NONLINEAR SEA LEVEL VARIATIONS IN THE EQUATORIAL PACIFIC DUE TO ENSO

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ABSTRACT. Gridded sea level anomaly time series from TOPEX/Poseidon and Jason-1 satellite altimetry have been processed in order to detect nonlinearity of sea level change in the period 1993-2003. Basic statistics, such as standard deviation, skewness and kurtosis, along with testing hypothesis served well the purpose of statistical evaluation. The data obtained by both satellites have been merged by applying the offset between two time series, separately for each location grid. In order to infer nonlinear features of sea level variation, four specific terms (linear trend, annual oscillation, semiannual component and alias-type 62-days oscillation) have been removed from the merged time series for each grid. It has been shown that the particularly meaningful departures from the normal distribution of sea level change are present within the equatorial zone in the Pacific and Indian Oceans. This finding has been associated with the asymmetry between strengths of El Niño and La Niña episodes. The interpretation of the results has been based on geophysics of Kelvin and Rossby ocean waves which drive the ocean part of the ocean-atmosphere coupling in the El Niño/Southern Oscillation (ENSO). It has been argued that the nonlinear heating, occurring only during strong ENSO episodes, can be responsible for local nonlinear sea level change during such considerable ENSO events.

1. RECENT RESULTS

There is a wealth of observational evidence that the El Niño/Southern Oscillation (ENSO) phenomenon is somehow controlled by nonlinear processes. This is due to the nonlinear dynamical heating of the sea surface of the tropical Pacific which is the case during strong warm and cold ENSO episodes (Jin et al., 2003; An and Jin, 2004). There are also statistical investigations which show that both sea surface temperature and sea level anomalies in the equatorial Pacific depart from the normal distribution (Burgers and Stephenson, 1999; Niedzielski and Kosek, 2010a; Niedzielski, 2010). When the deviation from the normal distribution is linked to the asymmetry between El Niño and La Niña, one may infer that certain nonlinear processes are driving the oscillation in question (Hannachi et al., 2003). The asymmetry between warm and cold ENSO episodes has also been found in secular changes of ENSO, as inferred from simulated data (Hunt and Elliot, 2003).

However, recent studies indicate that linear models serve as reasonable tools for modelling and prediction of sea level anomalies from TOPEX/Poseidon and Jason-1 satellite altimetry (Niedzielski and Kosek, 2009; Niedzielski and Kosek, 2010b). This paper summarizes the results already published by the authors and provides a coherent picture of the current state-of-art in linear/nonlinear modeling of sea level fluctuations.

For the purpose of the exercises, the gridded data on sea level anomalies from TOPEX/Poseidon and Jason-1 – obtained courtesy of the Center for Space Research, University of Texas at Austin, USA – have been processed. The temporal coverage of the merged times series (TOPEX/Poseidon and Jason-1 data combined by taking into account the offset between the two) is 10.01.1993-14.07.2003 whereas the area is spatially limited by 65° S and 65° N parallels. There have been a few types of residuals calculated for the purpose of the analysis. Basically, they have been obtained be subtracting various trend and seasonal components from the input data (combinations of the following terms: linear trend, annual oscillation, semiannual component and alias-type 62-days oscillation). The aforementioned data pre-processing and statistical evaluation of nonlinearity have been performed gridwise.

The analysis focuses on two spatial extents: the east equatorial Pacific and the global ocean. The first area plays a key role in ENSO dynamics whereas the global approach allows one to evaluate if nonlinearities of sea level change are intrinsic only for the equatorial Pacific or have wider spatial occurrence.

The areas of the east equatorial Pacific with significant departures of sea level anomalies from the normal distribution correspond to four specific zones, i.e. the equatorial zone, the Intertropical Convergence Zone, the eastern Pacific warm pool and the continental shelf (Niedzielski, 2010). The results for coastal areas are rather uncertain due to inaccuracy of radar altimetry. However, all four zones are linked to ENSO forcing and it seems to be inevitably a key reason of the detected nonlinearities. The interpretation of deviations from a linear variability is based on the paper by Jin et al. (2003) who link the asymmetry of El Niño and La Niña episodes with the nonlinear heating of the sea surface. These four zones quite precisely fit the areas where linear predictions of sea level anomalies fail (Niedzielski and Kosek, 2009). This specific correspondence implies an intrinsic recommendation for using the nonlinear time series approach to anticipate future sea level change at different lead times.

A similar exercise has been performed for the global ocean (Niedzielski and Kosek, 2010a). It has been found that the equatorial Pacific and the tropical Indian Ocean are the main zones where the probability law of sea level anomalies departs from the normal distribution. This serves as a confirmation for the aforementioned asymmetry, the interpretation of which is probably of the same origin. The spatial pattern of the nonlinear signal in sea level anomalies has been shown to correspond to shapes typical for Kelvin and Rossby waves. The natural recommendation for modelling with nonlinear approaches has been formulated. However, as subsequently shown by Niedzielski and Kosek (2010b), it is tough to implement such an advice because – inferring simple low-order time series models – the goodness-of-fit is better for linear techniques than for the nonlinear ones. It should be noted that the prediction performance of such models has not been checked in this exercise.

2. CONCLUSIONS

Recent investigations carried out by the authors of this paper and published elsewhere show that it is rather difficult to unequivocally recommend particular models capable to describe the nonlinear sea level anomalies present in the equatorial Pacific and the tropical Indian Ocean. In the light of the comparison between the prediction accuracy of sea level anomalies and the nonlinear variability of sea level change it appears to be crucial to implement nonlinear time series models for forecasting purposes. However, at this stage of the analysis, the structure of such models is rather tough to find. Low-order generalised autoregressive conditional heteroscedastic models have been shown to be inadequate, even though they offer time-varying variance modelling. The explanation of the correspondence between the nonlinear sea level changes and the optimal models for them remains to be ambiguous. Thus, a further research in this field seems to be highly recommended.

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