An Overview of Satellite Remote Sensing Products

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- Research Interests:
  - Cloud and Radiation (11)
  - Radiation Budget (12)
  - EAST-AIRE (6)
  - GCM Validation (3)
  - Cloud Remote Sensing (6)
  - Aerosol Retrieval and Forcing (11)
  - Fire Monitoring & Mapping (17)
  - UV Remote Sensing (5)
  - Land Remote Sensing (12)
  - Scene ID, BRDF and NB-BB Corrections (10)
  - Sensor Calibration (7)
  - Miscellanies (10)
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Satellite Orbits

- Geosynchronous
- Sunsynchornous
- Low equatorial

Operational Weather Satellites

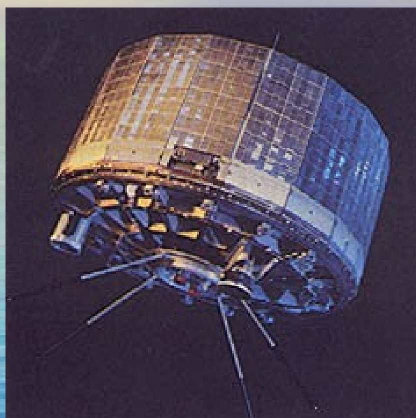
Geostationary Satellites

- Geostationary Operational Environmental Satellites (GOES) (1975-present)
  - High temporal resolution geosynchronous satellites fixed over the equator
    - hemispheric views of the Earth every 15-30 minutes
    - Orbit at 35,800 km (22,300 miles)

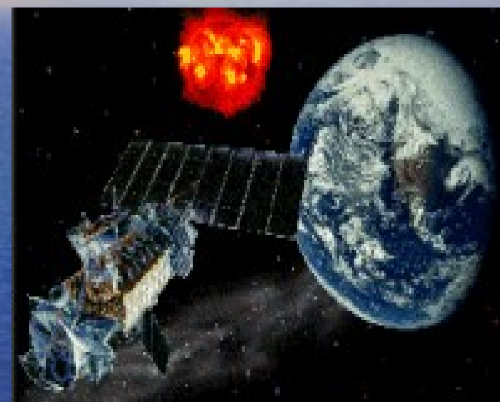
- Other countries: Meteosat (Europe), GMS (Japan), FY (China) INSAT (India) complement GOES-E and GOES-W in a global meteorological geosynchronous constellation


METEOR
(Russia)
850 KM
GOES-E
(USA)
75°W
GOES-W
(USA)
135°W
GEOSTATIONARY ORBIT
POLAR ORBIT
35 800 Km
SUBSATELLITE
POINT
GMS
(Japan)
140°E
FY-2
(China)
105°E
METEOSAT
(EUMETSAT)
0°Longitude
TIROS
(USA)
GOMS
(Russia)
76°E

Operational Satellites



TIROS



DMSP

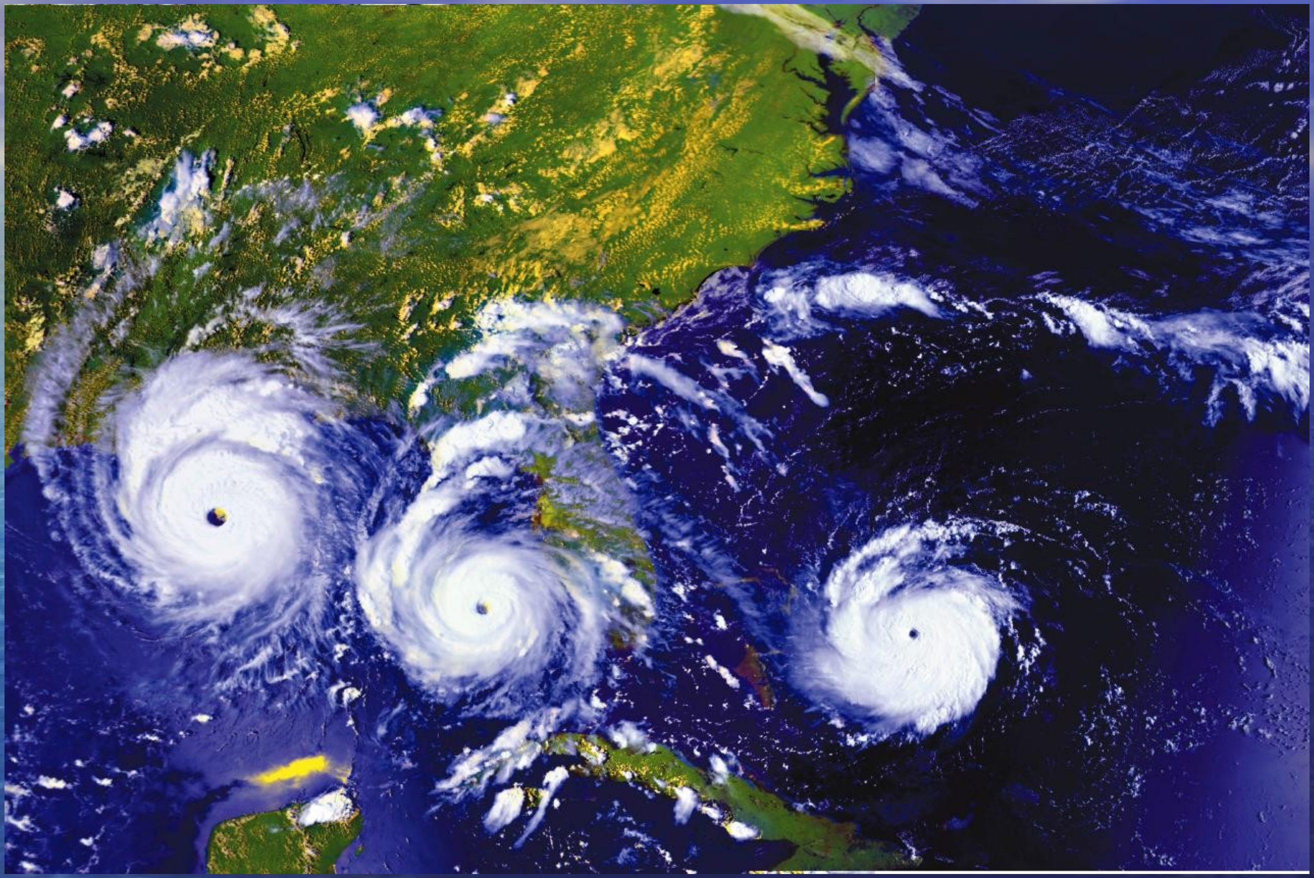
NPOESS

GOES

Meteosat

Fengyun

Hurricane Monitoring by GOES



- This is a time lapse view of hurricane Andrew.
- The pictures are exactly one day sequential.

Operational Weather Satellites

Polar-orbiting Satellites

- POES (Polar-Orbiting Operational Environmental Satellites)
  - TIROS-N (1978) & NOAA 6-18 (1979-present)
  - Remote sensing at moderate resolution of the Earth’s land, ocean, and atmosphere
  - Orbit from 830 km (morning) to 870 km (evening)
    - backbone of the US (NOAA’s) operational meteorological program
    - operational instruments AVHRR, HIRS/MSU/SSU (TOVS), SBUV

Future Polar Orbiters

- NPP (NPOESS Preparatory Program: combined between EOS & NPOESS)
- NPOESS (National Polar-orbiting Operational Environmental Satellite System)

POES Instruments

- Advanced Very High Resolution Radiometer (AVHRR)
  - Six channel radiometer
  - Radiation detection imager
  - Cloud cover and surface temperature
- High Resolution Infrared Radiation Sounder (HIRS)
- Advanced Microwave Sounding Unit-A (AMSU-A, AMSU-B)

Uses of Satellites

- GOES: Forecasting, advanced warning
- POES: Atmospheric data
- Dust storms, icebergs, volcanoes, fires, floods, tropical cyclones

NASA Satellite and Sensors

Resource Satellite

- Landsat (1972-present)
  - Remote sensing at high spatial resolution of the Earth's land
  - Open skies policy of access to data on the world's environment
  - ERTS-1 renamed Landsat 1 in January 1975

Radiation Research Satellite

- Nimbus (launches 1964-1978)
  - Successor to the polar-orbiting TIROS 1-3 series
  - Medium resolution satellites with sensors for monitoring the Earth's atmosphere (ozone and other trace gases in the stratosphere, aerosols, radiation budget, clouds, temperature), oceans (ocean color & sea surface temperature), and cryosphere (sea ice)

NASA Satellite and Sensors

Radiation Research Satellite

- Earth Radiation Budget Experiment (1985-1989, 1985-2005)
  - launch October 5, 1984)
    - Earth radiation budget and solar occultation of aerosols and ozone
    - first science satellite launched by the shuttle (Challenger; Sally Ride)
- Cloud and Earth's Radiant Energy System (CERES) (2000-present)

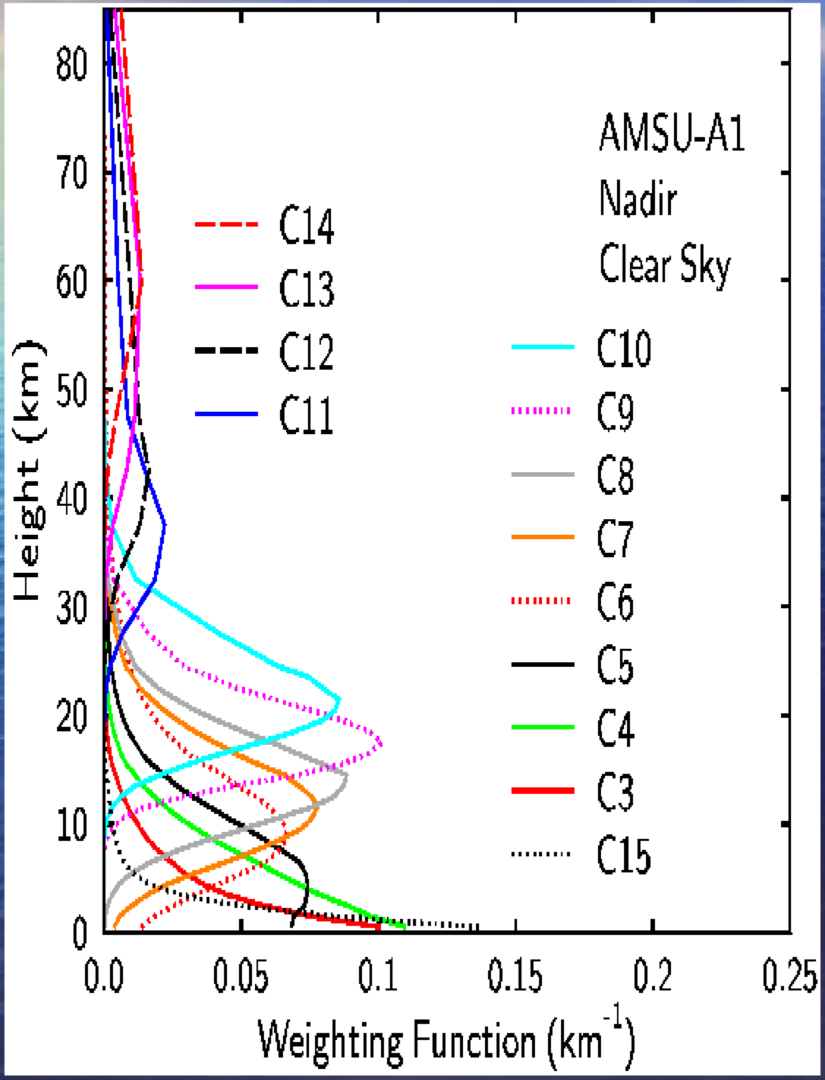
Precipitation

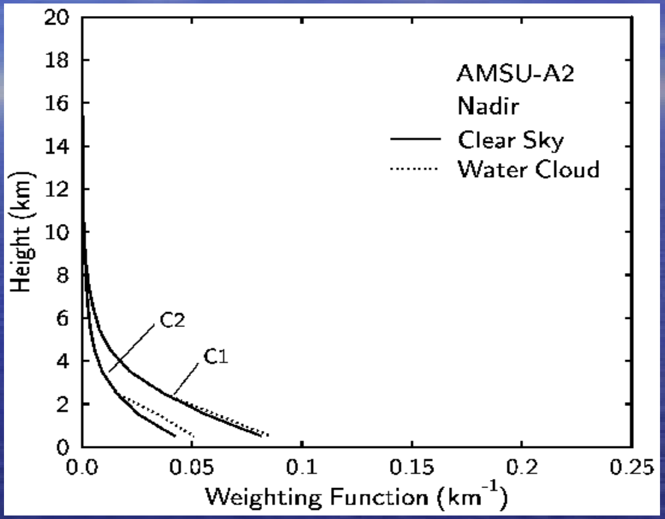
- TRMM (Tropical Rainfall Measuring Mission; launch November 27, 1997)
  - tropical rainfall measurement using spaceborne radar and passive microwave sensing (joint NASA & NASDA)

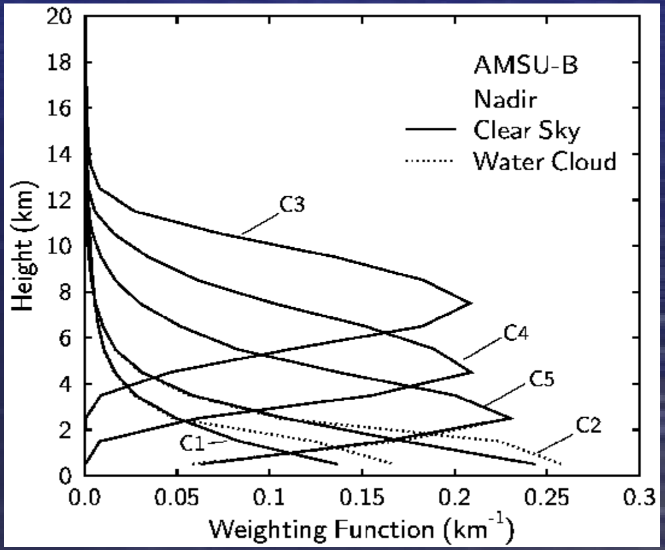
Atmospheric Profile

- TOVS/ATOVS, HIRS, AMSU, etc.
- UARS (Upper Atmosphere Research Satellite, launch September 14, 1991
  - global photochemistry of the upper atmosphere
  - launched by the shuttle (Discovery)

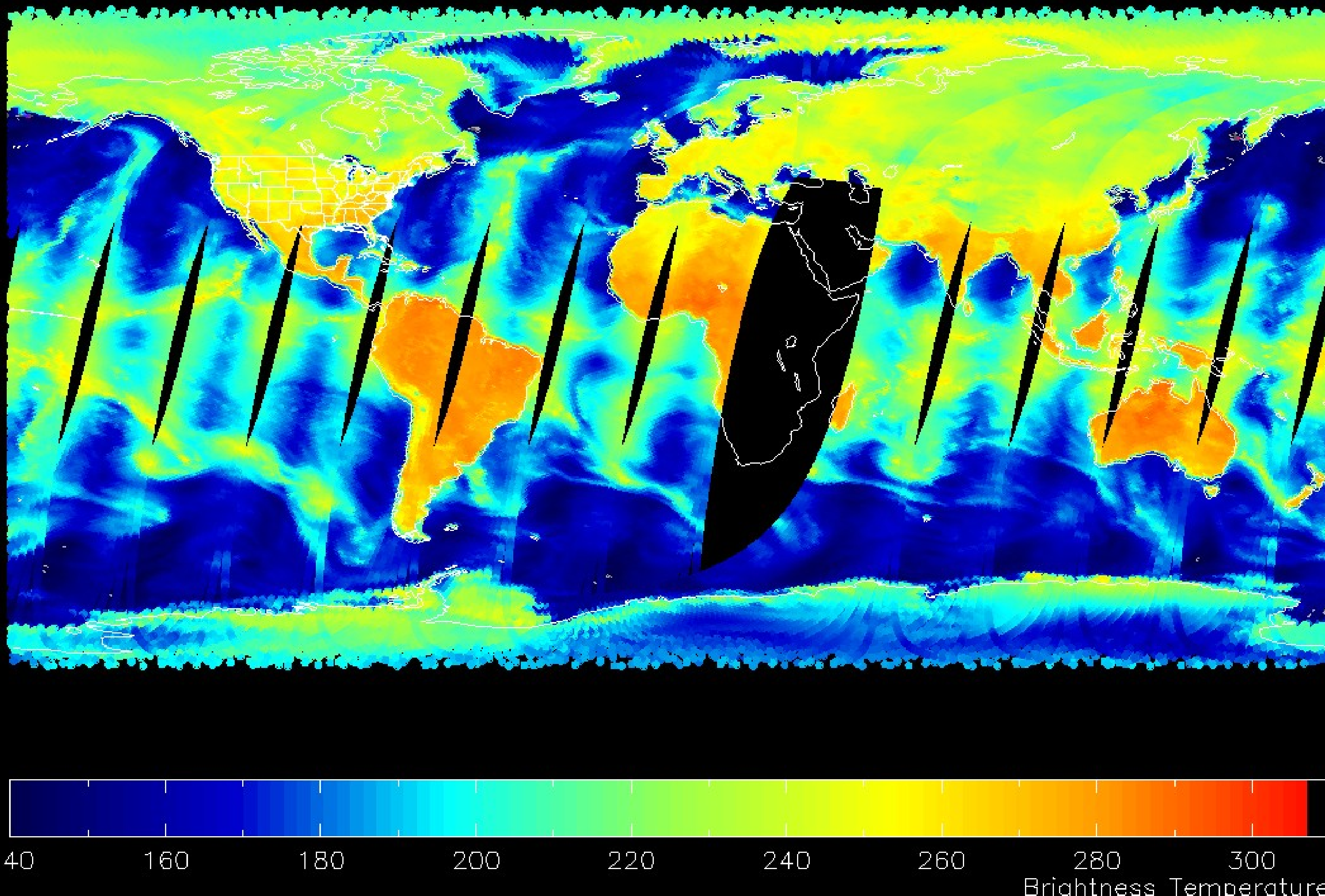
AMSU Weighting Functions



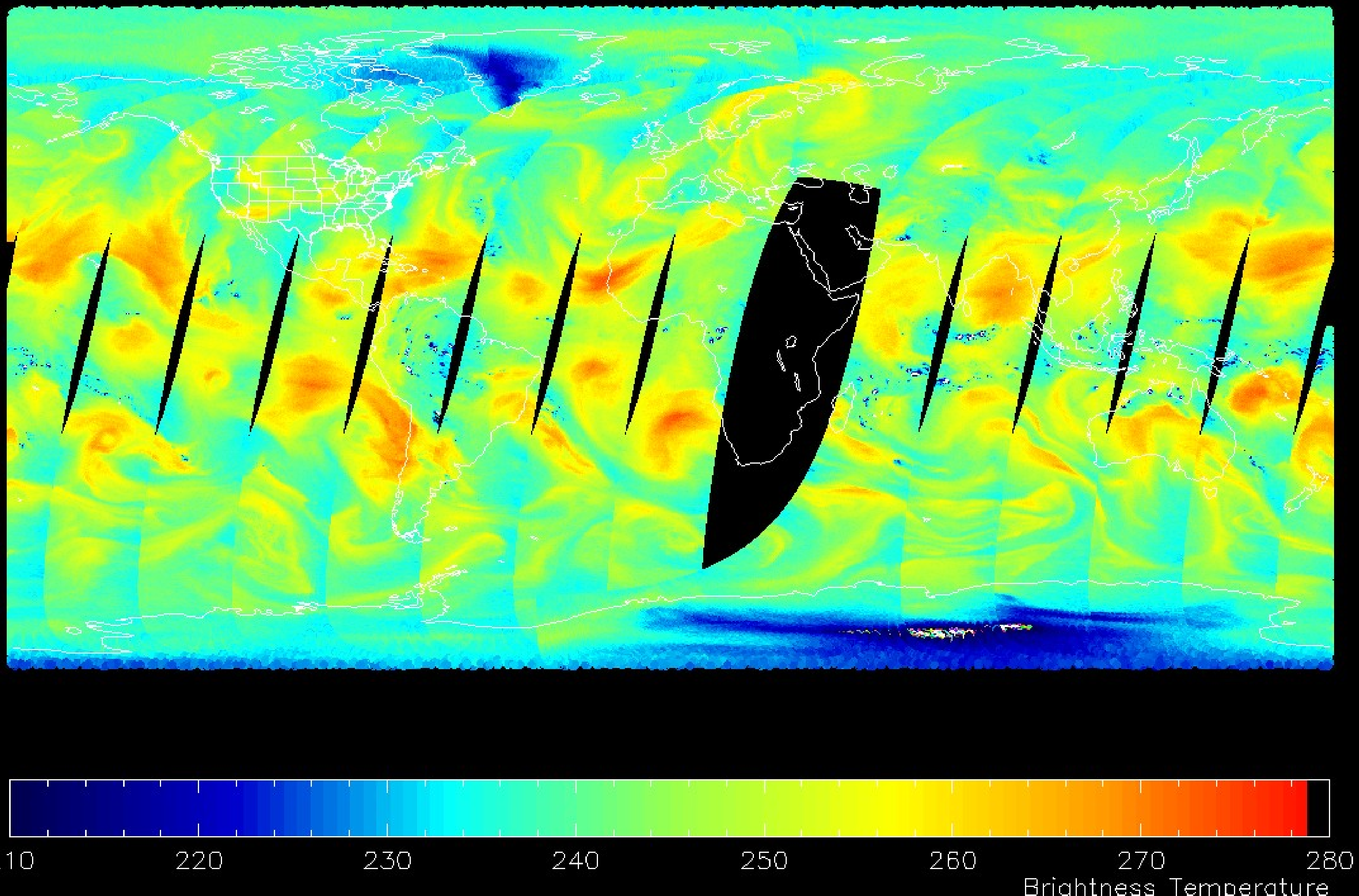




NOAA16 AMSU-A CHANNEL 1 23.8 GHz Feb 9 2005 Descending



NOAA16 AMSU-B CHANNEL 3 183.31+-1 GHz Feb 9 2005 Descending



Earth Science Mission Profile 1997 - 2003

12 December 2001

EOSDIS VERSION RELEASES: 8/94 V0; 8/97 V1; 7/99 V2.0; 12/99 V2; 7/01 V3; 9/02 V4

1997 | 1998 | 1999 | 2000 | 2001

OrbView-2[1]
8/1/97
705 km
98.2°
12:00 PM
SeaWiFS

TRMM
11/27/97
402 km
35°
CERES
LIS
VIRS
TMI
PR
(Japan)

Landsat 7
4/15/99
705 km
98.2°
10:05 AM
ETM+

QuikScat
6/19/99
803 km
98.6°
10:15 AM
SeaWinds

Terra (AM)
12/18/99
720 km
98.1°
10:40 AM
CERES (2)
MISR
MODIS
ASTER
(Japan)
MOPITT
(Canada)

ACRIMSAT
12/20/99
720 km
98.1°
10:00 AM
ACRIM III

NMP/EO-1
11/21/00
705 km
98.2°
10:01 AM
ALI
Hyperion
Atmospheric Corrector

QuikTOMS
9/21/01
800 km
97.3°
10:30 AM
TOMS

2001 | 2002 | 2003

Jason-1
(France)
12/7/01
1336 km
66°
JMR
TRSR
LRA
Poseidon 2
DORIS
(France)

METEOR 3M/SAGE III
(Russia)
12/10/01
1020 km
99.5°
9:30 AM
SAGE III

ESSP/GRACE
3/02
485 km
89°
KBR
GPS
SuperStar
(US/France)

Aqua (PM)
3/02
705 km
98.2°
1:30 PM
AIRS
AMSU-A
CERES (2)
MODIS
HSB *(Brazil)*
AMSR-E
(Japan)

SORCE
7/02
640 km
40°
TIM
SIM
SOLSTICE
XPS

ICESat
10/02
600 km
94°
GLAS
GPS

ADEOS II
(Japan)
11/02
803 km
98.6°
10:15 AM
SeaWinds
AMSR
GLI
ILAS-2
(Japan)
POLDER
(France)

Aura (CHEM)
9/03
705 km
98.2°
1:45 PM
MLS
TES
HIRDLS
(UK/US)
OMI
(Netherlands/ Finland)

Spacecraft not provided by NASA

Items in italics not funded by NASA

Currently in orbit

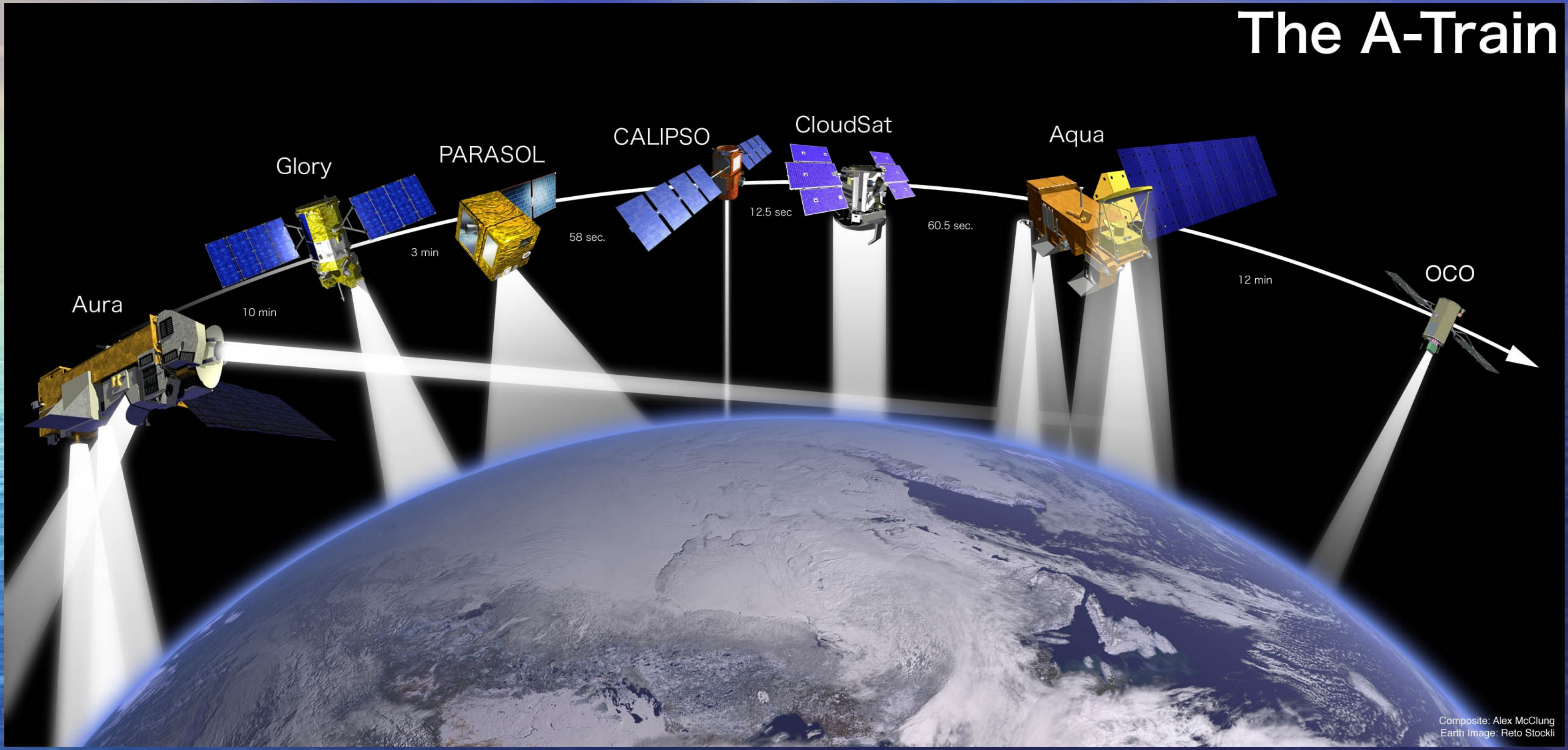
Launch Failure

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

EOS Missions

Landsat 7
QuikScat
Terra
ACRIMSAT
Jason-1
SAGE III
Aqua
ICESat
SORCE
Aura

The Afternoon Constellation "A-Train"



- The Afternoon constellation consists of 7 U.S. and international Earth Science satellites that fly within approximately 30 minutes of each other to enable coordinated science
- The joint measurements provide an unprecedented sensor system for Earth observations

Introduction of the NASA Earth Observing System (EOS)

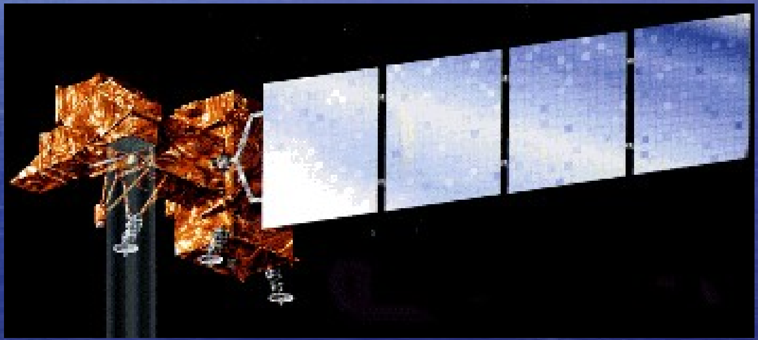
Terra (AM) 1999

Terra conducts many of its observations simultaneously, allowing for new ways of integrating different geophysical information

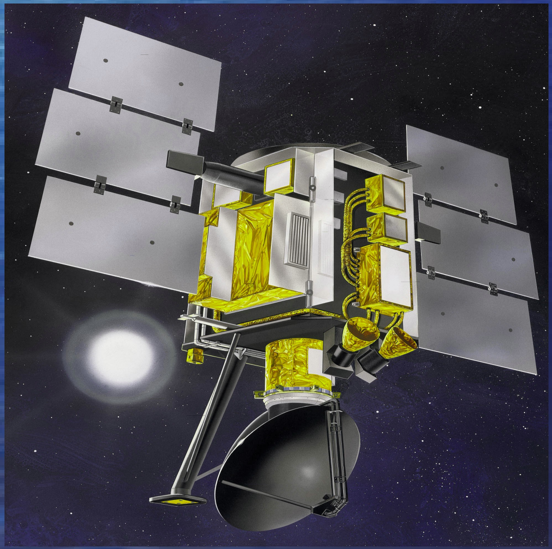
- *Aqua (PM) 2002*
- *Aura (CHEM) 2004*

NASA Spacecraft Fleet

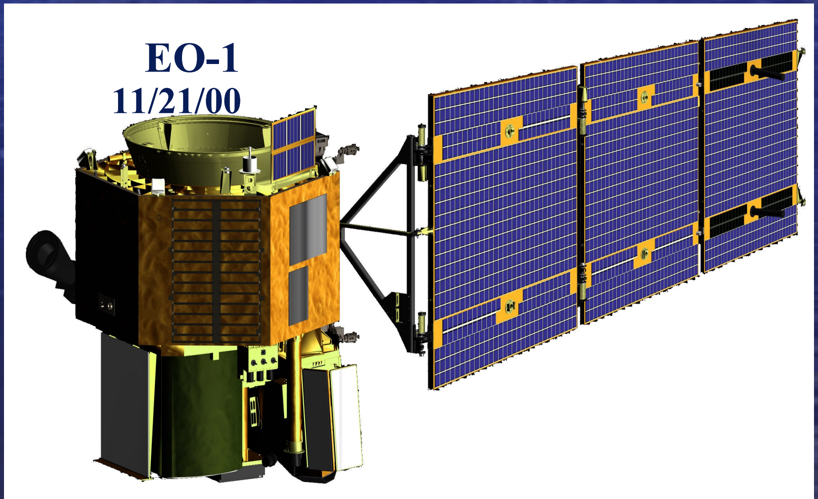
TRMM
11/27/97



Landsat 7
4/15/99

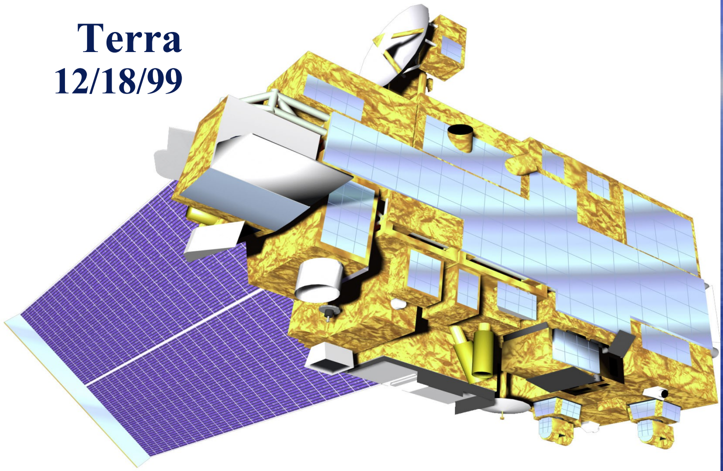


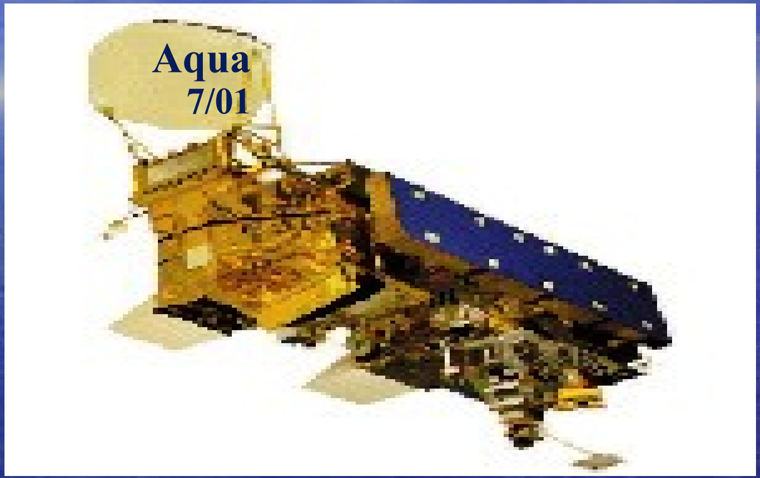
QuikScat
6/19/99

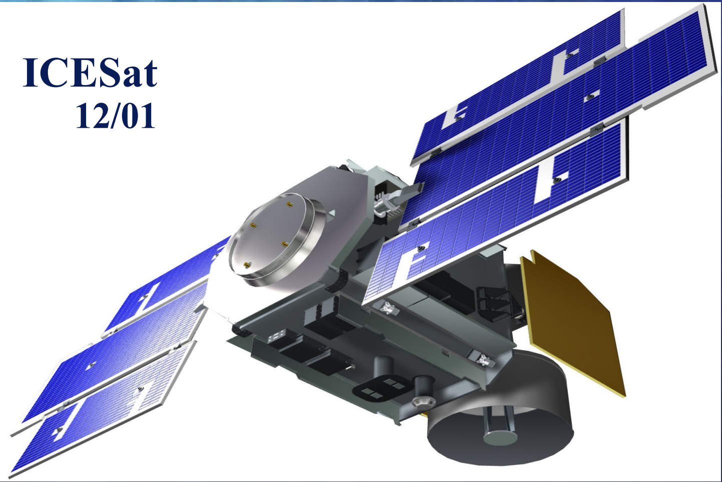


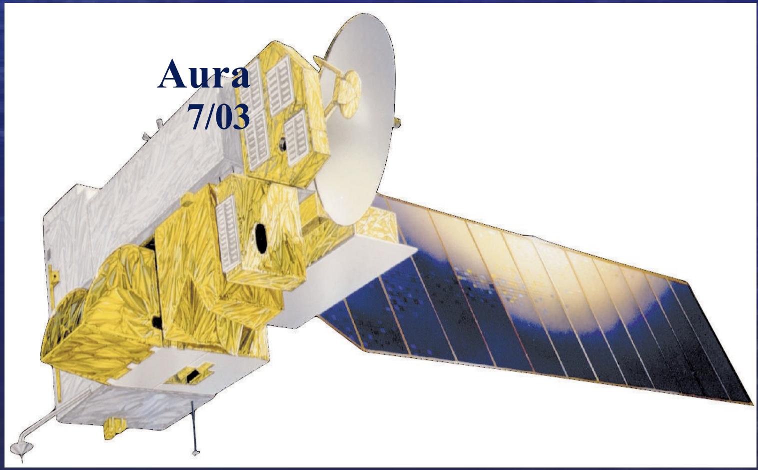
EO-1
11/21/00

NASA Spacecraft Fleet









Key Areas of Uncertainty in Understanding Climate & Global Change

- Earth’s radiation balance and the influence of clouds on radiation and the hydrologic cycle
- Oceanic productivity, circulation and air-sea exchange
- Transformation of greenhouse gases in the lower atmosphere, with emphasis on the carbon cycle

Key Areas of Uncertainty in Understanding Climate & Global Change

- Changes in land use, land cover and primary productivity, including deforestation
- Sea level variability and impacts of ice sheet volume
- Chemistry of the middle and upper stratosphere, including sources and sinks of stratospheric ozone
- Volcanic eruptions and their role in climate change

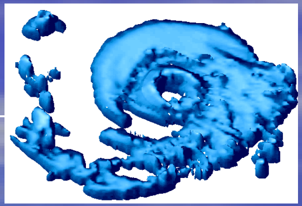
Remote Sensing Products Available

- Atmospheric properties
  - Rainfall amount
  - Cloud cover and cloud optical properties
  - Aerosol properties
  - Ozone, water vapor, and other stratospheric gas concentrations
    - Solar and lunar occultation
    - Backscattered ultraviolet
    - Microwave and thermal limb emission
  - Vertical distribution of cloud and aerosol properties using radar and lidar

Remote Sensing Products Available

- Land Surface properties
  - Vegetation index, spectral and angular reflectance, land cover & land cover change
  - Snow cover using microwave and optical systems
  - Topography of ice sheets using active lidar systems
- Ocean
  - Sea surface temperature using thermal and microwave methods
  - Sea surface topography from radar altimeters
  - Vector winds over the ocean using scatterometry
  - Sea ice using microwave and optical systems
  - Chlorophyll concentration and biological productivity of the oceans

The Tropical Rainfall Measuring Mission (TRMM)



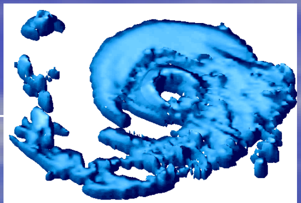
- The Tropical Rainfall Measuring Mission (TRMM) is an experimental satellite developed jointly by the United States (NASA) and Japan (NASDA).

- TRMM carries the first satellite-borne radar capable of estimating the detailed three-dimensional structure of rain. The satellite also carries passive visible/infrared and microwave instruments for observing rain.

- TRMM was launched in 1997 with an expected lifetime of 3 to 6 years.

- TRMM achieves almost complete data coverage of the tropics (37 S to 37 N latitude) every two days.

- Data resolution varies by instrument: 2 km horizontal (VIRS); 4 km horizontal and 250 m vertical (PR); and 6 to 50 km horizontal (TMI).



TRMM Instruments and Variables

Heritage

AVHRR
(NOAA polar orbiter)
GOES[1]
(NOAA geostationary)

SSM/I
(DMSP polar orbiter)

TRMM Instruments

VIRS – Visible and Infrared Scanner
$0.63\ \mu m$ (visible), $1.6\ \mu m$, $3.8\ \mu m$ (near IR),
$10.8\ \mu m$ and $12.0\ \mu m$ (window channels)

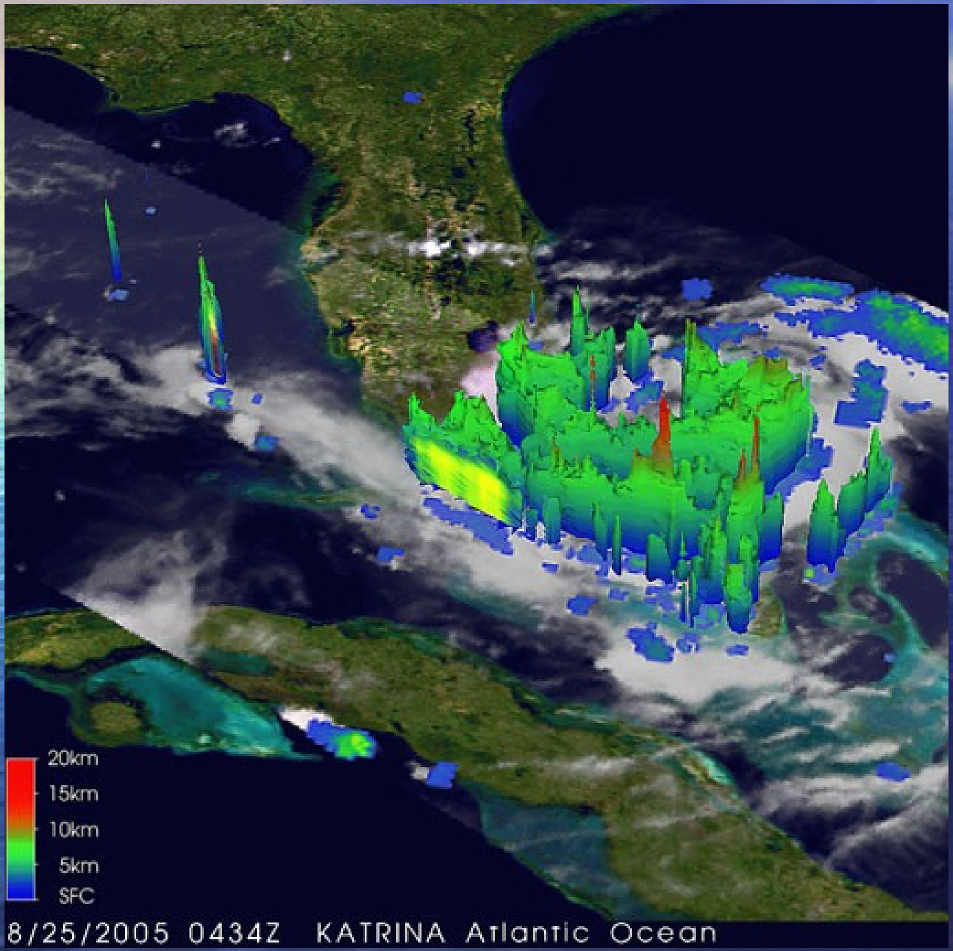
TMI – TRMM Microwave Imager
10.7 , 19 , 21 , 37, and 86 GHz

PR – Precipitation Radar, 13.8 GHz

Some Physical Variables Estimated by TRMM

Rainfall (mm/hr)
Cloud Liquid Water (g/m^3)
Cloud Ice (g/m^3)
Cloud Top Height (m)
Cloud Type (convective/stratiform)
Height of Bright Band (m)

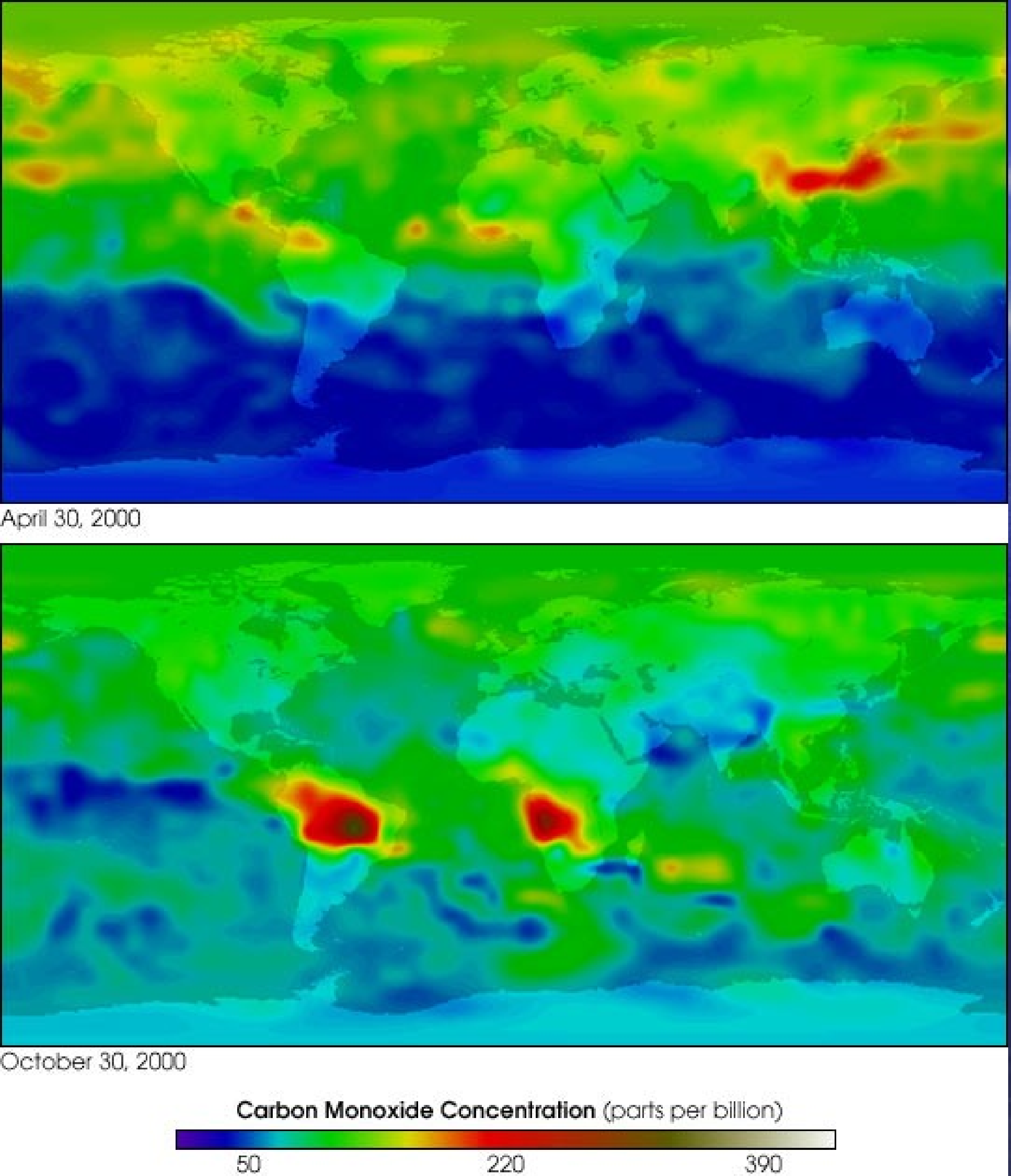
[1] The GOES Precipitation Index (GPI) is calculated from GOES channel 4 which covers approximately $10.5\text{-}11.5\ \mu m$. Rain(5day, 5x5degree) = 3 mm/hr A(235k) / A(total). [Arkin, 1979]



- This picture of hurricane Katrina is another image with superimposed data.
- This time it is the vertical height of the precipitation in the clouds.

MOPITT

First Global Carbon Monoxide (Air Pollution) Measurements



MOPITT CO Data

CURRENT MODIS PRODUCTS

MOD01 Level-1A Radiance Counts
MOD02 Level-1B Calibrated Relocated Radian
-also Level 1B "subsampled" 5kmX5km produ
MOD03 Relocation Data Set
MOD04 Aerosol Product
MOD05 Total Precipitable Water
MOD06 Cloud Product
MOD07 Atmospheric profiles
MOD08 Gridded Atmospheric Product (Level-
MOD09 Atmospherically-corrected Surface Reflectance
MOD10 Snow Cover
MOD11 Land Surface Temperature & Emissivit
MOD12 Land Cover/Land Cover Change
MOD13 Vegetation Indices
MOD14 Thermal Anomalies, Fires & Biomass Burning
MOD15 Leaf Area Index & FPAR
MOD16 Surface Resistance & Evapotranspiration
MOD17 Vegetation Production, Net Primary Productivity
MOD18 Normalized Water-leaving Radiance
MOD19 Pigment Concentration
MOD20 Chlorophyll Fluorescence
MOD21 Chlorophyll_a Pigment Concentration
MOD22 Photosynthetically Active Radiation (PAR)

MOD23 Suspended-Solids Conc, Ocean Wa
MOD24 Organic Matter Concentration
MOD25 Coccolith Concentration
MOD26 Ocean Water Attenuation Coefficien
MOD27 Ocean Primary Productivity
MOD28 Sea Surface Temperature
MOD29 Sea Ice Cover
MOD31 Phycoerythrin Concentration
MOD32 Processing Framework & Match-up Database
MOD35 Cloud Mask
MOD36 Total Absorption Coefficient
MOD37 Ocean Aerosol Properties
MOD39 Clear Water Epsilon
MOD43 Albedo 16-day L3
MOD44 Vegetation Cover Conversion
MODISALB Snow and Sea Ice Albedo

MODIS TERRA Satellite Specification Overview

Orbit:	705 km, 10:30 a.m. descending node or 1:30 p.m. ascending node, sun-synchronous, near-polar, circular
Scan Rate:	20.3 rpm, cross track
Swath Dimensions:	2330 km (across track) by 10 km (along track at nadir)
Telescope:	17.78 cm diam. off-axis, afocal (collimated), with intermediate field stop
Size:	1.0 x 1.6 x 1.0 m
Weight:	250 kg
Power:	225 W (orbital average)
Data Rate:	11 Mbps (peak daytime)
Quantization:	12 bits
Spatial Resolution:	250 m (bands 1-2)
(at nadir):	500 m (bands 3-7), 1000 m (bands 8-36)
Design Life:	5 years

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

Primary Use	Band	Bandwidth[1]	Spectral Radiance[2]	Required NEΔT(K)[3]
Surface/Cloud Temperature	20	3.660-3.840	0.45	0.05
	21	3.929-3.989	2.38	2.00
	22	3.929-3.989	0.67	0.07
	23	4.020-4.080	0.79	0.07
Atmospheric Temperature	24	4.433-4.498	0.17	0.25
	25	4.482-4.549	0.59	0.25
Cirrus Clouds	26	1.360-1.390	6.00	150[4]
Water Vapor	27	6.535-6.895	1.16	0.25
	28	7.175-7.475	2.18	0.25
	29	8.400-8.700	9.58	0.05
Ozone	30	9.580-9.880	3.69	0.25
Surface/Cloud Temperature	31	10.780-11.280	9.55	0.05
	32	11.770-12.270	8.94	0.05
Cloud Top Altitude	33	13.185-13.485	4.52	0.25
	34	13.485-13.785	3.76	0.25
	35	13.785-14.085	3.11	0.25
	36	14.085-14.385	2.08	0.35

[1] Bands 1 to 19, nm; Bands 20-36, μm

[2] $(W/m^2\text{-}\mu m\text{-}sr)$

[3] SNR=Signal-to-noise ratio; NEΔT=Noise-equivalent temperature difference — Performance goal is 30%-40% better than required

[4] SNR

MODIS Operational Cloud Products

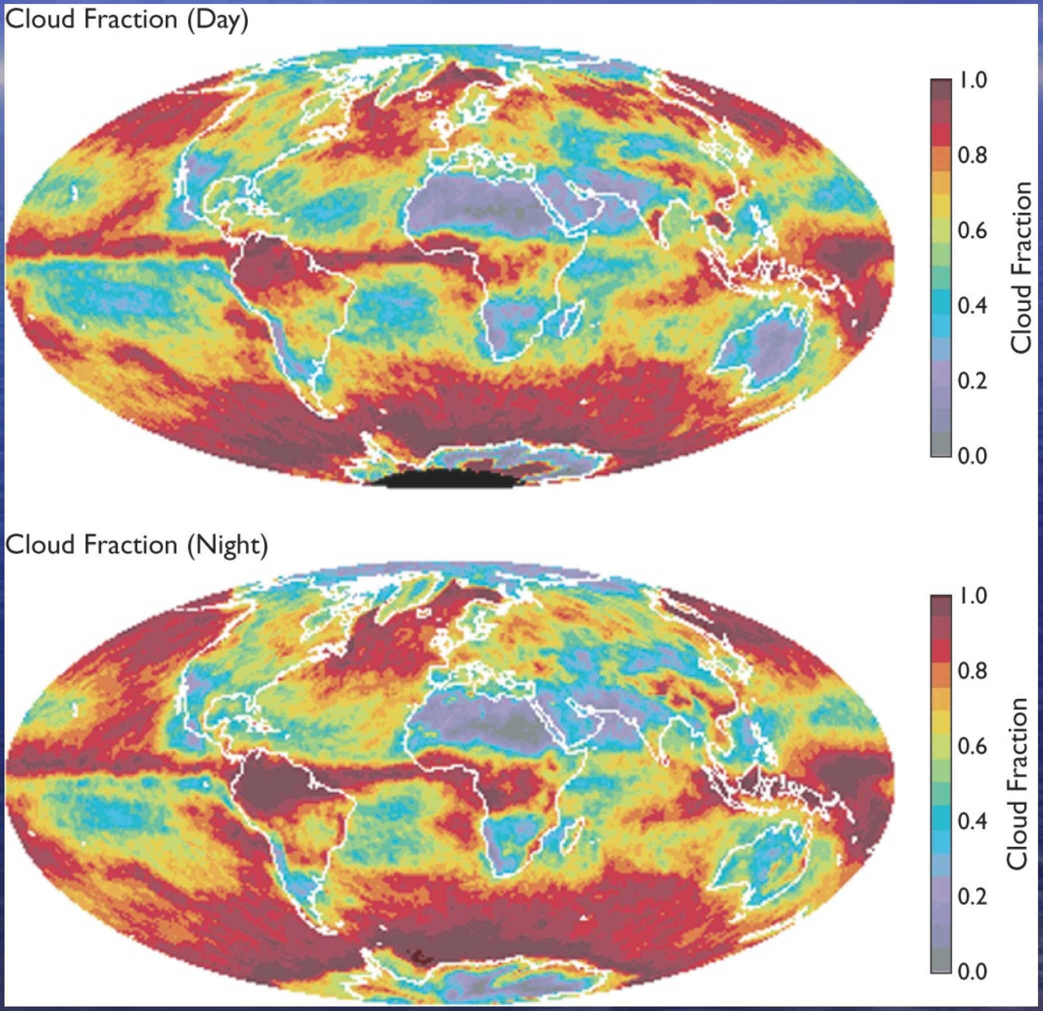
- Pixel level products (Level-2)
  - Cloud mask (*S. A. Ackerman, R. A. Frey, U. Wisconsin/CIMSS)*
    - 1 km, 48-bit mask/12 spectral tests, clear sky confidence in bits 1,2
  - Cloud top properties – W. *P. Menzel, R. A. Frey, U. Wisconsin/CIMSS*
    - Cloud top pressure, temperature, effective emissivity
    - 5 km, CO_2 slicing for high clouds, 11 µm for low clouds
  - Cloud optical & microphysical properties – *M. D. King, S. Platnick, GSFC*
    - optical thickness, τ_c, effective particle size, r_e, water path, thermodynamic phase
    - Primary r_e from 2.1 µm band
  - IR-derived thermodynamic phase – *B. A. Baum, U. Wisconsin/SSEC*
    - SDS name Cloud_Phase_Infrared (day, night, and combined)
  - Cirrus reflectance (via 1.38 µm band) – *B. C. Gao, Naval Res. Lab*
    - SDS name Cirrus_Reflectance
- Gridded & time-averaged products (Level-3)
  - Scalar statistics, 1-D and 2-D histograms
  - Contains all atmosphere products (clouds, aerosol, atmospheric profiles)

Monthly Mean Cloud Fraction (S. A. Ackerman – Univ. Wisconsin)

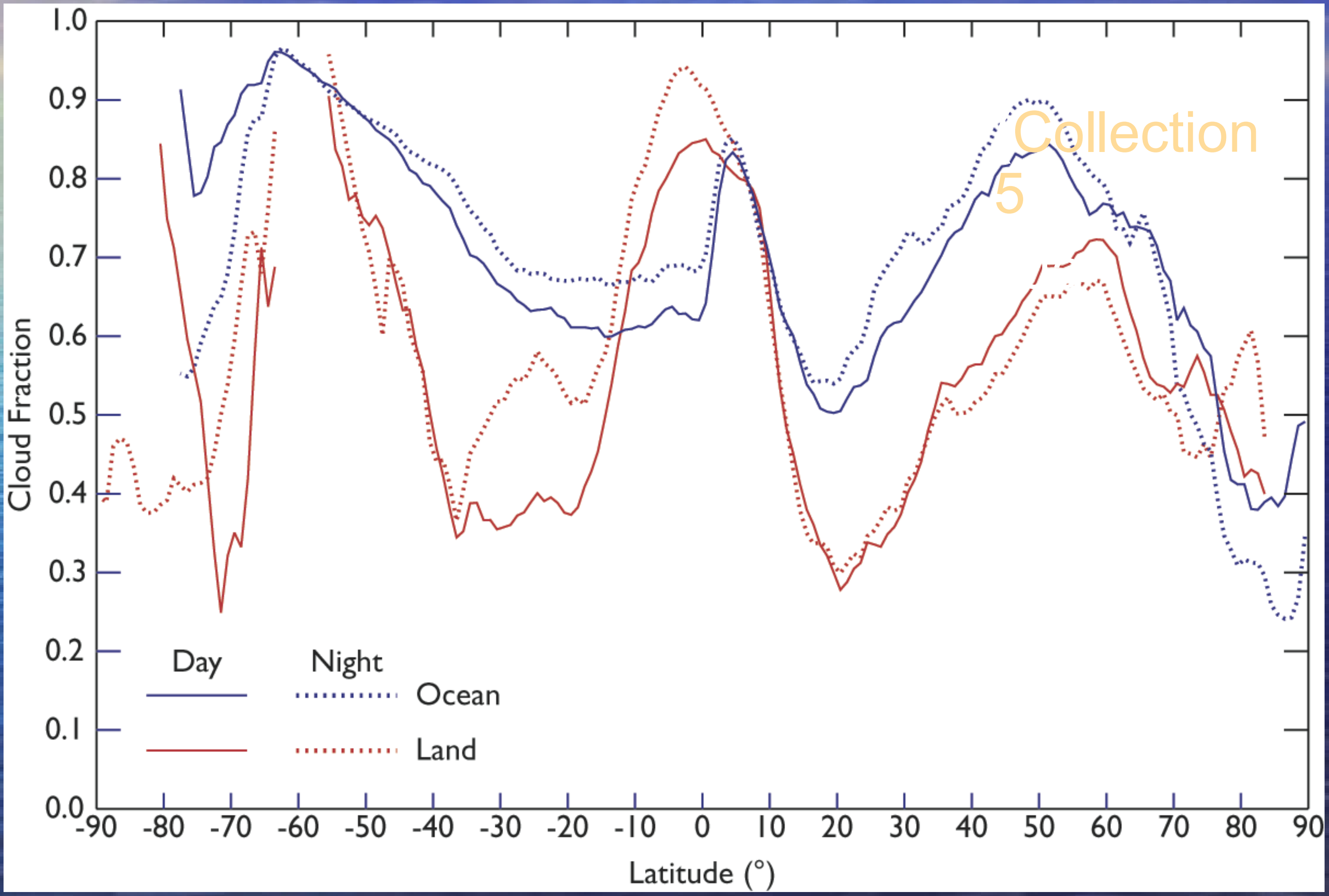
April 2005 (Collection 5)
Aqua

Cloud_Fraction_Day_Mean_Mean

Cloud_Fraction_Night_Mean_Mean



Zonal Mean Cloud Fraction
(S. A. Ackerman,– Univ. Wisconsin)



Status of GCM-derived High, Mid and Low Clouds

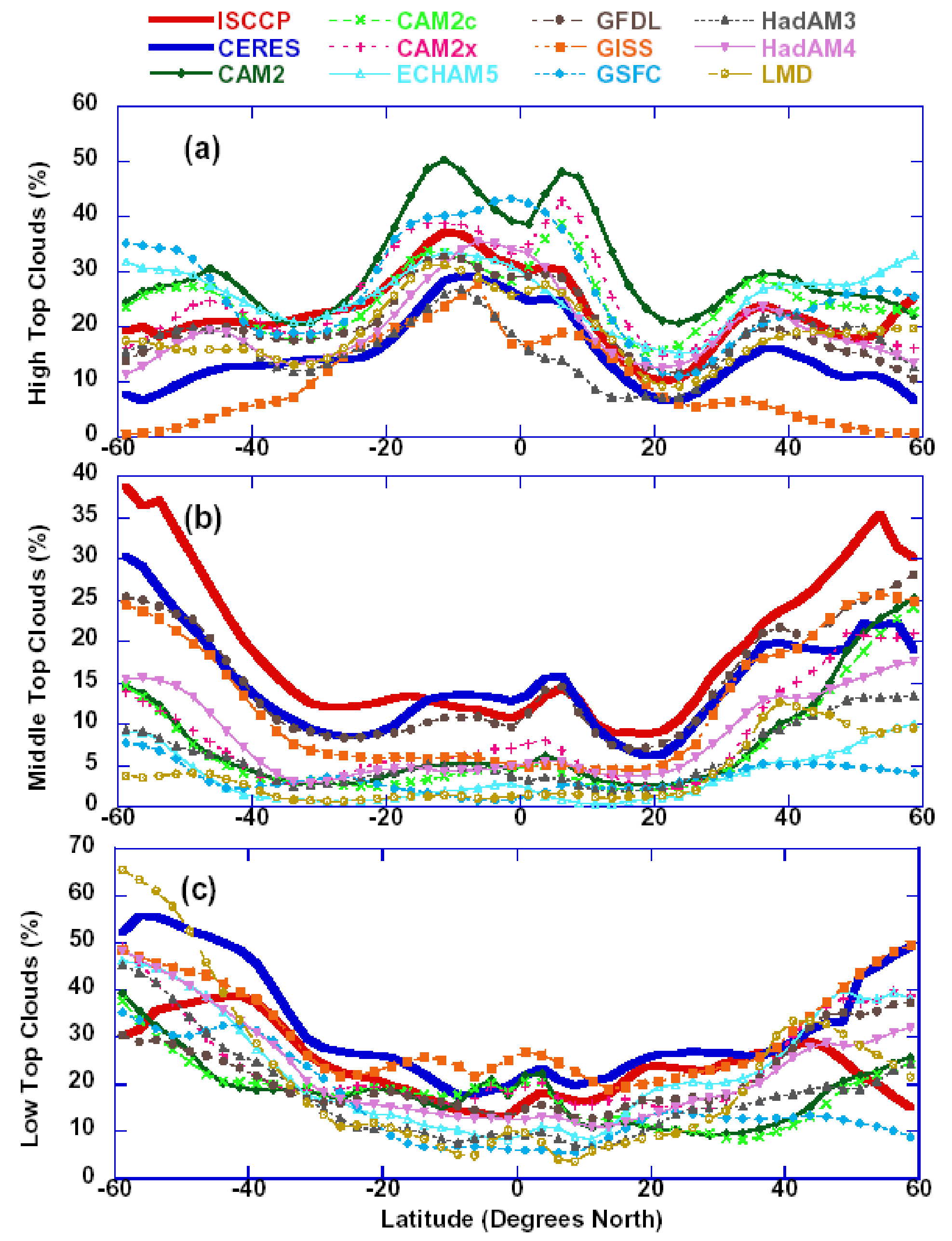
Satellite cloud products

⇒ GCM validations

High cloud

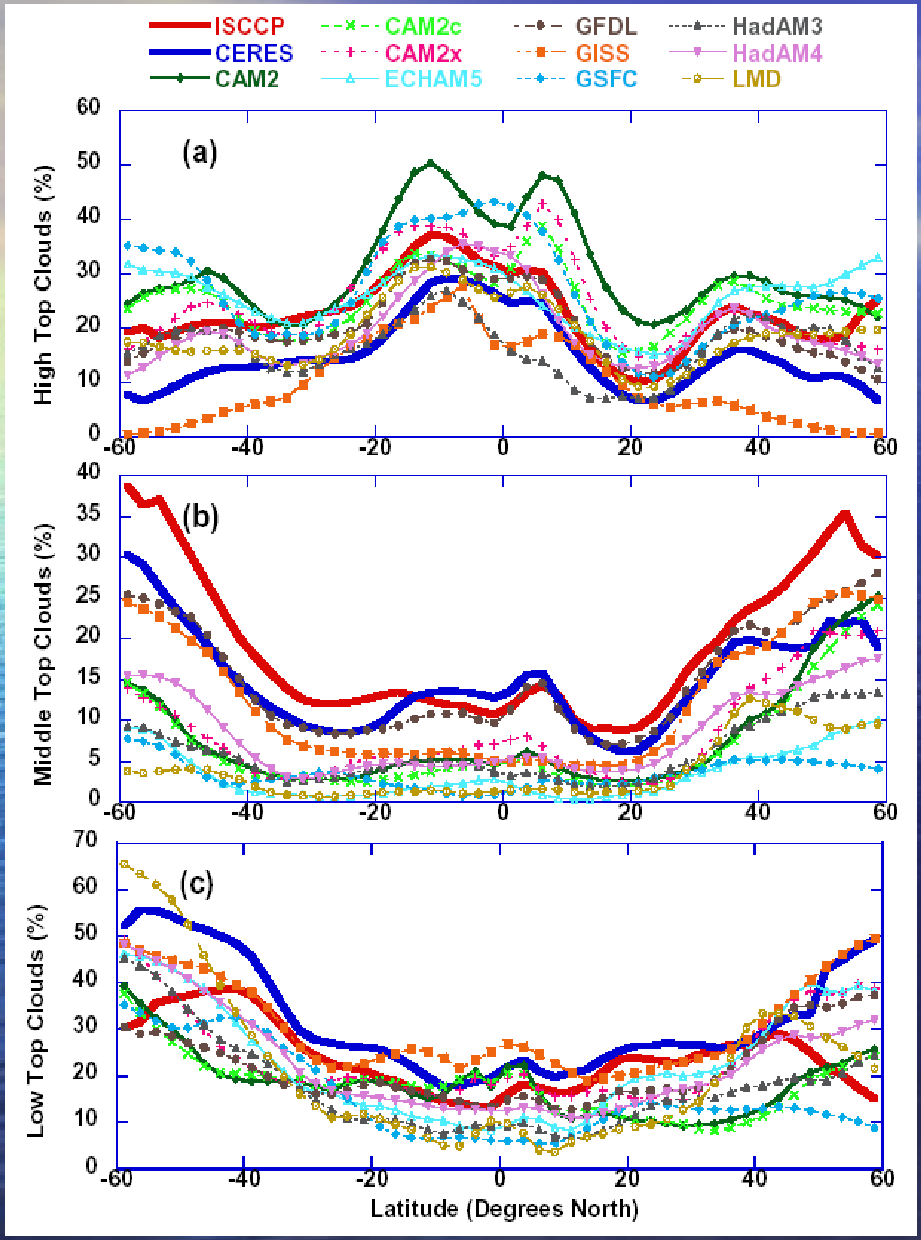
Mid cloud

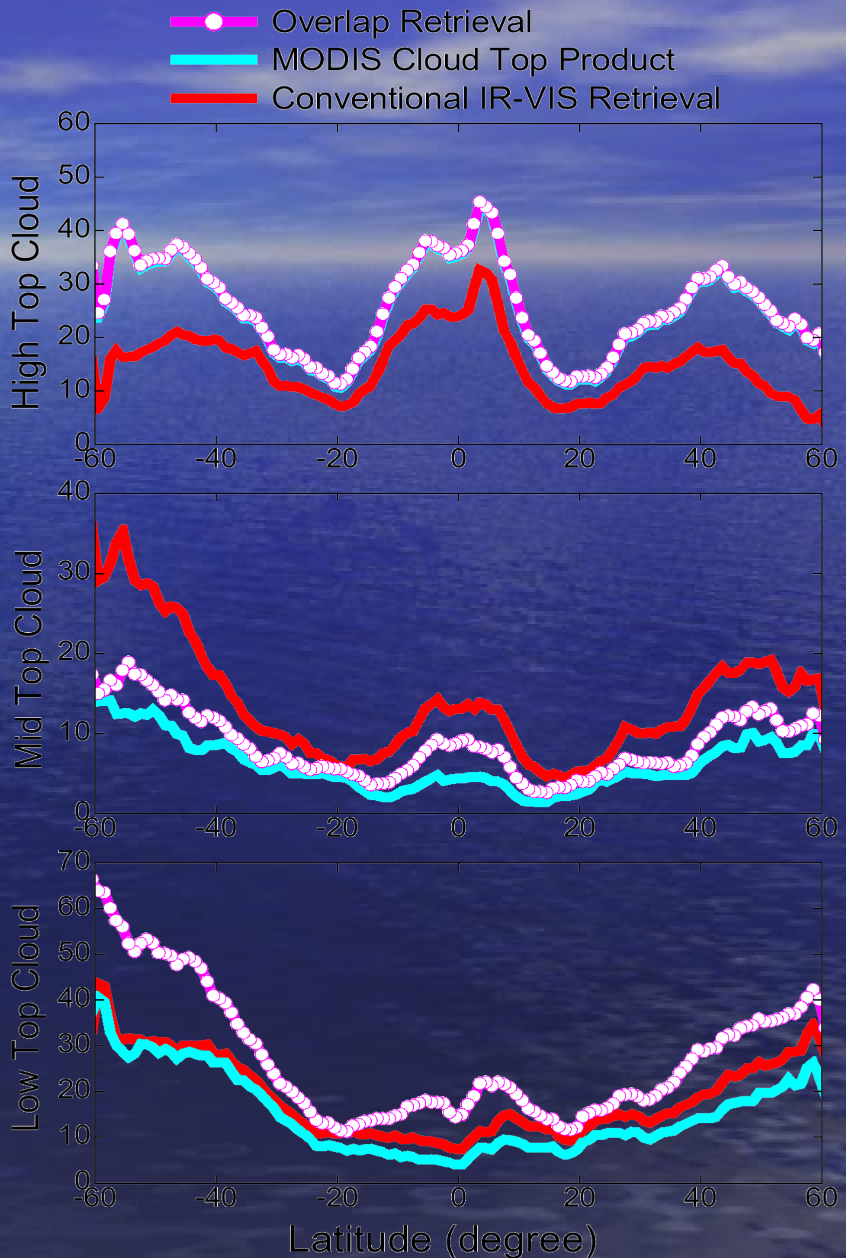
Low cloud



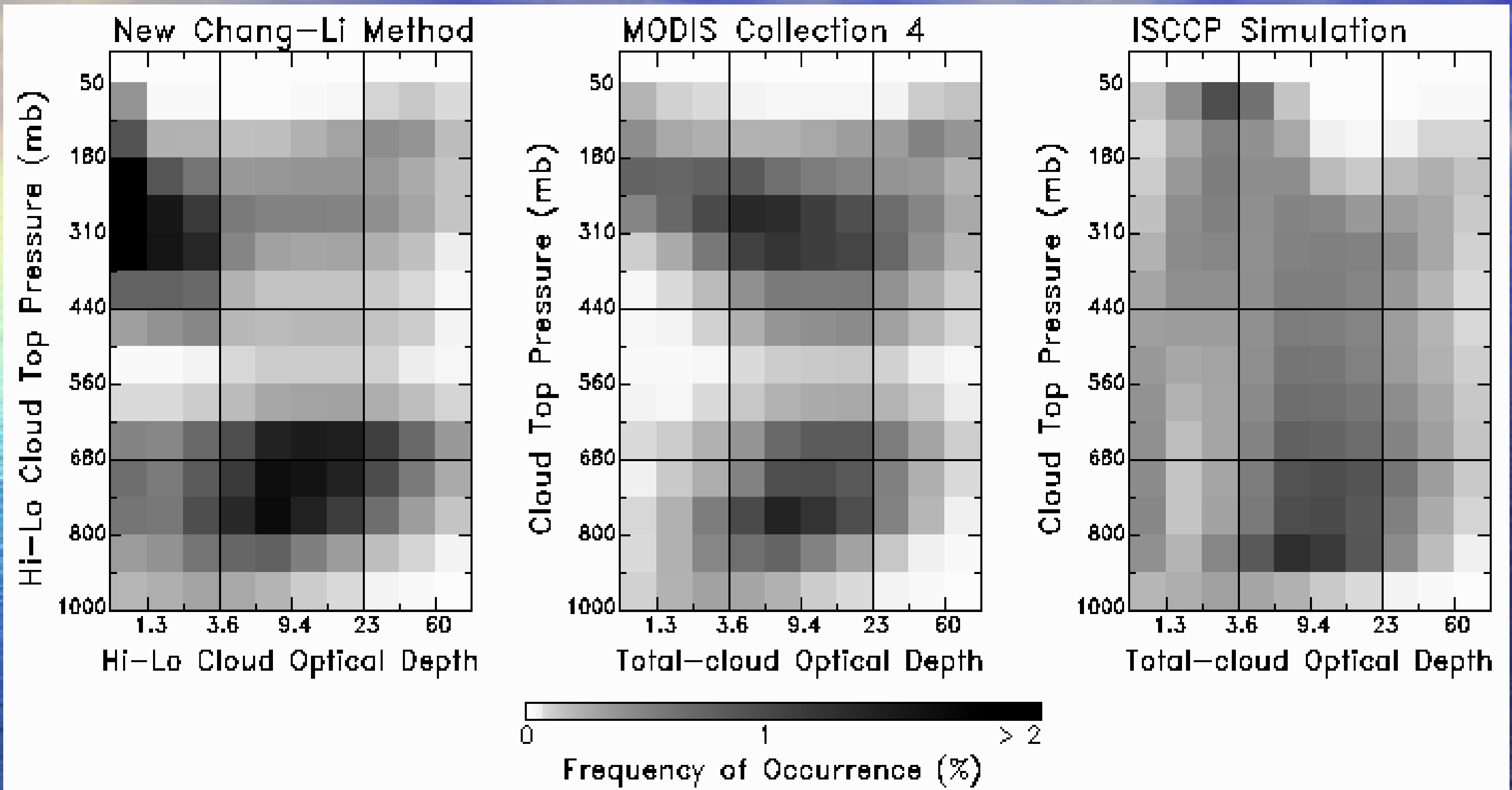
(Zhang et al. 2005, JGR)

Comparisons of High, Mid, Low Cloud Amounts



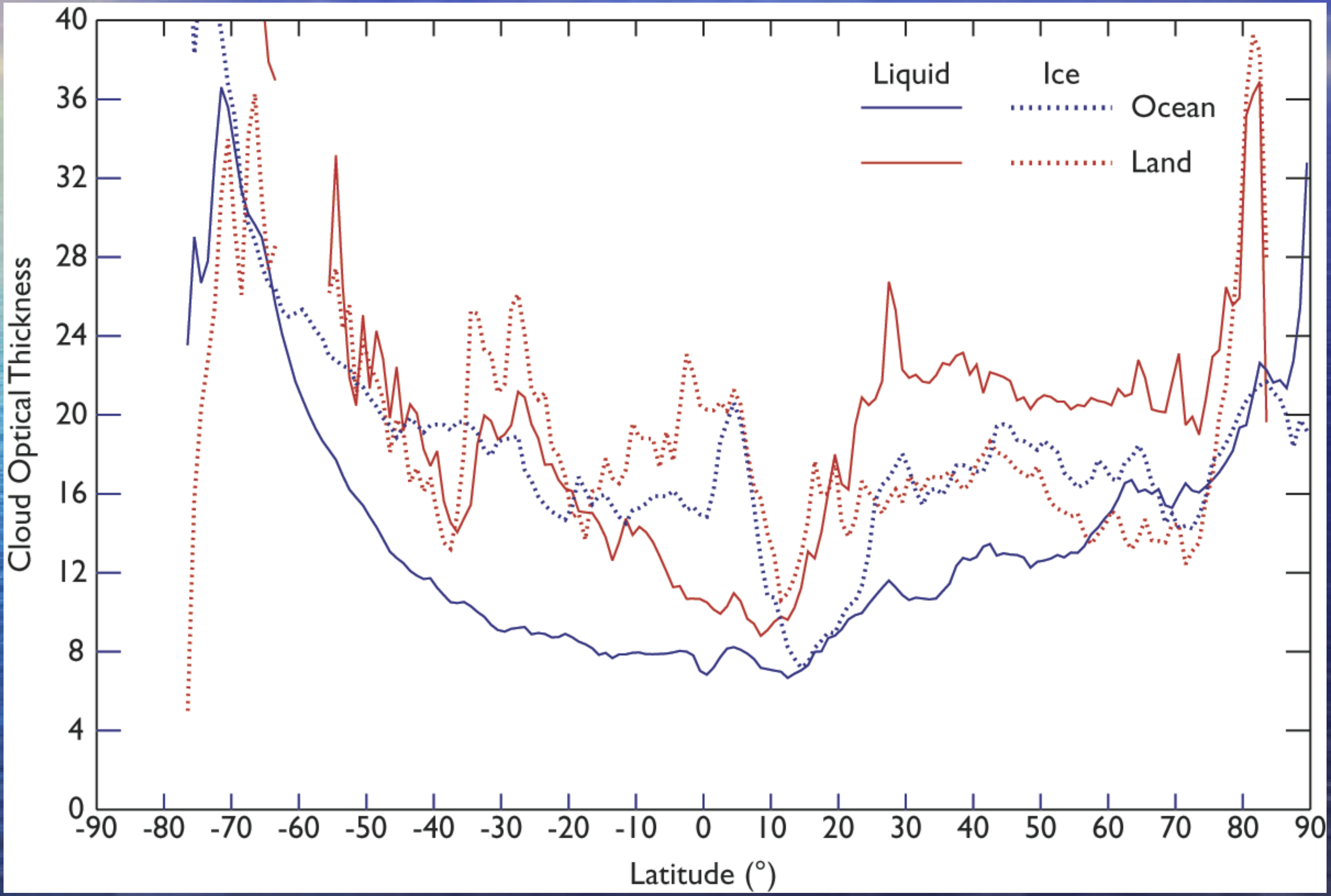


Comparisons of Cloud Top Pressure vs. Cloud Optical Depth



- All three methods applied to April 2001 Terra/MODIS data

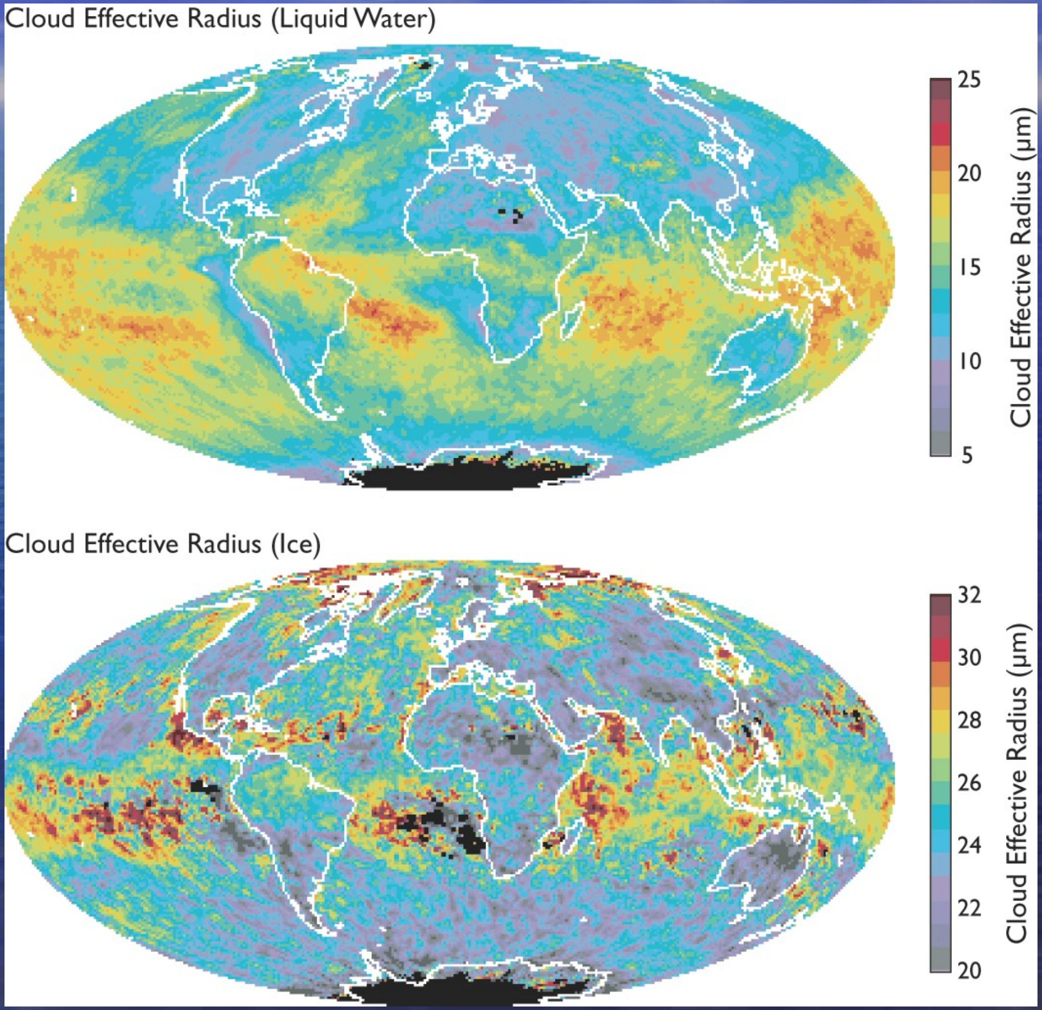
Zonal Mean Cloud Optical Thickness (M. D. King, S. Platnick et al. – NASA GSFC)



April 2005 (Collection 5) Aqua

Monthly Mean Cloud Effective Radius (M. D. King, S. Platnick et al. – NASA GSFC)

April 2005 (Collection 5)
Aqua (QA Mean)



SSM/I Cloud Liquid Water Algorithm: Operational at FNMOC and NESDIS

Pros:

- *Semi-Physical with easy understanding*
- *Large dynamic range (rain and non-rain)*
- *Clean background due to uses of real measurements*
- *Validated with ASTEX data for non-raining clouds*

Cons:

- *Difficult to accommodate information from new channels and ancillary data*
- *Cloud layer temp is implicit*

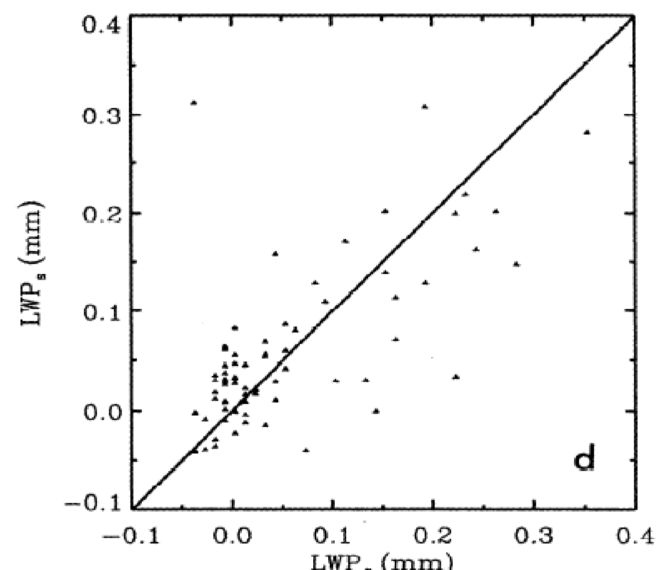
$$\mathrm{LWP} = \begin{cases} \mathrm{LWP}_{19V} & \text{if} \quad \mathrm{LWP}_{19V} \geq 0.70\ \mathrm{mm} \\ \mathrm{LWP}_{37V} & \text{if} \quad \mathrm{LWP}_{37V} \geq 0.28\ \mathrm{mm} \quad \text{or} \quad \mathrm{WVP} \geq 30\ \mathrm{mm}, \\ \mathrm{LWP}_{85H} & \text{otherwise} \end{cases}$$

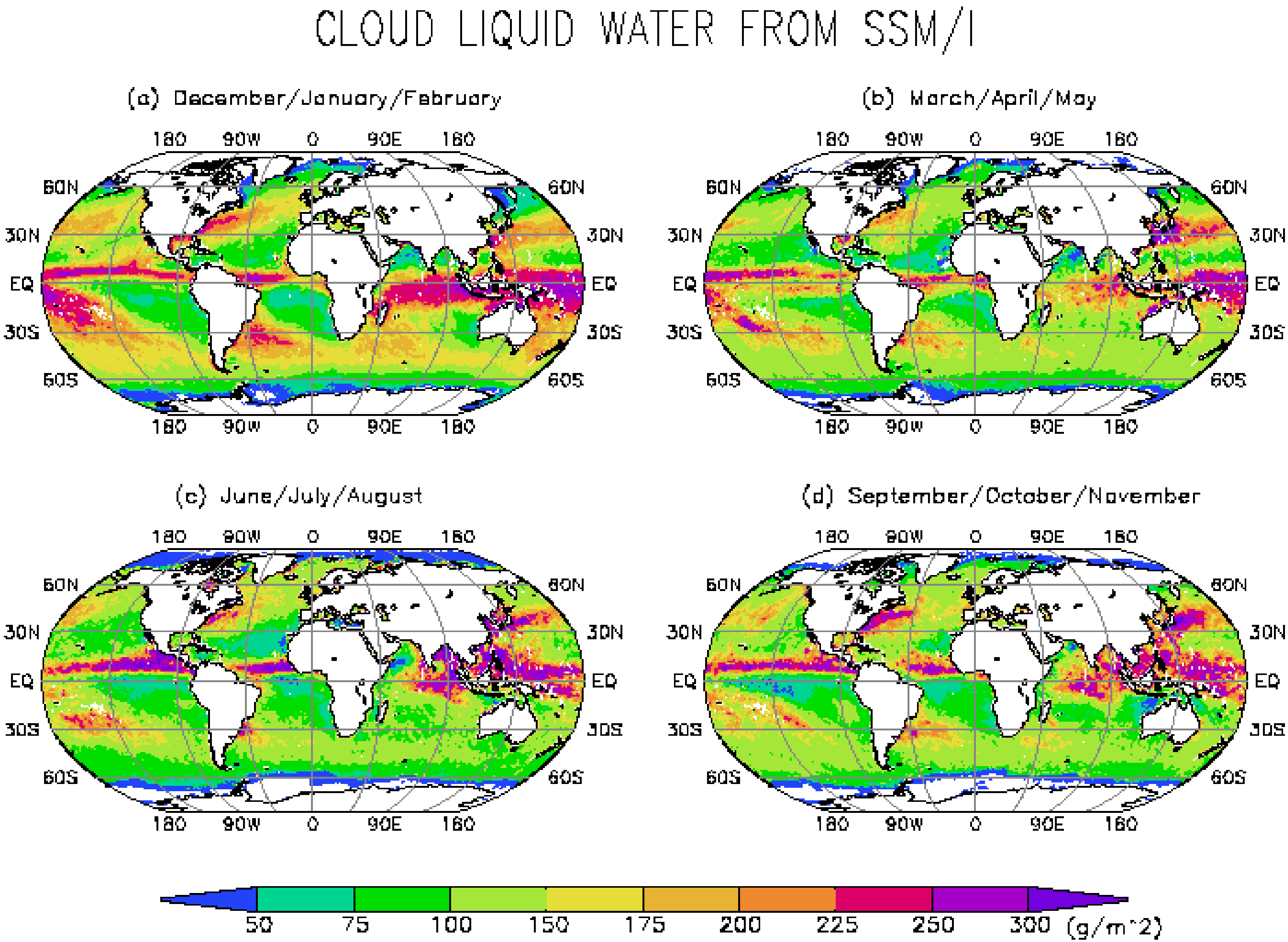
TABLE 1. The coefficients for LWP algorithms.

LWP_{chan}	TB_1, TB_2	a_0	a_1[a]	a_2[a]
LWP_{19V}	TV19, TV22	−3.20[b]	2.80	0.42
LWP_{37V}	TV37, TV22	−1.66[c]	2.90	0.35
LWP_{85H}	TH85, TV22	−0.44[c]	−1.60	1.35

[a] Based on global clear sky measurements.
[b] Based on simulated "measurements" calculated from radiative transfer model.
[c] Based on collocated ground-based and satellite measurements for LWP_{37V} and LWP_{85H}.

$$\mathrm{LWP}_{chan} = a_0[\ln(290 - \mathrm{TB}_1) - a_1 - a_2 \ln(290 - \mathrm{TB}_2)],$$




CLOUD LIQUID WATER FROM SSM/I
(a) December/January/February
(b) March/April/May
(c) June/July/August
(d) September/October/November
180 90W 0 90E 180
60N 30N EQ 30S 60S
50 75 100 150 175 200 225 250 300 (g/m^2)

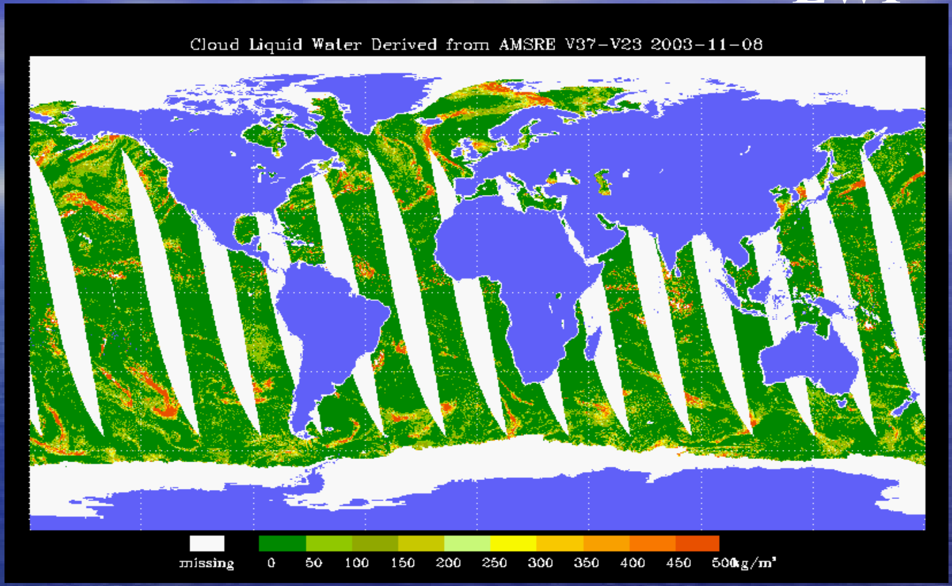
AMSR-E LWP&RWP Algorithms

The same physical retrieval with modification for AMSR-E channels

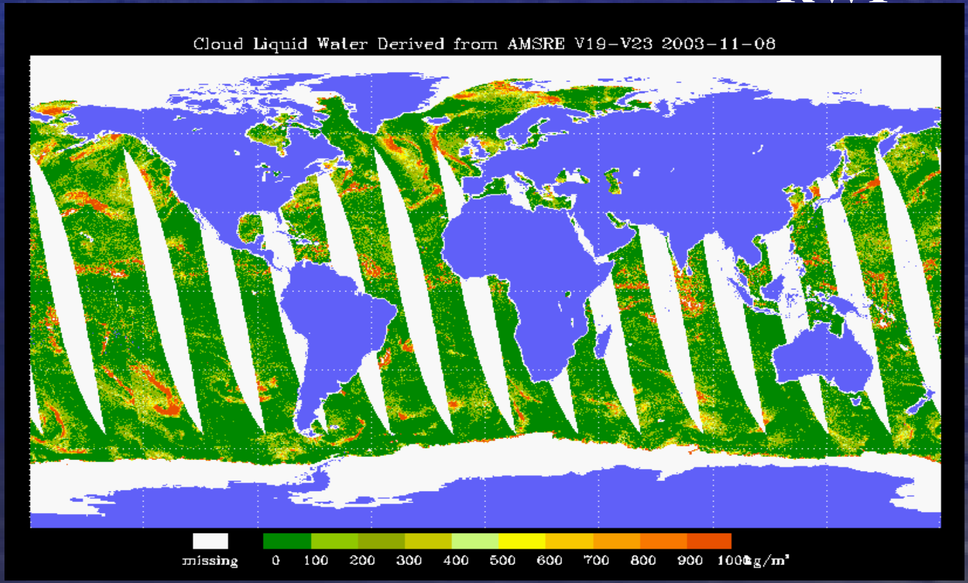
23.8, 37 V-pol for LWP and WVP,
23.8, 18 V-pol for RWP

LWP = a0 [ln(Ts-TV37)- a1 ln(Ts-TV23)-a2]
WVP = b0 [ln(Ts-TV37)- b1 ln(Ts-TV23)-b2]
RWP = c0 [ln(Ts-TV18)- c1 ln(Ts-TV23)-c2]

LWP

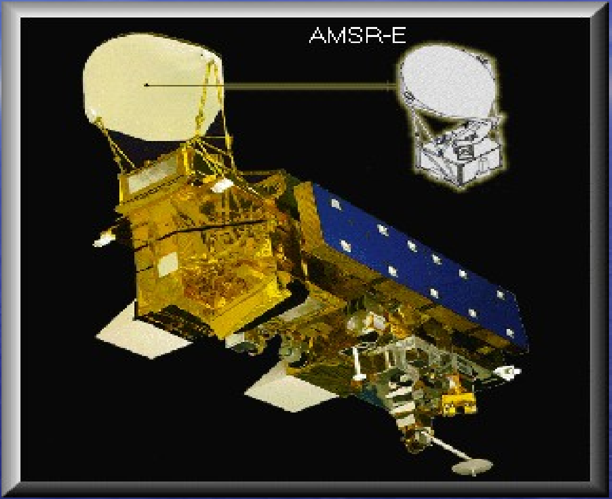


RWP



Aqua AMSR-E Products

- Ocean products : RWP,CWP,SST,SSW,CIWP,TWP, Rain rate, Sea ice concentration
- Land products: LST, Soil moisture,Rain rate,Snow cover, Snow/Ice Types, Snow equivalent water



Parameters	SMMR (Nimbus-7)	SSM/I (DMSP-F08,F10,F11,F13,F15)	AMSR (Aqua, ADEOS-II)
Time Period	1978 to 1987	1987 to Present	Beginning 2001
Frequency (GHz)	6.6, 10.7, 18, 21, 37	19.3, 22.3, 36.5, 85.5	6.9, 10.7, 18.7, 23.8, 36.5, 89.0
Sample Footprint Sizes (km)	148 x 95 (6.6 GHz) 27 x 18 (37 GHz)	37 x 28 (37 GHz) 15 x 13 (85.5 GHz)	74 x 43 (6.9 GHz) 14 x 8 (36.5 GHz) 6 x 4 (89.0 GHz)

TRMM Sensors

Precipitation radar (PR):

- 13.8 GHz
- 4.3 km footprint
- 0.25 km vertical res.
- 215 km swath

Microwave radiometer (TMI):

- 10.7, 19.3, 21.3, 37.0
- 85.5 GHz (dual polarized except for 21.3 V-only)
- 10x7 km FOV at 37 GHz
- 760 km swath

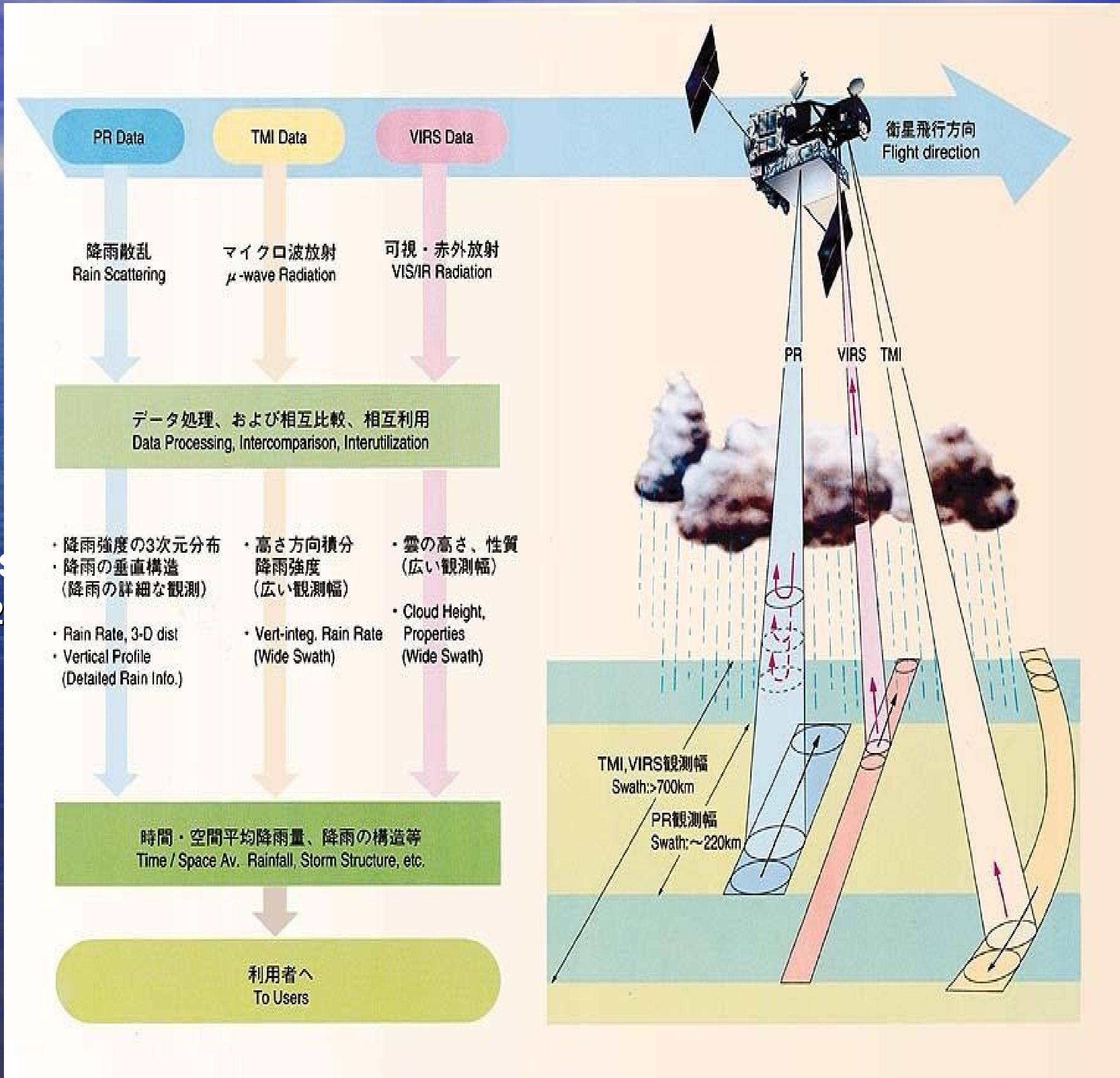
Visible/infrared radiometer (VIRS

- 0.63, 1.61, 3.75, 10.8, and 12
- at 2.2 km resolution

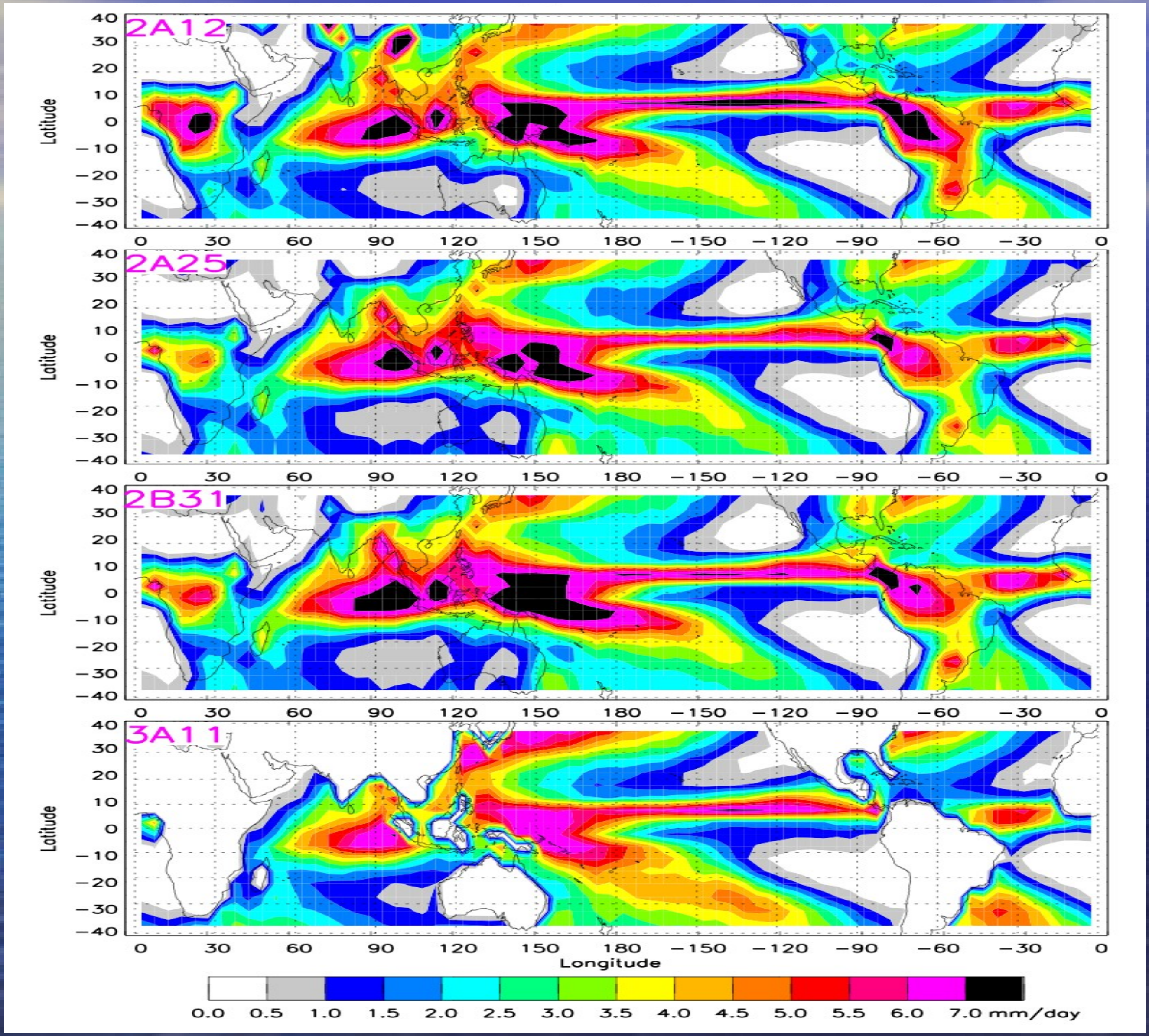
Additional EOS instruments:

CERES (Cloud & Earth Radiant Energy System) 720 km swath

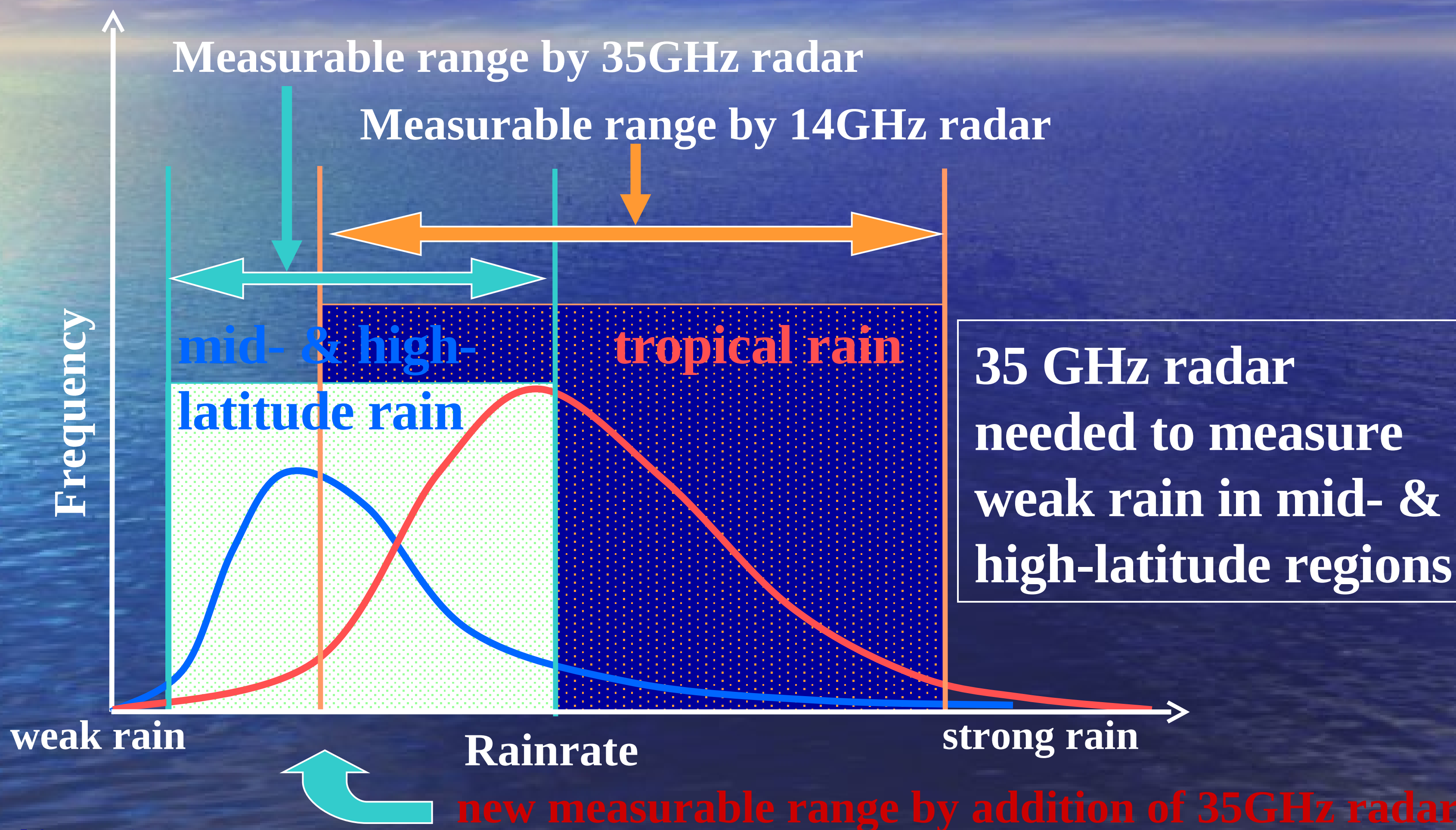
LIS (Lightning Imaging Sensor)



1998-2005 Mean Monthly Rainfall (5°x5°)



Need for 35 GHz Radar



35 GHz radar needed to measure weak rain in mid- & high-latitude regions

(T. Iguchi; CRL)

GPM Mission Concept

Main Role of Core Satellite

- *Better understand dynamics, macrophysics, & microphysics of precipitation and precipitating-storm lifecycles.*
- *Obtain long record of 4D distributions of rainfall, latent heat production, and rain DSD properties.*
- *Train, reference, & calibrate rain retrieval algorithms used with other constellation satellite radiometers.*

Space Hardware

GPM Core Satellite

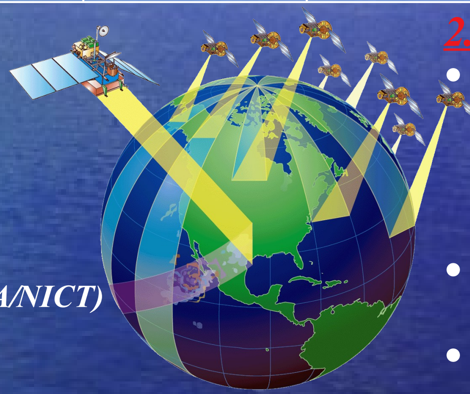
GPM Constellation Satellites (8)

Main Role of Constellation Fleet

- *Provide sufficient global temporal sampling to significantly reduce uncertainties in short-term rainfall accumulations impacted by diurnal and semi-diurnal variations.*
- *Provide full global (pole-to-pole) coverage.*
- *Extend scientific and societal applications in areas of climate, weather, & hydrometeorology.*

1. GPM Core Satellite

- *(1) TRMM-like spacecraft (NASA).*
  non-sunsynchronous orbit
  ~ 65° inclination
  ~400 km altitude
- *(2) H2-A rocket launch (JAXA).*
- *(3) DF crosstrack-scan radar -- DPR (JAXA/NICT)*
  Ku-Ka Bands (13.6 - 35.5 GHz)
  ~ 5 km horizontal resolution
  ~250 m vertical resolution
- *(4) MF conical-scan radiometer -- GMI (NASA/Industry)*
  (10.7V/H, 18.6V/H, 23.8V, 37V/H, & 89V/H)
  (HF channels option pending -- 166V/H & 183±3/6/9H)



2. GPM Satellite Constellation

- *(1) Dedicated Constellation Satellites, Satellites of Opportunity carrying PMW rain-radiometers (co-existing experimental & operational platforms), and Backup Satellites carrying arbitrary PMW radiometers.*
- *(2) Revisit time:*
  3-hour for ~90% of time
- *(3) Both sun- & non-sunsynchronous orbits:*
  500-900 km altitudes

3. Precipitation Processing System (PPS)

- *(1) Acquire essential L0 and/or L1 data from Core and all Constellation satellites.*
- *(2) Produce, distribute, and arrange for archive of all GPM precipitation products -- as defined by GPM partners.*
- *(3) Support GV Supersite operations with standard data communications protocol.*

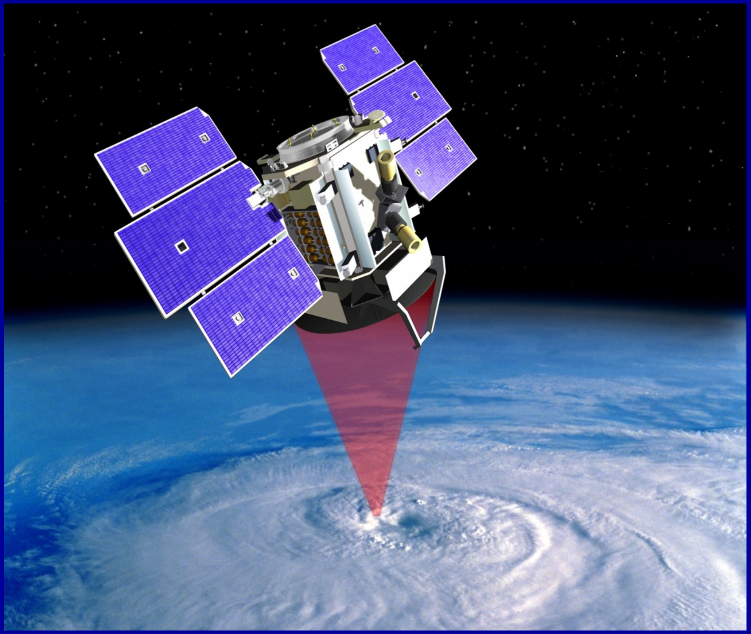
4. International GV Research Program

- *(1) Global network of GV Standard Sites, Supersites, & Virtual Sites operating variety of research-quality precipitation, cloud, and other in situ / remote sensing instruments and instrument systems.*
- *(2) GV Program supports: (1) generation, distribution, and archival of standard GV products; (2) detection / reporting of instantaneous satellite retrieval errors and consequent improvement of algorithms; (3) statistical characterization of retrieval errors; (4) test-bedding of GV technologies; & (5) hosting of field campaigns.*
- *(3) GV Supersites conduct operations for near-realtime error characterization & algorithm improvement programs through standardized reporting protocol to PPS.*

CloudSat Mission Overview

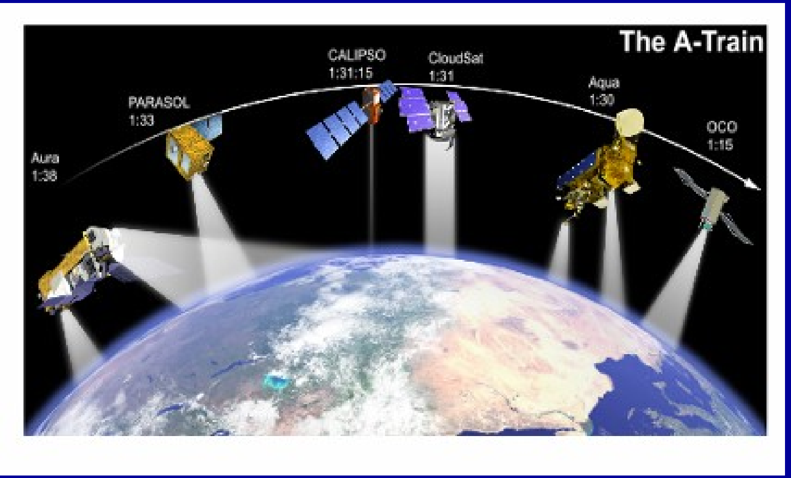
Mission Features

- *First spaceborne 94-GHz Cloud Profiling Radar (CPR)*
- *705 km altitude, sun sync orbit*
- *Launch date: April 28, 2006*
- *CPR is jointly developed by NASA JPL and Canadian Space Agency (CSA)*



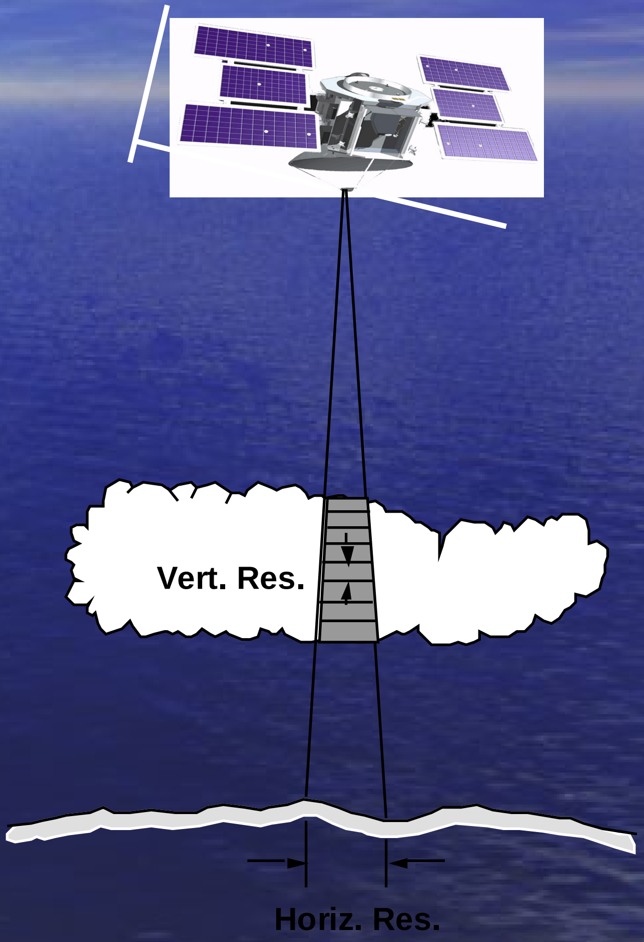
Objectives

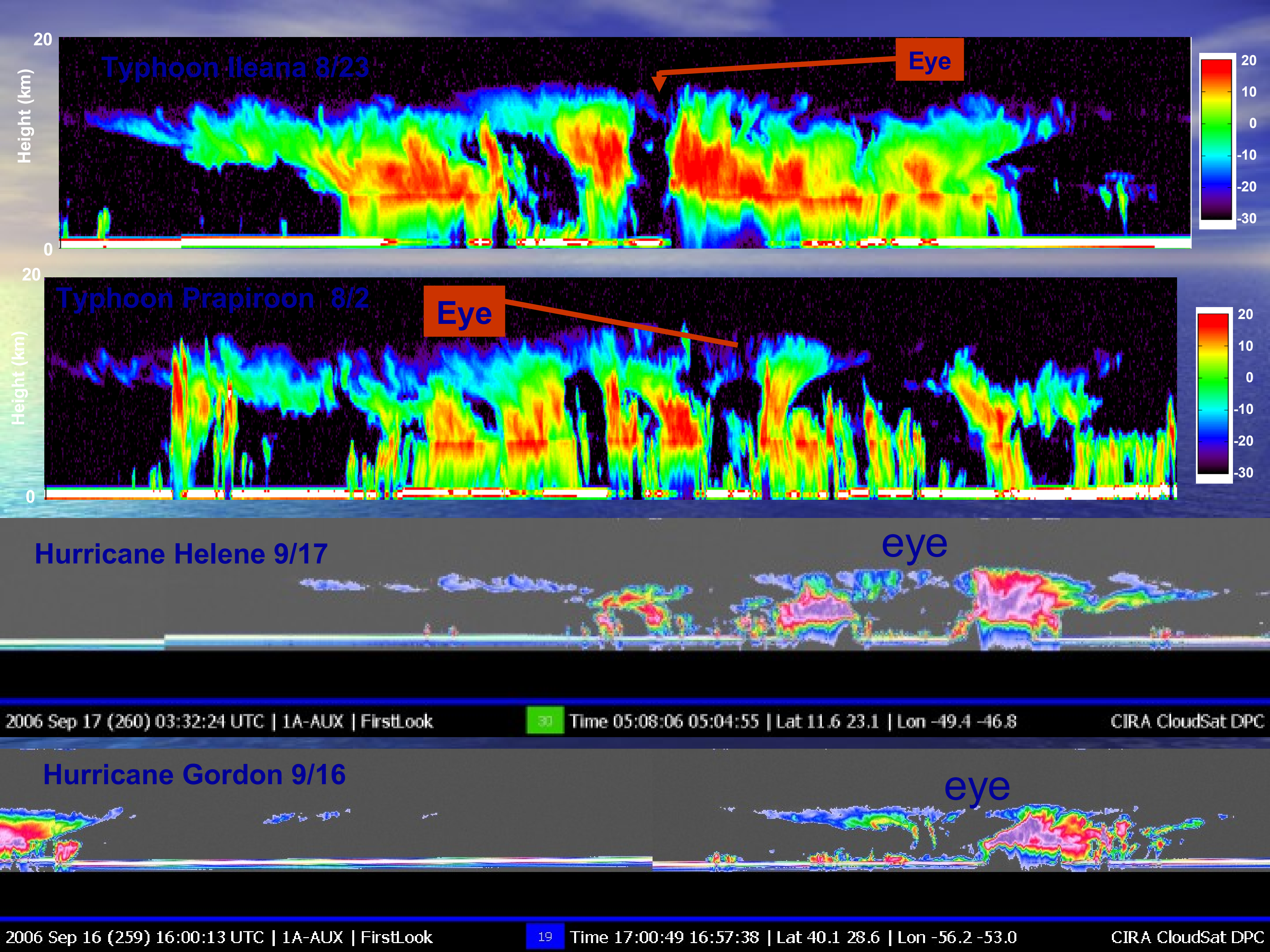
- *Measure vertical structure of clouds and quantify their ice and water content*
- *Improve weather prediction and understanding of climatic processes*
- *Investigate effect of aerosols on clouds and precipitation*
- *Investigate the utility of 94 GHz radar for spaceborne remote sensing*



CPR Overview

- Nadir-pointing 94-GHz radar
  - Measure cloud reflectivity vs. altitude profile along nadir track
  - Vertical resolution ~500 m
  - Horizontal resolution ~1.4 km
  - Sensitivity of -28 dBZ
  - Dynamic range: 80 dB
  - Capture low reflectivity clouds and surface return
- Technical resource allocations:
  - Mass: 250 kg
  - Power: 230 W
  - Data rate: 25 kbits/sec





Typhoon Ileana 8/23
Eye
Height (km)
20
0
20
10
0
-10
-20
-30
Typhoon Prapiroon 8/2
Eye
Height (km)
20
0
20
10
0
-10
-20
-30
Hurricane Helene 9/17
eye
2006 Sep 17 (260) 03:32:24 UTC | 1A-AUX | FirstLook
30
Time 05:08:06 05:04:55 | Lat 11.6 23.1 | Lon -49.4 -46.8
CIRA CloudSat DPC
Hurricane Gordon 9/16
eye
2006 Sep 16 (259) 16:00:13 UTC | 1A-AUX | FirstLook
19
Time 17:00:49 16:57:38 | Lat 40.1 28.6 | Lon -56.2 -53.0
CIRA CloudSat DPC

Aerosol Size Distribution

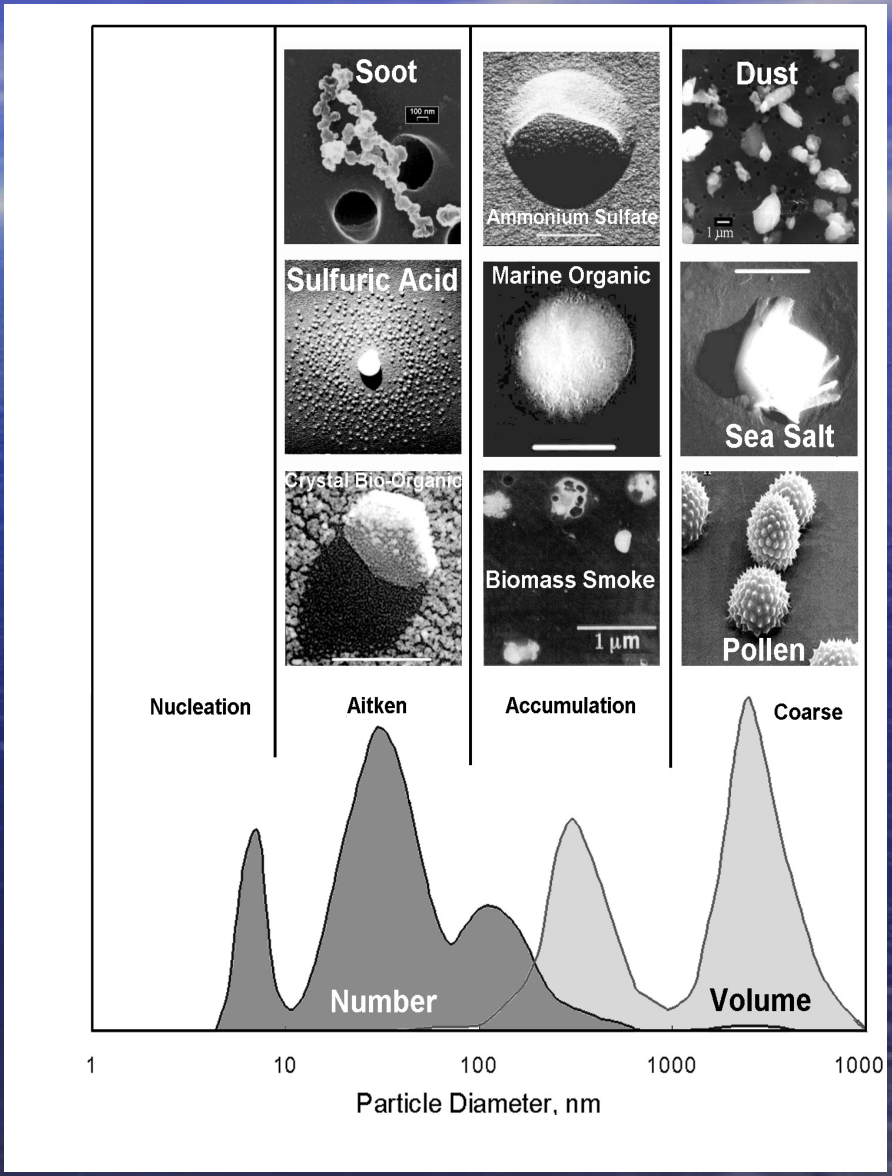
It presents 3 modes :

- « **nucleation** »: radius is between 0.002 and 0.05 μ m. They result from combustion processes, photo-chemical reactions, etc.

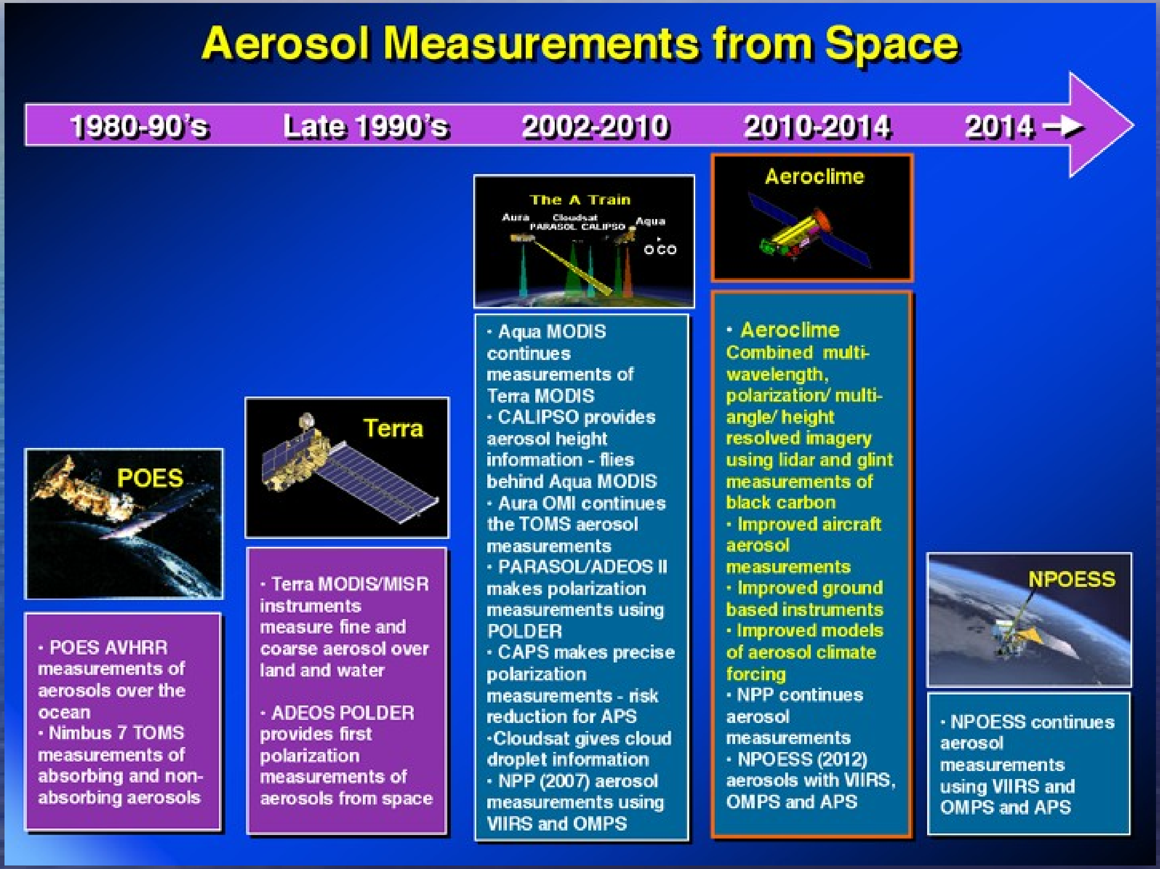
- « **accumulation »:** radius is between 0.05 μ m and 0.5 μ m. Coagulation processes.

- « **coarse** »: larger than 1 μ m. From mechanical processes like aeolian erosion.

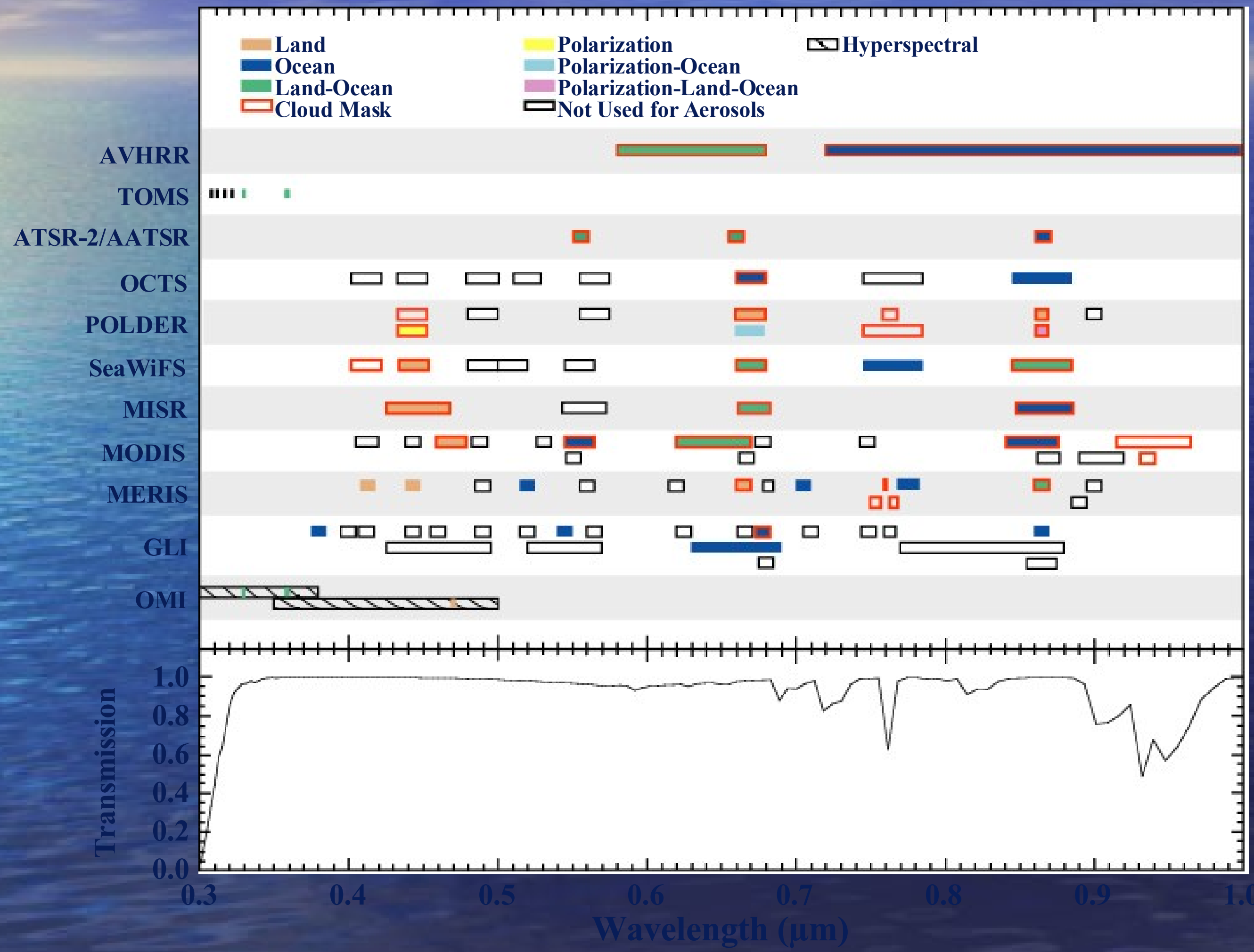
« fine » particles (nucleation and accumulation) result from anthropogenic activities, coarse particles come from natural processes.



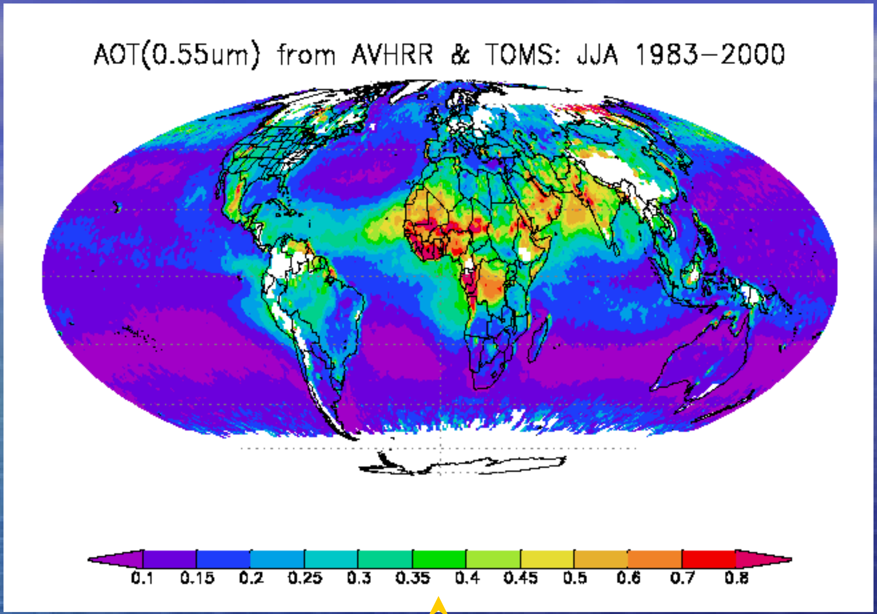
Timeline for Aerosol Measurements

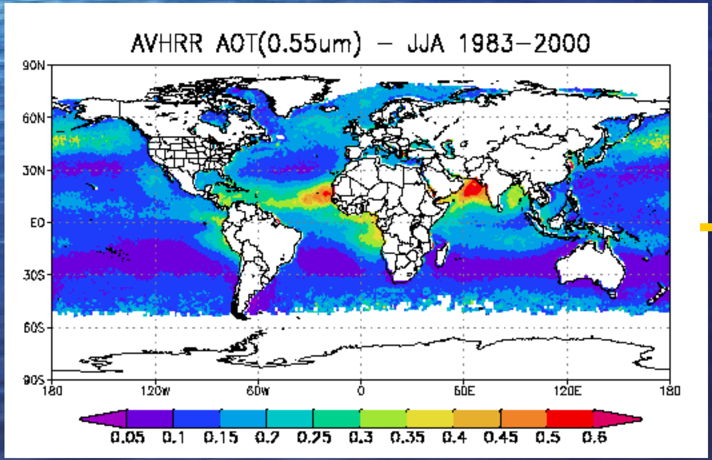


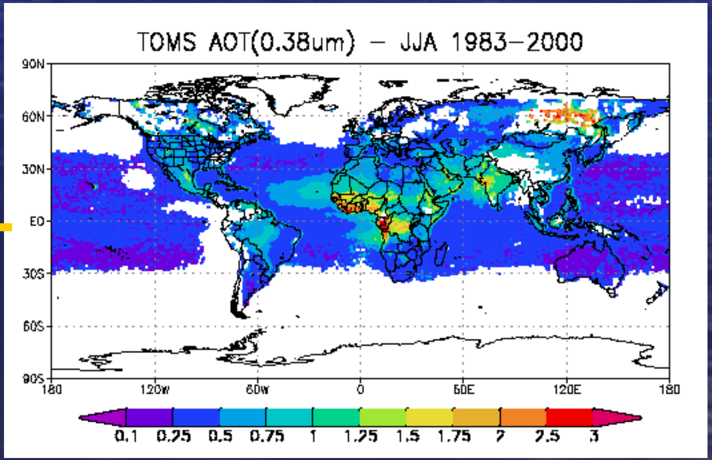
Aerosol Properties



An Application: AOT (0.55μm) Composite of TOMS and AVHRR







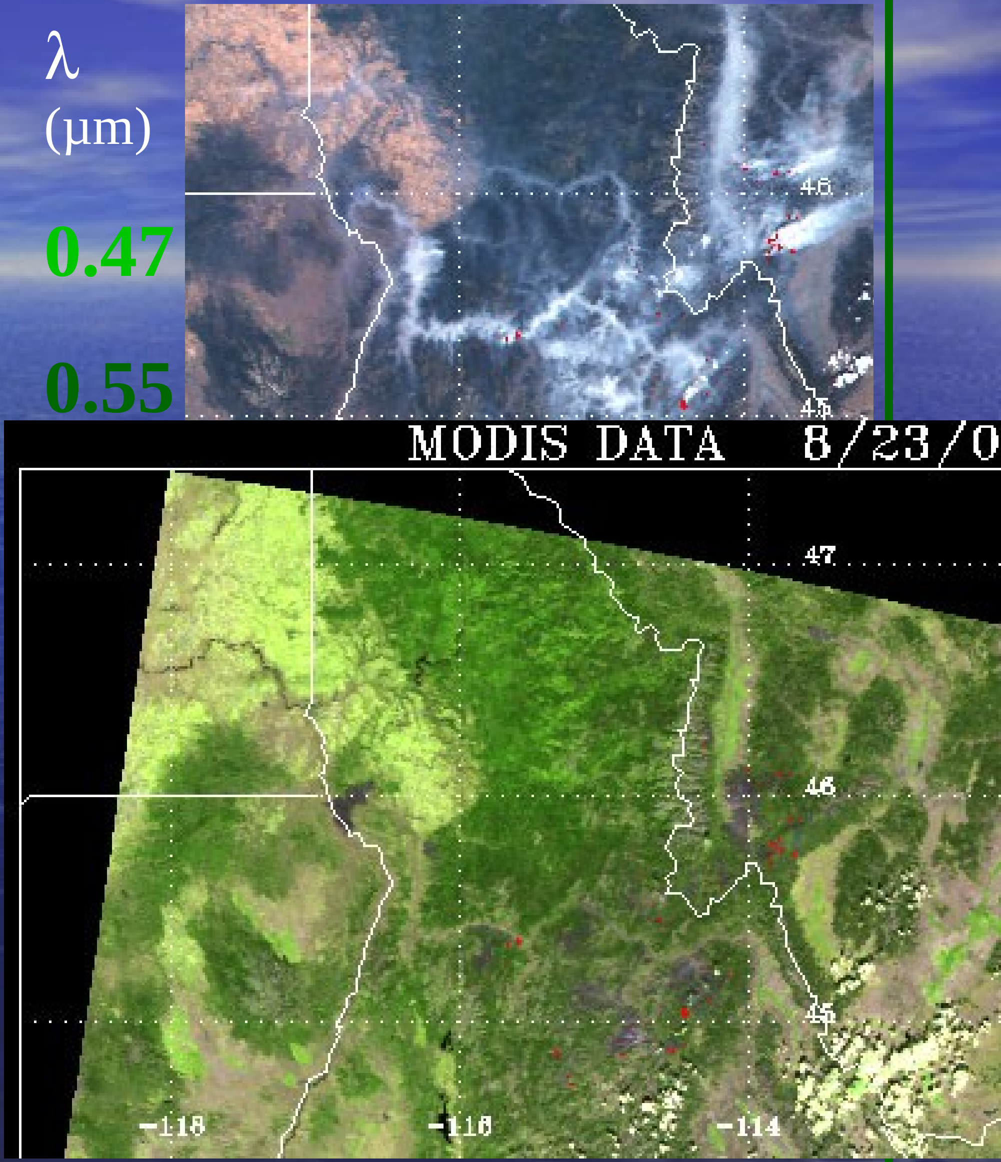
Land algorithm:

- Find surface reflectance at 0.47, 0.66 µm from the reflectance at 2.1µm
- Estimate the aerosol path radiance (L_p) from the excess radiance reflected to space
- Estimate the aerosol type from L_p (0.66)/ L_p (0.47)
- Estimate aerosol optical thickness from the excess L_p (0.66) & L_p (0.47)

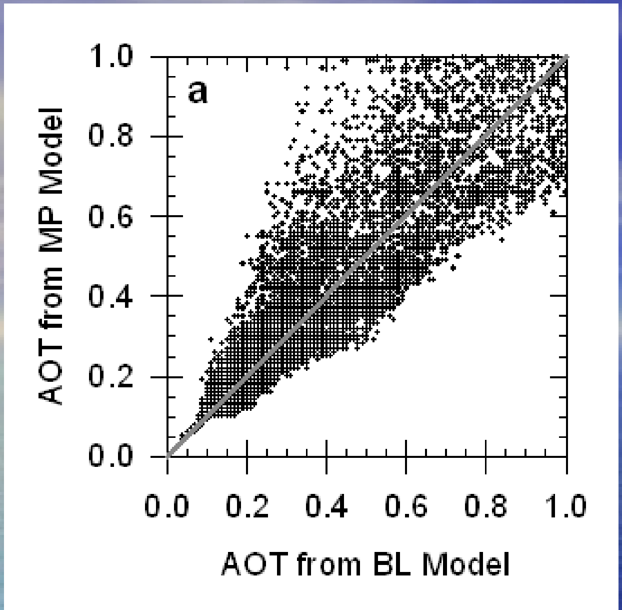
λ (µm)

0.47

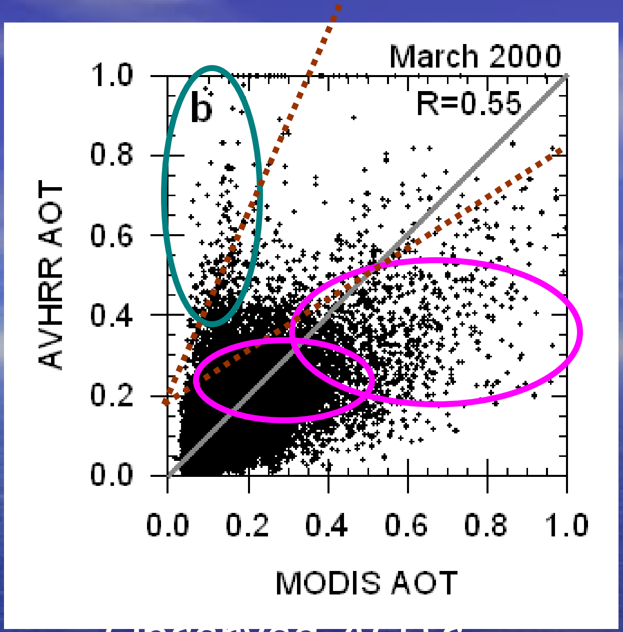
0.55



2.1



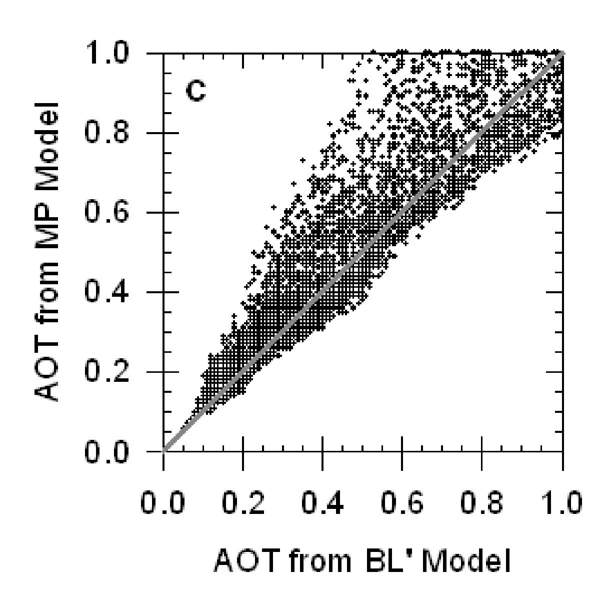
Overall Impact



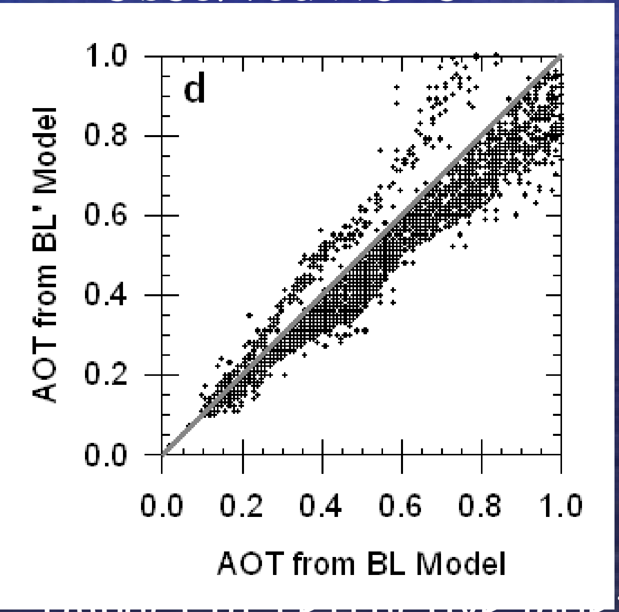
Observed AOTs

Misclassification of aerosol as cloud by AVHRR?
Or cloud contamination in MODIS?

Cloud contamination in AVHRR?



Impact of size distribution function difference

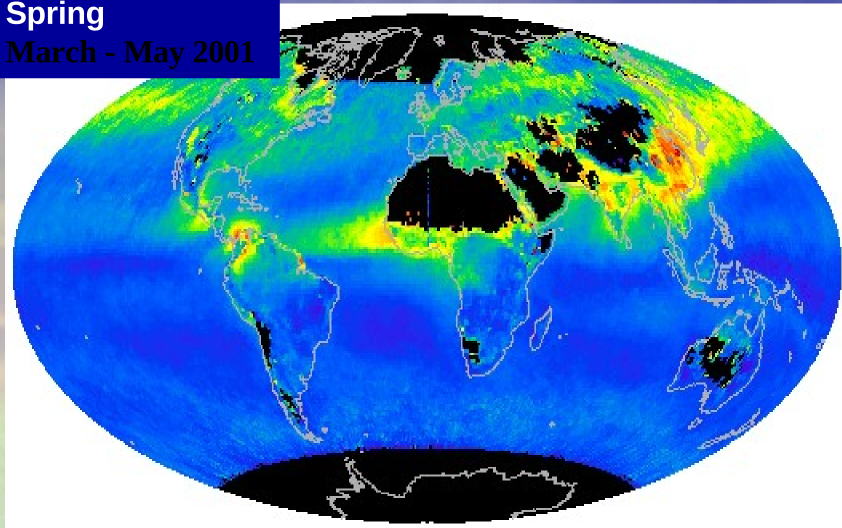


Impact of refractive index difference

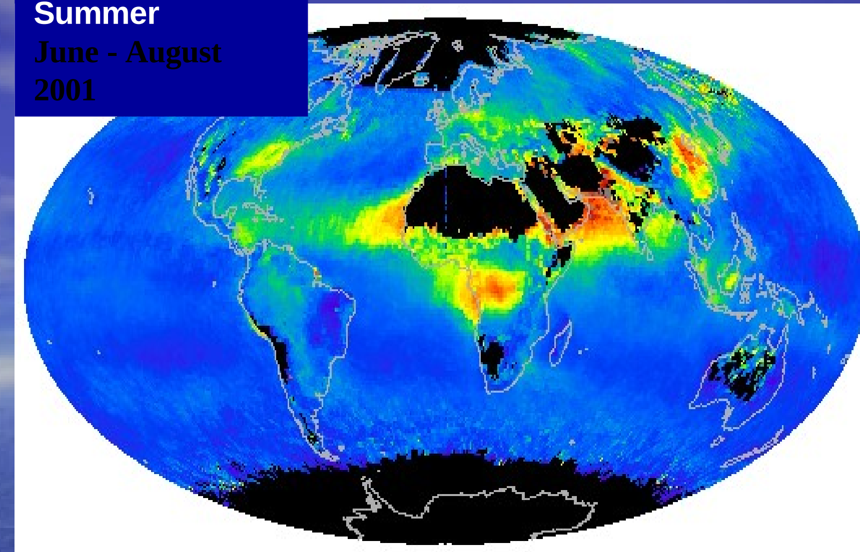
The range of discrepancies due to aerosol model difference can be as large as a factor of two

Jeong and Li (2005)

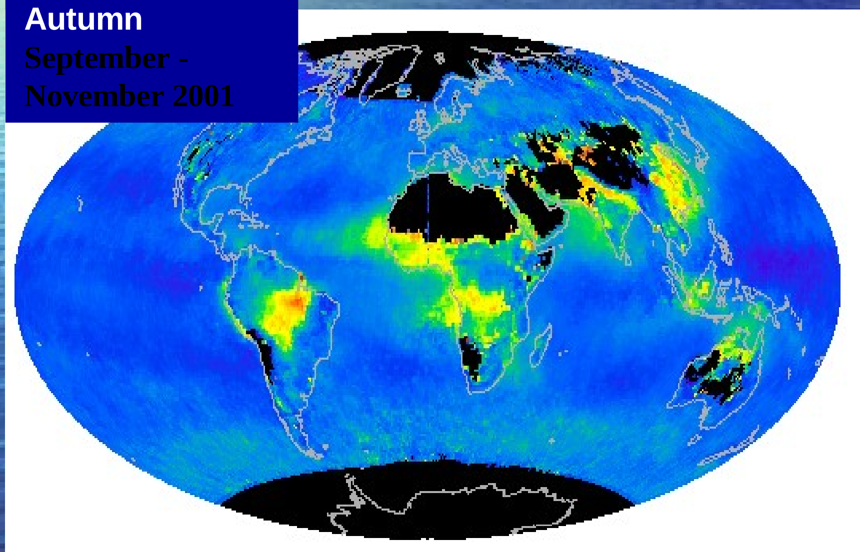
Spring
March - May 2001



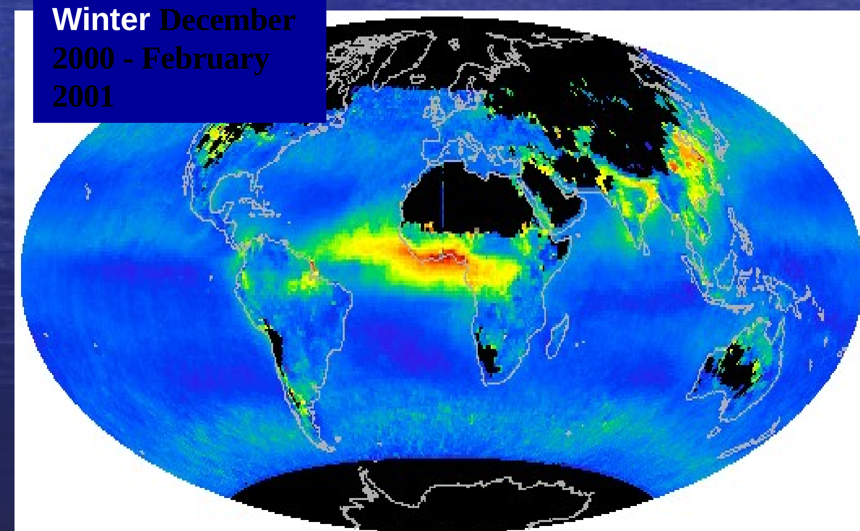
Summer
June - August 2001



Autumn
September - November 2001



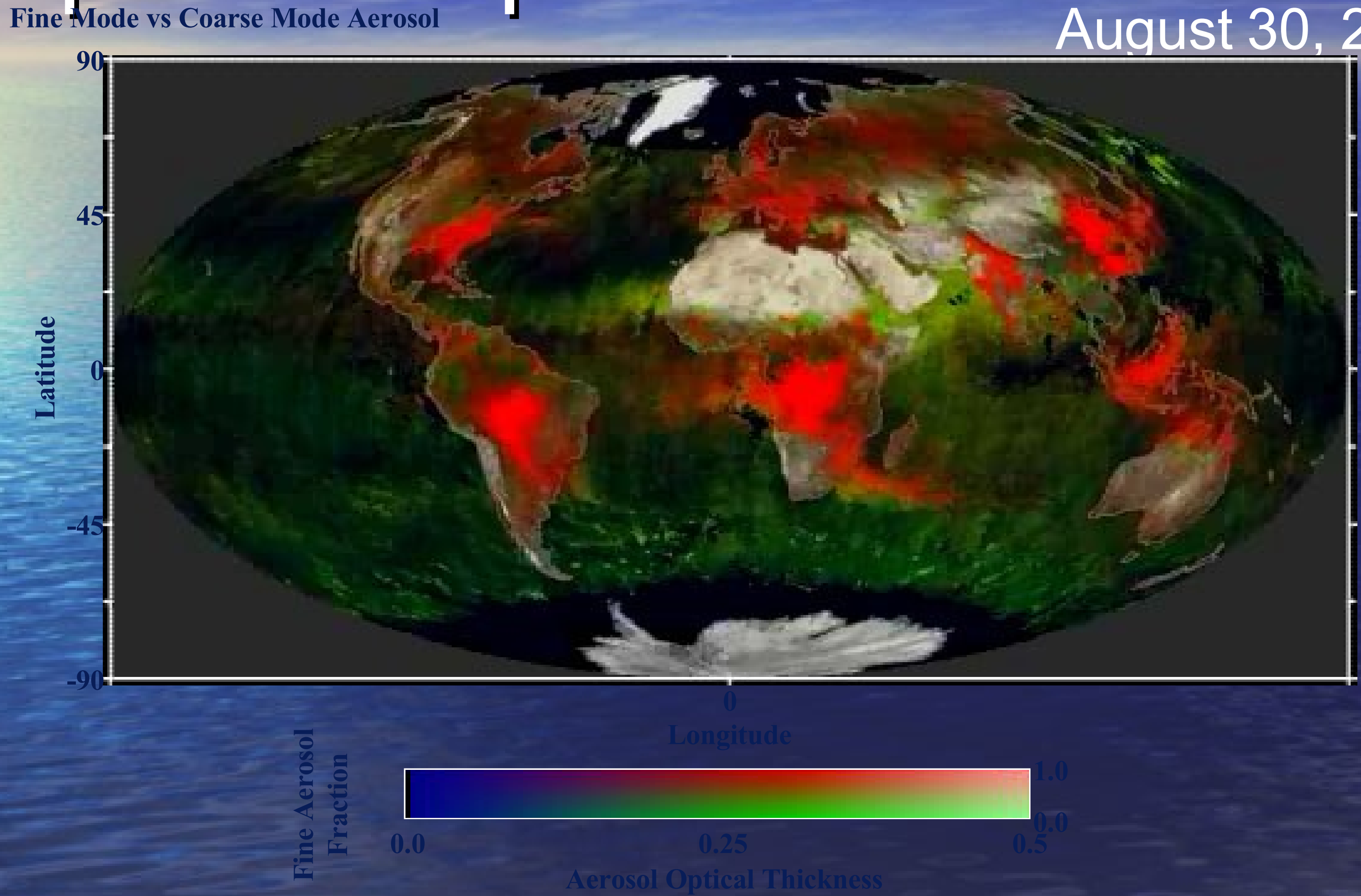
Winter December 2000 - February 2001



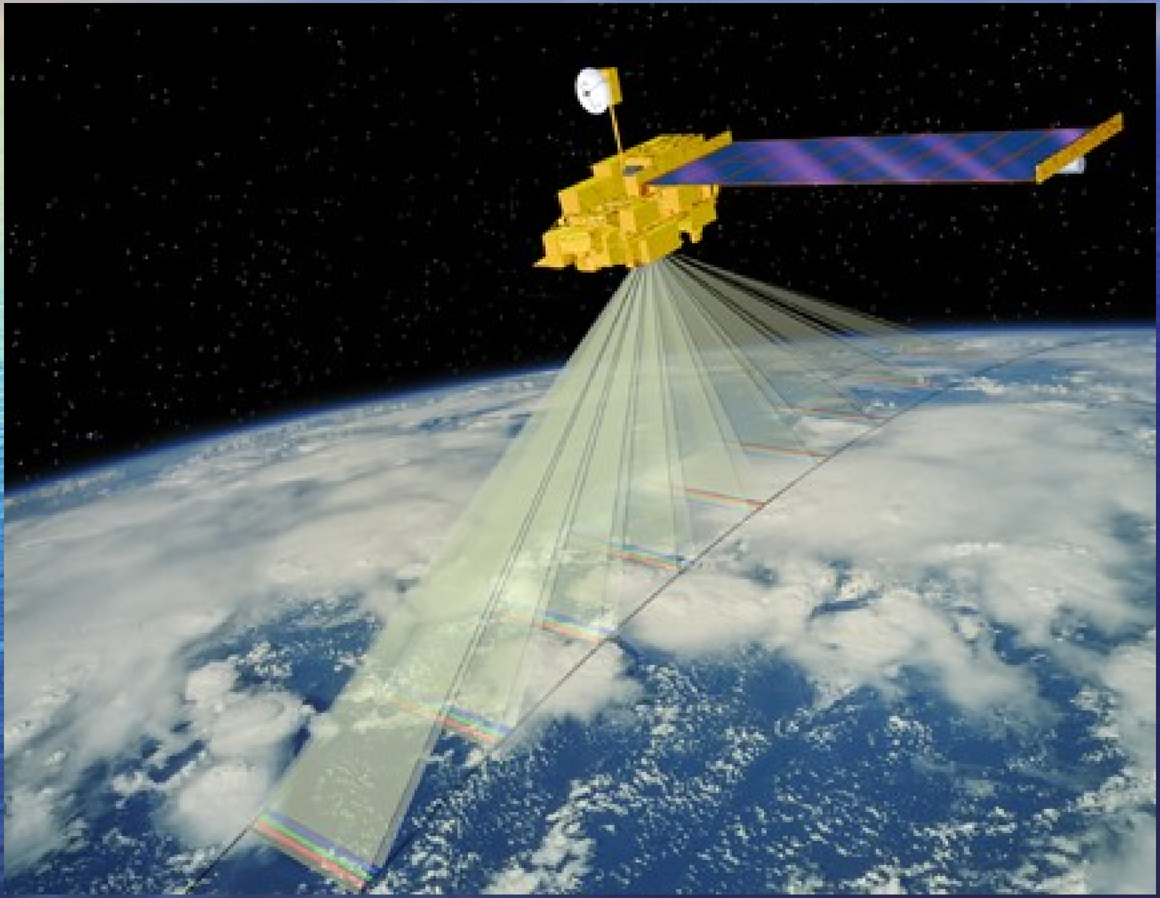
Average optical thickness

Terra/MODIS Global Aerosol Optical Properties

August 30, 2001



Multi-angle Imaging SpectroRadiometer (MISR)

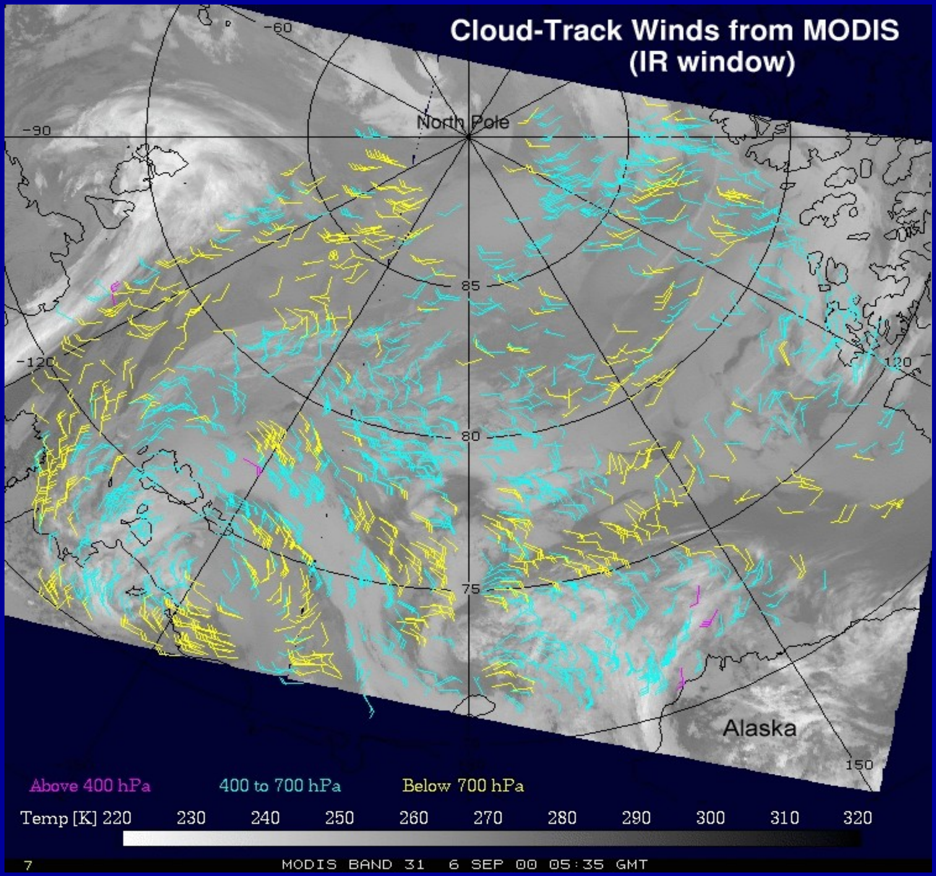


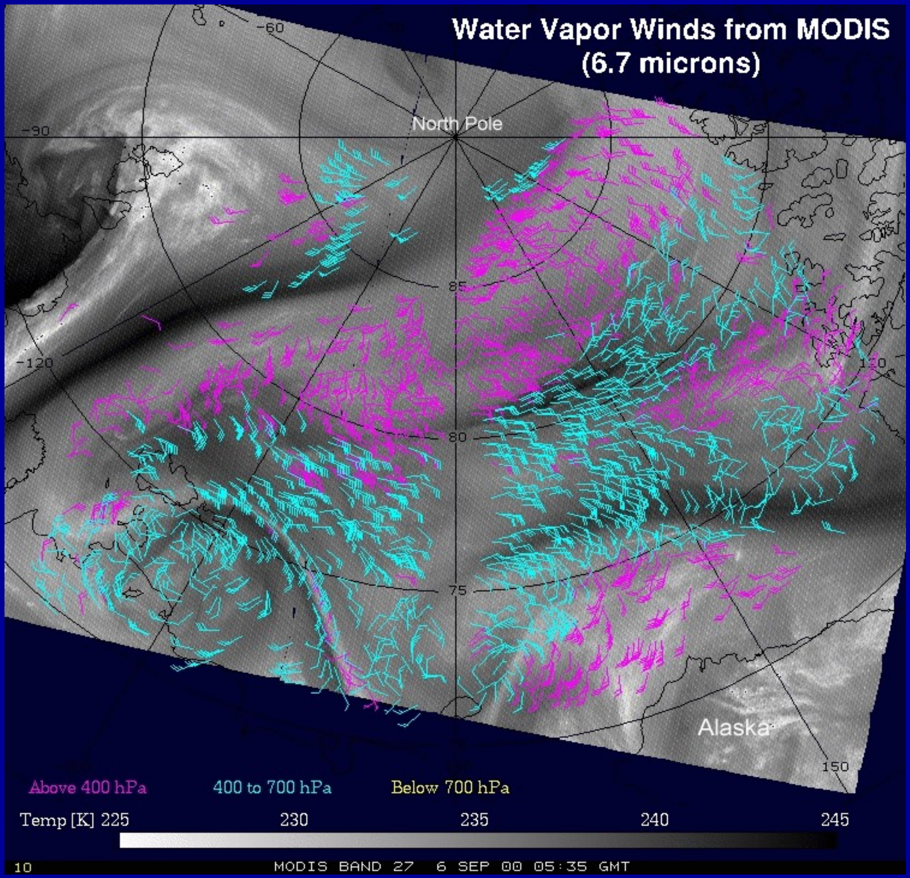
- MISR sees the Earth at 9 look angles, which enables stereoscopic images; unprecedented for studies of land surface cover, cloud & aerosol structures, & angular reflectance

Winds from MODIS: An Arctic Example

(MENZEL, ET AL.)

Cloud-track winds (left) and water vapor winds (right) from MODIS for a case in the western Arctic. The wind vectors were derived from a sequence of three images, each separated by 100 minutes. They are plotted on the first 11 μ m (left) and 6.7 μ m (right) images in the sequence.



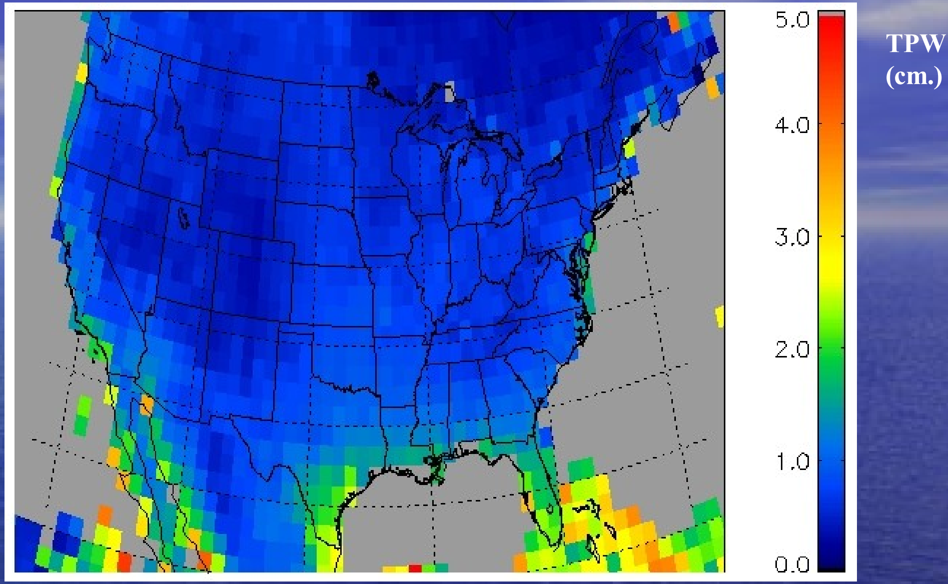


MODIS Water Vapor Product

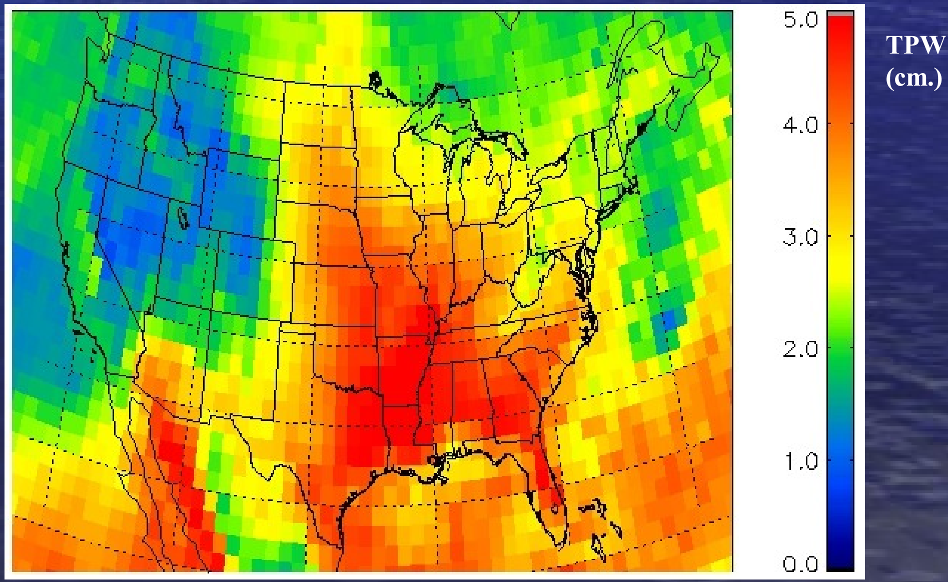
(a): a monthly-mean Level 3 water vapor image over the continental U.S., portions of Mexico and Canada for January, 2001;

(b): similar to (a), except for July, 2001.

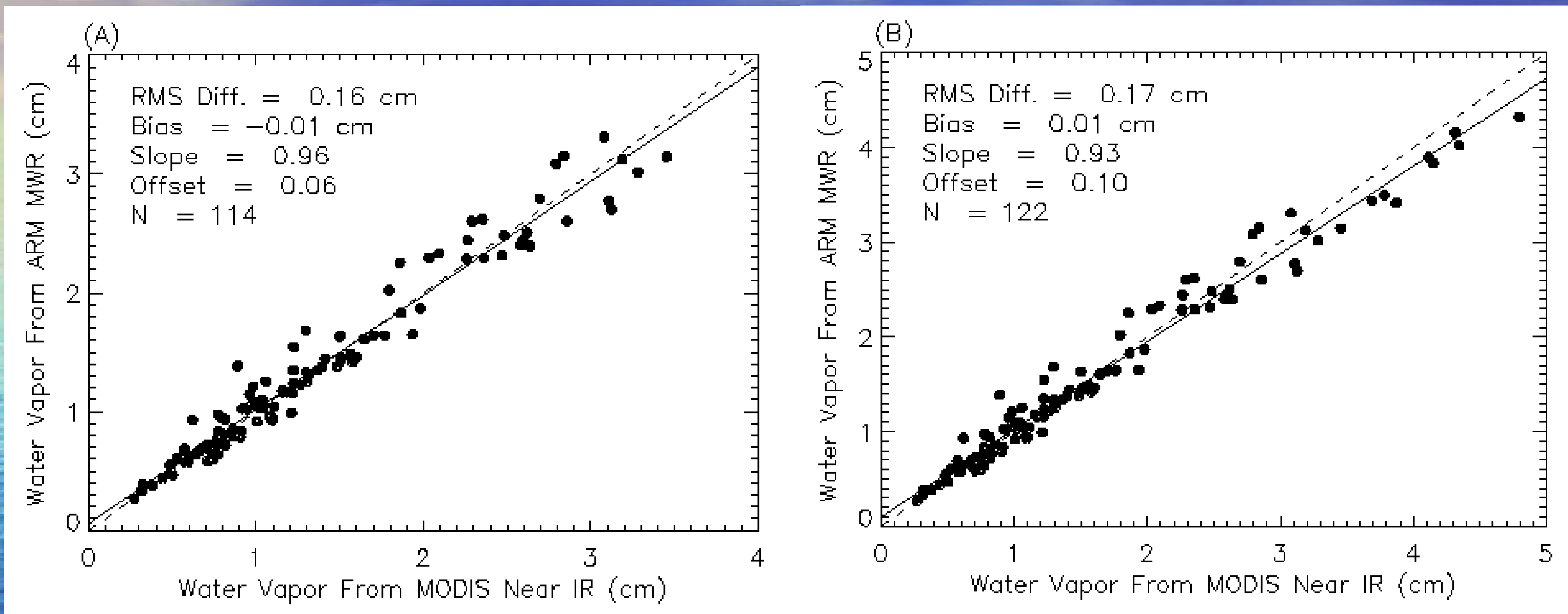
a.



b.



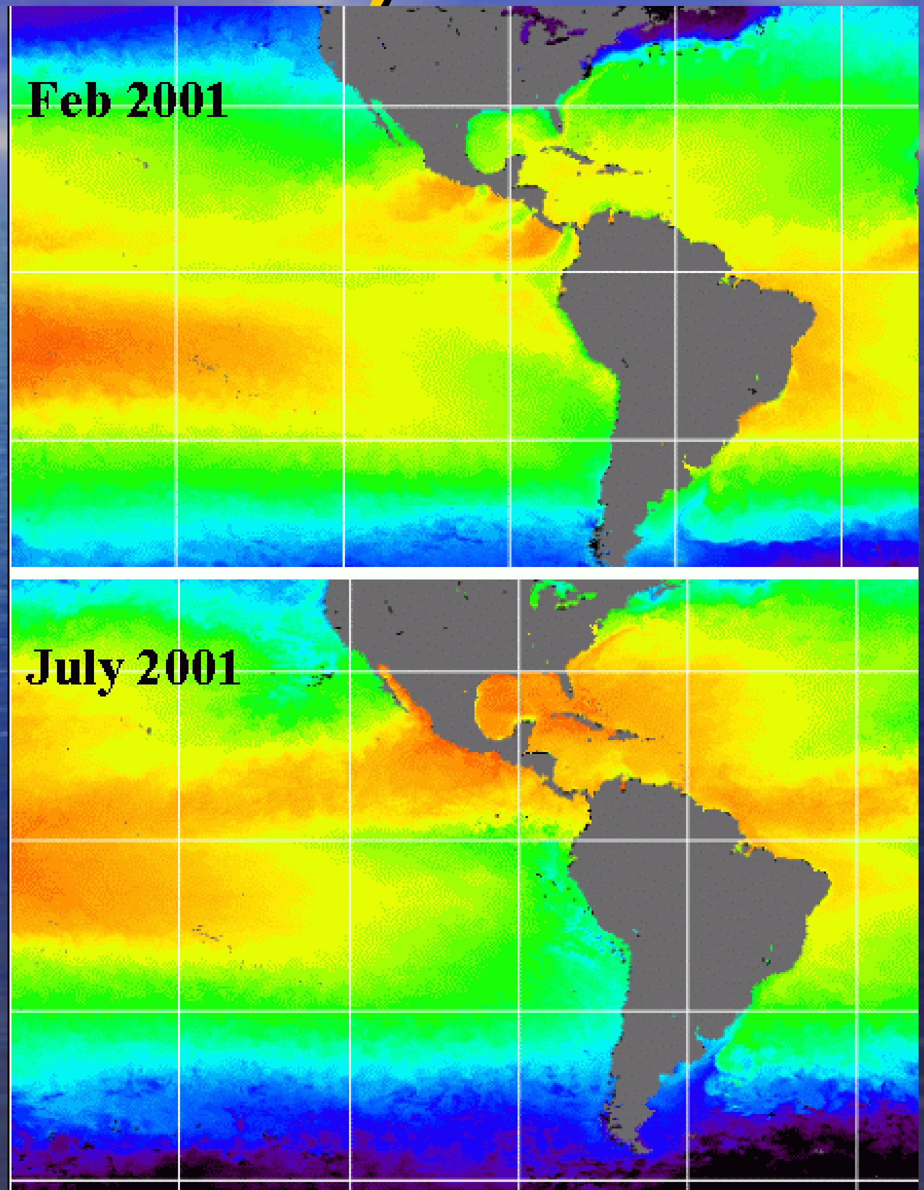
VERSUS GROUND MEASUEMENTS



(a): a scatter plot between the water vapor values measured with a ground-based upward-looking microwave radiometer at a site in the Southern Great Plains in Oklahoma and those retrieved from images of MODIS near-IR channels for a time period between November 2000 and December 2001 and for column water vapor amounts less than 3.5 cm;

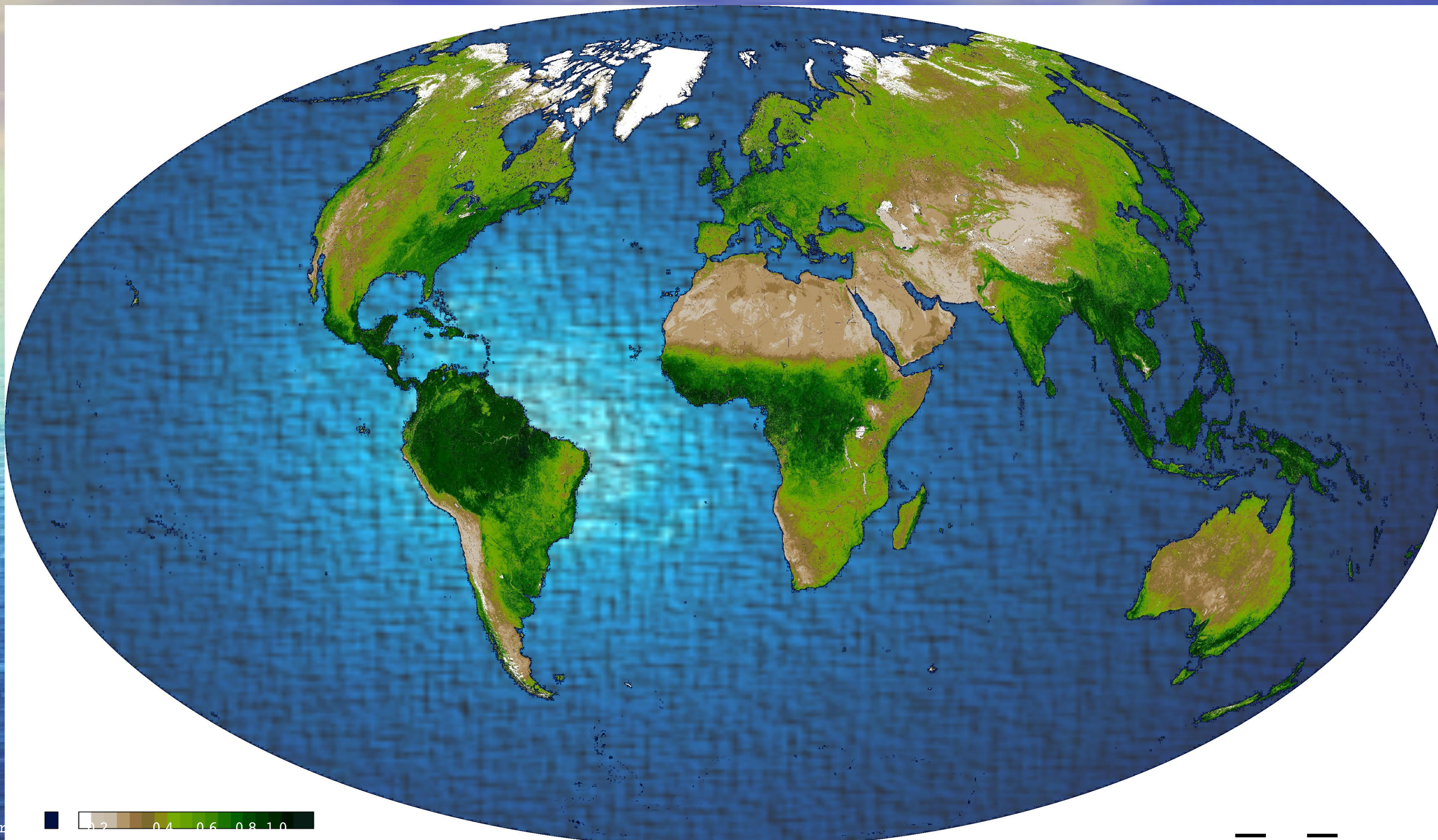
(b) similar to (a) except that the data points for water vapor amounts greater than 3.5 cm are included in the analysis.

MODIS NIGHTTIME SST (11 MICROMETER) FEB/JULY 2001



(Global EVI composite fall 2000)

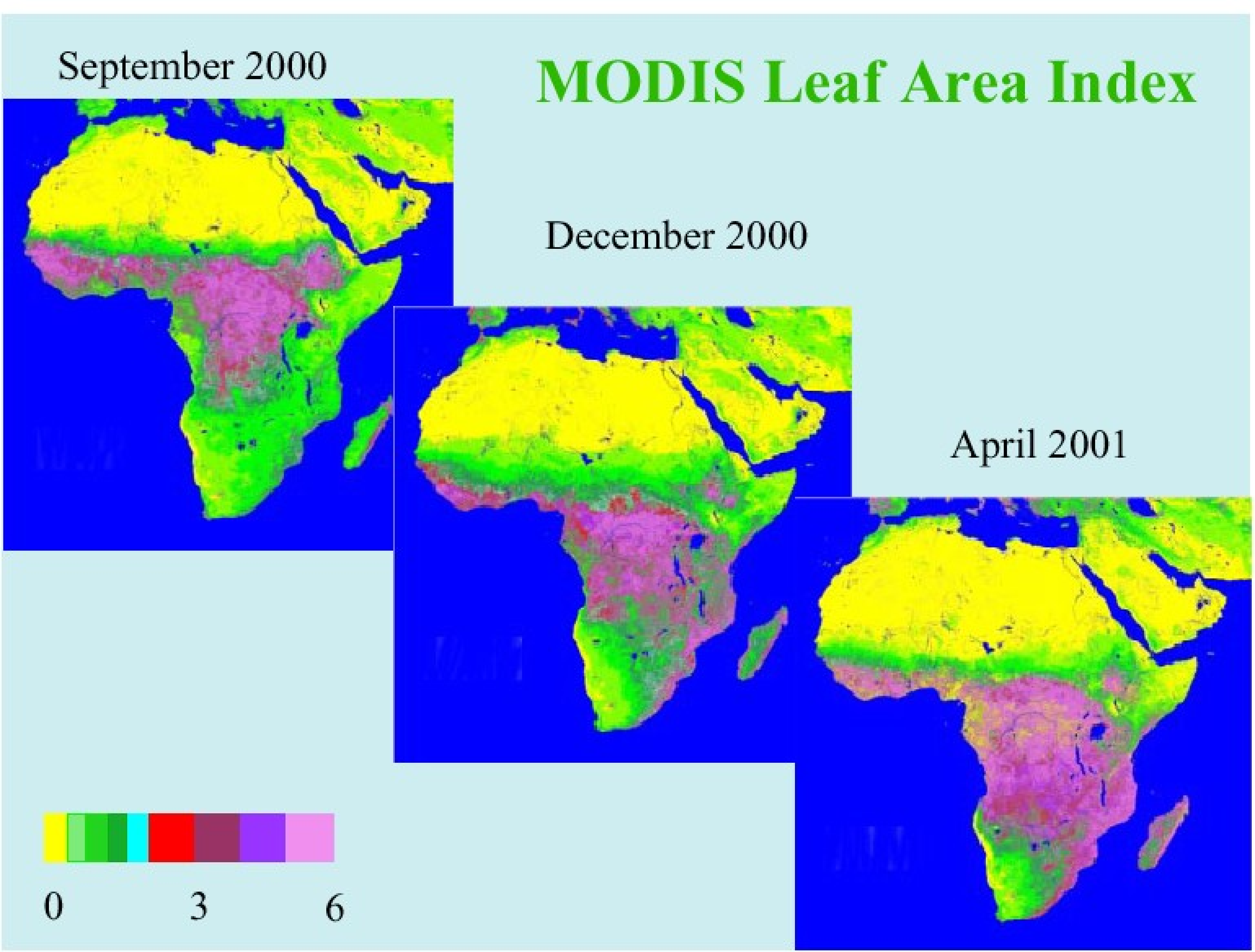
(Spatial and temporal intercomparisons of vegetation activity)



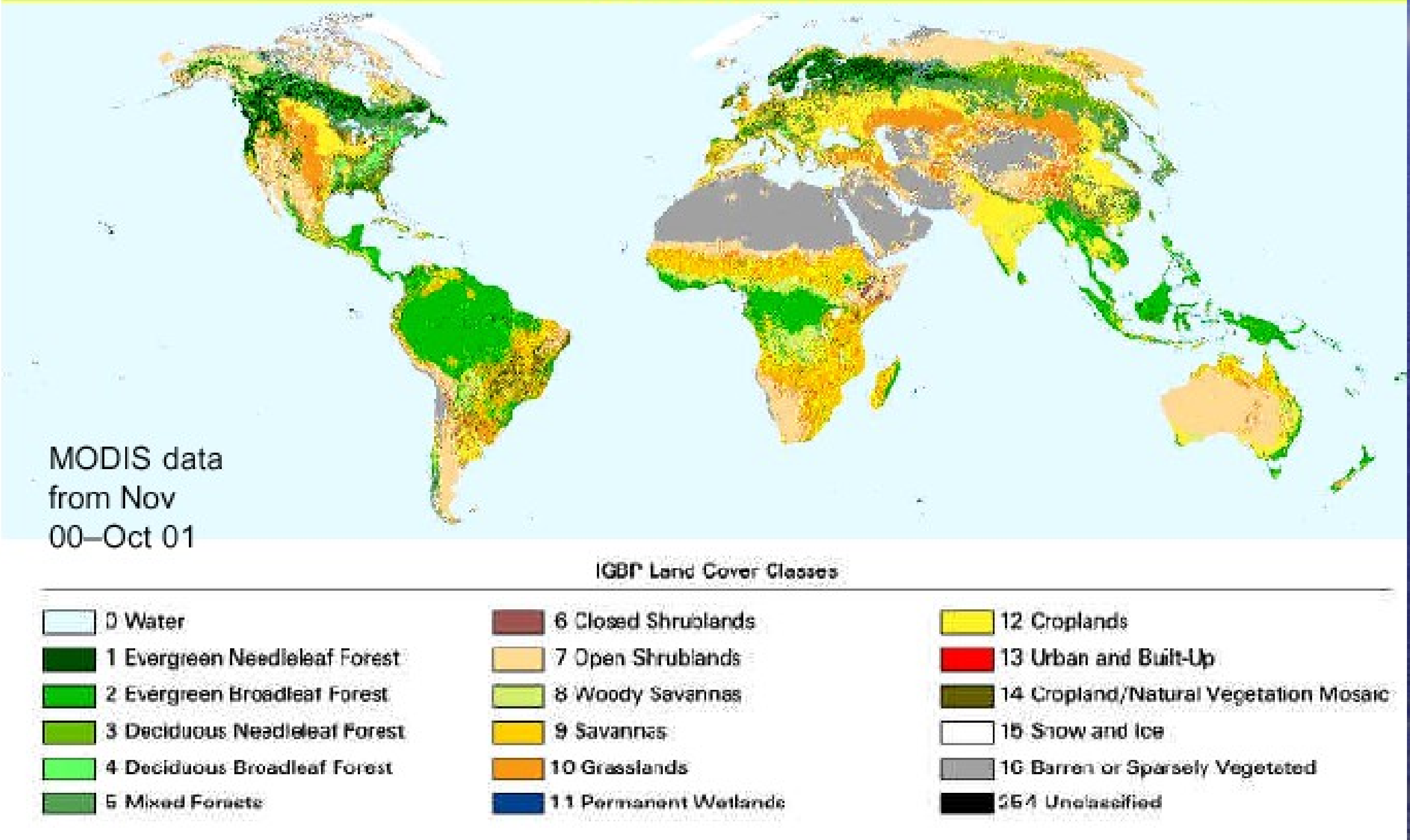
water

Hammer Aitoff Projection

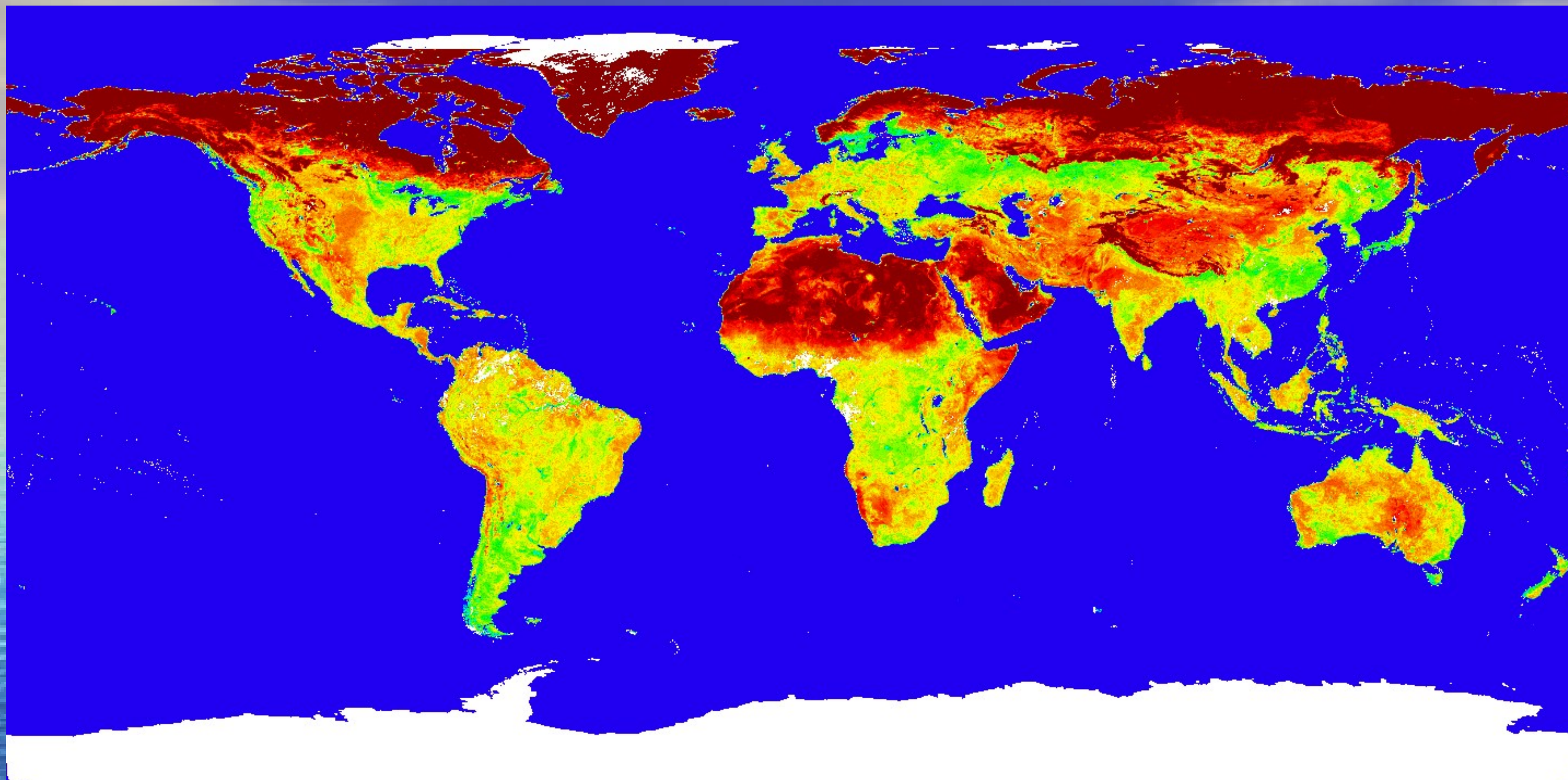
Global Leaf Area Index



Consistent Year Land Cover Product June 02—IGBP

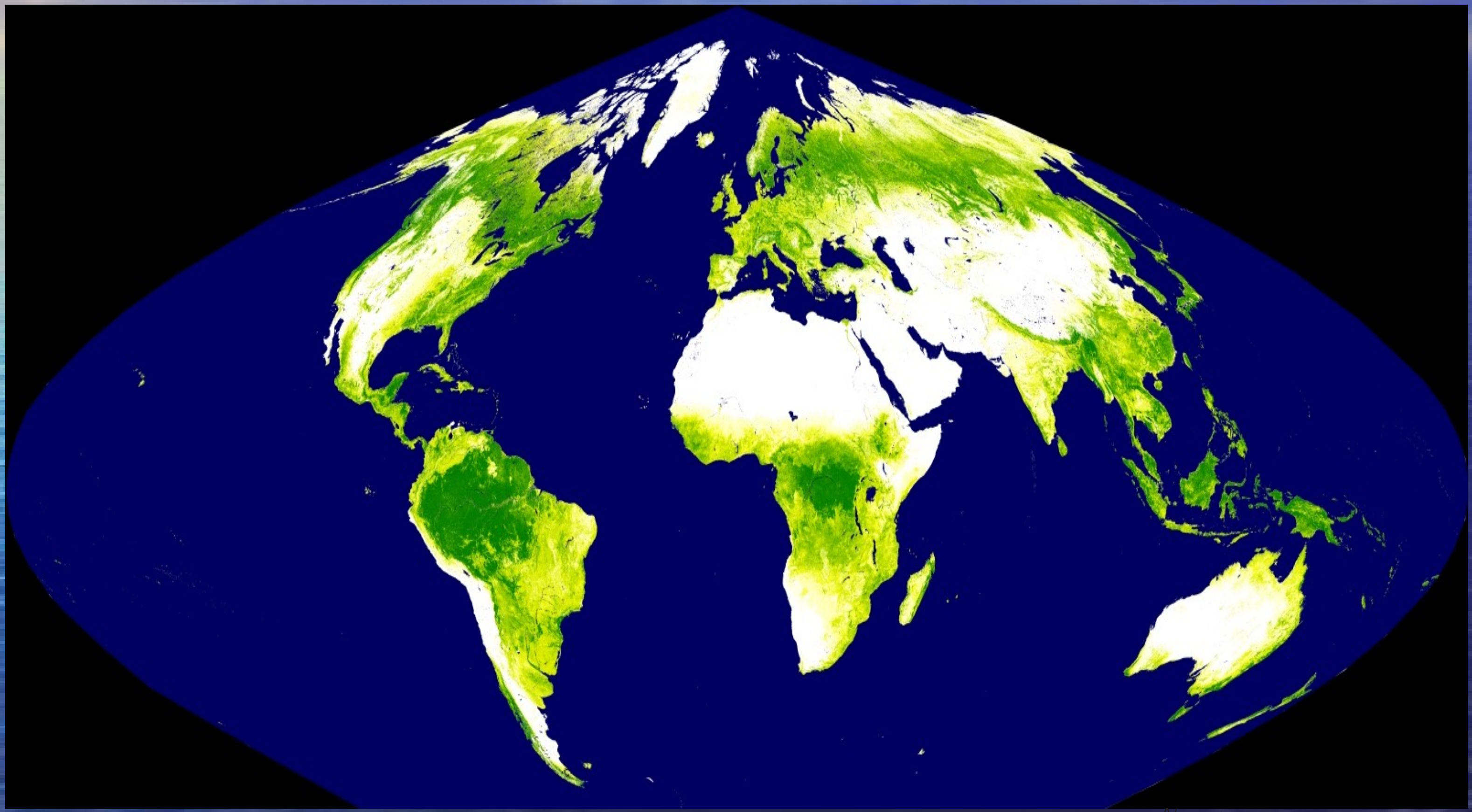


CMG Broadband Albedo (0.3-5.0mm)
7 - 22 April, 2002 (Strahler/Boston U.)



No Data

MODIS 500 meter global percent forest cover for 2000

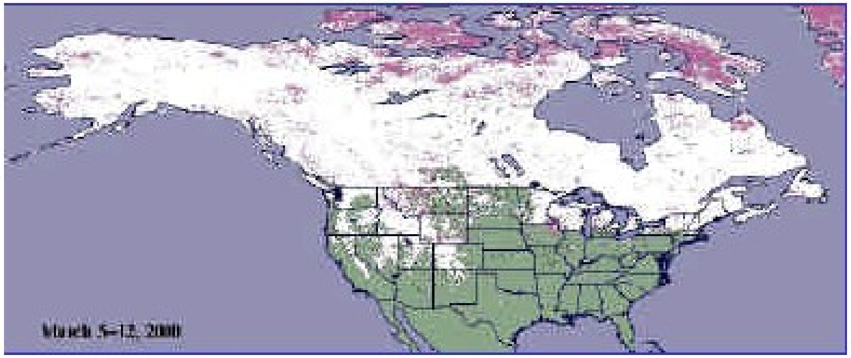


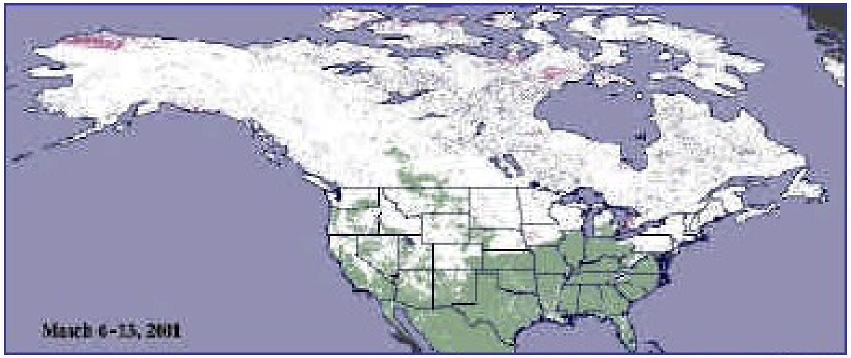
% tree cover

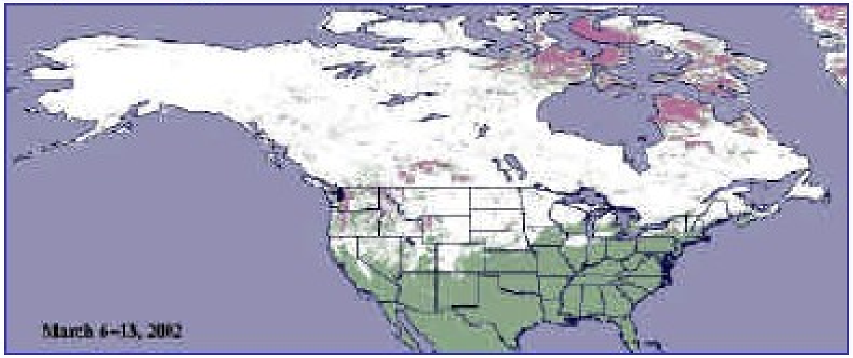
0% 100%

Interannual Comparisons

(8-day composite CMGs show maximum snow cover for the period)







Thanks