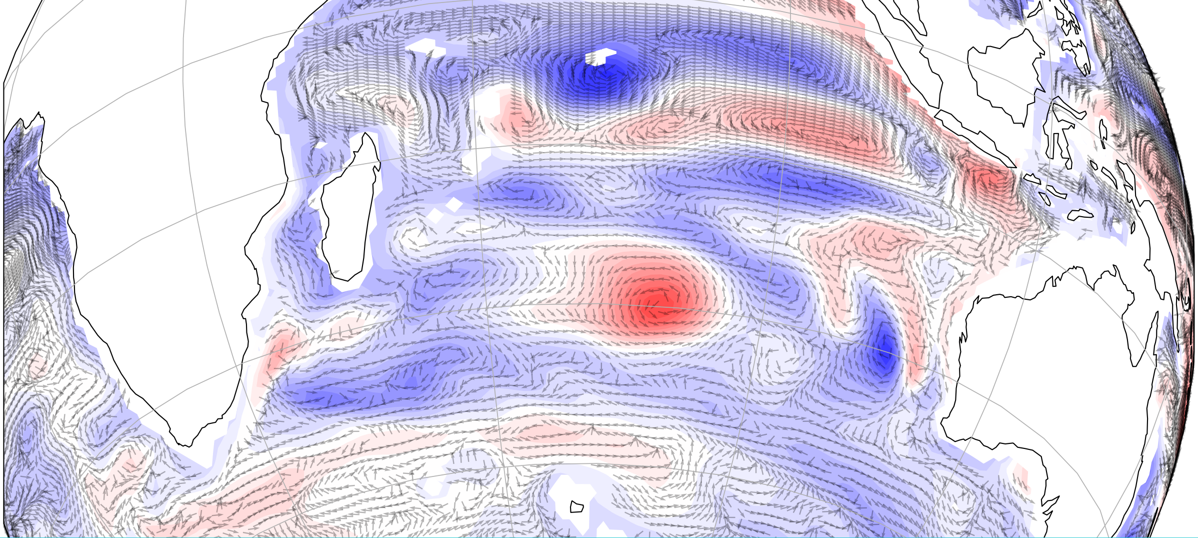


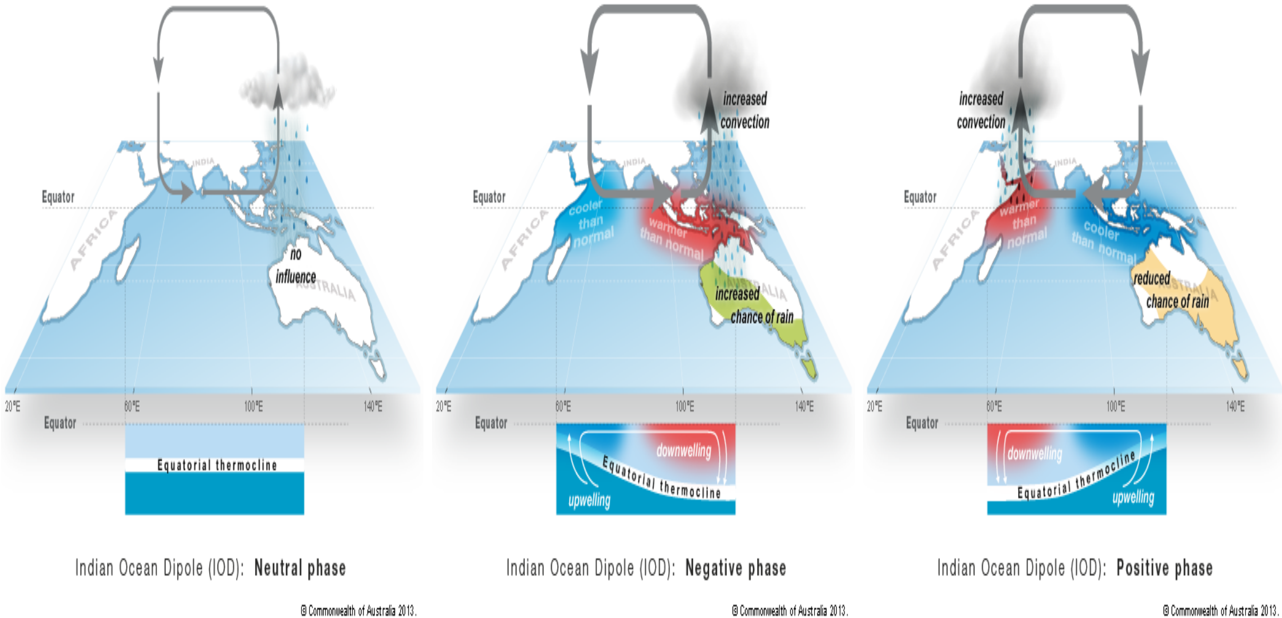
Subsurface variability and teleconnections in the Indian Ocean

Chris Chapman, Bernadette Sloyan, Terry O'Kane

Didier Monselasen, Matt Chamberlain, James Risbey

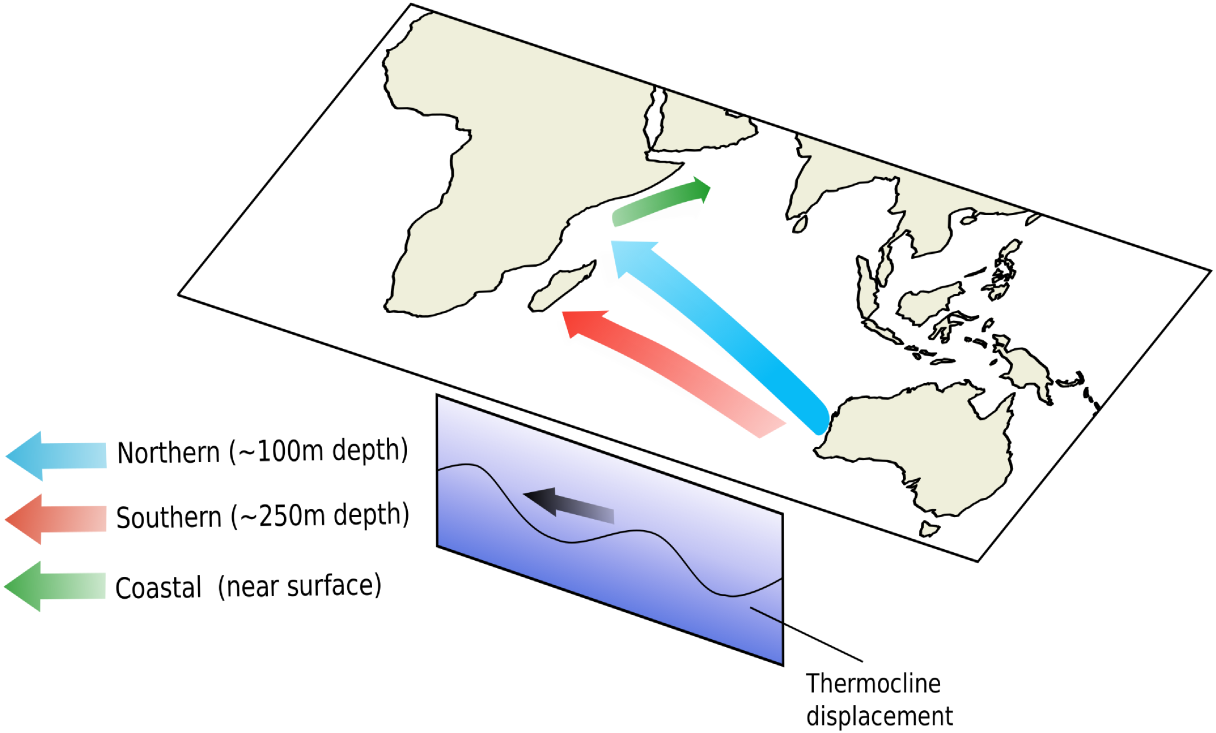
CSIRO Oceans and Atmosphere Decadal Forecasting Project
www.csiro.au

Variability and Circulation in the Indian Ocean



Source: Commonwealth Bureau of Meteorology

Physical Mechanism of Teleconnection



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Physical Mechanism of Teleconnection

- Some signature in SSH altimetry (Briol & Morrow 2000);
- Intrinsic mode found in long, ocean-only, coarse resolution models (O'Kane et al. 2014; Wolff & Cessi 2016) and SODA reanalysis (Vargas-Hernandez et al. (2014);
- Possible signature in sea-surface salinity (Menendez et al. (2015);
- Not yet noted in in-situ measurements (we're working on it).

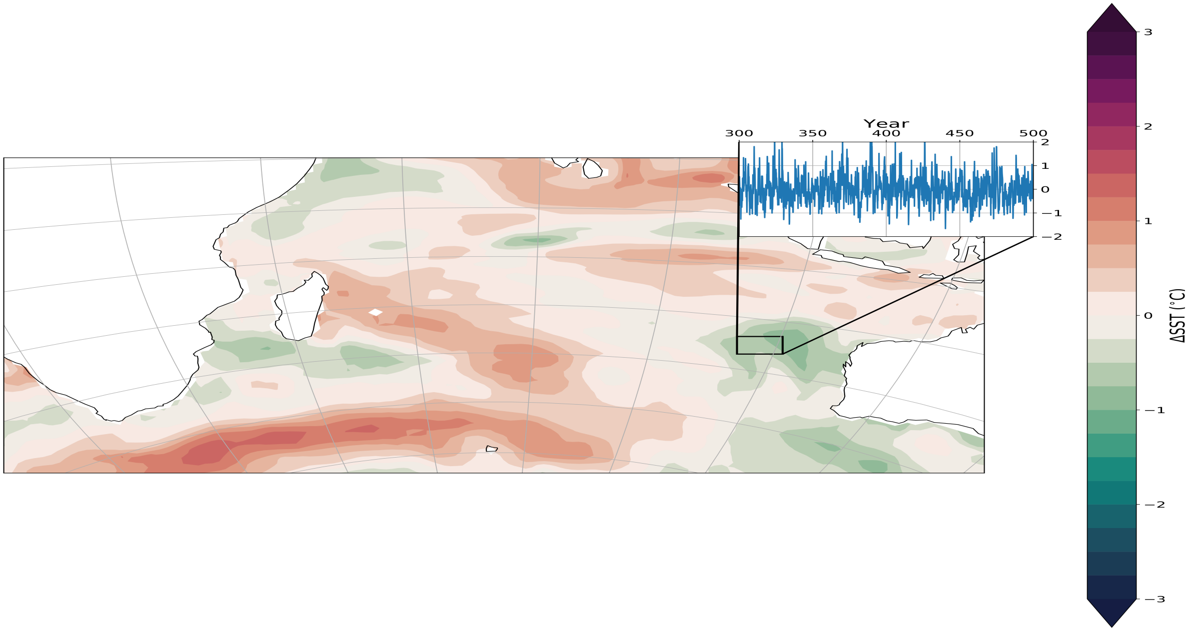
Coupled Climate Model

- We use the DFP's Climate Analysis Forecast Ensemble (CAFÉ) modelling system (O'Kane et al. 2018);
- Very similar to GFDL's CM2.1 (modified ocean grid);
- MOM4 ocean model; AM2 atmosphere; SIS sea-ice; LM2 land surface;
- $\sim 1^\circ$ grid in the ocean, telescopes to $\sim 1/3^\circ$ near the equator, 2.5° in the atmosphere;
- Restoring to WOD climatology below 2000m depth (1 year restoring time scale);

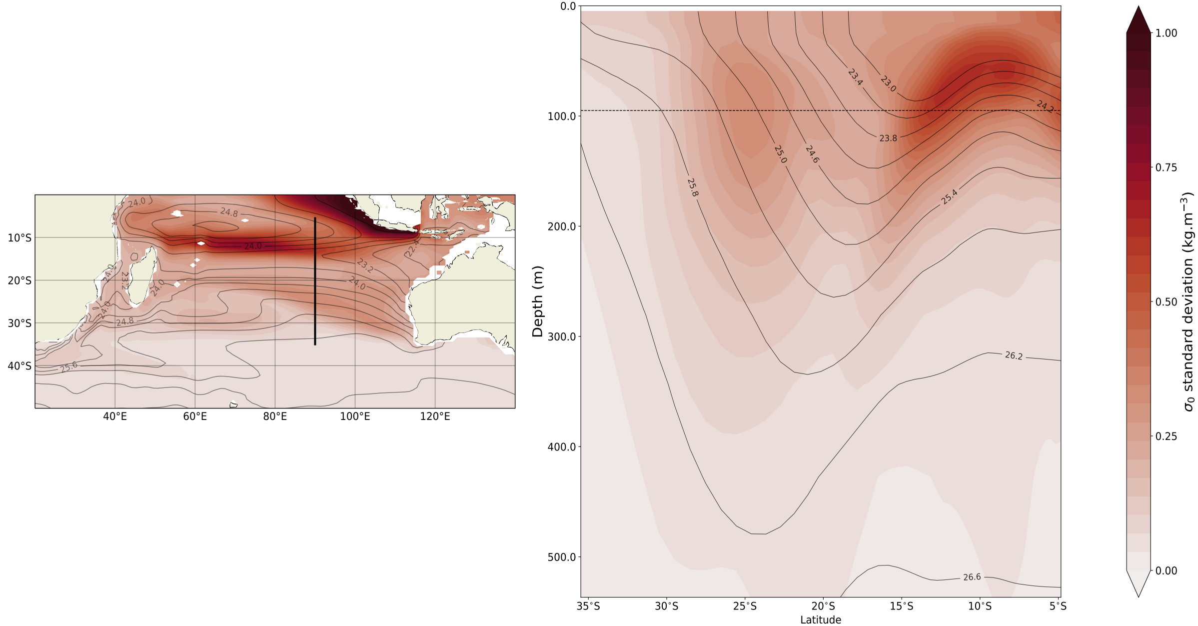
CLIMATE ANALYSIS FORECAST ENSEMBLE system

Coupled Climate Model

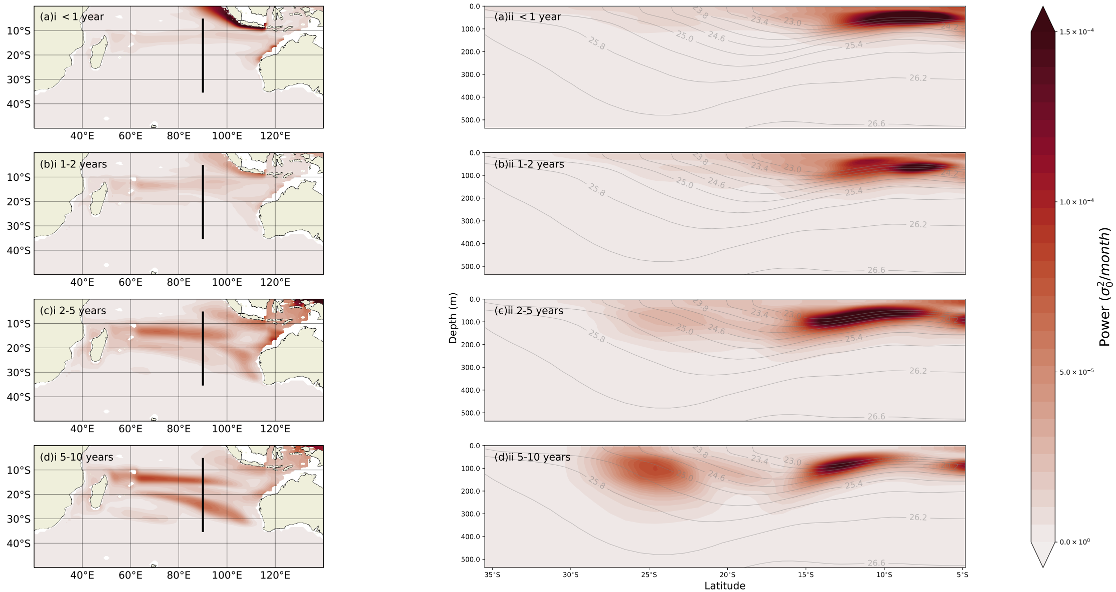
- 500 year long control simulation - final 200 years used after the model is in an ”almost” equilibrium state;



Physical Mechanism of Teleconnection



Physical Mechanism of Teleconnection



In band variance of σ_θ (surface referenced)

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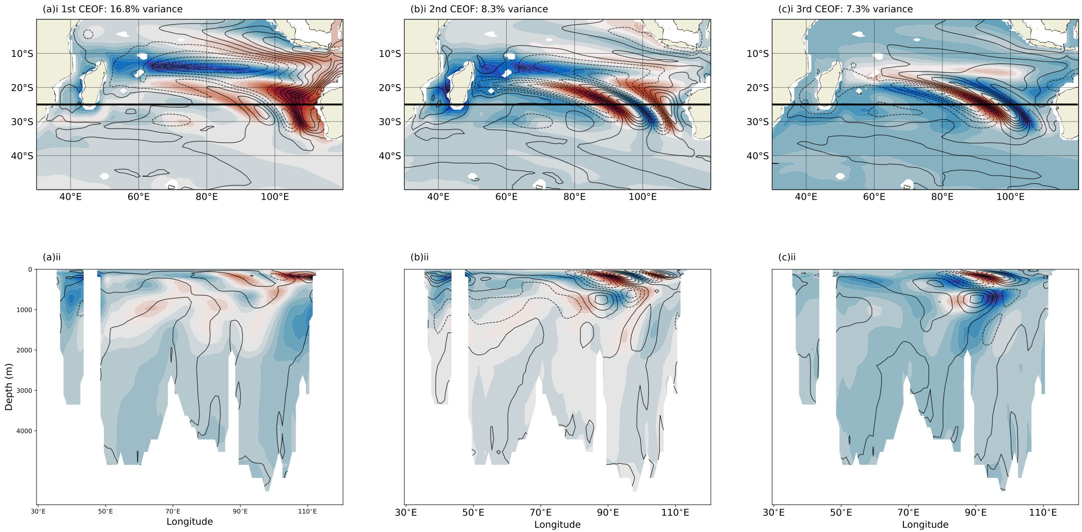
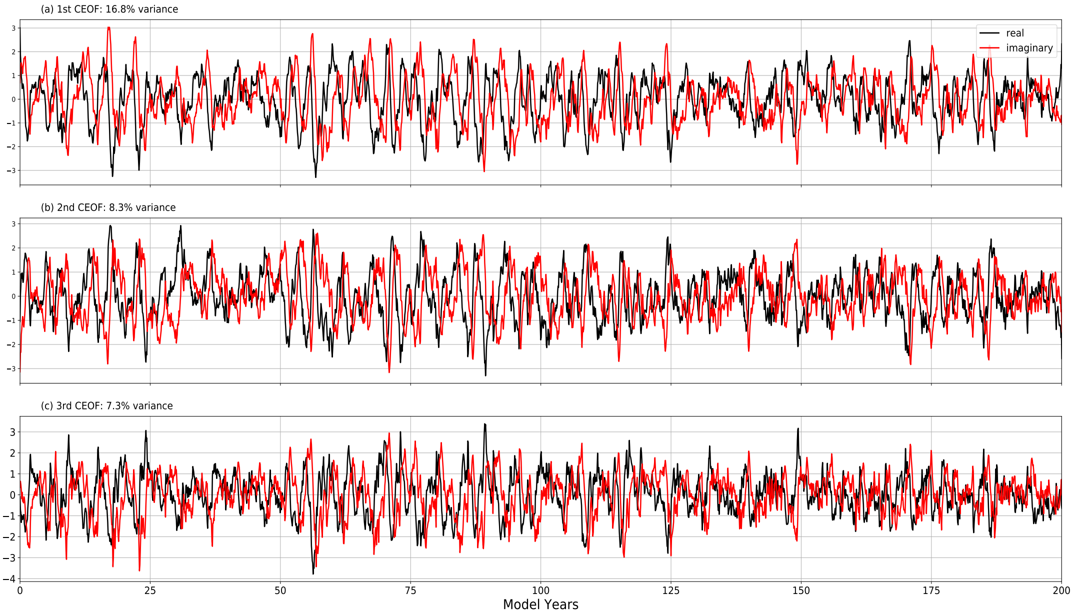
Physical Mechanism of Teleconnection



3D complex (Hilbert) EOFs of σ_θ (referenced to the surface)
Colors: real part; contours: imaginary part

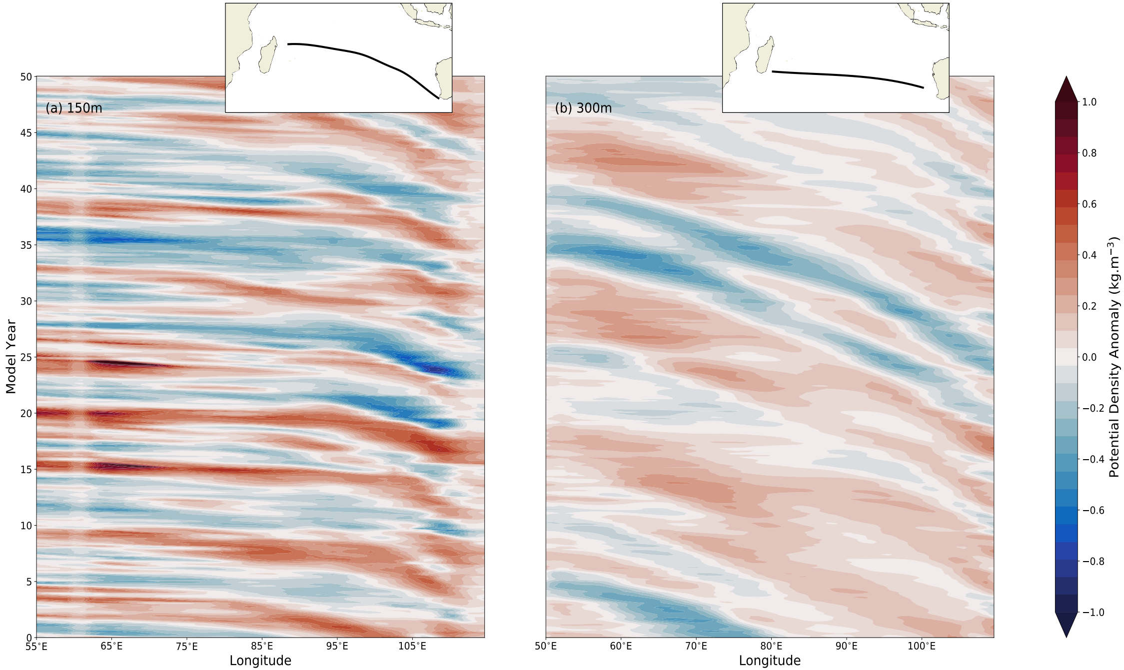
Physical Mechanism of Teleconnection



Complex EOF time series

Black: real component; red: imaginary part

Physical Mechanism of Teleconnection



Hovmöller (longitude/time) plots of σ_θ along the northern (left) and southern (right) waveguides

Summary of the Propagating Disturbance

- Basin crossing time scale: $\sim$4 years;
- Length Scale: 500–1000km;
- Propagation speed: 10cm/s (substantially slower than theoretical Rossby wave speed);
- Likely substantially non-linear;
- Shows evidence of topographic interaction;

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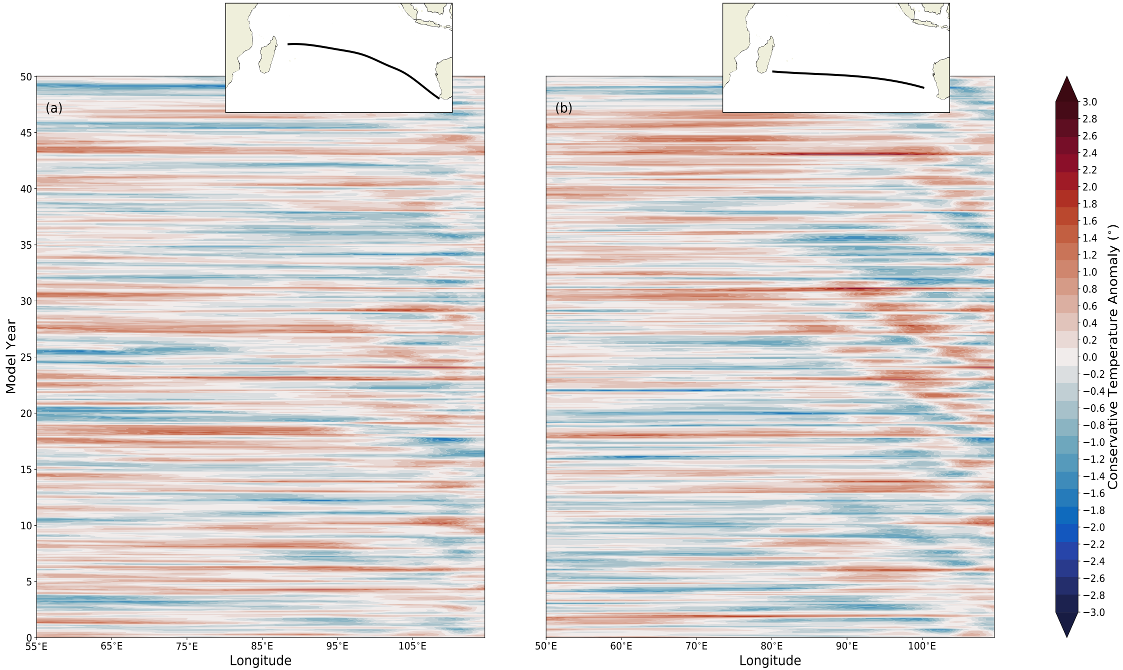
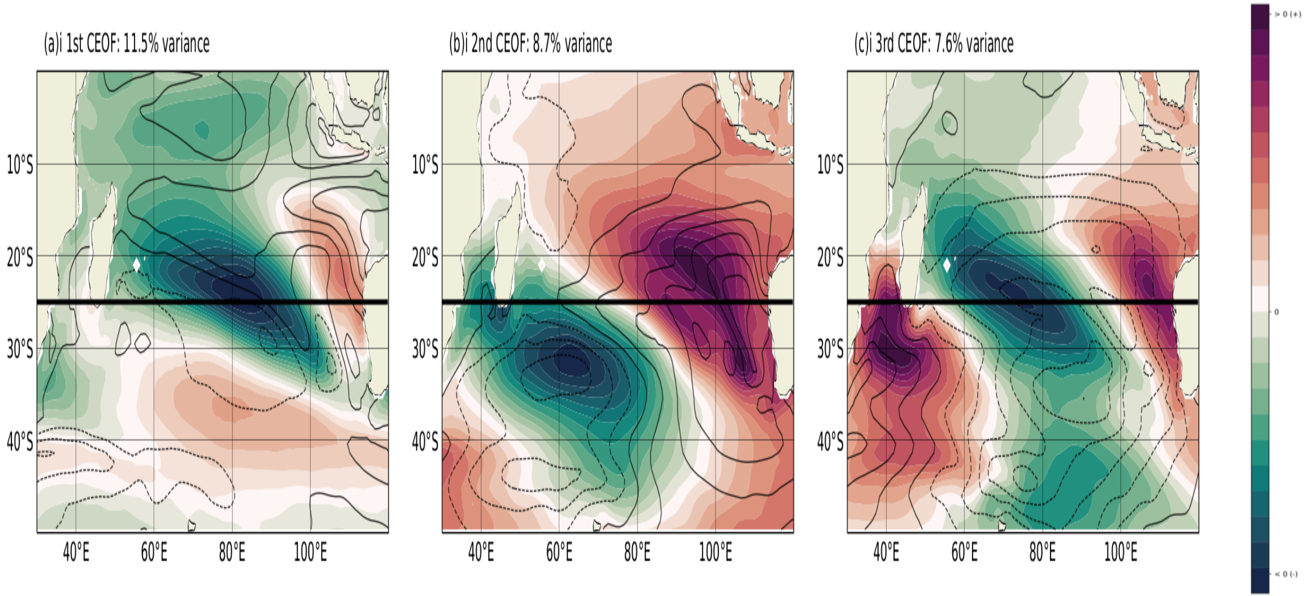
Influence on the Upper Ocean



Hovmöller (longitude/time) plots of σ_θ along the northern (left) and southern (right) waveguides

Influence on the Upper Ocean



Complex (Hilbert) EOFs of SST
Colors: real part; contours: imaginary part

Influence on the Upper Ocean

To quantify the influence of the propagating disturbance on the surface ocean, we calculate the *Dynamic Height Anomaly* or *Relative Geostrophic Streamfunction* from model temperature and salinity:

$$\psi_g(x, y, t; p, p_{\mathrm{ref}}) = -\int_{p_{\mathrm{ref}}}^{p} \delta(x, y, t; p')\, dp' \tag{1}$$

where:

δ=specific volume anomaly (function of temperature and salinity); and

$\mathbf{e}_z \times \nabla\psi_g(p, p_{\mathrm{ref}}) = f[\mathbf{u}(p) - \mathbf{u}(p_{\mathrm{ref}})]$

Has the benefit of being a *depth integrated measure*

Essentially the thermal wind.

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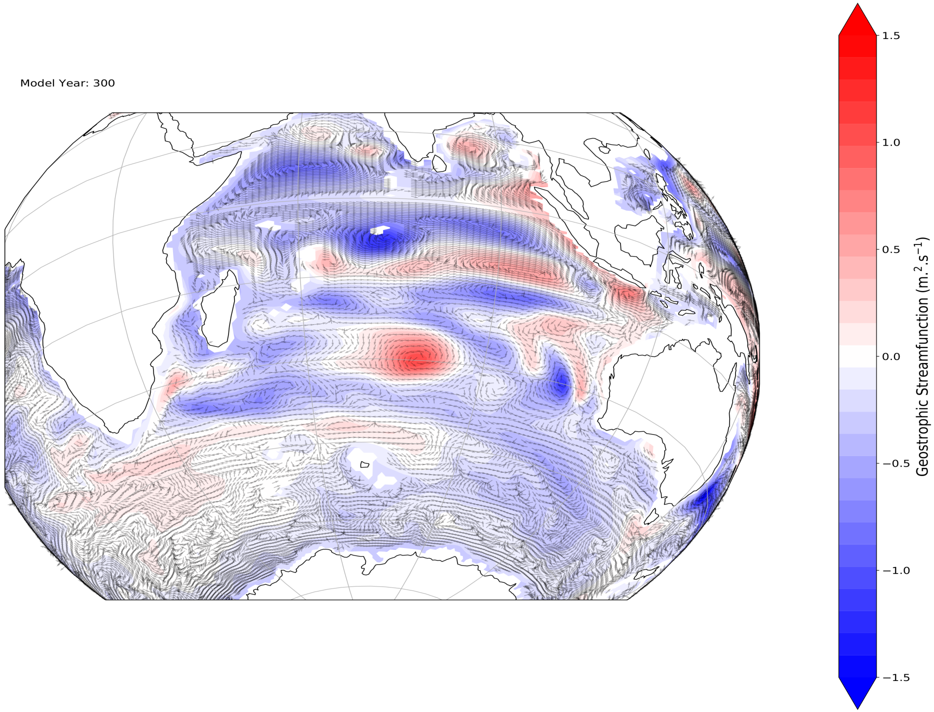
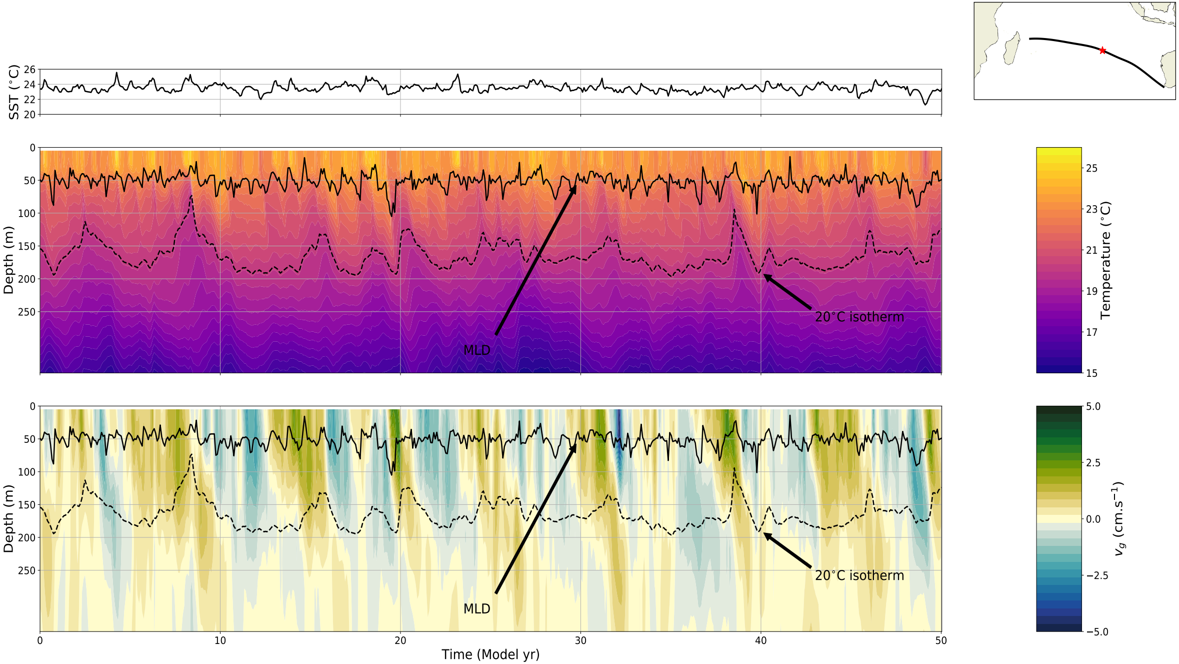
Influence on the Upper Ocean



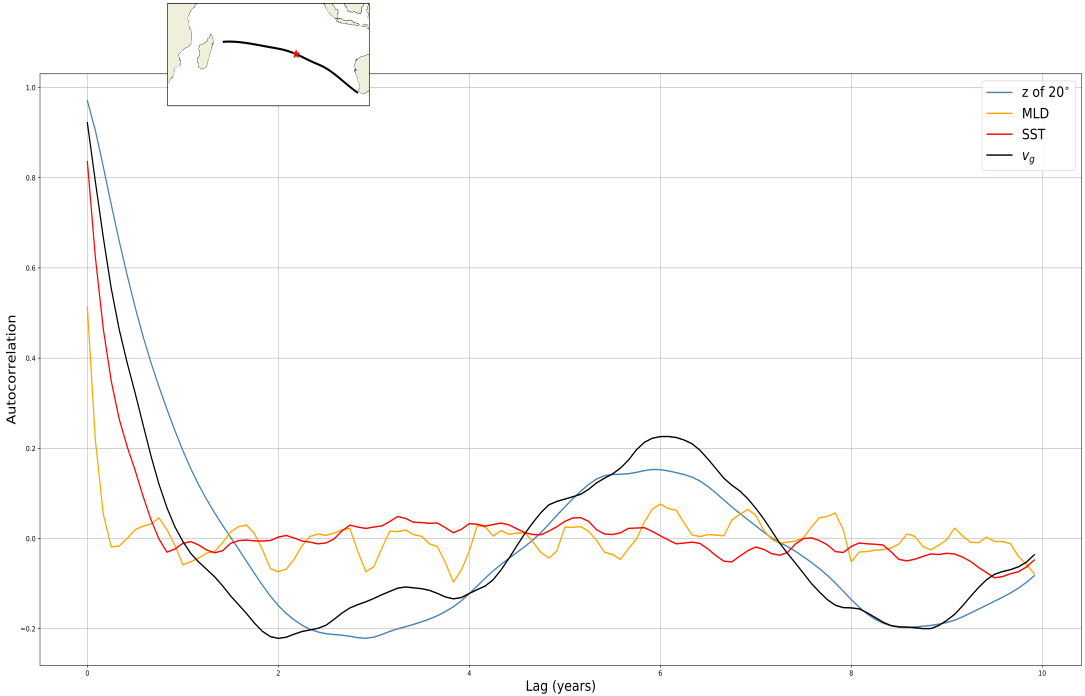
Colors: Geostrophic streamfunction anomaly referenced to 500db
Vectors: Surface Geostrophic Current (relative to 500db flow)

Influence on the Upper Ocean



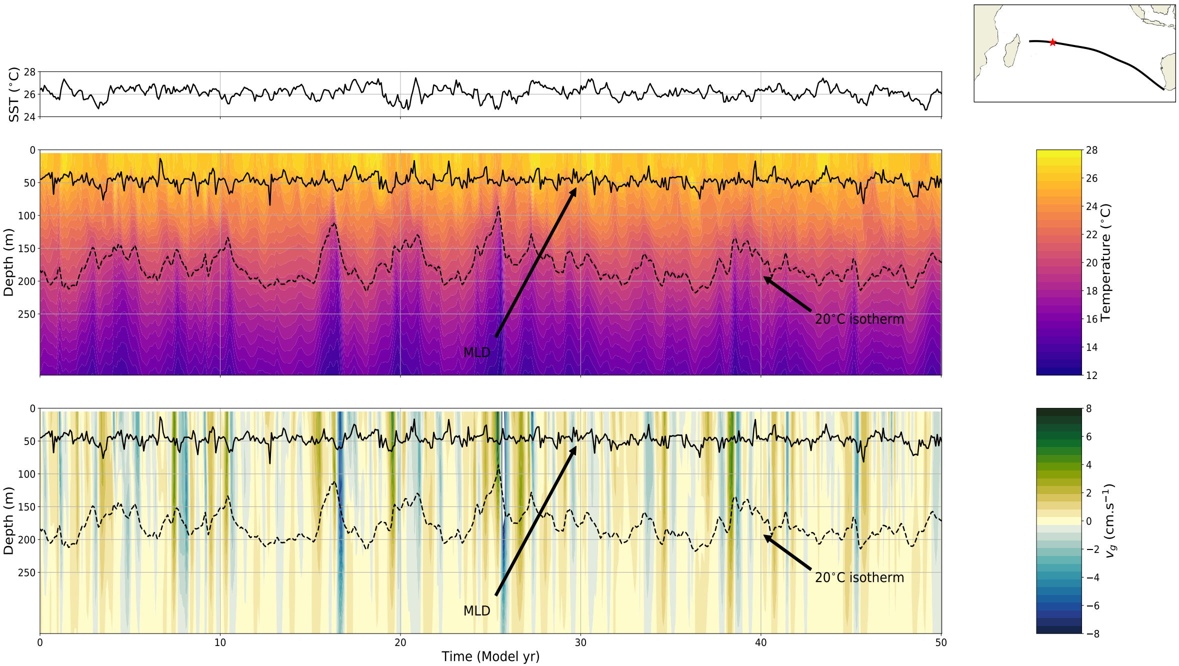
Top: SST;
Middle: Temperature depth/time profile;
Bottom: v_g depth/time profile

Influence on the Upper Ocean



Lagged autocorrelation function at lags between 1 month and 10 years

Influence on the Upper Ocean



Top: SST;
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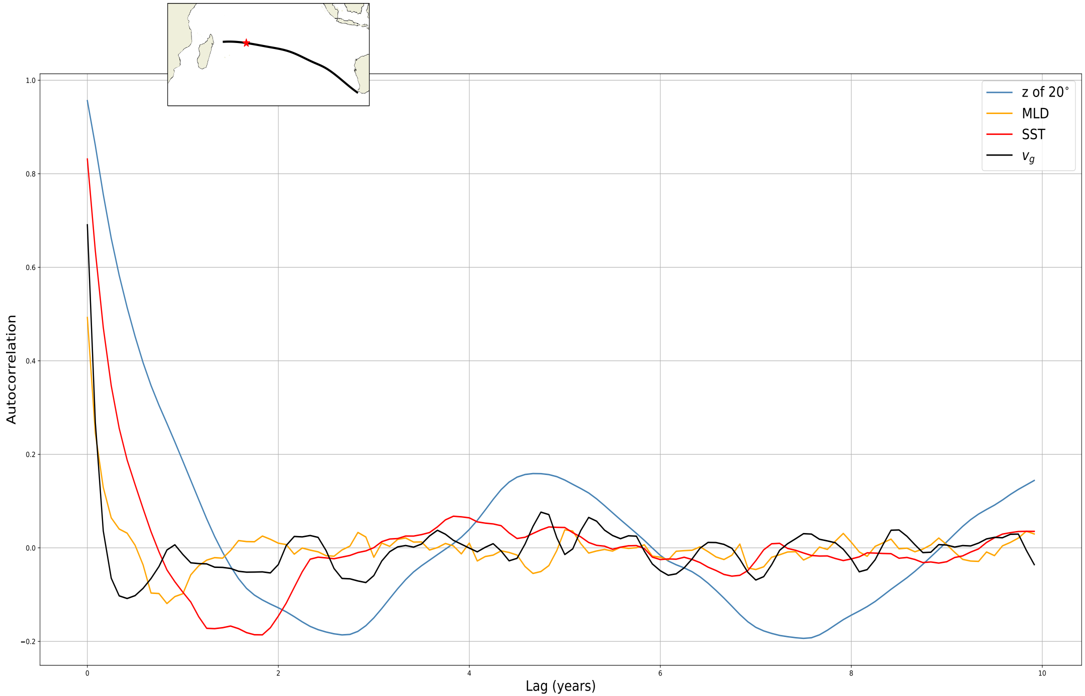
Influence on the Upper Ocean



Lagged autocorrelation function at lags between 1 month and 10 years

Influence on the Upper Ocean

1D mixed layer heat budget:

$$\rho_0 C_p \left[\frac{\partial \Theta}{\partial t} + \mathbf{u} \cdot \nabla_{xy} \Theta + w \frac{\partial \Theta}{\partial z} \right] = \frac{\partial Q_{\text{net}}}{\partial z} \qquad (2)$$

where Θ= conservative temperature (TEOS-10)

integrate over the temporally varying mixed layer depth $h(t)$

$$\frac{\partial \tilde{\Theta}}{\partial t} \approx \mathcal{F}_{\text{Atmos.}} + \mathcal{F}_{\text{Eddies}} - \lambda \overline{\Theta} \qquad (3)$$

where: $\overline{\Theta} = \int_{h(t)}^{0} \Theta dz$

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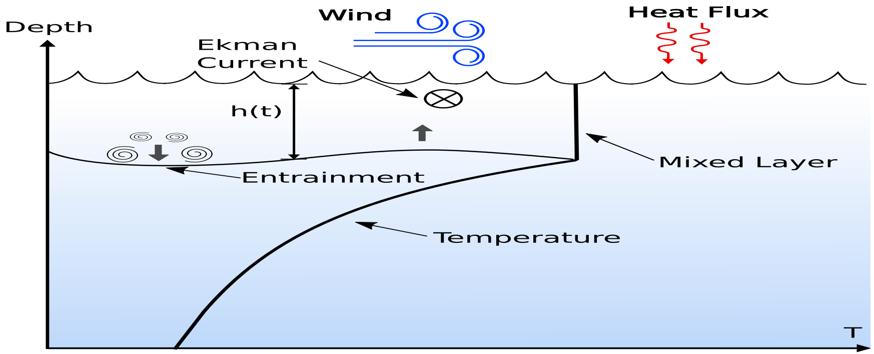
Influence on the Upper Ocean

$$\frac{\partial\overline{\Theta}}{\partial t} \approx \mathcal{F}_{\text{Atmos.}} + \mathcal{F}_{\text{Eddies}} - \lambda \qquad overline\Theta$$

$$\begin{aligned}
\mathcal{F}_{\text{Atmos.}} &= \text{Surf. Heat Flux} + \text{Ekman Advection} + \text{Ekman Pumping} \\
\mathcal{F}_{\text{Eddies}} &= \text{Geostrophic Advection} + \text{Entrainment at MLD Base} \\
\lambda &= \text{damping parameter (inverse decay timescale)}
\end{aligned}$$



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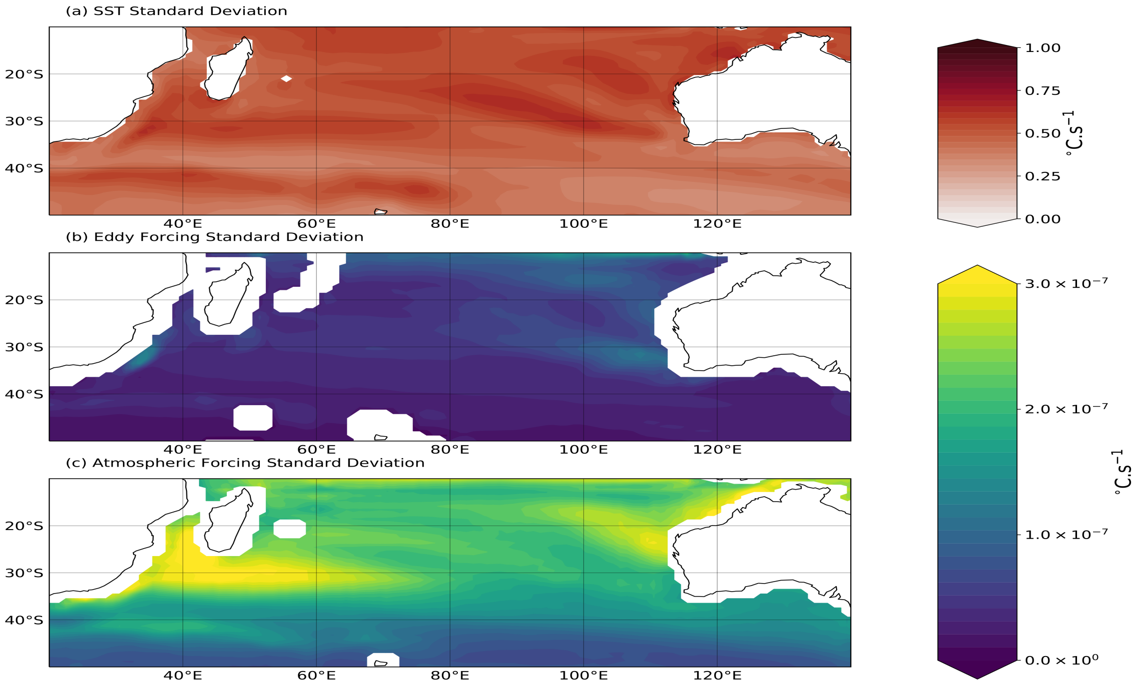
Influence on the Upper Ocean



Standard Deviation of the (top): SST; (middle); Eddy Forcing; and (bottom): Atmospheric Forcing.

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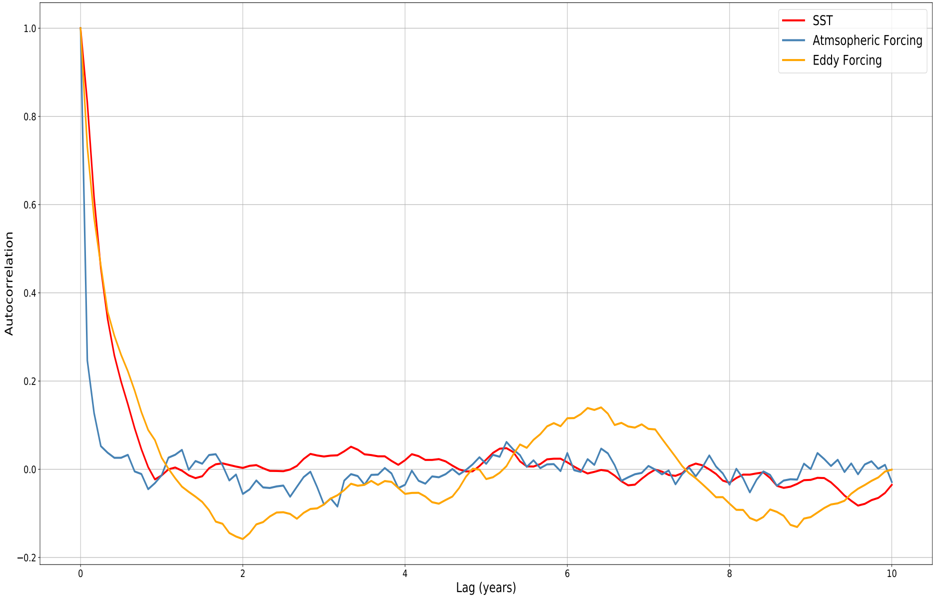
Influence on the Upper Ocean



Autocorrelation structure of the individual terms in the MLD heat budget.

Stochastic Model of the SST variation

In spectral space, MLD heat budget becomes:

$$\left(\omega^2 + \lambda^2\right) P_{\Theta\Theta} = P_{F_{\text{atmos}} F_{\text{atmos}}} + P_{F_{\text{eddy}} F_{\text{eddy}}} - P_{F_{\text{atmos}} F_{\text{eddy}}} - P_{F_{\text{eddy}} F_{\text{atmos}}} \tag{4}$$

where $P_x y$ = is the power spectrum of the x and y (so we include cross terms)

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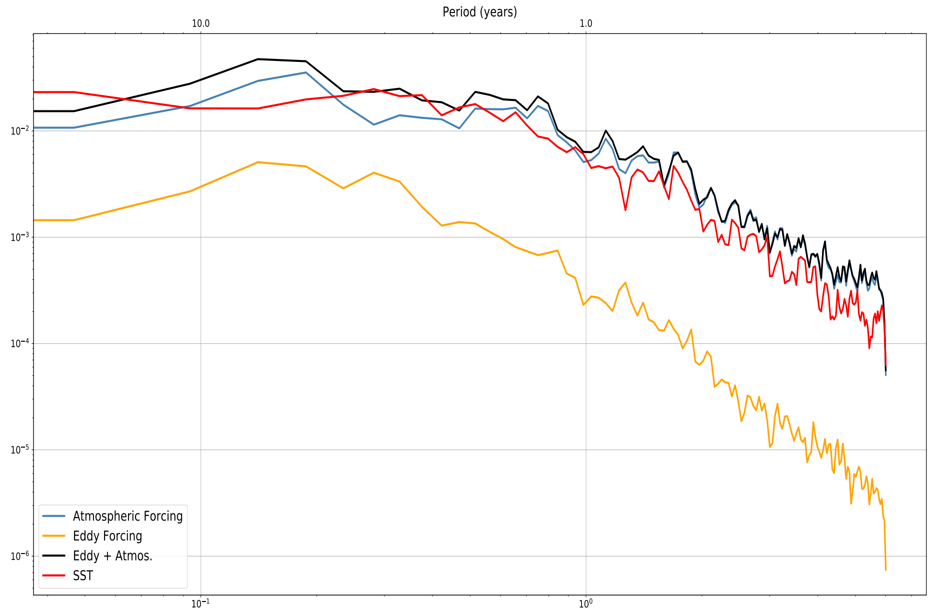
Influence on the Upper Ocean



Power Spectrum of the stochastic model of SST variation

Conclusions

- Robust signature of variability on long (2-5 years) in the sub-surface Indian ocean;
- Teleconnection between eastern and western sides of the basin;
- Feature has a substantial surface expression and influence on SSTs on long time scales;
- Intrinsic mode: shows some predectability.

Thank You

CSIRO Oceans and Atmosphere

Chris Chapman

t +61 402 089 180

e chris.chapman@csiro.au

w http://www.chrischapman.eu/