Remote sensing of the oceans
Active sensing

- Gravity
- Sea level
  - Ocean tides
  - Low frequency motion
- Scatterometry
- SAR

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

Shape of the earth

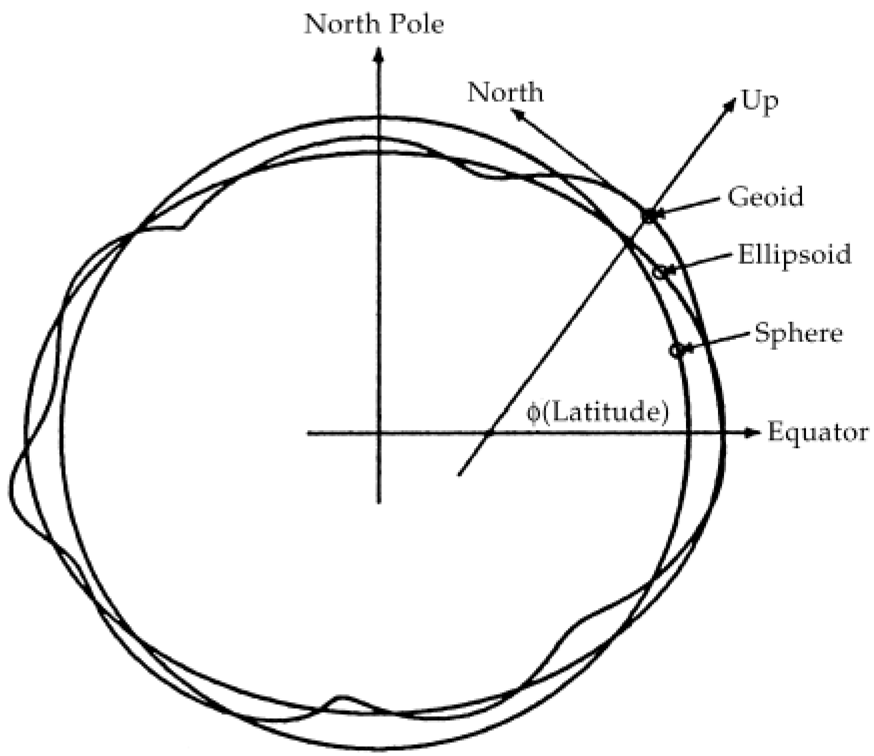
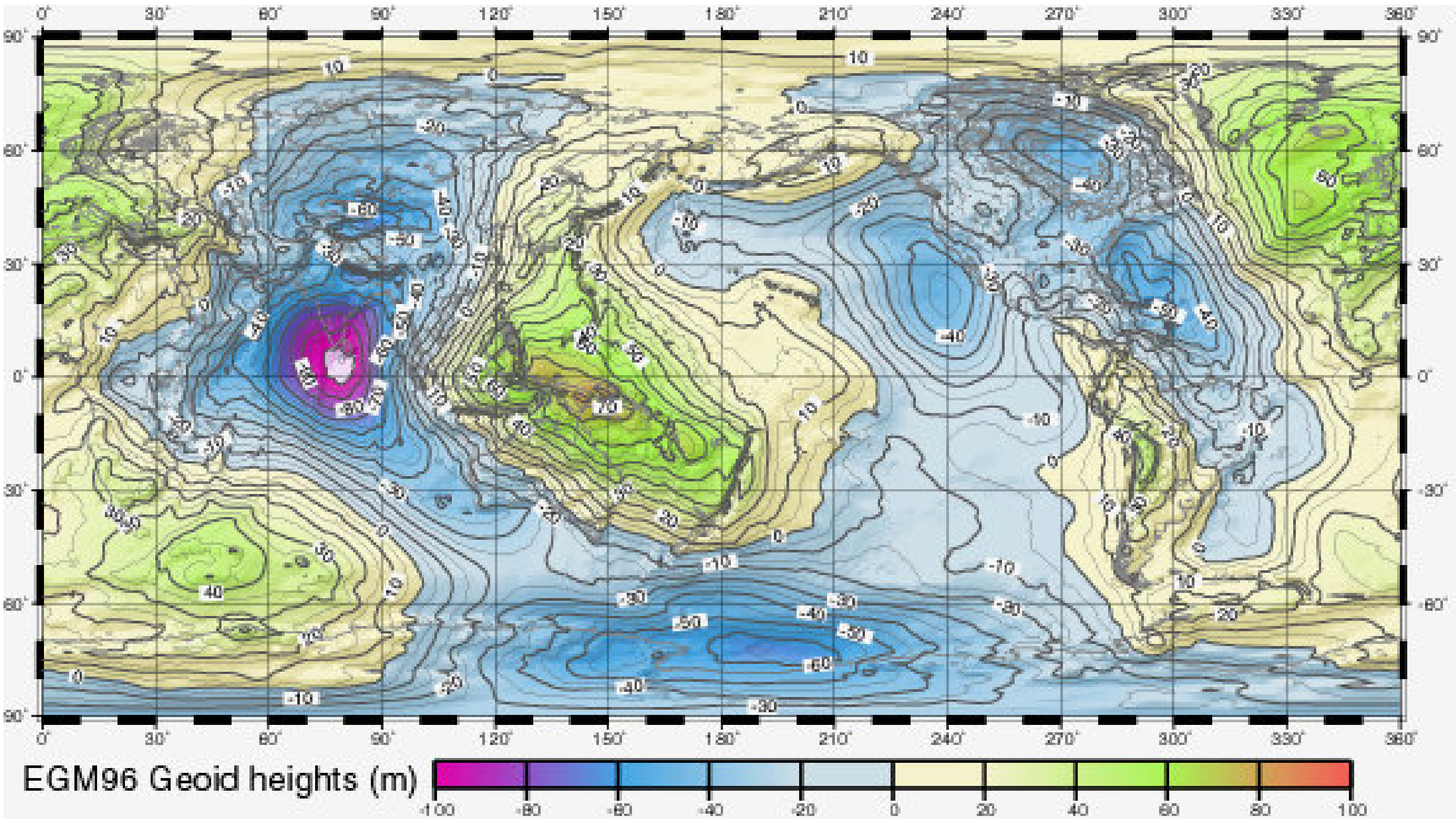


Fig. 9.17 Equipotential surface models for earth.

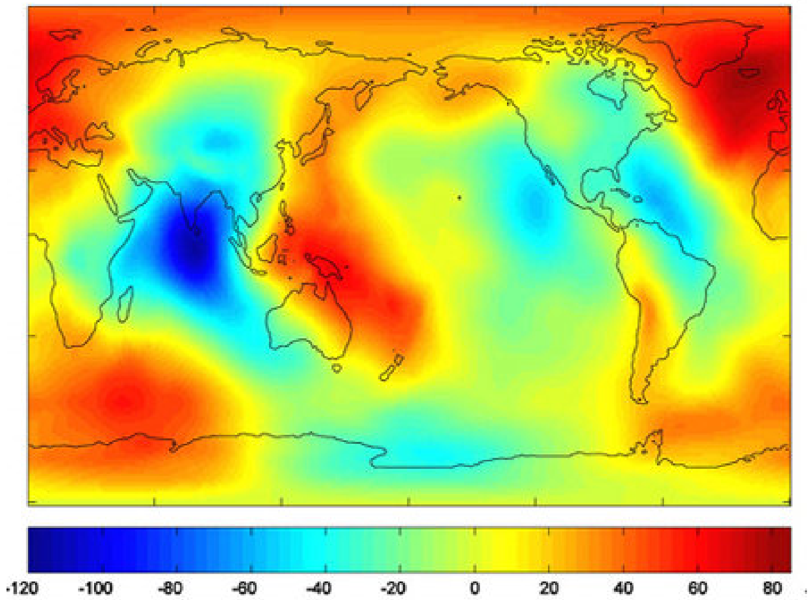
Geiod

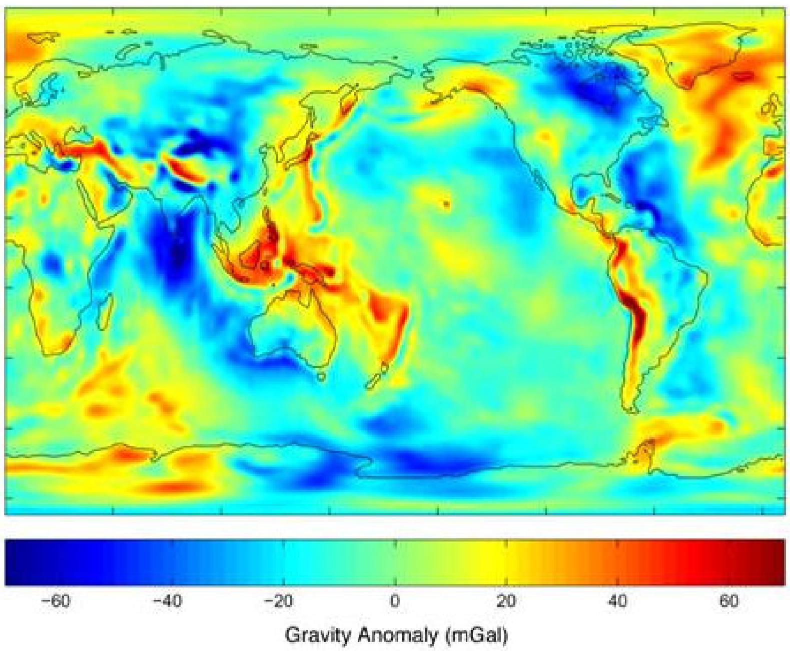
geoid: The equipotential surface of the Earth's gravity field which best fits, in a least squares sense, global mean sea level



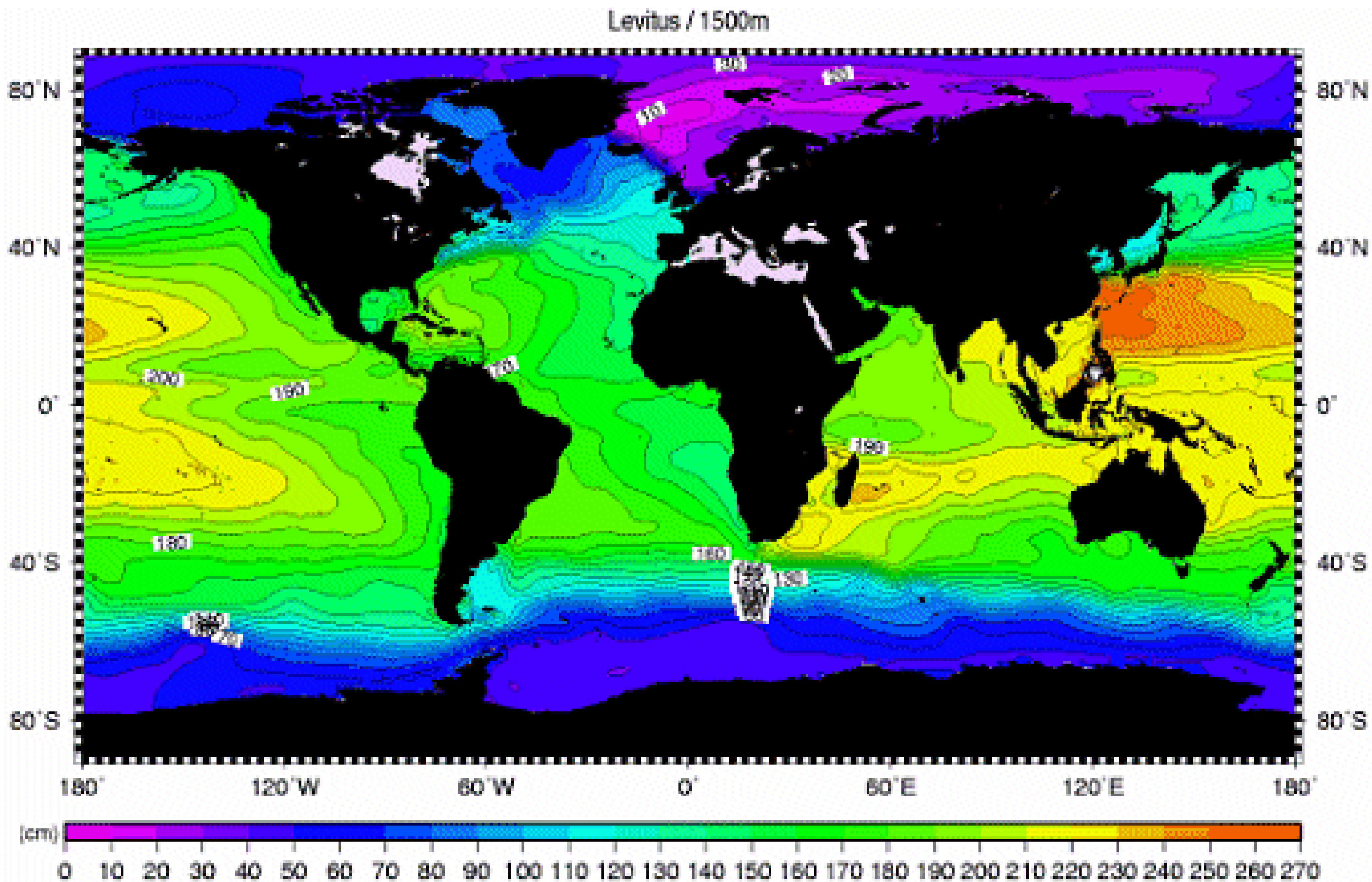
Geoid vs gravity

Anomalies from a reference ellipsoid





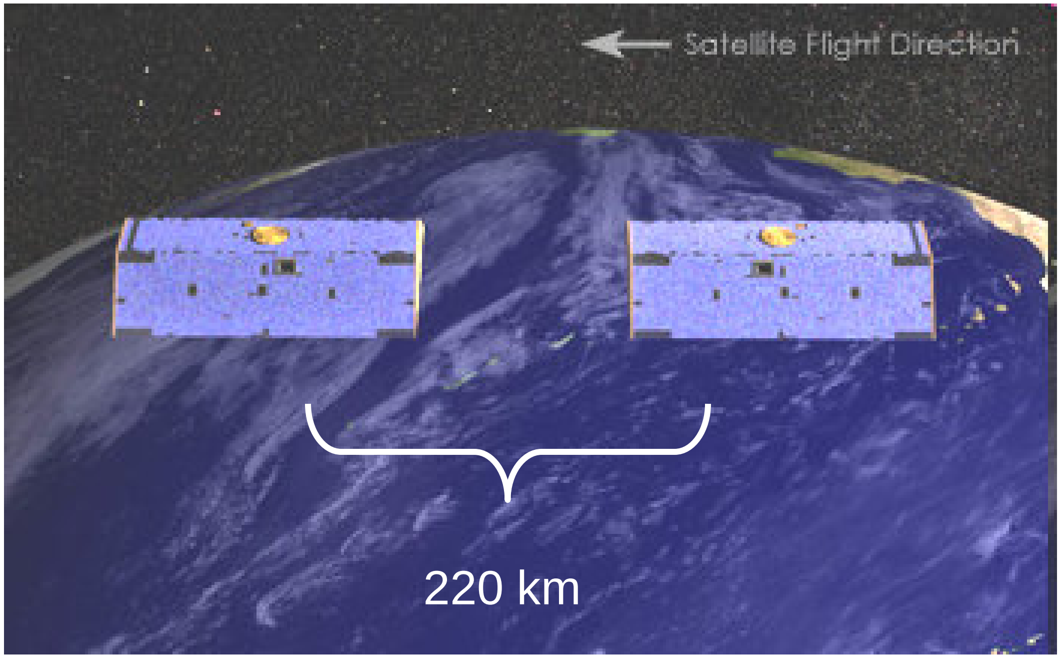
Mean dynamic topography



Time-dependent Gravity

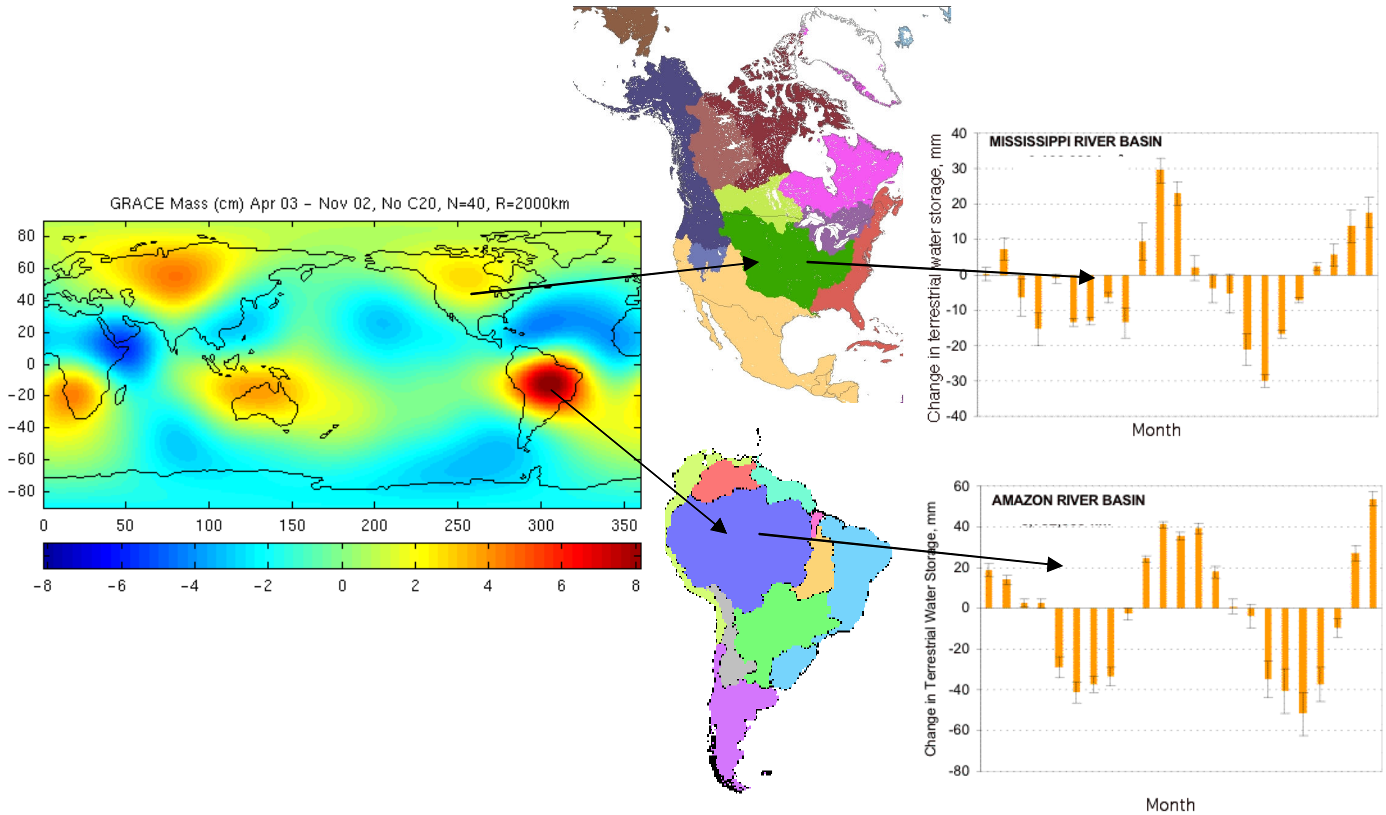
GRACE (2002-pres)
(Gravity Recovery and Climate Experiment)

500km orbit.

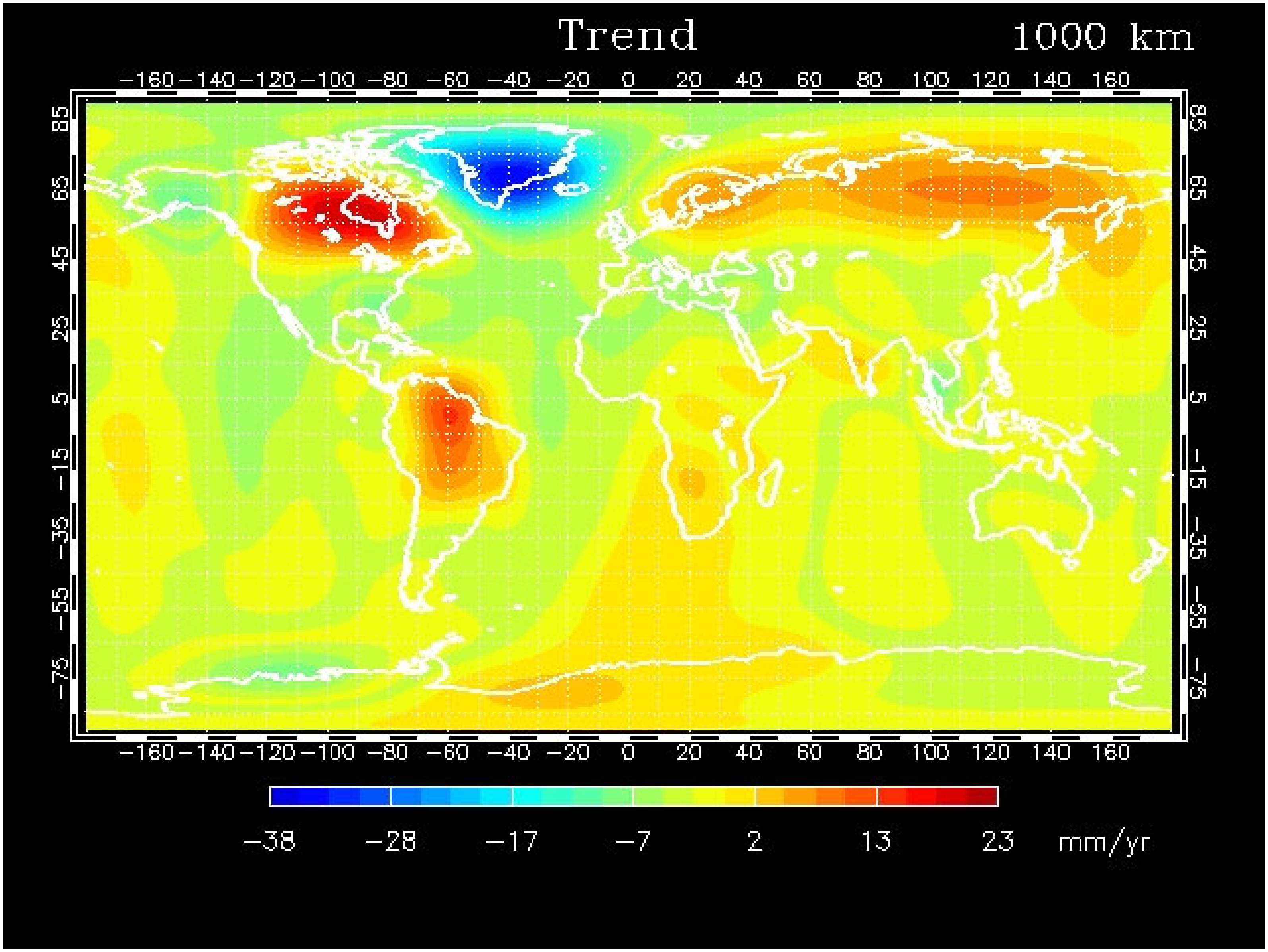


Distance accurate to 10µm

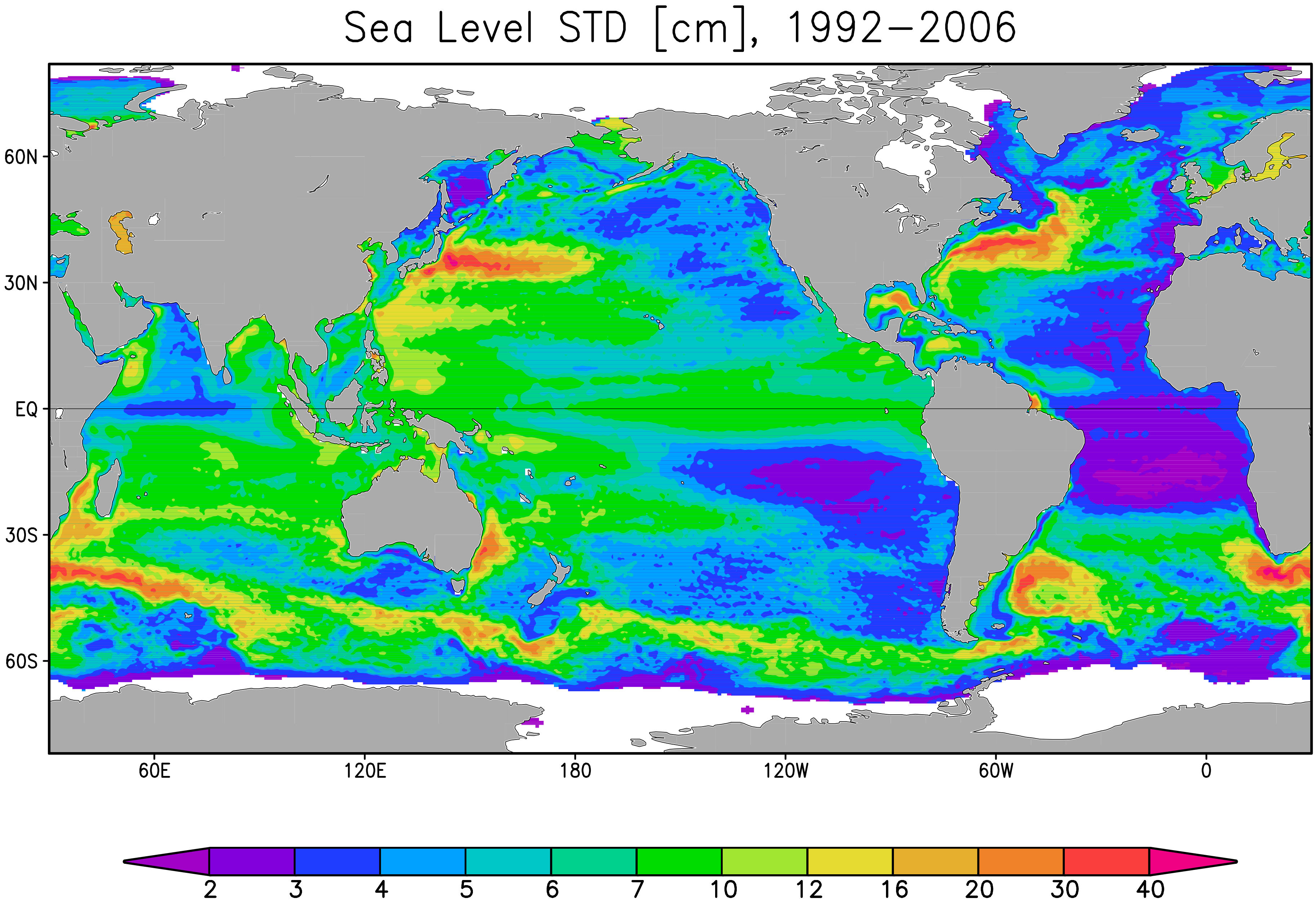
Estimation of basin-scale ΔTWS, validation and uncertainty



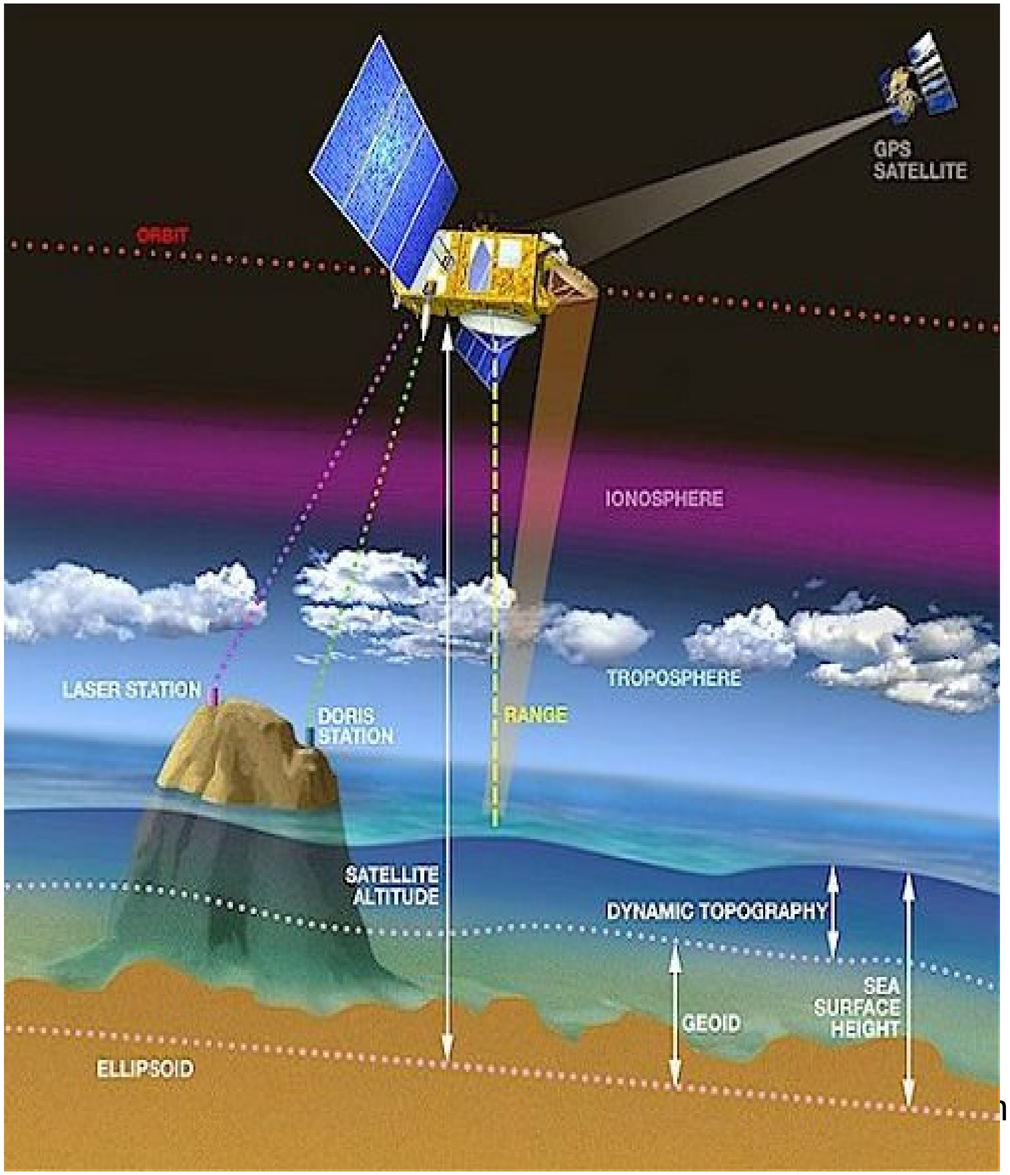
Geoid trend



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

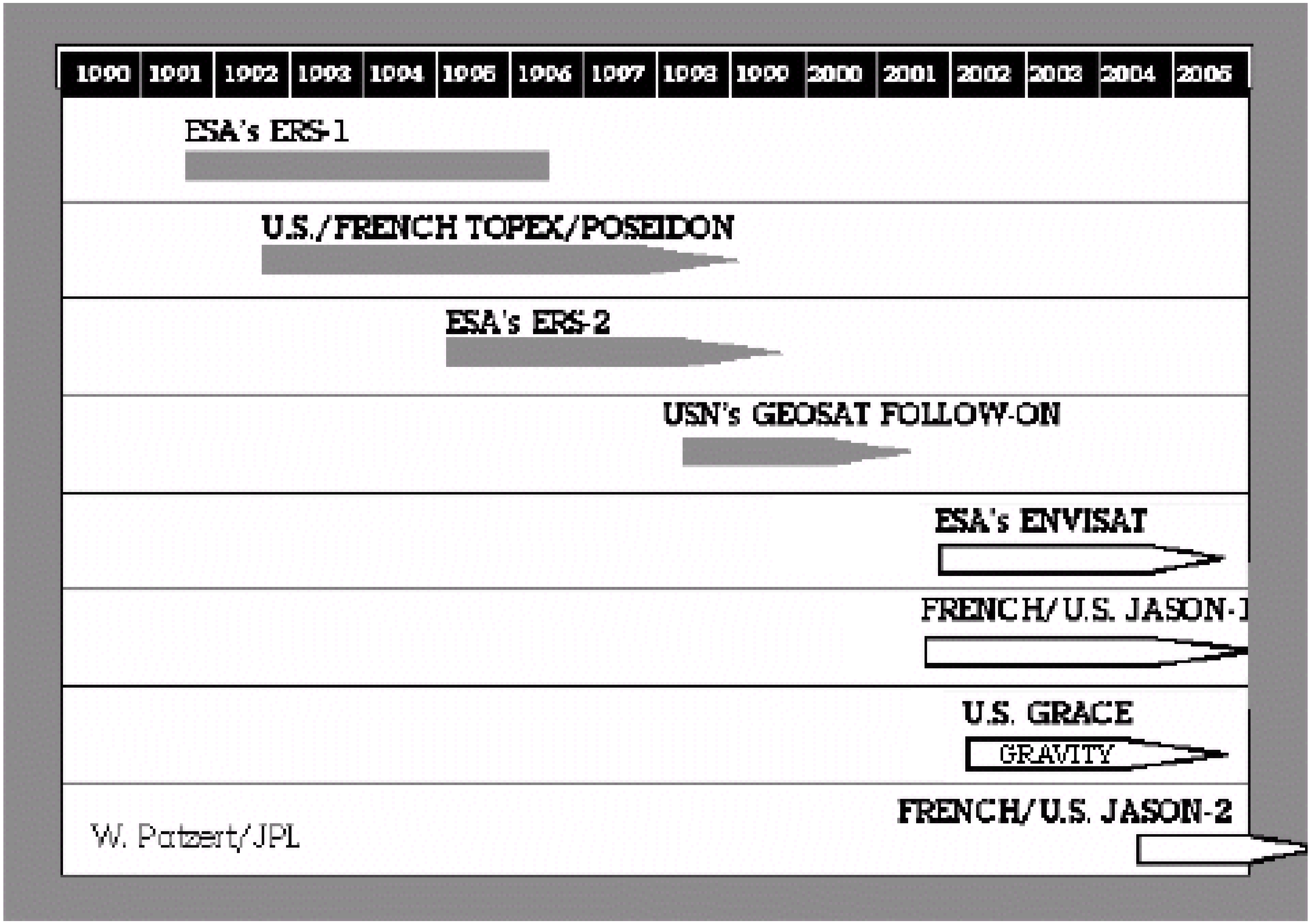

Sea Level STD [cm], 1992–2006
60N
30N
EQ
30S
60S
60E
120E
180
120W
60W
0
2
3
4
5
6
7
10
12
16
20
30
40

Radar altimeters

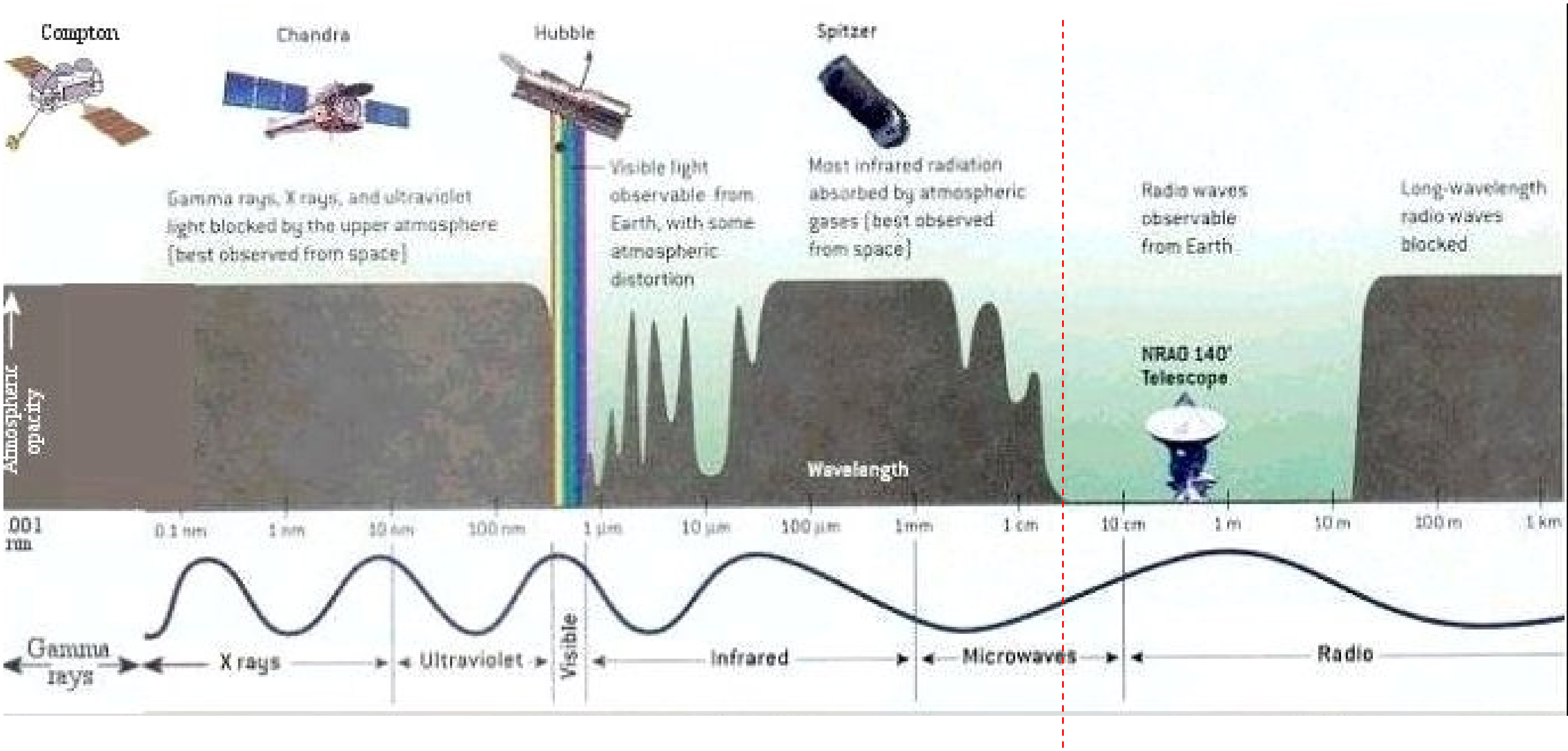


Radar altimeters derive a precise measurement of the round-trip time between the satellite and and infer the satellite-to-ocean range.

Summary of altimeter missions



Atmospheric absorption



2.2cm (Ku-band)

odin.physastro.mnsu.edu/~eskridge/astr101/atmospheric_windows.jpg

Altimeter physics: pulse-limited

For Geosat: pulse width: t_p=3 ns corresponding to a bandwidth of 0.3 GHz and ~1700 pulses/sec.

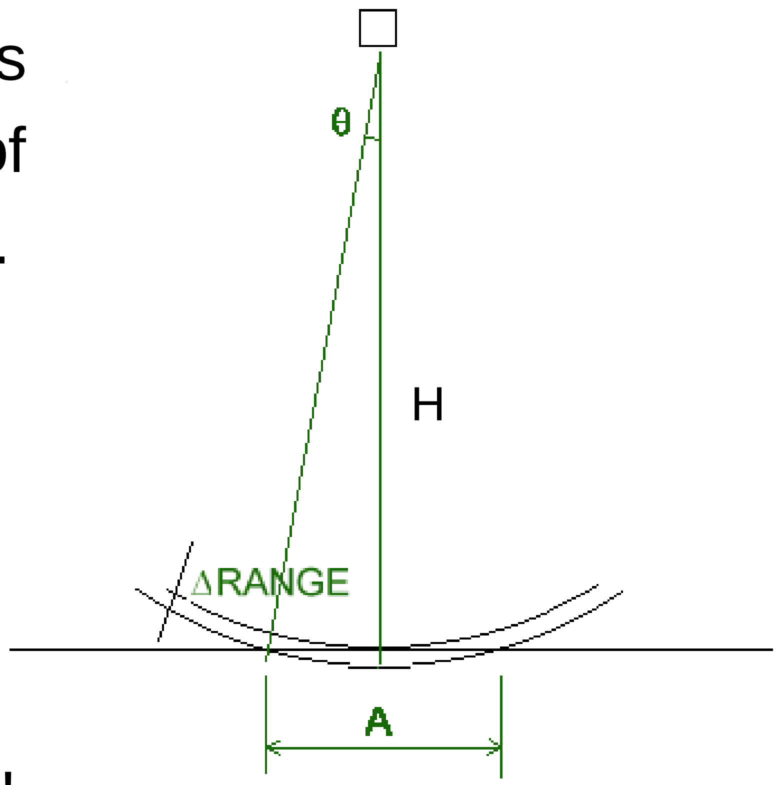
H = 800km

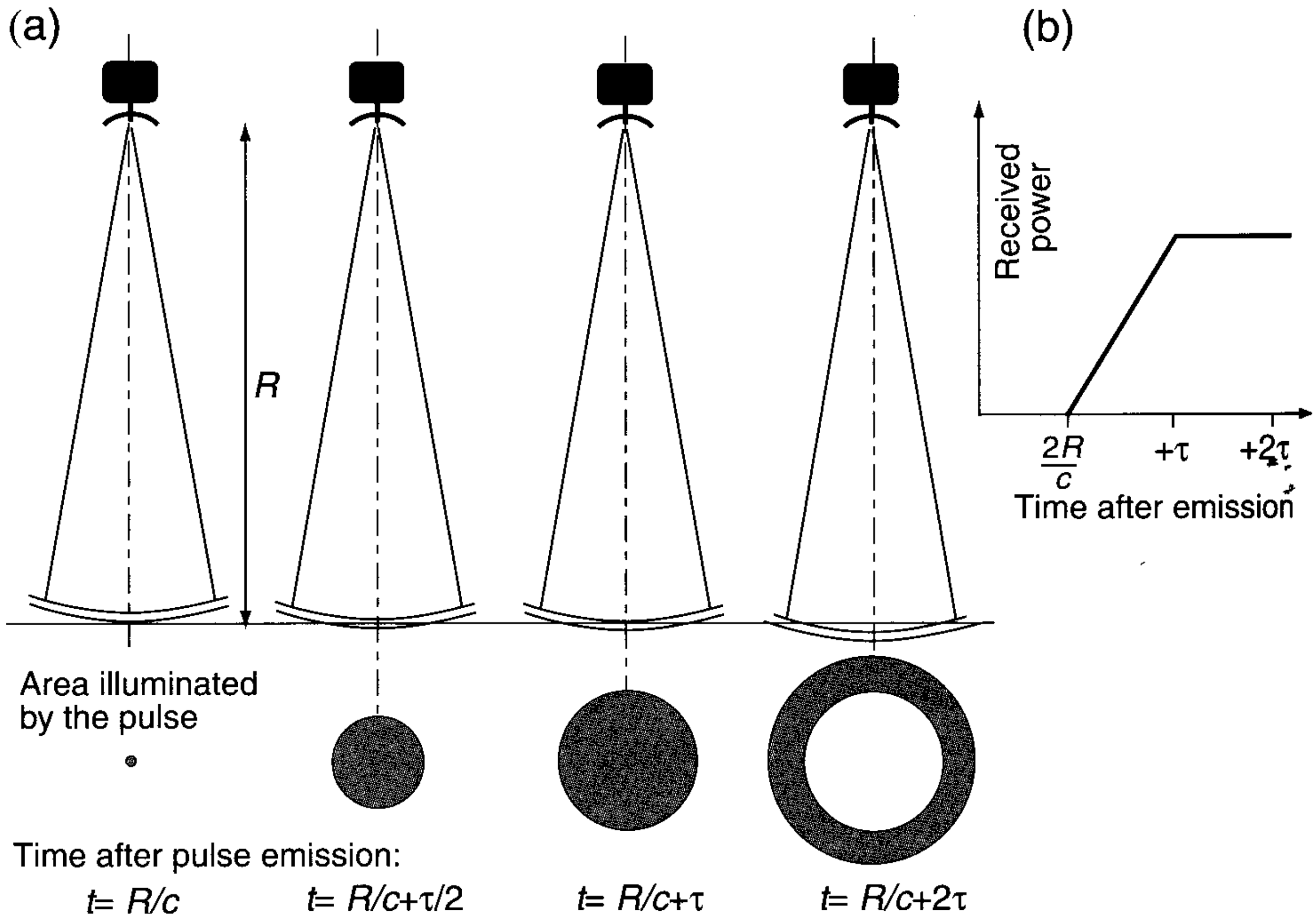
Range = ct/2 where t=5ms

$L_p = ct_p = 3x10^8$ x 3ns = 1m

Since $((A/2)^2+H^2)=(L_p+H)^2$

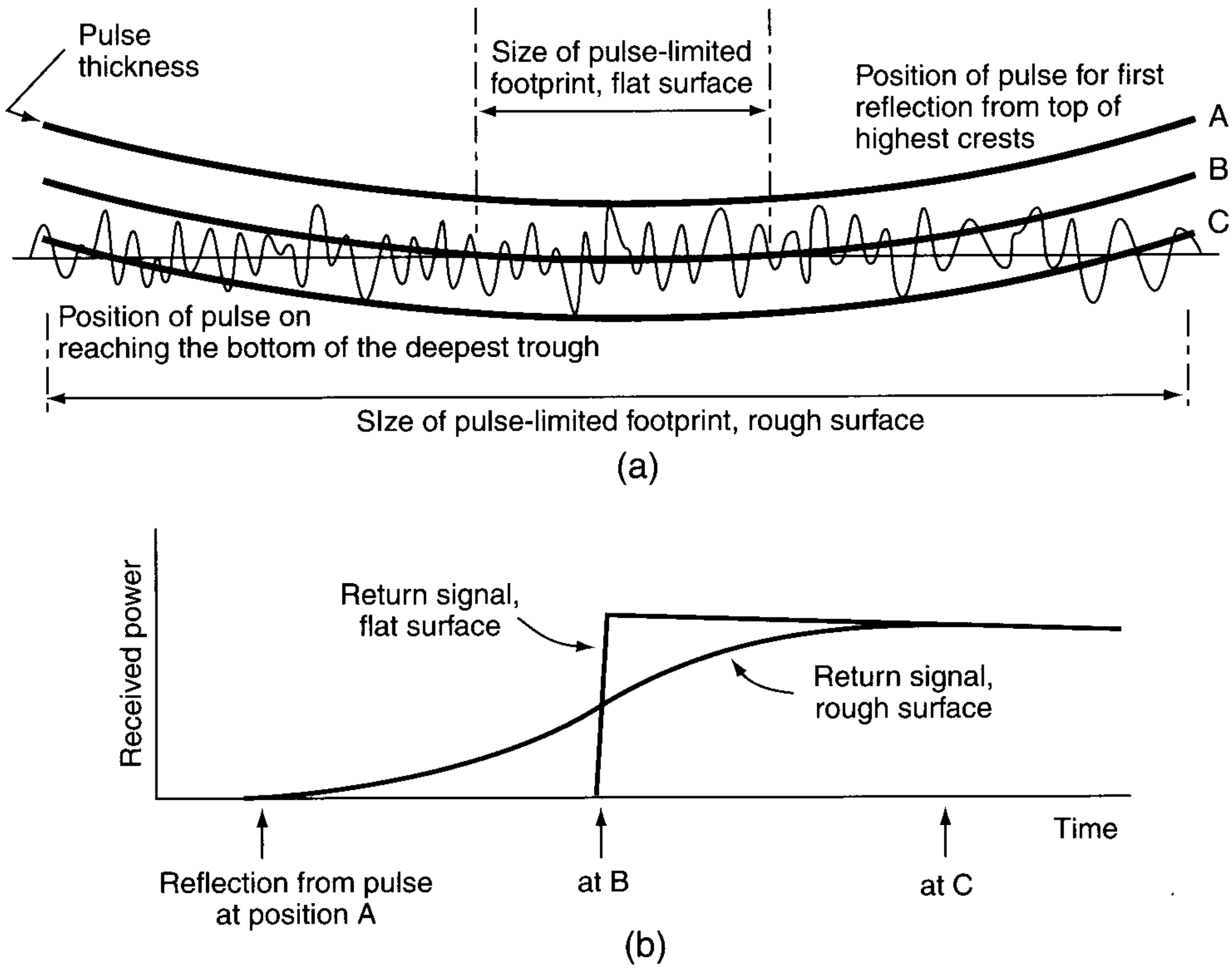
$A = (HL_p/2)^{1/2}$ = 2.4km footprint!




(a)
R
Area illuminated
by the pulse
Time after pulse emission:
t= R/c
t= R/c+τ/2
t= R/c+τ
t= R/c+2τ
(b)
Received
power
2R
c
+τ
+2τ
Time after emission

IoE

Modeling the impact of surface waves



$$\Pr obability\ distribution: G(h) \approx e^{-(\frac{h^2}{2\Delta h^2})}; \quad h_{1/3} = 4\Delta h$$

$$if\ \ G(t_w) \approx 1/2\ then$$

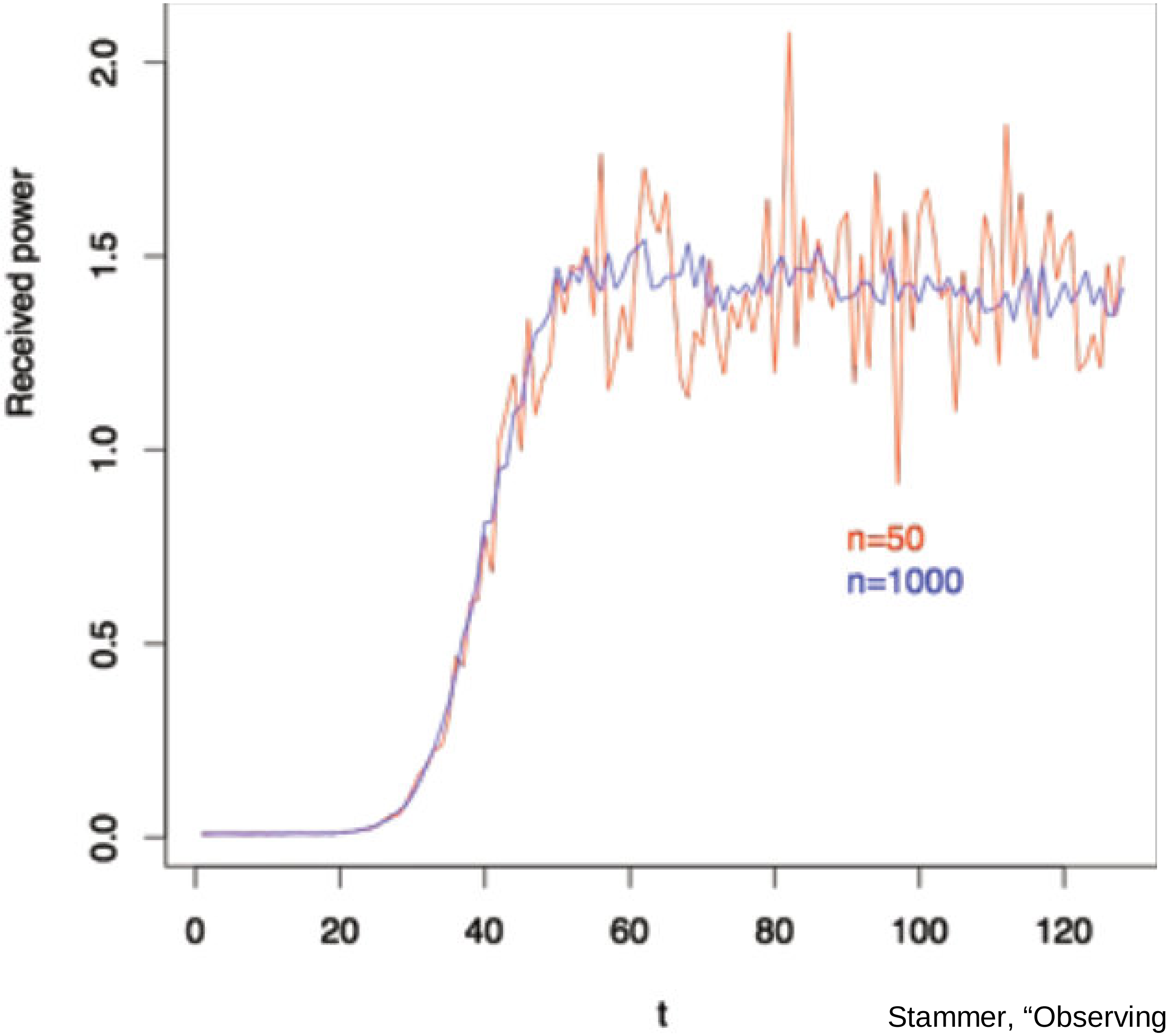
$$t_w = \frac{4\Delta h}{c}(\ln 2)^{1/2} = \frac{h_{1/3}}{c}(\ln 2)^{1/2}$$

If $h_{1/3}$ = 2m then t_w= 3ns and the footprint expands to 3.5km

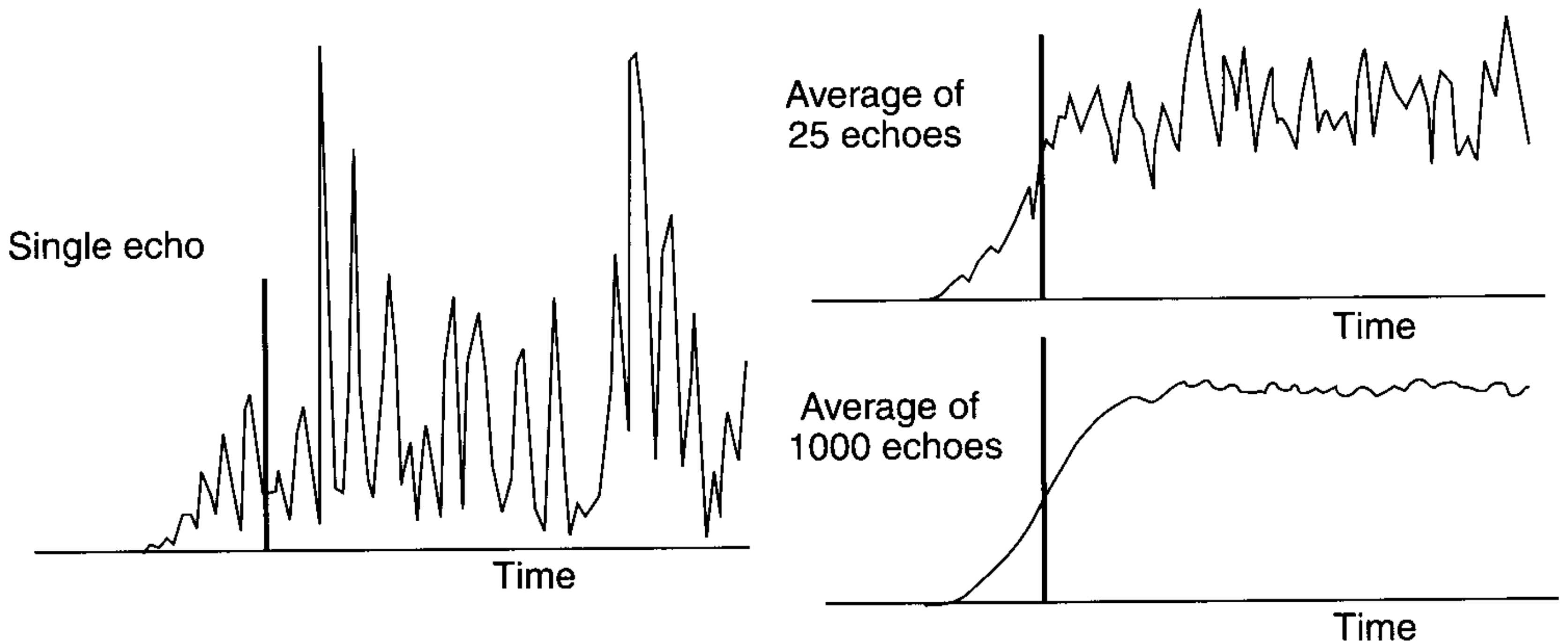
Additional issues

- **Need to average** To get 2cm accuracy when a single pulse only resolves ~ 1m we need to average 10^4 pulses (assumes random heights!). At 1700 pulses/sec this means we need to average ~ 5 sec. Because of the rate of travel of the satellite this means we cannot resolve features at finer than 25km resolution along-track!
- **Need to adjust gate timing** The pulses are tracked by electronic gates. Over land and ice the timing varies so much that Geosat and Topex altimeters lose lock on the pulses and must re-acquire ERS-1/2 altimeters are better able to track over land.

Effect of averaging radar pulses



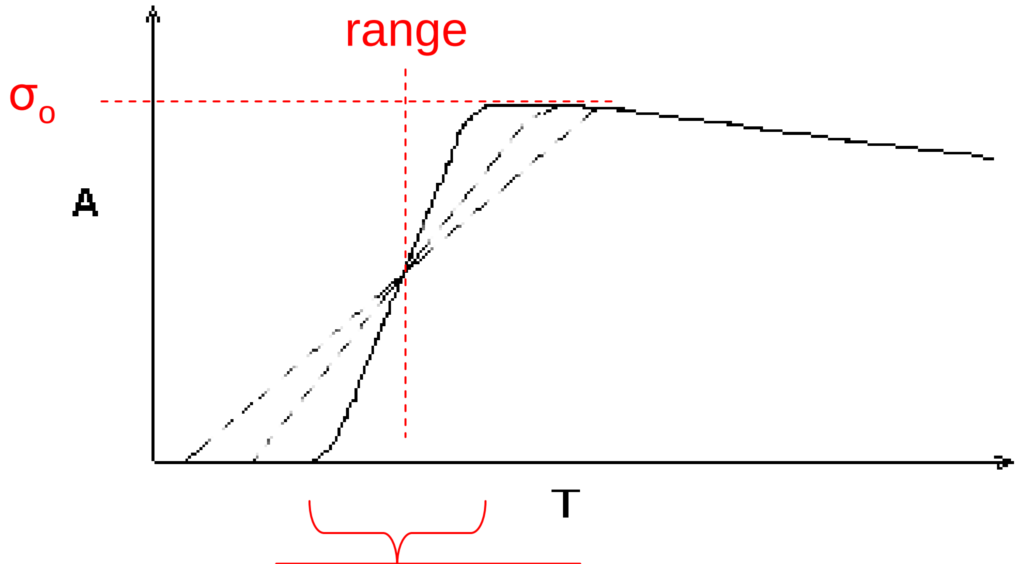
Stammer, "Observing the ocean using satellite altimeter data" unpublished


Single echo
Time
Average of
25 echoes
Time
Average of
1000 echoes
Time

IoE

Modeling radar returns

Empirical 3-parameter Brown model of pulse shape



$$t = \sqrt{t_p{}^2 + t_w{}^2}$$

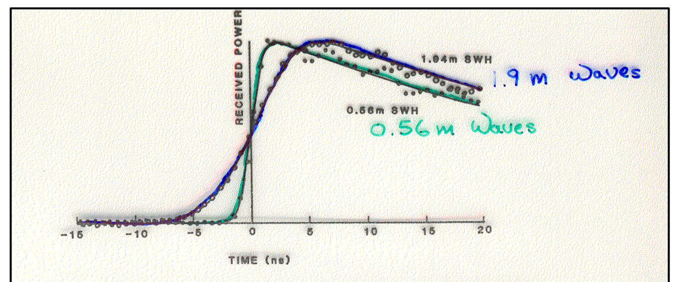
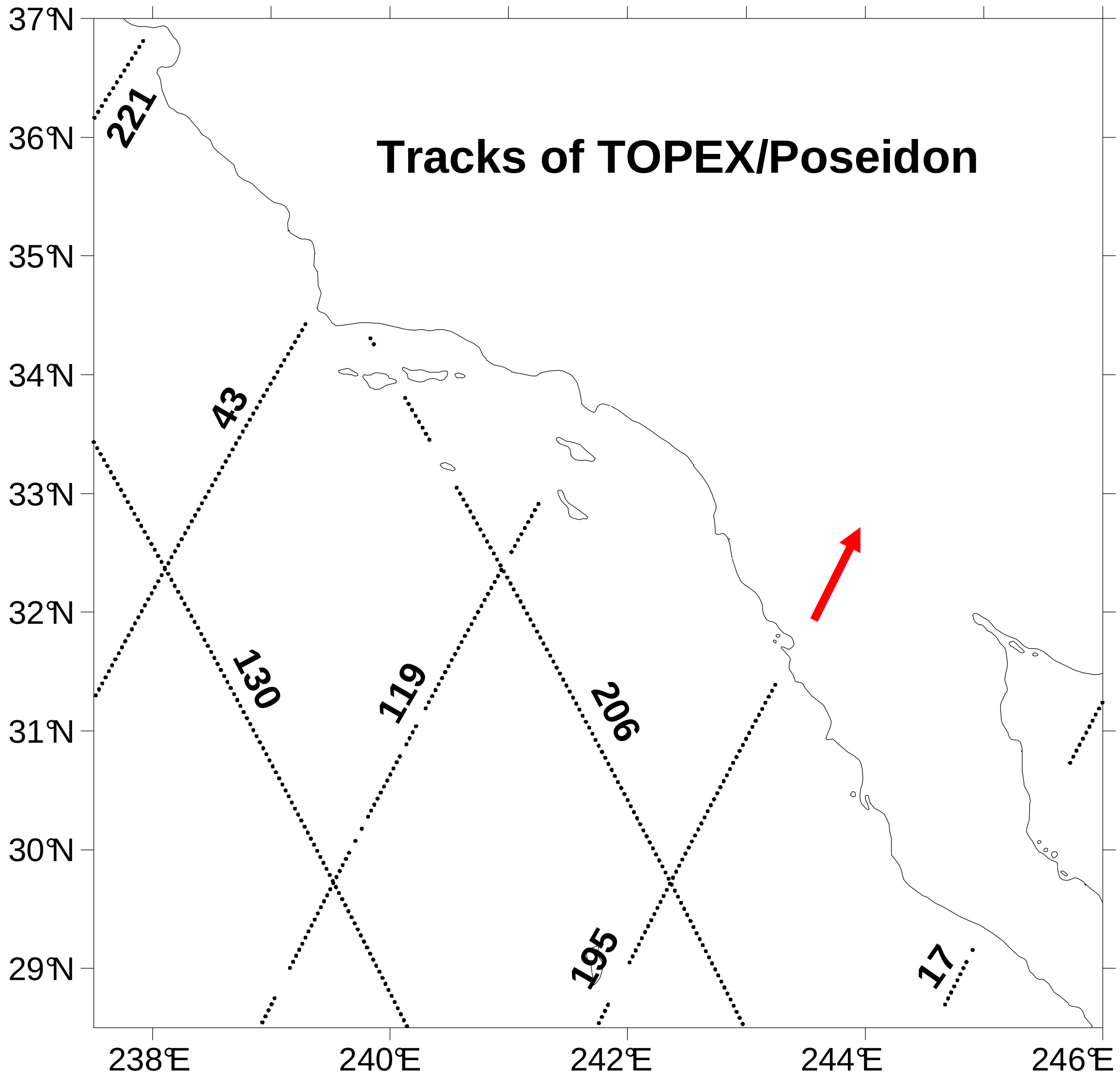


Fig. 9.2 – Smooth curves fitted through averaged altimeter pulse shapes corresponding to two different sea states. SWH = significant wave height. (From Walsh, Uliana, & Yaplee (1978))

Differences between ascending and descending tracks

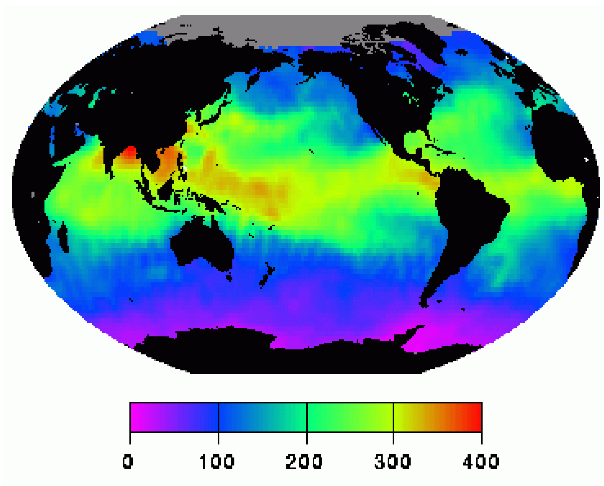


Measurement/geophysical errors

- **Sea State Bias:** troughs of the waves preferentially reflect back toward radar. Lowers estimated sea level by ~$0.05H_{1/3}$ leading to a 0.05 - 0.10 m bias
- **Ionospheric Delay** - electron plasma in the ionosphere slows radar pulses. Smallest at 6 AM largest at 12 noon. Dual frequency radars correct for this at > 50 km scales.
- **Dry Atmosphere** – dry atmosphere slows radar pulses (function of index of refraction. Typically ~2.3 m
- **Wet troposphere** – humidity further delays radar pulses. Typically ~0.06 - 0.30 m
- **Orbit Error** – lack of knowledge of the orbital position used to cause ~1m errors. Corrected for by use of repeat tracks and wavenumber filtering. With GPS tracking this error is now ~0.02m.

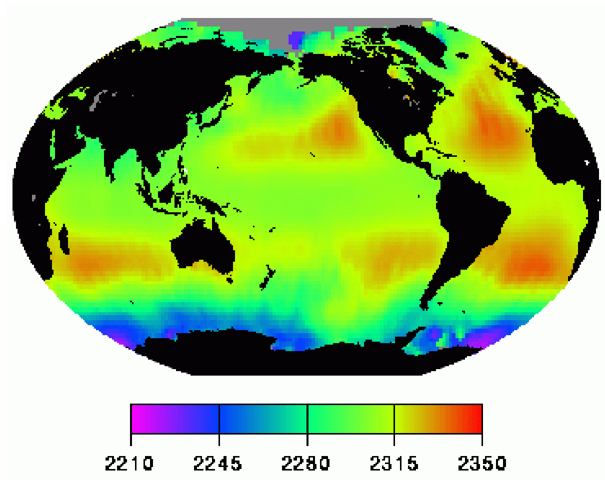
Geophysical corrections

Wet tropospheric water vapor correction

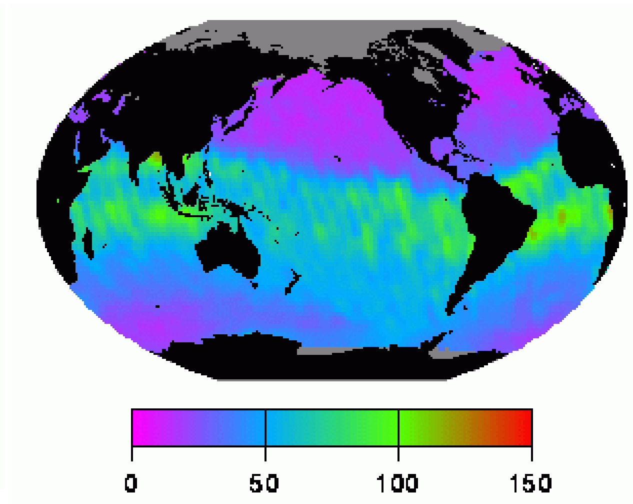


mm

Dry atmosphere correction

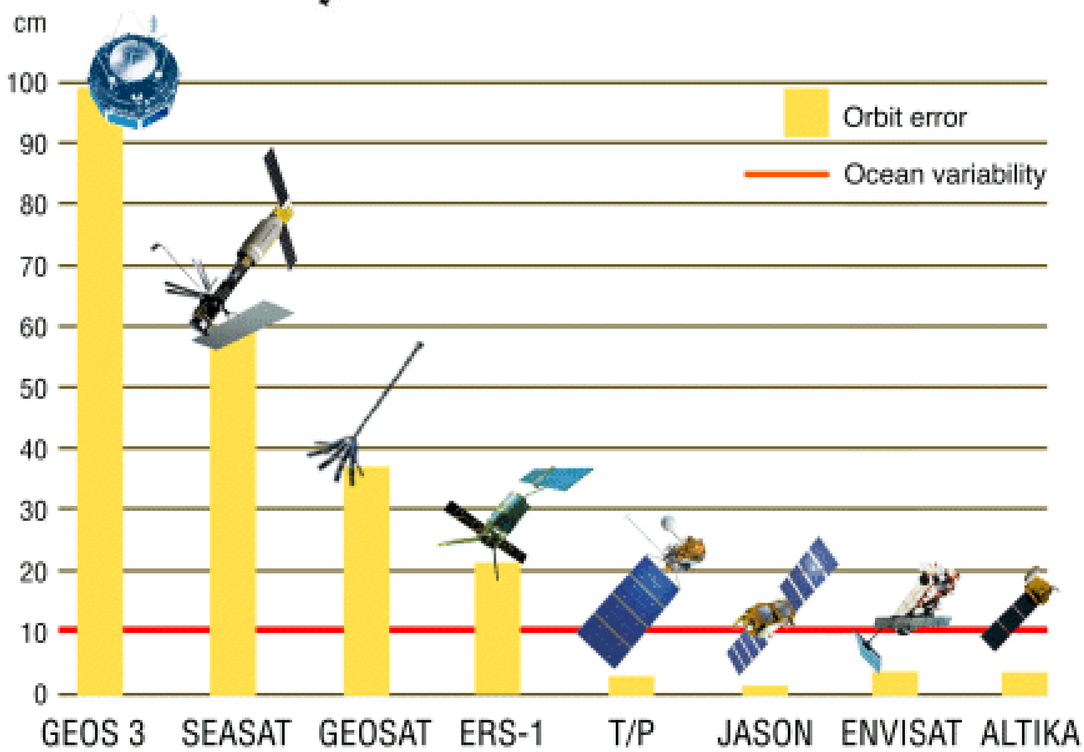


Ionospheric correction

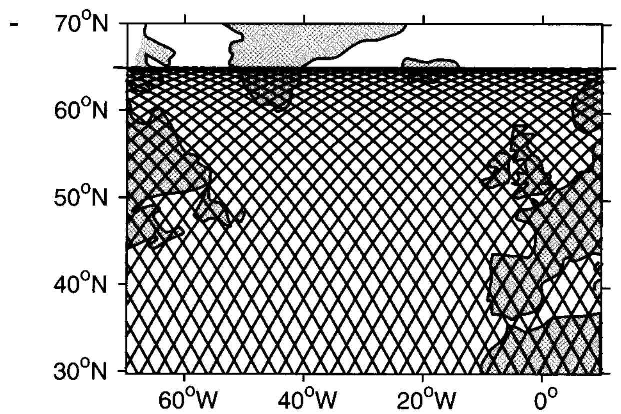


http://iliad.gsfc.nasa.gov/opf/algorithms/wet_geosat.html

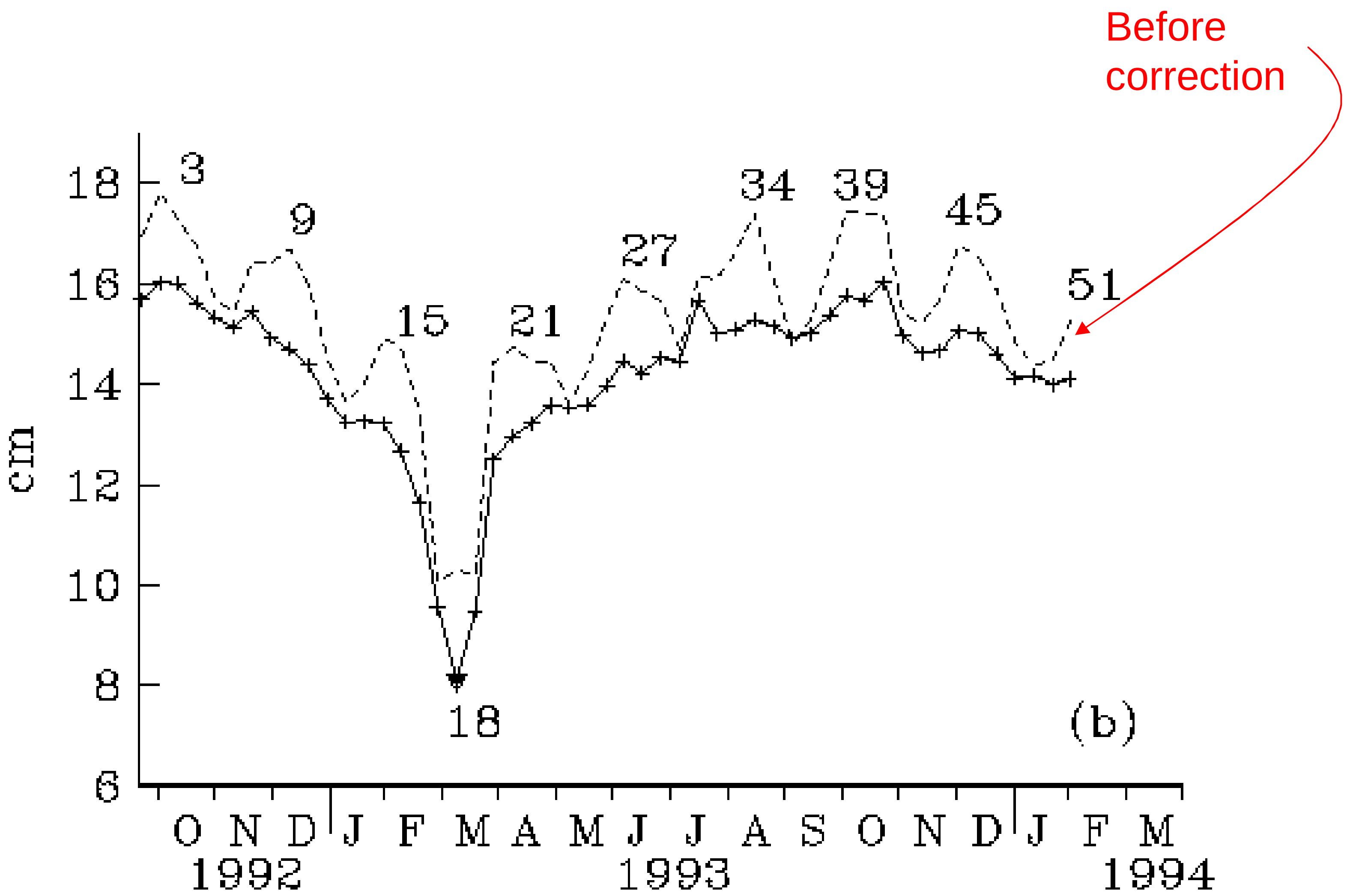
Orbit Error



10-dy T/P orbit tracks



Tidal aliasing



Cheney et al. (1994)

- PERIOD OF M_2 TIDE: $\frac{1}{.517}$ cy/day
- REPEAT PERIOD OF TOPEX: $\frac{1}{9.92}$ cy/day

ACTUAL SEA LEVEL HEIGHT

$$\eta(t) = \eta_0 \cos\left(\frac{2\pi}{.517} t\right)$$

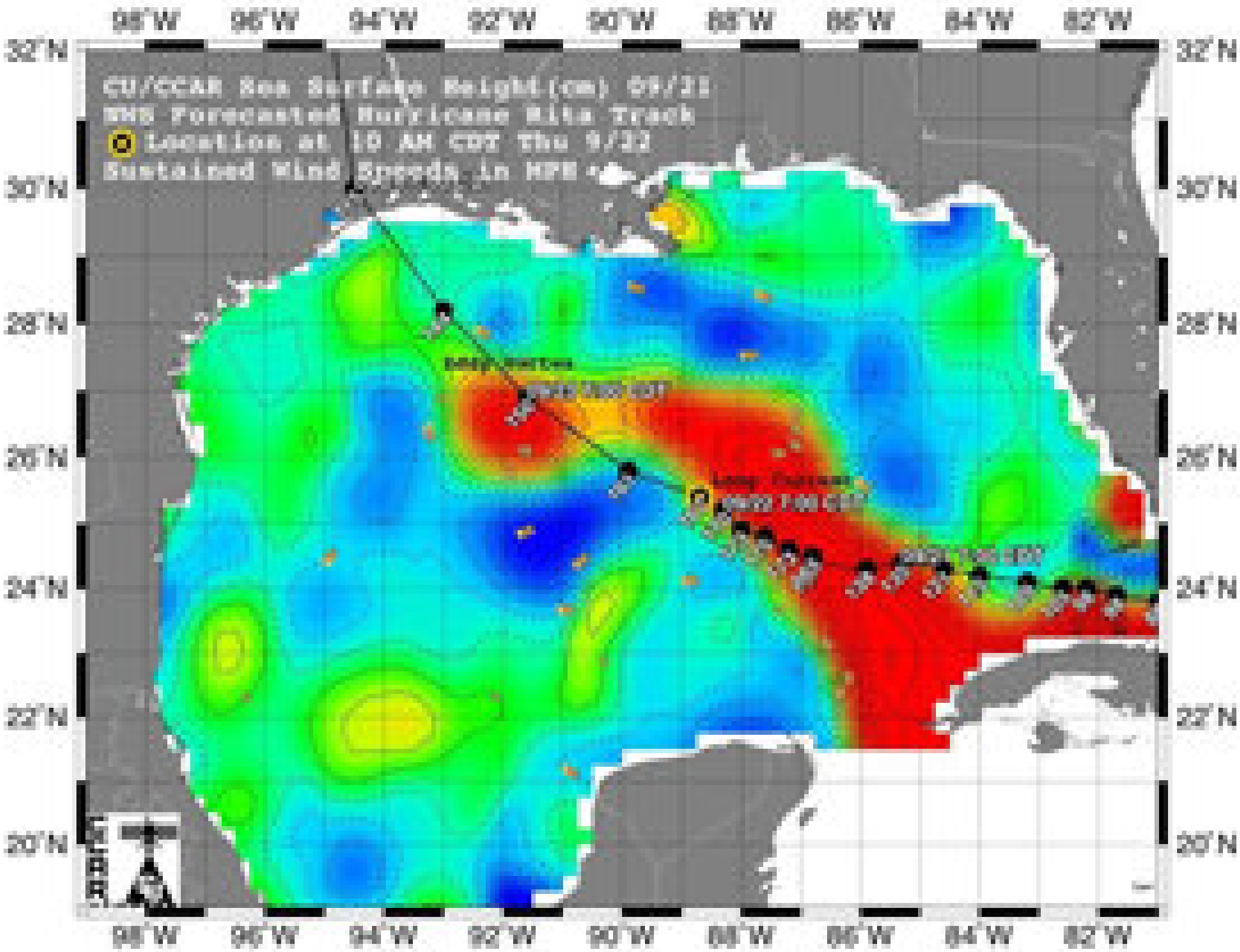
SAMPLED SEA LEVEL HEIGHT

$$\eta(i\Delta) = \eta_0 \cos\left(\frac{2\pi}{.517} i\Delta\right) \qquad \Delta = 9.92$$

$$= \eta_0 \cos(2\pi i \, 19.19) = \eta_0 \cos(2\pi .187 i + 2\pi \, 19 i)$$

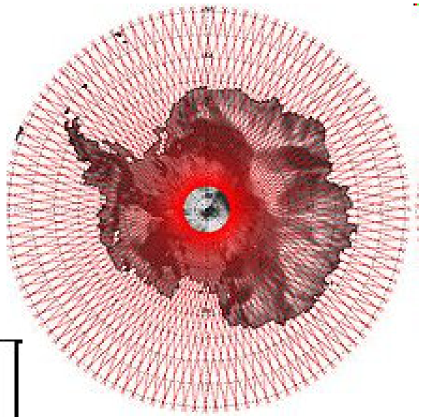
$$= \eta_0 \cos\left(\frac{2\pi}{5.33} i\right)$$

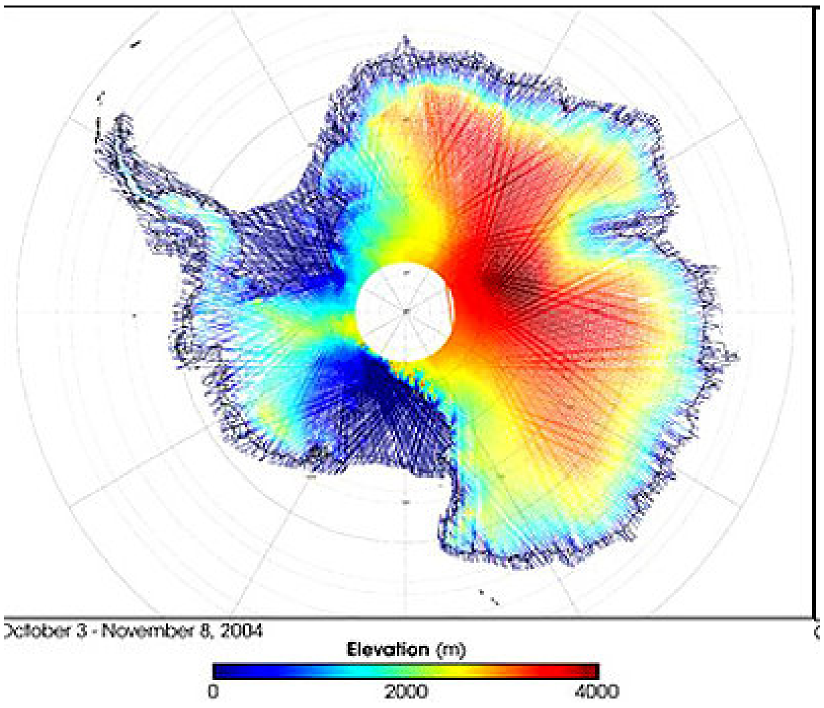
ALIASING PERIOD: 5.33×9.92 = 53 DAYS


CU/CCAR Sea Surface Height(cm) 09/21
NWS Forecasted Hurricane Rita Track
Location at 10 AM CDT Thu 9/22
Sustained Wind Speeds in MPH
98°W
96°W
94°W
92°W
90°W
88°W
86°W
84°W
82°W
32°N
30°N
28°N
26°N
24°N
22°N
20°N

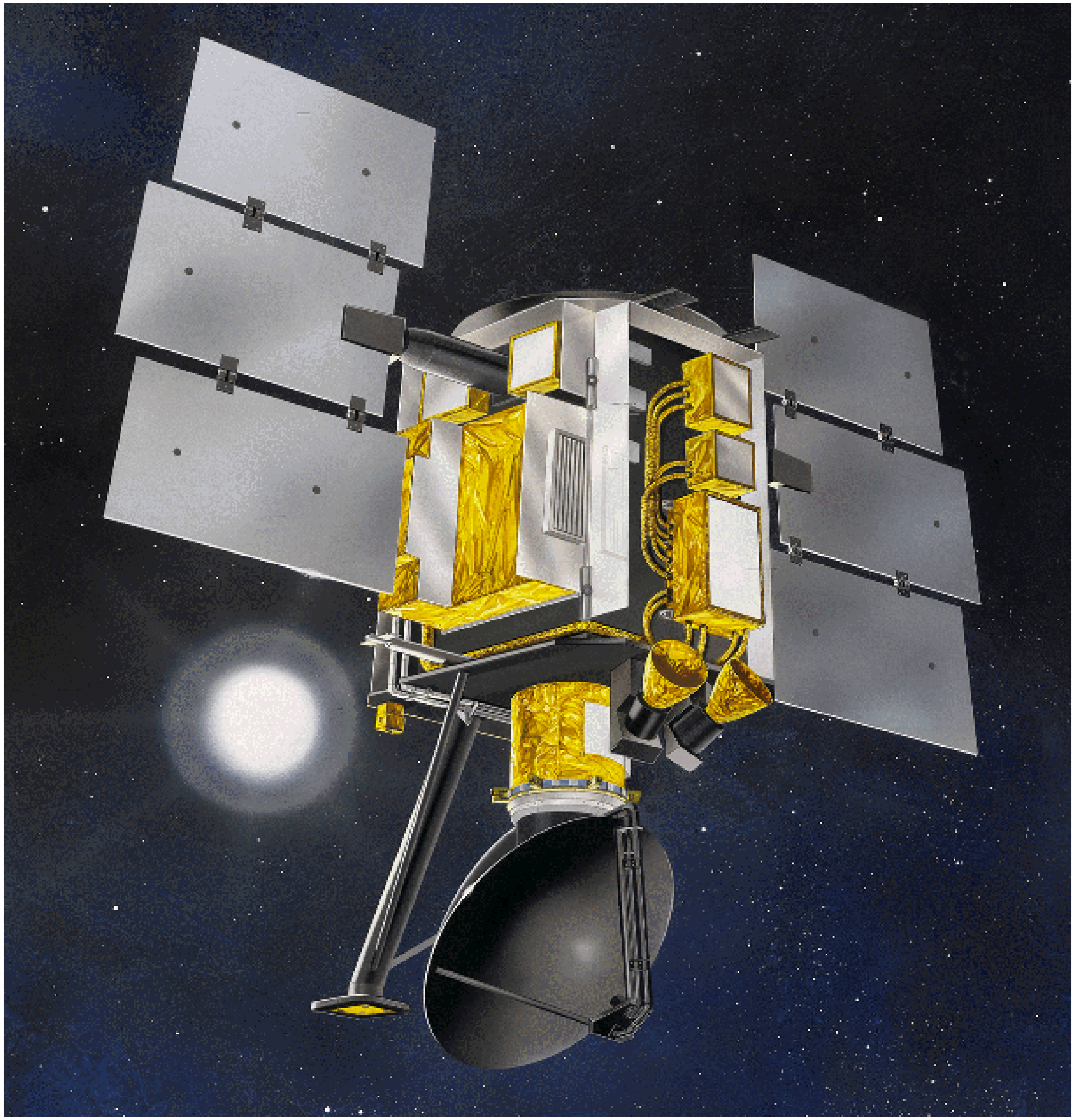
Icesat (2003-2010)
(laser beam-limited altimeter)

Altitude: 705km
Orbit: near-polar
Footprint: 70 m
Separation between footprints: 170m





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.

Scatterometry: exploiting σ_o

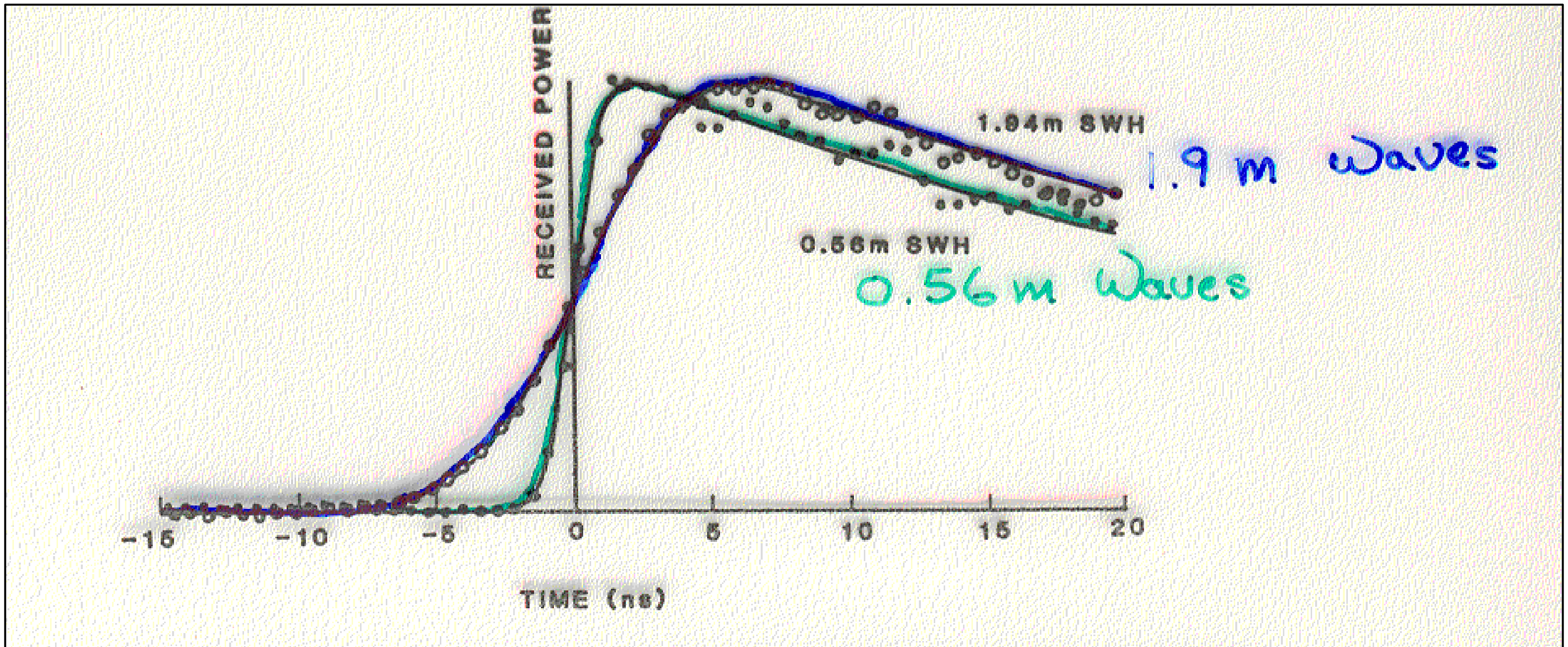
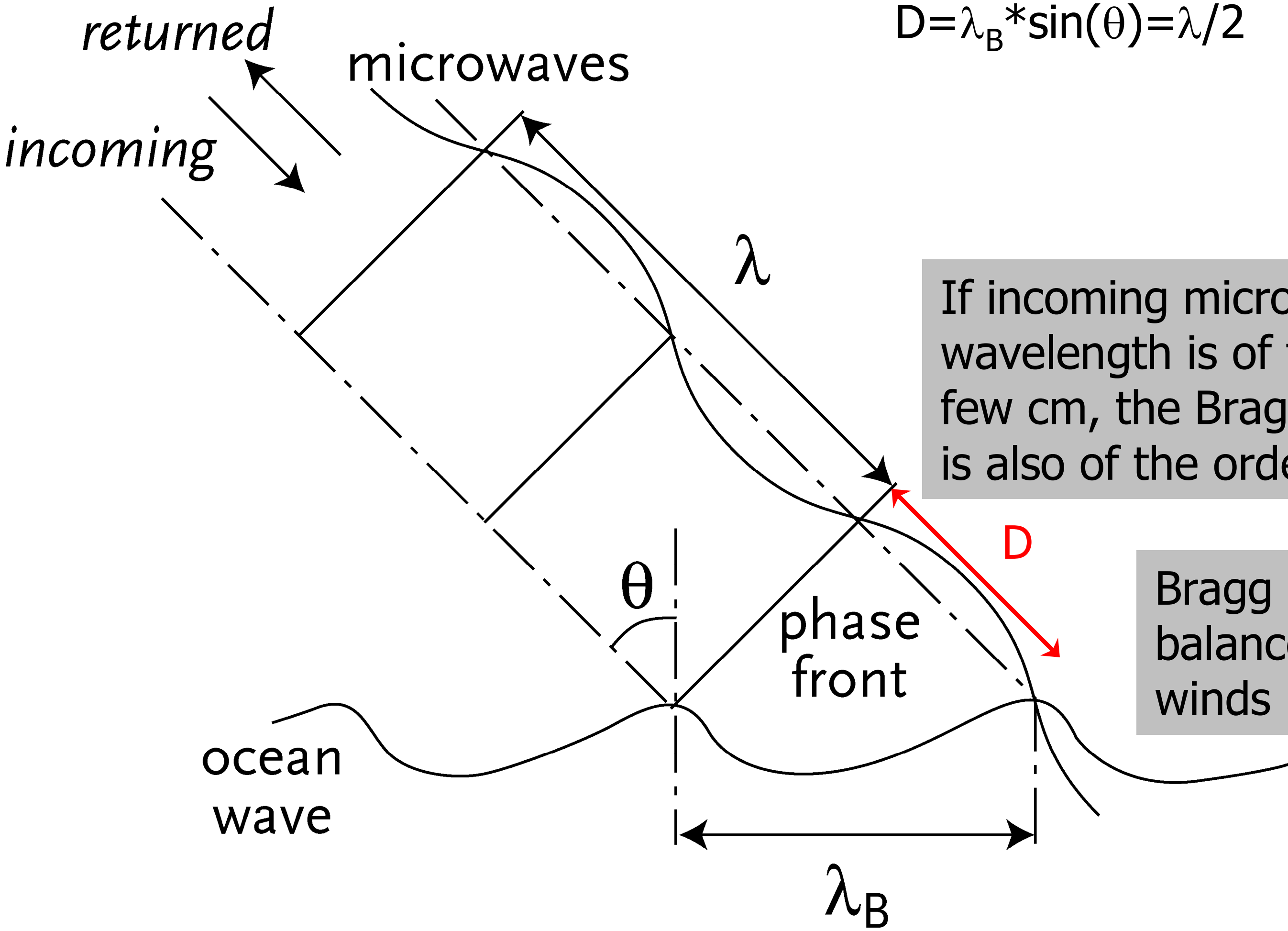


Fig. 9.2 – Smooth curves fitted through averaged altimeter pulse shapes corresponding to two different sea states. SWH = significant wave height. (From Walsh, Uliana, & Yaplee (1978))

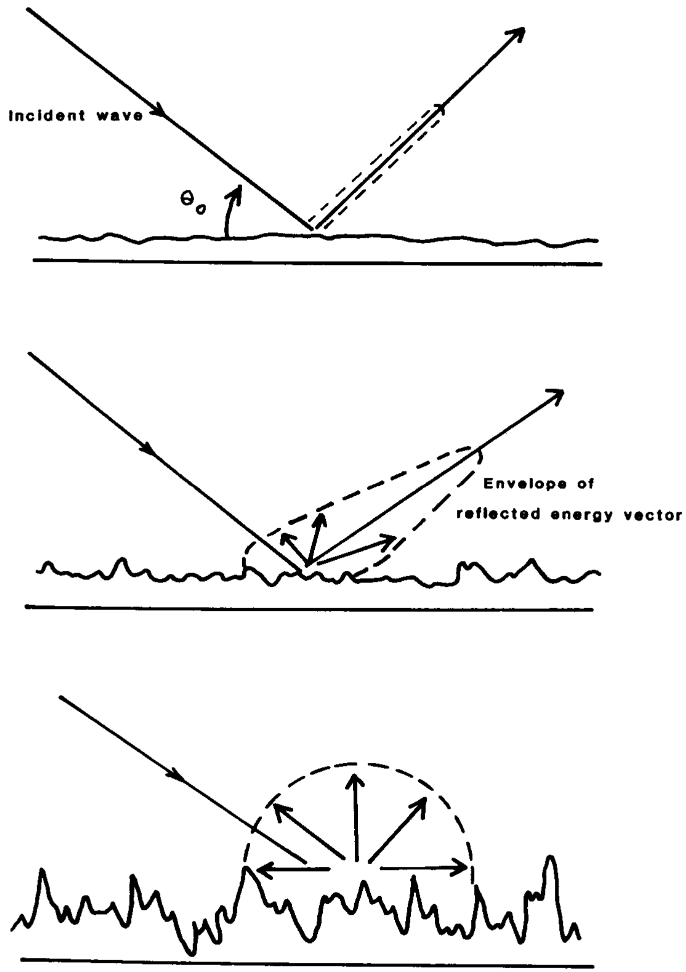
$D = \lambda_B * \sin(\theta) = \lambda/2$



If incoming microwave wavelength is of the order of a few cm, the Bragg wavelength is also of the order of a few cm

Bragg waves are in balance with local winds

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.

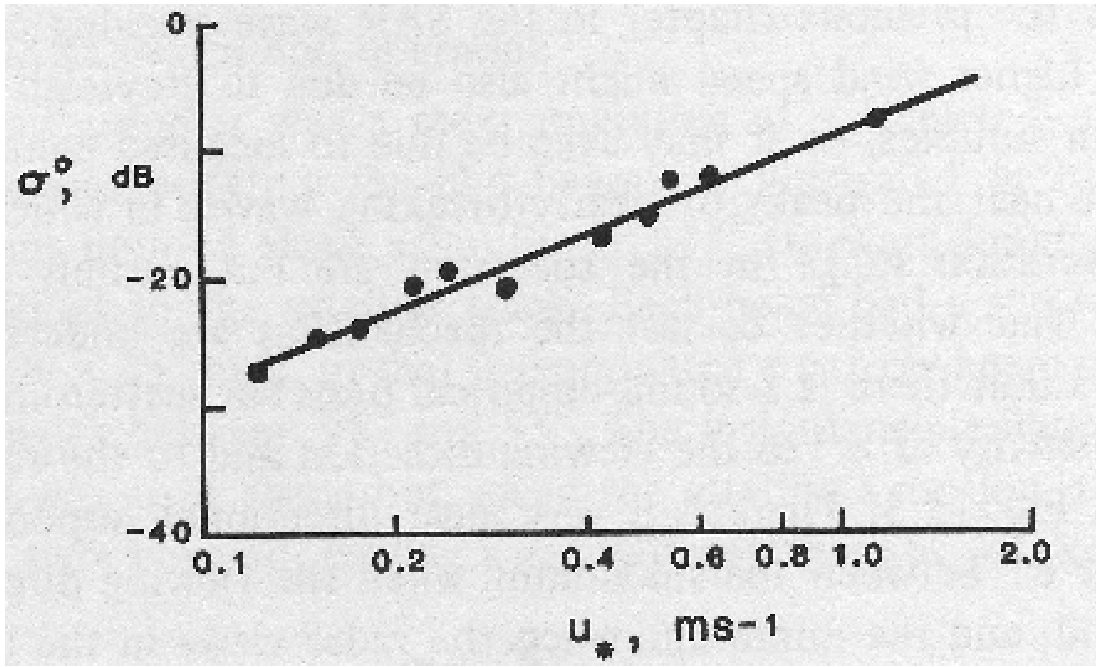


Microwave scatterometer is based on the principle of the resonant Bragg scattering.

For a smooth surface, oblique viewing of the surface with active radar yields virtually no return. If the surface is rough, significant backscatter occurs.

IoE

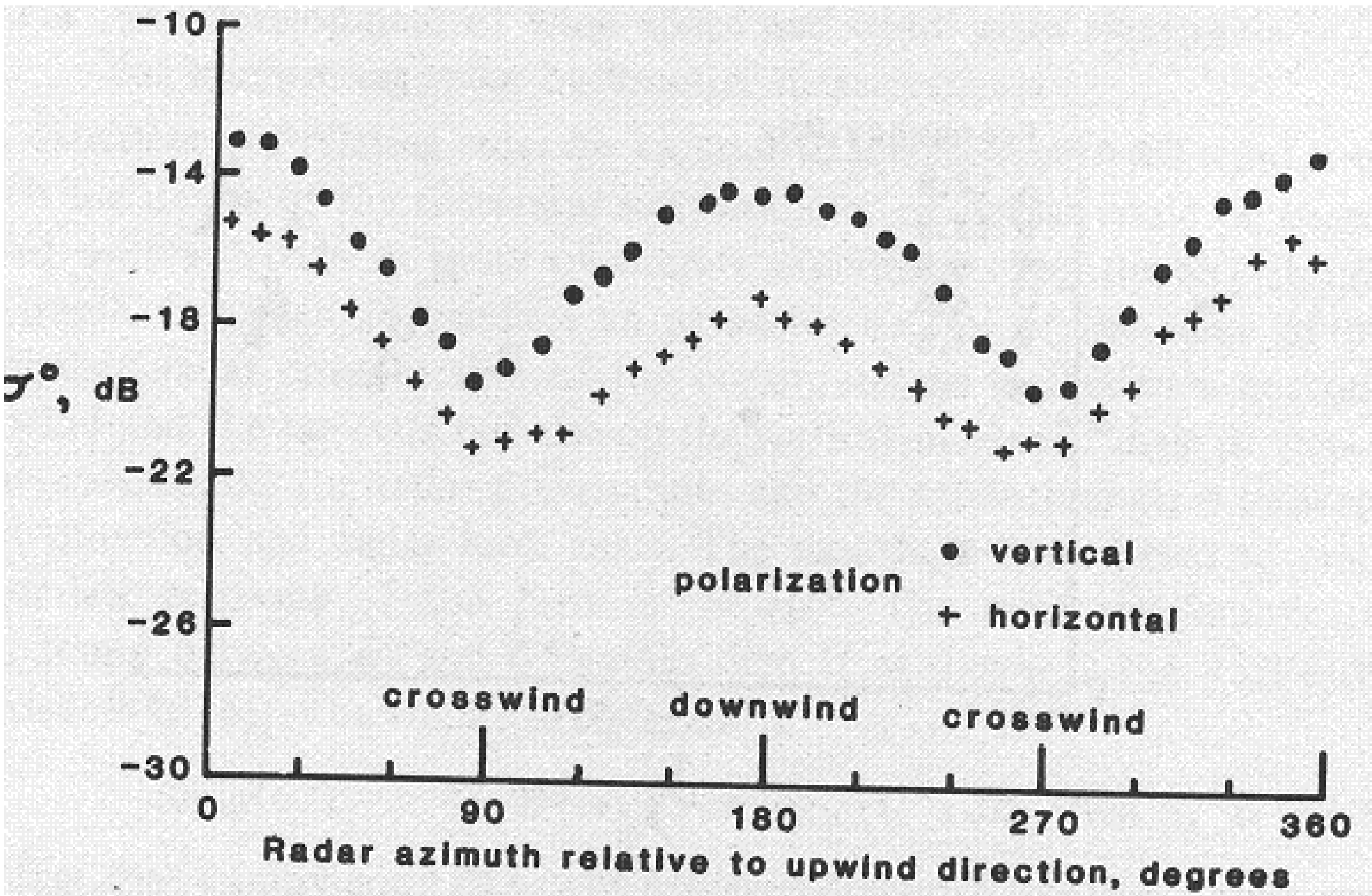
Geophysical model functions



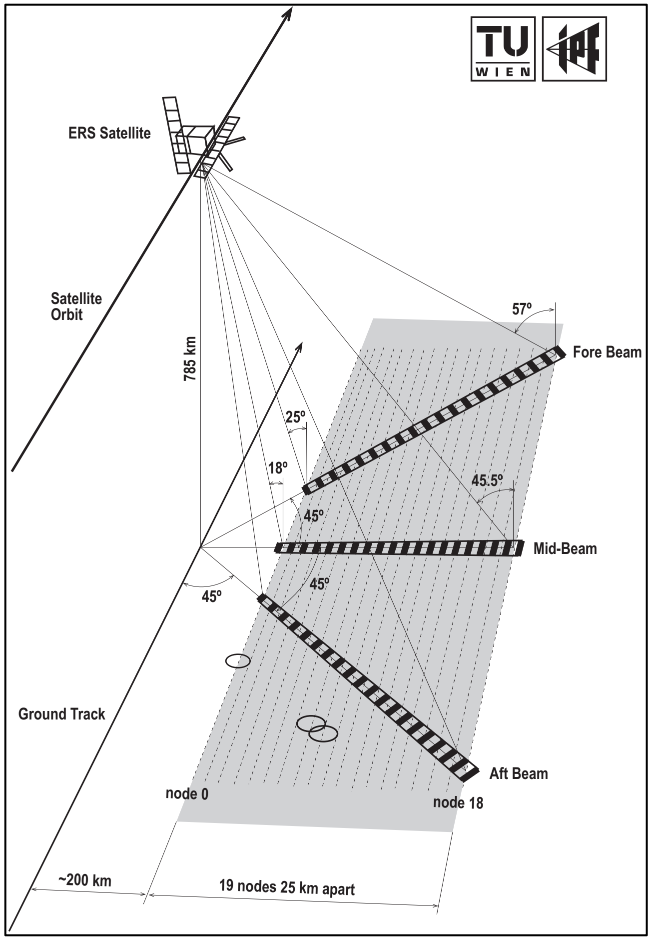
$$\log_{10}(\sigma^{o}) = -48.59027 + 19.9658 \log_{10} u^{*} \text{ dB.}$$

where $\tau = \rho U^{*2}$

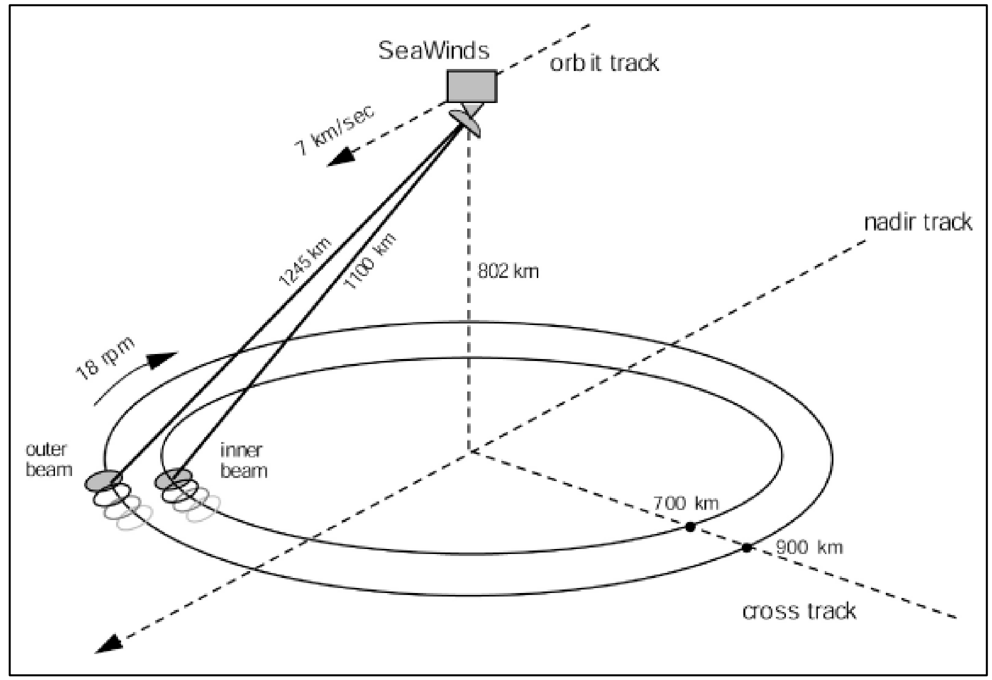
Dependence of σ_o on viewing angle and polarization



ERS1/2 and QuikSCAT designs

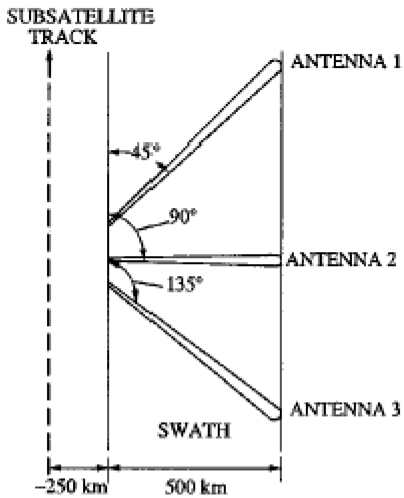


C-band (5GHz) ERS1/2

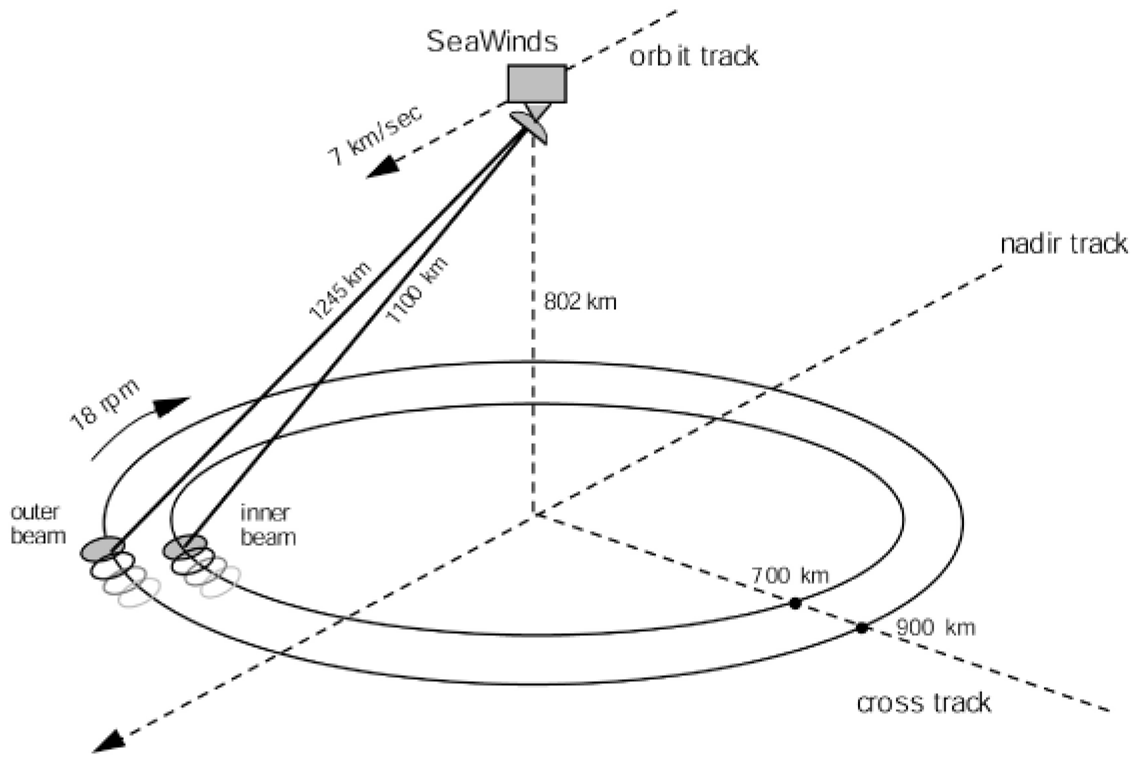


Ku-band (14GHz) QuikSCAT

Scatterometer wind direction retrieval



Discrete angular beams



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

Differences between ERS1/2 and QSCAT

Random error

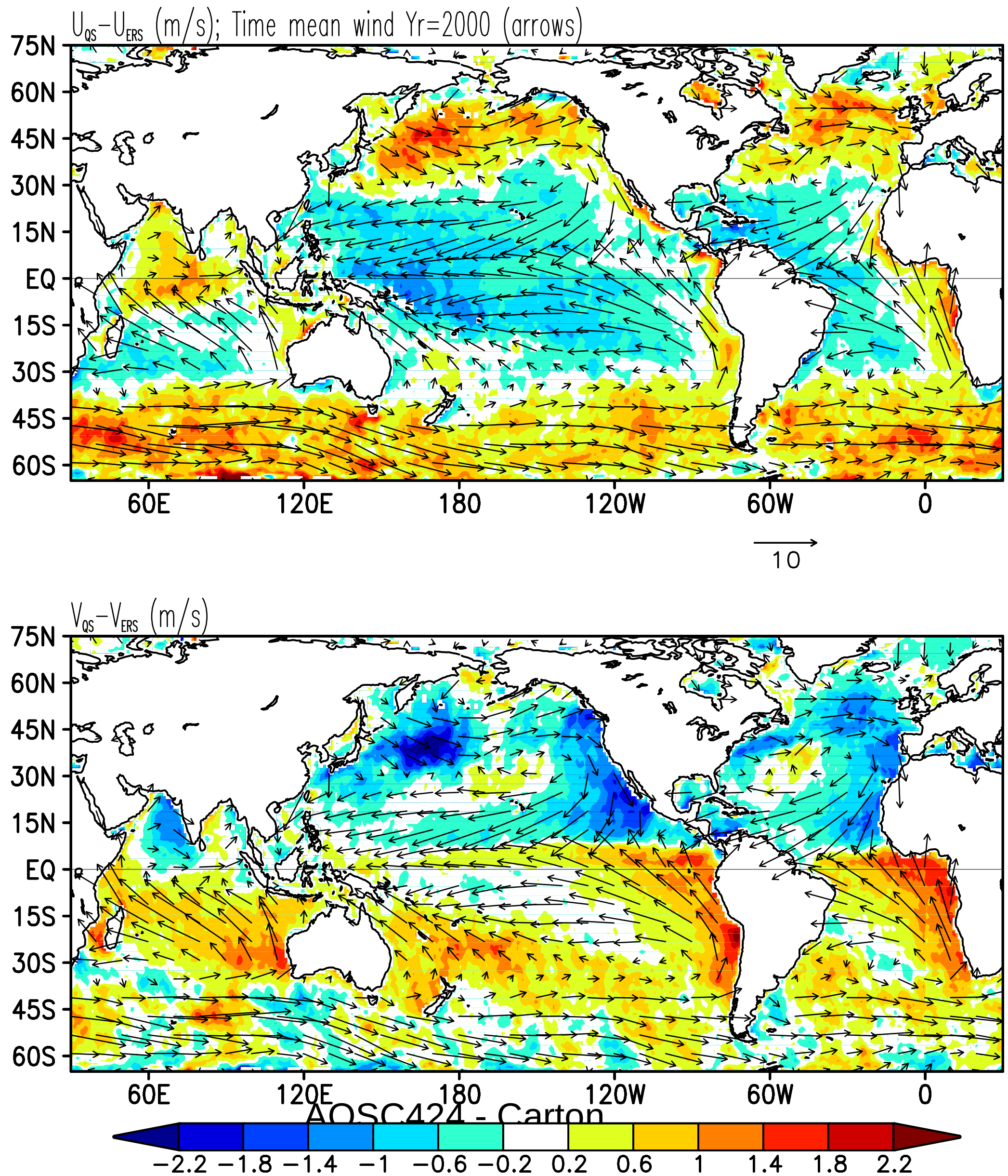
Speed ±2m/s

Direction: ±20º

Altitude: 803 km

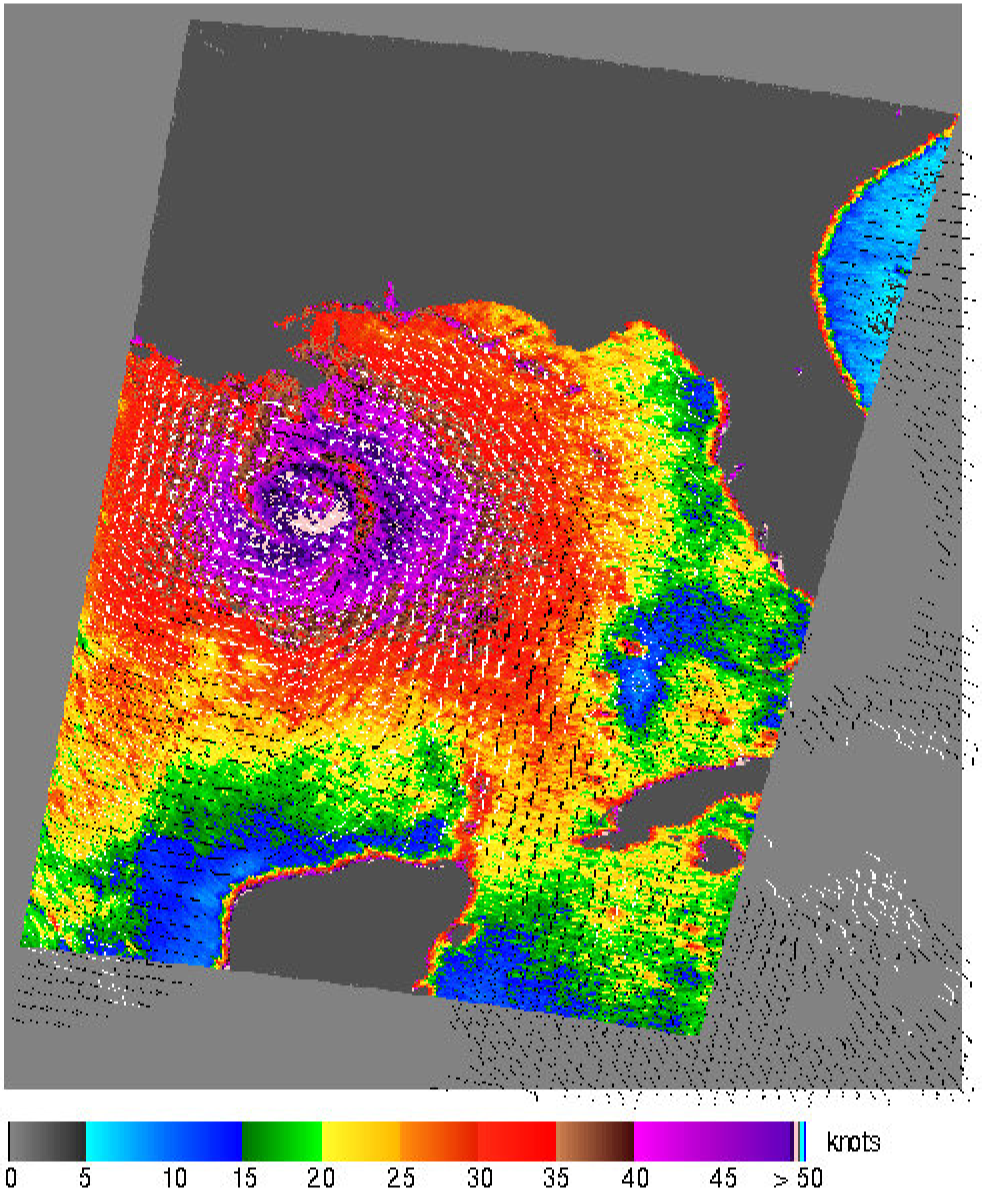
Footprint: 25km Swath width: 1,800 km

Coverage: 90% of Earth's surface in one day,

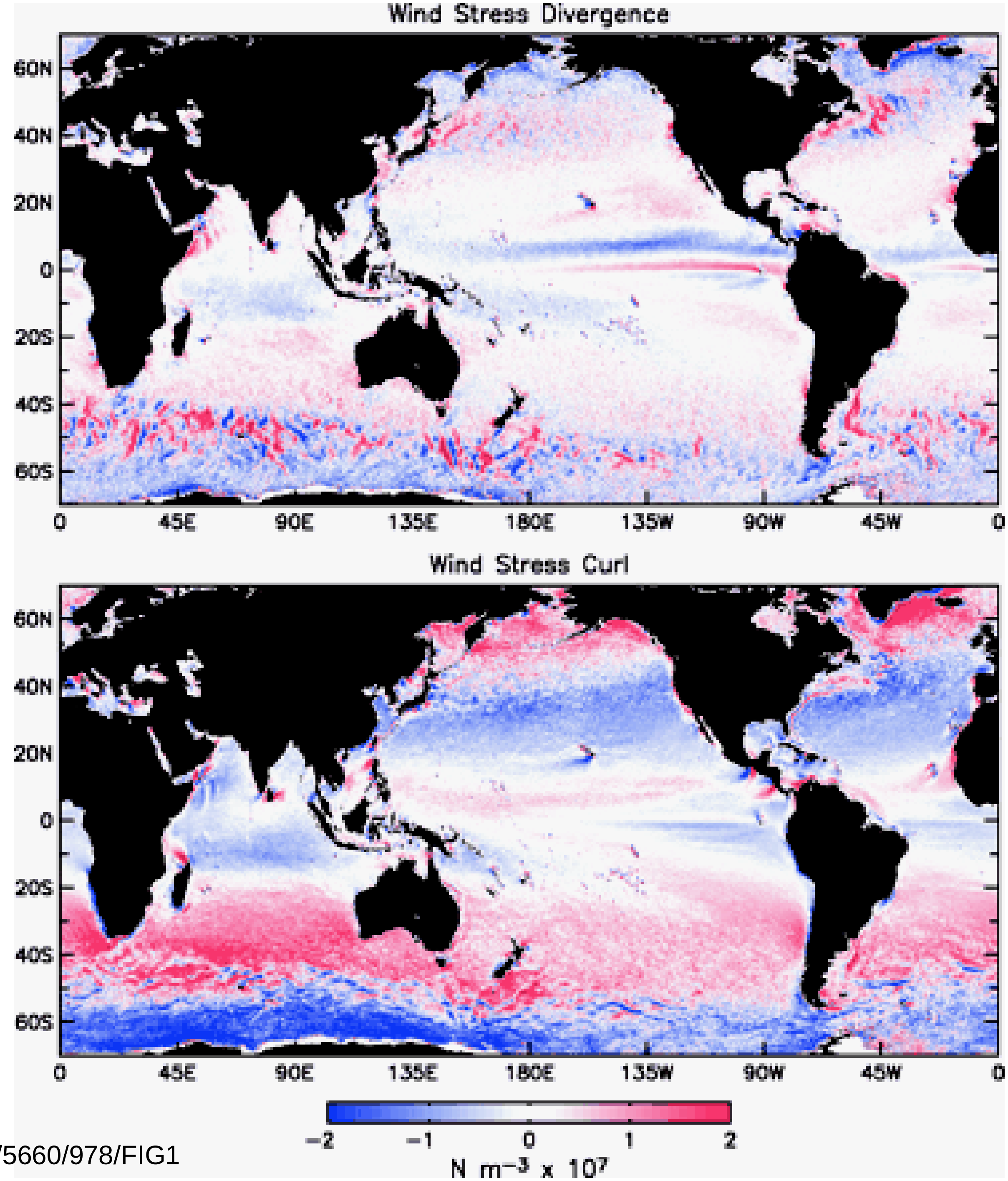


Katrina
(Category 4)

QuikSCAT winds 8-29 at landfall.

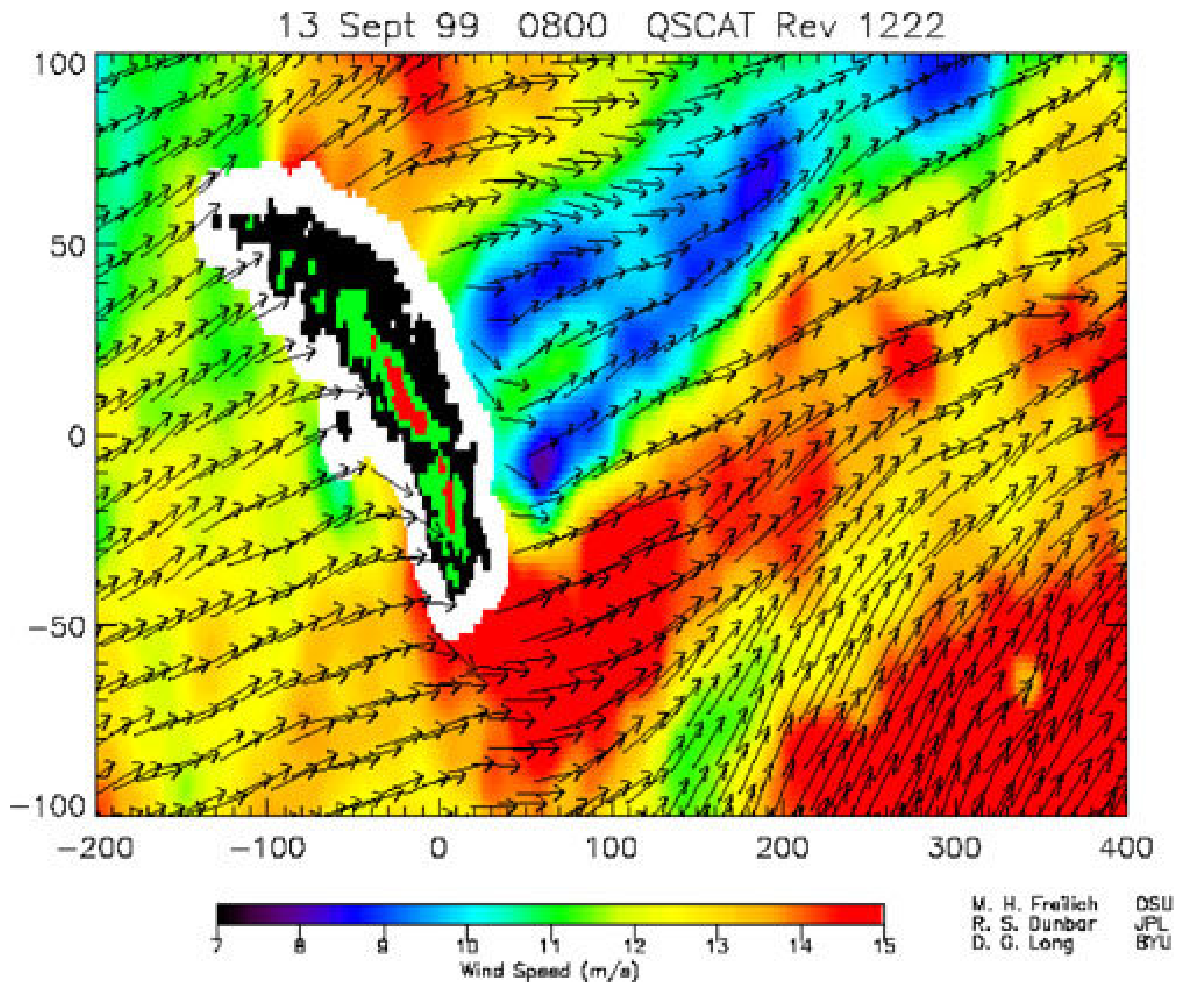


4-year mean Divergence and curl



Chelton et al, Science, 2004:
http://www.sciencemag.org/cgi/content/full/303/5660/978/FIG1

Detail in the South Atlantic

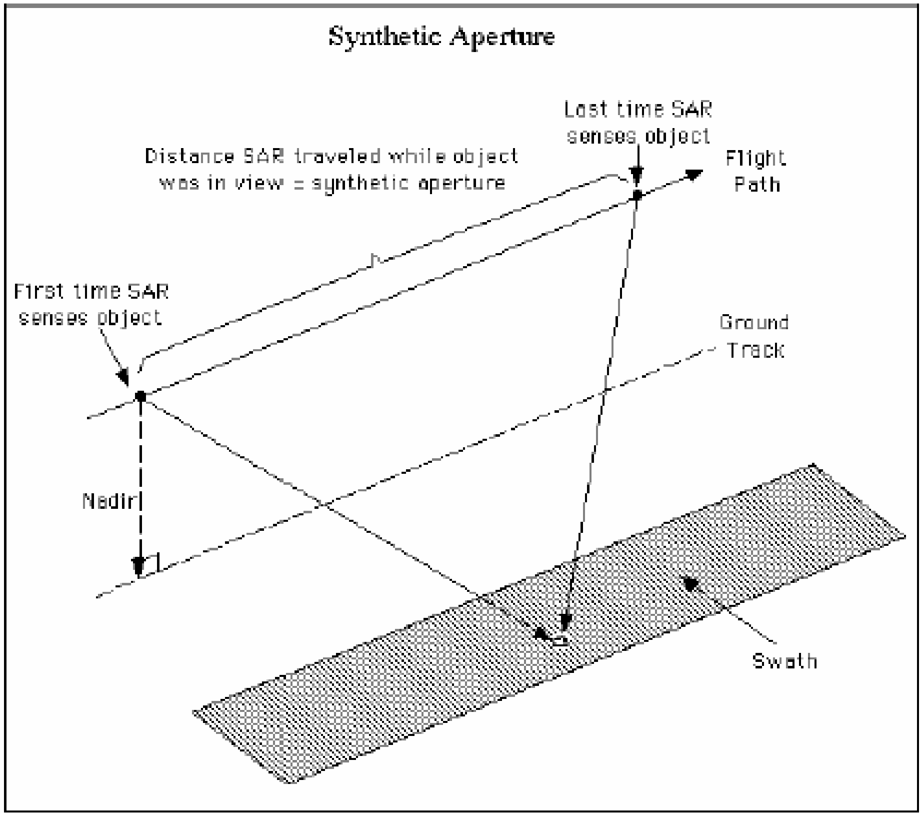


Winds around South Georgia showing island effects

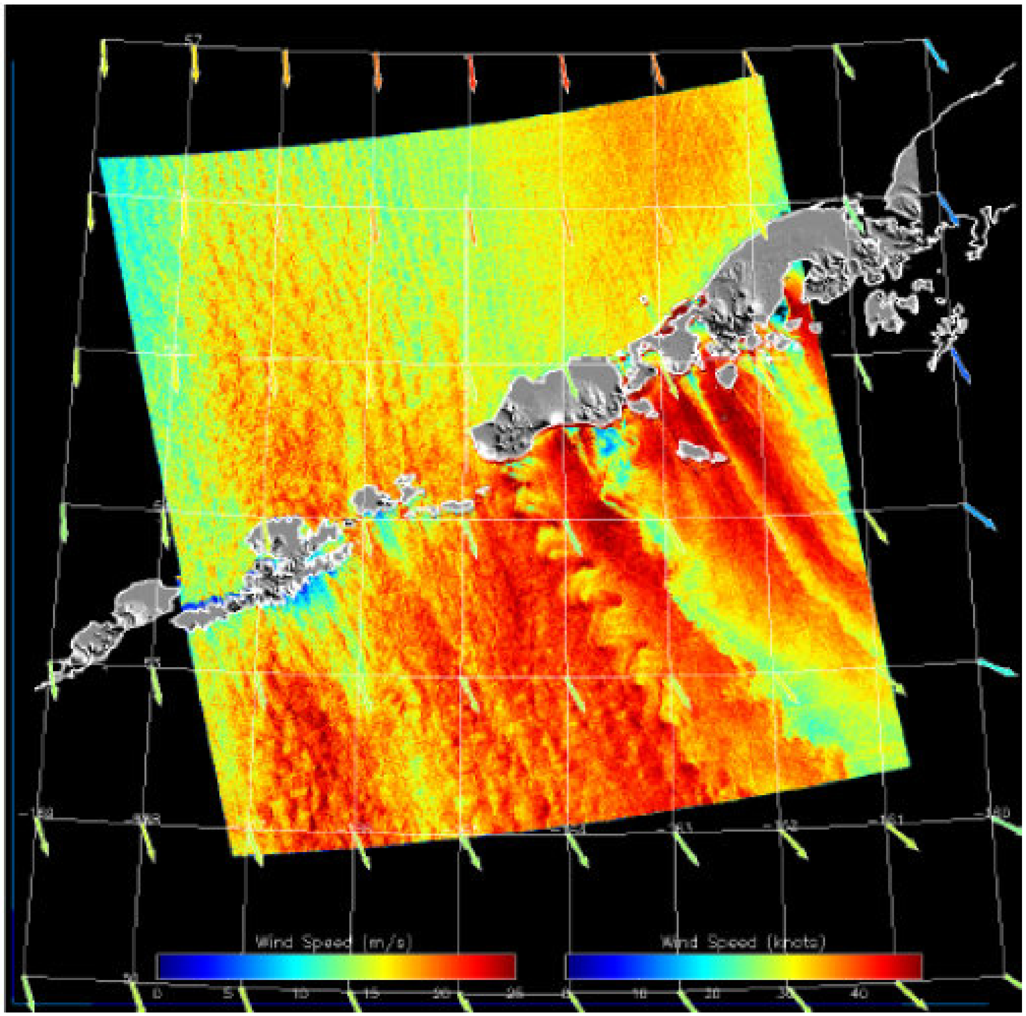
Synthetic Aperture RADAR

exploits the different doppler freq associated with different angles

- For 5.3 GHz (C-Band) use of SAR reduces effective resolution from 30 km to 9m.

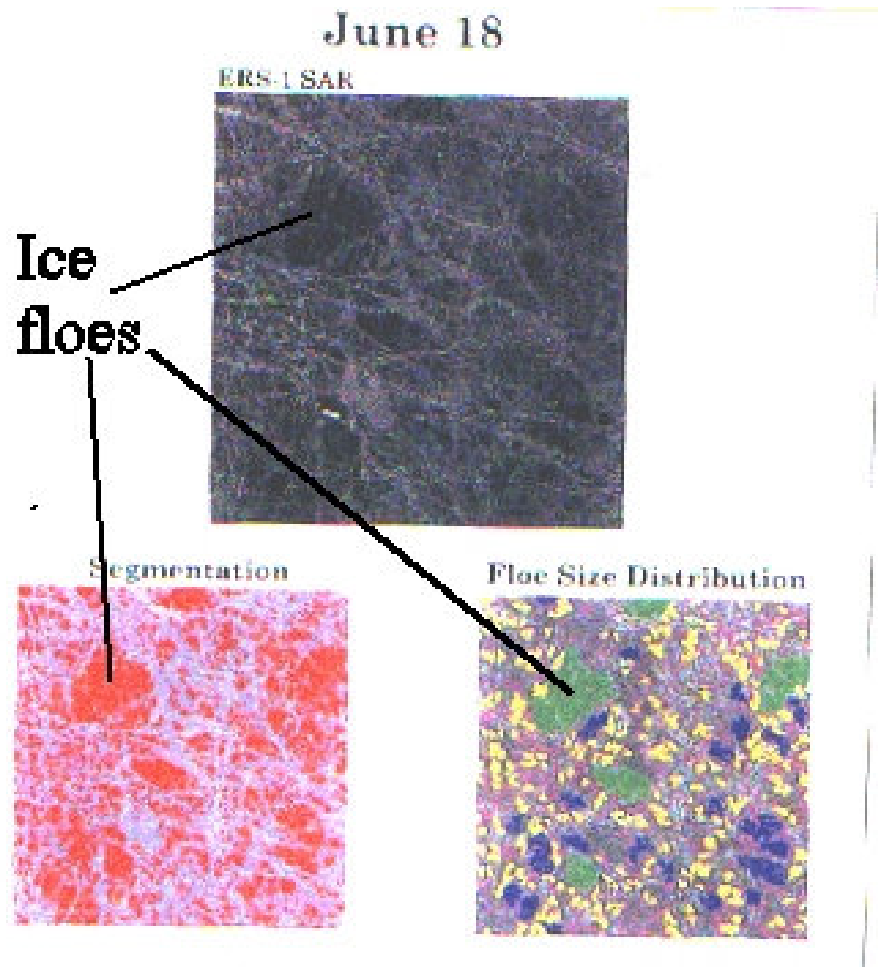


http://www.atlsci.com/library/sar_theory.html


Wind Speed (m/s)
0
5
10
15
20
25
Wind Speed (knots)
10
20
40

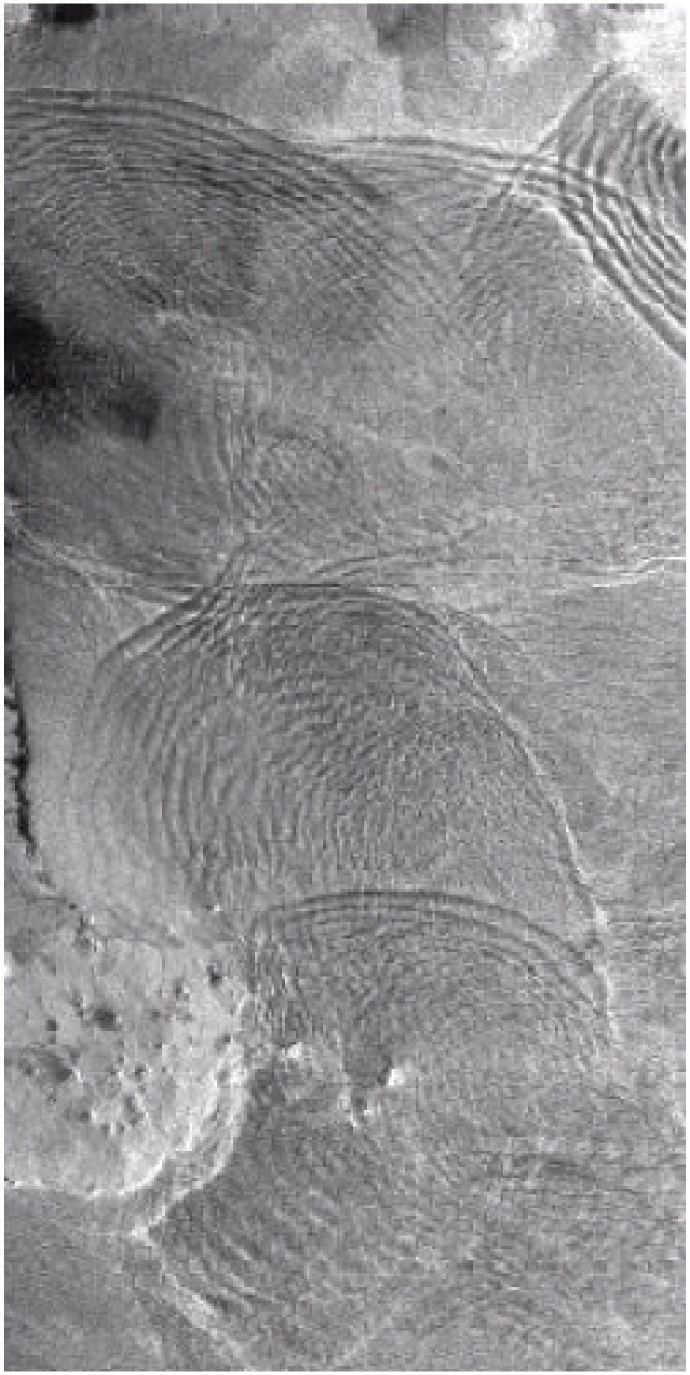
Ice flow detection with SAR

- Ice floes appear darker due to the presence of a layer of melt water overlying the ice surface
- The presence of this water layer decreases backscatter toward the radar system, resulting in a darker appearance



Slide curtesy: Ken Pryor
NOAA/NESDIS/STAR

Internal tide fronts



References

- Lee-Lueng Fu (Editor), Anny Cazenave, *Satellite Altimetry and Earth Sciences: A Handbook of Techniques and Applications*, 2000
- 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.