Regional and coastal long-term sea level change assessment from geodetic data

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Introduction

The Sea Level Climate Change Initiative (SL CCI) focuses on constructing a multi-mission Sea Level Fundamental Climate Data Record (FCDR) and Essential Climate Variables (ECV) for the time interval 1993-2015. The highly accurate dataset are used for studying sea level variations in response to climate variability and climate change, for measuring the rate of sea level rise and for investigating the main climatic causes.

Aim of the study at TU Darmstadt is to assess in a regional study if the expected quality of the CCI products has been reached. It focuses in two European regions, where reliable data exist: the Mediterranean Sea (RegA) and the German Bight (RegB).

Validation Approach

Tasks of TUDa in the SLCCI project are as follows:

1. To assess the quality and characterize the errors of the CCI sea level climate variables in the Mediterranean Sea against gravity data and hydrological data and models. The ECV CCI sea level are validated against the total sea level change derived from mass-induced change and steric sea level components. The strait flows at Gibraltar derived from the water budget closure is compared to in-situ and model data correcting the GRACE signal for the continental hydrology contaminating the GRACE basin averages,
2. To assess the quality and characterize the errors of ECV climate variables and along-track FCDR CCI data records against geodetic-referenced in-situ data in both the Mediterranean Sea and the German Bight.
3. To derive zenith total water from GNSS observations for computation and evaluation of improved tropospheric correction in coastal zone in the German Bight.

Example for Task 1: Observed sea level from CCI ECV gridded data (Figs 1,2) and computed sea level using other observations (e.g.GRACE) and model data (Fig. 3).

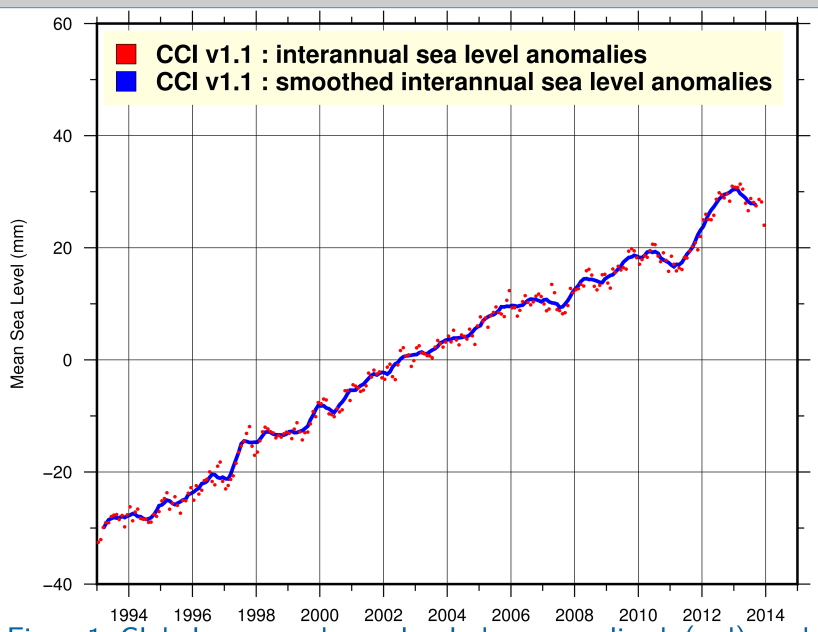

Fig. 1 Global averaged sea level de-seasonalized (red) and smoothed (blue)

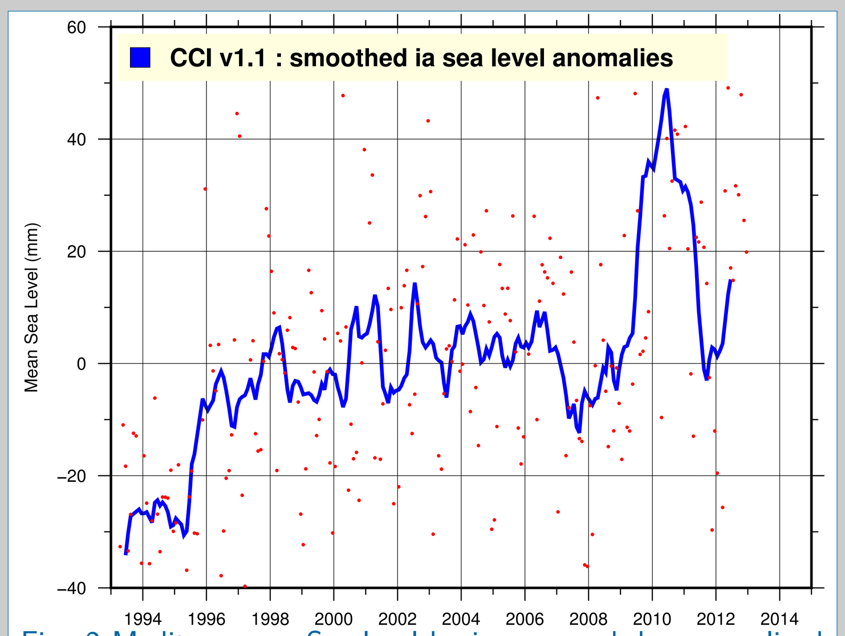

Fig. 2 Mediterranean Sea level basin averaged de-seasonalized (red) and smoothed (blue)

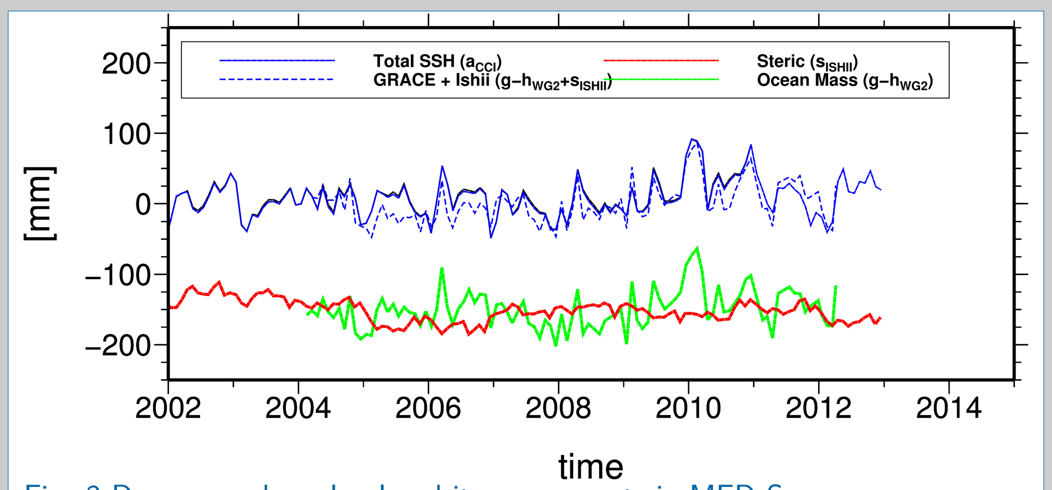

Fig. 3 De-seasoned sea level and its components in MED Sea

- The expected accuracy of the sea level trend from CCI is different for global and regional analysis (less than 1 mm/yr and than 0.5 mm/yr respectively for regional and global studies).
- The global trend is 3.1 ± 0.5 (including measurement errors) and the CCI regional trend is 2.2 ± 0.5 for the MED Sea. In the Mediterranean Sea the rise is not uniform (Figs 1, 2). The error of the trend accounts for the temporal auto-correlation of the time-series.

Regional Sea Level budget

The validation strategy consists in combining different types of datasets to estimate the sea level change and to regionally verify the closure of the water budget. Three components are estimated : (1) the steric contribution from in situ temperature and salinity (2) the mass of the ocean water from GRACE data, (3) the sea level variability from the CCI ECV data. Each of them is also estimated from the other two (indirect estimate) and the difference between direct and indirect estimates is computed. This gives an indication on the accuracy of each quantity, assuming that other two are correct. The second part of the strategy will consists in the verification of the water balance closure over the Mediterranean Sea basin given by precipitation, evaporation, river run-off, the flow at the Gibraltar and Bosphorus strait and the mass variation in the basin (Fenoglio et al., 2013).

- Sea level: Two time-series of basin averaged sea level in the time interval between January 1993 and December 2012 are derived from AVISO and from CCI ECV gridded data (Fig. 4). They have correlation 0.9915 and rms difference 8.1 mm, maximum difference is 30 mm. Between January 2003 and December 2012 the correlation is 0.9917 and rms difference 7.8 mm, maximum difference is 30 cm. Annual and semi-annual components are estimated and eliminated from the basin average to obtain the interannual residuals (Fig. 8). A moving running average is computed (Fig. 7).
- Mass component: Basin averages of seawater mass change are from the GRACE GFZ-Release 5. Version RL5 extends from January 2003 to February 2013, version RL5a from April 2002 until now. Main difference between RL05 and RL05a is the treatment of orbit parameters in final processing step, with orbit parameters fixed in RL05 and free in RL05a (Dahle, 2015). We notice a larger variability in December 2010 in the RL05a version (Fig. 8). Differences between the GFZ versions and other products need to be further analysed.
- Steric sea level: the steric component of sea level is evaluated from the globals Ishii and EN4 databases. The steric signal from the two datasets is similar at interannual scales. However the trends differ by 2.9 mm/yr. Analysis of ocean model data is now foreseen.

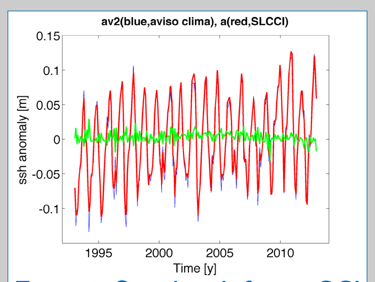

Fig. 4 Sea level from CCI and AVISO

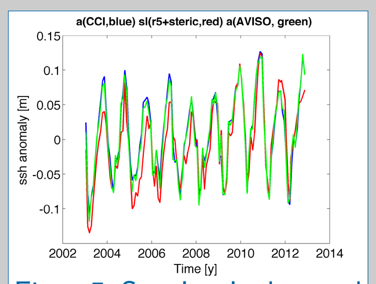

Fig. 5 Sea level observed (b,g) and computed from GRACE e steric (r)

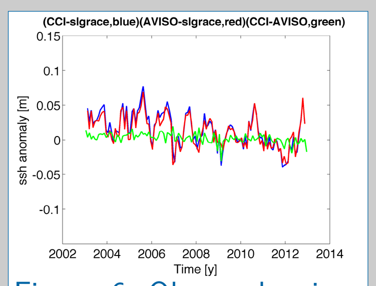

Fig. 6 Observed minus computed sea level

- Validation: The sea level CCI ECV products are validated by studying the agreement with the sum of the mass and steric component. between January 2003 and December 2012. The sea level from RL5a realizes the best agreement with CCI. For smoothed time-series the correlation is 0.8914 and the std of differences is 11 mm, with RL05 the correlation is lower (0.75) (Fig. 9). The correlation is 0.92 and the std 23 mm for the monthly time series, is 0.89 and 11 mm for the interannual time series.

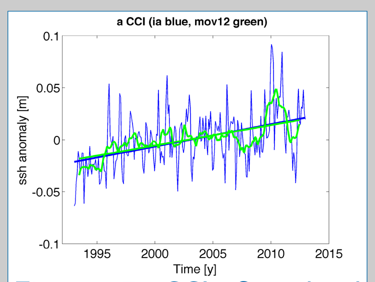

Fig. 7 CCI Sea level residuals interannual and smoothed

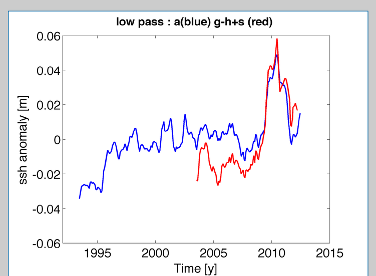

Fig. 8 Smoothed observed and computed sea level (R5a)

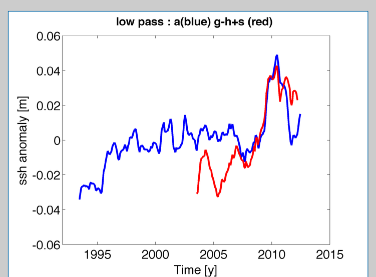

Fig. 9 Smoothed observed and computed sea level (R5)

The best agreement between direct and indirect total sea level is obtained with the AVISO data and the GRACE RL5a version (Fig. 10). For de-seasonalized data correlation and RMS of the difference are 0.88 and 17 mm using AVISO and 0.84 and 21 mm using CCI. The difference of the trends is 0.1 mm/yr and the trends amount to 3.6 mm/yr. Using CCI the difference of the trends is 1 mm/yr.

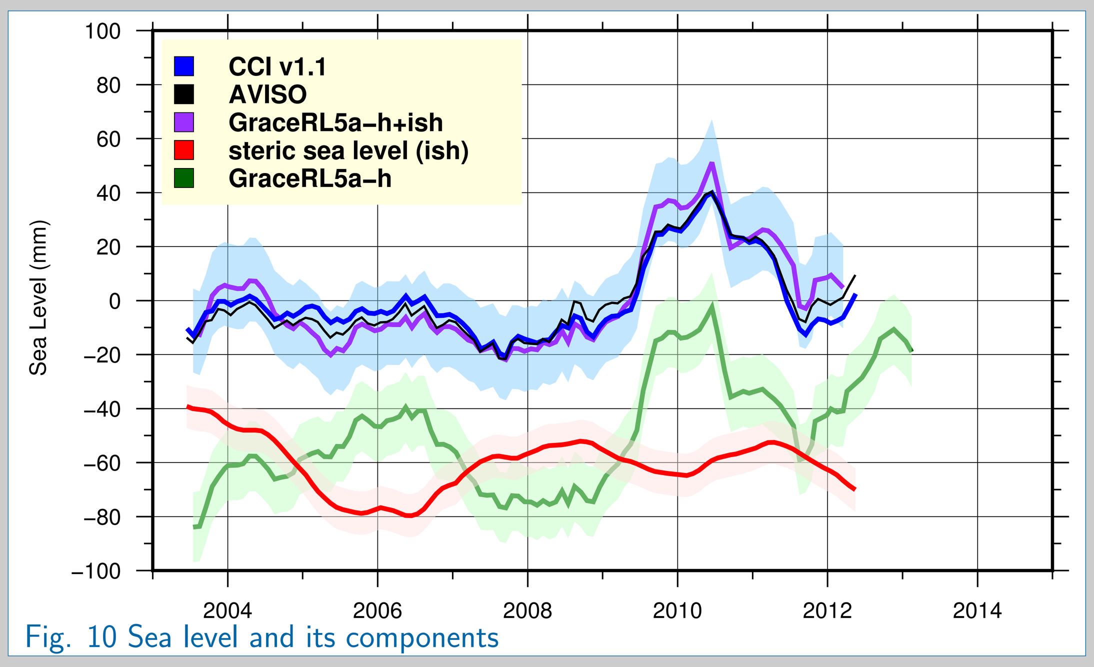

Fig. 10 Sea level and its components

Conclusions

- RegA: Trend in sea level over 1993-2013 (20 years) smaller than global mean (2.2 +/- 0.4 mm/yr)
- RegA: Step-wise increase of sea level in 1993-2013, CCI and AVISO very similar (corr 0.99, std 8 mm)
- RegA: Sea level budget over GRACE period 2003-2013 almost closed with steric and mass contribution (corr 0.89, std 11 mm between CCI and computed sea level, smoothed time series). Mass component dominates.
- RegB: SAR and PLRM products do not have relative bias
- RegB: precision: SAR more precise than PLRM
- RegB: accuracy : SAR SWH more accurate than PLRM (with and without LUT)

In-situ validation against geodetic data

The validation strategy consists in an absolute comparison of altimeter products with in-situ geodetic-referenced data. The three parameters considered are sea surface height above the reference ellipsoid (SSH), significant wave height (SWH) and wind speed at 10 m above the sea surface (U10). The work includes:

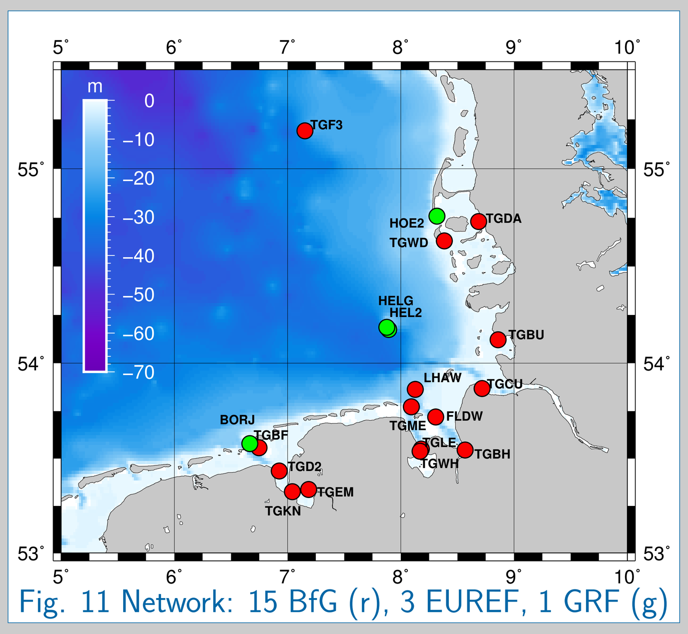

Fig. 11 Network: 15 BfG (r), 3 EUREF, 1 GRF (g)

- computation of GNSS Station coordinates, trend of vertical component, Zenith Total Delay (ZTD)
- in-situ validation of along-track CCI products and other products. Evaluation of improved UPorto tropo-correction using GNSS ZTD in RegB.
- in-situ validation of CCI ECV monthly products, land vertical movement from altimeter and TG to be compared to the trend derived from GNSS.
- validation of along-track CryoSat-2 Synthetic Aperture Radar (SAR) ESRIN and Pseudo Low Resolution Mode (PLRM) RADS data

  We apply waveform zero-padding, identical environmental, geophysical, and atmospheric attenuation corrections, Look Up Table (LUT) in SAR to correct for approximations of the Point Target Response (PTR) applied in retracking.

  Our results show that:
  - precision : for SSH and SWH is higher in SAR than in PLRM (factor 2), for U10 is 1.4 times higher in PLRM than in SAR. At 2 m SWH, SAR precision is 0.9 cm, 6.6 cm and 5.8 cm/s for SSH, SWH and U10.
  - accuracy: for SSH and U10 is comparable in SAR and PLRM
  - accuracy: for SWH is higher in SAR than in PLRM.
  - consistency between PLRM and SAR data: no bias and rms differences of 3 cm, 21 cm, and 0.26 m/s for SSH, SWH, and U10

  For maximum distance of 20 km between altimeter and in situ data and more than 10 km from coast, the minimum values obtained for their rms differences are 7 cm, 14 cm, and 1.3 m/s for SAR and 6 cm, 29 cm, and 1.4 m/s for PLRM. See comparison of SAR, PLRM and in-situ data in figs. 12, 13, 14. Differences of SAR and PLRM results are larger for SWH. See differences for SLA and SWH as function of SWH in Figs. 14,15,16.

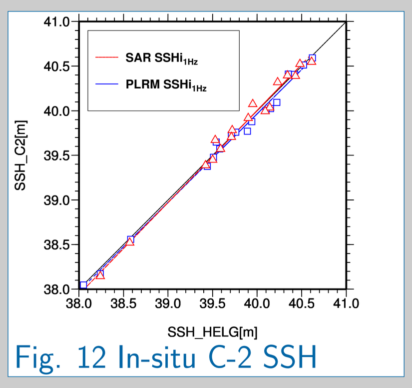

Fig. 12 In-situ C-2 SSH

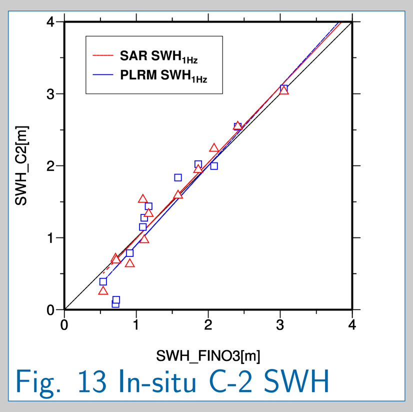

Fig. 13 In-situ C-2 SWH

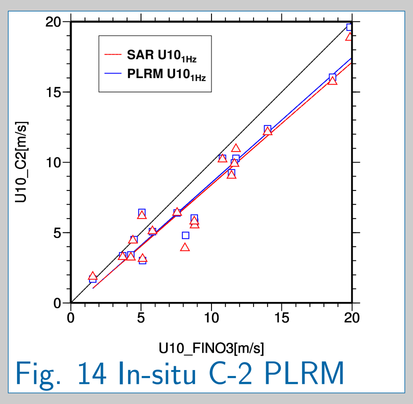

Fig. 14 In-situ C-2 PLRM

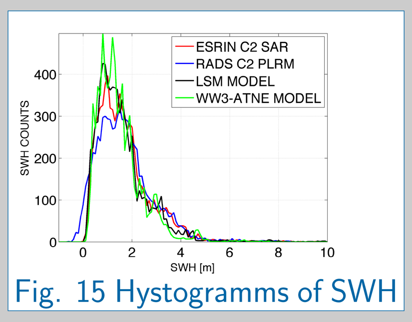

Fig. 15 Histogramms of SWH

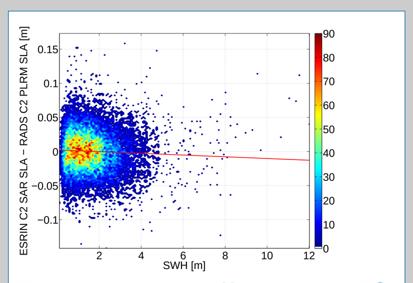

Fig. 16 Differences ESRIN/SAR and RADS/PLRM for SSH

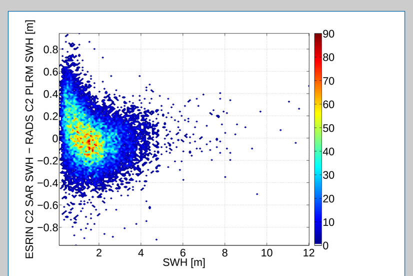

Fig. 17 Differences as above for SWH

Look Up Tables are then applied in both schemes to correct for approximations applied in both retracking procedures (Figs. 18, 19). The analysis is performed during four years, from July 2010 to Mai 2014, and confirms the good consistency between PLRM and SAR data.

The effect of the LUT is relevant for the SWH, with a reduction of 10% of the RMS differences. No relevant changes are seen in the range and wind speed parameters.

The application of the LUT causes also an increase in the precision of the SWH in PLRM. Without LUT the precision of SWH was a factor 2 higher in SAR than in PLRM. With LUT the factor is reduced and the precision in PLRM is 1 cm for all the wave heights.

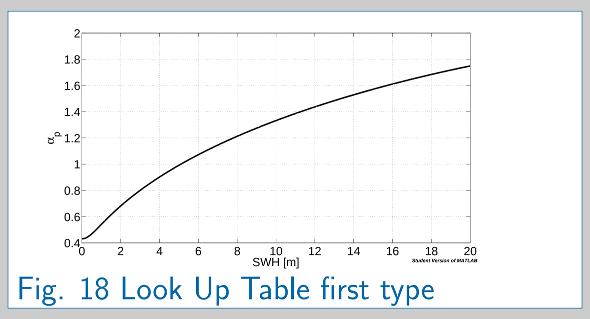

Fig. 18 Look Up Table first type

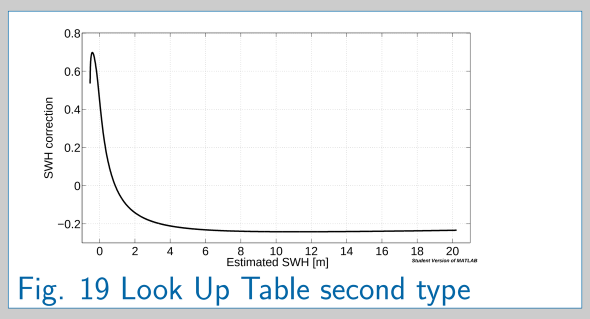

Fig. 19 Look Up Table second type

Finally the in-situ analysis shows that SSH and U10 have comparable accuracy in SAR and PLRM, while SWH has still a significantly higher accuracy in SAR. With a maximum distance of 20 km between altimeter and in-situ data, the minimum values obtained for their rms differences are 10 cm, 18 cm, and 1.9 m/s for SAR and 8 cm, 22 cm, and 1.8 m/s for PLRM.

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