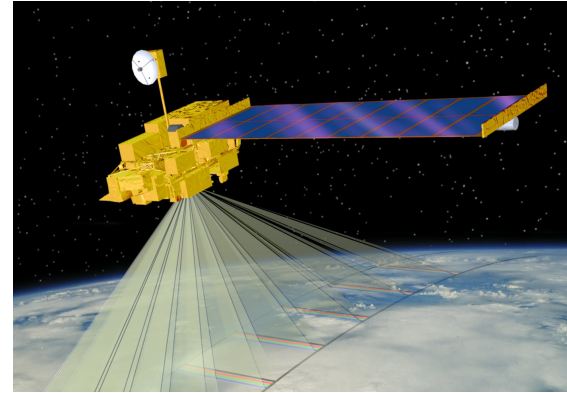
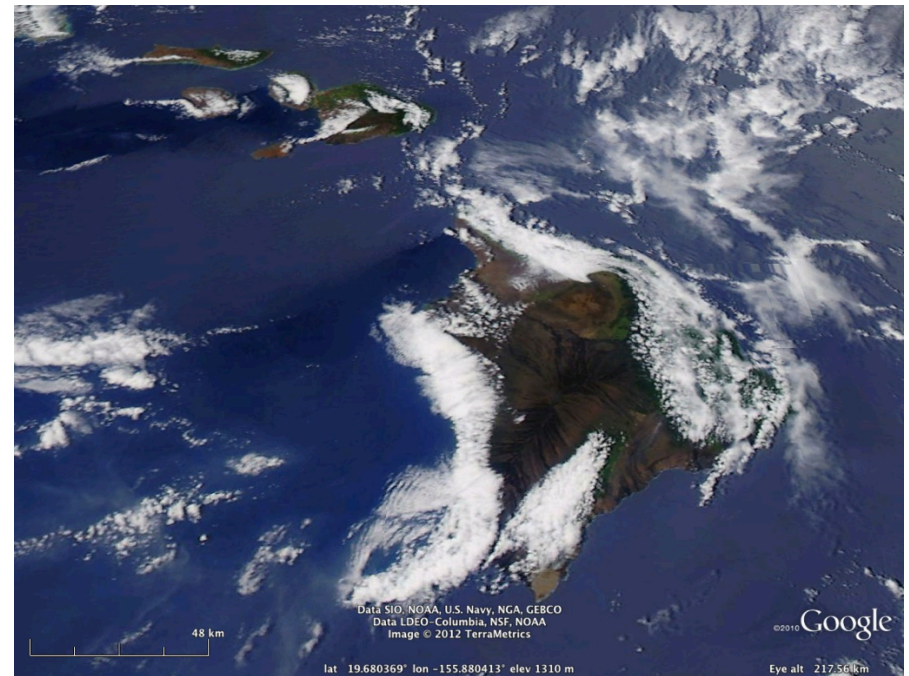


Introduction to the MODIS sensor and products



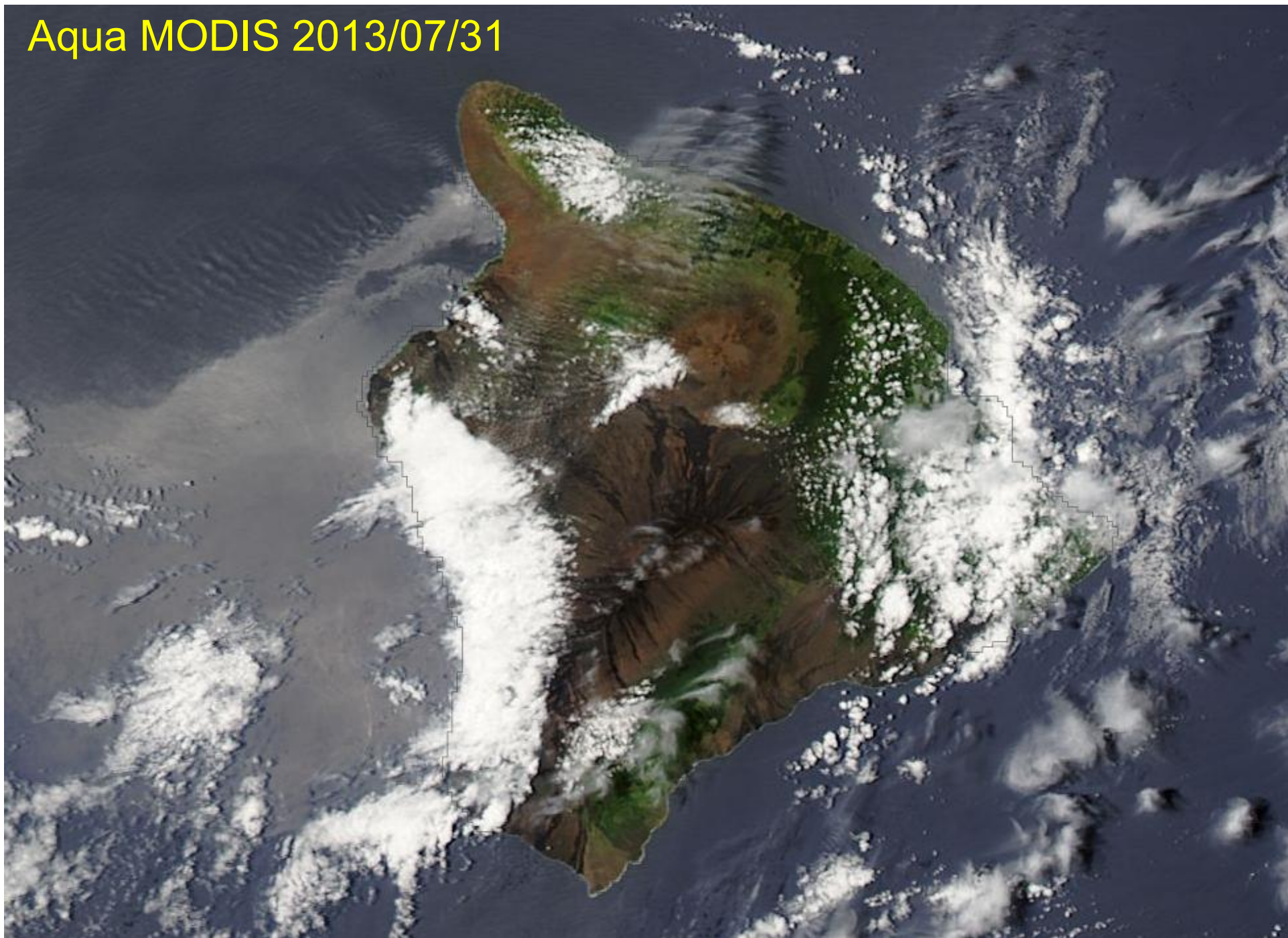
**VIIRS/MODIS Workshop
Honolulu Hawaii
August 2013**



Liam Gumley
Space Science and Engineering Center
University of Wisconsin-Madison



Aqua MODIS 2013/07/31



Earth Observing System (EOS)

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

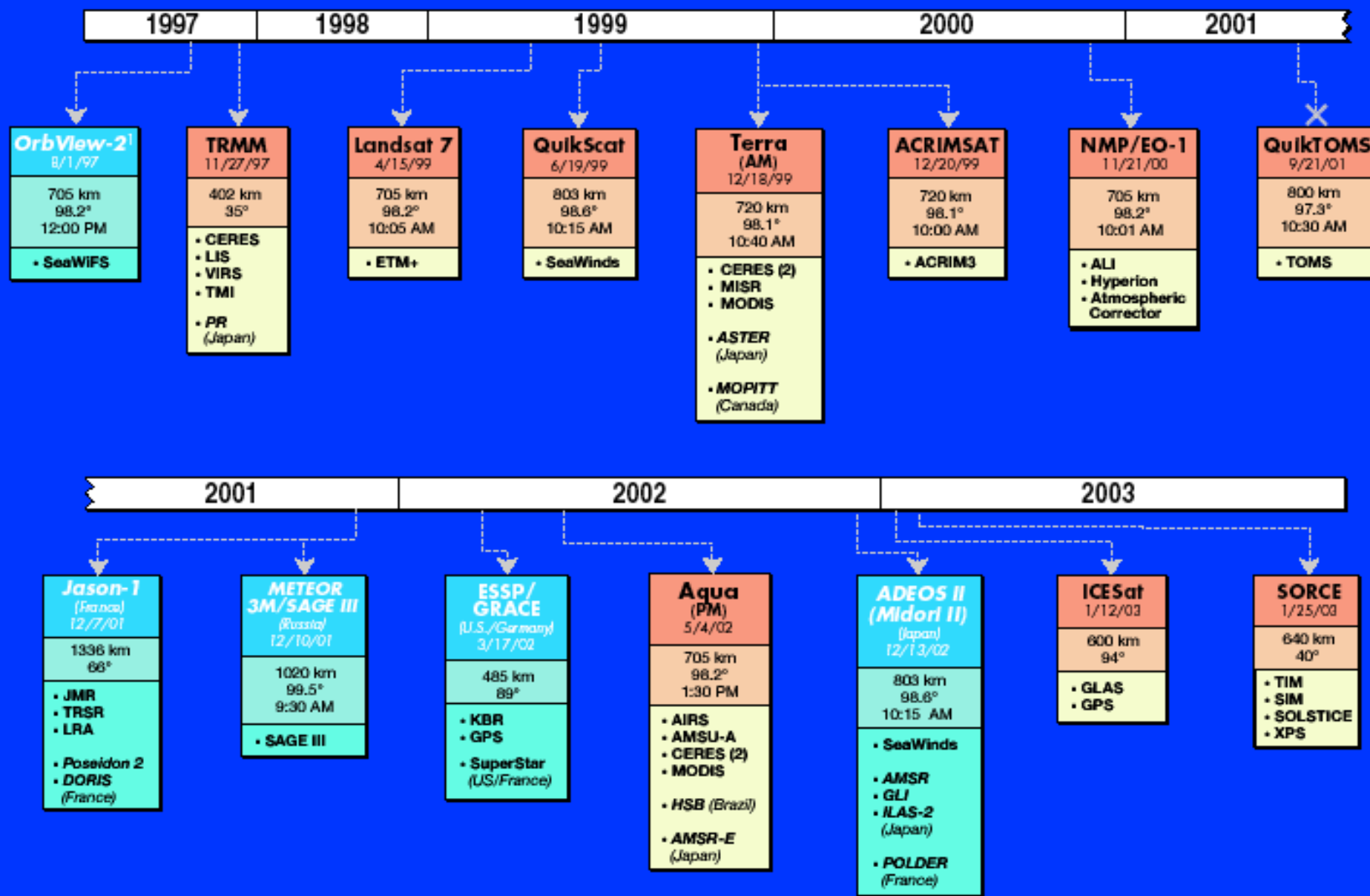
The Earth Observing System (EOS) is intended to measure the impact of human activities and other phenomena on the world's climate over a period spanning nearly two decades ...

It is the biggest single science program in the world ...

- Charles F. Kennel

Earth Science Mission Profile 1997 - 2003

Revised: 29 June 2004



Spacecraft not provided or is partly provided by NASA

Items in italics not funded by NASA

Currently in orbit

Launch Failure

¹ OrbView-2 is not provided or operated by NASA but is a data buy

Terra



Launched: Dec. 18, 1999

10:30 am descending node

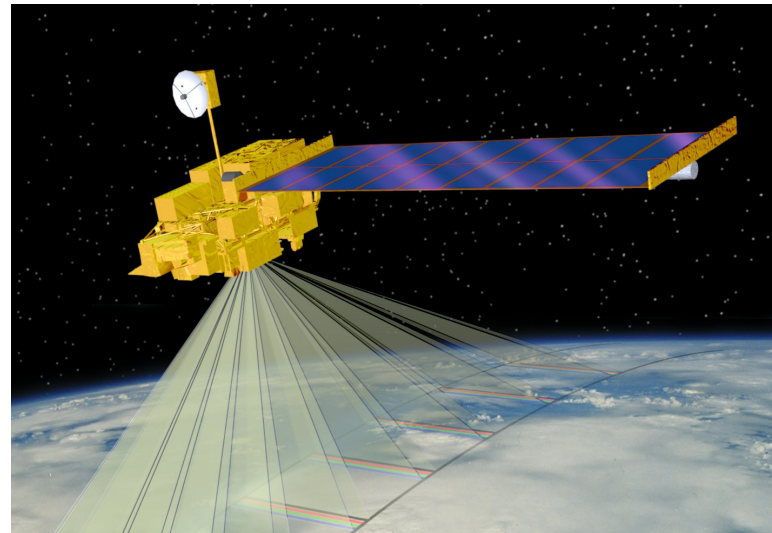
ASTER: Hi-res imager

CERES: Broadband scanner

MISR: Multi-view imager

MODIS: Multispectral imager

MOPITT: Limb sounder



Expected lifetime > 15 years

Terra MODIS first light image, 24 Feb. 2000

Birdfoot Delta
Mississippi River
USA



Aqua



Launched: May 4, 2002
1:30 pm ascending node

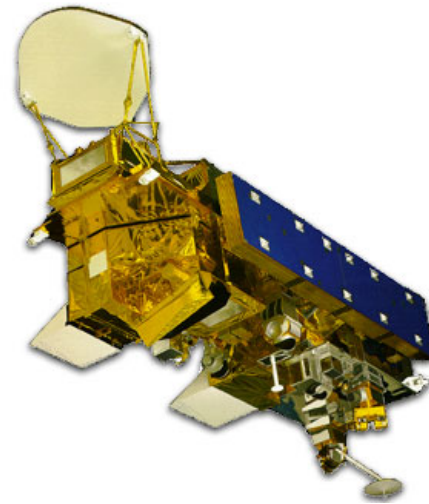
AIRS: Infrared sounder

AMSR-E: Microwave scanner

AMSU: Microwave scanner

CERES: Broadband scanner

MODIS: Multispectral imager



Expected lifetime > 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

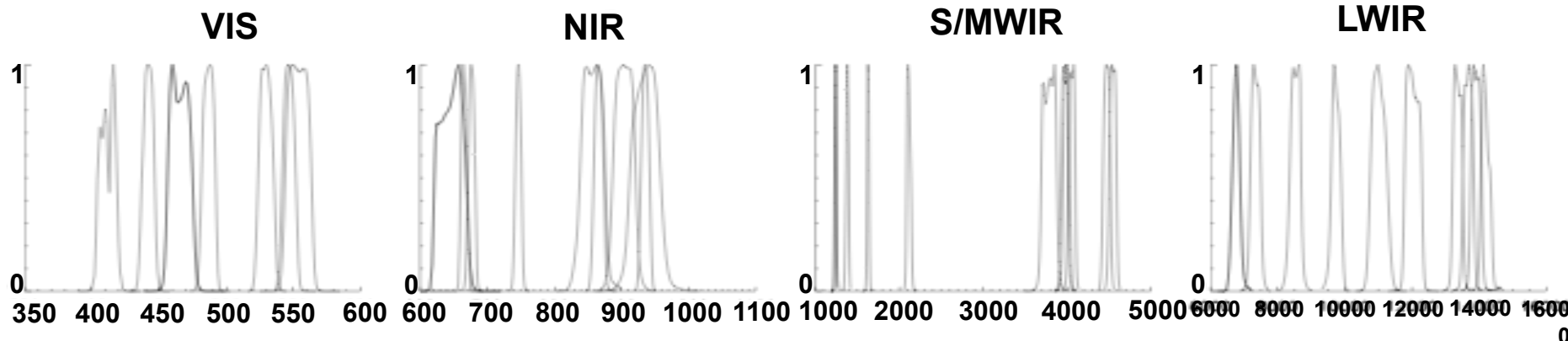
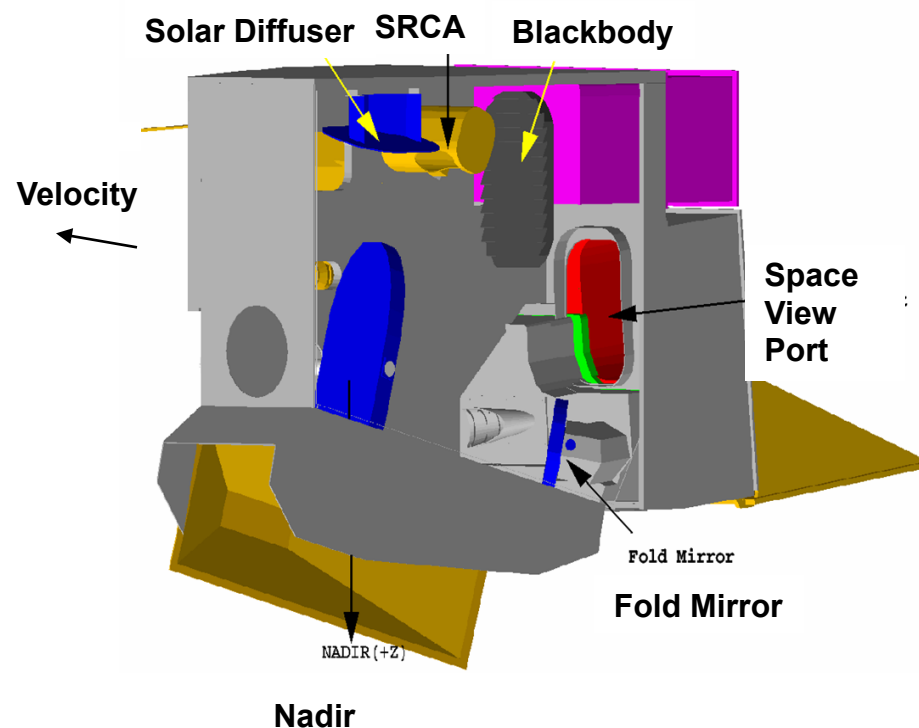
Spatial resolution: 2 bands @ 250 m; 5 @ 500 m; 29 @ 1000 m

Major differences:

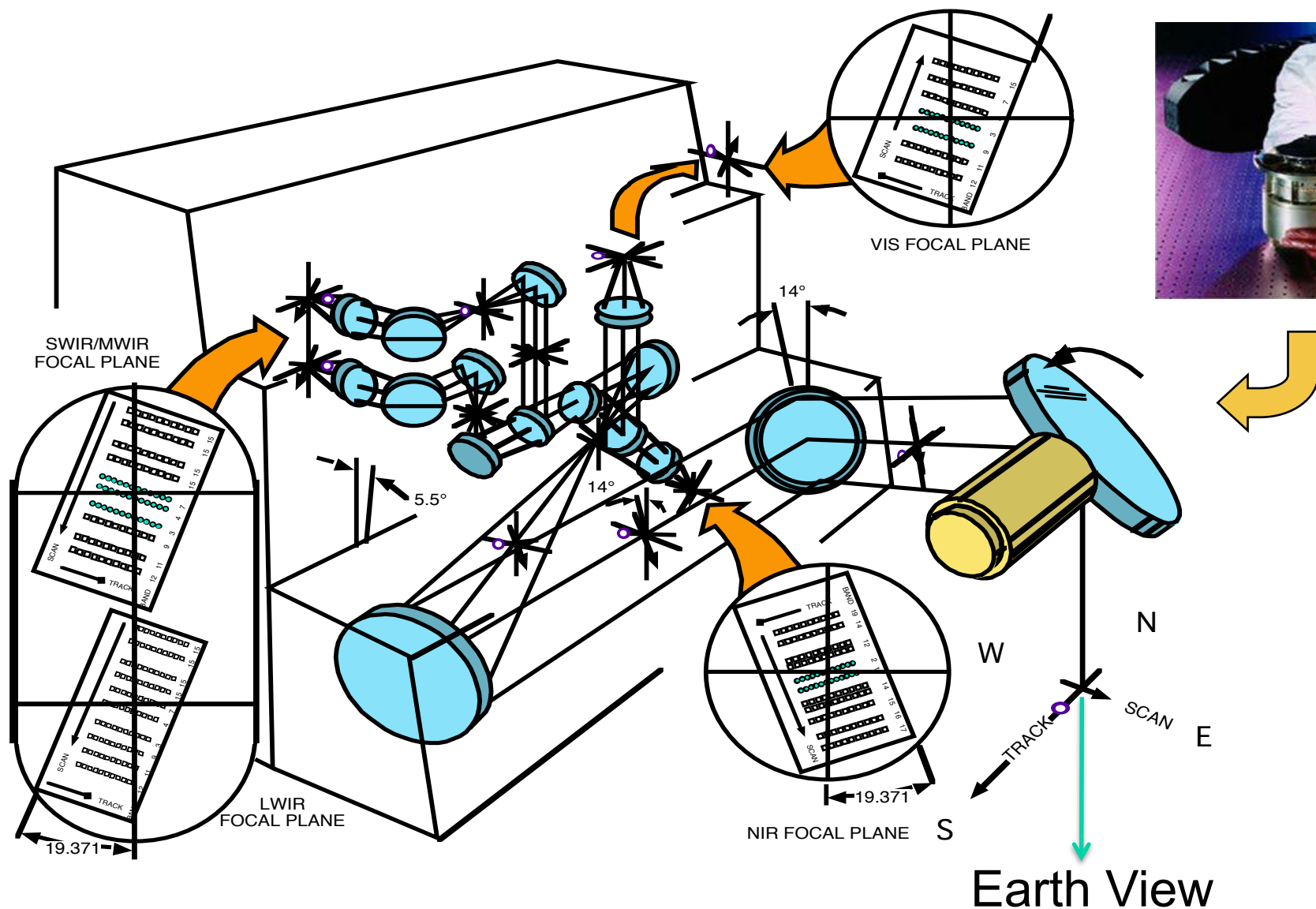
- Many spectral bands (490 detectors)
- Multiple samples along track on each earth scan
- Higher spatial resolution
- On-orbit radiometric, spatial, and spectral calibration
- Improved radiometric accuracy and precision (12-bit)
- Improved geolocation accuracy
- Higher data rate requiring X-band direct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

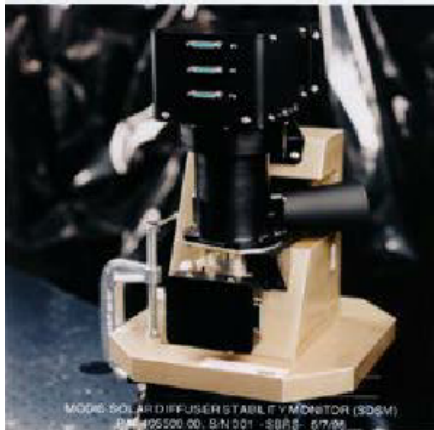


MODIS On-board Calibrators

SD



SDSM

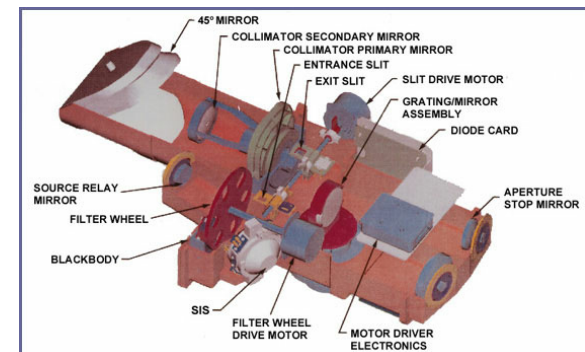


- **SD** – Solar Diffuser for RSB calibration, SD BRDF determined from pre-launch, referenced to a transfer standard calibrated at NIST
- **SDSM** – Solar Diffuser Stability Monitor for tracking SD degradation
- **BB** – Blackbody (12 thermistors reference to NIST standard) for TEB calibration. Emissivity 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

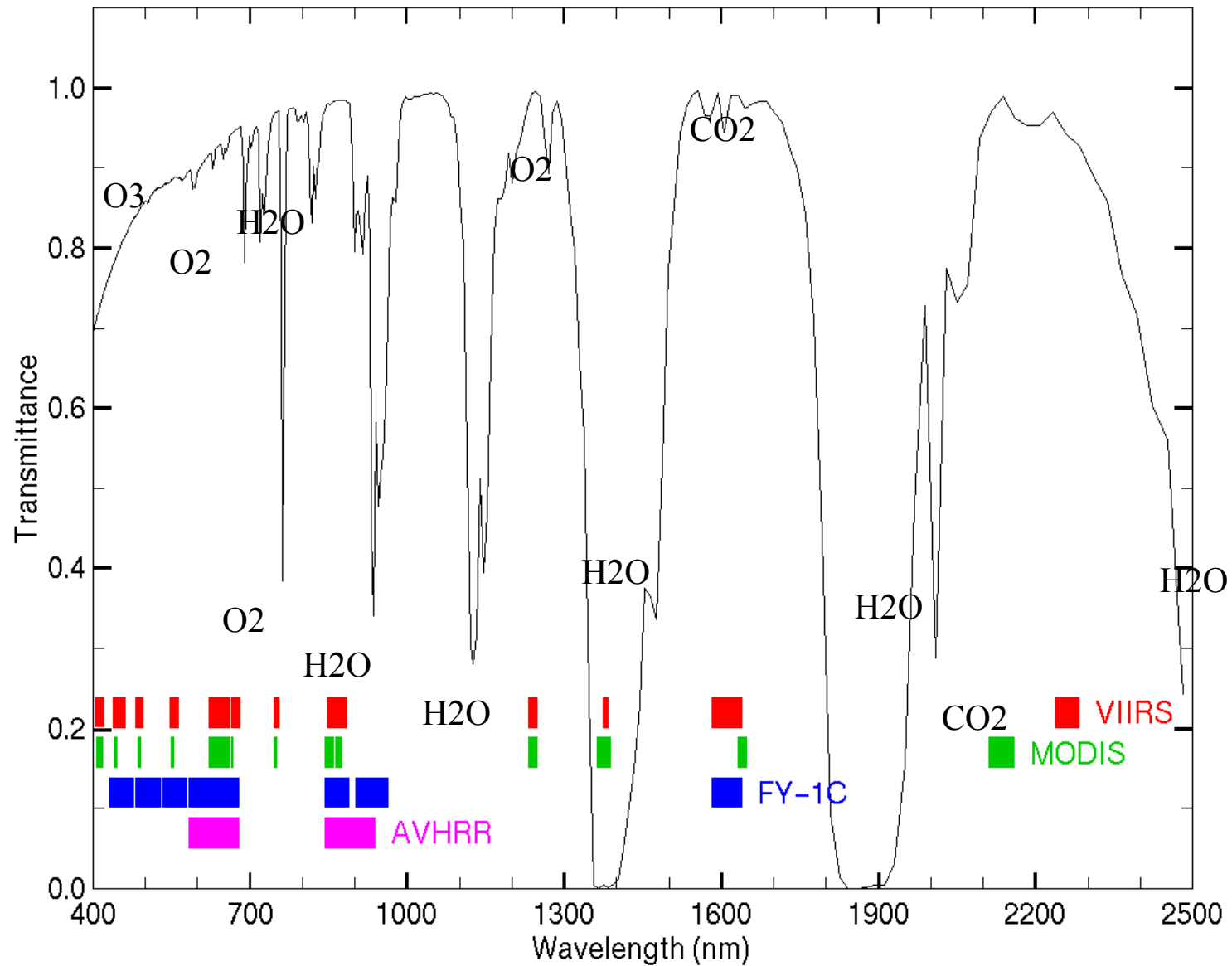
MODIS Reflected Solar Bands

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			

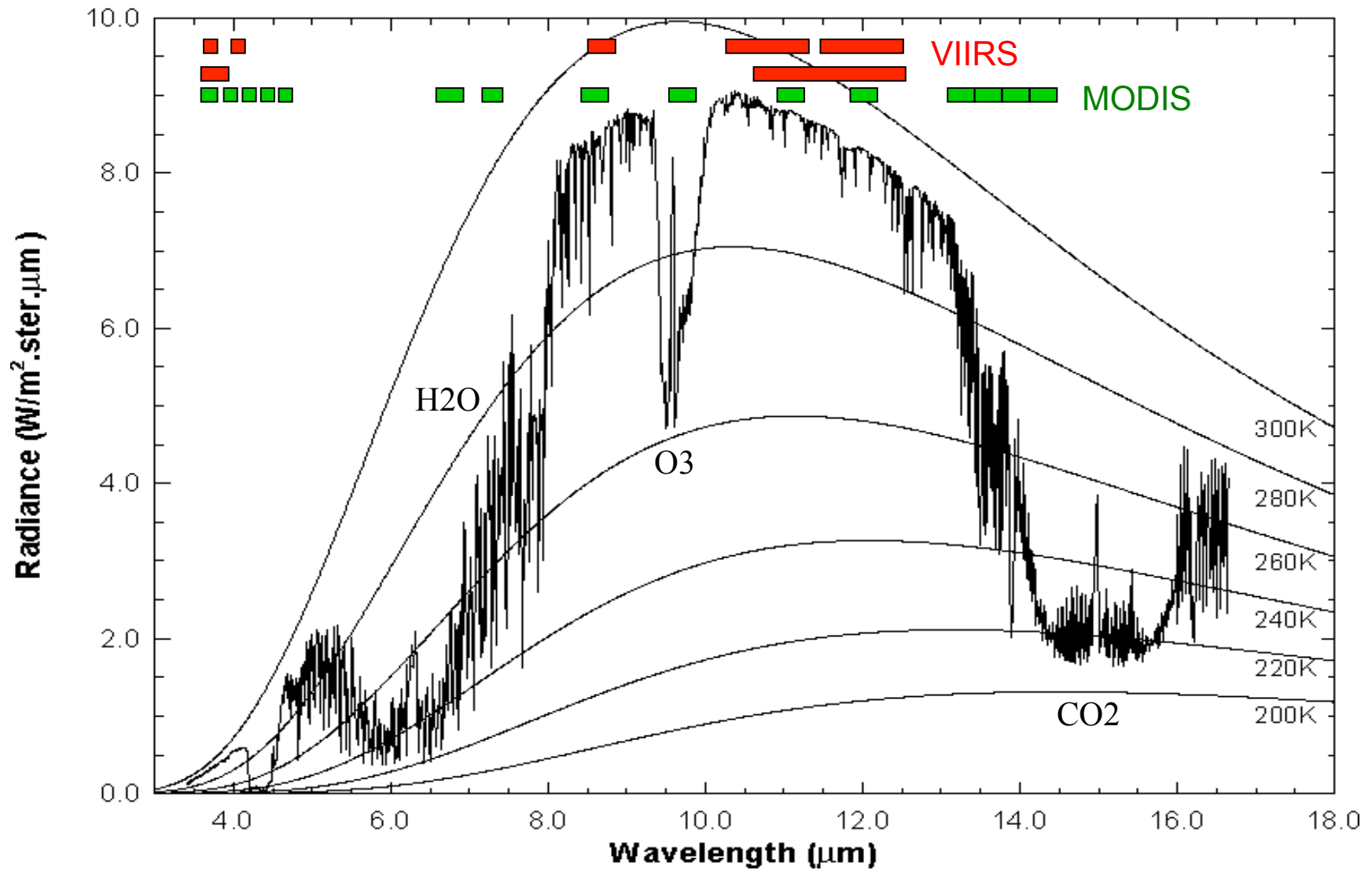
MODIS Thermal Emissive Bands

Primary Atmospheric Application	Band	Bandwidth ¹	T _{typical} (K)	Radiance ² at T _{typical}	NE ^Δ T (K) Specification	NE ^Δ 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

Visible/Near-Infrared Transmittance Spectrum



Thermal Infrared Absorption Spectrum



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

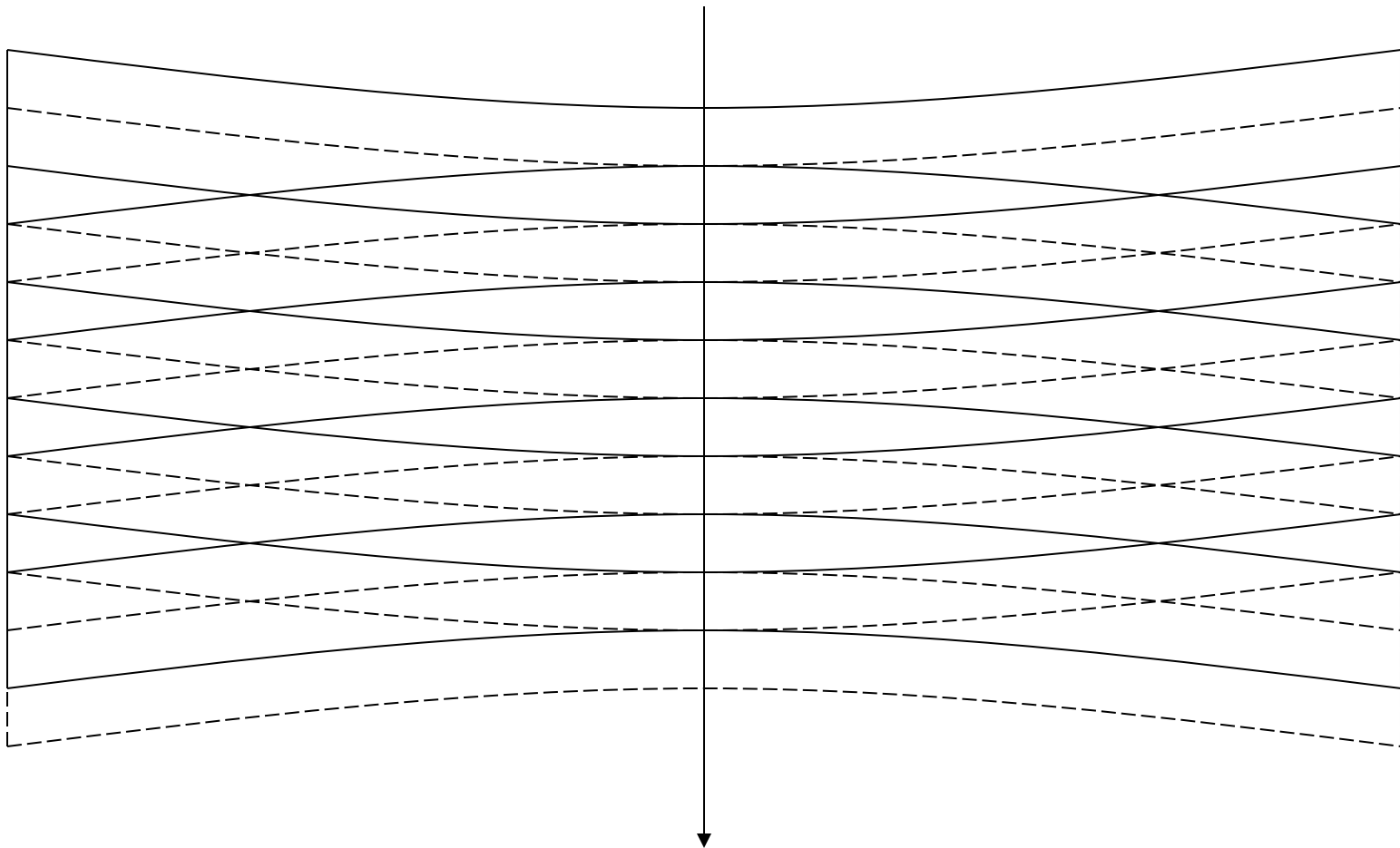
Scan rate: 1.477 scans/sec

Scan angle: +/- 55 degrees

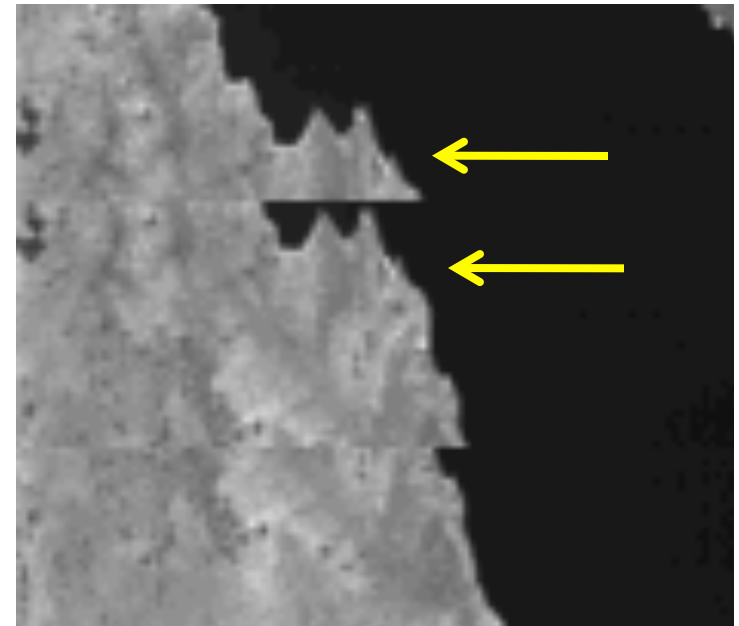
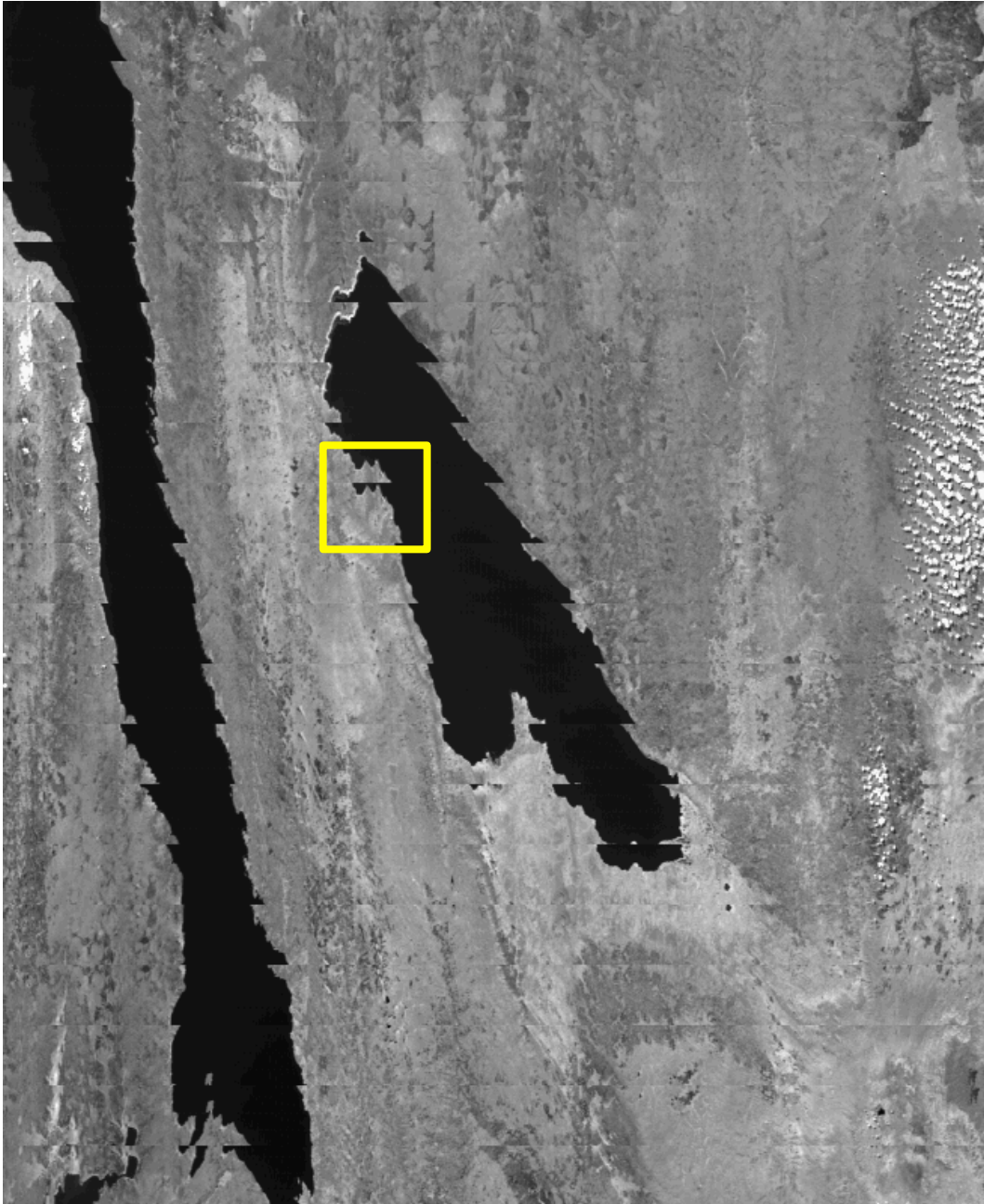
Swath width: 2330 km across track, 10 km along track

MODIS Bowtie

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



MODIS bowtie artifacts at edge of swath



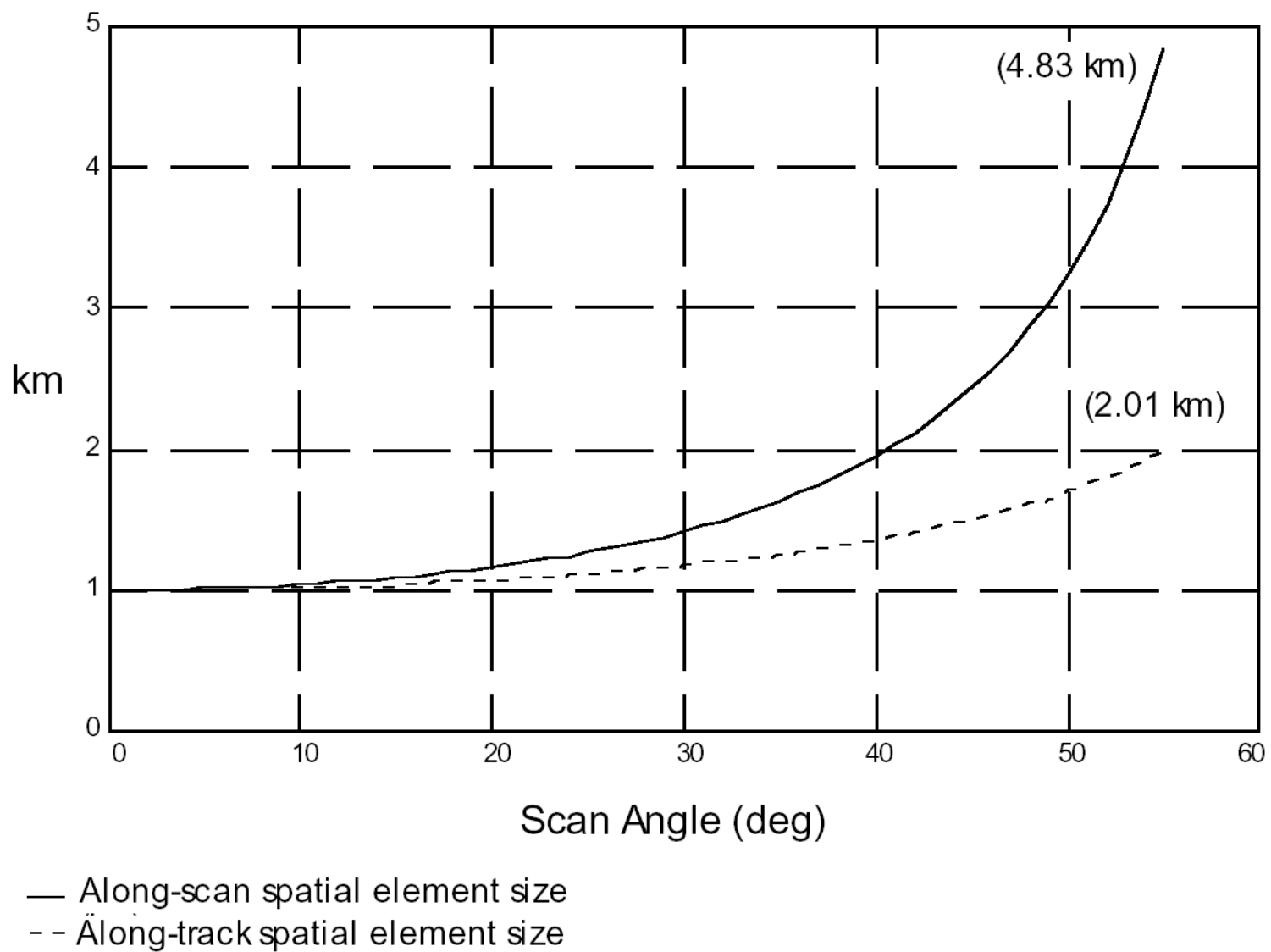
Band 2 (0.87 micron)

250 meter resolution

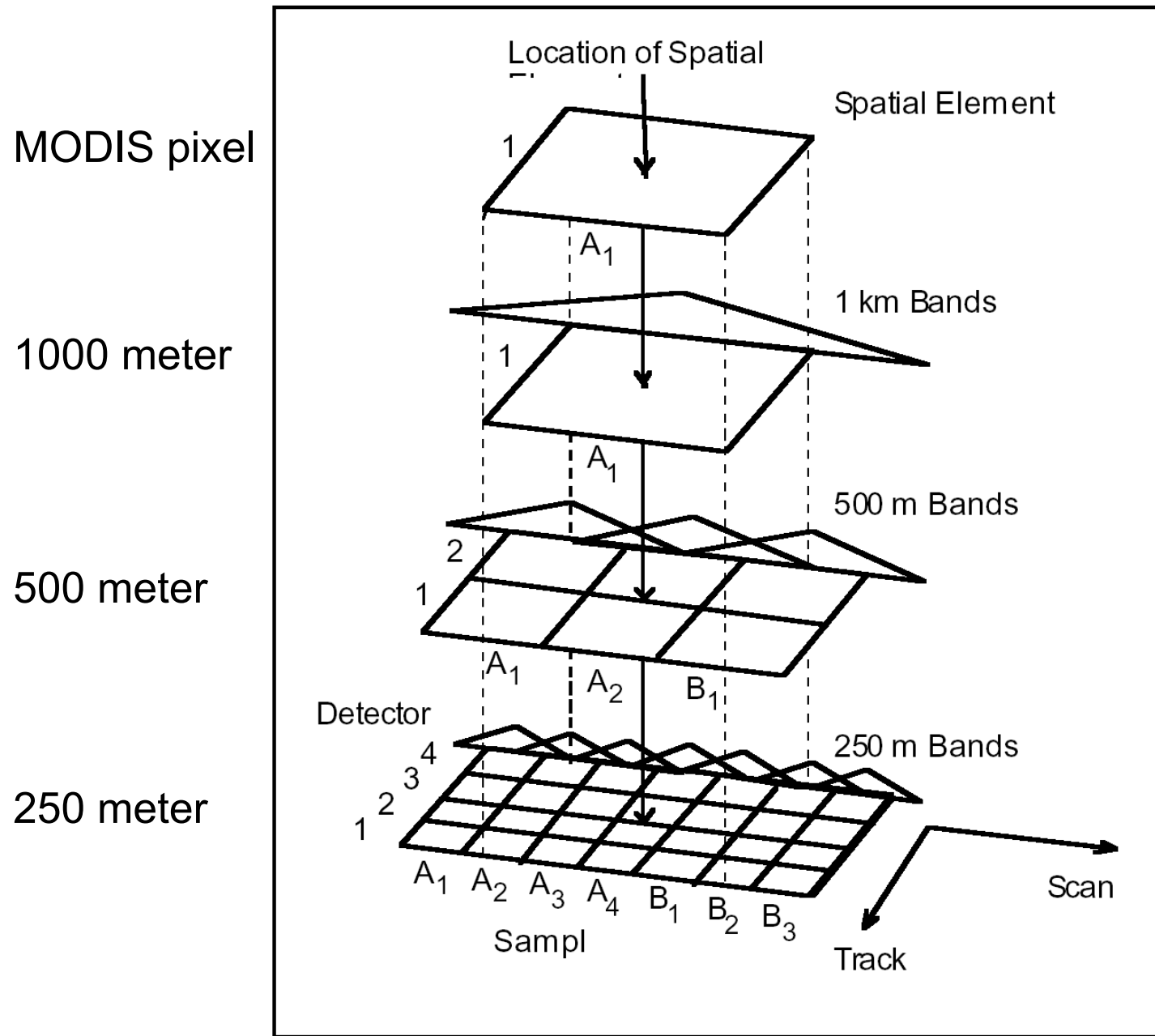
Bowtie Artifacts

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. Are also present on next generation of operational polar orbiting imagers (VIIRS on NPP/JPSS-1)

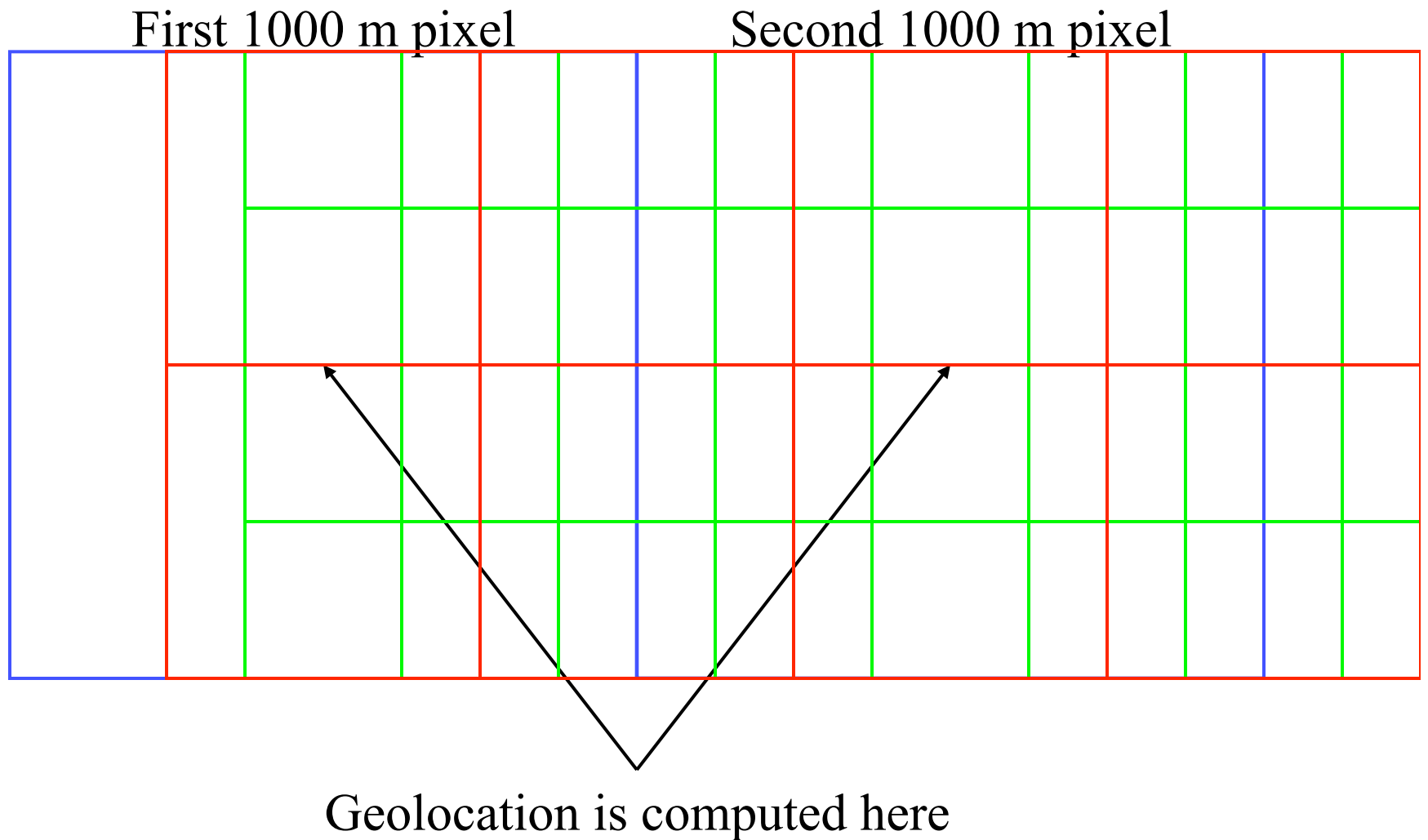
Growth of MODIS 1 km pixel with scan angle



Inter-band Registration



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

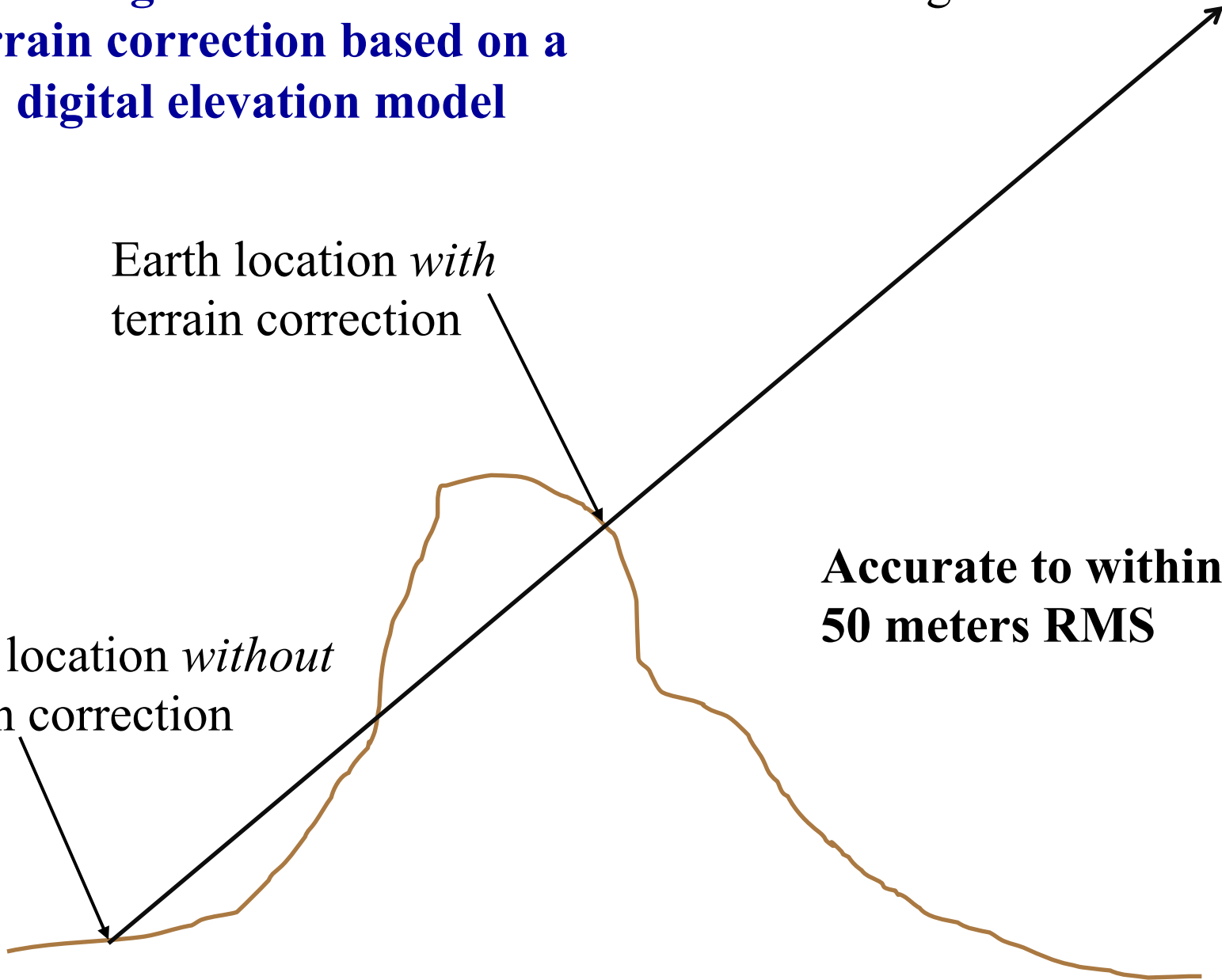
**MODIS geolocation includes
terrain correction based on a
digital elevation model**

Line of sight to sensor

Earth location *with*
terrain correction

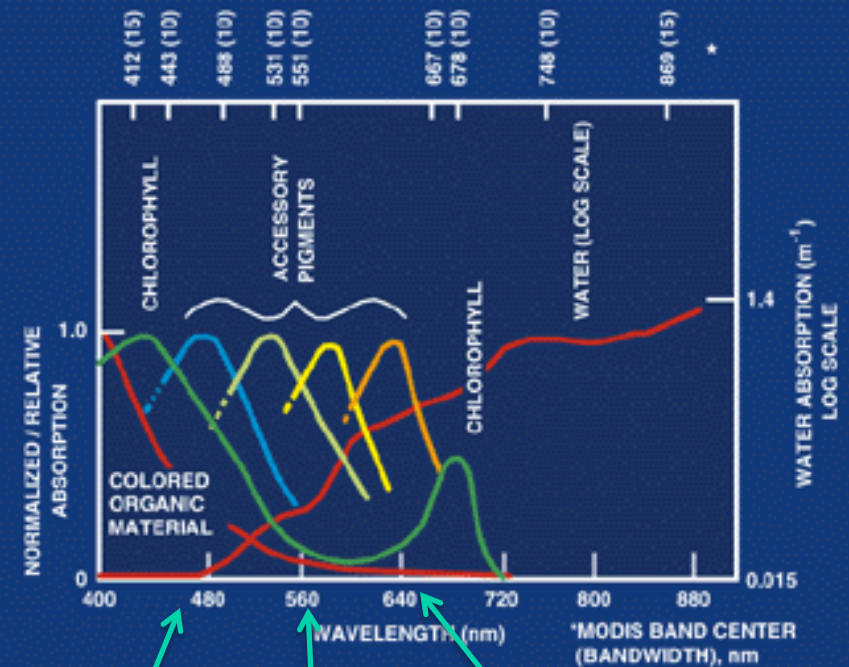
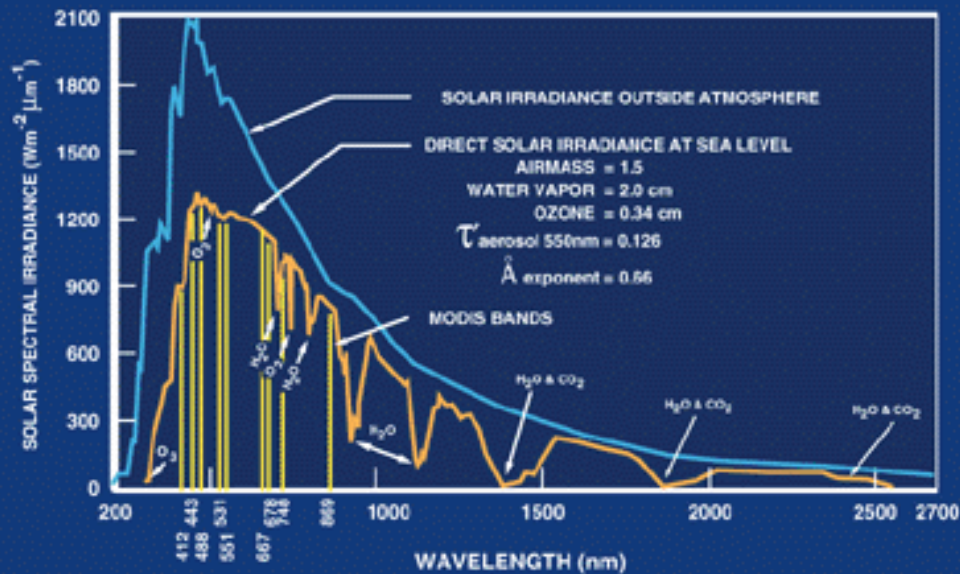
Earth location *without*
terrain correction

**Accurate to within
50 meters RMS**



MODIS Ocean Applications

OCEAN-SOLAR RADIATION

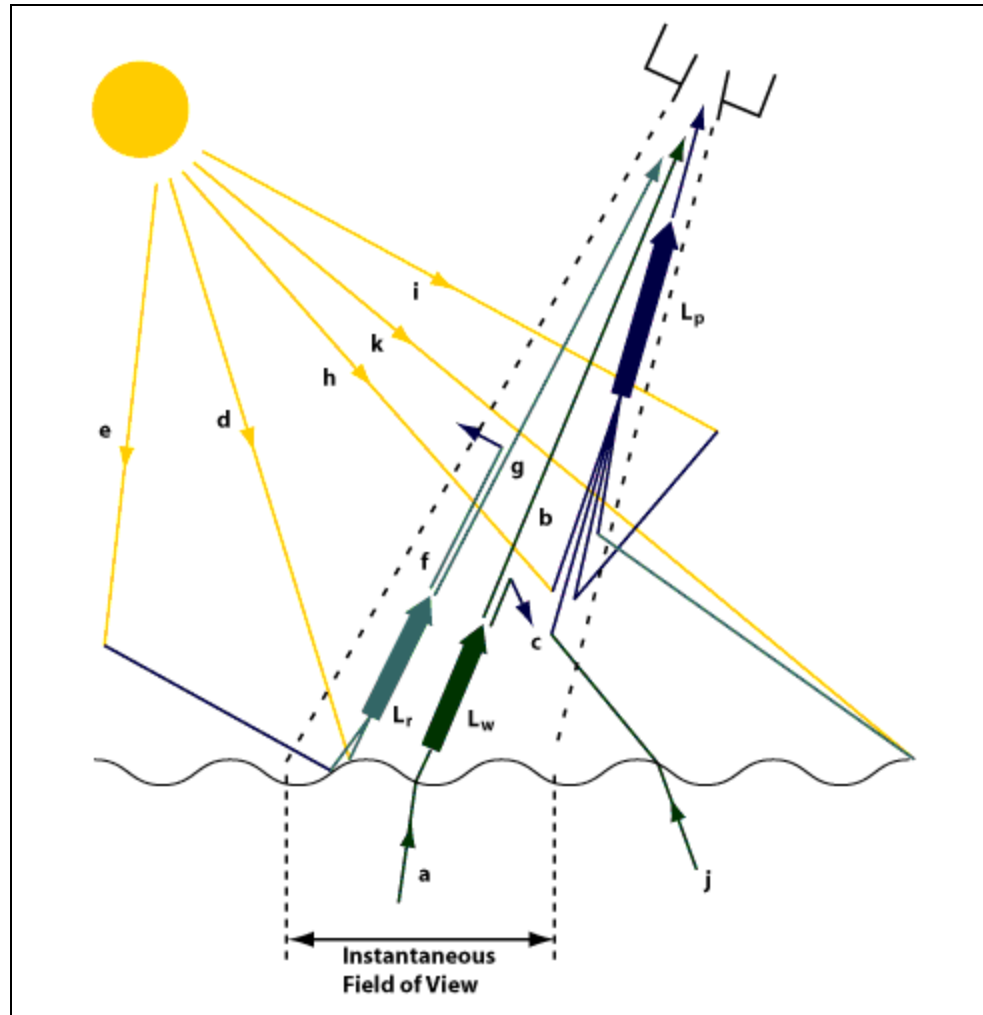


Blue

Green

Red

Atmospheric correction is critical for ocean color



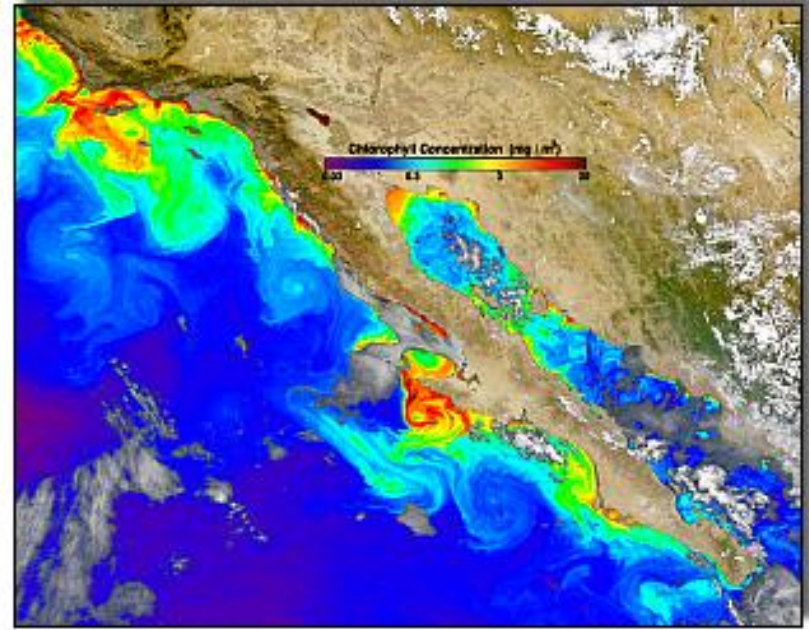
L_w – only 5% of signal reaching satellite: rest due to L_p

L_p components: molecular (Rayleigh) & aerosols

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)

Chlorophyll



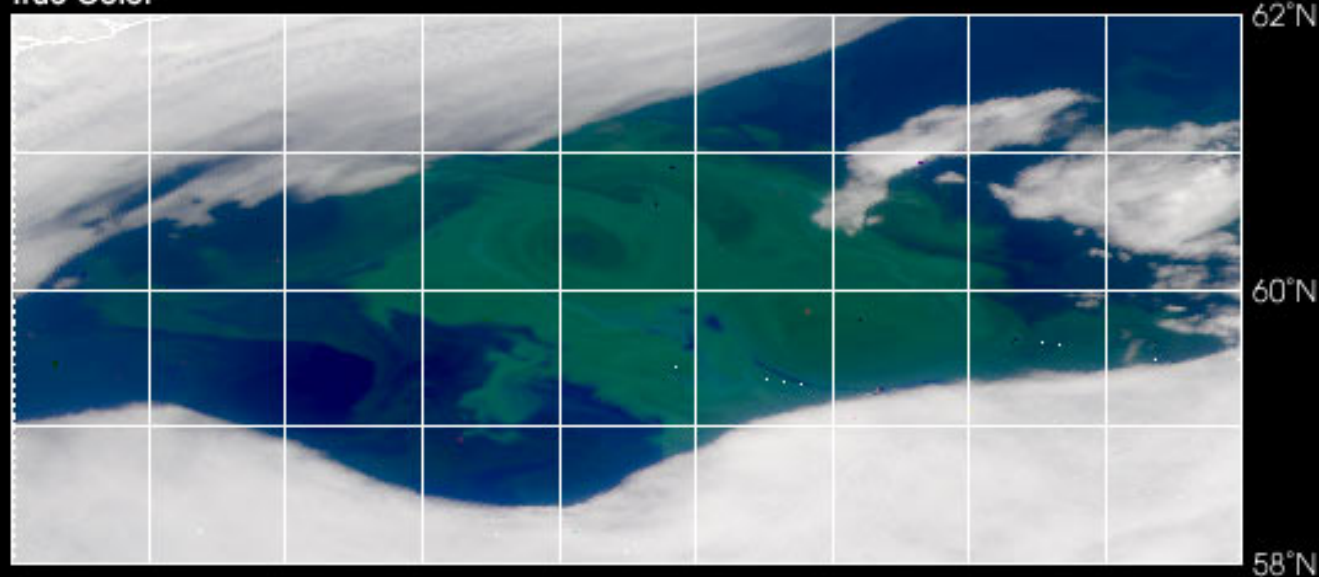
August 10, 2003

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

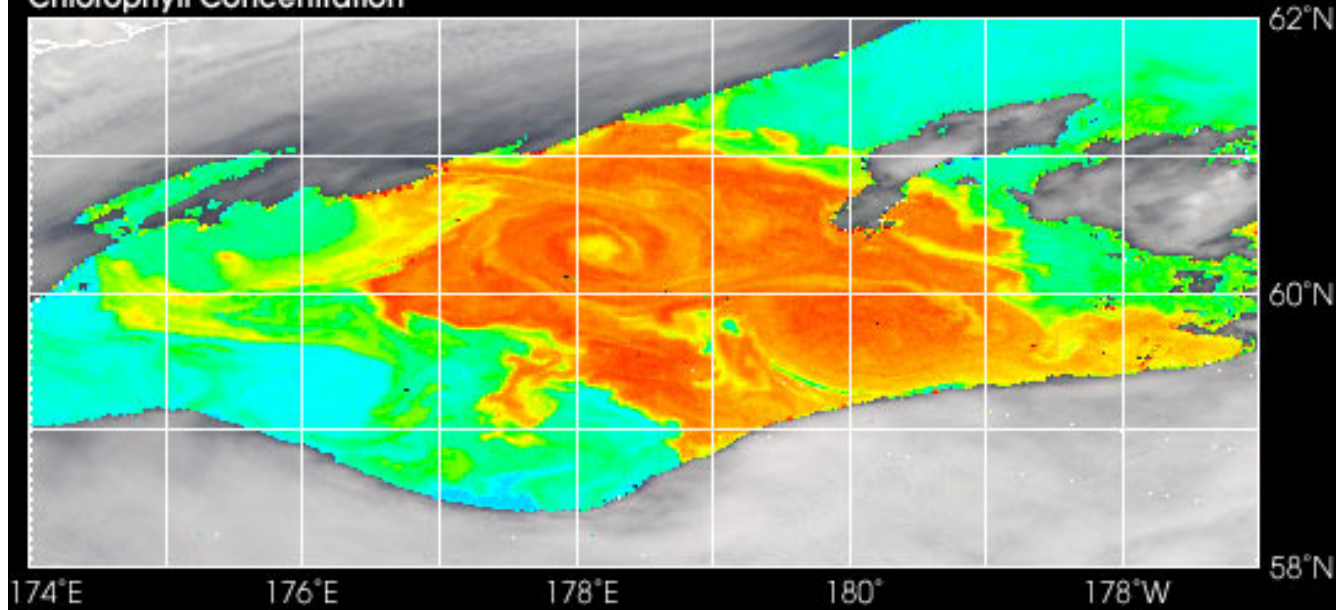
Dominant band shifts from blue to green with increasing chlorophyll concentration.

Index of the change in spectral shape \Rightarrow chlorophyll

True Color



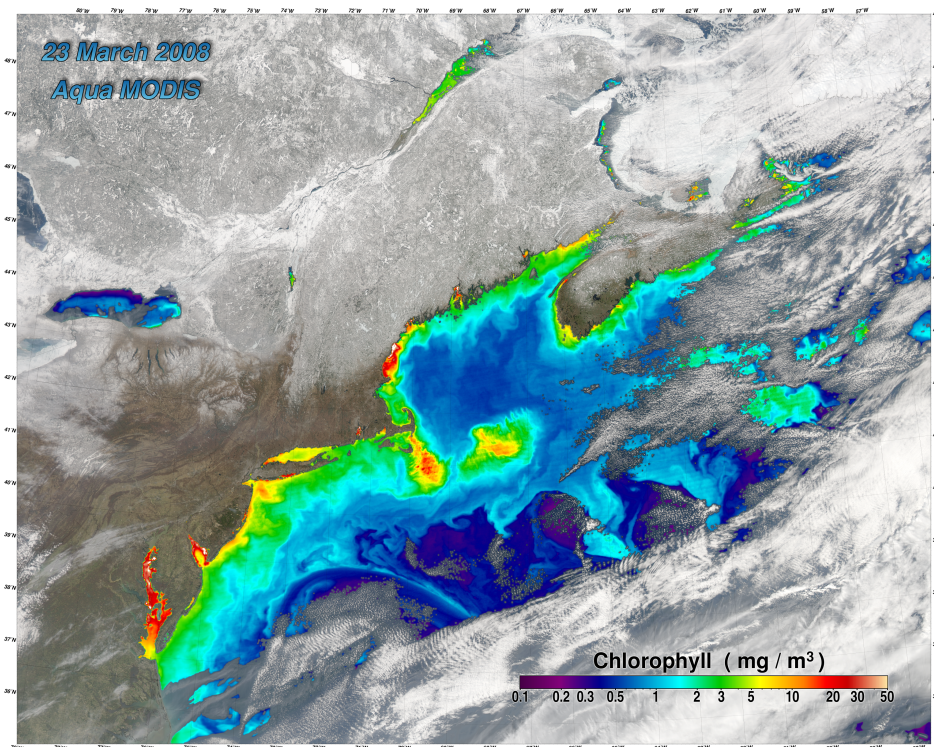
Chlorophyll Concentration



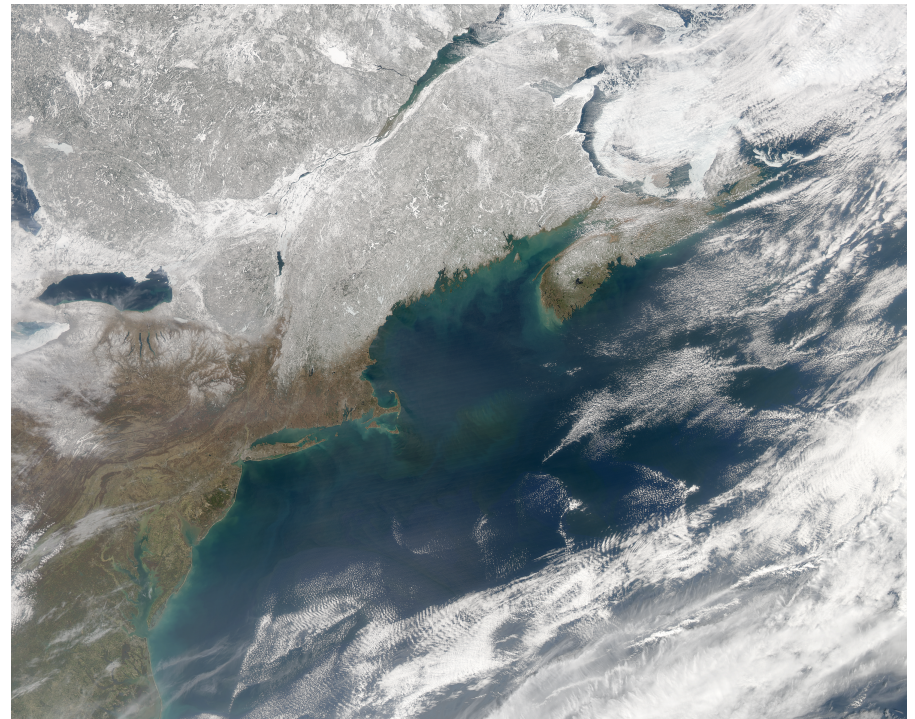
Chlorophyll Concentration (mg/m^3)



March 23, 2008 MODIS Aqua Northeast USA and Canada

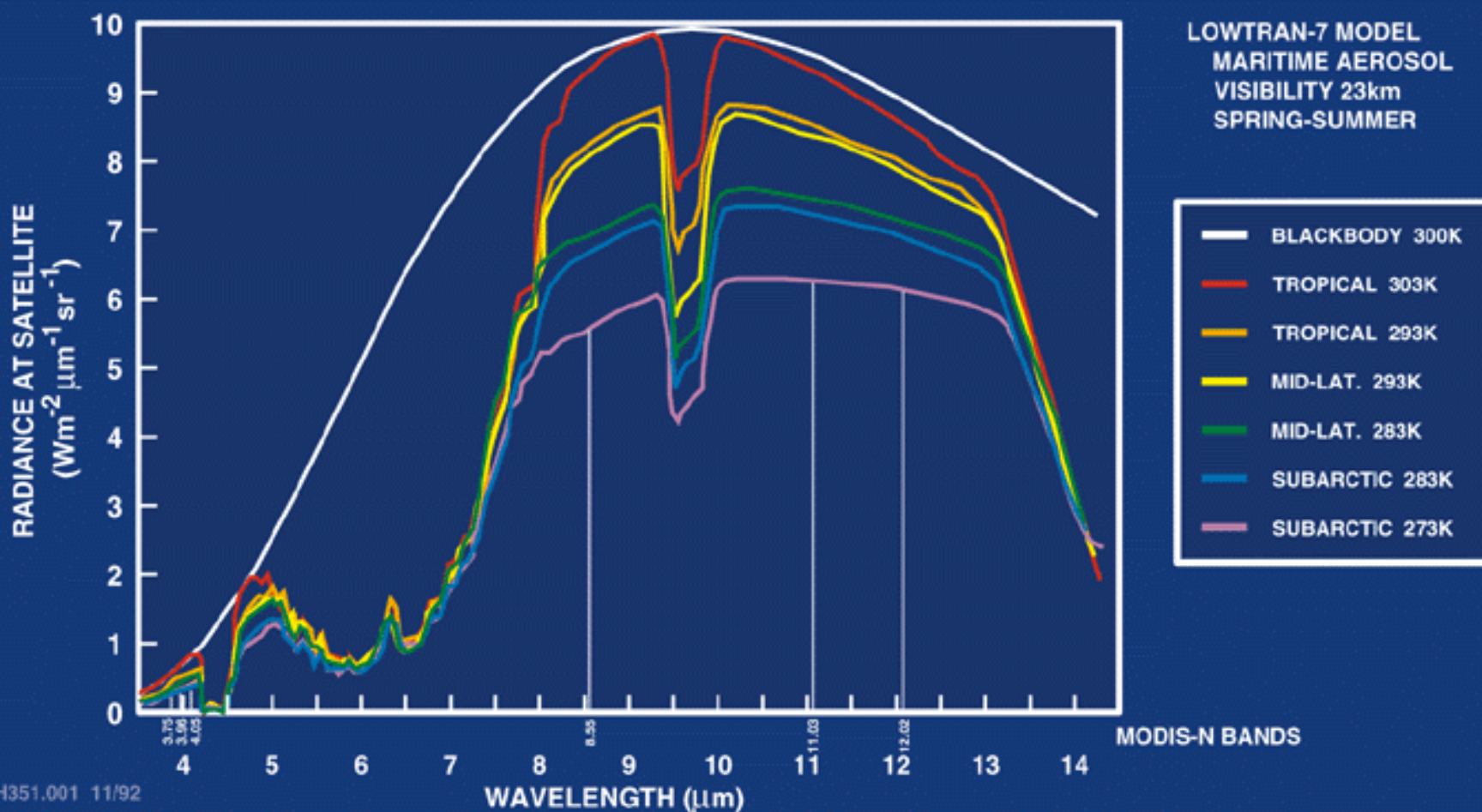


Chlorophyll concentration

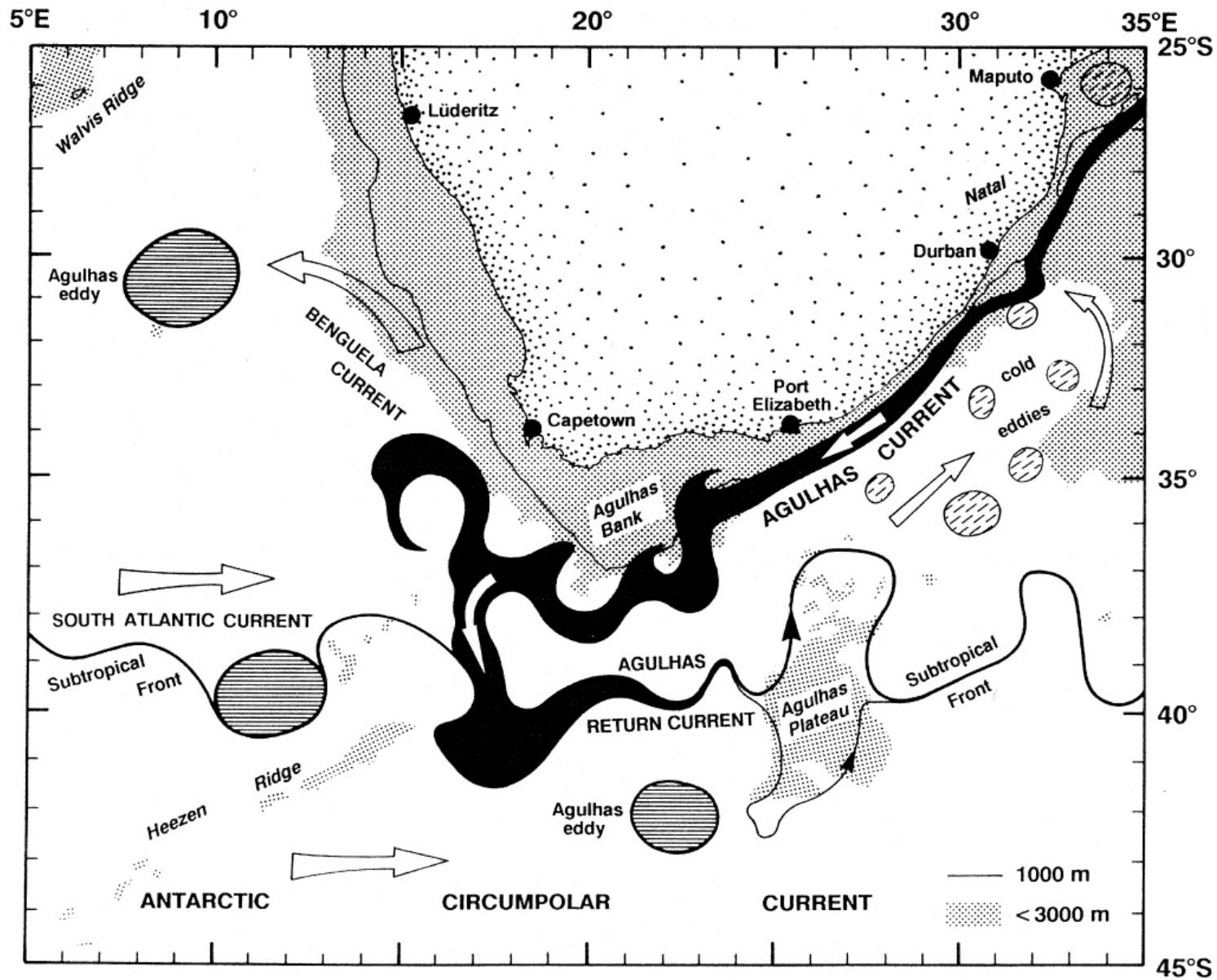


True color

MODIS SEA SURFACE TEMPERATURE

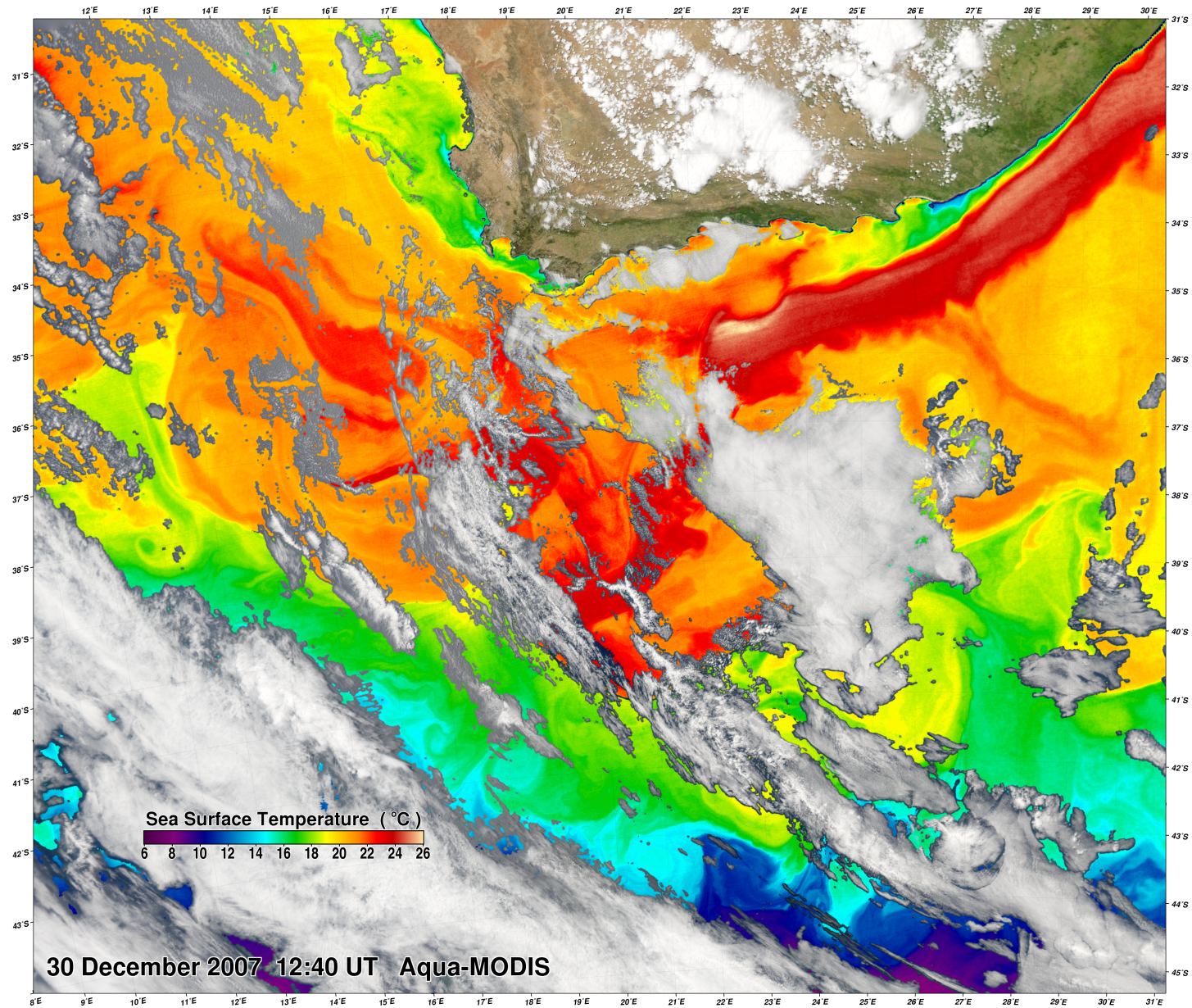


Ocean currents near Southern Africa

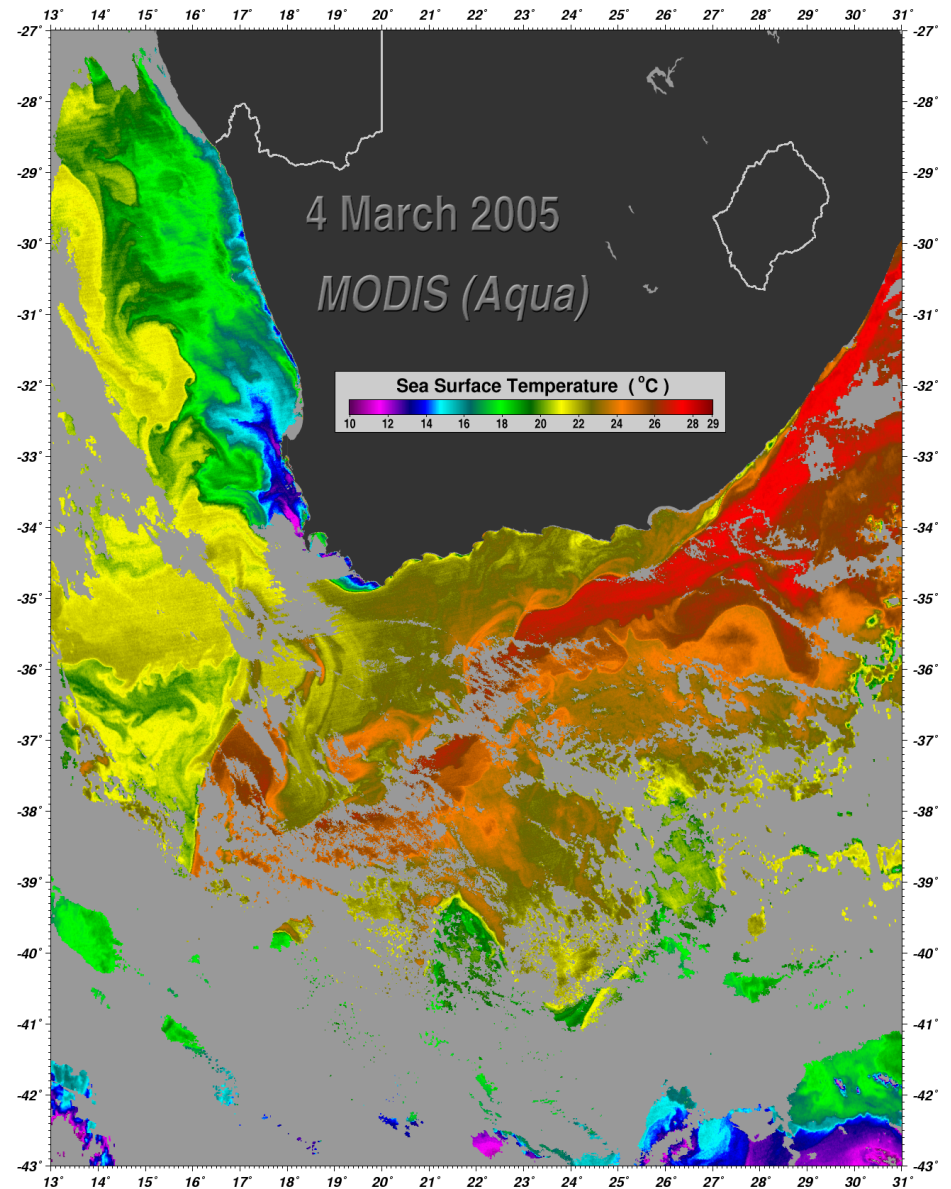
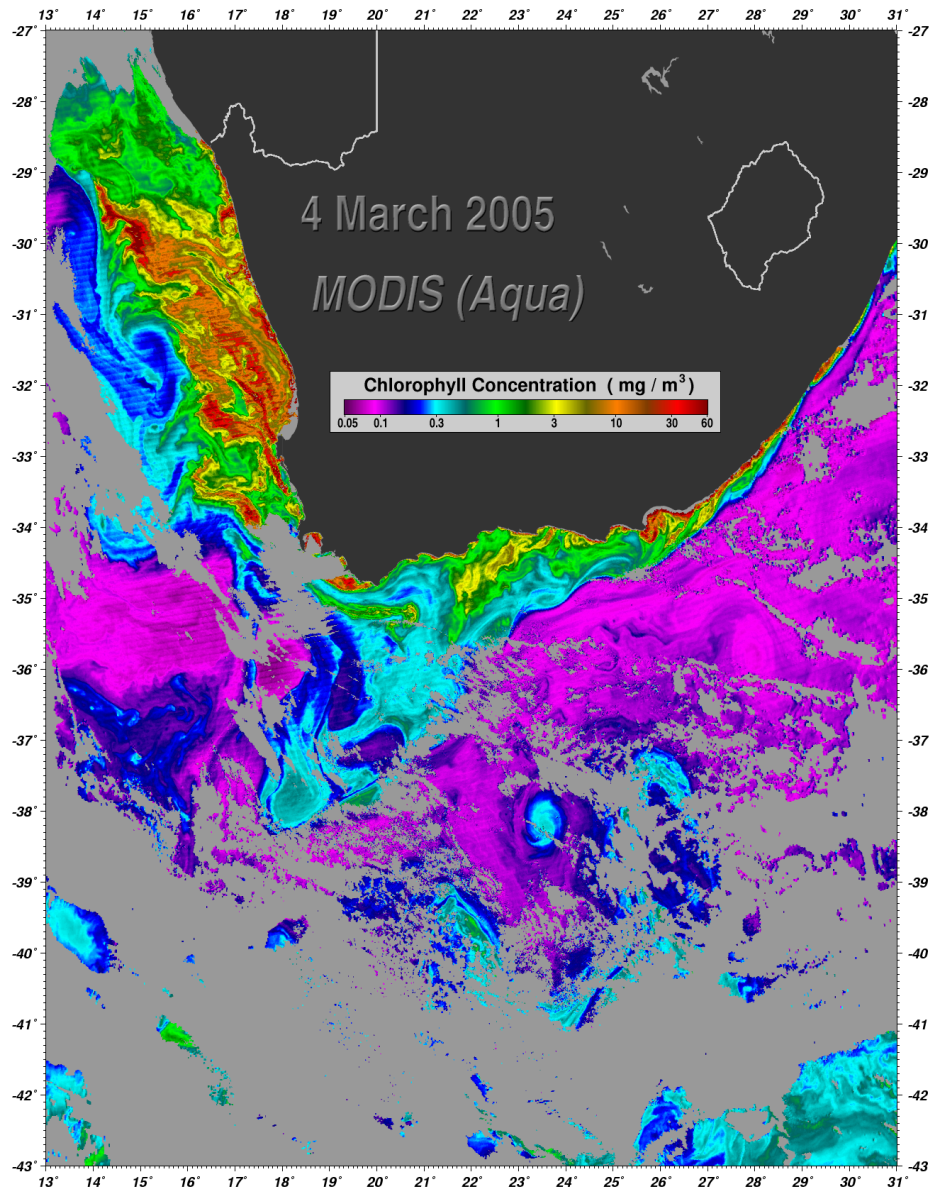


Peterson and Stramma, 1991

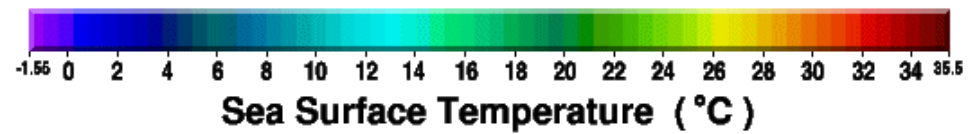
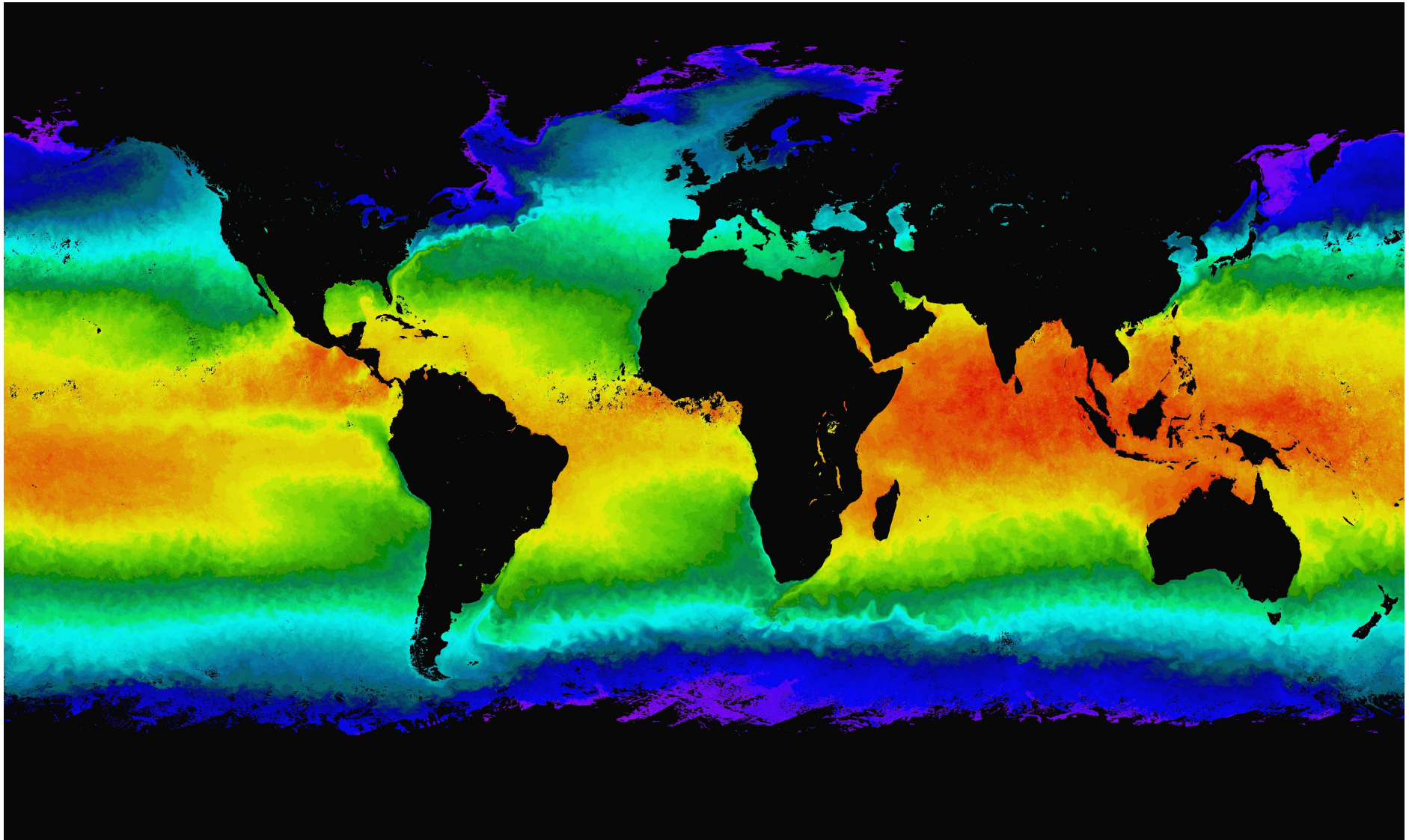
Agulhas & Benguela Currents



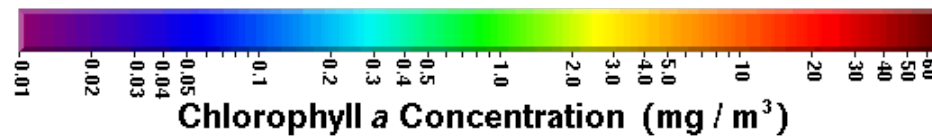
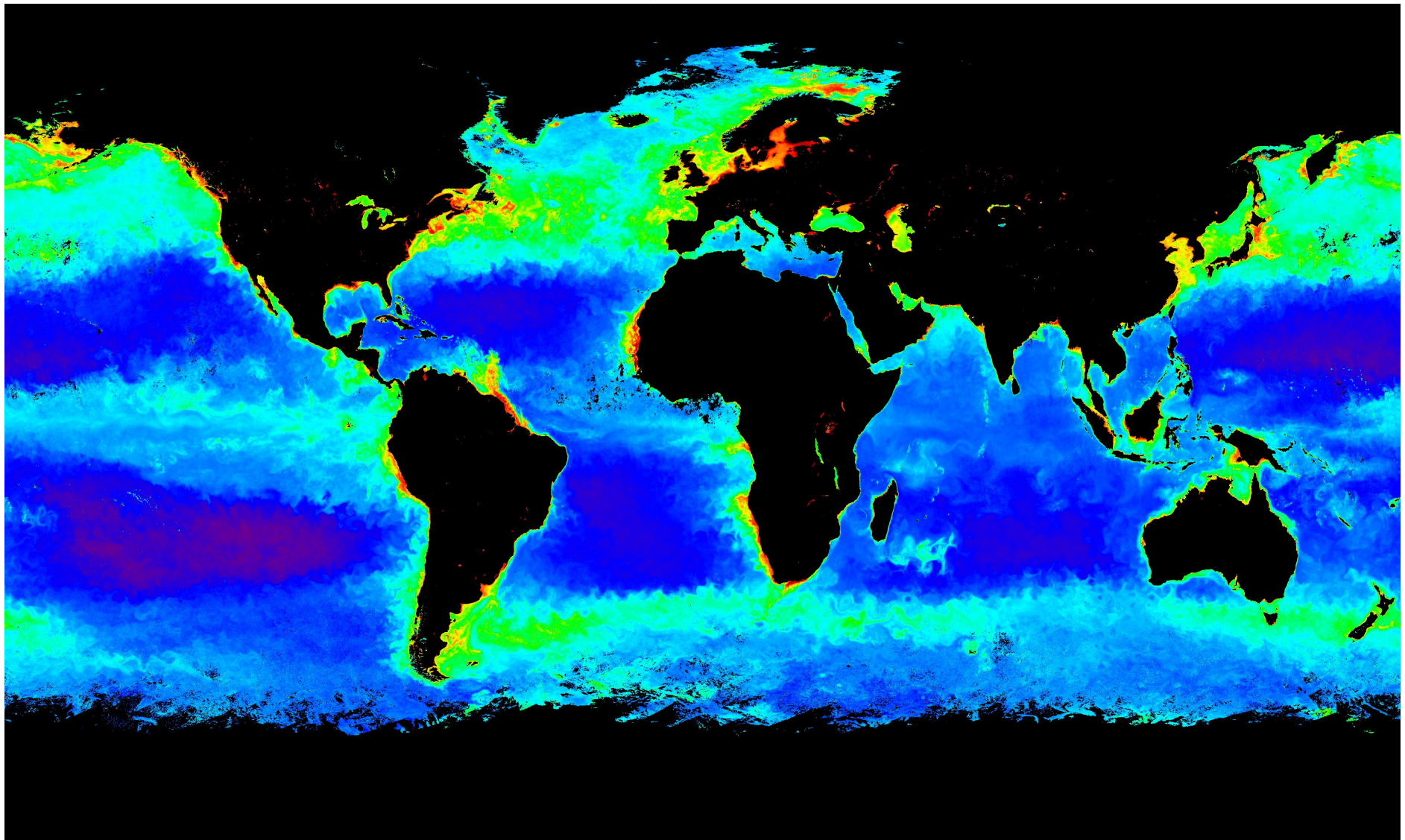
Agulhas & Benguela Currents

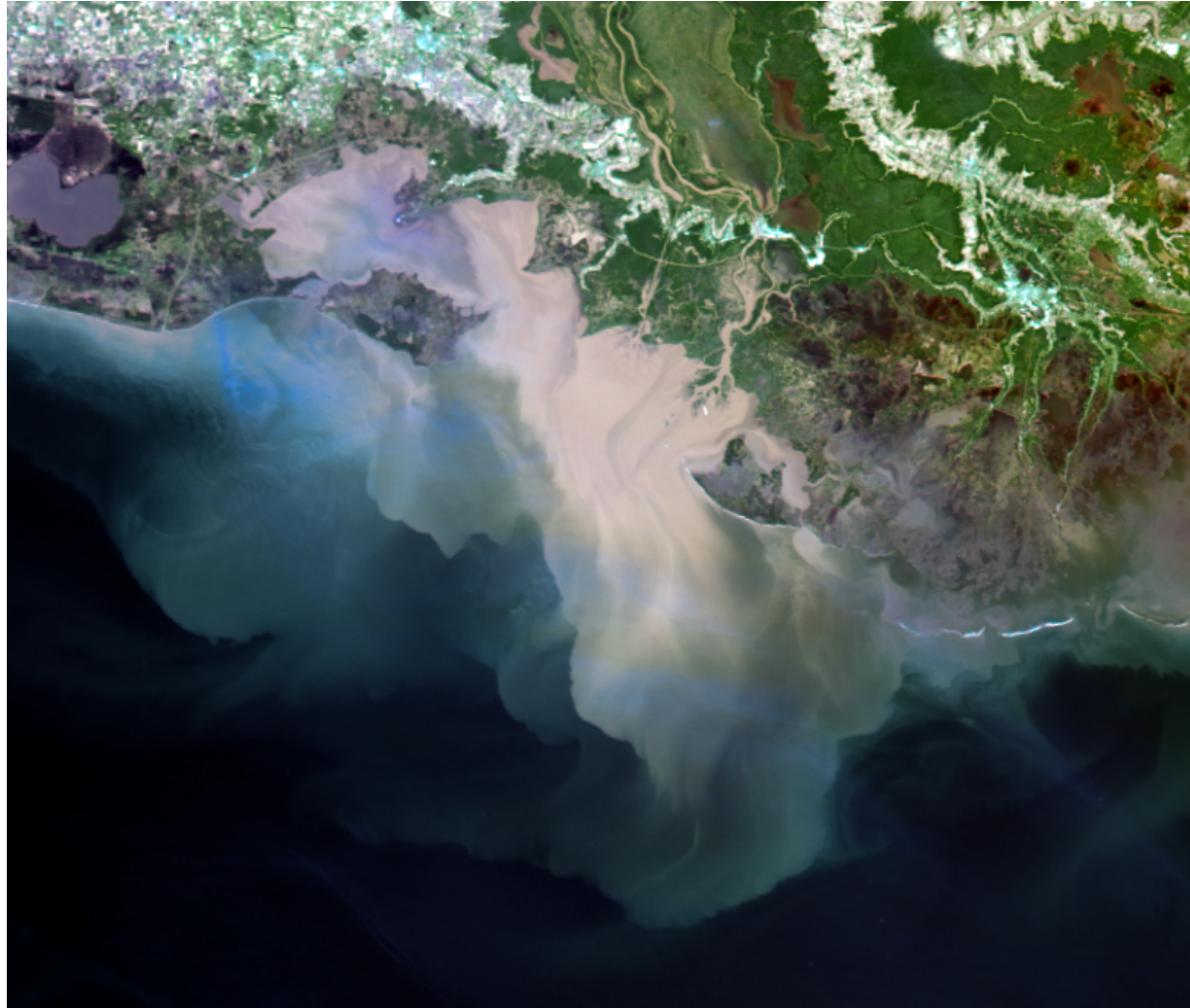


Aqua MODIS Sea Surface Temperature, April 2004



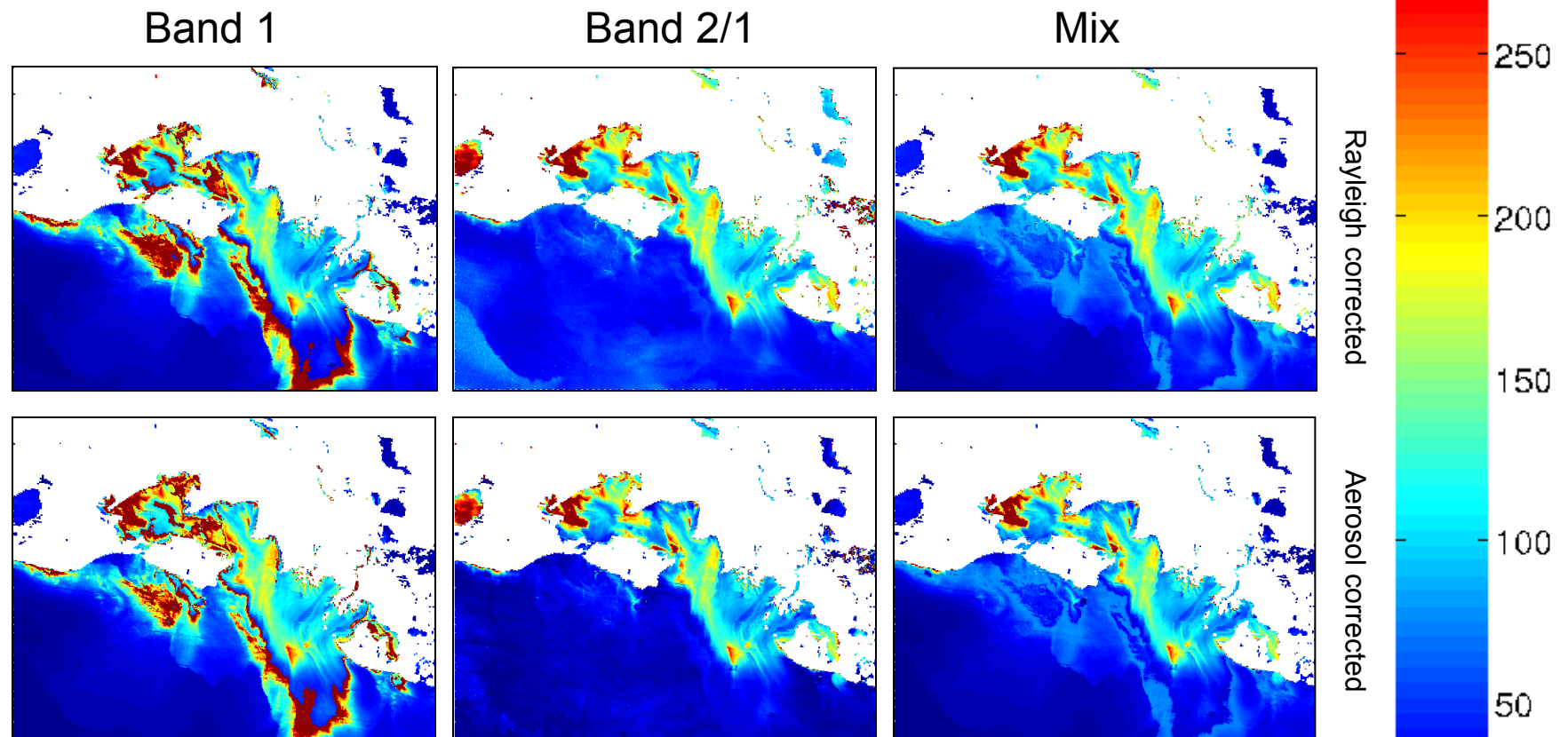
Aqua MODIS Chlorophyll Concentration, April 2004





MODIS Terra true color image of the Atchafalaya Bay region of the Gulf Coast for 21st March, 2001.

Suspended Sediment Concentration



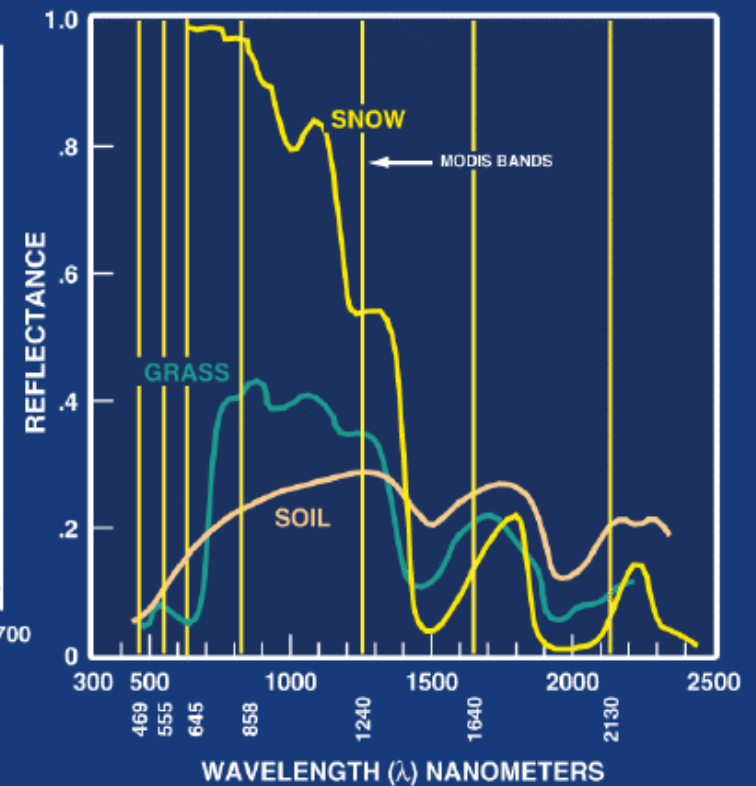
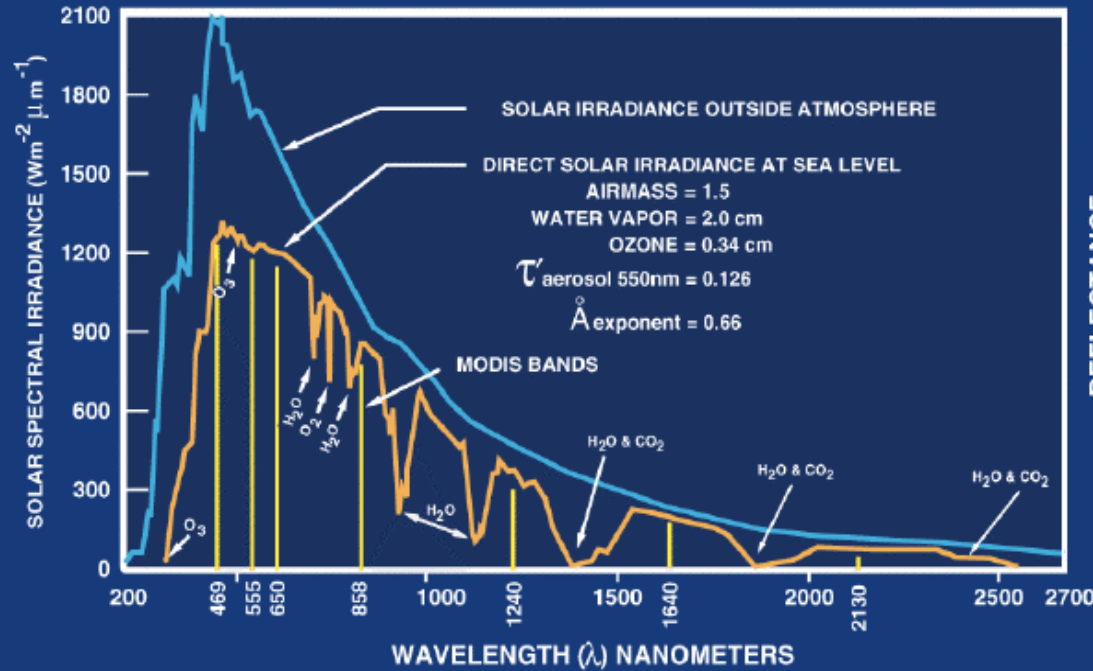
Suspended sediment concentration from $R_{rs}(1)$, from $R_{rs}(2)/R_{rs}(1)$ and from a weighted mix of these. The upper panels give the retrieved SSC for a Rayleigh only atmospheric correction, the lower panels are for an Aerosol + Rayleigh correction. The Band 2/1 ratio method is less sensitive to the atmospheric correction and is applied where high sediment concentrations cause the band 1 method to lose precision. The weighted mix is one approach to fix this.

MODIS Land/Surface Applications

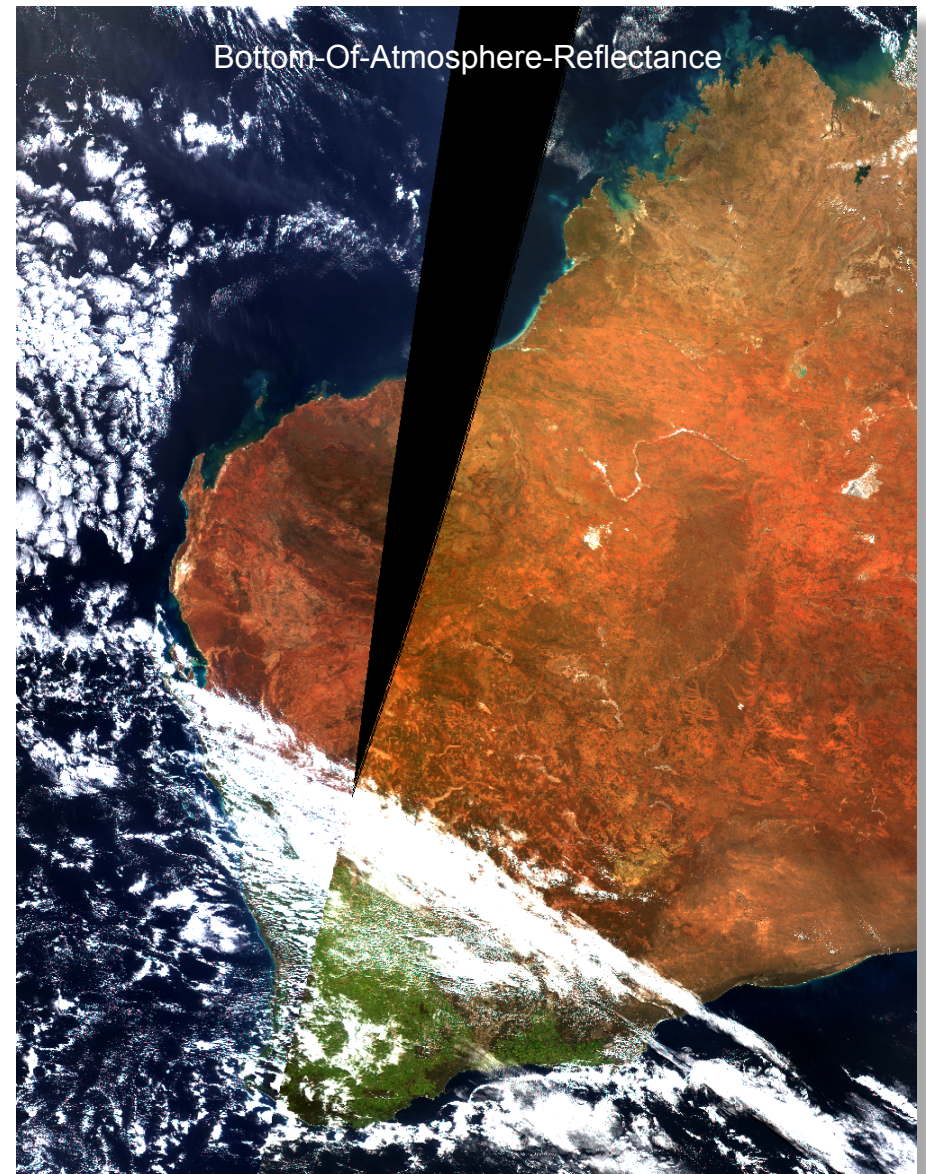
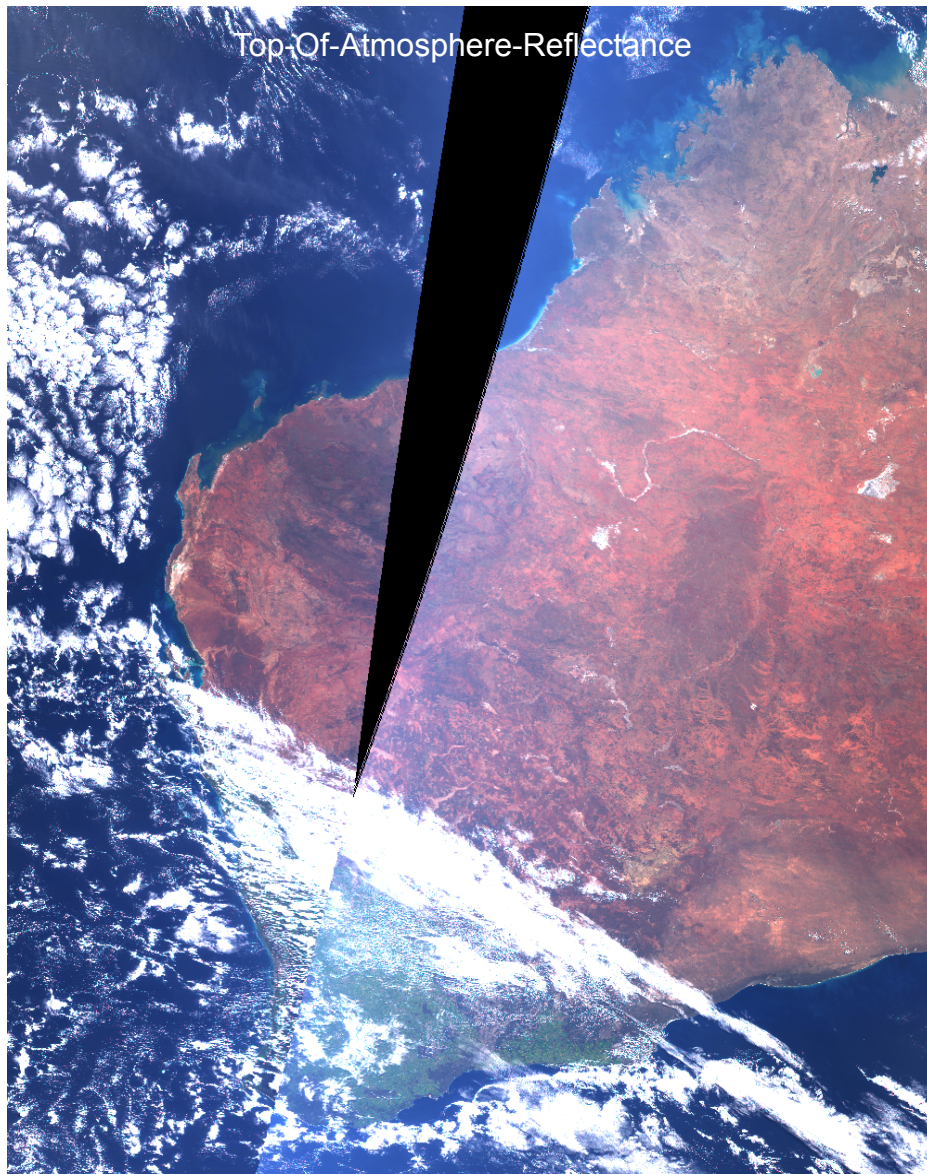
MODIS Land Products

- MOD 09 - Land 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 - Nadir BRDF Adjusted Reflectance
- MOD 44 - Vegetation Cover Conversion

LAND-SOLAR RADIATION

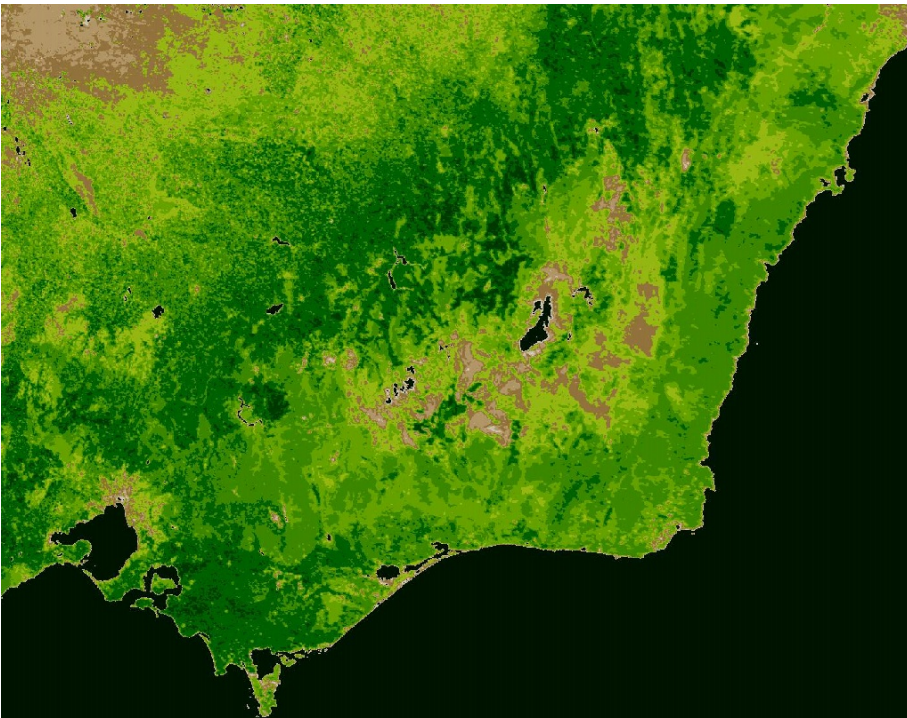


Atmospheric scattering is removed to retrieve surface properties

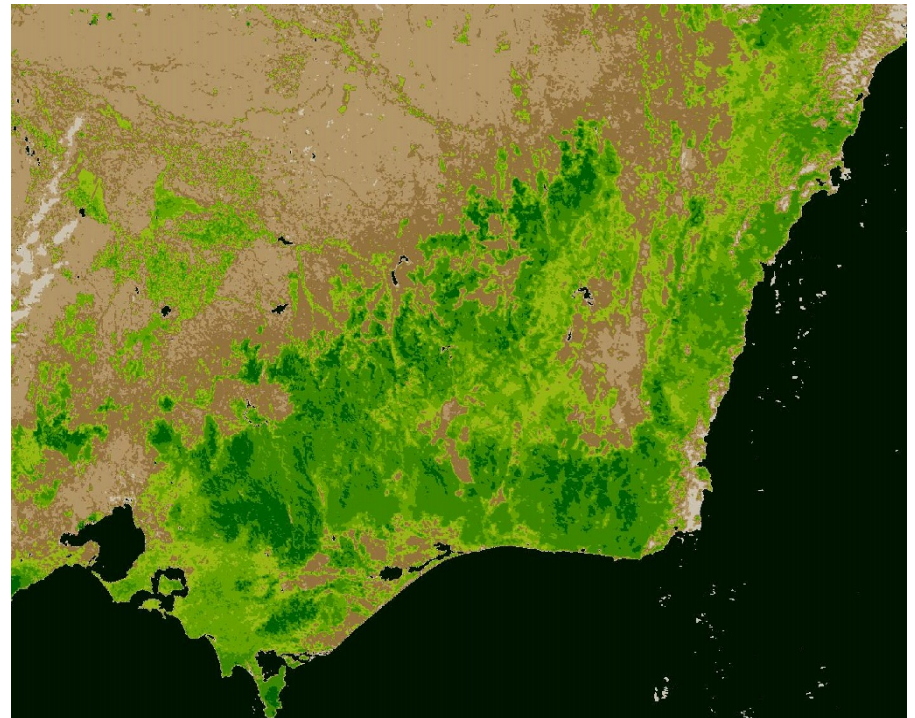


Terra MODIS 09/09/2003 01:27UTC 03:04UTC

Normalized Difference
Vegetation Index
South East Australia

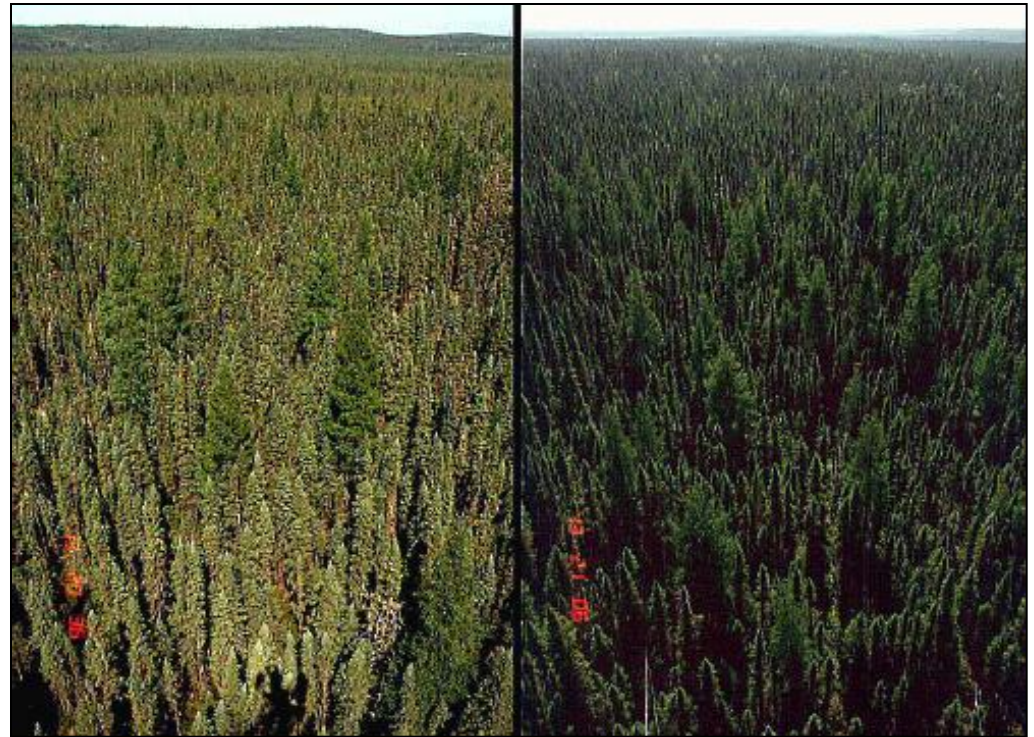
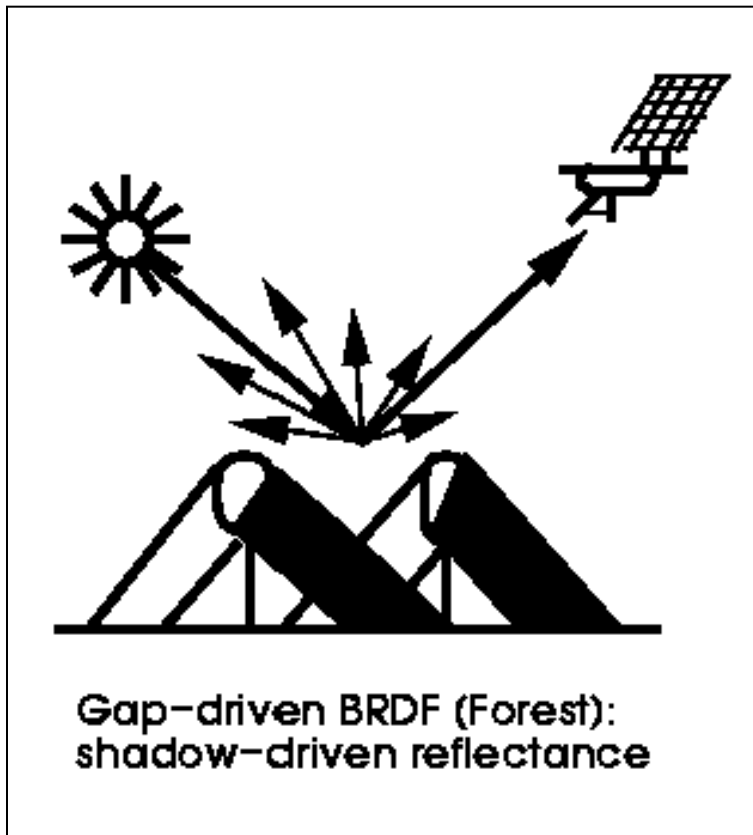


Nov 2003
Spring



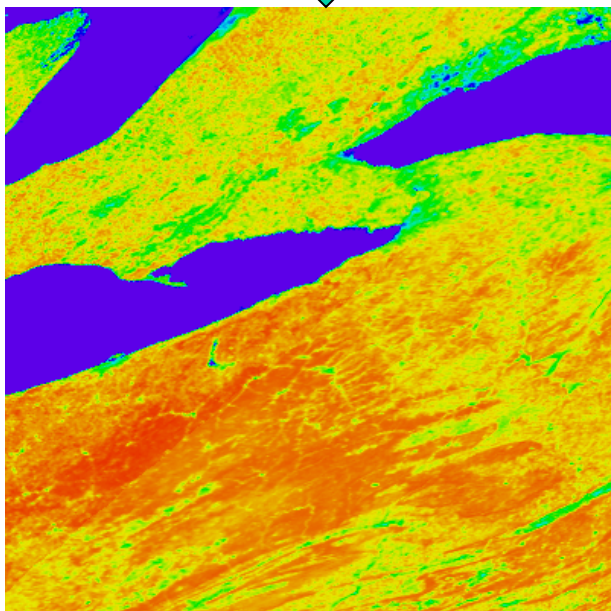
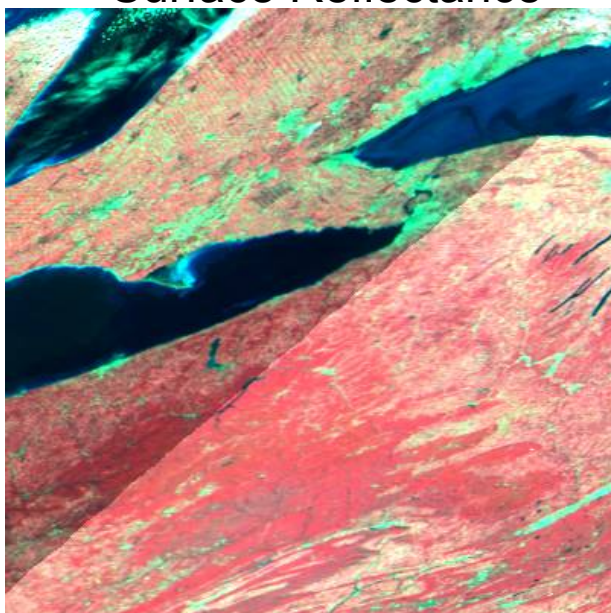
Apr 2004
Fall

BRDF Example

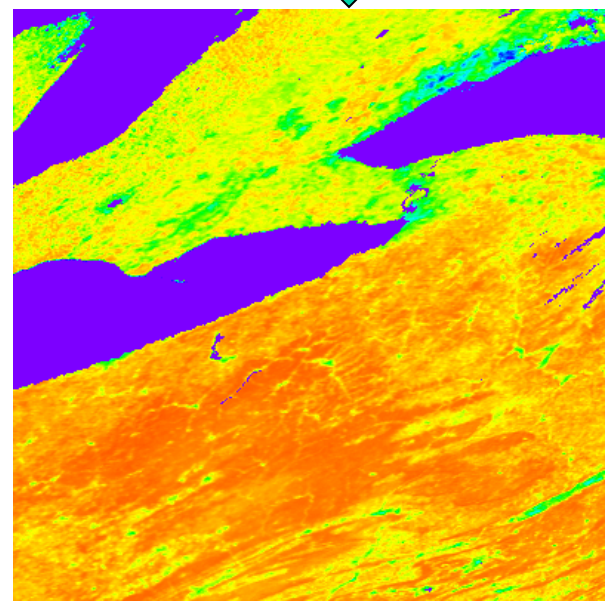
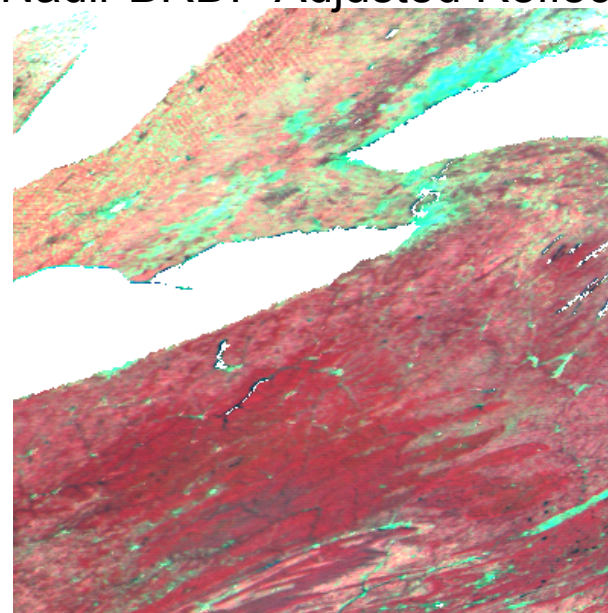


Black spruce forest in Canada.
Left, looking away from the sun
Right, looking towards the sun

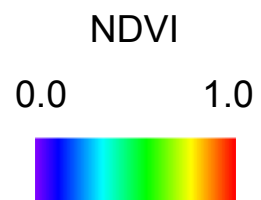
Surface Reflectance



Nadir BRDF-Adjusted Reflectance



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

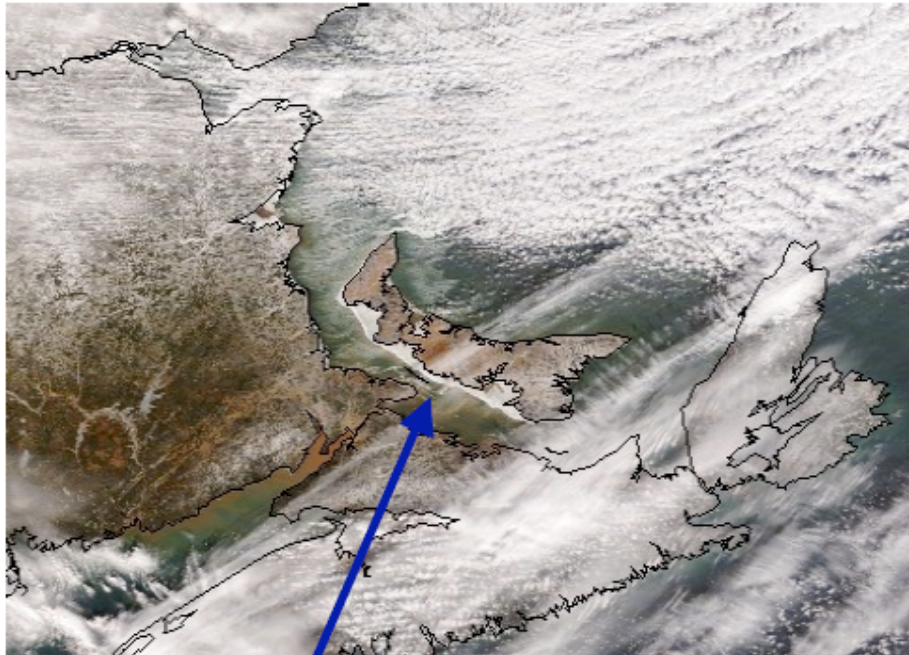


Canadian Ice Service integrates MODIS into operational data stream for ice monitoring

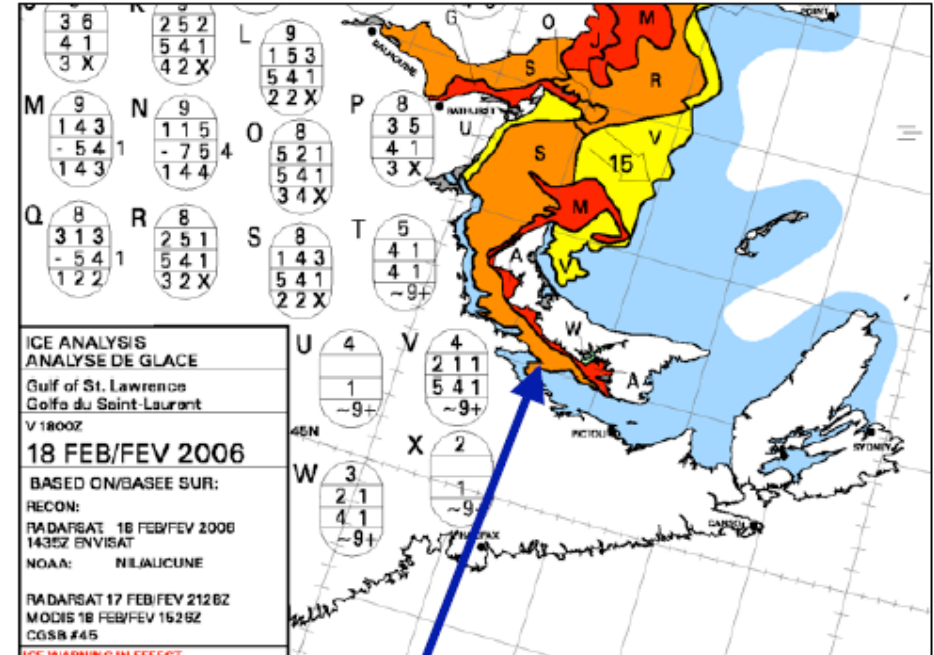
CIS data suite includes RadarSat and Envisat (SAR); AMSR, QuikScat and SSM/I (microwave); MODIS, OLS, NOAA and GOES (visible images).

- MODIS supplements SAR data in clear sky conditions.
- 250 meter resolution true color GeoTIFF images are obtained daily from SSEC for Great Lakes, Hudson Bay, Labrador coast, and Gulf of St. Lawrence.

MODIS helps to define ice boundary along southern Prince Edward Island

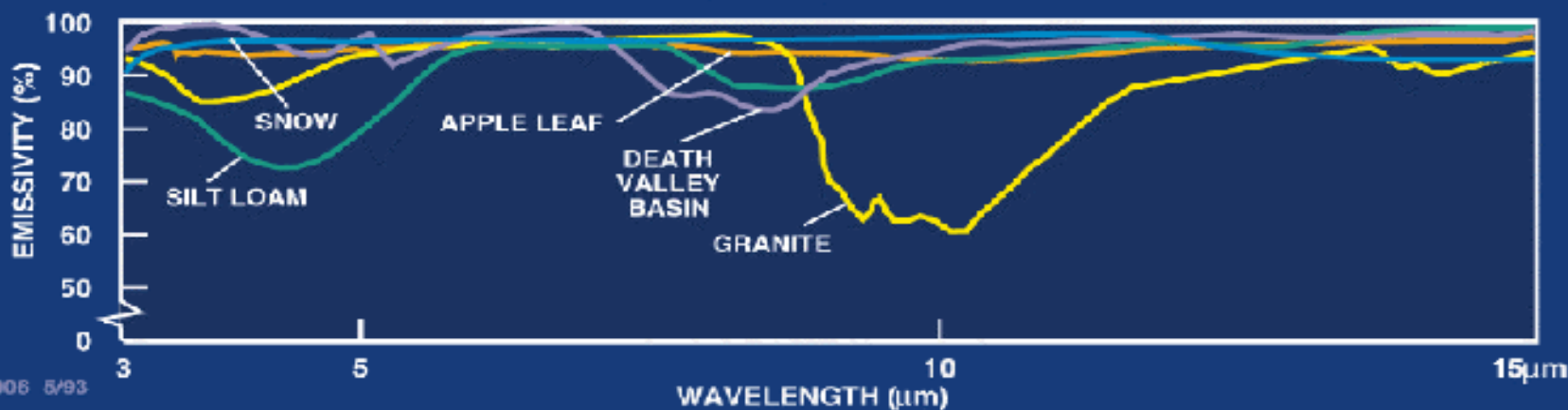
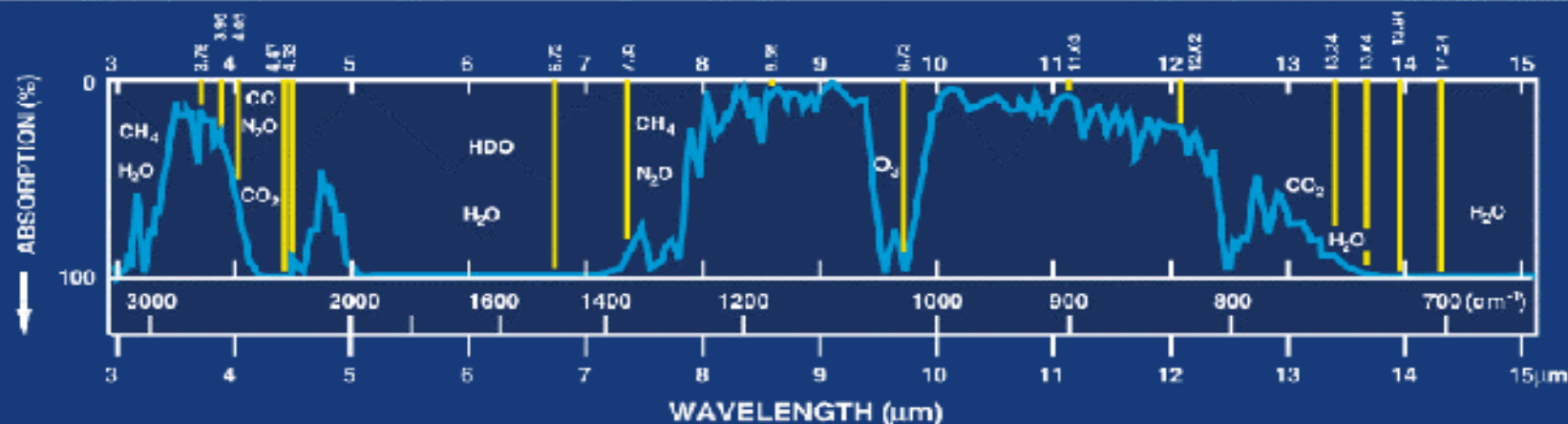


MODIS DB image 2006/02/18 15:26 UTC



CIS Ice Analysis 2006/02/18

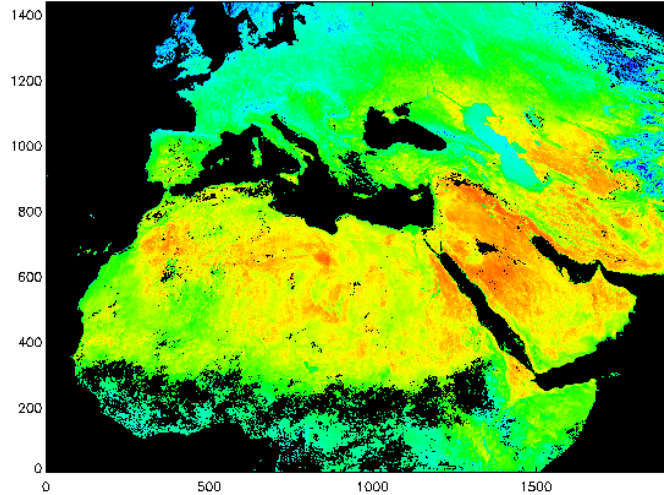
LAND - THERMAL RADIATION



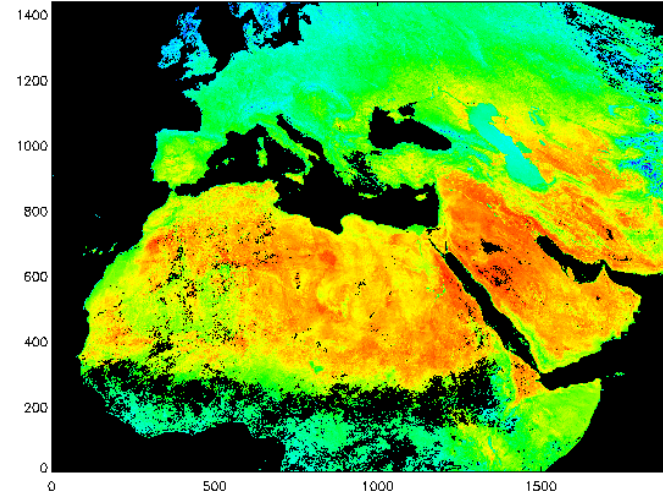


LSTs retrieved from Terra and Aqua MODIS data on data days 176-177 and 185-190 (06/25-26 & 07/4-9) to show spatial distribution of the diurnal variation

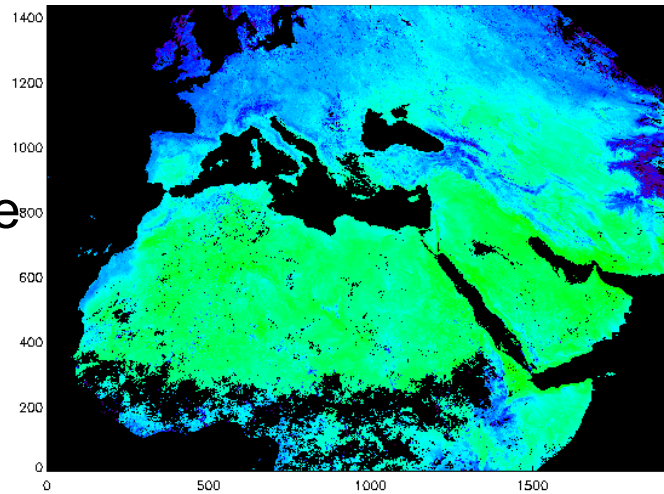
daytime
Terra



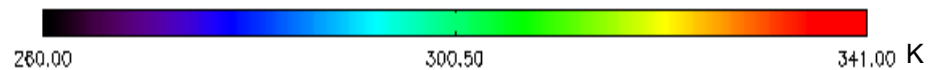
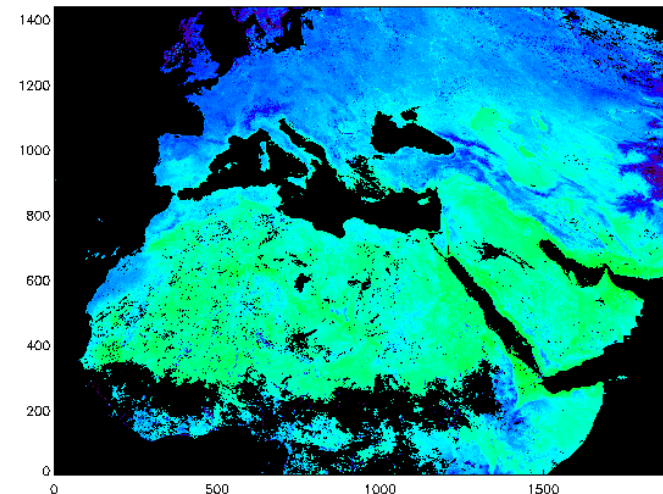
daytime
Aqua



nighttime
Terra

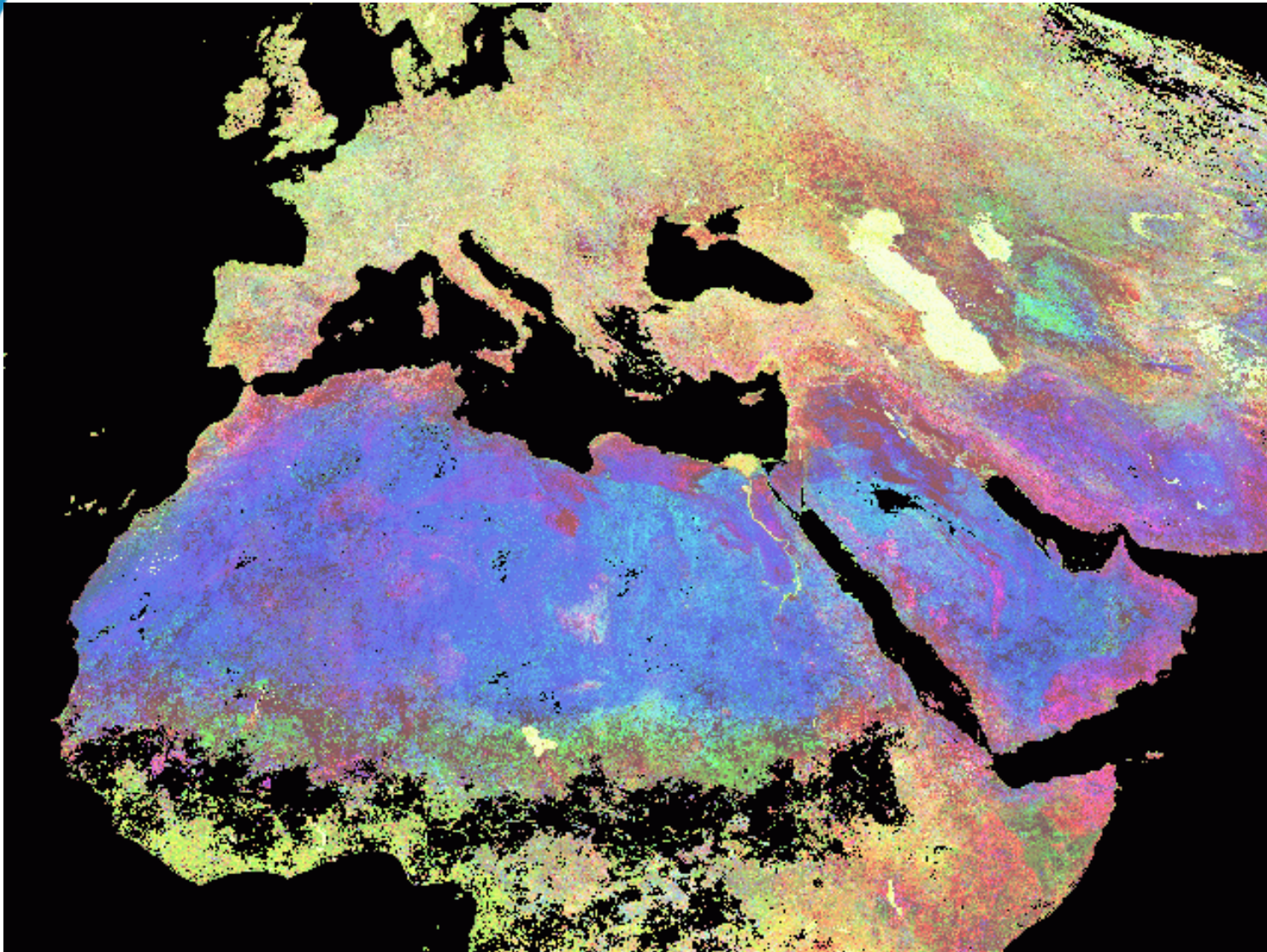


nighttime
Aqua





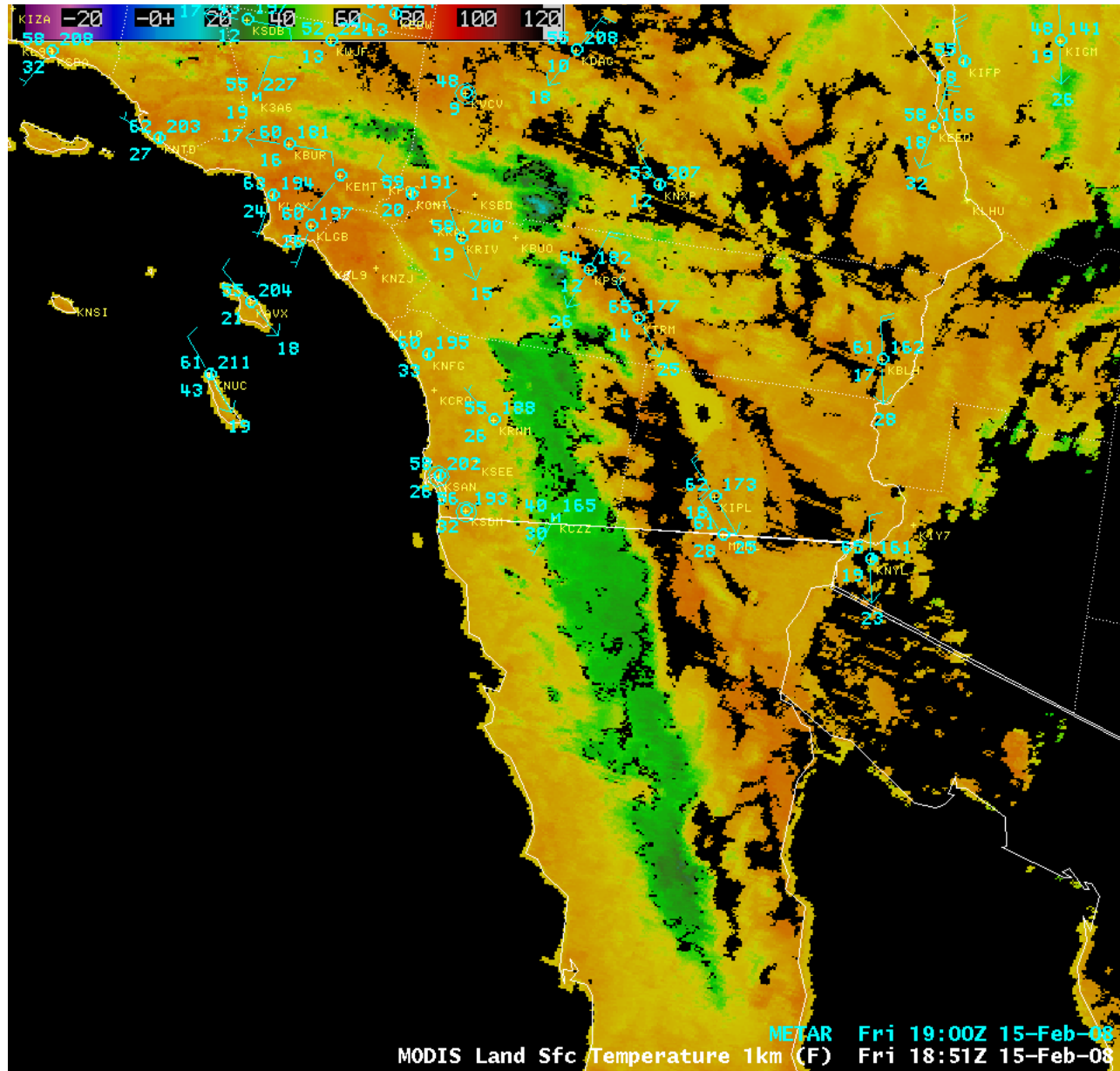
Surface emissivities retrieved by Terra and Aqua MODIS



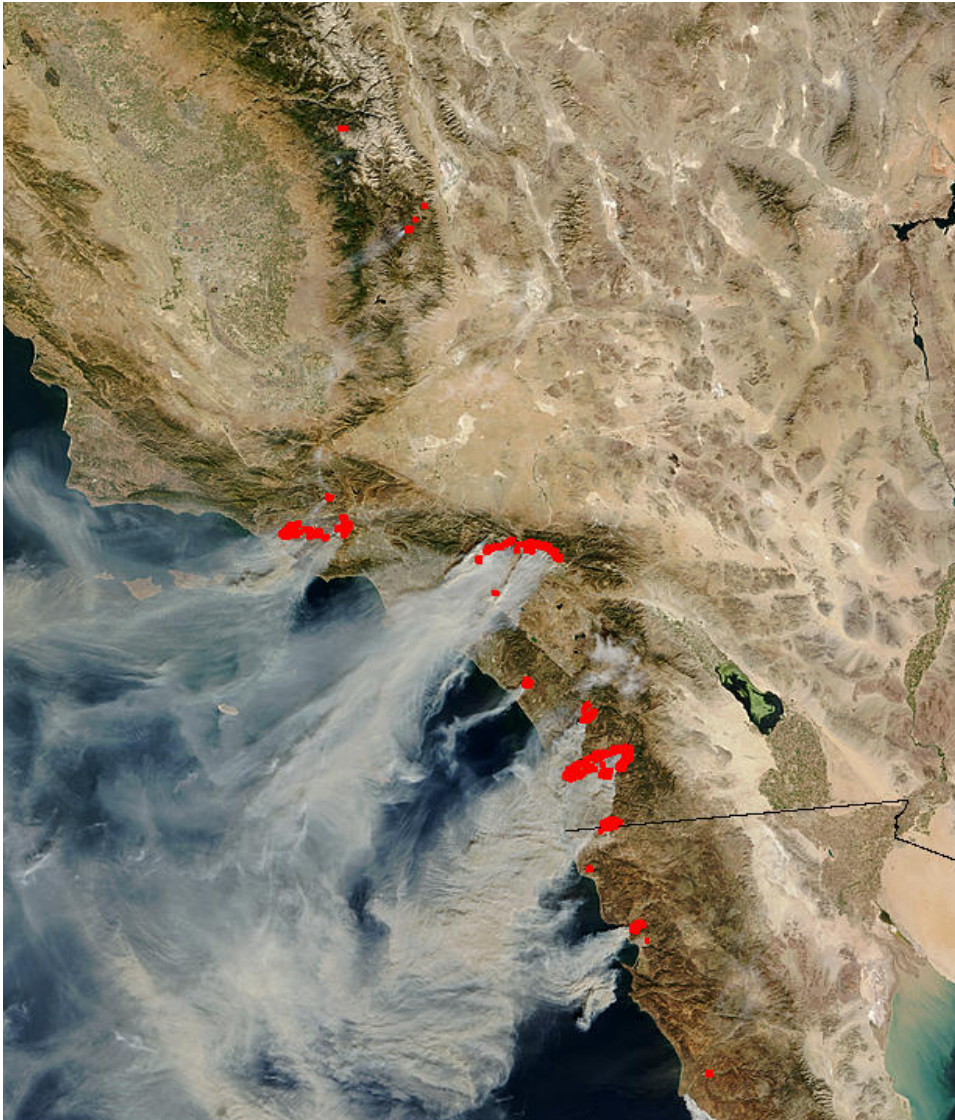
MODIS True Color



MODIS Land Surface Temperature



MODIS Active Fire Detection

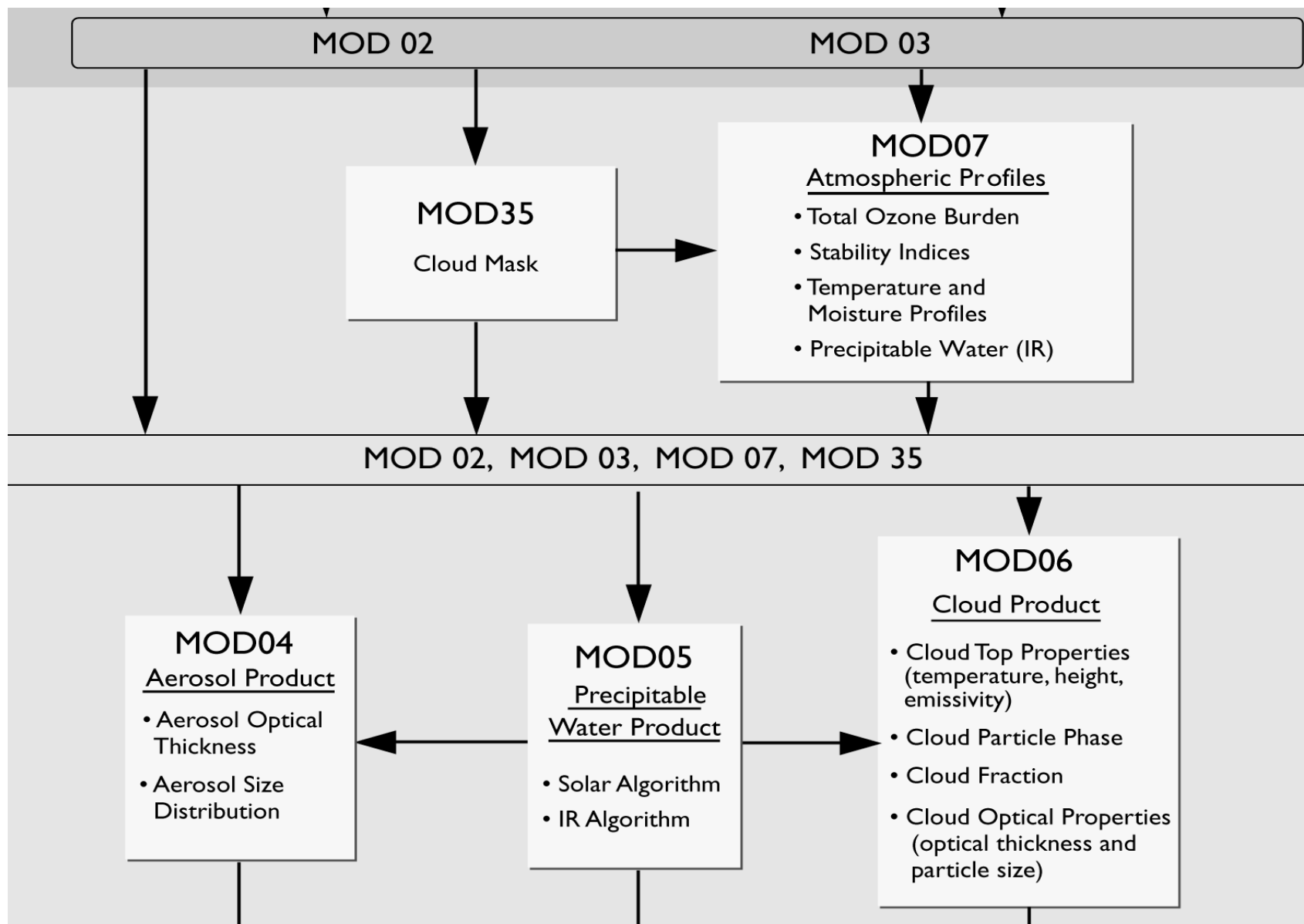


- The algorithm considers the spectral signature (in middle and thermal infrared) of each pixel and compares it to the non-burning surrounding pixels
- The natural variability of the surrounding background is taken into account
- Fewer false detections than traditional threshold-based algorithms
- Sensitive enough to detect small fires

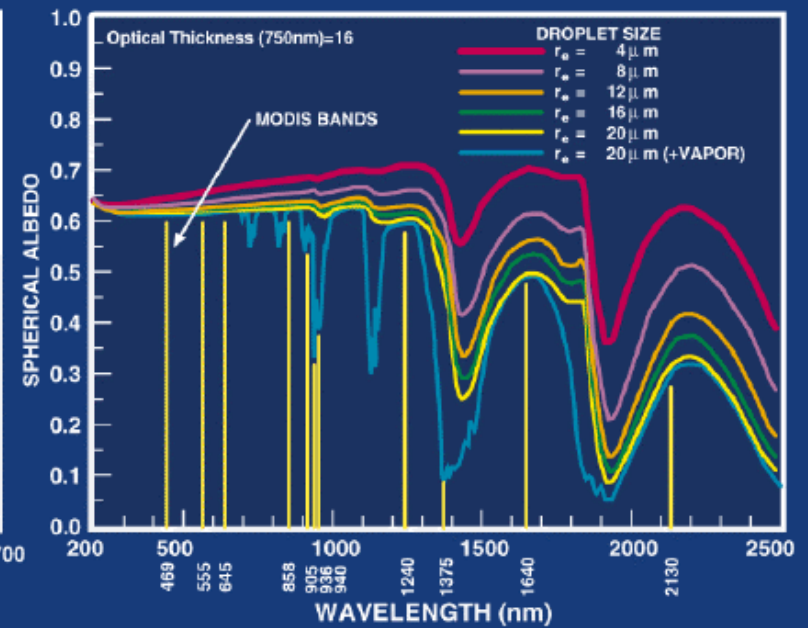
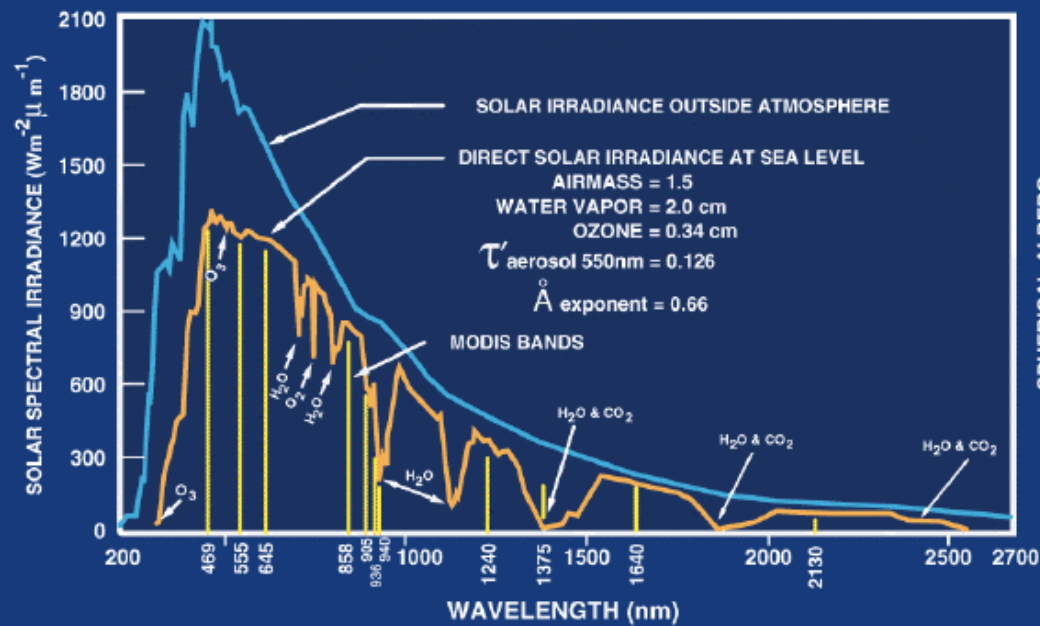
California – 10/26/03

MODIS Atmosphere Applications

MODIS Atmosphere Product Flowchart

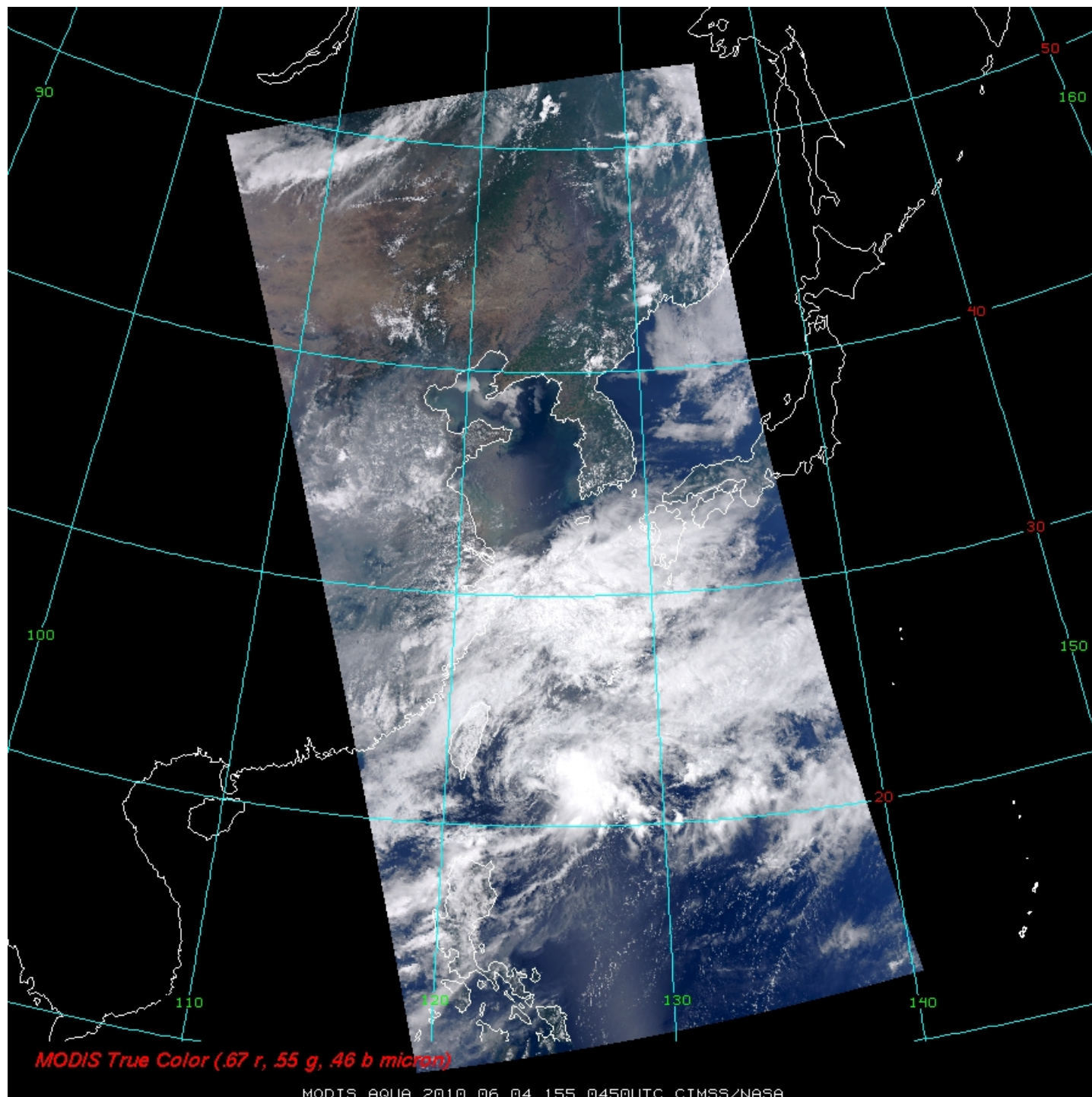


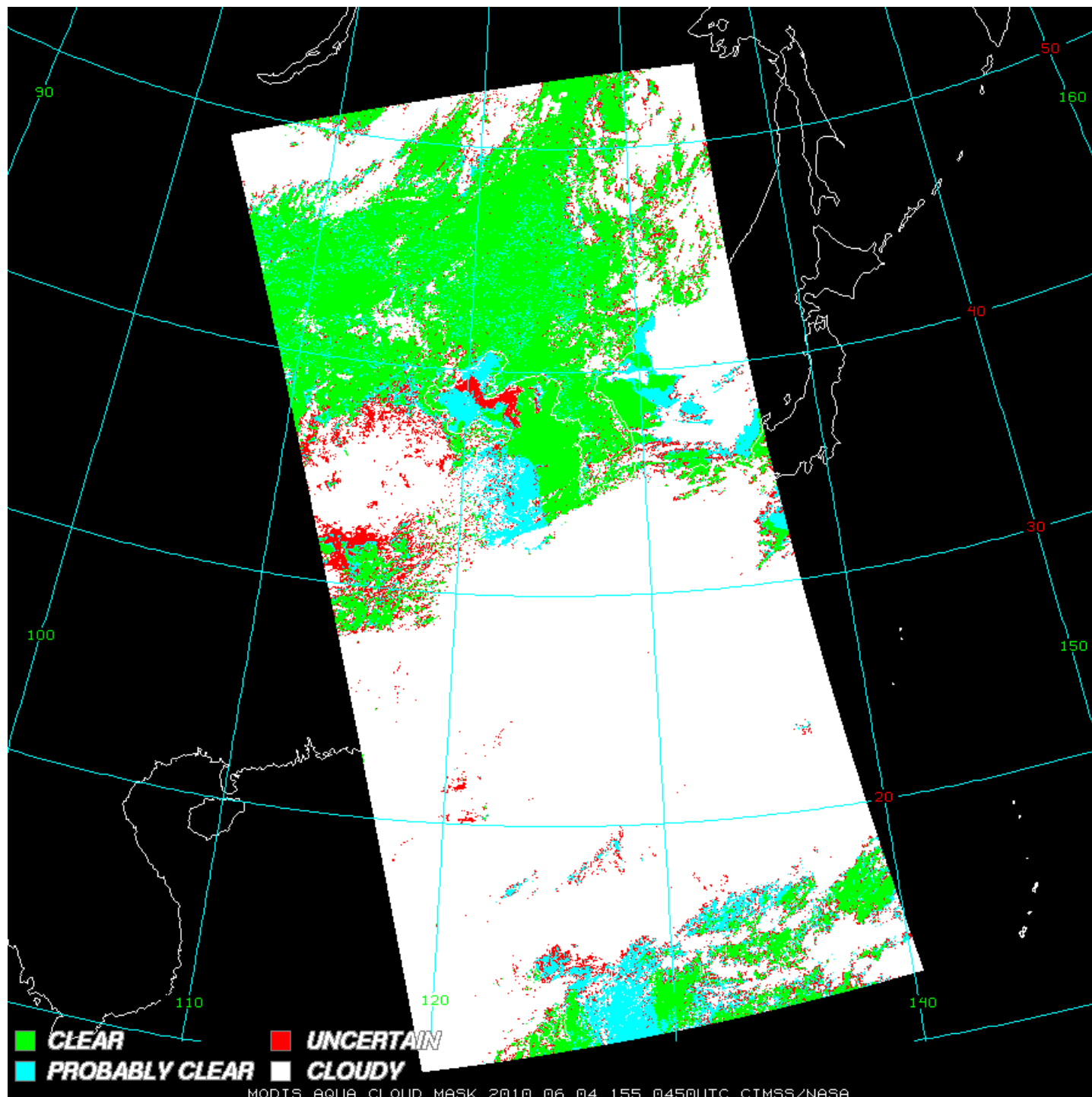
ATMOSPHERE-SOLAR RADIATION



MODIS Cloud Mask

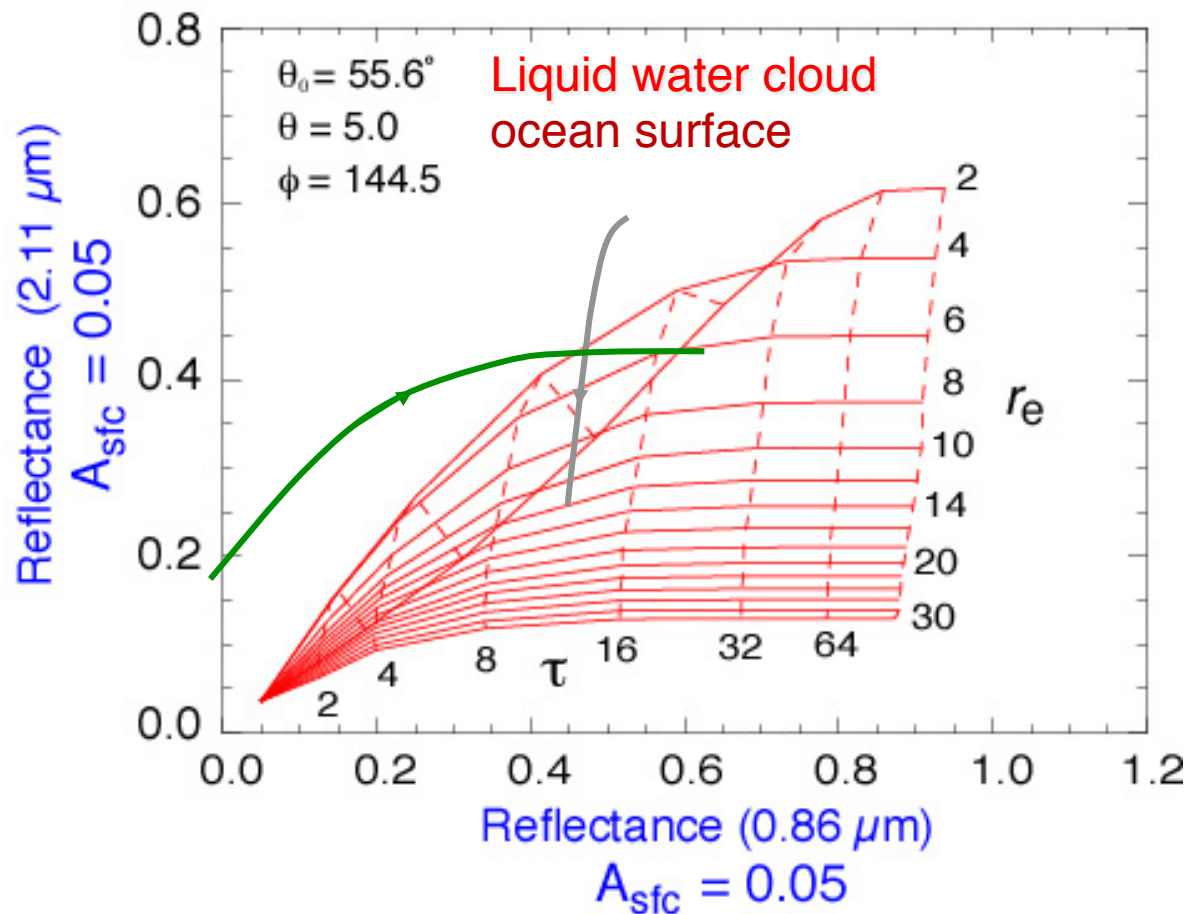
- **1 km** spatial resolution **day & night**, (250 m day)
 - **19 spectral bands** (0.55-13.93 μm , incl. 1.38 μm)
 - 11 individual spectral tests (function of 5 processing paths) combined for initial pixel confidence of clear
 - temporal consistency test over ocean, desert (nighttime); spatial variability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





MODIS Cloud Optical Properties

MODIS observations at 0.66, 0.86, 1.6, 2.1, and 3.7 microns contain information about the cloud droplet size and optical properties.

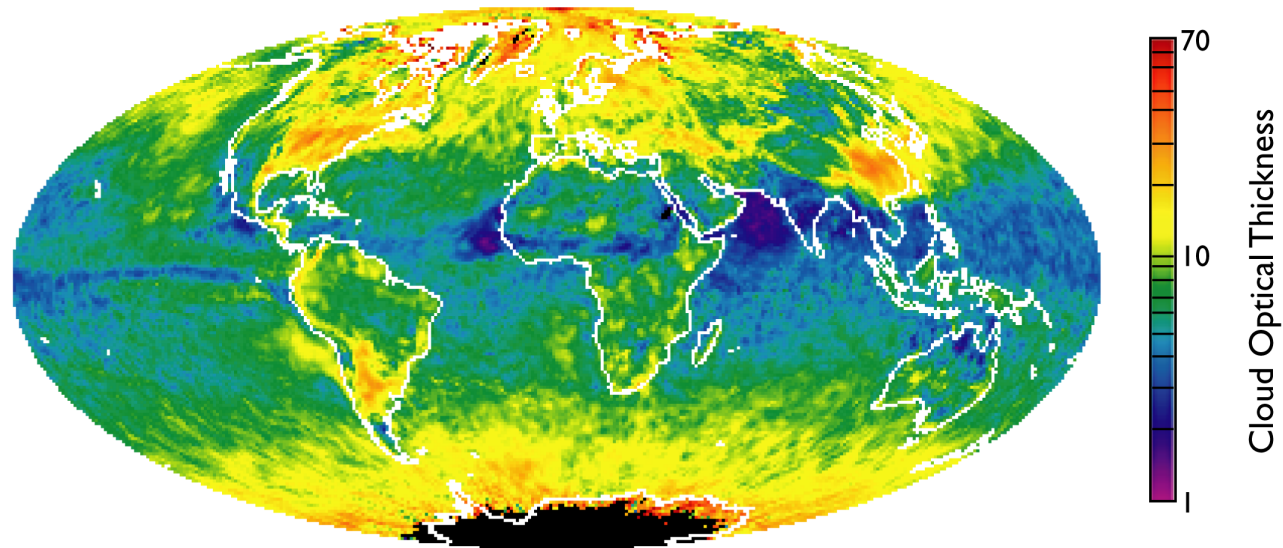


$2.1 \mu\text{m}$ absorption increases with particle size, little effect at $0.86 \mu\text{m}$

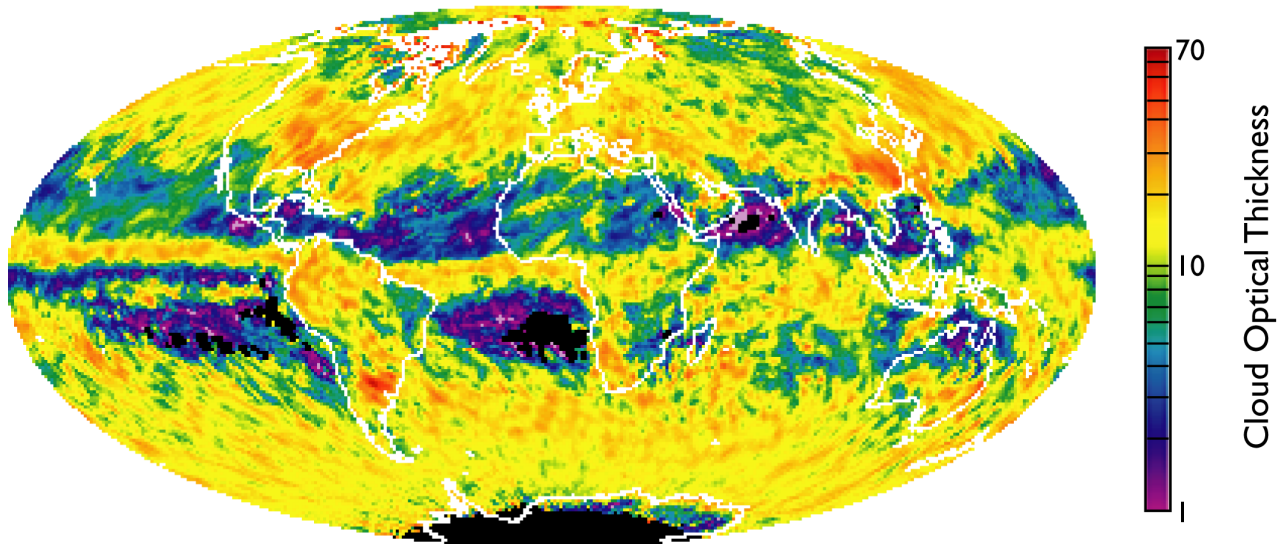
$2.1 \mu\text{m}$ reflectance reaches limiting values with optical thickness

Monthly Mean Cloud Optical Thickness

Cloud Optical Thickness (Water)

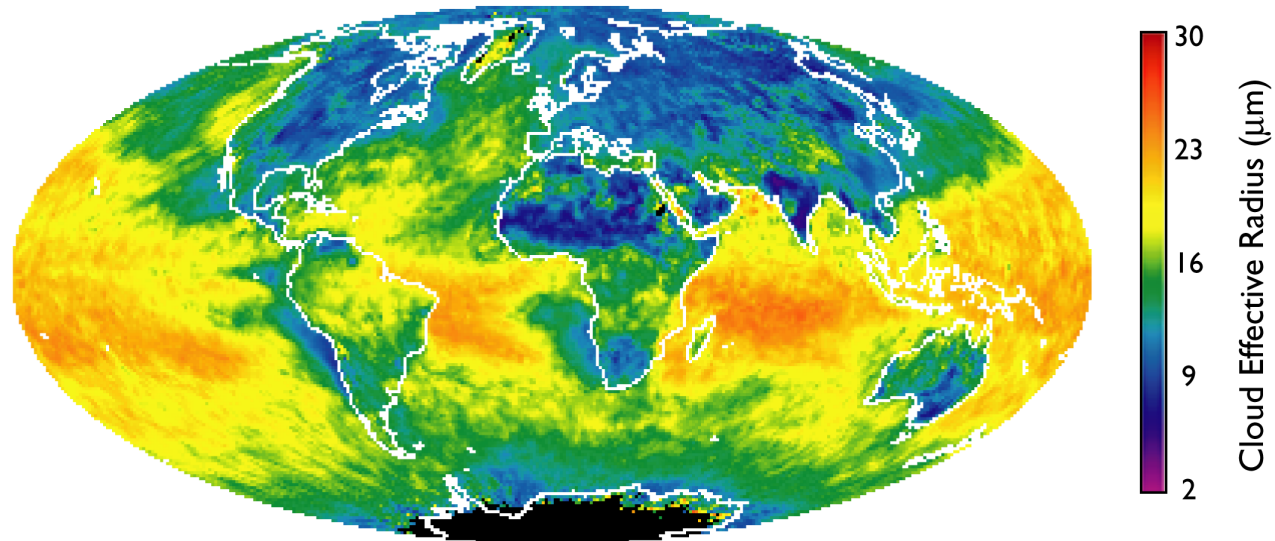


Cloud Optical Thickness (Ice)

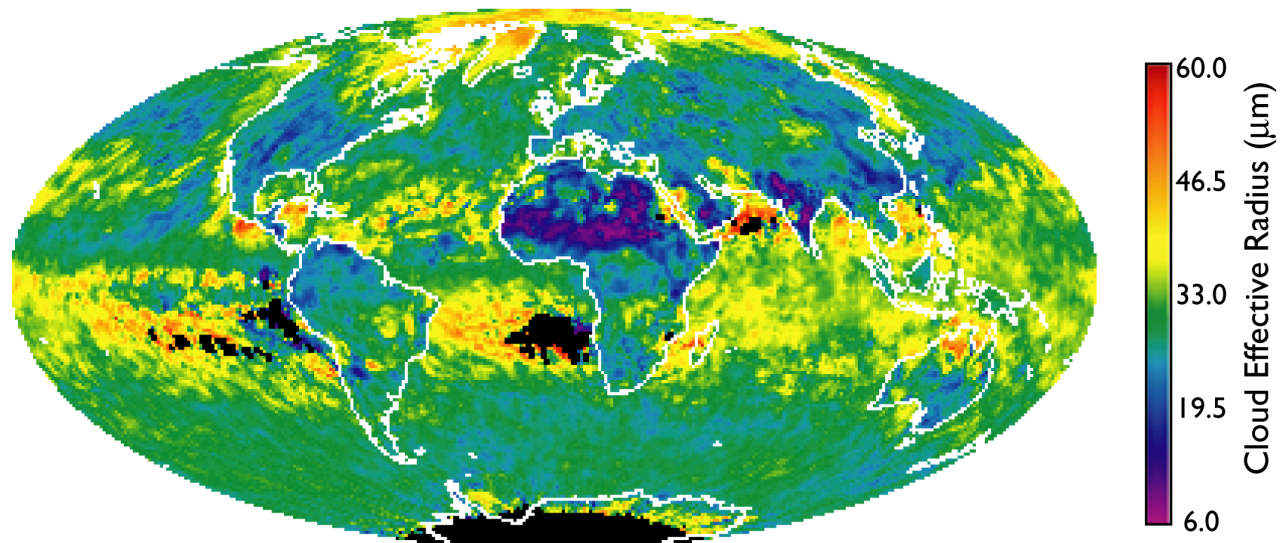


Monthly Mean Cloud Effective Radius

Cloud Effective Radius (Water)

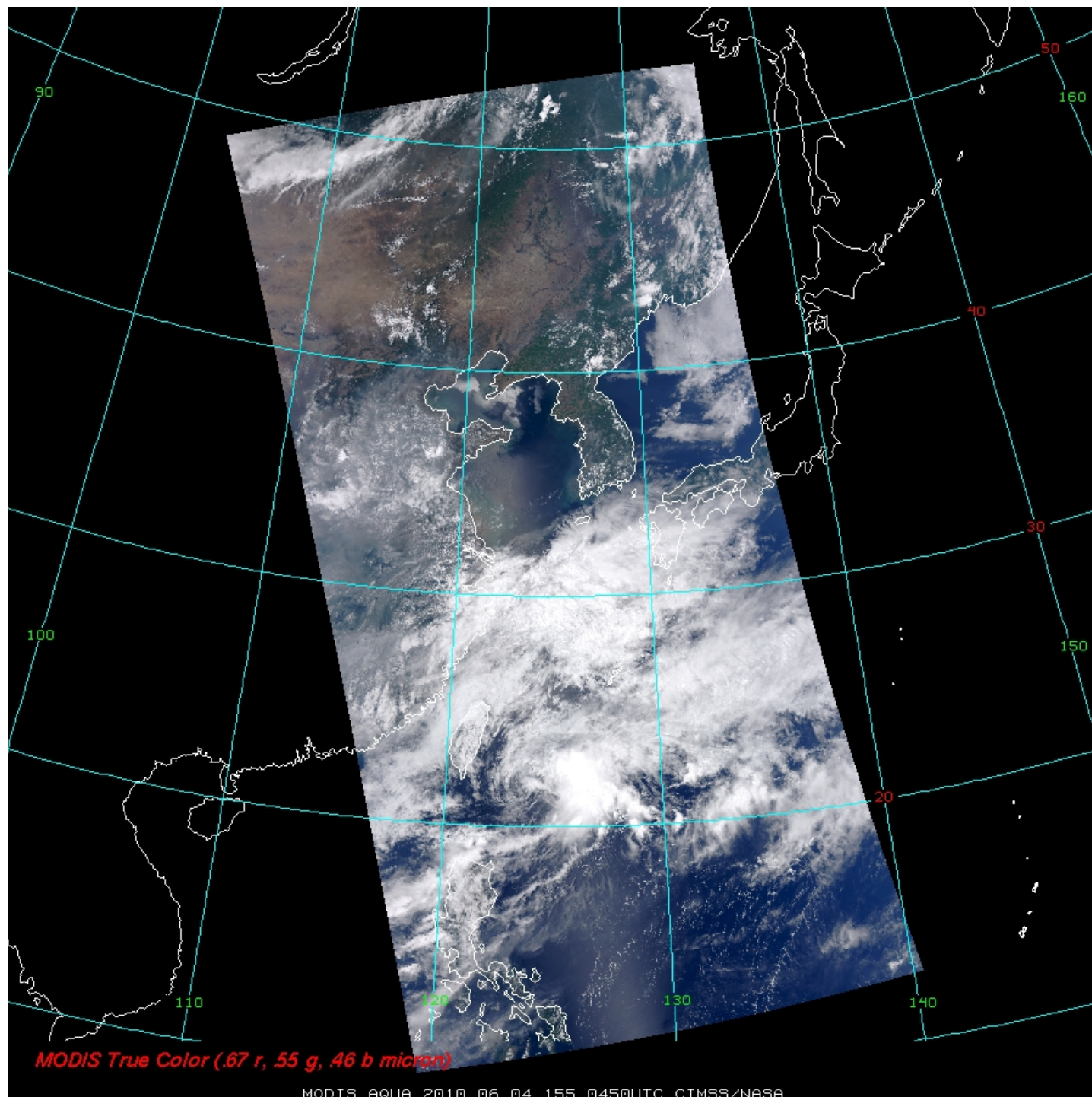


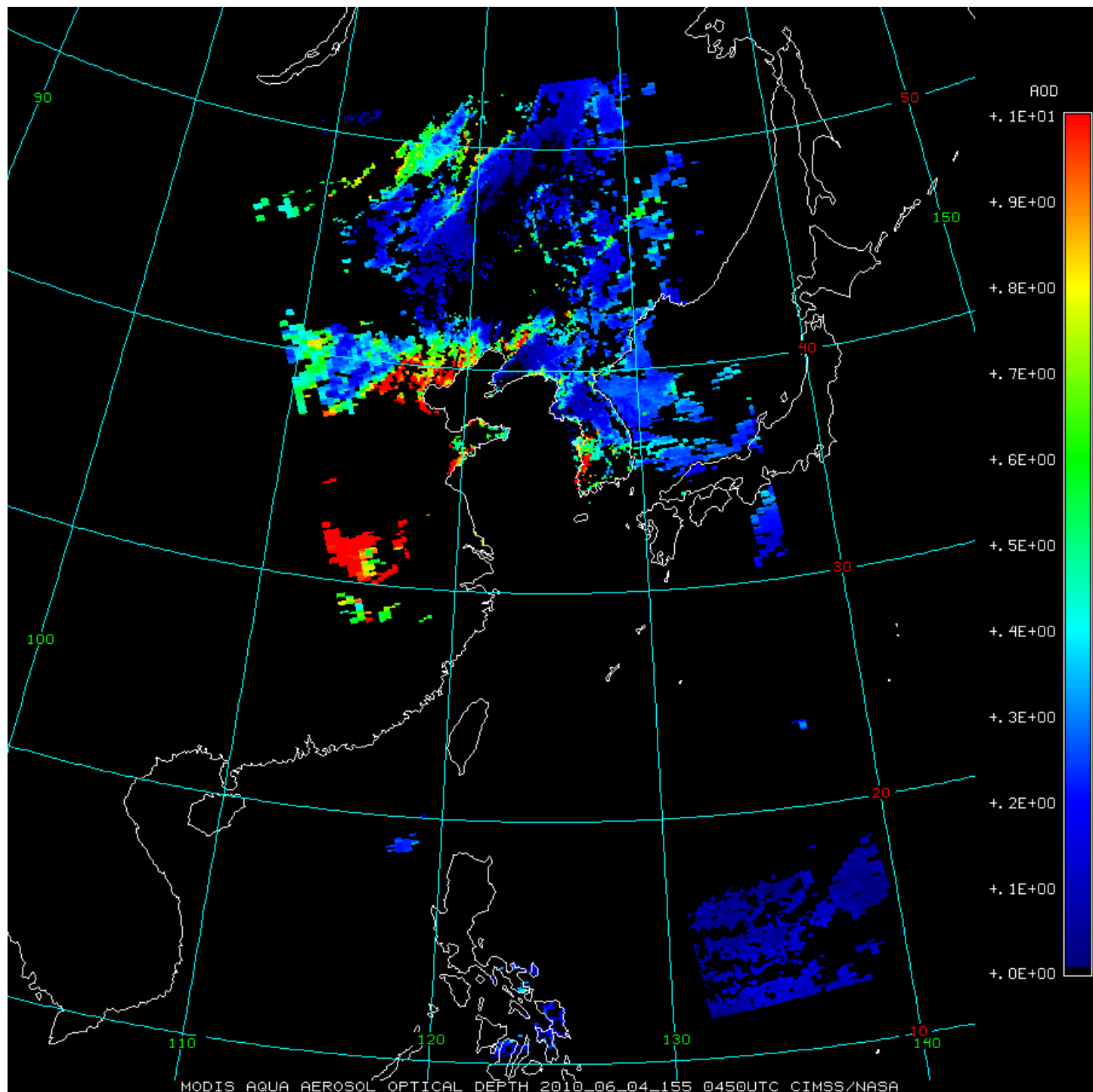
Cloud Effective Radius (Ice)



MODIS Aerosol Product

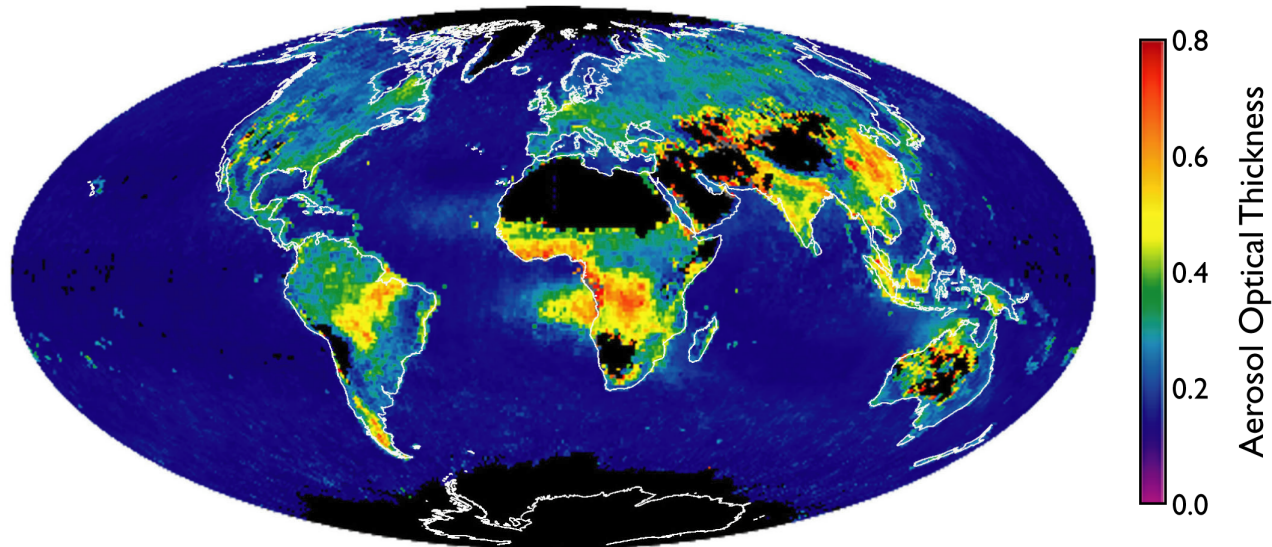
- Separate aerosol retrieval algorithms for land and water
- Algorithm matches observed reflectances to a lookup table of precomputed reflectances for a wide variety of aerosol conditions
- Over land, atmospheric and land surface reflectance are separated by estimating the surface contribution from the measured reflectance at 2.13 microns for dark targets
- Final land products include aerosol optical thickness at 0.47, 0.56, and 0.65 microns at 10-km spatial resolution, and the fine mode (radius 0.6 micron) fraction of the aerosol optical thickness at 0.56 microns
- Over ocean the surface contribution to the total reflectance is small and can be calculated
- Retrieved aerosol products are represented by the best fits between observed reflectance and the lookup table
- Ocean products include aerosol optical thickness at 0.47, 0.56, 0.65, 0.86, 1.24, 1.64, and 2.13 microns at 10-km spatial resolution, effective radius of the particle population, and fine mode fraction



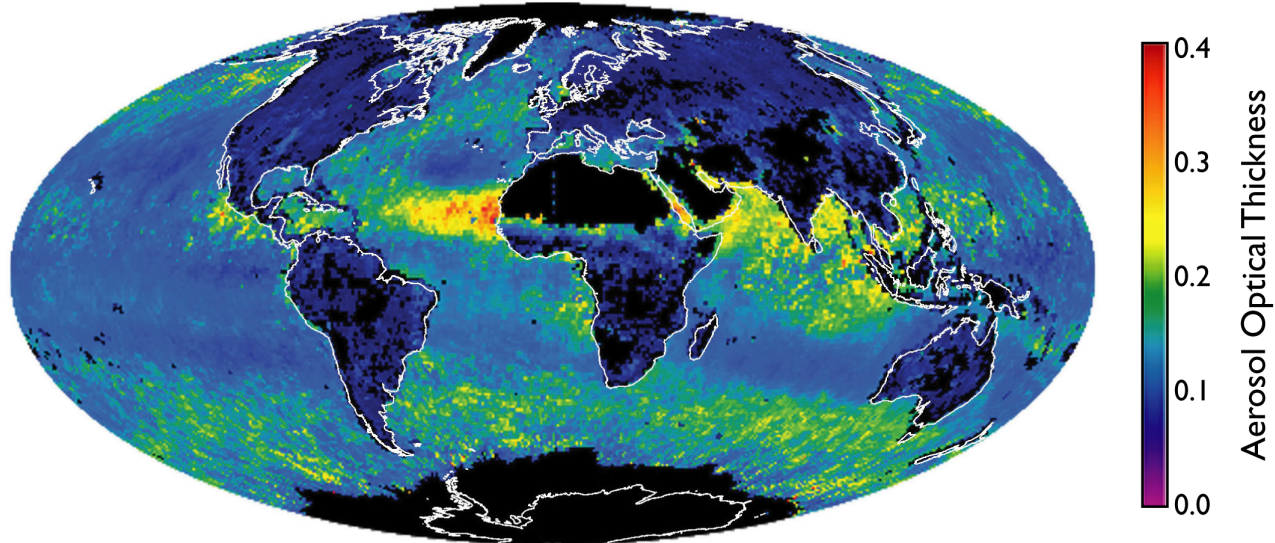


Monthly Mean Aerosol Optical Thickness

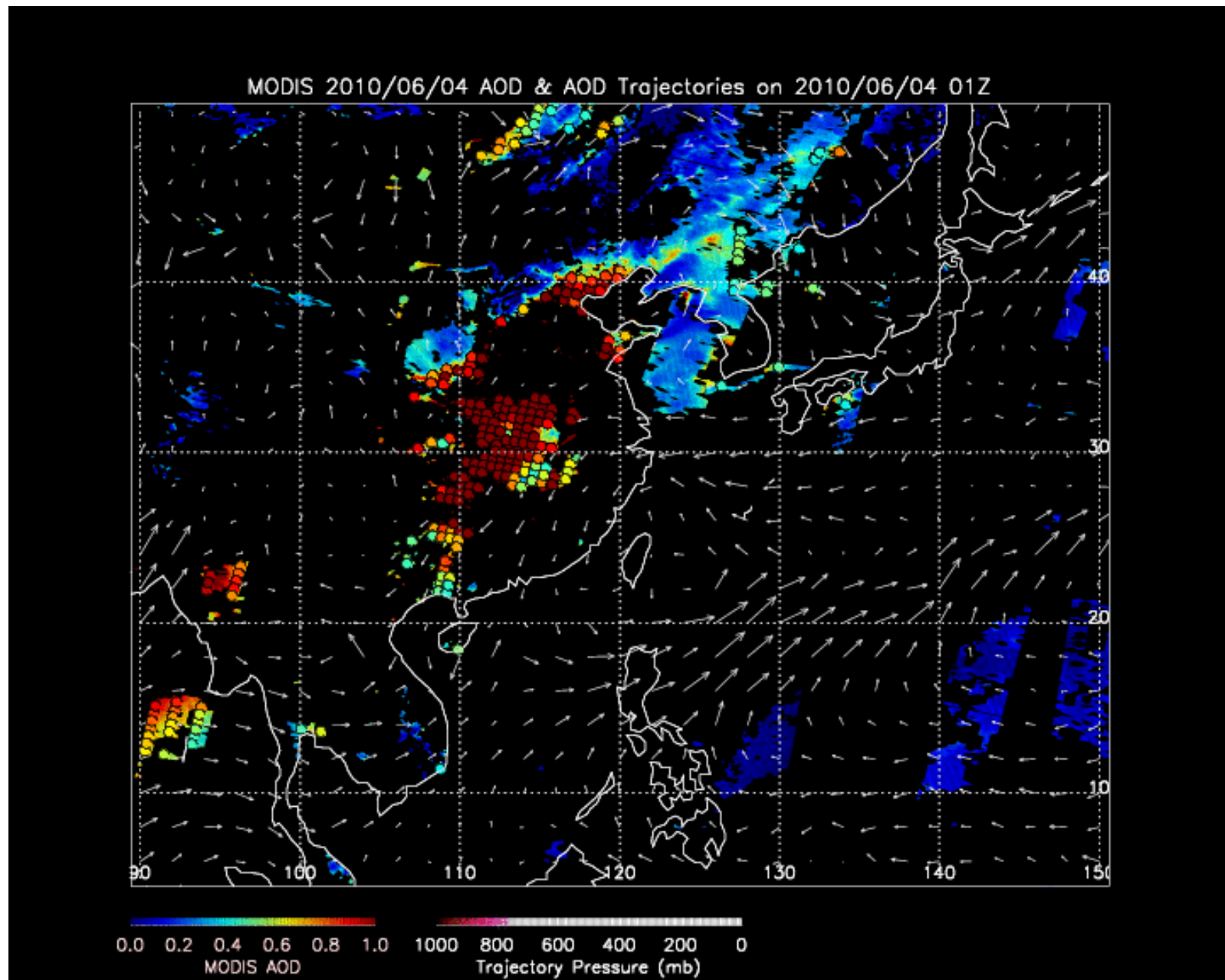
Aerosol Optical Thickness (Fine Mode)



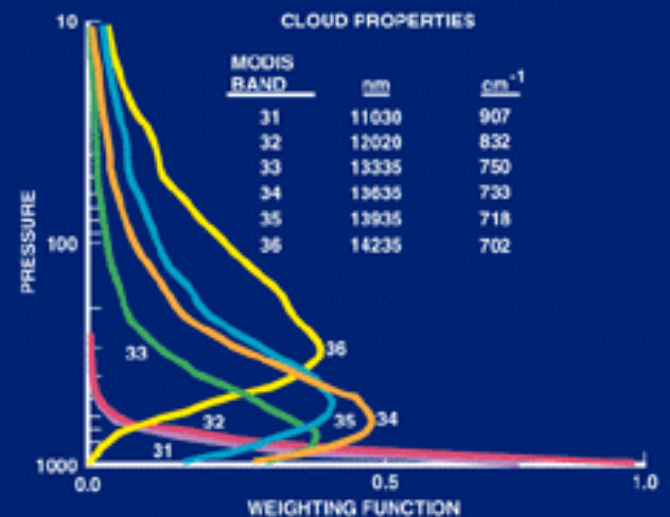
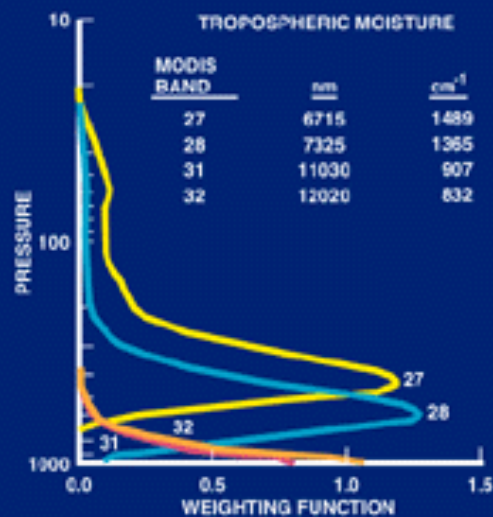
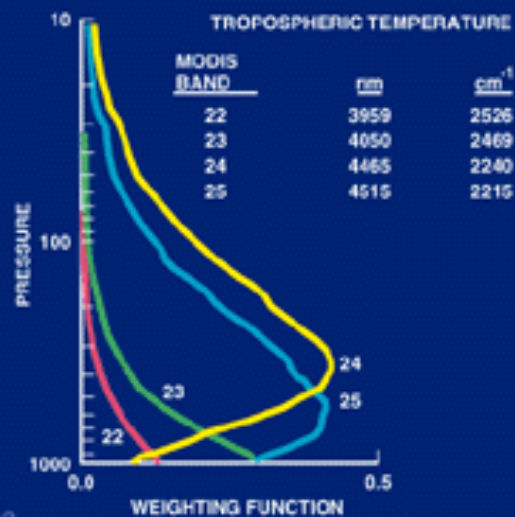
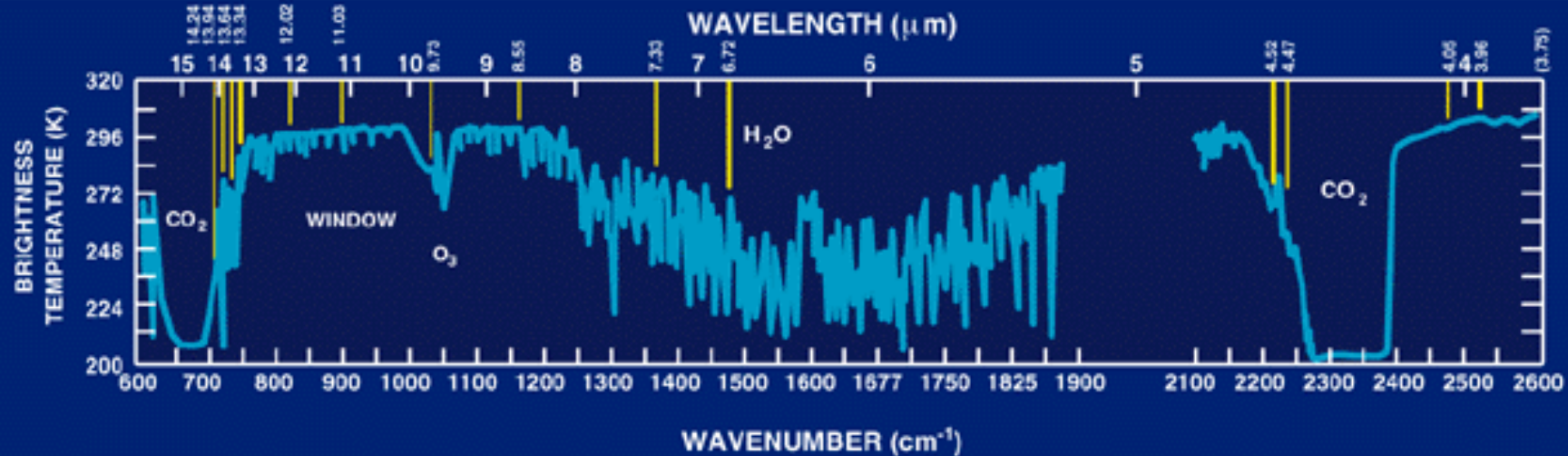
Aerosol Optical Thickness (Coarse Mode)



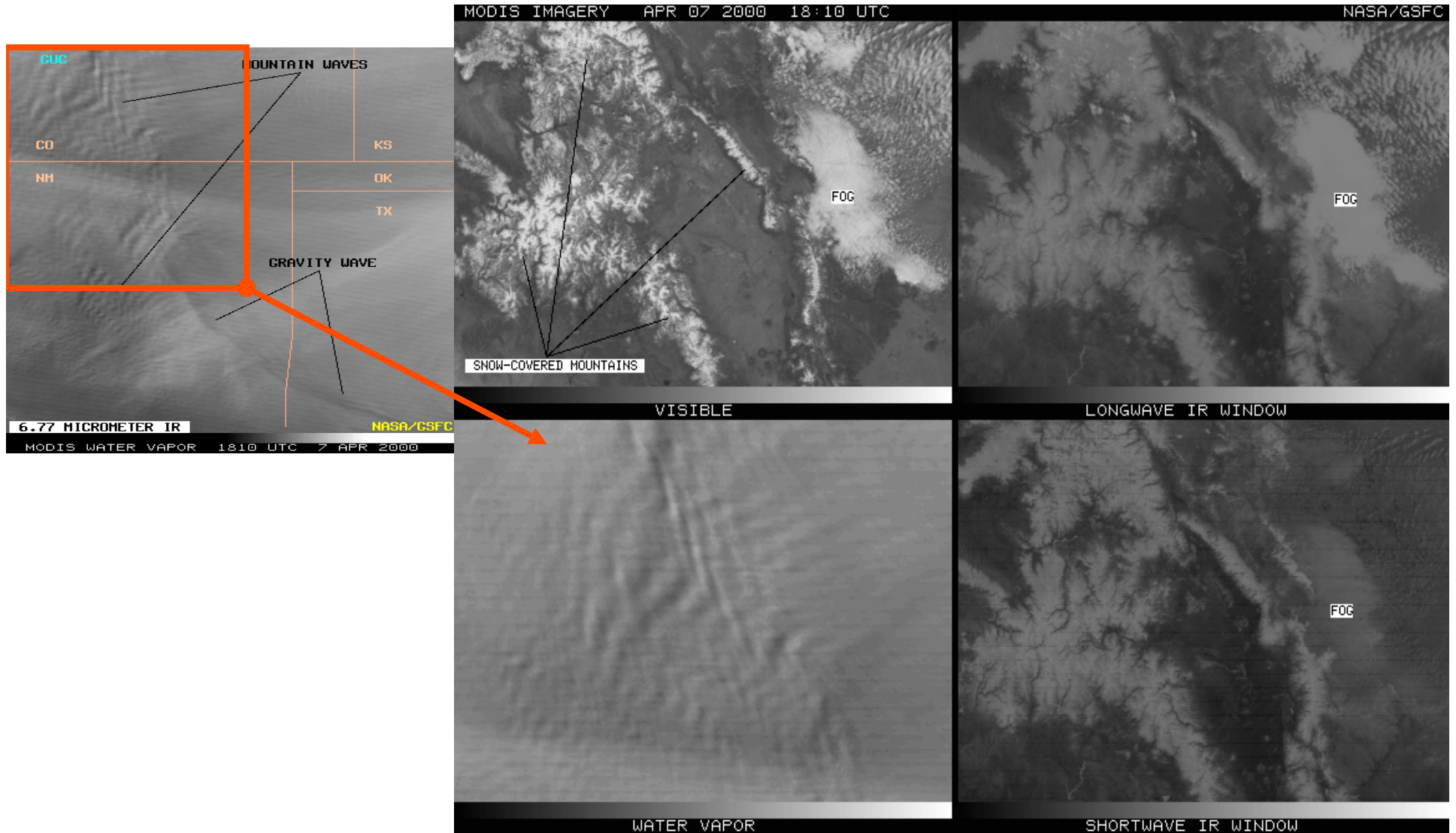
MODIS IDEA-I Product for 2010/06/04



ATMOSPHERE - THERMAL RADIATION

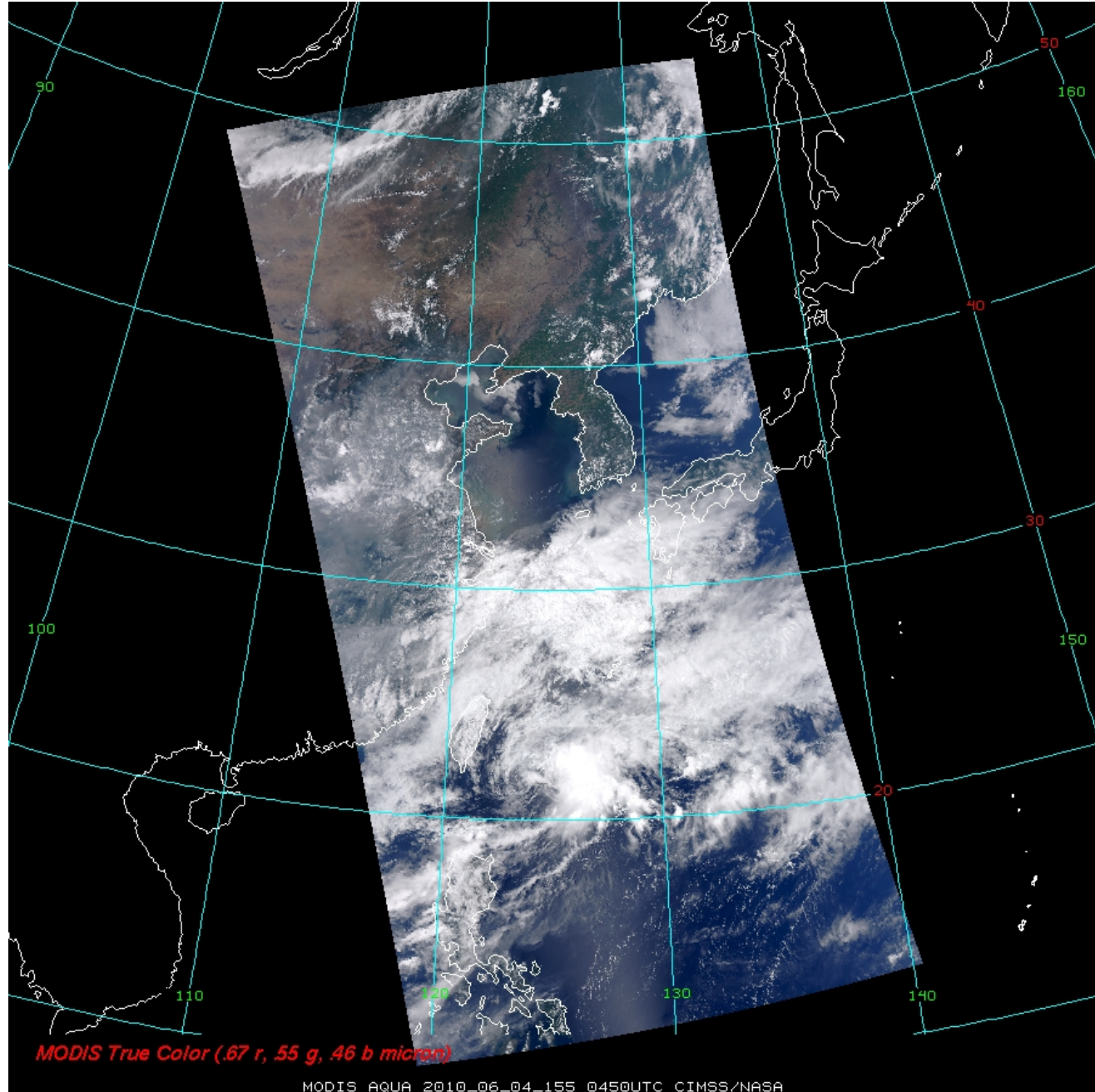


Four Panel Zoom of Cloud-Free Orographic Waves revealed in Water Vapor Imagery



Aqua MODIS True Color Image: 2010/06/04

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



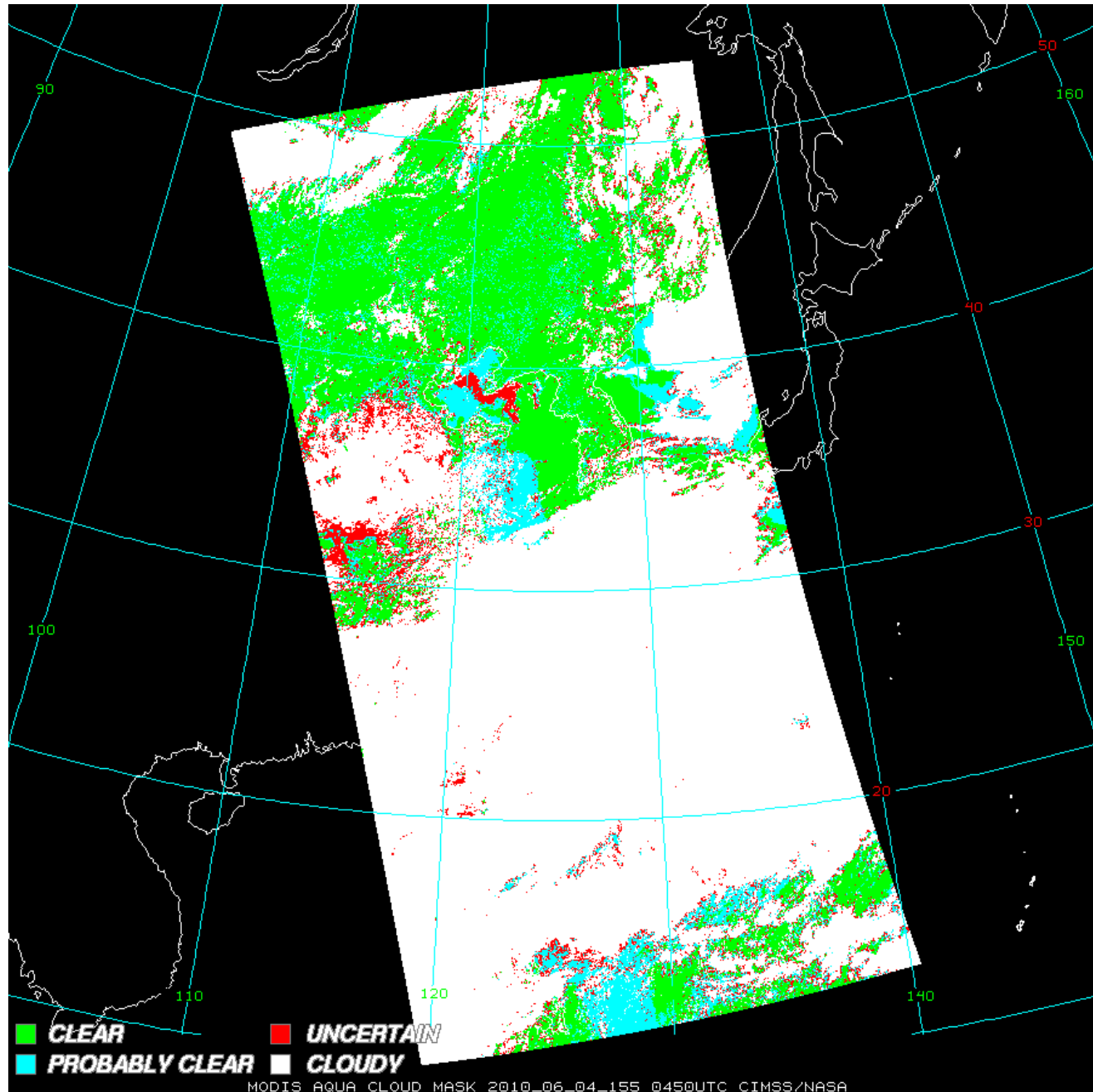
MODIS Cloud Mask Product (MOD35)

Clear and
Cloudy Sky
(everywhere)

Day/Night

1 km resolution

Fuzzy logic
spectral tests



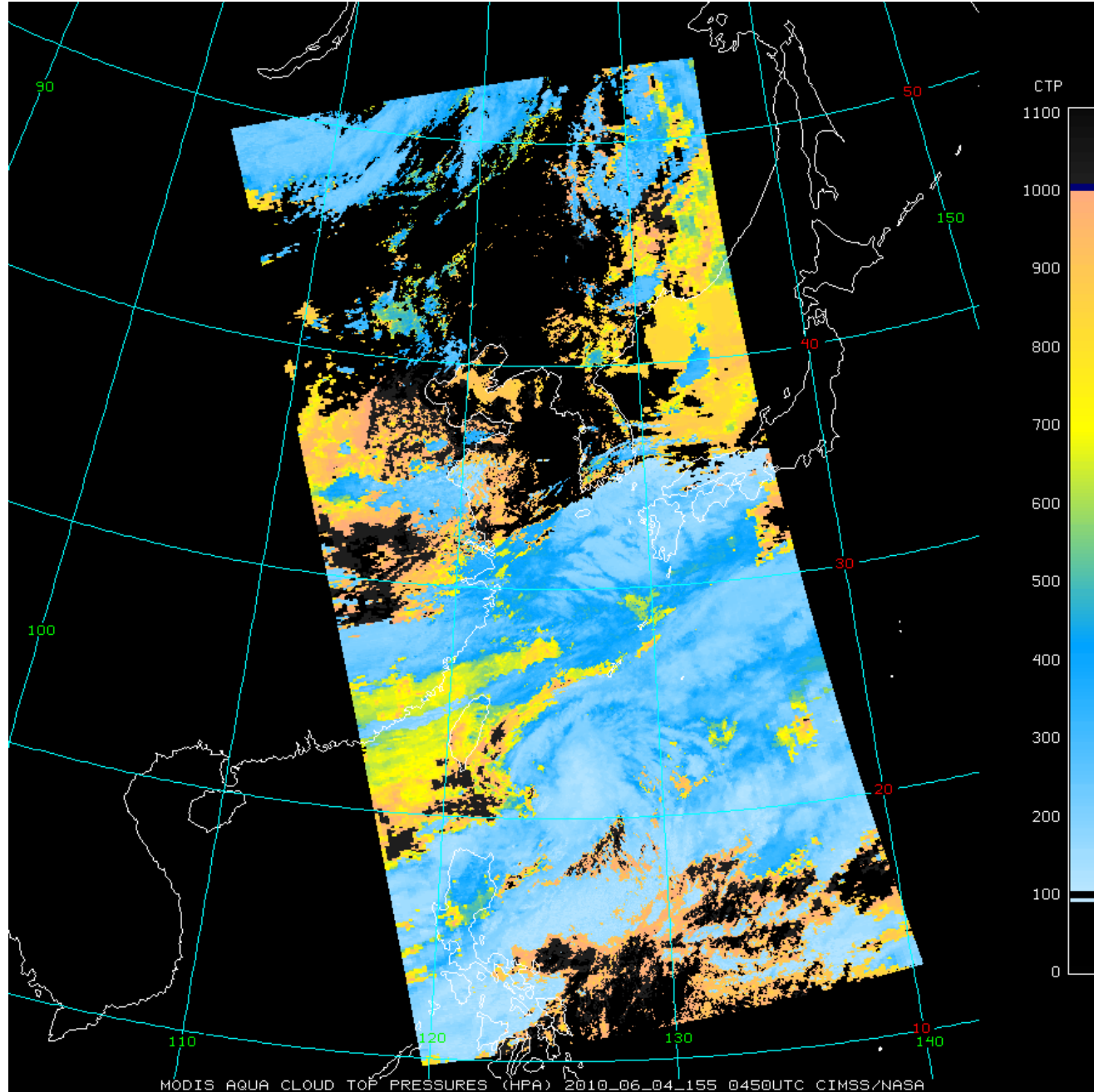
MODIS Cloud Top Pressure Product (MOD006)

Cloudy Sky
Only

Day/Night

5 x 5 km
resolution

CO₂ slicing
algorithm



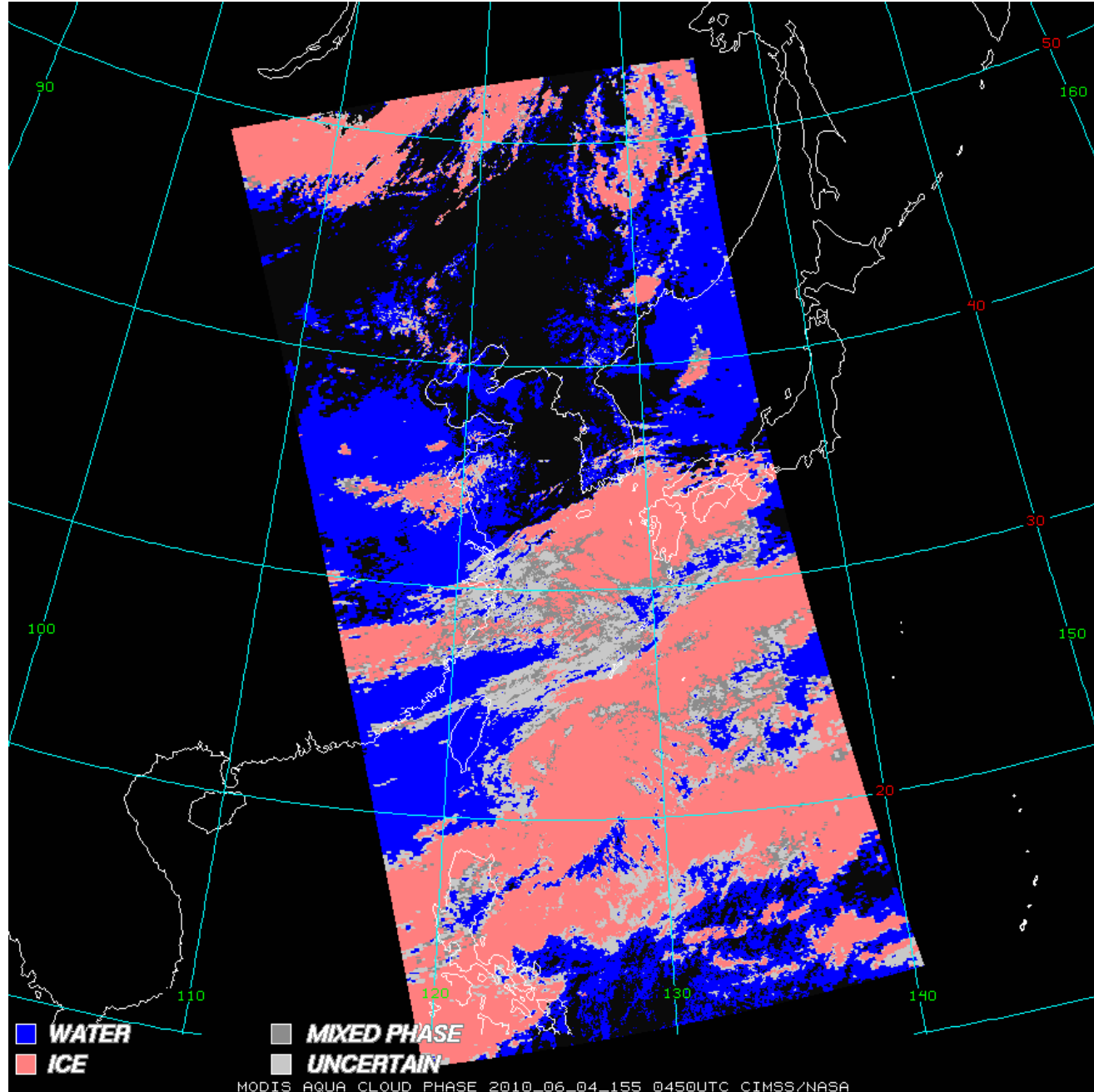
MODIS Cloud Phase Product (MOD006)

Cloudy Sky
Only

Day/Night

5 x 5 km
resolution

Threshold
Algorithm



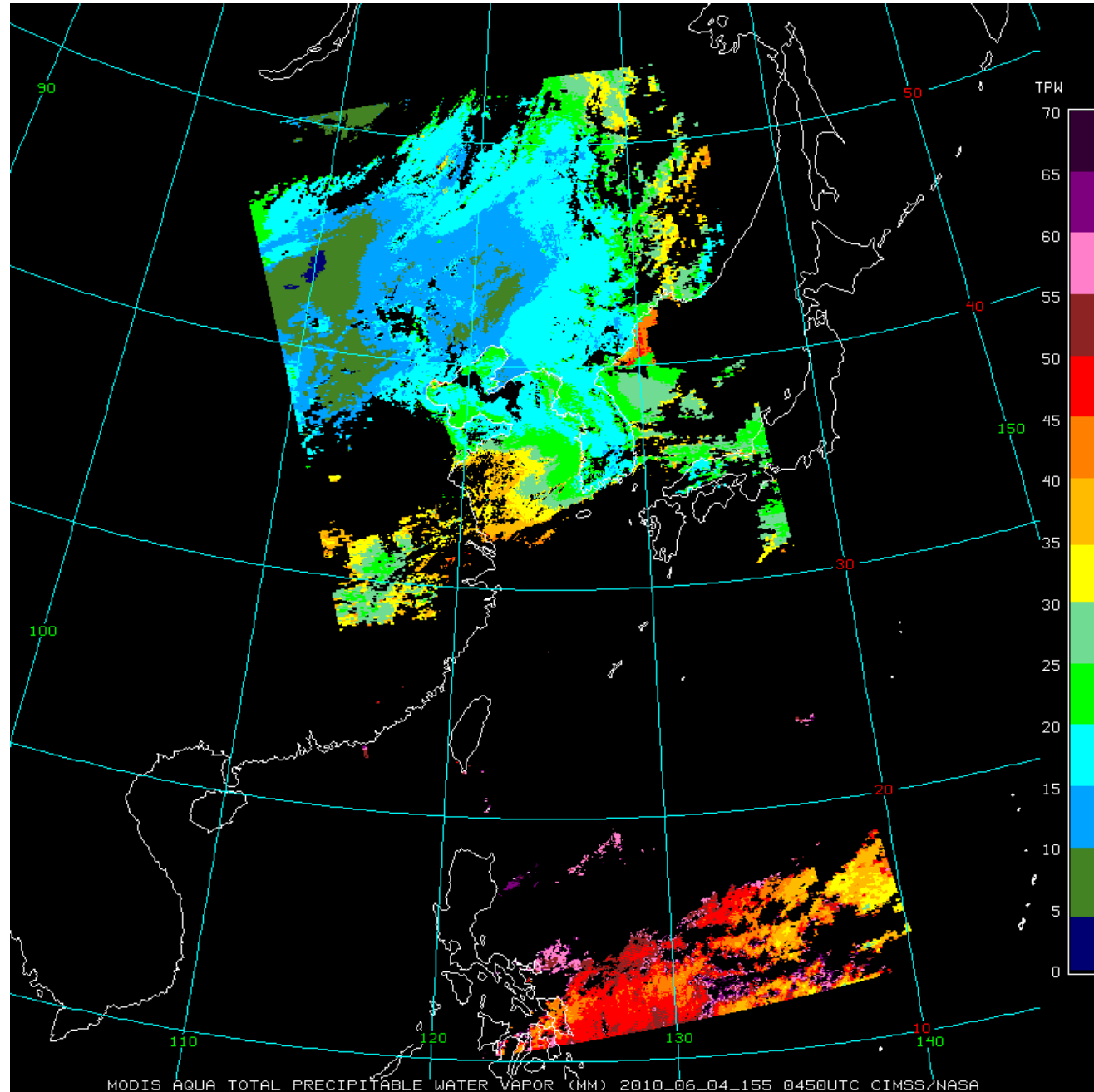
MODIS Water Vapor Product (MOD07)

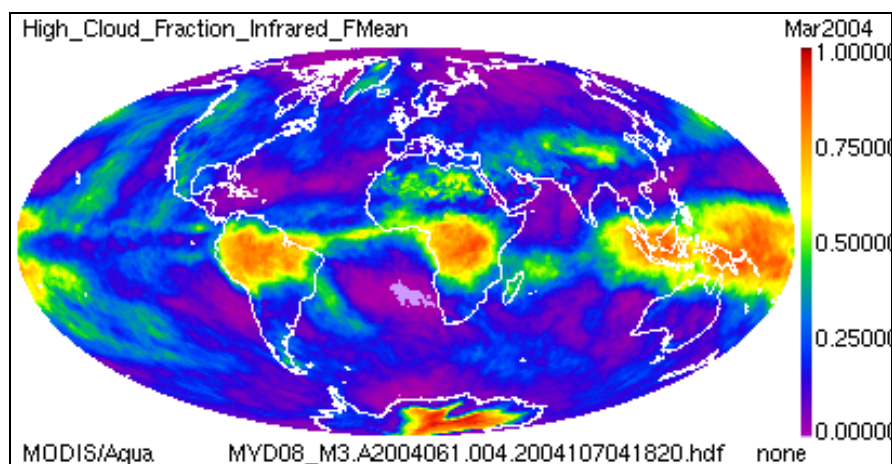
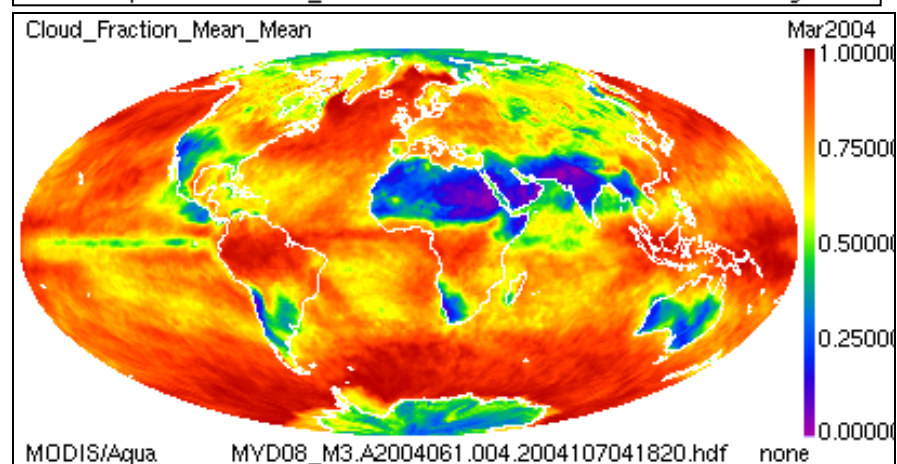
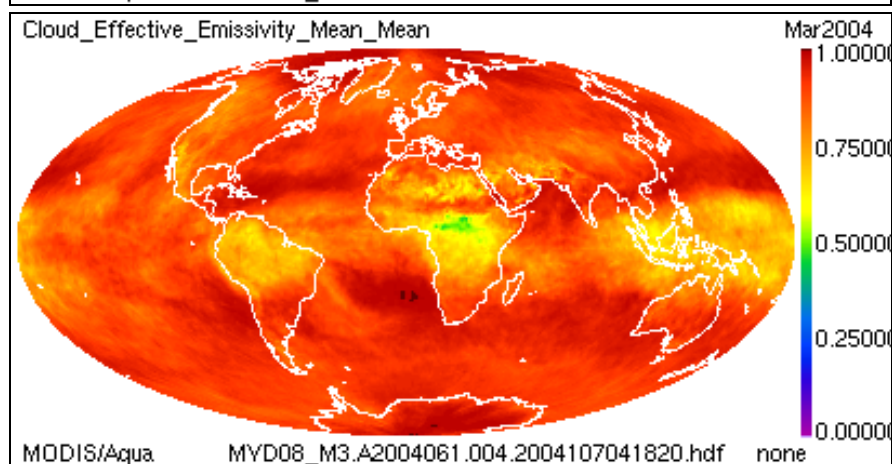
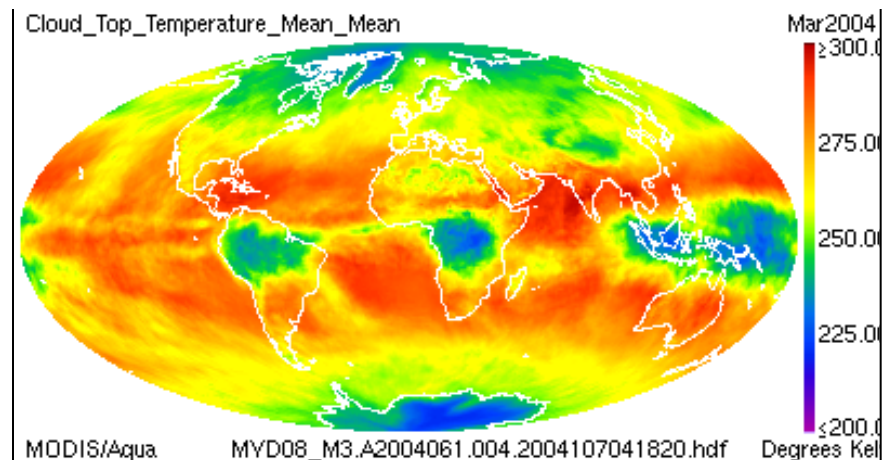
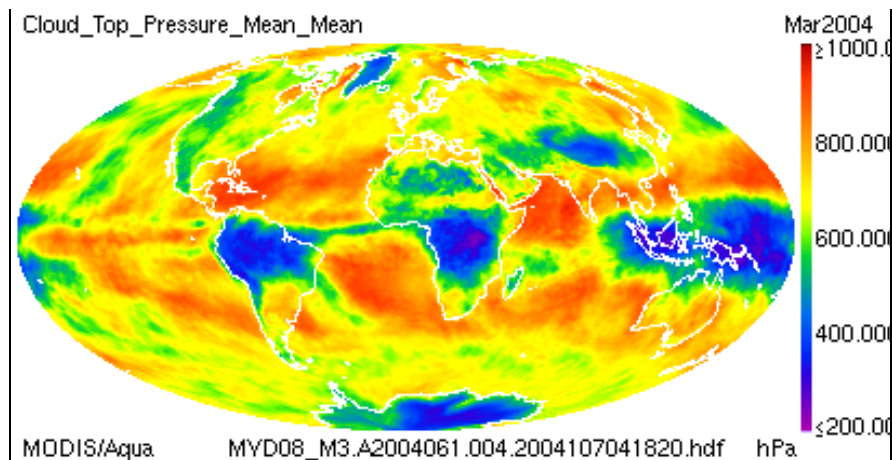
Clear Sky Only

Day/Night

5 x 5 km
resolution

Statistical
Algorithm





MODIS Cloud Top Properties Level 3 Products March 2004

End of Part One

