Observation Impact Statements for operational ocean forecasting

Forecasting R&D Technical Report no. 568

9 October 2012

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Abstract

FOAM is the Met Office's operational ocean forecasting system. As part of GODAE-OceanView we have run a series of operational observing system experiments. Between February and July 2011 we ran a system parallel to the operational suite which is identical except that certain observation types are excluded. At the start of each month the parallel system was reset to the operational restart and a run started with a different observation type excluded. The data withheld for each month were: February - XBT; March - TAO; April - Jason-2; May - All altimeter; June - AVHRR; and July - Argo data.

We show that the observing systems offer a good deal of complementary information. Withholding XBT causes little impact on globally averaged metrics, for example RMS observation-minus–background differences. Locally however we see long lasting temperature impacts (±1ºC) from the observations. Withholding TAO/TRITON data results in a global 8% increase in the RMS temperature observation-minus-background differences. In the tropical Pacific the increase in error is 37%. Withholding Jason-2 data results in a 4% increase in the RMS SSH (sea surface height) observation-minus-background differences. We also see impacts on other model variables; there are around ±2ºC small scale changes in 100m temperature and around ±0.2 psu changes in surface salinity. Withholding all altimeter data leads to a 16% increase of the RMS SSH observation-minus-background error. We also see impacts on other model variables; there are differences of at least ±2ºC in 100m temperature and at least ±0.2 psu in surface salinity. Withholding AVHRR produces significant impacts around ±1ºC in model sea surface temperature. These changes are seen down to the base of the mixed layer, but there is little or no effect below this. Withholding Argo data for one month leads to a 5% increase in the RMS observation-minus-background differences. We also see impacts on other model variables. For instance, there are large scale changes of +/-5cm in SSH. This implies that if Argo data were excluded for the long term that the performance of altimeter assimilation would be degraded.

Contents

1. Introduction

The ocean observing network consists of a number of different observing systems. Investigating the impact of observations in various applications is important for the funders of the current observing network and to contribute to the decisions on future observing systems. As part of GODAE OceanView we have performed a number of Observing System Experiments (OSEs) to assess the impact of the observing network on FOAM the Met Office's open ocean assimilation and forecasting system. An OSE involves running a copy of an existing assimilation run where some observations are excluded. The difference between this run and the original run assimilating all the observations allows a detailed assessment of the impact the observations have on the assimilation system.

GODAE OceanView[1] is the follow on to GODAE (Global Ocean Data Assimilation Experiment) (Smith and Lefebvre 1997; Bell et al. 2010) which was an international group focussed on the development of operational ocean analysis and forecasting systems. Many members of GODAE now have operational ocean analysis and forecasting systems. The follow on, GODAE OceanView, is therefore directed at sustaining and developing the systems, including the vital ocean observing systems required for operational ocean analyses and forecasts. The OSEs form a part of this effort, in allowing us to demonstrate the value of the existing observing network to our ocean forecasting systems.

There are a number of approaches for assessing the value and impact of observations. The OSEs mentioned above have the benefit of being reasonably straightforward to implement. They are, however, expensive since each OSE requires another run of the data assimilation system. The OSSE (Observation System Simulation Experiment) is similar to the OSE but uses simulated data to test the assimilation system allowing future potential observing systems to be assessed. Another approach which may be cheaper than the OSEs is to use diagnostics of the assimilation to calculate observation sensitivities or observation information content (Rodgers 2000, Cardinali et al. 2004, Desroziers et al. 2005, Chapnik et al. 2006). These can give the (linear) sensitivity of the assimilation to all the observations at the same time. The observation information content calculation (see Moore et al 2011) requires the Kalman Gain matrix and the adjoint to the observation operator which may not be readily available for all systems. The analysis correction data assimilation used in FOAM does not have the required quantities immediately to hand. FOAM is now moving to NEMOVAR which may make calculating observation information content easier (but this requires further investigation). If in future, we implement such a scheme the OSE experiments will provide a useful set of comparisons.

For the moment, we perform a series of OSEs in a pseudo-operational context; running an identical copy of the operational system with the same forcing and observations only with certain observations excluded. We can then compare the results with the system assimilating all the data in order to assess the impact of the data excluded. These experiments are run for a month starting with the same initial model fields as the operational run but then allowing the run to evolve separately during that time.

Each set of OSE results is presented in the form of an OIS (Observation Impact Statement). This can be viewed as a self contained assessment of the impact of the observation type on FOAM. Each OIS is structured as follows: a summary containing a

[1] Work Plan GODAE OceanView: https://www.godae-oceanview.org/science/work-plan/

few of the main results; a disclaimer to emphasise that the results are specific to the FOAM system; a system description; an explanation of the method of running the OSE; a results and discussion section containing the key results and discussion of these; and a supplementary information section which contains some additional information useful for comparison with the other OISs.

It is important to emphasise in cases where the observation impact seems low this may be because of the limitations of the experiments (each over only one month) and limitations of the abililty of FOAM system to use the information provided by the observations. Also, we have only assessed a limited range of diagnostics and it is often the case that some diagnostics show a bigger impact of particular OSE than others.

The OIS for XBT is in section 2, TAO/TRITON in section 3, Jason-2 altmeter in section 4, all altimeters in section 5, AVHRR in section 6 and Argo in section 7. The OIS sections are followed by a discussion and summary of the overall results.

2. Observation Impact Statement for XBT - February 2011

D. Lea. Met Office, Exeter, UK

For GODAE OceanView

2.1 Summary

A parallel version of the FOAM operational system was run, during February 2011, withholding all XBT observations in order to assess the impact of these data on the system. XBT data form only 3.7% of the total temperature profiles assimilated into FOAM. The impact on globally averaged metrics, for example RMS observation-minus–background differences, is negligible. Locally however we see long lasting temperature impacts (±1°C) from the observations.

2.2 Disclaimer

The results are derived only from the FOAM system. Any statements about the information content of an observing system may be strongly dependent on the model and data assimilation system. The impact of the observations may also be underestimated due to the short time over which the experiment was run.

2.3 System description

FOAM (Forecasting Ocean Assimilation Model) is the Met Office's short range (0 to 6 day) operational open ocean forecasting system. Remotely sensed satellite SST (sea surface temperature) and in-situ SST data, profile temperature and salinity data, SLA (sea level anomaly) altimeter data and sea ice concentration data are assimilated in the NEMO (Nucleus for European Modelling of the Ocean) model using the analysis correction assimilation scheme. Data is assimilated into a global model at ¼º resolution and various nested models at 1/12º. The experiments below use only the global model. See Storkey et al 2010 for more details on FOAM. The operational system runs back 48 hours each day and assimilates all the available data in two 24 hour periods (day minus 1 and day minus 2). Running back an extra 24 hours means that data that arrive late can be used to improve the results. The results below are all taken from the day minus 2 period.

2.4 Method

In this study we perform an OSE (Observing System Evaluation); running an identical copy of the operational system with the same forcing and observations only with XBT observations excluded. We can then compare the results with the system assimilating all the data in order to assess the impact of the data excluded. The "no XBT" experiment was run for all of February 2011 starting from the same initial model fields as the operational run but then allowing the "no XBT" experiment to evolve separately during that time.

Fig 2.1a shows the locations of temperature profile observations in February 2011. These observations include Argo profiles, other CTDs, moored buoys as well as XBTs. XBTs, shown in Fig 2.1b, form only 3.7% of the total temperature profile observations in this month.

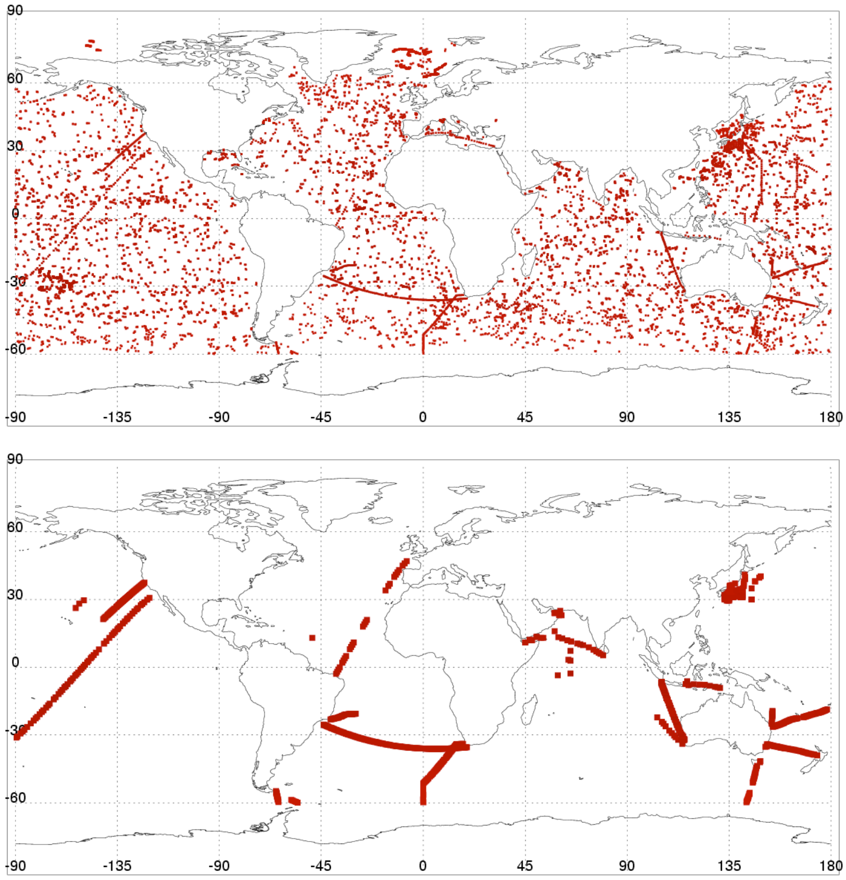

Fig 2.1. (a) Locations of all the temperature profile data assimilated into the operational system in Feb 2011, 23243 profiles in total. (b) Locations of the XBT data which are excluded in the “no XBT” run, 852 profiles in total.

2.5 Results and Discussion

The impact locally near XBT observations is significant. The impacts on the temperature of the model by the end of the month can be 1ºC or more (Fig 2.2). There are also some temperature changes in highly eddying regions e.g. the Gulf Stream which are not close to any XBT observations. These are most likely caused by chaotic error growth of small perturbations.

The XBT line in the eastern Pacific was observed from the 9 Feb 2011 starting near California to the 21 Feb 2011 ending near Australia. The information from these observations has spread much further than that from another XBT line in the South Atlantic observed later in the month (13 Feb 2011 to 21 Feb 2011). The scale of the structures suggests that the XBT data may be observing mesoscale features not predicted by the model or seen in any other data set. These changes in temperature will impact on the density gradients in the ocean and therefore the currents. The data can be seen also to have a mostly local impact on the model sea surface height (SSH) at the end of the month (Fig 2.3).

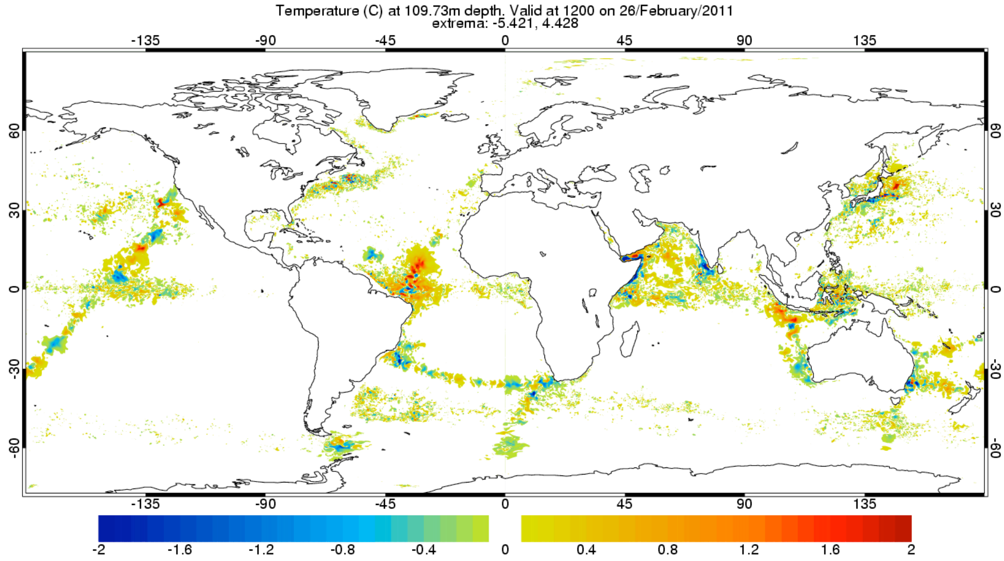

Fig 2.2. Map of the temperature difference (Operational minus “No XBT”) in ºC at 109.7 m depth. Derived from daily average fields from the last day of XBT OSE period.

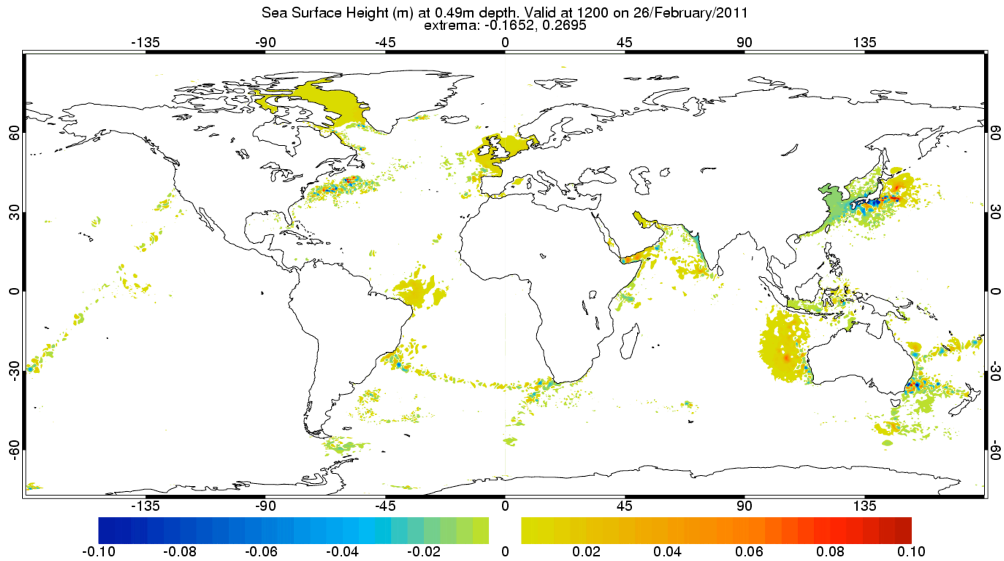

Fig 2.3. Map of the SSH difference (Operational minus “No XBT”) in m. Derived from daily average fields from the last day of XBT OSE period.

Area averaged observation-minus-model-background statistics are shown in Fig 2.4. The statistics for both the operational and “no XBT” run are calculated from all temperature observations including the XBT data. These show very little effect from not assimilating the XBT data. We also average the statistics over a number of standard areas. Out of these standard areas one of the biggest impacts of the XBT data is in the Indian Ocean. Even here the impact is relatively minor with less than 5% reduction in the RMS in a range of depths between 300 m and 1000 m. This may be explained by the relatively dense sampling of that region by XBT data (see Fig 2.1b) in Feb 2011.

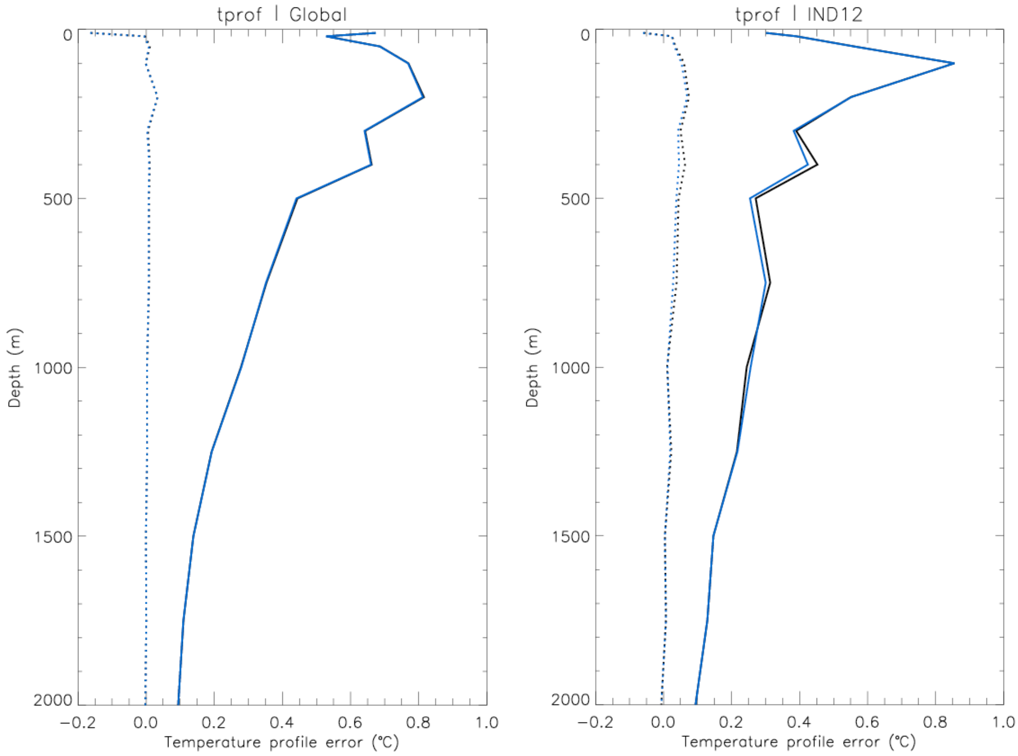

Fig 2.4. Profile of temperature observation–minus-background statistics in ºC averaged globally (a) and over the Indian Ocean (b) as a function of depth for the operational run (black), and the "no XBT" run (blue). The RMS observation-minus-background values are shown as solid lines and the mean observation-minus-background values are shown by dotted lines.

2.6 Reference

Storkey, D.; Blockley, E.W.; Furner, R.; Guiavarc'h, C.; Lea, D.; Martin, M.J.; Barciela, R.M.; Hines, A.; Hyder, P.; and Siddorn, J.R. Forecasting the ocean state using NEMO: The new FOAM system. Journal of Operational Oceanography, 3(1), pp 3-15. 2010.

2.7 Supplementary information

	Operational	No XBT
SST in-situ / ºC	0.620 (-0.114)	0.619 (-0.113)
SST AATSR / ºC	0.450 (-0.003)	0.450 (-0.003)
SSH / m	0.075 (-0.003)	0.075 (-0.003)
Sea ice conc / fraction	0.043 (-0.001)	0.043 (-0.001)
Profile T / ºC	0.594 (-0.022)	0.595 (-0.021)
Profile S / psu	0.106 (0.002)	0.106 (0.002)

Table 2.1. Global summary observation minus background statistics, RMS (and mean in brackets) for different observation types accumulated over February 2011. For both runs we are comparing to all observations including XBT.

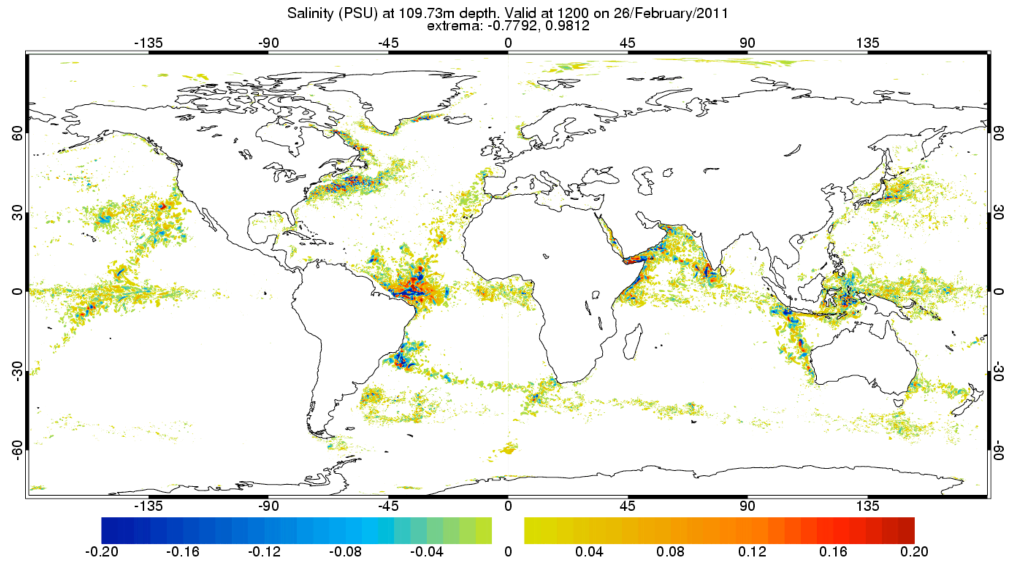

Fig 2.5. Map of the salinity difference (Operational minus “No XBT”) in psu at 109.7 m depth. Derived from daily average fields from the last day of XBT OSE period.

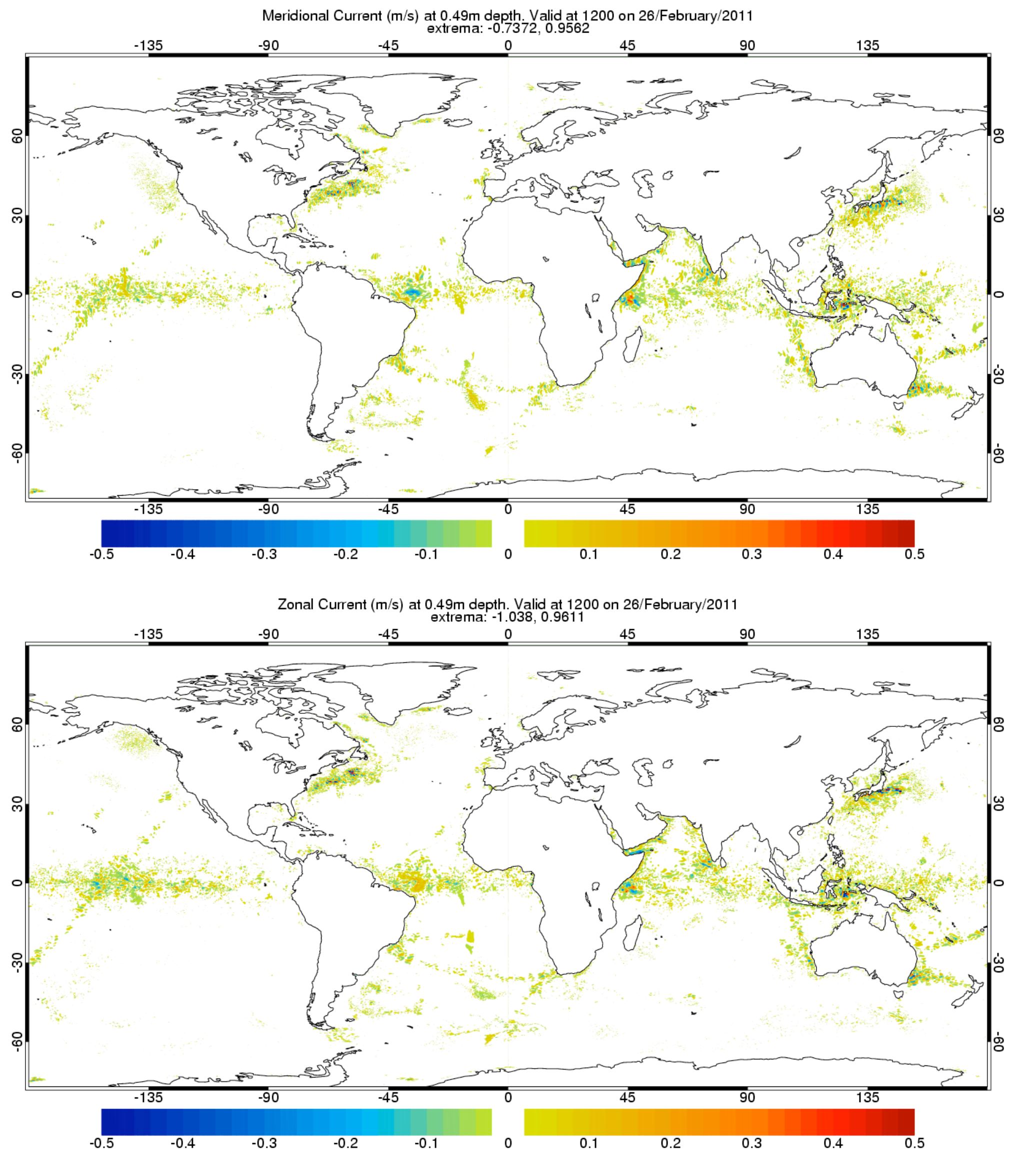

Fig 2.6. Maps of the surface meridional and zonal current differences in m s^{-1} (Operational minus “No XBT”) at the surface. Derived from daily average fields from the last day of XBT OSE period.

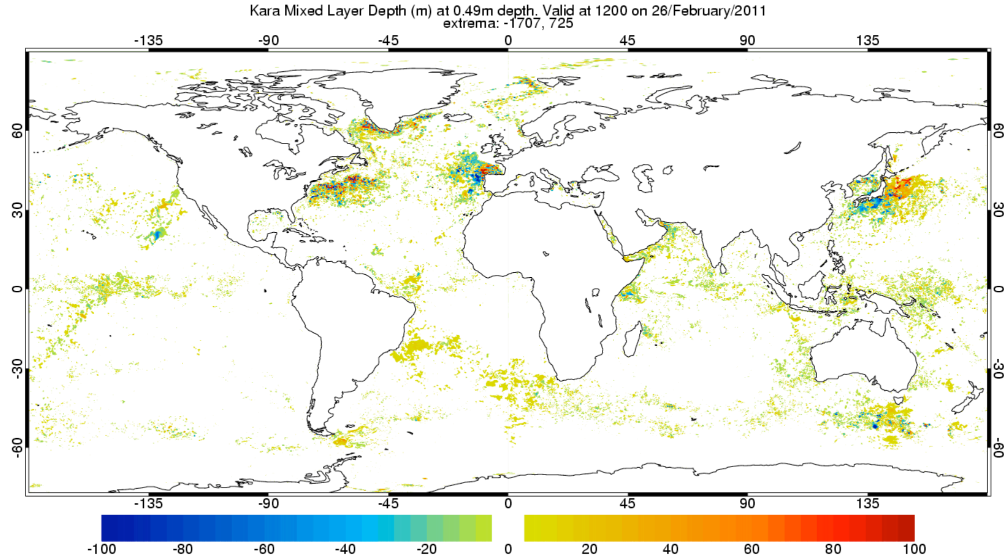

Fig 2.7. Map of the change in the Kara mixed layer depth in m (Operational minus "No XBT"). Derived from daily average fields from the last day of XBT OSE period.

	Operational	No XBT
Zonal velocity (ms^{-1})	0.251 (-0.005)	0.250 (-0.005)
Meridional velocity (ms^{-1})	0.216 (-0.009)	0.215 (-0.009)

Table 2.2. Global summary of drifter velocity observation minus background statistics, RMS (and mean in brackets) for the u and v velocity component accumulated globally over Feb 2011. This shows only negligible differences between the operational and OSE run.

3. Observation impact statement TAO/TRITON - March 2011

D. Lea. Met Office, Exeter, UK

For GODAE OceanView

3.1 Summary

A parallel version of the FOAM operational system was run, during March 2011, withholding all TAO/TRITON observations in order to assess the impact of these data on the system. TAO/TRITON data form 14% of the total subsurface temperature and 13% of salinity observations assimilated into FOAM. Withholding TAO/TRITON data results in a global 8% increase in the RMS temperature observation-minus-background differences. In the tropical Pacific the increase in error is 37%.

3.2 Disclaimer

The results are derived only from the FOAM system. Any statements about the information content of an observing system may be strongly dependent on the model and data assimilation system. The impact of the observations may also be underestimated due to the short time over which the experiment was run.

The results may also be seasonally dependant. For this experiment it is also worth noting that the results may depend on the ENSO state. In March 2011 there was a strong La Nina with the NINO3.4 index at around -1.0.

3.3 System description

FOAM (Forecasting Ocean Assimilation Model) is the Met Office's short range (0 to 6 day) operational open ocean forecasting system. Remotely sensed satellite SST (sea surface temperature) and in-situ SST data, profile temperature and salinity data, SLA (sea level anomaly) altimeter data and sea ice concentration data are assimilated in the NEMO (Nucleus for European Modelling of the Ocean) model using the analysis correction assimilation scheme. Data is assimilated into a global model at ¼º resolution and various nested models at 1/12º. The experiments below use only the global model. See Storkey et al 2010 for more details on FOAM. The operational system runs back 48 hours each day and assimilates all the available data in two 24 hour periods (day minus 1 and day minus 2). Running back an extra 24 hours means that data that arrive late can be used to improve the results. The results below are all taken from the day minus 2 period.

3.4 Method

In this study we perform an OSE (Observing System Evaluation); running an identical copy of the operational system with the same forcing and observations, with TAO/TRITON (Tropical Atmosphere Ocean TRIangle Trans-Ocean buoy Network) observations excluded. TAO/TRITON is an array of moored buoys measuring temperature and salinity at various depths down to 500m deep. We compare the results of a system excluding TAO/TRITON with the system assimilating all the data in order to assess the impact of the data. The "no TAO/TRITON" experiment was run for all of June 2011 starting from the same initial model fields as the operational run but then allowing the "no TAO/TRITON" experiment to evolve separately during that time.

(a) (b)

Fig 3.1a shows the locations of temperature profile observations in March 2011. These observations include Argo profiles, other CTDs, moored buoys and XBTs. Out of 867922 individual subsurface temperature observations 124530, or 14%, are TAO/TRITON observations. Out of 708319 individual salinity observations 94021 or 13% are TAO/TRITON observations. Fig 3.1b shows the distribution of TAO/TRITON observations in March 2011. In the tropical Pacific (15ºS to 15ºN) it does form the majority of the profiles (5157 out of 6508). Note the vertical sampling of the TAO/TRITON array is much sparser than say Argo so the majority of individual observation points even in the Pacific come from Argo.

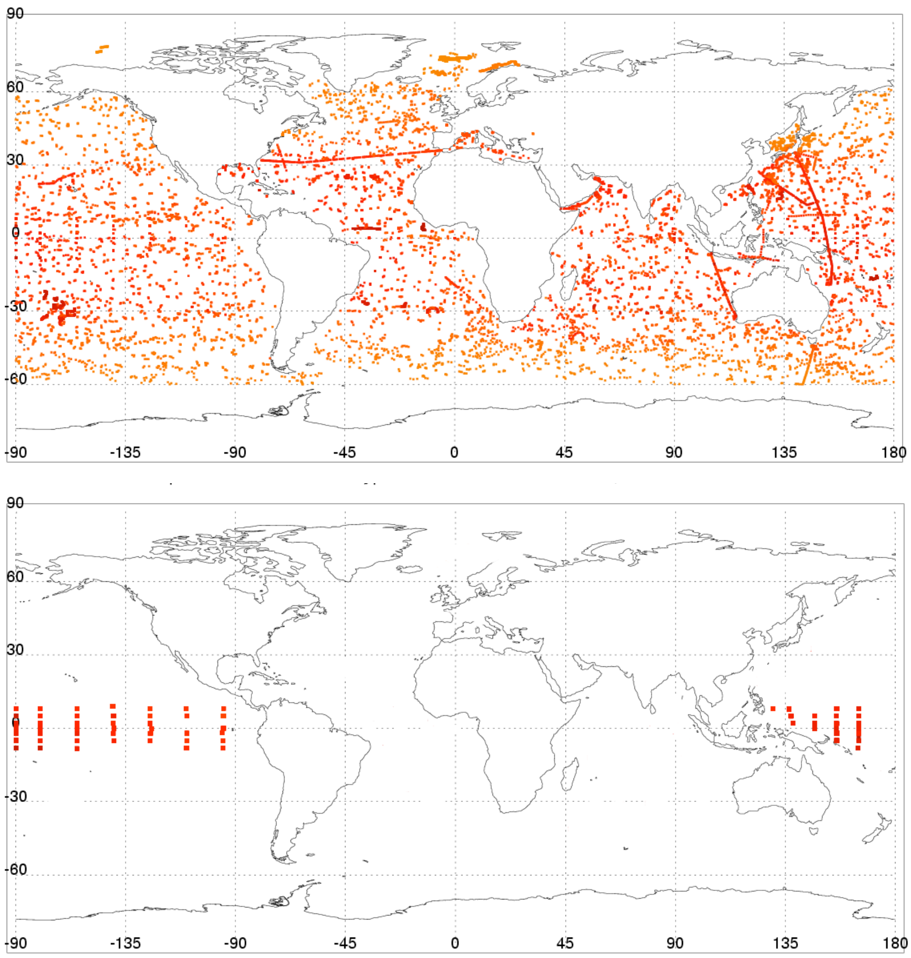

Fig 3.1. (a) Locations of all the temperature profile data assimilated into the operational system in March 2011, 25585 profiles in total. (b) Locations of the TAO/TRITON data which are excluded in the “no TAO/TRITON” run, 20428 profiles in total.

3.5 Results and Discussion

TAO/TRITON data is an important observing system for FOAM. In the tropical Pacific there is a dramatic increase in the RMS observation-minus-background of profile temperature (37%) and salinity (51%) (see Table 3.1) when TAO/TRITON data is excluded. The impact on the tropical Pacific can also be seen to lesser extent in the globally averaged profile innovations (Table 3.2). There is little or no impact on the SST or SSH statistics however. There is also much smaller impact on the profile statistics if only data other than TAO/TRITON is considered (not shown). This indicates that the impact is rather localised to the area directly observed by TAO/TRITON. The impact of

TAO/TRITON data may be so large because this is a region where the model has significant errors which is relatively sparsely observed by Argo. Another possibility is that the impact may over emphasised because the same location is observed every day.

	Operational	No TAO/TRITON
SST in-situ / ºC	0.356 (-0.162)	0.358 (-0.156)
SST AATSR / ºC	0.367 (-0.012)	0.365 (-0.007)
SSH / m	0.041 (-0.010)	0.041 (-0.009)
Profile T / ºC	0.435 (0.013)	0.596 (-0.036)
Profile S / psu	0.100 (-0.002)	0.151 (-0.001)

Table 3.1. Tropical Pacific (20ºS to 20ºN) summary observation minus background statistics, RMS (and mean in brackets) for different observation types accumulated in the region over March 2011. For both runs we are comparing to all observations including TAO/TRITON.

	Operational	No TAO/TRITON
SST in-situ / ºC	0.598 (-0.130)	0.598 (-0.129)
SST AATSR / ºC	0.459 (-0.017)	0.458 (-0.015)
SSH / m	0.073 (-0.002)	0.073 (-0.002)
Sea ice conc / fraction	0.040 (-0.002)	0.040 (-0.002)
Profile T / ºC	0.585 (-0.019)	0.634 (-0.011)
Profile S / psu	0.111 (0.000)	0.129 (0.000)

Table 3.2. Global summary observation minus background statistics, RMS (and mean in brackets) for different observation types accumulated over March 2011. For both runs we are comparing to all observations including TAO/TRITON.

Plotting the observation-minus-background statistics of temperature and salinity as a function of depth (Fig 3.2) shows that the impact of the TAO/TRITON is seen only in depths less than 1000m. There is a peak in the impact at 200m and another smaller peak around 500m. These reflect the depths of the temperature and salinity observations which are in the range of 0-300m and at 500m. The gap in TAO/TRITON observations at 400m is reflected in the lack of change in the innovations at that depth. Essentially there are no observations to see any change.

The assimilation of TAO/TRITON data has little impact near the surface in temperature but has a large impact on the salinity because the temperature is well observed by many satellite SST observations while there are few surface salinity observations to constrain the salinity.

(a) (b)

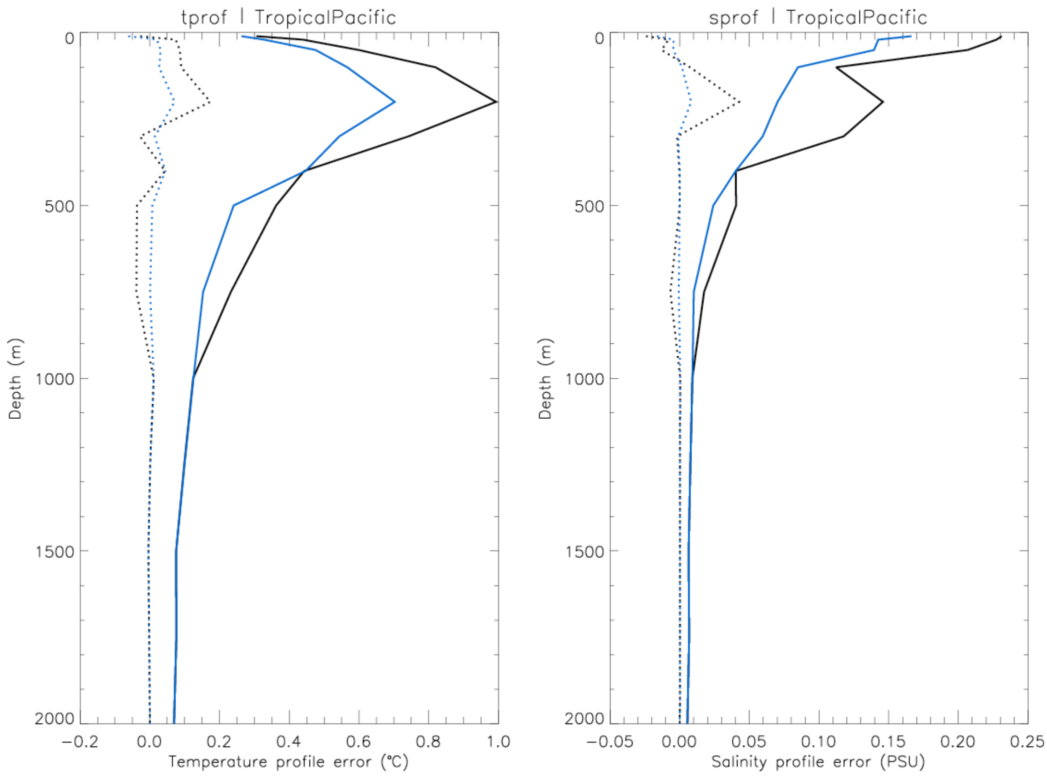

Fig 3.2. Tropical Pacific area observation-minus-background statistics, RMS for (a) temperature profile and (b) salinity profile data. The black lines show results for the no TAO/TRITON run and the blue for the operational run. RMS errors as a function of depth are plotted as solid lines and mean errors are plotted as dotted lines.

The impact of the removal of TAO/TRITON data is also seen in the global averaged profile statistics. It is apparent that this is simply because the tropical Pacific is included in the global statistics and not because there are significant impacts propagating away from the region.

The localised impact of the TAO/TRITON data can be seen by examining the model difference fields at 100 m at the end of the month (Fig 3.3). Information generally propagates eastward at the equator at this depth. The effect of this can be seen in Fig 3.3 particularly at 135ºW. On the timescale of the 1 month OSE run the impact is generally trapped within ±10º of latitude. The equivalent plot of the salinity differences at 100m (Fig 3.4) also shows evidence of the advection of information particularly in with a few degrees of the equator.

Outside of the tropics there are some differences seen in the OSE run (see Figs 3.3 and 3.4). This illustrates the difficulty of running an OSE in alongside an operational system which is being upgraded from time to time. The OSE run must as far as possible replicate the operational system. Unfortunately, in this month there was a parallel suite (PS26) running where the FOAM suite was being forced by an upgraded atmospheric model. On the 16th March 2011 this parallel suite was made operational using the model restart from the parallel run. Because the operational restart was switched, there was no straightforward way for the OSE to follow this resulting in the extra-tropical differences observed. Fortunately, this switch of restarts had little impact in the tropical oceans.

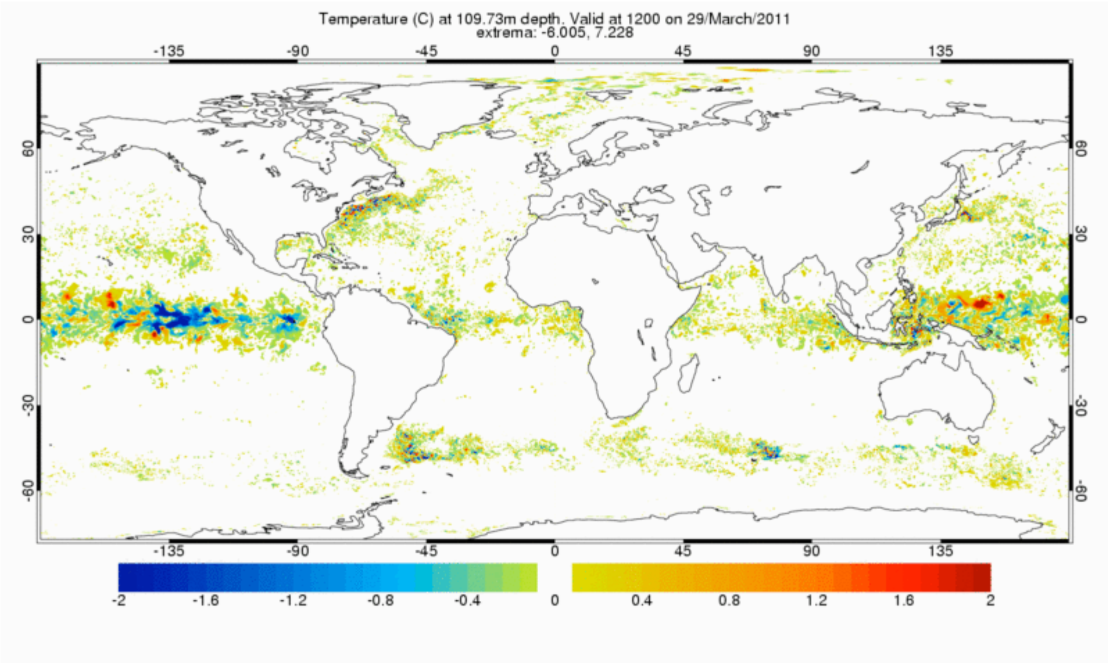

Fig 3.3. Map of the temperature difference (Operational minus “No Argo”) in ºC at 100m. Derived from daily average fields at the end of TAO/TRITON OSE period.

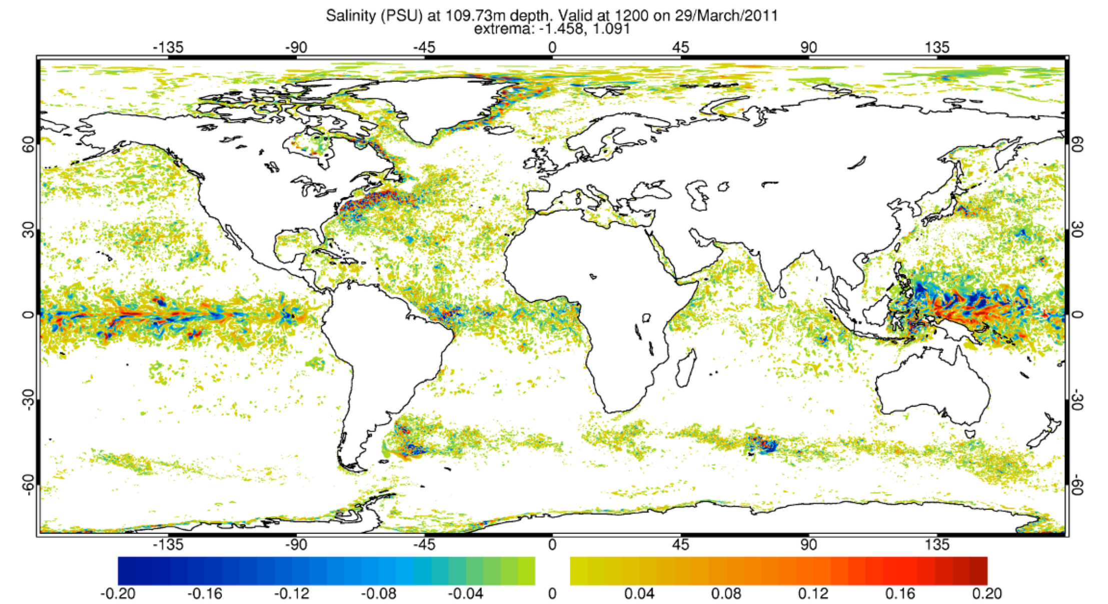

Fig 3.4. Map of the salinity difference (Operational minus “No Argo”) in psu at 100m. Derived from daily average fields at the end of TAO/TRITON OSE period.

Looking at vertical sections across the Pacific along the equator (Fig 3.5) the biggest impacts of removing TAO/TRITON data are seen in the thermocline region which is deepest in the west (~200m) and shallowest in the east (~100m). The plots early in the OSE period show localised effects near the mooring locations. The information is then seen to propagate away from the observation locations. Eastward propagation is particularly notable in the eastern part of the section. In the western part of the section there is evidence of weak westward propagation above 200m and perhaps eastward below 200m.

(a)

(c)

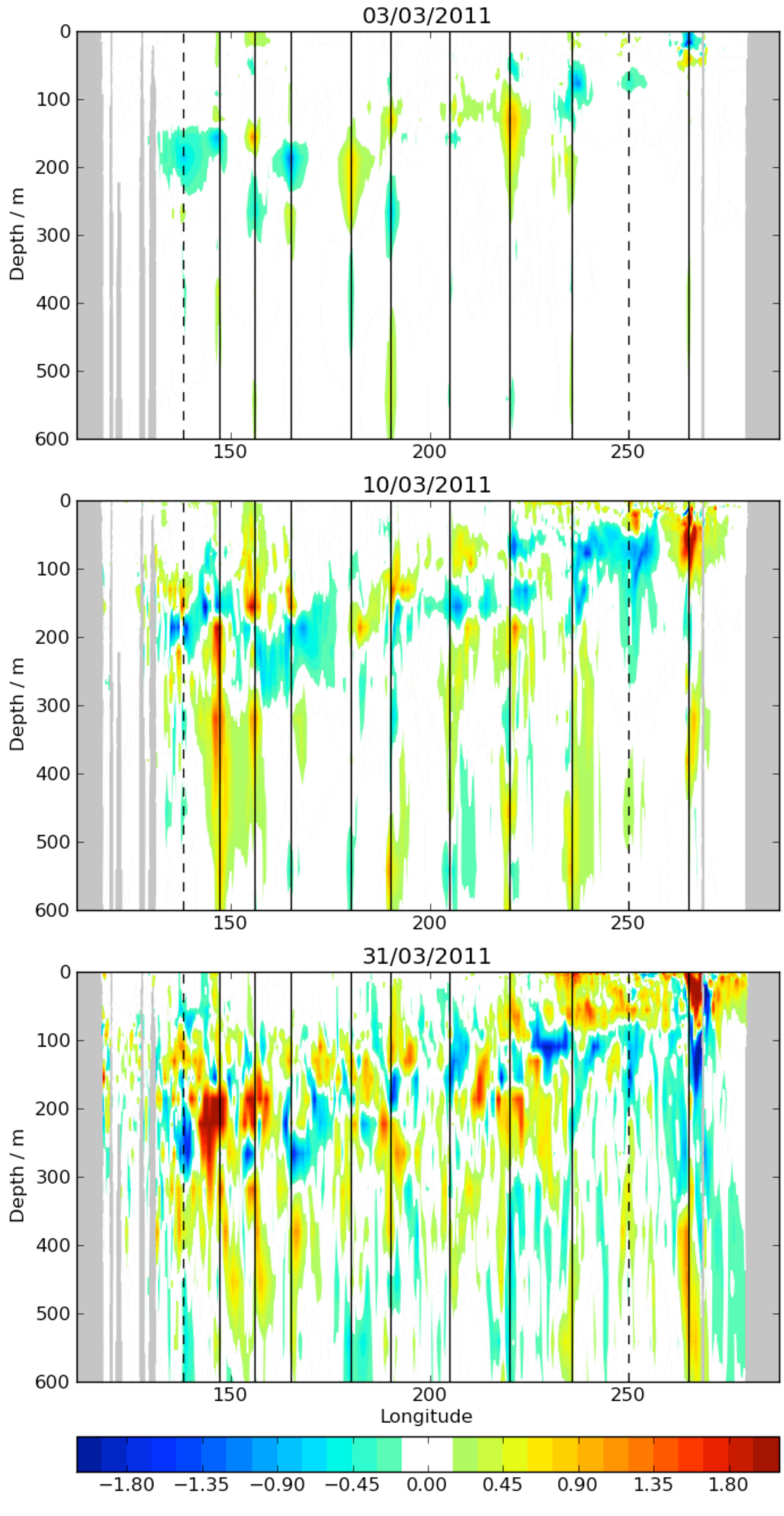

Fig 3.5. Equatorial vertical section the of the temperature difference (Operational minus “No TAO/TRITON”) in ºC across the Pacific from 120ºE to 80ºW at various times throughout the OSE run. The solid lines show the longitude of the equatorial TAO/TRITON moorings. The dashed lines show moorings which are within 5 degrees latitude of the equator, but not on the equator.

At the end of the OSE period there are some impacts on the depth of the thermocline (or 20ºC depth in Fig 3.6) and also the gradient of the thermocline. Most of the depth changes are small scale and possibly random or chaotic. The exception is at 140º-150ºW where assimilating the TAO/TRITON data results in a 30m increase in the thermocline depth. In Fig 3.6 the 18C and 22C depths are also plotted which shows that there is a sharpening in the gradient mostly where the thermocline is shallower. Overall the "no TAO/TRITON" run has an average T18º-T22º depth difference of 34.6m while in the operational run the depth difference is 31.6m. It is a common defect of models to have a too diffuse thermocline so in this regard the assimilation of TAO/TRITON data seems to be having a positive impact.

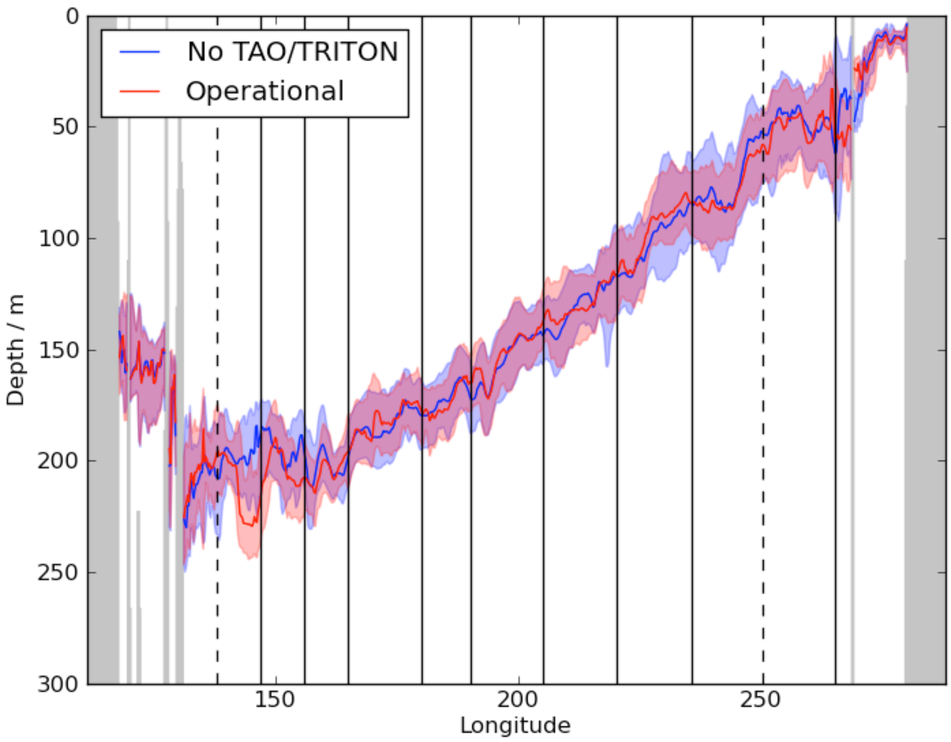

Fig 3.6. Equatorial vertical section the of the depth of 20ºC isotherm red line for Operational run and blue line for the No TAO/TRITON run across the Pacific from 120ºE to 80ºW at various times throughout the OSE run. The boundaries of the shaded areas give the depths of the 22ºC and 18ºC isotherms. The solid lines show the longitude of the equatorial TAO/TRITON moorings. The dashed lines show moorings which are within 5 degrees latitude of the equator, but not on the equator.

3.6 Reference

Storkey, D.; Blockley, E.W.; Furner, R.; Guiavarc'h, C.; Lea, D.; Martin, M.J.; Barciela, R.M.; Hines, A.; Hyder, P.; Siddorn, J.R. Forecasting the ocean state using NEMO: The new FOAM system. Journal of Operational Oceanography, 3(1) February 2010 , pp 3-15

(a) **(b)**

3.7 Supplementary information

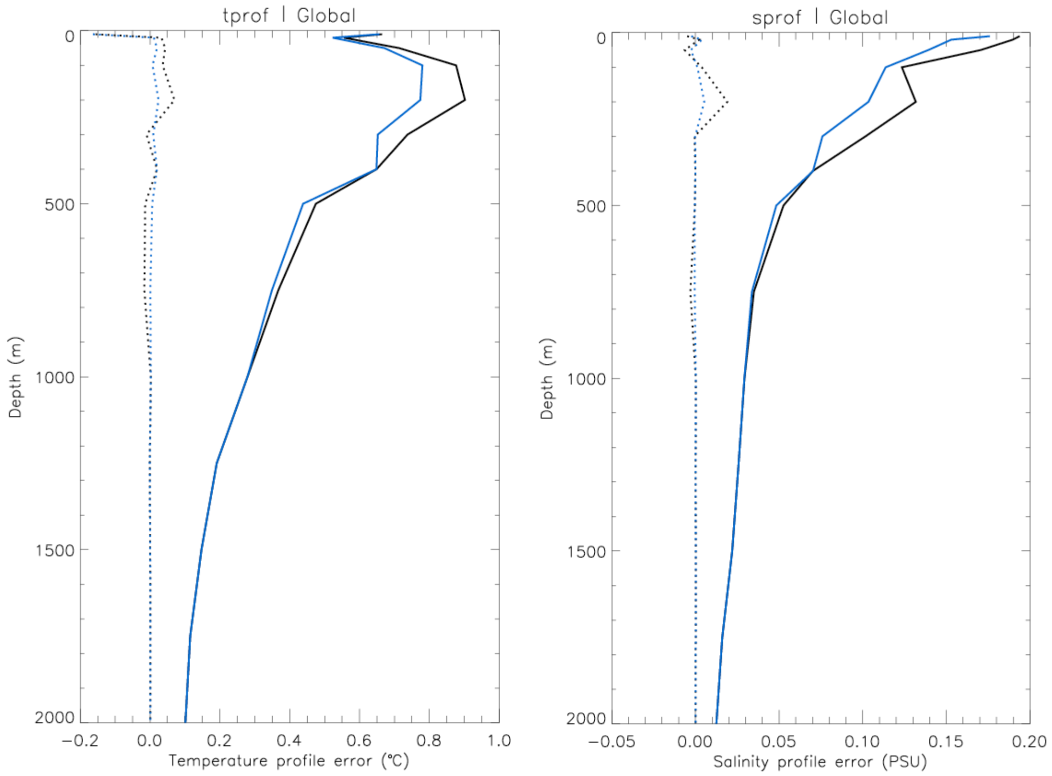

Fig 3.7. Global area observation minus background statistics, RMS for (a) temperature profile and (b) salinity profile data. The black lines show results for the no TAO/TRITON run and the blue for the operational run. RMS errors as a function of depth are plotted as solid lines and mean errors are plotted as dotted lines.

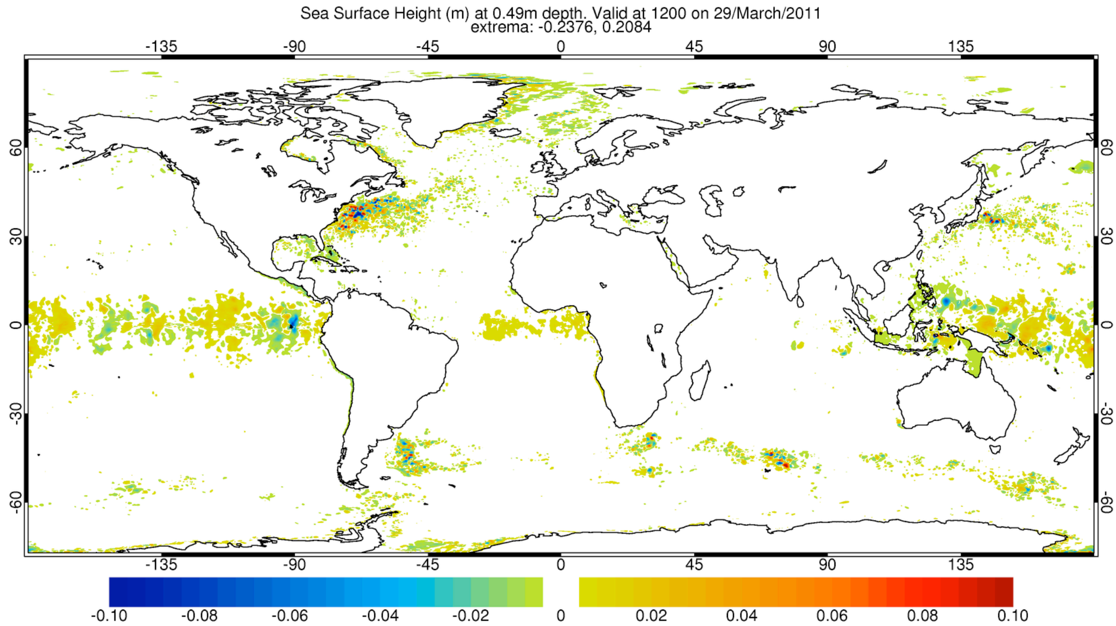

Fig 3.8. Map of the SSH difference (Operational minus “No TAO/TRITON”) in m. Derived from daily average fields at the end of TAO/TRITON OSE period.

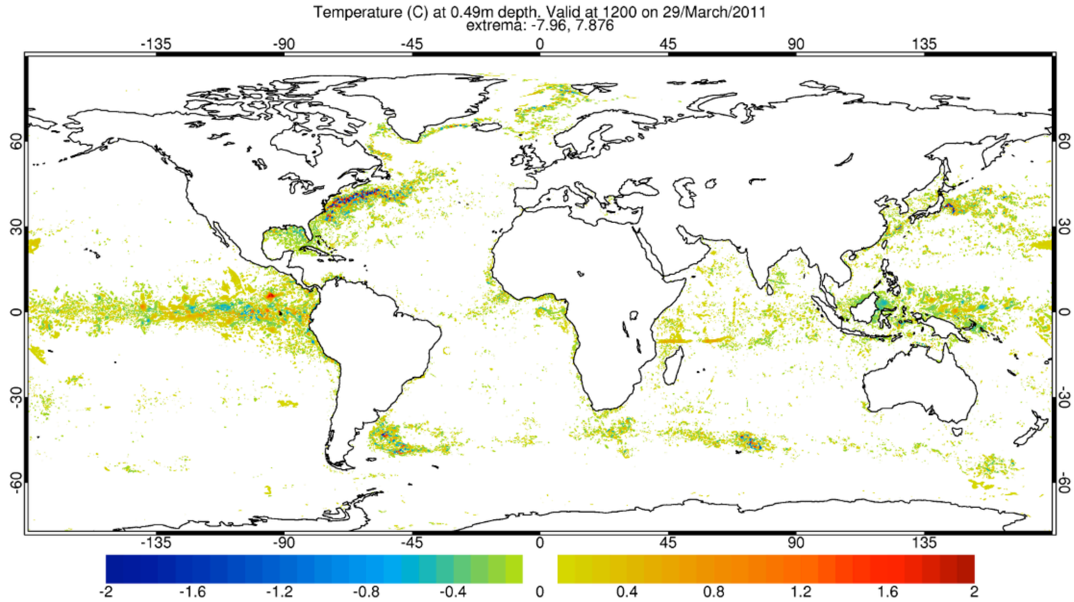

Fig 3.9. Map of the temperature difference (Operational minus “No TAO/TRITON”) in ºC at the surface. Derived from daily average fields at the end of TAO/TRITON OSE period.

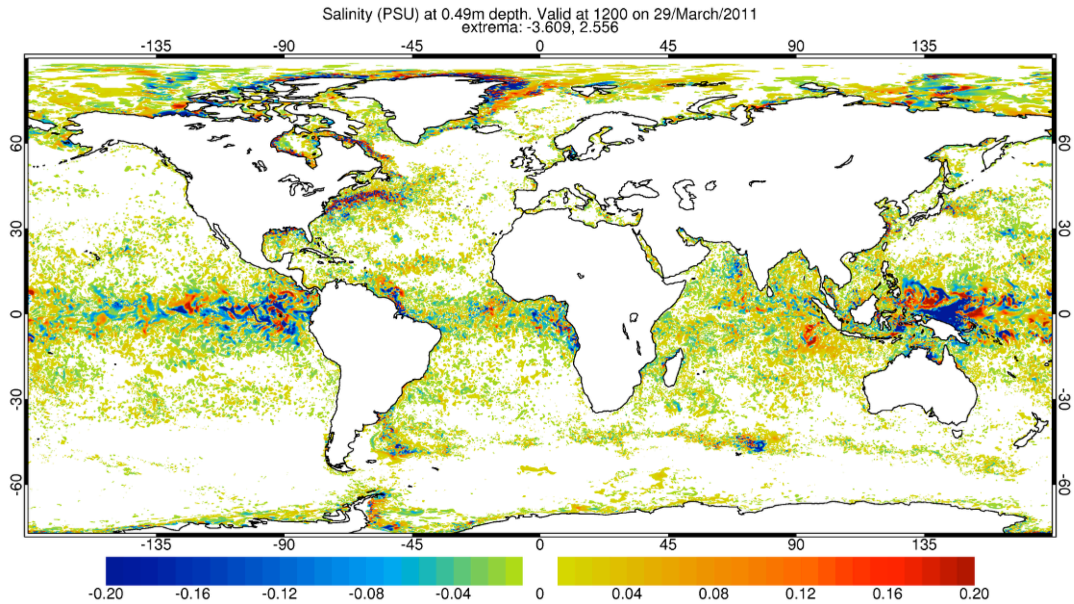

Fig 3.10. Map of the salinity difference (Operational minus “No TAO/TRITON”) in psu at the surface. Derived from daily average fields at the end of TAO/TRITON OSE period.

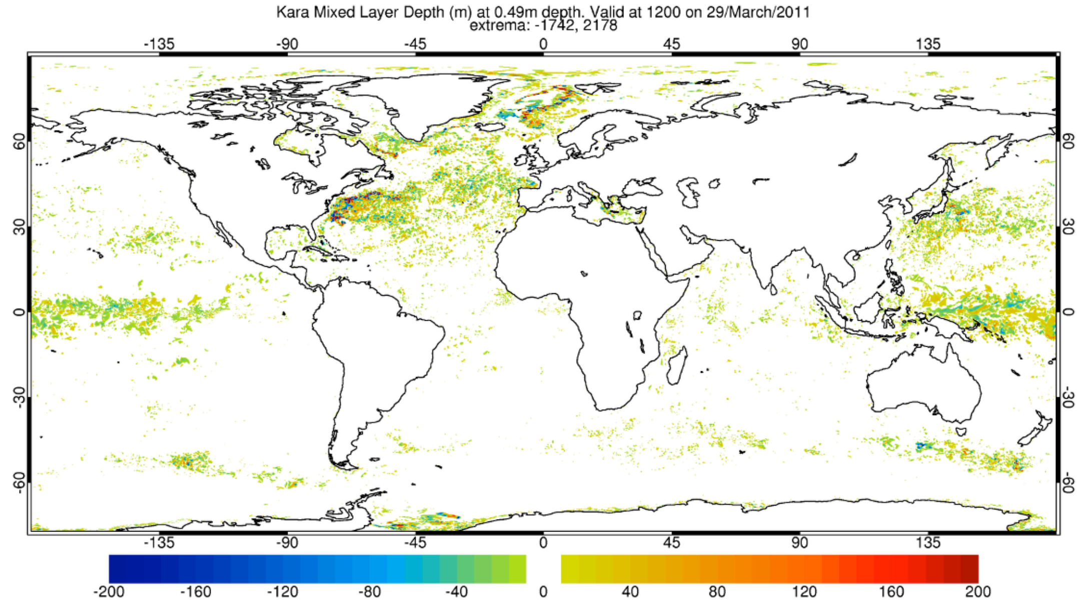

Fig 3.11. Map of the Kara mixed layer difference (Operational minus “No TAO/TRITON”) in m at the surface. Derived from daily average fields at the end of TAO/TRITON OSE period.

	Operational	No TAO/TRITON
Zonal velocity (ms^{-1})	0.237 (-0.010)	0.237 (-0.010)
Meridional velocity (ms^{-1})	0.206 (-0.009)	0.205 (-0.009)

Table 3.3. Global summary of drifter velocity observation minus background statistics, RMS (and mean in brackets) for the u and v velocity component accumulated globally over Mar 2011. This shows only negligible differences between the operational and OSE run.

	Operational	No TAO/TRITON
Zonal velocity (ms^{-1})	0.234 (-0.084)	0.234 (-0.084)
Meridional velocity (ms^{-1})	0.211 (-0.027)	0.211 (-0.026)

Table 3.4. Tropical Pacific summary of drifter velocity observation minus background statistics, RMS (and mean in brackets) for the u and v velocity component accumulated over Mar 2011. This shows only negligible differences between the operational and OSE run.

4. Observation impact statement: Jason-2 altimeter - April 2011

D. Lea. Met Office, Exeter, UK
Revised: 23 May 2012

For GODAE OceanView

4.1 Summary

A parallel version of the FOAM operational system was run, during April 2011, withholding Jason-2 altimeter observations in order to assess the impact of these data on the system. At the time Jason-1 and ENVISAT altimeters were also observing the ocean so withholding Jason-2 removed 43% of the altimeter data. Withholding Jason-2 data results in a 4% increase in the RMS SSH observation-minus-background differences. We also see impacts on other model variables; there are around ±2ºC small scale changes in 100m temperature and around ±0.2 psu changes in surface salinity.

4.2 Disclaimer

The results are derived only from the FOAM system. Any statements about the information content of an observing system may be strongly dependent on the model and data assimilation system. The impact of the observations may also be underestimated due to the short time over which the experiment was run.

4.3 System description

FOAM (Forecasting Ocean Assimilation Model) is the Met Office's short range (0 to 6 day) operational open ocean forecasting system. Remotely sensed satellite SST (sea surface temperature) and in-situ SST data, profile temperature and salinity data, SLA (sea level anomaly) altimeter data and sea ice concentration data are assimilated in the NEMO (Nucleus for European Modelling of the Ocean) model using the analysis correction assimilation scheme. Data is assimilated into a global model at ¼º resolution and various nested models at 1/12º. The experiments below use only the global model. See Storkey et al 2010 for more details on FOAM. The operational system runs back 48 hours each day and assimilates all the available data in two 24 hour periods (day minus 1 and day minus 2). Running back an extra 24 hours means that data that arrive late can be used to improve the results. The results below are all taken from the day minus 2 period.

4.4 Method

In this study we perform an OSE (Observing System Evaluation); running an identical copy of the operational system with the same forcing and observations, with Jason-2 altimeter observations excluded. We compare the results with the system assimilating all the data in order to assess the impact of the data excluded. The "no Jason-2" experiment was run for all of April 2011 starting from the same initial model fields as the operational run but then allowing the "no Jason-2" experiment to evolve separately during that time. It is important to note that FOAM altimeter is sourced through AVISO[2] and it is multi-mission data where Jason-2 data is used to correct the other altimeter data using the track crossovers. This means that the OSE is not a full test of the loss of Jason-2 since its impact is still felt through the corrections in Jason-1 and ENVISAT altimeter data.

[2] http://www.aviso.oceanobs.com/

Fig 4.1 shows the locations of Jason-2 observations in April 2011. In April there are a total of 1134330 altimeter observations of which 495429 (43%) are Jason-2 observations.

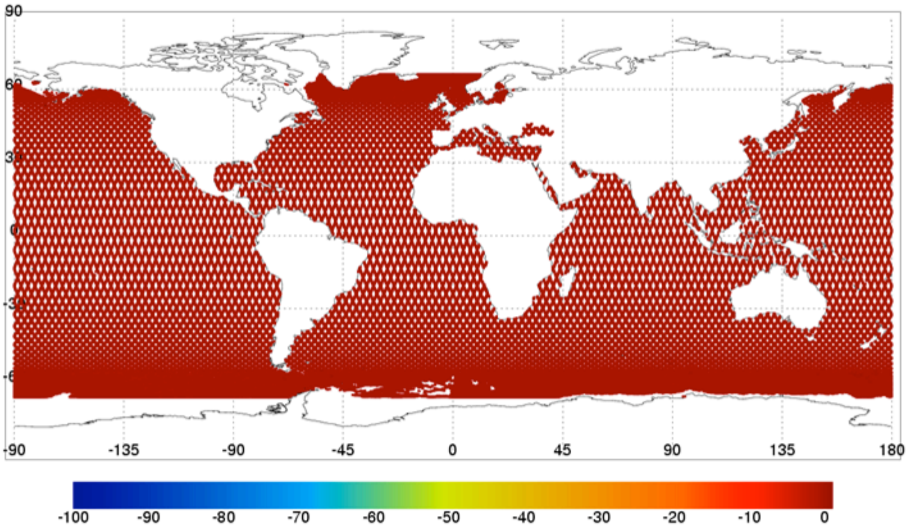

Fig 4.1. Jason-2 along-track data assimilated into the operational system in April 2011, 495429 data-points in total.

4.5 Results and Discussion

The impact of excluding Jason-2 data on global observation-minus-background statistics is show in Table 4.1. There is a small increase in the RMS for all observation types in-situ SST (2.7%), AATSR SST (1.3%), SSH (3.9%), profile temperature (1.6%) and profile salinity (2.4%) in the Jason-2 OSE.

	Operational	No Jason 2 altimeter
SST in-situ / ºC	0.594 (-0.105)	0.610 (-0.109)
SST AATSR / ºC	0.480 (-0.016)	0.486 (-0.017)
SSH / m	0.073 (-0.002)	0.076 (-0.002)
Profile T / ºC	0.575 (-0.011)	0.584 (-0.013)
Profile S / psu	0.125 (0.002)	0.128 (0.002)
Sea ice concentration	0.040 (-0.001)	0.040 (-0.001)

Table 4.1. Global summary of observation minus background statistics, RMS (and mean in brackets) for different observation types accumulated globally over April 2011. For both runs we are comparing to all observations including all altimeter data.

A time series of the SSH observation-minus-background shows that removing the Jason-2 data takes some time to show its full impact (Fig 4.2). This may be a result of the 10 day repeat cycle whereby the effect of removing Jason-2 is only fully evident at the next cycle. As the “No Jason-2” run is still drifting after 10 days it is probably the case that the model retains information from previous cycles. Recall that both the operational and OSE run start with the same initial conditions.

a) (b)

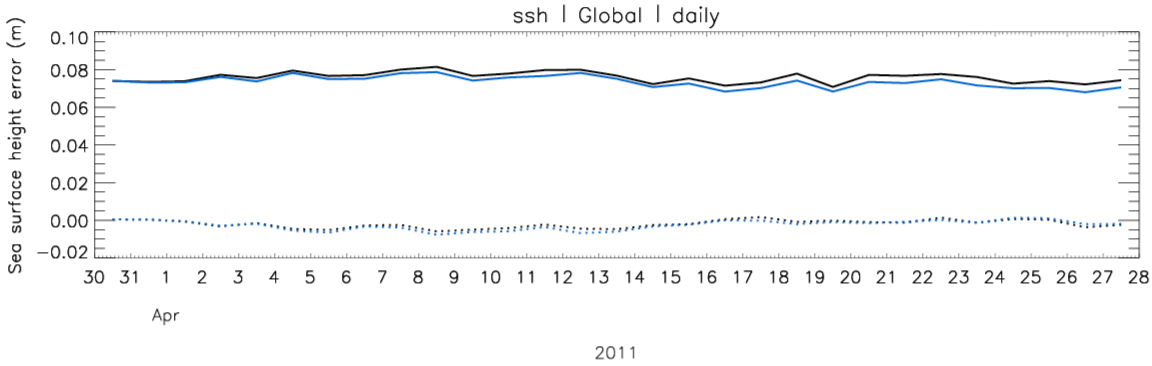

Fig 4.2. Observation minus background timeseries statistics. The black lines show results of the no J2 run and the blue of the operational run. RMS errors plotted as solid lines and mean errors are plotted as dotted lines.

The observation-minus-background statistics of temperature as a function of depth (Fig 4.3) show the impact of the Jason-2 data is concentrated in the sub-surface. In FOAM the altimeter assimilation uses the Cooper-Haines (1996) scheme to convert SSH increments into temperature and salinity increments. The scheme tends to produce the biggest increments near the thermocline (or pycnocline).

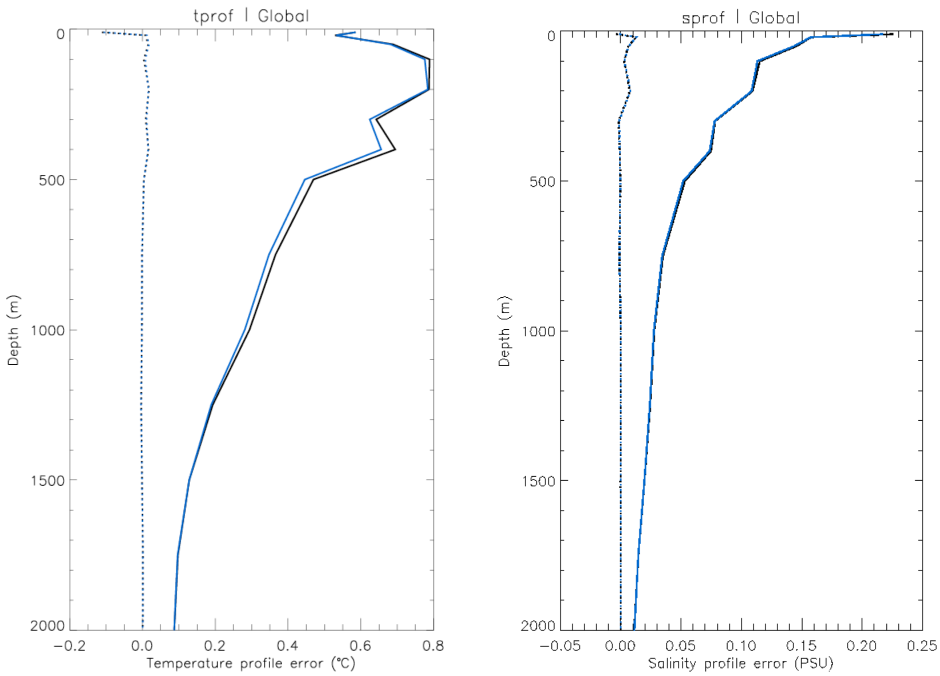

Fig 4.3. Observation minus background statistics for (a) temperature profile and (b) salinity profile data. The black lines show results for the no J2 run and the blue for the operational run. RMS errors as a function of depth are plotted as solid lines and mean errors are plotted as dotted lines.

The model field differences of SSH at the end of the OSE period (Fig 4.4) show significant mesoscale impacts from not assimilating Jason-2. These differences are greatest in the regions with strong mesoscale variability, for example the Gulf Stream, Kuroshio and Antartic Circumpolar Current.

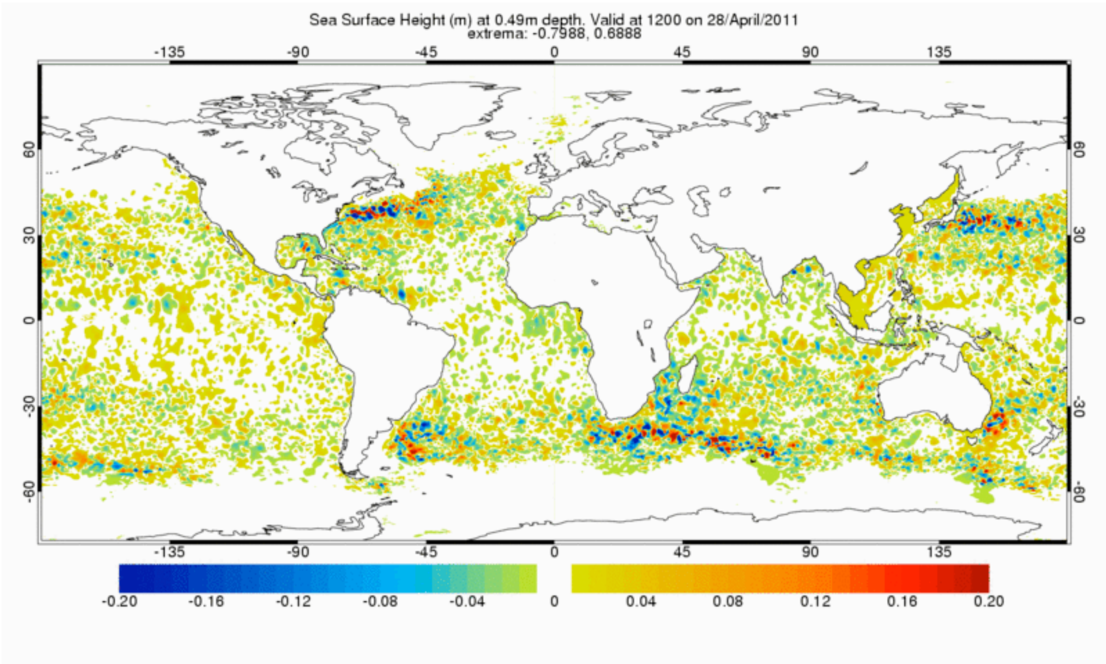

Fig 4.4. Map of the SSH difference (Operational minus “No Jason-2”) in m. Derived from daily average fields at the end of Jason-2 OSE period.

The impact of Jason-2 is also strongly evident in the 100m temperature (Fig 4.5). There are large ±2ºC mesoscale differences particularly in regions of strong mesoscale variability coincident with the large SSH differences. However, there are also large temperature differences in the equatorial regions even though the SSH signal is quite weak, presumably a consequence of the strong vertical gradient in temperature.

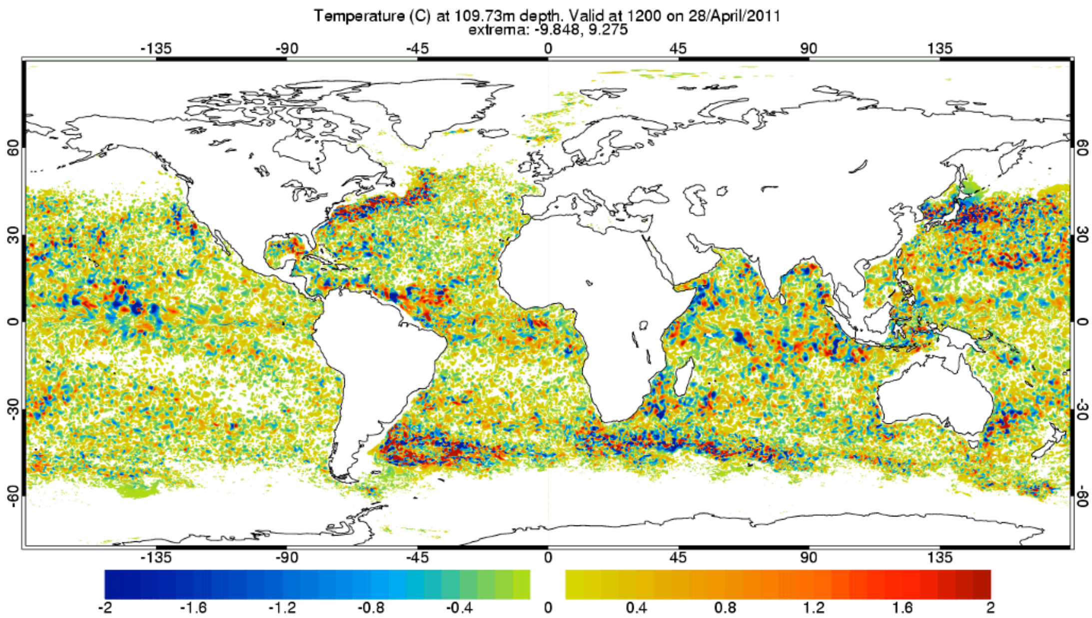

Fig 4.5. Map of the temperature difference (Operational minus “No Jason-2”) in ºC at 100m. Derived from daily average fields at the end of Jason-2 OSE period.

The effect of removing Jason-2 altimeter data can also be seen in comparison of the two runs' velocities to that derived from drifter observations. The drifters are drogued at 15m depth. The model daily mean currents at 15m depth are compared to a velocity calculated from the drifter positions over that day (as in Blockley et al 2012). A number of QC checks are performed and any drifters which are known to have lost their drogue are excluded from the comparison. Table 4.2 shows the statistics of the model and observed velocity. The RMS error increases by 3% and 2% for the zonal and meridional velocity components, respectively. Time-series plots (not shown) indicate that the error increases in time so the statistics may underestimate the ultimate impact of not assimilating Jason 2 data.

	Operational	No Jason 2 altimeter
Zonal velocity (ms^{-1})	0.222 (-0.009)	0.228 (-0.010)
Meridional velocity (ms^{-1})	0.201 (-0.002)	0.206 (-0.002)

Table 4.2. Global summary of drifter velocity observation minus background statistics, RMS (and mean in brackets) for the u and v velocity component accumulated globally over April 2011.

4.6 References

Blockley, E. W.; Martin, M. J.; and Hyder, P. Validation of FOAM near-surface ocean current forecasts using Lagrangian drifting buoys, Ocean Sci., 8, 551-565, doi:10.5194/os-8-551-2012. 2012.

Cooper, M.; and Haines K. Altimetric assimilation with water property conservation. Journal of Geophysical Research, 101(C1), pp1059-1077. 1996.

Storkey, D.; Blockley, E.W.; Furner, R.; Guiavarc'h, C.; Lea, D.; Martin, M.J.; Barciela, R.M.; Hines, A.; Hyder, P.; Siddorn, J.R. 2010. Forecasting the ocean state using NEMO: The new FOAM system. Journal of Operational Oceanography, 3(1), pp 3-15.

4.7 Supplementary information

	Operational	No Jason 2 altimeter
SST in-situ / ºC	0.636 (-0.090)	0.651 (-0.099)
SST AATSR / ºC	0.547 (-0.018)	0.550 (-0.017)
SSH / m	0.068 (-0.007)	0.071 (-0.009)
Profile T / ºC	0.691 (-0.060)	0.691 (-0.062)
Profile S / psu	0.247 (0.013)	0.256 (0.011)
Sea ice concentration	0.038 (-0.003)	0.038 (-0.003)

Table 4.3. North Atlantic regional summary of observation minus background statistics, RMS (and mean in brackets) for different observation types accumulated in the North Atlantic over April 2011.

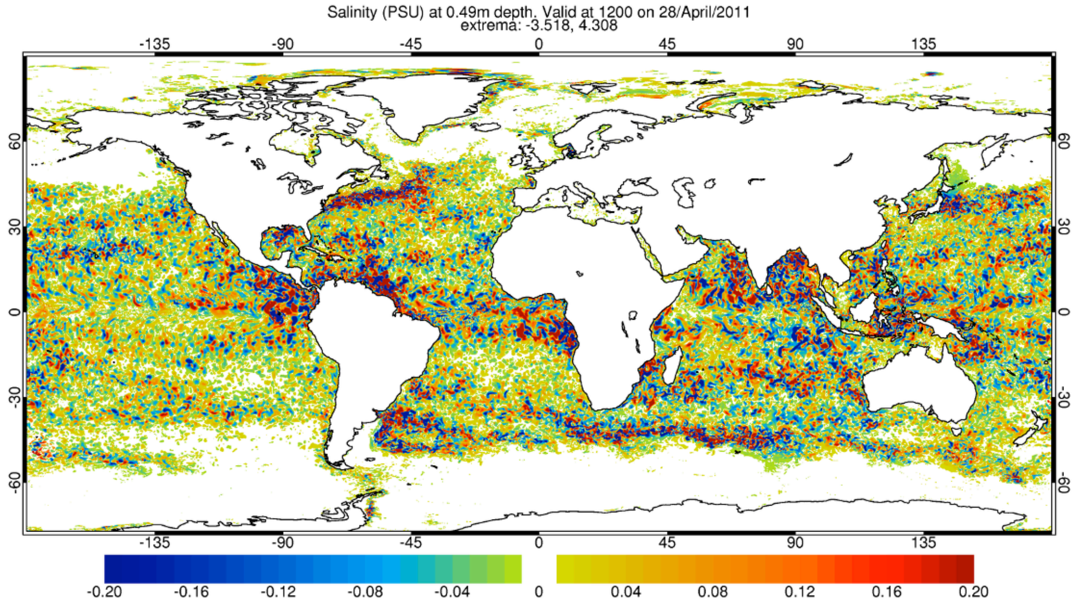

Fig 4.6. Map of the salinity difference (Operational minus “No Jason-2”) in psu at the surface. Derived from daily average fields at the end of Jason-2 OSE period.

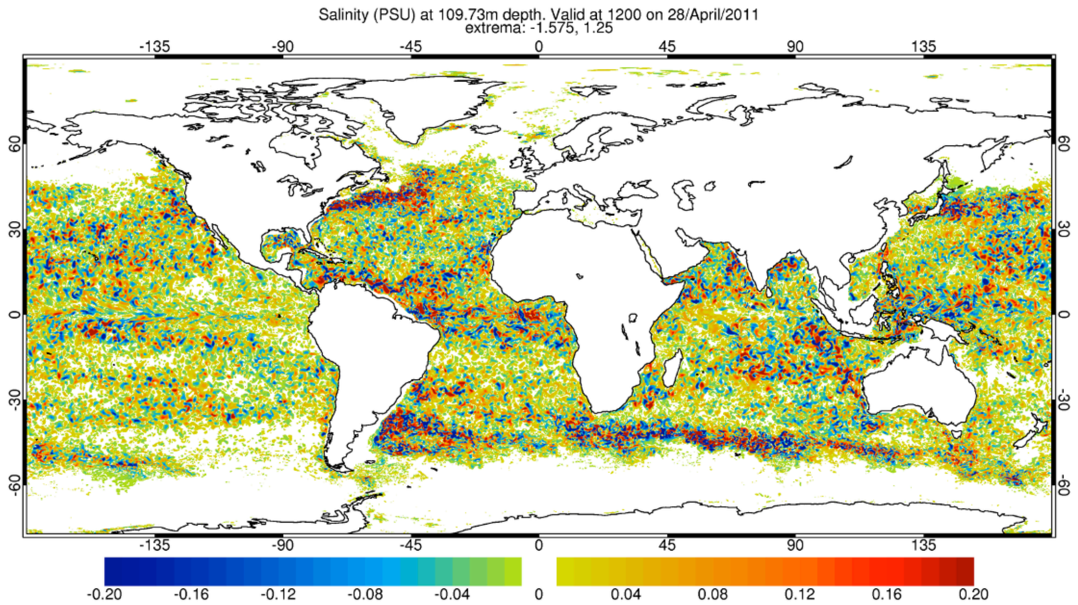

Fig 4.7. Map of the salinity difference (Operational minus “No Jason-2”) in psu at 100m. Derived from daily average fields at the end of Jason-2 OSE period.

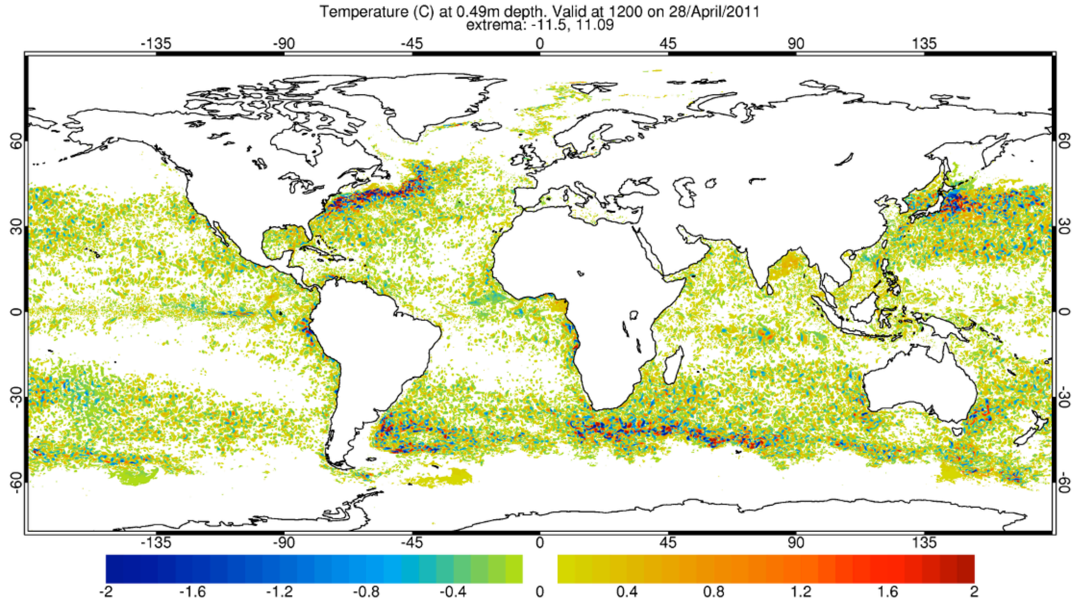

Fig 4.8. Temperature difference (Operational minus “No Jason-2”) in ºC at the surface. Derived from daily average fields at the end of Jason-2 OSE period.

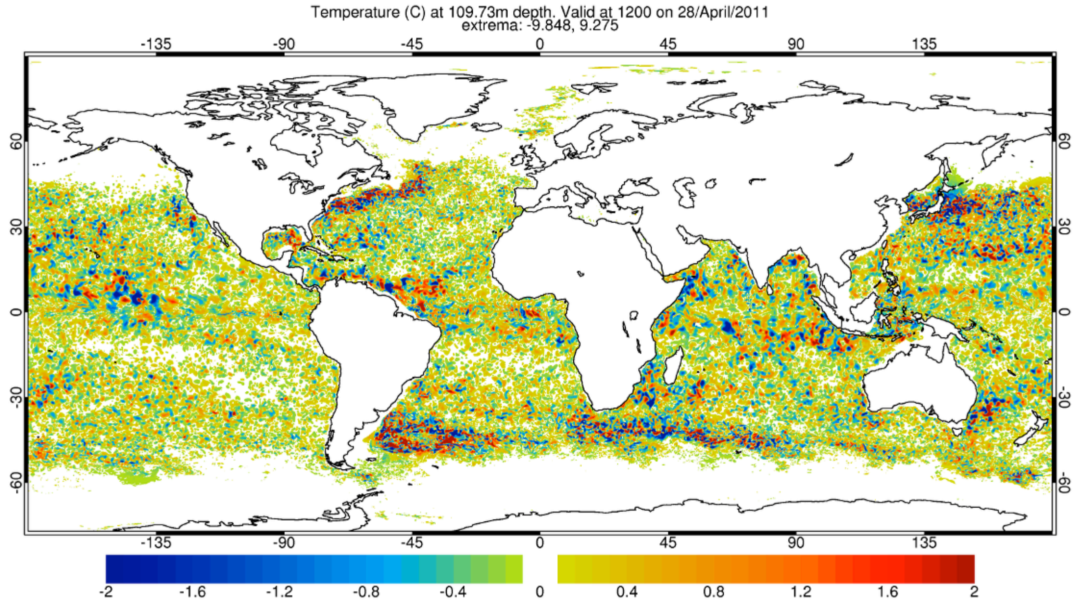

Fig 4.9. Temperature difference (Operational minus “No Jason-2”) in ºC at 100m. Derived from daily average fields at the end of Jason-2 OSE period.

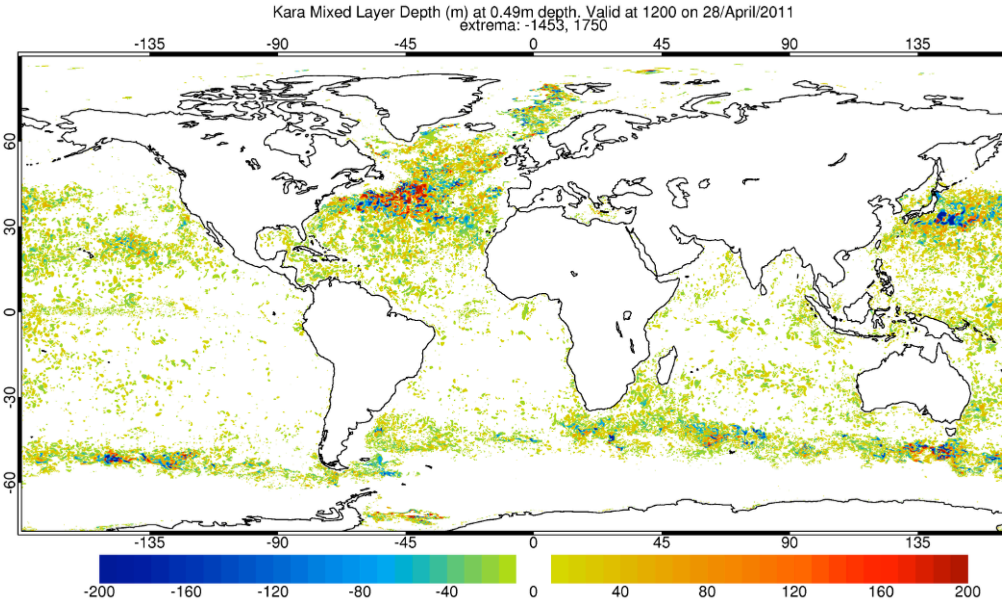

Fig 4.10. Kara mixed layer depth difference (Operational minus “No Jason-2”) in m. Derived from daily average fields at the end of Jason-2 OSE period.

5. Observation impact statement: All altimeters - May 2011

D. Lea. Met Office, Exeter, UK
Revised: 23 May 2012

For GODAE OceanView

5.1 Summary

A parallel version of the FOAM operational system was run, during May 2011, withholding all altimeter observations in order to assess the impact of these data on the system. Withholding all altimeter data leads to a 16% increase of the RMS SSH observation-minus-background error. We also see impacts on other model variables; there are differences of at least ±2ºC in 100m temperature and at least ±0.2 psu in surface salinity.

5.2 Disclaimer

The results are derived only from the FOAM system. Any statements about the information content of an observing system may be strongly dependent on the model and data assimilation system. The impact of the observations may also be underestimated due to the short time over which the experiment was run.

5.3 System description

FOAM (Forecasting Ocean Assimilation Model) is the Met Office's short range (0 to 6 day) operational open ocean forecasting system. Remotely sensed satellite SST (sea surface temperature) and in-situ SST data, profile temperature and salinity data, SLA (sea level anomaly) altimeter data and sea ice concentration data are assimilated in the NEMO (Nucleus for European Modelling of the Ocean) model using the analysis correction assimilation scheme. Data is assimilated into a global model at ¼º resolution and various nested models at 1/12º. The experiments below use only the global model. See Storkey et al 2010 for more details on FOAM. The operational system runs back 48 hours each day and assimilates all the available data in two 24 hour periods (day minus 1 and day minus 2). Running back an extra 24 hours means that data that arrive late can be used to improve the results. The results below are all taken from the day minus 2 period.

5.4 Method

In this study we perform an OSE (Observing System Evaluation); running an identical copy of the operational system global model with the same forcing and observations, with altimeter observations excluded. We compare the results with the system assimilating all the data in order to assess the impact of the data excluded. The "no altimeter" experiment was run for all of May 2011 starting from the same initial model fields as the operational run but then allowing the "no altimeter" experiment to evolve separately during that time.

There are 1078113 altimeter observations are available in May 2011. All are excluded in the "no altimeter" run.

5.5 Results and Discussion

The impact of excluding all altimeter data on global observation-minus-background statistics is shown in Table 5.1. There is a 16% increase in the RMS SSH error from 7.4 cm to 8.6 cm and an increase bias of 2 cm averaged over 1 month. The in-situ SST, AATSR SST, profile temperature and salinity suffer from somewhat increased RMS by 1.9%, 1.9%, 1.3% and 0.8%, respectively.

	Operational	No Altimeter
SST in-situ / ºC	0.628 (-0.117)	0.640 (-0.111)
SST AATSR / ºC	0.472 (-0.001)	0.481 (0.002)
SSH / m	0.074 (-0.002)	0.086 (-0.018)
Profile T / ºC	0.606 (-0.017)	0.614 (-0.017)
Profile S / psu	0.128 (-0.000)	0.129 (-0.000)
Sea ice concentration	0.043 (0.001)	0.043 (0.001)

Table 5.1. Summary observation minus background statistics, RMS (and mean in brackets) for different observation types accumulated globally over May 2011. For both runs we are comparing to all observations including all altimeter data.

In the previous month we tested excluding Jason-2. It is interesting to note that in that case the increase in the RMS for temperature and salinity observations was somewhat higher even though we were still assimilating the other altimeters. While we are not comparing the same month, this gives an indication that the other altimeters are not as beneficial to FOAM as Jason-2. After the OSEs were run we discovered that there was a fault in the upstream processing of altimeter data by AVISO which resulted in excessive small scale filtering of Jason-1 and Envisat altimeter data used in FOAM (but not Jason-2). This may explain the results of this OSE. We would need to repeat the OSE to confirm this.

A timeseries of the SSH observation-minus-background RMS and mean errors in Fig 5.1 shows a steady increase in the RMS and a steady decrease in the mean of the “No Altimeter” OSE relative to the operational run. Note the largest part of the RMS increase comes from an increase in the standard deviation. The reason for the mean bias is because the global model has a freshwater imbalance whereby the evaporation, precipitation and river inflow are not balanced. Without altimeter assimilation to correct the mean free surface height it rises by around 3cm over the month.

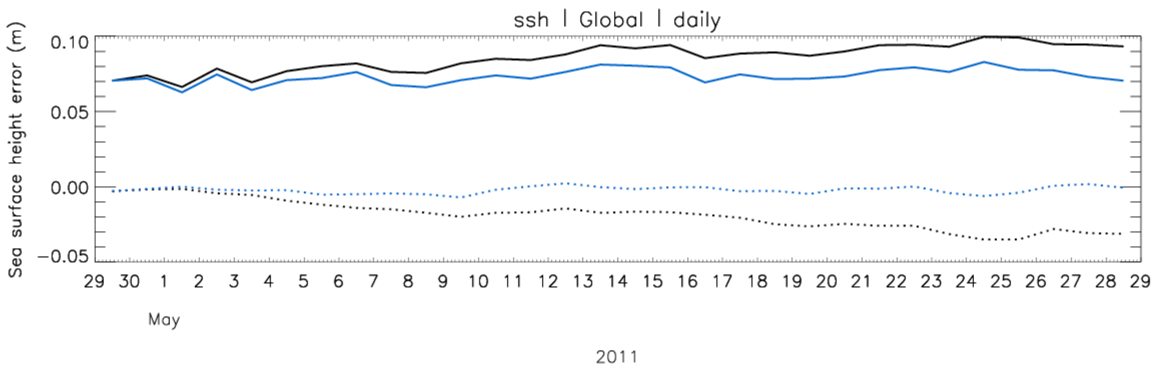

Fig 5.1. Observation minus background timeseries statistics. The black lines show results of the no altimeter run and the blue of the operational run. RMS errors are plotted as solid lines and mean errors are plotted as dotted lines.

a) (b)

The observation-minus-background temperature as a function of depth (Fig 5.2) shows a slight increase in RMS in the range of 0-200m. The increase is smaller than the result for the Jason-2 OSE, probably for the reasons discussed above.

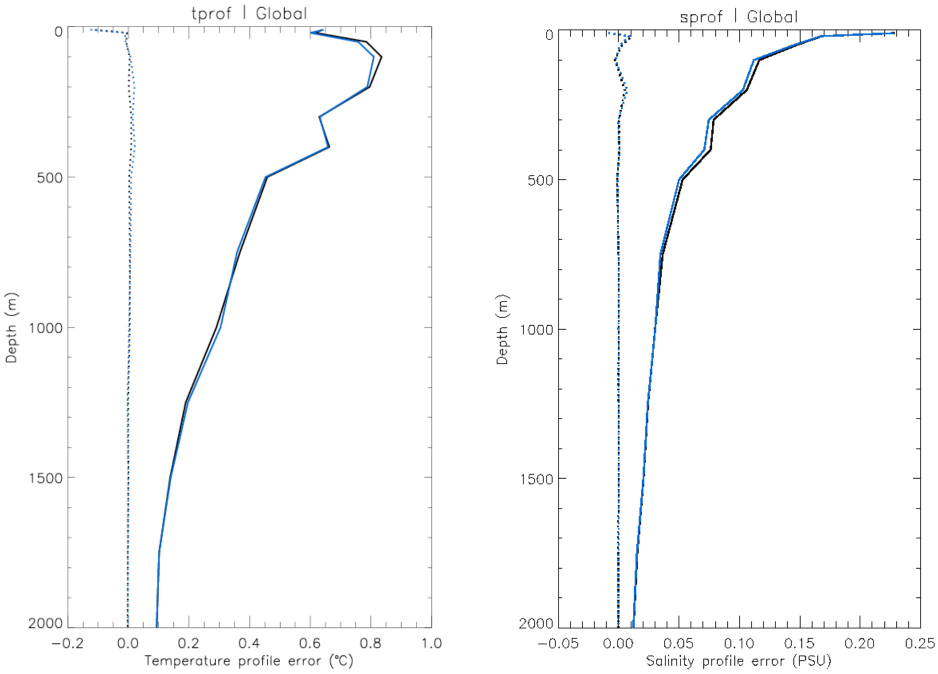

Fig 5.2. Observation minus background statistics for (a) temperature profile and (b) salinity profile data. The black lines show results for the no altimeter run and the blue for the operational run. RMS errors as a function of depth are plotted as solid lines and mean errors are plotted as dotted lines.

The drift in the model SSH is very evident in the difference plot of the model SSH at the end of the month between the operational and the all altimeter OSE (Fig 5.3). There are also very large (±20cm) differences in the mesoscale.

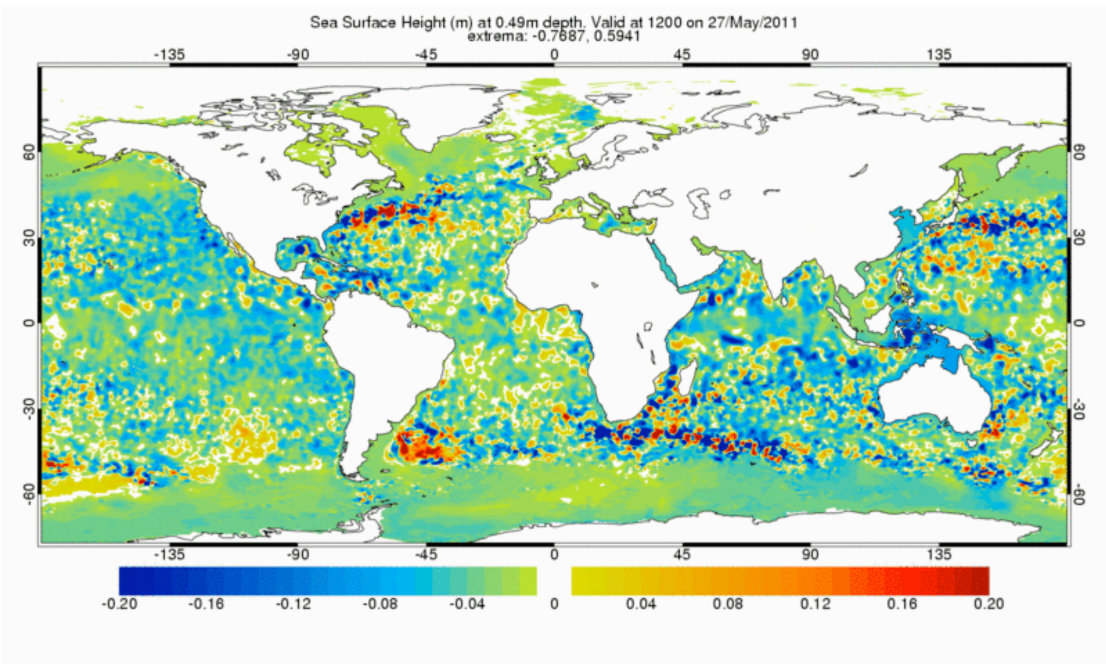

Fig 5.3. SSH difference (Operational minus “No altimeter”) in m. Derived from daily average fields at the end of altimeter OSE period.

The impact of removing all altimeters is seen in a difference map of the 100m temperature. At least ±2ºC mesoscale differences are seen in Fig 5.4. These are significantly more widespread than the equivalent plot from the Jason-2 OSE. As with the Jason-2 OSE there are very large changes in the tropical temperatures despite the relatively small SSH signal in those regions, presumably a consequence of the strong vertical gradient in temperature.

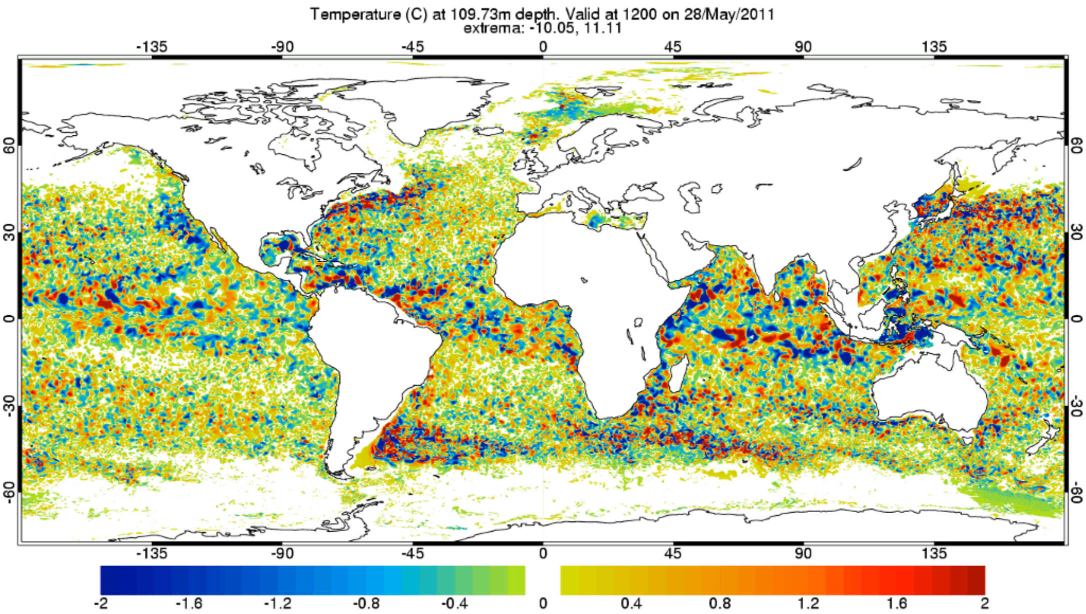

Fig 5.4. Temperature difference (Operational minus “No altimeter”) in ºC at 100m. Derived from daily average fields at the end of altimeter OSE period.

The effect of removing all altimeter data can also be seen in comparison of the two runs' velocities to that derived from drifter observations. The drifters are drogued at 15m depth. The model daily mean currents at 15m depth are compared to a velocity calculated from the drifter positions over that day (as in Blockley et al 2012). A number of QC checks are performed and any drifters which are known to have lost their drogue are excluded from the comparison. Table 5.2 shows the statistics of the model and observed velocity. The RMS error increases by 3% for the zonal and meridional velocity components. Time-series plots (not shown) indicate that the error increases in time so the statistics may underestimate the ultimate impact of not assimilating altimeter data.

	Operational	No altimeter
Zonal velocity (ms^{-1})	0.225 (-0.004)	0.231 (-0.003)
Meridional velocity (ms^{-1})	0.209 (-0.000)	0.216 (-0.001)

Table 5.2. Global summary of drifter velocity observation minus background statistics, RMS (and mean in brackets) for the u and v velocity component accumulated globally over May 2011.

It is interesting that the degradation of the fit to drifter currents is roughly the same whether Jason-2 data are excluded or all data are excluded. This is consistent with the comparisons to other statistics and indicates that at this time Jason-2 was the most beneficial to FOAM of all the altimeters.

5.6 References

Blockley, E. W.; Martin, M. J.; and Hyder, P. Validation of FOAM near-surface ocean current forecasts using Lagrangian drifting buoys, Ocean Sci., 8, 551-565, doi:10.5194/os-8-551-2012. 2012.

Storkey, D.; Blockley, E.W.; Furner, R.; Guiavarc'h, C.; Lea, D.; Martin, M.J.; Barciela, R.M.; Hines, A.; Hyder, P.; Siddorn, J.R. 2010. Forecasting the ocean state using NEMO: The new FOAM system. Journal of Operational Oceanography, 3(1), pp 3-15.

5.7 Supplementary information

	Operational	No Altimeter
SST in-situ / ºC	0.688 (-0.100)	0.696 (-0.093)
SST AATSR / ºC	0.534 (-0.031)	0.546 (-0.022)
SSH / m	0.070 (-0.011)	0.084 (-0.024)
Profile T / ºC	0.715 (-0.024)	0.729 (-0.019)
Profile S / psu	0.244 (0.003)	0.244 (0.005)
Sea ice concentration	0.038 (0.001)	0.037 (0.001)

Table 5.3. North Atlantic summary observation minus background statistics, RMS (and mean in brackets) for different observation types accumulated in the north Atlantic over May 2011.

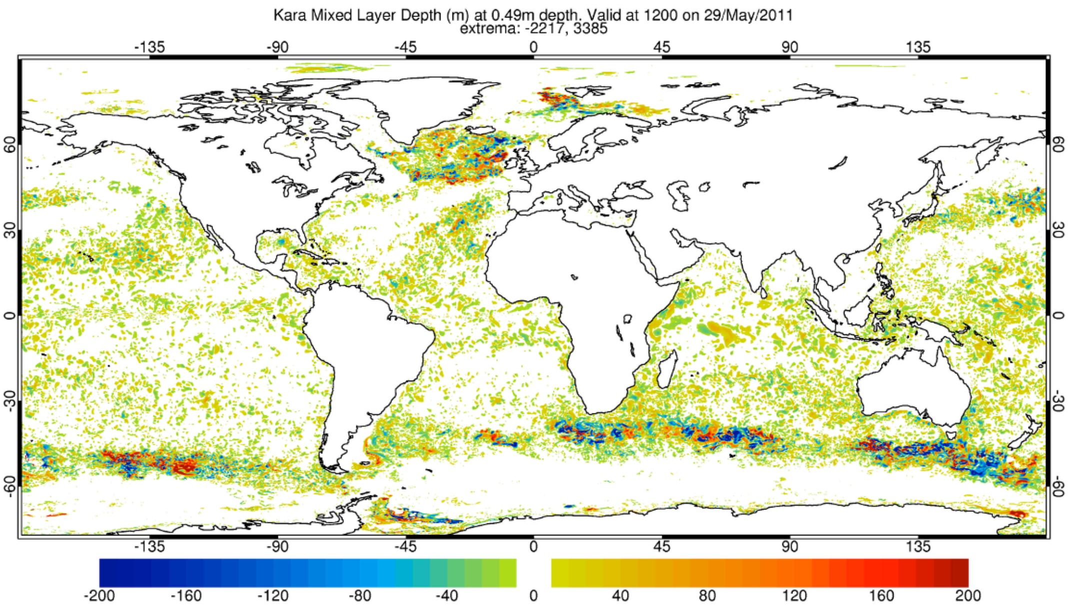

Fig 5.5. Kara mixed layer depth difference (Operational minus "No altimeter") in m. Derived from daily average fields at the end of altimeter OSE period.

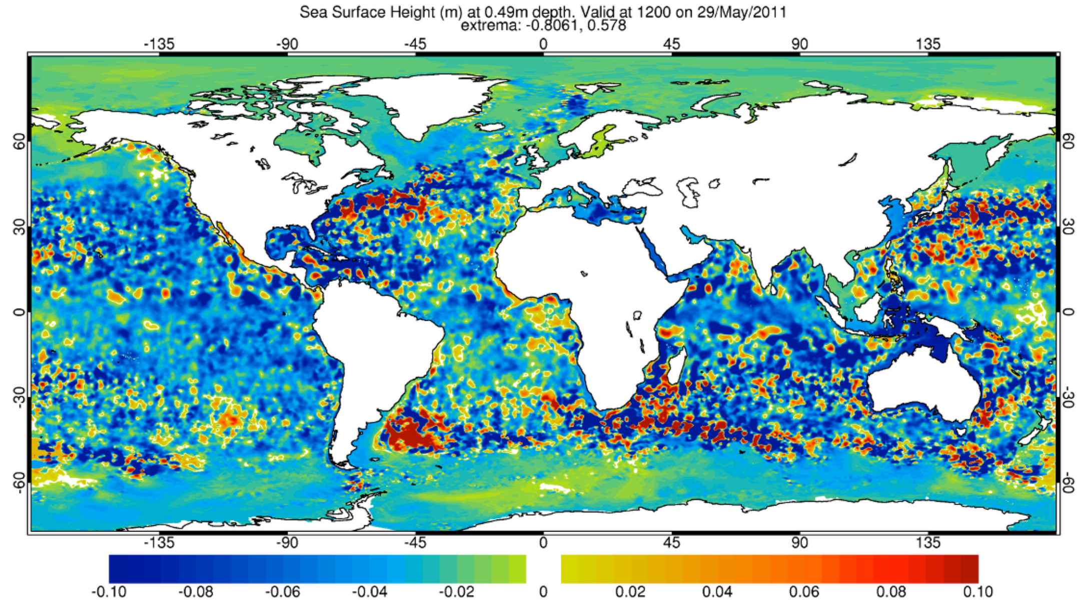

Fig 5.6. SSH difference (Operational minus “No altimeter”) in m. Derived from daily average fields at the end of altimeter OSE period.

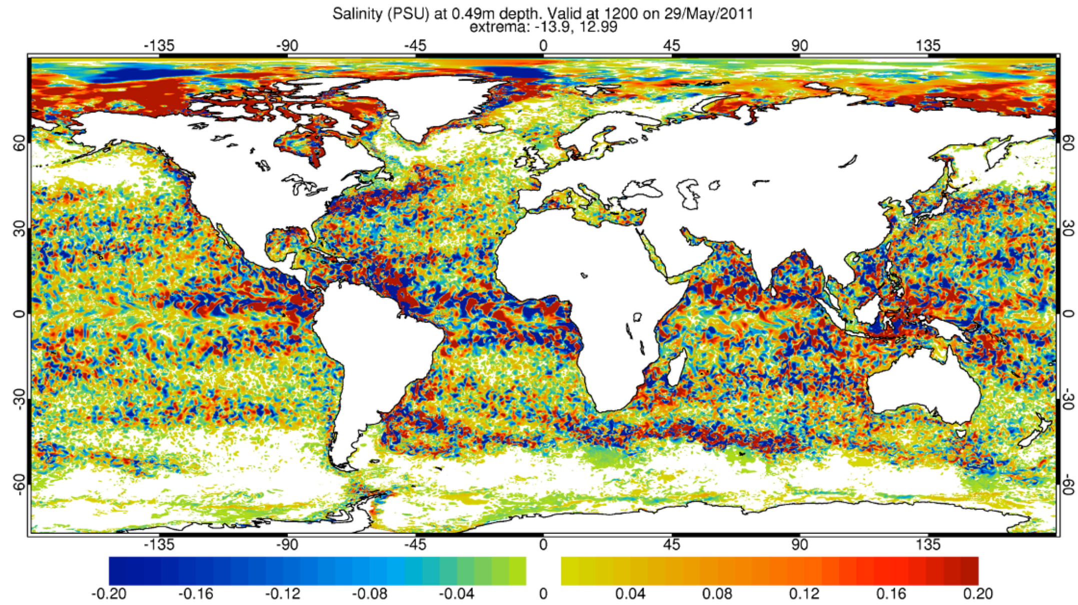

Fig 5.7. Salinity difference (Operational minus “No altimeter”) in psu at the surface. Derived from daily average fields at the end of altimeter OSE period.

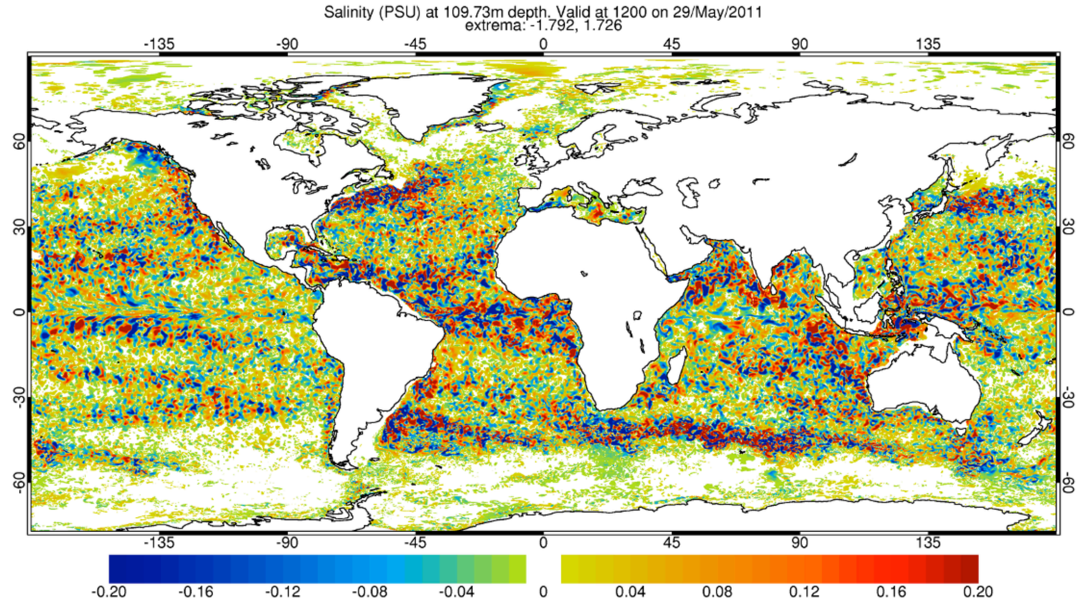

Fig 5.8. Salinity difference (Operational minus “No altimeter”) in psu at 100m. Derived from daily average fields at the end of altimeter OSE period.

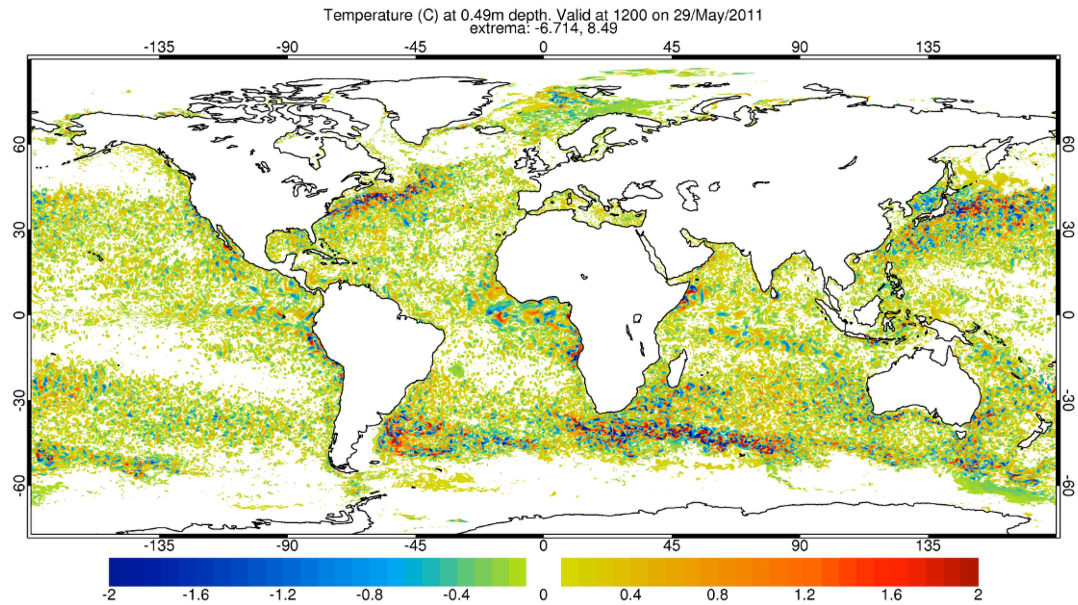

Fig 5.9. Temperature difference (Operational minus “No altimeter”) in ºC at the surface. Derived from daily average fields at the end of altimeter OSE period.

6. Observation Impact Statement AVHRR (NOAA & METOP) - June 2011

D. Lea. Met Office, Exeter, UK

For GODAE OceanView

6.1 Summary

A parallel version of the FOAM operational system was run, during June 2011, withholding all AVHRR (NOAA 18 and METOP-A) observations in order to assess the impact of these data on the system. The data form 33% of the SST observations on average though they are greater than 50% near the coasts and at low latitudes. In these locations there can be significant impacts around ±1ºC. These changes are seen down to the base of the mixed layer, but there is little or no effect below this. There is little impact on most other model fields, for example SSH is little changed.

6.2 Disclaimer

The results are derived only from the FOAM system. Any statements about the information content of an observing system may be strongly dependent on the model and data assimilation system. The impact of the observations may also be underestimated due to the short time over which the experiment was run.

6.3 System description

FOAM (Forecasting Ocean Assimilation Model) is the Met Office's short range (0 to 6 day) operational open ocean forecasting system. Remotely sensed satellite SST (sea surface temperature) and in-situ SST data, profile temperature and salinity data, SLA (sea level anomaly) altimeter data and sea ice concentration data are assimilated in the NEMO (Nucleus for European Modelling of the Ocean) model using the analysis correction assimilation scheme. Data is assimilated into a global model at ¼º resolution and various nested models at 1/12º. The experiments below use only the global model. See Storkey et al 2010 for more details on FOAM. The operational system runs back 48 hours each day and assimilates all the available data in two 24 hour periods (day minus 1 and day minus 2). Running back an extra 24 hours means that data that arrive late can be used to improve the results. The results below are all taken from the day minus 2 period.

6.4 Method

In this study we perform an OSE (Observing System Evaluation); running an identical copy of the operational system with the same forcing and observations, with AVHRR observations excluded. We can then compare the results with the system assimilating all the data in order to assess the impact of the data excluded. The "no AVHRR" experiment was run for all of June 2011 starting from the same initial model fields as the operational run but then allowing the "no AVHRR" experiment to evolve separately during that time.

For the June 2011 period, there are 2,429,832 NOAA AVHRR observations and 6,421,770 METOP AVHRR points assimilated into FOAM. There are total of 26,570,218 observations. This means we remove 33% of the SST observations in no AVHRR run. Other SST datasets are assimilated these are AASTR and AMSRE. The geographic distribution of the data removed is not uniform as can seen in Fig 6.1 which shows the percentage in data that is AVHRR as a function of location. In the less cloud covered regions and around the coasts AVHRR is an important dataset with 40% or more of the SST data coming from AVHRR.

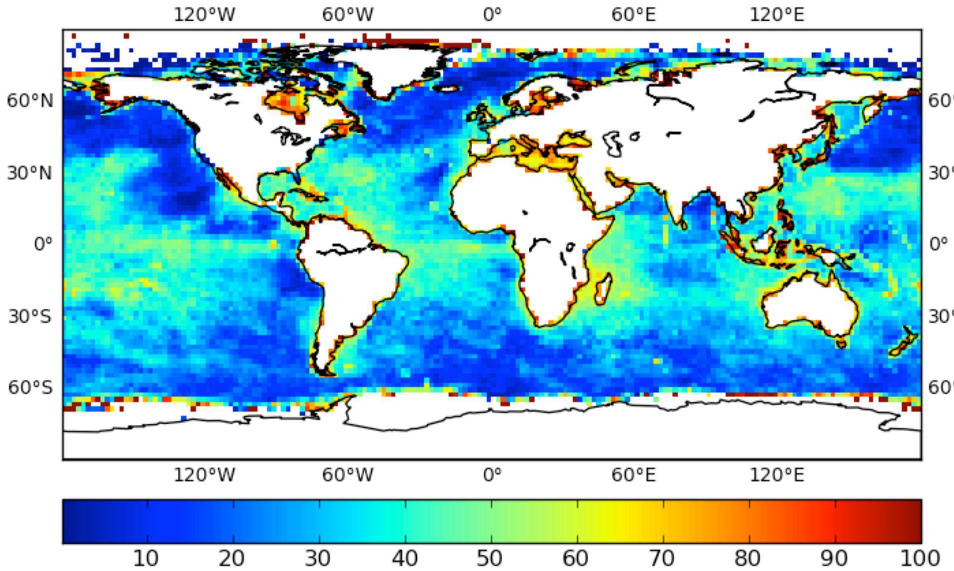

Fig 6.1. Percentage of SST observations that are AVHRR in 2º by 2º bins for the "No AVHRR" OSE period.

6.5 Results and Discussion

Summary global monthly average observation-minus-background statistics are shown in Table 6.1. The fit to AVHRR and AATSR data is improved when we assimilate that data by 1.7% and 2.8% respectively. A little care is needed with these comparisons since the data are SST bias corrected relative to AATSR inside the data assimilation system. There is little impact on the SSH, profile temperature and salinity from not assimilating AVHRR.

	Oper	No AVHRR
SST in-situ / degC	0.631 (-0.119)	0.617 (-0.108)
SST AVHRR / degC	0.537 (-0.202)	0.546 (-0.196)
SST AATSR / degC	0.502 (0.002)	0.516 (0.011)
SSH / m	0.076 (-0.004)	0.076 (-0.004)
Profile T / degC	0.619 (-0.020)	0.621 (-0.018)
Profile S / psu	0.121 (0.004)	0.120 (0.004)

Table 6.1. Summary observation minus background statistics, RMS (and mean in brackets) for different observation types accumulated globally over June 2011. For both runs we are comparing to all observations including AVHRR data.

Even though there is much other SST data assimilated there are still significant differences, up to 1ºC, in the model SST after 1 month (Fig 6.2). The biggest differences are seen locally in regions where the AVHRR observations are the greater part of the total SST observations (Fig 6.1). Areas with strong AVHRR impacts include the coastal regions, the Mediterranean, the equatorial regions and the west coast of Africa, all where the fraction of SST observations which are AVHRR is over 50%.

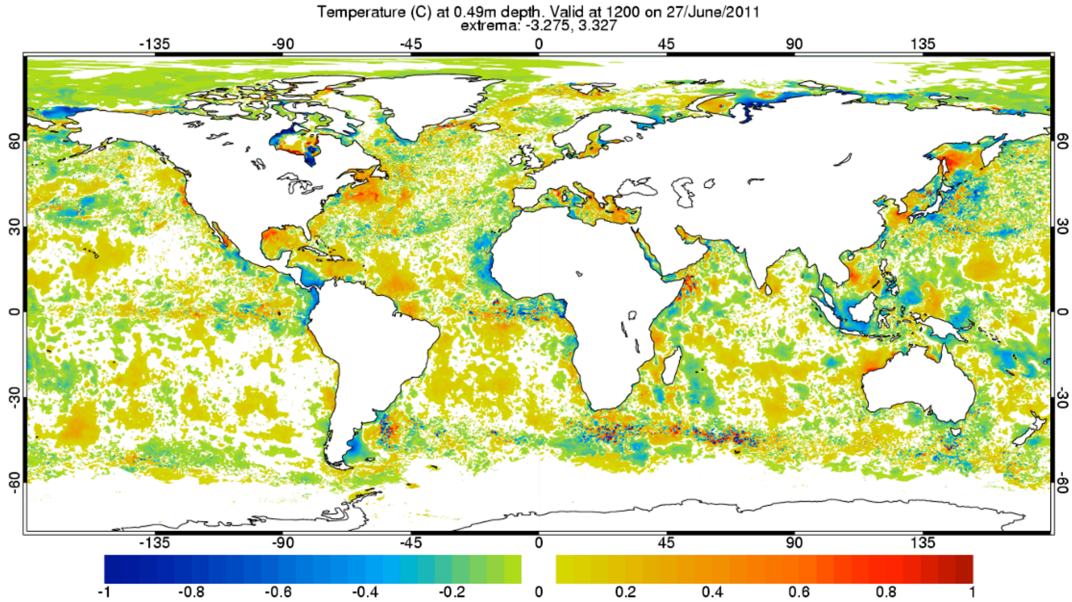

Fig 6.2. Temperature difference (Operational minus “No AVHRR”) in ºC at the surface. Derived from daily average fields at the end of AVHRR OSE period.

At 100m depth the temperature differences are mostly limited to regions where the mixed layer is 100m deeper which is the mostly in the southern hemisphere in June. The SST assimilation scheme projects the increments resulting from SST data down through the mixed layer so this result is not too surprising. The differences on the equator are likely due to model mixing which is perhaps spuriously caused by the assimilation (Balmaseda et al. 2007). This is mitigated by the pressure correction bias correction scheme (Bell et al 2004).

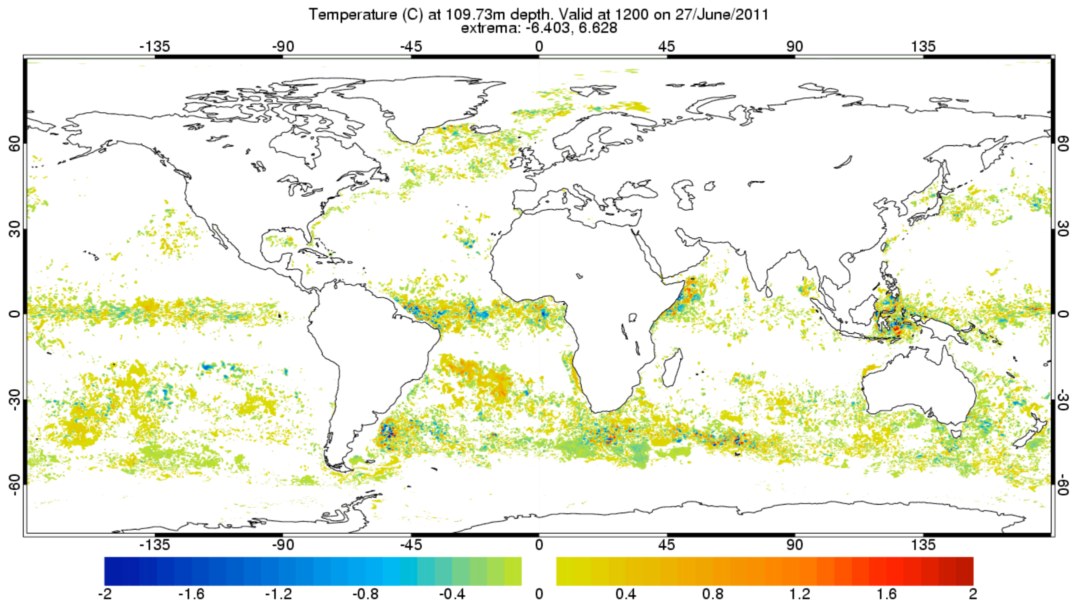

Fig 6.3. Temperature difference (Operational minus “No AVHRR”) in ºC at 100m. Derived from daily average fields at the end of AVHRR OSE period.

The differences in the other model fields are generally small. The surface salinity difference (Fig 6.4) shows small scale differences in the equatorial region and a curious large change in the Arctic salinity (assimilating AVHRR data makes the Arctic saltier. This is associated with a decrease in the Arctic temperature (Fig 6.2) when we assimilate AVHRR data which means there is less melting of ice and therefore less freshening of the surface water. Note it appears that the some of data may be suspect in the Arctic particularly AASTR which had many data points apparently in the ice pack.

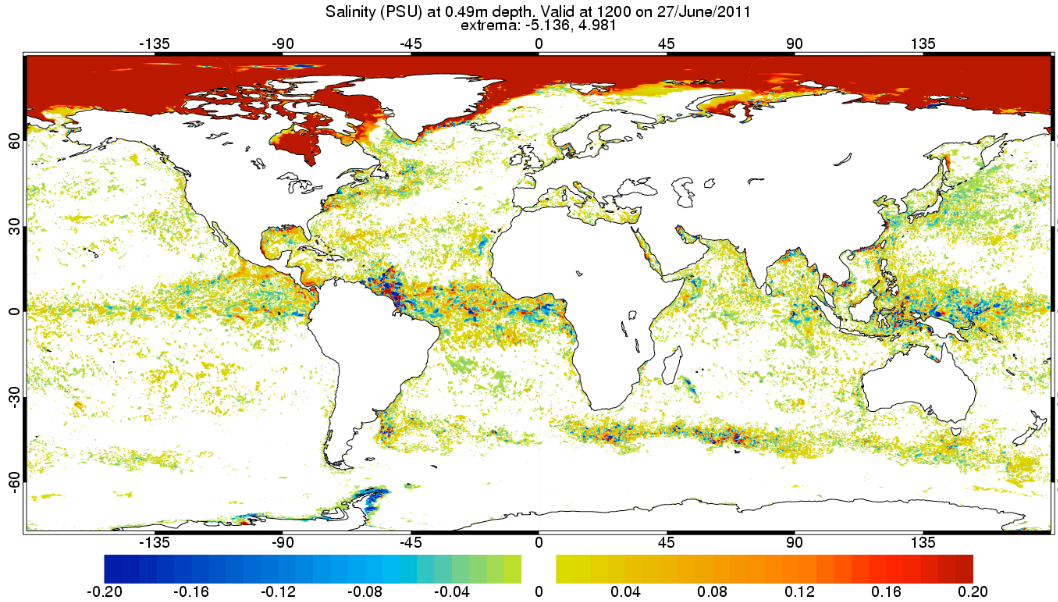

Fig 6.4. Salinity difference (Operational minus "No AVHRR") in psu at the surface. Derived from daily average fields at the end of AVHRR OSE period.

6.5 Reference

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Bell, M. J.; Martin, M. J.; and Nichols, N. K. Assimilation of data into an ocean model with systematic errors near the equator. *Q. J. R. Meteorol. Soc.* **130**, pp. 873–893. 2004.

Storkey, D.; Blockley, E.W.; Furner, R.; Guiavarc'h, C.; Lea, D.; Martin, M.J.; Barciela, R.M.; Hines, A.; Hyder, P.; Siddorn, J.R. 2010. Forecasting the ocean state using NEMO: The new FOAM system. Journal of Operational Oceanography, 3(1), pp 3-15.

6.6 Supplementary information

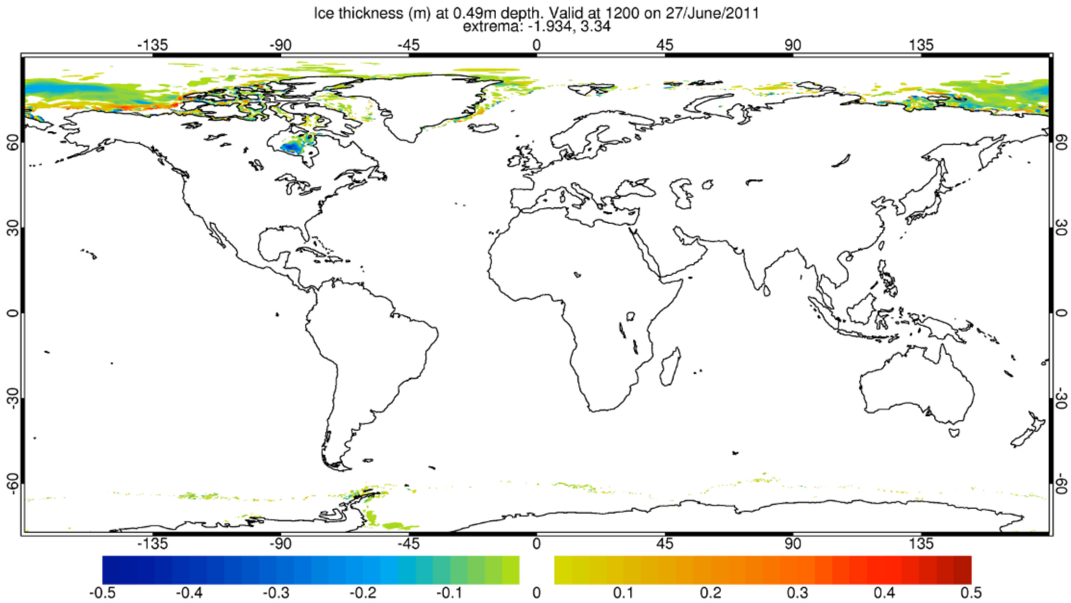


Fig 6.5. Ice thickness difference (Operational minus "No AVHRR") in m. Derived from daily average fields at the end of AVHRR OSE period.

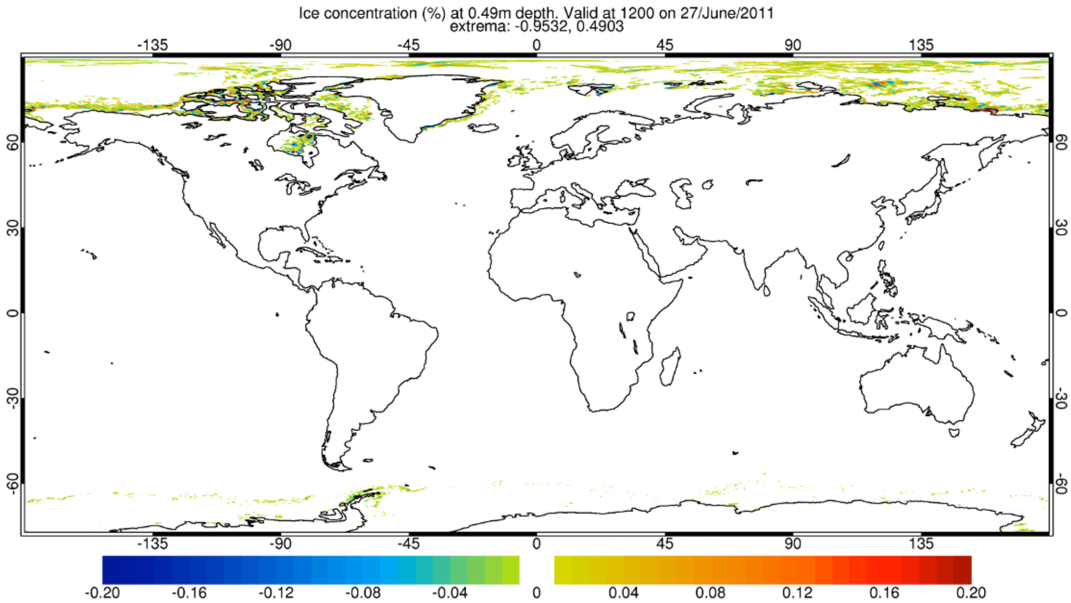


Fig 6.6. Ice concentration difference (Operational minus "No AVHRR"). Derived from daily average fields at the end of AVHRR OSE period.

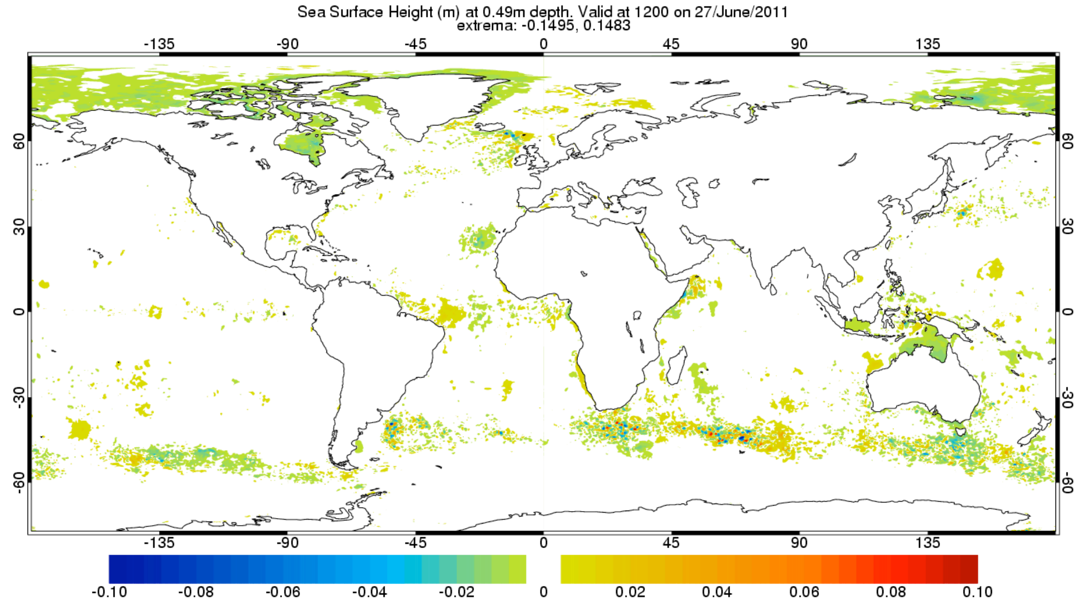


Fig 6.7. SSH difference (Operational minus “No AVHRR”) in m. Derived from daily average fields at the end of AVHRR OSE period.

	Operational	No AVHRR
Zonal velocity (ms^{-1})	0.230 (0.006)	0.230 (0.006)
Meridional velocity (ms^{-1})	0.216 (0.005)	0.216 (0.005)

Table 6.2. Global summary of drifter velocity observation minus background statistics, RMS (and mean in brackets) for the u and v velocity component accumulated globally over June 2011. This shows only no significant differences between the operational and OSE run.

7. Observation Impact Statement for Argo - July 2011

D. Lea. Met Office, Exeter, UK

For GODAE OceanView

7.1 Summary

A parallel version of the FOAM operational system was run, during July 2011, withholding all Argo temperature and salinity observations in order to assess the impact of these data on the system. Argo data form 75% of the total subsurface temperature and 85% of salinity observations assimilated into FOAM. Withholding Argo data leads to a 5% increase in the RMS observation-minus-background differences. We also see impacts on other model variables. For instance, there are large scale changes of ±5cm in SSH.

7.2 Disclaimer

The results are derived only from the FOAM system. Any statements about the information content of an observing system may be strongly dependent on the model and data assimilation system. The impact of the observations may also be underestimated due to the short time over which the experiment was run.

7.3 System description

FOAM (Forecasting Ocean Assimilation Model) is the Met Office's short range (0 to 6 day) operational open ocean forecasting system. Remotely sensed satellite SST (sea surface temperature) and in-situ SST data, profile temperature and salinity data, SLA (sea level anomaly) altimeter data and sea ice concentration data are assimilated in the NEMO (Nucleus for European Modelling of the Ocean) model using the analysis correction assimilation scheme. Data is assimilated into a global model at ¼º resolution and various nested models at 1/12º. The experiments below use only the global model. See Storkey et al 2010 for more details on FOAM. The operational system runs back 48 hours each day and assimilates all the available data in two 24 hour periods (day minus 1 and day minus 2). Running back an extra 24 hours means that data that arrive late can be used to improve the results. The results below are all taken from the day minus 2 period.

7.4 Method

In this study we perform an OSE (Observing System Evaluation); running an identical copy of the operational system with the same forcing and observations, with Argo observations excluded. We can then compare the results with the system assimilating all the data in order to assess the impact of the data excluded. The "no Argo" experiment was run for all of July 2011 starting from the same initial model fields as the operational run but then allowing the "no Argo" experiment to evolve separately during that time.

Fig 7.1a shows the locations of temperature profile observations in July 2011. These observations include Argo profiles, other CTDs, moored buoys and XBTs. Out of 868576 individual subsurface temperature or salinity observations 652758, or 75%, are Argo observations. Out of 744156 individual salinity observations 634272 or 85% are Argo observations. Fig 7.1b shows the distribution of Argo observations in July 2011.

(b)

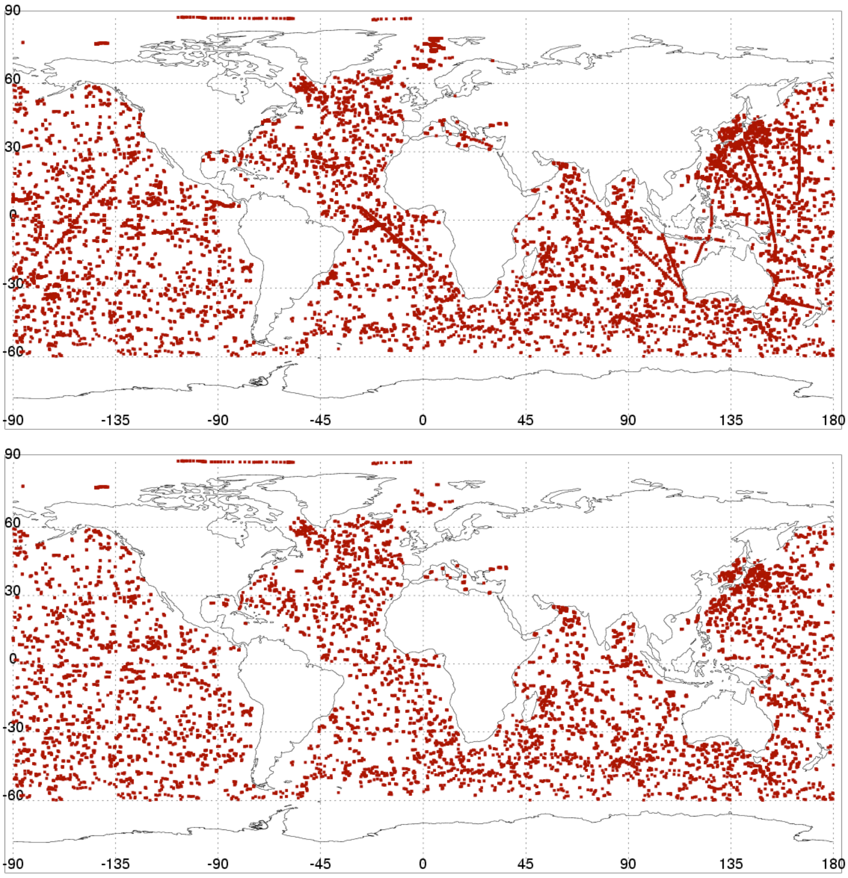


Fig 7.1. (a) Locations of all the temperature profile data assimilated into the operational system in July 2011, 25733 profiles in total. (b) Locations of the Argo data which are excluded in the “no Argo” run, 8866 profiles in total.

7.5 Results and Discussion

Given that Argo data is the predominating observing system for the subsurface ocean it is not surprising that assimilating Argo data has a significant impact on globally. Summary global and monthly average observation-minus-background statistics are shown in Table 7.1. The fit to both profile temperature and salinity is 5% worse without Argo. Strangely the fit to in-situ SST is 2% better without Argo data. A possible reason for this is that there is a bias between Argo data and the in-situ SST data. We have no explanation for this result at this time. It should be noted that 1 month may not be long enough to see the full impact of removing Argo data. Previous experience in FOAM suggests that the subsurface can take up to 1 year to spin-up (or spin-down).

	Operational	No Argo
SST in-situ / ºC	0.671 (-0.113)	0.655 (-0.129)
SST AATSR / ºC	0.524 (0.014)	0.527 (0.011)
SSH / m	0.074 (-0.004)	0.073 (-0.004)
Sea ice conc / fraction	0.056 (0.003)	0.055 (0.003)
Profile T / ºC	0.680 (-0.027)	0.728 (-0.025)
Profile S / psu	0.132 (0.001)	0.139 (0.004)

Table 7.1. Summary observation minus background statistics, RMS (and mean in brackets) for different observation types accumulated globally over July 2011. For both runs we are comparing to all observations including Argo.

The impact of the Argo data in model temperature is very significant particularly below the surface. In the mixed layer and at the surface the temperature is constrained by the assimilation of SST data. The model level at 29.44 m depth is below the mixed layer in much of the northern hemisphere in July, but in the southern hemisphere this is well within the mixed layer. Thus there is a much greater impact at the end of July from removing Argo data in the north (~±2 ºC) than in the south (<±0.5 ºC) at 29.44 m (Fig 7.2a). As we move to 100 m larger parts of the southern hemisphere are below the mixed layer and the impact of Argo data is consequently greater (Fig 7.2b).
Another notable feature is the large effect of Argo data near Japan which is associated with a relatively high density of Argo floats.

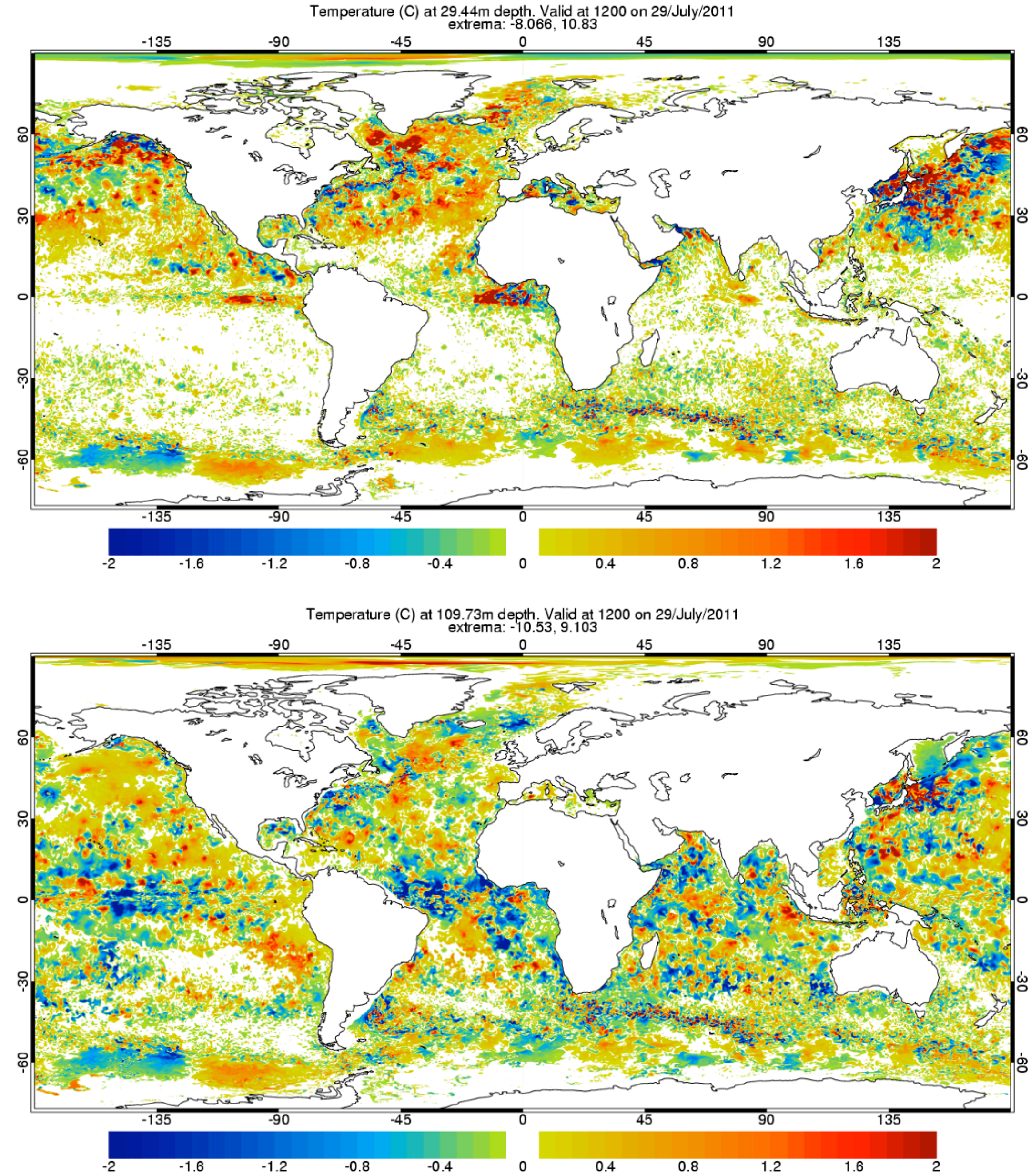


Fig 7.2. Map of the temperature difference (Operational minus “No Argo”) in ° C at (a) 29.44 m depth and (b) 109.73 m depth. Derived from daily average fields at the end of Argo OSE period.

We do not currently assimilate remotely sensed surface salinity data from SMOS or Aquarius, so there is typically very little salinity data apart from Argo. Consequently the impact on the model salinity of removing Argo is significant even at the surface (Fig 7.3a).

The significant impact on the surface salinity in the Arctic is surprising. There a few Argo floats in the Arctic (Fig 7.1b) which have some impact on the salinity at 100 m but the impact at the surface seems disproportionate. A possible cause may be a feedback with the LIM ice model where the change in the surface temperature affects the ice concentration resulting in further changes in the salinity.

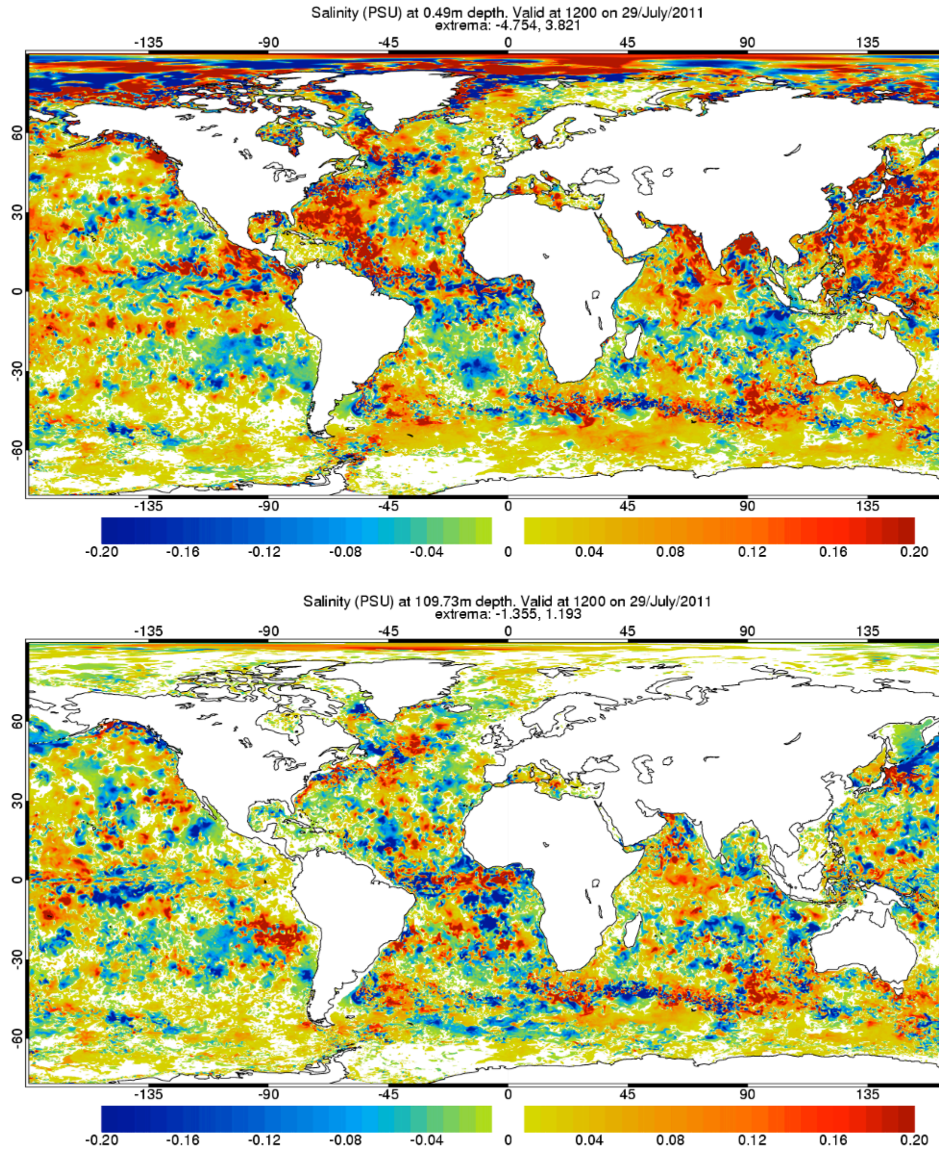


Fig 7.3. Maps of the salinity differences in psu at (a) the surface and (b) 109.73m depth (Operational minus “No Argo”). Derived from daily average fields at the end of Argo OSE period.

The removal of Argo data also has a significant impact on other model variables. Significant large scale changes in SSH of up to ±5 cm occur (Fig 7.4) despite assimilation of altimeter data. Presumably this is the result of model biases, perhaps a drift in the water mass properties, which cannot be corrected from altimeter data alone.

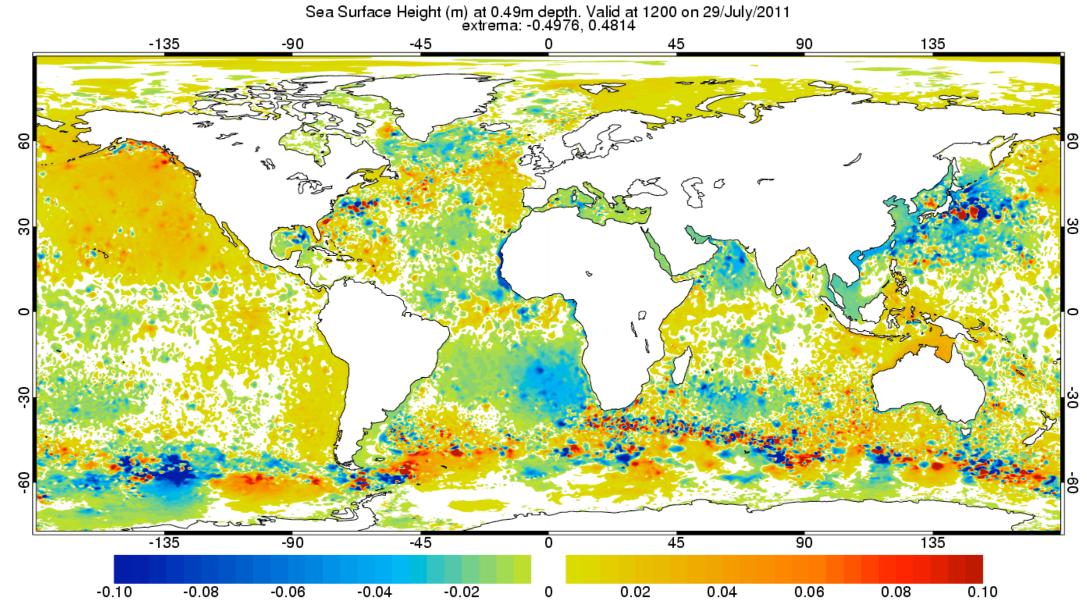


Fig 7.4. Map of the sea surface height difference (Operational minus “No Argo”) in m. Derived from daily average fields at the end of Argo OSE period.

7.6 Reference

Storkey, D.; Blockley, E.W.; Furner, R.; Guiavarc'h, C.; Lea, D.; Martin, M.J.; Barciela, R.M.; Hines, A.; Hyder, P.; Siddorn, J.R. 2010. Forecasting the ocean state using NEMO: The new FOAM system. Journal of Operational Oceanography, 3(1), pp 3-15.

(a) **(b)**

7.8 Supplementary information

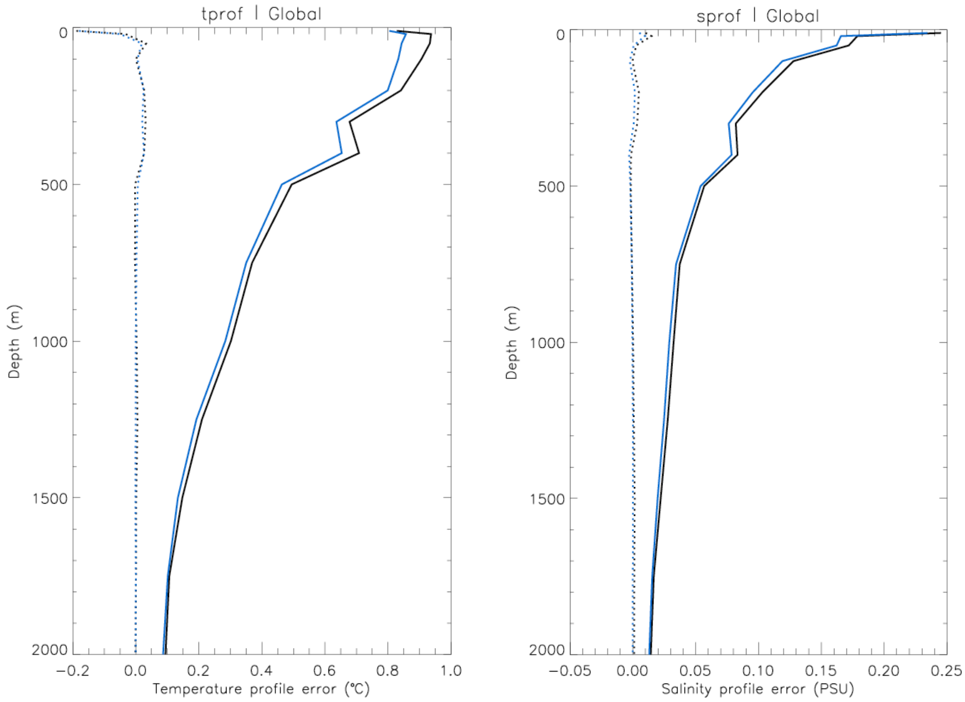


Fig 7.5. Observation minus background statistics, RMS for (a) temperature profile and (b) salinity profile data. The black lines show results for the no Argo run and the blue for the operational run. RMS errors as a function of depth are plotted as solid lines and mean errors are plotted as dotted lines.

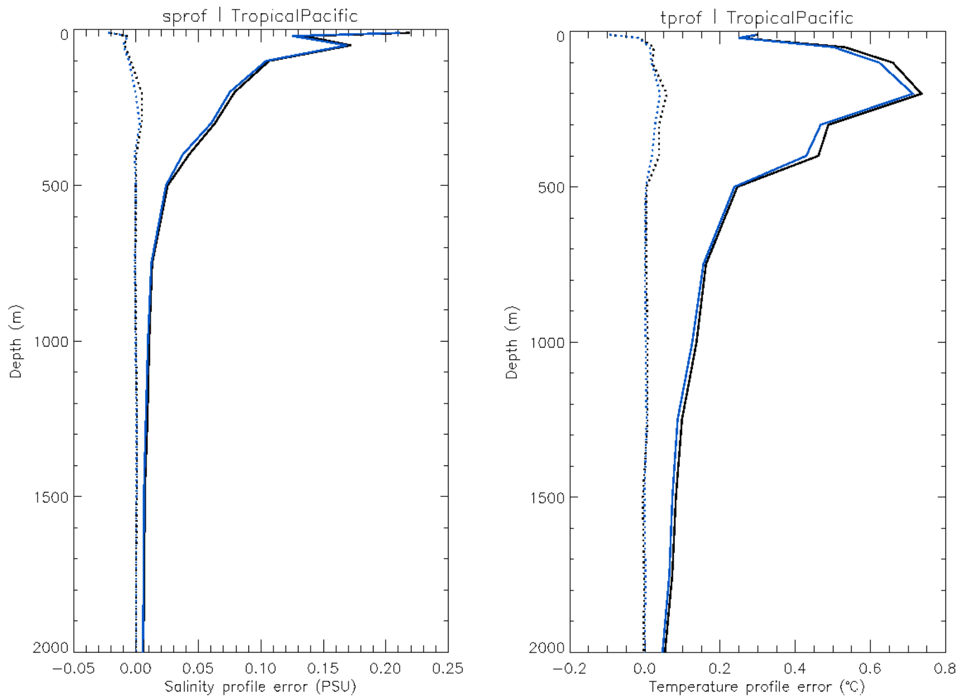


Fig 7.6. Observation minus background statistics, RMS for (a) temperature profile and (b) salinity profile data in the Tropical Pacific. The black lines show results for the no Argo run and the blue for the operational run. RMS errors as a function of depth are plotted as solid lines and mean errors are plotted as dotted lines.

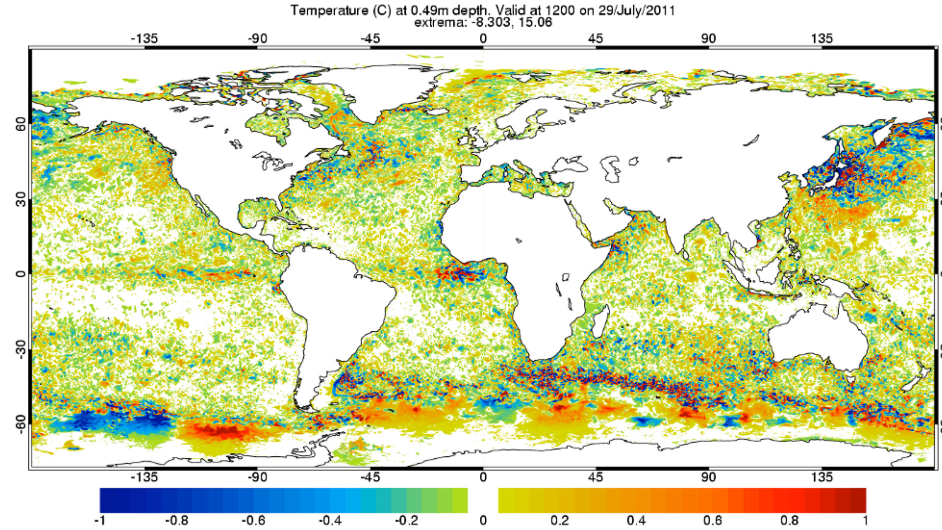


Fig 7.7. Map of the temperature difference (Operational minus “No Argo”) in ºC at the surface. Derived from daily average fields at the end of Argo OSE period.

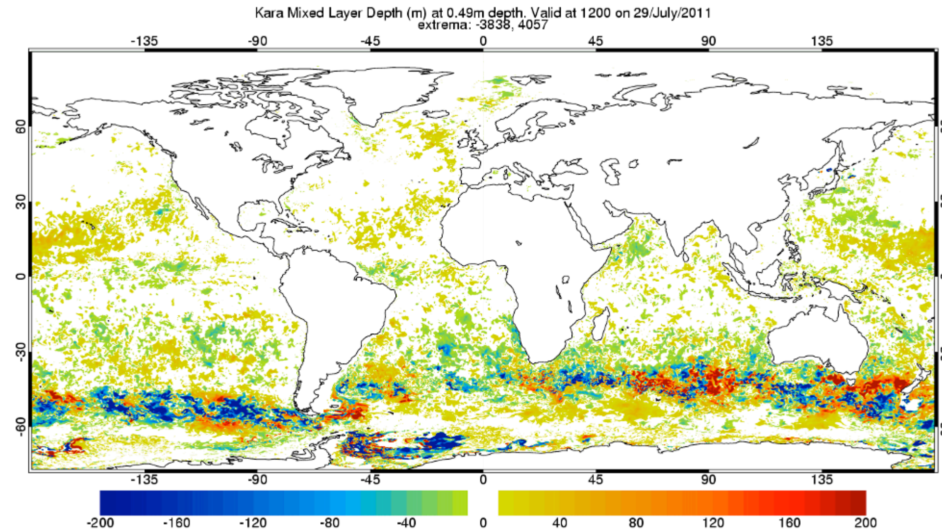
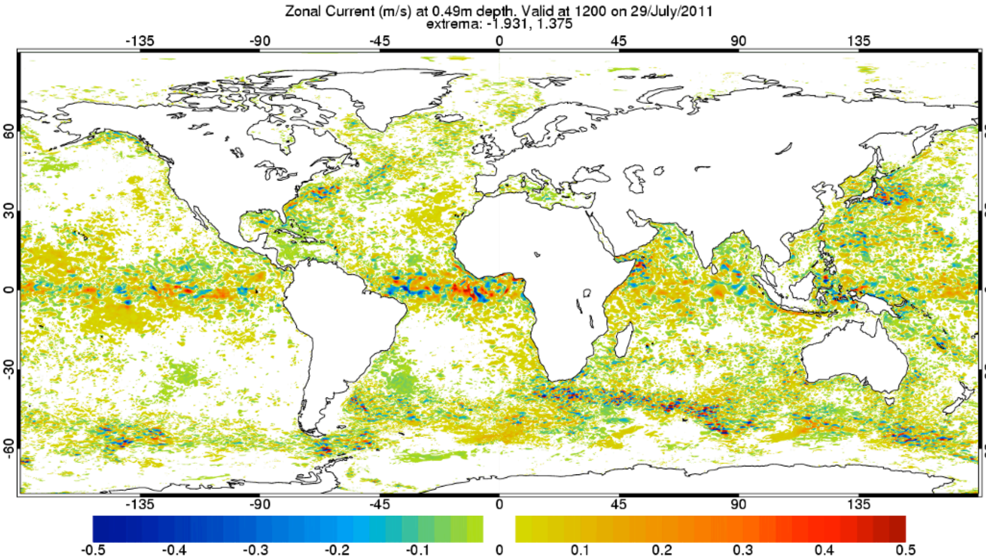


Fig 7.8. Map of the Kara mixed layer depth difference (Operational minus “No Argo”) in m. Derived from daily average fields at the end of Argo OSE period.



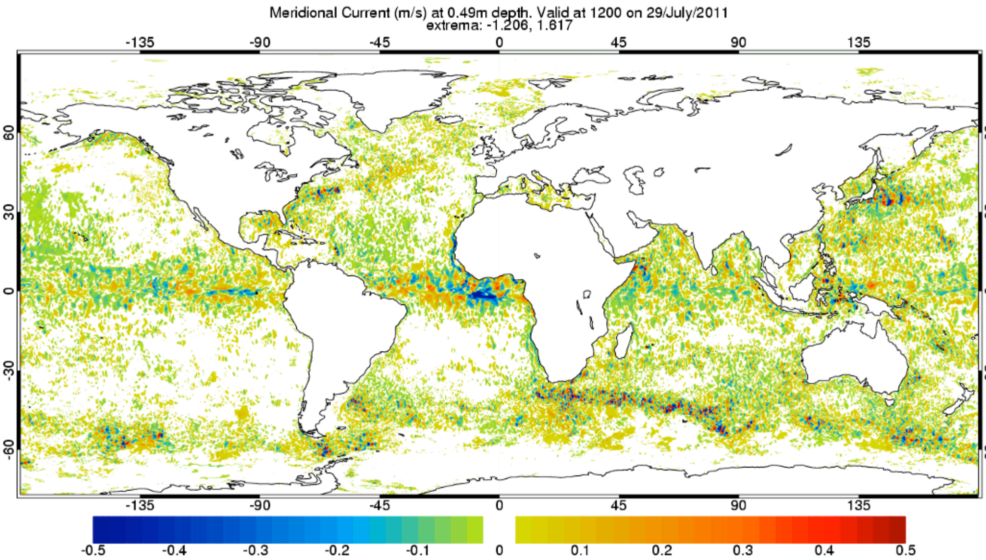


Fig 7.9. Maps of the (a) zonal and (b) meridional current difference (Operational minus “No Argo”) in m s^{-1}. Derived from daily average fields at the end of Argo OSE period.

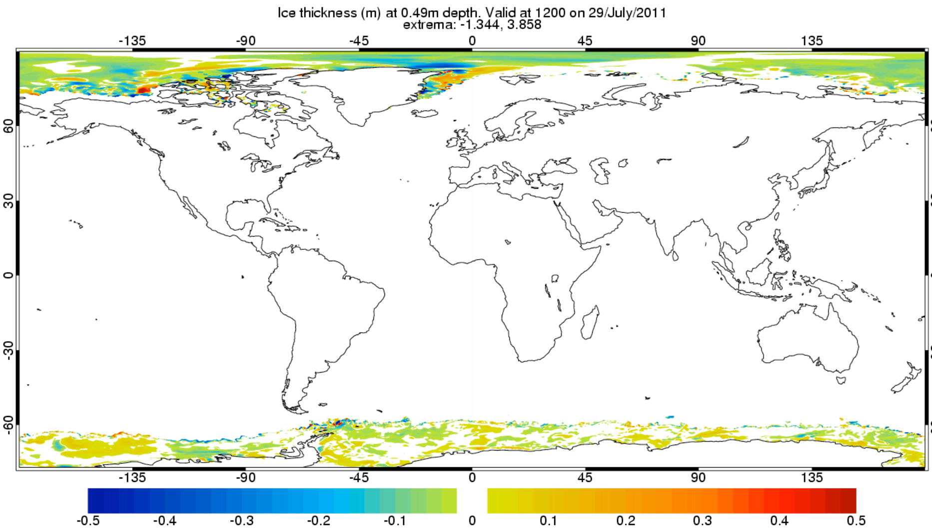


Fig 7.10. Map of the ice thickness difference (Operational minus "No Argo") in m. Derived from daily average fields at the end of Argo OSE period.

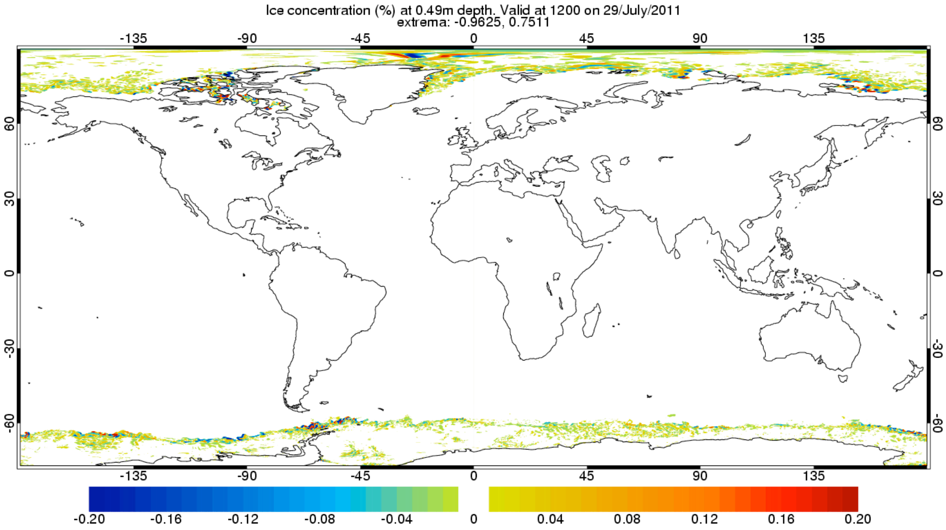


Fig 7.11. Map of the ice concentration difference (Operational minus "No Argo"). Derived from daily average fields at the end of Argo OSE period.

	Operational	No Argo
Zonal velocity (ms^{-1})	0.232 (-0.001)	0.233 (-0.002)
Meridional velocity (ms^{-1})	0.213 (0.012)	0.215 (0.012)

Table 7.2. Global summary of drifter velocity observation minus background statistics, RMS (and mean in brackets) for the u and v velocity component accumulated globally over Jul 2011. This shows only negligible differences between the operational and OSE run.

8. Summary/conclusions

In order to assess the impact of different observing systems we have performed a number of observing system experiments with the operational FOAM system. These involve running a copy of the FOAM operational suite and excluding a particular observing system for a period of 1 month. In February 2011 XBT was excluded, in March 2011: TAO/TRITON, in April 2011: Jason-2, in May 2011: all altimeter, in June 2011: AVHRR, in July 2011: Argo.

The main result is that the observing network provides a good degree of complementary information. XBT data while it has little global impact has considerable and persistent (at least 1 month) impact locally. TAO/TRITON has a big impact in the Tropical Pacific, and these data are complemented by Argo data which have global but sparser coverage and consequently lower impact in the Tropics. Altimeter data has a strong impact on the mesoscale unmatched by other data types. This is evident in the small scale changes in 3D model temperature and salinity and when altimeter data is excluded there is a notable degradation in the fit to the mesoscale dominated drifter surface currents. Such an impact on the fit to surface currents is not seem with other observation types. Though, there is a some evidence that excluding Argo data ultimately degrades the fit to drifter currents. It may be that biases in the temperature and salinity, which develop when Argo data are not assimilated, prevent the model from producing a good fit to the altimeter data. We can also see mesoscale structures in the AVHRR SST data, however FOAM is unable to use this to directly correct the circulation and so there is no impact seen on the fit to drifter currents. The AVHRR SST data impact and value is largely in temperature near the surface in the mixed layer. It is clear that there is some redundancy of the SST data particularly in cloud free regions, however this does have the benefit of making the system more robust to loss of a particular satellite, for example.

One conclusion of this work is that many of the impacts of removing the data take some time to become fully evident. So it may be useful to perform longer OSEs in future in order to see the full impact of removing a particular data type. Though performing longer OSEs is of course costly since each requires a full run of the system.

One main weakness of the work is that it is specific to the FOAM system. This is slowly being addressed as other GODAE partners begin to perform their own OSEs. This will allow much more robust statements about the information content of particular observing systems on ocean forecasting systems in general since we will be testing them in different models and different data assimilation systems.

As the observing system and the FOAM system changes in future, we will need to rerun the OSEs since the results are particular to the observing network, model and data assimilation used at the time. This motivates future work which may investigate the correlation of other observation information metrics, which may be cheaper to calculate. This will allow real time assessment of the impact of the observing network without the expense of running many OSEs.

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