Some background physical oceanography you need to know

Mean Temperature at 0m

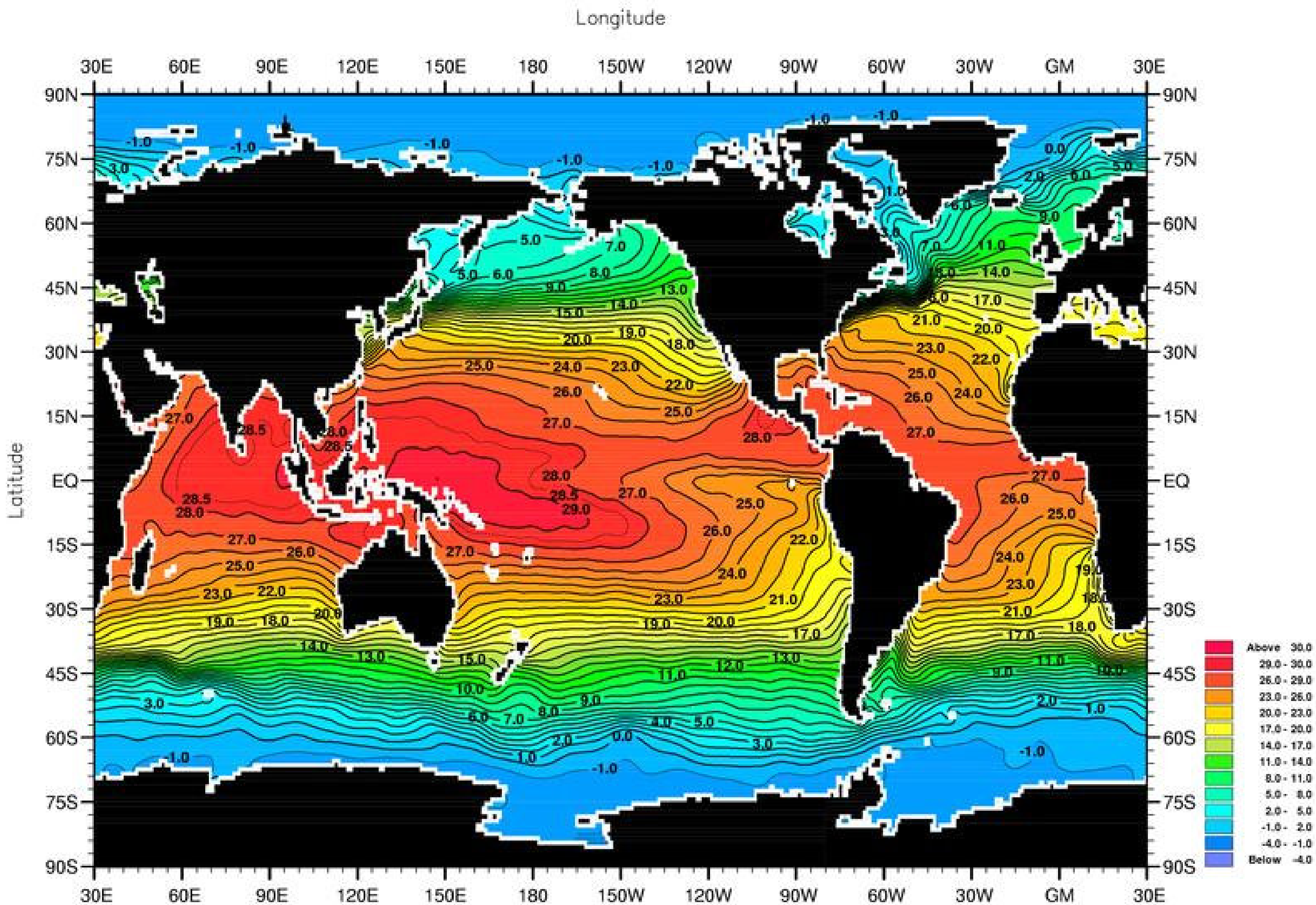


Fig. A2-1. Annual mean temperature (°C) at the surface.

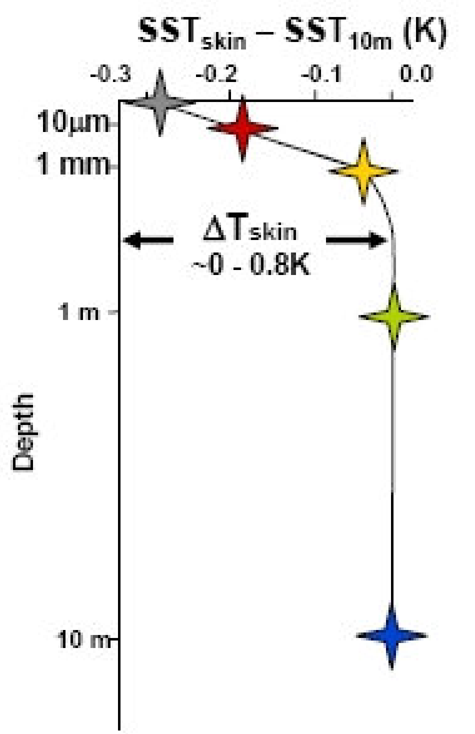
Minimum Value= -1.93 Maximum Value= 29.93 Contour Interval: 1.00

Stephens et al., NOAA, 2002

World Ocean Atlas 2001
Ocean Climate Laboratory/NODC

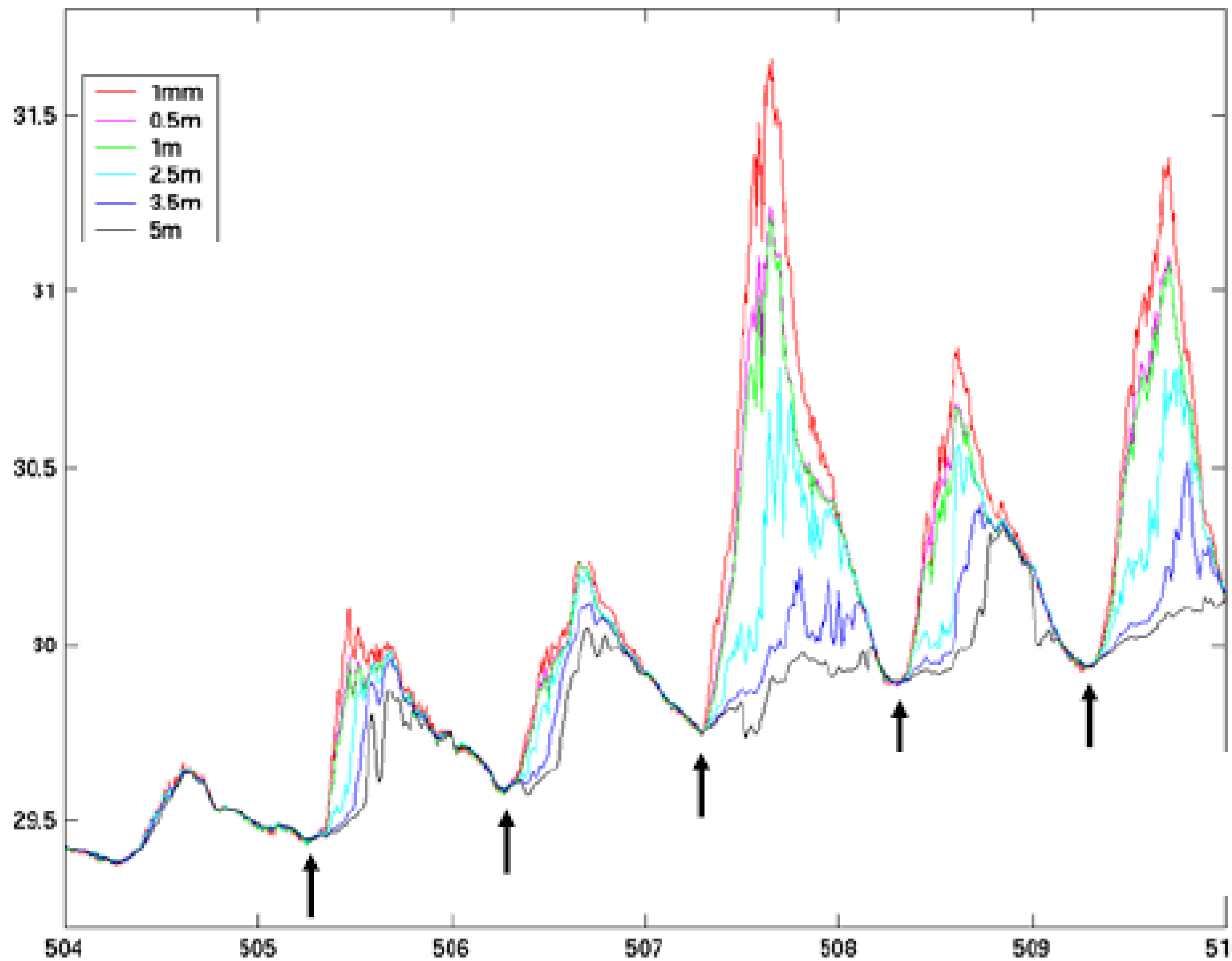
Nearsurface structure of Temp

NIGHT



(a) Night time situation, light wind

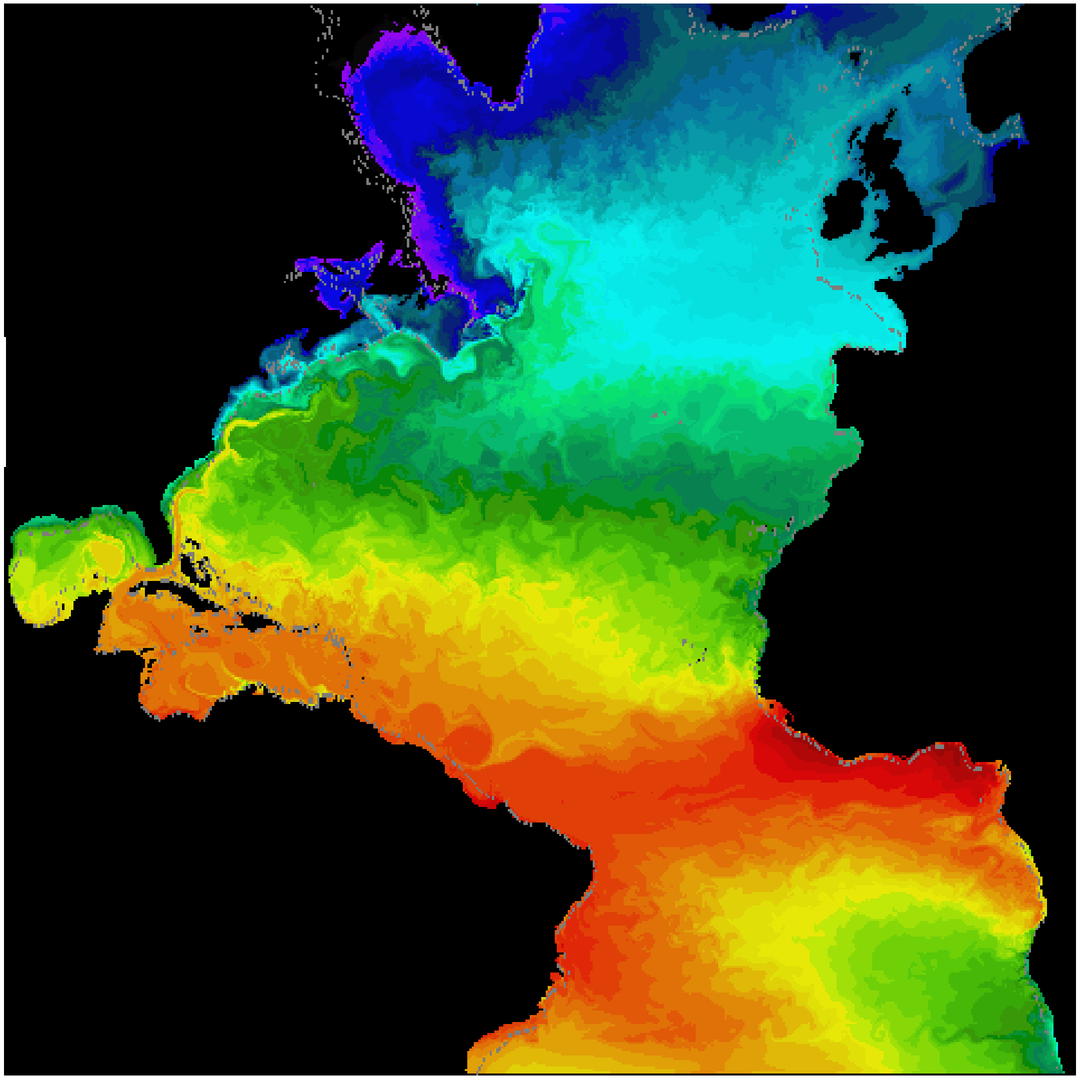
Temperature →



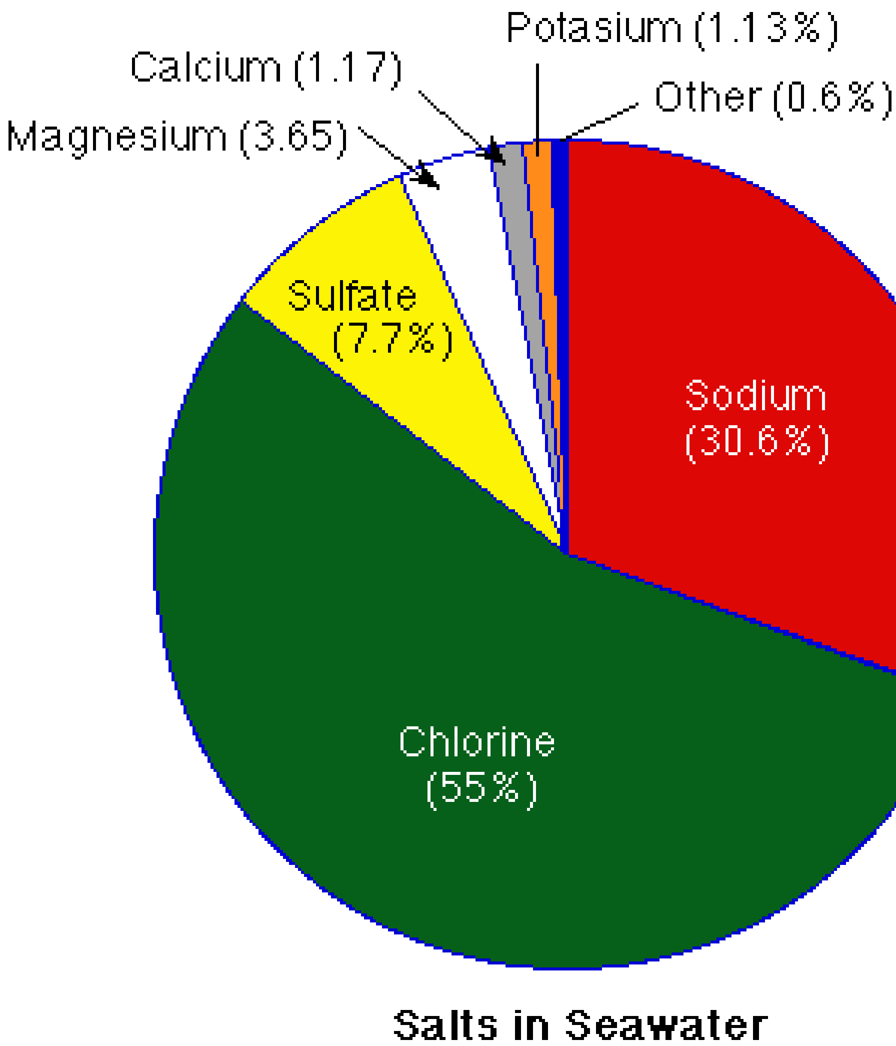
Arabian Sea WHOI Mooring Data - Spring 1995

Day →

SST spatial and temporal variability



Ocean salinity



Remote Sensing: passive, ocean

http://omp.gso.uri.edu/doee/science/physical/salt5.gif

Mean Salinity at ~ 0m

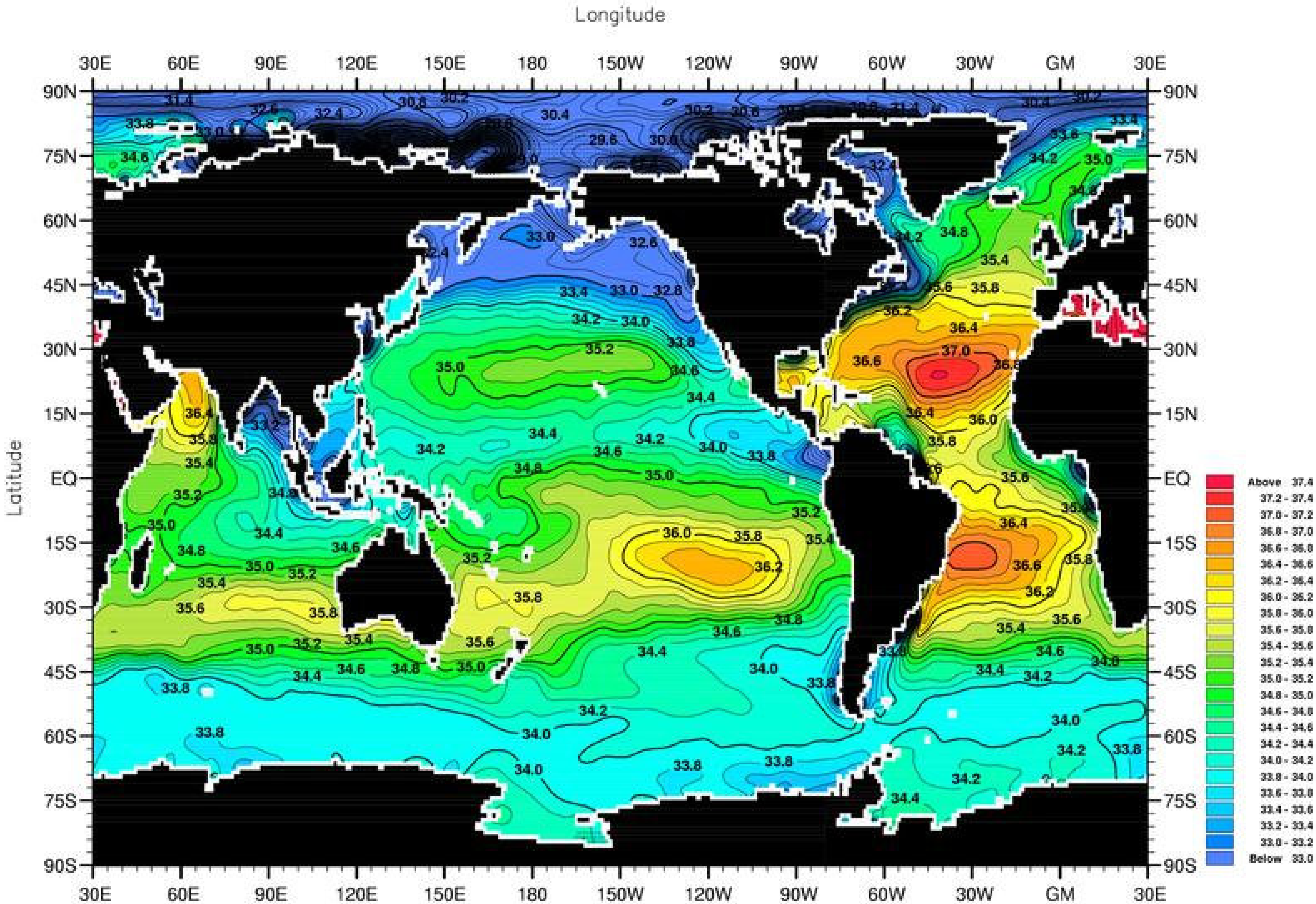


Fig. A2-1. Annual mean salinity (PSS) at the surface.

Minimum Value= 2.37 Maximum Value= 40.37 Contour Interval: 0.20

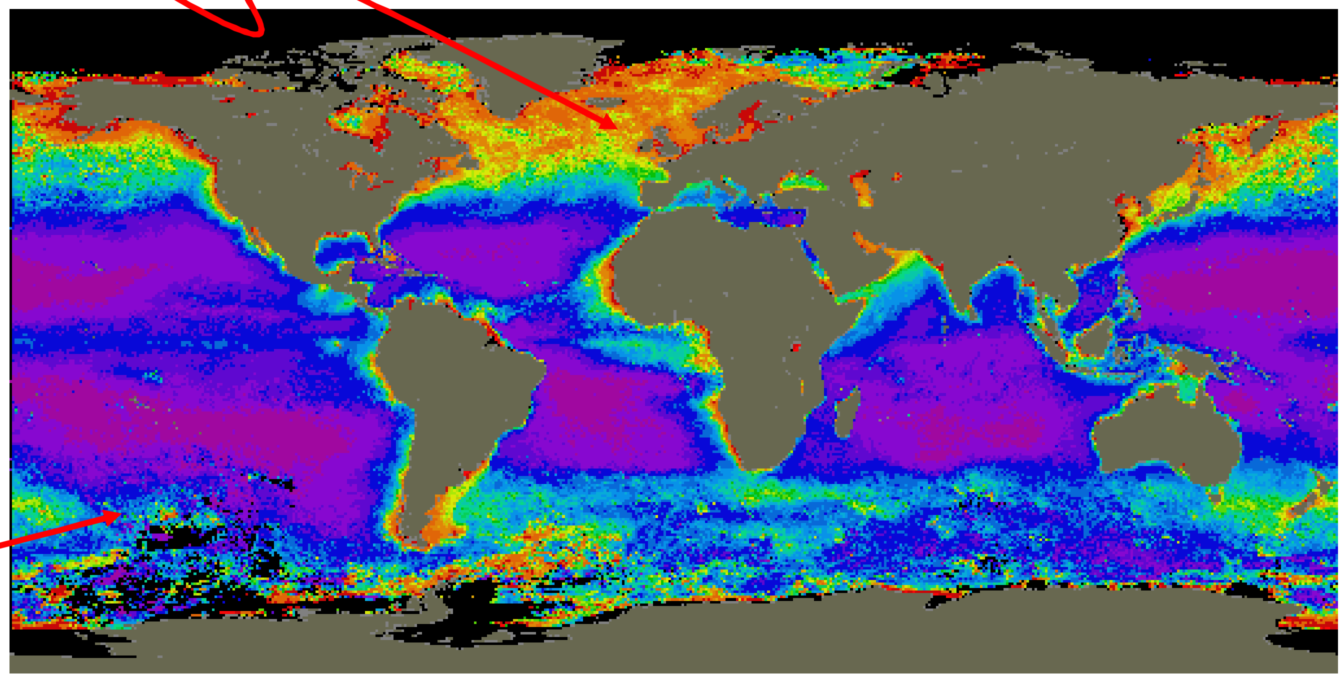
World Ocean Atlas 2001
Ocean Climate Laboratory/NODC

Biomass of the oceans

Coccolithophores

Emiliania huxleyi

Cyanobacteria



http://www.coa.edu/faculty/webpages/stodd/oceanweb/oceanography/Oceanlectures02/Lecture12/sld016.htm

*Behrenfeld et al. Limnol. Oceanogr. 42, 1–20 (1997)

Some history

1975: GEOS (Geodynamics Experimental Ocean Satellite) 3 (lasted 3.5 years) (NASA)

- radar altimeter (sea level) and laser tracking

1978: Seasat (lasted 110 days) (NASA)

- radar altimeter (sea level)
- Scanning Multichannel Microwave Radiometer (rain)
- Synthetic Aperture Radar (surface, internal waves)
- Scatterometer System (surface winds)
- Visible and Infrared Radiometer (SST, ocean color)

1978: Advanced Very High Resolution Radiometer (AVHRR) aboard TIROS-N (later versions still in orbit)

- Visible and Infrared Radiometer (SST)

1978: CZCS aboard Nimbus-7 (lasted 9years)

- ocean color

1985: GeoSat (4 years) (US Navy)

- Radar altimeter (sea level)

1990s: NSCAT,TOPEX/POSEIDON,TRMM, ERS1/2,…

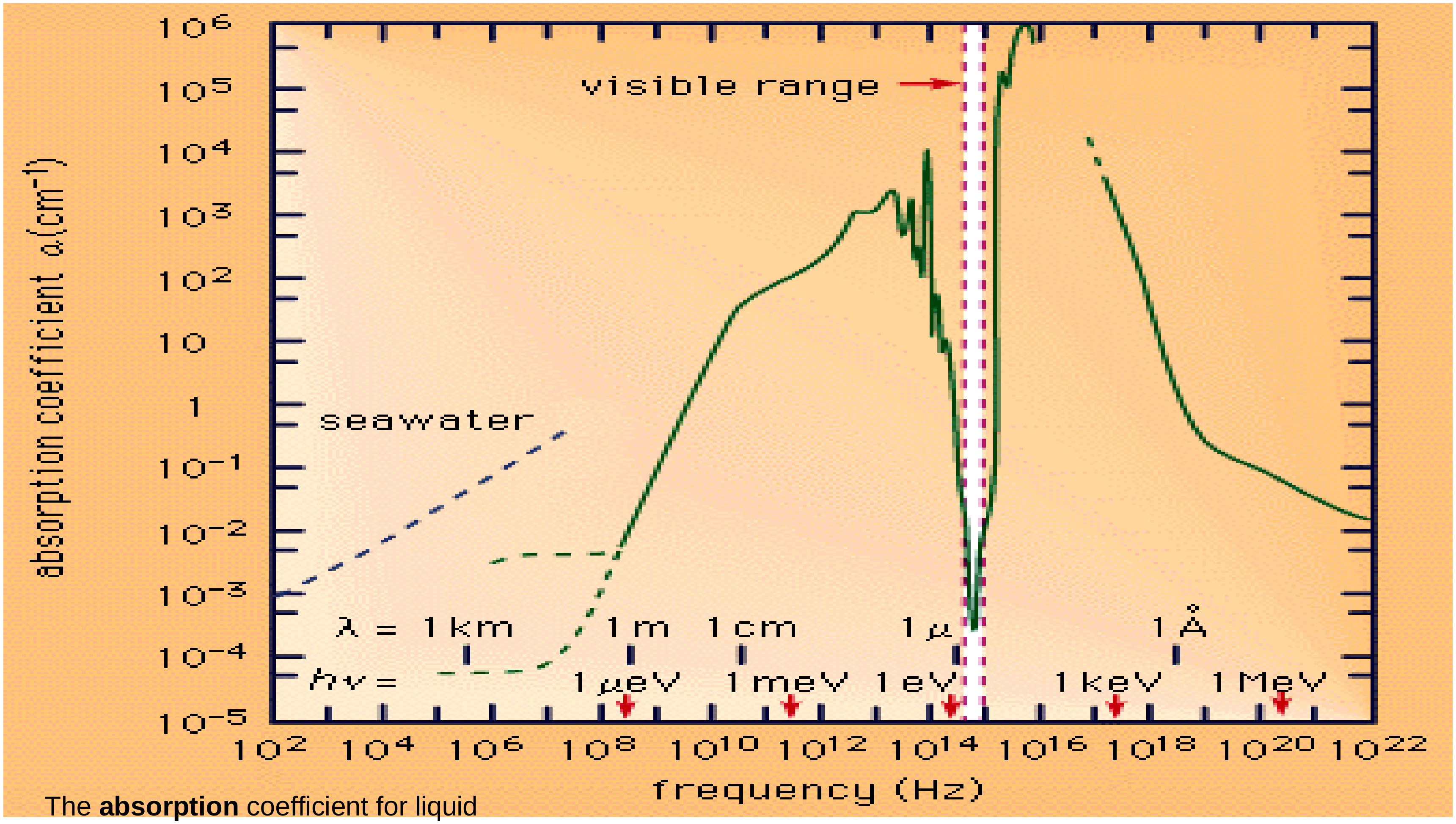
Science of ocean remote sensing

Locations: science.nasa.gov/realtime/jtrack/Spacecraft.html, www.n2yo.co

- **Absorption, reflectance** and **emission**
- **SST**
  - Infrared and microwave sensing
- **SSS**
- **Color**
    - Chlorophyll
    - Ocean fronts
    - Blooms
    - Sediment transport

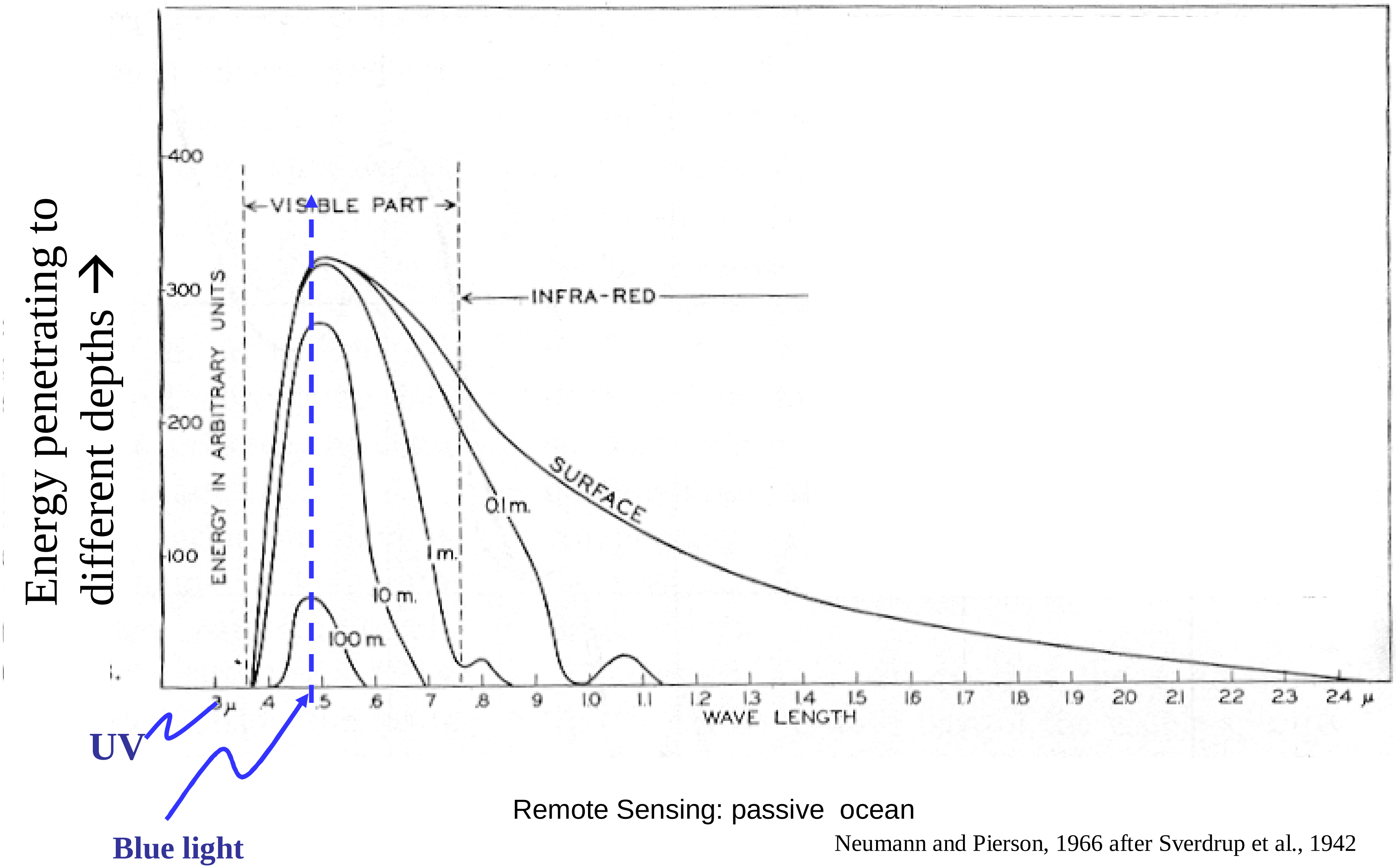
(I may cover remote sensing of gravity)

Absorption with wavelength (clear water)



The **absorption** coefficient for liquid **water** as a function of frequency. From J.D. Jackson, *Classical Electrodynamics,* copyright © 1975 by John Wiley & Sons, Inc.

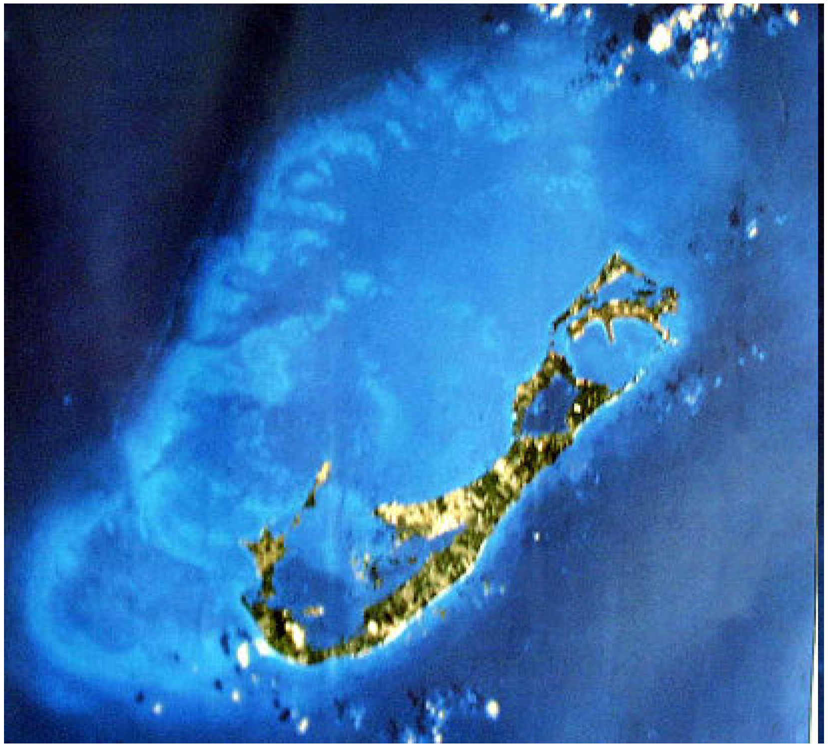
Transmission



Remote Sensing: passive ocean

Neumann and Pierson, 1966 after Sverdrup et al., 1942

Clear water in the oligotrophic subtropics

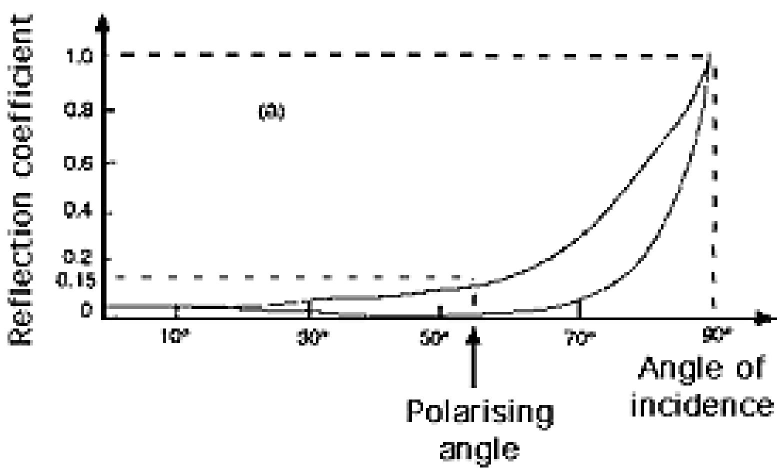


Polarization of reflectance

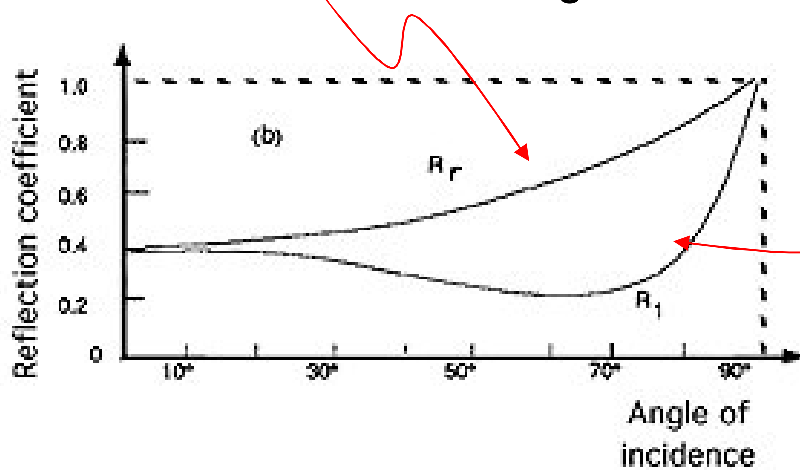
perpendicular to the plane of incidence

parallel to the plane of incidence

clear

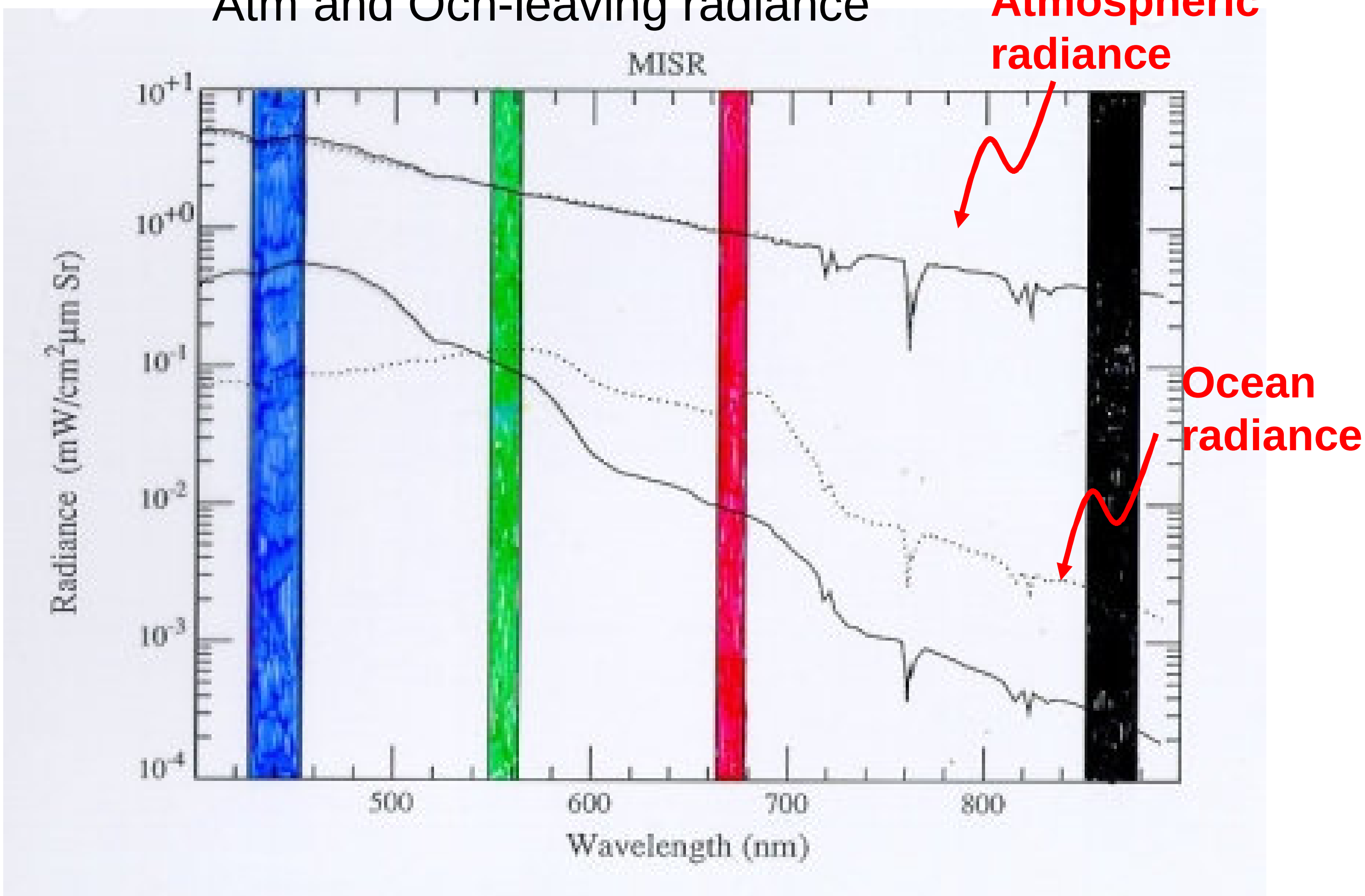


absorbing



Chl-a dependence of scattering

Atm and Ocn-leaving radiance

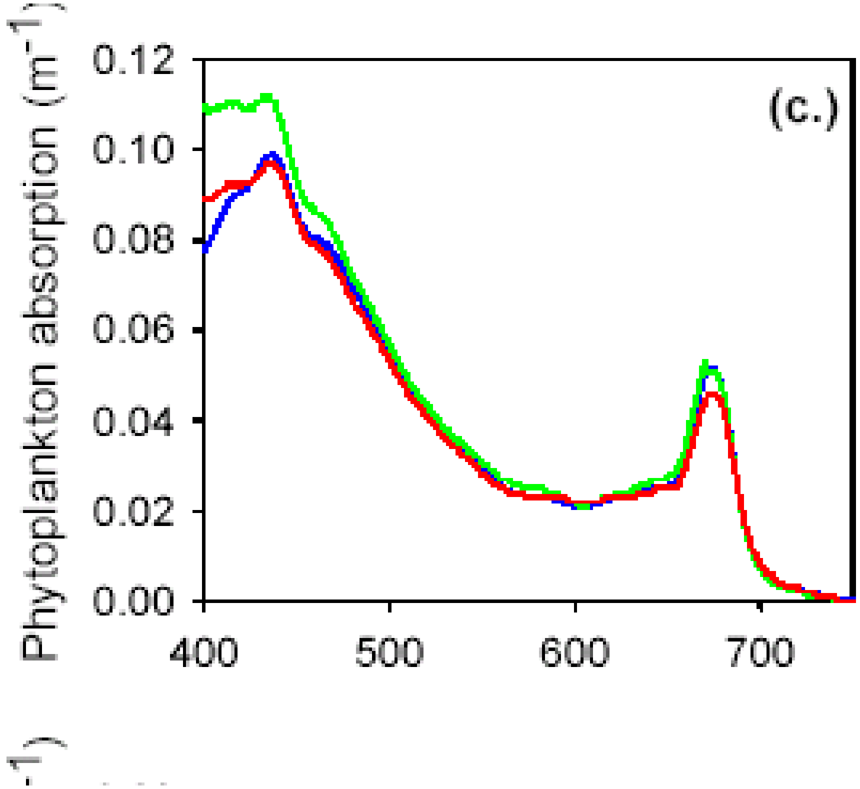


Photosynthetic pigments

- Chlorophyll a
  - Contained in all photosynthetic plants. Absorbs strongly at 0.675 microns (red) and 0.440 microns (blue)
- Chlorophyll b
- Chlorophyll c

Accessory pigments

- Caratenoids
  - e.g. beta-carotene which is in all phytoplankton. Is yellowish to redish.
- Biliproteins
  - Found in some blue-green and red algae



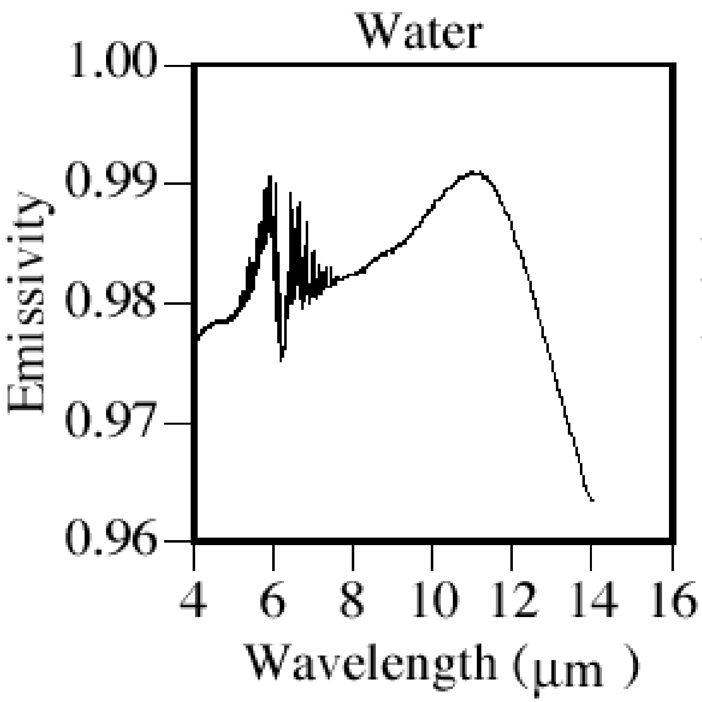
Brightness temperature and emissivity

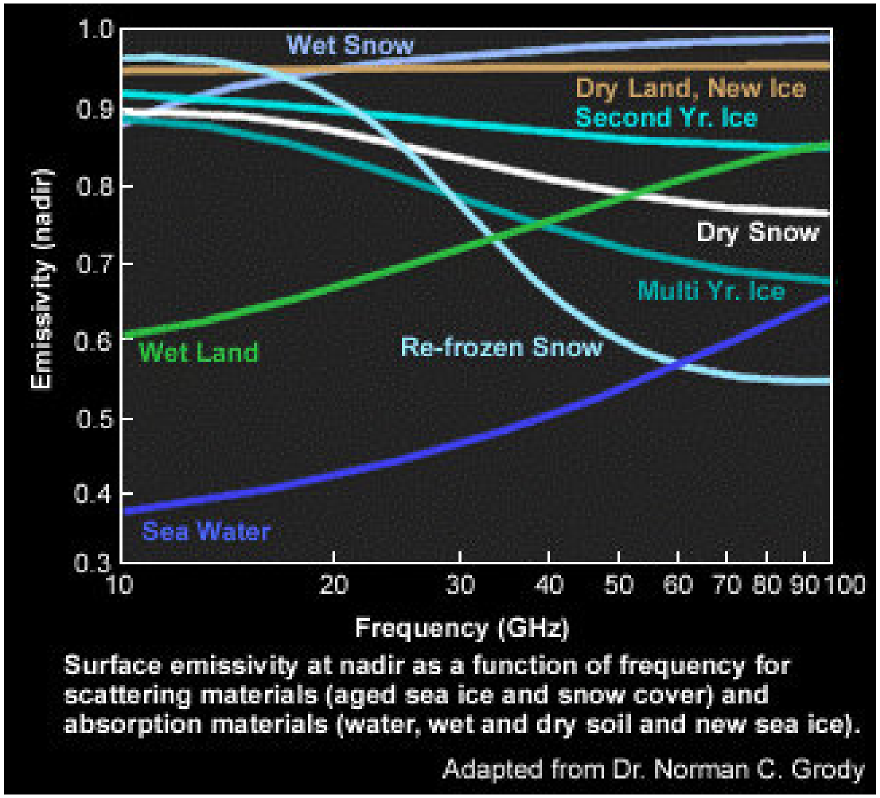
- **Brightness temperature**: temperature at which a black body in thermal equilibrium with its surroundings would have to be to duplicate the observed intensity of a grey body at a frequency ν
- **Emissivity**: ratio of energy radiated by a particular material to energy radiated by a black body at the same temperature.

Emissivity with wavelength

$I_e = \varepsilon\, I_b(Temp) + R\, I_s$

microwave (0.1 cm<λ< 100 cm),





www.heliosat3.de/e-learning/remote-sensing/Lec5.pdf

Brightness temperature vs frequency and SST

effective upward radiance

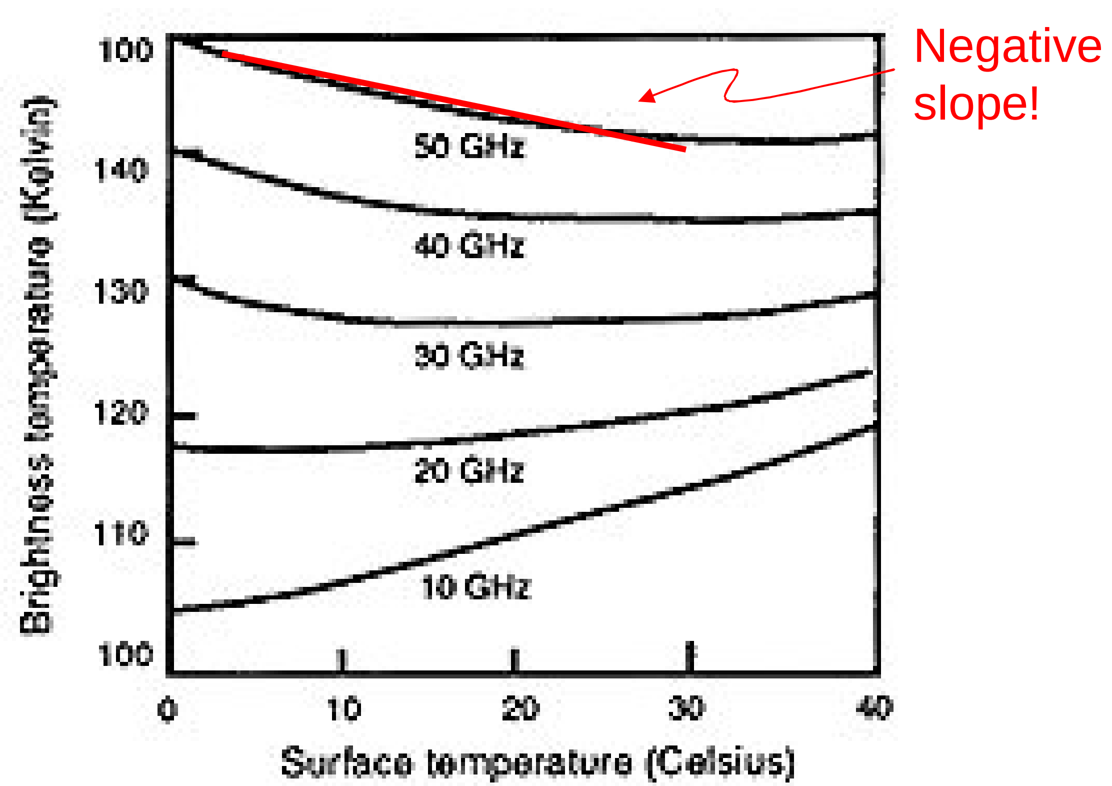
$I_e = \varepsilon\, I_b(\text{Temp}) + R\, I_s$

$I_e = \varepsilon\, I_b(\text{Temp}) + (1 - \varepsilon)\, I_s$

$I_e = I_s + \varepsilon\, (I_b - I_s)$

$I_s < I_b$ generally if sky is cold so the effective temperature $T_e < T$

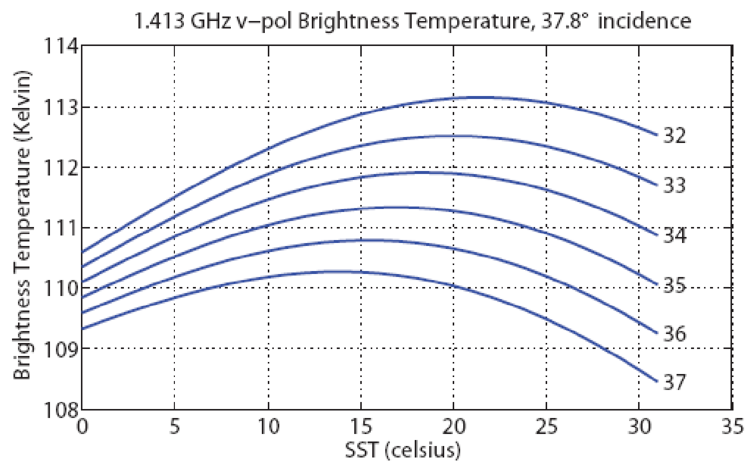
plane surface (no waves)

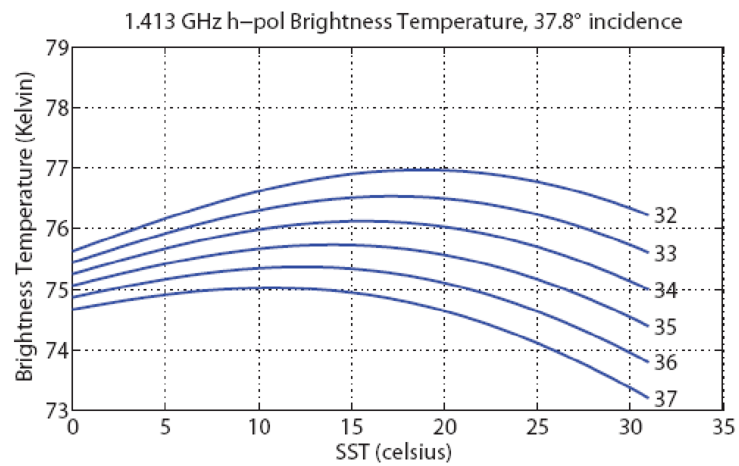


http://ceos.cnes.fr:8100/cdrom-00/ceos1/science/platt/pages/platt5.htm

brightness temperature vs salinity

L-band



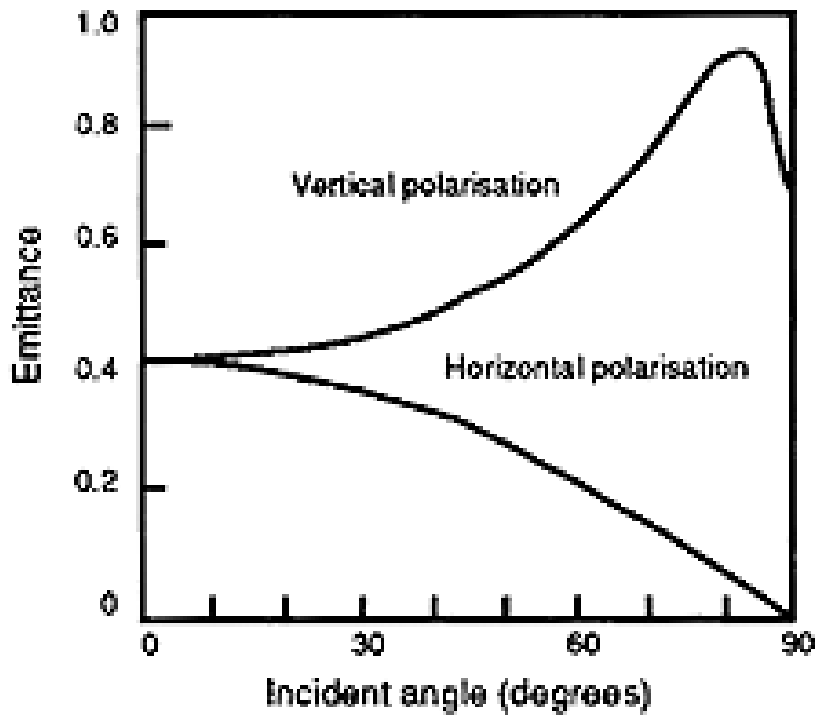


Aquarius will exploit this dependence to obtain an SSS measurement with an expected ~0.2PSU accuracy at monthly timescales.

Lagerloef et al., 2007:

passive ocean

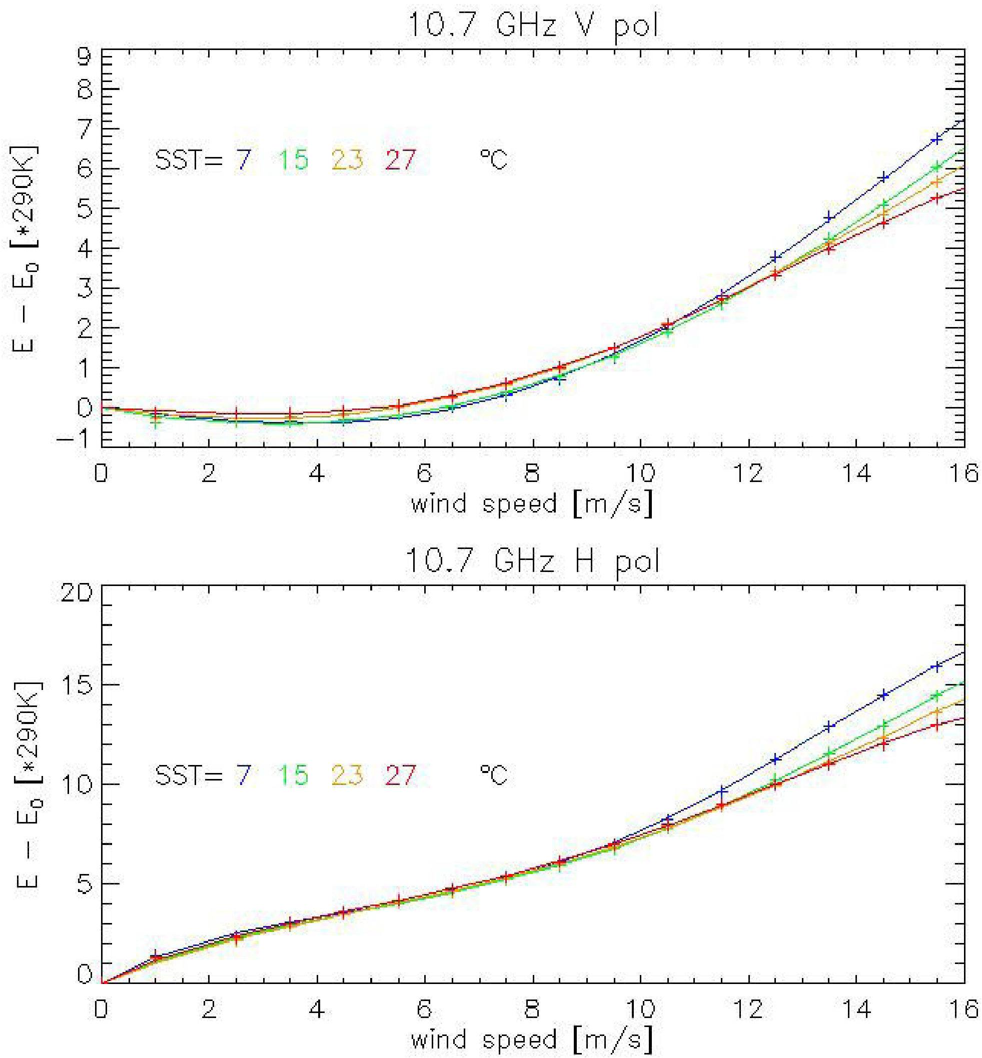
Emissivity polarization as a function of incidence angle



lambda = 1.55cm and T = 300 K

http://ceos.cnes.fr:8100/cdrom-00/ceos1/science/platt/pages/platt5.htm

Emissivity-dependence on Wind-induced surface roughness



WINDSAT exploits these dependences to determine wind stress.

van Delst, P. ar

The satellites

Satellite detection of 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 or 3cm)**
  - 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 band: AVHRR

Advanced Very High Resolution Radiometer

Characteristics

Orbit: 2399 km wide swath, 833 km altitude. 14 orbits/dy

Sensor: 4-channel radiometer, first carried on TIROS-N (1978). latest version is AVHRR/3, with 6 channels, (1998)

Cloud Detection

Maximum Temperature – Compare obs in a small surface area over a relatively short period of time. *poor for persistent, thin clouds.*

Two Wavelength infrared -- 3.7 µm and 10.5 µm. If different, small, undetected clouds in the scene.

spatial Variability -- temperatures of clouds assumed more variable than SST

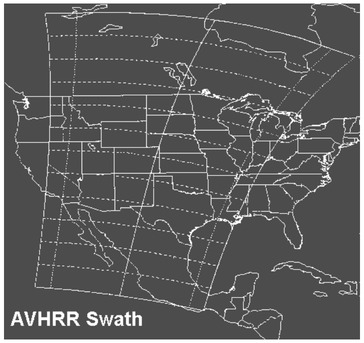
Two Wavelength Visible-Infrared -- use reflected sunlight to detect clouds

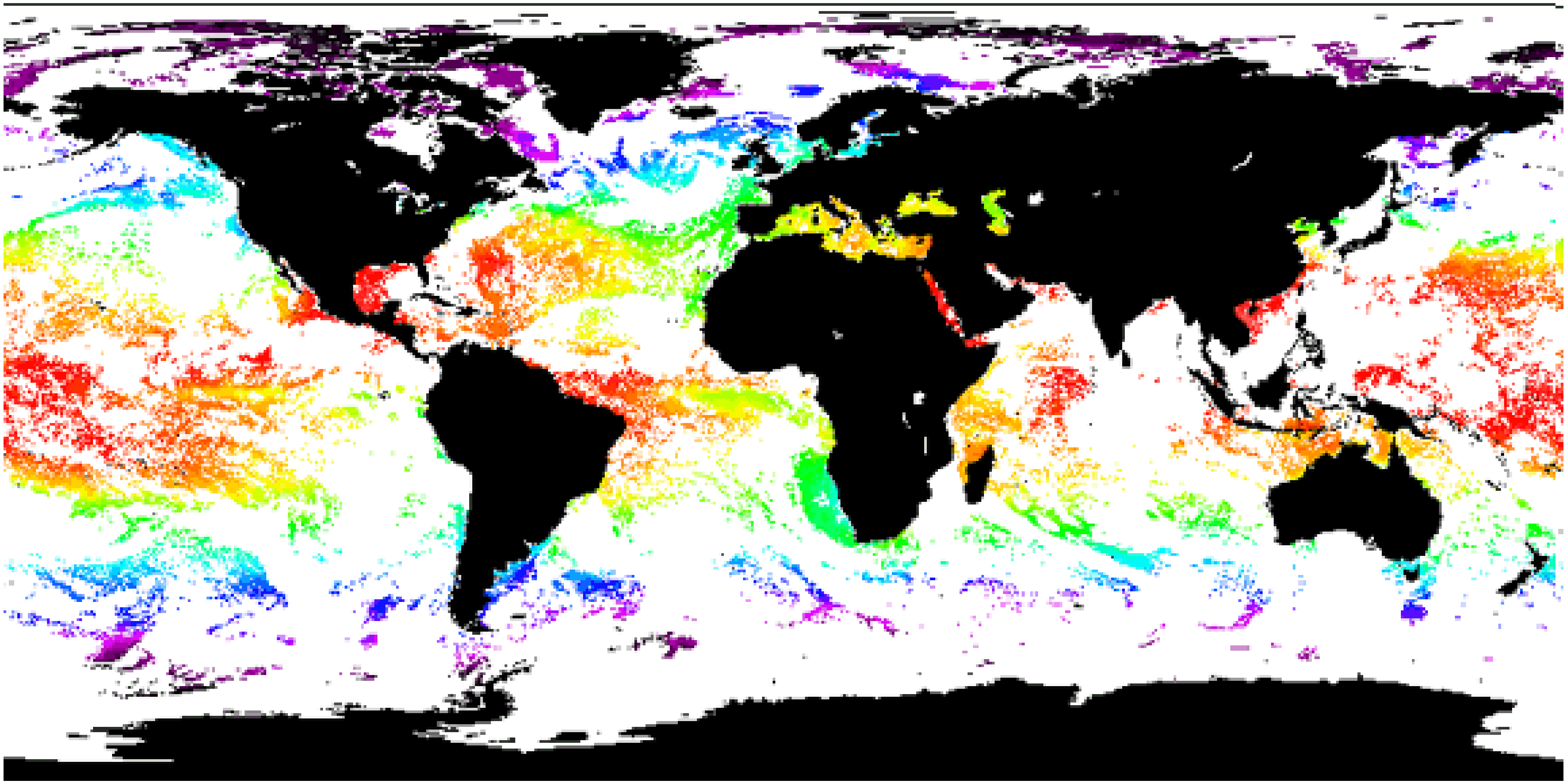
Water vapor Correction

Single-Wavelength Corrections--many instruments use only a single IR wavelength, usually 10.5 µm. If so, use climatological estimates of water vapor or regional radiosonde observations.

Two-Wavelength Corrections--10.5 µm is much more sensitive to water vapor than radiation at 3.7 µm. Difference in temperature is used to correct for water vapor.

Typical AVHRR coverage

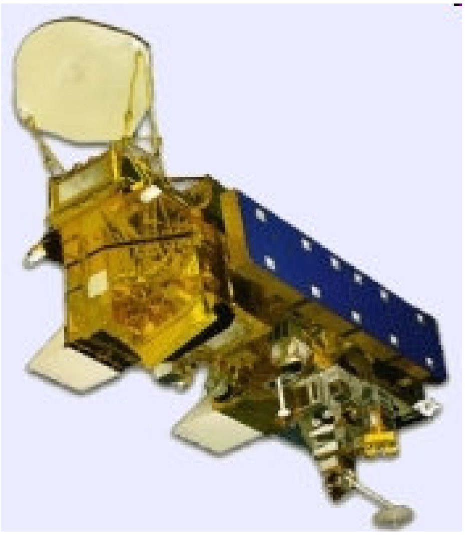




Remote Sensing: passive ocean

http://edc.usgs.gov/glis/graphics/guide/avhrr/figure1.gif

AMSRE: passive microwave radiometer

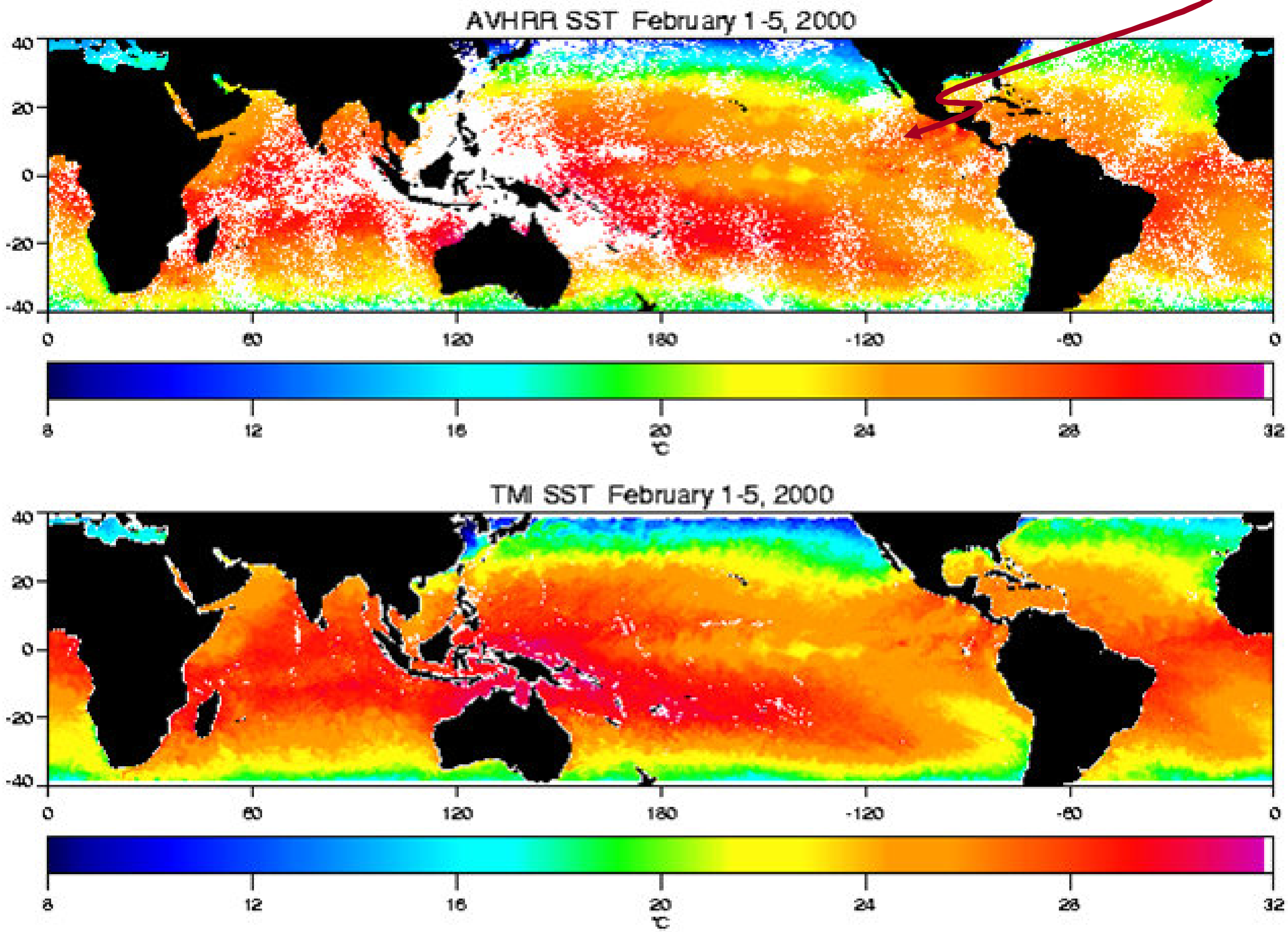


AMSR-E on the Aqua

- Scanning radiometer (40 rpm).
- Altitude: 705 km, swath width:1445 km
- 6 frequencies ranging from 6.9 to 89.0 GHz measuring both horizontally and vertically polarized radiation
- Spatial res: 25km-50km

Comparison of Infrared vs microwave coverage

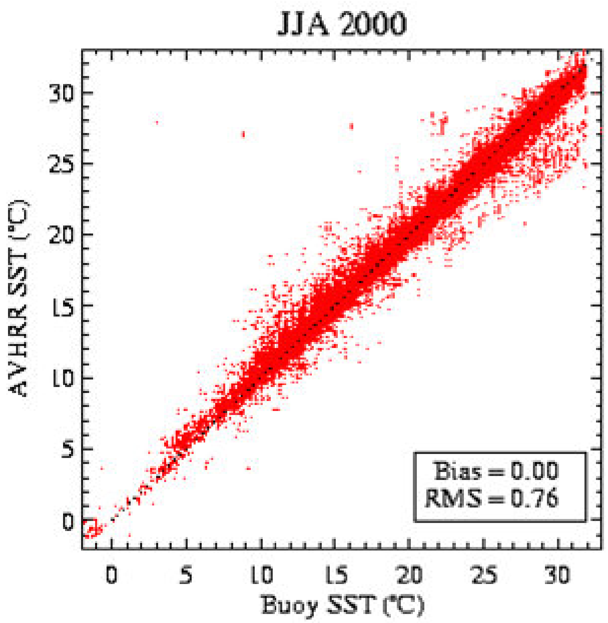
More cloud contamination



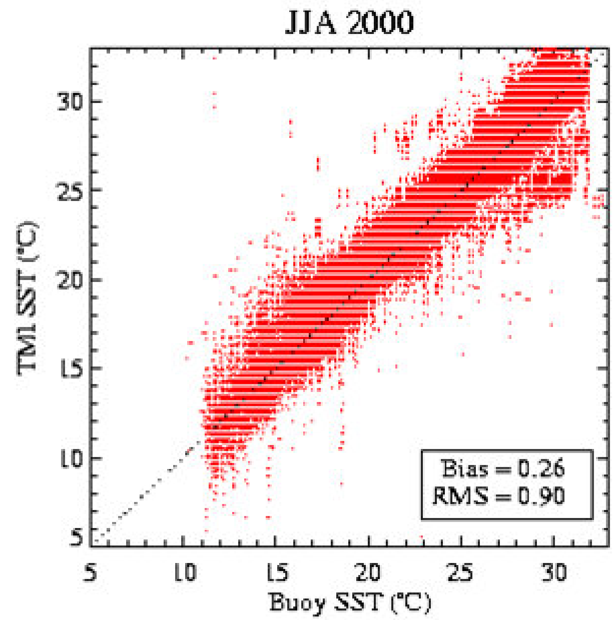
John Maurer, UC Boulder http://cires.colorado.edu/~maurerj/class/SST_presentation.htm

Comparison of Infrared vs microwave accuracy

infrared



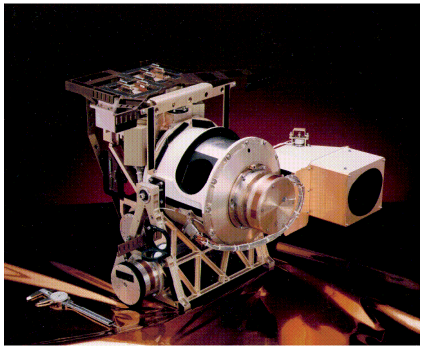
microwave



Larger uncertainty

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

Satellite detection of Chl-a



•**SeaWiFS** (1997-):

8 spectral bands. Resolution LAC: 1.1km, GAC: 4km

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

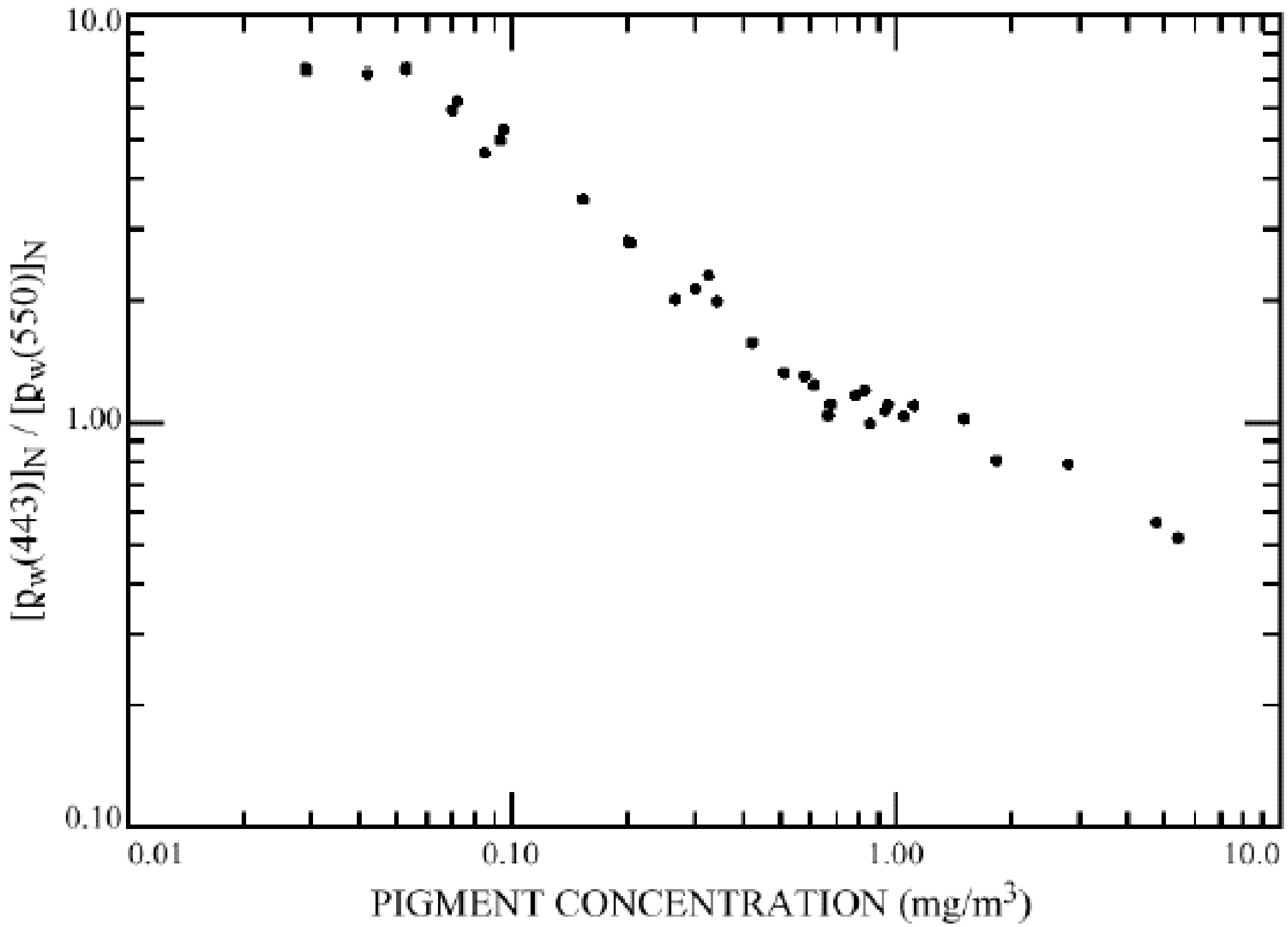
8/ 865 (near IR): Atmospheric correction, aerosol radiance

•**MODIS** (on Aqua 1999- and Terra 2001-):

36 spectral bands

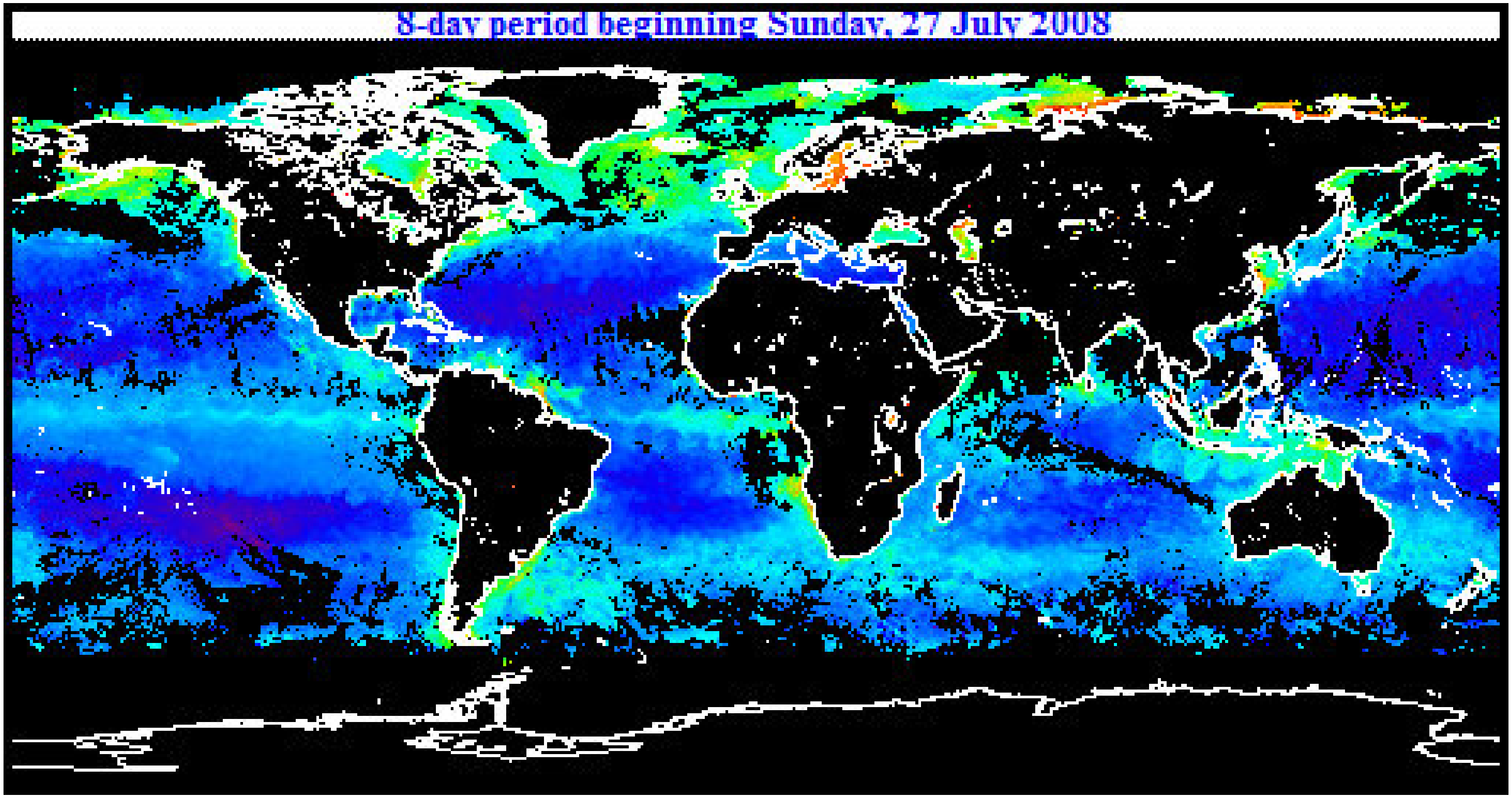
a Lec13.pdf Source unknown

Relationship between passive radiance and Chl-a concentration



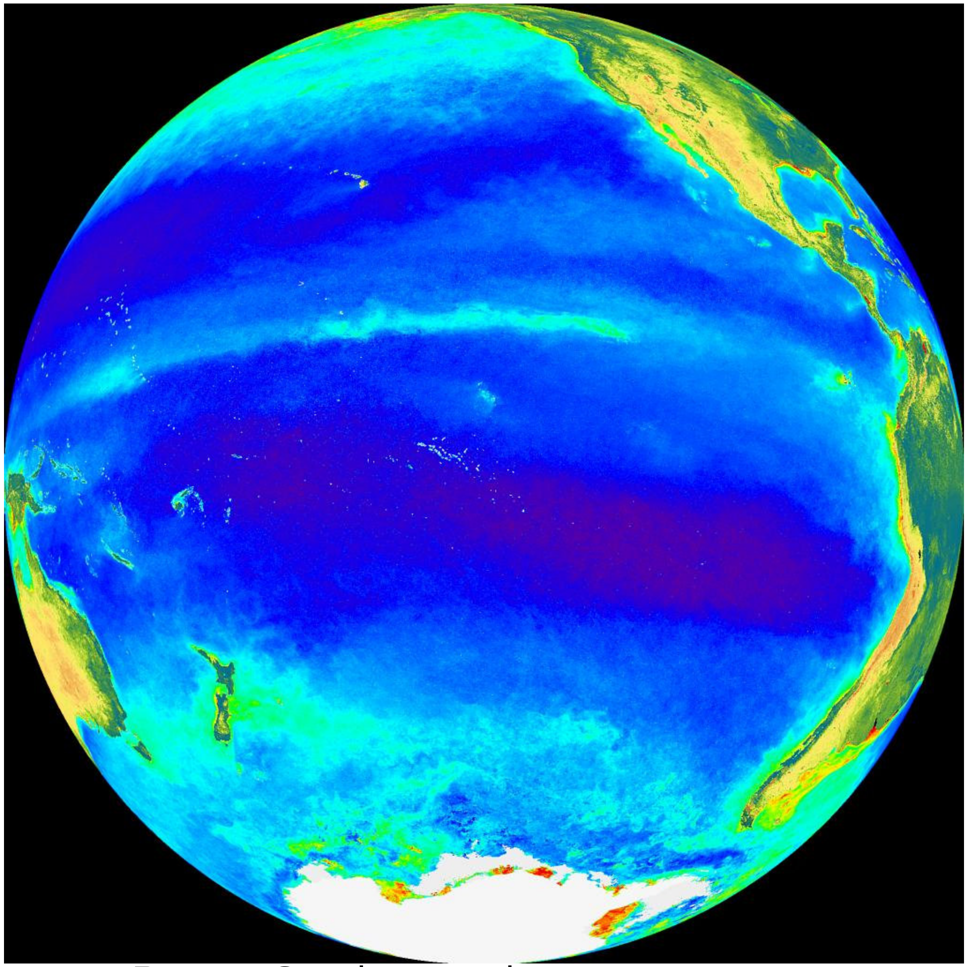
Gordon et al. (1988)

A picture showing MODIS 8-dy average



Ocean color

Annual mean plankton distribution



Remote Sensing: passive ocean

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

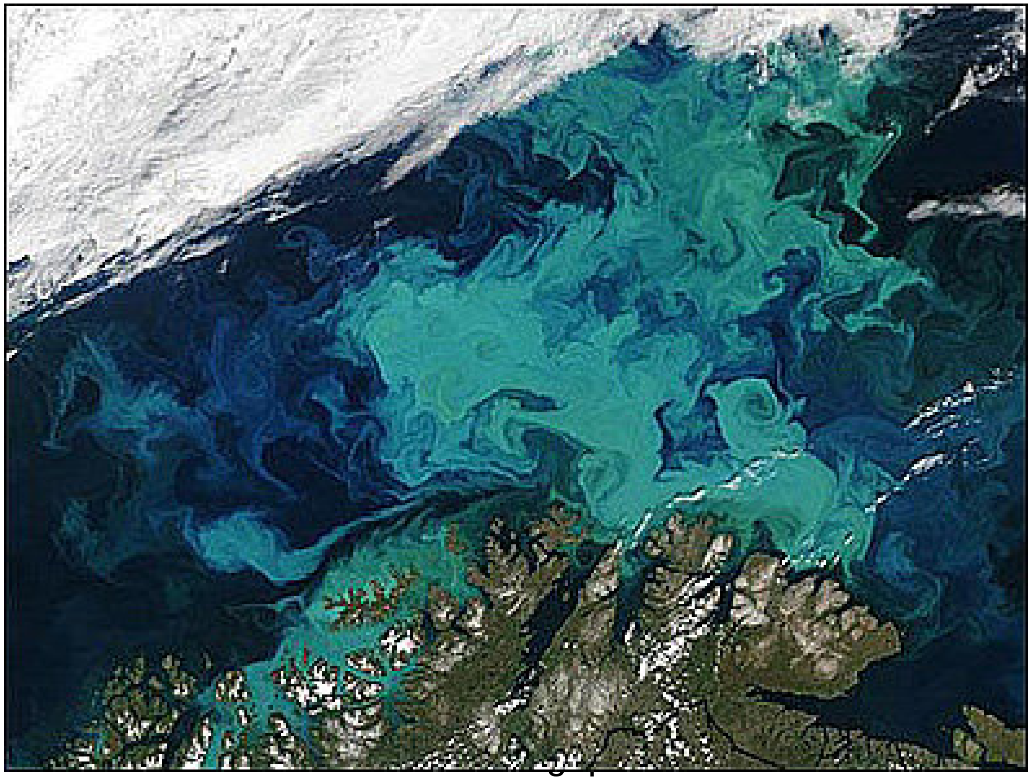
Coccolithophore bloom

Coccolithophores live on the surface in still, nutrient-poor water such as subpolar regions
Their CaCO3 shells stain the water a milky white.
Empirical detection algorithms depend on excess nadir water-leaving radiance at e.g. 550nm.

Coccolithophores

Emiliania huxleyi

Bloom of CCs



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

Cyanobacteria bloom in the Baltic Sea in July 2008

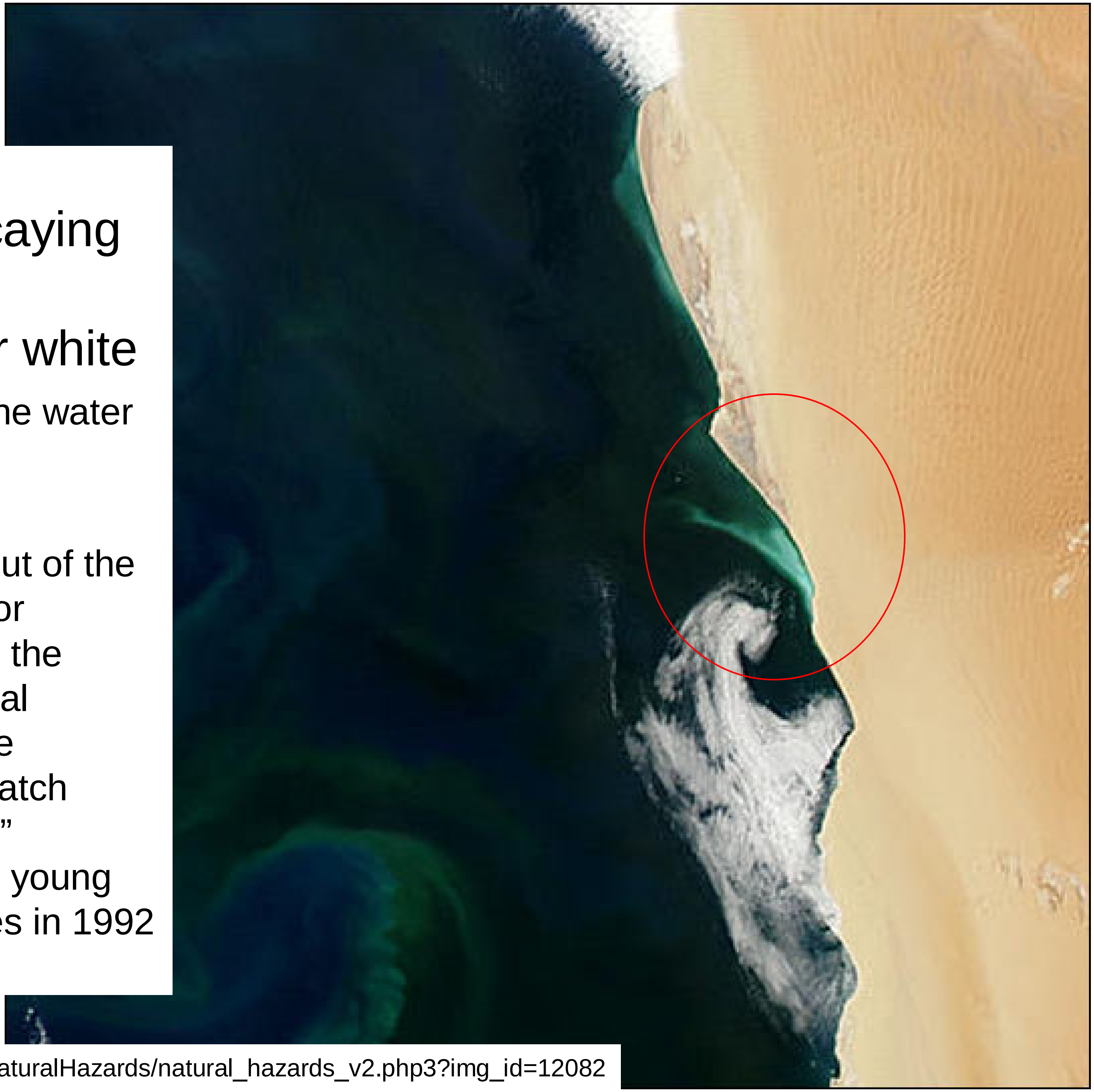
Cyanobacteria blooms in the Baltic in recent summers appear to result from high nutrient runoff. They are responsible for the development of anoxic dead zones as a result of phytoplankton decay.

River delta sediment

Remote Sensing: passive ocean

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

H_2SO_4 off Namibia



- Caused by decaying diatoms
- Forms granular white sulfur, which tints the water bright green.
- Kills fish
    - "lobsters walk out of the ocean gasping for breath," much to the delight of the local residents and the seabirds who snatch them up for food"
    - killed two billion young Cape Hake fishes in 1992 to 1993.

http://earthobservatory.nasa.gov/NaturalHazards/natural_hazards_v2.php3?img_id=12082

Ocean salinity

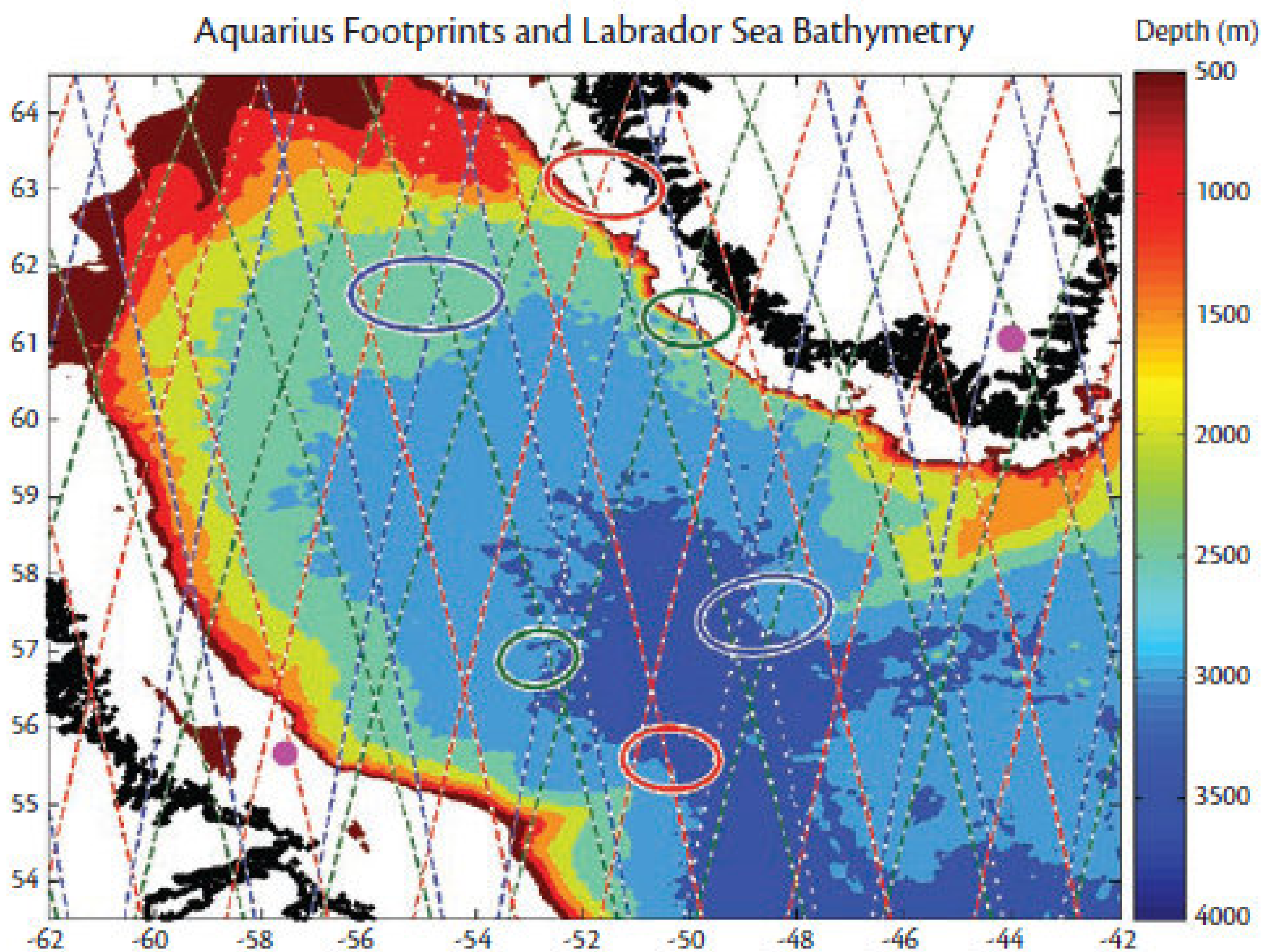
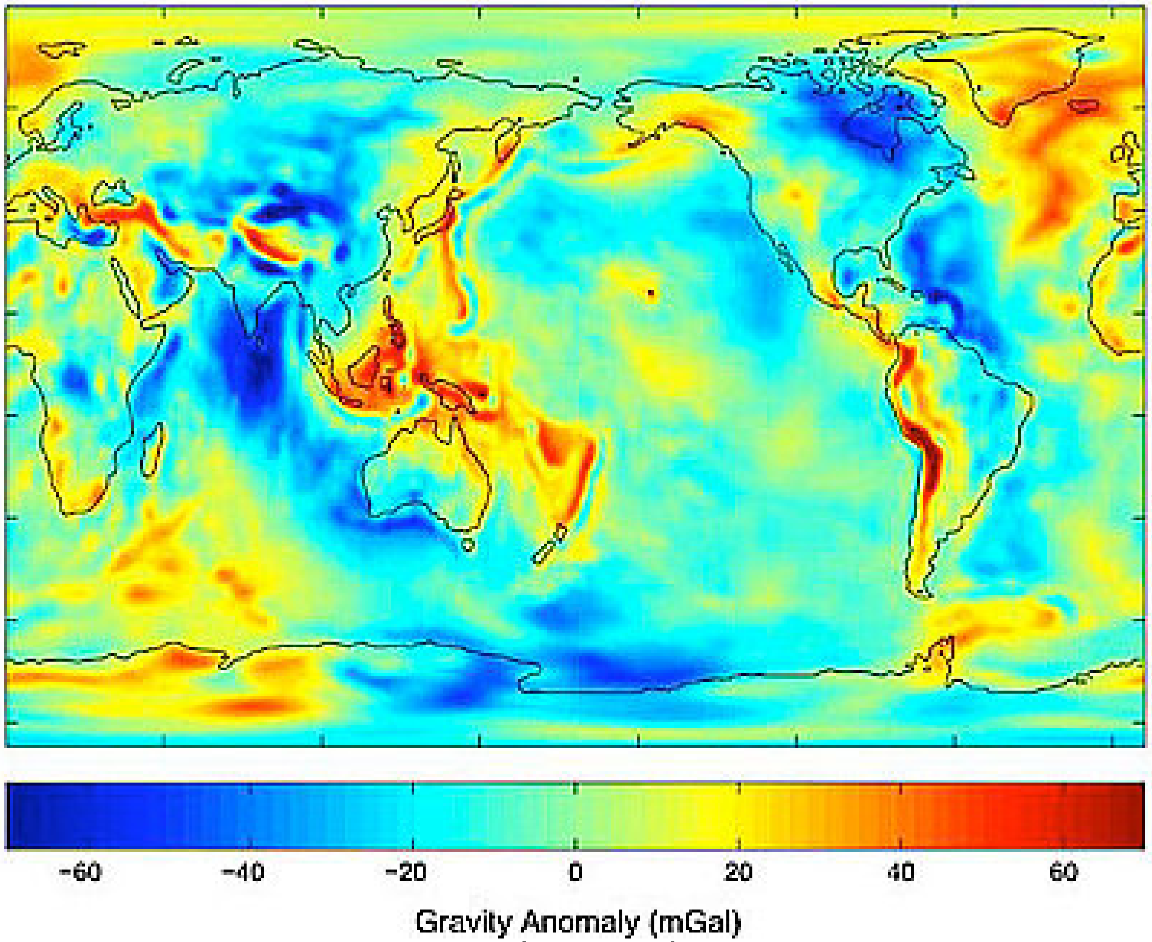


Figure 4. The Aquarius beam pattern superimposed on a bathymetry map of the Labrador Sea. Colors indicate the three Aquarius beams: inner (green), middle (red), and outer (blue). Ascending tracks are oriented southeast to northwest.

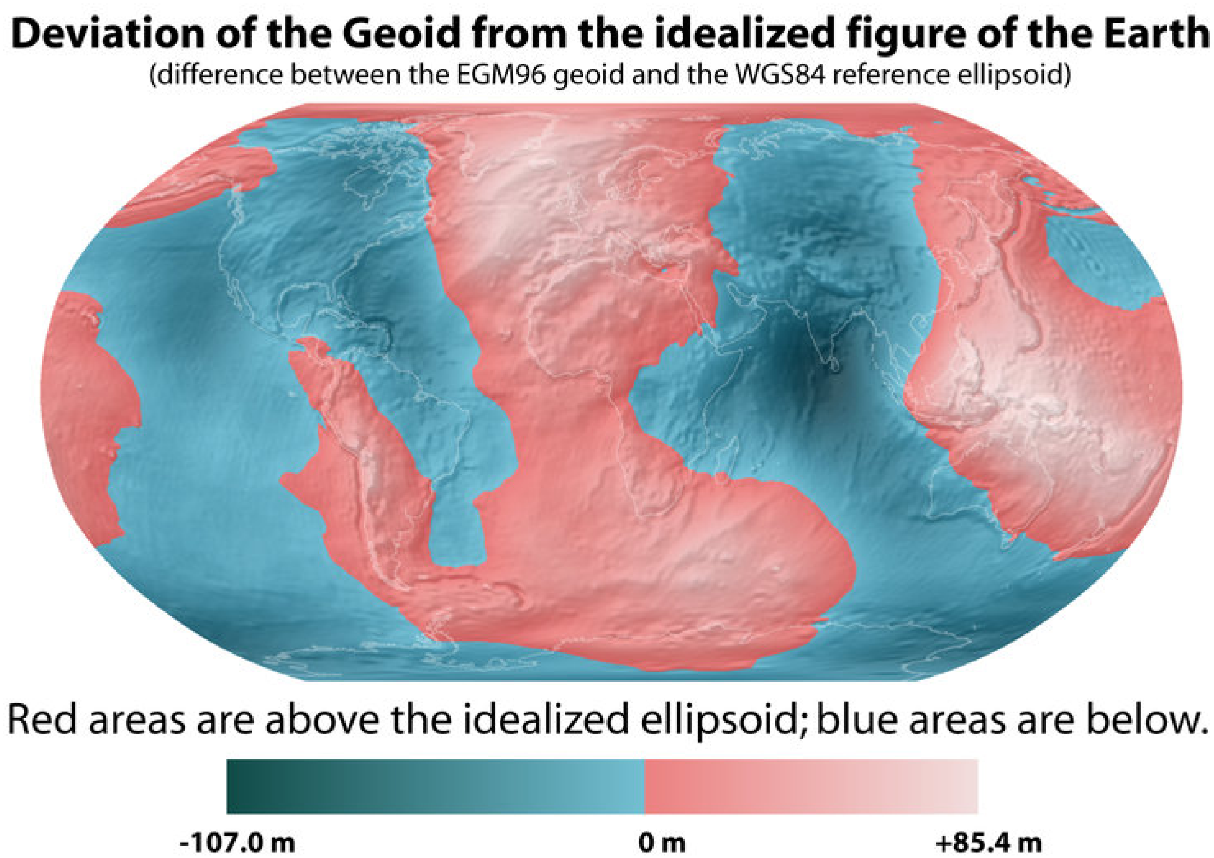
LBand: 1.4GHz

Earth gravity



Remote Sensing: passive ocean

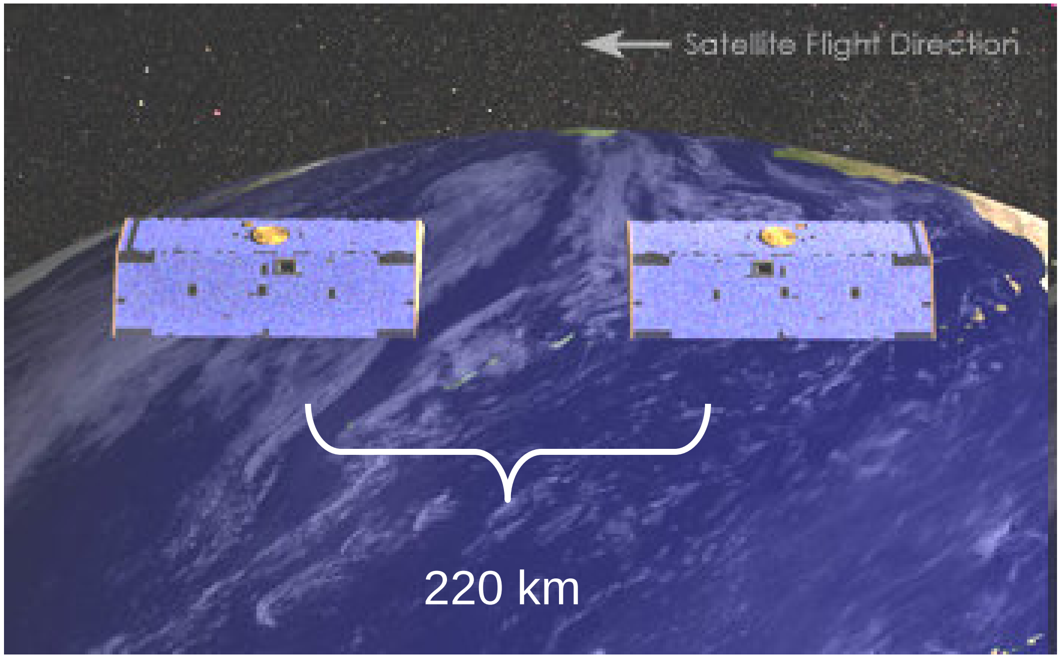
Earth's geoid



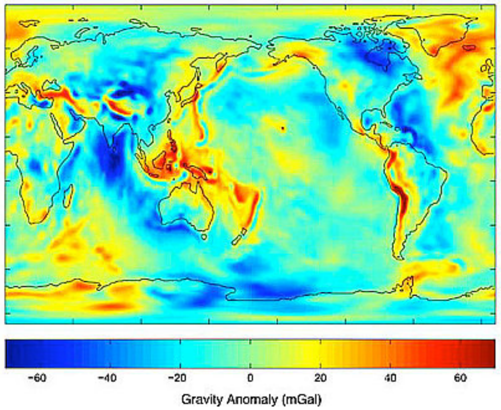
Time-dependent Gravity

GRACE
(Gravity Recovery and
Climate Experiment)

500km orbit.



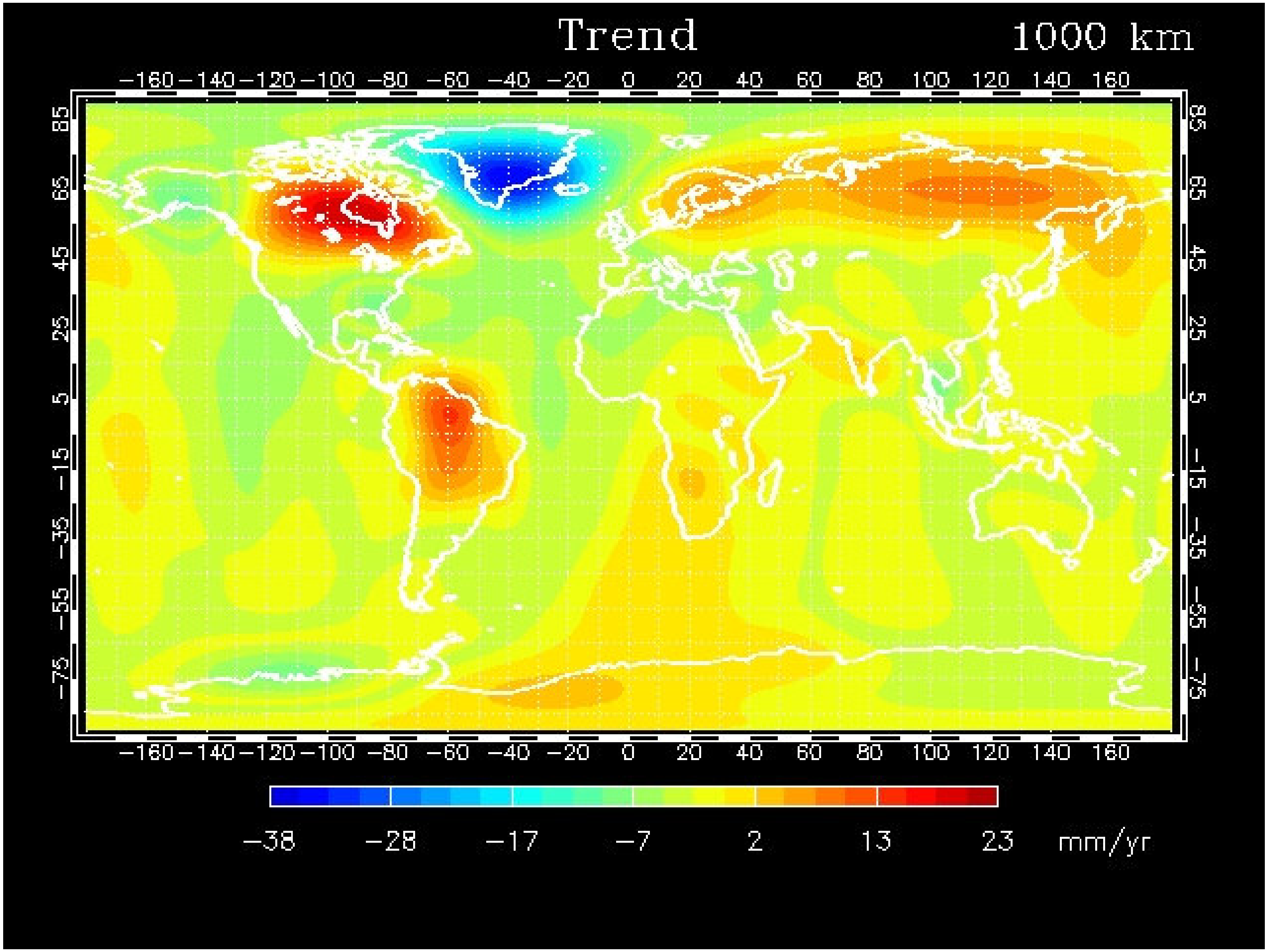
Distance accurate to 10μm



Remote Sensing: passive ocean

http://www.csr.utexas.edu/grace/gravity/

Geoid trend



Trend
1000 km
−160 −140 −120 −100 −80 −60 −40 −20 0 20 40 60 80 100 120 140 160
85 65 45 25 5 −15 −35 −55 −75
−38 −28 −17 −7 2 13 23 mm/yr

References

- NASA tutorial: http://rst.gsfc.nasa.gov/Front/tofc.html
- UIUC tutorial: http://ww2010.atmos.uiuc.edu/(Gh)/guides/rs/home.rxml
- Lillesand, T.M., and R.W. Kiefer, *Remote Sensing and Image Interpretation*, 724 pp., John Wiley and Sons, Inc., New York, 2000.

Band no.	Centre Wavelength (nm)	Band width (nm)	NESR ($Wm^{-2}sr^{-1}\mu m^{-1}$)	Applications potential
1	412	10	0.025	Yellow substance absorption
2	443	10	0.025	Suitable for low chlorophyll , yellow substance
3	490	10	0.022	Suitable for moderate chlorophyll, yellow substance, phycoerithrin
4	510	10	0.018	For high chlor., chlor species, TSM, phycoerithrin, algal blooms
5	555	10	0.015	For high chlor., chlor species, TSM, algal blooms
6	620	10	0.014	TSM, algal blooms
7	670	10	0.012	Algal blooms, base line for chlor. fluorescence
8	681	7.5	0.010	Chlor. Fluorescence for high concentrations
9	710	10	0.010	NIR band, extrapolation to VIS bands better, base line for chlor. fluorescence
10	780	10	0.010	Atmos. correction, avoids O_2 A abs. band in
11	870	<20	0.010	Atmos. correction, good separation from the previous bands, better for coastal waters
12	1010	20	0.020	Atmos. correction, good for coastal waters, useful for aerosol and & foam discrimination