SYMPOSIUM OP'24 ADVANCING OCEAN PREDICTION SCIENCE FOR SOCIETAL BENEFITS

A Machine Learning Framework for Short-term Prediction of Sea Level Anomalies and Surface Currents

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1. INTRODUCTION

- Why should we predict sea level and surface currents ?

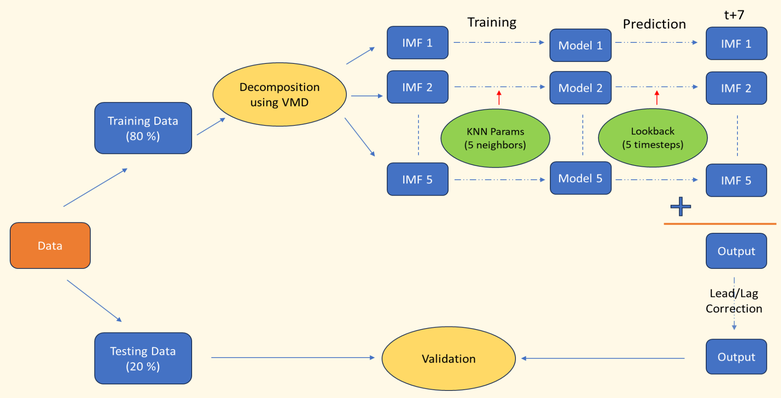
and much more ..

- Most of the recent predictions have been conventionally carried out using **ocean general circulation models** which solve **dynamical equations** but suffer from unreliability stemming from **inaccurate initial conditions, approximations in model physics, errors in atmospheric fluxes**, etc.
- Recent years have seen an abundance of research endeavors that have used diverse **Machine Learning (ML) techniques** to model sea levels at in-situ locations or over a small area.
- **Kartal and Altunkaynak (2024)[1]** compared hybrid models that combine decomposition methods with ML algorithms for sea level prediction at a tide gauge location.

2. SETUP

HYBRID MODEL

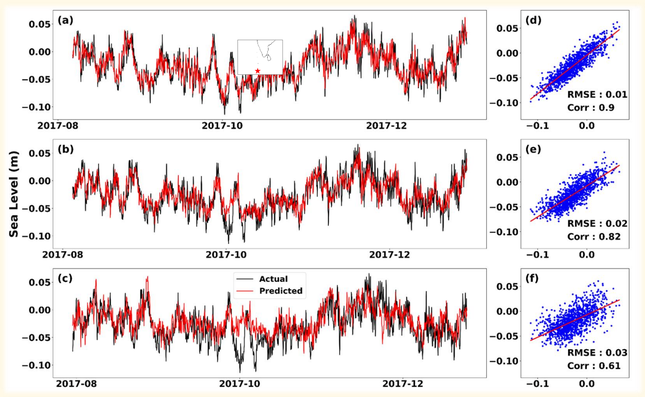
K Nearest Neighbours (KNN) + Variational Mode Decomposition (VMD)



3. RESULTS

SEA LEVEL

The model was tested on 3-hourly averaged de-tided SLA observations at a tide gauge in the Maldives (0.687°S, 73.152°E) during the period of 2016-2017 for three different leadtimes.

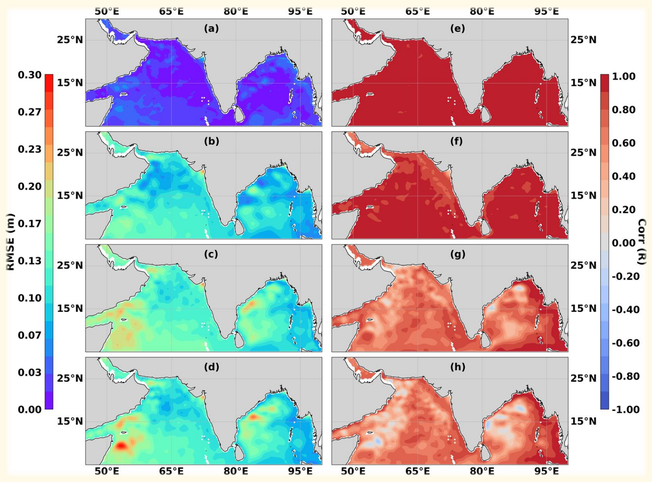


The time series of 3-hourly averaged SLA from the Maldives tide gauge (black) and the KNN-VMD model (red) with a lead time of (a) 21 hours, (b) 63 hours and (c) 7 days with corresponding scatter plots on the right.

The KNN-VMD model accurately predicts high-frequency SLA with a 21-hour lead time, achieving an RMSE of 1 cm and a correlation of 0.9 (>99% significance). Predictive skill declines with lead time but remains reasonable, with an RMSE of ~3 cm and a correlation of 0.61 at 7 days.

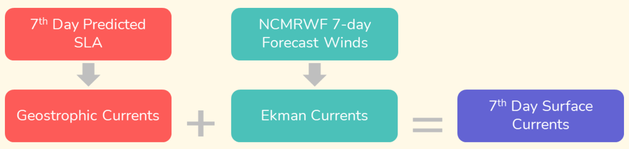
Over a region..

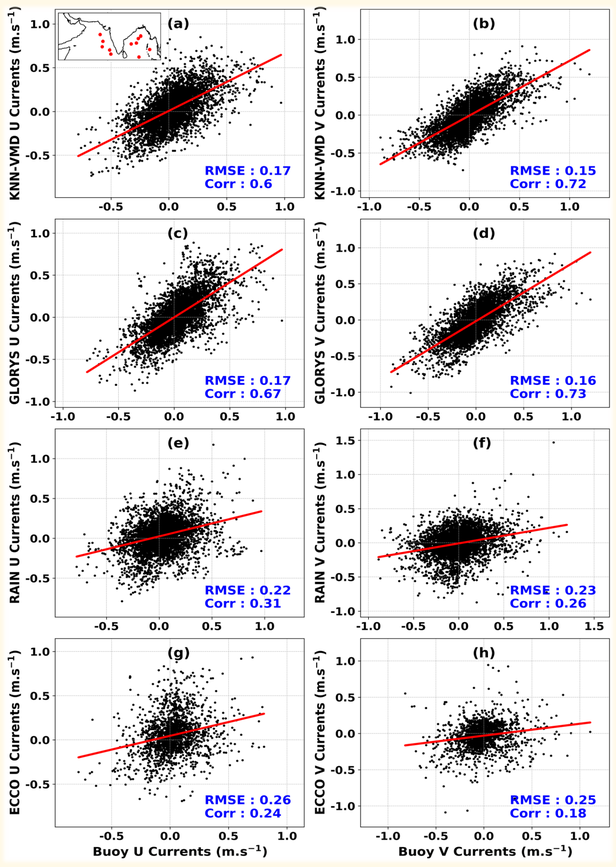
A similar framework was used to forecast daily-averaged SLA at each grid-point over the NIO (5°N-30°N; 45°E-100°E) with a lead time of **7 days** using historical daily-averaged SLA data from **AVISO** and is compared against analyses from **GLORYS** (1/12°), Regional Analysis of Indian Ocean (**RAIN**, 1/12°) and **ECCO2** (1/4°).



RMSE (meters) (left) and Correlation (right) of SLA from (a,e) hybrid model, (b,f) GLORYS, (c,g) RAIN, and (d,h) ECCO2 with respect to altimetry SLA for the period 2019-2020.

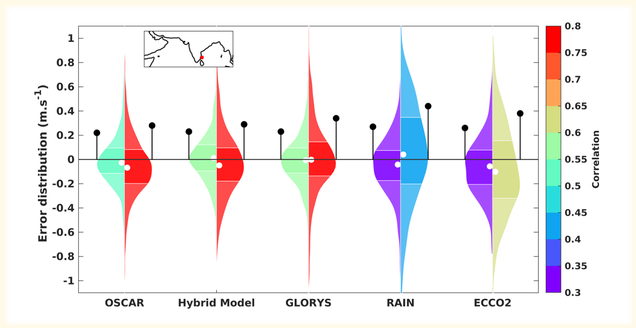
SURFACE CURRENTS





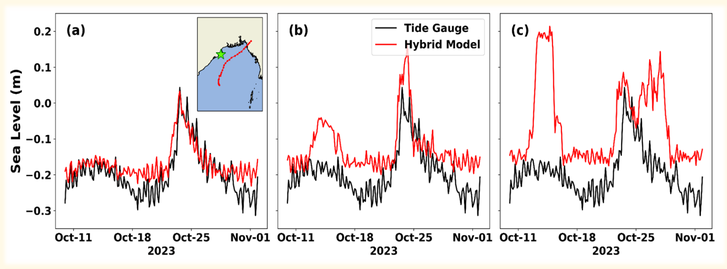
Scatter plots comparison of the surface zonal (left) and meridional (right) currents from (a,b) Hybrid (c,d) GLORYS, (e,f) RAIN, and (g,h) ECCO2 with surface currents from 12 OMNI buoys over NIO (see inset of (a) for buoy locations).

Coastal currents



Violin plots for the error distribution ($m.s^{-1}$) in daily-averaged surface zonal (left) and meridional (right) currents from OSCAR, Hybrid, GLORYS, RAIN and ECCO2 with respect to daily-averaged HF-RADAR surface currents observations during 2019–2020. The colour represent the correlation between observation and model.

An Extreme event..



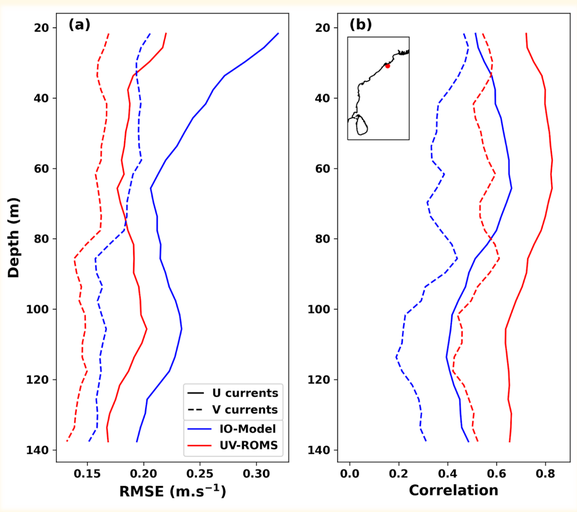
The 3-hourly averaged de-tided SLA from a tide gauge (black) located in Bay of Bengal about 180 km away from the very severe Hamoon cyclone (Oct 21-24 2023) track and forecasted SLA from the KNN-VMD model (red) with a lead time of (a) 21 hours, (b) 63 hours and (c) 7 days.

An Application..

As an application of the model data, we assimilated the predicted 'synthetic' currents to the Indian Ocean ROMS (1/12 degree) model using Local Ensemble Transform Kalman Filter (**LETKF) scheme** and compared the modelled subsurface currents with **ADCP currents**.

The 2 model setups compared are :
IO Model : Assimilates SST, SLA and in-situ temperature and salinity from various platforms but does not assimilate currents.

UV-ROMS : Assimilates no other observations except the synthetic surface currents.



(a) RMSE ($m.s^{-1}$) and (b) Correlation in zonal (solid) and meridional (dashed) currents across depths from UV-ROMS (red) and IO model (blue) with respect to observed currents from an ADCP located at 85.8°E, 19.4°N off the east coast of India. Location of ADCP shown in the inset of (b).

This framework provides an avenue to assimilate SLA & surface current "observations" during the forecast which promises to improve the entire three-dimensional ocean state forecast.

4. SUMMARY

- This study introduces a novel methodology of predicting daily-averaged SLA and surface currents over north Indian Ocean with a lead of 7 days using a hybrid univariate ML framework on IMFs of SLA.
- Under this framework, short-term forecast of SLA can be treated as a collection of low-dimensional independent systems (local) in contrast to numerical models where SLA is dependent (non-local) .
- The 7th day forecasted SLA demonstrates exceptional accuracy. Its accuracy reaches or surpasses the reanalyses from state-of-the-art dynamical systems. The RMSE is less than altimetry precision of 4 cm.
- This framework works during extreme events as well. The mesoscale eddies are also better reproduced in this framework compared to dynamical systems (not shown here).
- The 7th day predicted currents (including coastal current) from this framework show comparable accuracy to the GLORYS Re-analysis, while also exceeding the skill of both the RAIN and ECCO models.
- The assimilation of these predicted currents enhances the accuracy of subsurface currents across depths.

5. REFERENCES

1. Kartal, E., & Altunkaynak, A. (2024). Empirical-singular-wavelet based machine learning models for sea level forecasting in the bosphorus strait: A performance analysis. Ocean Modelling, 188, 102324. https://doi.org/10.1016/j.ocemod.2024.102324

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