AtlantOS

Project	AtlantOS – 633211
Deliverable number	8.5
Deliverable title	Reanalysis for MSFD
Description	[see DoA]
Work Package number	8
Work Package title	Societal benefits from observing/information systems
Lead beneficiary	Met Office
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Submission data	06 October 2017
Due date	1 October 2017
Comments	

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement nº 633211.

Last updated: 06 October 2017

Reanalysis for MSFD

This report gives a brief summary of progress to date in Task 8.6 of AtlantOS. At the time of writing (September 2017) results are being written up in a paper for the peer-reviewed literature (Tinker et al., in prep.), expected to be submitted in Autumn 2017. To maintain the confidentiality of the peer review process only a brief summary of the results of the paper are presented here. The paper will be linked to this deliverable report as soon as it is published. In the mean time access to the paper while under review may be requested from the lead authors of this report at jonathan.tinker@metoffice.gov.uk and richard.wood@metoiffice.gov.uk .

Motivation and overall plan

Monitoring environmental quality indicators for MSFD, and sustainable management of fisheries, require the best possible estimates of the three-dimensional state of the shelf seas, now and in the recent past (reanalyses).
AtlantOS Task 8.6 is a pilot project aiming to demonstrate the value of AtlantOS open ocean observations in improving physical and biogeochemical reanalyses of the North West European Shelf, using the North West European Shelf (NWS) regional reanalysis system of the Copernicus Marine Service as a testbed.
In AtlantOS WP1, the influence of various Atlantic Ocean observation types on reanalyses of the open ocean state will be assessed. In Task 8.6, we will drive the Copernicus NWS model, with different estimates of the open ocean boundary conditions, to assess the impact of the boundary conditions on the NWS state. Taken together, these two strands of work will allow us to assess the impact of different Integrated Atlantic Ocean Observing System observation types in constraining the shelf seas state.
As a by-product we will obtain insight into the influence of the open ocean on the shelf seas, leading to more confident attribution of the causes of observed changes on the shelf. Task 8.6 will also work closely with representative national and international end-users to assess the value of these enhanced reanalysis products for managing MSFD compliance and fisheries.

Summary of results

This deliverable (D8.5) reports on the availability and performance of the NWS physical reanalysis product, along with preparatory work for the main modelling experiment of Task 8.6, which will be performed and analysed in the period 2017-2018. Most of the NWS reanalysis production has been performed under other projects, and the main work under AtlantOS to date has been to extend the reanalysis evaluation to include two key time series sites (required to confirm that the model we are using is suitable for the task, and to aid communication with users on reanalysis quality), and to perform a statistical analysis of the reanalysis to provide a baseline idea of the links between ocean boundary conditions and the shelf seas state. The results of this will be used to guide the experimental design of the main model runs, focusing on areas where influence from the open ocean is most likely to be detected.

Description and availability of NWS reanalysis:
The NWS reanalysis covers the period January 1985 to June 2014 and is based upon the Forecasting Ocean Assimilation Model Atlantic Margin Model (FOAM AMM7), covering the region [40°4'N, 19°W] to [65°N, 13°E] with a horizontal resolution of approximately 7 km square, and 51 vertical levels using a hybrid ('s-sigma') terrain following coordinate. Hydrodynamic calculations are performed by the Nucleus for European Modelling of the Ocean (NEMO) system, and the 3DVar NEMOVAR system is used to assimilate sea surface temperature observations. The model is forced at the surface by ERA-interim winds, atmospheric temperature, and precipitation fluxes.

Horizontal boundary conditions are provided by a FOAM ocean simulation (Bell et al. 2000) prior to 1990, and by the GloSea5 global climate model reanalysis (MacLachlan et a. 2014) thereafter. Boundary conditions in the Baltic Sea are taken from the IOM-GETM model and the CMEMS Baltic sea regional analysis
(http://marine.copernicus.eu/services-portfolio/access-to-products/?option=com_csw&view=details&product_id=BALTICSEA_ANALYSIS_FORECAST_PHY_003_006).
E-Hype data (Donnelly et al. 2013) are used for river inputs.

The reanalysis was conducted in four sections: January 1984 -> March 1989; April 1989 -> December 2003; January 2004 -> June2012; July2012->June 2014. Each of these sections was initialised separately, creating the possibility of discontinuities. However, evaluation against time series observations (see below) suggests that physical variables can evolve smoothly across the section boundaries, reflecting the largely externally forced nature and short spin-up time of the NWS.

Physical outputs are provided both as monthly means and as daily 25 hour, decided, averages. Output variables are:

- Northward and eastward velocity
- Potential temperature
- Salinity
- Mixed layer depth

The reanalysis has been made freely available through the Copernicus Marine Environment Monitoring Service (CMEMS: http://marine.copernicus.eu/). Detailed user documentation (http://marine.copernicus.eu/documents/PUM/CMEMS-NWS-PUM-004-009-011.pdf) and a baseline evaluation of the reanalysis (Wakelin et al. 2016 http://marine.copernicus.eu/documents/QUID/CMEMS-NWS-QUID-004-009-011.pdf), are available through the CMEMS portal.

Evaluation of reanalysis:
A baseline evaluation of the reanalysis is presented by Wakelin et al. (2016), focusing on evaluating the mean state of the reanalysis fields against independent observations. Results are summarised by Wakelin et al. (2016) as follows:

- **Temperature:** Integrated over the whole domain, the bias in surface temperature is 0.4°C. Mean biases in the near surface layer (above 5m depth) have magnitude less than ~0.5°C while the largest errors ~-2°C are in the Bay of Biscay between 800m and 2000m deep.
- **Salinity:** Biases, on the practical salinity scale, are generally of magnitude less than 0.5. However, in the coastal regions of the Southern Bight of the North Sea, salinity is typically ~2 too fresh while the surface layer in the Irish Sea is ~0.5 too saline.
- **Currents:** Comparison with climatology at 15m depth shows that the reanalysis simulation reproduces major current systems in the region.
- **Transport:** For the transport of volume through standard sections there is fair agreement with the (limited) observational estimates available.
- **Tidal elevations:** The M2 constituent of tidal elevation has RMSE of 11.6 cm for amplitude and 15.6° for phase. The amplitude is underestimated in the Irish Sea and Southern Bight and overestimated in large tidal areas such as the Bristol Channel. The phase error is largest in the Southern Bight and German Bight.

Wakelin et al. (2016) also show some domain-wide metrics of interannual variability. Many features of the observed interannual variability of SST are captured by the reanalysis, albeit with a generally reduced range of the seasonal cycle (Figure 1).

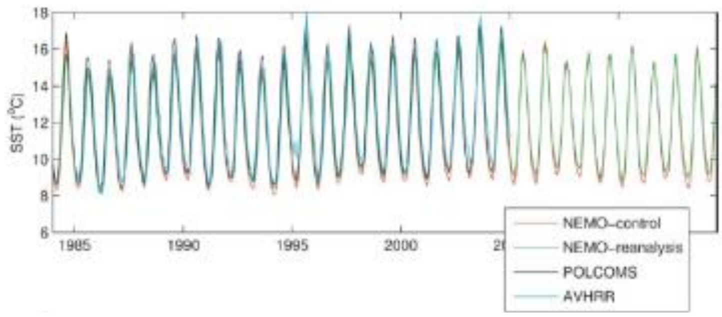

Figure 1:
Domain averaged SST for the NWS reanalysis (green) and Pathfinder V5 AVHRR data (cyan). Red and black curves show two non-assimilating ocean mode runs for comparison. From Wakelin et al. 2016

Interannual variability in salinity shows some quite large RMS errors when compared against all available instrumental observations in the domain. However there is no strong bias (Figure 2).

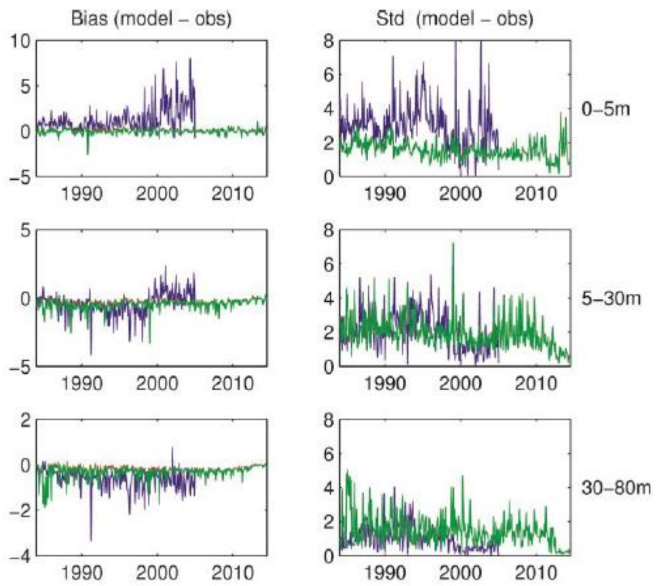

Figure 2:
Bias and standard deviation in reanalysis salinities, compared against all available observations in the domain, in various depth ranges (green). Red and blue curves show two non-assimilating ocean mode runs for comparison. From Wakelin et al. 2016

While the overall analysis of time- and domain-mean errors of Wakelin et al (2016) is useful to give a general impression of reanalysis quality, it is more user-relevant to assess the ability of the reanalysis to reconstruct interannual variability at specific sites. Therefore, under AtlantOS we have extended the evaluation of Wakelin et al. 2016 to assess interannual variability at two stations in the NWS domain where long observed time series are available (surface salinity from the Harwich-Hook of Holland ferry in the Southern North Sea, temperature profiles and surface salinity at the Western Channel Observatory off Plymouth, UK). The observations at these stations were not assimilated into the reanalysis so they provide an independent test of the reanalysis skill.

The reanalysis does a good job of reconstructing the pronounced interannual variations in Southern North Sea salinity from the Harwich ferry data (Figure 3), as well as some features of the Western Channel salinity (Figure 4).

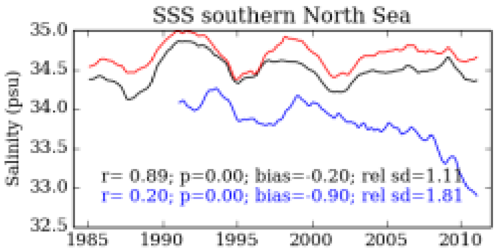

Figure 3:
Sea surface salinity in the Southern North Sea from the Harwich-Hook of Holland ferry observations (red) and the NWS reanalysis (black). Corresponding time series from the GloSea5 global reanalysis system is shown for comparison (blue). From Tinker et al. (in prep. 2017)

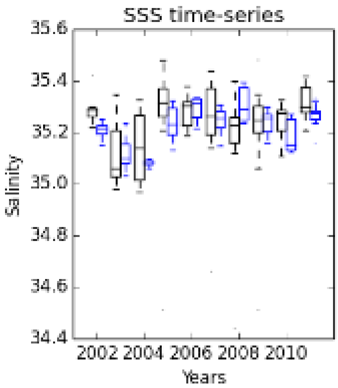

Figure 4:
Sea surface salinity in the Western Channel Observatory E1 observations (black) and the NWS reanalysis (blue). All available observations are shown using box-and-whisker plots. From Tinker et al. (in prep. 2017).

Our evaluation also shows that the regional reanalysis product adds realism to ocean state estimates for the NWS when compared with a state-of-the-art *global* ocean reanalysis system GloSea5 (MacLachlan et al. 2014). The GloSea5 reanalysis assimilates a wide range of observations, including altimetry and Argo, into a global NEMO configuration at a resolution of 0.25°, to produce global ocean state estimates from 1992 to present. While it has been shown to produce good estimates of aspects of large scale ocean variability such as the Atlantic Meridional Overturning Circulation (Jackson et al. 2016), the resolution of the GloSea5 reanalysis is low for the shelf seas, and it lacks crucial shelf seas physics such as tidal mixing and interannually varying river inputs. This leads to biases and inability to capture observed variability on the NWS (e.g. Figures 3 and 5). From an end user perspective this shows that regional shelf seas reanalyses (possibly driven by open ocean boundary conditions from the global reanalyses) are a vital step in deriving useful marine environmental information and in delivering value from the open ocean observations of the Integrated Atlantic Ocean Observing System to users working nearer the coasts.

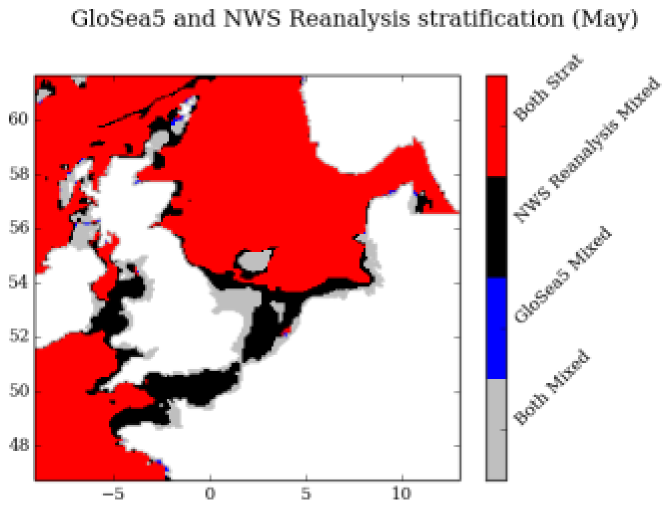

Figure 5:
Differences in NWS stratification in May, between the NWS reanalysis and a global ocean reanalysis (used in the Met Office's GloSea5 seasonal forecast system). Black areas show where the NWS reanalysis is well-mixed but GloSea5 is stratified, while blue areas show the converse. Areas where both systems agree are shown in red and grey. From Tinker et al (in prep. 2017).

Influence of open ocean boundary conditions on the NWS:
As preparation for the next phase of the work, to evaluate the influence of open ocean boundary conditions on the NWS ocean state, we have evaluated correlations between year-to-year variability in temperature and salinity in different NWS regions in the reanalysis, and the corresponding open ocean boundary conditions (and other climatic drivers). While the correlations do not establish causal links they do point to likely causal relationships and these will help us to focus our numerical experimentation in the next phase of the work. For example the correlations suggest that open ocean salinity at the southern part of the NWS domain boundary influences salinities onto the shelf including the English Channel and Southern North Sea (Figure 6); this is a region where the reanalysis appears to have skill in reconstructing the variability found in independent observations (Figures 3 and 4), so it will be a focus for our future experiments. Such relationships also suggest some potential for seasonal predictability of the NWS environmental state, though this needs to be explored further.

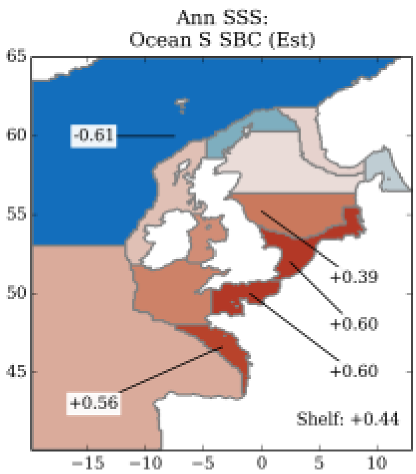

Figure 6:
Correlations of annual mean sea surface salinity in different regions of the NWS reanalysis, with open ocean salinity on the southern part of the domain boundary. Only statistically significant correlations are shown. From Tinker et al. (in prep. 2017).

Relevance to AtlantOS

The results so far have established that the NWS reanalysis and its underlying model are viable tools to explore the role of the open ocean in forcing variability on the NWS. It has been shown to produce good estimates of interannual variability in sea surface salinity at two locations where independent observed time series are available. The reanalysis data themselves and associated documentation have been made freely available through CMEMS. A preliminary correlation analysis suggests that the NWS does indeed respond to variability in the open ocean, suggesting that an Integrated Atlantic Ocean Observing System for the open North Atlantic could add skill and value to NWS state estimates and forecasts. The next steps (below) will aim to quantify the influence of the open ocean, before synthesising with other work in AtlantOS to assess the value of the Integrated Atlantic Ocean Observing System for regional marine management.

Next steps and links to other AtlantOS activities

The next step is to perform sensitivity studies in which the NWS model is forced with different estimates of the open ocean boundary conditions, to establish a more rigorous causal relationship between the open ocean and the NWS (as opposed to the correlation studies performed so far). This builds on previous work by the project team to model impacts of 21st Century climate change on the NWS (Tinker et al. 2016).

Work currently in progress in AtlantOS Tasks 1.3 and 7.4 aims to assess the impact of different observation types on open ocean state estimates, through Observing System Simulation Experiments and Observing System Evaluation techniques; this work will therefore quantify the influence of different open ocean observations on the boundary conditions for the NWS. Towards the end of AtlantOS we will perform a synthesis of these results with ours in Task 8.6, to assess the likely value of open ocean observations to better constrain the state of the NWS. This will form an important element of deliverable D8.16.

In parallel with this modelling work, Task 8.6 will engage with potential end users in the fisheries and MSFD areas, to better understand the key user requirements in terms of data types, spatio-temporal resolution, quality and availability. Preliminary contacts and one initial site visit have been made with users in these sectors. This is viewed as an ongoing discussion throughout the project, with outcomes and recommendations to be reported in D8.16, as well as feeding into broader discussions of user requirements in WP8.

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