Continental Shelf Research ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Continental Shelf Research

journal homepage: www.elsevier.com/locate/csr

Decadal sea level variability in the East China Sea linked to the North Pacific Gyre Oscillation

Jae-Hong Moon [a,*], Y. Tony Song [b]

[a] Department of Earth and Marine Science, Jeju National University, Ara 1 Dong, Jejusi 690-756, Republic of Korea
[b] Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA

ARTICLE INFO

Article history:
Received 7 November 2015
Received in revised form
26 April 2016
Accepted 4 May 2016

Keywords:
Regional sea level
Decadal variability
PDO
NPGO
Wind stress curl

ABSTRACT

In view of coastal community's need for adapting to sea level rise (SLR), understanding and predicting regional variability on decadal to longer time scales still remain a challenging issue in SLR research. Here, we have examined the low-frequency sea level signals in the East China Sea (ECS) from the 50-year hindcast of a non-Boussinesq ocean model in comparison with data sets from altimeters, tide-gauges, and steric sea level produced by in-situ profiles. It is shown that the mean sea levels in the ECS represent significant decadal fluctuations over the past 50 years, with a multi-decadal trend shift since the mid-1980s compared to the preceding 30 years. The decadal fluctuations in sea level are more closely linked to the North Pacific Gyre Oscillation (NPGO) rather than the Pacific Decadal Oscillation, which reflects the multi-decadal trend shift. A composite analysis indicates that wind patterns associated with the NPGO is shown to control the decadal variability of the western subtropical North Pacific. A positive NPGO corresponds to cyclonic wind stress curl anomaly in the western subtropical regions that results in a higher sea level in the ECS, particularly along the continental shelf, and lower sea levels off the ECS. The reverse occurs in years of negative NPGO.

© 2016 Elsevier Ltd. All rights reserved.

1. Introduction

Since the launch of the altimeters, substantial progress has been made in understanding sea level changes in both global and regional scales. The altimeters providing nearly global sampling of sea level revealed a sharp rising of sea level rise (SLR) trend over the past two decades, showing sea level variations occurring over a wide range of temporal scales (Church and AWhite, 2006; Ablain et al., 2009; Cazenave and Llovel, 2010; Hamlington et al., 2014). However, the sea level changes are not geographically uniform but rather show great regional differences. Unlike the global mean SLR, regional sea level patterns may be more complicated as its signal is mixed with that due to dynamical ocean responses to natural climate variability.

The East China Sea (ECS) is a semi-enclosed marginal sea of the Northwestern Pacific, surrounded by Korea, China and the chain of Ryukyu Island. The ECS is the central basin among the Asia Marginal Seas, including the South China Sea on the west, the Yellow Sea on the north, and the East/Japan Sea on the east. The marginal seas have a total area of 4.65×10^6 km^2 (about half size of Australia), surrounded by 11 countries: China, Korea, Japan, the Philippines, Indonesia, Brunei, Malaysia, Singapore, Thailand, Cambodia, and Vietnam. These counties account for over 2 billion of the human inhabitants (mid-2005 estimate), nearly one third of the world population, with denser population along the coasts. These populations are impacted by all coastal manifestations of global climate change, particularly sea level rise and frequent tropical storms (Anderson et al., 2001).

The ECS is an extremely dynamic region forced by various conditions, such as the western boundary Kuroshio, the East Asian monsoon system, and the Pacific climate variability, and thus its sea level changes are subject to these systems (Zheng et al., 2006). The altimetry-based sea level in the ECS refers to regional fluctuations at seasonal to inter-annual time scales, with a rising trend over the past two decades (Zuo et al., 2012; Wang et al., 2015). At inter-annual time scale, there is a clear link between the ECS sea level and the El Niño-Southern Oscillation (ENSO): El Niño events are generally flowed by sea level falls, while sea level rises during La Niña periods (Zuo et al., 2012). In contrast, seasonal variability is mainly related to the regional surface air-sea fluxes (J. H. Moon and Song, 2013; J.-H. Moon and Song, 2013).

On decadal and longer time scales, however, little study has been done on the sea level variability in the ECS. In general, the change of regional sea level can be affected by upper-ocean responses to large-scale climate variability (e.g., Merrifield, 2011; Bromirski et al., 2011; Qiu and Chen, 2012). The climate variability

* Corresponding author.
E-mail address: jhmoon@jejunu.ac.kr (J.-H. Moon).

http://dx.doi.org/10.1016/j.csr.2016.05.003
0278-4343/© 2016 Elsevier Ltd. All rights reserved.

Please cite this article as: Moon, J.-H., Song, Y.T., Decadal sea level variability in the East China Sea linked to the North Pacific Gyre Oscillation. Continental Shelf Research (2016), http://dx.doi.org/10.1016/j.csr.2016.05.003

in the North Pacific are characterized by climate modes of oceanic variability: the PDO, which is defined as the dominant mode of the North Pacific sea surface temperature variability (Mantua et al., 1996) and the more recently recognized North Pacific Gyre Oscillation (NPGO), which explains low-frequency fluctuations of salinity and nutrients in the Northeast Pacific and captures changes in strength of the North Pacific Current (Di Lorenzo et al., 2009) and of the Kuroshio-Oyashio Extension (Ceballos et al., 2009). A connection between the ECS sea level and the North Pacific climate variability was identified by Han and Huang (2008), who focused on the sea level changes in the ECS. Using a 10-year record from the T/P satellite altimeters and sparsely distributed tide gauges, they argued that the sea level variability is negatively correlated with the PDO on inter-annual and longer time scales.

As aforementioned, understanding inter-annual sea level changes in the ECS have been improved by satellite altimeters. However, relatively short records of altimeter data do not allow evaluation of ocean state prior to 1993, and thus less attention has been given to the spatial and temporal variability of sea level in the ECS associated with the Pacific climate variability. Here, we attempt to characterize and quantify decadal regional sea level changes in the ECS using tide gauges sea surface height (SSH), altimetry-based SSH, in situ-derived steric sea level (SSL) and a non-Boussinesq OGCM, which allows sea level to rise as a direct response to ocean heating. Through this paper, we emphasize the relationship between the regional sea level in the ECS and the large-scale North Pacific climate, particularly on decadal time scale.

2. Data and a non-Boussinesq ocean model

Monthly merged product of several altimeter missions (TOPEX/Poseidon, Jason-1, ERS-1, ENVISAT) are used to estimate recent regional sea level changes. The SSH data were produced and distributed by AVISO (http://www.aviso.oceanobs.com/) as part of the Ssalto ground processing segment. Tide gauge records at 6 stations in the ECS (symbol ▴ in Fig. 1), with 30–50 years of data available at most station, are also examined to compare the decadal sea level variations (Fig. 1).

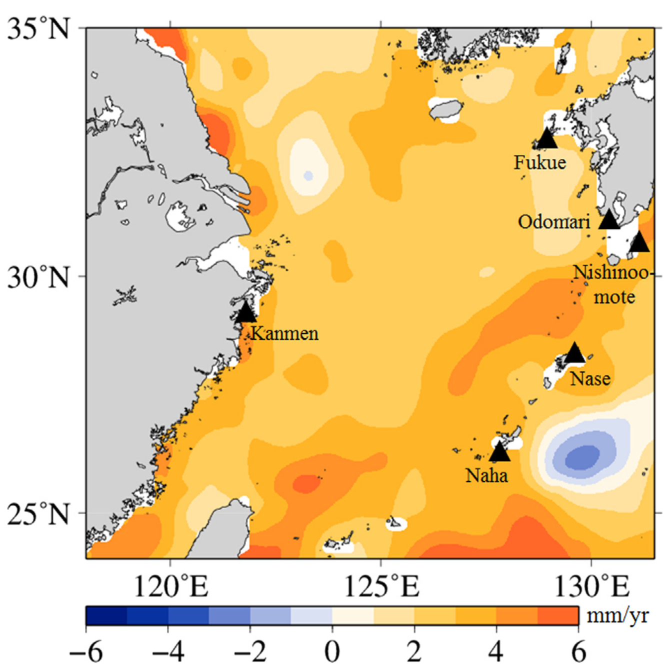

Fig. 1. Sea level trend over the East China Sea (ECS) derived from altimetry from 1993 to 2010. Tide gauge stations used in this analysis are marked by Symbol ▴.

Because thermal steric expansion associated with changing in temperature is the most important cause for the sea level changes and their regional differences, in this study we examine SSL from in situ upper 700 m ocean profiles. The monthly objectively analyzed subsurface temperature and salinity for the period 1960–2010 is the newest available dataset produced by Ishii and Kimoto, 2009, hereafter IK2009. The SSL has been computed at each 1° grid point of temperature and salinity by integrating down to 700 m.

$$SSL = \int_{-H}^{0} \frac{\rho_0(x, y, z) - \rho(x, y, z, t)}{\rho_0(x, y, z)} dz \tag{1}$$

where $\rho_0(x, y, z)$ is the reference density; a function of temperature and salinity in climatology and depth, z. $\rho(x, y, z, t)$ is a nonlinear function of temperature and salinity.

A non-Boussinesq ocean model is employed to avoid uncertainties involving the Boussinesq approximations in representing the sea level, its regional changes, and thermal expansion (De Szoeke and Samelson, 2002; Song and Hou, 2006). The model was configured globally with a 1/4° horizontal resolution with 30 terrain-following vertical levels, and initialized with climatological temperature and salinity from the World Ocean Atlas (WOA) 2001. It was spun up for 60 years with National Centers for Environmental Prediction (NCEP)/National Center for Atmospheric Research (NCAR) monthly climatology (Kalnay et al., 1996) to reach an approximately steady state. The model was then forced by 6 hourly NCEP/NCAR reanalysis products from 1958 to 2010, which is one of the products most frequently used to force OGCM and has the longest available record length compared to other products. No water mass from the land-based water is added to the ocean but the evaporation minus precipitation distribution is still applied, indicating that the model SSH is essentially the steric height.

Two climate indices representing oceanic expressions of atmospheric variability in the mid-latitude Pacific are used in this study. One is the time series of PDO from the Joint Institute for the Study of the Atmosphere and Ocean (JISAO; http://jisao.washington.edu/). The PDO is the first principal component of North Pacific SST variability in the region poleward of 20°N (Mantua et al., 1996). The other is the NPGO index, which is defined as the second dominant mode of SSHa variability in the region by 25°N −62°N, 180°–110°W (Di Lorenzo et al., 2008). The NPGO data (second principal component of model-derived SSH) was obtained from the Web site (http://www.o3d.org/npgo).

3. Multi-decadal regional sea level trends

During the altimetry period, most of the regions in the ECS experience SLR (Fig. 1), with a mean rate of ~3.5 mm/year which is a little higher than the global mean. Relatively strong SLR trends are detected along the ECS shelf break, where the Kuroshio intrudes onto the northern shelf of Taiwan and extends farther northeastward along the shelf from north of Taiwan to the south of Kyushu. Mesoscale activity associated with westward propagating eddies may produce the sea level fall around the southeast of Okinawa Island (e.g., Konda et al., 2005).

Using long-term SSL and model results, we can investigate how the ECS sea levels have changed temporally and spatially prior to 1993. Time series of annual mean sea level variations in the ECS over the 1960–2010 are presented in Fig. 2a, which compares the model SSH anomalies (black) with altimeter (blue), and the SSL (gray). The sea level data was regionally averaged in the region of 118–132°E and 24–35°N. The model sea level agrees well with the SSL derived from in-situ measurements over the 50-year period

Download English Version:

https://daneshyari.com/en/article/5764407

Download Persian Version:

https://daneshyari.com/article/5764407

Daneshyari.com