REQUEST FOR A SPECIAL PROJECT 2023–2025

MEMBER STATE: ……UK…………………………………………………..…

Principal Investigator[1]**:** ……Bo Dong ……………………………………………………………….……

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Other researchers: Keith Haines, Hao Zuo (ECMWF)…………………..……

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Project Title: Improving the ORAS5 Global Ocean Reanalysis using a Smoother Algorithm……………………………………………………………
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If this is a continuation of an existing project, please state the computer project account assigned previously.	**SP** ________________	
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2023	
Would you accept support for 1 year only, if necessary?	YES ☒	NO ☐

Computer resources required for 2022-2024: (To make changes to an existing project please submit an amended version of the original form.)		**2023**	**2024**	**2025**
High Performance Computing Facility	(SBU)	200,000	1,250,000	2,500,000
Accumulated data storage (total archive volume)[2]	(GB)	1,200	72,000	144,000

Continue overleaf

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[1] The Principal Investigator will act as contact person for this Special Project and, in particular, will be asked to register the project, provide annual progress reports of the project's activities, etc.

[2] These figures refer to data archived in ECFS and MARS. If e.g. you archive x GB in year one and y GB in year two and don't delete anything you need to request x + y GB for the second project year etc.

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Extended abstract

Introduction

Ocean reanalysis products are valuable sources for studying historical changes and variations in the ocean state and circulation (Lea et al., 2006; Balmaseda et al., 2015; Jackson et al., 2016, 2019; Buizza et al., 2018; Uotila et al., 2018). Most of the existing global ocean reanalysis products are generated using conventional sequential assimilation approaches (e.g., 3DVar), as are used for initialised forecasts, which can only take account of past observations. However the memory of the ocean is much longer, perhaps up to a few months in the subsurface ocean, and the observations are sparse, such that only limited information are being assimilated. This means that an ocean reanalysis could seek to use more “future data”, which would be especially beneficial for locations not observed in the recent past, to help produce the best state estimation on a given day. A second problem with sequential analysis systems is that they are sensitive to the sudden introduction of new data as it becomes available, especially for the inhomogeneous in situ observing system we have for the subsurface oceans. This can lead to discontinuous changes in analysed properties such as ocean heat content, as data are assimilated. These sudden discontinuities may be problematic for using reanalysis timeseries for following climate signals in the oceans, and for trying to infer information about processes that are not being properly represented by the models.

There are approaches to overcome these problems theoretically, such as 4DVar and Kalman smoothers. However, these methods are computationally expensive and are not generally used in high resolution models such as those in operational oceanography. Here we introduce a new time smoothing approach for application to large global ocean reanalysis systems that have already been run in “forward mode” (using past data). The smoothing makes use of the history of stored data increments to produce a more physically plausible time-evolving ocean state with smoother temporal adjustments towards the available observations. We have tested this new method in the Lorenz 1963 model, as well as the Met Office FOAM reanalysis, both show that the errors have been reduced effectively (Fig. 1 from Dong et al. 2021). In the work proposed here we will explore how the smoother works when longer assimilation time windows have already been used in the ECMWF ORAS5 system. We also hope to gain from the improved treatment of bias that has been applied in ORAS5 which should allow the smoothing timescales in the subsurface ocean to be extended for longer than we have applied before.

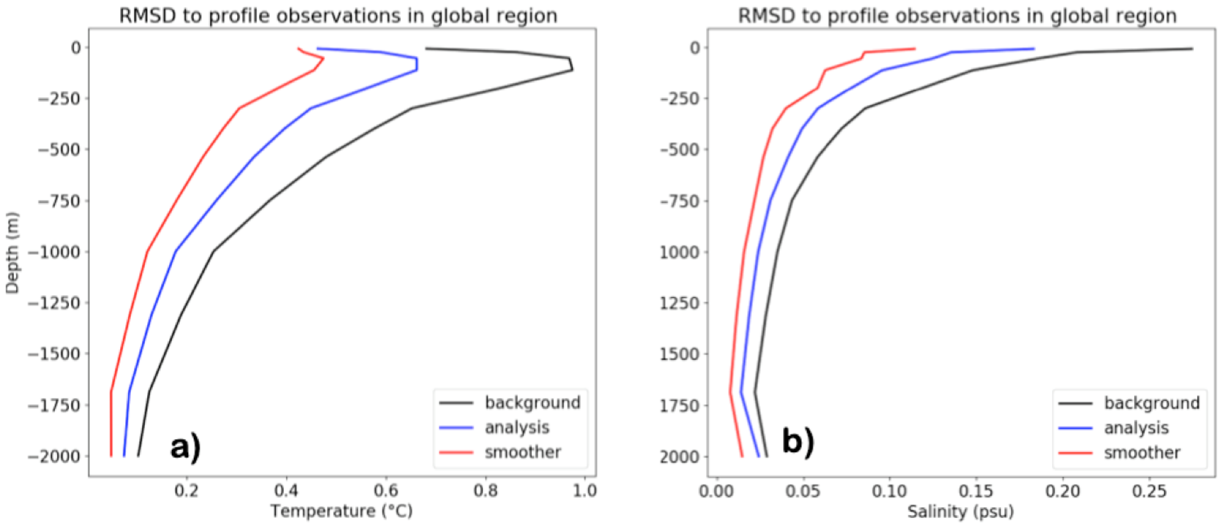

Fig. 1. Smoother application in the Met Office Glosea5 reanalysis**.** (a) Global average RMS errors in Temperature (°C) as a function of depth for the Background (1-day forecast) fields (black), the Analysis fields (blue), and the Smoother fields (red). (b) As in (a) but for Salinity (PSU).

Smoother algorithm

We define A_t to be the original forward analysed field during analysis window t, and I_t to be the increment field applied during this window used to produce A_t. We also define $\gamma < 1$ as the increment decay rate per assimilation window and note that this could be chosen to vary spatially or to be different for different variables if required. The smoother solution in window t is denoted S_t. The basic smoother algorithm can then be written;

$$S_0 = A_0 + \gamma(I_1) + \gamma^2(I_2) + \gamma^3(I_3) + \gamma^4(I_4) + \ldots\ldots; \tag{1}$$

so that increments from future windows ($t>0$) decay by a factor γ per assimilation window in their influence on S_0. Similarly we can write;

$$S_1 = A_1 + \gamma(I_2) + \gamma^2(I_3) + \gamma^3(I_4) + \gamma^4(I_5) + \ldots\ldots; \tag{2}$$

and by rearrangement we can find;

$$S_0 = A_0 + \gamma(S_1 - A_1 + I_1) \quad = A_0 + SI_0, \tag{3}$$

$$\text{and} \;\; SI_0 = \gamma(SI_1 + I_1), \tag{4}$$

where $SI_t = S_t - A_t$ is the “smoother increment”. This recursive relationship allows the smoother to be run backwards in time starting with the final analysed time window tf, and with $SI_{tf} = 0$ (there being no future increments).

The decay timescale τ (in assimilation window units) associated with the smoothing can be defined by the relationship;

$$\gamma^\tau = 1/e \;\; or \;\; \tau = -1/ln(\gamma). \tag{5}$$

Another insightful quantity is the total number, NS, of whole future assimilation increments contributing to each smoother increment SI;

$$NS = \gamma/(1-\gamma). \tag{6}$$

So for example $\gamma=0.7$ corresponds to a decay timescale τ ~3 windows, with NS~2.3 future window increments contributing to each smoother increment, and $\gamma=0.98$ would correspond to τ~50 windows and NS=49 future window increments.

Objectives

1) Evaluate the performance of the smoother in the 5-day window, 0.25 degree global ORAS5 ocean reanalysis

2) Further improve the results by tuning the smoother decay parameter according to the ocean circulation and mixing timescales.

3) Collaborate with ECMWF scientist to publish an improved ocean reanalysis dataset based on the original ORAS5 reanalysis

4) Test the smoother on the new ORAP6 reanalysis

5) Co-supervise University of Reading meteorology department MSc projects on these topics with ECMWF scientists

Proposed experiments, timeline and technical requirements

Year 1

Test the smoother algorithm using the ORAS5 reanalysis for the year 2019. Data files we will use include 5-day mean temperature, salinity and velocity fields and their 5-day assimilation window increments. As the outputs include same fields, with same format as the original reanalysis, we require 1200 GB storage space for data, and 200,000 SBU to run the smoother on a single core postprocessor. As well as the PI we intend to involve MSc students from Reading doing their summer dissertation projects to help test and tune smoothing algorithms

Year 2

Test the effects of smoothing for a pre-Argo year to see whether larger improvements can be gained. Tune the smoother decay parameter to further improve the smoothing results. Look at feasibility to extend the analysis period to 1975-2022. A total of 72,000 GB storage and 1,250,000 SBU are required.

Year 3

Apply the tuned smoother on the newly released ORAP6 reanalysis. Estimated storage and SBU needed are 144,000 and 2,500,000 respectively

References

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