Sea level variability from surface loading effects neglected in volume-conserving models

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Summary

Forcing by freshwater fluxes implies variable surface loads that are not treated in volume-conserving ocean models. Under the assumption of an equilibrium response, such surface loads merely lead to spatially uniform fluctuations in mean sea level, which carry no dynamical significance. A barotropic model forced by realistic freshwater fluxes is used to test the validity of the equilibrium assumption on seasonal to daily timescales. The simulated departures from equilibrium have amplitudes at least two orders of magnitude weaker than those of the forcing. Such dynamic signals are nevertheless not small compared to those of a pure equilibrium response, particularly at submonthly periods. Standard deviations of nonequilibrium signals are below 1 mm over most of the deep ocean. Larger values (up to 1 cm) can be found in some shallow and semi-enclosed seas. In comparison, non-equilibrium signals driven by atmospheric pressure loading are an order of magnitude larger, except in a few shallow, coastal regions in the tropics, and at low frequencies in general, for which forcing by freshwater flux is much stronger than by

Motivation

- Do we need to worry about sea level variability not usually considered in volume-conserving or Boussinesq models?
- Does a correction based on equilibrium response to loading by such volume-changing effects work?
- Do such effects matter for interpretation of low frequency variability in sea level?
- Do such effects introduce variability at high frequencies that one may want to model when dealiasing satellite data?

Model and forcing

- Shallow-water dynamics on a sphere
- Barotropic numerical model on a 1.125x1.125 degree grid
- Forced by freshwater fluxes from ECMWF reanalysis (ERA-40) for year 2001
- Equilibrium sea level solution is simply the time integral of the net freshwater flux over the ocean

Domain and topography

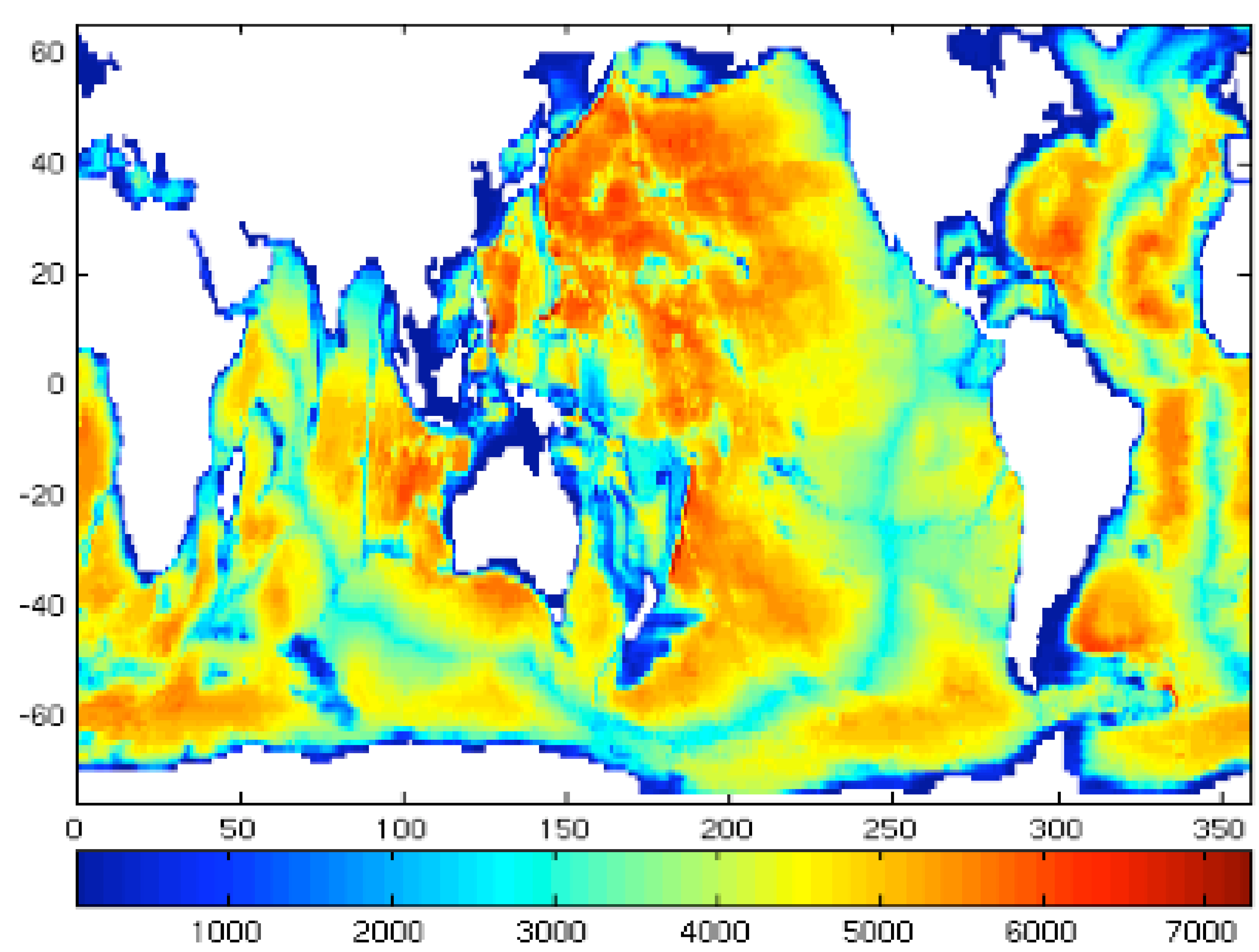

Figure 1. Coastal geometry and bottom topography in meters. Note the shallow regions and semi-enclosed areas included in the model domain and the exclusion of the Arctic.

Standard deviation of forcing

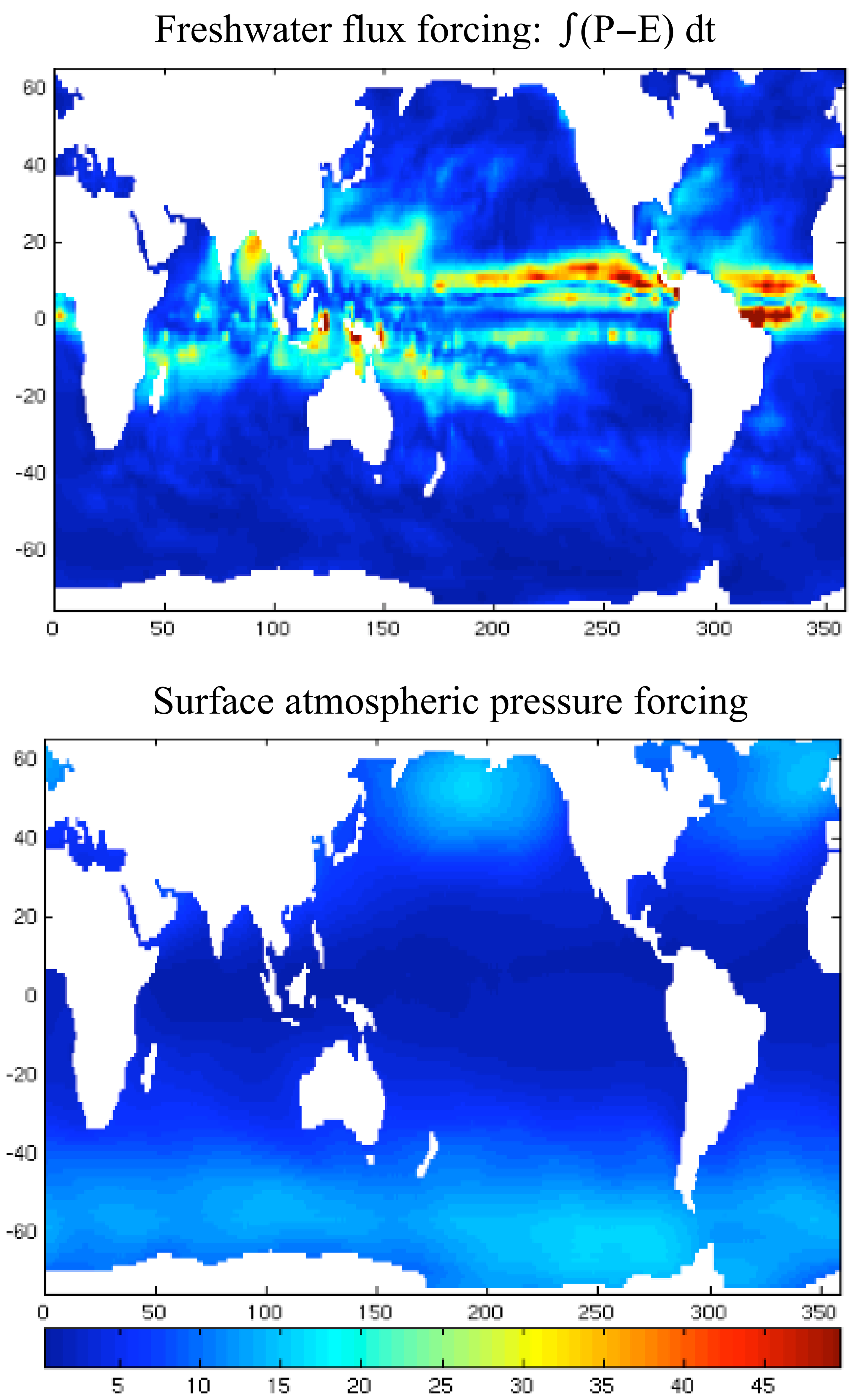

Figure 2. Comparison of variability in freshwater forcing and surface pressure forcing in equivalent centimeters of water. Detrended series have been used.

Forcing spectra

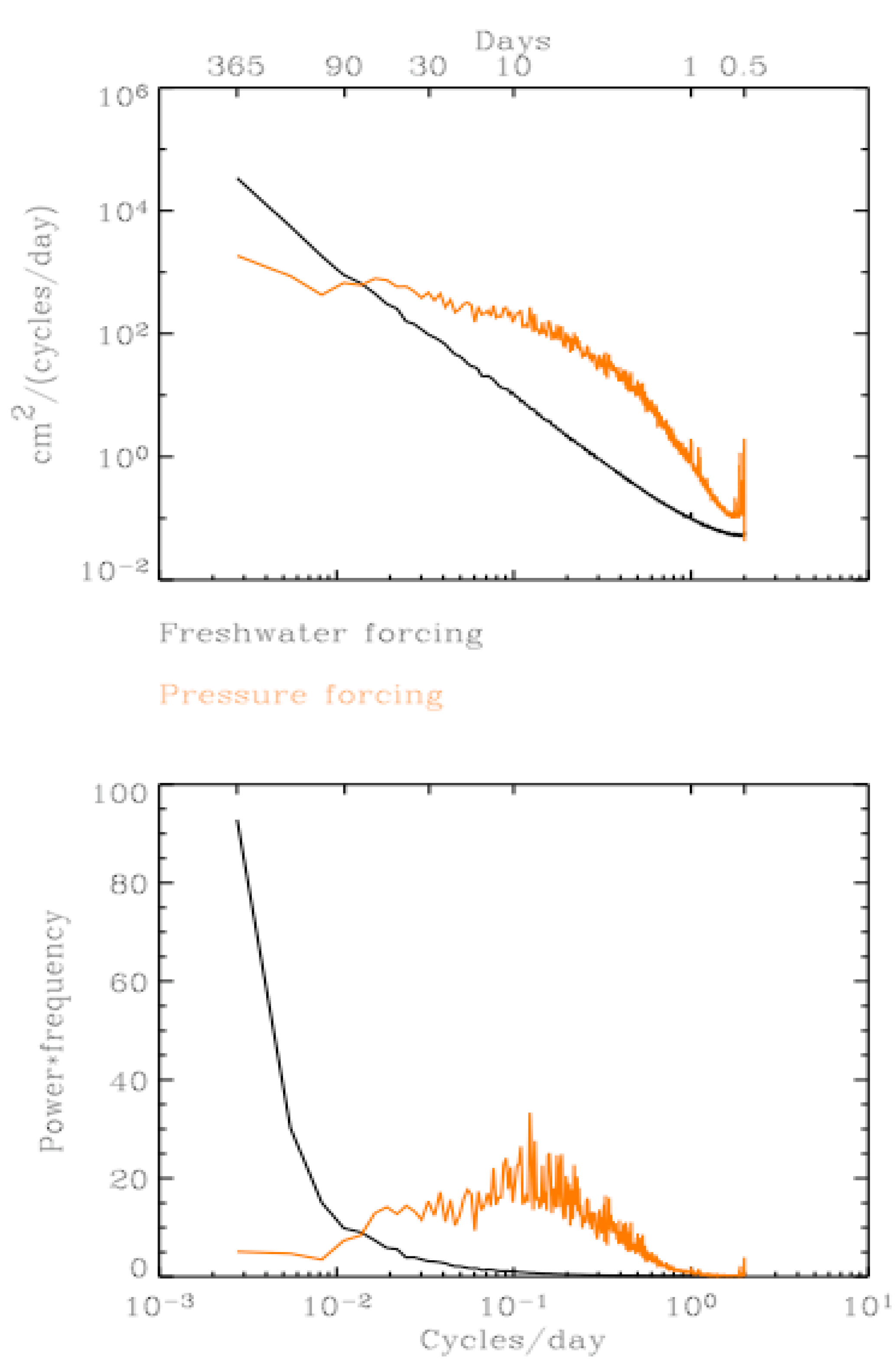

Figure 3. Comparison of freshwater and surface atmospheric pressure forcing spectra obtained by averaging the periodograms from all ocean model grid points. Bottom panel shows same spectra plotted in variance-preserving form.

• Freshwater forcing can be much stronger than pressure forcing, particularly in the tropical regions

• Most variance in freshwater forcing contained at seasonal timescales, in contrast with pressure forcing

Response to freshwater forcing

Deviations from equilibrium

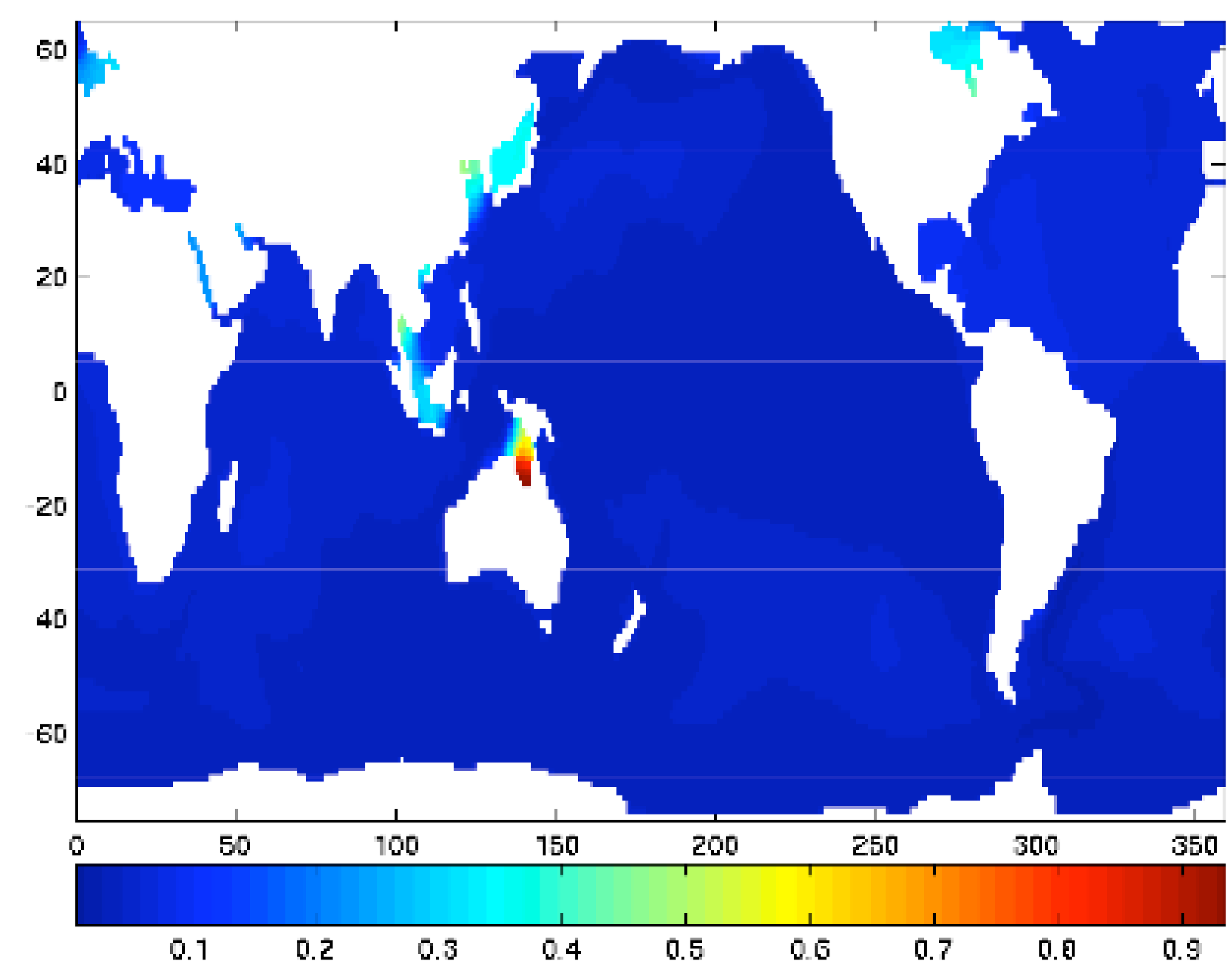

Figure 3. Standard deviation of dynamic sea level (cm) or root-mean-square amplitude of departures from an equilibrium response.

Some local time series

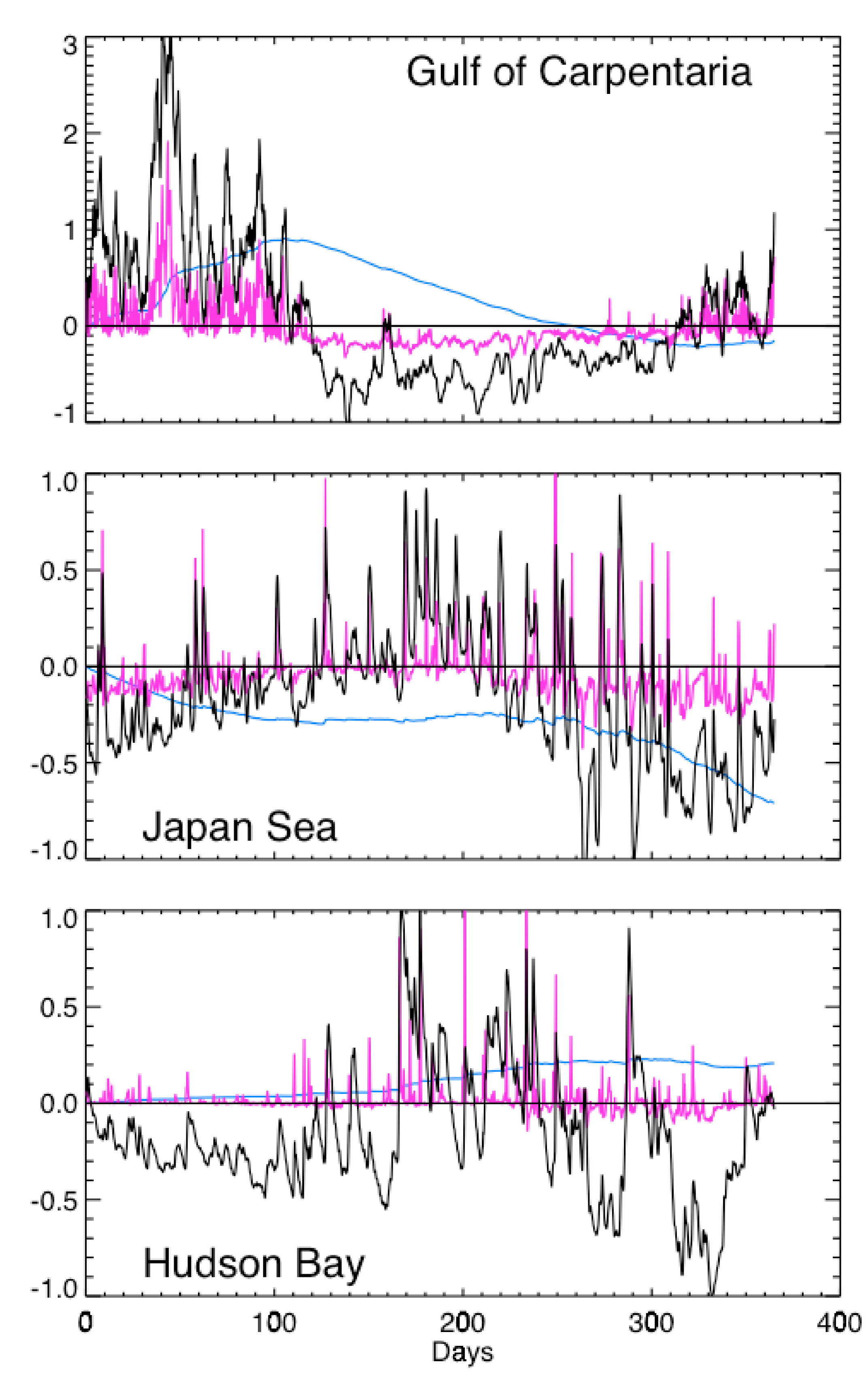

Figure 4. Amplitude of the dynamic sea level signal (black; units of *cm*), forcing (blue; units of *m*), and precipitation minus evaporation (magenta; accumulated water over 6 hours in *cm*) for 3 regions with enhanced nonequilibrium response in Figure 3.

• Nonequilibrium signals forced by freshwater fluxes are < 1 mm rms over deep ocean, largest signals (~1 cm rms) in shallow and constricted coastal regions

• Slow variability dominates the forcing but largest nonequilibrium signals are on rapid timescales (tendency for dynamic response increases with frequency)

• Visible signals at monthly and longer time scales

• Rapid dynamic signals apparently connected to local forcing, nonlocal effects important for longer period signals (e.g., in Hudson Bay over first few months)

Comparison of dynamic response under freshwater and pressure forcing

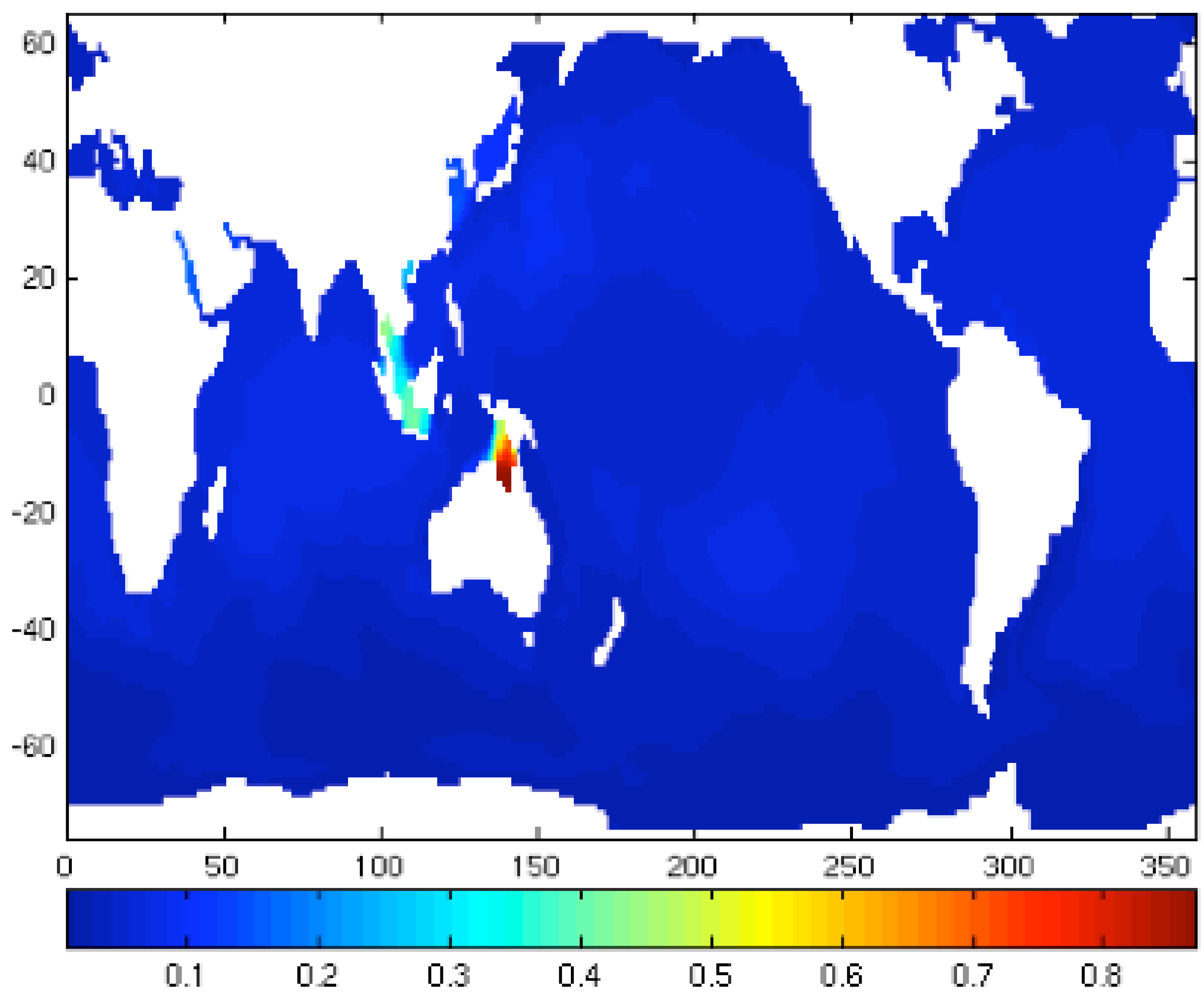

Figure 5. Ratio of the standard deviation of nonequilibrium signals forced by freshwater fluxes to that that of nonequilibrium signals forced by atmospheric pressure.

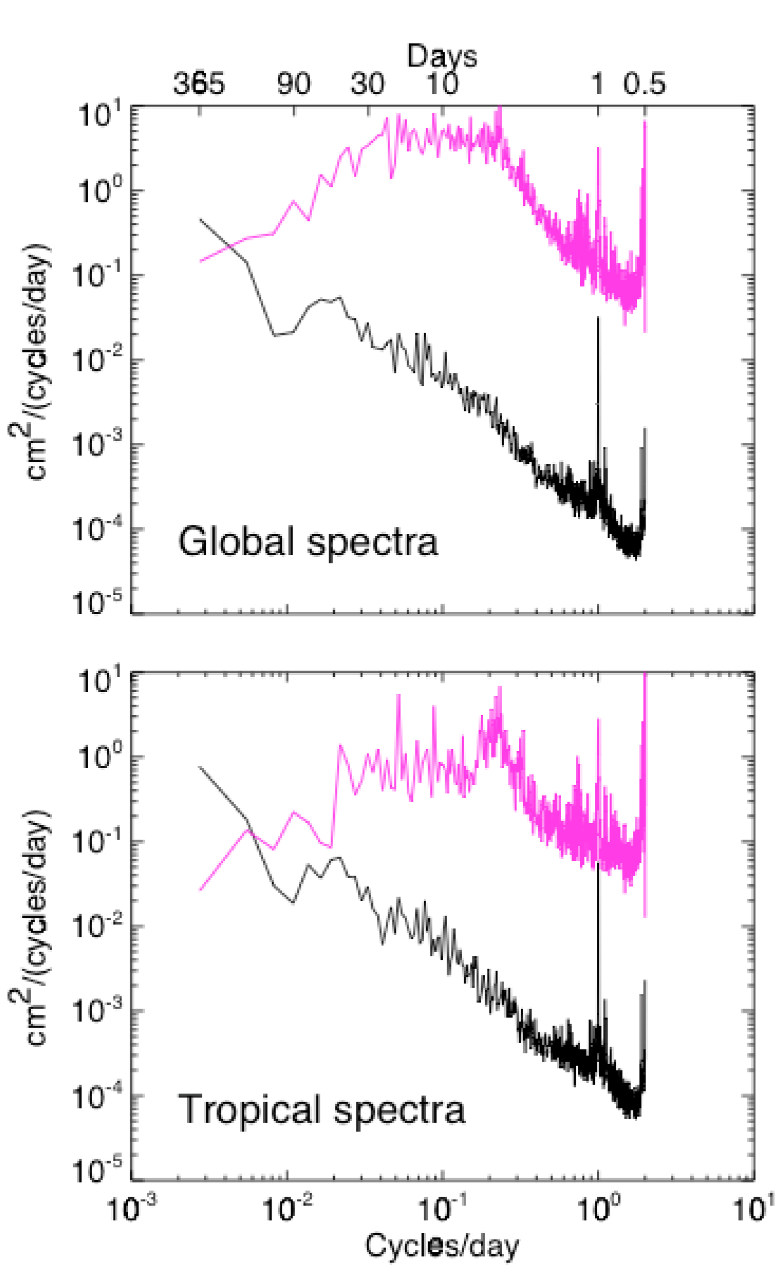

Figure 6. Spectra of nonequilibrium sea level signals forced by freshwater fluxes (black) and pressure (purple) obtained by averaging the periodograms for global and tropical oceans.

• Dynamic sea level variance from freshwater effects negligible compared to that from pressure effects except in some low latitude coastal regions and at seasonal timescale

• Stronger dynamic response to pressure at high frequencies consistent with the stronger forcing

How good is equilibrium assumption?

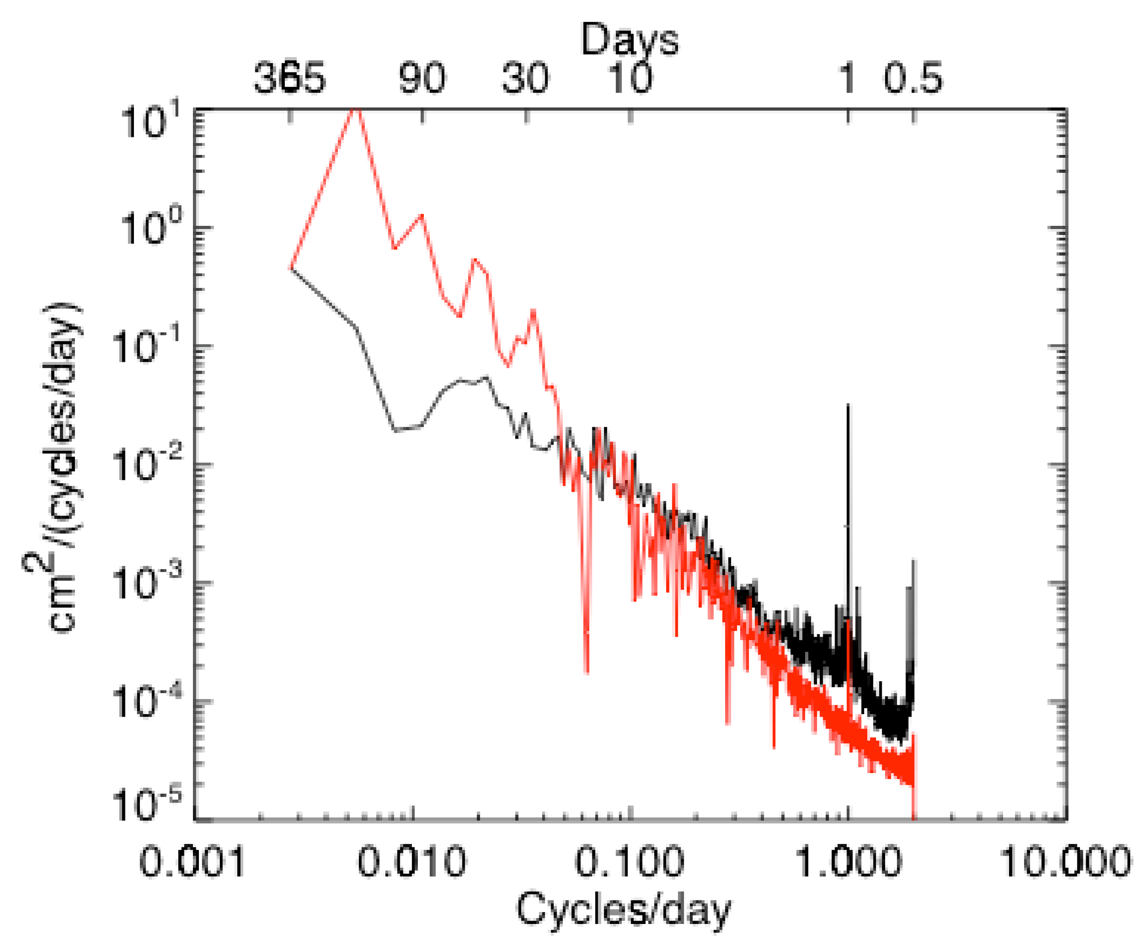

Figure 7. Spectra of nonequilibrium (black) and equilibrium (red) sea level signals.

• Based on relative amplitude of spectra in Figure 7, equilibrium assumption not a good one at submonthly periods, possibly also at the annual period

Some final points

• Equilibrium assumption not strictly applicable over a large range of frequencies, mostly because equilibrium signal is small residual of the local freshwater flux forcing

• Neglect of freshwater surface loads unlikely to induce errors larger than 1 cm rms

• Implementation of freshwater forcing in barotropic modeling relatively straightforward

• Usefulness of such modeling approach to improve estimation of seasonal cycle or dealiasing procedures still to be tested against data