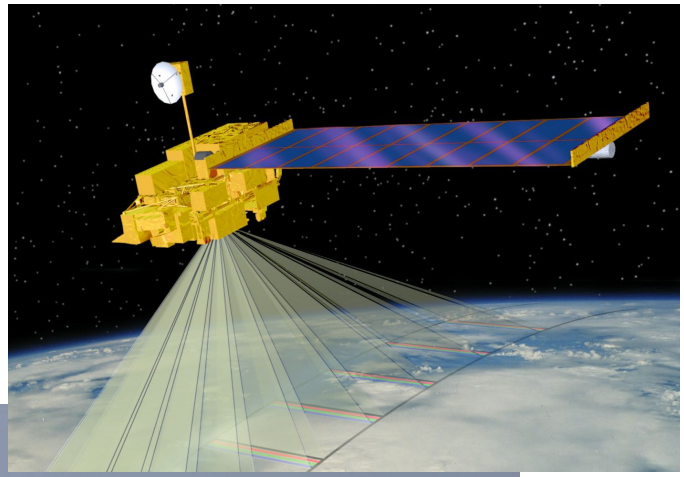
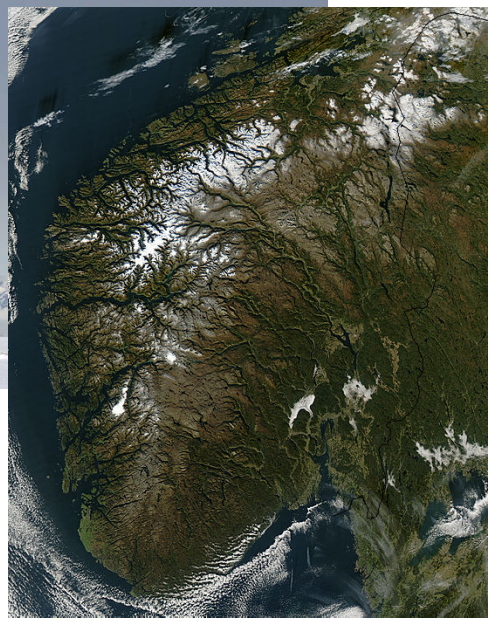
Introduction to MODIS



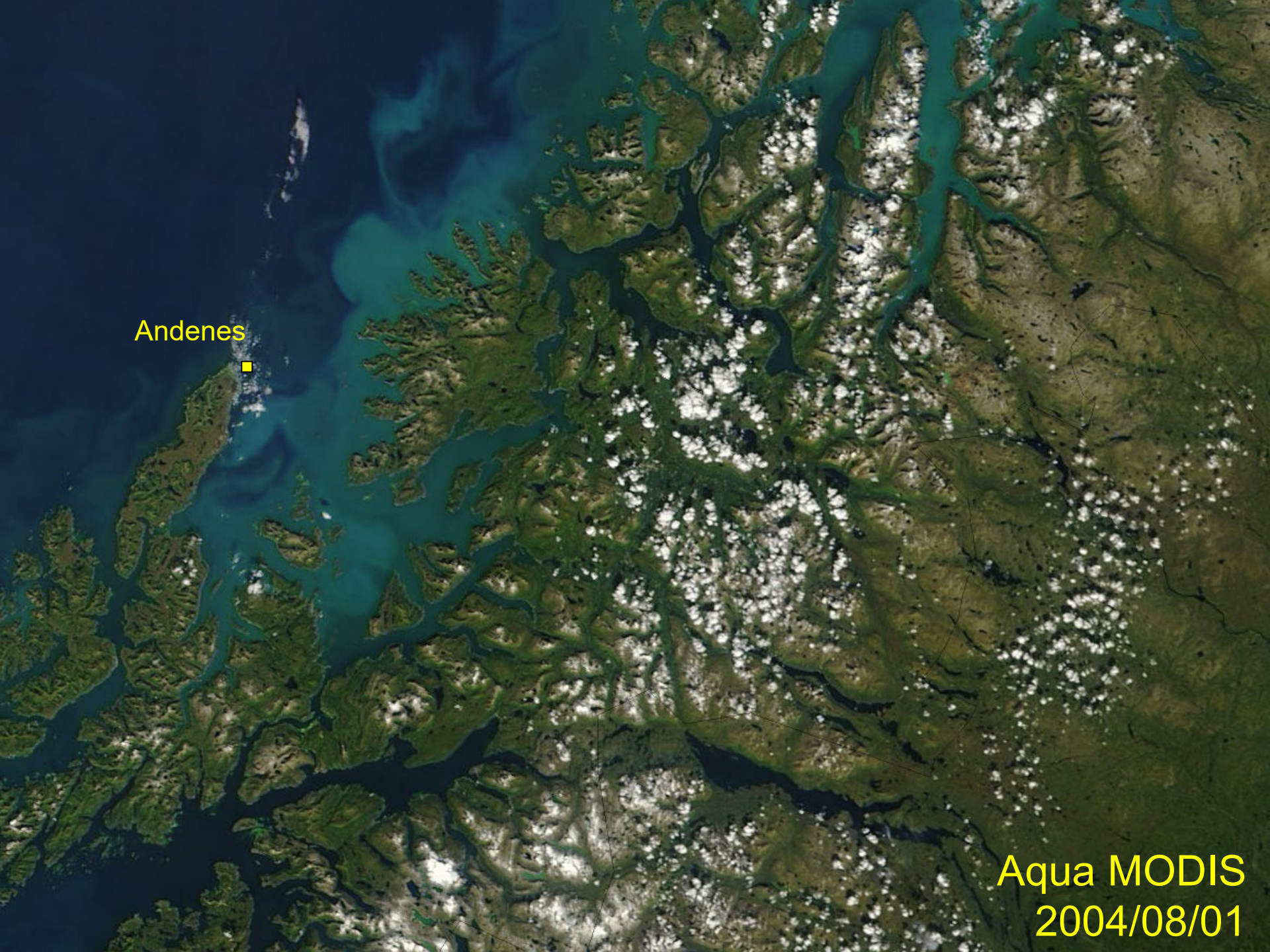


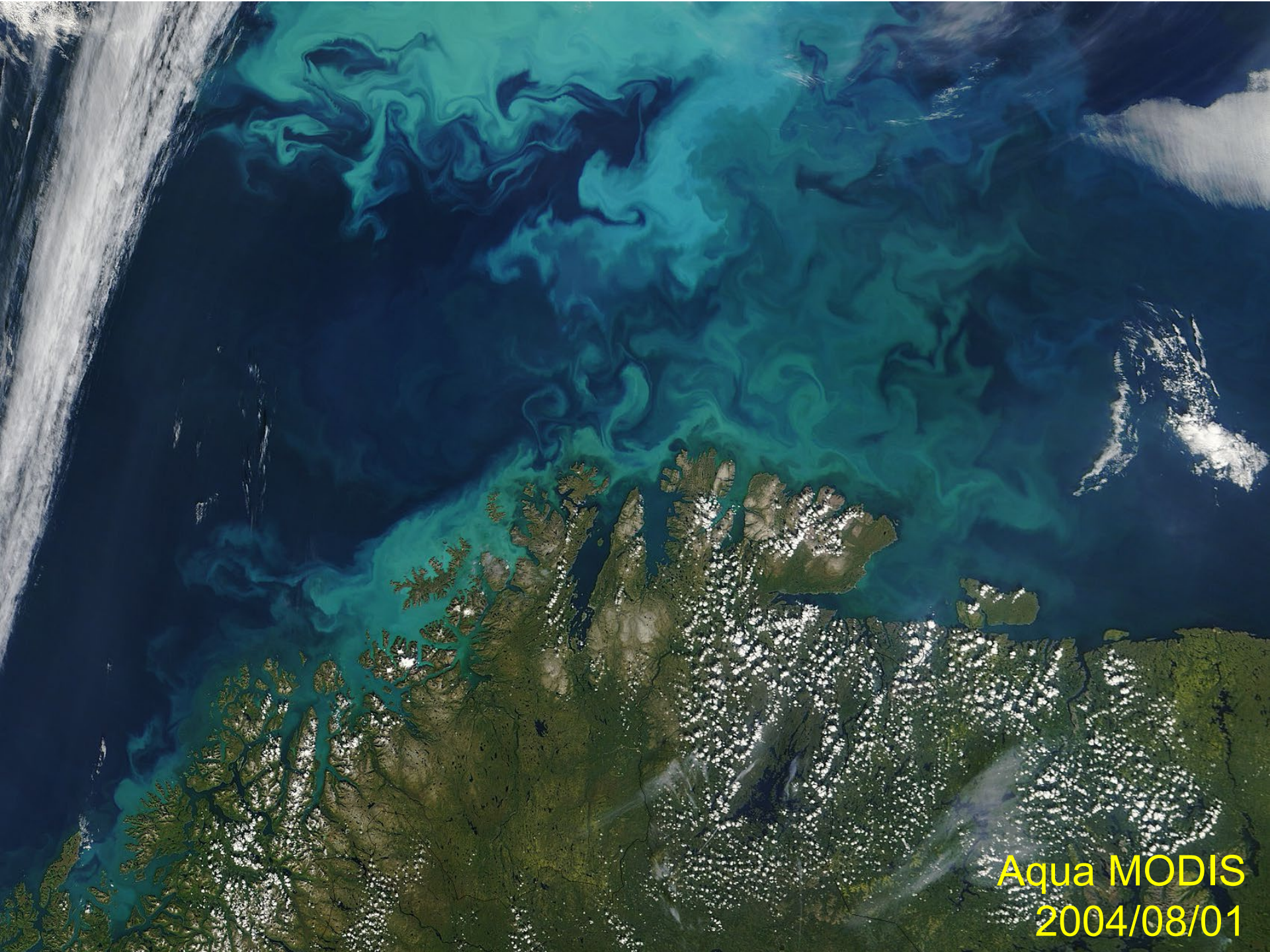
MODIS Workshop
Andenes Norway
Feb 28 - Mar 2, 2005

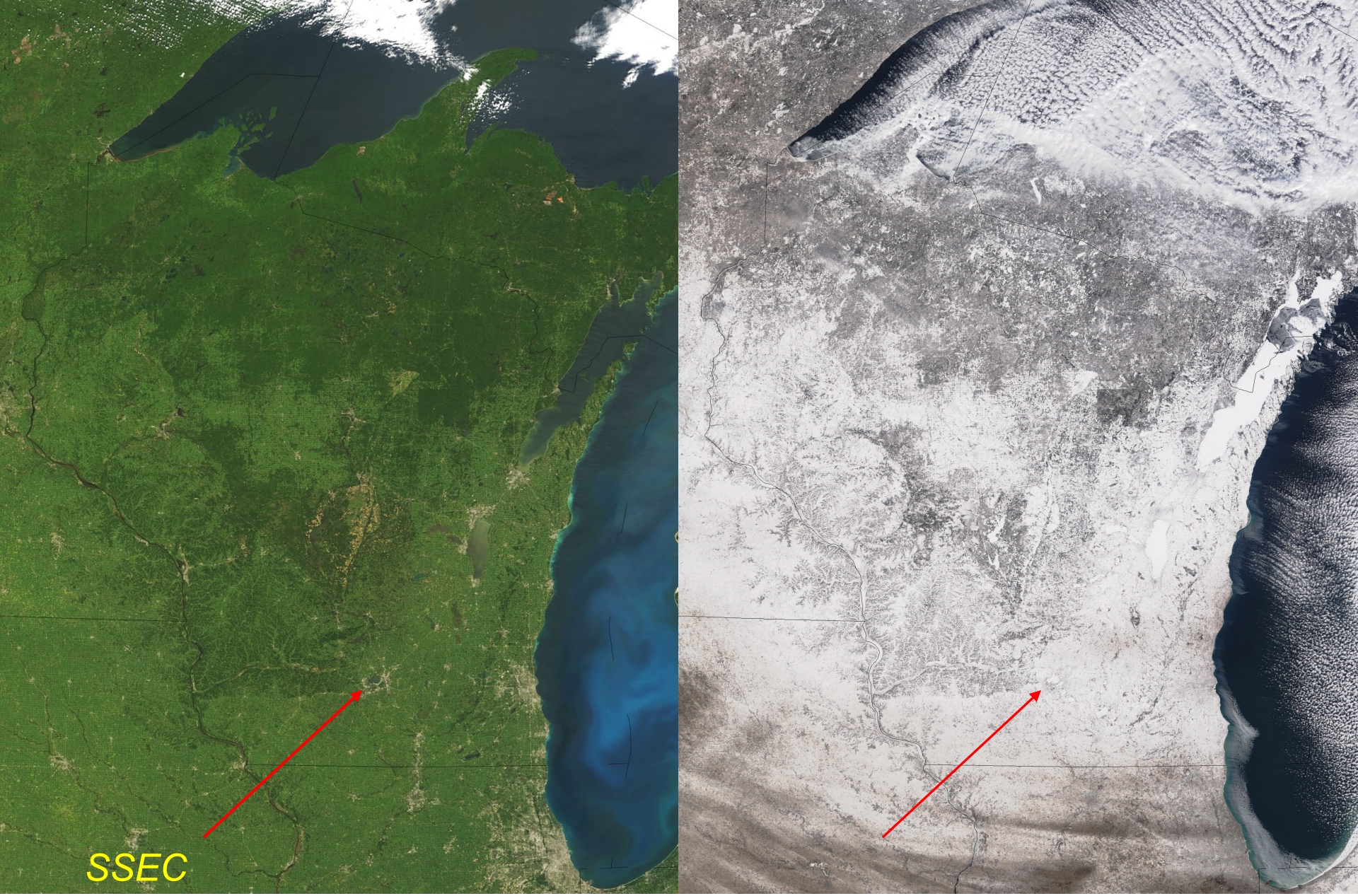
Liam Gumley
Space Science and Engineering Center
University of Wisconsin-Madison

CIMSS

SSEC


Andenes
Aqua MODIS
2004/08/01


Aqua MODIS
2004/08/01



Visit Wisconsin: Beautiful in Summer and Winter

EOS Direct Broadcast Reception and Processing at SSEC

Objectives: Routine acquisition and processing of EOS direct broadcast data. Distribution of software for data processing.

Accomplishments:

- Ground station operational January 2001. Have acquired more than 13,000 Terra and Aqua passes.
- MODIS, AIRS/AMSU, AMSR-E Level 1B data and browse images, and Level 2 products, are produced automatically and made available via anonymous FTP, DODS and Web.
- IMAPP software for processing EOS direct broadcast data now in use in USA, UK, Germany, Russia, Japan, China, S. Korea, Singapore, Australia, Antarctica (to name a few).

SSEC X-band Groundstation

SeaSpace 4.4 meter antenna; operational since Jan. 2001.

Receives Terra, Aqua, Oceansat, ERS-2, Radarsat, ADEOS-II.

Line of sight to the horizon in all directions.

Terra Overpass Prediction 2005/03/28

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.

Introduction to MODIS

Terra

Launched: Dec. 18, 1999

10:30 am descending

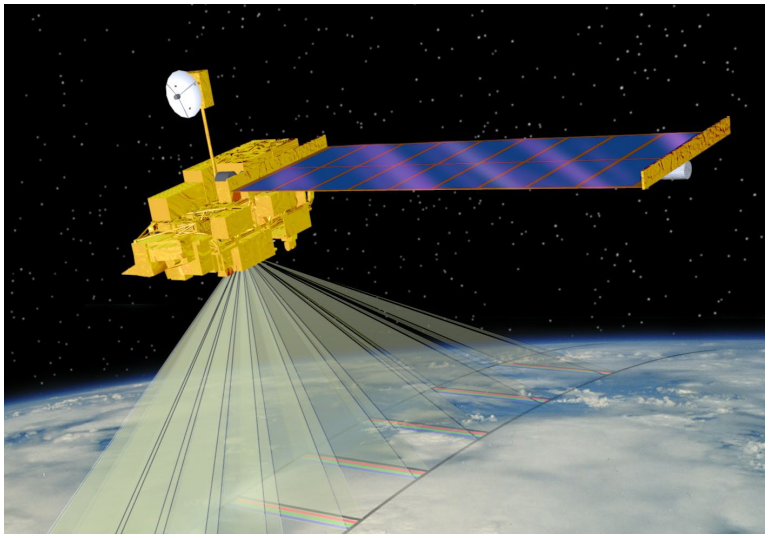
ASTER: Hi-res imager

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

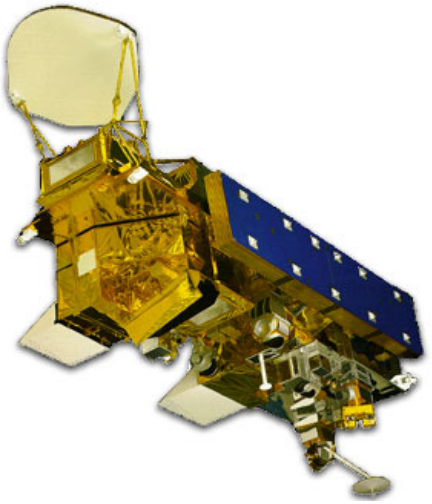
AMSR-E: Microwave scanner

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

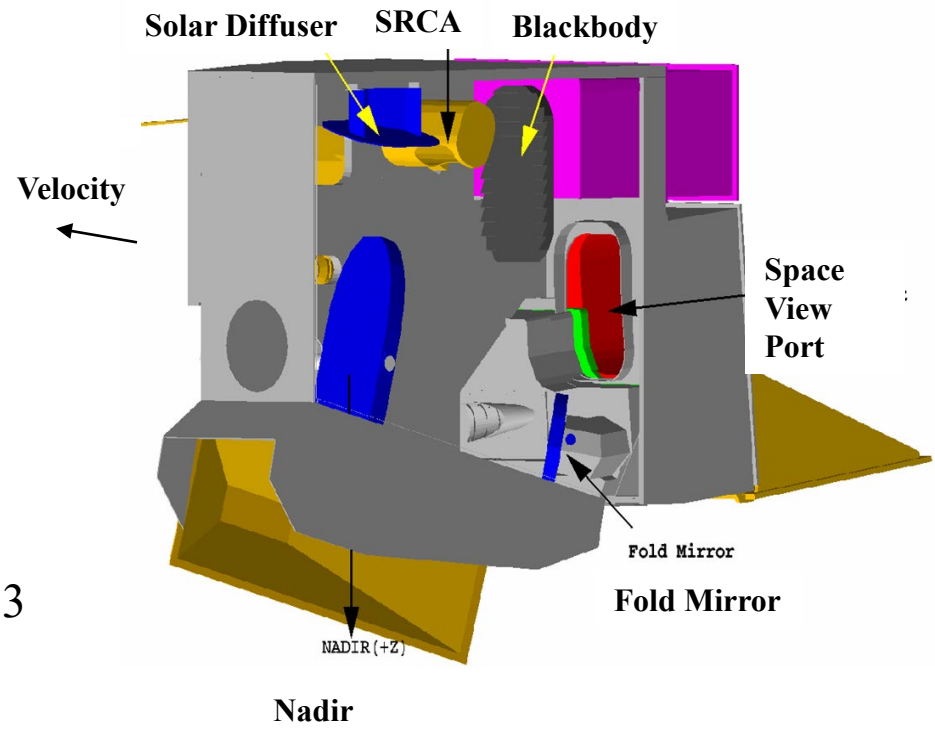
Spatial resolution: 2 bands @ 250 m; 5 @ 500 m; 29 @ 1000 m

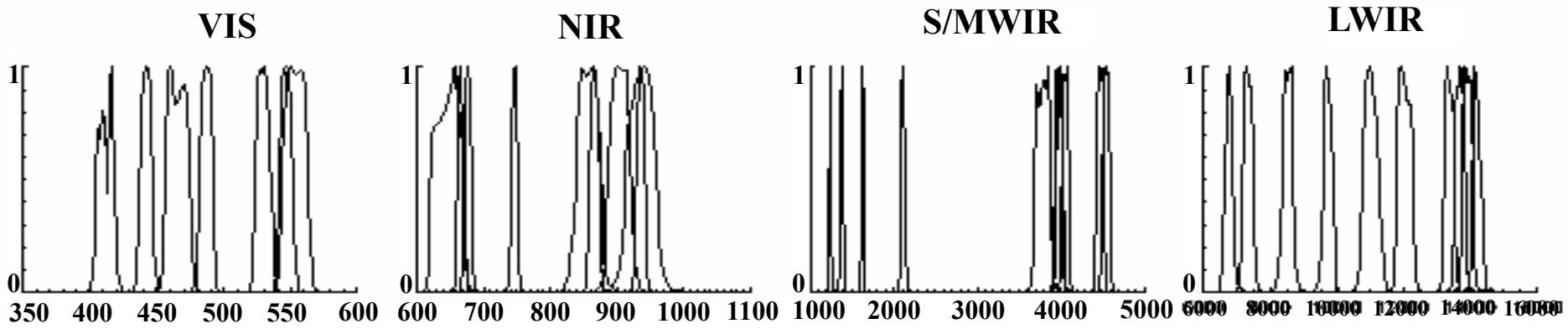
Major differences:

- 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

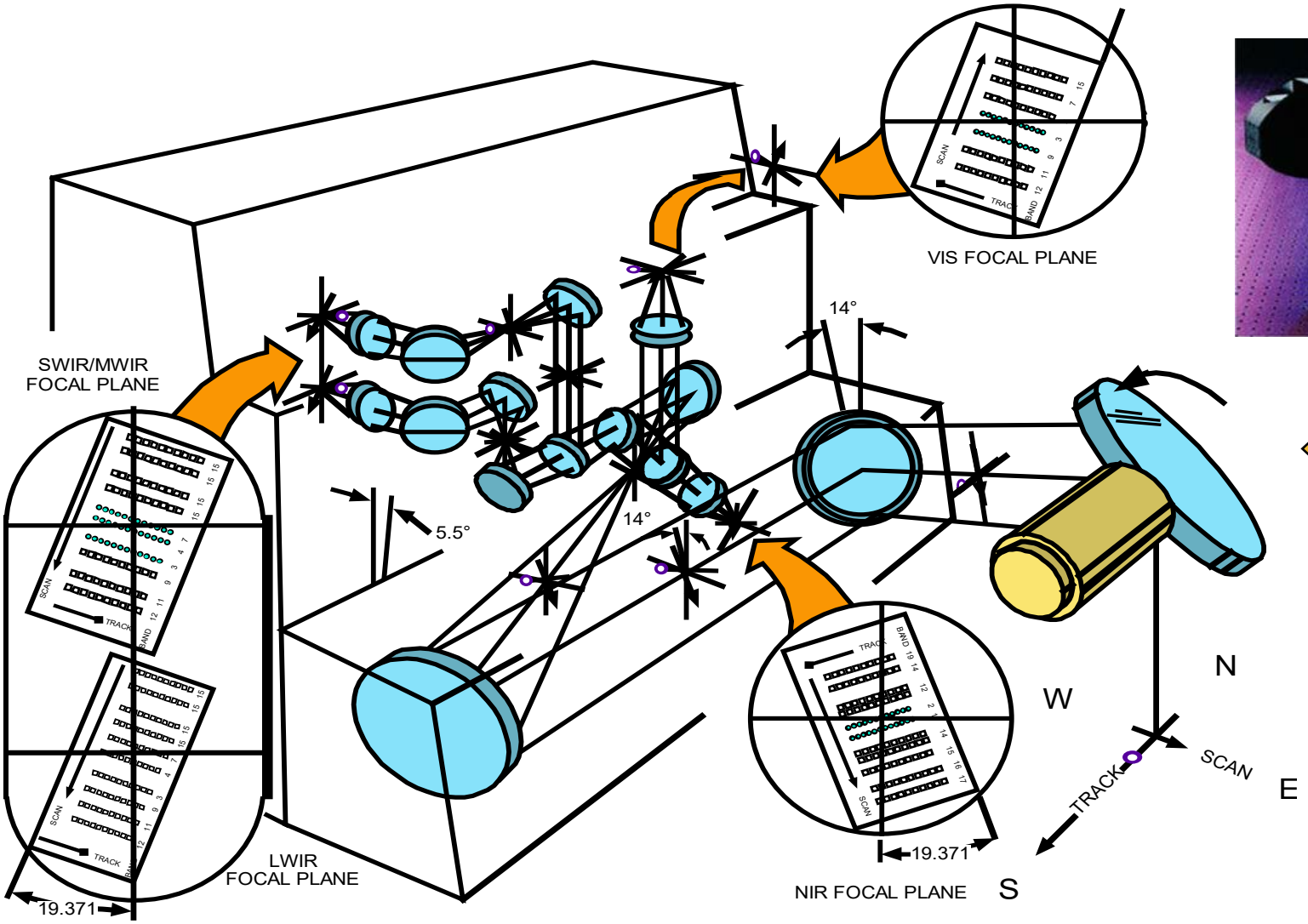
Instrument Overview

- 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



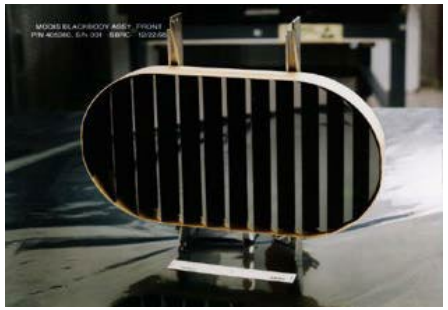
On-board Calibrators

- **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

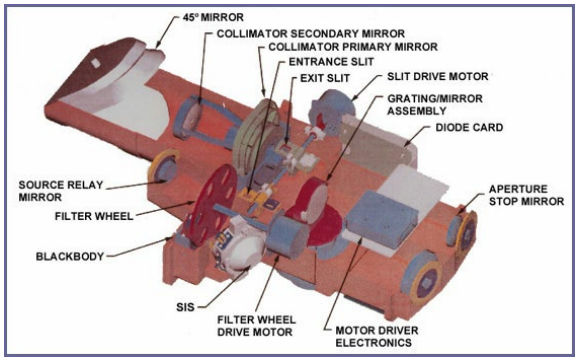
SD

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

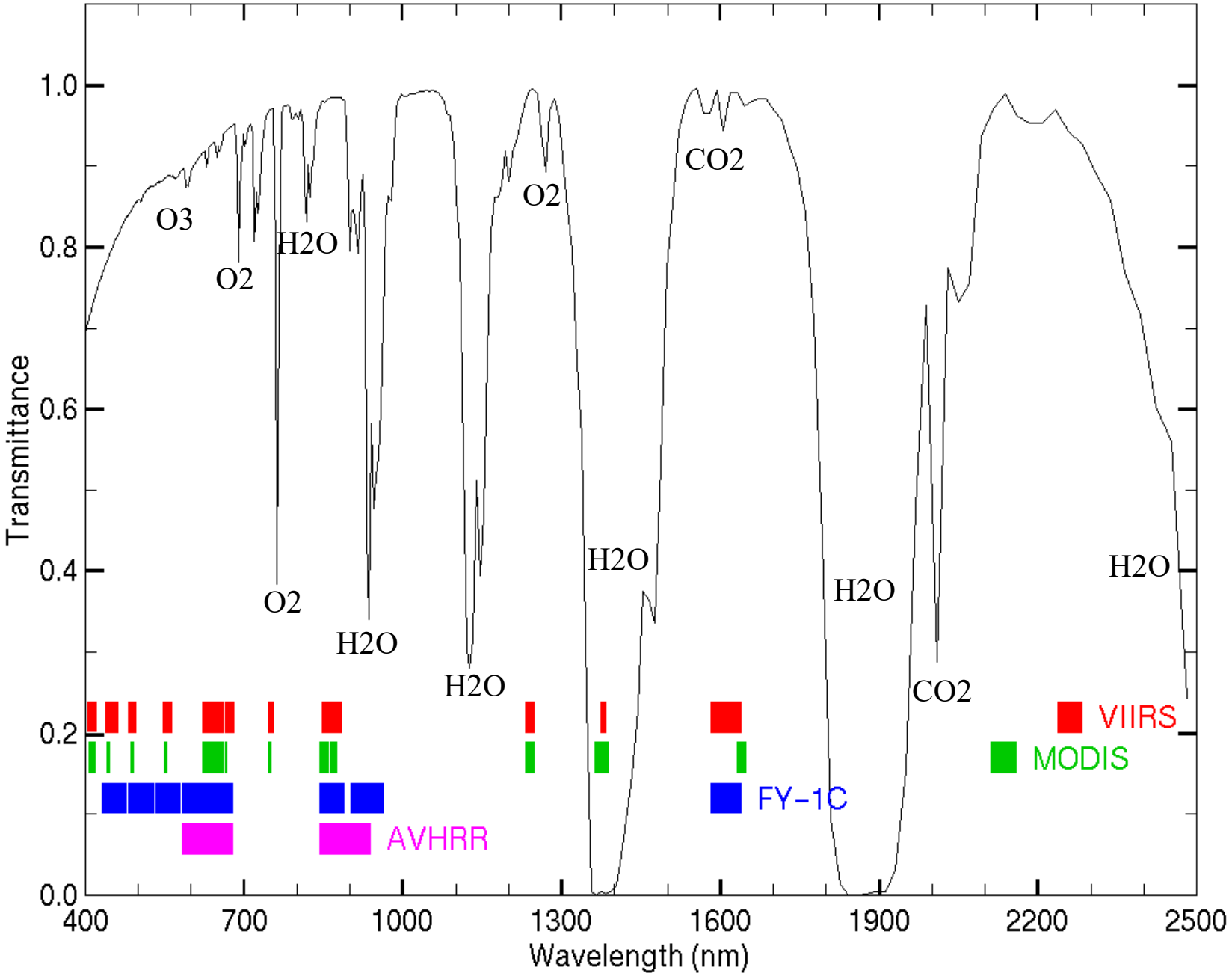
MODIS Reflected Solar Bands

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

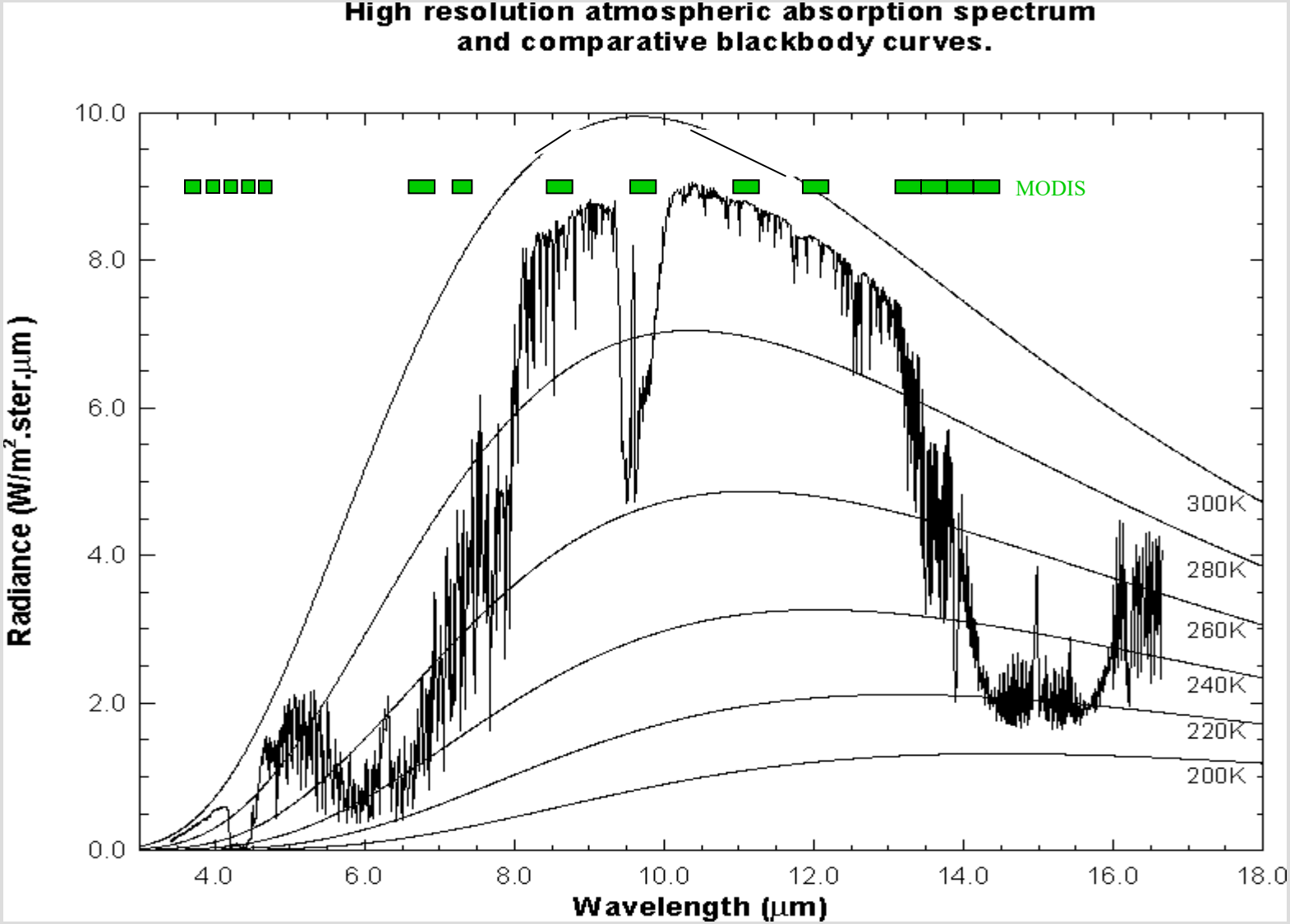
MODIS Thermal Emissive Bands

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

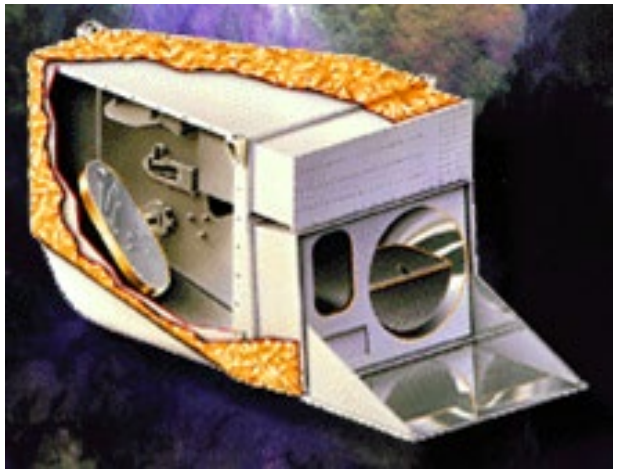
VIIRS, MODIS, FY-1C, AVHRR



MODIS IR Spectral Bands

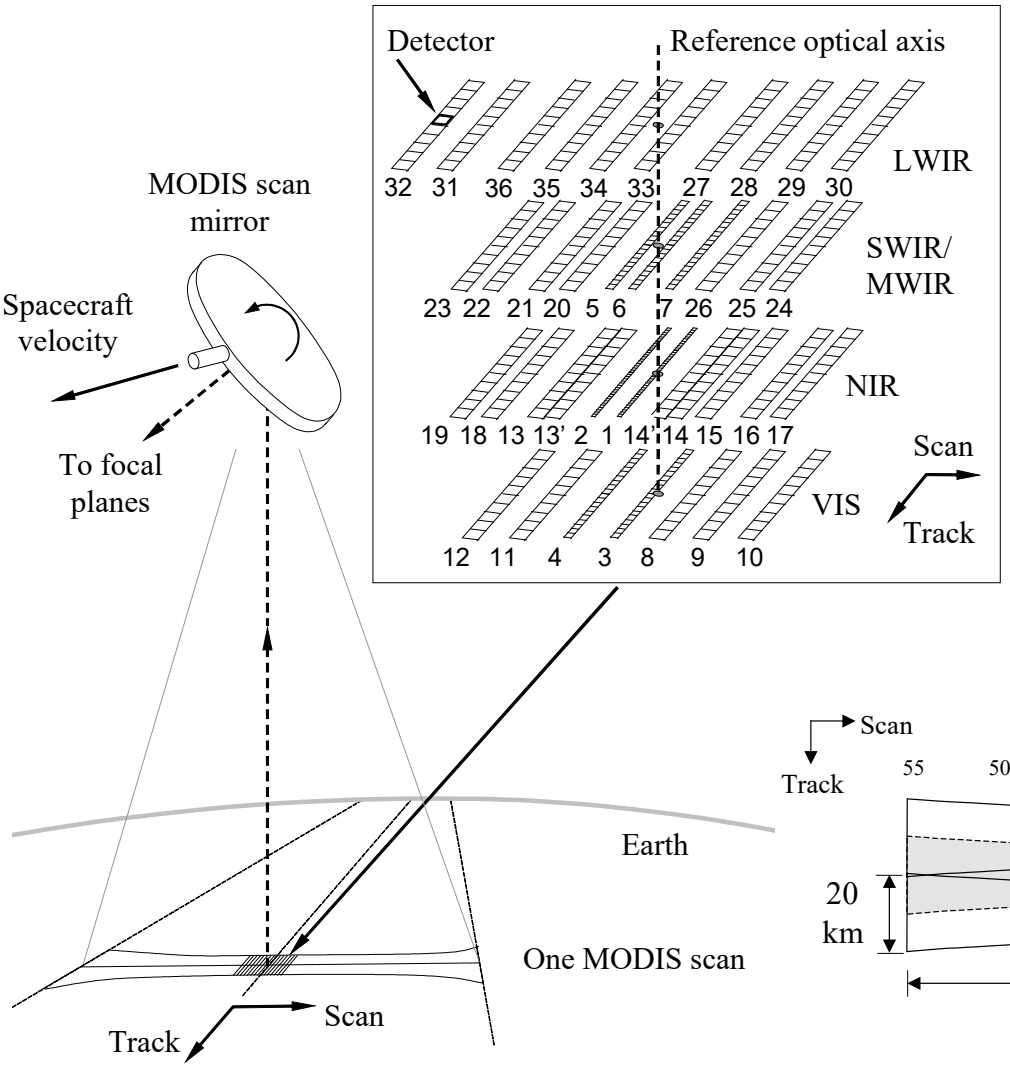


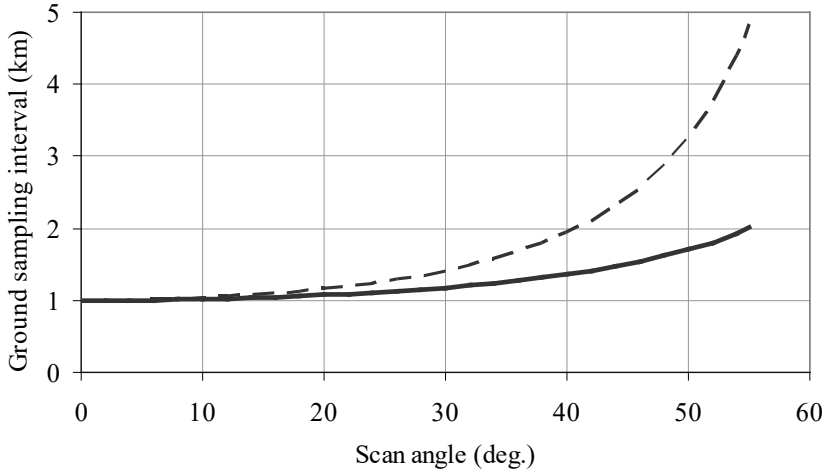
MODIS Geolocation

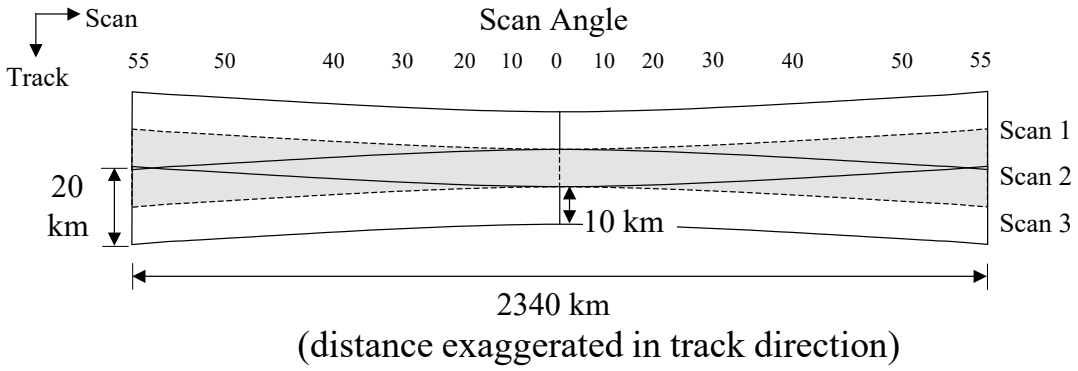


- Geolocation accuracy specification is 150 m (1 σ) and goal is 50 m (1 σ) at nadir
- Geolocation goal driven by Land 250 m change product requirements
- MODIS is a moderate resolution whisk-broom sensor with 36 spectral bands; 2 at 250 m, 5 at 500 m and 29 at 1 km nadir spatial resolution
- "Ideal"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

MODIS Scan Geometry

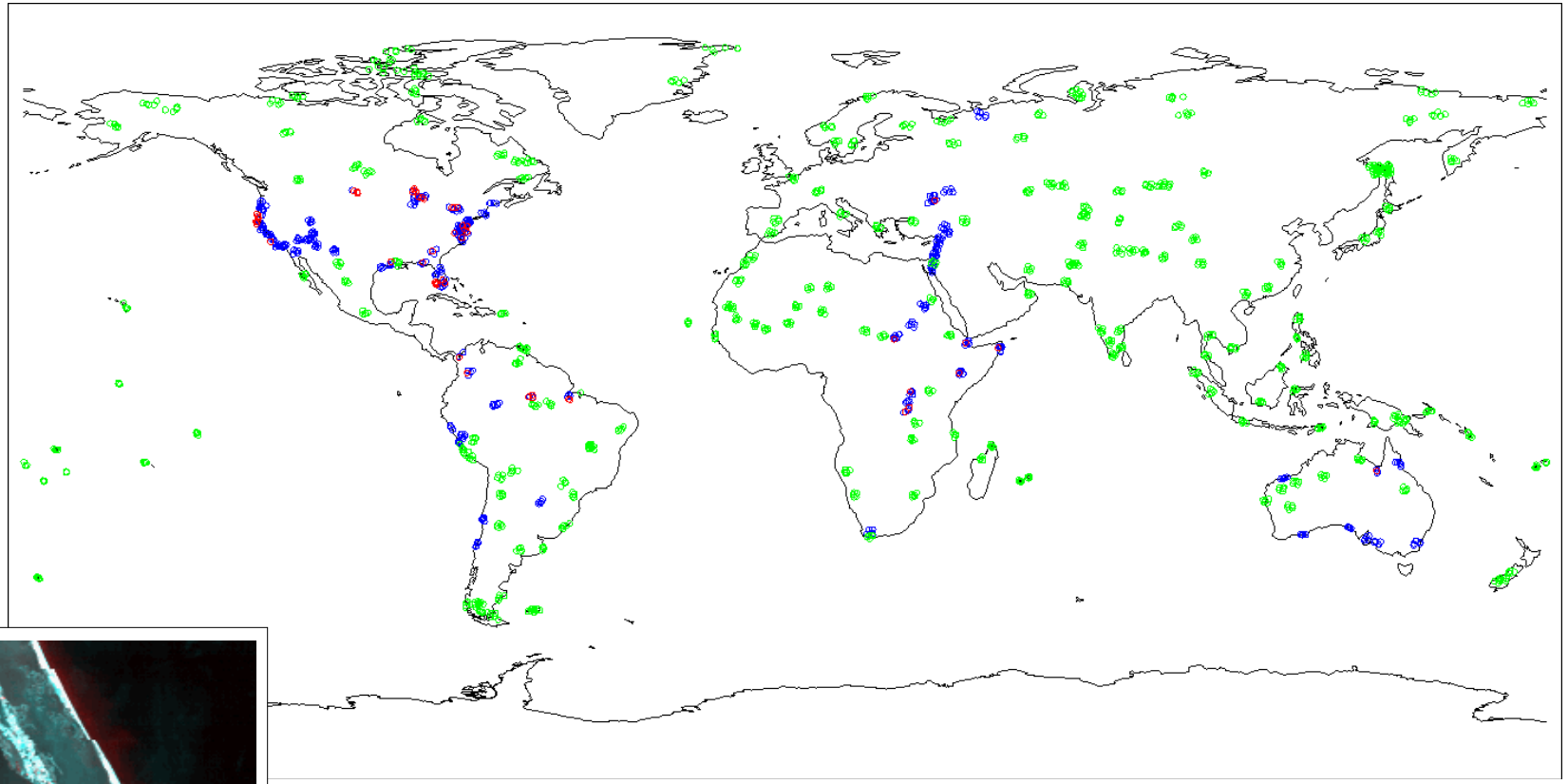






(distance exaggerated in track direction)

Ground Control Points (GCPs)



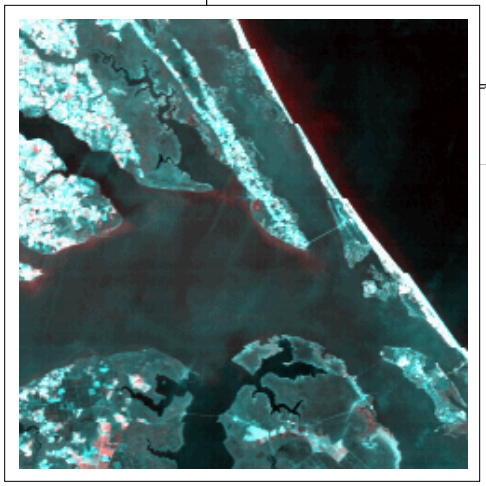


Image chips from Landsat TM/ETM scenes

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

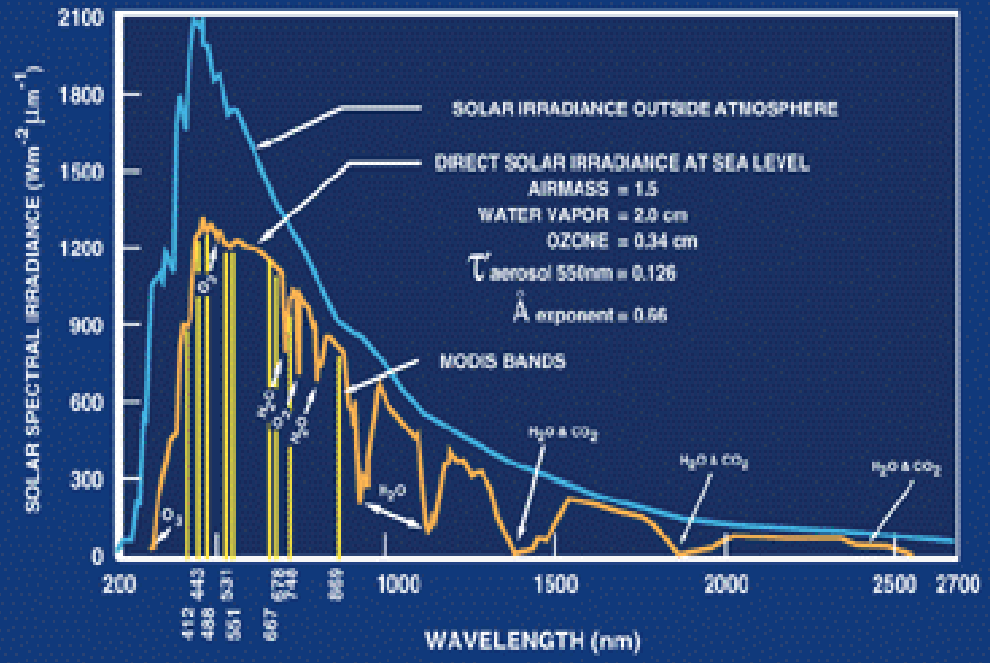
Aqua

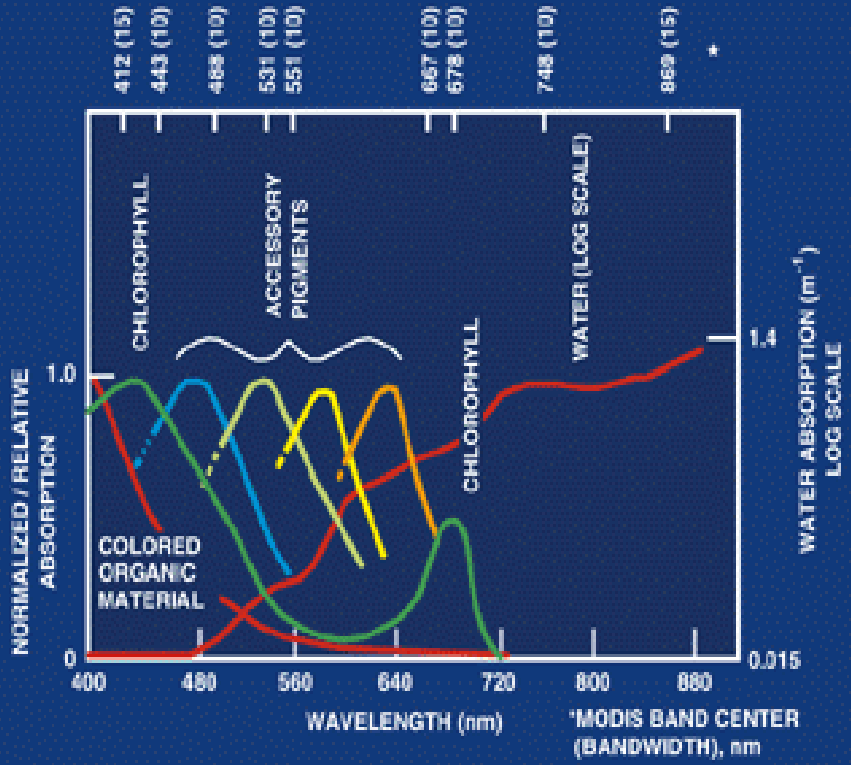
- Good results – RMS error is better than goal in track direction but slightly over goal in scan direction (but much better than specification – 150 m)
- Early post-launch coordinate system issue resolved before C4
- Definitive ephemeris is used for best results – causes up to 24 hr processing delay

	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

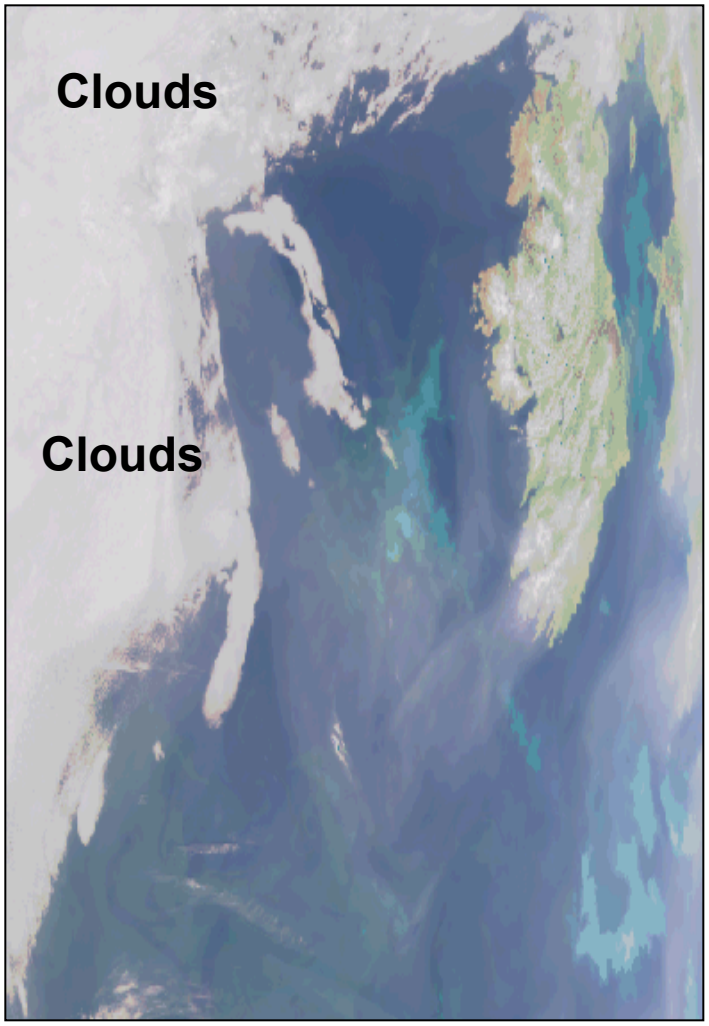
MODIS Ocean Applications

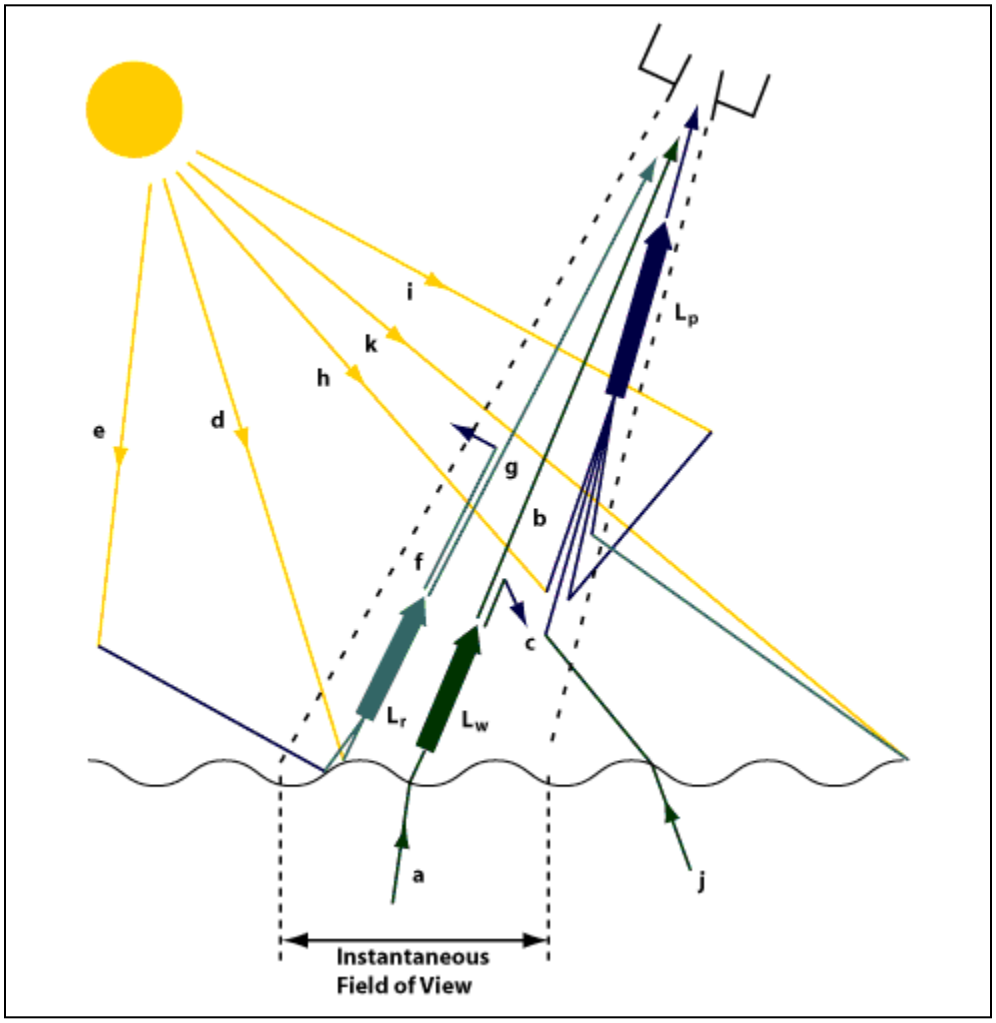
OCEAN-SOLAR RADIATION



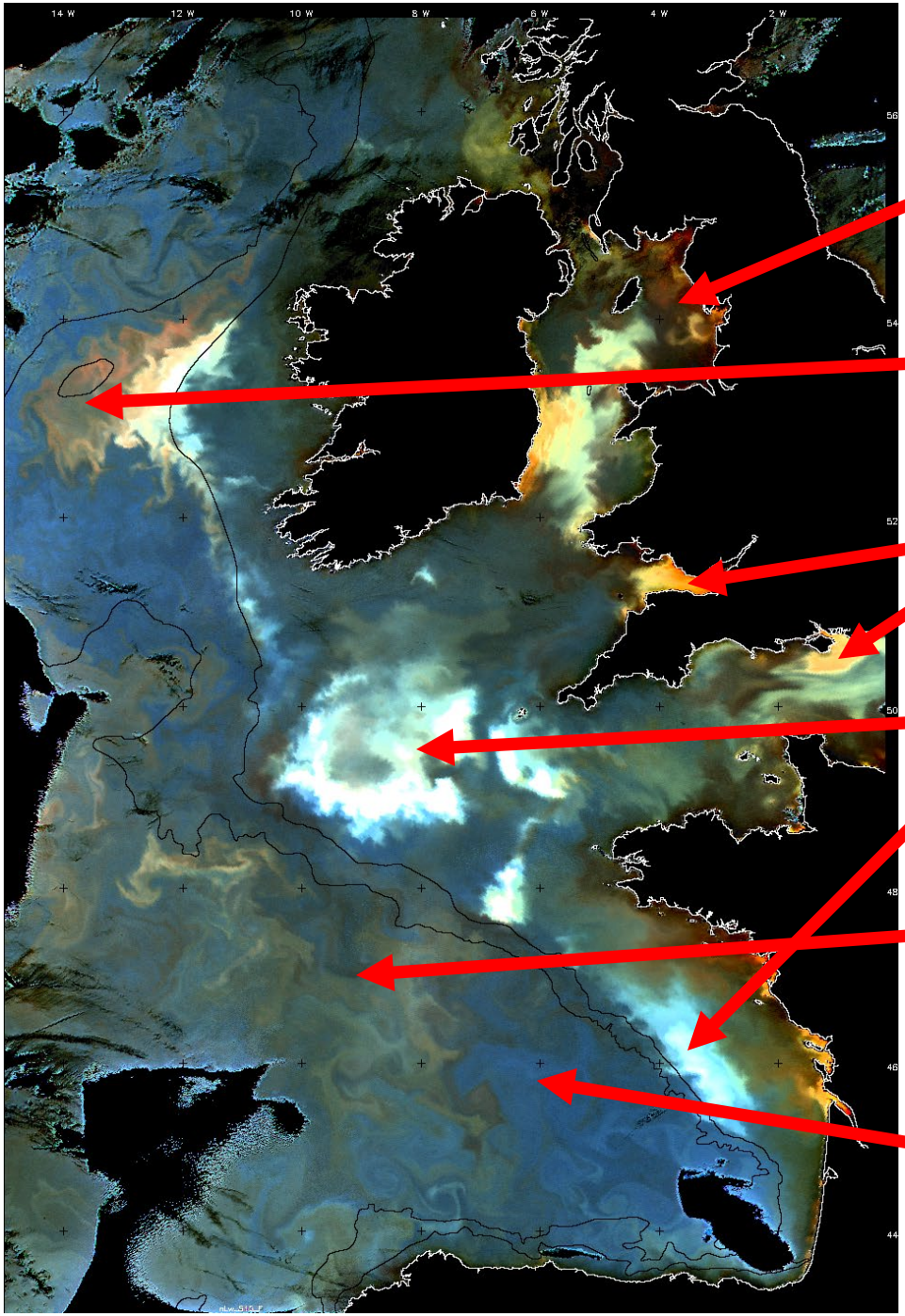


Atmospheric correction is critical for ocean color





- 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?

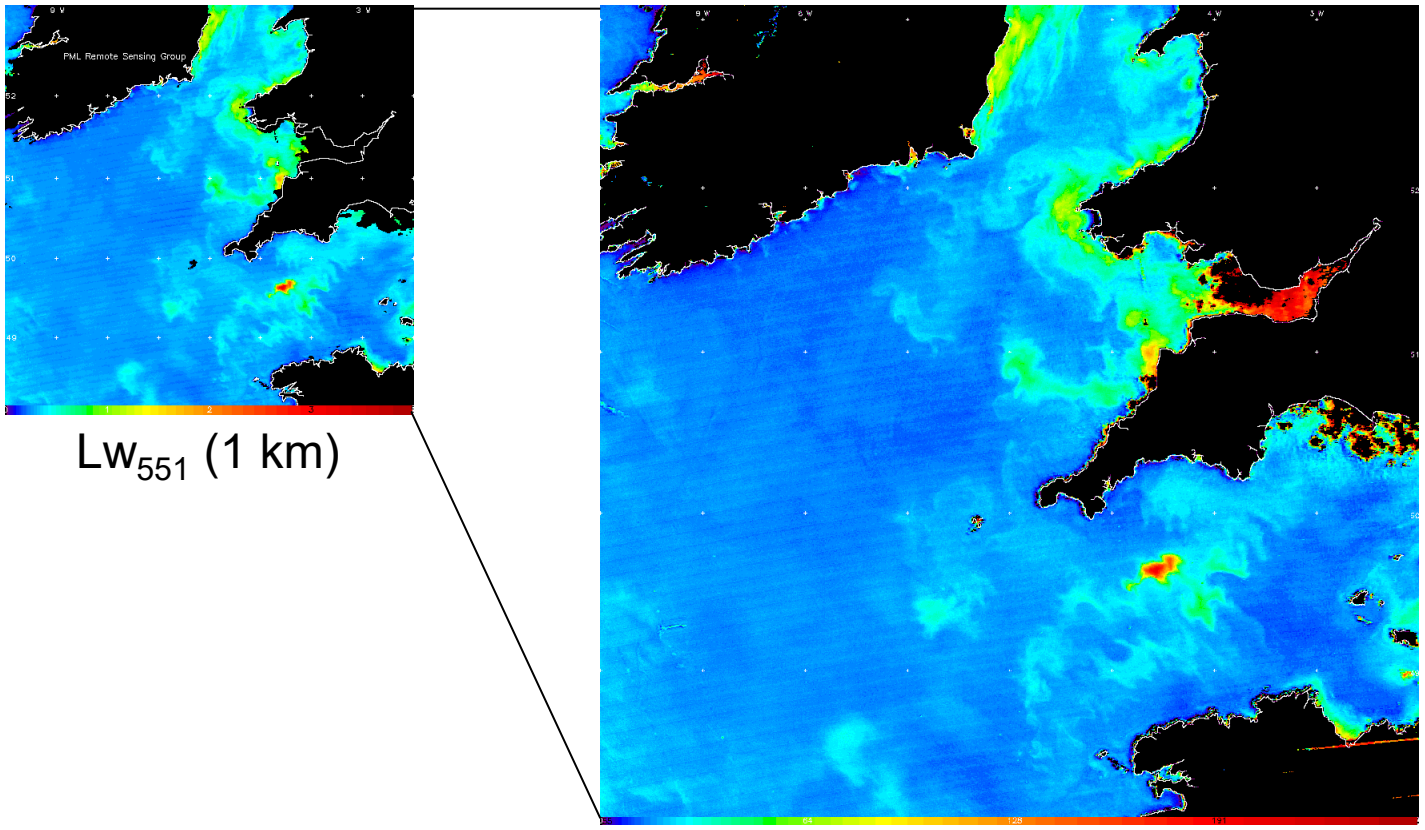
Sediment

Coccolithophores

Phytoplankton – fine eddy structure

Clear blue ocean

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

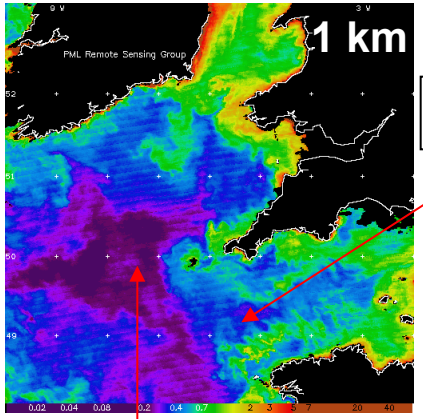


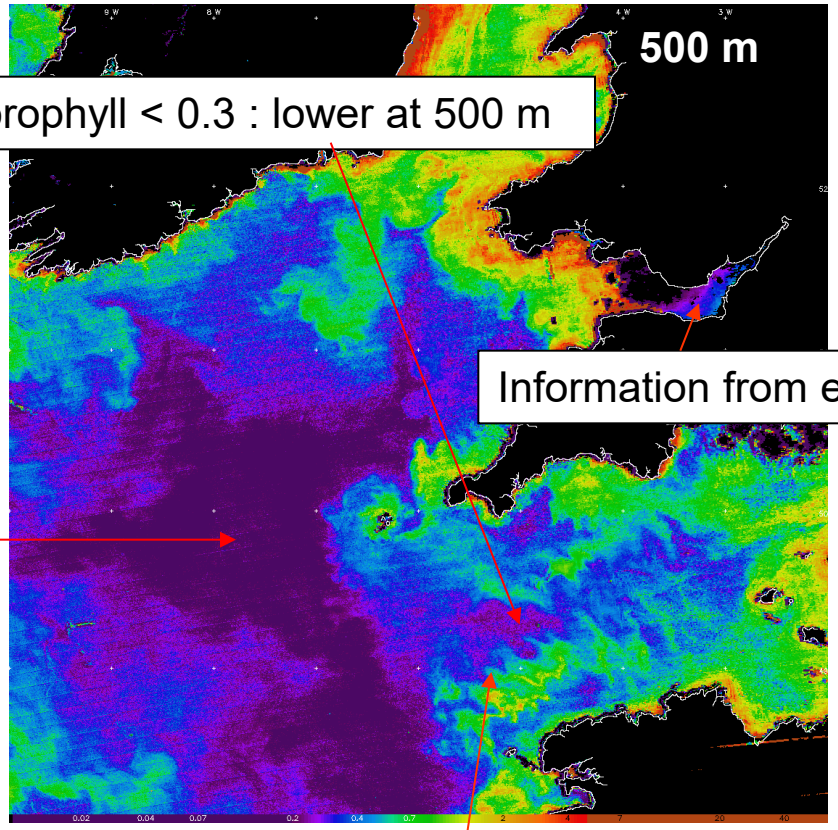
Lw_{551} (1 km)

Lw_{555} (500 m)

Lw

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





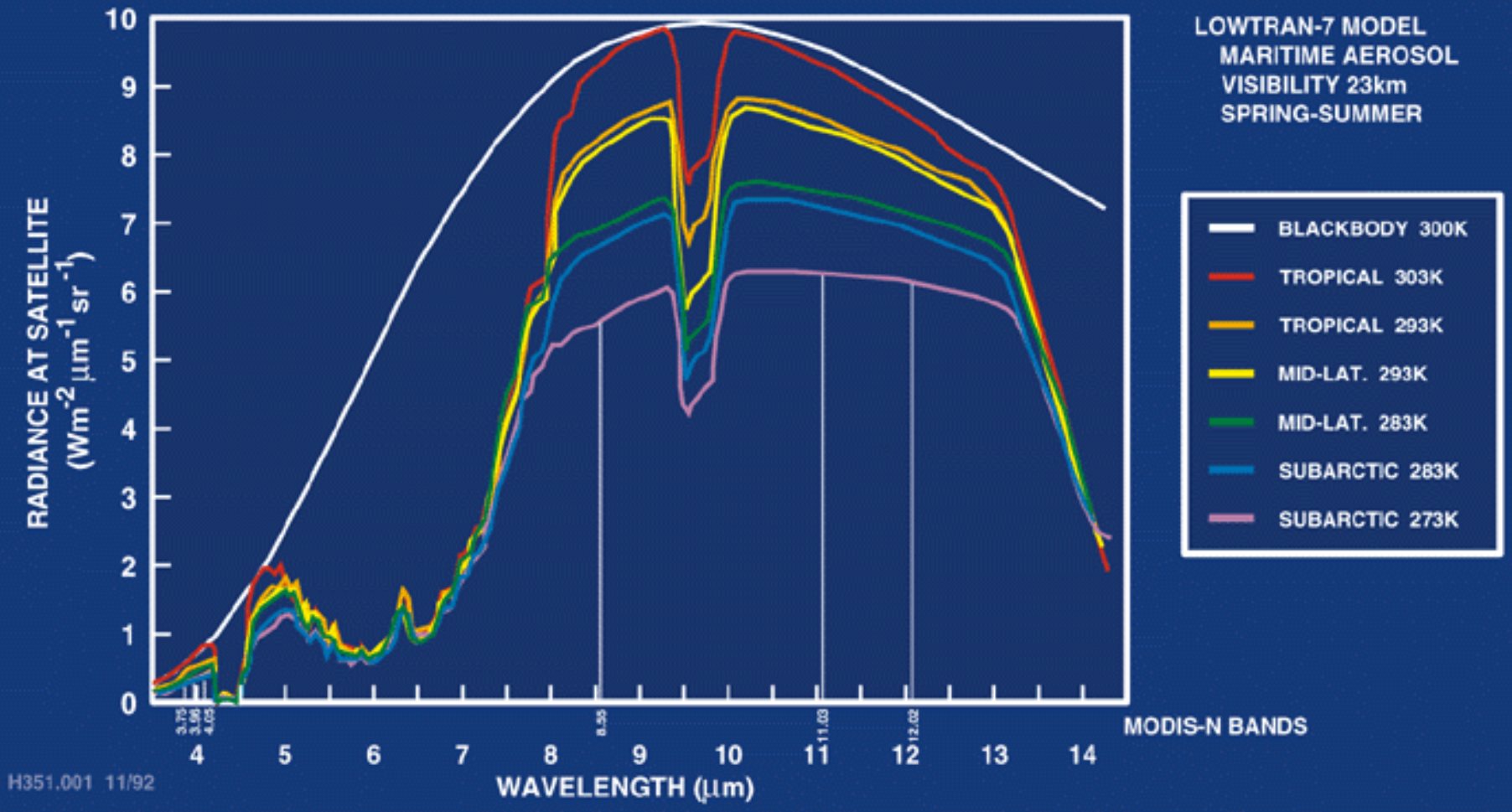
low chlorophyll < 0.3 : lower at 500 m

Information from estuaries

Same broad-scale features

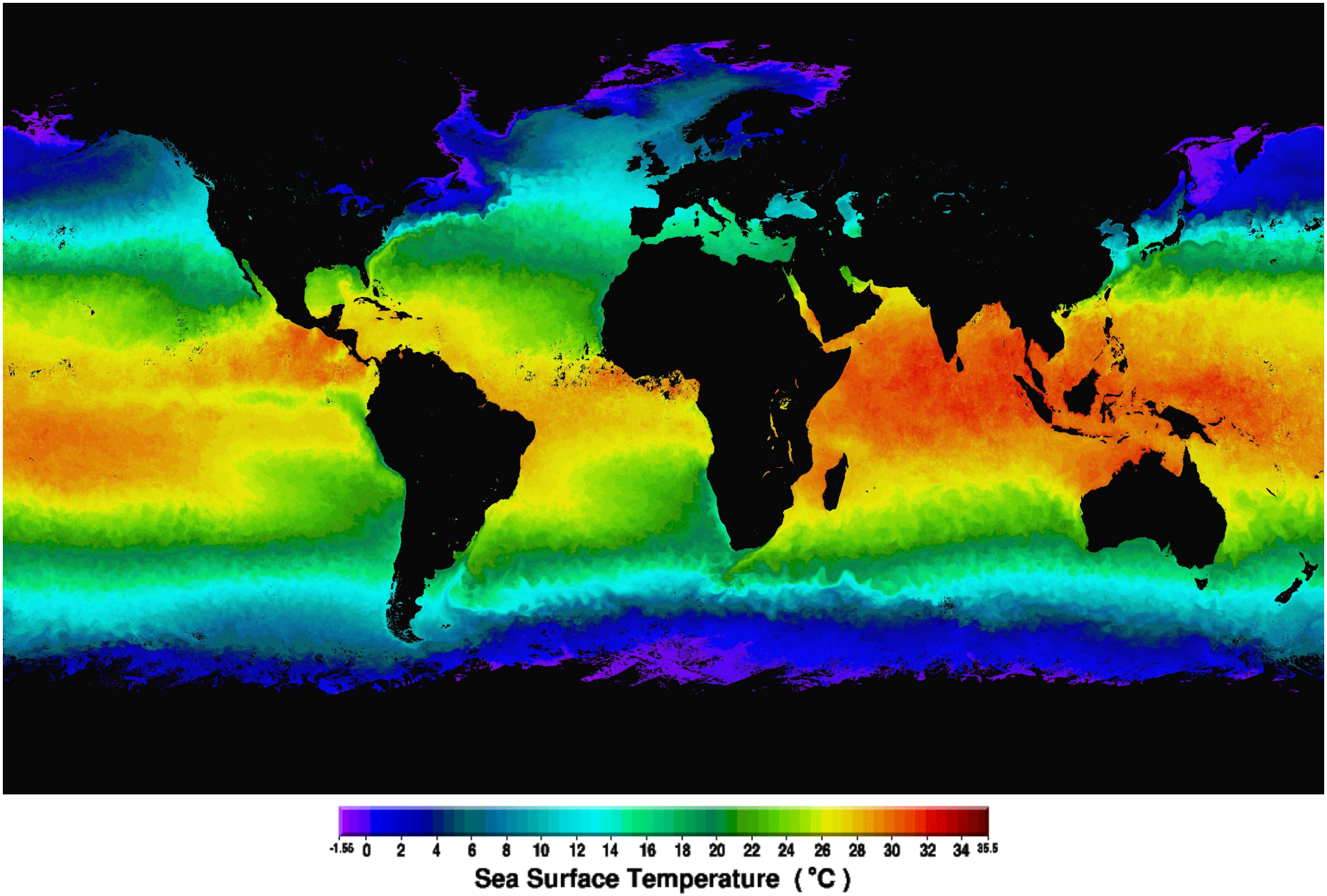
Bloom fine-scale structure

MODIS SEA SURFACE TEMPERATURE

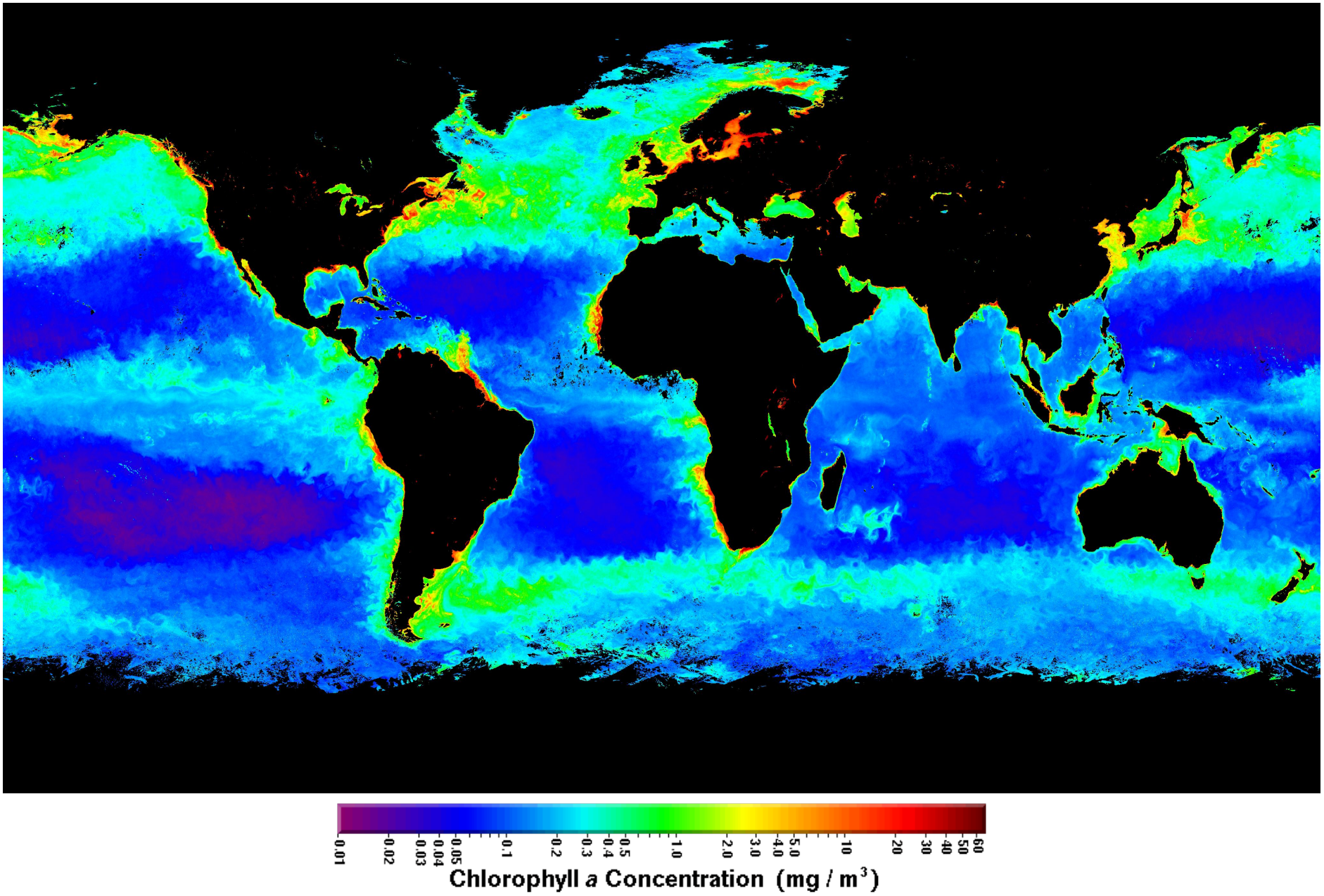


H351.001 11/92

Aqua MODIS Sea Surface Temperature, April 2004

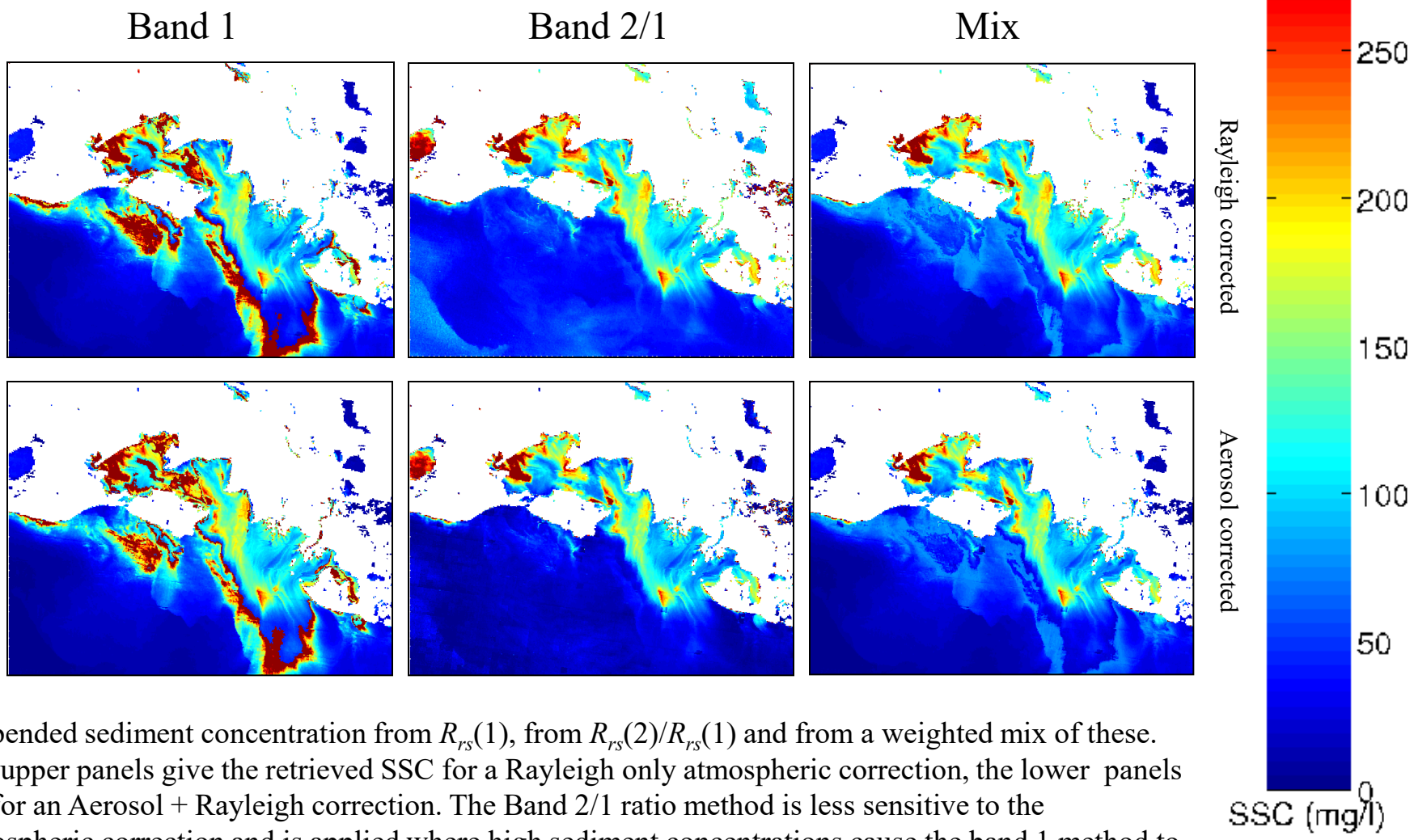


Aqua MODIS Chlorophyll Concentration, April 2004



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

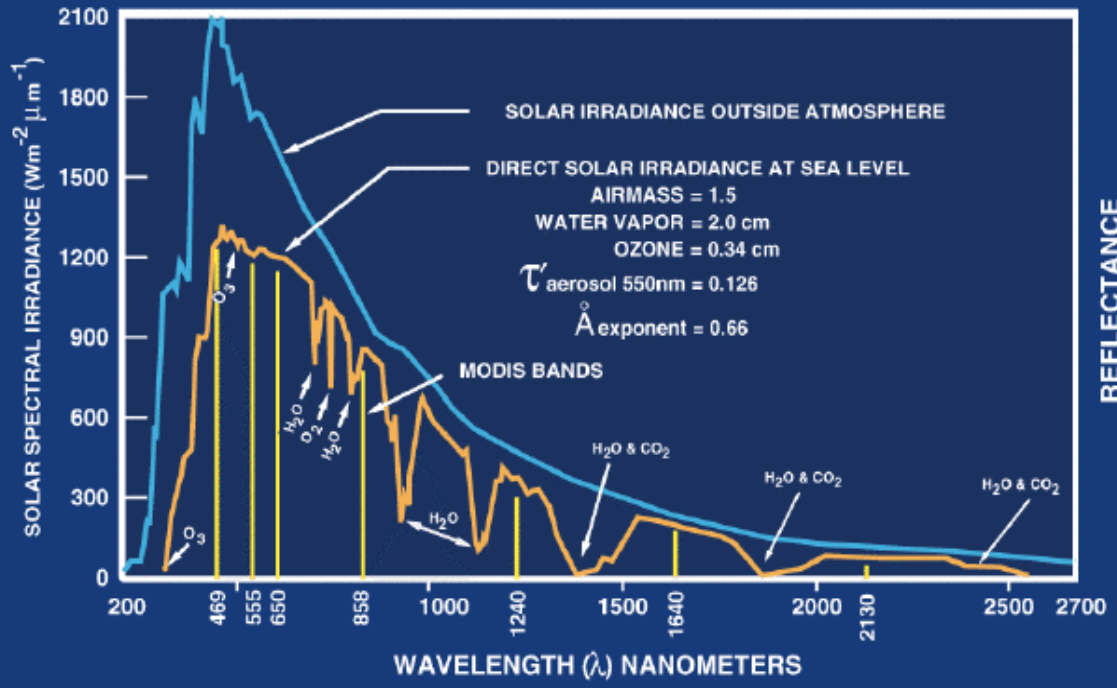
Suspended Sediment Concentration

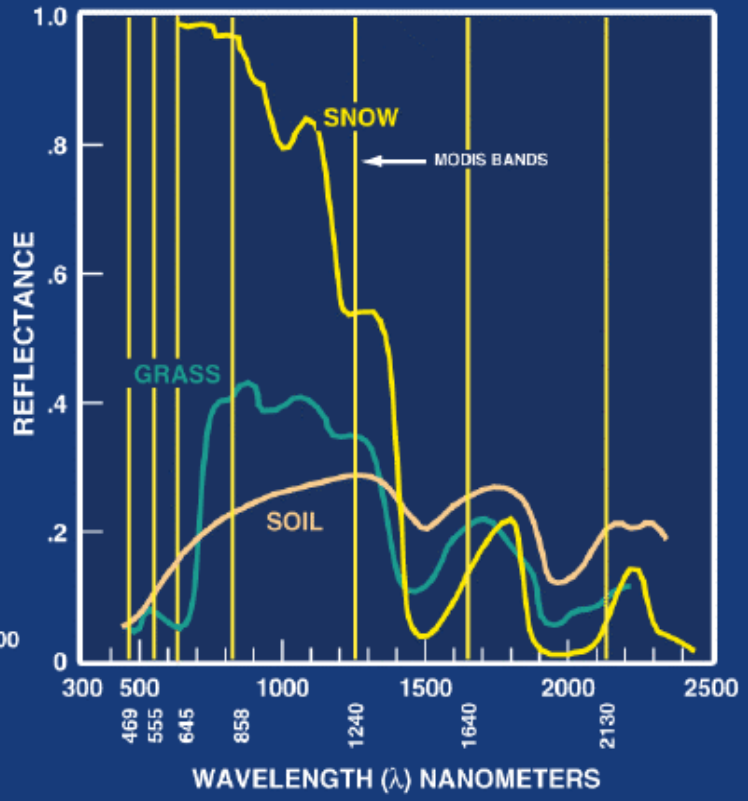


Suspended sediment concentration from $R_{rs}(1)$, from $R_{rs}(2)/R_{rs}(1)$ and from a weighted mix of these. The upper panels give the retrieved SSC for a Rayleigh only atmospheric correction, the lower panels are for an Aerosol + Rayleigh correction. The Band 2/1 ratio method is less sensitive to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

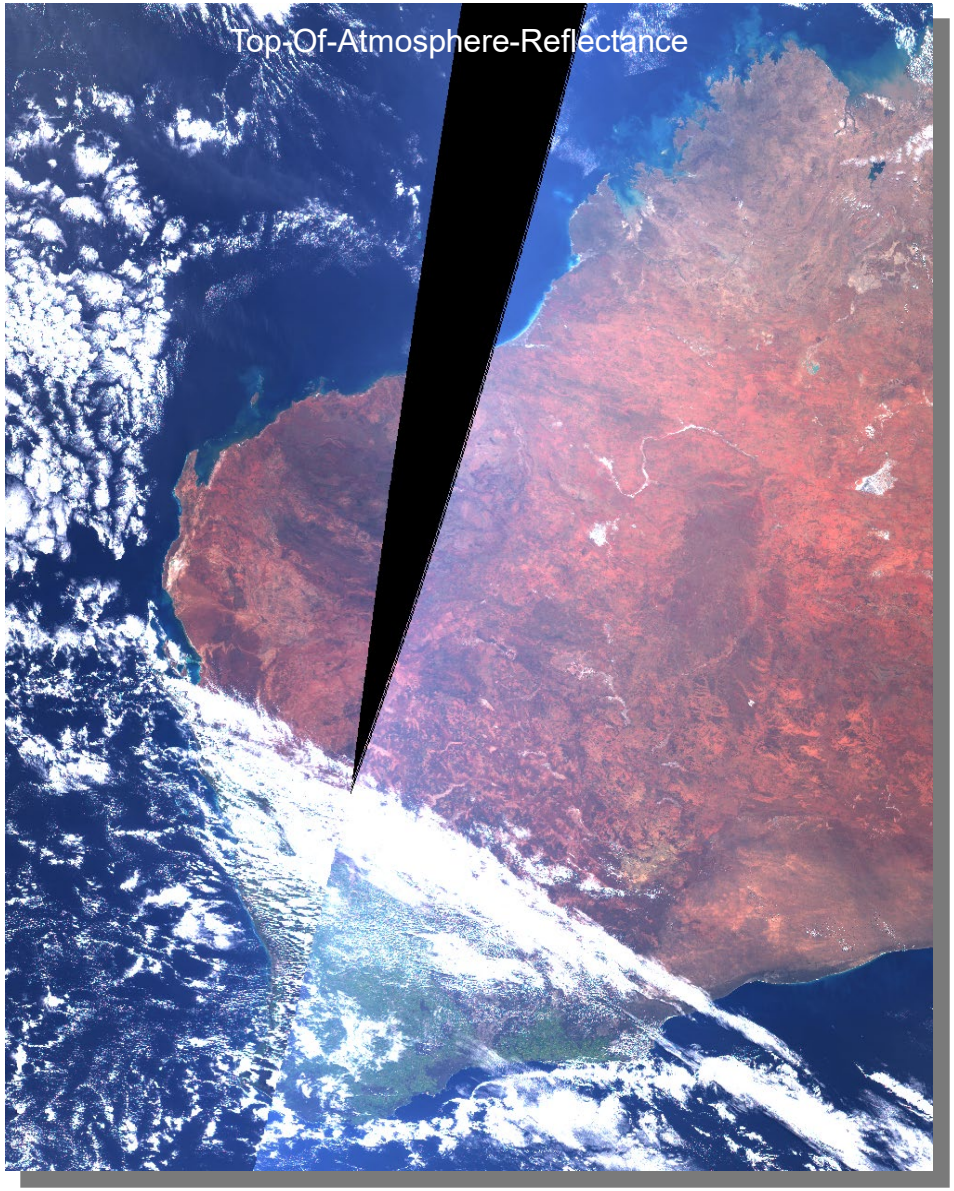
MODIS Land/Surface Applications

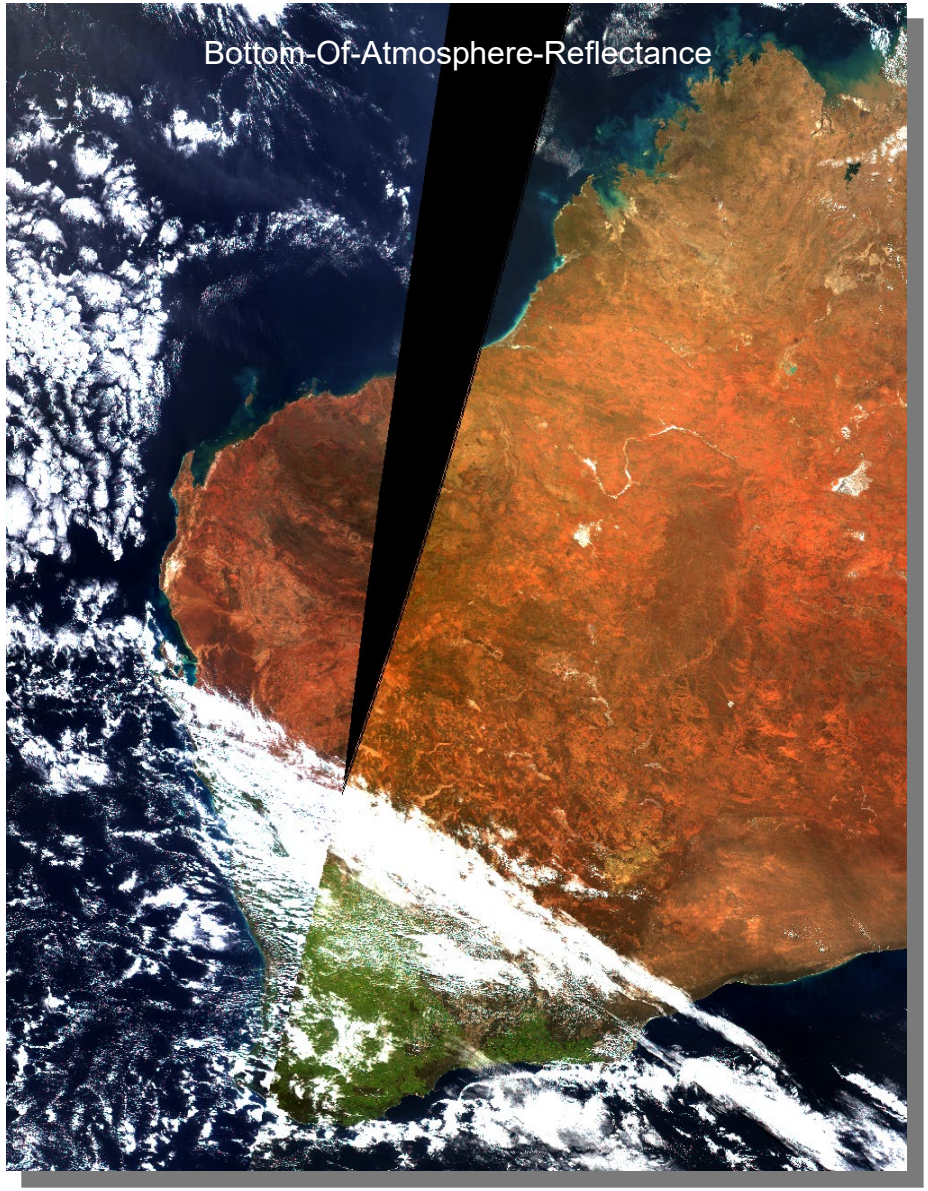
LAND-SOLAR RADIATION





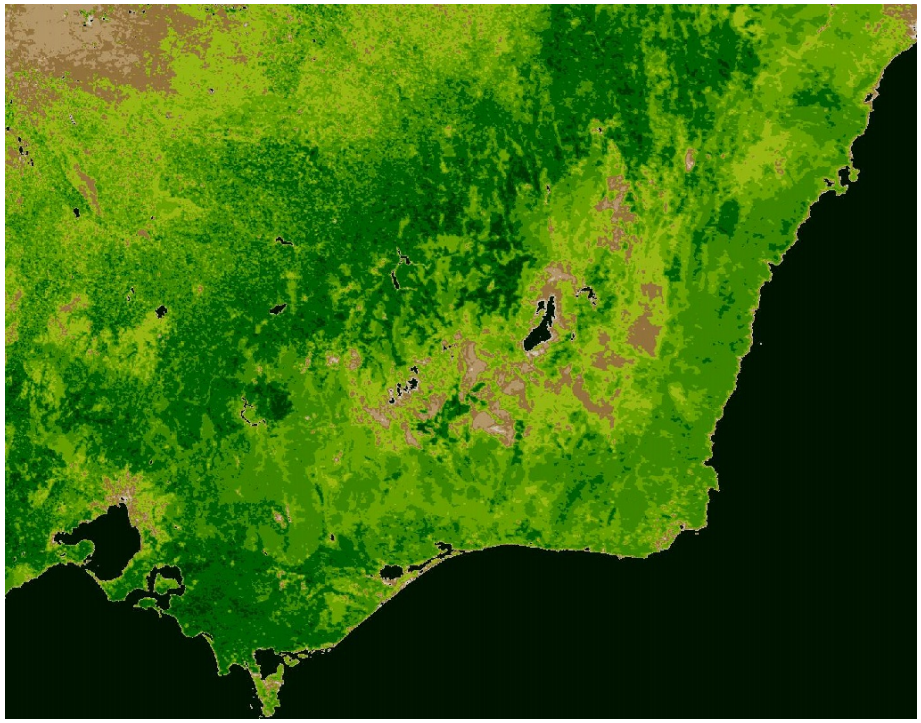
Atmospheric contribution is removed to retrieve surface properties



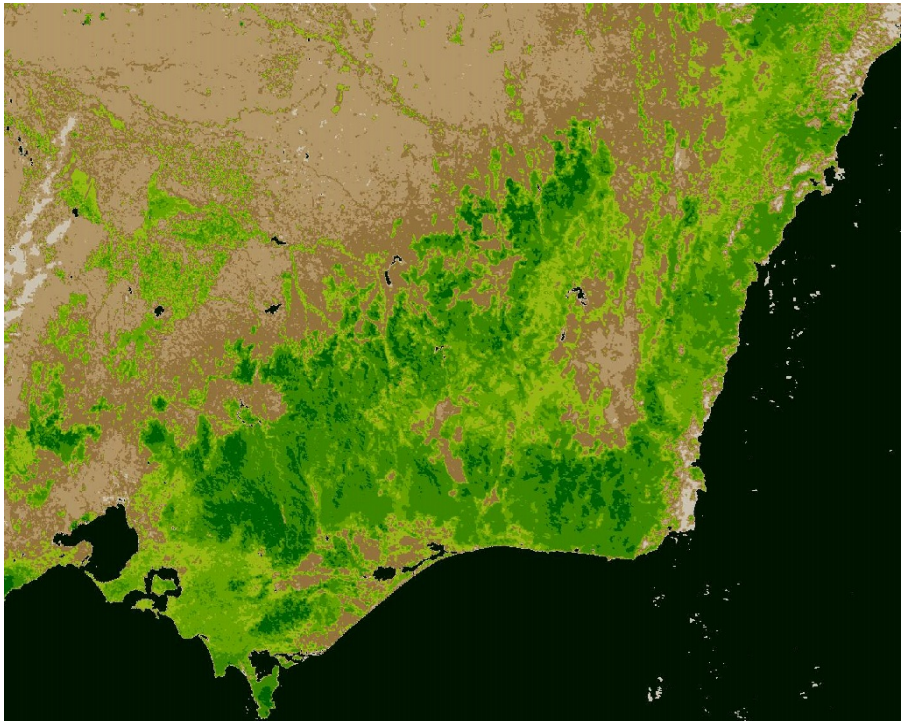


Terra MODIS 09/09/2003 01:27UTC 03:04UTC

NDVI South East Australia

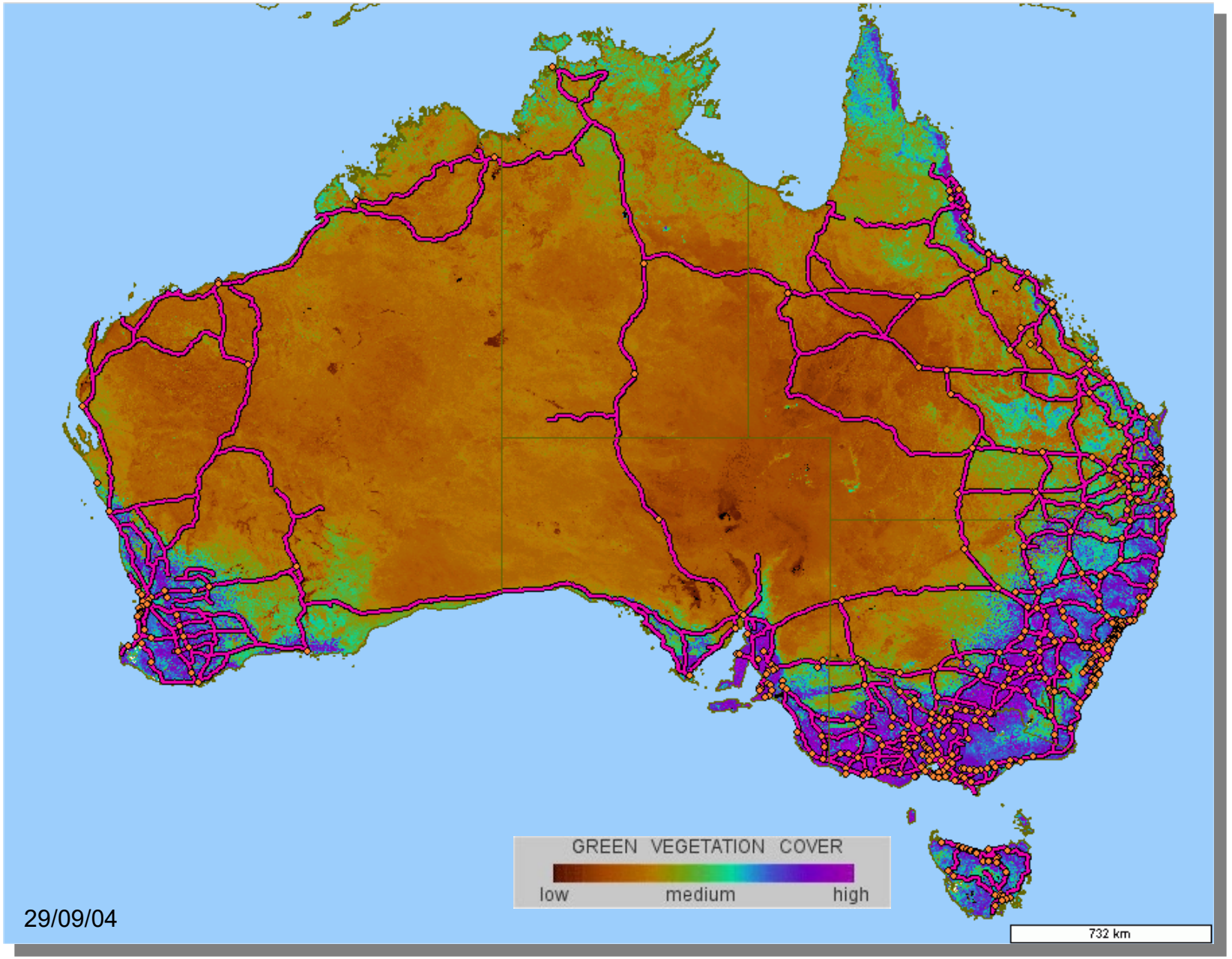


Nov 2003



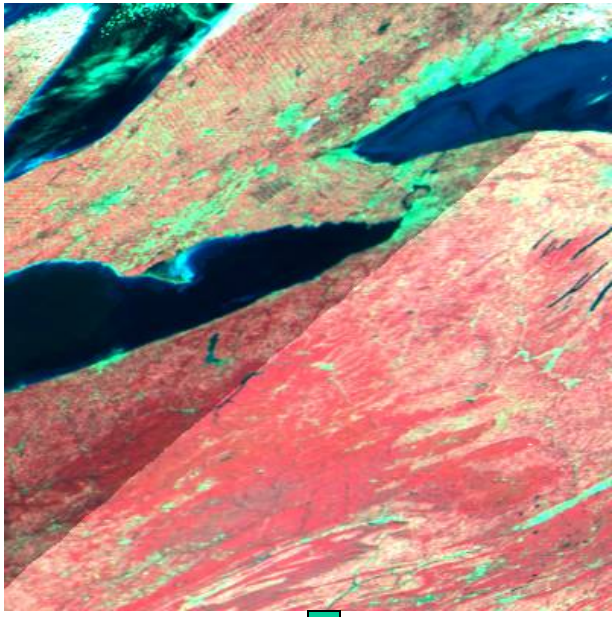
Apr 2004

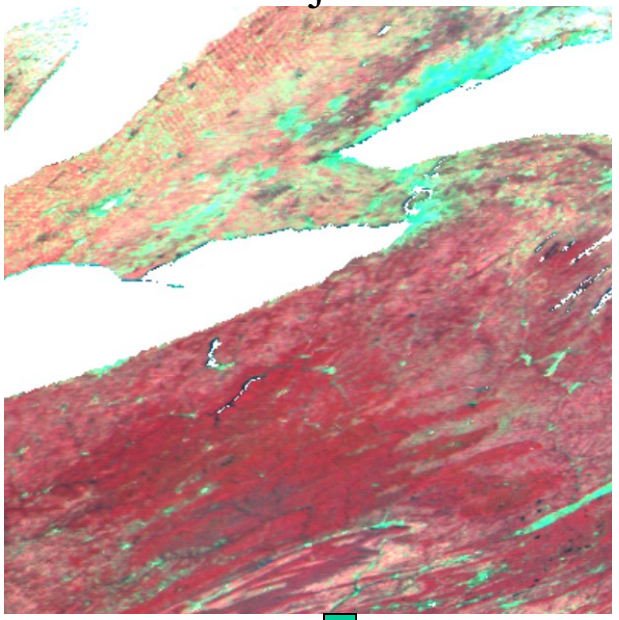
Australia NDVI Composite Map



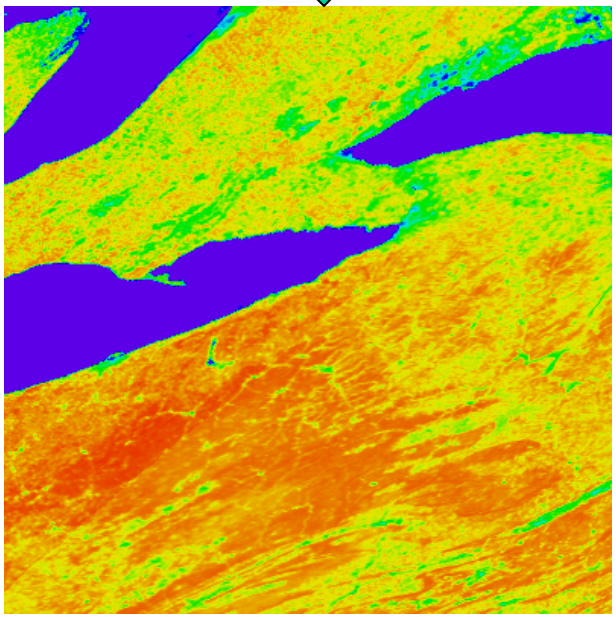
Surface Reflectance

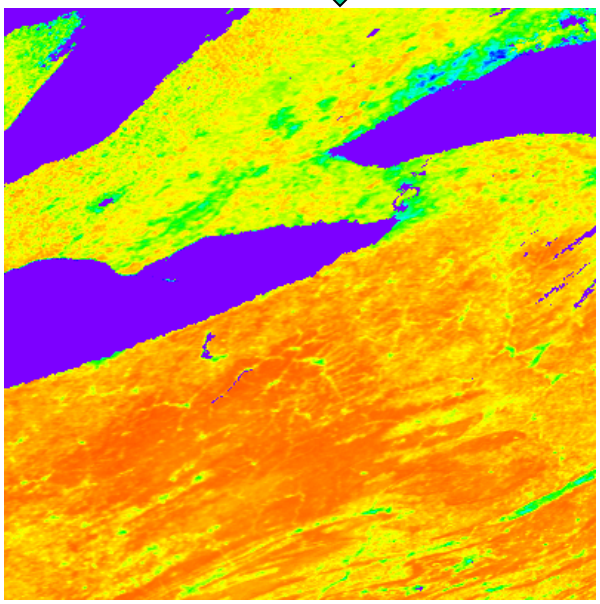
Nadir BRDF-Adjusted Reflectance





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





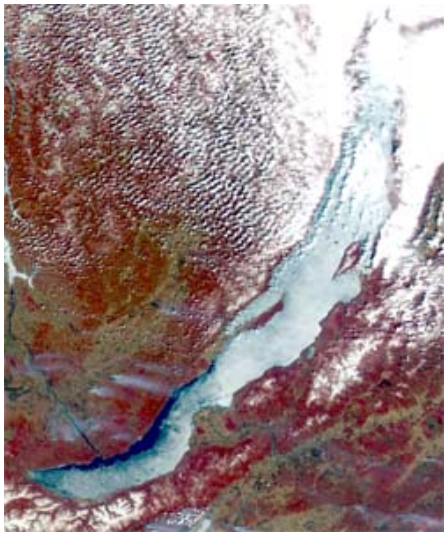
NDVI

0.0 1.0

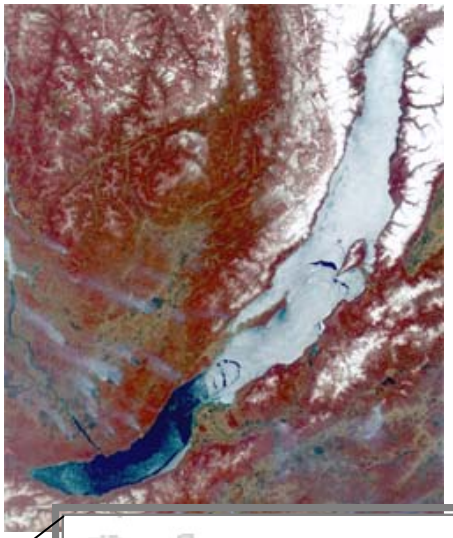
Baikal lake ice monitoring.

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

2003-05-02



2003-05-06



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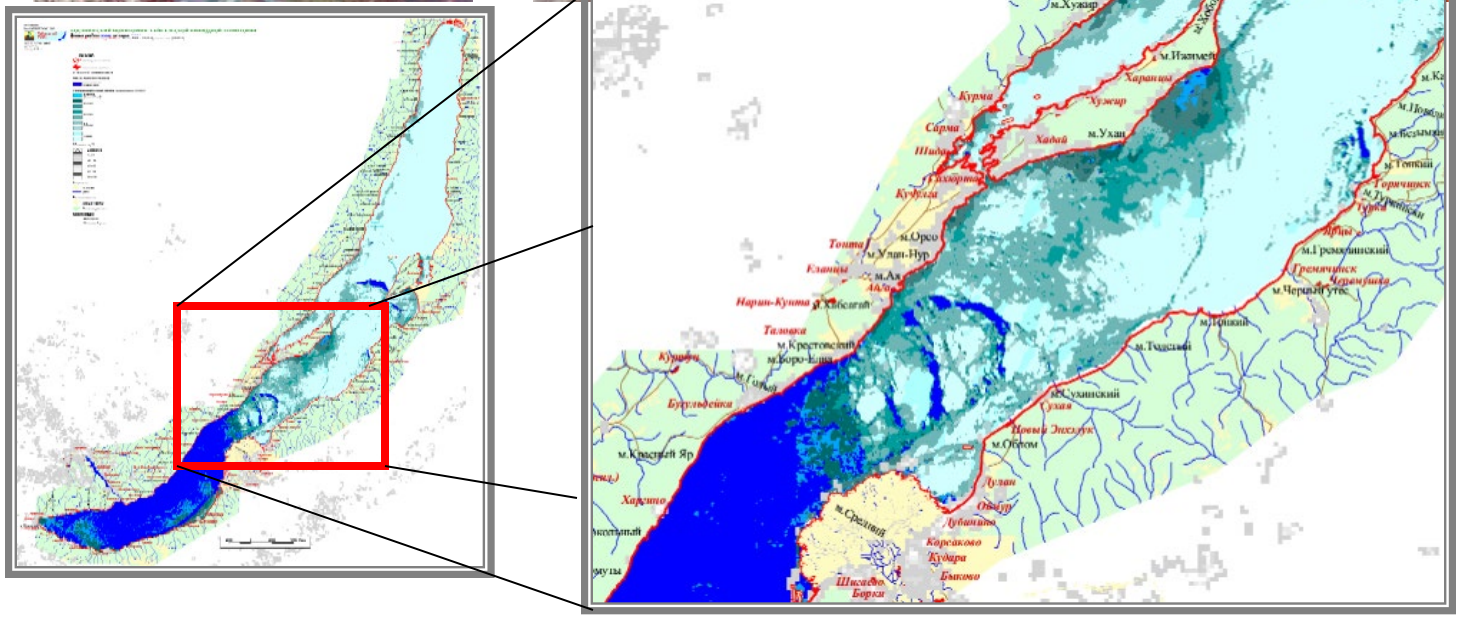
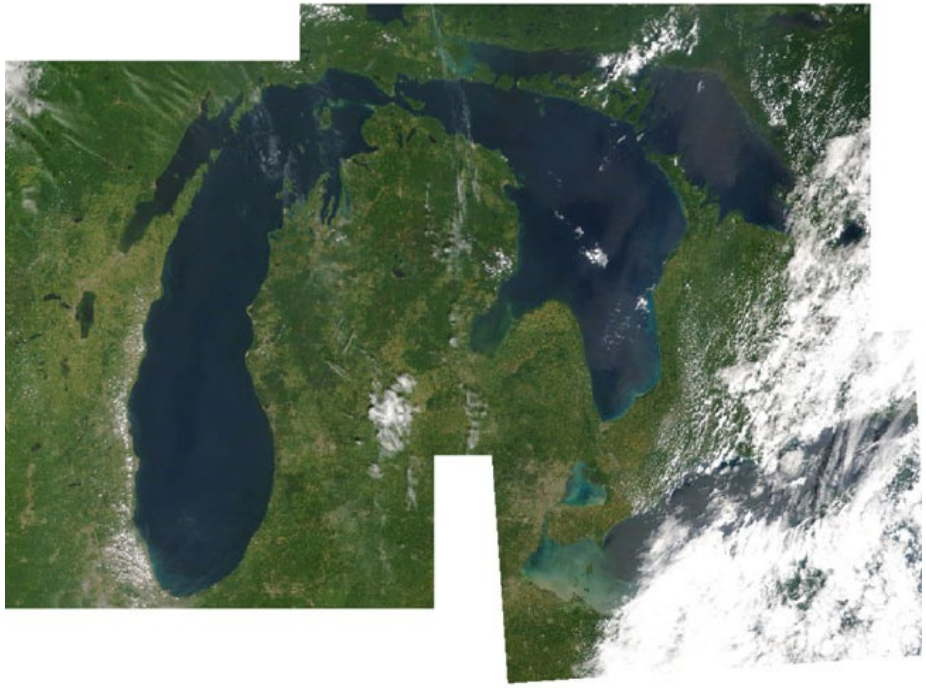


Realtime GeoTIFF products for Ice Monitoring

Terra and Aqua MODIS 250 meter true color images are produced daily at SSEC for the Great Lakes and Northeast Canada.

GeoTIFF format in UTM projection (GIS compatible).

NOAA Coastwatch, National Ice Center, and Canadian Ice Service download the images in realtime.



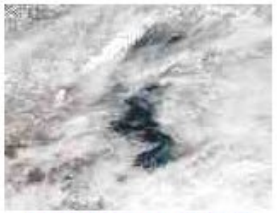
NOAA CoastWatch - Great Lakes Region

Lake Michigan MODIS Imagery - True Color, 250 m Resolution

Current time: 03/24/2005 14:17:55 GMT

Page: 1 of 4

1 2 3 4


03/23/2005 18:17 GMT


03/23/2005 16:38 GMT

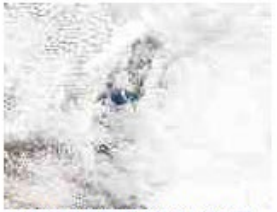

03/22/2005 19:12 GMT


03/22/2005 17:33 GMT


03/22/2005 15:56 GMT

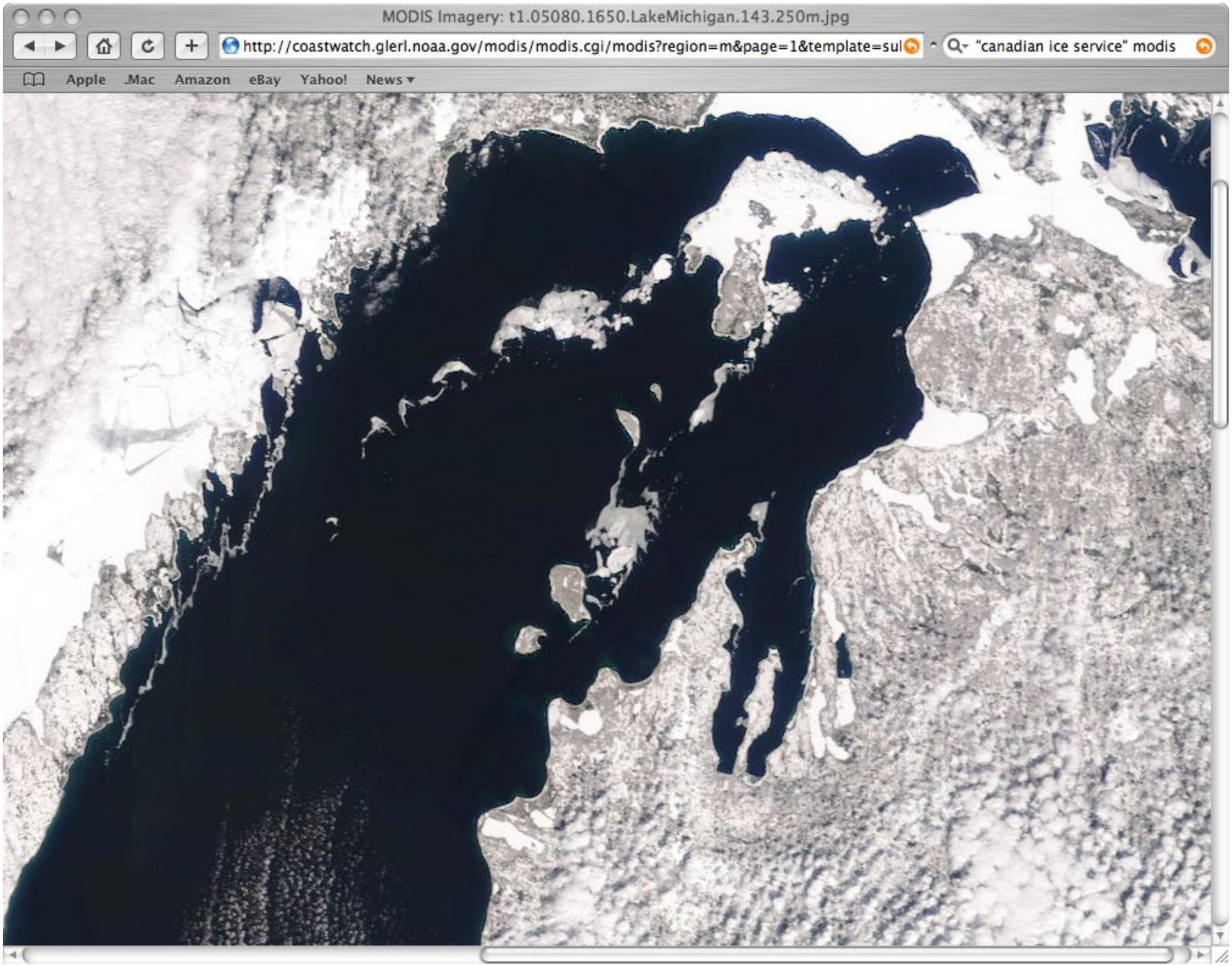

03/21/2005 18:29 GMT


03/21/2005 16:50 GMT


03/20/2005 19:24 GMT

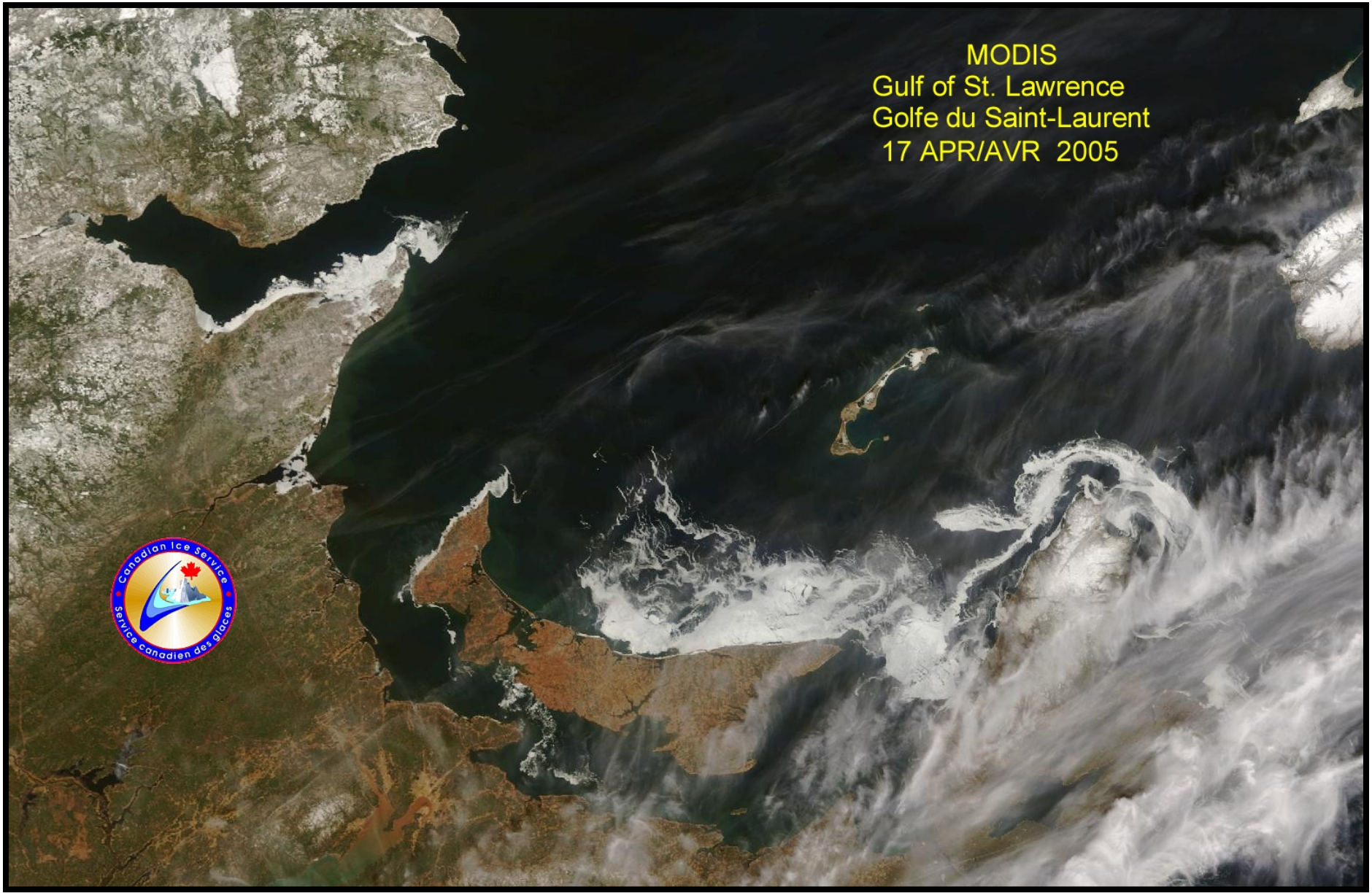

03/20/2005 16:08 GMT

MODIS data acquired by direct broadcast and processed at the Space Science and Engineeering Center, University of Wisconsin-Madison

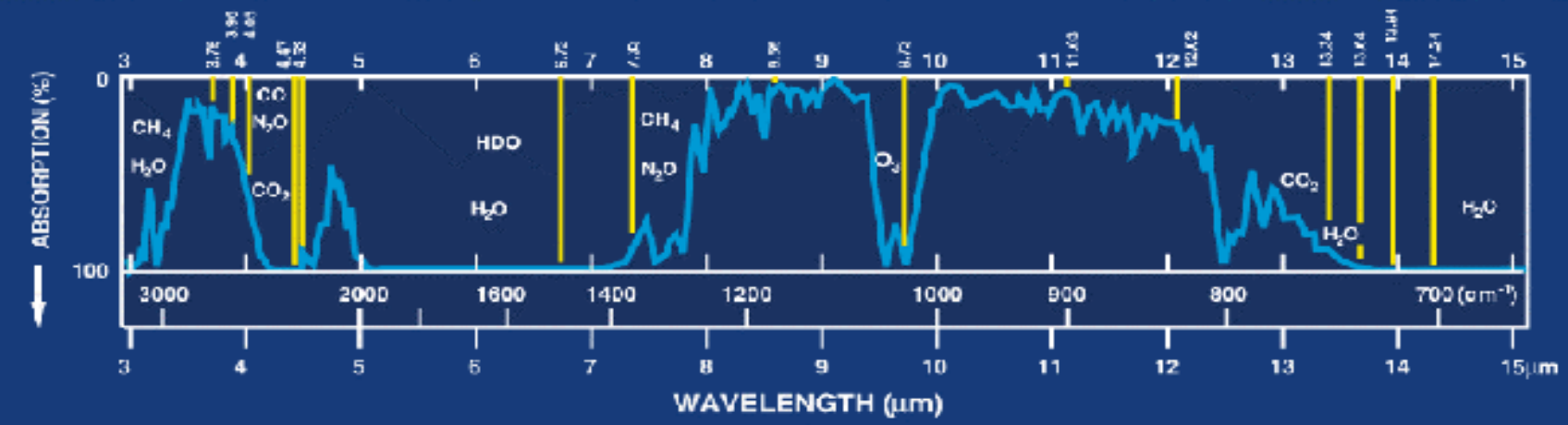

MODIS Imagery: t1.05080.1650.LakeMichigan.143.250m.jpg
http://coastwatch.glerl.noaa.gov/modis/modis.cgi/modis?region=m&page=1&template=sul
"canadian ice service" modis
Apple
.Mac
Amazon
eBay
Yahoo!
News

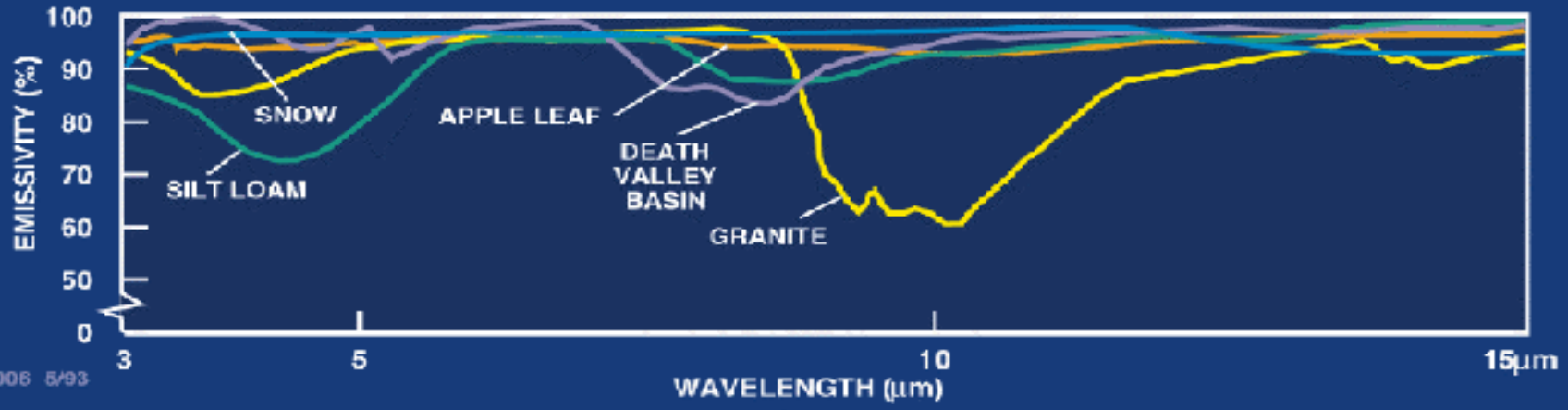
Canadian Ice Service Example

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



LAND - THERMAL RADIATION

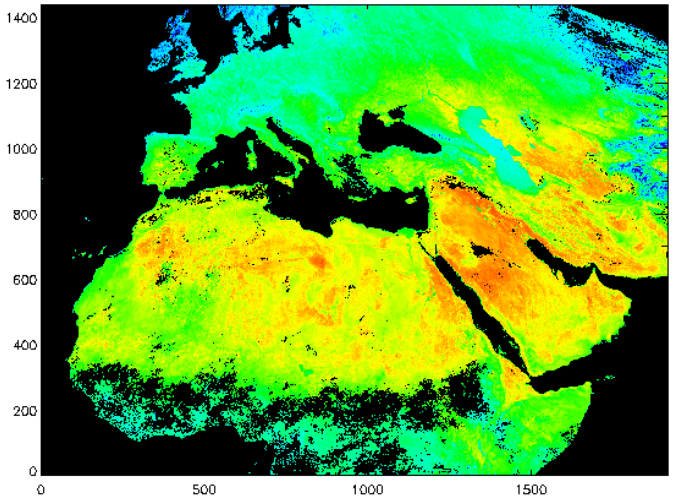


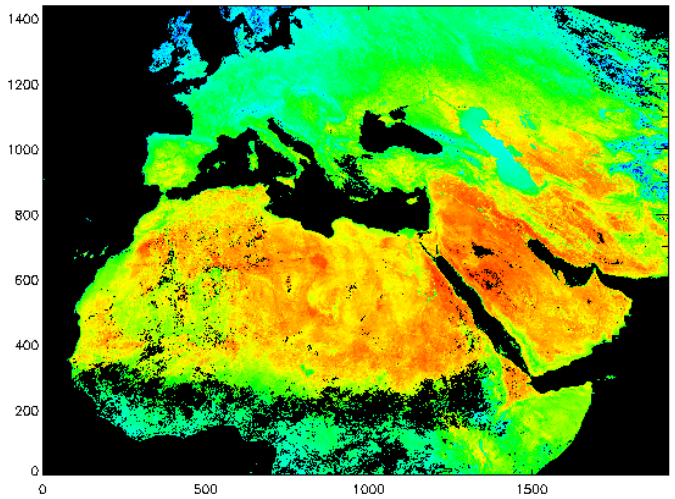


C351.006 5/93

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

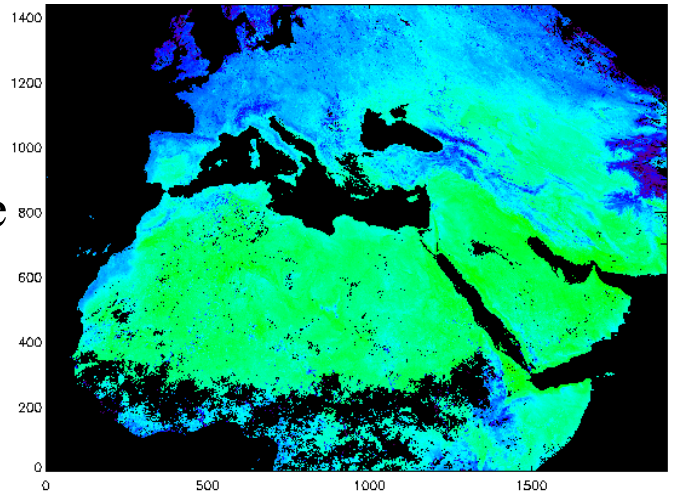
daytime Terra

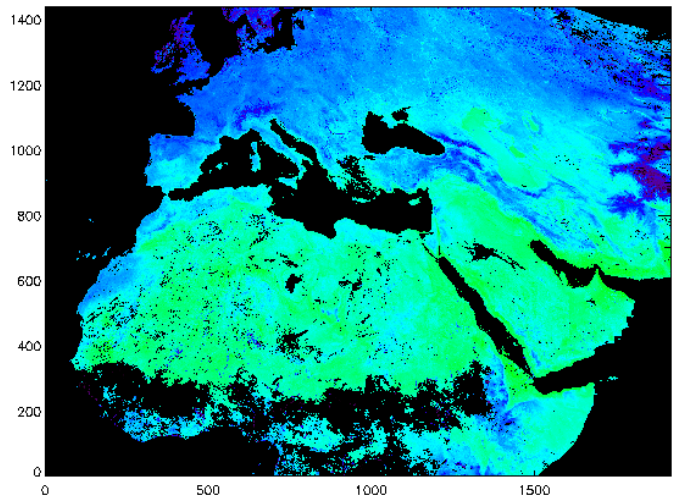




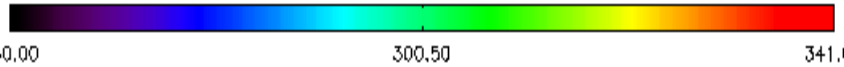
daytime Aqua

nighttime Terra

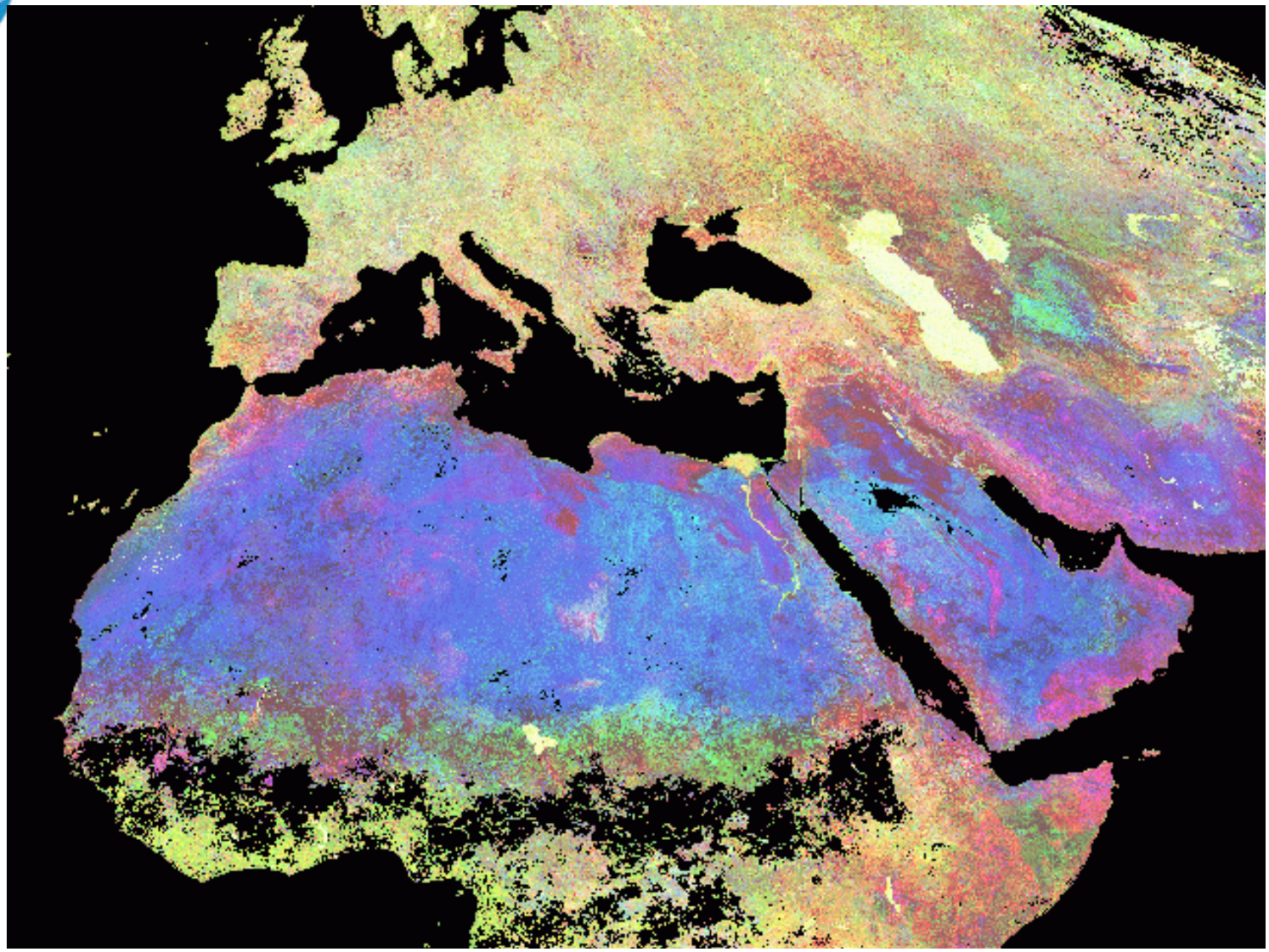




nighttime Aqua

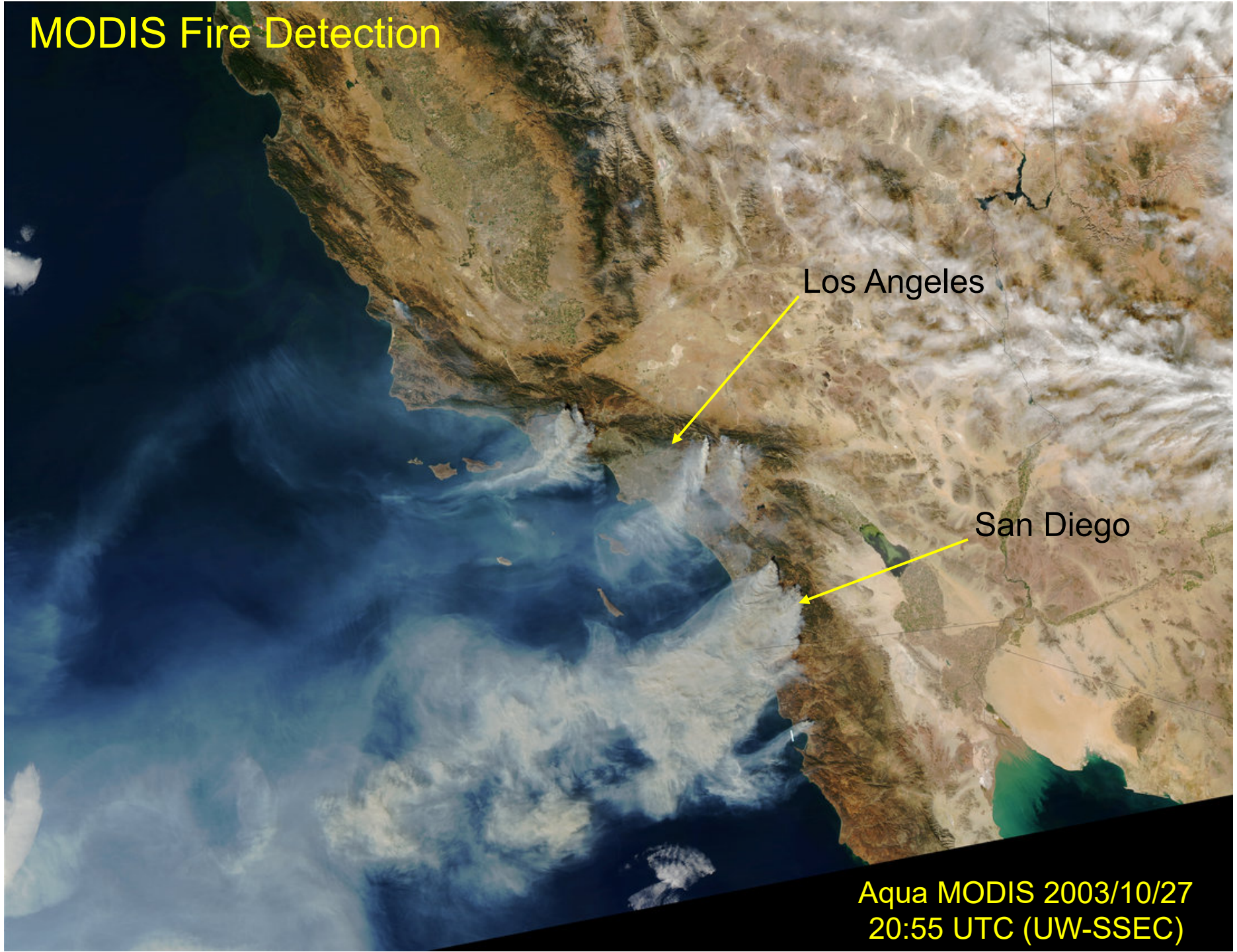


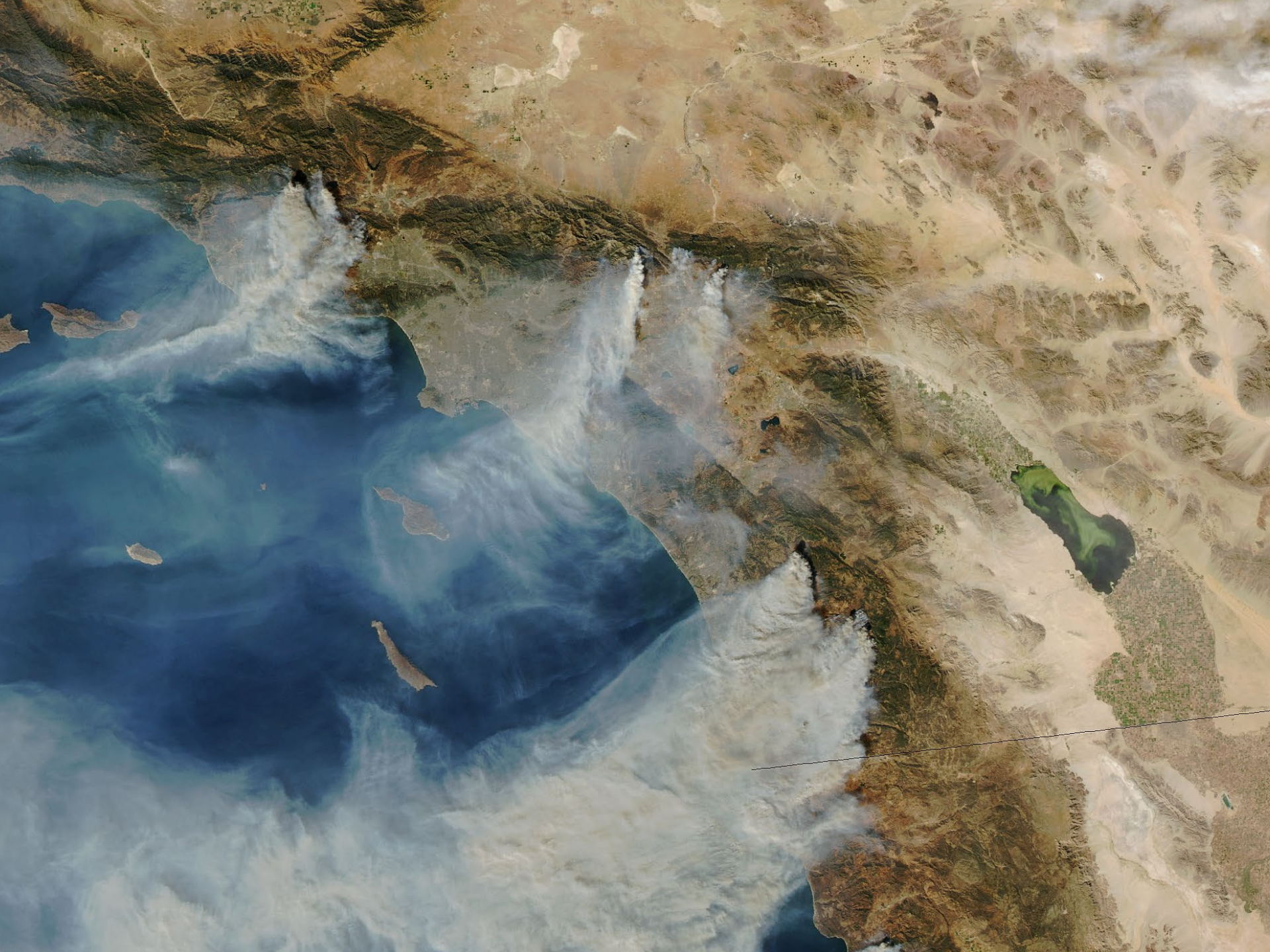
Surface emissivities retrieved by Terra and Aqua MODIS



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

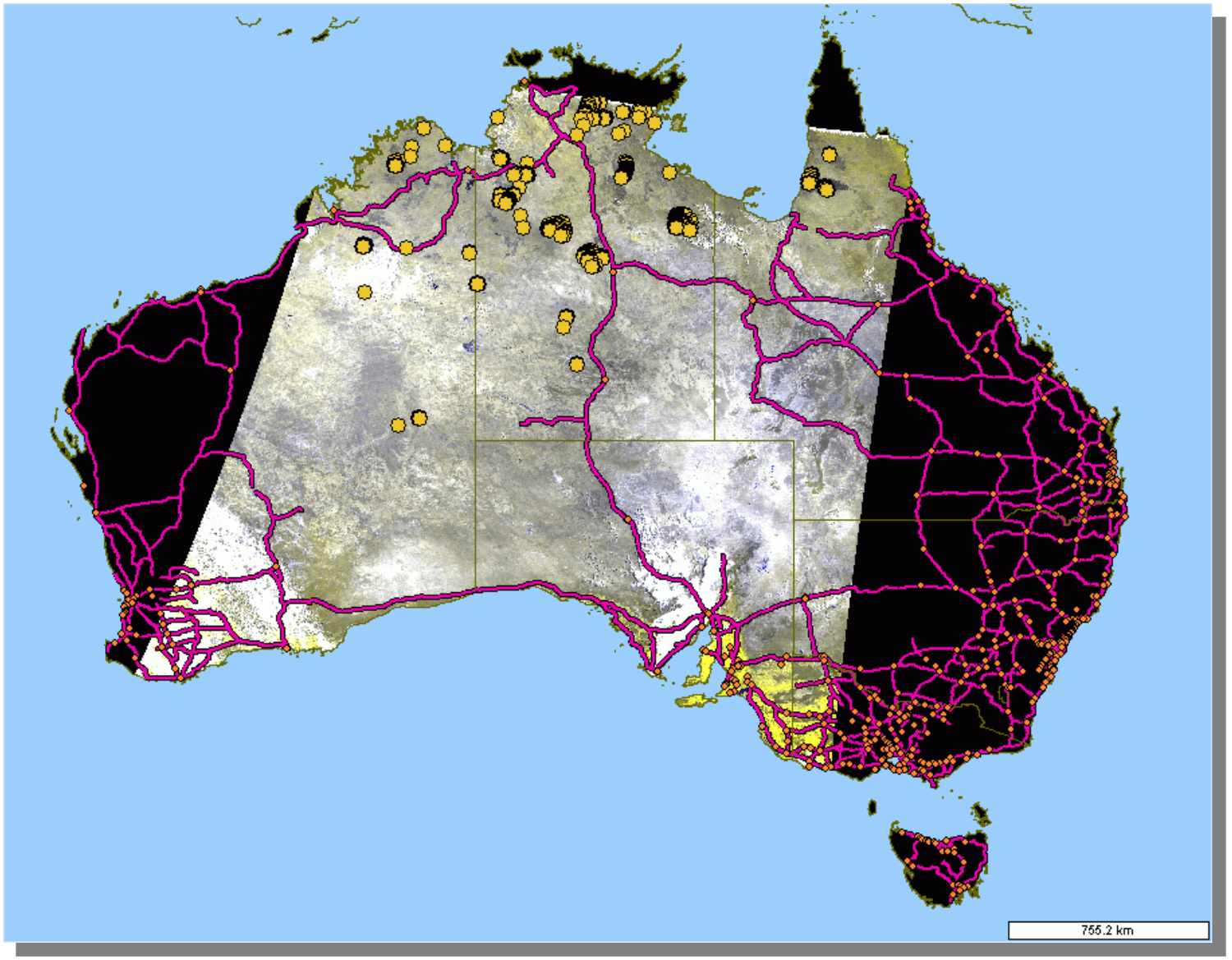

MODIS Fire Detection
Los Angeles
San Diego
Aqua MODIS 2003/10/27
20:55 UTC (UW-SSEC)



Near Real Time Hotspots and Images for Burnt Area, Smoke and Cloud Identification

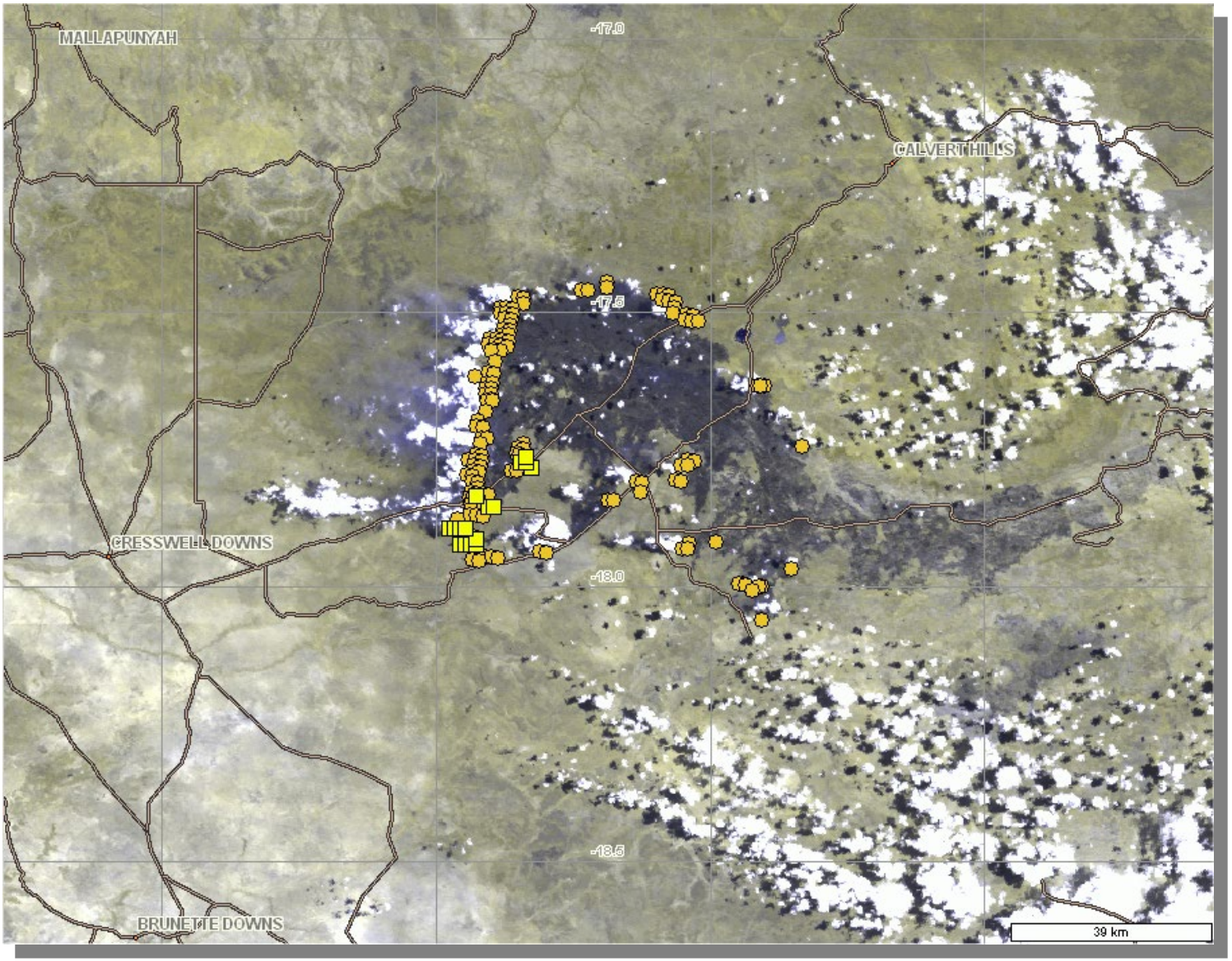
available on-line within 1h of acquisition

06/10/04
09:20WST



Near Real Time Hotspots and Images for Burnt Area, Smoke and Cloud Identification

available on-line within 1h of acquisition

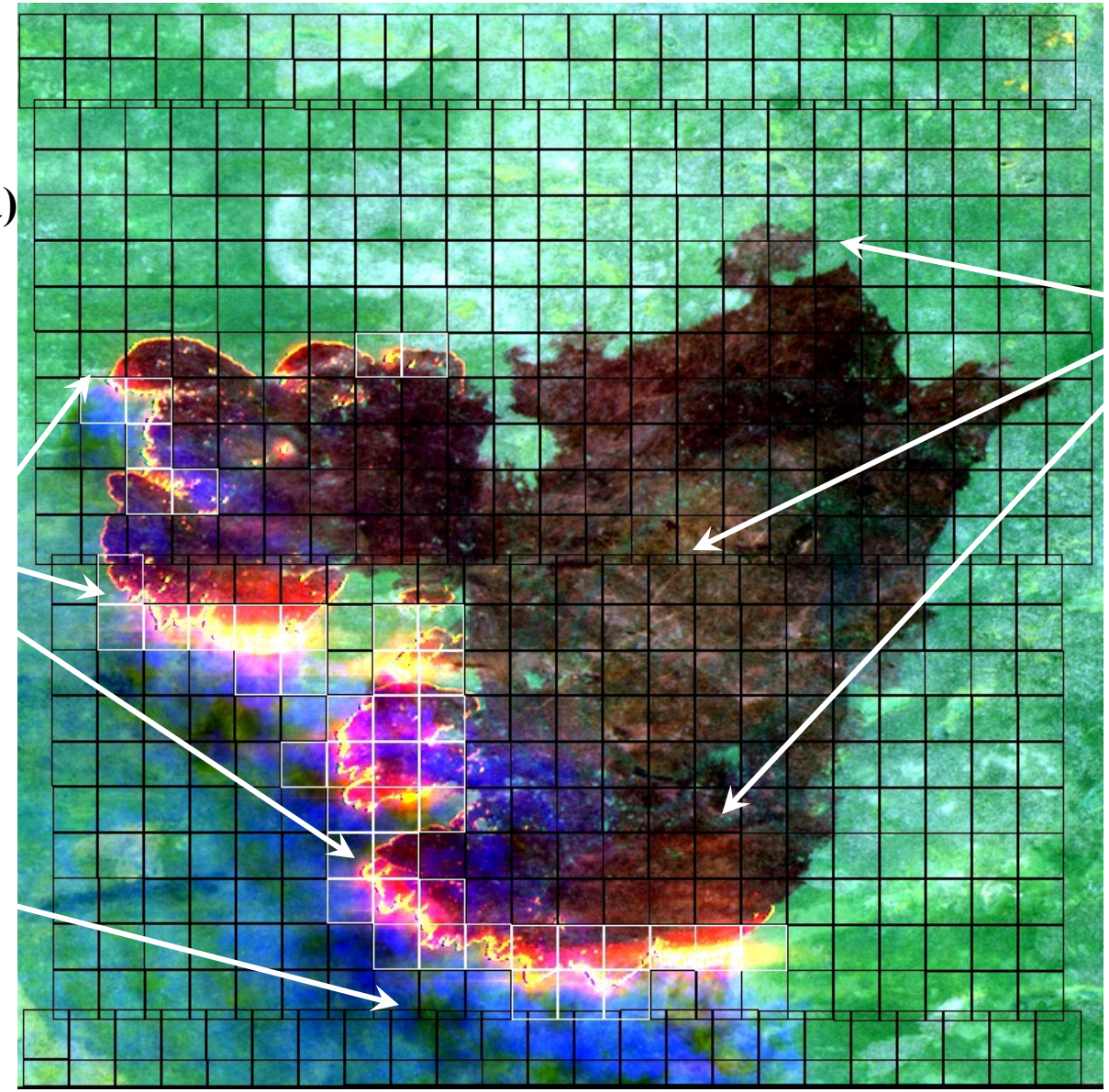


06/10/04
09:20WST

Legend
- roads - primary GA
- roads - other
- city / town
- State Boundaries
- map grid - 1 degree
- NOAA FHS-00:00 to 06:00
- NOAA FHS-06:00 to 12:00
- NOAA FHS-12:00 to 18:00
- NOAA FHS-18:00 to 24:00
- MODIS FHS-00:00 to 06:00
- MODIS FHS-06:00 to 12:00
- MODIS FHS-12:00 to 18:00
- MODIS FHS-18:00 to 24:00

Active Fire Validation
Collocating ASTER and MODIS data

Aug 17 2001
09:08 UTC
18.8S 19.9 E
(NE Namibia)



White squares:
MODIS fire pixels

Burn scar

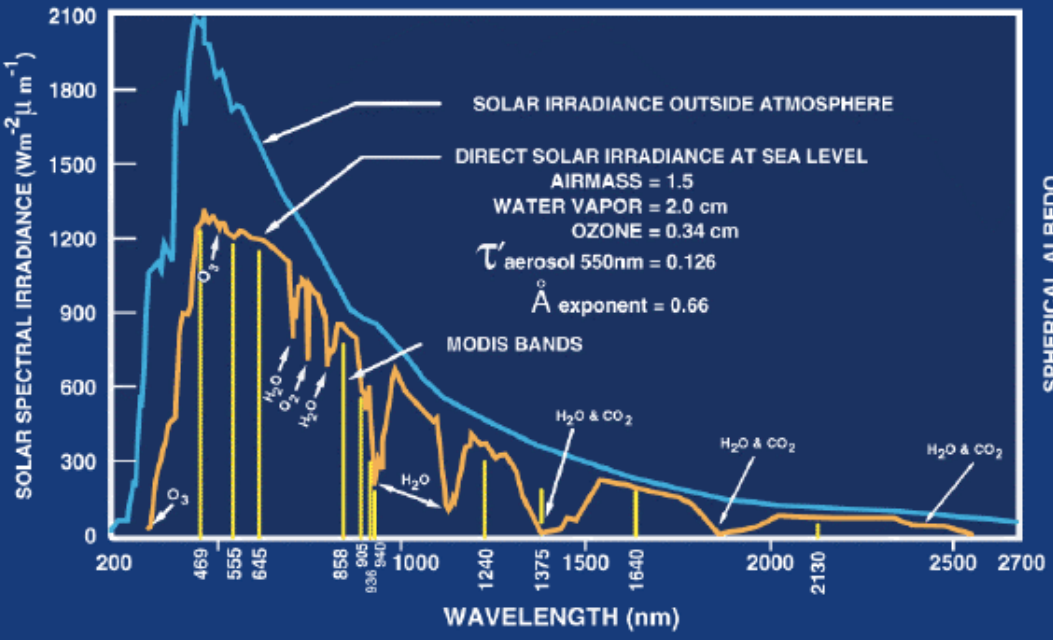
Fire fronts

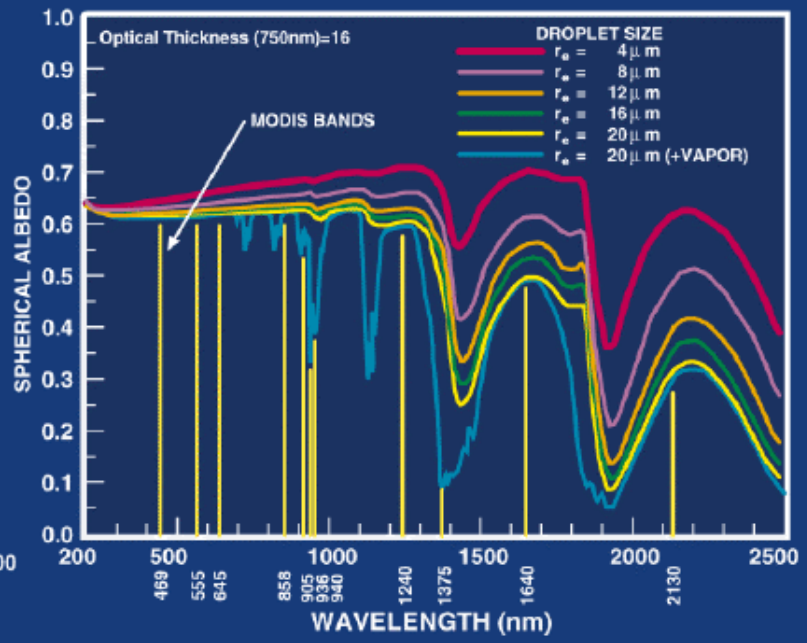
Smoke

R: 2.16 µm
G: 1.65 µm
B: 0.56 µm

MODIS Atmosphere Applications

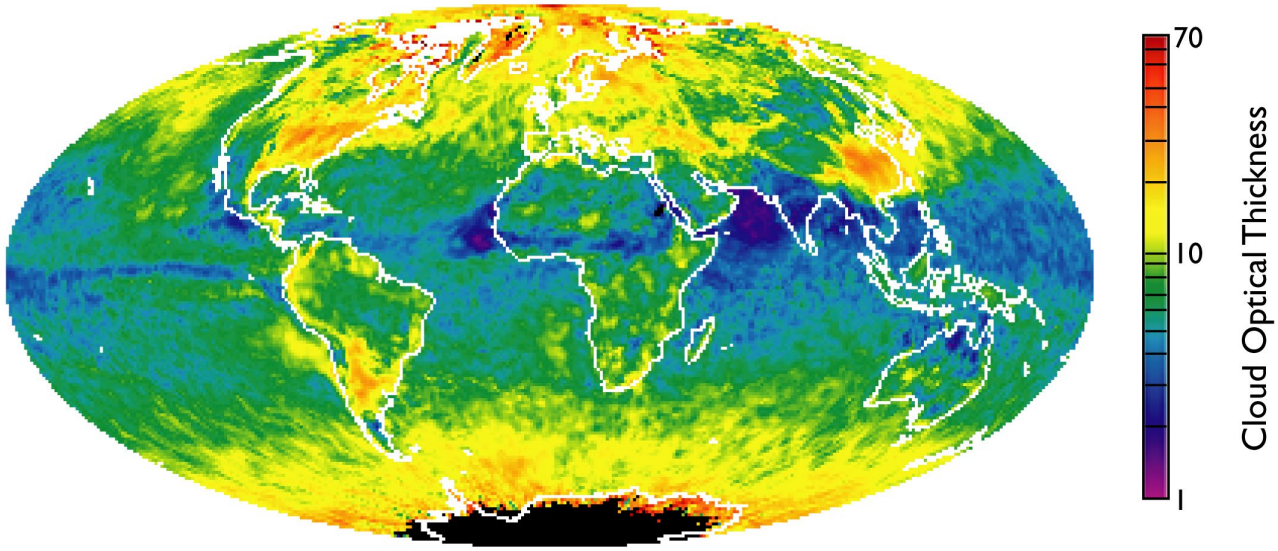
ATMOSPHERE-SOLAR RADIATION



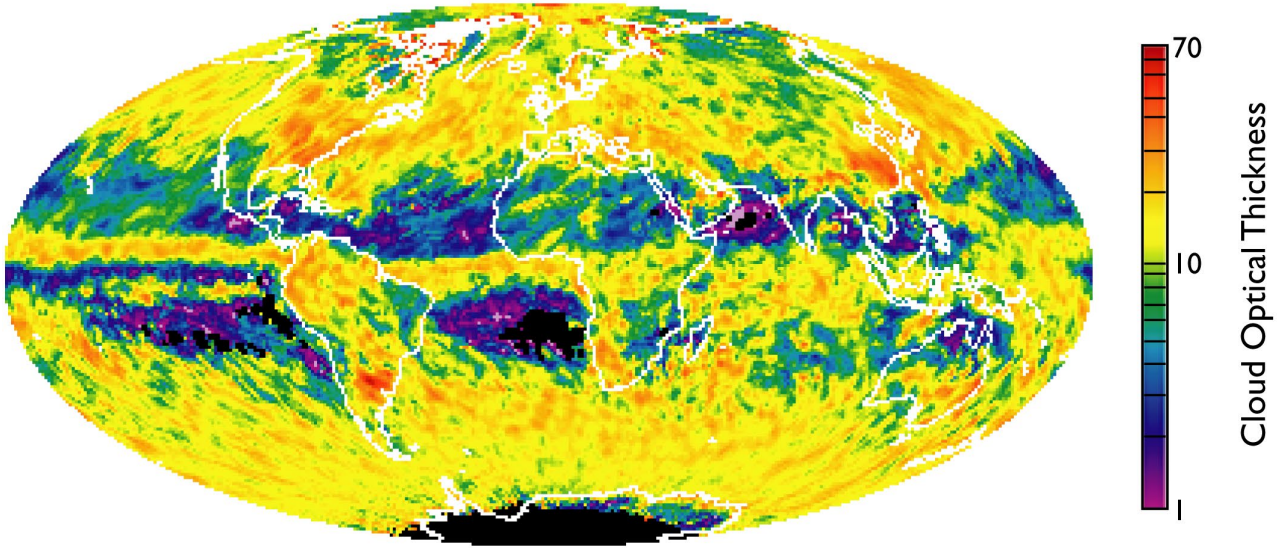


Monthly Mean Cloud Optical Thickness

Cloud Optical Thickness (Water)

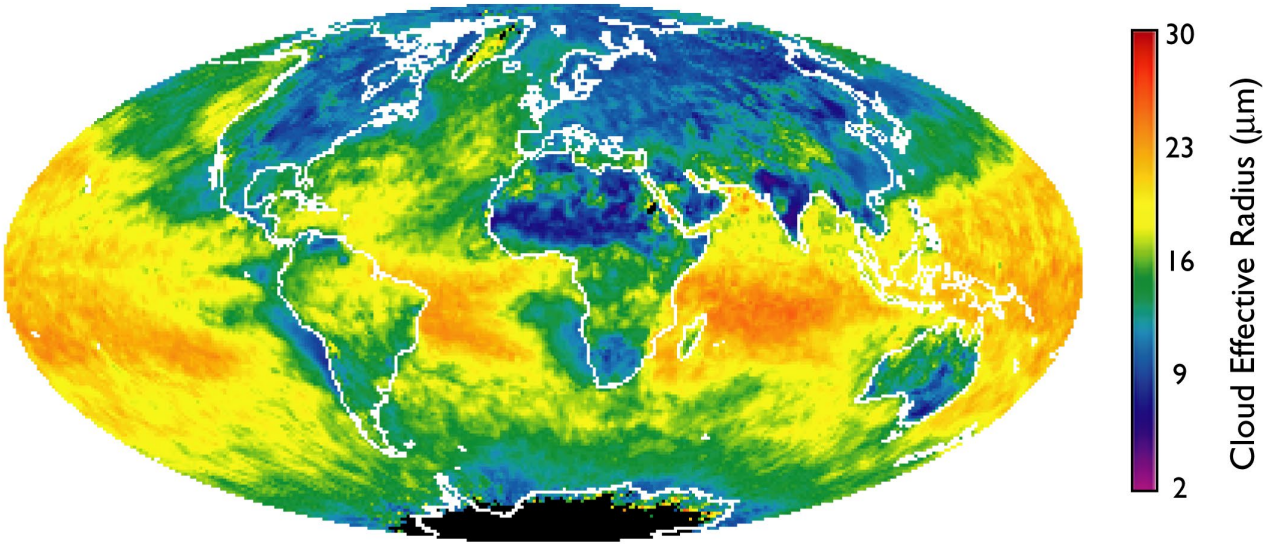


Cloud Optical Thickness (Ice)

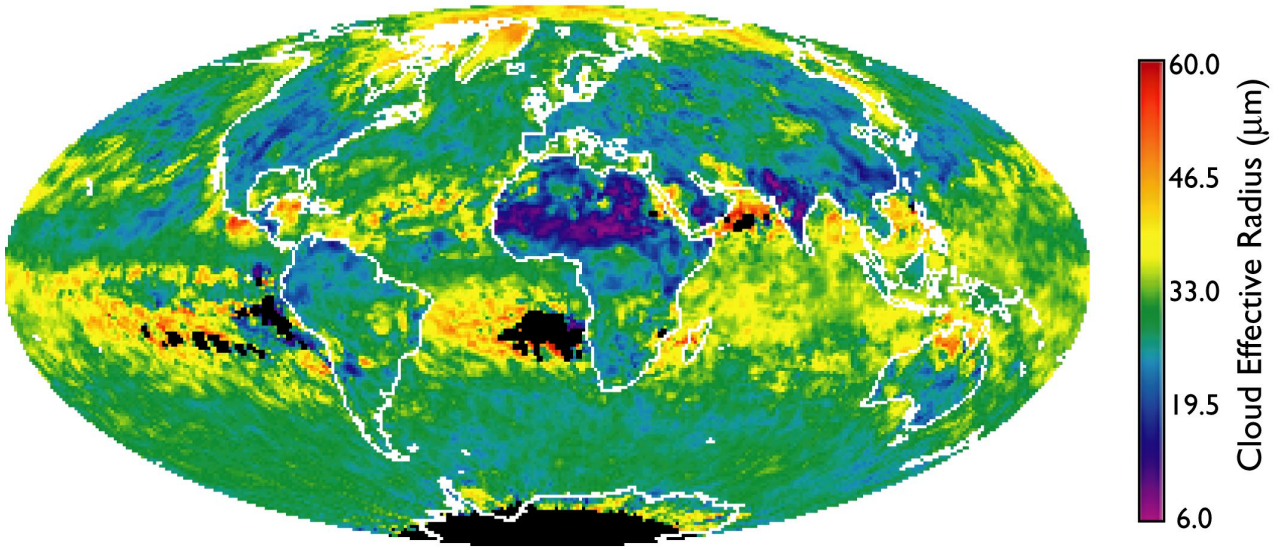


Monthly Mean Cloud Effective Radius

Cloud Effective Radius (Water)

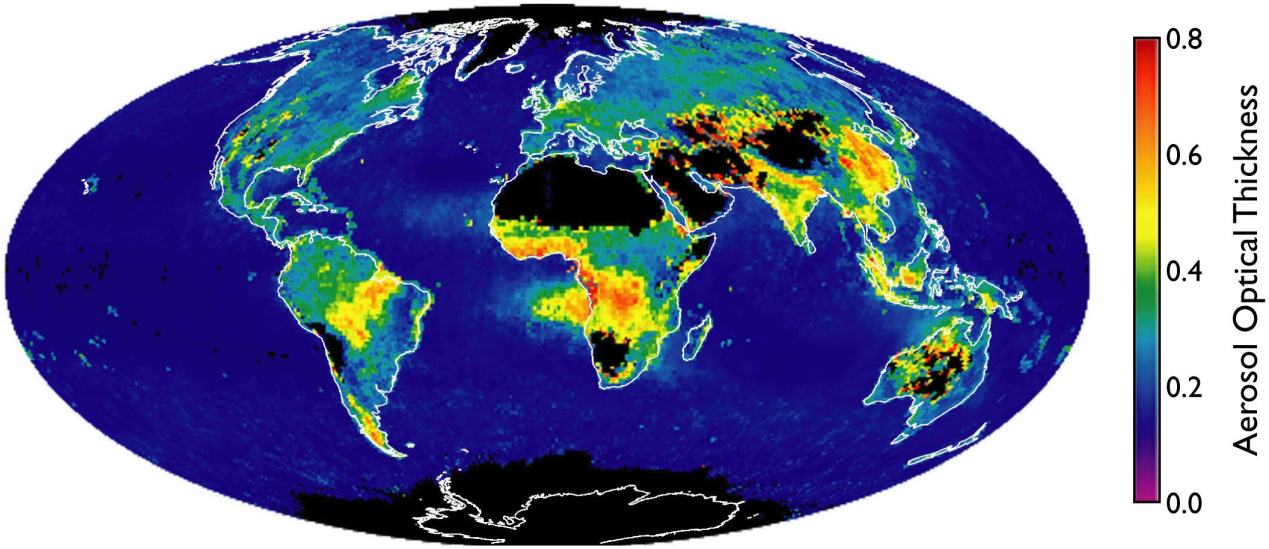


Cloud Effective Radius (Ice)

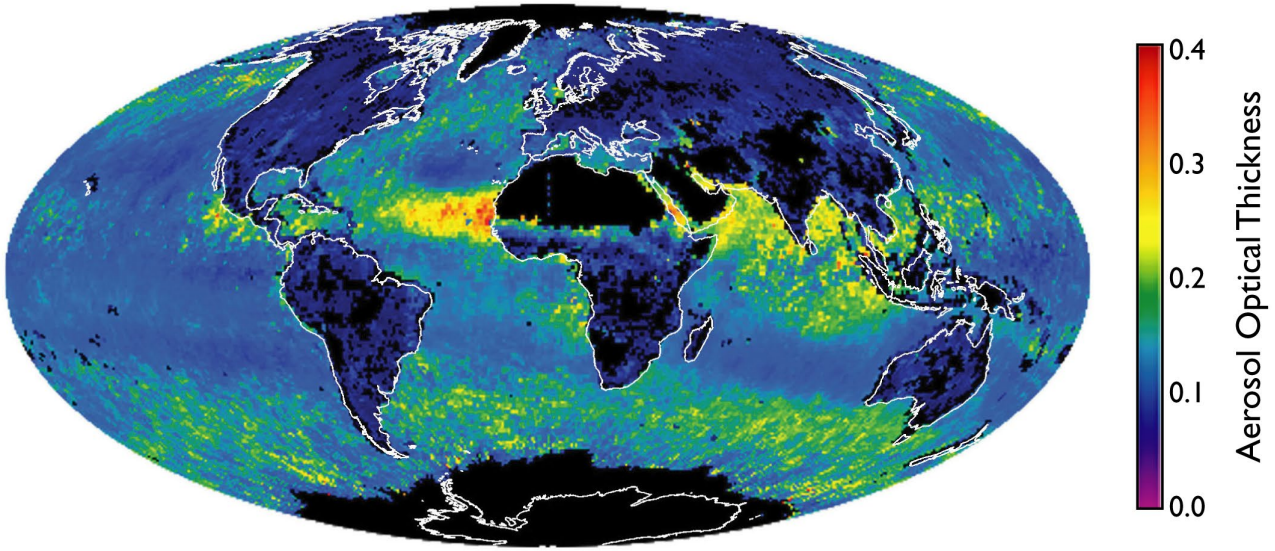


Monthly Mean Aerosol Optical Thickness

Aerosol Optical Thickness (Fine Mode)



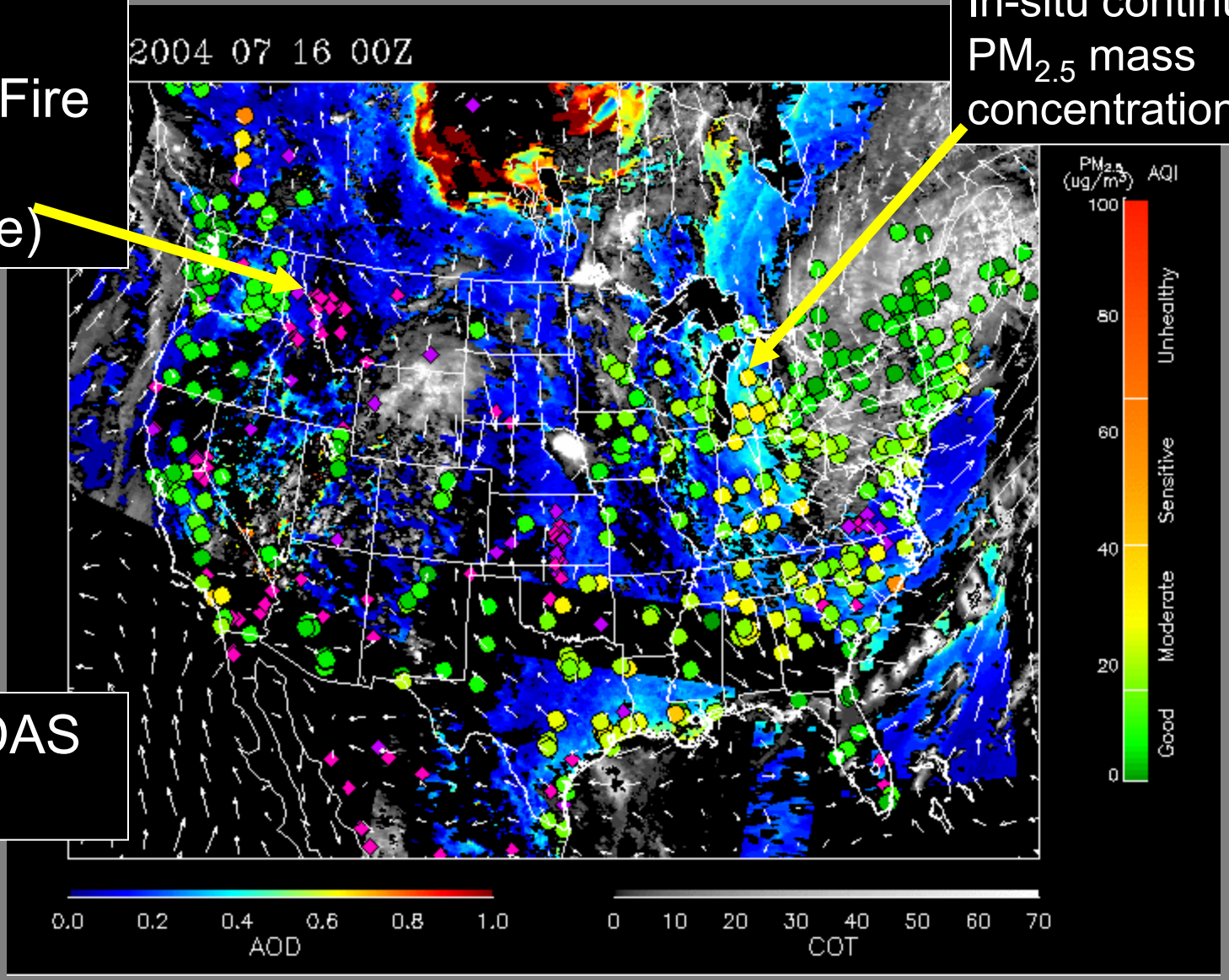
Aerosol Optical Thickness (Coarse Mode)



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

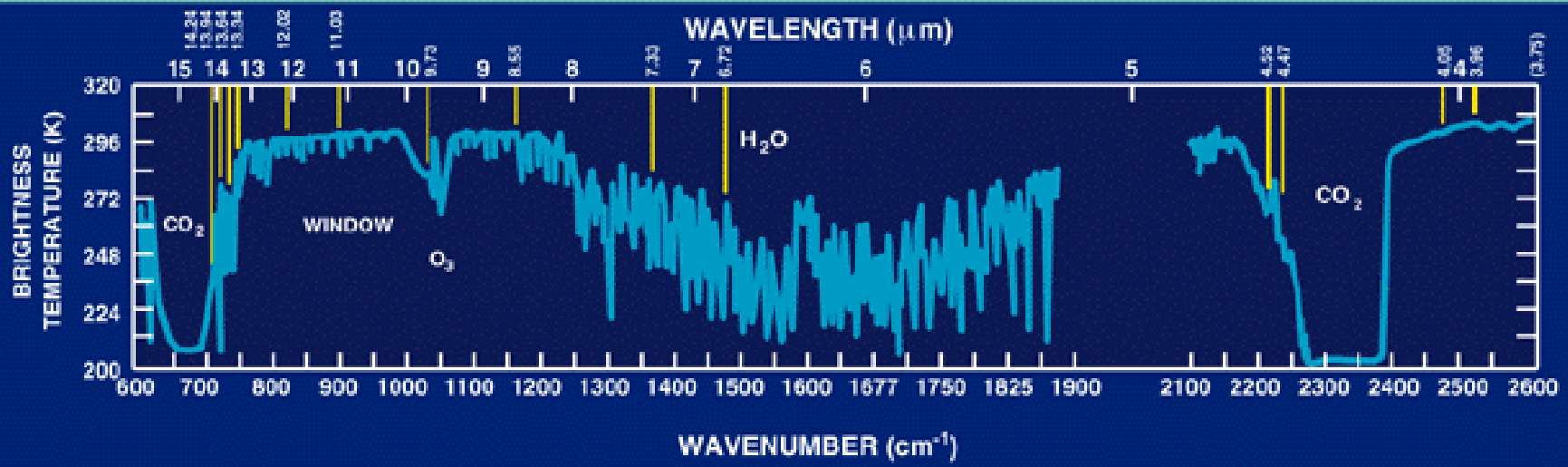
Half-hourly WF-ABBA Fire Locations (pink-purple)

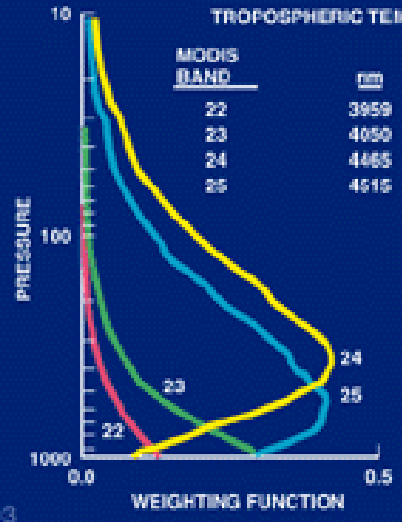
In-situ continuous $PM_{2.5}$ mass concentration data

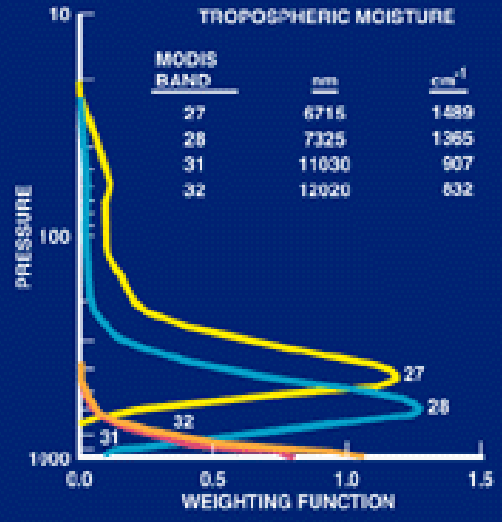


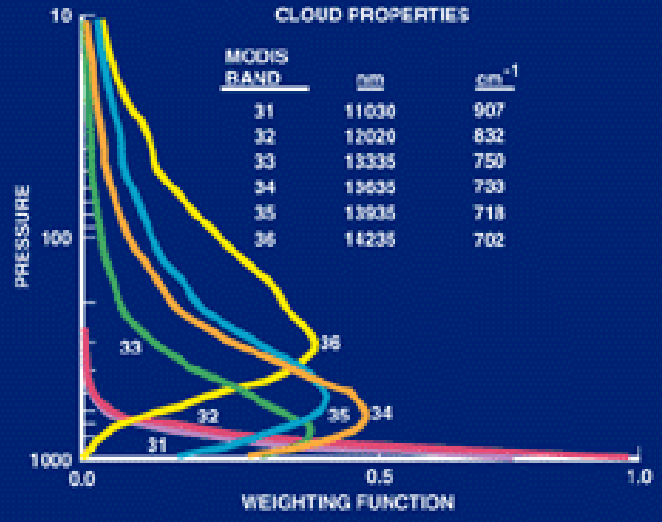
850 mb EDAS wind fields

ATMOSPHERE - THERMAL RADIATION

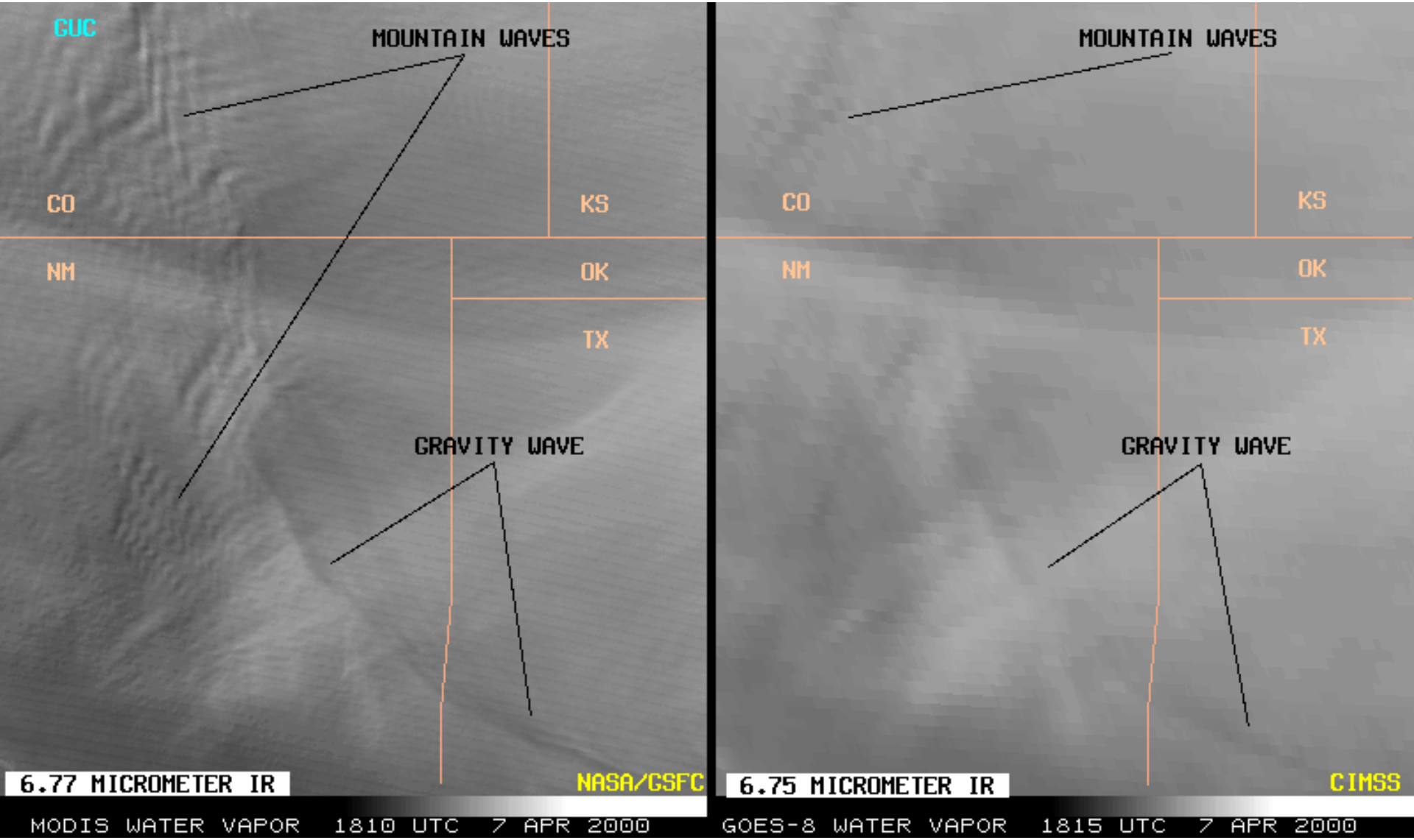




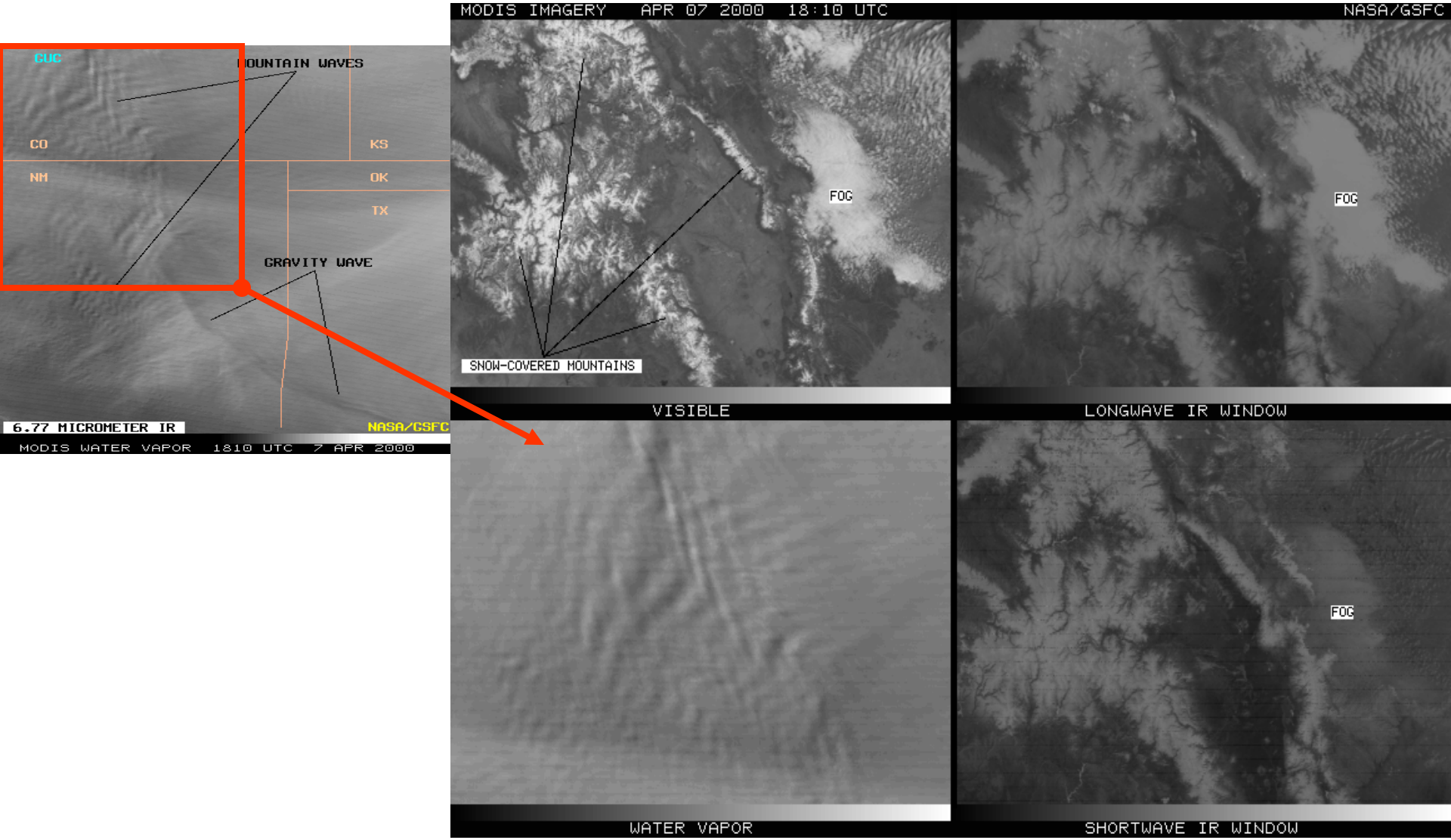




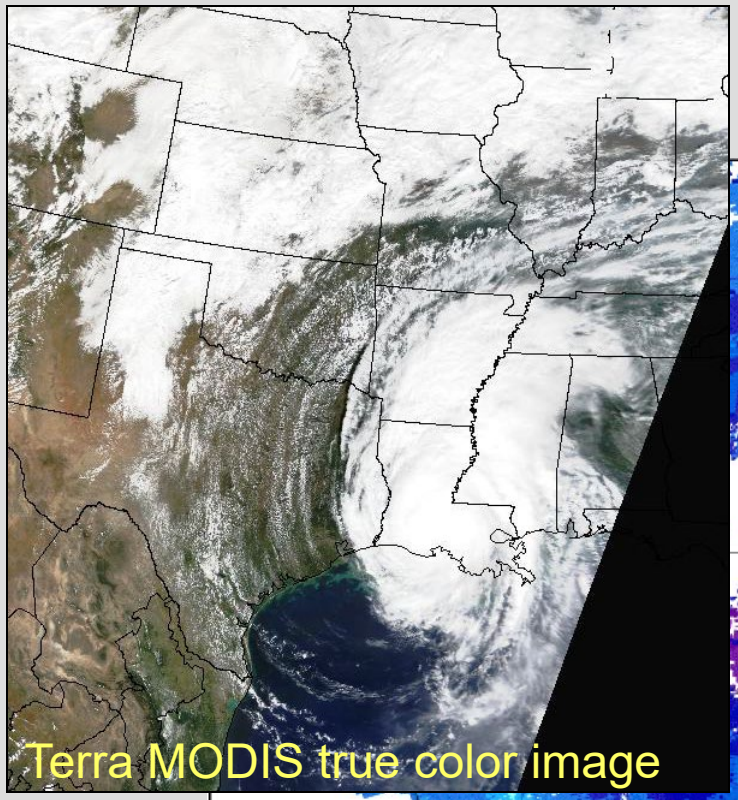
MODIS 1 km resolution reveals fine-scale structure

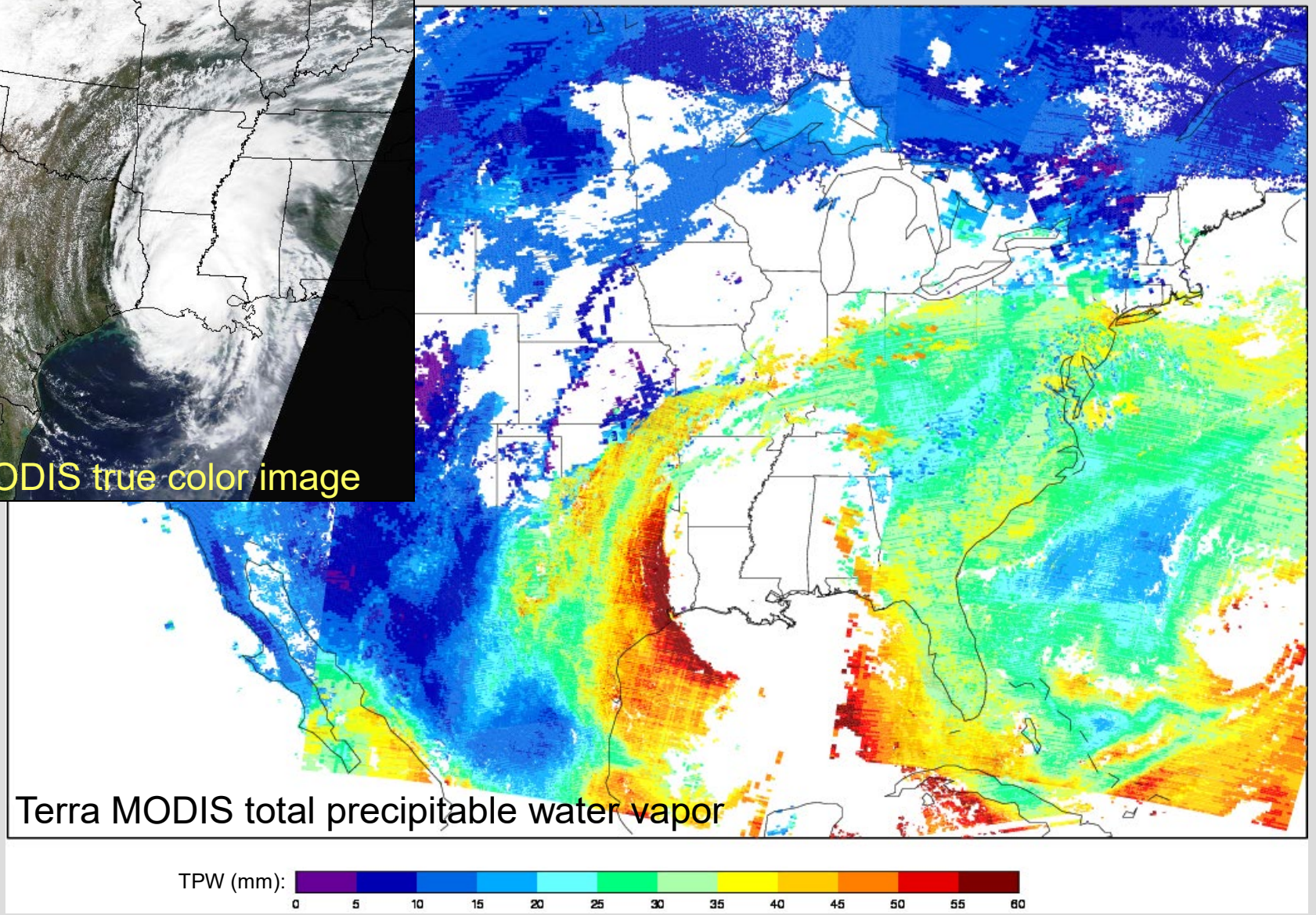


Four Panel Zoom of Cloud-Free Orographic Waves revealed in Water Vapor Imagery

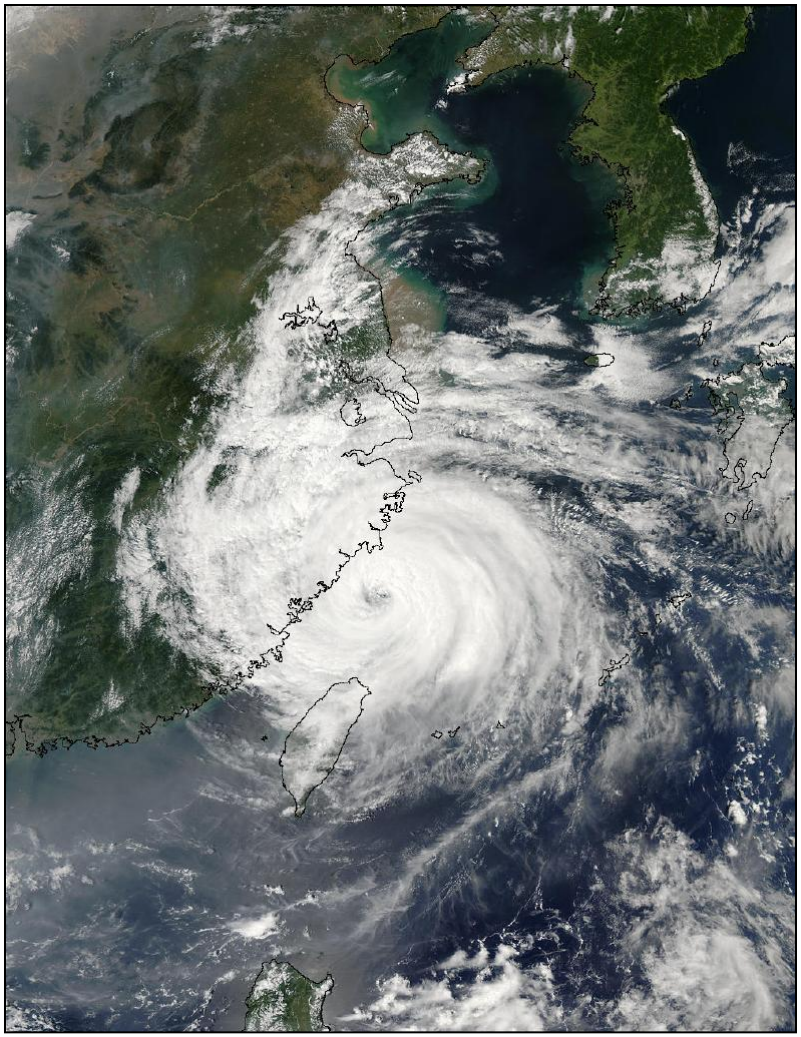


Hurricane Lili, 2 October 2002
Terra MODIS direct broadcast



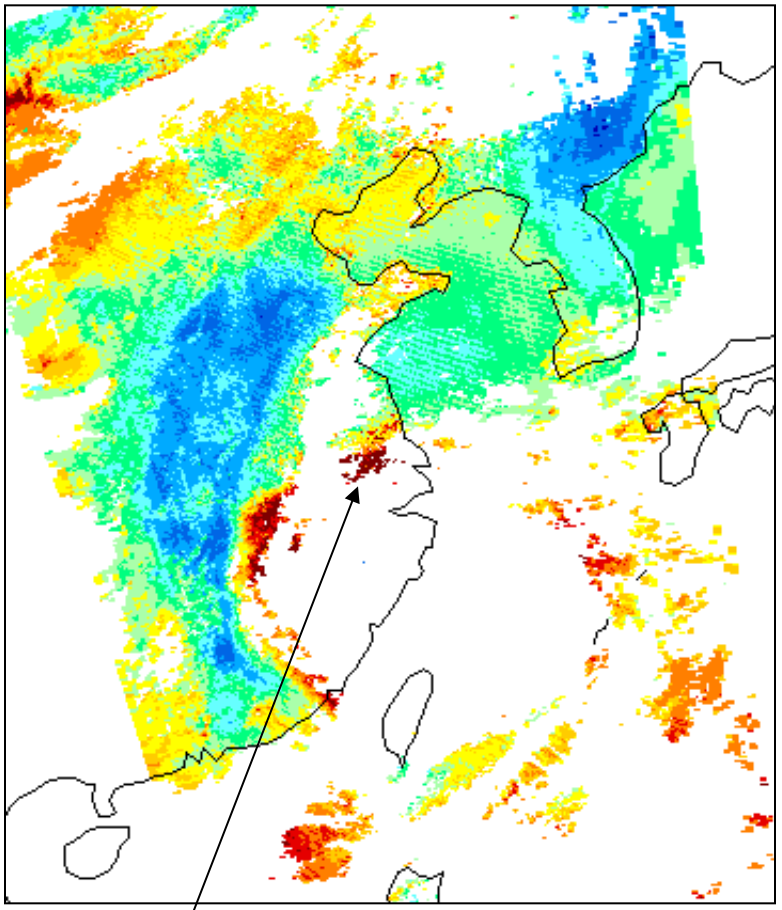


Typhoon Sinlaku, 7 September 2002
Aqua MODIS



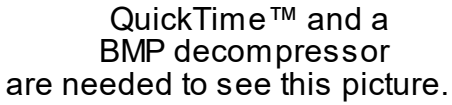
Aqua MODIS true color image

Total Precipitable Water Vapor



TPW = 72.5 mm

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)

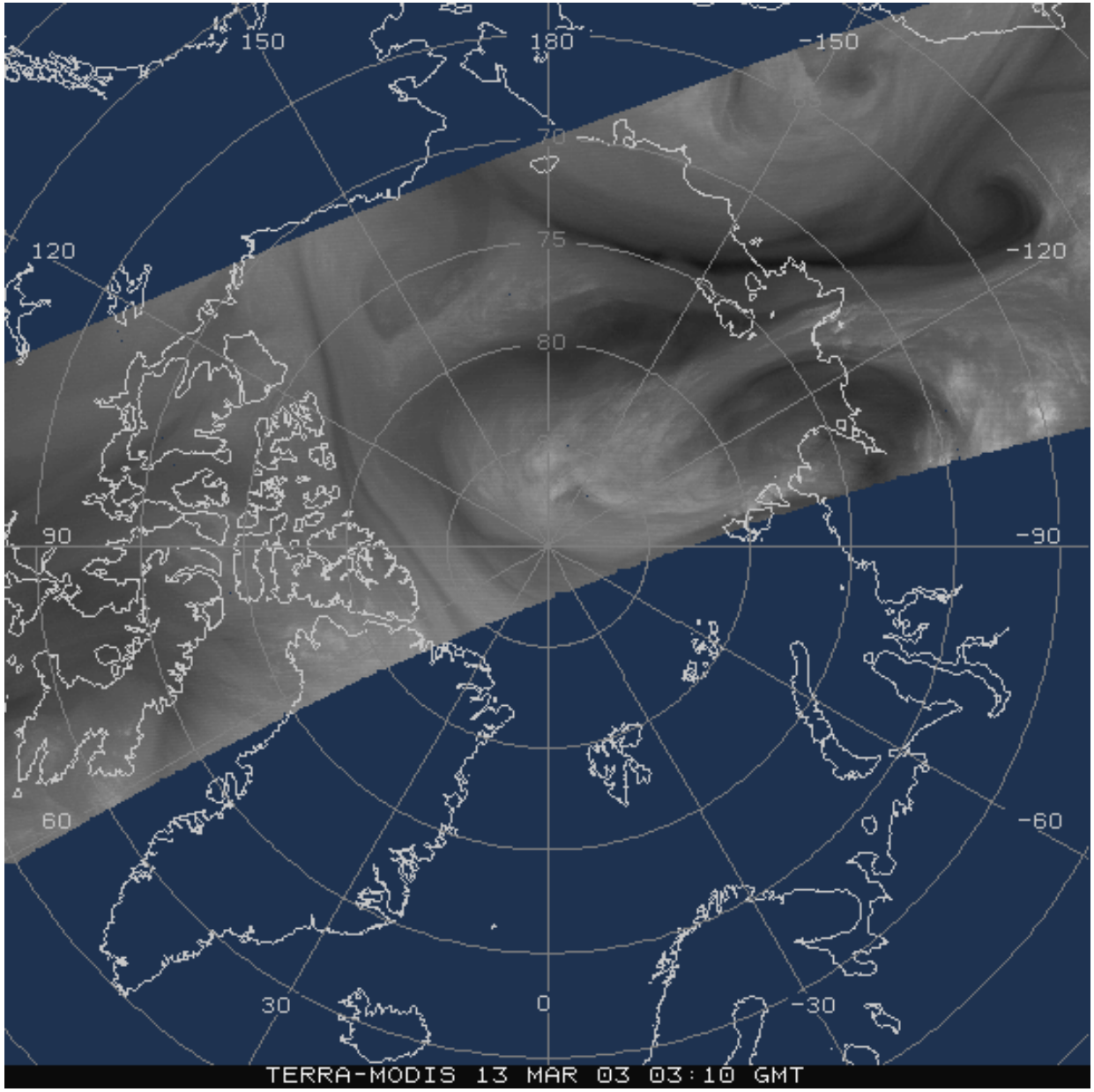
* Indian monsoon evident Jun-Jul-Aug

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

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

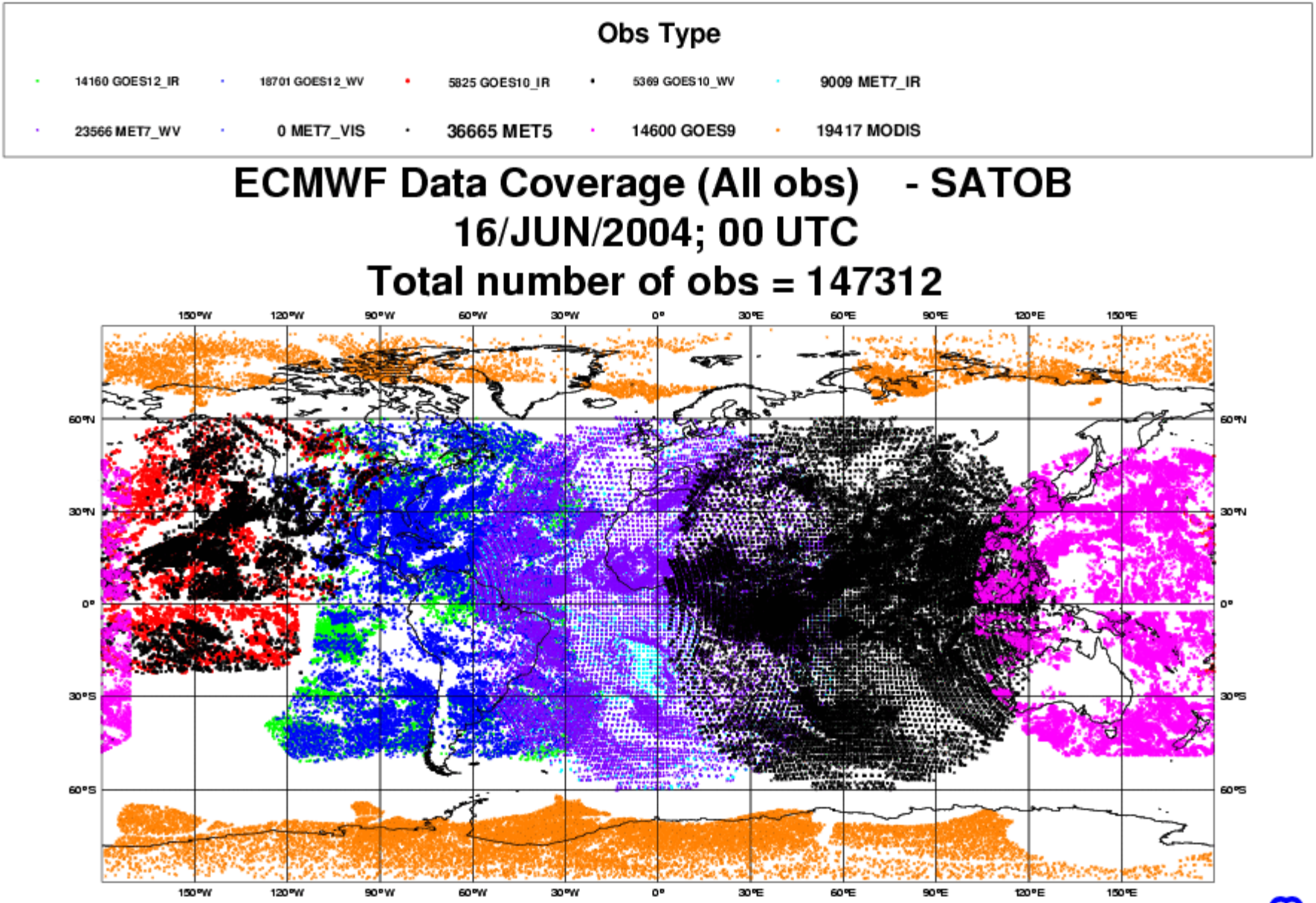
* TPW follows the Sun – latitudinal moisture bands connecting
  continents drift N & S with seasons

MODIS 1 km WV images over North Pole

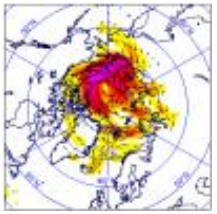


MODIS winds filling observing system void

Being used operationally since Jan 2003



MODIS Winds in NWP

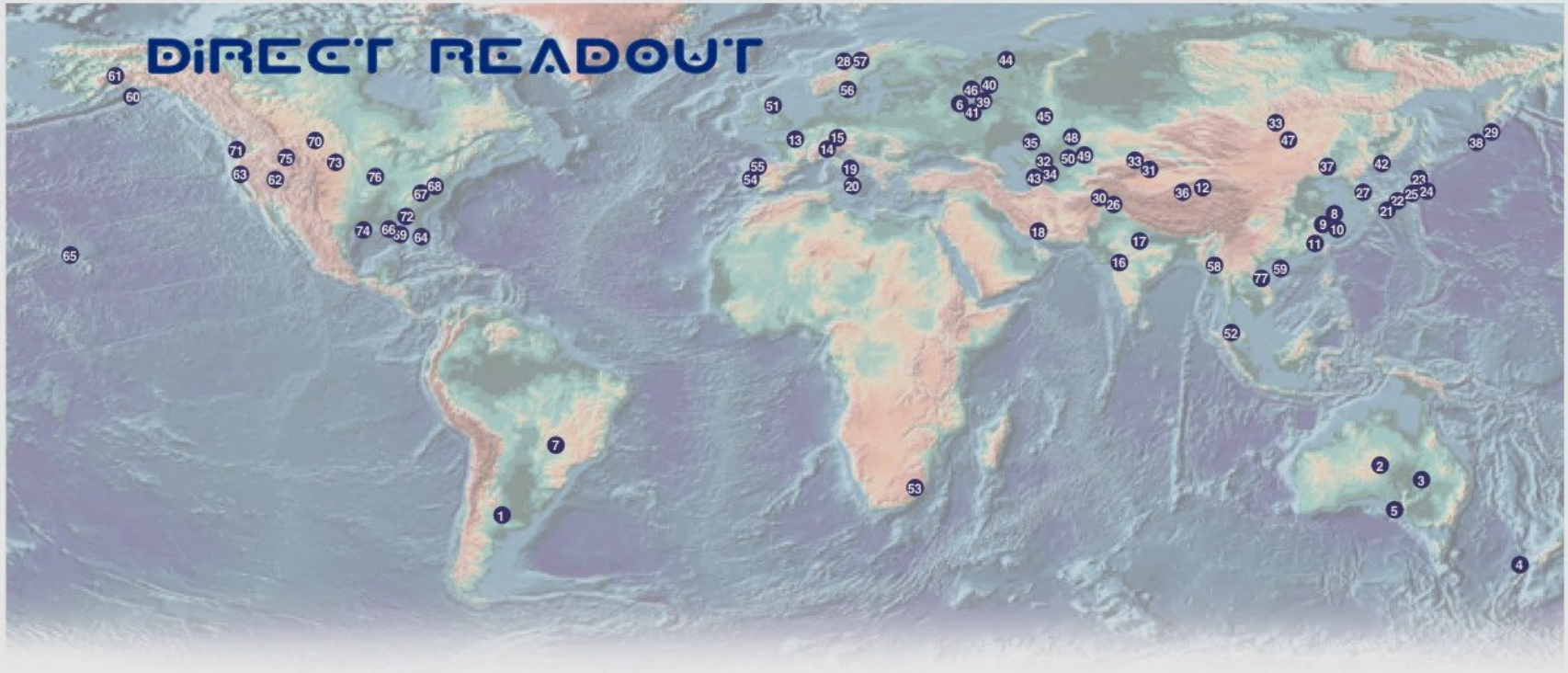


Current Users:

- European Centre for Medium-Range Weather Forecasts (ECMWF; Lueder von Bremen and Jean-Noel Thepaut) - Using winds in **operational** system.
- NASA Global Modeling and Assimilation Office (GMAO; Lars Peter Riishojgaard and Yanqiu Zhu) - Using winds in **operational** system.
- Japan Meteorological Agency (JMA; Masahiro Kazumori) – Using winds in **operational** system (Arctic only)
- Canadian Meteorological Centre (CMC; Real Sarrazin) – Using winds in **operational** system.
- US Navy, Fleet Numerical Meteorology and Oceanography Center (FNMOC; Pat Pauley and Chuck Skupniewicz) – Using winds in **operational** system.
- UK Met Office (Mary Forsythe and Howard Berger) – Using winds in **operational** system.
- National Centers for Environmental Prediction (NCEP/EMC; John LeMarshall, Jim Jung, Tom Zapotocny) - Engaged in impact studies. Plan to go operational in June 2005.
- Deutscher Wetterdienst (DWD; Alexander Cress) – Using winds in experimental system
- NCAR Antarctic Mesoscale Model (AMPS; Dale Barker) – Beginning to test the winds over Antarctica.
- Other (incomplete information): Chinese meteorological agency, one or more countries involved in HIRLAM.

MODIS Direct Broadcast

EOS Direct Broadcast Sites



More then 100 receiving stations around the world


北京
Beijing


Moscow


Madison, Wisconsin


Benevento, Italy

Advantages of DB:

- Facilitates access to advanced sensors, precursor to NPP/NPOESS
- Local control and autonomy gives users freedom to tailor operations
- Timeliness for responding to natural hazards and providing information for decision makers.
- Local researchers are free to develop and refine algorithms tuned for local conditions

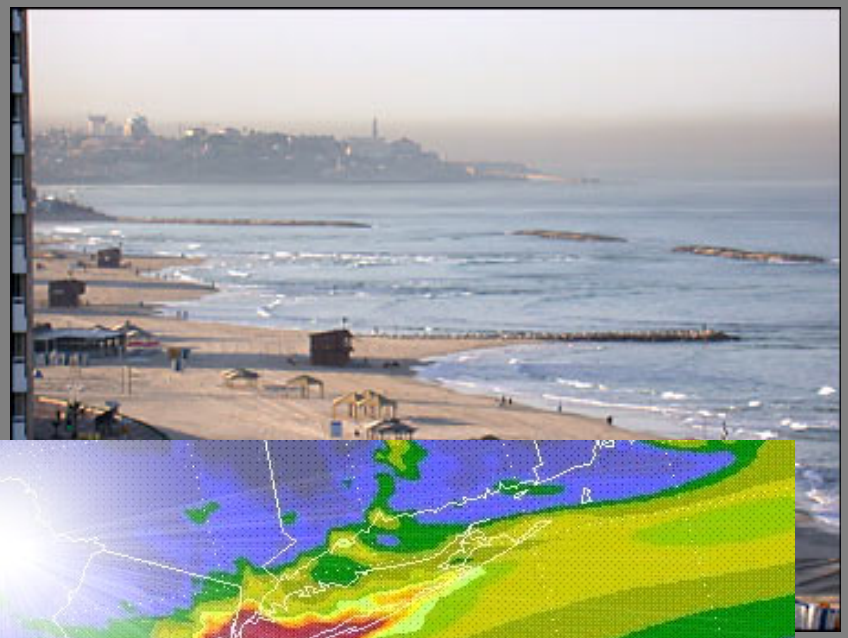
Processing software is freely available

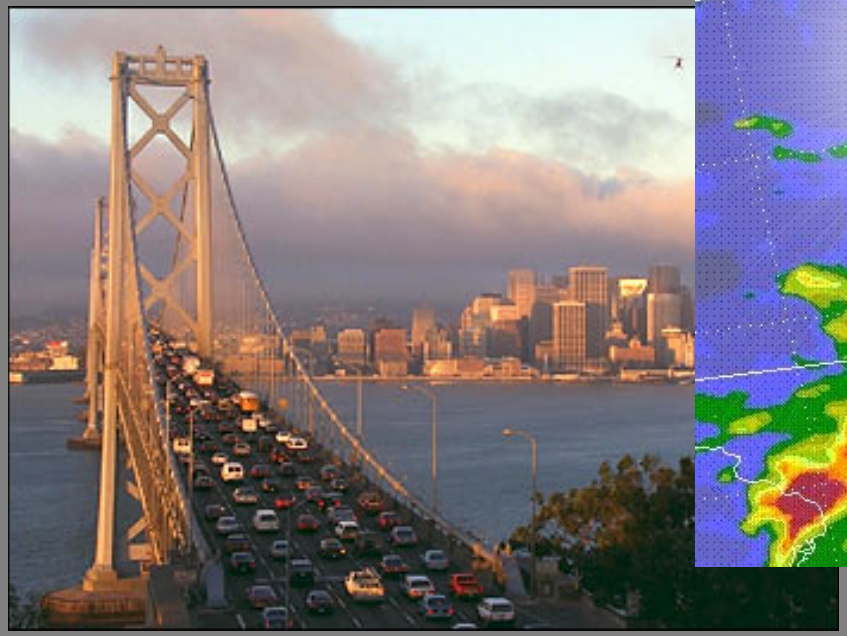
Processing Task	Software Package
Convert raw telemetry to sorted instrument packets (Level-0)	RT-STPS
Convert Level-0 to calibrated earth-located radiances and reflectances (Level-1B)	MODISL1DB
Convert Level-1B to geophysical products such as cloud mask, NDVI, aerosol, fire detection, ocean color (Level-2)	IMAPP, DAAC, SeaDAS
Visualization and Reprojection	Hydra, HDFLook, MS2GT, MRTSwath

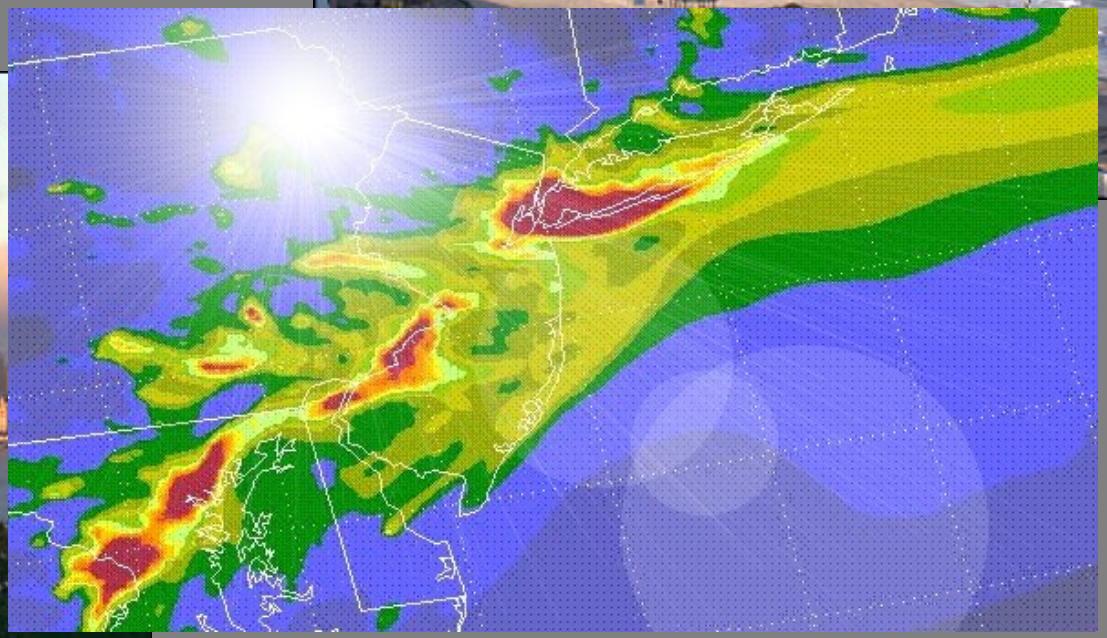
Application:
Air Quality Forecasting in US

Infusing Satellite Data into Environmental Air Quality Applications (IDEA)

NASA-EPA-NOAA partnership to improve air quality assessment, management, and prediction by infusing satellite measurements (NASA) into air quality analyses (EPA, NOAA) for public benefit.



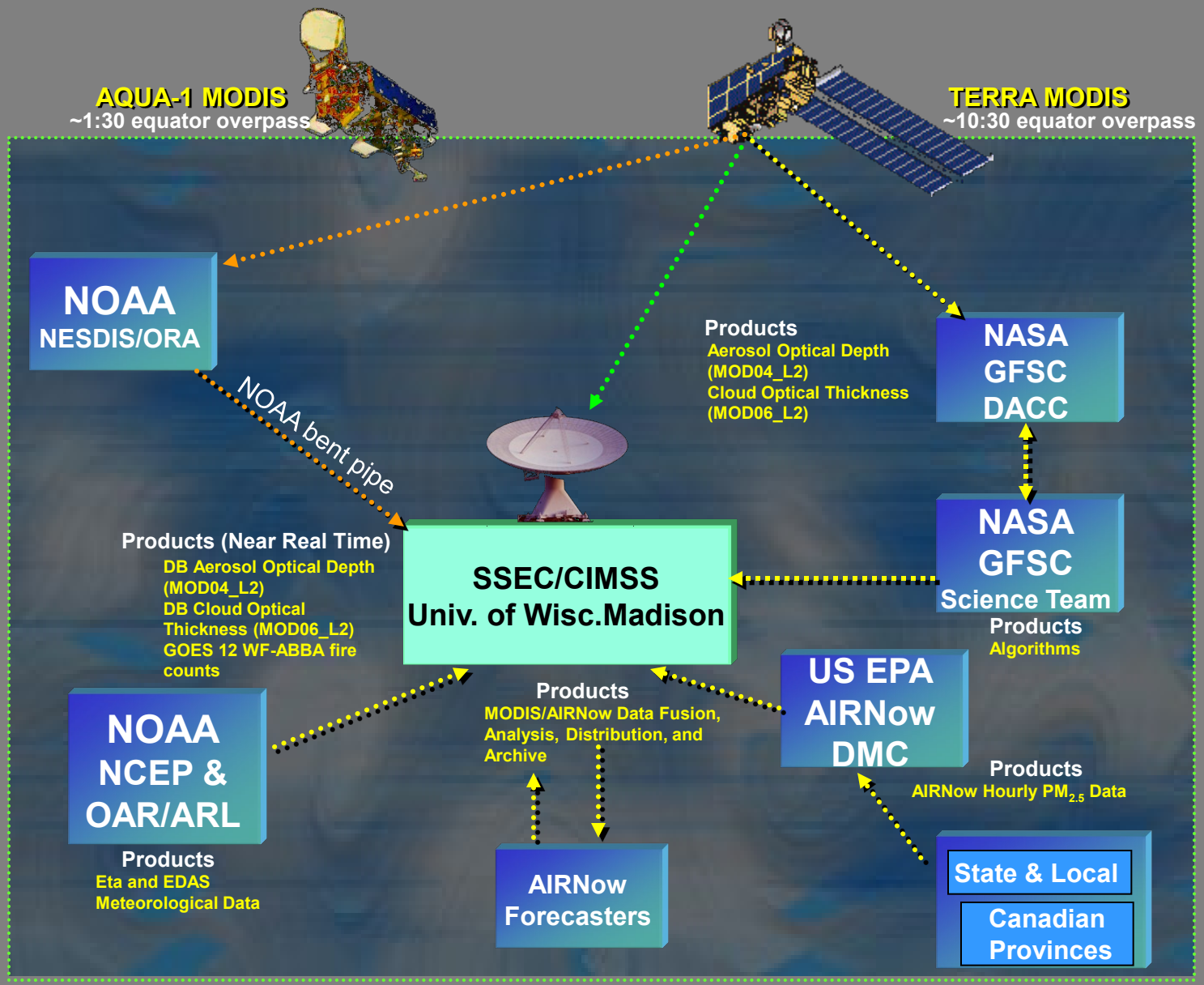




Part of NASA Earth Science strategy to demonstrate practical uses of NASA remote sensing observations

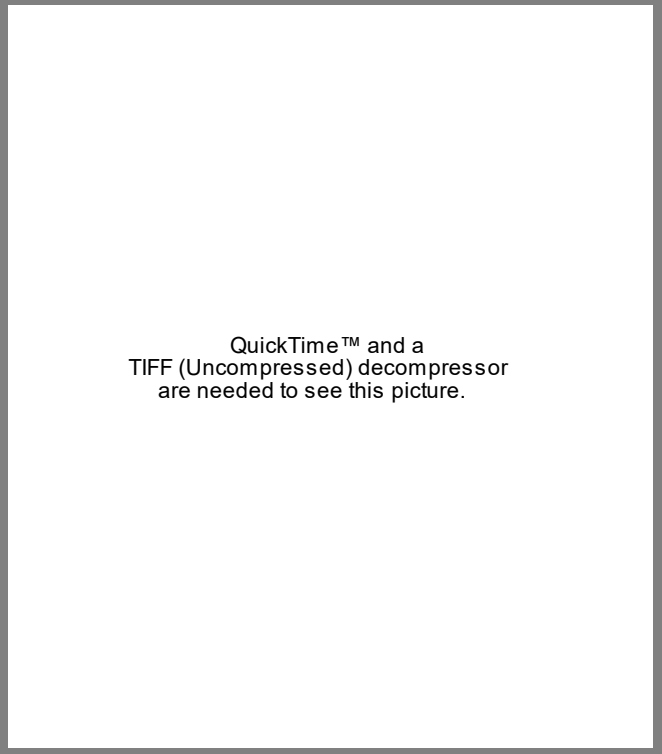
IDEA Data Flow Diagram

Not a Simple Straightforward Accomplishment



What is PM2.5?

- Particulate matter less than 2.5 microns in diameter.
- Product of combustion of fossil fuels, wood burning, industry.
- Able to penetrate to deepest parts of lungs; linked with asthma, bronchitis, shortness of breath, premature death.
- Major contributor to reduced visibility and acid rain

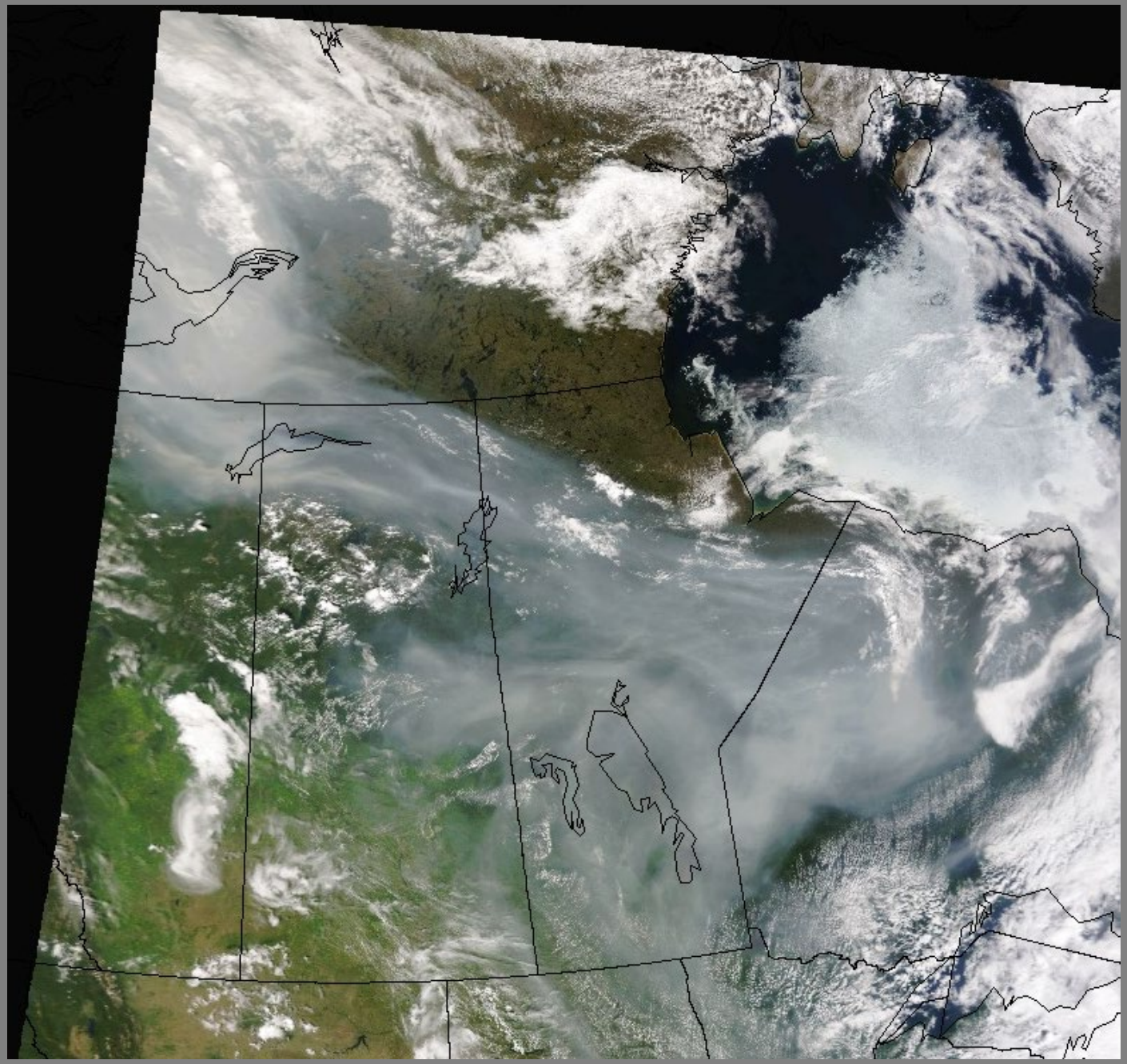


Air Quality Index for Particles

Index Values	Category	Cautionary Statements	$PM_{2.5}$ (ug/m^3)	PM_{10} (ug/m^3)
0-50	Good	None	0-15.4	0-54
51-100	Moderate	Unusually sensitive people should consider reducing prolonged or heavy exertion	15.5-40.4	55-154
101-150	Unhealthy for Sensitive Groups	Sensitive groups should reduce prolonged or heavy exertion	40.5-65.4	155-254
151-200	Unhealthy	Sensitive groups should avoid prolonged or heavy exertion; everyone else should reduce prolonged or heavy exertion	65.5-150.4	255-354
201-300	Very Unhealthy	Sensitive groups should avoid all physical activity outdoors; everyone else should avoid prolonged or heavy exertion	150.5-250.4	355-424

Source: US EPA, 1997

Terra MODIS true color image 17 July 2004

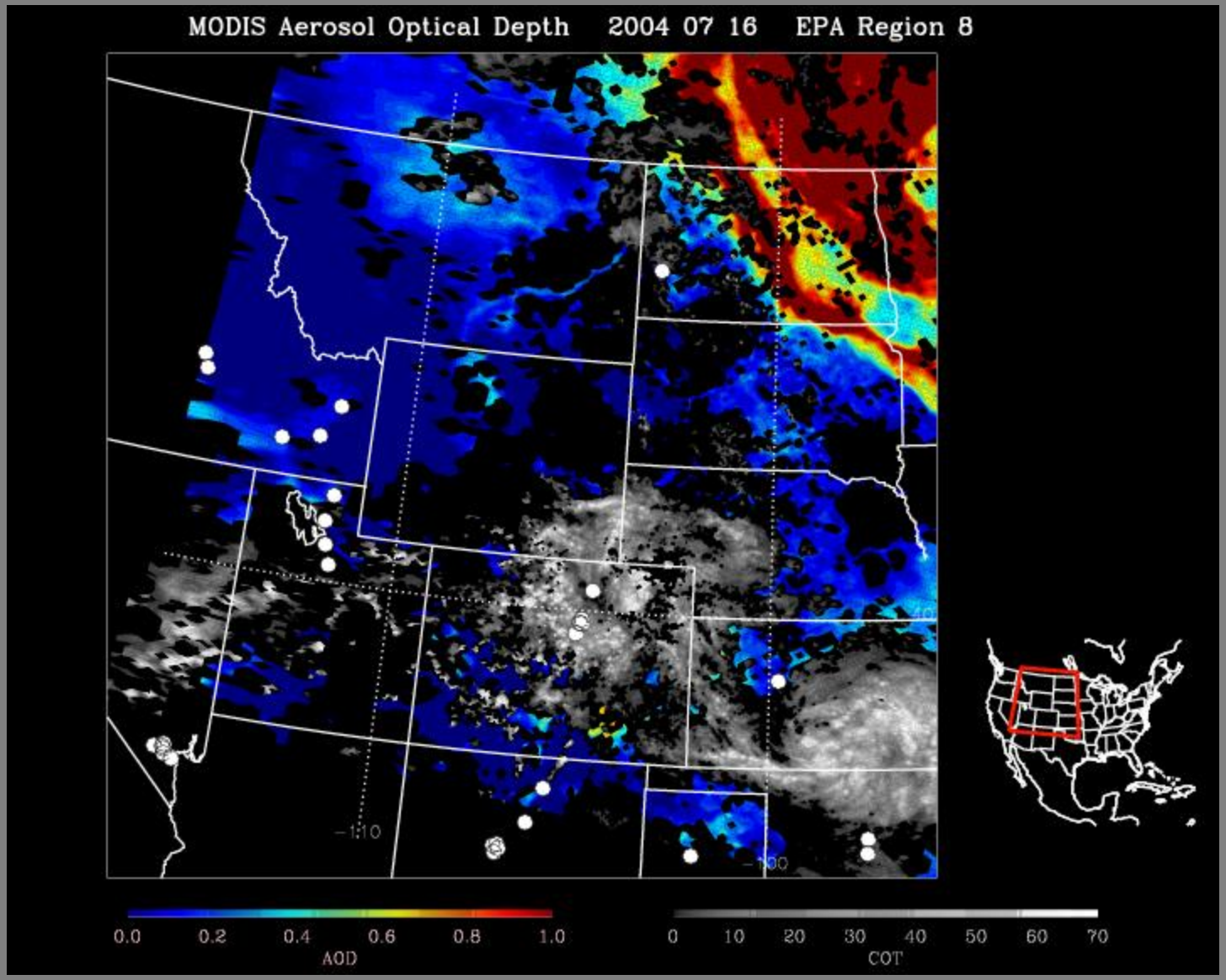


IDEA
Forecast Tools and Products

(Example from July 2004 Aerosol Outbreak)

- Regional Summary Plots of MODIS Aerosol Optical Depth and Cloud Optical Thickness
- MODIS Aerosol Optical Depth 48 hour Trajectories Forecast
- Composite PM2.5/MODIS Aerosol Optical Depth Data Fusion 3-day Animation
- Time-series between MODIS Aerosol Optical Depth and PM2.5 (1hr and 24hr) Mass Concentration
- National Correlation Map between PM2.5 and MODIS Aerosol Optical Depth
- Daily Forecast Discussion and Blog

Regional Summary Plots of MODIS Aerosol Optical Depth and Cloud Optical Thickness



IDEA
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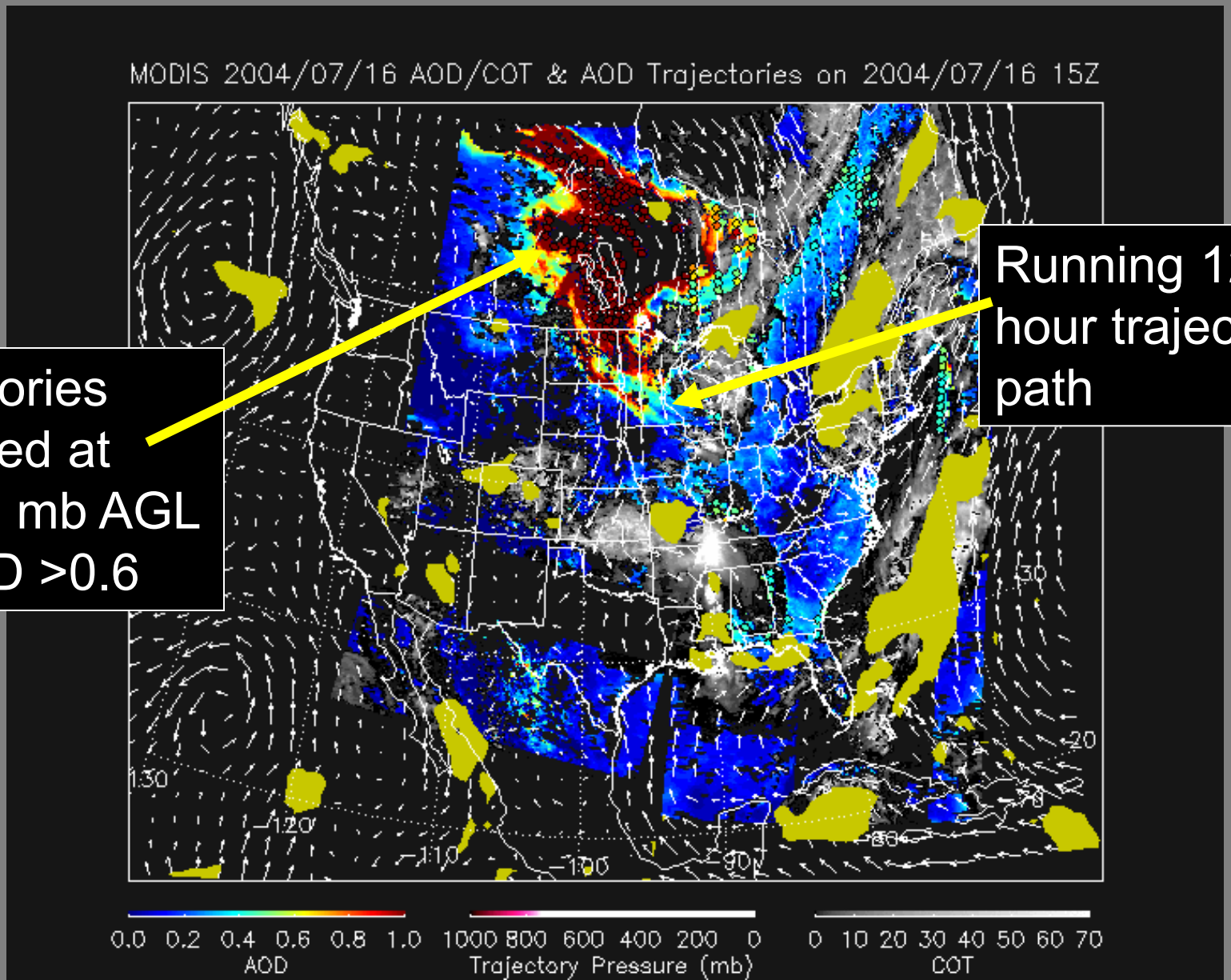
MODIS Aerosol Optical Depth 48 hour Air Parcel Forecast Trajectories (16 July 2004)



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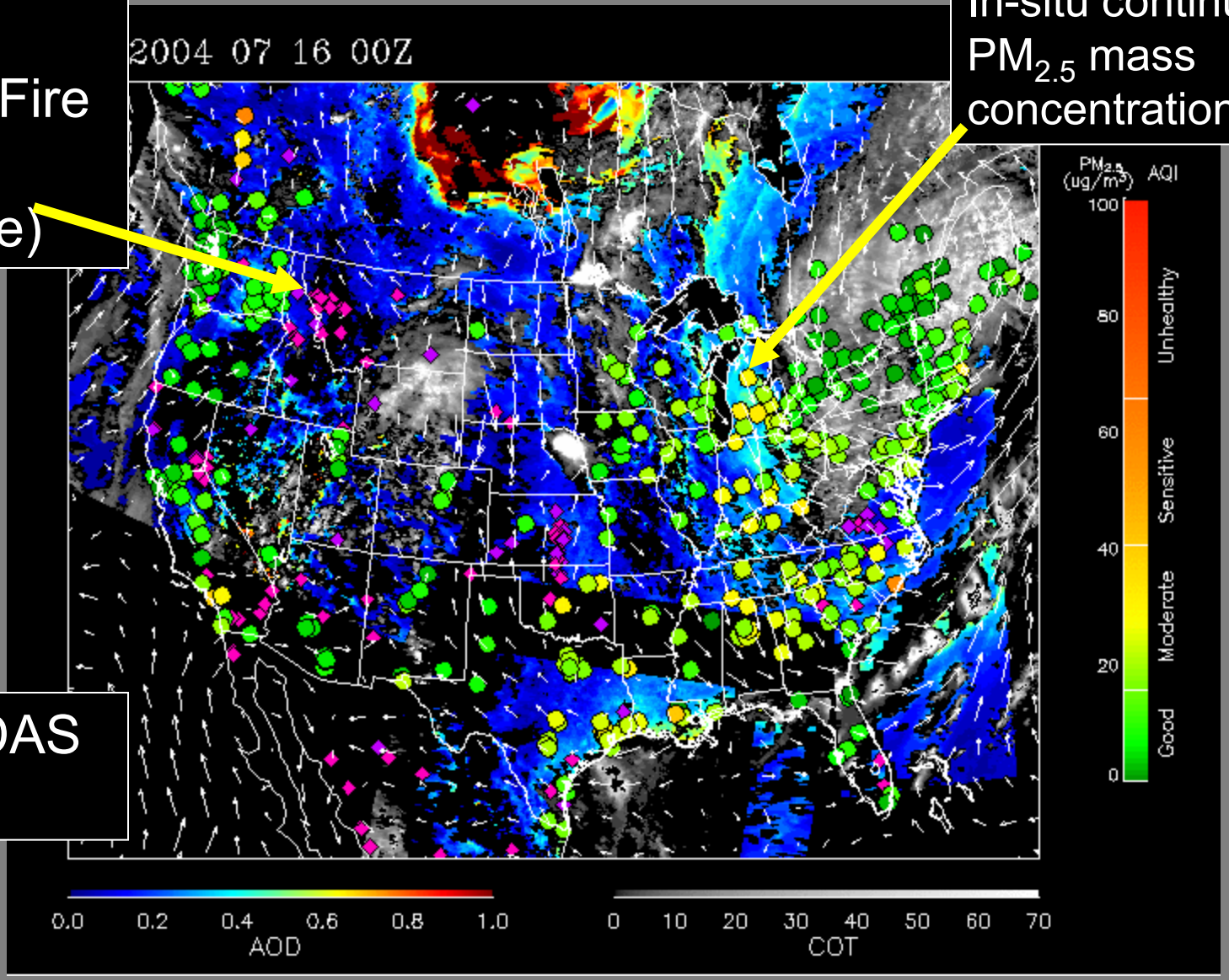
Composite PM2.5/MODIS Aerosol Optical Depth Data Fusion 3-day Animation

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

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



850 mb EDAS wind fields

IDEA
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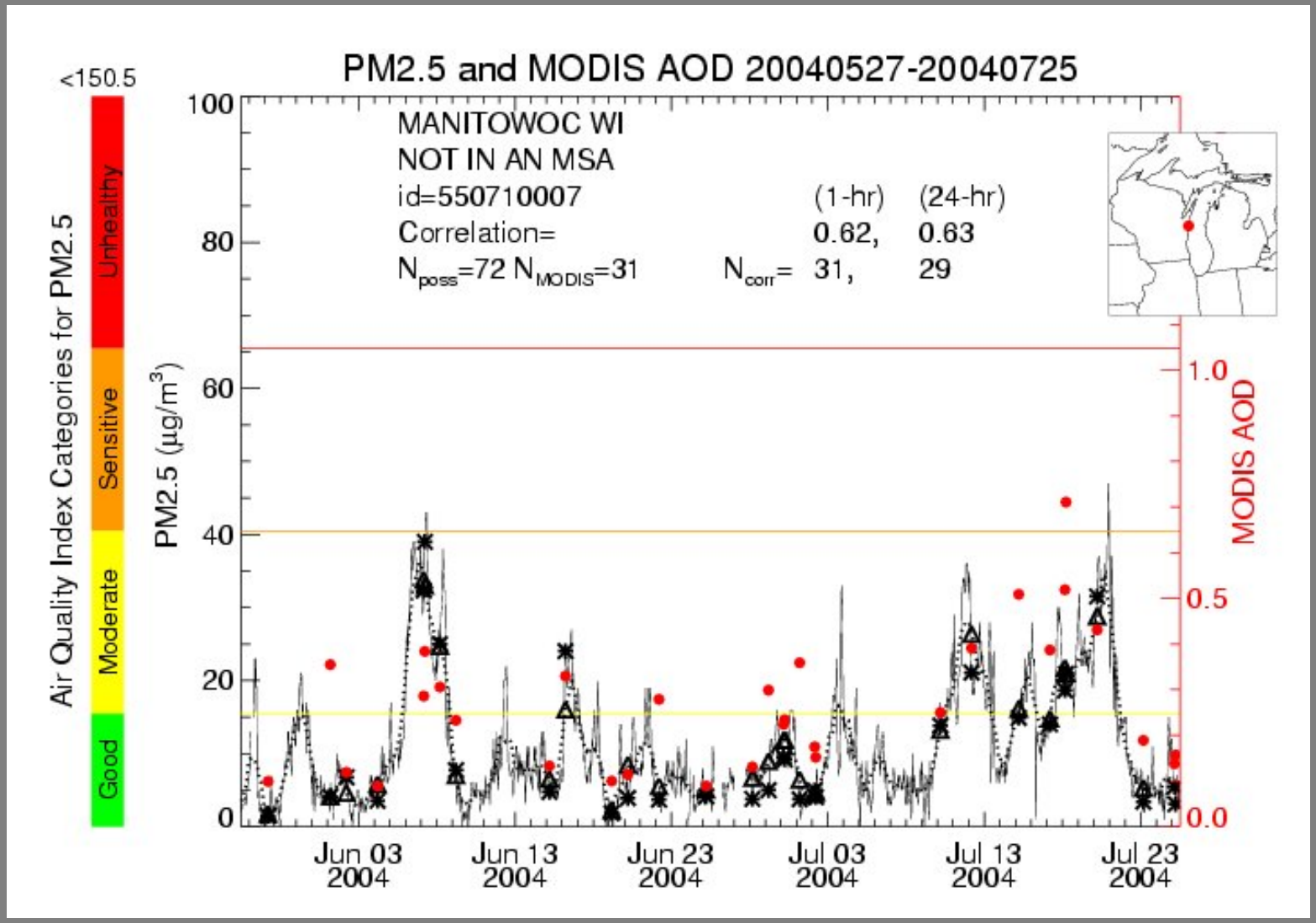
Time-series between MODIS Aerosol Optical Depth and PM2.5 (1hr and 24hr) Concentrations



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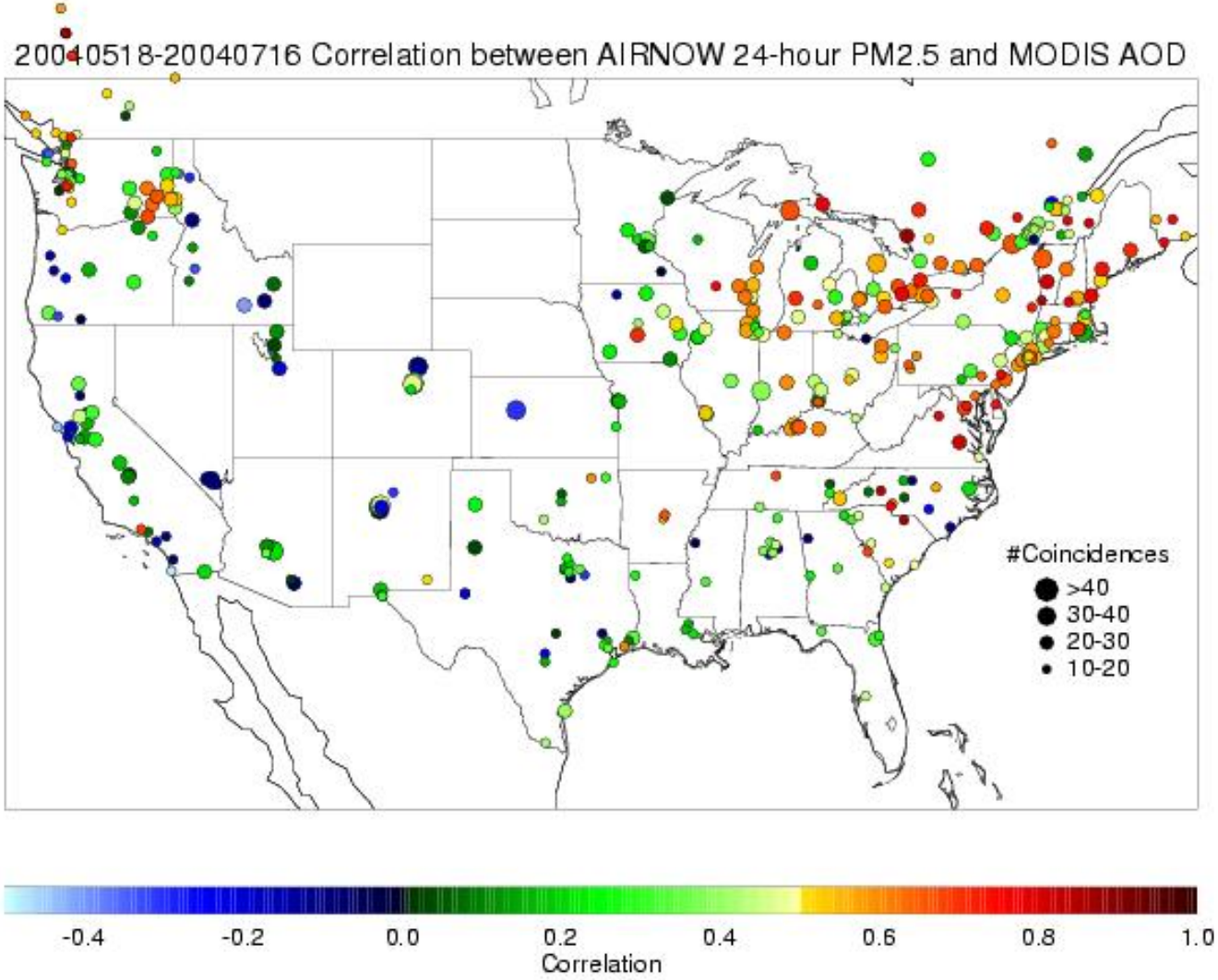
National Correlation Map between PM2.5 Mass Concentraton and MODIS Aerosol Optical Depth



IDEA Forecast Discussions