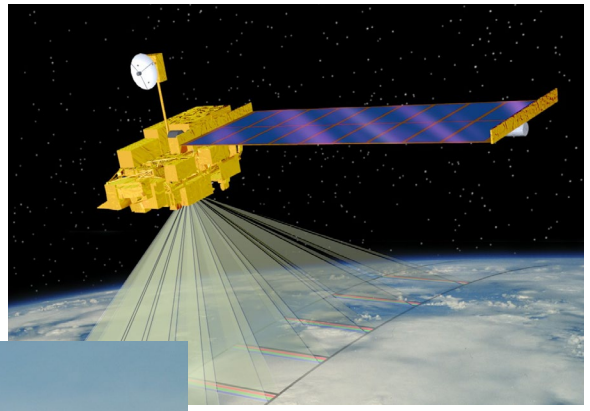
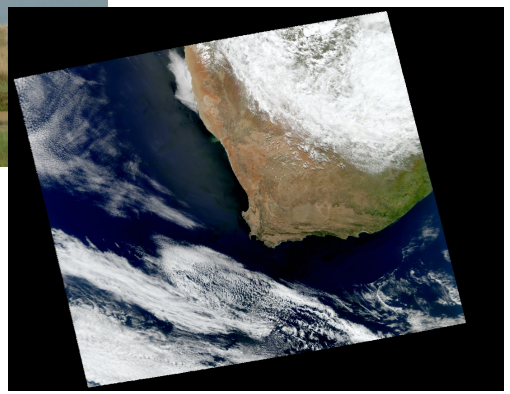
Introduction to MODIS

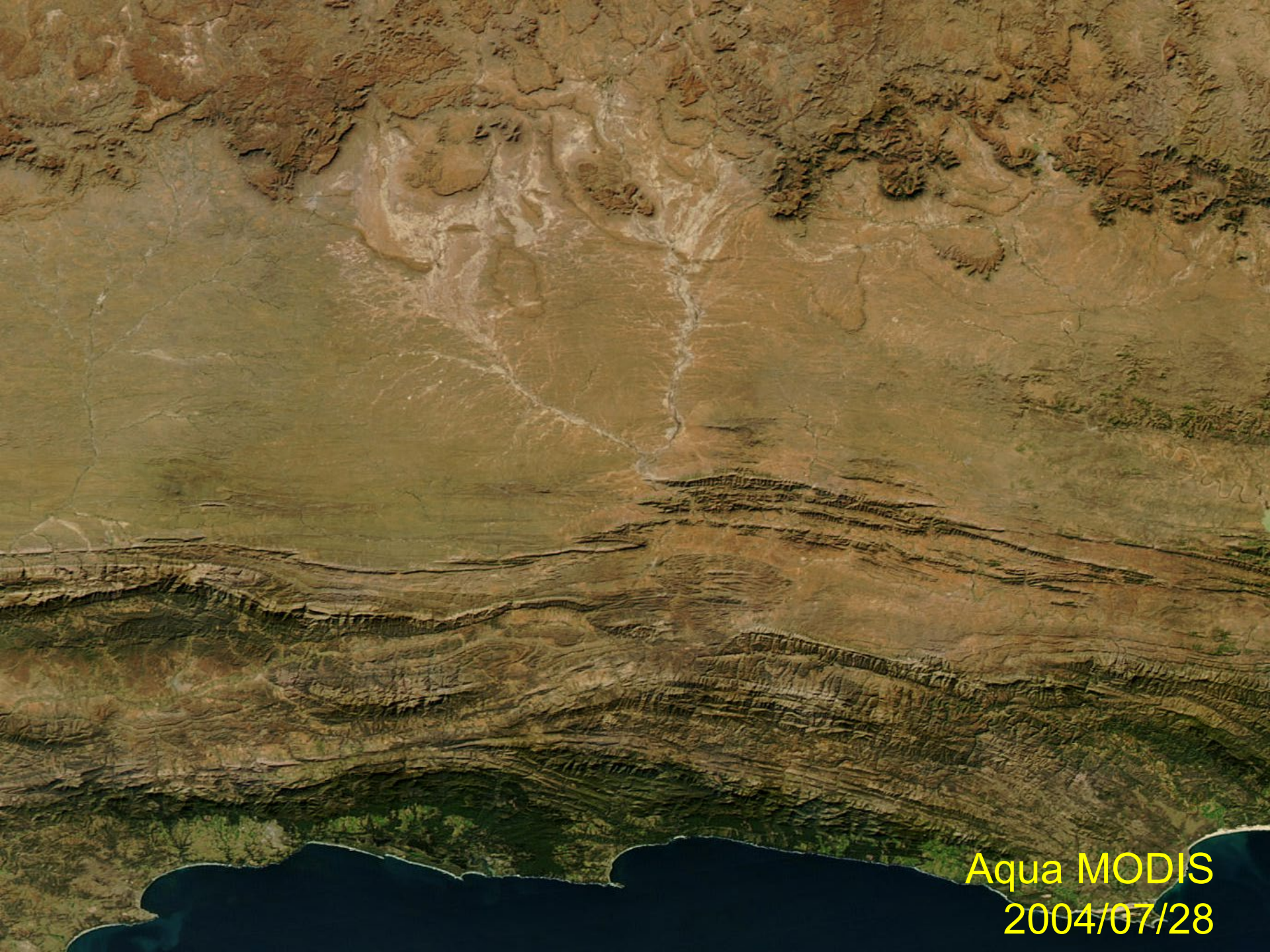


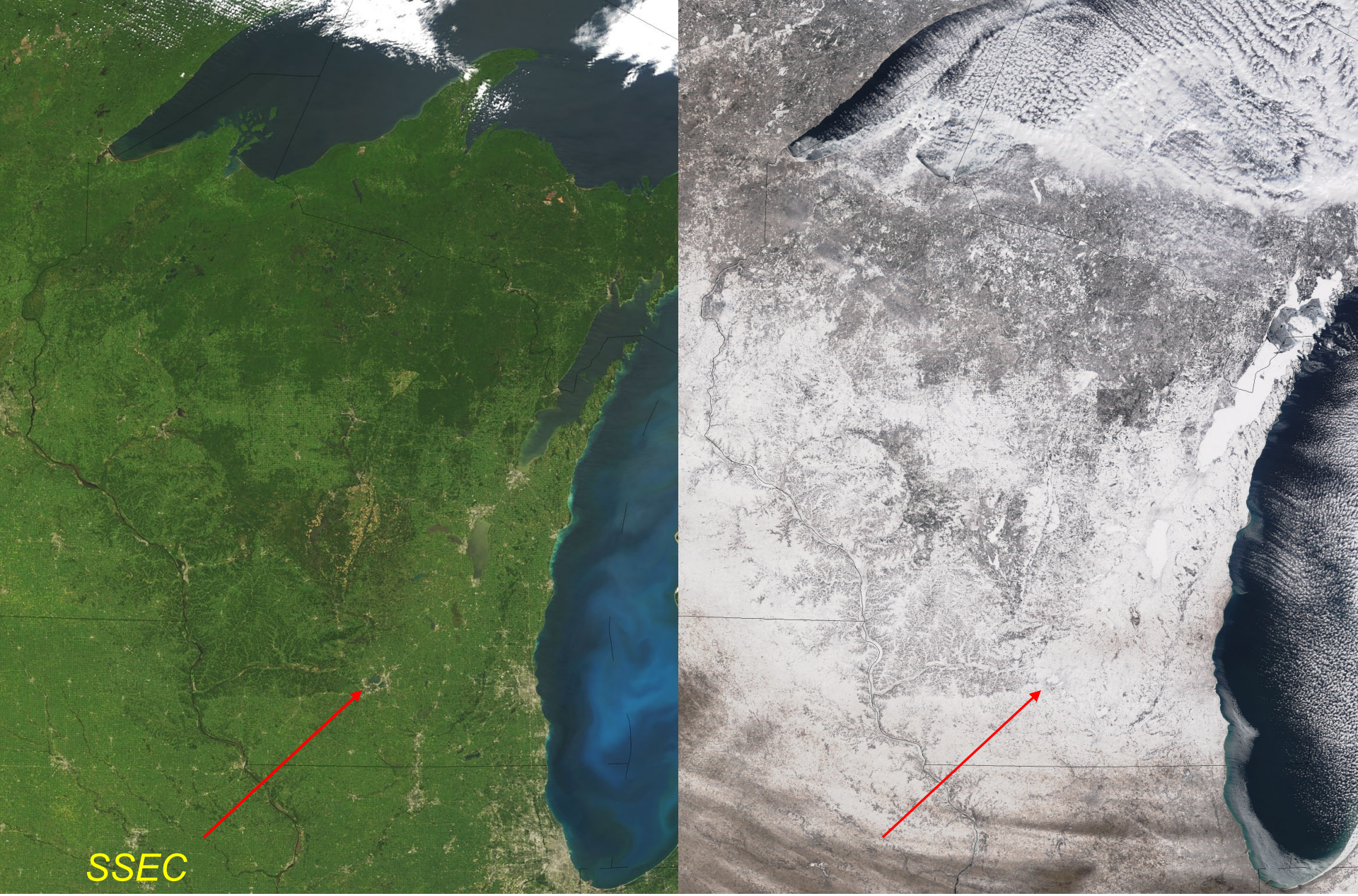


MODIS/AIRS Workshop
Pretoria, South Africa
April 4 - 7, 2006

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

CIMSS SSEC


Aqua MODIS
2004/07/28



Visit Wisconsin: Beautiful in Summer and Winter

Slide Credits

University of Wisconsin-Madison: Paul Menzel, Steve Ackerman, Paolo Antonelli, Chris Moeller, Kathy Strabala, Bryan Baum, Suzanne Seemann.

MODIS Science Team: Michael King, Steve Platnick, Eric Vermote, Robert Wolfe, Bob Evans, Jacques Descloitres, Jack Xiong.

Other colleagues: Wenjian Zhang, Stefan Maier, Jackie Marsden, Jamie Shutler, Tim Smyth, Roger De Abreu, Gerardo Lopez.

Introduction to MODIS

Terra

Launched: Dec. 18, 1999

10:30 am descending

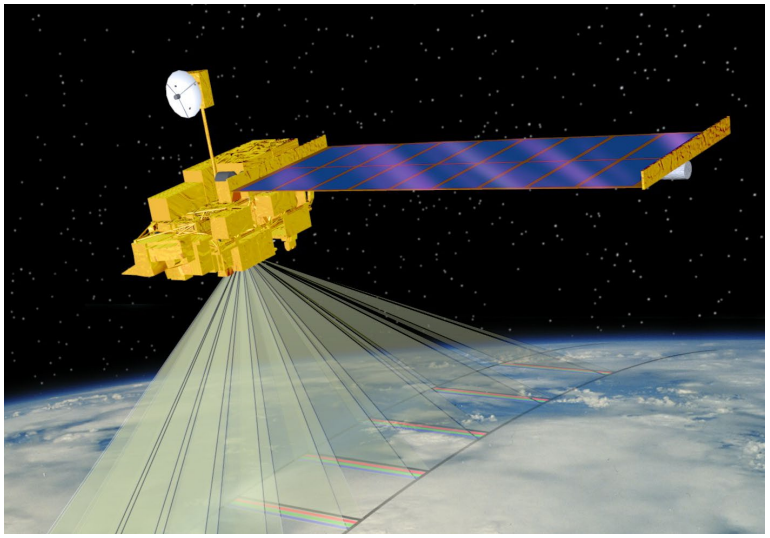
ASTER: Hi-res imager

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

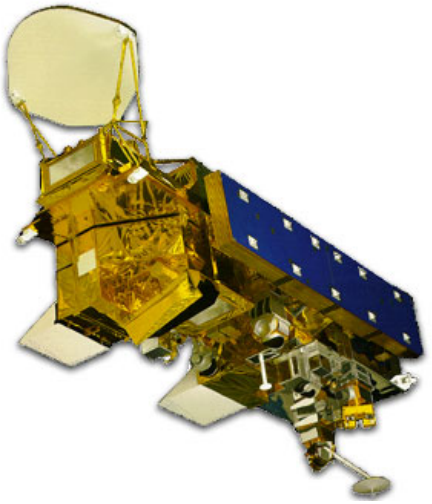
AMSR-E: Microwave scanner

AMSU: Microwave scanner

CERES: Broadband scanner

HSB: Microwave sounder

MODIS: Multispectral imager



Formation Flyers

Coordinated observations by multiple sensors
without the risk of one large platform

Morning Train (10:30 am)

- Terra (multidisciplinary)
- Landsat-7 (land)
- EO-1 (technology)
- SAC-C (GPS water vapor)
- NPP (EOS/NPOESS bridge)

Afternoon Train (1:30 pm)

- Aqua (multidisciplinary)
- Aura (chemistry)
- Cloudsat (cloud radar)
- CALIPSO (cloud lidar)
- Parasol (polarimetry)
- NOAA-16 (weather)

Moderate resolution imaging spectroradiometer (MODIS)

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

Spectral coverage: 36 bands from 0.4 to 14.2 microns

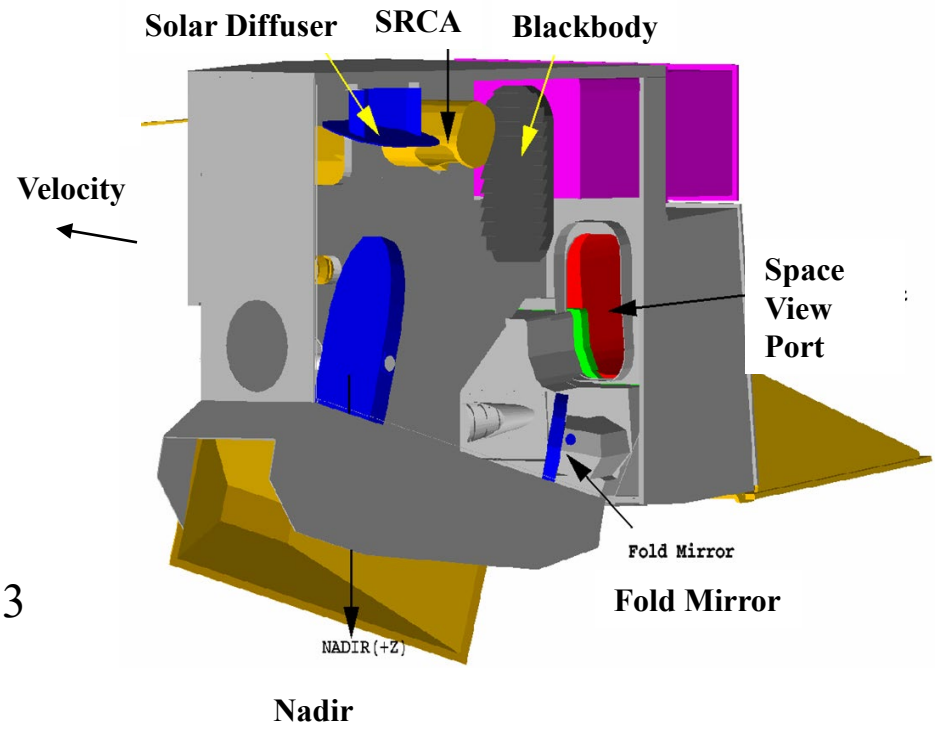
Spatial resolution: 2 bands @ 250 m; 5 @ 500 m; 29 @ 1000 m

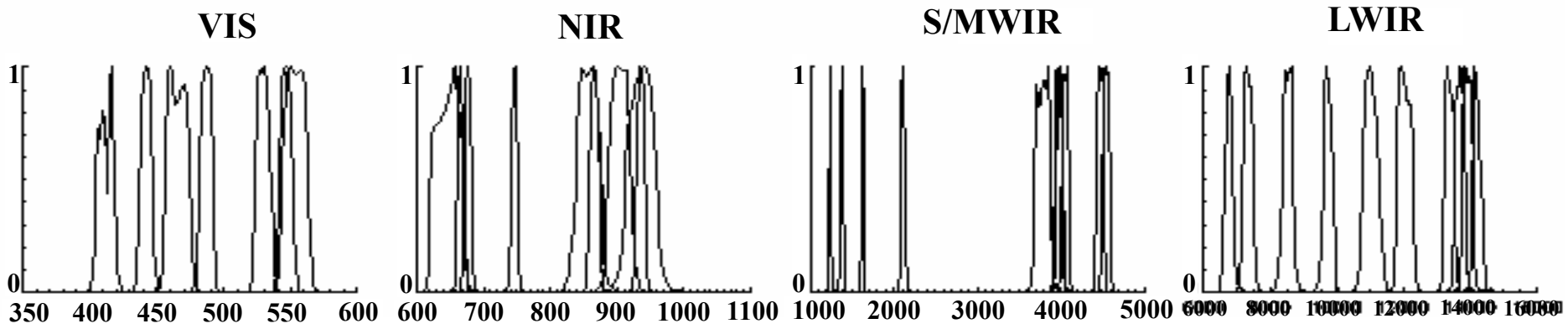
Major differences:

- 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

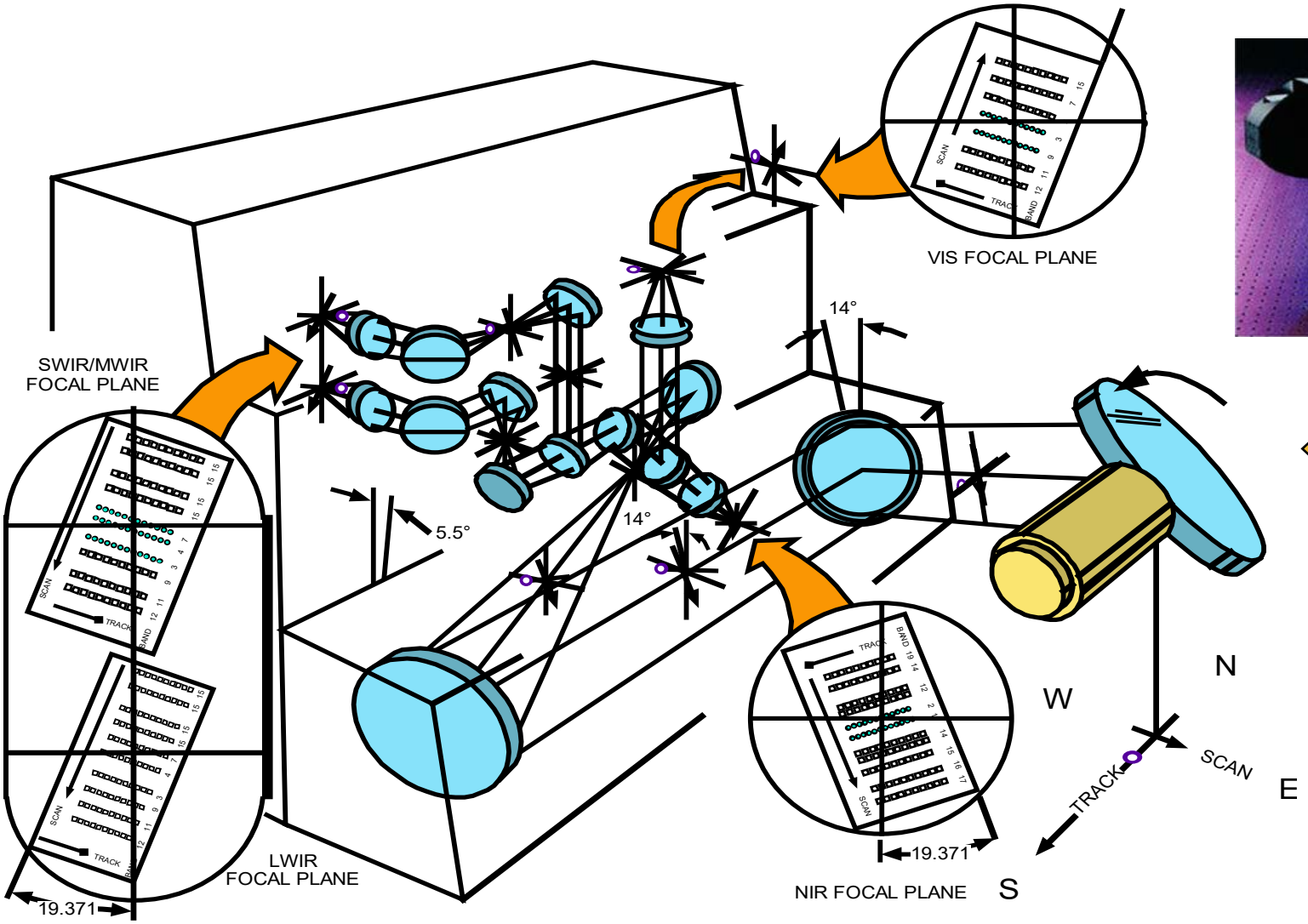
Instrument Overview

- 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



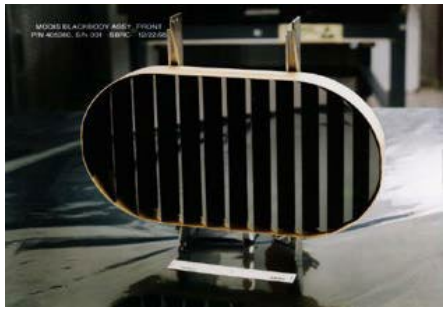
On-board Calibrators

- **SD** – 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

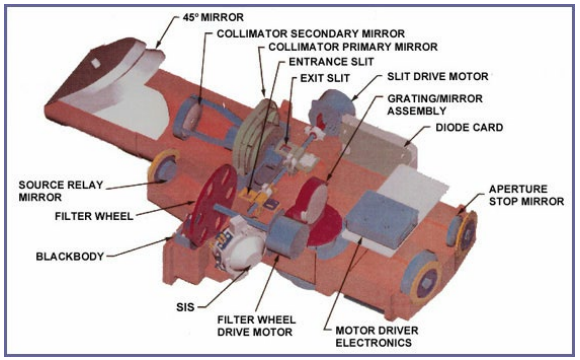
SD

SDSM

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 utilize all the spectral information?

Data rate:

Orders of magnitude larger than heritage sensors

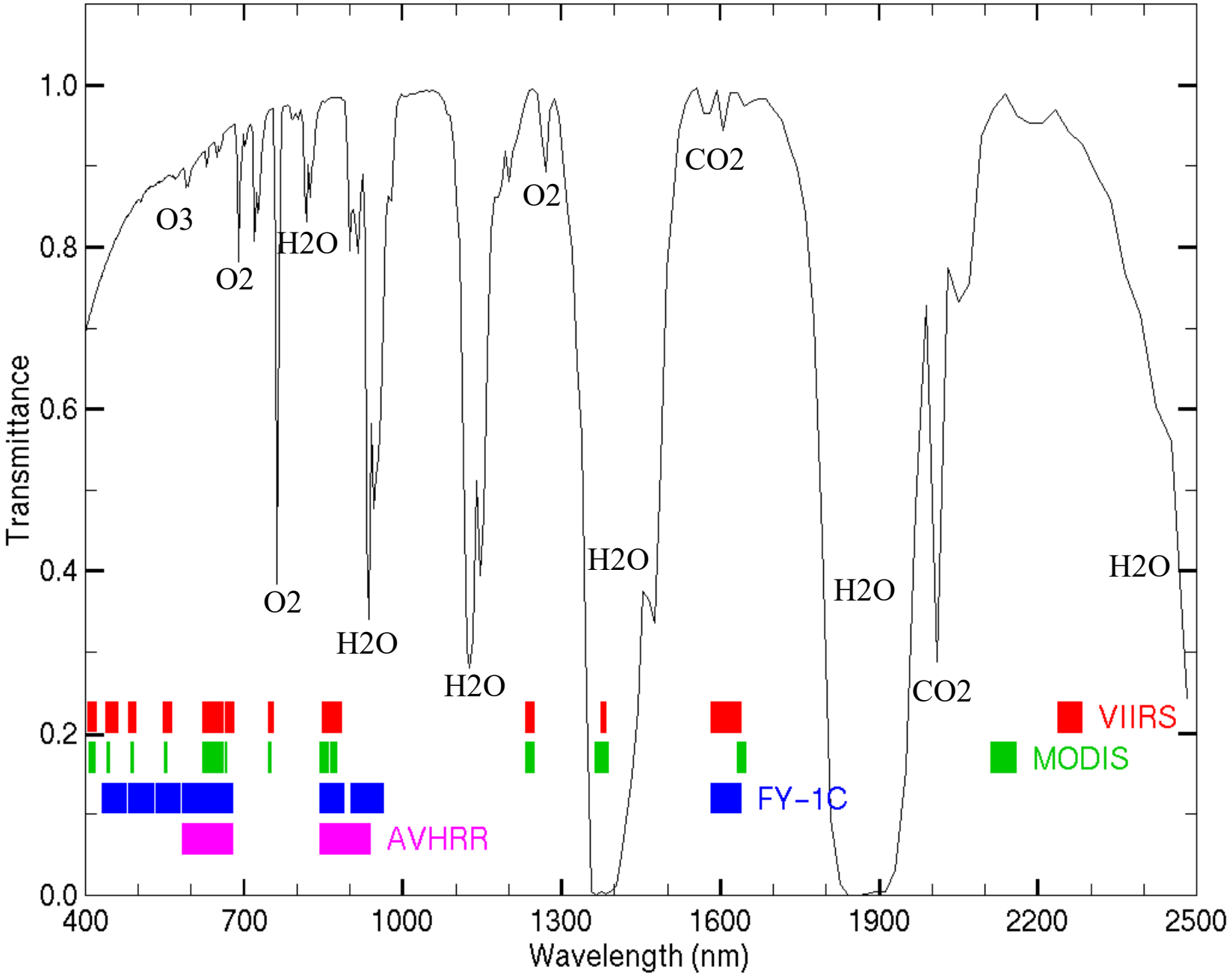
MODIS Reflected Solar Bands

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

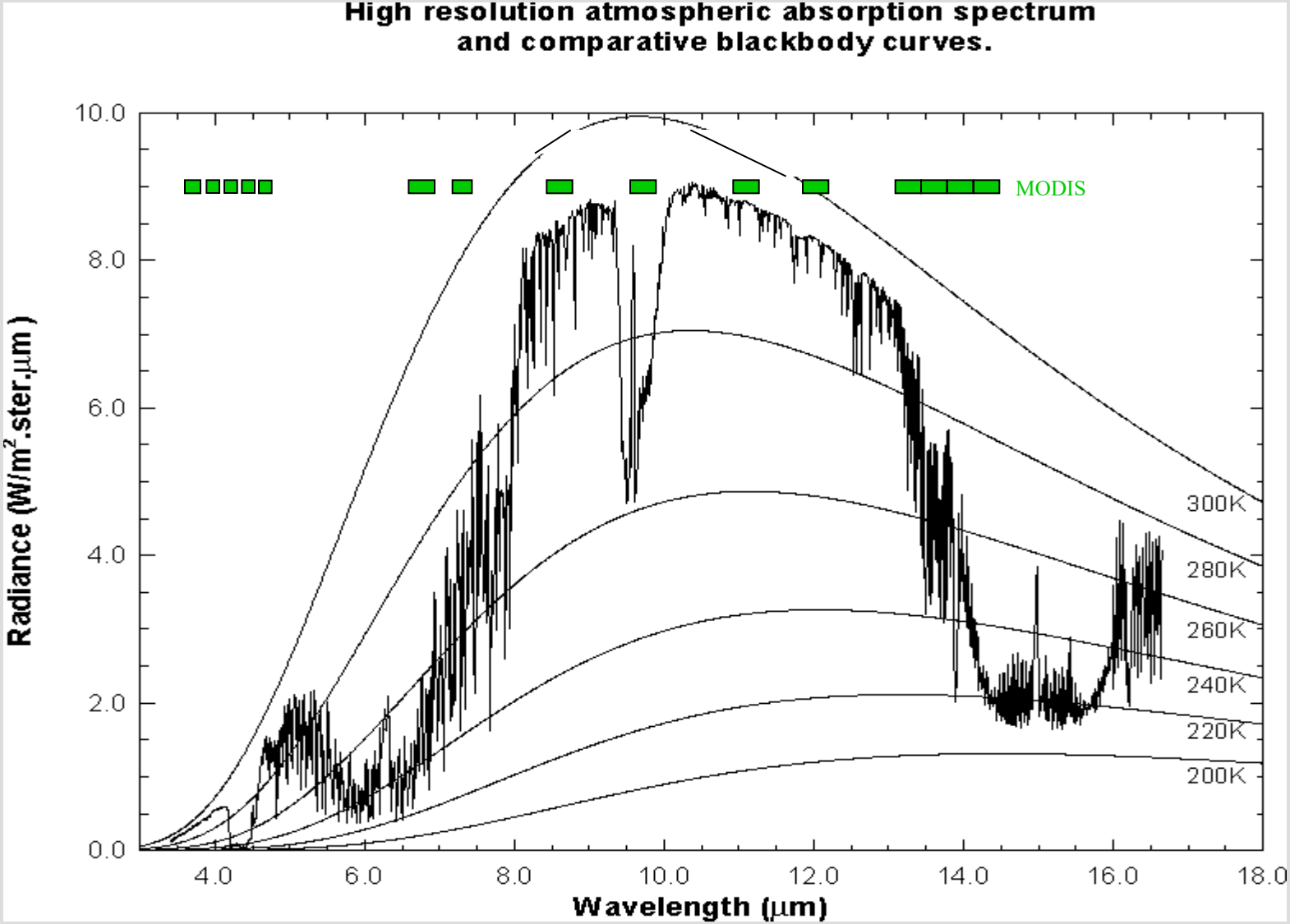
MODIS Thermal Emissive Bands

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

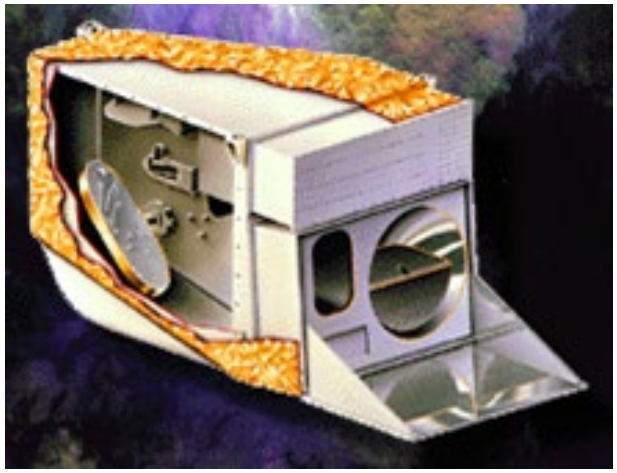
VIIRS, MODIS, FY-1C, AVHRR



MODIS IR Spectral Bands

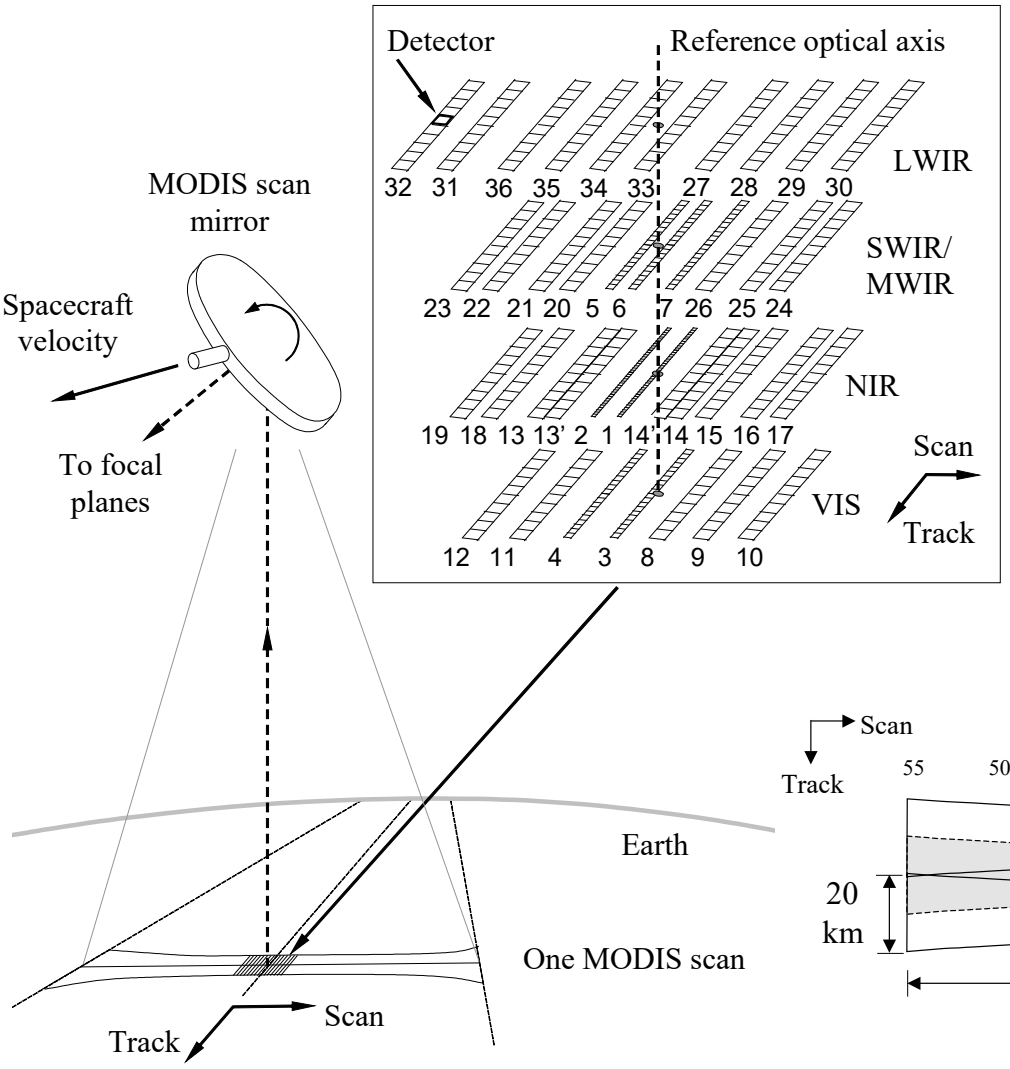


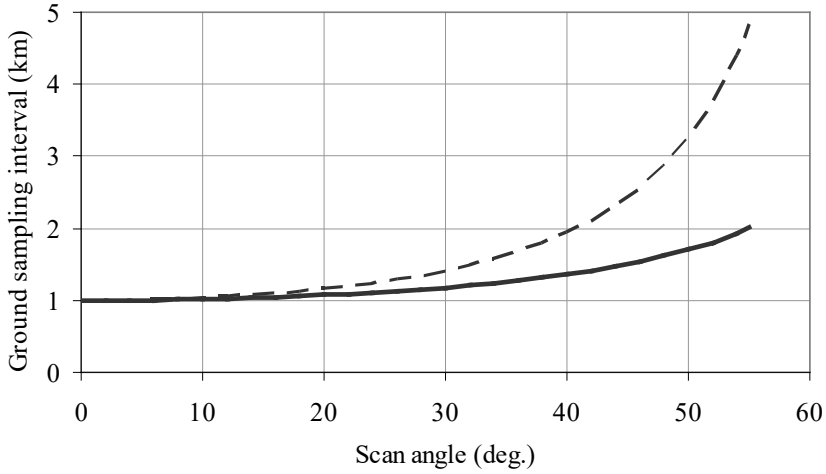
MODIS Geolocation

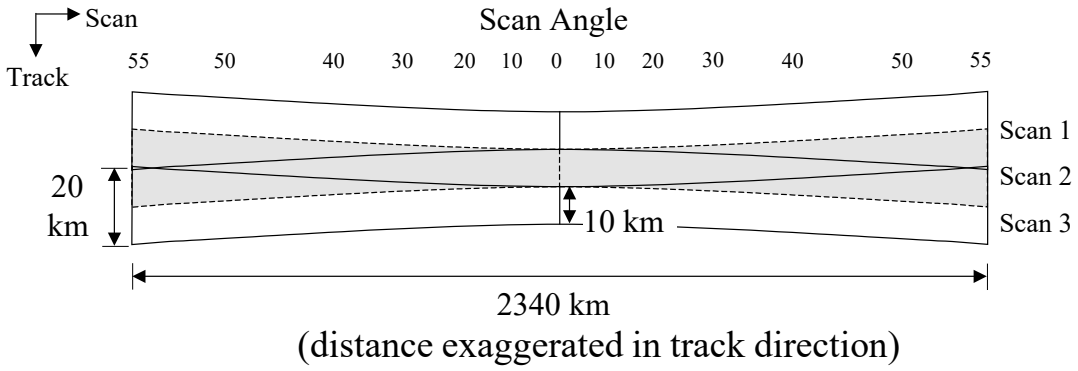


- Geolocation accuracy specification is 150 m (1 σ) and goal is 50 m (1 σ) at nadir
- Geolocation goal driven by Land 250 m change product requirements
- MODIS is a moderate resolution whisk-broom sensor with 36 spectral bands; 2 at 250 m, 5 at 500 m and 29 at 1 km nadir spatial resolution
- "Ideal" band is geolocated
  - 250m band 1 (645 nm, "red")

MODIS Scan Geometry

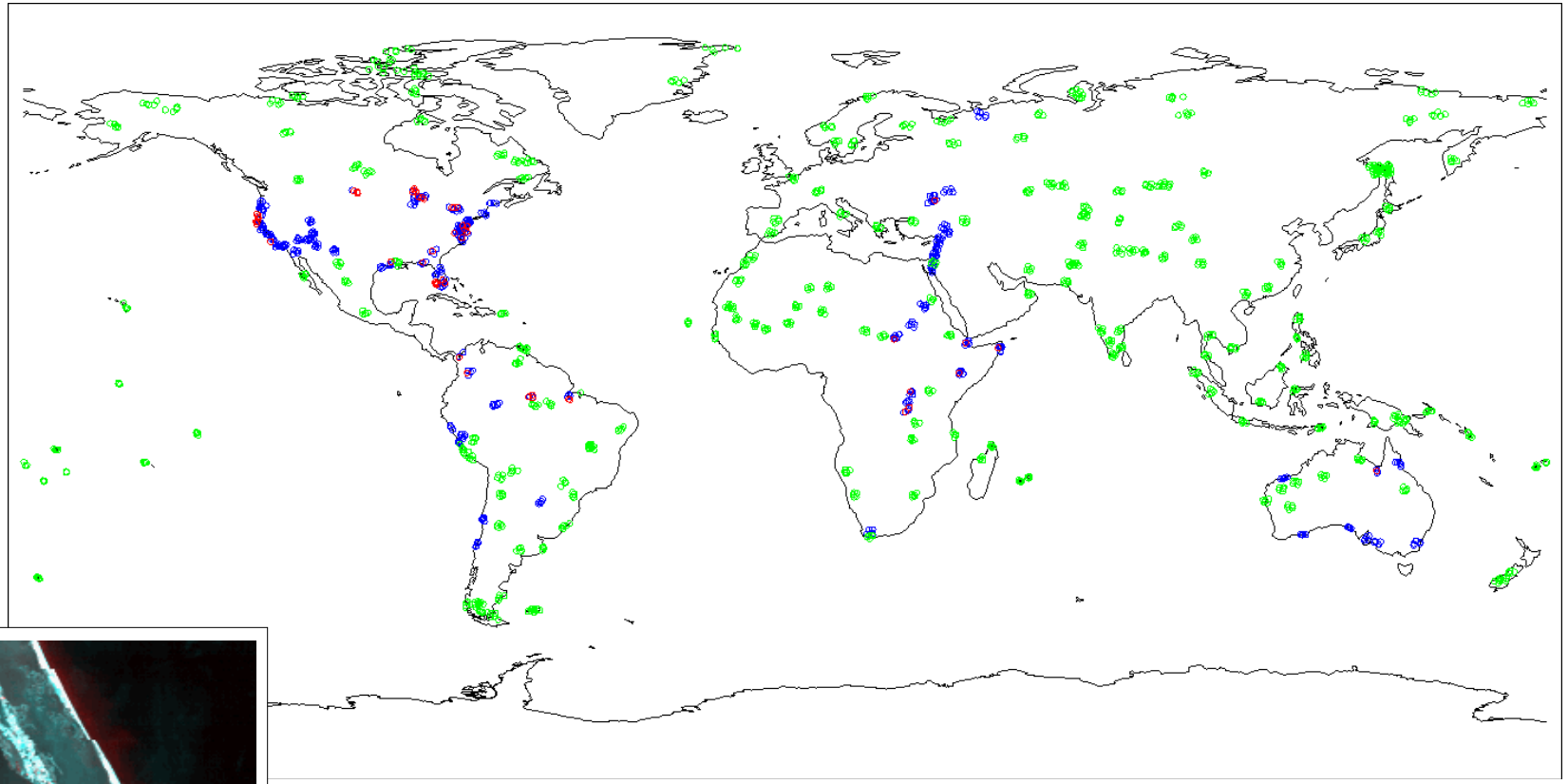






(distance exaggerated in track direction)

Ground Control Points (GCPs)



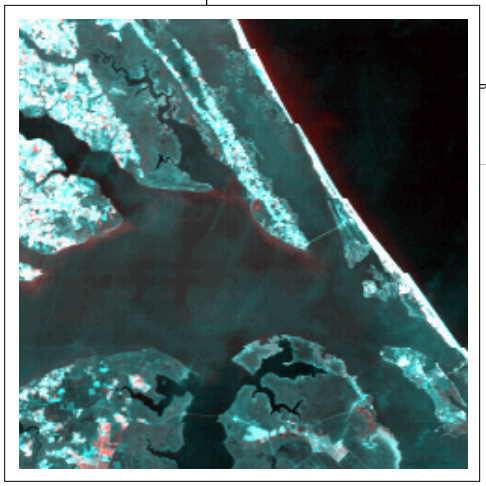


Image chips from Landsat TM/ETM scenes

366 old chips (blue)
51 chips removed (red)
990 new chips (green)

Geolocation Collection 4 (C4)

Terra

- Excellent results – Root Mean Square (RMS) error in nadir equivalent units is better than accuracy goal
- Small remaining northern/ southern hemisphere difference
- Large errors occur after orbit maneuvers (about 6 per year)
  - accuracy in following orbit suspect

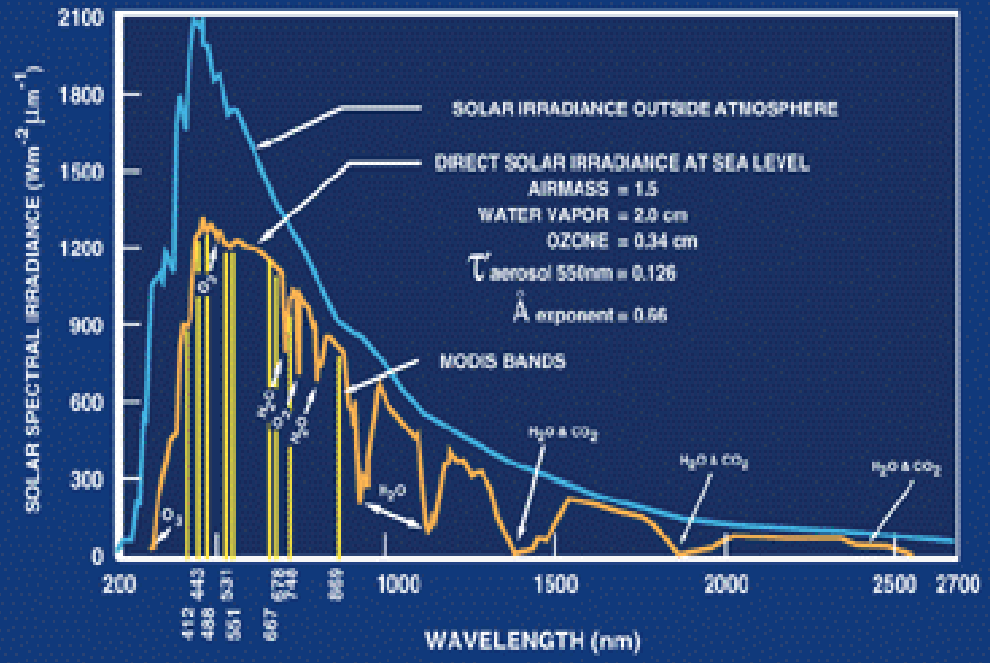
Aqua

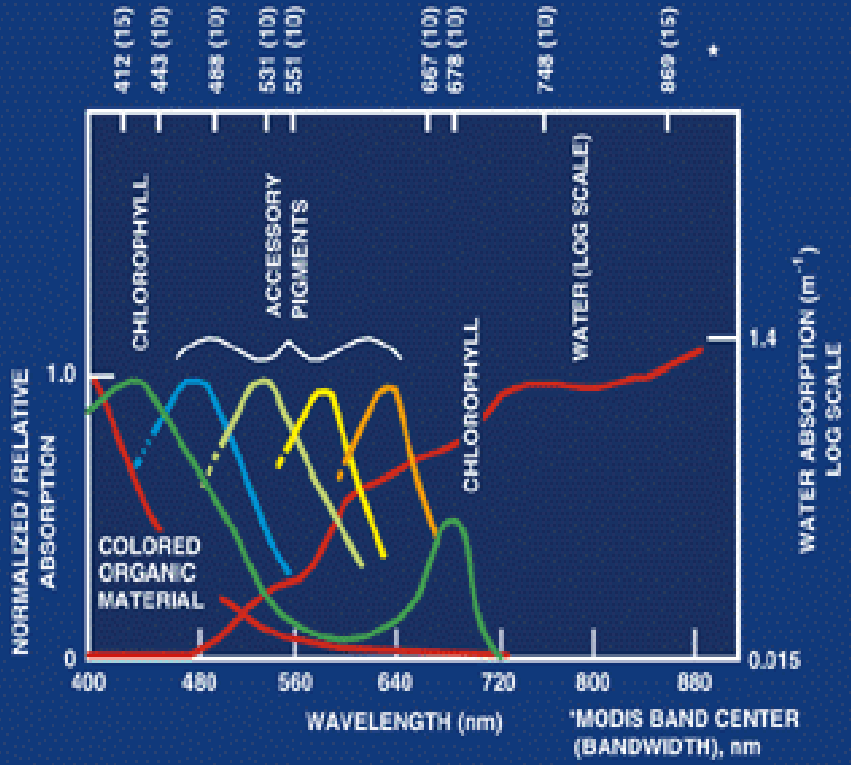
- Good results – RMS error is better than goal in track direction but slightly over goal in scan direction (but much better than specification – 150 m)
- Early post-launch coordinate system issue resolved before C4
- Definitive ephemeris is used for best results – causes up to 24 hr processing delay

	Terra	Aqua
Along-track RMS error (m)	38	43
Along-scan RMS error (m)	43	56
Years	4.0	1.6
Ground Control Point Match-ups/day	83	74

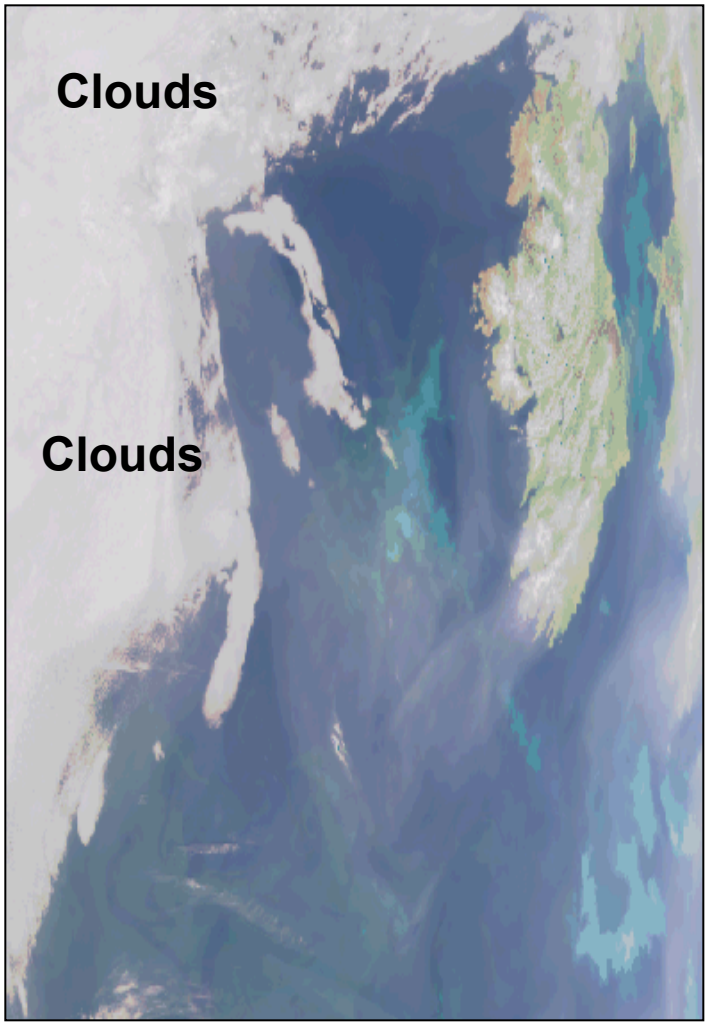
MODIS Ocean Applications

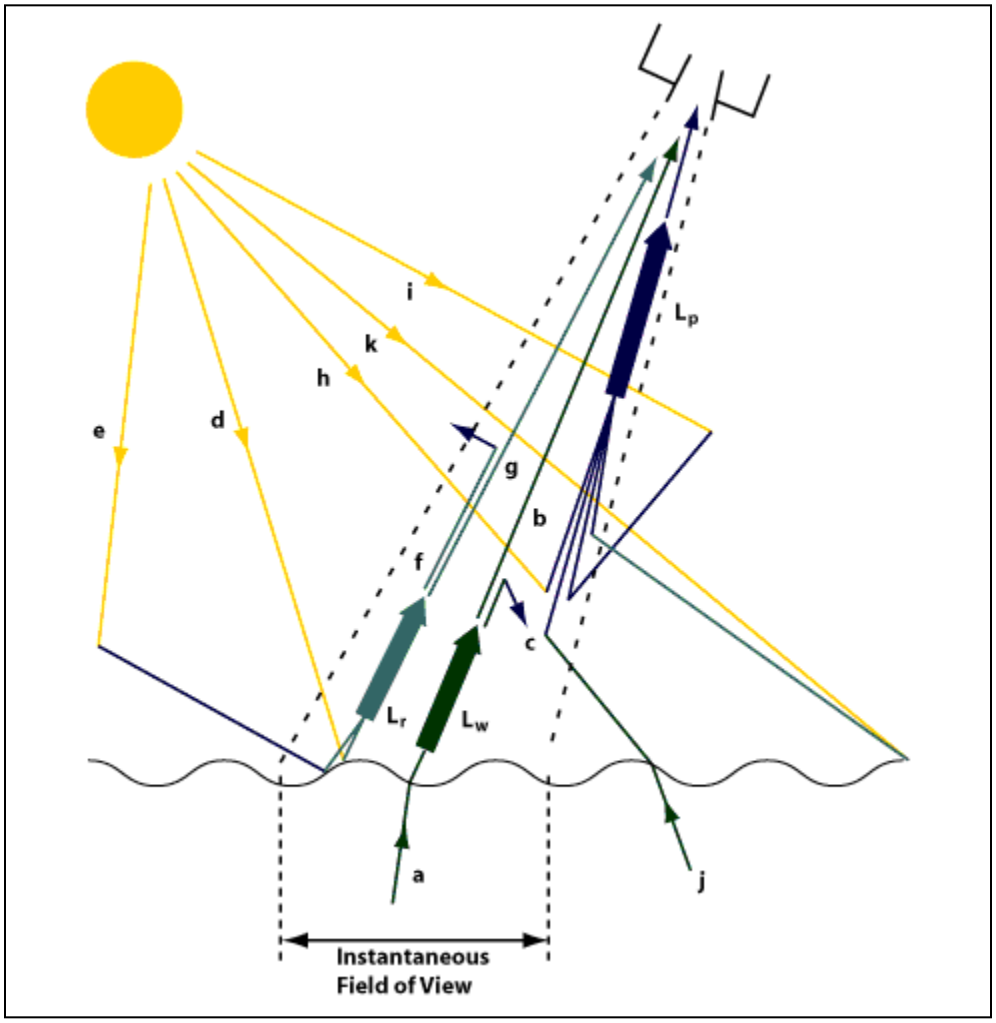
OCEAN-SOLAR RADIATION



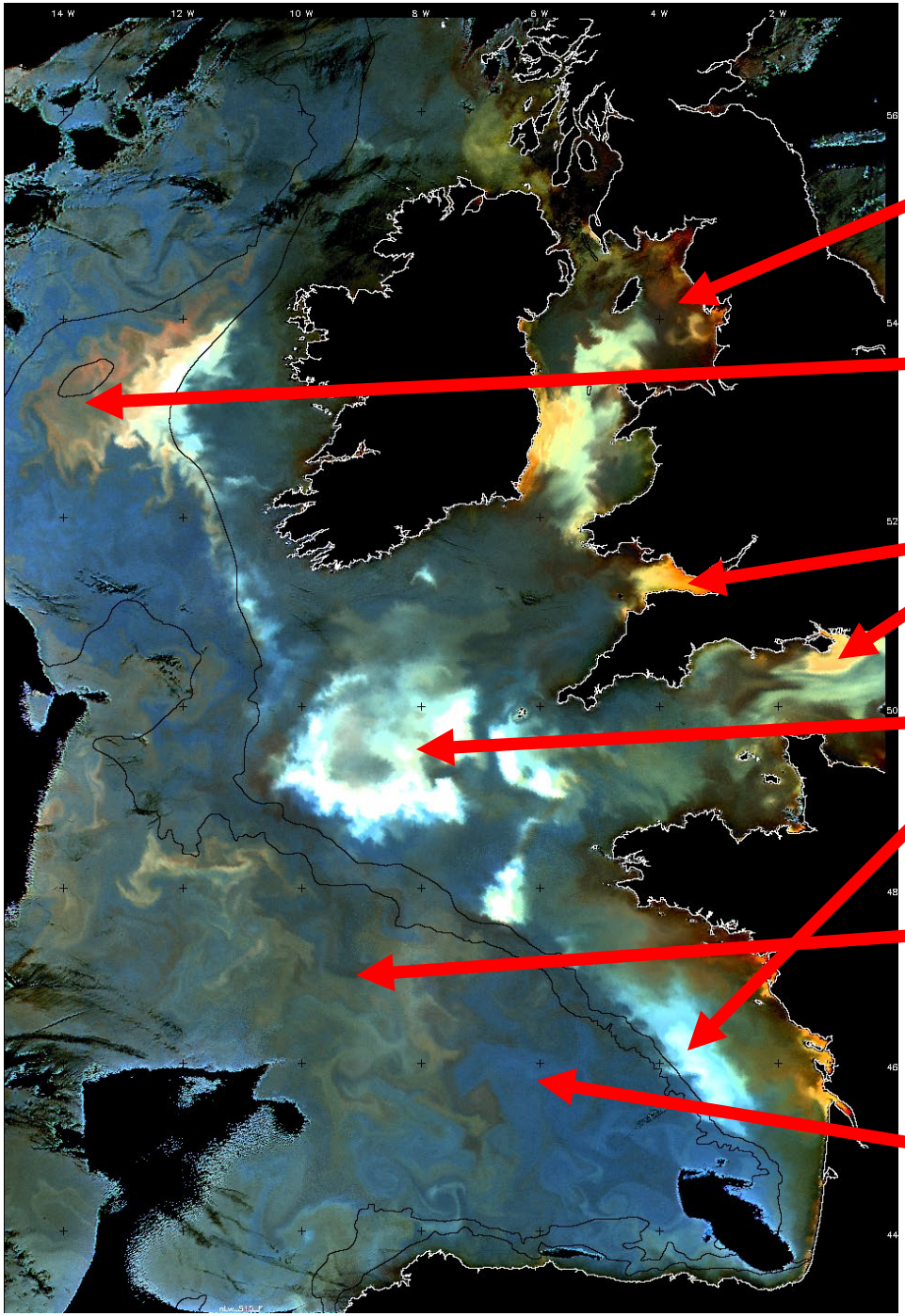


Atmospheric correction is critical for ocean color





- 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



CDOM

bloom?

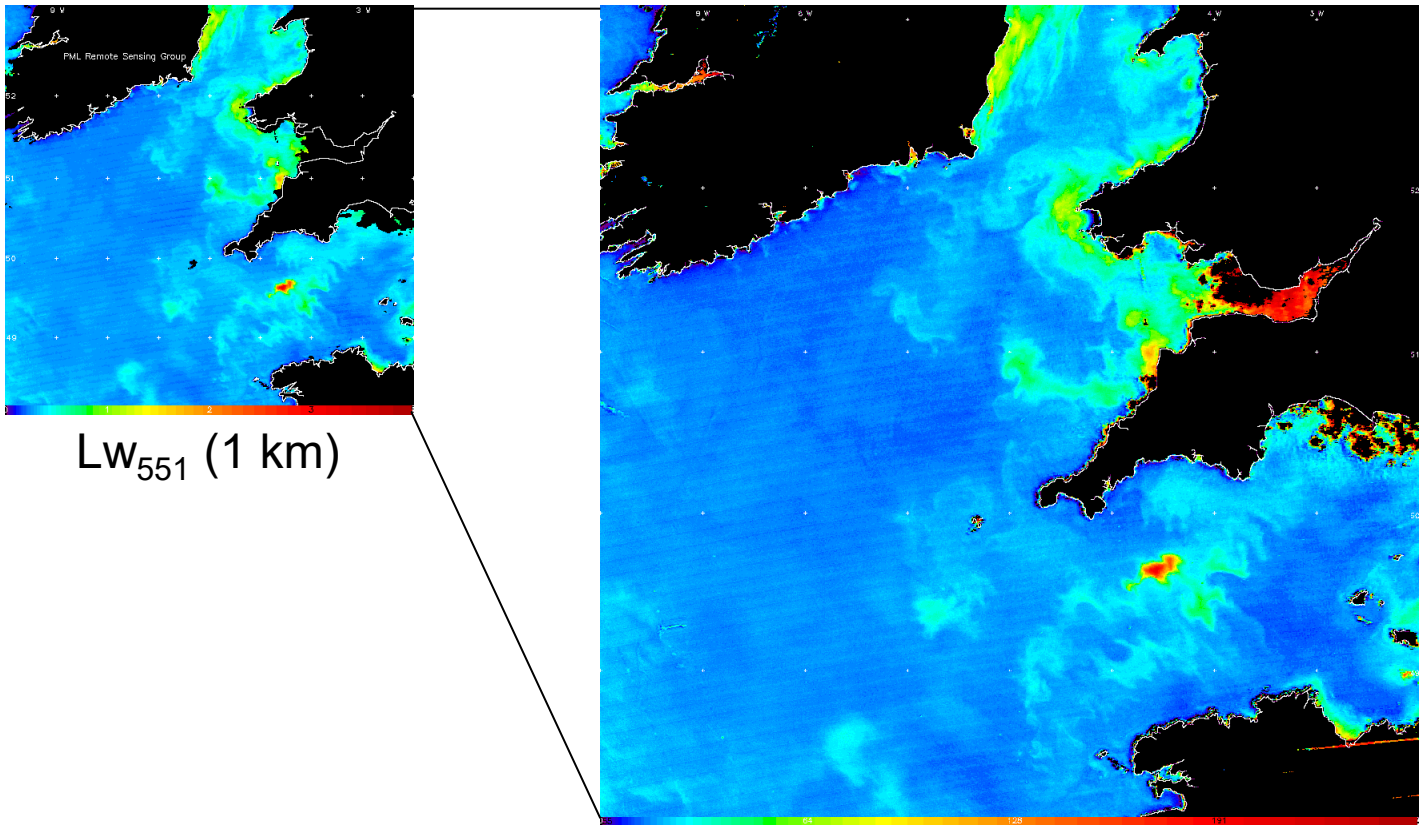
Sediment

Coccolithophores

Phytoplankton – fine eddy structure

Clear blue ocean

U.K. South West Approaches: 11 July 2005 13:38 UTC Aqua

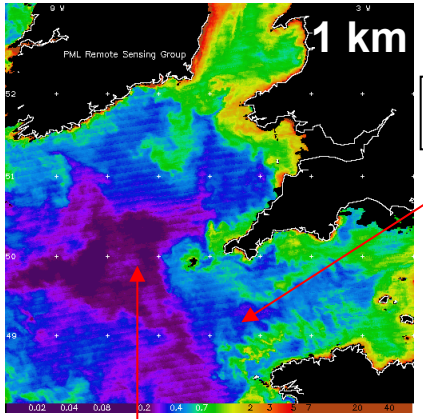


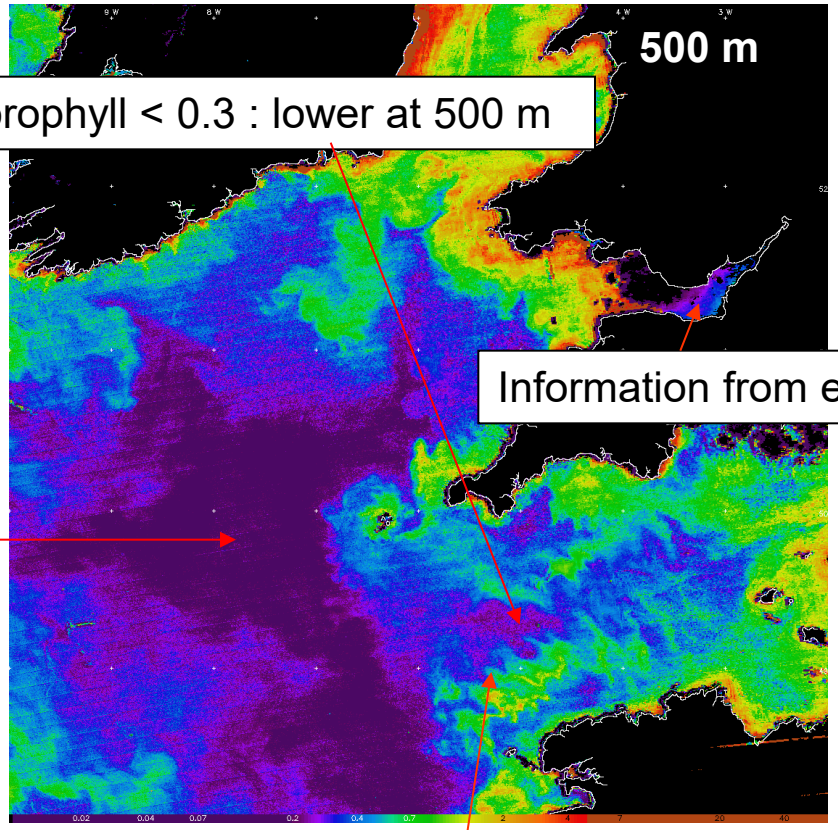
Lw_{551} (1 km)

Lw_{555} (500 m)

Lw

U.K. South West Approaches: 11 July 2005 13:38 UTC Aqua Chl





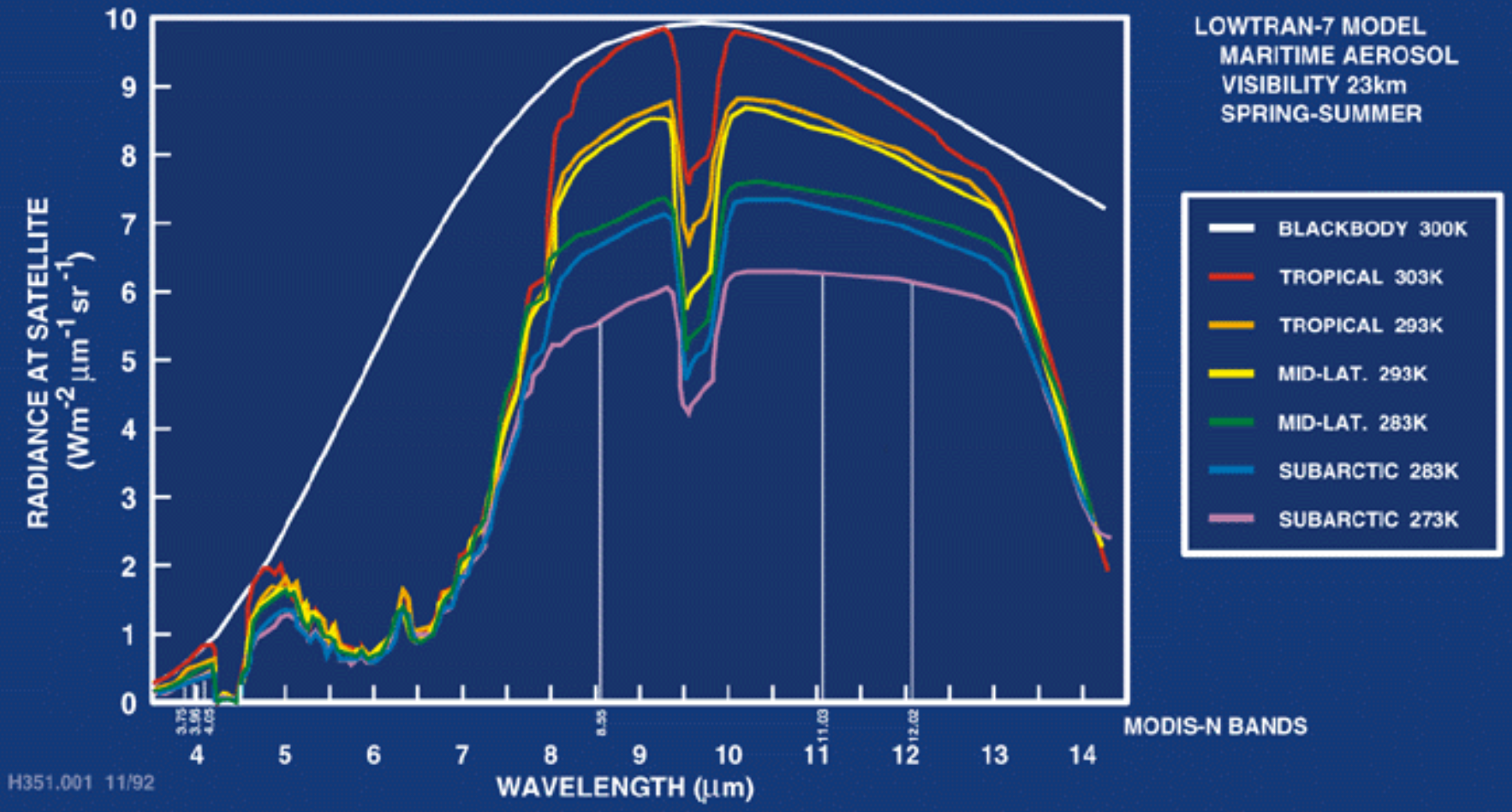
low chlorophyll < 0.3 : lower at 500 m

Information from estuaries

Same broad-scale features

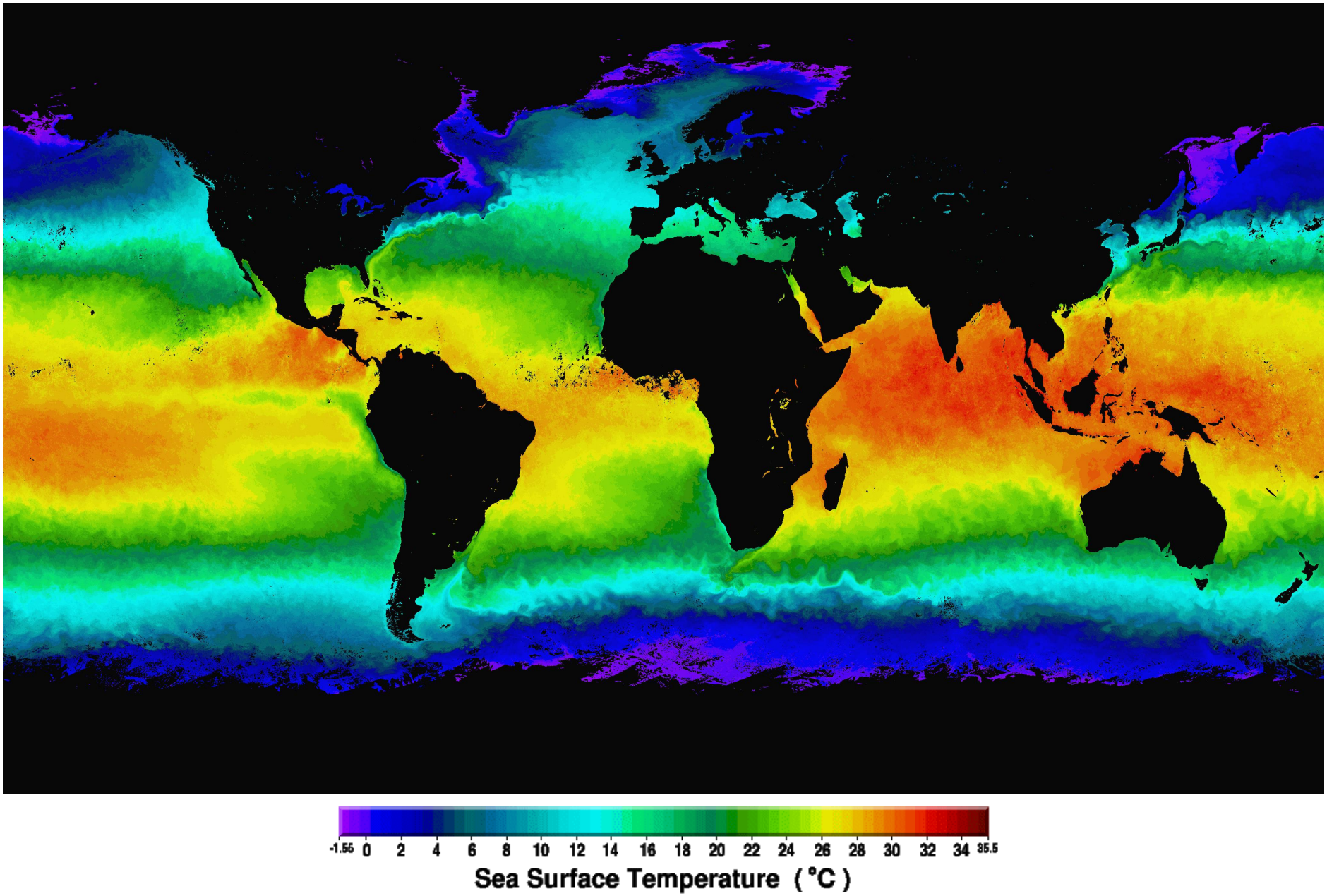
Bloom fine-scale structure

MODIS SEA SURFACE TEMPERATURE

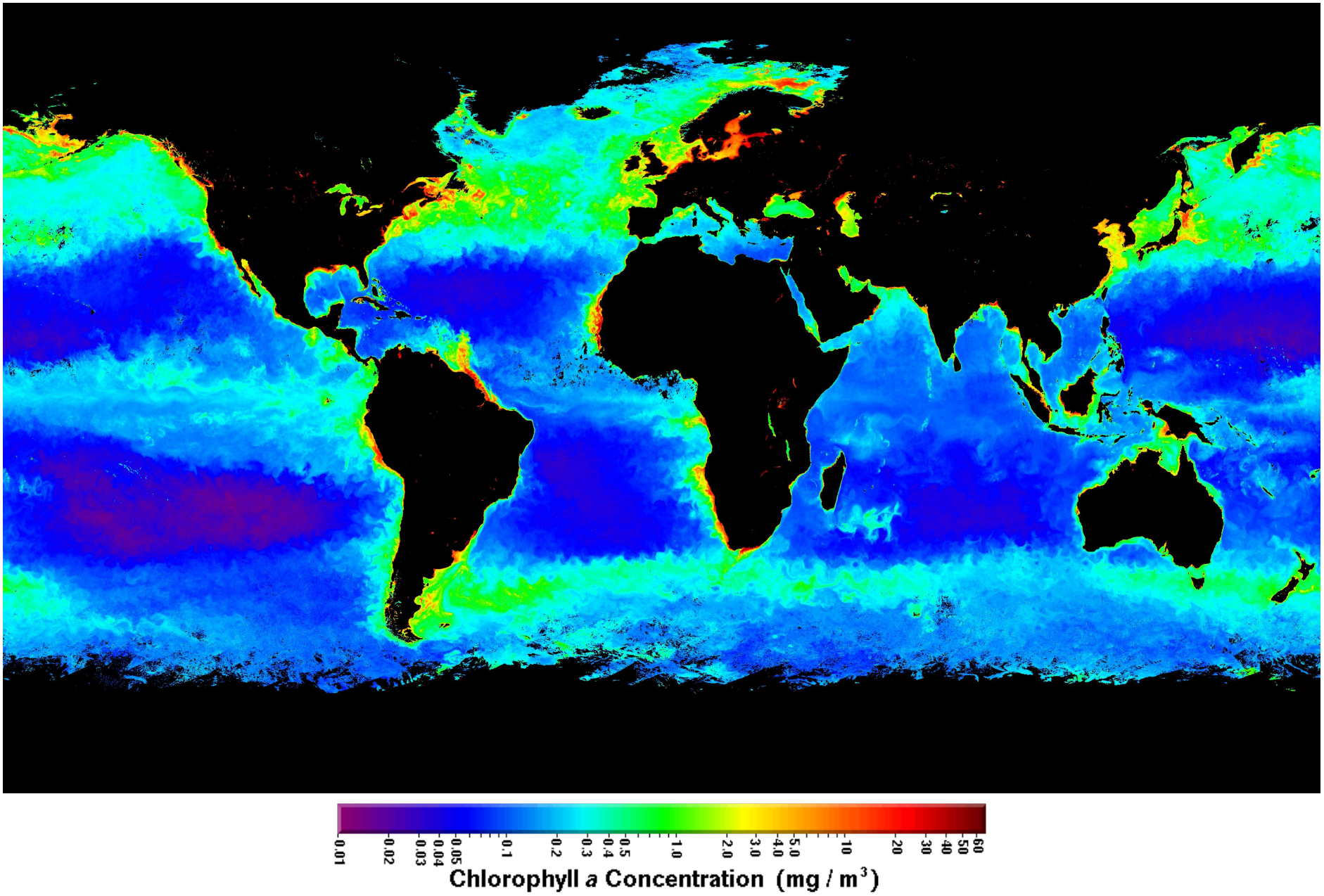


H351.001 11/92

Aqua MODIS Sea Surface Temperature, April 2004

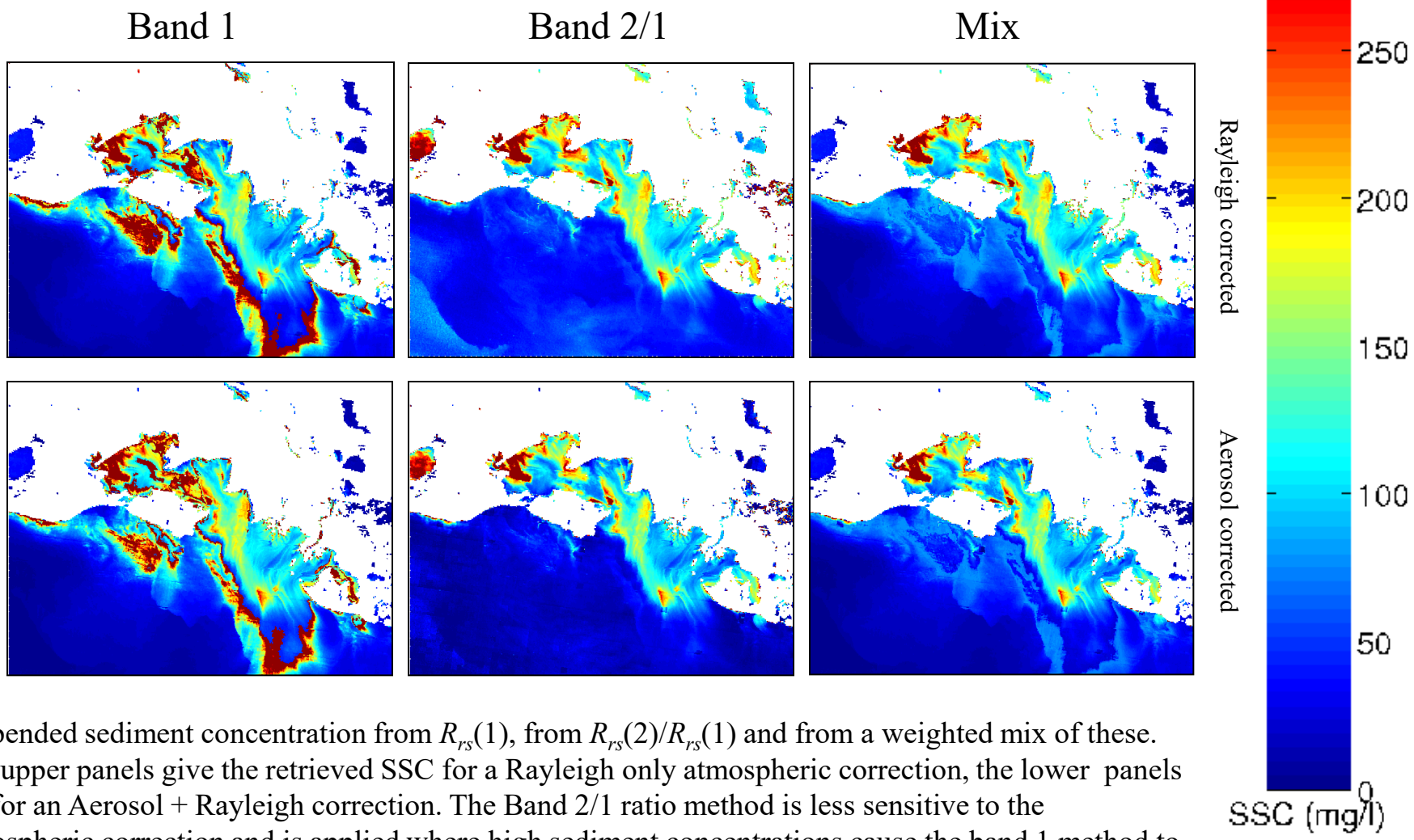


Aqua MODIS Chlorophyll Concentration, April 2004



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

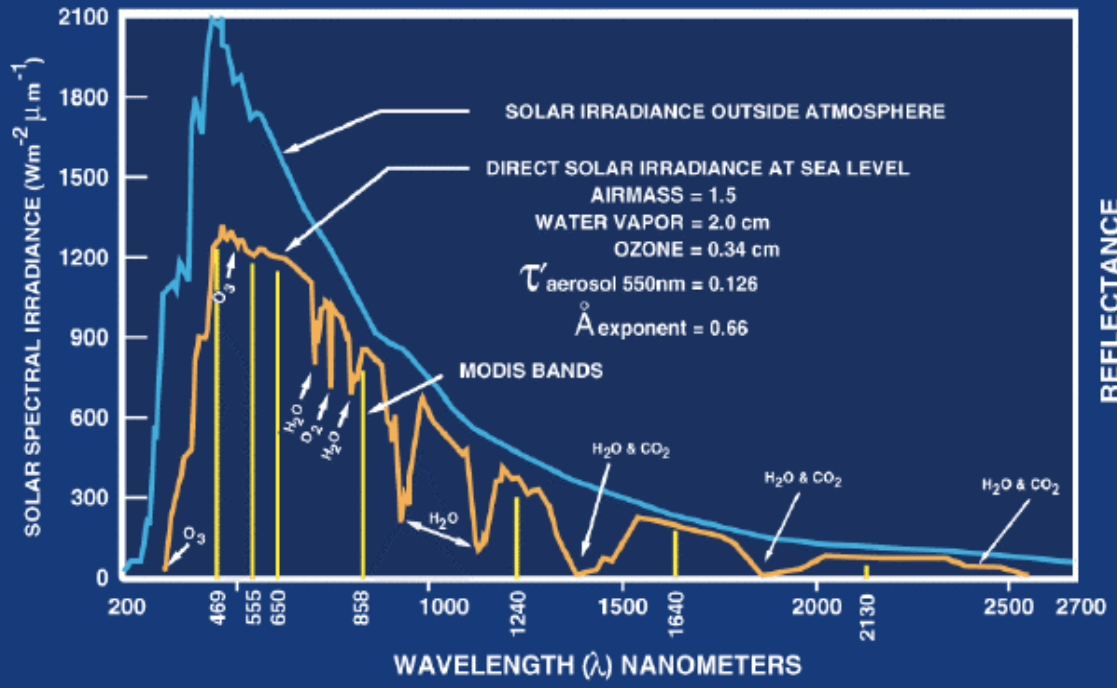
Suspended Sediment Concentration

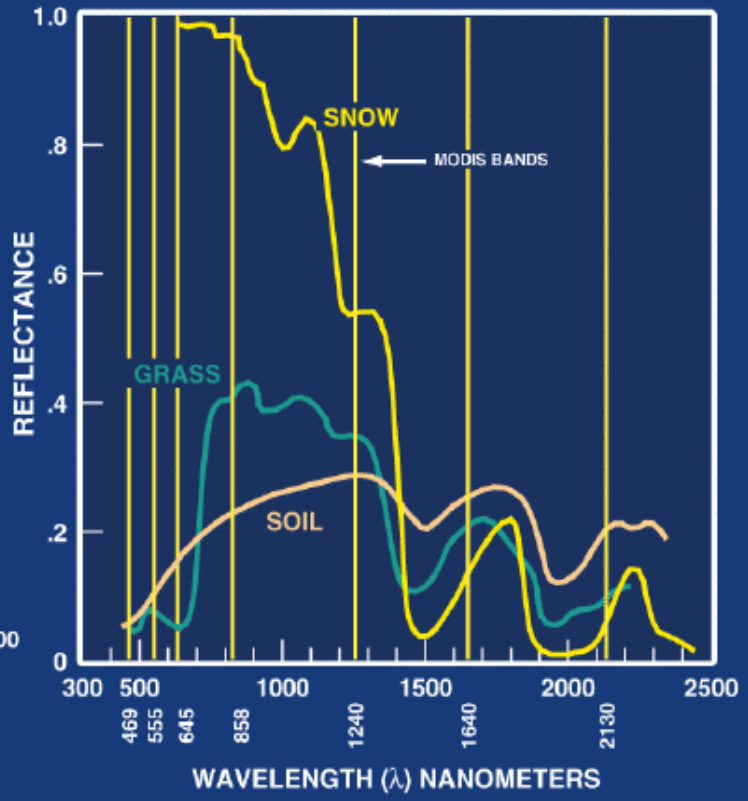


Suspended sediment concentration from $R_{rs}(1)$, from $R_{rs}(2)/R_{rs}(1)$ and from a weighted mix of these. The upper panels give the retrieved SSC for a Rayleigh only atmospheric correction, the lower panels are for an Aerosol + Rayleigh correction. The Band 2/1 ratio method is less sensitive to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

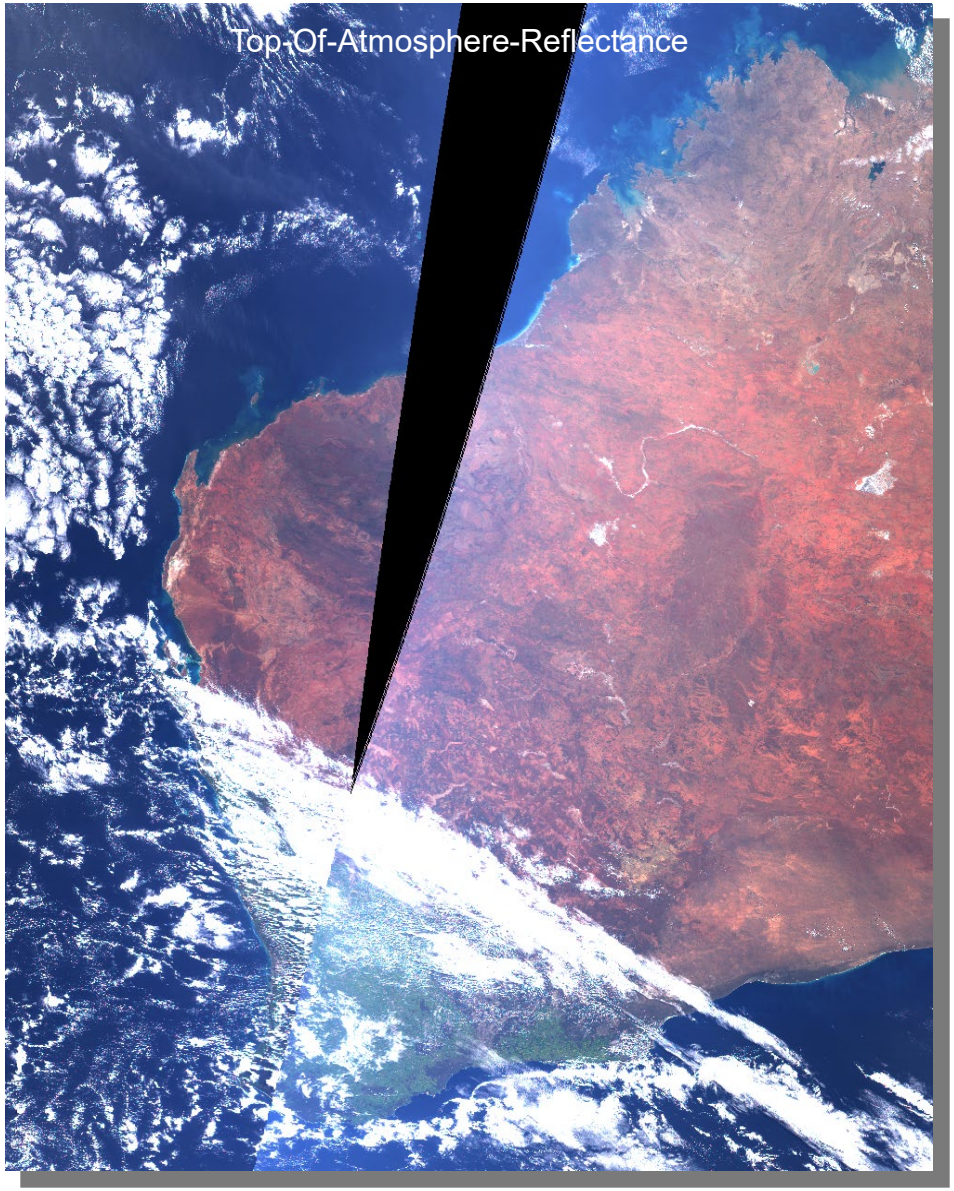
MODIS Land/Surface Applications

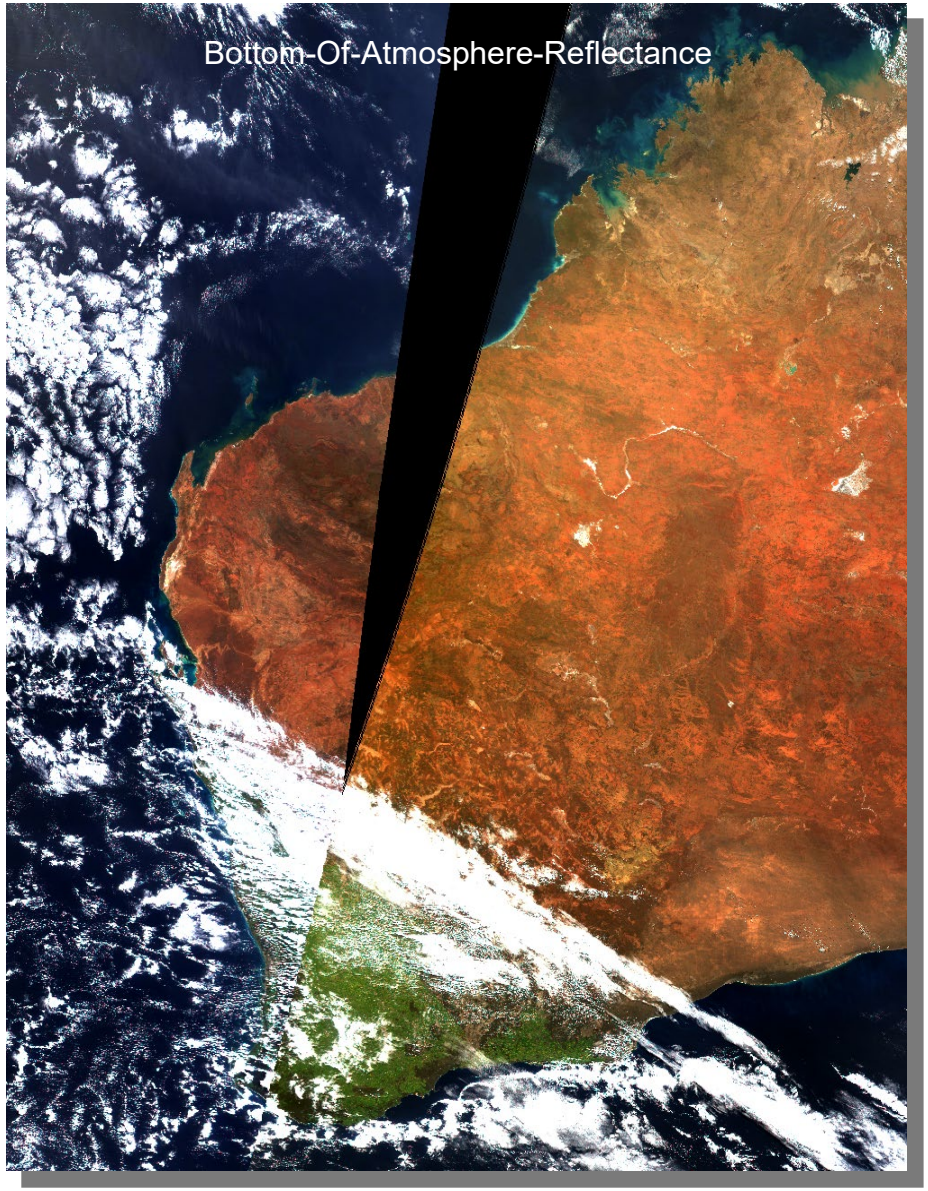
LAND-SOLAR RADIATION





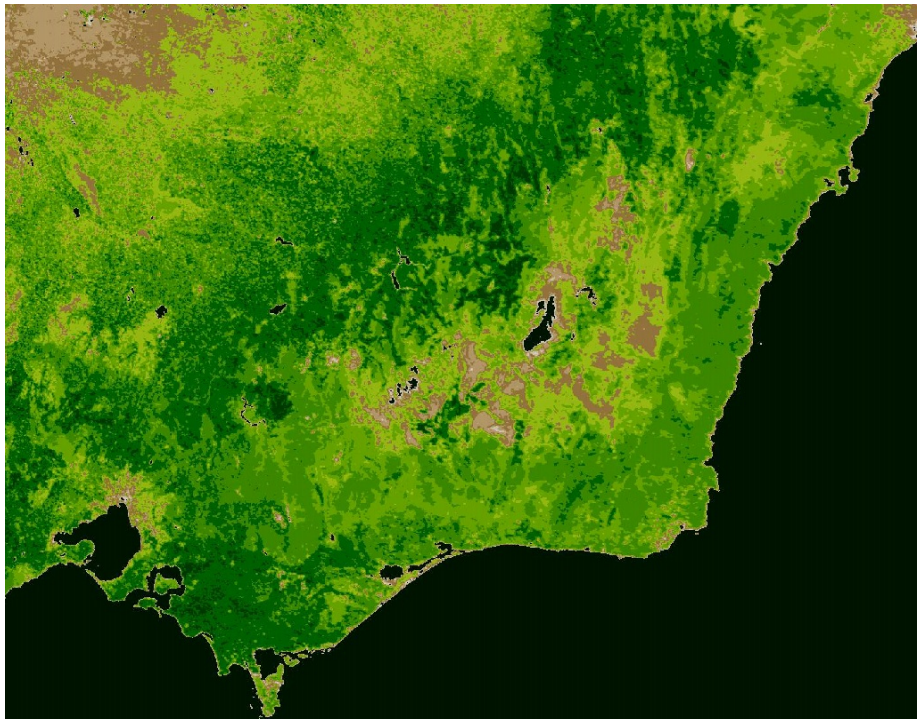
Atmospheric contribution is removed to retrieve surface properties



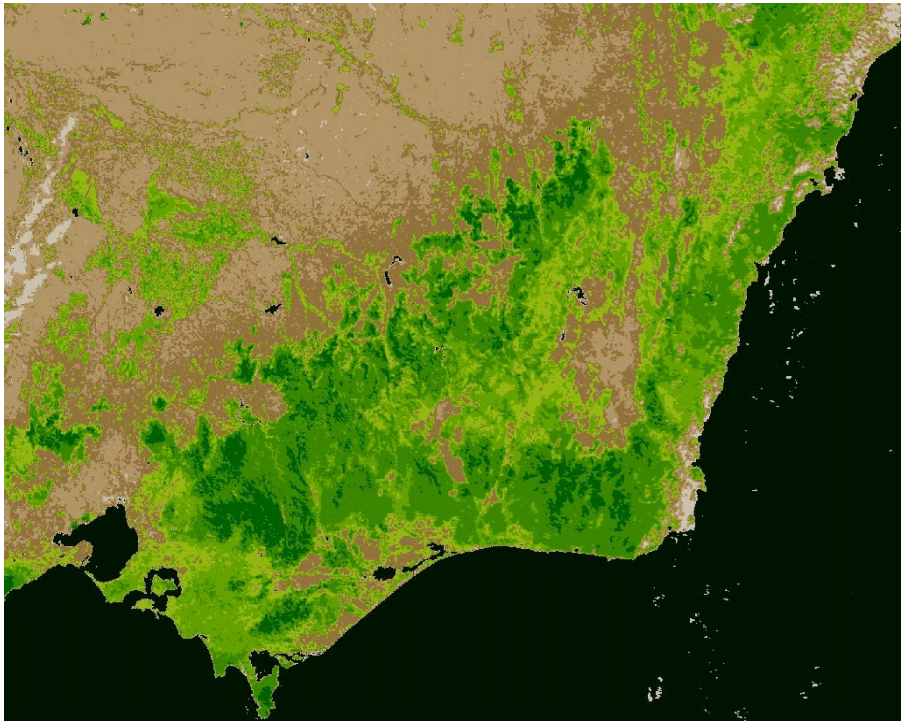


Terra MODIS 09/09/2003 01:27UTC 03:04UTC

NDVI South East Australia



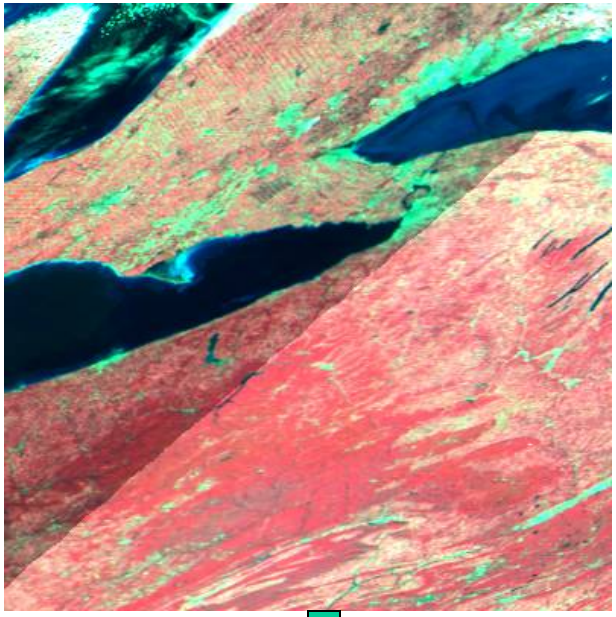
Nov 2003

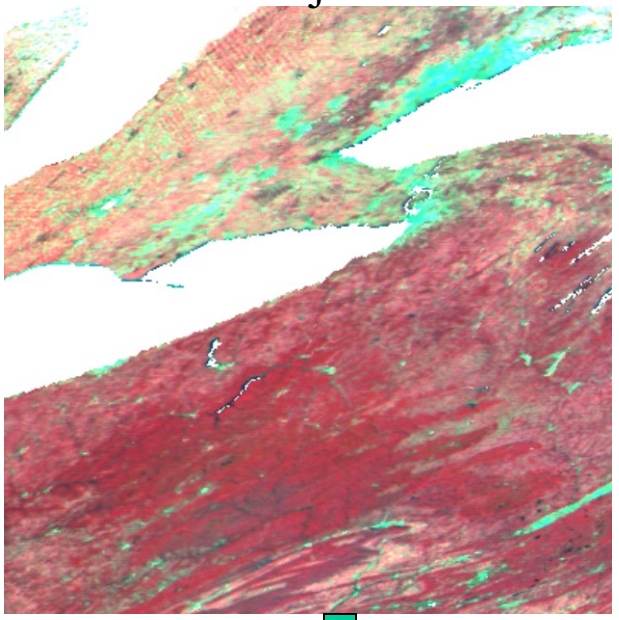


Apr 2004

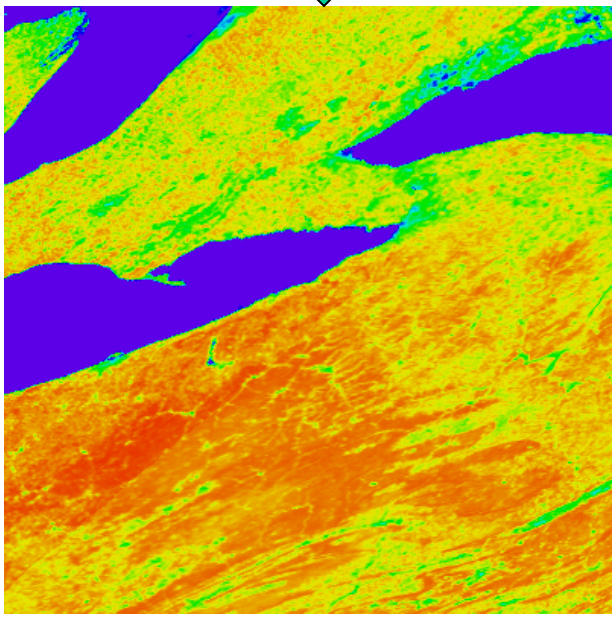
Surface Reflectance

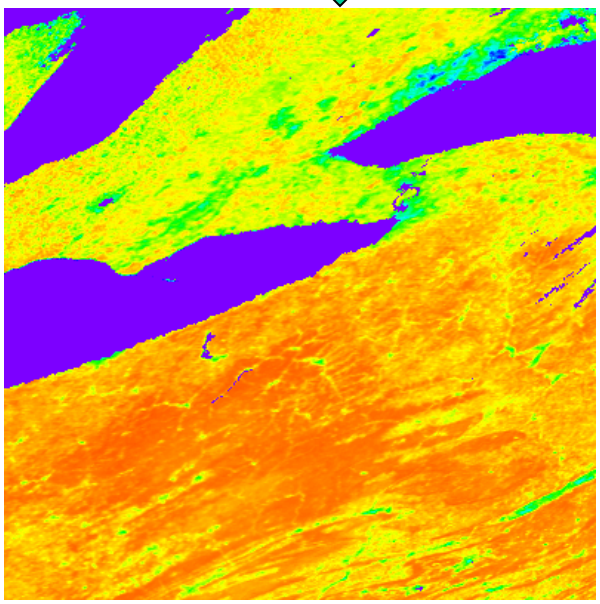
Nadir BRDF-Adjusted Reflectance





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





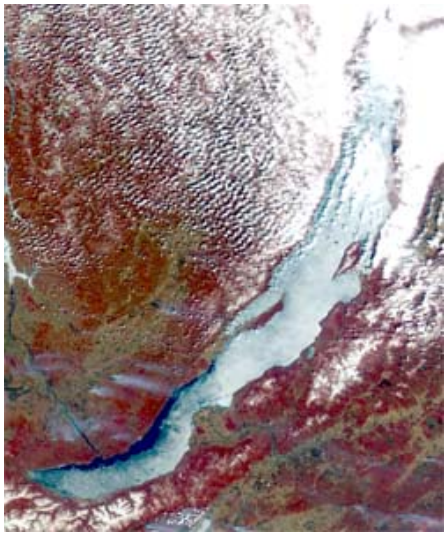
NDVI

0.0 1.0

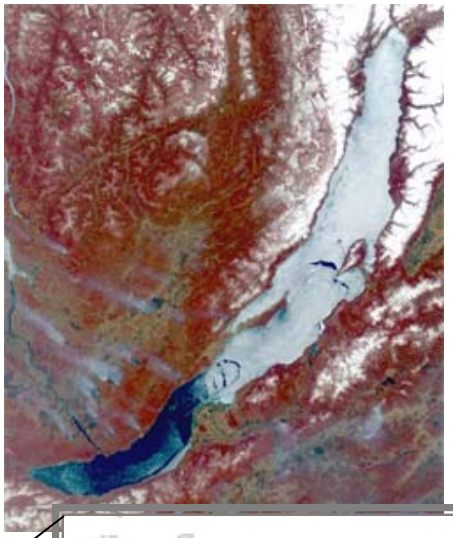
Baikal lake ice monitoring.

BRICC, Baikal Regional Information and Computer center. (Irkutsk)

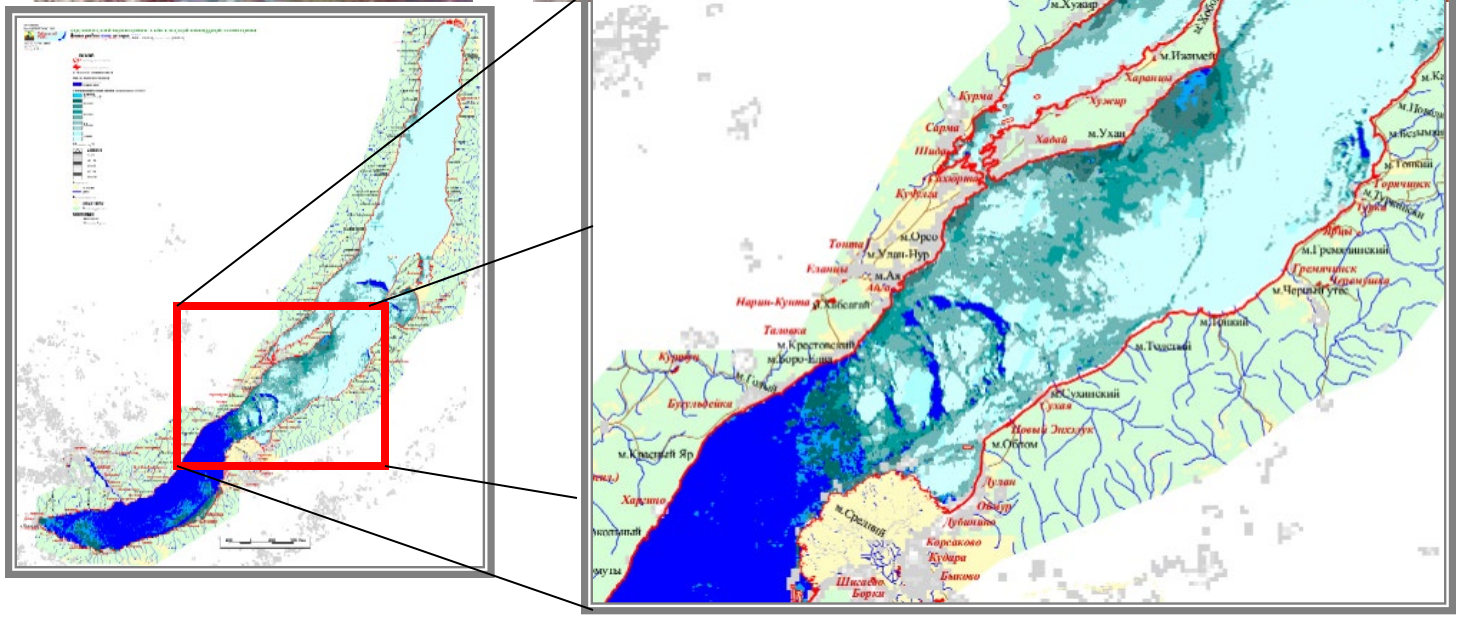
2003-05-02



2003-05-06

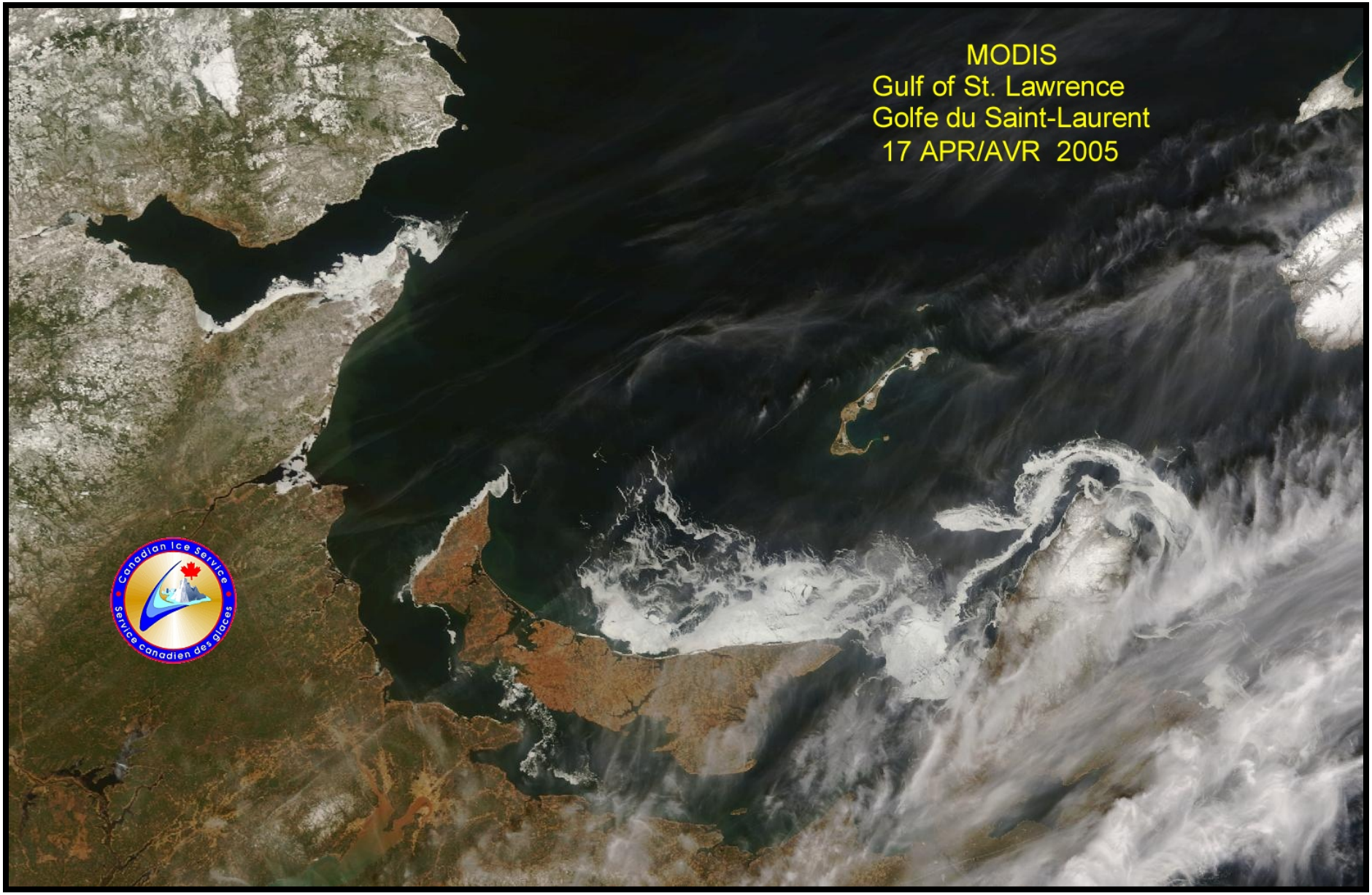


2003-05-19

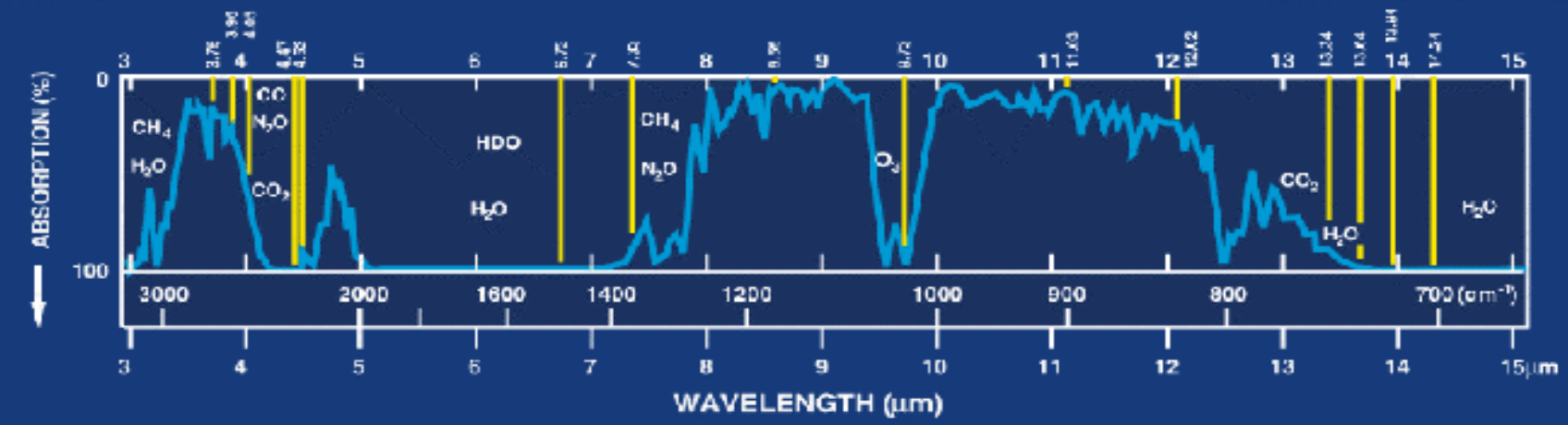


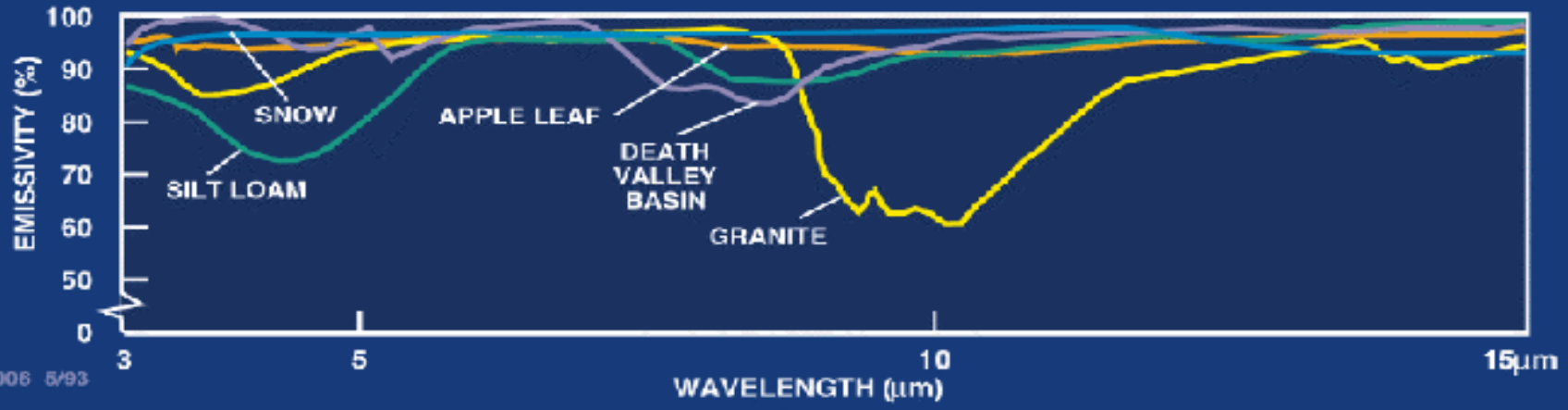
Canadian Ice Service Example

http://ice-glaces.ec.gc.ca/



LAND - THERMAL RADIATION

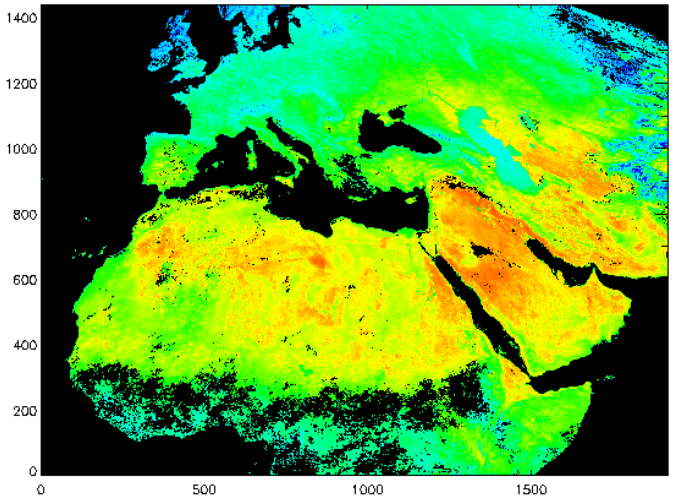


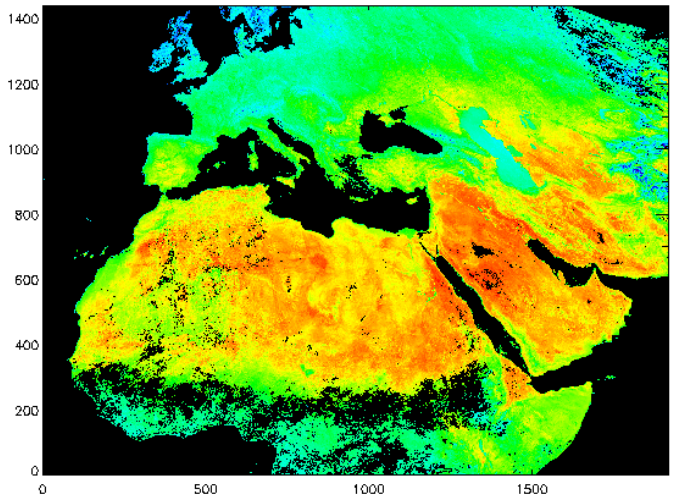


C351.006 5/93

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

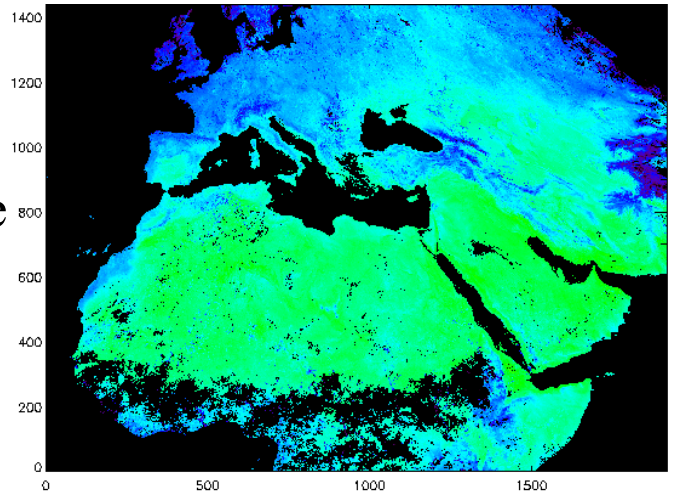
daytime Terra

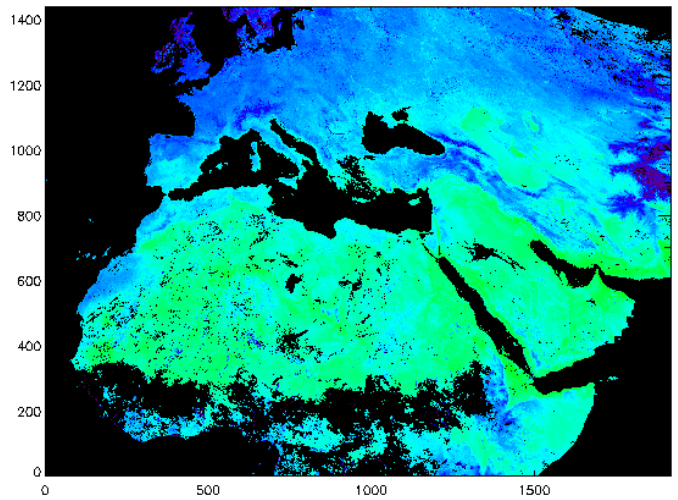




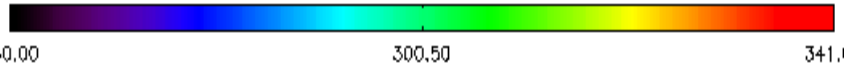
daytime Aqua

nighttime Terra

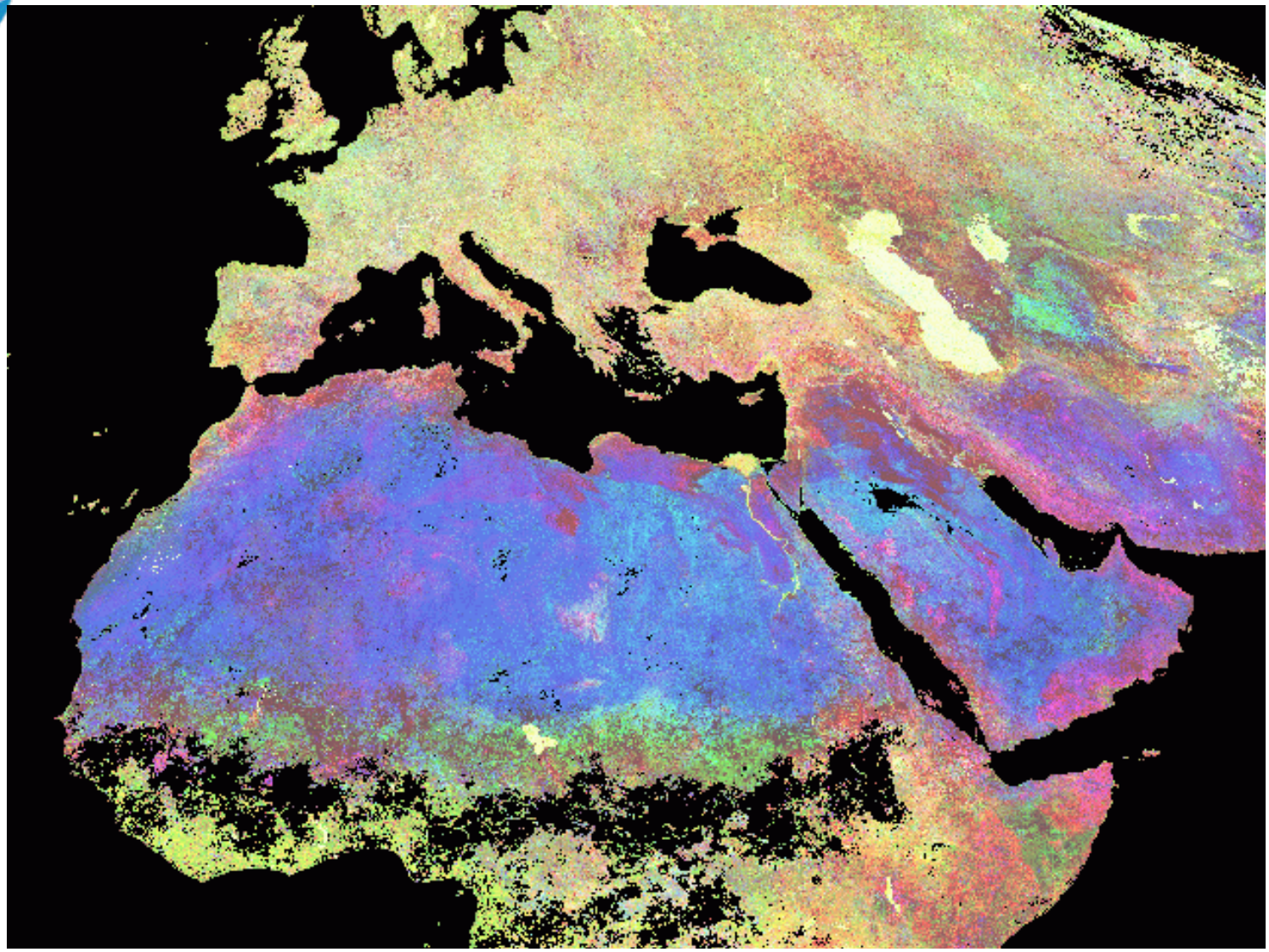




nighttime Aqua

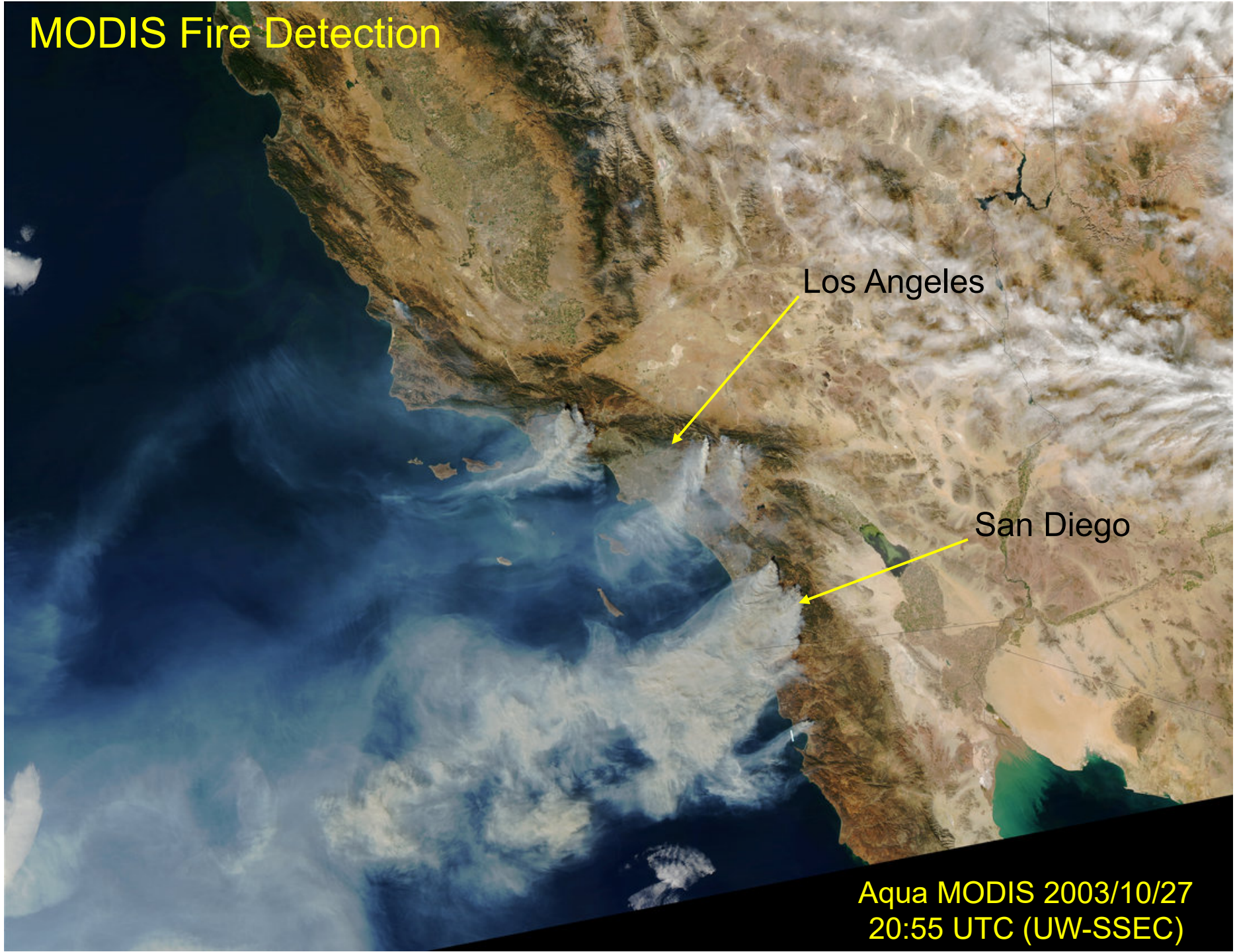


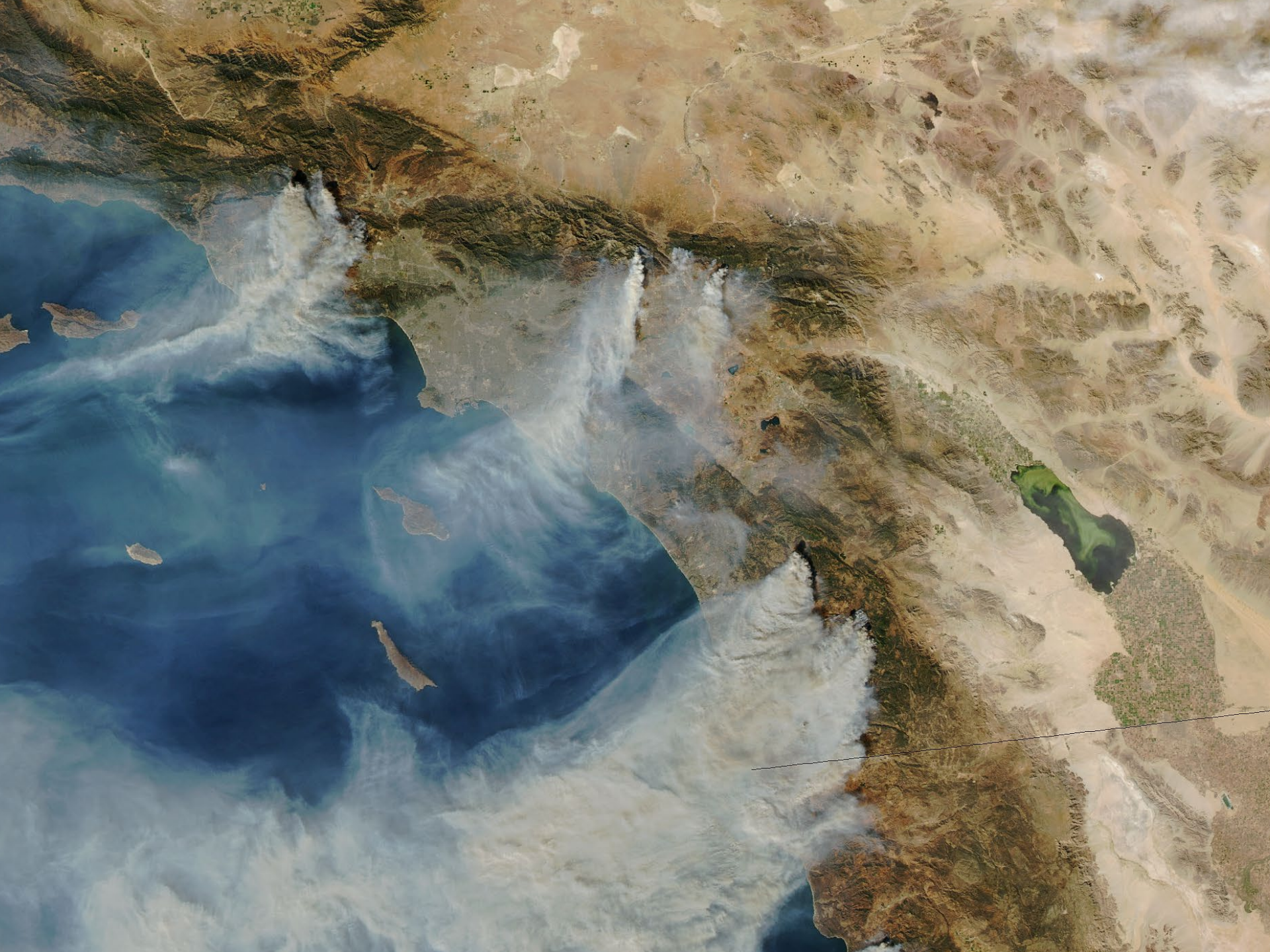
Surface emissivities retrieved by Terra and Aqua MODIS



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


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



Rapid fire detection program

Web fire products Mexico and CA

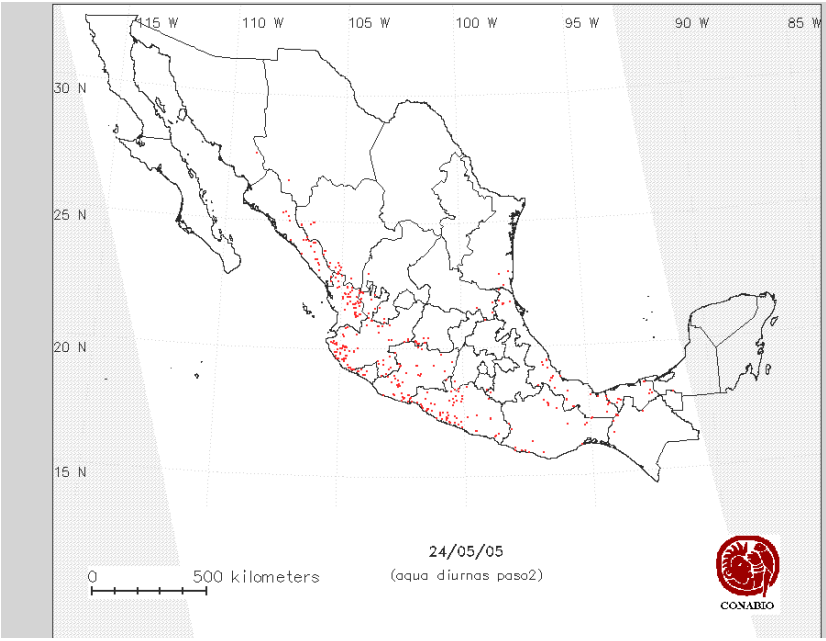
- Response time next fire season < 40 min
- Detailed maps of forest fire sites
- Low to high tech information provision

  e-mail > ArcSDE server > pdf reports > ArcIMS map

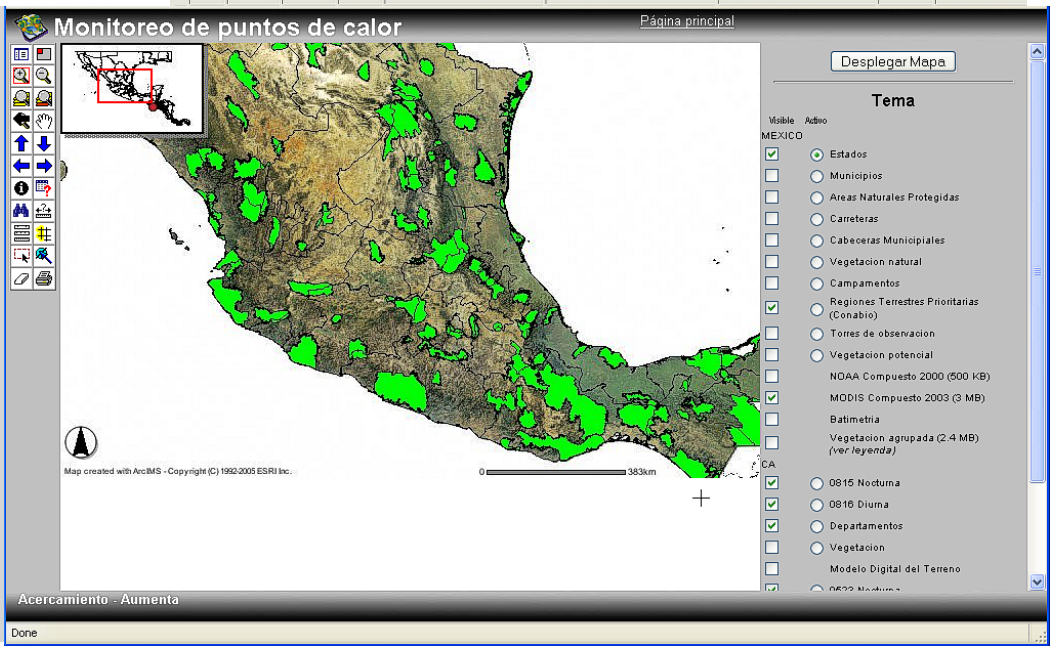
Report tables

Indice	Total de pixeles	Longitud	Latitud	Tipo de Vegetación	Municipio/Estado	Areas naturalesprotegidas	Pendiente	Indice depropagación
1	1	-90 45 40	19 10 6	Pastizal cultivado	Champoton,Campeche	NO AFECTA	0 °	NA
2	1	-92 8 21	18 13 16	Popal	Palizada,Campeche	LAGUNA DE TERMINOS	0 °	NA
3	1	-91 21 12	18 4 36	Pastizal cultivado	Carmen,Campeche	NO AFECTA	0 °	NA
4	1	-104 12 14	19 16 50	Pastizal cultivado	Manzanillo,Colima	NO AFECTA	0 °	NA
5	1	-104 24 12	19 13 56	Pastizal inducido	Manzanillo,Colima	NO AFECTA	0 °	NA
6		-104 20 11	19 12 54	Selva baja caducifolia con vegetacion secundaria arbustiva	Manzanillo,Colima	NO AFECTA	1 °	Alto
6	2	-104 19 37	19 12 55	Selva baja caducifolia con vegetacion secundaria arbustiva	Manzanillo,Colima	NO AFECTA	2 °	Muy alto

Quicklook images



Hot spot images

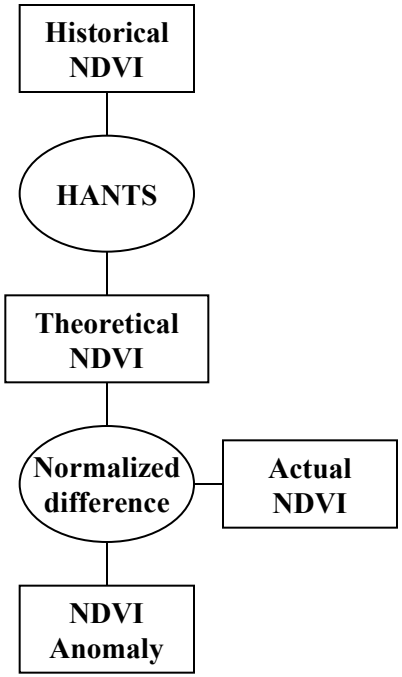


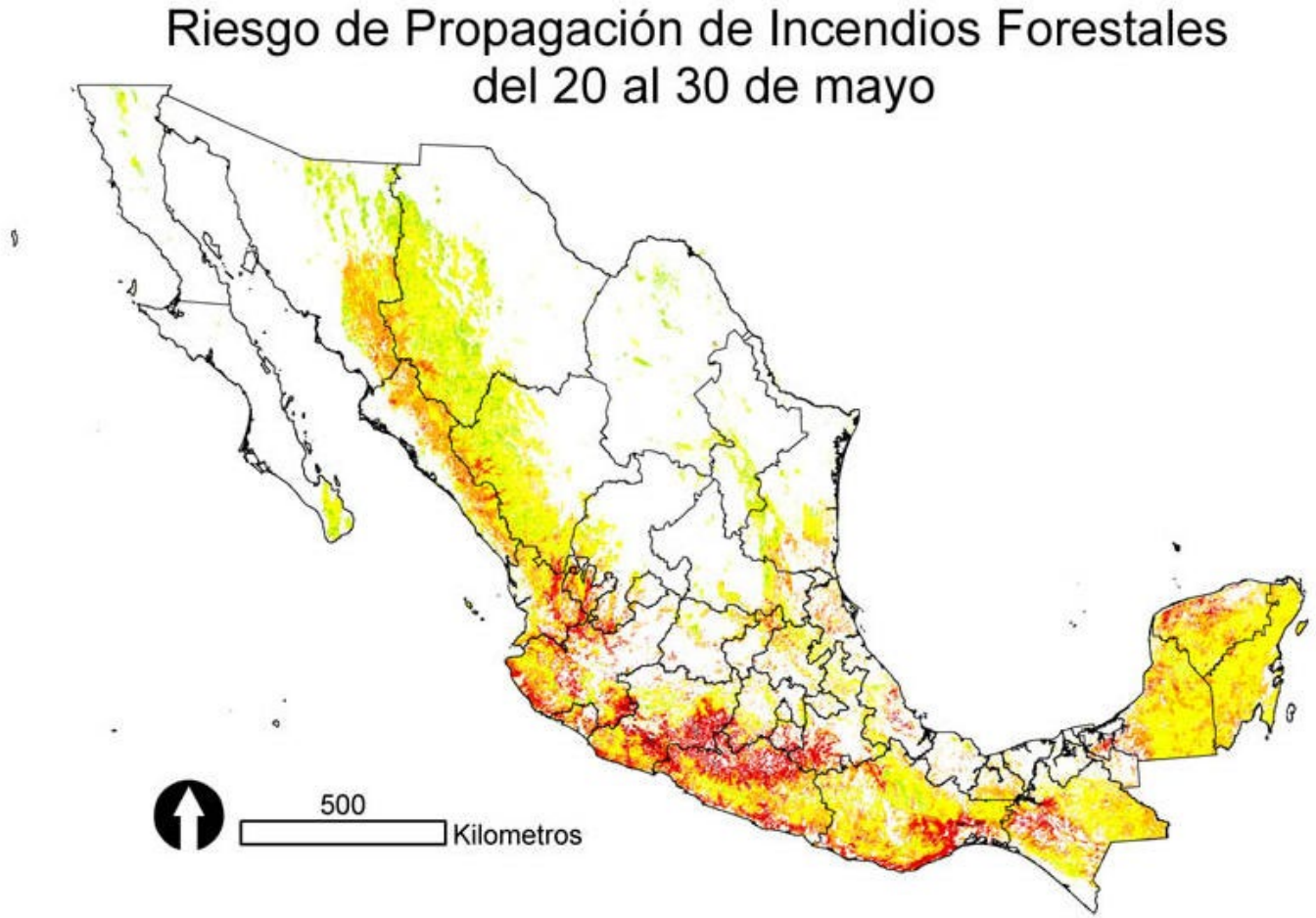
EVI im

CONABIO

Fire propagation risk

- Historical NDVI series, 36 months

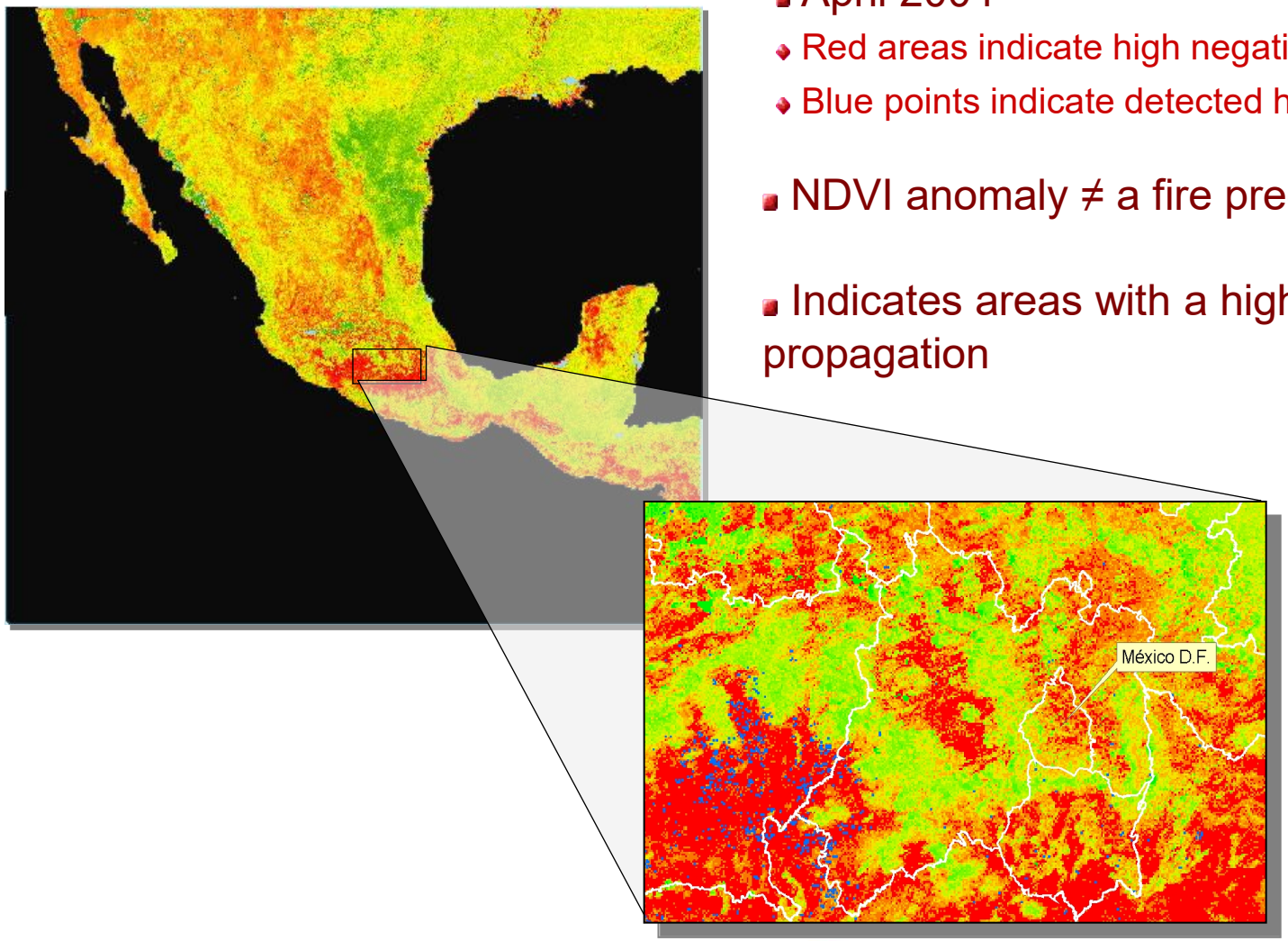




- Vegetation Cycles
  - Perennial
  - Deciduous
  - Agricultural areas

CONABIO

Fire propagation risk

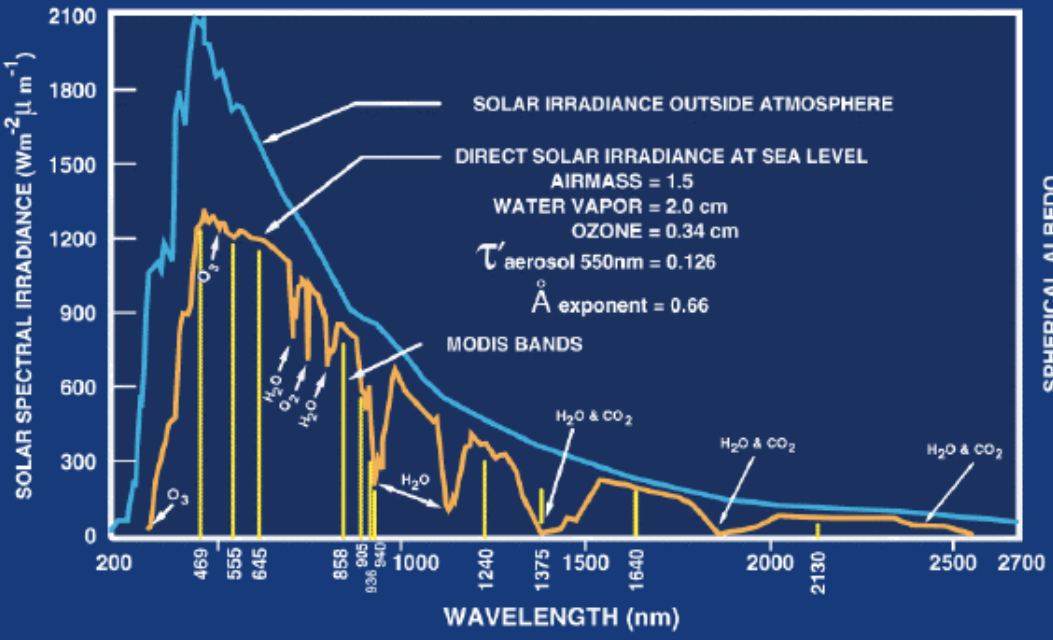


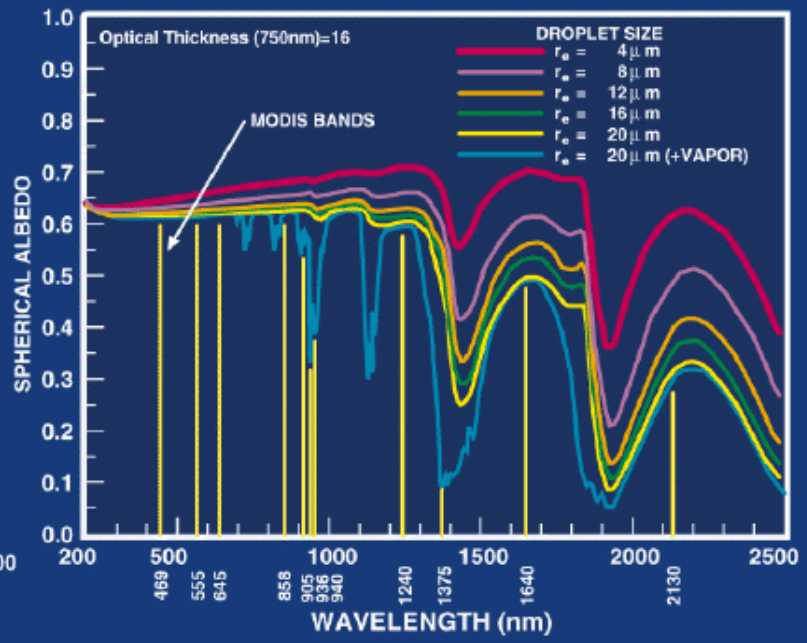
- April 2004
  - Red areas indicate high negative NDVI anomaly
  - Blue points indicate detected hot spots
- NDVI anomaly ≠ a fire prediction tool
- Indicates areas with a higher risk of propagation

CONABIO

MODIS Atmosphere Applications

ATMOSPHERE-SOLAR RADIATION

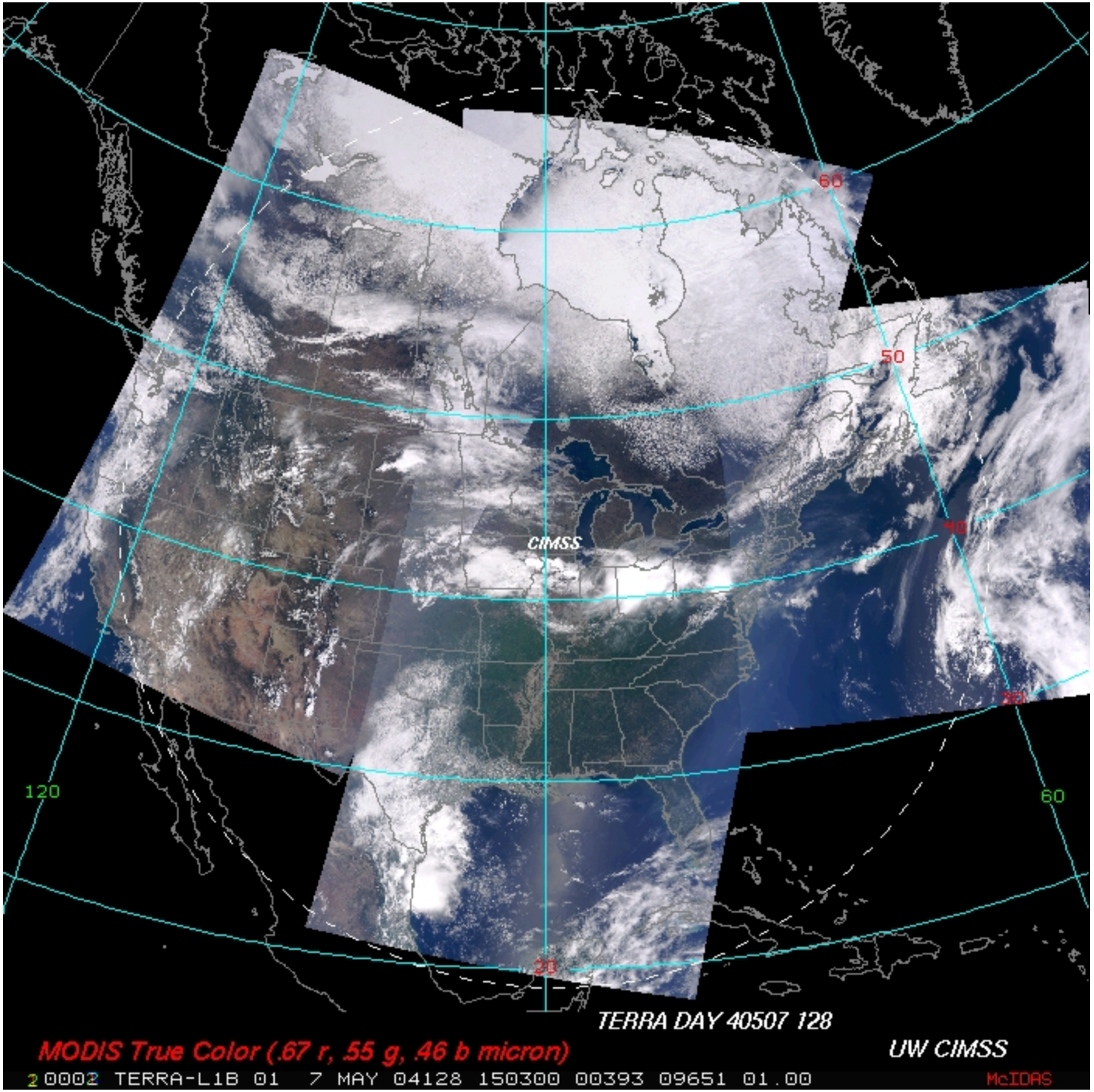




MODIS Cloud Mask

- **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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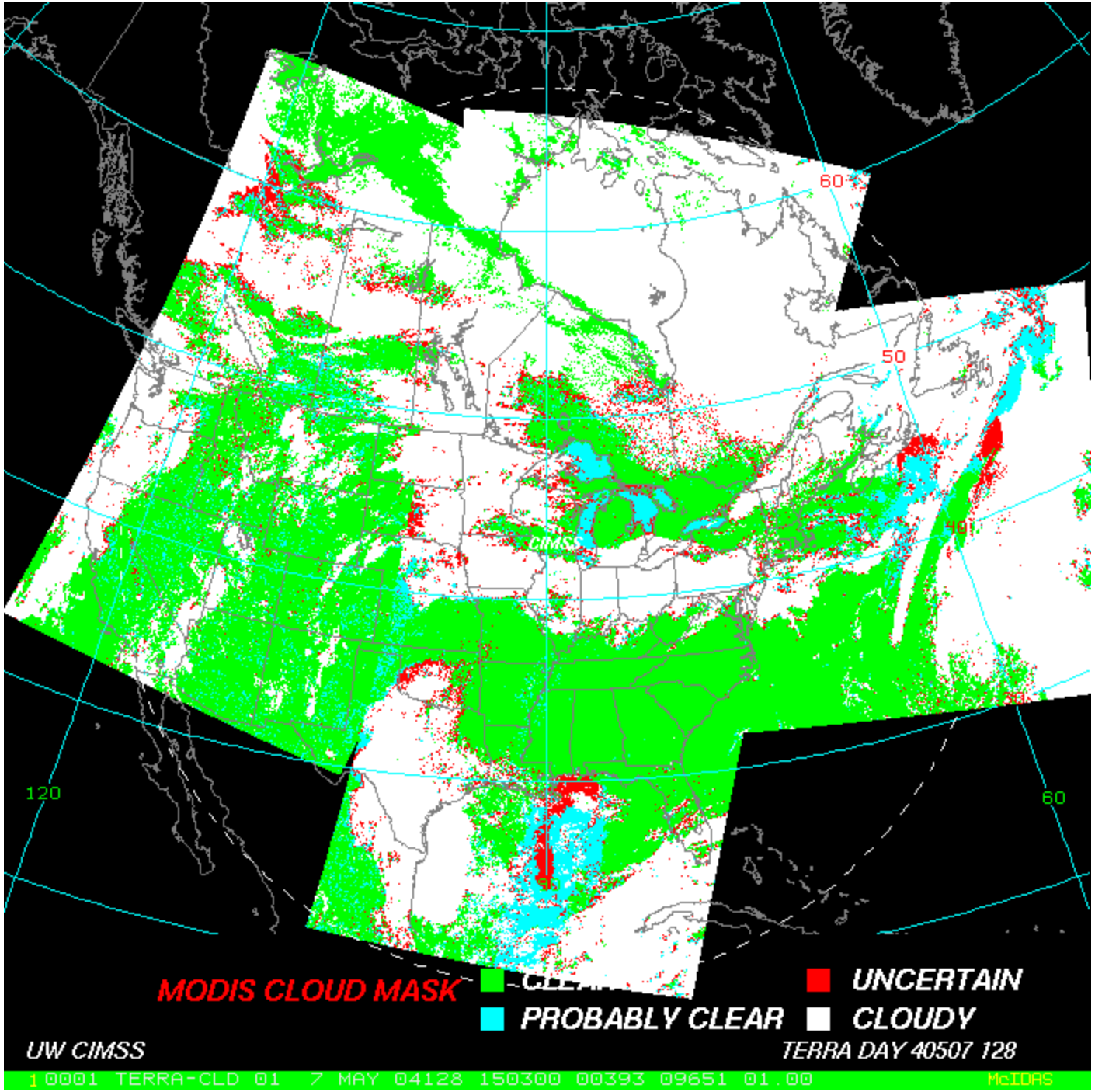
CIMSS
TERRA DAY 40507 128
MODIS True Color (.67 r, .55 g, .46 b micron)
UW CIMSS
2 0002 TERRA-L1B 01 7 MAY 04128 150300 00393 09651 01.00
McIDAS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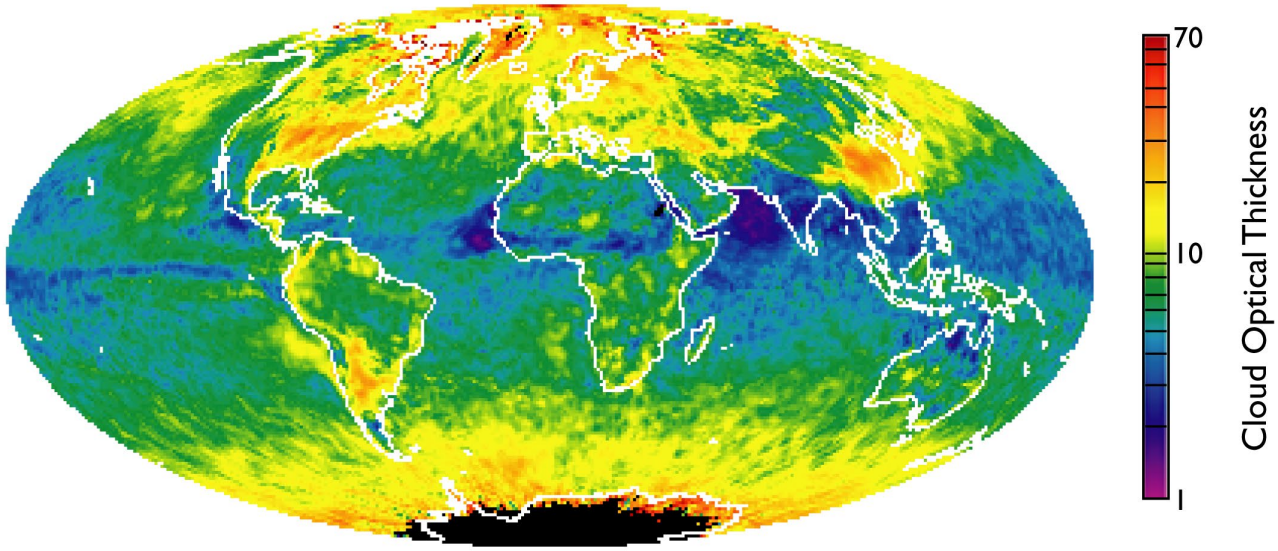
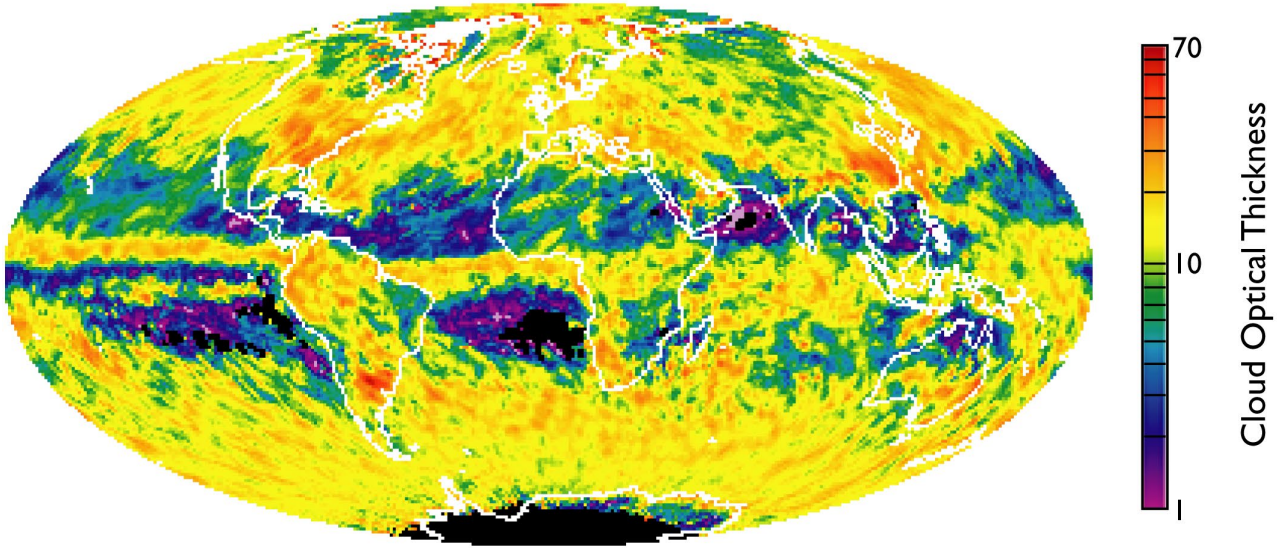
MODIS CLOUD MASK
UNCERTAIN
PROBABLY CLEAR
CLOUDY
UW CIMSS
TERRA DAY 40507 128
1 0001 TERRA-CLD 01 7 MAY 04128 150300 00393 09651 01 00
McIDAS

Monthly Mean Cloud Optical Thickness

Cloud Optical Thickness (Water)

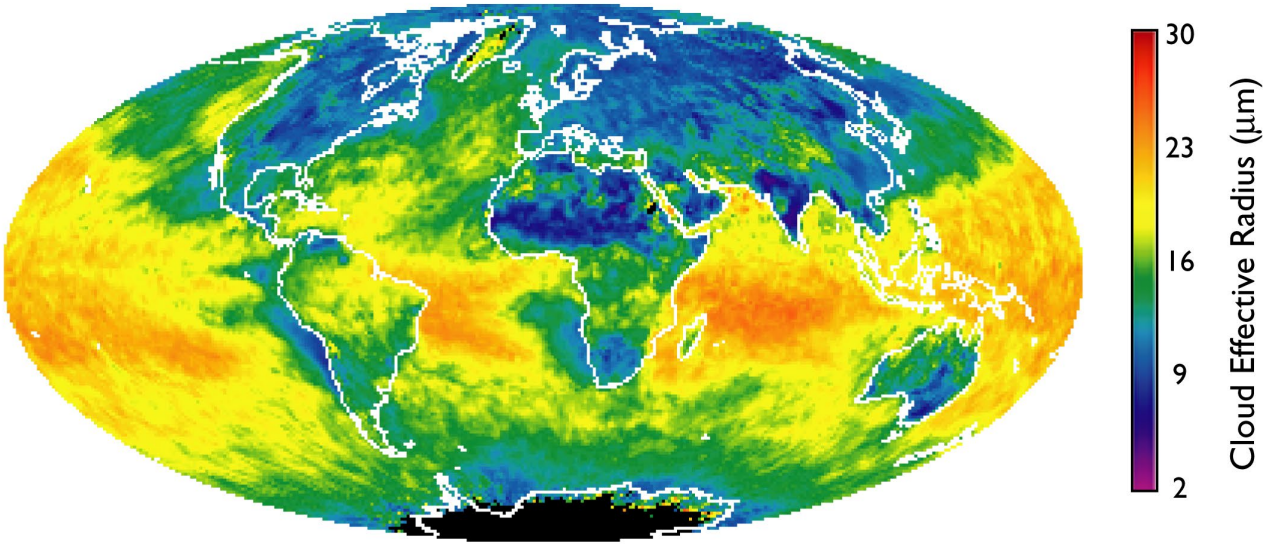


Cloud Optical Thickness (Ice)

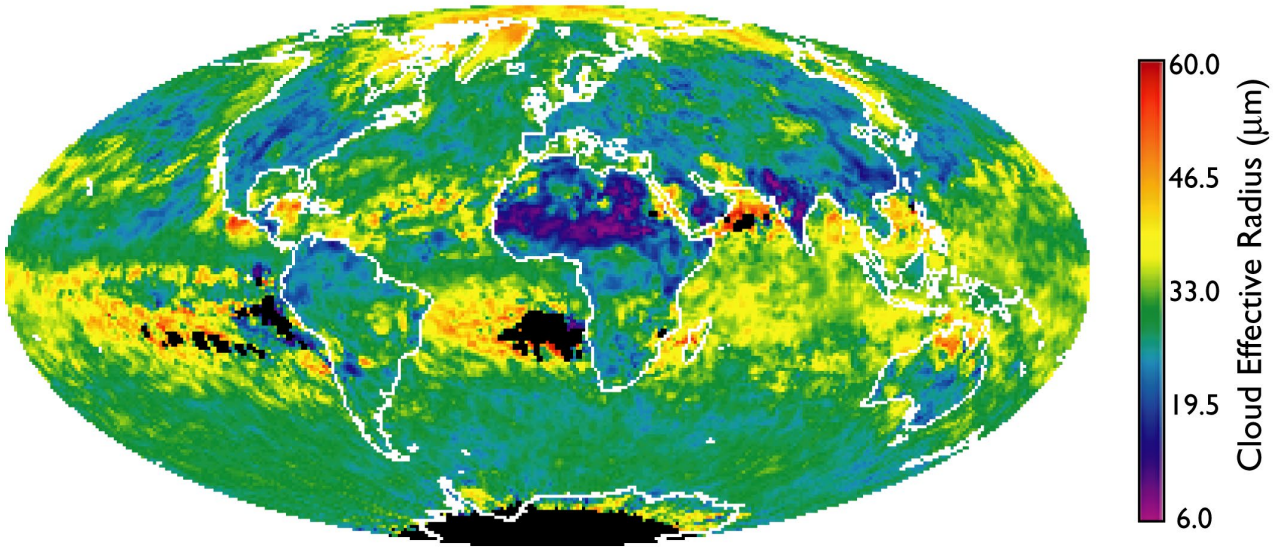


Monthly Mean Cloud Effective Radius

Cloud Effective Radius (Water)

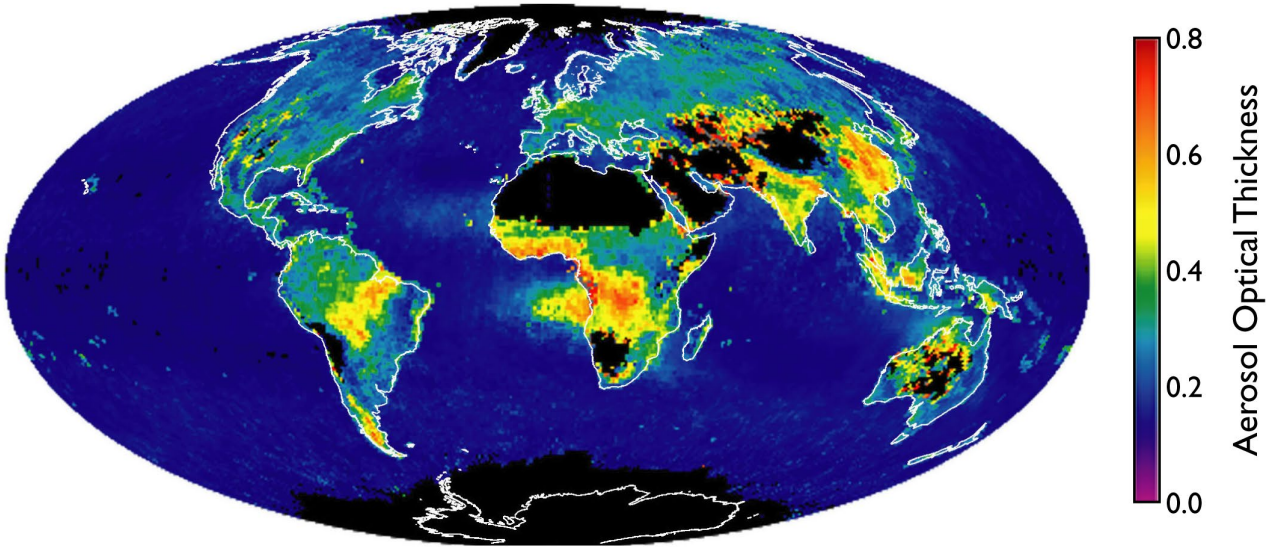


Cloud Effective Radius (Ice)

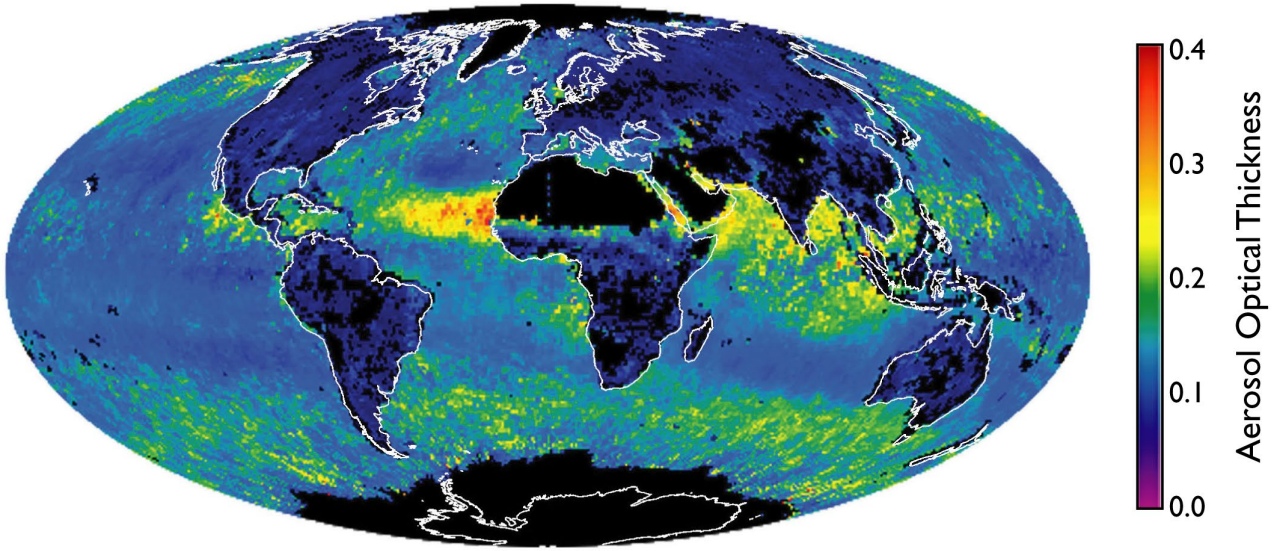


Monthly Mean Aerosol Optical Thickness

Aerosol Optical Thickness (Fine Mode)



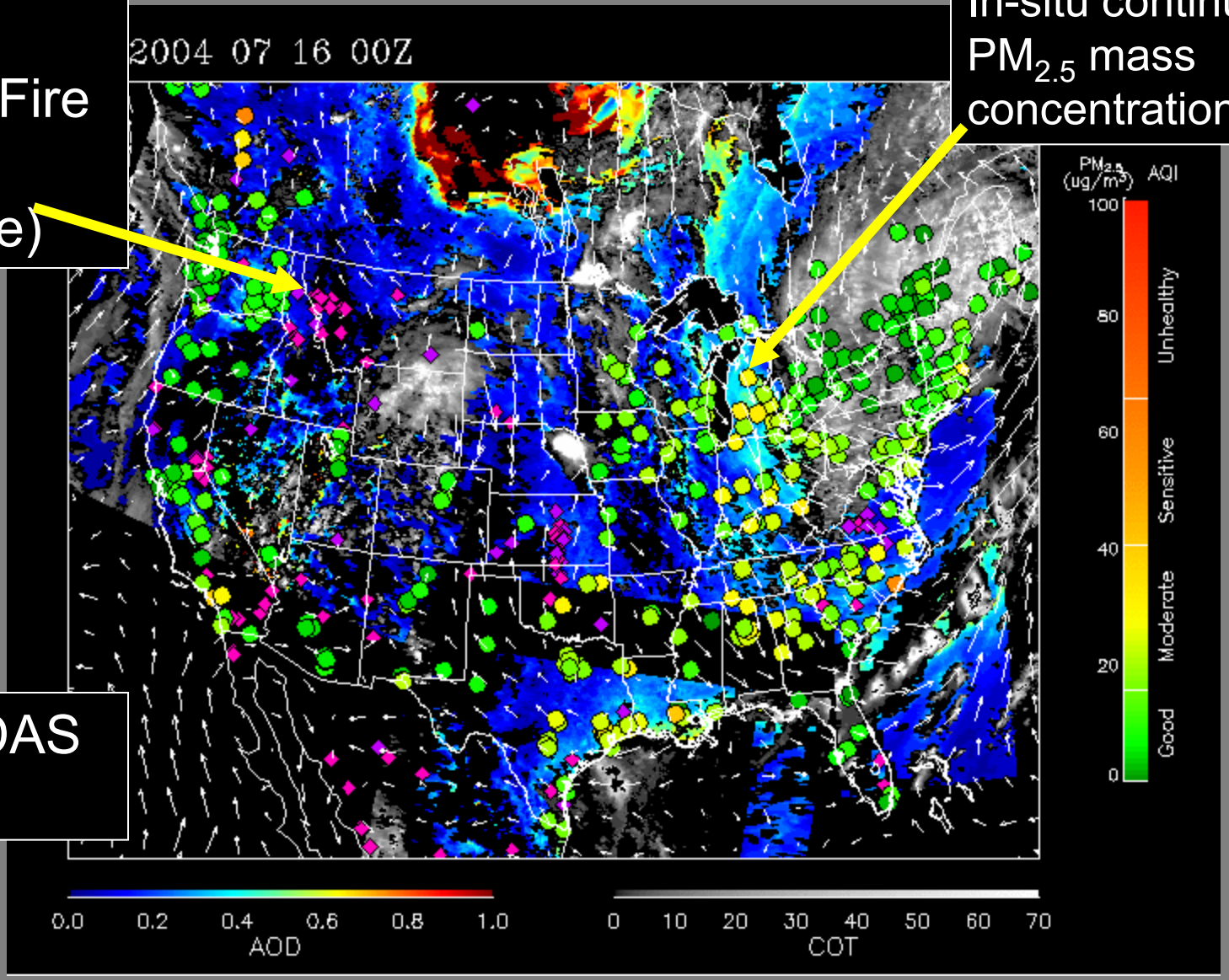
Aerosol Optical Thickness (Coarse Mode)



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

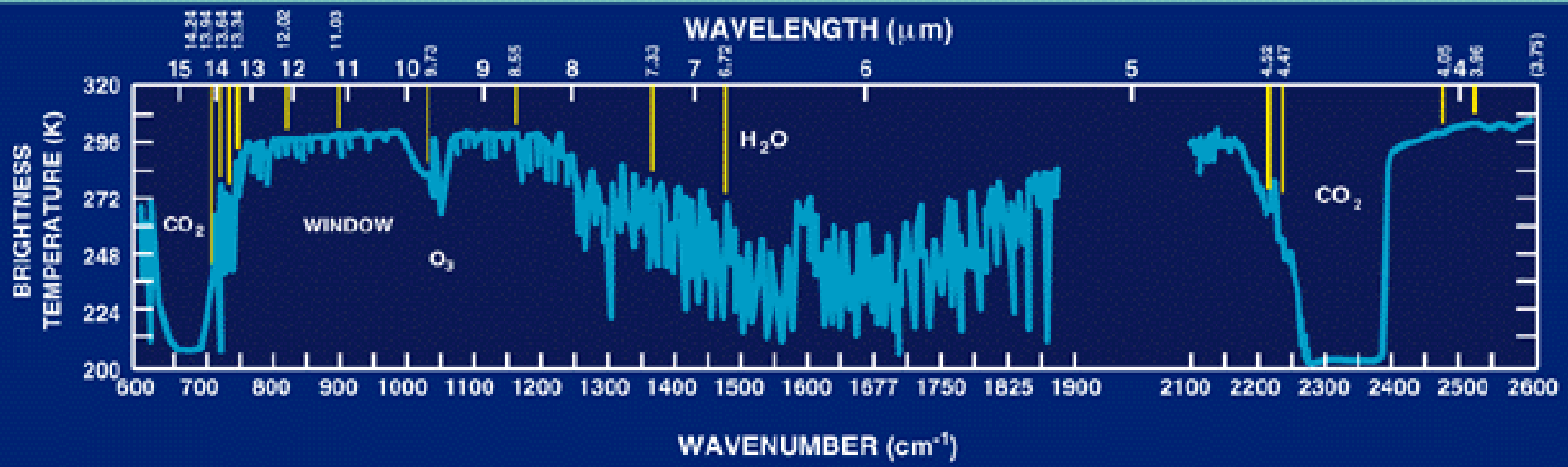
Half-hourly WF-ABBA Fire Locations (pink-purple)

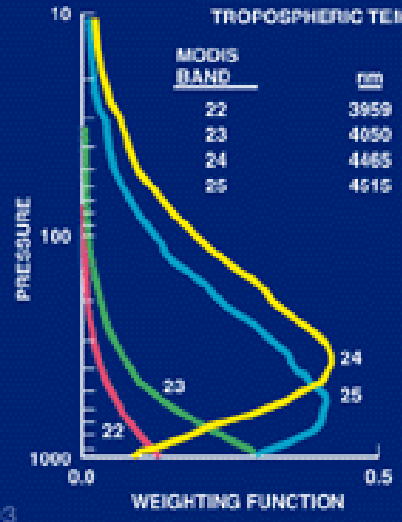
In-situ continuous $PM_{2.5}$ mass concentration data

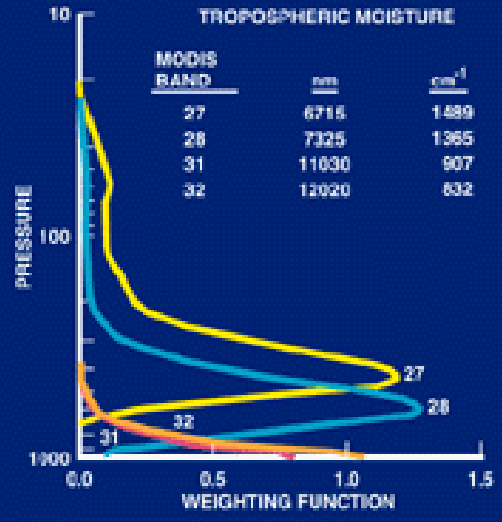


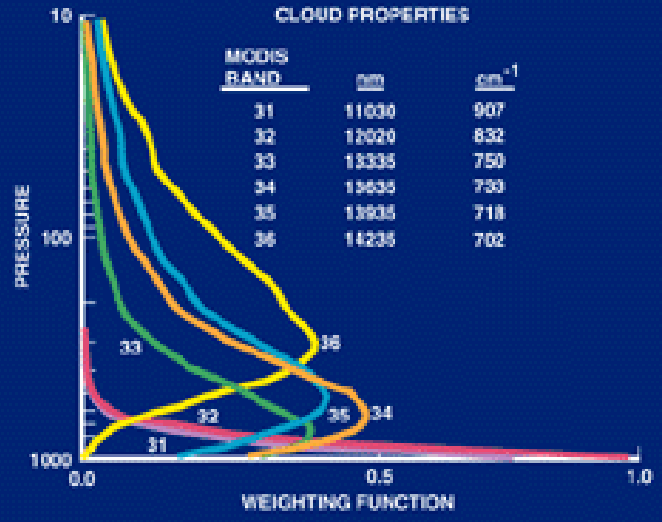
850 mb EDAS wind fields

ATMOSPHERE - THERMAL RADIATION

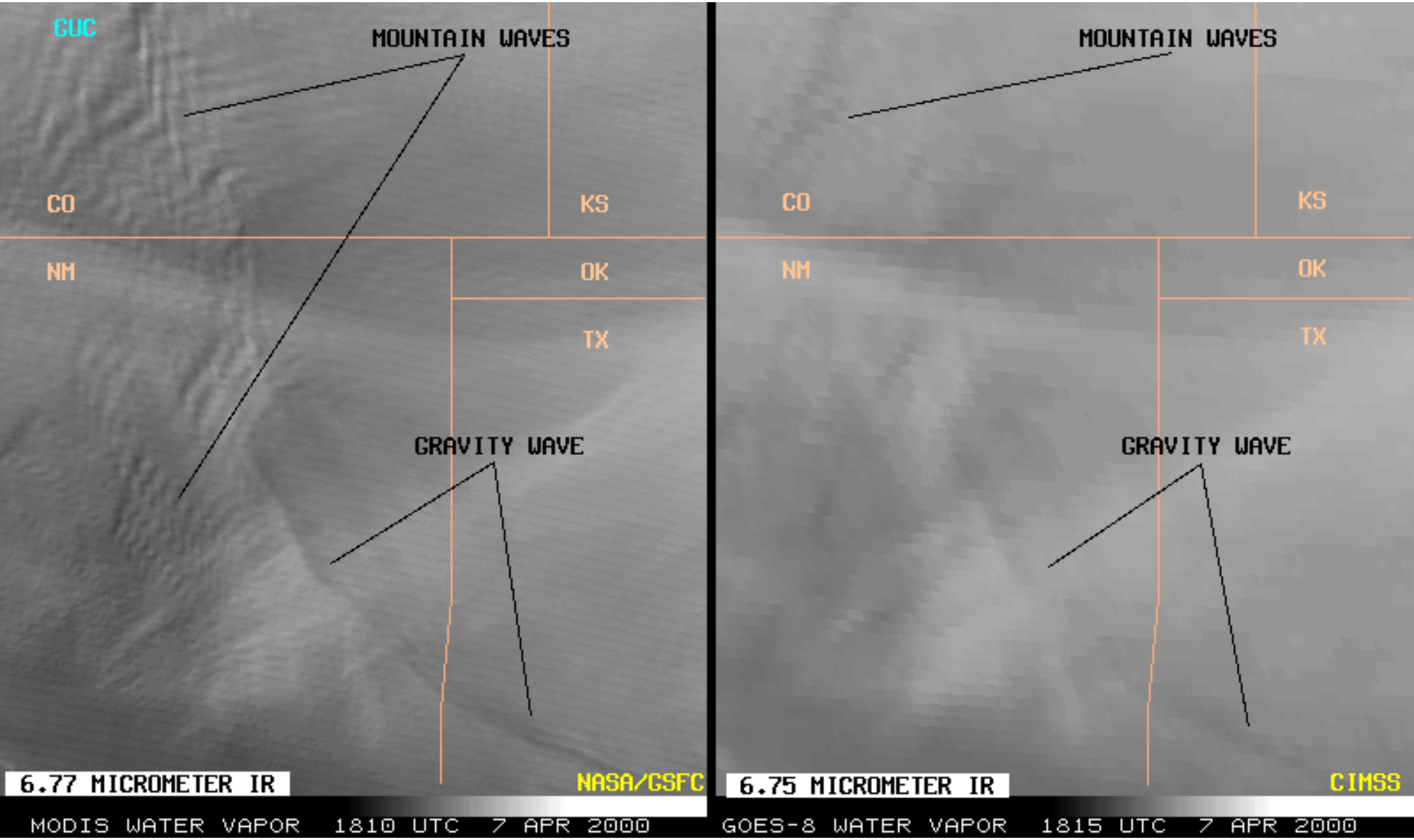




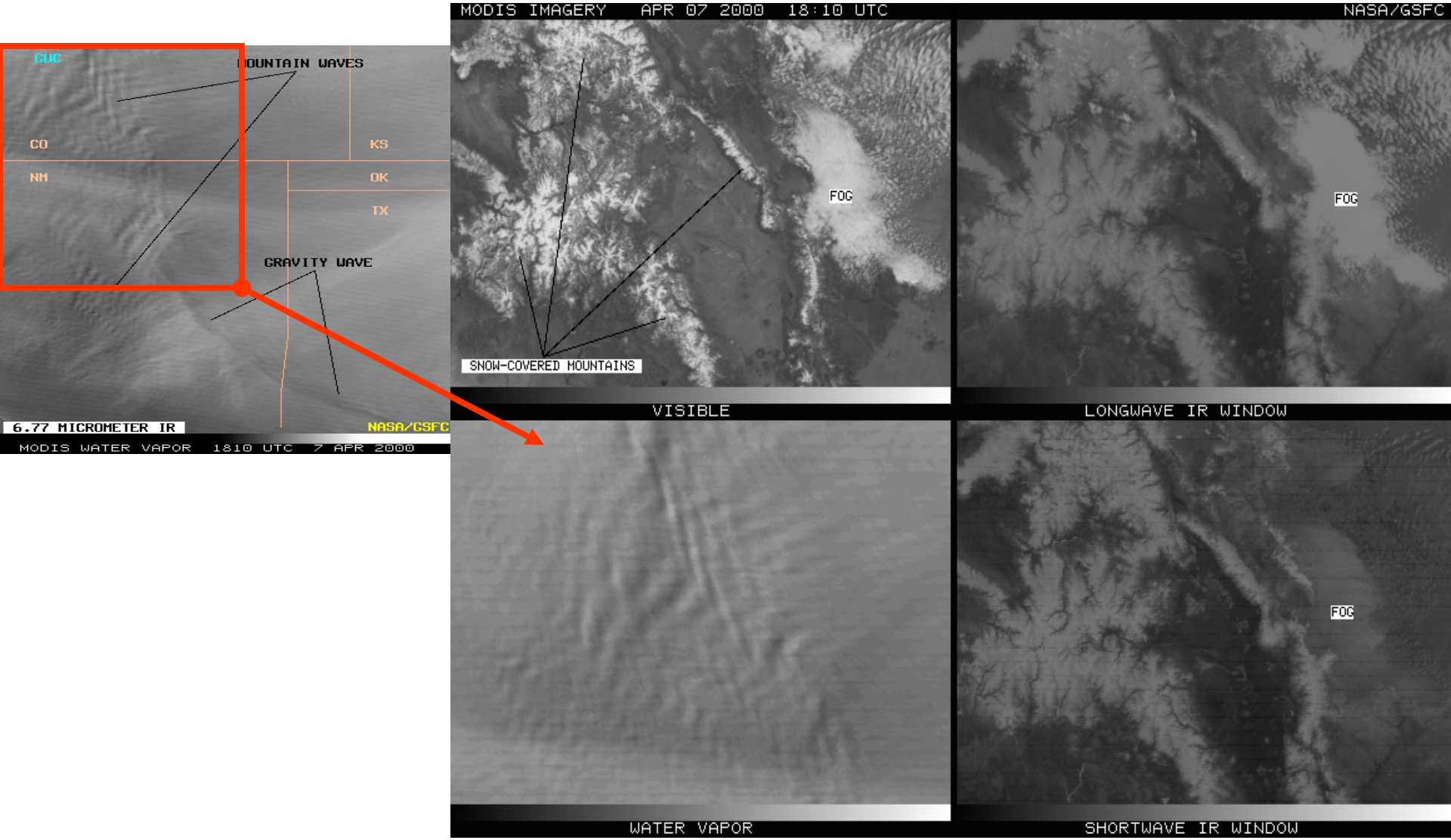




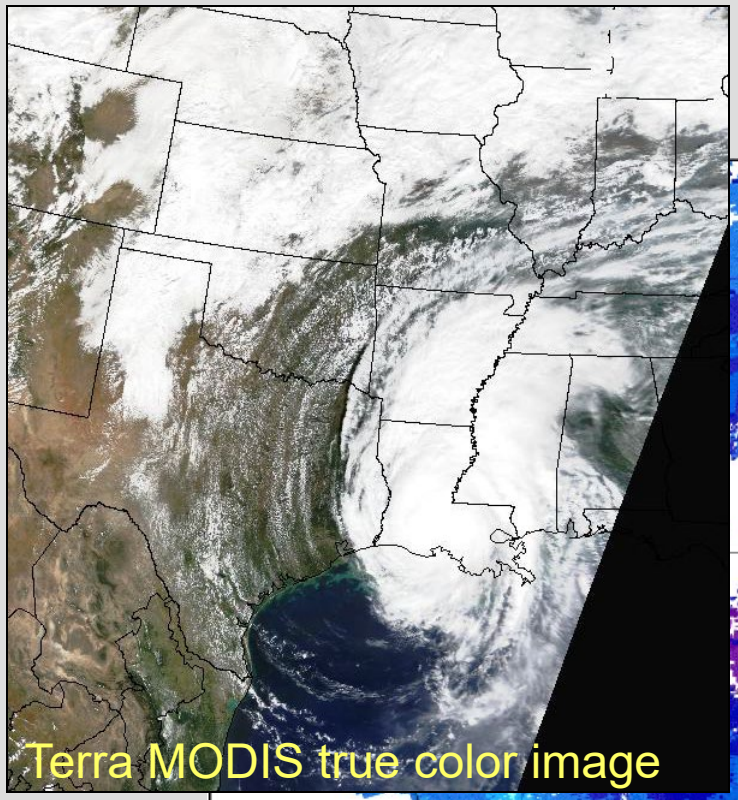
MODIS 1 km resolution reveals fine-scale structure

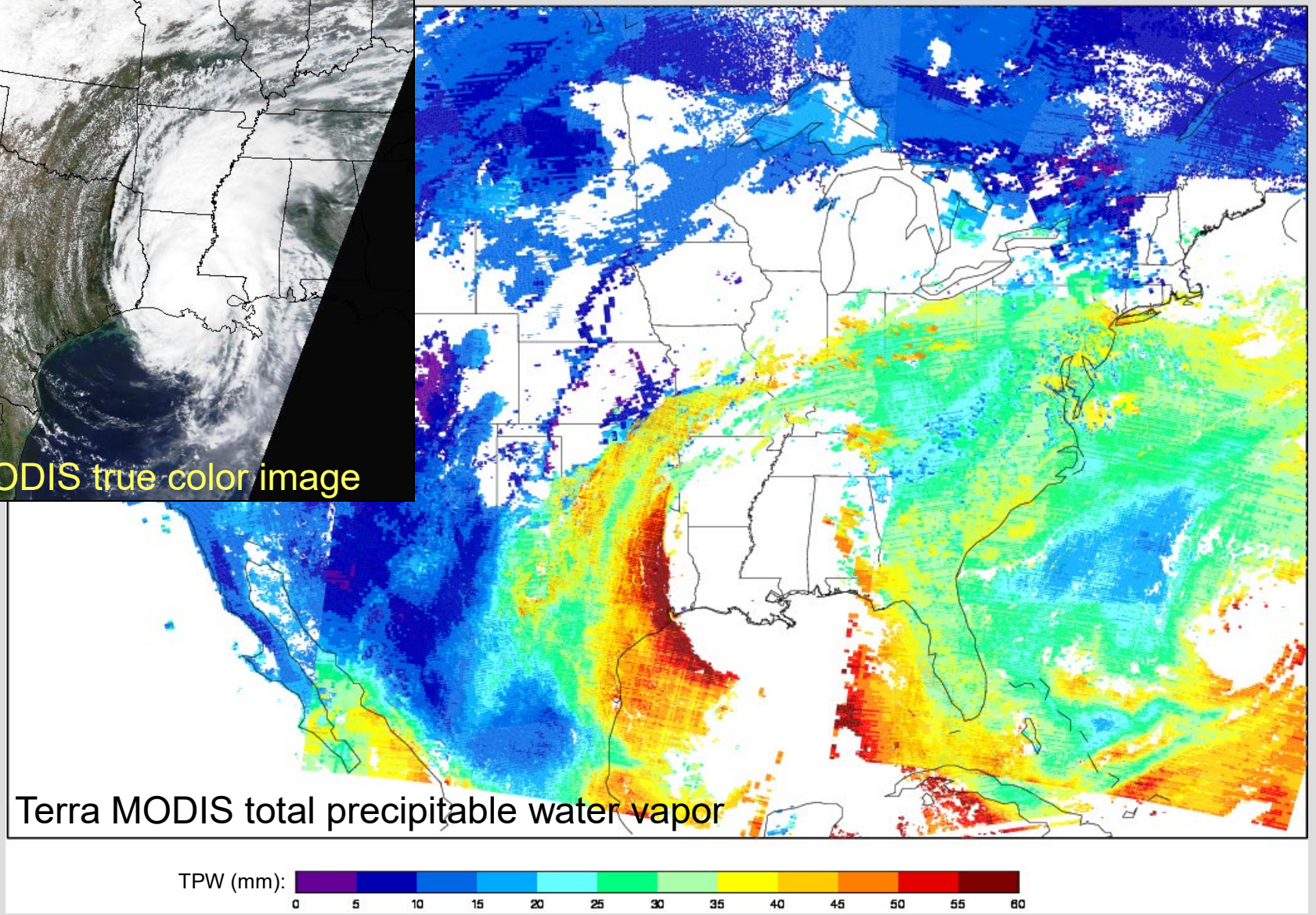


Four Panel Zoom of Cloud-Free Orographic Waves revealed in Water Vapor Imagery

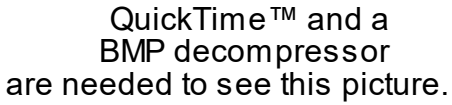


Hurricane Lili, 2 October 2002
Terra MODIS direct broadcast





Terra MODIS global water vapor product



May-July 2002 trends inferred from daily MODIS TPW

* Continuous pulsing motion of moisture is evident

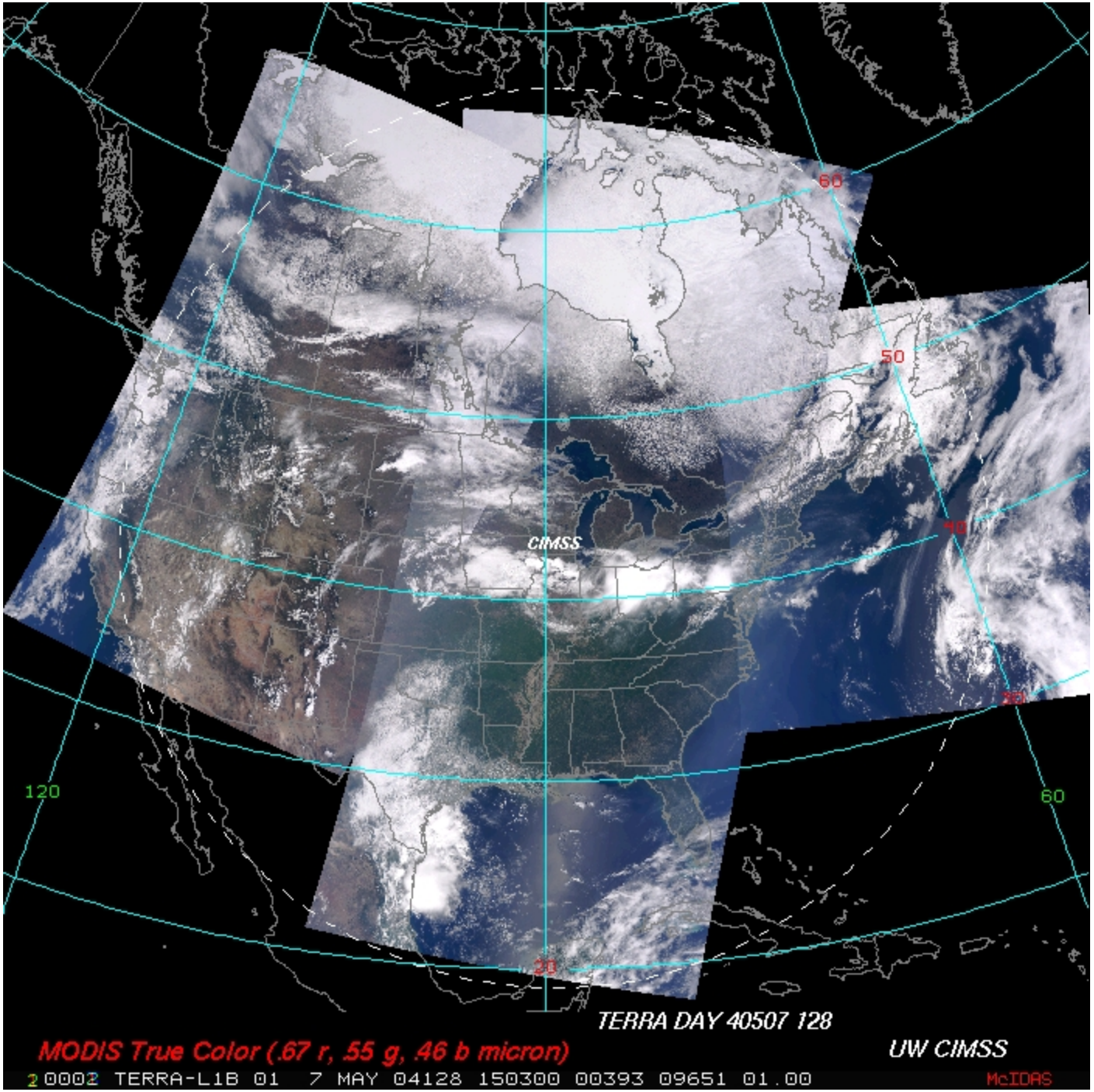
* Global circulations are obvious esp around subtropical highs
  (e.g. clockwise around Bermuda high in Jun,
  counter clockwise around southern Pacific high in Dec)

* Indian monsoon evident Jun-Jul-Aug

* Gulf of Mexico moisture moving into central US appears May - Jun

* Indonesian region has year round high moisture (often global max)

* TPW follows the Sun – latitudinal moisture bands connecting
  continents drift N & S with seasons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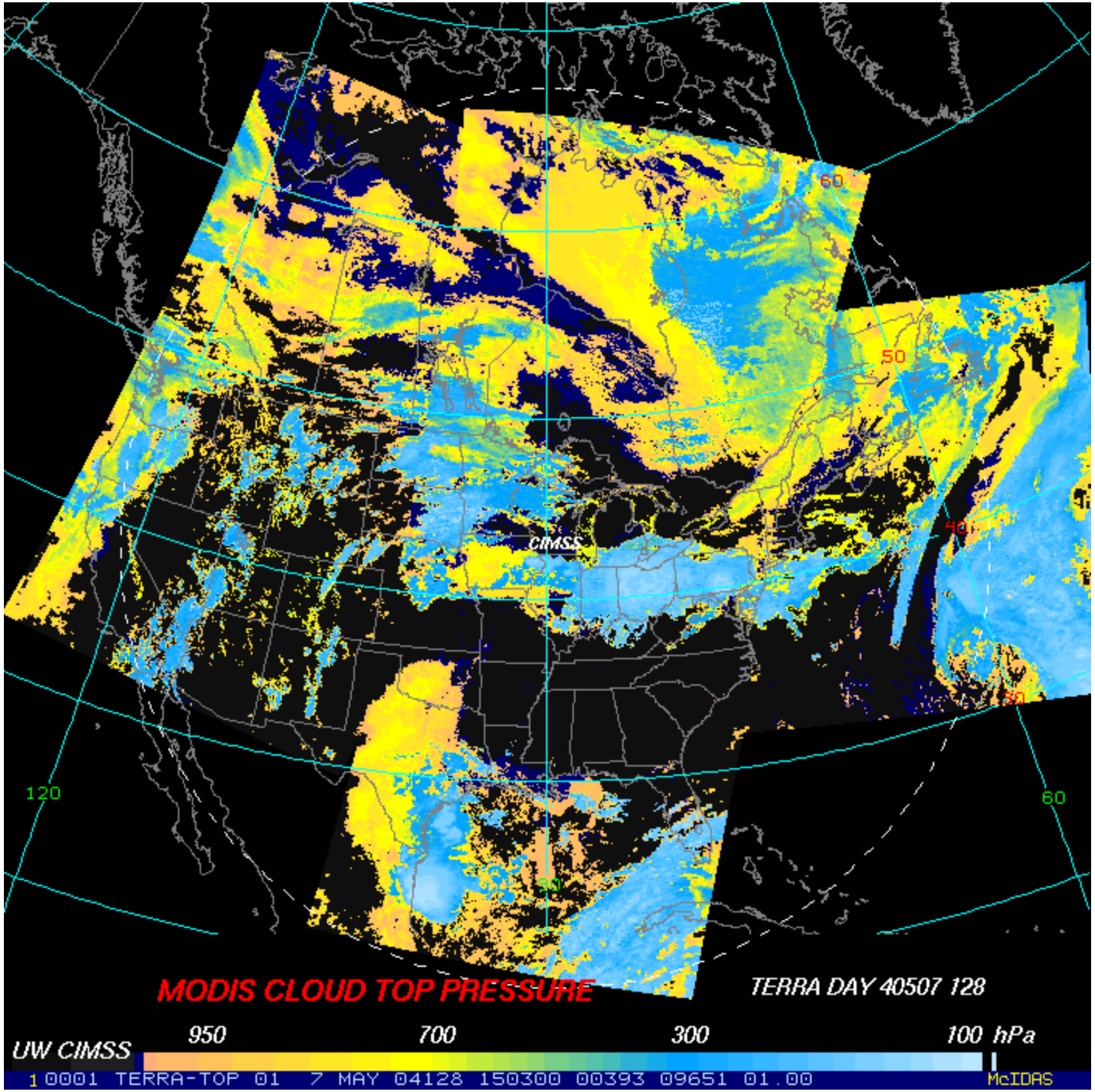
CIMSS
TERRA DAY 40507 128
MODIS True Color (.67 r, .55 g, .46 b micron)
UW CIMSS
2 0002 TERRA-L1B 01 7 MAY 04128 150300 00393 09651 01.00
McIDAS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CIMSS
MODIS CLOUD TOP PRESSURE
TERRA DAY 40507 128
UW CIMSS
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700
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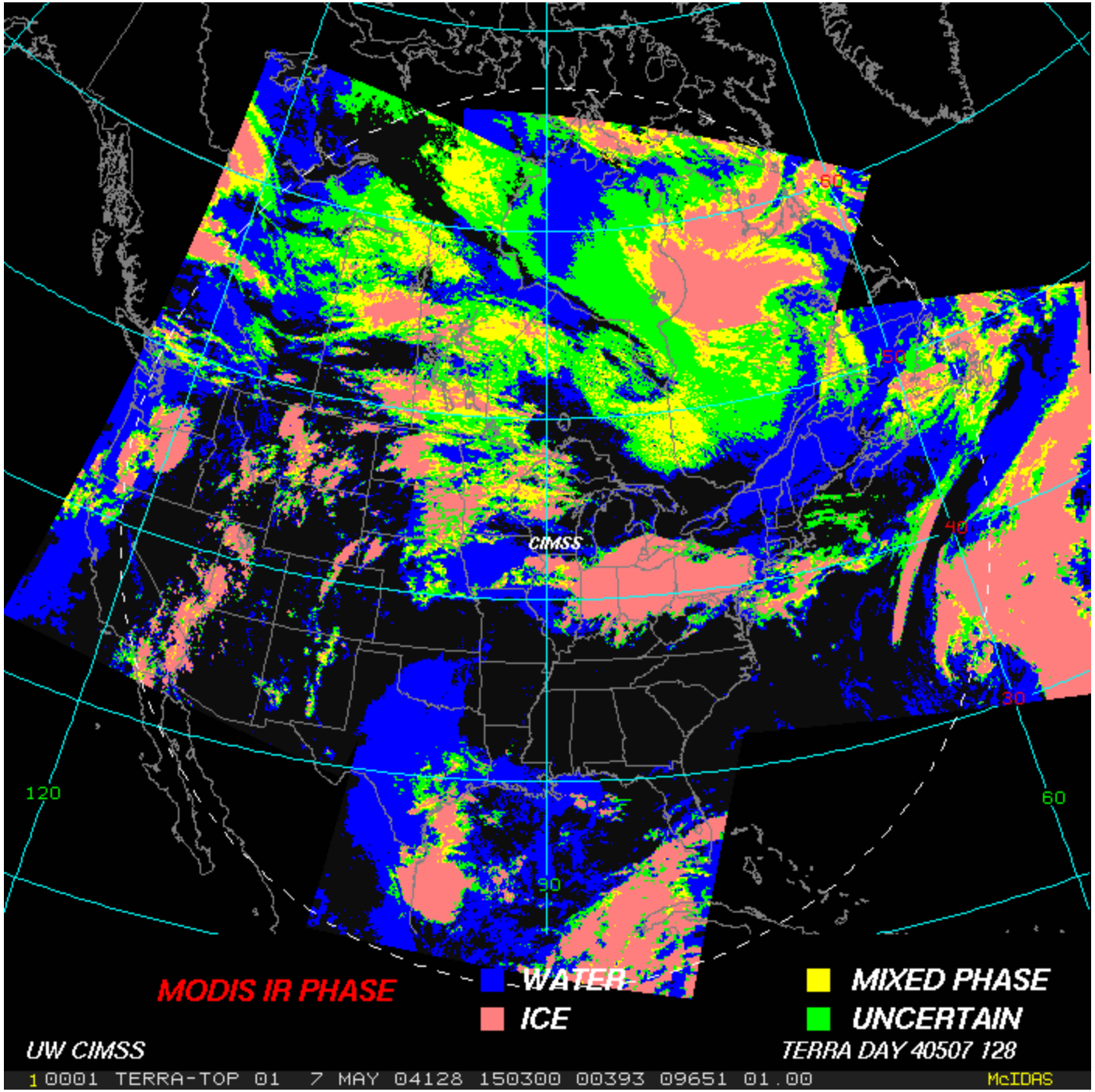
100 hPa
1 0001 TERRA-TOP 01 7 MAY 04128 150300 00393 09651 01.00
McIDAS


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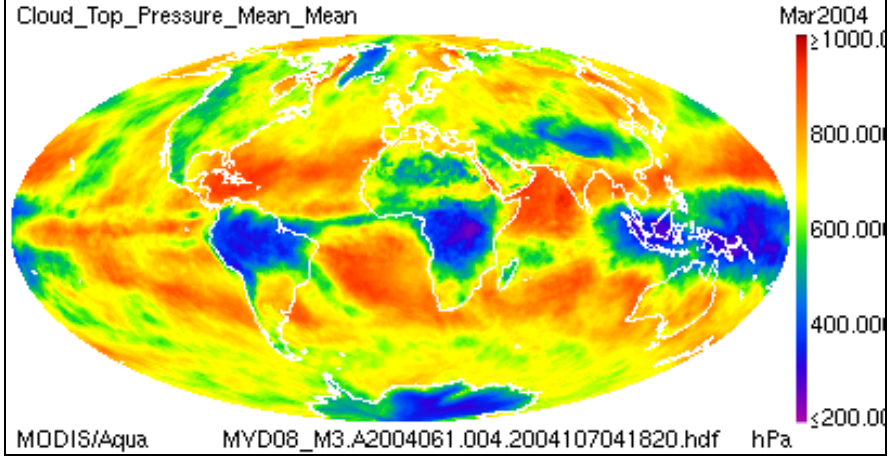

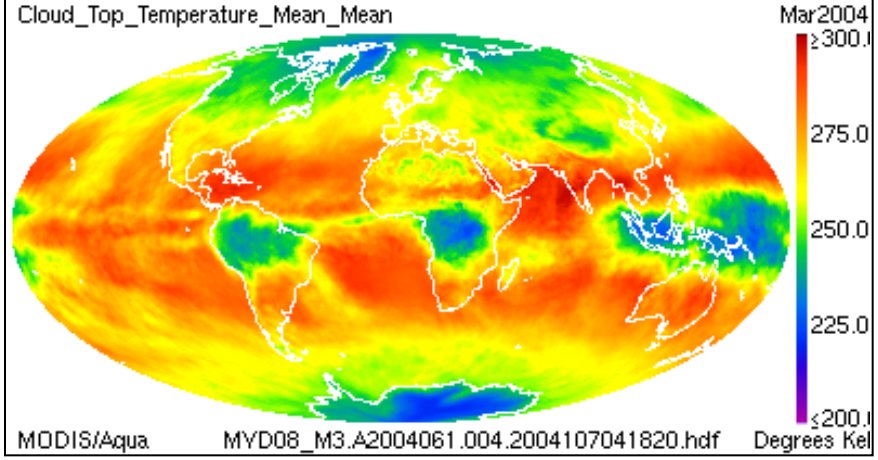

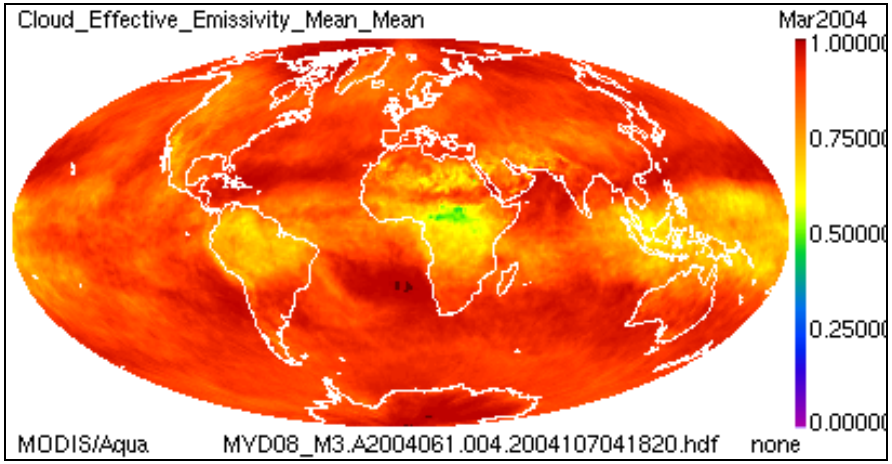

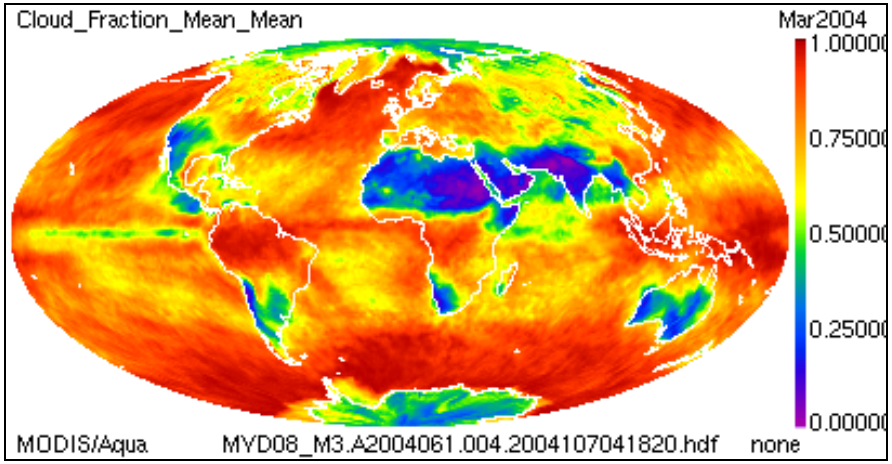

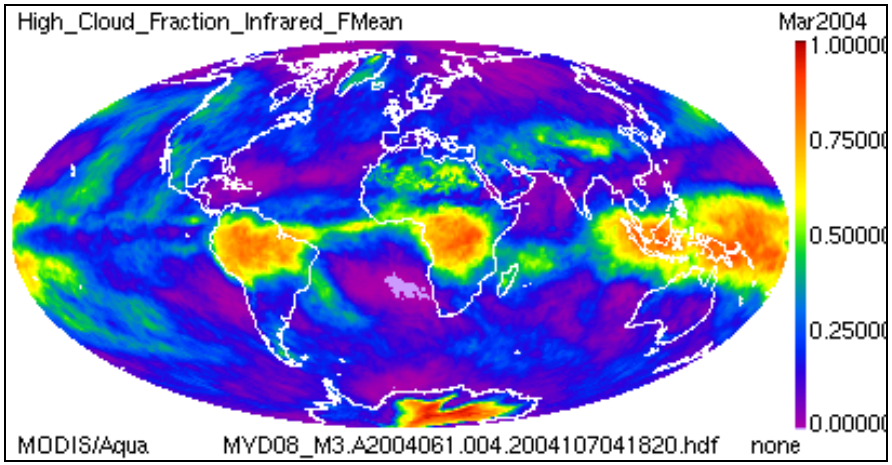

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