Forecasting the Ecology of the Red Sea using a Cluster of Regional 1D Marine Ecosystem Assimilative Models

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Abstract

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1. Introduction

Marine ecosystem forecasting is needed because....

- HAB affect public health, desalination and coastal economy
- predicting chlorophyll can help fisheries
- For research: better understand the large-scale ecosystem
- Especially usefull because we lack data about the subsurface phenomena

Marine ecological models are one way to make such forecasting.

- marine ecology models represent biogeochemical interactions as differential equations.
- Can be as simple as NPZ or as complex and complete as ERSEM.

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...But are expensive and difficult to tune, and subject to various sources of uncertainties.

- (*Anderson*, 2005) lot of under-determination
- require coupling physics + biology
- Circulation models very expensive, because high-resolution grids and number of involved PDEs.

Data assimilation and parameter estimation techniques are used to improve and tune the models, but 3D models are still expensive to run.

In this article we investigate ways to simulate and predict 3D ecosystems more cheaply by running many parallel 1D regional models.

- Divide the domain into small regions with similar ecology using advanced clustering techniques
- Build 1D model for each identified region
- Ensure parametrization is better for each region
- apply data assimilation techniques on the 1D models for efficient calculations.

We are going to test that idea on the Red Sea because....

- Red Sea is an interesting environment: extreme temperatures and salinity
- Very rich and preserved ecosystem
- Unexplored environment
- Lack of data: therefore developing models is important

We will use the SEIK data assimilation scheme, because....

- Assimilation constrains the model, reduces underdetermination, and imporves forecasting
- Mitigates the fact that initial conditions, parameters and physics are subject to uncertainties.
- SEIK is better than SEEK for strongly nonlinear models

We will assimilate Chl data because it is currently the best available data for the Red Sea.

- Chl data allows to observe large scale ecological patterns with high spatial and temporal coverage.
- Compared with in situ data that are limited in time and space, and expensive.
- However chl data suffers from missing values due clouds, aerosols, etc.
- Also bad values near the coast, case II waters
- Both problem particularly affect the southern Red Sea, that has nearly no observation in the summer during some months.

What we are going to do in this paper step by step.

- Fill the data with DINEOF
- Apply clustering to the Red Sea
- Implement 1D models and assimilation schemes
- Run models with assimilation
- Analyze results and compare to findings in previous studies

What is new in this paper and why.

- We use CCI data: which is a new dataset, not fully exploited in Red Sea.
- We do eco-region clustering for the first time in the Red Sea.
- We have assimilation of ecological model with hybrid-SEIK published for the first time.
- We improve our understanding of the Red Sea ecology in its different parts.

Introduce sections.

2. Data

2.1. CCI chlorophyll data

We use CCI chlorophyll data because it has more coverage..

- Single satellite CHL data products have a lot of missing data especially during summer in the South
- CCI data, merges three different sensors and uses the POLYMER algorithm.
- As a result the coverage increases dramatically.
- This is the first dataset that has significant coverage in the southern Red Sea, and that is why we will use it.
- We use 4km resolution L3 CHL product between such and such coordinates.
- We use weekly data for the clustering and 8days data for the assimilation

With a quick look at the data this is what we see....

- plot coverage
- plot average chlorophyll
- plot seasonal chlorophyll

2.2. DINEOF

There are still missing data in CCI, so we use DINEOF for data filling because....

- DINEOF is an EOF based non parametric data filling methods
- introduced orignally by *Beckers and Rixen* (2003)
- Has been applied to geoscience datasets, in particular to chl datasets
- Shown in *Taylor et al.* (2013) to be more efficient that its competition.

More or less this is the way DINEOF works....

- Describe here the algo

This is how we applied DINEOF....

- Choices of parameters and cross validation method and why we made these choices.

Present and discuss the results of DINEOF.

- Show minimization of error plot.
- Show the filling of a region.

2.3. Clustering

To identify the ecological regions, we cluster the Red Sea using clustering algorithms on the CHL data. We chose GMM because....

- There are many clustering algorithms on the market: for example...
- Discuss advantages and inconvenients of some of them (find reference)
- Finally we tried some of them and found that GMM was given better results, in comparison to what we expected.

This is more or less the way GMM works....

- Describe how GMM algo works

This is how we used it....

- We wanted 3 broad regions in the northern, central and southern Red Sea.
- We ran GMM with k varying from 3 to 7.
- We looked at some of this tests to see if the clusters where good.
- At the end we settled with k=? because it was good for our purposes and the regions where closed to to what *Raitsos et al.* (2013) found.

This is what we got....

- Show plot of clusters
- Comment on clusters, and what was found by *Raitsos et al.* (2013).

3. Clustered 1D Modeling and Assimilation

3.1. 1D-ERSEM model

Description of ERSEM.

- ERSEM develop originally for the northern Sea
- Complete ecology modeling
- Been applied in many ecosystem
- in particular used for the Red Sea simulation *Triantafyllou et al.* (2013)
- Very complex: many parameters and variables

Initialization/Parameters/Forcing.

- We initialize with the values found by *Triantafyllou et al.* (2013)
- The nutrients are initialized using the values of WOA
- Parameters are chosen like this
- Forcing come from the simulation by *Yao et al.* (2014a,b)

3.2. Data Assimilation

We chose SEIK DA scheme because....

- Data assimilation is necessary to improve the forecasting skill of complex geophysical models
- It constrains models that are imperfect and whose parametrization is difficult to do.
- SEEK has a long history in assimilation into ecological models.
- Its ensemble variant SEIK, has been shown to behave better for very nonlinear systems

Brief description of the SEIK algorithm.

- Show the steps of the SEIK scheme

Implementations.

- How we implemented the filter.

4. Results

4.1. Output evaluation

Here, we compare the results of the free-run with the assimilated-run. We show that we have a good prediction skill, and that the assimilation improves the model.

Plot some models output vs the data and qualitative comments.

Discuss different metrics to evaluate model and DA schemes.

Show a couple metrics on our results.

Impact of assimilation on the subsurface variables.

4.2. Analysis

Here we look at the results and interpret them biologycally. Do we find comparable results as Acker, Raitsos, Weiker, etc. What can we say about the hypothesis that they made about he process that drive primary productivity in the Red Sea.

Discuss differences between climatology and 2003-2004.

Comment on the role of overturning and stratification.

What is the limiting nutrient?.

$$\frac{N3N + N4N}{N1P}$$

vs Redfied ratio

Compute production at different time of years and compare with Weikert1987/Acker2008/Koblentz.

Study the DCM.

5. Conclusion

Summary of the proposed approach

Are several 1D paralled 1D models a good alternative to 3D simulations?

What did we learn about the Red Sea ecology?

Future works?

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