A new CAL/VAL proposition based on the sea level budget in the center of mass.

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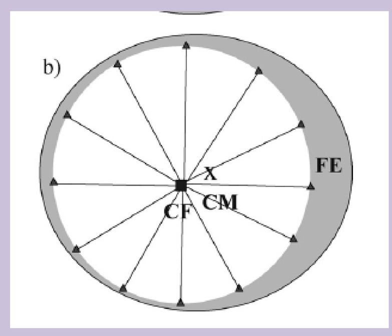
Context

The comparison with in situ Argo profiles and GRACE-based ocean mass has proven to be useful to detect global and regional drift in sea level estimates from satellite altimeters. It is also routinely used to assess the impact of new altimeter standards in sea level products and detect anomalies at interannual time scales. So far, the classical approach is to estimate the steric sea level from a combination of GRACE and satellite altimetry observations and validate it against Argo observations.
Historically, GRACE and satellite altimetry data are combined in a reference frame centered on the center of figure of the Earth (CF) for this purpose. This approach is sensitive to the uncertainty in the geocenter motion which limits significantly the accuracy of the cal/val method at both global and regional scales. Yet, GRACE and satellite altimeters move around the center of mass of the Earth (CM) and theoretically the projection of GRACE and altimetry observations in reference frame centered on the CF is not necessary for the cal/val. In this study we combine for the first time new satellite altimetry products with new GRACE observations reprocessed with orbits centered on the CM. We compare this combination with Argo data at both global and regional scale. This approach enables to remove the source of uncertainty associated with the geocenter motion and enables to reach an unprecedented accuracy in the cal/val method based on Grace and Argo.

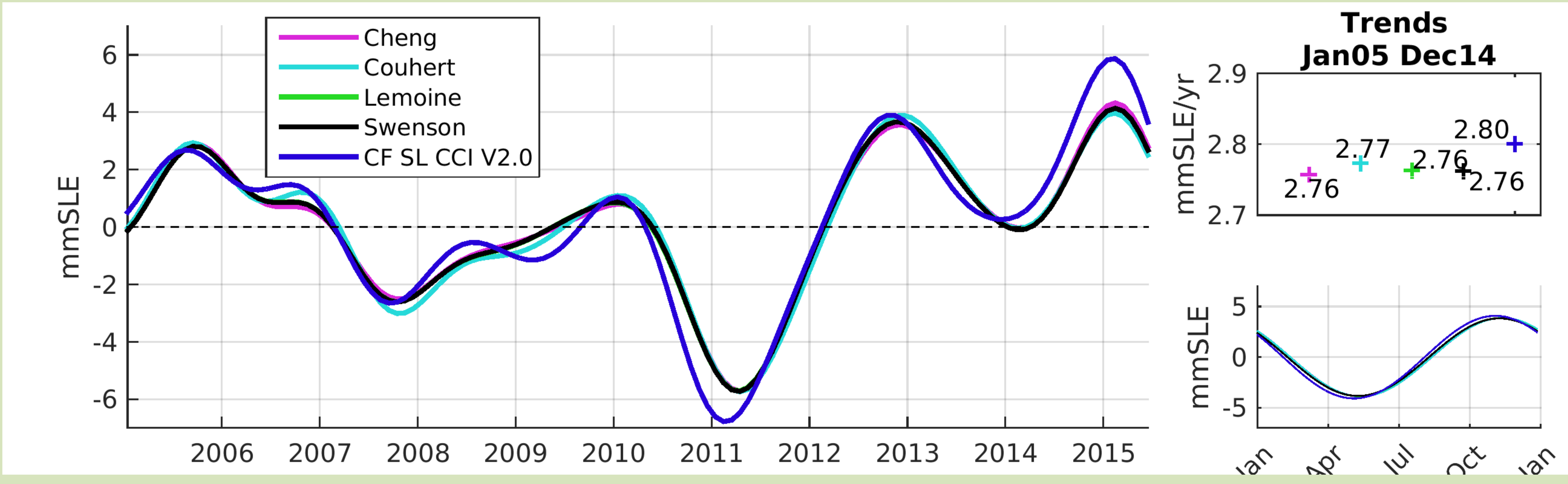


A) CM vs CF from Wu et al 2012

Altimetry data used

Altimetry gridded maps (CMEMS, SL from CCI) are provided (mostly) in the center of figure for comparisons with tide gauge records(Ablain et al 2015).

We recomputed the orbits of Jason 1 and 2 to get them in a reference frame centered on the CM. We reprocessed the altimetry data with these orbits to get Altimetry measurements in the CM. We test 4 different geocenter motions in the reprocessing of orbits which yielded to 4 gridded solutions, an example of the effect is shown in Fig C.



C) Global sea level attending to the geocenter motion considered in the CM detrended low pass filtered time series (a) Trends for Jan 2005 –Dec 2014 (b) and annual cycle (c). GSL from SL CCI V2.0 in the CF is shown for comparaison pourpuse

Source	Trend error (mm/yr)
Orbit (Beckley et al., Ablain et al.)	0.21
Wet atmos. (TMR/JMR drift) (Ablain et al.)	0.25
Dry atmos. (pressure fields) (Ablain et al.)	0.08
Sea state bias (Ablain et al.)	0.08
Quadratic sum	**0.33**
Tide gauge calibration (Micthum and Nerem; Beckley et al.; Ablain et al.)	0.33

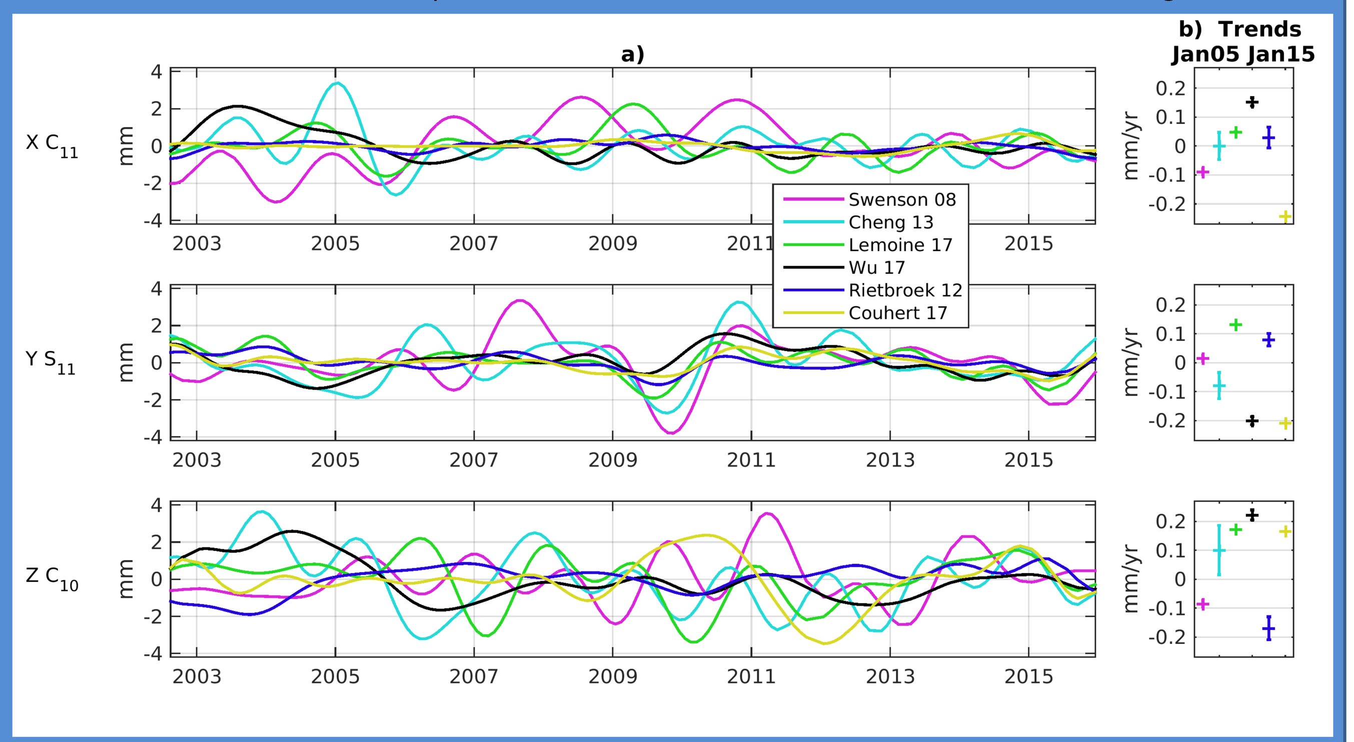
D) Global mean sea level trend: error budget since 2004. updated from Ablain et al. (2015)

Geocenter motion

The geocenter correction applied to altimetry and GRACE enables to translate satellite measurements that are done in a reference frame centered on the Earth center of mass (CM) to a reference frame that is centered on the Center of figure (CF). In this new reference frame satellite observations can be compared with in situ data. The vector CM-CF is named geocenter motion. Although there is a good agreement between different estimates on the annual cycle, the spread in trends are important.

Considered in the study:
Cheng et al. (2013),
Couhert et al. (2017),
Lemoine et al. (2016),
Swenson et al. (2008).

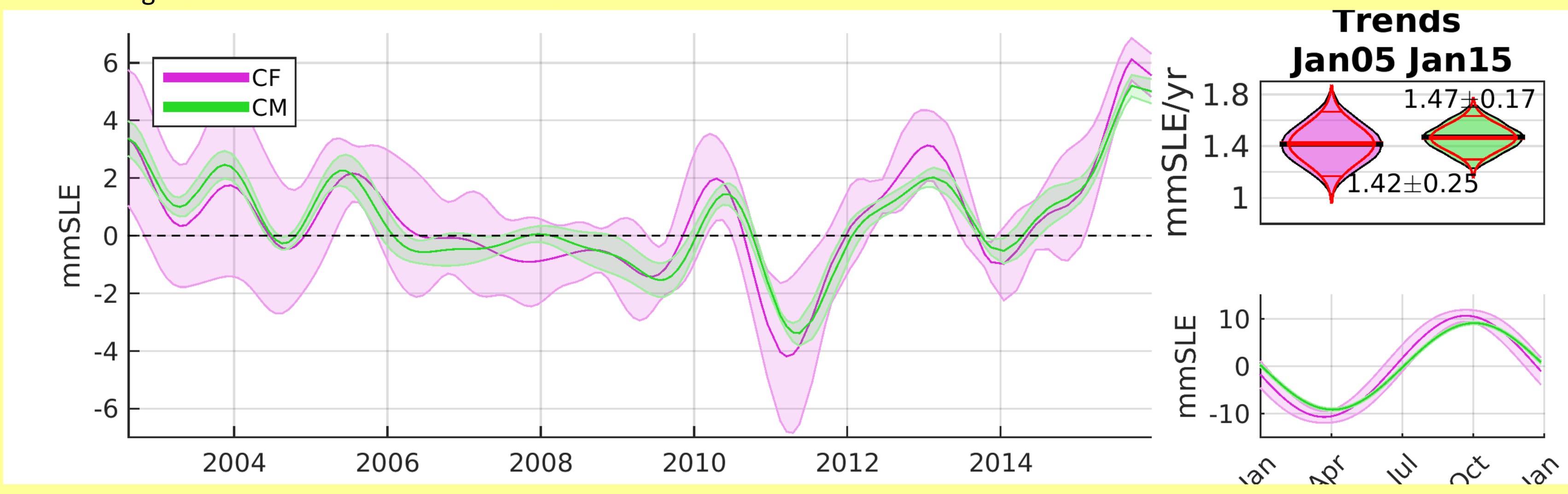
Shown in the figure but not used:
Wu et al.(2017),
Rietbroek et al.(2012)



B) Geocenter motion detrended low pass filtered time series (a) Trends for Jan 2005 –Jan 2015 (b)

Ocean Mass from Grace

The Gravity Recovery and Climate Experiment (GRACE) mission has been providing precise, time-varying measurements of the Earth's gravitational field since 2002. Once corrected for the solid Earth changes, this gravity field can be converted in mass water changes. GRACE data are originally expressed in the center of mass (because GRACE can not observe the geocenter motion). However GRACE solutions are often translated in a reference frame centered on the CF to enable comparisons with in situ data. Figure D show the ocean mass in the CM.



E) Global Ocean Mass from GRACE detrended low pass filtered time series (a) Trends histogram for Jan 2005 –Jan2015 (b) and annual cycle (c). Red lines corresponds to the hypothetical Gaussian distribution.

We build an ensemble including the state-of-the-art corrections:

- 5 Processing centers: (CSR,GFZ, GRGS,JPL and TUG)
- 2 Earth Oblateness time series: Cheng et al 2013 and Lemoine et al 2016)
- 5 Filtering : P3M6 from Chen et al. (2007) and 4 ddk filters from Kusche et al. (2009)
- 3 GIA models : A et al.(2013), Stuhne and Peltier (2015) and Purcell et al. (2016)

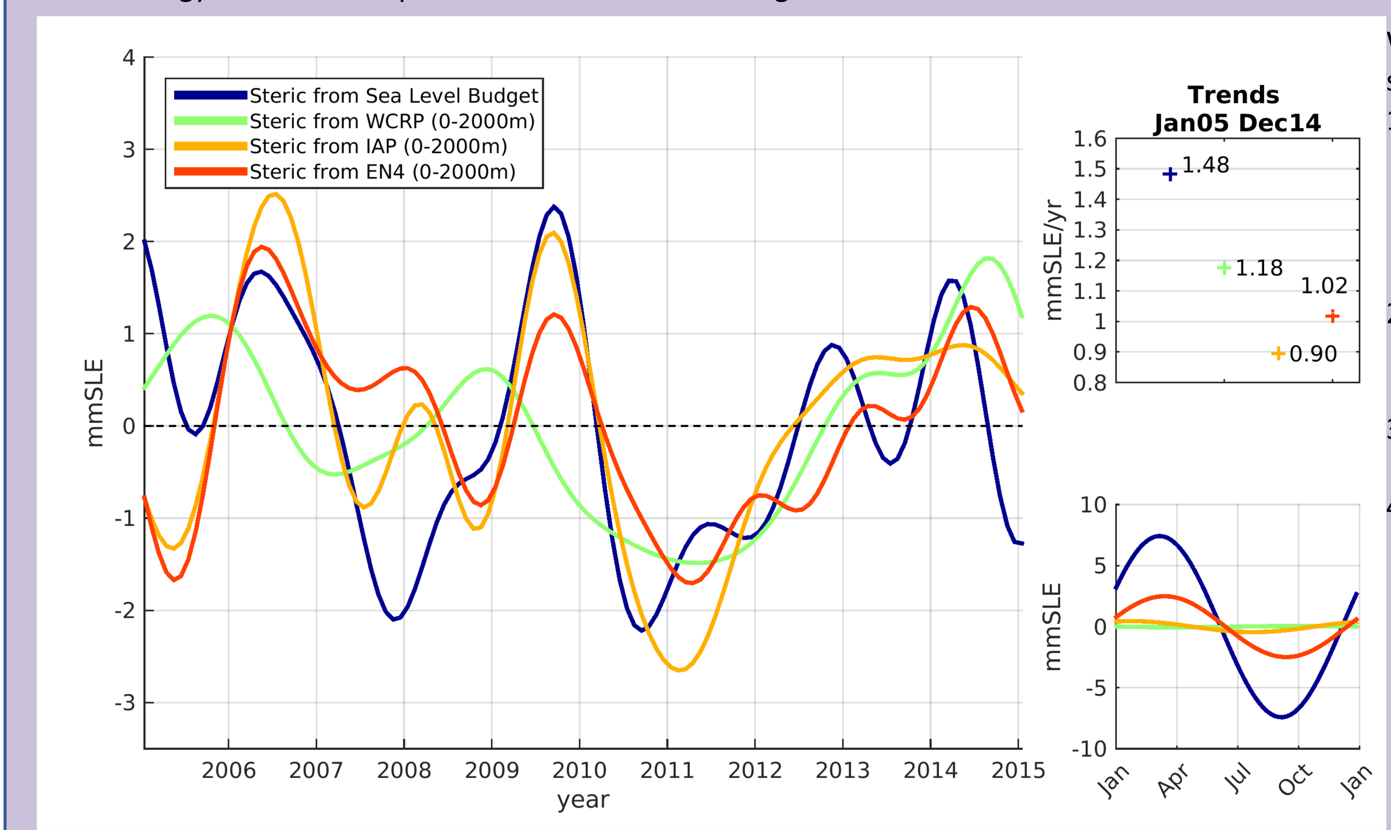
Trend error (mm/yr)	CF	CM
Processing center	0.09	0.07
Geocenter motion	0.21	0.00
$C_{2,0}$	0.02	0.02
Filtering	0.02	0.02
Leakage correction	0.08	0.08
GIA	0.12	0.12
Total Uncertainty	0.27	0.16

F) Sources of uncertainty in Global ocean mass trend Jan 2005 Dec 2015 from Blazquez et al. (2018)

First results

Steric estimation from different observing systems

The Ocean Thermal expansion is directly related to the Ocean Heat content, which is one of the major parameter to measure the Earth Energy Imbalance responsible of the Climate Change.



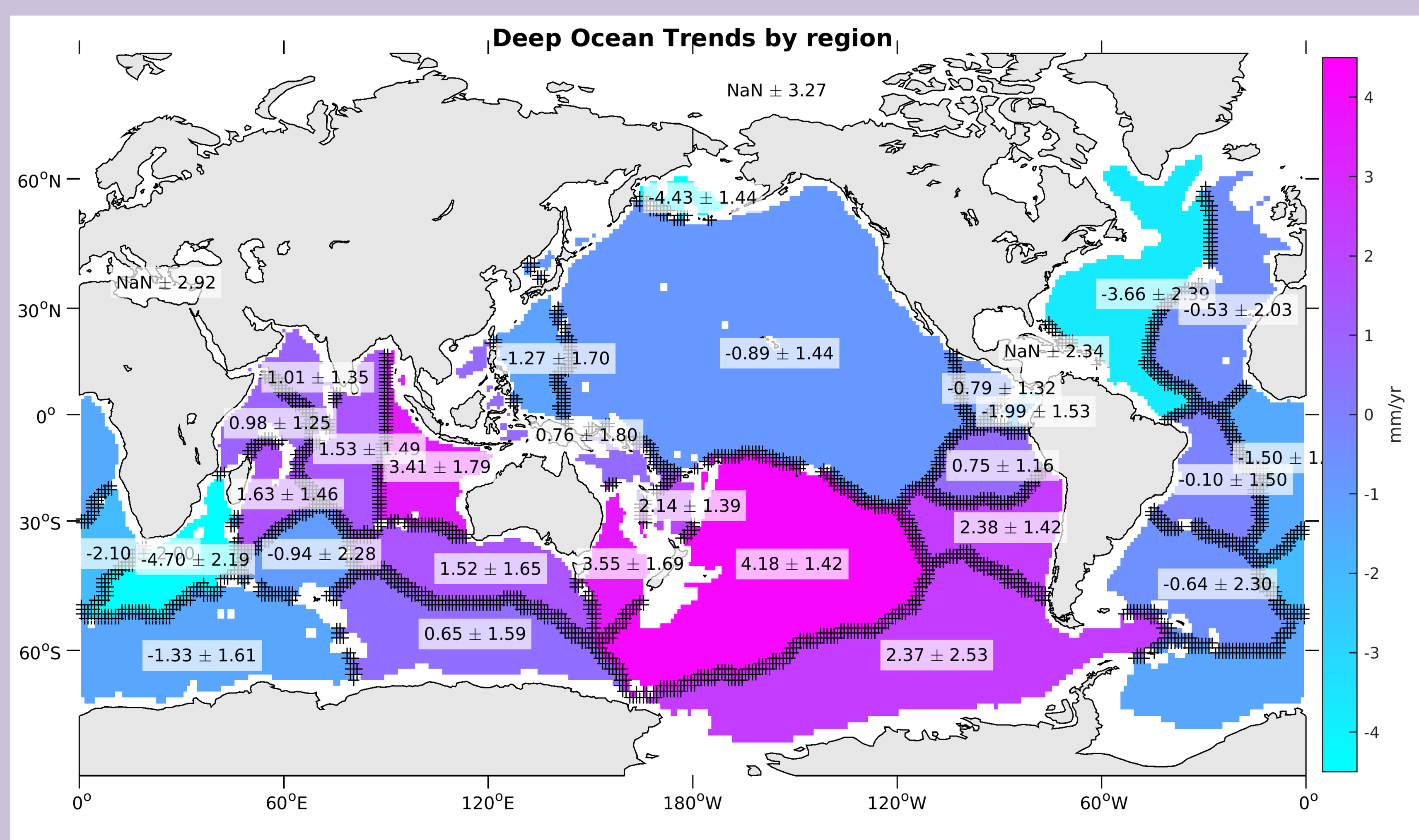
We estimate this steric from several sources.

1) Steric from Sea Level budget. Using the Global sea level from Altimetry minus the ocean mass from GRACE.
2) Steric from WCRP mean of several products published in the WCRP
3) Steric from IAP (Argo based)
4) Steric from EN4 reanalysis (Argo Based)

G) Global steric sea level detrended low pass filtered time series (a) Trends for Jan 2005 –Dec 2014 (b) and annual cycle (c).

Deep ocean estimation

The deep ocean trend is computed as the difference between the altimetry, the ocean mass and the steric sea level for the first 2000m from IAP and EN4.



H) Deep Ocean estimation. The uncertainty is computed considering the uncertainty of 0,33 from the altimetry, the uncertainty from grace ensemble and the differences between IAP and EN4 steric fields

Perspectives

- The uncertainty in the global mean sea level rise from altimetry seems only slightly sensitive to the geocenter motion used: **±0,02 mm/yr at 1,65 σ** from Figure C although the values are smaller than in the CF. We need to further analyse these differences, specially the correction between Jason1 and Jason 2
- There is an important reduction in the uncertainty in the global GRACE ocean mass trend from the CF to the CM from **±0,27 mm/yr at 1,65 σ to ±0,16 mm/yr at 1,65 σ.**
- The steric estimation from different observing system reveals a good agreement in the interannual variability. We need to analyse the differences in the trends where the estimation in the CM is greater than the estimations from ARGO profiles by 0,30 mm/yr (considering WCRP's trend), as a consequance the deep ocean trends estimated by the sea level budget results greater than previous analysis and need to be further analysed.
- These results are preliminary. We want to cross validate the results with steric data and we want to analyse the effect of the ocean mask used. (We only consider latitudes under 66° and no marginal seas which corresponds to 77% of the ocean)
- We plan to compare the interannual with estimations from CERES