

Rebuttal

We would like to thank the anonymous reviewer for the thorough review. We agreed with practically all of the comments and we improved the paper based on these comments. Additionally, we applied some small changes to the methodology section, which are addressed at the bottom of the rebuttal.

The updated manuscript will be added with marked changes.

Review of Sub-basin scale sea level budgets from satellite altimetry, Argo floats and satellite gravimetry in the North Atlantic by Marcel Kleinherenbrink, Riccardo Riva, and Yu Sun. Submitted to Ocean Science.

Reviewed on 19 August 2016.

General comments

The paper attempts merging sealevel from altimetry with GRACE gravity fields and steric height from Argo floats to close the sea level budget of sub-basin scale areas in the North Atlantic. Different GRACE products are intercompared with convincing results, both in seasonal and interannual variability and trends. The analysis is thorough and worth publication. In some respect the paper appears quite technical, and it should be noted that main aim of the study is to determine which GRACE product and data processing method is most appropriate to achieve the desired result, i.e. agreement of observed sealevel (from altimetry), and calculated sealevel from mass changes (GRACE) and steric changes (from Argo floats).

The selection of the study area (North Atlantic) and its subdivision into smaller polygons is somewhat arbitrary. I was not able to proofread all equations stated by the authors, I assume that all calculations have been made correctly. I have a few general comments, and a number of minor comments regarding spelling, figure layout etc., which I would appreciate to be addressed by the authors.

Specific comments

As stated above, the entire paper is quite technical. Physical oceanography and special characteristics of the region are not really addressed; basically it looks like the North Atlantic and the sub-regions have been selected arbitrarily just to have a reasonable area to investigate which GRACE product fits best. This might be made more clear - this is not so much a paper for readers interested in the North Atlantic, but more for those interested in GRACE and sea level studies.

To make clear that the paper is primarily interesting for sea level and GRACE researchers we changed the title to:

"Sub-basin scale sea level budgets from satellite altimetry, Argo floats and satellite gravimetry: a case study in the North Atlantic"

We added a motivation why we apply the method to the North Atlantic at the end of

the introduction on page 3.

There is no specific requirement for the shape and size of the polygons except for the 1 mm/yr error on the trends, which is mentioned in Sect. 4.3 and Sect. 5.2. However, in the introduction of Sect. 5.2 we state that we try not to cut through the major oceanographic features and the Atlantic is divided in the middle by the Mid-Atlantic ridge.

The authors claim that all three underlying datasets (Argo, GRACE, Altimetry) have been specially processed for this study. While GRACE is introduced in comparatively detail, the introduction of the Argo- and especially the Altimetry data could be more thorough.

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P3 L19: How is the alongtrack altimetry data processed? E.g. any de-tiding, smoothing, ...? This could be described in more detail.

On page 5/6 we added a short discussion on the geophysical corrections applied in the study. Additionally, we added some references to read more about the geophysical corrections.

Besides this, we believe that the latitude dependent intermission bias of Ablain et al. (2015) and the averaging method are described in enough detail to be reproducible.

We think that the mean steric sea level estimates from Argo are reproducible as well. However, we added a line in the Argo section on page 9 stating that the main purpose of handling Argo this way is to get a full variance-covariance matrix for the steric sea level grid.

There are quite a number of different GRACE products, degrees/orders, Wiener filters etc. Sometimes, it is difficult for the reader to keep track. A shorter, clear designation of the different products, and / or splitting the text into shorter sub-sections might help to make the organization of the paper more clear.

We created a table with designations for the various GRACE solutions in section 2. All references to specific GRACE solutions are replaced by their respective designations (not marked).

The figures are good, clear and appropriate. However, all explanations (units, variables, etc.) are described in the captions only. It might be an idea to write units directly on the axes or colour bars. In case of multi-panel figures, the panels should be labelled with a), b), c) and so on, or write the name of the GRACE product used in the panel (e.g. ITSg). In the present state, the figures look very clear, but it is tedious to find out and remember what the blue line in the middle right panel stands for.

We added units and labels on the axis of all figures and updated captions to all figures. Every colorbar has been widened. For the time series, legends are added.

P4 L6: This statement is confusing: Why don't the Argo floats resurface in the South Atlantic? Moreover, is this relevant at all for the present study of the North Atlantic?

What we actually meant was that in 2004 barely any Argo floats were present in the South Atlantic. Sentence removed.

P4 L16-19: This suggests that the variance-covariance matrices are incorrect for at least one of these time periods. Can you state a reference for this claim?

That the variance-covariance matrices vary not much month-to-month over these

periods is stated on the README of their website.
<ftp://ftp.csr.utexas.edu/outgoing/grace/README>

We added a reference to Klinger 2016. They showed that the variability of the gravity fields over the ocean during repeat orbits is much larger and therefore the variance-covariance matrices should be quite different during these periods.

Table 4: How is - 1.21 (i.e. absolute value larger than 1) for NA with CSR96+A. possible? I would expect values to be in the range -1 ... 1, but not beyond. Moreover, I understand -1 to explain 100% of the variability, but in anticorrelation, suggesting that something is seriously wrong in this particular solution.

There is a difference between computing the explained variance between two time series and between a model fitted through the time series with the original time series. In case a model is explaining a fraction of the variance it is indeed the case that the values will never exceed -1 or 1. However we are comparing two independent time series, suppose 'A' and 'B'. Let's recall the formula for explained variance (EV):

$$EV=1-\text{var}(A-B)/\text{var}(A)$$

Suppose now that B has a variance 10 times larger than A, then $\text{var}(A-B)$ will become big, while $\text{var}(A)$ is still small. As a result $\text{var}(A-B)/\text{var}(A)$ can become larger than 2 and therefore the EV more negative than -1. B is in our case Argo+GRACE and A altimetry.

We added the sentence:

'Note that the value -1.21 for the CSR96-W gravity fields indicates that variance increases after its subtraction from altimetry, which indicates that the Argo+GRACE time series is substantially noisier than the altimetry time series.'

Technical corrections

P2 L9: Better write “That study...” - “this study” suggests that this study (submitted to OS) is meant.

Changed 'this' into 'that'.

Fig 1: The colour bars are too narrow, it is hardly possible to assign colours from the maps to certain numbers. Draw the colour bars larger. Use only a few distinct colour levels (e.g. 0 to 10, 10 to 20, 20 to 30 and so on) both in the map and in the colour bar would make visual assignment much clearer than the present continuous colour scale. Write units (mm, or mm/yr) on the colour bars (see general remarks).

We changed the color levels, increase the width of the colorbar and added units.

P3 L4: write (Kusche, 2007; Kusche et al., 2009)

Updated.

Fig. 5: The colour bar is too narrow. See remark to Fig. 1.

The colorbars have been widened.

P14 L20: “Secondly, compared to Scripps the grids, the other two methods are slightly noisier.” This sentence is unclear or grammatically wrong.

Changed to: “Secondly, the grid computed in this study and the Glorys grid exhibit

more short-wavelength spatial variability than the Scripps grid.”

Fig. 7: Explain the polygons in the first row in the caption. They should also be explained in the text; I did not find any explanation except on P17 L10. It remains guesswork to the reader to determine what the three polygons should be. Do I see it correctly that they should be a zonally oriented rectangle, a meridionally oriented rectangle, and a square, all partially overlapping? Did you have a particular reason why you chose this particular location in the North Atlantic? The three polygons could be drawn in different colours or in more different linestyles.

In the caption of Fig. 6 the polygons are introduced. On page 16 a sentence is added: “The location is chosen in the middle of the Atlantic to avoid effects of hydrological leakage.” The lines of the polygons have now different colors to make them more distinguishable.

P17 L21: Spelling: “Even though” should be in two words.

Spelling changed.

Fig. 8: Caption: “Portrait” and “landscape” is ok for paper orientation in printers, but not for describing geographical orientation. Use “meridional” and “zonal” instead.

Changed to “meridional” and “zonal”.

P19 L8: Polygon H is introduced only in the next section.

Changed to “west of the Mediterranean”.

P19 L12: spelling: “tongue”

Spelling changed.

P20 L1: grammar: delete second “on the”: “...chosen based on the criterion that the error does not...”

Second “on the” removed.

Fig. 10: caption: “the sum of the two components in blue” - unclear what components are meant. Steric + OBP? The letters “A” to “J” are hard to read, they should be larger and/or in bold face.

Fig. 8: The letters are in bold font.

Fig. 9: Caption updated “the sum of steric sea level and OBP in blue”

Fig. 10: Idem.

P23 L7: “even though” in two words

Spelling changed.

P23 L9: “overestimation” in one word

Spelling changed.

P26 L10: grammar: write “They also suffer from...” without “s” at the end of “suffer”

The 's' removed

P28 L25: Ablain et al. (2015): The list of authors appears to be incomplete. Similarly for Cabanes et al. (2013), Cazenave et al. (2008), Våge et al. (2009).

In the first submission references with more than six authors were made in the following way:
author 1, author 2, author 3, author 4, author 5, ..., last author, (year). Article. Journal, etc.

We added now all authors for the following six references with more than six authors:

Ablain et al. (2015)
Cabanès et al. (2013)
Cazenave et al. (2008)
Von Schuckmann et al. (2014)
Storto et al. (2015)
Vage et al. (2009)

Additional corrections by author

P10 L5 and L12: Changed 'correlations' into 'covariances'

P10 L8 and Eq. 21: Changed steric sea level 's' into 'h'

P10 L10: Changed the subscript 'ssla' to 'ssl,g'

P10 L13: Removed 'g' from subscripts

P5 L25: Changed 'with calibrated variance-covariance matrices' into 'with full variance-covariance and normal matrices'