Altimetric Observations of Midlatitude and Equatorial Rossby Waves

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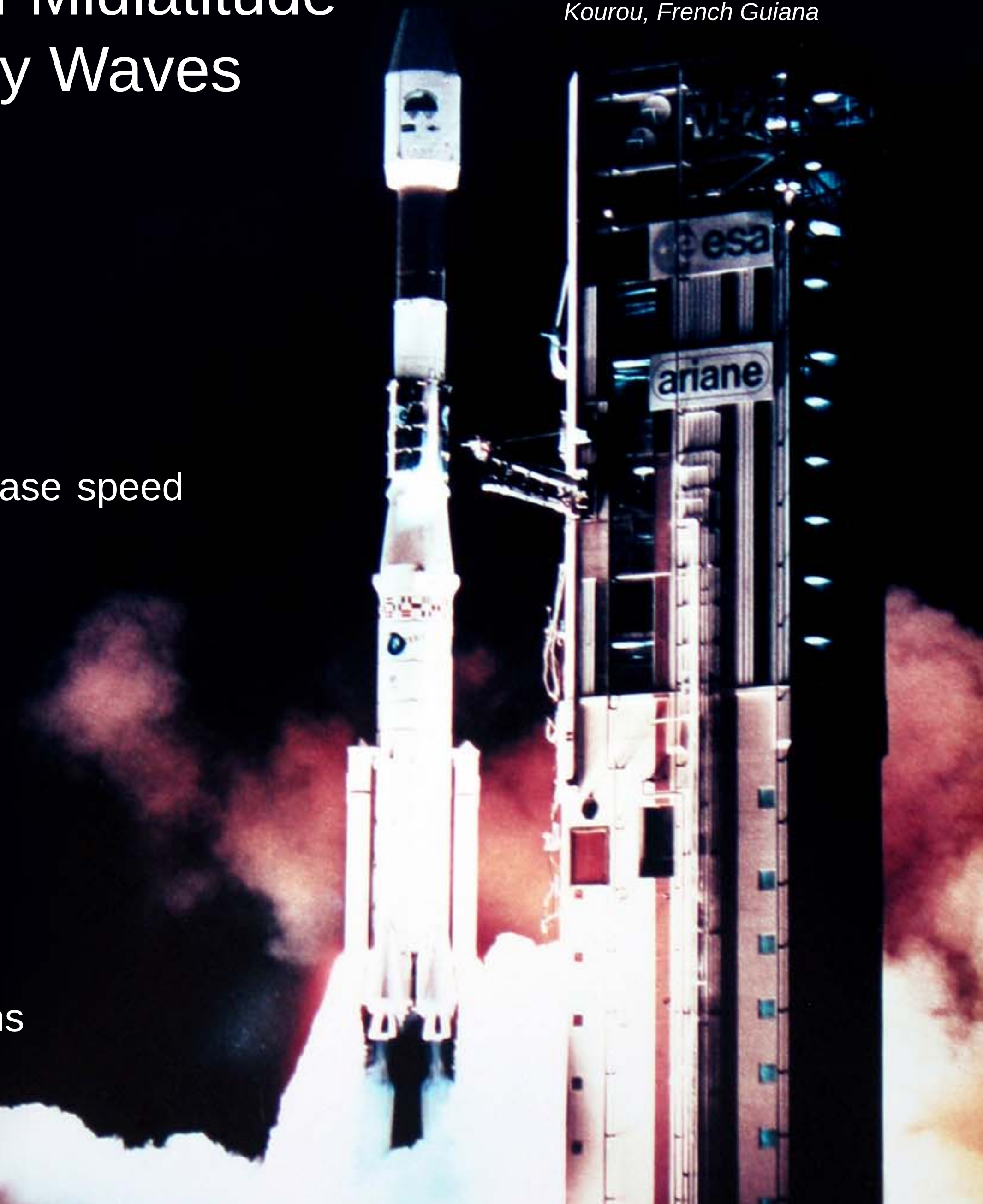
Oregon State University

TOPEX/POSEIDON Launch
10 August 1992
Kourou, French Guiana



Overview:

- Historical estimates of westward phase speed
- Equatorial Rossby waves
  - phase speeds
  - latitudinal structures
- Midlatitude Rossby waves
  - phase speeds
  - dispersion
  - other features
- Outstanding Issues and Conclusions

Aurora Borealis
Over Northern Canada
15 November 2003

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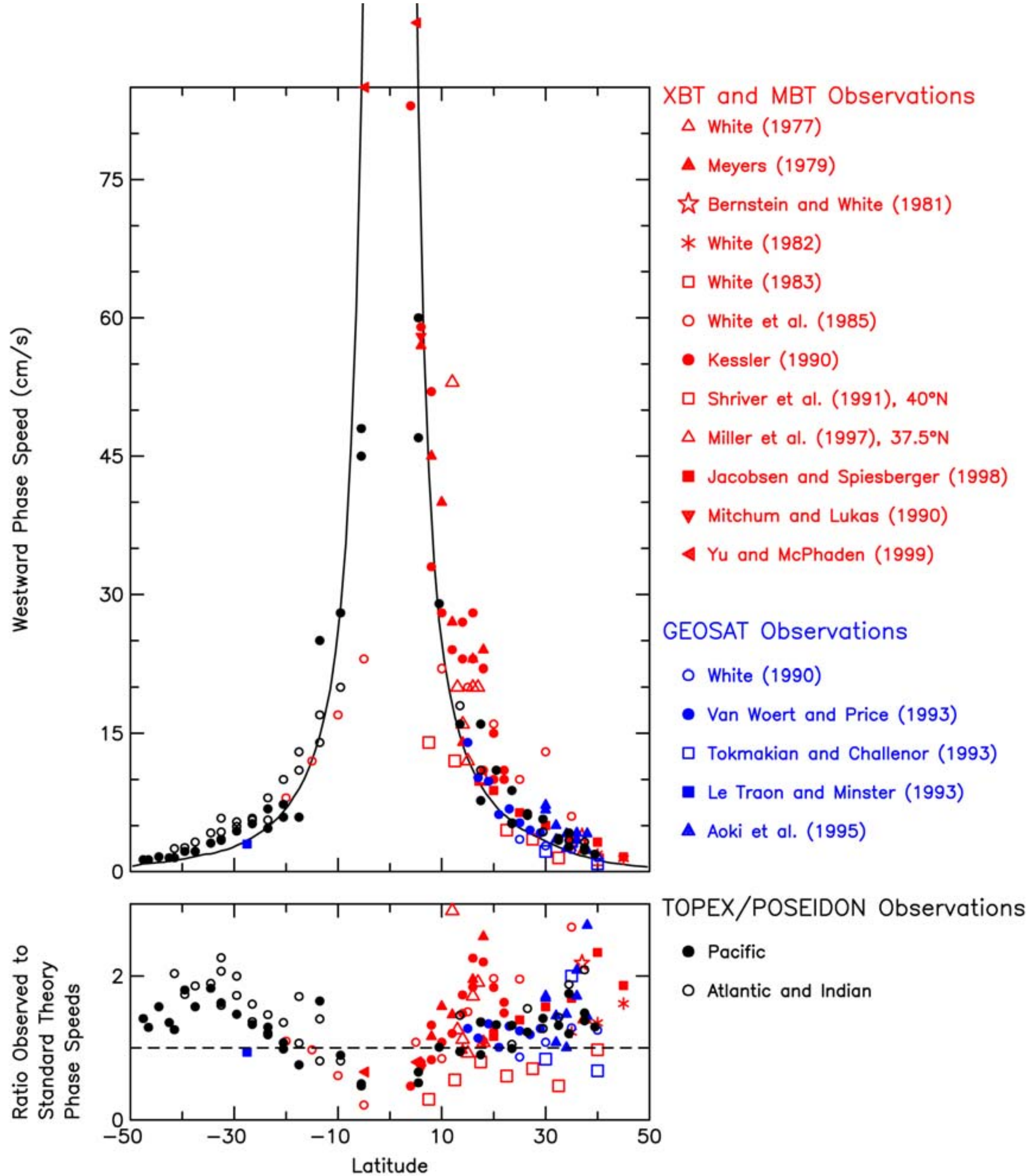
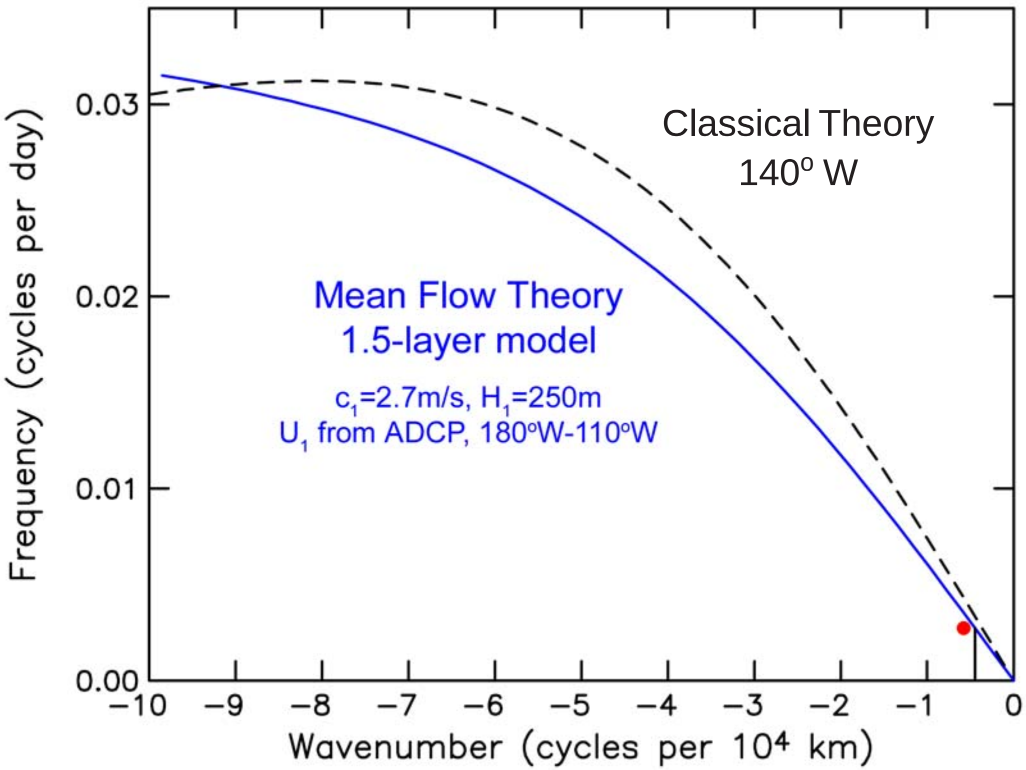


Westward Phase Speed (cm/s)
Ratio Observed to Standard Theory Phase Speeds
Latitude
XBT and MBT Observations
White (1977)
Meyers (1979)
Bernstein and White (1981)
White (1982)
White (1983)
White et al. (1985)
Kessler (1990)
Shriver et al. (1991), 40°N
Miller et al. (1997), 37.5°N
Jacobsen and Spiesberger (1998)
Mitchum and Lukas (1990)
Yu and McPhaden (1999)
GEOSAT Observations
White (1990)
Van Woert and Price (1993)
Tokmakian and Challenor (1993)
Le Traon and Minster (1993)
Aoki et al. (1995)
TOPEX/POSEIDON Observations
Pacific
Atlantic and Indian

Equatorial Rossby Wave Dispersion



Phase Speed from Classical Theory

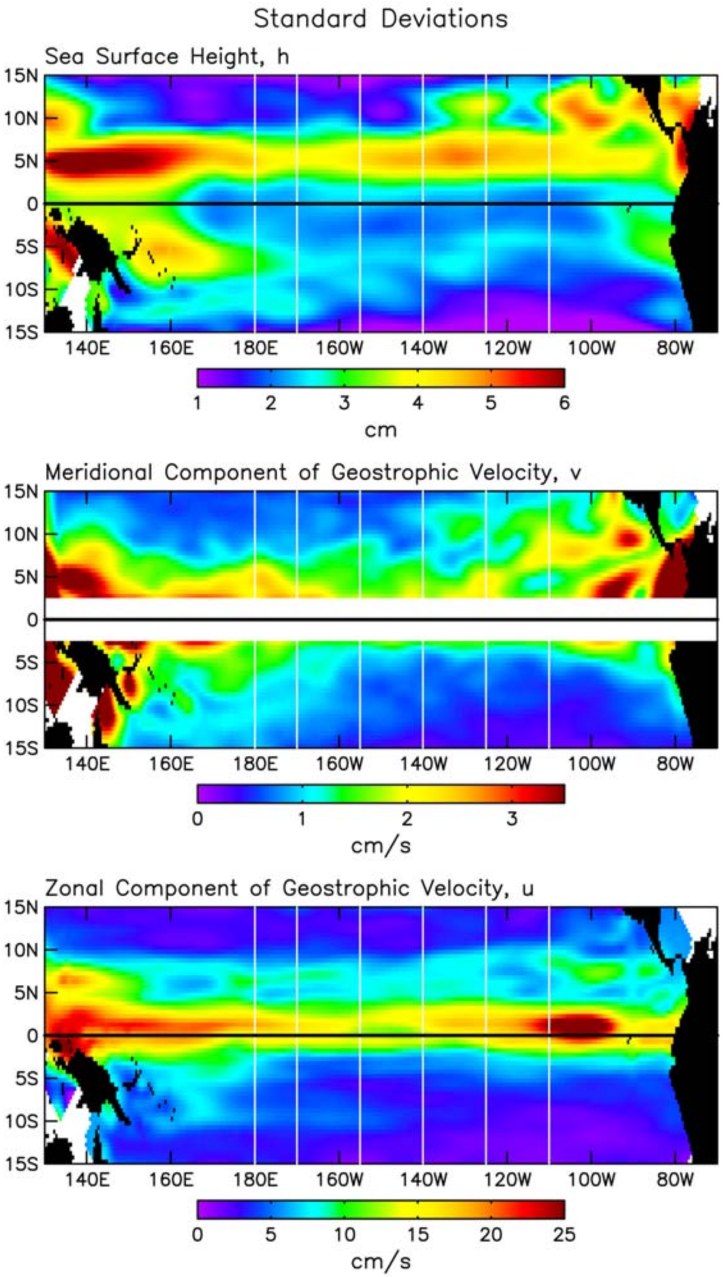
90 cm/s at Annual Period

Phase Speed Observations

58 cm/s	Meyers (1979)
50 cm/s	Mitchum & Lukas (1990)
58 cm/s	Kessler (1990)
60 cm/s	Susanto et al. (1998)
55 cm/s	Chelton et al. (2003)

Mean Flow Theories

Philander (1979)
Chang and Philander (1989)
Zheng et al. (1994)
Chelton et al. (2003)
71 cm/s at Annual Period



Observations of Latitudinal Asymmetry

Thermocline Variability from Hydrographic Data:

Meyers (1979)
Lukas and Firing (1985)
Kessler (1990)
Kessler and McCreary (1993)
Yu and McPhaden (1999)

SSH Variability from Altimeter Data:

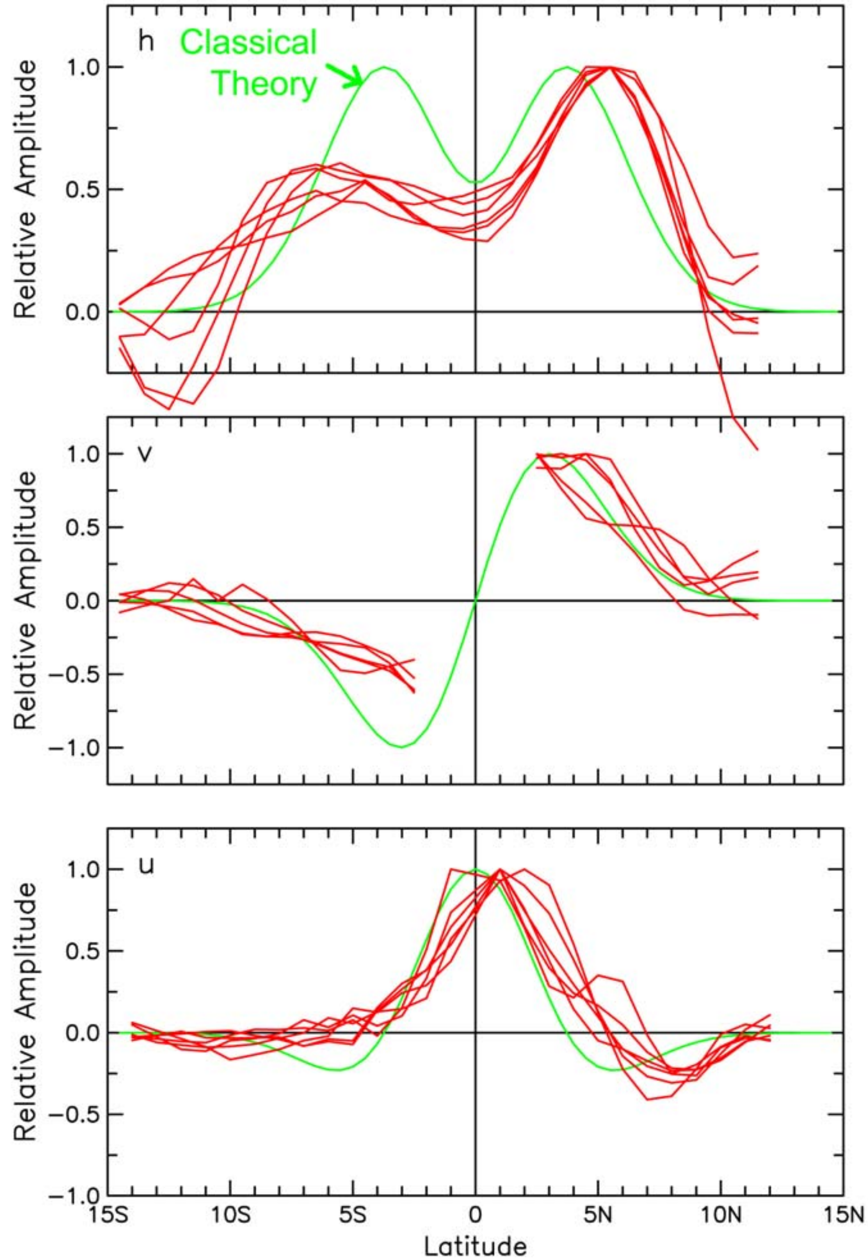
[Delcroix et al. (1991)]
[Delcroix et al. (1994)]
Susanto et al. (1998)
Chelton et al. (2003)

Meridional Velocity Variability from Altimeter Data:

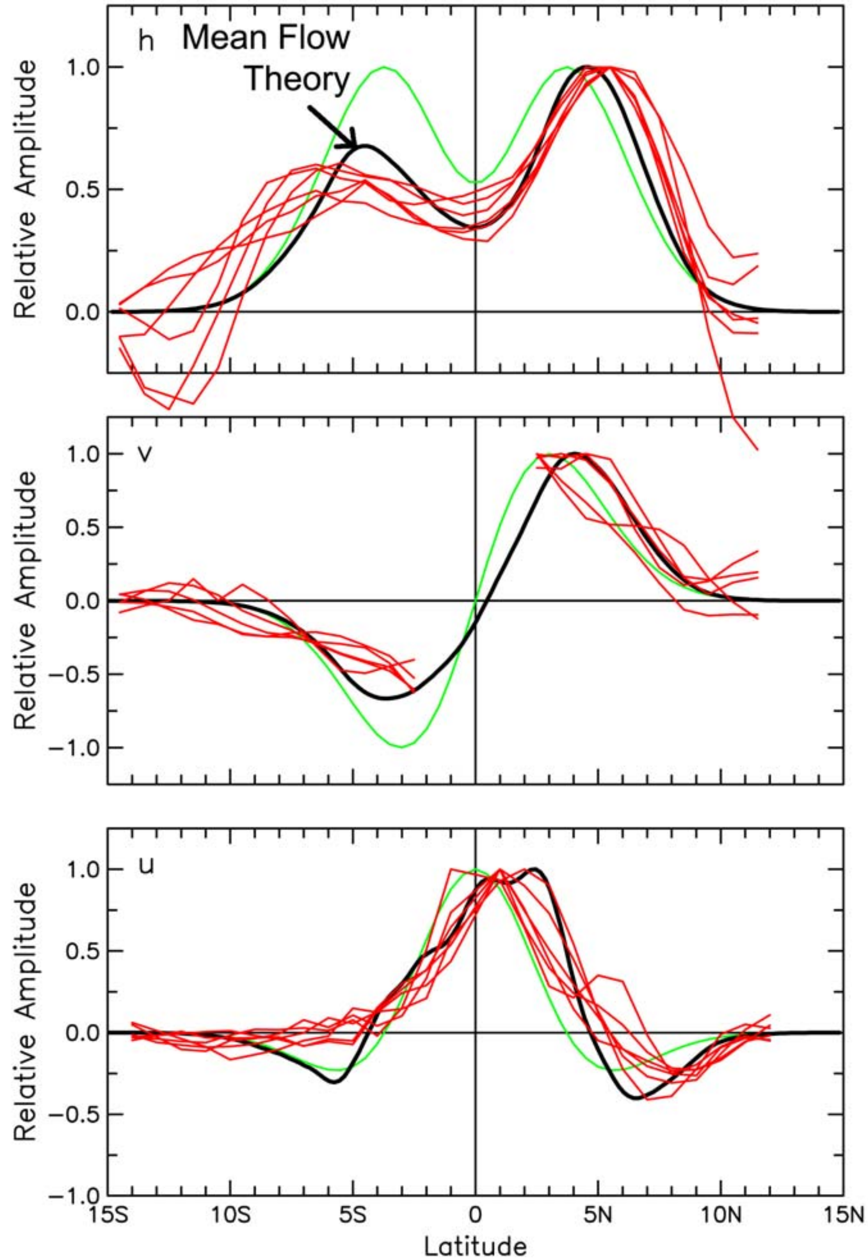
Chelton et al. (2003)

Zonal Velocity Variability from Altimeter Data:

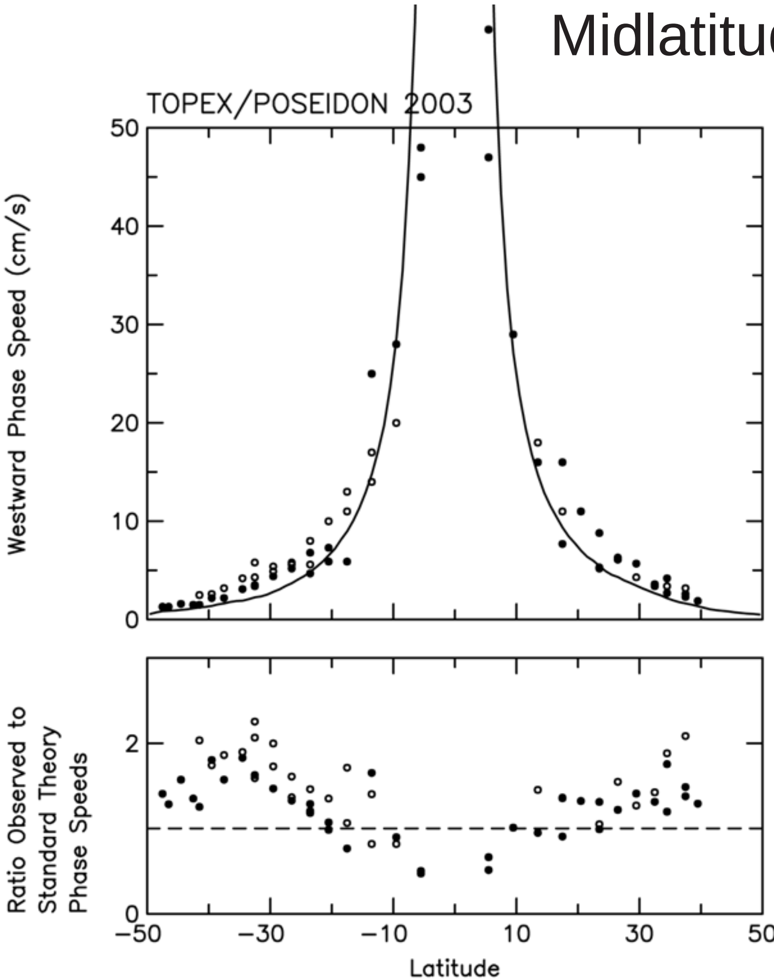
[Delcroix et al. (1991)]
[Delcroix et al. (1994)]
Chelton et al. (2003)

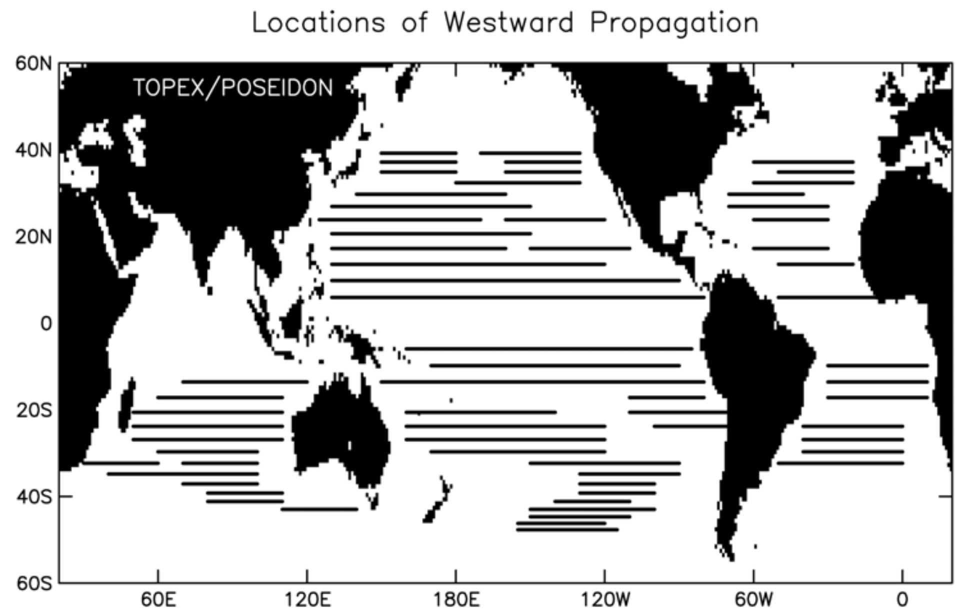


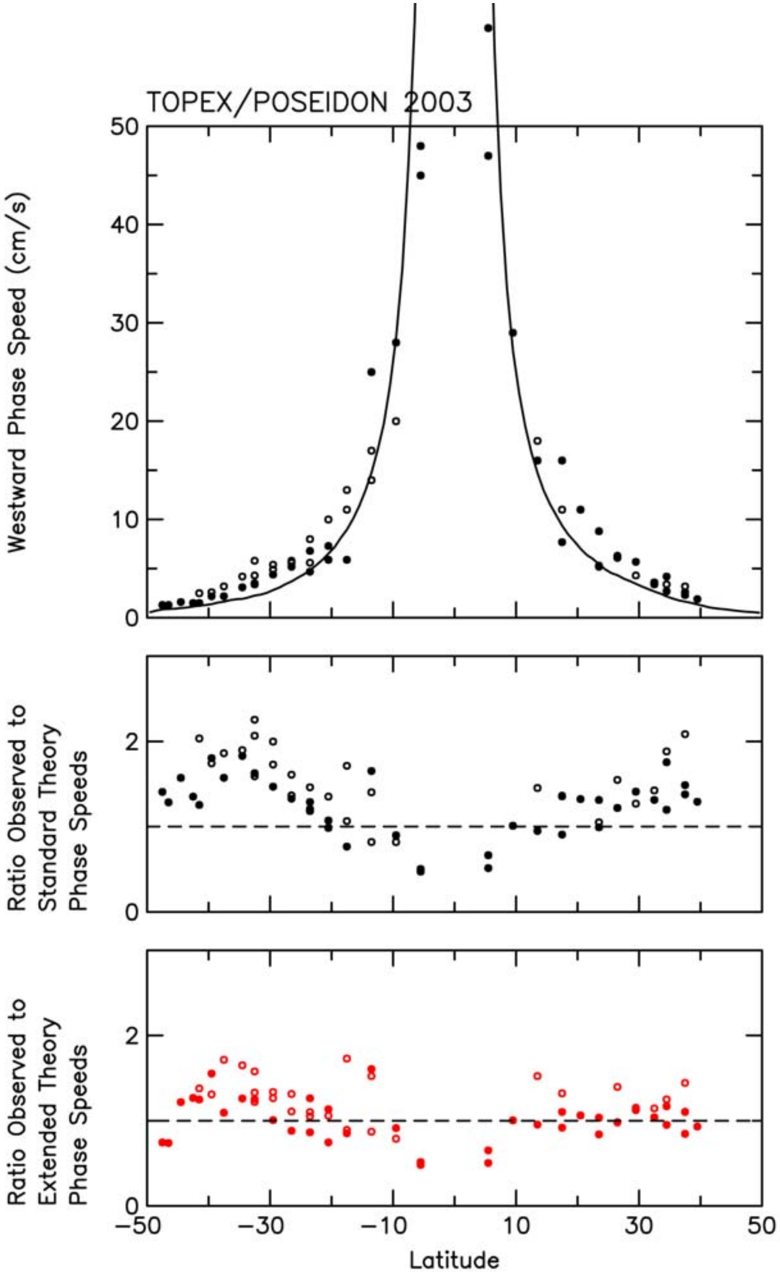
h
Classical
Theory
v
u
Relative Amplitude
1.0
0.5
0.0
−0.5
−1.0
15S
10S
5S
0
5N
10N
15N
Latitude


h
Mean Flow Theory
v
u
Relative Amplitude
1.0
0.5
0.0
−0.5
−1.0
15S
10S
5S
0
5N
10N
15N
Latitude

Midlatitude Rossby Waves







Theories for Fast Midlatitude Rossby Waves

Superposition of Traveling and Standing Waves

White (1977)
Qiu et al. (1997)

Note that these models cannot explain the observed fast phase speeds

Mean Flow Effects

Killworth et al. (1997)
Dewar (1998)
de Szoeke and Chelton (1999)
Liu (1999)
Yang (2000)

Coupled Ocean-Atmosphere Interaction

White et al. (1997)
White (2000)
White (2001)
White and Annis (2003)

Bottom Topography Effects

Killworth and Blundell (1999)
Tailleux and McWilliams (2000)
Tailleux and McWilliams (2001)
Tailleux (2003)

Combined Mean Flow and Topography Effects

Killworth and Blundell (2003a,b)

Zang and Wunsch (1999)

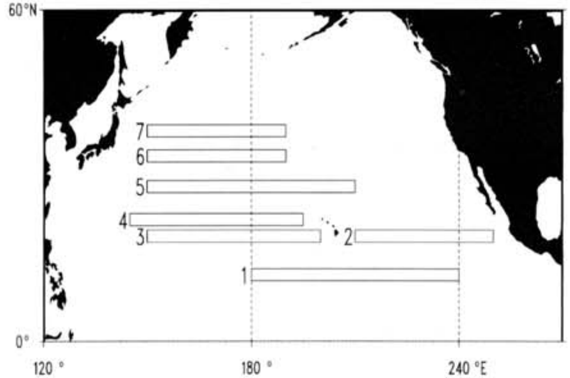


FIG. 1. Rectangles are the seven areas chosen to study the frequency wavenumber spectrum of sea surface height variability.

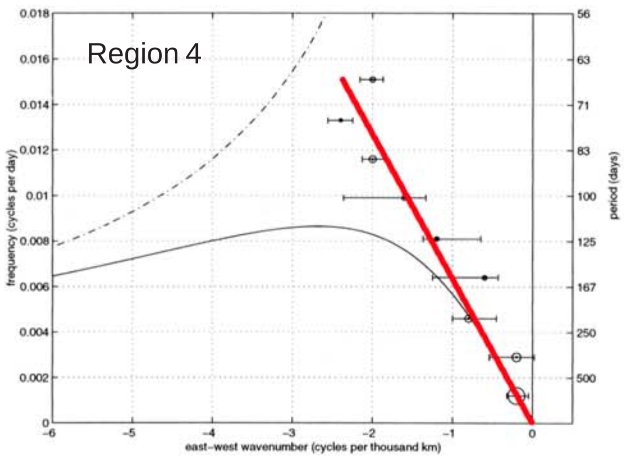


FIG. 4. Frequency–zonal wavenumber spectra of Area 4. The peak in each frequency band in Fig. 3 is indicated by a dot here. The magnitude of each peak is denoted by the size of the circle around that peak. The dash–dot and solid curves denote the barotropic and first baroclinic Rossby wave dispersion curves with $l = 0$, respectively. At the lowest frequencies, the barotropic curve is visually indistinguishable from $k = 0$. Uncertainty estimates are derived from the 95% confidence interval (Capon and Goodman 1970) for the peak values; see the appendix. The zonal wavenumber interval represents those wavenumbers where the background energy surrounding the apparent peak is larger than or equal to the lower limit of the confidence interval.

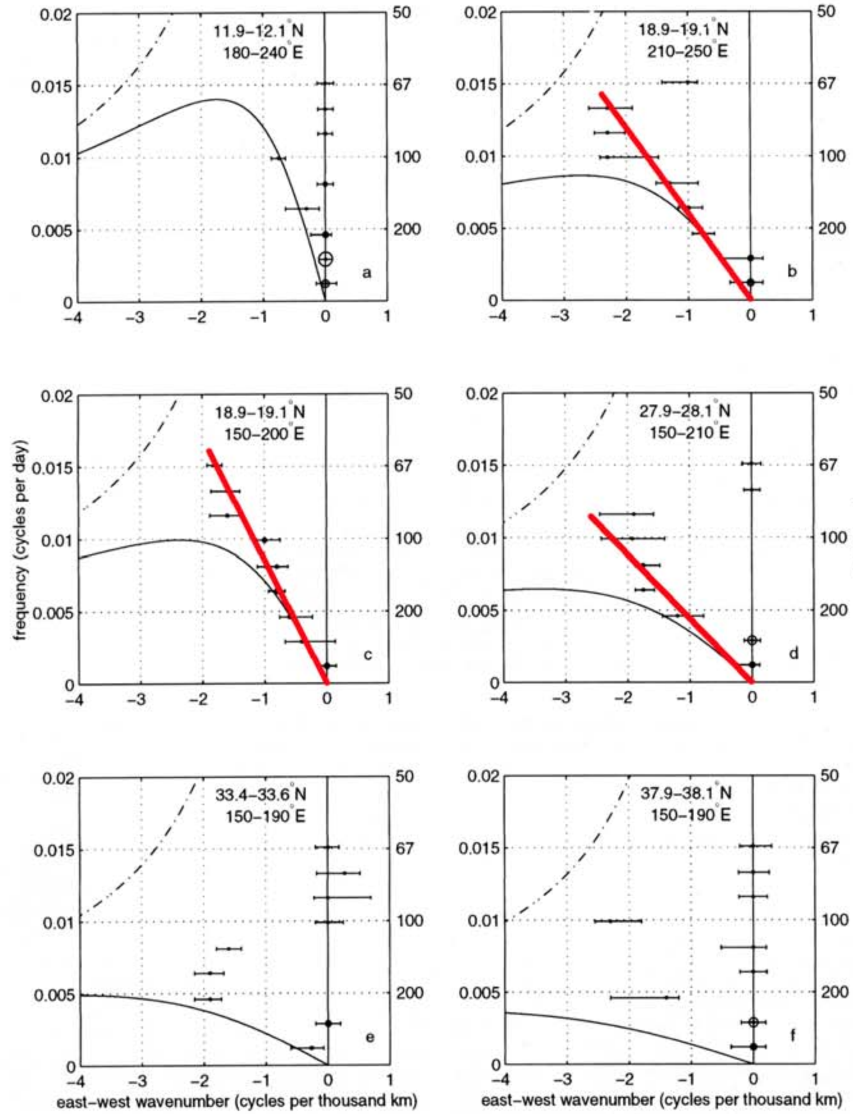
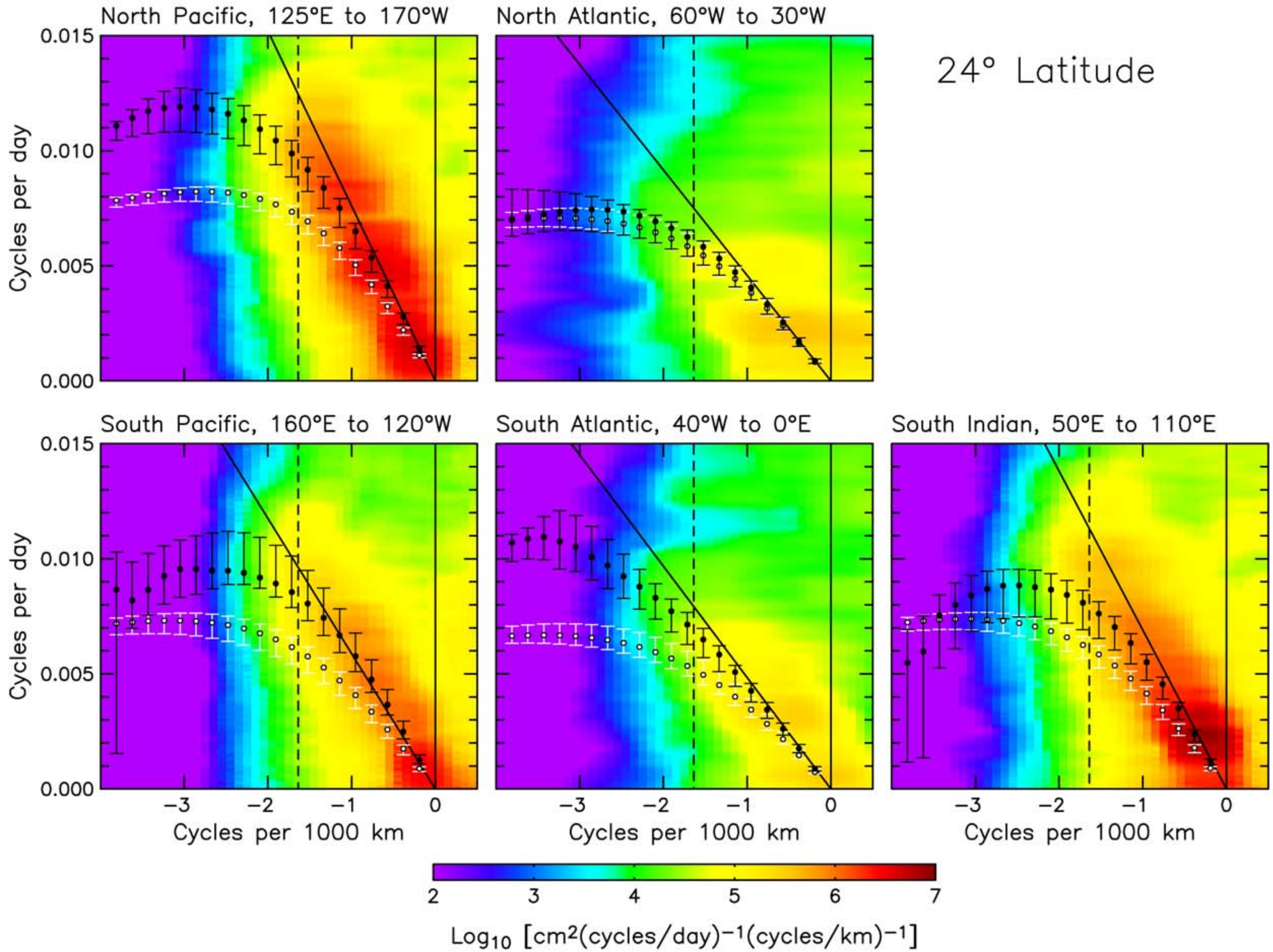
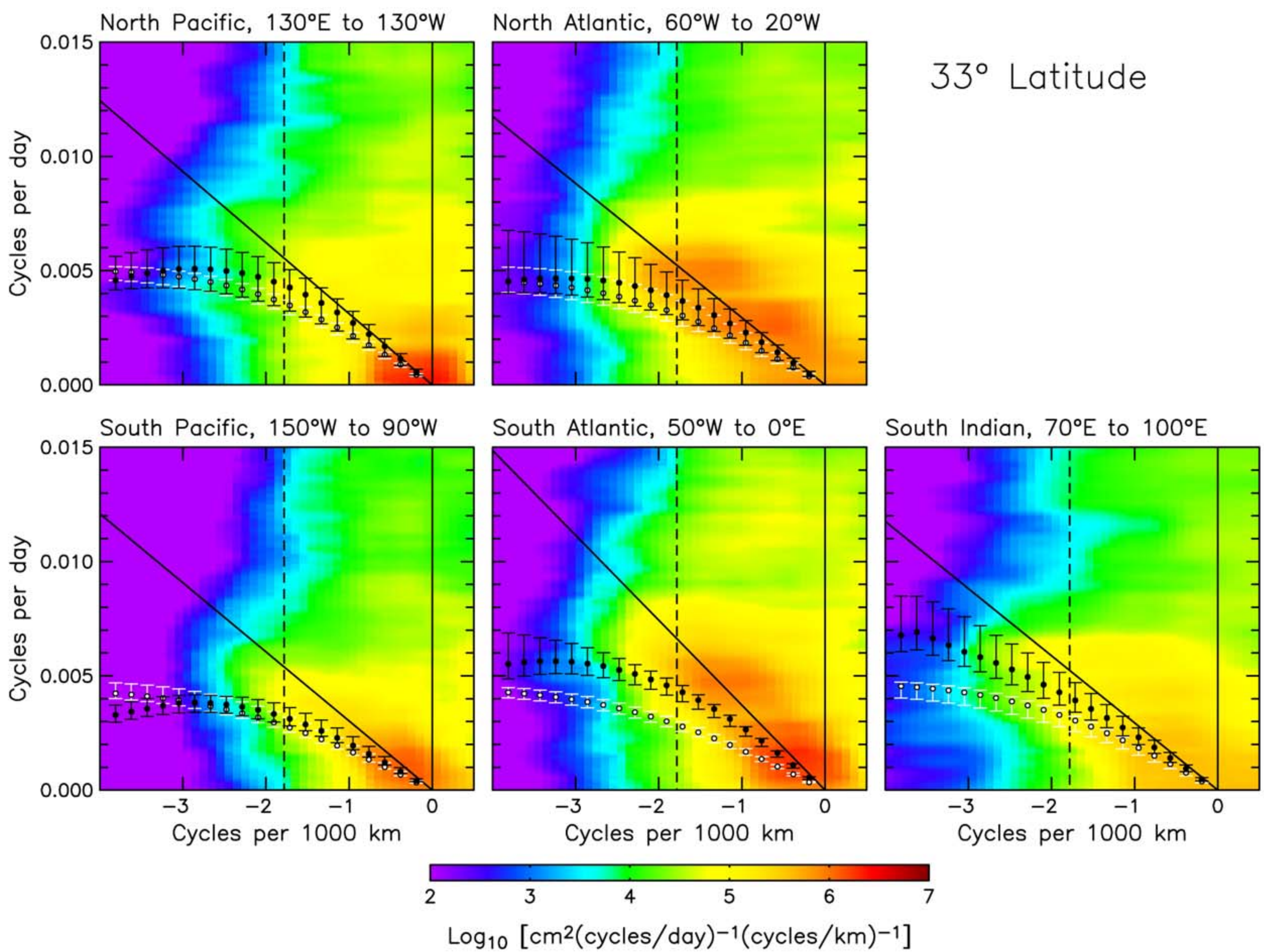


FIG. 5. Same as in Fig. 4 except (a) for Area 1, (b) Area 2, (c) Area 3, (d) Area 5, (e) Area 6, and (f) Area 7.


North Pacific, 125°E to 170°W
North Atlantic, 60°W to 30°W
24° Latitude
South Pacific, 160°E to 120°W
South Atlantic, 40°W to 0°E
South Indian, 50°E to 110°E
Cycles per day
Cycles per 1000 km
0.015
0.010
0.005
0.000
−3
−2
−1
0
2
3
4
5
6
7
Log10 [cm2(cycles/day)−1(cycles/km)−1]

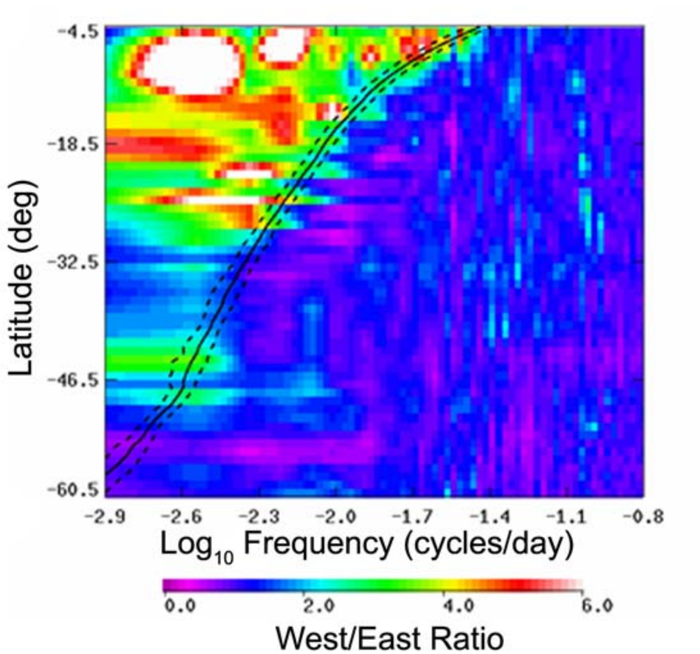


North Pacific, 130°E to 130°W
North Atlantic, 60°W to 20°W
33° Latitude
South Pacific, 150°W to 90°W
South Atlantic, 50°W to 0°E
South Indian, 70°E to 100°E
Cycles per day
0.015
0.010
0.005
0.000
−3
−2
−1
0
Cycles per 1000 km
2
3
4
5
6
7
Log10 [cm2(cycles/day)−1(cycles/km)−1]

Latitudinal Variation of the Frequency Distribution of Energy

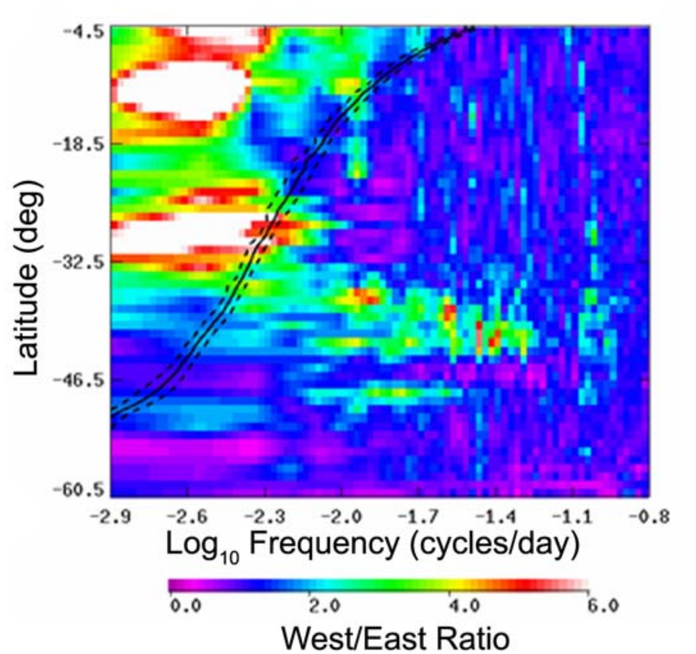
(Fu, 2003)

South Pacific Ocean



Solid Line: Critical Frequency of 1st-mode Baroclinic Rossby Waves
Dashed Lines: +/- 1 std dev

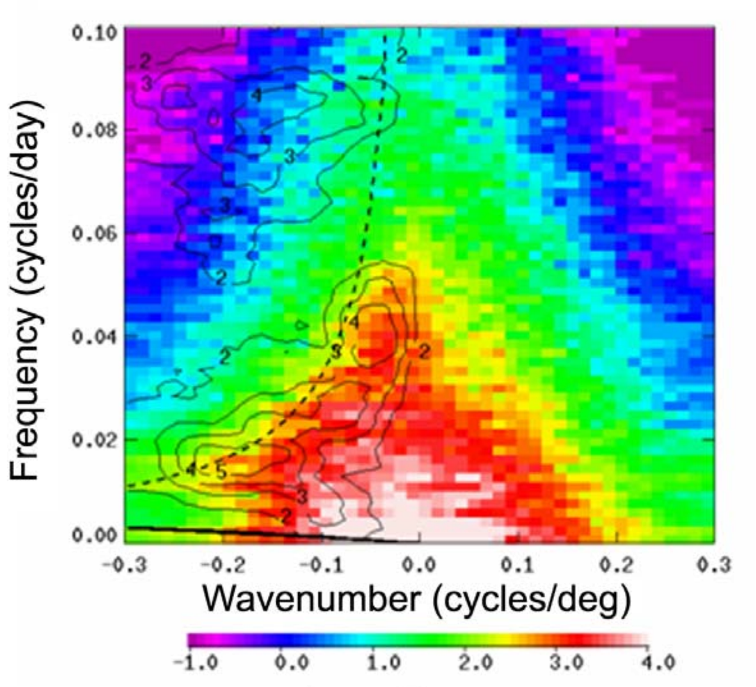
South Atlantic Ocean



Solid Line: Critical Frequency of 1st-mode Baroclinic Rossby Waves
Dashed Lines: +/- 1 std dev

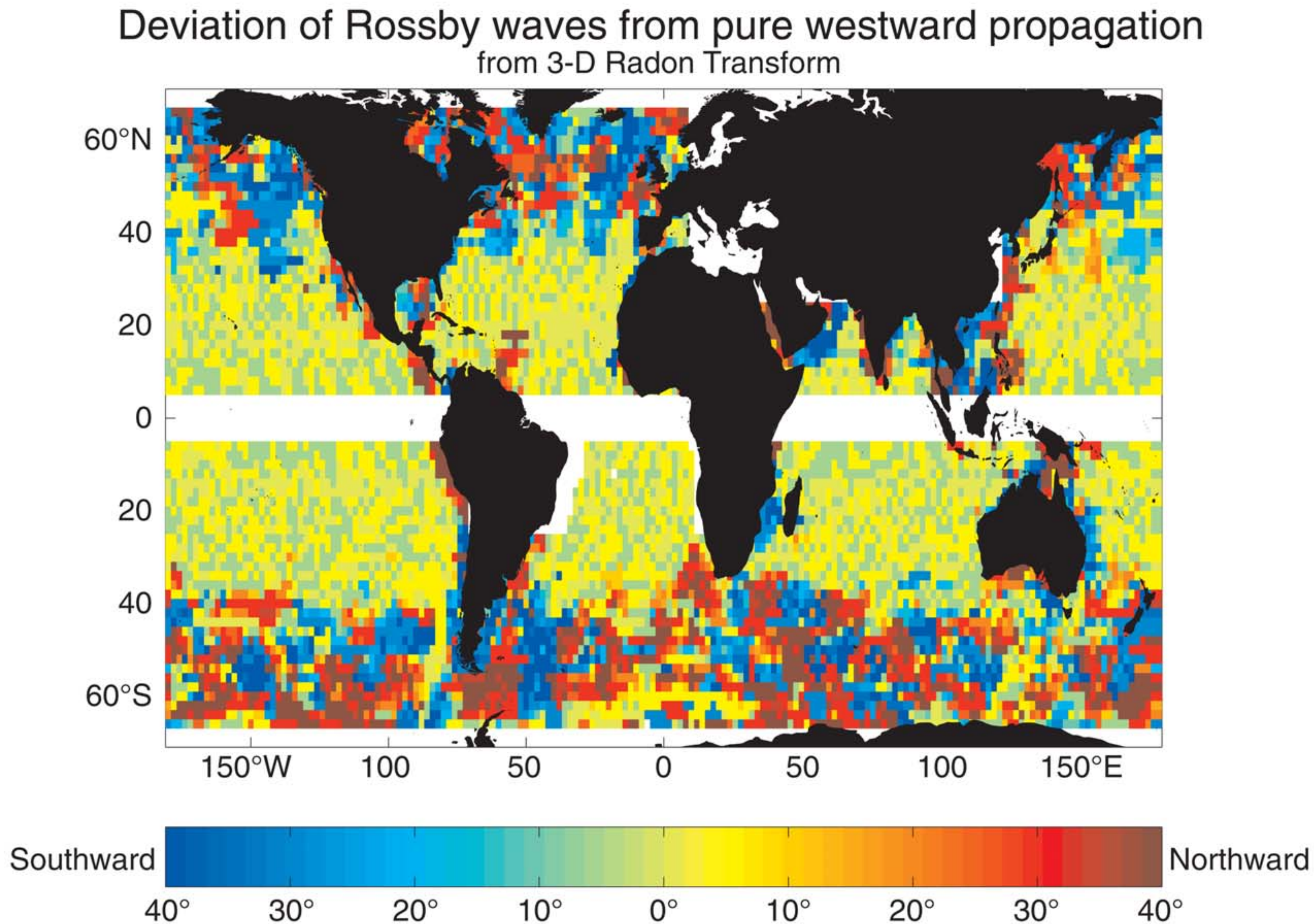
Wavenumber-Frequency Spectrum along 40^o S in the South Atlantic

(Fu (2003)



Log$_{10}$ Power

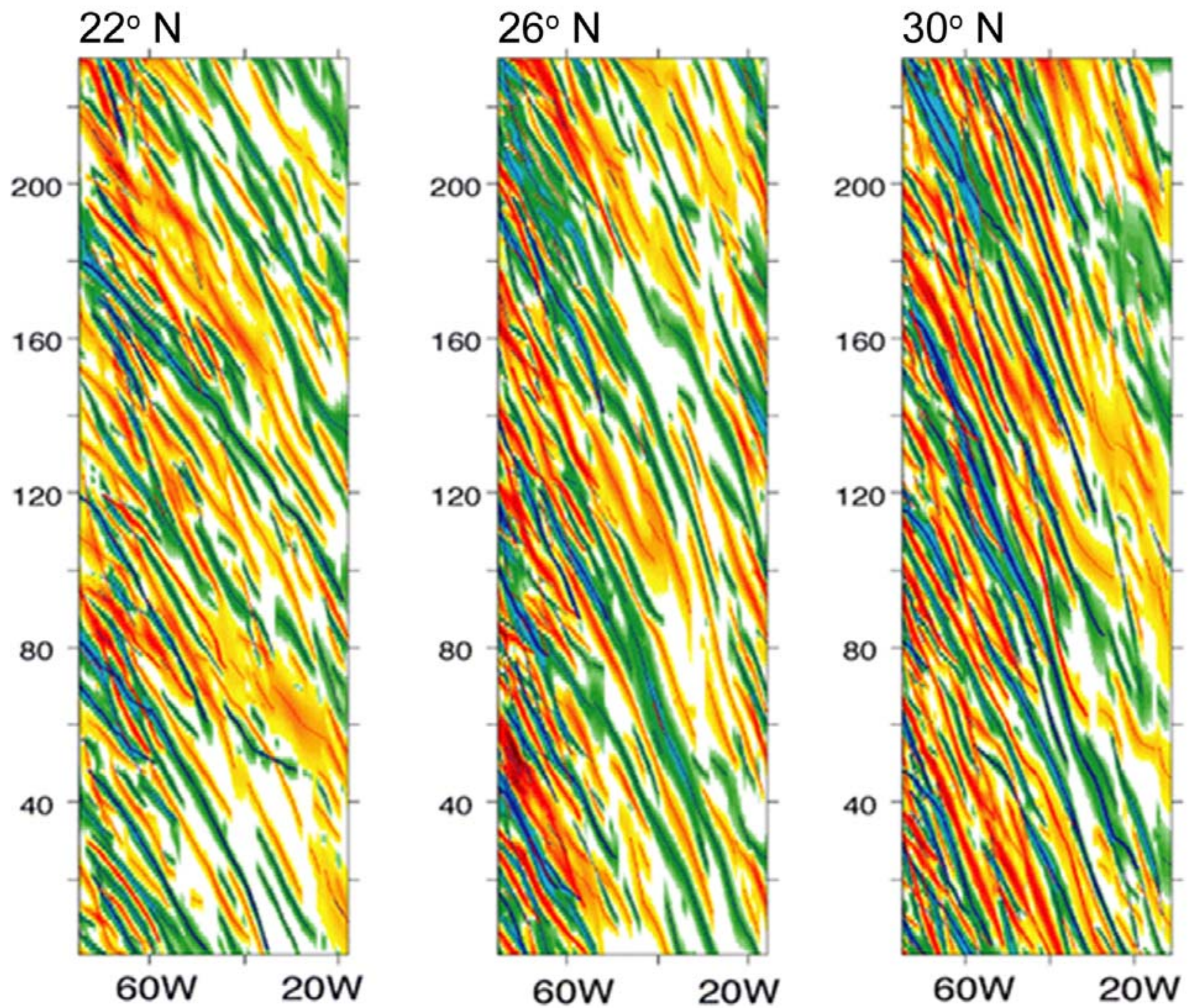
Solid line: Baroclinic Dispersion Relation
Dashed line: Barotropic Dispersion Relation
Contours: Ratio of Westward/Eastward Energy



Courtesy of D. Cromwell
(after Challenor et al., 2001)

North Atlantic Feature Tracking by Gaussian Model Fitting

(Cipollini and Challenor, 2003)



Rossby Wave Influence on Ocean Biology

(Cipollini et al., 2001; Uz et al., 2001; Siegel, 2001; Quartly et al., 2003; Killworth et al., 2003)

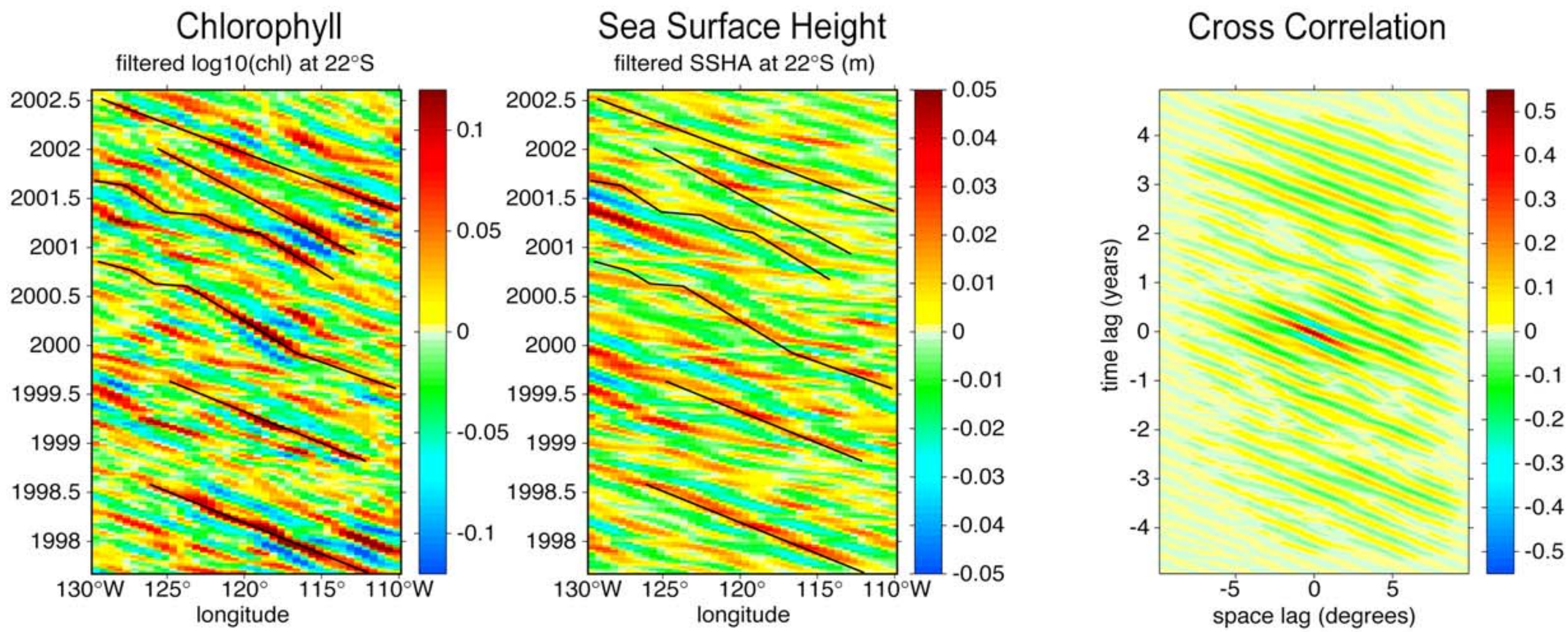


Figure for the South Pacific from Killworth et al. (2003)

Controversy:

What is the mechanism for Rossby wave induced westward propagation of Chl anomalies?

- Passive horizontal advection against a mean meridional gradient of Chl *(Killworth et al., 2003)*
- Chl response to vertical upwelling of nutrients into the euphotic zone (the “rototiller effect”)?
- Vertical upwelling of subthermocline Chl into the surface layer?

Coupled Ocean-Atmosphere Rossby Waves

(White, 2000; White, 2001; White and Annis, 2003)

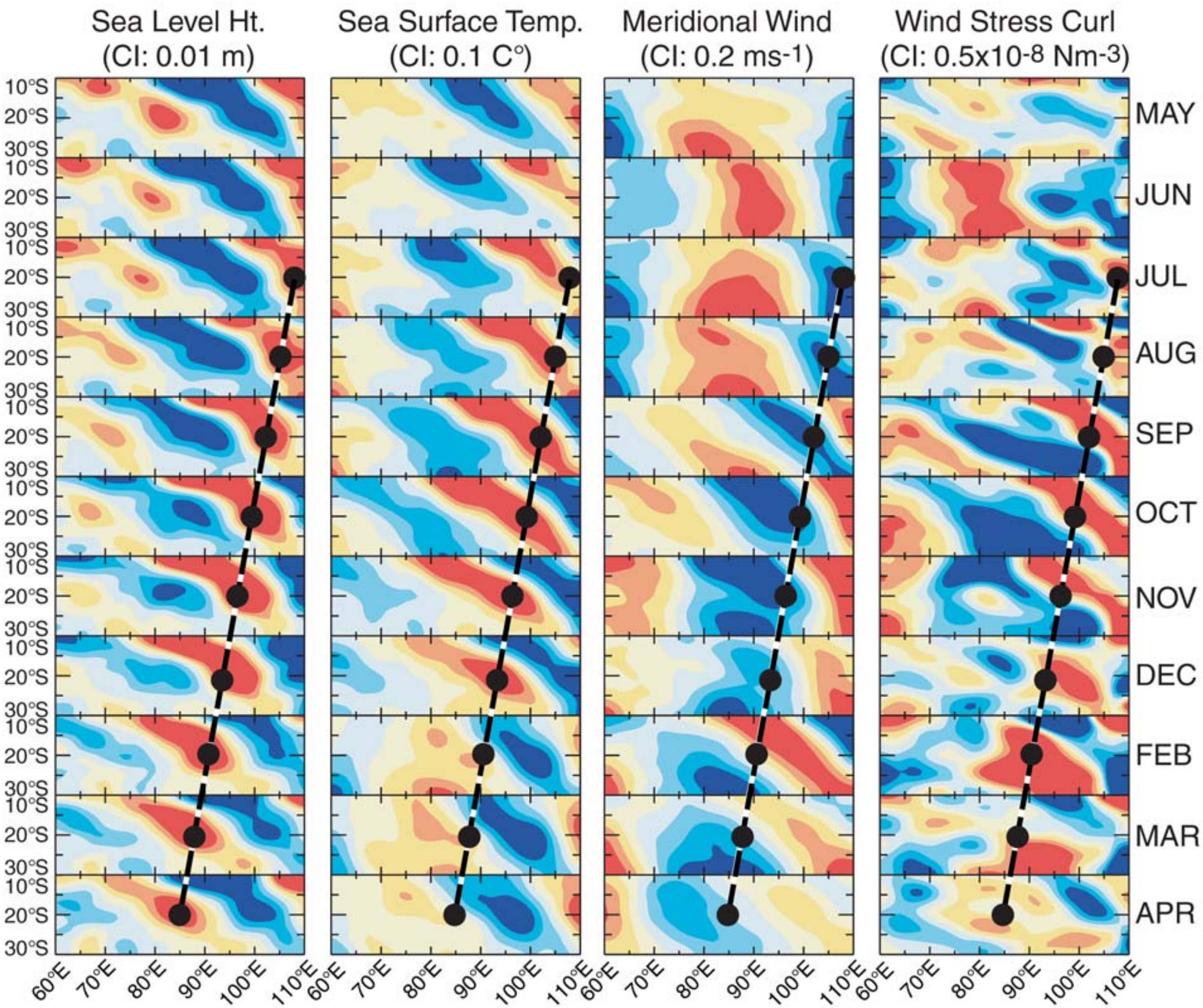


Figure from White and Annis (2003)

Outstanding Issues for Midlatitude Rossby Waves

- What is the generation mechanism for the observed westward propagating SSH variability?
- Why is westward propagation broad-banded in frequency outside of the tropics, rather than being dominated by the annual cycle?
- Why is there little evidence for meridional propagation between 40^{o}N and 40^{o}S?
- Why is the observed westward propagation nondispersive over the range of wavenumbers resolved by the T/P (and now Jason) sampling pattern?
- Are the westward propagating features Rossby waves or eddies?
- What are the mechanisms for the coupling between Rossby waves and:
  - the overlying wind field;
  - the biology.

Outstanding Issues for Equatorial Rossby Waves

- Why are the observed phase speeds slower than predicted by any of the theories developed to date?
- Why are the maxima of equatorial Rossby waves displaced to higher latitudes in the southern hemisphere than in the northern hemisphere?
- What role does basin geometry play in determining the phase speed and geographical variations in the latitudinal structure of equatorial Rossby waves?
  - Is it coincidental that the Pacific transit time of annual equatorial Rossby waves is just about exactly one year?

Aurora Borealis
Over the Labrador Sea
15 November 2003

Conclusions

Jason Launch
7 December 2001
Vandenberg, California

- Satellite altimetry has revolutionized the ability to observe westward propagating variability throughout the world ocean.
- The 11-year T/P data record reveals numerous inconsistencies between the observations and the classical theories.
- Theoretical developments have identified several important effects on the dynamics of Rossby waves:
  - vertical and horizontal shears of the background mean currents;
  - bottom topography;
  - coupled ocean-atmosphere interaction.
- It is no longer possible to defend the classical theories. We must:
  - Continue forward with further theoretical developments;
  - Identify distinguishing features of the various theories in order to determine the most important dynamical factors that influence Rossby waves.
- High resolution of SSH fields constructed from the tandem T/P - Jason data record will likely prove essential for understanding the dynamics of westward propagating SSH variability