Ocean Remote Sensing Introduction and IR

Ted Strub

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CIOSS – Cooperative Institute for

Oceanographic Satellite Studies

Oregon State University

Introduction: Basic methodology for passive and active ocean remote sensing + sea surface temperature (SST)

Seelye Martin (2004): An Introduction to Ocean Remote Sensing

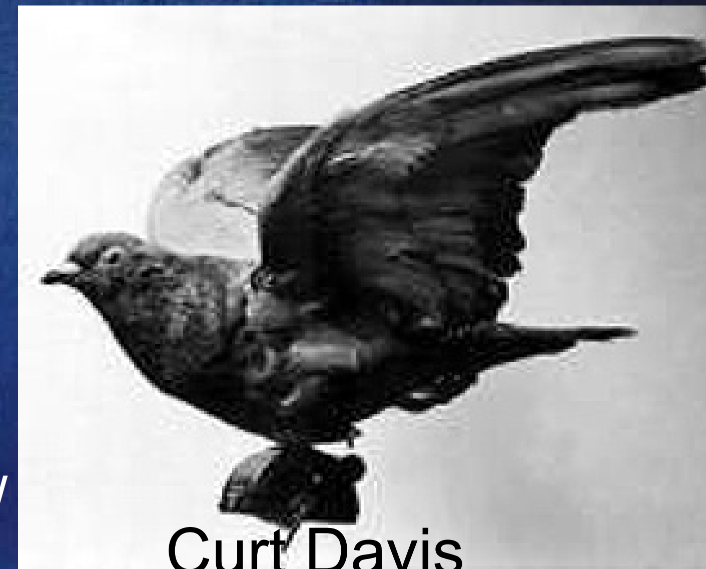
Remote Sensing Pioneers

Early Days

Mike Freilich

Dudley Chelton

Mark Abbott/
Ricardo Letelier/
Peter Strutton



Curt Davis

NPOESS EDR-to-Sensor Mapping

= Primary Ocean Parameter

= Secondary Ocean Parameter

- Atm Vert Moist Profile
- Atm Vert Temp Profile
- Imagery
- Sea Surface Temperature
- Sea Surface Winds
- Soil Moisture
- Aerosol Optical Thickness
- Aerosol Particle Size
- Aerosol Refractive Index
- Albedo (Surface)
- Auroral Boundary
- Auroral Energy Deposition
- Auroral Imagery
- Cloud Base Height
- Cloud Cover/Layers
- Cloud Effective Part Size
- Cloud Ice Water Path
- Cloud Liquid Water
- Cloud Optical Thickness
- Cloud Particle Size/Distrib
- Cloud Top Height

- Cloud Top Pressure
- Cloud Top Temperature
- Down LW Radiance (Sfc)
- Down SW Radiance (Sfc)
- Electric Fields
- Electron Density Profile
- Energetic Ions
- Geomagnetic Field
- Ice Surface Temperature
- In-situ Plasma Fluctuation
- In-situ Plasma Temp
- Ionospheric Scintillation
- Med Energy Chgd Parts
- Land Surface Temp
- Net Heat Flux
- Net Solar Radiation (TOA)
- Neutral Density Profile
- Ocean Color/Chlorophyll
- Ocean Wave Character ★
- Outgoing LW Rad (TOA)
- O_3 – Total Column Profile

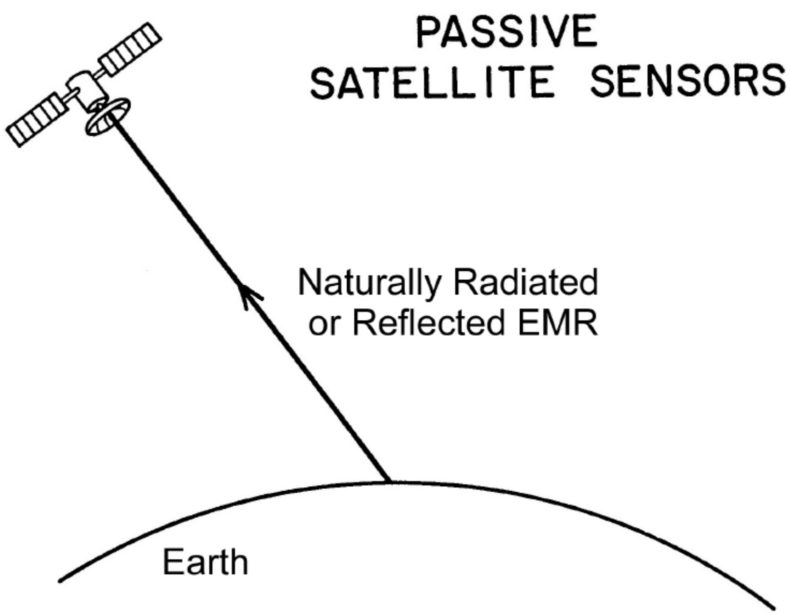
- Precipitable Water
- Precipitation Type/Rate
- Pressure (Surface/Profile)
- Sea Ice Characterization
- Sea SFC Height/TOPO
- Snow Cover/Depth
- Solar Irradiance
- Supra-Therm-Aurora Prop
- Surface Type
- Active Fires (Application product)
- Surface Wind Stress
- Suspended Matter
- Total Water Content
- Vegetative Index

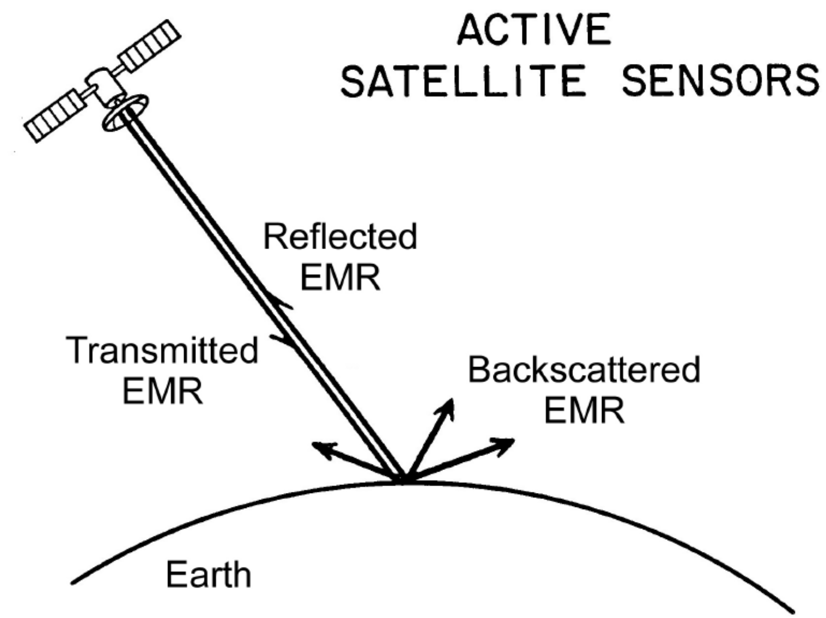
LEGEND

VIIRS (24)	GPSOS (2)
CMIS (19)	ERBS (5)
CrIS/ATMS (3)	TSIS (1)
OMPS (1)	ALT (3)
SES (13)	APS (4)

☆ - Key Performance Parameters

★ Including Surface Roughness (SAR)





Passive Remote Sensing: Reception of emitted, reflected or scattered EMR at the satellite sensor, after it travels from the ocean through the atmosphere: used with visible, IR and microwave wavelengths/frequencies.

Active Remote Sensing: Reception of the reflection of a transmitted pulse of EMR, after interacting with the surface of the ocean and travelling through the atmosphere (twice): used with microwave frequencies (except lidars).

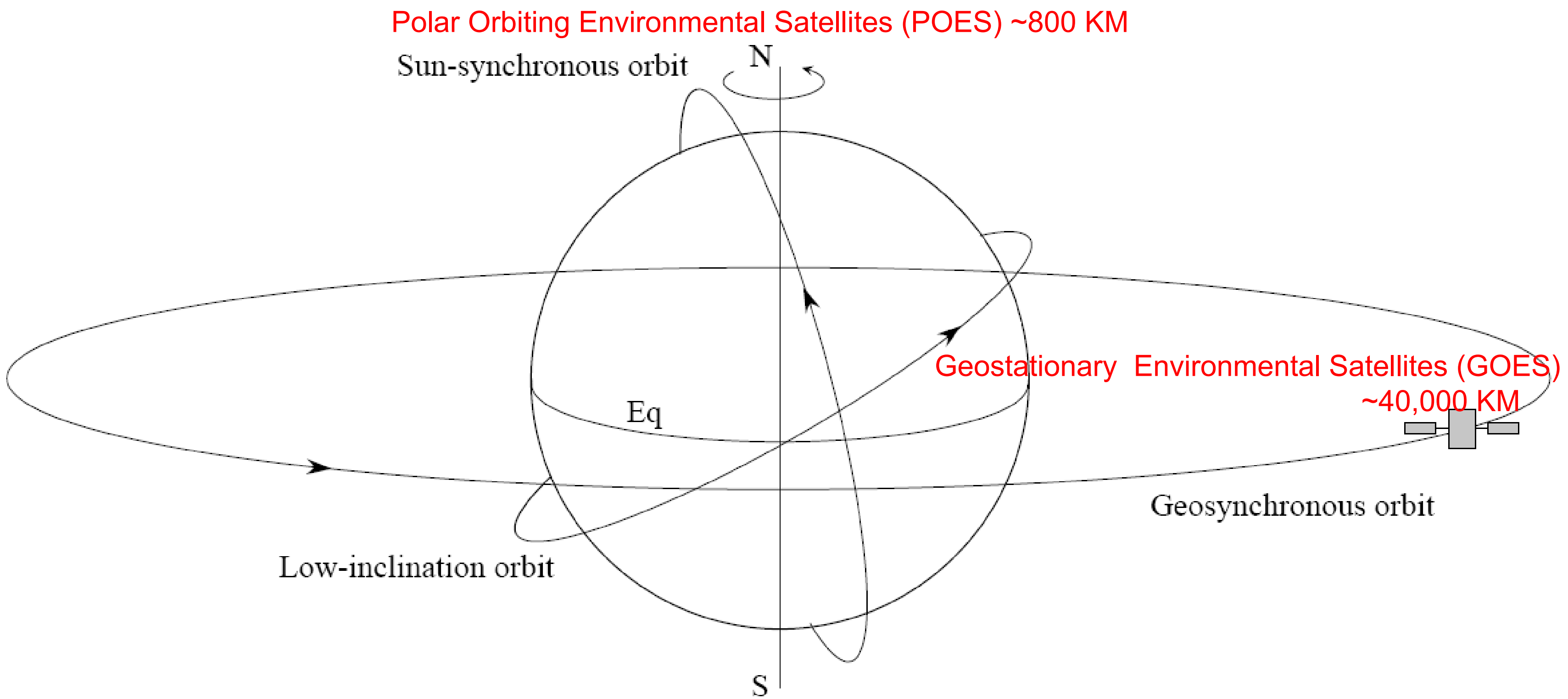


Fig. 1.3. Examples of the sun-synchronous, geosynchronous and low inclination orbits, where 'Eq' is the equator (Adapted from Asrar and Dozier, 1994, Figure 3).

Martin

What Do We “Sense”?

What Do We “Sense”?

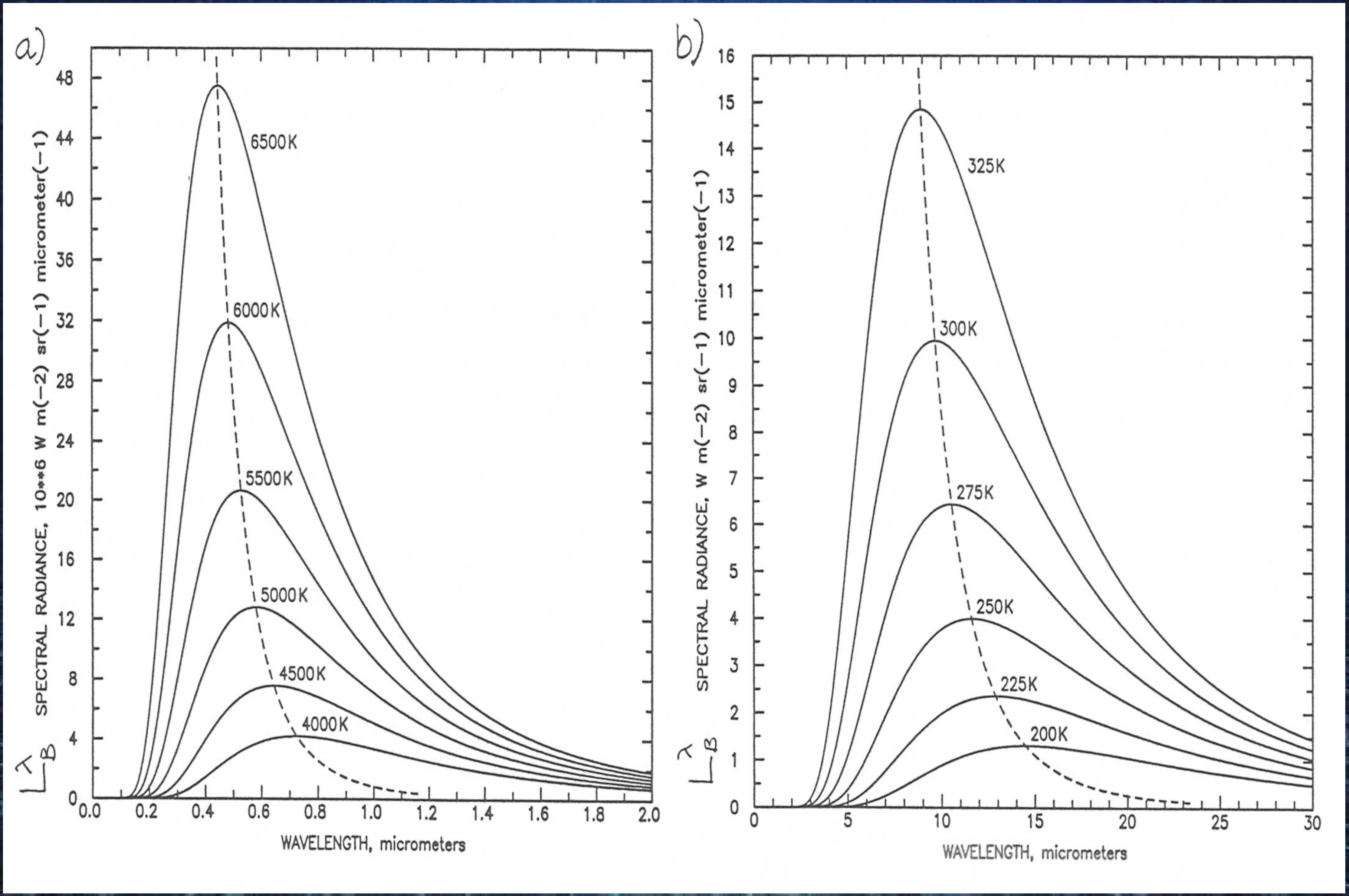
EMR = Electromagnetic Radiation

All “things” emit EMR, with characteristics determined by their:

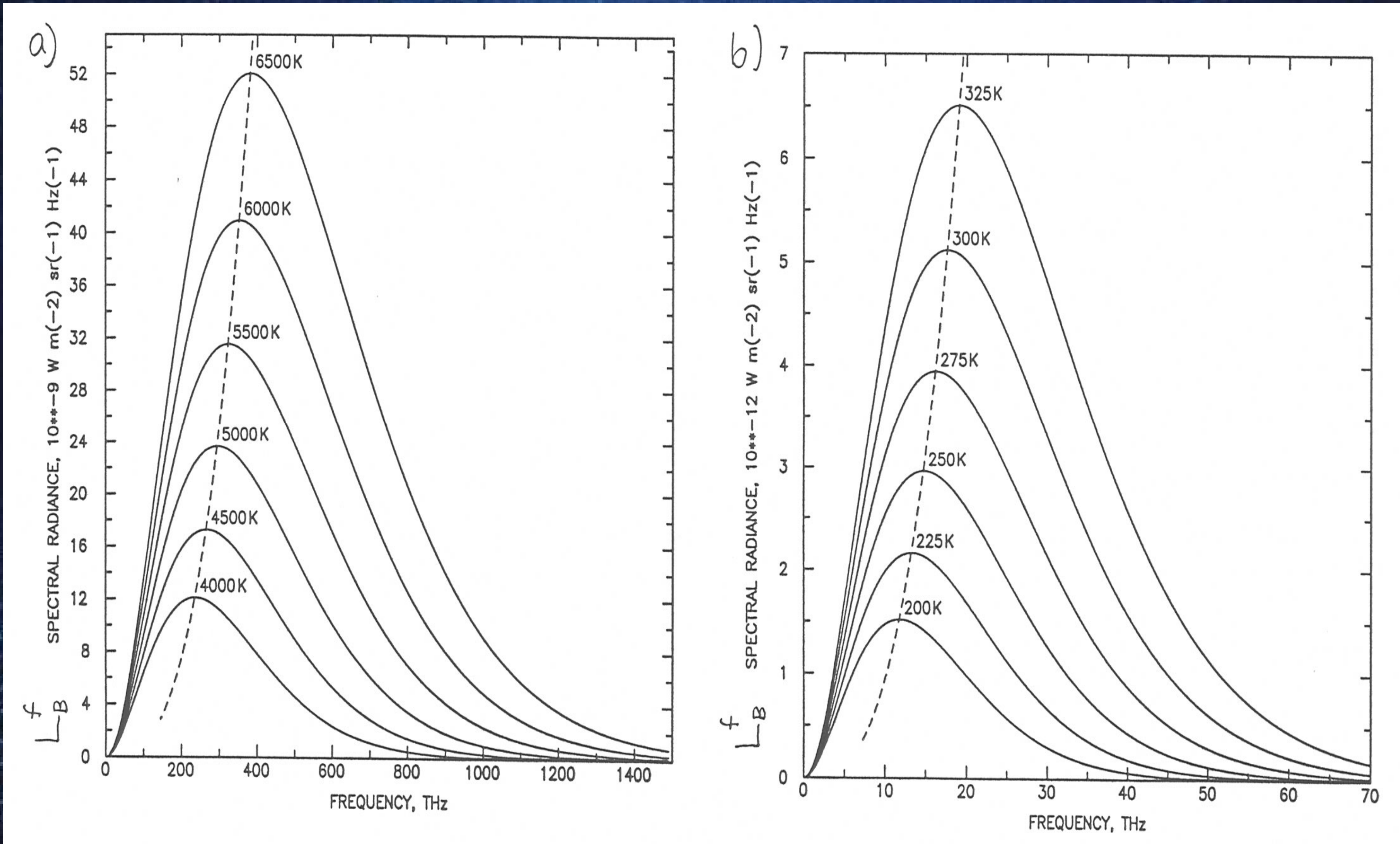
• temperature (Planck’s function)

• emissivity (a function of wind speed, temperature, salinity, etc.)

Black Body Radiation



Black Body Radiation



Inverting the Planck Blackbody Function (including emissivity):

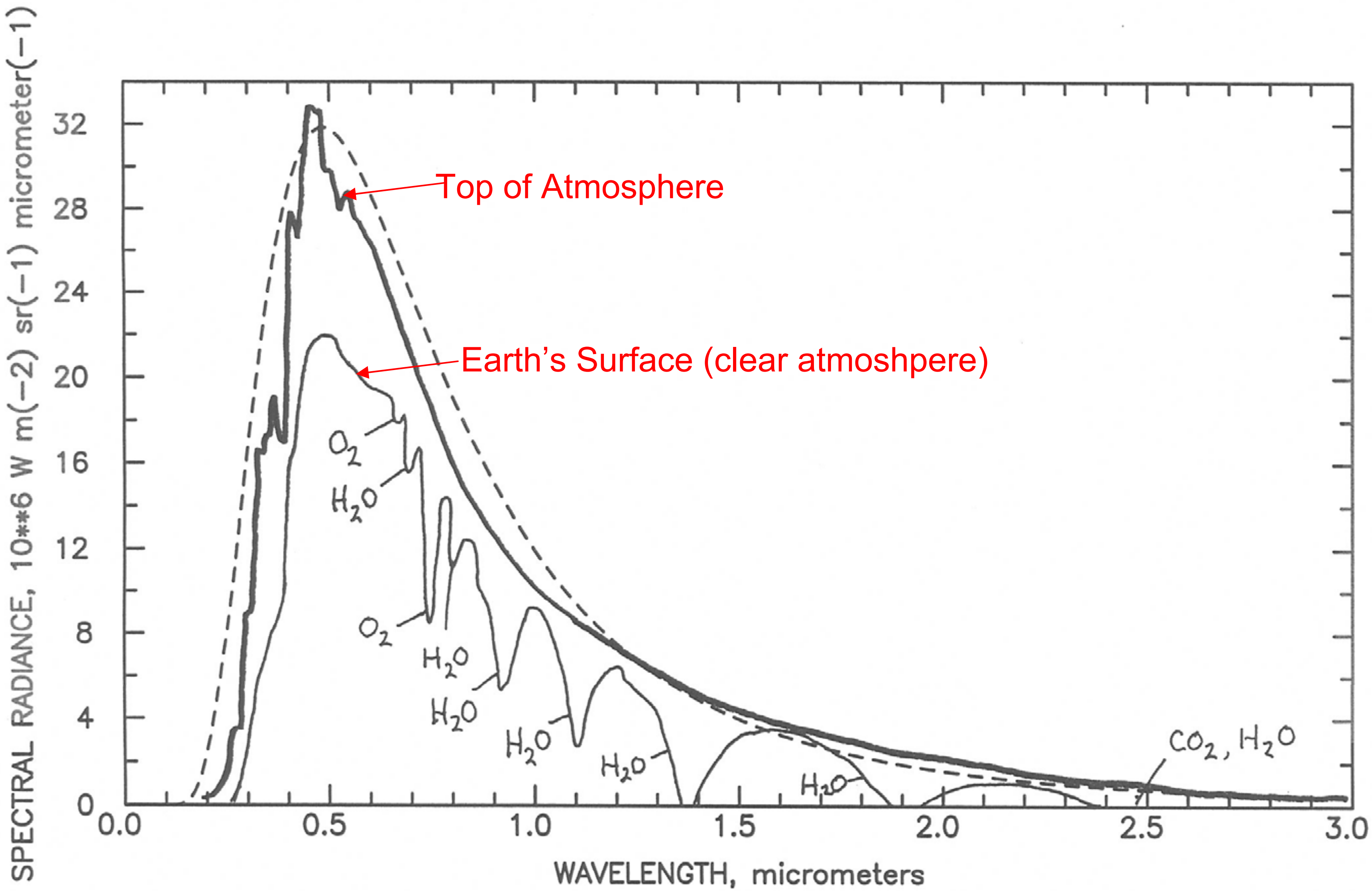
If we measure the water leaving spectral radiance just above the water surface, we can find the temperature from a single wavelength by inverting Planck's equation. We include the emissivity, ε^{λ}, although it is approximately 1 (~0.98) for water.

$$L^{\lambda} = \epsilon^{\lambda} \cdot \frac{C_1}{\lambda^5} \cdot \frac{1}{e^{\frac{C_2}{\lambda T}} - 1}$$

$$T_B = T_S = \frac{C_2}{\lambda \cdot \ln\left[\frac{\epsilon^{\lambda} \cdot C_1}{L^{\lambda} \cdot \lambda^5} + 1\right]}$$

When we measure L^{λ} at the satellite, we set $\varepsilon^{\lambda}=1$ and call T_B the "brightness temperature", the temperature that exactly corresponds to that amount of radiation from a perfect black body. If there were a vacuum between the surface of the water and the satellite and if we included the correct emissivity, the corrected (for emissivity) brightness temperature would be equal to the surface temperature. Because the components of the atmosphere absorb, emit and (possibly) scatter IR radiation, we must correct the brightness temperature for atmospheric effects to estimate SST.

What Gets Through The Clear Atmosphere?



Martin – EMR Uses

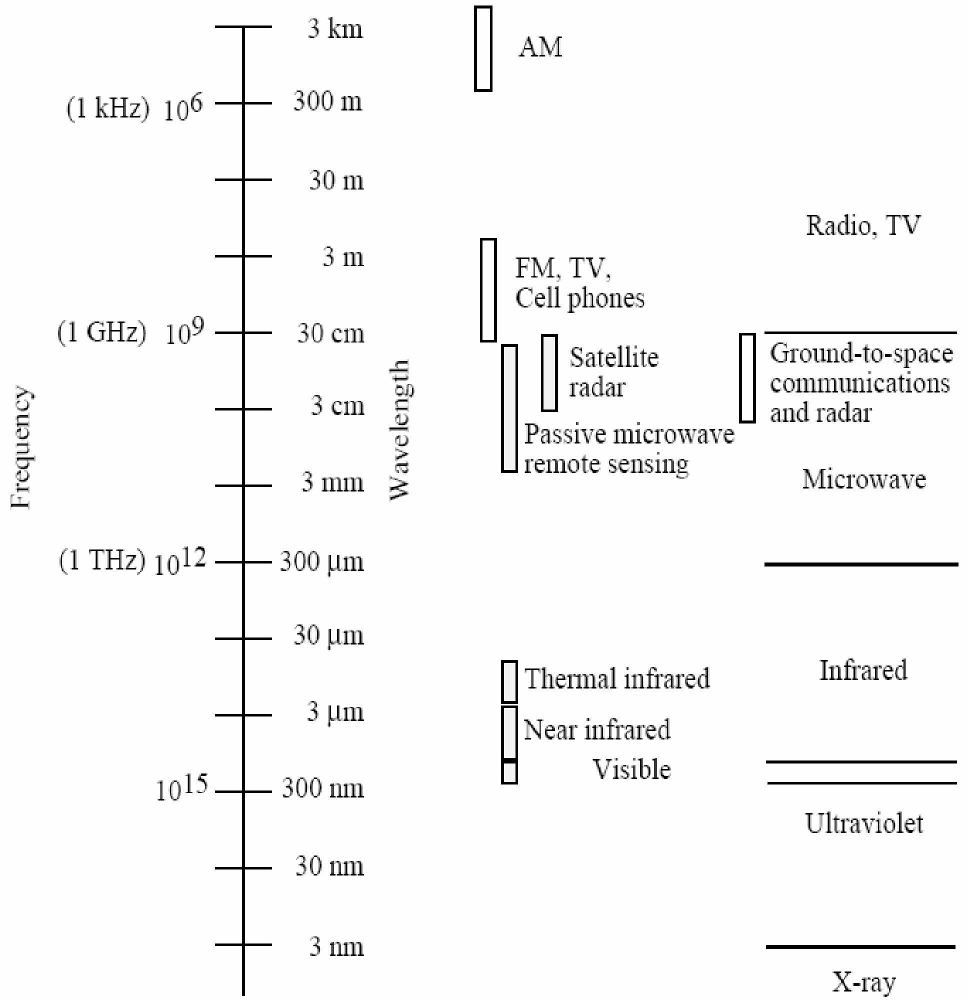
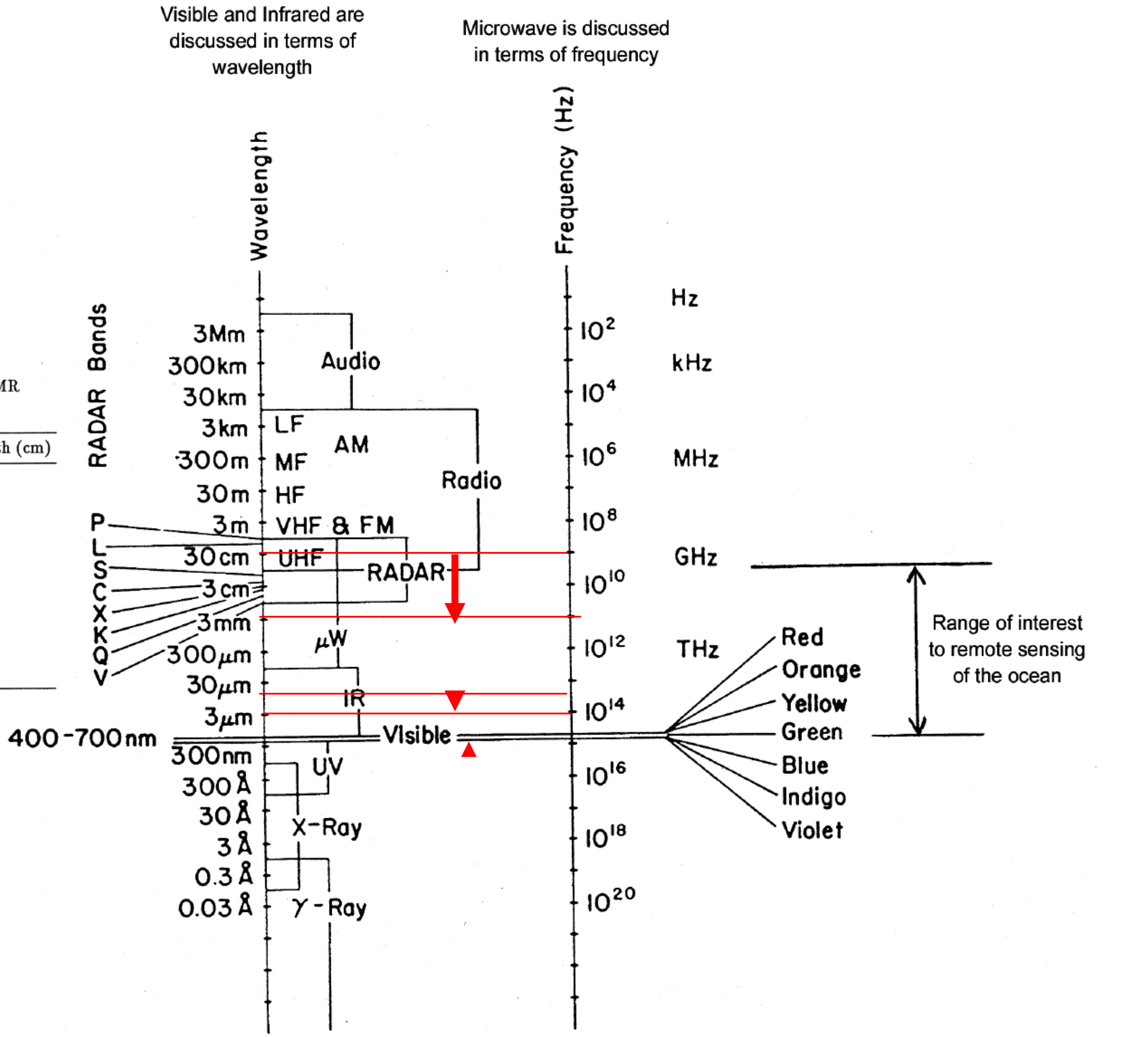


Fig. 3.2. The electromagnetic spectrum and its uses as a function of frequency and wavelength. The gray bars show the bands used in satellite remote sensing.

Definitions of Spectral Bands of Electromagnetic Radiation

Table 3.3. Naming conventions for radar bands of EMR
(1 GHz = 10^9 Hz)

Designation	Frequency range (GHz)	Center wavelength (cm)
P	0.225 – 0.390	100
L	0.390 – 1.55	30
S	1.55 – 5.20	9
C	3.90 – 6.20	6
X	6.20 – 10.90	3.5
K_u	10.90 – 18.00	2.1
K	18.00 – 26.00	1.4
K_a	26.00 – 36.00	1.0
Q	36.00 – 46.00	0.7
V	46.00 – 56.00	0.6
W	56.00 – 100.00	0.4



General case of passive remote sensing of the ocean.

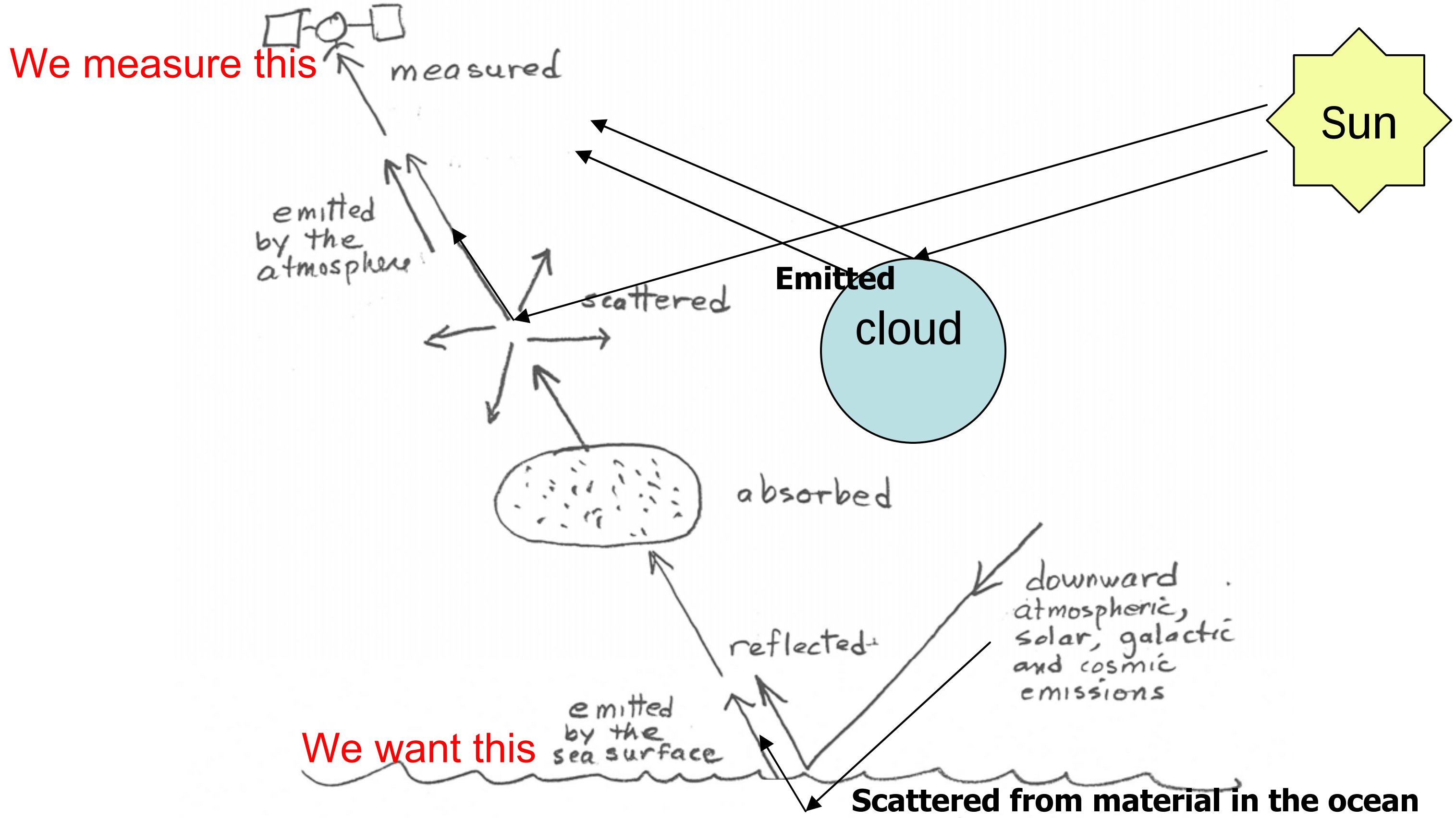


Figure 4.1. A schematic summary of radiative transfer of EMR from the sea surface to a radiometer onboard a satellite.

Skin Depth (EMR energy e-folding depth) for Pure Water

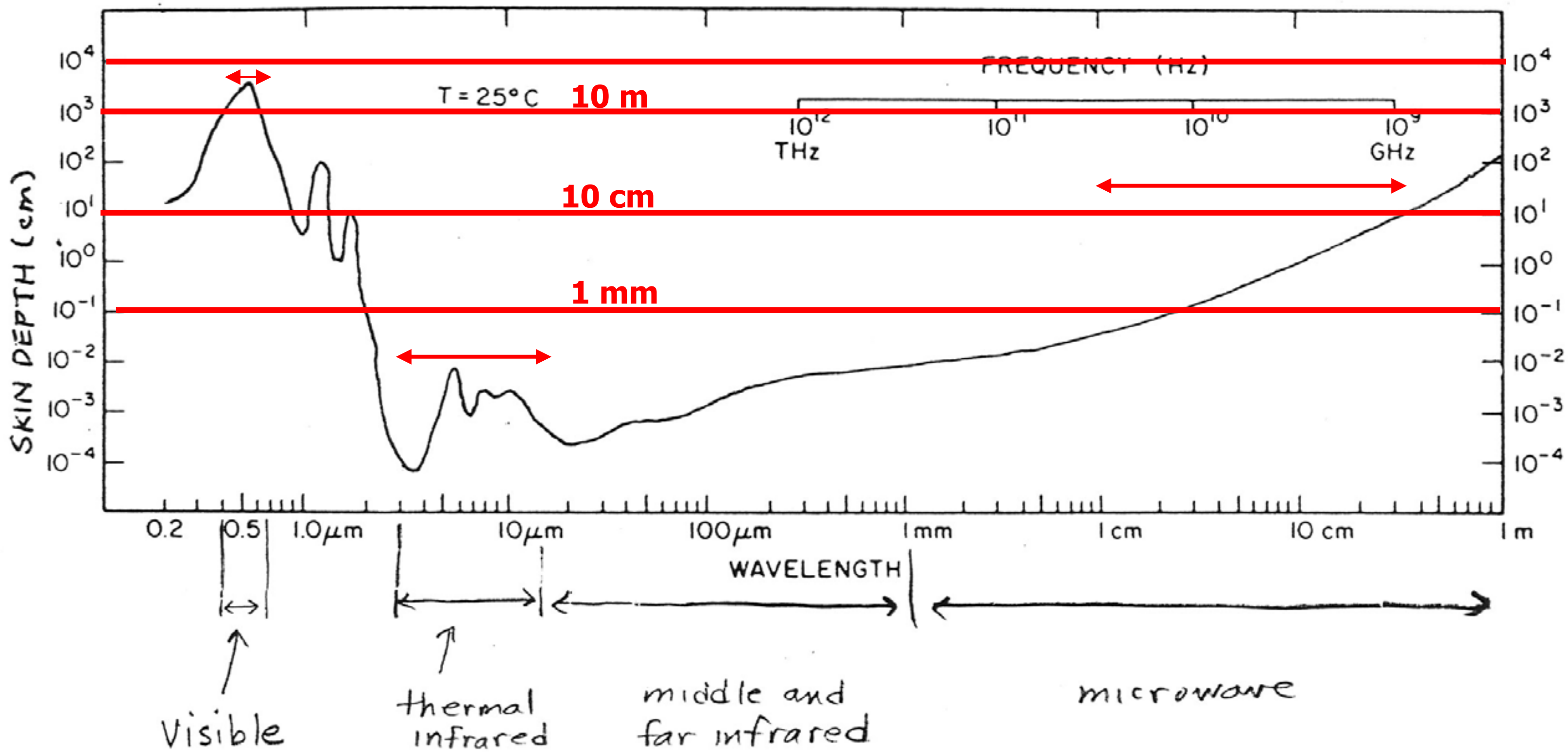


Figure 3.10. The skin depth given by (3.51) for the energy of EMR in pure water at temperature 25°C as a function of the wavelength of EMR. (After Maul, 1985, p. 106.)

Transmittance – visible, clear atmosphere;
But opaque to clouds.

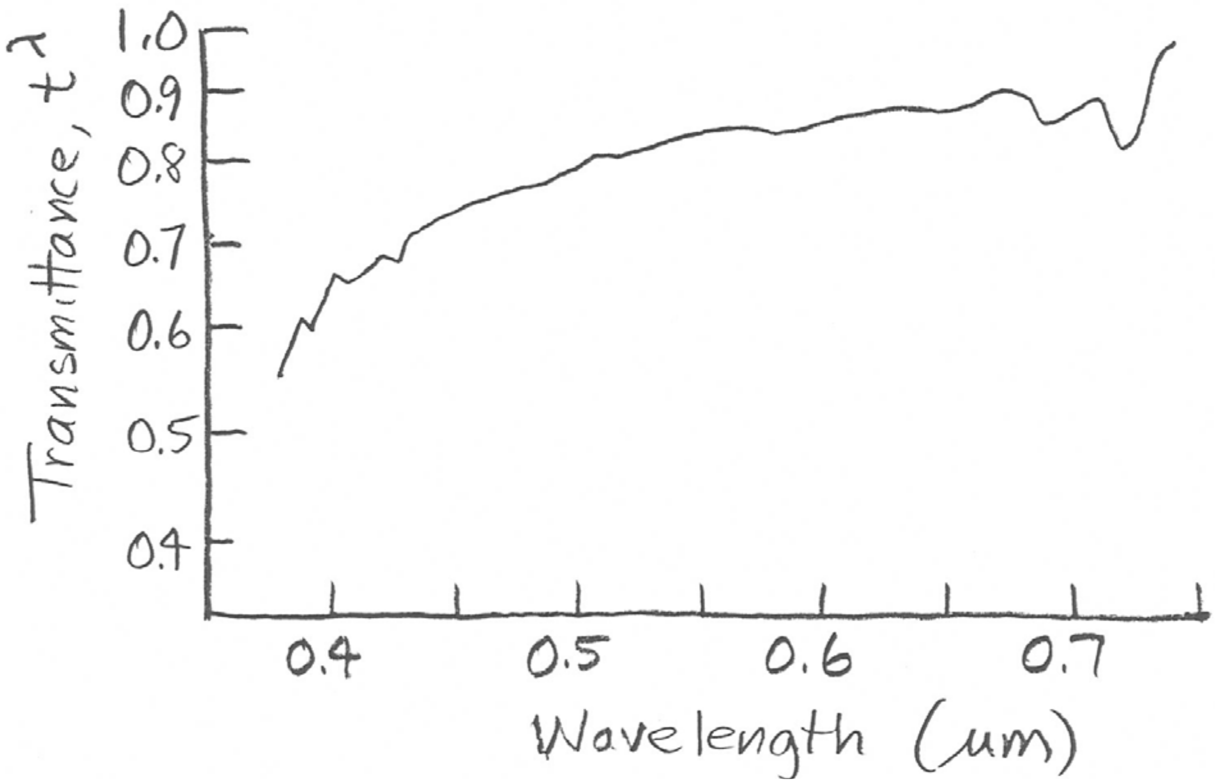


Figure 4.13. The transmittance of the atmosphere at 0° incidence angle as a function of wavelength in the visible band for a very clear atmosphere. (After Stewart, 1985.)

Visible Oceanographic Remote Sensing

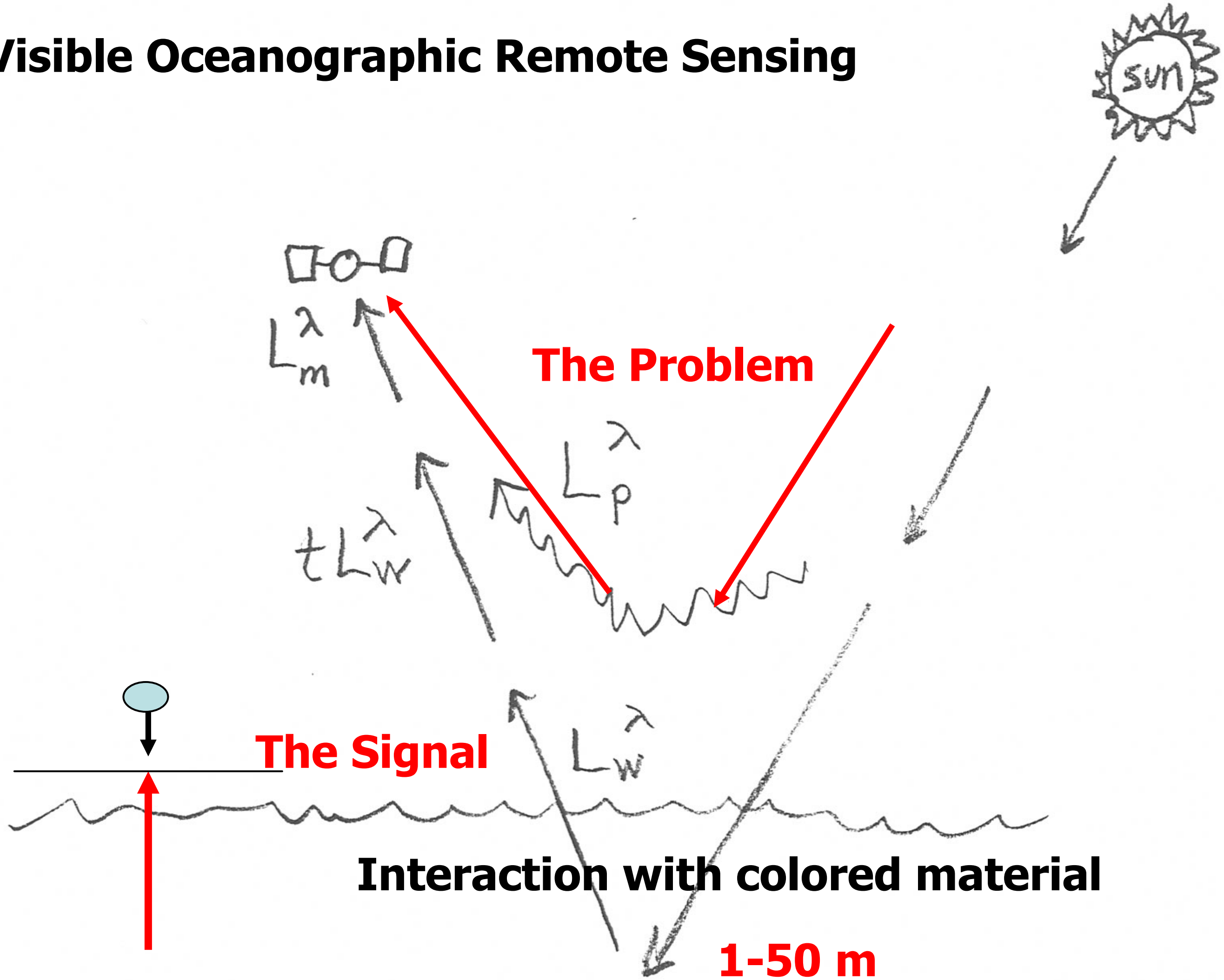
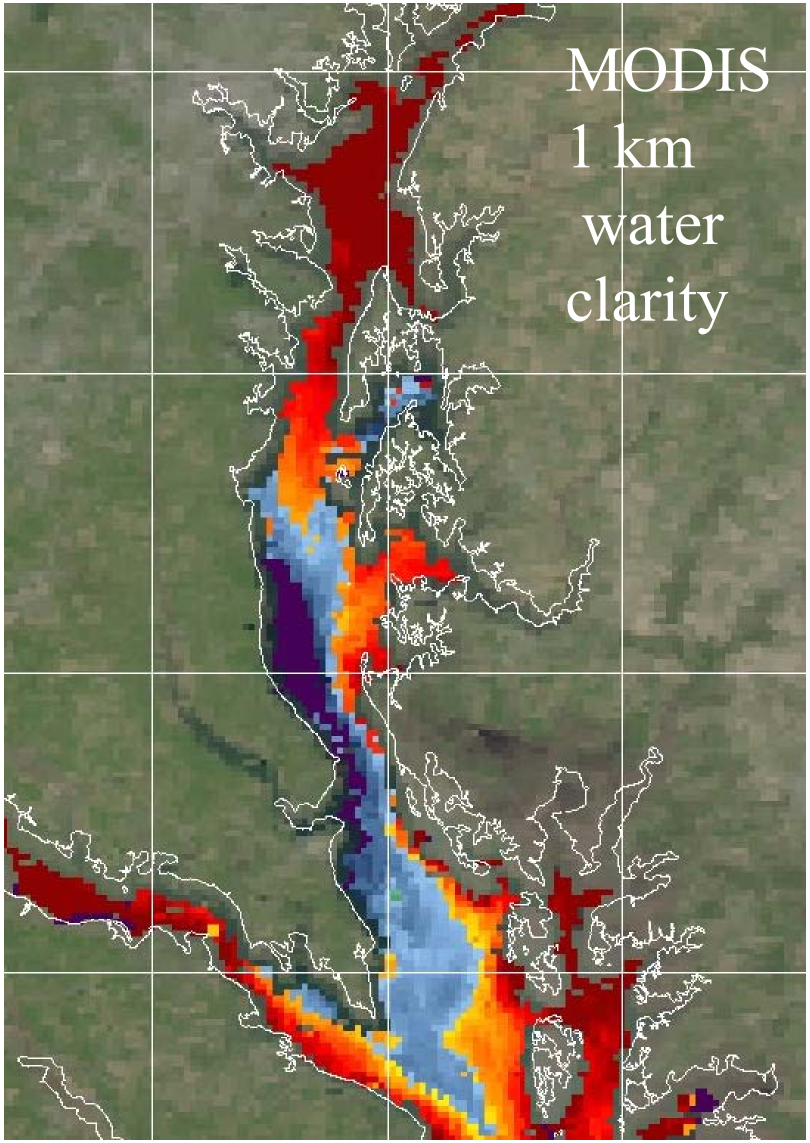
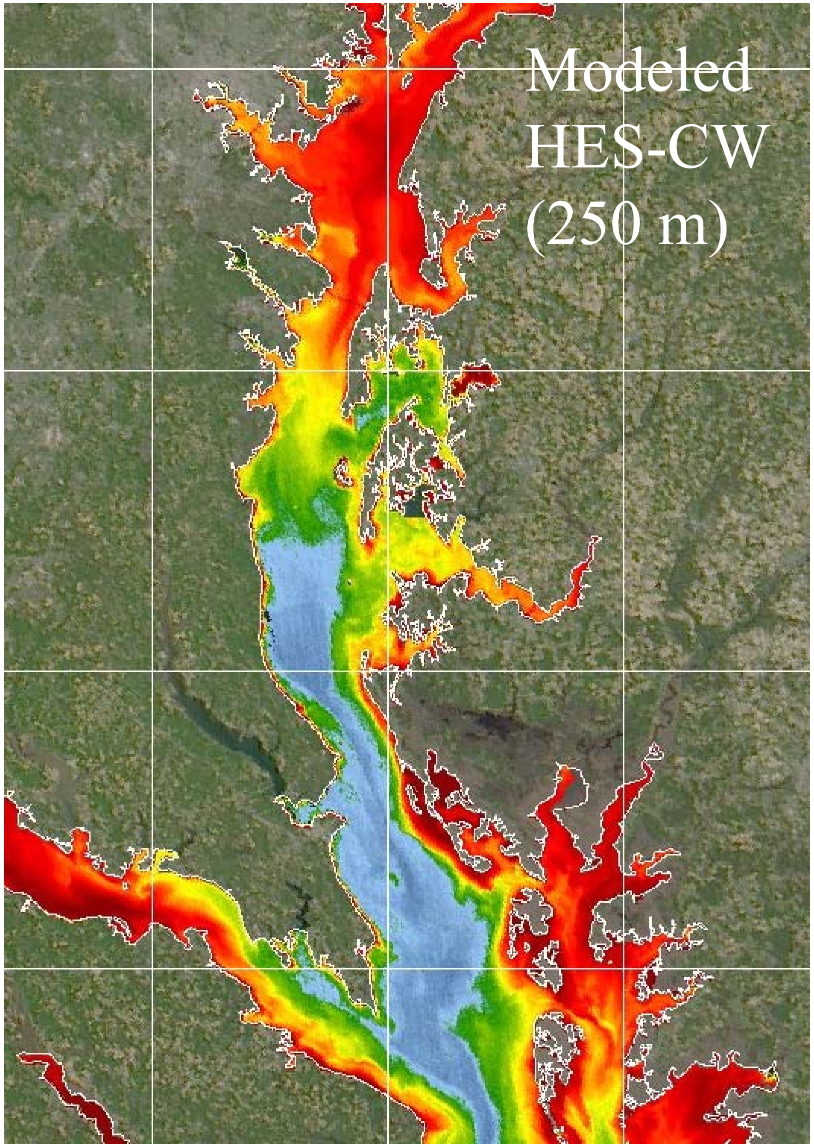


Figure 4.25. A schematic summary of the contributions to the spectral radiance measured by a satellite in the visible band of the electromagnetic spectrum.

SST and Ocean Color: Higher spatial resolution critical to monitor complex coastal waters





IR Oceanographic Remote Sensing

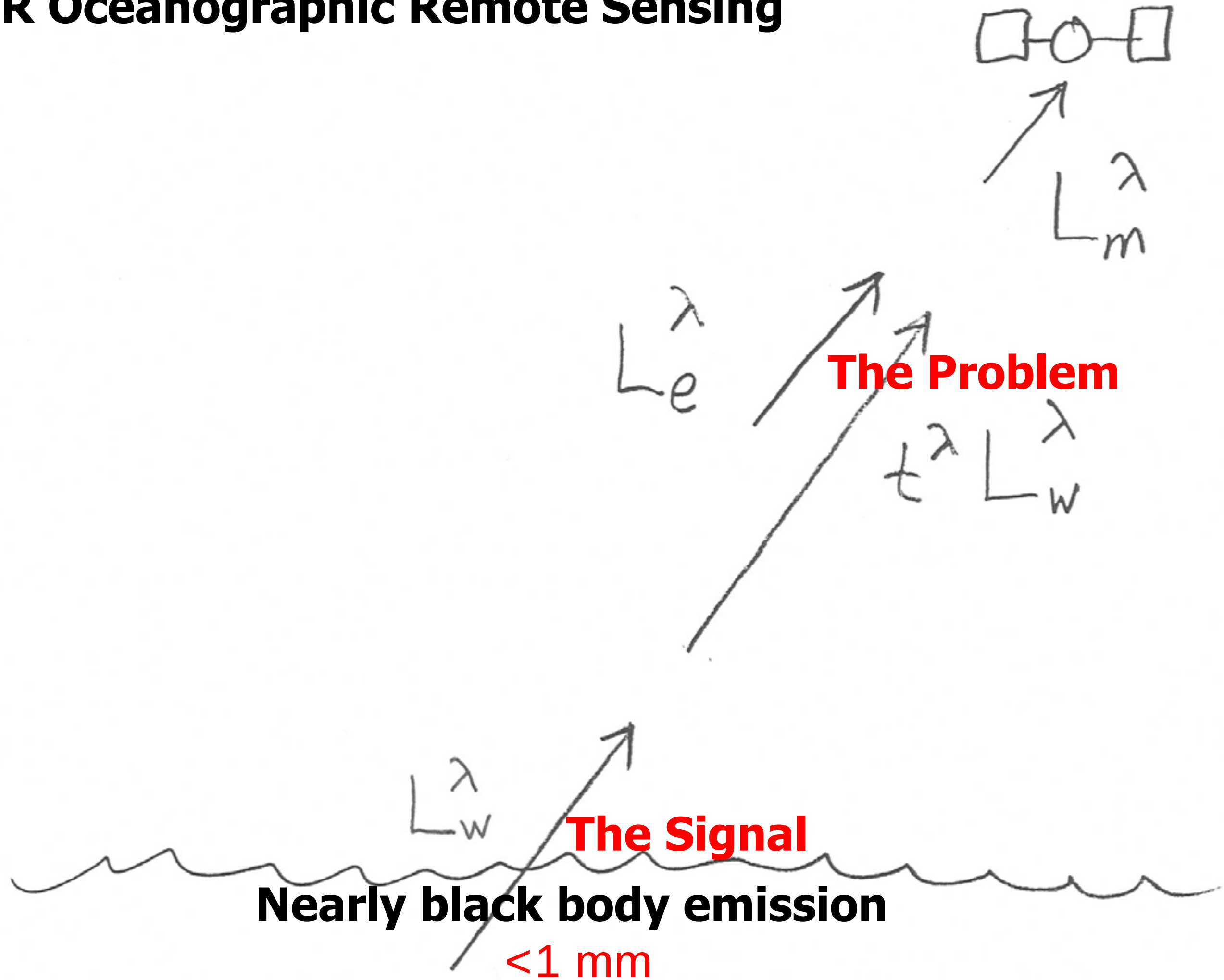


Figure 4.26. A schematic summary of the contributions to the spectral radiance measured by a satellite in the infrared band of the electromagnetic spectrum.

Skin Depth (EMR energy e-folding depth) for Pure Water

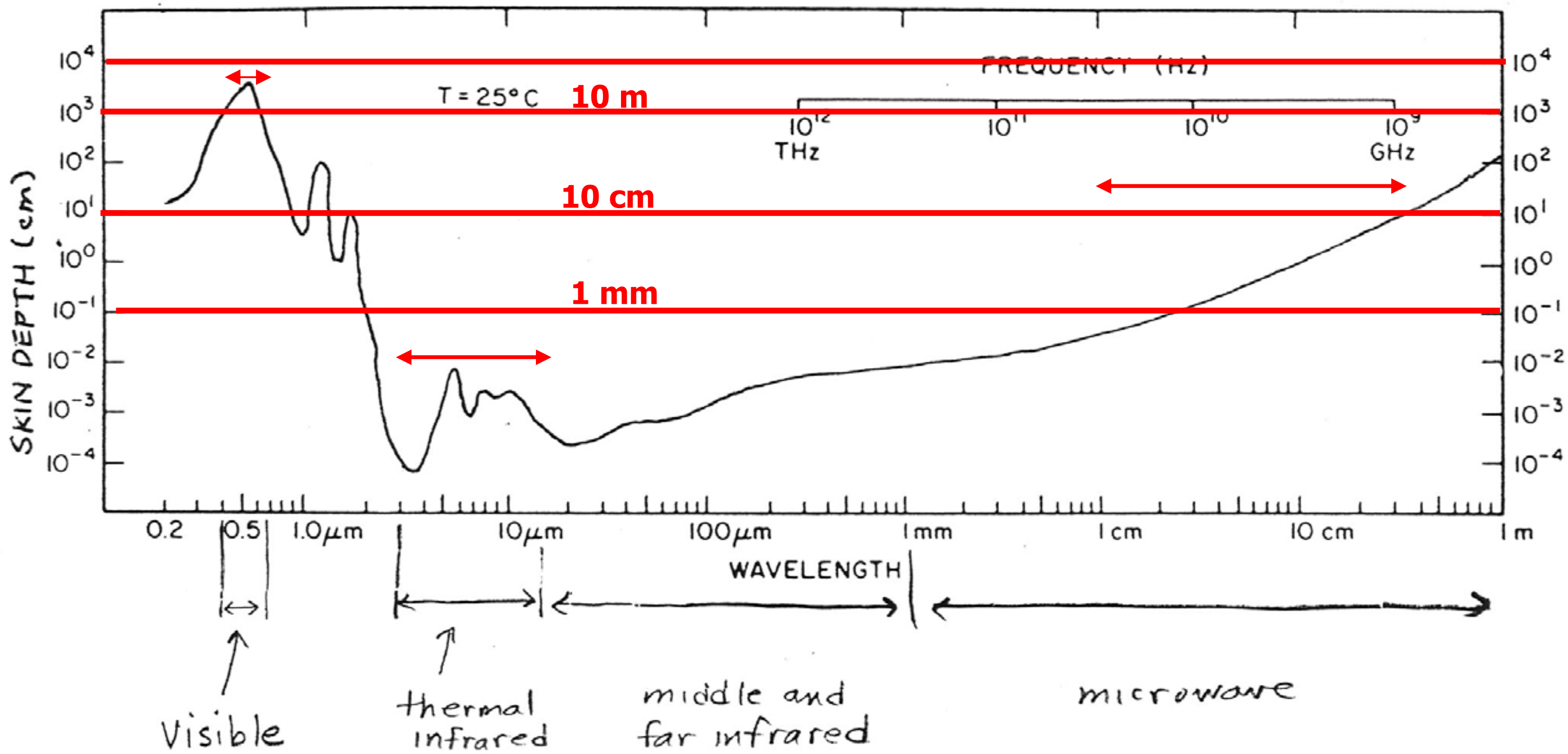
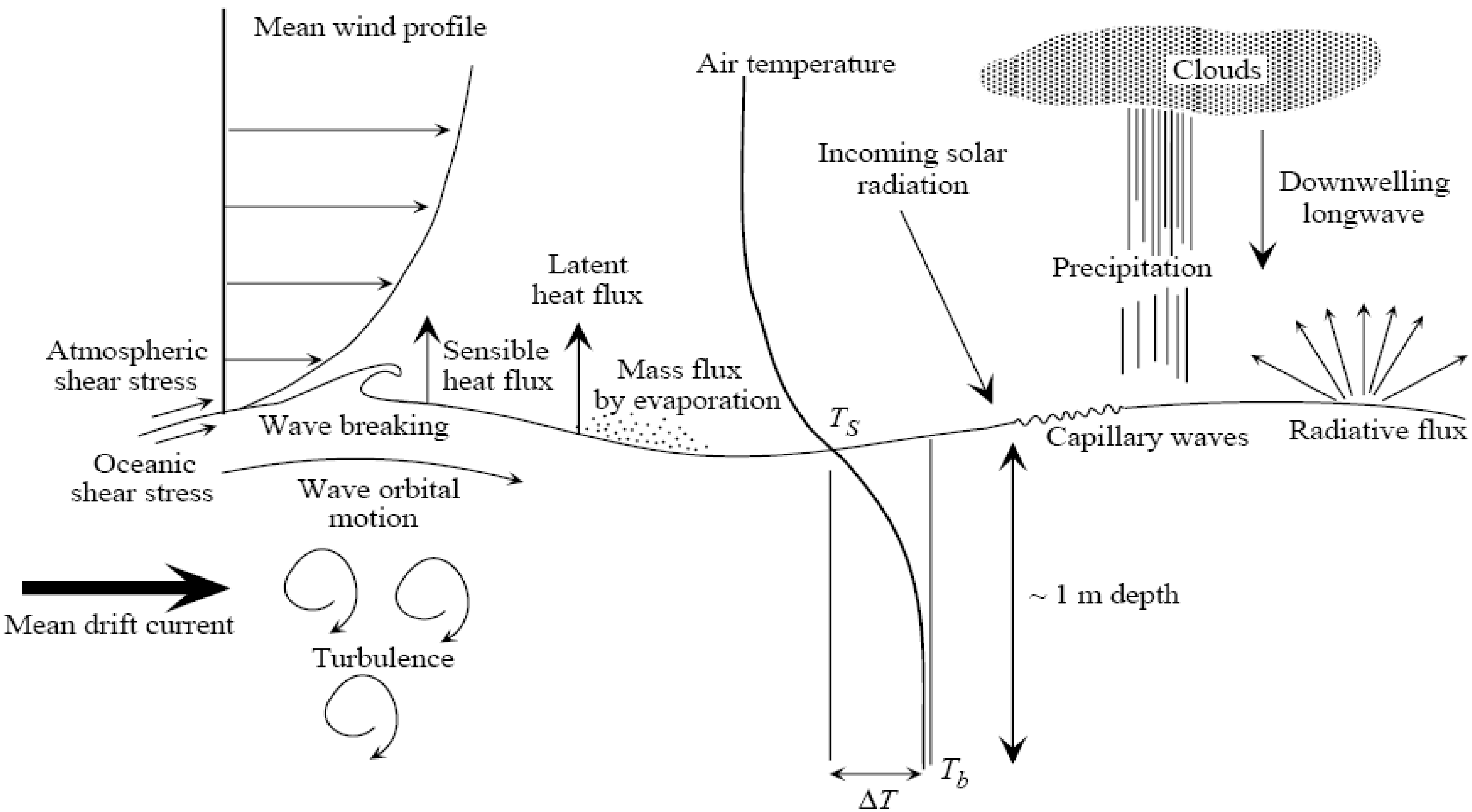
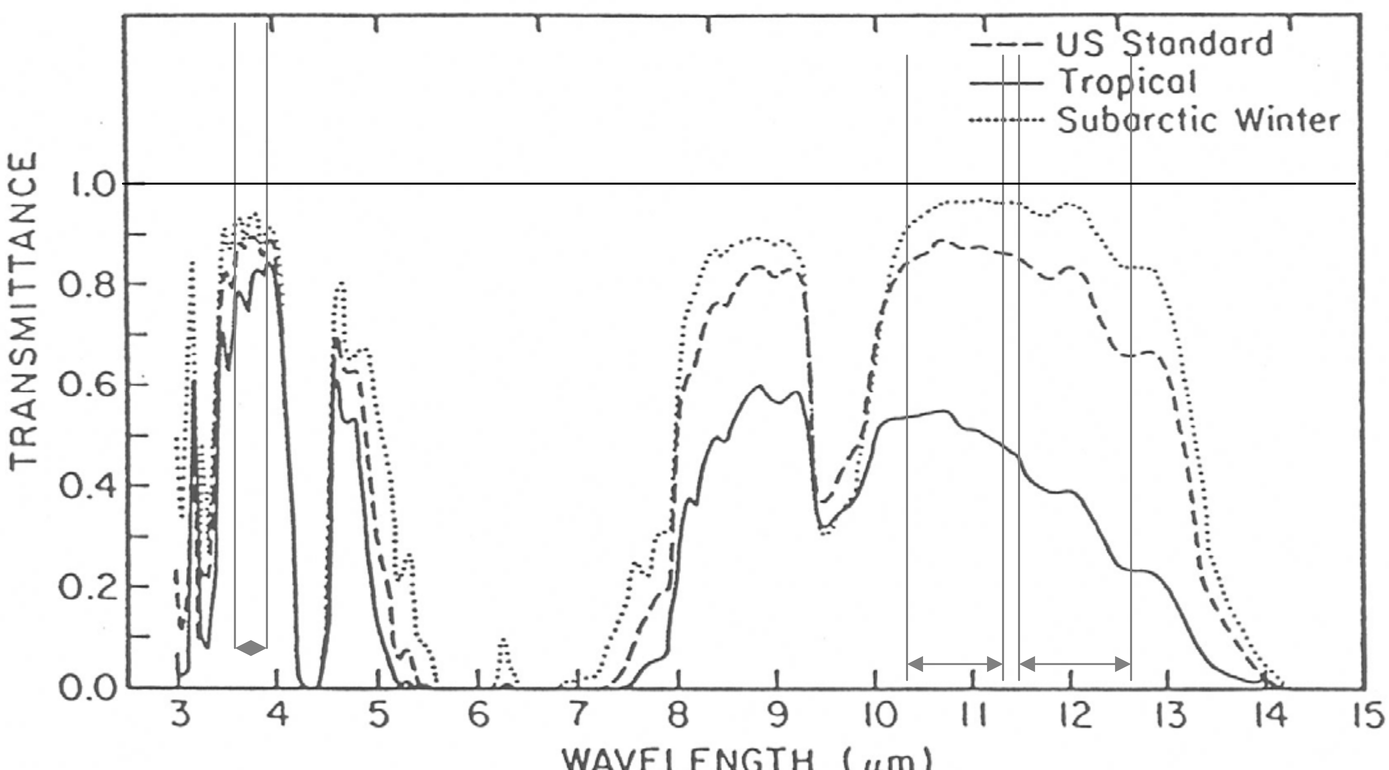


Figure 3.10. The skin depth given by (3.51) for the energy of EMR in pure water at temperature 25°C as a function of the wavelength of EMR. (After Maul, 1985, p. 106.)

Over the upper several meters, Martin's Figure 7.3 show a range of processes that act to mix the surface. Without these processes, the temperatures in the "skin" could be much cooler or warmer than the temperatures even 1 m below. Early users of satellite SST had to determine when the skin SST represented the deeper "mixed-layer" temperatures. In some regions and under some conditions (weak winds, strong heating), a thin warm layer can hide the underlying SST structure.



Most of the absorption/re-emission of IR in the atmosphere is caused by a few gasses that are relatively well mixed, and by water vapor, ozone and aerosols, that are not well mixed. The well mixed components cause a constant difference in temperature between the surface and the satellite. The variable components must be detected and corrected for using multiple wavelengths. The difference in transmittance due to water vapor is shown in Chelton, Figure 4.14. The Subarctic Winter atmosphere has the least water vapor and the Tropical has the most. Differences in sensitivity to water vapor is seen for AVHRR channels 3, 4, and 5 (3.55-3.93, 10.3-11.3 and 11.5-12.5 μm)



Transmittance – IR, clear atmospheres (different water vapor).

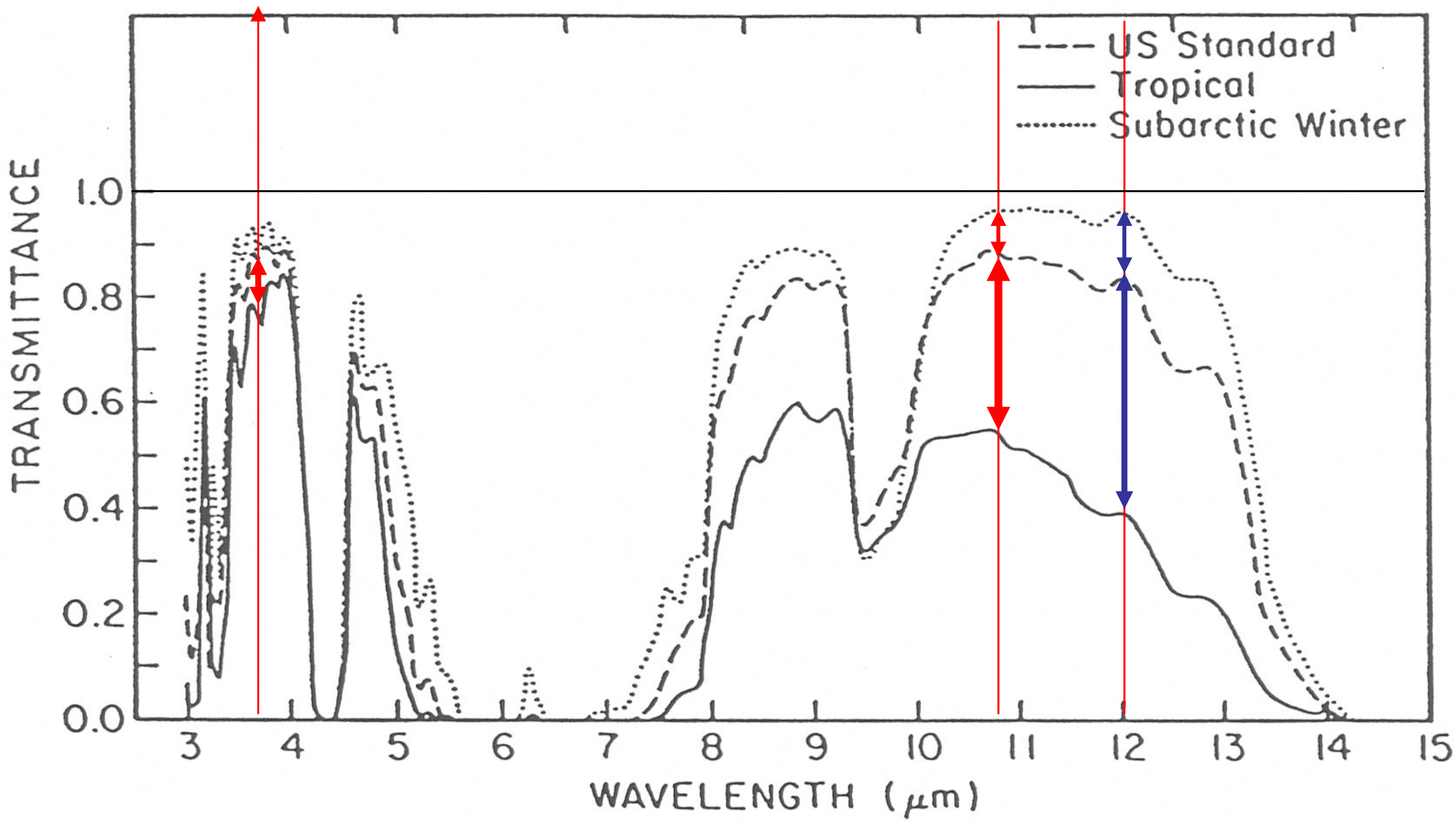
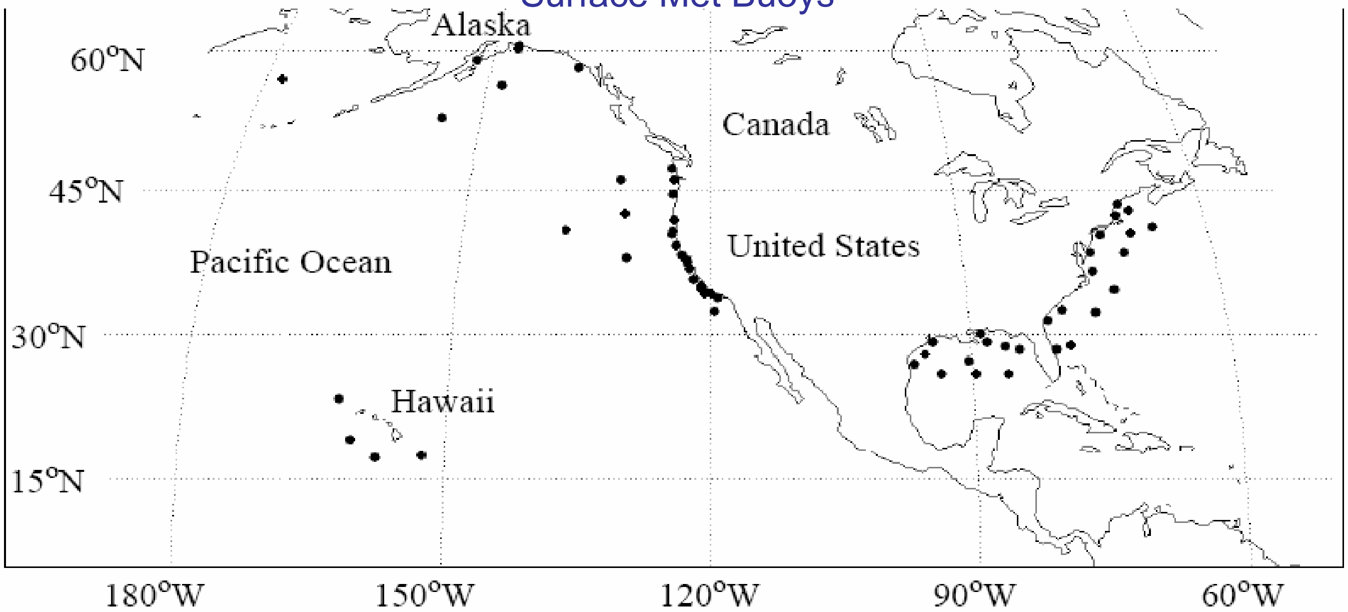


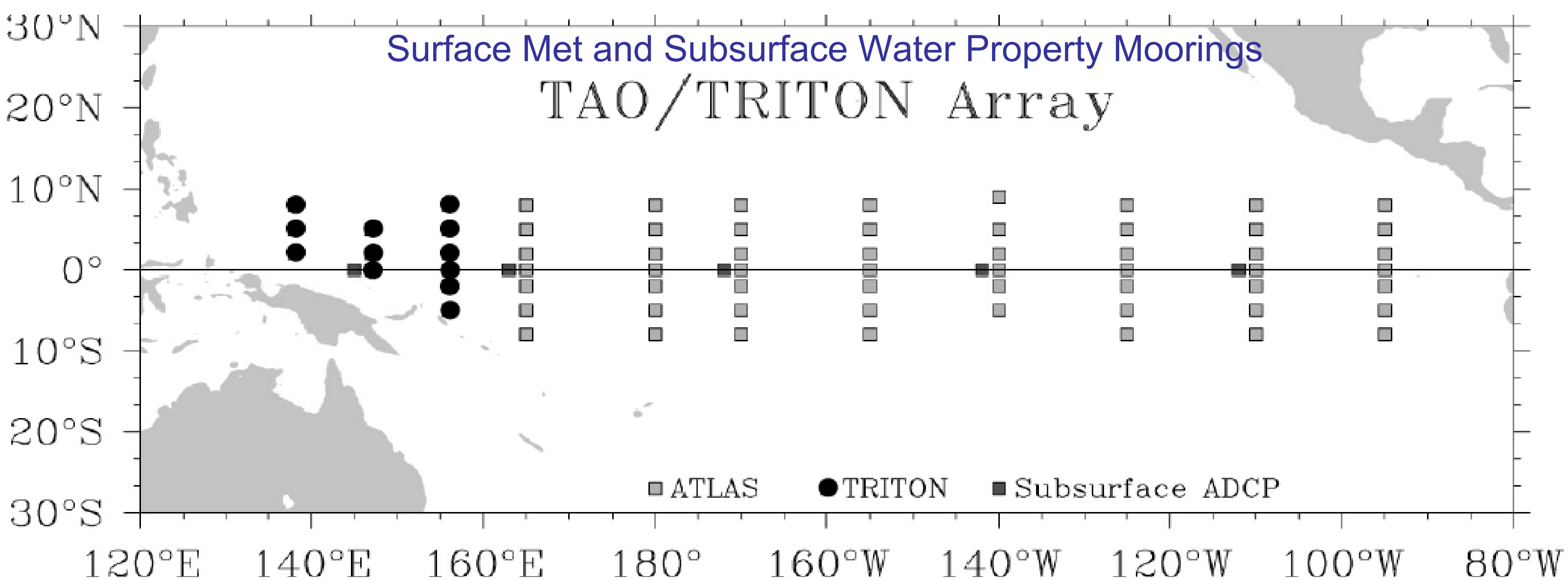
Figure 4.14. The transmittance of the atmosphere at 0° incidence angle as a function of wavelength in the infrared band for a clear atmosphere with three different water vapor concentrations. (After Maul, 1985.)

What can we see without satellites (surface measurements?)

Surface Met Buoys

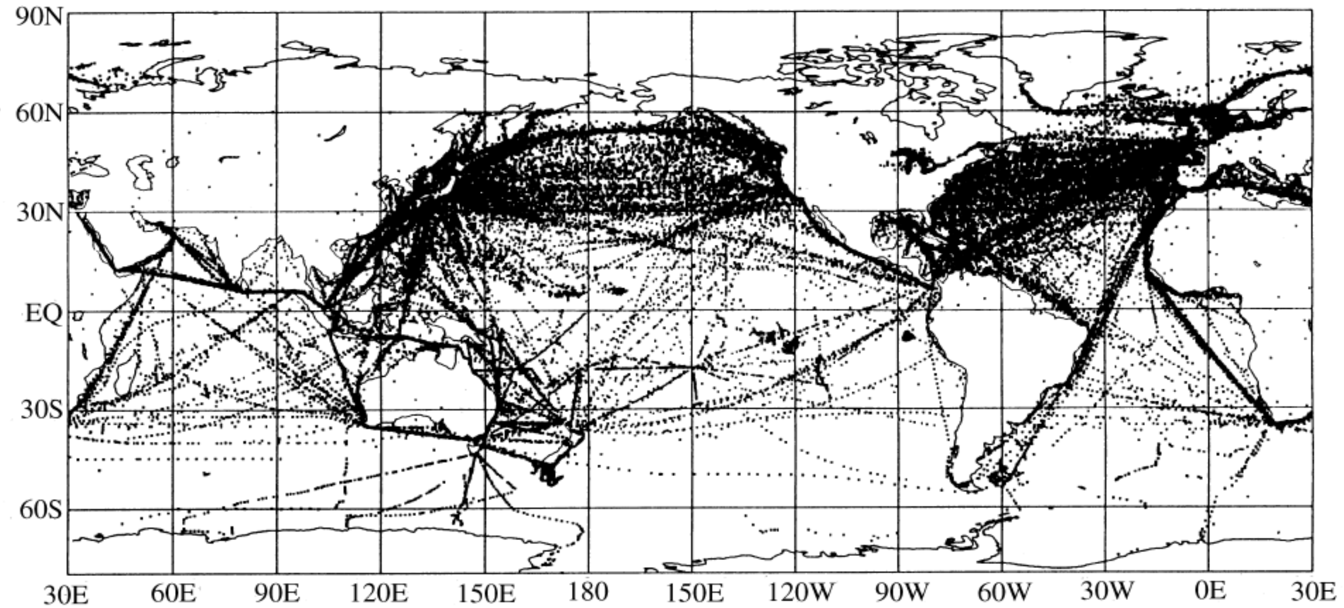


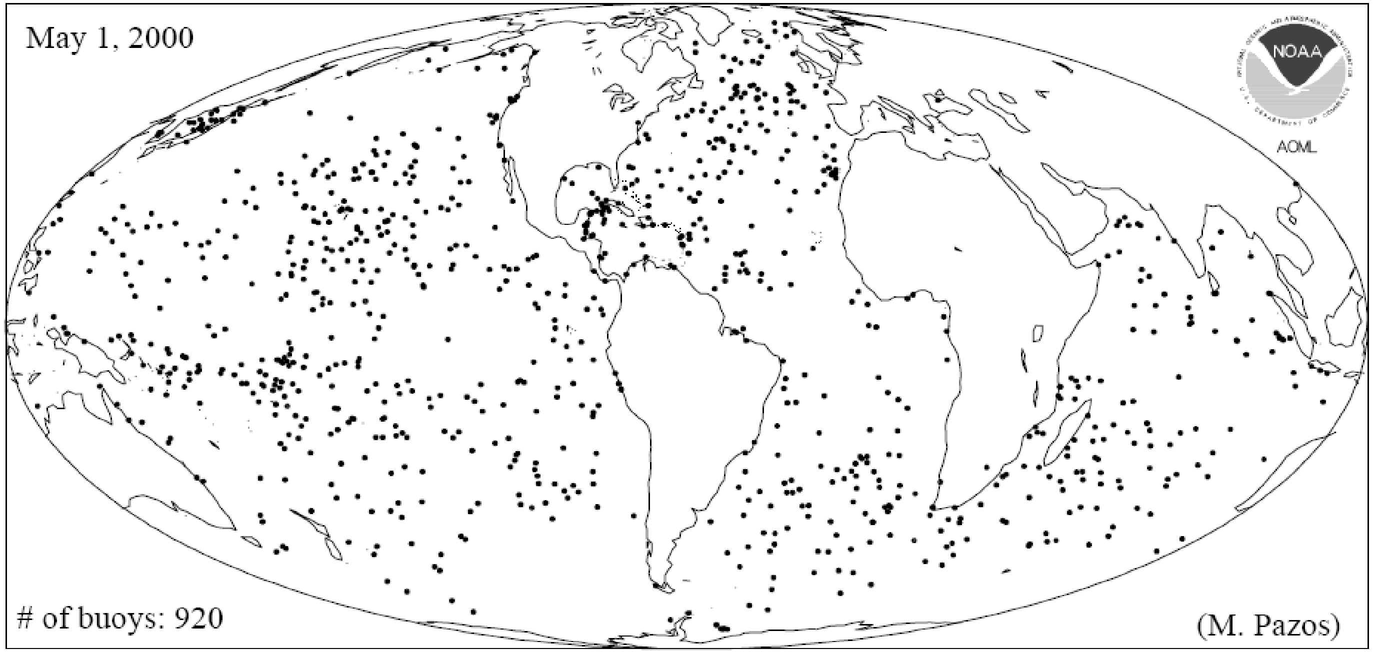
Surface Met and Subsurface Water Property Moorings

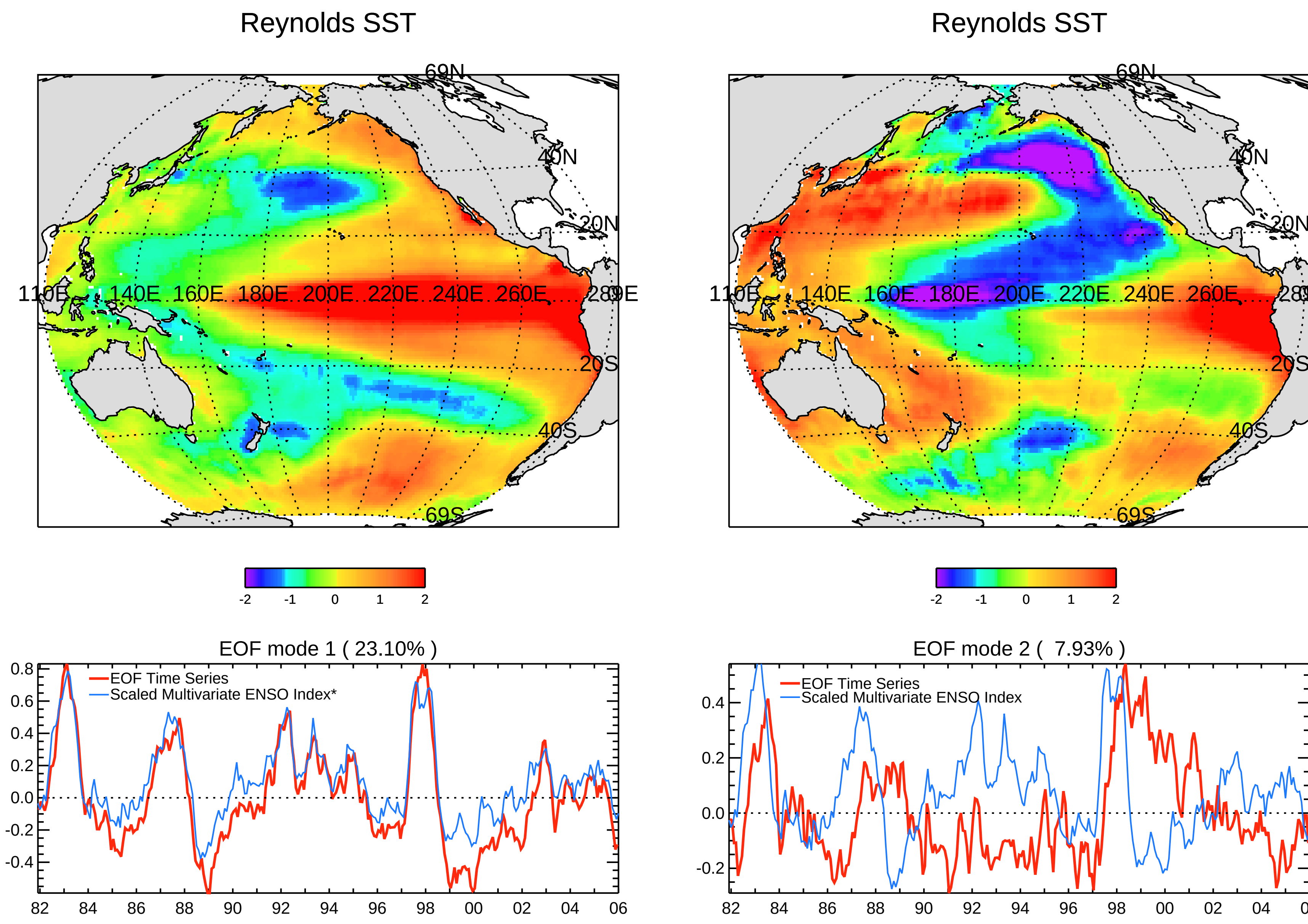


What can we see without satellites (surface measurements?)

Merchant ship surface measurents







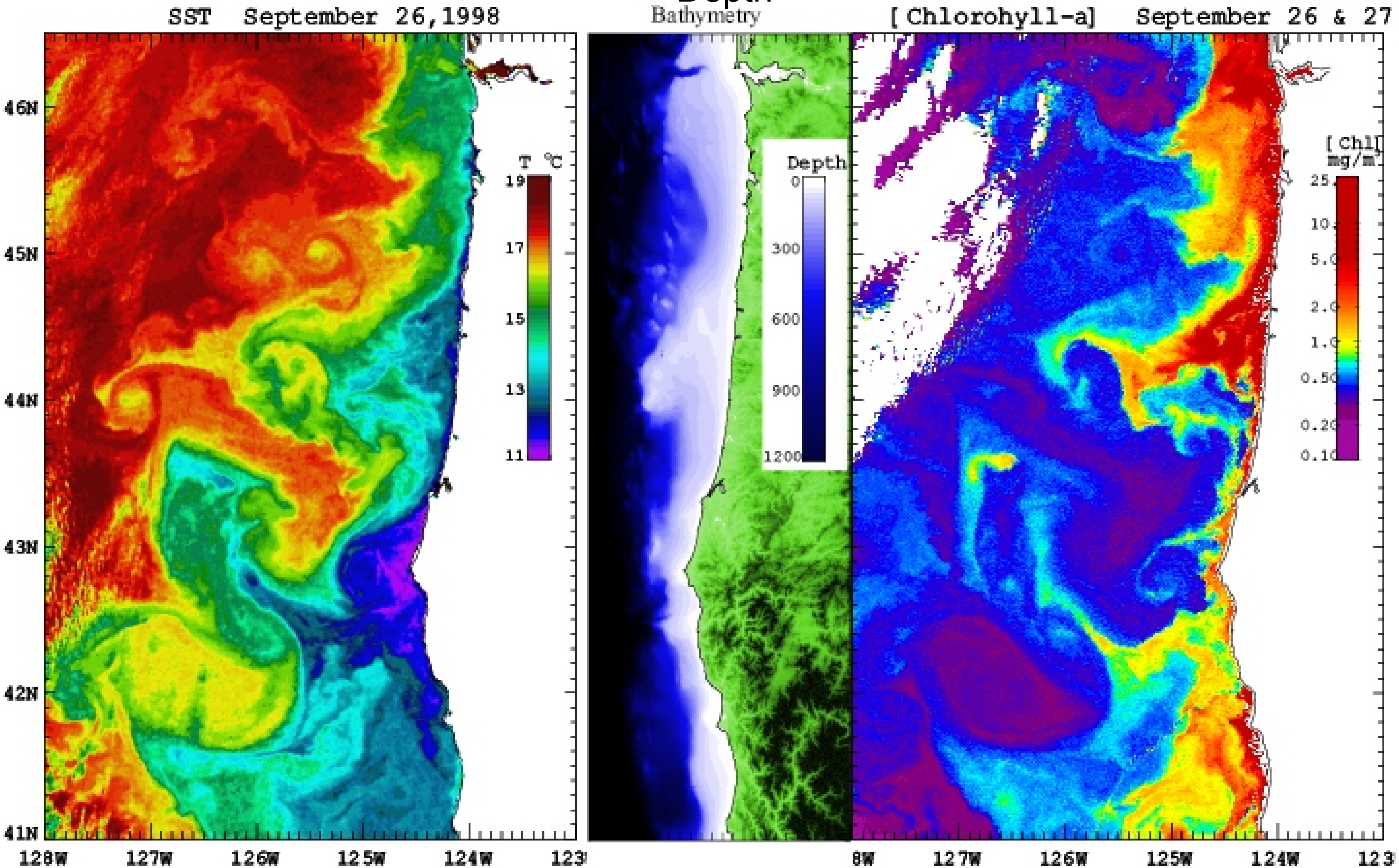
*www.cdc.noaa.gov/people/klaus.wolter/MEI/

Feb 17 06

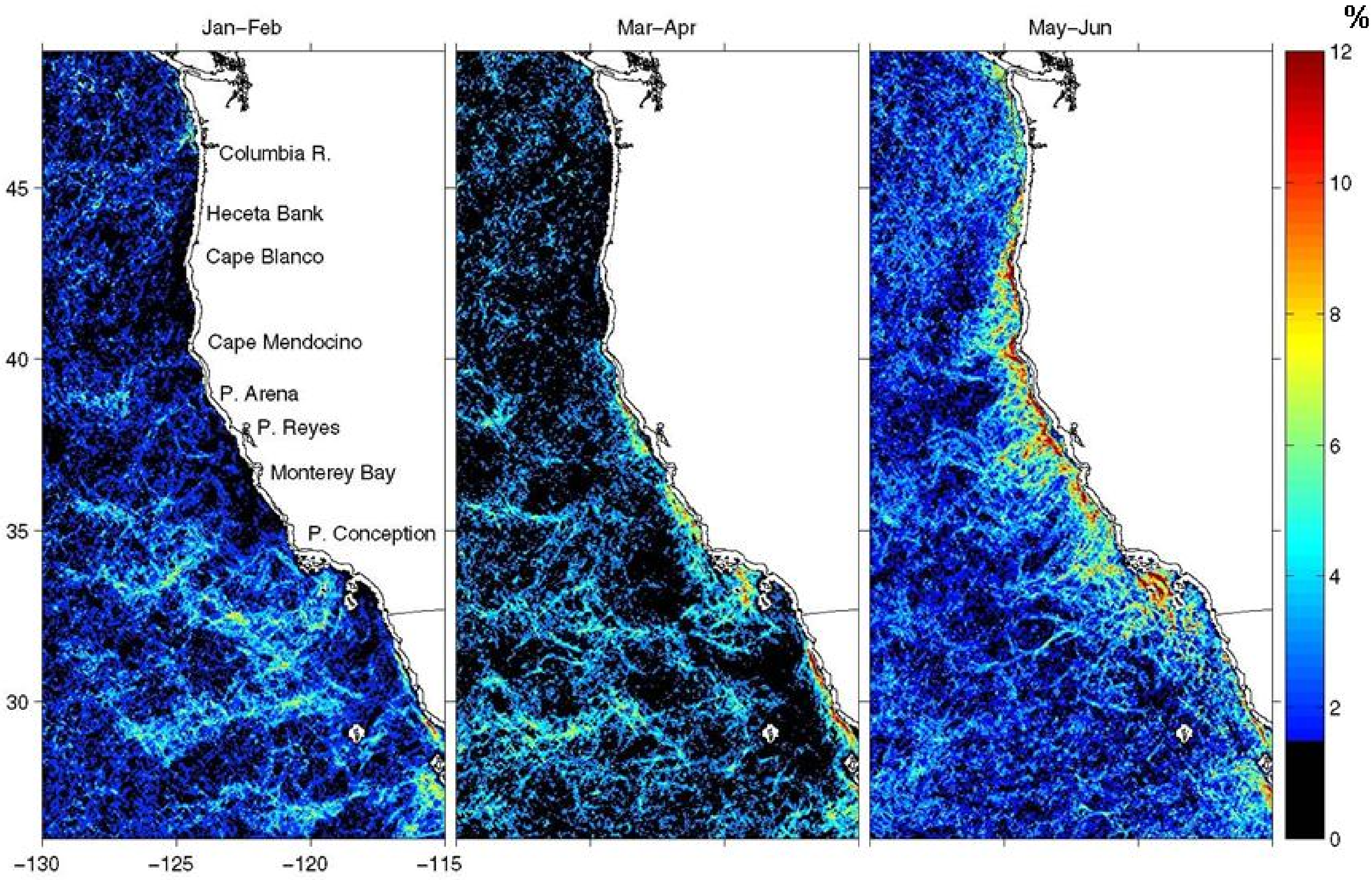
SST

Depth

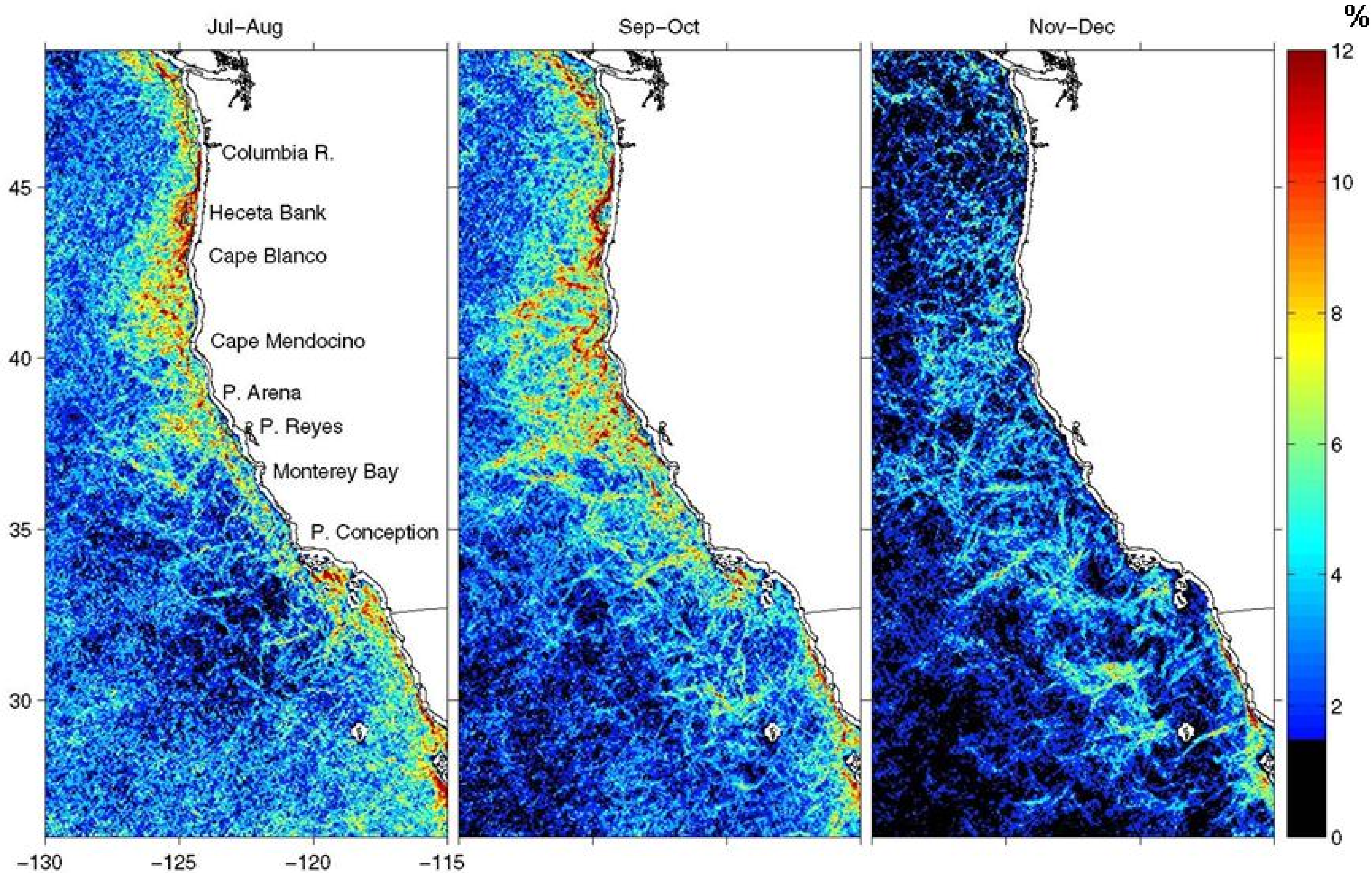
Chlorophyll-a



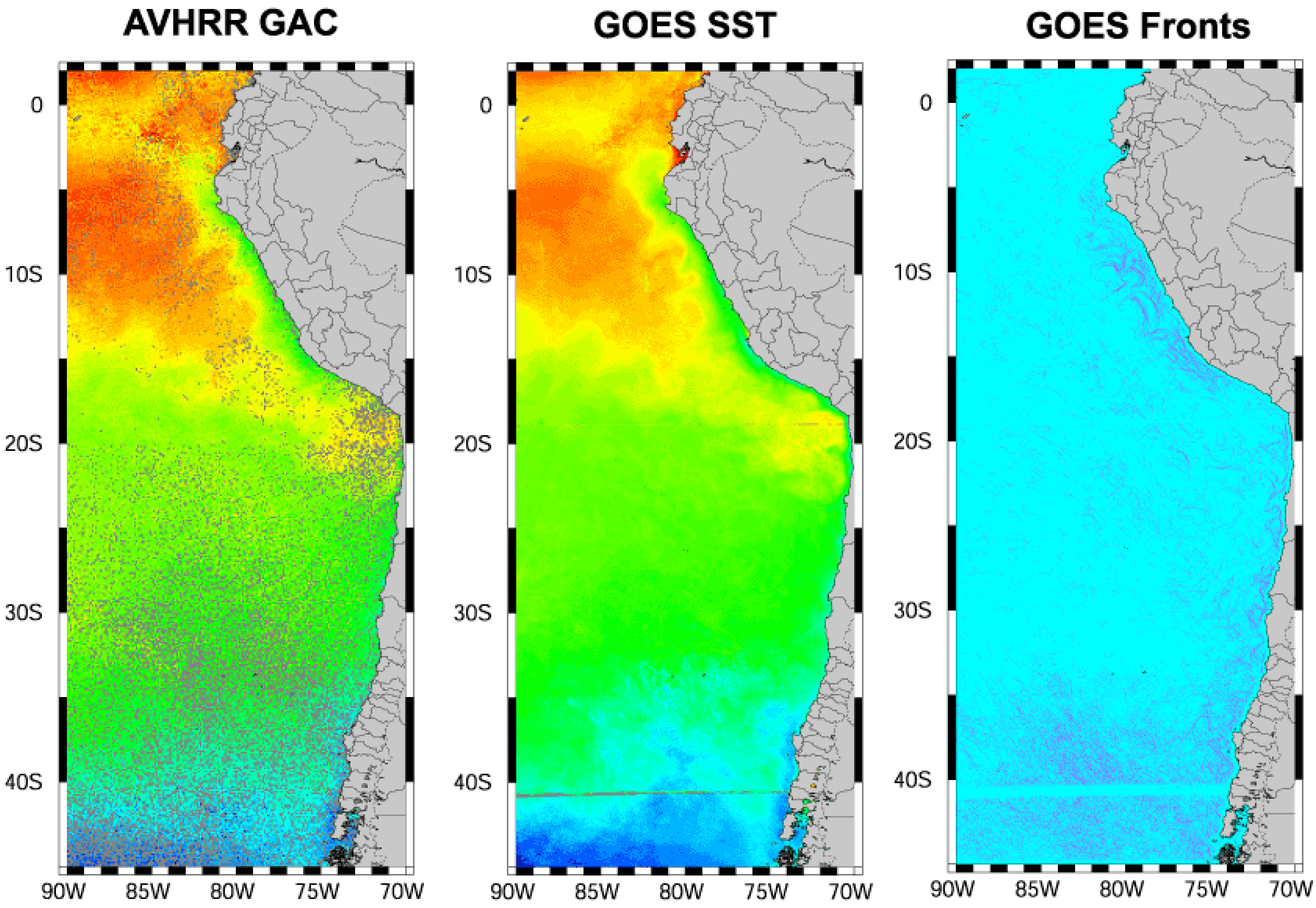
Probability of detecting a SST front (4 year average)



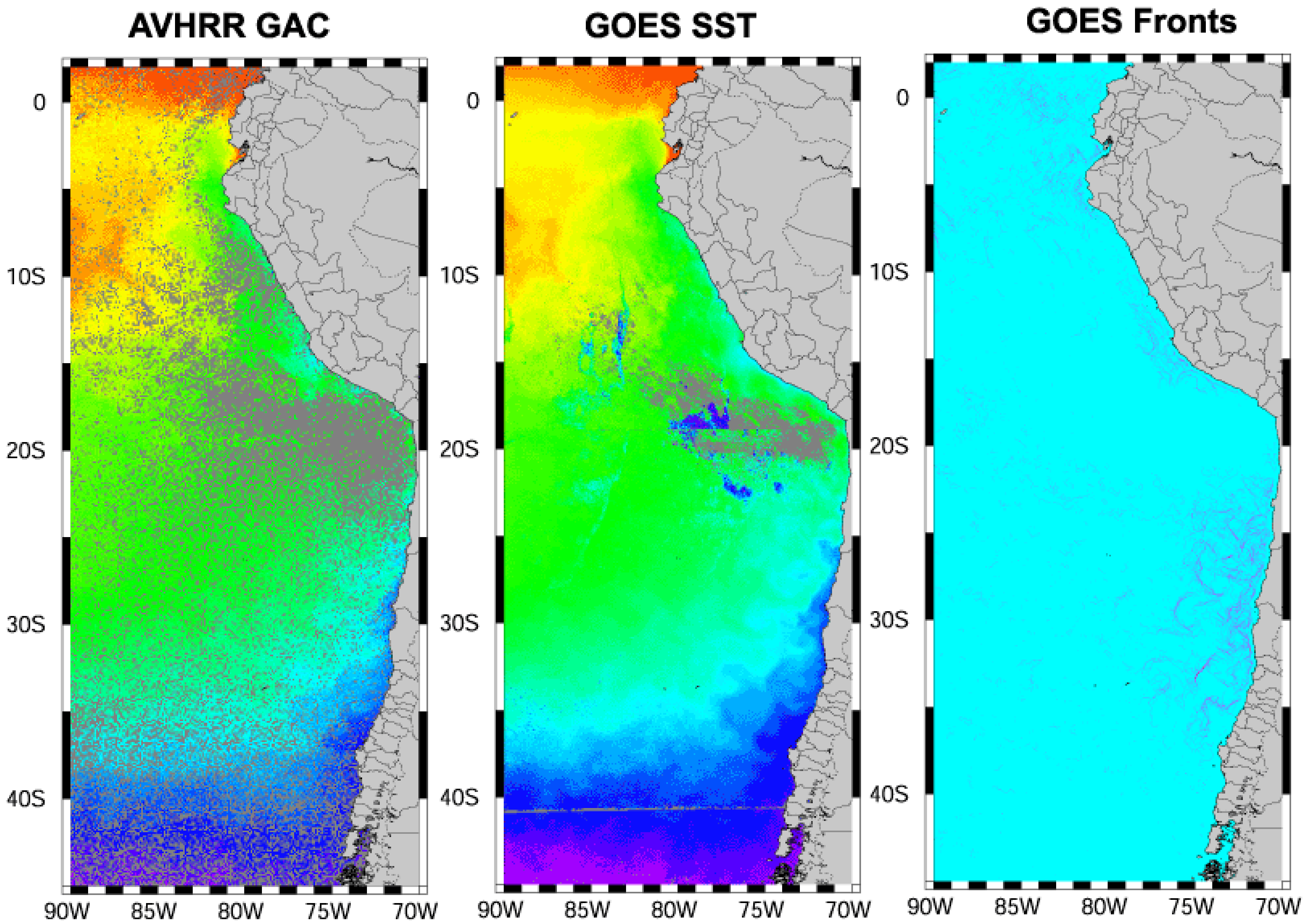
Probability of detecting a SST front (4 year average)

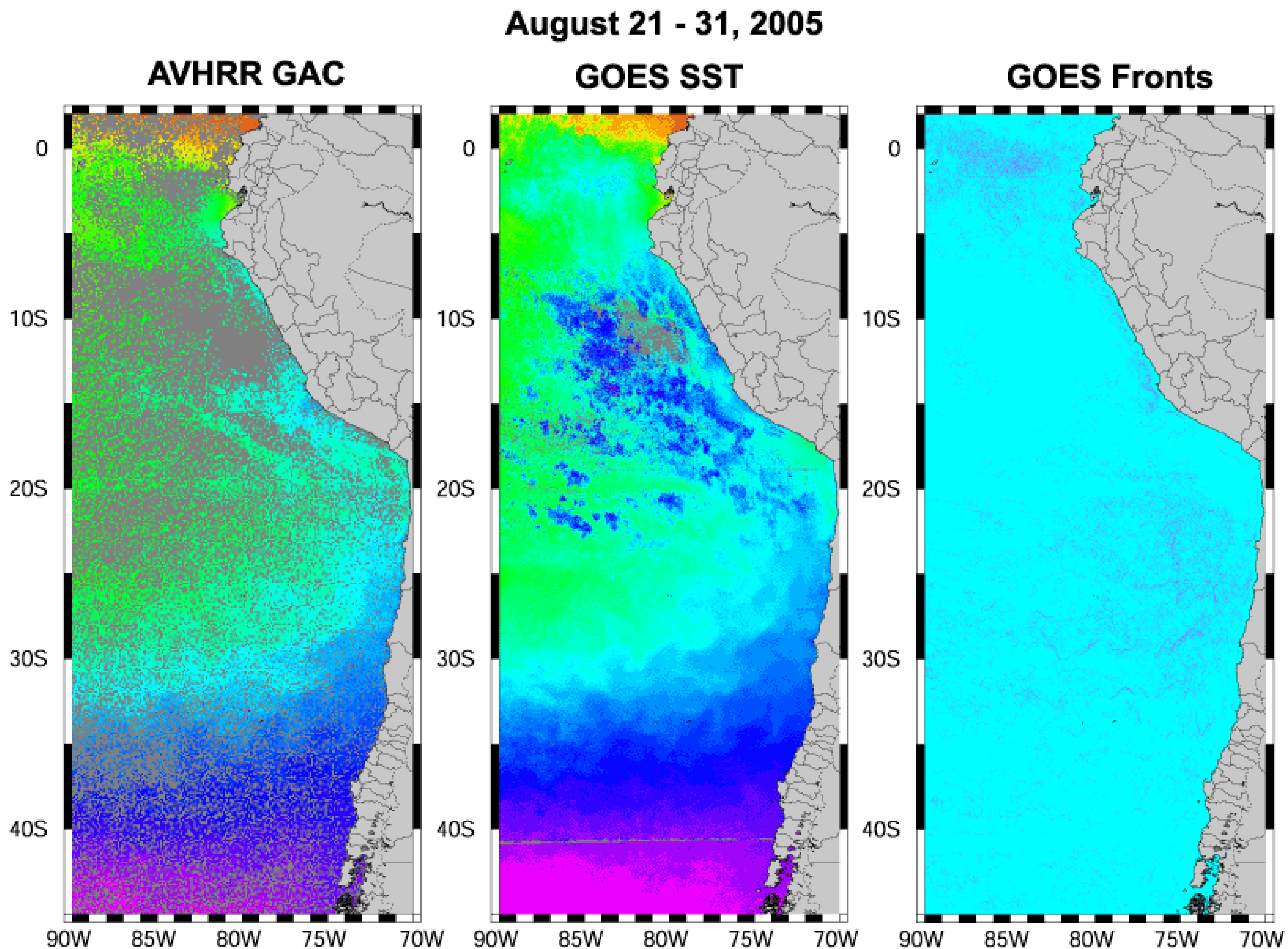


February 3 - 12, 2005



May 15 - 24, 2005





August 21 - 31, 2005
AVHRR GAC
GOES SST
GOES Fronts
0
10S
20S
30S
40S
90W
85W
80W
75W
70W

Transmittance – Microwave, clear atmospheres (different water vapor).

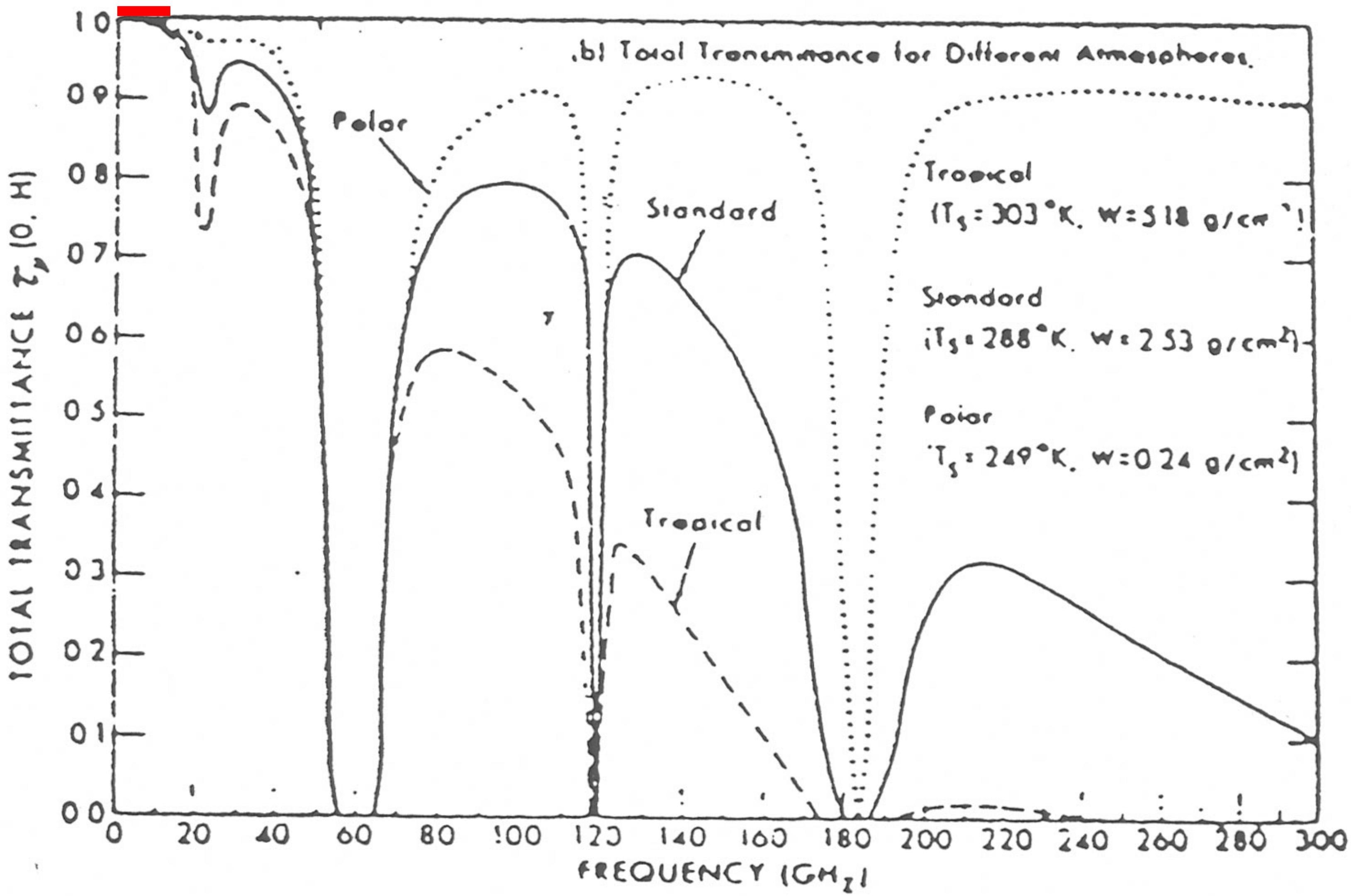
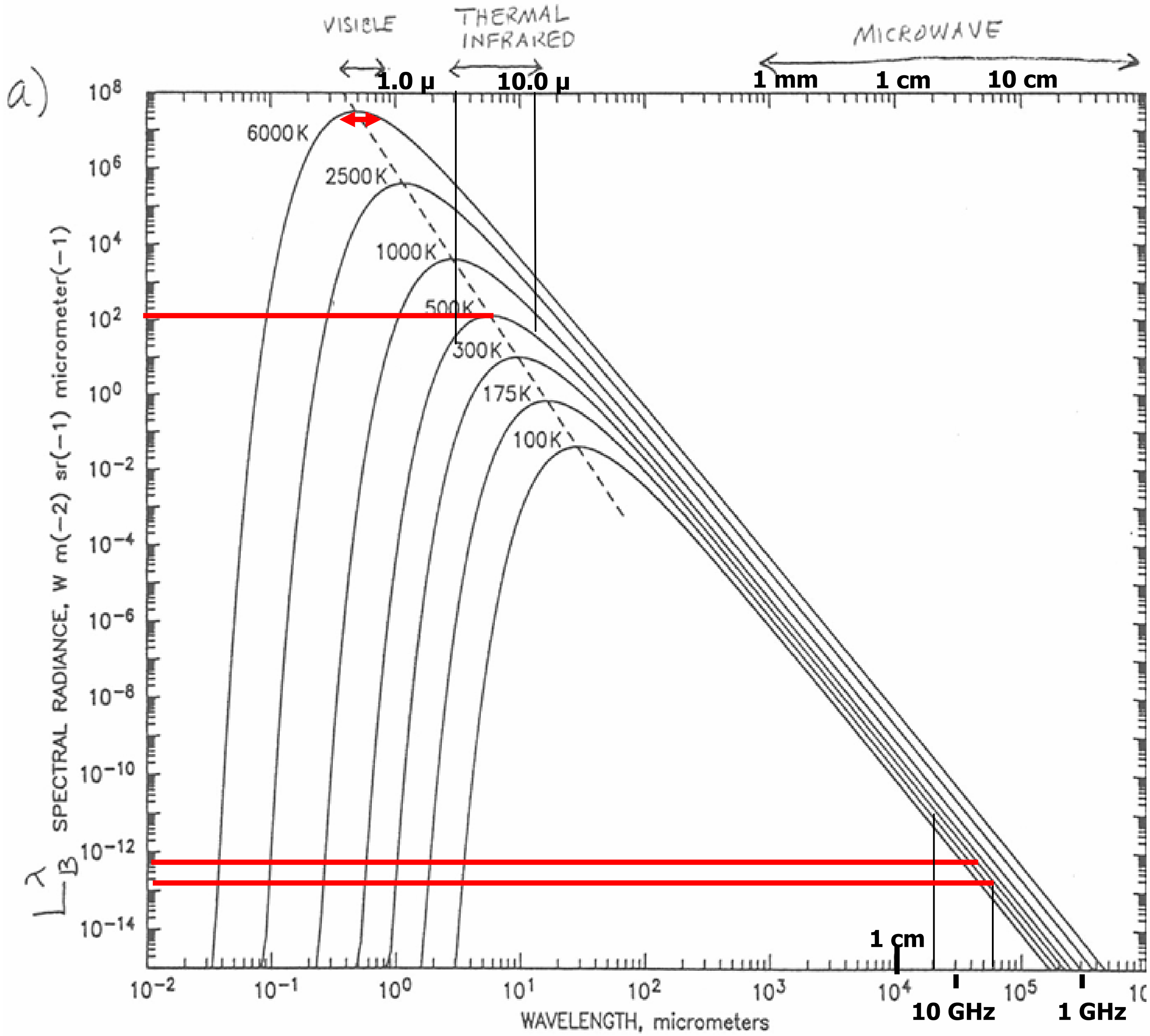
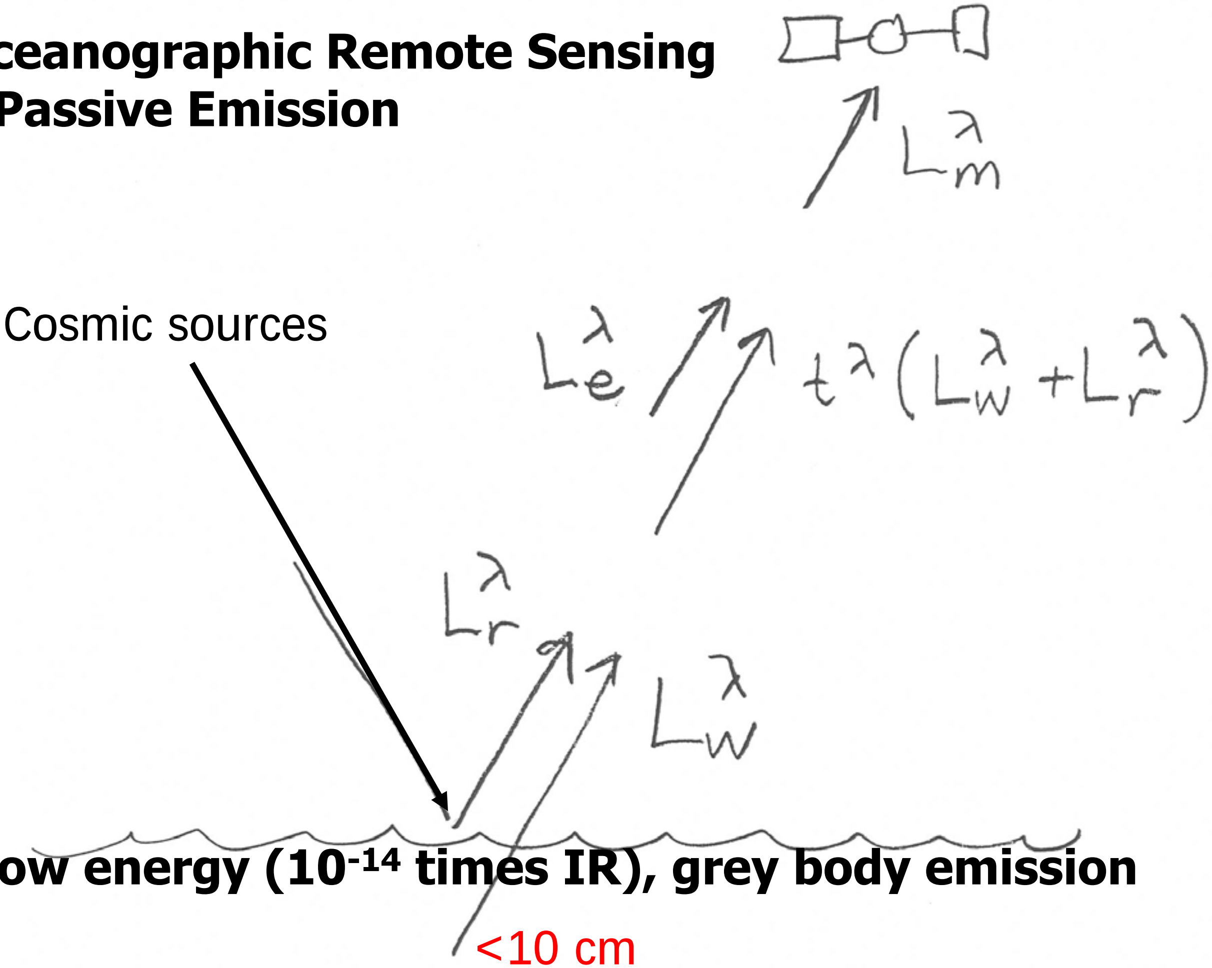


Figure 4.15. The transmittance of the atmosphere at 0° incidence angle as a function of frequency in the microwave band for a clear atmosphere with three different water vapor concentrations.



Planck’s Function in log-log plot for Spectral Radiance as a function of Wavelength

Microwave Oceanographic Remote Sensing
Passive Emission



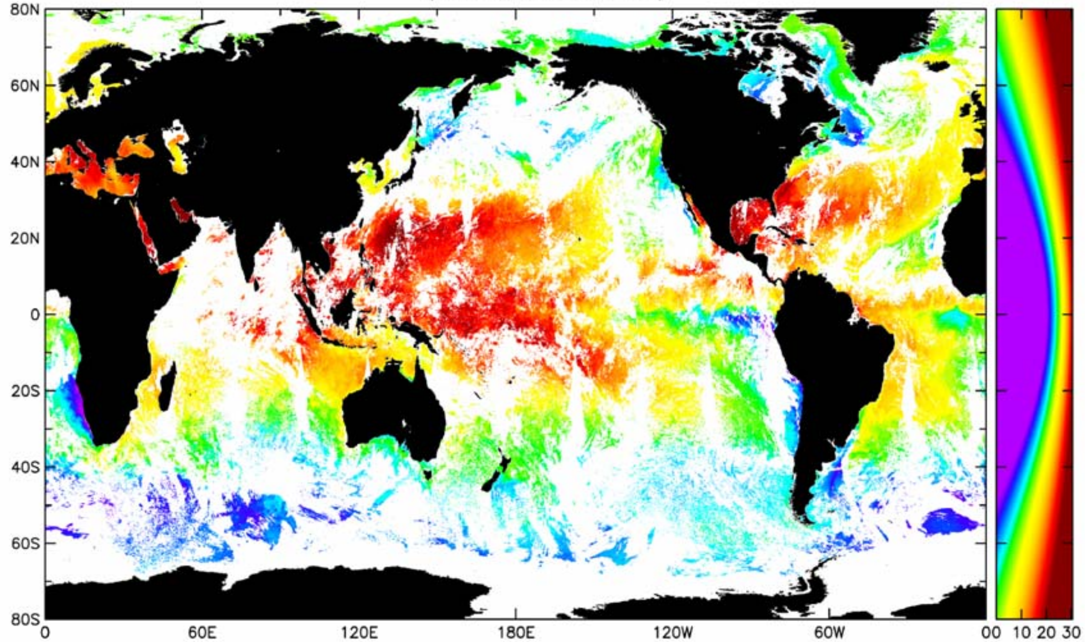
Very low energy (10^{-14} times IR), grey body emission

Figure 4.27. A schematic summary of the contributions to the spectral radiance measured by a satellite in the microwave band of the electromagnetic spectrum.

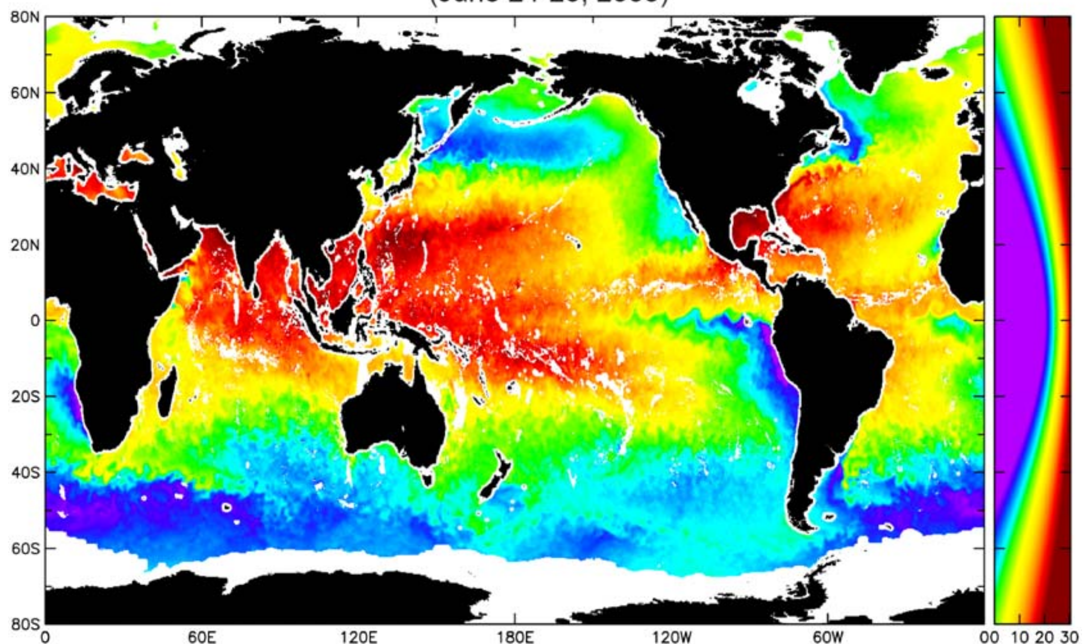
Why Use Microwave?

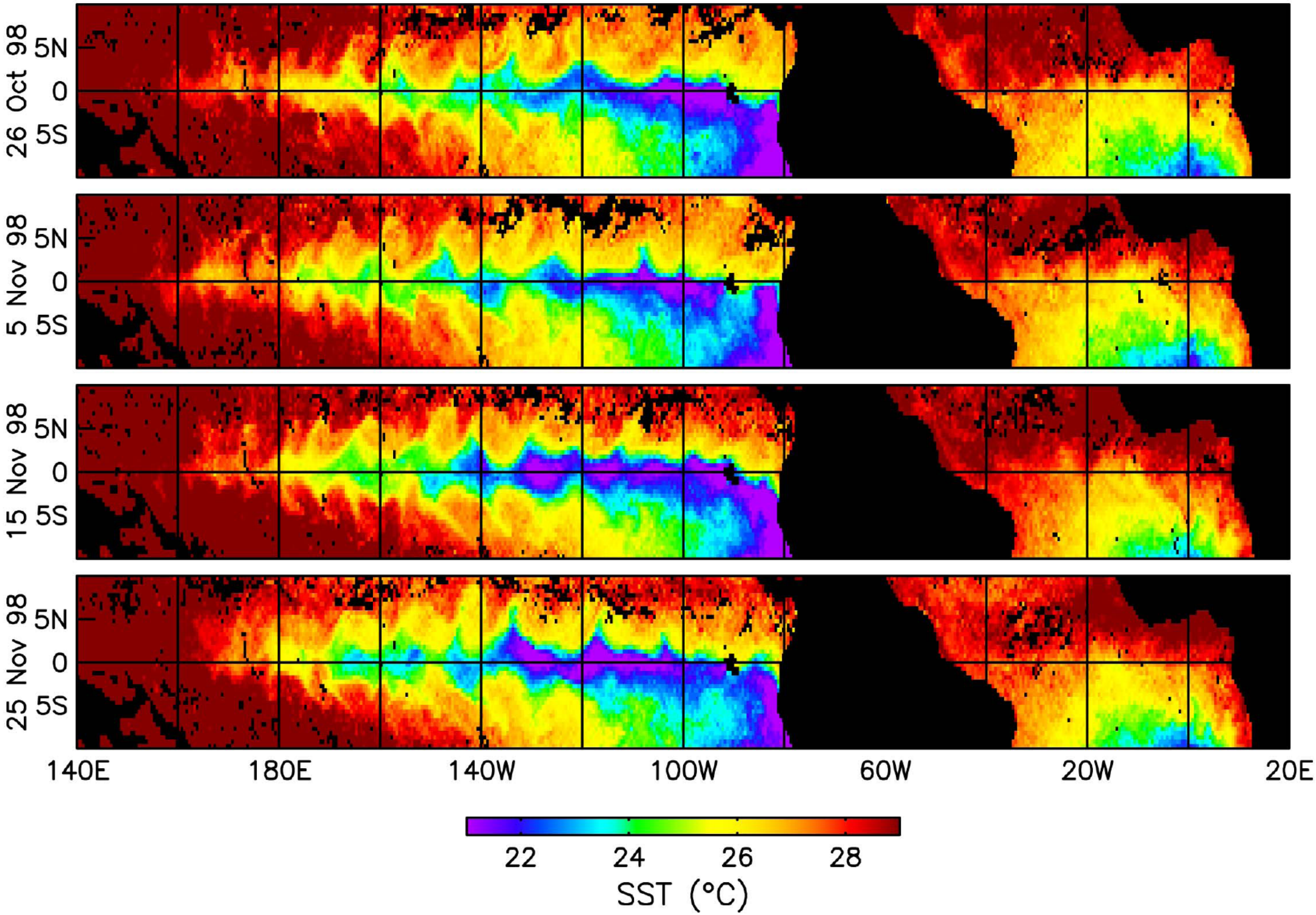
Clouds!

2-Day Average Infrared Measurements of SST from the AVHRR
(June 24-25, 2003)



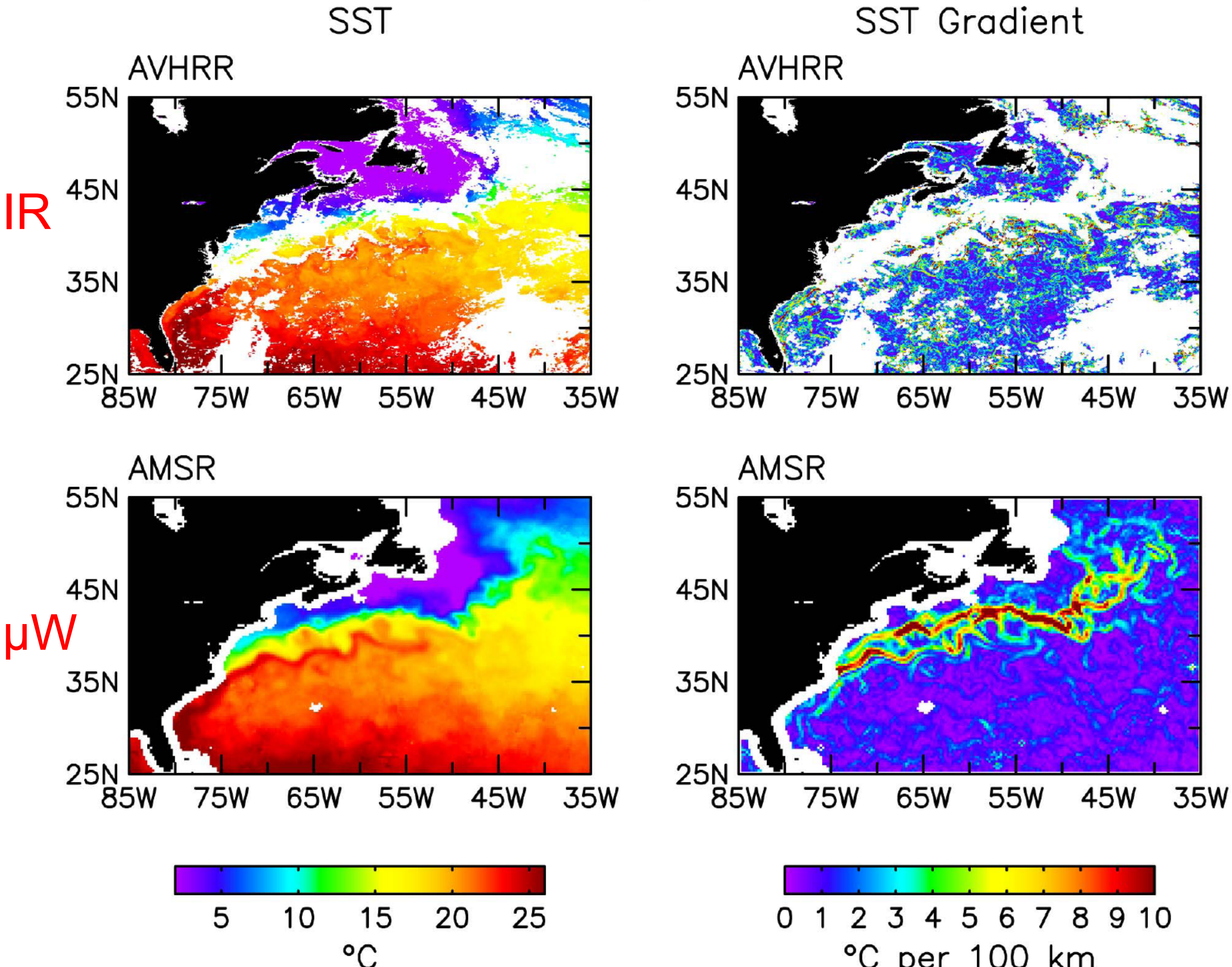
2-Day Average Microwave Measurements of SST from the AMSR
(June 24-25, 2003)




26 Oct 98
5 Nov 98
15 Nov 98
25 Nov 98
5N
0
5S
140E
180E
140W
100W
60W
20W
20E
22
24
26
28
SST (°C)

Gulf Stream (North Atlantic Ocean)

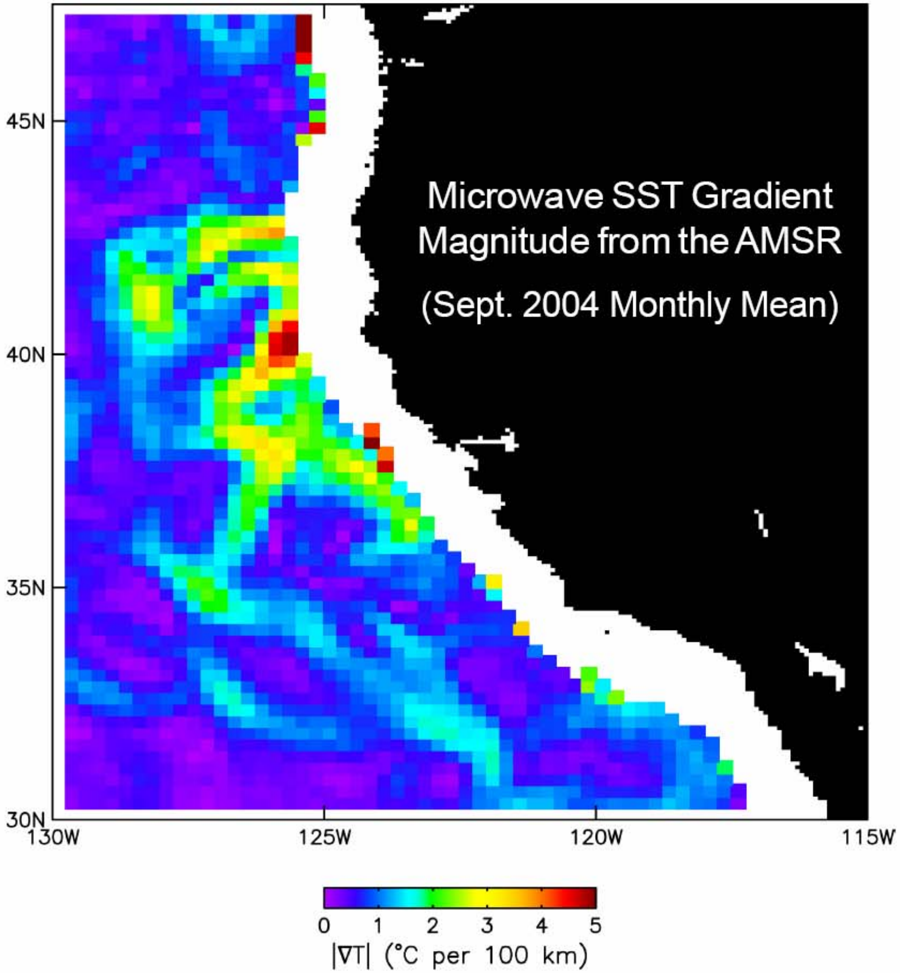
1 May 2003

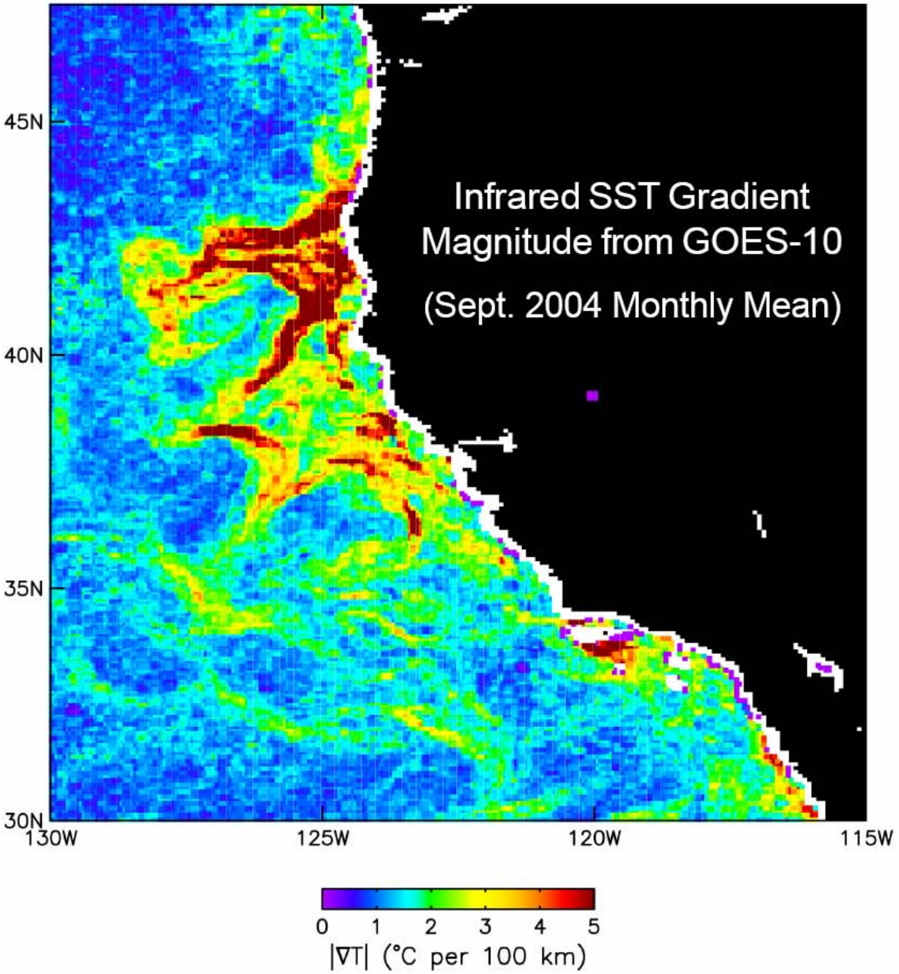


Why not use Microwave?
Resolution and Land Masking

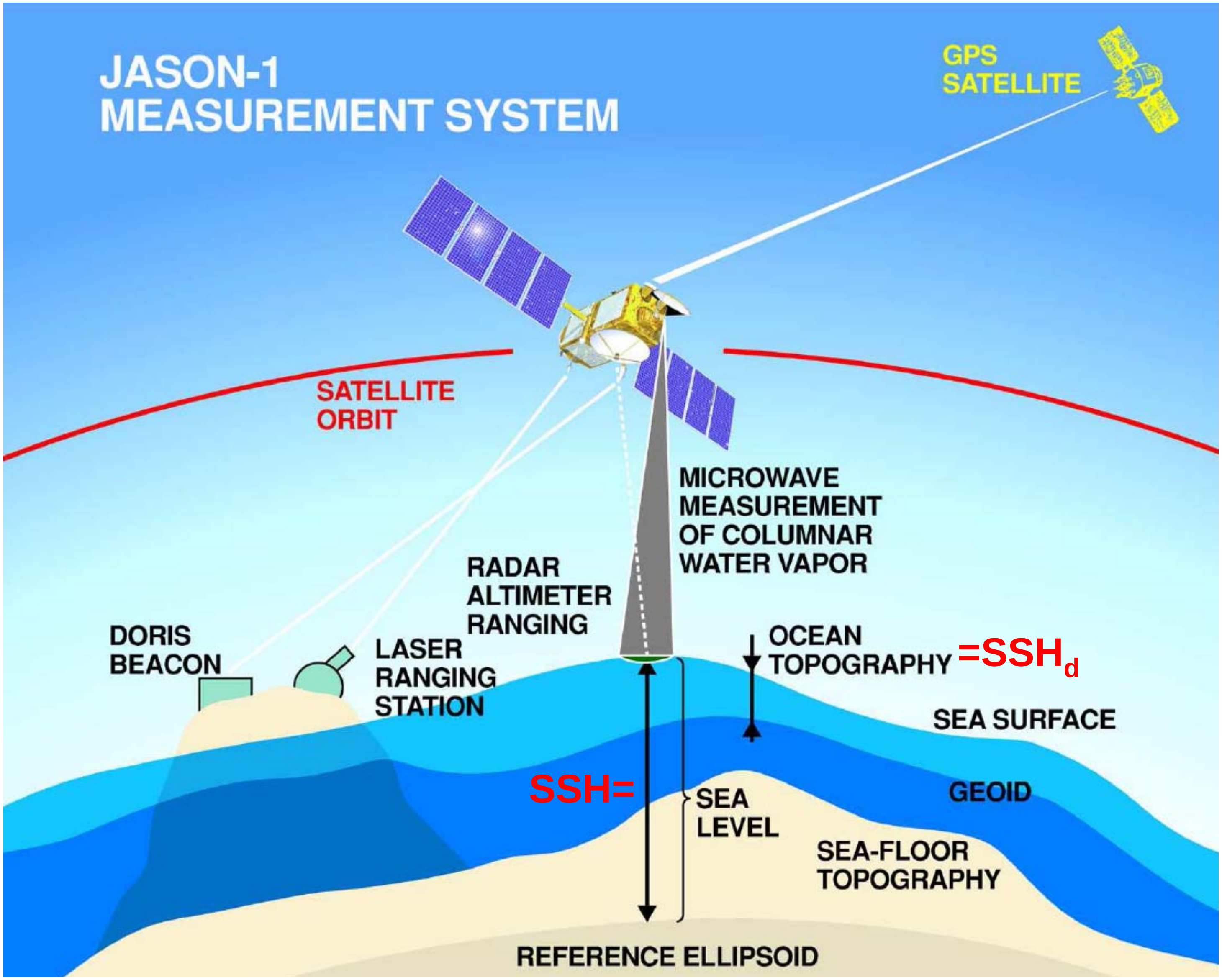
The primary limitations of microwave estimates of SST are:

- *the large footprint size of ~50 km, compared with ~1 km for infrared estimates of SST.*
- *the inability to measure SST closer than about 1.5 footprints from land because of antenna sidelobe contamination.*

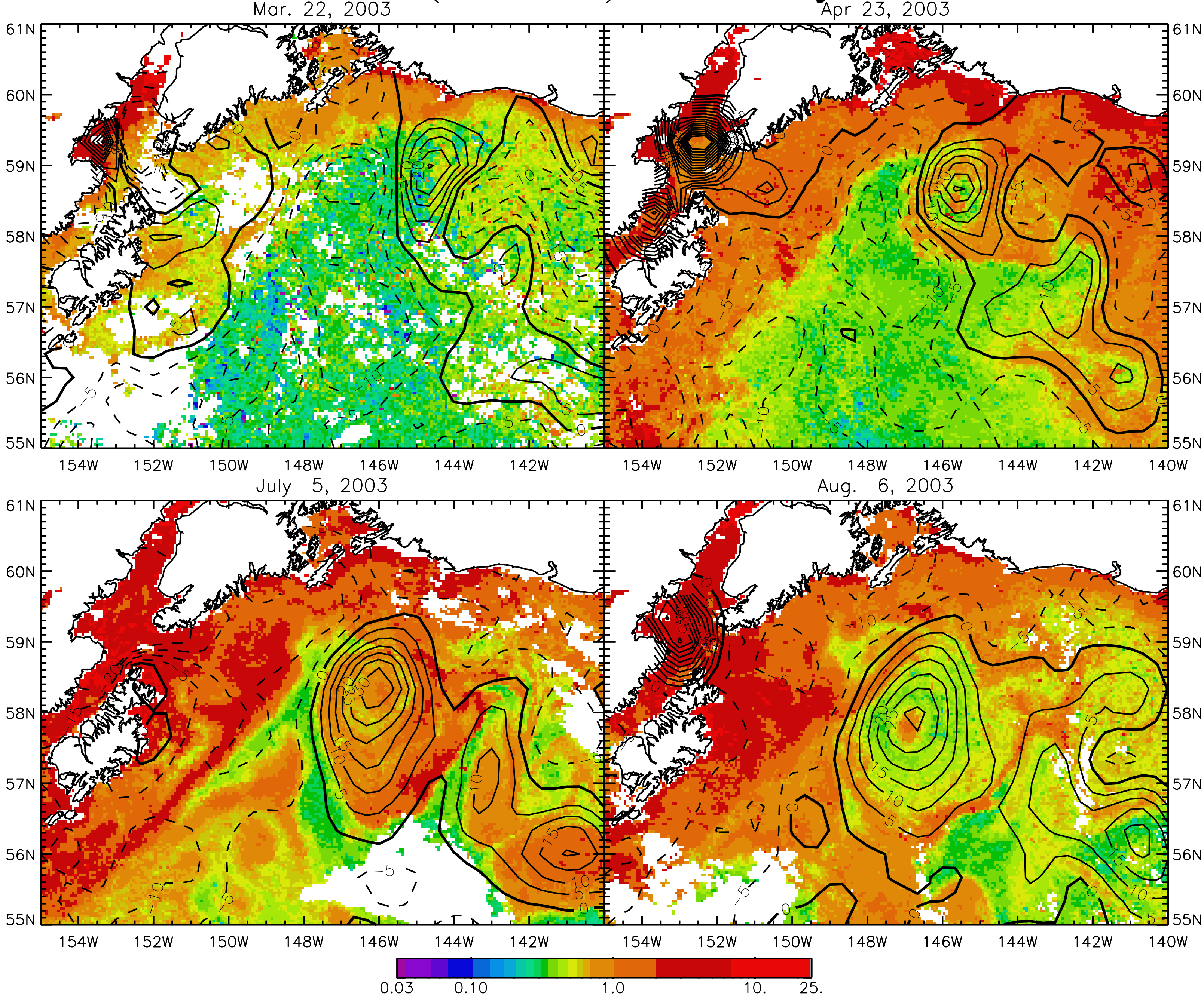




Active Radar – Altimeter: Measures SSH ?what is that?



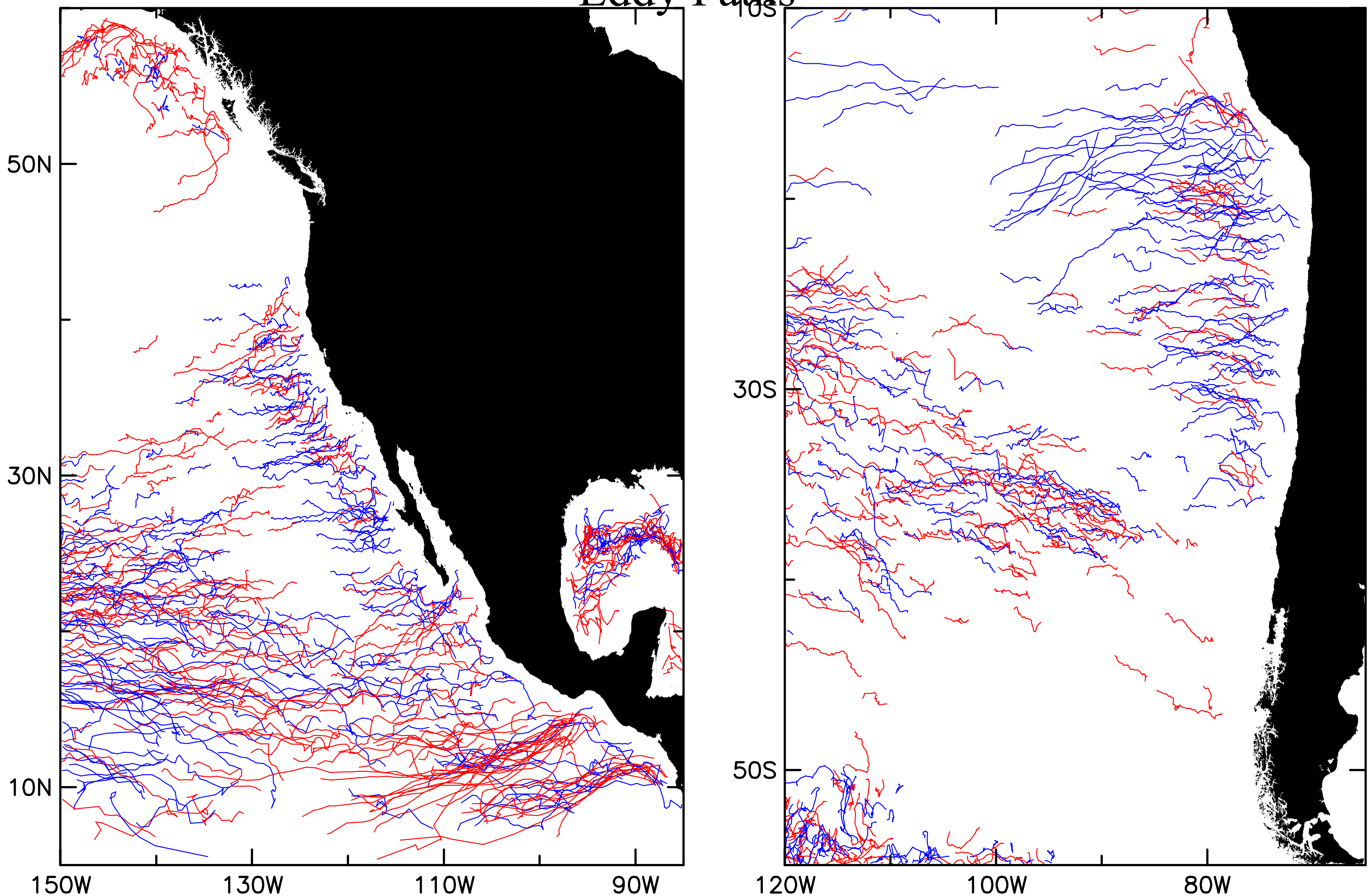
AVISO SLA (contours) over 9-day SeaWiFS Chl



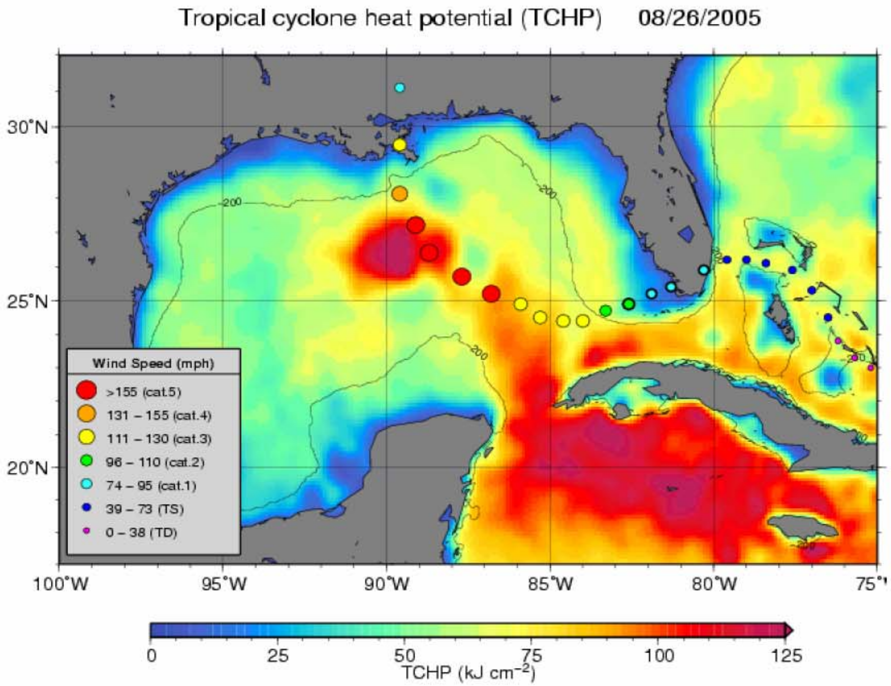
Mar 8 06

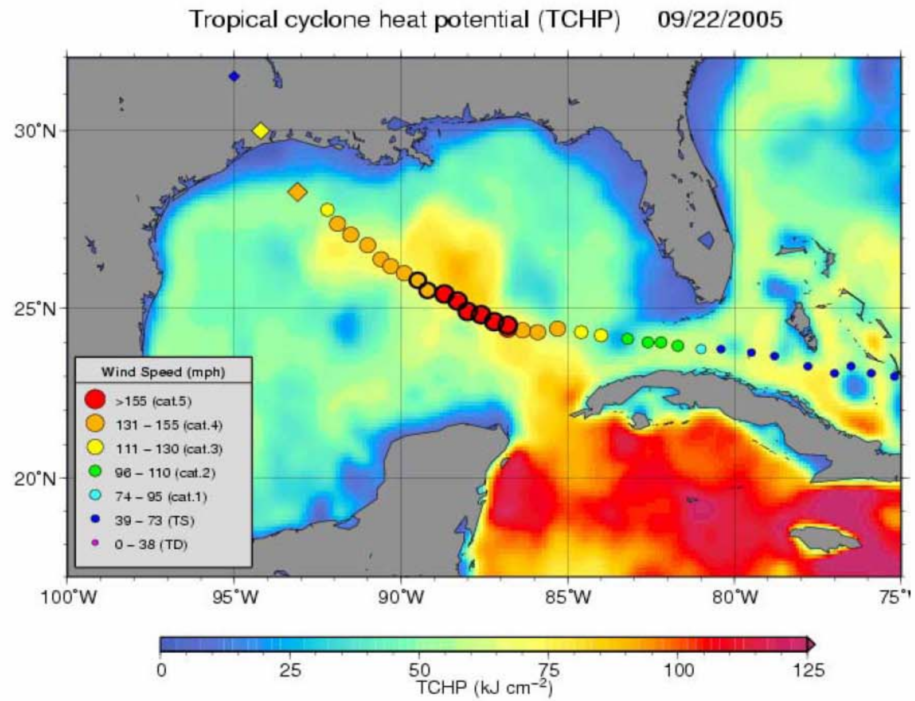
D. Chelton, M. Schlax, R. Samelson and R. deSzoeke

Eddy Paths



Packing Heat in the Gulf

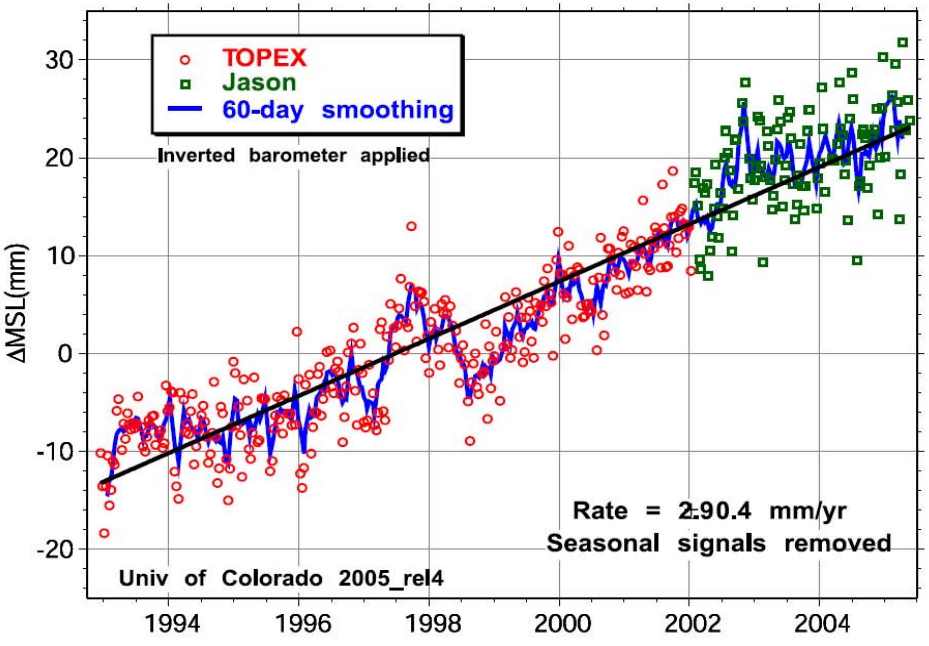


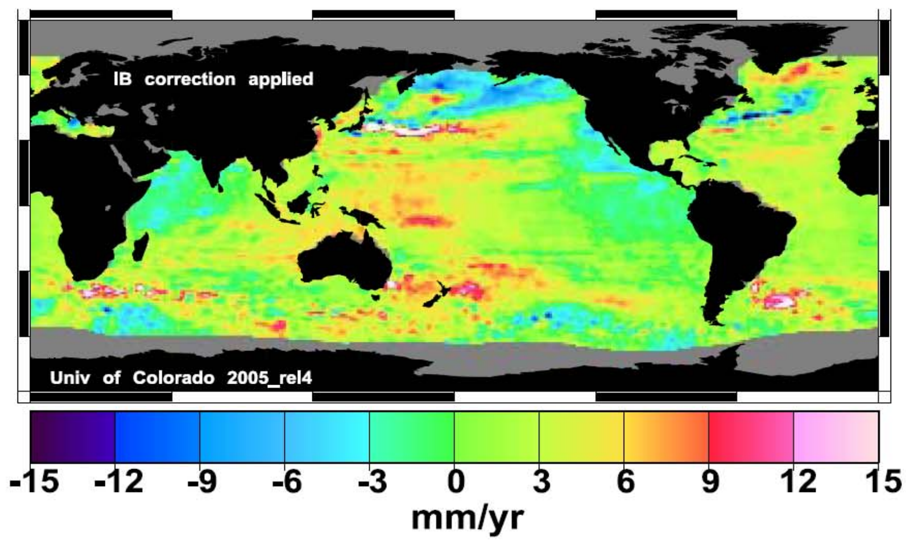


(G. Goni and J. Trinanes, NOAA/AOML)

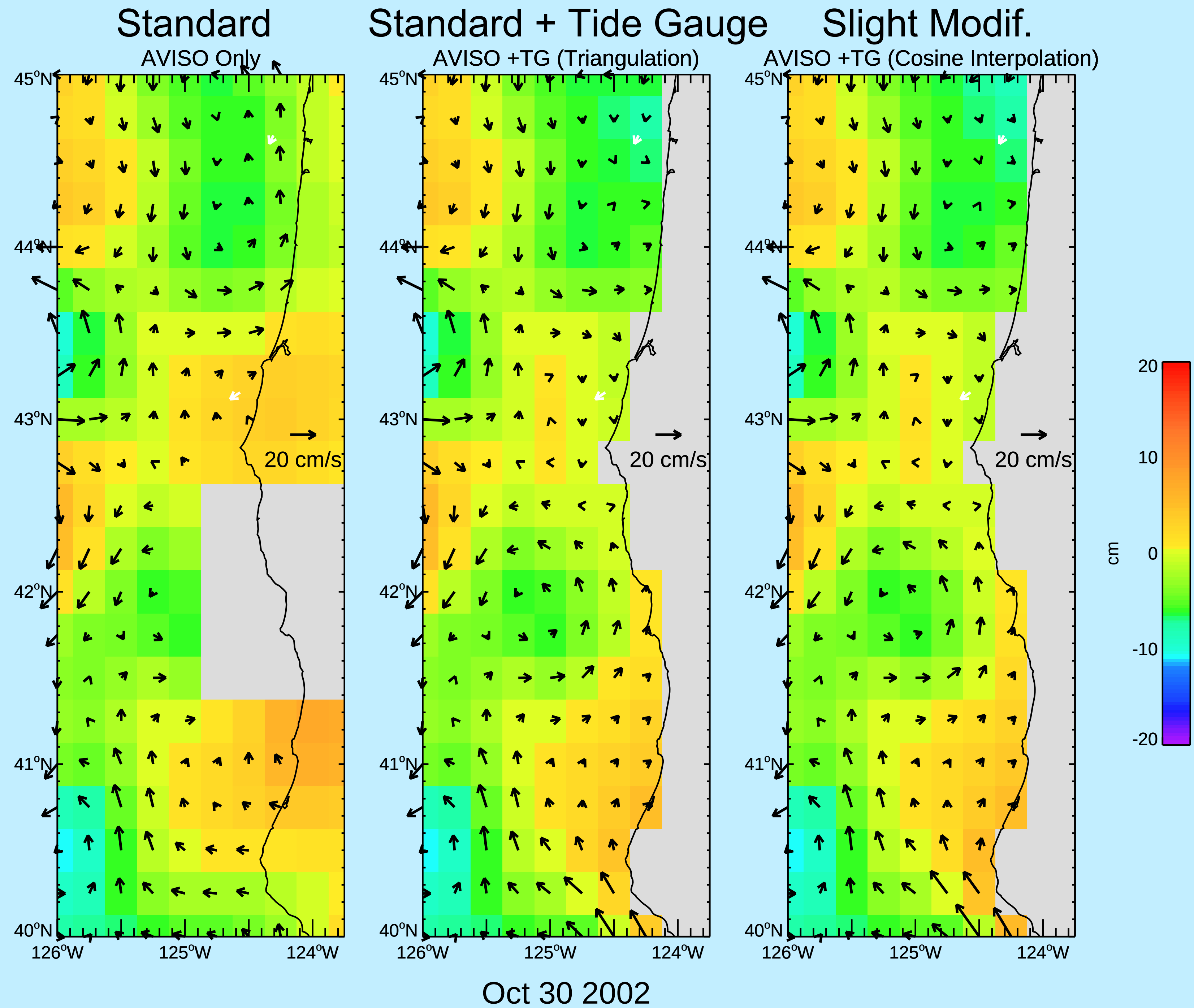
Tropical Cyclone Heat Potential (TCHP) fields are derived from altimetry data for hurricanes Katrina (left) and Rita (right) in 2005. The path of each hurricane is indicated with circles, their size and color representing intensity (see legend), as the storms made their way across the Gulf of Mexico. Both hurricanes rapidly intensified to category 5 as they passed over the Loop Current and a warm ring, then diminished to category 4 and category 3, respectively, by the time they traveled over cooler waters outside the warm ring. NOAA's Atlantic Oceanographic and Meteorological Laboratory uses blended satellite altimetry data, including those from NASA's TOPEX/Poseidon and Jason-1 missions, to estimate TCHP (a measure of the oceanic heat content from the sea surface to the depth of the 26°C isotherm) in the Gulf of Mexico in near-real time. High values of TCHP may be linked to hurricane intensification. These fields are critical to scientists and forecasters in better understanding the link between the ocean and the intensification of hurricanes. See http://www.aoml.noaa.gov/phod/cyclone/data/ for more information.

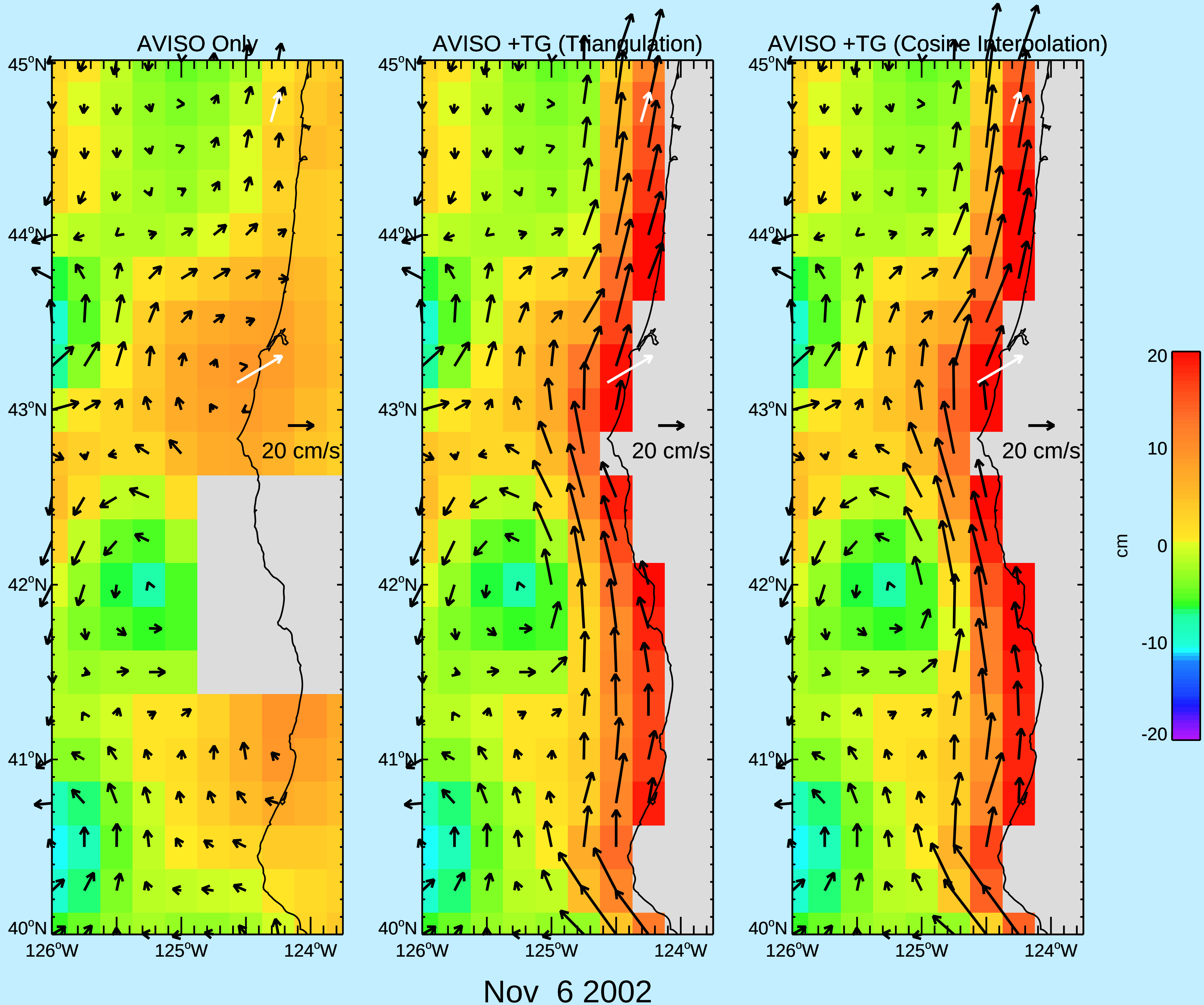
Altimeter Estimates of Global Sea Level Rise





Leuliette, E. W, R. S. Nerem, and G. T. Mitchum, 2004: Calibration of TOPEX/Poseidon and Jason altimeter data to construct a continuous record of mean sea level change. *Marine Geodesy*, **27**(1-2), 79-94. (http://sealevel.colorado.edu)


Standard
Standard + Tide Gauge
Slight Modif.
AVISO Only
AVISO +TG (Triangulation)
AVISO +TG (Cosine Interpolation)
45°N
44°N
43°N
42°N
41°N
40°N
126°W
125°W
124°W
20 cm/s
20
10
0
-10
-20
cm
Oct 30 2002



AVISO Only
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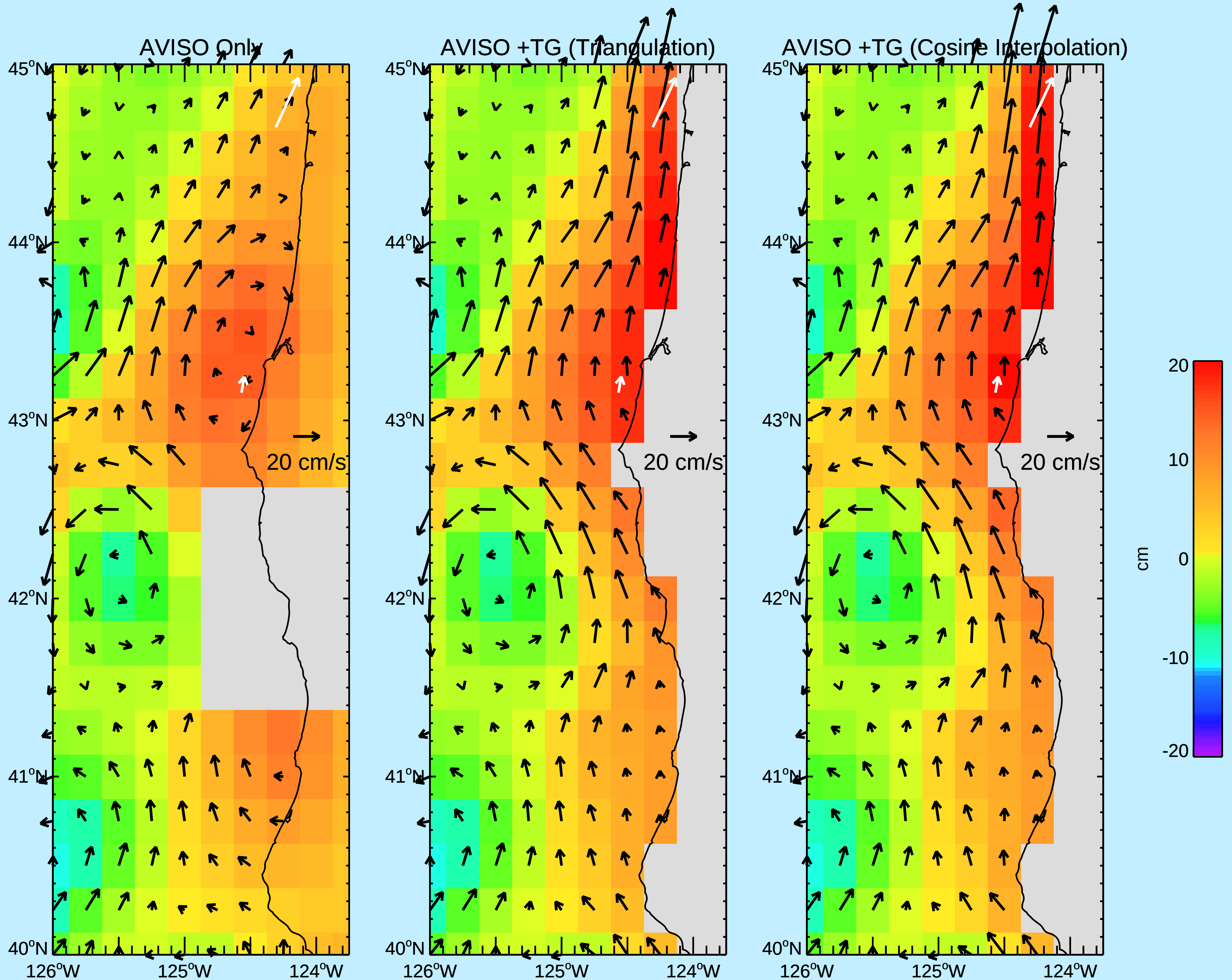
20 cm/s
cm
20
10
0
-10
-20
Nov 6 2002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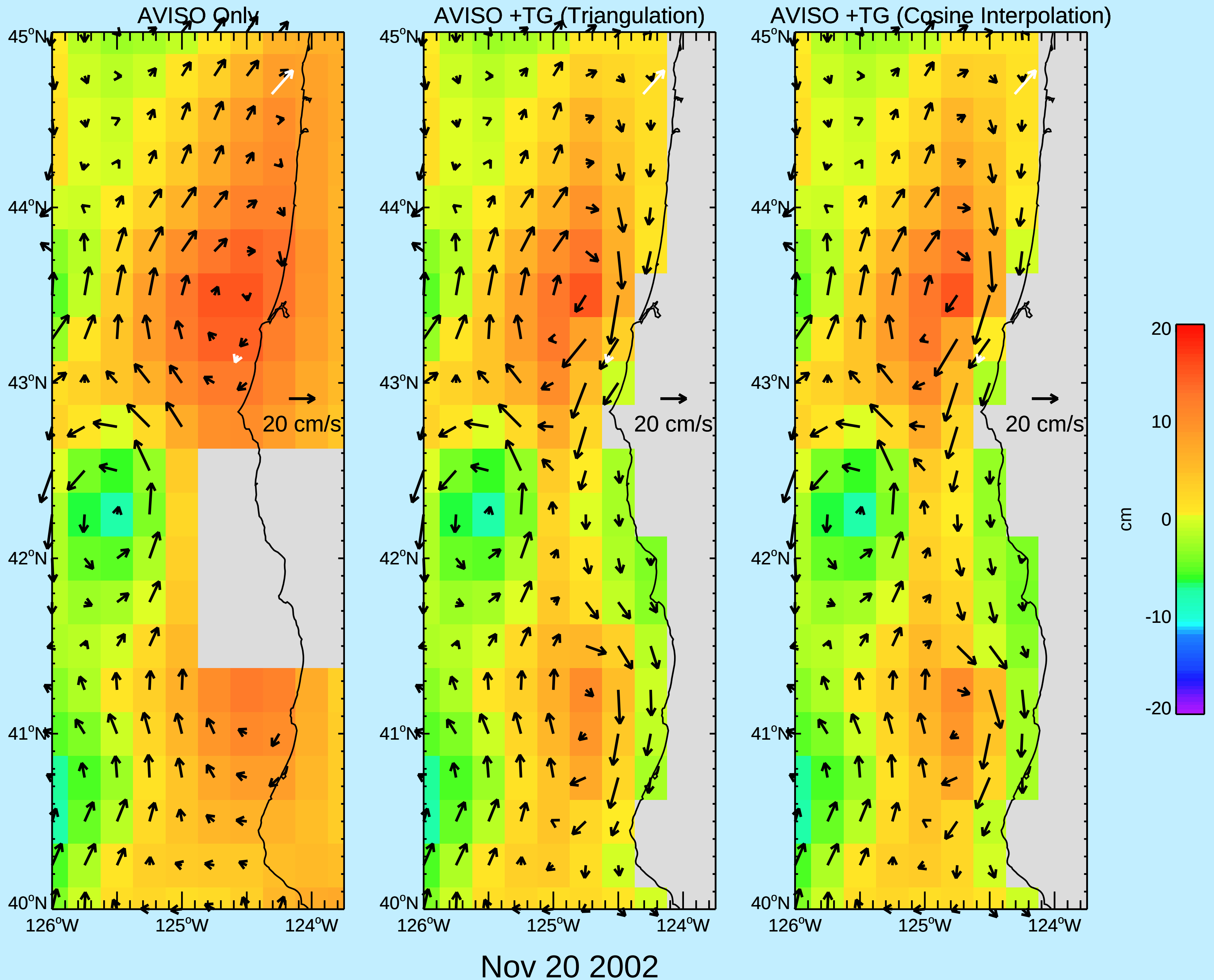
125°W
124°W
20 cm/s
20
10
0
-10
-20
cm

Nov 13 2002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AVISO +TG (Cosine Interpolation)
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44°N
43°N
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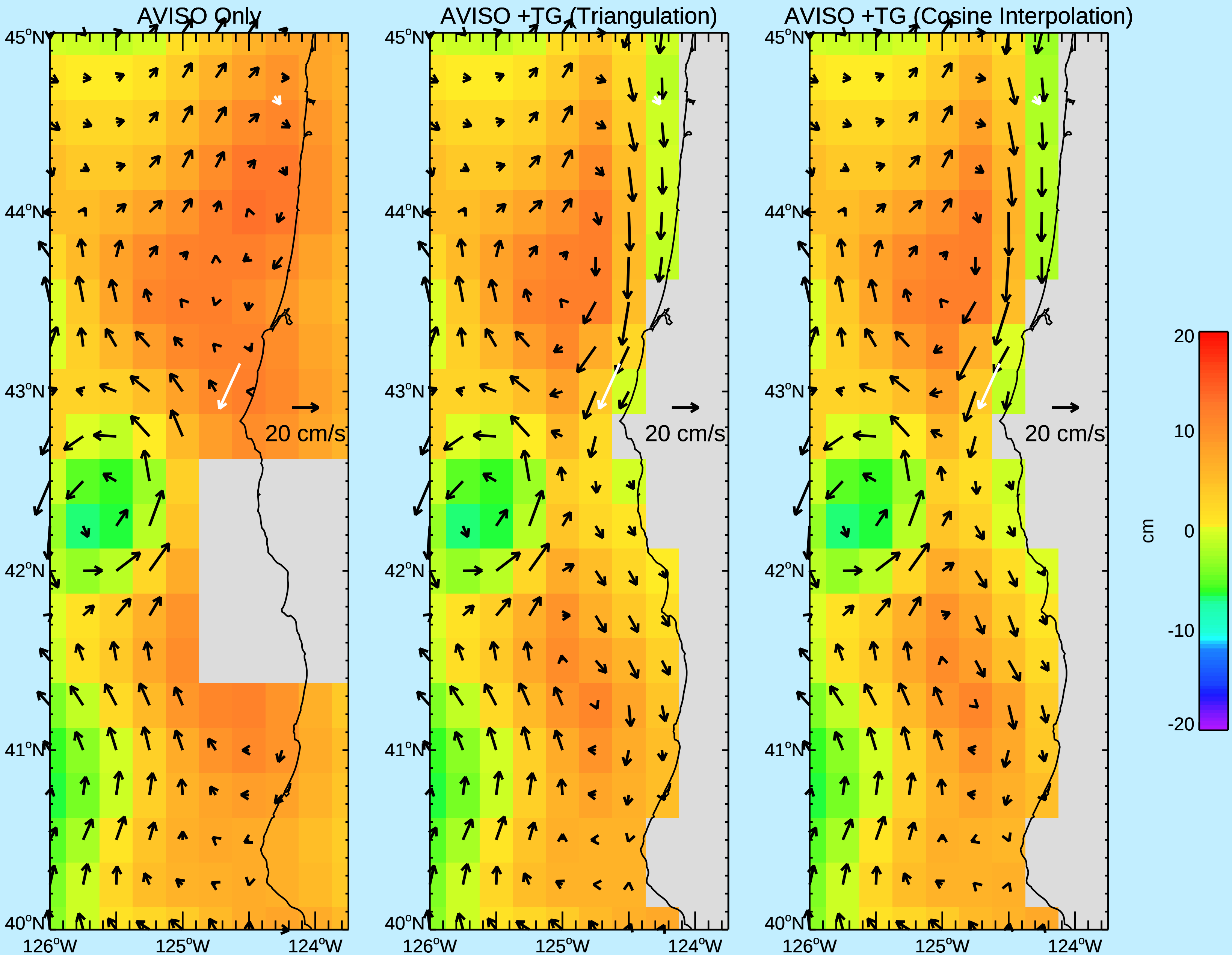
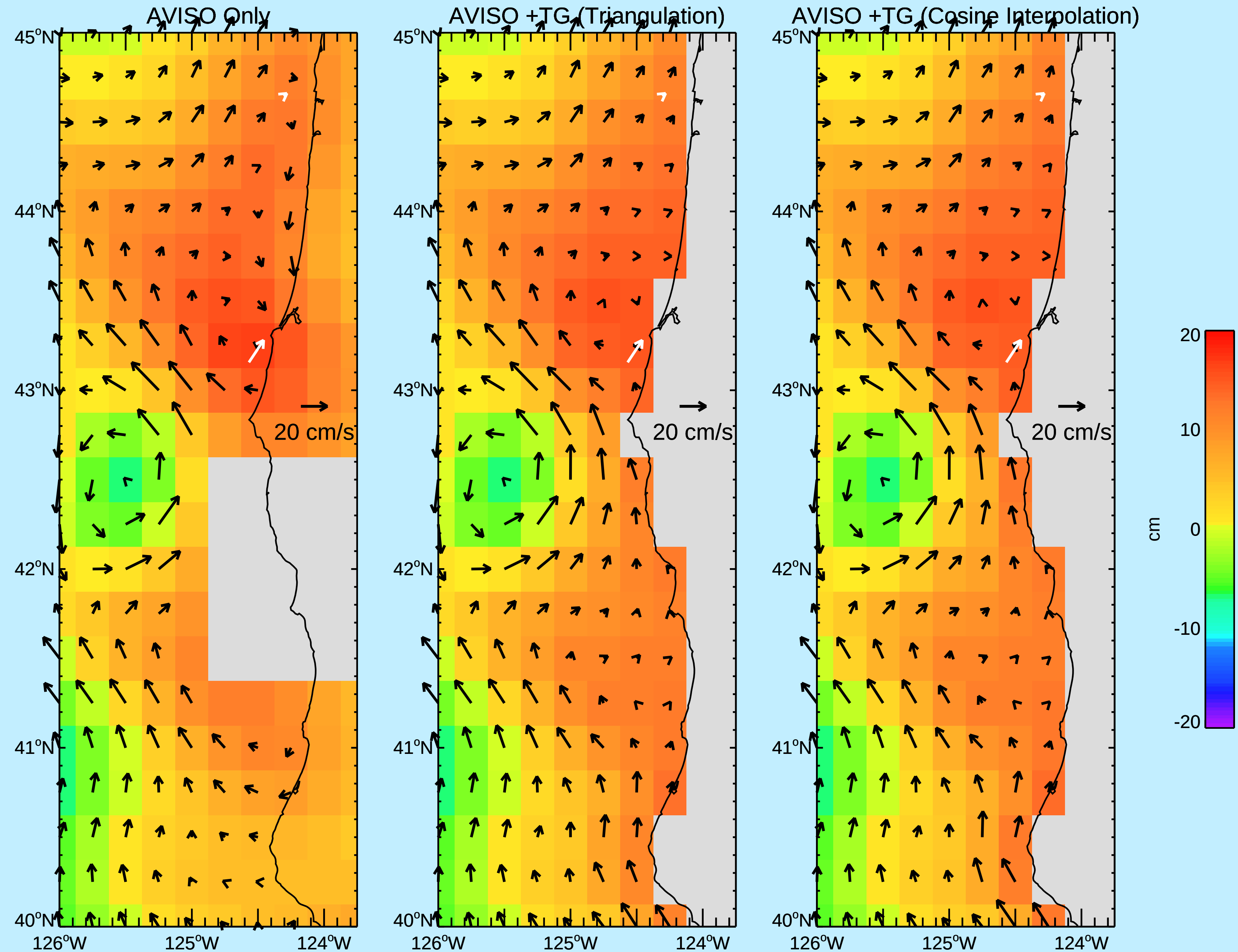
126°W
125°W
124°W
20 cm/s
20
10
0
-10
-20
cm
Nov 20 2002

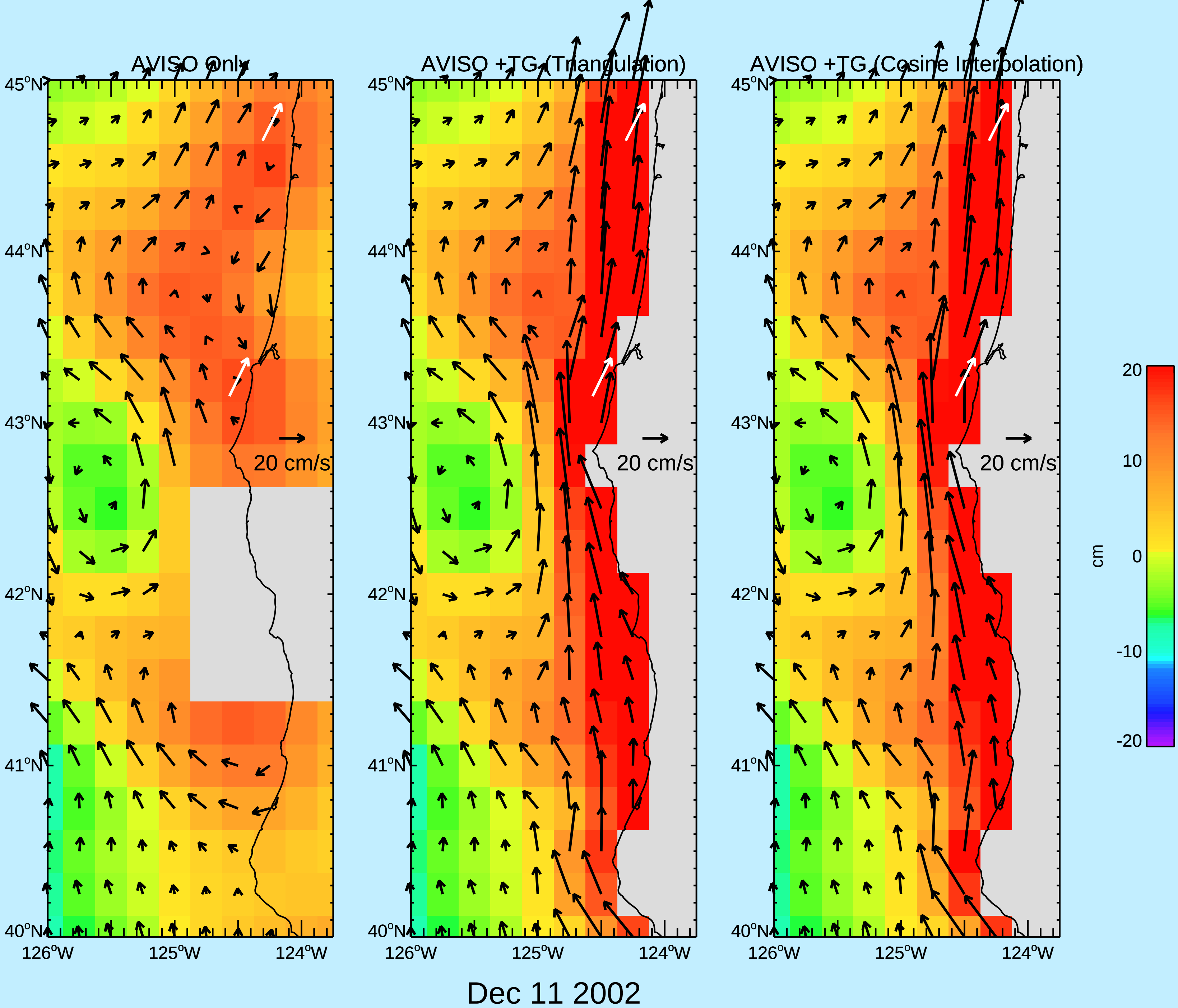

AVISO Only
AVISO +TG (Triangulation)
AVISO +TG (Cosine Interpolation)
45°N
44°N
43°N
42°N
41°N
40°N
126°W
125°W
124°W
20 cm/s
20
10
0
-10
-20
cm

Nov 27 2002



AVISO Only
AVISO +TG (Triangulation)
AVISO +TG (Cosine Interpolation)
45°N
44°N
43°N
42°N
41°N
40°N
126°W
125°W
124°W
20 cm/s
20
10
0
-10
-20
cm

Dec 4 2002


AVISO Only
AVISO +TG (Triangulation)
AVISO +TG (Cosine Interpolation)
45°N
44°N
43°N
42°N
41°N
40°N
126°W
125°W
124°W
20 cm/s
20
10
0
-10
-20
cm
Dec 11 2002

Radar Scatterometry

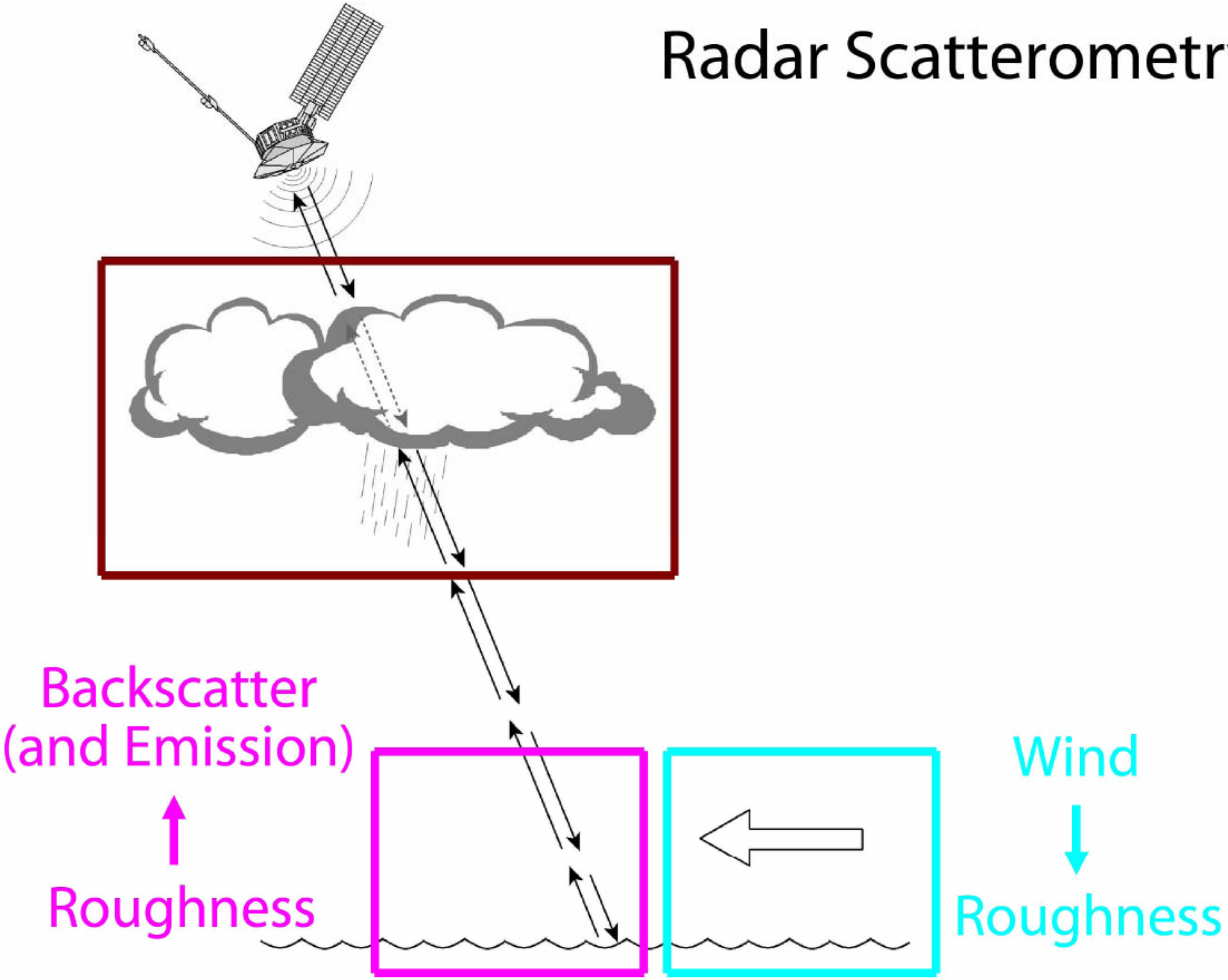


Figure courtesy of M. Freilich

Resonant Bragg Scattering from Wavelengths Approximately Equal to that of the Radar Signal (~2 cm for a scatterometer frequency of 13.5 GHz)

$$\lambda_B = \frac{n}{2}\frac{\lambda}{\sin\theta}$$

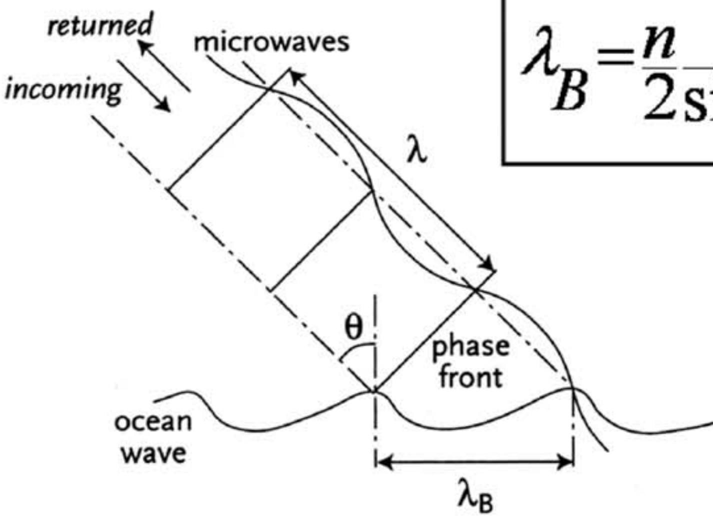


Figure 11. Bragg scattering: A plan-parallel radar beam with wavelength λ hits the rough ocean surface at incidence angle θ, where capillary gravity waves with Bragg wavelength λ_B will cause microwave resonance.

Figure courtesy of A. Stoffelen

Centimetric Roughness: Gravity-Capillary Waves

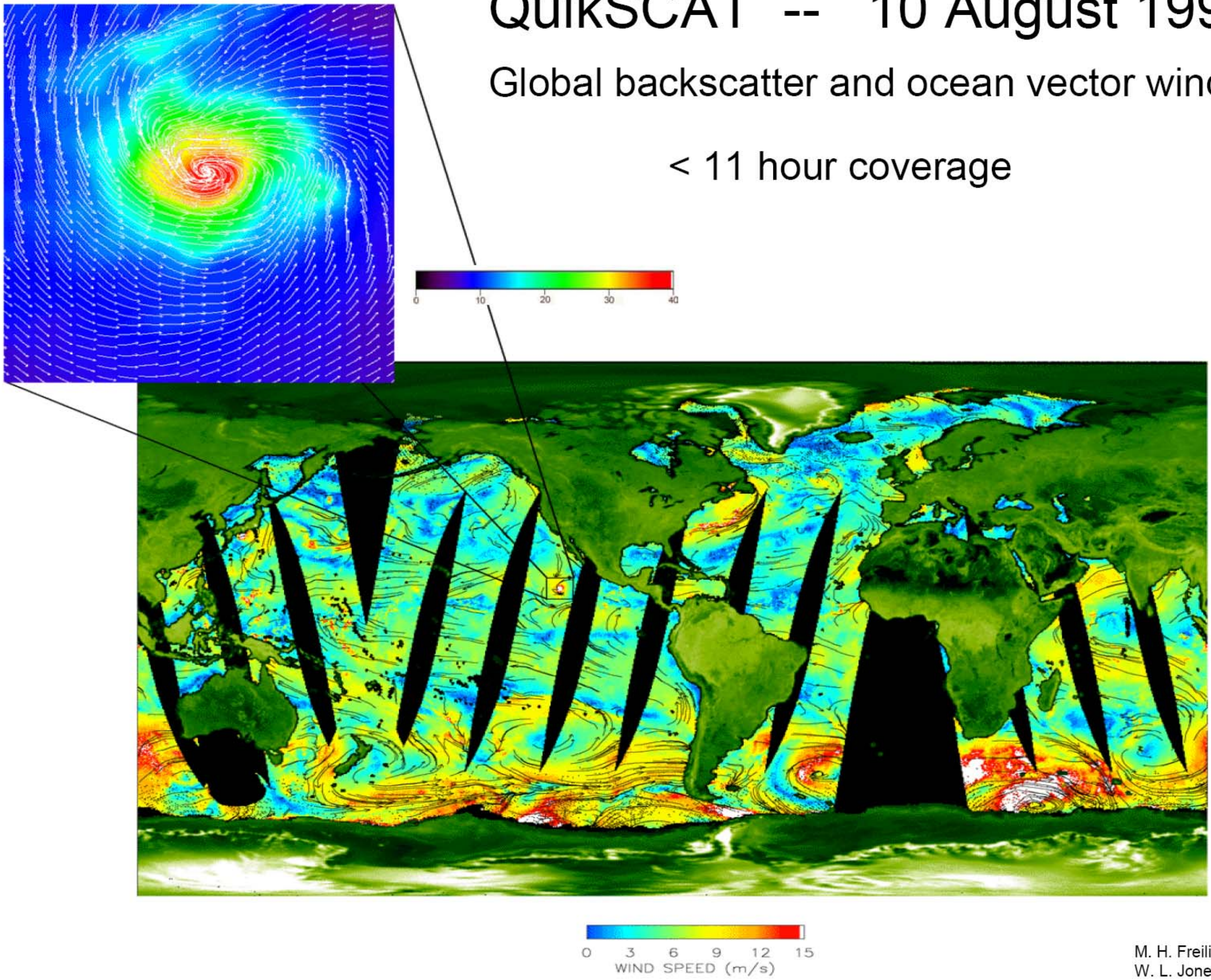
Figure courtesy of M. Freilich

QuikSCAT -- 10 August 1999

Global backscatter and ocean vector winds

< 11 hour coverage

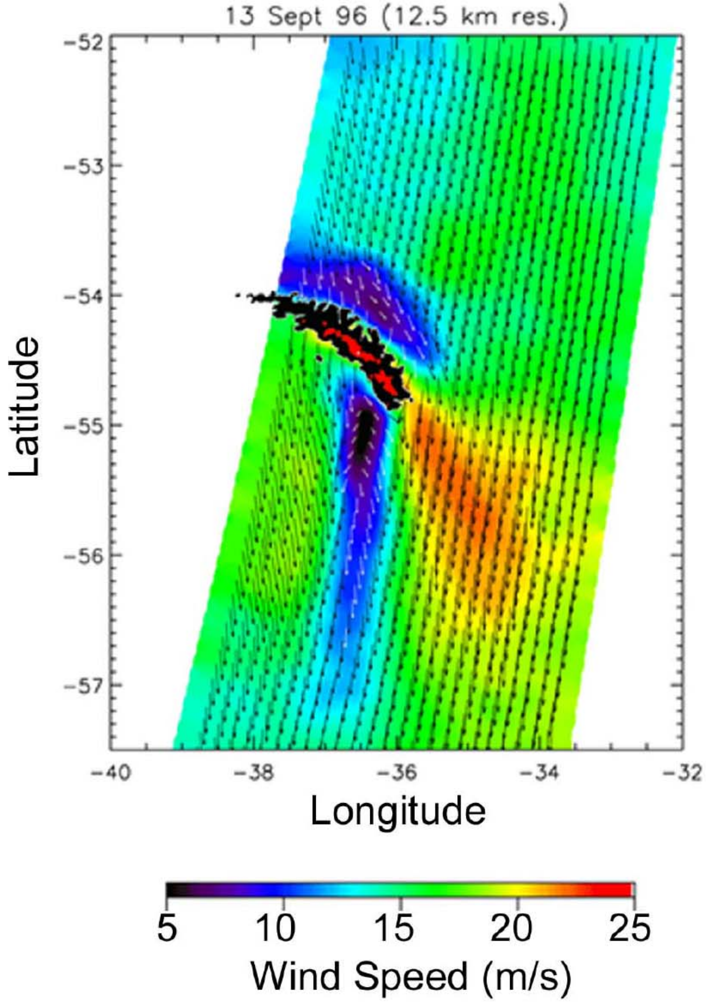
Hurricane Dora



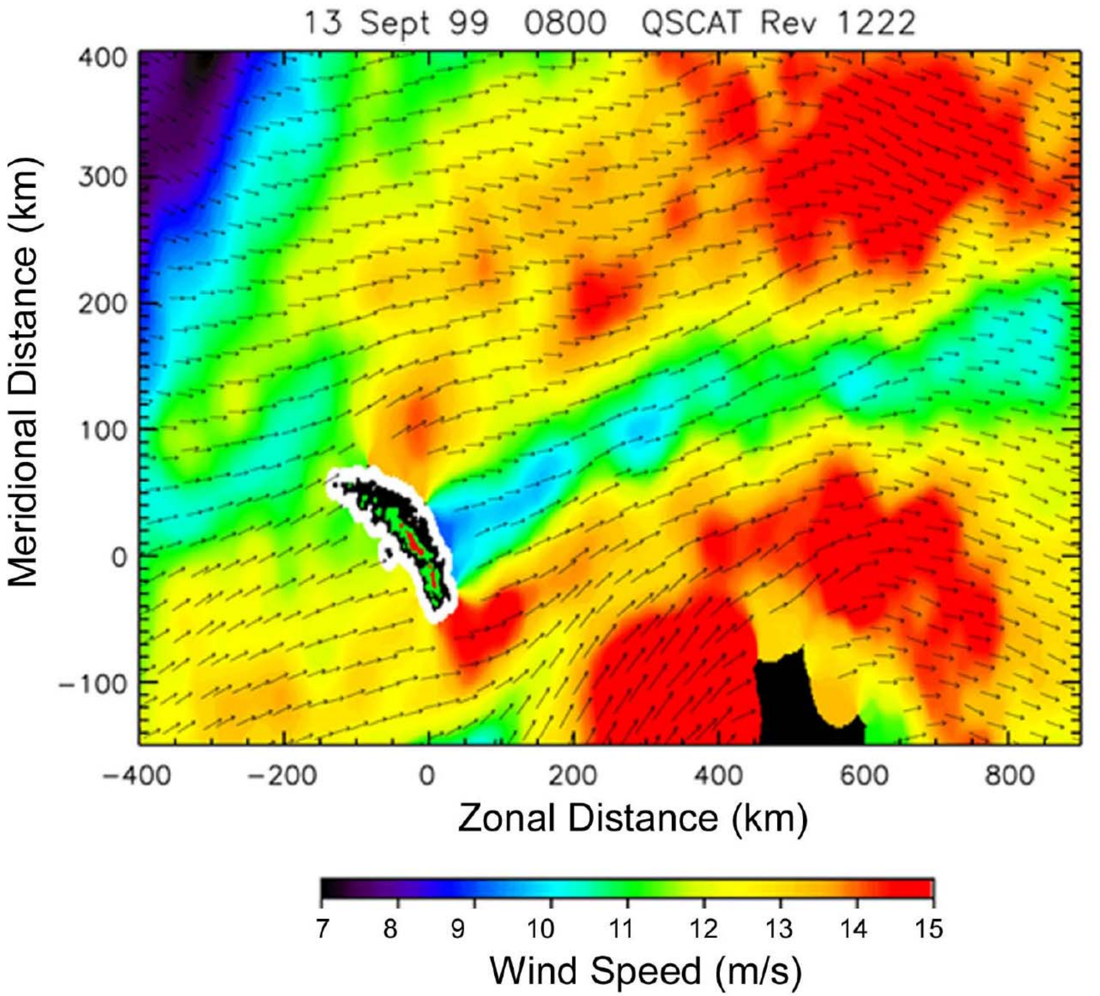
M. H. Freilich COAS/OSU
W. L. Jones UCF

Wind Shadows Behind South Georgia Island

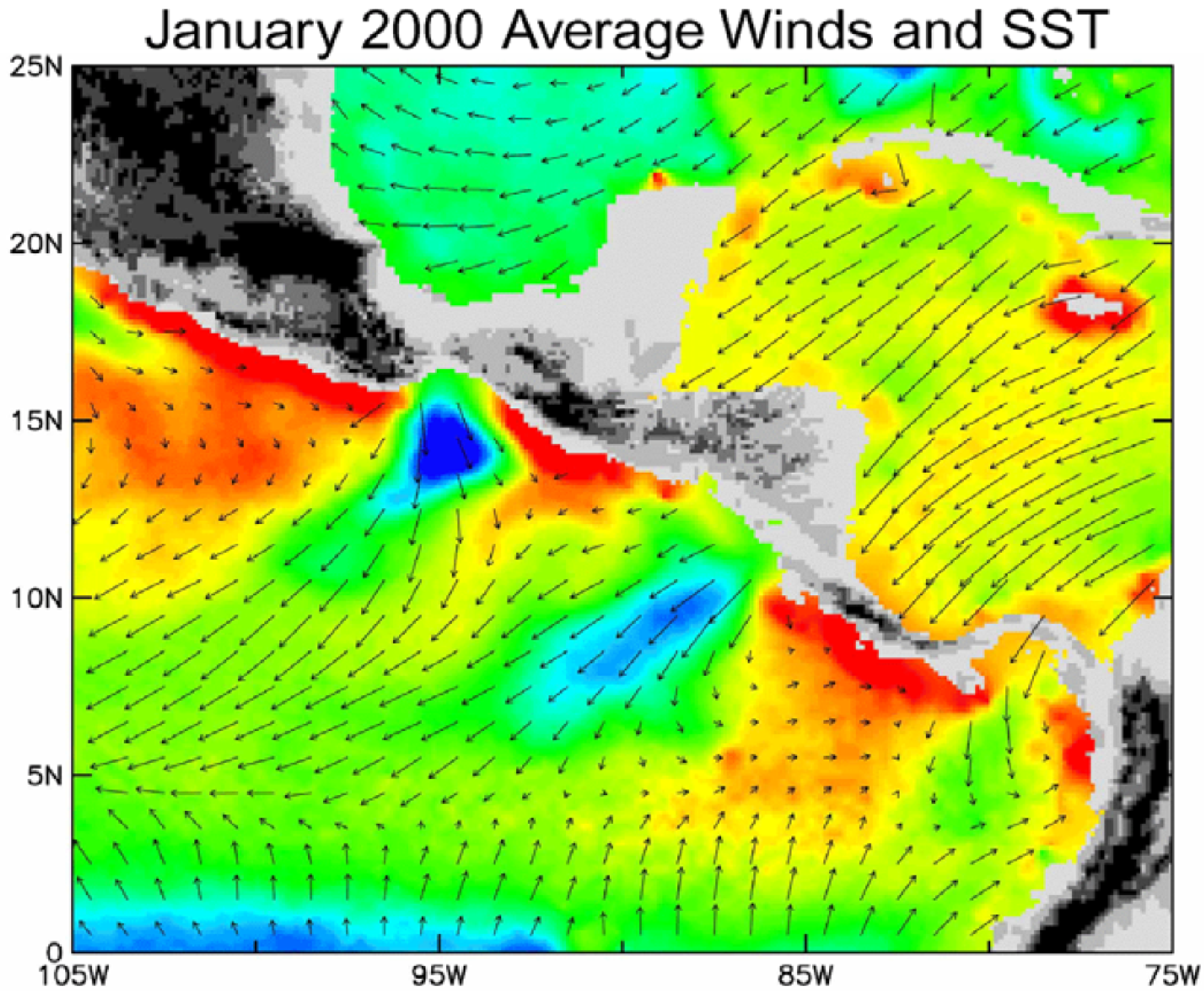
NSCAT Example



QuikSCAT Example

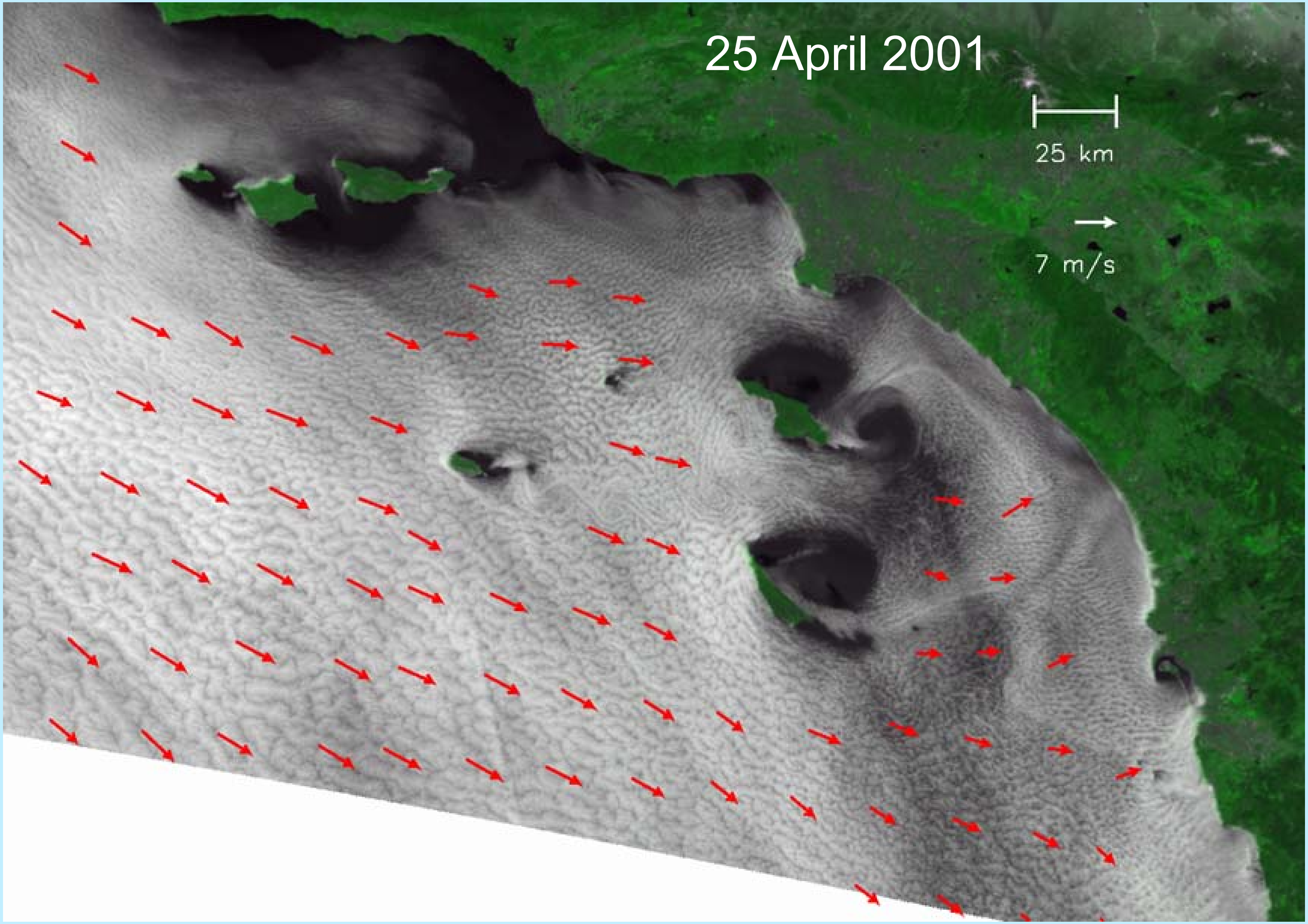


Figures courtesy of M. Freilich

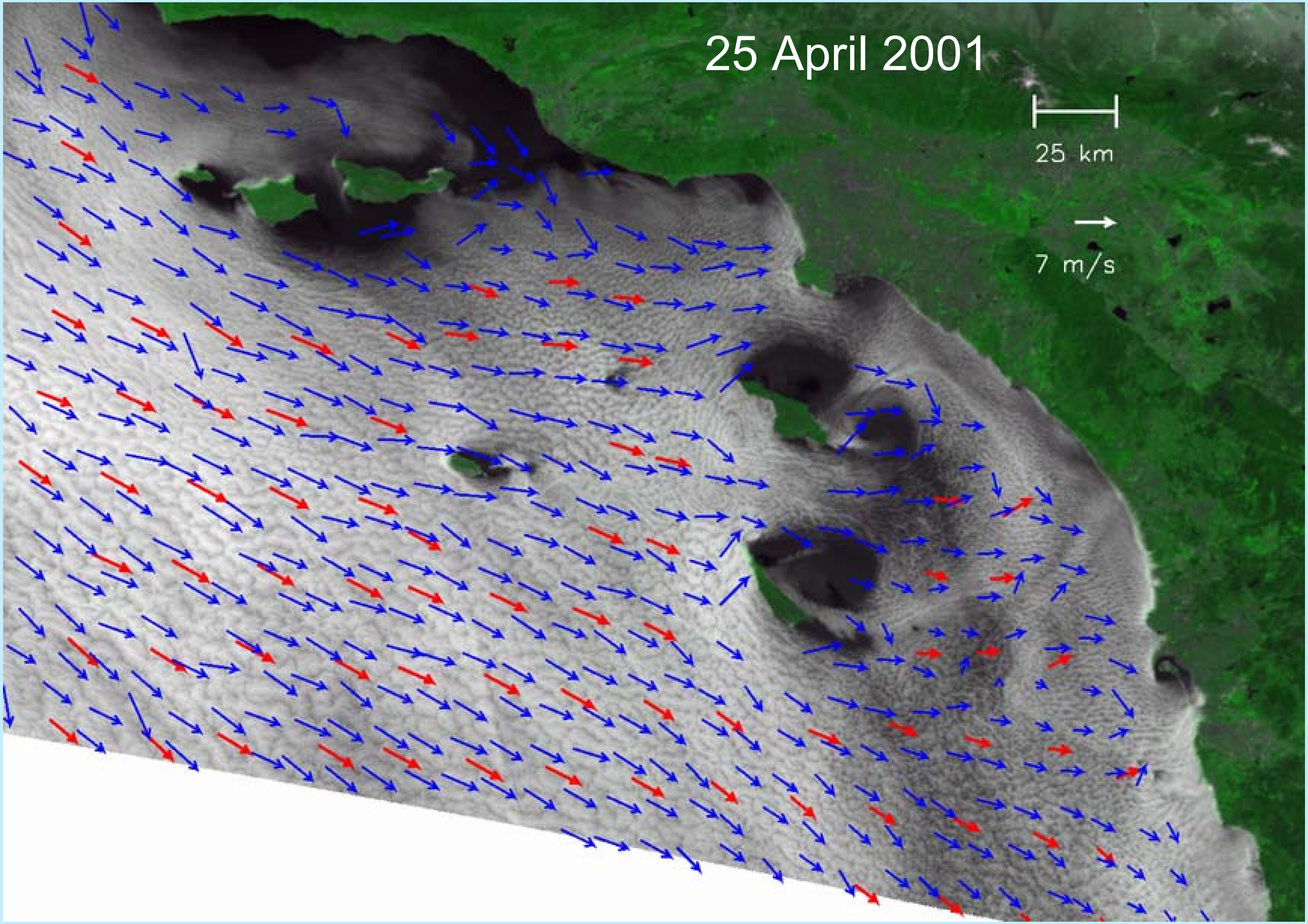

January 2000 Average Winds and SST
25N
20N
15N
10N
5N
0
105W
95W
85W
75W

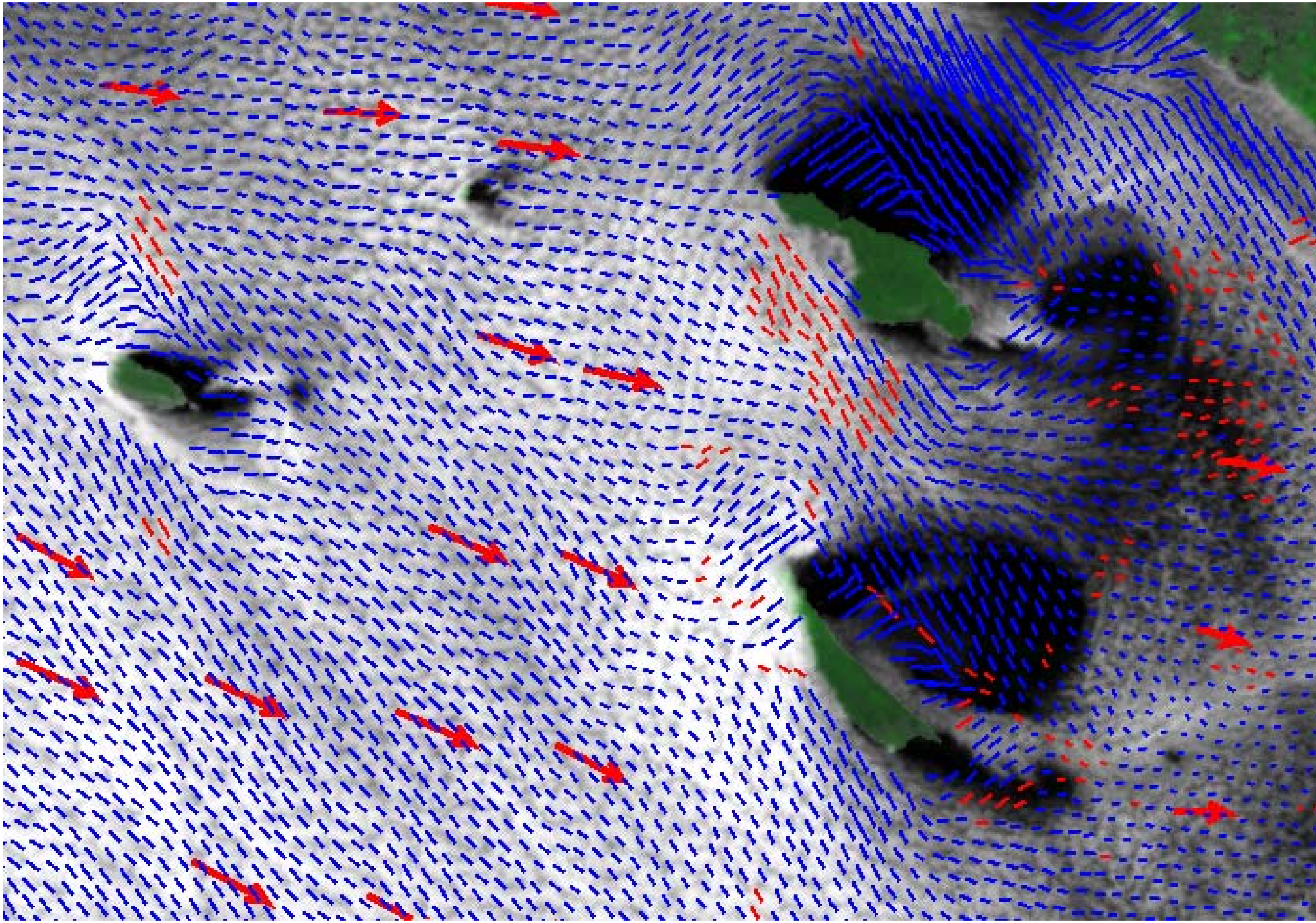
High Resolution QuikSCAT Coastal Winds

- First slide shows "standard" QuikSCAT microwave scatterometer wind vectors (red)
  - Resolution is 25km
  - Land mask is ~35km, fixed
- Second slide shows *new* high resolution QuikSCAT coastal wind vectors (blue)
  - Resolution is 12.5km
  - Land mask is between 1km and 10km, variable



25 April 2001
25 km
7 m/s


25 April 2001
25 km
7 m/s



David Long

Summary

- Although only a few oceanographic parameters can be observed from satellites, they include the primary forcing by wind stress, the basic circulation (geostrophic and Ekman surface transports), the response of SST (involving mixed layer depth) and lower trophic levels in the marine ecosystem (phytoplankton).
- We are at the beginning of a period of comprehensive global and coastal ocean observations and modeling, moving oceanography into a new, operational phase, complementing the present meteorological operational systems.
- Remote sensing will form an important component of the ocean observing systems, along with new in situ tools.

DILBERT

August 16, 2000