Kelvin waves and Tropical Instability Waves in the Equatorial Pacific Ocean

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ROMS Meeting, Hobart, Australia
17th October 2016

Outline

1. Introduction: ENSO, Tropical Instability Waves and Kelvin Waves
2. Modulation of TIW amplitude by Kelvin Waves (Holmes and Thomas (2016) JPO)
3. Influence of TIWs on ENSO in a simple coupled model (work in progress)

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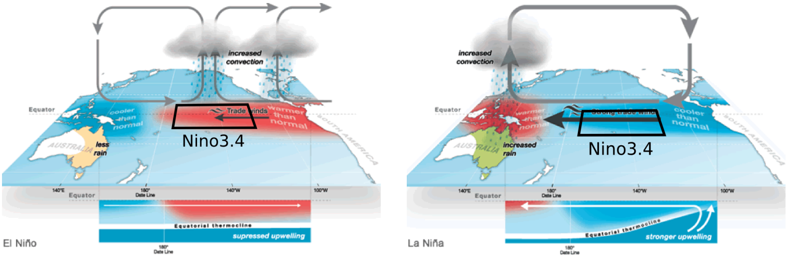
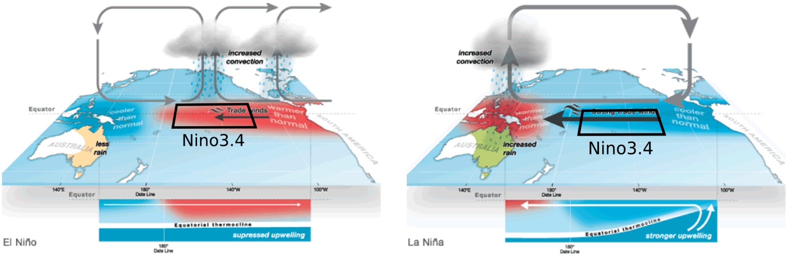


Figure: (left) El Niño conditions (right) La Niña conditions (from BOM)



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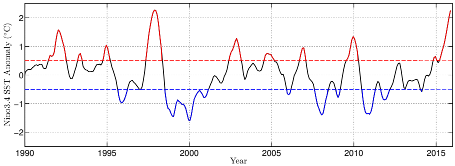


Figure: Niño 3.4 index: sea surface temperature (SST) between 120°W-170°W, ±5°N.

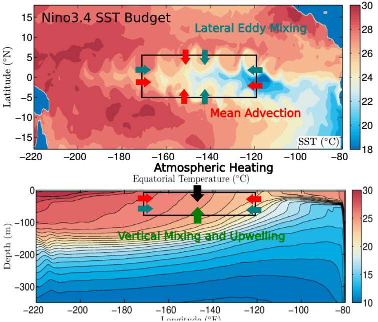
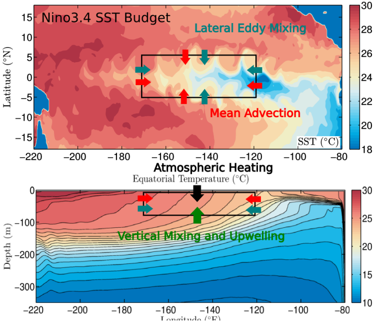


Figure: (top) SST and (bottom) equatorial temperature in the Pacific from a model.

$$\frac{\partial SST}{\partial t} = \text{Mean Advection} + \text{Lateral Eddy Mixing} + \text{Atmospheric Heating} + \text{Vertical Mixing and Upwelling}$$



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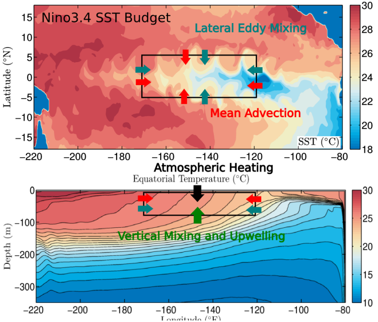
All of these terms are thought to make important contributions (Jochum and Murtugudde (2006), Menkes et. al. (2006) [3, 6]).



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At intraseasonal timescales:

- Tropical Instability Waves (TIWs)
- Equatorial Kelvin Waves

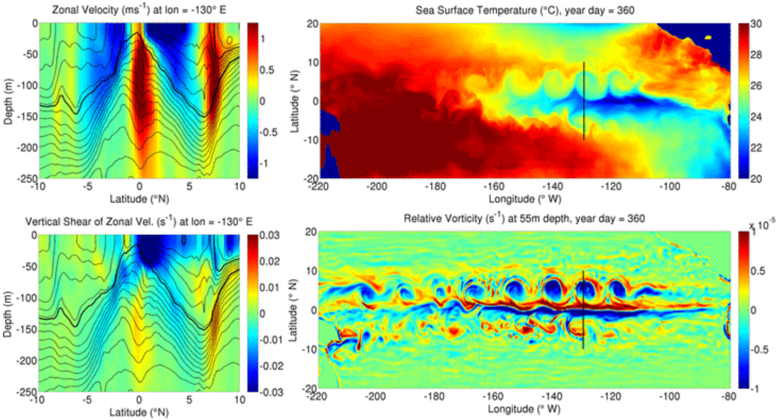

Figure: ROMS simulations of the equatorial Pacific. $\mathbf{1/4^\circ}$ horizontal resolution, 50 vertical levels, CORE-NYF [4] climatological forcing, KPP [5] vertical mixing.

Equatorial Kelvin Waves

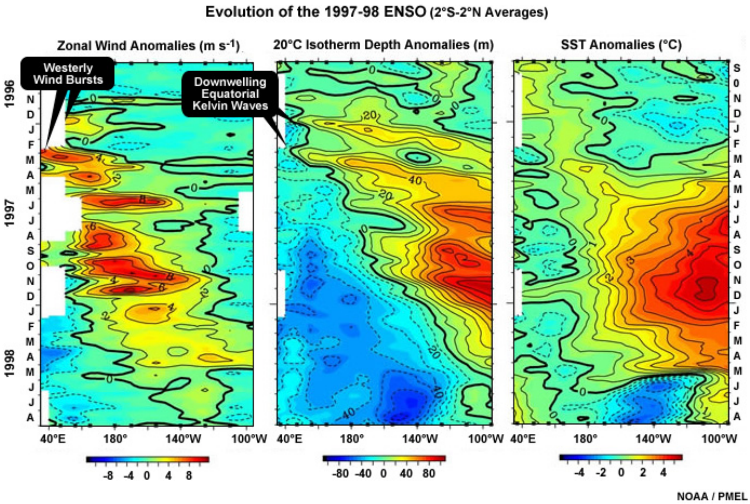

Figure: Evolution of equatorial zonal wind stress, 20°C isotherm depth and SST during the 1997-1998 El Nino.

Interactions between Kelvin Waves and TIWs: Observations

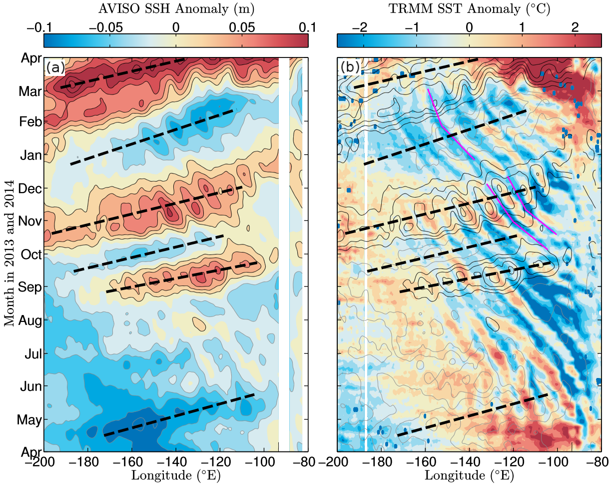

Figure: (a) AVISO SSH anomalies between ±2°. Black (gray) contours show positive (negative) perturbation SSH. (b) TRMM SST anomalies between 1°N and 2°N. (c) SST variance (red) and SSH anomalies 140°W and 120°W.

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Research Question and Modelling Approach

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1. Remove seasonal cycle using July-December averaged CORE-NYF forcing $\Longrightarrow$ *Statistically-steady* TIW field.
2. Insert Kelvin wave pulses using momentum nudging
3. Examine changes in the TIWKE budget.

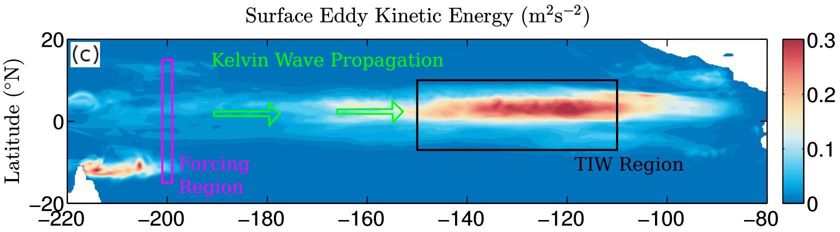

Figure: EKE from the last year of the control simulation.

The TIWKE budget

The TIWKE, or EKE,

$$\mathcal{K} = \frac{1}{2}\rho_0\left(\overline{u'u'} + \overline{v'v'}\right),$$

is governed by,

$$\frac{\partial \mathcal{K}}{\partial t} = -\nabla \cdot \left(\mathcal{K}\boldsymbol{U} + \overline{\boldsymbol{u}'P'} + \frac{1}{2}\rho_0\overline{\boldsymbol{u}'(u'u' + v'v')}\right) + \rho_0\overline{w'b'} + \rho_0\overline{\boldsymbol{u}_h' \cdot \boldsymbol{F}_H'} - \rho_0\overline{\boldsymbol{u}'u'} \cdot \nabla U - \rho_0\overline{\boldsymbol{u}'v'} \cdot \nabla V. \quad (1)$$

The RHS terms are mean advection, pressure fluxes, TIW advection, PE conversion, friction and shear production.

The most important shear production term is,

$$LSP = -\rho_0\overline{u'v'}\frac{\partial U}{\partial y}$$

The TIWKE budget in the control simulation

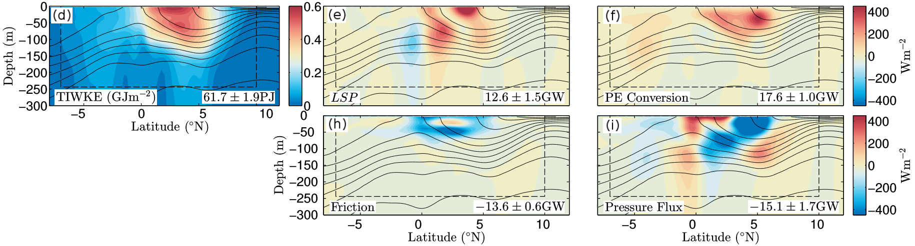

Figure: Latitude-Depth plots of (d) TIWKE and (e-i) the main TIWKE budget terms between 150°W and 110°W.

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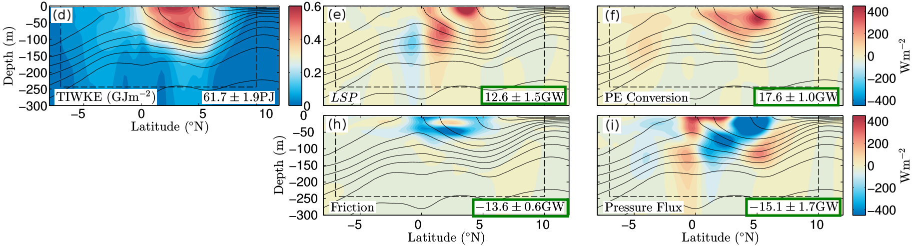

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TIWKE is produced by *LSP* and PE conversion and removed via friction and pressure flux radiation.

Kelvin wave forcing

Downwelling and upwelling Kelvin wave pulses forced using momentum nudging in Western Pacific. 10-member ensemble used to separate TIWs

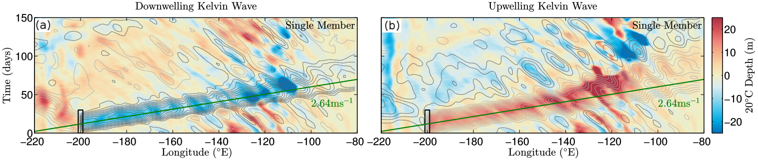

Figure: (a-d) Time-longitude plots of equatorial 20°C isotherm depth anomalies. (e-f) Time-longitude plot of the TIWKE integrated over the top 244m and between 7°S and 10°N. Also shown are 0.01m contours of SSH anomalies.

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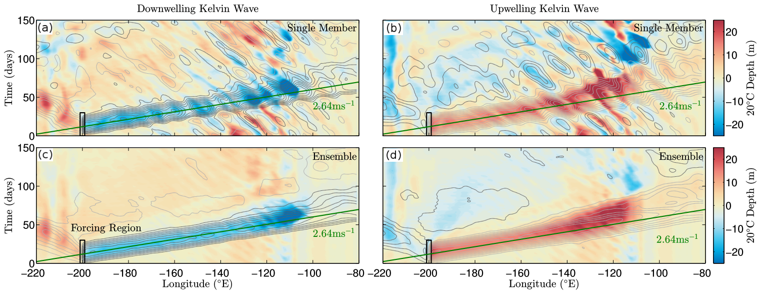

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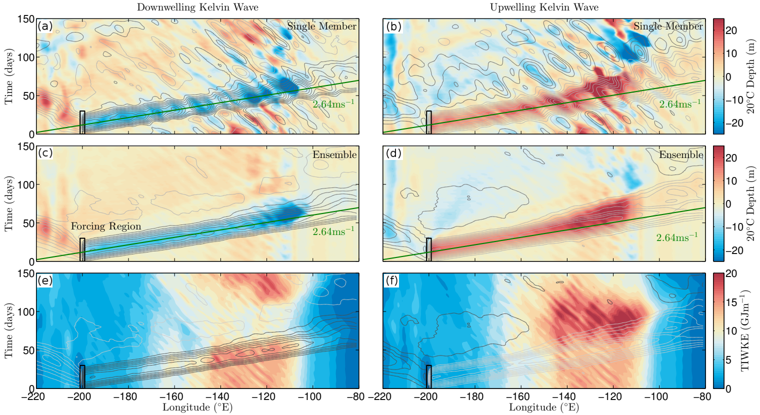

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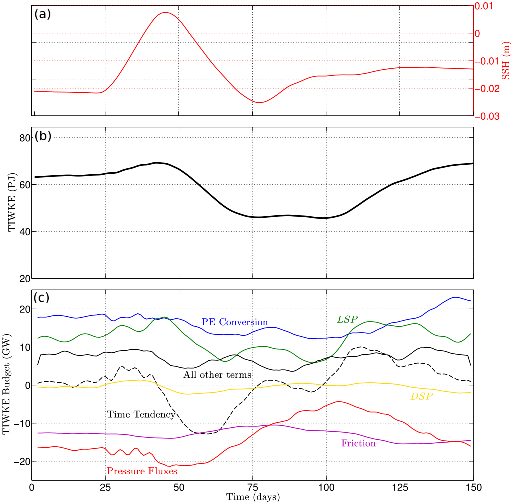
Downwelling Kelvin wave: Changes in the TIWKE budget



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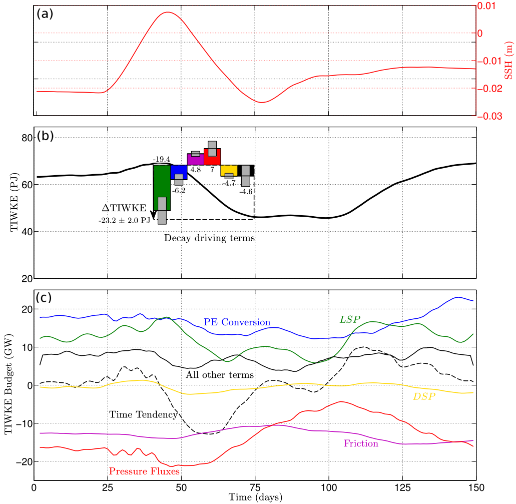

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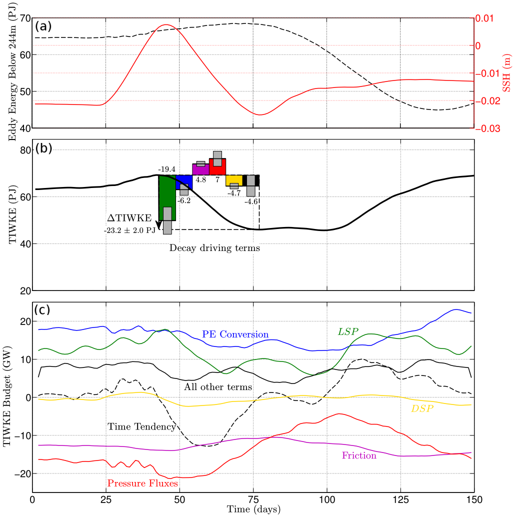

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Kelvin wave induced changes in the zonal currents

Changes in $LSP = -\rho_0 \overline{u'v'} \frac{\partial U}{\partial y}$ are the main driver of changes in TIWKE.
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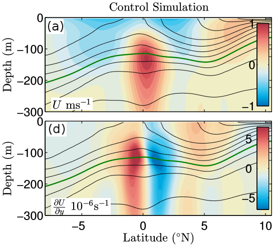

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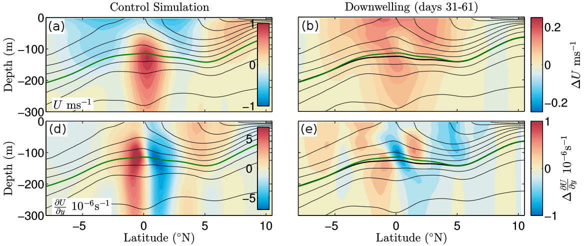

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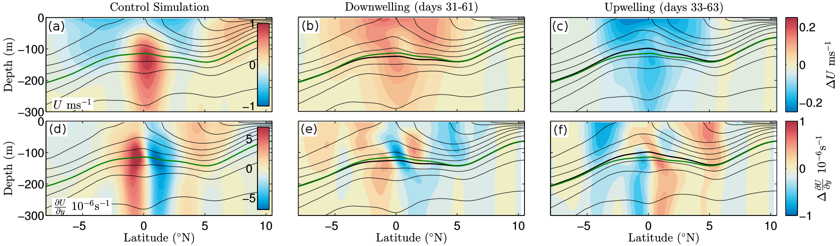

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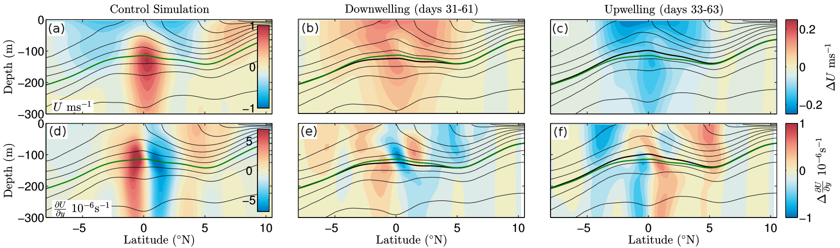

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However, changes in $\frac{\partial U}{\partial y}$ alone only explain a portion of the changes in LSP.

$$LSP = -\rho_0 \overline{u'v'} \frac{\partial U}{\partial y} = -\mathcal{K} \frac{\overline{u'v'}}{\frac{1}{2}\left(\overline{u'u'} + \overline{v'v'}\right)} \frac{\partial U}{\partial y}$$

Decompose changes in *LSP* into changes in TIWKE, changes in the correlation between u' and v' and changes in $\frac{\partial U}{\partial y}$.

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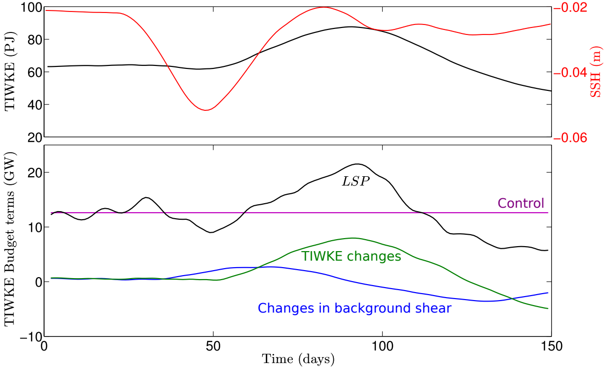

Figure: Decomposition of changes in LSP for the upwelling experiment.

$$\frac{\partial T}{\partial t} = \nabla \cdot \left(\boldsymbol{U}\overline{T} + \overline{v'T'} \right) + \text{Other terms}$$

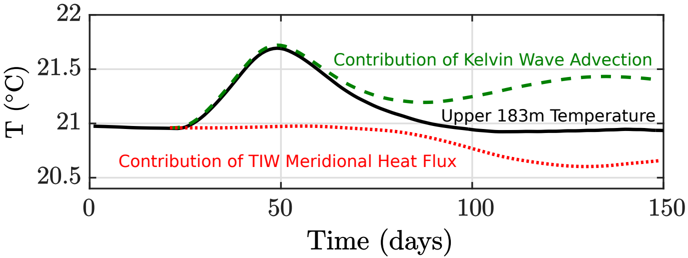

Figure: Heat content (expressed as an average temperature) and mean and eddy heat flux convergences above −183m between 150°W and 110°W, ±3.75°

Summary

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- The main negative feedback is **energy radiation via waves**
- Changes in TIW heat fluxes limit the Kelvin wave heat content anomaly

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TIWs and ENSO

Question: How do TIWs influence the initiation and strength of ENSO events?

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Motivation: TIWs gain energy from non-linear hydrodynamic instabilities, and thus can vary stochastically. This produces rectified low-frequency variability.

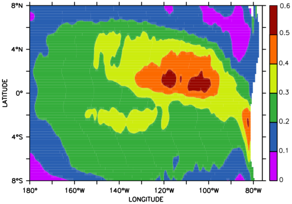

Figure 3. Standard deviation of interannual SST in the Pacific Ocean.

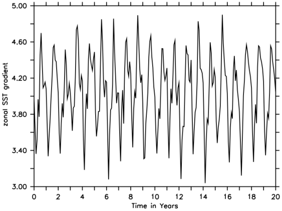

Figure 4. Difference between the western basin SST (averaged from 3°S–3°N and from 160°E–160°W) and the eastern basin SST (averaged from 3°S–3°N and from 160°W–90°W).

Figure: Interannual SST variability driven by internal oceanic variability in a $1/4^{\circ}$, 12-vertical levels ocean model (Jochum and Murtugudde (2004) [2])

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Approach: Couple ROMS to a simplified atmospheric model. Aim to:

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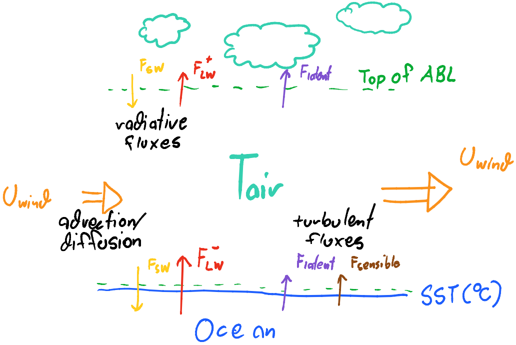
Simple atmospheric model:

- ABLM: Atmospheric boundary layer model for heat fluxes
- STATS_ENSO: Simple statistical relationship for wind stresses

Better represents air-sea exchange by allowing air **temperature and humidity** (T_{air} and Q_{air}) to react to changes in SST. Based on Seager et. al. (1995) [7] and Deremble et. al. (2013) [1] (cheapAML).



$$\frac{\partial T_{air}}{\partial t} = \underbrace{-\nabla \cdot (\boldsymbol{U} T_{air} - \kappa \nabla T_{air})}_{\text{adv-diff}} + \underbrace{\frac{1}{\rho_a C_p h}\left(F^+ - F^-\right)}_{\text{diab}} - \underbrace{\frac{1}{r_T}(T_{air} - T_b)}_{\text{rstr}}$$

Wind speeds are the sum of the background CORENYF forcing plus a term proportional to the ROMS Nino 3.4 SST anomaly (averaged over previous month)

$$U_{10}(x, y, t) = U_{10}^{\mathrm{CORENYF}}(x, y) + \alpha SST'_{N34}(t) U_{10}^{*}(x, y)$$

TIWs and ENSO: Statistical wind forcing

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$U_{10}^{*}(x,y)$, $V_{10}^{*}(x,y)$ determined from observational regression

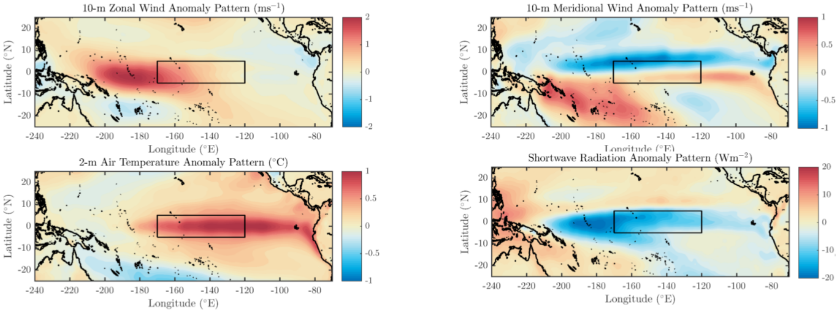
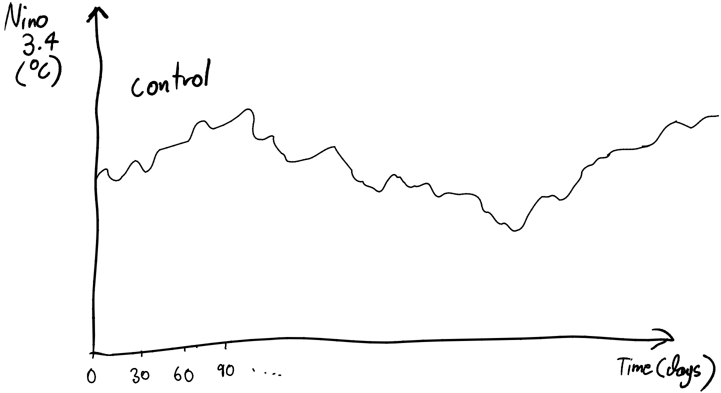


Figure: ERA Interim (1982-2014) monthly anomalies of bulk forcing parameters regressed onto NCEP OISST Nino 3.4

Planned experiments:

Initiate upwelling and downwelling Kelvin waves at differing phases of internal TIW variability. Examine spread in subsequent response of coupled system.



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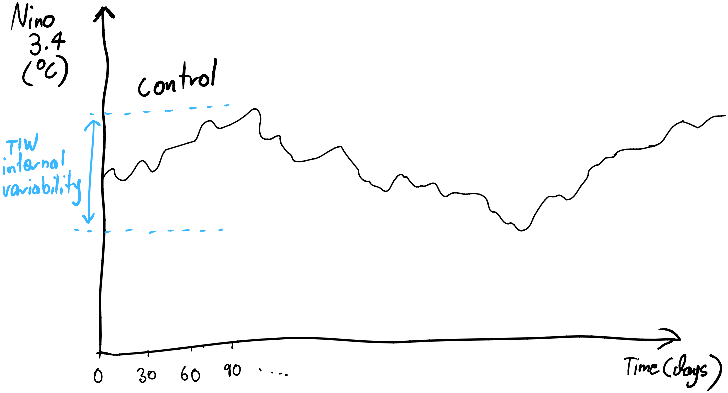

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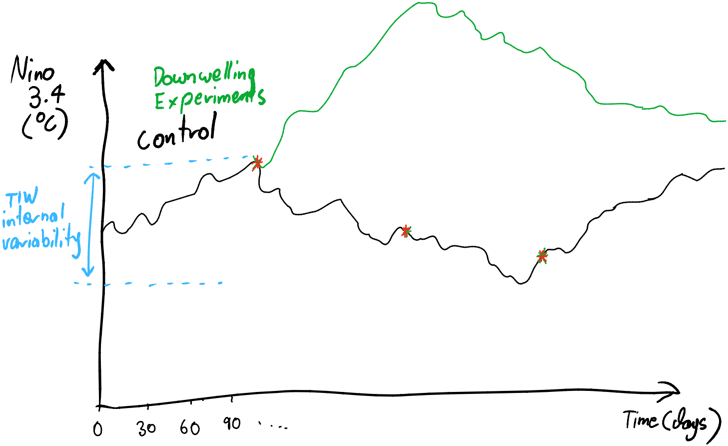

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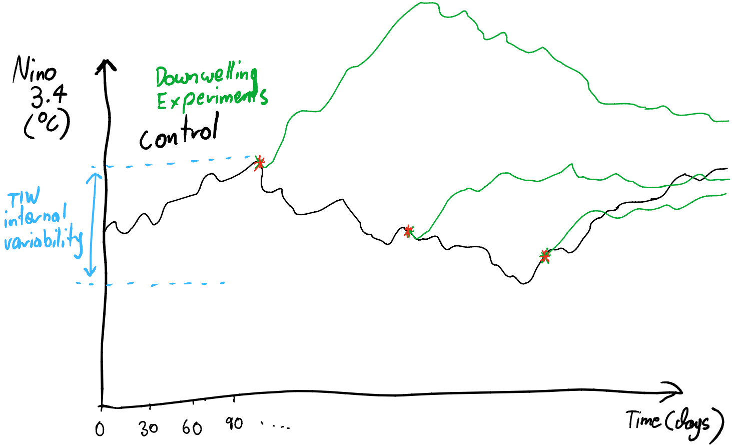

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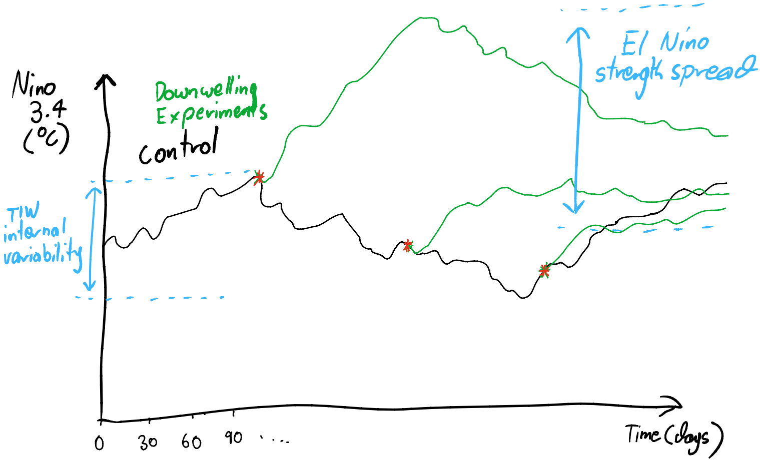

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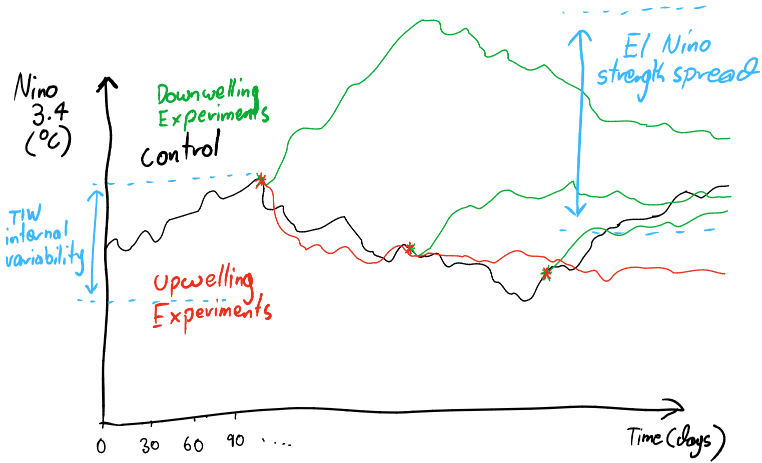

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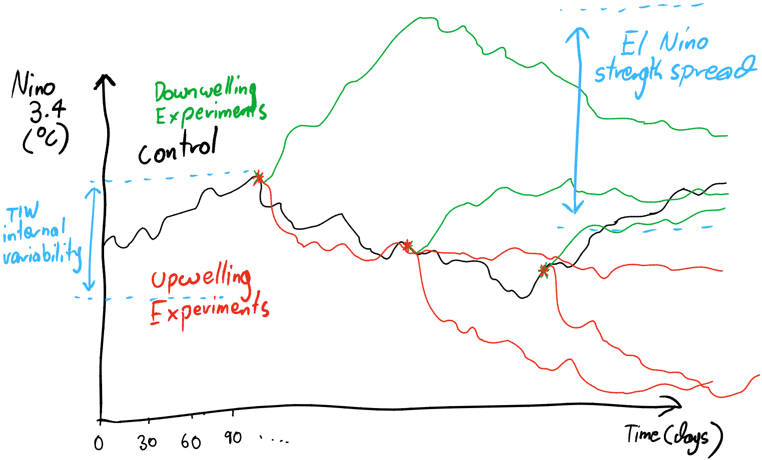

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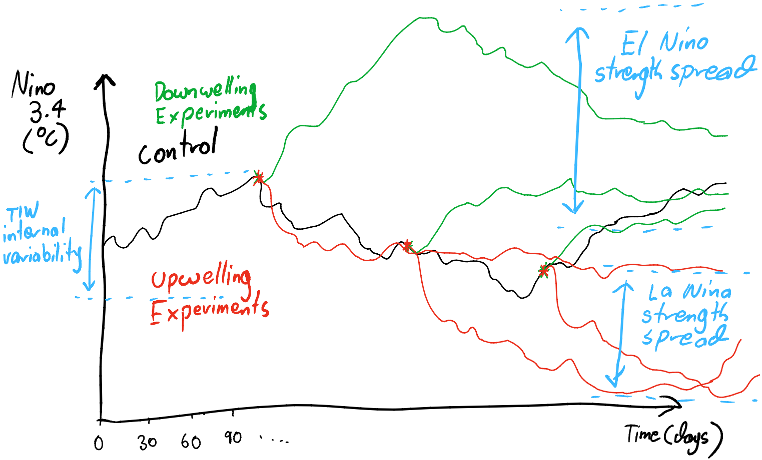

TIWs and ENSO: Statistical model initial results

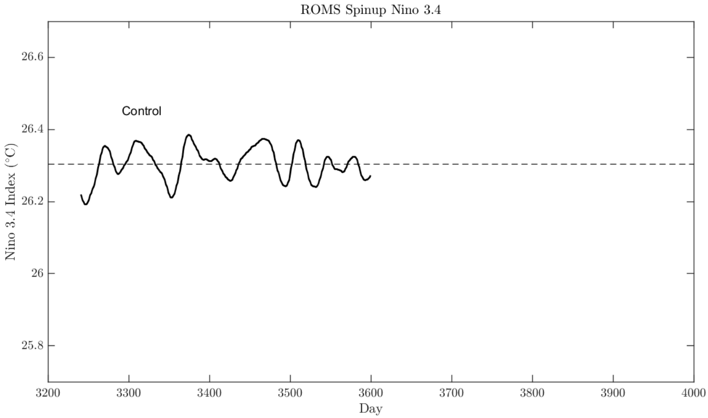

Figure: Nino 3.4 time series for different experiments

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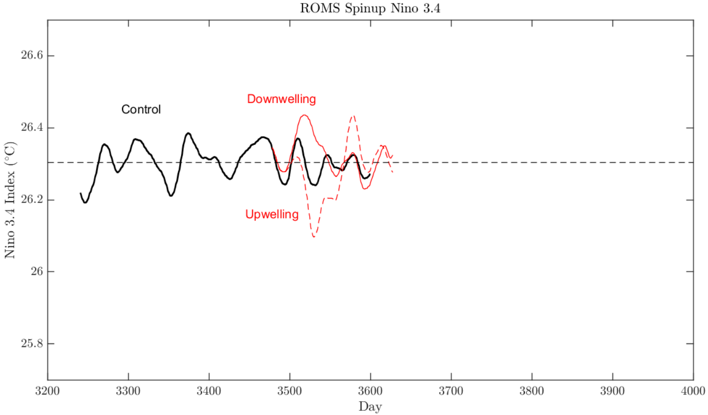

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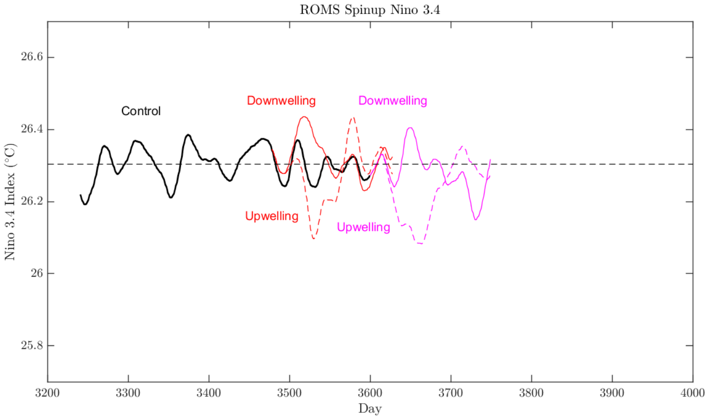

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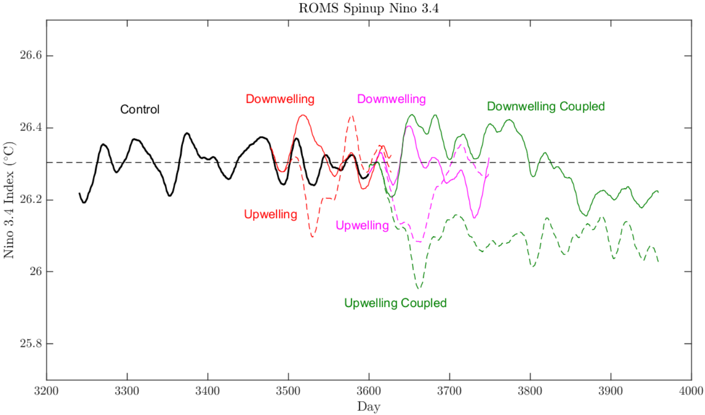

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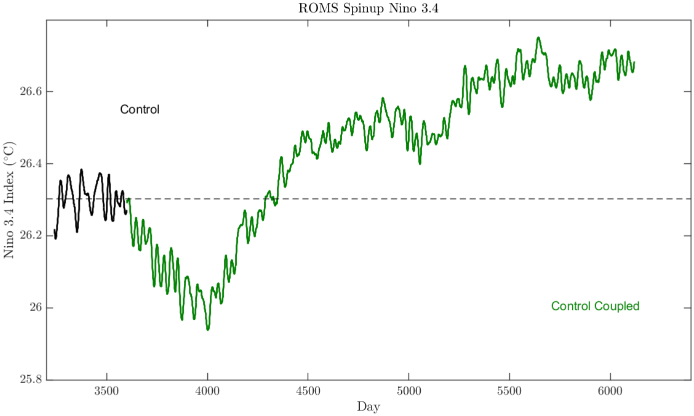

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TIWs and ENSO: Summary

TIWs may influence interannual coupled variability in the Pacific because

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Thank you! Comments, questions, advice?

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The TIWKE budget in the control simulation

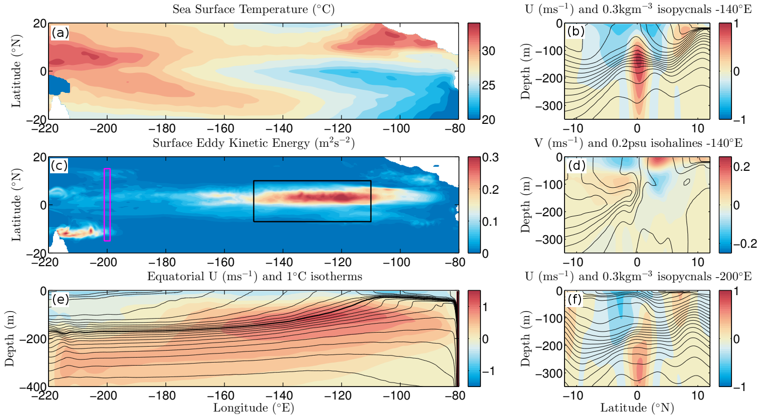


Figure: Control simulation circulation

The TIWKE budget in the control simulation

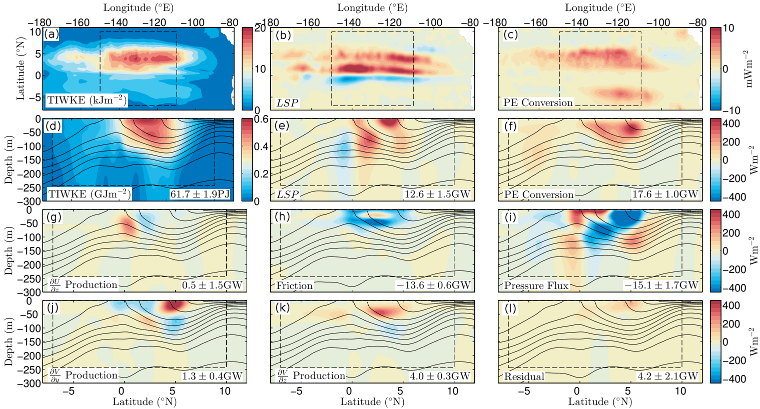


Figure: Latitude-Depth plots of (d) TIWKE and (e-i) the main TIWKE budget terms between 150°W and 110°W.

Downwelling Kelvin wave: Changes in the TIWKE budget

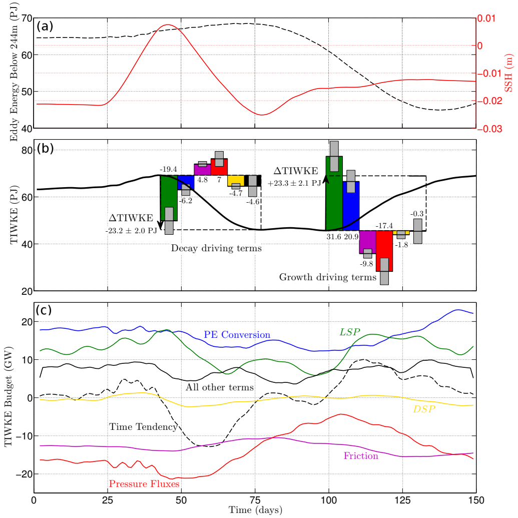
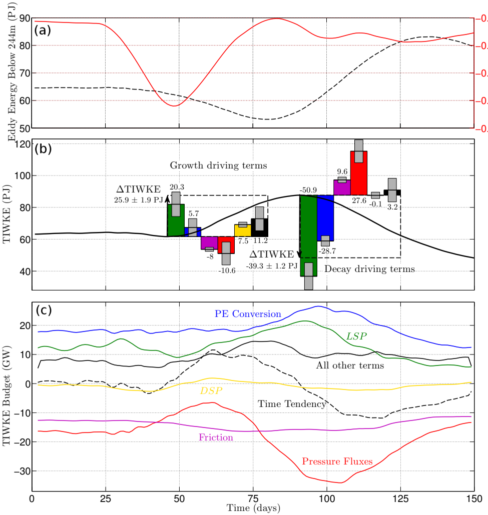


Figure: TIWKE and budget between 150°W, 110°W, 7°S, 10°N and above 244m for the downwelling Kelvin wave. (a) Eddy energy below 244m and SSH. (b) TIWKE. (c) TIWKE budget

Upwelling Kelvin wave: Changes in the TIWKE budget



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Decomposition of changes in *LSP*

$$LSP = -\rho_0 \overline{u'v'} \frac{\partial U}{\partial y} = -\mathcal{K} \frac{\overline{u'v'}}{\frac{1}{2}\left(\overline{u'u'} + \overline{v'v'}\right)} \frac{\partial U}{\partial y}$$

Decompose changes in *LSP* into changes in TIWKE, changes in the correlation between u' and v' and changes in $\frac{\partial U}{\partial y}$.

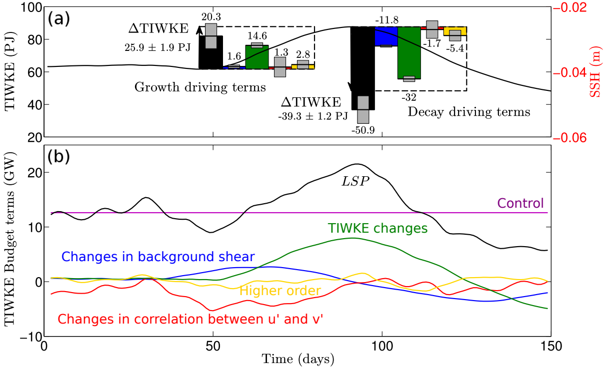


Figure: Decomposition of changes in *LSP* for the upwelling experiment.

Kelvin wave induced changes in the TIWs Reynold's stresses

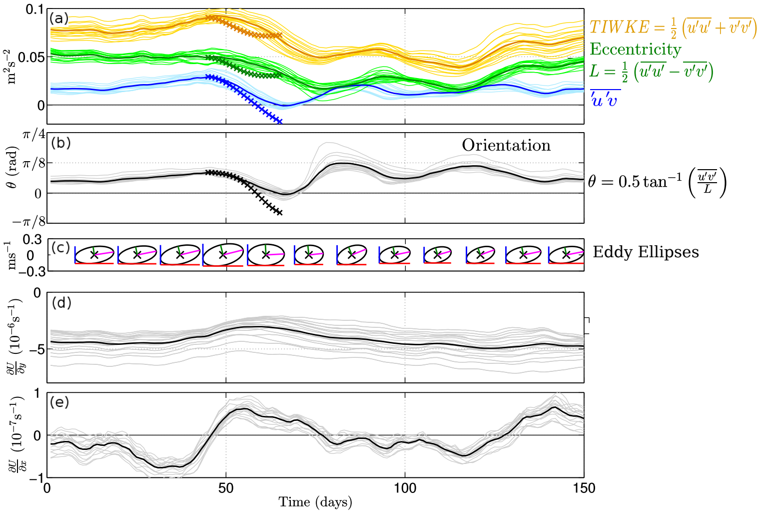
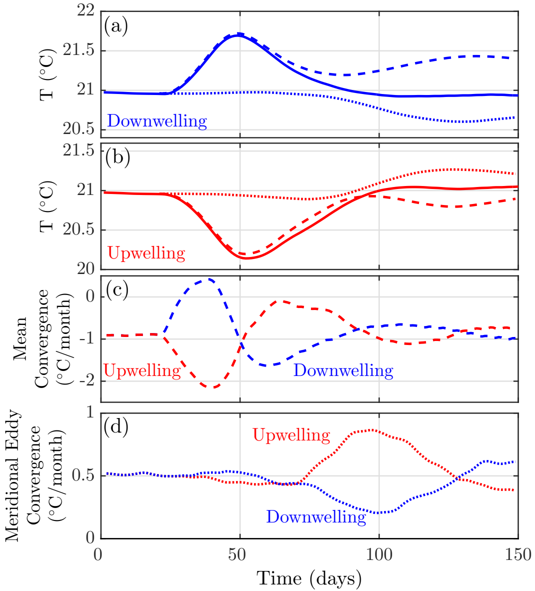


Figure: Time series of properties averaged between 1°N, 1.75°N, 92m to 63m depth in the downwelling experiment.

Kelvin wave induced changes in the TIWs Reynold's stresses



Checkerboard patterns in SST

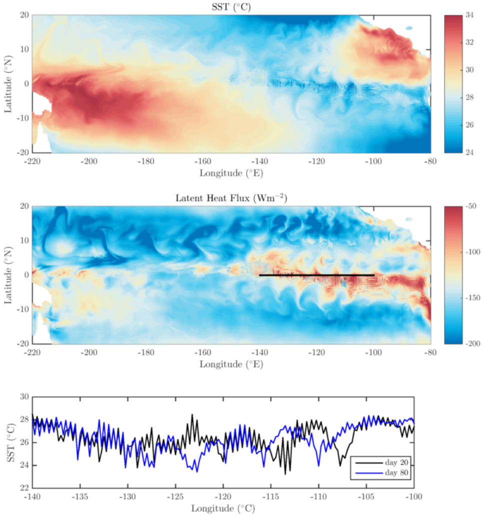


Figure: SST and latent heat flux from a single day for a spinup experiment with constant January-June CORENYF forcing.