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Interactive comment on "How essential are Argo observations to constrain a global ocean data assimilation system?" *by* V. Turpin et al.

V. Turpin et al.

eremy@mercator-ocean.fr

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Firstly, we would like to thank the referee for its attentive reading and the very interesting remarks and questions that are raised.

Referee comment: The study withholds Argo observations, which are the majority of in-situ real-time observations available for real-time global forecasting, to try to understand how important these are for 'constraining' water mass properties in order to produce more accurate global ocean forecasts. I have two main points for discussion.

Firstly, the study mainly focusses on the impact on analysis error, which can be less meaningful than forecast error. This is because the observations can easily be over fitted to create an analysis with low errors and physical fields in the model, which

can lead to a poor forecast which would imply dynamical adjustment indicative of an unbalanced analysis.

Answer: We totally agree with this remark. From the beginning of the study, we were convinced that focusing on analysis fields only would not be fully relevant to assess the impact because of the use of non-independent data. In order to take that aspect into account, we organized the article around the following scheme: first we compare the $\frac{1}{4}$ degree analyzed fields with the Argo profiles and then we check that the changes seen in the different OSE analysis correspond to improvements in term of forecast error reduction (table 3 and 4).

Figure 3 and 4 focus on the performance of the system when Argo is not assimilated. We compared the analysis with the not assimilated Argo observations for the last 6 months of experiment. In fact, the initial state is influenced by Argo assimilation, but we assume that after 6 months without Argo assimilation there the spin down period is enough (we will come back to this later). Figure 5 and 6 compares analyzed fields from Run-Ref (all data assimilated) and Run-NoArgo for temperature and salinity. These comparisons are used to quantify the amount of information that Argo brings to the system. This comparison shows the difference in the analyzed field whether Argo profiles are assimilated or not. At that stage, we do not argue that the analyzed field with Argo is better that the analyzed field without Argo. Actually, figure 7 and 11 are the only figures which compares analyzed field to assimilated Argo Data. This result has to be discussed in regards to figure 3 and 4. The differences between figure 3/4 and 7/11 shows the quantity of information the system has extracted from Argo profiles. I insist on the fact that we do not conclude at that point that the forecast is better when Argo is assimilated.

In a second step, we calculate assimilation statistics based on innovations. Figure 13 to 16 quantify the improvement on innovation, i.e. the improvement of the forecasting system. From that point we can conclude that Argo profile assimilation has a strong impact on the system and this impact is an improvement of the forecasted fields. Then

Argo assimilation is improving the $\frac{1}{4}$ degree Mercator forecasting system.

We will be clearer in the paper about that point and the limitations of looking at analysed fields at first place, before looking at the innovation statistics.

Referee comment: Secondly, it usually takes of the order of years to spin-up a free model interior state to be relatively constrained to Argo data. Since the ocean interior changes slowly and is relatively immune to surface forcing at these timescales, there should be memory of the constrained water masses that persists for some time, even after when the observations are turned off. Here we would expect a spin-down time where the errors grow to something like double those from climatology and saturate around this level. This could actually have a similar timescale and I think this effect is probably embedded in the results of the experiments presented in this study. The improvements in the statistics presented suggest this to me. Whilst the study has merit, is only one of a few on the subject, and provides important information around the impact of Argo in ocean forecasting, it could do a more cleaner approach to either addressing the problem or framing the language around the experiments and results that is clearer on the limitations.

Answer: We address this spin-down issue by focusing on the last 6 months of the experiment. The diagnostic of the spin down period on temperature and salinity in regards of depth have been made but not shown. The figure 1 and 2 in this response show the 1-year misfit evolution for an experiment with no in situ data assimilated. We can see that the misfits to the Argo data are increasing in the first 6 months for T and S from surface to 700m depth. At depth, it seems that the trend for salinity innovation stay constant after 6 months, as the one for temperature could be not exactly in equilibrium. However, it is quiet hard to evaluate the time for speed down in a one year exercise because of the error due to seasonal cycle. Most of the operational forecasting system sees innovations increasing during spring. We will address this issue in the discussion with a more detailed explanation on the choice of focusing on the last 6 months of the experiment and the limitations.

P1149 L2: ECMWF acronym wrong, change ‘of’ to ‘for’.

This will be changed in the text.

L5-10: It would be good to get a clear idea about the sequential DA scheme, when analyses are done, what is the observation window in relation to the cycle, is it centered or asymmetric?

We will add more details on the DA scheme in the section 2.1. The length of the assimilation window is 7-day with an analysis done in the middle of the window (3.5 day).

L15-25: How were the observations processed prior to assimilation? What was done to account for measurement and representation error. Apart from the usual QC, were they converted into superobservations? With the in-situ data, how were they treated in the vertical to represent the model layers?

The in situ data comes from the Coriolis database where automated QC are done. A subsampling is done before assimilation to keep only one observation per platform per day, within a distance of 0.1°. Only one value is kept on the vertical for each model layer. The observation error variance specified in the assimilation scheme takes into account a representativity error and an instrument error, much smaller than the representativity error. That information will be added in the section 2.2.

P1150 L5: Some repetitive text regarding Argo P1151

We will remove the duplicate information.

P1151 L10-15: Regarding point 3, it seems like there were still other in-situ obs assimilated in this experiment, which would try to constrain the system. Were these sparse enough to have no impact on the results?

The number of non-Argo data has been evaluated, and their spatial distribution is described in figure 1c. They constrain the system. However, this study focuses on the impact of Argo profiles in the operational system, in which other data, including “non Argo” in situ profiles are part of. We did not assess here the impact of the other in situ data even if it probably interacts with the Argo data in some regions and at some period. This is also the case for SST and altimetry data which also influence the T and S fields via the multivariate model error specification.

Also, the experiments that assimilate SLA and SST without Argo still project information from the observations into the subsurface and influence the error. Was there any improvement in subsurface compared to the free run? If there was, this should be accounted for in determining the Argo impact.

Figure 13 to 16 shows a strong improvement in subsurface when SST and SLA are assimilated. The forecast skill improvement in table 3 and 4 are calculated comparing Run NoArgo and Run-Ref. In both experiments SLA and SST improvement in subsurface is already taken into account. It is not part of that calculation.

P1153 L14: In places there are mixed pronoun references, this needs to be made consistent. For example Antarctic Ocean and Southern Ocean, which are the same are used interchangeably.

We will homogenize the pronoun references.

L20: How do we know that the salinity bias is not from a projection of SST and SLA into the model through the assimilation, rather than a model bias. Is the same bias in the noArgo as the free run?

From figure 16, we can see that the forecast error is larger for the free run than the NoArgo run from the surface to 700 m approximatively. Below that depth, the Run No Argo shows larger error due to an erroneous projection of SLA observations at depth.

P1154: L12: Reduction of the misfits is obvious, shows that the analysis is working.

We will replace our sentence with your suggestion.

L22: The word ‘current’ is a pronoun and should be capitalized here and in other places in the text. Eg should be ‘Aghulas Current’

We will correct that.

L25: Argo seems crucial to improve the model: : :.So far you have talked about improving the fitting of an analysis rather than improving the actual model. Also, all free models have substantial sub-surface errors when compared to Argo, so its essential that they are assimilated in order to improve the initial conditions for forecasting the ocean. Similarly as for other observations. It’s the obvious problem of trying to forecast the weather without observations to initialise the state, it is just not possible.

You are right, we will remove the word model which is not correct. The goal here is not to improve the model, only to reduce the misfits by estimating a correction to the model (the increment).

P1155: L: The use of RMS in the analysis, which is more correctly written as RMSD, may not be as robust a measure as mean absolute deviation (MAD). To paraphrase a recent study ‘RMSD tends to be dominated by a relatively small number of innovation elements with large magnitudes and may not accurately represent overall system performance in the whole domain. These elements may correspond to either less observed or more chaotic parts of the model, or be caused by observations with large errors – as the metric does not take into account the observation error.

It is true that the RMS is not the best metrics. We checked here that the PDF of the innovations in temperature and salinity do not show too much large values far from the center and that the shape is still close to a Gaussian curve at different depths. Figure 3 and 4 here show the PDF of the innovations at 900 m depth.

L5: English P1157: L2-5: The term ’Heat Content’ does not need to be capitalised as a Pronoun.

We will correct that in the text.

L11-12: The error estimates change also as a function of the number of observations, which can make comparison tricky.

In this section, we wanted to test the robustness of the heat content estimate when the Argo array changes. We compare the heat content estimates in the different OSE, it shows large differences. We do not try to evaluate the quality of the different estimates as this is impossible due to the lack of observations. We will make that point clearer in the text.

L24: Think 'western boundary current' should be 'western boundary currents'.

We will correct that in the text.

P1158: L21: What prevented the error stats being calculated in observation space rather the binning.

We found that showing statistics on bins was clearer than showing maps at different depth with "dots" at all the observation location over the last 6 months.

If 2x2 degree boxes were done to make a spatial map of the error, it would be good to know how many observations went into each box in order to understand if there are sampling differences that may influence the interpretation of the result.

The size of the squares represented every 2*2 degree depends on the number of data that are used to calculate the RMS in that box and the legend is in the bottom left corner of the plot.

P1159: L11: Remove 'region' after 'Southern Ocean'.

We will correct that in the text.

L21-25: Forecast innovation error implies the calculation of the deviations in observation space using un-assimilated and independent observations. It is not clear from what is presented in the text that this is true.

The forecast innovation error in the different experiments is computed using not yet assimilated or un-assimilated observations only. We will make that point clearer in the text.

P1161: L1-5: As mentioned before it takes at least a year, but more likely several, to spin-up Argo into a global ocean modelling system. Are the _1yr experiments long enough to get the right results? I would have expected to see errors go down from no Argo to full Argo greater than the overall 20% reduction. Usually the errors of all variables are at least halved by data assimilation.

SST and SLA and non Argo in situ data are assimilated when we calculate that 20% reduction, only due to the data assimilation of Argo. Maybe it would have been interesting to compare this numbers calculated for the first 6 month too. For sure a longer experiment would have answered more questions we ask now. We will mention that as a limitation of our study.

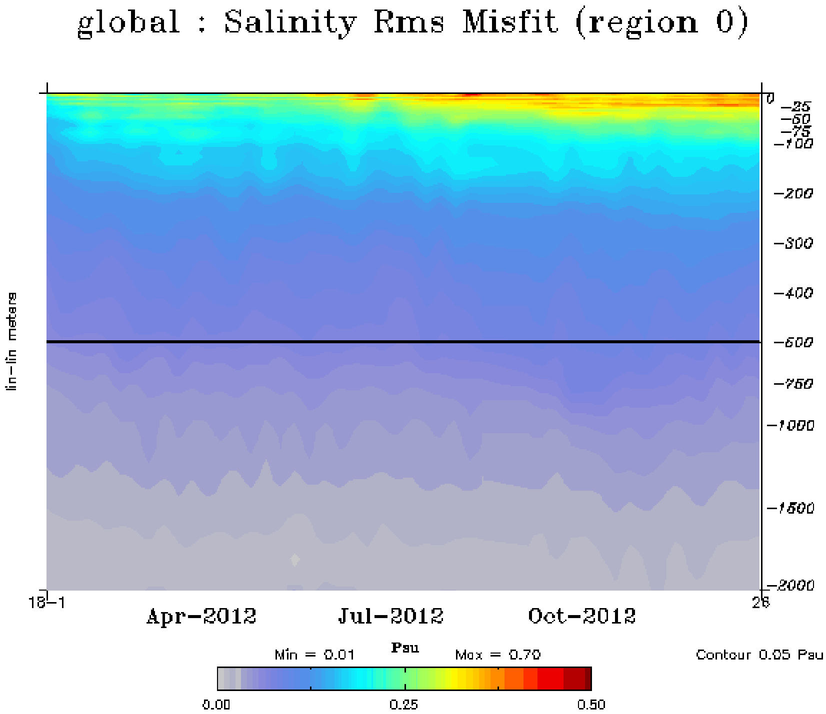
P1162: L14: ACC- know what it is but it's not defined for the reader.

We will define it explicitly.

L21: English

Discrepancies will be replaced by differences.

Interactive comment on Ocean Sci. Discuss., 12, 1145, 2015.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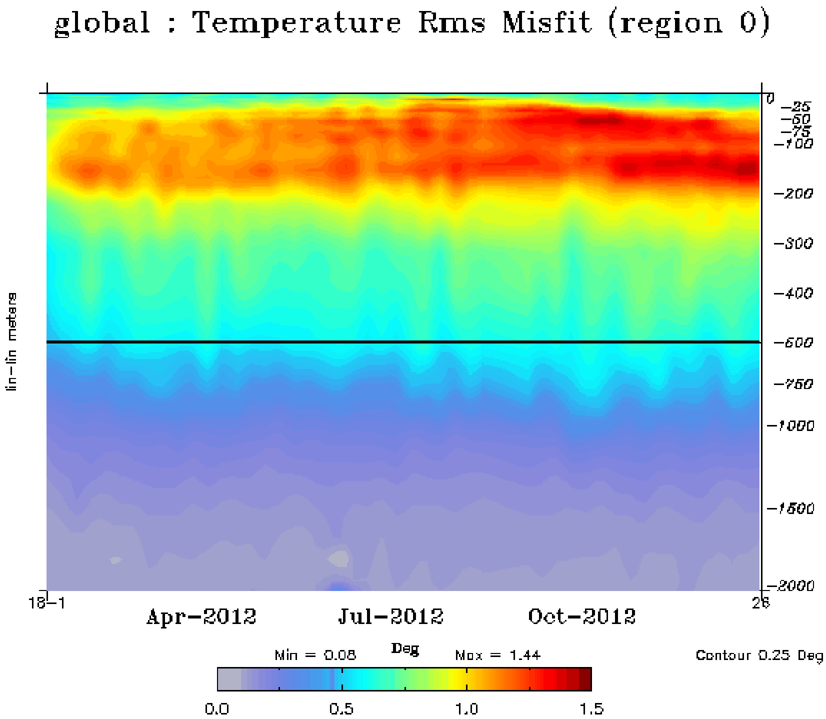
lin–lin meters
0
–25
–50
–75
–100
–200
–300
–400
–500
–750
–1000
–1500
–2000
18–1
Apr–2012
Jul–2012
Oct–2012
26
Min = 0.01
Psu
Max = 0.70
Contour 0.05 Psu
0.00
0.25
0.50

Fig. 1.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lin–lin meters
0
–25
–50
–75
–100
–200
–300
–400
–500
–750
–1000
–1500
–2000
18–1
Apr–2012
Jul–2012
Oct–2012
26
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Deg
Max = 1.44
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0.5
1.0
1.5

Fig. 2.

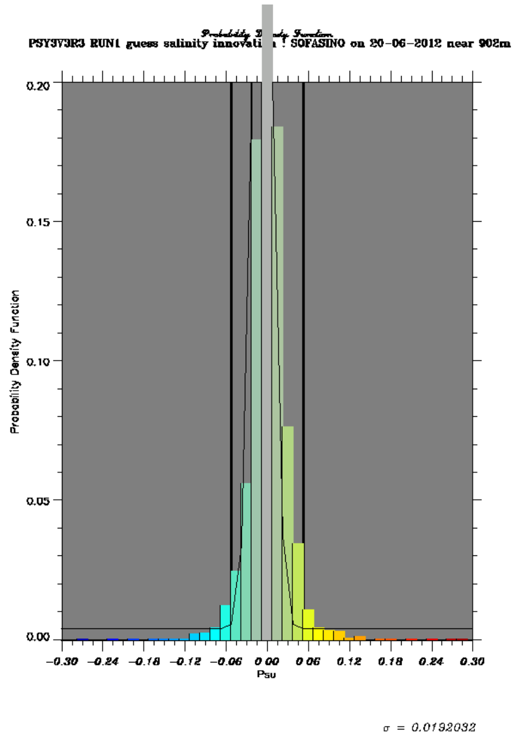

Fig. 3. PDF of the salinity innovations at 900 m depth

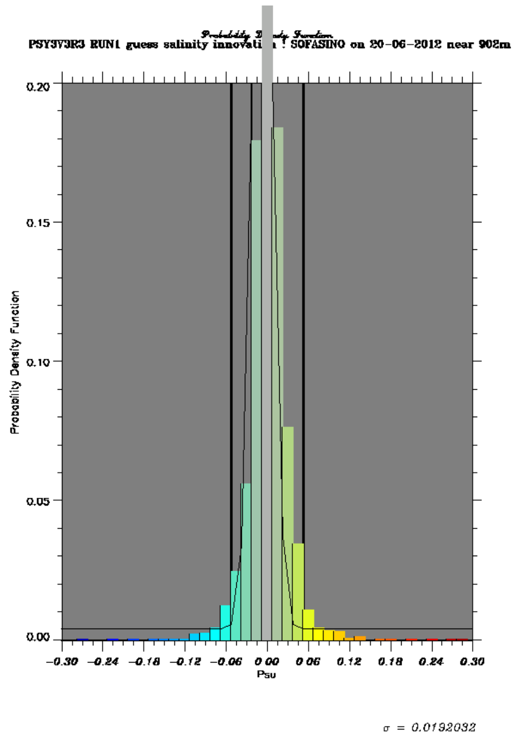

Fig. 4. PDF of the temperature innovations at 900 m depth