Nonlinear Short-Term Upper Ocean Circulation Variability in the Western Tropical Pacific

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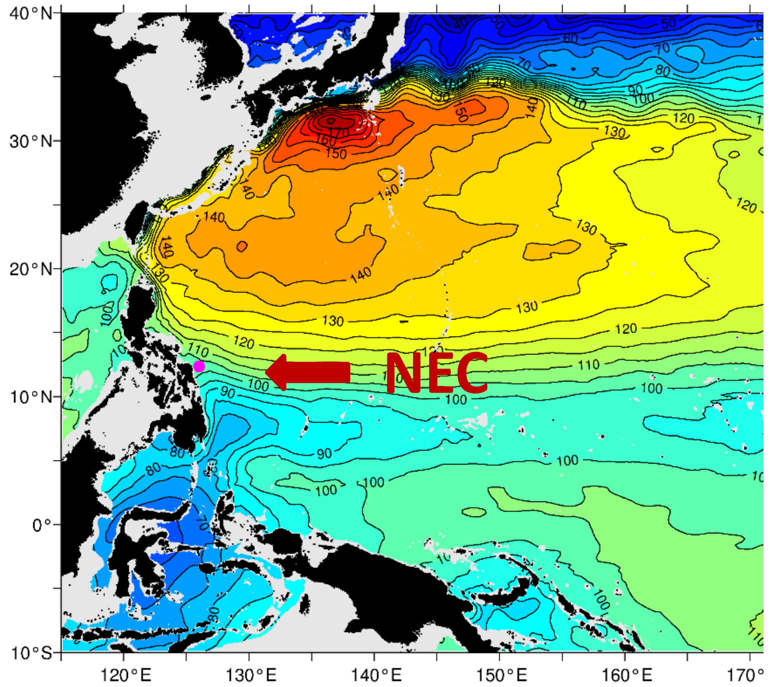
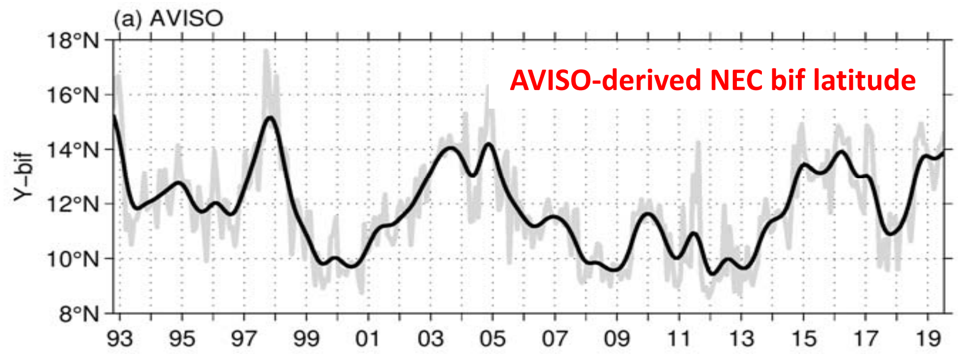
Low-frequency sea level & circulation variability in tropical Pacific can be understood as wind-forced baroclinic responses





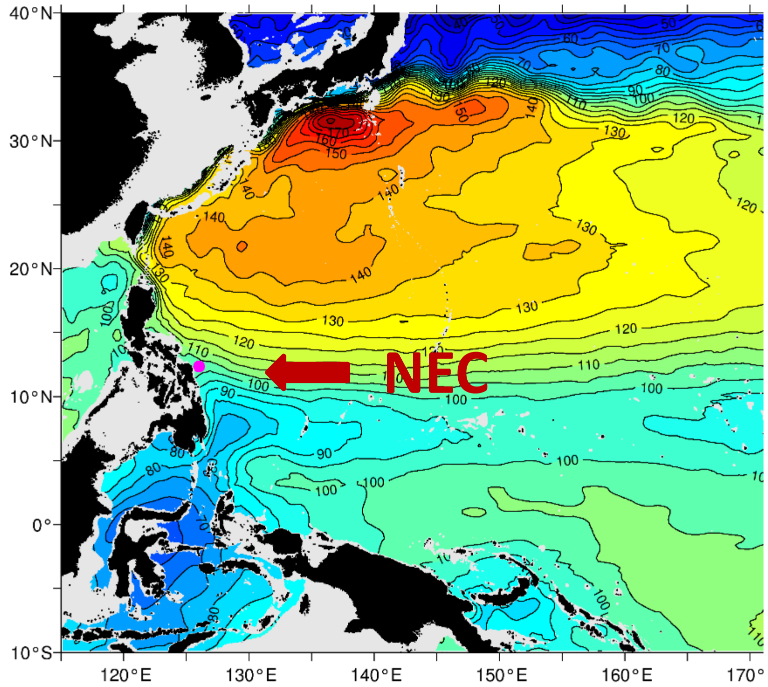
- **Utilize the weekly AVISO SSH anomaly data**
- **Add mean SSH field of Rio et al. (2009): mean NEC bifurcation at ~12°N**
- **Calculate meridional geostrophic velocity as a function of y along the Philippine coast:**

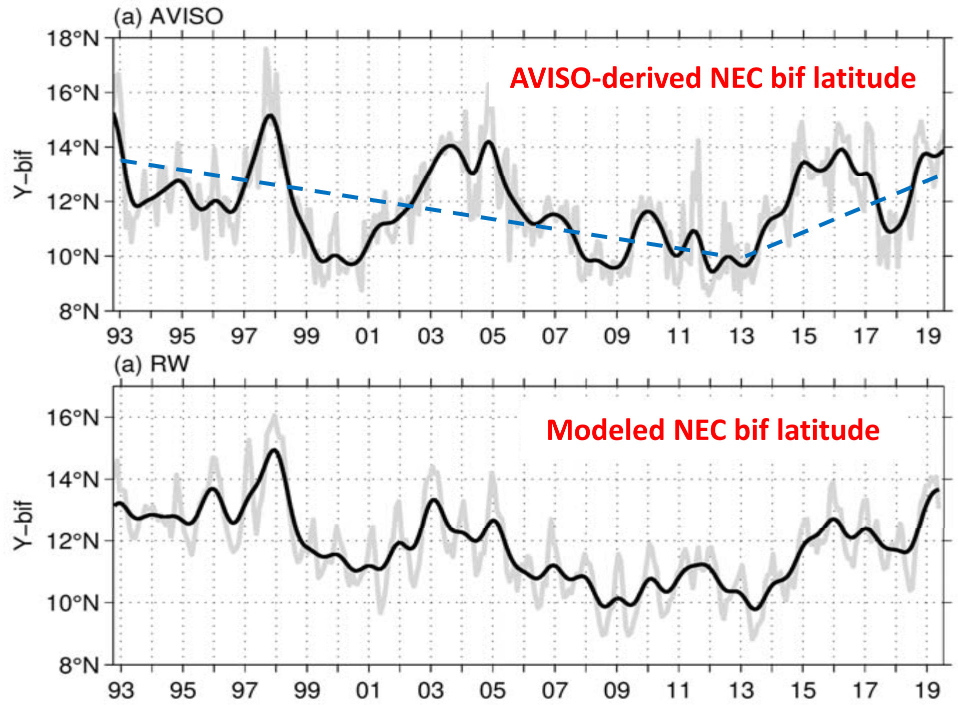
$$v_g(y,t) = \frac{g}{f}\left[h_e(y,t) - h_w(y,t)\right],$$

where h_w is SSH in 1°-band east of the coast & h_e in 1°-band further to the east

- **NEC bifurcation latitude $Y_b(t)$ is defined at where $v_g = 0$**

Low-frequency sea level & circulation variability in tropical Pacific can be understood as wind-forced baroclinic responses



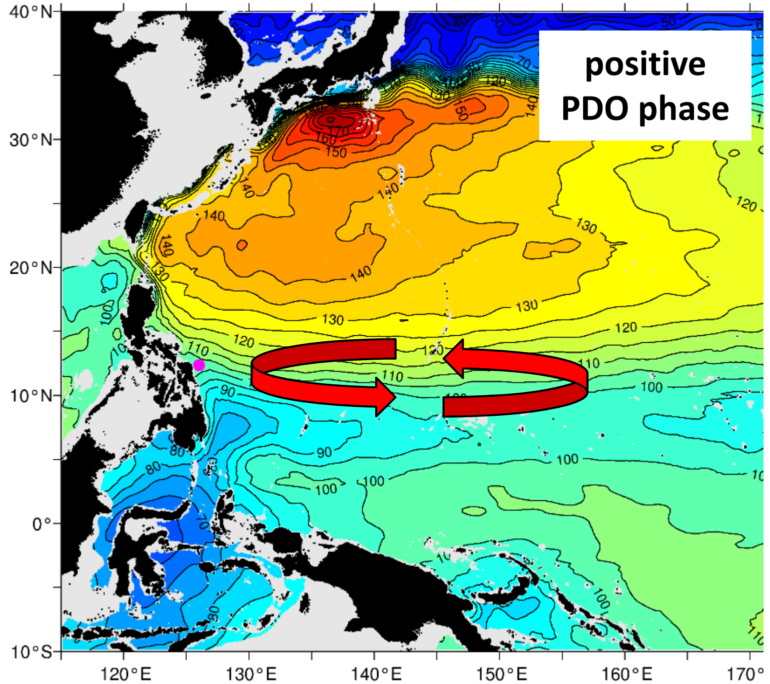


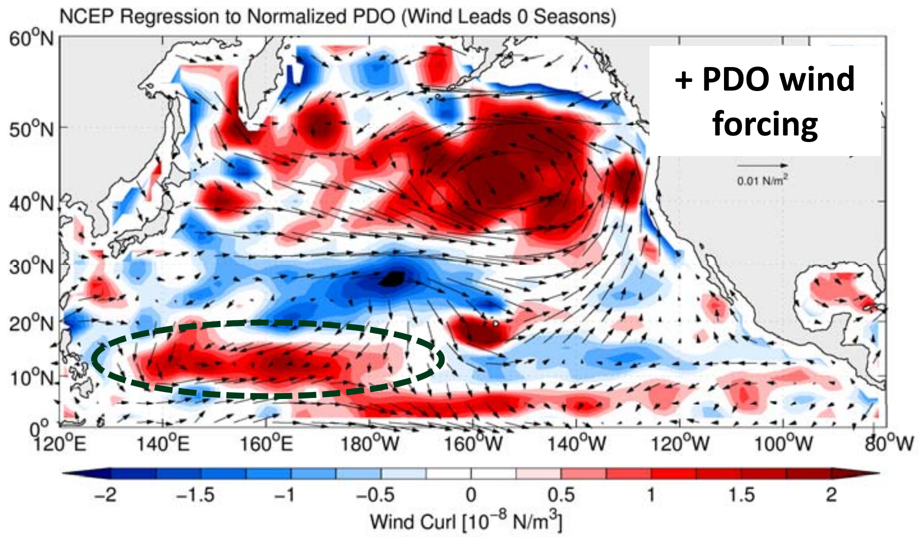
- NEC position change can be represented by sea level change off the Philippine coast
- Low-frequency sea level change is governed by wind-forced baroclinic RW dynamics:

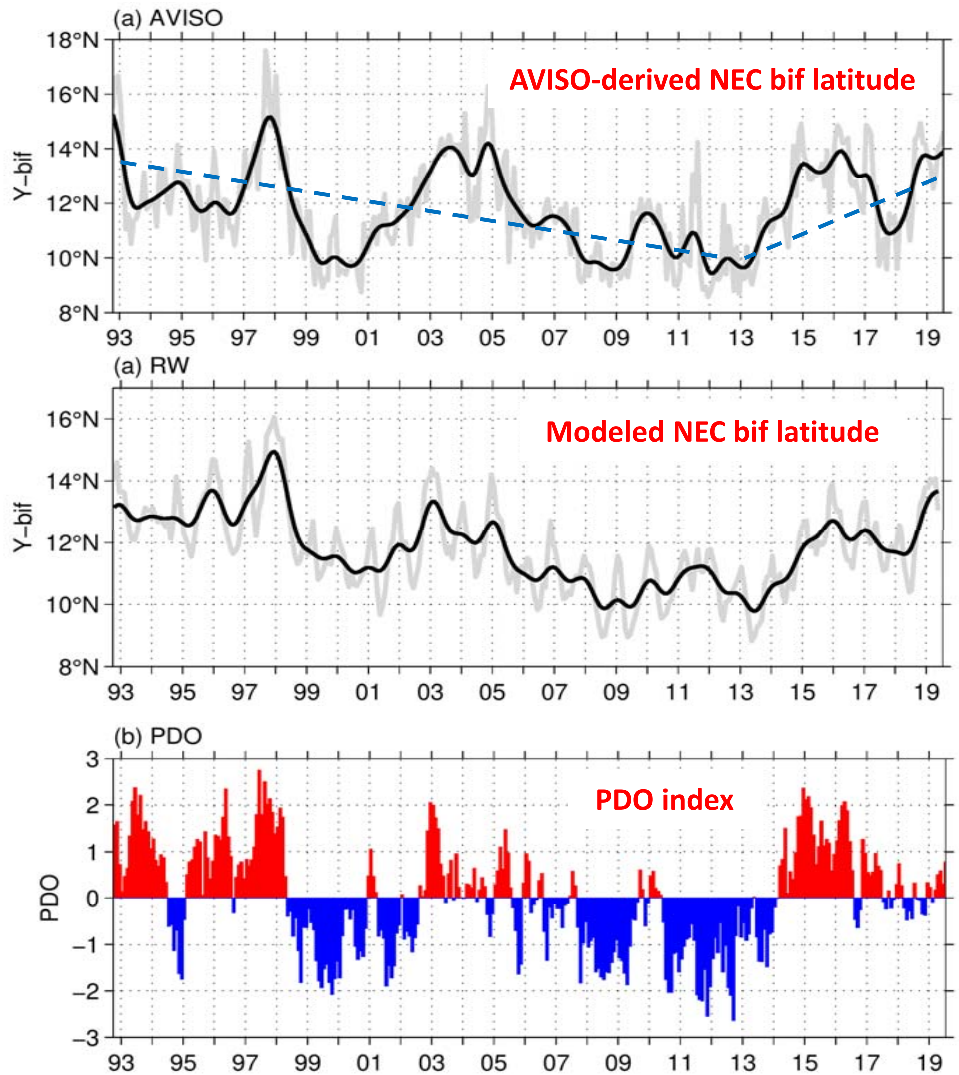
$$\frac{\partial h'}{\partial t} - c_R \frac{\partial h'}{\partial x} = -\frac{g'}{g\rho_o} \operatorname{curl}\left(\frac{\boldsymbol{\tau}}{f}\right) - \epsilon h'$$

Ekman pumping

Low-frequency sea level & circulation variability in tropical Pacific can be understood as wind-forced baroclinic responses

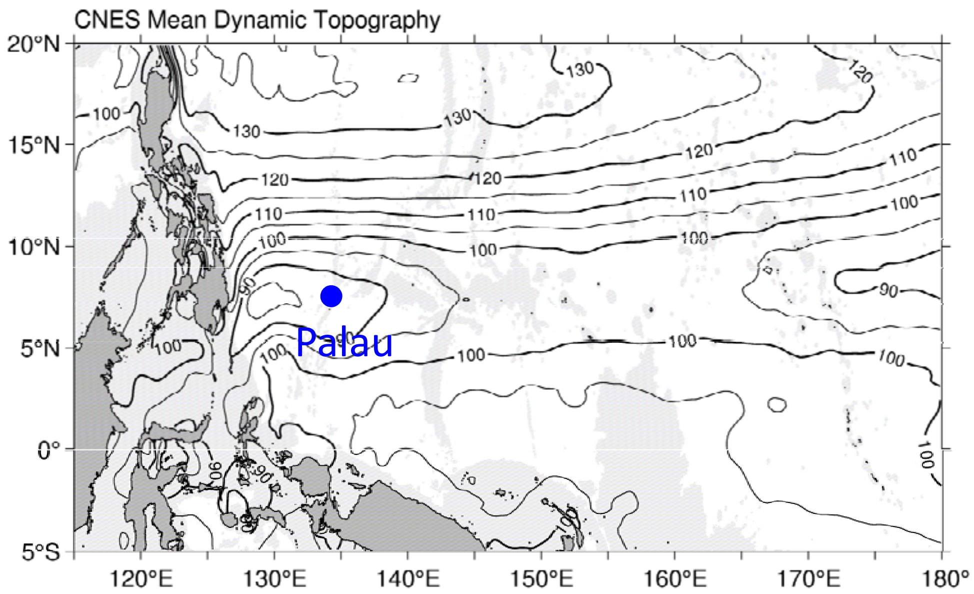




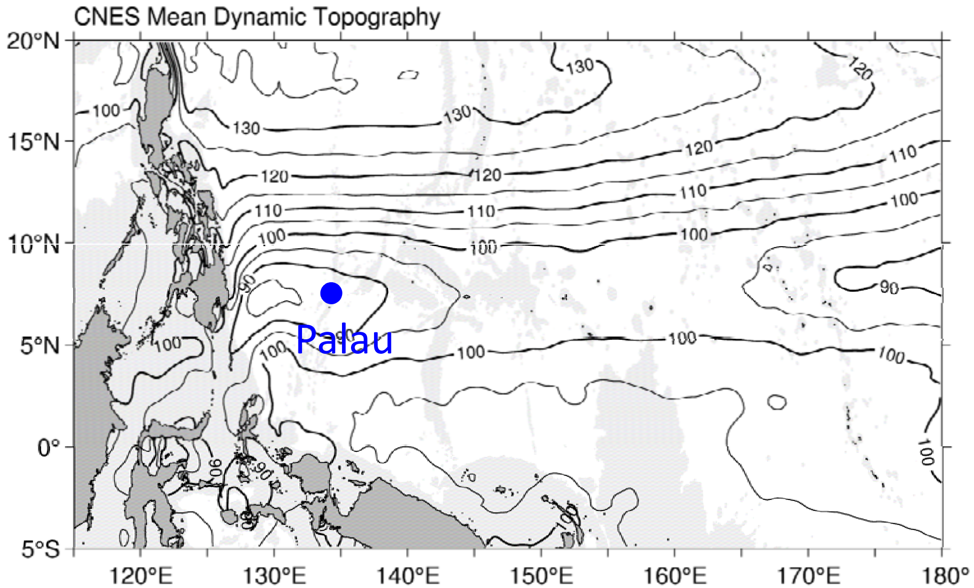


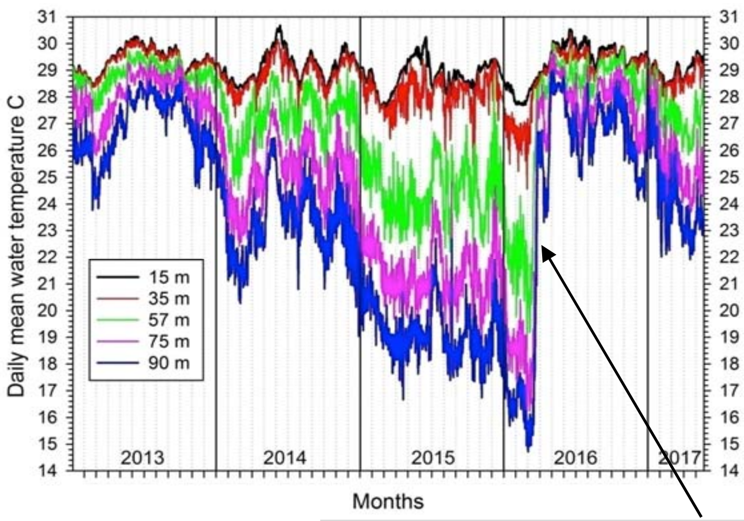
+ PDO forcing → Ekman suction off Philippines → low sea level → poleward NEC shift

- Is the linear RW dynamics valid for upper ocean variability around Palau ?



- Is the **linear RW dynamics** valid for upper ocean variability around **Palau** ?

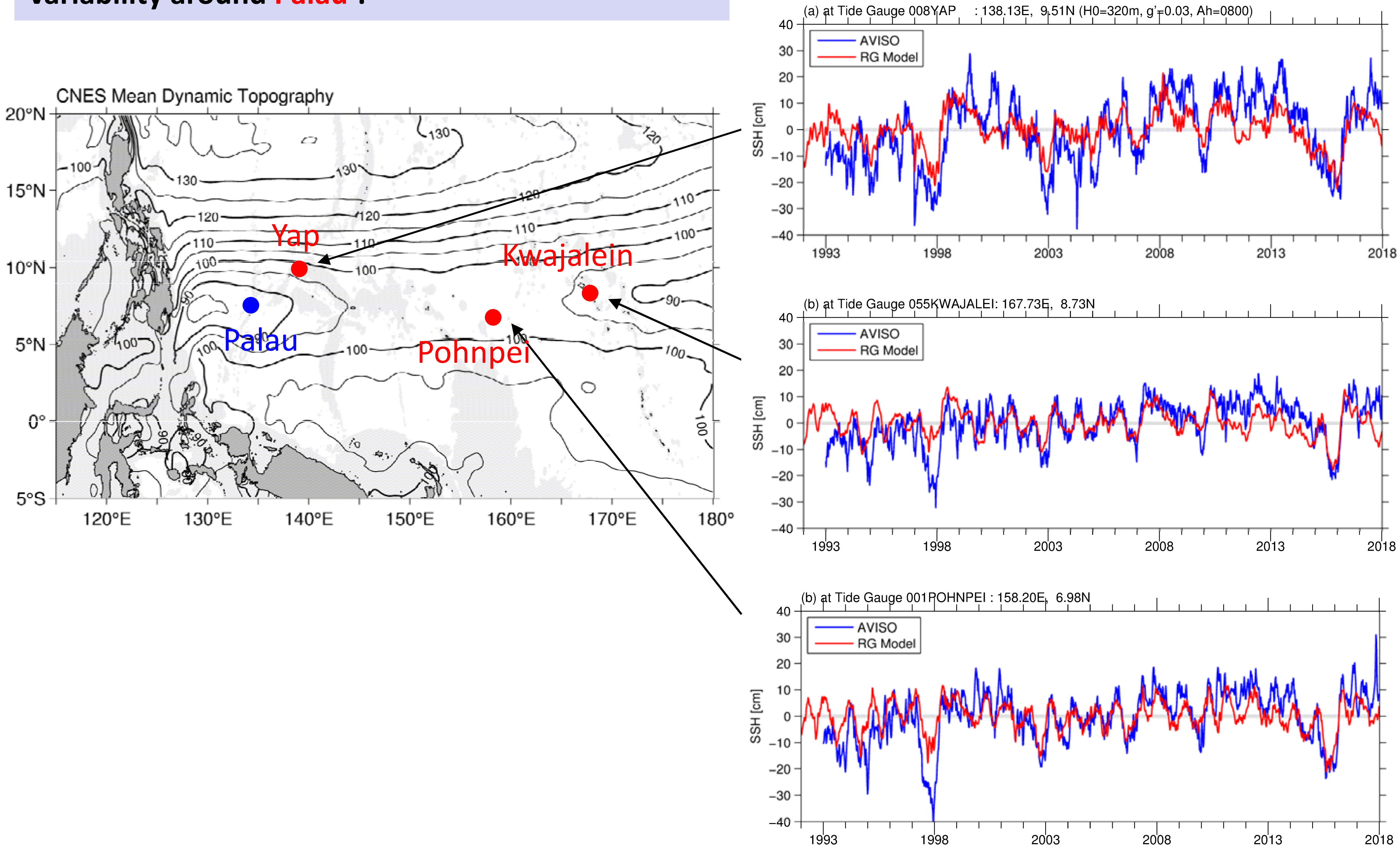




ΔT > 14°C at Palau in < 2 months

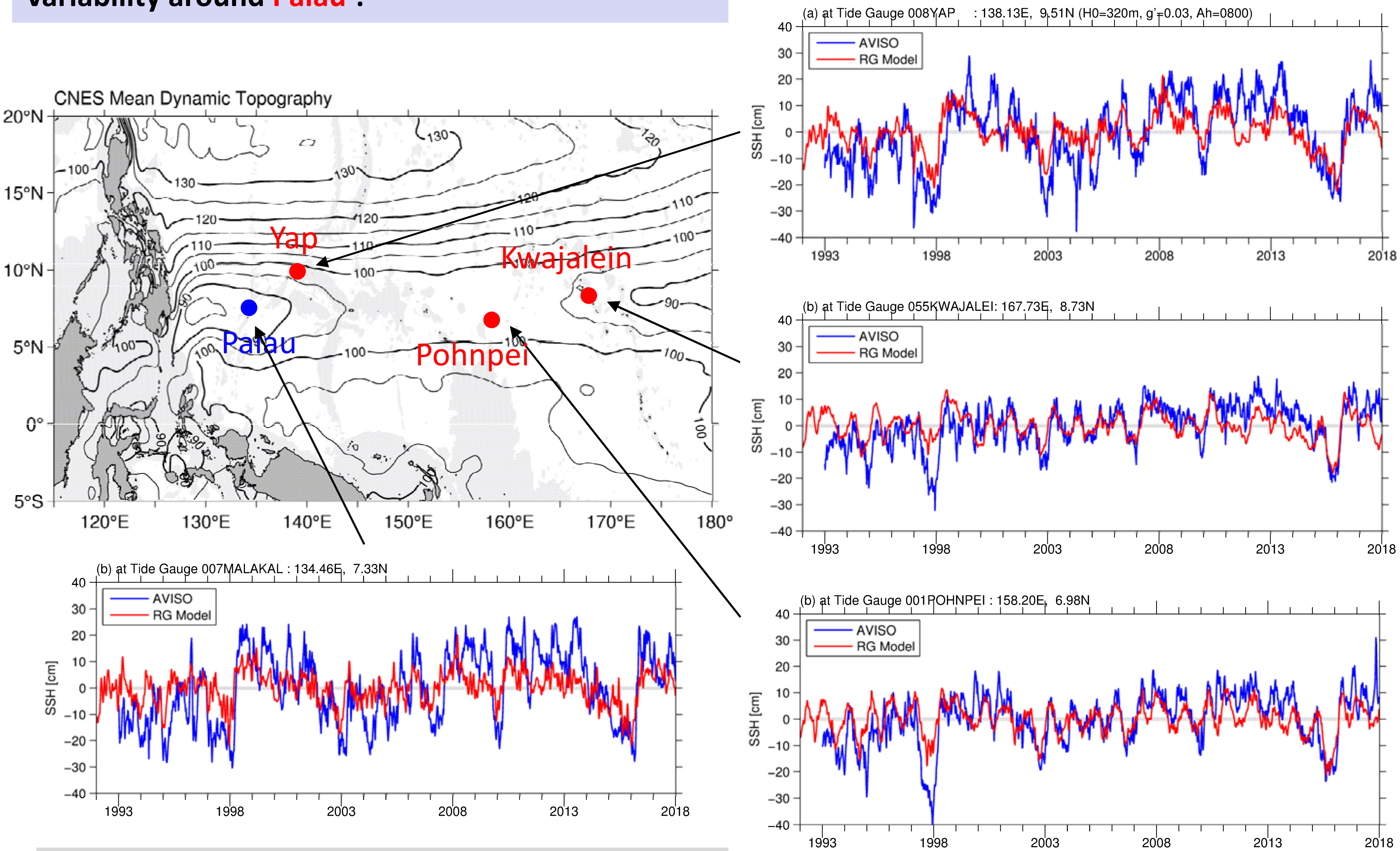
Thermal stress on shallow reef off Palau
(Colin 2018, TOS)

- Is the **linear RW dynamics** valid for upper ocean variability around **Palau** ?



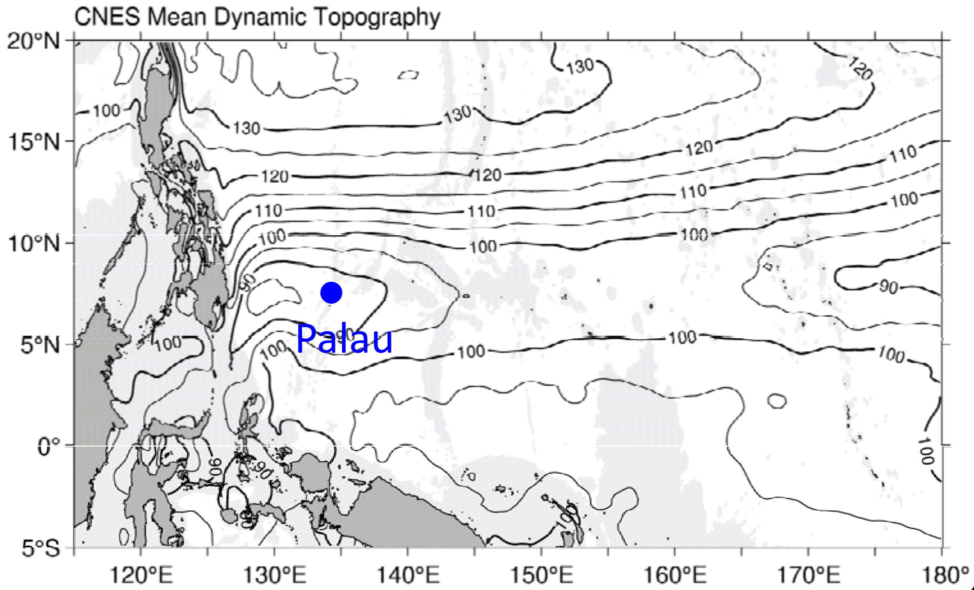
- **Linear RW model** does a reasonable job hindcasting the observed SSH variability

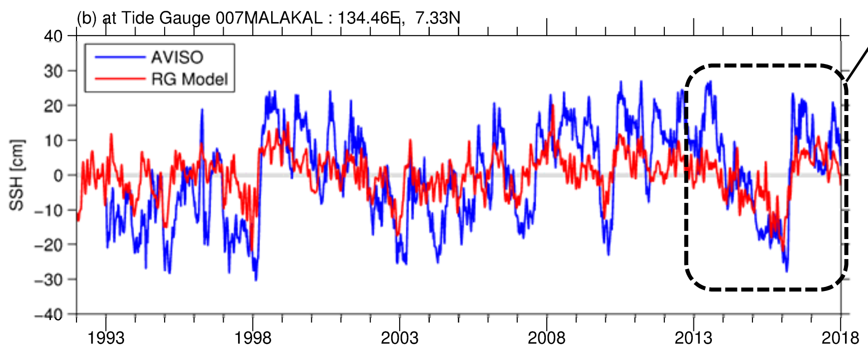
- **Is the linear RW dynamics valid for upper ocean variability around Palau ?**



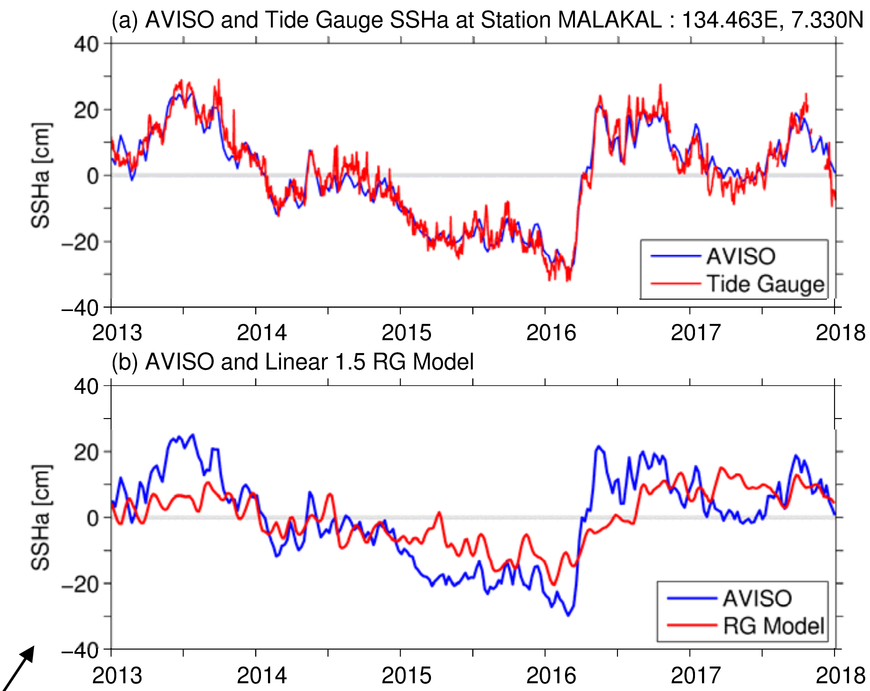
- **At Palau, SSH variability is significantly under-estimated by the linear RW model**

- **A closer look at the upper ocean variability at Palau during the 2016 El Niño → La Niña transition**



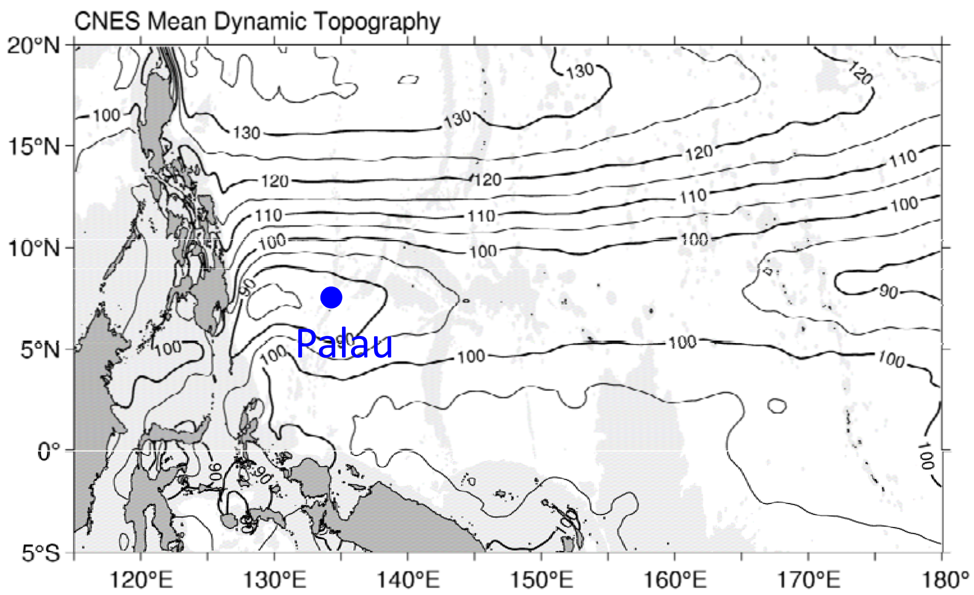


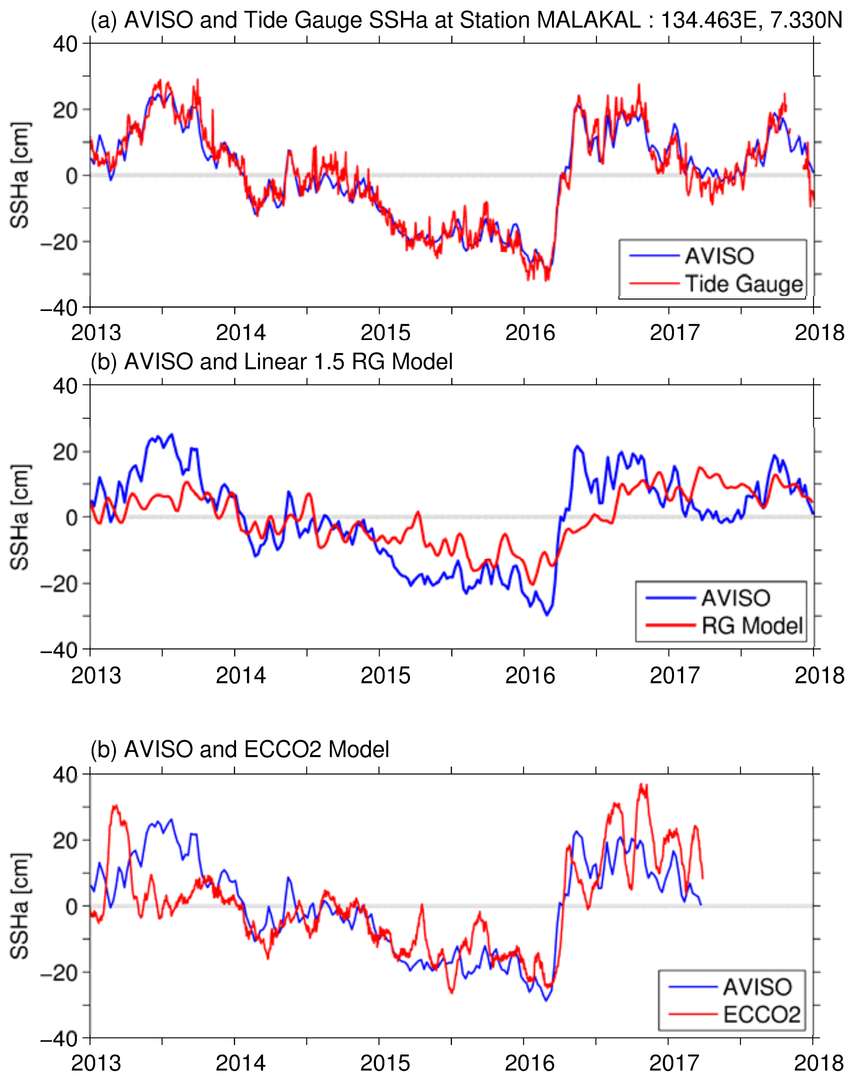
- **At Palau, SSH variability is significantly under-estimated by the linear RW dynamics**



- **During the El Niño → La Niña transition in early 2016, the linear model-simulated SSH jump is too small & too diffused!**

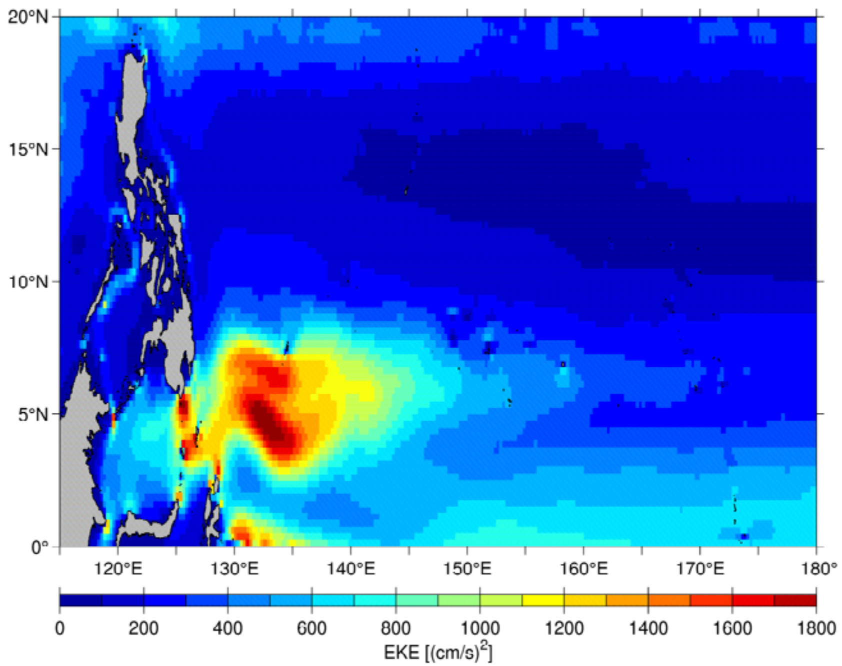
- **A closer look at the upper ocean variability at Palau during the 2016 El Niño → La Niña transition**

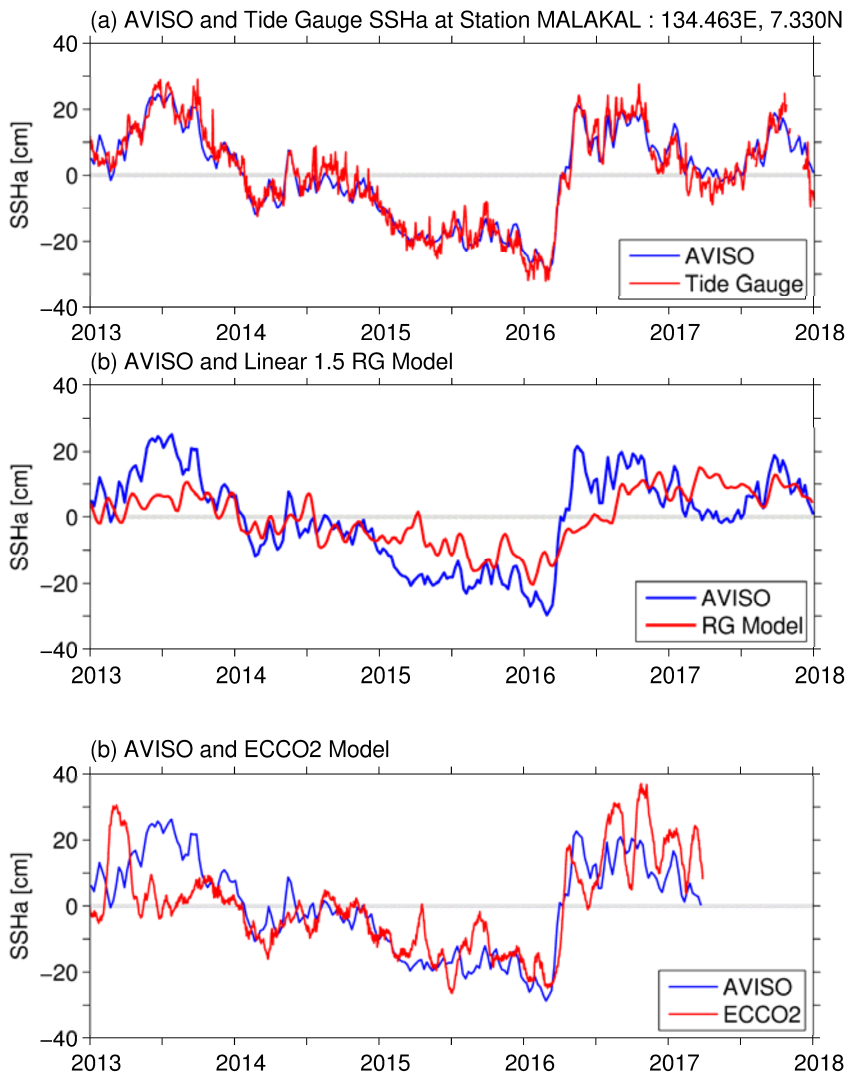




- **To explore the intrinsic nonlinear processes, we analyze the eddy-permitting ECCO2 state estimate that captured well the short-term variability around Palau**

• **Quantifying linear vs. nonlinear processes from the 1/4° eddy-permitting ECCO2 state estimate**





• **The area surrounding Palau is where EKE has a regional maximum → potential break-down of linear vorticity dynamics**

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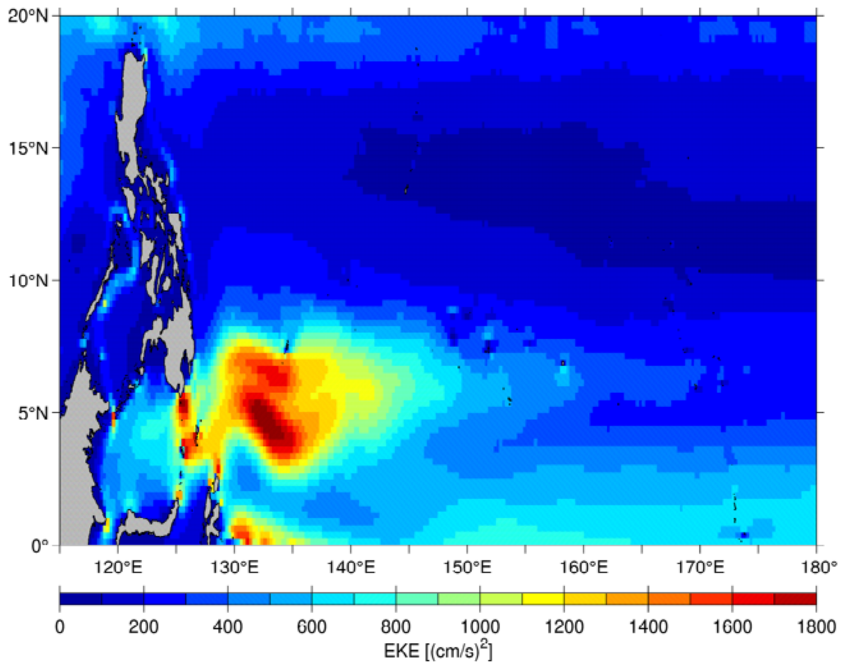
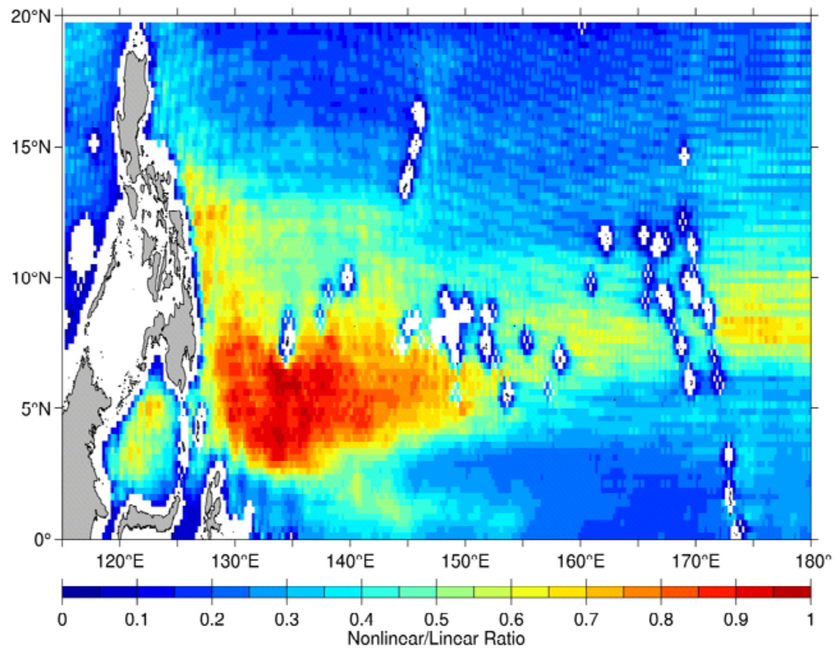


- **The area surrounding Palau is where EKE has a regional maximum → potential break-down of linear vorticity dynamics**

$$\frac{\partial h'}{\partial t} = \underbrace{-\nabla\cdot\left(\boldsymbol{u}'\bar{h}\right) - \nabla\cdot\left(\bar{\boldsymbol{u}}h'\right)}_{\text{linear processes}} \underbrace{- \nabla\cdot\left(\boldsymbol{u}'h'\right)}_{\text{nonlinear processes}}$$

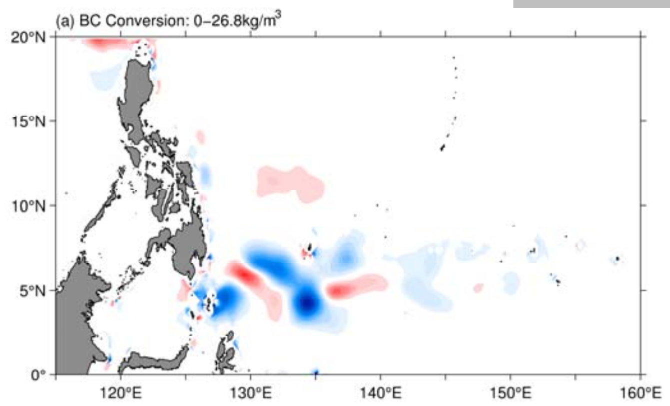
linear processes **nonlinear processes**



- **Ratio of nonlinear/linear processes contributing to $\partial h'/\partial t$ → the region south of Palau forms a high-ratio hot spot**

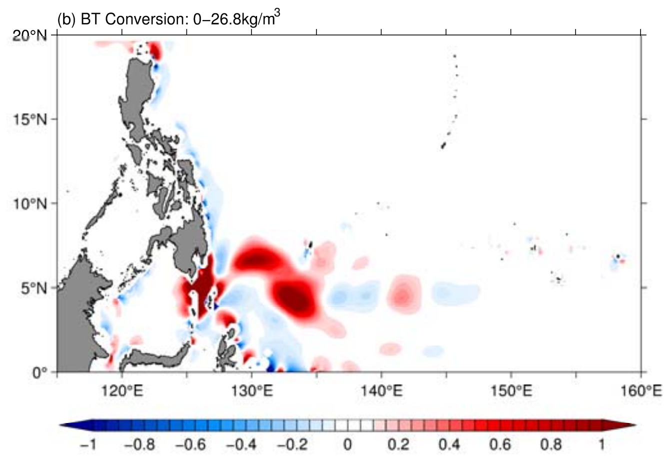
- **What is the energy source underlying the regional eddy variability around Palau ?**

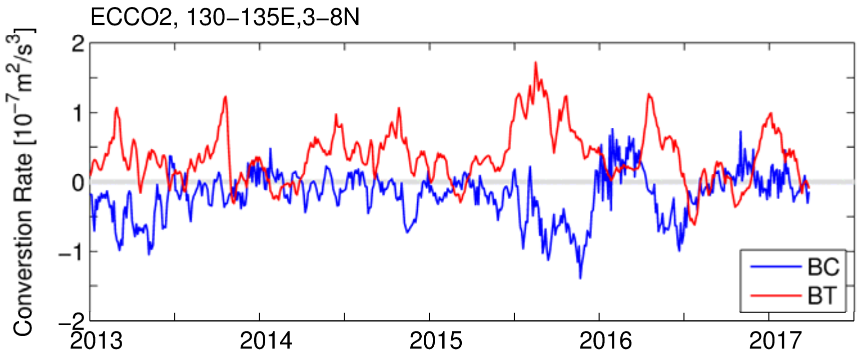
baroclinic conversion rate = $-\frac{g}{\rho_o}w'\rho'$



barotropic conversion rate =

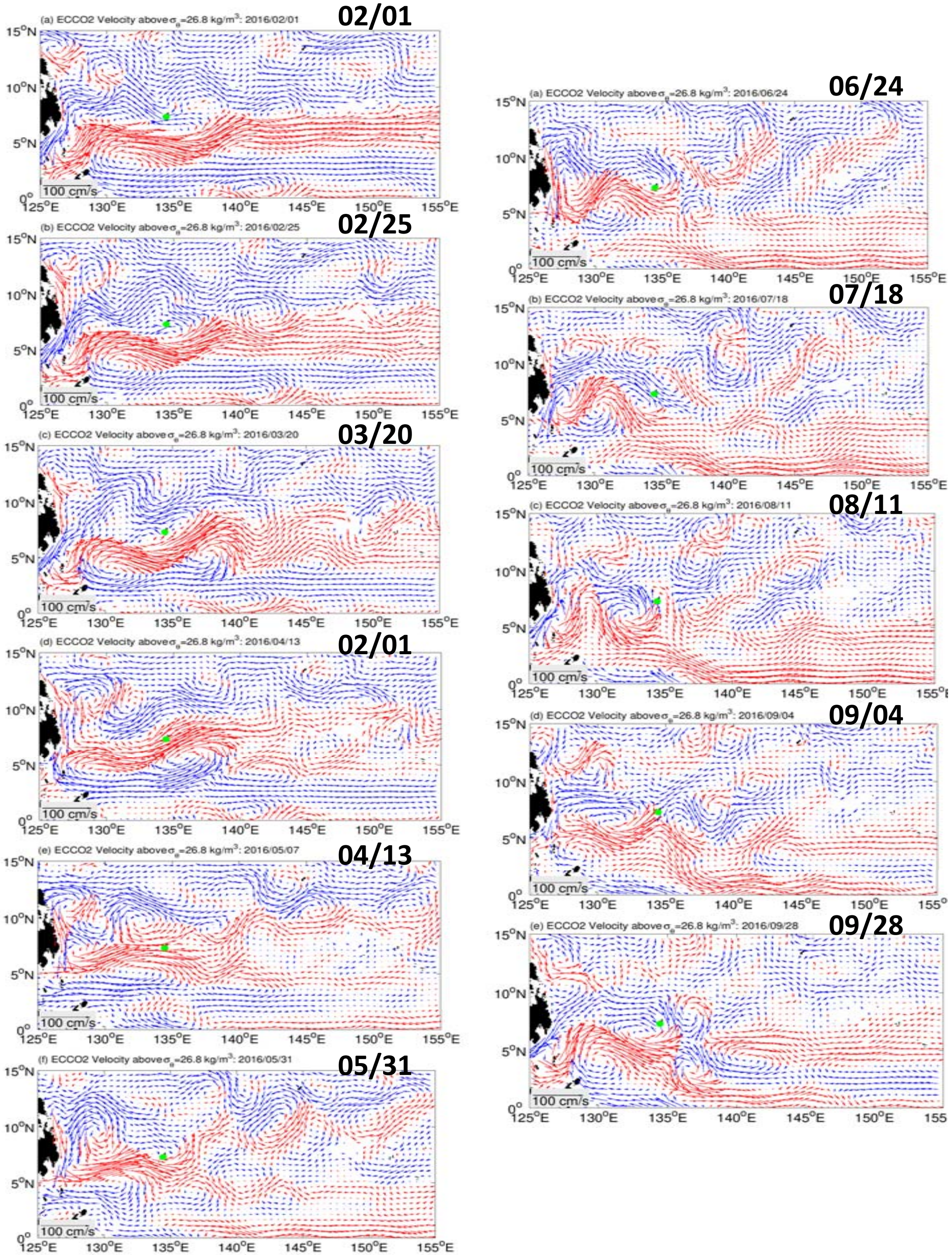
$$-(\boldsymbol{u}'u')\cdot\nabla\bar{u}-(\boldsymbol{u}'v')\cdot\nabla\bar{v}$$





- **Intensity of NECC's barotropic instability is modulated interannually; strengthened NECC during El Nino years favors stronger instability**

- **In the region south of Palau, eddy energy is mostly derived from mean lateral shear of NECC via barotropic instability**



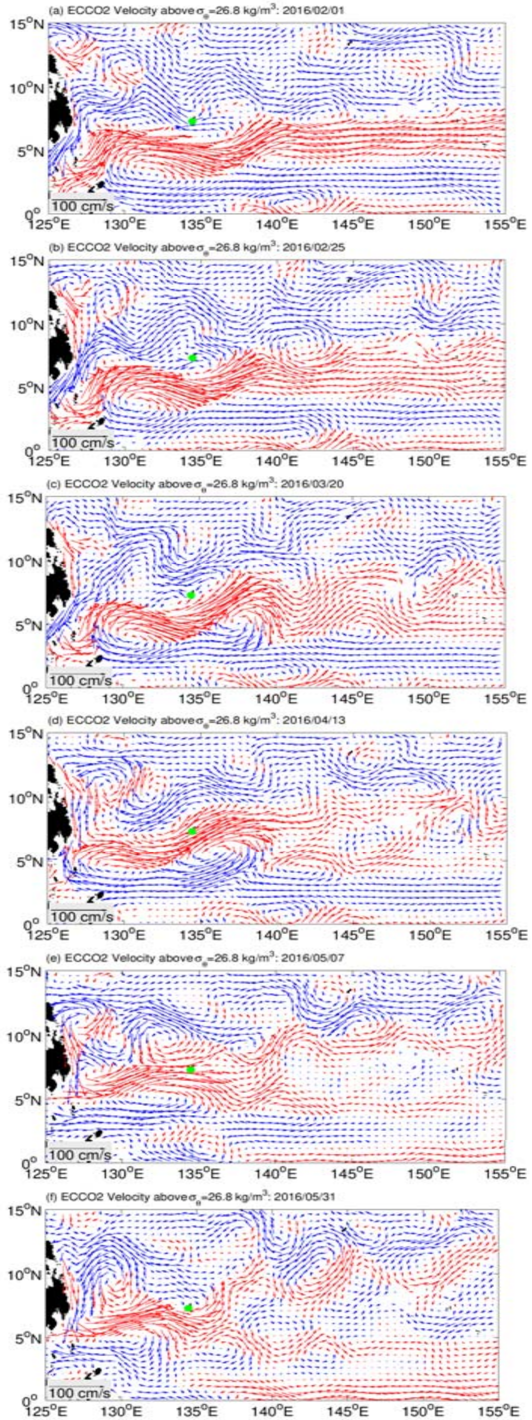
- Upper ocean evolution from the ECCO2 state estimate

- When an El Niño event ends, trade winds recover & generate intense off-equatorial downwelling RWs

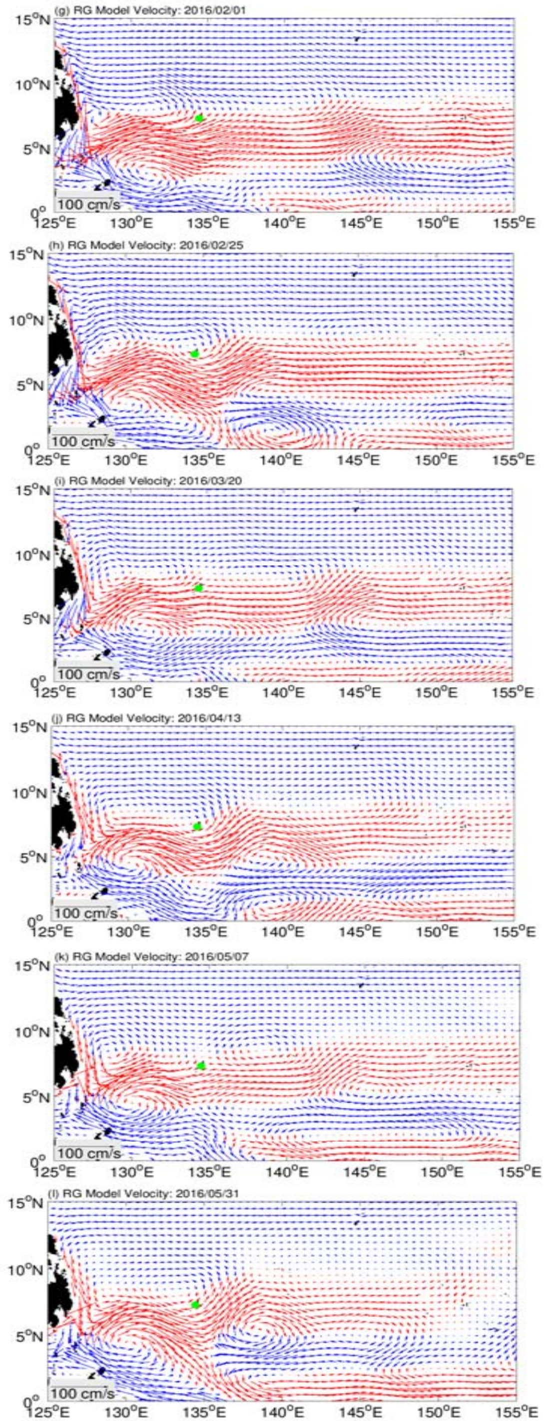
- As these intense RWs propagate westward into the Philippine Sea, they interact with horizontally-sheared NECC & lead to barotropic instability

- The instability breaks down the NECC, causing short-term, large-amplitude thermal/circulation fluctuations around Palau

- **Upper ocean evolution from the ECCO2 state estimate**



- **Upper ocean evolution from the linear RG model**



Summary

- Palau is located at the northern boundary of a "shadow zone" where wind-forced linear vorticity dynamics breaks down
- Barotropically-unstable NECC west of 150°E is responsible for the presence of this shadow zone
- Effect of nonlinearity is enhanced during the El Niño → La Niña transition when intense, wind-forced, downwelling RWs impinge on the seasonally poleward-migrating NECC