"A Basin-Wide Oscillation of the Mediterranean Sea"

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Introduction

Satellite altimetry reveals a prominent basin-wide oscillation of sea level in the Mediterranean Sea (Figure 1). The oscillation is largely seasonal but also varies at shorter periods and is nearly uniform in phase and amplitude across the basin. The nature of this oscillation is examined using the ECCO ocean circulation model and data assimilation system.

Observed Variability

While seasonal cycles commonly have large-scale coherence, a basin-wide coherence is peculiar for higher frequency variability. Therefore, we focus here on the non-seasonal component of sea level variability unless noted otherwise. A mean seasonal cycle from 1993 to 2001 is computed and subtracted from TOPEX/POSEIDON (T/P) observations. The basin-average sea level across the Mediterranean Sea (red curve in Figure 2) varies with an amplitude of about 10 cm with prominent periods ranging from a few weeks to several months. (There is also a weaker interannual component.) The spatial structure of the first Empirical Orthogonal Function (EOF; Figure 3), based on correlation, is nearly uniform across the basin and accounts for 53% of the observed non-seasonal variability. The amplitude time-series of this EOF (blue curve in Figure 2) is practically identical to the basin-averaged sea level variability.

ECCO Model

The ECCO model (simulation) successfully resolves much of the observed variability. The model's basin-averaged sea level is comparable to that of T/P (Figure 4), and the models first EOF (Figure 3) is also similar to that of T/P accounting for 83% of the model variability. The larger fraction of variance the model EOF explains of its fluctuation compared to that of T/P's EOF, may be due to the model's lack of small-scale variability and/or the observation's (3-day maps) inaccuracy in resolving higher frequency oscillations. Given the skill, the model provides a suitable means to analyze the nature of the observed sea level variability.

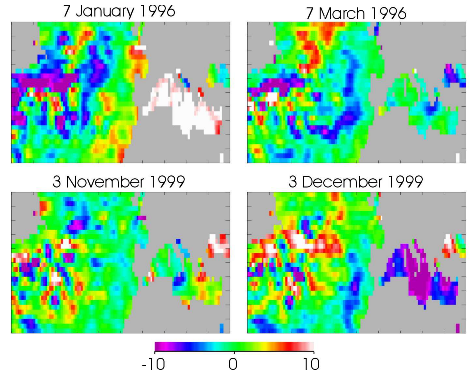

Fig 1: Sea Level Anomalies (cm) Relative to Mean Annual Cycle. (TOPEX/POSEIDON) (An animation is available.)

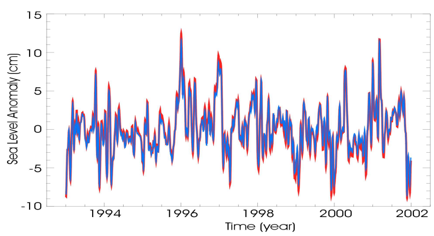

Fig 2: Basin-Mean (red) and the First Principal Component (blue) of Non-Seasonal Mediterranean Sea Sea Level (T/P).

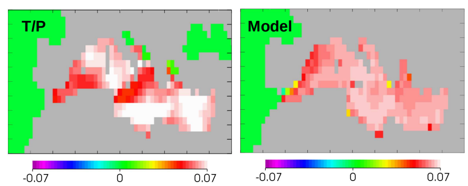

Fig 3: First EOF of Non-Seasonal Mediterranean Sea Sea Level Variability; T/P (left), ECCO model (right)

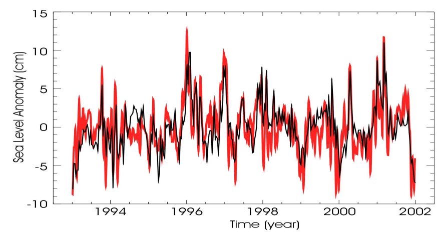

Fig 4: Basin-Mean Mediterranean Sea Sea Level; T/P (red), ECCO model (black).

The Nature of the Oscillation

The forcing responsible for the variability is examined by comparing the model solution with another that is forced by time-mean winds in place of time-variable winds, thus isolating the effects of time-variable diabatic forcing. Figure 5 shows that wind forcing and diabatic forcing result in similar, but separate, seasonal variability, but that non-seasonal fluctuation (right) is mostly wind-driven. Moreover, the wind-driven response is largely barotropic, as evidenced by the agreement between residual sea level (difference between black and red in Figure 5) and ocean bottom pressure (cyan). In fact, fluctuation of mean sea level across the Mediterranean Sea is consistent with net transport variation through Gibraltar Strait (Figure 6).

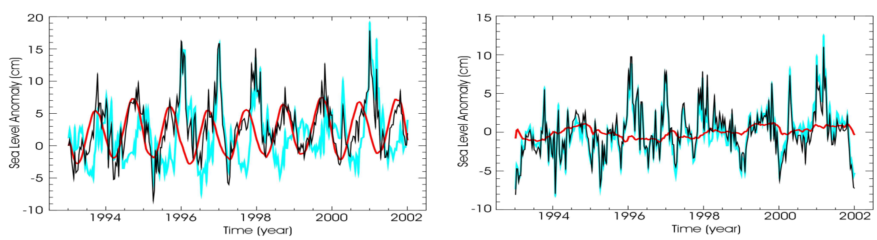

Fig 5: Basin-Mean Model Sea Level Variability (left; all frequencies) and its Non-Seasonal Component (right): total sea level (black), diabatic component (red), and ocean bottom pressure (blue).

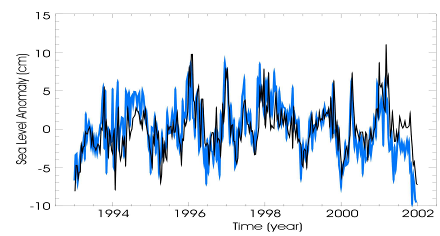

Fig 6: Model Net Transport Through Gibraltar Strait Divided by Area of the Mediterranean Sea (blue) and Model Basin-Mean Mediterranean Sea Sea Level (black).

Model Sensitivity

The model adjoint is used to identify the region of which wind is responsible for the observed basin-wide sea level variability. The sensitivity of basin-averaged sea level (10-day mean) to 10-day averaged wind-stress is computed using the ECCO model adjoint. Figure 7 shows examples of this sensitivity. Sensitivity is largest in the Gibraltar Strait, and becomes smaller with increasing lag in time. That such sensitivity is consistent with actual model fluctuations is evidenced by the agreement between the model's basin-averaged sea level and an inner product of these sensitivities with wind anomaly (Figure 8). The variability of the winds themselves is also relatively large in the vicinity of the Strait (Figure 9). In combination, winds in the vicinity of the Strait account for the basin-wide oscillation of sea level in the Mediterranean Sea (Figure 10). In particular, zonal winds account for most of this variability.

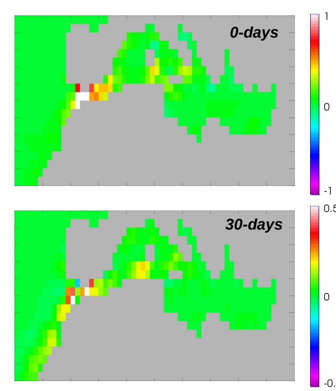

*Fig 7: Model Sensitivity of Basin-Mean SSH to Zonal Wind (cm/N/m**2); Instantaneous Winds (top), Winds 30-days Prior (bottom).*

Conclusion

Winds, especially zonal winds in the Strait of Gibraltar, cause net transport in and out of the Mediterranean Sea. The Mediterranean Sea responds barotropically, with sea level changing in near uniform phase across the entire basin. The oscillation ranges in periods from a few weeks to interannual time-scales, including the seasonal cycle.

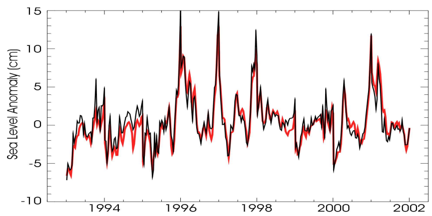

Fig 8: Basin-Mean SSH Anomaly Estimated by Adjoint Sensitivity to Wind (up to 360-day lag) (red) and that by Model Simulation (black).

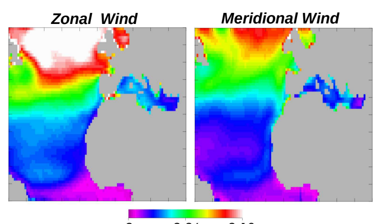

*Fig 9: Standard Deviation of NCEP Winds (N/m**2).*

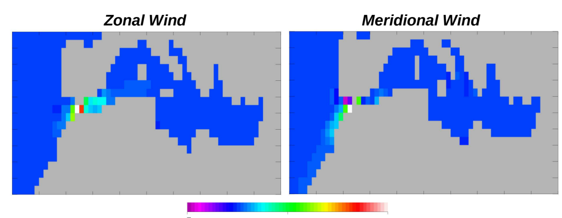

Fig 10: Percentage Variance (%) of Basin-Average Sea Level Accounted for by Winds at Individual Locations.