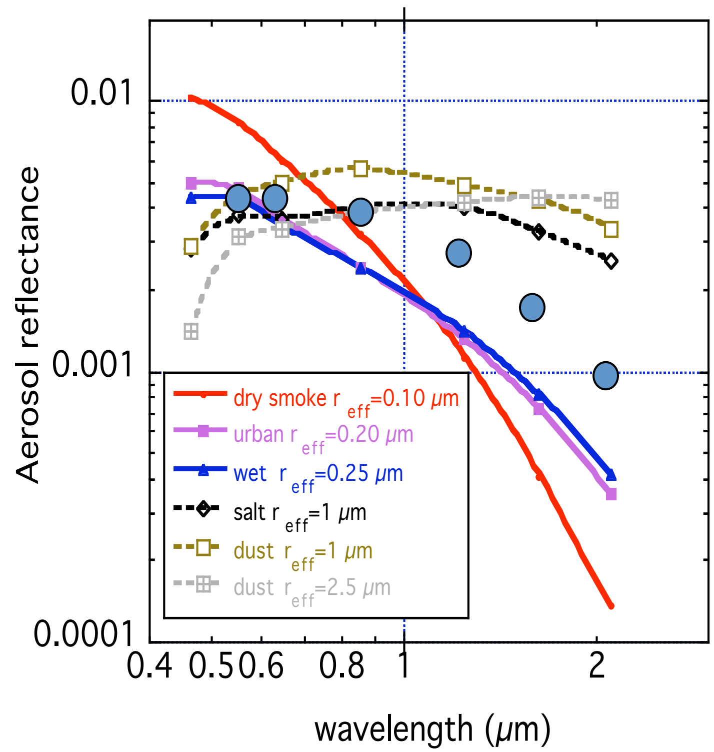


# The Ocean Algorithm

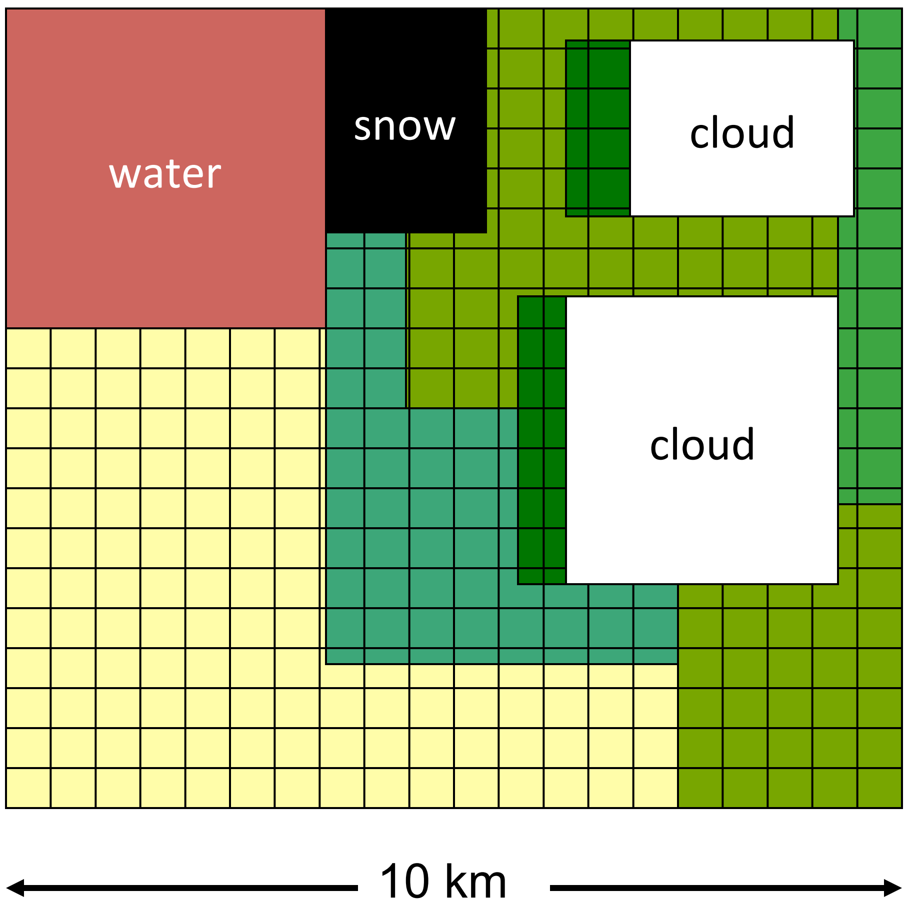


Choice of 4 fine modes
and 5 coarse modes

In order to minimize
($\rho_{meas}$ - $\rho_{LUT}$) over 6 wavelengths



# MODIS Over Land Algorithm
# 20 x 20 pixels at 500 m resolution
# (10 km at nadir)




400 total
- 56 water

344
- 24 snow

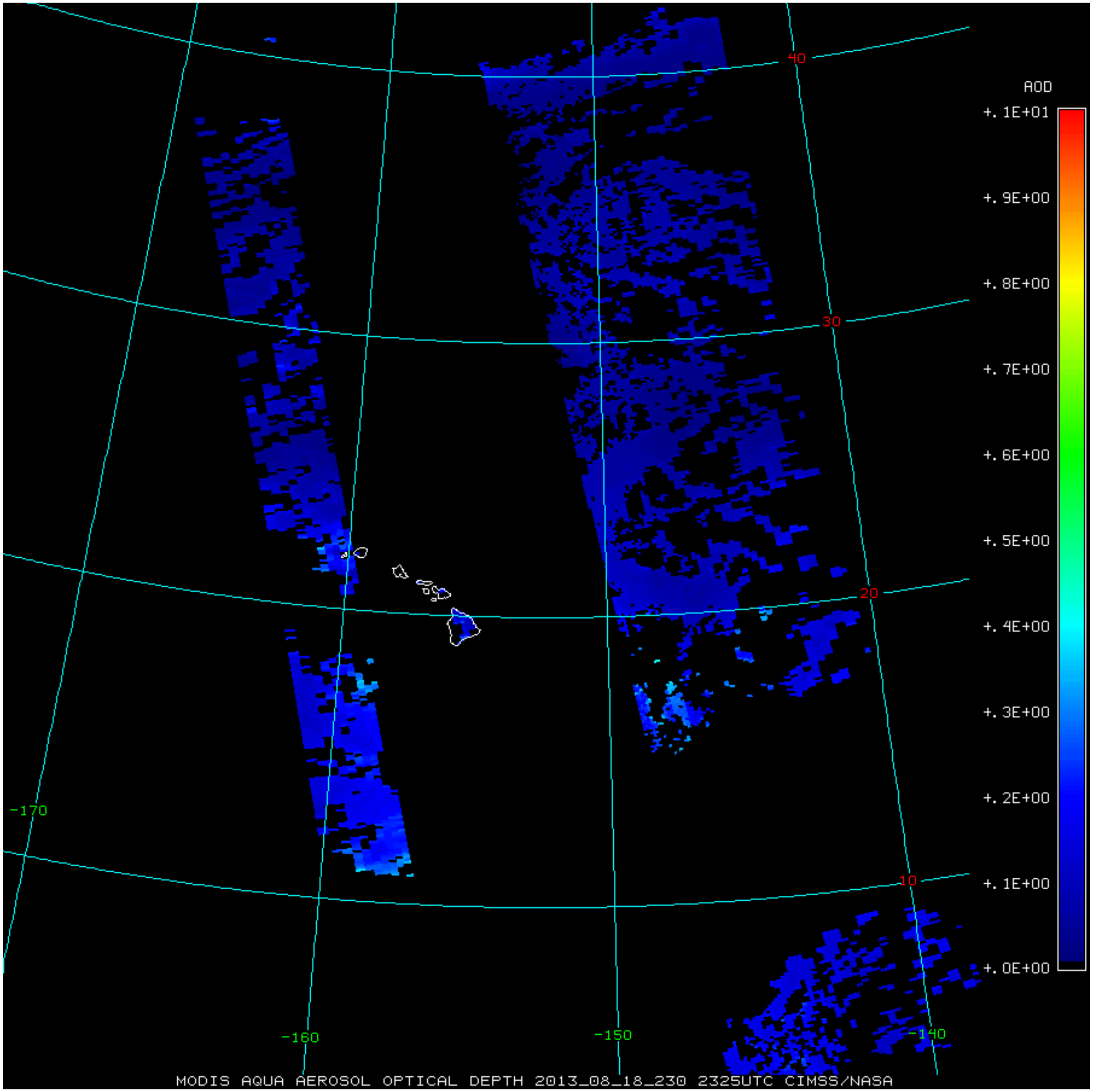
320
- 55 cloud

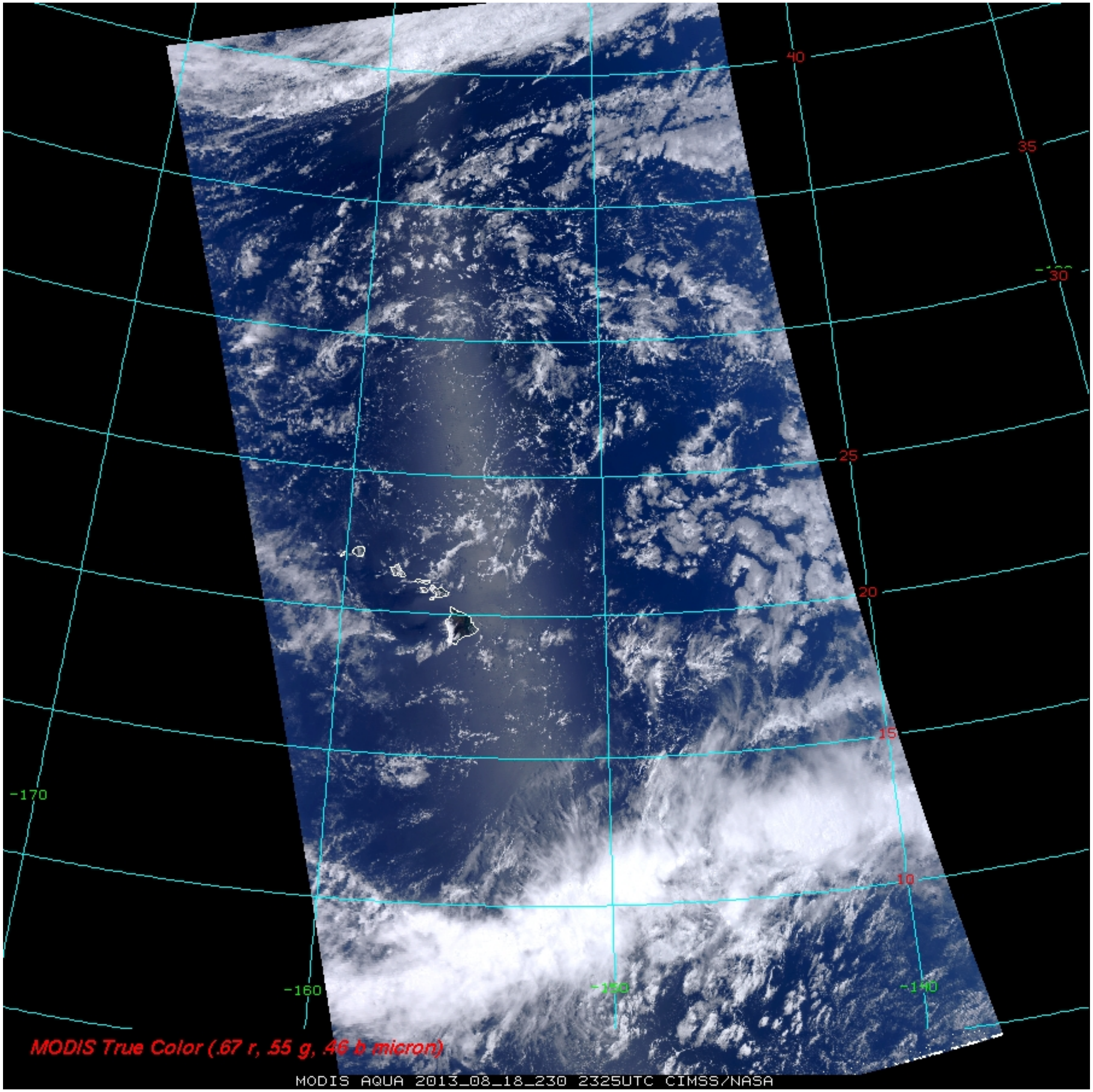
265
-116 "bright"

149 "good"

Discard brightest 50% and darkest 20% of the 149 good pixels.

44 pixels


40
30
20
10
-170
-160
-150
-140
AOD
+.1E+01
+.9E+00
+.8E+00
+.7E+00
+.6E+00
+.5E+00
+.4E+00
+.3E+00
+.2E+00
+.1E+00
+.0E+00
MODIS AQUA AEROSOL OPTICAL DEPTH 2013_08_18_230 2325UTC CIMSS/NASA


40
35
30
25
20
15
10
-170
-160
-150
-140
MODIS True Color (.67 r, .55 g, .46 b micron)
MODIS AQUA 2013_08_18_230 2325UTC CIMSS/NASA

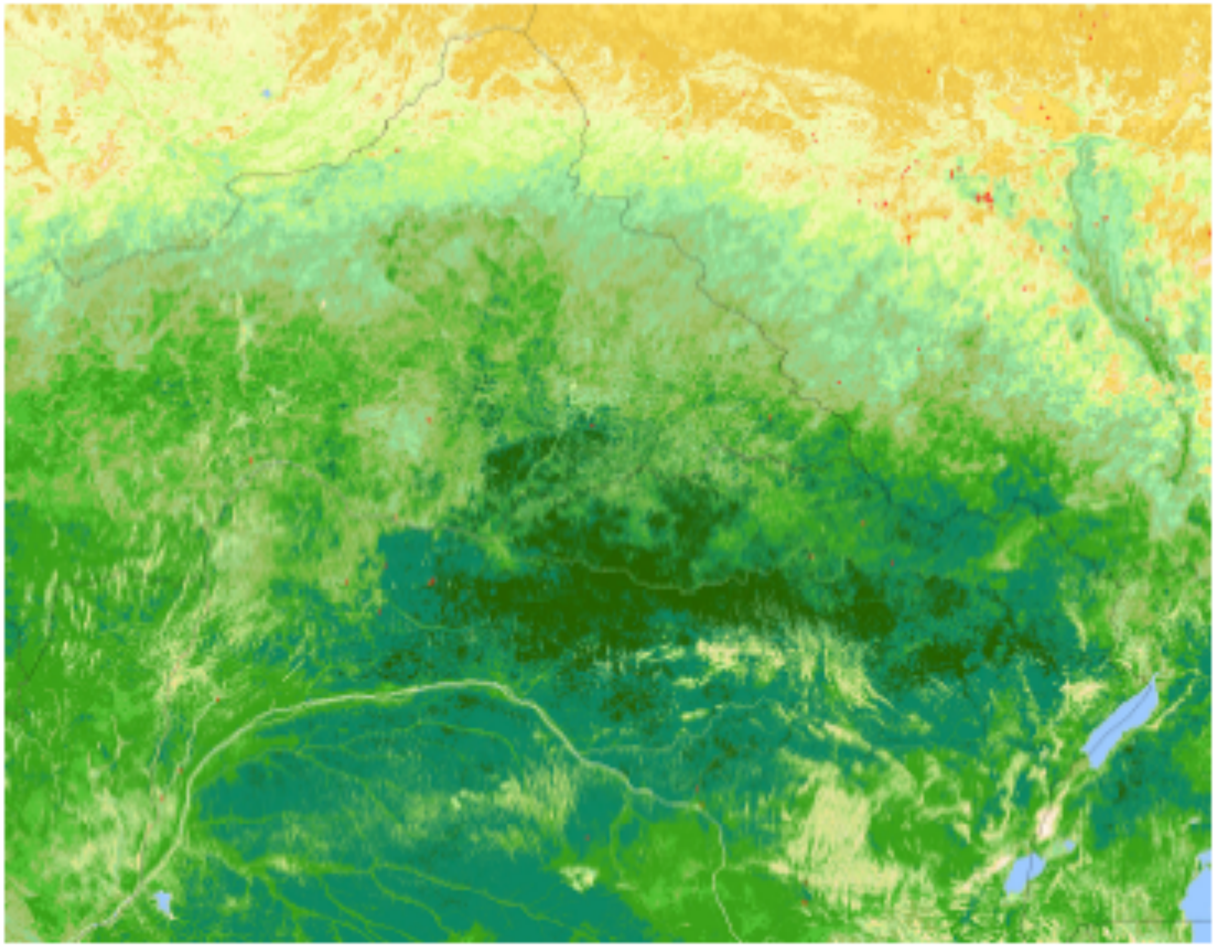
# References

Levy, R. C., L. A. Remer, and O. Dubovik, 2007: Global aerosol optical properties and application to Moderate Resolution Imaging Spectroradiometer aerosol retrieval over land. J. Geophys. Res., 112, D13210

Levy, R. C., L. Remer, S. Mattoo, E. Vermote, and Y. J. Kaufman, 2007: Second-generation algorithm for retrieving aerosol properties over land from MODIS spectral reflectance. J. Geophys. Res., 112, D13211, 22 pages.

Remer, L. A., Y. J. Kaufman, D. Tanre, S. Mattoo, D. A. Chu, J. V. Martins, R-R. Li, C. Ichoku, R. C. Levy, R. G. Kleidman, T. F. Eck, E. Vermote, & B. N. Holben, 2004: The MODIS Aerosol Algorithm, Products and Validation. Journal of Atmospheric Sciences, 64, 4, 947-973.

# 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

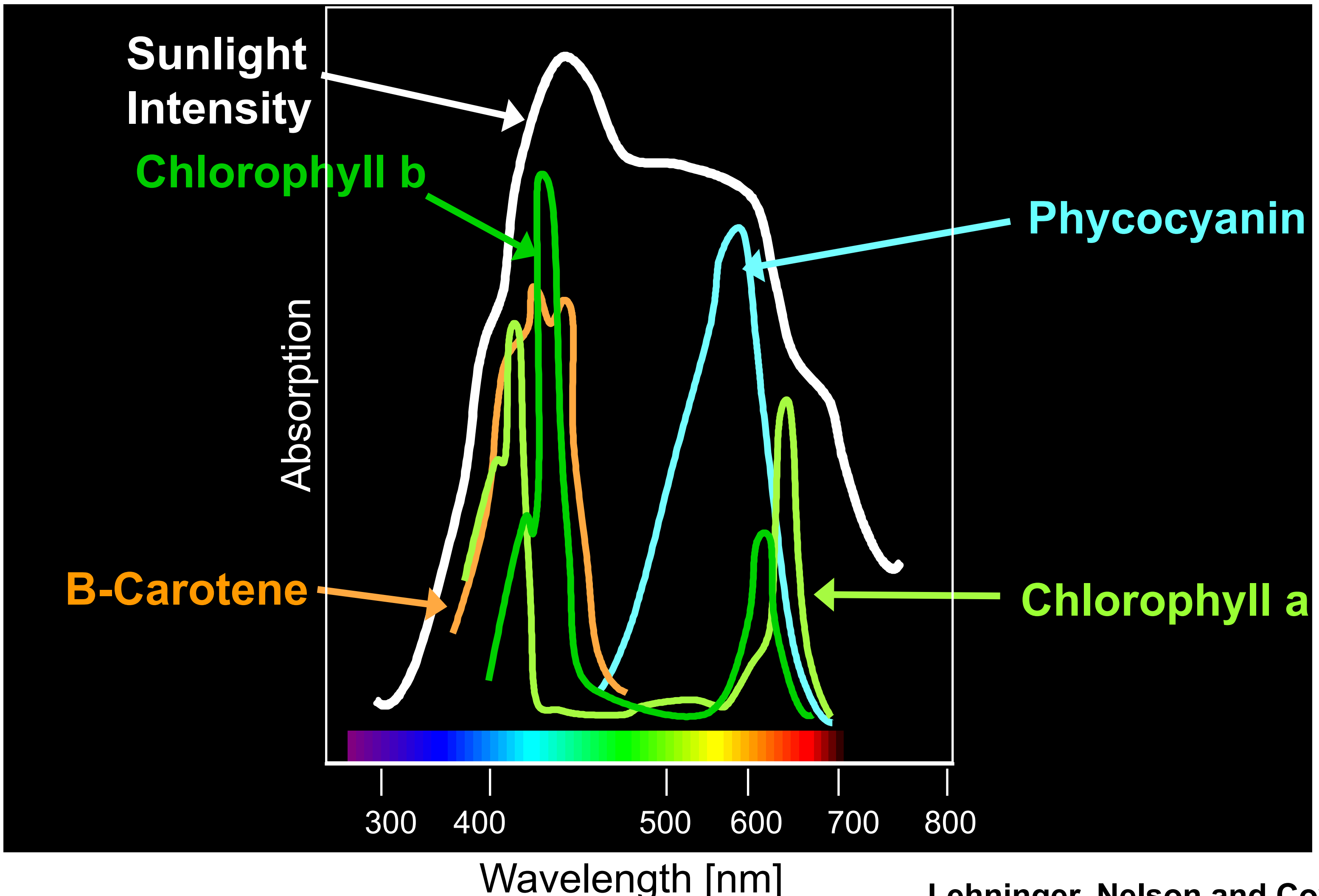
$$6CO_2 + 6H_2O + h\nu \rightarrow C_6H_{12}O_6 + 6O_2$$

- 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

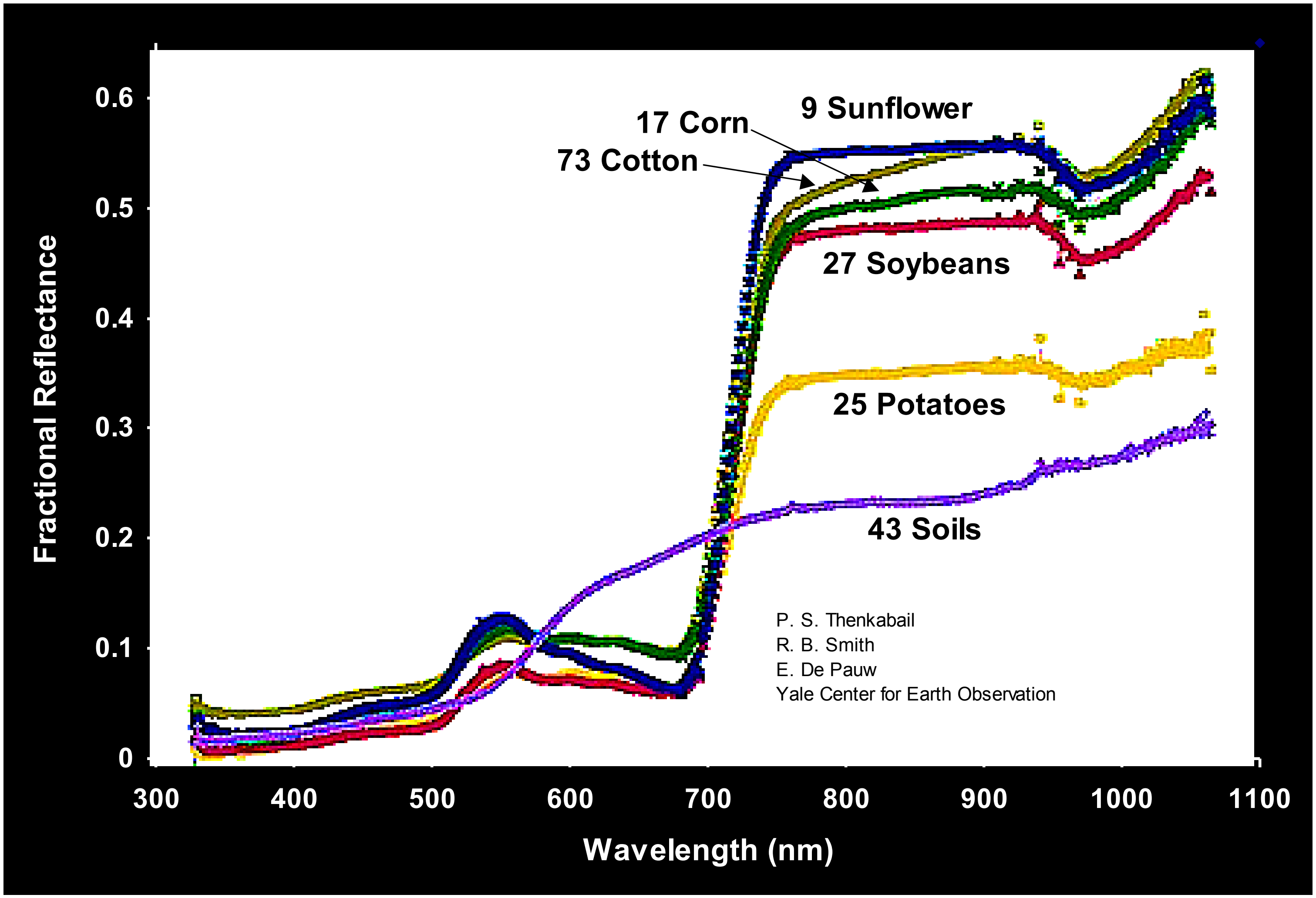
# Theoretical description

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

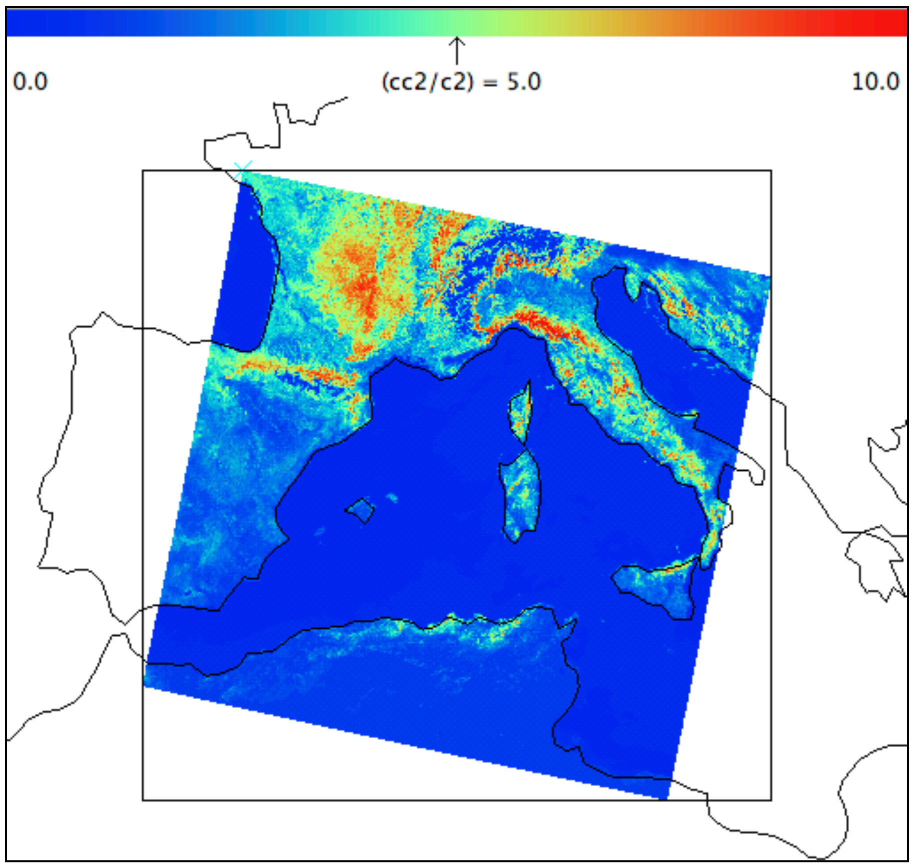
Contrast between RED and NIR responses is correlated to vegetation amount

# 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



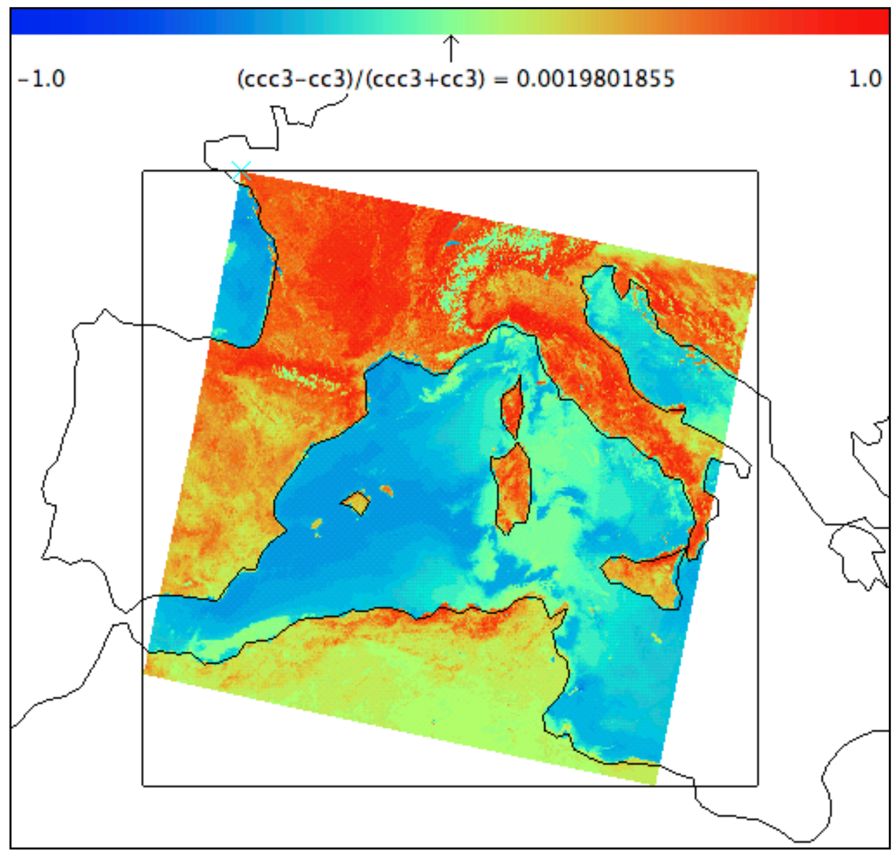
# Normalized Difference Vegetation Index (NDVI)

Defined as the ratio

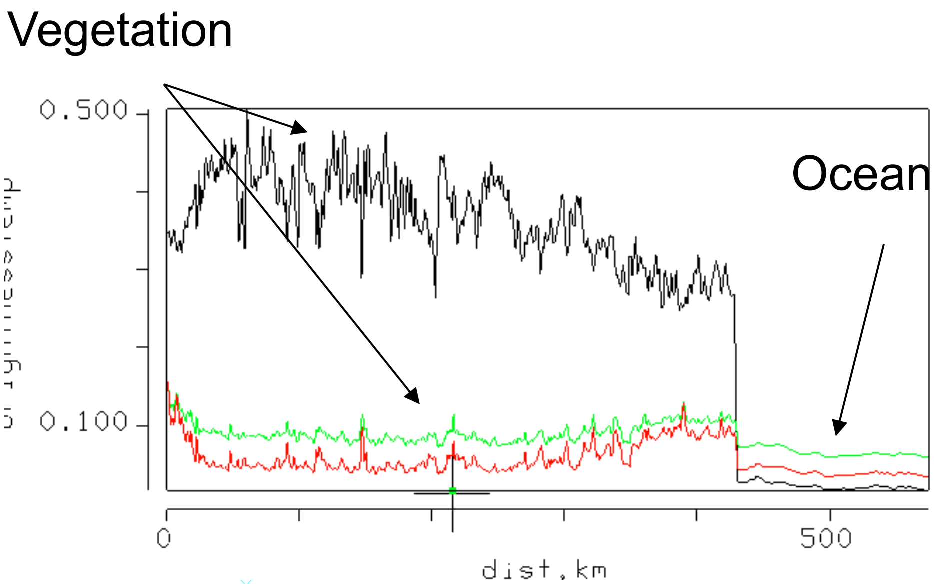
$$(X_{nir} - X_{red})/(X_{nir} + X_{red})$$

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

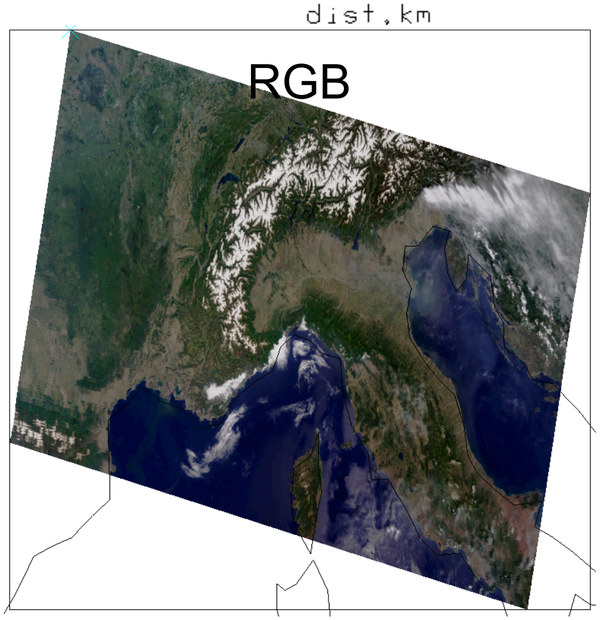
| Applications: | |
|---|---|
| Vegetation Monitoring | Agricultural Activities |
| Drought studies | Landcover Change |
| Public Health Issues (mosquitos) | Climate Change Detection |
| Net Primary Production | Carbon Balance |

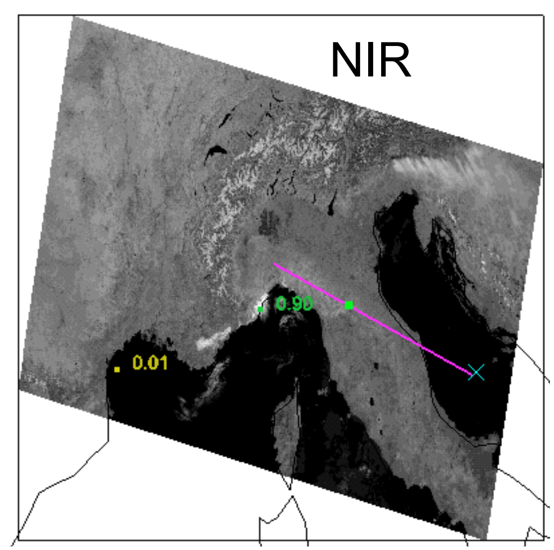


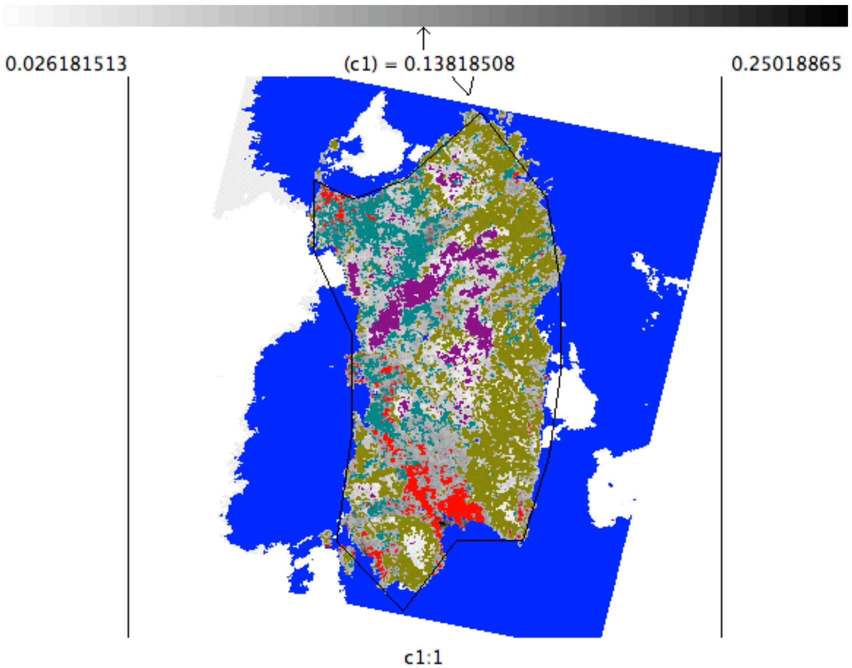
# NIR and VIS over Vegetation and Ocean



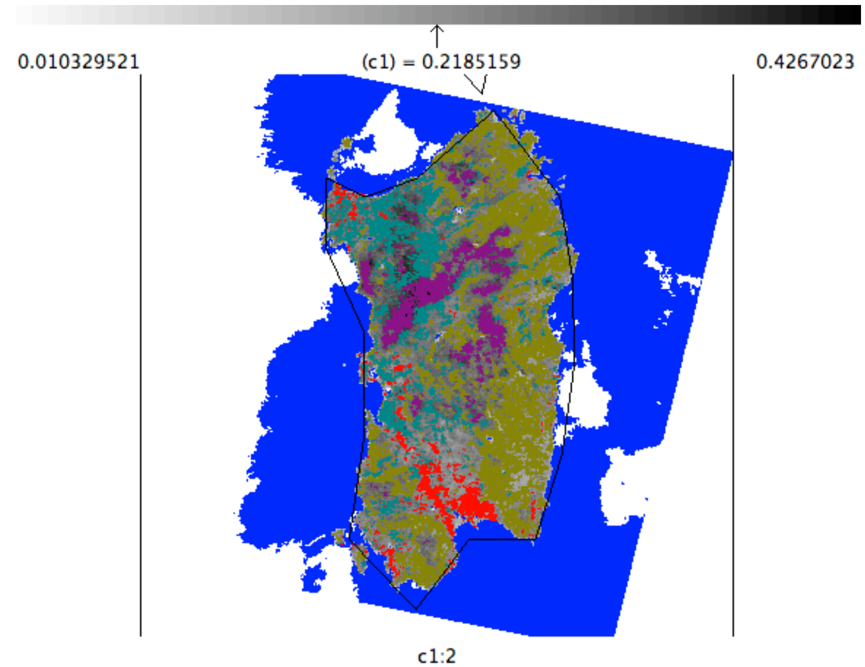

NIR (.86 micron)
Green (.55 micron)
Red (0.68 micron)



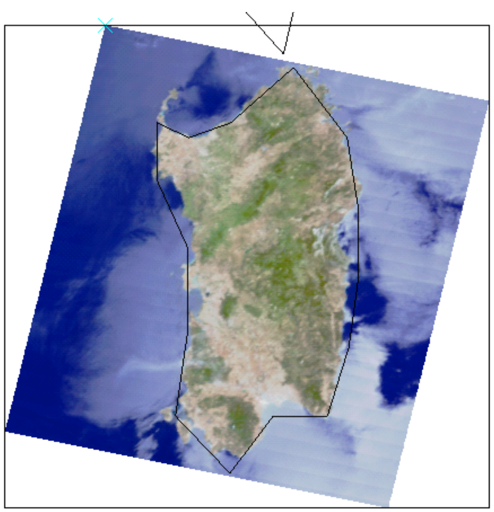





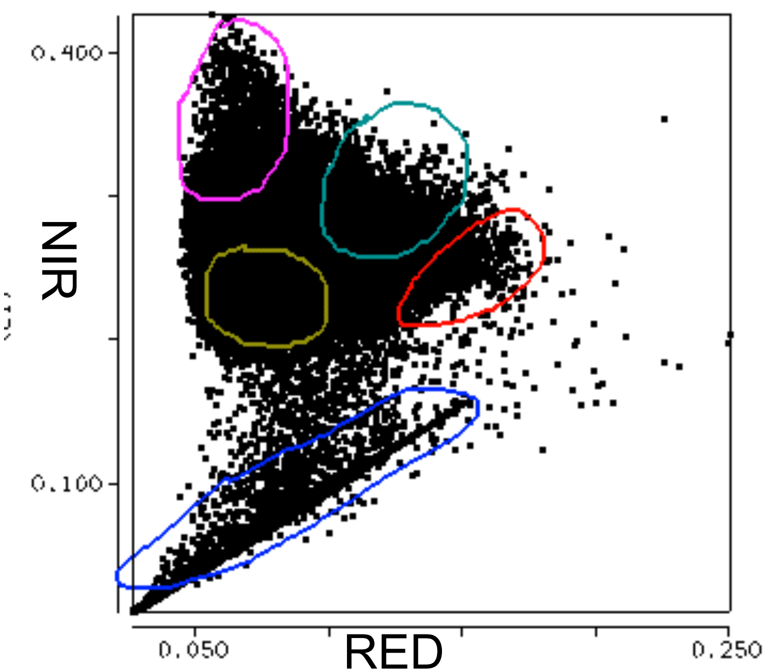

RED




NIR



True Color



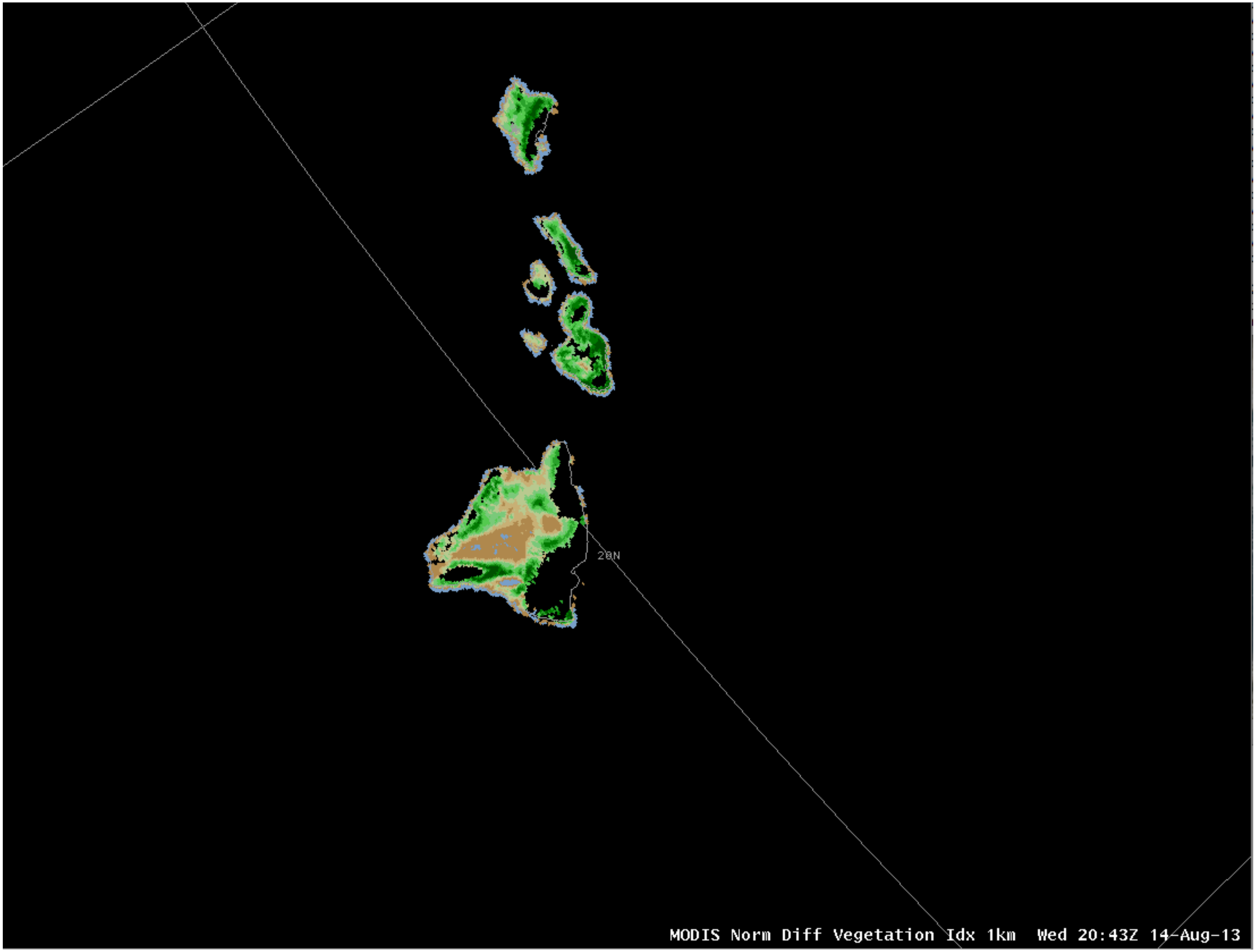

Dense Vegetation

Less Vegetation

Less Vegetation

Barren Soil

Ocean


20N
MODIS Norm Diff Vegetation Idx 1km  Wed 20:43Z 14-Aug-13

# Using MODIS Sun Glint Patterns

- What is sun glint?
- Application
  - Identifying regions of calm waters
  - Relationship of calm waters and sea surface temperatures

"Mirror" reflection of sunlight off calm water.

## Sun Glint

Simple example where your eye is the sensor

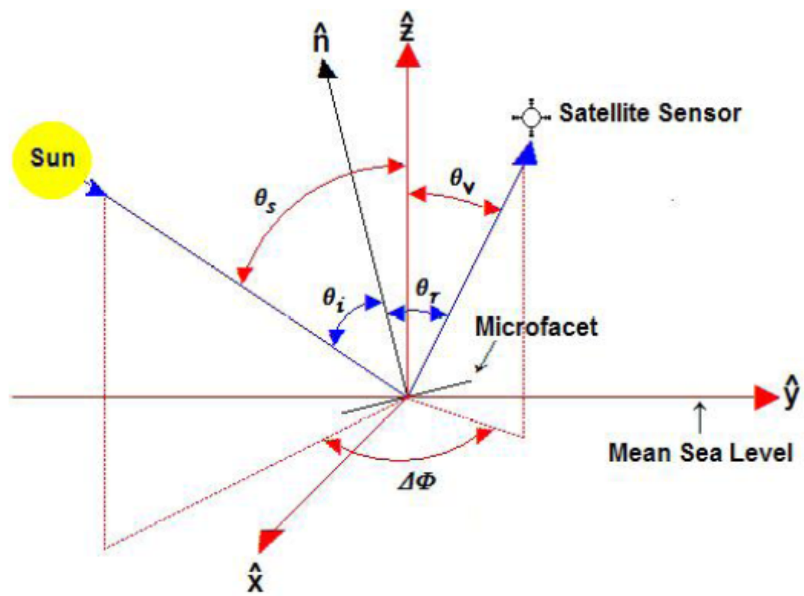
Sun Glint Ellipse Defined by: $\theta_r < 36$

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

Where $\theta_v$ = Viewing Zenith Angle

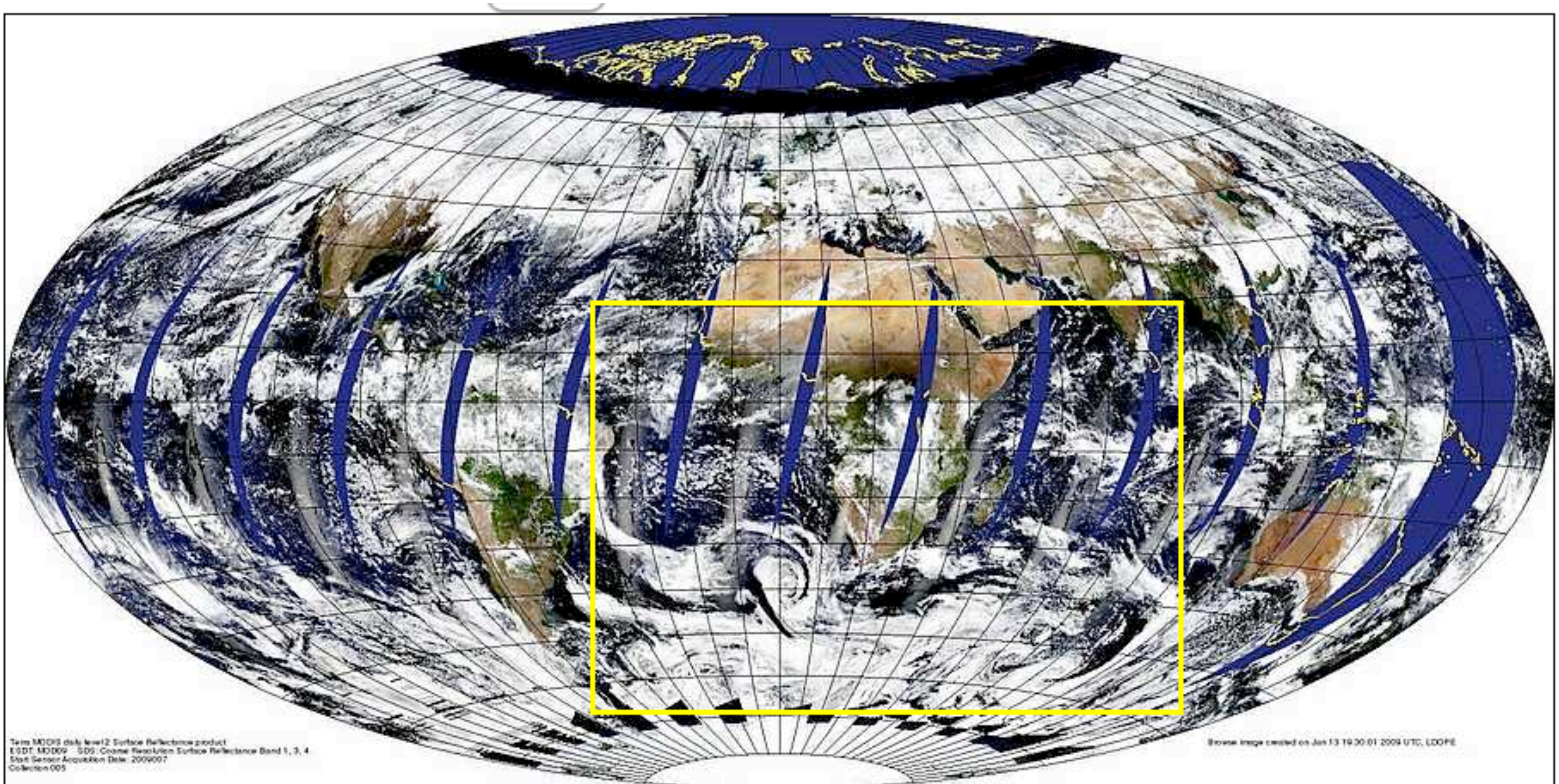
$\theta_s$ = Solar Zenith Angle

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

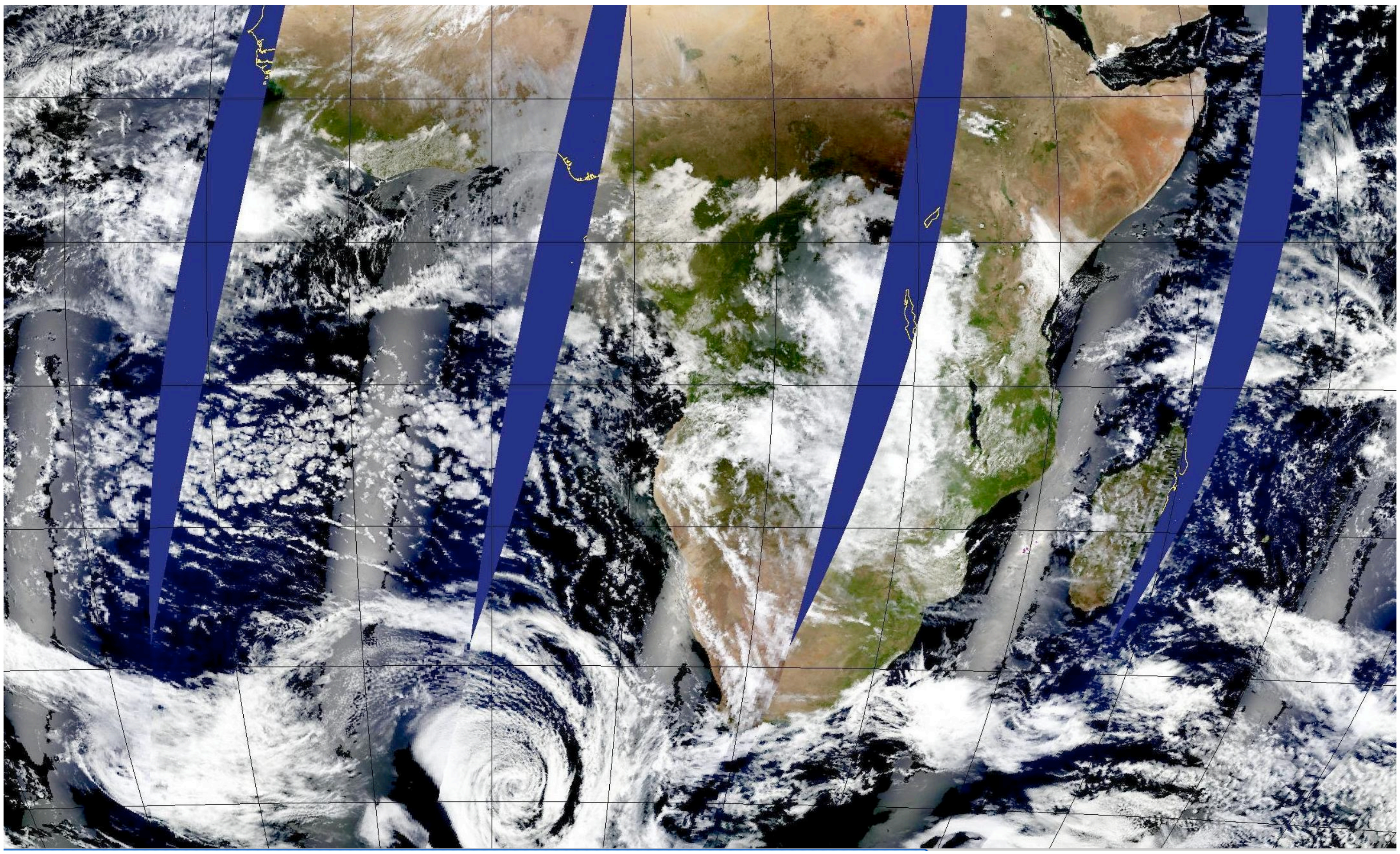


# Aqua MODIS Sun Glint Example

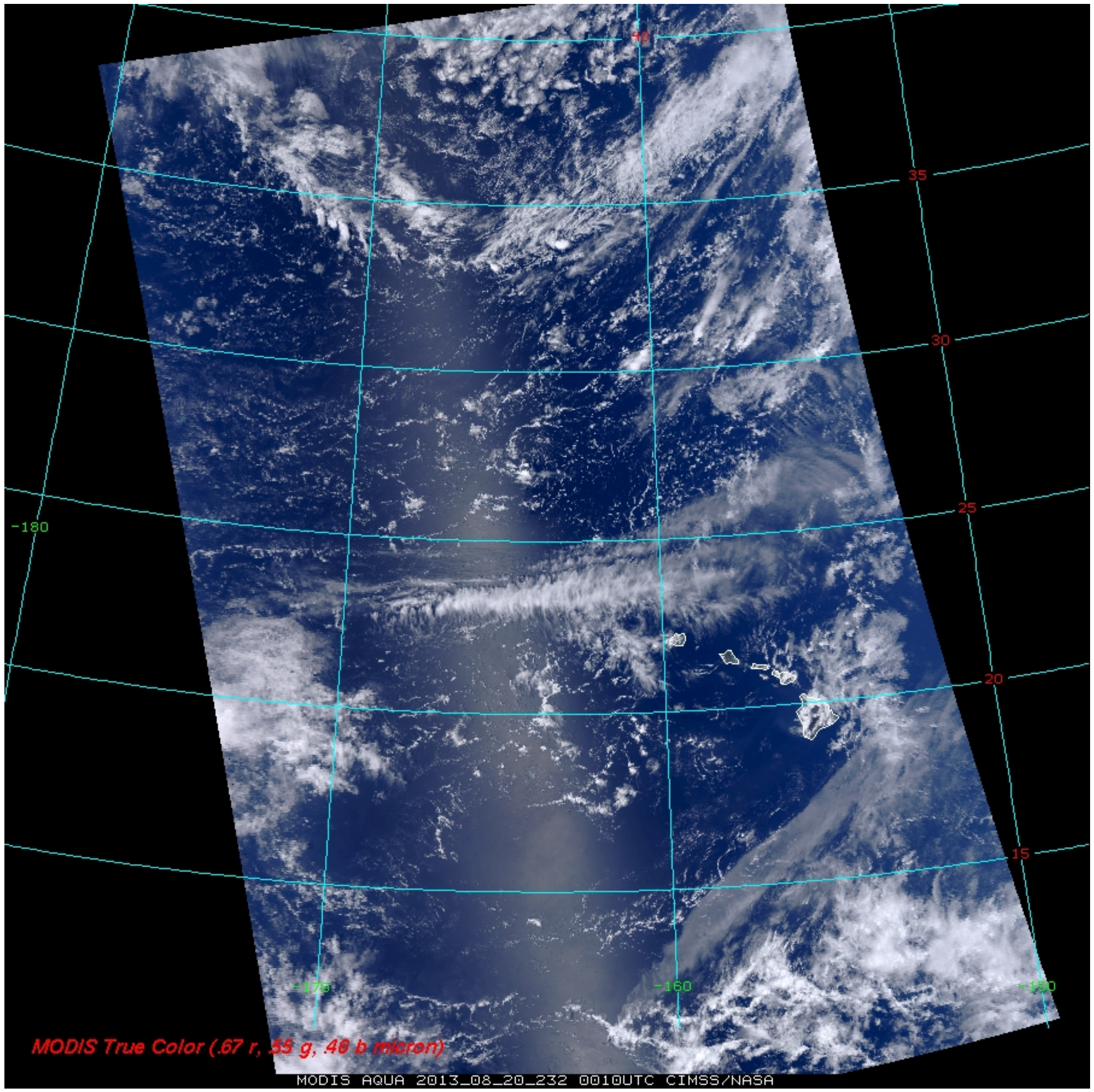
## 7 January 2009



# Sun Glint Patterns

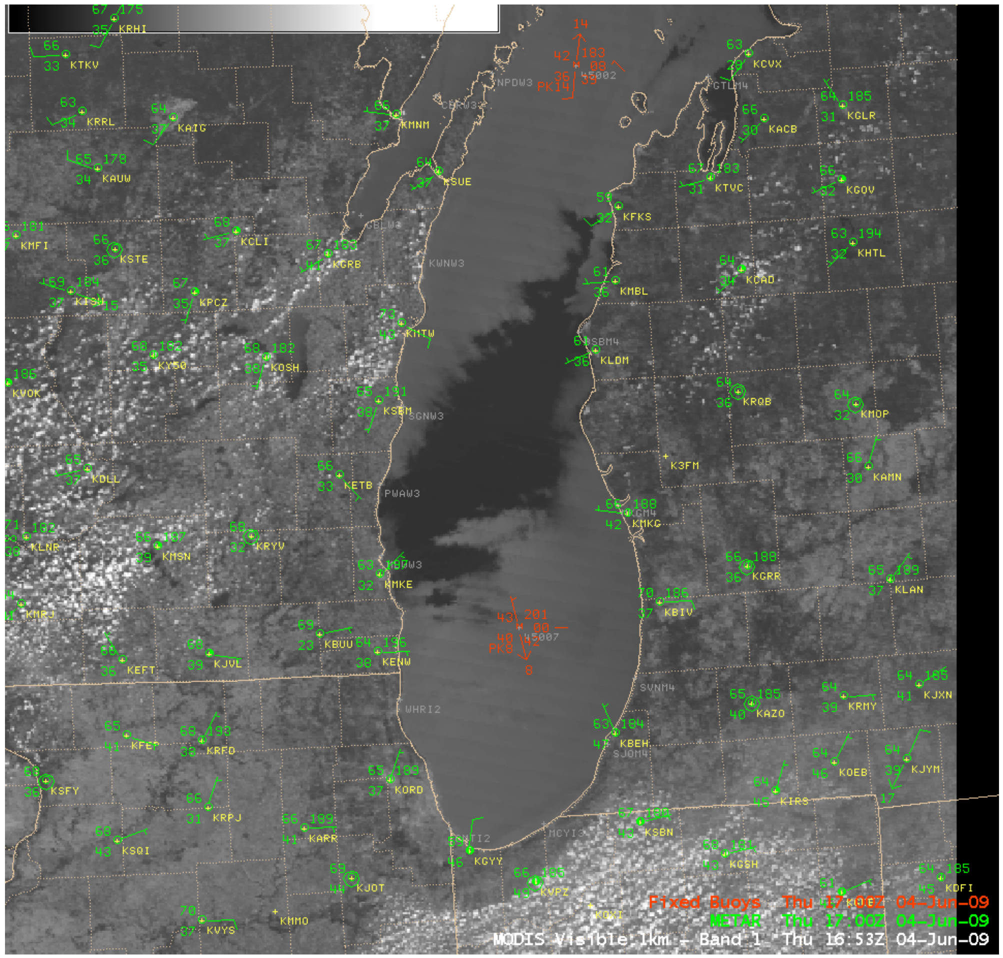


# Sunglint Pattern – HCC Antenna Pass



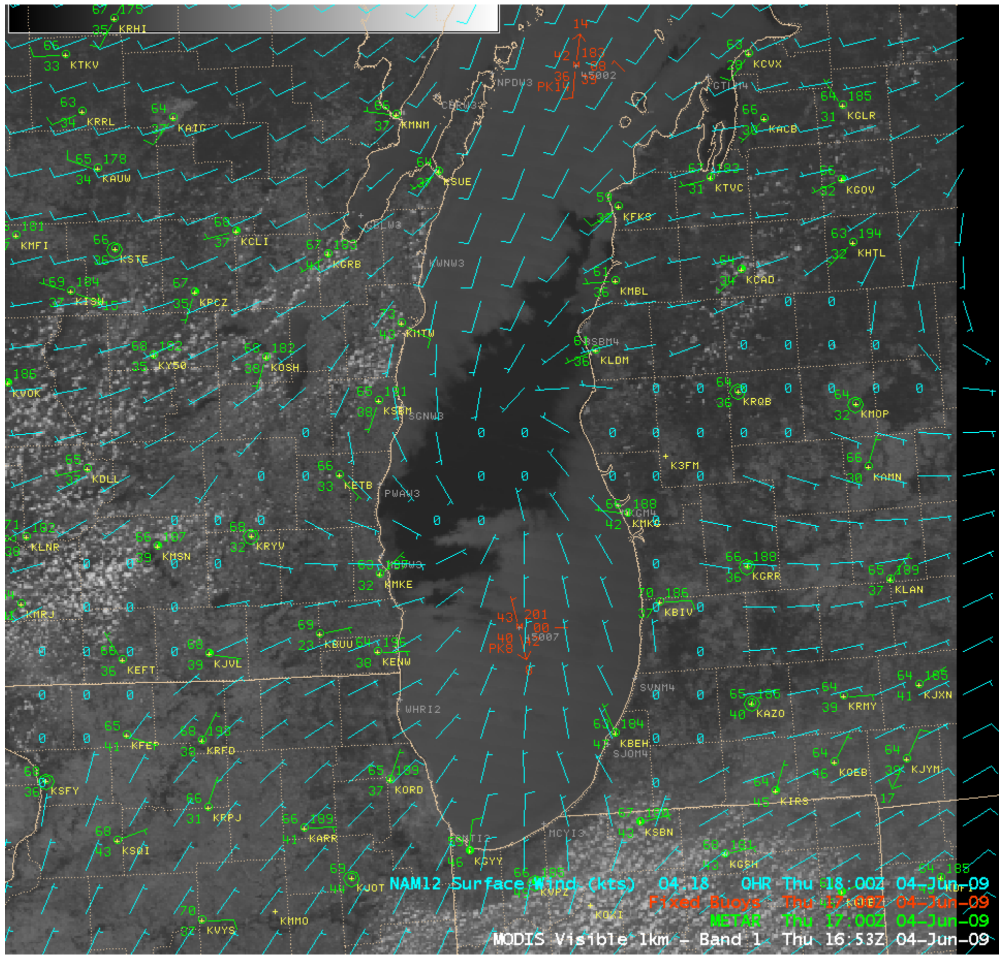
# Example From Lake Michigan

## 4 June 2009



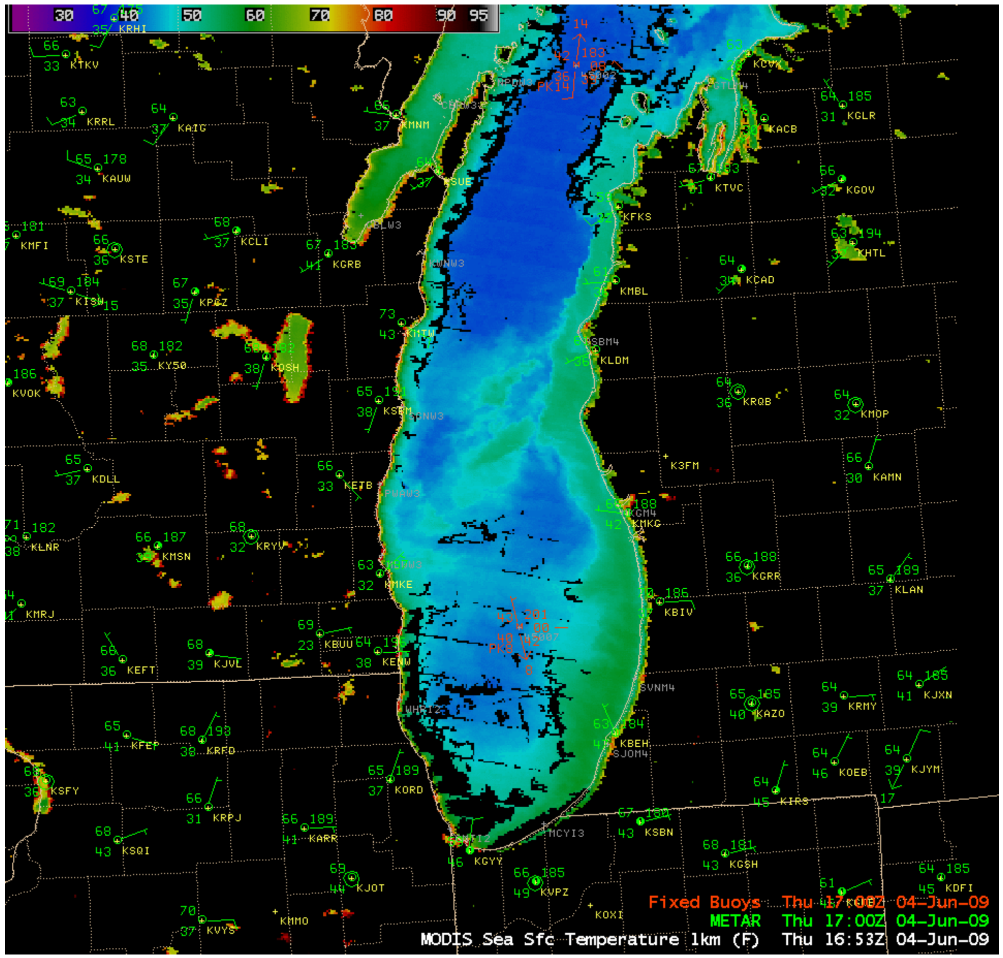
# Numerical Weather Prediction

## Wind analysis 18 UTC 4 June 2009

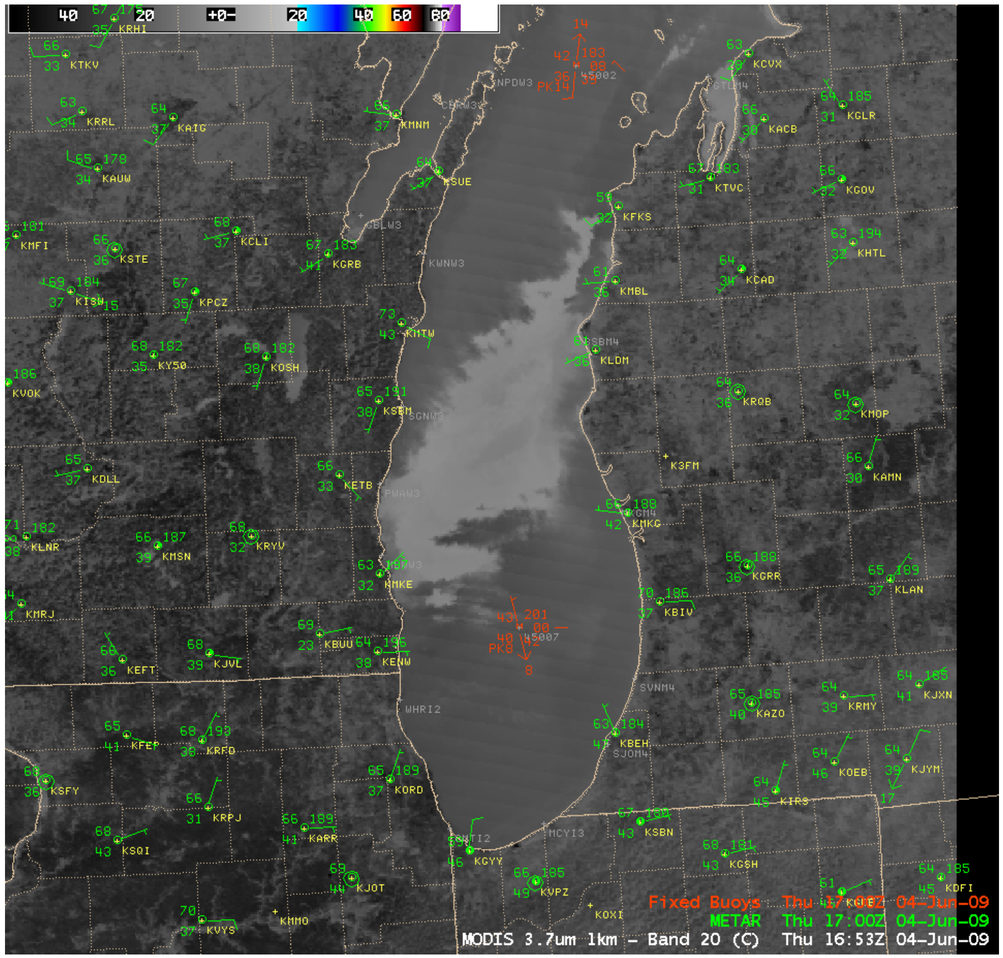


# MODIS Sea Surface Temperatures

## 4 June 2009

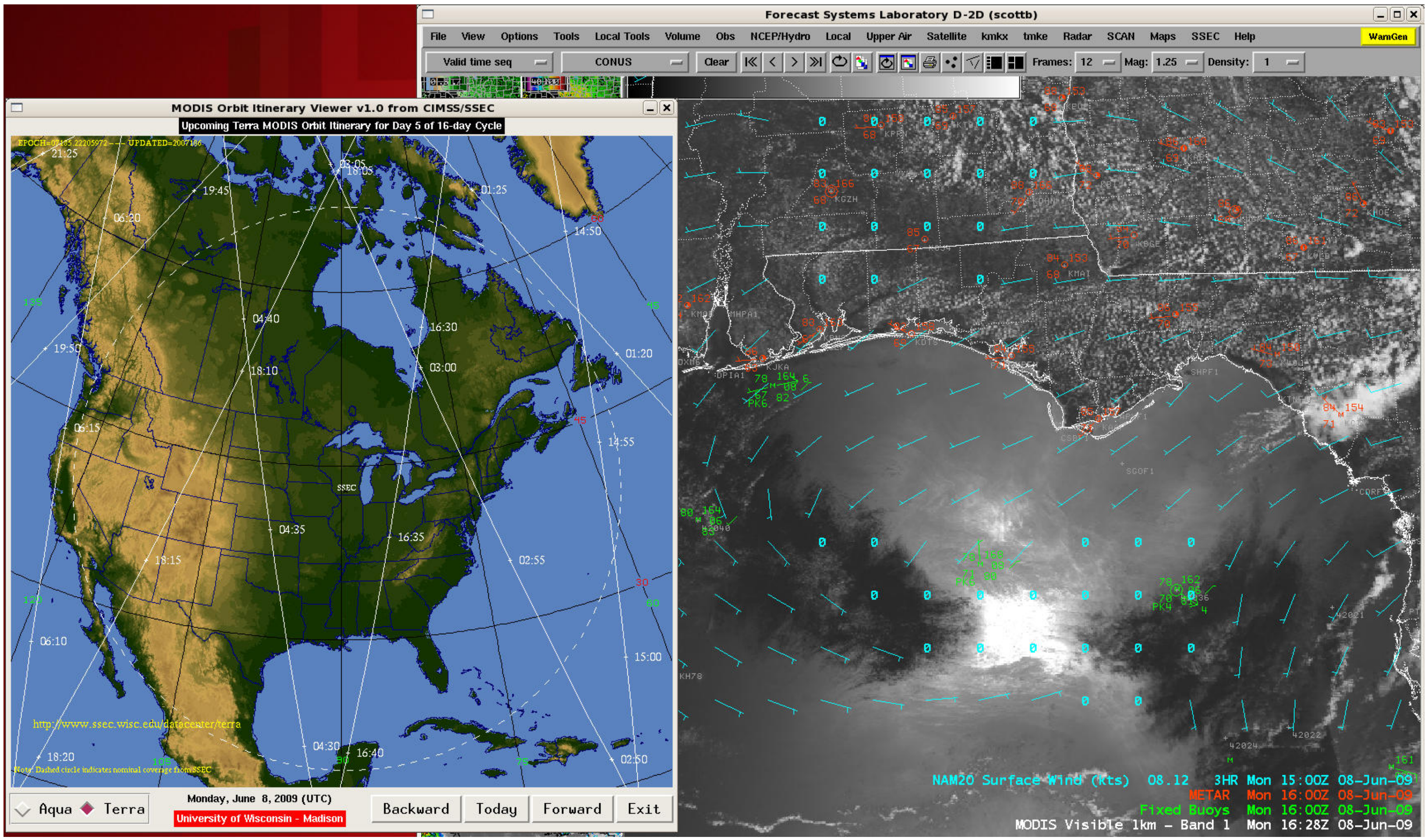


# MODIS 4 µm Brightness Temperatures



# MODIS Sunglint Pattern

## 8 June 2009



# MODIS LST and buggers



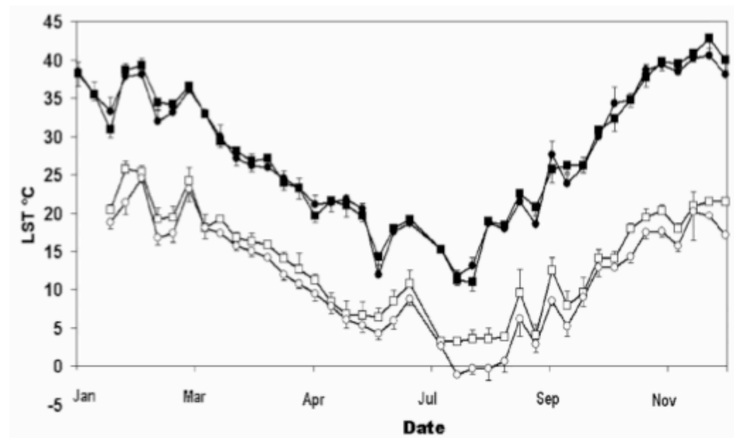



**Fig. 4.** Annual variation (2003) of diurnal land surface temperature (LST day) produced by the MODIS sensor (closed symbols) and LST night (open symbols) in locality groups of high (squares) and low (circles) house infestation rate. LST values are 8-d composites.

Reference: X. Porcasi, , S. S. Catala, H. Hrellac, M. C. Scavuzzo, D. E. Gorla, 2006: Infestation of Rural Houses by Triatoma Infestans (Hemiptera: Reduviidae) in Southern Area of Gran Chaco in Argentina, J. Med. Entomol. 43(5): 1060-1067.