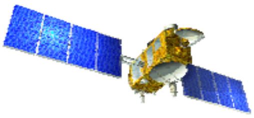
Error estimation of the global and regional mean sea level trends from Jason-1 and TOPEX/Poseidon altimetry data



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Overview

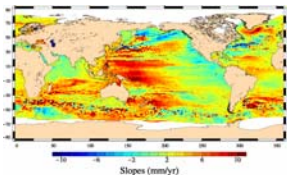
This study aims at presenting the estimation of the different errors which can impact the global and regional MSL trends. The potential drifts detected in the orbit models and in the geophysical corrections-as wet troposphere and atmospheric corrections are the main sources of error impacting the MSL trends :

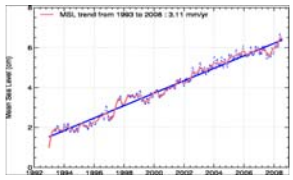
-The use of different orbit solutions provided by JPL, CNES and GSFC allow to estimate the MSL slope uncertainty
- Concerning the geophysical corrections, a similar method is applied using different meteorological models (NCEP, ECMWF, ERA40).
- Other sources of slope discrepancies have been identified and estimated: the error due to the Sea Surface Height (SSH) bias at the connection point between Jason-1 and TOPEX/Poseidon

MSL series, but also between Side-A and Side-B TOPEX altimeters.
Finally, the combination of all errors provides an error estimate of global MSL trends. Taking into account the covariance of each error through an inverse method allows to calculate a more realistic overall error budget.

Mean Sea Level trends

The global Mean Sea Level (MSL) derived from satellite altimetry (T/P and Jason-1) is now used as the reference for climate studies. Using improved altimeter data updated with the best geophysical corrections, a global rate of 3.11 mm/yr is obtained over the 15 year period from 1993 to 2008 (MSL AVISO website http://www.jason.oceanobs/msl) when the post glacial rebound is not applied. Besides, the regional sea level trends obtained after mixing all altimetric missions, highlight an inhomogeneous repartition of the ocean elevation with local MSL slopes ranging from +/- 10 mm/year.

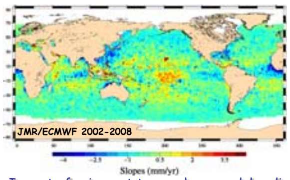


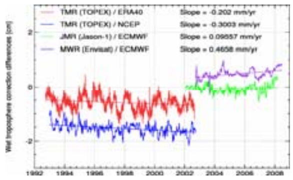


Global and Regional MSL trends over the 1993-2008 period derived from Jason-1 and T/P

Wet troposphere correction

Wet troposphere corrections derived from Microwave Radiometers on-board of Altimetry missions (Jason-1, T/P, and Envisat) are compared to the ones derived from meteorological model fields (ECMWF, ERA40, NCEP), in terms of long term stability. This yields a 0.3 mm/yr global slope uncertainty which can reach 2 or 3 mm/yr in wet areas. In addition, the physical evolutions (in relation ship with the rise of vapor content or ENSO oscillations) of the wet troposphere correction is a limiting factor in the accurate calibration of radiometer or model. Finally, the wet troposphere correction appears to be a main source of error for the MSL calculation.

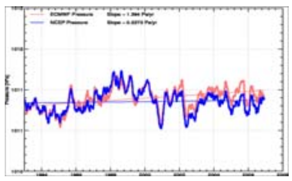




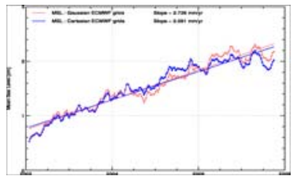
Impact of using wet troposphere model radiometers (ECMWF,ERA40,NCEP) instead of radiometers (TMR,JMR,AMR) on global and regional MSL trends

Pressure fields

Differences between NCEP (reanalysis) and ECMWF model highlight a relative weak long term trend differences (about ~1 Pa/yr). Then the impact on the global MSL trend through IB and dry troposphere corrections is lower than 0.1 mm/yr. However, unexplained jumps in operational pressure fields (about 2.5 mm) impact the global MSL trend by 0.2 mm/yr over the Jason-1 period.



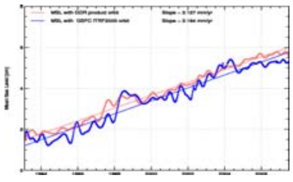
Global slope of pressure over ocean derived from ECMF and NCEP models

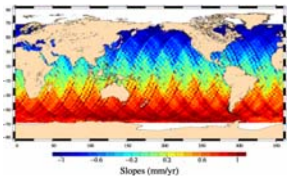


MSL over Jason-1 period using ECMWF pressure fields derived from Gaussian and rectangular grids

Orbit reference

The impact of orbits on the MSL trends is sensitive to the reference frames and gravity models applied. For instance, using last ITRF2005 solution in the MSL calculation (CNES GDR-C for Jason-1 and GSFC for T/P) instead of ITRF2000 as now, leads to hemispheric differences close to 1 mm/yr but the impact on global MSL trend is weaker around 0.1 mm/yr. Orbit calculation is also the source of uncertainties separating ascending and descending passes for the MSL calculation. Then, a realistic error budget ranging from 0.1 to 0.15 mm/yr on the global MSL trend can be allocated to the orbit calculation.



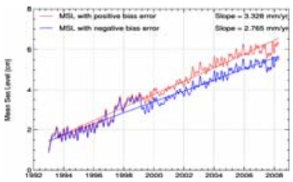


Impact of using ITRF2005 GFSC orbit on global and regional MSL trends / ITRF2000 GSFC orbit (regional trends only computed on Jason-1 period).

Uncertainties while connecting altimetric series

MSL reference derived from Jason-1 and T/P is split into 3 altimeter series : Topex A, Topex B, Jason-1. In order to connect them correctly, SSH biases have to be applied :
- Topex A / Topex B = 5 mm +/- 2 mm
- Topex B /Jason-1 = 75 mm +/- 1 mm

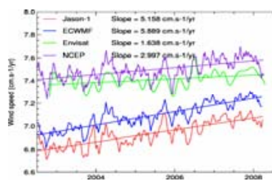
But the uncertainties in bias estimations induce additional errors in the overall global MSL trend between 0.10 and 0.25 mm/yr.



Impact of SSH bias uncertainty on the global MSL trend

Others potential errors

Other factors could impact the global MSL trend as the altimeter instrumental ageing for instance. Thanks to precise monitoring of all altimetric parameters and cross-calibration against other missions, potential drifts in the altimeter wind speed (derived from Sigma0 parameter) have been detected. An uncertainty varying between 2 and 4 cm.s-1/yr can then be considered, impacting the MSL evolution from 0.05 to 0.10 mm/yr over the entire period through the sea state bias correction.



Global wind speed trends over ocean derived from Jason-1, Envisat, ECMWF and NCEP models.

Error budget on the global MSL trend

Minima and maxima errors have been synthesized below for each contribution :

Source of error for the MSL calculation	MSL trend uncertainties from 1993 to 2008	
	Minima	Maxima
Orbit : Cnes POE (GDR B) for Jason-1 and GSFC (ITRF2000) for T/P.	0.10 mm/yr	0.15 mm/yr
Radiometer Wet troposphere correction: JMR (GDR B) & TMR (with drift correction).	0.20 mm/yr	0.30 mm/yr
Dynamical atmospheric and dry troposphere corrections using ECMWF pressure fields.	0.05 mm/yr	0.10 mm/yr
Sigma0 drift impacting altimeter wind speed and sea state bias correction	0.05 mm/yr	0.10 mm/yr
Bias uncertainty to link TOPEX A and TOPEX B, and TOPEX and Jason-1. .	0.10 mm/yr	0.25 mm/yr

The sum of these different contributions on Jason- 1 and T/P time series lead to an upper bound of the total MSL slope error.

Upper Bound MSL Trend Error < 0.9 mm/yr

Realistic error on the global MSL trend

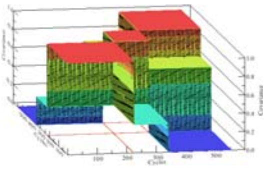
Assuming MSL rise is linear, we can use an inverse method (Bretherton et al.) instead of a classical least square method to take into account the different errors impacting the MSL estimation in the covariance matrix Rvv. This leads to a more realistic error estimate.

$$x_{est} = R_{xx} H^T (H R_{xx} H^T + R_{vv})^{-1} z$$

$$C_{xx} = R_{xx} - R_{xx} H^T (H R_{xx} H^T + R_{vv})^{-1} H R_{xx}$$

After filling the Rvv matrix considering the pessimistic error contributions, the global MSL trend within has been calculated in the following **95 % confidence interval** :

Global MSL Trend = 3.1 mm/yr +/- 0.6 mm/yr



Covariance matrix Rvv for SSH bias errors

Conclusion

These results allows us to have a better confidence in the long-term MSL evolution. The slope and the error estimation can be refined analyzing more thoroughly the different parameter contributions and their error characterization through the covariance matrix Rvv.

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