Frequency and wavenumber power spectra of sea surface heights and observational error models

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JCSDA 6th Workshop on Satellite Data Assimilation
June 10-11, 2008, Holiday Inn, BWI Airport Conference Center,
890 Elkridge Landing Rd., Linthicum, MD 21090

OUTLINE

- Motivation
- Spatial variability of sea surface heights
- Temporal variability: contributions of baroclinic and barotropic modes
- Comparison with observations of sea level variability simulated by GMAO Poseidon ocean model at tide gauge locations
- Conclusions

The Goal:

To address error modeling for data assimilation purposes, reflecting the difference in averaging of physical field by the model grid and by the observing systems.

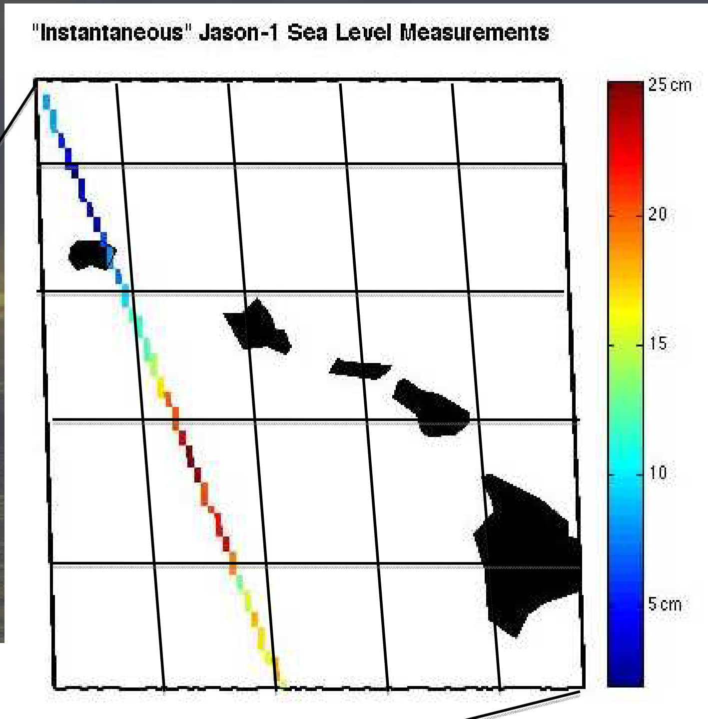
Consider a typical situation in ocean modeling:
Model: grid resolution – 30km x 60km,
Data: Sea surface height altimetry – 7km footprint;
SST – 1-4-25km averages, depending on the product;
In situ observations – local.

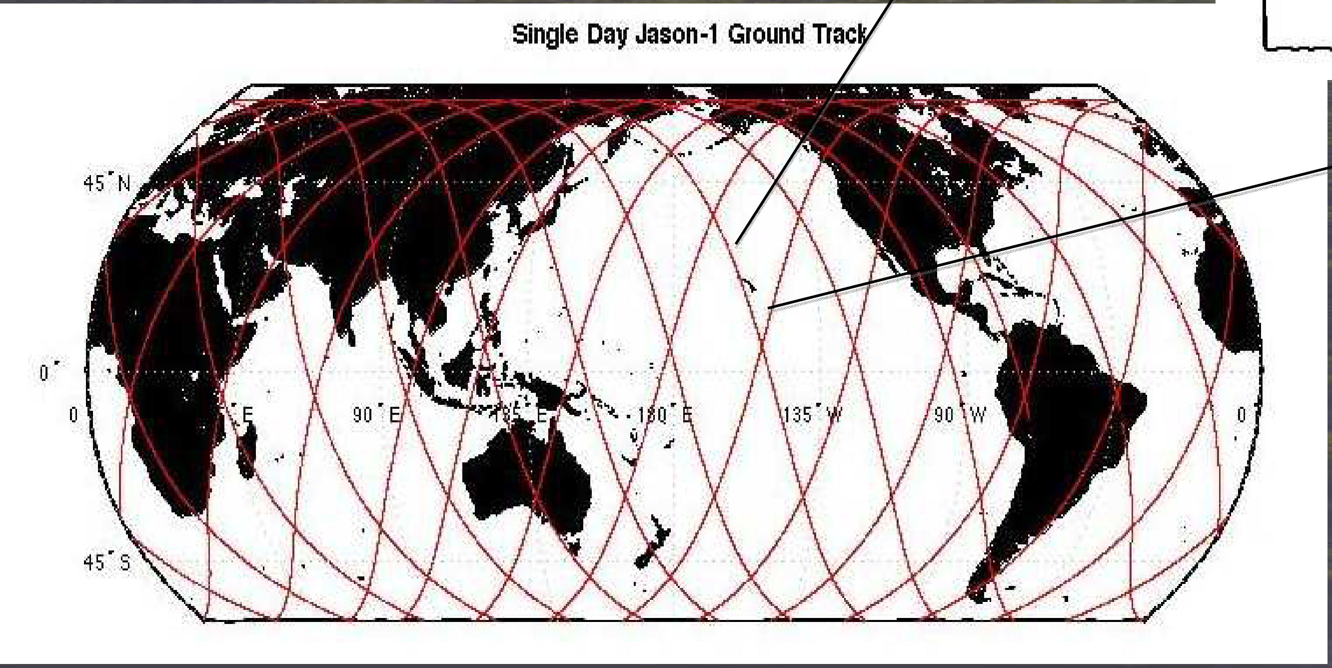
What is the error of the data with regards to the model grid values? It needs to be specified for the assimilation procedures.

In addition to measurement error of the data, we need to take into account the error due to the difference in averaging of the physical field by the model and by different types of the observing systems.

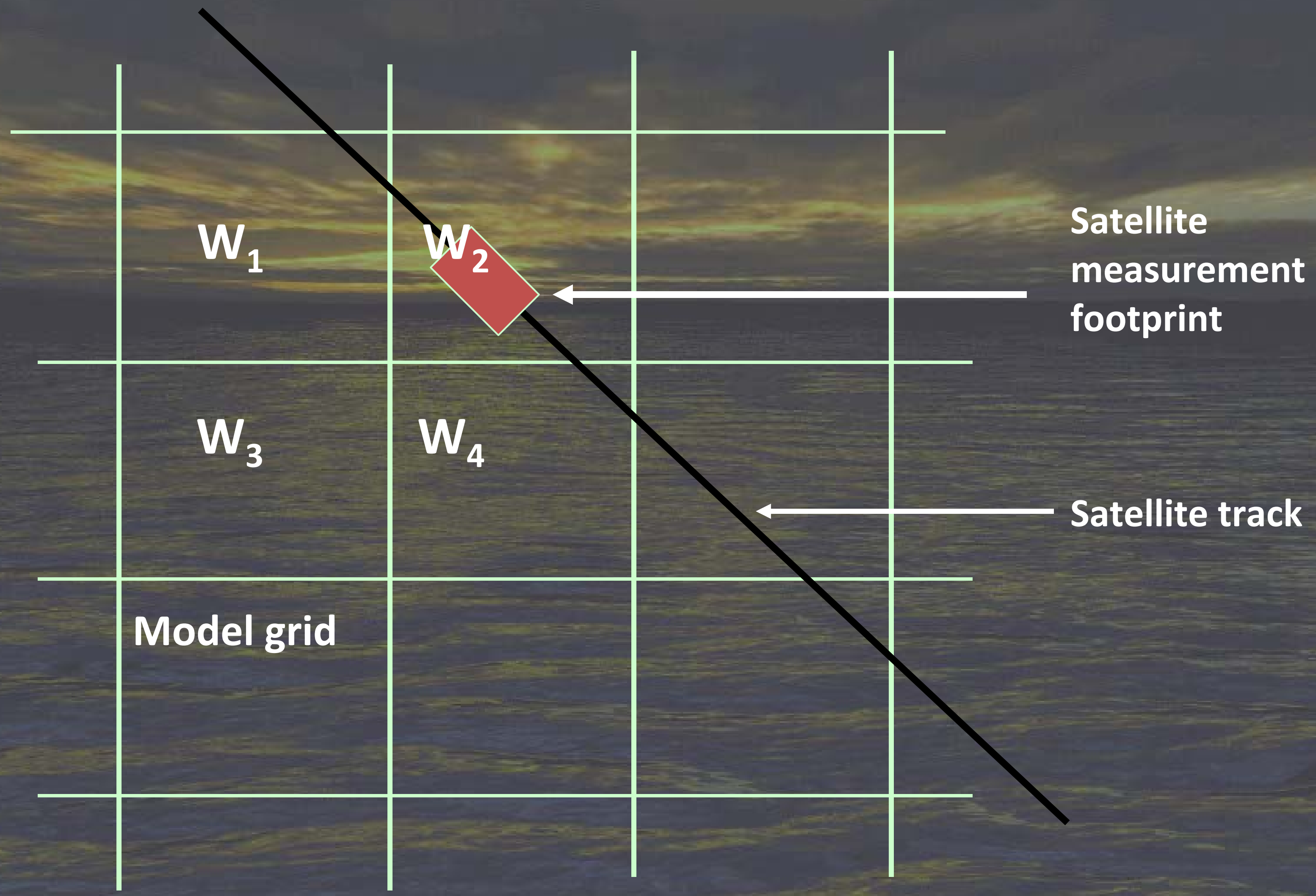
Are our error estimates consistent with each other and with data differences?

In the case of satellite altimetry observations are only available along ground tracks





Model and data values



$$S^o = Hs = W_1 s_1 + W_2 s_2 + W_3 s_3 + W_4 s_4$$

Spectral representation of data error

$$Hs + \varepsilon = s^o$$

$$Hs = \int W(\vec{x}) s(\vec{x}) d\vec{x}$$

$$s^o = \int W^o(\vec{x}) s(\vec{x}) d\vec{x}$$

$$\varepsilon = \int (W^o(\vec{x}) - W(\vec{x})) s(\vec{x}) d\vec{x}$$

Assume

$$s(\vec{x}) = \int f(\vec{k}) e^{i\vec{k}\vec{x}} d\vec{k},$$

then

$$\varepsilon = \int d\vec{k} f(\vec{k}) \int (W^o(\vec{x}) - W(\vec{x})) e^{i\vec{k}\vec{x}} d\vec{k} = \int w(\vec{k}) f(\vec{k}) d\vec{k},$$

where

$$w(\vec{k}) = \int (W^o(\vec{x}) - W(\vec{x})) e^{i\vec{k}\vec{x}} d\vec{k}.$$

Let $P(\vec{k})$ be a power spectrum of $s(\vec{x})$:

$$\langle f(\vec{k}) f(\vec{k'})^* \rangle = P(\vec{k}) \delta(\vec{k} - \vec{k'}).$$

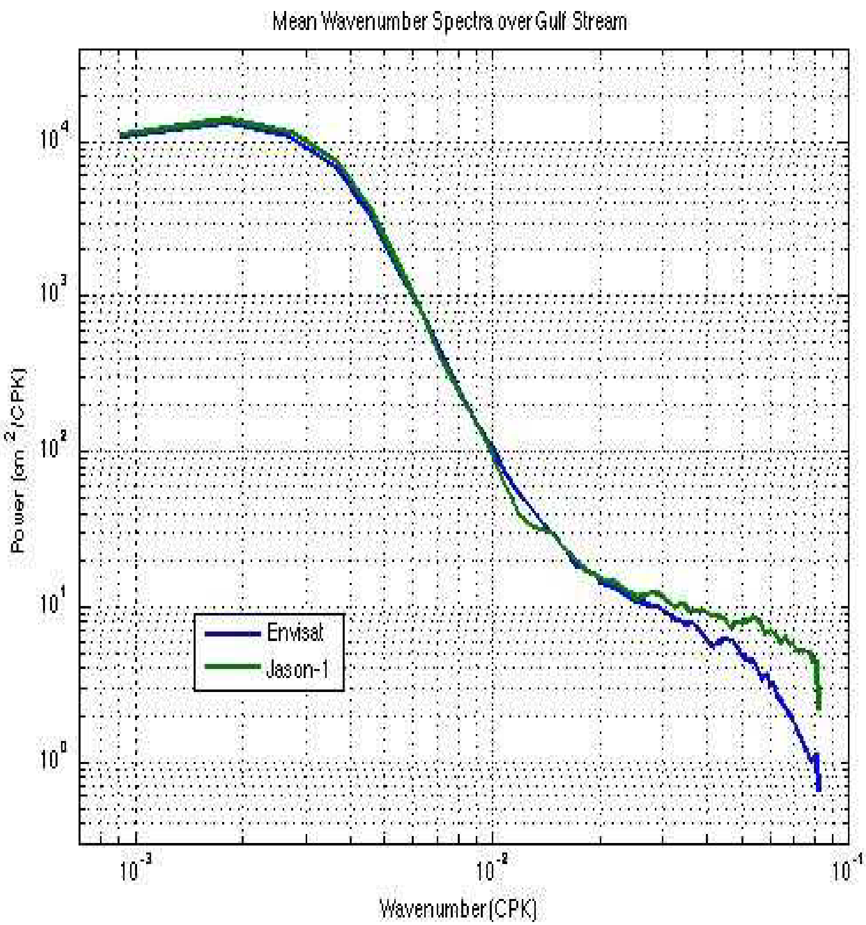
Then

$$\langle \varepsilon^2 \rangle = \int P(\vec{k}) |w(\vec{k})|^2 d\vec{k}.$$

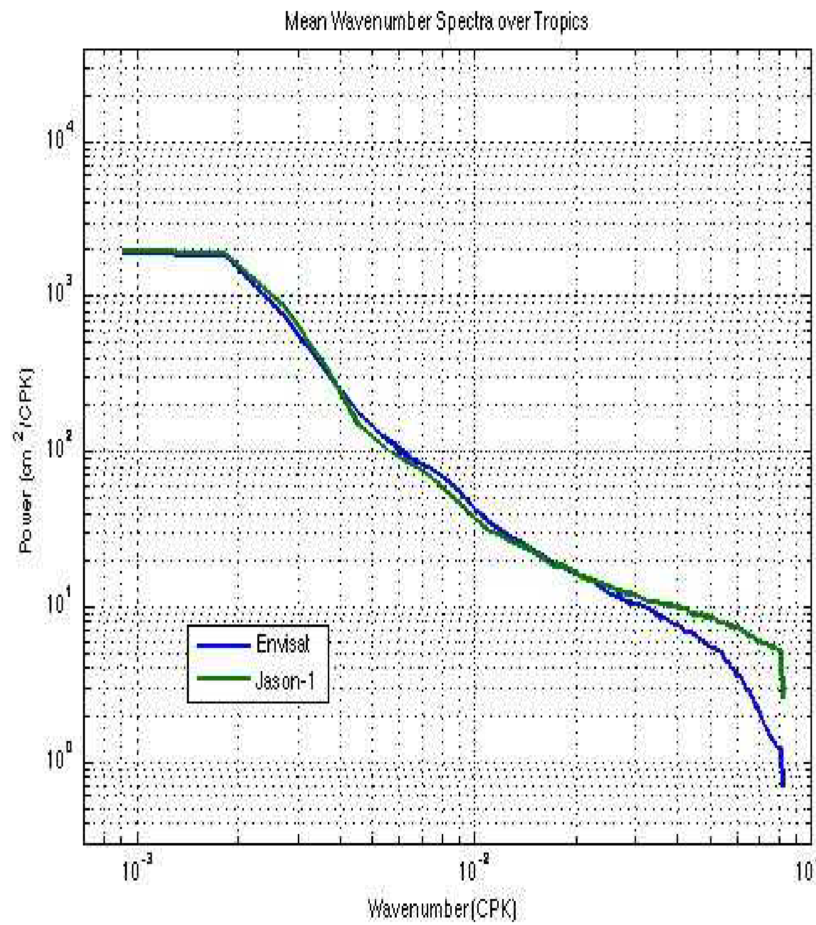
SPATIAL VARIABILITY

Wavenumber Spectra: Jason and Envisat

Gulf Stream

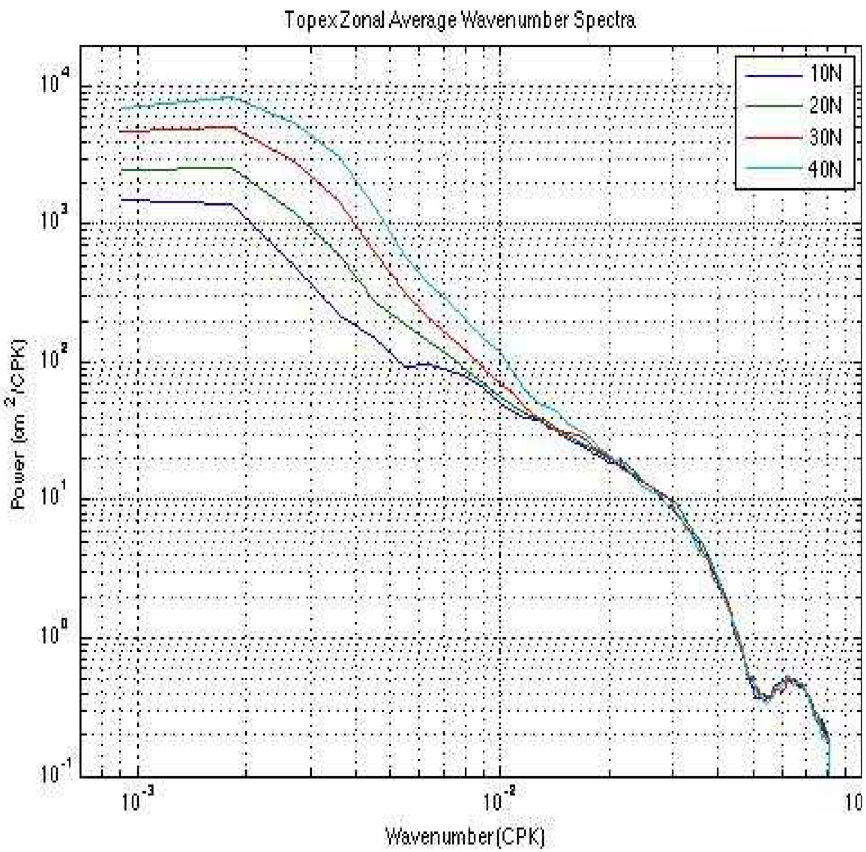


Tropics

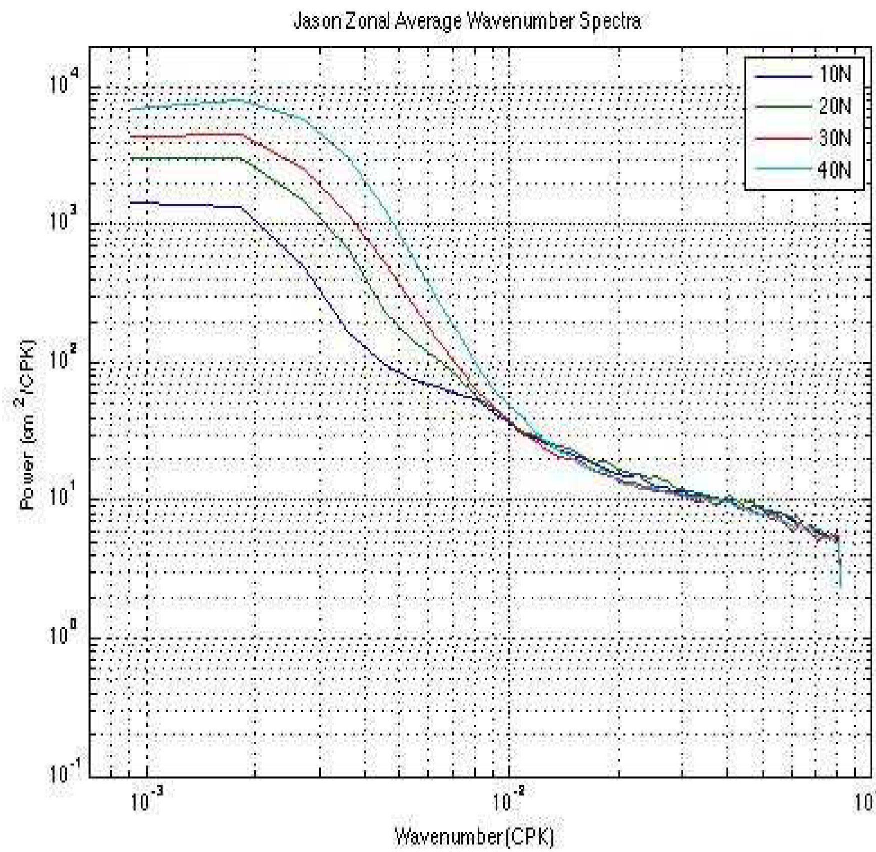


Zonal mean wavenumber spectra

Topex

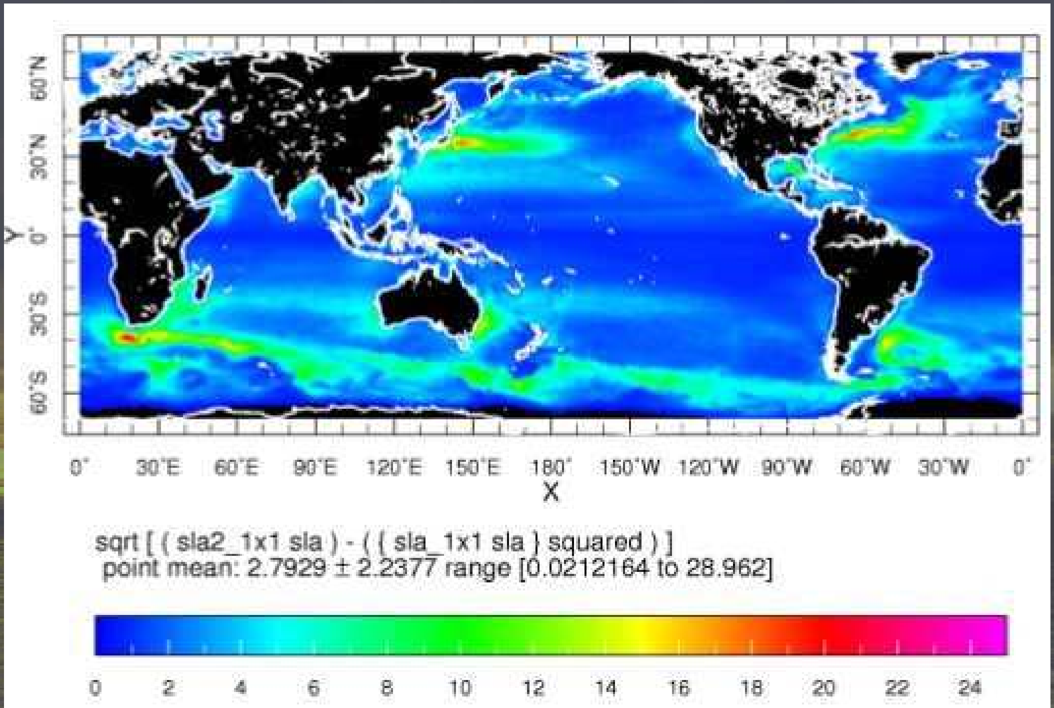


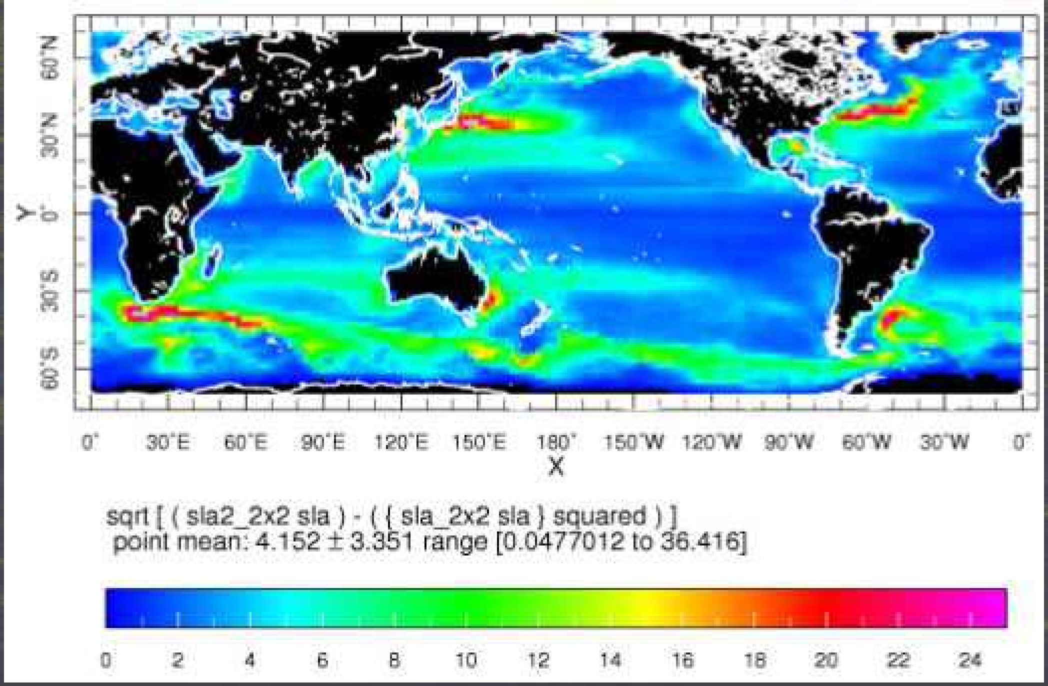
Jason



notice constant “noise” level below 100km

Spatial standard deviation of 1/3º gridded AVISO delayed-mode reference merged altimetry products within 1x1º and 2x2º boxes





TEMPORAL VARIABILITY

Temporal sampling error:

Due to sampling frequency of altimetry (9.91 days for Topex and Jason), high-frequency (HF) variability – with periods 20 days and shorter, is aliased.

Primary drivers of high frequency variability:

$$SLA_{HF} = h_{IB} + h_p + h_w + h_t$$

Static "IB" response to pressure

Dynamic response to pressure

Dynamic response to wind

Tides

Fukumori et al. [1998] in the simulations using MOM have found major regional differences in frequency content of sea surface height variability connected to barotropic vs baroclinic variability prevalence.

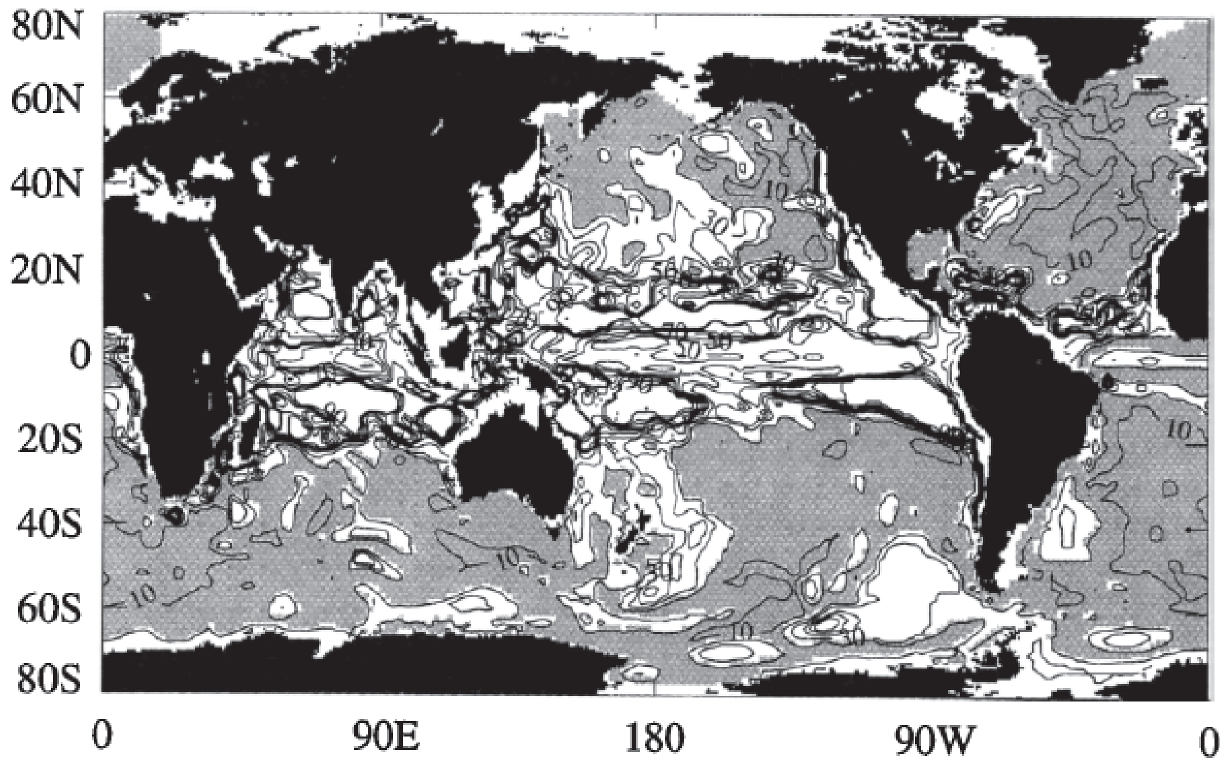


Figure 4. The period above and below which half the intraseasonal (period shorter than 180 days) sea level fluctuations occur. Contour interval is 10 days (saturated at 100 days). Regions with a half-energy period shorter than 20 days are shaded.

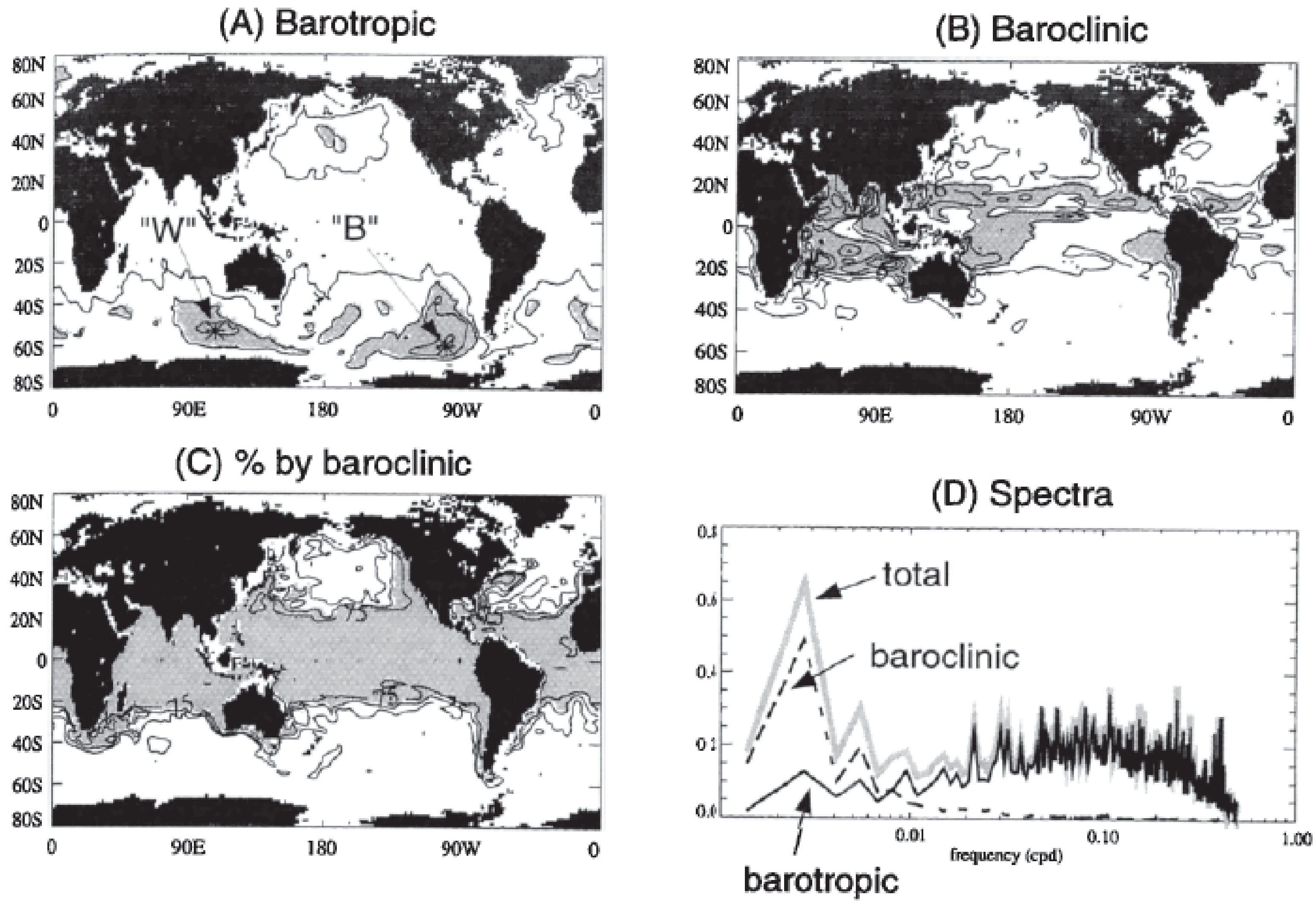


Figure 12. Wind-driven sea level change as a function of dynamic mode; (a) barotropic mode, (b) baroclinic mode, and (c) percentage of Figure 12b to total wind-driven variability. (d) Average frequency spectra of the two components in variance-preserving form normalized by the total variance. Different wind-driven spectra in Figure 12d are barotropic (solid black), baroclinic (dashed), and total sea level (gray). Contour intervals are 2 cm (Figures 12a and 12b) and 25% (Figure 12c). Shaded regions denote values larger than 4 cm (Figures 12a and 12b) (as in Figure 7) and 50% (Figure 12c). Asterisks denoted "W" and "B" in Figure 12a are in the local maximum of sea level variability and are further examined in section 3.5.

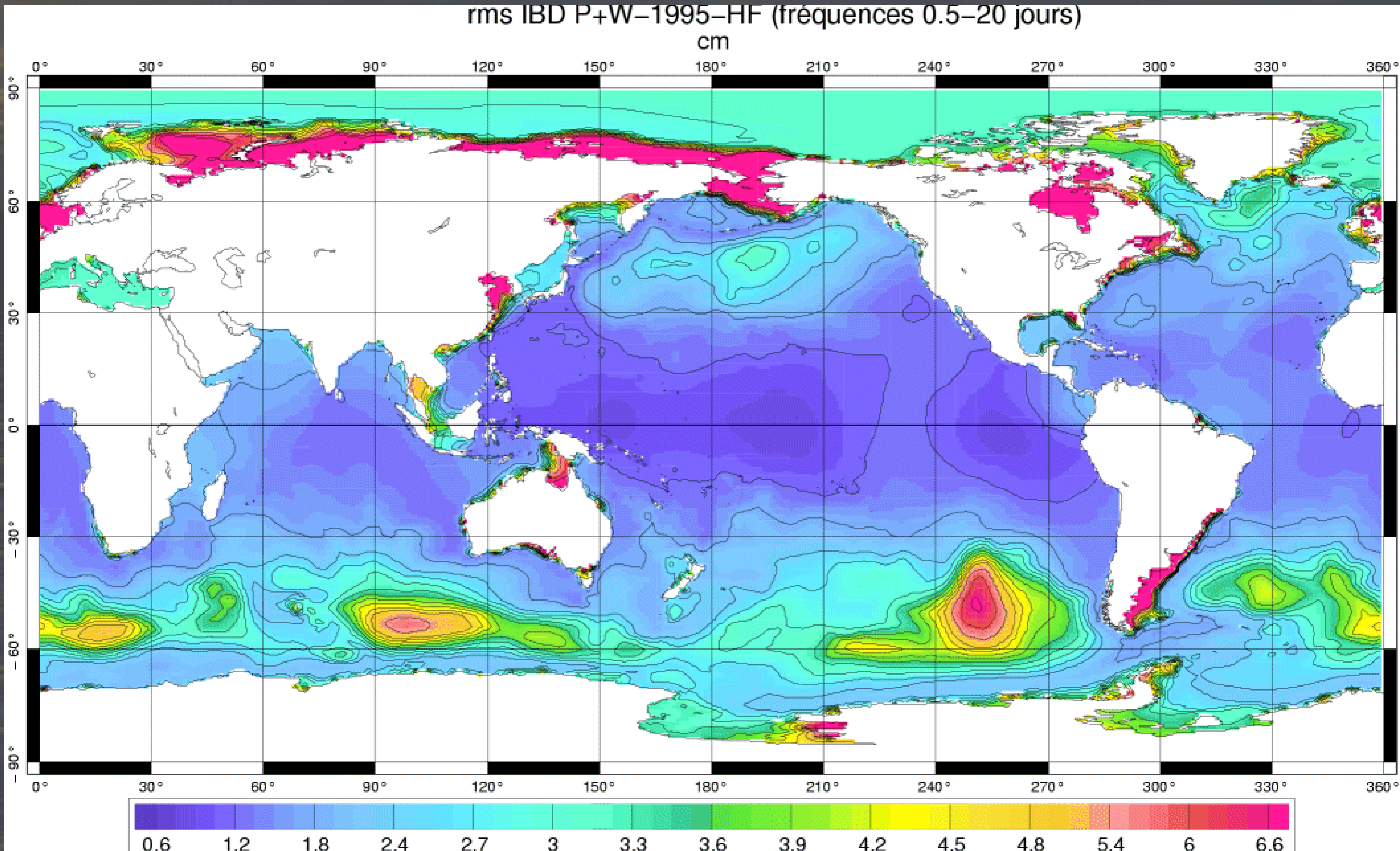
- Tidal signal removed by FES2004 tidal model, accuracy ~1cm

AVISO Dynamic Atmospheric Correction:

- Static “Inverted Barometer” response to pressure removed using ECMWF pressure field

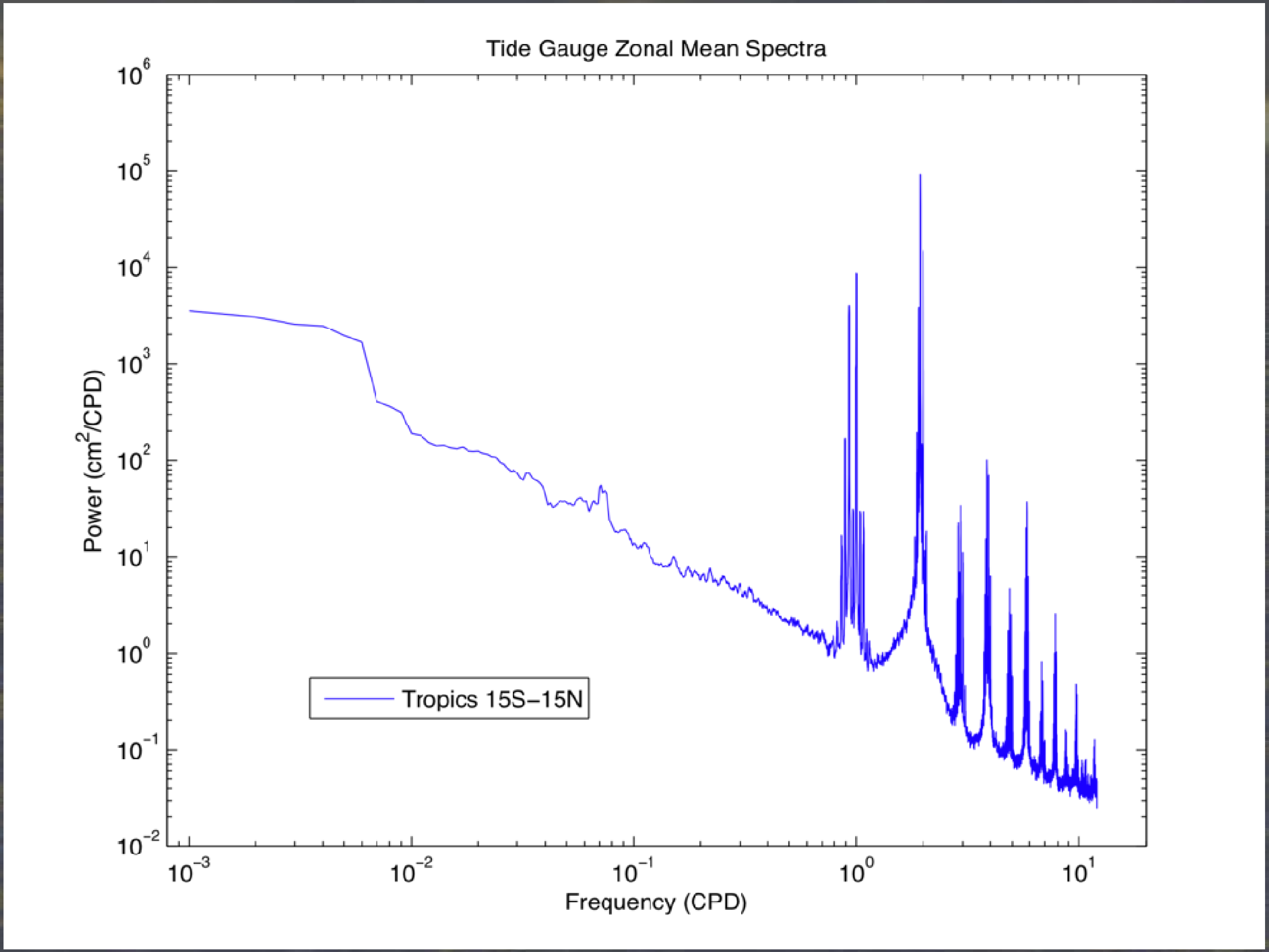
- Dynamic response to wind and pressure removed by Mog2D FE barotropic model; this removal is now routinely applied to the altimetry data in order to reduce aliasing of variability with periods shorter than 20 days; in this work we apply it to tide gauge data in order to make it comparable to altimetry and to the GMAO simulations with the reduced-gravity Poseidon ocean model.

RMS Pressure+Wind Effect in Mog2D

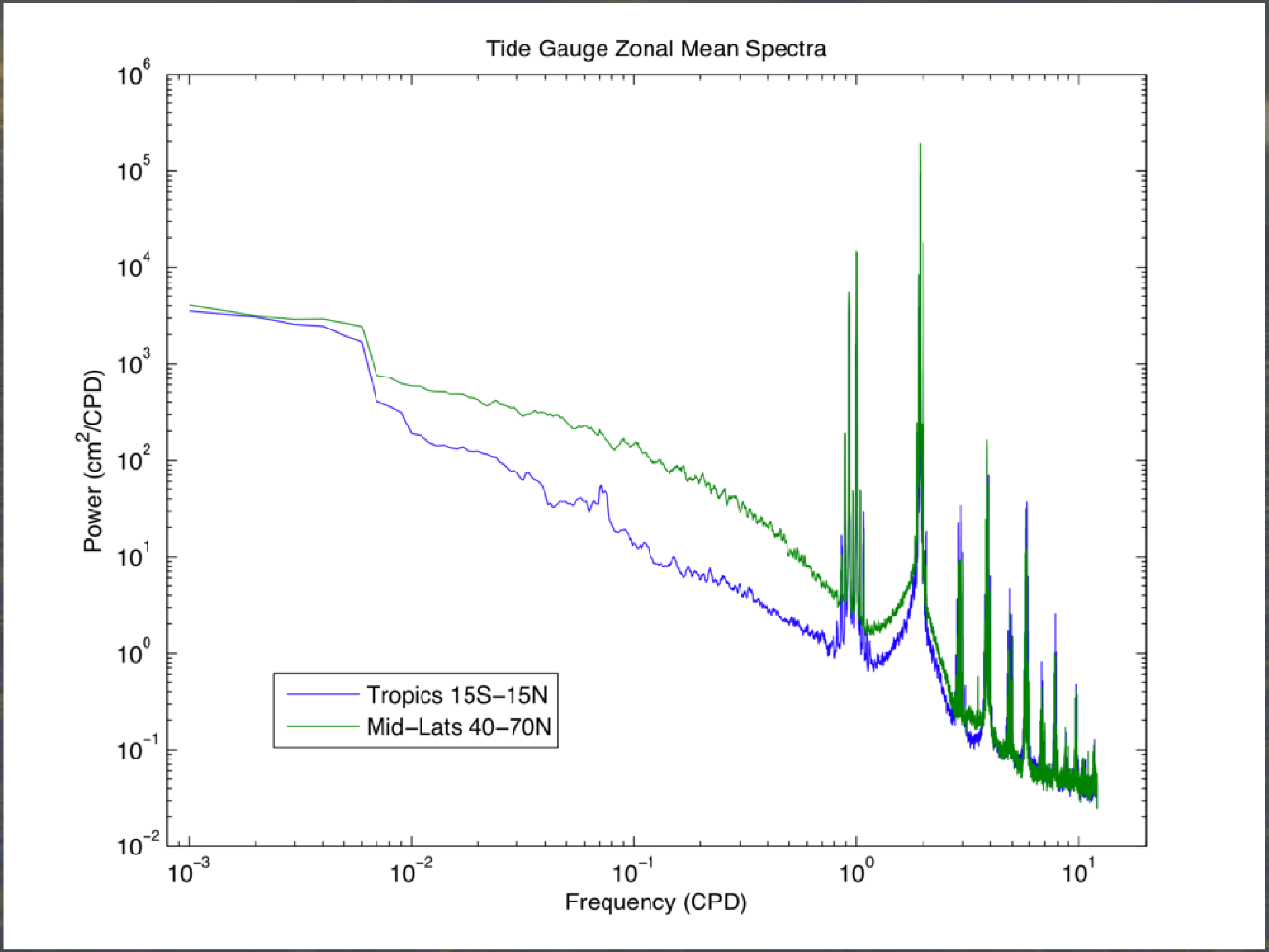


Source: AVISO website

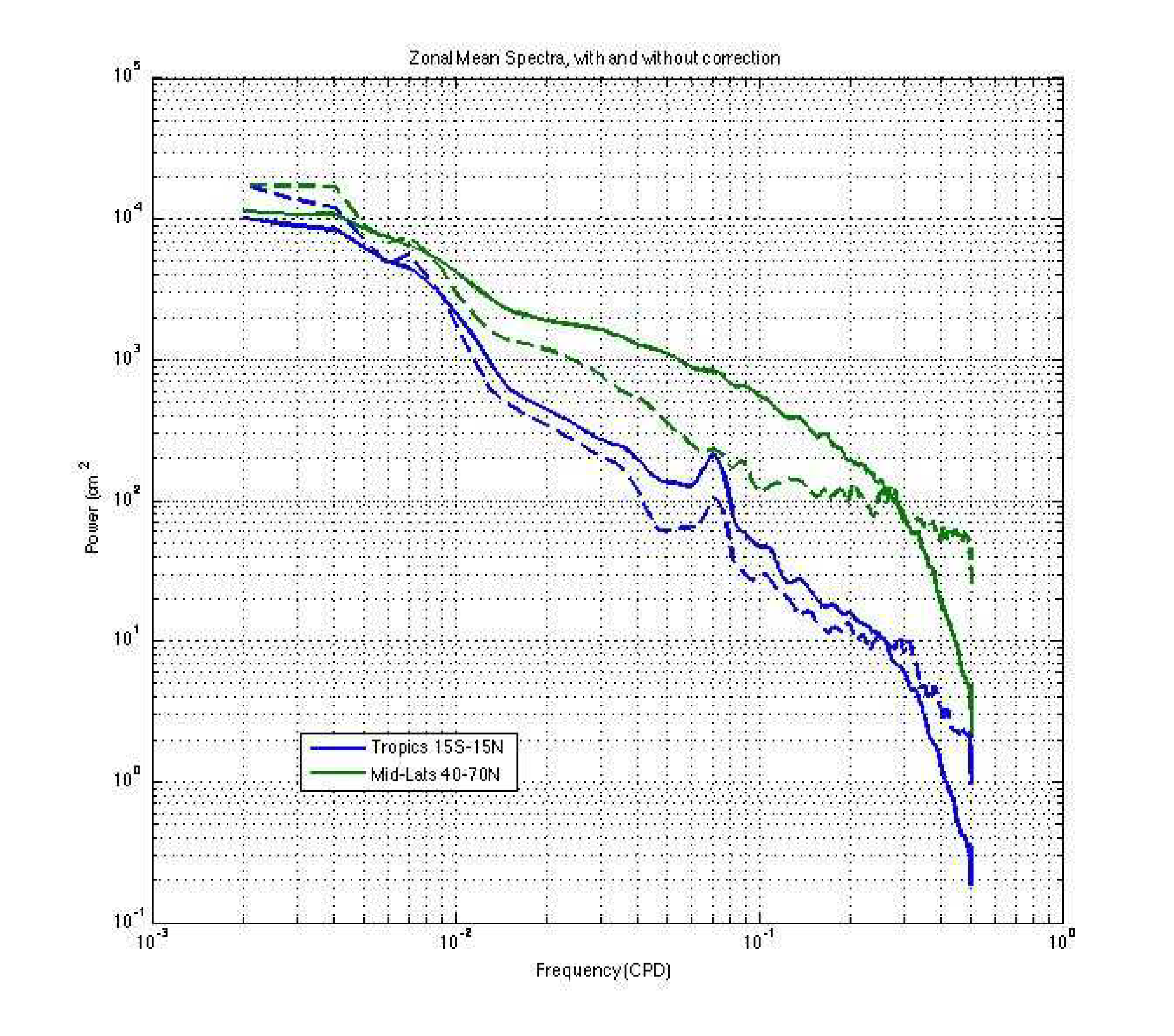
Temporal variability from tide gauges



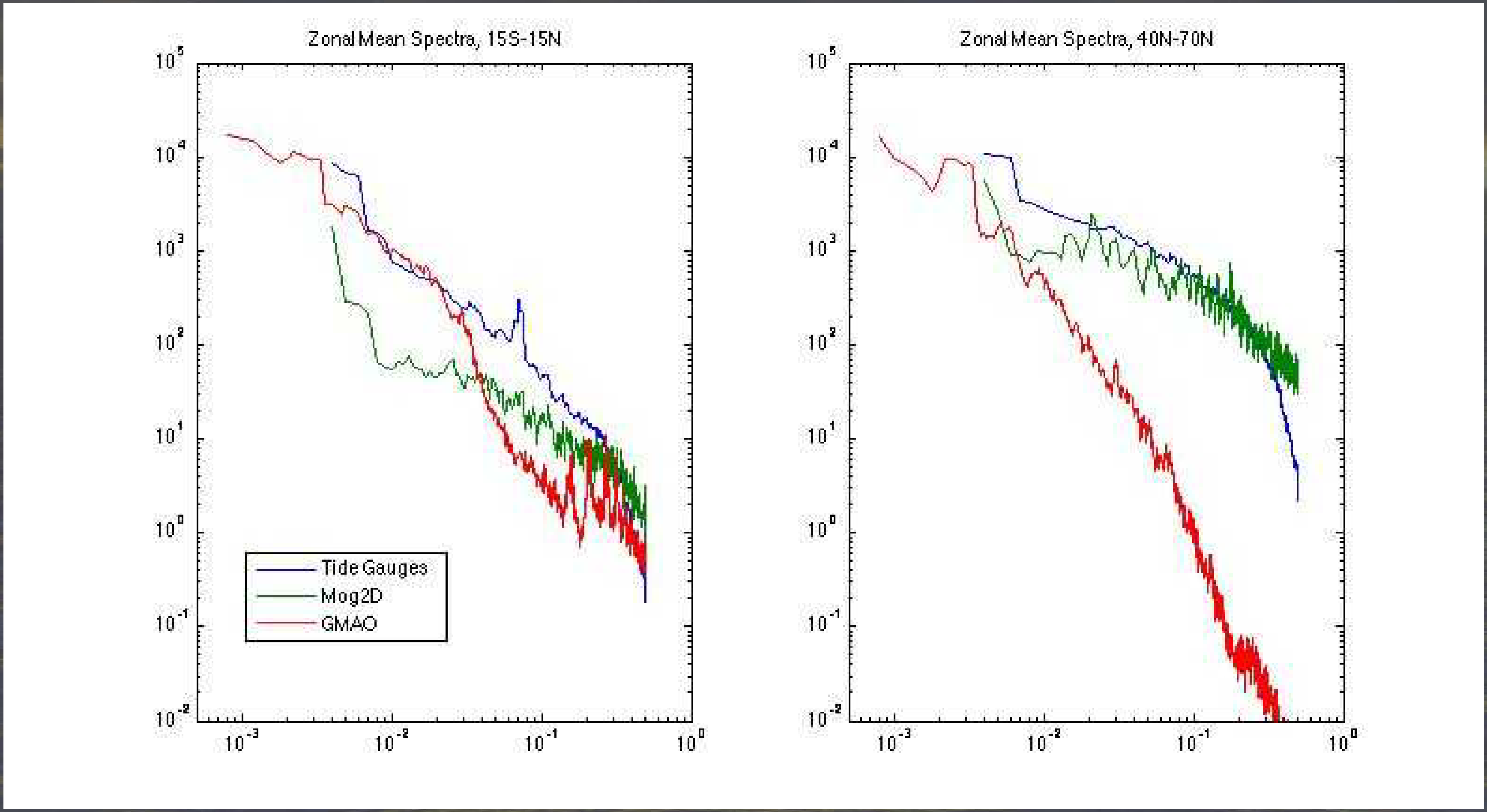
Greater atmospheric effects at higher latitudes



Tide gauge spectra after MOG2D correction

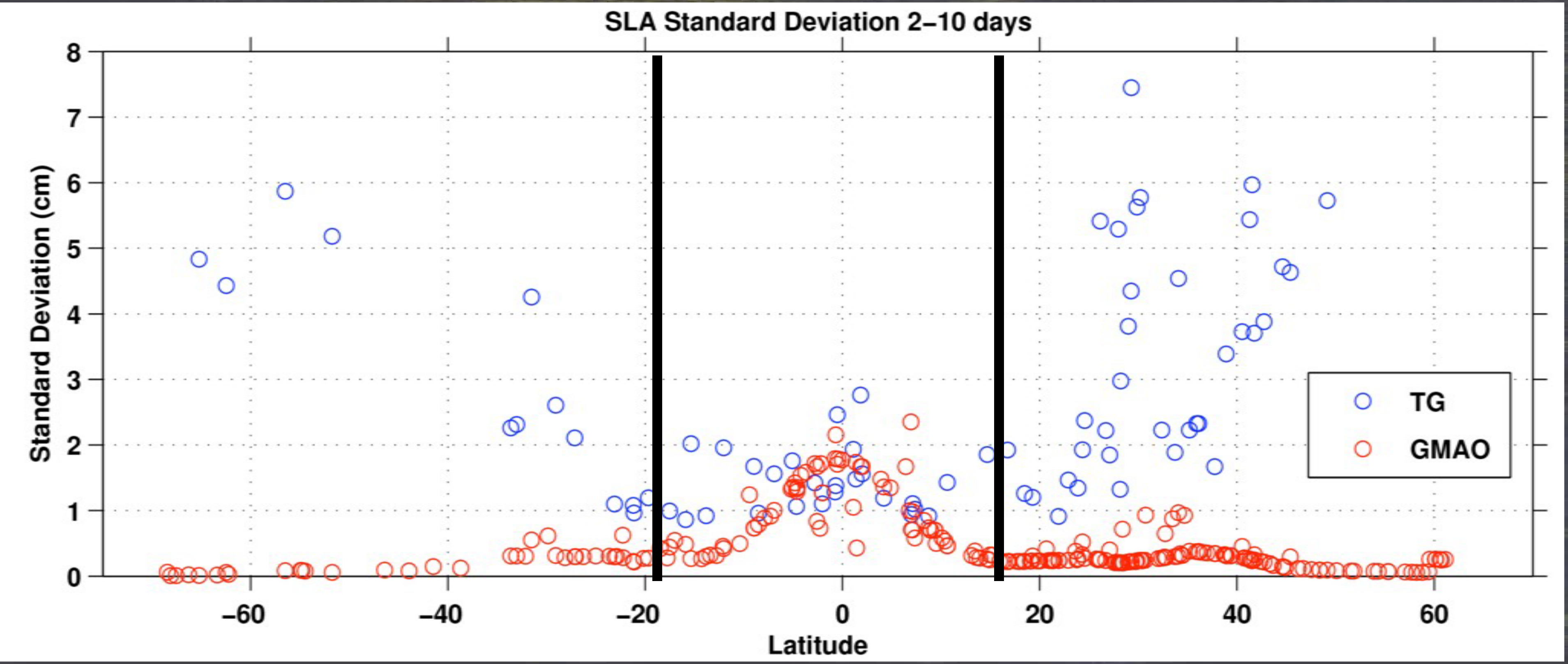


GMAO Poseidon, Mog2D, and TG Spectra

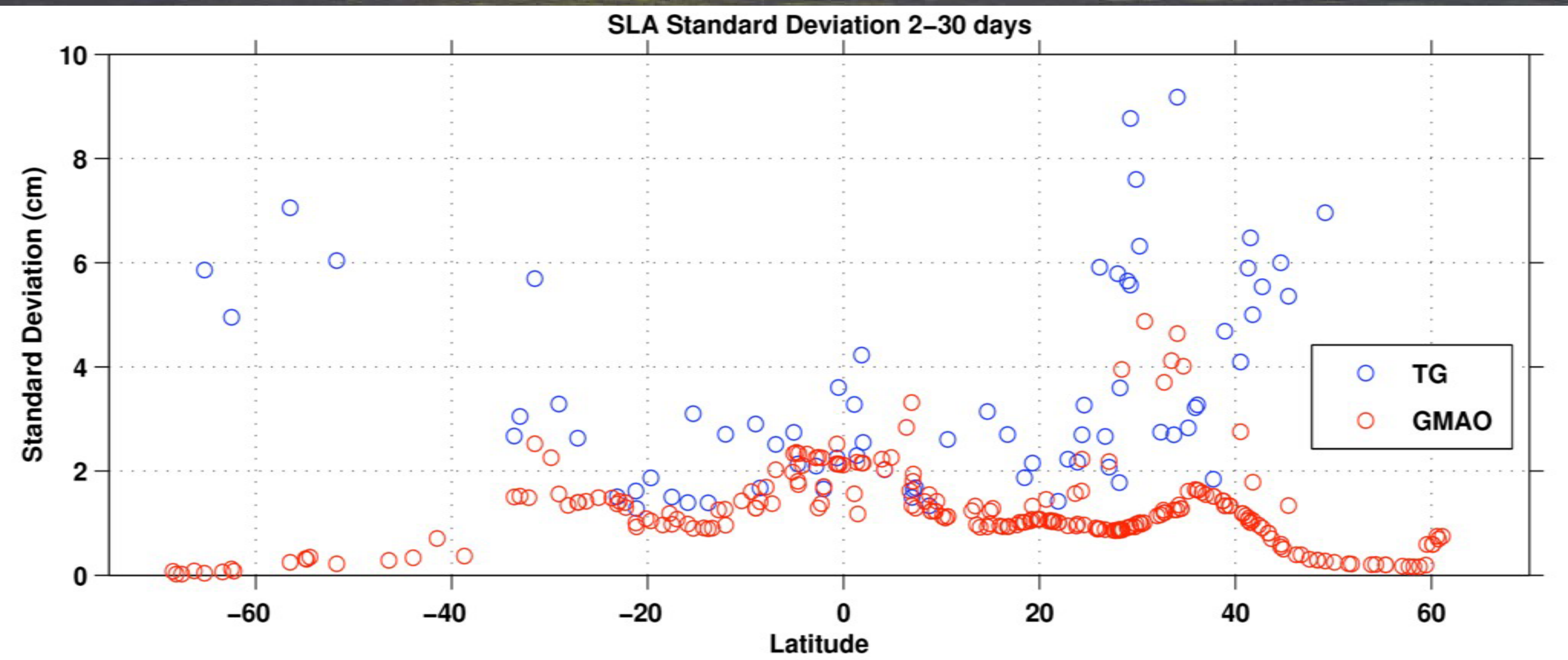


Variability at higher latitudes and higher frequencies is predominantly barotropic, and is reproduced well by the Mog2D model output (obtained from AVISO); frequency is in cycle/day, spectral power is in cm2day/cycle.

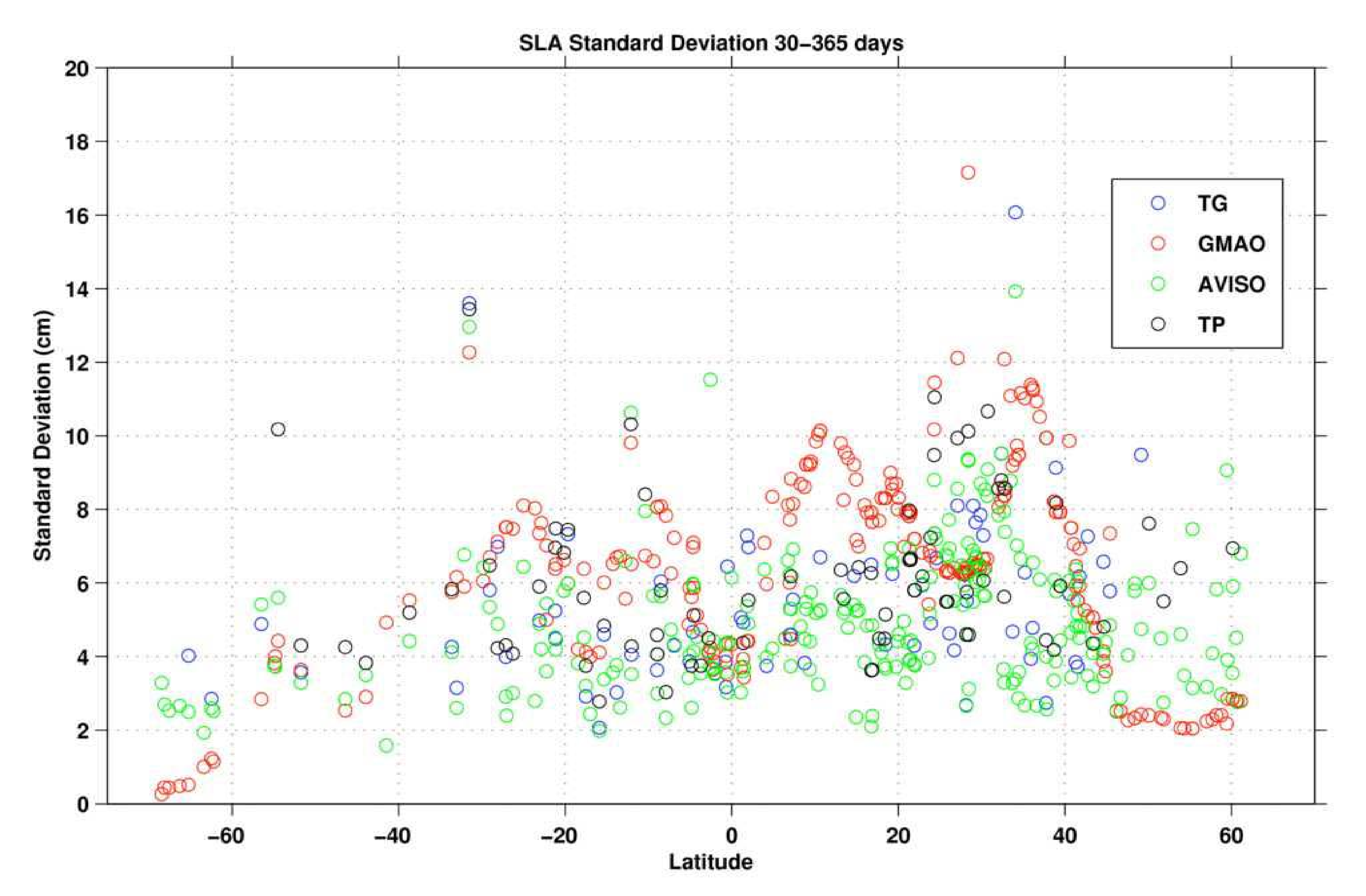
Tide gauge variance is calculated from daily-averaged time series from University of Hawaii database. Tides are removed by harmonic analysis, and atmospheric effects are reduced using correction series from the MOG2D model. Multi-taper spectra are calculated from these adjusted time-series, and then integrated over desired frequency ranges.



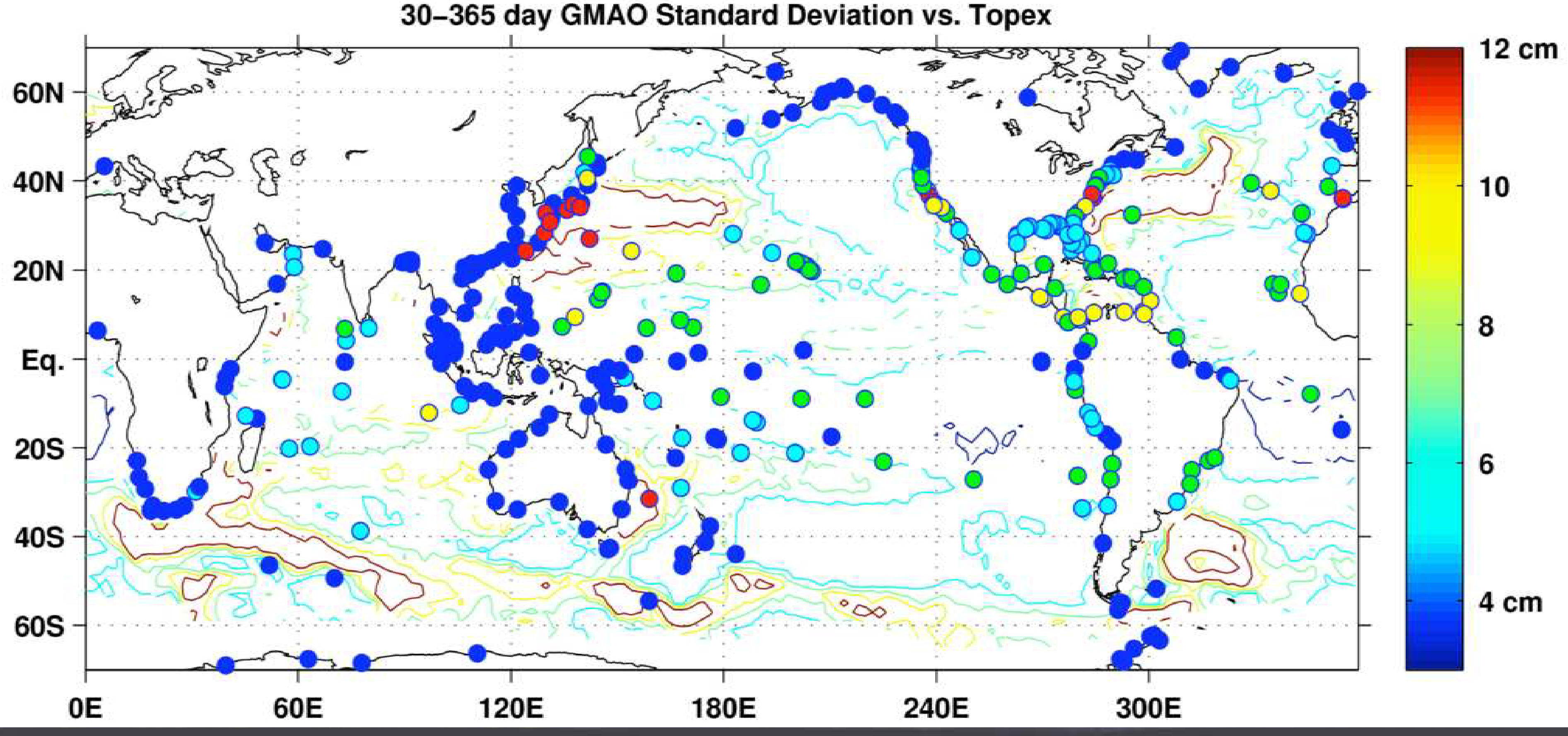
At submonthly time scales baroclinic variability simulated by the reduced-gravity GMAO Posiedon is comparable to the total sea level height variability from tide gauges in the large area of tropics (for 2-10 days variability on the previous slide it compared well only near Equator).



Model variability on monthly-to-annual timescales is much larger and generally comparable to observations. This figure includes tide gauges, AVISO gridded weekly altimetry, and along-track Topex/Poseidon data (10-day repeat). The model tends to overestimate variability at certain peaks (25S, 10S, 15N, 35N), and still underestimates at extreme latitudes.



Baroclinic variability, simulated by the reduced-gravity version of the GMAO Poseidon model, is compared here at the tide gauge locations to the map of monthly-to-annual variability from Topex/Poseidon altimetry.



Conclusions and Outlook

1. We performed a systematic intercomparison of spatial and temporal variability of sea surface heights in satellite altimetry, tide gauges, and ocean model simulations (baroclinic and barotropic components).
2. More work is needed targeted at constraining short-term and small-scale area of wavenumber-frequency spectra, which truly controls a component of the observational error due to imperfect sampling/inconsistent averaging.

Special thanks to our GMAO collaborators:
Michele Rienecker, Christian Keppenne, and Jossy Jacob

Joint Center for Satellite Data Assimilation