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What are the Processes Behind Decadal Scale Sea Level Variability in the North Atlantic?

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Abstract

Over the past decade, our view of global sea level has been revolutionised by satellite altimetry. Altimetry images have made it clear that sea level varies very significantly on regional scales. However, to examine variability on decadal time-scales we rely on coastal measurements from the global array of tide gauges and aim to gain insight from numerical ocean models.

We examine the patterns of decadal variability in the North Atlantic ocean shown by tide gauges over the past 50 years and explore the processes that underlie this variability with a high resolution isopycnic ocean model. Our eventual aim is to understand how thermosteric changes in sea level in the mid-ocean are reflected in the coastal ocean.

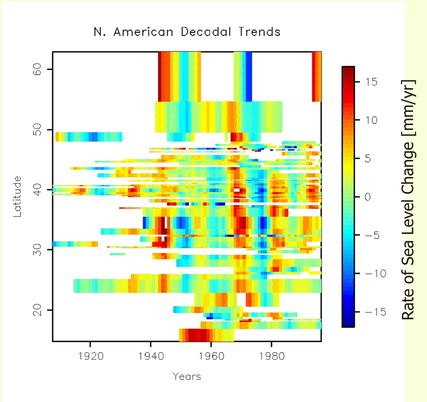
We find that the model is able to reproduce much of the decadal variability seen in tide gauges along the eastern US when forced by ECMWF reanalysis data. As found by Hong et al (2000), the dominant process behind the decadal variability is wind stress. However we find that similar linkages between atmospheric forcing and coastal sea level also appear to occur at higher frequencies.

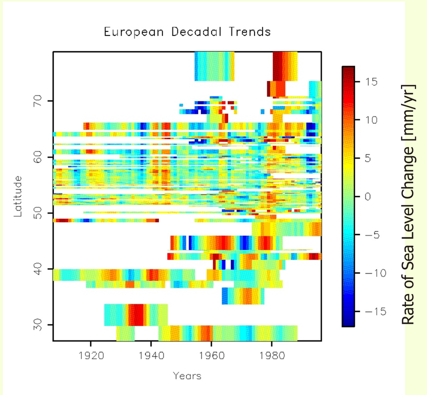
1. Introduction

Sea level shows strongly coherent variability at all latitudes around the coastline of the north Atlantic on decadal time scales.

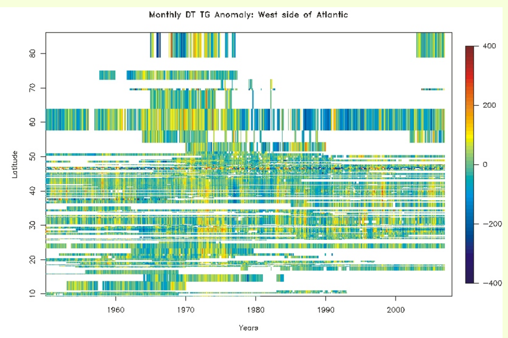
Using a simple forced long Rossby wave model of thermocline response to wind forcing and a complementary coastal model Hong et al (2000) were able to explain 80-90% of the decadal scale variance observed at tide gauges along the east coast of the United States. Hong et al's work therefore demonstrated that the open ocean wind-stress curl dominates decadal scale variability in the sub-tropical gyre of the North Atlantic.

Here we begin to extend these ideas to the sub-polar gyre and the coast of western Europe as well as exploring variability at annual and monthly periods.

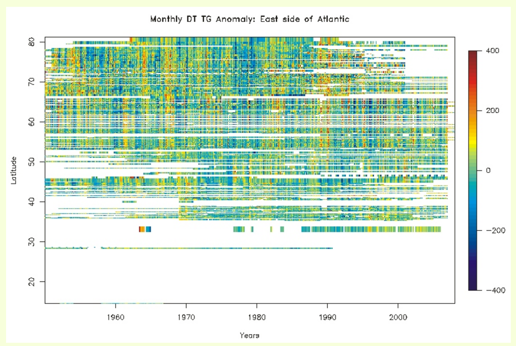




2. Higher Frequency Variability



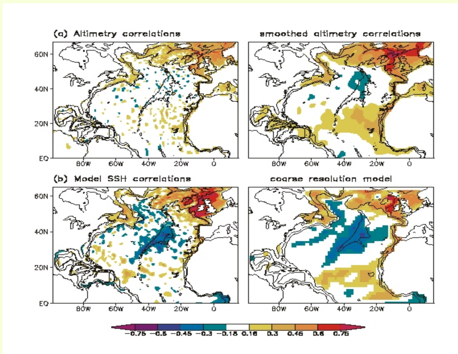
The coherence of sea level along the coast line seen at decadal periods is also evident at annual and monthly periods. This coherence extends across the gyre boundary and is present on both US east coast and the west European coast.



Coherent signals at monthly periods suggest the propagation of coastally trapped waves, similar to those described by Johnson and Marshall (2002).

3. Correlation Along Coastlines from Altimetry

High frequency signals along coastlines are seen both in the model and by satellite altimetry. Hughes and Meredith (2006) correlated sea surface height along the 1000m isobath just to the west of Scotland (which had been high pass filtered for periods less than 1 year) with sea surface height everywhere else. This showed narrow bands of significance over long sections of the coast, again showing how coastally trapped signals propagate.



4. Tide Gauge Data

Monthly mean tide gauge data were supplied by the Permanent Service for Mean Sea Level (Woodworth and Player, 2003). Data are from the Revised Local Reference data set which corrects for local datum changes.

For decadal rates of change, only time series which were at least 70% complete were included.

5. Model Description

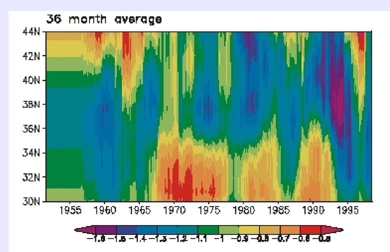
An isopycnic model, MICOM 2.7 (Bleck and Smith, 1990), of the N Atlantic was used, covering 35°S-65°N and 98.5°W-19°E (Roussenov et al, 2007). The horizontal resolution is 0.23° on a Mercator grid with 15 σ_2 isopycnal layers in the vertical plus a surface mixed layer with variable density.

Topography was taken from ETOPO5 averaged within the model grid. At the northern and southern boundaries sponge layers are incorporated below the mixed layer.

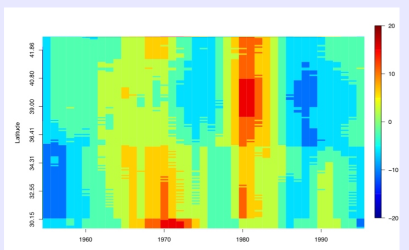
Realistic surface forcing was based on the ECMWF reanalysis for the period 1957-2000.

6. Wind Stress Curl

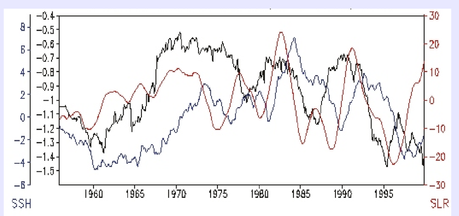
The wind stress curl is compared with the computed decadal rate of sea level variation along the US east coast in the model. There is broad agreement between the high rates of increasing sea level south of 36° N from the mid 60s to mid 70s, in the early 80s and around 1990. Note the reversal in sign of the wind stress curl north of 36° N and the correlation between the high rate around 1980.



Wind stress curl at 20° W

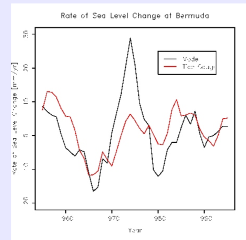


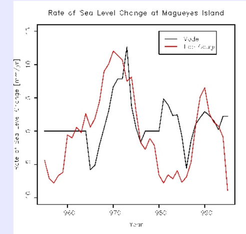
Rate of sea level change along the US east coast [mm/yr]



The relationship between the wind stress curl (black), the sea level anomaly (blue) and the rate of sea level rise at 32° N (red) illustrates that there is more to the decadal signal than just wind stress forcing.

7. Model Performance





MICOM is a model of much greater complexity than the quasi-geostrophic model employed by Hong et al (2000), and can therefore reproduce a much wider range of variability. In addition to this higher frequency variability the decadal scale is also well reproduced.

Following Hong et al, we compare the model output (red) with the tide gauge data at Bermuda (32° 22' N 64° 42' W) (top) and at Magueyes Island (17° 58' N 67° 03' W) (bottom). The correlation at Bermuda is 0.54 and is significant at the 95% level.

8. Discussion

Hong et al (2000) demonstrated that the decadal scale variability in sea level along the US east coast in the sub-tropical gyre is dominated by variations in wind stress in the open ocean. This variability is reproduced within the much more complex MICOM model as is higher frequency variability on the time scale of months to years.

Hong et al's model of Rossby wave propagation is not easily extended to either the sub-polar gyre, nor the European coast. Furthermore, it is also unable to accommodate the strongly coherent higher frequency variability that is seen in tide gauges and altimetry.

There are good reasons to expect that variability in the sub-polar gyre will experience stronger heat forcing, especially at high latitudes. However it is clear that patterns of thermal forcing will also affect the wind stress and so it is difficult to separate out these effects.

Future work will examine whether high latitude thermal forcing signals, which are seen to propagate in the deep western boundary current through the meridional overturning circulation, are able to force Rossby wave variability after reaching the European coast.

References

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