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Ocean Science Discussions

Interactive comment on "Sea level variability in the Arctic Ocean observed by satellite altimetry" *by* P. Prandi et al.

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Arctic Ocean sea level variability observed by satellite altimetry
Response to Anonymous Referee 1

P. Prandi

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I would like to thank the referee for his review of this manuscript. Following his general comments on the paper we tried to improve the clarity and robustness of the paper. I hope that in the revised version, the data used and the methods used to process them are now clearly explained. We also tried to strengthen the uncertainty assessment, especially reagrding trend estimations. However there are limits one cannot overcome, in-situ data in the Arctic are scarce, the coverage is poor, and altimetry suffers from limitations due to the presence of sea ice. This paper is therefore a first attempt to study sea level variability in the Arctic Ocean from observations over the recent period and the conclusions we are able to draw from the data are not as robust as they could be in other regions of the globe.

The response to detailed comments is provided below.

1 Sea Level Anomaly is used and the SLA acronym is introduced here and used in the rest of the paper,

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2 the section devoted to the description of tide gauge data has been modified, we tried to improve the overall clarity and more specifically the correction of the GIA effect.

- Vertical motion of the tide gauge benchmark in response to crustal motion has to be corrected before comparing with satellite altimetry data : at a given station, if the absolute sea level (measured by altimetry) is constant, an uplift of the ground implies a relative sea level drop on the tide gauge record,
- The model used to correct tide gauges records from vertical land motions due to GIA processes is selected after a comparison of tide gauges and colocated altimetry records. Applying the ICE_5G_VM4 model reduces the mean drift and the standard deviation of these drifts,

3 a) a more detailed description of the EN3 dataset was added, the quality of the analysed fields is dependent on the data availablity and the error covariance scales used, unfortunately such information (an estimation error for example) is not available,

b) profiles collected from other sources within the framework of the ASBO project were included in the EN3 analysis, the original data sources are now mentioned in the paper,

c) quantifying this leakage effect, is not easy, especially as we are using already processed grids, but we provide a reference for this effect, and link to the data description,

d) the mean depth corresponds to the mean (over all profiles used for a given monthly analysis) of the largest depth at which a valid T/S data is available for each profile. This definition is added to the paper,

e) we added a figure showing the number of profiles in each grid box to illustrate the spatial coverage of the profiles used in the analysis,

f) one explanation for the strange lack of data in 2007–2008 (given it corresponds to the IPY period) is that these data were not yet available at the time the analysis was performed,

g) the different steps of the steric SLA estimation are now detailed in the revised version.

4 we added more details to the processing of GRACE data, concerning the GIA correction and the correction of continental leakage, however we did not reprocess the data but rather used them as is.

5 We changed the figure in order to display the time series averaged over the same area, and not over the largest area available for each dataset, with this modification, trends are no longer in agreement and we tried to mention trend values with caution.

b) in the revised version of the paper, we tried present estimates of the different statistical parameters with caution,

c) we performed a Monte-Carlo simulation and the results suggests that the trend uncertainty is about 2.5 mm/yr for the altimetry, mass and mass+steric time series and a little lower for the steric only time series. However, it is likely a lower bound of the uncertainty as no systematic error of the measurement systems are included in this estimate.

6 *mean SLA* refered to the regional mean SLA time series, as opposed to the global mean time series, it was changed to *regional SLA*,

7 In this paper, we focus on trend estimates and therfore mentioned only the trend. In the revised version, the larger impacts of serial correlation on statistical estimates is aknowledged.

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8 on the figure, we added the time series for GRACE mass and steric height as well as altimetry and the sum of GRACE and steric height,

9 the one standard deviation (of the data used in the spatial average at each time step) levels are represented on figure XX, for the sake of clarity, these are only displayed for the altimetry and mass plus steric time series,

11 The seasonnal cycle is estimated over the 2003-2009 tiem span when all three data types (altimetry, steric and GRACE) are available, therefore only 7 points are averaged to give the seasonal estimate for each month, the different spatial coverage is taken into account by applying the satellite altimetry spatial bias to the GRACE and steric datasets before estimating the seasonal cycle. I've tried to improve the manuscript regarding this point,

12 The sentence has been modified, the goal here is to apply the altimetric spatial bias (not available in ice-covered areas) to the GRACE and steric datasets which are defined at any given space and time,

13 RMS is the root mean square, but it might be clearer to consider the standard deviations instaead,

14 *most important* refered to the fact that the highest SLA RMS levels are found in this region, the formulation has been changed to *largest RMS levels*,

15 the tide prediction is only one of the errors affecting satellite altimetry in the Canadian Arctic Archipelago region, we changed the sentence to make that clearer,

16 the number of samples, as well as statistical significance levels for the extrema of correlation found between altimetry and tide gauges times series were added. In addition, it is stated that stations where correlation failed the 99% confidence level test were removed from the analysis.

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17 the 200 km radius is used to constrain the method to extract the satellite altimetry time series corresponding to a TG station not too far from this station,

18 the trend estimates were re-evaluated over the are effectively observed by altimetry and the sentence has been changed in the revised version of the paper,

19 collocated refers to the fact that in the comparison to TG process, an altimetry time series is extracted from the grids at each tide gauge station posistion, the term has been removed to avoid the confusion,

20 the term *mean drift* is explained, we also tried to clarifiy ythe difference between the drifts estimated over the longest period available (not always the same for the TG and altimetry data) and the drift estimated after strictly using the data over the same period (shorter periods but consistent between the two techniques),

21 this part was reformulated to some extent, 39 comparisons between tide gauges and satellite altimetry are used to perform the regional mean comparison,

22 there are big differences between Giles et al.'s figure 2 and this papers' figure 3, I think these can be explained by the fact that Giles et al are only considering the western Arctic (70°N–82°N/130°N-180°N) and this part of the basin shows the increase in the doming of the Beaufort Gyre. In this paper, we consider the whole basin, and it is therefore difficult to compare the two figures. I guess a better comprison would be to look at Giles et al.'s figure 1-b and this work's figure 8.

23 the EOF analysis of satellite altimetry SLA in the Beaufort Gyre region was removed, as well as figure 9, as it did not provide new results compared to Giles et al. In section 3.3, the description of the EOF analysis has been improved.

24 the SLA standard map shows high levels of variability along the coasts of the Arctic Ocean, but using the RMS does not allow to attribute this variability to a type of signal (intra-annual, annual or inter-annual). When performing the EOF analysis

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of September mean fields, intra-annual signals are removed. Finding a similar pattern for the first mode with the variability concentrated along the coasts is a hint that at least part of the total variability (measures by the SLA standard deviation) originates from inter-annual processes. The text has been modified to clarify this point.

25 we added the number of monthly fields used in the decomposition (17) along with a reference to Preisendorfer (1988) for the EOF methodology.

26 I believe this is the right place for introducing the Mog2d model as we do not really discuss its application to altimetry but rather use it to demonstrate the the variability observed by altimetry at interannual time scales results from atmospheric forcings. Mog2d is commonly used in the altimetric community, and appeared to be a good choice for this investigation.

27 in this paper, Proshutinsky and colleagues found that several of the AOMIP models displayed a first EOF correlated with the AO, but the spatial patterns are somewhat different, some of them show a pattern similar to the altimetry.

28 in general, time series in the Arctic interior are affected by intra-annual gaps (the further north, the longer the gaps). However, we did check that almost all grid points were effectively observed in the first (1993) and last year (2009) of the record to avoid fitting trends over different time ranges. When this is not true, it appears clearly on the trend map blue/red values in the Canadian Arctic Achipelage and North of the Beaufort Sea,

29 we added a map to display the spatial coverage,

30 using an inverse method, we tried to estimate the uncertainty affecting local trends. The figure is added to the revised version of the paper and the methodolgy used to derive this map is descibed in the paper.

31 the figure and the corresponding part in the paper have been removed.

32 the high frequency part only of the model results are used to correct the altimetry data. Here we analyse the low-frequency part of the model outputs which are independent from the altimetry. Finding a similar pattern suggests that the altimetry observes a SLA signal resulting from atmospheric forcings. The text was changed to clarify the relation between model and altimetry data.

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