Stationary SSt estimation using ERS1 and topex/poseidon data in the western mediterranean area

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Abstract

ERS1 Exact Repeat Mission (ERM) and TOPEX/POSEIDON data have been analyzed trackwise to separate via collocation filtering the stationary SST from the time dependent SST in residuals between altimetric data and geoid model (GEOMED). The stacked tracks have been merged via a cross over adjustment assuming TOPEX/POSEIDON as reference frame. Using a 2-dimensional covariance function, estimated from stacked ERS1/ERM data, collocation filtering has been applied also to the Geodetic Mission data to separate the stationary SST from the time dependent part. The filtered geodetic tracks have been then trackwise connected to the reference frame defined by TOPEX/POSEIDON and ERS1/ERM. Thus an improved estimate of the stationary SST has been obtained due to the dense coverage of data mainly related to the geodetic ERS1 mission.

Introduction

The main outcome of the processing of altimeter data is the estimate of Sea Surface Topography (SST), which gives relevant information on ocean circulation.

Many different methods have been applied to extract and/or separate the stationary part of the SST from the time varying component (Rummel, 1993).

Furthermore, different satellite altimeter missions have provided large data sets which should be integraded to give a unique estimate of the SST. In doing that, particular care must be devoted to the features of the various altimeter missions. Different resolutions in time and space and different precisions of the altimter data and of the satellite orbits must be taken into account.

In this paper, the stacking procedure described in Barrile et al. (1995) is applied to TOPEX/POSEIDON and ERS1/ERM data in the western part of the Mediterranean Sea. Furthermore, an attempt is done to filter ERS1 Geodetic Mission observations over the same area in order to estimate the stationary part of the SST in these data. The procedure that was adopted is again based on collocation: we try to estimate the stationary SST in the geodetic data using a covariance function coming from the stationary signal that we got on the repeated ERS1 tracks.

In this way a coherent signal was obtained both on repeated data and on Geodetic Mission data and a remarkable improvement in the stationary SST estimate was obtained.

The dataset

The boundaries of the test area are 30°45° 0°19° (the Adriatic Sea is not included). In this area the following altimetric data have been considered:

- TOPEX/POSEIDON fully corrected Sea Surface Height (SSH). The data of twelve Exact Repeat Missions (10-day repeat) from November '92 to October '93 have been selected. One over three consecutive ERM has been chosen, with a time interval of about thirty days one from the other.

- ERS1 fully corrected SSH. Eleven ERM (35 day repeat) of phase C have been selected from October '92 to October '93

- ERS1 Geodetic Mission (168 day repeat, phase E) fully corrected SSH from April '94 to October '94

The TOPEX/POSEIDON and ERS 1 data have been corrected in an homogeneous way. The orbits of both satellites, referred to the GRS80 Reference Ellipsoid, have been calculated at DEOS - Delft.

The ground track patterns of the above data are plotted in fig. 1, fig.2, fig. 3

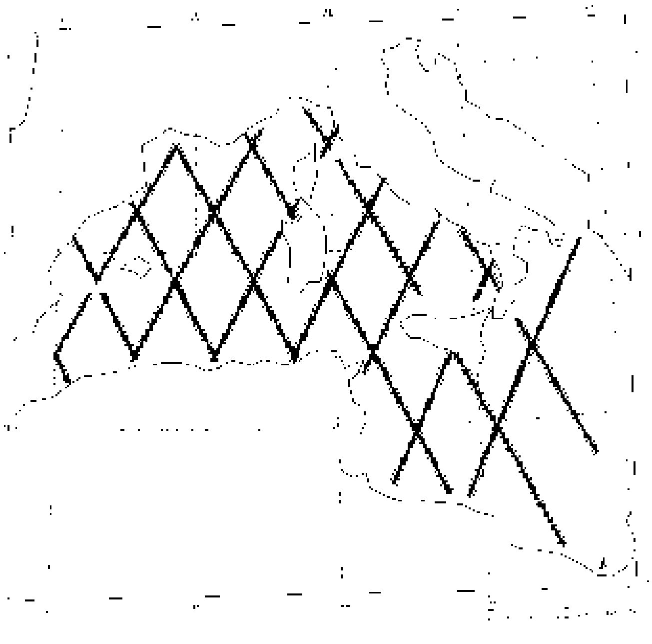

Fig. A TOPEX/POSEIDON ground track pattern

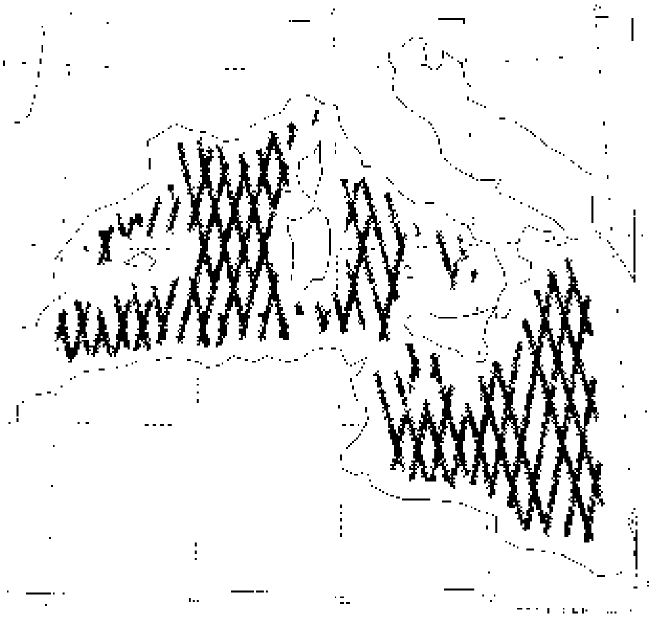

Fig. B ERS1/ERM ground track pattern

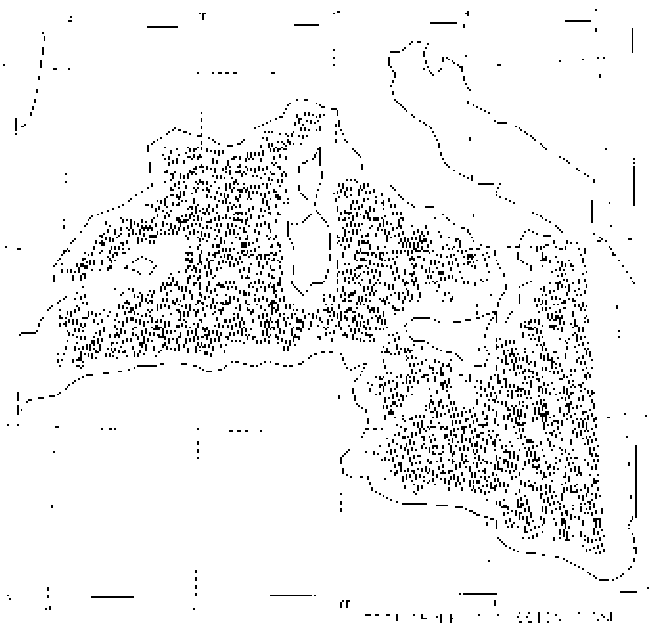

Fig. C ERS1 Geodetic Mission ground track pattern

The GEOMED geoid (Barzaghi, Brovelli and Sanso', 1993) has been used to reduce the SSH. It is a gravimetric geoid computed on a 5' 5' grid via remove restore technique and fast collocation. This is a quite detailed geoid and, on consequence, no relevant geopotential signal should be left in the residual =SSH-N. The GEOIP program (Tscherning et al, 1994) has been used to get N in the altimetric points.

The stacking procedure

The difference between the fully corrected TOPEX/POSEIDON and ERS1/ERM Sea Surface Height (SSH) and the GEOMED Geoid (N) has been modelled as follow:

$$(P,t)=SSH(P,t)-N(P)=SST^{(0)}(P)+SST^{(t)}(P,t)+N(P)+(P,t) \qquad (1)$$

where

- $SST^{(0)}(P)$is the stationary Sea Surface Topography;

- $SST^{(t)}(P,t)$ is the time dependent Sea Surface Topography;

- N(P) is the residual geoid;

- (P,t) is the residual radial orbit error.

The residual radial orbit error have been modeled as a bias for the TOPEX/POSEIDON tracks and as a linear trend for ERS1/ERM.

Taking into account the repeated tracks, equation (1) has to be modified in

$$(P^k,t^k)=SSH(P^k,t^k)-N(P^k)=SST^{(0)}(P^k)+SST^{(t)}(P^k,t^k)+N(P^k)+(P^k,t^k) \qquad (2)$$

where k labels the different repetitions of the same track.

For each group of repeated tracks, a common origin has been calculated as the southernmost point belonging to the group and a curvilinear abscissa x^k has been derived for all the points of the repeated track itself.

In order to remove the residual radial orbit error from each track of each group, a bias (TOPEX/POSEIDON) and a bias and a tilt (ERS1/ERM) have been estimated trackwise in the values via least square adjustment.

After the removal of the residual radial orbit error we obtain

$$(P^k,t^k)= SST^{(0)}(P^k)+ SST^{(t)}(P^k,t^k)+N(P^k) \qquad (3)$$

A 1D collocation filtering, based on the x^k values, has been used to separate the time dependent part of SST from the stationary part. It allows to separate a correlated signal from an incorrelated component.

$SST^{(0)}(P^k)$ doesn't depend on time so that the different repeats of $SST^{(0)}$ are correlated since they are samples of the same function. On the other hand, different repeats of $SST^{(t)}$ are not in general correlated since they occur at different times and different physical phenomena act at these times. So we split the values into a signal component equal to $SST^{(0)}(P^k)$+ $N(P^k)$ and a noise component $SST^{(t)}(P^k,t^k)$+outliers. Having done this assumption, we compute for each group of repeated tracks the empirical covariance function of the signal using all (P^k,t^k) values, then we fit it with a proper covariance model and we estimate $SST^{(0)}(P^k)$ by means of the collocation formula:

$$SST^{(0)}(P^k{}_i)=C_{ss}(P^k{}_i,P^l{}_n)C^{-1}(P^l{}_n.P^j{}_m)(P^j{}_m,t^j{}_m) \qquad (4)$$

Either collocation filtering and collocation prediction on a regularly distributed points along the tracks has been performed.

It must be noticed that the assumption of having a monodimensional signal is accetable since a repeat track has a maximum distance from the others belonging to the same group less than 1 km. This procedure has also the advantage of automatically removing the outlier contained in the data. An example of the trackwise 1D filtering procedure is shown in Fig. 4 and Fig. 5 on a TOPEX track.

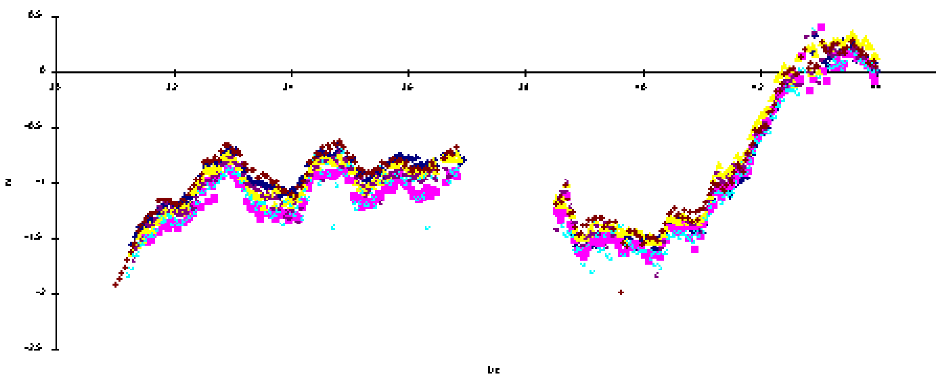

Fig. D TOPEX repeat track = SSH - N (m)

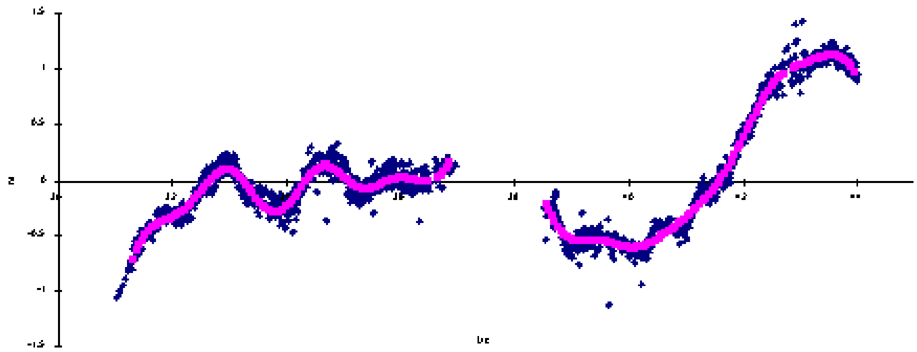

Fig. E TOPEX repeat track = SSH - N - and predicted signal (m)

The internal consistency of the stacked signal both for TOPEX/POSEIDON and for ERS1/ERM was tested via cross over analysis (Barzaghi et al, 1991, Schrama, 1989). The statistics of the cross over differences of the raw and stacked data are shown in the following tables. It must be underlined that as the stacking procedure have been made trackwise a cross over adjustement is needed to obtain a surface.

before c.o. adj (bias only)	after c.o adj (bias only)
n= 4246 E= -0.005 m = 0.134 m	n= 4246 E= 0.000 m = 0.053 m

Tab. A Statistics of cross over differences of raw TOPEX/POSEIDON data

before c.o. adj (bias only)	after c.o adj (bias only)
n= 19 E= -0.410 m = 0.291 m	n= 19 E= -0.001 m = 0.031 m

Tab. B Statistics of c.o differences of stacked TOPEX/POSEIDON data

before c.o. adj	after c.o adj
n= 7724 E= -0.006 m = 0.125 m	n= 7724 E= 0.000 m = 0.039 m

Tab. C Statistics of c.o. differences of raw ERS1/ERM data

before c.o. adj	after c.o adj
n= 81 E= -0.009 m = 0.112 m	n= 81 E= 0.000 m = 0.004 m

Tab. D Statistics of c.o. diffrences of stacked ERS1/ERM data

Filtering ERS1 geodetic mission data

The stacked ERS1/ERM and TOPEX/POSEIDON filtered data represent a sample of the stationary SST that we want to estimate. As it can be seen from the pattern of ERS1/ERM and Geodetic Mission tracks, the latter are denser in space and can provide valuable information on SST, provided that one is able to filter these data in a coherent way with respect to the signal derived in the 1D analysis. To do that, we use a 2D collocation filtering based on an empirical covariance function estimated areawise on all the ERS1/ERM stacked data (see Fig. 6). Through this function, collocation should recognize in the Geodetic Mission data the same stationary signal estimated in the repeated tracks.

The GEOMED geoid was subtracted to the Geodetic Mission data: then a bias and a tilt were estimated and removed from the residuals. This reduced data set and 1D predicted ERS1/ERM values, derived in the stacking procedure, were then used together to perform a 2D collocation filtering on the Geodetic Mission and on the ERS1/ERM data.

These last predicted values have been used to compare the 1D filtering procedure with the 2D one.

The differences between the values predicted via the 2D and the 1D approach were calculated and reduced by a bias and a tilt. The statistics of the resulting differences are listed in table 5, while in Fig.7 it is shown an example of such a comparison.

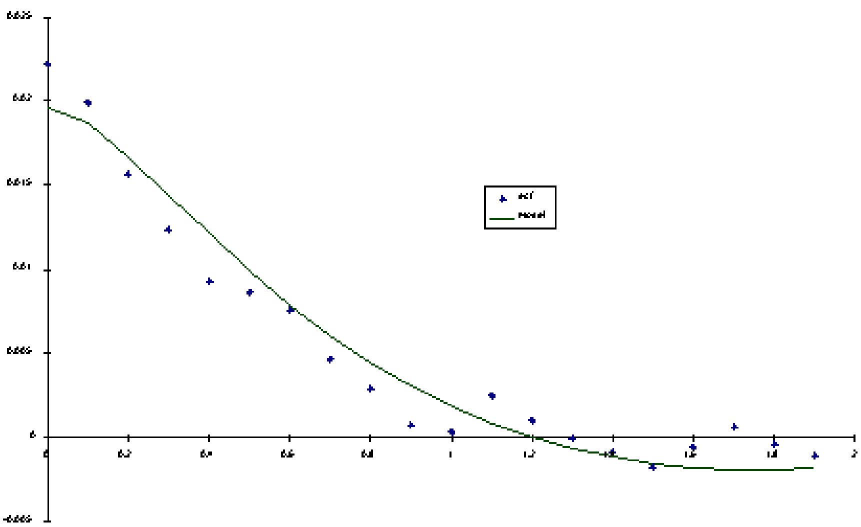

Fig. F 2D empirical covariance function of ERS1/ERM stacked data and best fit model (m^2)

As it is expected, a smoother signal is obtained using the 1D procedure but, nevertheless, a satisfactory coherence between 1D and 2D signals is reached: hence, we can assume that the same holds also on the Geodetic Mission data.

n= 4819 E= 0.000 m = 0.046 m

Tab. E Statistics of differences between 1D and 2D collocation predicted values over ERS1/ERM tracks

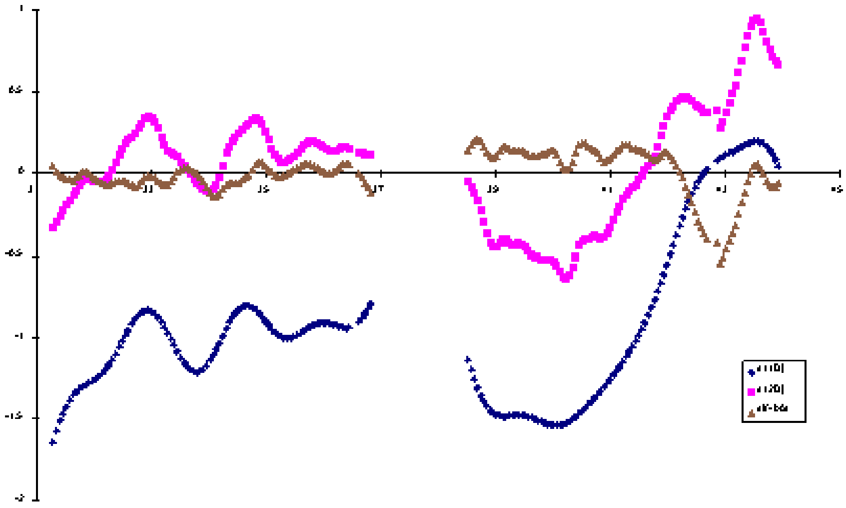

Fig. G ERS1/ERM track - Comparison between 1D and 2D collocation prediction (m)

Merging filtered data assuming topex/poseidon as reference

The mean bias with respect to the GEOMED geoid for each group of repeated TOPEX/POSEIDON tracks has been calculated and added to the stacked signal.

Then, a cross over adjustment has been performed (bias only) on the obtained data. The surface resulting from the cross over adjustment on this stacked data set up the reference frame (defined except for a bias) for our SST$^{(0)}$.

before c.o. adj (bias only)	after c.o adj (bias only)
n= 19 E= -0.003 m = 0.039 m	n= 19 E= -0.000 m = 0.027 m

Tab. F Statistics of cross over differences of TOPEX/POSEIDON stacked data plus mean bias

The stacked ERS1/ERM tracks have been then merged to this TOPEX/POSEIDON reference surface via cross over adjustment keeping the TOPEX/POSEIDON tracks fixed. The internal consistency of the surface obtained merging TOPEX/POSEIDON and ERS1/ERM data is expressed in the following statistics.

before c.o. adj	after c.o adj
n= 120 E= -0.010 m = 0.149 m	n= 120 E= -0.001 m = 0.017 m

Tab. 7 Statistics of c.o. diferences of TOPEX/POSEIDON and ERS1/ERM

The last step of the procedure to obtain the stationary SST is to merge the filtered ERS1 Geodetic Mission surface to the reference surface of TOPEX/POSEIDON and ERS1/ERM. A bias and a tilt were estimated using the cross over differences between this reference surface and each Geodetic Mission filtered track. All the Geodetic tracks were therefore trackwise corrected for their own trend.

The final Stationary Sea Surface Topography is shown in Fig. 8

The statistics of the residual cross over differences between the Geodetic Mission filtered tracks reduced to the TOPEX/POSEIDON - ERS1/ERM frame and the frame itself are listed in Tab. 8

n= 599 E= -0.007 m = 0.151 m

Tab. 8 Statistics of residuel cross over differences between Geodetic Mission filtered tracks reduced to the TOPEX/POSEIDON - ERS1/ERM frame and the frame itself

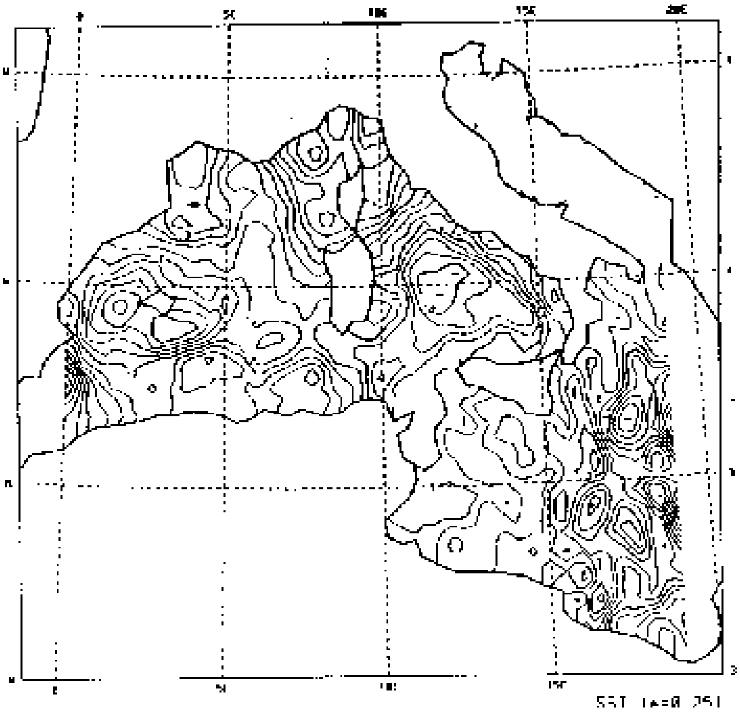

Fig. 8 The stationary SST (e=0.25 m)

Conclusions

The whole procedure gave good results but from the last step, i.e. the one used to merge the geodetic data to the reference frame formed by TOPEX/POSEIDON and ERS1/ERM.

Both the 1D filtering and the 2d filtering applied to repeated and Geodetic Mission data respectively proved to be effective and gave coherent results.

Refinements must be considered when glueing filtered geodetic data to TOPEX/POSEIDON - ERS1/ERM frame.

The trackwise procedure that we adopted produced unsatisfactory results, poorer than expected.

In fact, it must be noticed that the congruence between 1D and 2D filtering over repeated tracks is at level of 5 cm (see statistics in Tab. 5), while the final statistics of the residual cross over differences between TOPEX/POSEIDON - ERS1/ERM frame and filtered geodetic data led to a standard deviation of 15 cm (see Tab. 8). Part of this variability can be connected to the higher frequency content of the geodetic filtered data (see also Fig. 7) but we still believe that this cannot account for such a large discrepancy between the two standard deviations. Then, future investigations must be done on such a step to define a more reliable procedure to accomplish it.

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