Direct temporal cascade of temperature variance in eddy-permitting simulations of multidecadal variability

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Motivations

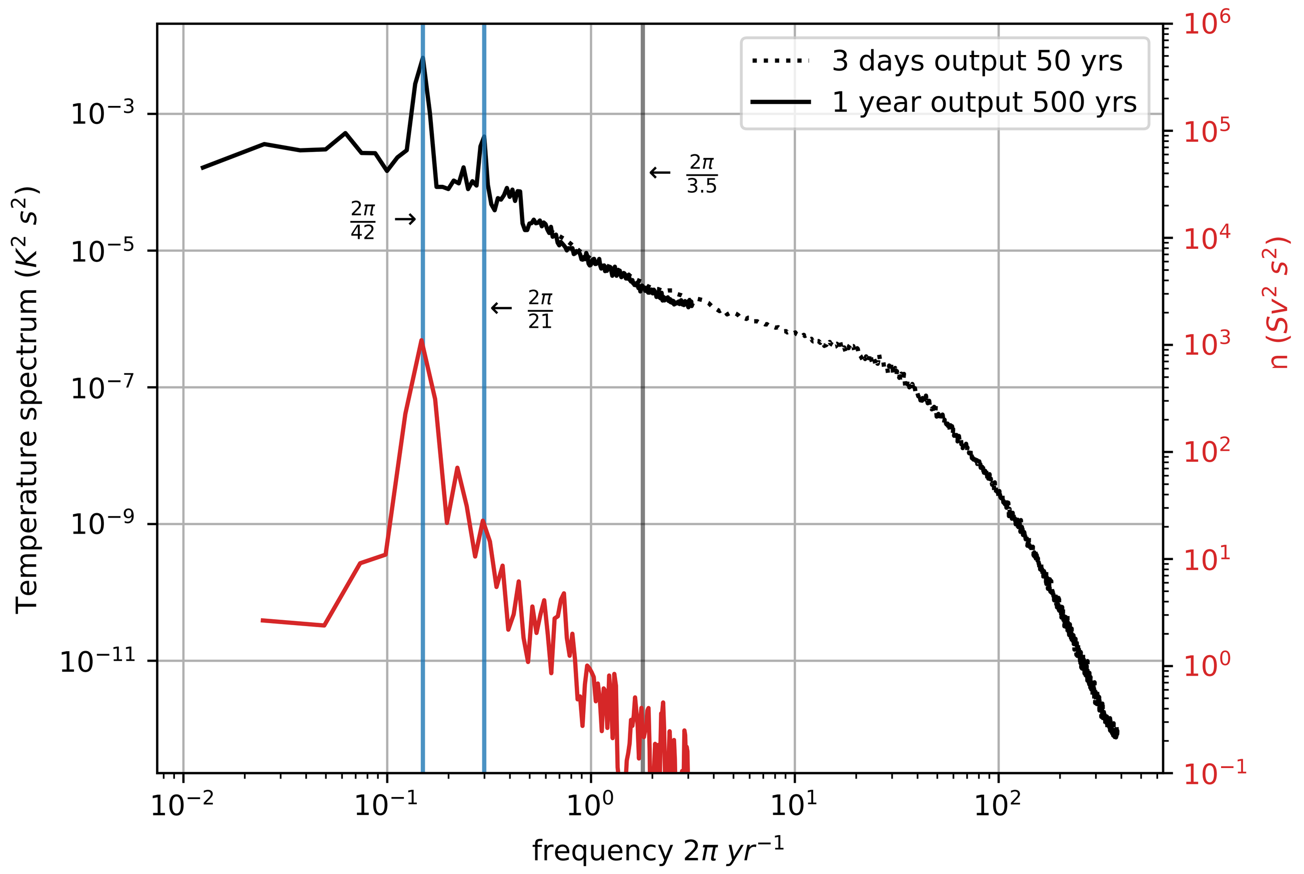
The existence of basin-scale multidecadal fluctuations of the North Atlantic Sea Surface Temperature (SST) is long established.

One of the mechanism proposed to explain the observed low frequency SST variation is related to intrinsic unstable interdecadal ocean modes. The mode's existence was first shown in a rectangular flat-bottomed single-hemispheric basin, with prescribed surface heat fluxes and Planetary Geostrophic dynamics (Greatbatch 1995).

In this configuration, a large scale baroclinic instability continuously feeds large scale planetary waves (Colin de Verdiere & Huck 1999). The planetary waves give rise to SST and Meridional Overturning Circulation variability.

The study of Huck et al. 2015 suggested that the large-scale mode is robust to meso-scale turbulence. However, the interaction between the low frequencies and the high frequencies associated with turbulence is an open question (Arbic et al. 2014). For instance, can the meso-scale turbulence be a source term for the low frequency variability ?

We answer this question using a numerical experiment allowing both high and low frequencies and a new diagnostic of temperature variance fluxes in frequency space.



Volume average of the temperature spectrum as a function of frequency calculated from 1 year average output over 500 years (black line) and 3 days average output over 50 years (dashed black line).

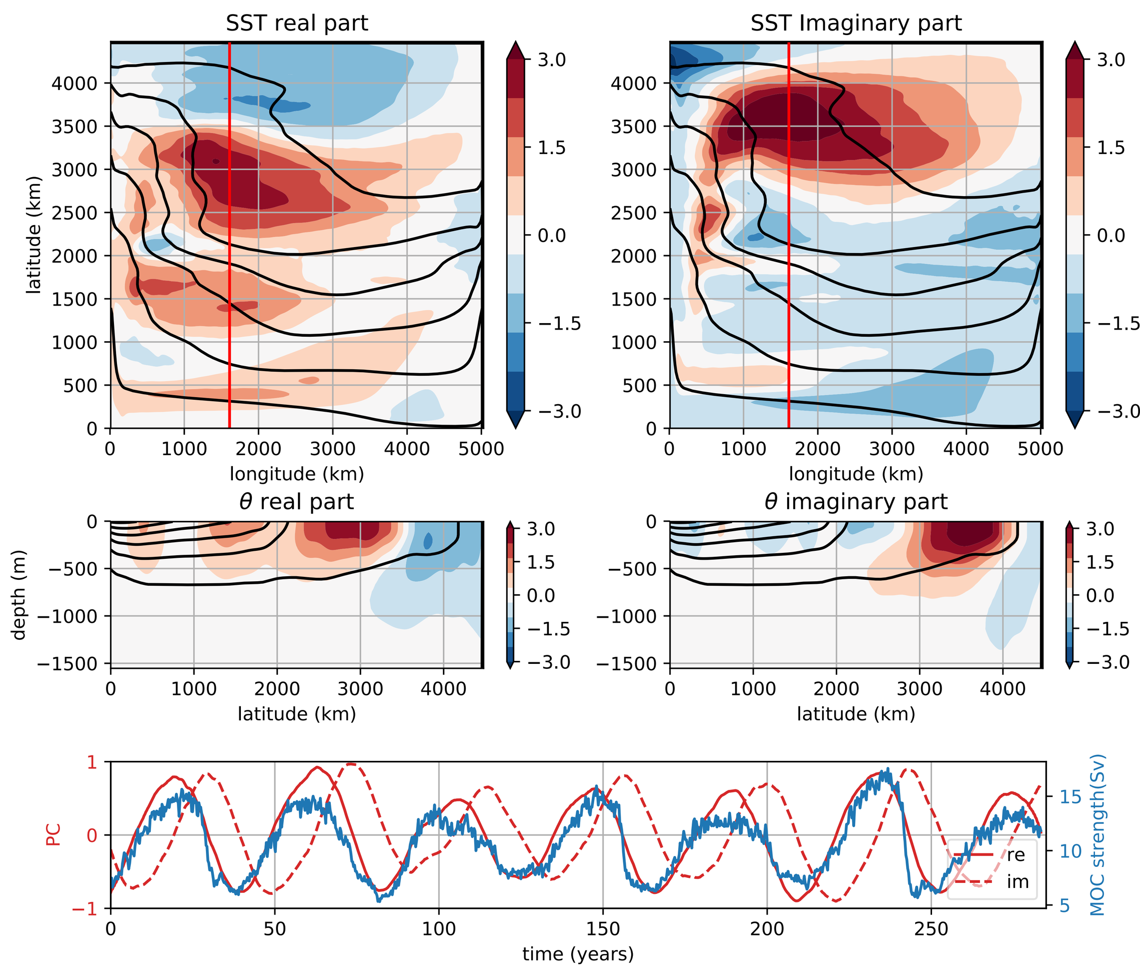
Numerical setup

MITgcm, rectangular flat bottom basin with a Cartesian geometry on a β-plane.

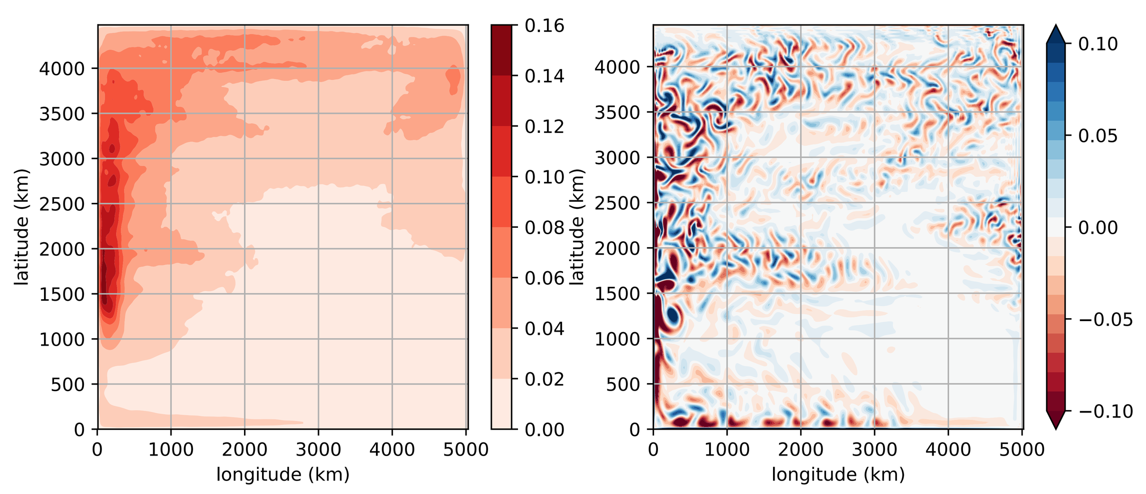
Linear equation of state for density with constant salinity

Eddy permitting resolution of 20 km, 40 levels.

Forced by zonally uniform steady heat flux at the surface, zero wind stress.



First Complex EOF accounting for 60% of the variability. Top left: real part, top right imaginary part. Middle left: real part of the meridional section shown by a red line on the top panels, middle right: imaginary part. Black contours show isotherms of the time mean temperature. Bottom: real (red plain) and imaginary (red dotted) part of the principal component. The blue line shows the MOC strength.



Left: standard deviation of Sea Surface Height (in m) Right: snapshot of the ratio of the surface relative vorticity $\partial_x v - \partial_y u$ and f.

Diagnostic of temperature variance fluxes in frequency space

$\theta = \overline{\theta} + \theta'$ with $\overline{\theta}$ the time mean and θ' the anomaly

$$\frac{\partial \theta'}{\partial t} = -\overline{\mathbf{u}} \cdot \nabla \theta' - \mathbf{u}' \cdot \nabla \overline{\theta} - \mathbf{u}' \cdot \nabla \theta' + \overline{\mathbf{u}' \cdot \nabla \theta'} + \mathrm{D}'.$$

Temperature spectral transfers are calculated by multiplying the discrete Fourier Transform in time of each component by the conjugate of the Fourier transform of θ at every grid point, and integrated over the 3D domain.

$$\mathrm{Tr}_{\mathrm{mean}}(\omega) = -\int_V \Re\left(\hat{\theta}'^*(\omega)\left(\widehat{\overline{\mathbf{u}}.\nabla\theta'}(\omega) + \widehat{\mathbf{u}'.\nabla\overline{\theta}}(\omega)\right)\right)\mathrm{d}V,$$

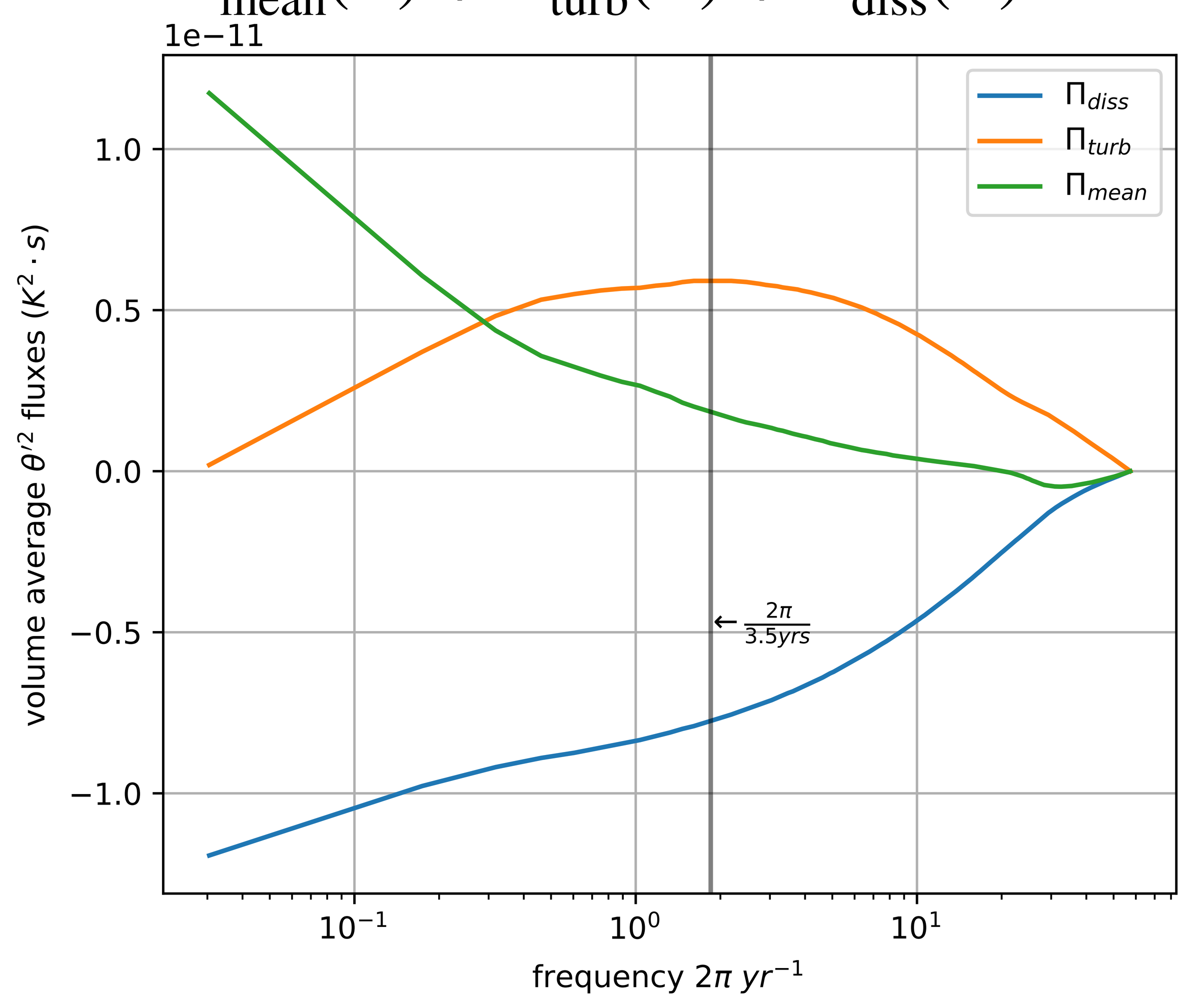
$$\mathrm{Tr}_{\mathrm{turb}}(\omega) = -\int_V \Re\left(\hat{\theta}'^*(\omega)\left(\widehat{\mathbf{u}'.\nabla\theta'}(\omega)\right)\right)\mathrm{d}V,$$

$$\mathrm{Tr}_{\mathrm{diss}}(\omega) = \int_V \Re\left(\hat{\theta}'^*(\omega)\widehat{\mathrm{D}'}(\omega)\right)\mathrm{d}V$$

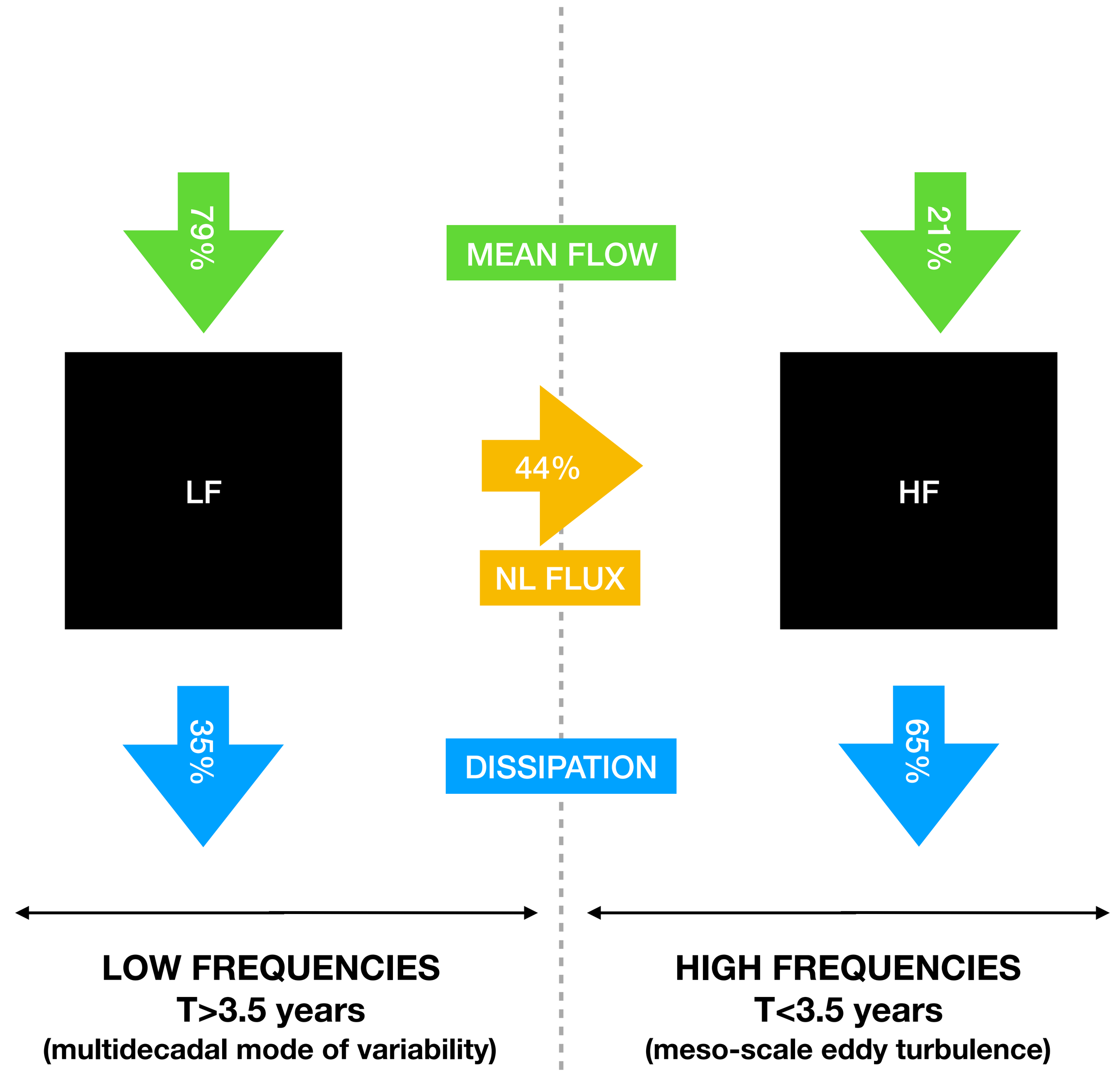
If $Tr_X(\omega) > 0$ (< 0) then X (mean, turb or diss) acts to increase (decrease) the temperature variance at frequency ω.

$$\Pi(\omega) = \int_{\omega}^{\omega_{max}} \mathrm{Tr}(\omega')\mathrm{d}\omega',$$

$$\Pi_{\mathrm{mean}}(\omega) + \Pi_{\mathrm{turb}}(\omega) + \Pi_{\mathrm{diss}}(\omega) = 0$$



Temperature variance fluxes as a function of frequency for Π_{diss} (blue), Π_{turb} (orange) and Π_{mean} (green) The vertical line at $2\pi/3.5$ years corresponds to the maximum of Π_{turb} and is used to separate the High and Low-Frequencies



Schematic showing the temperature variance fluxes between low-frequencies reservoir and high-frequencies reservoir. All percentage are expressed with respect to the total flux of temperature variance from the mean flow $\Pi_{\mathrm{mean}}(\omega_{min})$.

Conclusion

In our idealized simulations,

-High-frequencies are a sink of temperature variance for the low-frequencies.

-The turbulent flux of temperature variance from low to high-frequencies compensates the unbalance between mean flow forcing and dissipation at low and high-frequencies

References:

Greatbatch & Zhang 1995 Jclim *An interdecadal oscillation in an idealized ocean basin forced by constant heat flux*

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