Ocean Observations

Online textbook at

http://www-pord.ucsd.edu/~ltalley/sio210/pickard_emery/chapter_6.pdf

A story told by Senya Grodsky/UMCP

Retrospective story

“From wooden bucket to modern satellite sensors”

Why we care about data taken by obsolete methods?

All data are to be used in order to construct the longest possible records of the ocean climate.

In-situ observations

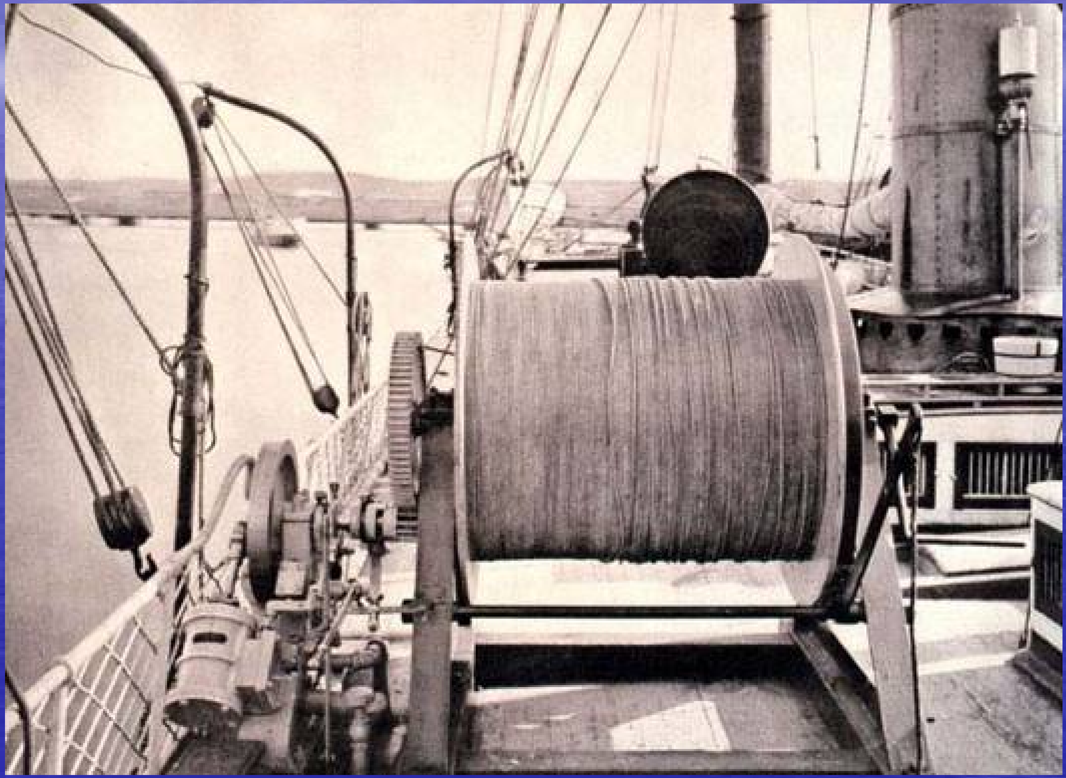
Remote Sensing

In-situ observations	Remote Sensing
High precision	Retrieve variables from E/M fields
Vertical resolution	N/A
All ocean variables	Only surface variables
Limited coverage	Global coverage

In situ observations

- Temperature and salinity
- Velocity

Blake



Steel wire cable for dredging and anchoring. (from Blake, NOAA Photo Library)
http://oceanexplorer.noaa.gov/history/breakthru/media/13_steeldredge.html

Early days of observational oceanography

Early days tools for measuring SST

(a) Traditional wooden bucket used to collect surface samples. (b) Special bucket samplers for sea surface temperature measurements. On the right is a canvas bucket and the two on the left are metal containers (Folland et al, 2000).

Temperature of water samples on board can differ from in-situ temperature, due to sun heating, evaporation, etc.

→ In-situ temperature measurements

Early da…

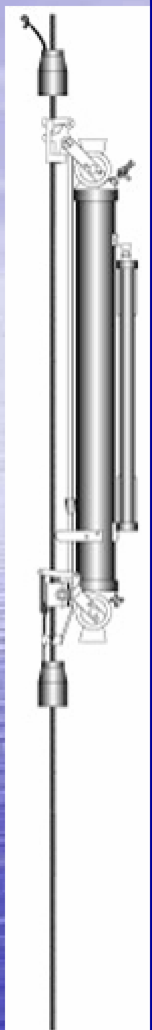
The reversing thermometer measurements need performing a buoy station to deploy the chain that is time consuming.

Thermometer depth is calculated given the rope deviation from the vertical. This is subject to errors at strong drift and in the presence of vertically sheared currents.

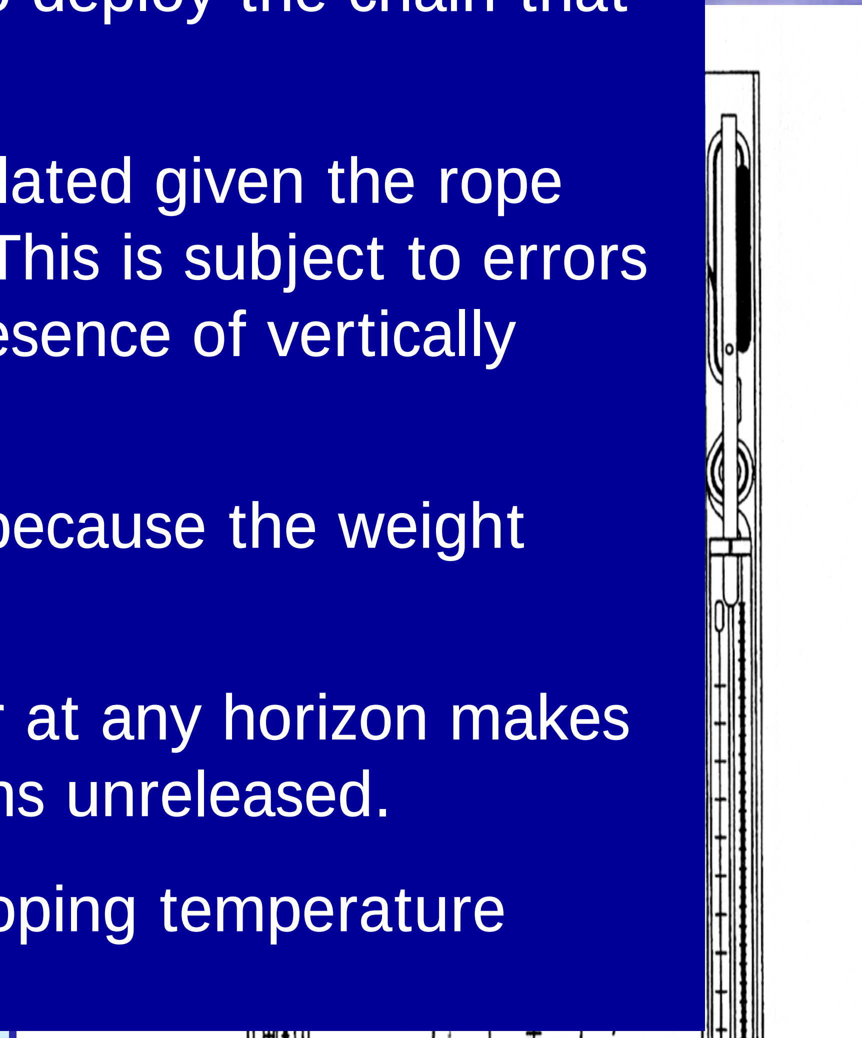
Vertical sampling is limited because the weight needs space to accelerate.

Failure of a reversing sensor at any horizon makes all sensors at deeper horizons unreleased.

Oceanographers start developing temperature profiling instruments.



Nansen water bottles before (I), during (II), and after (III) reversing. (From Dietrich et al. 1980)



Water sampling bottles (Nansen Bottles) for mounting individually on a wire with reversing thermometer racks.

Temperature measurements

- MBT
- XBT
- CTD
- PALACE floats (evolving into ARGO)
- Moored buoys

Number of grid points on a 2x2 deg grid filled with data. Data ... verage

... mes from

MBT- Mechanical Bathythermograph

XBT- Expandable Bathythermograph

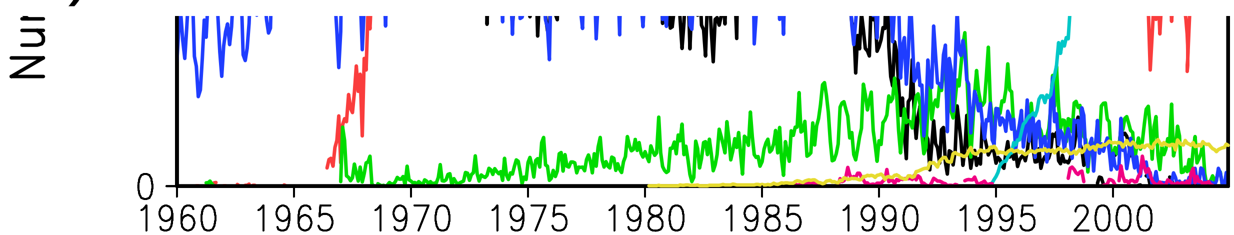
CTD- Conductivity, Temperature, Depth

OSD- Ocean Station Data (Bravo in the Labrador Sea, Bermuda, Hawaii, etc)

PFL- Profiling Floats (RAFOS evolving in ARGO)

DRB- Drifting Buoys

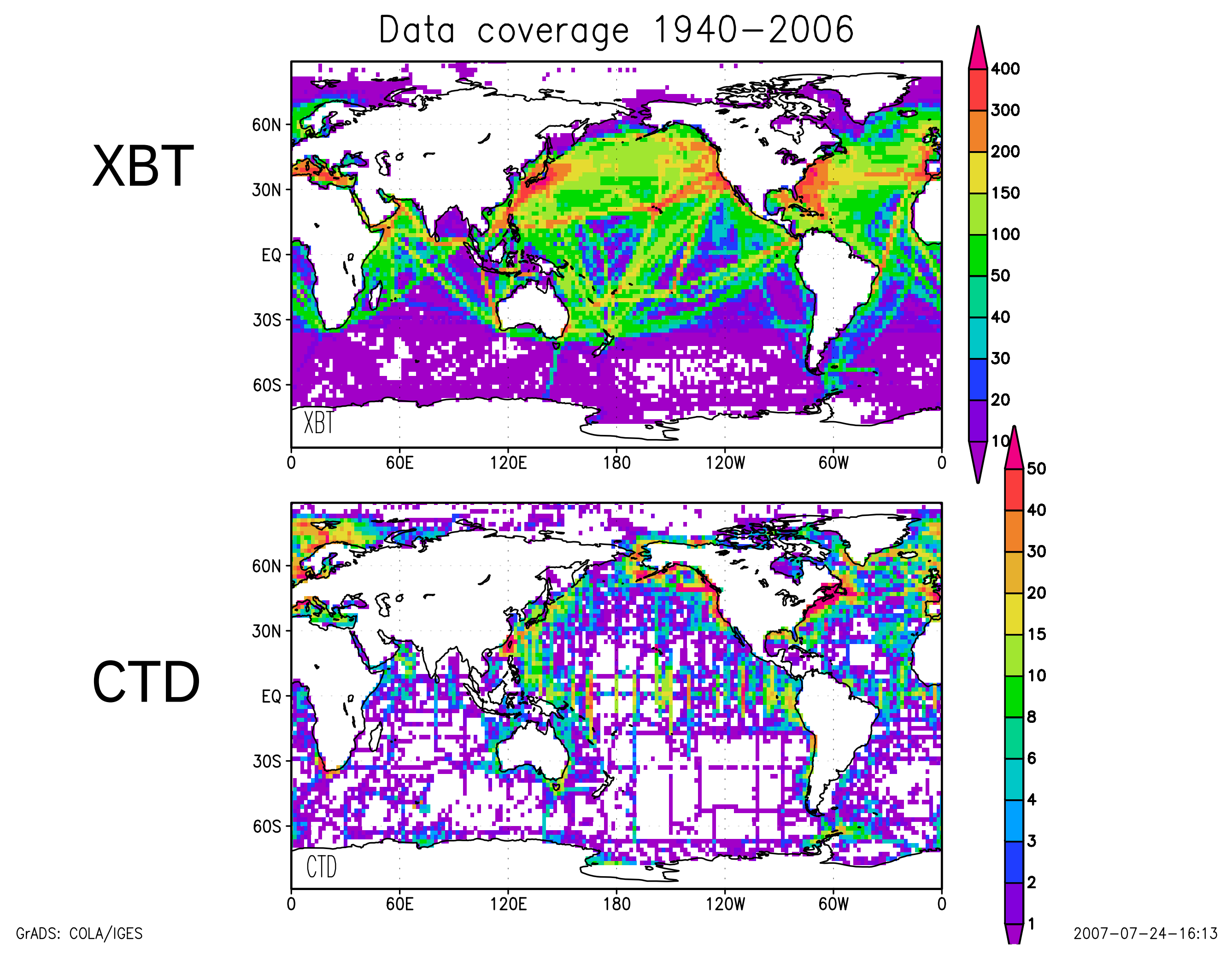
MRB- Moored Buoys (TAO-Pacific, PIRATA-Atlantic)

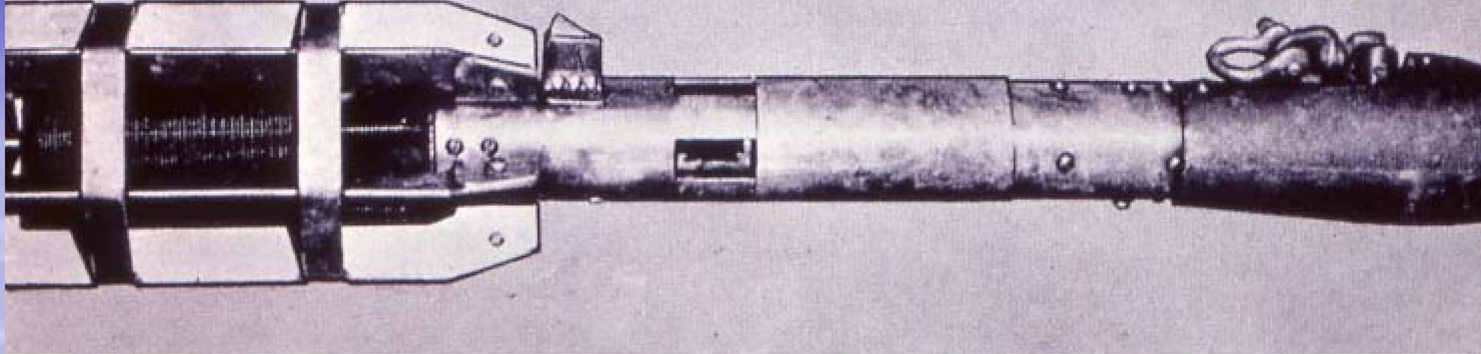


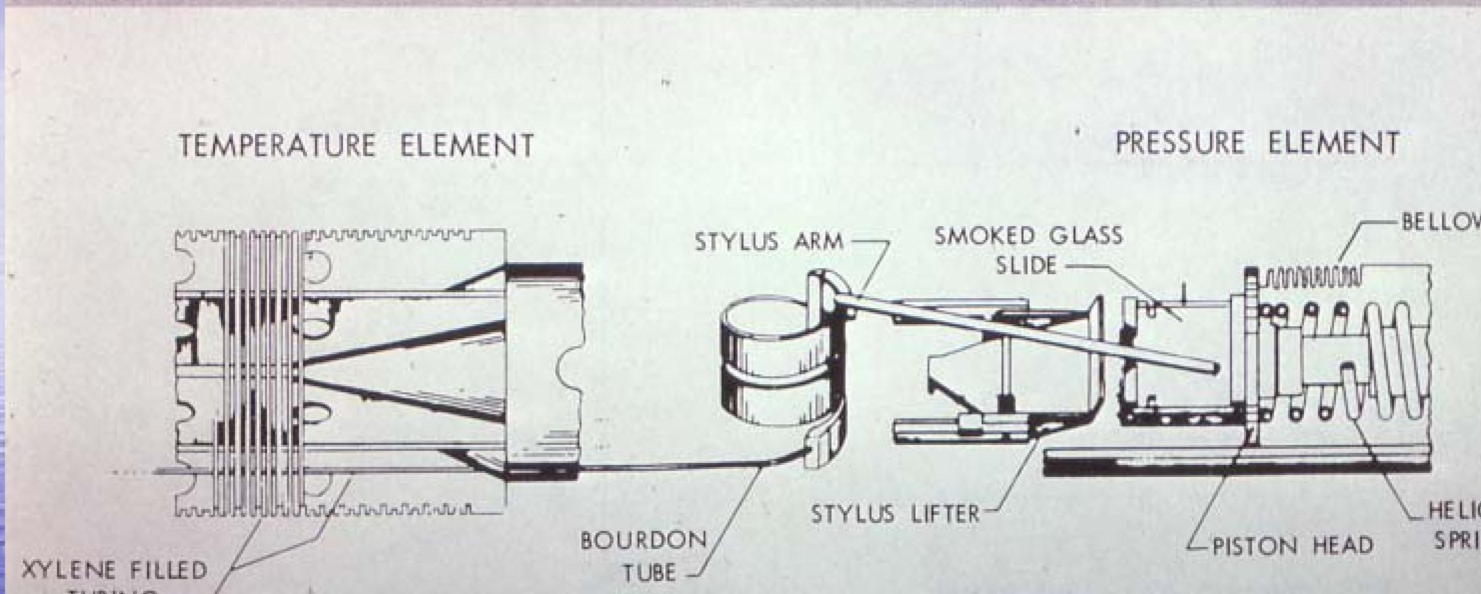
Number of points on a 2º x 2º x month grid filled with data.

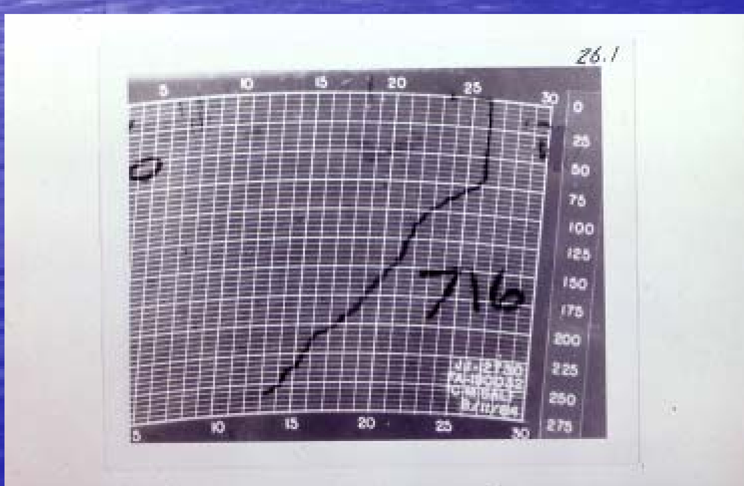
XBT

CTD





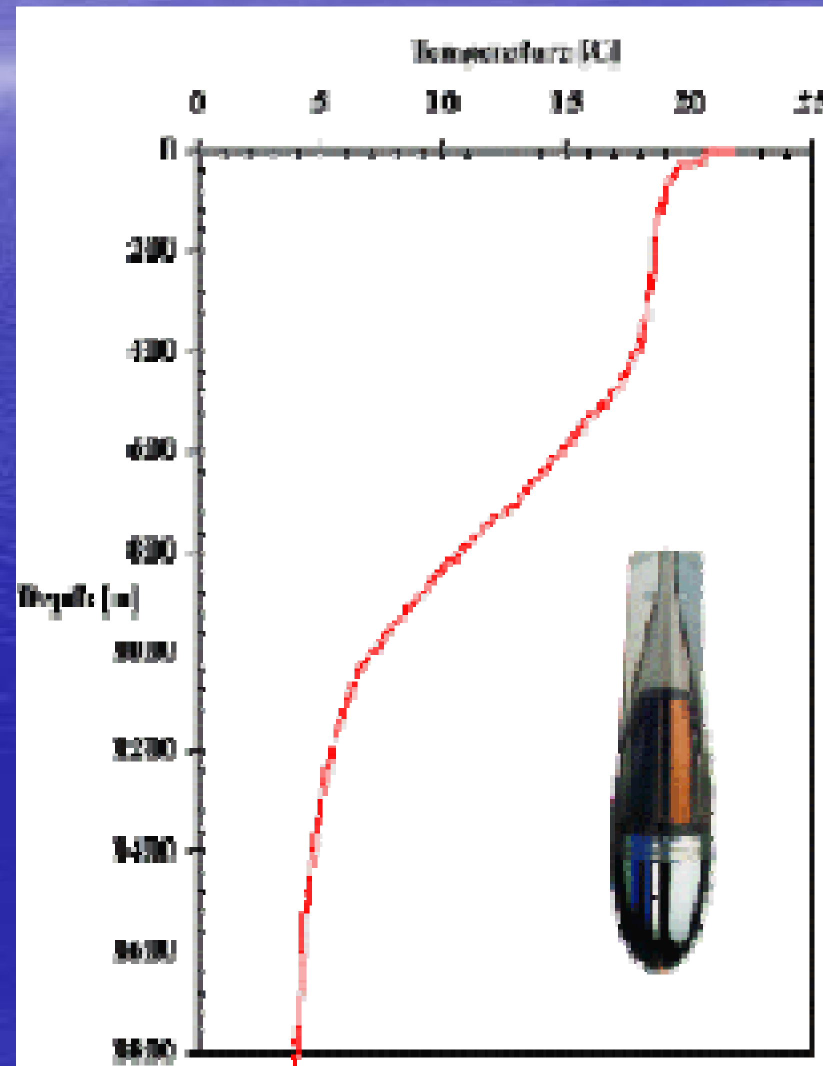




Mechanical bathythermograph (MBT), in use from 1951 to 1975. It is obsolete now and is replaced by **expandable bathythermograph** (XBT)

MBT temperature profile

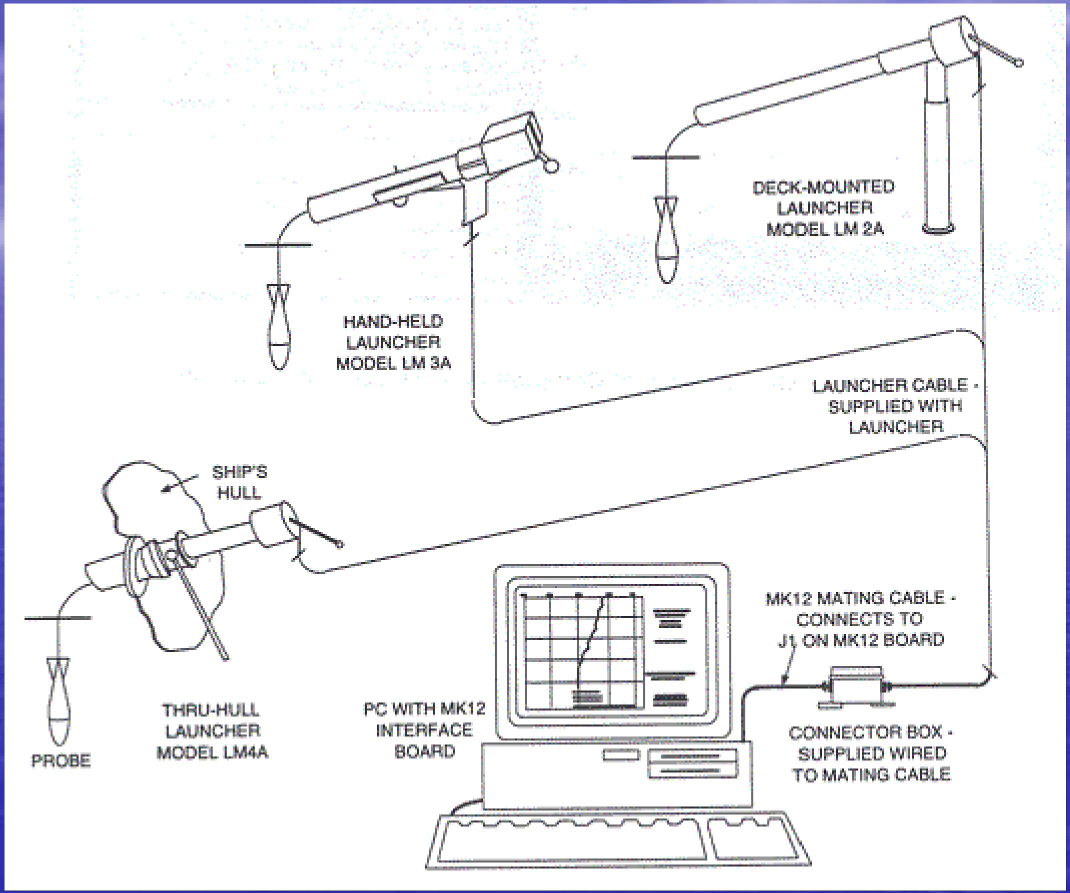
XBT
(Expendable Bathythermograph)



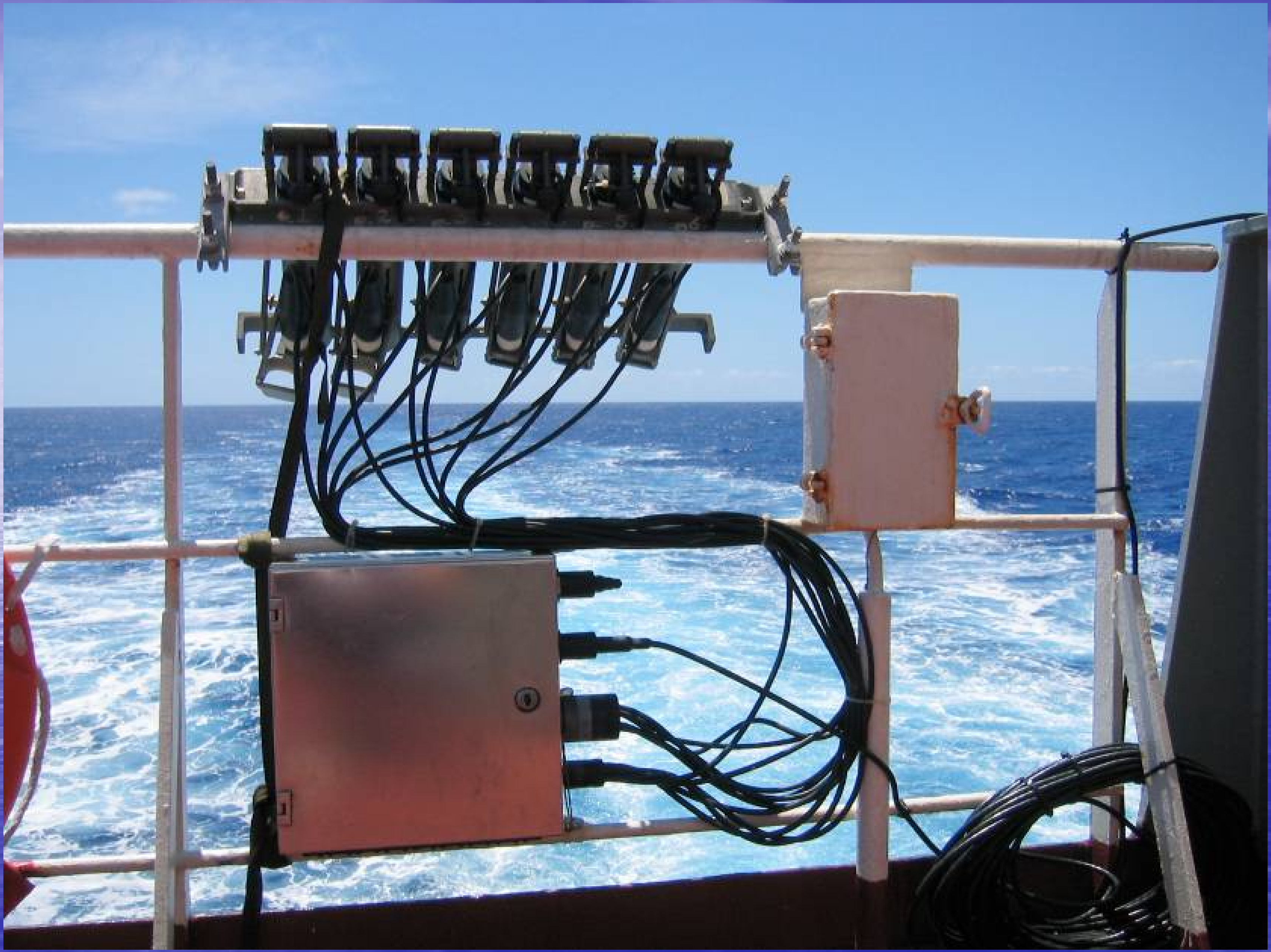
- May be deployed underway. Deployment may be automatic
- Thermistor error: ~0.1C
- Limited generally 400m (T4) – 750m (T7)
- Droprate error: ~1%
- RMSnoise/RMSsignal: 8%
- Total: 5×10^6 since the 1960's

Air-dropped: AXBT (pictures from Sippican)

XBT by Lockheed Martin Sippican, Inc

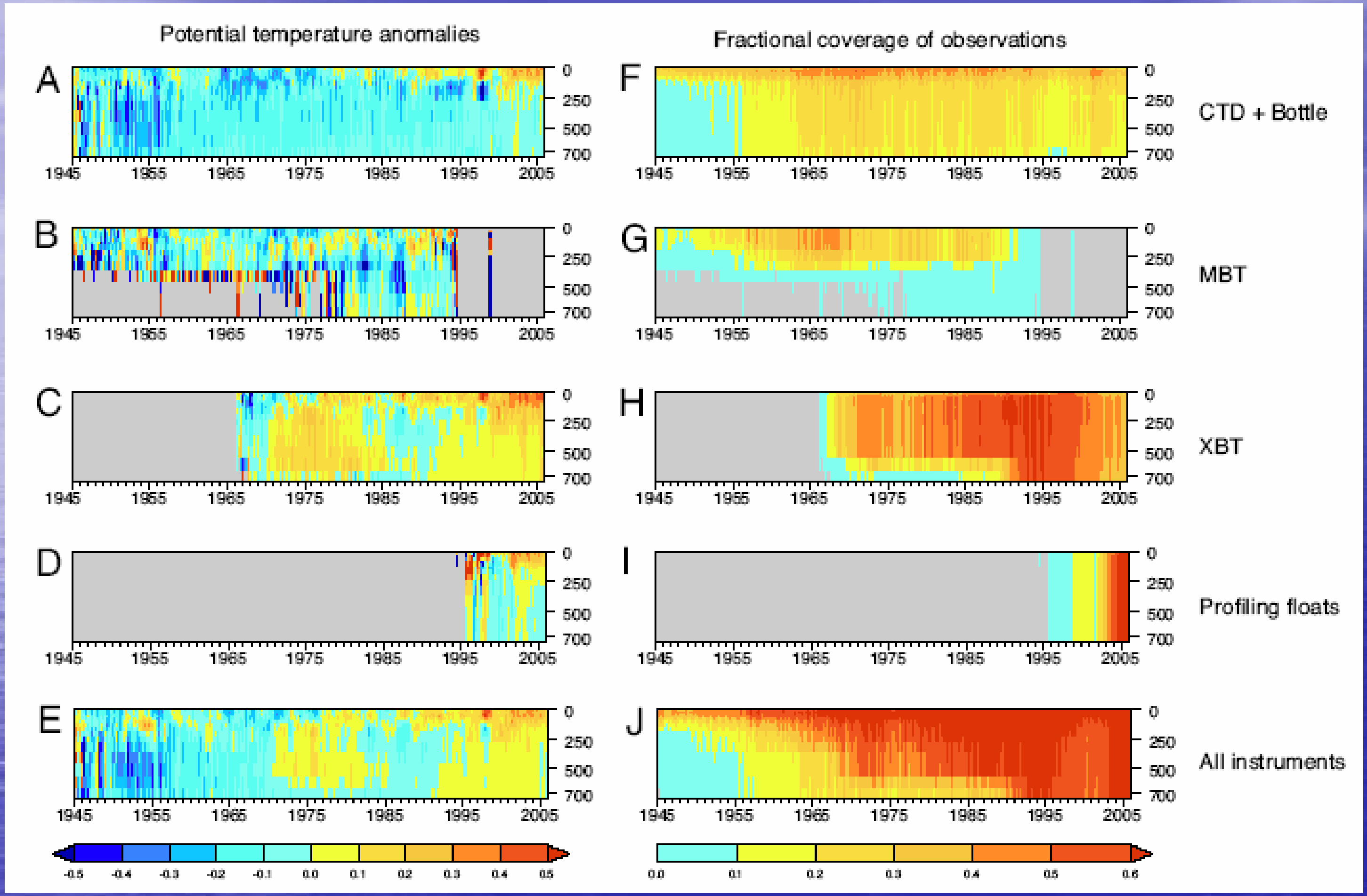


As an XBT drops down, the cooper wire is released from the instrument body. The wire electrical resistance changes as a function of the depth integrated temperature. XBT is an easy to launch instrument. It is widely used from voluntary observing ships. But instrument depth is not measured and is calculated based on the drop rate relationship ← Potential source of bias.

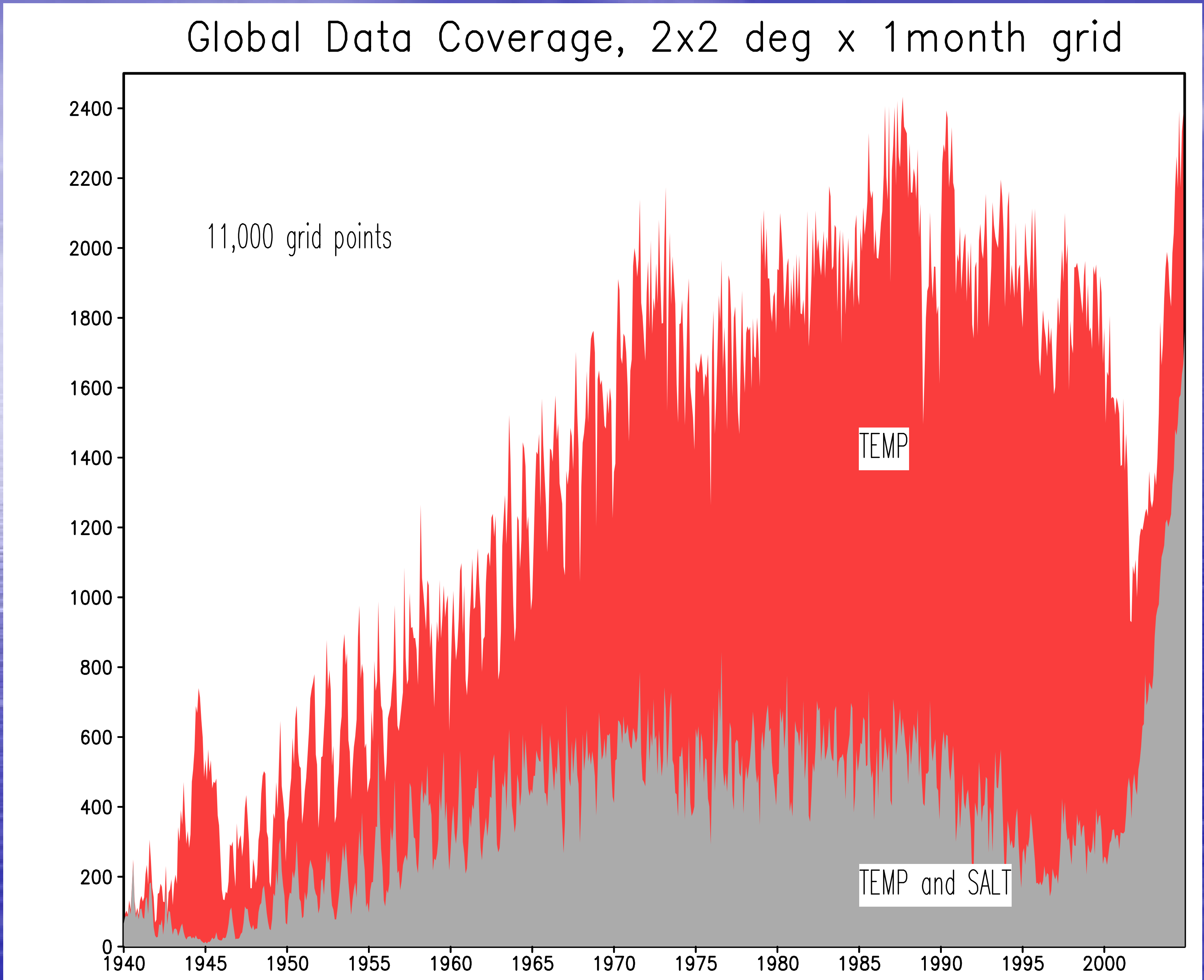


XBT autolauncher developed for multiple probes by Scripps Institution of Oceanography (courtesy G. Pezzoli and D. Roemmich).

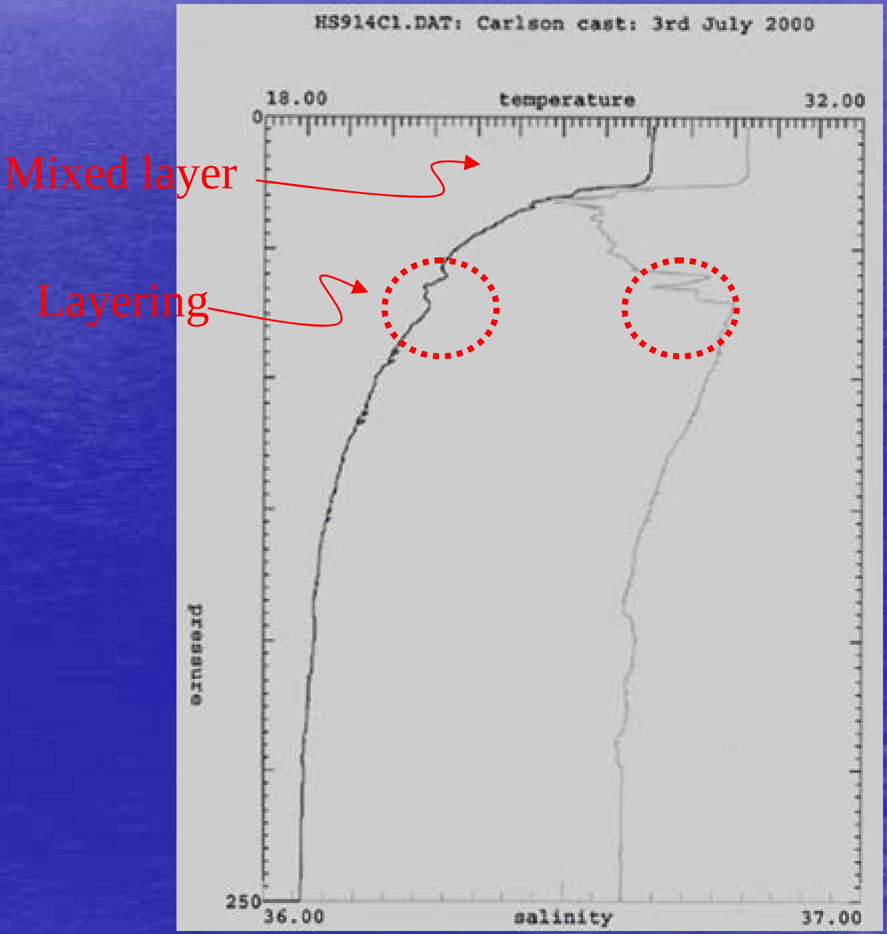
Warming of the Global Ocean. Bias of the XBT instrumentation.



Time series of layer-averaged monthly potential temperature anomalies and the area fraction of the global ocean observed at each level. Data are separated by instrument type and by combining all instruments. Missing data are denoted by gray areas. (**K. M. AchutaRao et al., 2007)**


Global Data Coverage, 2x2 deg x 1month grid
11,000 grid points
TEMP
TEMP and SALT
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000

CTD
(Conductivity, Temperature, Depth probe)



- Requires motionless platform, winch
- May carry rosette for nutrients, etc.
- Full depth
- Measures salinity, possibly O2
- Temperature error: 0.015C
- RMSnoise/RMSsignal: 2%

Neil-Brown Mark IV CTD

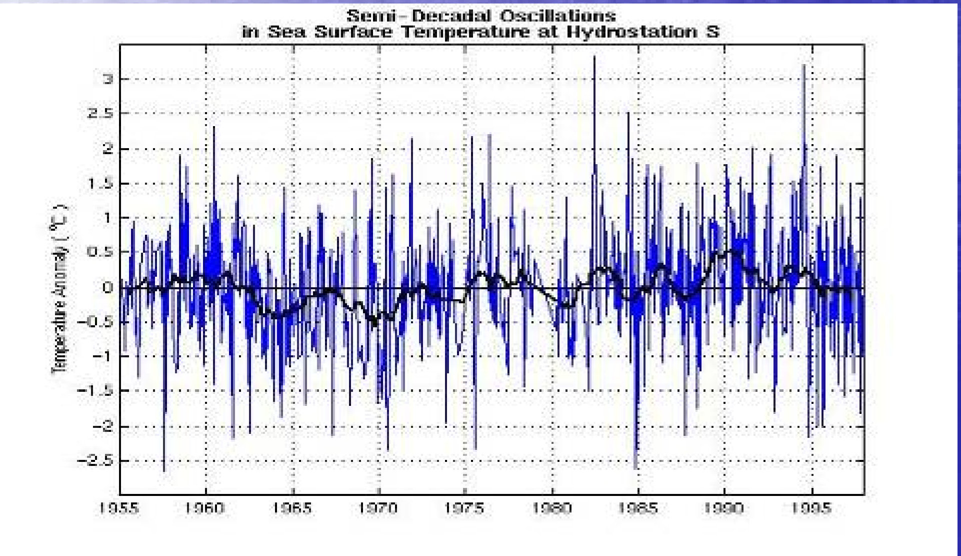
Seabird CTD

The Neil Brown CTD is lowered through the water on the end of an electrical conductor cable that transmits the information to computers or recorders on board ship.

The Seabird CTD eliminates the complex infrastructure of having a conducting wire to transfer the signal from the CTD to the ship. It records internally and can be used with a simple support cable or on a mooring. Upon return to the surface this CTD is plugged into a computer and the data are downloaded for processing and display.

Station time series
(Bermuda and Hawaii)

- http://hahana.soest.hawaii.edu/hot/
- http://www.bbsr.edu/

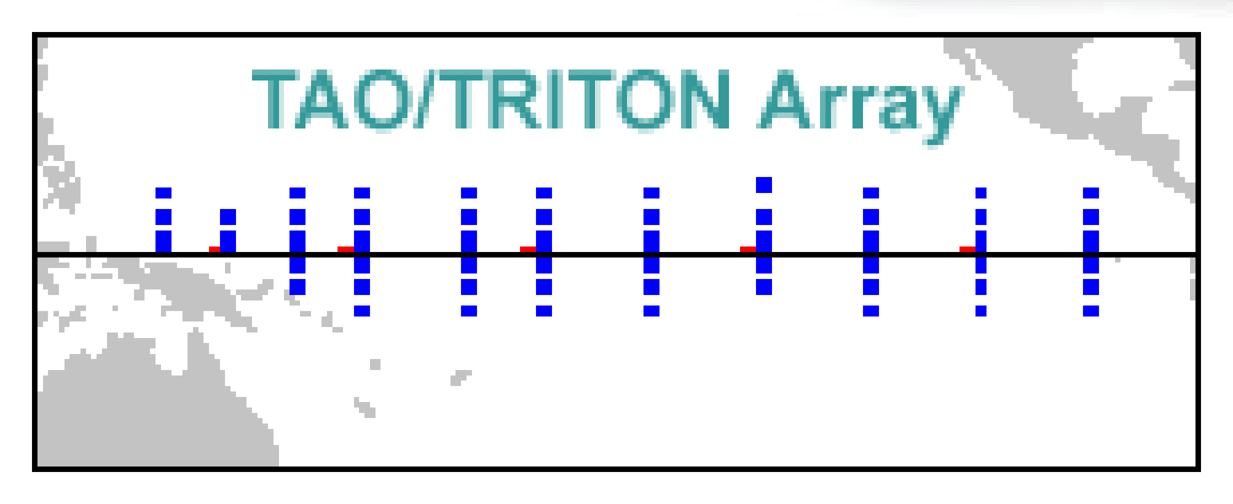


http://www.bbsr.edu/users/ctd/motero/HSsst.html

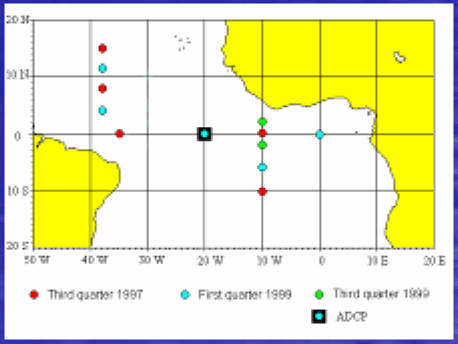
Bermuda surface mooring

http://www.opl.ucsb.edu/btm_text/buoy_photos.html

TAO /PIRATA tropical moorings



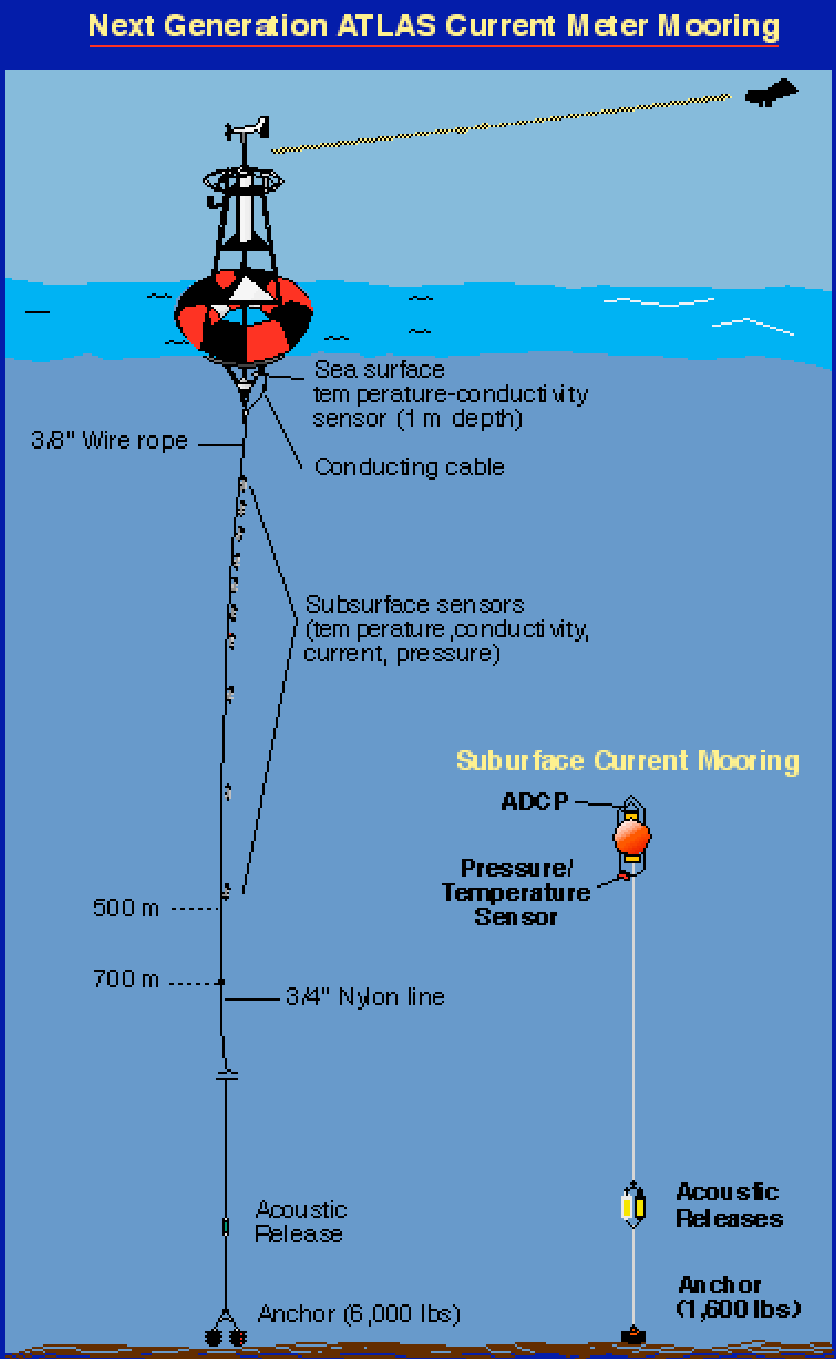
http://www.pmel.noaa.gov/tao/proj_over/proj_over.html



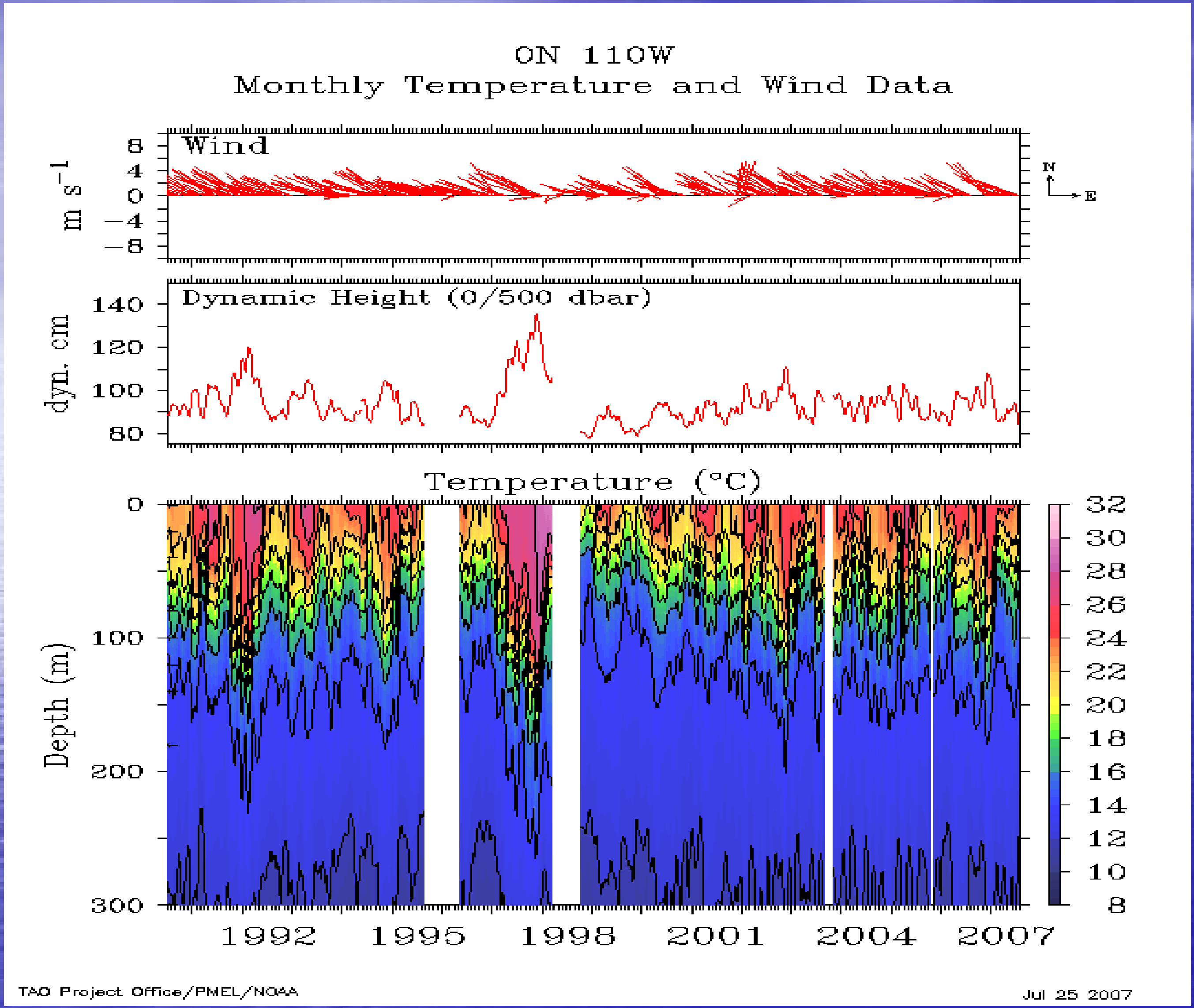
- http://www.pmel.noaa.gov/tao

http://www.brest.ird.fr/pirata/reseauus.html

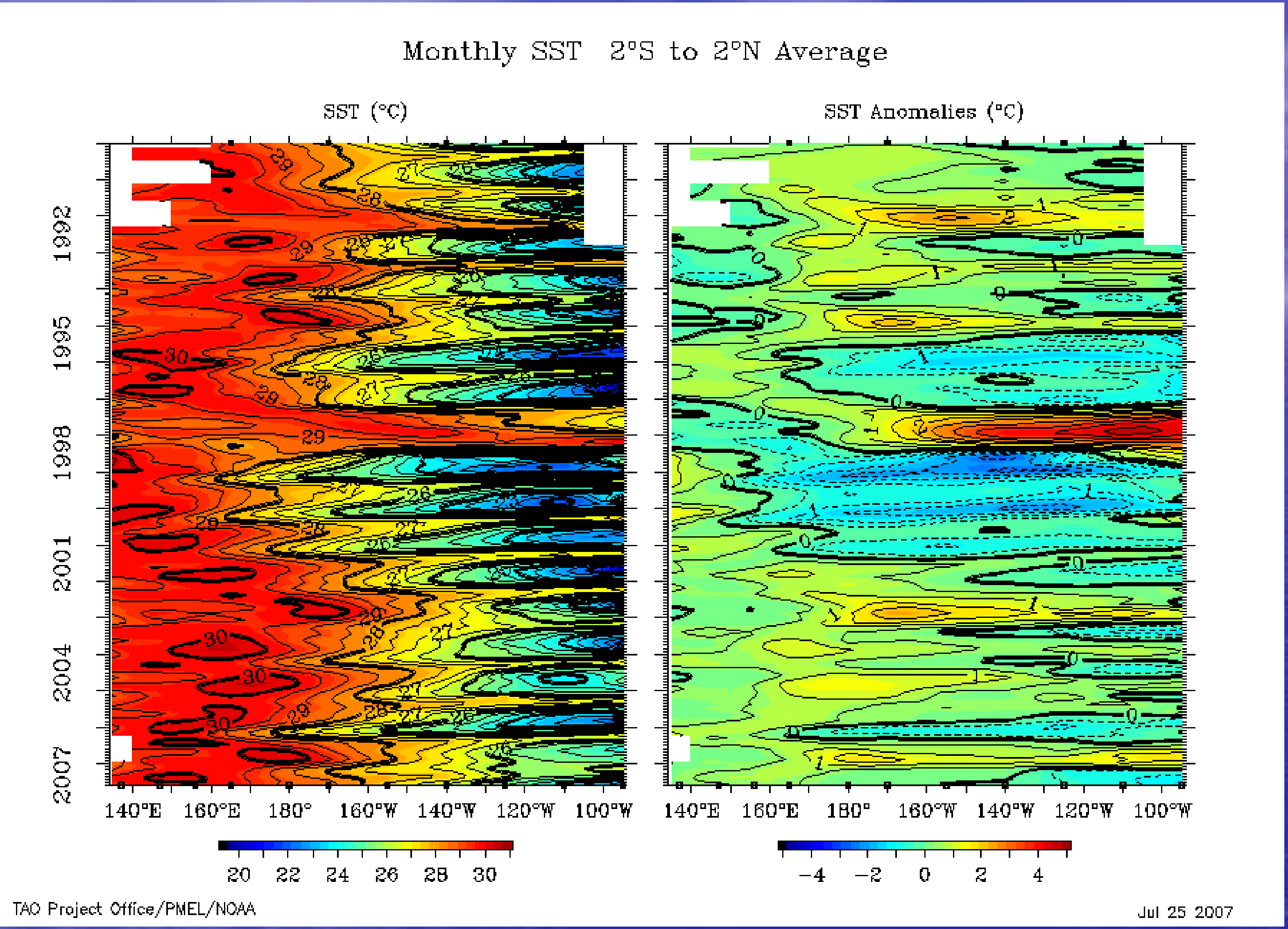
TAO buoys being serviced.



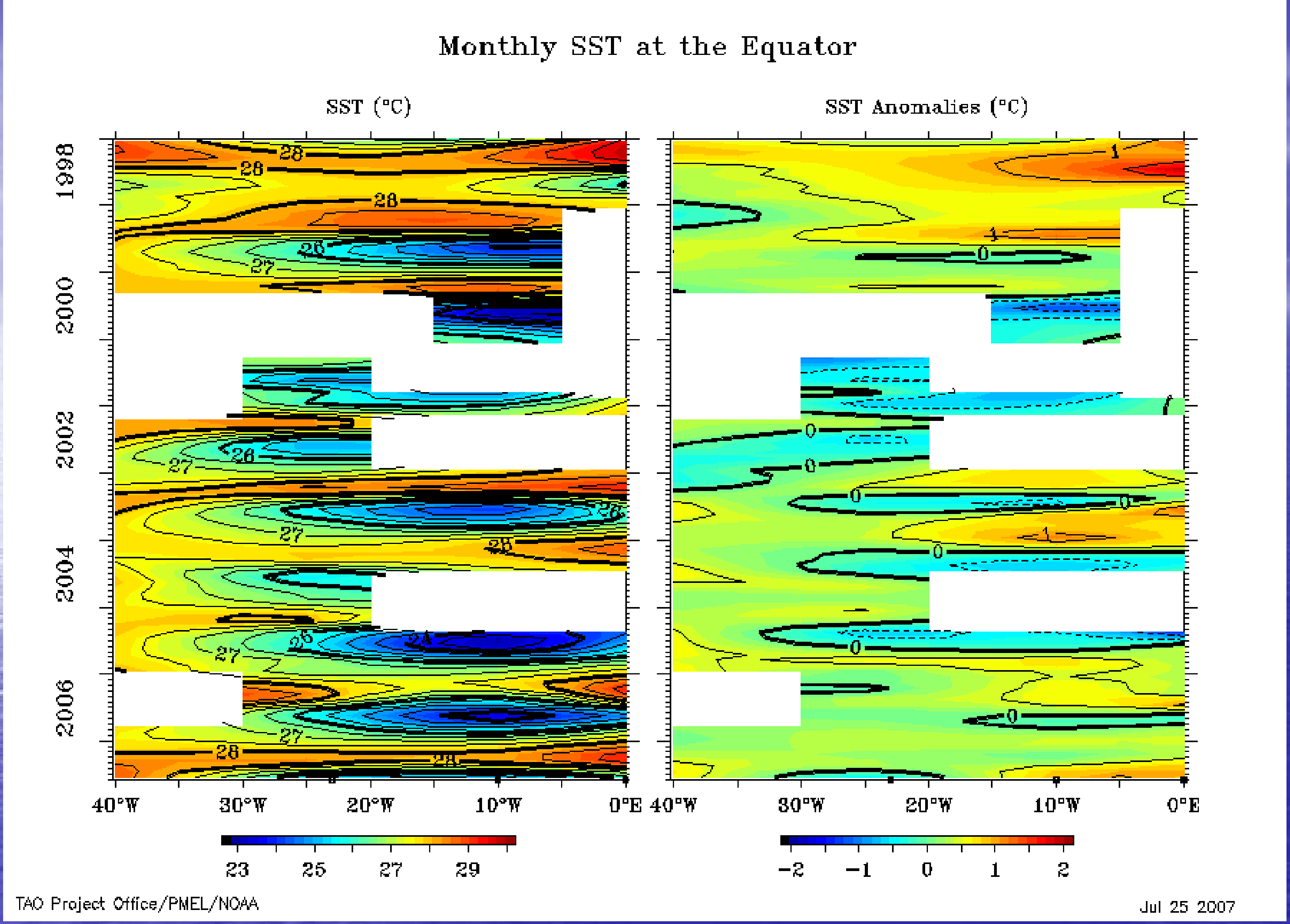
(b) Layout of TAO mooring. (From the TAO website at NOAA/PMEL: http://www.pmel.noaa.gov/tao)



Time series of wind, dynamic height and temperature in the vertical at 0N, 110W



Time – longitude diagram of surface temperature along the equator in the Pacific. Note up to 5 degC warm anomaly in the eastern equatorial sector during the 1997-98 record El Nino.

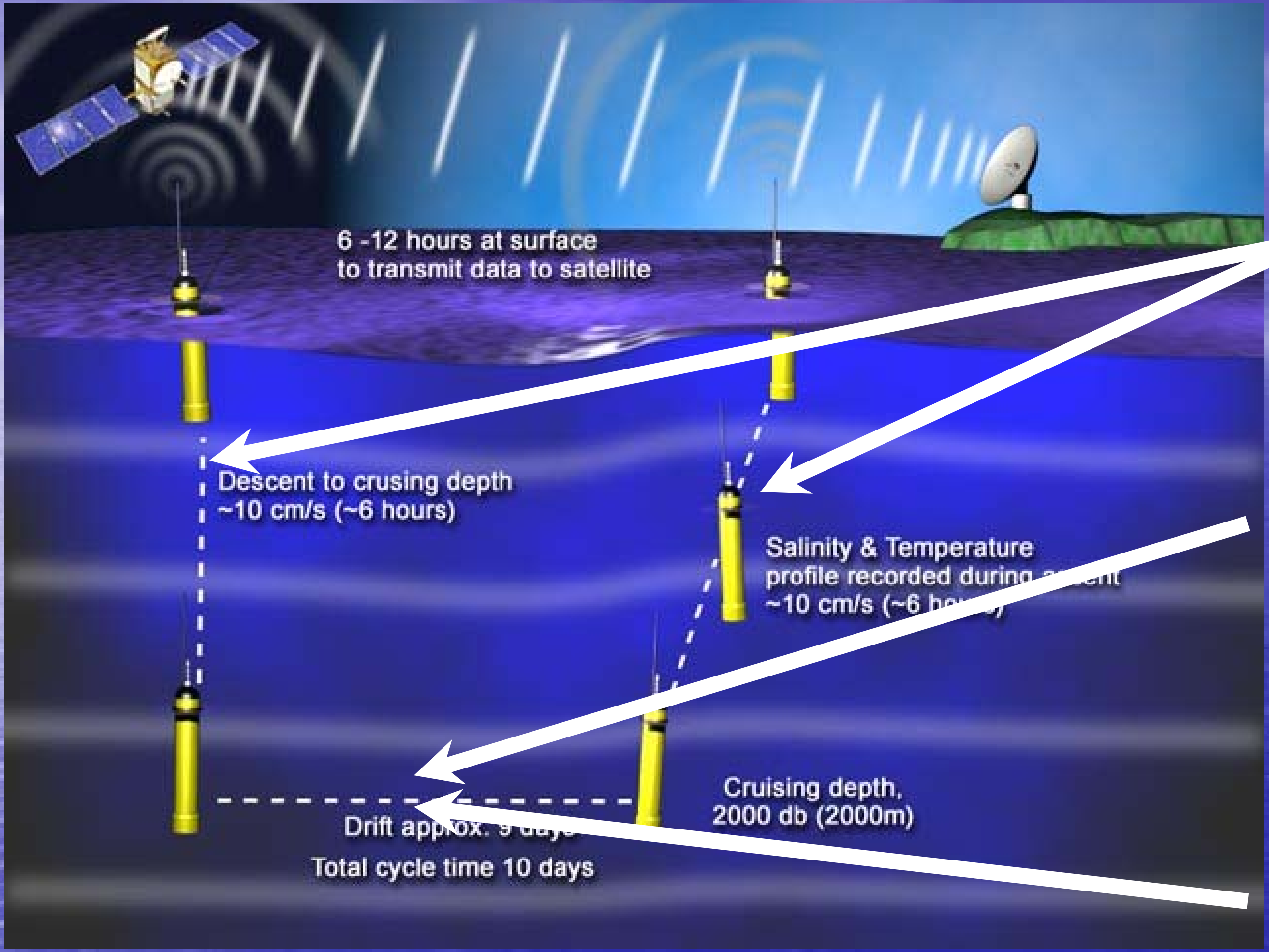


Time – longitude diagram of surface temperature along the equator in the Atlantic. Note up to 2 degC warm anomalies in the eastern equatorial sector that are referenced as the Atlantic Ninos (after the Pacific El Nino).

Standard ocean measurements are taken on board of research (or voluntary observing) vessels or from ocean moorings.

Ship time is costly. Buoy servicing also requires ship time.

Oceanographers launch development of profiling floats.



T(z), S(z) during ascent and descent

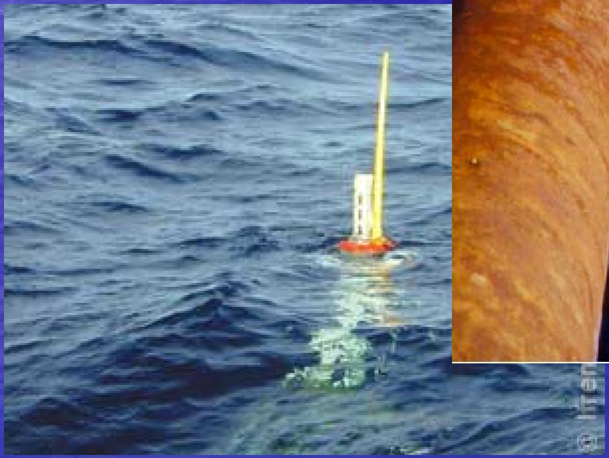
T(d), S(d) at cruising depth z=d

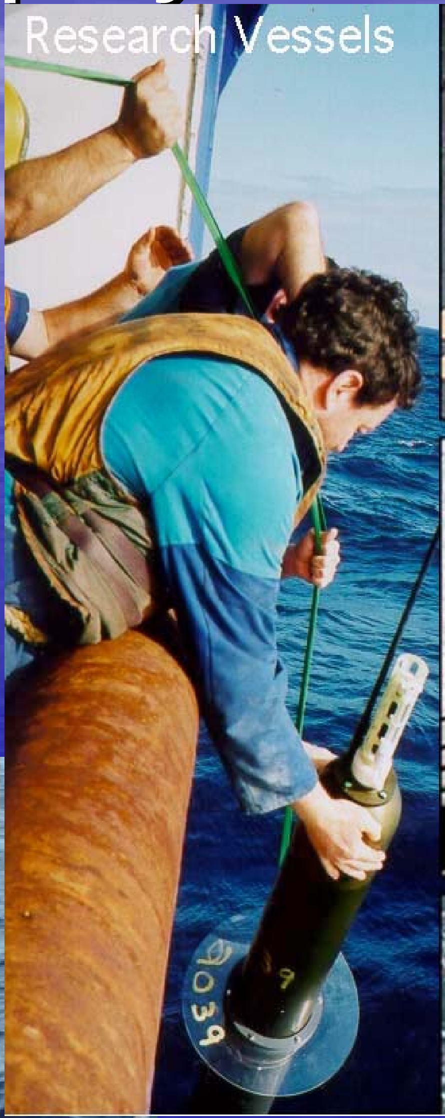
Average velocity at cruising depth

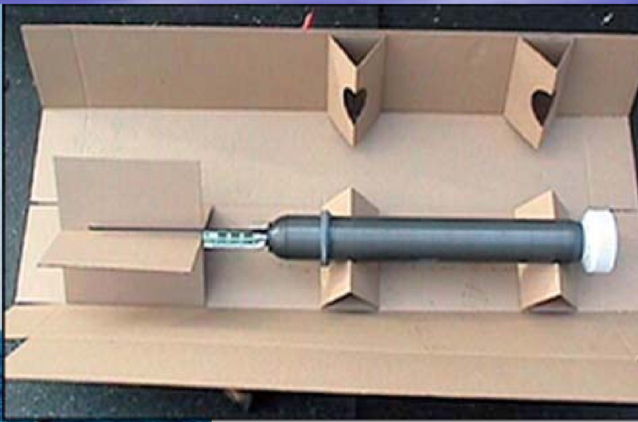
Simple Mission Operation: The float descends to cruising depth, drifts for several days, ascends while taking salinity and temperature profiles, and then transmits data to satellites.

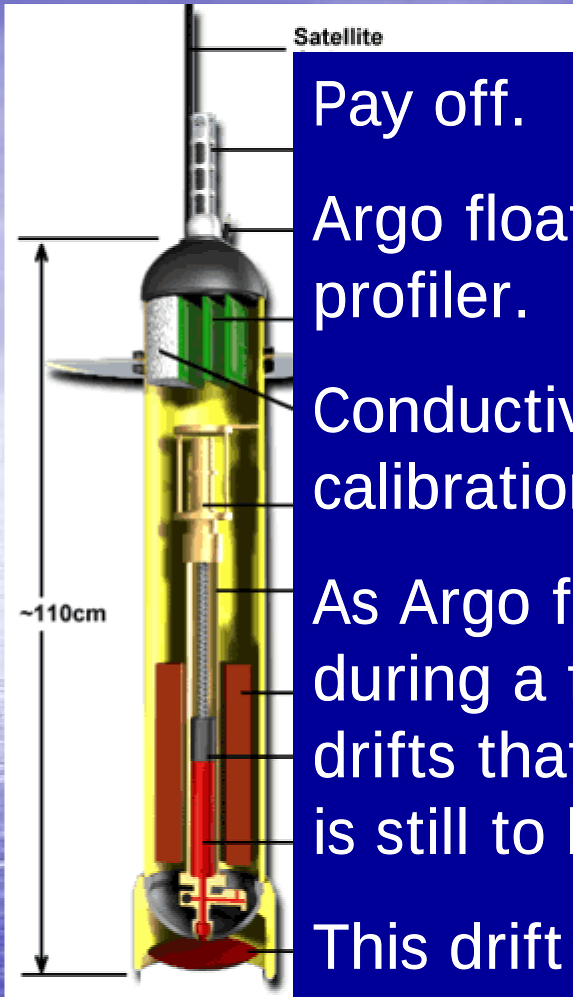
All the mission parameters, such as the drift depth, vertical sampling resolution, and time on the surface, can be tailored to suit the operating region.

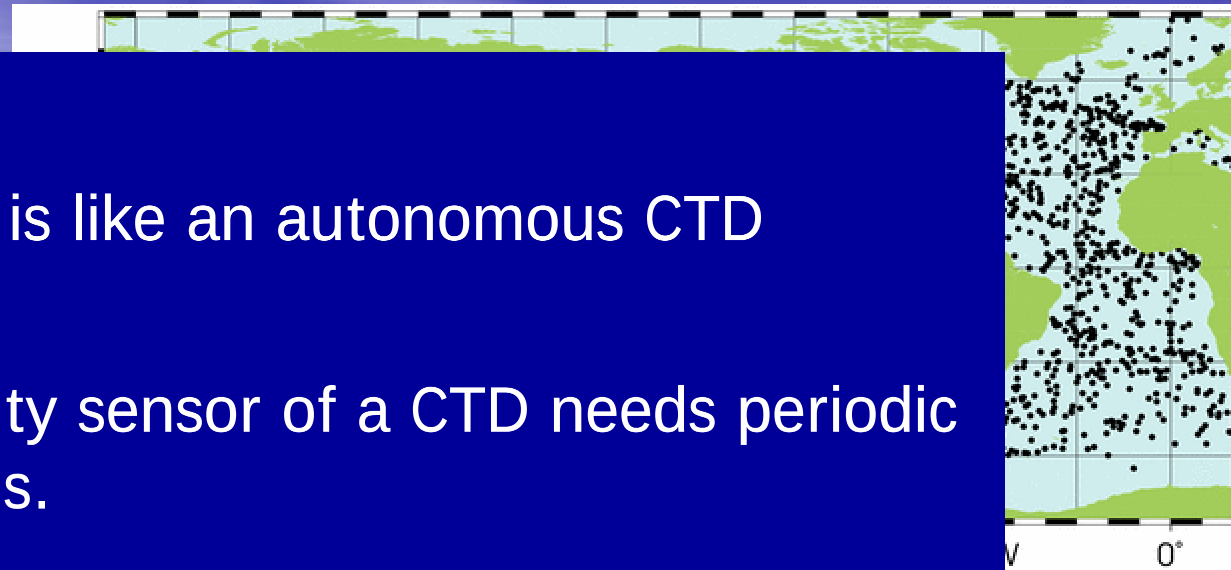
Argo deployment











Pay off.

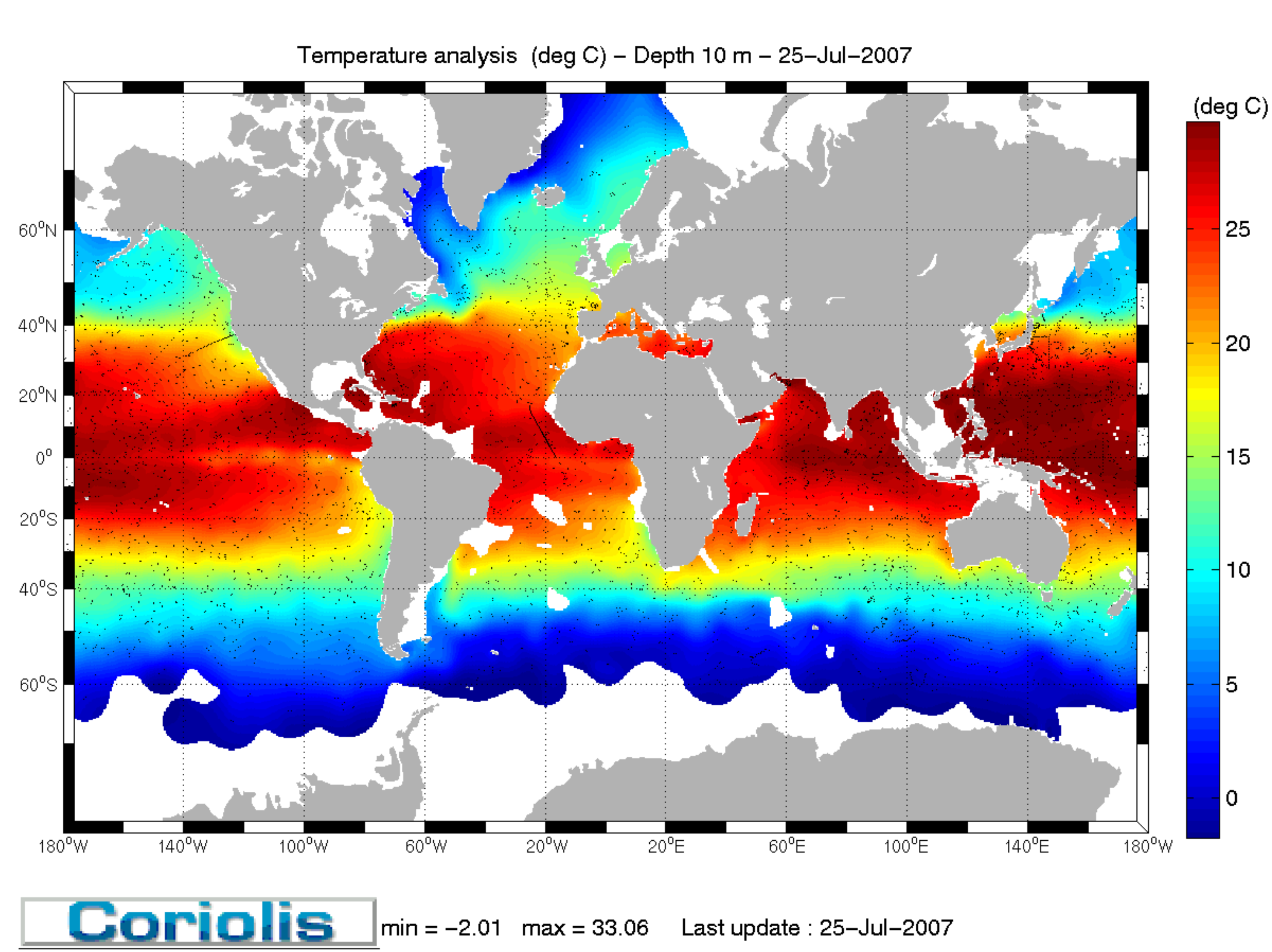
Argo float is like an autonomous CTD profiler.

Conductivity sensor of a CTD needs periodic calibrations.

As Argo float is launched and operates during a few years the conductivity sensor drifts that affects salinity data. This problem is still to be solved.

This drift is of the order of 0.1 psu during a lifetime. It is negligible comparing to spatial variation of salinity over the Global Ocean. But the drift creates substantial problems for putting the ARGO data into climate time series.

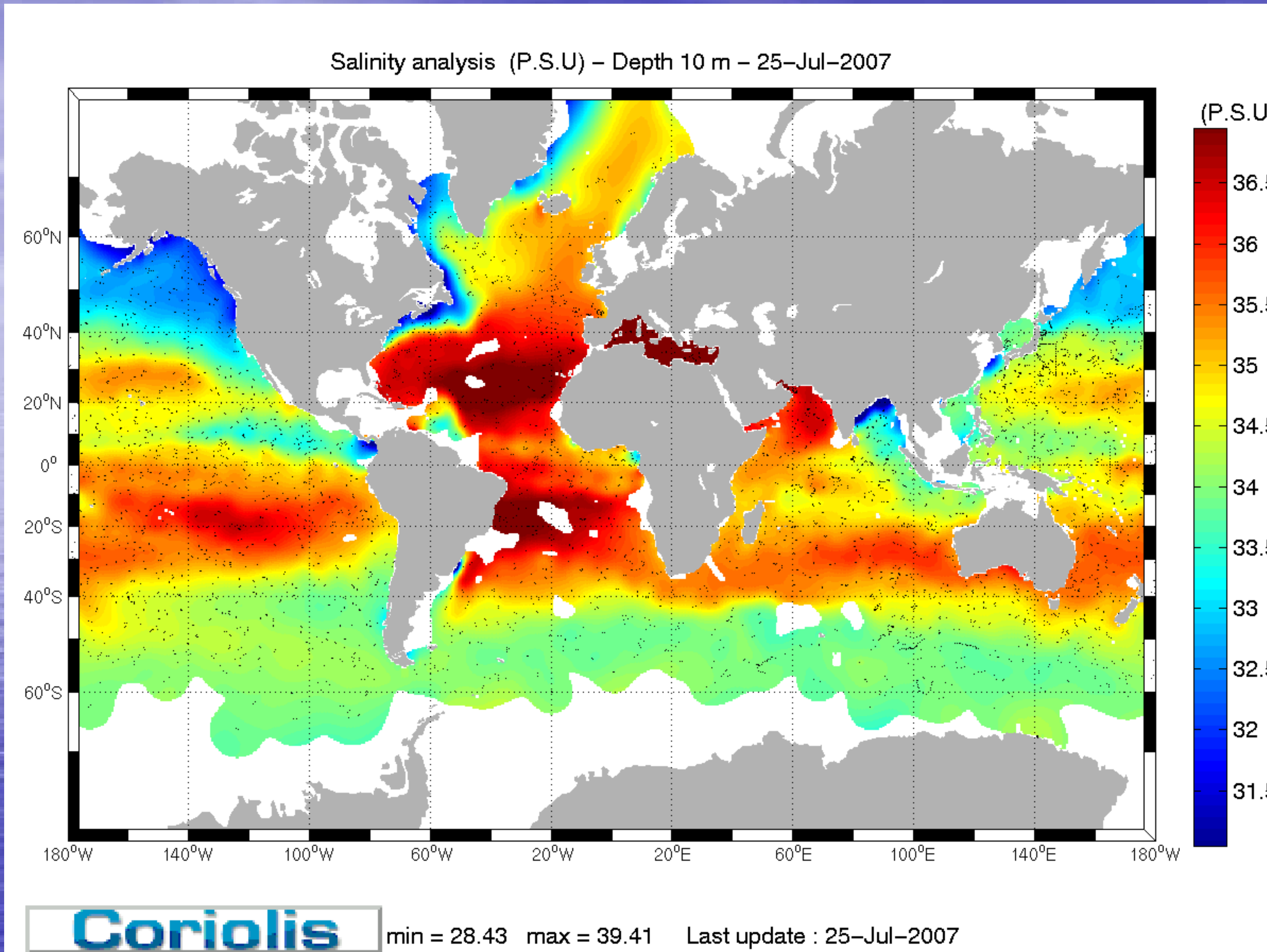
Hydraulic pu
that changes
profiler that,
its buoyancy



CORIOLIS 10m-depth temperature analysis

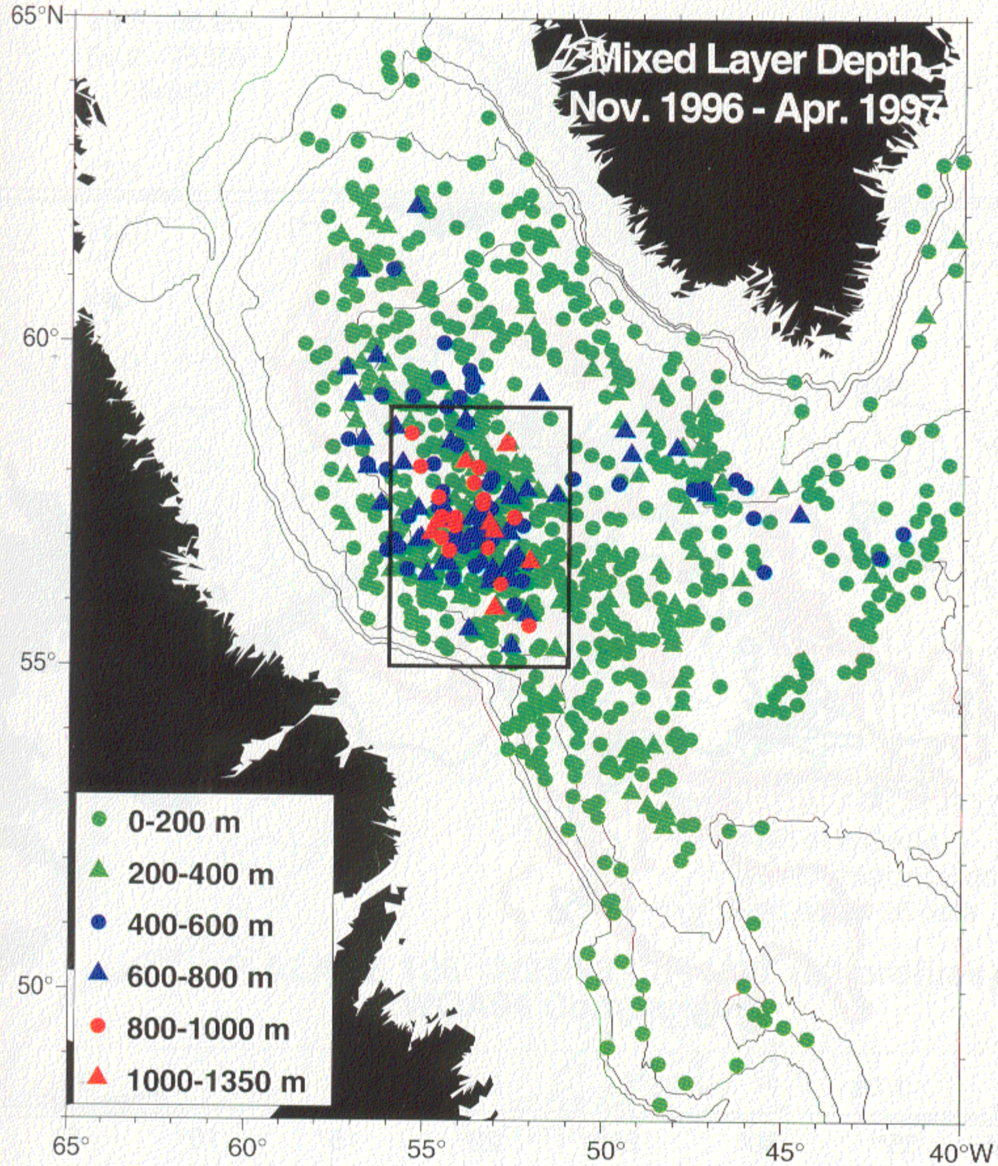
The operational analysis system set up by the CORIOLIS data center in France produces temperature and salinity gridded fields by using profiles from the data base.

These profiles are for more than 80% acquired within the Argo program. The system is based on an statistical estimation method (objective analysis).



CORIOLIS 10m-depth salinity analysis. Data are available at http://www.coriolis.eu.org/cdc/ObjectivesAnalysis/objective_analyses.htm

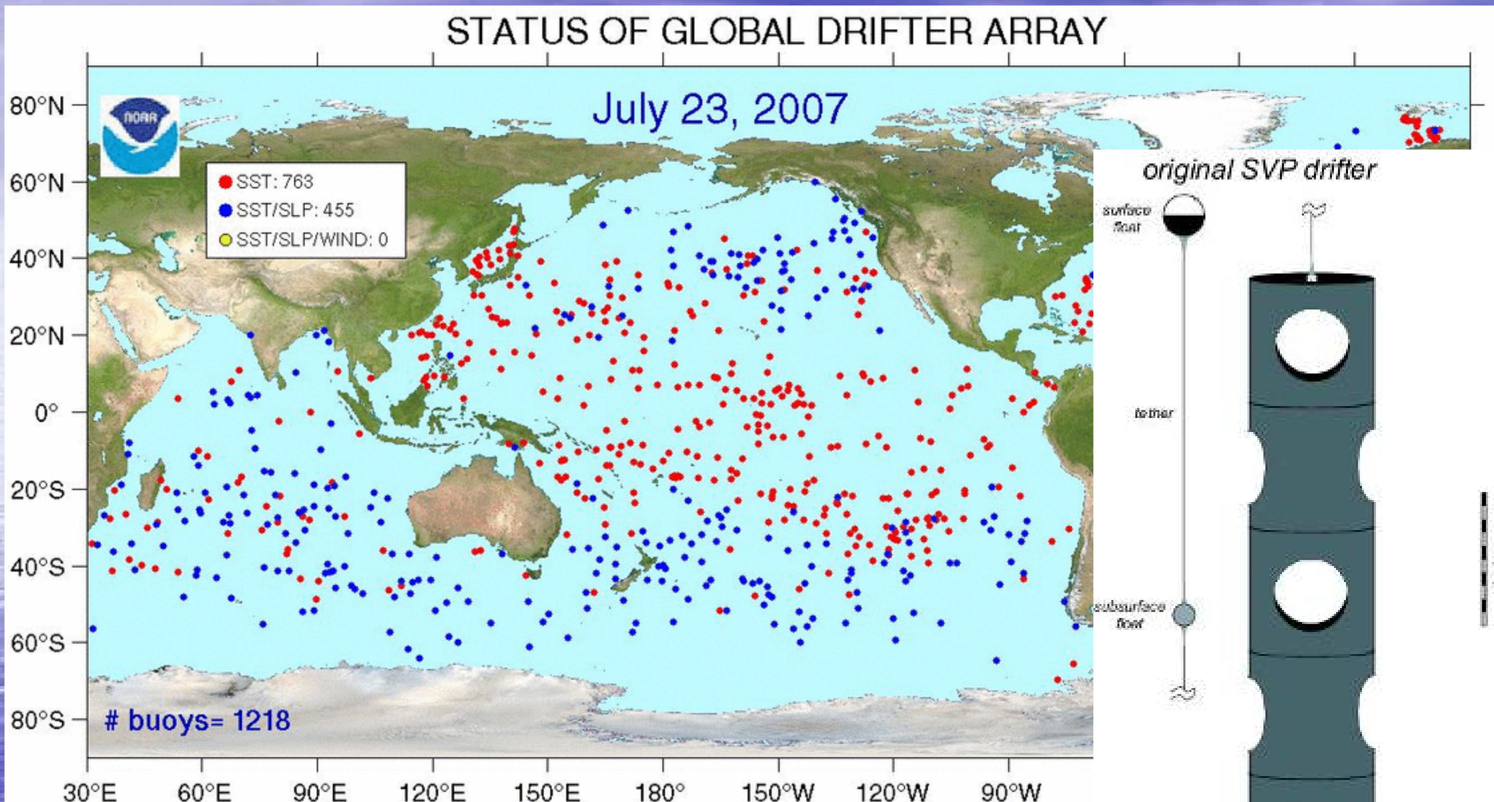
Mixed layer depth from ARGO

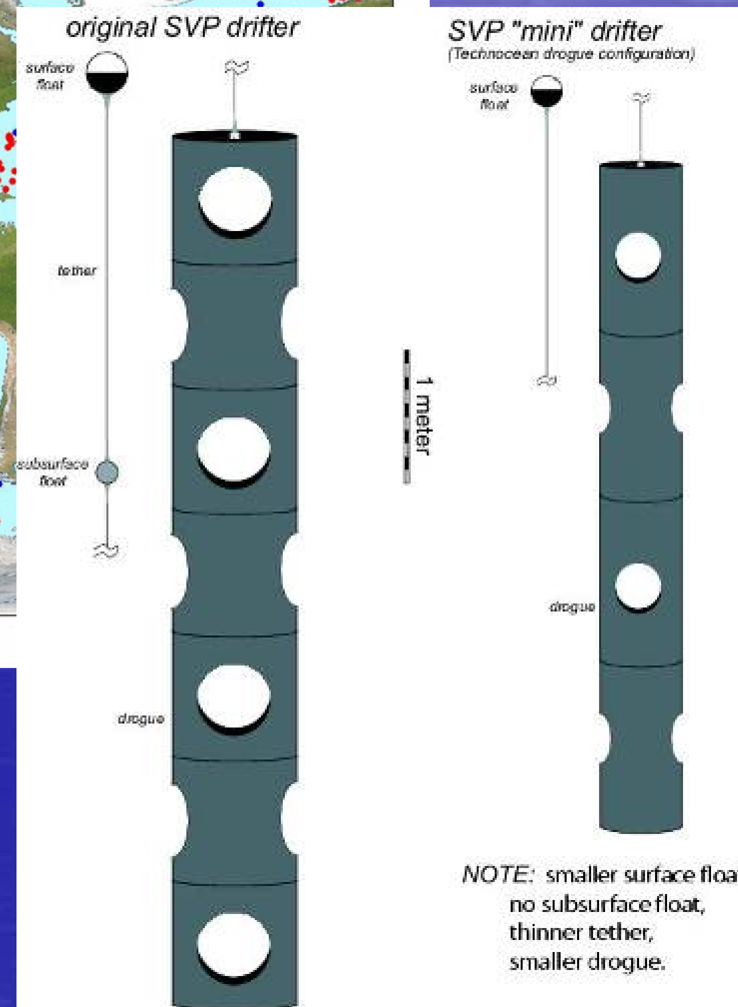


2.10 (see p. 135) Mixed-layer depths in the Labrador Sea reported in real time by P-ALACE floats between
er 1996 and April 1997. From Lavender *et al.* (2000b).

Velocity measurements

- Drogued surface drifters
- ADCPs
- Propeller-type current meters
- CODAR





http://www.aoml.noaa.gov/phod/dac/gdp.html

Surface drifter construction

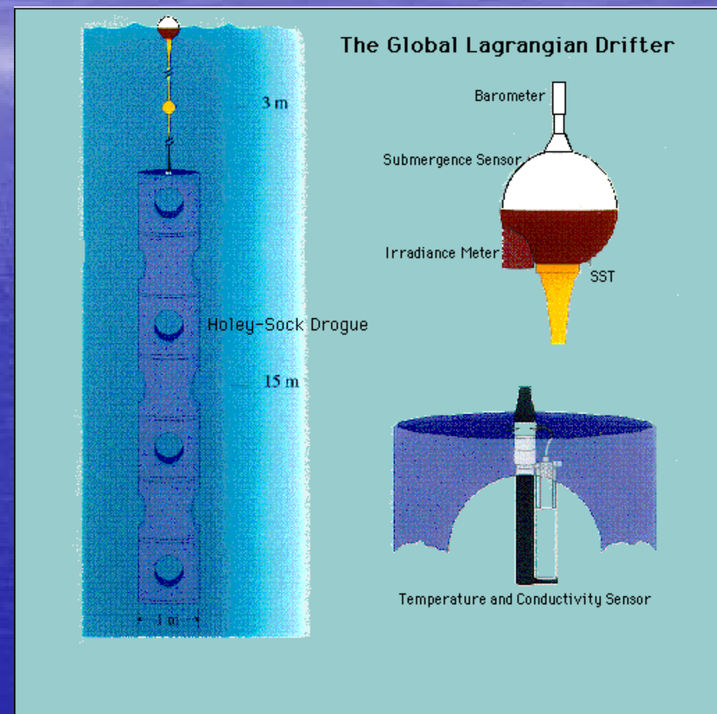
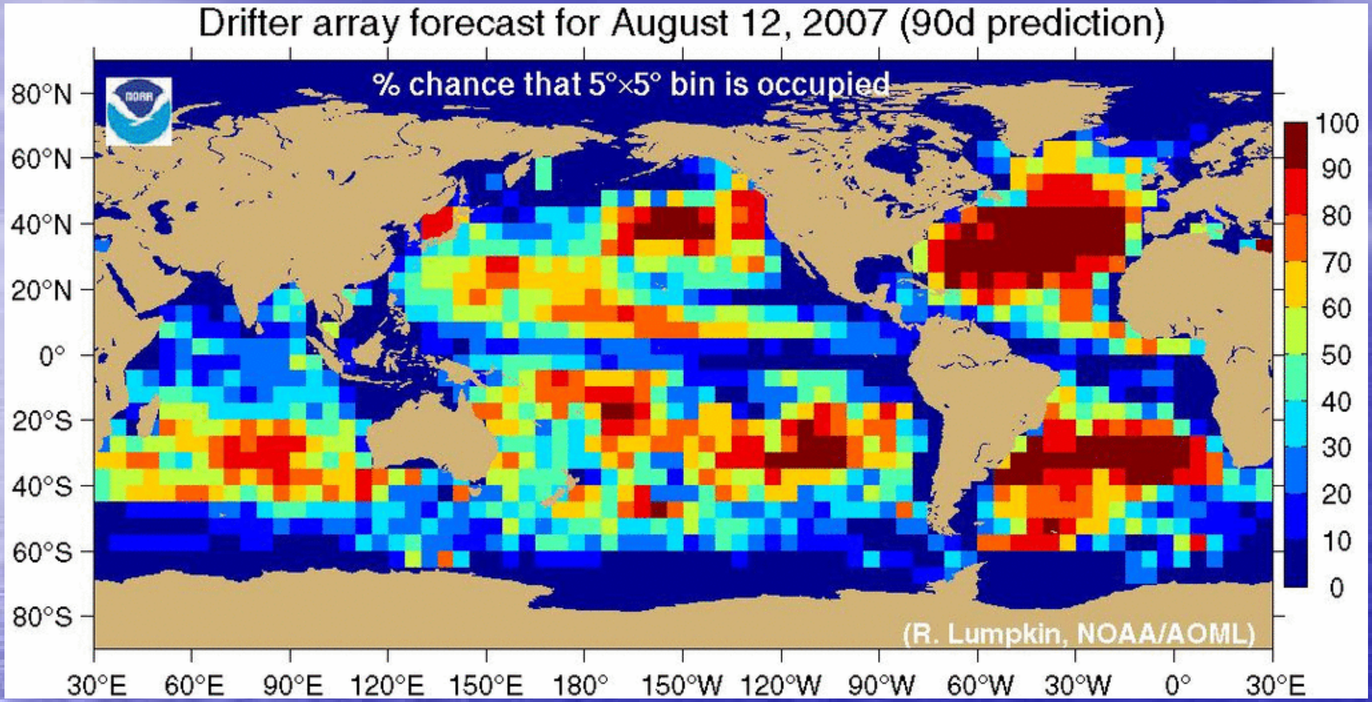
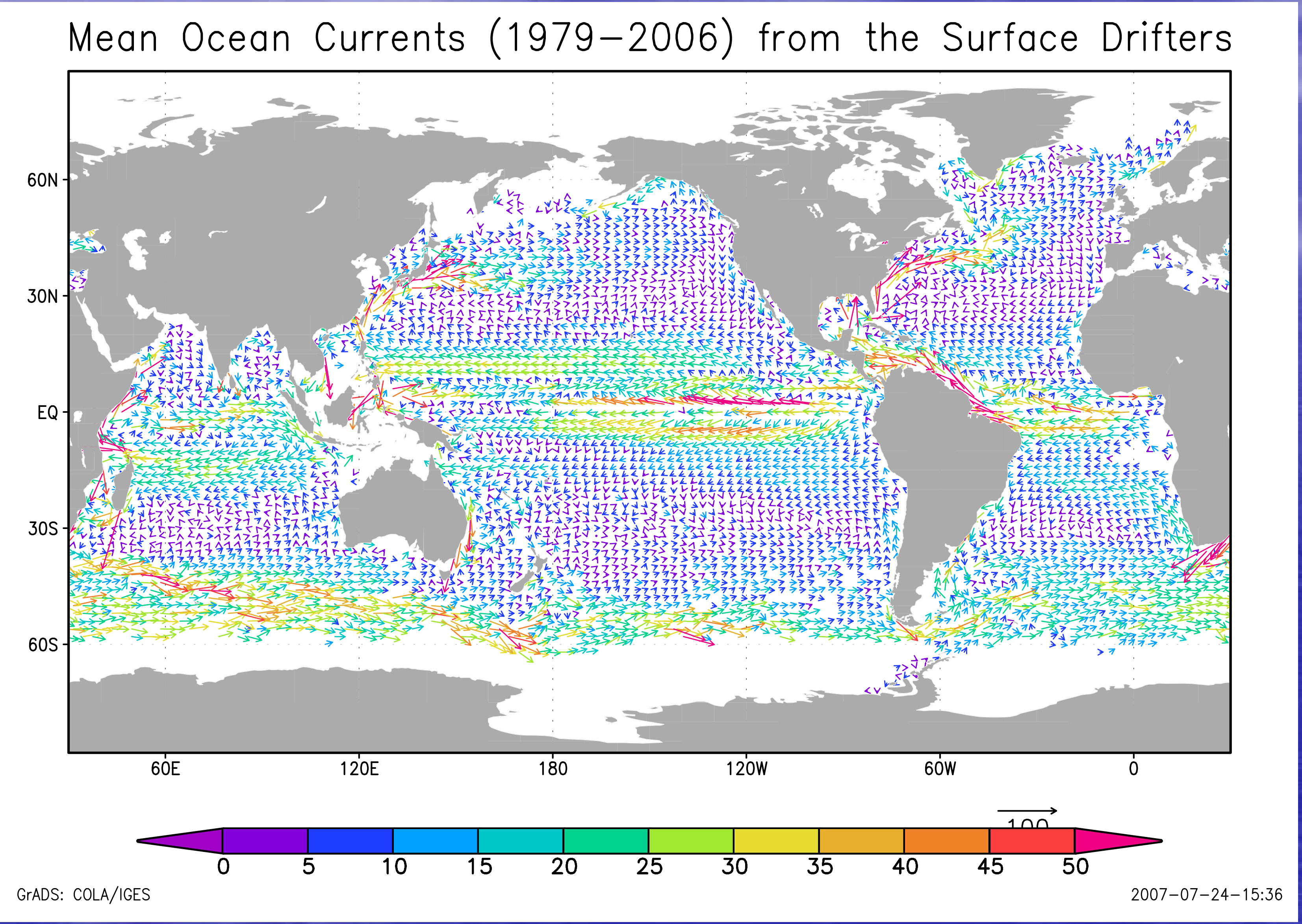


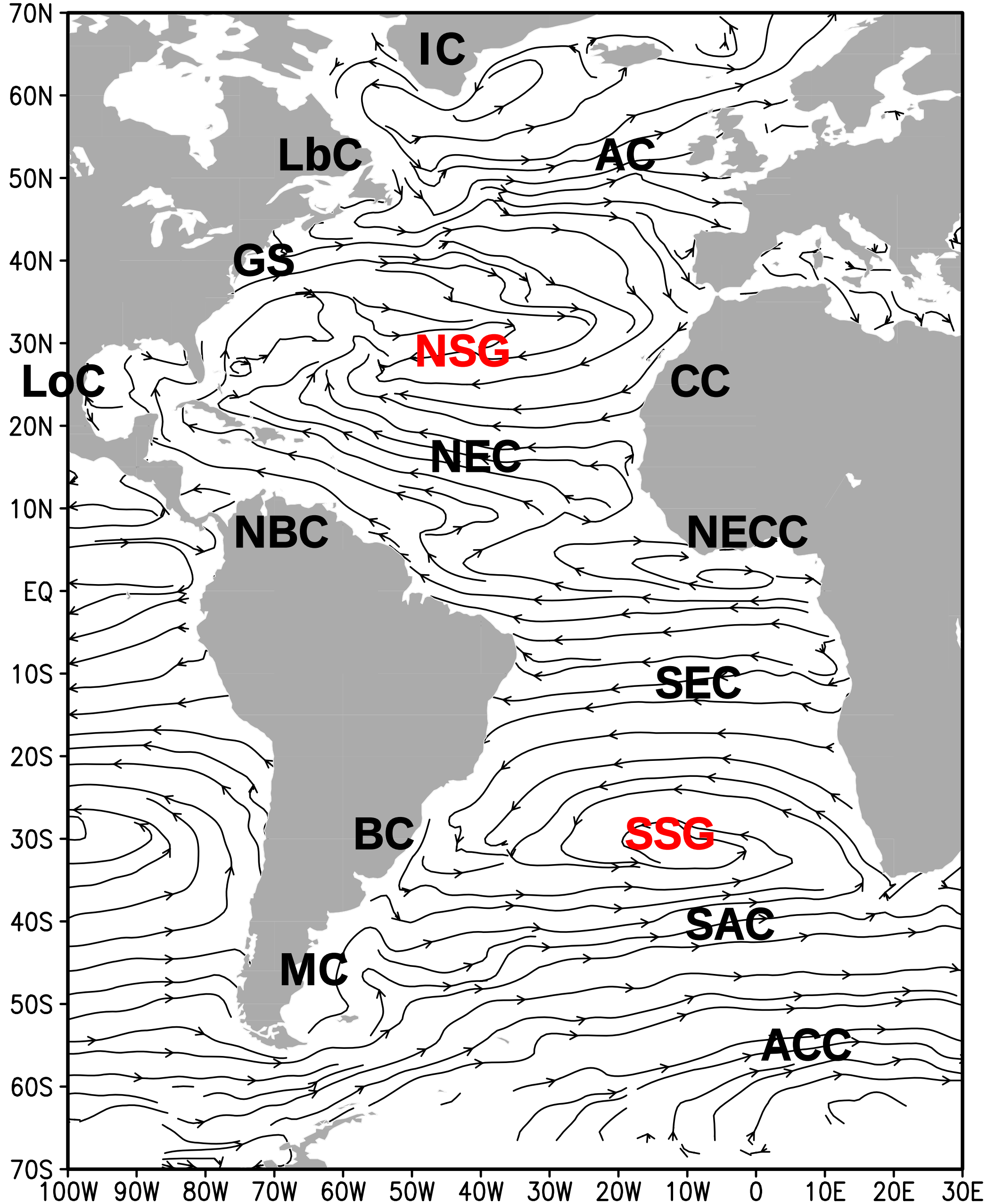
Diagram displaying the low-cost Global Lagrangian Drifter on the left hand side, and schematics of the sensor attachments (barometer, submergence, SST, irradiance and SEACAT), on the right hand side. Most drifters are also equipped with drogue sensors that indicate drogue loss. Buoys without drogues do not depict ocean currents accurately, because the drifter becomes susceptible to wave and wind action. Drifters transmit sensor data to satellites that determine the buoy's position and relay the data to Argos ground stations. Service Argos provides raw drifter data to the DAC where the data is processed and distributed.



Drifter array forecast for August 12, 2007 (90d prediction)
% chance that 5°×5° bin is occupied
80°N
60°N
40°N
20°N
0°
20°S
40°S
60°S
80°S
30°E
60°E
90°E
120°E
150°E
180°
150°W
120°W
90°W
60°W
30°W
0°
30°E
100
90
80
70
60
50
40
30
20
10
0
(R. Lumpkin, NOAA/AOML)


Mean Ocean Currents (1979–2006) from the Surface Drifters
60N
30N
EQ
30S
60S
60E
120E
180
120W
60W
0
100
0
5
10
15
20
25
30
35
40
45
50
GrADS: COLA/IGES
2007–07–24–15:36

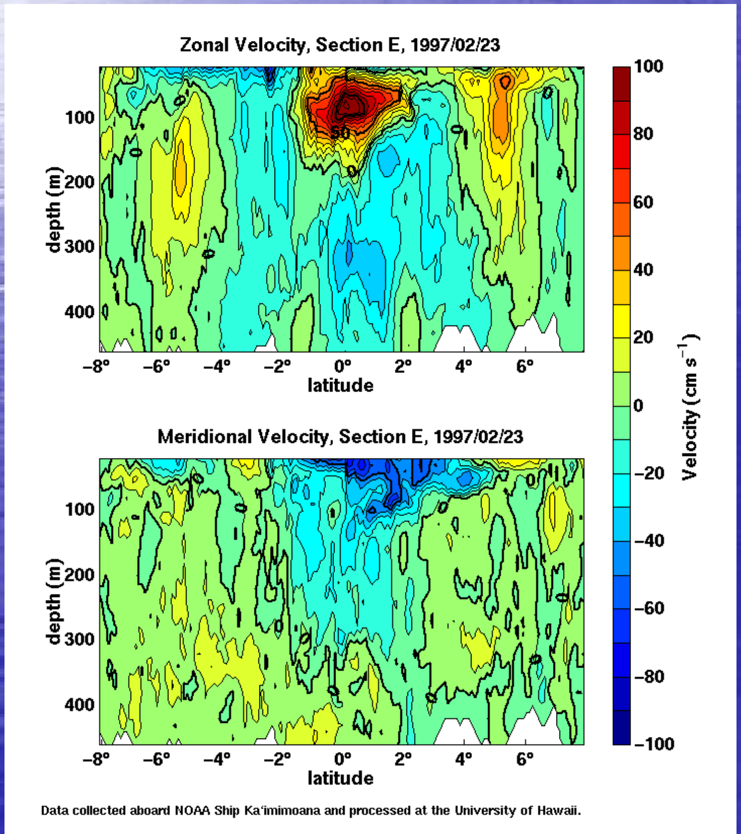
1979–2006 mean Atlantic circulation (streamfunction)



Surface drifter currents

Acoustic Doppler Current Profilers

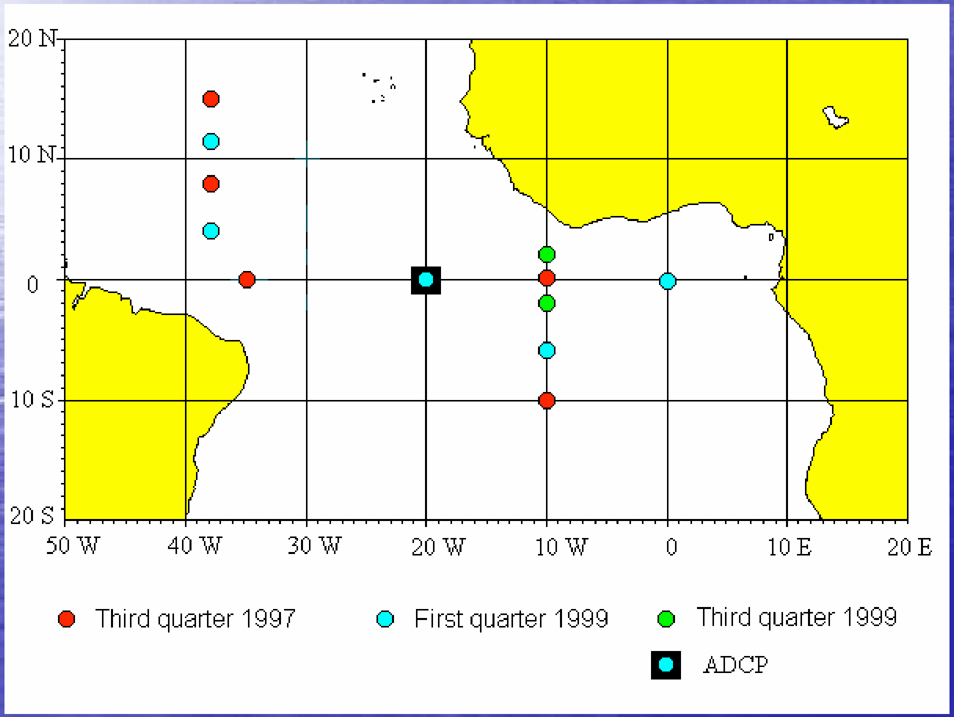
- Depth range varies with frequency
  - 600 kHz 70-85m
  - 300 kHz 240-300m
- Shipboard data archived Joint Archive for Shipboard ADCP
  - http://ilikai.soest.hawaii.edu/sadcp

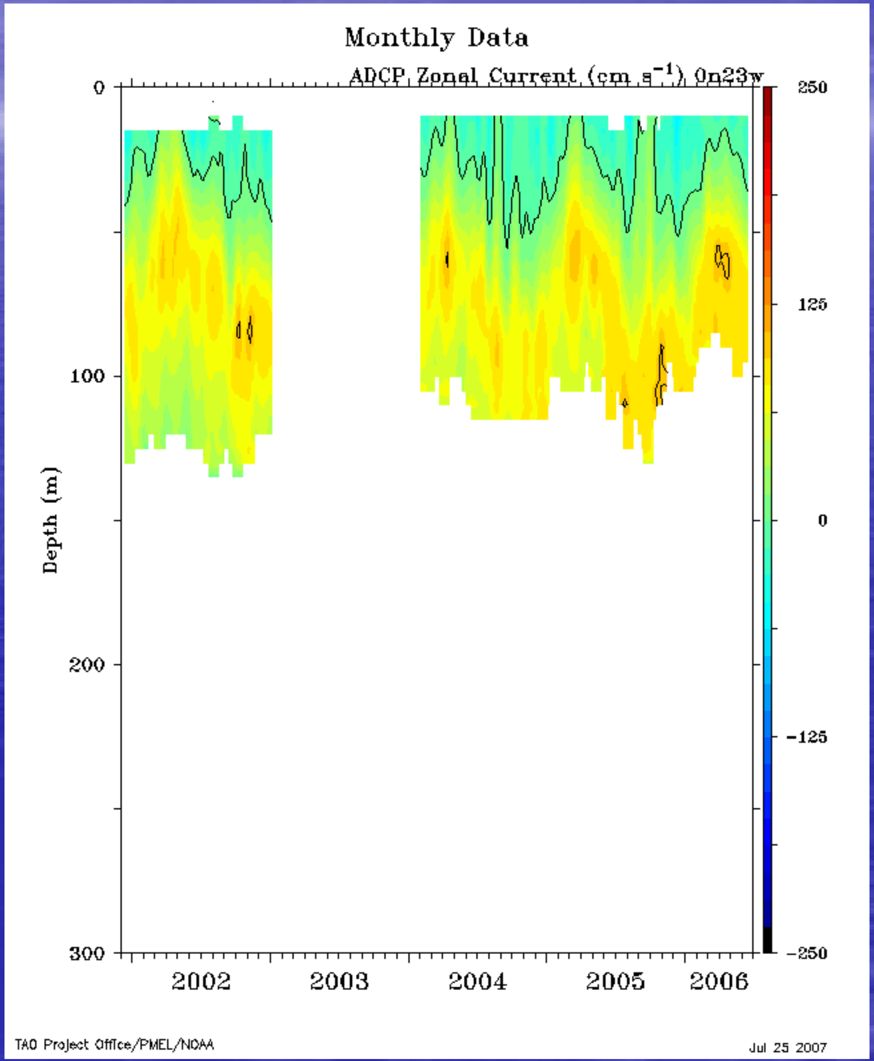


http://www.rdinstruments.com/hadcp.html

Ship section across the equator:
http://moli.soest.hawaii.edu/kaimi/ka9701L1/sectE.gif

Zonal currents from ADCP installed on the PIRATA mooring in the equatorial Atlantic at 0N, 23W





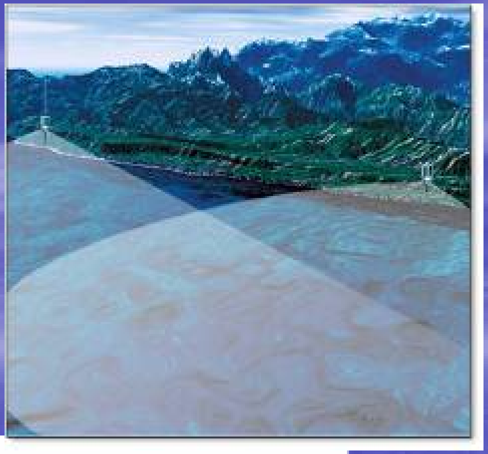
Vector Measuring Current Meter (VMCM)

Batteries →

Sea Tech Transmissometer →

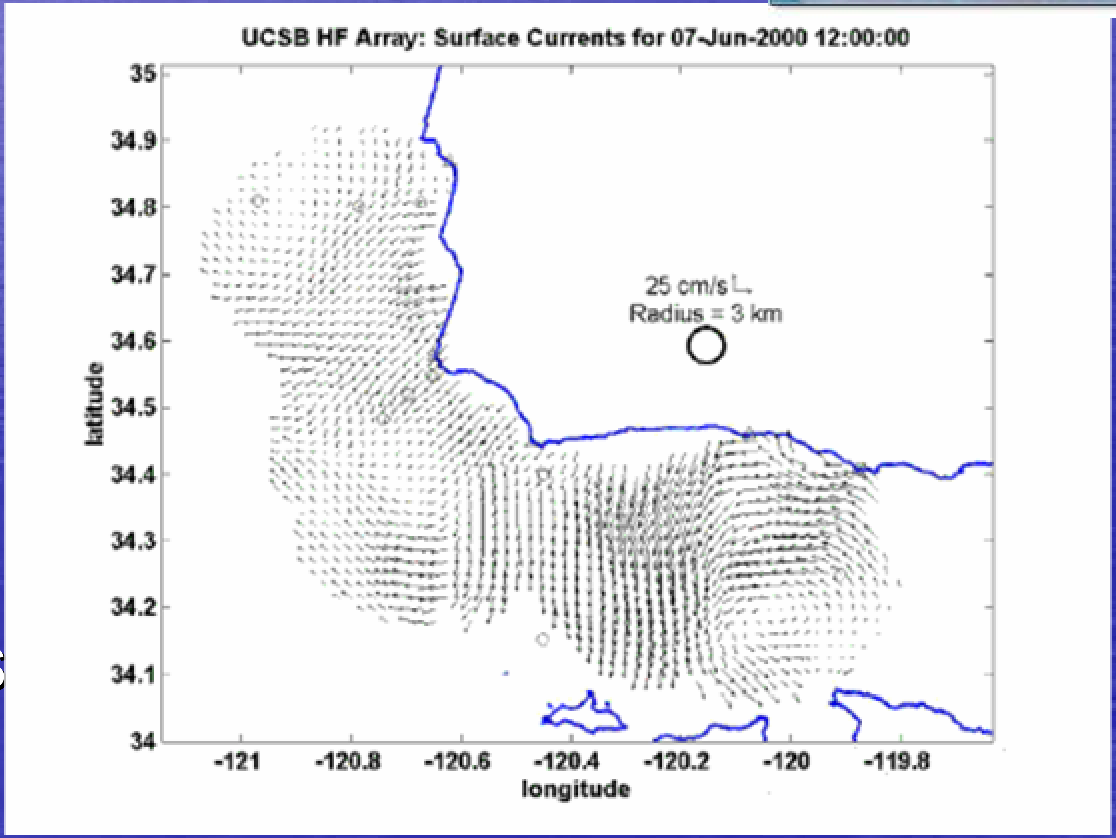
http://woodshole.er.usgs.gov/staffpages/mmartini/instment/vmboston.htm

CODAR



http://www.codaros.com/seasonde.htm

- Bragg scattering of RADAR pulse
- 50 Watt transmitter at 13 Mhz
- Range: 40-70km, 1km res

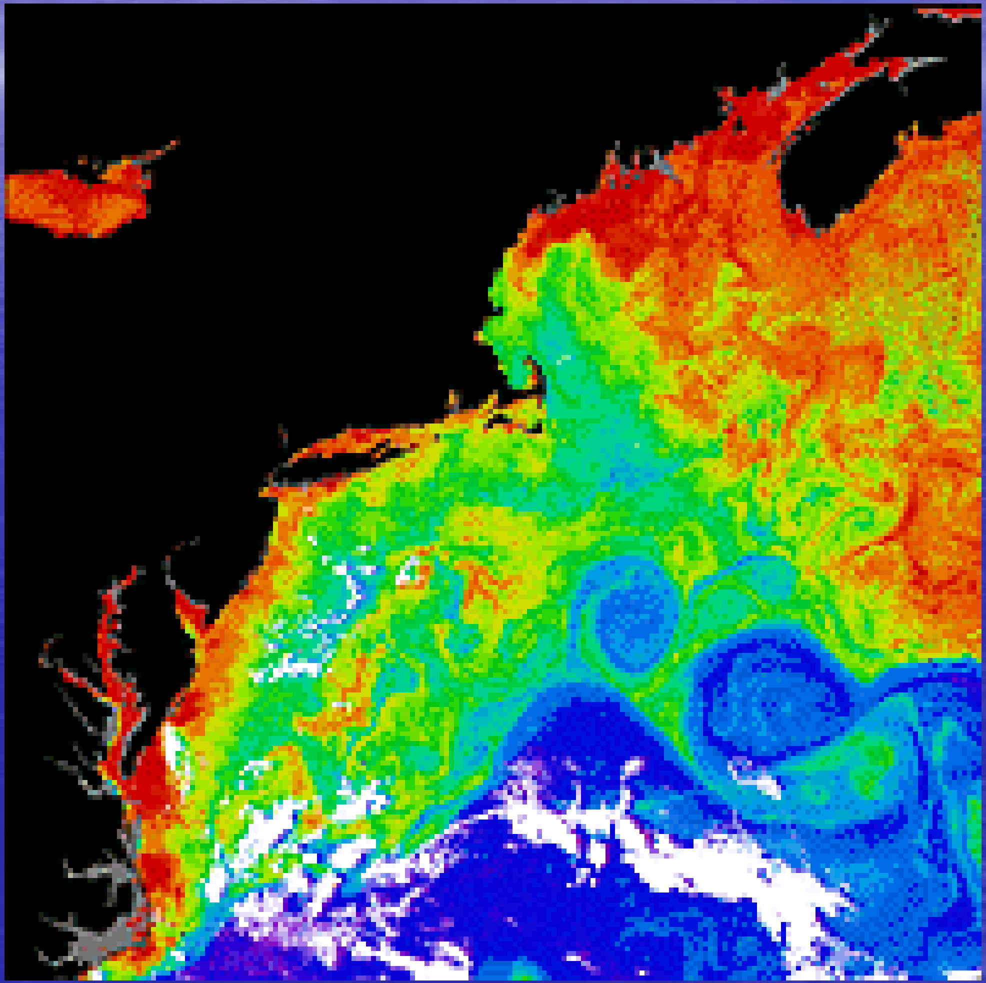


http://www.icess.ucsb.edu/iog/codar.htm

Remote sensing of the oceans

- Orbits
- Electromagnetic spectrum
  – Atmospheric absorption, properties of the ocean
- Passive vs Active instruments
  – Lots of examples

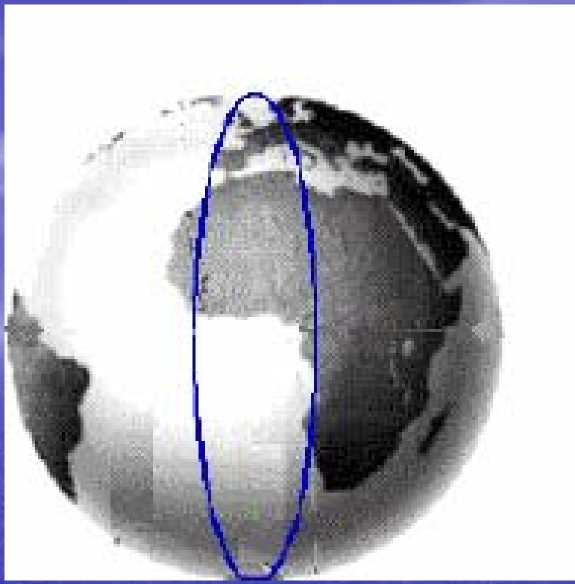
Ocean color



http://daac.gsfc.nasa.gov/CAMPAIGN_DOCS/OCDST/what_is_ocean_color.html

Orbits

- Low Earth Orbit (400-1500 km) :
  - often sun-synchronous orbit
- High Earth Orbit (36000 km):
  - Geosynchronous orbit



Near polar orbit

Footprints of GOES and Meteosat

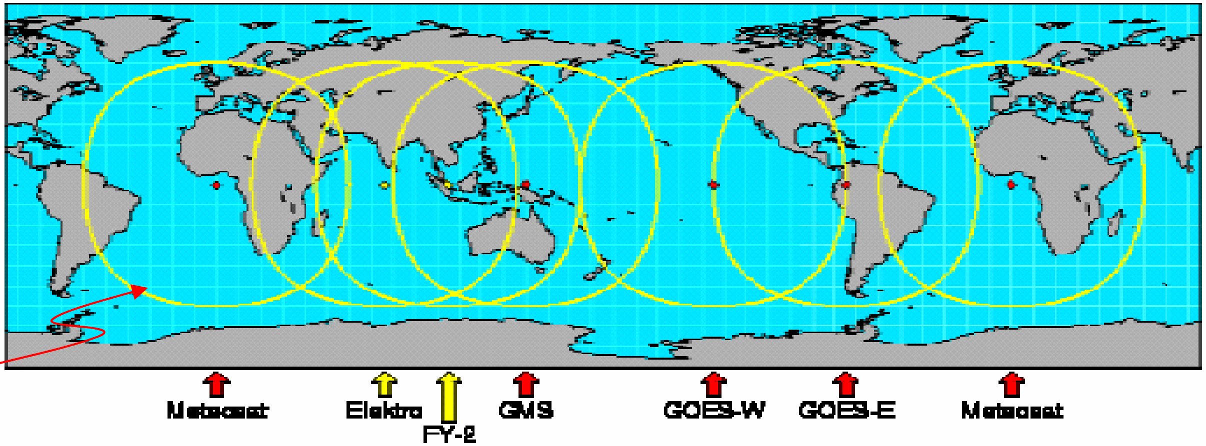


Figure 3.3 Example of geostationary satellite coverage

Passive sensors

Detect the Sun radiation reflected by the Earth of the Earth thermal radiation

SST

Ocean color

Active Sensors

Send electromagnetic pulse and detect the backscattered radiation.

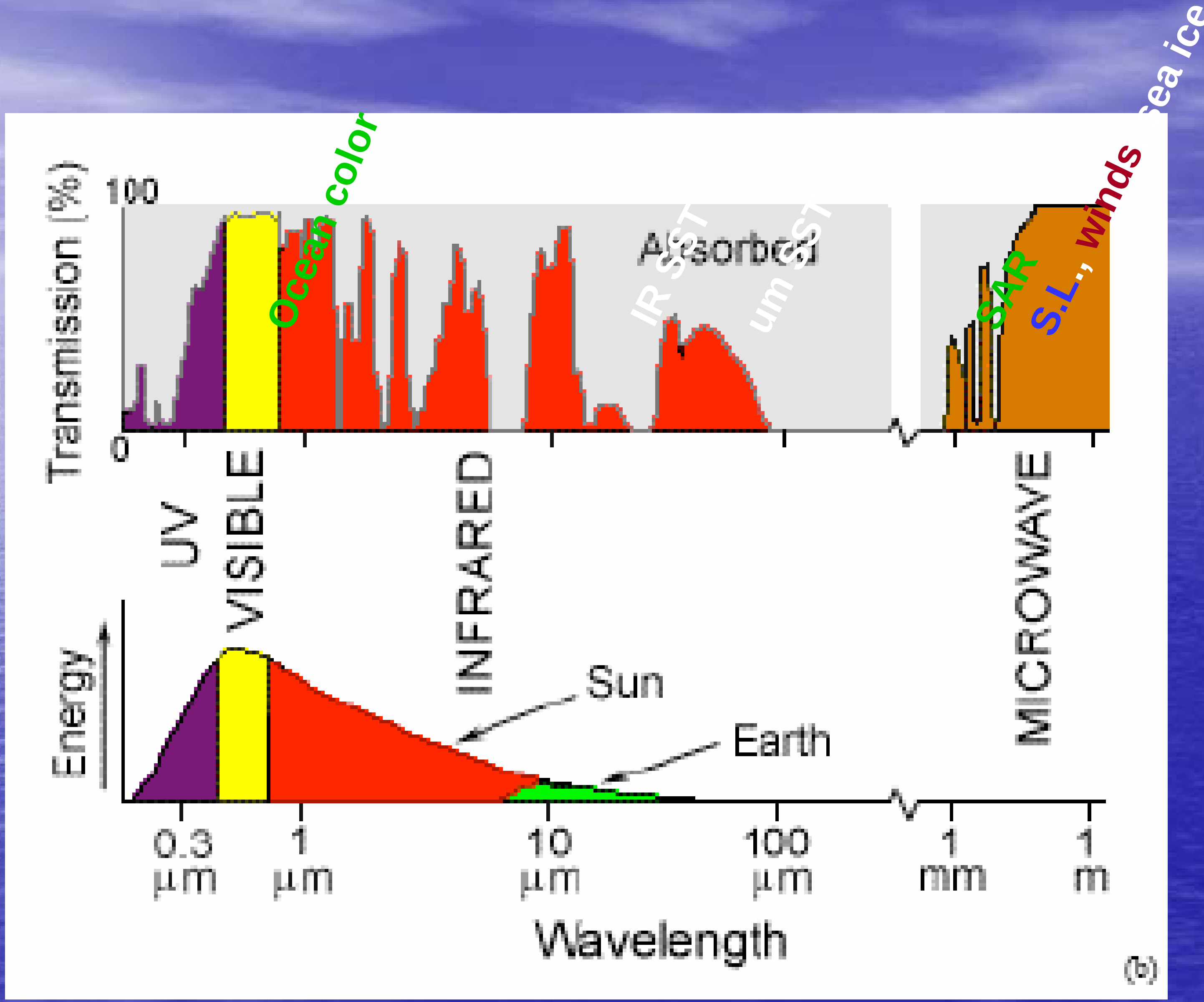
Ocean winds

Sea level

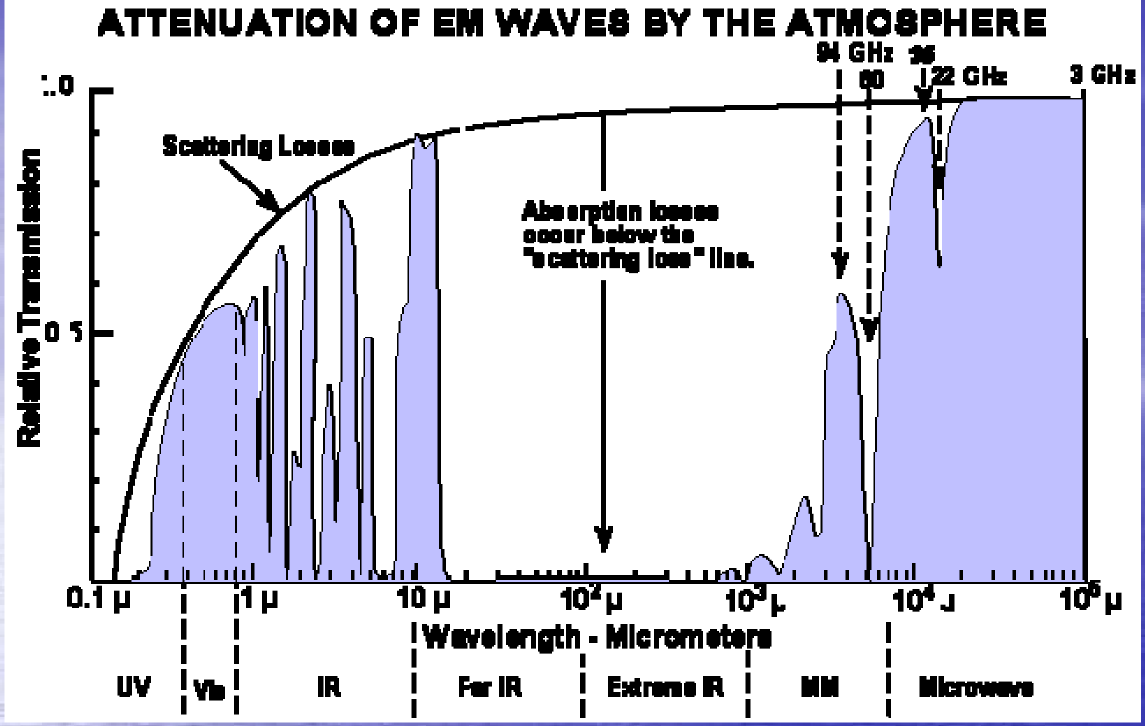
Precipitation

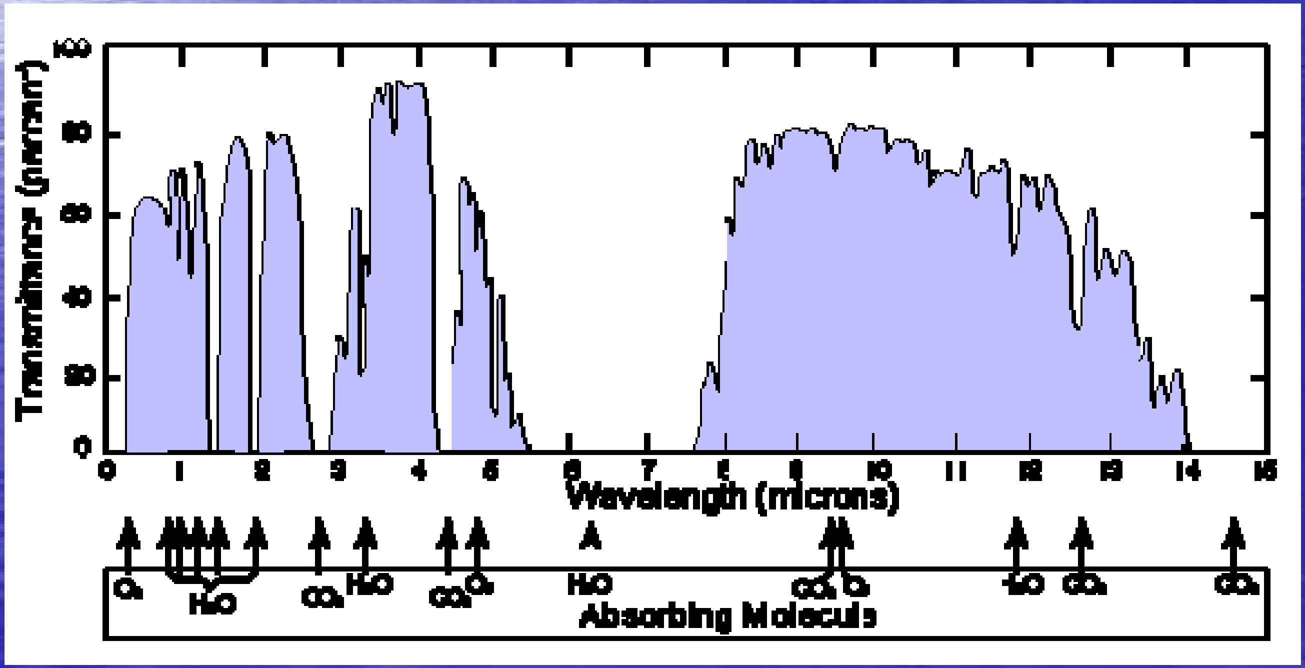
Surface Waves

Surface heat flux

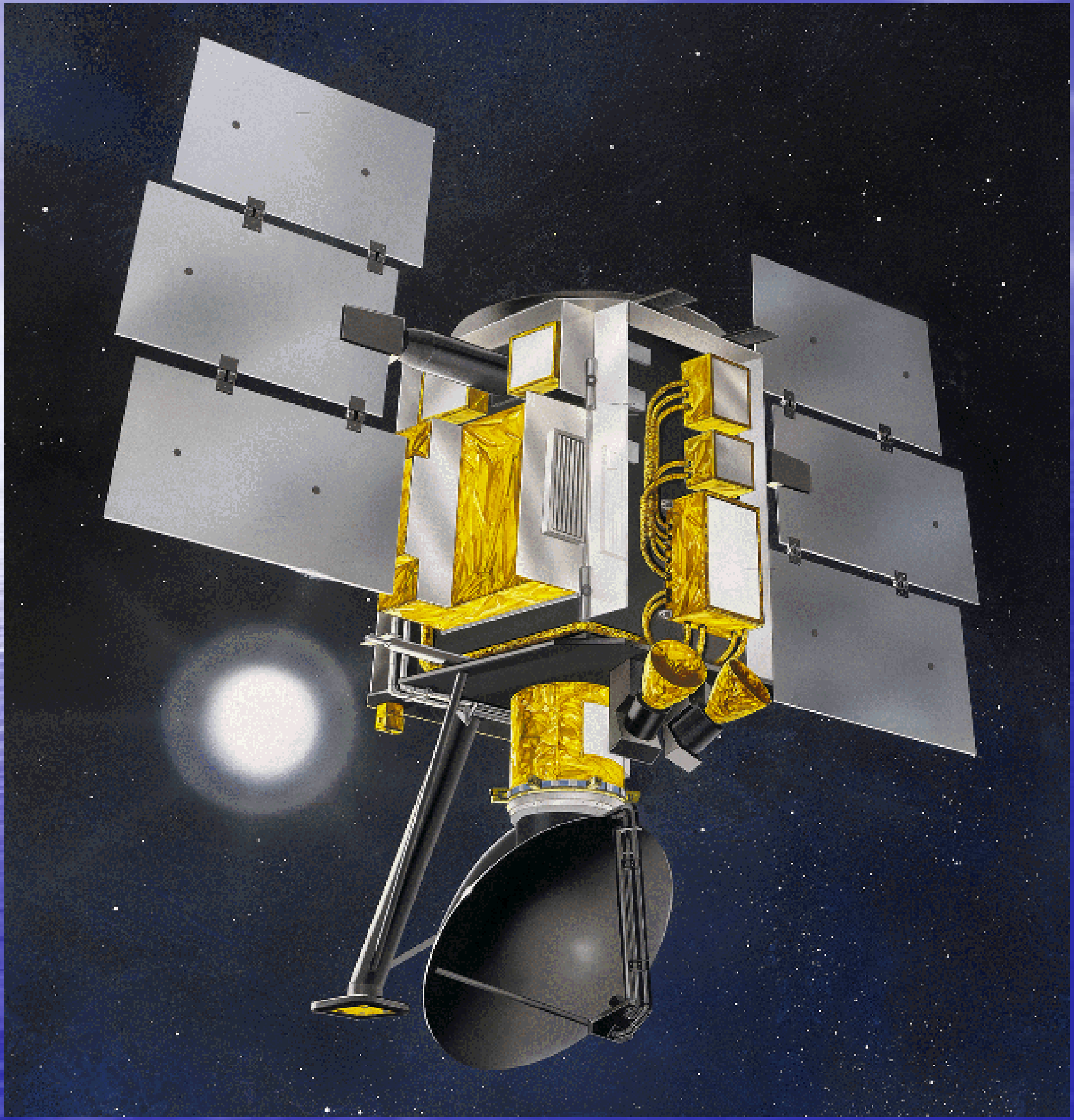


http://rseol.gsfc.nasa.gov

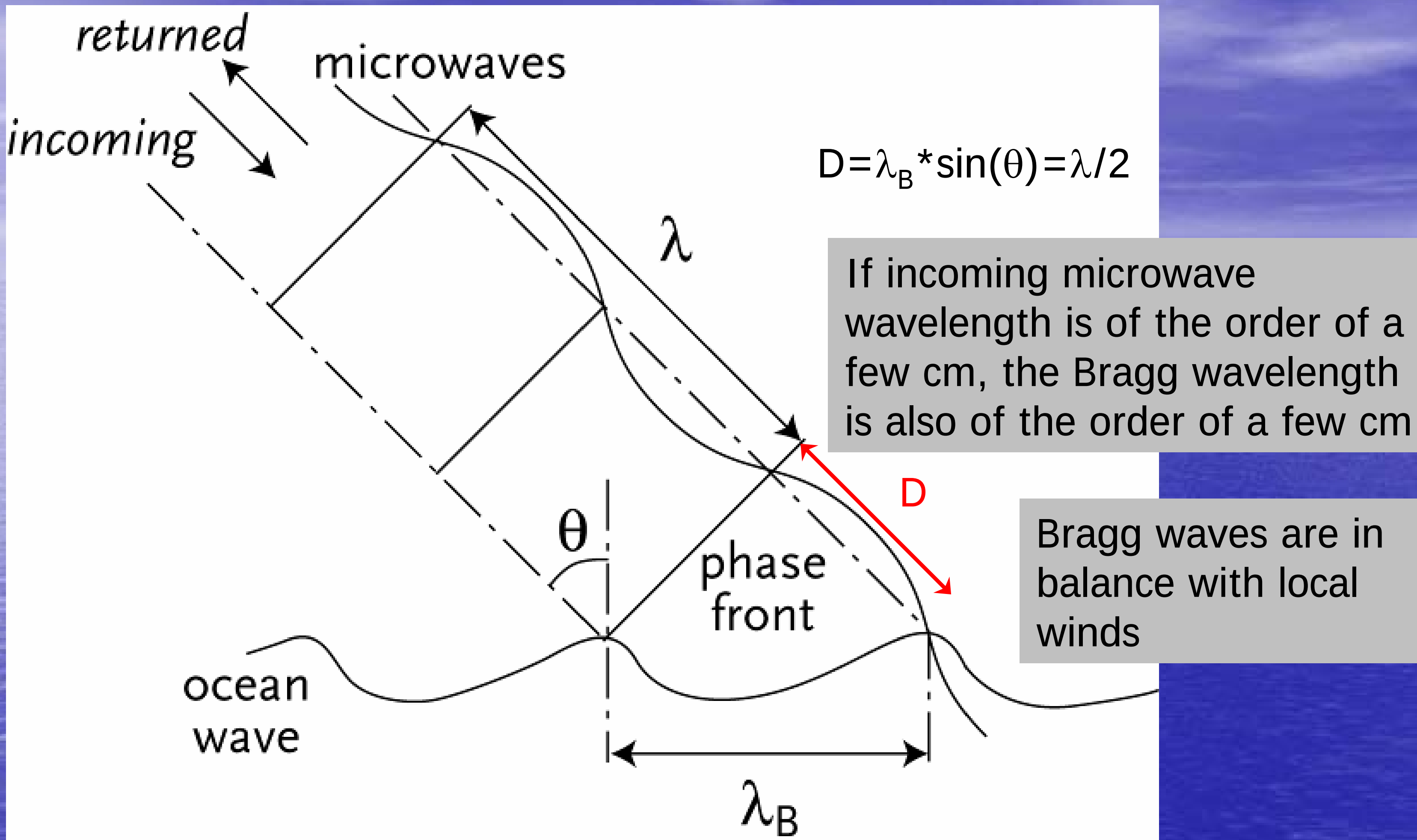

ATTENUATION OF EM WAVES BY THE ATMOSPHERE
Scattering Losses
Absorption losses occur below the "scattering loss" line.
94 GHz
60
35
22 GHz
3 GHz
Relative Transmission
0.5
0.1 μ
1 μ
10 μ
10^2 μ
10^3 μ
10^4 μ
10^5 μ
Wavelength - Micrometers
UV
Vis
IR
Far IR
Extreme IR
MM
Microwave


Transmittance (percent)
100
80
60
40
20
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Wavelength (microns)
O_3
H_2O
CO_2
H_2O
CO_2
O_3
H_2O
CO_2
O_3
H_2O
CO_2
CO_2
Absorbing Molecule

Scatterometry, Satellite ocean winds

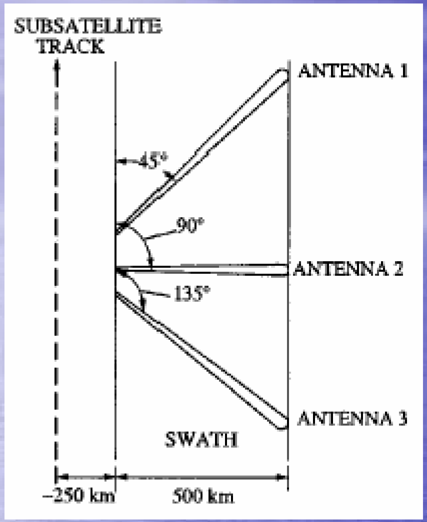


Scatterometer measures the normalized radar cross-section of the ocean surface (by comparing the power of transmitted and returned signals) from which the near-surface wind is estimated. Radar cross-section is a function of the ocean surface roughness which is created primarily by wind-generated waves. Thus wind speed and direction can be inferred.

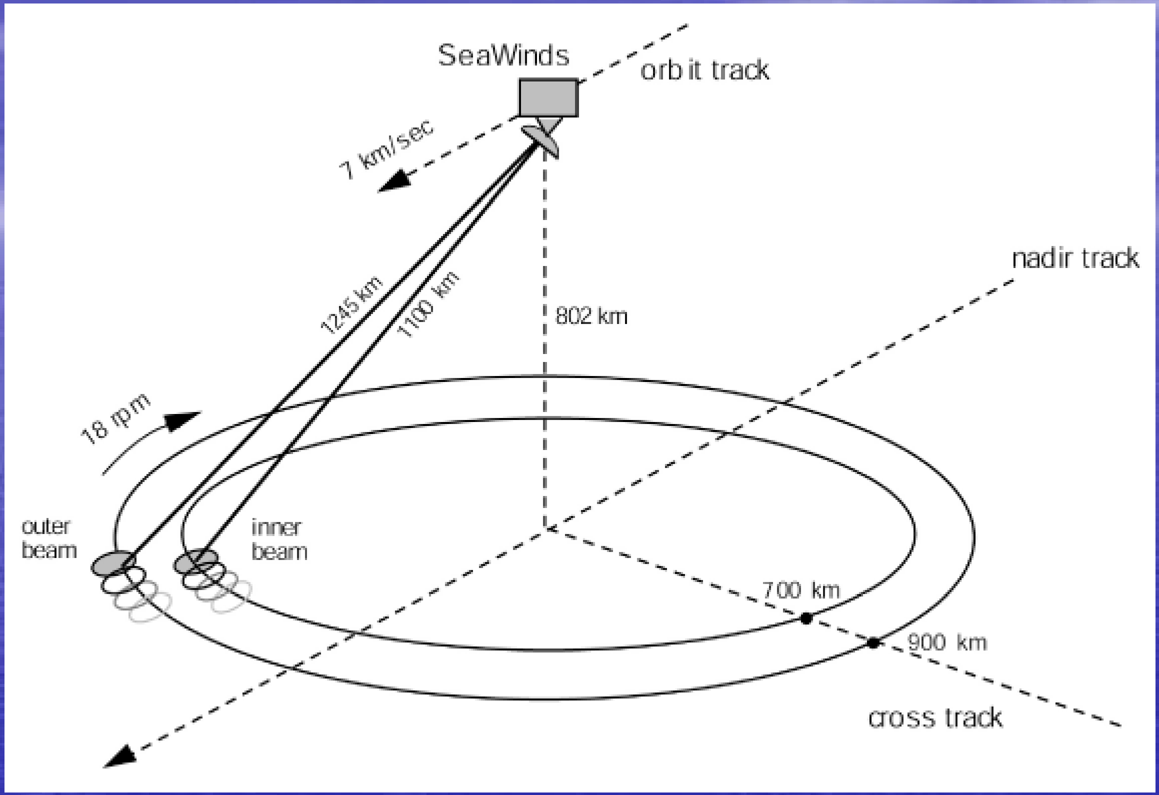


Bragg scattering: A plan-parallel radar beam with wavelength λ hits the rough ocean surface at incidence angle θ, where capillary gravity waves with Bragg wavelength λ_B will cause microwave resonance.

Scatterometer wind direction retrieval



Discrete angular beams



Conical angular scanning. SeaWinds viewing geometry. Image courtesy of Spencer, Wu, and Long (2000).

Mean winds are significant in the trade wind areas and south of 40S.

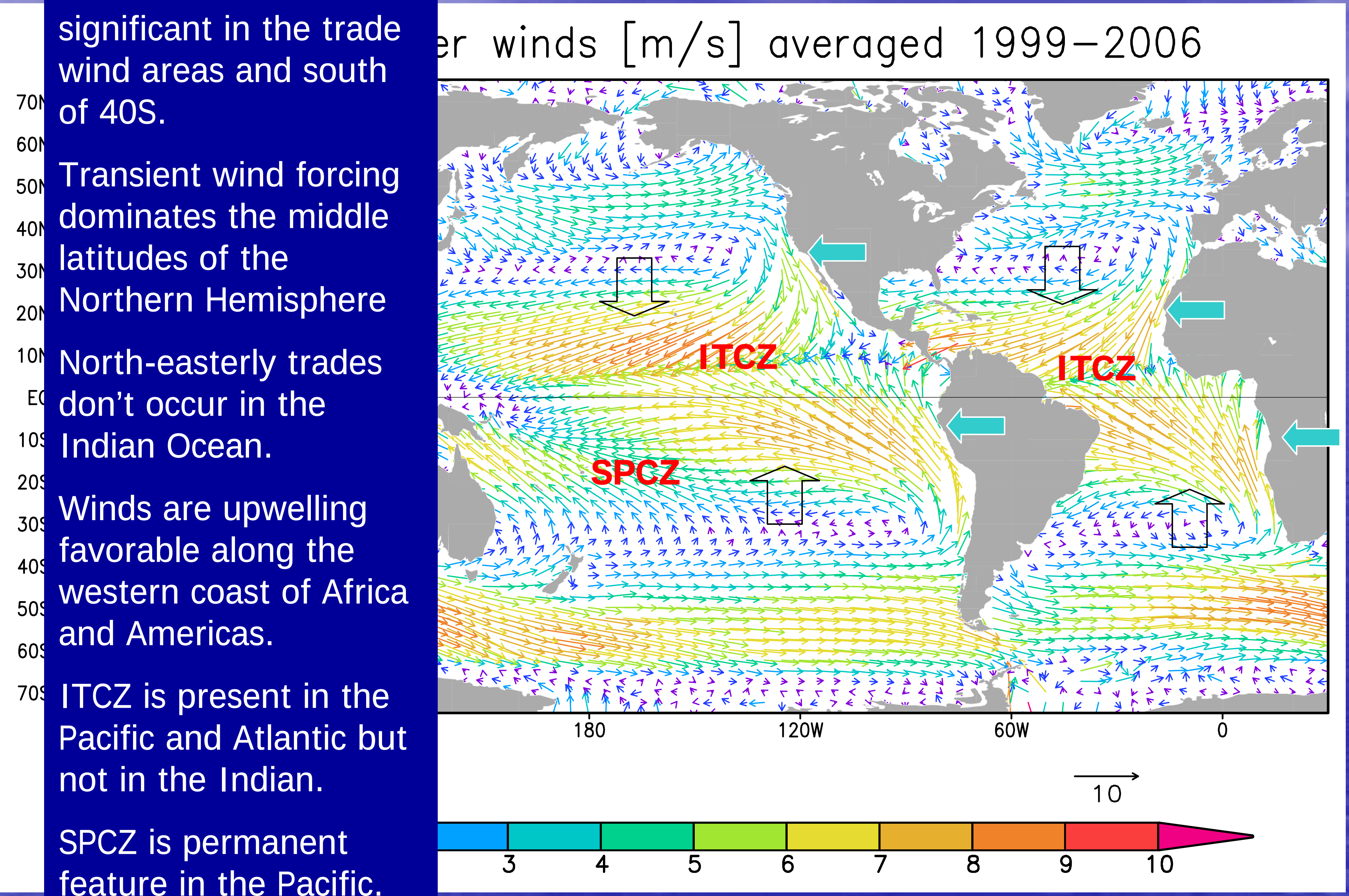
Transient wind forcing dominates the middle latitudes of the Northern Hemisphere

North-easterly trades don't occur in the Indian Ocean.

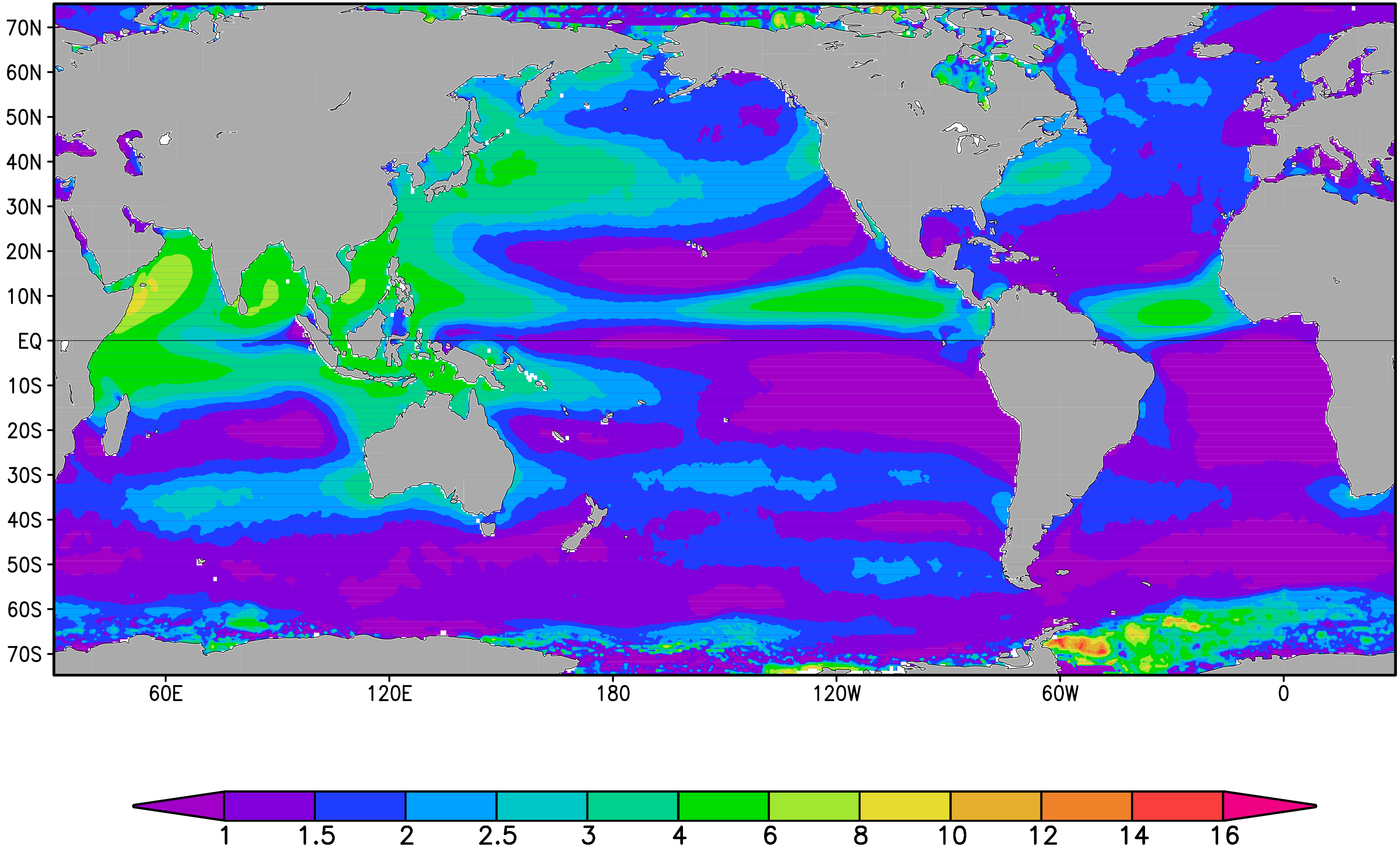
Winds are upwelling favorable along the western coast of Africa and Americas.

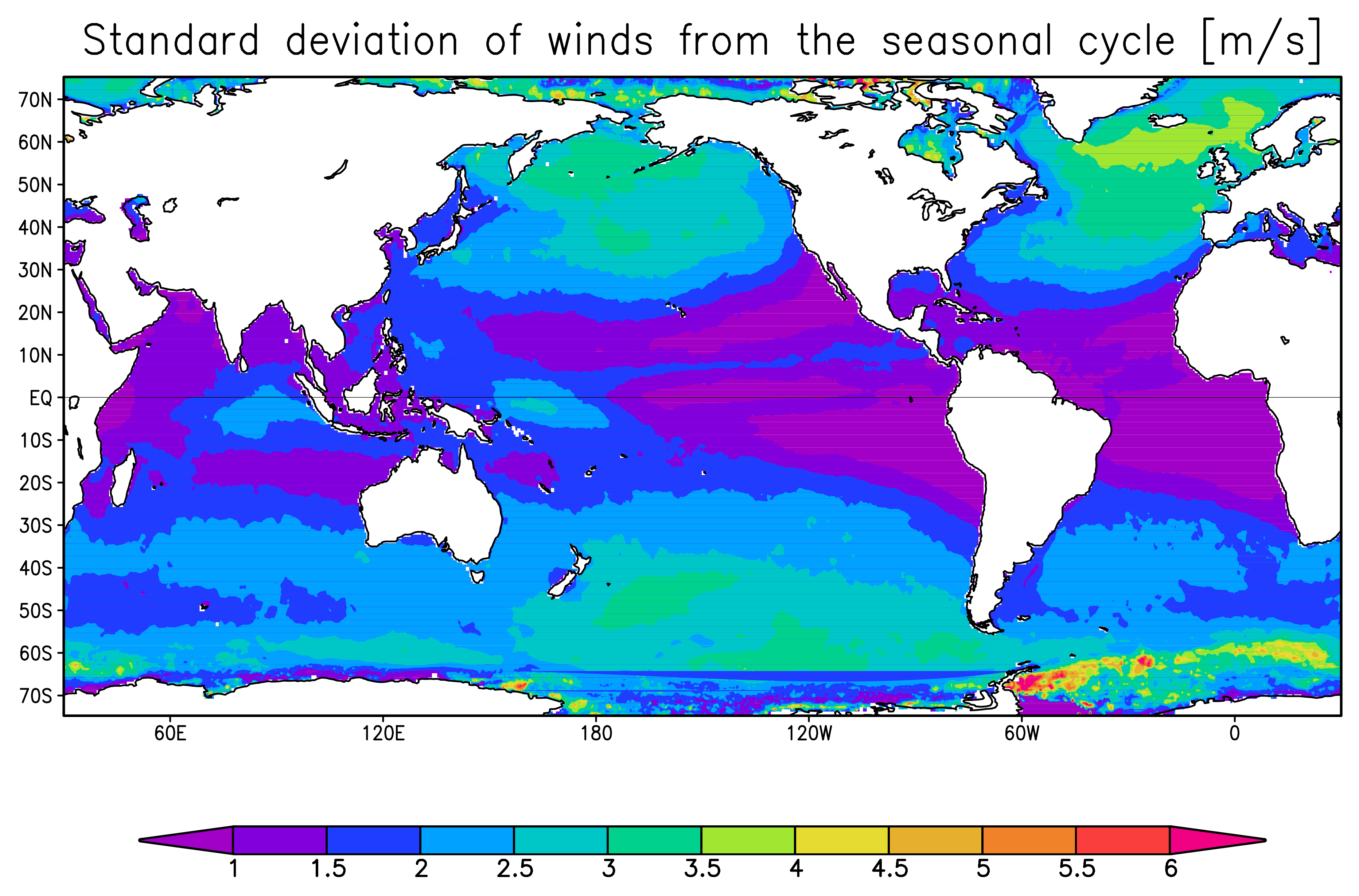
ITCZ is present in the Pacific and Atlantic but not in the Indian.

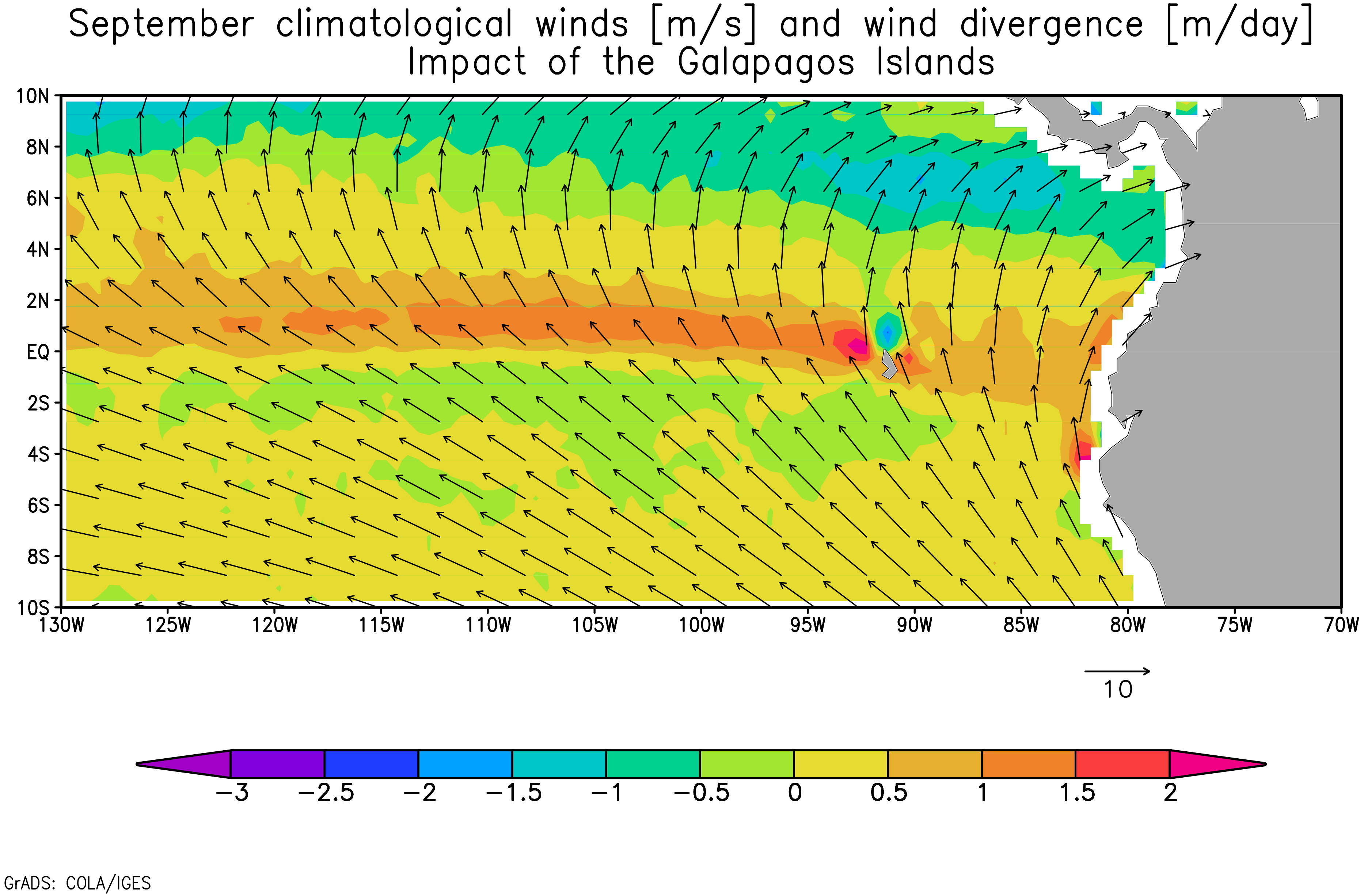
SPCZ is permanent feature in the Pacific. SACZ doesn't show up in mean winds.

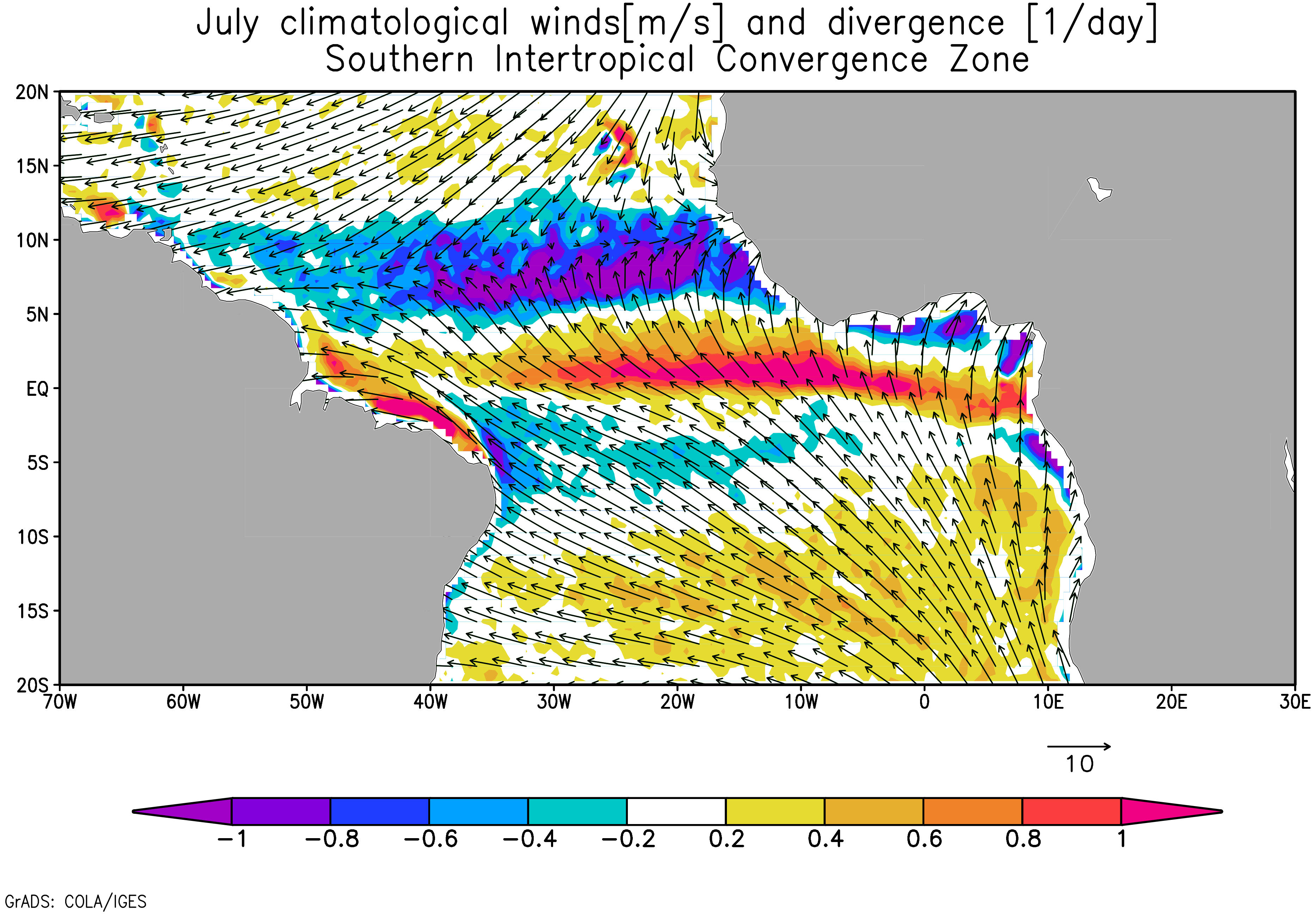


Standard Deviation of seasonaly averaged winds [m/s]



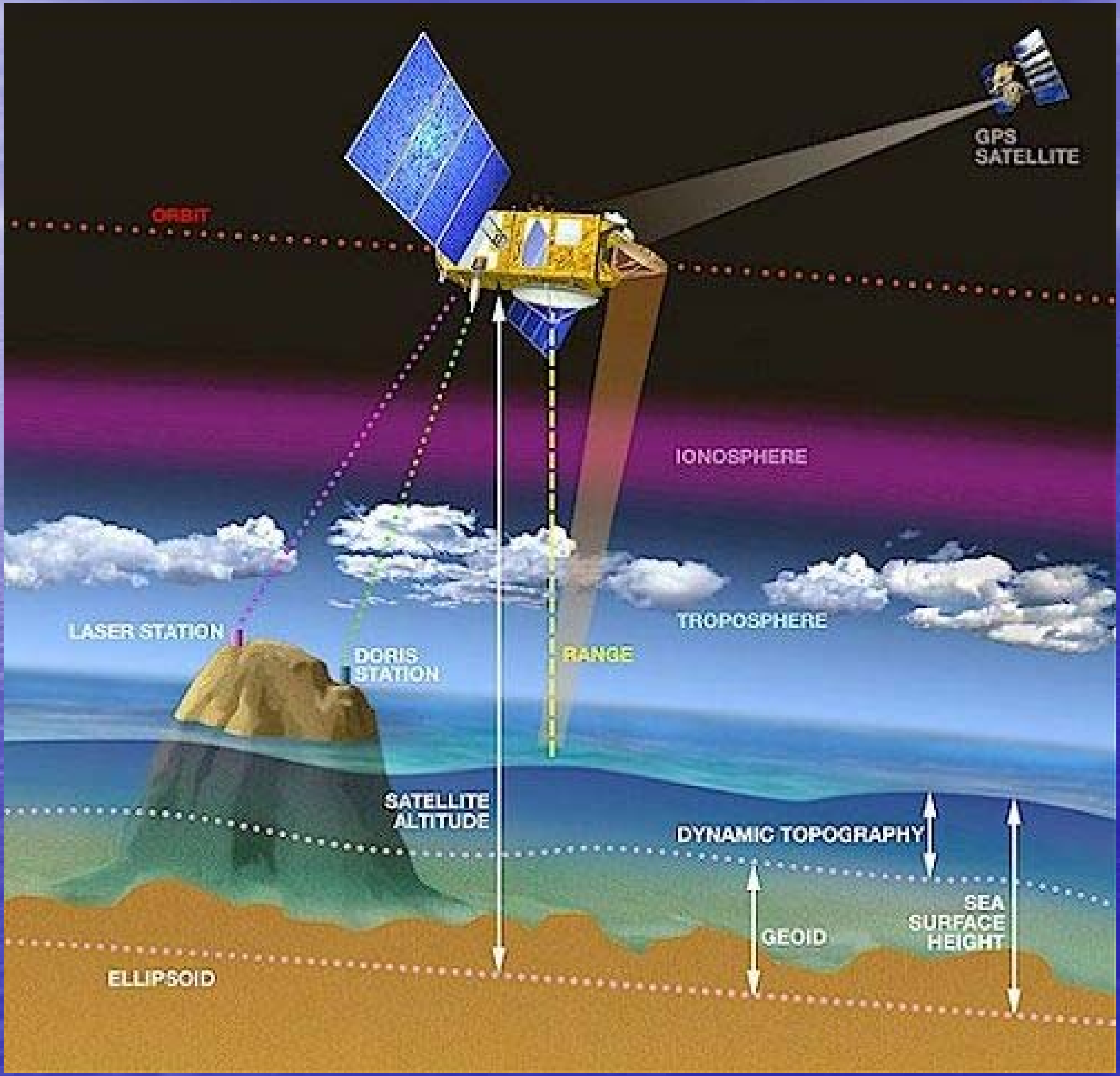

Standard deviation of winds from the seasonal cycle [m/s]
70N
60N
50N
40N
30N
20N
10N
EQ
10S
20S
30S
40S
50S
60S
70S
60E
120E
180
120W
60W
0
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6


September climatological winds [m/s] and wind divergence [m/day]
Impact of the Galapagos Islands
10N
8N
6N
4N
2N
EQ
2S
4S
6S
8S
10S
130W
125W
120W
115W
110W
105W
100W
95W
90W
85W
80W
75W
70W
10
−3
−2.5
−2
−1.5
−1
−0.5
0
0.5
1
1.5
2
GrADS: COLA/IGES



July climatological winds[m/s] and divergence [1/day]
Southern Intertropical Convergence Zone
20N
15N
10N
5N
EQ
5S
10S
15S
20S
70W
60W
50W
40W
30W
20W
10W
0
10E
20E
30E
10
−1
−0.8
−0.6
−0.4
−0.2
0.2
0.4
0.6
0.8
1
GrADS: COLA/IGES

Satellite altimetry



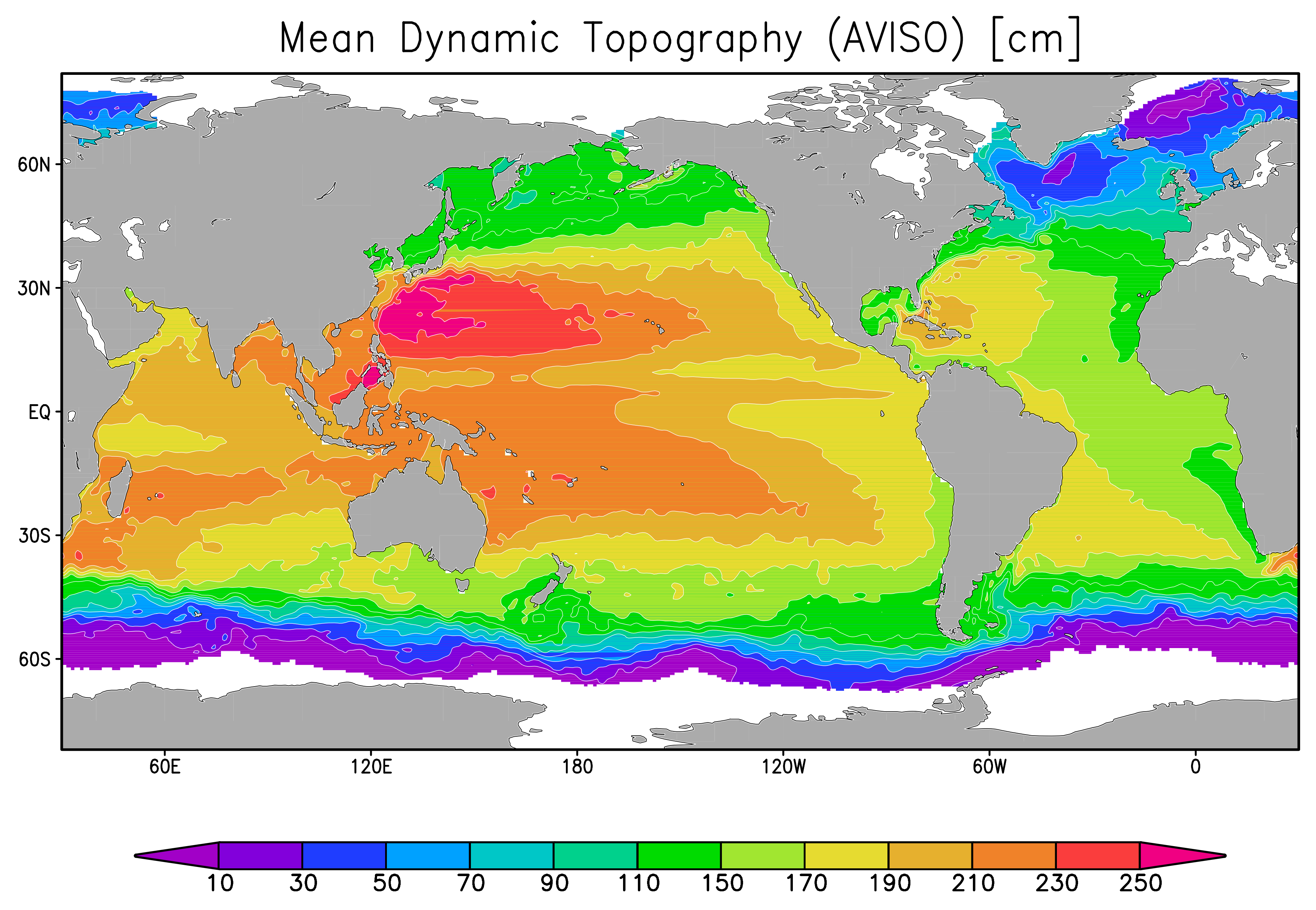
http://www.aviso.oceanobs.com

Satellite altimetry allows to measure the Sea Surface Height (SSH) with a few centimeters precision.

Unfortunately, the satellite orbit is referenced to the earth ellipsoid, and the sea surface elevation measured is also reference to the ellipsoid. This elevation contains the marine geoid plus the sea elevation due to the oceanic circulation (ie the dynamic topography).

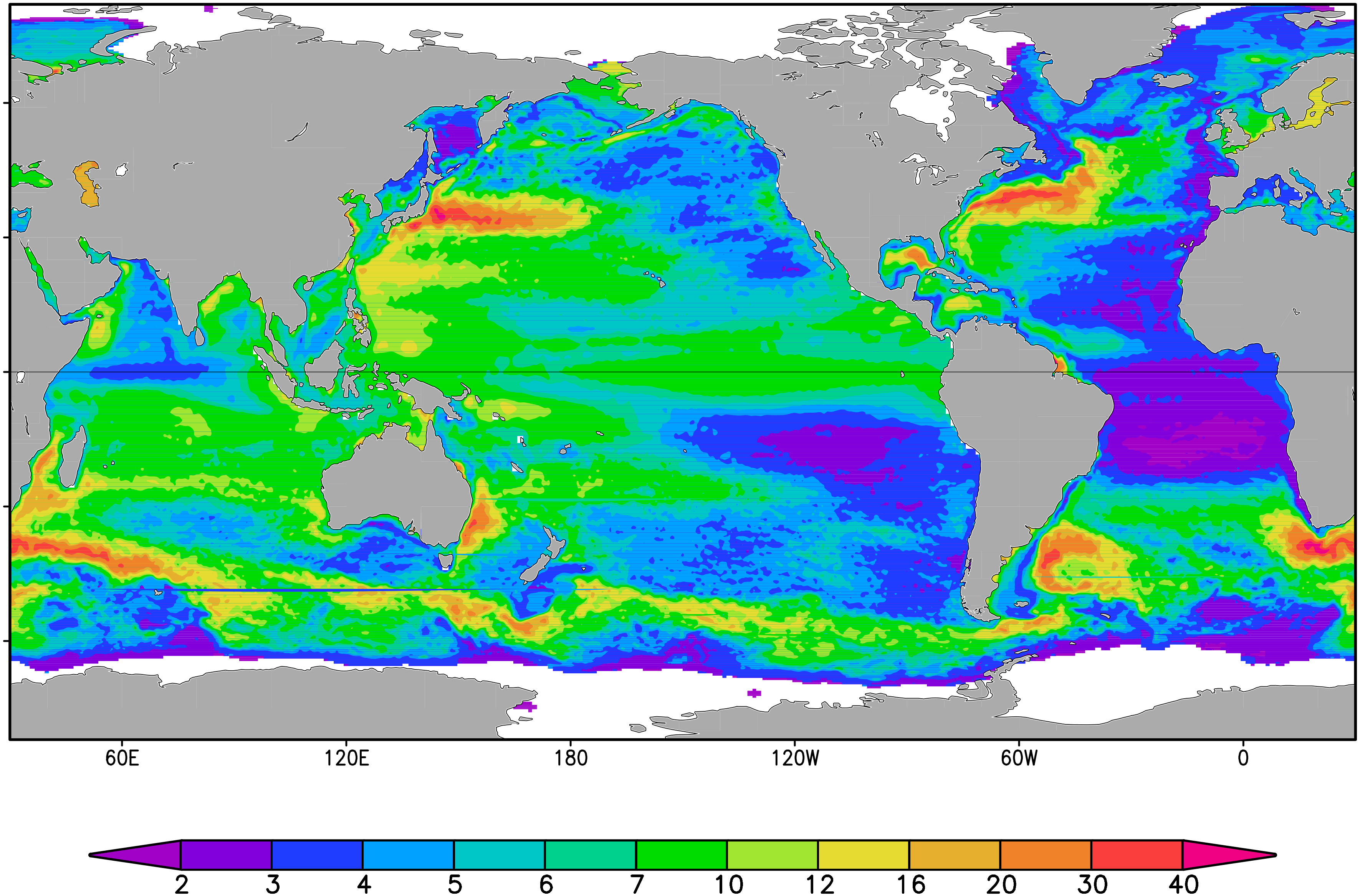
The marine geoid is poorly known (precision of a meter…) but is stationary (not changing over the time). In that way, what we do is to remove the Mean Sea Height (after several altimetric measurements over the same point of the ocean, a mean temporal value can be calculated, and this mean sea height would contains the marine geoid plus the permanent height of the dynamic topography). Then we obtain Sea Level Anomalies.

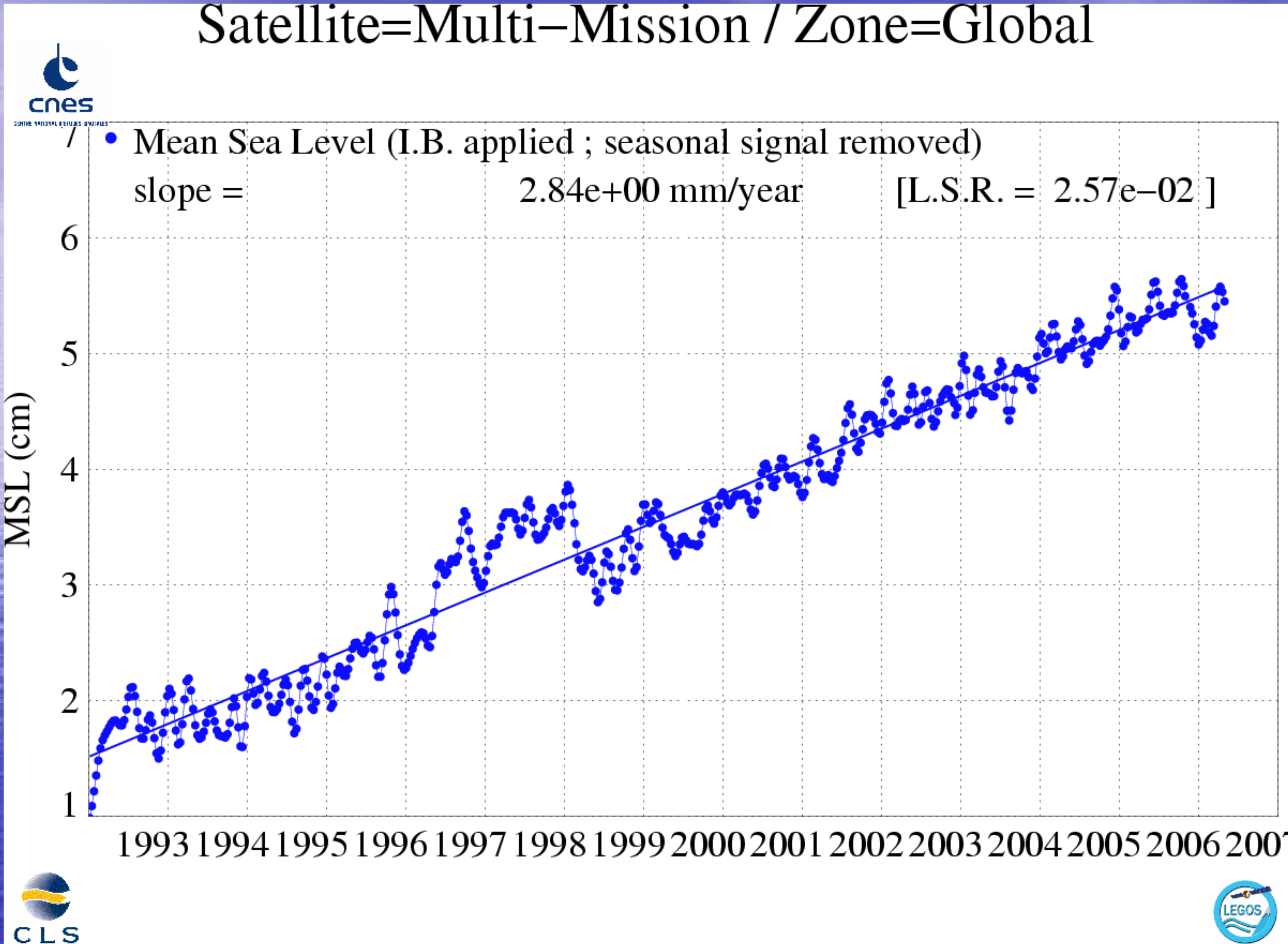
So we can study the VARIABLE PART of the ocean circulation!



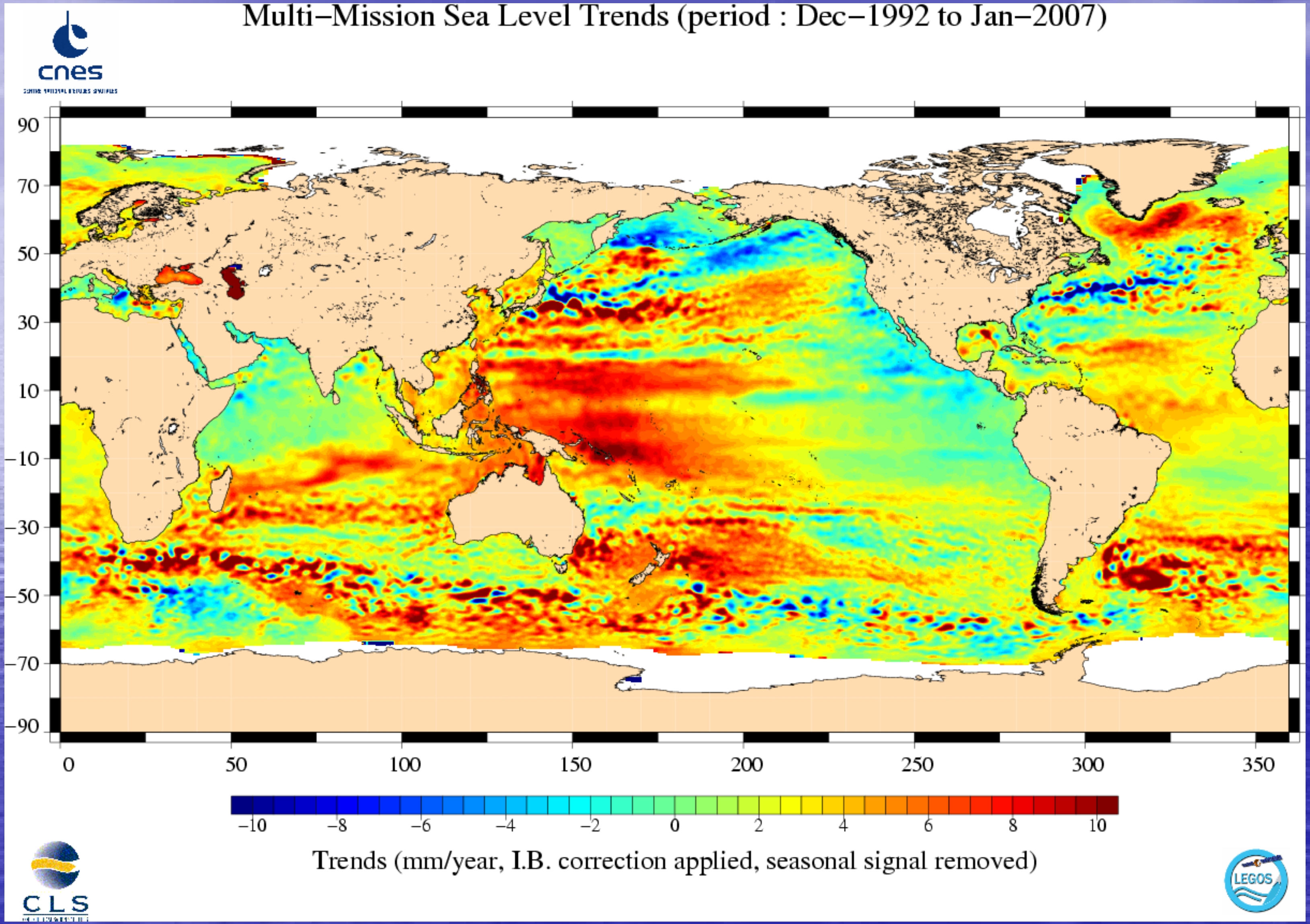
Mean Dynamic Topography (AVISO) [cm]
60N
30N
EQ
30S
60S
60E
120E
180
120W
60W
0
10
30
50
70
90
110
150
170
190
210
230
250

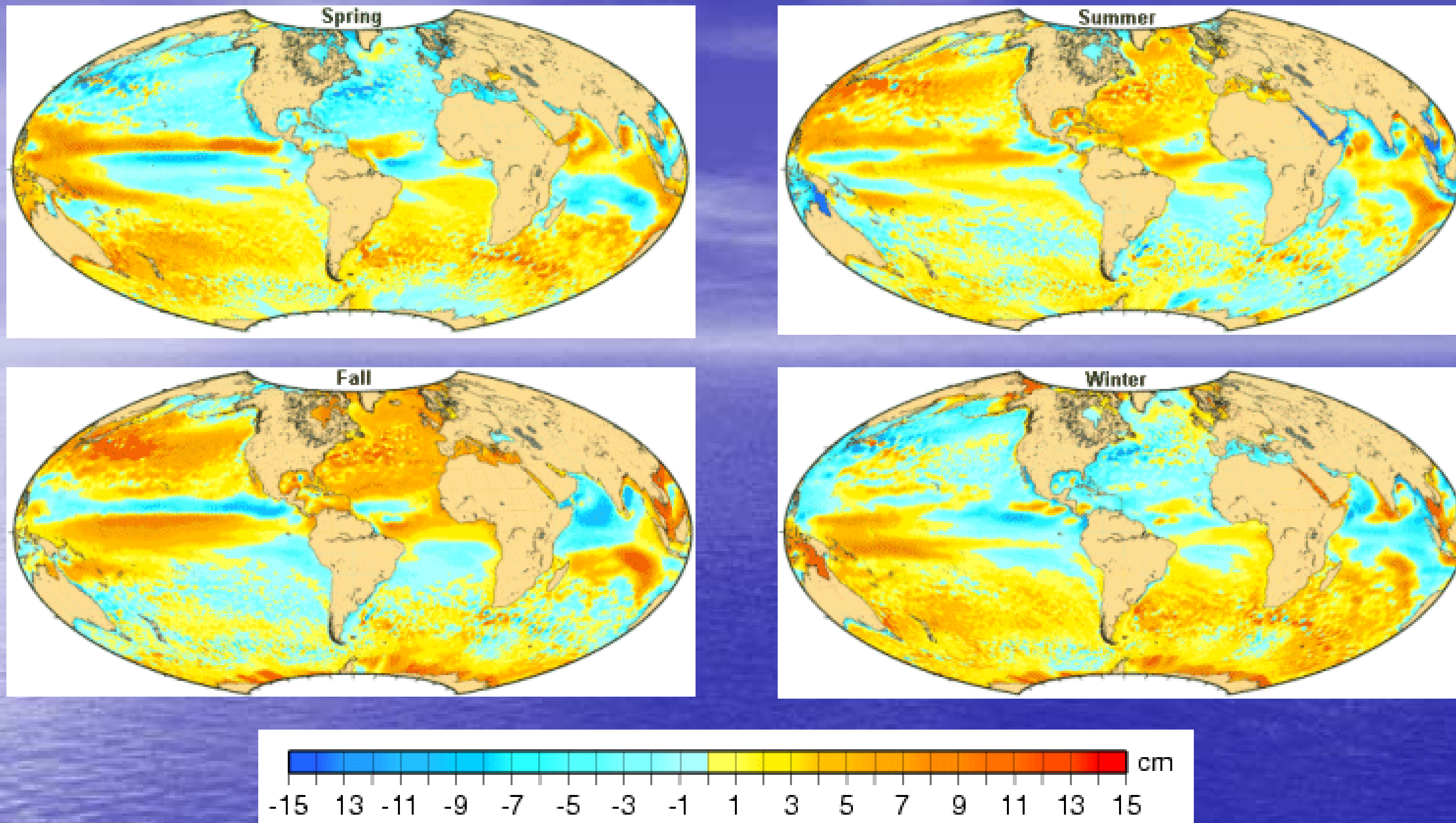
Sea Level STD [cm], 1992–2006





Satellite=Multi−Mission / Zone=Global
Mean Sea Level (I.B. applied ; seasonal signal removed)
slope = 2.84e+00 mm/year [L.S.R. = 2.57e−02]
MSL (cm)
1
2
3
4
5
6
7
1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007

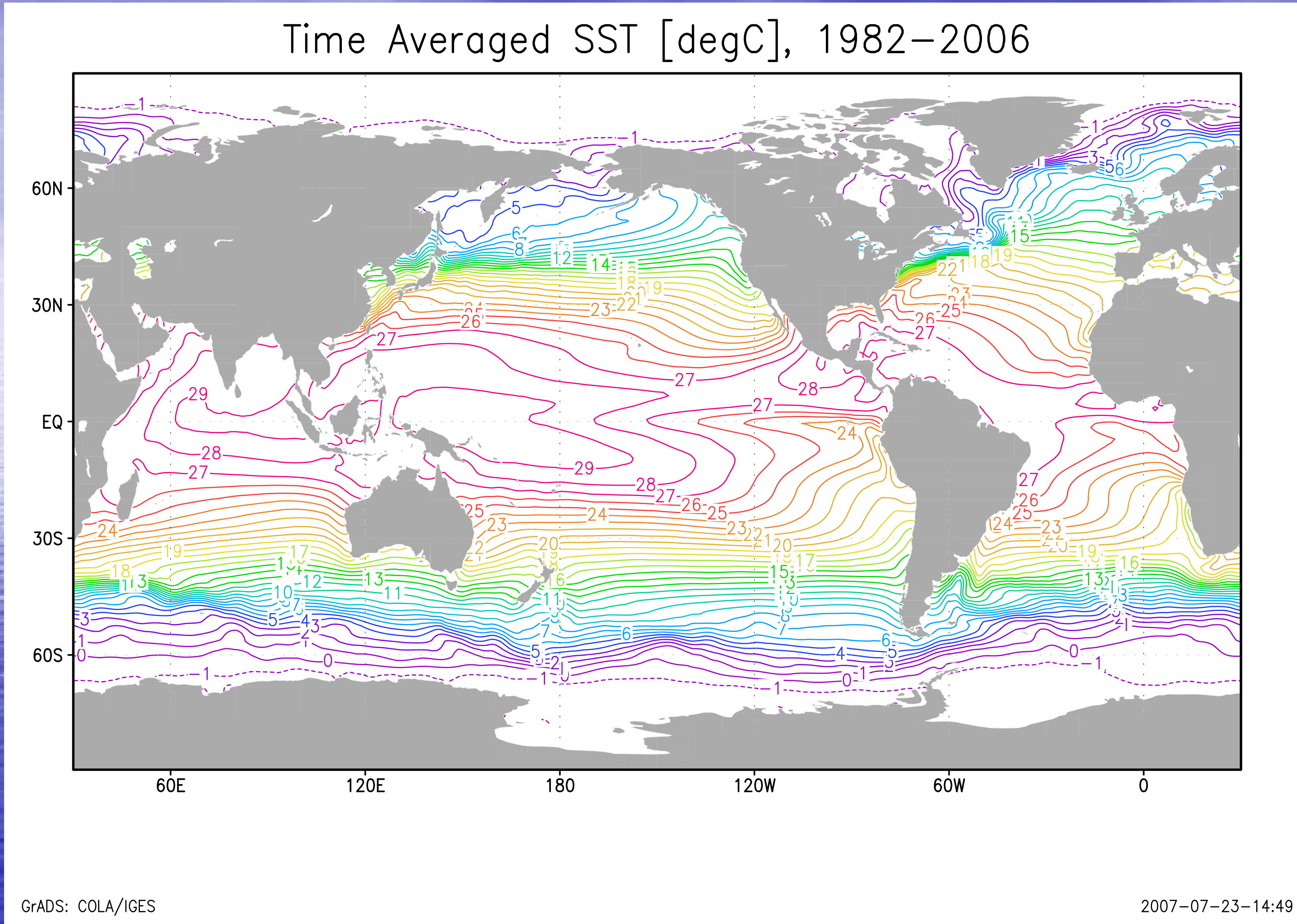

Multi–Mission Sea Level Trends (period : Dec–1992 to Jan–2007)
cnes
90
70
50
30
10
–10
–30
–50
–70
–90
0
50
100
150
200
250
300
350
–10
–8
–6
–4
–2
0
2
4
6
8
10
Trends (mm/year, I.B. correction applied, seasonal signal removed)
CLS
LEGOS



Seasonal variation of sea level. The water warms in Summer, and cools in Winter, thus explaining a difference of about + or - 10 cm in the sea level between the seasons, with the seasons being inversed in the Northern and Southern Hemisphere.

Moreover, ocean stays warm or cold for some time, with a roughly two months delay with the calendar seasons, thus explaining the highs or lows in Fall or Spring.

The amplitude of the variations in sea level due to the seasons shows the quantity of heat kept in stock in the ocean, and thus its impact on the climate.


Time Averaged SST [degC], 1982–2006
60N
30N
EQ
30S
60S
60E
120E
180
120W
60W
0
GrADS: COLA/IGES
2007–07–23–14:49

Satellite SST datasets

- Objectively analyzed AVHRR (Infra Red) plus *in situ* SST (*Reynolds and Smith*), 1982-present

http://www.emc.ncep.noaa.gov/research/cmb/sst_analysis/

- Microwave SST from the Tropical Rainfall measuring Mission Temperature Microwave Imager (TMI), 1998-present

http://www.ssmi.com

SST

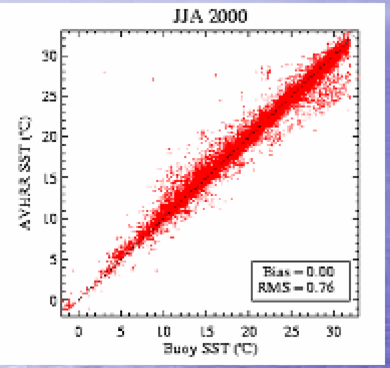
- **Infrared (near 3.7 µm for night, near 10 µm for day)**
  - Advanced Very High Resolution Radiometer (AVHRR)
  - Along-Track Scanning Radiometer (ATSR [ERS series])
  - Geostationary Operational Environmental Satellite (GOES) Imager
  - Moderate Resolution Imaging Spectro-radiometer (MODIS)
- **Microwave (7-10 GHz)**
  - Scanning Multichannel Microwave Radiometer (SMMR)
  - TRMM Microwave Imager (TMI)
  - Advanced Microwave Scanning Radiometer (AMSR)

John Maurer, UC Boulder http://cires.colorado.edu/~maurerj/class/SST_presentation.htm

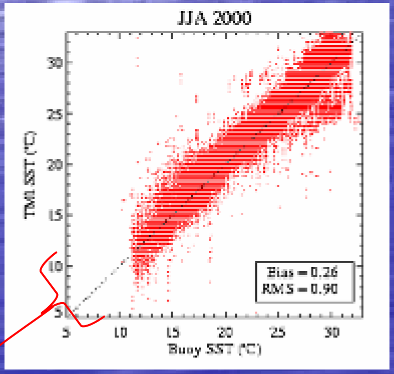
Infrared vs microwave SST

Better coverage vs better spatial resolution & accuracy

infrared

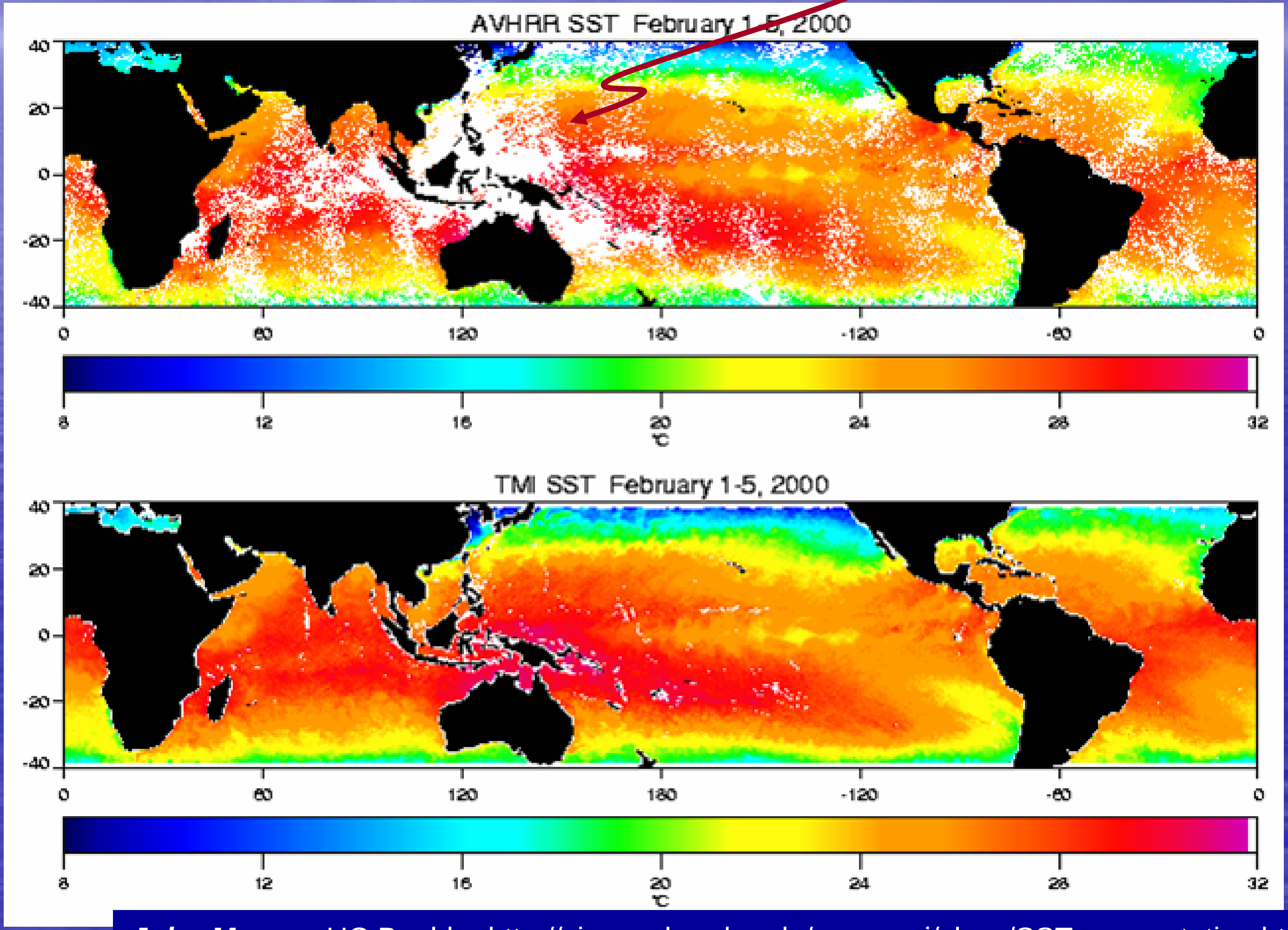


microwave

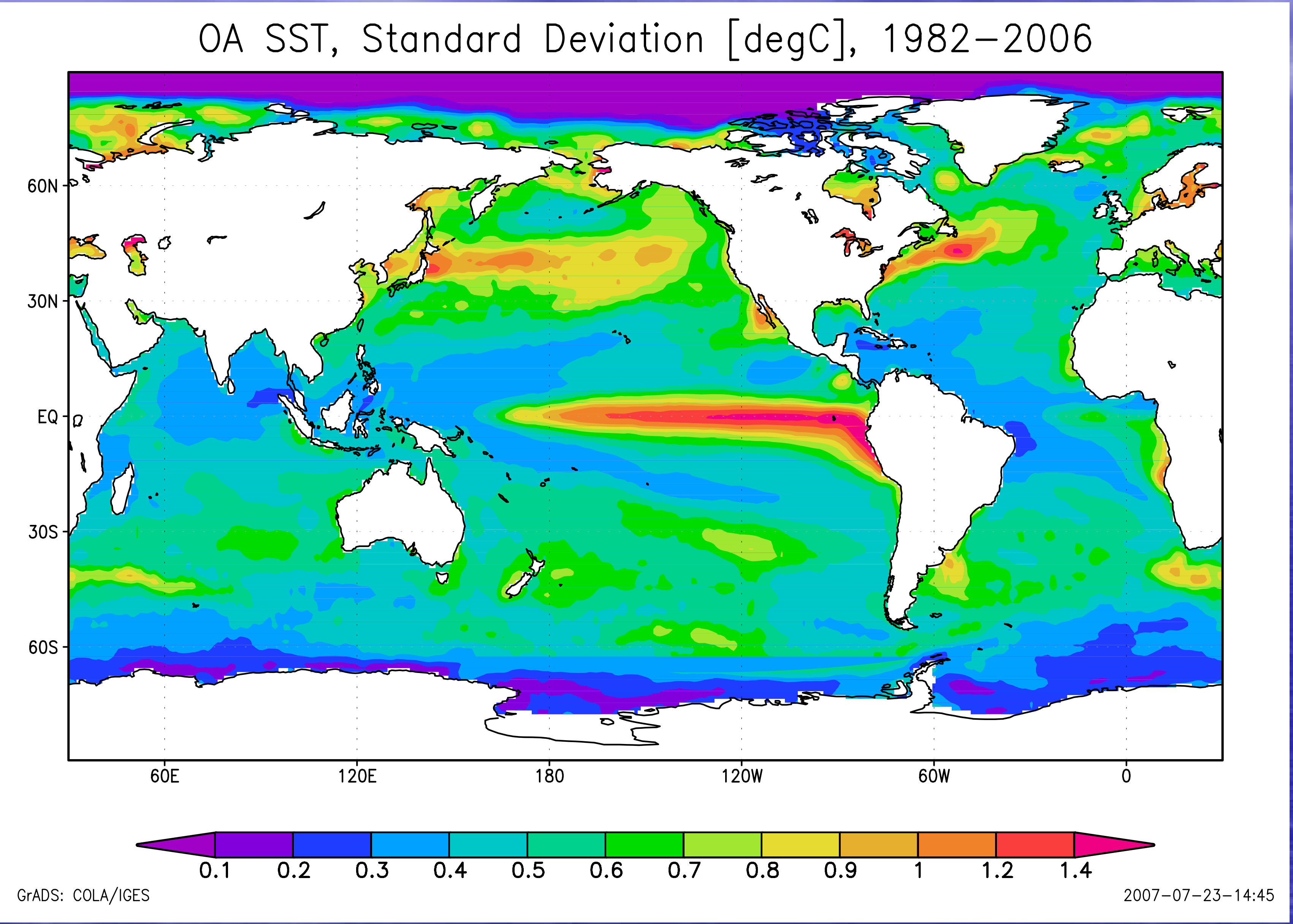


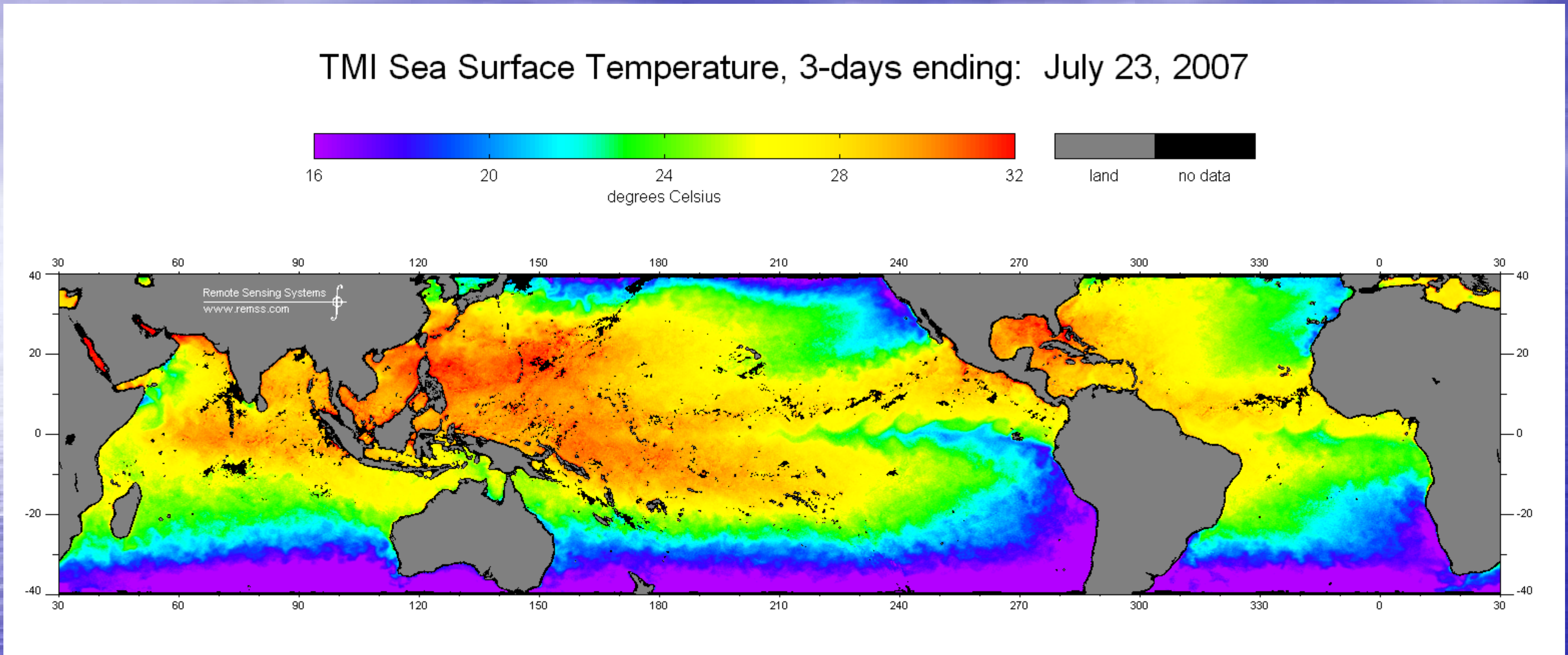
Larger uncertainty

More cloud contamination

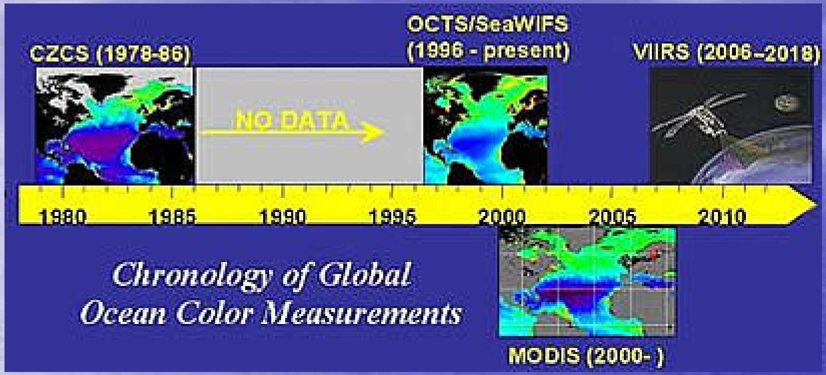


John Maurer, UC Boulder http://cires.colorado.edu/~maurerj/class/SST_presentation.htm


OA SST, Standard Deviation [degC], 1982–2006
60N
30N
EQ
30S
60S
60E
120E
180
120W
60W
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.2
1.4
GrADS: COLA/IGES
2007–07–23–14:45



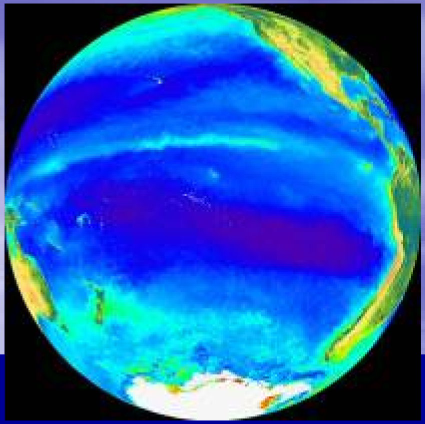
TMI Sea Surface Temperature, 3-days ending: July 23, 2007
16
20
24
28
32
degrees Celsius
land
no data
Remote Sensing Systems
www.remss.com
30
60
90
120
150
180
210
240
270
300
330
0
40
20
-20
-40



http://disc.gsfc.nasa.gov/oceancolor/

(Figure Courtesy of Dr. Michael Behrenfeld)

Ocean color channels



- SeaWiFS (1997-):

  8 spectral bands

  1/ 412 nm (violet): Gelbstoffe

  2/ 443 (blue): Chlorophyll

  3/ 490 (blue-green): Pigment absorption (Case 2), K(490)

  4/ 510 (blue-green): Chlorophyll

  5/ 555 (green): Pigments, sediments

  6/ 670 (red): Atmospheric correction

  7/ 765 (near IR): Atmospheric correction, aerosol radiance

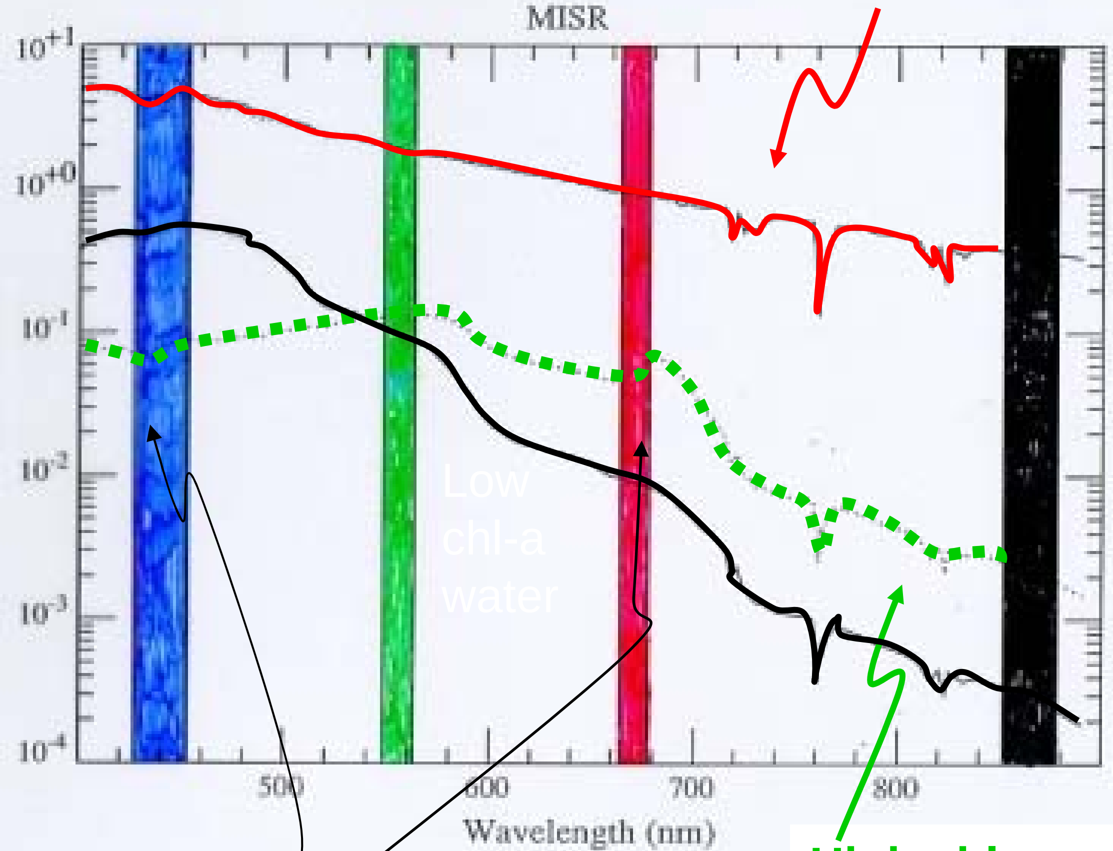
  8/ 865 (near IR): Atmospheric correction, aerosol radiance

- MODIS

  (on Aqua 1999- and Terra 2001-):

  36 spectral bands

Atm and ocn-leaving radiance

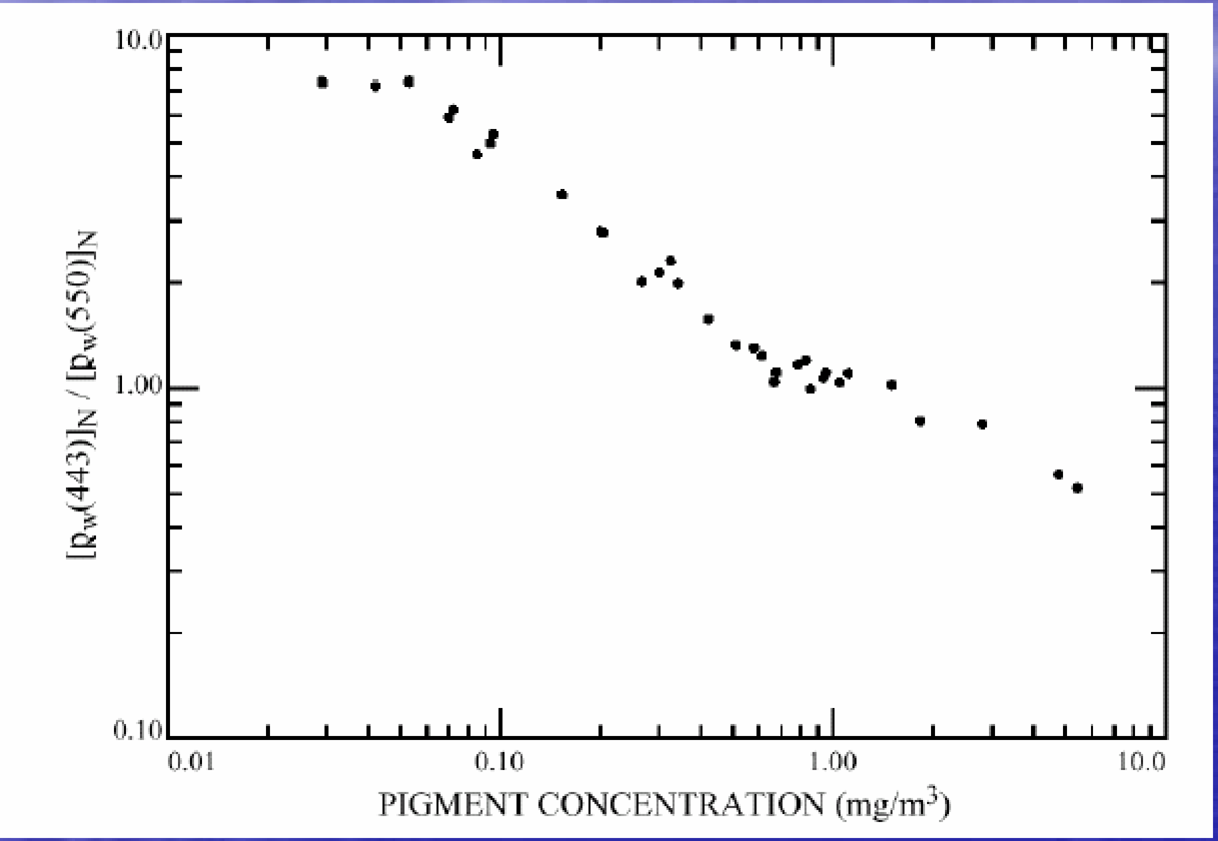


Atmospheric radiance: 90% scattering

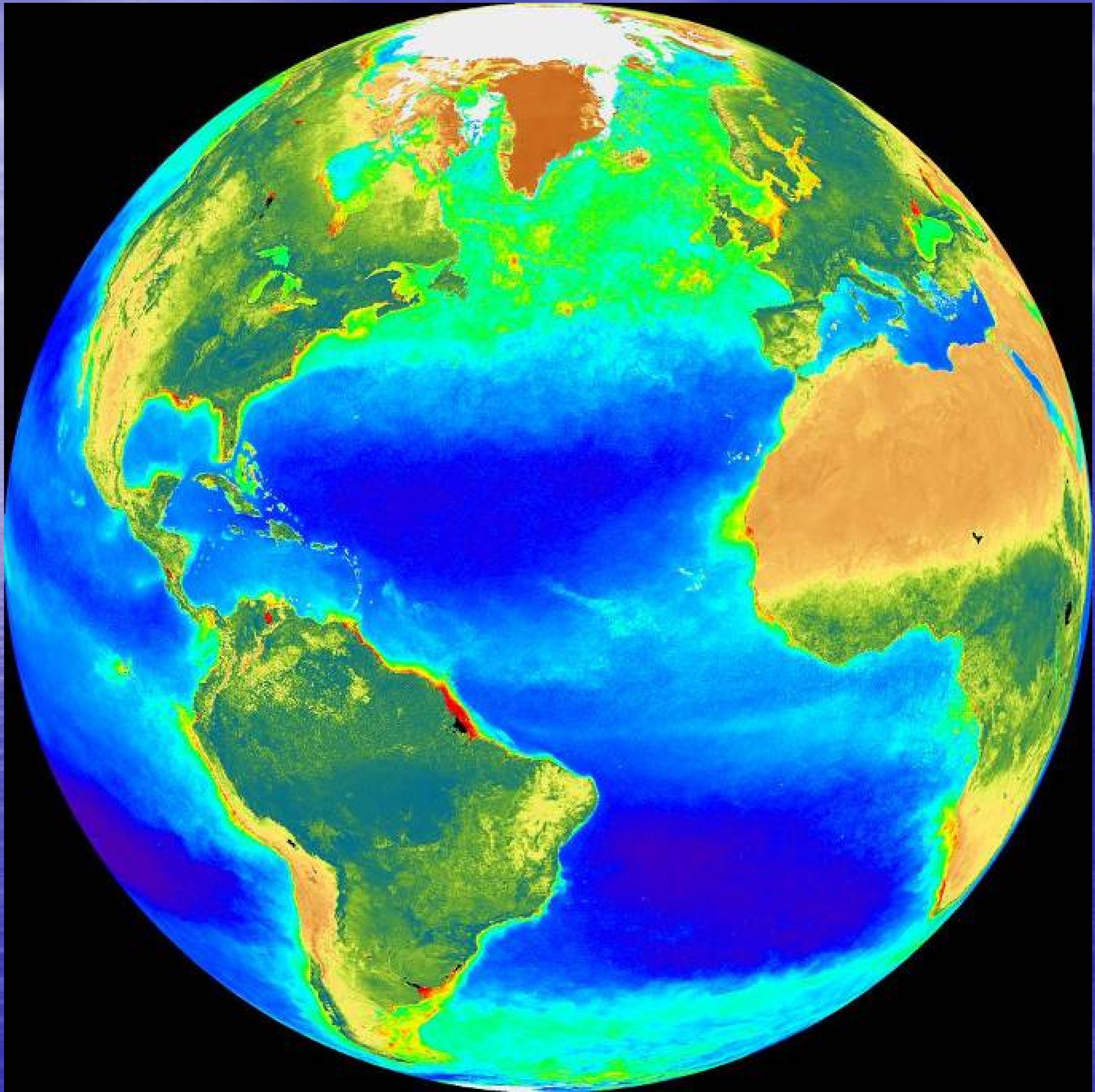
Chl-a absorbs at 440, 675nm

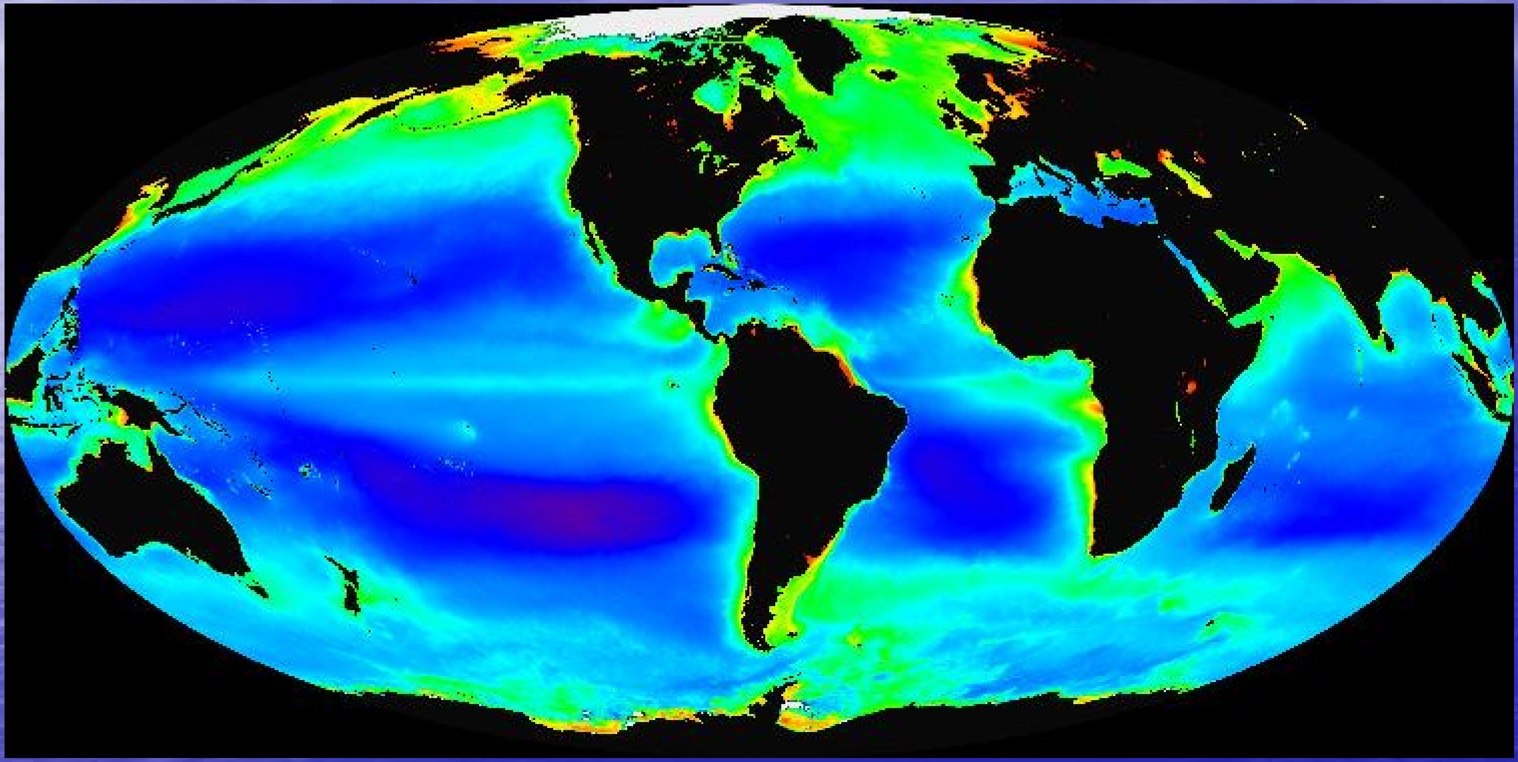
High chl-a water ~10% reflec.

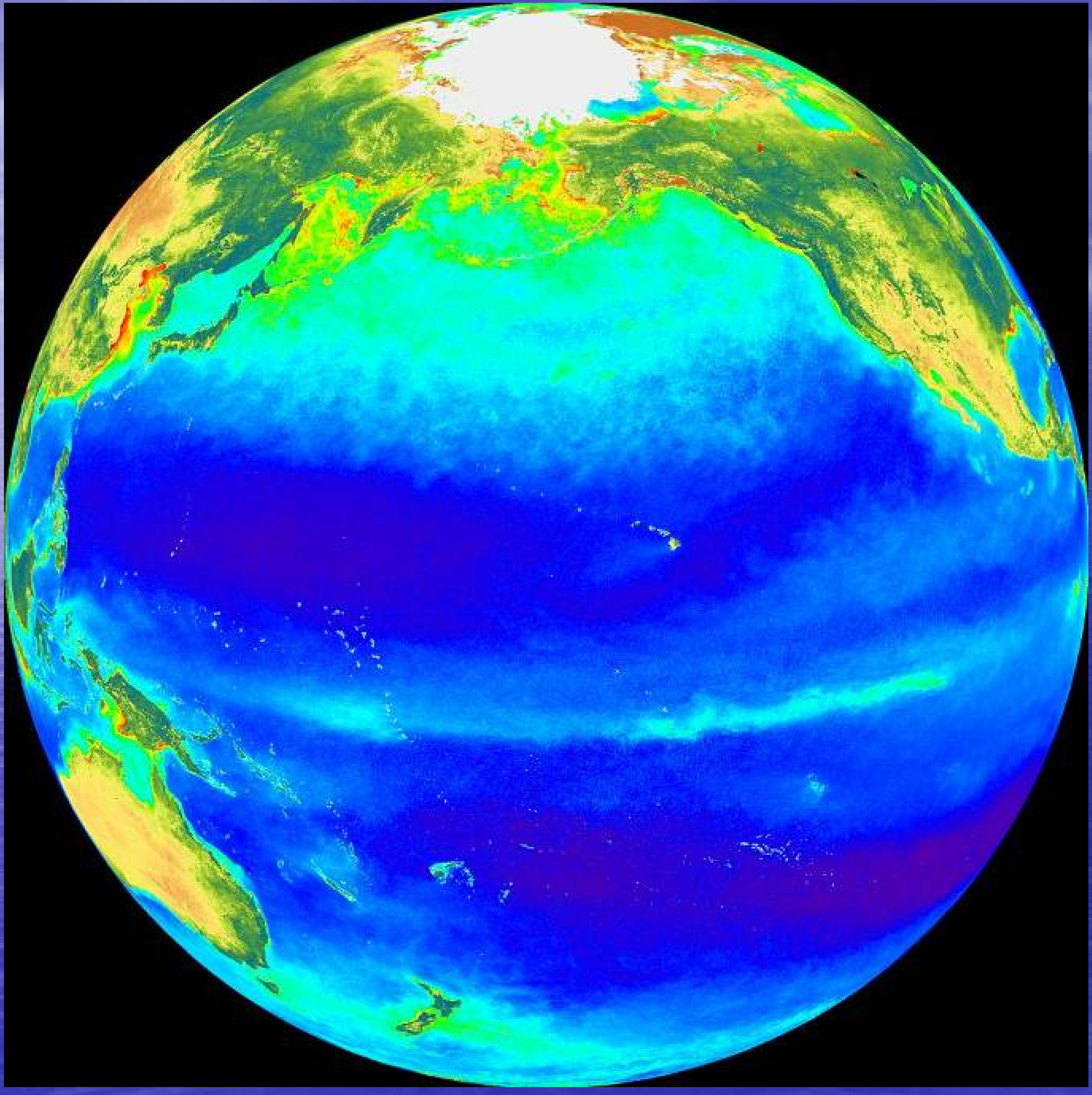
Relationship between passive radiance and pigment concentration

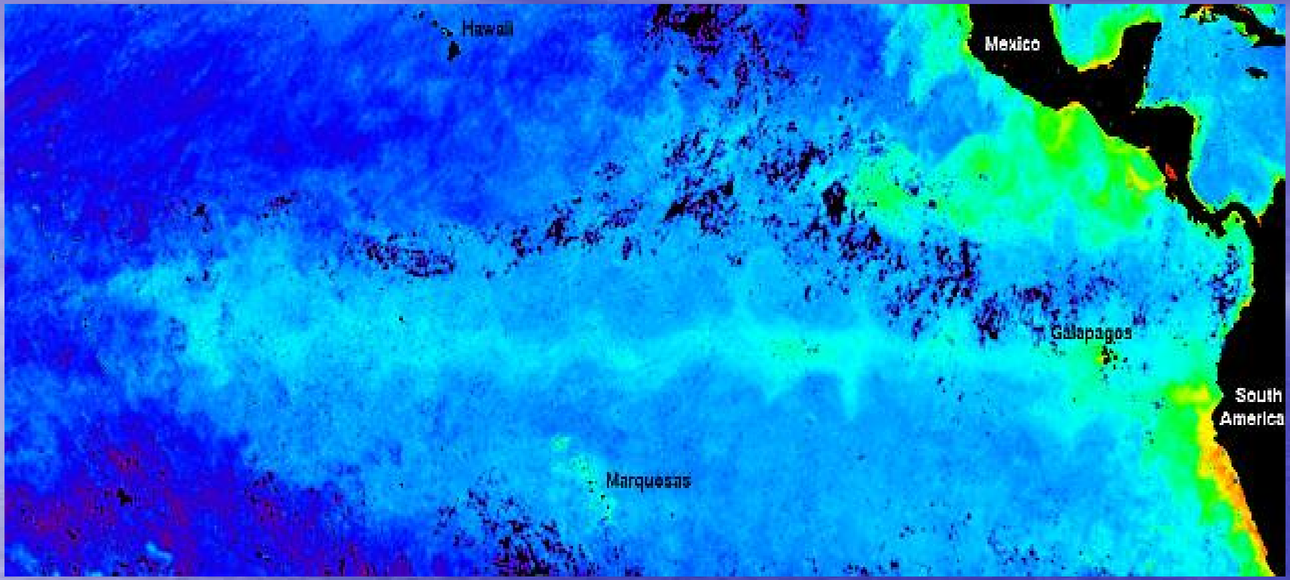


Gordon et al. (1988)





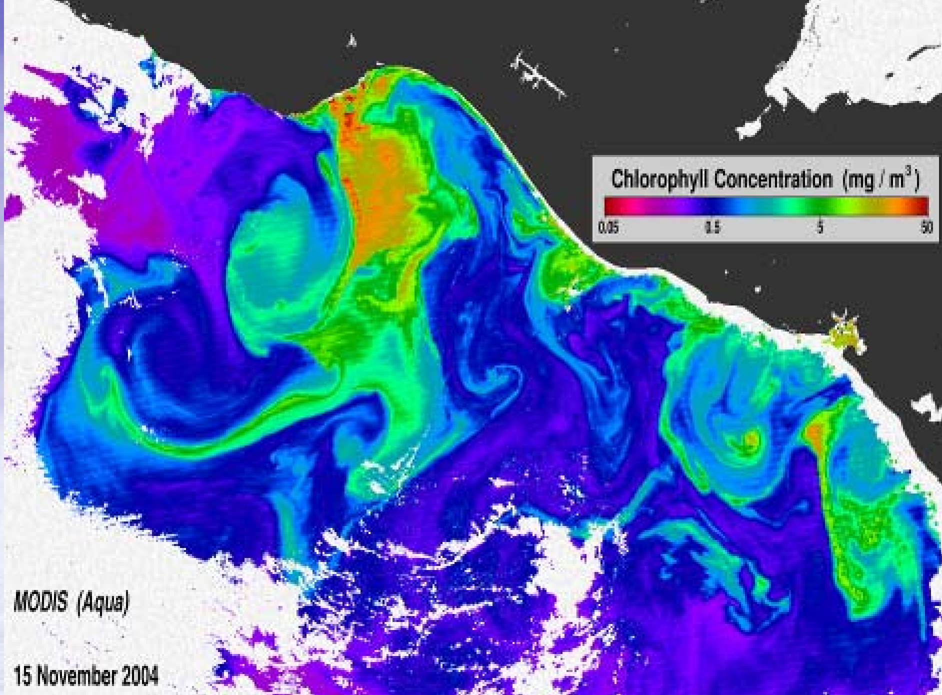


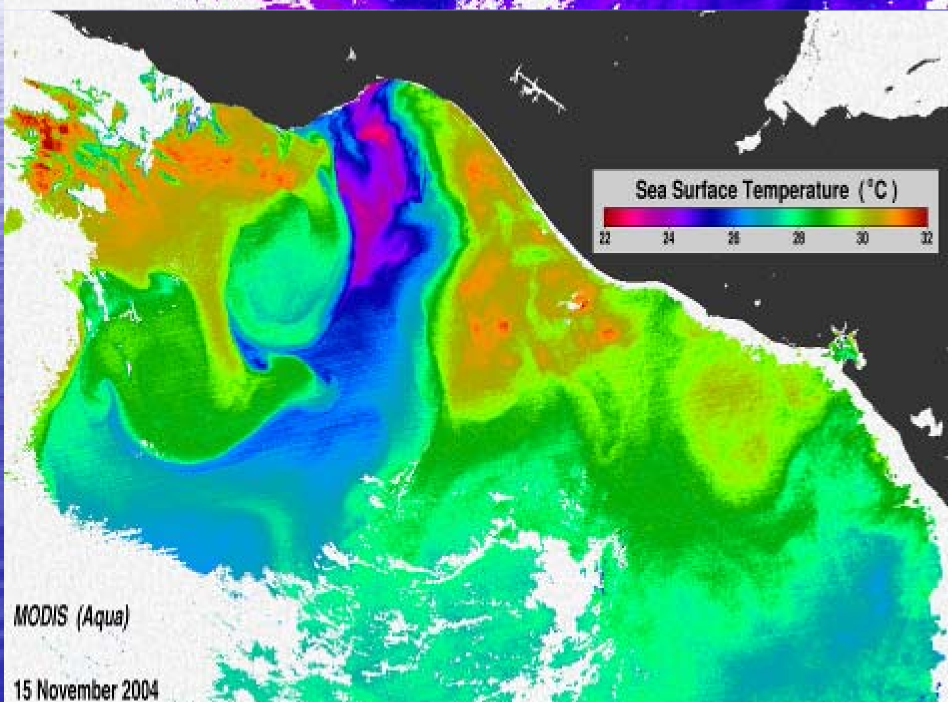


***Catch the Wave*: Equatorial Pacific Waves**

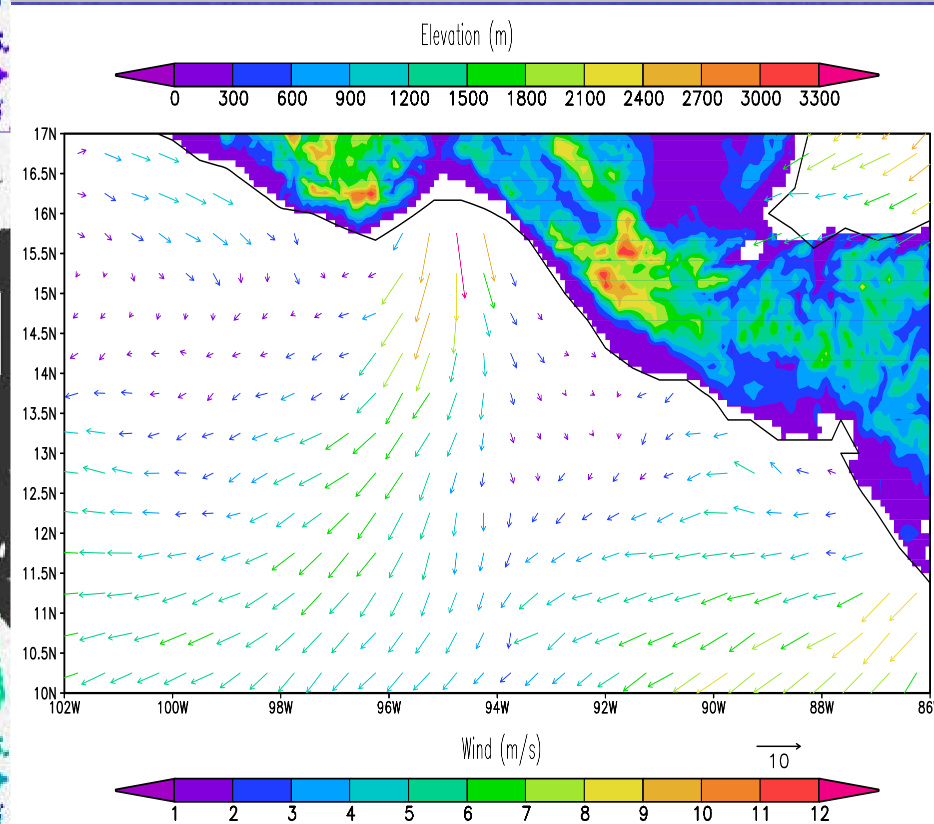
This eleven-day SeaWiFS chlorophyll-a composite January 8-18, 2002 shows the rather remarkable development of a series of equatorial Pacific tropical instability waves. The enhanced chlorophyll concentrations associated with the waves extend from the region just west of the Galapagos Islands along the equator to the dateline - a distance of nearly 10,000 kilometers.

Wind blowing across the Gulf of Tehuantepec causes upwelling of cold, nutrient-rich water which fuels phytoplankton blooms.





Quickscat Winds (m/s) 15 November 2004



Where we hope to see the biggest advances in the ocean observing system?

Remote sensing

Ocean salinity from space (AQUARIUS mission)

In-situ

Progress of the ARGO float Program