Ocean Color Time Series Project
NASA REASoN CAN

Goal:

Provide consistent, seamless time series of Level-3 ocean color data from 1979, with a 9-year gap (1987-1996)

Emphasize consistent algorithms and calibration methodologies

Produce Climate/Earth Science Data Records (CDR/ESDR) of ocean color

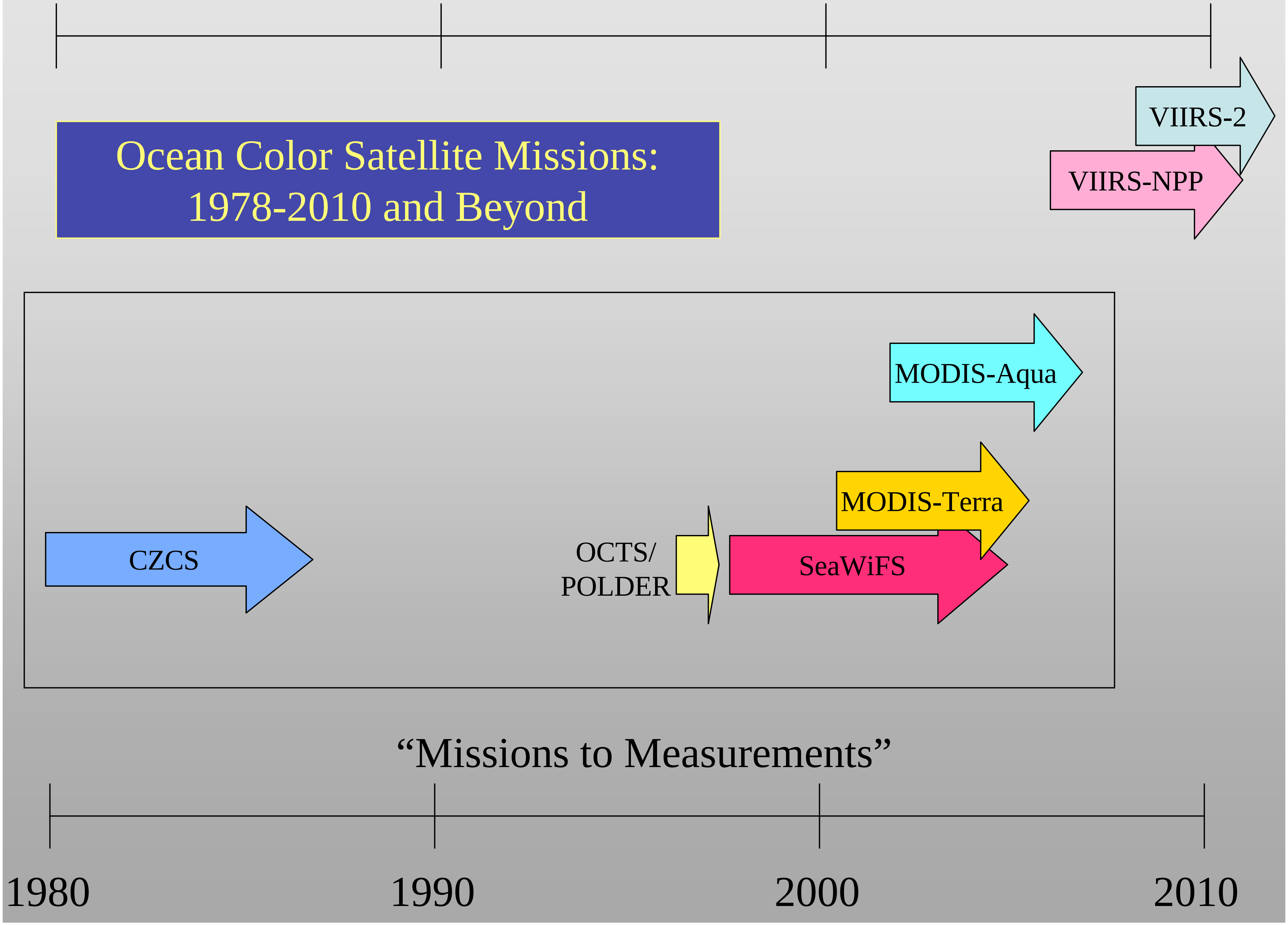
Make CDR’s available to the public

CDR: A time series of sufficient length, consistency, and continuity to determine climate variability and change
National Research Council, 2004

Technical Definition of Consistent/Seamless:

- all temporal sensor artifacts removed
- no obvious interannual discontinuities unattributable to natural variability
- all known mission-dependent biases removed or quantified
- similar data quality and structure

Ocean Color Satellite Missions: 1978-2010 and Beyond



VIIRS-2

VIIRS-NPP

MODIS-Aqua

MODIS-Terra

CZCS

OCTS/
POLDER

SeaWiFS

“Missions to Measurements”

1980
1990
2000
2010

Ocean Color Time Series

REASoN CAN Team:

Watson Gregg, NASA/Global Modeling and Assimilation: Oversight, Data Analysis

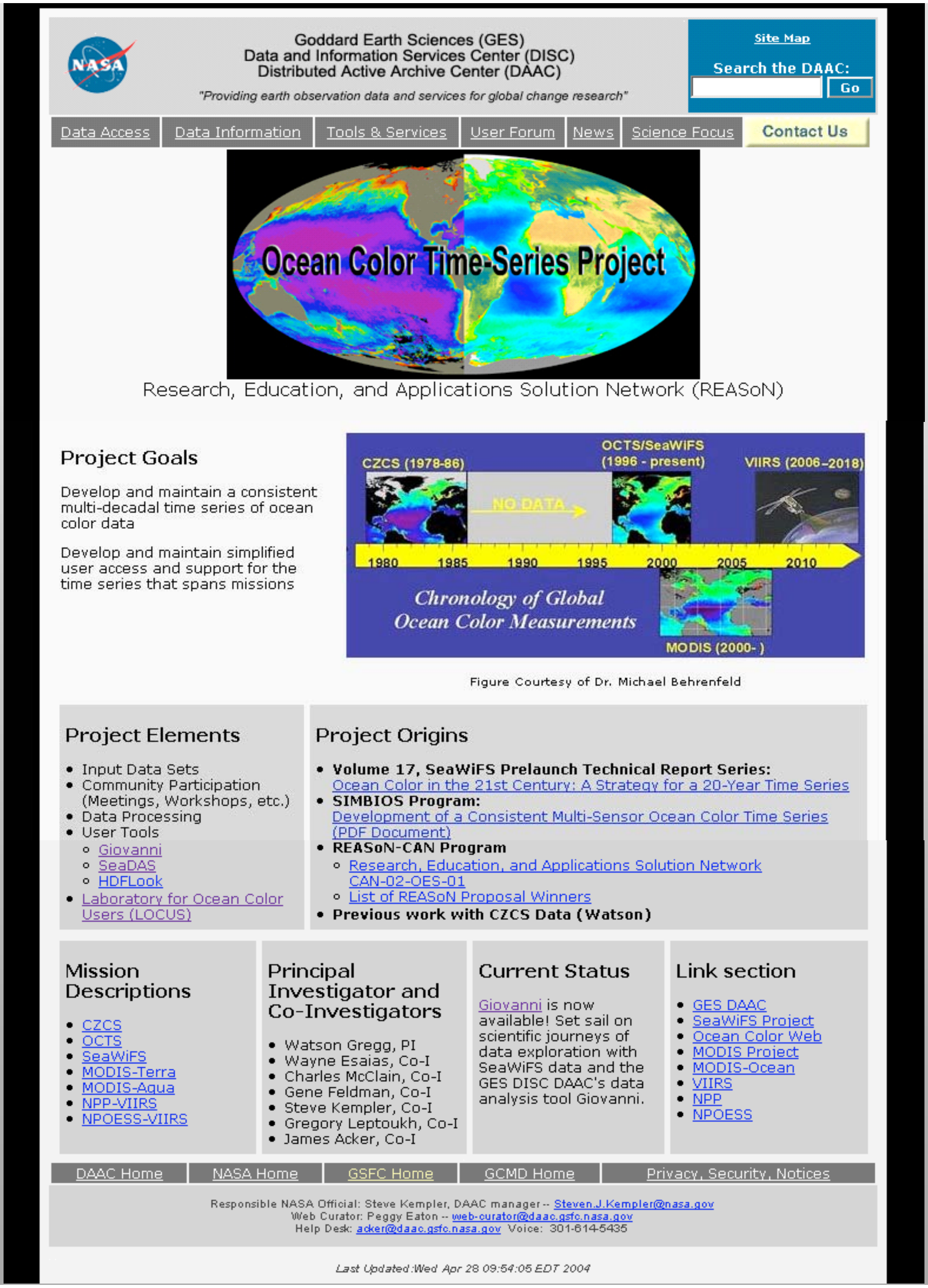
DAAC: Data Access and Visualization, Archival, Distribution
Jim Acker, NASA/GES-DAAC
Steve Kempler, NASA/GES-DAAC
Greg Leptoukh, NASA/GES-DAAC

OBPG: Data Processing, In Situ Data Collection, Coincident Data Merging
Gene Feldman, NASA/Ocean Color Processing
Chuck McClain, NASA/Ocean Color Processing

UCSB: Coincident Data Merging/ Data Technology
Jim Frew, Stephane Maritorena, David Siegel

Consistent Ocean Color Time Series Requires Similar

1) Calibration
2) Algorithms
3) Spatial and Temporal Resolution (Level-3)
4) Data Format
5) Access
6) Analysis Tools
7) Bias characterization



Goddard Earth Sciences (GES)
Data and Information Services Center (DISC)
Distributed Active Archive Center (DAAC)

"Providing earth observation data and services for global change research"

Research, Education, and Applications Solution Network (REASoN)

Project Goals

Develop and maintain a consistent multi-decadal time series of ocean color data

Develop and maintain simplified user access and support for the time series that spans missions

Figure Courtesy of Dr. Michael Behrenfeld

Project Elements

- Input Data Sets
- Community Participation (Meetings, Workshops, etc.)
- Data Processing
- User Tools
    - Giovanni
    - SeaDAS
    - HDFLook
- Laboratory for Ocean Color Users (LOCUS)

Project Origins

- **Volume 17, SeaWiFS Prelaunch Technical Report Series:** Ocean Color in the 21st Century: A Strategy for a 20-Year Time Series
- **SIMBIOS Program:** Development of a Consistent Multi-Sensor Ocean Color Time Series (PDF Document)
- **REASoN-CAN Program**
    - Research, Education, and Applications Solution Network CAN-02-OES-01
    - List of REASoN Proposal Winners
- **Previous work with CZCS Data (Watson)**

Mission Descriptions

- CZCS
- OCTS
- SeaWiFS
- MODIS-Terra
- MODIS-Aqua
- NPP-VIIRS
- NPOESS-VIIRS

Principal Investigator and Co-Investigators

- Watson Gregg, PI
- Wayne Esaias, Co-I
- Charles McClain, Co-I
- Gene Feldman, Co-I
- Steve Kempler, Co-I
- Gregory Leptoukh, Co-I
- James Acker, Co-I

Current Status

Giovanni is now available! Set sail on scientific journeys of data exploration with SeaWiFS data and the GES DISC DAAC's data analysis tool Giovanni.

Link section

- GES DAAC
- SeaWiFS Project
- Ocean Color Web
- MODIS Project
- MODIS-Ocean
- VIIRS
- NPP
- NPOESS

Responsible NASA Official: Steve Kempler, DAAC manager -- Steven.J.Kempler@nasa.gov
Web Curator: Peggy Eaton -- web-curator@daac.gsfc.nasa.gov
Help Desk: acker@daac.gsfc.nasa.gov Voice: 301-614-5435

Last Updated:Wed Apr 28 09:54:05 EDT 2004

SST: increased 0.2^{o}C in 20 years
= 1% change, or 0.05%/year
Estimated from Reynolds using AVHRR

SeaWiFS: Maximum difference over lifetime
(highest annual mean – lowest annual mean)
= 5%

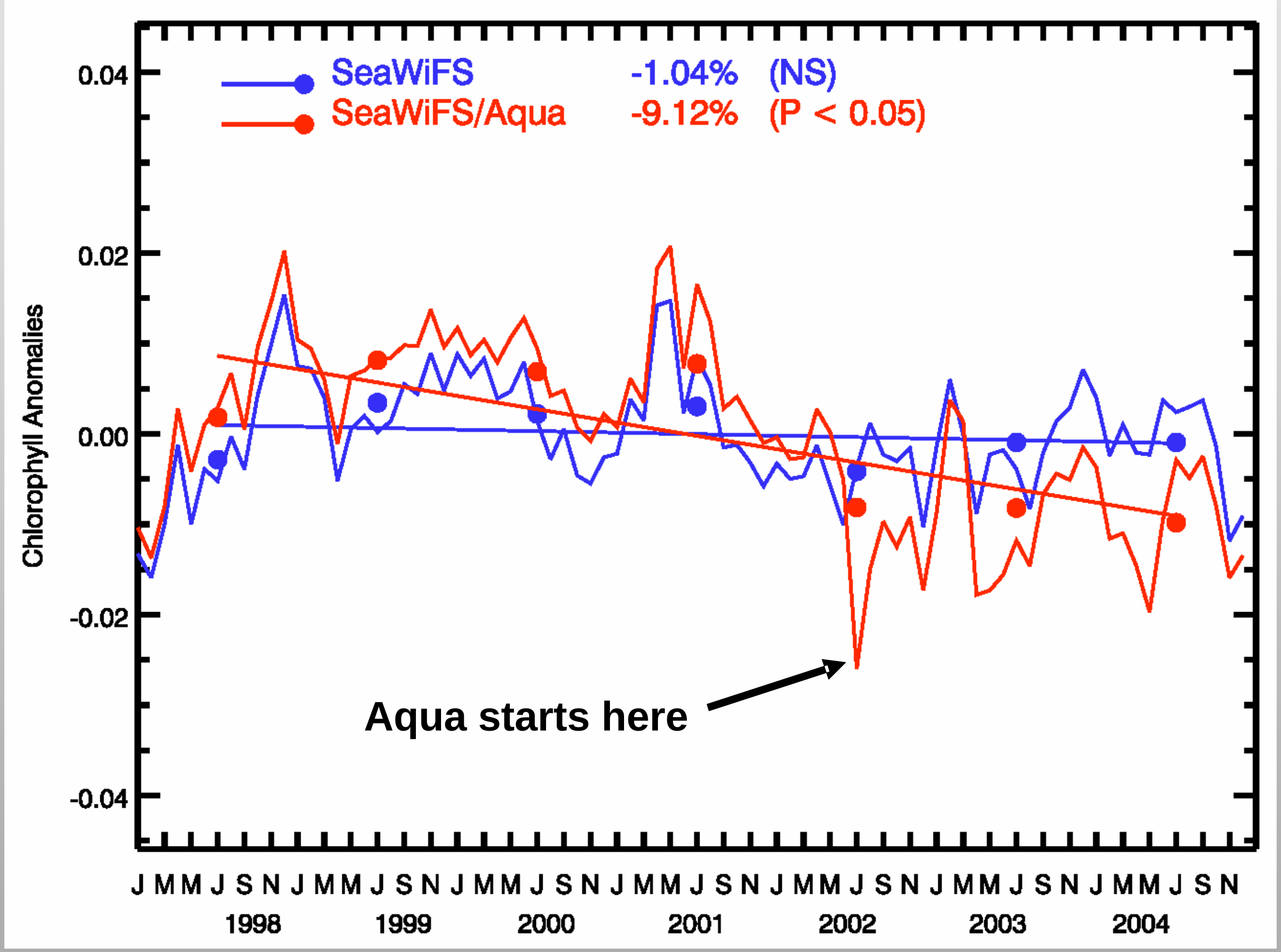
Surface Air Temperature:
increased 1^{o}C in 100 years
= 5% change, or 0.05%/year
Estimated from thermometers, tree rings,
ice boreholes

The REASoN Project has now completed data records for

OCTS (RV1)
SeaWiFS (V5.1)
MODIS-Aqua (V1.1)

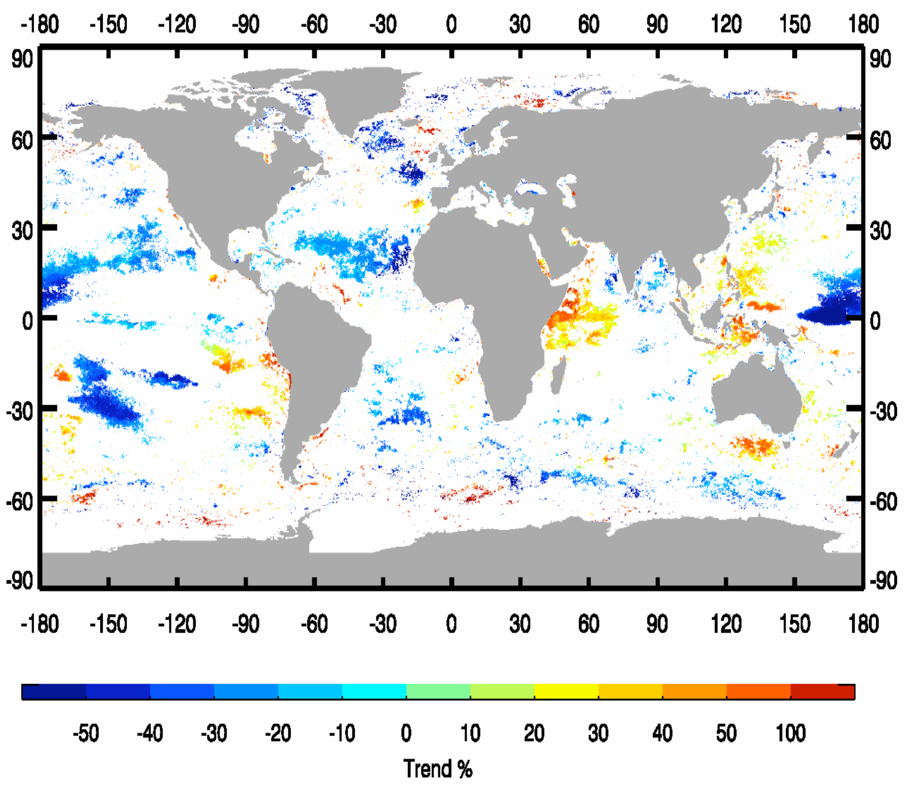
using consistent processing methodologies as defined

Global Annual Trends using SeaWiFS, and SeaWiFS/Aqua

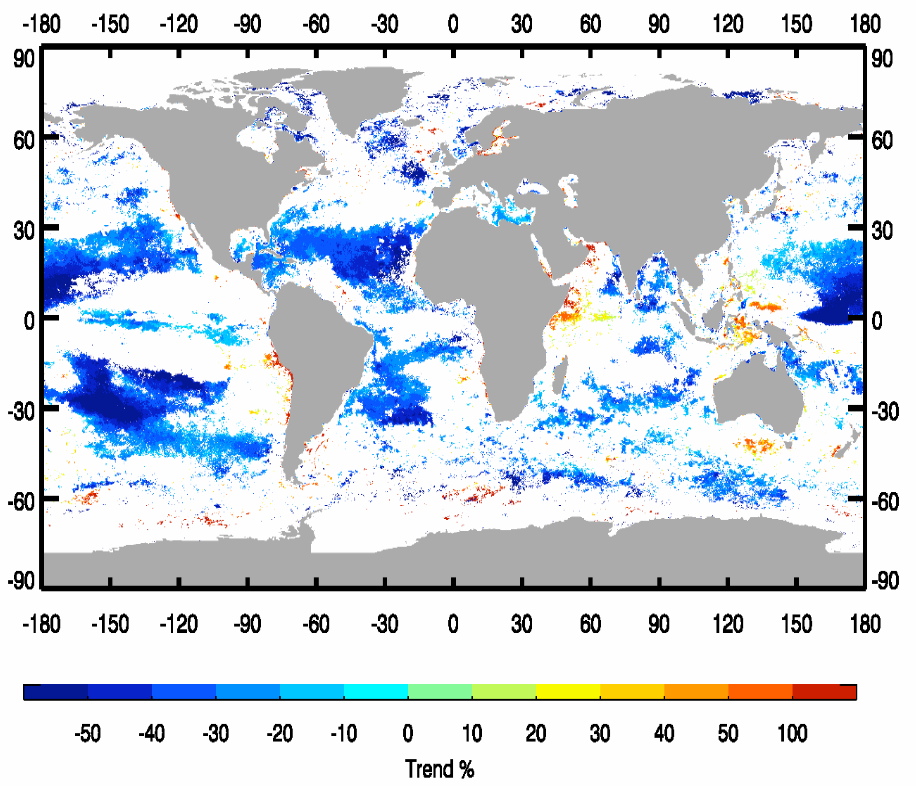


Regional Annual Trends

SeaWiFS

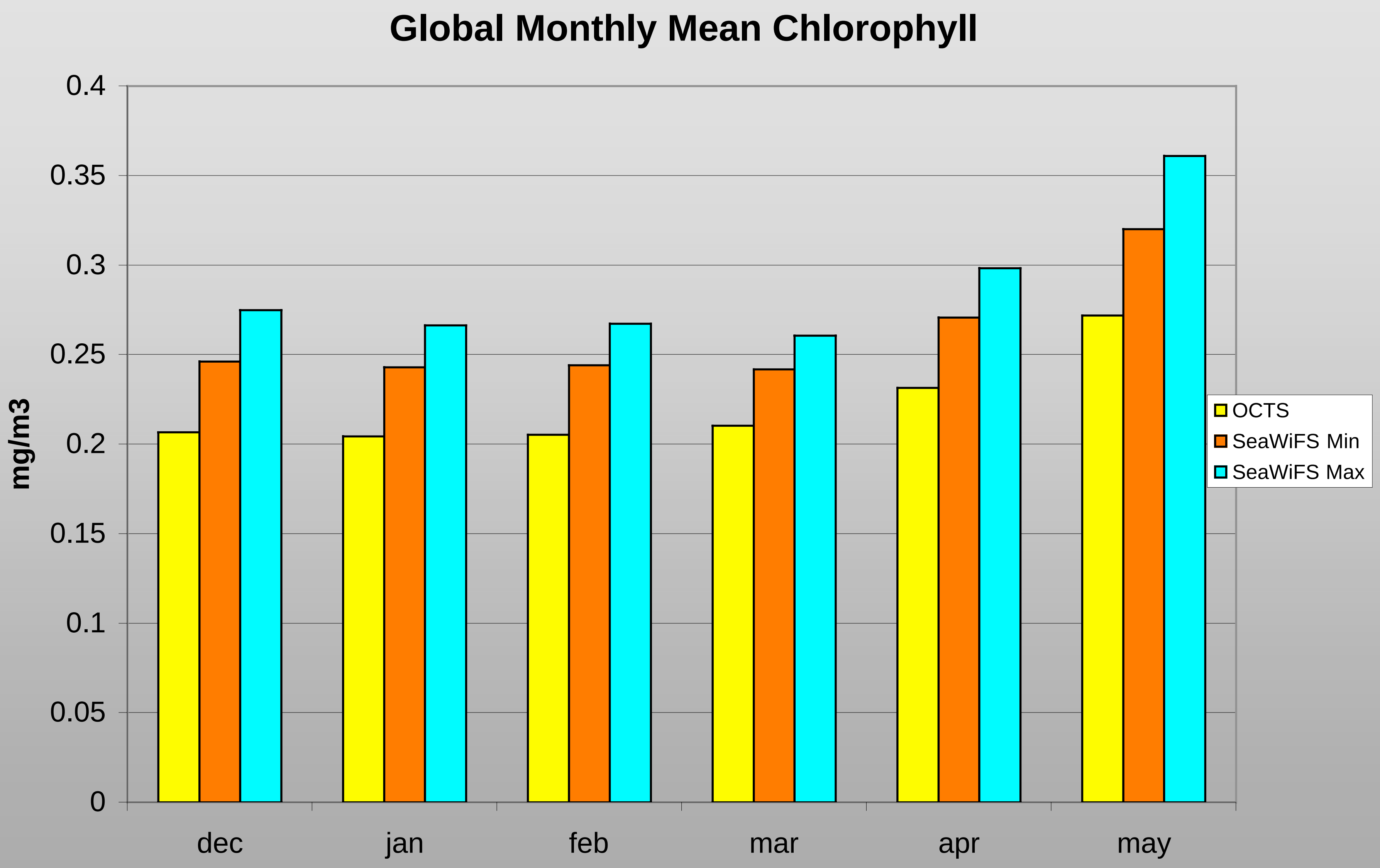


SeaWiFS/Aqua



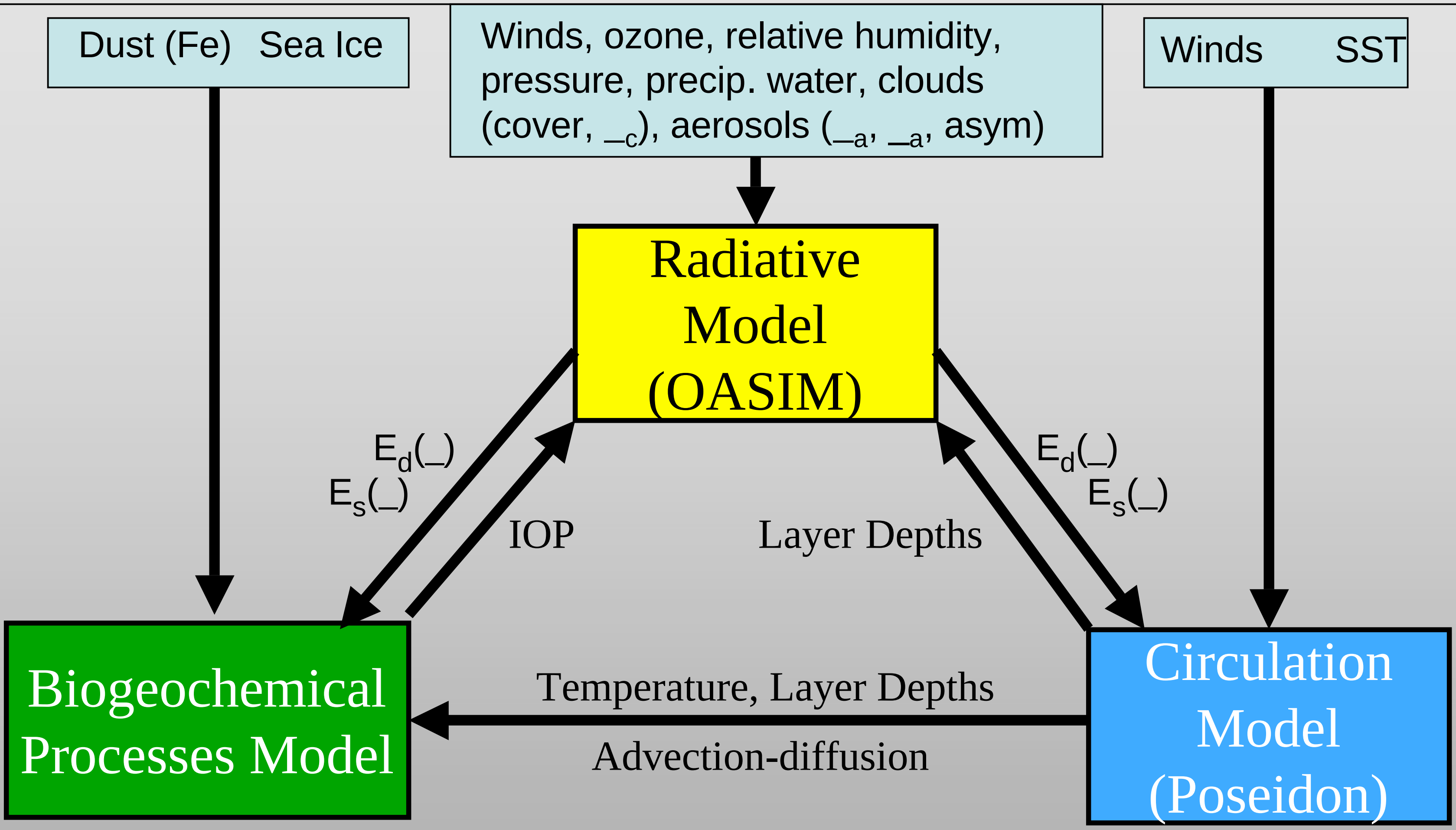
Linear trends using 7-year average/composite images were calculated, and when significant ($P < 0.05$), shown here.

OCTS



Nearly constant offset: about 15% ± 1.5%

NASA Ocean Biogeochemical Model (NOBM)



Dust (Fe) Sea Ice

Winds, ozone, relative humidity, pressure, precip. water, clouds (cover, _$_{c}$), aerosols (_$_{a}$, _$_{a}$, asym)

Winds SST

Radiative Model (OASIM)

E_d(_)
E_s(_)

IOP

Layer Depths

E_d(_)
E_s(_)

Biogeochemical Processes Model

Temperature, Layer Depths

Advection-diffusion

Circulation Model (Poseidon)

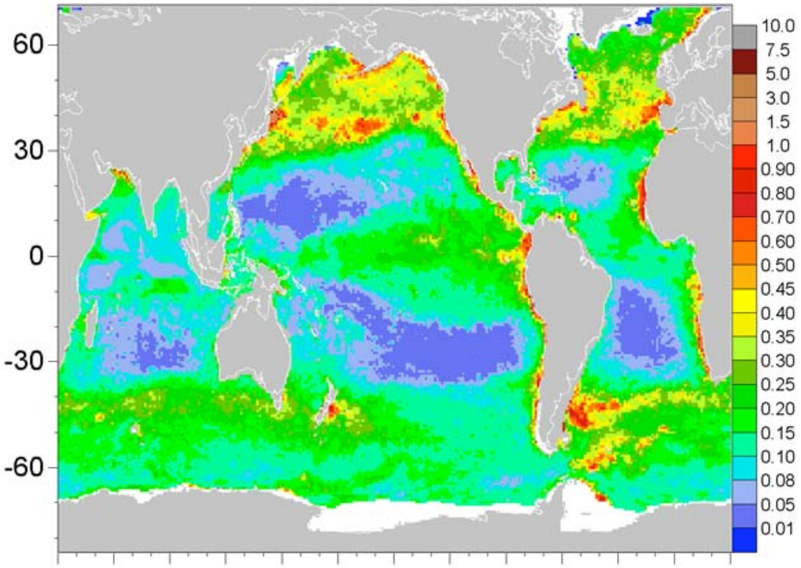
Outputs:

Chlorophyll, Phytoplankton Groups
Primary Production
Nutrients
DOC, DIC, pCO_2
Spectral Irradiance/Radiance

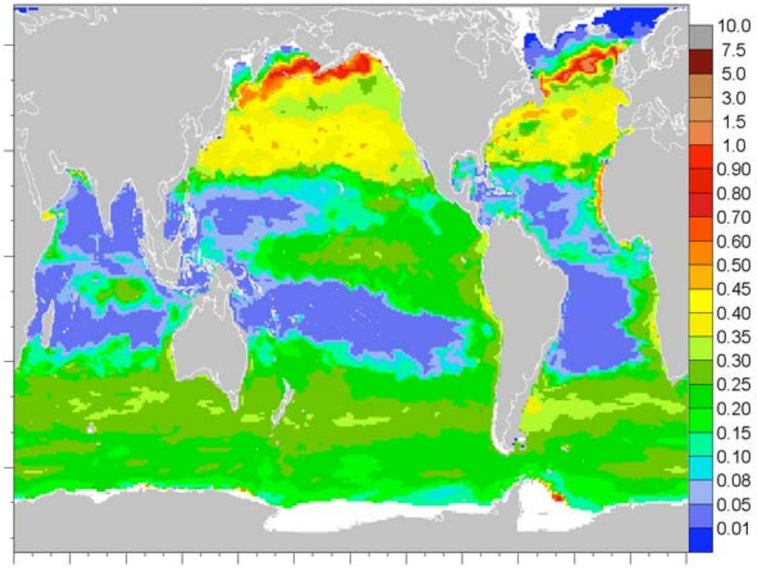
Global model grid:
domain: 84°S to 72°N
1.25° lon., 2/3° lat.
14 layers

Trends 1998-2004

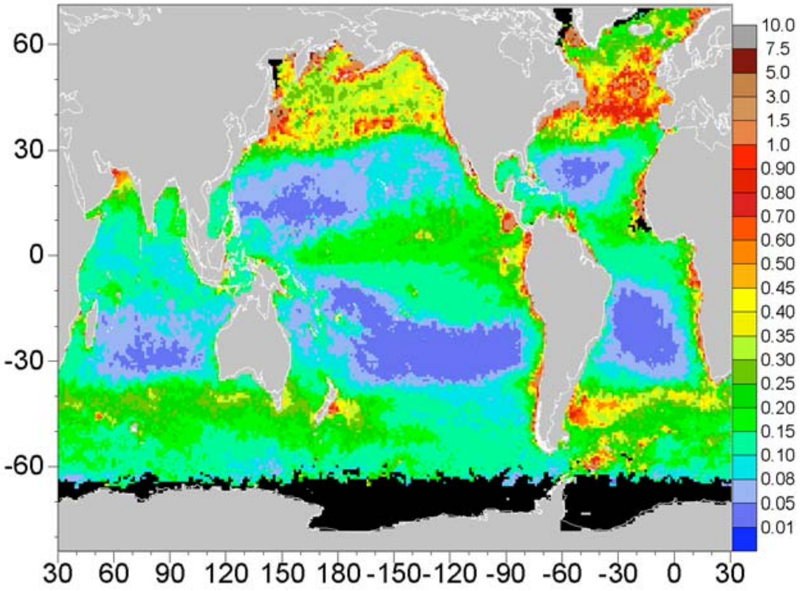
Data/Model	Linear Annual Trend
SeaWiFS	-0.71% ns
NOBM Free Run	0.18% ns
NOBM assimilation SeaWiFS	-0.98% ns



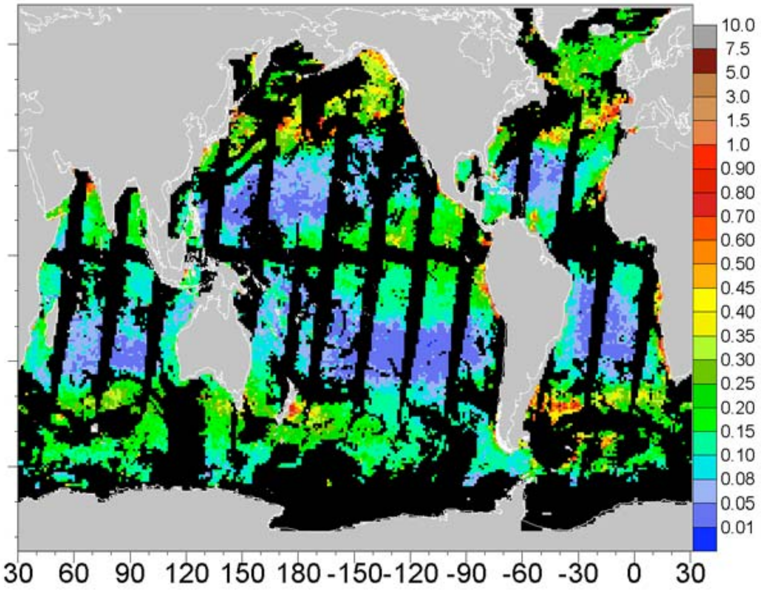
Assimilated Chlorophyll Apr 1 2001



Free Run Model Chlorophyll Apr 1 200



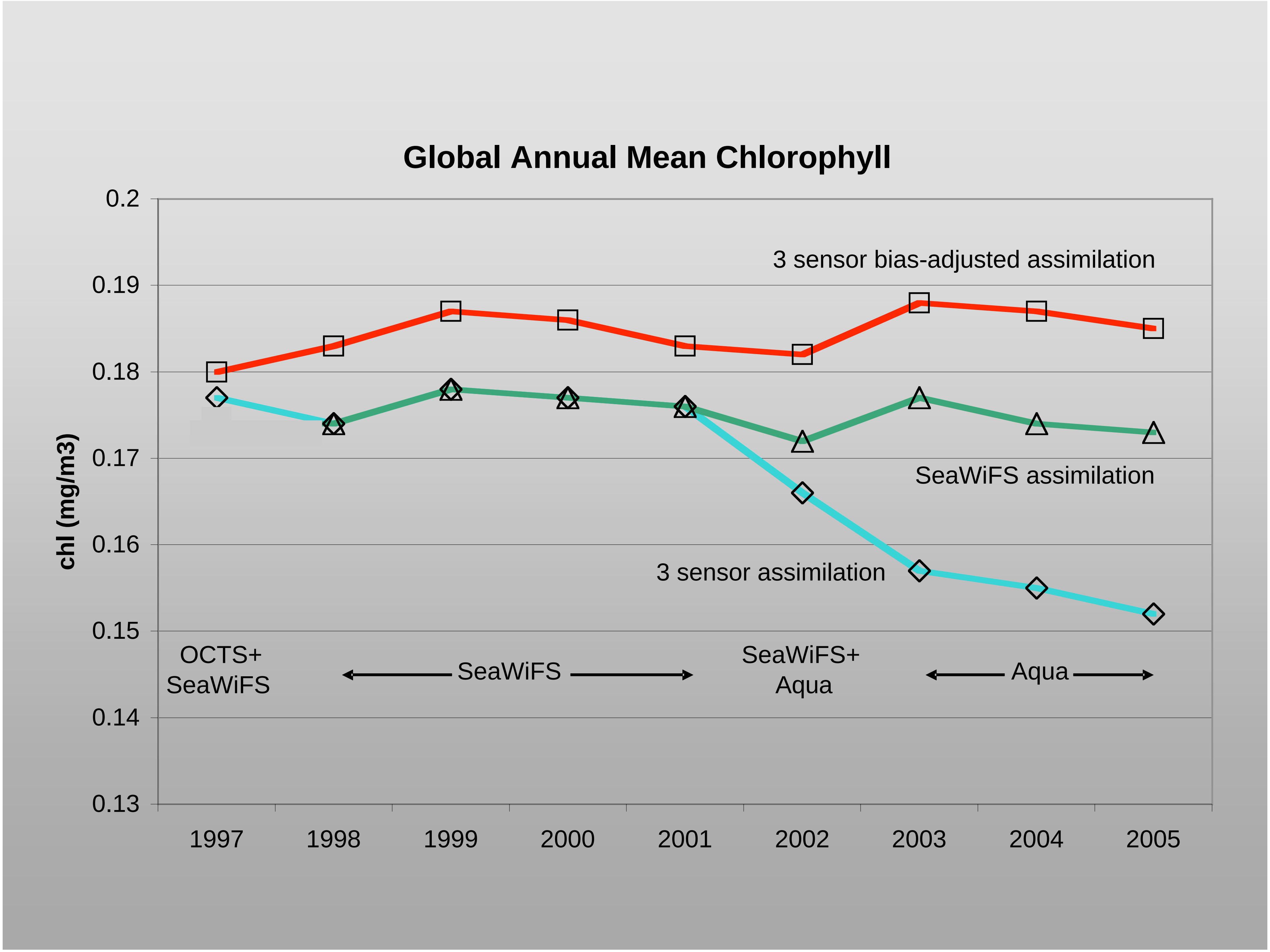
Monthly SeaWIFS Chlorophyll Apr 2001



Daily SeaWiFS Chlorophyll Apr 1 2001

Compared to In situ Data

	Bias	Uncertainty	N
SeaWiFS	-1.3%	32.7%	2086
Free-run Model	-1.4%	61.8%	4465
Assimilation Model	0.1%	33.4%	4465


Global Annual Mean Chlorophyll
chl (mg/m3)
0.2
0.19
0.18
0.17
0.16
0.15
0.14
0.13
1997
1998
1999
2000
2001
2002
2003
2004
2005
3 sensor bias-adjusted assimilation
SeaWiFS assimilation
3 sensor assimilation
OCTS+
SeaWiFS
SeaWiFS
SeaWiFS+
Aqua
Aqua

Advantages of Data Assimilation

- Achieves desired consistency, with low bias
- Responds properly to climatic influences
- Full daily coverage – no sampling error
- Effective use of data to keep model on track
- Only spatial variability required from sensors

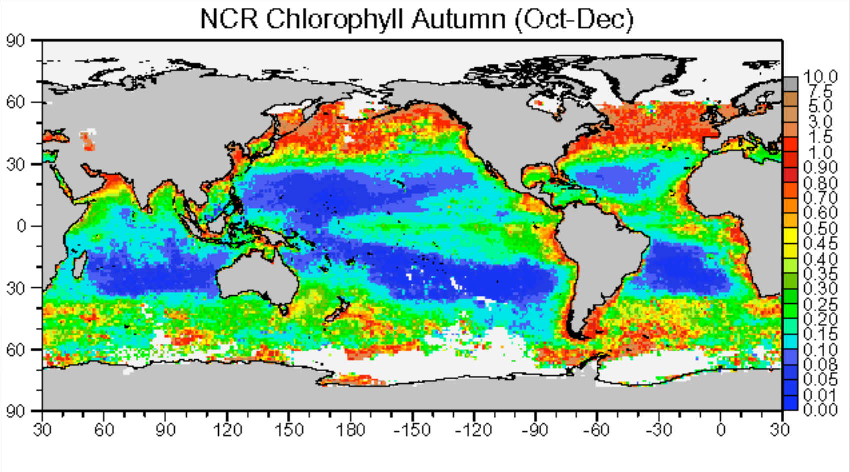
Disadvantages of Data Assimilation

- Low resolution (for now)
- No coasts (for now)
- Excessive reliance on model biases
- Cannot validate model trends with sensor data

Can the CZCS provide a Climate Data Record?

CDR: A time series of sufficient length, consistency, and continuity to determine climate variability and change
National Research Council, 2004

CZCS



The most ground breaking biological satellite in history

More than 1000 peer-reviewed publications

Major scientific advances

- Unprecedented view of spatial variability (gyres, coasts)
- Immenseness of the North Atlantic spring bloom
- Iron hypothesis
- Validation of first ocean biology models
- Importance of CDOM, aerosols, Case 1 and Case 2 waters
- Warm core rings, cold core rings
- Associations between tuna populations and fronts
- First data-driven estimates of global primary production
- First attempts at biological satellite data assimilation
- Established chlorophyll as a climate variable

CZCS Deficiencies

1) Low SNR

2) 5 bands, only 4 of which quantitatively useful
   -- limits aerosol detection capability

3) Navigation

4) Polarization

5) El Chichon

6) Anomalous behavior post-1981

7) Sampling

Ocean Color Missions: Bands

	CZCS	OCTS	SeaWiFS	Terra	Aqua	VIIRS
410 nm		410	412	411	411	412
443 nm	443	443	443	442	442	445
490 nm		490	490	488	488	488
510 nm	520	520	510	531	531	
555 nm	550	565	555	551	551	555
670 nm	670	670	670	667	667	672
765 nm		765	765	746	746	746
865 nm		865	865	846	846	865

CZCS Aerosol Workarounds

Evans and Gordon, 1994, JGR

Fixed aerosol type (epsilon)

Advantages: simple to implement
led to data access, major advances in knowledge
Disadvantages: all variability assumed to be oceanic in origin
single scattering aerosols
underestimates of chlorophyll

Gregg et al., 2002 Applied Optics

Characterize aerosols in clear water, extrapolate using statistical 2-D methods (objective analysis), access SeaWiFS multiple scattering tables

Advantages: coincident
variability partitioned among aerosols and ocean
preserves knowledge derived from actual data
2-D objective extrapolation
multiple scattering aerosols
clear water represents approx. 90% of oceans
Disadvantages: extrapolation is statistical
requires aerosol fronts and chlorophyll fronts are uncorrelated

Antoine et al., 2005, JGR

Iterate between pre-defined optical representation in the ocean (Morel ocean) and atmosphere (Angstrom atmosphere) to obtain numerical convergence

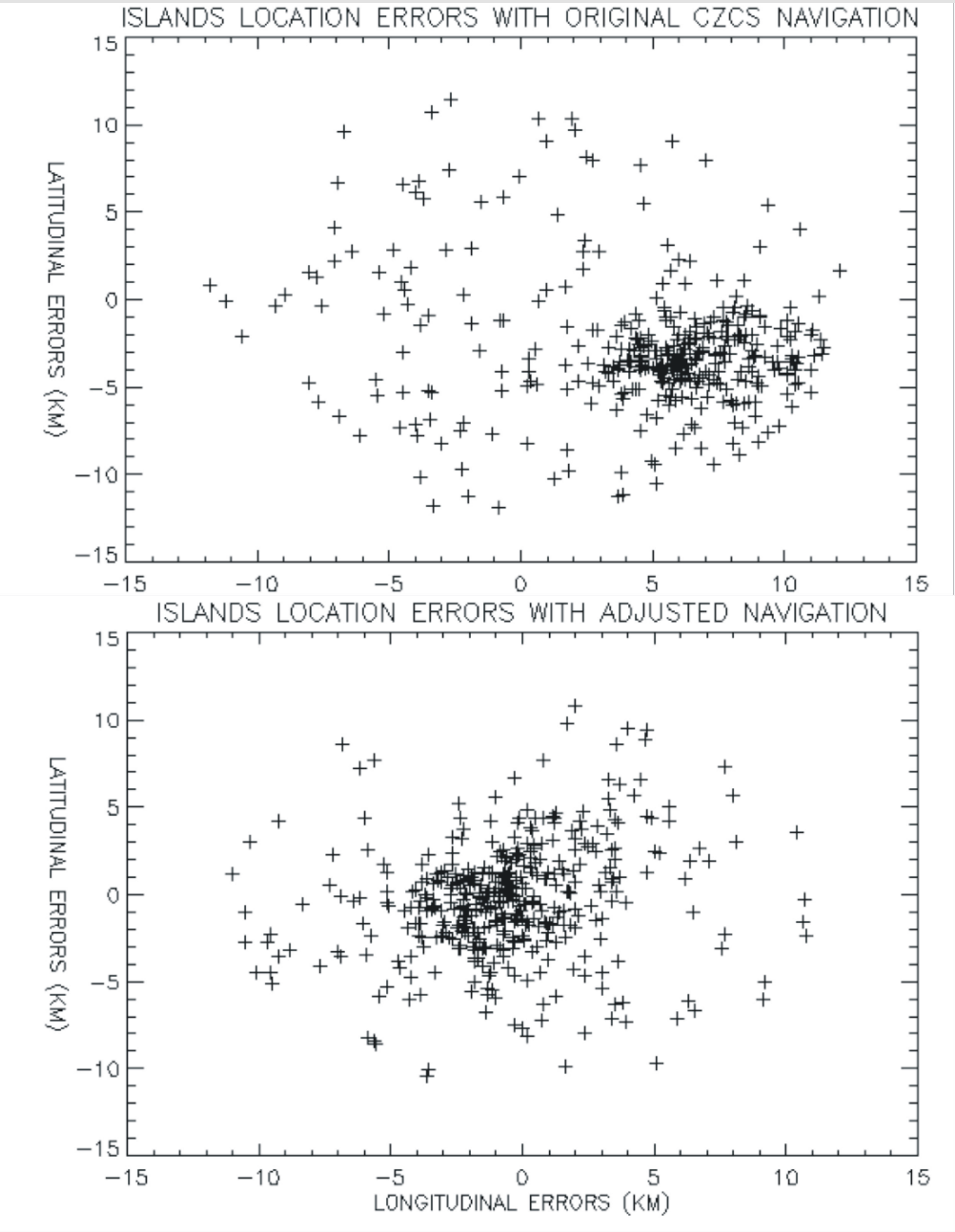
Advantages: coincident
preserves knowledge derived from actual data
variability partitioned among aerosols and ocean
Disadvantages: single scattering aerosols
only works in optically well-behaved areas

REASoN V2, Sep. 2006

Fixed aerosol model (maritime 99% humidity), CZCS-derived multiple scattering tables

Advantages: simple to implement
multiple scattering aerosols
Disadvantages: all variability assumed to be oceanic in origin

CZCS
Navigation



1989 data set

Gregg et al.,
2002

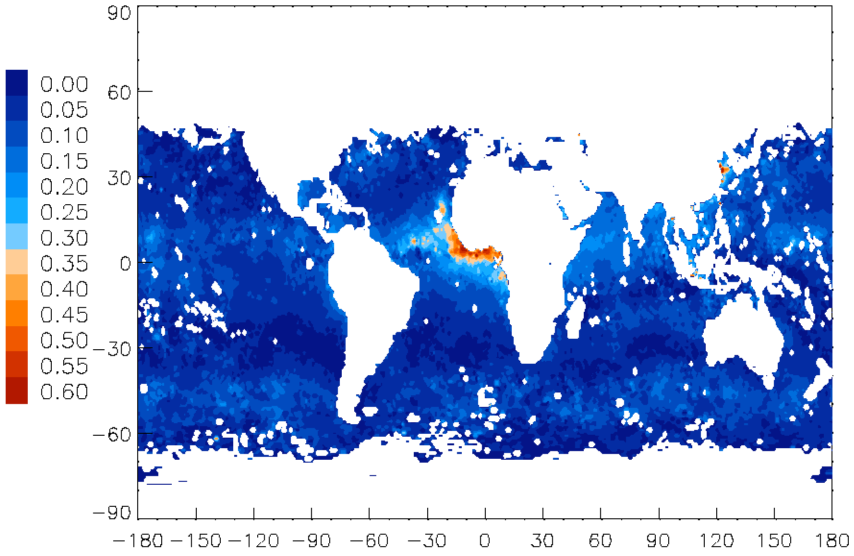
CZCS Polarization

Exists, and is tilt-dependent

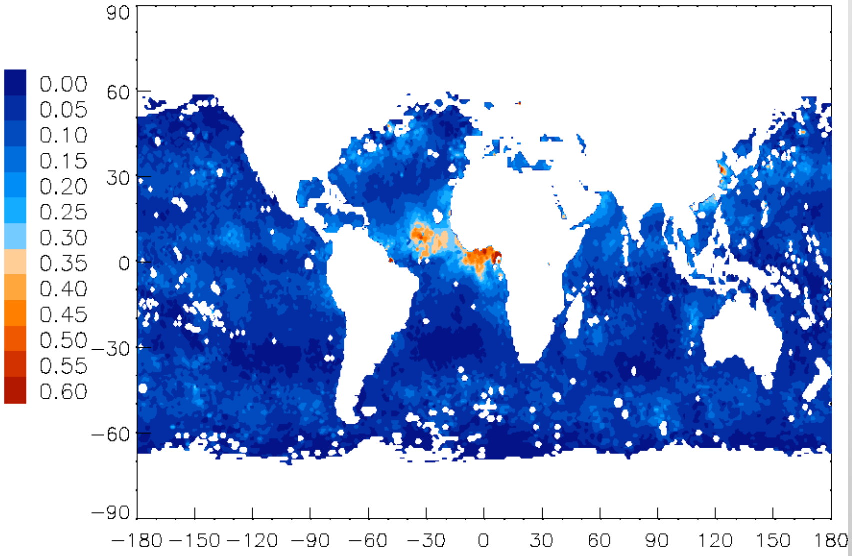
Gordon: band-to-band polarization is removed through in situ calibration
residual tilt-dependent polarization is maximum <1 digital count

El Chichon

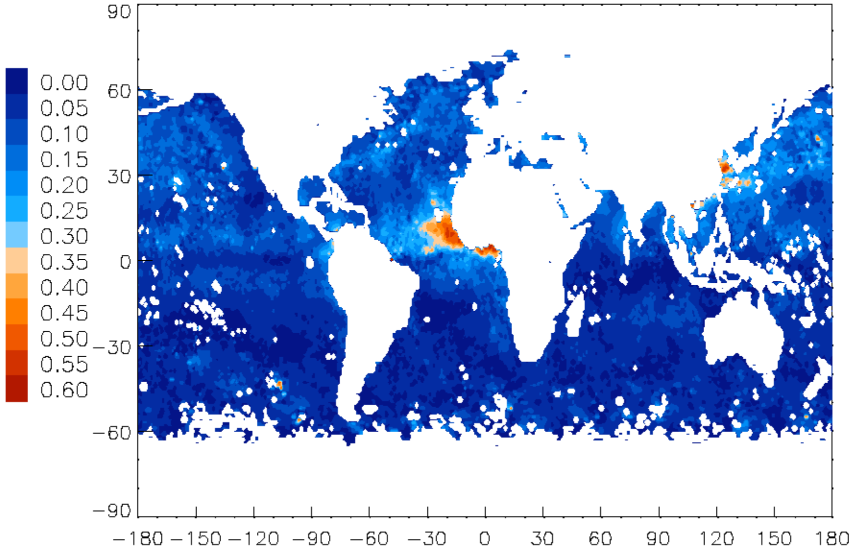
Massive volcanic eruptions, late March 1982, early April 1982 (2)



PATMOS AOT 1982 01



PATMOS AOT 1982 02



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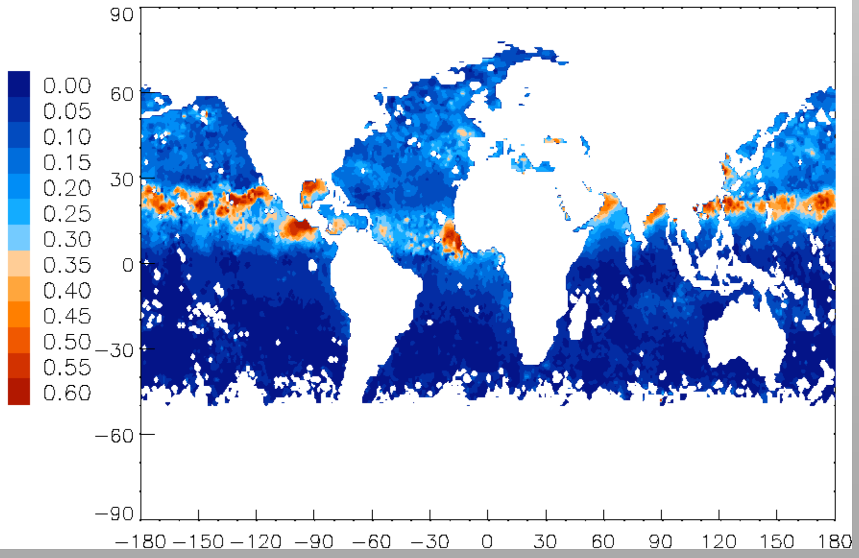

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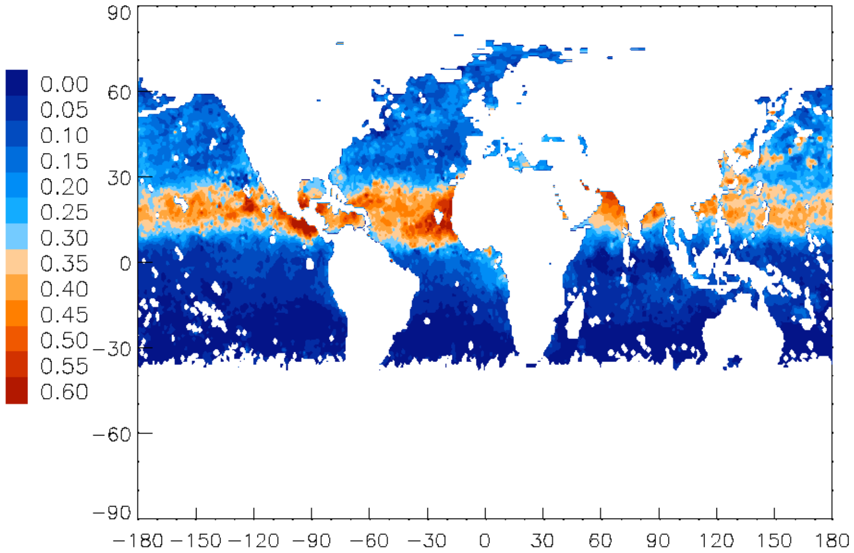
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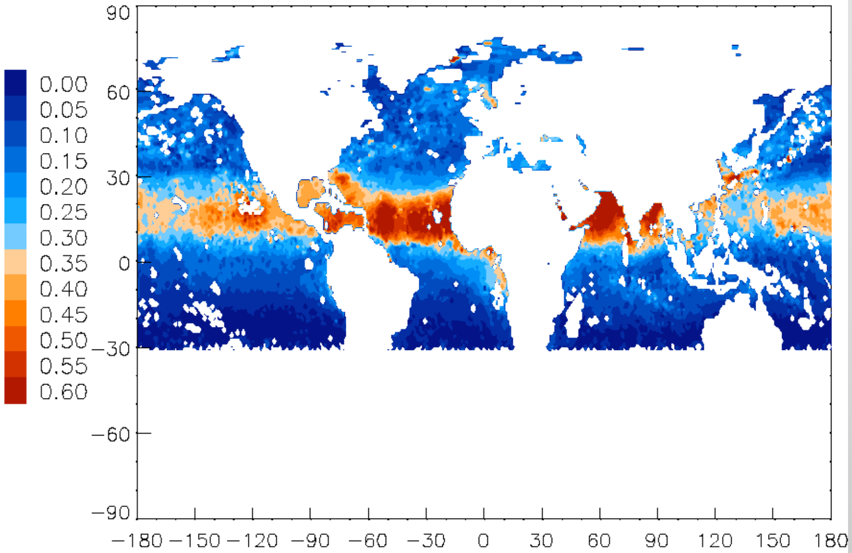
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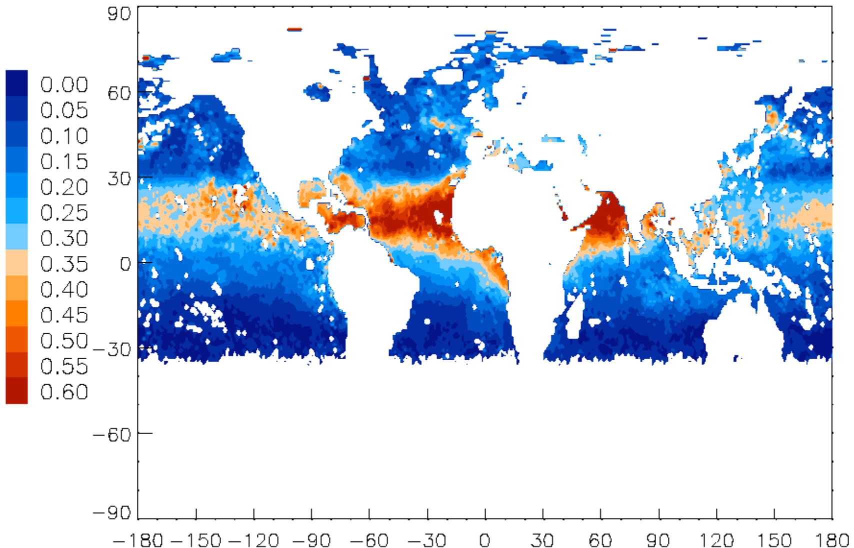
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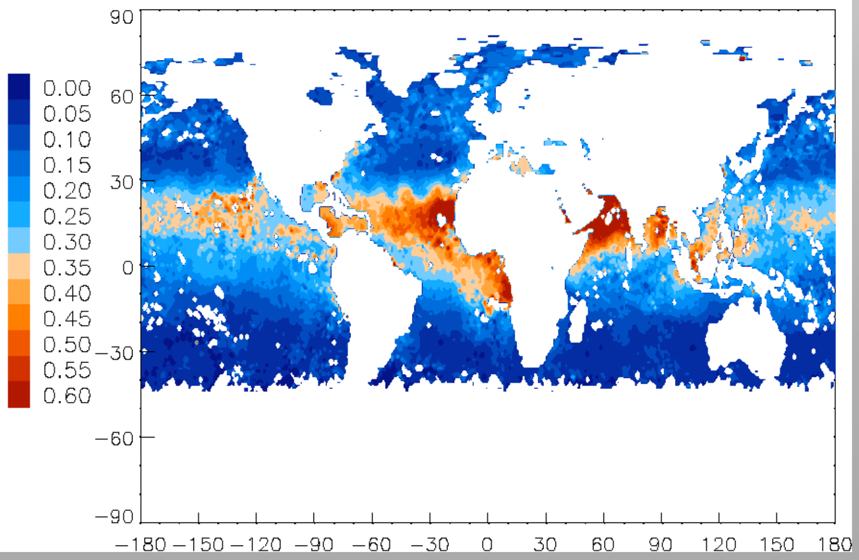
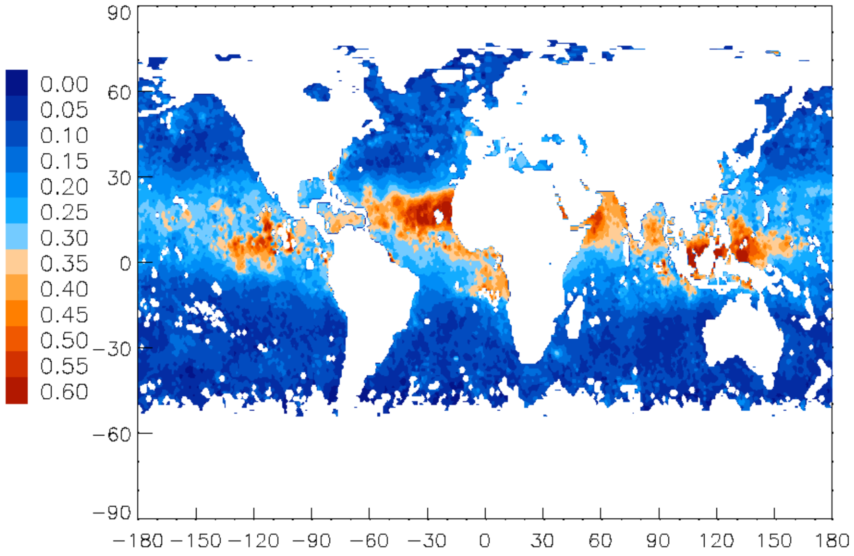

PATMOS AOT 1982 08

PATMOS AOT 1982 09



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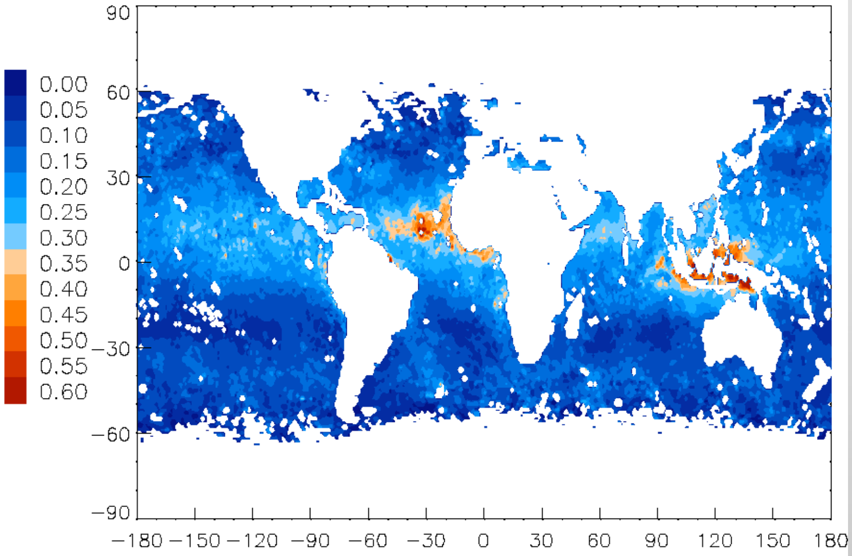
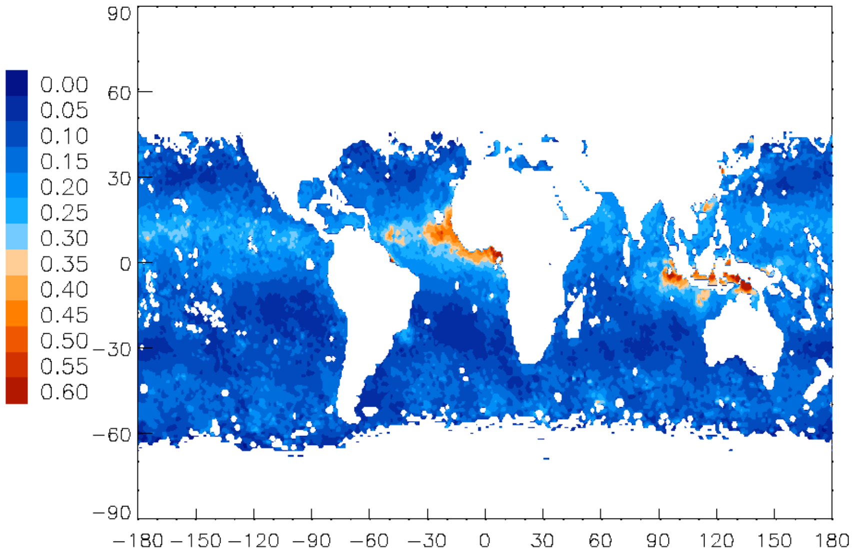
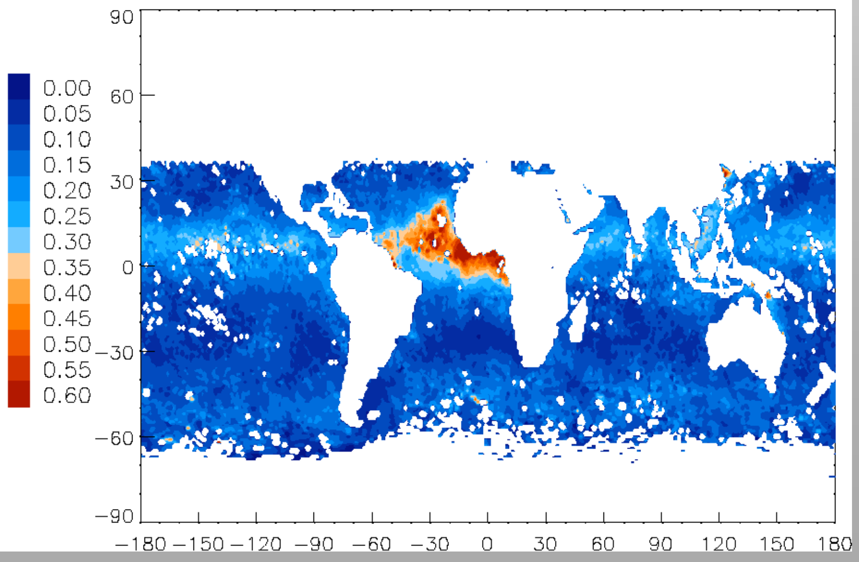


PATMOS AOT 1982 11

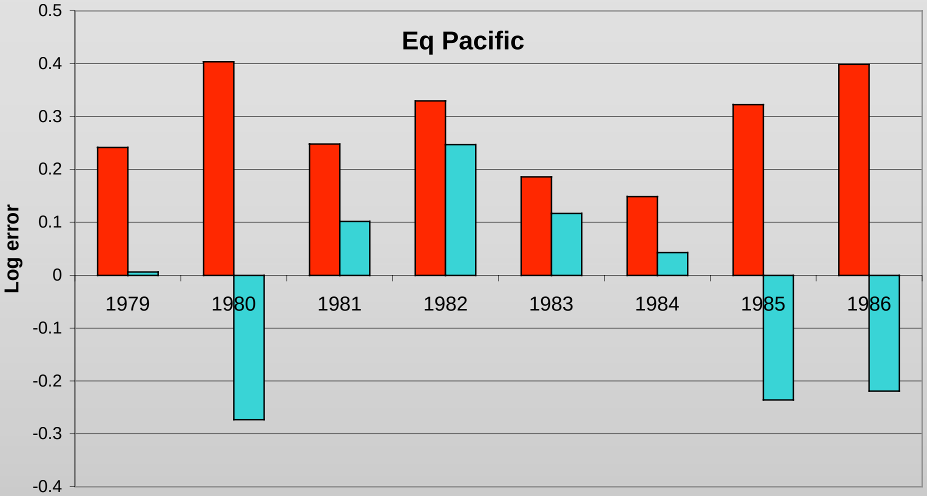


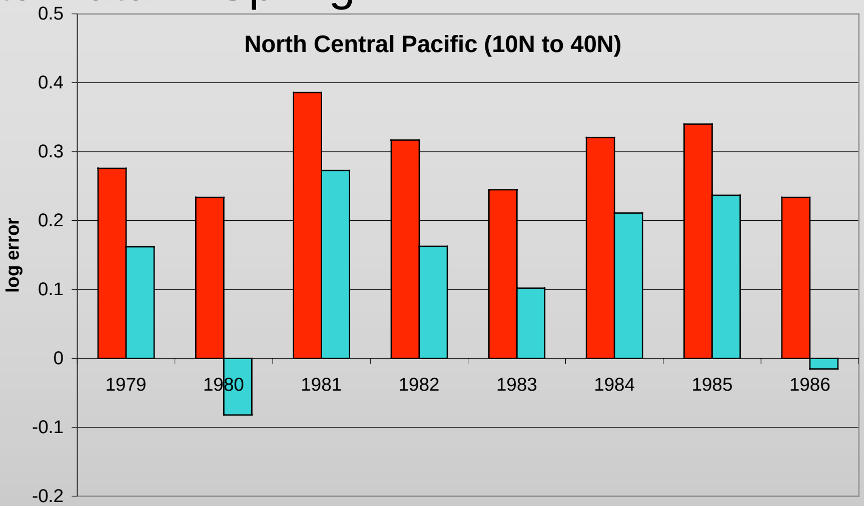
PATMOS AOT 1982 12

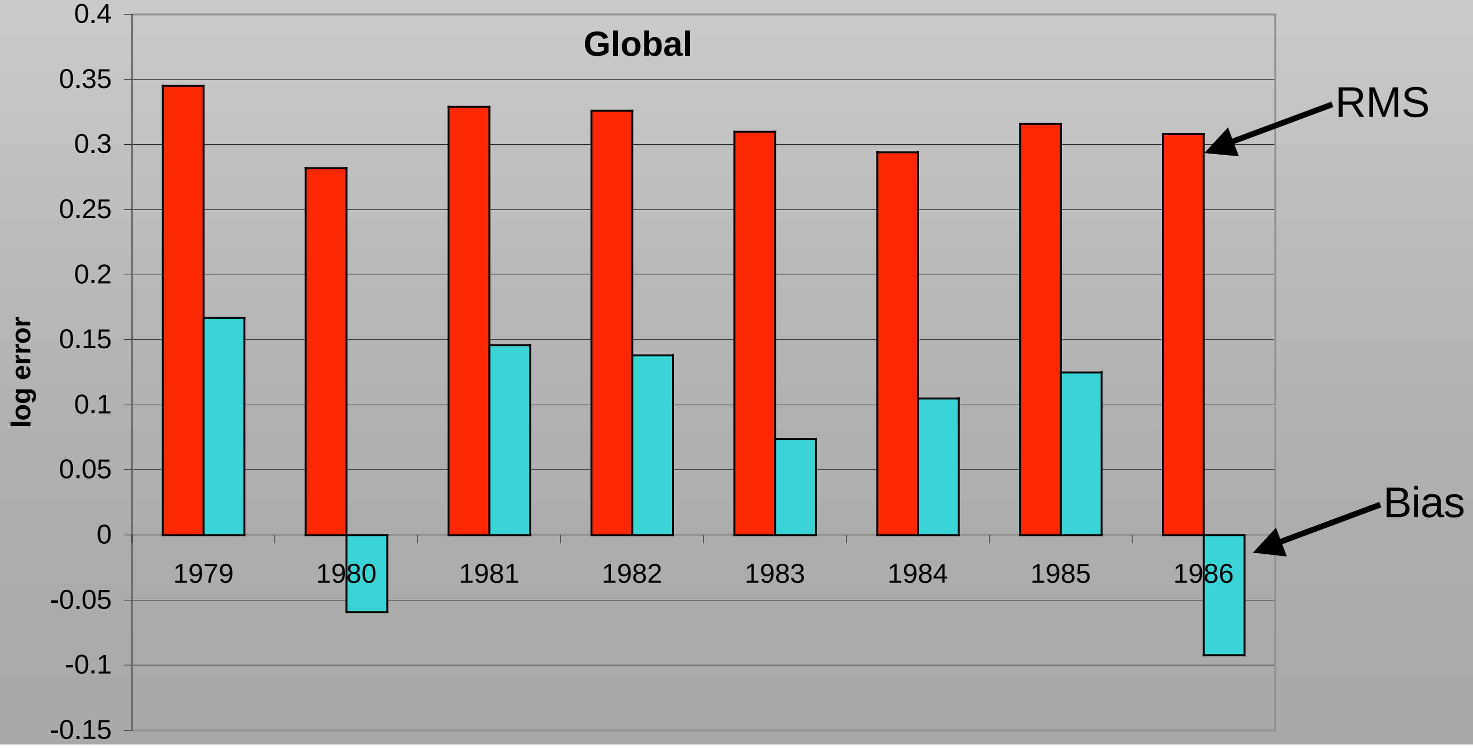


Gordon and Castano 1988: up to tau = 0.4, effect = 1-2 digital counts at $L_a(443)$

Comparisons with In situ Data in Spring


Eq Pacific

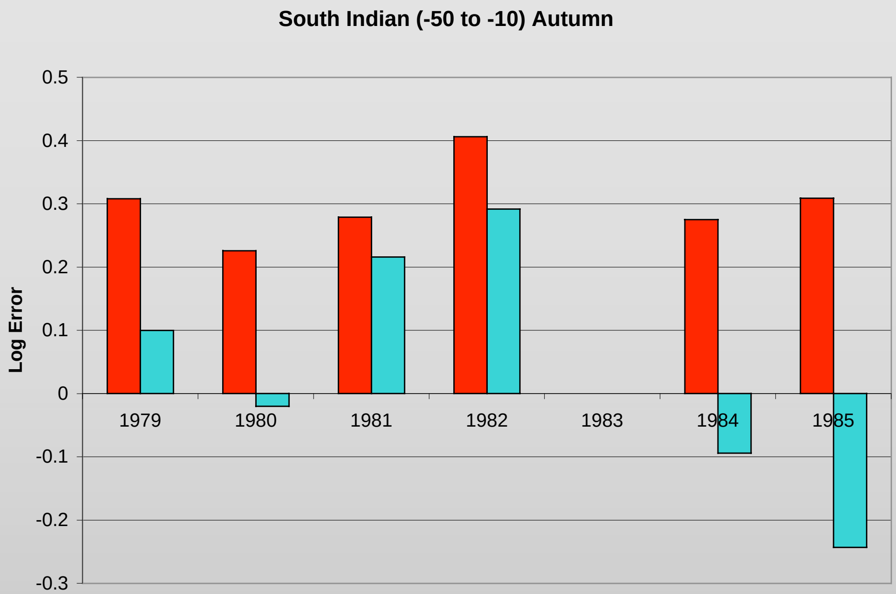

North Central Pacific (10N to 40N)


Global

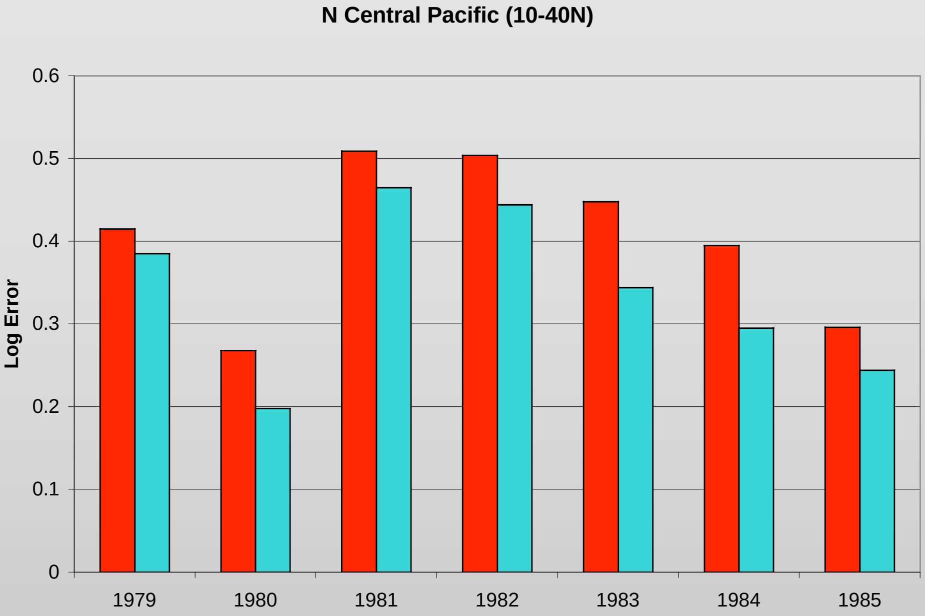
All missions have “events”

SeaWiFS:

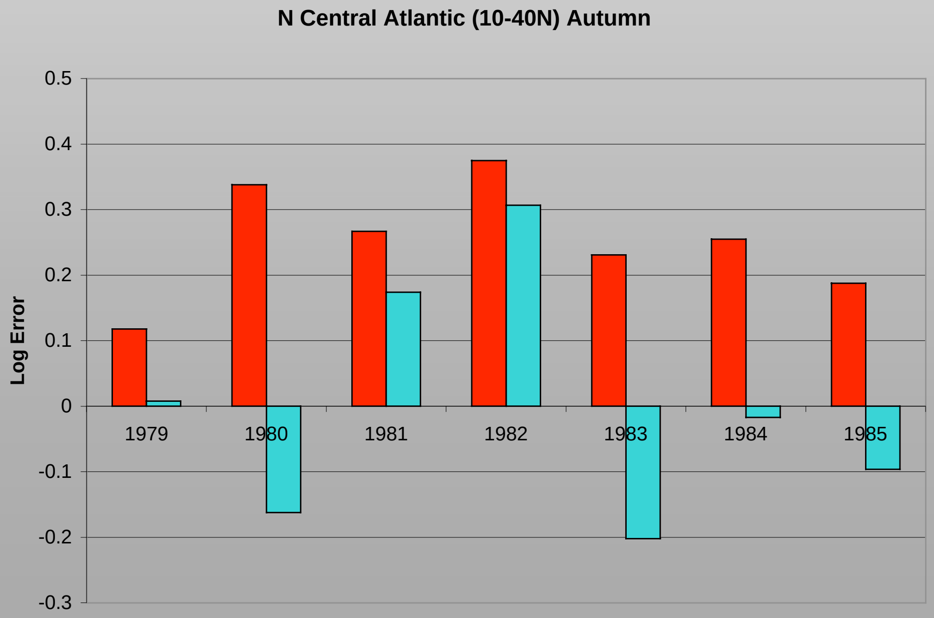
- 3 El Ninos (1997-1998; 2002-2003; now)
- 1 major 2.5-year La Nina (1998-2000)
- 26 named tropical storms/hurricanes 2005
  - (overall increased frequency and intensity of hurricanes)
- Canadian wildfires 2002
- Indonesian wildfire 1997
- Largest fires in history in Alaska 2004
- Biomass burning in Africa and South America
- Asian Brown Cloud
- Great Saharan Dust Storm 2004, 2006



South Indian (-50 to -10) Autumn



N Central Pacific (10-40N)



N Central Atlantic (10-40N) Autumn

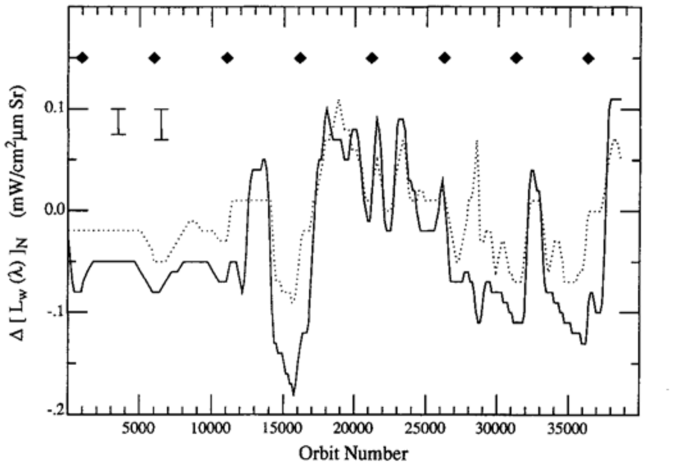
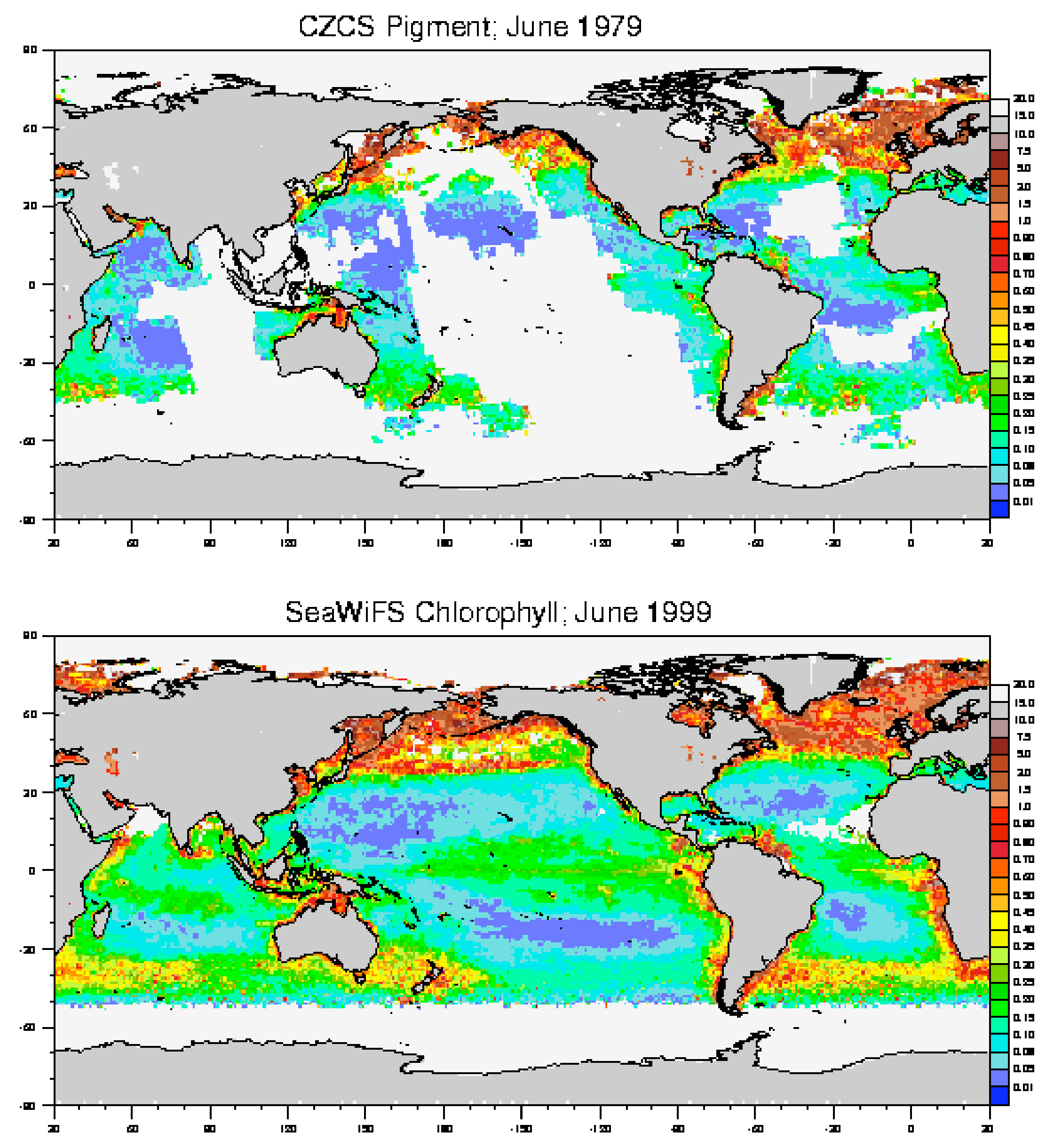


Figure 4. Calibration variation in the bands at 520 nm (solid curve) and 550 nm (dotted curve). The solid diamonds correspond to the beginning of each calendar year, starting with 1979. The two error bars at the upper left are the radiances corresponding to 1 digital count of the CZCS (shorter bar is for 550 nm).

CZCS Sampling


CZCS Pigment; June 1979

SeaWiFS Chlorophyll; June 1999

Time Series Issues

1) How calibrate historical and future sensors, maintaining consistency?

2) Is BRDF a good idea?

3) Can we define more rigorous metrics than in situ comparisons, that constrain global mean estimates?

4) Is it acceptable to have two data streams:
    - operational (best available methods; mission-dependent)
    - climate (maximum commonality/consistency of methods)?

5) How much consistency can we achieve without resorting to post-processing methods (blending of in situ data, assimilation)?

    Is this necessary?