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Chaoctic Behavior of Sea Level Oscillations in a Mediterranean semi-enclosed Basin

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We investigate the properties of a marine dynamical system by means of time series of the sea level height at four locations (Souvala, Ag. Marina, Vouliagmeni, Salamina) in the Saronikos Gulf of the Aegean Sea. Measurments were carried out from 7/86 to 9/87 by the University of Athens. The temporal resolution ot the records is 10 min.

In order to characterize the dynamics, we estimate the dimension of the underlying system and we compute its Lyapunov exponents. Our analysis was carried out for each station individually and when feasible for the concatenated time series (all stations together).

We adapted a decorrelation time equal to 600x10 min. From the data of every station the state vector was generated and the phase space was produced for embedding dimensions two to twelve. For every embedding dimension the scaling exponent (correlation dimension) was estimated. In every station the scaling exponent reaches a saturation value, which specifically is: 8.8 (Salamina), 8.7 (Souvala), 8.6 (Ag. Marina), and 9.1 (Vouliagmeni). The estimated correlation dimensions are not integers suggesting that the attractor is not topological but is a fractal set (chaotic attractor). The calculations were performed using the CRAY computer in the National Center for Supercomputing Applications in Urbana, Illinois.

The Lyapunov exponents are related to the mean rate of divergence of nearby trajectories in phase space and measure therefore, how unpredictable is the evolution of the dynamical system. They were calculated for every station separately and for the concatenated time series. In doing that, we assume that the concatenated series could have been just one observable from our dynamical system. This assumption is justified from the results reported above which indicate that the four stations behave more or less as being parts of a single dynamic system encompassing the whole gulf.

Thus, for example, the calculated Lyapunov exponents for Salamina and for the concatenated time series are: (Salamina (N=62,184) 0.091, 0.036, -0.006, -0.051, -0.106, -0.237), (All stations (N=233,213) 0.095, 0.038, -0.008, -0.046, -0.105, -0.256).

In all cases we obtain two positive Lyapunov exponents. This is an indication of chaotic attractor in higher than three dimensions.

The fact that the magnitude of the two positive Lyapunov exponents differs by a factor of three indicate that the chaotic dynamics arise from the interplay of two indepedent mechanisms of instability one of which is more important than the other.

The sum of the two largest positive exponents is found between 0.090 and 0.133/10 min. This is an estimate of the Kolmogorov entropy whose inverse (inverse of divergence rate) provides an estimate of the mean predictability time of the signal. Thus we obtain that the signals involved have an intrinsic predictability time of at least one hour but less than two hours.

There are at least three negative exponents. Since the largest positive exponent is about a factor of two greater than the absolute value of the largest negative exponent it may be that a time scale dominating the system exist.

In almost all cases we observe a very close to zero negative value for the third Lyapunov exponent. This is in accordance with the fact that one of the exponents must always be zero expressing that there is no contraction along the direction of the orbit.

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From the estimation of the dimension of the attractor and the calculation of the Lyapunov exponents, of the underlying dynamical system, we have provided strong evidence that the variability of sea level in a part of the Aegean Sea can be attributed to a single chaotic dynamical system of a few degrees of freedom with a low dimensional attractor.

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