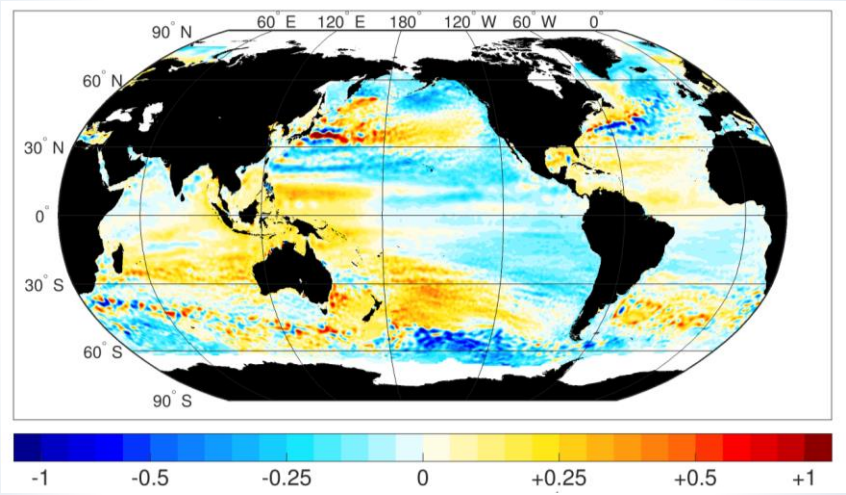
Sea Level, Subsurface Gradients, and the Temporal Variability of Mesoscale Eddies

Andrew Delman (Jet Propulsion Laboratory, California Institute of Technology)
Tong Lee (Jet Propulsion Laboratory, California Institute of Technology)
Bo Qiu (University of Hawai‘i, Mānoa)



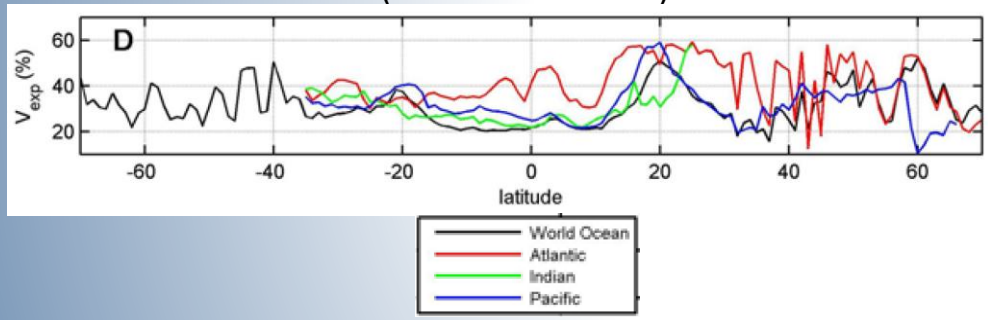
Sea level trend minus global mean (cm yr^{-1}), 1993-2016

Jet Propulsion Laboratory
California Institute of Technology

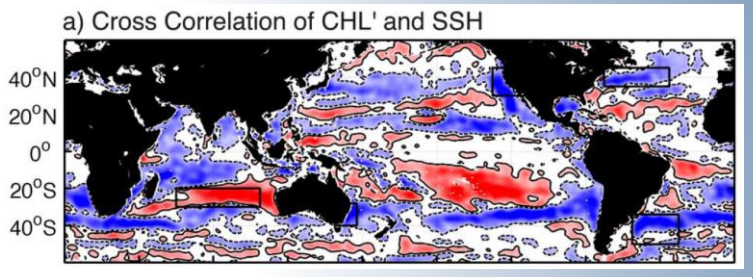
Sources and Sinks of Ocean Mesoscale Eddy Energy workshop – Tallahassee, FL
14 March 2019

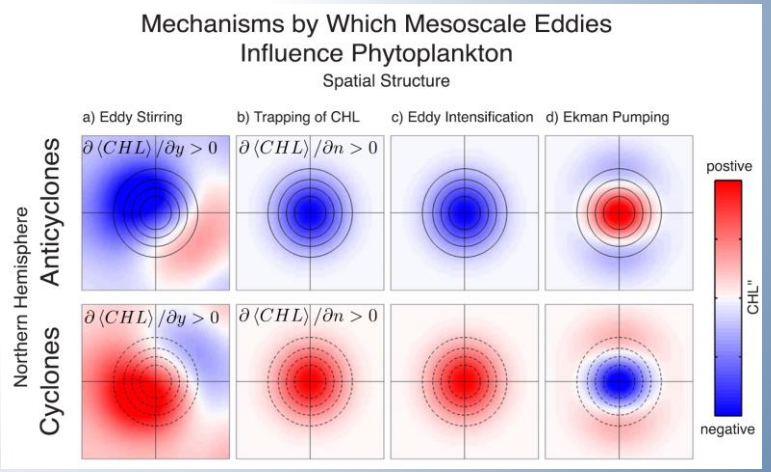
Motivation: Oceanic mesoscale dynamics play a pivotal role in the climate system, and in marine ecosystems

Eddy meridional heat transport variance, as % of total (Volkov et al. 2008)



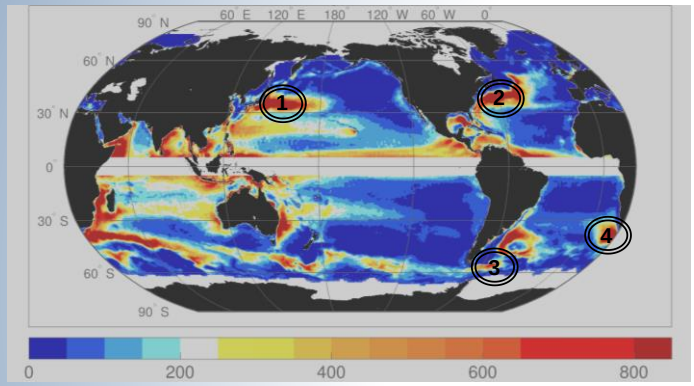
Relationship between chlorophyll anomalies, SSH, and eddies (Gaube et al. 2014)



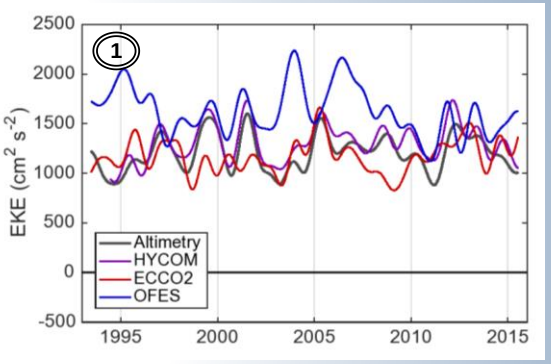


The temporal variability of eddy kinetic energy (EKE) at interannual/decadal timescales is generally not well represented in ocean models

EKE time mean ($cm^2\ s^{-2}$), from gridded altimetry (CLS/CNES)



Kuroshio Extension EKE, low-pass filtered for periods > 14 months

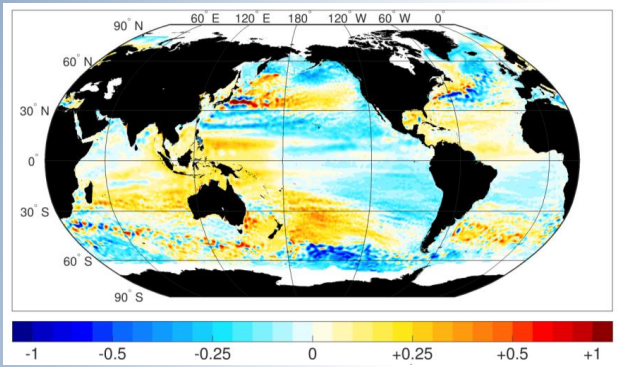


Surface EKE correlations between altimetry and models, with 14-month low pass filter

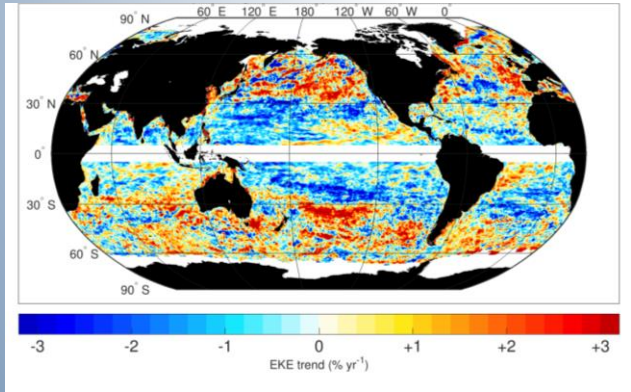
Altimetry correlation with…	HYCOM GOFS 3.1 Rean	ECCO2	OFES 0.1° NCEP
Kuroshio Extension (1)	**0.89**	0.22	0.03
Gulf Stream Extension (2)	**0.76**	-0.03	0.10
Drake Passage outflow (3)	0.25	0.09	0.17
Agulhas rings (4)	**0.49**	-0.14	0.09

The oceanic mesoscale may influence regional rates of sea level change

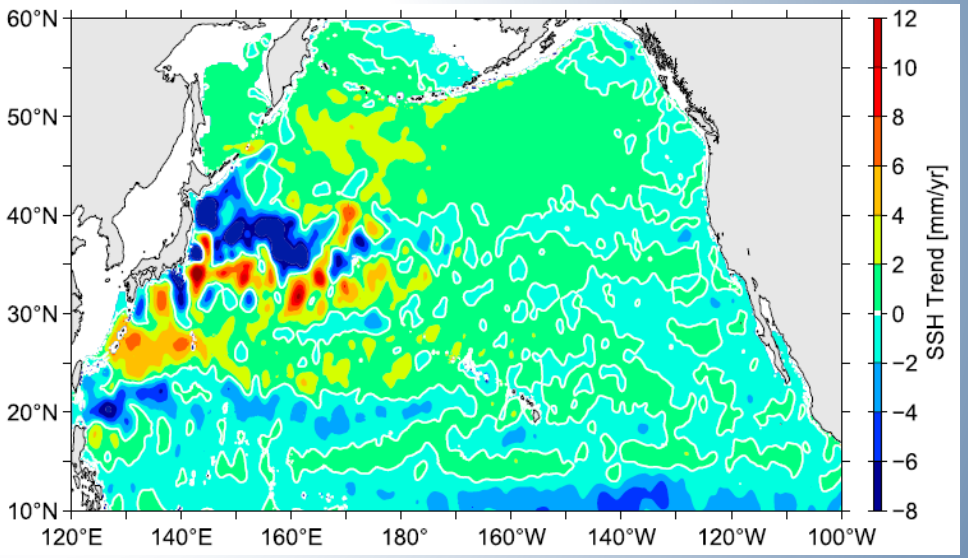
Sea level trend minus global mean (cm yr^{-1}), 1993-2016



Eddy kinetic energy (EKE) trend (% yr^{-1}), 1993-2016



Difference in sea level trend (1992-2013) forced by wind stress & eddy momentum fluxes, vs. wind stress alone (Qiu et al. 2015)



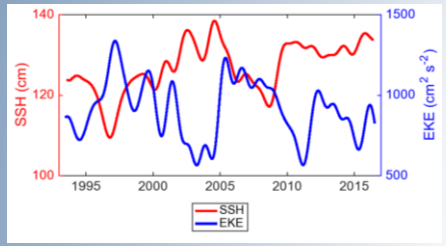
Research focus

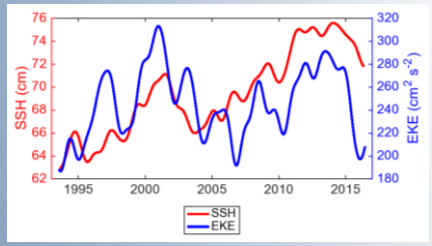
- **Where are interannual and decadal changes in eddy kinetic energy (EKE) associated with changes in local sea surface height (SSH)?**

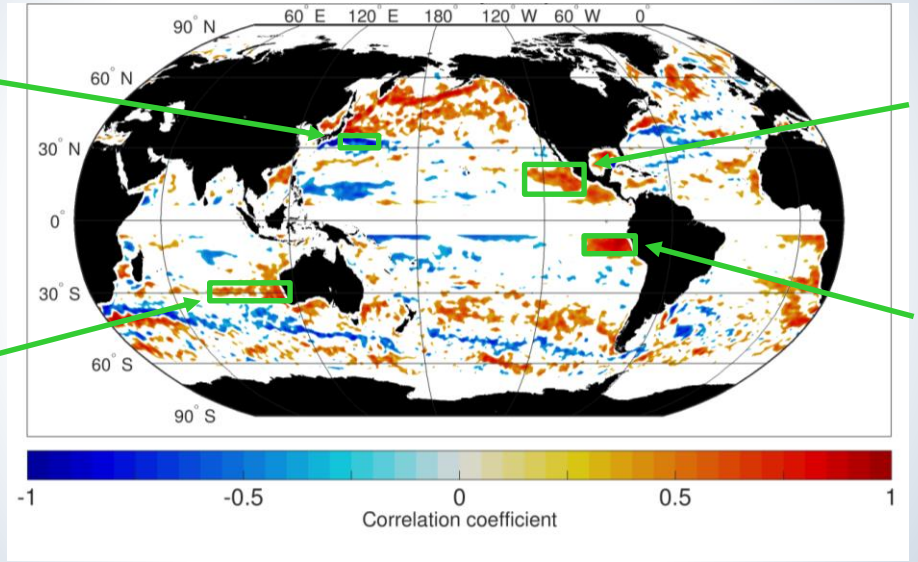
- **What does this imply about the relationship between mesoscale energy (represented by EKE) and the large-scale circulation (represented by SSH) on these timescales?**
  - Do mesoscale eddies influence interannual/decadal changes in sea level?
  - Are sea level variations a useful indicator of areas where large-scale atmospheric or oceanic forcing influences the variability of mesoscale eddy activity?

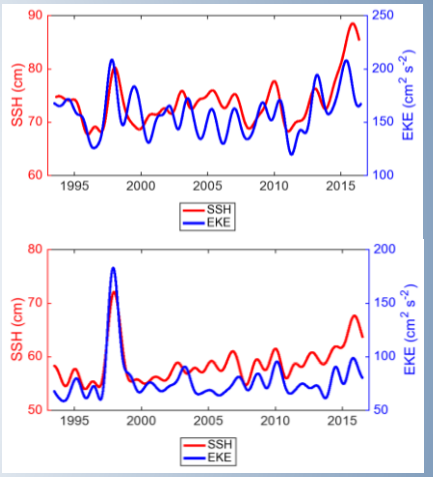
Sea level and EKE co-variations

Local correlation of SSH and EKE, at interannual/decadal timescales
(only correlations of >95% significance are shaded)







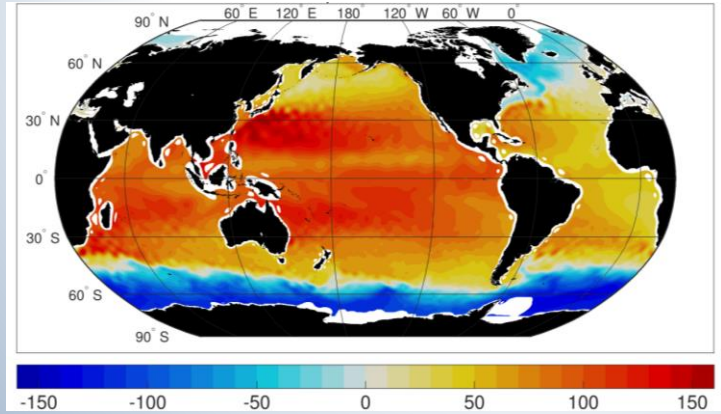


- Change in sign of SSH-EKE correlation occurs across many strong currents
- SSH-EKE correlations are robustly positive in more places than they are negative
  - Higher sea level tends to be associated with higher eddy activity…why?

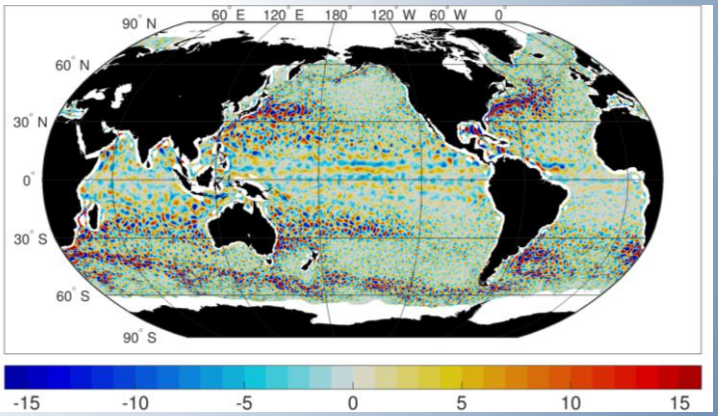
Forcing by the mesoscale: defining anticyclonic vs. cyclonic mesoscale features

- We consider the relative contribution of anticyclonic vs. cyclonic mesoscale phenomena to EKE, as follows:
  - Low-pass spatial filter SSH in two dimensions, with the cutoff wavelength varying by latitude
  - The residual is the **mesoscale SSH or SSH_{meso}**
  - $SSH_{meso} > 0$: anticyclonic eddies (and other mesoscale phenomena)
  - $SSH_{meso} < 0$: cyclonic eddies/other mesoscale phenomena

Snapshots of SSH components on 1998 Jan 01



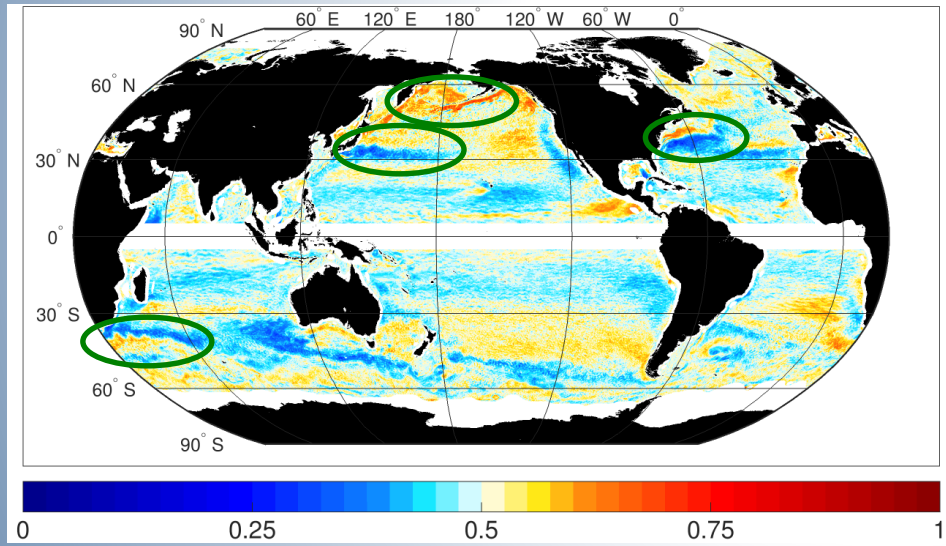
Low-passed SSH_{lp} (cm)



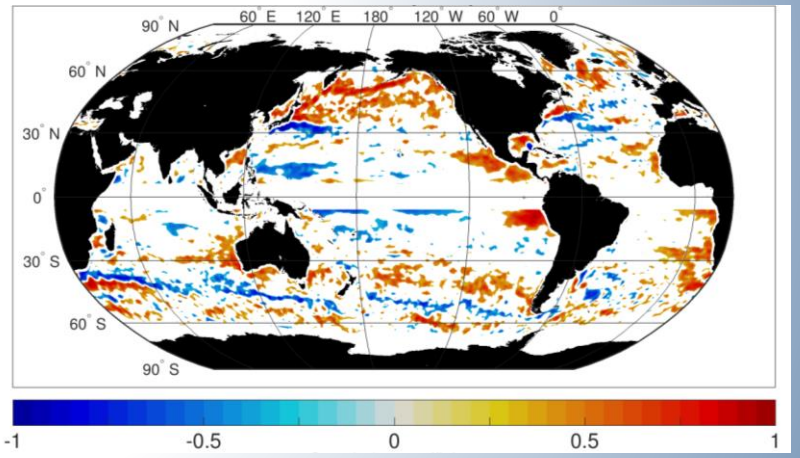
Mesoscale SSH_{meso} (cm)

EKE impact on sea level variability due to anticyclonic/cyclonic bias?

- An anticyclonic or cyclonic bias at mesoscales appears to be responsible for the SSH-EKE relationship in many areas, most notably near strong currents.
  - More anticyclones + higher EKE → higher sea level locally
  - More cyclones + higher EKE → lower sea level locally



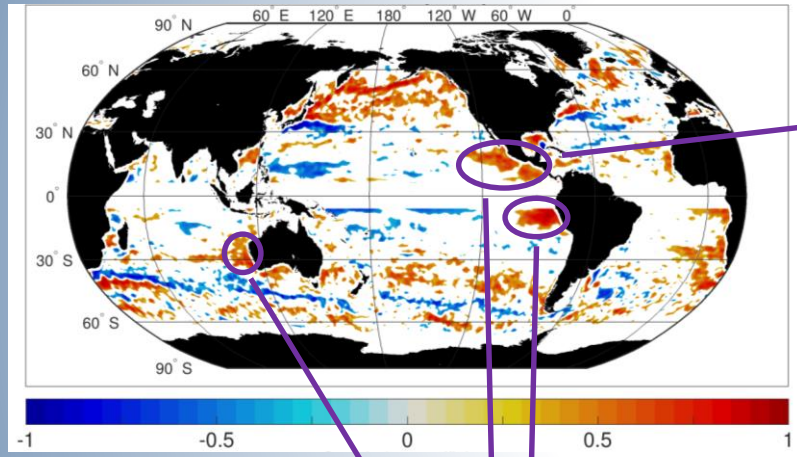
Fraction of EKE associated with positive SLA_{meso}



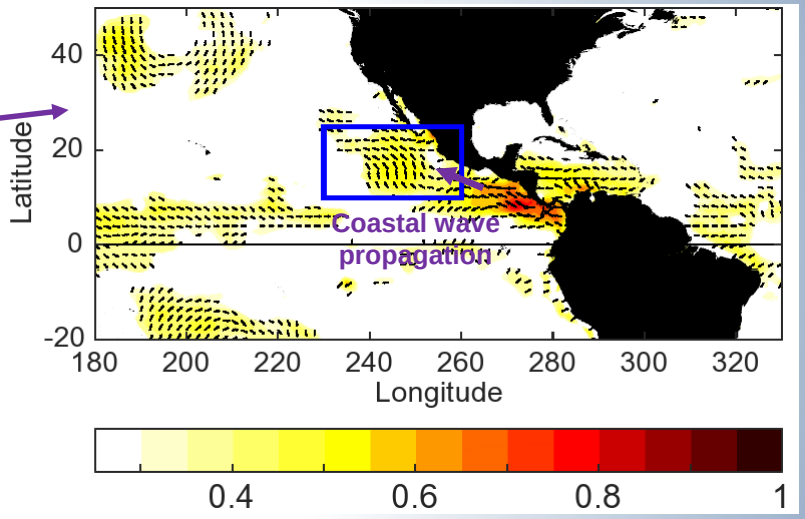
Local SSH-EKE correlation coefficient

Forcing of mesoscale variability by the atmosphere

- Surface winds (and planetary waves generated by them) may drive interannual/decadal variations in eddy generation, particularly near eastern boundaries



Local SSH-EKE correlation coefficient

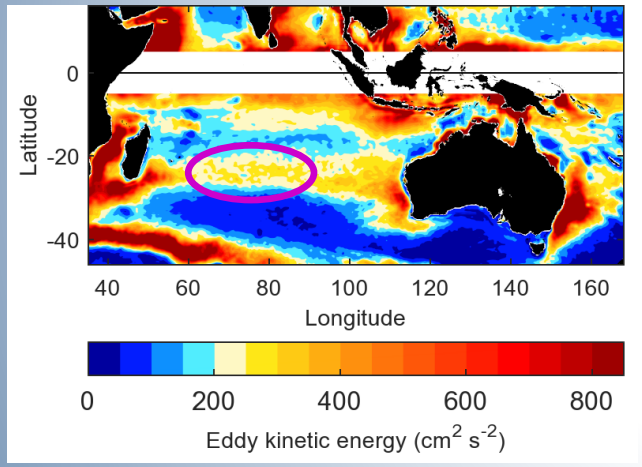


Box-averaged EKE correlated with CCMP 10 m wind:
Wind leads EKE by 6 months

- EKE variability in the lower-latitude Pacific and Indian Oceans is forced largely by wind and planetary waves associated with ENSO

Influence of subsurface gradients on interannual/decadal EKE variability

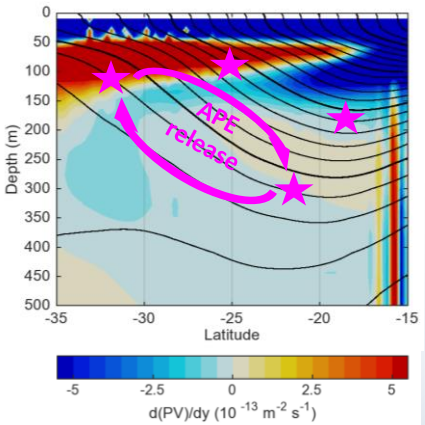
- In the central Indian Ocean between 30°-20°S, we found that the time-mean EKE maximum was coincident with the **lateral density gradient**
- The EKE time variability appears to be explained in part by changes in the **along-isopycnal potential vorticity (PV) gradient** (Delman et al. 2018)



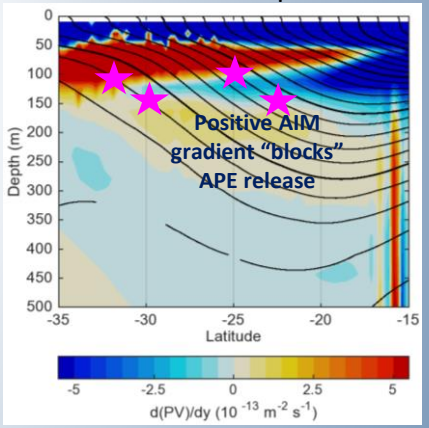
Time mean surface EKE from altimetry

Meridional, along-isopycnal PV gradient from ECCO2

High EKE composite

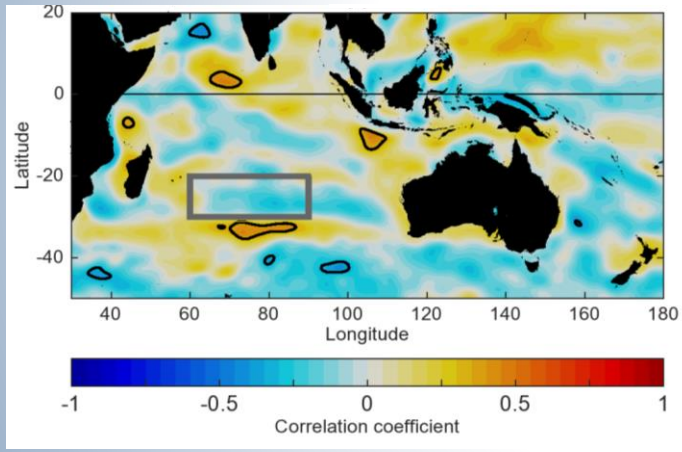


Low EKE composite

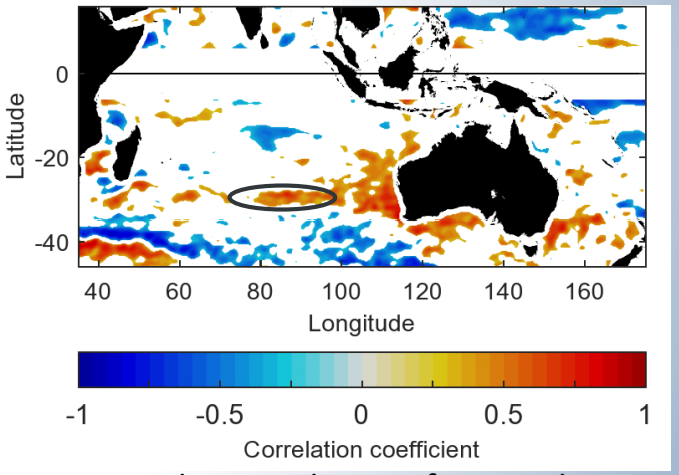


Subsurface gradients and interannual/decadal EKE: related to SSH anomalies?

- **Higher EKE** in this region is associated with a subsurface positive PV anomaly near 30°S, in turn likely induced by **anticyclonic wind stress curl** anomalies
- These anticyclonic wind stress curl anomalies might also force a positive SSH anomaly, explaining the **positive SSH-EKE correlation** in the region



Correlation of wind stress curl, leading mesoscale EKE in **gray box** by 6 months, ID timescales



Zero-lag correlation of SSH and EKE anomalies, ID timescales

Conclusions

- SSH anomalies (an indicator of large-scale variability) co-vary with surface EKE anomalies (indicator of mesoscale variability) on interannual/decadal timescales, in many parts of the ocean

Mesoscale → large-scale variability?

Large-scale → Mesoscale variability?

Strong frontal jets

↓

Preference for anticyc/cyc on flanks

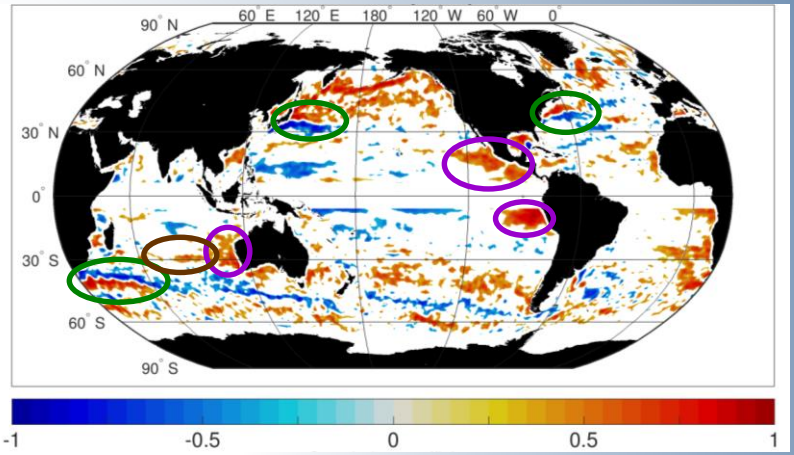
Winds & planetary waves

↓

Subsurface density/PV gradients

↑

EKE anomalies → **SSH anomalies**



Local SSH-EKE correlation coefficient, at interannual/decadal timescales

- A regional study considering some of these mechanisms in the subtropical Indian Ocean was recently published: Delman, A. S., Lee, T., & Qiu, B. (2018). Interannual to multidecadal forcing of mesoscale eddy kinetic energy in the subtropical southern Indian Ocean. *J. Geophys. Res. Oceans*, 123. https://doi.org/10.1029/2018JC013945.

Jet Propulsion Laboratory
California Institute of Technology

jpl.nasa.gov

This research was supported in part by an appointment to the NASA Postdoctoral Program at the Jet Propulsion Laboratory, administered by Universities Space Research Association under contract with NASA.
The authors acknowledge AVISO+, CNES, and Copernicus for providing access to gridded dynamic topography and eddy trajectory data.