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Methods for Data Assimilation for the Purpose of Forecasting in the Gulf of Cambay (Khambhat)

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ABSTRACT

Fluid dynamics, wind wave modeling describes the effort to depict the sea state and predict the evolution of the energy of wind waves using numerical techniques. These simulations consider atmospheric wind forcing, nonlinear wave interactions, and frictional dissipation, and they output statistics describing wave heights, periods, and propagation directions for regional seas or global oceans. forecast has been a key area of investigation and if certain methods can be plotted in order to help in improvement of the forecast it would be salutary to the development in this direction.

Keywords : Arabian Sea,Ocean data Assimilation, Climat Change, Kalman Filter, Quasi Geostrophic.

I. INTRODUCTION

Gulf of Khambhat - earlier known as Gulf of Cambay - centers around findings made in December 2000 by the National Institute of Ocean Technology (NIOT). NIOT came across palaeo river channels in the sea. These were seen by the scientists involved to be the extension of the present day major rivers of the area. In a similar marine survey, in a Coastal Research Ship during 1999-2000 when Dr S Badrinaryan was the Chief Scientist, several unusual frames of Side Scan Sonar images were encountered. These had square and rectangular features in an arranged geometric fashion which are not expected by the scientist in the marine domain. As per the scientist involved such features are unlikely to be due to natural marine geological processes. This made the scientists suspect that human workmanship must have been involved here. The surveys were followed up in the following years and a couple of palaeo channels of old rivers were discovered in the middle of the Khambhat area under 20-40m water depths, at a distance of about 20 km from the present day coast.

The Gulf of Khambhat was formed by a major rift that resulted in a down sliding of the Khambhat region. The area is very tectonically active today, and several faults can be found in the gulf. Periodic earthquakes also occur here. This knowledge has led several archeologists to state that the site is not in a secure enough context to be reliably dated. Because of the tectonic activity and strong currents, these archeologists claim that there is not sufficient stratification to be sure the recovered artifacts can be associated with the site.

The Gulf of Cambay (Khambhat)has two important branches — the Gulf of Aden in the southwest, connecting with theRed Sea through the strait of Bab-el-Mandeb; and the Gulf of Oman to the northwest, connecting with the Persian Gulf. There are also the gulfs ofCambay and Kutch on the Indian coast.

Figure 1.

II. METHODS AND MATERIAL

2.1 Area of Study

Ocean data assimilation is a general methodology for estimating values for dynamically evolving oceanic variables by combining the information contained in dynamical ocean models and in observational data. This combination of information generates an estimate of the current state of these variables – an analysis – which may then be used as an initial condition for later numerical forecasting of future ocean conditions. The complex relationship between the various relevant dynamic variables in the ocean produces a chaotic pattern to the growth, with time, of measured differences between forecasts generated from similar initial conditions. Hence the accuracy of analyses is one of the key factors limiting the accuracy of ocean forecasting as a predictive tool.

Many current data assimilation methods are based upon the concept of a 'most-likely' estimate, a representative state that has the greatest probability of having occurred, given previous forecasts and the result of all available observations. The analysis thus represents the modal state of any forecast ensemble and, it is argued, the best viable choice for an initial condition for future deterministic forecast. Analogy can be drawn with the parameterization of small scale mixing processes. There exist myriad possible arrangements of a dynamic variable on scales well below that being modelled. However if an assumption is made as to the probability density of the various arrangements (as is made for example in the mathematical modelling of Brownian motion) and the most likely estimator of the states assumed true (in this case through application of the central limit theorem), then a modelling assumption is generated (Fickian diffusion) which is applicable on the scales of interest.

2.2 Geographical Area of Investigation:

Gulf of Khambhat (between 72°2′E to 72°6′E and 21° to 22°2′N) is one of the major fishing areas along western coast of India . It is about 80 km wide at mouth and tapers to 25 km along the coast. It is about 140 km in length and is characterised by several inlets and creeks formed by the confluence of rivers. The Gulf of Khambhat is shallow with about 30 m average depth and abounds in shoals and sandbanks. It is known for its extreme tides. The tidal range at Gulf of Khambhat is known to be one of the largest along the Indian coastline.

2.3 Some Usefulness of Gulf of Cambay (Khambat)

1. World's largest man made fresh water reservoir in the sea.
2. Highest importance and priority to irrigation and drinking water for Saurashtra and Central Gujarat regions.
3. The Reservoir will have the storage more than double the Sardar Sarovar (Narmada Reservoir) capacity.
4. 10.54 lakh ha land in 39 talukas of 6 districts of Saurashtra region will get irrigation benefit facility including rejuvenation of rivers. More than 60 existing dams will get permanently filled up with water.
5. Wind and solar energy will be generated which can also be used for lifting fresh water from the reservoir to the canal.
6. Bhavnagar port will get revived which will result into speedy development of the region.
7. There will be large saving in travel time and fuel due to reduction in distance by about 200 km between Bhavnagar to Surat-Mumbai.
8. Saline ground water of coastal area of Saurashtra & Central Gujarat will get converted into fresh water with reduction in soil salinity.
9. Substaintial improvement in ground water quality as well as soil salinity of coastal area of Saurashtra & Central Gujarat.
10. About 2 lakh ha land along the periphery of the reservoir will be opened up for development towards value-based land utilization.

11. Enhanced benefit of world class industrial estate like Dahej and Dholera will be available to Bhavnagar/Saurashtra region.

III. TRADITIONAL DATA ASSIMILATION METHODS

The theory behind the derivation of the BLUE equation forms the basis for many modern assimilation techniques, including the Kalman filter, Kalman smoother, 3D-VAR and 4D-VAR techniques. Many operational ocean forecasting centres use variations on these methods. For example, the UK Met Office Forecasting Ocean Assimilation Model (FOAM) uses an Analysis Correction Method (ACM) (Lorenc et al., 1991) to assimilate temperature and salinity profiles. The basis of the ACM is an iterative approximation converging to the BLUE analysis described below. The European Centre for Medium-range Weather Forecasting (ECMWF) uses a 4D-VAR scheme for its operational ocean model, run to assimilate observations over a ten day time window.

- The overall focus of this thesis is:
- To understand the benefits and issues involved in using phase error assimilation methods in a general, mathematically rigorous and physically consistent ocean fore-casting system.
- To what extent is it feasible to decouple the observed error signal in ocean analyses consistently into signals due to pure phase error and amplitude error?
- Given that real oceanographic observations are noisy and limited in scope and number, can a study of novel phase correction algorithms give a quantitative understanding of how observations relate to model data in such methods and what constraints on observations are required?
- Is it possible to develop efficient algorithms which maximise the utility of displacement assimilation techniques, for example in terms of the use of the information contained within observations, in the same way that 4D-VAR methods allow the use of multiple nonlinear observations taken at different times?

IV. Research Gaps identified in the proposed field of Investigation:

In the Indian context, the recent finding, that amongst the oceans, the warming of the Indian Ocean is second highest , is a cause of worry and calls for immediate attention. Even though climatological studies have been done in the past in the Indian Ocean encompassing the Arabian Sea and the Bay of Bengal , a comparative analysis of the changing Sea Surface Temperature (SST) pattern the gulfs of Arabian Sea (Persian Gulf, Gulf of Oman, Gulf of Aden, Gulf of Kutch, and Gulf of Khambhat) and the Red sea has not been done. The gulfs of the Arabian Sea are not just strategically important with rich sources of oil and natural gas but are also the hot spots of the marine biodiversity. However, in the recent years, there has been an expeditious change in the marine ecosystem of the eastern and western gulfs of the Arabian Sea and the Red Sea, owing to anthropogenic interference. Since 1990s, 40% of the coasts of the Persian Gulf have been modified . The Persian Gulf and the Red Sea areas have been reported to be warming rapidly owing to the developmental projects undertaken in the surrounding coastal countries . The Gulf of Kutch on the Indian coast is being aggressively developed as oil importing bases because of its proximity to the Middle East countries [29]. In general, the issues of common concern in the eastern and western gulfs of the Arabian Sea and the Red Sea include various anthropogenic activities like industrialization, coastal infrastructure development projects, setting up of new ports and oil terminals, oil pollution from shipping industry, overfishing, dredging, and increase in tourism and recreational activities, resulting in habitat destruction, changes in temperature and salinity profile, and causing a significant loss of biodiversity .

In this regard, the present work was taken up to study the monthly, seasonal, and annual pattern of Sea Surface Temperature (SST) and to analyse its changing pattern with emphasis on interannual variability in the eastern (Gulf of Kutch and Gulf of Khambhat) and the western gulfs (Persian Gulf, Gulf of Oman, and Gulf of Aden) of the Arabian Sea and the Red sea.

For each of the defined areas of study, the monthly images were masked to avoid the influence of the land and clouds using the image processing software ENVI 4.1 and ERDAS 9.0. For analysis all the pixels of the study area were included. Care was taken to exclude the pixels with zero values while averaging. Following Joint Global Ocean Flux Study (JGOFS) , the four climatological seasons described here are(a)northeast monsoon (December–March) (NEM),(b)spring intermonsoon (April-May) (SIM),(c)southwest monsoon

(June–September) (SWM), and(d)fall intermonsoon (October-November) (FIM).The climatological mean (CM_{25}) of 25 years (1985–2009) for each month was calculated by averaging the monthly mean (). The interannual variability was analyzed using the monthly normalized anomalies, computed by subtracting the monthly climatological mean (CM_{25}) from the monthly mean () of each year, and normalized to the standard deviation for that month (SD_{25}) and given asThe seasonal and annual normalized anomalies were computed by averaging the monthly normalized anomalies over appropriate seasons and years. Coefficient of variation (CV) was used to express the magnitude of interannual variability in the annual and the seasonal SST for the eastern and the western gulfs of the Arabian Sea and the Red sea and is calculated asTo study the effect of El Niño and La Niña, comparison with ENSO (El Niño-Southern Oscillation) was carried out using the multivariate ENSO index, that is, MEI index, provided by the climate diagnostic centre (http://www.cdc.noaa.gov/).

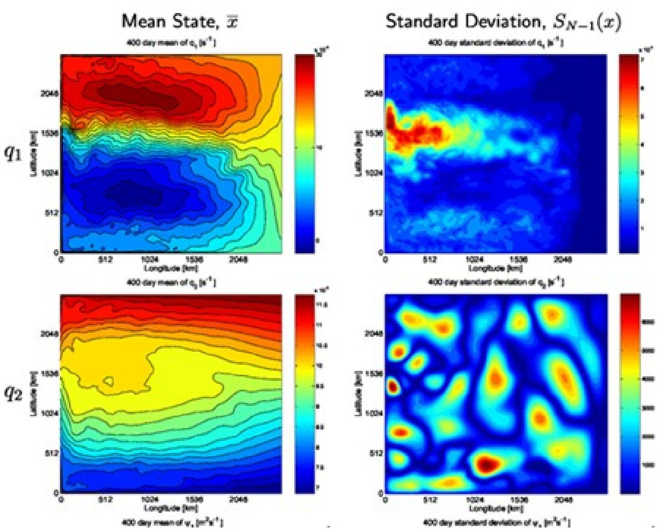
V. Hypothesis to be tested

We investigate the behaviour of various phase correction assimilation methods when applied to idealized problems in a simple Quasi-Geostrophic (QG) ocean model. This simple model allows simulation of mesoscale features and unobserved dynamical variables. We present a variety of new phase error assimilation methods and compare them to traditional techniques.
We find that for suitable assimilation problems these new techniques do need to provide some benefit. We shall also present a discussion of the principles, advantages and limitations of the identical twin methodology for investigating data assimilation techniques, re-views the general issues involved in numerical ocean modelling and introduces the particular implementation of a quasi-geostrophic two layer ocean model used for the experimental data presented in this thesis. The equation set is described with reference to its ability to represent real, or realistic, structures and features of the large-scale ocean circulation, thus presenting its suitability as a testbed for oceanographic data assimilation techniques. Different methods for generating model runs with qualitatively differing features are discussed, including both the relevance to current issues in operational oceanography and the relation to the theoretical displacement assimilation techniques shall be tested for further.

We shall be presenting a discussion, linked to the adiabatic assumption introduced in the previous chapter, for the use of assimilation techniques which conserve the integral material properties of ocean fluid parcels when performing assimilation with limited data. These conservation constraints are then connected to the related problem of assimilating phase errors into a system. Metrics on the relative magnitude of amplitude and phase errors in fully observed fields are developed and the behaviour of the metrics investigated for the QG ocean model under the application of a variety of traditional and novel assimilation schemes. An example of one operationally active adiabatic assimilation method, the Cooper & Haines scheme, is implemented in the context of the QG layer model and results are shown for the effect on observed and unobserved variables of assimilating surface stream-function. The effect of smoothed observations on small-scale features is discussed, with reference to feedback on large-scale circulation.

We shall introduce a new direct iterative method for phase correcting assimilation, comparable with 3D-VAR. The method is first derived theoretically, then implemented for a hierarchy of idealized ocean problems. Convergence is discussed, with reference to the theoretical limits available through rearrangement theory and an improved 'multigridding' algorithm developed. Finally the dependence of the method on observations is considered.

5. List of Figures



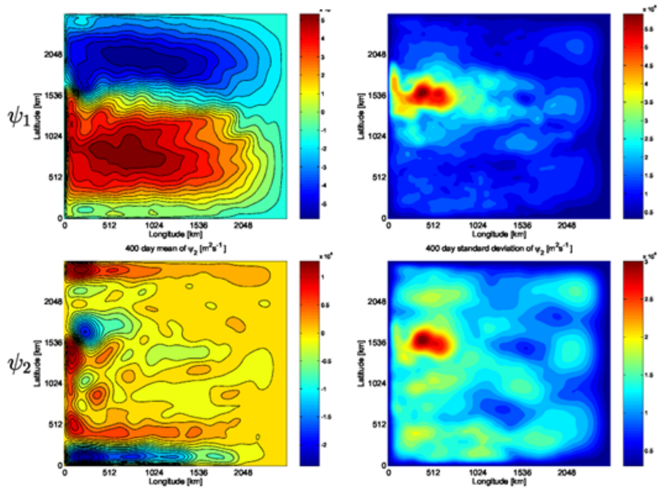


Figure 2. Long term mean state and standard deviations of q_i, ψ_i

mean : $\bar{x} = \sum_{i=1}^{800} \frac{x(t_0+12i \text{ hours})}{800}$ $\quad (S_{N-1}(x))^2 = \sum_{i=1}^{800} \frac{(x(t_0+12i \text{ hours})-x)^2}{799}$

VI. CONCLUSION

Conservation properties and phase error are closely related areas in which standard data assimilation algorithms may fail. There are several approaches which can act to alleviate this problem. The aim of this thesis has been to understand the benefits and issues involved in using phase error correction methods in a general, mathematically rigorous and physically consistent ocean forecasting system.

Most previous development in this area has been based in the context of extremely well observed systems. Here the approach has been to extend towards problems with limited observations and to examine destructively under what conditions such approaches fail. This is first performed for an algorithm based on the descent of a spatial cost-function analogous to 3D-VAR.

A novel approach based on a four dimensional algorithm equivalent to a modified version of the weak constraint 4D-VAR algorithm was developed and applied in the context of a quasi-geostrophic two-layer ocean model. This included the development of the forwards and adjoint models as well as error visualisation techniques.

This concluding chapter reviews the content of the thesis as a whole, summarizes the response to the key questions posed in Chapter 1, discusses the potential for the application of these results in operational ocean forecasting and finishes with an enumeration of possible directions for future work.

VII. REFERENCES

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