Forcing of sea level variability around Europe

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1. Mediterranean Sea Level

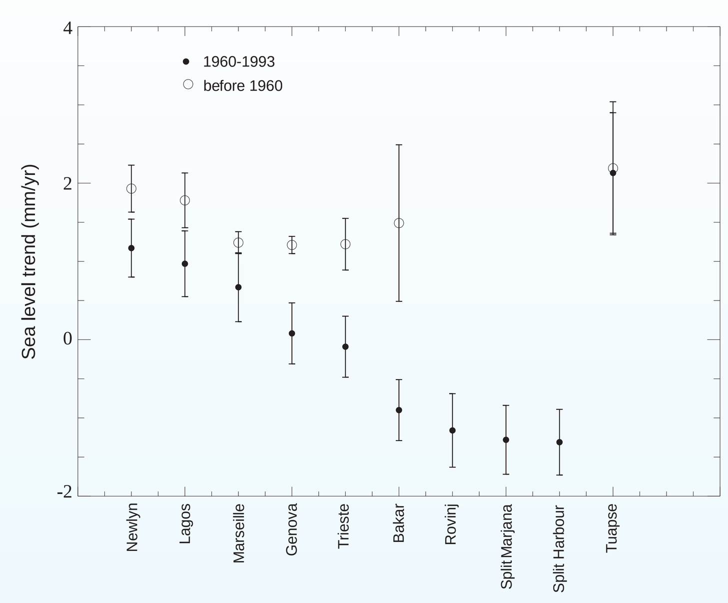

Figure 1. Sea level trends in the Mediterranean Sea before 1960 and between 1960 and 1993 (Tsimplis and Baker 2000). Newlyn at the Southwest of England, Port Tuapse at the Black Sea and Lagos (Portugal) are shown for comparison. The location of most stations is shown in Figure 2.

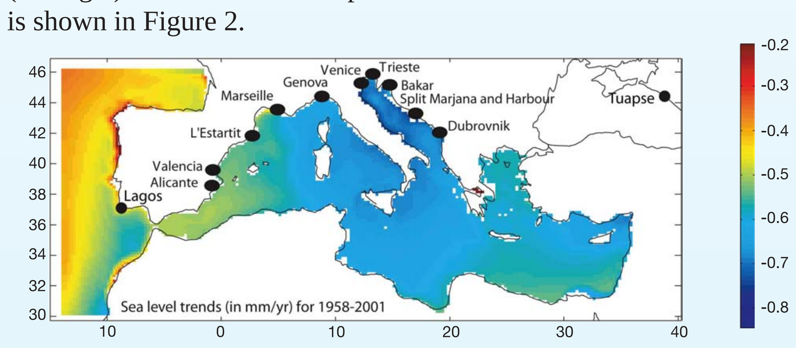

Figure 2. Sea level trends over the Mediterranean Sea estimated from a 2-d model for the period 1958-2001. These are caused by the wind and atmospheric pressure changes and do not include any other forcing factor. The atmospheric pressure and wind fields were produced through dynamical downscaling from the NCEP/NCAR global reanalysis, using the atmospheric limited area model REMO.
The model was run as part of the HIPOCAS project.

Mediterannean Sea level trends between 1960 amd the mid 1990s were very close to zero or negative (Figure 1, Tsimplis and Baker, 2000). This was a significant change from sea level trends in the first part of the 20th century which was not reflected, at least to the extent at the tide-gauges of Lagos and Newlyn, nor at the Black Sea tide gauge of Port Tuapse.The output of a barotropic version of the HAMburg Shelf Circulation Model (HAMSOM) with resolution of 1/4˚x 1/6˚ (Alvarez Fanjul et al, 1997) was used. The sea level trends of the model output are shown in Figure 2. Atmospheric forcing has imposed negative sea level trends over the Mediterranean between 1958-2001. The comparison of the tide-gauges with the model time series gave over the basin correlation coefficients of 0.7 or higher with the lowest values found near the Strait of Gibraltar where baroclinic effects are important. However, the model sea level was highly coherent overall the basin and highly correlated with the NAO index confirming the suggestions by Tsimplis and Josey (2001). Notably the correlation with the NAO remains high during the whole model period (Figure 3). However, the comparison of the trends estimated from the model with those estimated from the tide-gauges over the same period show significant discrepancies (Figure 4). These are caused by rapid sea level rise after 1993, because the comparison at the period 1958-1993 shows good agreement. This was first noted by Cazenave et al. (2001) The discrepancy is largest at the Eastern Mediterranean Sea indicating local nonatmospheric forcing as the source of the rapid sea level rise there. Although Cazenave et al (2001) found correspondance with SST the comparison with the T and S changes indicate that the steric effects have a very small contribution to the observed rapid sea level rise. Thus we suggest that oceanic circulation changes linked with the Eastern Mediterranean Transient (a change in the deep water formation region in the Eastern Mediterranean from the Adriatic Sea to the South Aegean) was the cause of the observed changes.

For details see:
Alvarez-Fanjul, E., B. PÈrez and I. RodrÌ'edguez, A description of the tides in the Eastern North Atlantic. Progr. Oceanogr., 40, 217-244, 1997
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Tsimplis M.N., E. Alvarez-Fanjul, D. Gomis, L. Fenoglio-Marc, B. PÈrez (2005), Mediterranean Sea level trends: Atmospheric pressure and wind contribution, Geophys. Res. Lett., 32, L20602, doi:10.1029/2005GL023867.

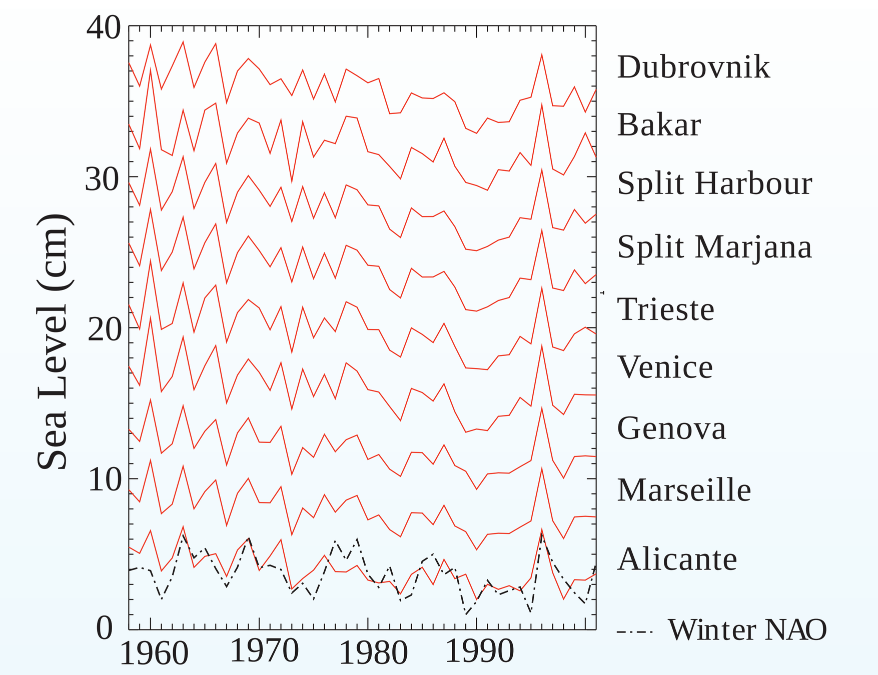

Figure 3. The model time series at grid points close to the various tide-gauges. The winter (December-March) NAO index is also shown. The atmospheric forcing in winter is clearly dominated by the NAO variability. This influence is steady and the correlation remains good in the 1990s.

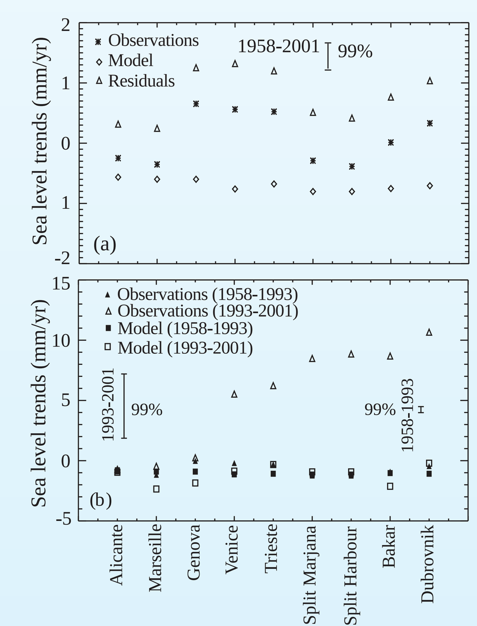

Figure 4. (a) Sea level trends for the period 1958-2001 for the tide-gauge data (stars), the model data (diamonds) and their difference (triangles); (b) Sea level trends for the model (squares) and the tide gauge data (triangles) for the periods 1958-1993 (filled symbols) and 1993-2001 (empty symbols). The error bars in the plot are empirical estimates derived from the spread of the trend values for segments of the time series with equal length (Tsimplis and Spencer, 1997).

2. Reconstruction of Mediterranean Sea level

The model sea level data permit us to estimate mean sea level variability for the whole basin.This is well correlated with the NAO index. Thus we use NAO recosntructions to extend the time series backwards in time (Figure 5). Although the usefulness of such time series is questionable as the influence of the NAO over Europe is variable in time they provide an opportunity to assess error bars related to the NAO variability and NAO induced trends.
At the bottom of Figure 5 a change in the sea level slope between 1900 and the 1960s and the period before is clear. Such variation is consistent with what the tide-gauges show.
Moreover the trends estimated from samples of the reconstructed sea level record indicates that even with 80 years of data the spread of the values is about 0.5 mm/yr and this spread is solely to the variation of the direct atmospheric forcing related to the NAO.

For details see: Gomis D., M.N.Tsimplis B. Martin-Miguez, A.W.Ratsimandresy, J. Garcia-Lafuente, S.A. Josey, Mediterranean Sea Level and barotropic flow through the Strait of Gibraltar for the period 1958-2001 and reconstructed since 1659. J. Geophys.Res. (Oceaans) (in press).

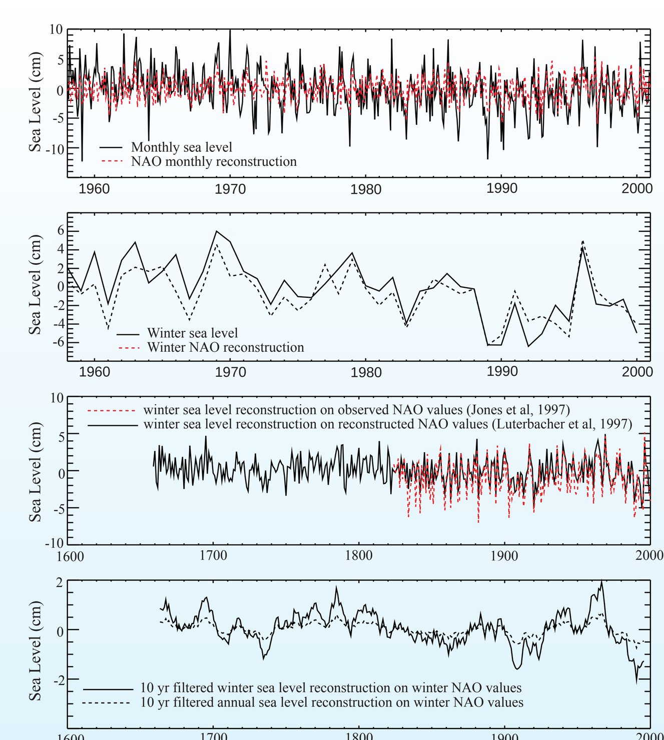

Figure 5. (a) Monthly sea level variability from the model and on the basis of monthly NAO values; (b) Winter sea level from the model and its NAO reconstruction for winter NAO values; (c) Winter sea level reconstructed from the observed winter NAO values of Jones et al., (1997) (red) and the winter sea level reconstruction on the basis of the winter NAO of Luterbacher et al. (2002); (d) A running mean 10 yr filter on the Reconstruction of winter sea level (continuous line) and the reconstruction of annual mean sea levels on winter NAOs from the same source (dotted line). Note the change in the sea level slope after 1900 and up to the late 1970s.

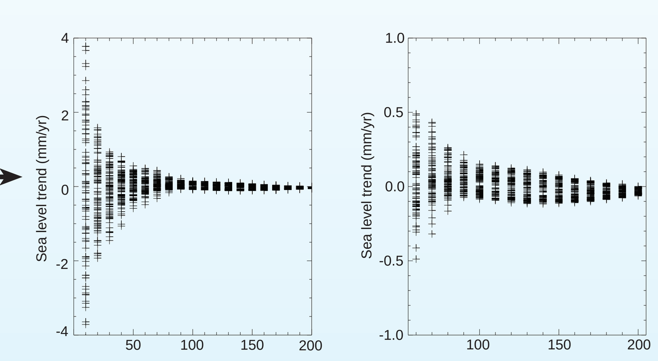

Figure 6. The sea level trends calculated for the reconstructed time series by selecting vparts of various lengths. The winter reconstructions are shown with the longer than 50 year segments repeated in the right.

3. Sea level rise in the Black Sea

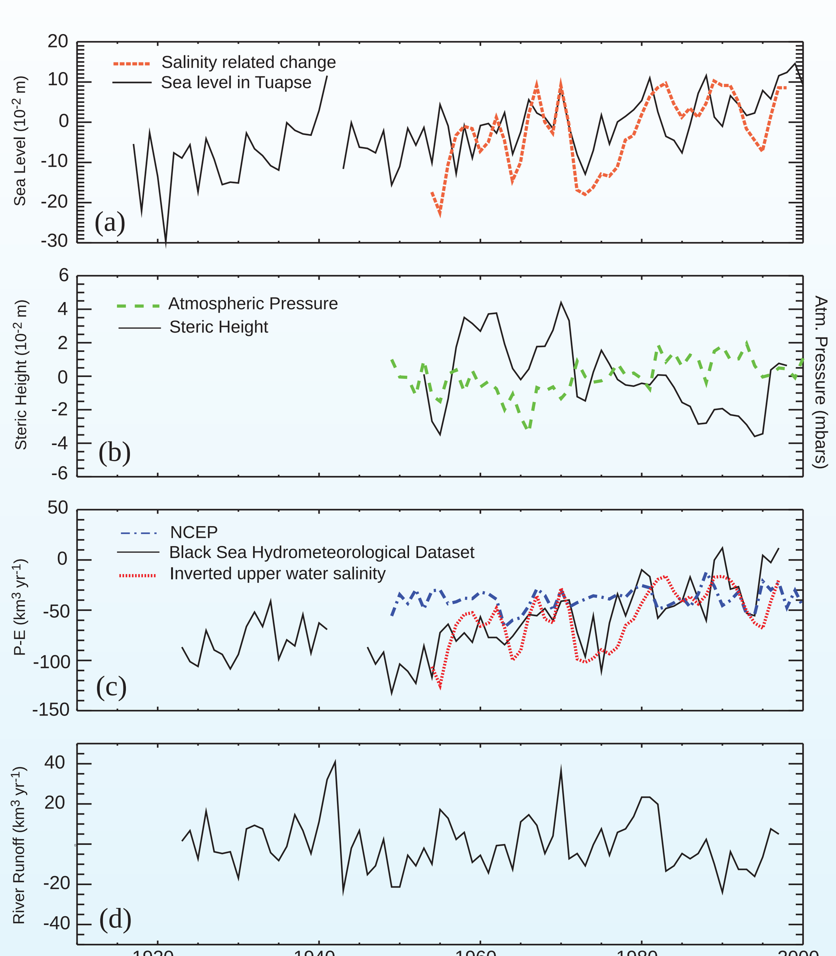

Figure 7. Variability of climatic parameters and sea level.(a) tide-gauge data from Tuapse and the salinity related change(red); (b) steric sea level calculated from Medar and atmospheric pressure changes (green); (c) P-E from the Black Sea hydrometeorological dataset, NCEP (blue) and inverse salinity (red); (d) river runoff. The inverted salinity time series has been arbitrarily scaled in (c).

Sea level in the Black Sea has been increasing even when the Mediterranean Sea level was going down (figure 1). Steric effects and atmospheric pressure variations do not produce significant changes either (Figure 7b, note that the inverse barometer is not applicable at the Black Sea). Salinity changes in the upper waters (0-30 m) can be used to estimate the freshwater balance assuming that the exchange with the lower waters is steady. This is done (Munk, 2003) as $\partial h_{eustatic} = h_{steric} \times [\rho/(\rho-\rho w)]$ and results in the curve at Figure 7a. Thus sea level rise is probably eustatic. However, river outflow although exhibiting strong valiability does not have a strong trends (Figure 7d). It is the E-P balance that has a strong trend consistent with the salinity changes and the sea level variability (Figure7c). This is caused by a decrease in evaporation rather than significant changes in precipitation. However, it should be noted that NCEP does not appear to have the same trend in evaporation as the Black Sea Hydrometeor-ological dataset.

For details see:
Tsimplis M.N., S.A. Josey, M. Rixen and E. Stanev (2004), On the forcing of sea level in the Black Sea, J.Geophys. Res. (Oceans), 109(C8) Art. No. C08015 Aug 24 2004

4. The North Sea

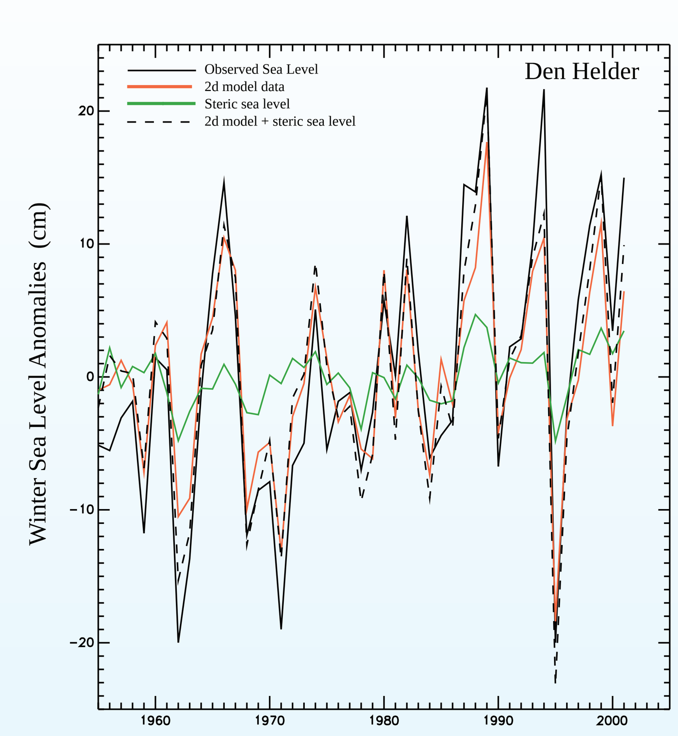

Figure 8. The observed winter sea level at Den Helder (solid line); the 2d hydrodynamic model output (red line), the steric sea level variability estimated on the assumption of constant salinity and 18 m water depth (green line) and the sum of steric + 2d model data (dashed line).

Sea level around the North Sea is dominated by direct atmospheric forcing effects and is well described by 2d models (Wakelin et al., 2003). An attempt to assess the contribution of local steric variability has been made at Den Helder (Netherlands) where daily observations of sea water temperature are available (Van Aken, 2003). Using winter data (when the water column is homogenised) and assuming a depth of 18 m the agreement between modelled+steric and observed sea level improved. The sea temperature is highly correlated to the NAO (0.878 degC/NAO unit) with a very small trend of 0.007 degC/yr corresponding to 0.18 mm/yr. The tide-gauge trend was 1.9 mm/yr and the model+steric time series trend was 1.6 mm/yr. Thus the discrepancy was about 0.3 mm/yr well within the confidence intervals.

For details see:
Tsimplis N.N. D.K. Woolf, T.J. Osborn, S. Wakelin, J. Wolf, R. Flather, A.G.P Shaw, P. Woodworth, P. Challenor, D. Blackman, F. Pert, Z. Yan and S. Jevrejeva (2005), Towards a vulnerability bassesment of the UK and northern European coasts: the role of regional climate variability. Phil. Transactions of the Royal Society-A. , 363 (1831) 1329-1359.
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Van Aken H.M., 2003, 140 years of daily observations in a tidal inlet (Marsdiep) ICES Marine Symposia, 219:359-361.
Wakelin, S.L., P.L. Woodworth, R.A. Flather and J.A. Williams, (2003). Sea level dependence on the NAO over the NW European Continental Shelf. Geophys. Res. Lett, 30(7) doi:10.1029, 2003.

5. Conclusions

Several factors influence regional sea level. These range from direct atmospheric forcing which demonstrates interdecadal and centenial variability to local steric effects, local eustatic changes and deep water formation events. Most of the variability observed is explained with some confidence leaving small residuals in trends to be attributed to non-regional or global forcing.

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