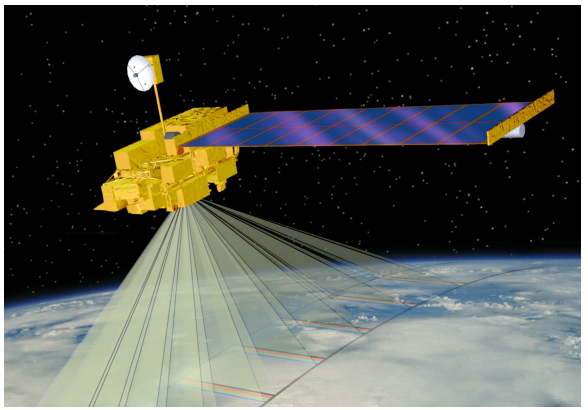
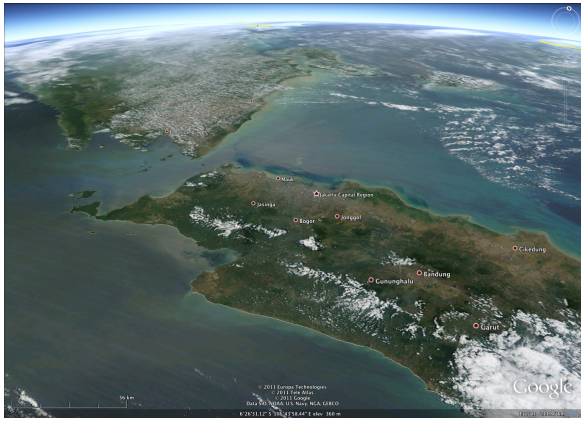
Introduction to the MODIS Sensor and Products

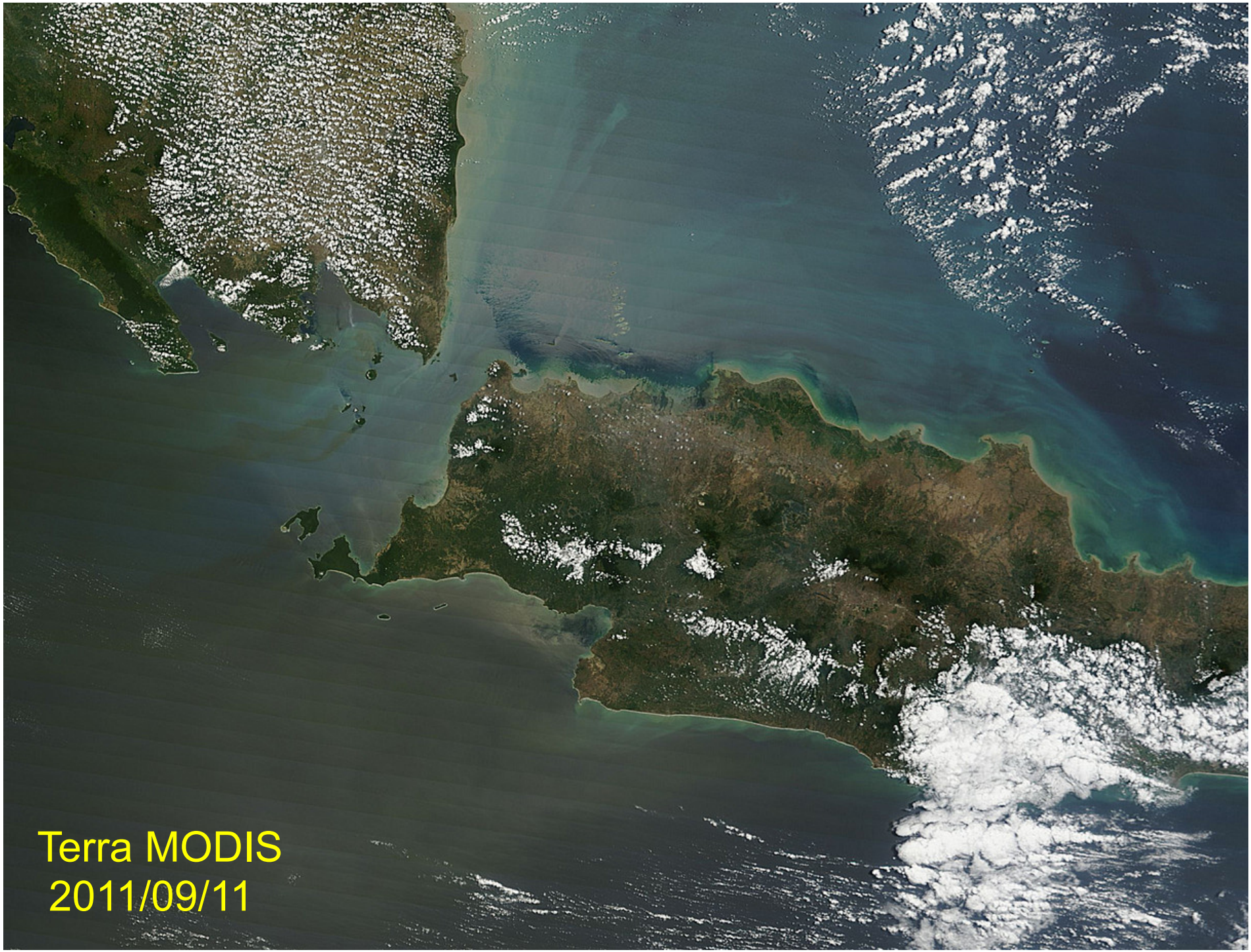


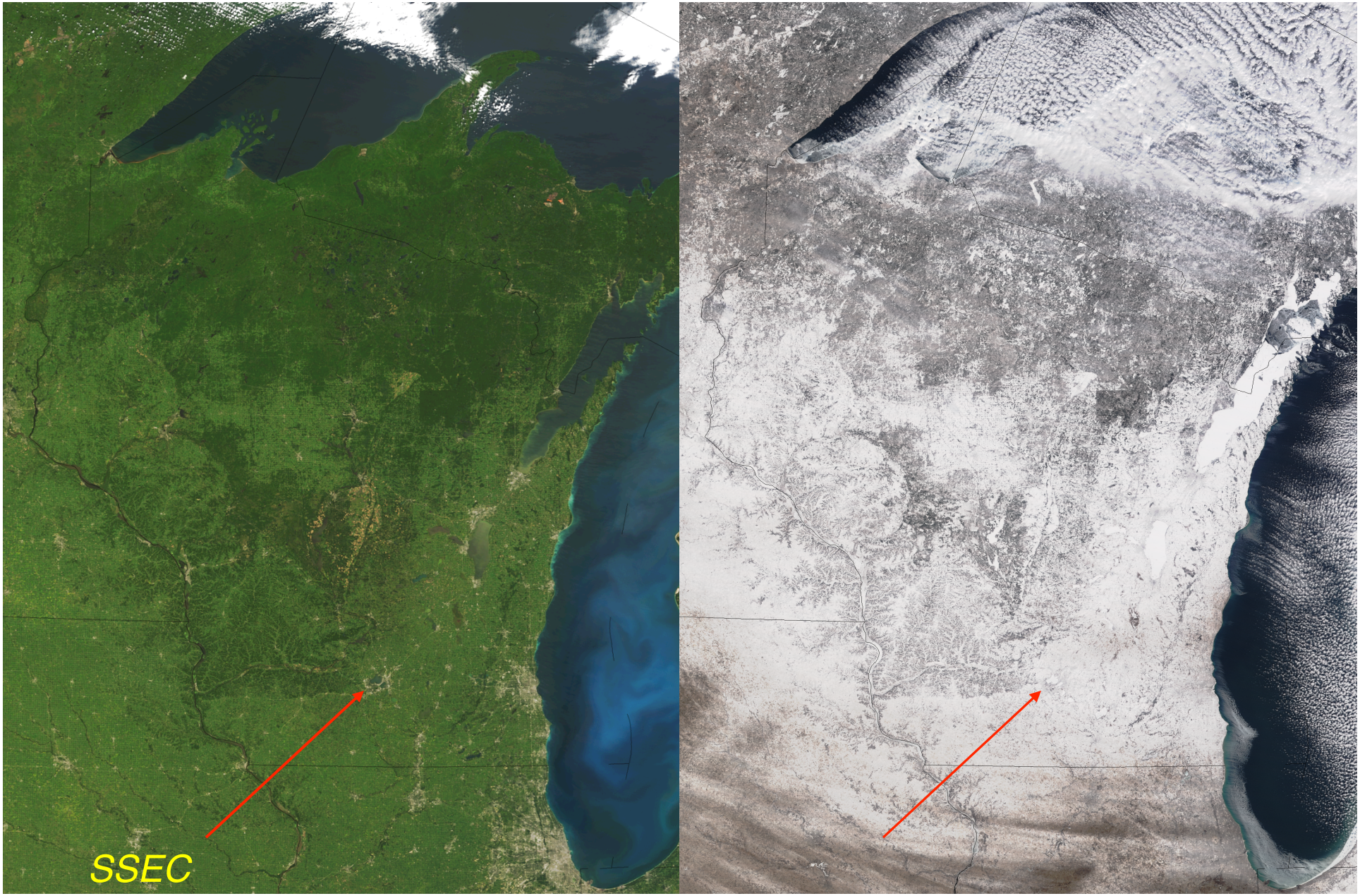
RA-V Training Workshop on Satellite Applications for Meteorology and Climatology
Citeko, Bogor–Indonesia
19 – 27 September 2011



Kathy Strabala (kathy.strabala@ssec.wisc.edu) and Liam Gumley
Space Science And Engineering Center
University Of Wisconsin-Madison

SSEC


Terra MODIS
2011/09/11



Visit Wisconsin: Beautiful in Summer and Winter

Earth Observing System (EOS)

The Earth Observing System is a constellation of NASA satellites for observing and quantifying global change processes

The Earth Observing System (EOS) is intended to measure the impact of human activities and other phenomena on the world's climate over a period spanning nearly two decades …

It is the biggest single science program in the world …

- Charles F. Kennel

Terra

Launched: Dec. 18, 1999

10:30 am descending node

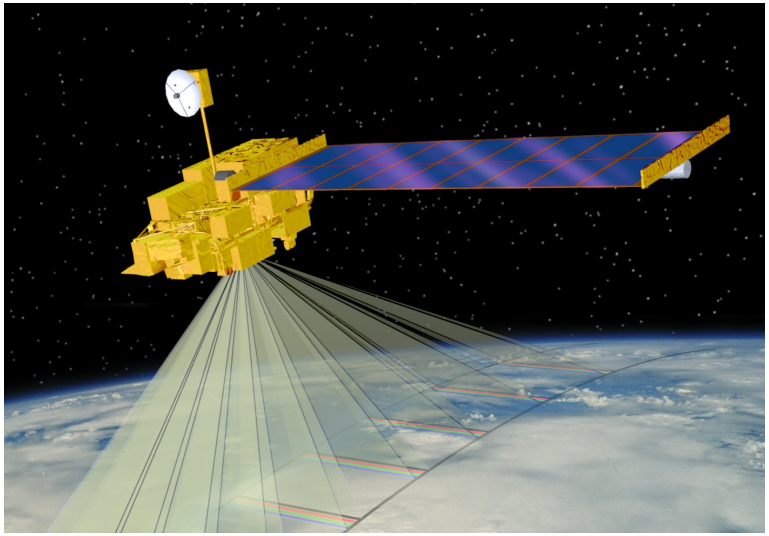
ASTER: Hi-res imager

CERES: Broadband scanner

MISR: Multi-view imager

MODIS: Multispectral imager

MOPITT: Limb sounder



Expected lifetime about 15 years

Terra MODIS first light image, 24 Feb. 2000

Birdfoot Delta
Mississippi River
USA

Aqua

Launched: May 4, 2002

1:30 pm ascending

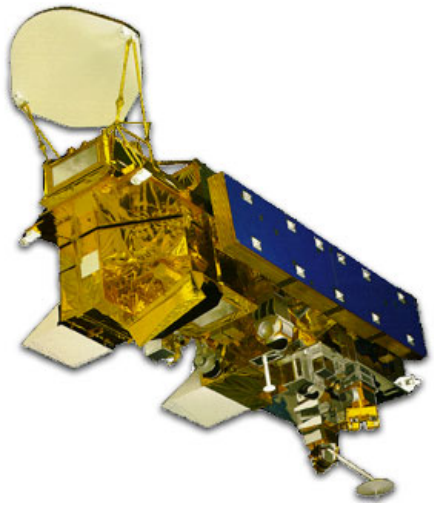
AIRS: Infrared sounder

AMSR-E: Microwave scanner

AMSU: Microwave scanner

CERES: Broadband scanner

MODIS: Multispectral imager



Expected lifetime about 15 years

Moderate Resolution Imaging Spectroradiometer (MODIS)

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

Spectral coverage: 36 bands from 0.4 to 14.2 microns

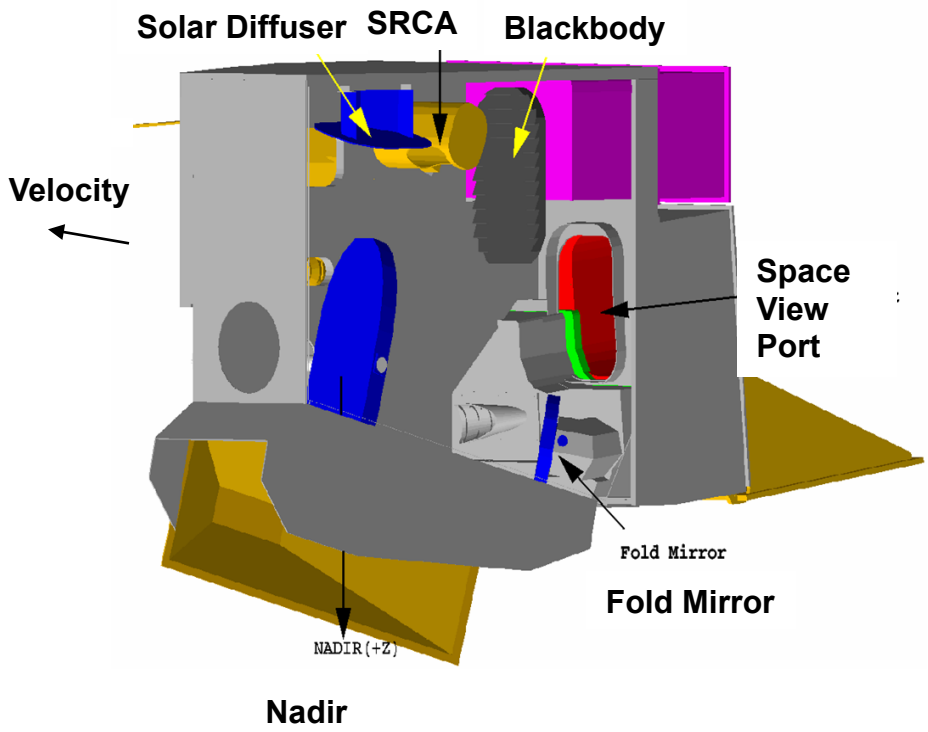
Spatial resolution: 2 bands @ 250 m; 5 @ 500 m; 29 @ 1000 m

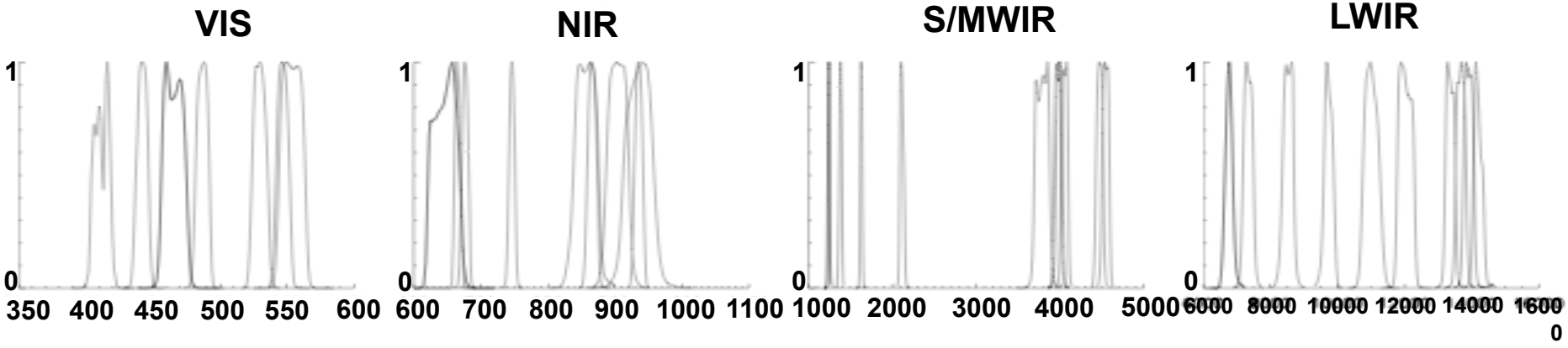
Major differences:

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

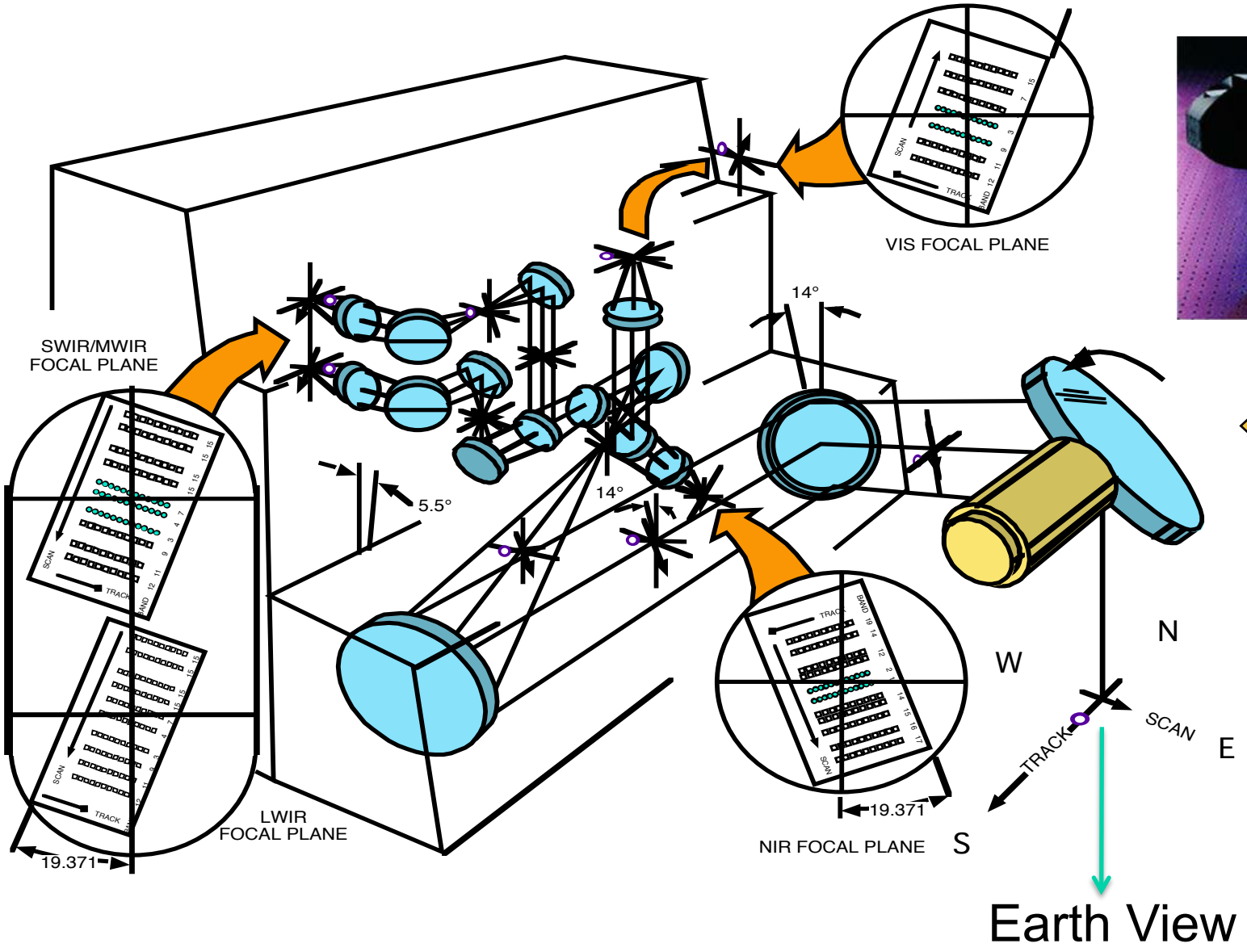
MODIS Instrument Overview

- 36 spectral bands (490 detectors) covering 0.4 to 14.5 μm
- 4 Focal Plane Arrays: Visible, Near Infrared, Shortwave Infrared, Longwave Infrared
- On-Board Calibrators: SD/SDSM, SRCA, and BB (plus space view)
- 12 bit (0-4095) dynamic range
- 2-sided Paddle Wheel Scan Mirror scans 2330 km swath in 1.47 sec
- Day data rate = 10.6 Mbps; night data rate = 3.3 Mbps





MODIS Optics System



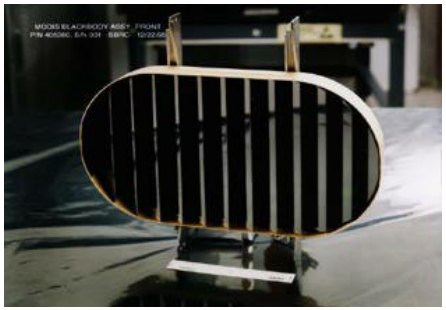
MODIS On-board Calibrators

SD

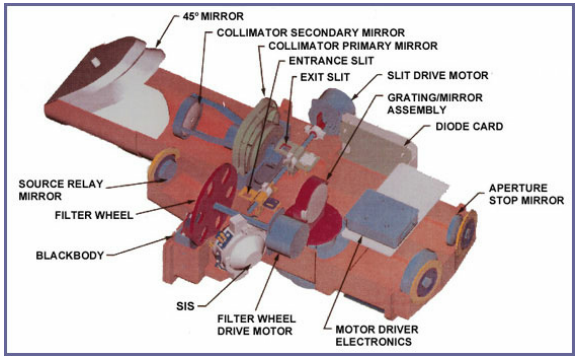
SDSM

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

BB



SRCA



MODIS Challenges

Multiple detectors:

- Detector differences are noticeable
- Dead or out-of-family detectors must be handled
- Multiple samples along track introduce bowtie distortion

Spectral information:

- Many interdependent bands
- How to use the spectral information? (algorithm design challenge)

Data rate:

- Orders of magnitude larger than heritage sensors

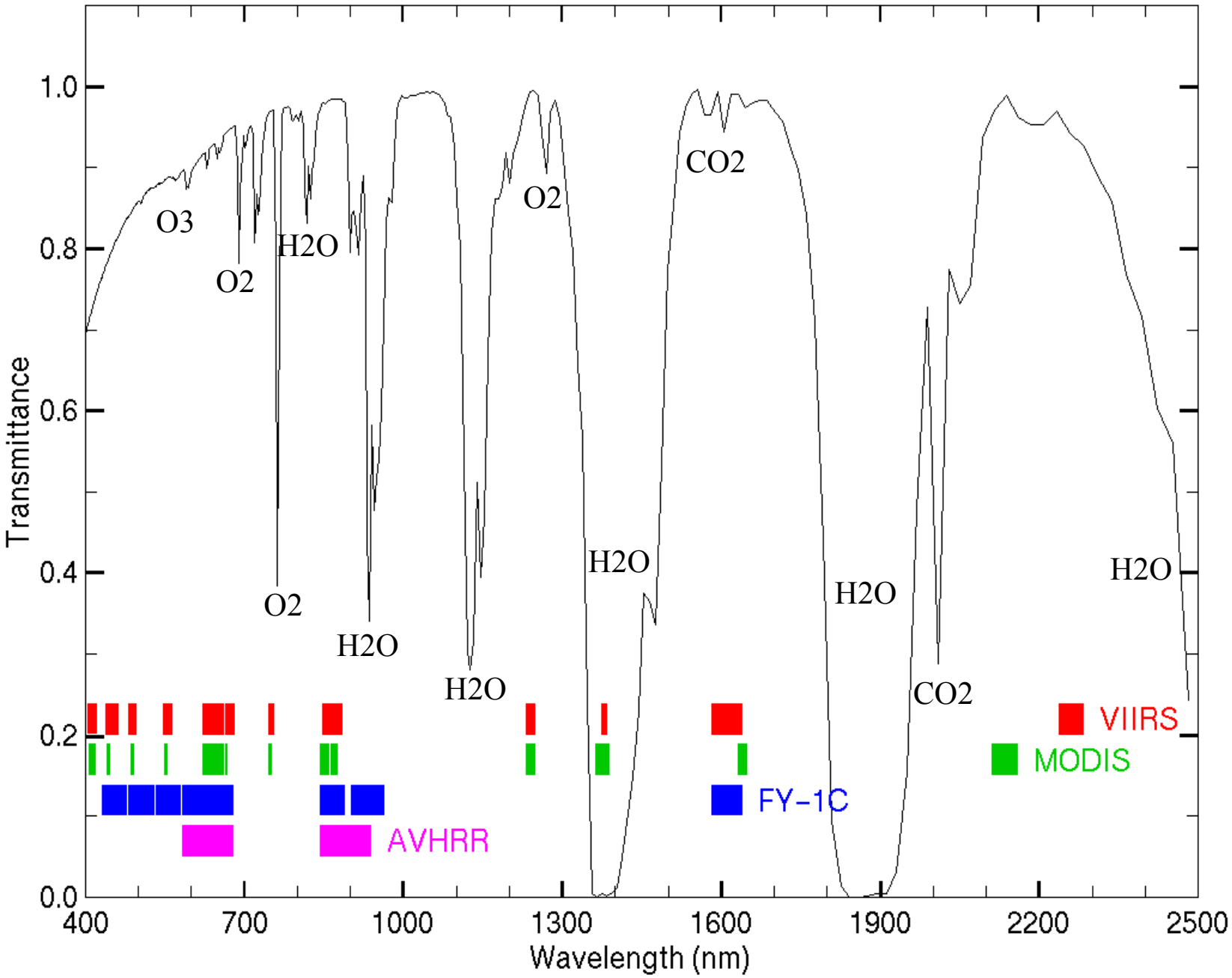
MODIS Reflected Solar Bands

Primary Use	Band	Bandwidth[1]	Spectral Radiance[2]	Required SNR[3]	
Land/Cloud/Aerosols Boundaries	1	620 - 670	21.8	128	250 meters
	2	841 - 876	24.7	201	
Land/Cloud/Aerosols Properties	3	459 - 479	35.3	243	500 meters
	4	545 - 565	29.0	228	
	5	1230 - 1250	5.4	74	
	6	1628 - 1652	7.3	275	
	7	2105 - 2155	1.0	110	
Ocean Color/ Phytoplankton/ Biogeochemistry	8	405 - 420	44.9	880	1000 meters
	9	438 - 448	41.9	838	
	10	483 - 493	32.1	802	
	11	526 - 536	27.9	754	
	12	546 - 556	21.0	750	
	13	662 - 672	9.5	910	
	14	673 - 683	8.7	1087	
	15	743 - 753	10.2	586	
	16	862 - 877	6.2	516	
Atmospheric Water Vapor	17	890 - 920	10.0	167	
	18	931 - 941	3.6	57	
	19	915 - 965	15.0	250	
Cirrus Clouds	26	1380			

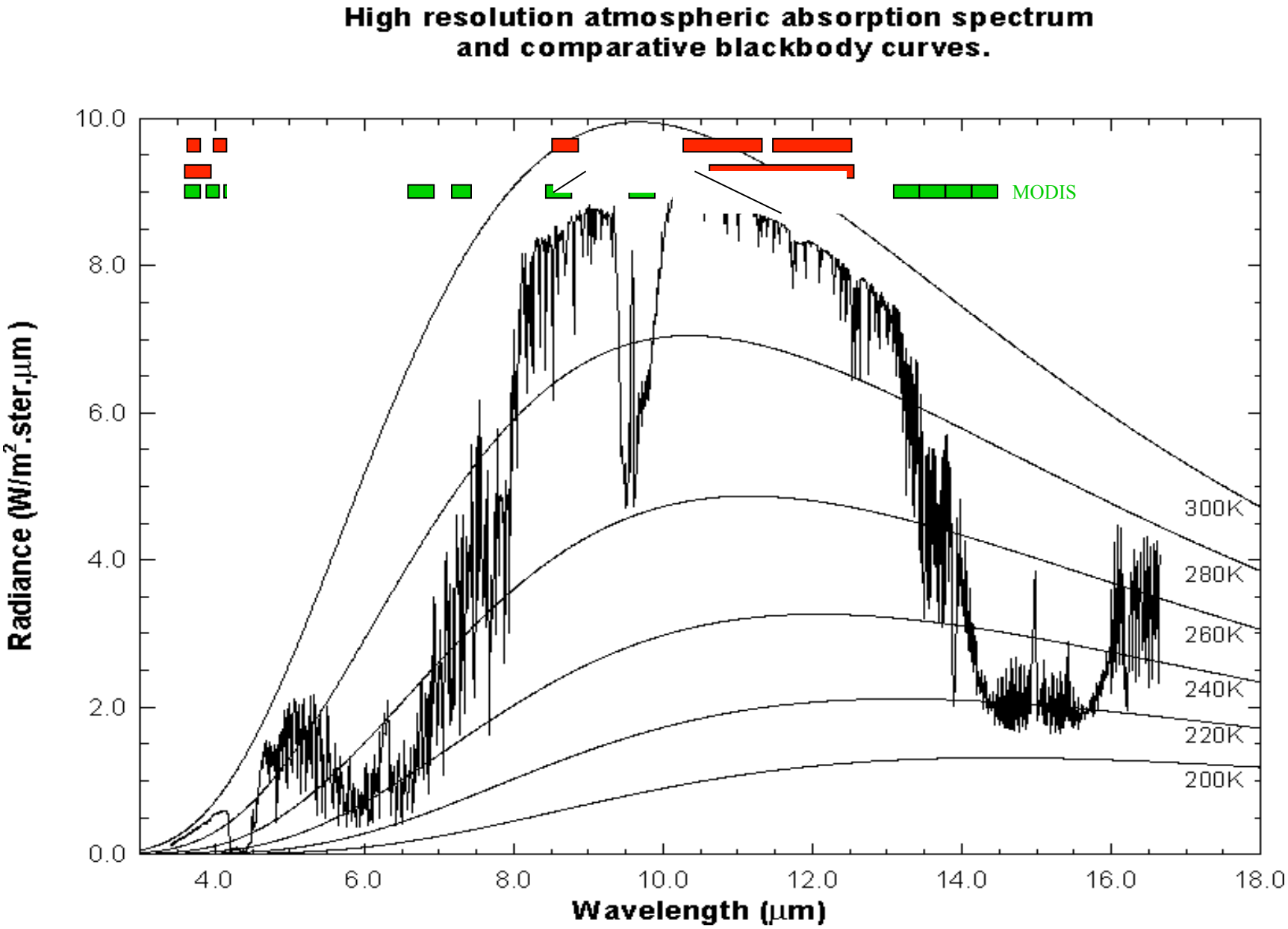
MODIS Thermal Emissive Bands

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

VIIRS, MODIS, FY-1C, AVHRR



MODIS IR Spectral Bands



MODIS Orbit and Scan Geometry

Terra: 10:30 am local descending

Aqua: 1:30 pm local ascending

Orbit period: 99 minutes

Repeat cycle: 16 days (same as Landsat; precisely controlled)

Scan mirror: Double sided, 20.3 revolutions/minute

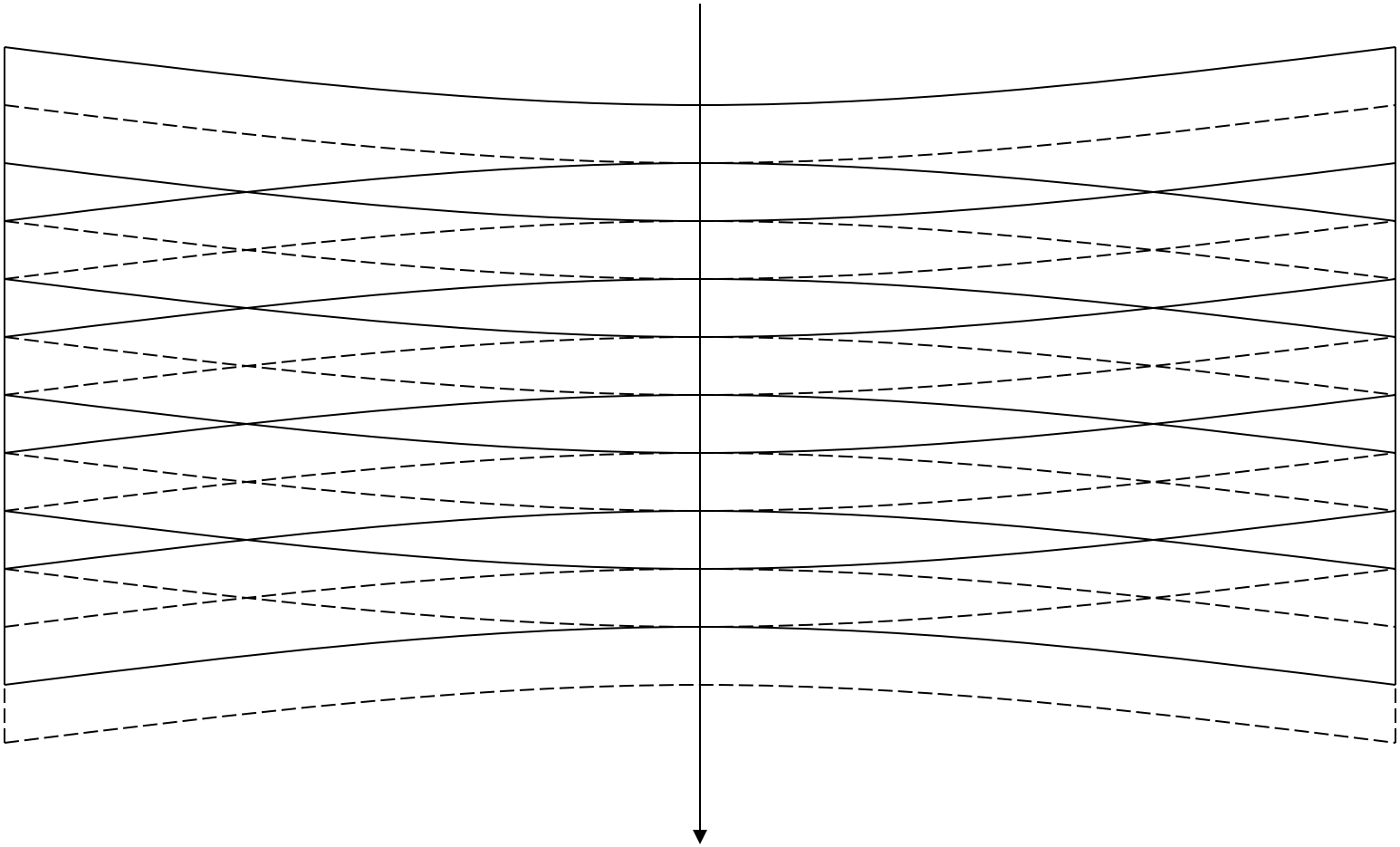
Scan rate: 1.477 scans/sec

Scan angle: +/- 55 degrees

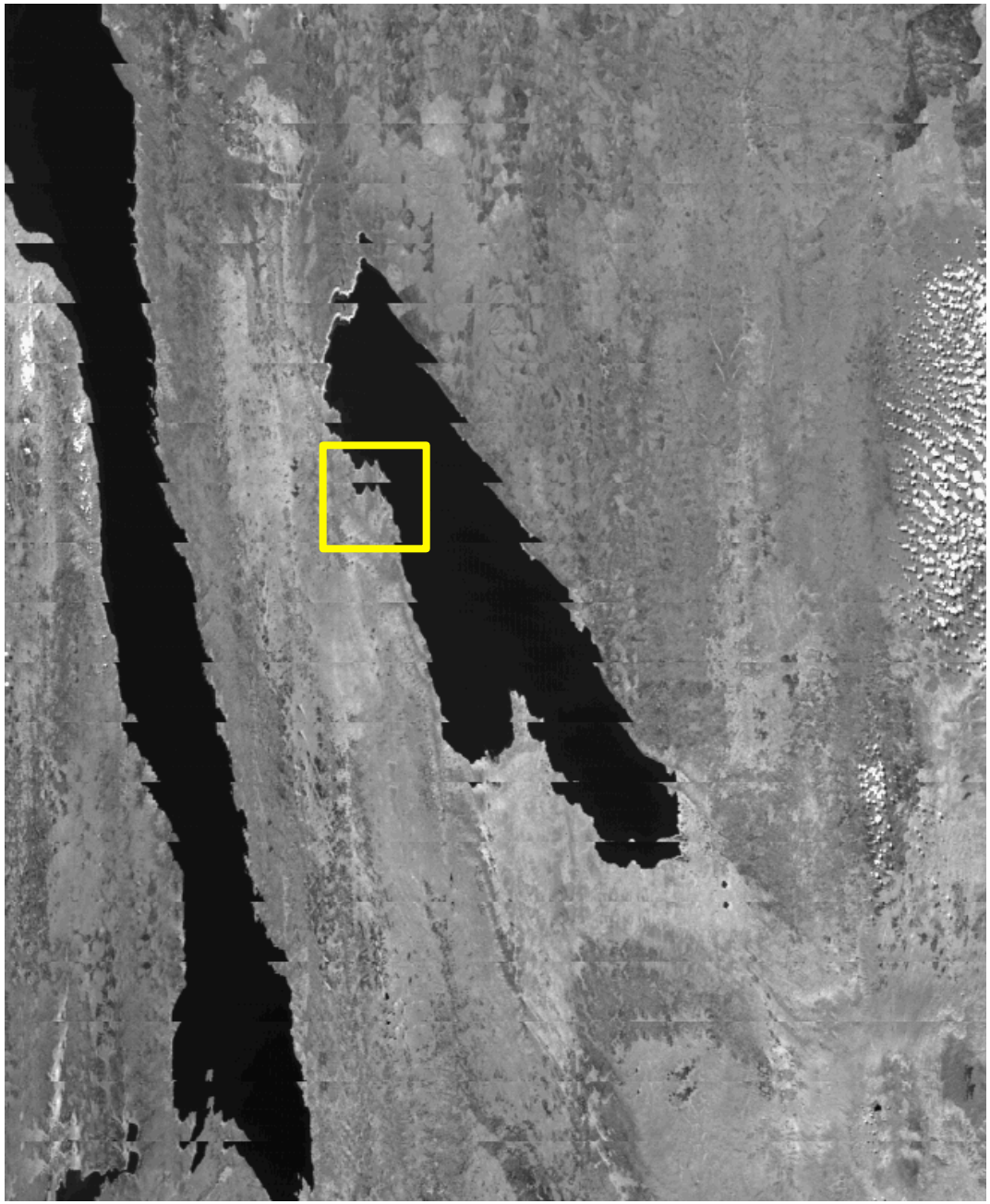
Swath width: 2330 km across track, 10 km along track

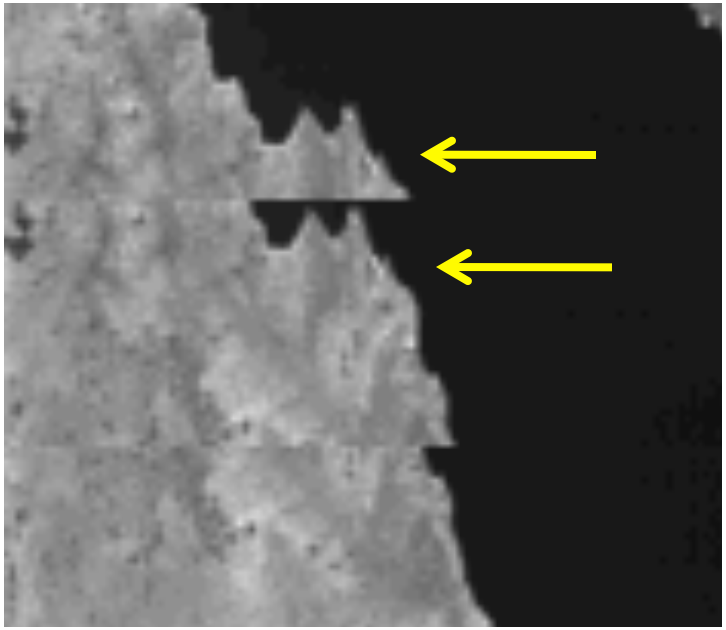
MODIS Bowtie

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



MODIS bowtie artifacts at edge of swath





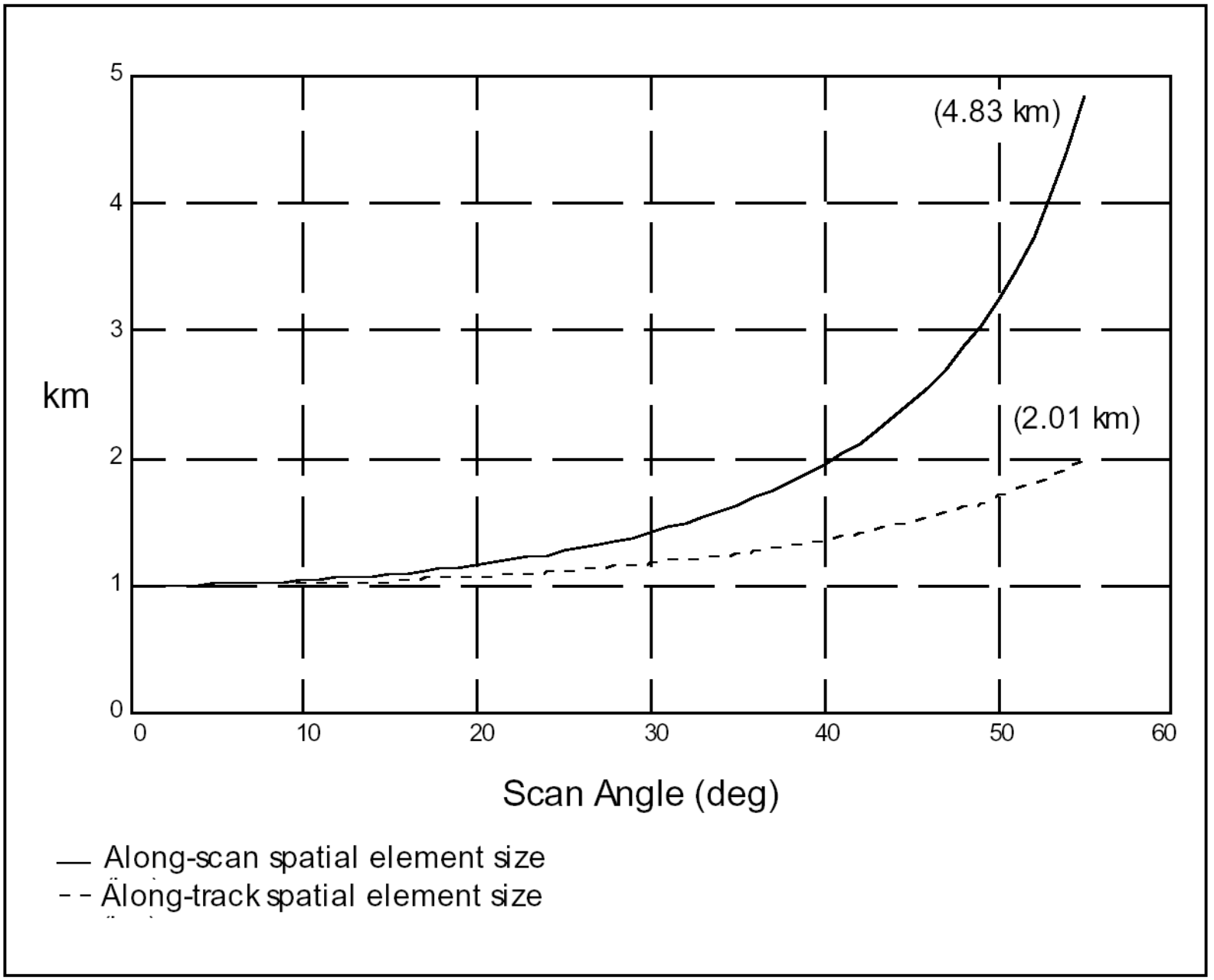
Band 2 (0.87 micron)

250 meter resolution

Bowtie Artifacts

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

Growth of MODIS 1 km pixel with scan angle



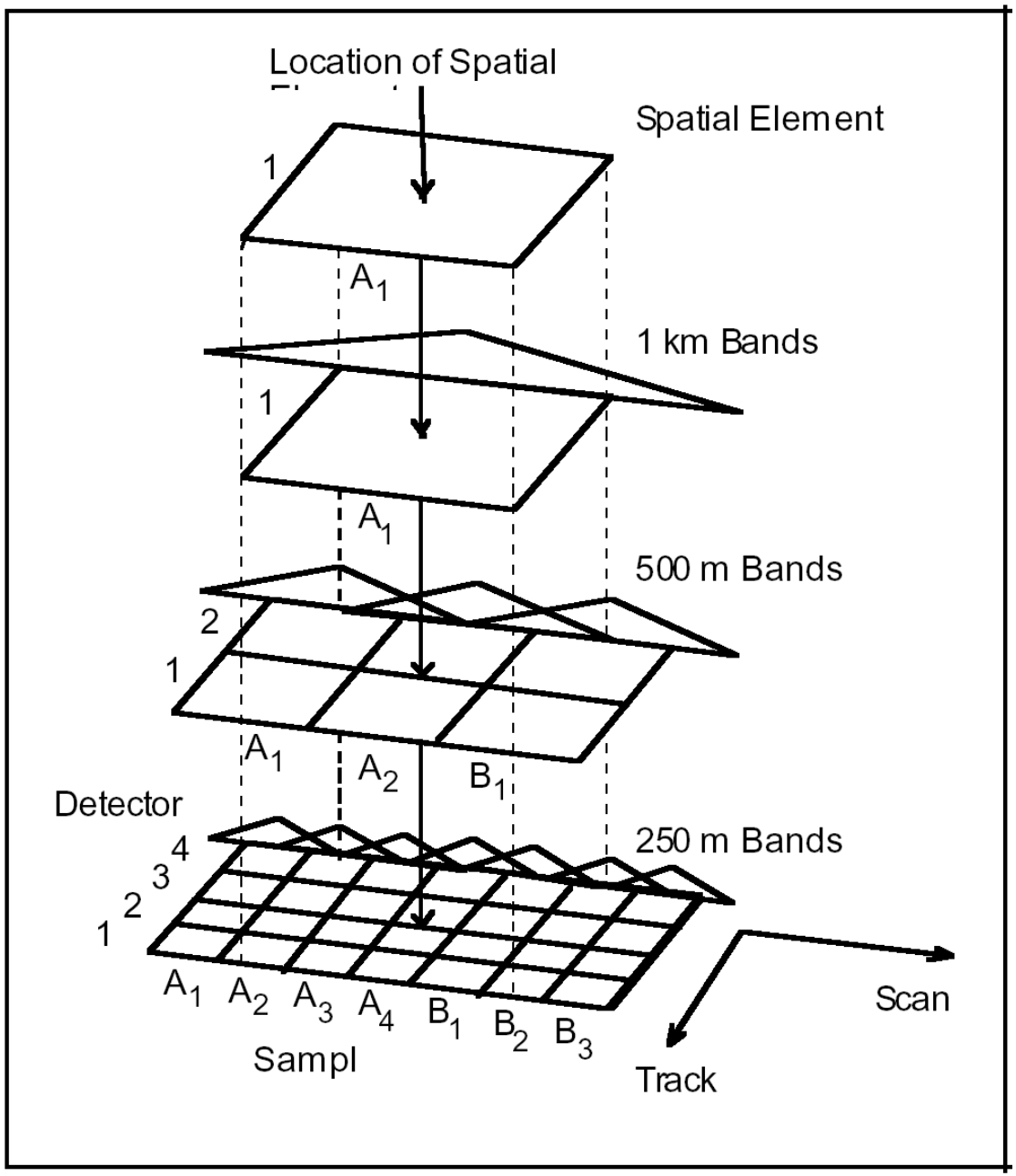
Inter-band Registration

MODIS pixel

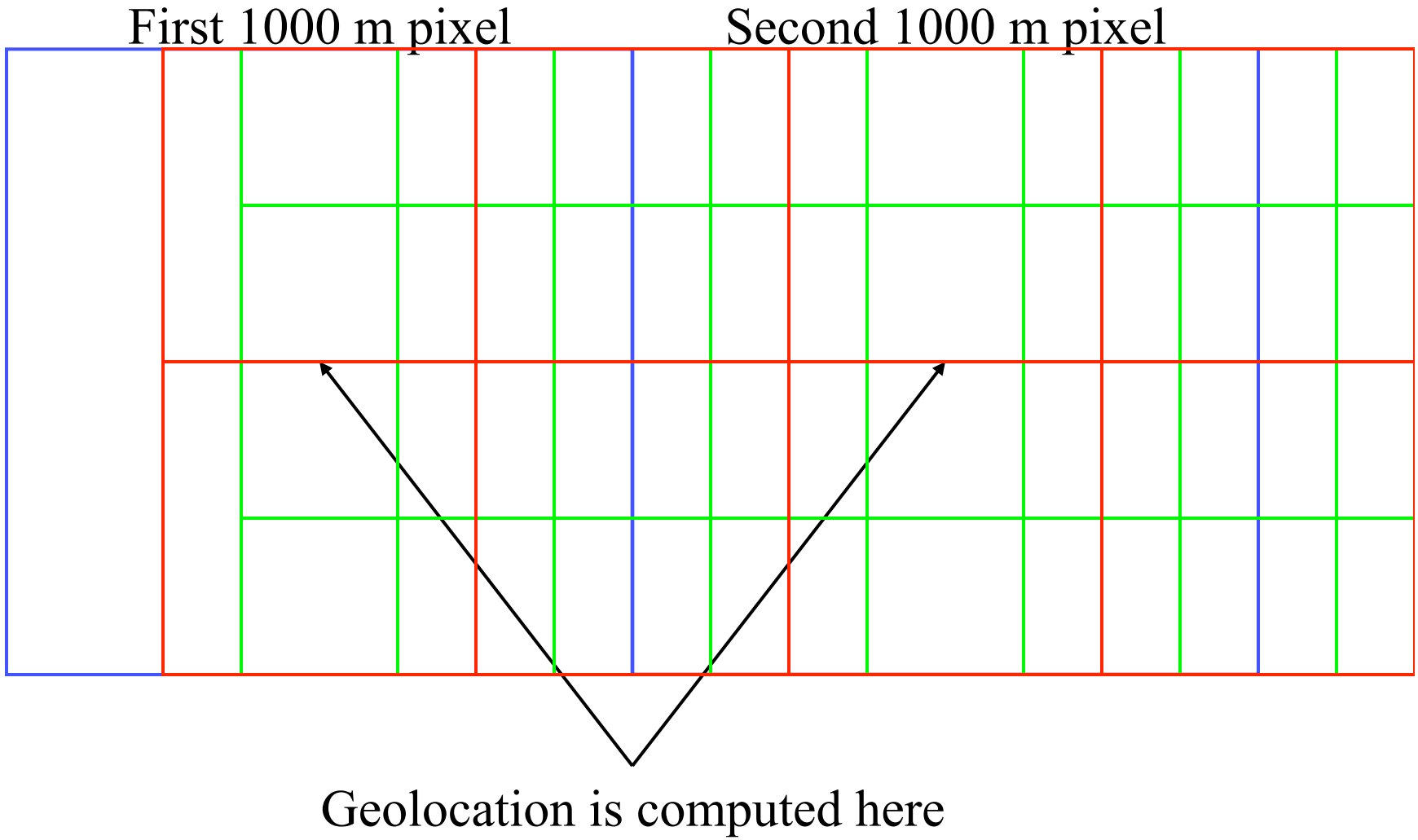
1000 meter

500 meter

250 meter



Nominal MODIS inter-band registration

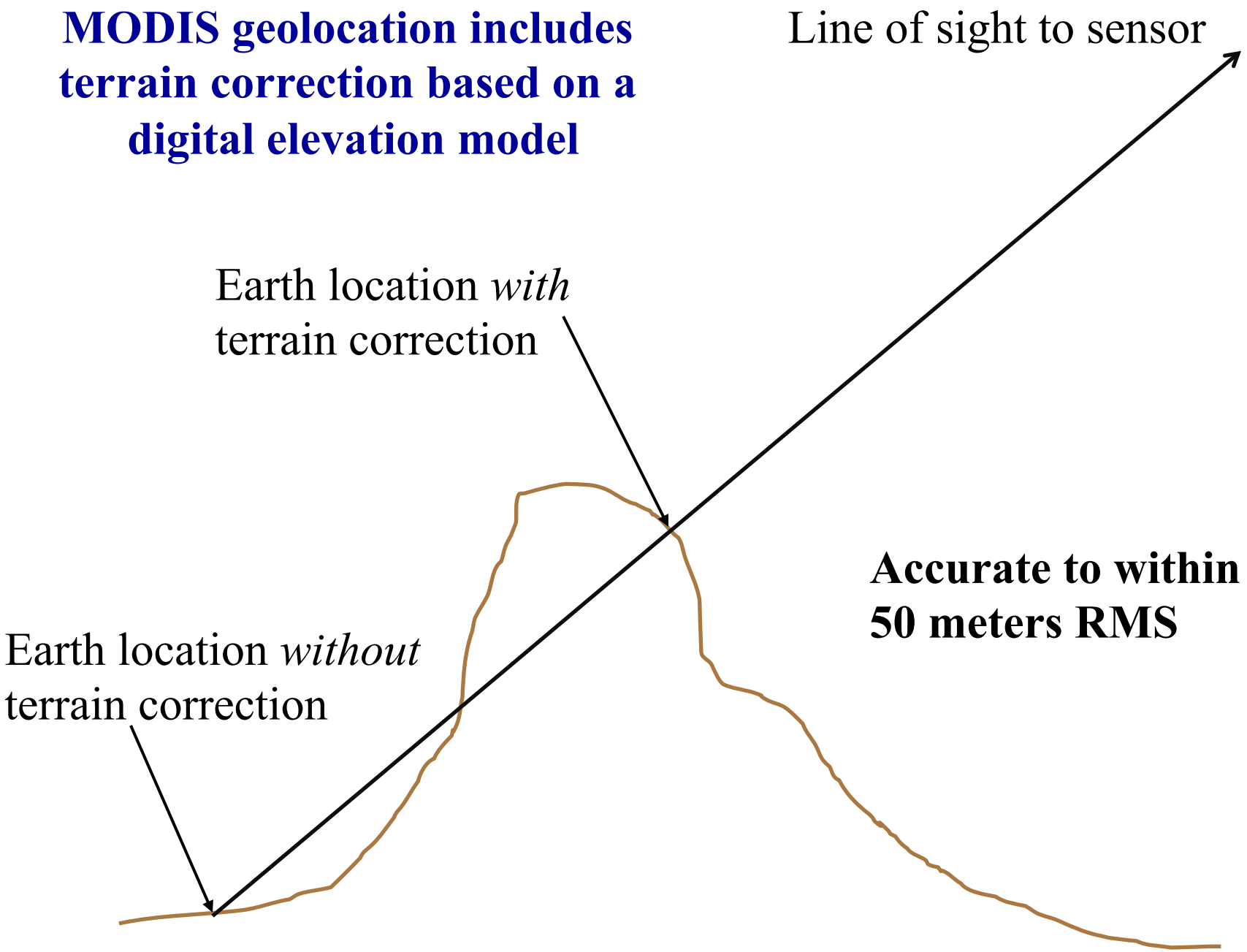


MODIS Geolocation

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

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

MODIS geolocation includes terrain correction based on a digital elevation model

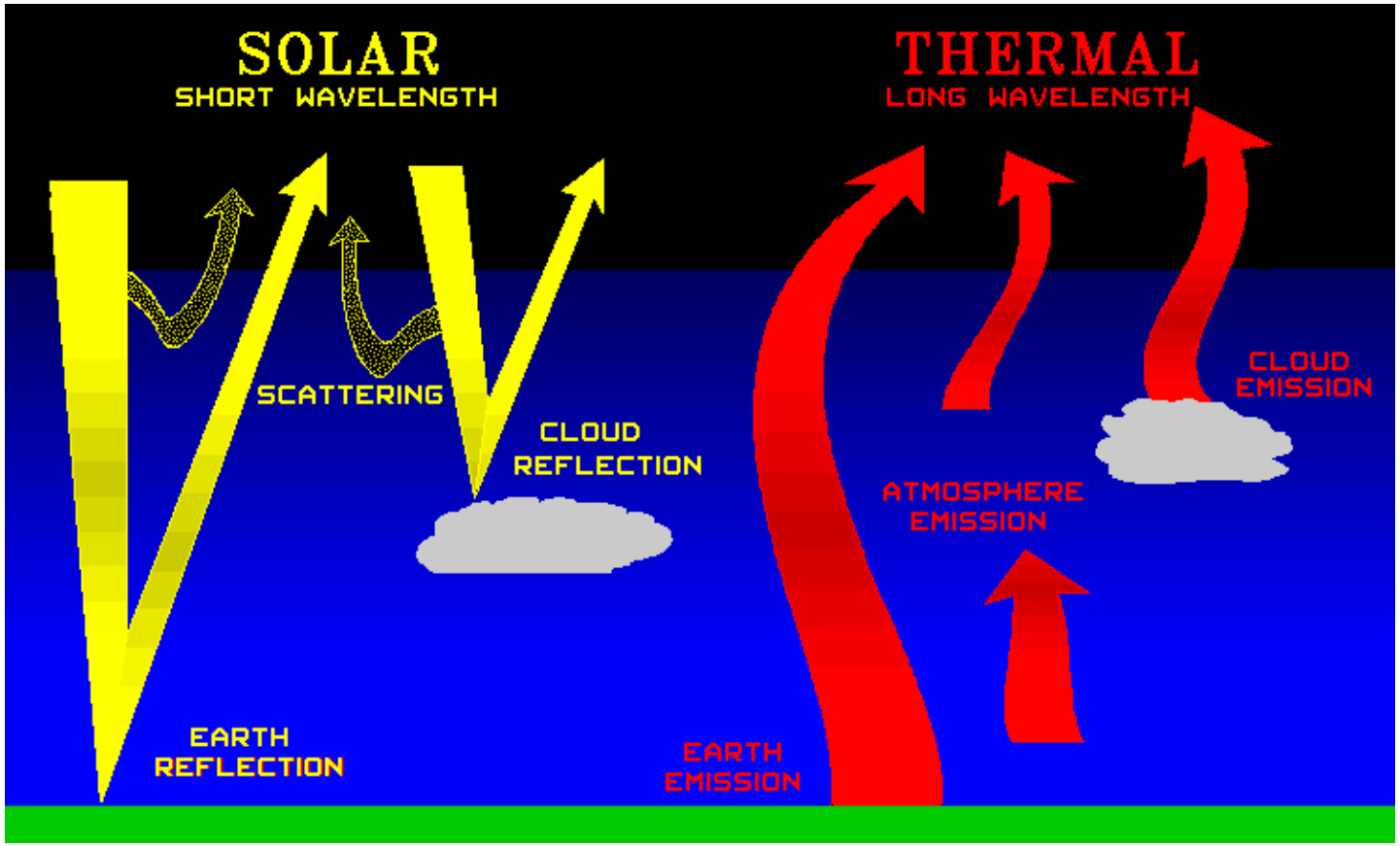


Quick Review of Remote Sensing Basic Theory

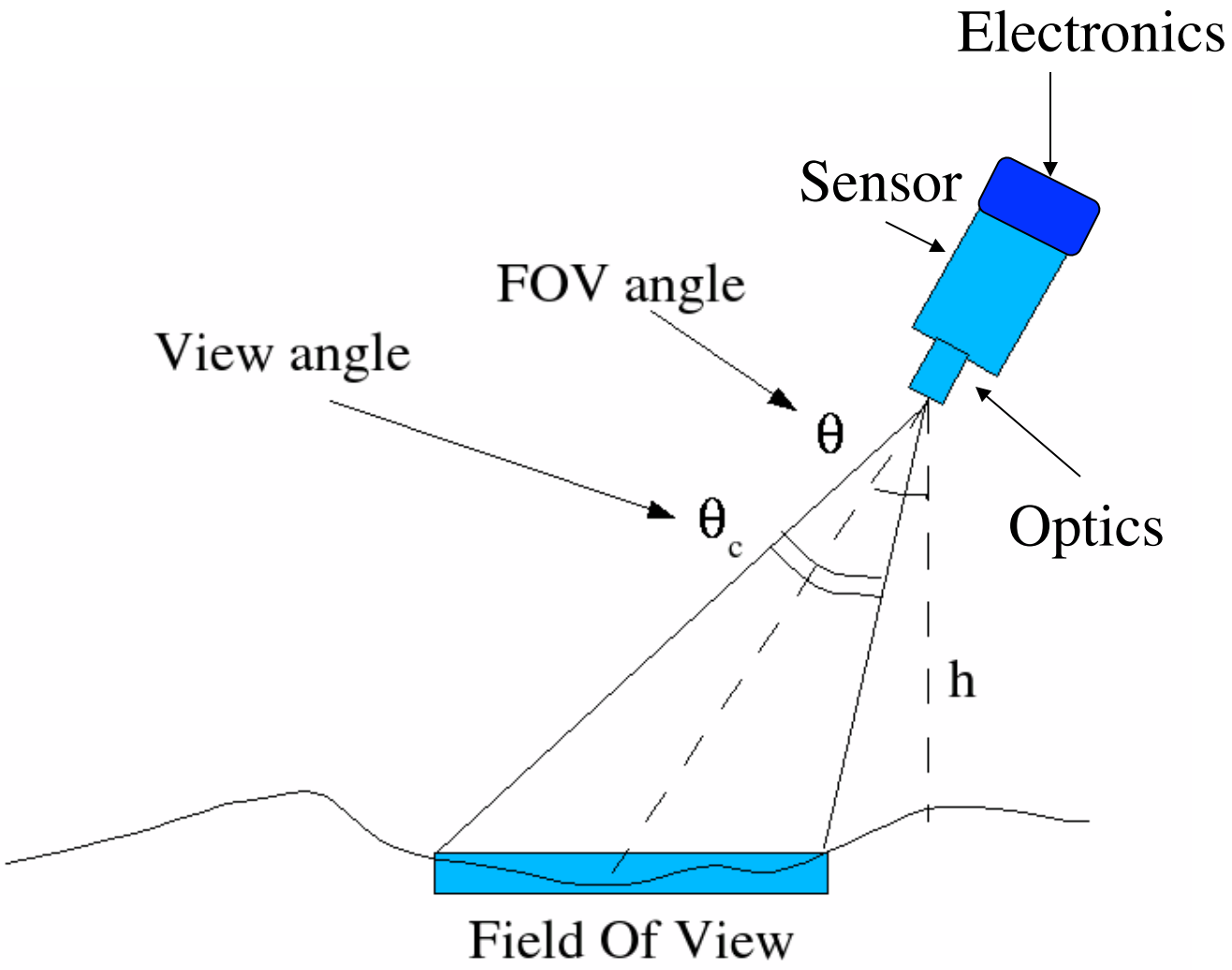
Paolo Antonelli
CIMSS
University of Wisconsin-Madison

Visible
(Reflective Bands)

Infrared
(Emissive Bands)



Sensor Geometry



Terminology of radiant energy

Energy from the Earth Atmosphere

over time is

Flux

which strikes the detector area

Irradiance

at a given wavelength interval

Monochromatic Irradiance

over a solid angle on the Earth

Radiance observed by satellite radiometer

is described by

The Planck function

Can be converted to

Reflectance or Brightness Temperatures

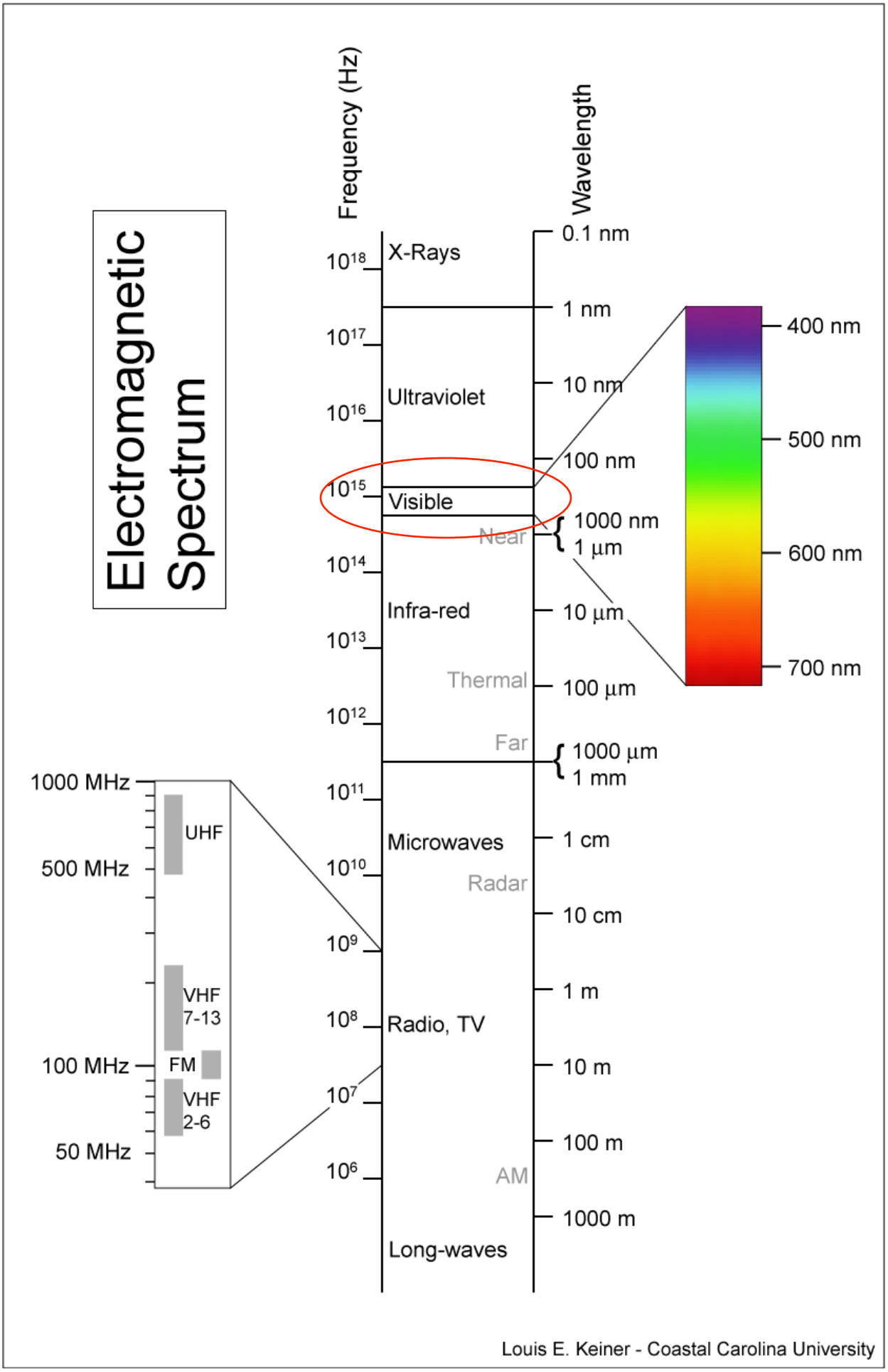
Visible: Reflective Bands

Used to observe solar energy reflected by the Earth system in the:

- Visible between .4 and .7 μm
- NIR between .7 and 3 μm

About 99% of the energy observed between 0 and 4 μm is solar reflected energy

Only 1% is observed above 4 μm


Electromagnetic Spectrum
Frequency (Hz)
Wavelength
10^{18}
X-Rays
0.1 nm
1 nm
10^{17}
10 nm
10^{16}
Ultraviolet
100 nm
10^{15}
Visible
400 nm
500 nm
600 nm
700 nm
1000 nm
Near
1 µm
10^{14}
Infra-red
10 µm
10^{13}
Thermal
100 µm
10^{12}
Far
1000 µm
1 mm
1000 MHz
UHF
500 MHz
10^{11}
Microwaves
1 cm
10^{10}
Radar
10 cm
10^{9}
1 m
VHF
7-13
10^{8}
Radio, TV
100 MHz
FM
10 m
VHF
2-6
10^{7}
50 MHz
100 m
10^{6}
AM
1000 m
Long-waves
Louis E. Keiner - Coastal Carolina University

Ocean: Dark

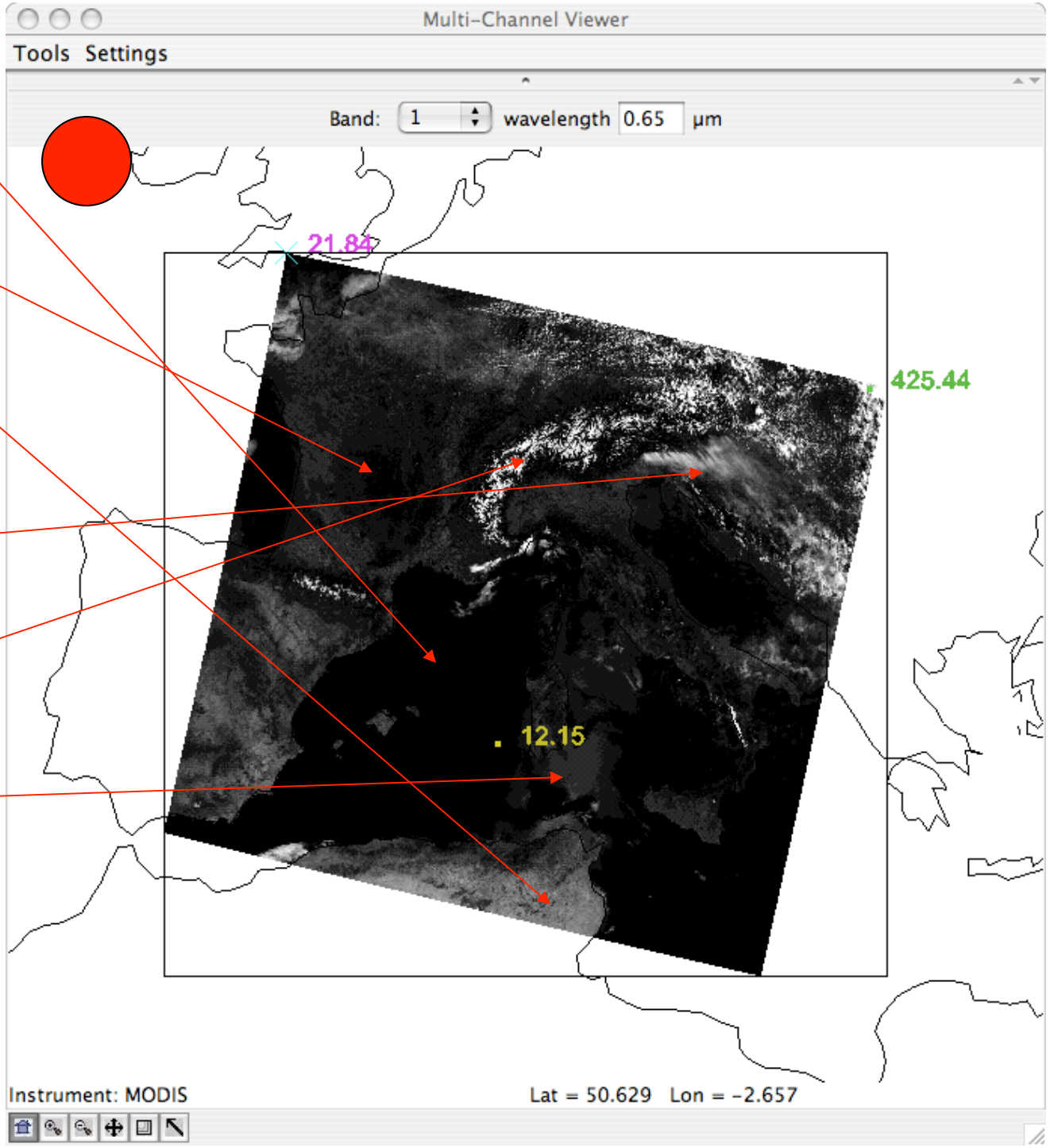
Vegetated Surface: Dark

NonVegetated Surface: Brighter

Clouds: Bright

Snow: Bright

Sunglint



Ocean: Dark

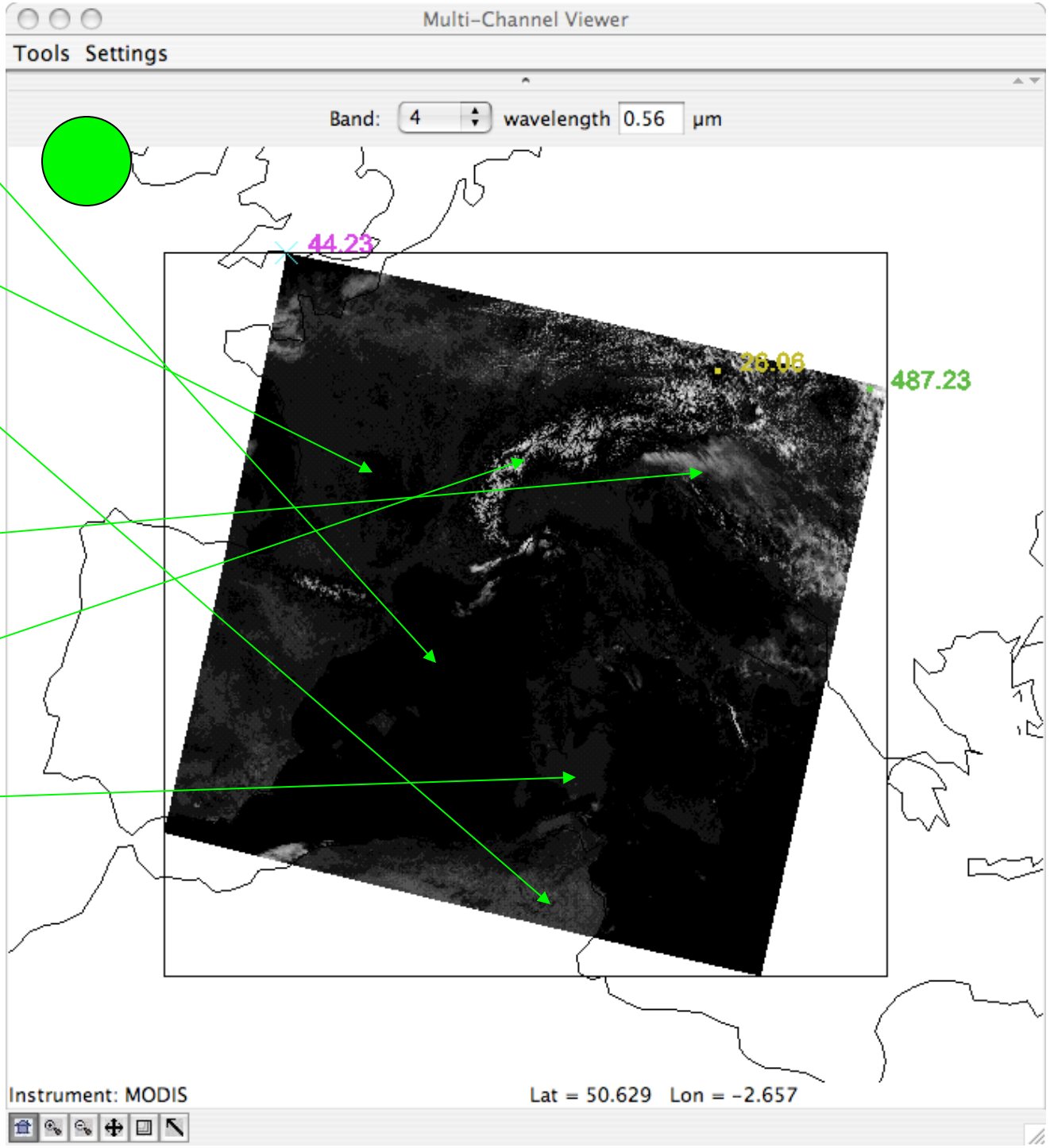
Vegetated Surface: Dark

NonVegetated Surface: Brighter

Clouds: Bright

Snow: Bright

Sunglint



Ocean: Dark

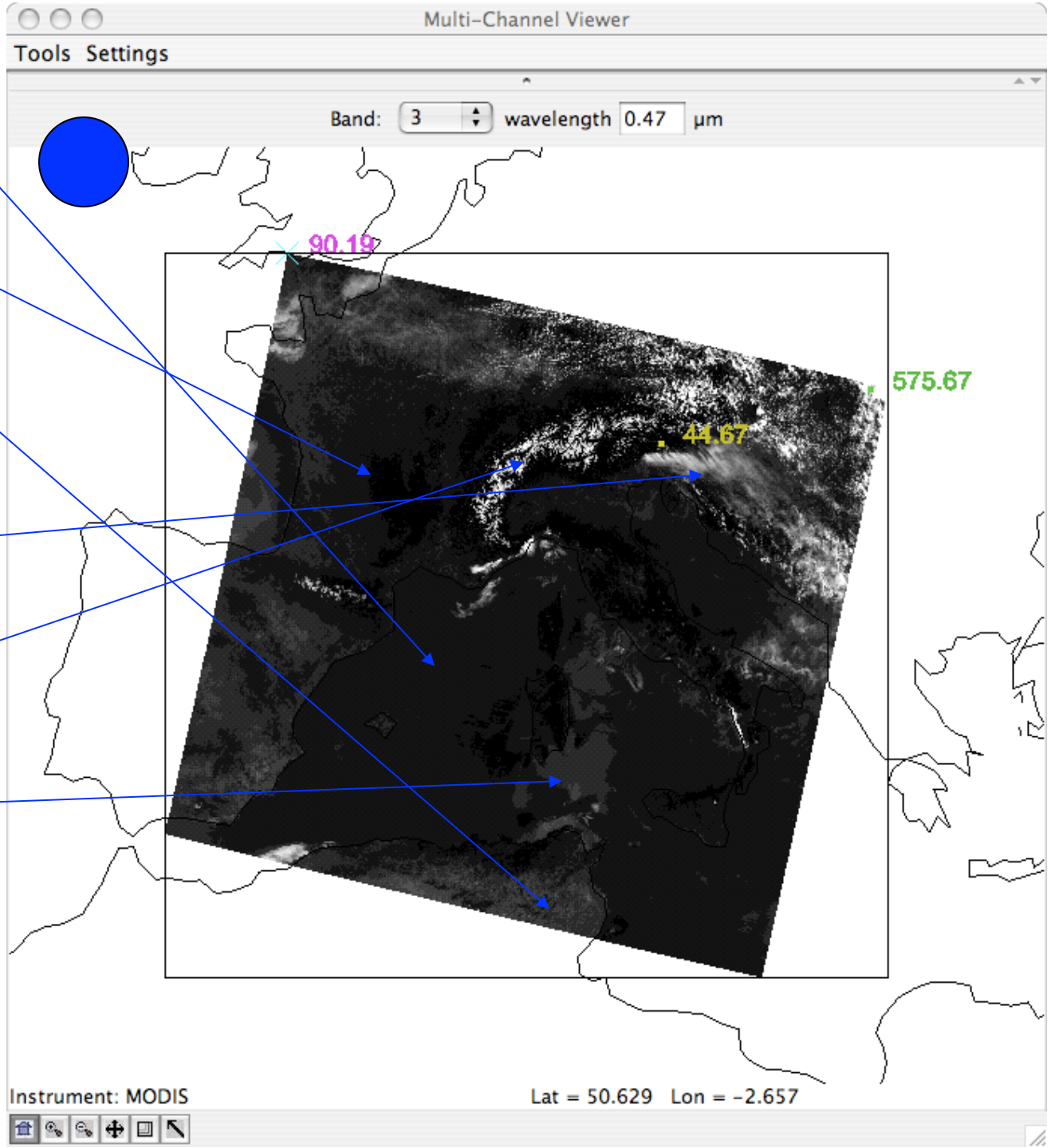
Vegetated Surface: Dark

NonVegetated Surface: Brighter

Clouds: Bright

Snow: Bright

Sunglint



Reflectance

- To properly compare different reflective channels we need to convert observed radiance into a target physical property

- In the visible and near infrared this is done through the ratio of the observed radiance divided by the incoming energy at the top of the atmosphere

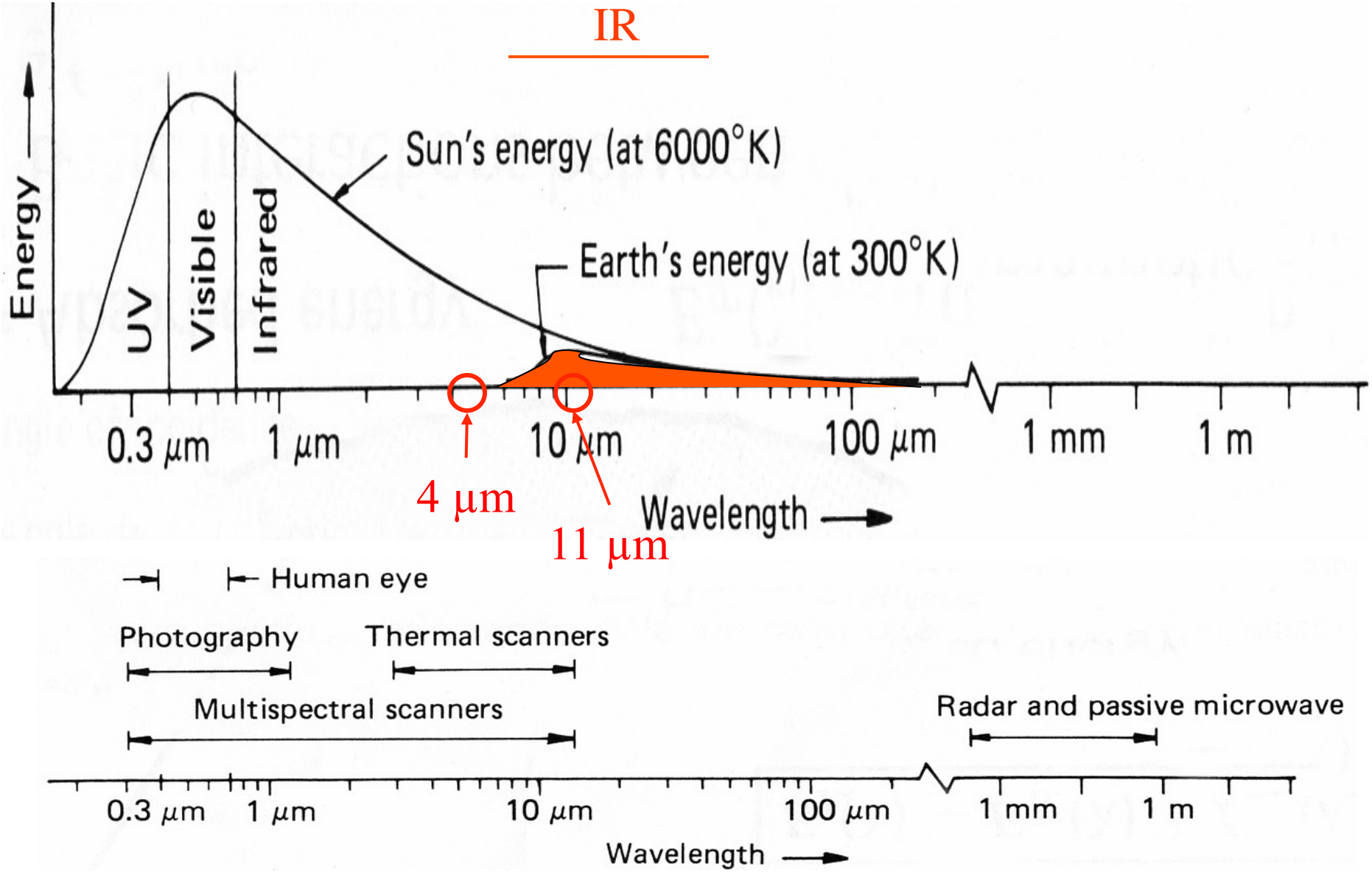
- The physical quantity is the Reflectance i.e. the fraction of solar energy reflected by the observed target

Emissive Bands

Used to observe terrestrial energy emitted by the Earth system in the IR between 4 and 15 μm

- About 99% of the energy observed in this range is emitted by the Earth
- Only 1% is observed below 4 μm
- At 4 μm the solar reflected energy can significantly affect the observations of the Earth emitted energy

Spectral Characteristics of Energy Sources and Sensing Systems



Brightness Temperature

- To properly compare different emissive channels we need to convert observed radiance into a target physical property

- In the Infrared this is done through the Planck function

- The physical quantity is the Brightness Temperature i.e. the Temperature of a black body emitting the observed radiance

Observed BT at 4 micron

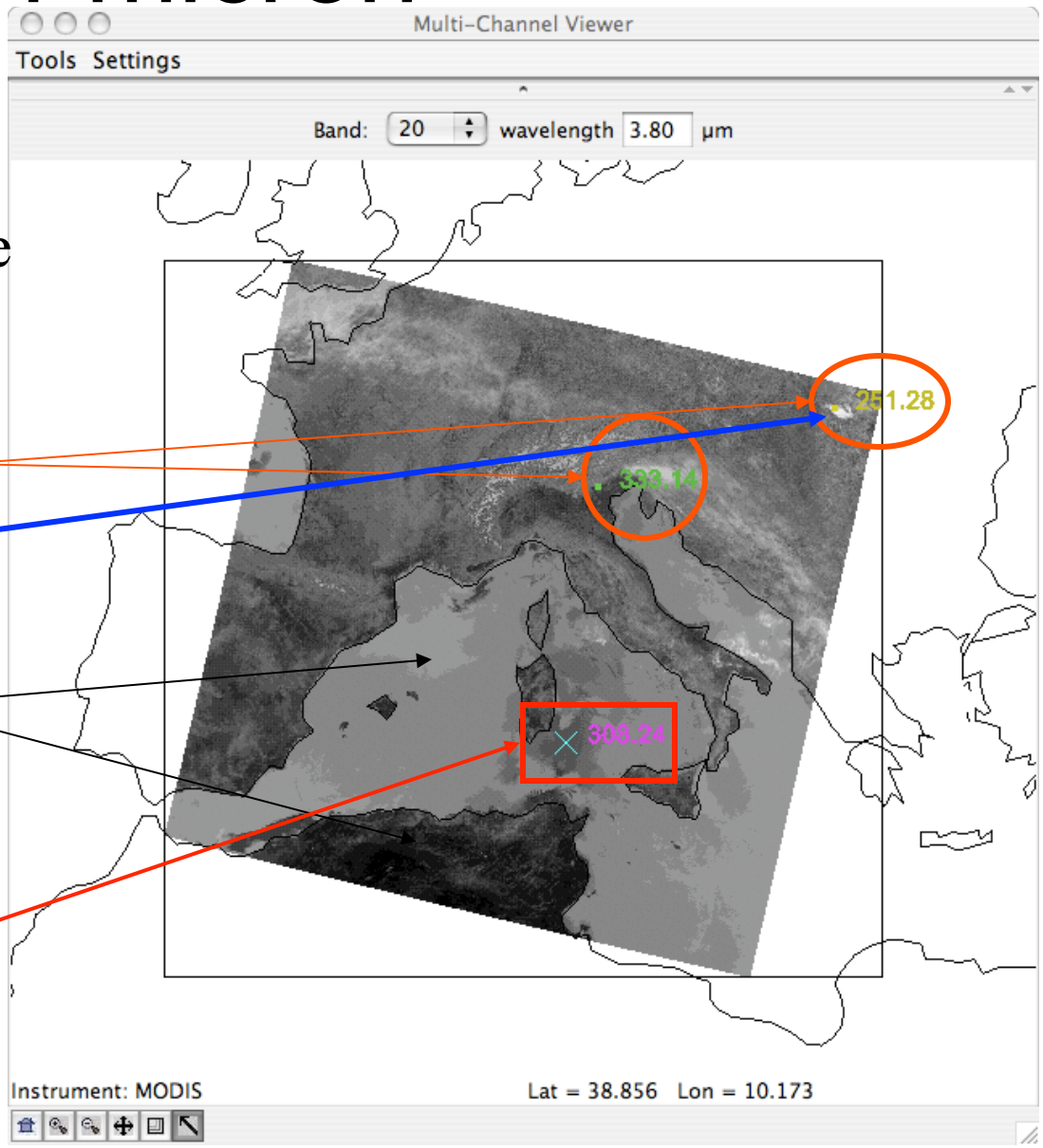
Window Channel:
- little atmospheric absorption
- surface features clearly visible

Range [250K 335K]
Celsius=Kelvin - 273.16

Clouds are cold

Values over land
Larger than over water

Reflected Solar everywhere
Stronger over Sunglint



Observed BT at 11 micron

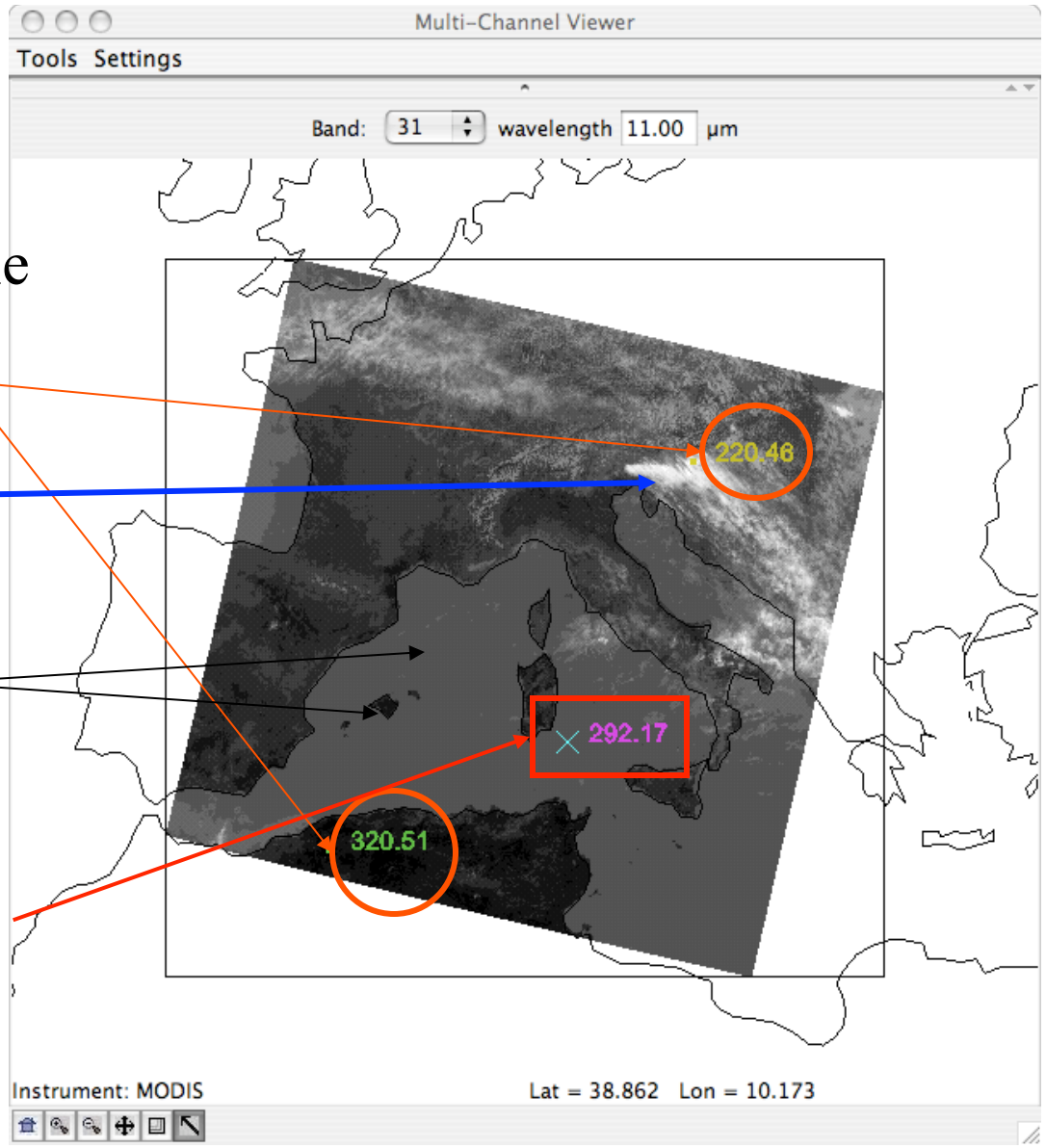
Window Channel:
- little atmospheric absorption
- surface features clearly visible

Range [220K 320K]
Celsius=Kelvin - 273.16

Clouds are cold

Values over land
Larger than over water

Undetectable Reflected Solar
Even over Sunglint



MODIS Atmosphere Products

MODIS Standard Products

Atmosphere

- **MOD 04 - Aerosol Product**
- *MOD 05 - Total Precipitable Water (Water Vapor)*
- **MOD 06 - Cloud Product**
  - ***Cloud Top Properties (MOD06CT)***
  - ***Cloud Phase (part of MOD06CT)***
  - *Cloud Optical Depth (MOD06OD)*
- **MOD 07 - Atmospheric Profiles**
- **MOD 35 - Cloud Mask**

MODIS Cloud Mask

- **1 km** spatial resolution **day & night**, (250 m day)
  - **19 spectral bands (0.55-13.93 µm, incl. 1.38 µm)**
  - 11 individual spectral tests (function of 5 processing paths) combined for initial pixel confidence of clear
  - temporal consistency test over ocean, desert (nighttime); spatial variability test over ocean
- **48 bits per pixel** including individual test results and processing path
- **Result classes are**

  Confident Clear, Probably Clear, Uncertain, Cloudy

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

IR Brightness Temperature Threshold Tests

BT11 < SST- 6 K (Reynolds blended SST global 1 degree - oisst.20060215
Land - GDAS sfc temp global 1 degree -gdas1.PGrbF00.060220.18z)

BT6.7 < Threshold mid-level cloud

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

IR Brightness Temperature Difference Tests

BT8 - BT11 > Threshold (High thin cloud)

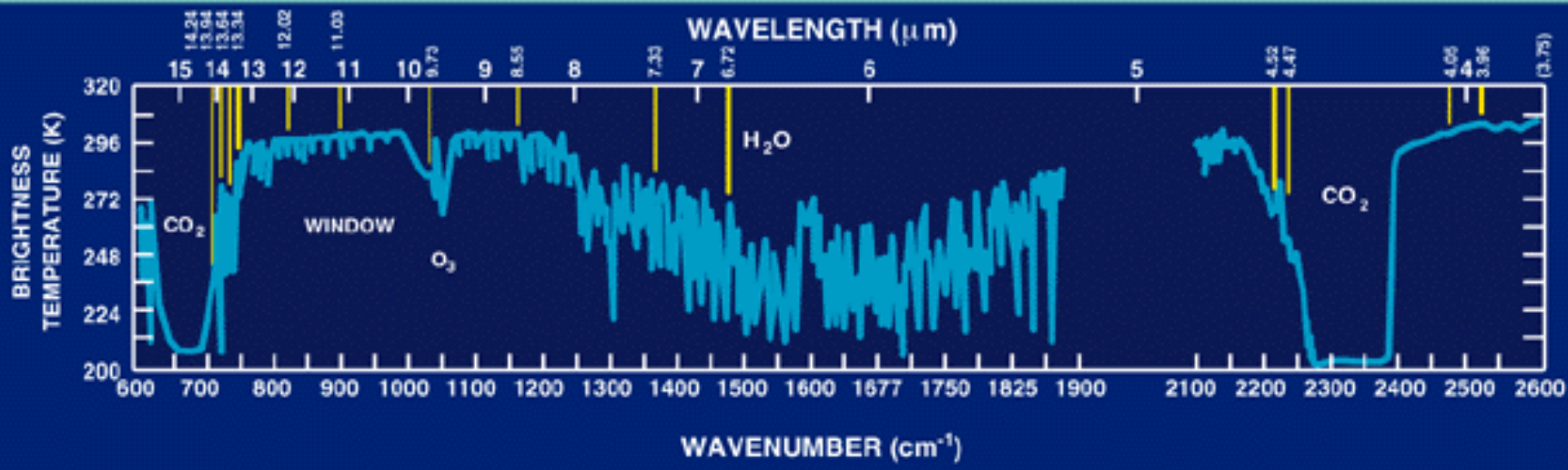
BT11-BT12 > Threshold (High thin cloud)

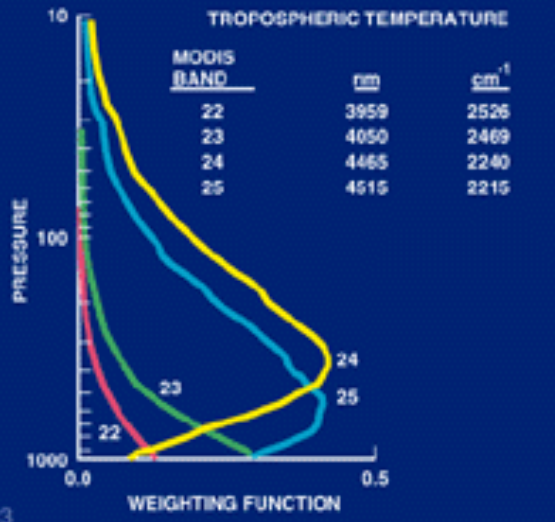
BT3.9 - BT11 > 12 K indicates daytime low cloud cover

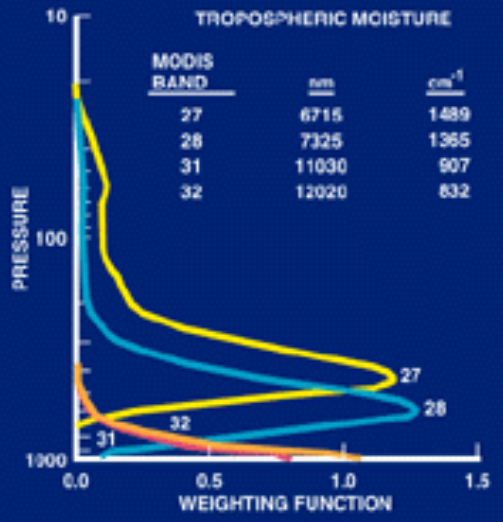
BT11 - BT6.7 large neg diff for clr sky over Antarctic Plateau winter

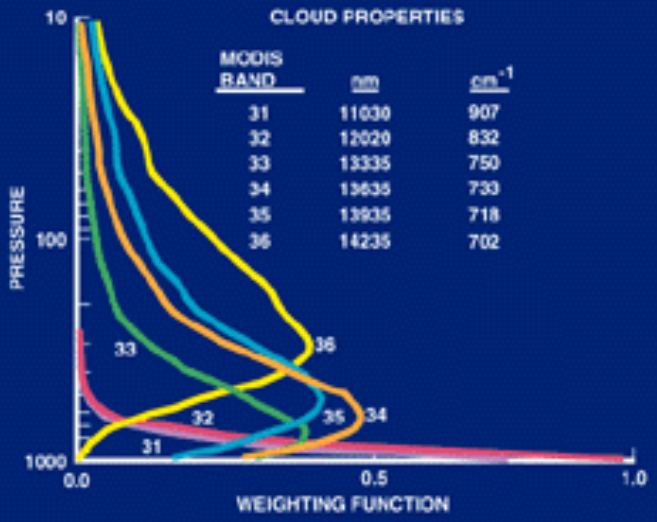
BT11 – BT7.3 Temperatures close in poles or snow/ice mean cloud

ATMOSPHERE - THERMAL RADIATION









Detecting Clouds (vis)

Reflectance Threshold Test

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

Near IR Thin Cirrus Test

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

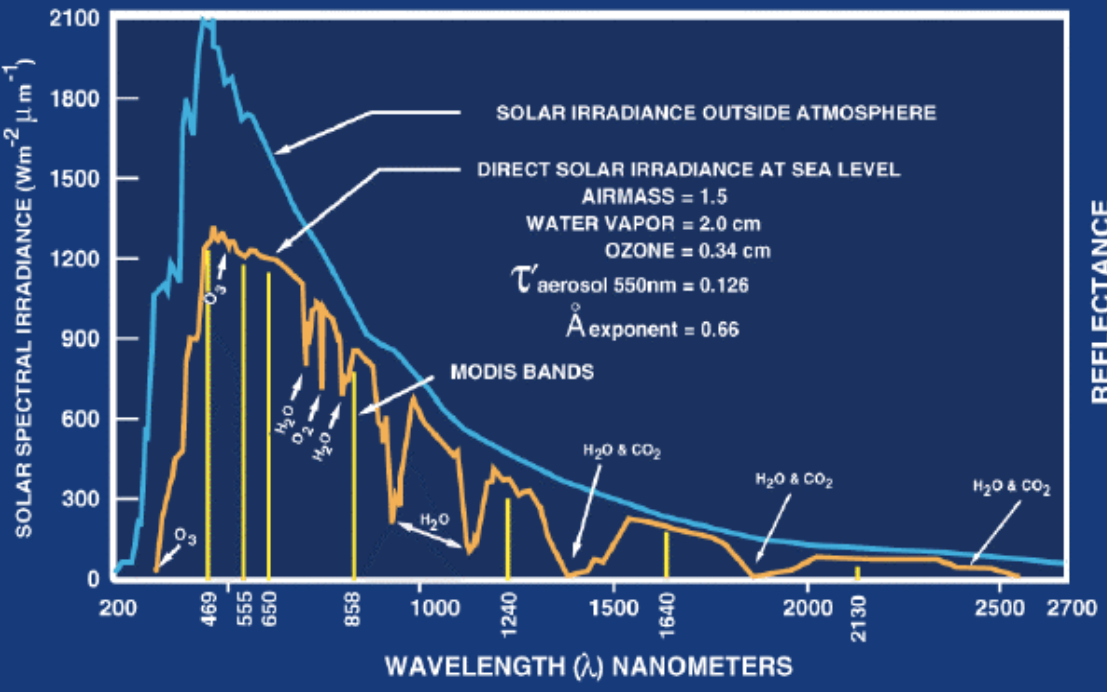
Reflectance Ratio Test

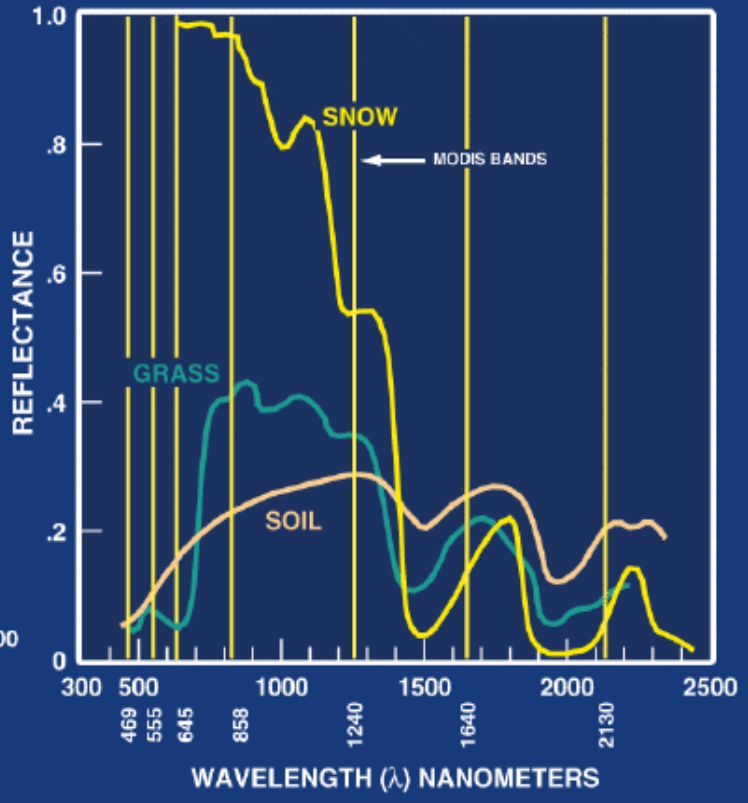
r.87/r.66 between 0.9 and 1.1 for cloudy regions
must be ecosystem specific – snow causes false signal

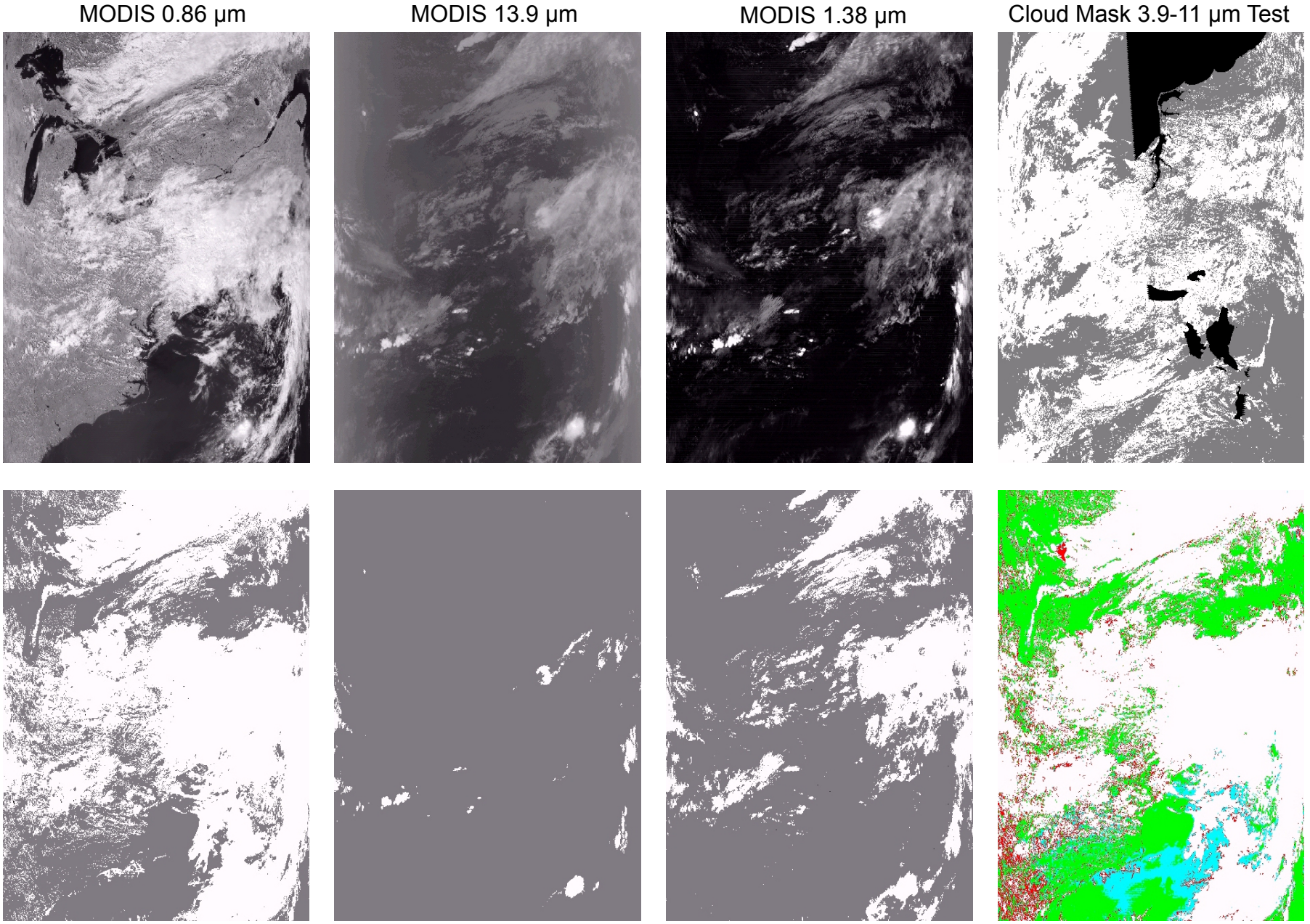
Snow Test

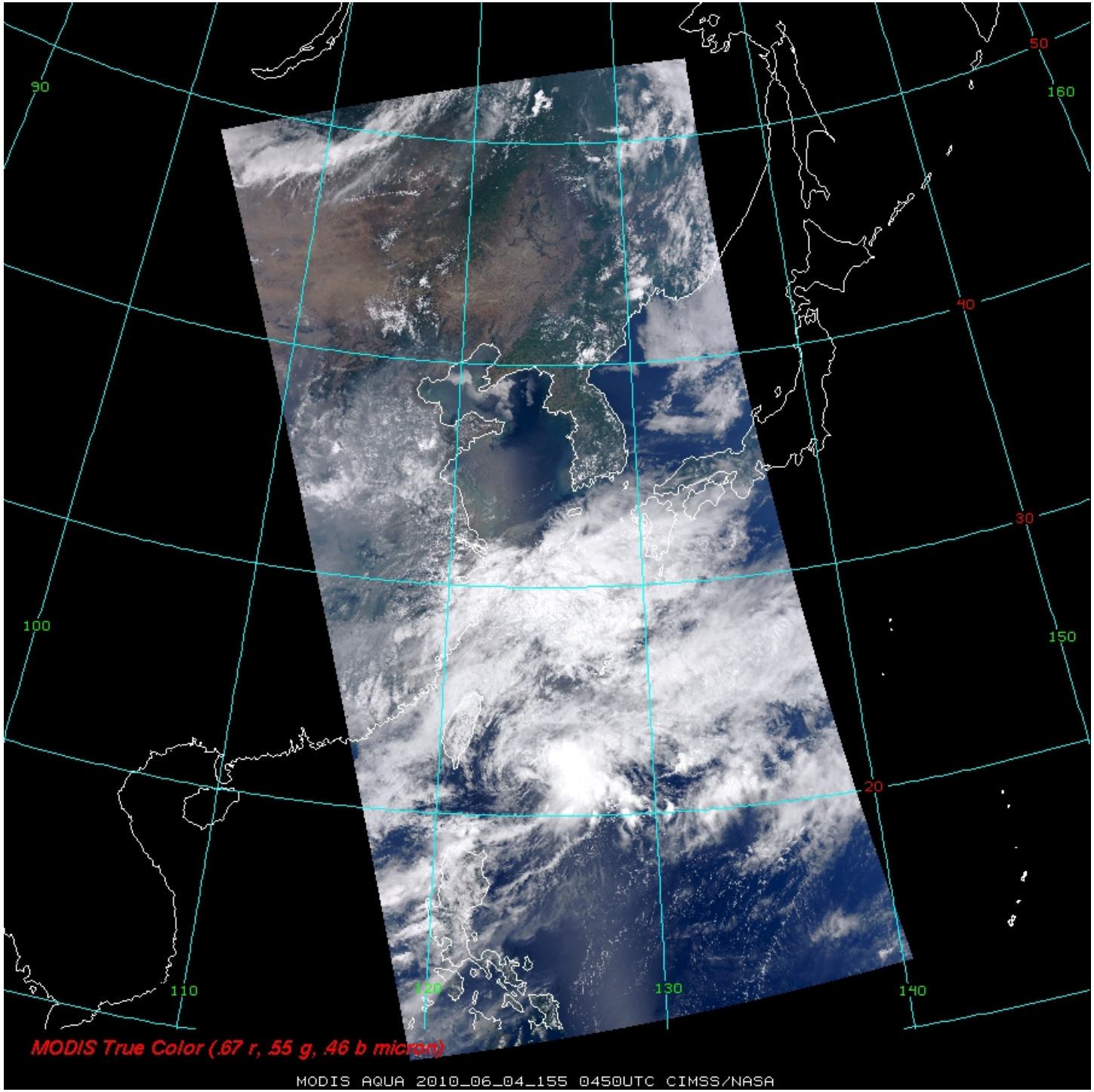
NDSI = [r.55-r1.6]/ [r.55+r1.6] > 0.4 and r.87 > 0.1 then snow

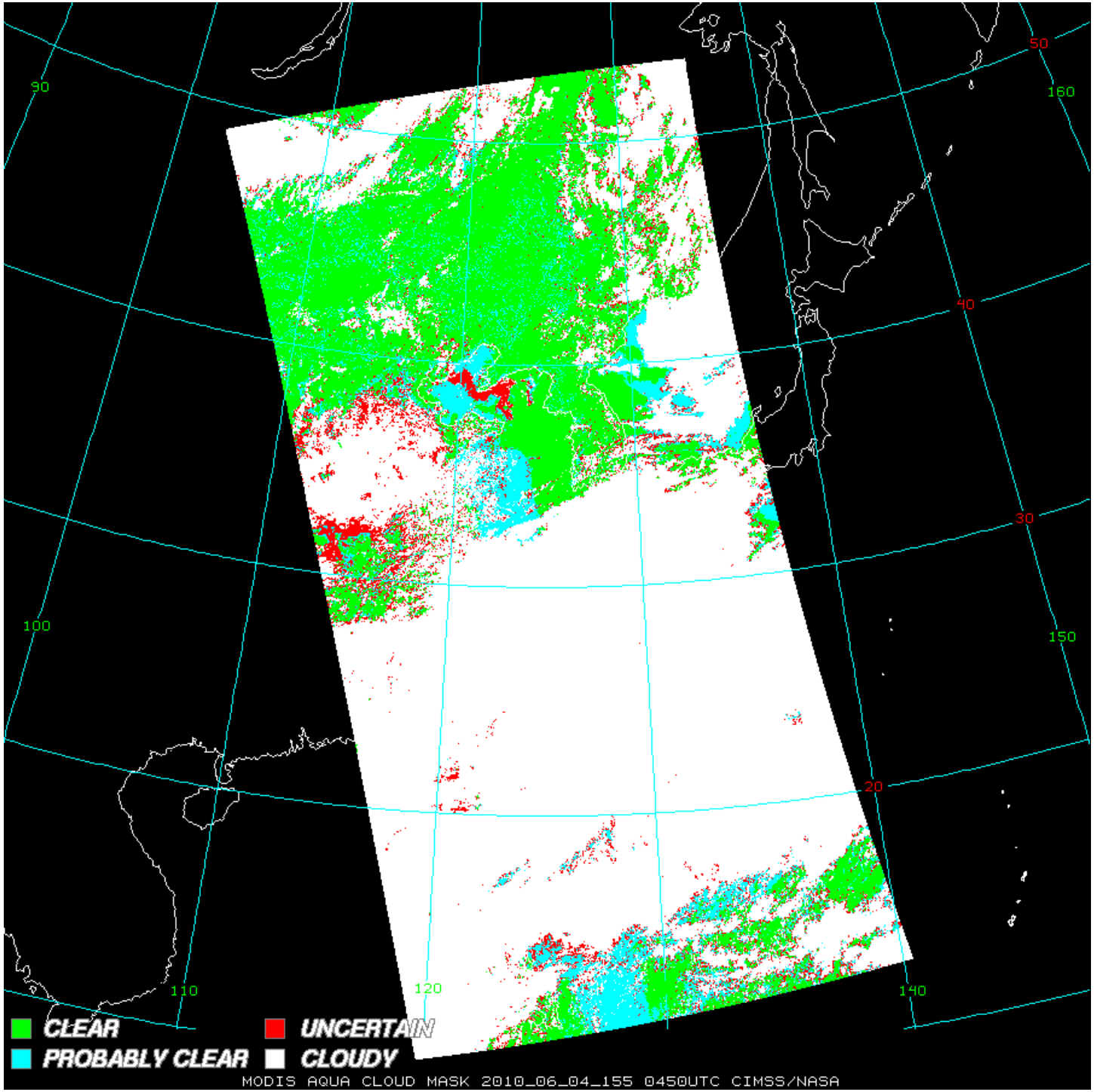
LAND-SOLAR RADIATION






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


90
50
160
40
30
100
150
20
110
120
130
140
MODIS True Color (.67 r, .55 g, .46 b micron)
MODIS AQUA 2010_06_04_155 0450UTC CIMSS/NASA


90
50
160
40
30
100
150
20
110
120
140
CLEAR
UNCERTAIN
PROBABLY CLEAR
CLOUDY
MODIS AQUA CLOUD MASK 2010_06_04_155 0450UTC CIMSS/NASA

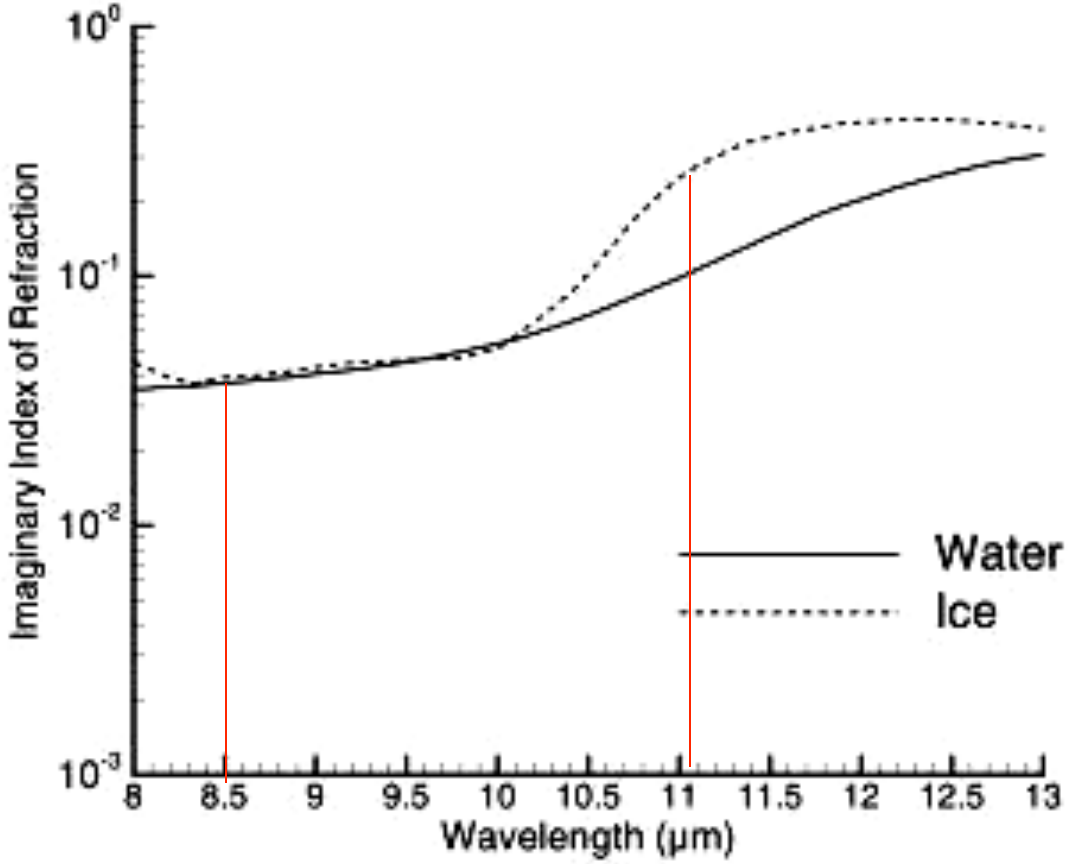
Known Problems

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

References

- Ackerman, S. A., K. I. Strabala, W. P. Menzel, R. A. Frey, C. C. Moeller, and L. E. Gumley, 1998: Discriminating clear sky from clouds with MODIS. J. Geophys. Res., 103, 32 141– 32 157.
- Frey, R., S. A. Ackerman, Y. Liu, K. I. Strabala, H. Zhang, J. Key, and X. Wang (2008), Cloud detection with MODIS: Part I. Improvements in the MODIS Cloud Mask for Collection 5, J. Atmos. Oceanic Technol., 25, 1057 – 1072.
- Ackerman, S. A., R. E. Holz, R. Frey, E. W. Eloranta, B. Maddux, and M. J. McGill (2008), Cloud detection with MODIS: Part II. Validation, J. Atmos. Oceanic Technol., 25, 1073 – 1086.

MODIS Cloud Phase (part of MOD06CT)



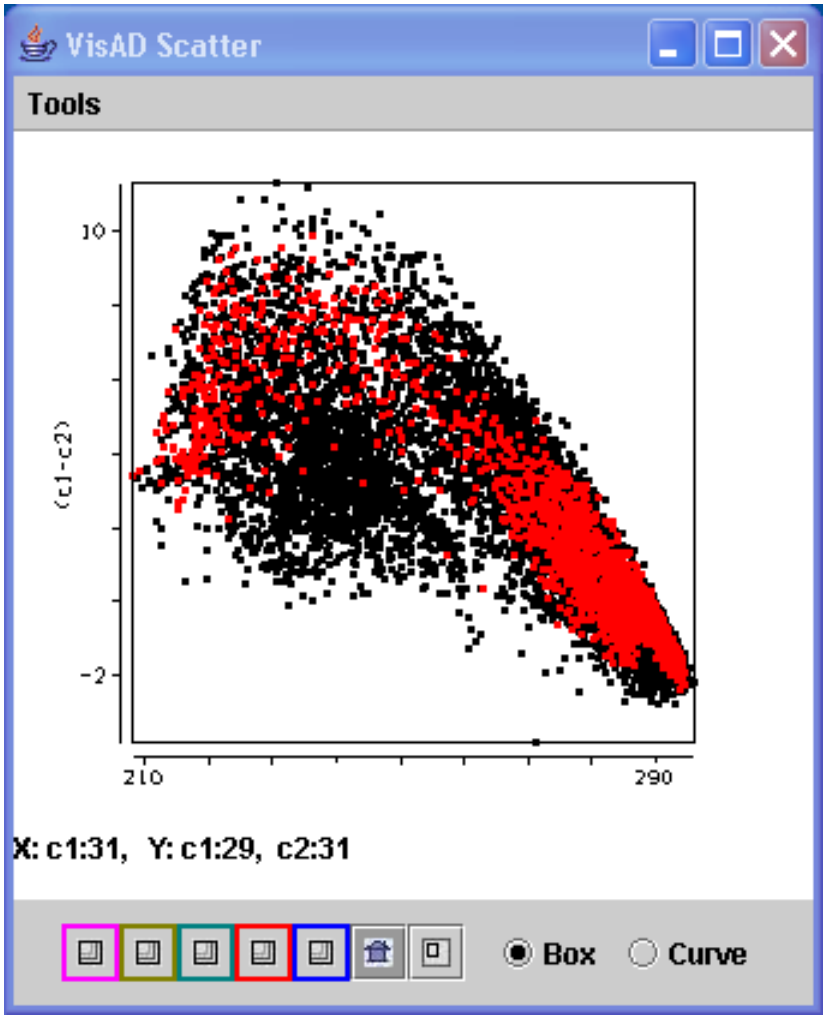
Imaginary Index of Refraction of Ice and Water
8 – 13 microns

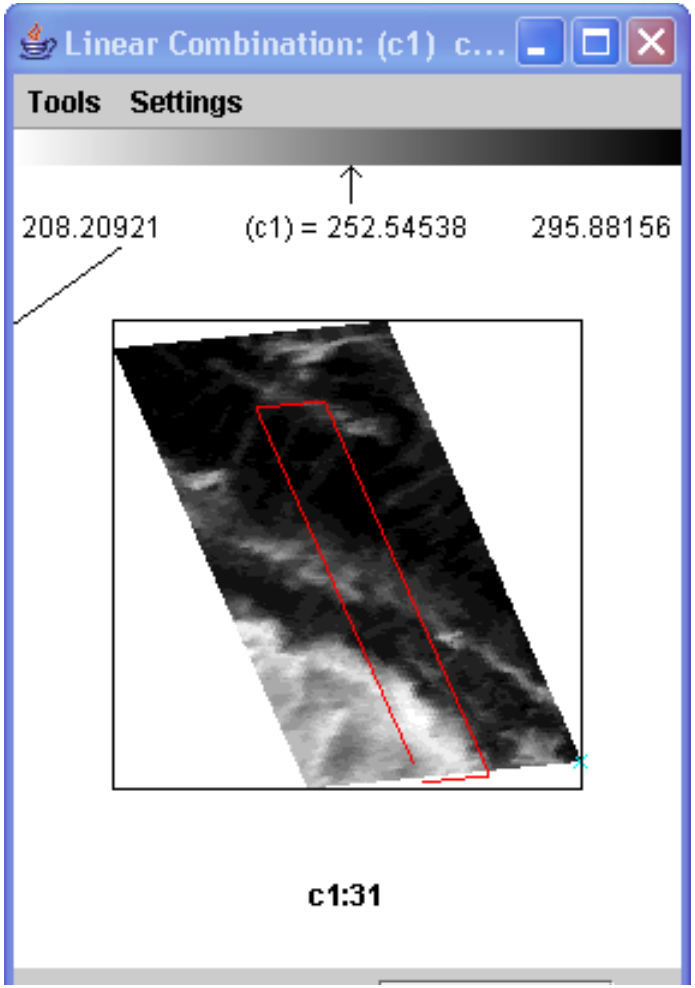
Cloud Phase

Dr. Bryan Baum SSEC

- 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

Ice 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

4 categories

1 – Water Cloud

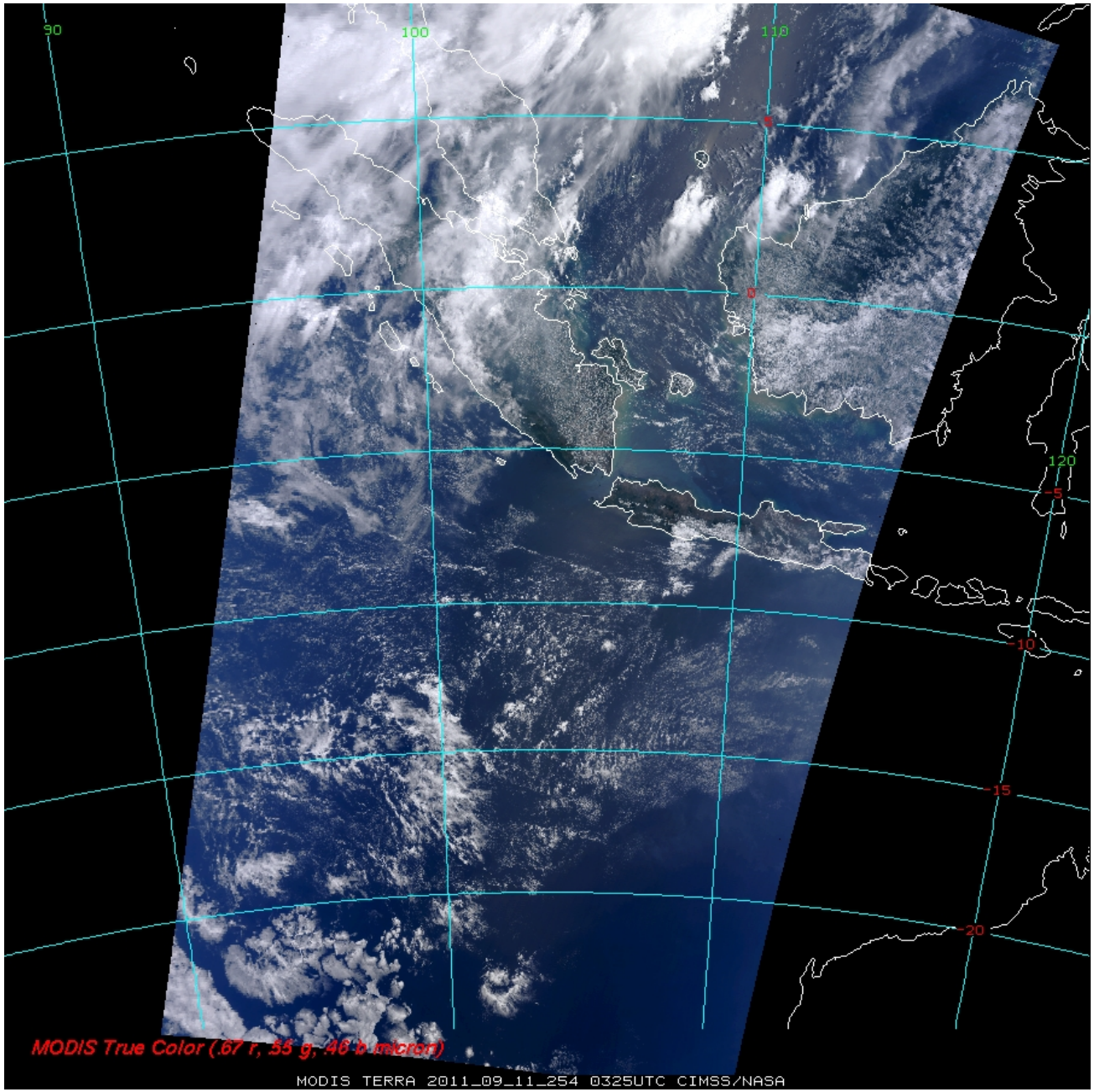
2 – Ice Cloud

3 – Mixed Phase Cloud

6 – Undecided

Terra MODIS True Color Image: 2011/09/11

Note land, ocean, sunglint, and mix of high clouds and low clouds.



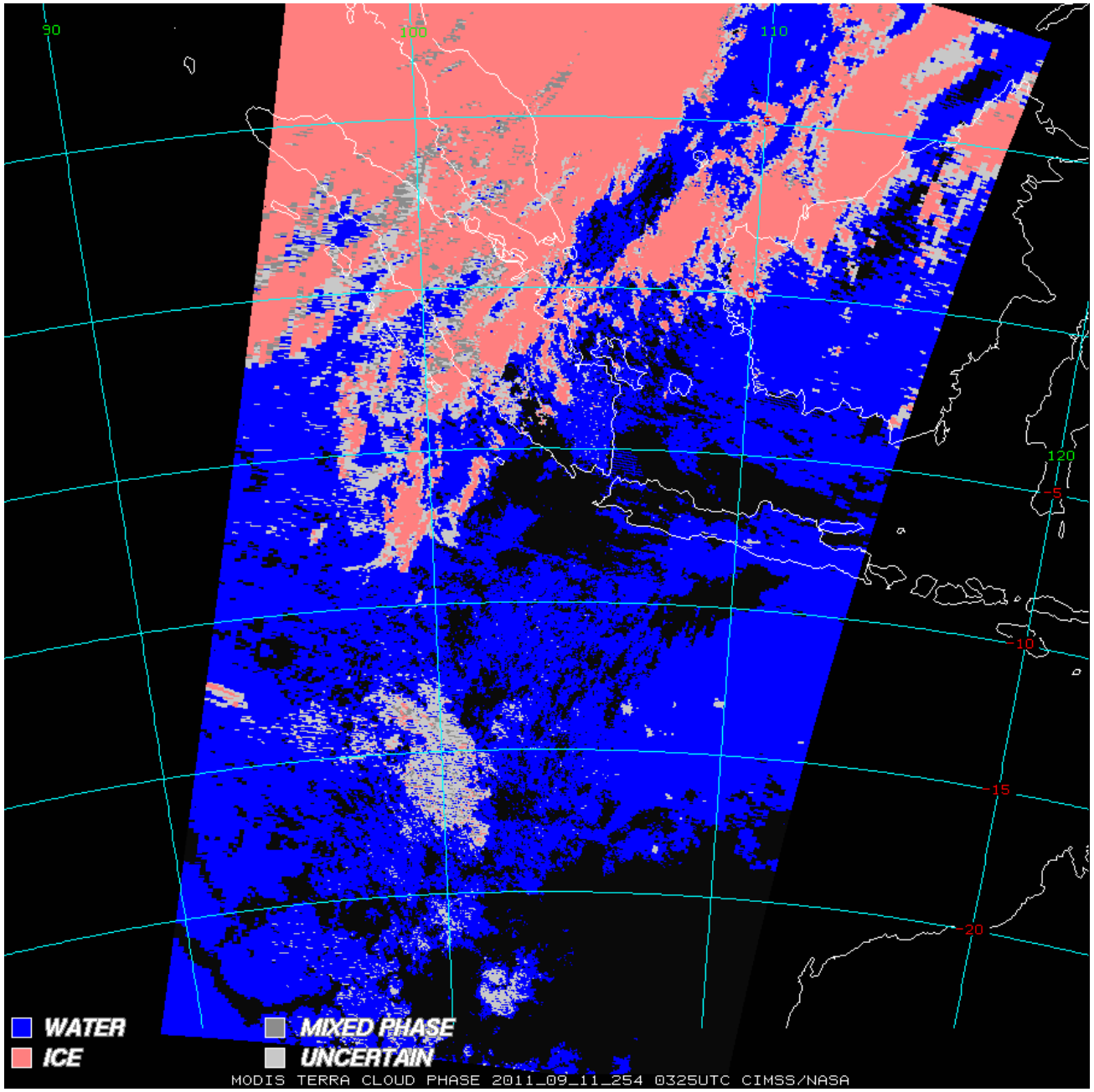
MODIS Cloud Phase Product (MOD06)

Cloudy Sky Only

Day/Night

5 x 5 km resolution

Threshold Algorithm



References

- Strabala, K. I., S. A. Ackerman, and W. P. Menzel, 1994: Cloud properties inferred from 8-12 μm data. *J. Appl. Meteor.*, ***33, 212-229.***

Applications

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

2. Climatological
   - Global Cloud Modeling - Ice and water clouds absorb and reflect differently at different wavelengths

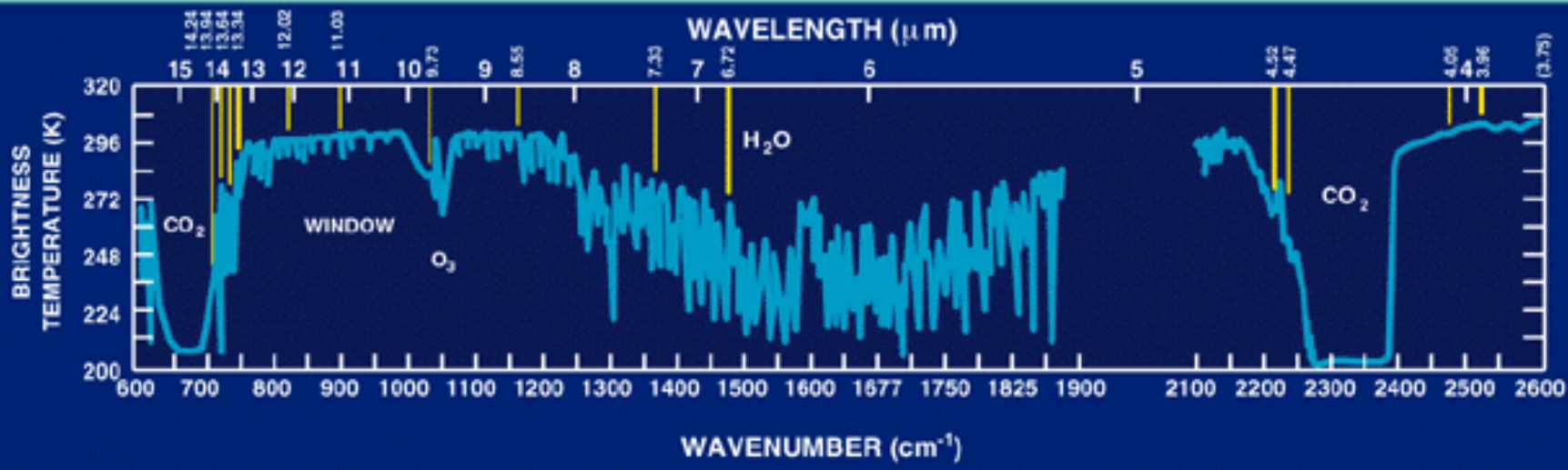
MODIS Cloud Top Properties (MOD06CT)

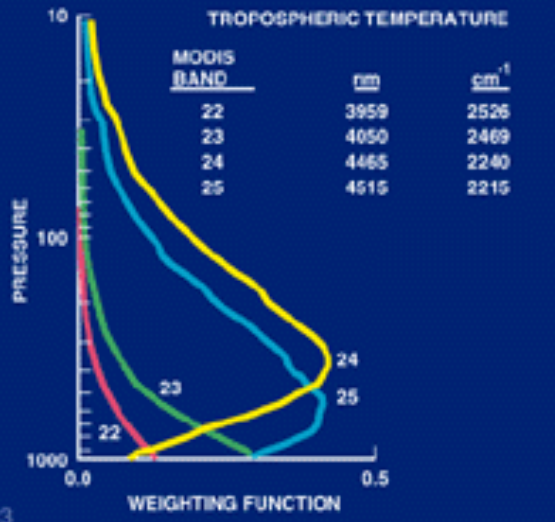
Cloud Top Properties

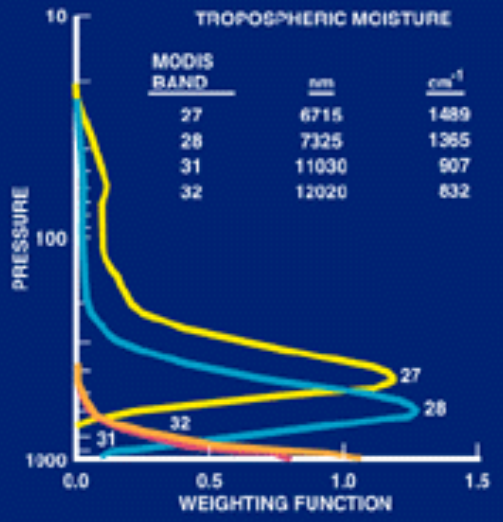
Menzel, Frey - SSEC

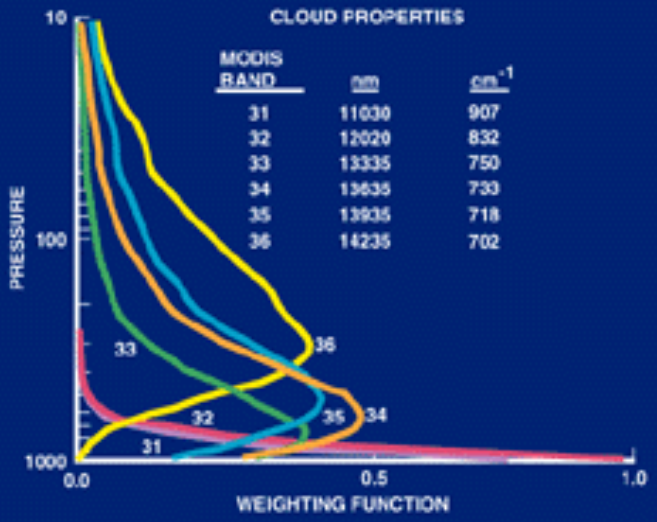
- Cloud Top Pressure, Temperature, Emissivity derived using CO_2 “slicing”
- MODIS product utilizes 4 spectral channels in the 13 – 14 μm region.
- 5x5 1 km pixel retrievals where at least 5 of the 1 km pixels are cloudy as determined by the cloud mask
- Cloud properties retrieved both day and night

ATMOSPHERE - THERMAL RADIATION

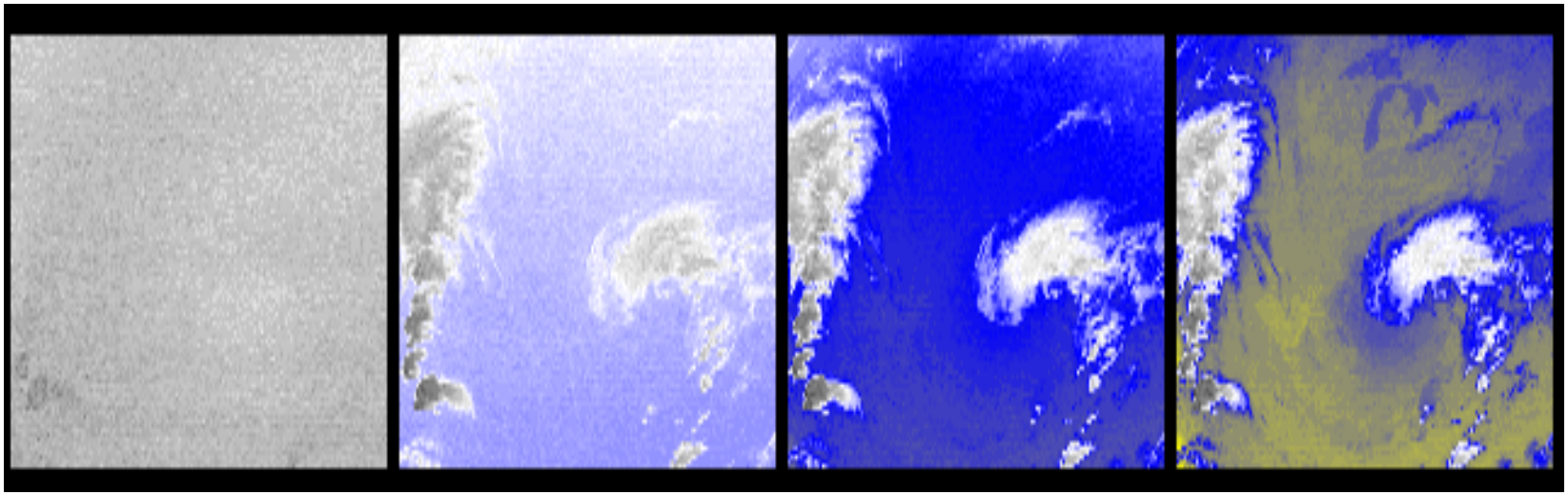




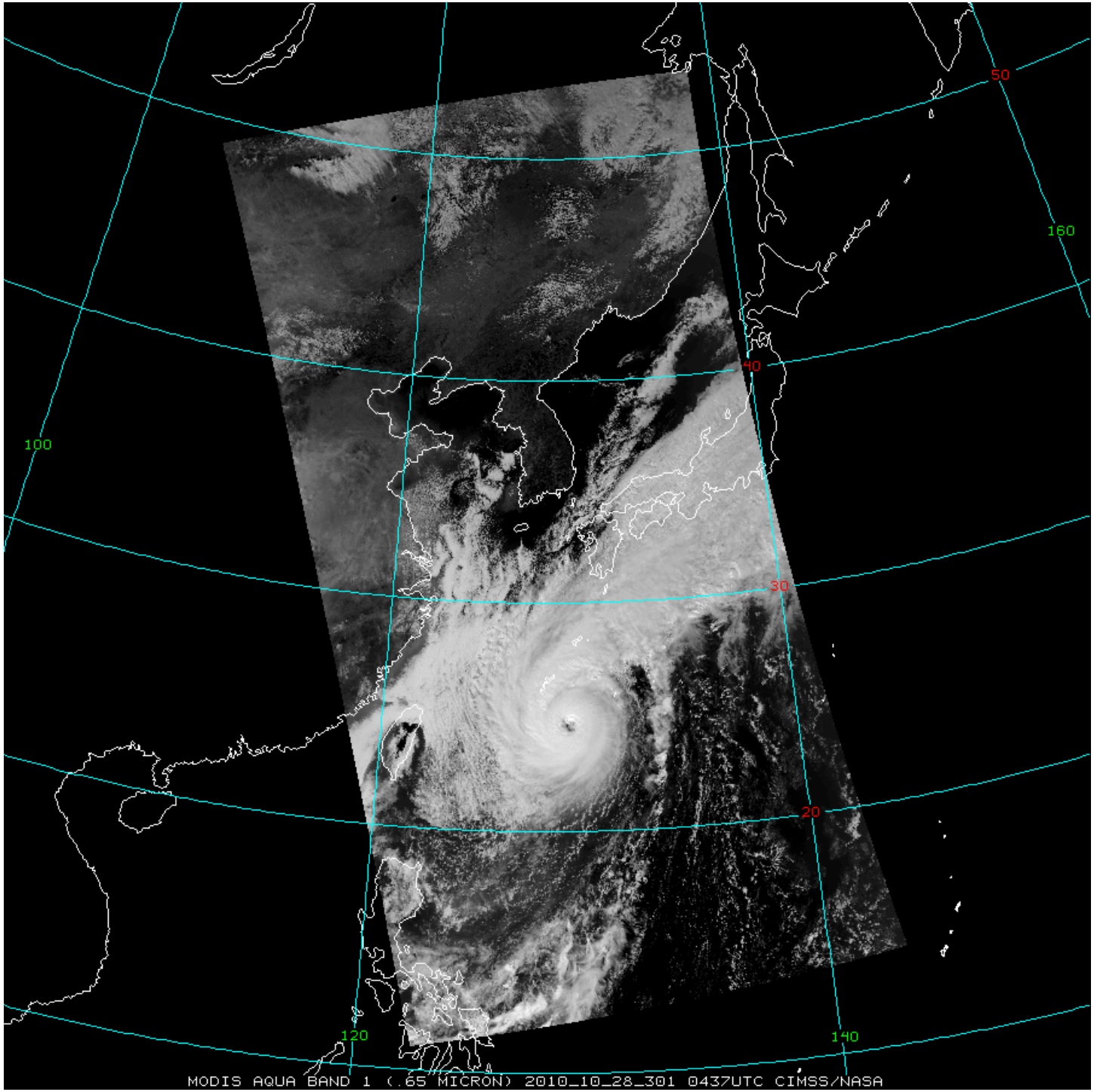


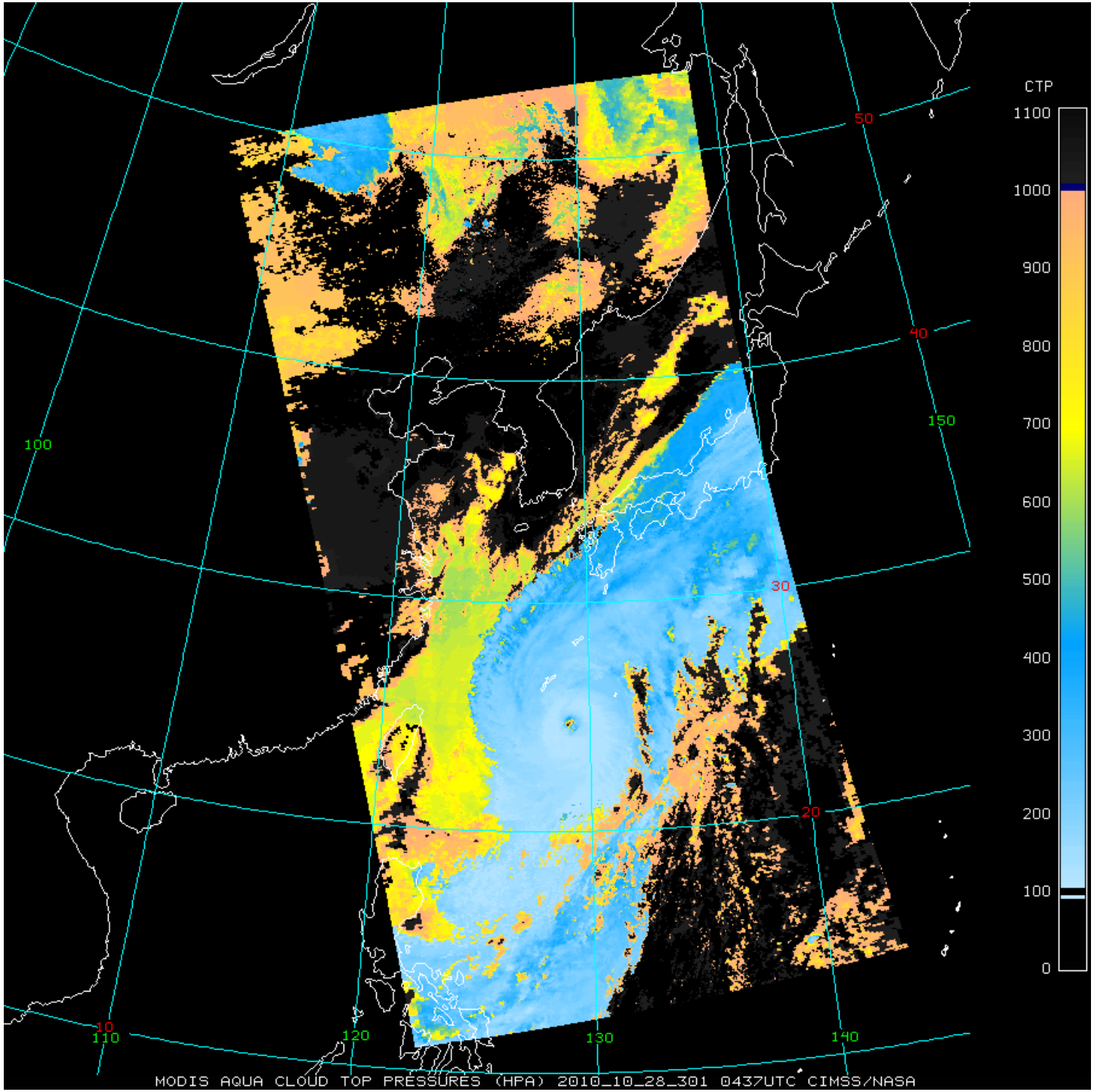


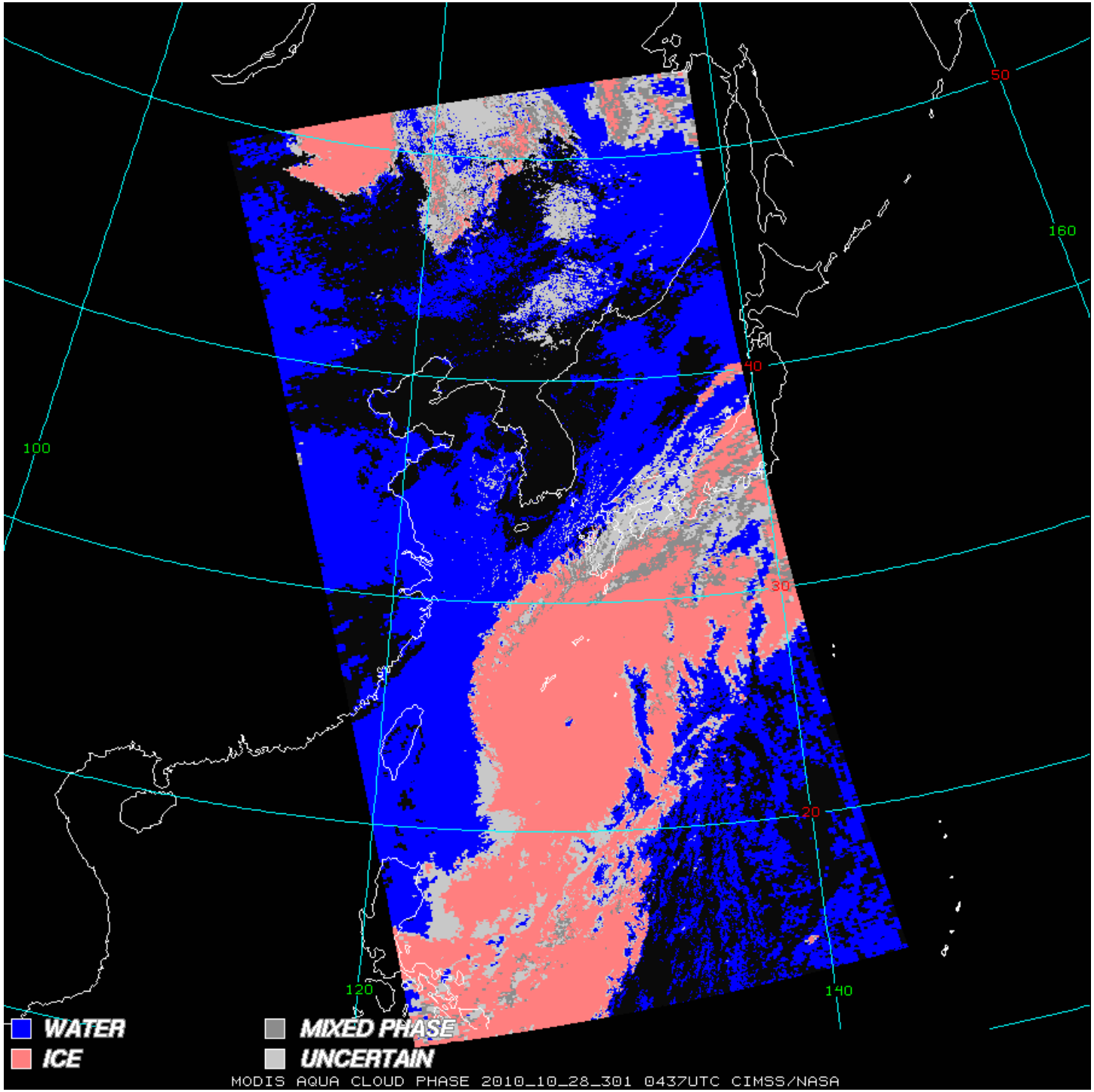
CO_2 channels see to different levels in the atmosphere

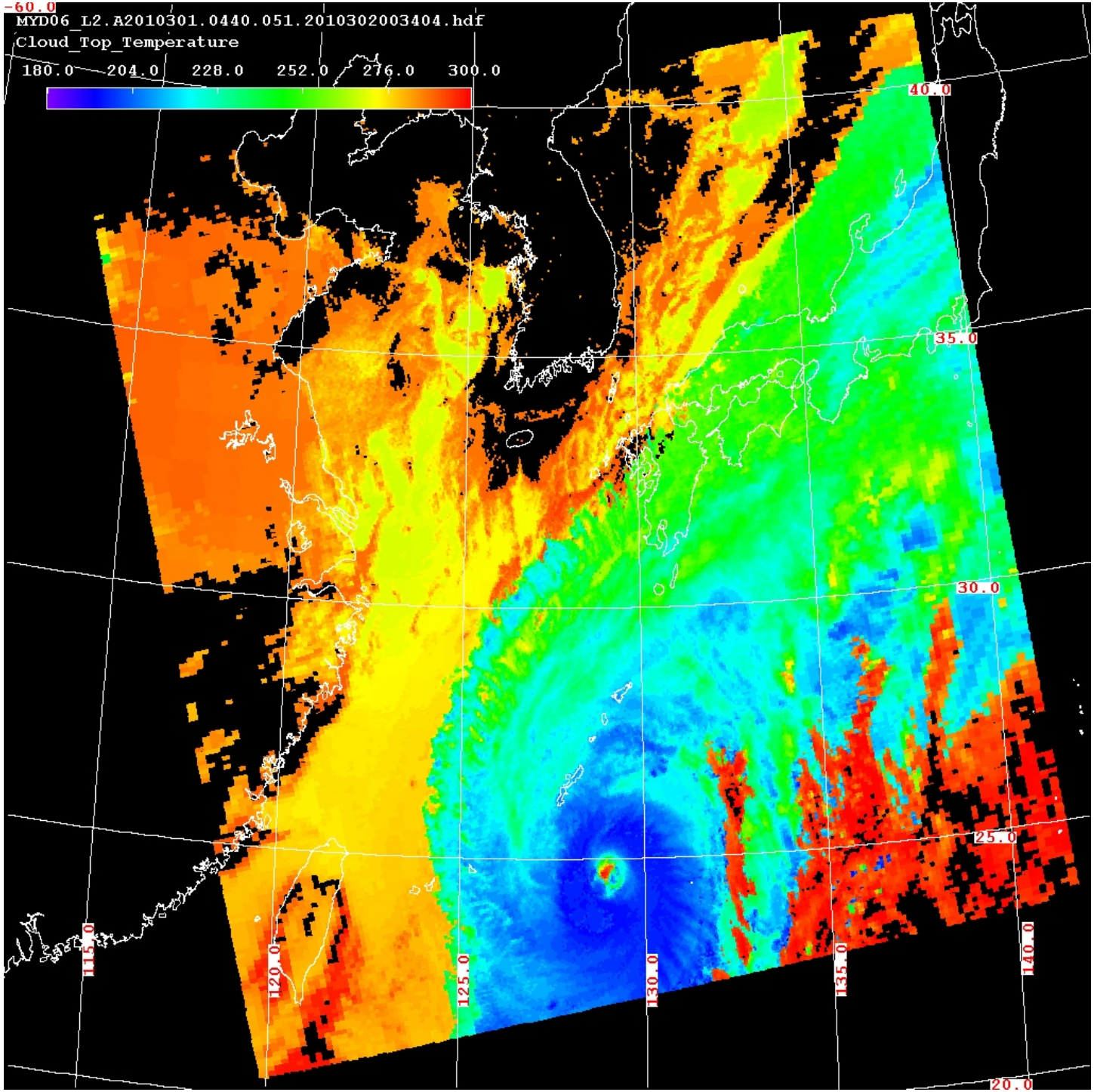


14.2 um 13.9 um 13.6 um 13.3 um


50
160
40
100
30
20
120
140
MODIS AQUA BAND 1 (.65 MICRON) 2010_10_28_301 0437UTC CIMSS/NASA


CTP
1100
1000
900
800
700
600
500
400
300
200
100
0
50
40
30
20
10
100
110
120
130
140
150
MODIS AQUA CLOUD TOP PRESSURES (HPA) 2010_10_28_301 0437UTC CIMSS/NASA


50
160
40
100
30
20
120
140
WATER
ICE
MIXED PHASE
UNCERTAIN
MODIS AQUA CLOUD PHASE 2010_10_28_301 0437UTC CIMSS/NASA


-60.0
MYD06_L2.A2010301.0440.051.2010302003404.hdf
Cloud_Top_Temperature
180.0
204.0
228.0
252.0
276.0
300.0
40.0
35.0
30.0
25.0
20.0
115.0
120.0
125.0
130.0
135.0
140.0

MOD06CT Key Output Parameters

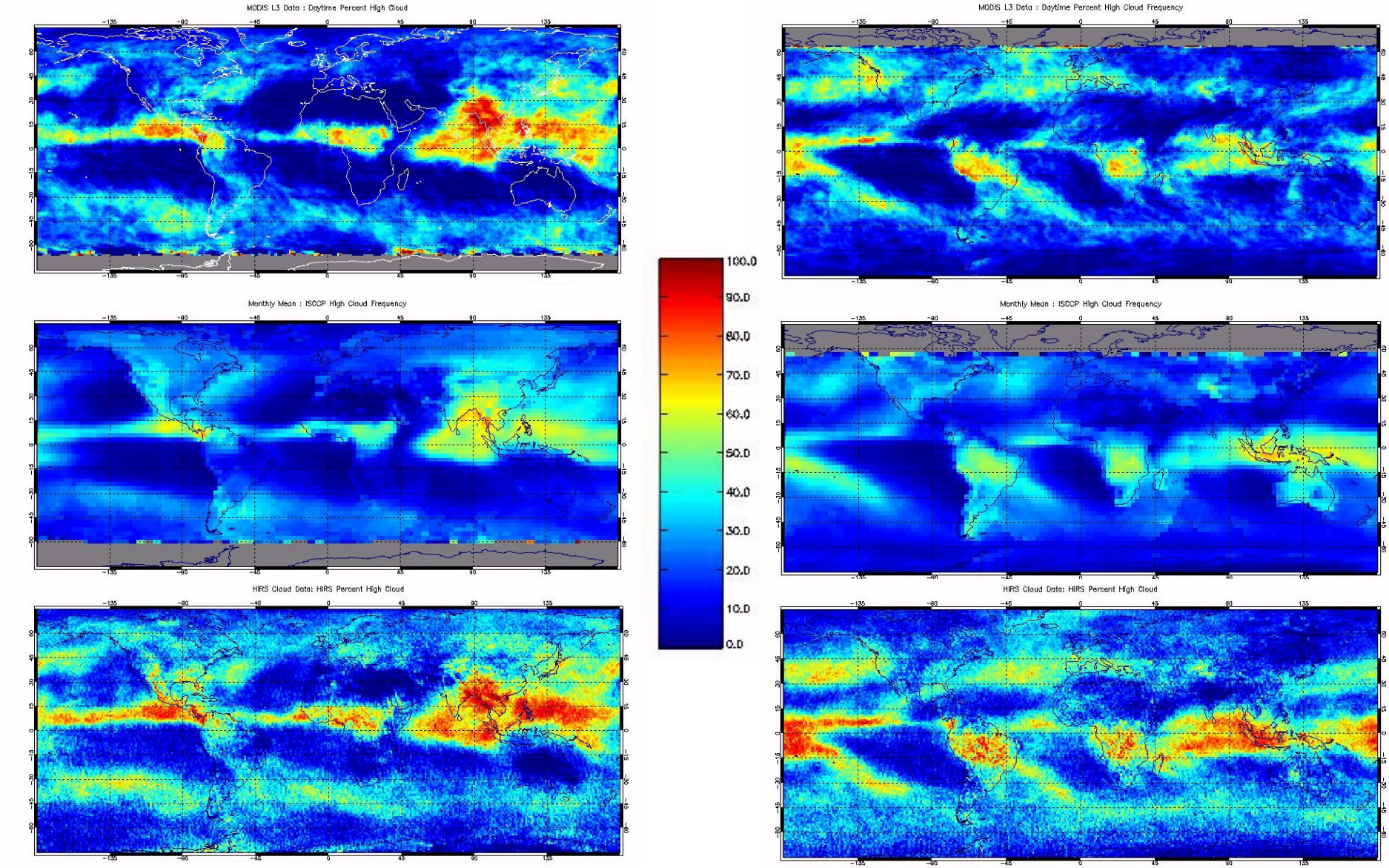
5x5 pixel (1km) resolution

- **Surface_Temperature (GDAS input)**
- **Surface_Pressure (GDAS input)**
- **Cloud_Top_Pressure**
- **Cloud_Top_Temperature**
- **Tropopause_Height**
- **Cloud_Fraction**
- **Cloud_Effective_Emissivity**
- **Cloud_Top_Pressure_Infrared**
- Brightness_Temperature_Difference_B29-B31
- Brightness_Temperature_Difference_B31-B32
- Cloud_Phase_Infrared
- Cloud Optical Depth (daytime – 1 km product)
- Cloud Effective Radius (daytime – 1km)

Known Problems

- Low cloud
  - Vantage point of satellite means more sensitive to high cloud than low cloud. New algorithm address this
- Solution converges on highest pressure level
  - Addressed with latest algorithm

Validation - Comparison of HIRS/ISCCP/MODIS High Cloud Frequency



July 2002

December 2002

References

Menzel, W. P., F. Richard, H. Zhang, D. P. Wylie, C. Moeller, R. E. Holz, B. Maddux, K. I. Strabala, and L. E. Gumley (2008), MODIS global cloud-top pressure and amount estimation: Algorithm description and results, J. Appl. Meteorol. Climatol., 47, 1175 – 1198, doi:10.1175/2007JAMC1705.1.

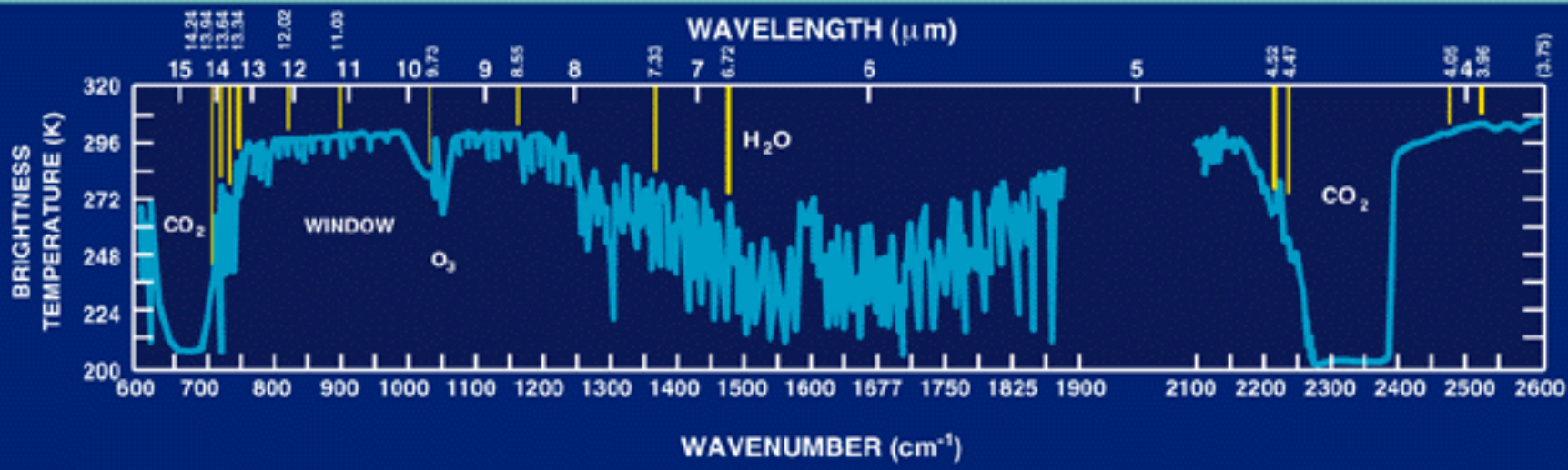
MODIS Atmospheric Profiles (MOD07)

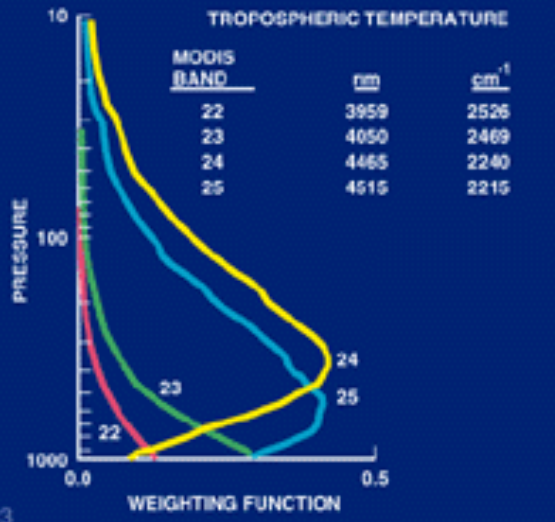
MODIS Atmospheric Profiles

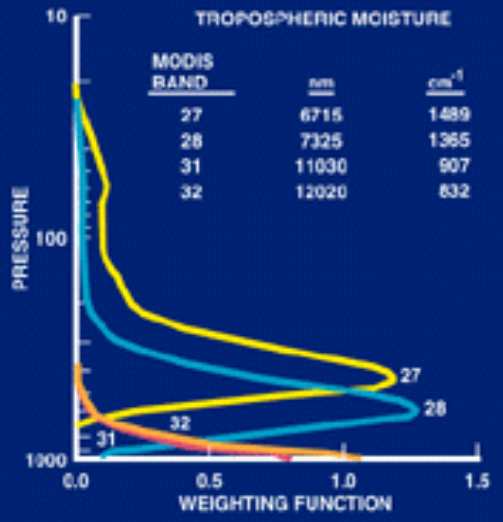
Eva Borbas, Suzanne Wetzel-Seemann SSEC

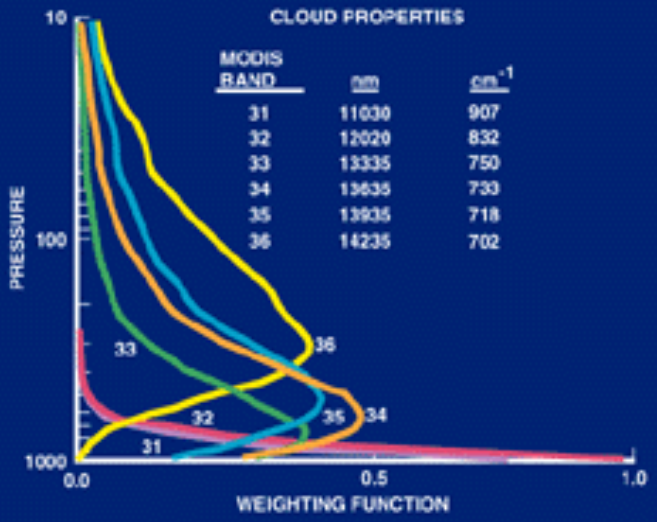
- Retrievals are performed in 5x5 FOV (approximately 5km resolution) clear-sky radiances over land and ocean for both day and night.
- Algorithm is a statistical regression and has the option for a subsequent nonlinear physical retrieval.
- Regression predictors include MODIS infrared radiances from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

ATMOSPHERE - THERMAL RADIATION







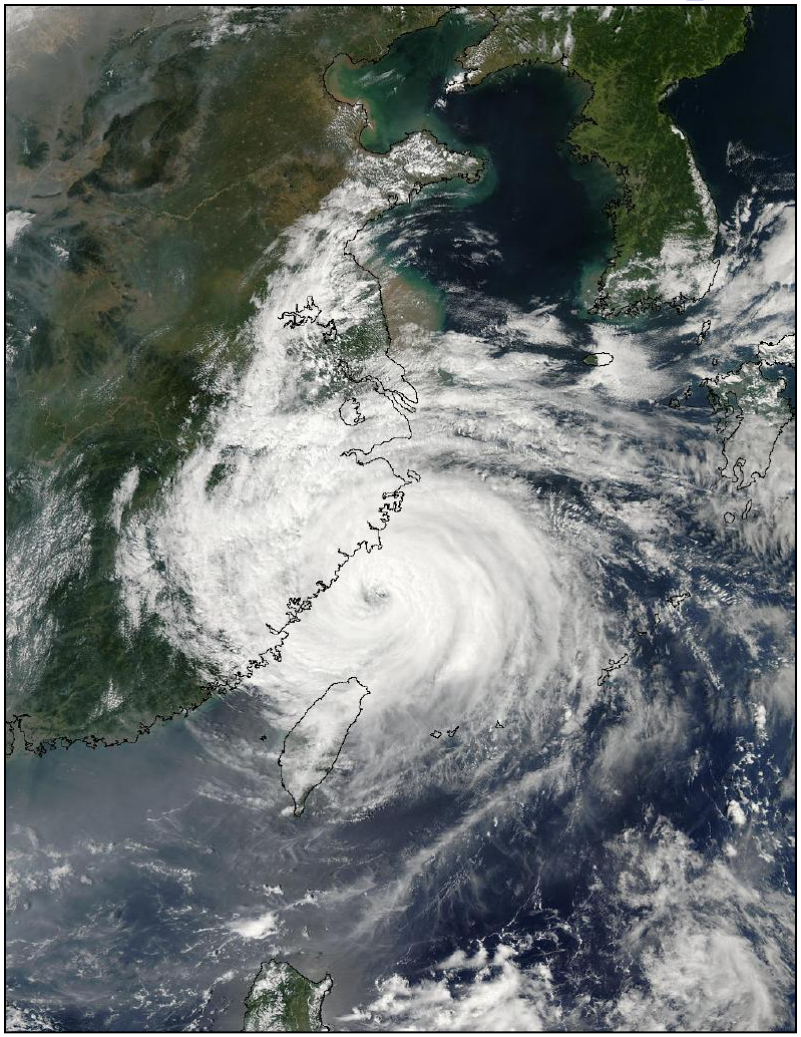


Atmospheric Profile Output

- Atmospheric precipitable water
  short Water_Vapor
  short Water_Vapor_Low
  short Water_Vapor_High
- Profiles of temperature and moisture (20 levels)
  short Retrieved_Moisture_Profile
  short Retrieved_Temperature_Profile
- Total column ozone
  short Total_Ozone

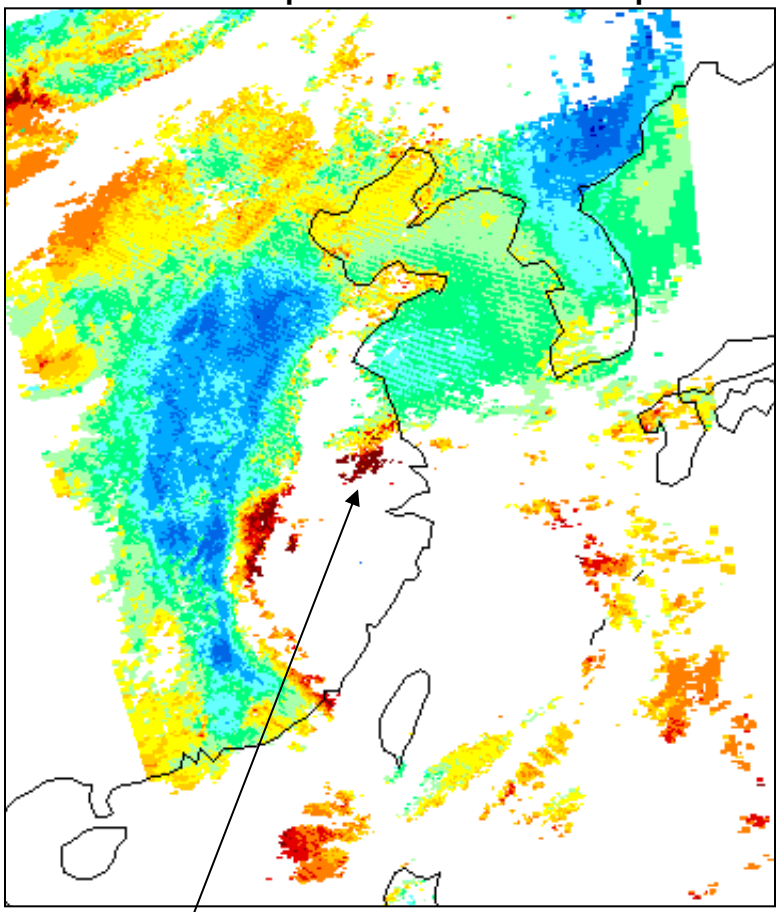
Pressure_Level = 05., 10., 20., 30., 50., 70., 100., 150., 200., 250., 300., 400., 500., 620., 700., 780., 850., 920., 950., 1000. ;

Typhoon Sinlaku, 7 September 2002
Aqua MODIS



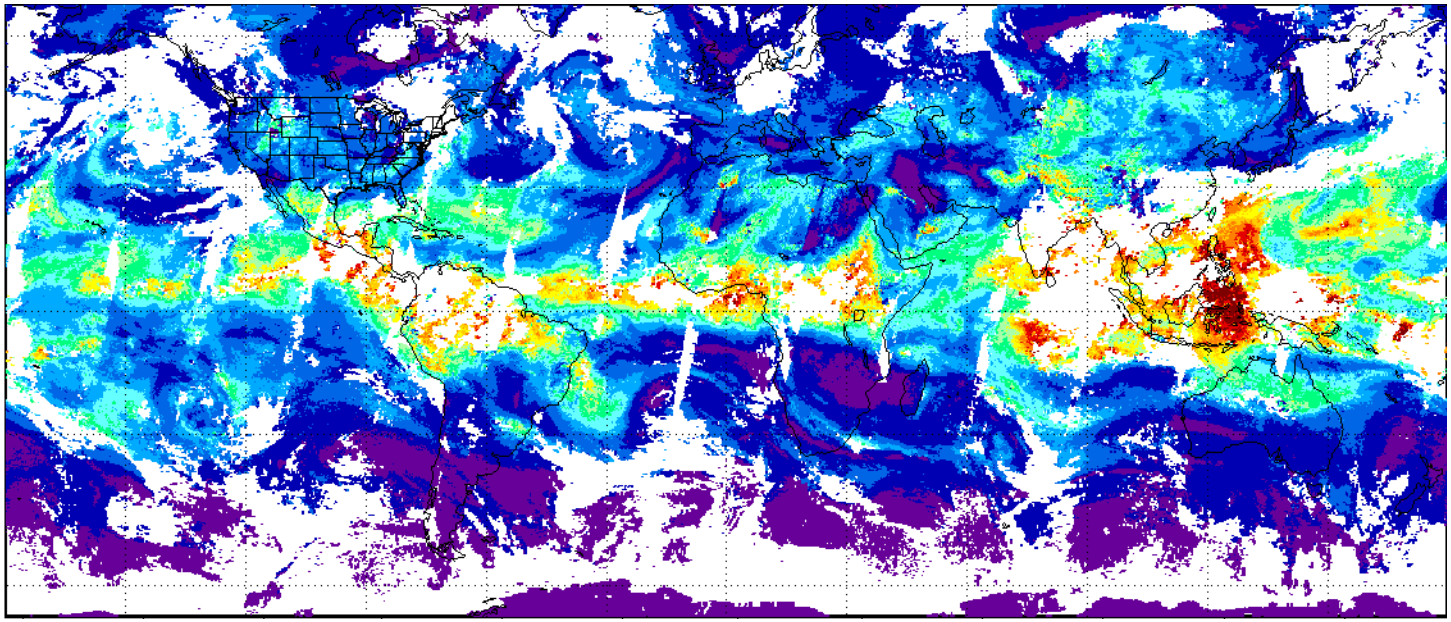
Aqua MODIS true color image

Total Precipitable Water Vapor



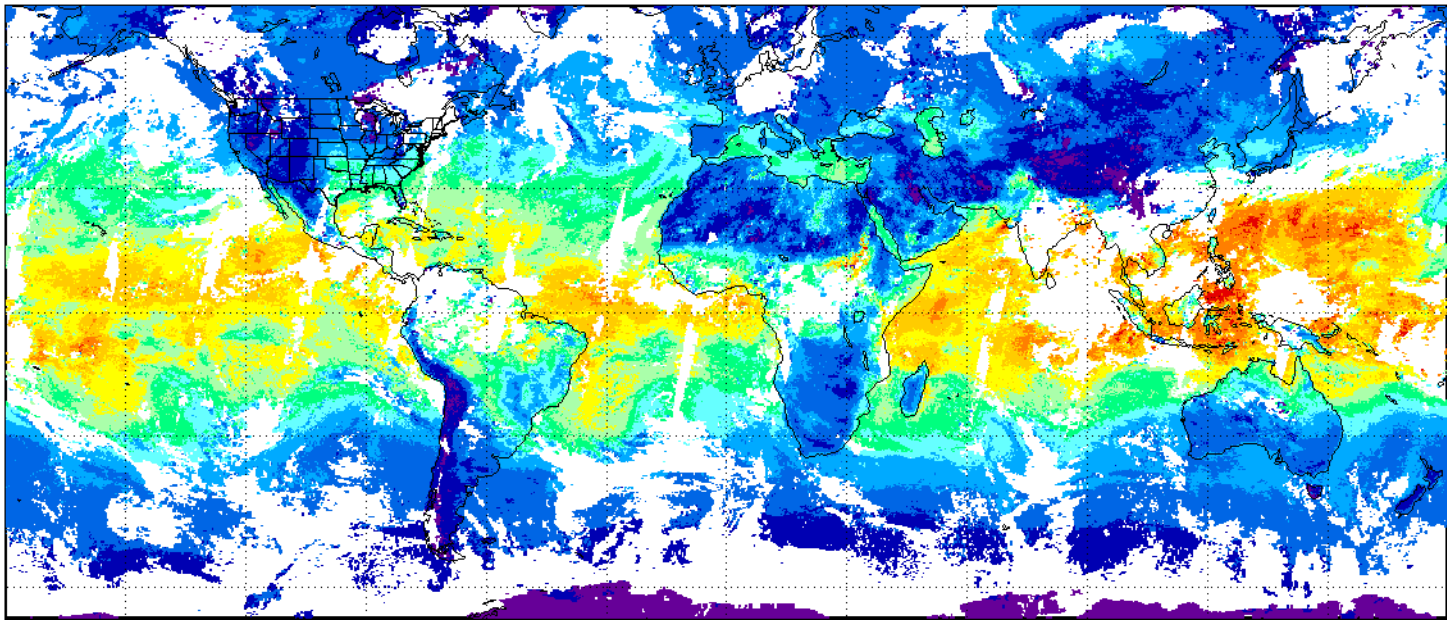
TPW = 72.5 mm

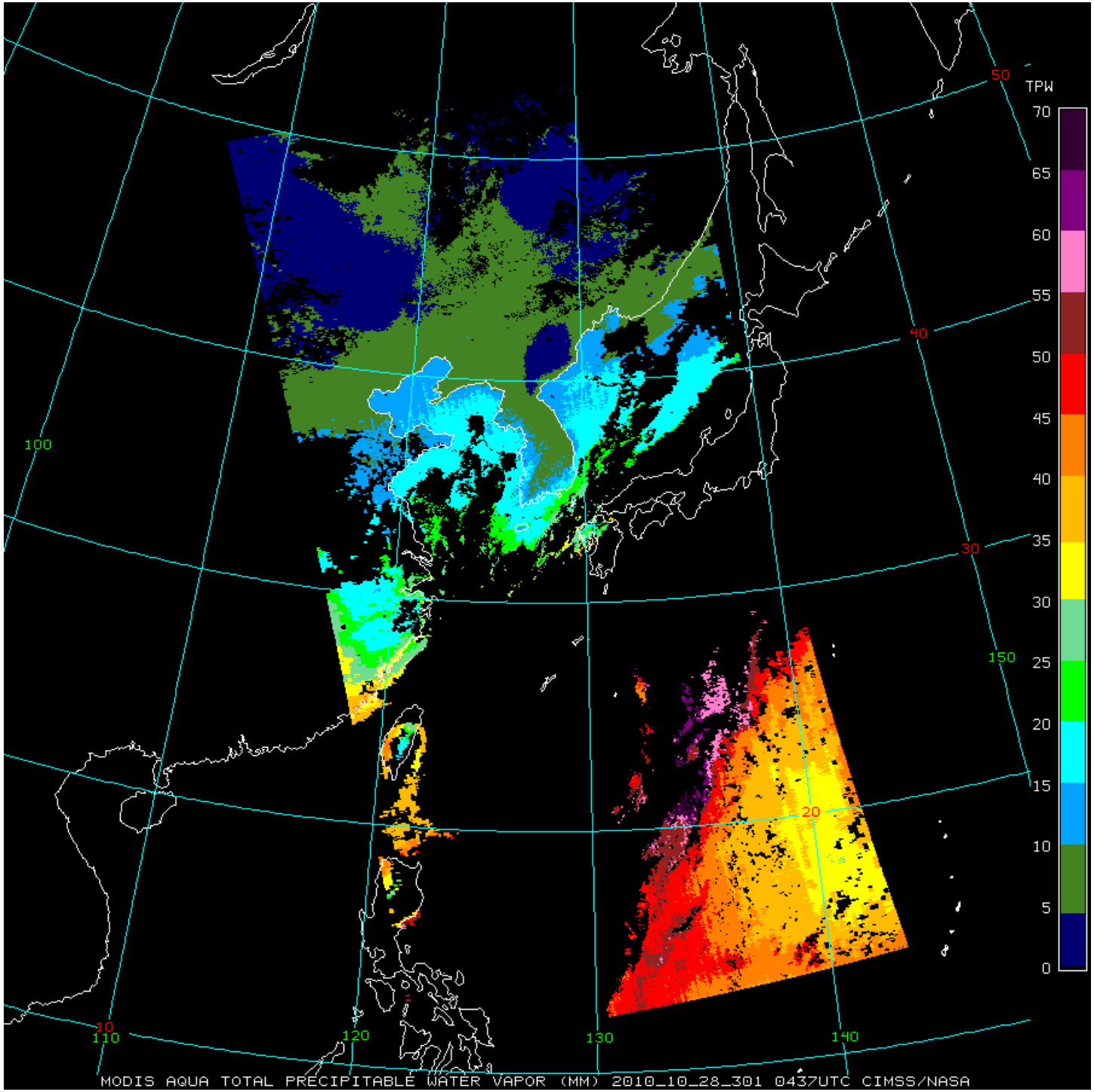
PW High
700-300 hPa

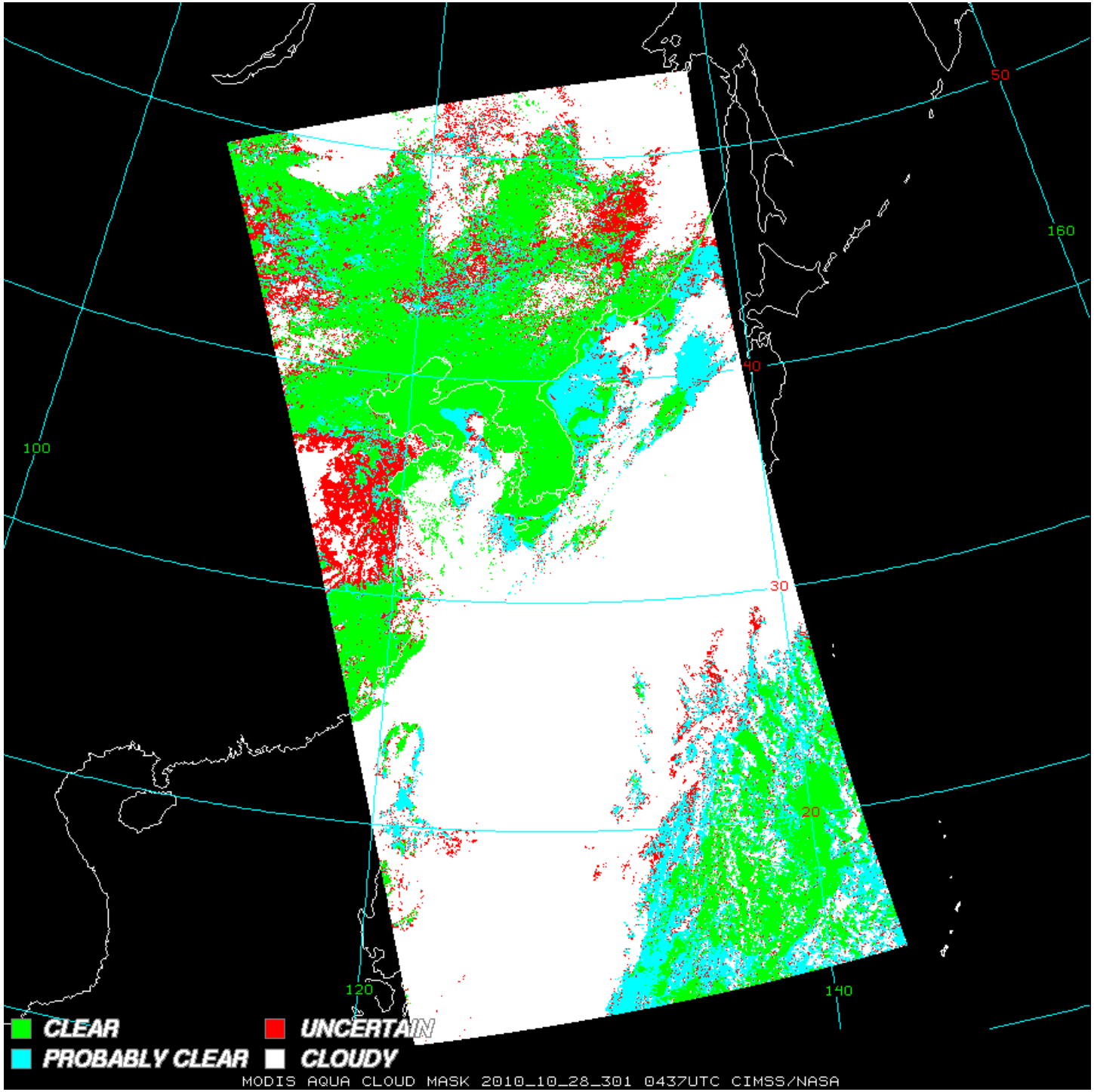


PW (mm): 0 3 6 9 12 15 18

PW Low
920 hPa - sfc




TPW
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
50
40
30
20
10
100
110
120
130
140
150
MODIS AQUA TOTAL PRECIPITABLE WATER VAPOR (MM) 2010_10_28_301 0437UTC CIMSS/NASA


50
160
40
100
30
20
120
140
CLEAR
UNCERTAIN
PROBABLY CLEAR
CLOUDY
MODIS AQUA CLOUD MASK 2010_10_28_301 0437UTC CIMSS/NASA

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.

Aniko Kern, Judit Bartholy, Eva E. Borbas, Zoltan Barcza, Rita Pongracz, Csaba Ferencz, 2008: Estimation of vertically integrated water vapor in Hungary using MODIS imagery. Advances in Space Research, 41, 1933-1945.

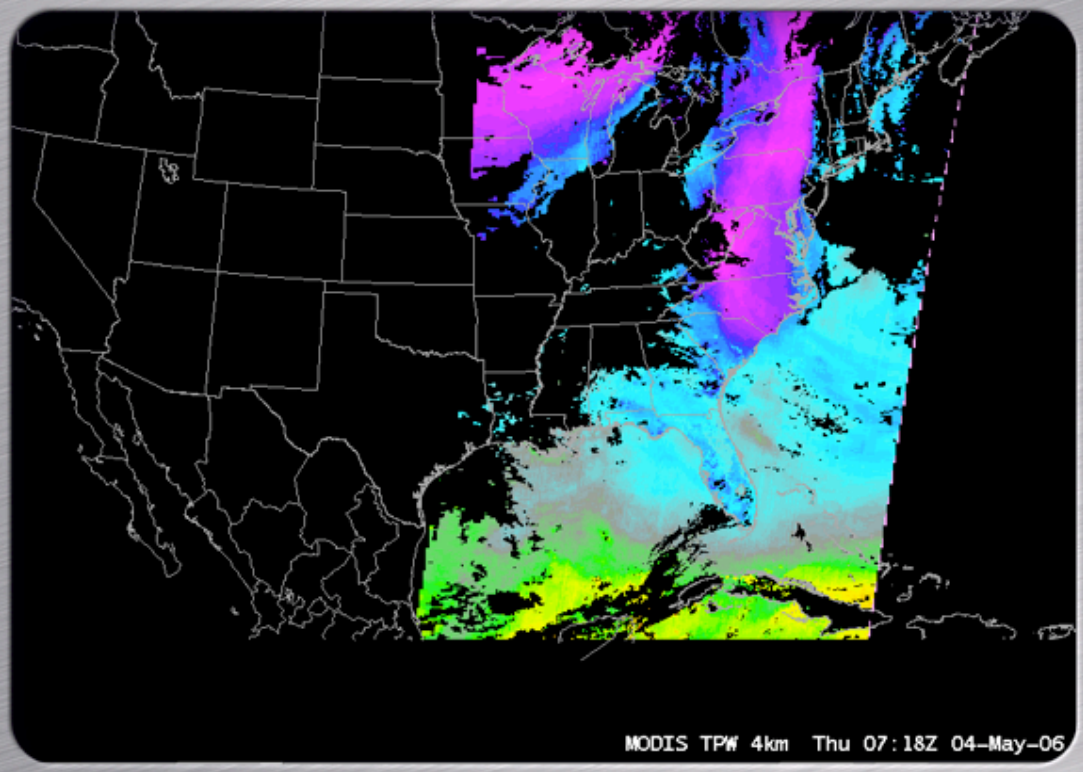
S. W. Seemann , E. E. Borbas , R. O. Knuteson , G. R. Stephenson and H.-L. Huang, 2008: Development of a global infrared land surface emissivity database for application to clear sky sounding retrievals from multispectral satellite radiance measurements. Journal of Applied Meteorology, vol. 47, p.108.

Applications

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

2. Climatological
   - Global Circulations Monitoring
   - Greenhouse Gas Measure

MODIS Imagery in AWIPS

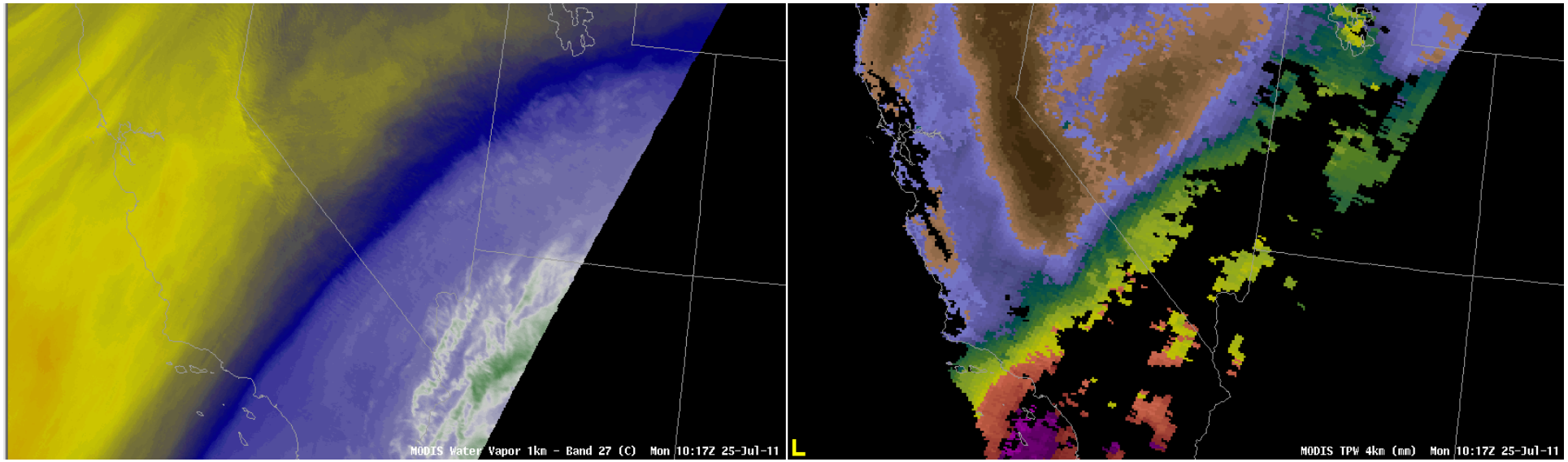


Total Precipitable Water

Support for Fire Weather Forecasts

AREA FORECAST DISCUSSION
NATIONAL WEATHER SERVICE SALT LAKE CITY UT
1024 AM MDT MON JUL 25 2011

.FIRE WEATHER...MODIS WATER VAPOR IMAGERY INDICATES THAT PRECIPITABLE WATER VALUES APPROACHING ONE INCH HAVE PUSHED AS FAR NORTH AS THE SOUTHERN WASATCH FRONT THIS MORNING. THIS SURGE OF MOISTURE IS ALSO BRINGING EXTENSIVE CLOUD COVER TO CENTRAL AND NORTHERN UTAH THIS MORNING....WITH DEEP MOISTURE MOVING NORTH BELIEVE THAT RISK FOR DRY THUNDERSTORMS IS LIMITED PRIMARILY TO THE LEADING EDGE OF THE MOISTURE SURGE ACROSS NORTHERN UTAH...ALTHOUGH FEEL COVERAGE OF POTENTIAL DRY STORMS WOULD BE LIMITED



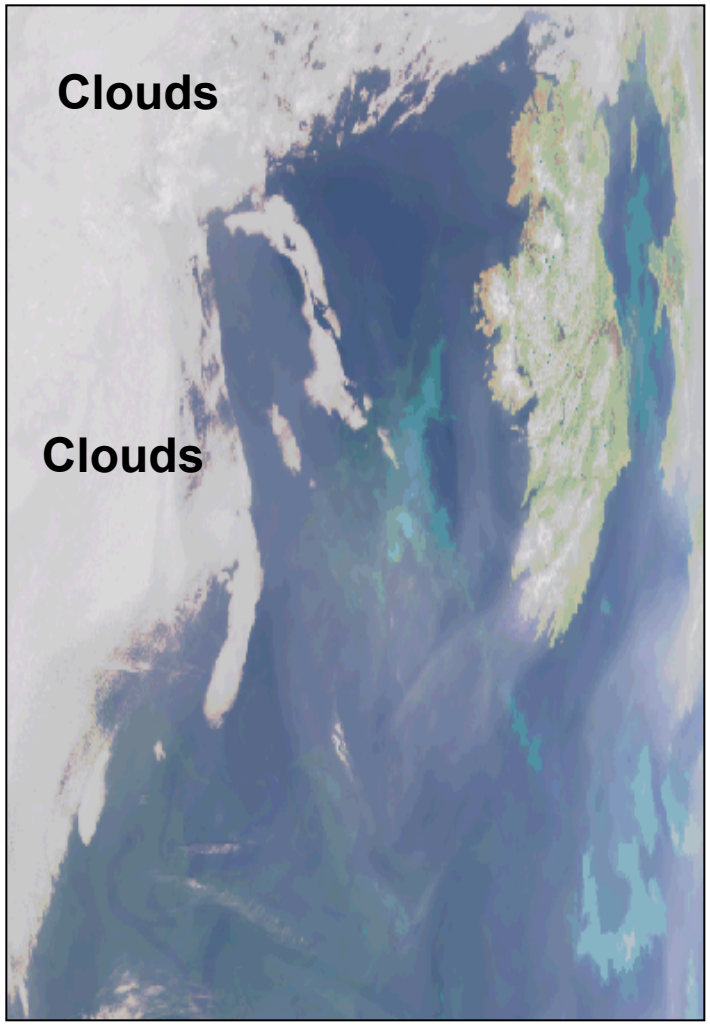
MODIS Imagery from UW SSEC Antenna 10:17 UTC 25 July 2011

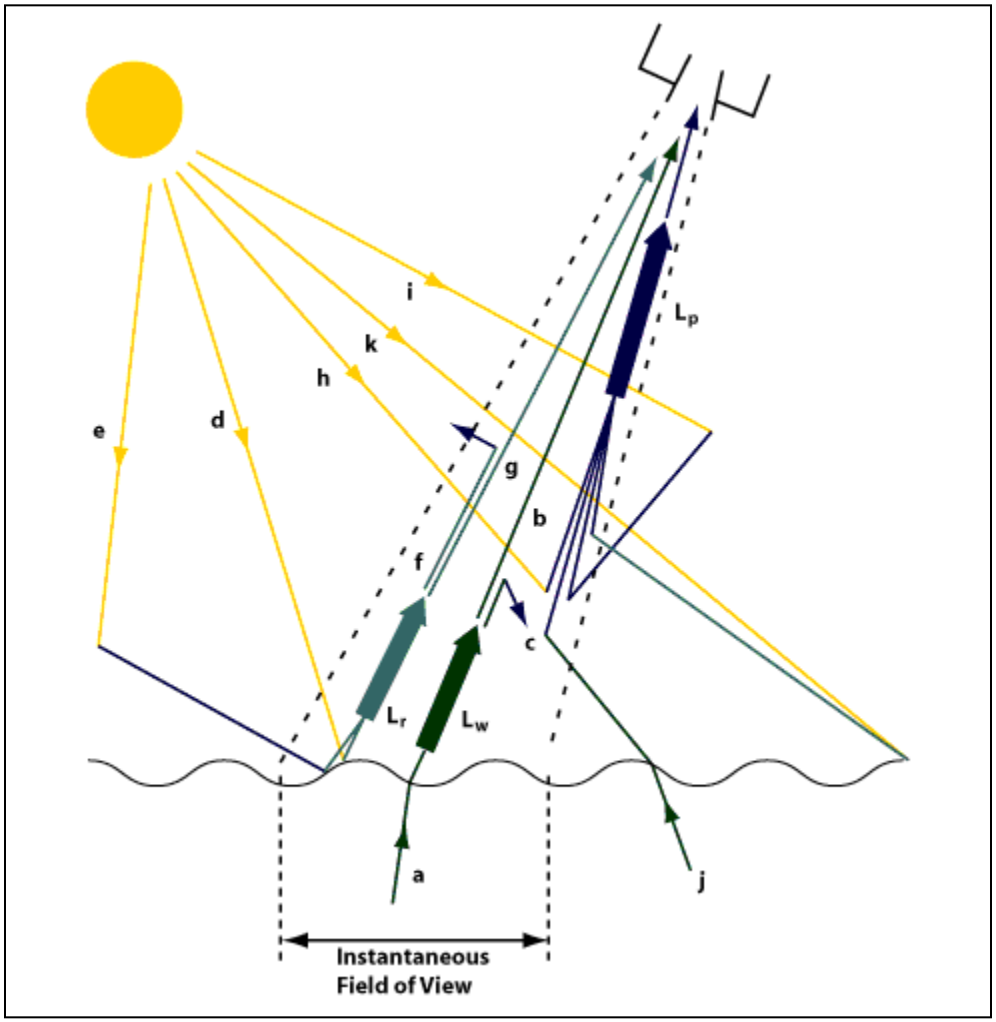
MODIS Ocean Products

MODIS Ocean 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)

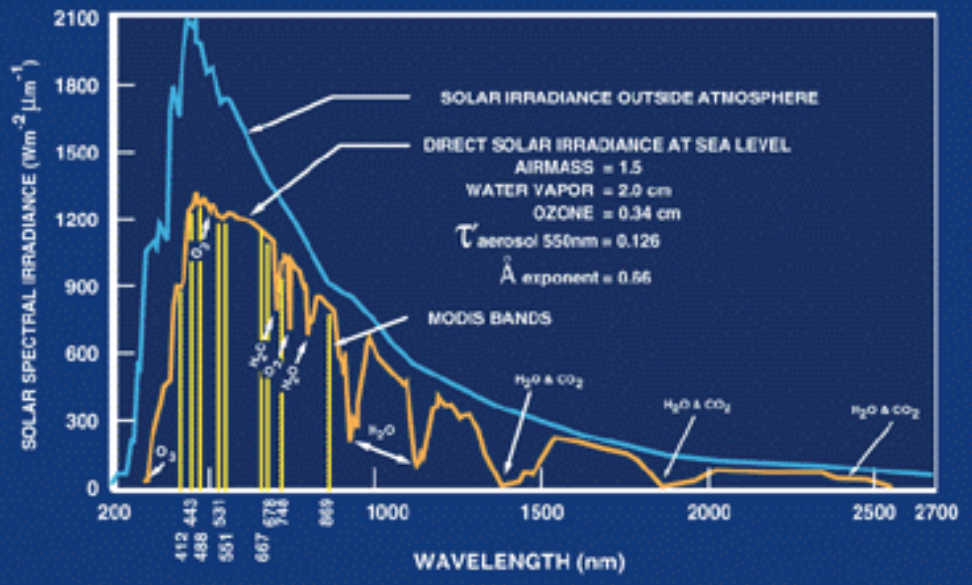
Atmospheric correction is critical for ocean color

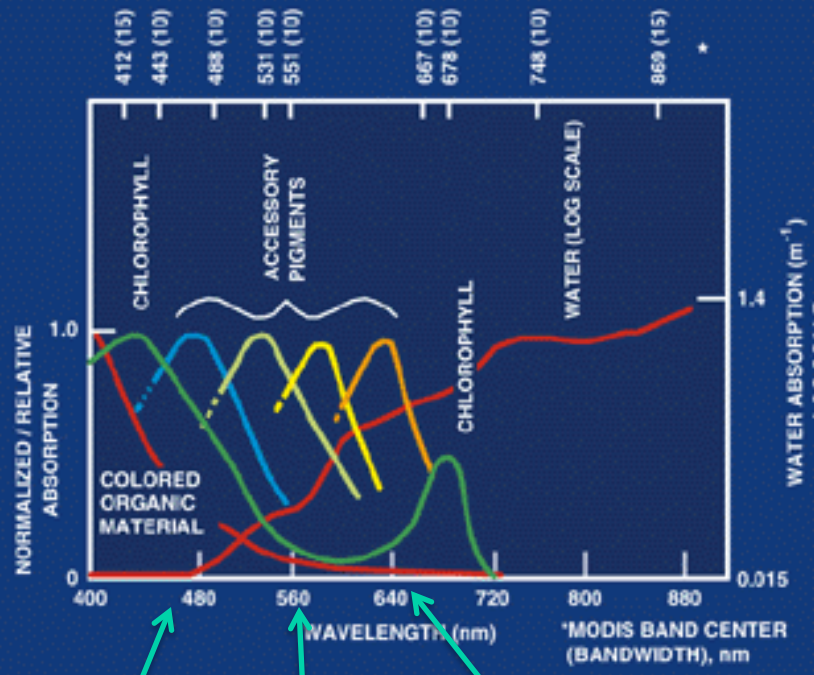




- cloud masking – less rigorous on sensors with no IR bands
- L_w – only 5% of signal reaching satellite: rest due to L_p
- L_p components: molecular (Rayleigh) & aerosols

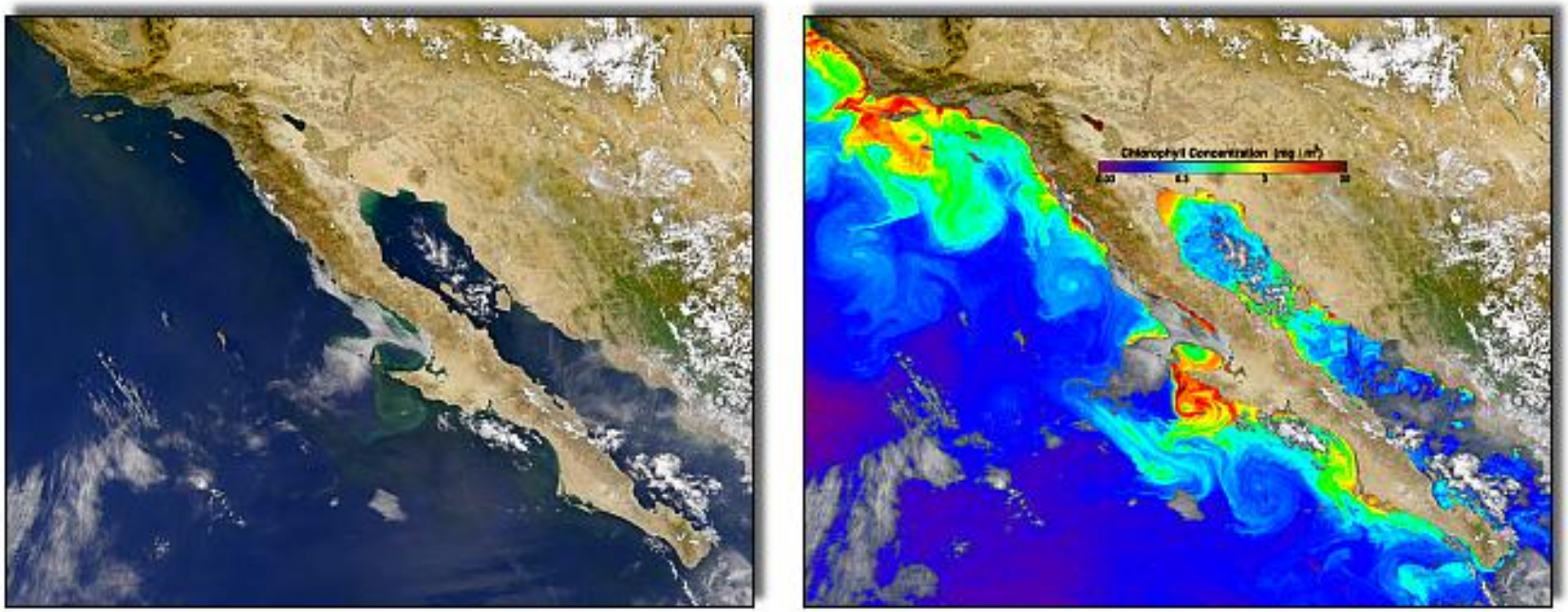
OCEAN-SOLAR RADIATION





Blue Green Red

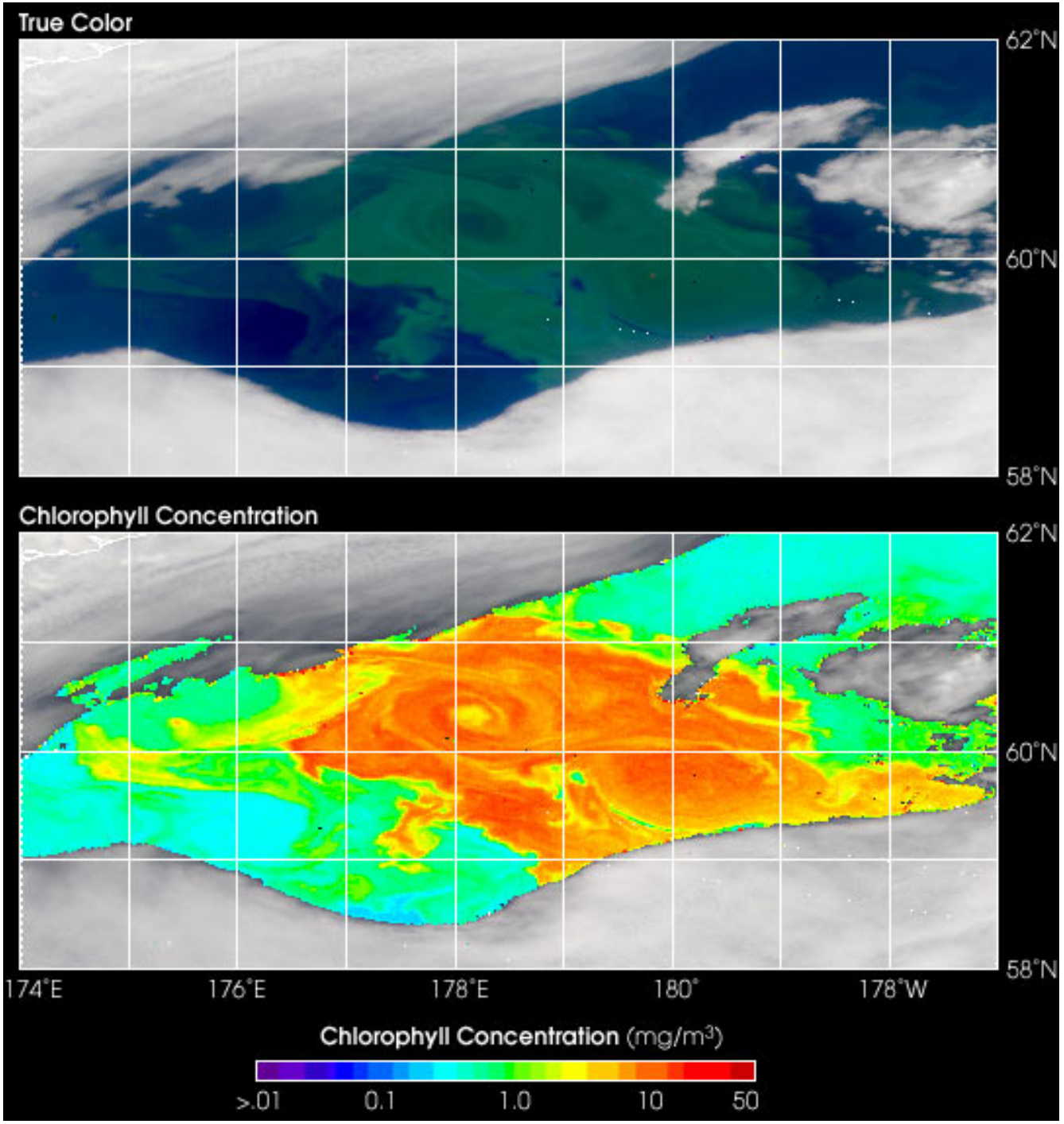
Chlorophyll



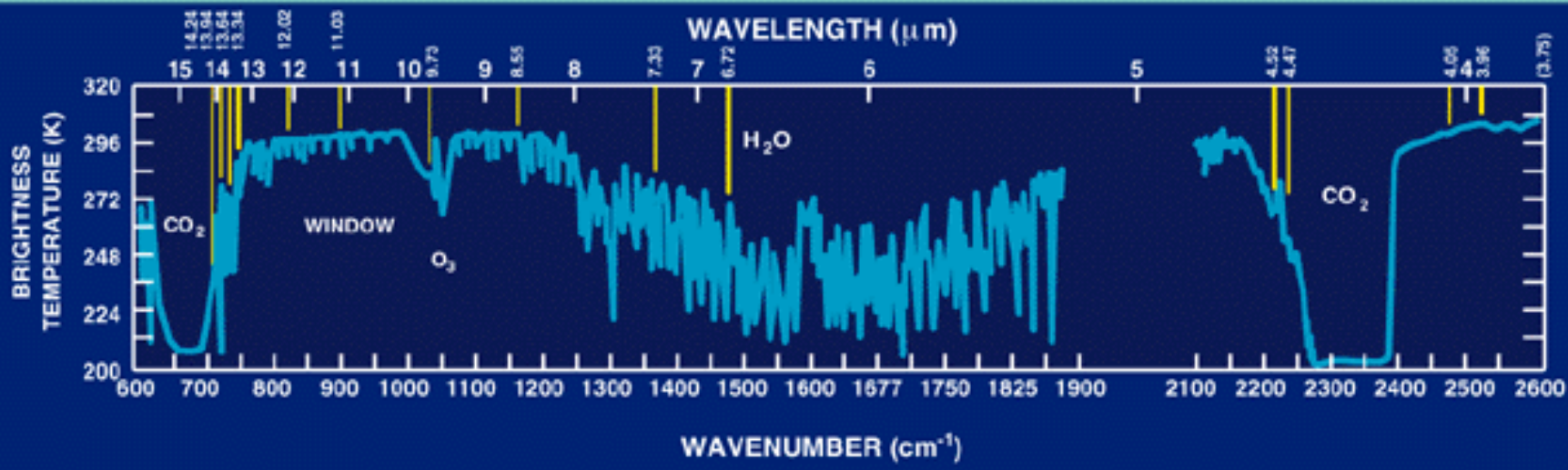
August 10, 2003

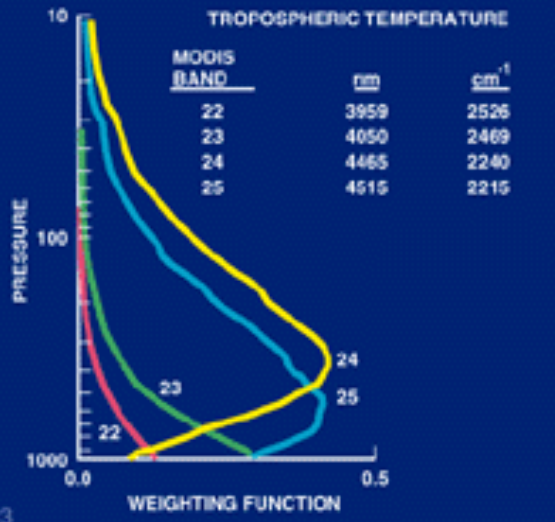
Strong absorption of the blue light by phytoplankton in chlorophyll-rich waters results in low water-leaving radiance in the blue bands.

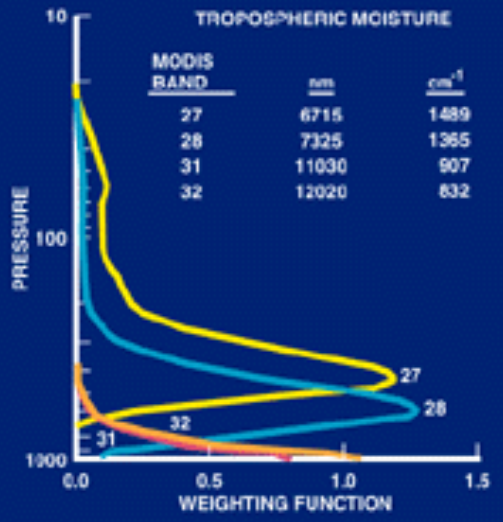
Dominant band shifts from blue to green with increasing chlorophyll concentration.

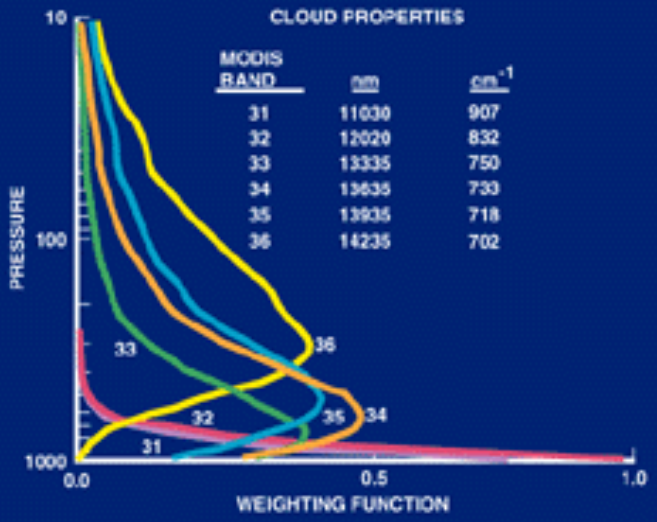

True Color
62°N
60°N
58°N
Chlorophyll Concentration
62°N
60°N
58°N
174°E
176°E
178°E
180°
178°W
Chlorophyll Concentration (mg/m3)
>.01
0.1
1.0
10
50

ATMOSPHERE - THERMAL RADIATION

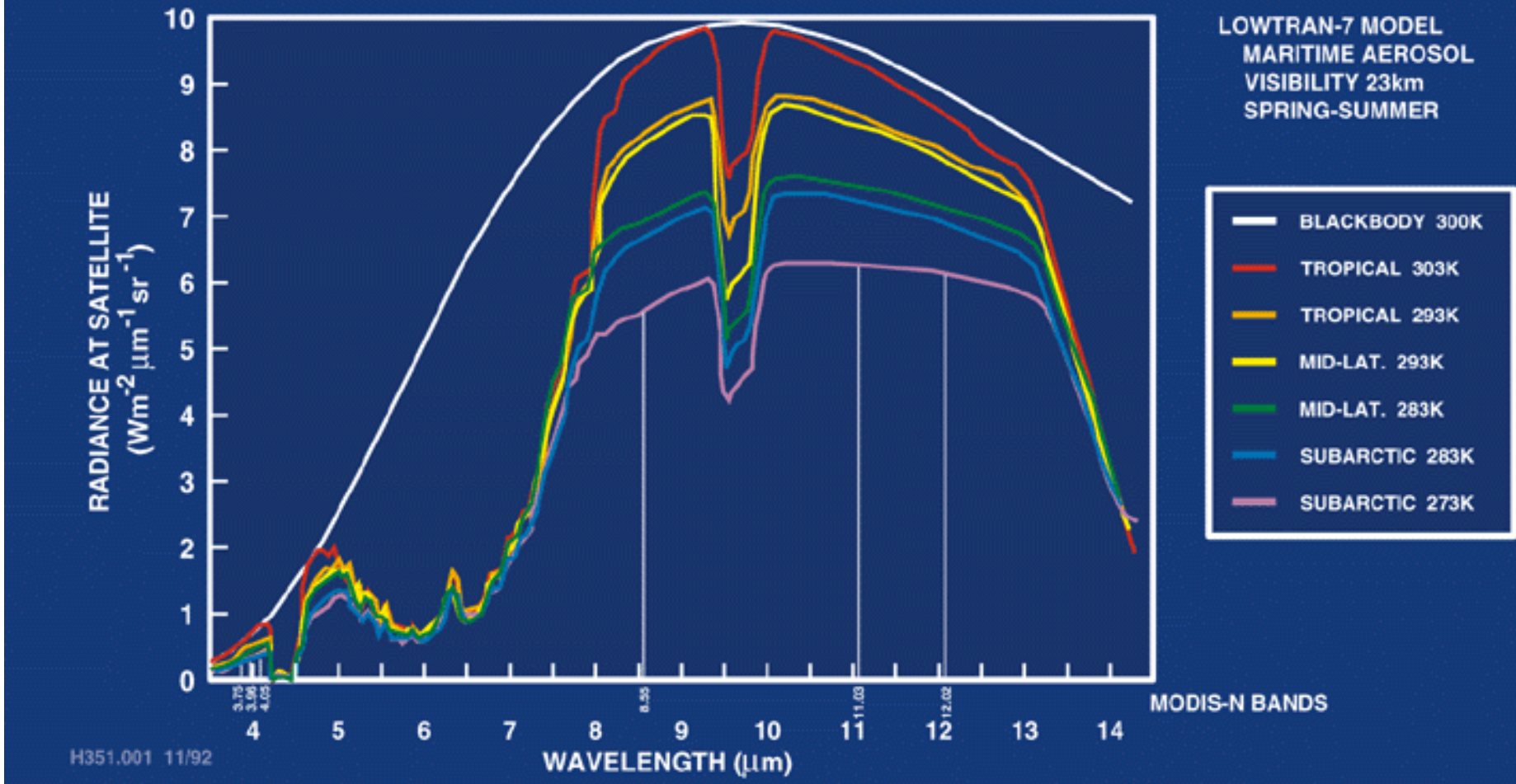








MODIS SEA SURFACE TEMPERATURE



H351.001 11/92

MODIS Longwave Infrared Sea Surface Temperature (c5)

dBT <= 0.5
sst = a00 + a01*BT11 + a02*dBT*bsst + a03*dBT*(1.0/mu - 1.0)

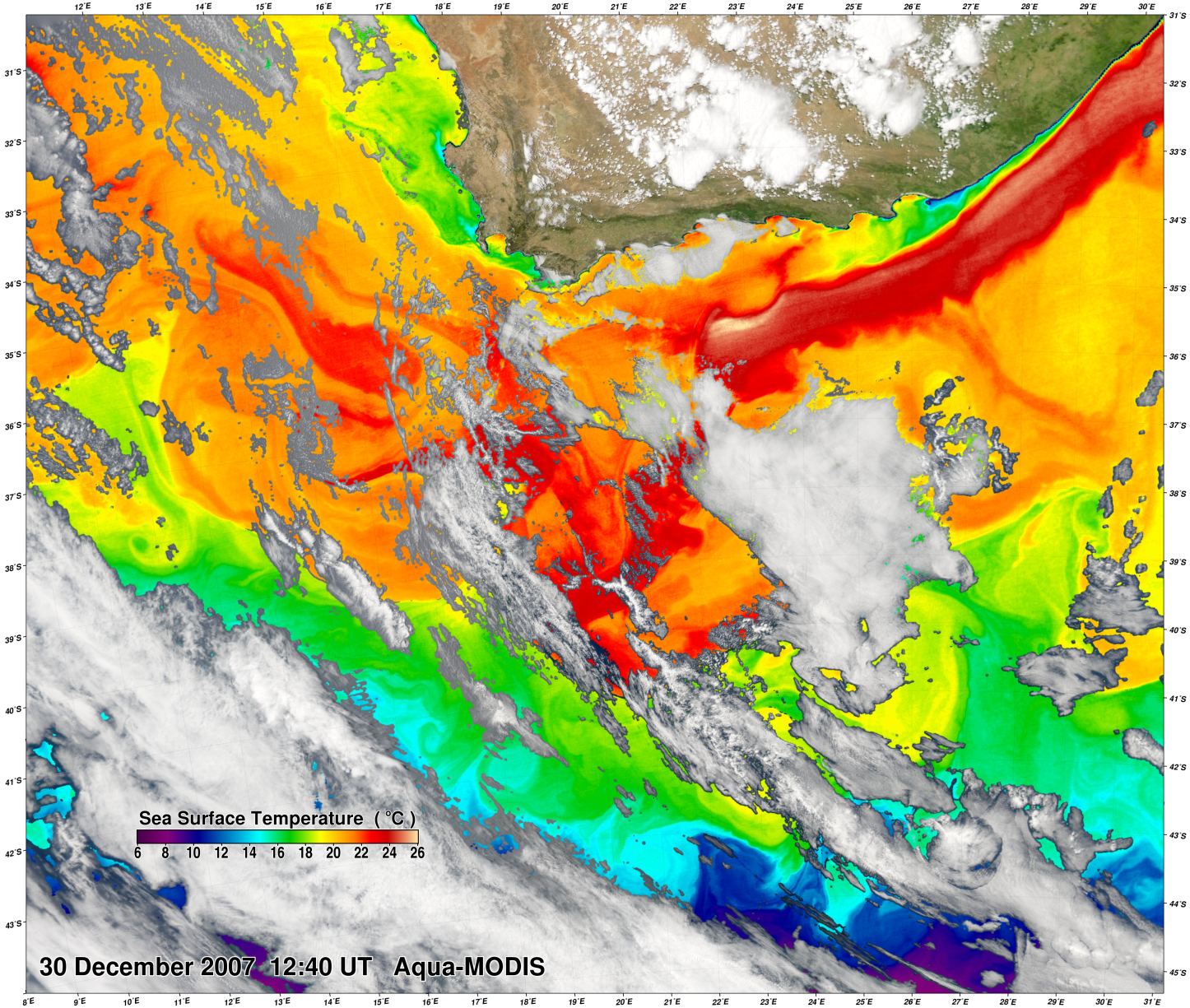
dBT >= 0.9
sst = a10 + a11*BT11 + a12*dBT*bsst + a13*dBT*(1.0/mu - 1.0)

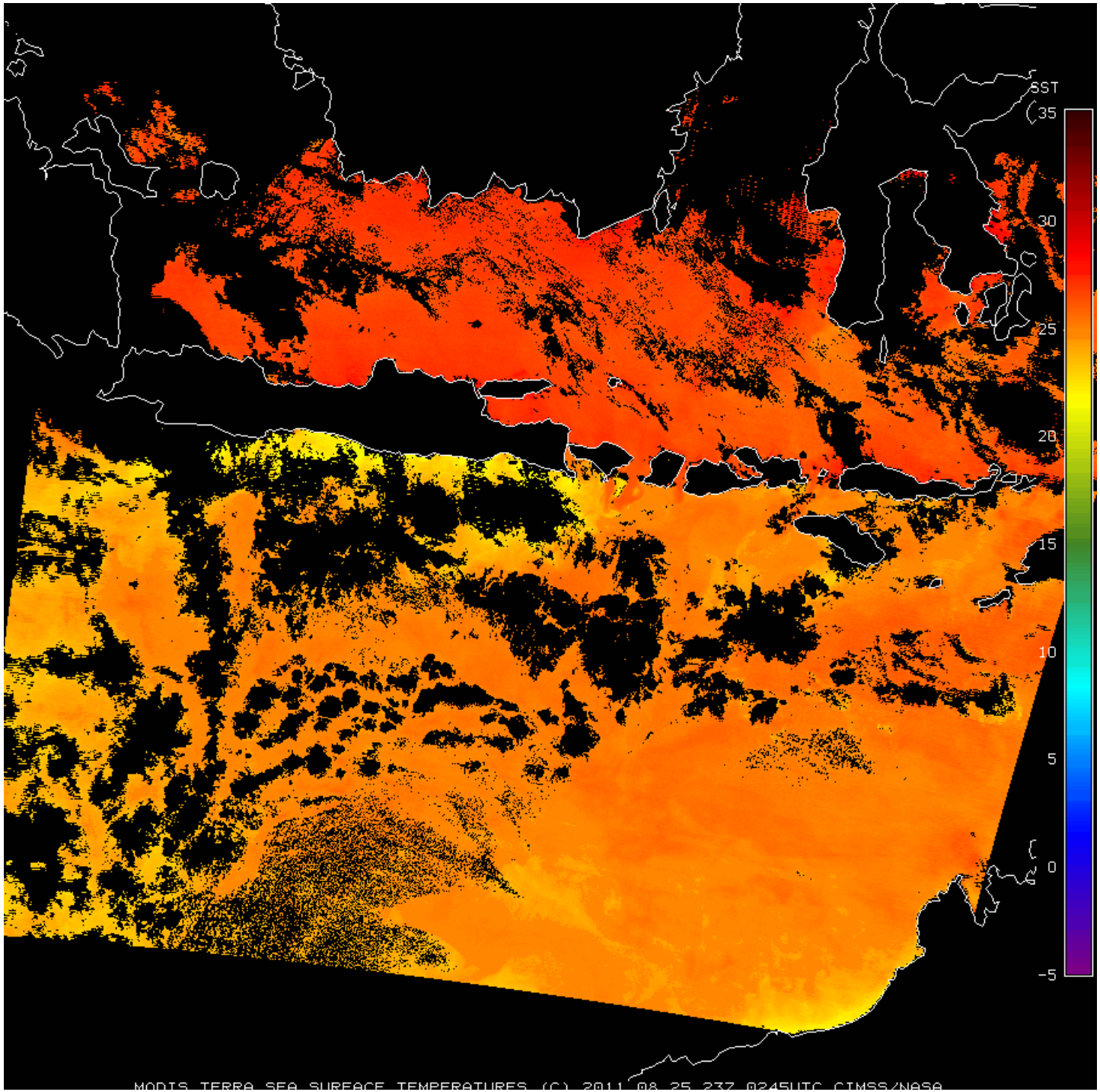
0.5 < dBt < 0.9
sstlo = a00 + a01*BT11 + a02*dBT*bsst + a03*dBT*(1.0/mu - 1.0)
ssthi = a10 + a11*BT11 + a12*dBT*bsst + a13*dBT*(1.0/mu - 1.0)
sst = sstlo + (dBT - 0.5)/(0.9 - 0.5)*(ssthi - sstlo)

where:

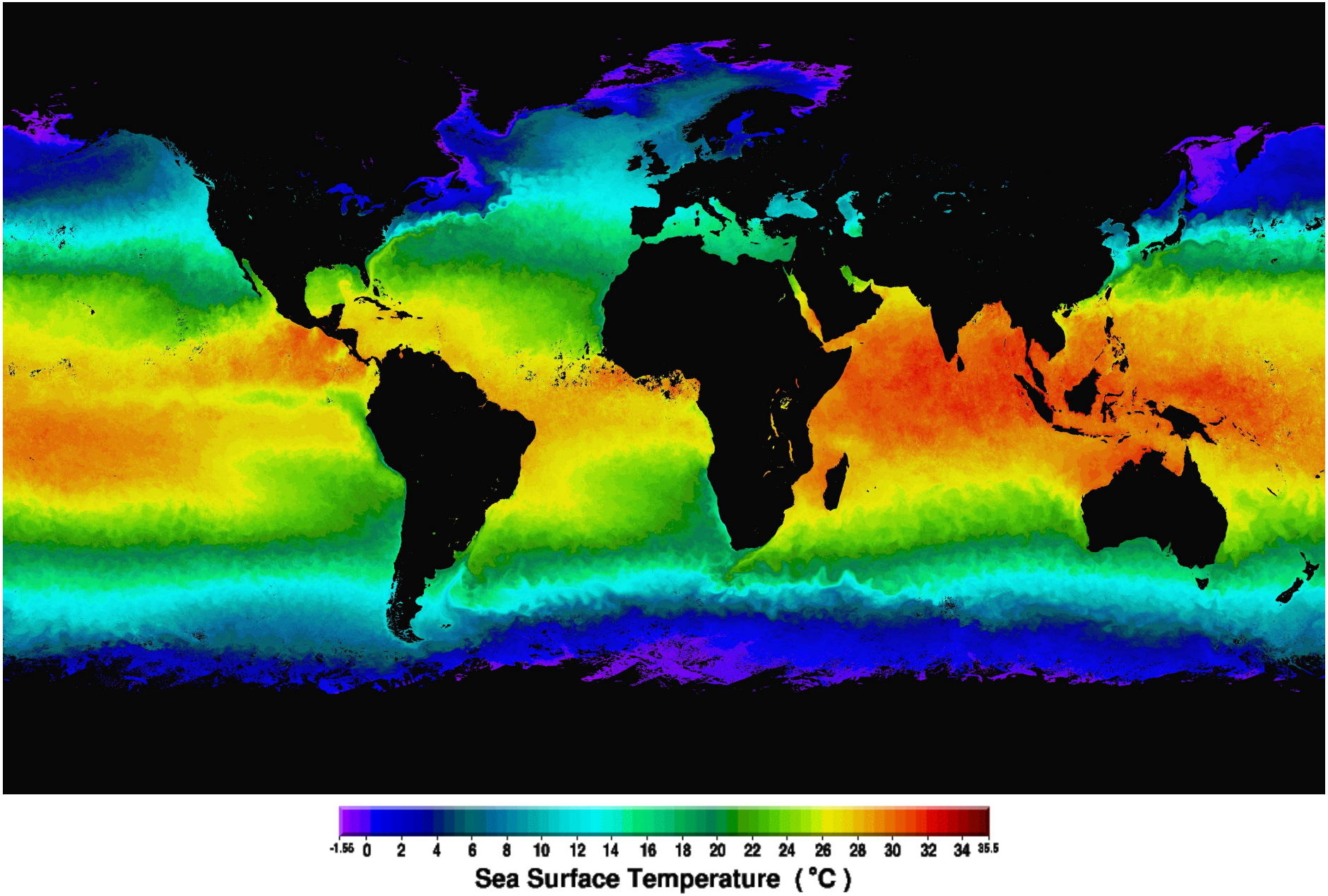
dBT = BT11 - BT12
BT11 = brightness temperature at 11 um, in deg-C
BT12 = brightness temperature at 12 um, in deg-C
bsst = Either sst4 (if valid) or sstref (from Reynolds OISST)
mu = cosine of sensor zenith angle
a00, a01, a02, a03, a10, a11, a12, a13 derived from match-ups

Agulhas & Benguela Currents

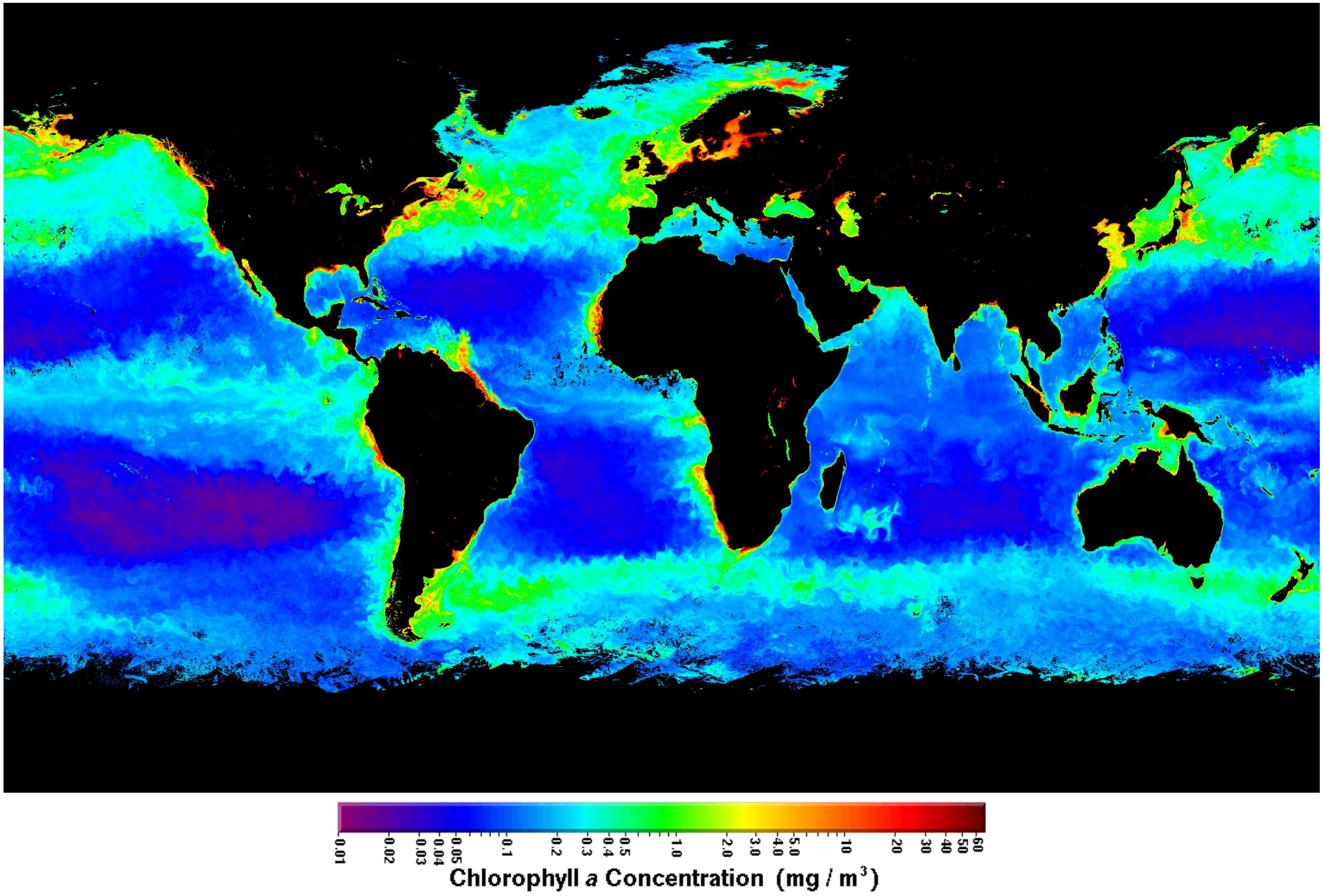



SST
35
30
25
20
15
10
5
0
-5
MODIS TERRA SEA SURFACE TEMPERATURES (C) 2011 08 25 237 0245UTC CIMSS/NASA

Aqua MODIS Sea Surface Temperature, April 2004



Aqua MODIS Chlorophyll Concentration, April 2004



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