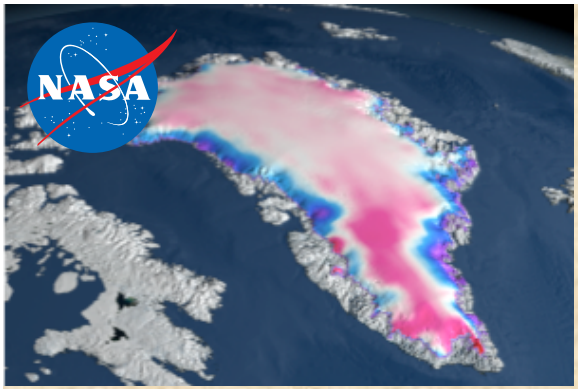
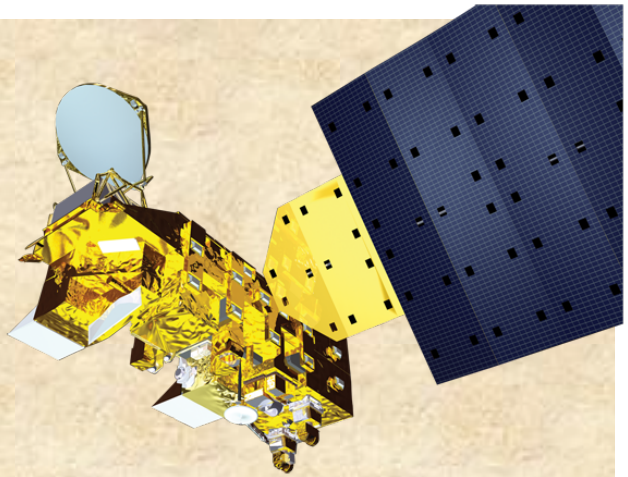




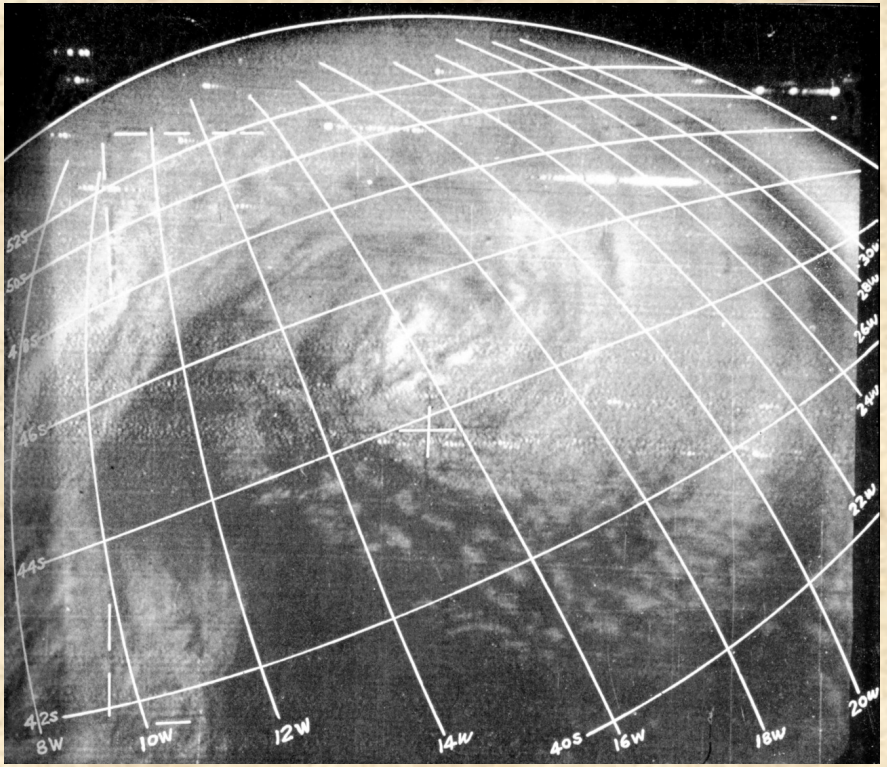
Satellite Contributions to Global Change Studies

Claire L. Parkinson
NASA Goddard Space Flight Center

NASA Earth System Science at 20: Accomplishments, Plans, and Challenges,
National Academy of Sciences Building, Washington, D.C.
June 22, 2009

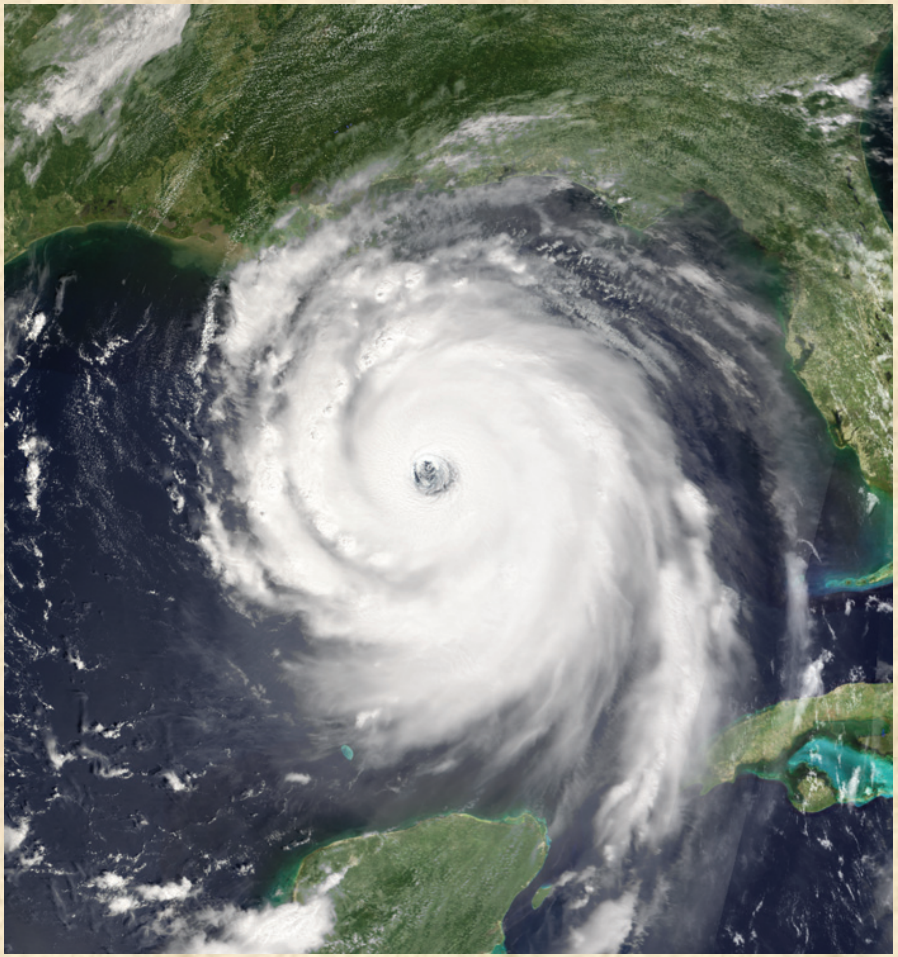
Images from TIROS 1, the First Successful Weather Satellite

TIROS 1 image of a mid-latitude cyclone, July 1961

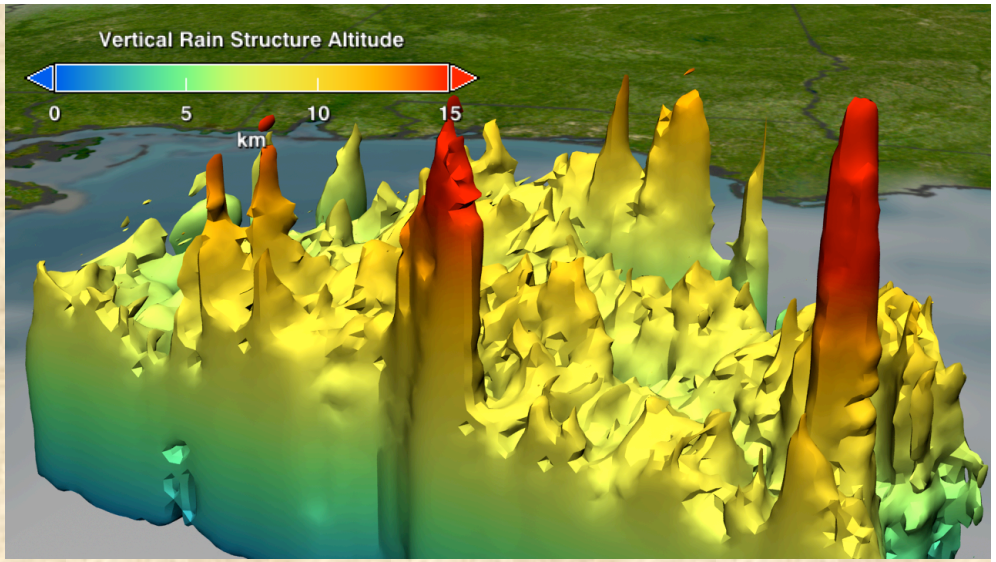


TIROS = Television and Infrared Observation Satellite

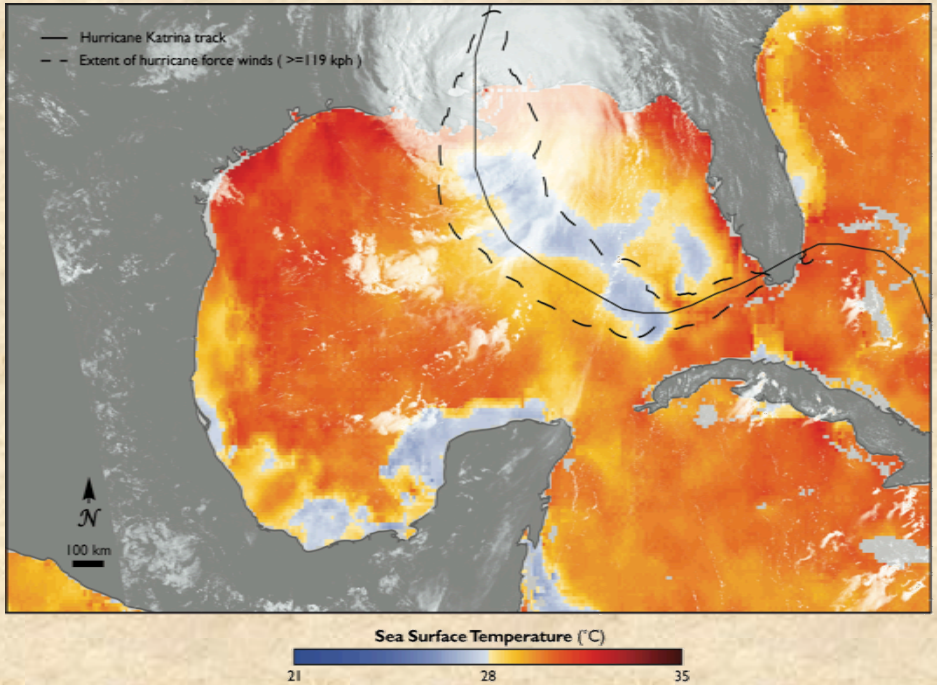
Hurricane Katrina as Viewed from Modern Satellites



8/25/2002, from the Terra MODIS

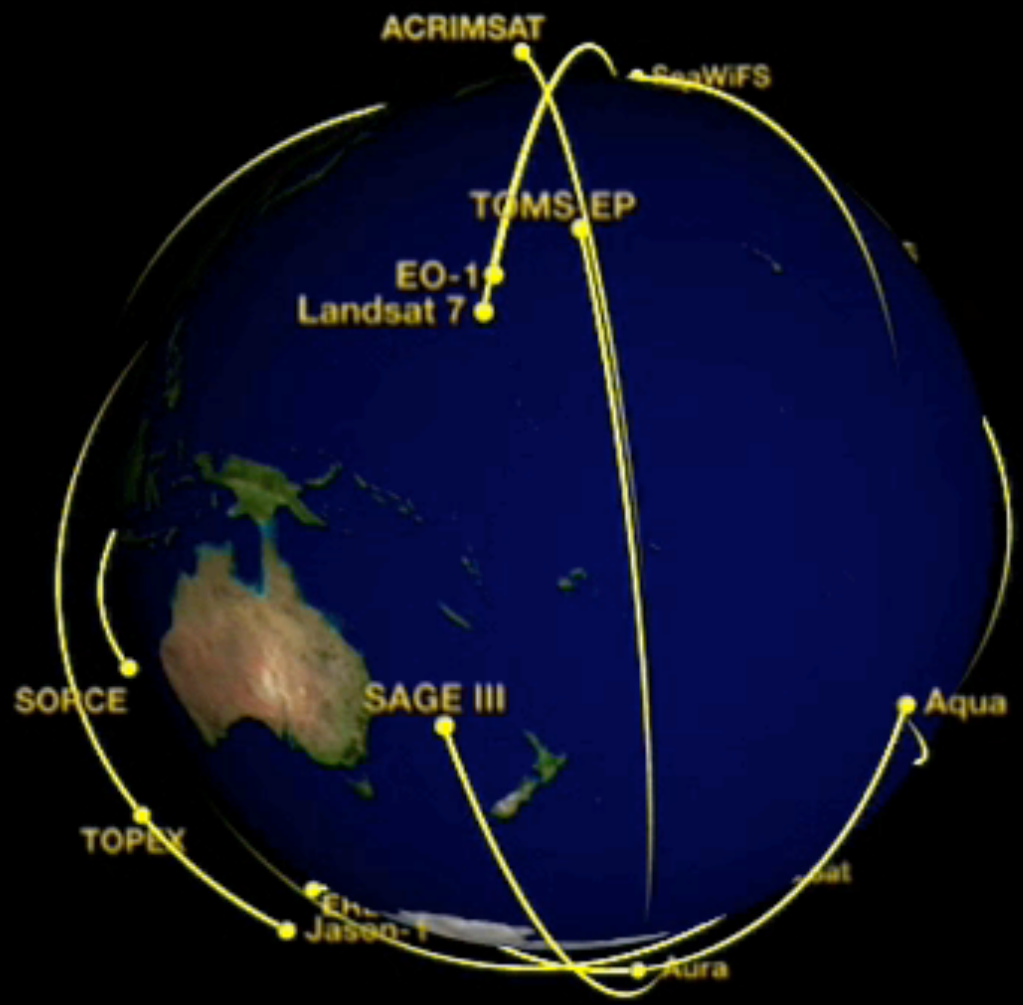


8/28/2002, from the TRMM Precipitation Radar

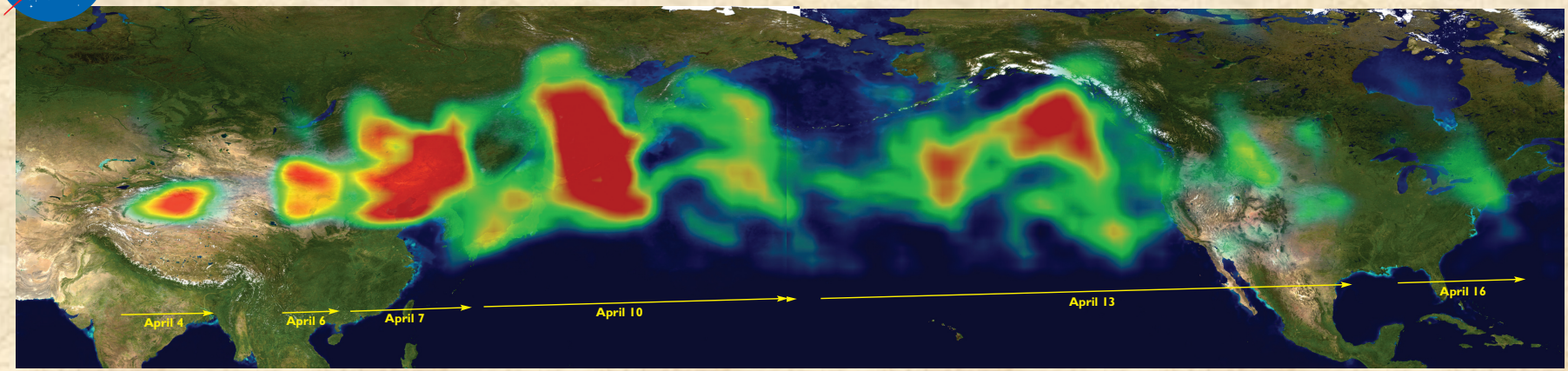


8/30/2005, from the Aqua AMSR-E and GOES

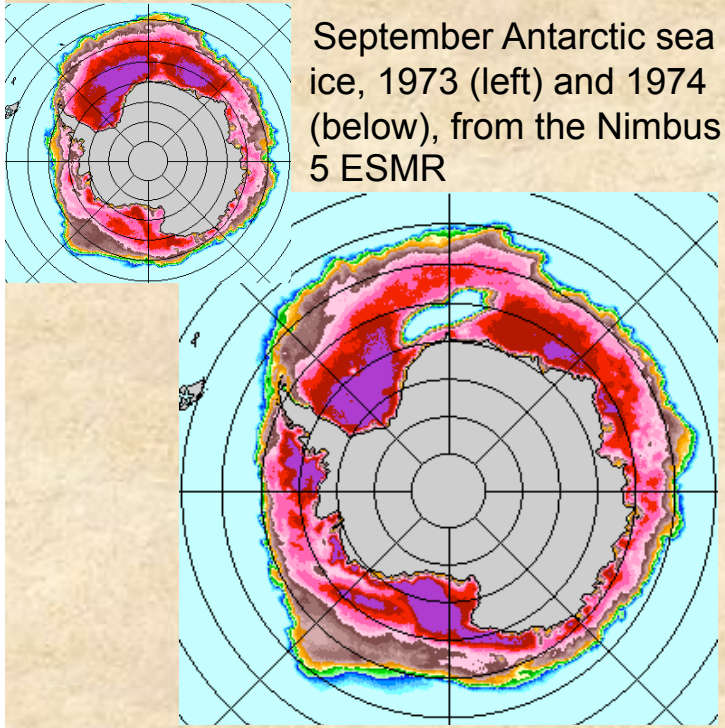
AMSR-E = Advanced Microwave Scanning Radiometer for EOS
GOES = Geostationary Operational Environmental Satellite
MODIS = Moderate Resolution Imaging Spectroradiometer
TRMM = Tropical Rainfall Measuring Mission (GSFC SVS image)


ACRIMSAT
SeaWiFS
TOMS EP
EO-1
Landsat 7
SORCE
SAGE III
Aqua
TOPEX
Jason-1
Aura

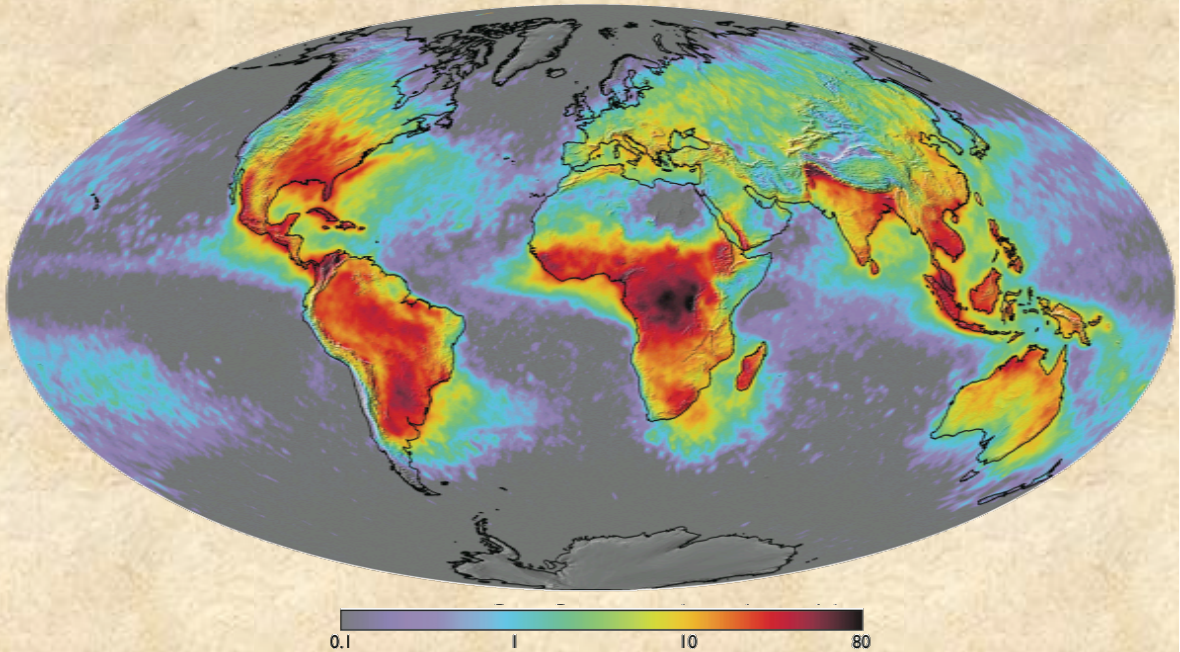
Sample Surprises from Satellites



Dust transport from western China eastward, April 4-16, 2001, from the Earth Probe TOMS (from Hsu et al. 2007)



September Antarctic sea ice, 1973 (left) and 1974 (below), from the Nimbus 5 ESMR

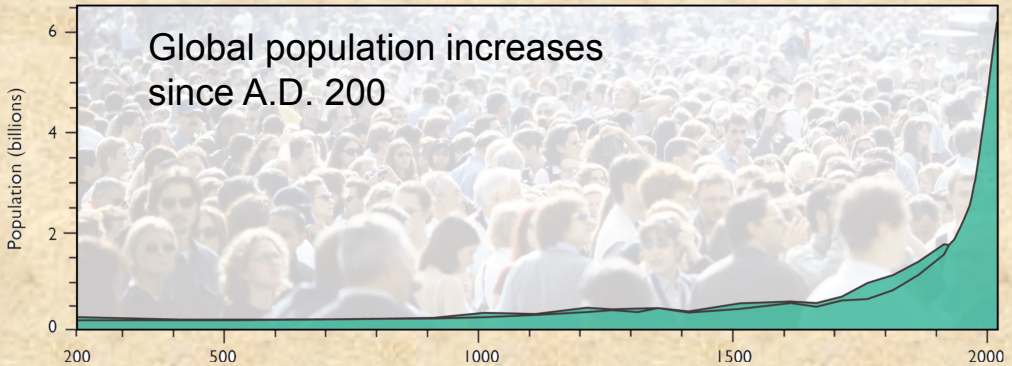


Annual lightning flashes per km^2, averaged for 4/1995 – 2/2003, from the OrbView 1 Optical Transient Detector and TRMM Lightning Imaging Sensor (from Goodman et al. 2007)

ESMR = Electrically Scanning Microwave Radiometer
TOMS = Total Ozone Mapping Spectrometer

Human Impacts

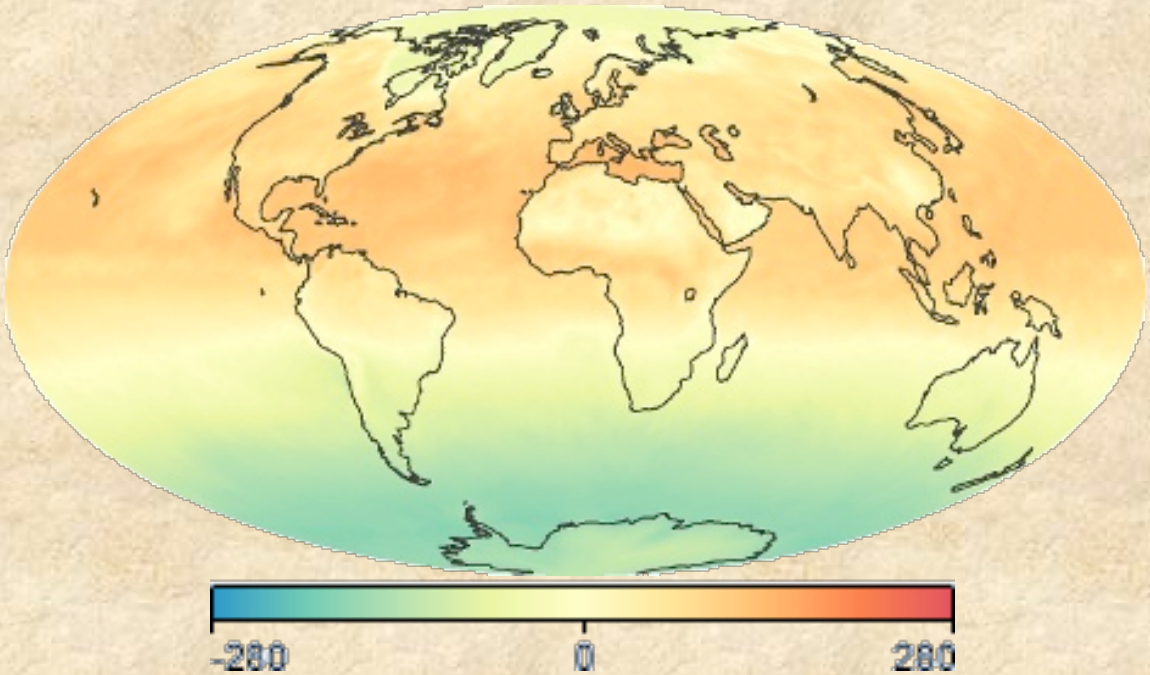
Industrialization, deforestation, and other land-use changes all have impacts.



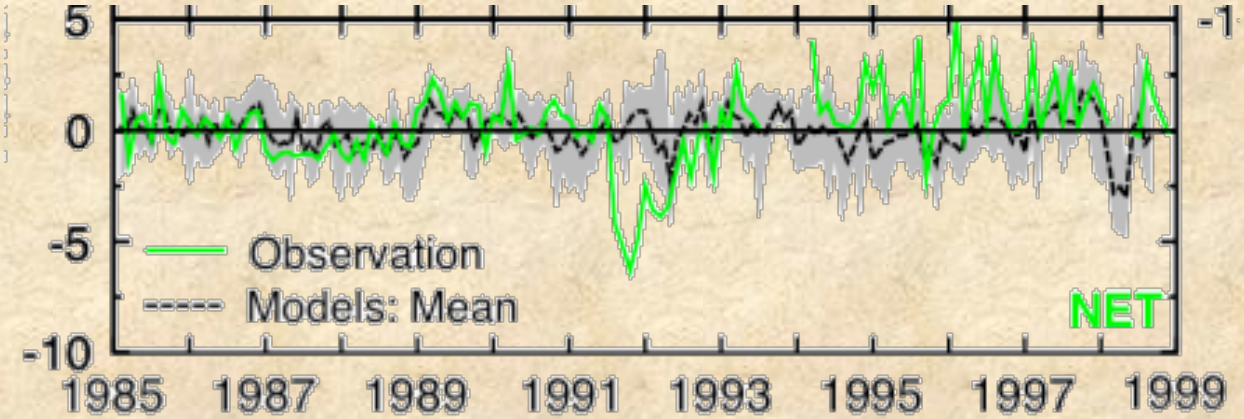
(Figures from *Our Changing Planet: The View From Space*, 2007; photos by K. Seto, ImageVortex.com, T. Landmann, left to right)

Net Radiation at the Top of the Atmosphere

Spatial distribution of net radiation (W/m^2), May 2009, from the Terra and Aqua Clouds and the Earth's Radiant Energy System (CERES) instrument



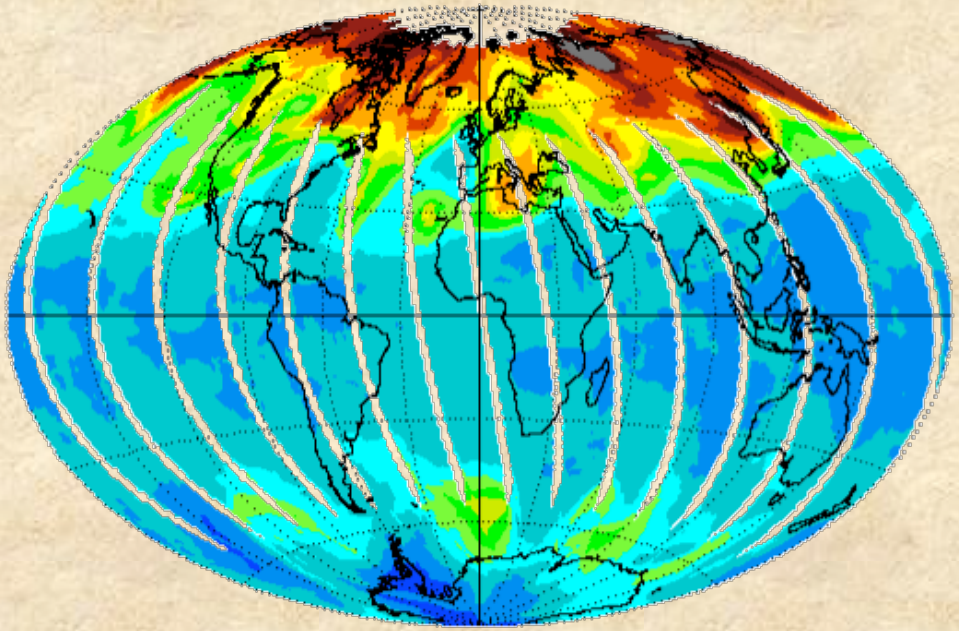
Net radiation anomalies, 1985-1999, from the Earth Radiation Budget Satellite's Nonscanner Wide Field of View instrument



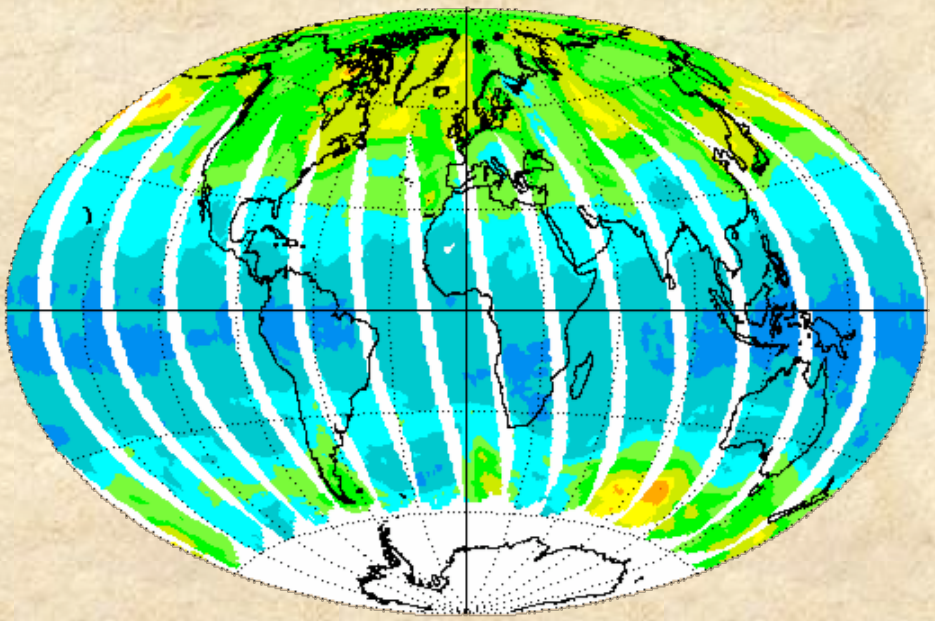
(Map from earthobservatory.nasa.gov; plot from Wong et al. 2006)

Total Ozone, March 7 and June 15, 2009,
from the Ozone Monitoring Instrument (OMI) on Aura

March 7, 2009

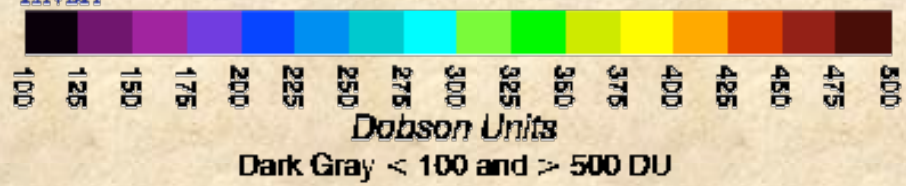


June 15, 2009



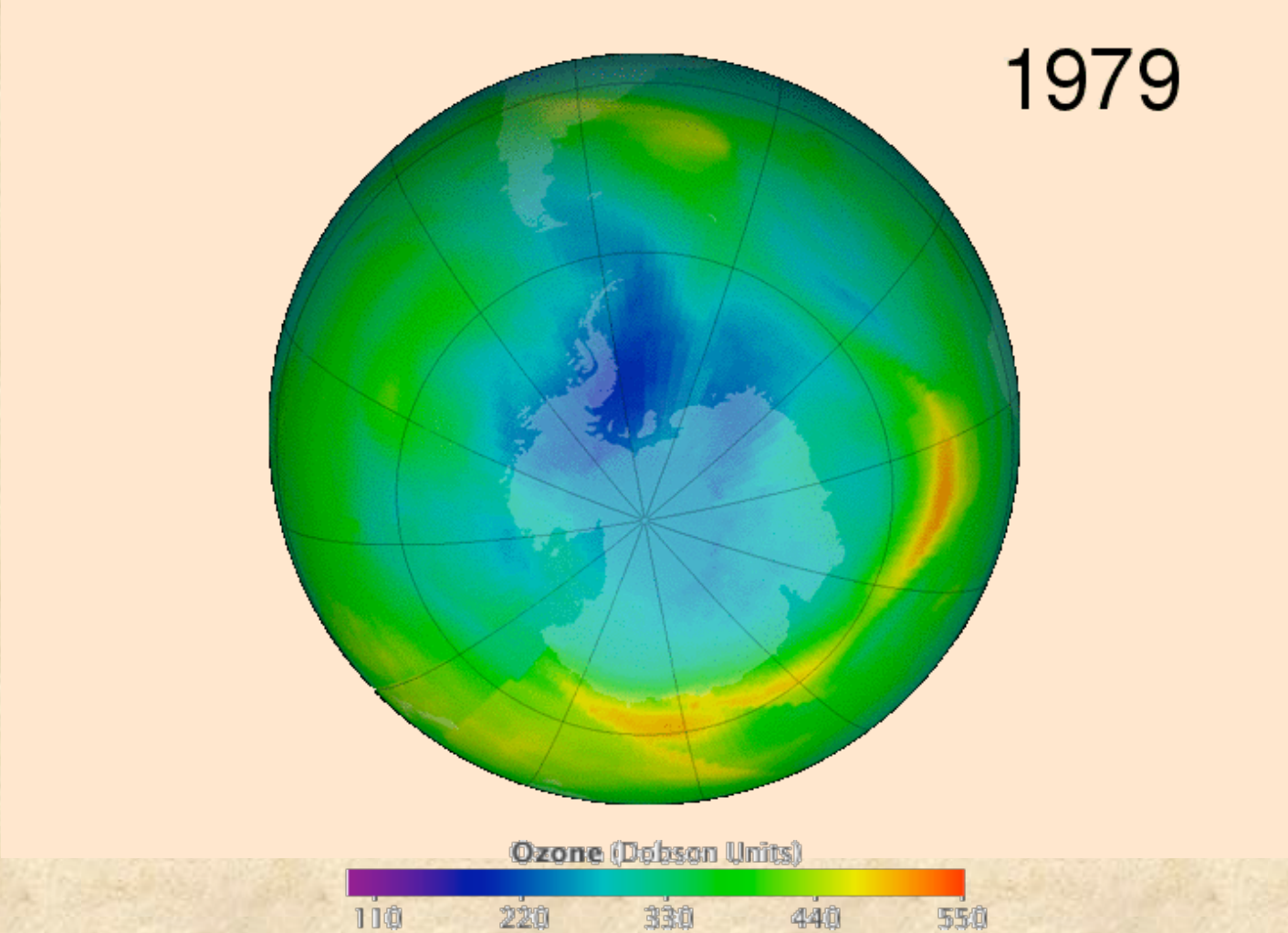
NIVR–FMI–NASA–KNMI

OMI



GSFC

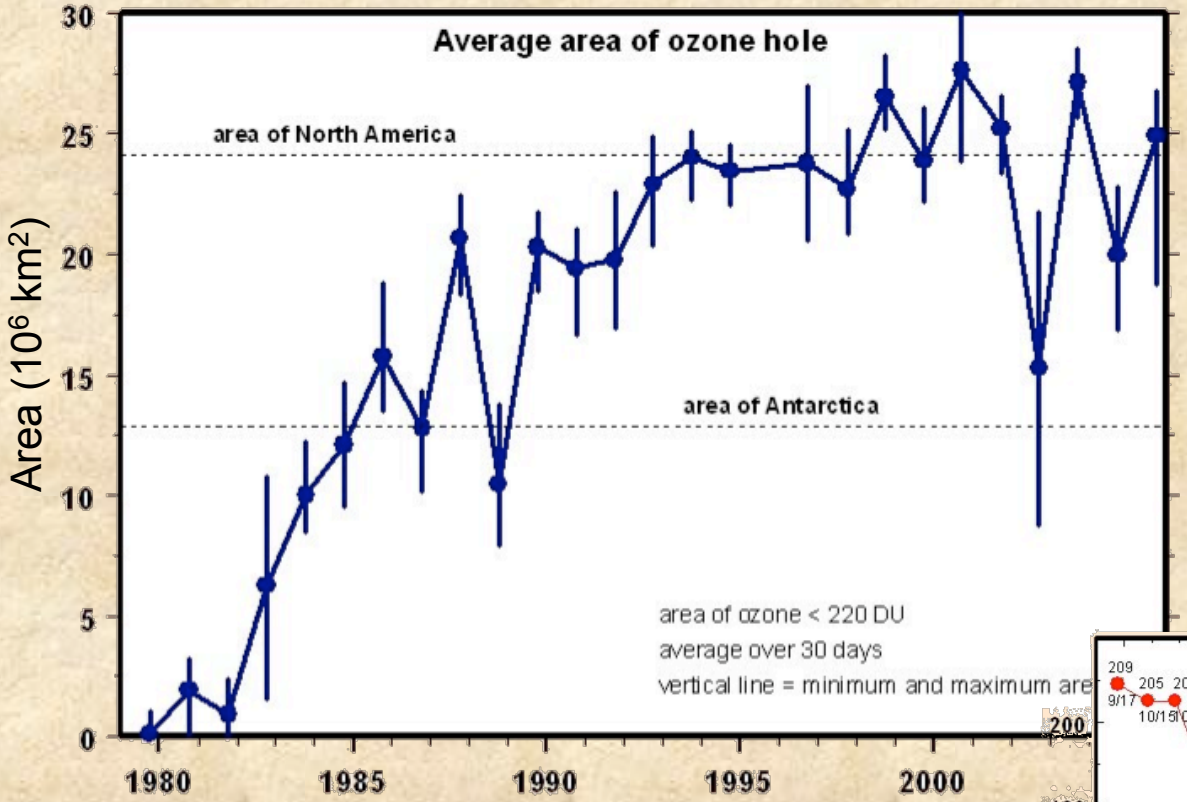
Antarctic Ozone Hole, 1979-2008,
from the Nimbus 7, Meteor 3, and Earth Probe TOMS (1979-2003) and the Aura OMI (2003-2008)

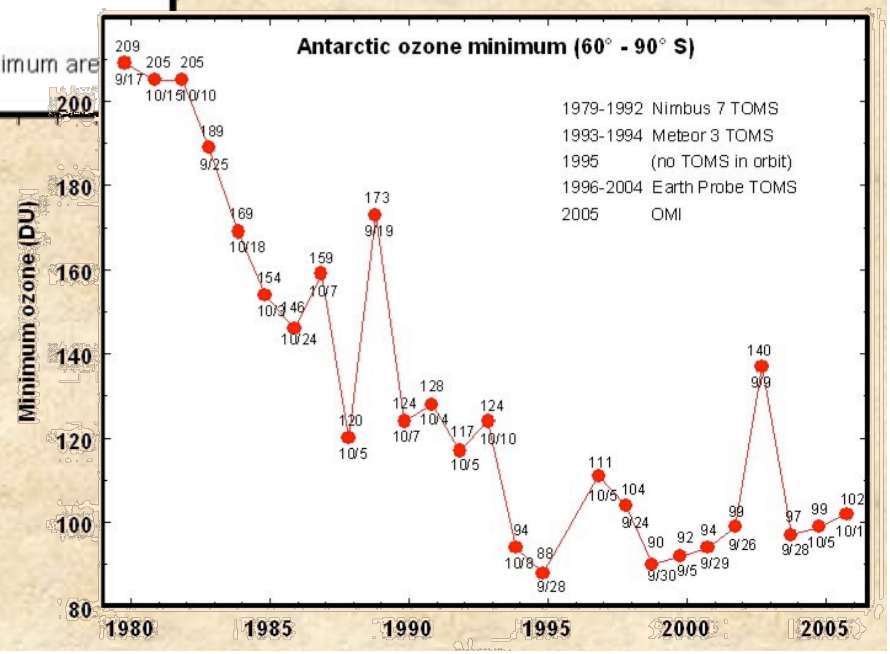


OMI = Ozone Monitoring Instrument (from the Netherlands)
TOMS = Total Ozone Mapping Spectrometer

(Images obtained from http://earthobservatory.nasa.gov)

Area and Depth of the Antarctic Ozone Hole, 1979 - 2006

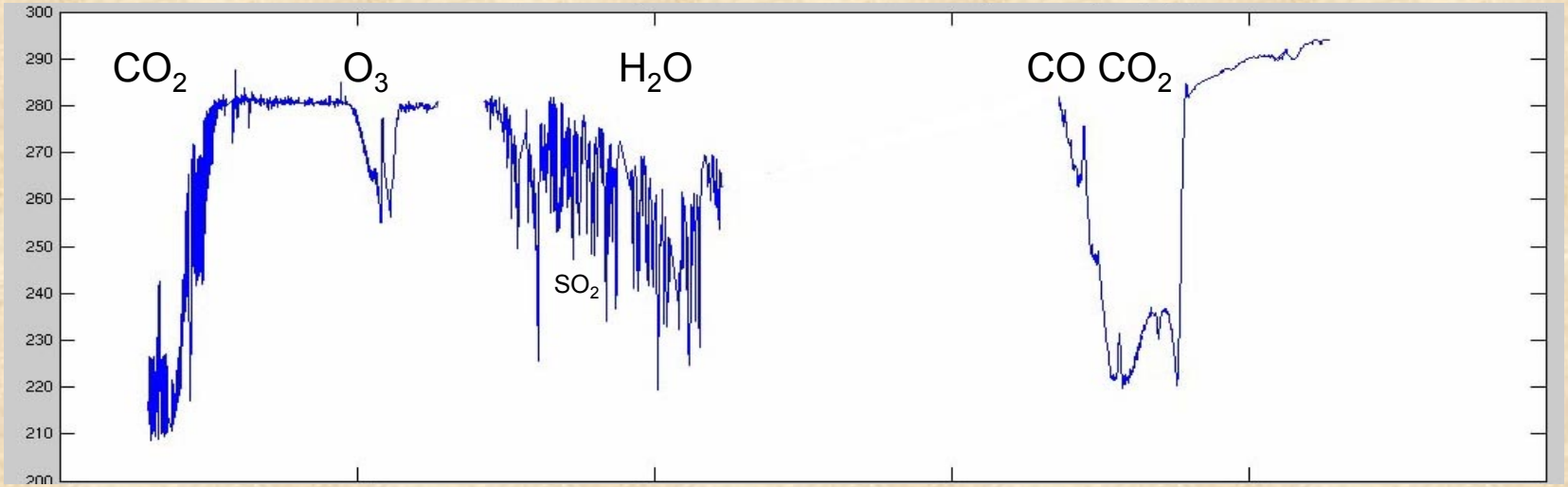




(Plots courtesy of the NASA GSFC Ozone Processing Team)

Sample Infrared Data at One Location and One Time, from the Aqua Atmospheric Infrared Sounder (AIRS)

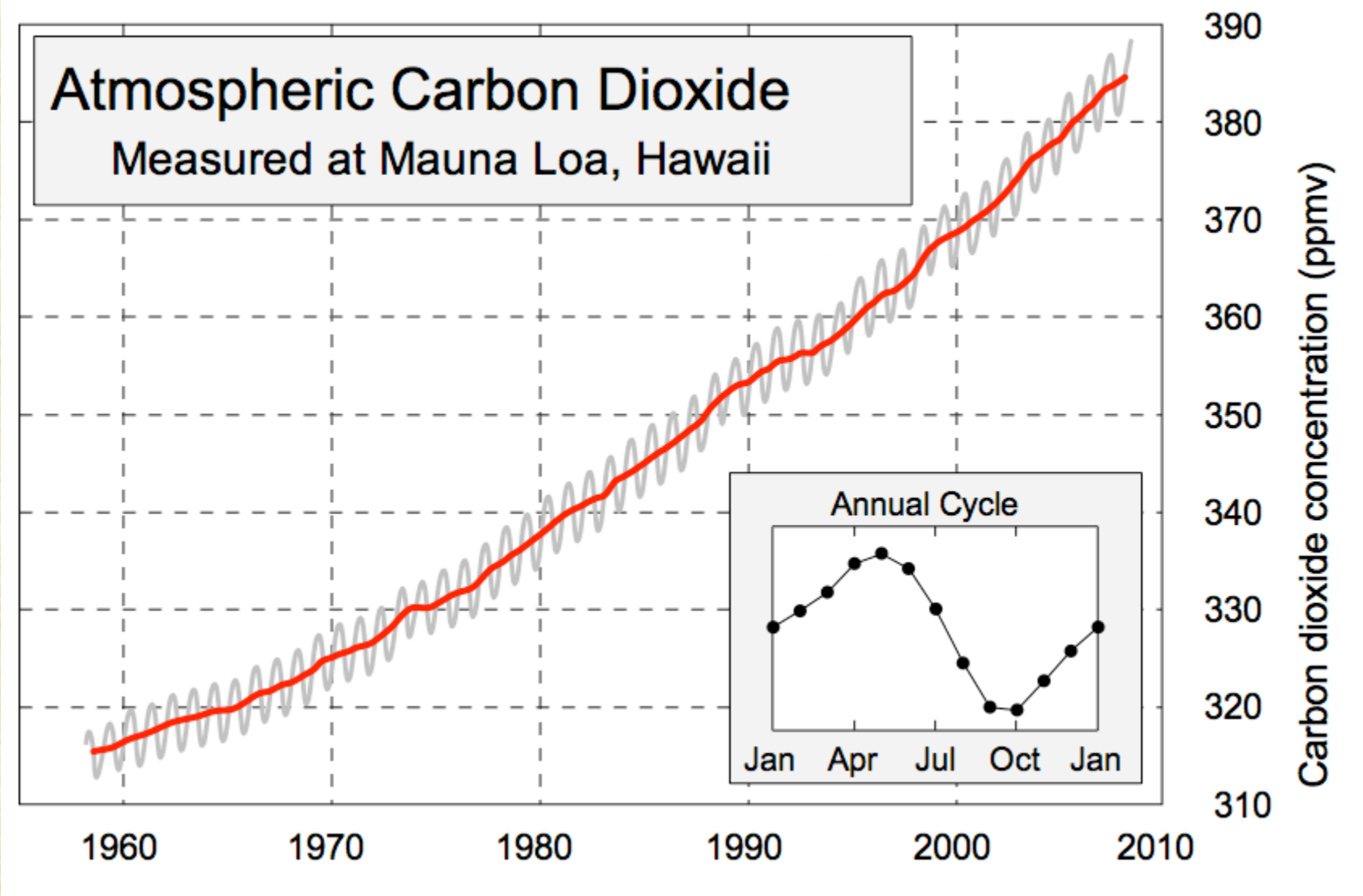
Data from all 2378 AIRS infrared channels for one footprint off the west coast of South Africa, June 13, 2002, 1:30 UTC.



500	1000	1500	2000	2500	wave number (cm^{-1})
20	10	6.7	5	4	wavelength (μm)

(Spectrum courtesy of M. Chahine and the AIRS Science Team)

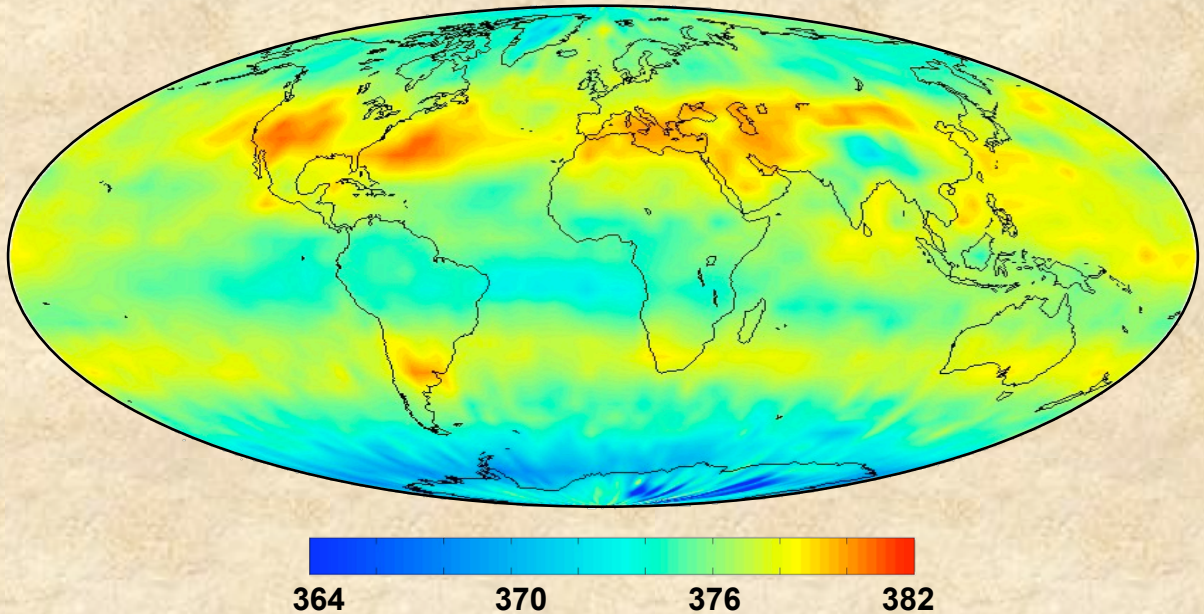
Keeling Curve: Atmospheric CO_2 Measured at Mauna Loa



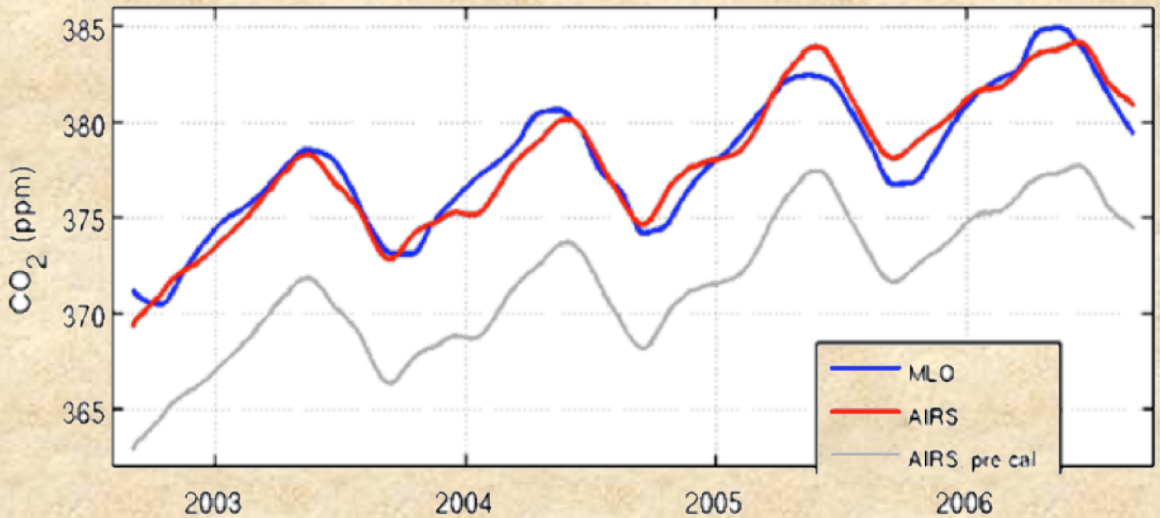
(Image from Wikipedia)

Mid-Troposphere CO_2 Results from the Aqua Atmospheric Infrared Sounder (AIRS)

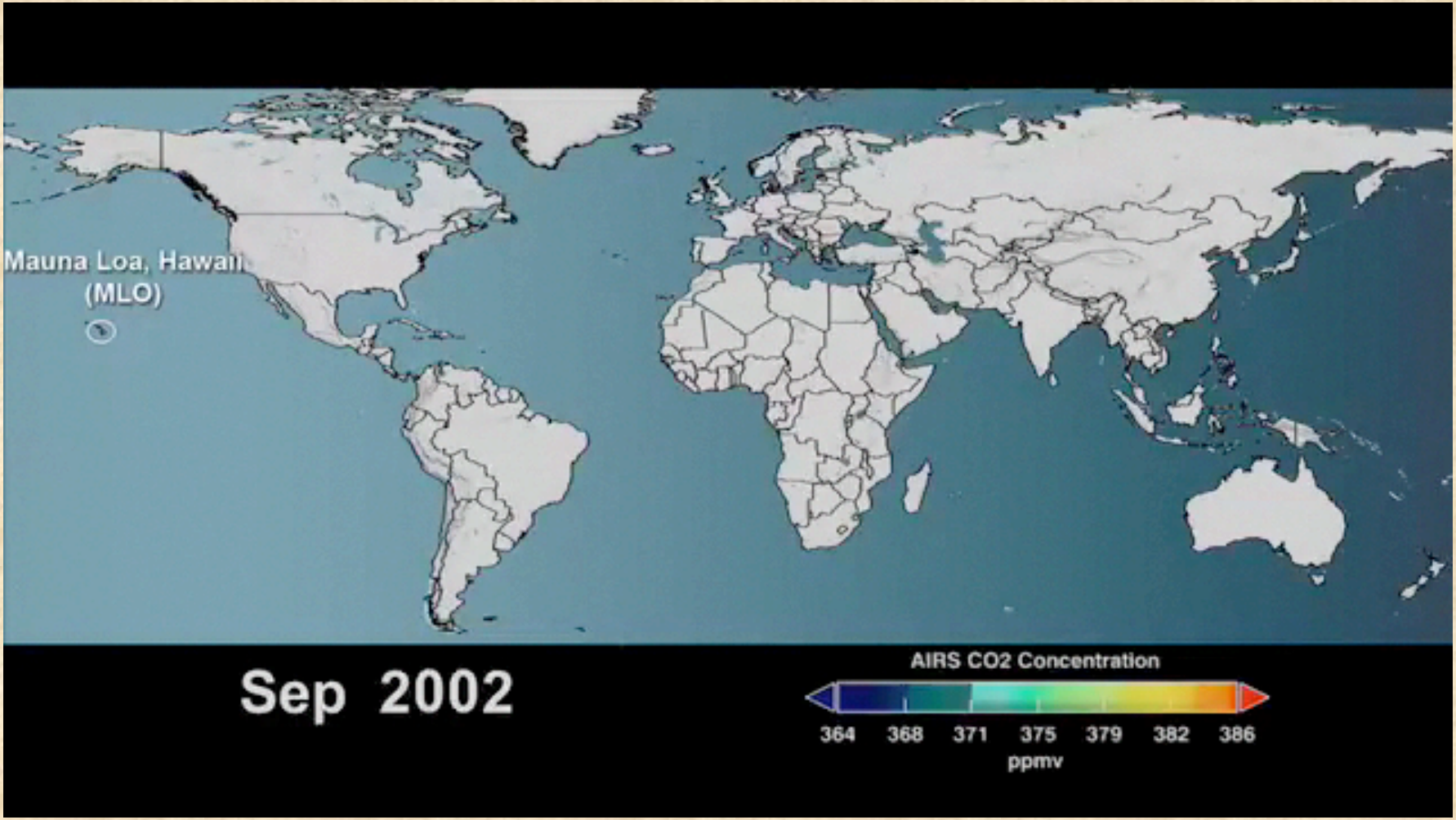
AIRS mid-troposphere CO_2 concentrations (ppm) for July 2003 (from Mous Chahine and the AIRS Science Team).



CO_2 time series from the Mauna Loa Observatory (MLO) and from AIRS retrievals for the Pacific Ocean before and after calibration (from Strow and Hannon 2008).



Aqua AIRS/AMSU Mid-Tropospheric CO_2 Product September 2002 – July 2008

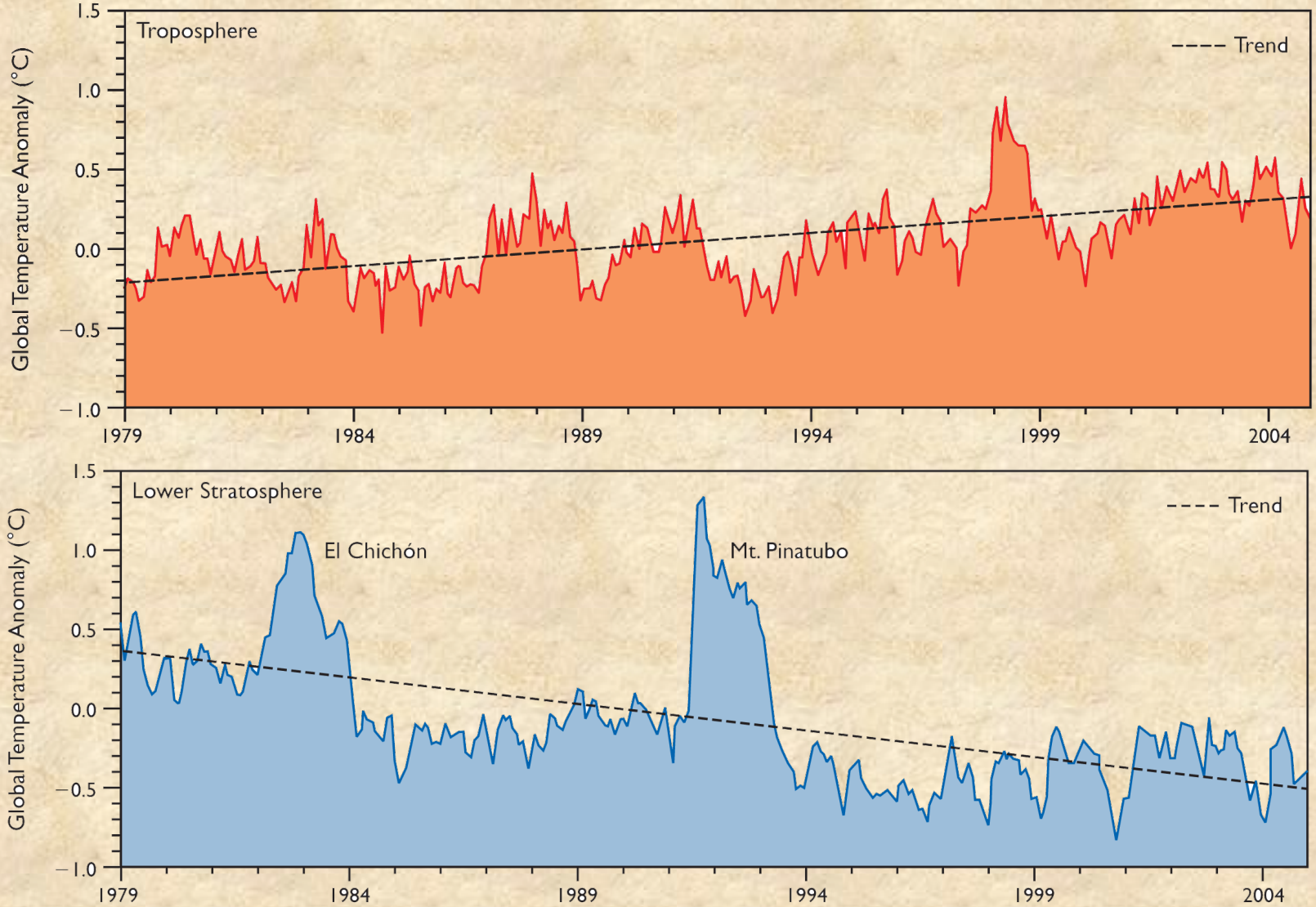


(Animation from Mous Chahine, the AIRS Science Team, and the NASA GSFC Scientific Visualization Studio [SVS])

AMSU = Advanced Microwave Sounding Unit

Global Temperature Trends in the Troposphere and Lower Stratosphere, 1979-2004,

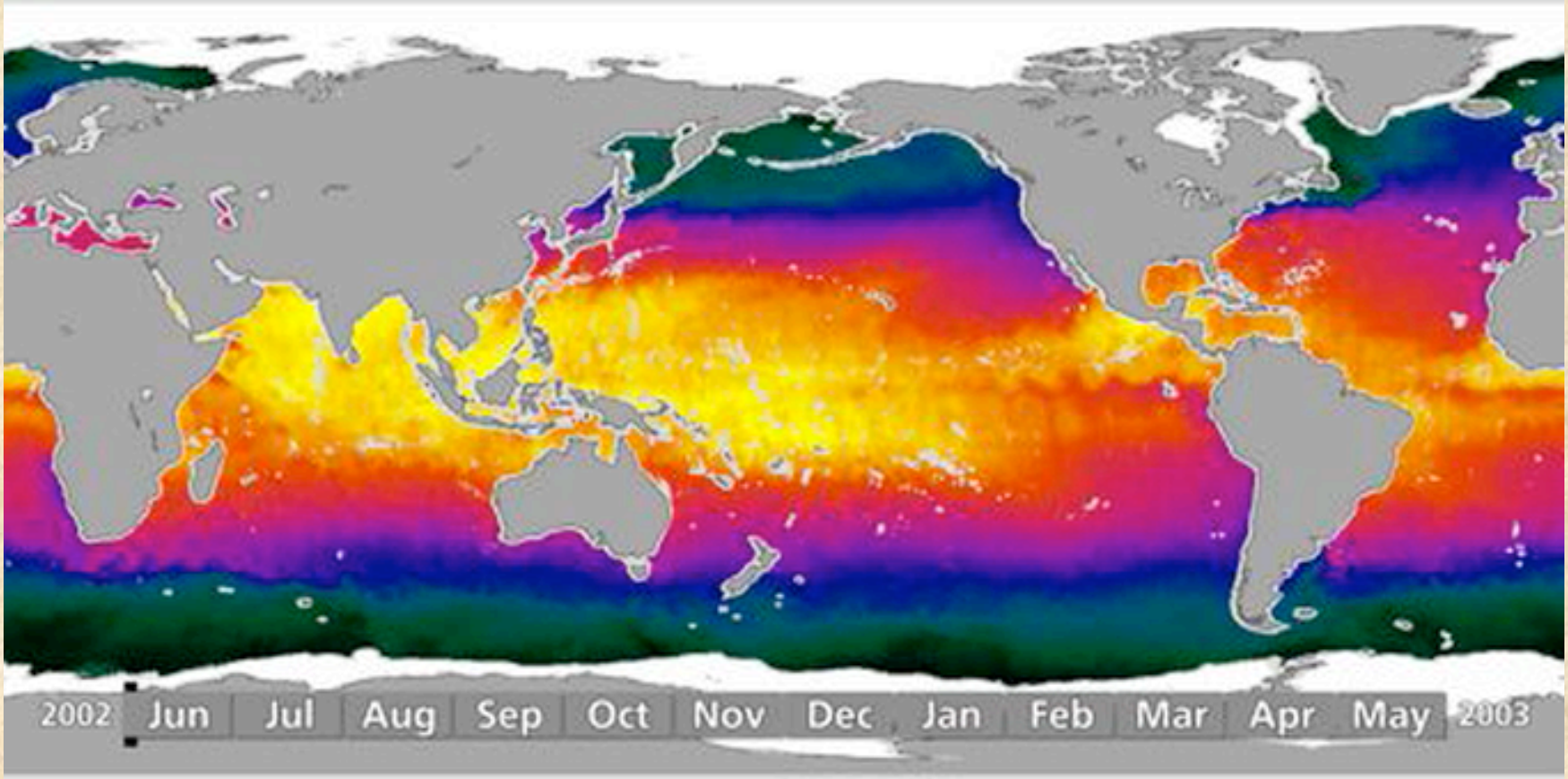
from the MSU on Tiros-N and NOAA 6-14



MSU = Microwave Sounding Unit

(From Fu and Johanson, in *Our Changing Planet: The View From Space*, 2007)

Sea Surface Temperatures, June 2002 - May 2003, from Aqua AMSR-E Data

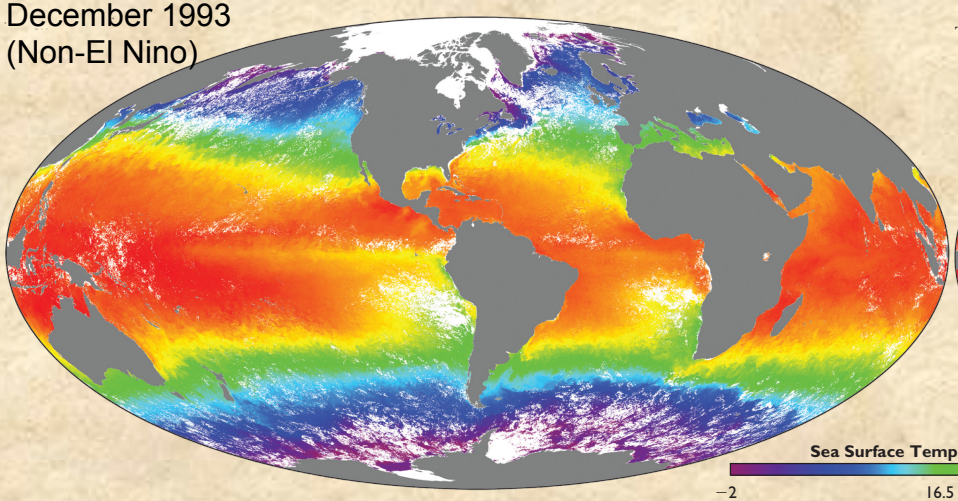


(Animation courtesy of JAXA)

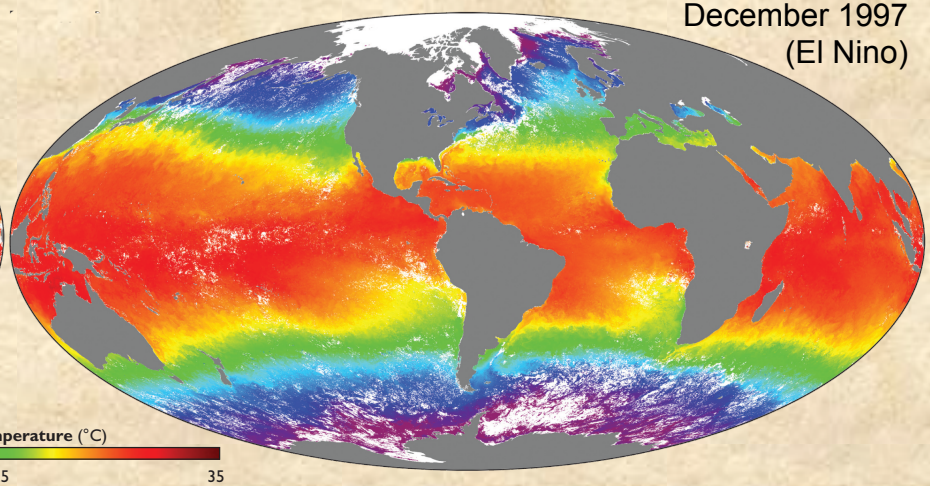
AMSR-E = Advanced Microwave Scanning Radiometer for the Earth Observing System (EOS), from Japan

Global Sea Surface Temperatures in December 1993 and 1997, from NOAA 11-14 AVHRR

December 1993
(Non-El Nino)



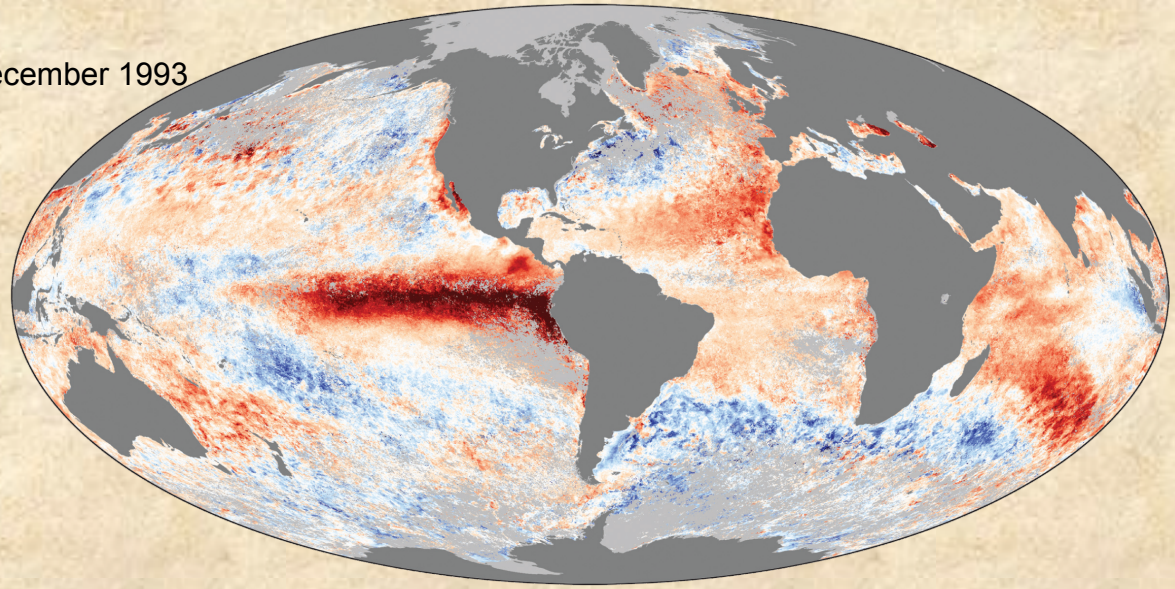
December 1997
(El Nino)



Sea Surface Temperature (°C)

−2 16.5 35

Difference Map:
December 1997 – December 1993



Sea Surface Temperature Difference (°C)

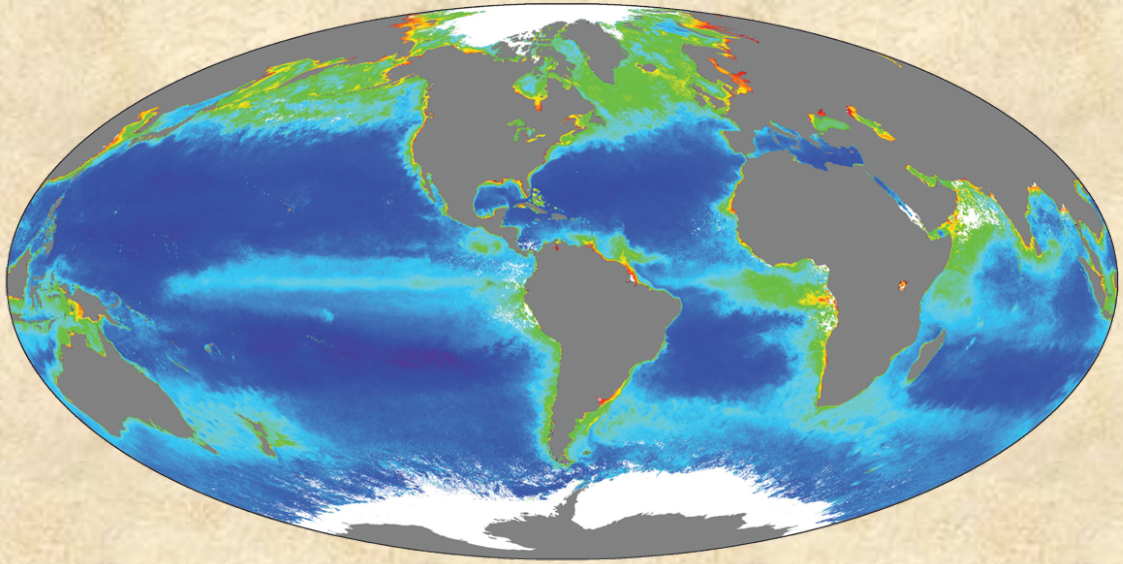
−5 0 5

AVHRR = Advanced Very High Resolution Radiometer

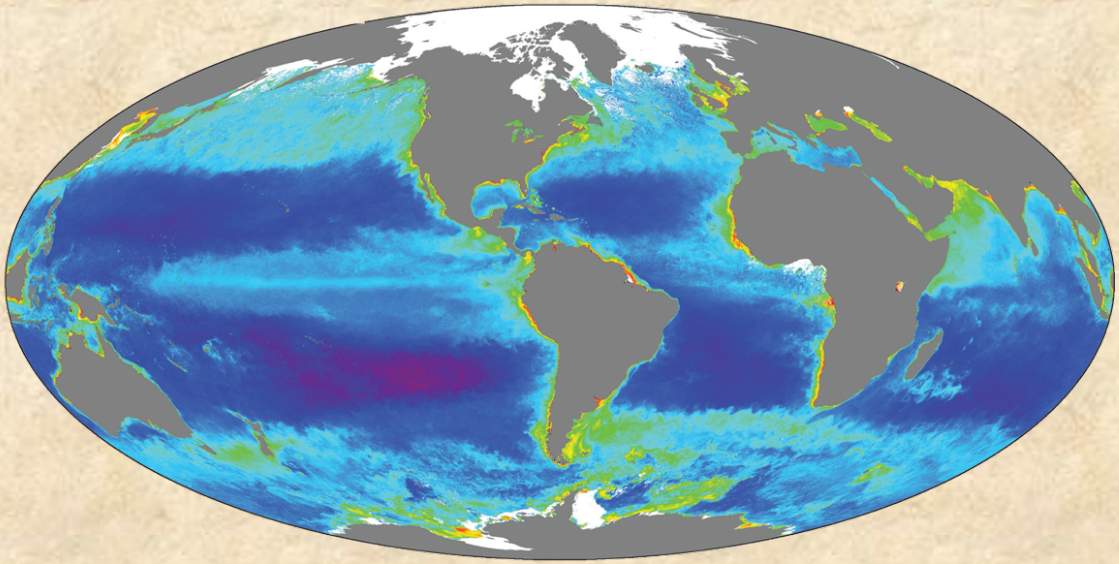
(Images from Minnett 2007)

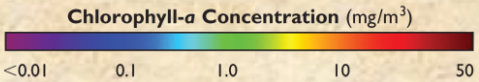
Seasonal Ocean Chlorophyll-*a* Concentrations, from the OrbView-2 SeaWiFS

Northern Hemisphere summer,
Southern Hemisphere winter, 2005



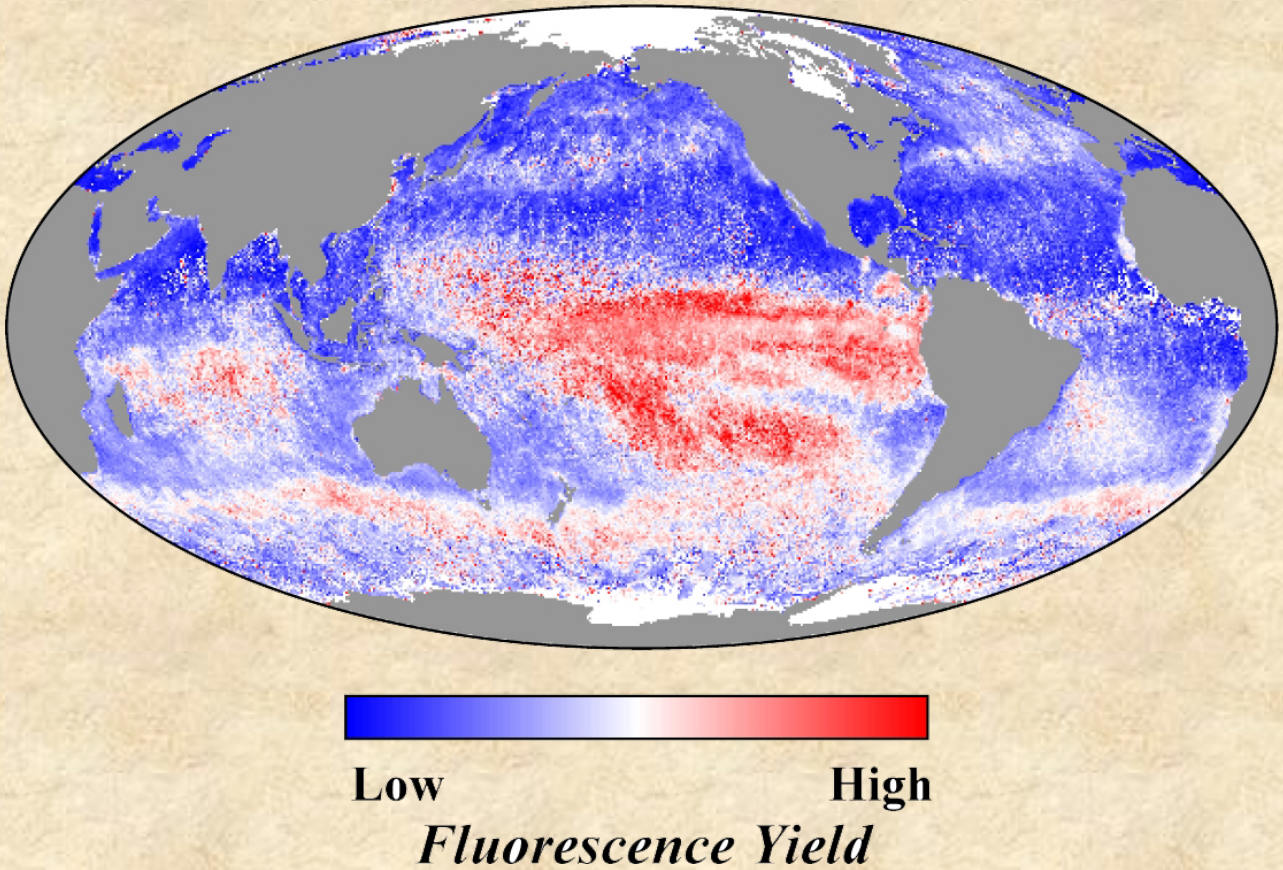
Northern Hemisphere winter,
Southern Hemisphere summer, 2006





SeaWiFS = Sea-viewing Wide Field-of-view Sensor
(Images from McClain and Feldman 2007)

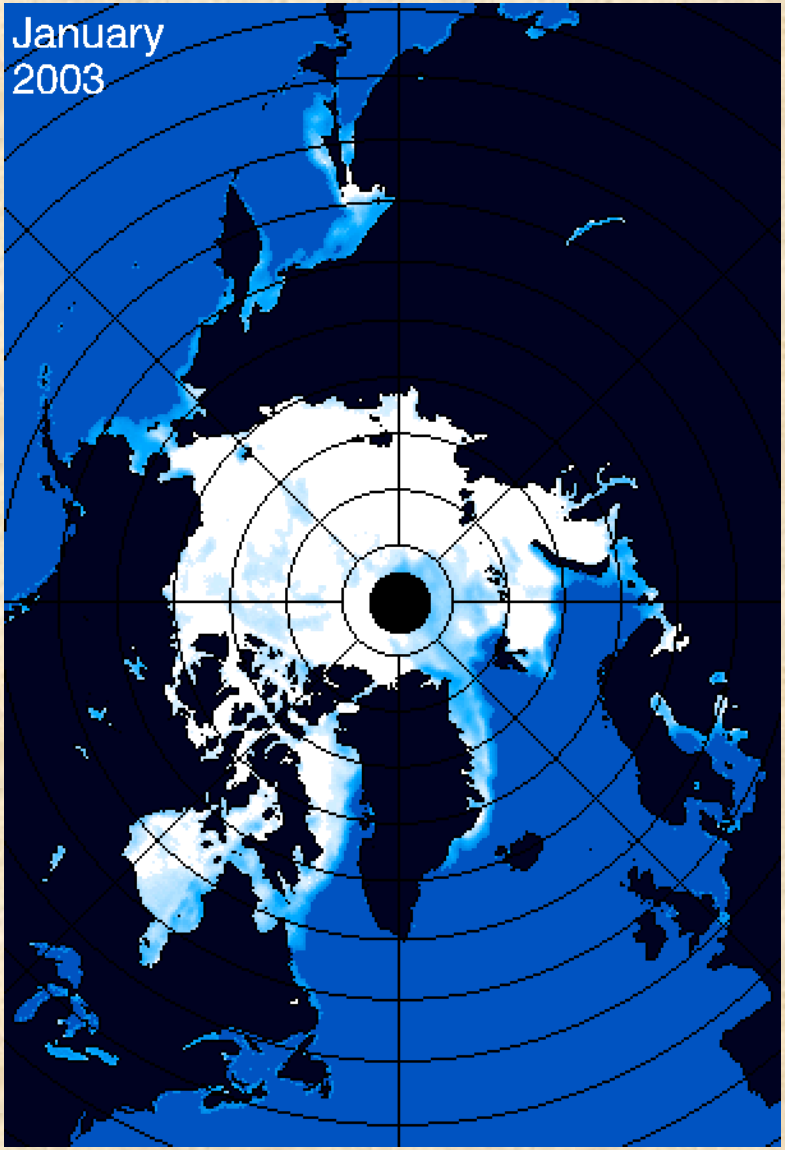
Global Fluorescence Yield by Ocean Phytoplankton, March-May 2004, a measure of the health of ocean plants, from the Aqua MODIS

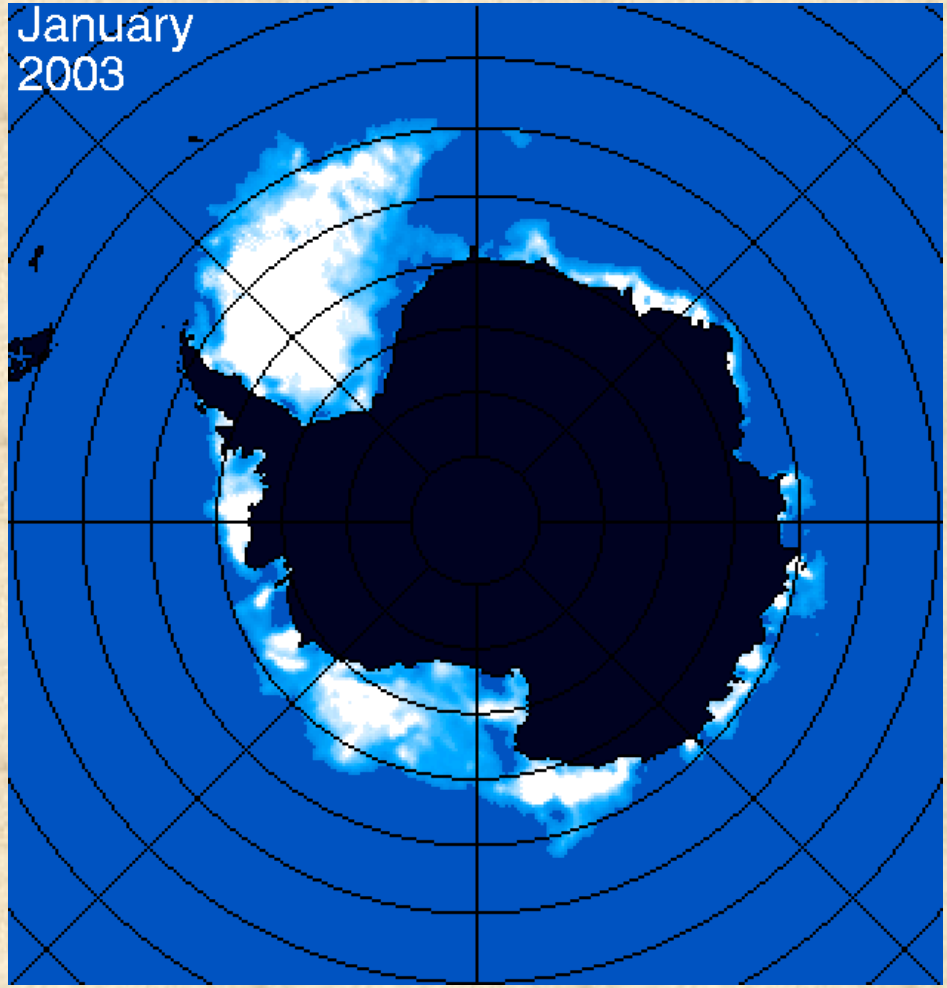


('Fluorescence yield' = the fraction of absorbed sunlight given off by plants as fluorescence.)

(From Behrenfeld et al. 2009)

Animation of 2003 Arctic and Antarctic Sea Ice Coverages from DMSP SSMI Data



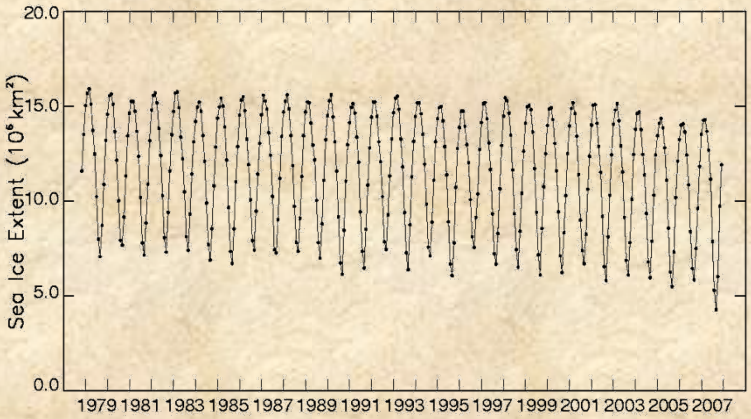


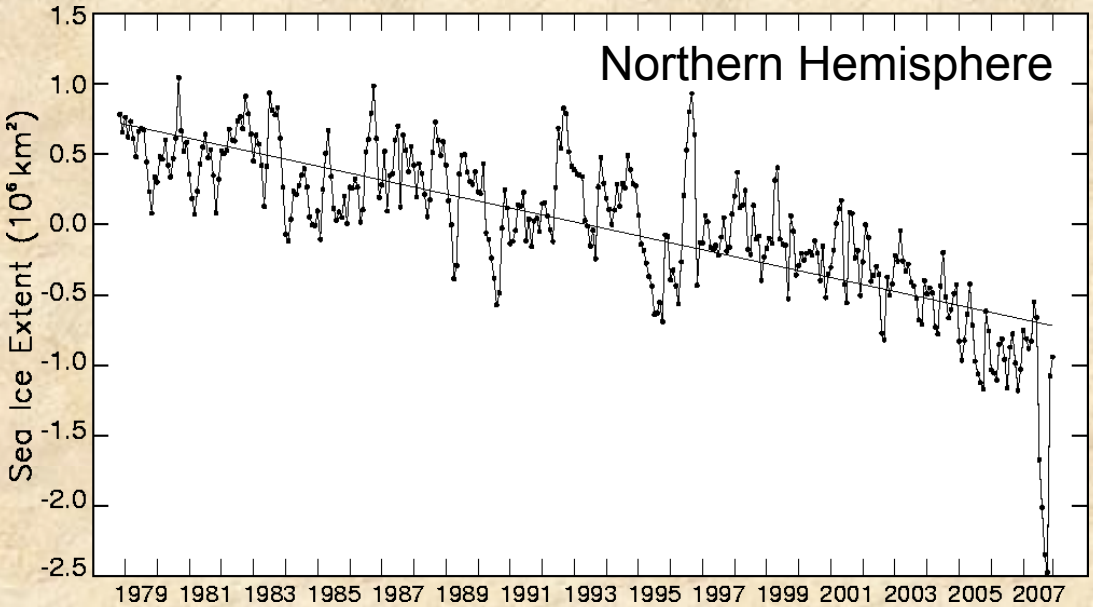
White: Highly compact ice
Shades of light blue: Less compact ice
Images every 4 days

DMSP = Defense Meteorological Satellite Program
SSMI = Special Sensor Microwave Imager

(Animations by N. DiGirolamo and C. Parkinson)

Arctic Sea Ice Extents and Trends, 11/1978 – 12/2007



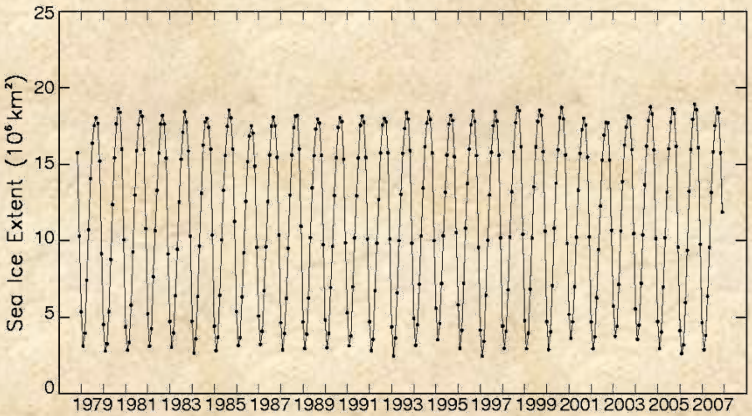


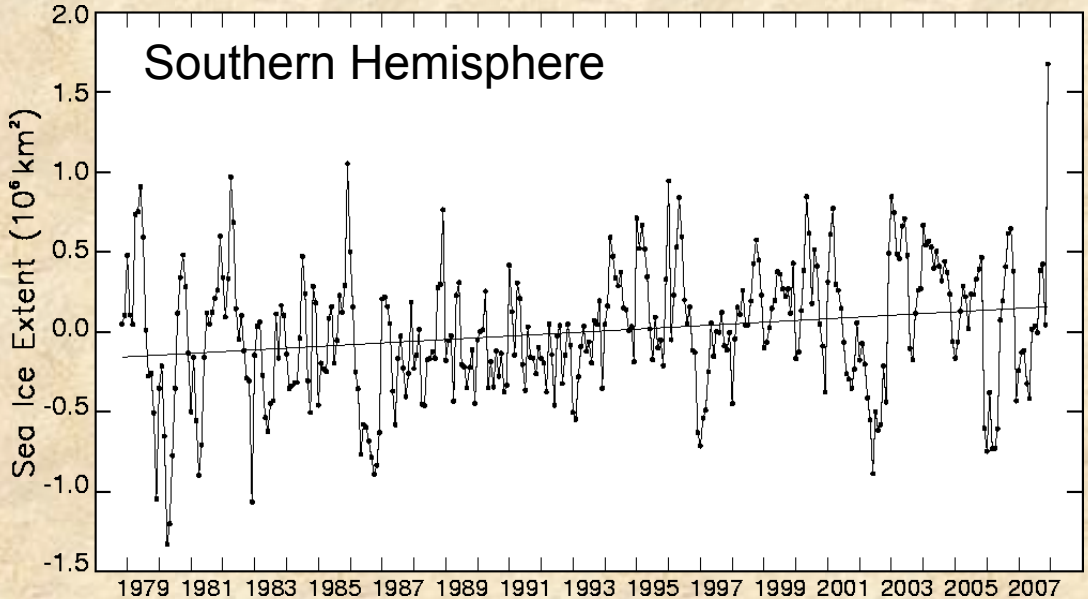
Monthly Arctic sea ice extents (above) and deviations (right), from Nimbus 7 SMMR and DMSP SSMI data

Arctic record low sea ice coverage, September 14, 2007, from Aqua AMSR-E data

SMMR = Scanning Multichannel Microwave Radiometer
(Plots updated from Parkinson et al. 1999.)

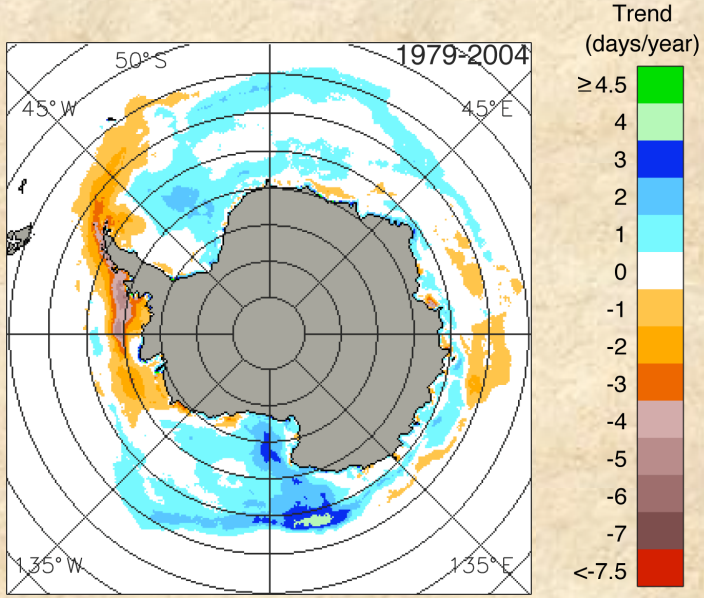
Antarctic Sea Ice Extents and Trends, 11/1978 – 12/2007





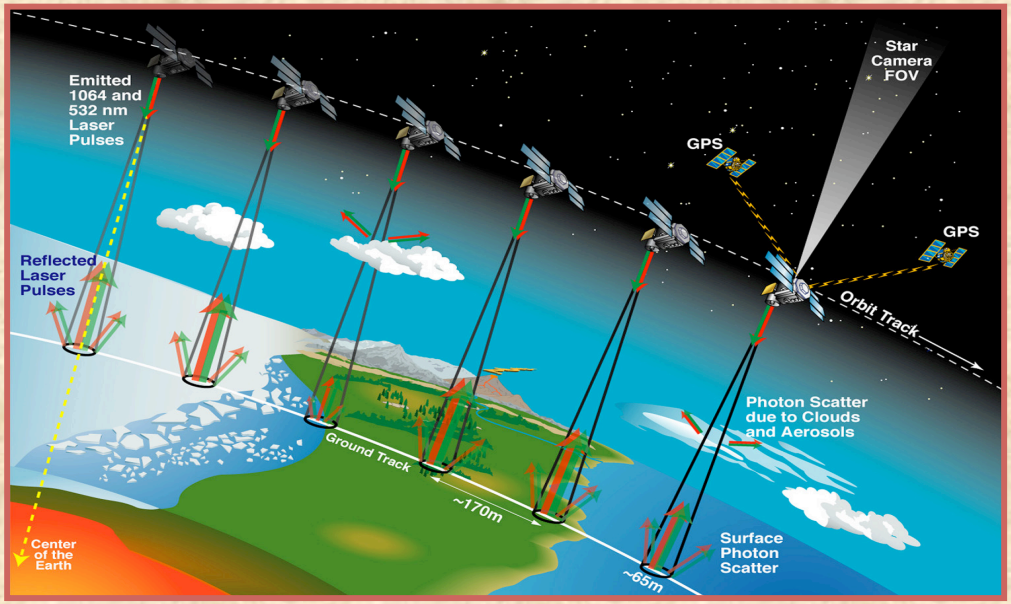
Monthly Antarctic sea ice extents (above) and deviations (right), from Nimbus 7 SMMR and DMSP SSMI data

Trends in the length of the sea ice season throughout the Southern Ocean, 1979-2004, from SMMR and SSMI data

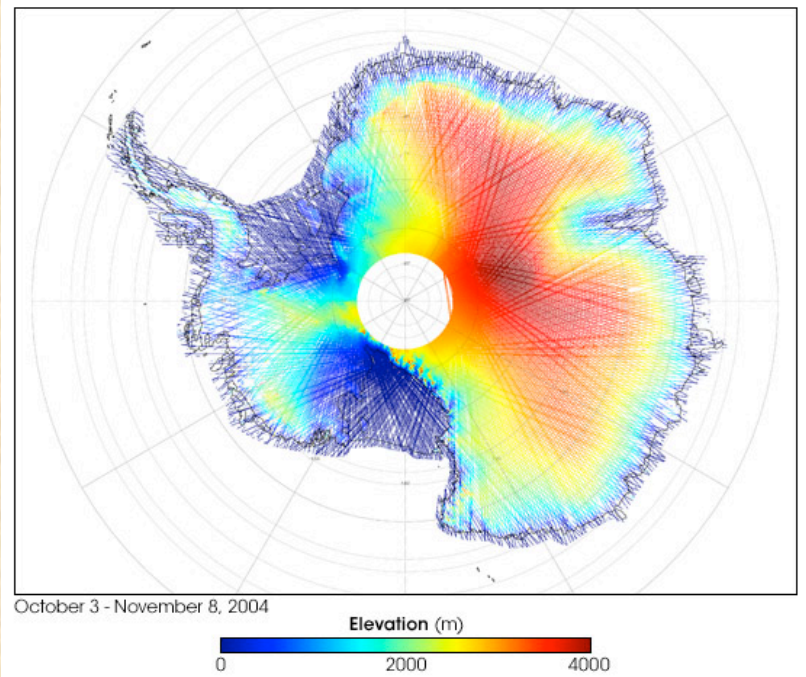


SMMR = Scanning Multichannel Microwave Radiometer
(plots updated from Zwally et al. 2002; map updated from Parkinson 2002)

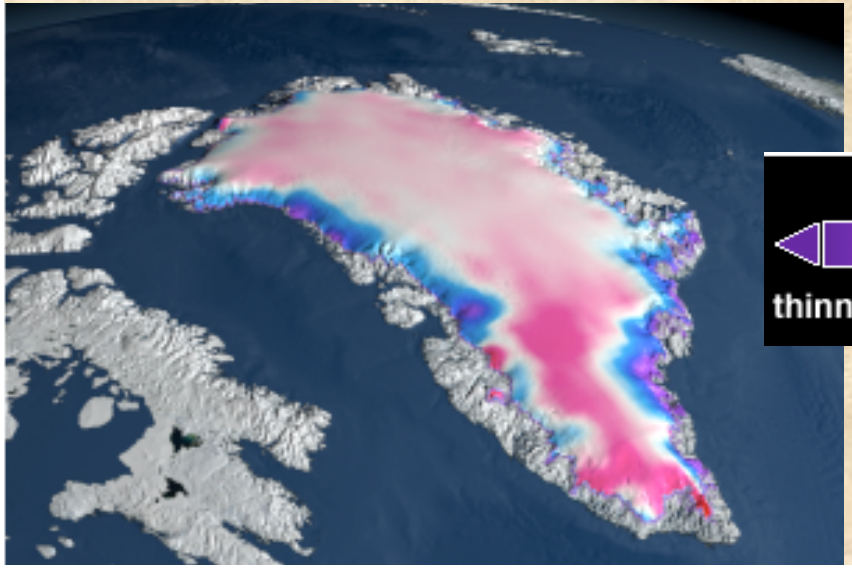
Laser Altimetry and Results from the Ice, Cloud, and Land Elevation Satellite (ICESat)



Schematic of laser altimetry



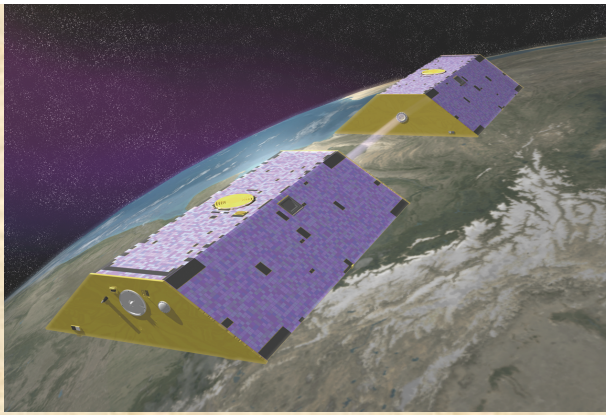
Antarctic ice sheet elevations



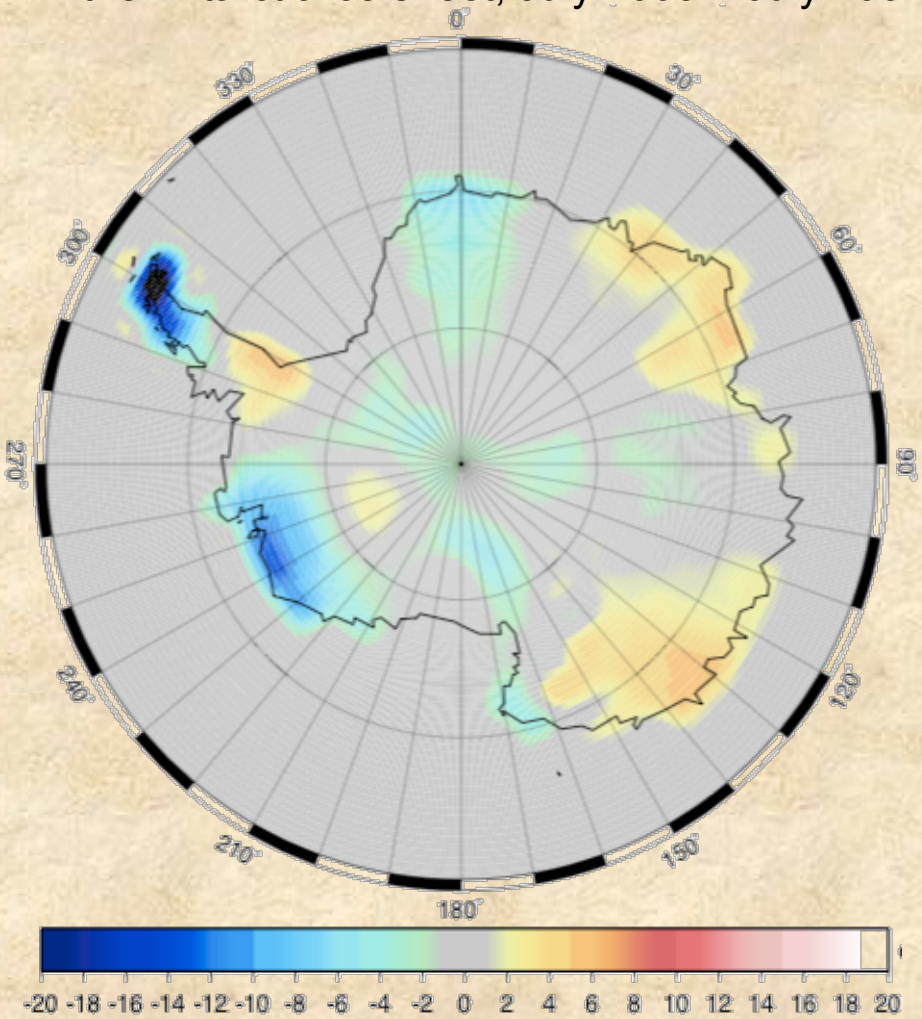
Elevation changes on Greenland, 2003-2006

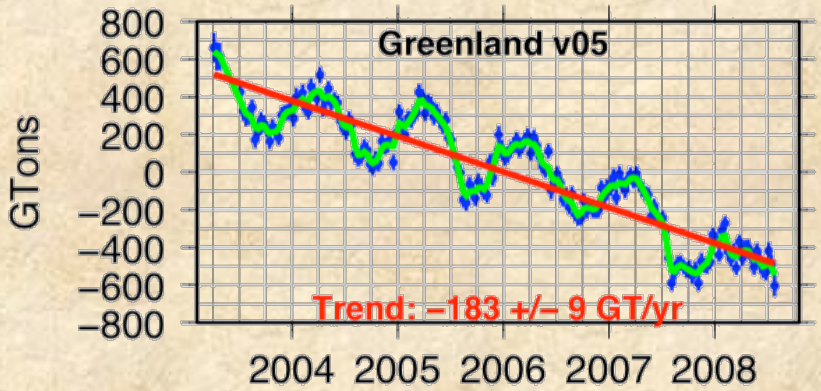
(schematic and images from the ICESat Science Team)

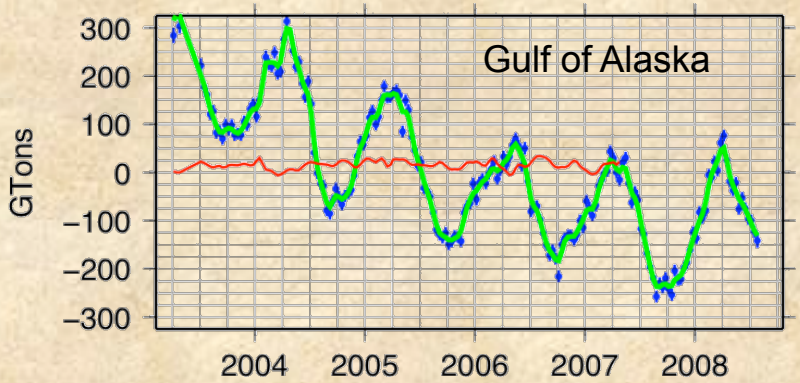
Trends in Ice Mass, from GRACE data



Trend in the equivalent depth of water (cm/yr)
in the Antarctic ice sheet, July 2003 – July 2007



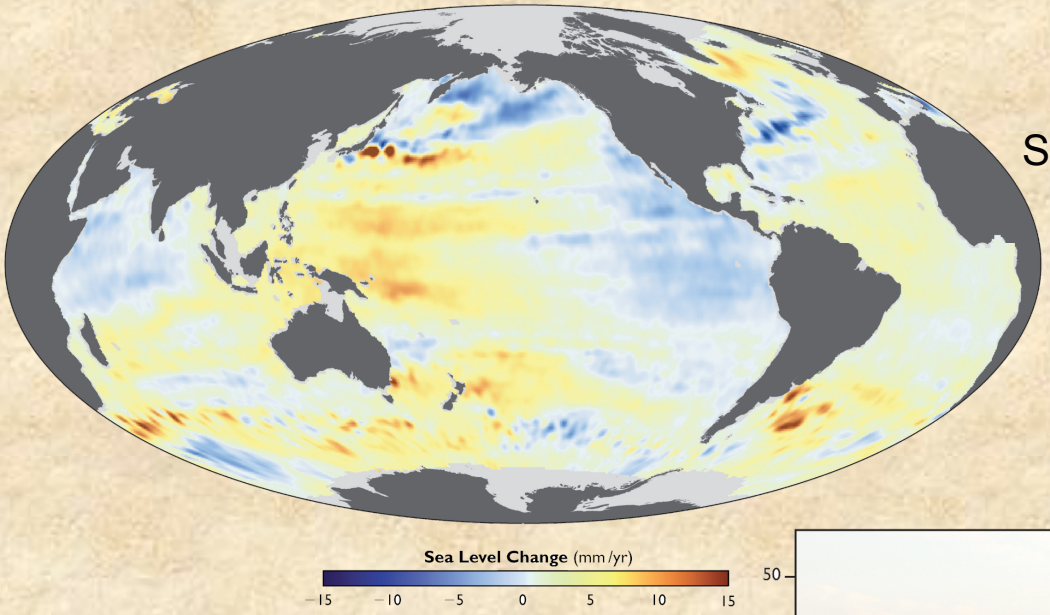




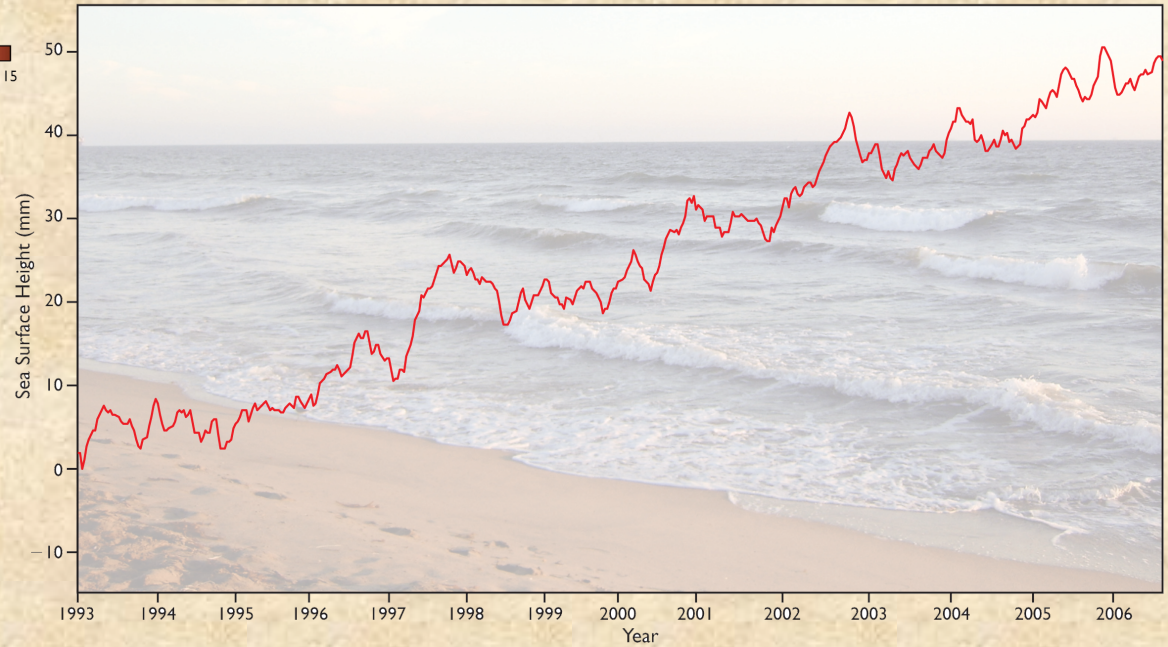
GRACE = Gravity Recovery and Climate Experiment

(Illustrations from Scott Luthcke)

Global Sea Level Change, 1993-2006,
from radar altimeters on TOPEX/Poseidon and Jason-1



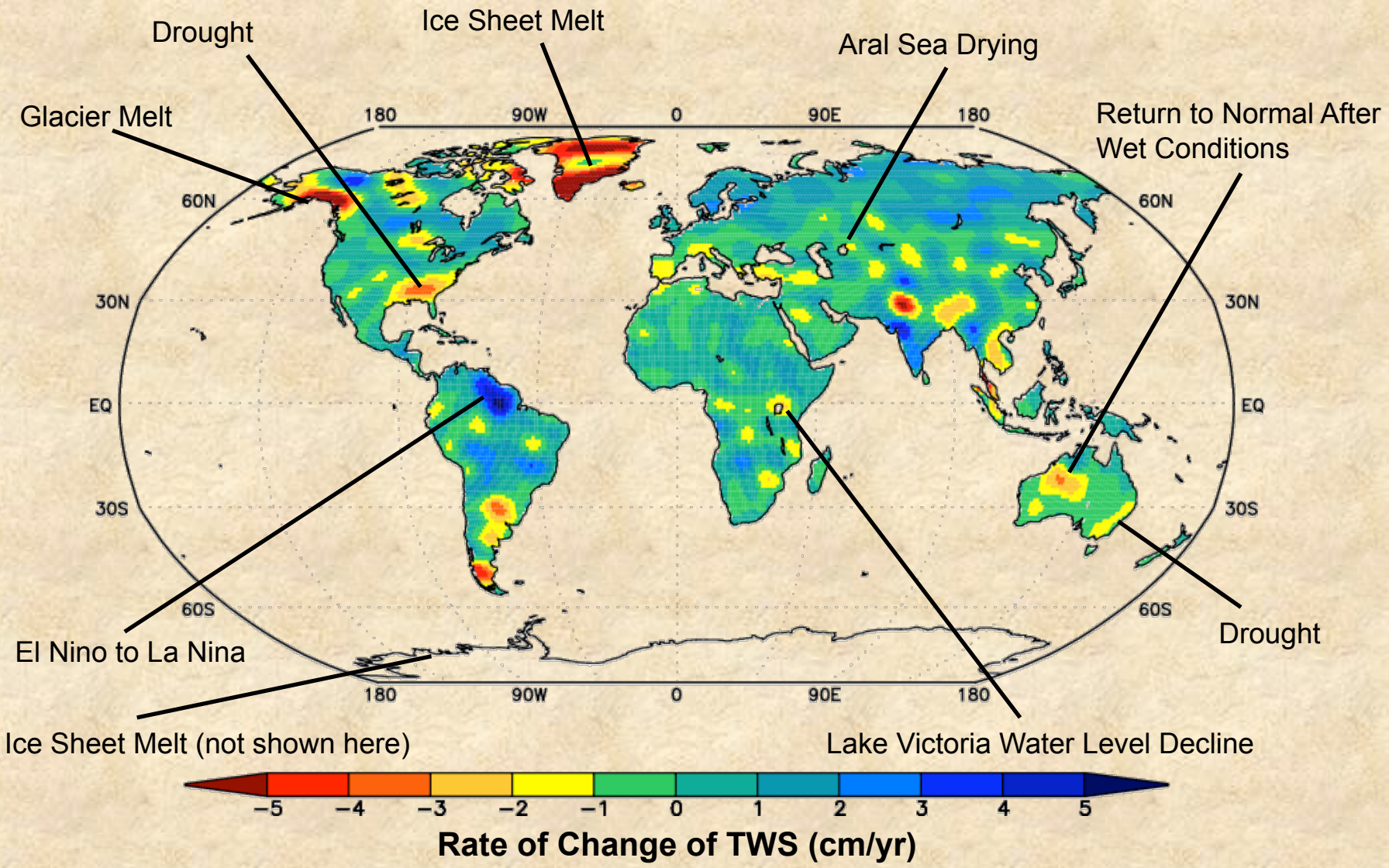
Spatial distribution of sea level change, 1993-2006



Globally averaged sea level rise, 1993-2006

(From Mitchum and Nerem, in *Our Changing Planet: The View From Space*, 2007)

Trends in Terrestrial Water Storage (TWS), 2002-2008, from GRACE Data



(Figure from Matt Rodell, 2009)

Changes in the Aral Sea, 1989-2009

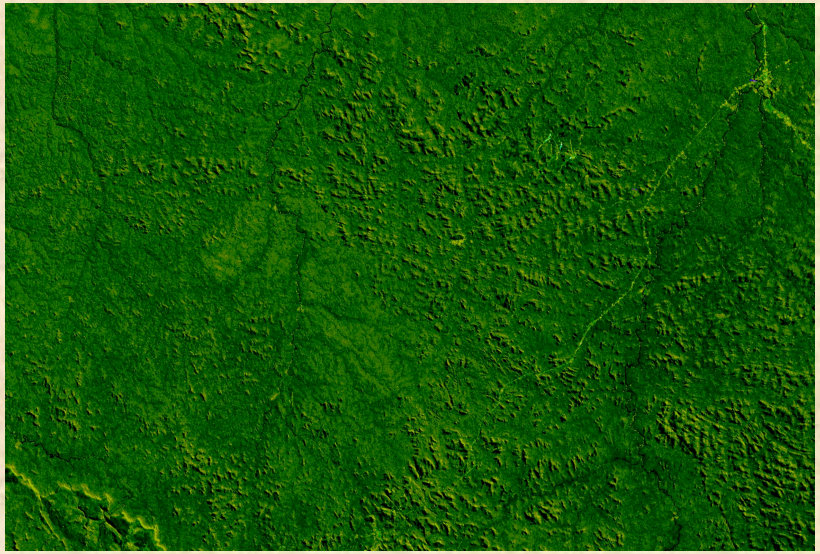
July - September 1989,
from Landsat

August 12, 2003,
from the Aqua MODIS

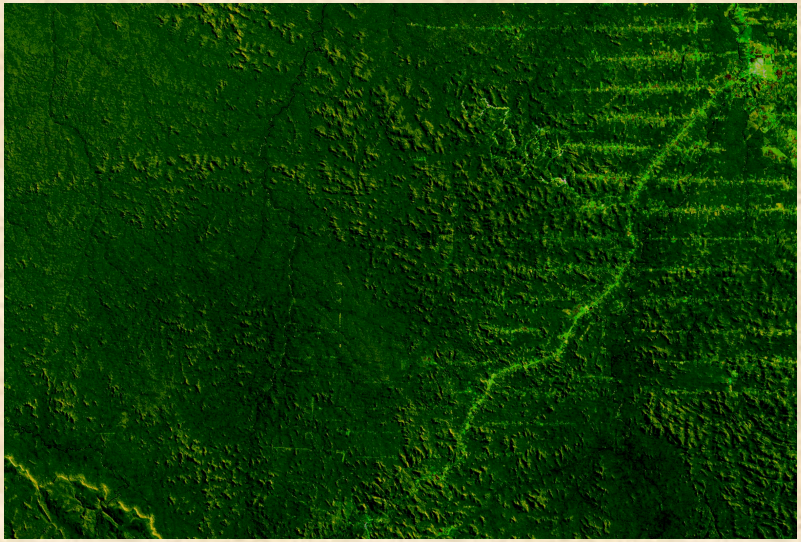
May 3, 2009,
from the Terra MODIS

Deforestation in Rondonia, Brazil, from Landsat

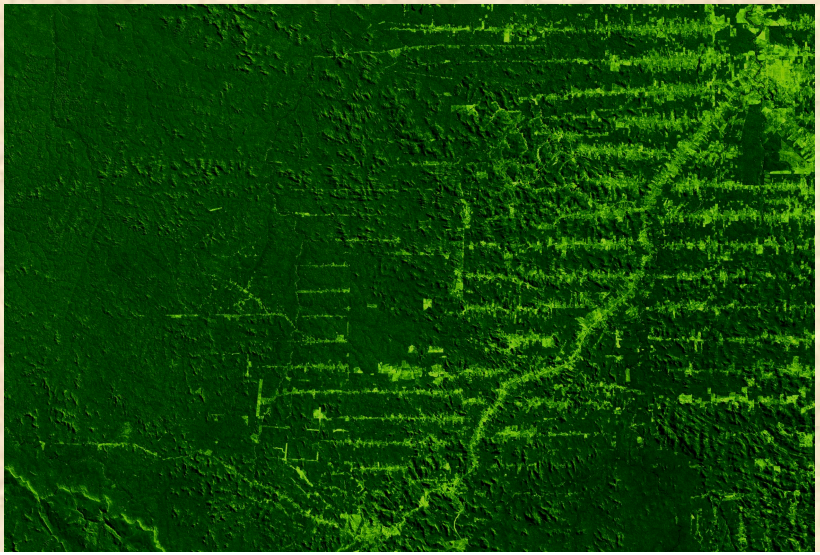
June 19, 1975, from Landsat 2



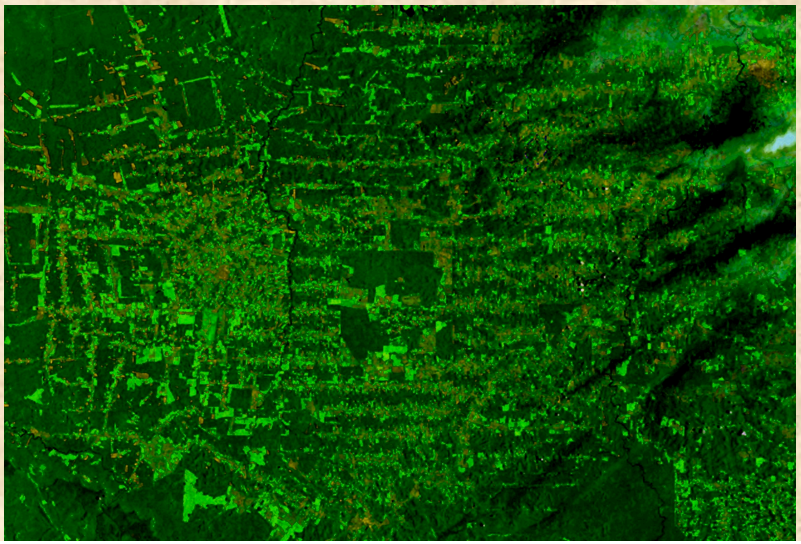
August 1, 1986, from Landsat 5



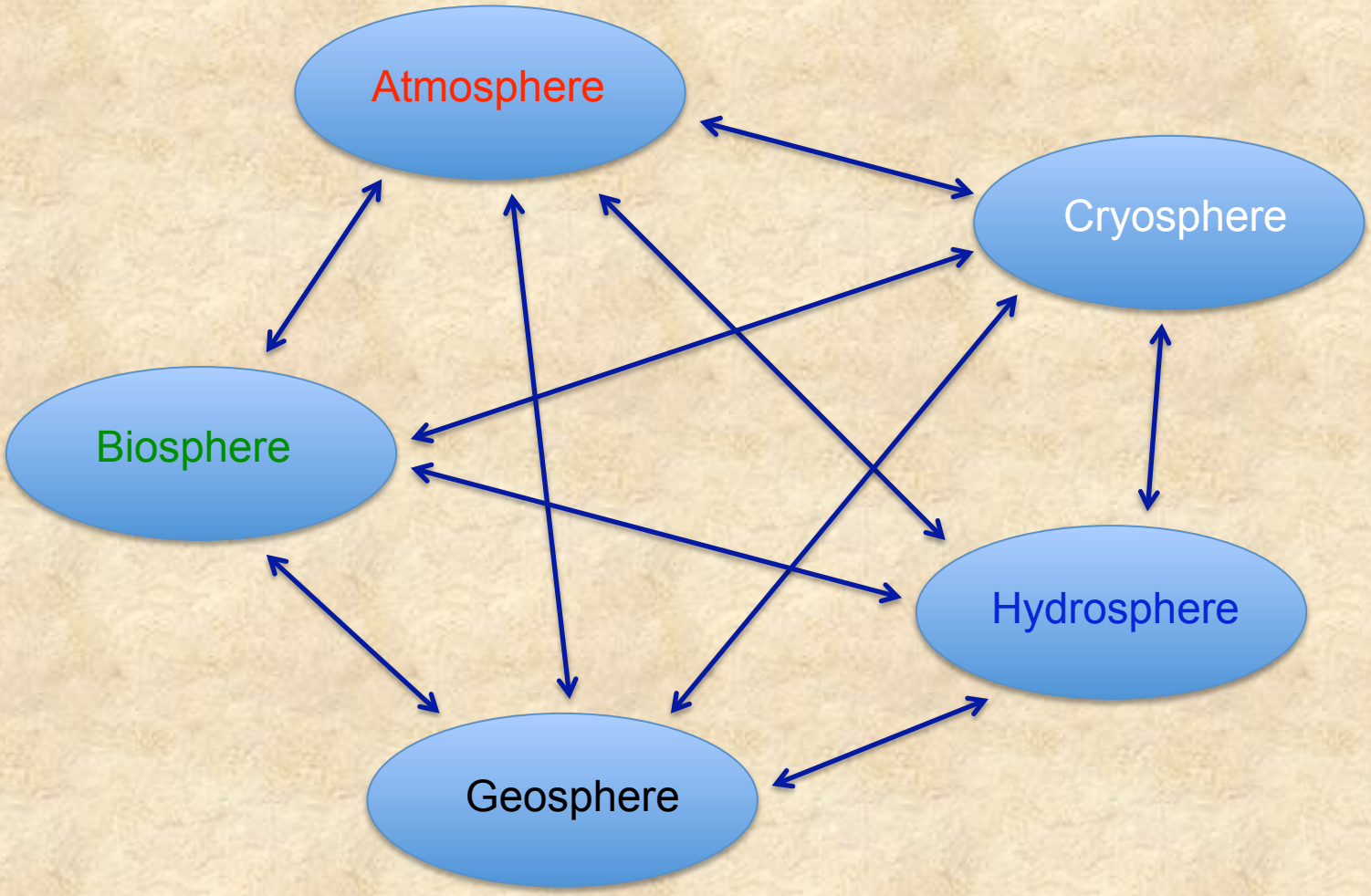
June 22, 1992, from Landsat 4



February 7, 2001 from Landsat 7



Interconnectedness of the Earth System Components



" When one tugs at a single thing in nature, he finds it attached to the rest of the world. " -- John Muir (1838-1914)

Sources

- Much of the illustrative material in this presentation comes from the book *Our Changing Planet: The View From Space*, edited by M. King, C. Parkinson, K. Partington, and R. Williams, and published by Cambridge University Press in 2007. This includes all of the following references:
  - Edwards 2007; Fu and Johanson 2007; Goodman et al. 2007; Hsu et al. 2007; McClain and Feldman 2007; Minnett 2007; Mitchum and Nerem 2007; Roy and Justice 2007; Seto 2007.
- Other cited references:
  - Behrenfeld, M. J., and 14 others, 2009: Satellite-detected fluorescence reveals global physiology of ocean phytoplankton, *Biogeosciences*, 6, 779-794.
  - Luthcke, S. B., A. A. Arendt, D. D. Rowlands, J. J. McCarthy, and C. F. Larsen, 2008: Recent glacier mass changes in the Gulf of Alaska region from GRACE mascon solutions, *Journal of Glaciology*, 54 (188), 767-777.
  - Parkinson, C. L., D. J. Cavalieri, P. Gloersen, H. J. Zwally, and J. C. Comiso, 1999: Arctic sea ice extents, areas, and trends, 1978-1996, *Journal of Geophysical Research*, 104 (C9), 20,837-20,856.
  - Parkinson, C. L., 2002: Trends in the length of the Southern Ocean sea-ice season, 1979-99, *Annals of Glaciology*, 34, 435-440.
  - Strow, L. L., and S. E. Hannon, 2008: A 4-year zonal climatology of lower tropospheric CO_2 derived from ocean-only Atmospheric Infrared Sounder observations, *Journal of Geophysical Research*, 113, D18302, doi:10.1029/2007JD009713
  - Wong, T., B. A. Wielicki, R. B. Lee III, G. L. Smith, K. A. Bush, and J. K. Willis, 2006: Reexamination of the observed decadal variability of the Earth radiation budget using altitude-corrected ERBE/ERBS Nonscanner WFOV data, *Journal of Climate*, 19, 4028-4040.
  - Zwally, H. J., J. C. Comiso, C. L. Parkinson, D. J. Cavalieri, and P. Gloersen, 2002: Variability of Antarctic sea ice 1979-1998, *Journal of Geophysical Research*, 107 (C5), 3041, doi: 10.1029/2029/2000JC000733.