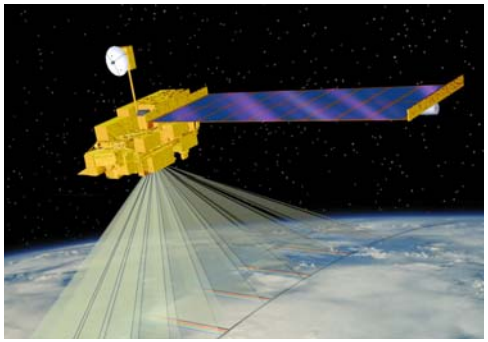
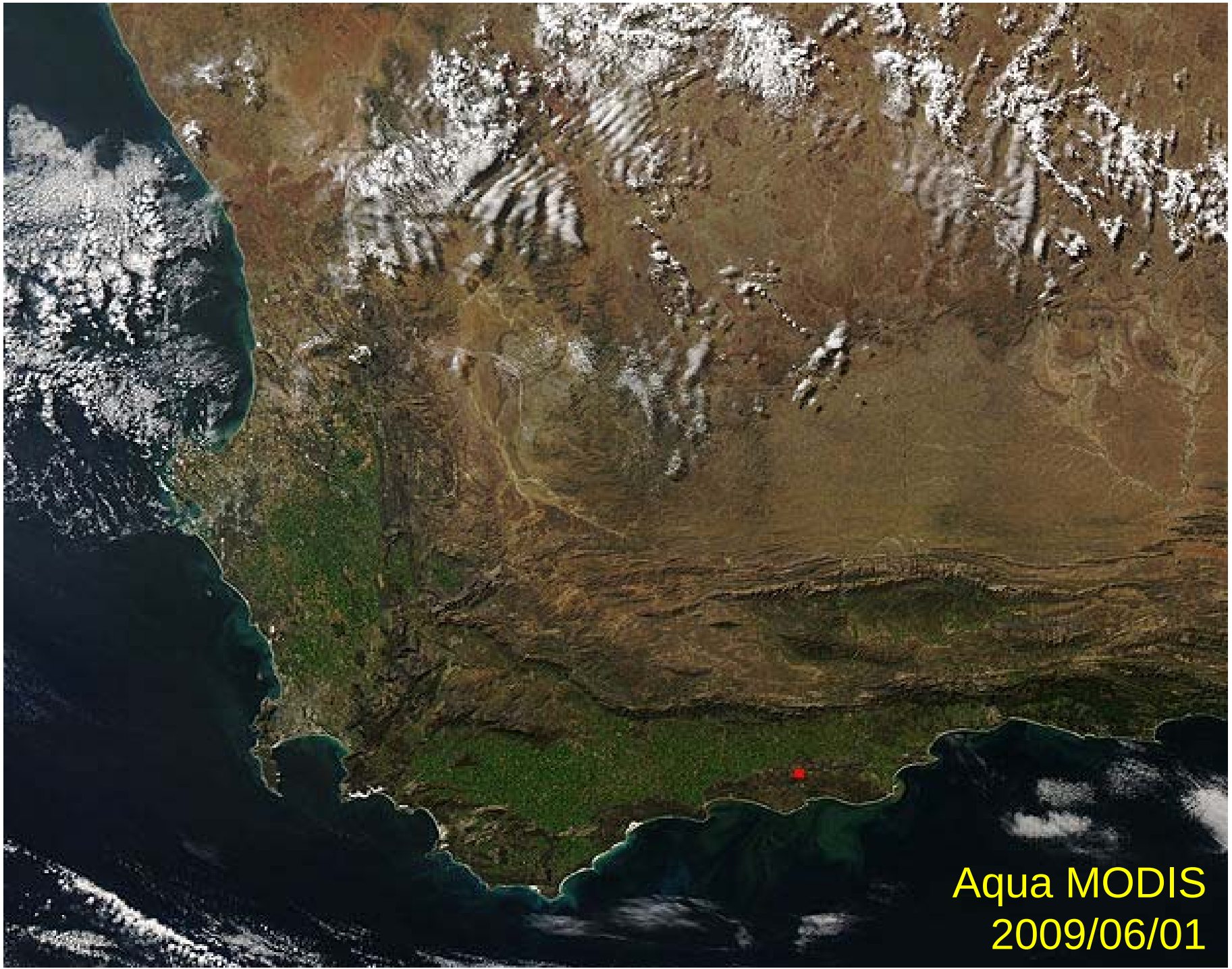
Introduction to MODIS

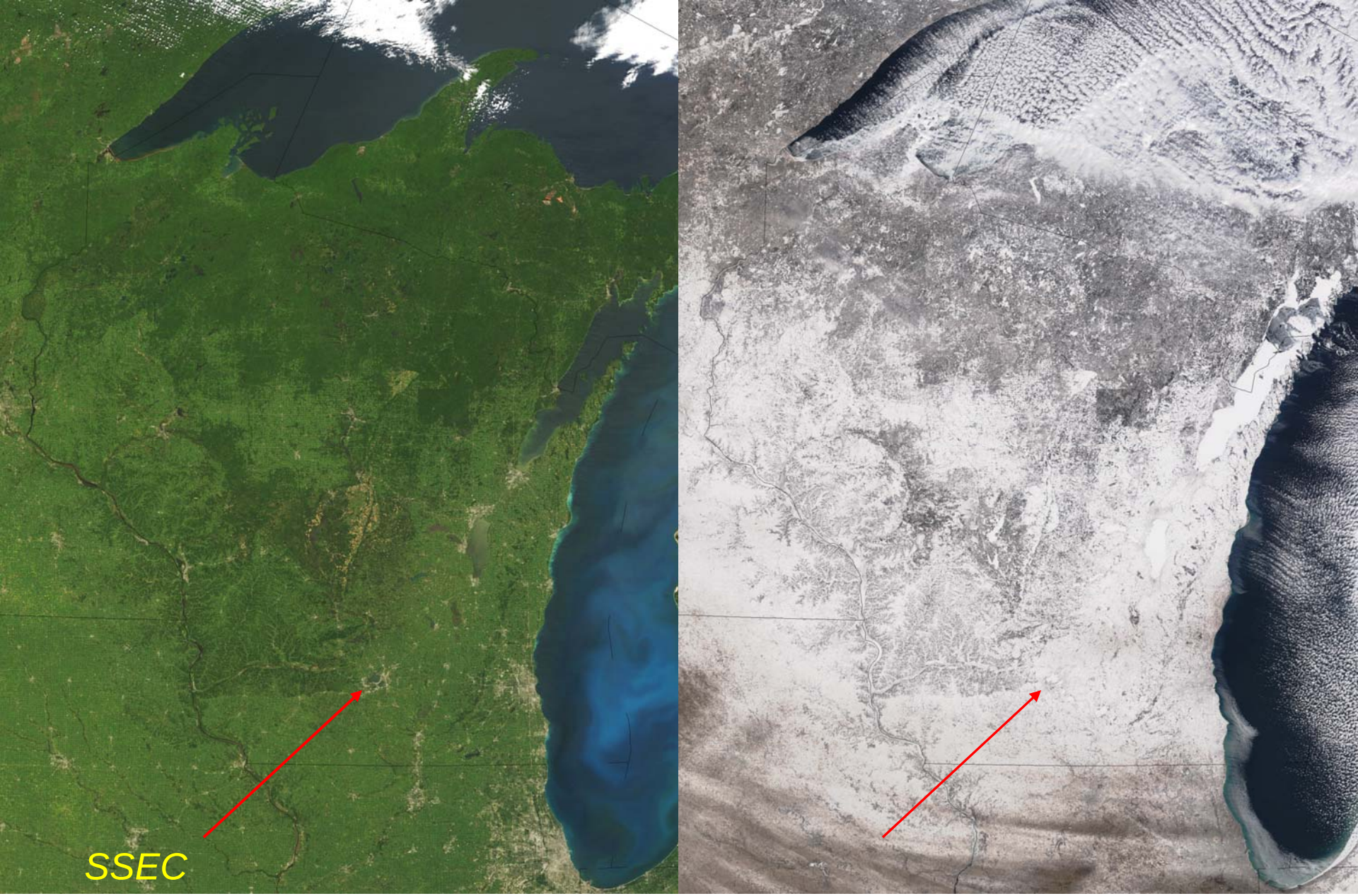


IGARSS 2009 SC-4
Stellenbosch, South Africa
July 7-10, 2009

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

CIMSS SSEC


Aqua MODIS
2009/06/01



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

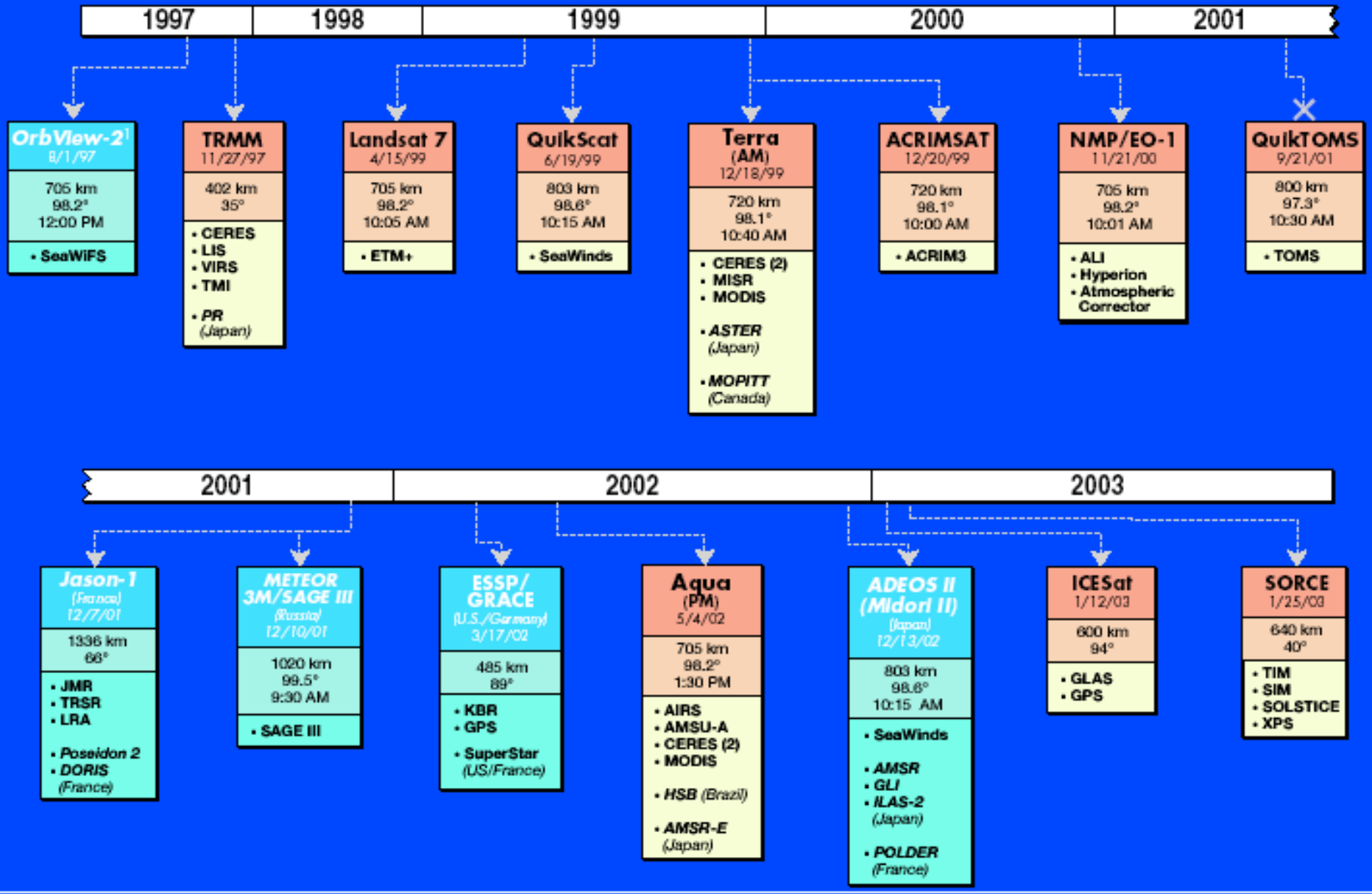
The Earth Observing System (EOS) is intended to measure the impact of human activities and other phenomena on the world's climate over a period spanning nearly two decades …

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

- Charles F. Kennel

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

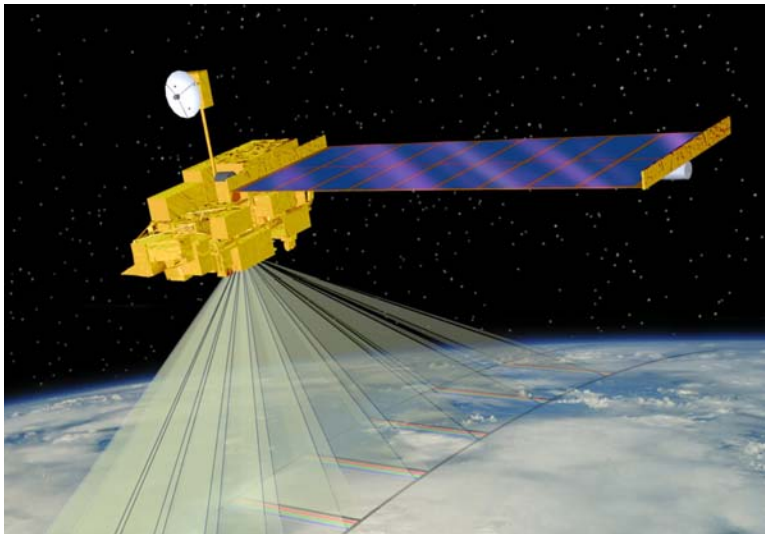
ASTER: Hi-res imager

CERES: Broadband scanner

MISR: Multi-view imager

MODIS: Multispectral imager

MOPITT: Limb sounder



Terra MODIS first light image, 24 Feb. 2000

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

Moderate Resolution Imaging Spectroradiometer (MODIS)

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

Spectral coverage: 36 bands from 0.4 to 14.2 microns

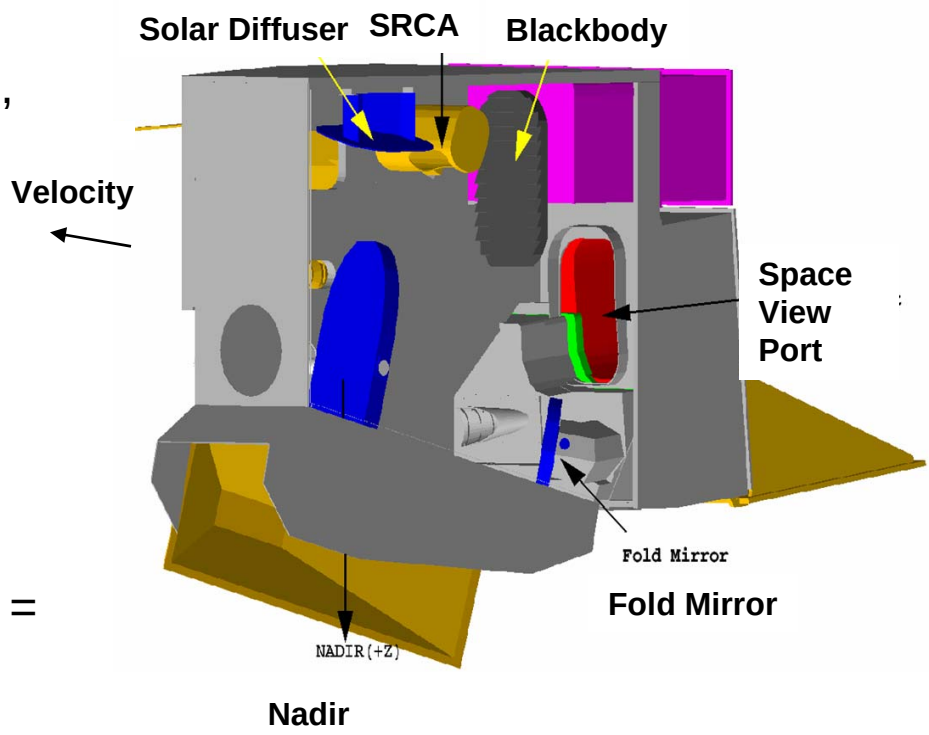
Spatial resolution: 2 bands @ 250 m; 5 @ 500 m; 29 @ 1000 m

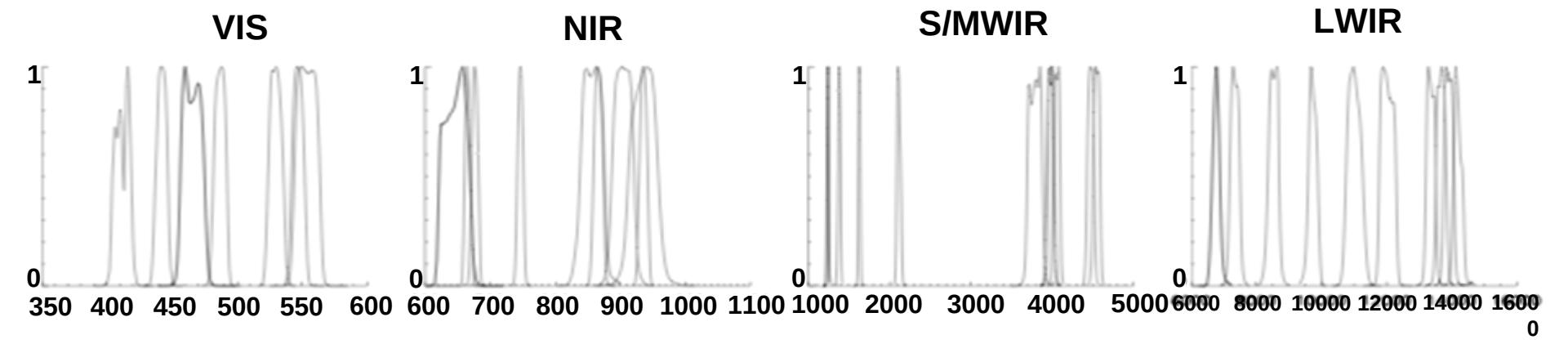
Major differences:

- More 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

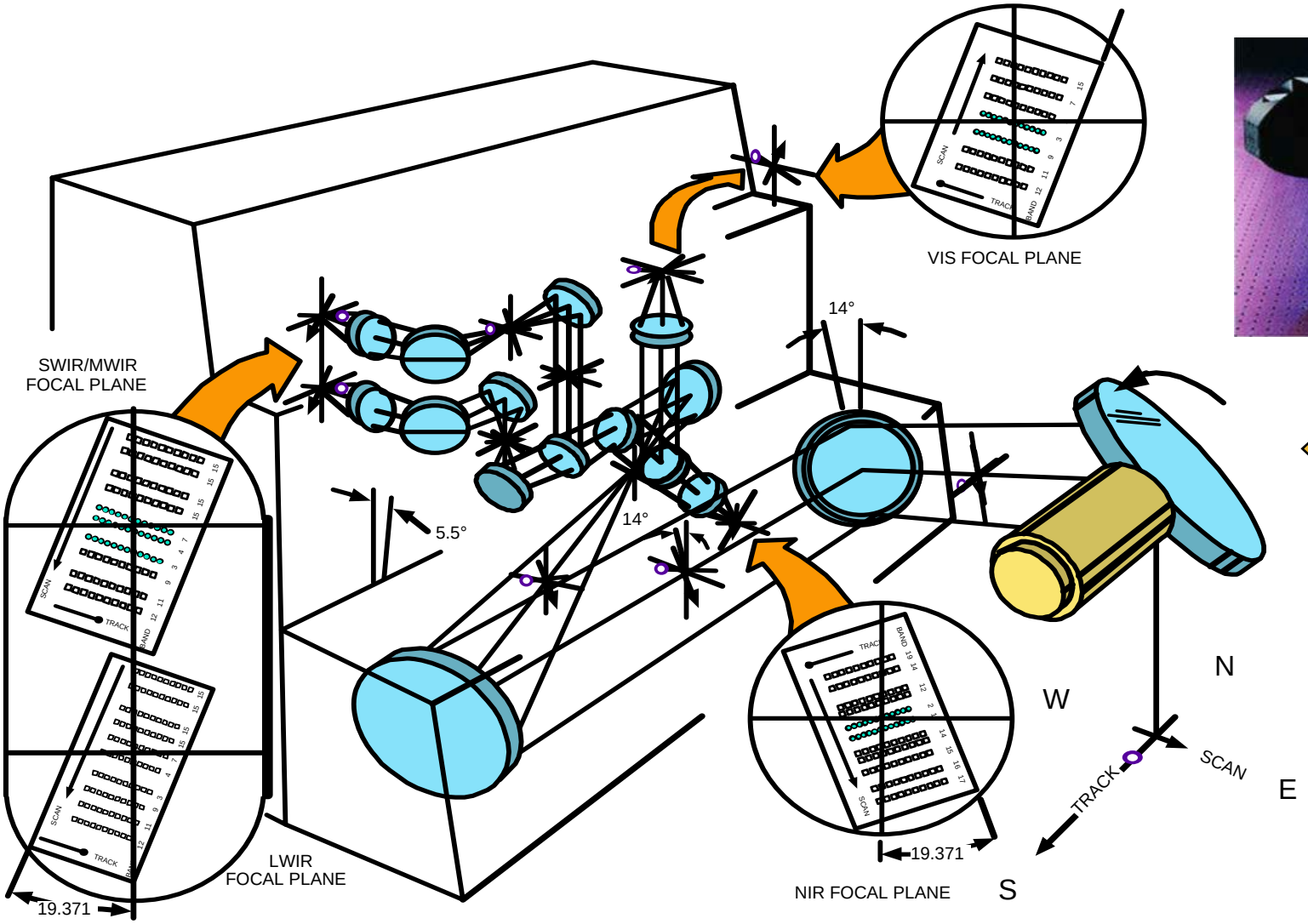
MODIS Instrument Overview

- 36 spectral bands (490 detectors) cover wavelength range from 0.4 to 14.5 μm
- Spatial resolution at nadir: 250m (2 bands), 500m (5 bands) and 1000m
- 4 FPAs: VIS, NIR, SMIR, LWIR
- 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 (100% duty cycle, 50% day and 50% night)





MODIS Optics System



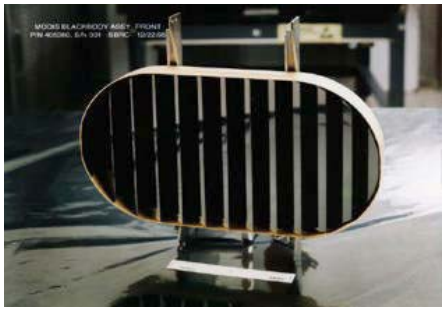
On-board Calibrators

SD

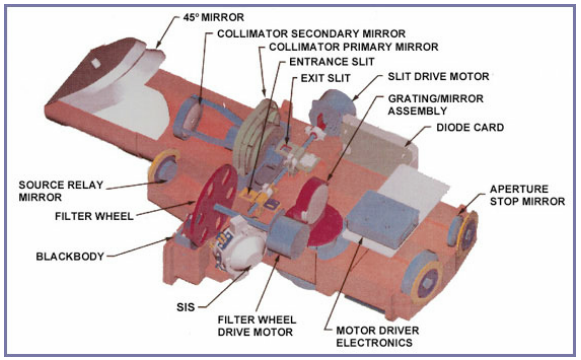
SDSM

- **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 challenge)

Data rate:

- Orders of magnitude larger than heritage sensors

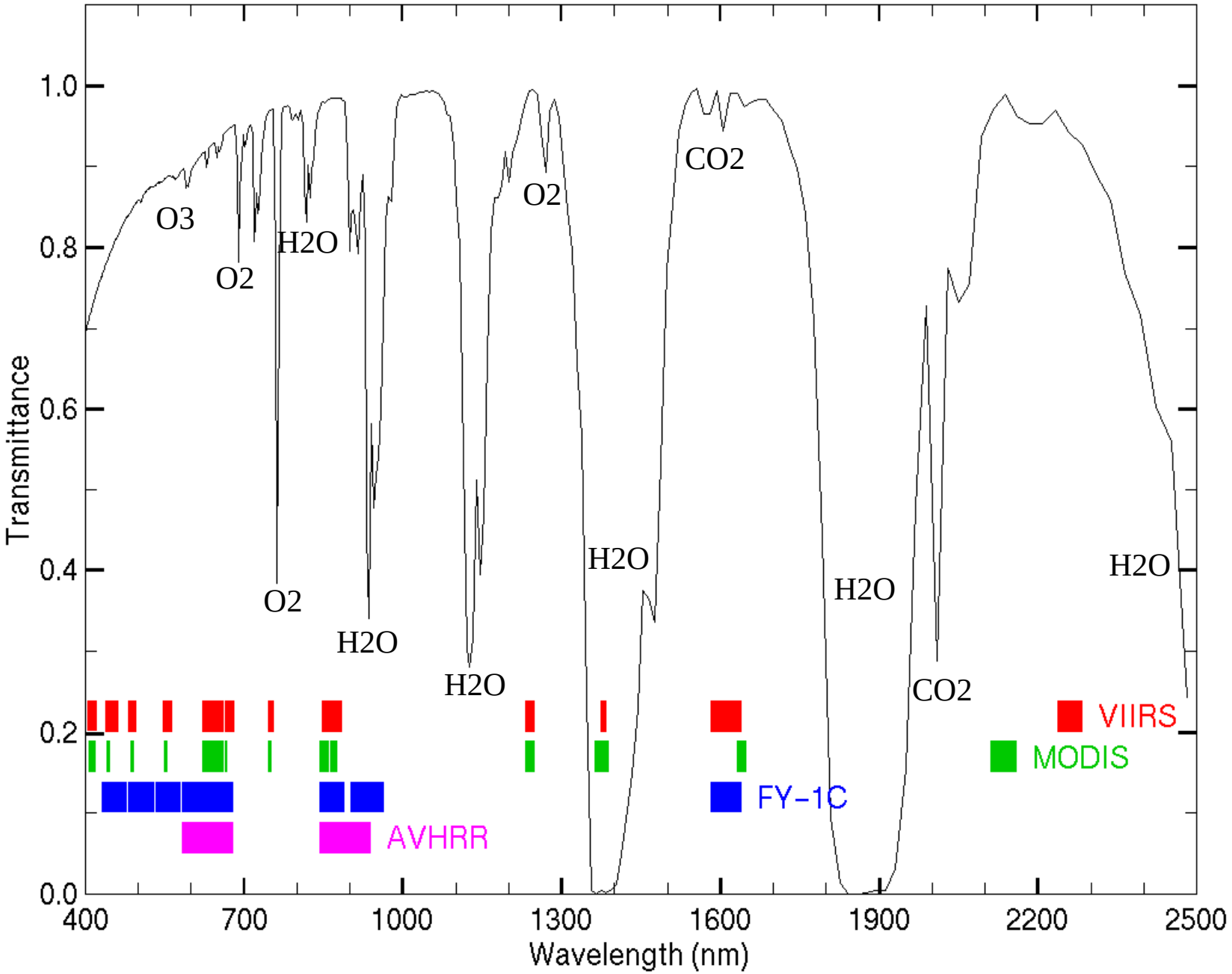
MODIS Reflected Solar Bands

Primary Use	Band	Bandwidth[1]	Spectral Radiance[2]	Required SNR[3]
Land/Cloud/Aerosols Boundaries	1	620 - 670	21.8	128
	2	841 - 876	24.7	201
Land/Cloud/Aerosols Properties	3	459 - 479	35.3	243
	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
	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

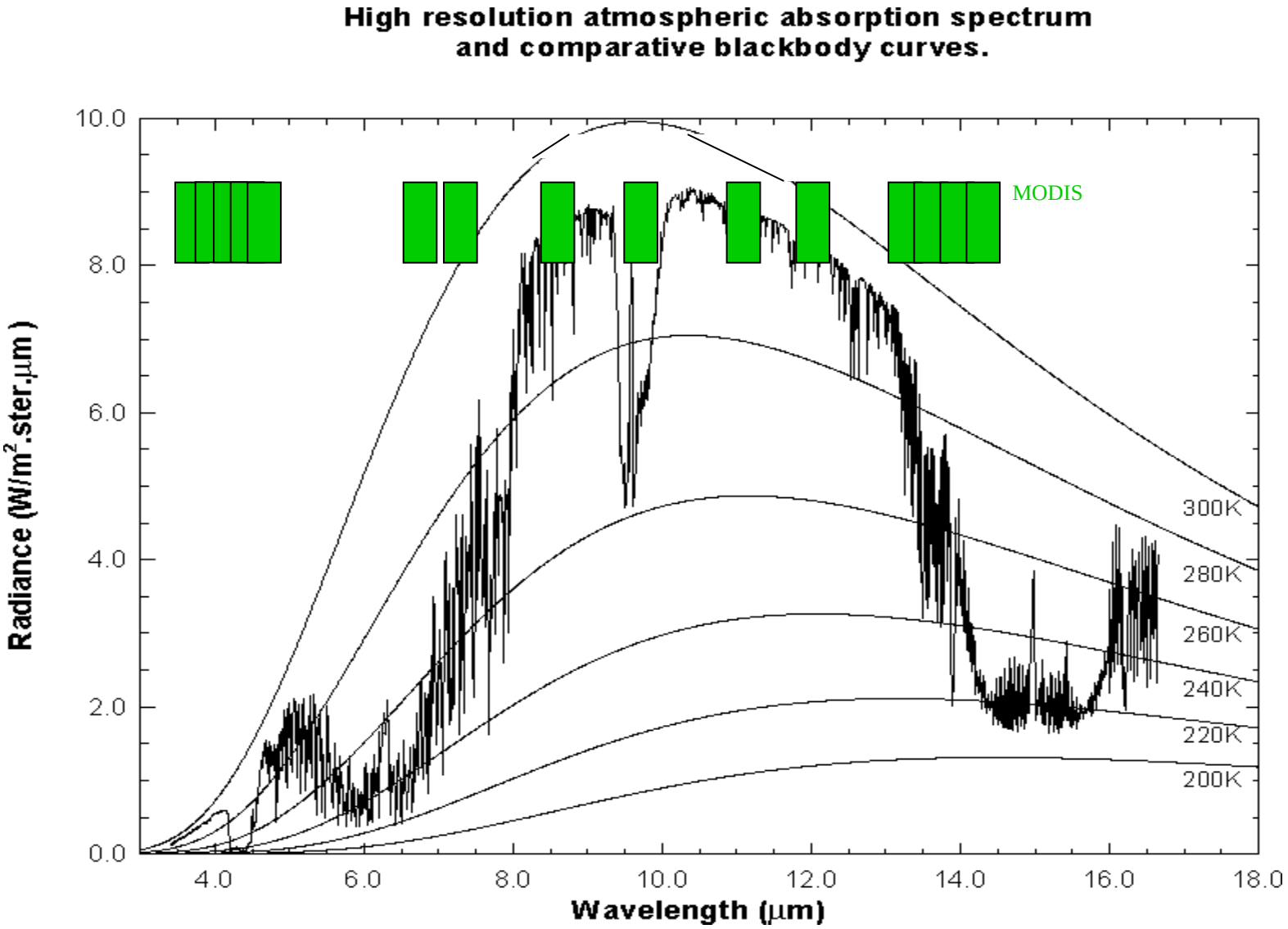
MODIS Thermal Emissive Bands

Primary Atmospheric Application	Band	Bandwidth[1]	$T_{typical}$ (K)	Radiance[2] at $T_{typical}$	NEΔT (K) Specification	NEΔT (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)

Scan mirror: Double sided, 20.3 revs/minute

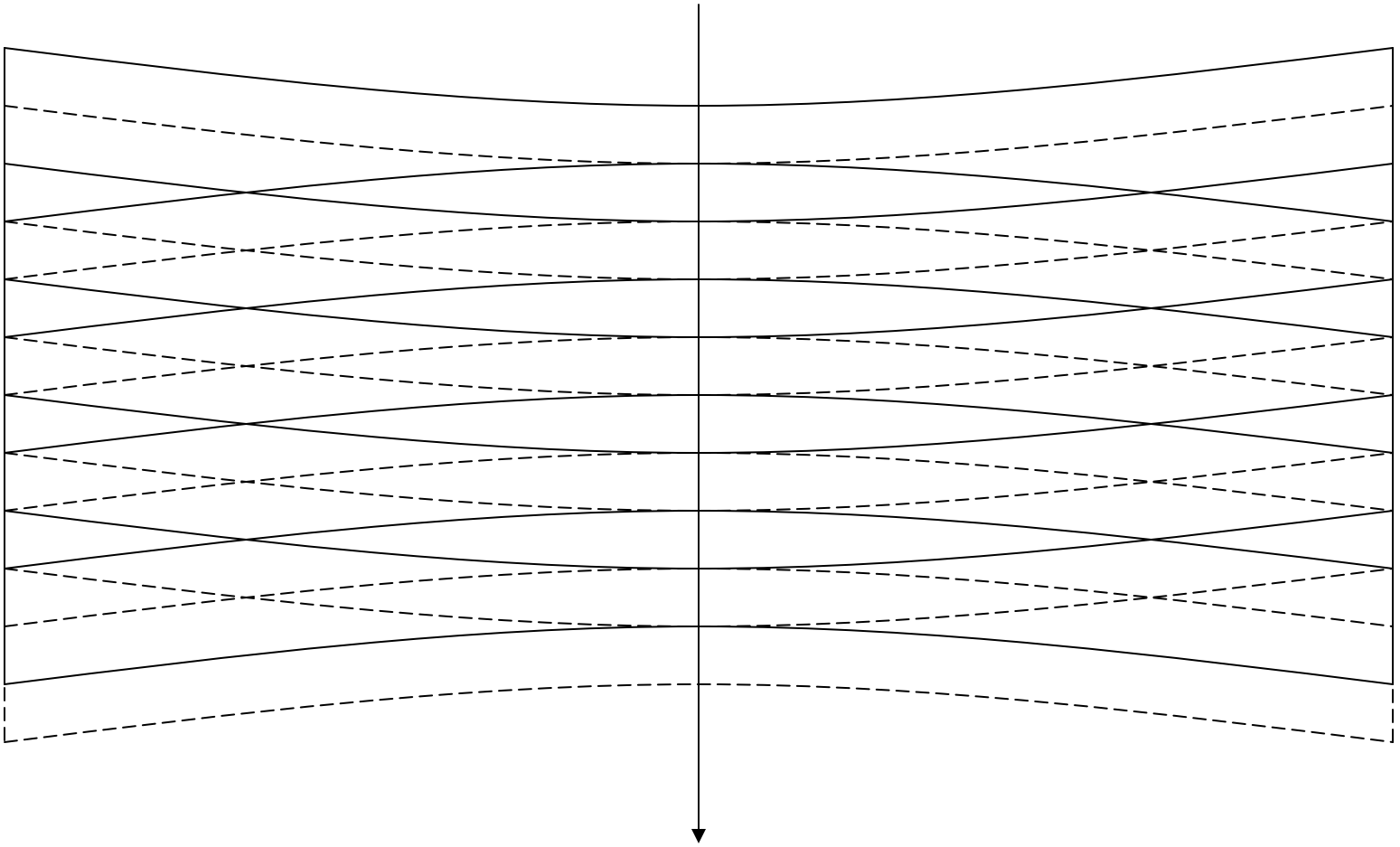
Scan rate: 1.477 scans/sec

Scan angle: +/- 55 degrees

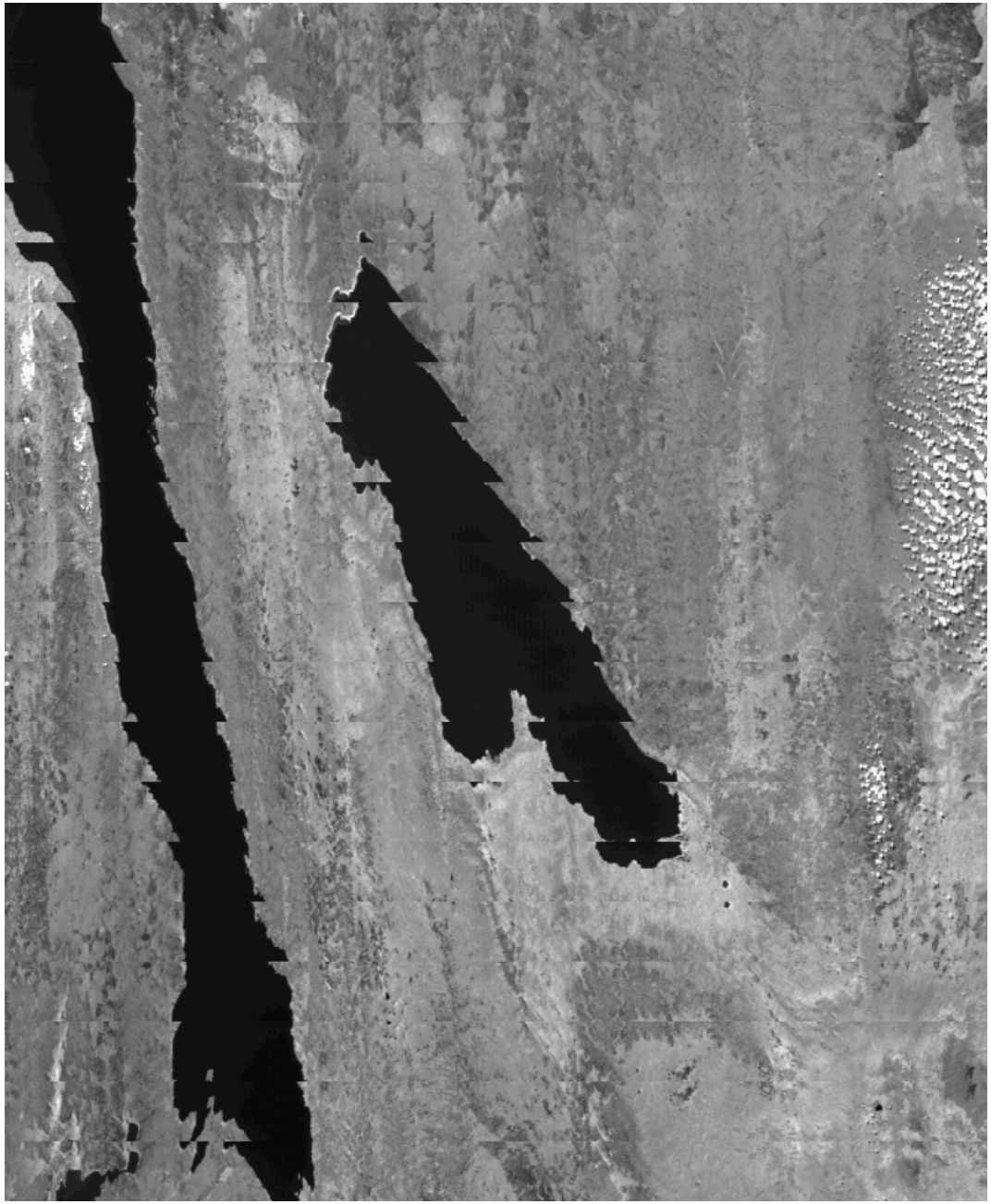
Swath width: 2330 km across track, 10 km along track

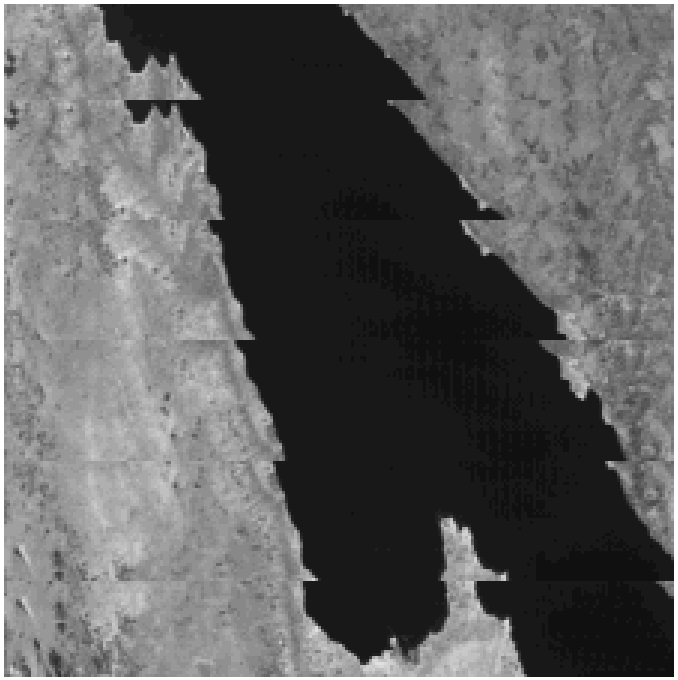
MODIS Bowtie

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



MODIS bowtie artifacts at edge of swath





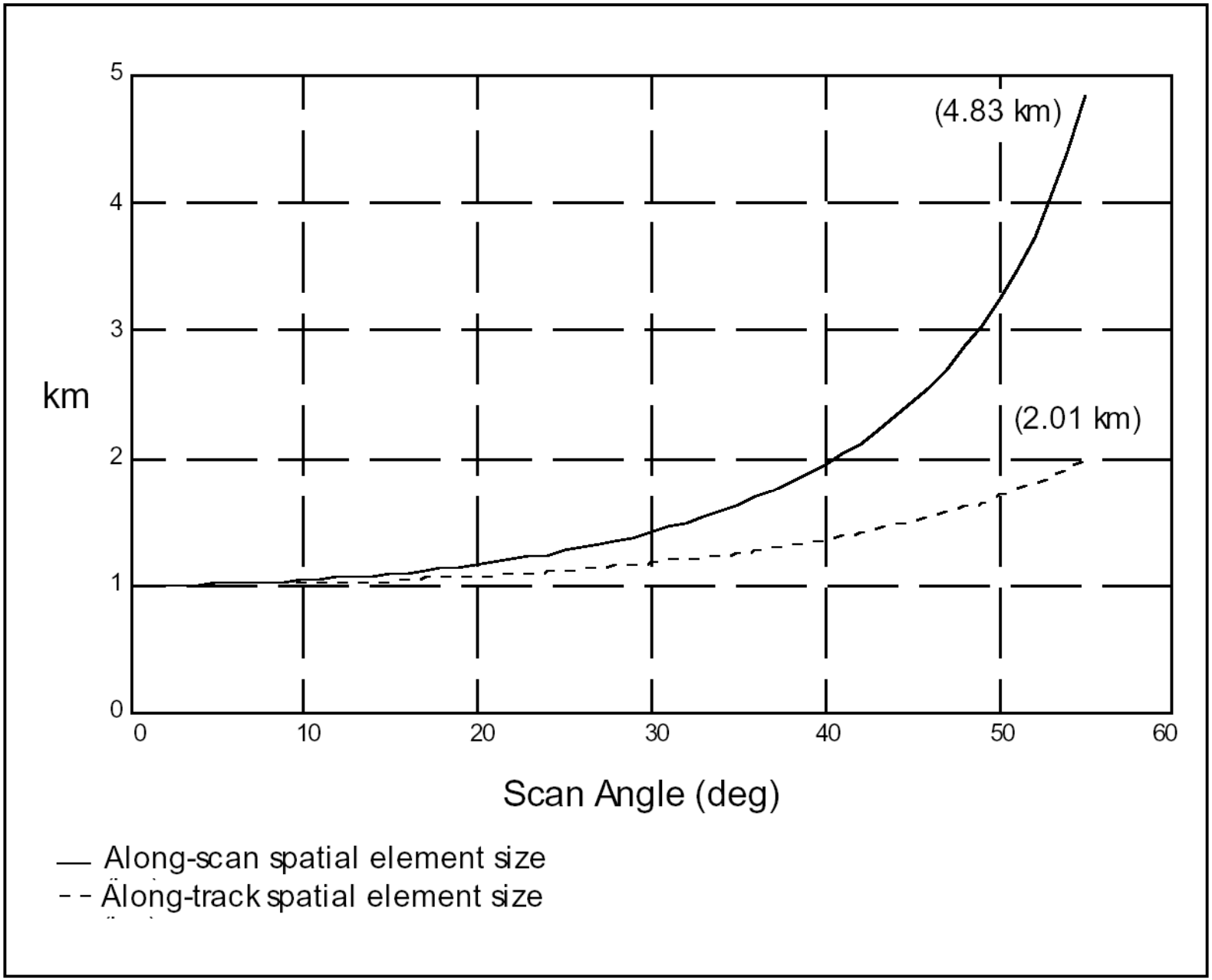
Band 2 (0.87 micron)

250 meter resolution

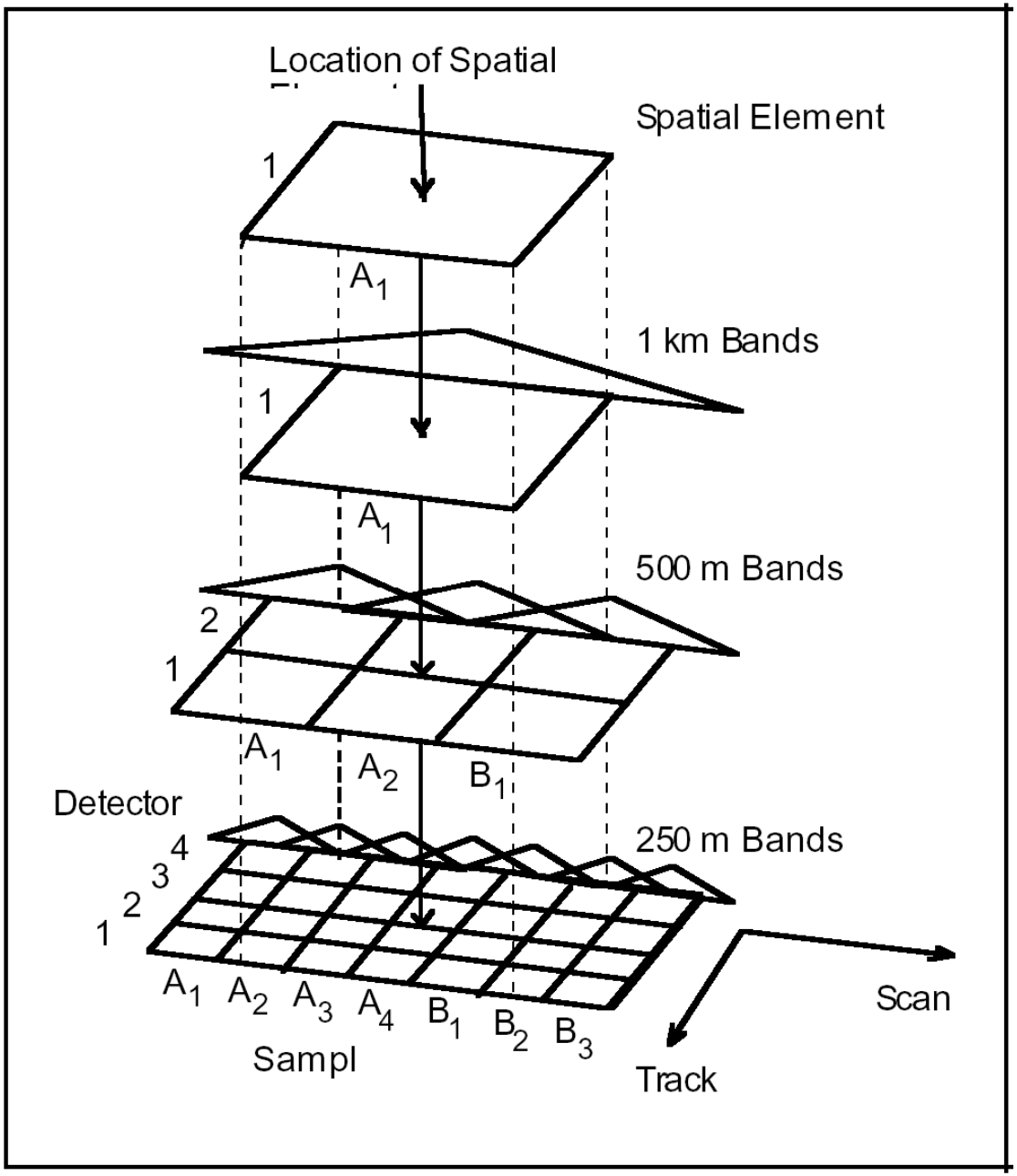
Bowtie Artifacts

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/NPOESS)

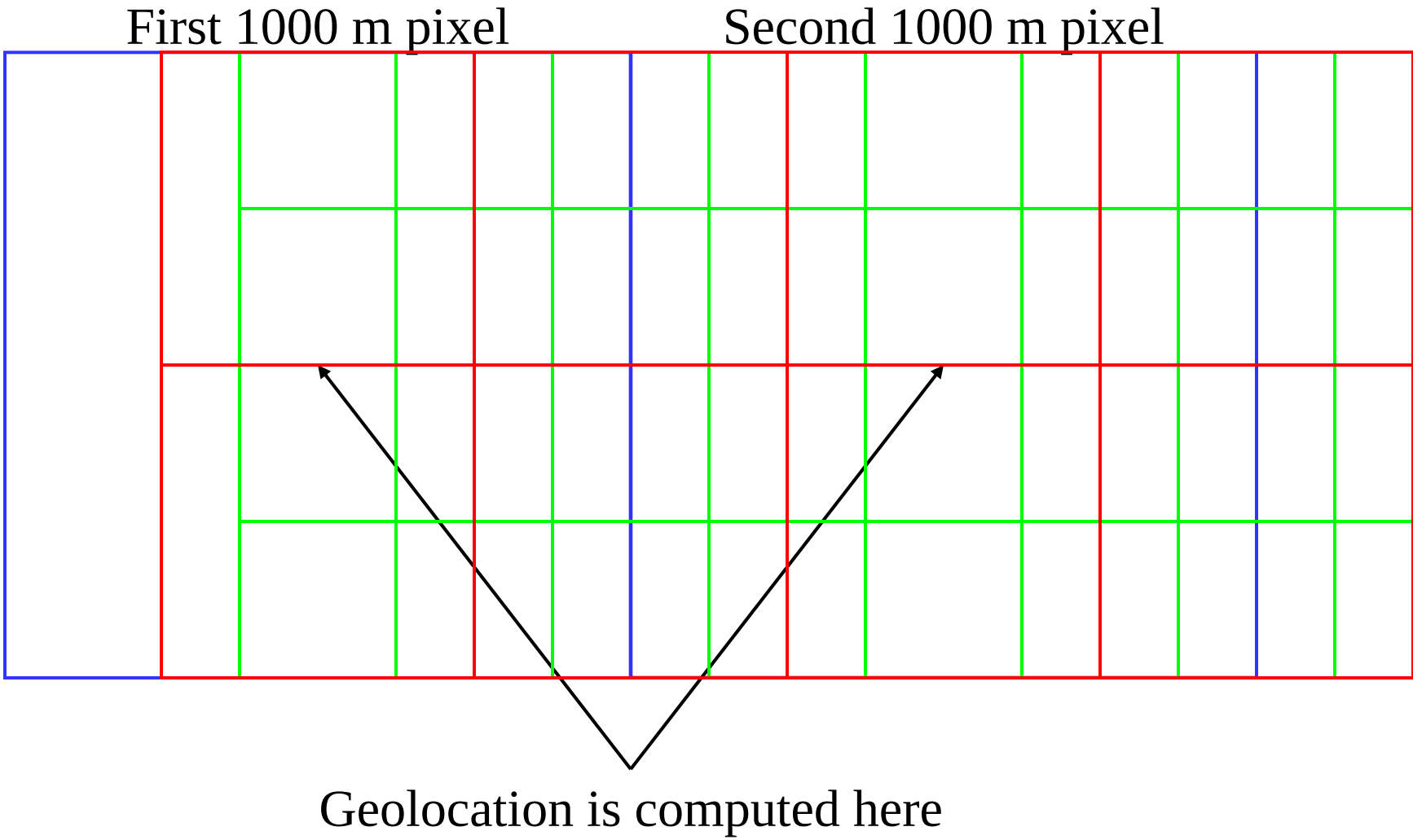
Growth of MODIS 1 km pixel with scan angle



Inter-band Registration



Nominal MODIS inter-band registration

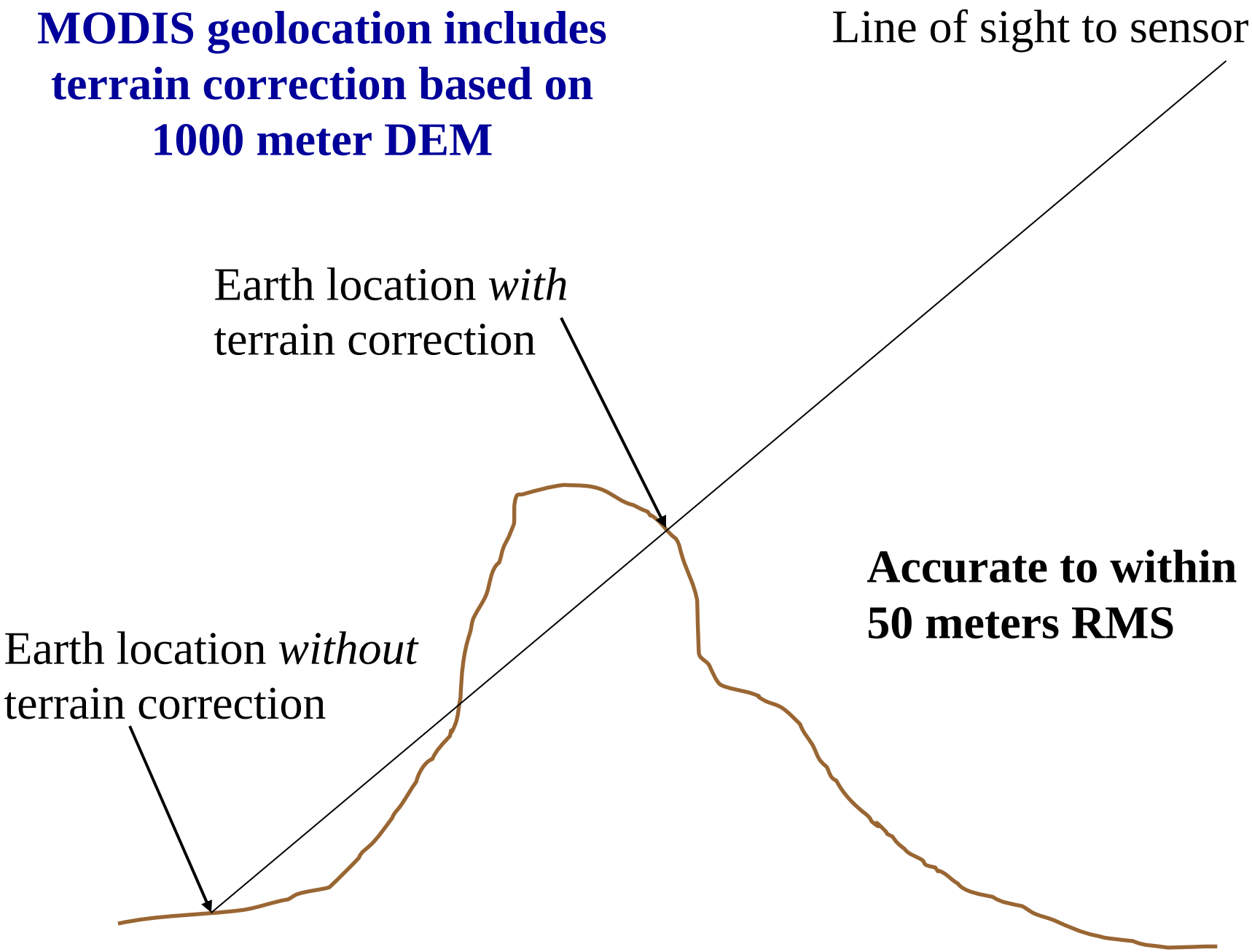


MODIS Geolocation

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

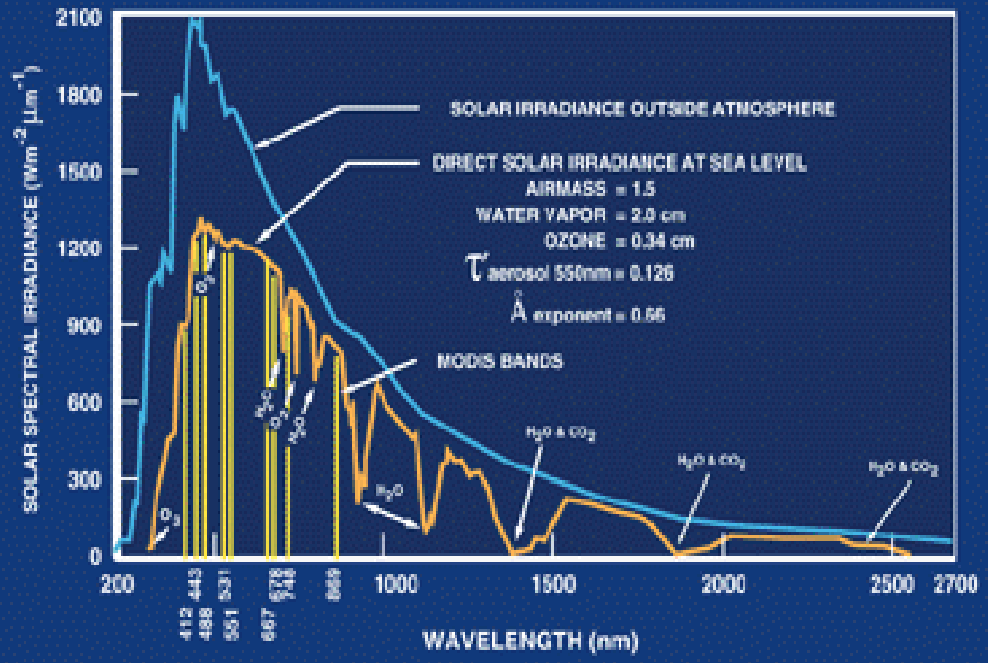
- Geodetic latitude (degrees, -90S to +90N)
- Geodetic longitude (degrees, -180W to +180E)
- Sensor zenith and azimuth (degrees, pixel to sensor)
- Solar zenith and azimuth (degrees, pixel to sun)
- Terrain height above geoid (meters)
- Land/Sea mask
    - 0: Shallow Ocean
    - 1: Land
    - 2: Ocean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

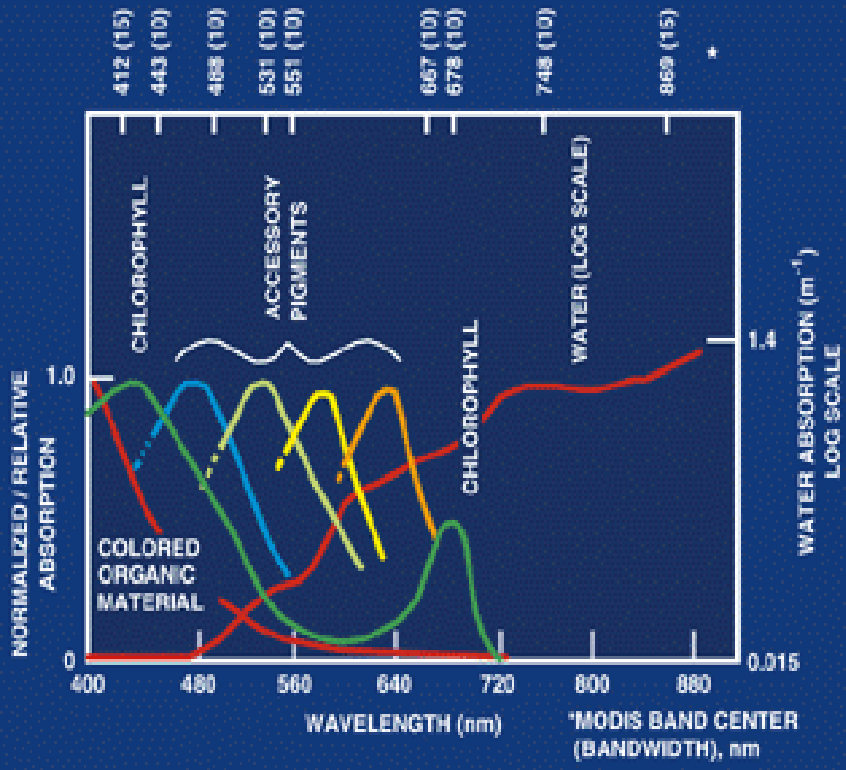
MODIS geolocation includes terrain correction based on 1000 meter DEM



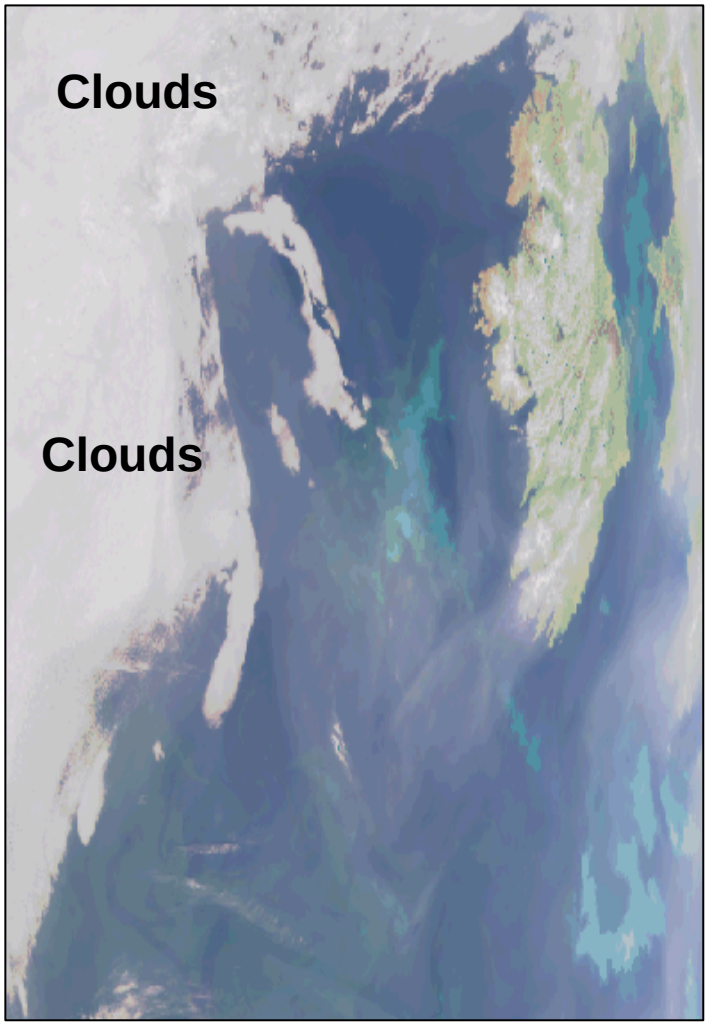
MODIS Ocean Applications

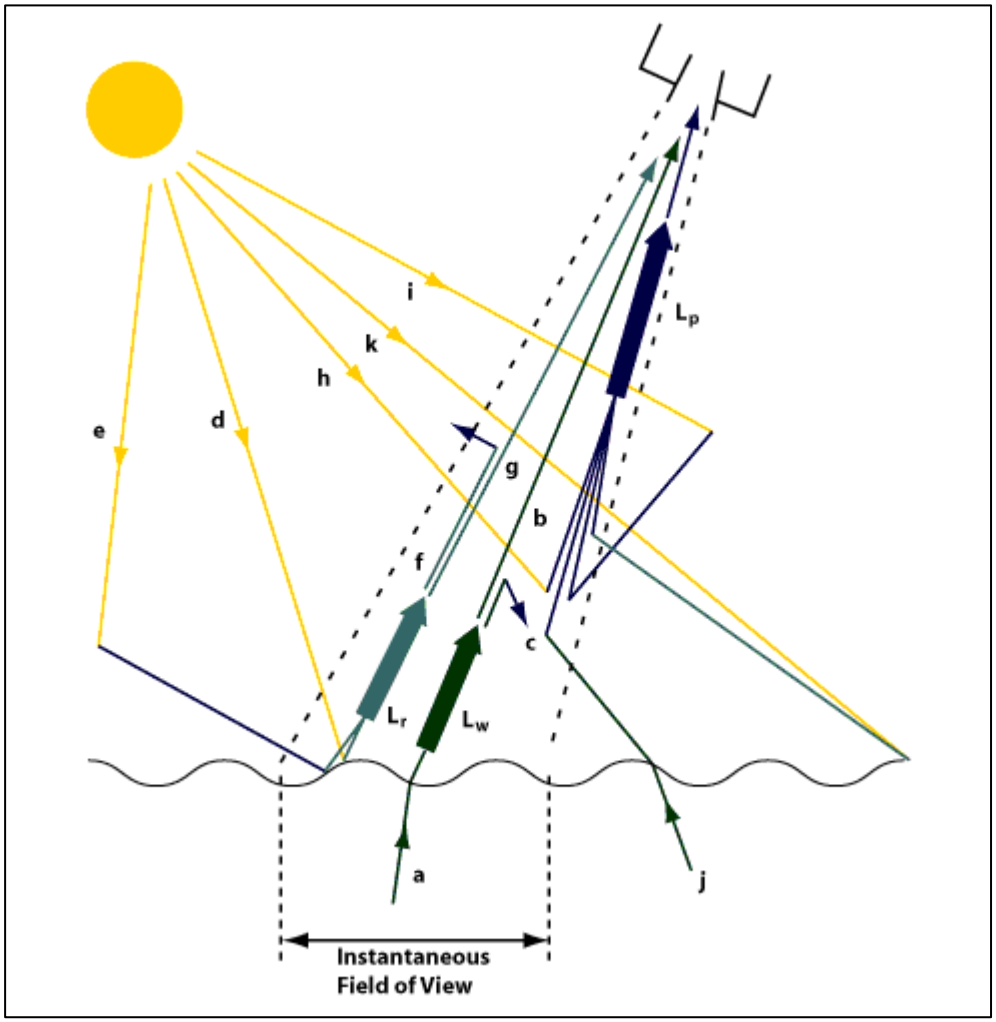
OCEAN-SOLAR RADIATION





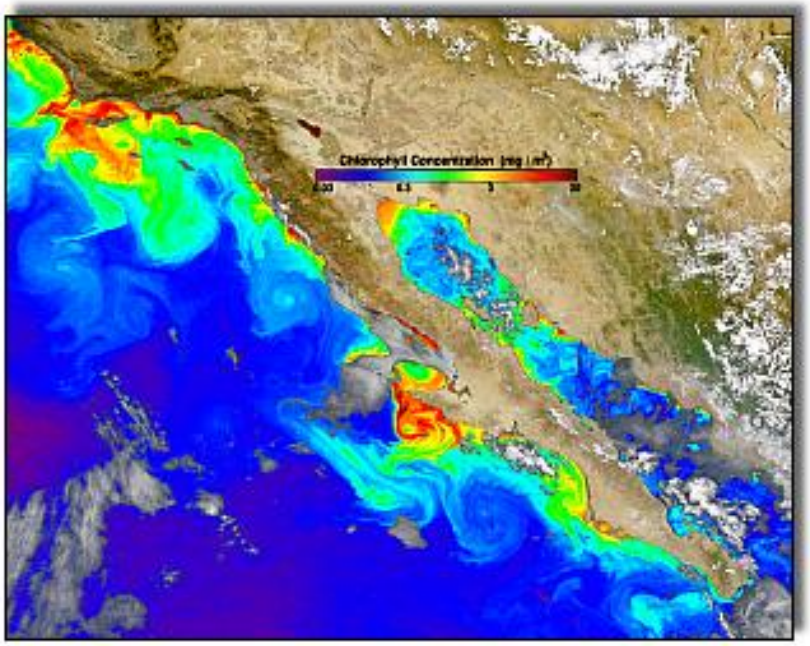
Atmospheric correction is critical for ocean color





- 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

Chlorophyll

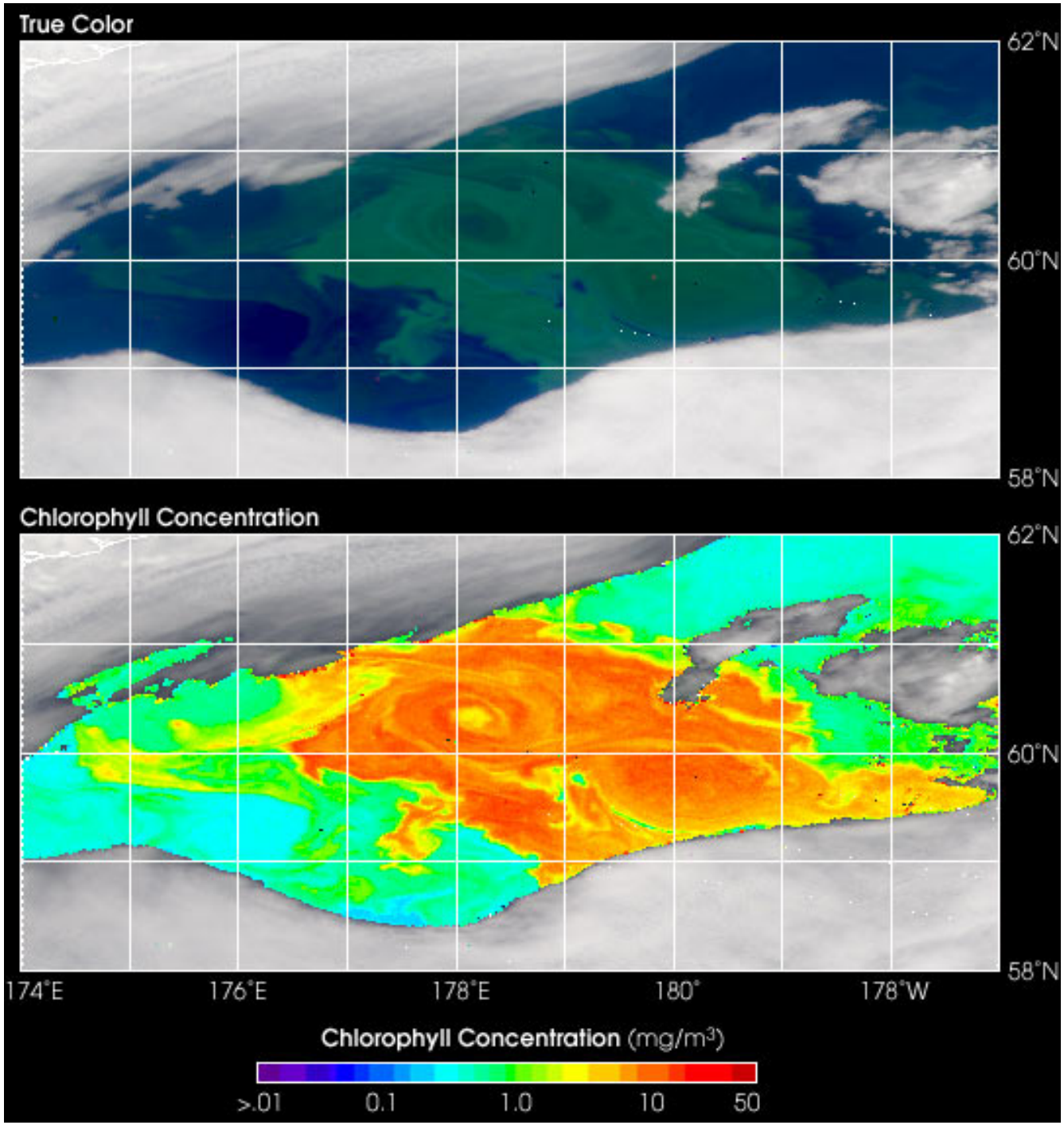


August 10, 2003

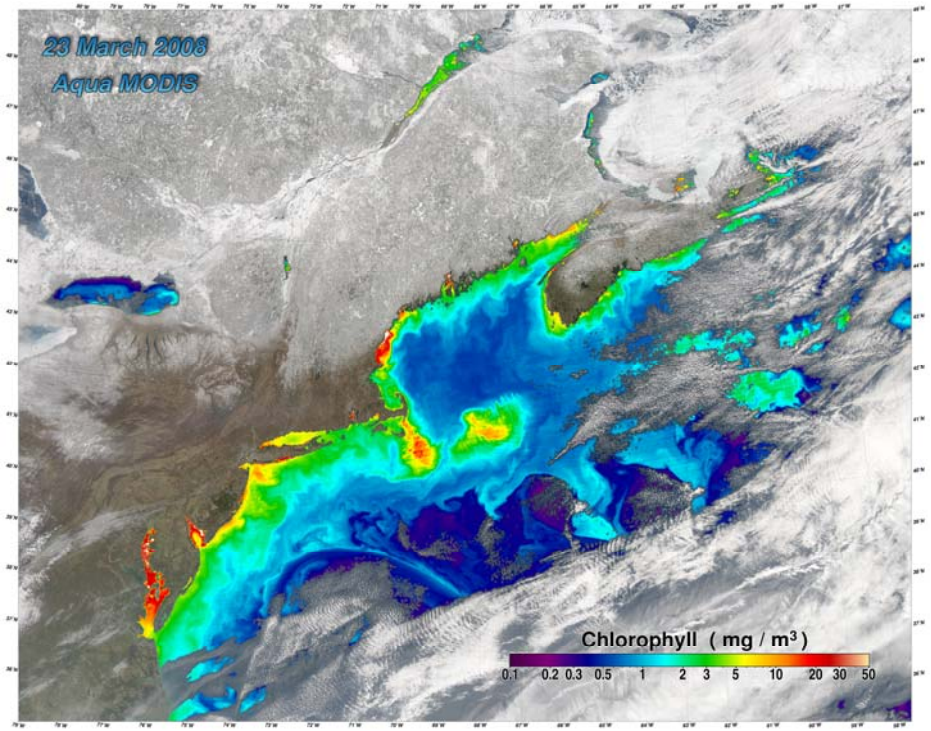
Strong absorption of the blue light by phytoplankton in chlorophyll-rich waters results in low water-leaving radiance in the blue bands.

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

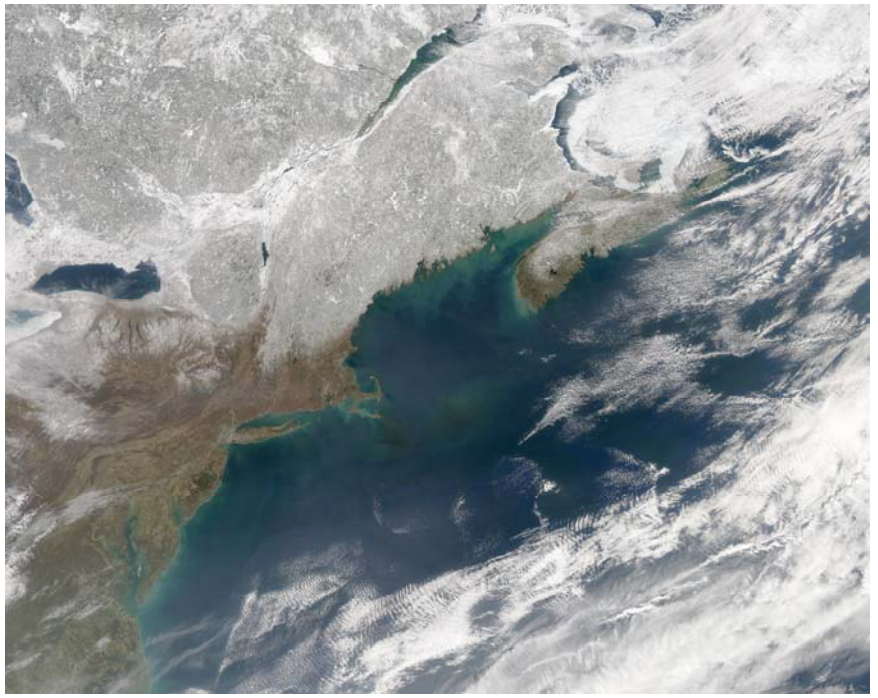
Index of the change in spectral shape ⇒ chlorophyll


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

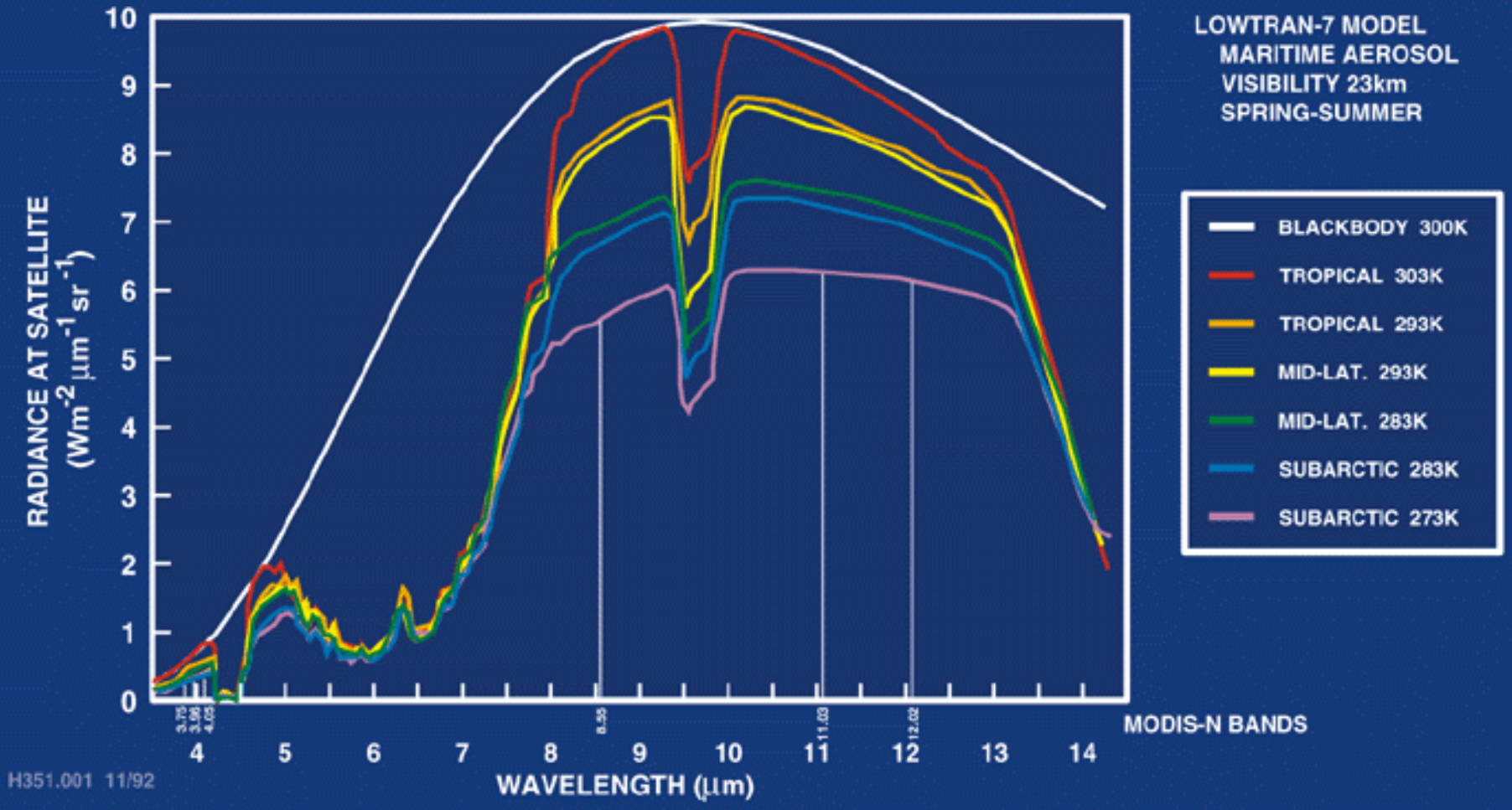


Chlorophyll concentration

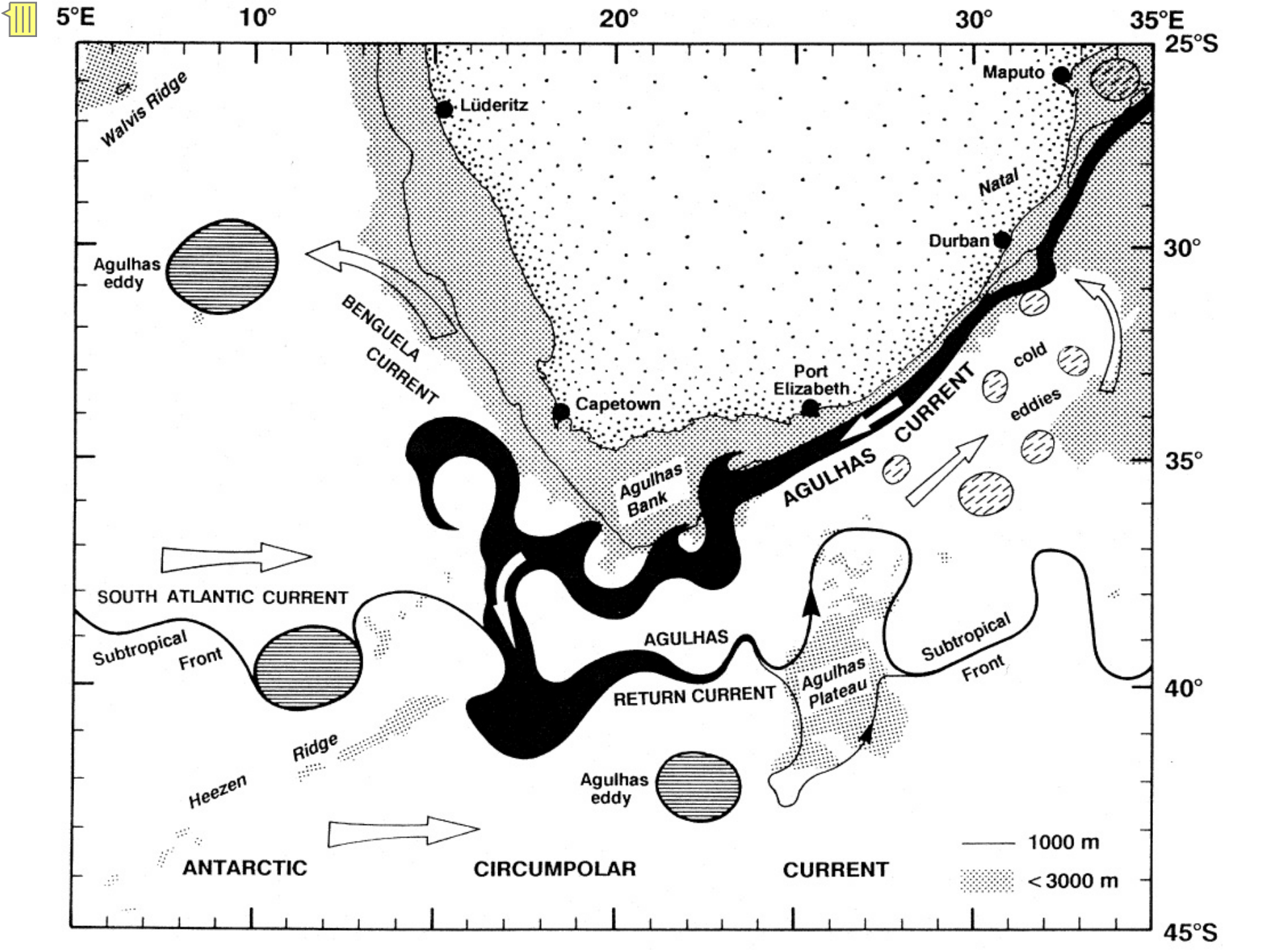


True color

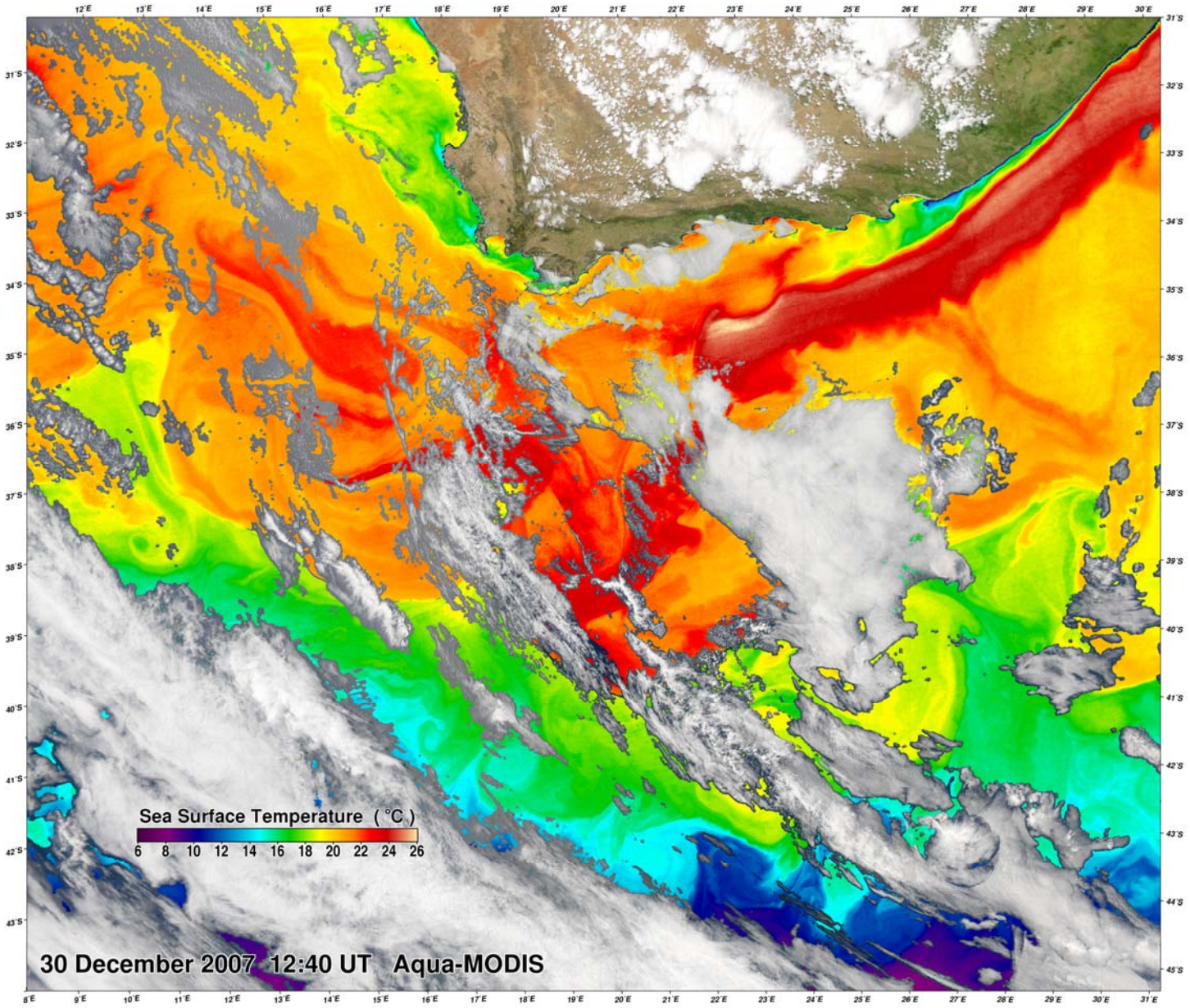
MODIS SEA SURFACE TEMPERATURE



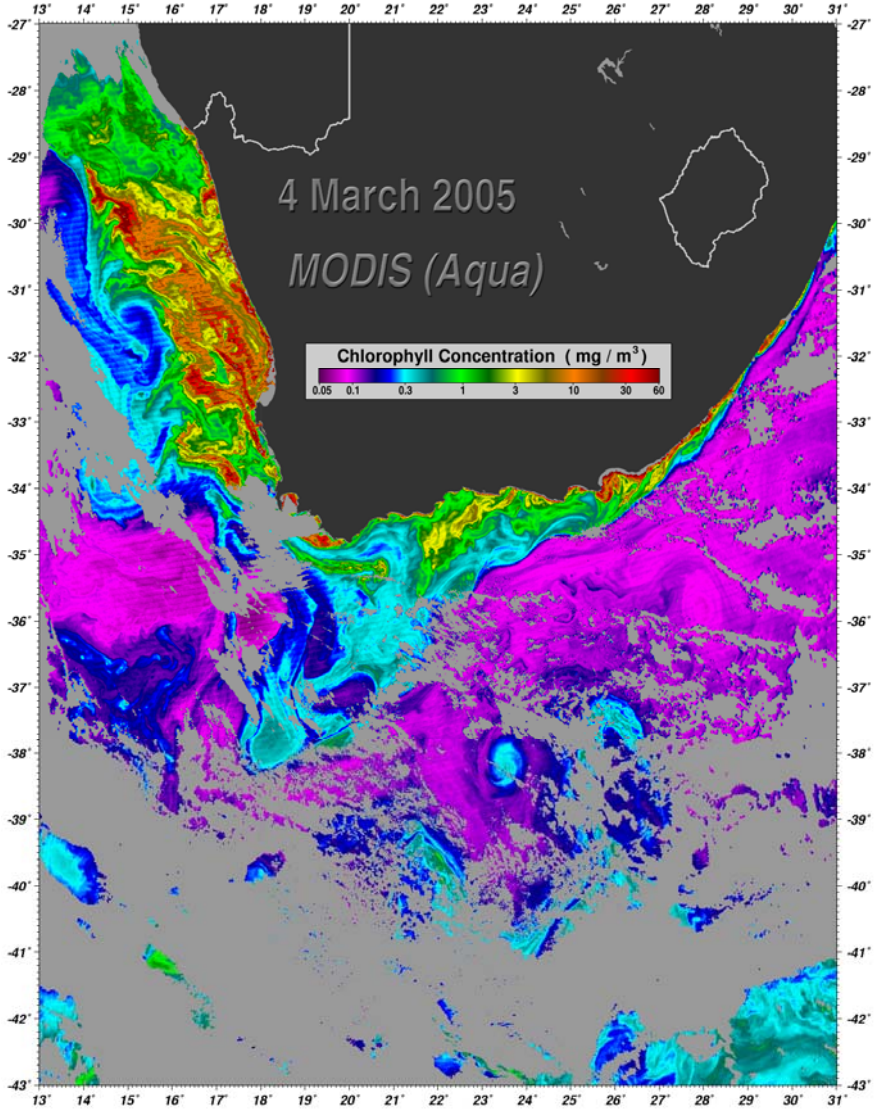
H351.001 11/92

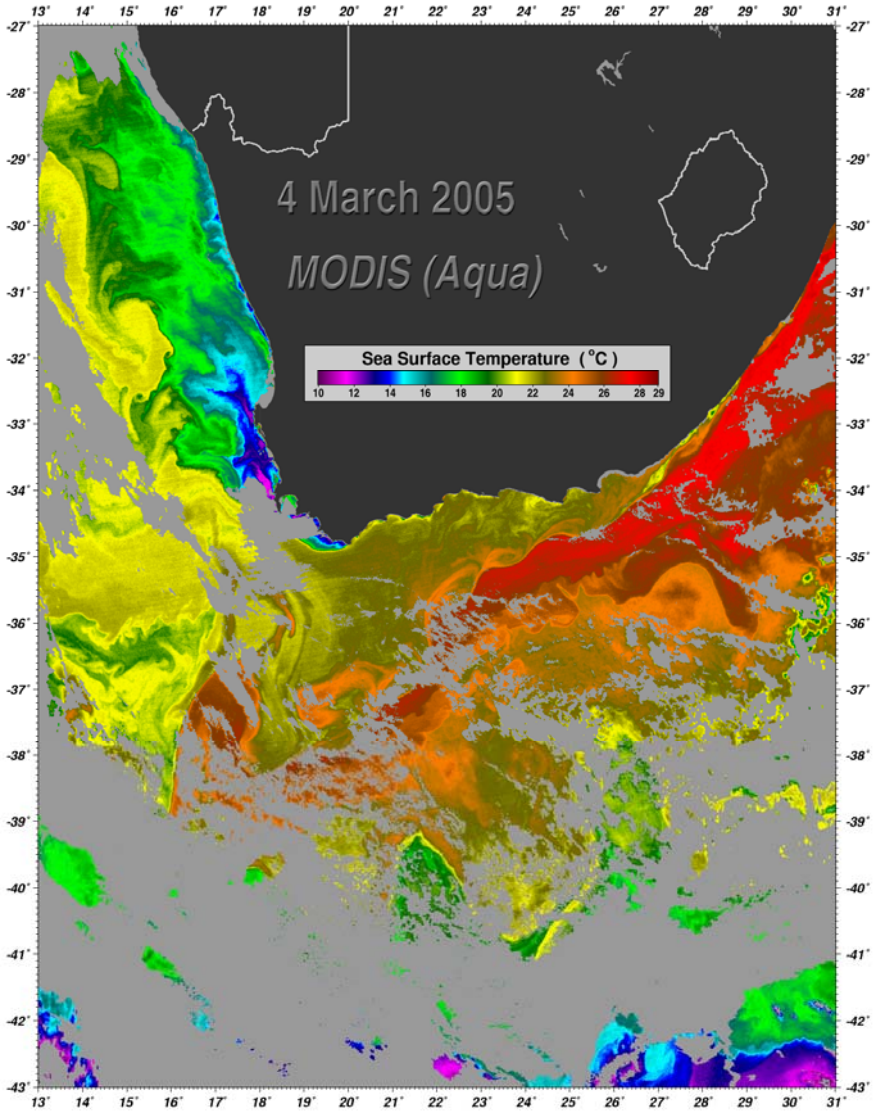

5°E
10°
20°
30°
35°E
25°S
30°
35°
40°
45°S
Walvis Ridge
Lüderitz
Maputo
Natal
Durban
Agulhas eddy
BENGUELA CURRENT
Capetown
Port Elizabeth
cold eddies
AGULHAS CURRENT
Agulhas Bank
SOUTH ATLANTIC CURRENT
Subtropical Front
AGULHAS RETURN CURRENT
Agulhas Plateau
Subtropical Front
Ridge
Heezen
Agulhas eddy
ANTARCTIC CIRCUMPOLAR CURRENT
1000 m
< 3000 m

Agulhas & Benguela Currents

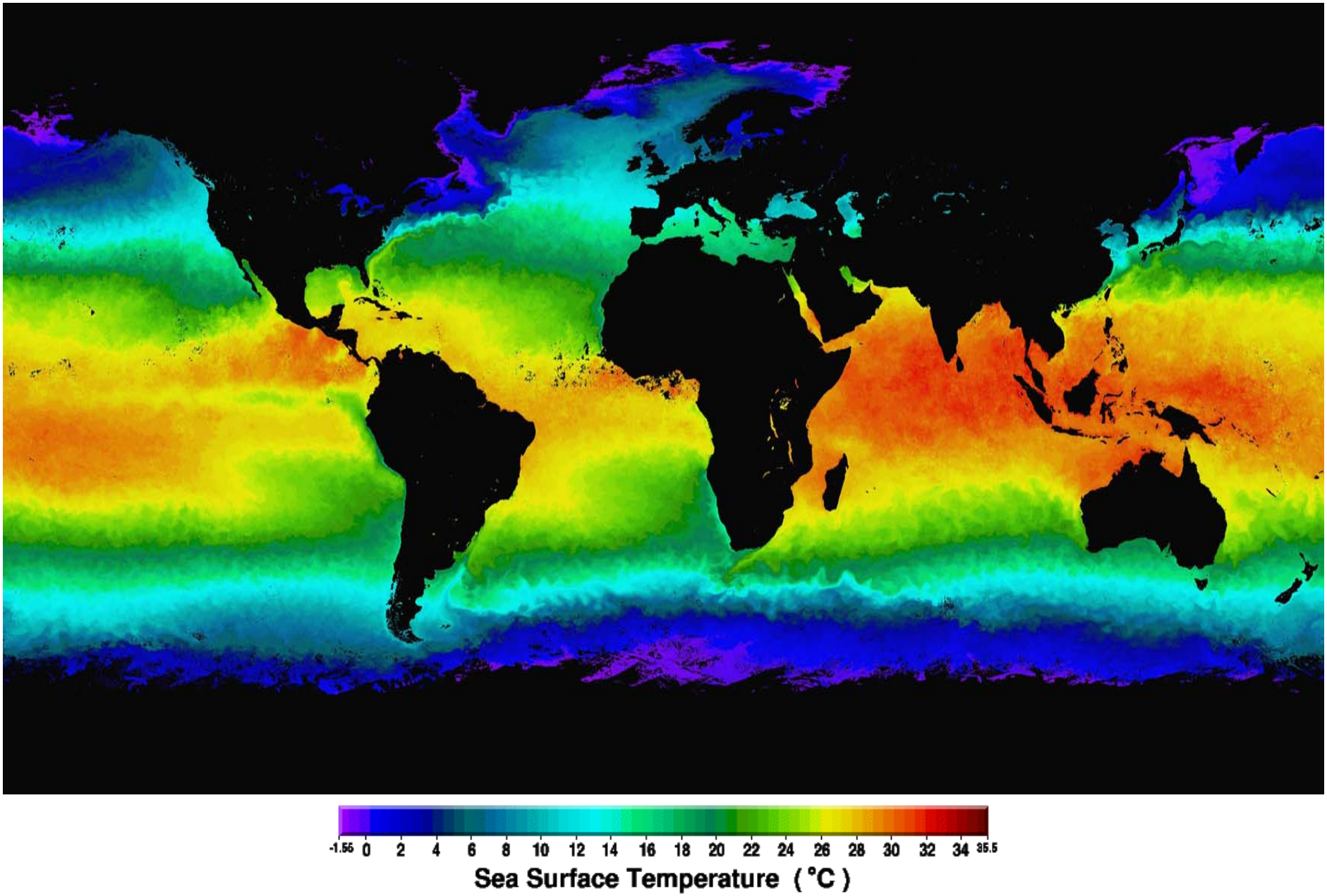


Agulhas & Benguela Currents

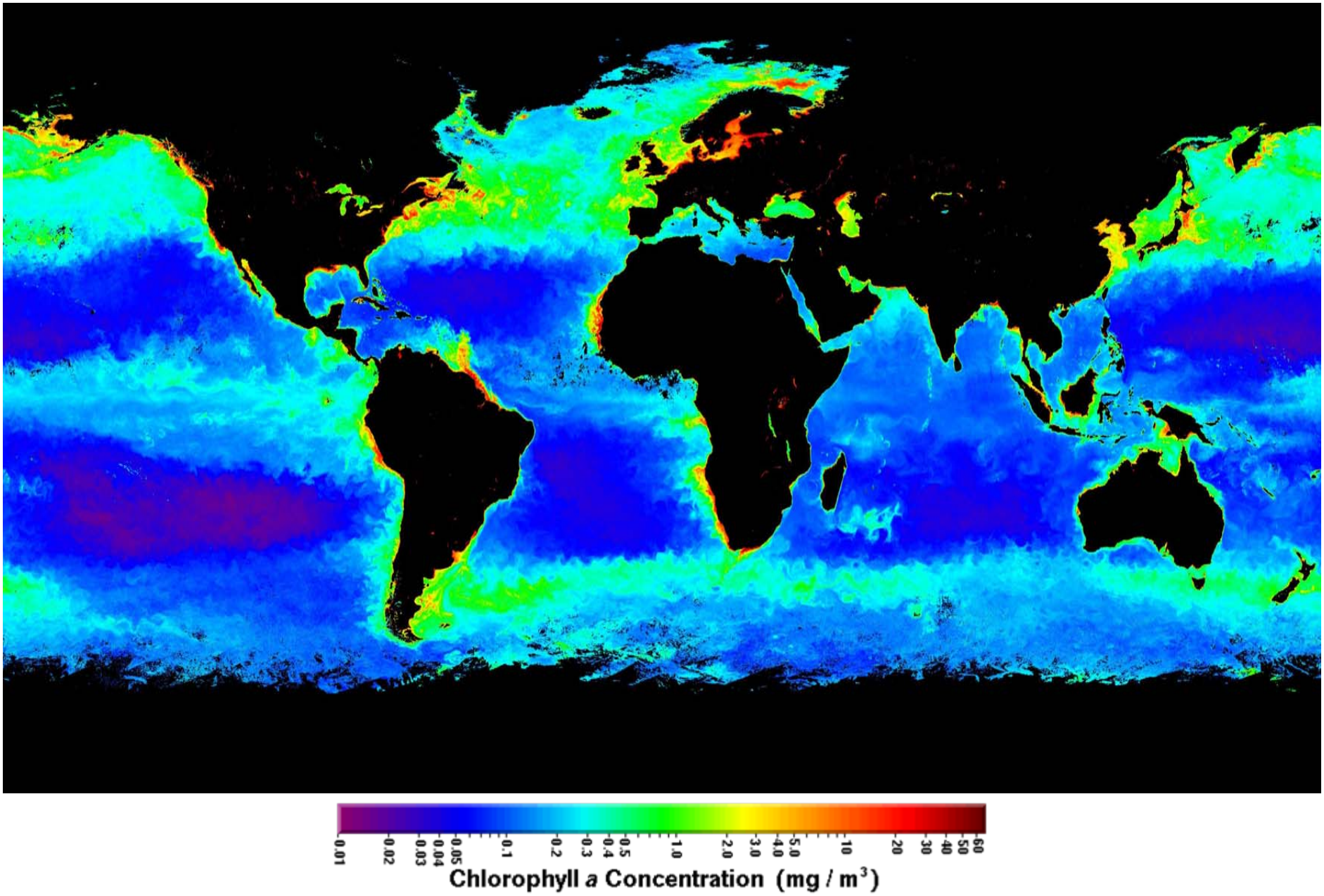




Aqua MODIS Sea Surface Temperature, April 2004

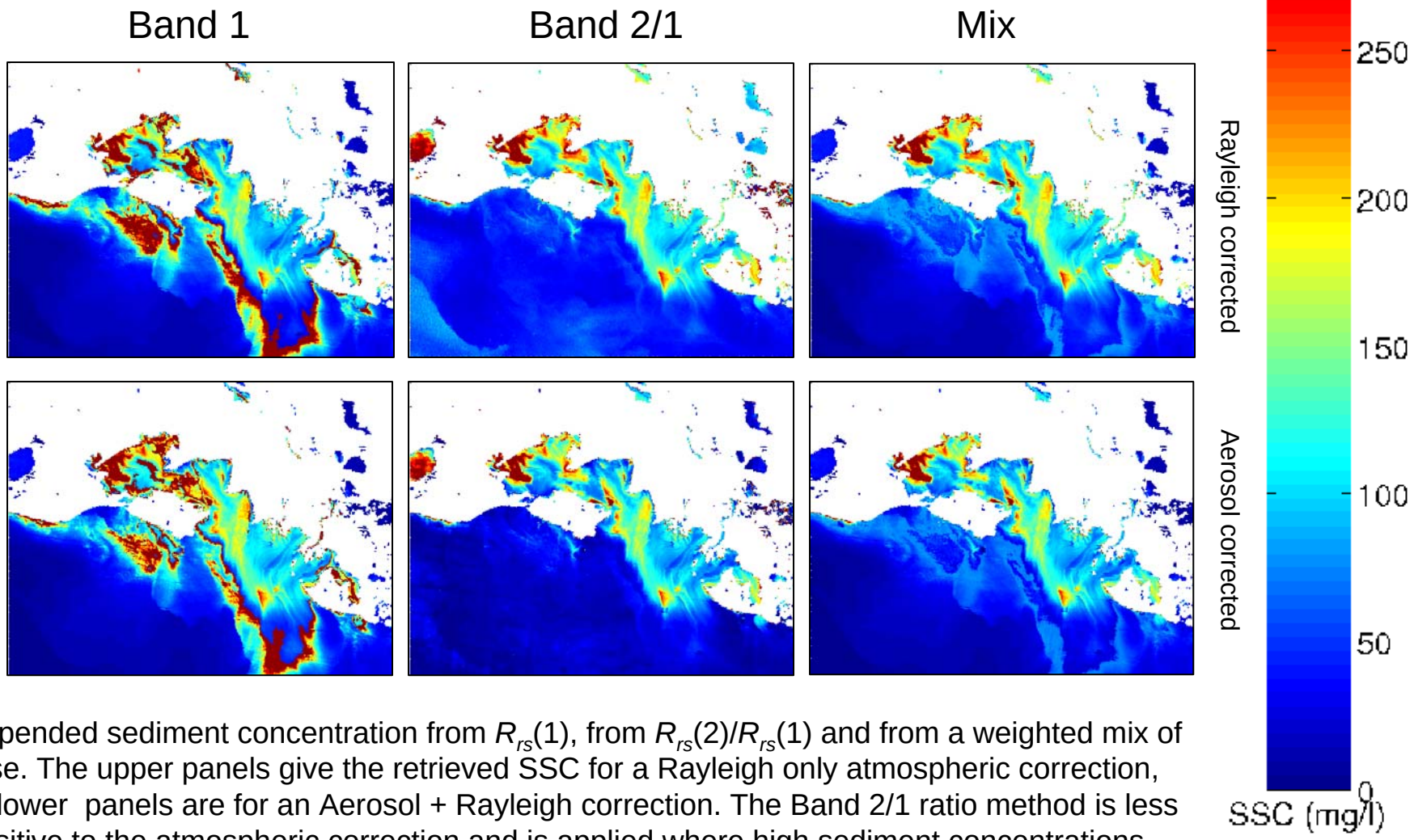


Aqua MODIS Chlorophyll Concentration, April 2004



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

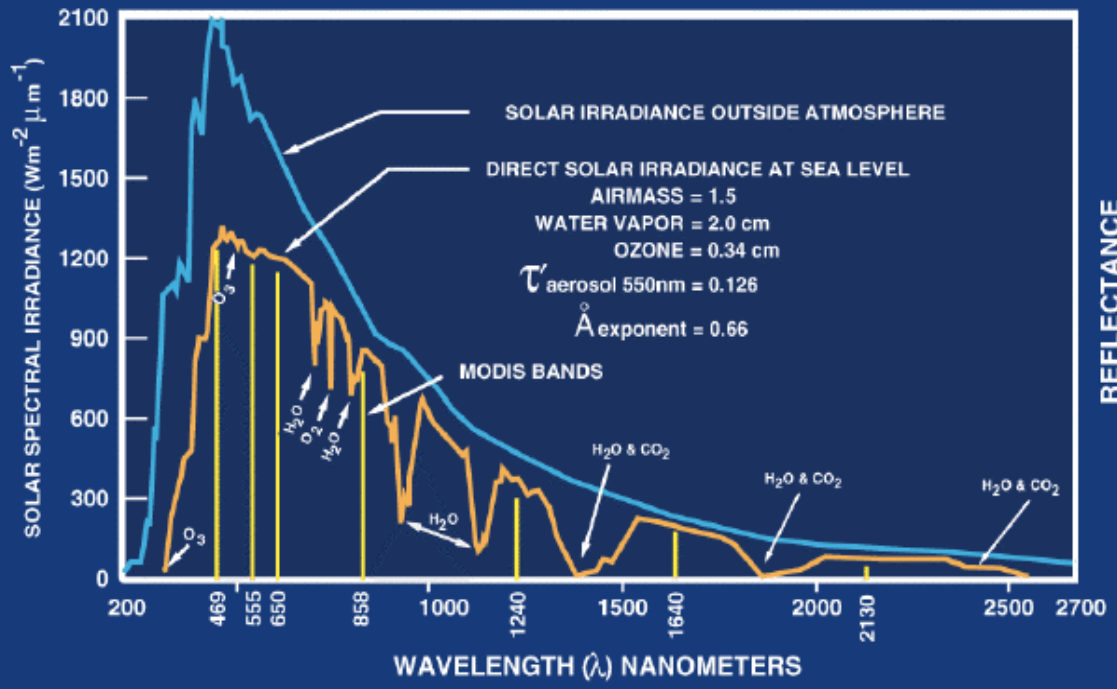
Suspended Sediment Concentration

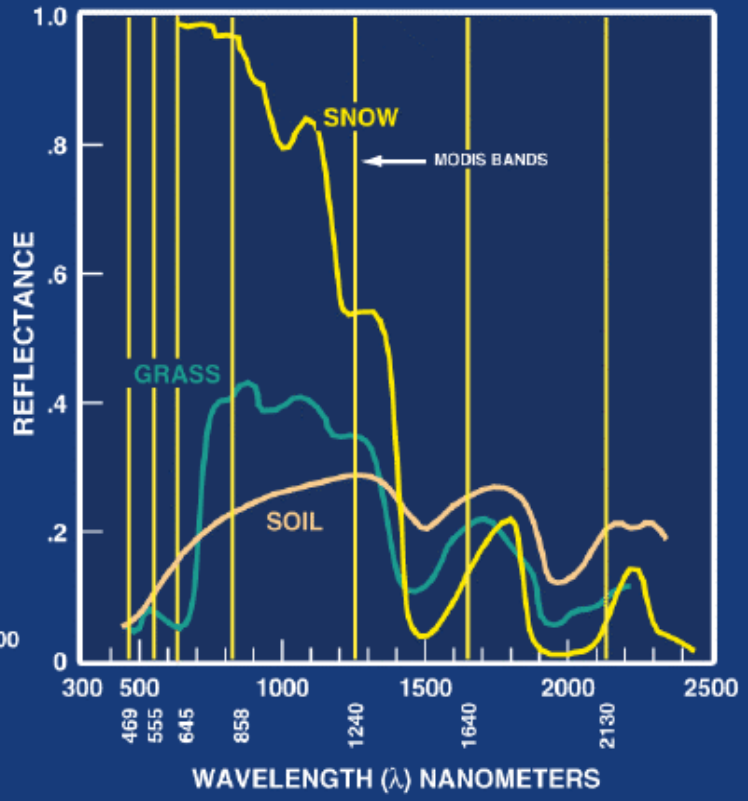


Suspended sediment concentration from $R_{rs}(1)$, from $R_{rs}(2)/R_{rs}(1)$ and from a weighted mix of these. The upper panels give the retrieved SSC for a Rayleigh only atmospheric correction, the lower panels are for an Aerosol + Rayleigh correction. The Band 2/1 ratio method is less sensitive to 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.

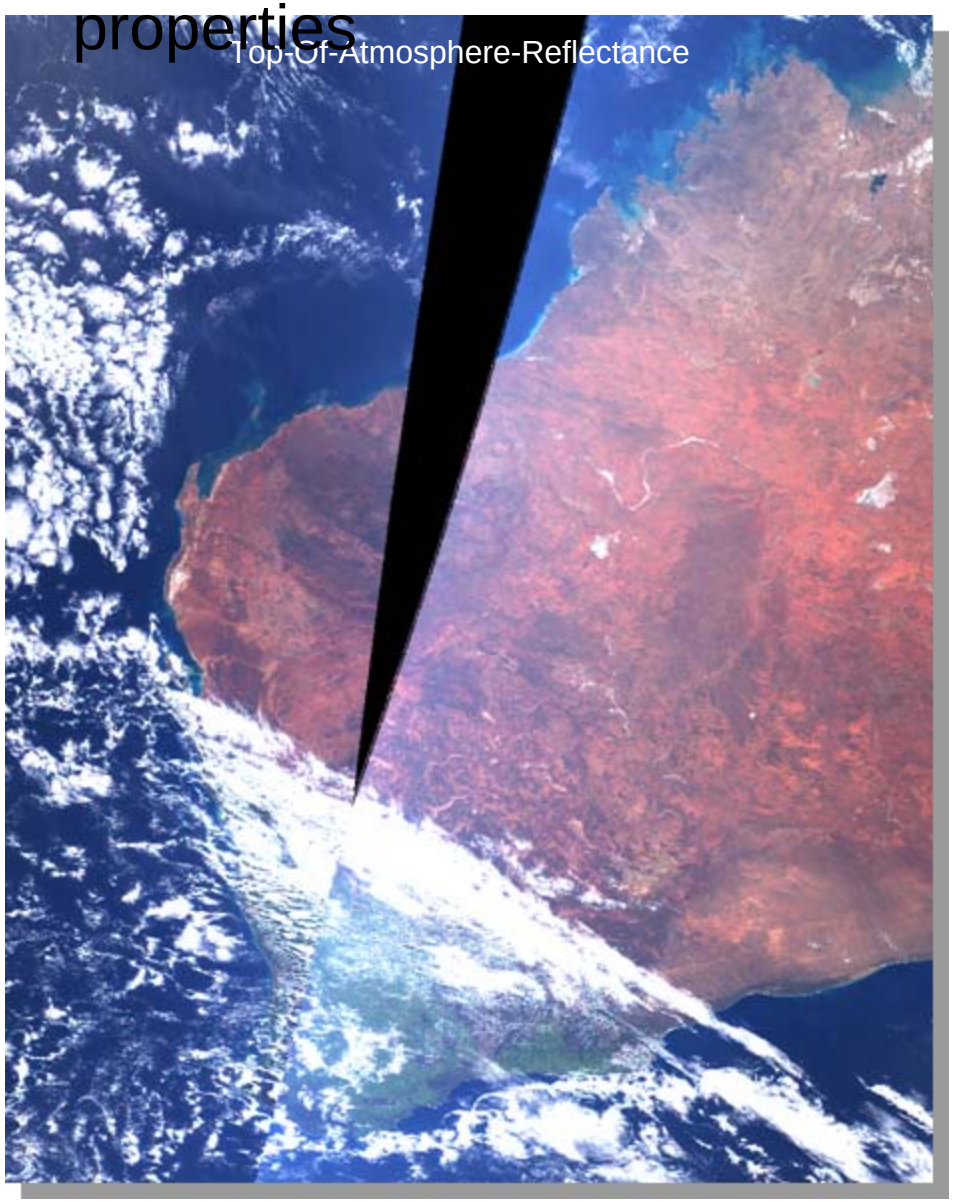
MODIS Land/Surface Applications

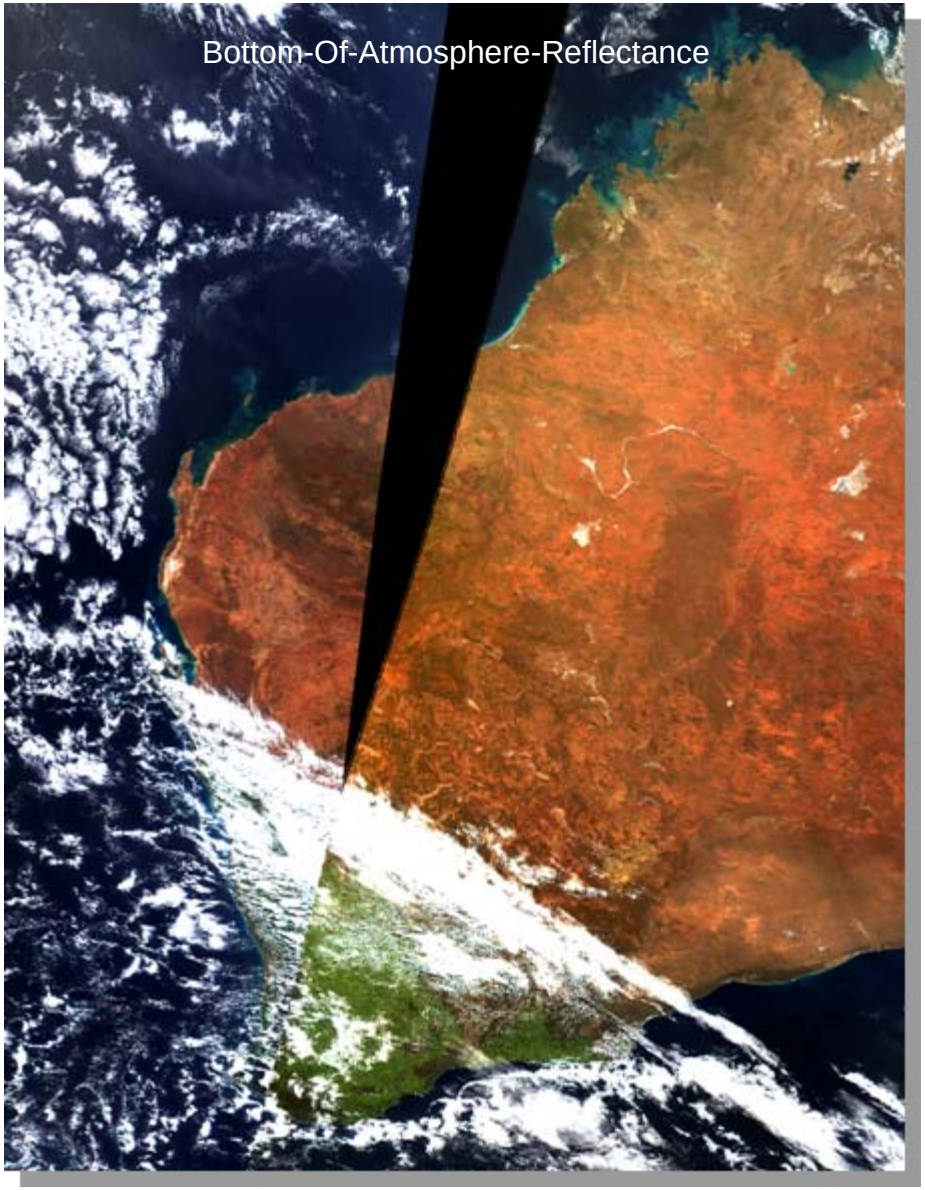
LAND-SOLAR RADIATION





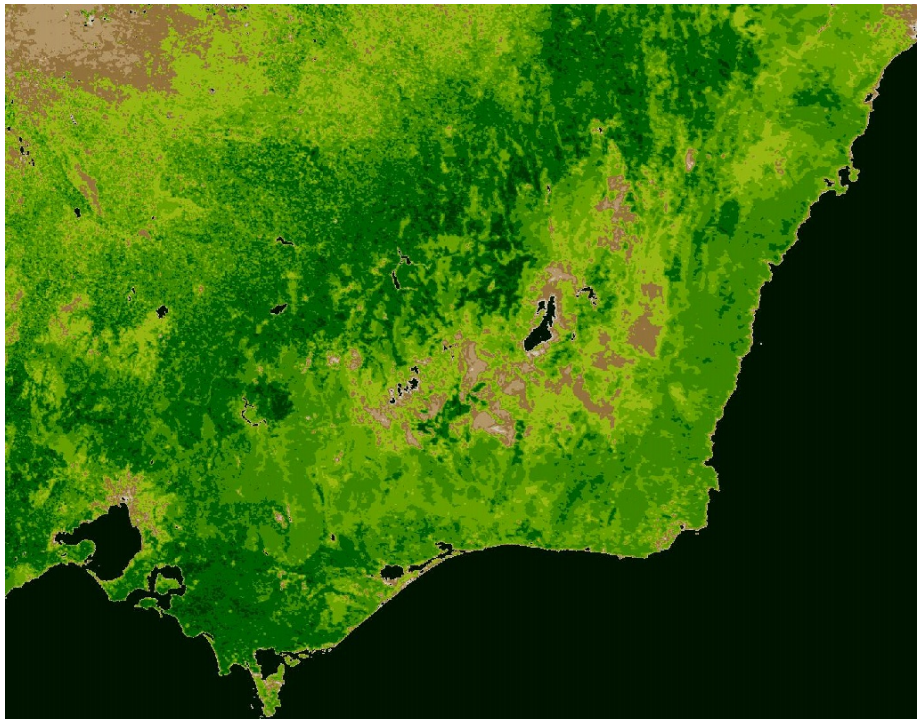
Atmospheric contribution is removed to retrieve surface properties



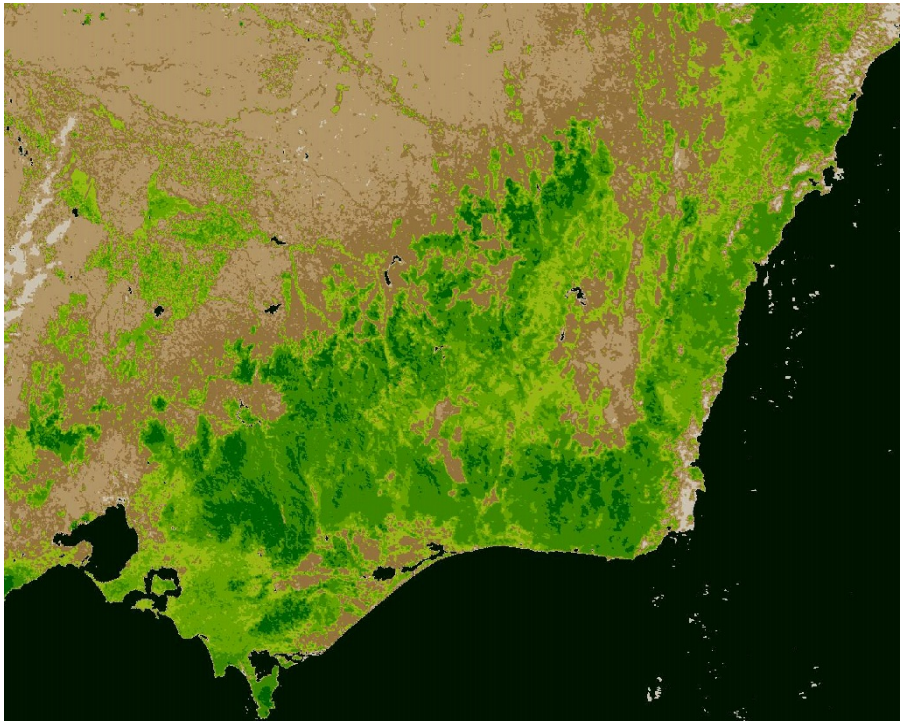


Terra MODIS 09/09/2003 01:27UTC 03:04UTC

NDVI South East Australia



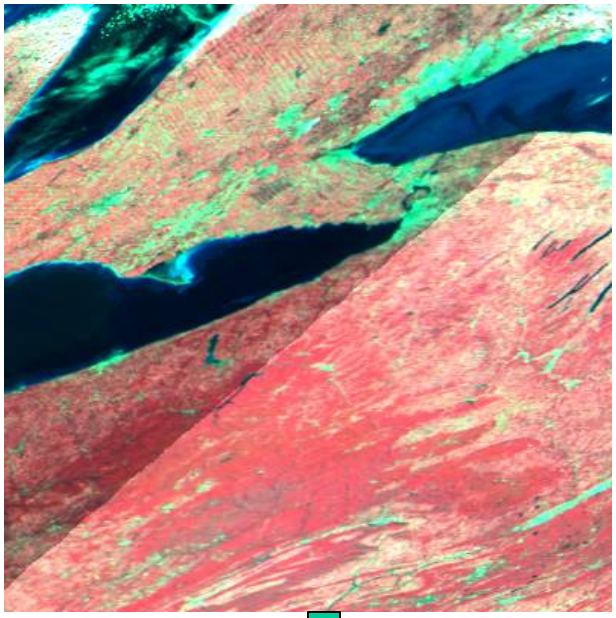
Nov 2003

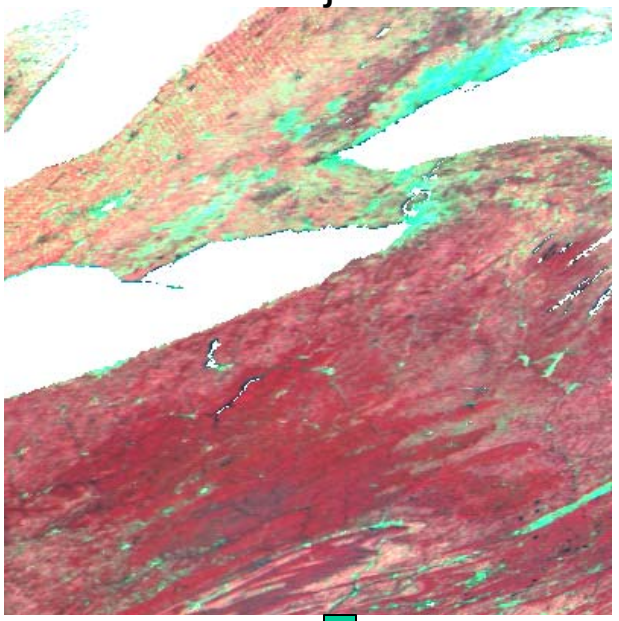


Apr 2004

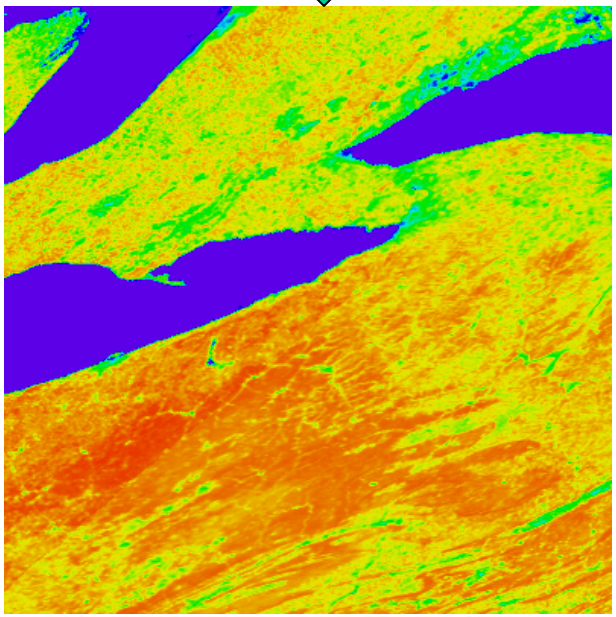
Surface Reflectance

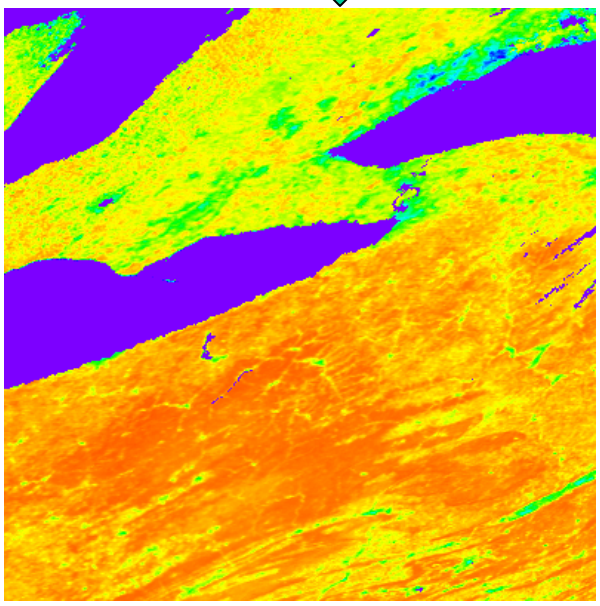
Nadir BRDF-Adjusted Reflectance





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





NDVI

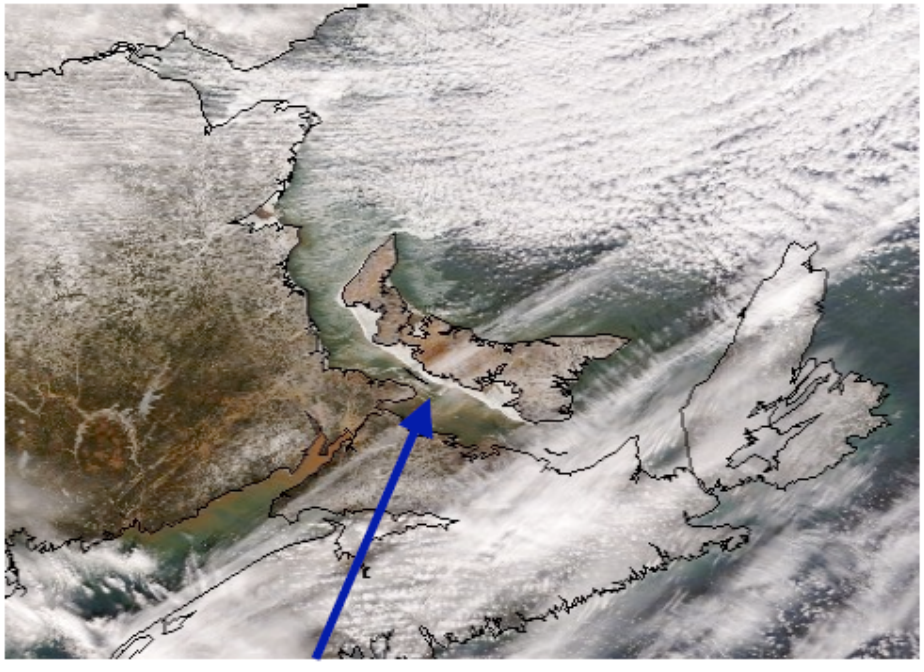
0.0 1.0

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

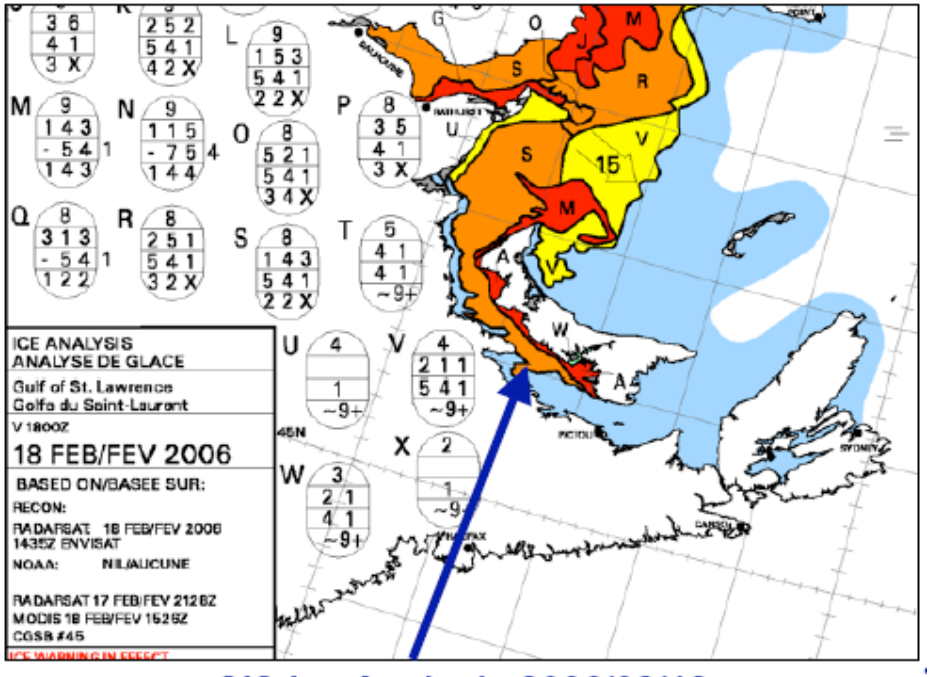
CIS data suite includes RadarSat and Envisat (SAR); AMSR, QuikScat and SSM/I (microwave); MODIS, OLS, NOAA and GOES (visible images).

- 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



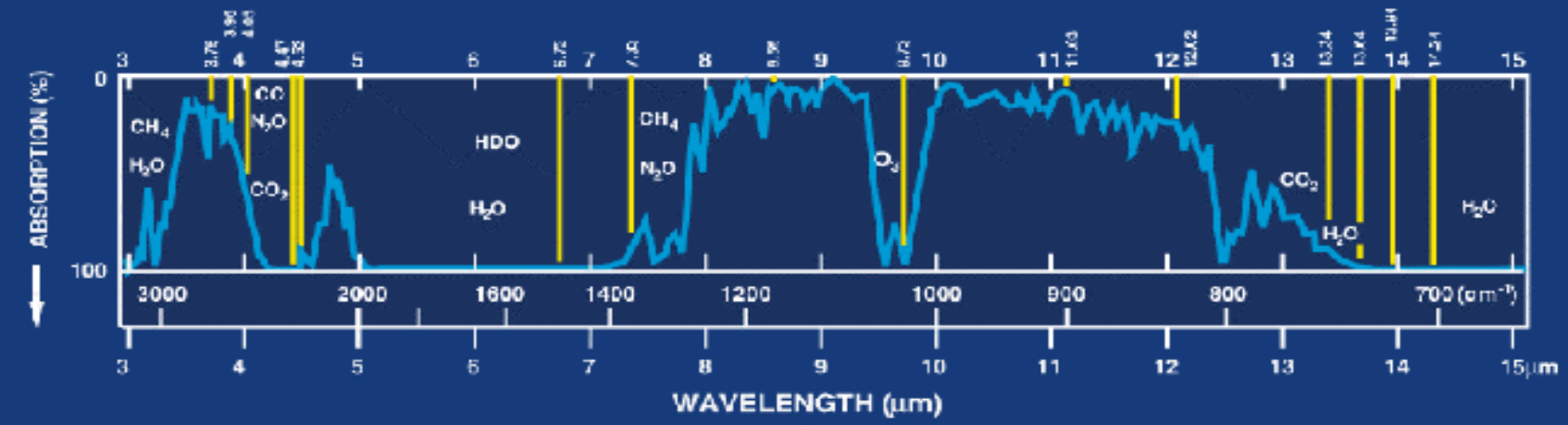
CIS Ice Analysis 2006/02/18

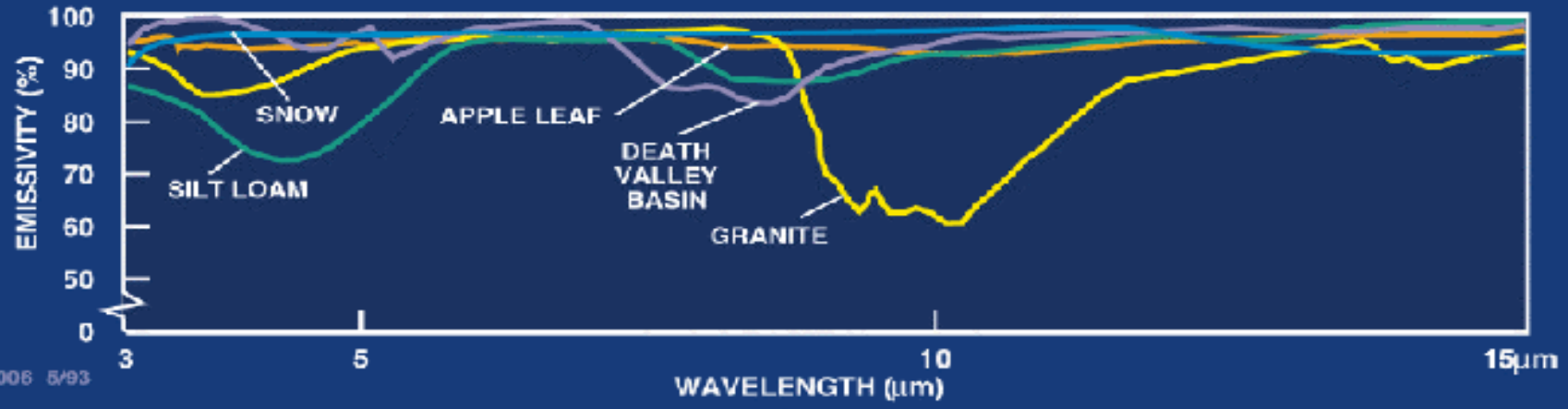
NOAA CoastWatch

CoastWatch Website

Lake Huron / Georgian Bay

LAND - THERMAL RADIATION





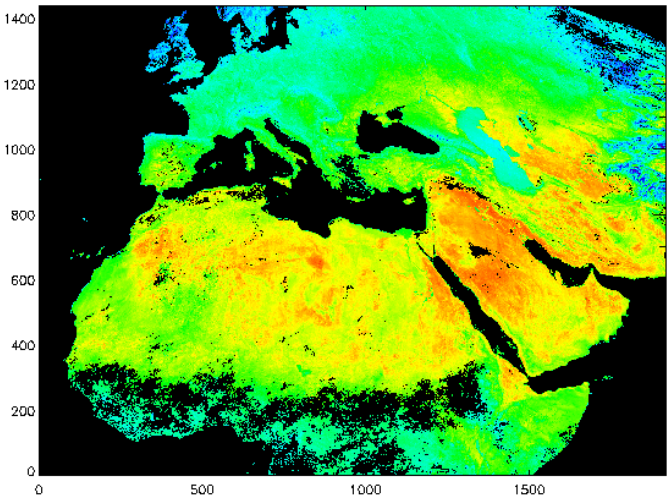
C351.006 5/93

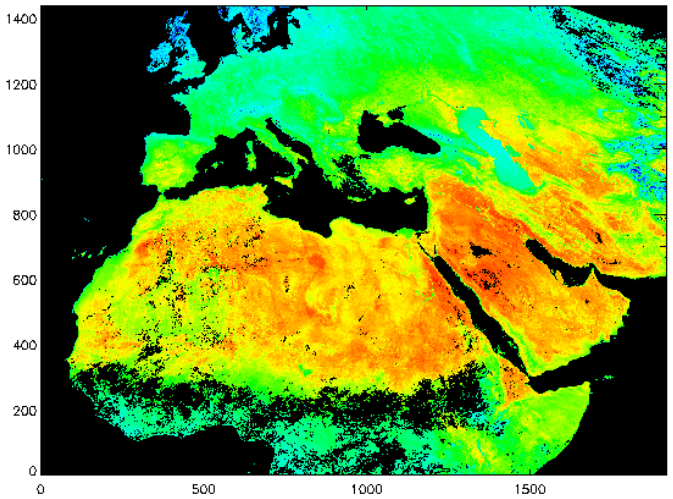
LSTs retrieved from Terra and Aqua MODIS data

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

to show spatial distribution of the diurnal variation

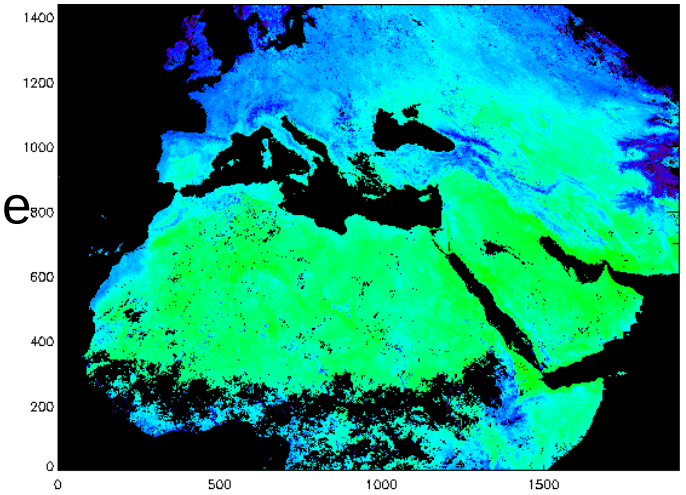
daytime Terra

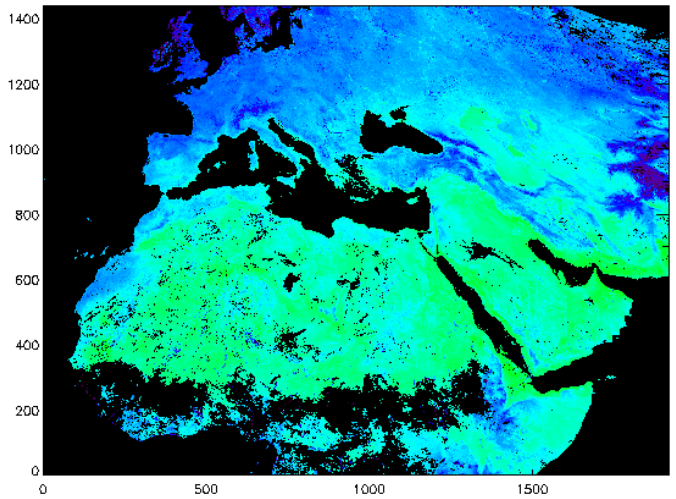




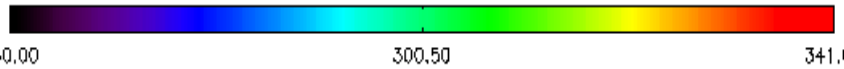
daytime Aqua

nighttime Terra

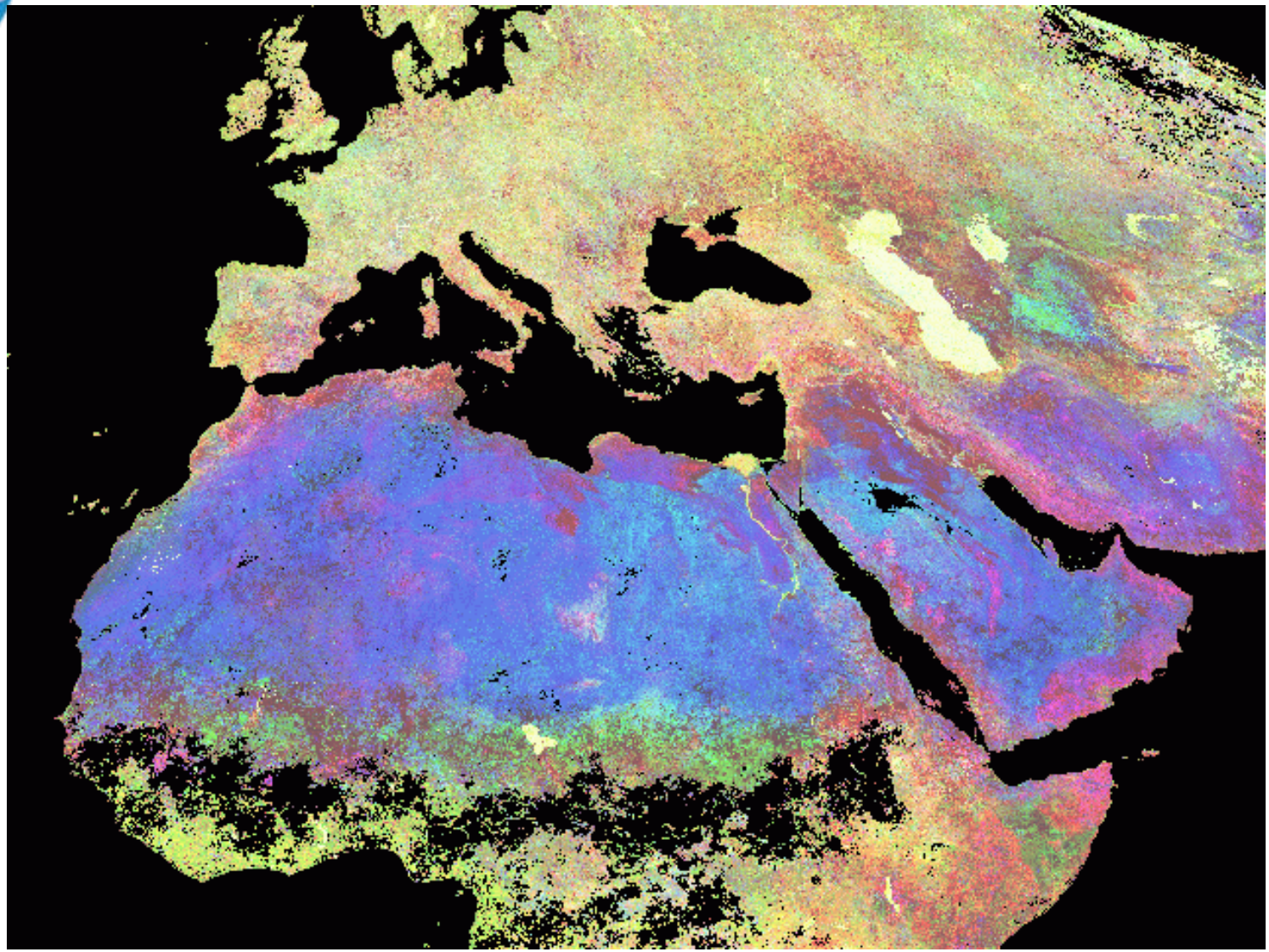




nighttime Aqua



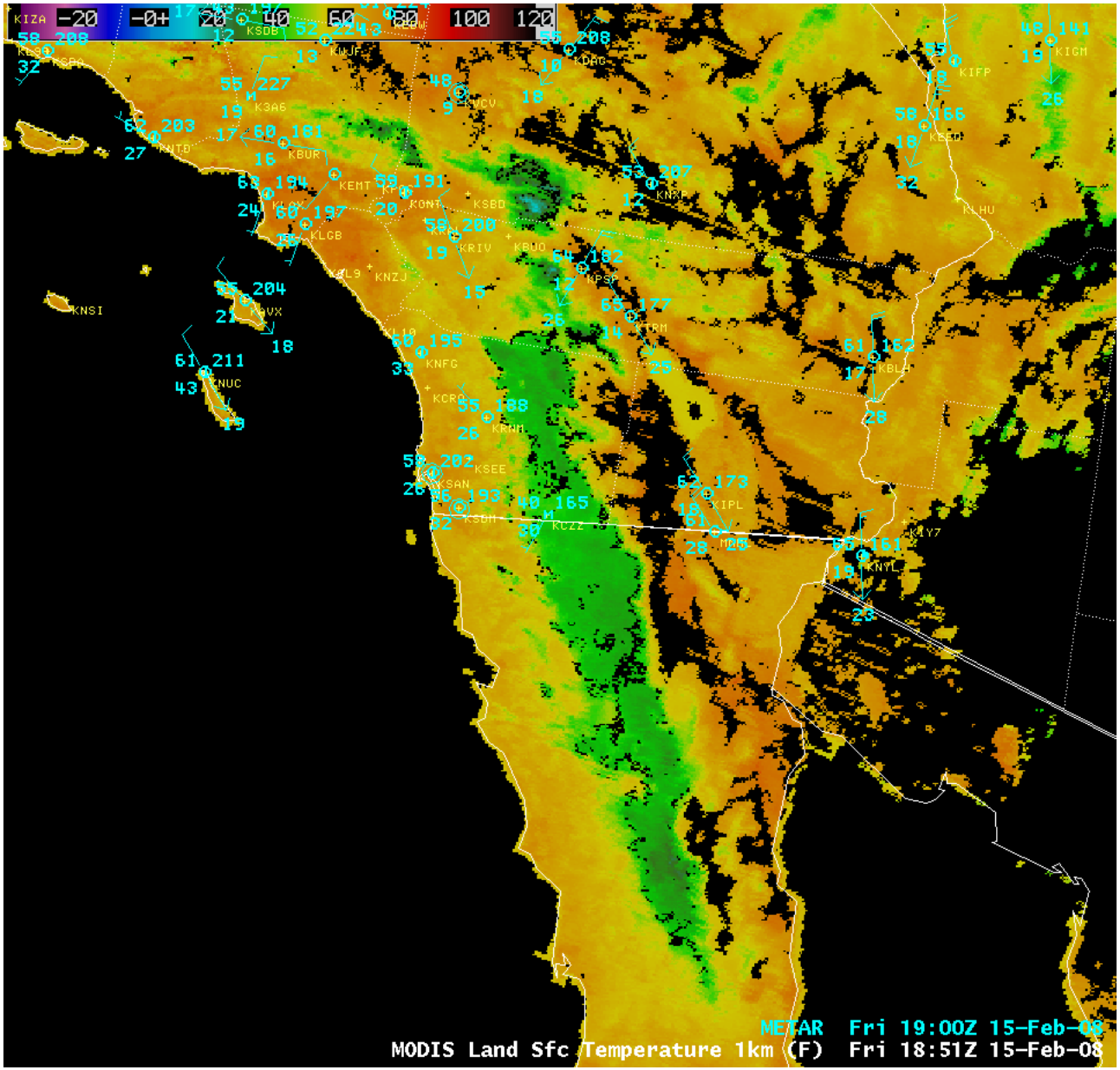
Surface emissivities retrieved by Terra and Aqua MODIS

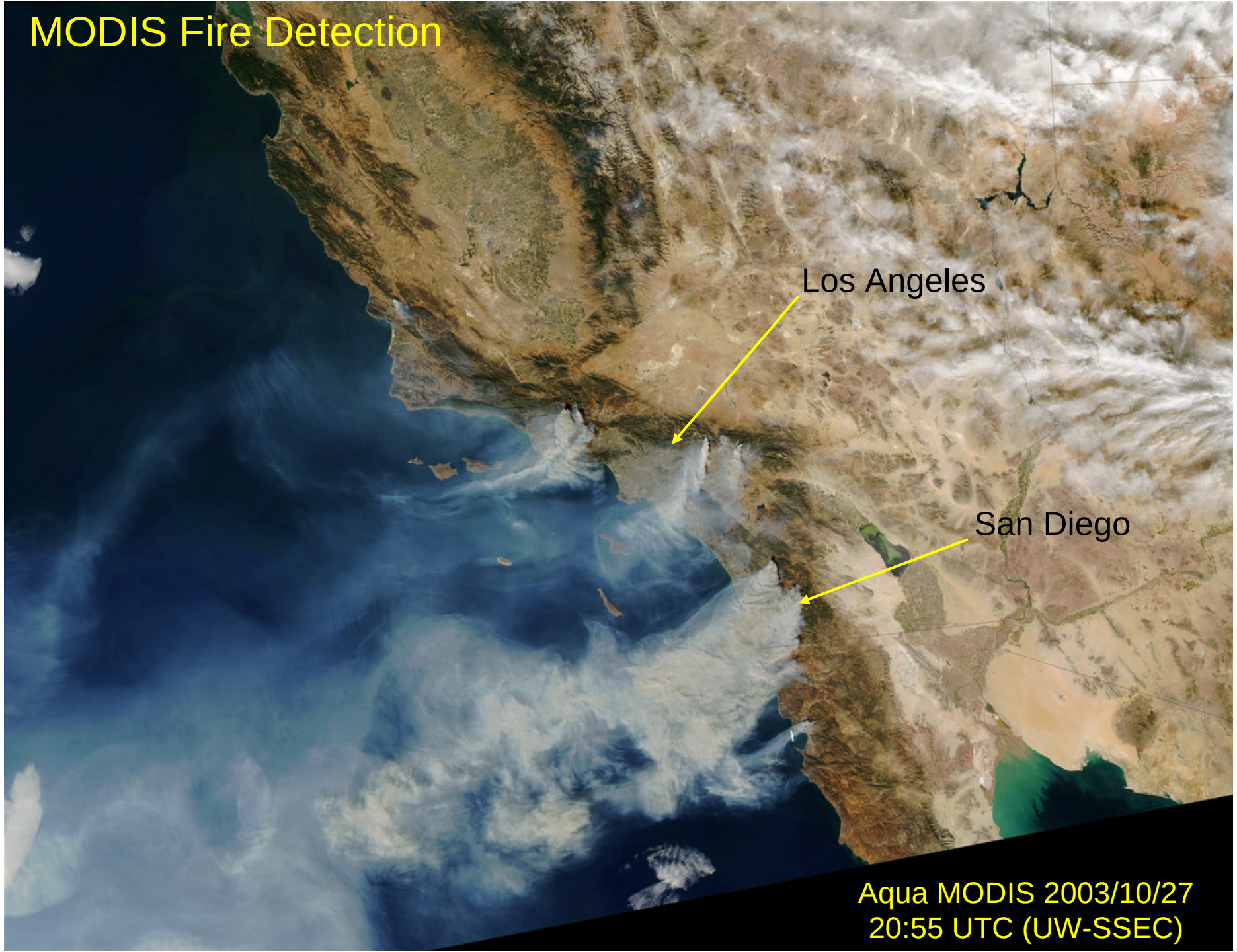


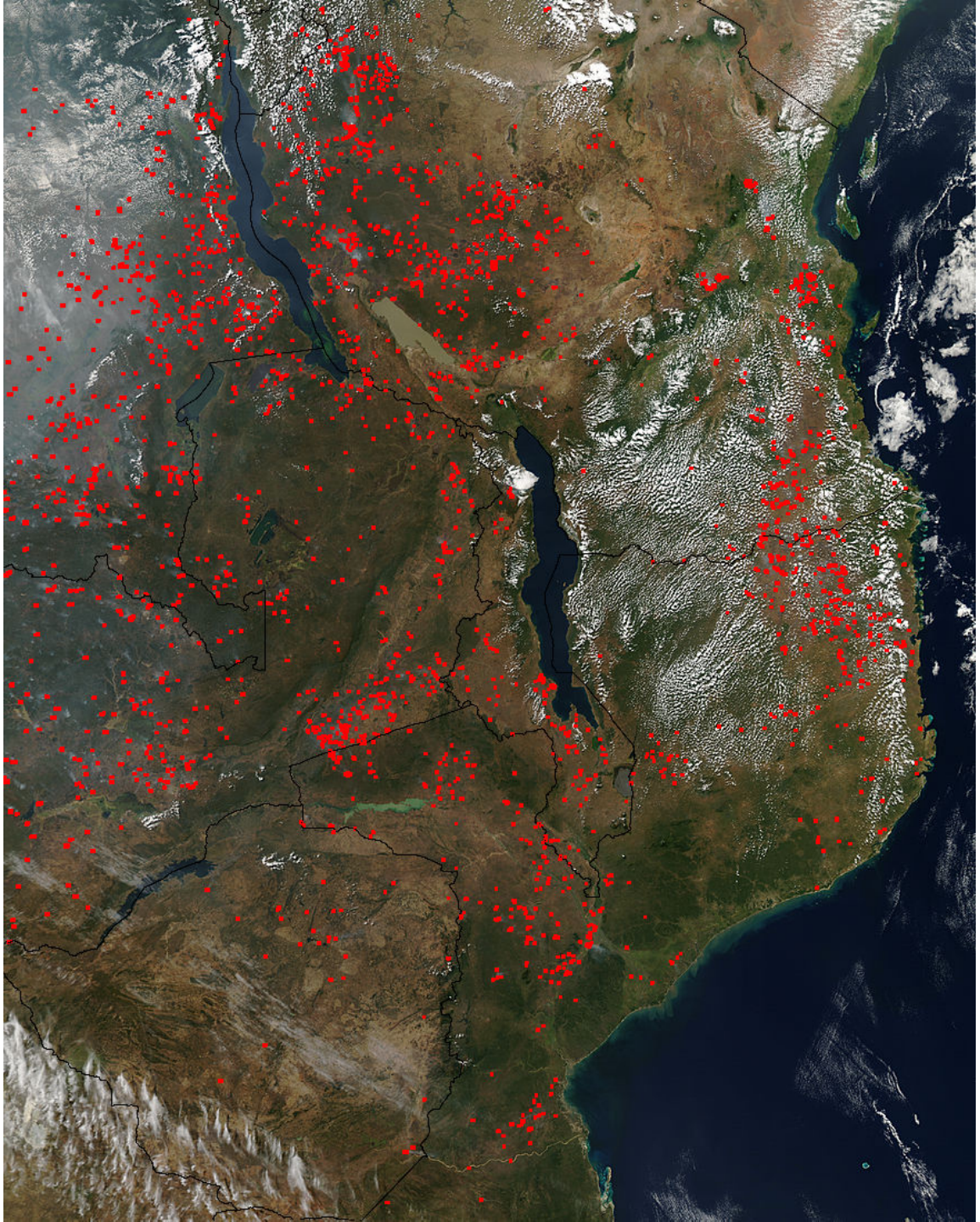
Color composite image with emissivities in bands 29, 31, and 32 as RGB components.

Institute for Computational Earth System Science
University of California, Santa Barbara


SSEC
Anaheim
Long Beach
Santa Ana
15
10
N
Santa Catalina Island
San Clemente Island
Alpine, CA
Ocotillo, CA
San Diego
Mexicali
8
805
2
1
Isla Montague
3
5
Baja California
© 2008 Tele Atlas
© 2008 LeadDog Consulting
© 2008 Europa Technologies
Image © 2008 DigitalGlobe
©2007 Google™
126 km
Pointer 32°03'38.41" N 116°23'13.72" W
Streaming 100%
Eye alt 424.81 km


KIZA -20 -0+ 20 40 60 80 100 120
MODIS Land Sfc Temperature 1km (F)
METAR Fri 19:00Z 15-Feb-08
Fri 18:51Z 15-Feb-08


MODIS Fire Detection
Los Angeles
San Diego
Aqua MODIS 2003/10/27
20:55 UTC (UW-SSEC)



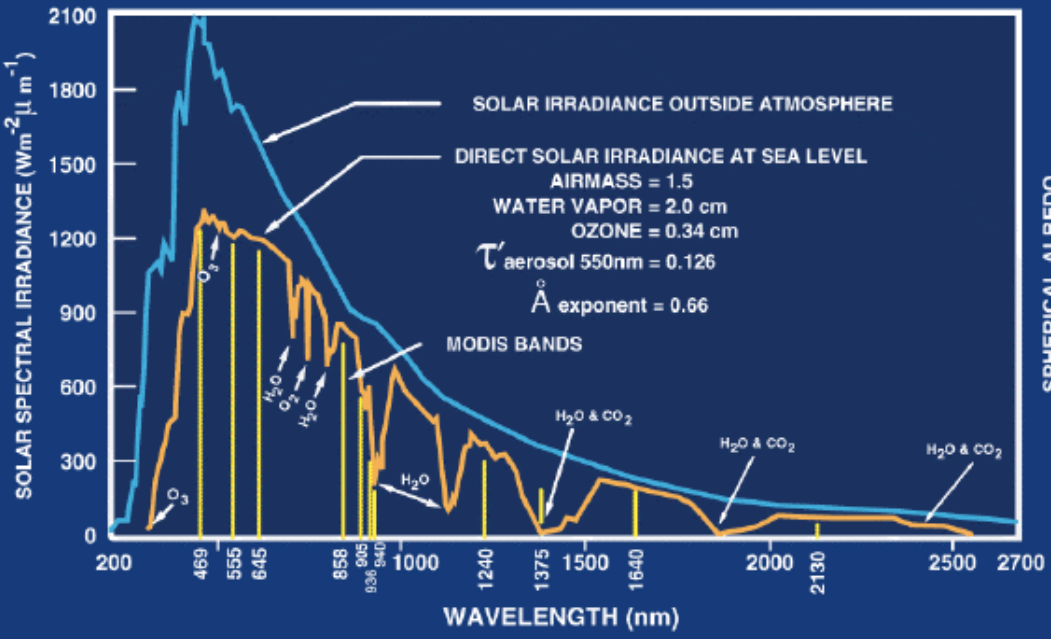
6/24/09

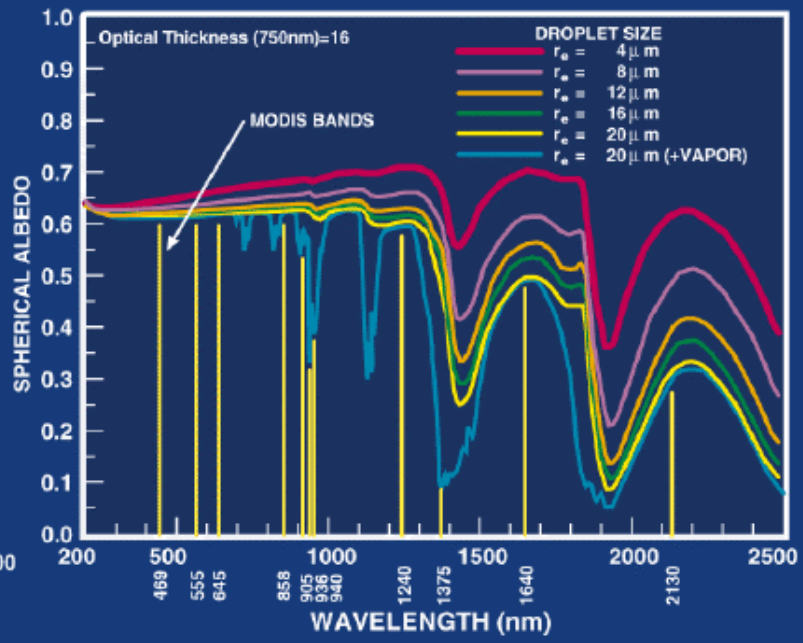
Aqua

MODIS

MODIS Atmosphere Applications

ATMOSPHERE-SOLAR RADIATION

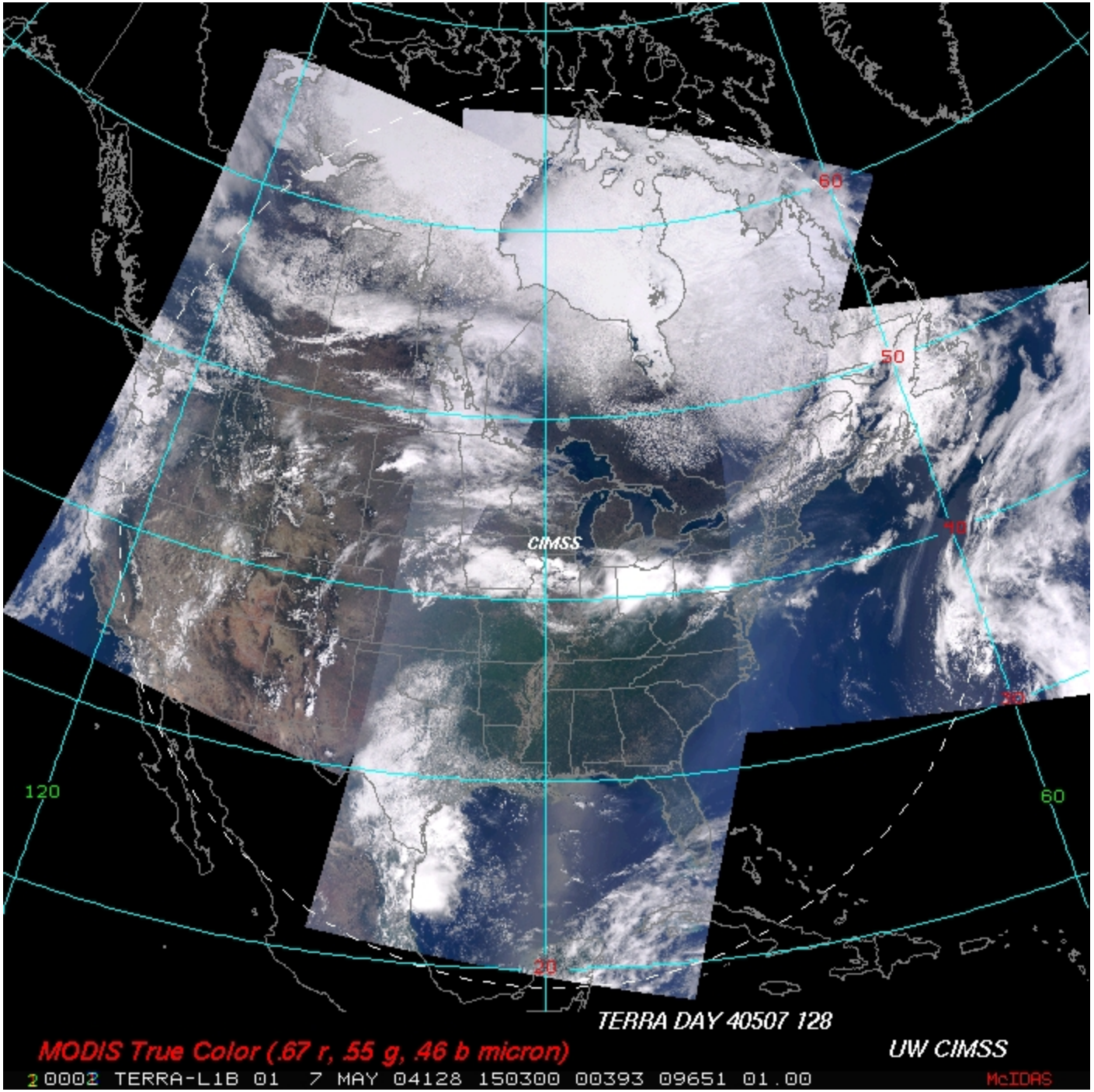




MODIS Cloud Mask

- **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


60
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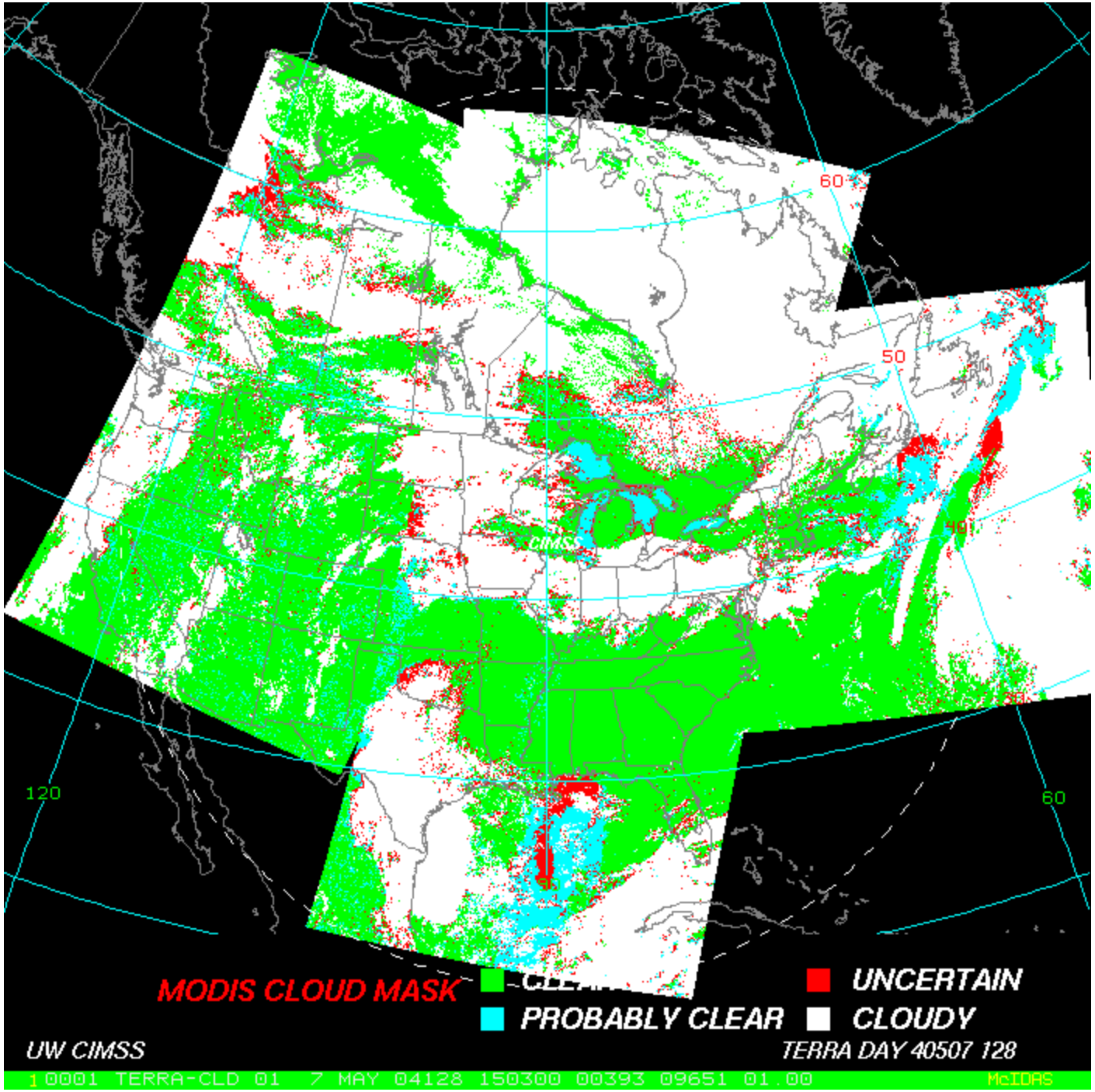
20
120
60
CIMSS
TERRA DAY 40507 128
MODIS True Color (.67 r, .55 g, .46 b micron)
UW CIMSS
2 0002 TERRA-L1B 01 7 MAY 04128 150300 00393 09651 01.00
McIDAS


60
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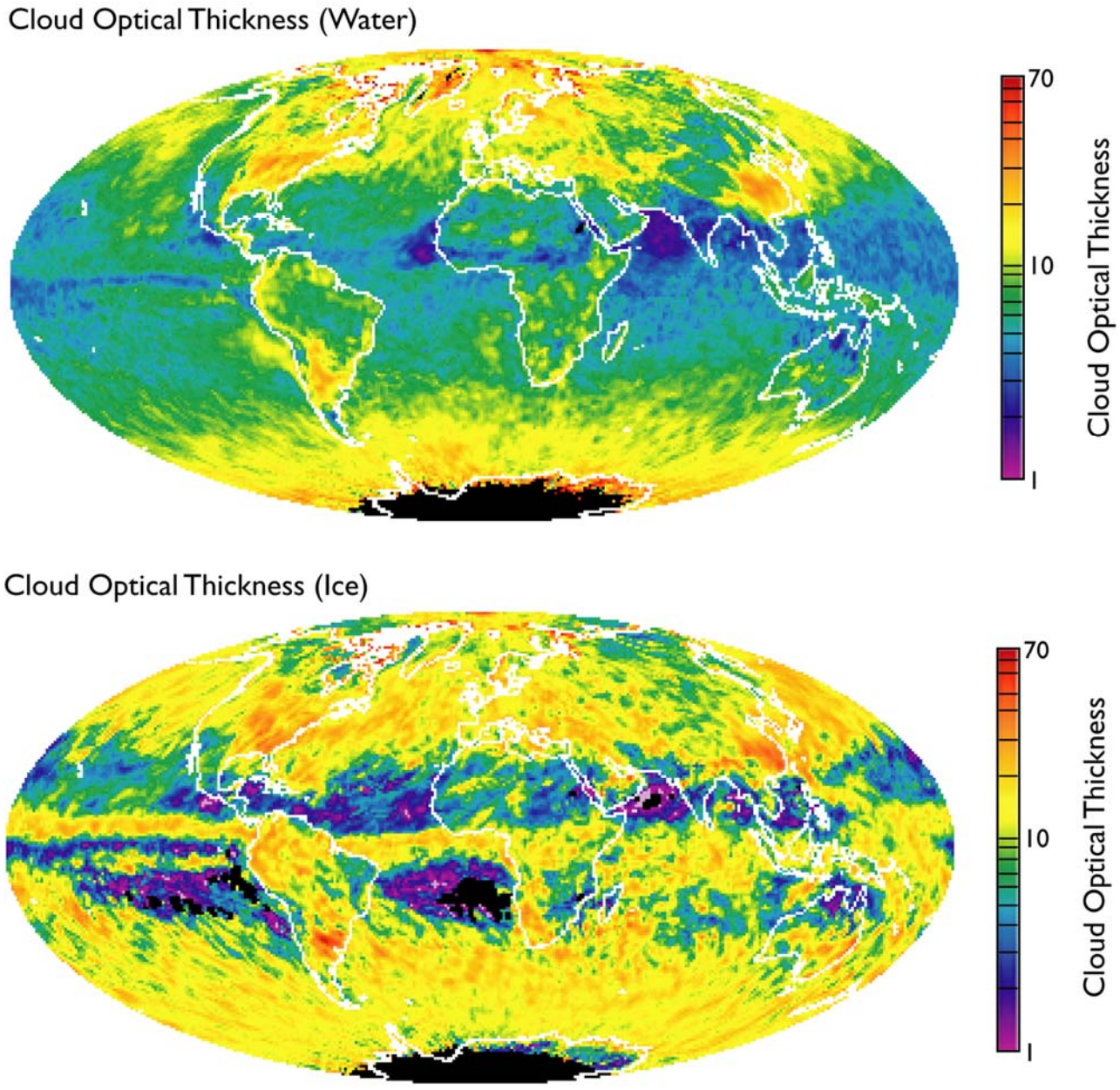
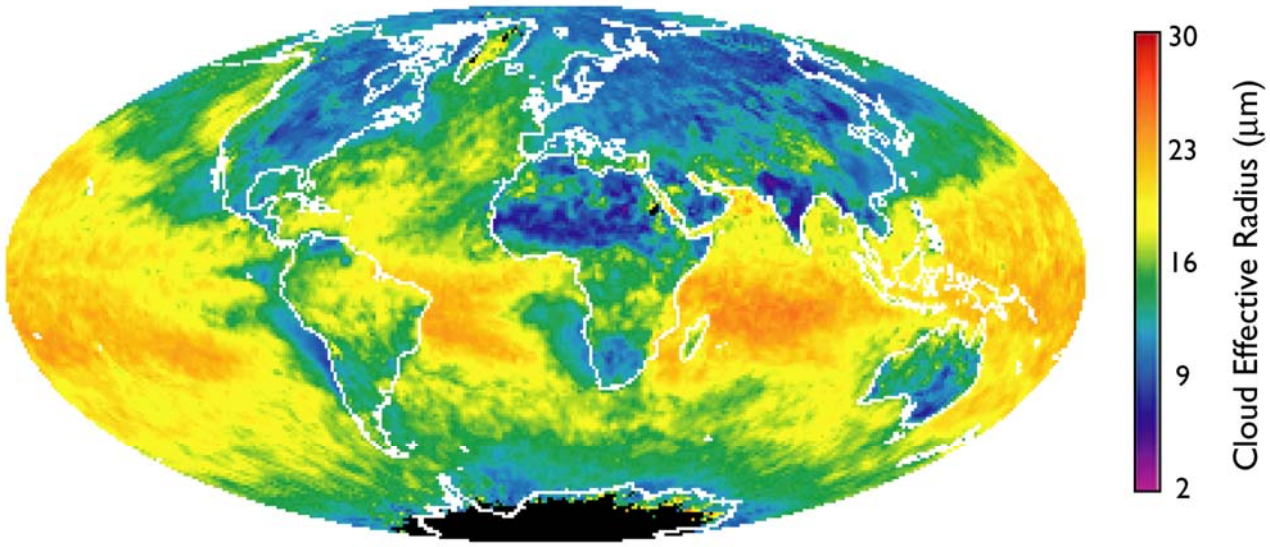
40
120
60
MODIS CLOUD MASK
UNCERTAIN
PROBABLY CLEAR
CLOUDY
UW CIMSS
TERRA DAY 40507 128
1 0001 TERRA-CLD 01 7 MAY 04128 150300 00393 09651 01 00
McIDAS

Monthly Mean Cloud Optical Thickness

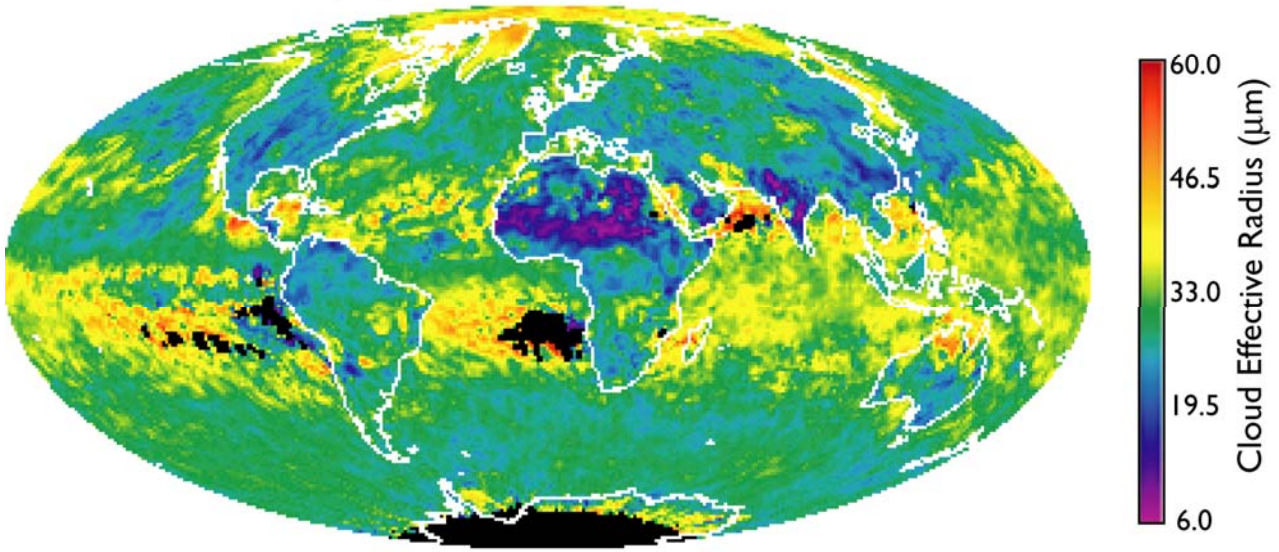


Monthly Mean Cloud Effective Radius

Cloud Effective Radius (Water)

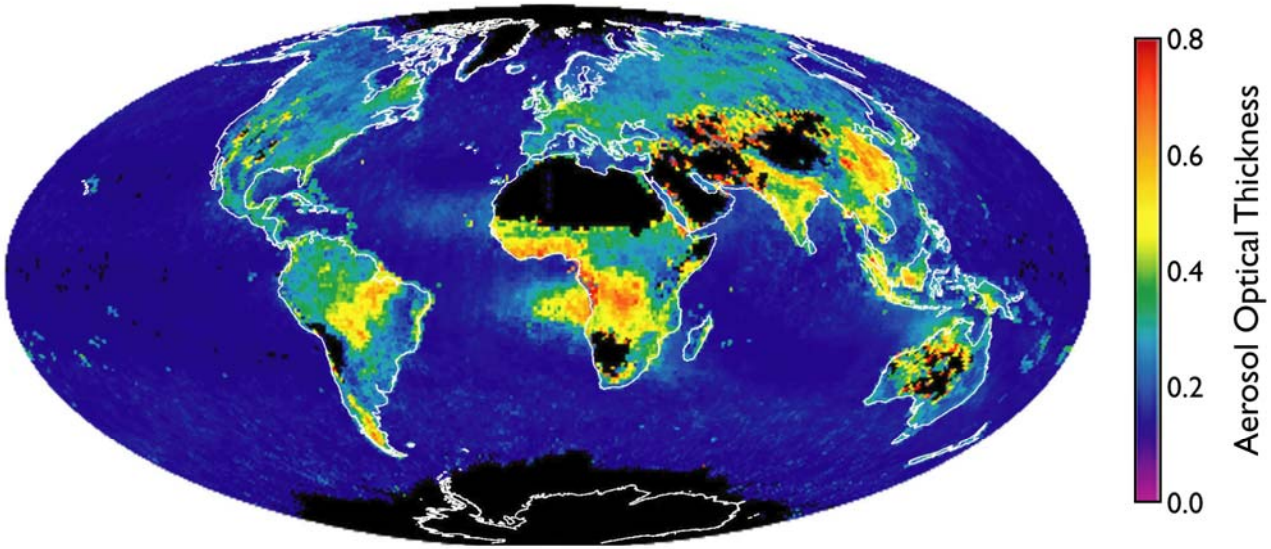


Cloud Effective Radius (Ice)

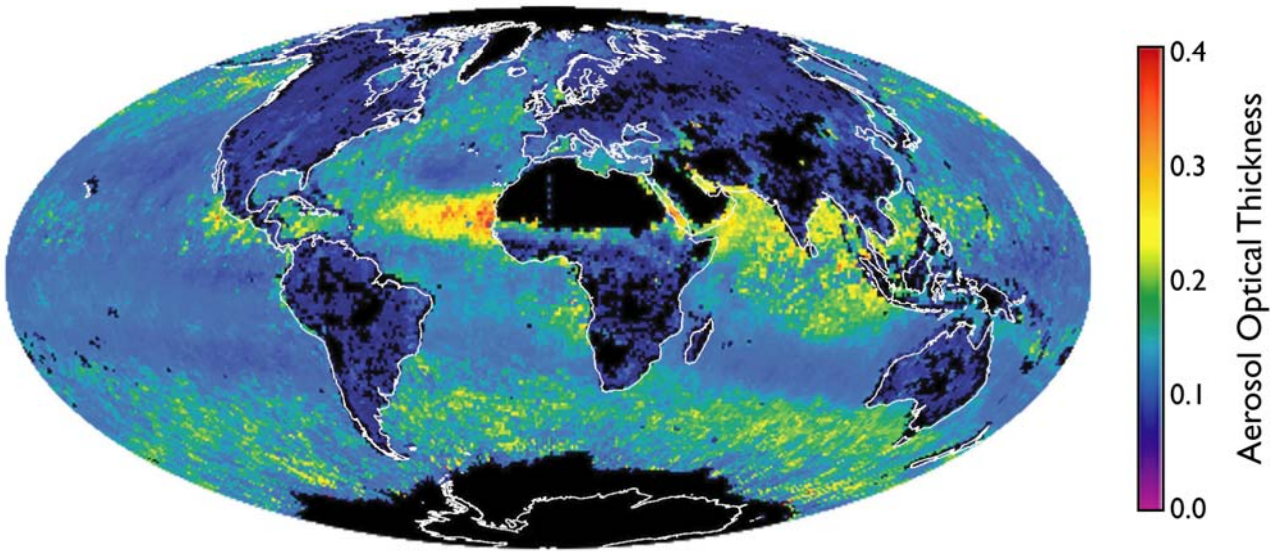


Monthly Mean Aerosol Optical Thickness

Aerosol Optical Thickness (Fine Mode)



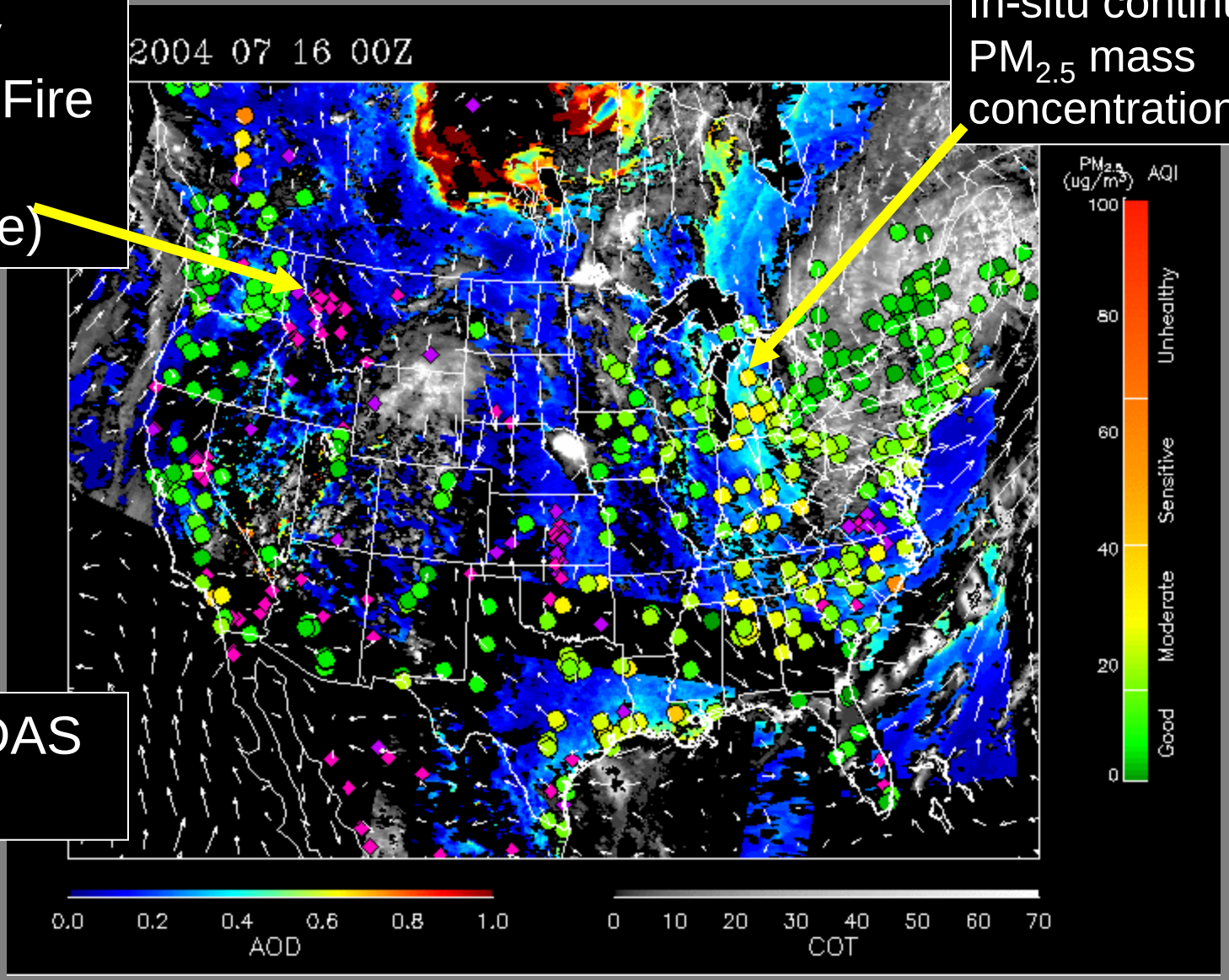
Aerosol Optical Thickness (Coarse Mode)



Composite PM2.5/MODIS Aerosol Optical Depth Data Fusion 3-day Animation

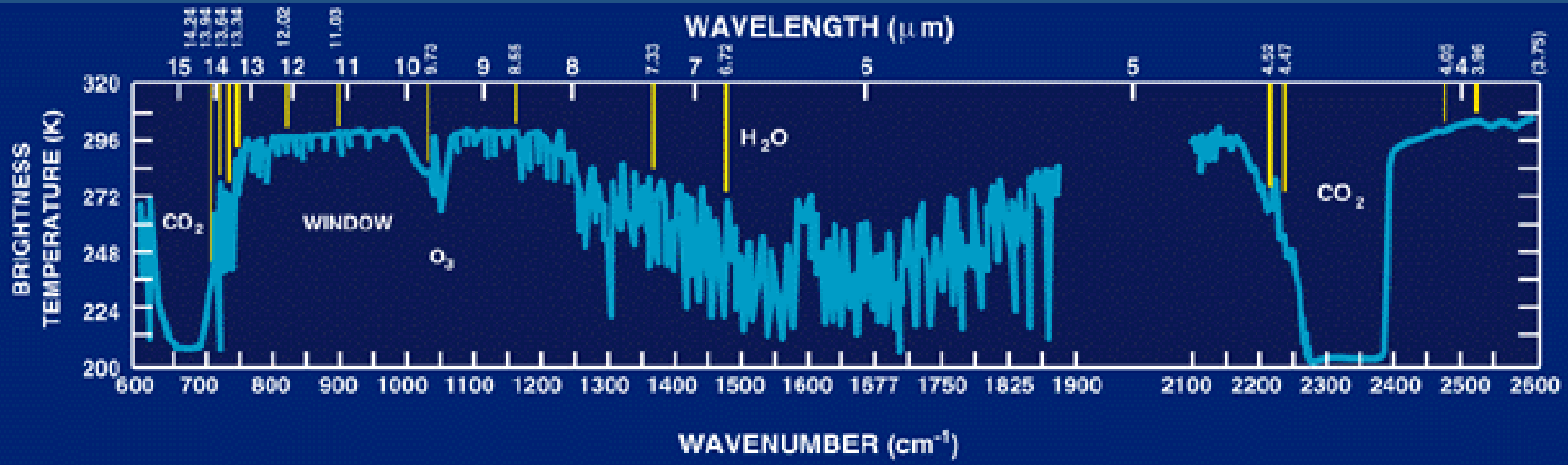
Half-hourly WF-ABBA Fire Locations (pink-purple)

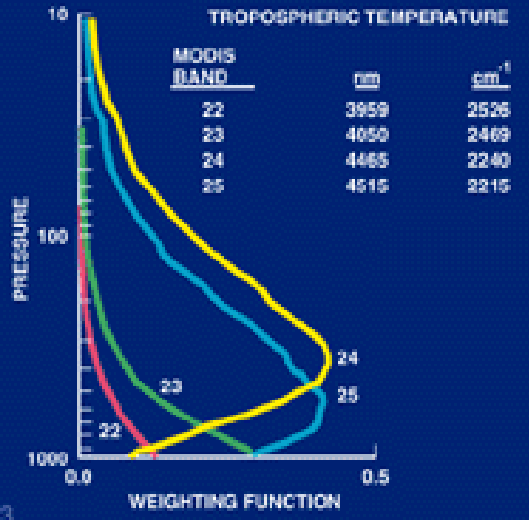
In-situ continuous $PM_{2.5}$ mass concentration data

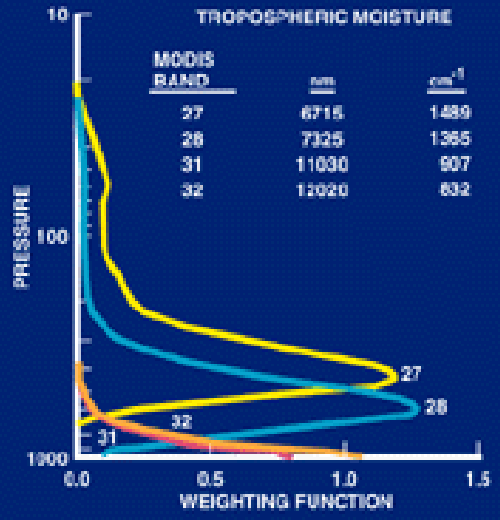


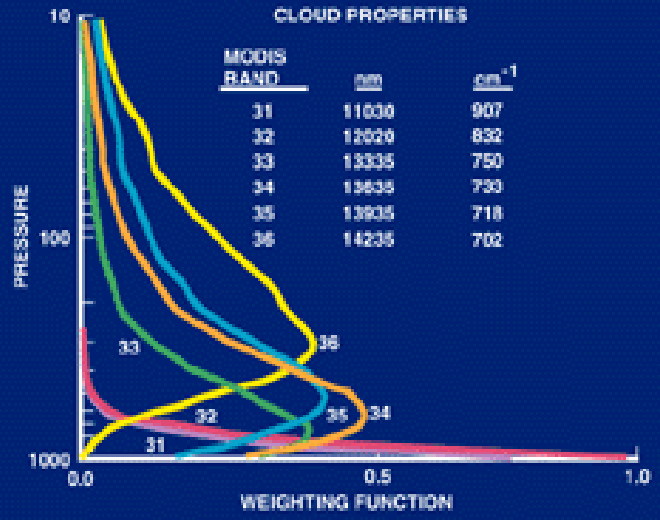
850 mb EDAS wind fields

ATMOSPHERE - THERMAL RADIATION

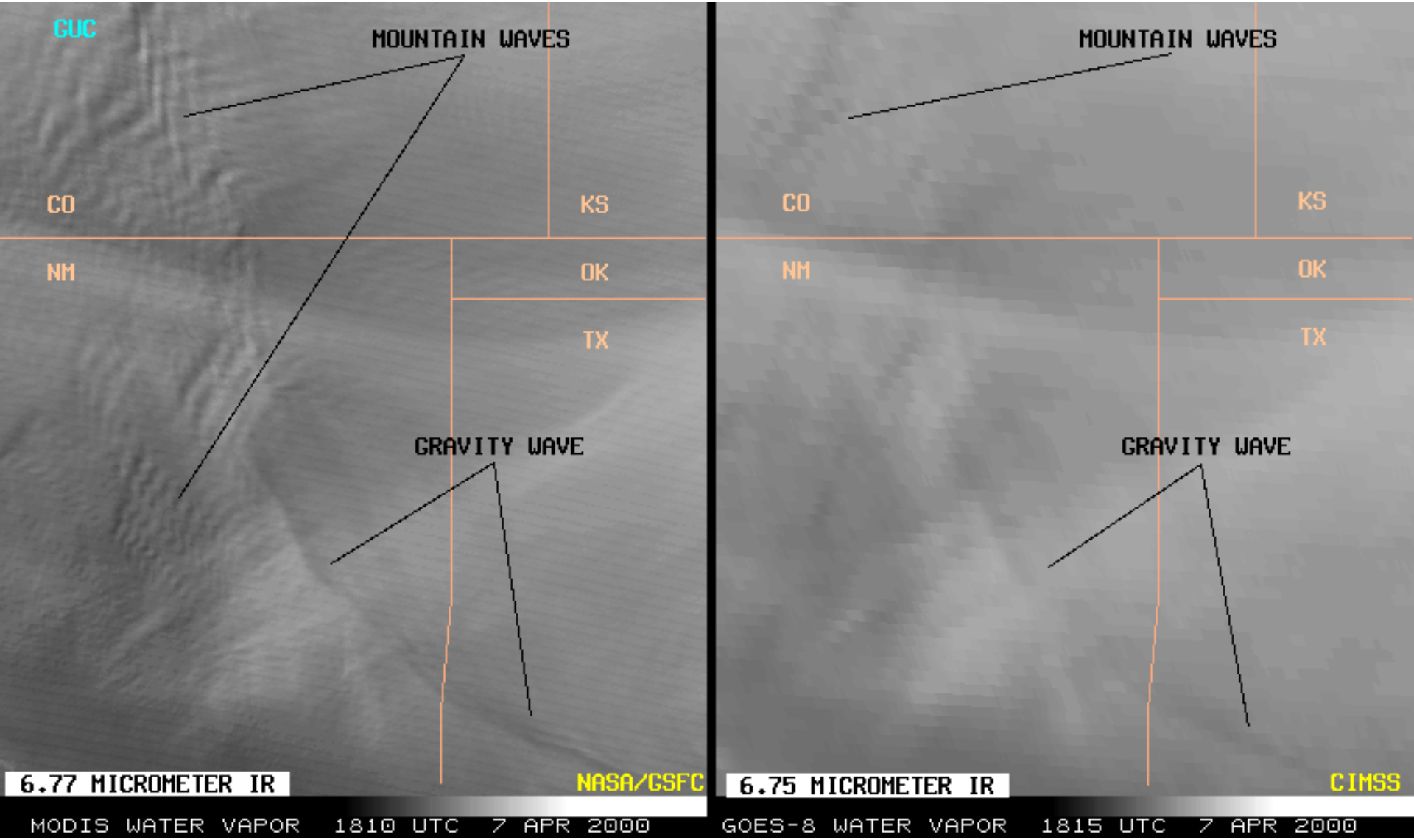




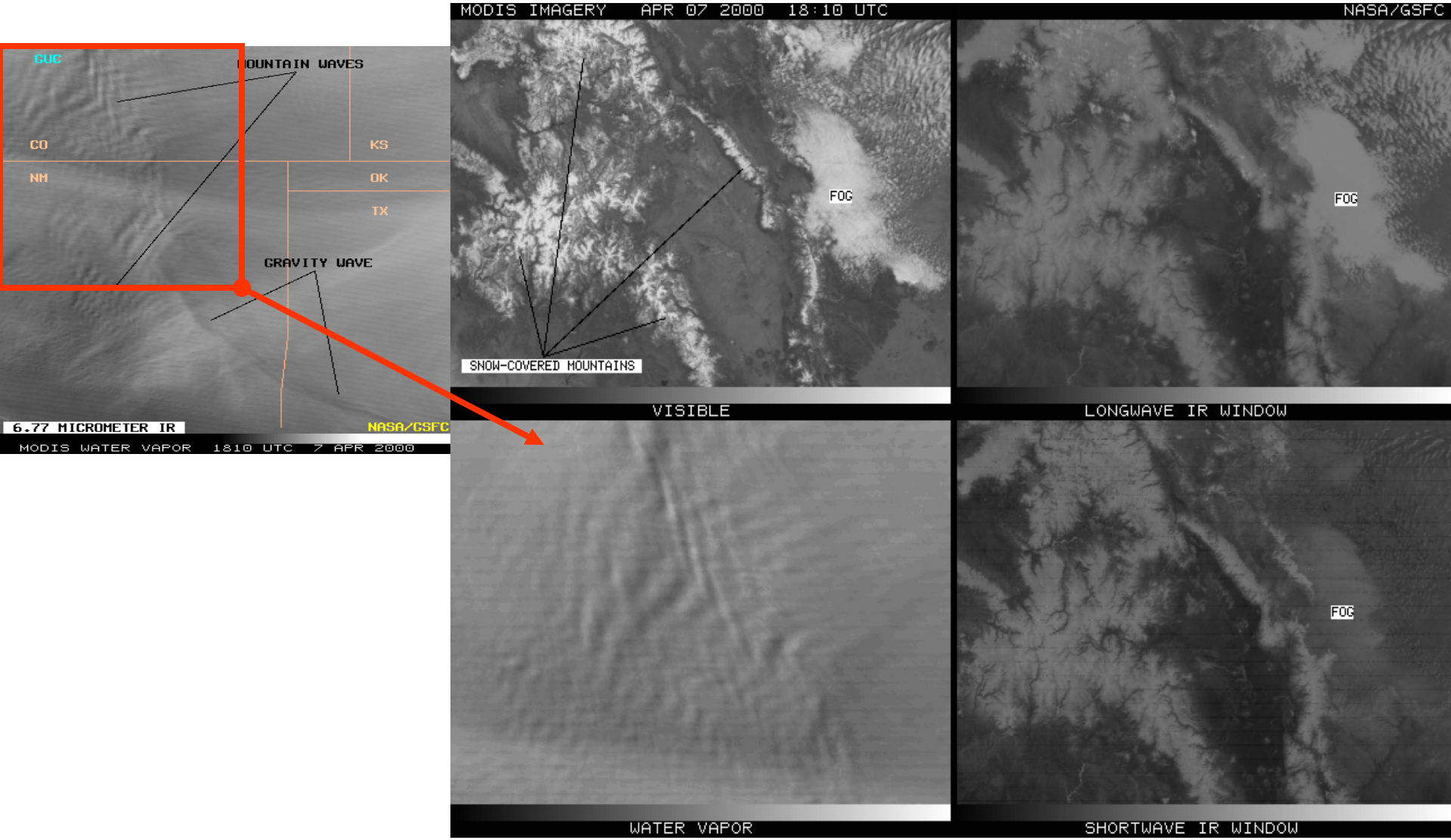




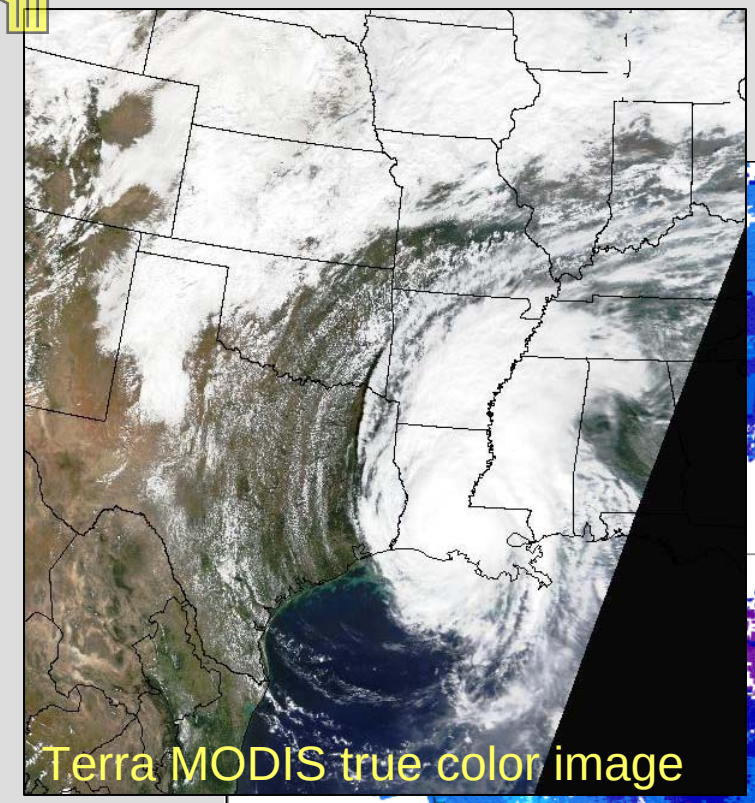
MODIS 1 km resolution reveals fine-scale structur

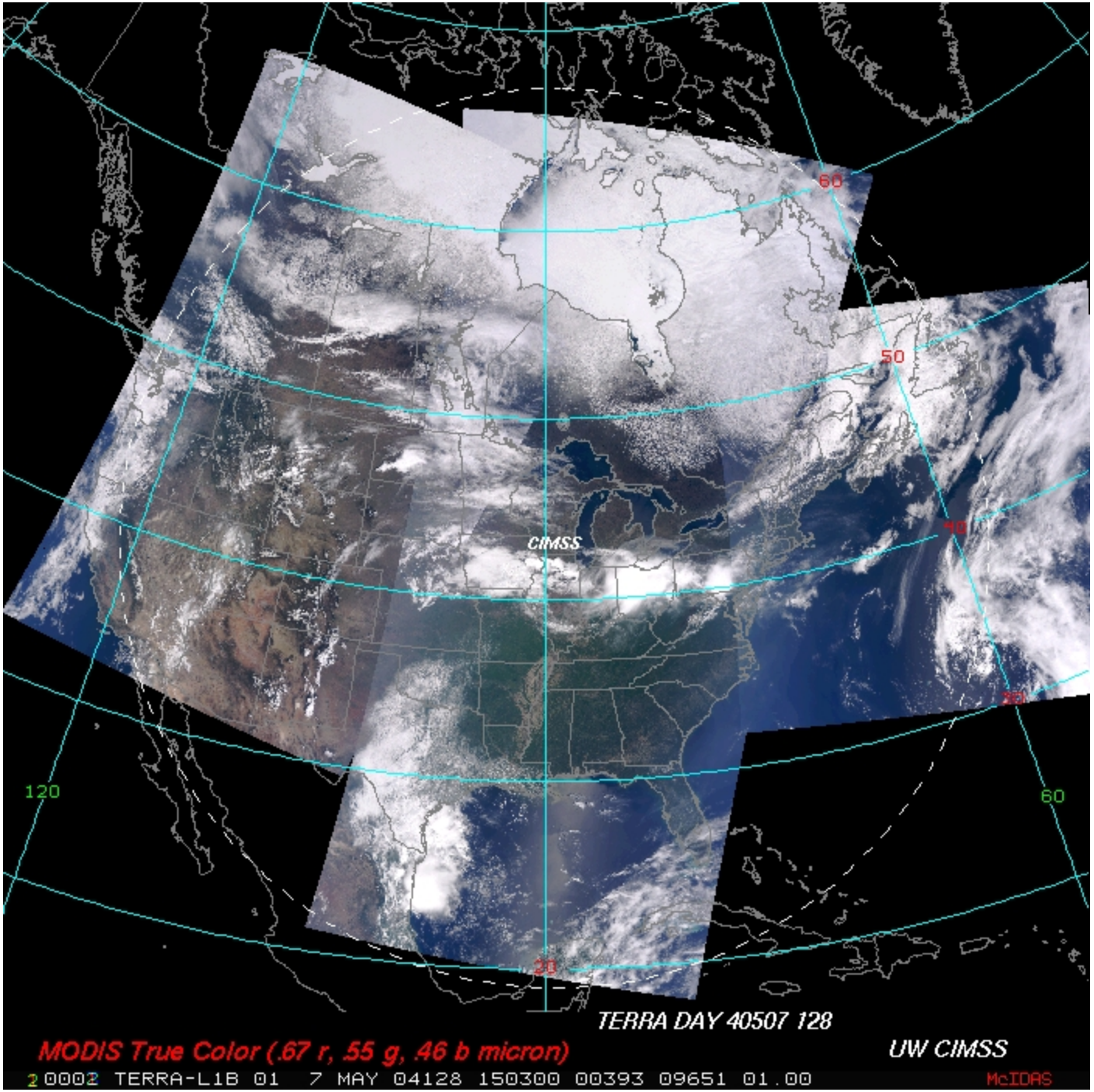


Four Panel Zoom of Cloud-Free Orographic Waves revealed in Water Vapor Imagery



Hurricane Lili, 2 October 2002
Terra MODIS direct broadcast

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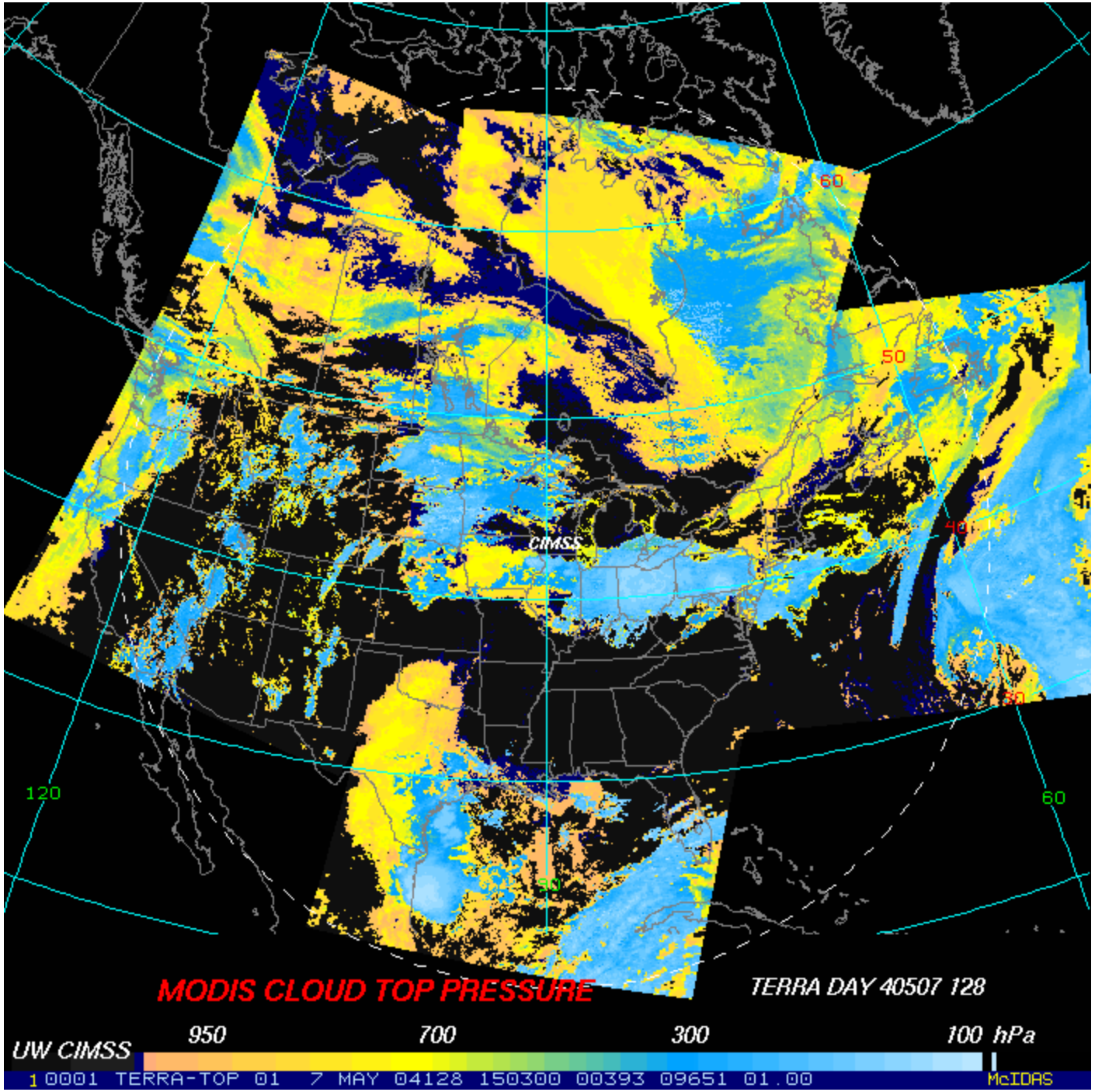
CIMSS
TERRA DAY 40507 128
MODIS True Color (.67 r, .55 g, .46 b micron)
UW CIMSS
2 0002 TERRA-L1B 01 7 MAY 04128 150300 00393 09651 01.00
McIDAS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120
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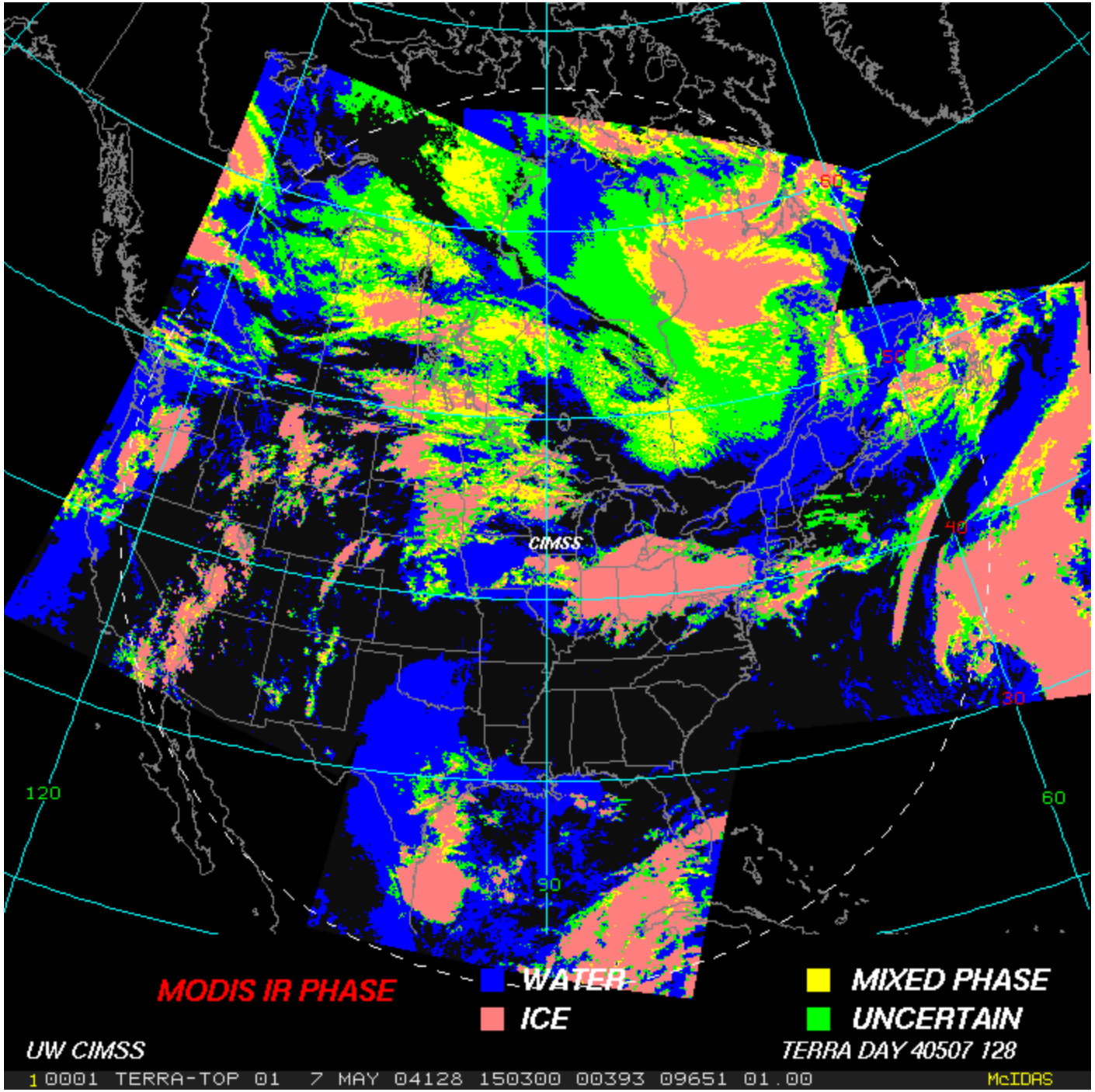
CIMSS
MODIS CLOUD TOP PRESSURE
TERRA DAY 40507 128
UW CIMSS
950
700
300
100 hPa
1 0001 TERRA-TOP 01 7 MAY 04128 150300 00393 09651 01.00
McIDAS


MODIS IR PHASE
WATER
ICE
MIXED PHASE
UNCERTAIN
UW CIMSS
TERRA DAY 40507 128
CIMSS
60
50
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120
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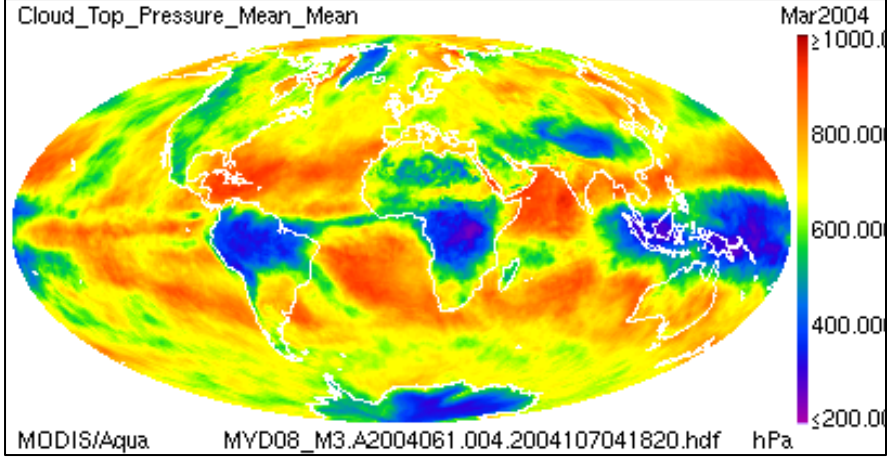
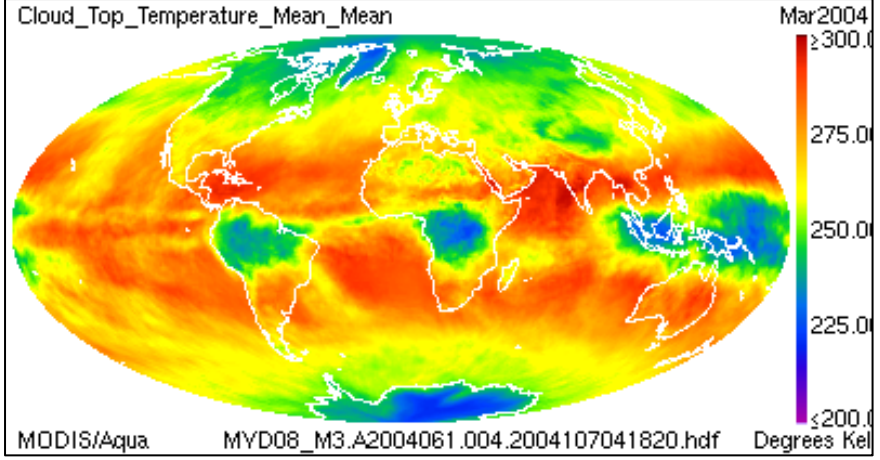
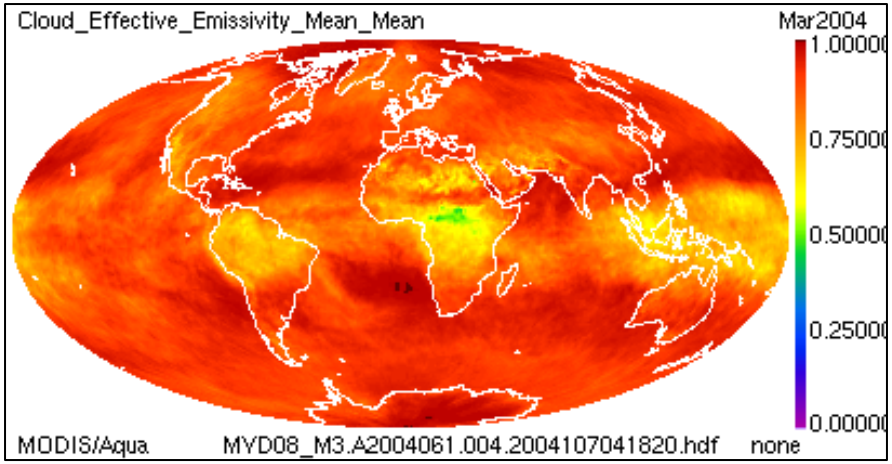
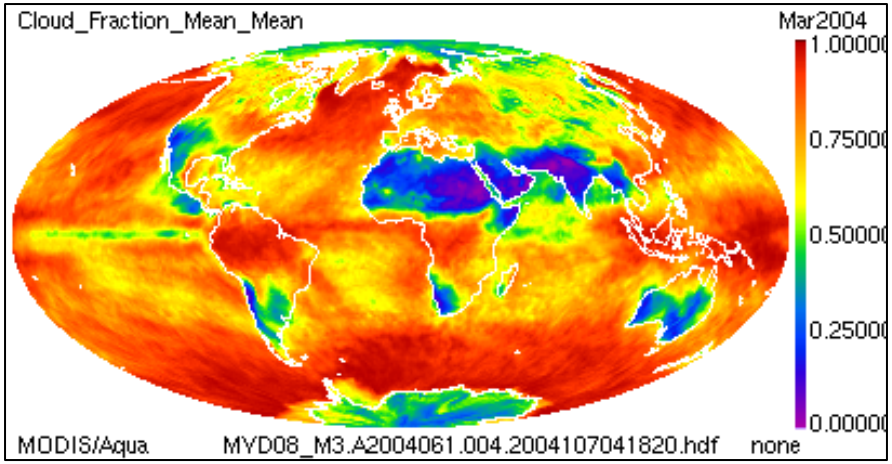
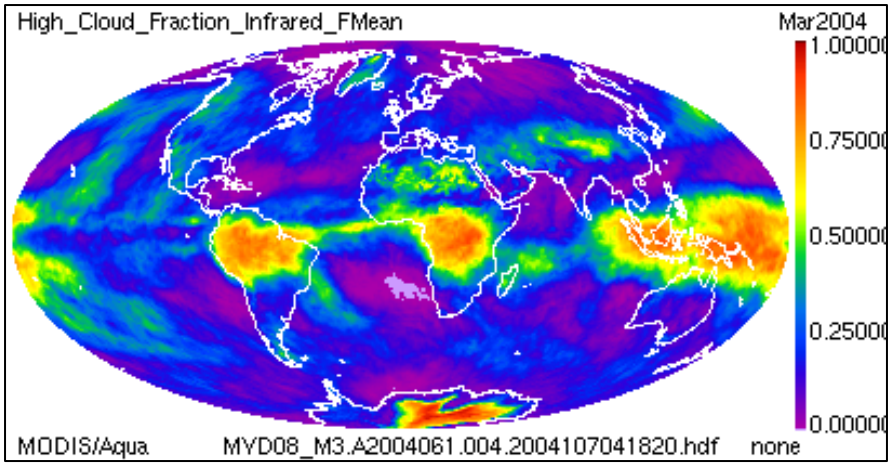
1 0001 TERRA-TOP 01 7 MAY 04128 150300 00393 09651 01.00
McIDAS











MODIS Cloud Top Properties Level 3 Products March 2004

End

Liam.Gumley@ssec.wisc.edu