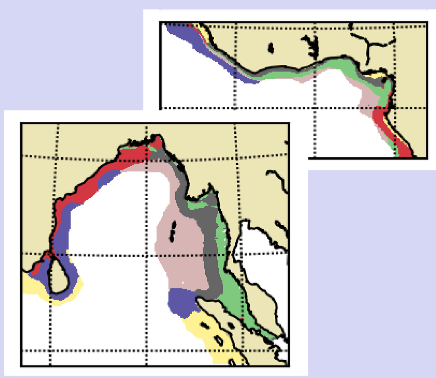
PML Plymouth Marine Laboratory

Listen to the ocean

suka@pml.ac.uk

Using Time Series Analysis to investigate patterns of change in coastal and shelf seas

Susan Kay, John Bruun
Plymouth Marine Laboratory



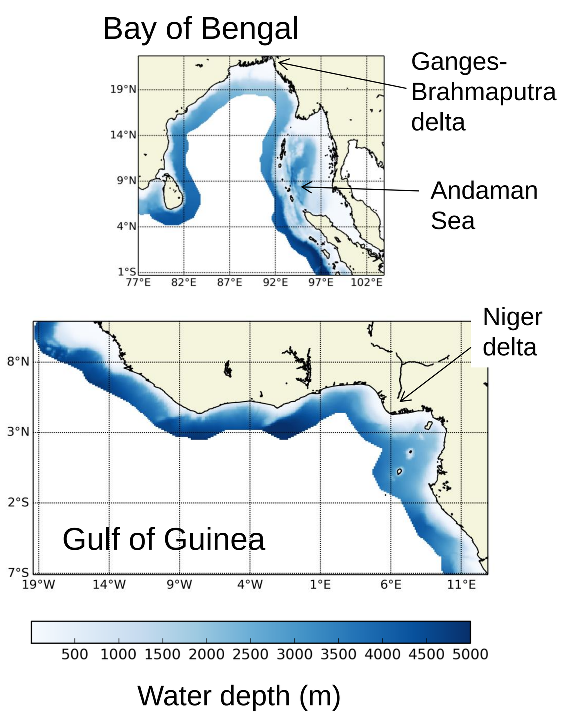
Time series analysis has been successfully applied to describe and understand patterns of variability at the basin scale[1]. Here we show that it can also be used to analyse time series for coastal regions, in this case model outputs from century-long projections under different climate models. Time series components vary across the model domain and the patterns of give insights into the key drivers of the system in different places. Changes in the model components over time give a synthesis of where changes may be expected under climate change.

Context and methods

Our study areas are the coastal regions of the Gulf of Guinea off west Africa and the Bay of Bengal in the north-east Indian Ocean. Both areas are densely populated and fish are an important part of the diet, providing protein and key nutrients[2]. Hence changes in marine production will have significant effects for lives and livelihoods.

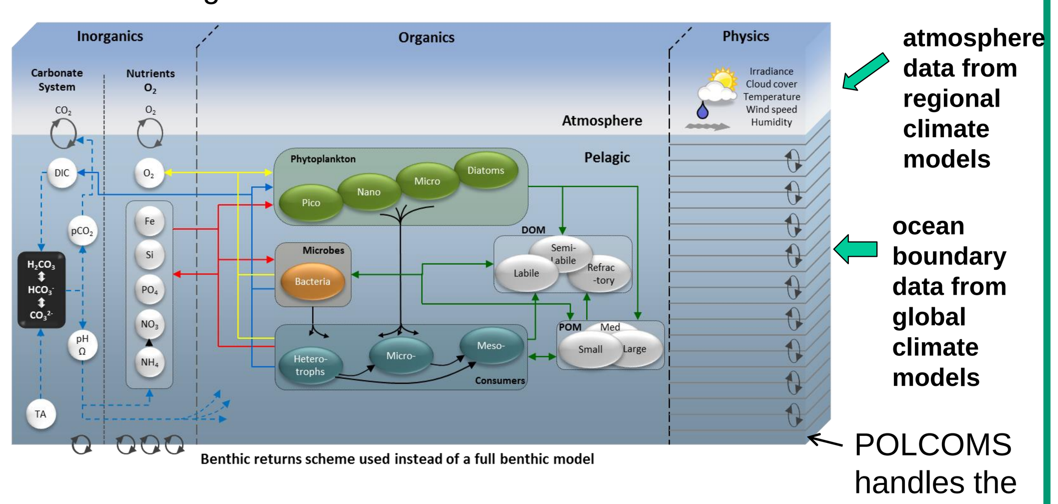
We applied time series analysis to projections of net primary production in both areas. The projections were drawn from physical-biogeochemical models (see rights) and covered the period 1970-2098. Analysis was applied to each point in the domain using the following initial model, which has the main features typical of earth systems:

total netPP =
steady state + 12 month component + 6 month component + trend + noise



Creation of projections

The time series analysed in this work are outputs from multidecadal runs of a POLCOMS-ERSEM coupled hydrodynamic model[3]. The model resolution was 0.1° in latitude and longitude, with 40 vertical levels at each point. Forcing at the atmospheric boundary came from regional climate models, downscaled from global models, and open ocean boundary conditions came from global climate models. In each domain the model was run three times using different climate forcing, to give some information about the range of possible future conditions. For the Gulf of Guinea the three climate models were based on RCP 8.5, and were drawn from the Africa CORDEX set: CanESM2, CNRM-CM5 and HadGEM2-ES. The Bay of Bengal model used three ensemble members of a HadGEM3 model based on the A1B SRES scenario, here called Q0, Q8 and Q16. River flows and nutrient loads are taken from a hydrological model run using the same climate data.



Schematic diagram of the ERSEM biogeochemical model

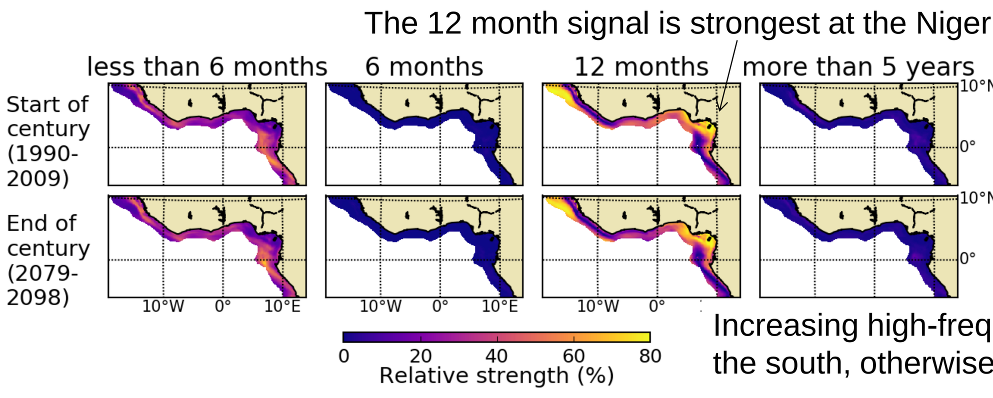
A note on model validation: very little insitu biogeochemical data is available for these areas. Comparison to satellite chlorophyll data shows that model tends to overestimate chlorophyll concentrations but give reasonably good agreement to patterns in time and space.

Key spectral components

based on analysis of 20-year periods

Time series analysis estimates the relative strength of each component.

The 12 month signal is strongest at the Niger delta

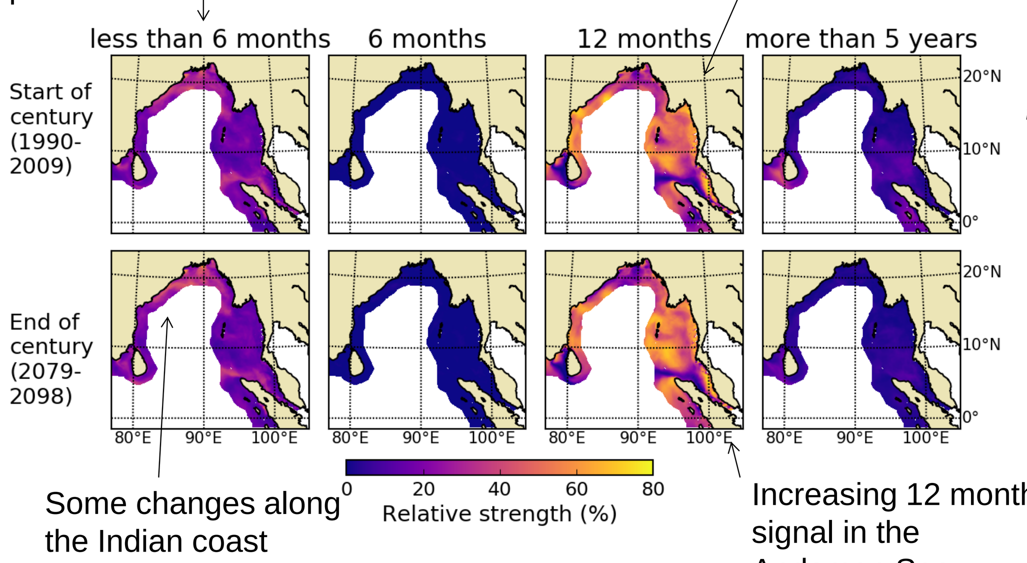


Increasing high-frequency signal in the south, otherwise fairly stable.

High frequencies occur near the Ganges-Brahmaputra river mouth, which has multiple peaks in flow

The 12 month component dominates in this strongly seasonal system

The 6 month signal is weak in both seas – more than two annual peaks occur.



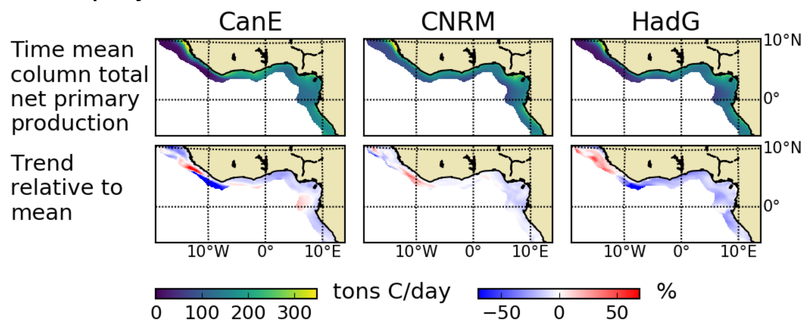
Some changes along the Indian coast

Increasing 12 month signal in the Andaman Sea

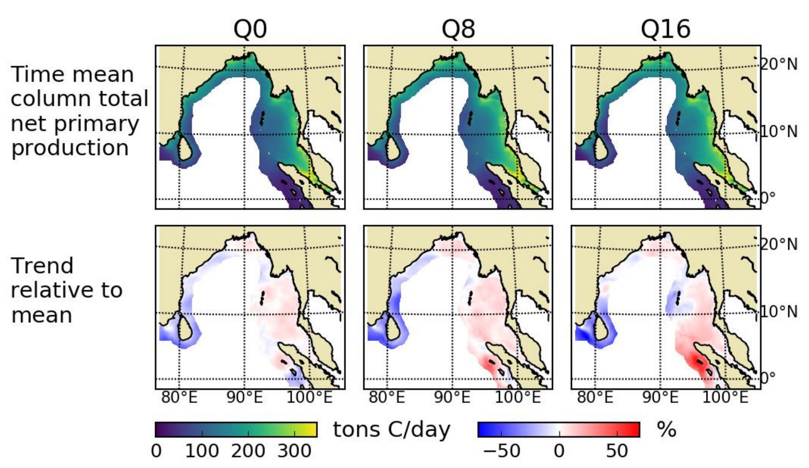
Trends

Based on analysis for 1970-2098

The columns show the three different climate models in each area. Mean production is similar between climate model but trends differ, indicating uncertainty in the projections.



The models agree on decreasing production south of the equator and along the west African coast, but differ elsewhere.

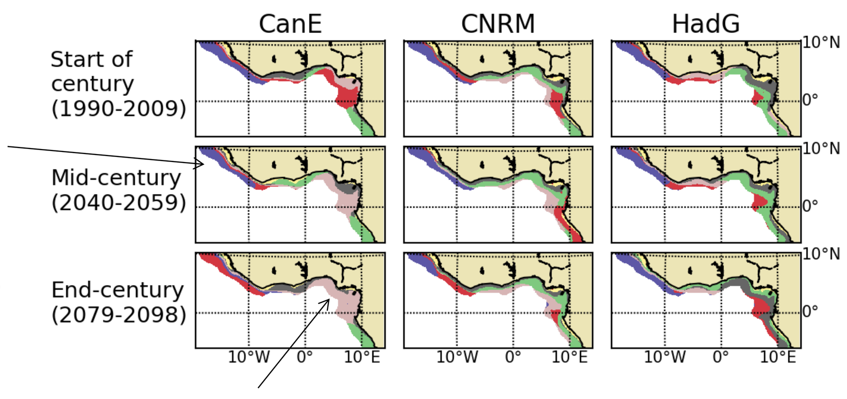


The broad picture is increasing production in the Andaman Sea, decreasing on the Indian coast, but details vary.

Identification of biomes and projected changes

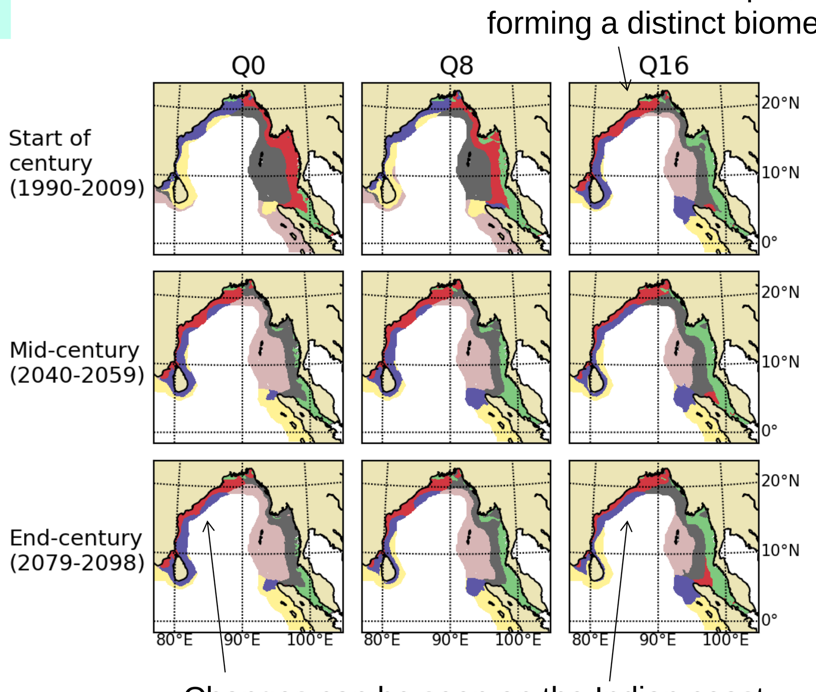
Note: 6 areas are identified in each case. Look for changes in positions of the boundaries, rather than the colours.

Linear features along the west African coast suggest the importance of coastal currents



Around the Niger delta there are some changes between start and mid-century, but the end is more similar to the start. River nutrients are projected to peak in mid-century then decrease again, due to changes in land use and water treatment.

The delta area is split, rather than forming a distinct biome.



The three climate models give broadly similar patterns, with the far south, the Andaman Sea and the Indian coast clearly distinct.

Changes can be seen on the Indian coast, otherwise the patterns are fairly stable

Self-organising map techniques identify areas in each domain which have common features in their time series (biomes).

Box-Jenkins Time Series Analysis

Box-Jenkins methods were developed for analysis of time series in financial contexts but since have been widely used elsewhere[4]. A model is developed using an initial assessment of the likely components of the system, in this case:

$$y_{ij\,t} = \mu_{ij} + a_1^{ij}\cos(2\pi f_1 t) + a_2^{ij}\sin(2\pi f_1 t) + a_3^{ij}\cos(2\pi f_2 t) + a_4^{ij}\sin(2\pi f_2 t) + a_5^{ij}\,t_t' + \eta_t^{ij}$$

Where f_1 is the 12 month frequency and f_2 the 6 month. Note that the 6 month component does not necessarily mean there is a process operating on a 6-month time scale, it can instead be the effect of a second 12-month cycle which peaks at a different time of year.

Maximum likelihood methods are then used to estimate the parameters and the results are validated using expert knowledge or independent data. In the work presented here, for example, we would expect the 12 month component to dominate, as primary production is sun-driven, but to have less importance near the equator.

This cycle of identify-estimate-validate can then be repeated to refine the initial and gain insights into the system.

Summary

TSA techniques previously used at basin scale can be successfully applied to coastal areas. When used with projections of environmental conditions under climate change they can be used to identify areas of stability and change. The Bay of Bengal is dominated by the annual season cycle and by fluctuating river flow, while the Gulf of Guinea is less strongly seasonal. Changes are projected along the Indian coast and in the area around the Niger delta.

Further work

The work presented here used model outputs: the same techniques applied to satellite chlorophyll data would give additional insights into current conditions. Comparison of results to the model-derived results presented here would give additional validation evidence for the model.

The TSA could be extended by adding other components into the model, in an iterative development loop; for example to investigate the lower frequency signals that do not have an obvious cause..

The Bay of Bengal projections were created in the project 'Assessing health, livelihoods, ecosystem services and poverty alleviation in populous deltas', project number NE-J002755-1, which was funded with support from the Ecosystem Services for Poverty Alleviation (ESPA) programme. The ESPA programme is funded by the Department for International Development (DFID), the Economic and Social Research Council (ESRC) and the Natural Environment Research Council (NERC).

The Gulf of Guinea work is carried out under the Deltas, vulnerabilty and Climate Change: Migration and Adaptation (DECCMA) project under the Collaborative Adaptation Research Initiative in Africa and Asia (CARIAA) programme with financial support from the UK Government's Department for international Development (DFID) and the International Development Research Centre (IDRC), Canada. The views expressed in this work are those of the creators and do not necessarily represent those of DFID and IDRC or its Boards Governors.

References

[1]Bruun et al. "Oceanic biogeochemical characteristic maps identified with holistic use of satellite, model and data" Geophysical Research Abstracts Vol. 16, EGU2014-15766, 2014
[2]Fernandes et al. "Projecting marine fish production and catch potential in Bangladesh in the 21st century under long-term environmental change and management scenarios. ICES Journal of Marine Science; doi:10.1093/icesjms/fsv217
[3]Holt, J. *et al.* Modelling the Global Coastal Ocean. *Philos. Trans. R. Soc. Math. Phys. Eng. Sci.* 367, 939–951 (2009).
[4]Young, PC (2011) Recursive Estimation and Time-Series Analysis, 2nd Ed, Springer-Verlag Berlin Heidelberg.

Contact us: PML, Prospect Place, The Hoe, Plymouth, PL1 3DH, United Kingdom T +44 (0)1752 633100 W www.pml.ac.uk E forinfo@pml.ac.uk