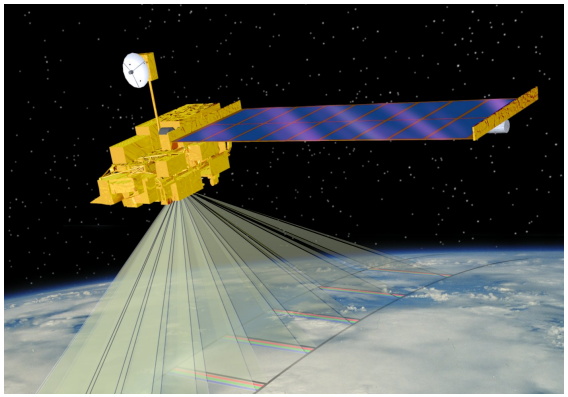
Introduction to the MODIS sensor and products



DB Applications Workshop
University of Puerto Rico - Mayaguez
April 2016

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

SSEC

Terra

Launched: Dec. 18, 1999

10:30 am descending node

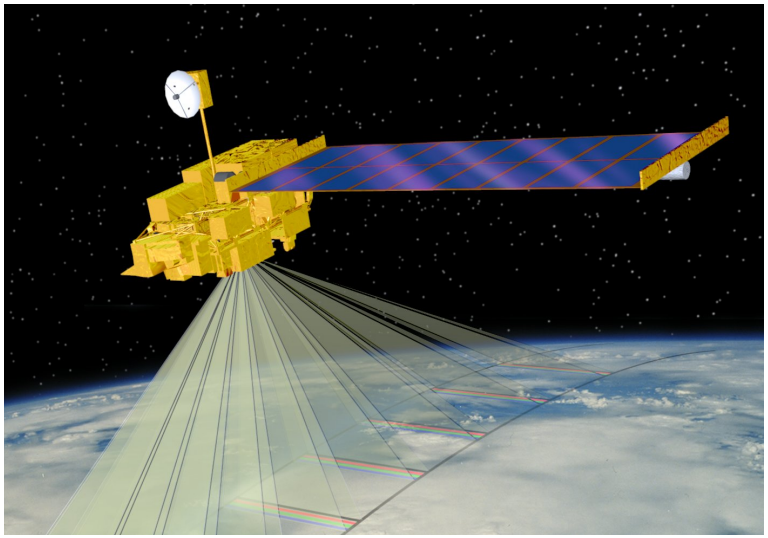
ASTER: Hi-res imager

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

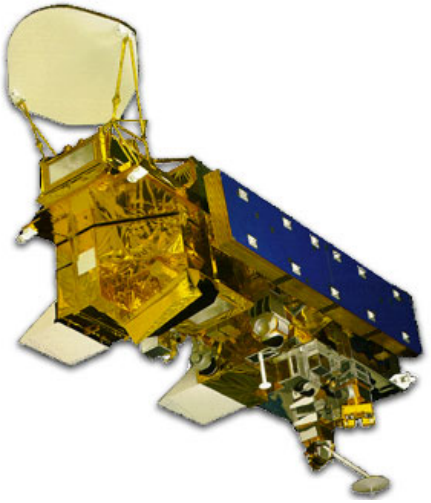
AIRS: Infrared sounder

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

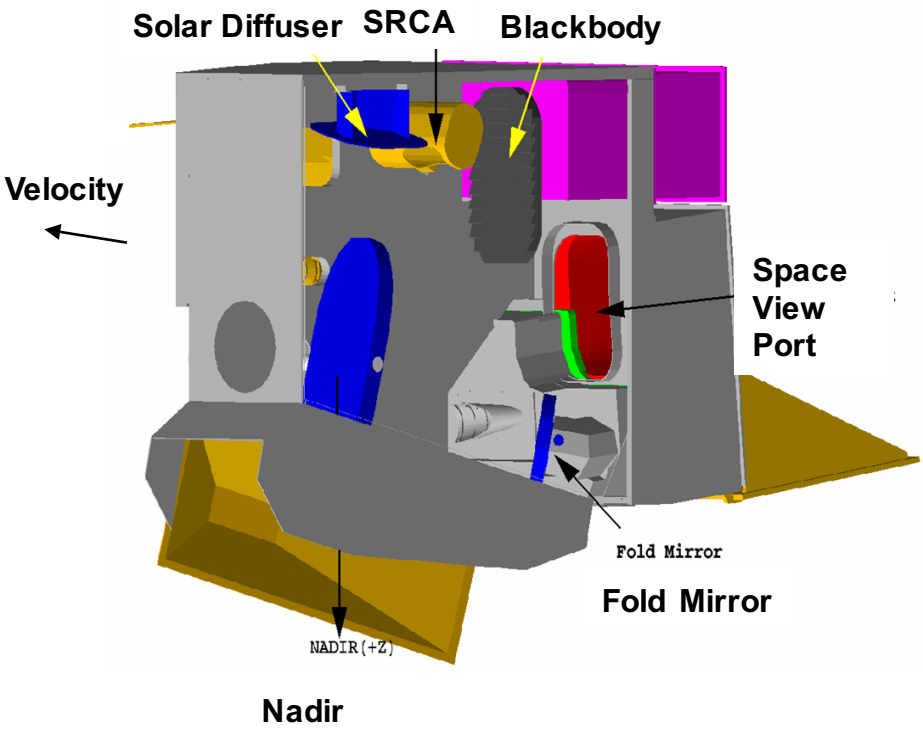
Spatial resolution: 2 bands @ 250 m; 5 @ 500 m; 29 @ 1000 m

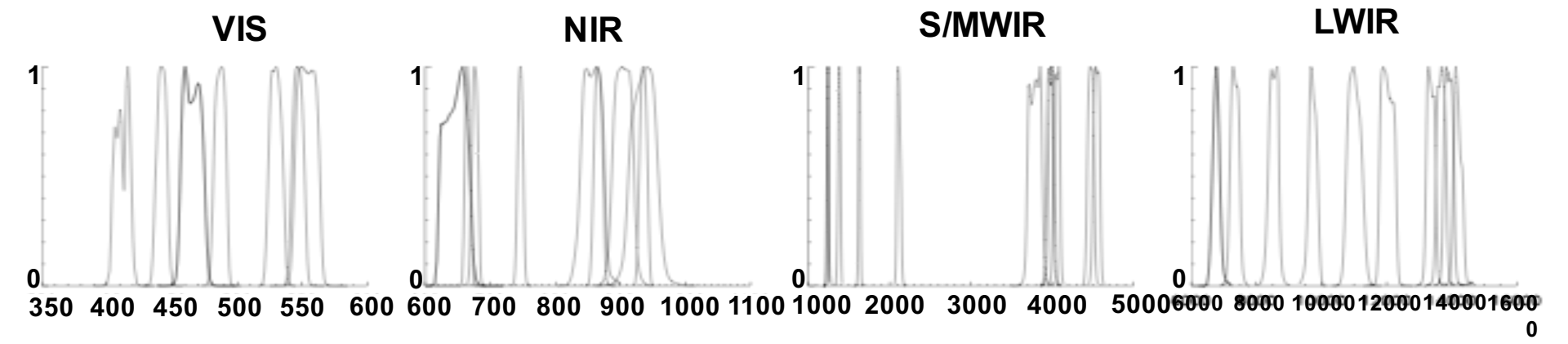
Major differences:

- 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





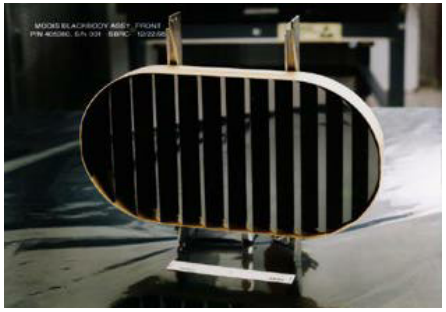
MODIS On-board Calibrators

SD

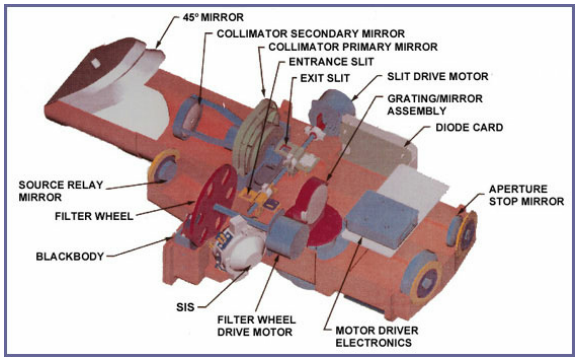
SDSM

- **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

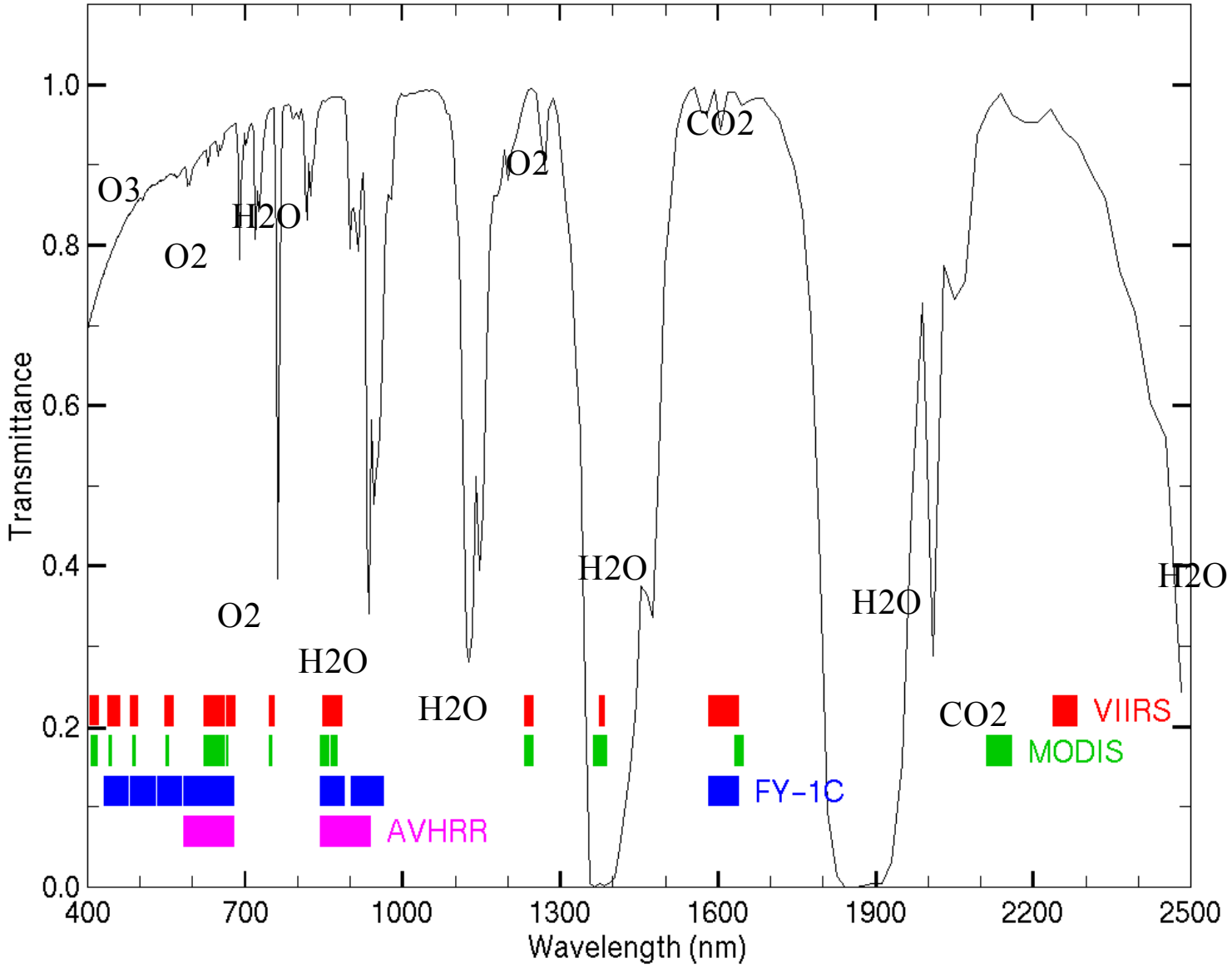
MODIS Reflected Solar Bands

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			

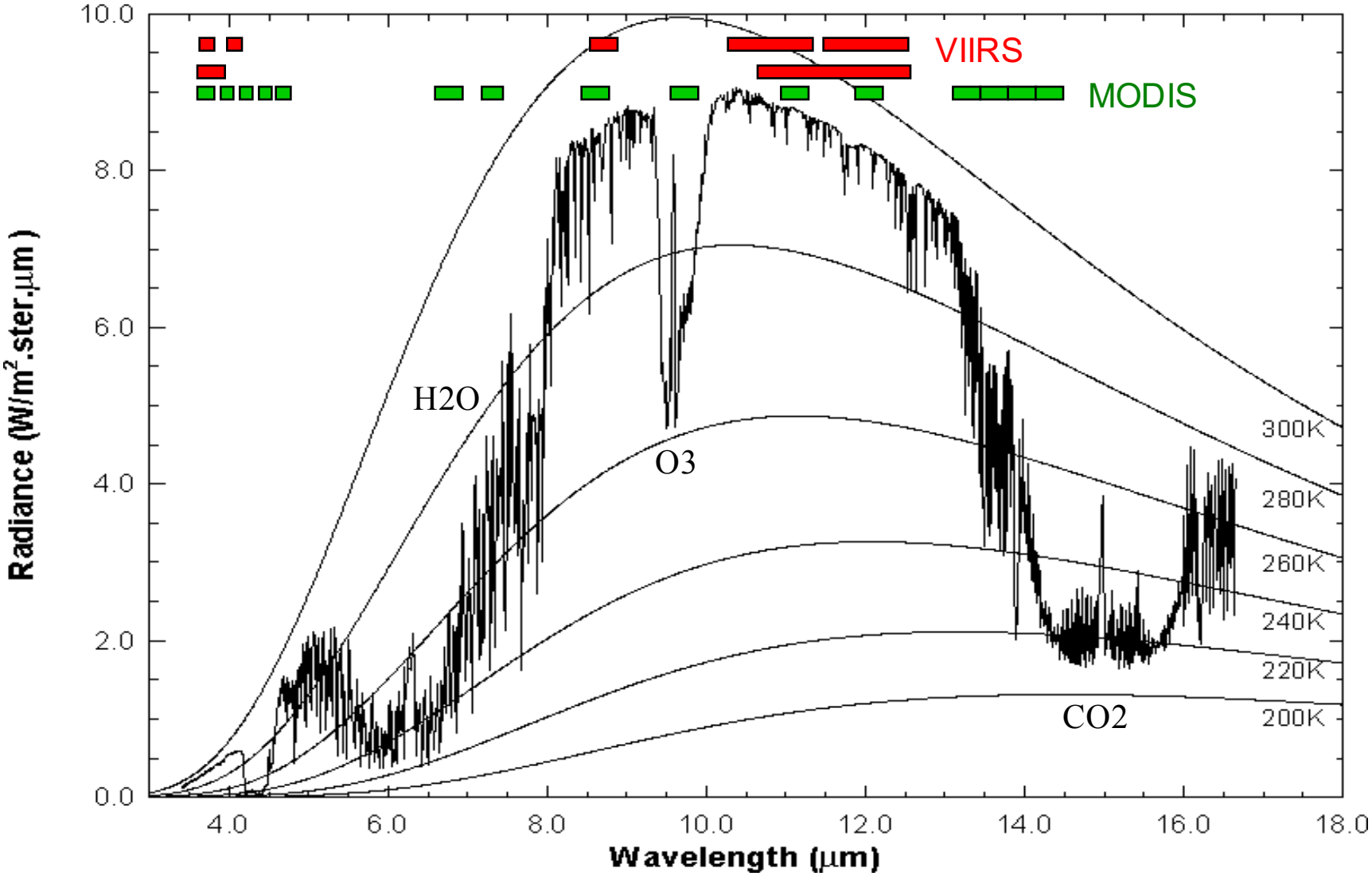
MODIS Thermal Emissive Bands

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

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

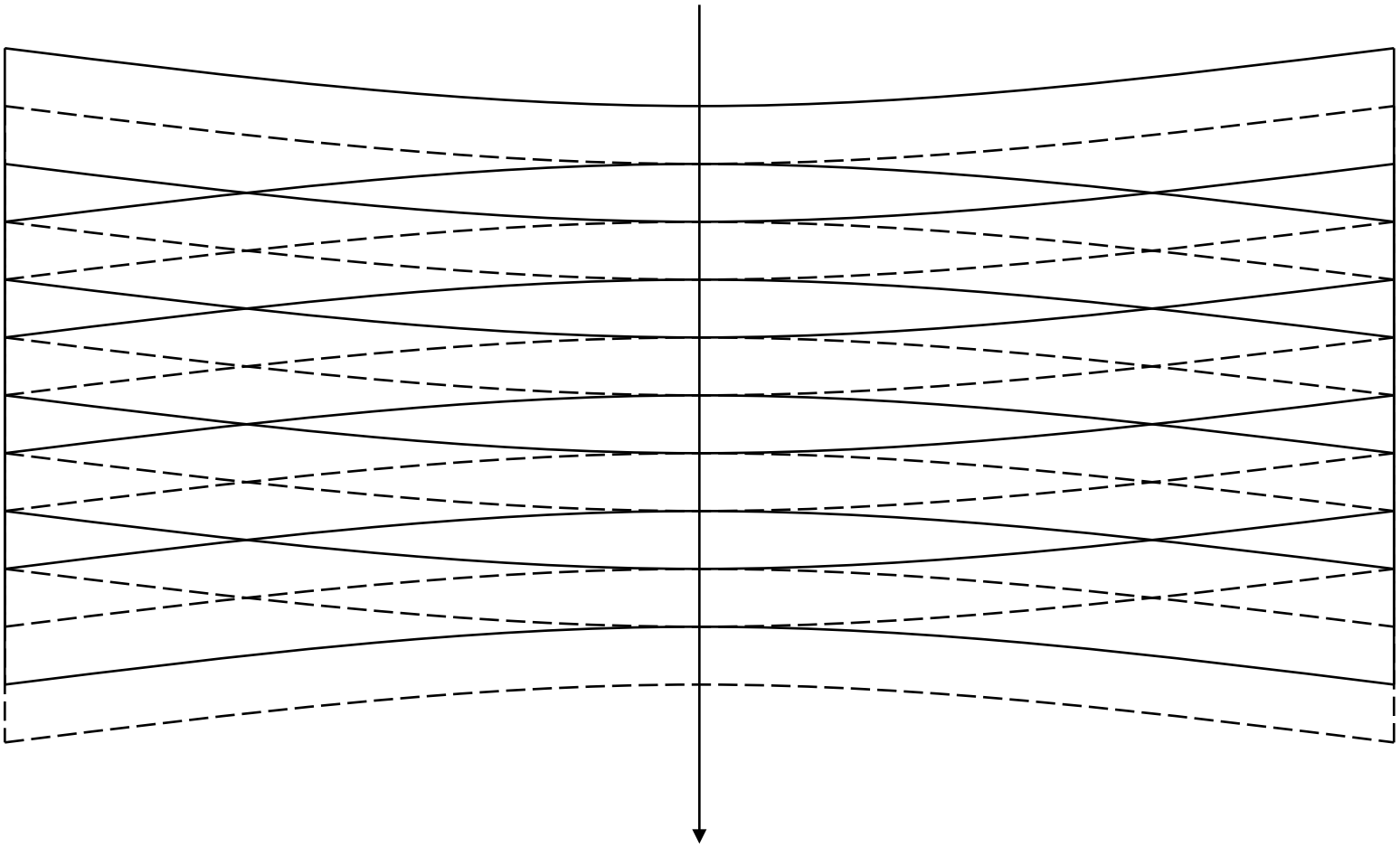
Scan rate: 1.477 scans/sec

Scan angle: +/- 55 degrees

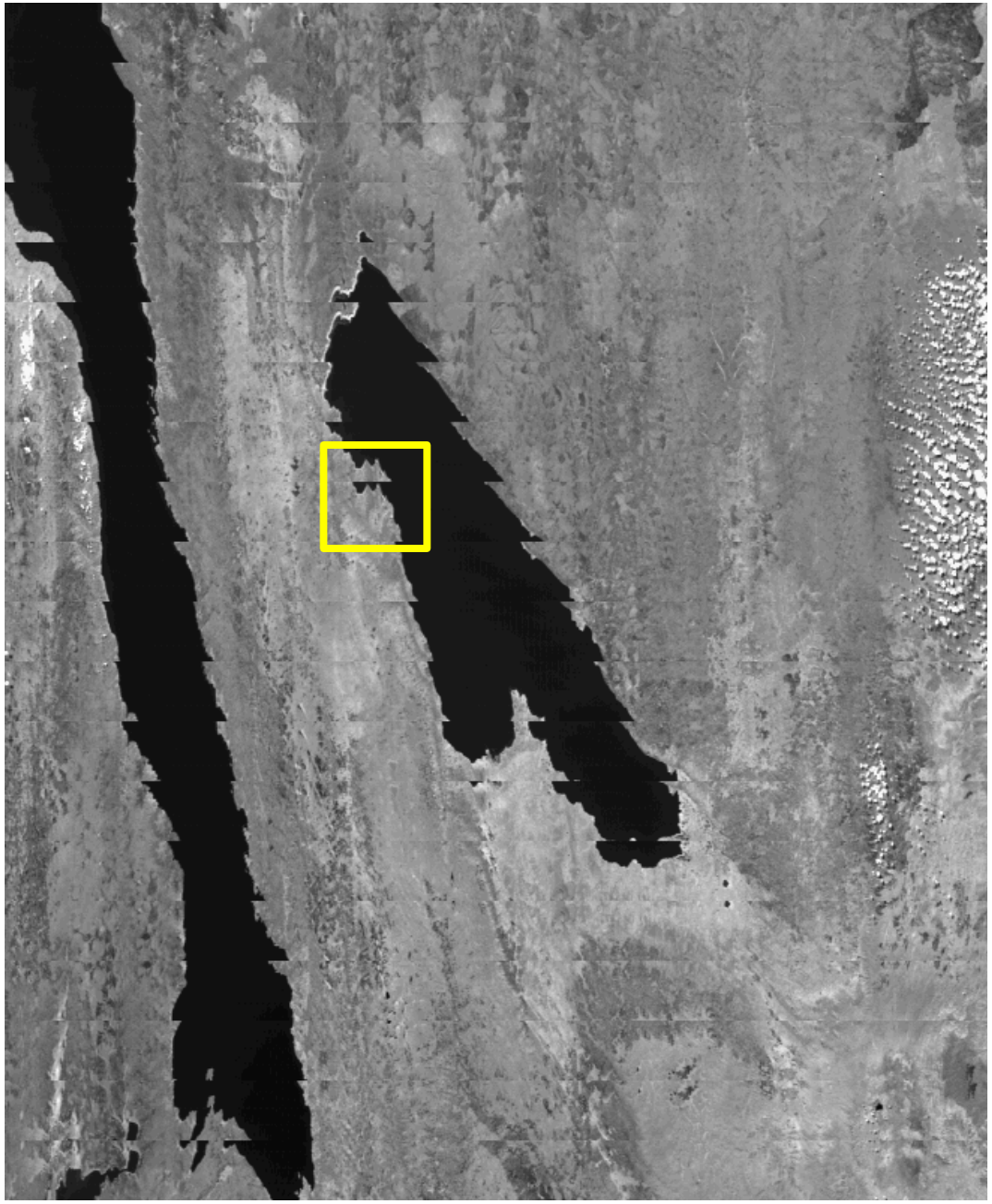
Swath width: 2330 km across track, 10 km along track

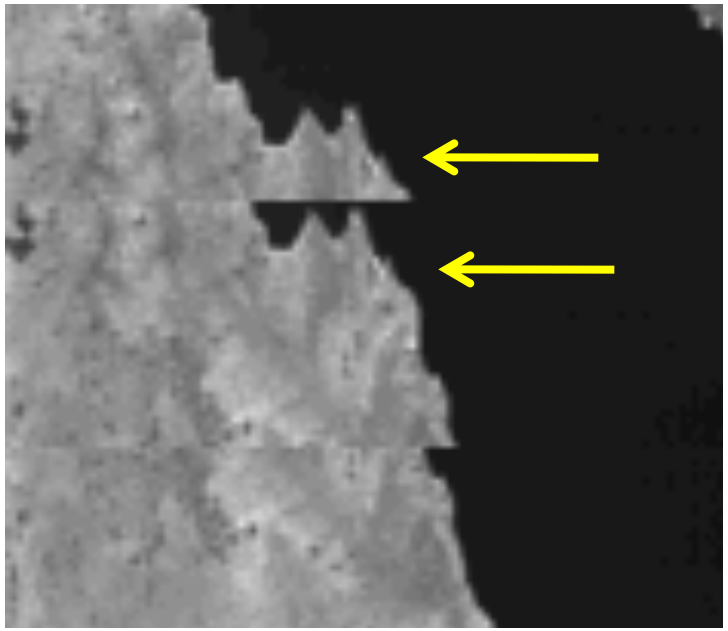
MODIS Bowtie

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



MODIS bowtie artifacts at edge of swath





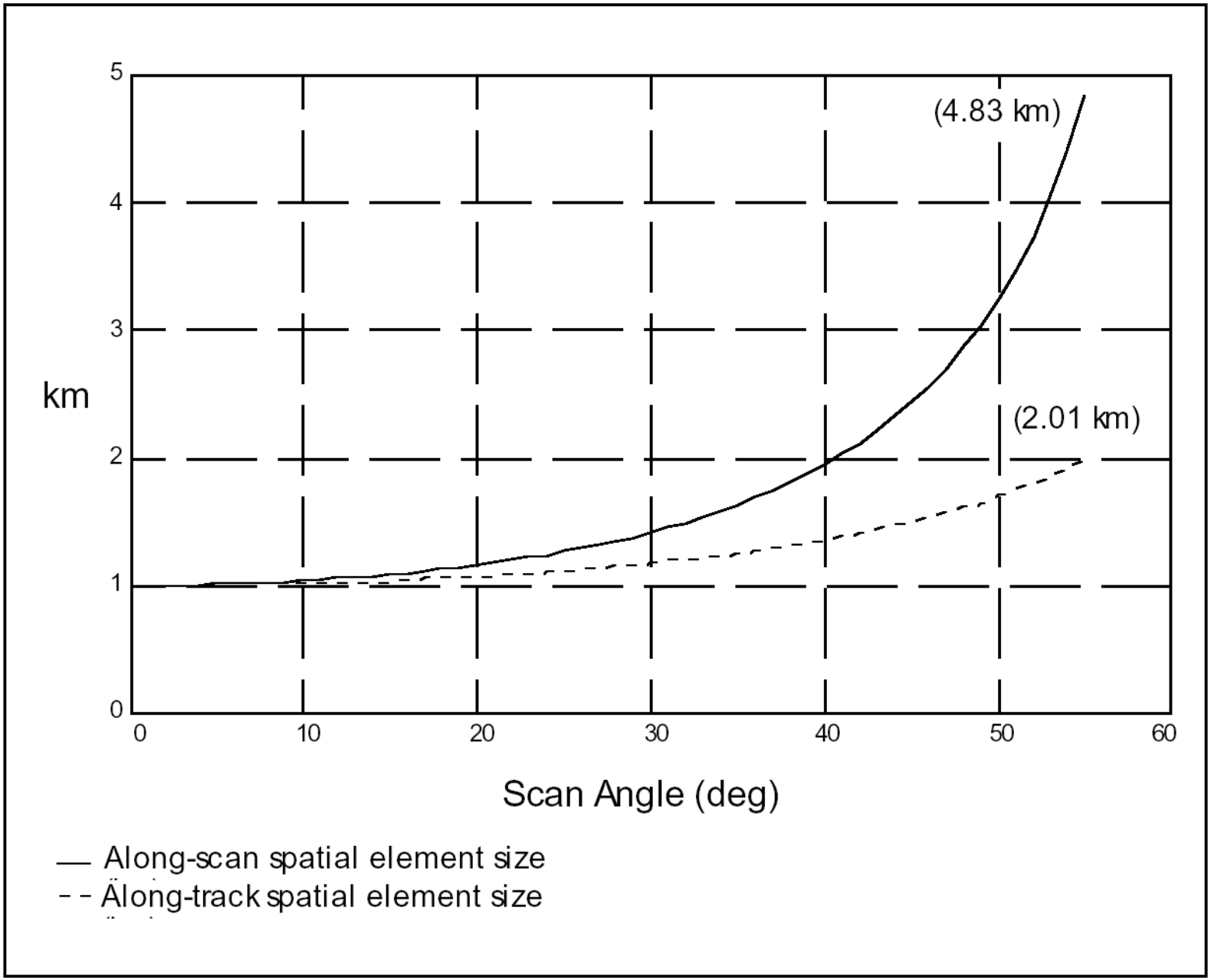
Band 2 (0.87 micron)

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



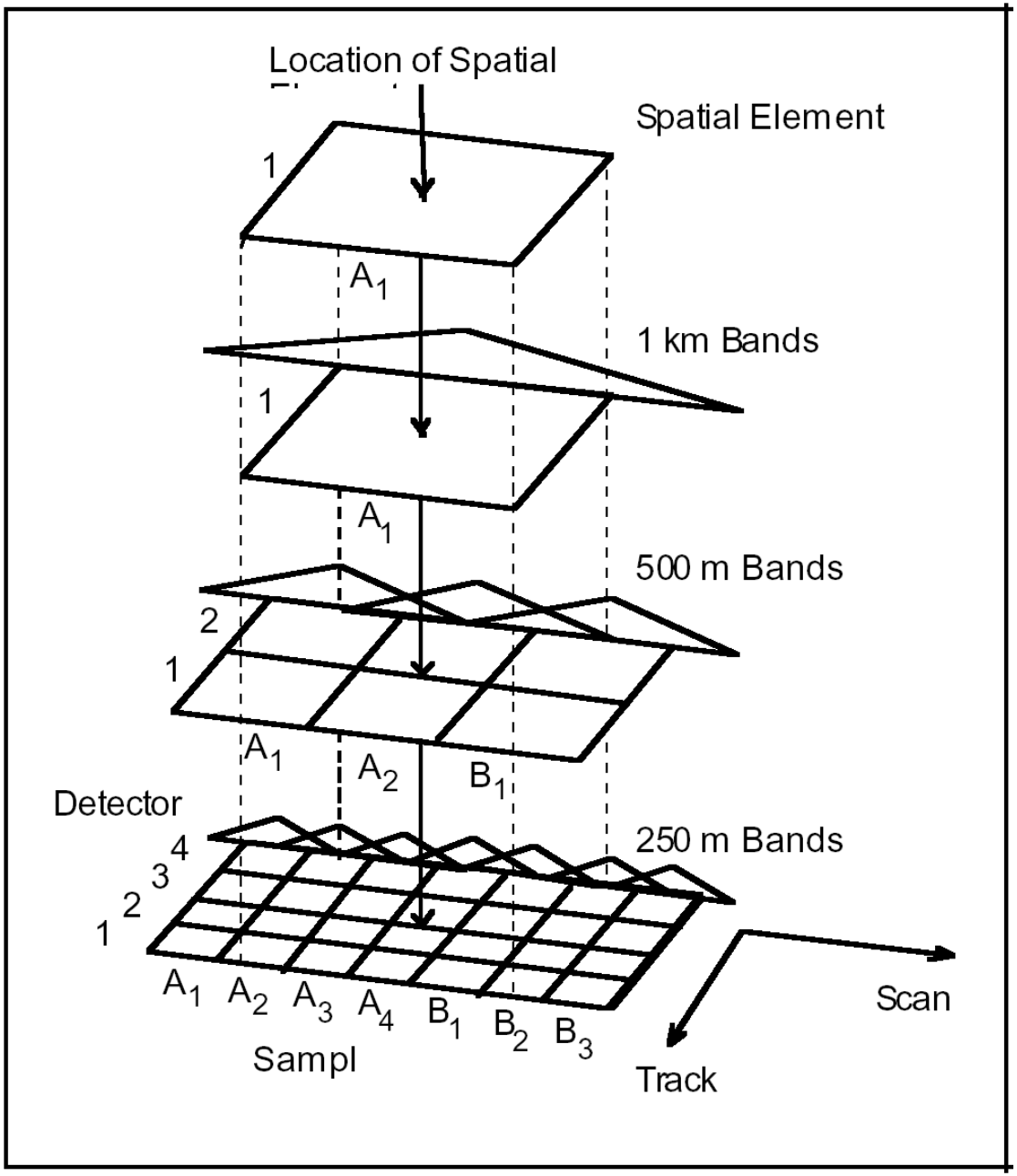
Inter-band Registration

MODIS pixel

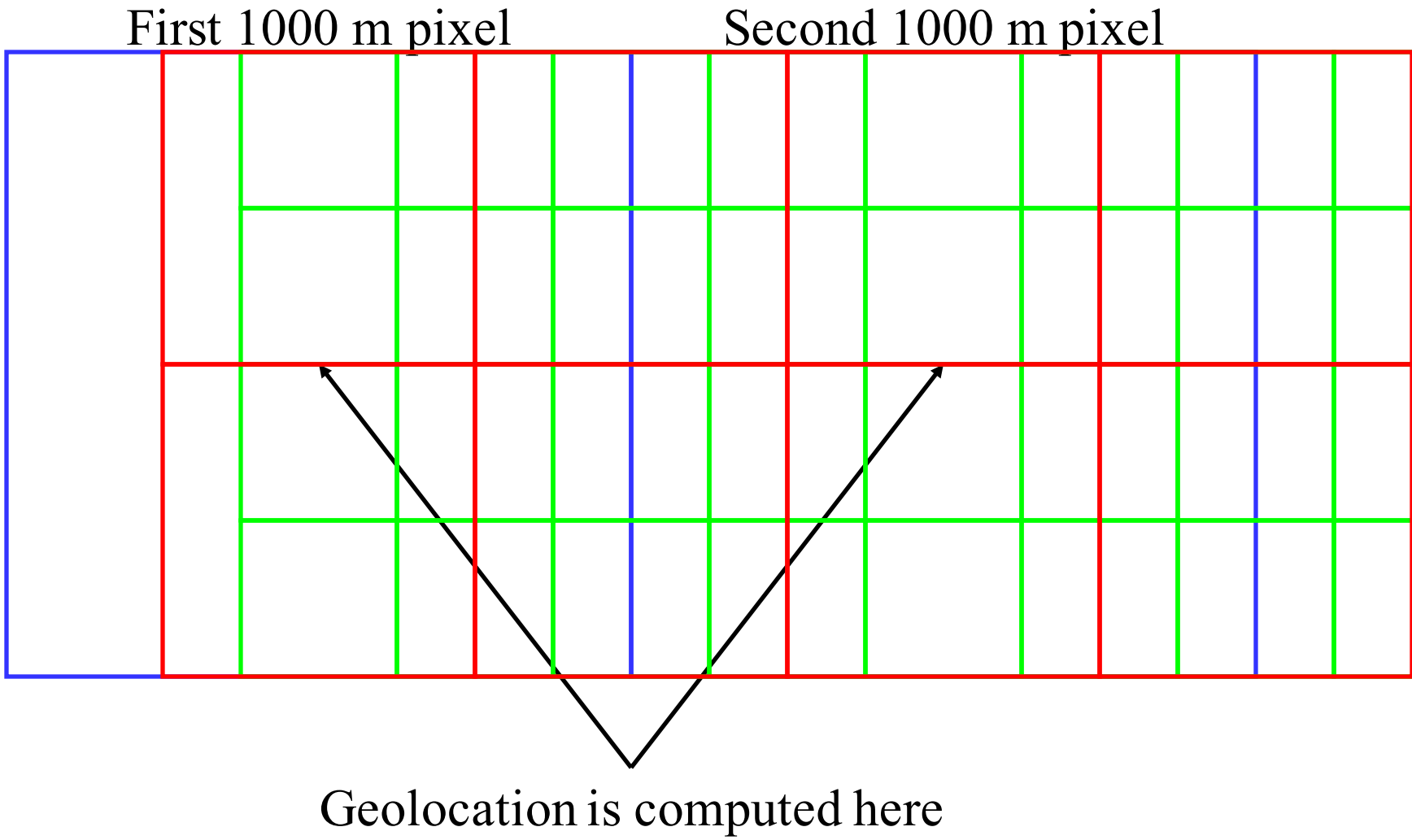
1000 meter

500 meter

250 meter



Nominal MODIS inter-band registration

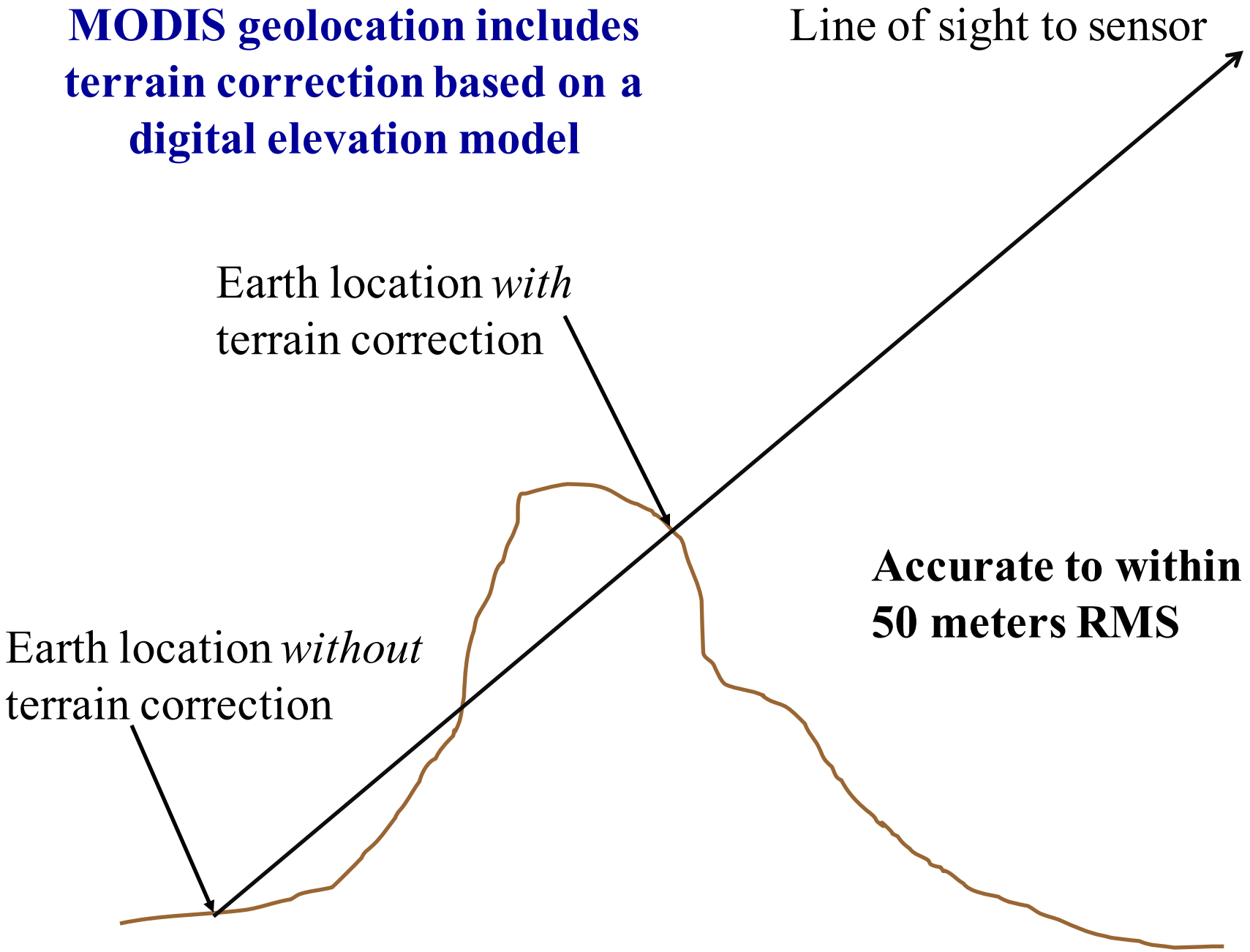


MODIS Geolocation

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

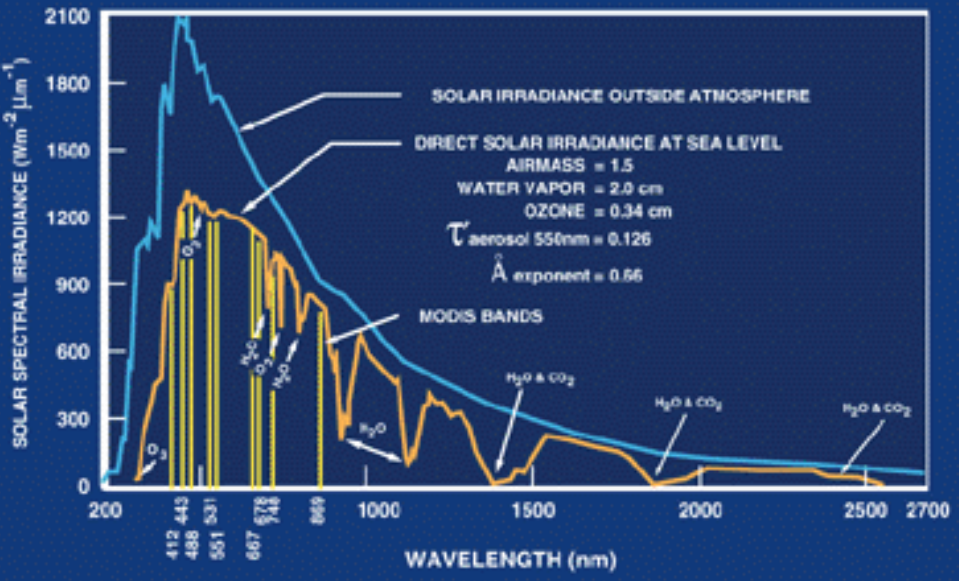
- Geodetic latitude (degrees, -90S to +90N)
- Geodetic longitude (degrees, -180W to +180E)
- Sensor zenith and azimuth (degrees, pixel to sensor)
- Solar zenith and azimuth (degrees, pixel to sun)
- Terrain height above geoid (meters)
- Land/Sea mask
    - 0: Shallow Ocean
    - 1: Land
    - 2: Ocean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

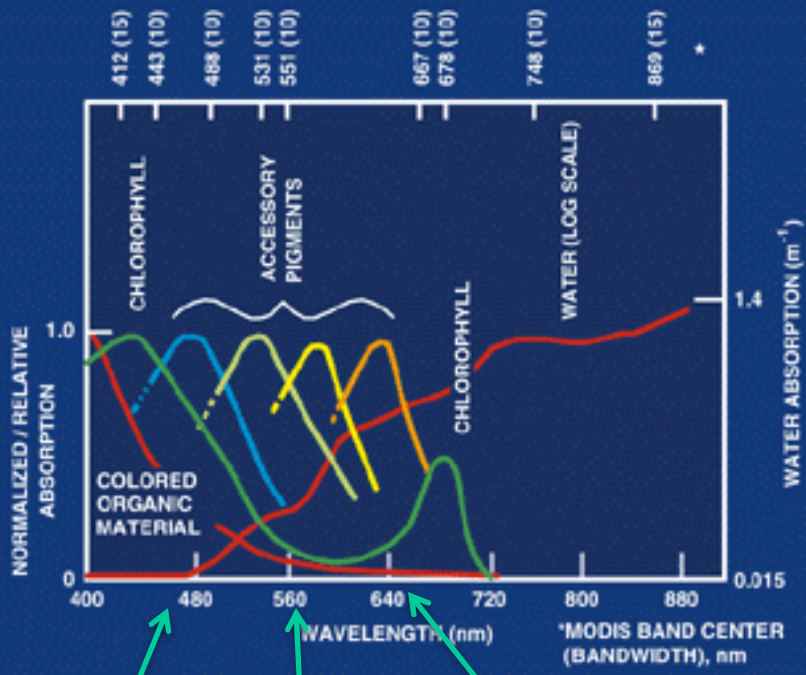
MODIS geolocation includes terrain correction based on a digital elevation model



MODIS Ocean Applications

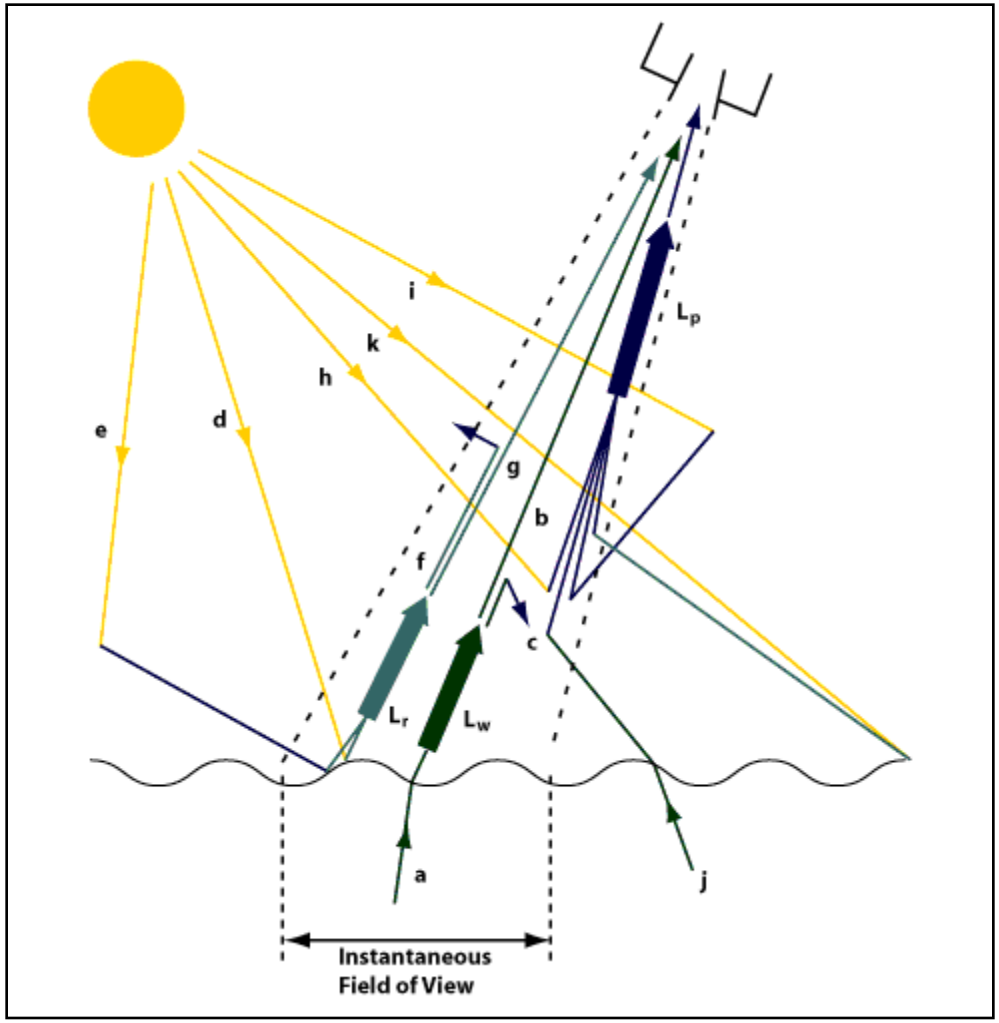
OCEAN-SOLAR RADIATION





Blue Green Red

Atmospheric correction is critical for ocean color



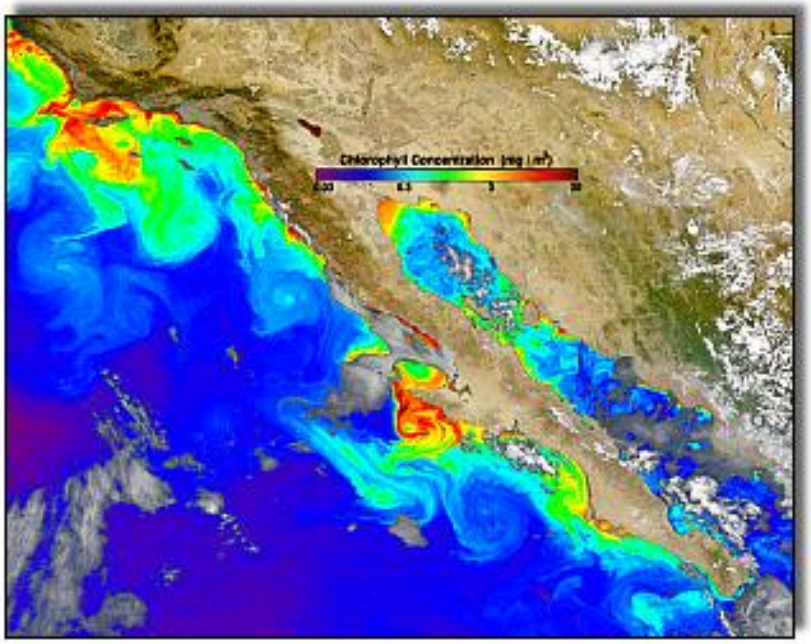
L_w – only 5% of signal reaching satellite: rest due to L_p

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

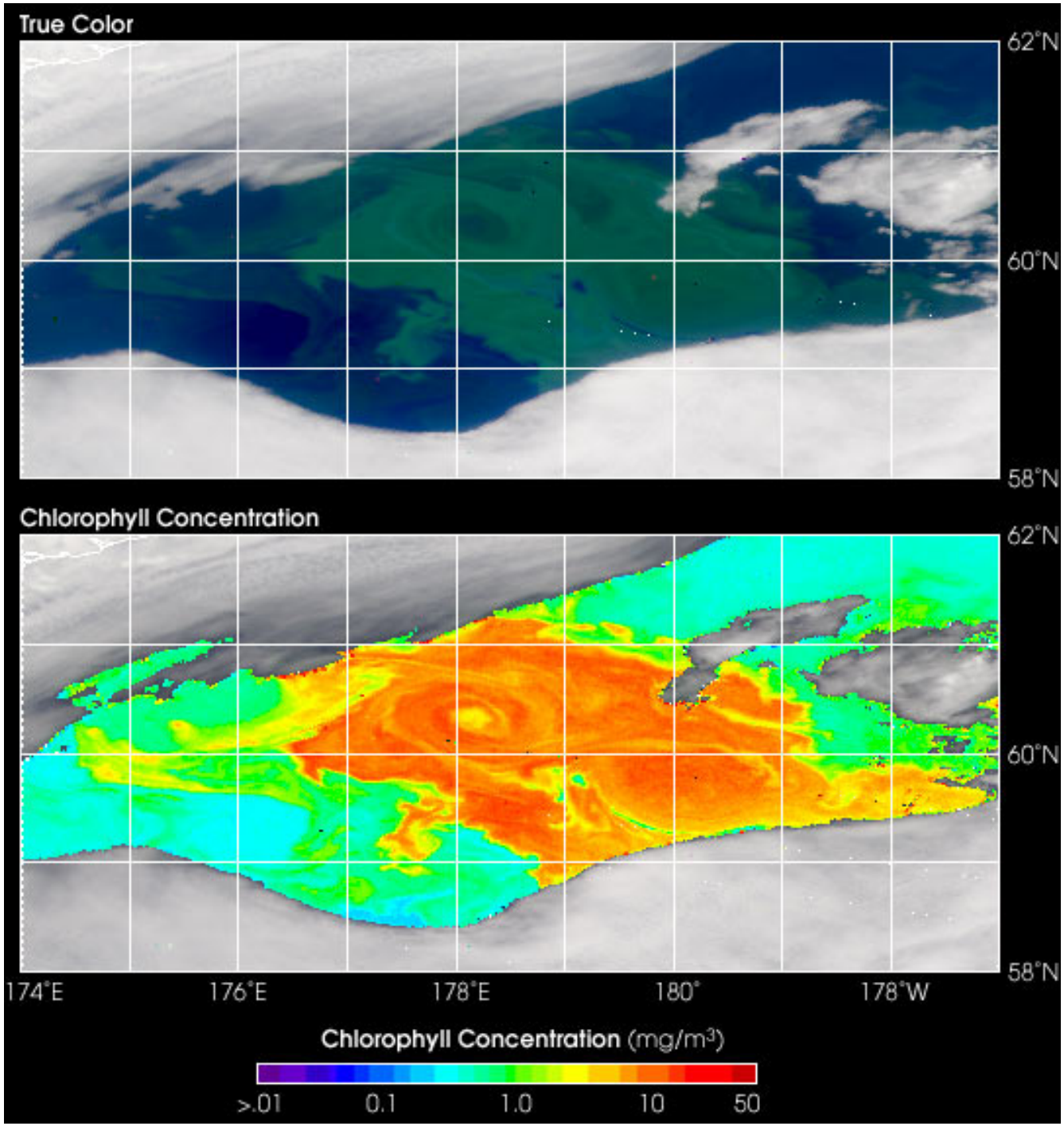


August 10, 2003

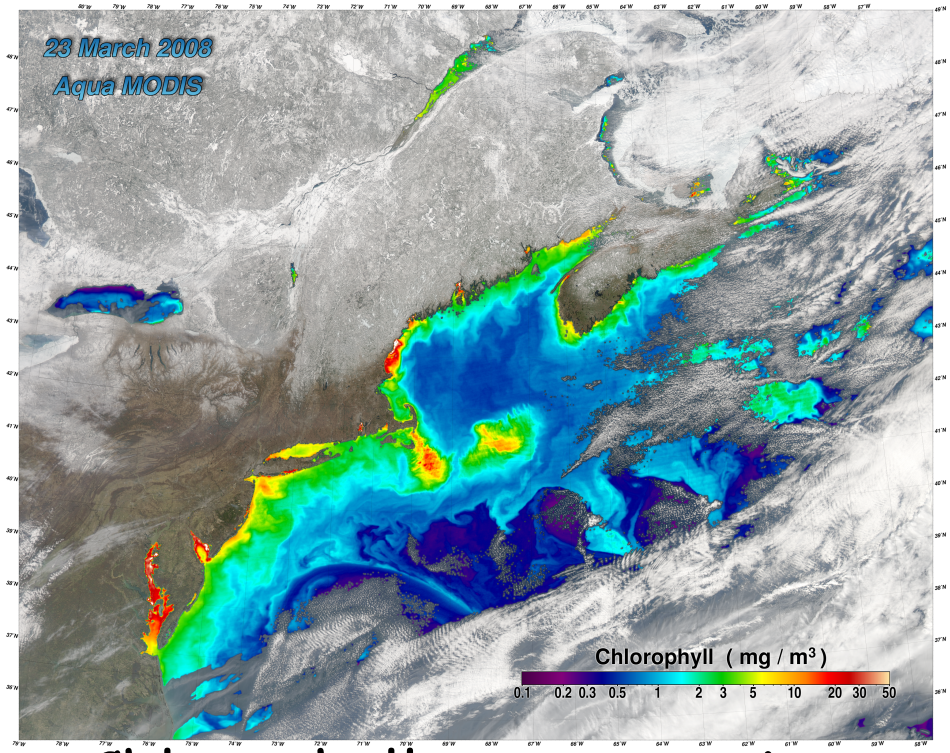
Strong absorption of the blue light by phytoplankton in chlorophyll-rich waters results in low water-leaving radiance in the blue bands.

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

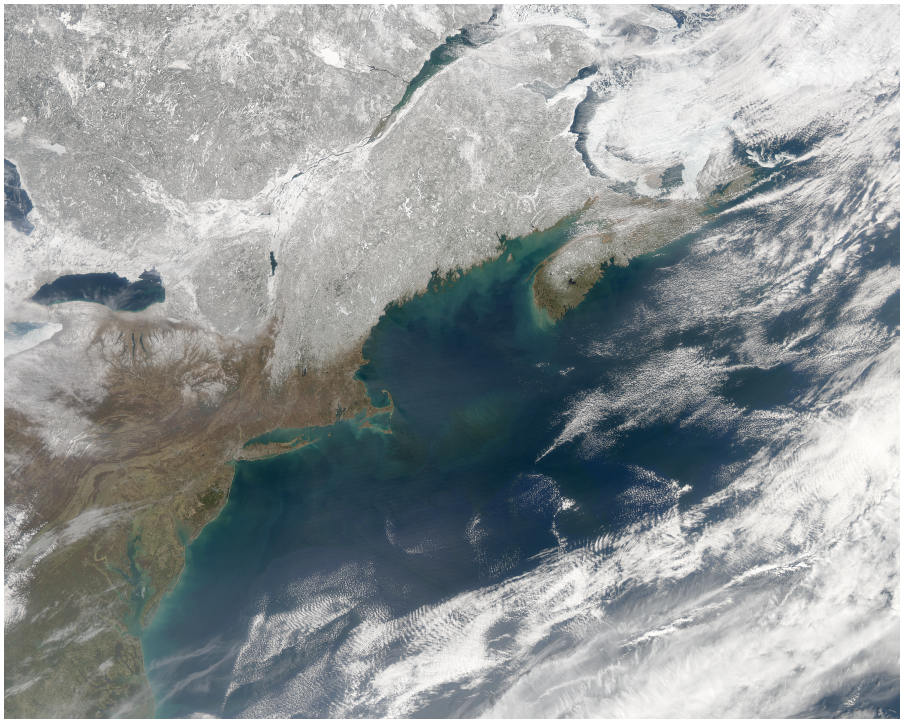
Index of the change in spectral shape ⇝ chlorophyll


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

March 23, 2008 MODIS Aqua
Northeast USA and Canada

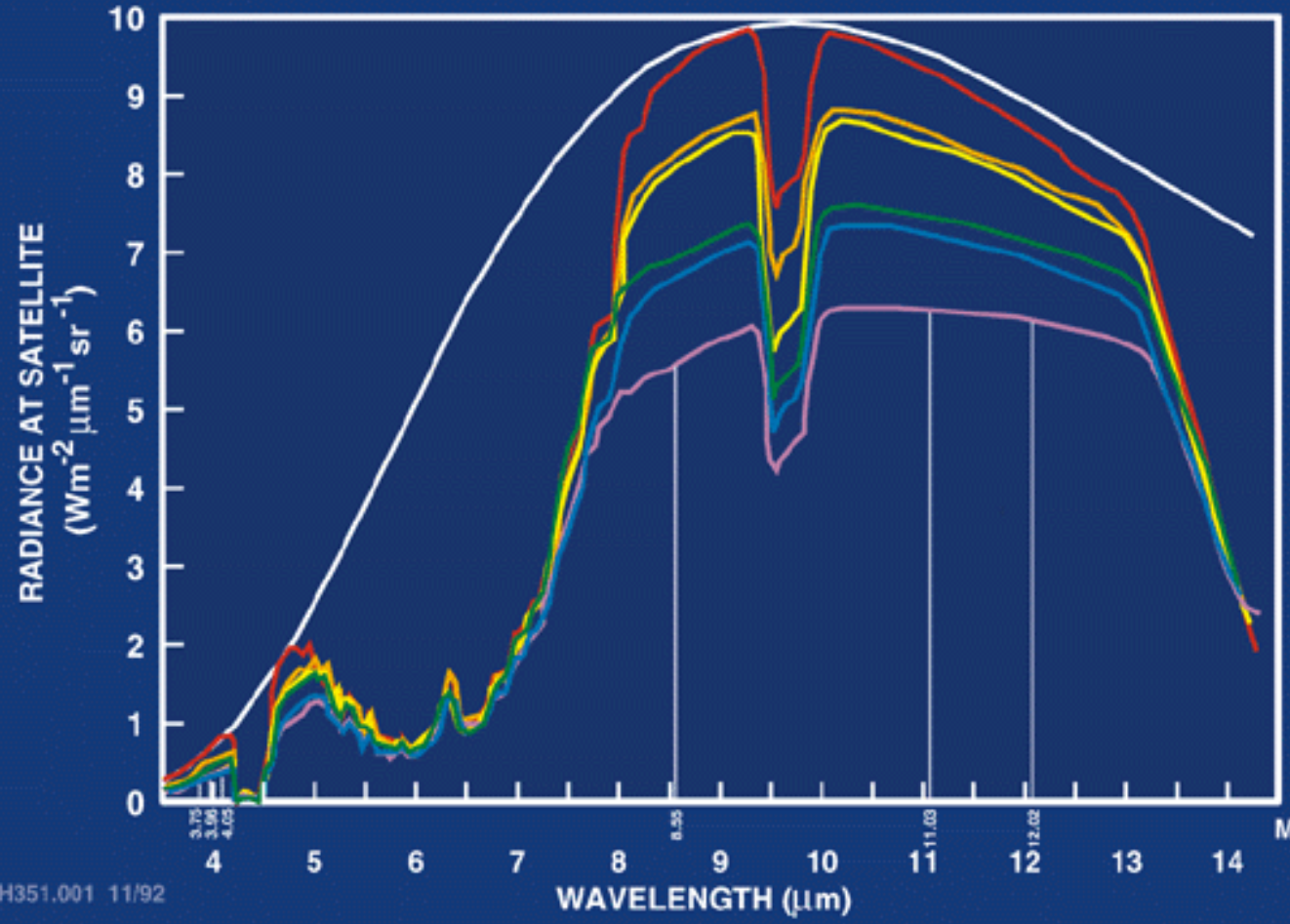


Chlorophyll concentration



True color

MODIS SEA SURFACE TEMPERATURE



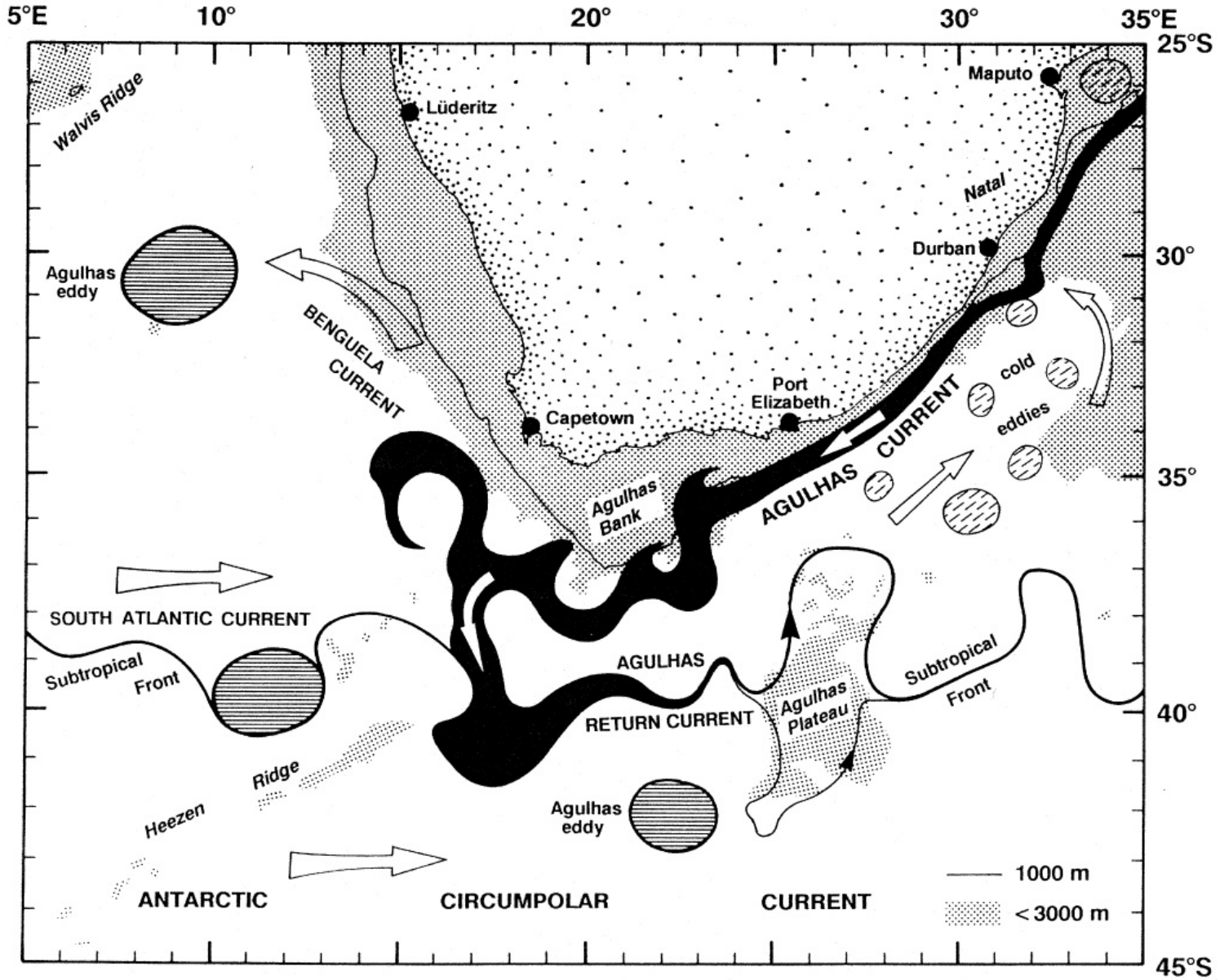
LOWTRAN-7 MODEL
MARITIME AEROSOL
VISIBILITY 23km
SPRING-SUMMER

- BLACKBODY 300K
- TROPICAL 303K
- TROPICAL 293K
- MID-LAT. 293K
- MID-LAT. 283K
- SUBARCTIC 283K
- SUBARCTIC 273K

MODIS-N BANDS

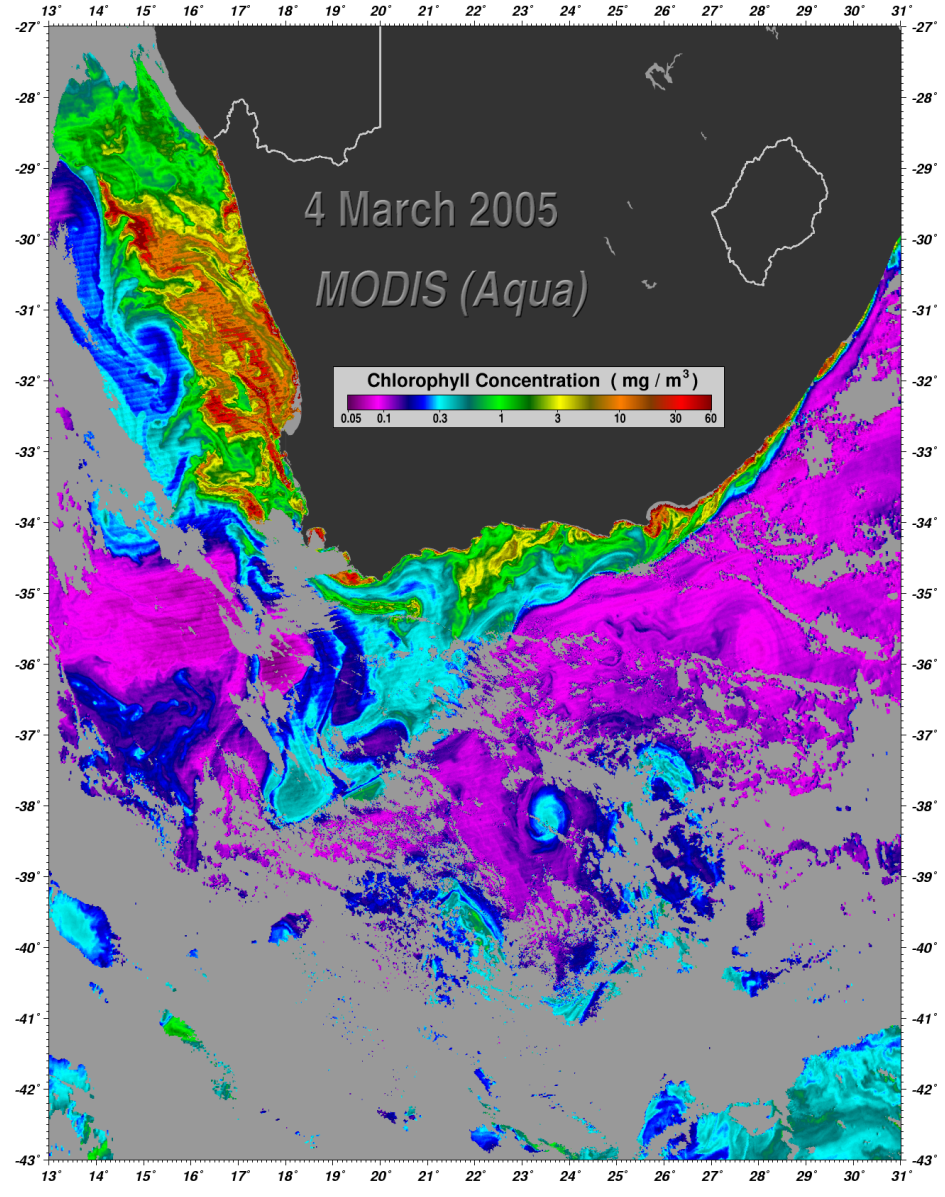
H351.001 11/92

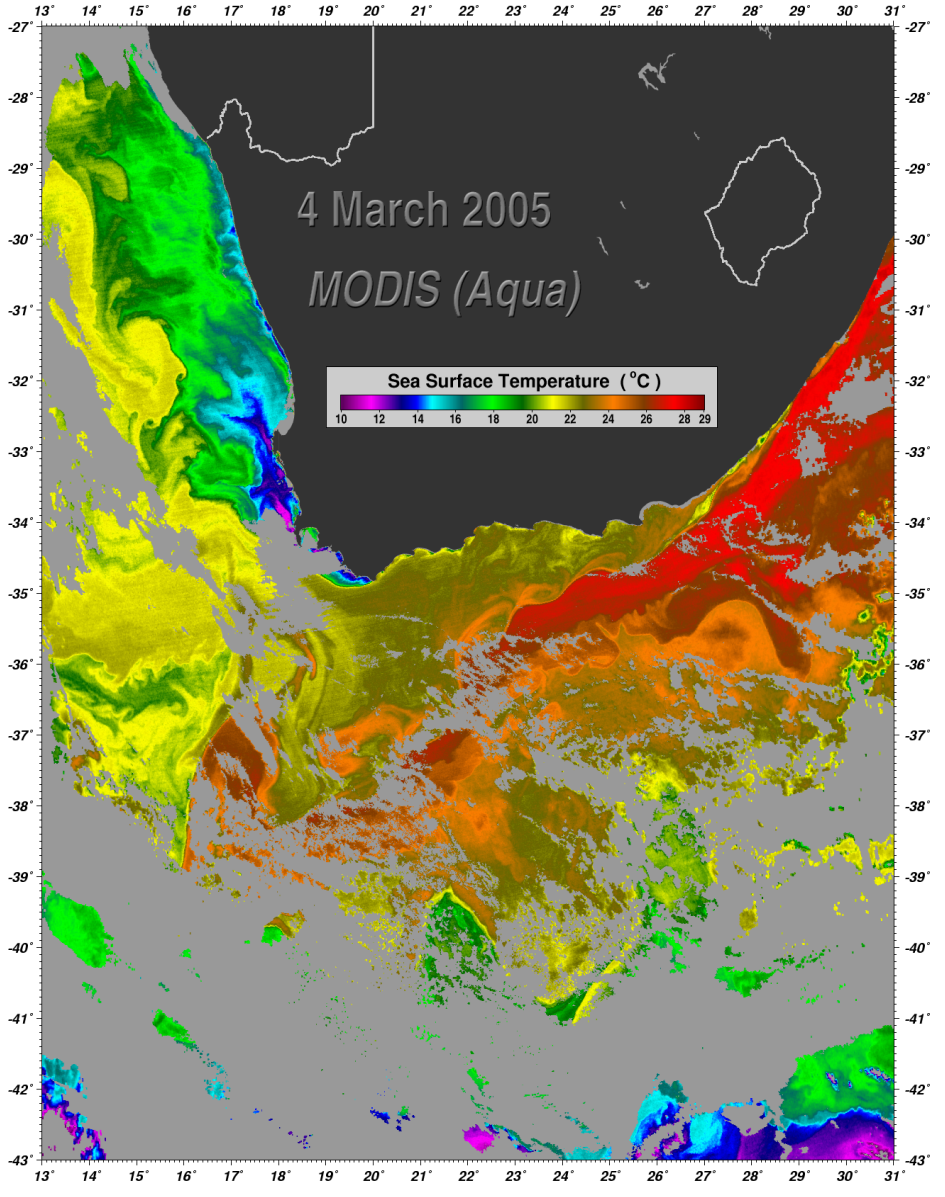
Ocean currents near Southern Africa



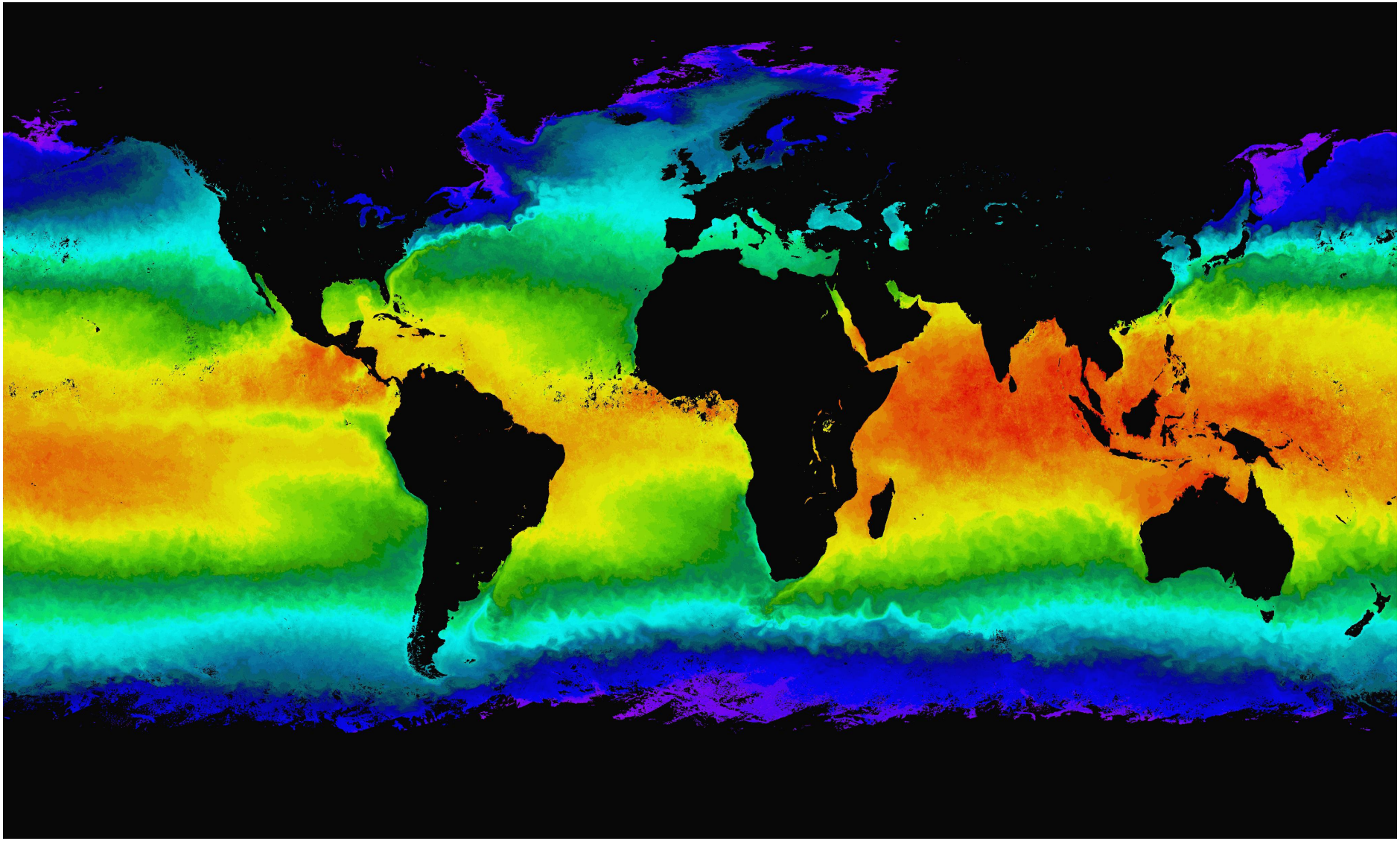
Peterson and Stramma, 1991

Agulhas & Benguela Currents

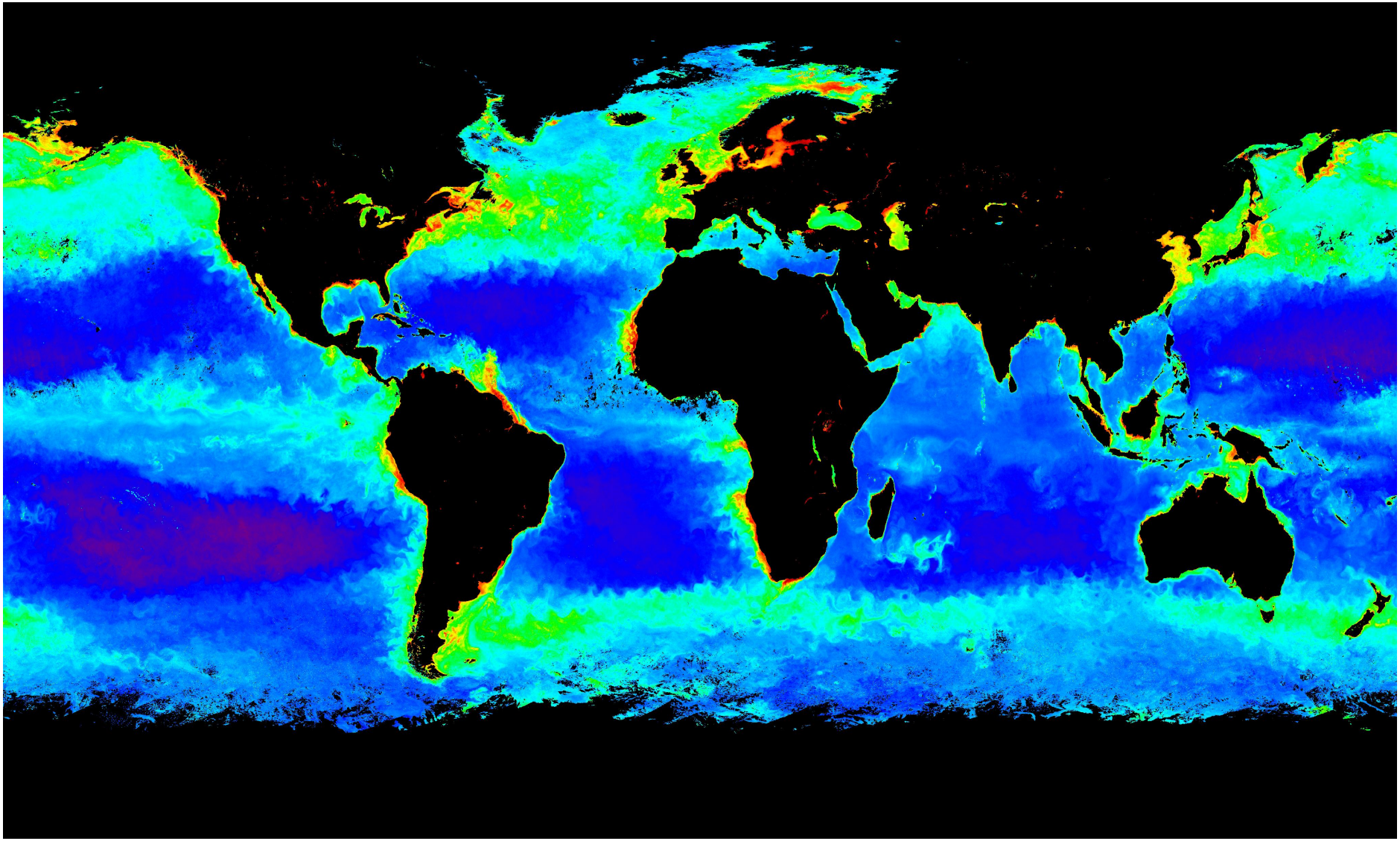


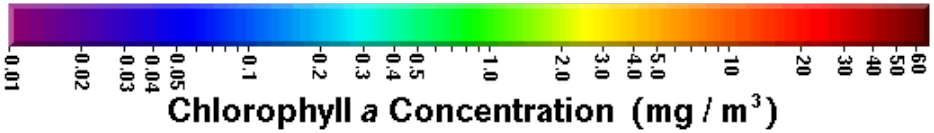


Aqua MODIS Sea Surface Temperature, April 2004



Aqua MODIS Chlorophyll Concentration, April 2004



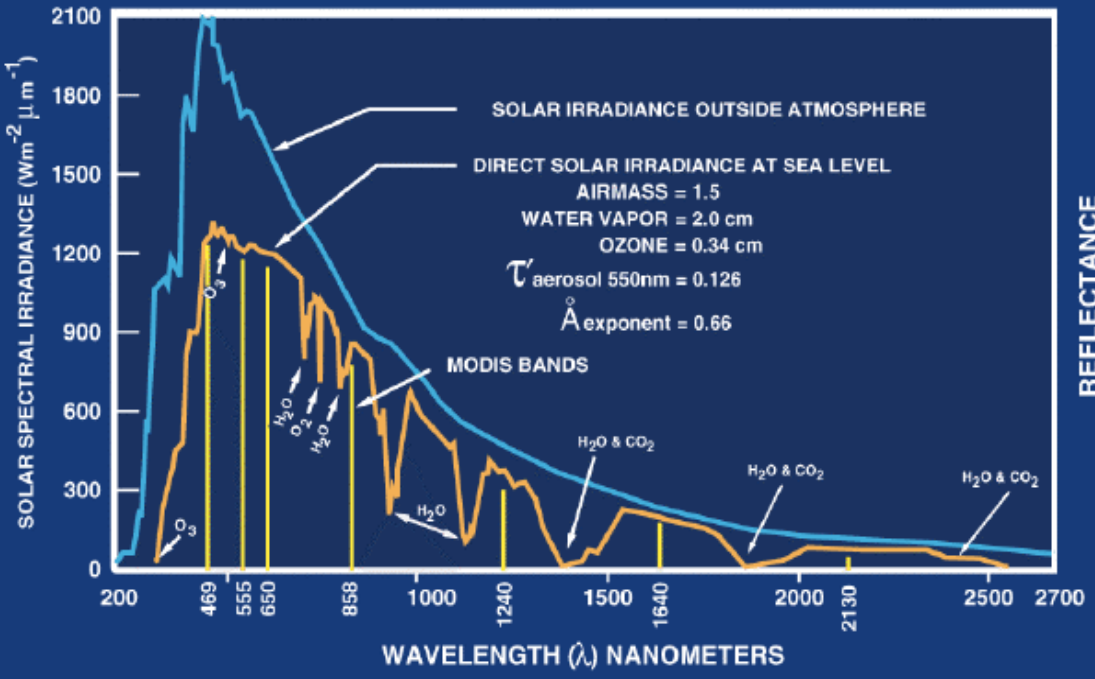


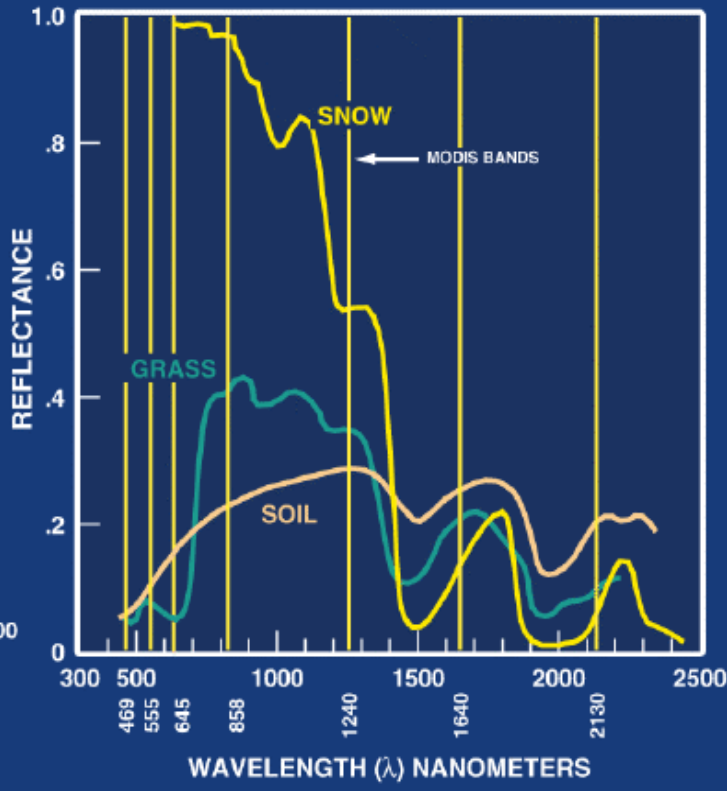
MODIS Land/Surface Applications

MODIS Land Products

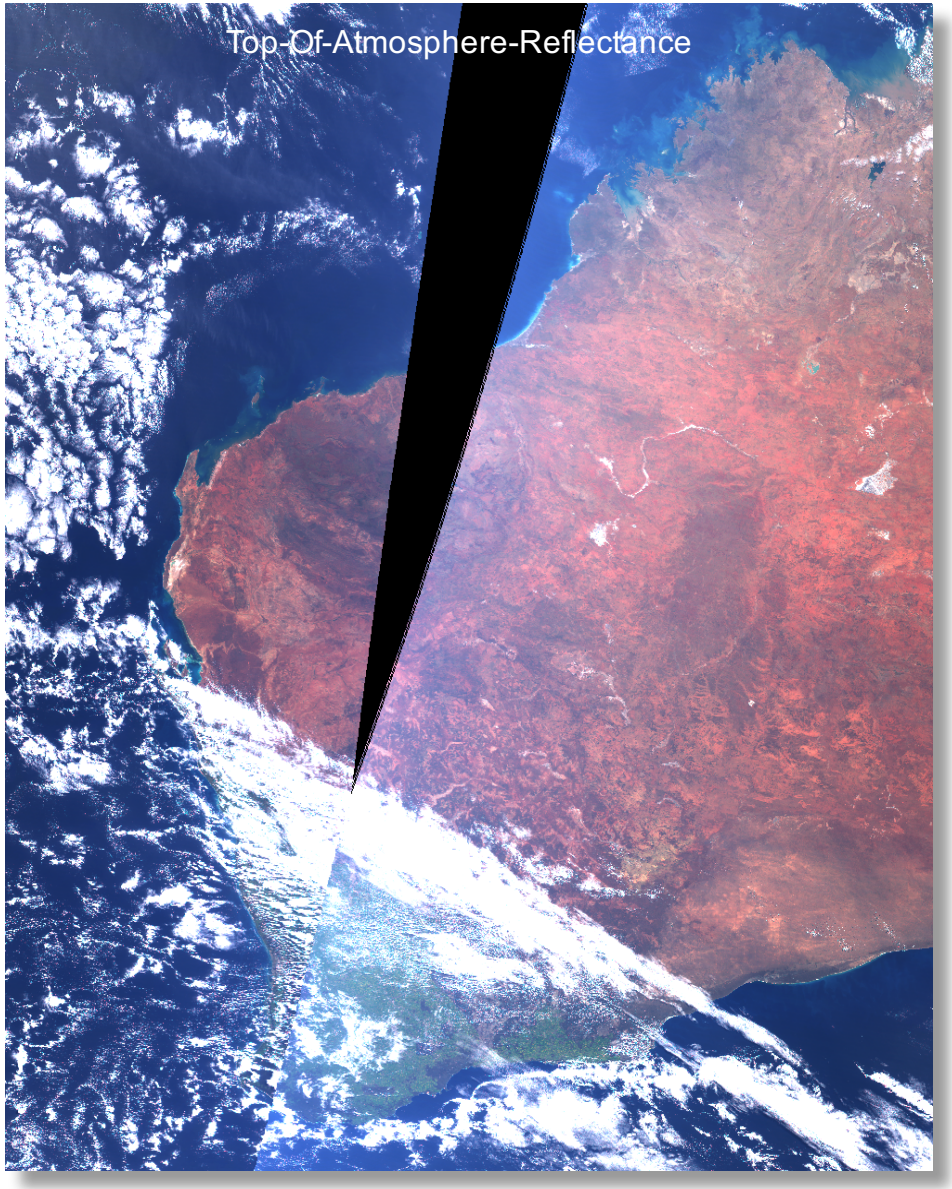
MOD 09 - Land Surface Reflectance
MOD 10 - Snow Cover
MOD 11 - Land Surface Temperature & Emissivity
MOD 12 - Land Cover/Land Cover Change
MOD 13 - Gridded Vegetation Indices (NDVI & EVI)
MOD 14 - Thermal Anomalies (Fires)
MOD 15 - Leaf Area Index & FPAR
MOD 16 - Evapotranspiration
MOD 17 - Net Photosynthesis and Primary Productivity
MOD 29 - Sea Ice Cover
MOD 43 - Nadir BRDF Adjusted Reflectance
MOD 44 - Vegetation Cover Conversion

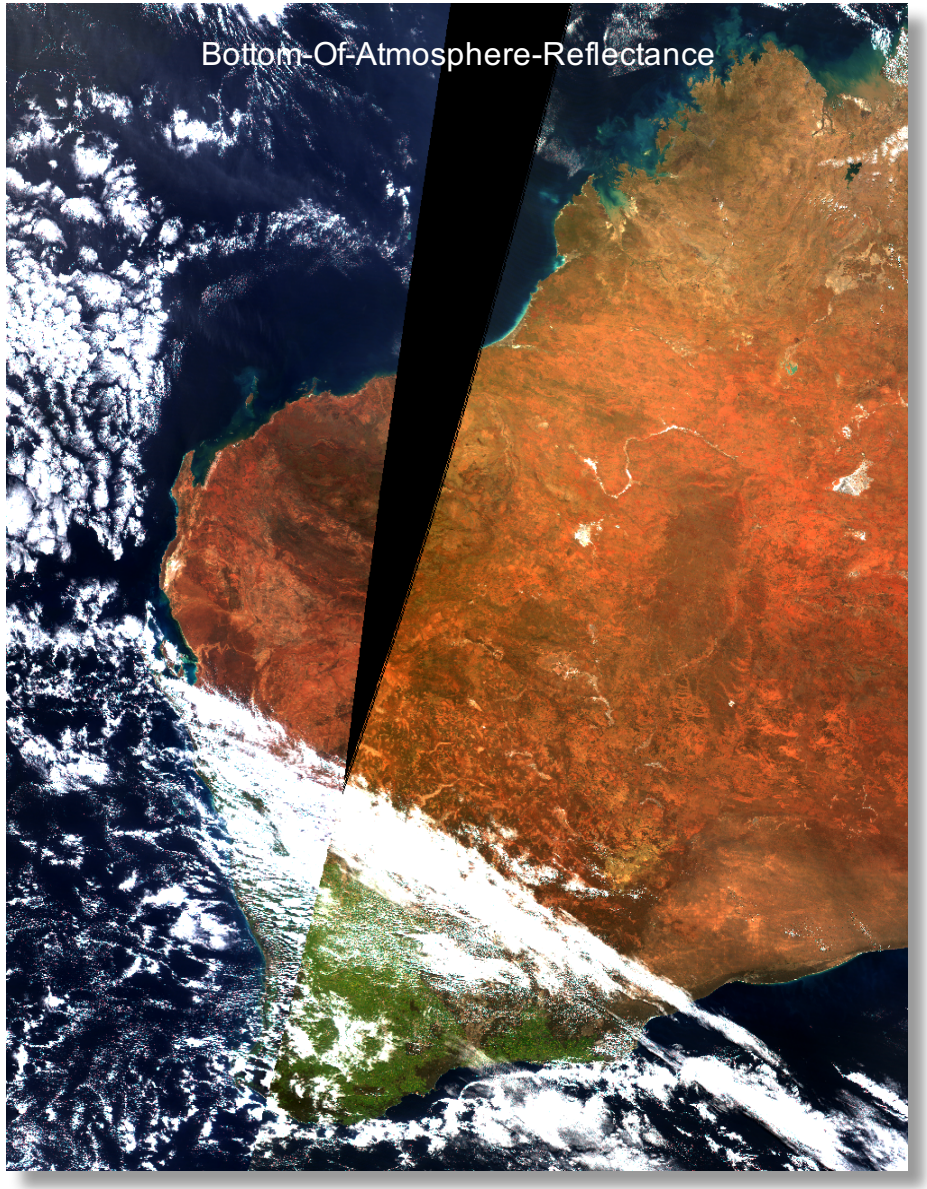
LAND-SOLAR RADIATION





Atmospheric scattering is removed to retrieve surface properties

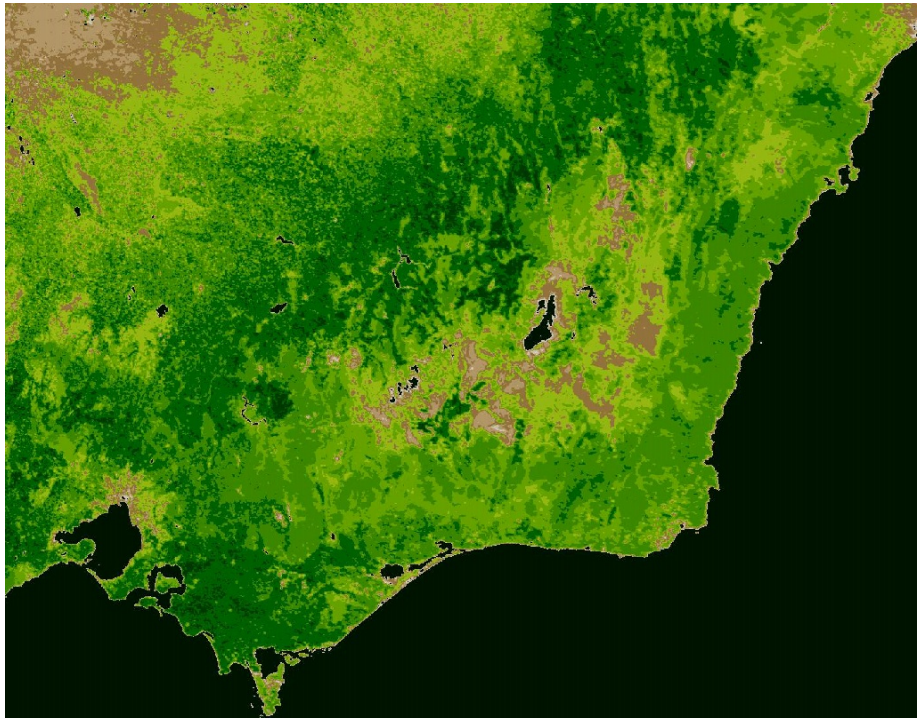




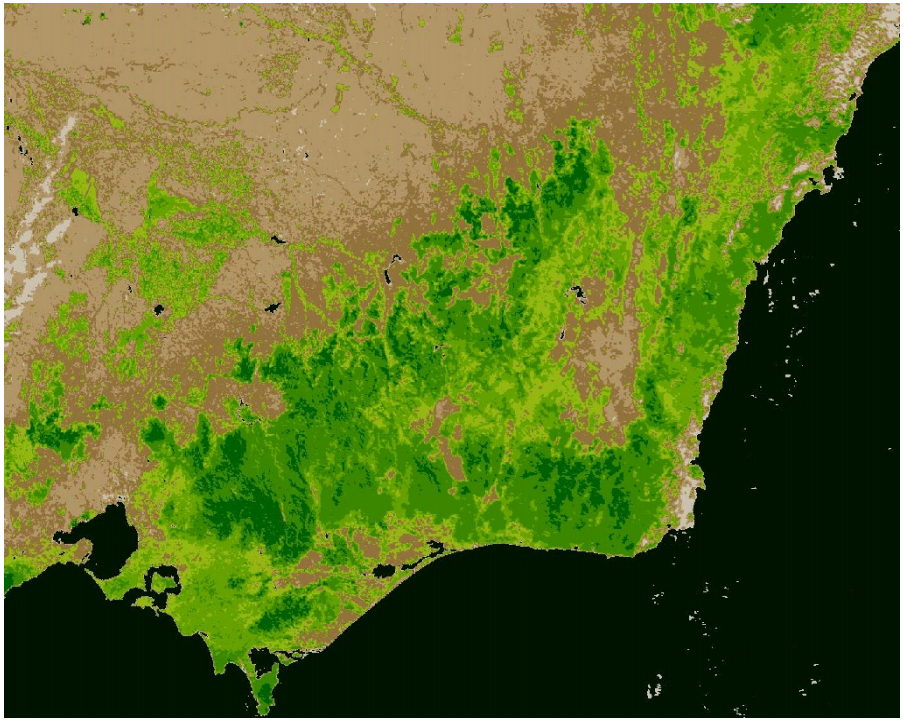
Terra MODIS 09/09/2003 01:27UTC 03:04UTC

Normalized Difference Vegetation Index

South East Australia

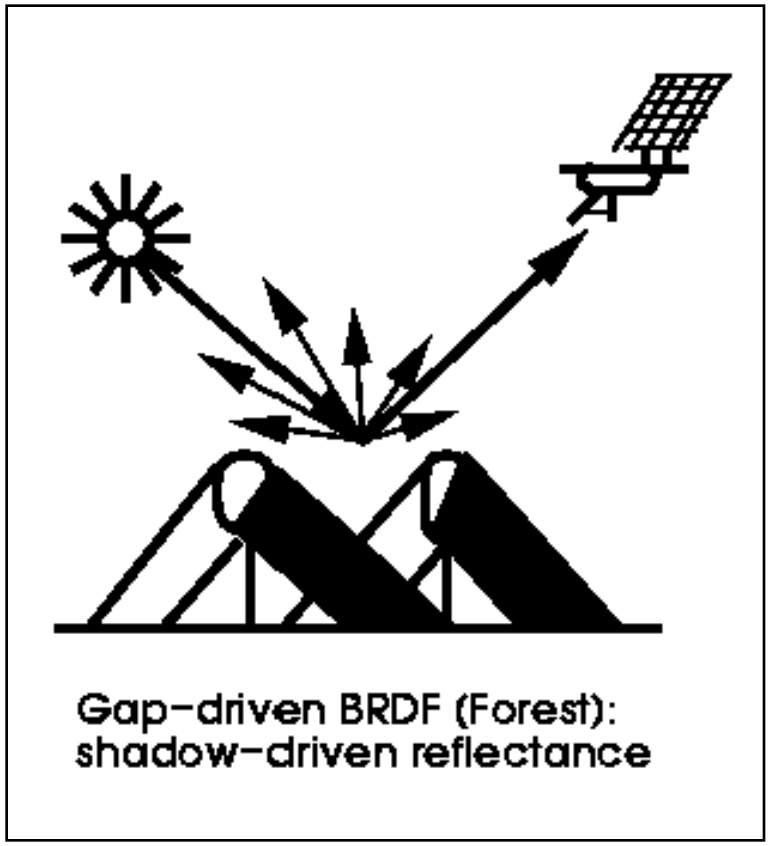


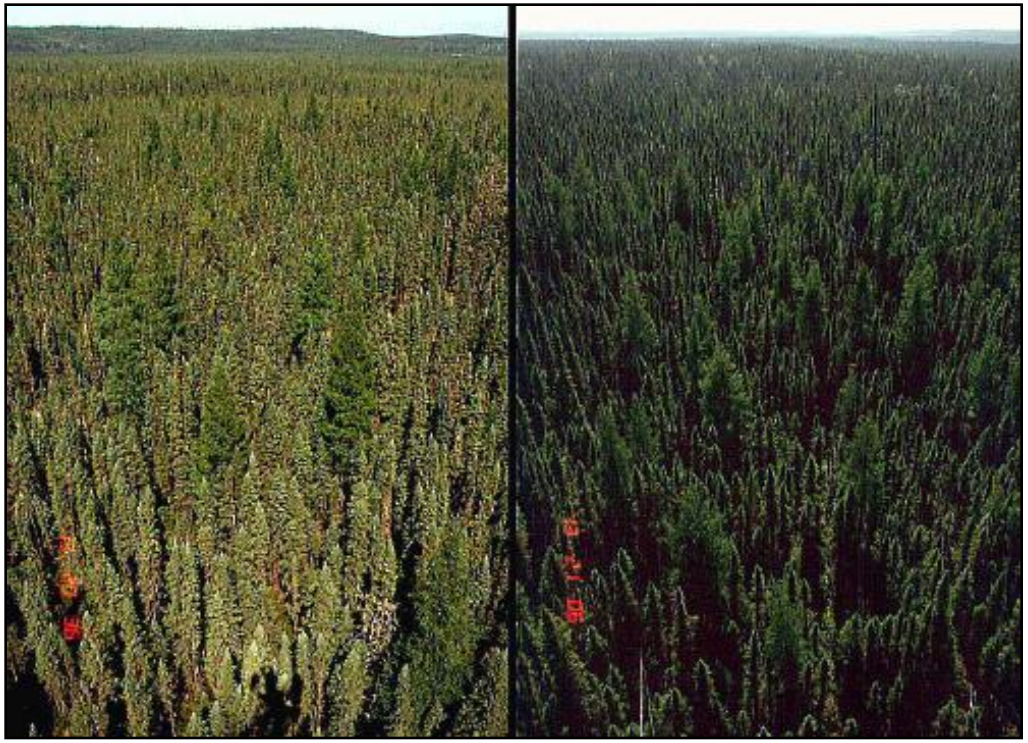
Nov 2003
Spring



Apr 2004
Fall

BRDF Example

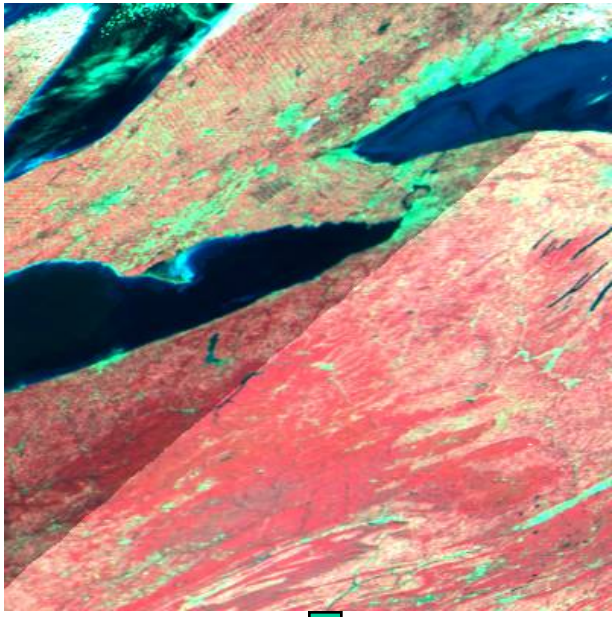


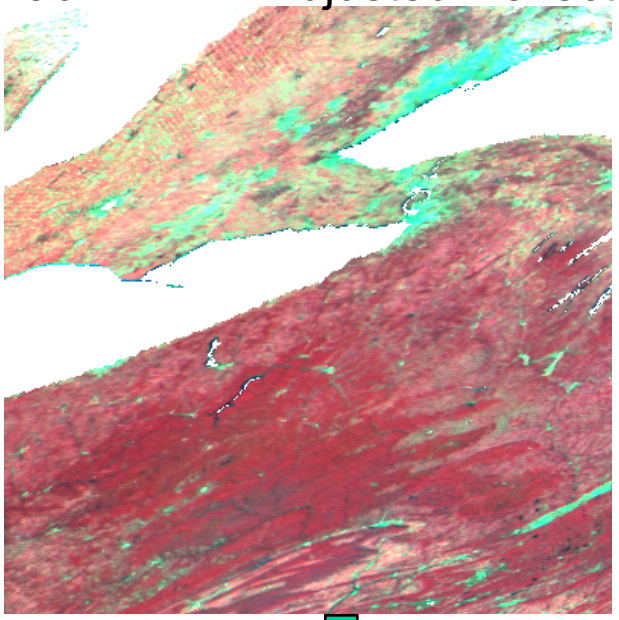


Black spruce forest in Canada.
Left, looking away from the sun
Right, looking towards the sun

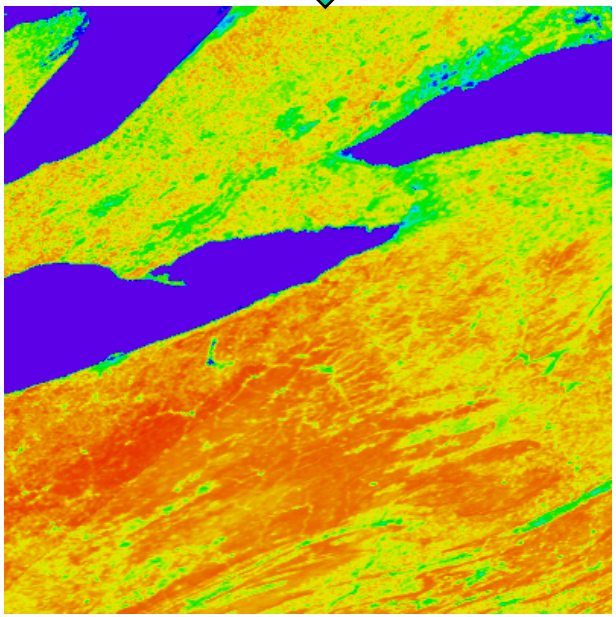
Surface Reflectance

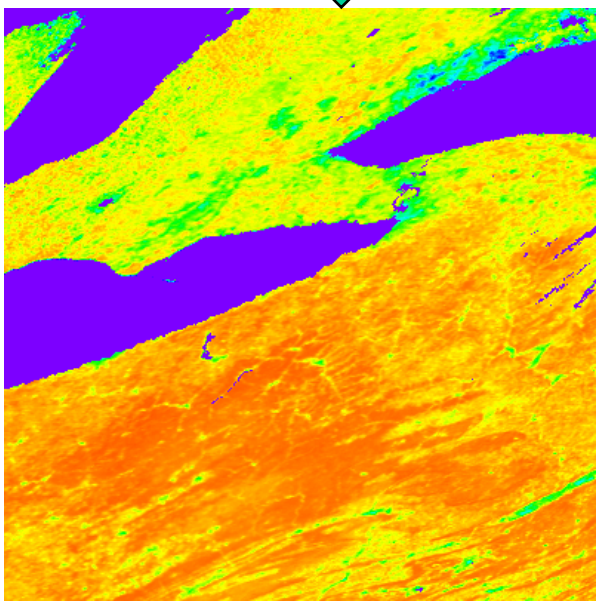
Nadir BRDF-Adjusted Reflectance





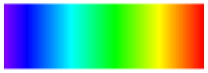
NIR (0.10-0.45)
Red (0.0-0.1)
Green (0.0-0.15)





NDVI

0.0 1.0

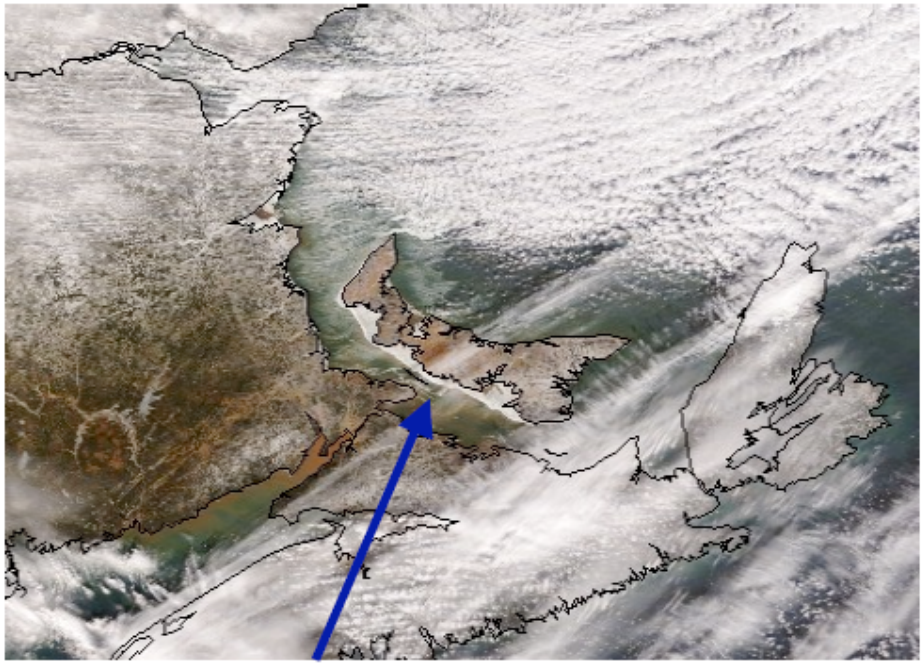


Canadian Ice Service integrates MODIS into operational data stream for ice monitoring

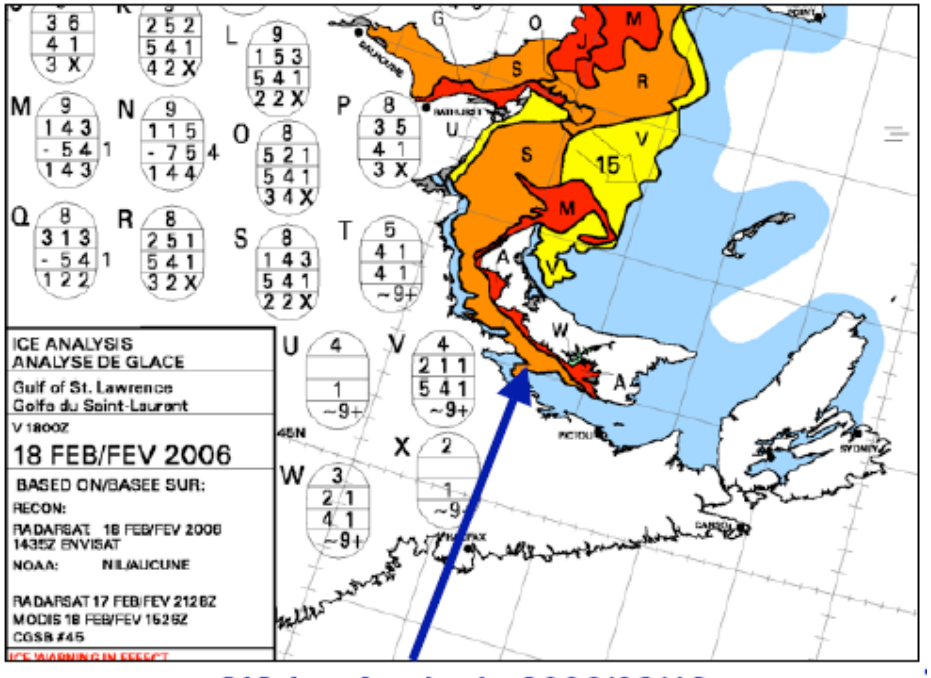
CIS data suite includes RadarSat and Envisat (SAR); AMSR, QuikScat and SSM/I (microwave); MODIS, OLS, NOAA and GOES (visible images).

- 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

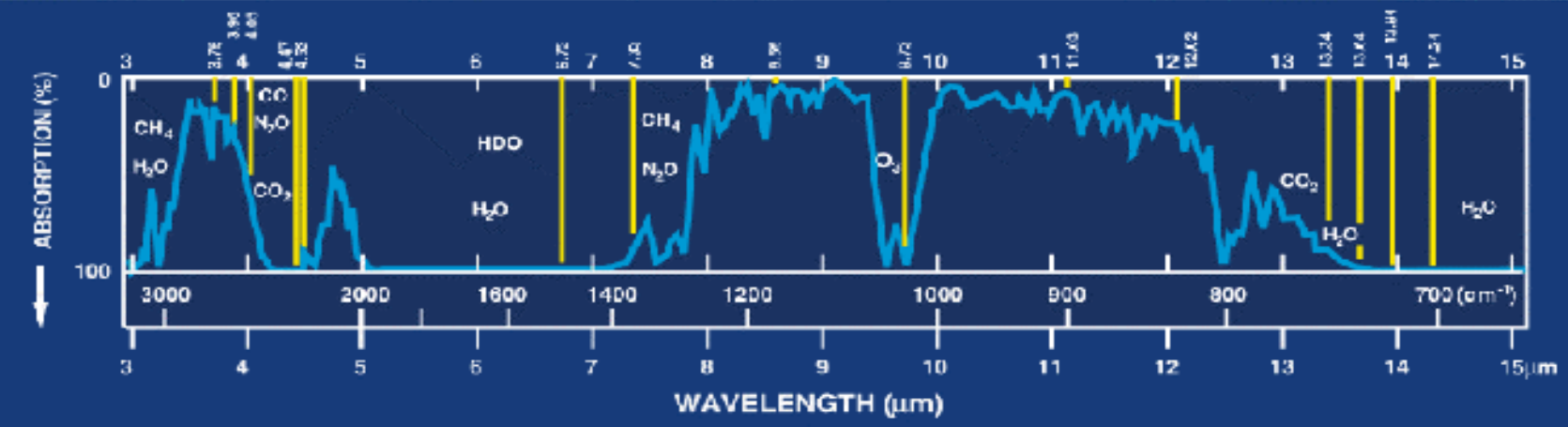


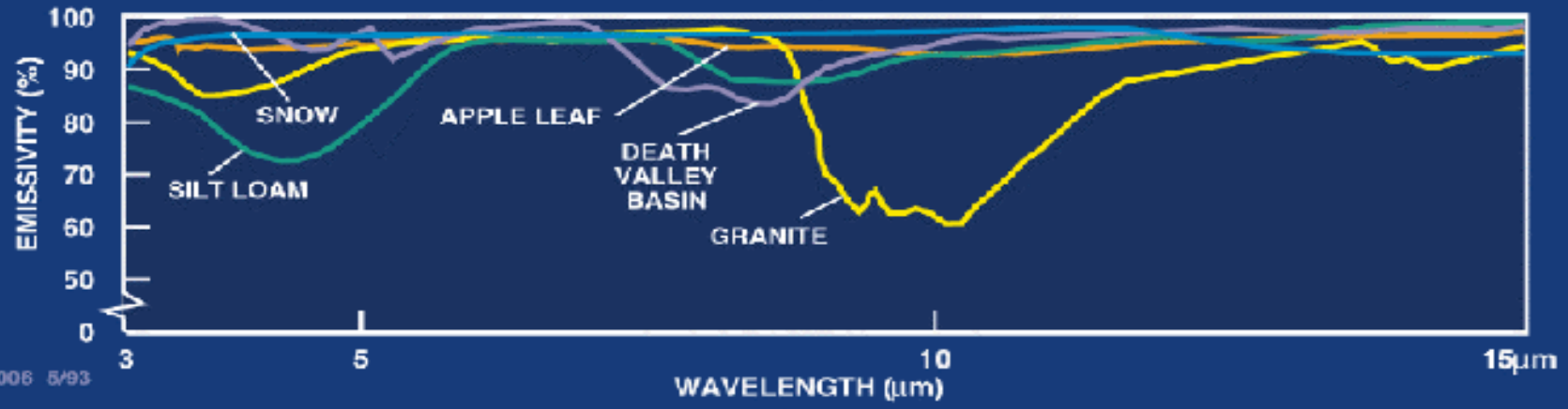
MODIS DB image 2006/02/18 15:26 UTC



CIS Ice Analysis 2006/02/18

LAND - THERMAL RADIATION





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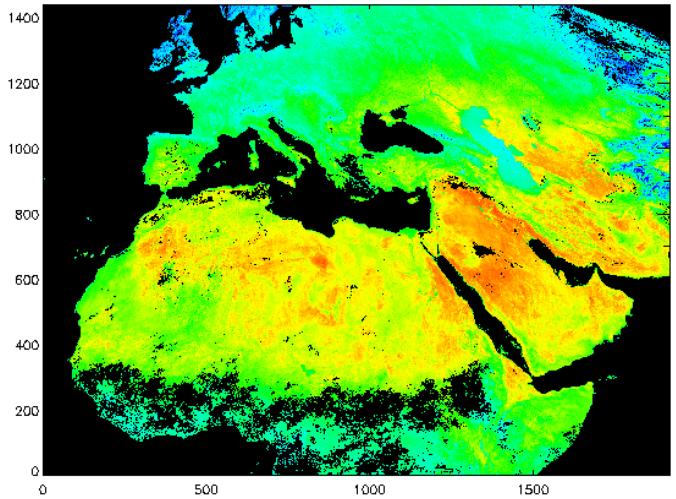
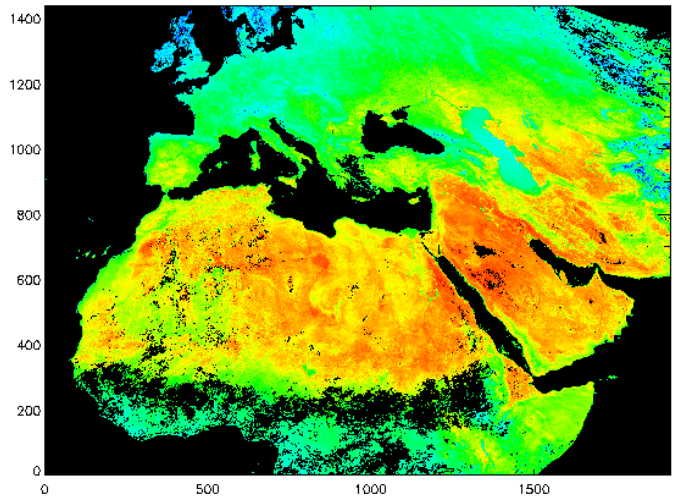
LSTs retrieved from Terra and Aqua MODIS data

on data days 176-177 and 185-190 (06/25-26 & 07/4-9)

to show spatial distribution of the diurnal variation

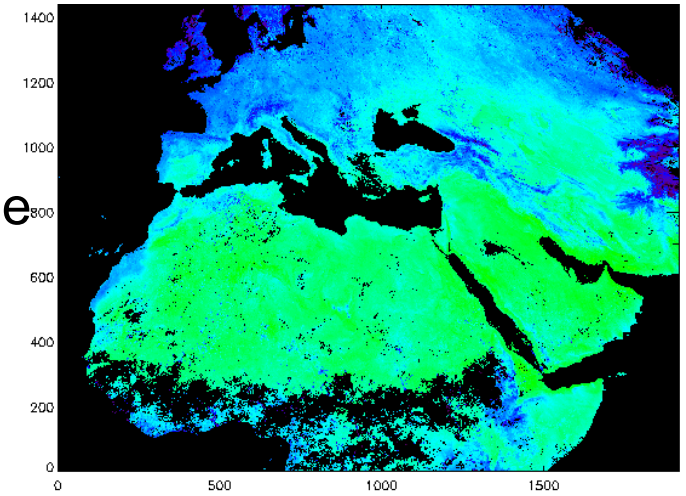
daytime Terra

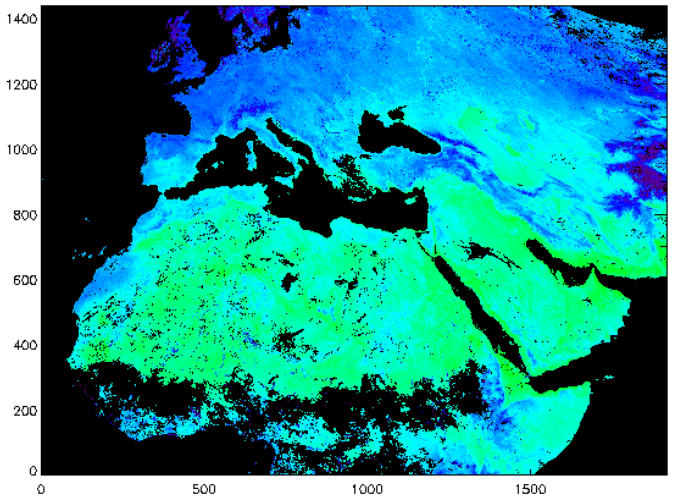




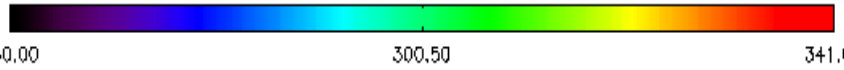
daytime Aqua

nighttime Terra



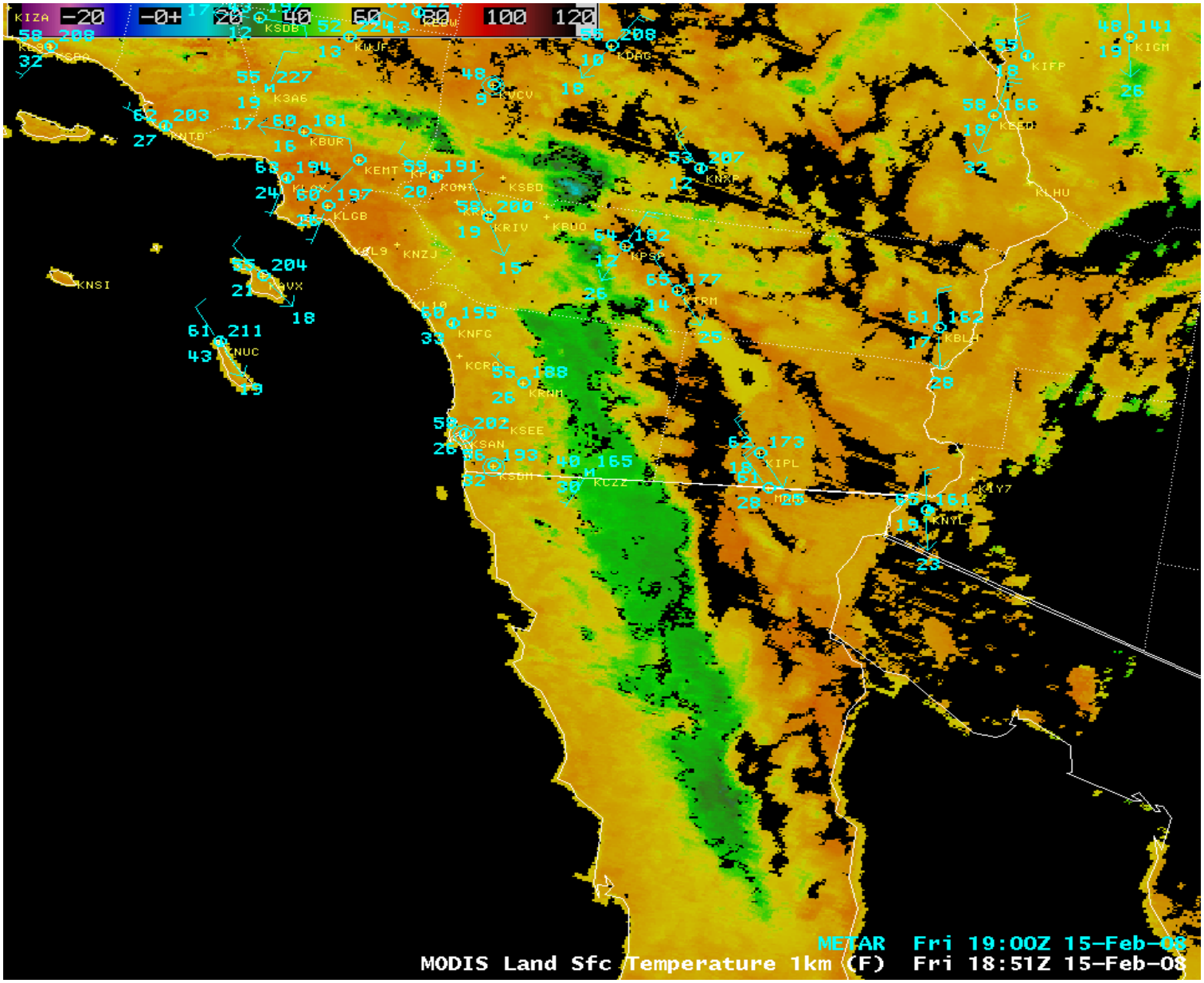


nighttime Aqua

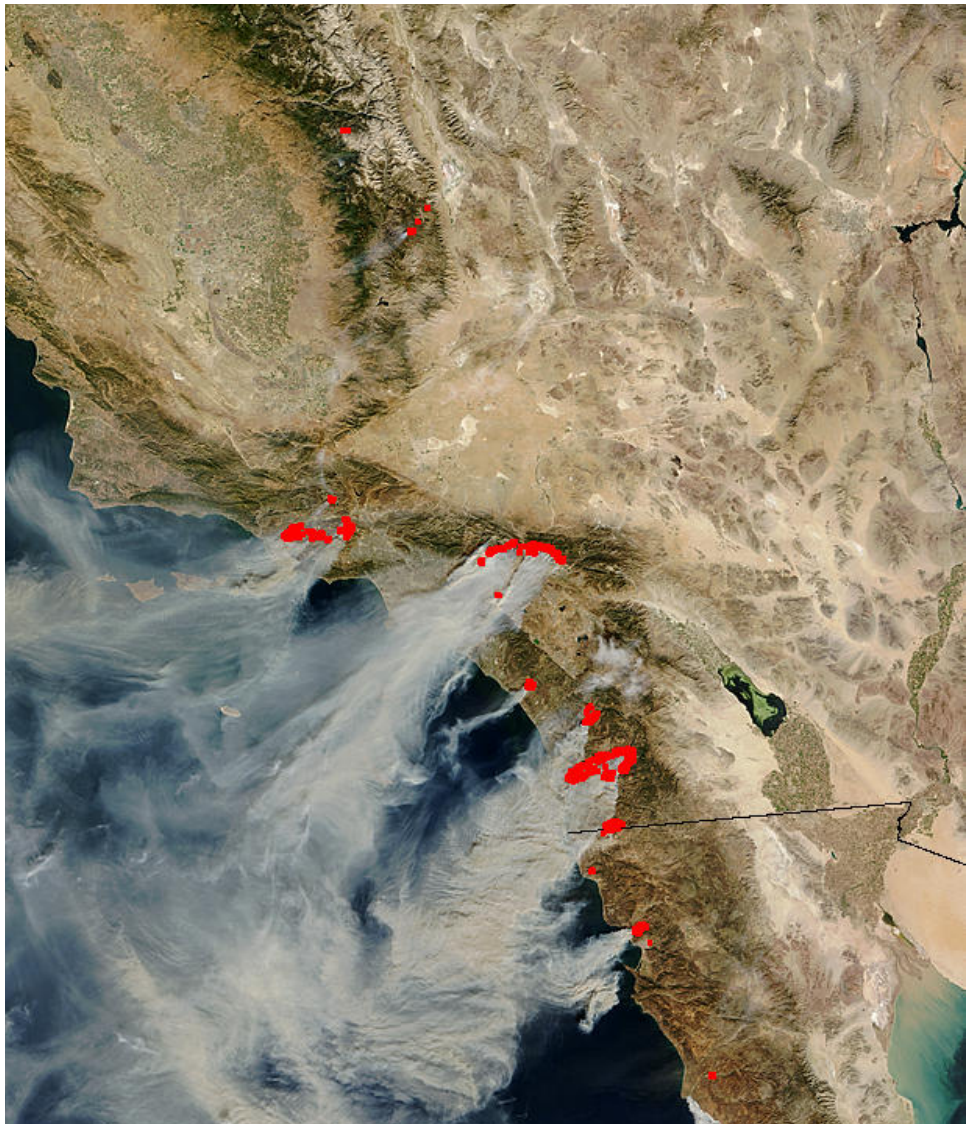


MODIS True Color

MODIS Land Surface Temperature



MODIS Active Fire Detection

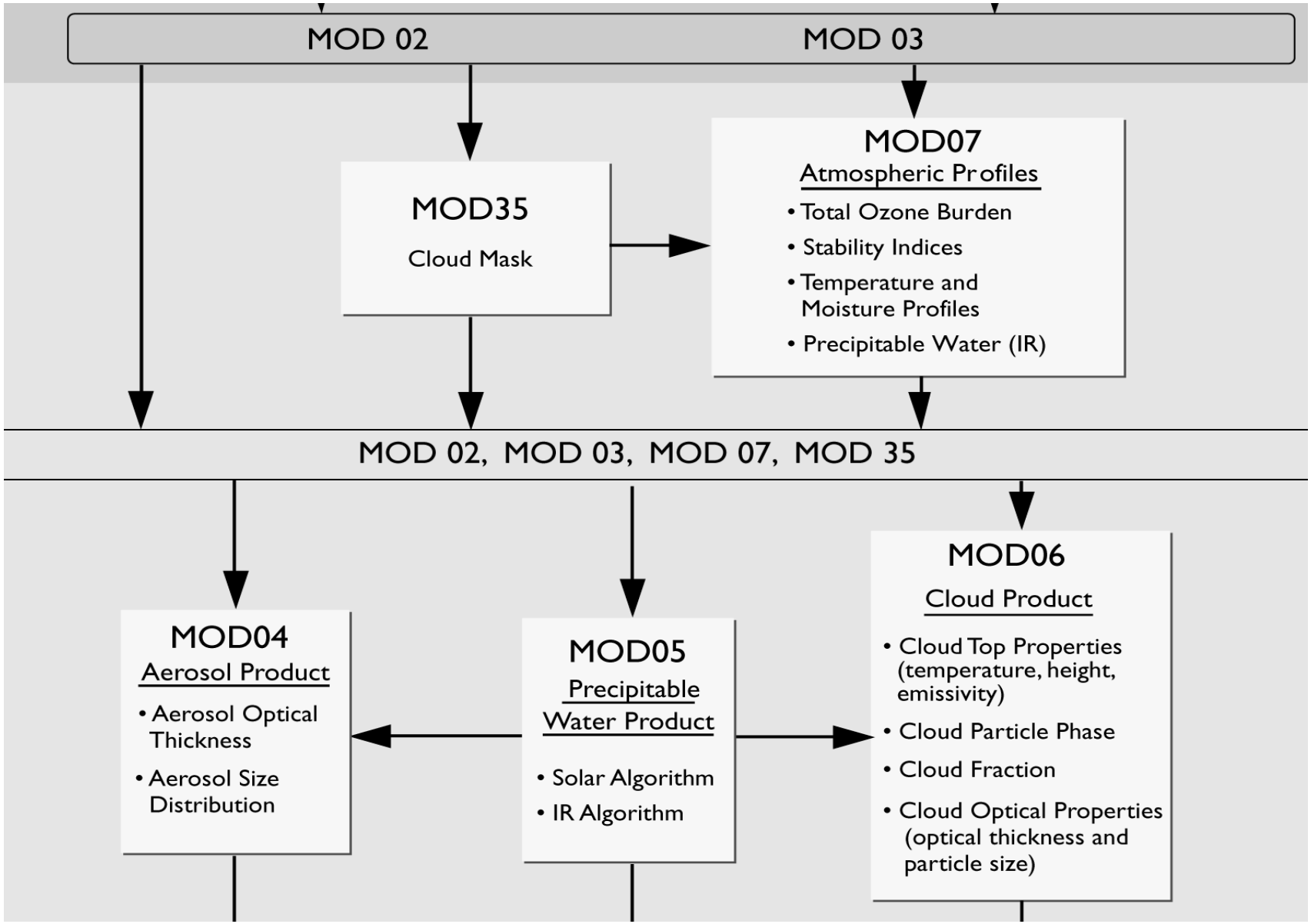


California – 10/26/03

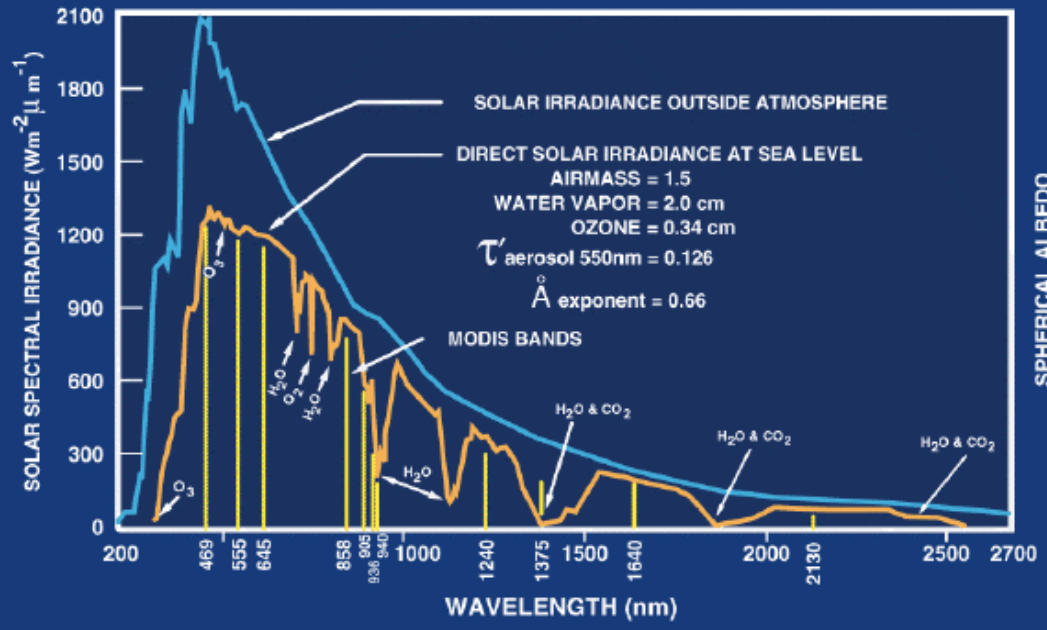
- The algorithm considers the spectral signature (in middle and thermal infrared) of each pixel and compares it to the non-burning surrounding pixels
- The natural variability of the surrounding background is taken into account
- Fewer false detections than traditional threshold-based algorithms
- Sensitive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

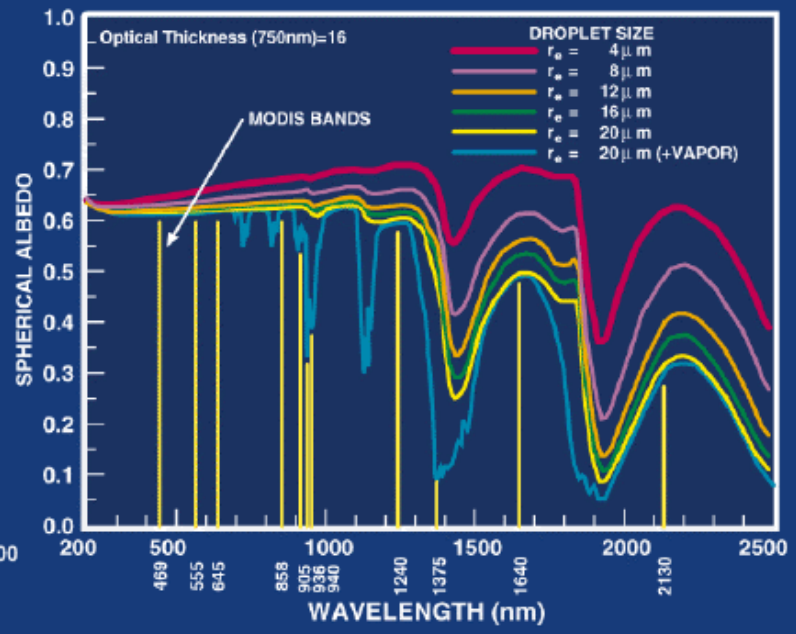
MODIS Atmosphere Applications

MODIS Atmosphere Product Flowchart



ATMOSPHERE-SOLAR RADIATION





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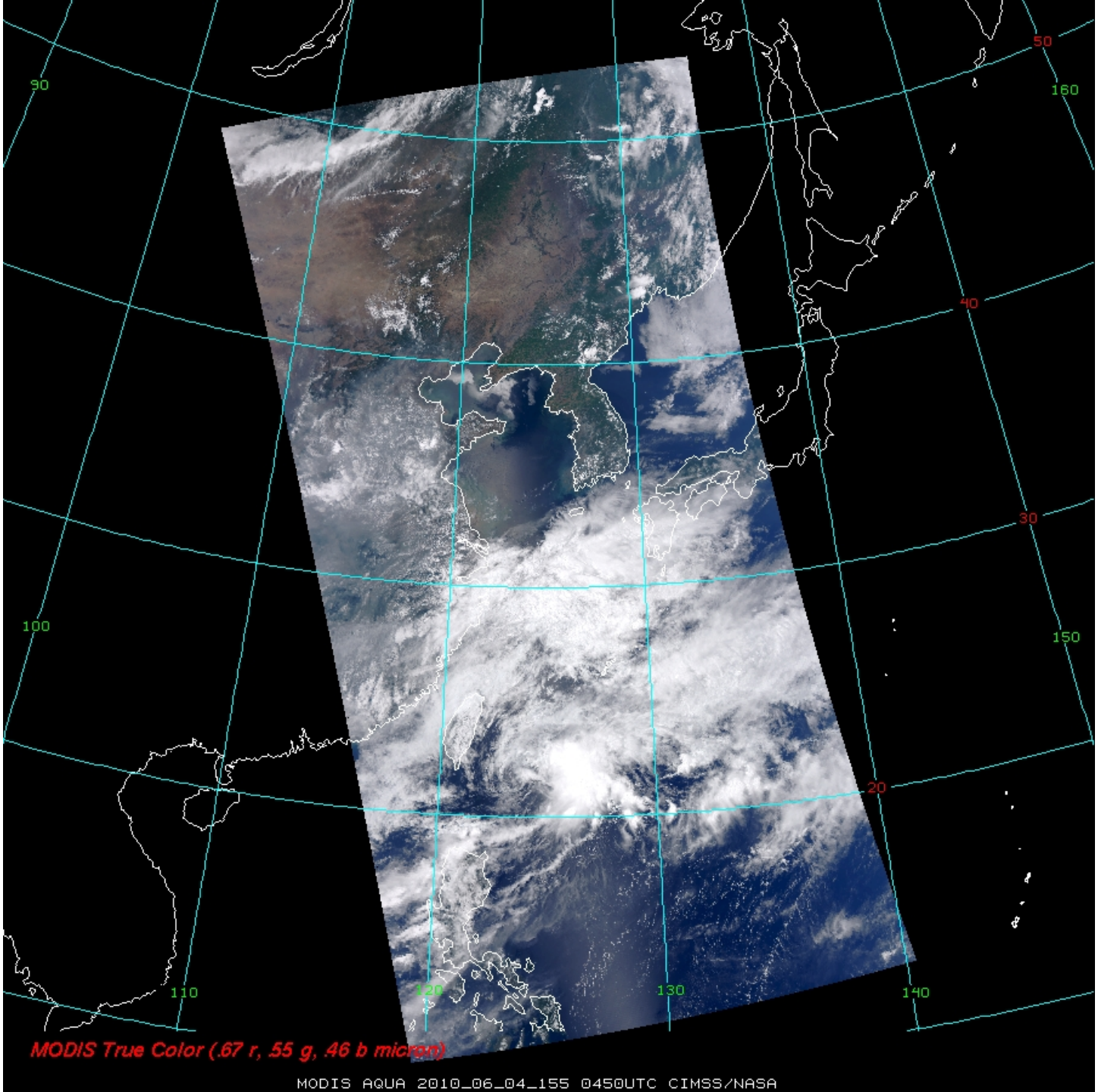
MODIS Cloud Mask

- **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


90
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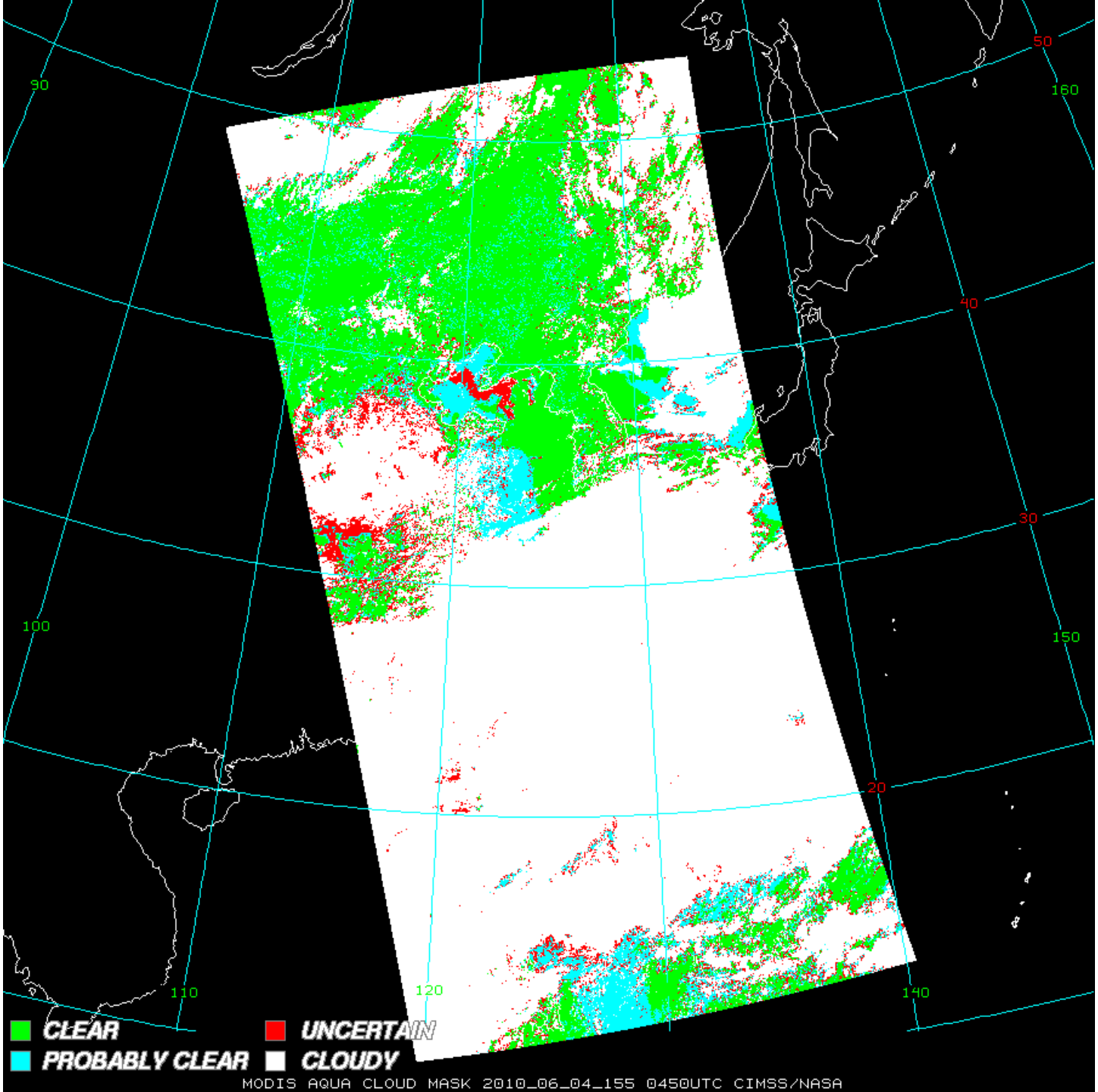
MODIS True Color (.67 r, .55 g, .46 b micron)
MODIS AQUA 2010_06_04_155 0450UTC CIMSS/NASA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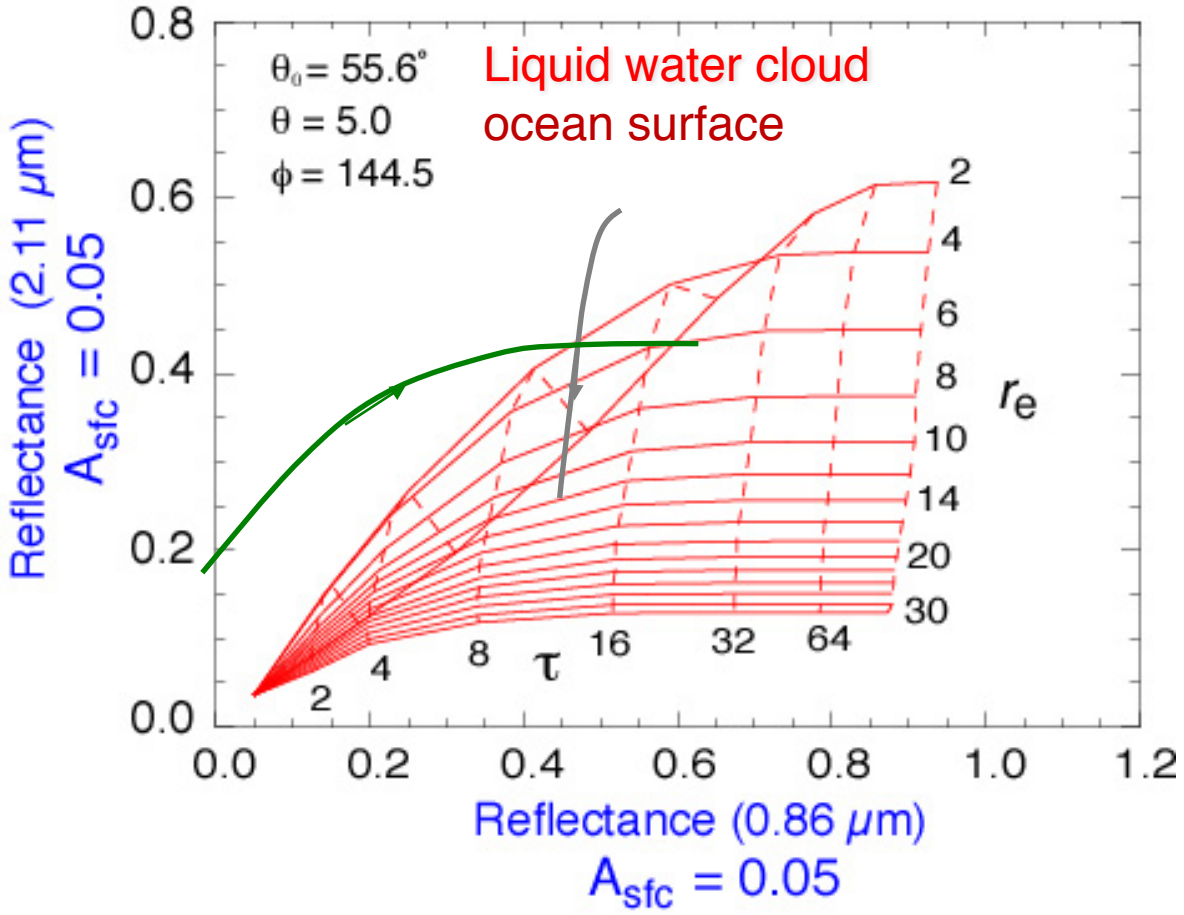
CLEAR
UNCERTAIN
PROBABLY CLEAR
CLOUDY
MODIS AQUA CLOUD MASK 2010_06_04_155 0450UTC CIMSS/NASA

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.



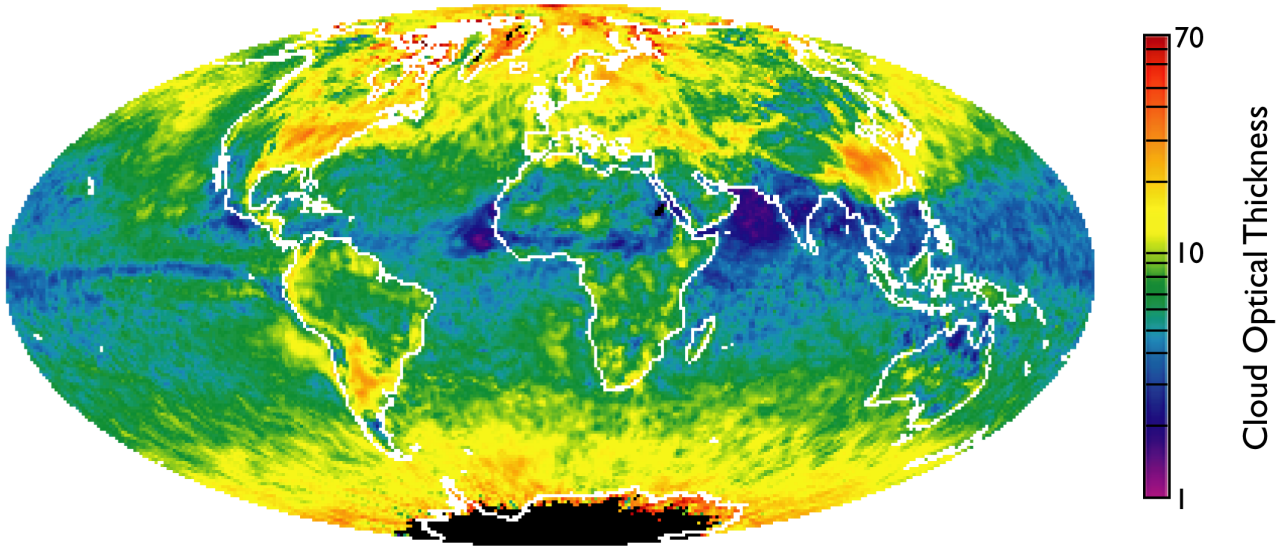
2.1 μm absorption increases with particle size, little effect at 0.86 μm

2.1 μm reflectance reaches limiting values with optical thickness

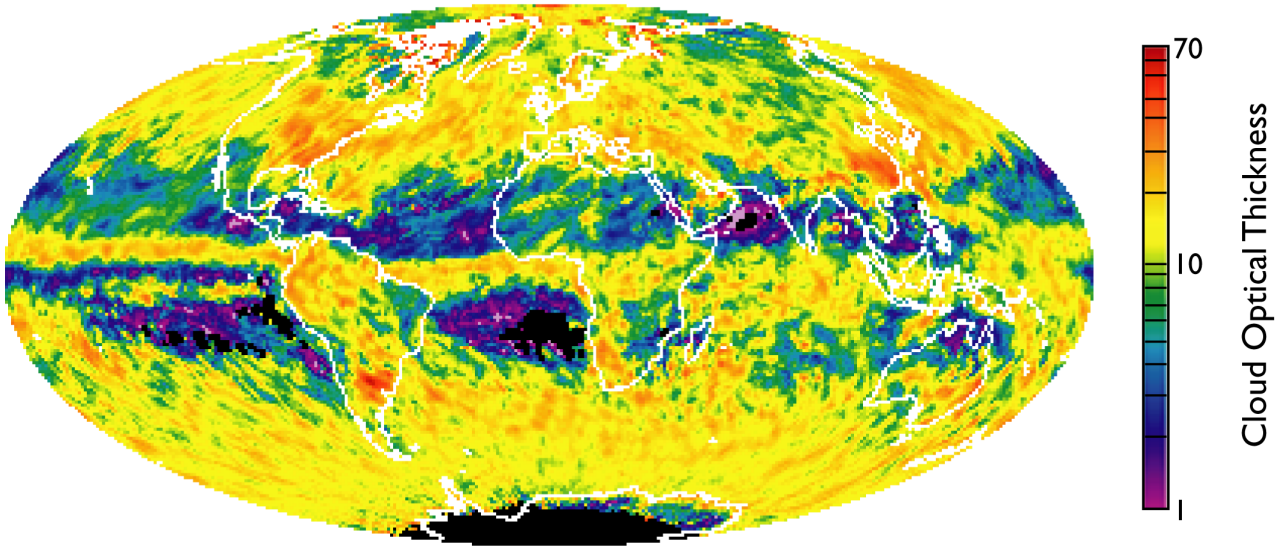
S. Platnick, ISSAOS '02

Monthly Mean Cloud Optical Thickness

Cloud Optical Thickness (Water)

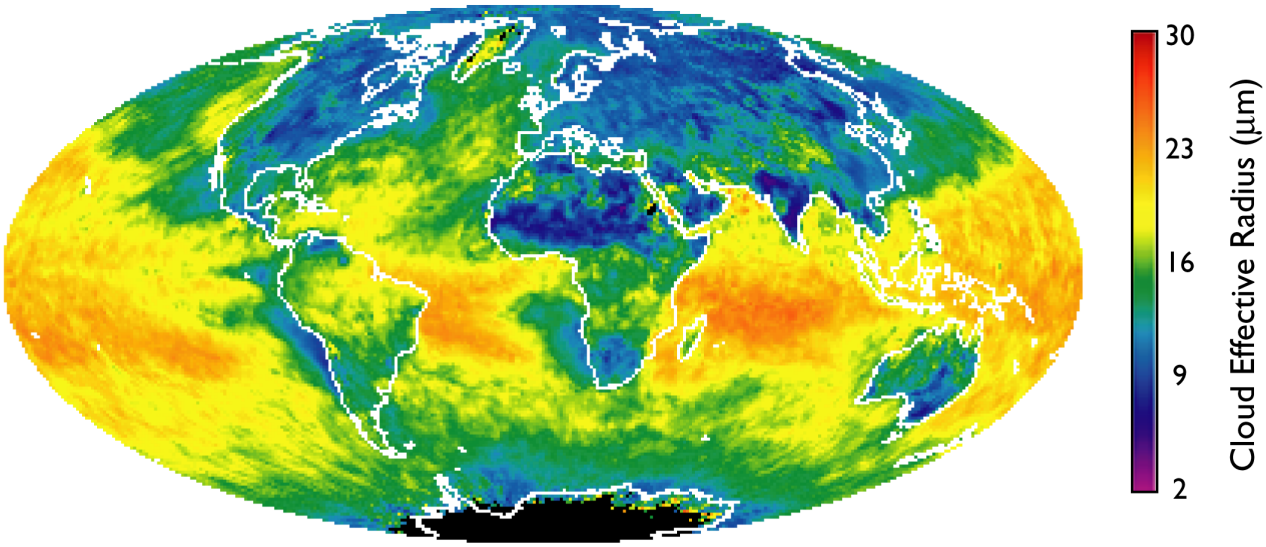


Cloud Optical Thickness (Ice)

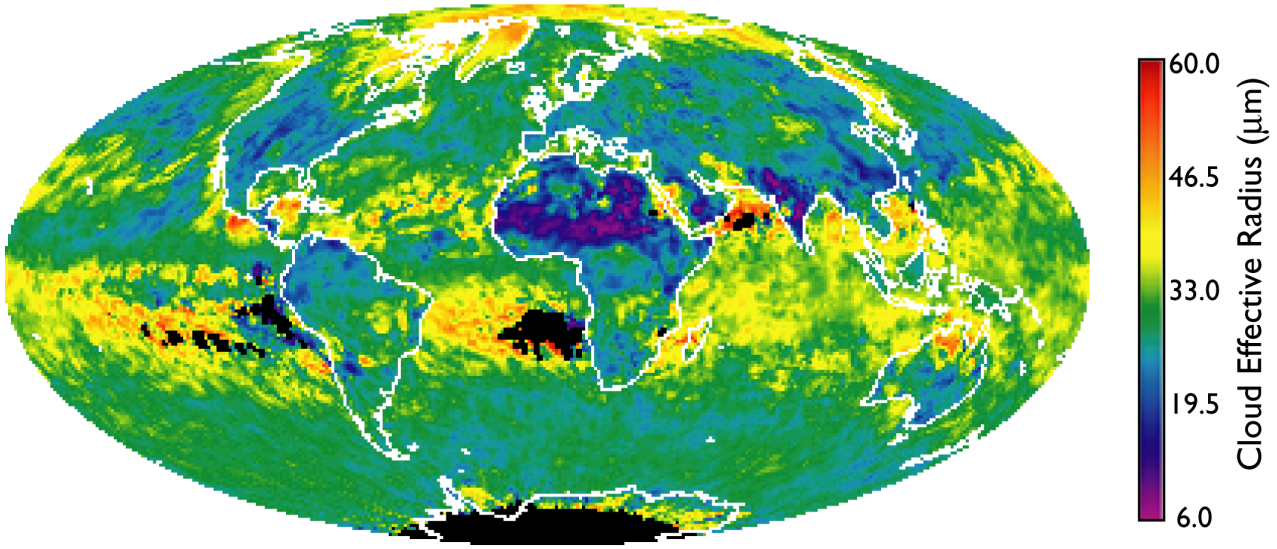


Monthly Mean Cloud Effective Radius

Cloud Effective Radius (Water)

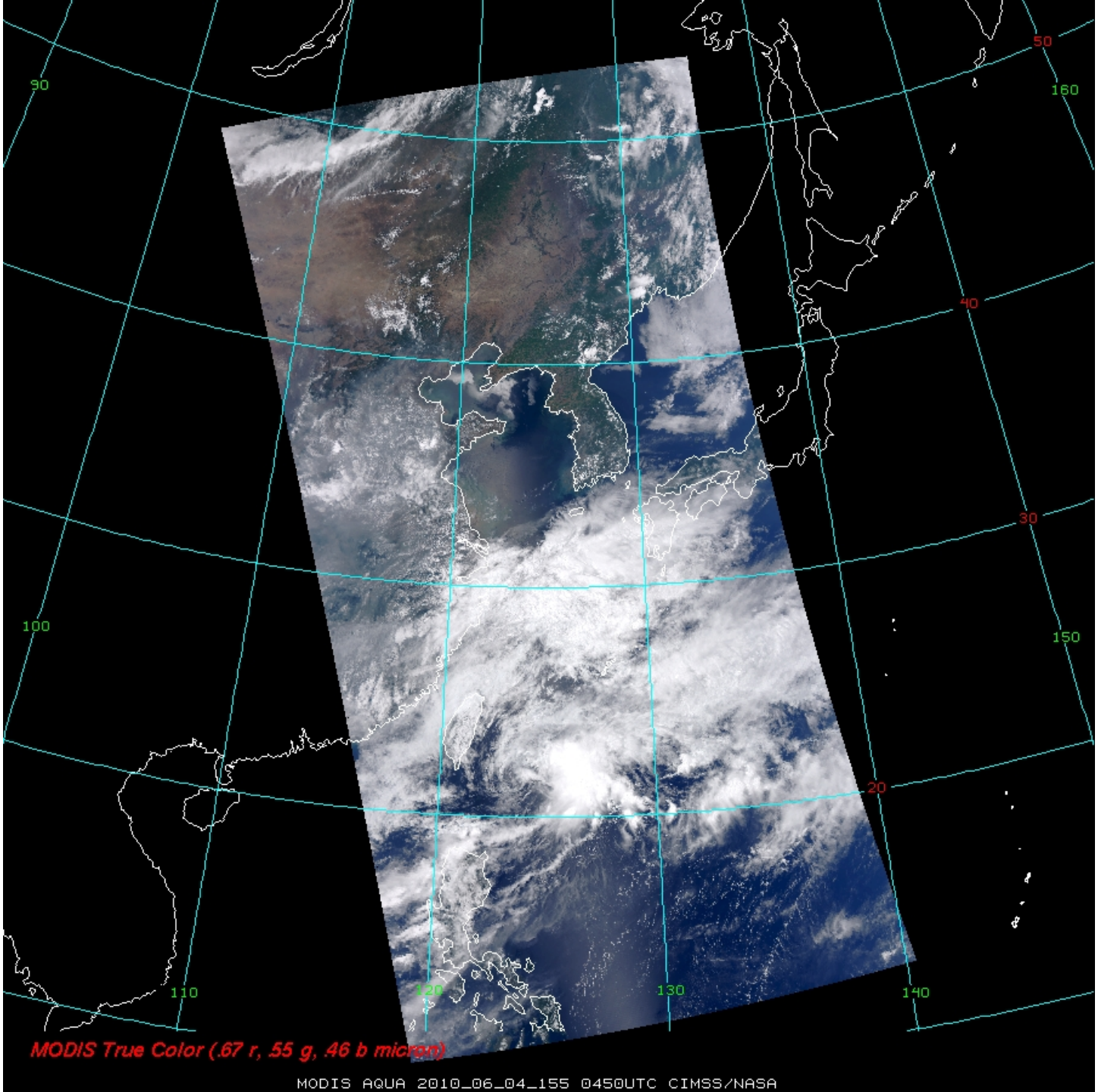


Cloud Effective Radius (Ice)



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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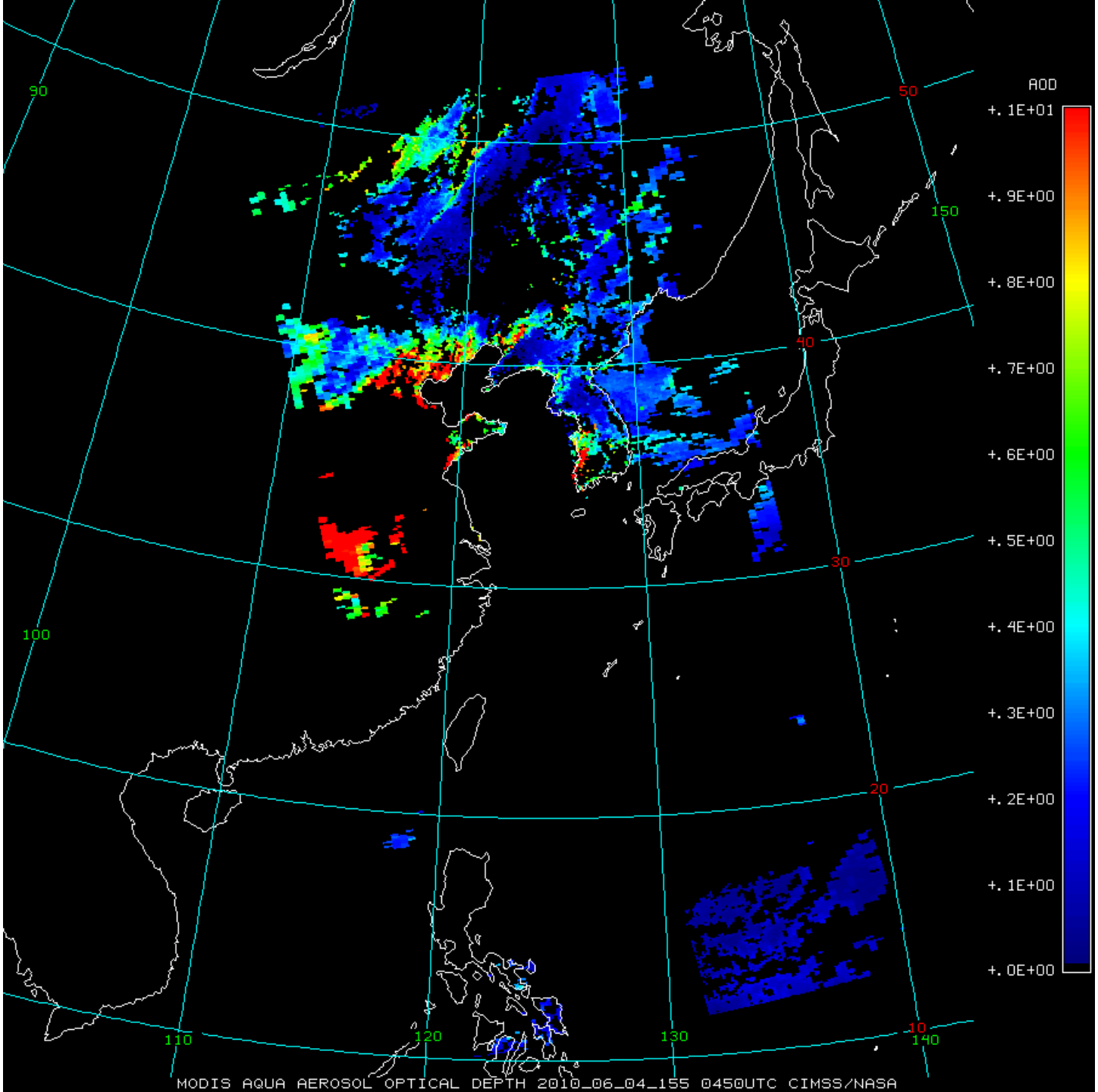
MODIS True Color (.67 r, .55 g, .46 b micron)
MODIS AQUA 2010_06_04_155 0450UTC CIMSS/NASA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+.6E+00
+.5E+00
+.4E+00
+.3E+00
+.2E+00
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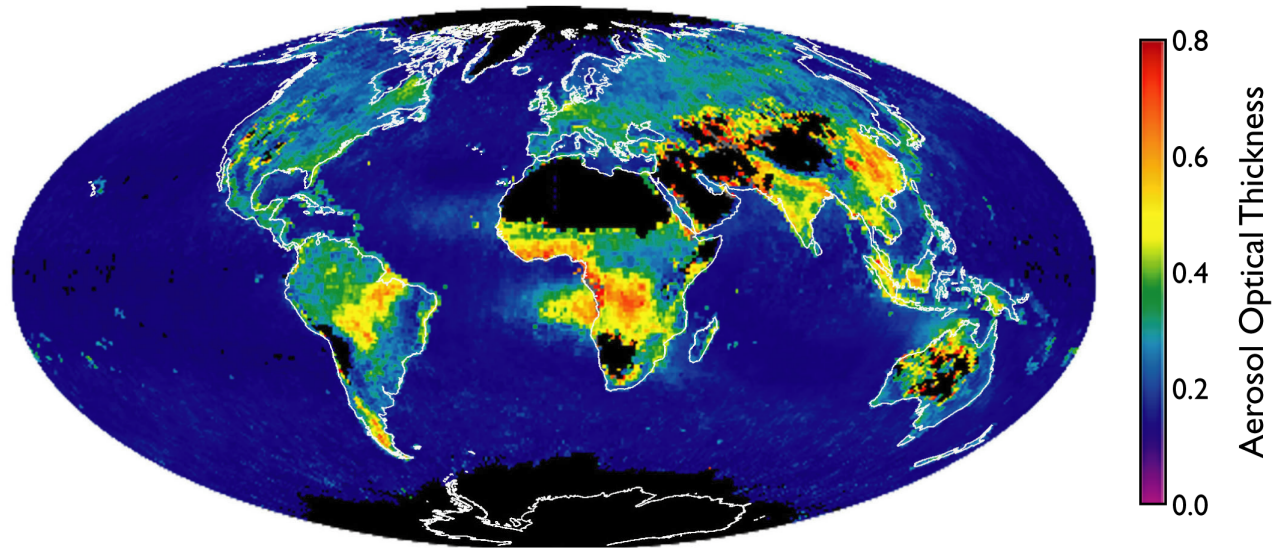
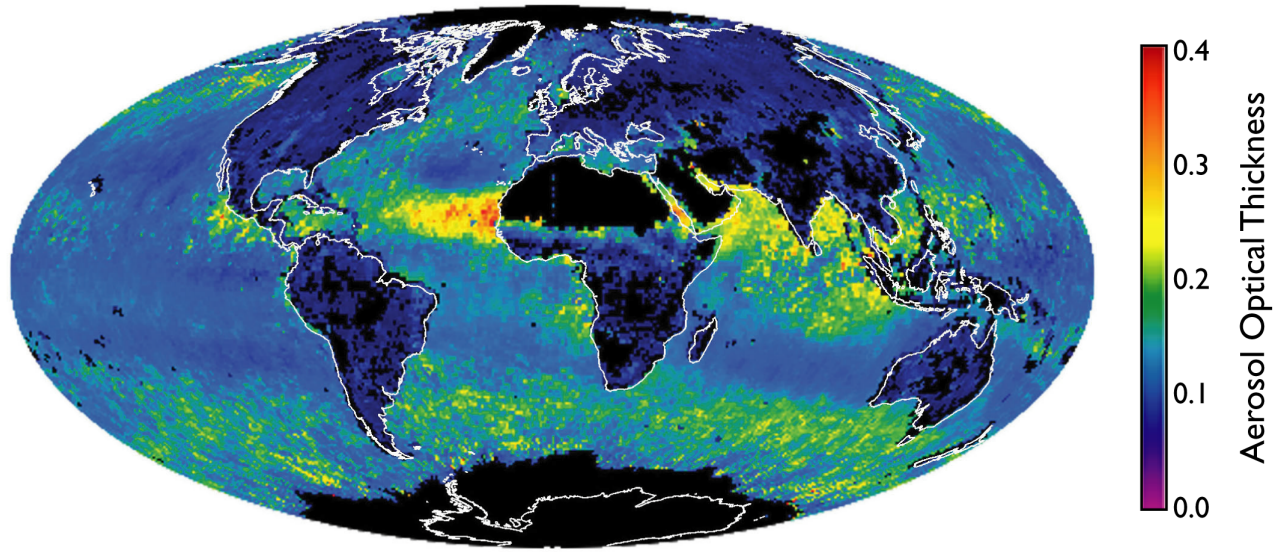
MODIS AQUA AEROSOL OPTICAL DEPTH 2010_06_04_155 0450UTC CIMSS/NASA

Monthly Mean Aerosol Optical Thickness

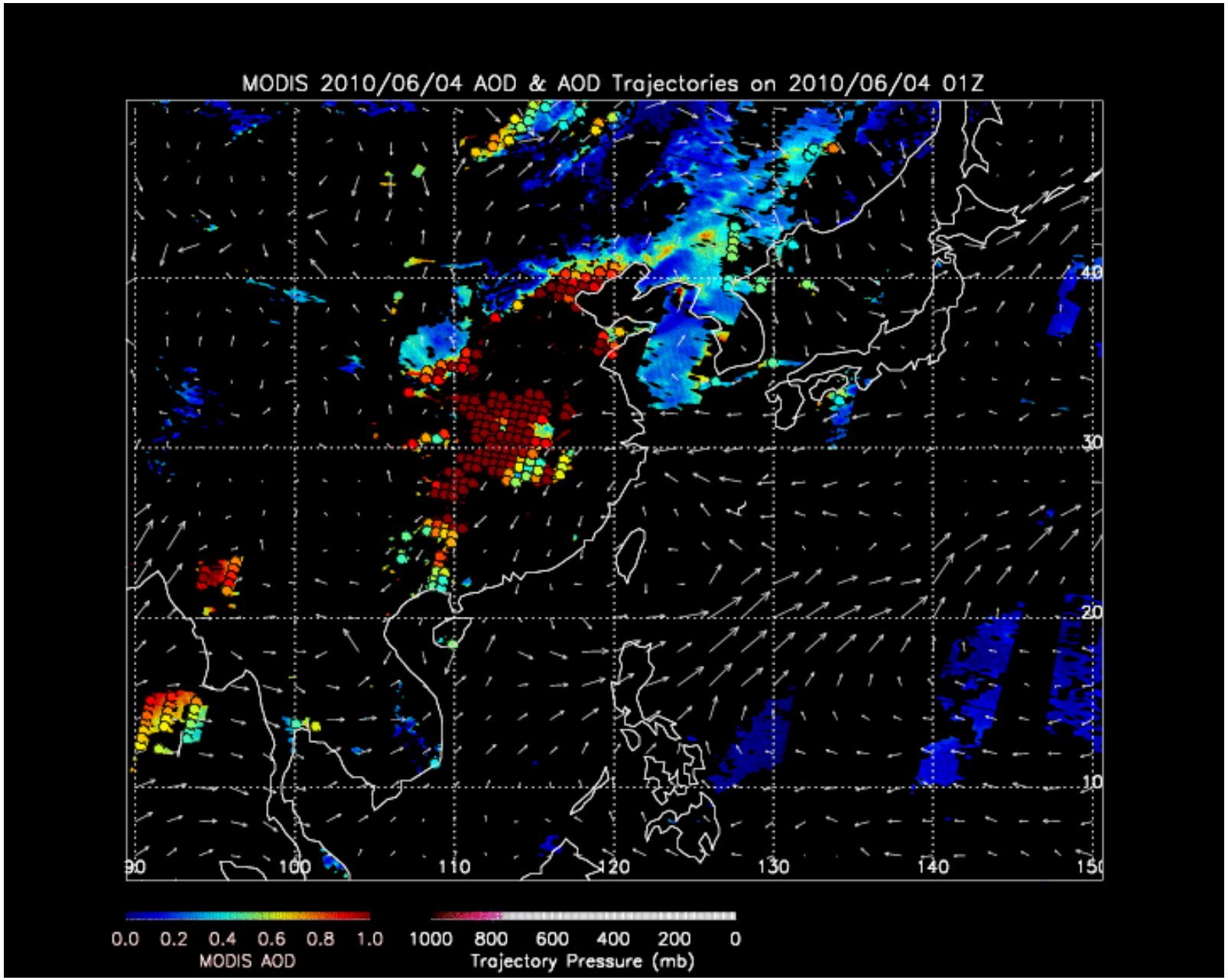
Aerosol Optical Thickness (Fine Mode)



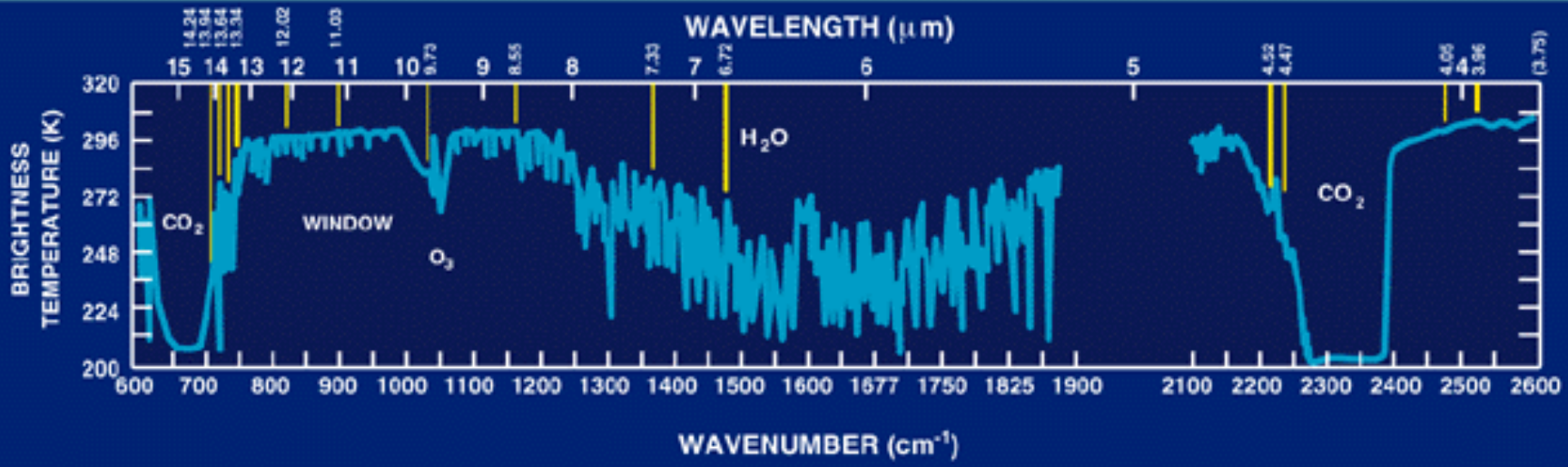
Aerosol Optical Thickness (Coarse Mode)

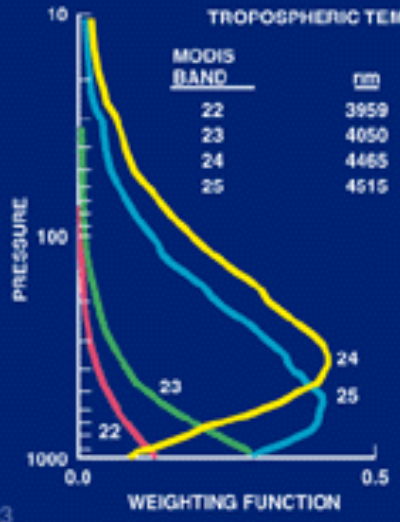


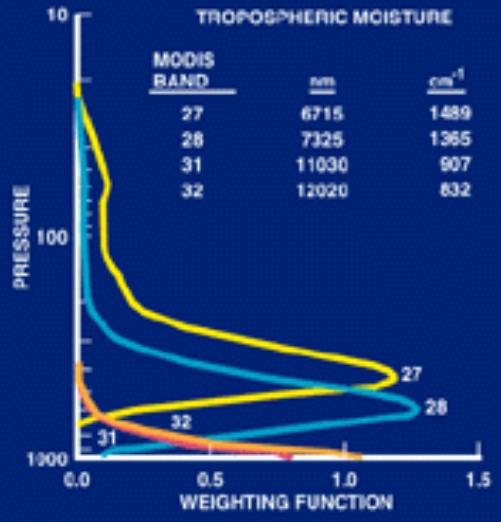
MODIS IDEA-I Product for 2010/06/04

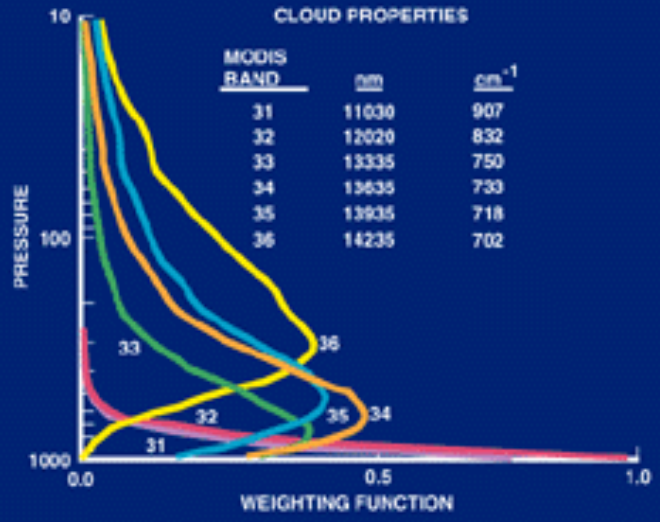


ATMOSPHERE - THERMAL RADIATION









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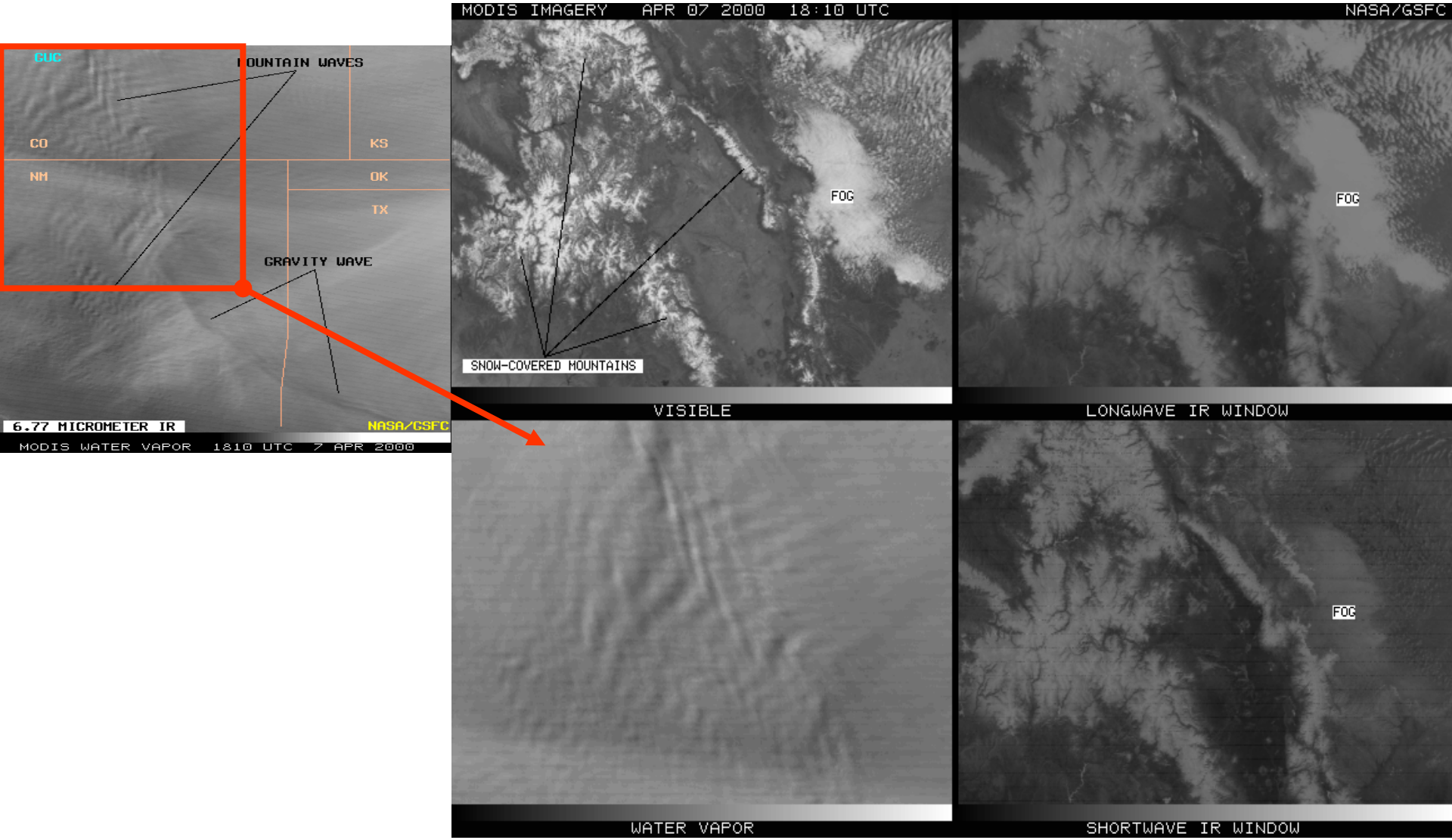
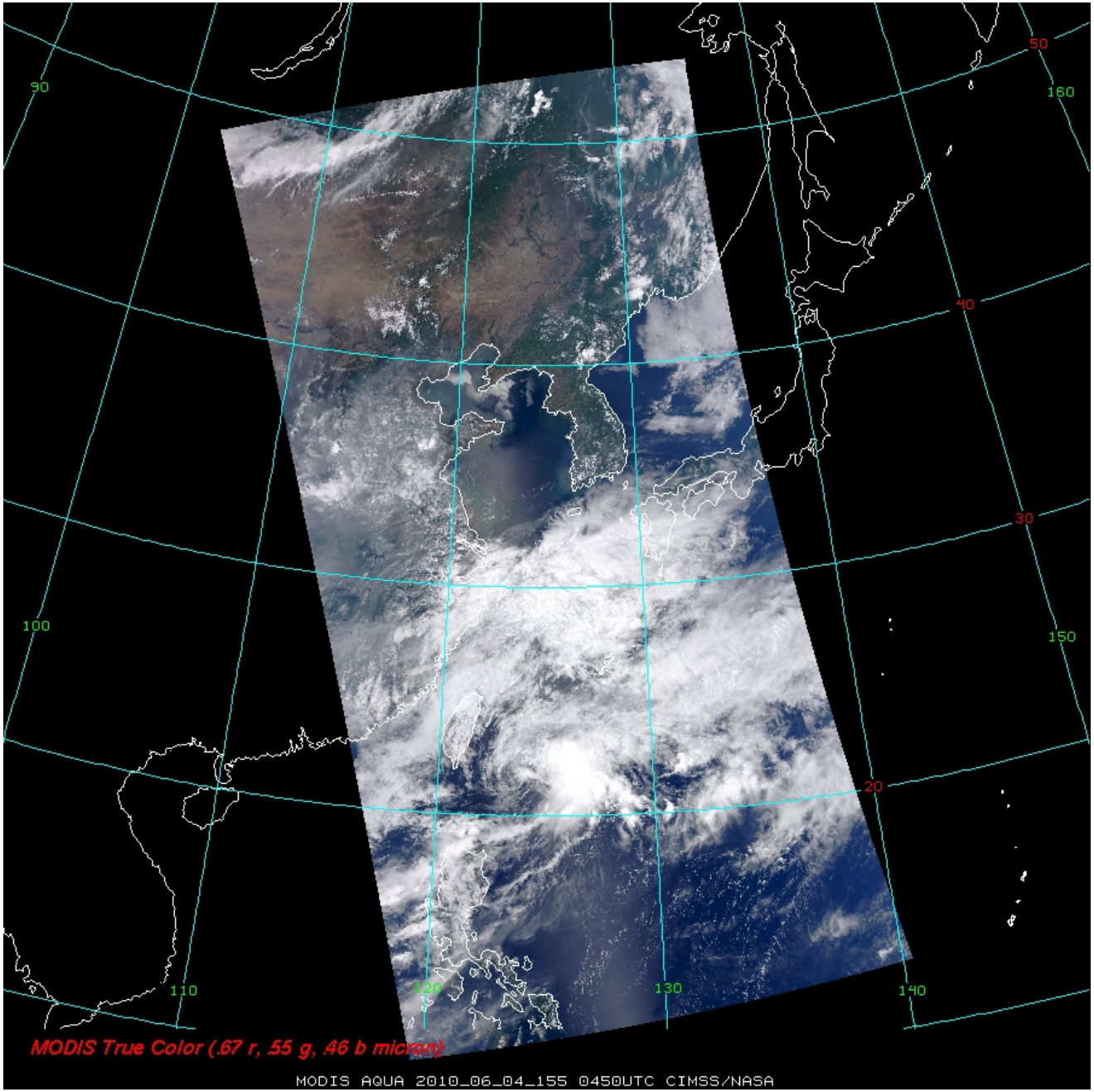
Four Panel Zoom of Cloud-Free Orographic Waves revealed in Water Vapor Imagery



Aqua MODIS True Color Image: 2010/06/04

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



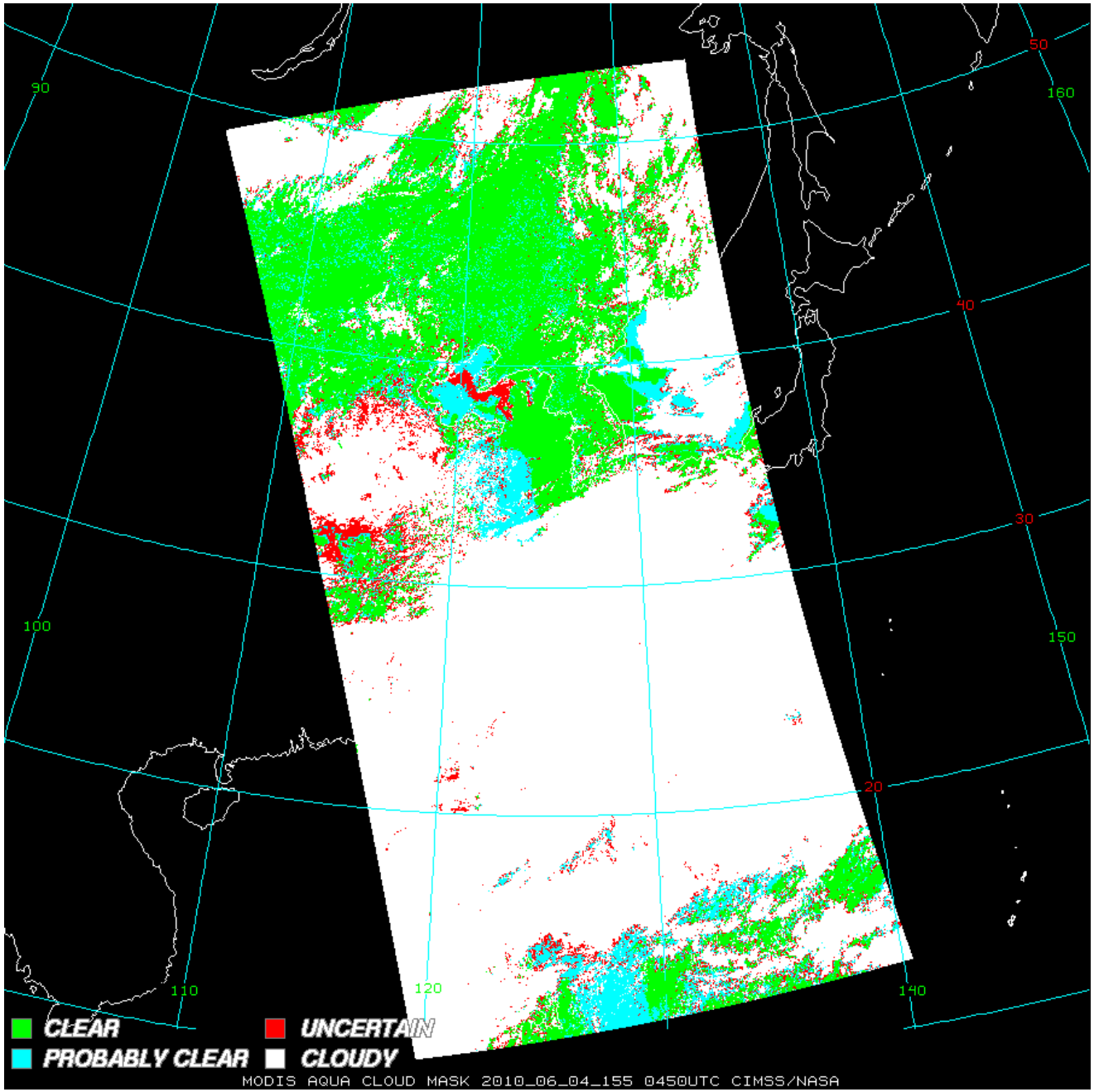
MODIS Cloud Mask Product (MOD35)

Clear and Cloudy Sky (everywhere)

Day/Night

1 km resolution

Fuzzy logic spectral tests



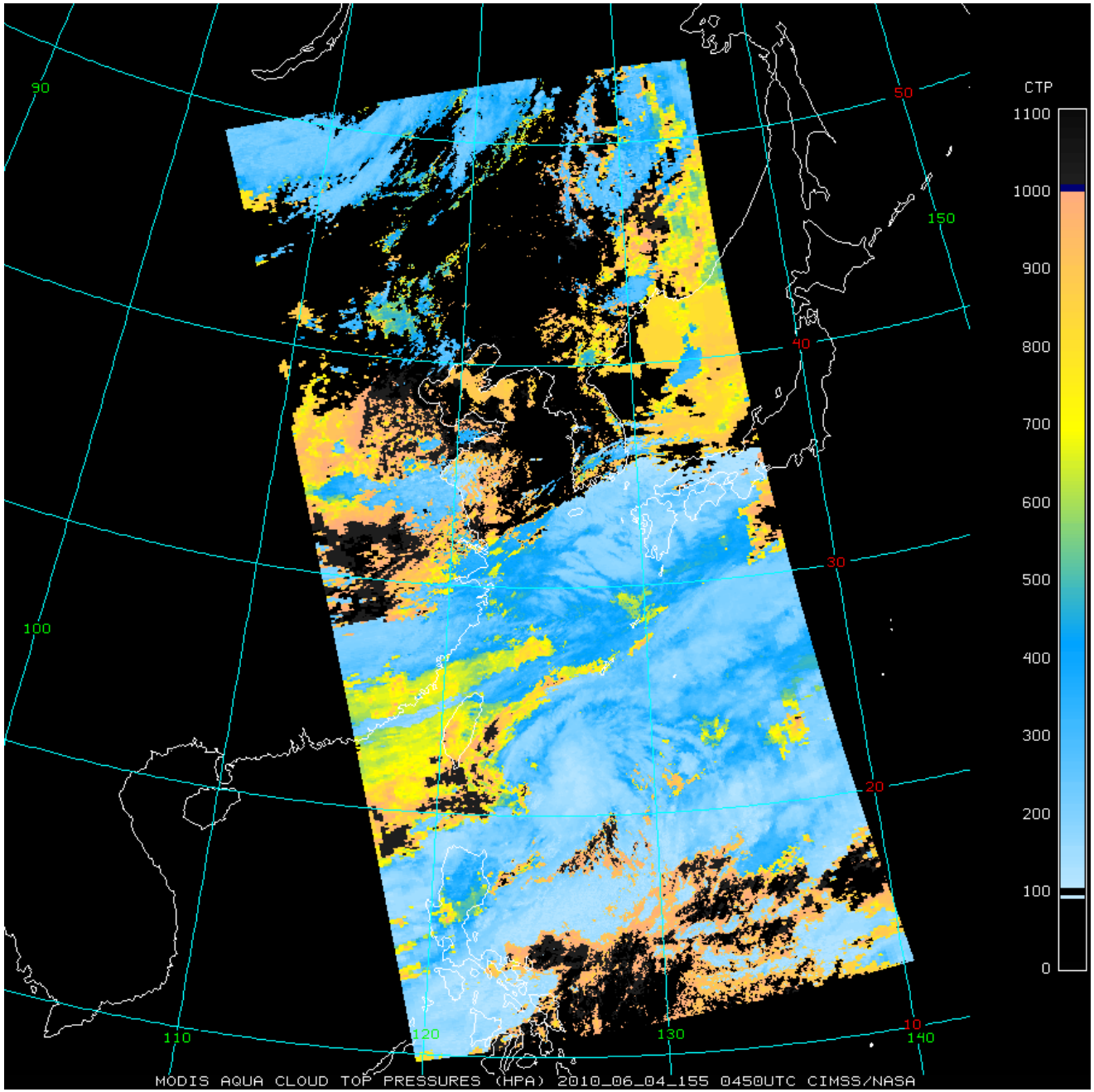
MODIS Cloud Top Pressure Product (MOD06)

Cloudy Sky Only

Day/Night

5 x 5 km resolution

CO_2 slicing algorithm



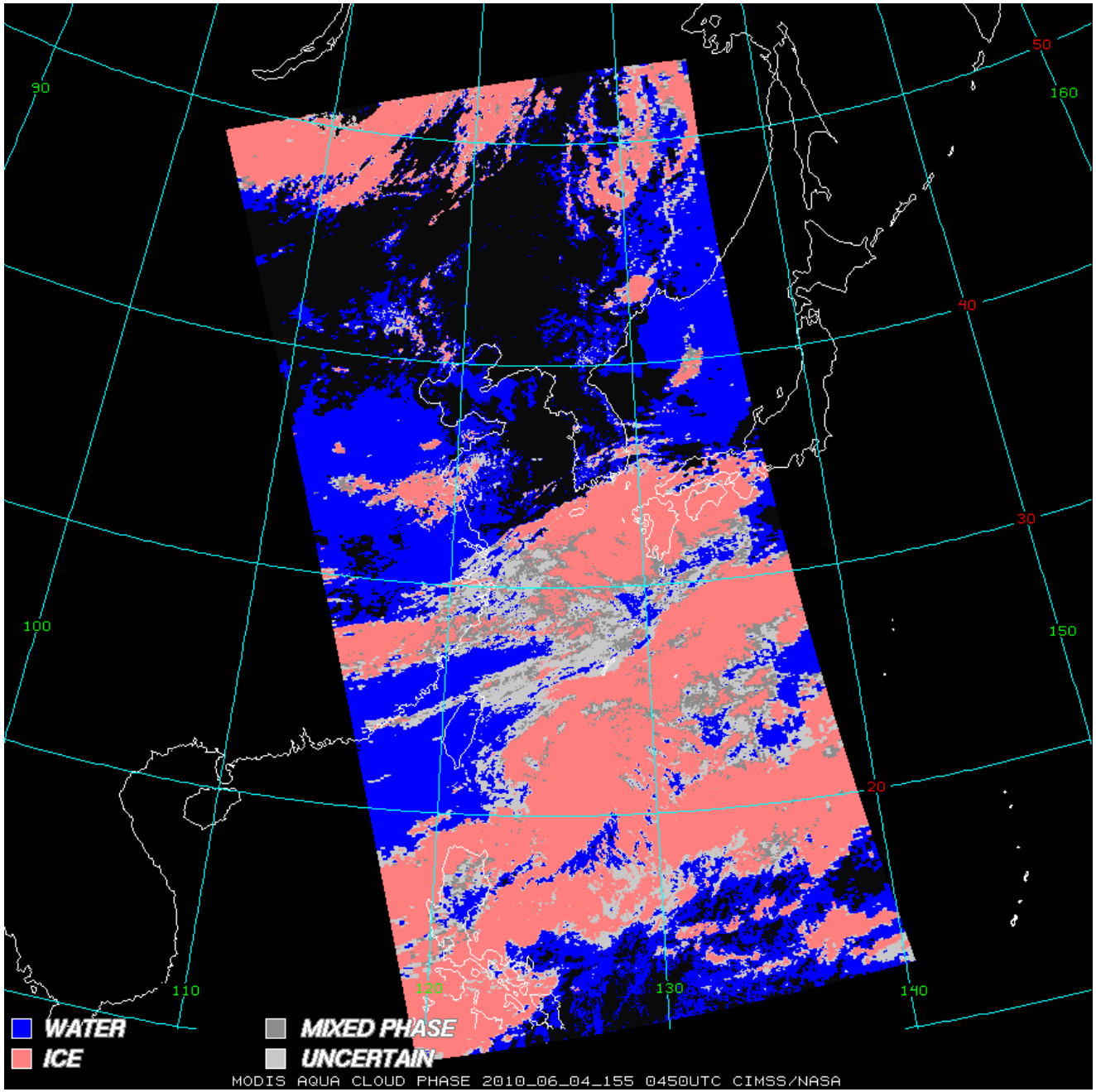
MODIS Cloud Phase Product (MOD06)

Cloudy Sky Only

Day/Night

5 x 5 km resolution

Threshold Algorithm



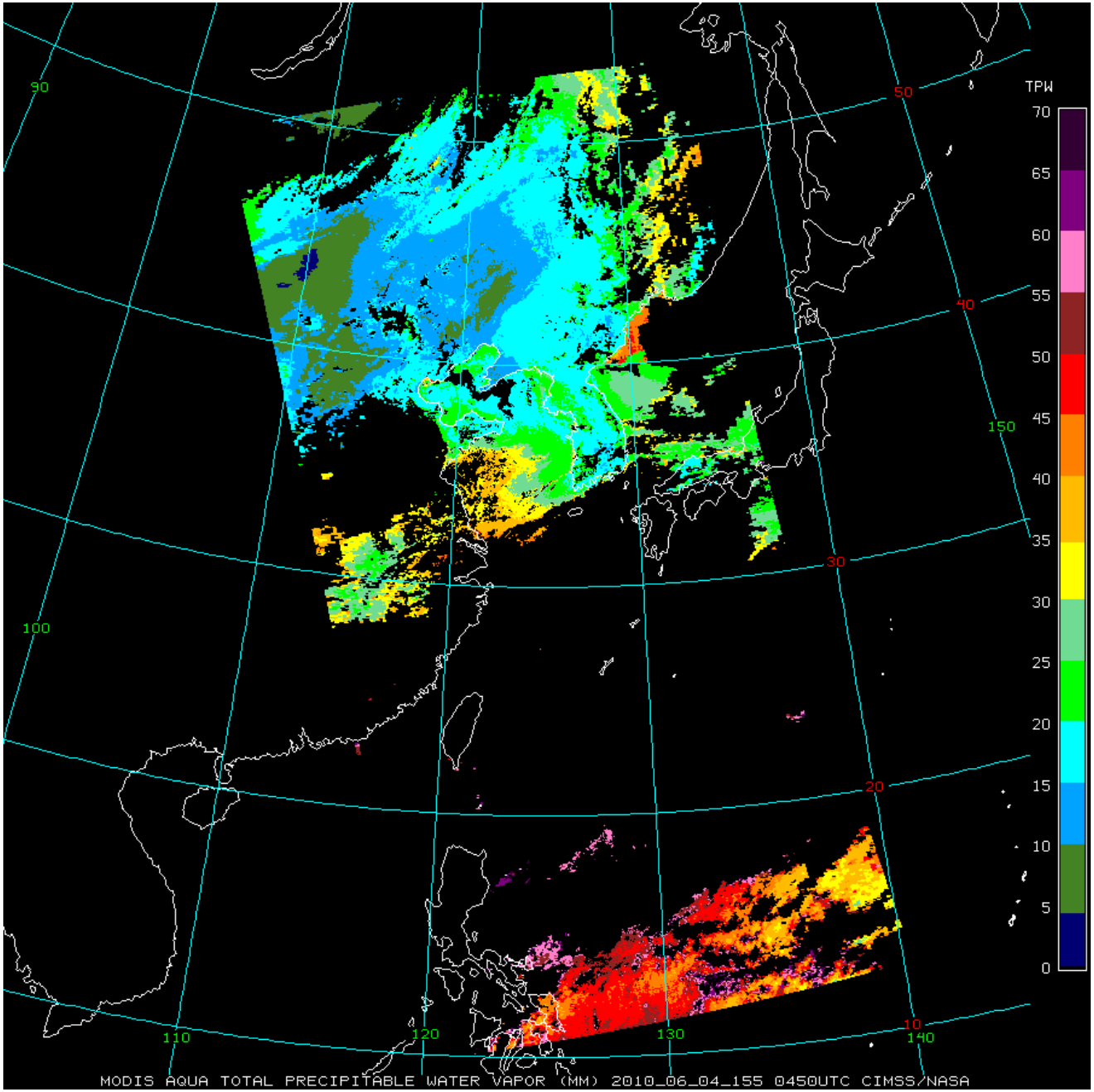
MODIS Water Vapor Product (MOD07)

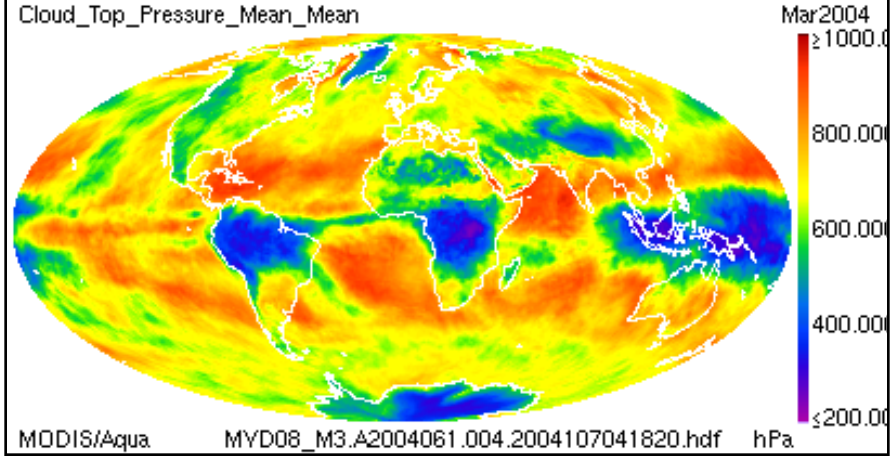
Clear Sky Only

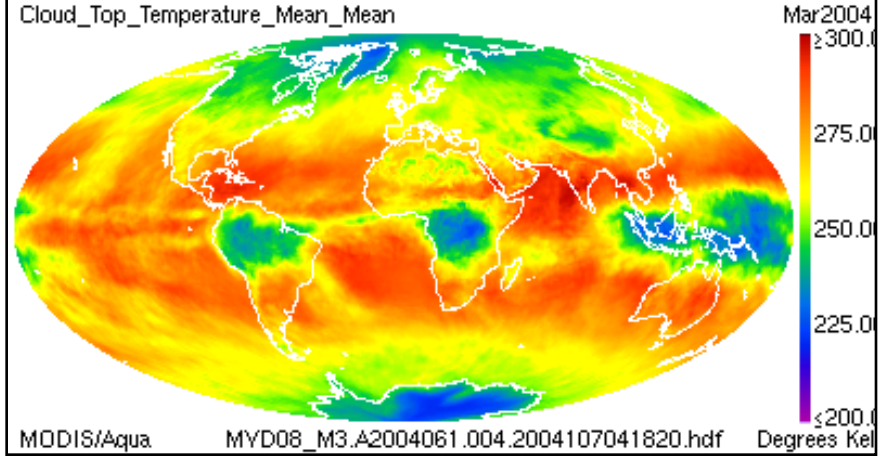
Day/Night

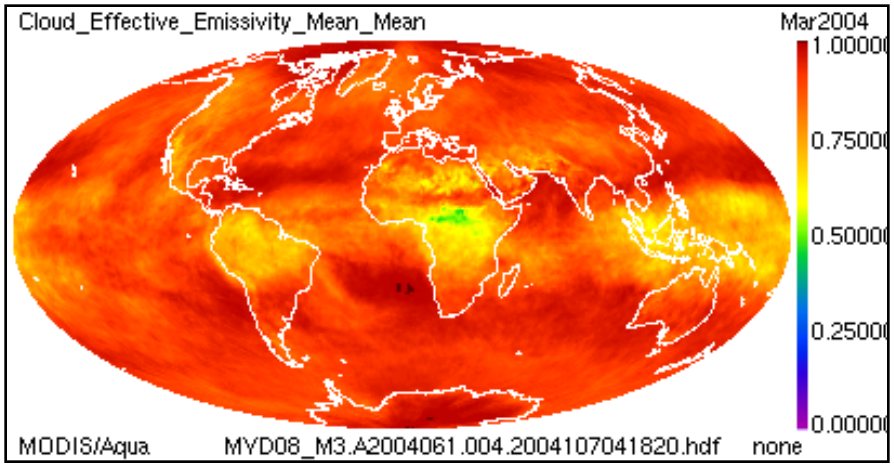
5 x 5 km resolution

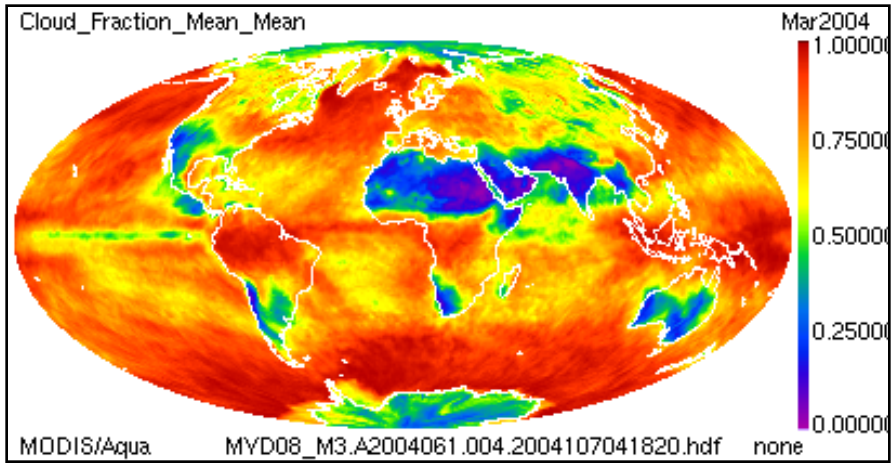
Statistical Algorithm

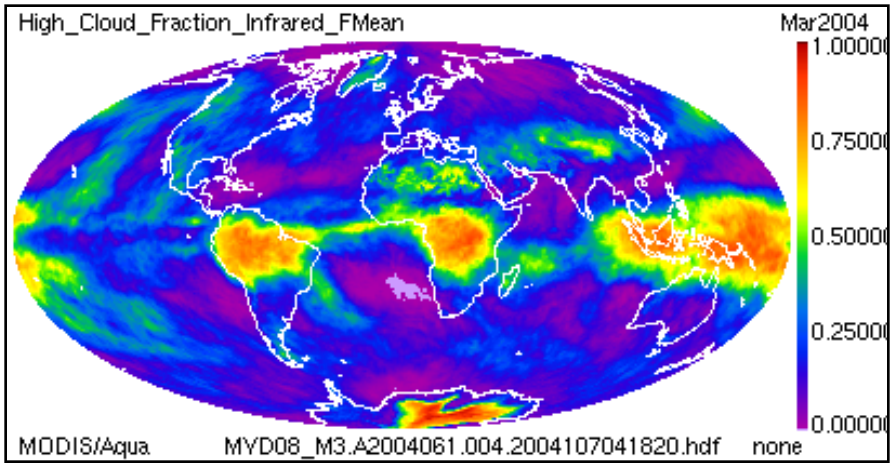












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End of Part One