Interannual to decadal ocean variability and predictability

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High resolution 4-D ocean models allowing for the existence of eddies are used with sea surface height (SSH) measurements from the TOPEX/POSEIDON altimeters to understand the variability seen at the ocean's surface and how this signal is related to the changes in the temperature and salinity in the ocean's interior. These analyses will continue with data from the Jason-1 satellite. Altimeters only "see" the surface, and a realistic ocean simulation helps to understand the physical processes contributing to the SSH changes. We also hope to understand how initial conditions affect the predictions in an ocean-atmosphere coupled model.

Objectives

Through the combined use of ocean simulations from a twenty-year time series, we are trying to understand the causes of the variability in global ocean circulation patterns, and determine if this variability can be predicted.

Approach

Several ocean simulations have been created or will be created by our research group, and more are to come. These simulations currently include a 20-year (1979-1998) simulation as well as a 41-year simulation (1958-1998). The ocean models are 4D simulations, with 20 to 40 vertical levels representing the varying ocean depths. Horizontal spacing has a resolution of about 1/6 to 2/3 degree (for example, each model grid represents an approximate 18 km to 60 km box). The simulations require that the ocean models be forced at the surface by winds, by heat (from the sun and from heat losses by the ocean), and by precipation and evaporation. To produce a simulation that corresponds to the referenced time periods, we use data produced by the European Centre for Medium Weather Forecasts and the US National Centers for Environmental Prediction. These data are a combination of observed measurements and a model, and when applied to the ocean model, result in a realistic simulation.

Evaluation and analysis of the simulations

The simulations are evaluated using both satellite data and in-situ data such as measurements from tide gauges and buoys. The in-situ data, especially the measurements of sea level made by the tide gauges, add to the confidence in the realism of the simulation during periods when no satellite data is available. The altimeter data sets are Geosat (approximately 1987-1989), TOPEX/ POSEIDON (1992-present), ERS-1 and 2 (1990s), and will include Jason-1 data. The model output, its forcing, and the observations are compared using a variety of methods, for example, time series analysis at a given location and spatial statistical methods. From these analyses, we can determine how much of the variability is a direct result of the forcing applied, and how much of the variability comes from other processes. We can also identify regions where the model represents the variability of the ocean particularly well. Figure 1 shows a time series of the average height anomaly along 35°N in the Pacific from a model (black line) and as measured from TOPEX/POSEIDON and Geosat (blue line). The heat content of the top 160 m of the model is in red and the North Pacific Climate Index is the black dashed line. The figure indicates that the simulation is similar to the observations and that the upper ocean, indicated by the heat content curve, is contributing to most of the variability at the low frequency.

Predictability of the ocean's variability

To understand if and where the ocean's circulation can be predicted through the use of satellite measured SSH, we will examine how the sea level at one location influences the variability downstream. A good example of this type of predictability is detecting the occurrence of an El Niño in the tropical ocean and then knowing that the signal travels northward along the western edge of the Americas at a later time. We will examine various locations around the globe to further explore this type of cause-and-effect variability.

Coupled ocean-atmosphere models are also useful to understand the predictability of the ocean's circulation. Depending on the initial

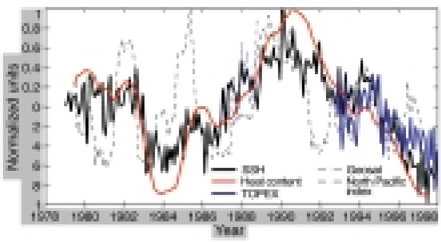

Figure 1: Time series of the basin averaged SSH anomaly, centered at 35°N in the Pacific, shows that the model reflects the observations. The black line is the estimated value from the simulation, the blue lines are the altimeter measurements, and the red line is the heat content of the simulation. The black dashed line is the North Pacific Climate Index, which reflects changes in atmospheric pressure in the central North Pacific. The units for all quantities have been scaled for comparison purposes.

conditions from which a simulation starts, the coupled models will produce different results. We will run a prototype coupled ocean-atmosphere model using, as part of our initial conditions, the state of the current ocean (temperature, salinity, and sea level) from the output of an assimilated model, run along with simulations using just the observed SSH and temperatures. In this type of simulation, the coupled ocean model can be initialized with observed data (including altimeter data) and then allowed to run forward into the future using the winds and other forcings from the atmospheric model. The resulting predicted field of sea level can then be compared with future altimeter observations.

Figure 2 shows plots of SSH anomalies across 15°N in the North Pacific. On the right is the simulated data plotted with longitude across the bottom and time on the vertical axis. The right panel is the SSH data from two satellites, TOPEX/ POSEIDON for the 1990s and Geosat during the 1980s. The figure shows how some of the signal moves westward in time, and if correlated with the underlying temperature field, the changes occuring in the east can indicate a change in the water temperature at the western boundary at a later date. This figure also shows the wide variation in the SSH with time which is important to know in the initialization of coupled ocean-atmosphere models.

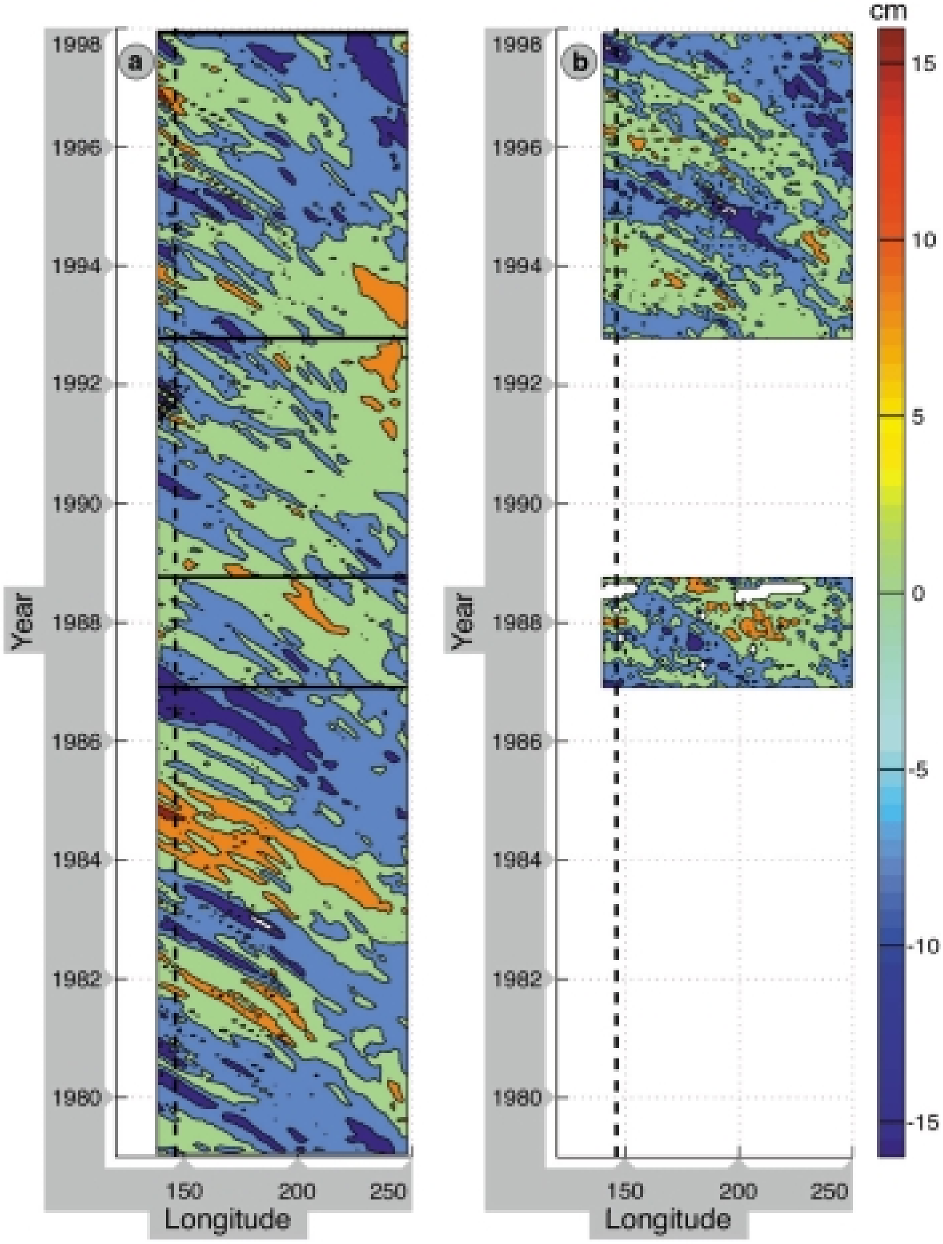

Figure 2: Time series of SSH anomalies along 15°N in the North Pacific. (a) output from a model and (b) observed values from 2 satellite altimeters. The color scale is in centimetres. The plots show the variability of the ocean on many time scales.

Anticipated Results

The anticipated results are to show:
• that altimeter data is useful in identifying areas of an ocean simulation which are realistic, and how and where the simulation can be improved. Also, what contributes to signal variability at a given location (for example, forcing and advection).
• that sea level measurements can be used to identify changes in sea surface height, and perhaps temperature, downstream at a later time.
• the influence of the initial conditions on the predictability of a coupled ocean-atmosphere model.

Significance of results

Ocean models are becoming more common as tools in trying to understand the ocean and its variability. More realistic simulations, result in higher confidence in the models, which in turn, helps in understanding scientific problems such as the role of the ocean in our global climate system. In addition, knowing how satellite altimeter data can be used to infer subsurface changes can aid in monitoring of our global oceans.

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