Modeling the response of the Mediterranean sea level to global and regional climatic phenomena

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Introduction & Objectives

Fluctuations in the level of the sea pose an issue of emerging importance, since latest scientific research shows a clear trend in the rise of the sea level. A crucial point to studying the variations of the sea surface is the correlations of Sea Level Anomaly (SLA) with global and regional climatic phenomena that influence the ocean state as well.

This work presents correlations of the Sea Level Anomaly (SLA) with global and regional climatic phenomena that influence the ocean state as well. The developed covariance functions are used in order to investigate any possible correlations with climate change indices over the Mediterranean Sea.

Three such indexes have been investigated. The first one is the well-known Southern Oscillation Index (SOI) corresponding to the ocean response to El Niño/La Niña-Southern Oscillation (ENSO) events (Fig.2 top). The next index investigated is the North Atlantic Oscillation (NAO) index, which corresponds to the fluctuations in the difference of atmospheric pressure at sea level between the Icelandic low and the Azores high (Fig.2 middle). The last index investigated is the Mediterranean Oscillation Index (MOI) which refers to the fluctuations in the difference of atmospheric pressure at sea level between Algiers and Cairo (Fig.2 bottom).

The goal is to come to some conclusions on the SLA correlation with global and regional climatic phenomena. A regional multiple regression analysis and a principal component analysis between sea level anomalies and these indexes is carried out to model any possible correlation between the Mediterranean sea level and these global and regional climatic phenomena.

Data used and corrections

The raw data used are SLA values from Jason-1 and Jason-2 (Fig. 1). satellites for a period of eleven years (2003-2013) within the entire Mediterranean Basin (30° ≤ ϕ ≤ 50° and -10° ≤ λ ≤ 40°).
The data have been downloaded from RADS server (DEOS Radar Altimetry Data System) in the form of SLAs relative to EGM2008, after applying all the necessary geophysical and instrumental corrections.

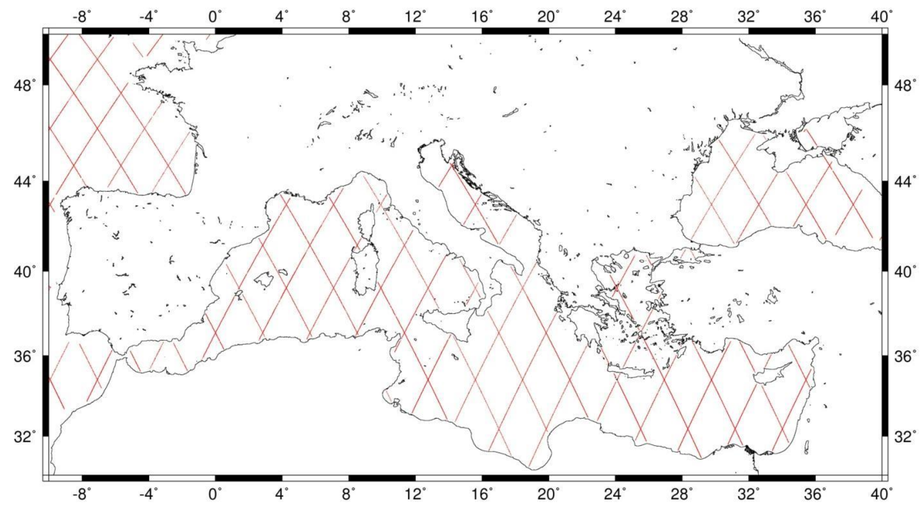


Figure 1: Jason-1 and Jason-2 data distribution.

Each Jason-1 and Jason-2 cycle consists of 254 passes with almost 15% of those having available observations in the Mediterranean Sea within the satellite's period of 10 days. For each year 36 cycles and ~92000 observations are available with a cross track spacing of 300km at the equator. For the present study, NAO, SOI and MOI data have been acquired from the Climate Research Unit of the University of East Anglia (http://www.cru.uea.ac.uk/)

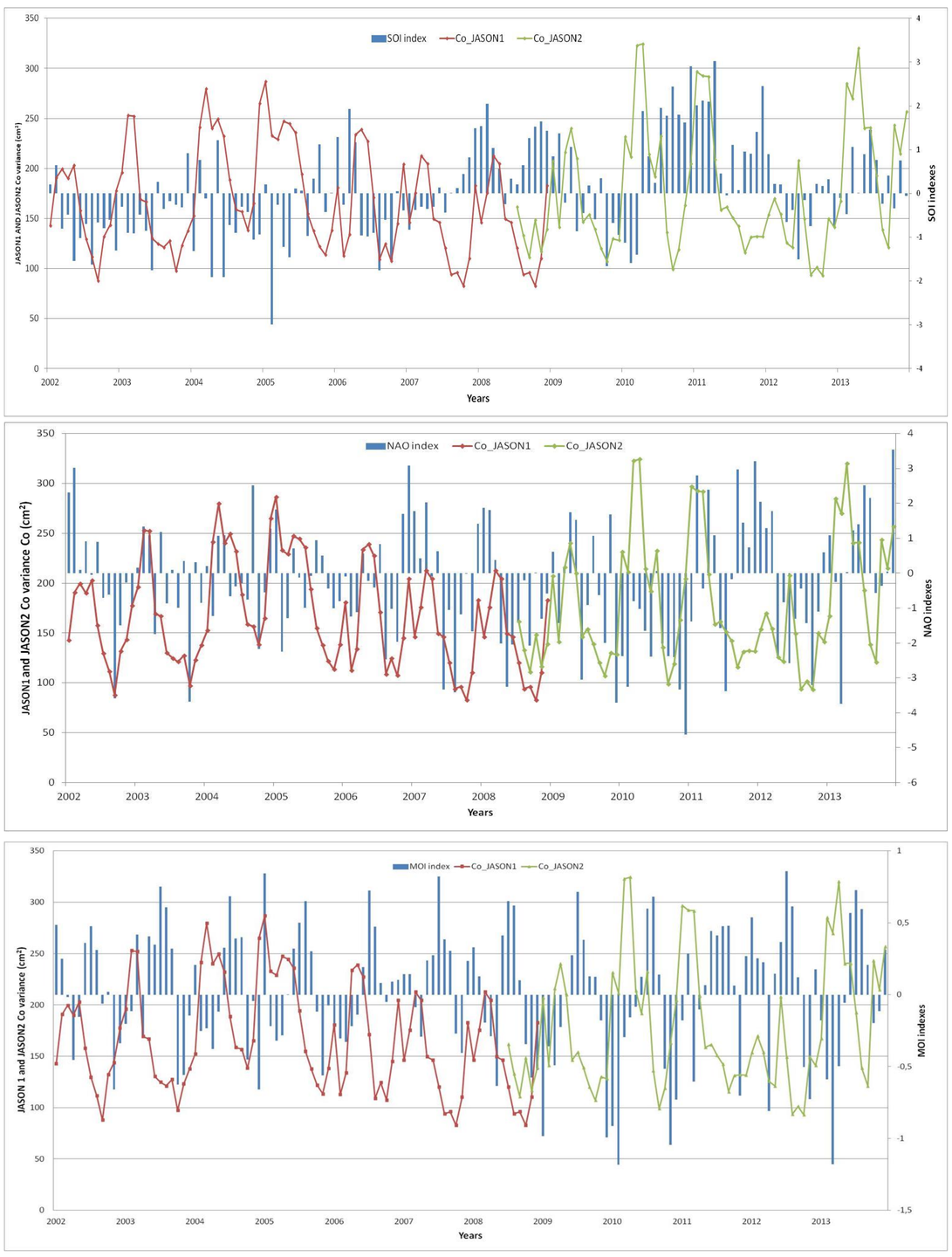


Figure 2: Jason-1 and Jason-2 SLA variances (from the monthly empirical covariance functions) fluctuations from 2003 to 2013 and correlation with SOI (top) and NAO (middle) and MOI (bottom).

From Fig. 2 it can be concluded that some correlation between ENSO events and SLA variations in the Mediterranean can be seen, even though with a phase offset of 3-6 months. The large negative values at the beginning of 2004 and 2005 are related to the highs in Mediterranean SLAs which appear in Spring of 2004 and in Summer of 2005. The El Niño appearance in March 2006 has a more rapid signature in the Mediterranean SLA data, since it results in significant increase in the SLA in June-July 2006, i.e., a time period of 5 months. The same behavior is evidenced for the La Niña events too, as it can be seen for the moderate occurrences in late 2007-early 2008 and for the strong event of late 2010 and early 2011. These result in significant depressions in the SLA variances, which reach their smallest values in Summer 2008 and in Spring 2011, i.e., with a time lag of ~3-5 months.
Given that El Niño and La Niña may not be representative for the Mediterranean Sea, due to their distance and the characteristics of the latter as a closed sea area, the NAO index should be more appropriate to indicate any correlation between atmospheric forcing and SLA variations. It is now evident that a stronger correlation can be seen, since the positive NAO values are related to more immediate depressions in the Mediterranean sea level, while negative ones to increased sea levels. Noticing are the large positive NAO values at the beginning of 2002, 2007, 2008, 2011 2012 which are immediately depicted as depressions in the Mediterranean SLA with a time lag of less one-two months. The same behavior is found for most winter months, i.e., a good correlation, while for summer months the response of the Mediterranean sea level to variations in NAO is not so well depicted (2002, 2004, 2006-2010 and 2012).
MOI should be the most proper measure of atmospheric forcing contribution to sea level variations in the Mediterranean. From Fig.2 it becomes clear that positive phases in MOI are related to depressions in the SLA due to dryer conditions, as can be seen in Summer 2002-2004, 2006-2008, 2009-2013. The same behavior can be seen for the negative MOI values, which result in increased sea levels as for example in early 2002, 2004-2007, 2010-2011 and 2013. In most cases trends in the SLA are directly correlated with MOI while NAO and MOI are also well correlated and follow each other, especially for the winter months. However, for few months (during Spring and Summer 2007) the NAO index presents a large negative value, signaling the interrelation of the Atlantic circulation and the variability in the Mediterranean. This anti-correlation between NAO and MOI and their disagreement in Spring and Summer signals that atmospheric conditions in the North Atlantic are not the dominant contributing factor for the Mediterranean Sea.

Regional multiple regression analysis

A regional multiple regression analysis between SLA Co values of JASON1 and JASON2 and SOI, MOI and NAO indexes is carried out to model the response of the Mediterranean to these global and regional climatic phenomena.

3 regression coefficients

$$C_O = b_1 \times MOI + b_2 \times SOI + b_3 \times NAO$$

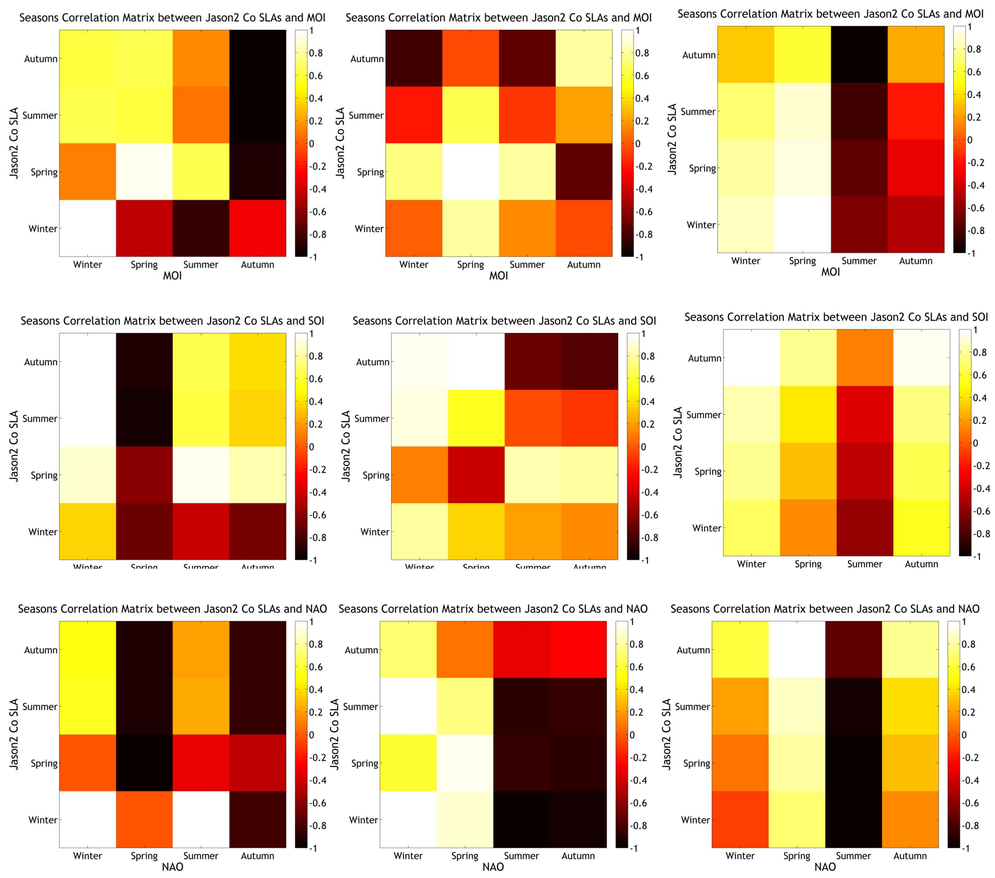
A linear regression with three regression coefficients between the Co values and tree indexes has been used. The values of the indexes have been normalized, using the minmax values of NAO, in order to take values to be coherent to each other.

Year	b_1	b_2	b_3
2002	6.198	-3.055	1.128
2003	6.839	0.365	0.285
2004	**8.564**	1.182	1.586
2005	**11.102**	-1.335	-1.708
2006	**9.144**	2.031	0.298
2007	5.808	1.844	0.952

Year	b_1	b_2	b_3
2008	2.882	2.508	-1.371
2009	5.234	3.032	0.209
2010	6.143	**0.666**	**3.407**
2011	2.464	**3.362**	-0.692
2012	5.436	2.224	-0.958
2013	5.598	**7.767**	**2.347**

The correlation between SLA and the indexes depicted in Fig. 2 is similar to the values of the regression coefficients. During all years, the coefficient of MOI takes the biggest values, resulting in good correlation with the SLA. The SOI coefficient values are smaller, while during the years that the ENSO events are strong (2011, 2013) b_2 is bigger than b_1. Finally, NAO coefficient b_3 takes absolute values close to 1 signaling that atmospheric conditions in the North Atlantic are not the dominant contributing factor for the Mediterranean Sea while the big value of 2010 can be attributed to the small value of SOI.

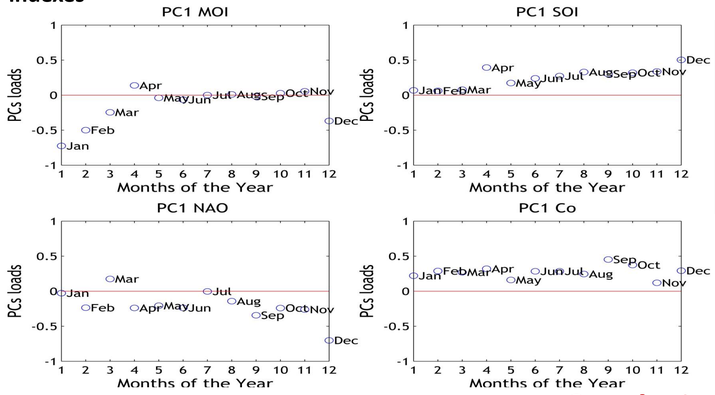
A correlation analysis is also carried out to model any seasonal correlation between SLA and these indexes. Four periods of 3 years (2002-2004, 2005-2007, 2008-2010, 2011-2013) have been checked while a monthly correlation for these periods was derived as well.



In Fig.3 correlation between seasons and indexes for a period of three years is depicted. Although a seasonal effect is not obvious, due to the fact that periods of three years are tested, it can be noticed that MOI and NAO are stronger correlated with SLA during the early months of each year. This is in line with the fact that NAO and MOI are well correlated and follow each other, especially during winter. On the other hand, the seasonal correlation between SOI and SLA depends on the strength of ENSO events and it is presented with a lag of 4-8 months.

Figure 3: Correlation between Seasons and MOI(top), SOI(middle) and NAO (bottom) for years (2002-2004, 2005-2007, 2011-2013) .

Finally a principal component analysis is carried out, employing all twelve years of JASON1/2 data and the SOI, NAO and MOI indexes



	PC1	PC1-PC2	PC1-PC2	PC1-PC4
MOI	0.414	0.612	0.740	0.835
SOI	0.447	0.710	0.806	0.869
NAO	0.316	0.505	0.655	0.758
Co	0.642	0.794	0.888	0.931

Percentage of the total variance in each PC

Figure 4: PCs loads for PC1 for MOI (left top), SOI (right top), NAO (left bottom) Co (right bottom),.

Conclusions

A regional multiple regression and a principal component analysis between sea level anomalies and the SOI, MOI and NAO indexes was carried out to model any possible correlation between the Mediterranean sea level and these global and regional climatic phenomena. It is obvious that the response of the Mediterranean Sea to atmospheric forcing within its vicinity is more predominant with MOI. Some correlation between ENSO events and SLA variations in the Mediterranean can be seen while NAO is well correlated with MOI and SLA for winter months. The small response of SLA in the Mediterranean sea level during Summer signals that atmospheric forcing is not the contributing factor to the steric sea level variations in the Mediterranean during the summer period. These facts are depicted in the values of the regression coefficients as well, where the MOI coefficient is dominant. Finally, from the analysis of the empirical covariance functions SLA, it is noticed that there is a significant annual variation which is evident for the entire period under study.

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