Wind−Forced vs Eddy−Driven Regional Sea Level Rise in the North Pacific Ocean

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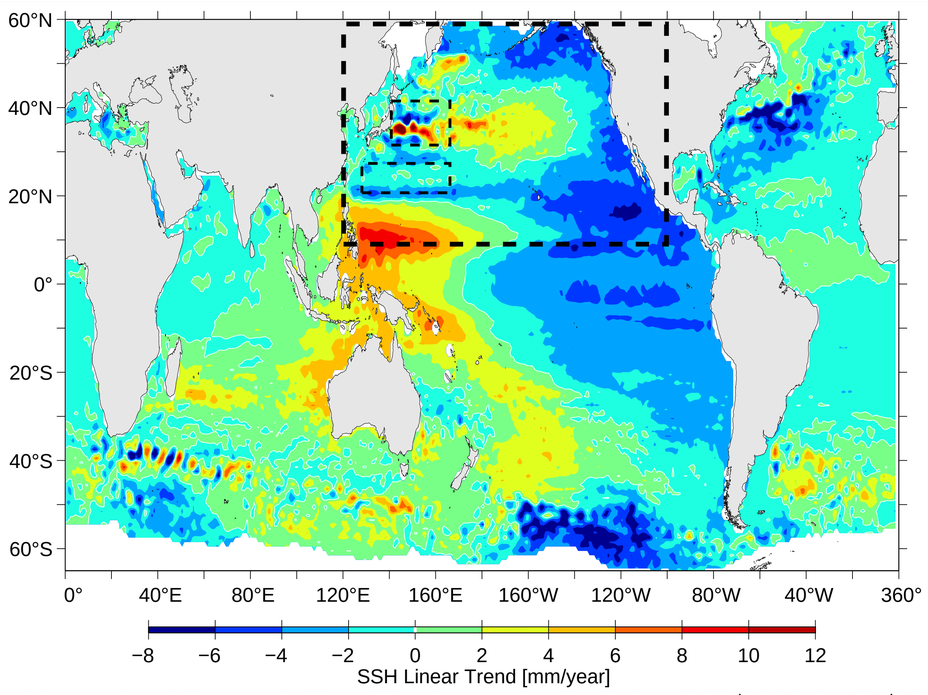
ABSTRACT

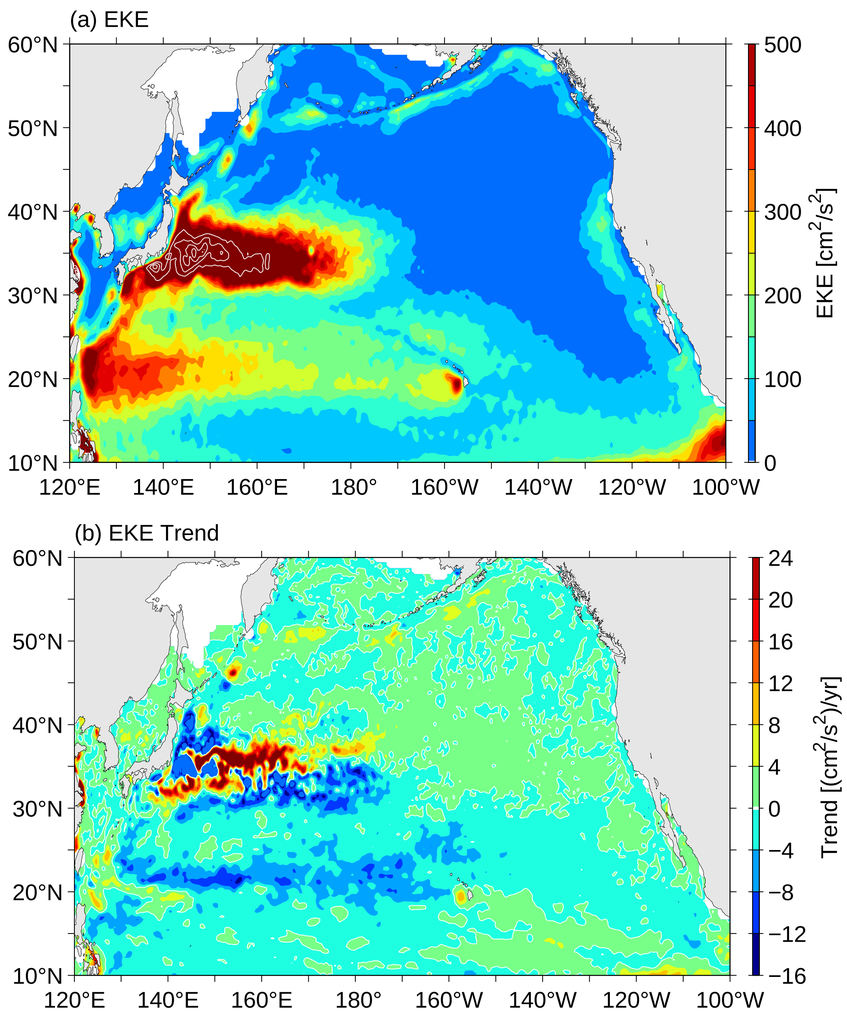
Regional sea level trend and variability in the Pacific Ocean have often been considered to be induced by low-frequency surface wind changes. In this study, we demonstrate that significant sea level trend and variability can also be generated by eddy momentum flux forcing due to time-varying instability of the background oceanic circulation. Compared to the broad gyre-scale wind-forced variability, the eddy-forced sea level changes tend to have sub-gyre scales and, in the North Pacific Ocean, they are largely confined to the Kuroshio Extension region (30°–40°N, 140°–165°E) and the Subtropical Countercurrent (STCC) region (18°–28°N, 130°–165°E).

Using a two-layer primitive-equation model driven by the ECMWF wind stress data and the eddy momentum fluxes specified by the AVISO sea surface height anomaly data, we quantified the relative importance of the wind- and eddy-forced regional sea level trends in the past two decades. It is found that the increasing (decreasing) trend south (north) of the Kuroshio Extension is due to strengthening of the regional eddy forcing over the past two decades. On the other hand, the decreasing (increasing) sea level trend south (north) of the STCC is caused by the decadal weakening of the regional eddy momentum flux forcing. These decadal eddy momentum flux changes are caused by the background Kuroshio Extension and STCC changes in connection with the Pacific decadal oscillation (PDO) wind pattern shifting from a positive to negative phase over the past two decades.

1. Altimetry Observed Sea Level Trend and EKE Trend



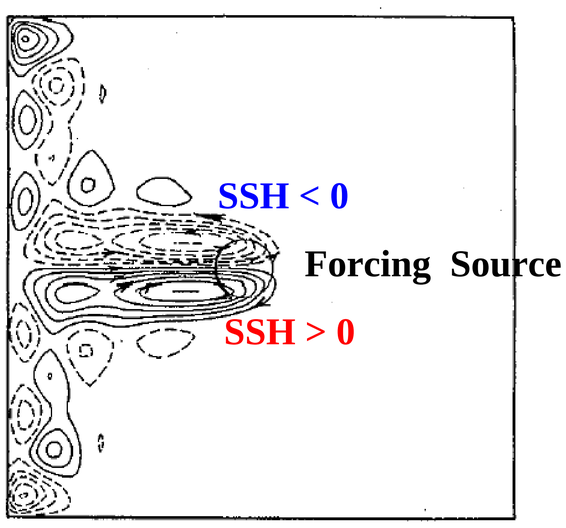
Linear trend in sea level from satellite altimeter measurements of 10/1992 to 12/2013. Notice that the global mean value of 3.2 mm yr^{-1} has been subtracted out to emphasize the regional sea level trend signals. White contours denote a zero relative trend.



Distribution of eddy kinetic energy in the North Pacific Ocean inferred from the AVISO SSH anomaly data. Thin white contours have an interval of 500 cm^2 s^{-2} starting from 1000 cm^2 s^{-2}.

Two high EKE latitudinal bands: (1) along 32°–38°N, where the western boundary current Kuroshio enters the open North Pacific Ocean basin and becomes a free, baroclinic unstable jet known as the Kuroshio Extension; (2) along 18°–28°N between Taiwan and Hawaii, where the eastward STCC and the underlying, westward-flowing, NEC result in baroclinic instability.

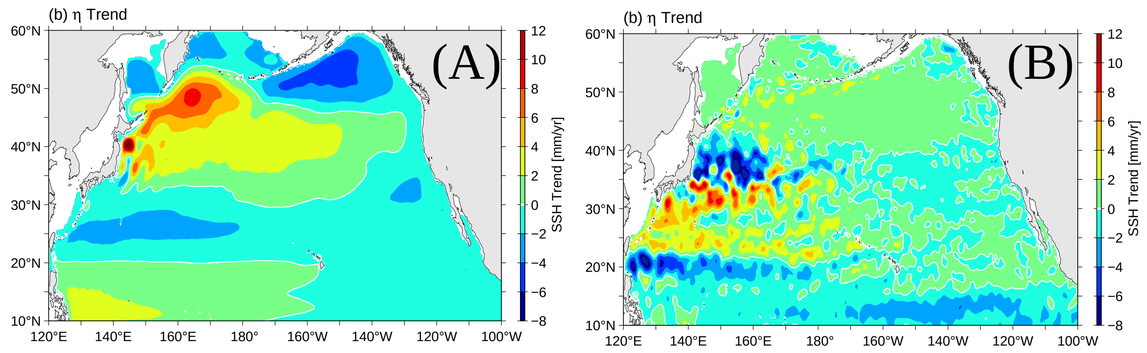
Linear Trend of EKE in the North Pacific Ocean. White contours denote a zero trend.

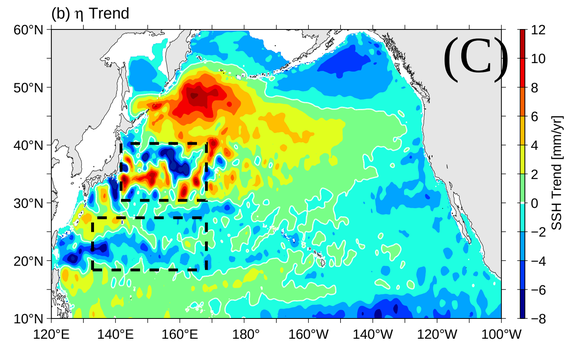


Theoretical study by Haidvogel and Rhines (1983, GAFD) indicates that eddy forcing drives a low (high) regional sea level northwest (southwest) of the forcing source.

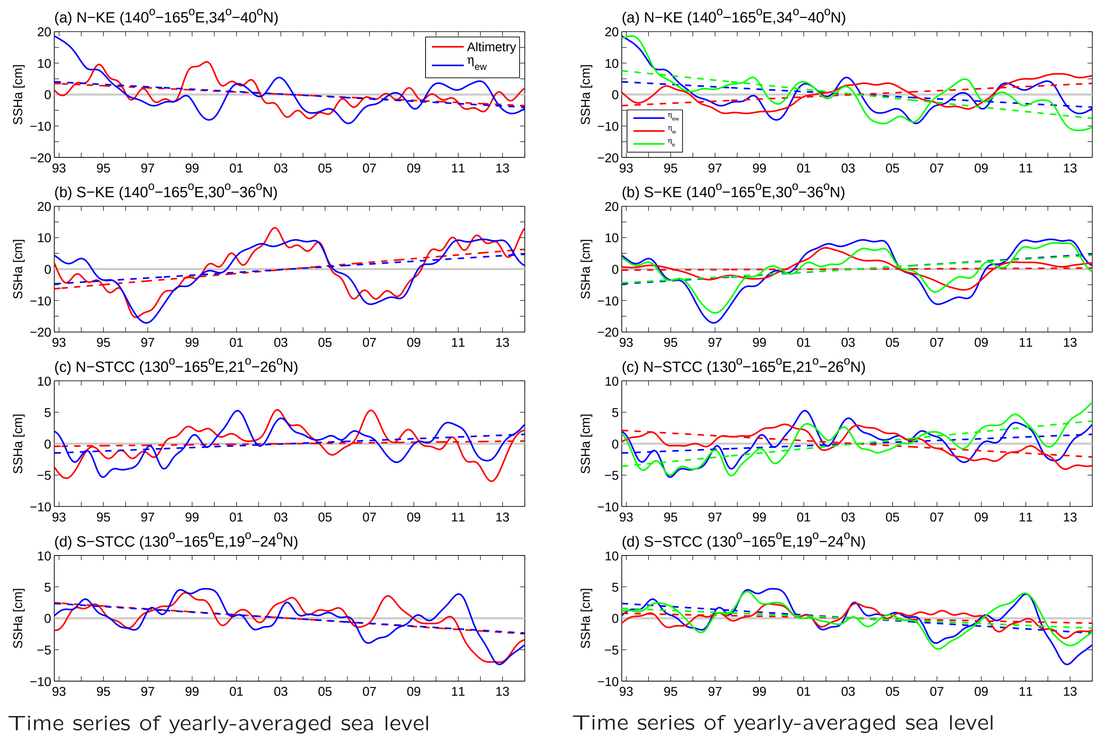
Support from NASA Ocean Surface Topography Science Team (OSTST) Is Acknowledged.

2. 2-Layer HIM Model Simulations





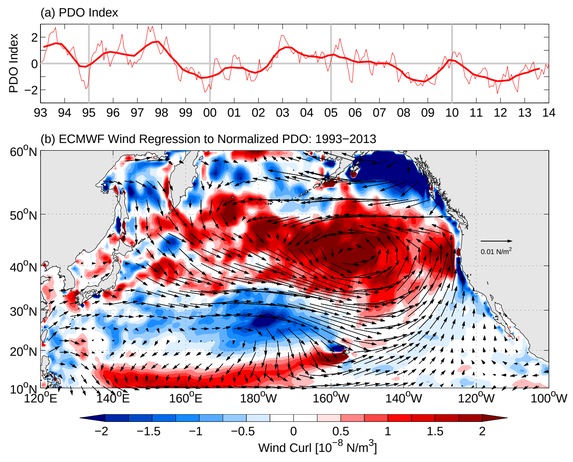
A. Wind forcing run: forced by the surface wind stress from ECMWF ERA-Interm reanalysis.
B. Eddy forcing run: forced by the eddy momentum fluxes inferred diagnostically from the AVISO SSH data.
C. Combined wind/eddy forcing run.



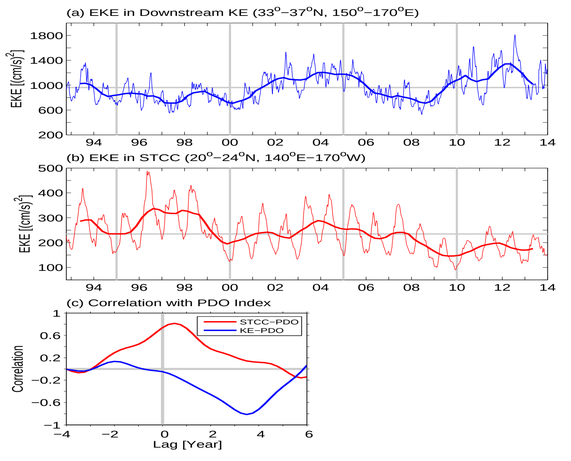
Time series of yearly-averaged sea level anomalies from AVISO observations (red lines) and from the combined wind/eddy forcing run (blue lines) in four sub-regions near KE and STCC. Straight dashed lines denote linear trends.

Time series of yearly-averaged sea level anomalies from HIM simulations: combined wind/eddy forcing run (blue lines, same as in the left plot), wind forcing run (red lines) , and the difference (green lines).

3. PDO Related Wind Forcing and Eddy Forcing



(a) Time series of Pacific decadal oscillation (PDO) index. Thick line denotes the yearly-average time series. (b) ECMWF surface wind stress vectors and curls (in color) regressed to the annually-averaged PDO time series.



Time series of AVISO EKE in (a) downstream KE and (b) STCC. Thick lines indicate yearly averages. (c) Lagged correlation between the PDO index and the EKE time series. A positive lag denotes the lead by the PDO index.

4. Summary

A. We demonstrate that significant sea level trend and variability can be generated by eddy momentum flux forcing due to time-varying instability of the background oceanic circulation.
B. Compared to the broad gyre-scale wind-forced variability, the eddy-forced sea level changes tend to have sub-gyre scales and, in the North Pacific Ocean, they are largely confined to the Kuroshio Extension region (30°–40°N, 140°–165°E) and the Subtropical Countercurrent (STCC) region (18°–28°N, 130°–165°E):
   - The increasing (decreasing) trend south (north) of the Kuroshio Extension is due to strengthening of the regional eddy forcing over the past two decades.
   - The decreasing (increasing) sea level trend south (north) of the STCC is caused by the decadal weakening of the regional eddy momentum flux forcing.
C. These decadal eddy momentum flux changes are caused by the background Kuroshio Extension and STCC changes in connection with the Pacific decadal oscillation (PDO) wind pattern shifting from a positive to negative phase over the past two decades.