Ocean Predict

SYMPOSIUM OP'24

In partnership with unesco Intergovernmental Oceanographic Commission

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

Data-Driven Forecasting of Residual Currents in Coastal Bays Using High-Frequency Radar Observations

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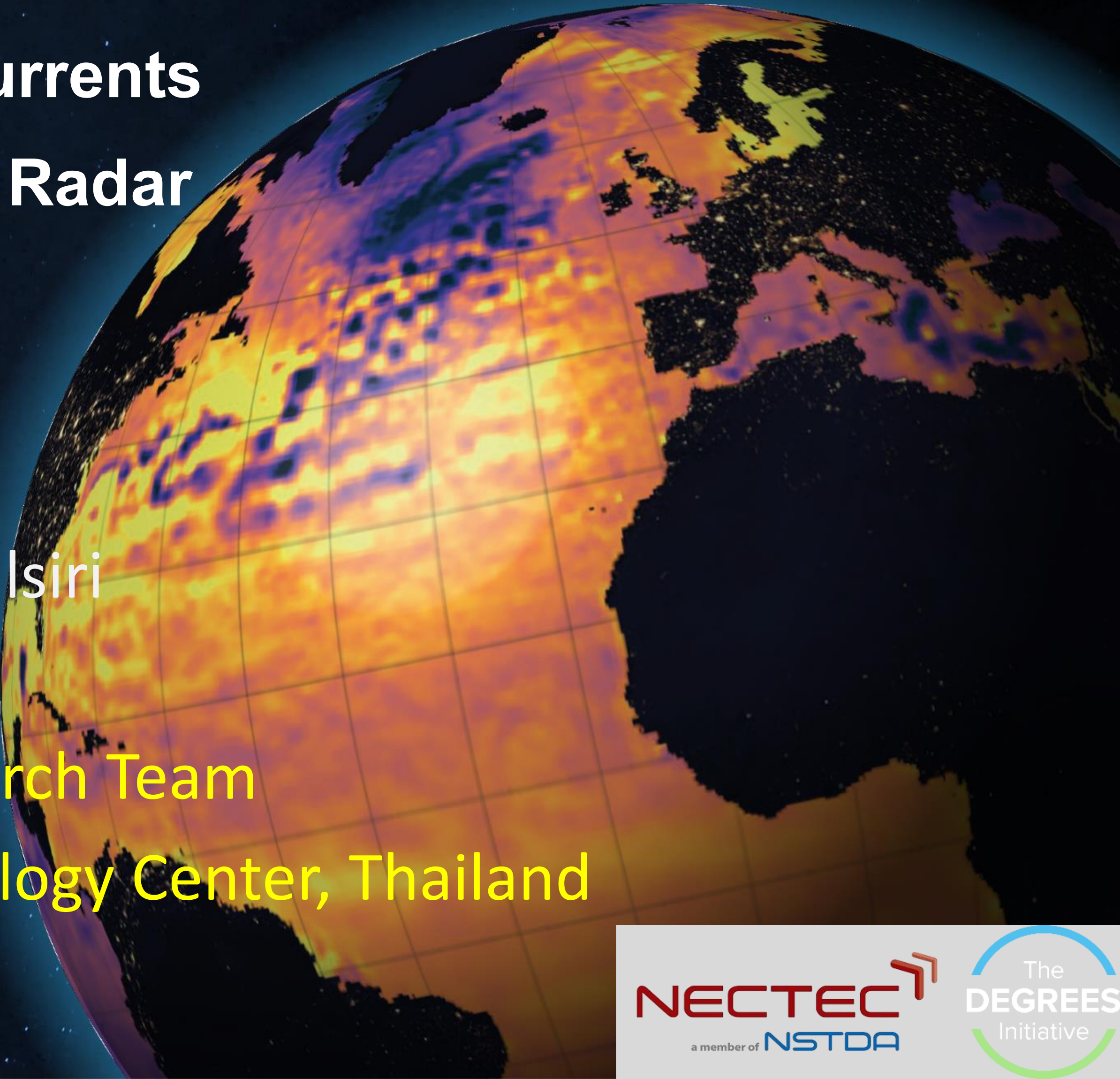

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Background and Significance

- Understanding and Predicting Residual Currents in Coastal Bays

Significance of the UGoT

The Upper Gulf of Thailand is vital to marine biodiversity, fisheries, and coastal communities.

Environmental Challenges

UGoT faces issues like pollution, habitat degradation, and water circulation complexities.

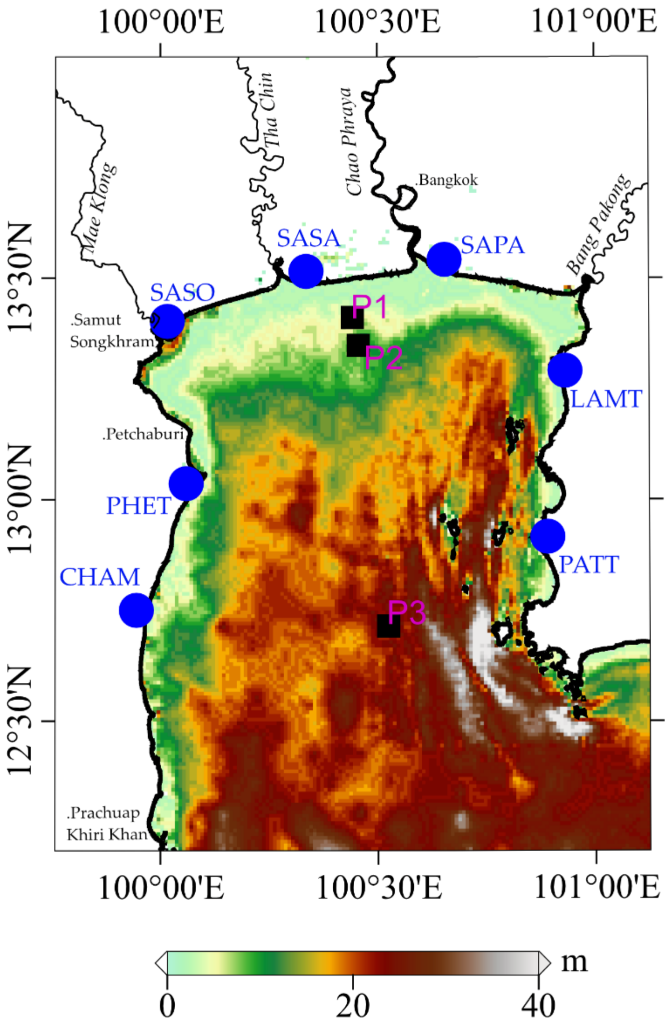
Goal of Study

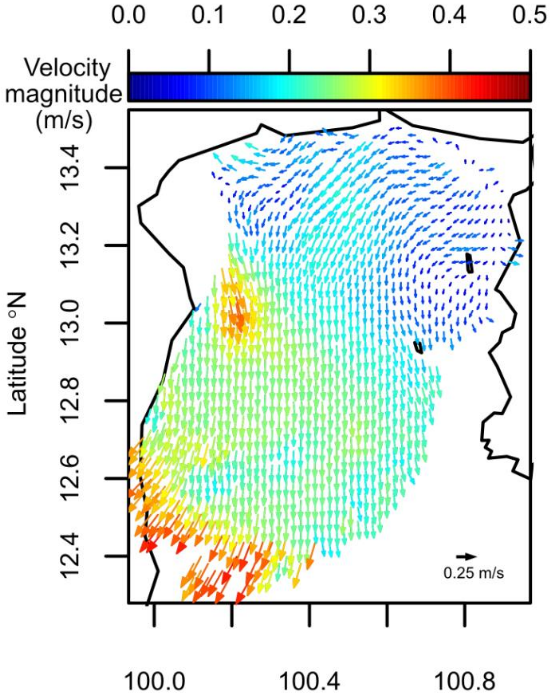
Developing a predictive model for residual currents to aid sustainable coastal management.

Methodology

• Data Collection and Analysis Techniques

- **High-Frequency Radar (HFSWR):** Captures sea surface dynamics with high resolution to monitor currents in the UGoT.
- Sea surface current data were collected from CORDAR high-frequency surface wave radar (HFSWR) deployed by Geo-Informatics and Space Technology Development Agency (GISTDA) along Thailand's coastlines. Operating at 13 and 25 MHz with 2 km spatial and 1-hour temporal resolution, this network provided 1128 snapshots from January 15 to March 2, 2015. A low-pass filter was applied to focus on residual currents, with minor limitations due to inaccuracies near islands and GDOP effects in some areas.





19 January 2015 at 08:00

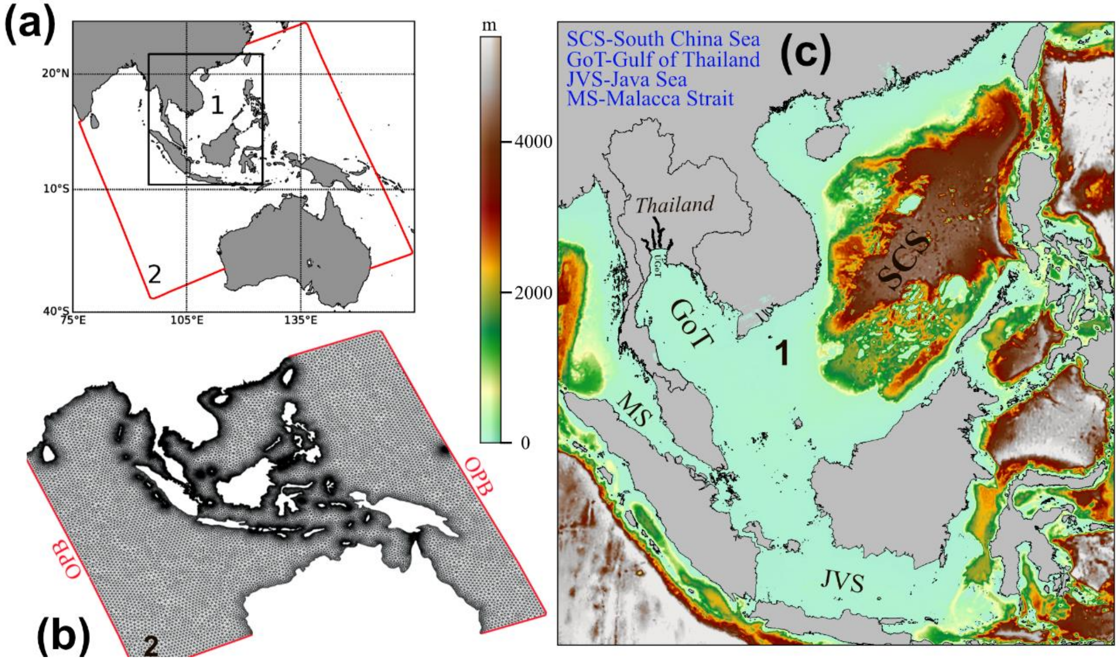
http://coastalradar.gistda.or.th/wp/

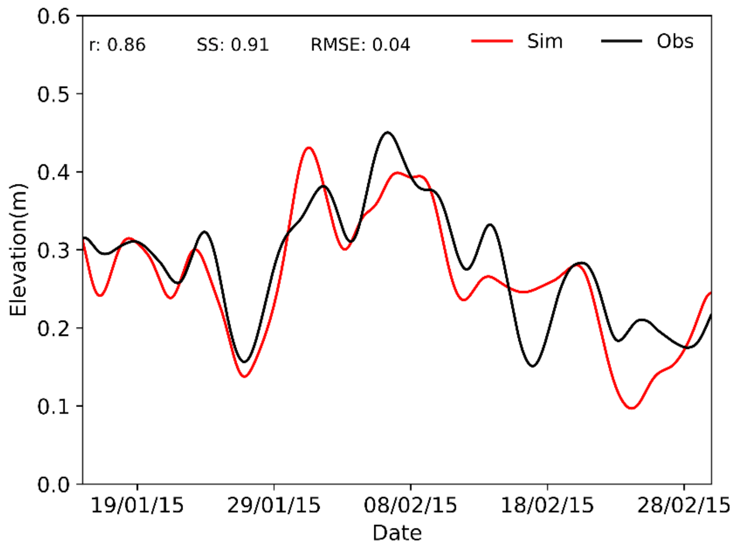
Methodology

- Data Collection and Analysis Techniques

- **Simulation Data (FVCOM):** Provides complementary data for modeling, focusing on wind-driven and seiche-influenced currents.

Parameter/Property	Value/Type
Time step (external mode)	10 seconds
Number of vertical sigma levels	5
Horizontal resolution	≈ 5.0 – 60.0 kilometers
Bathymetry	GEBCO (30 seconds)
Forcing field (wind)	NCEP Reanalysis dataset





Hourly time series of simulated (red) and observed (black) non-tidal water levels in the UGoT.

Methodology

• Data Collection and Analysis Techniques

- **Dynamic Mode Decomposition (DMD):** Used to isolate significant dynamic modes, revealing governing mechanisms of residual currents.

- DMD is a data-driven technique, capturing spectral dynamics by approximating the Koopman operator ($\boldsymbol{K}$). Unlike POD, DMD isolates growth, decay, and oscillations, making it ideal for understanding complex ocean currents.

To enhance analysis, a sparsity-promoting DMD (DMDSP) was applied to capture the most influential modes while balancing accuracy and sparsity. This method identifies dynamic phenomena within the data, emphasizing dominant modes, which helps in interpreting sub-monthly to longer-period oscillations efficiently

Dynamic Mode Decomposition (DMD) - Mode Computation Process

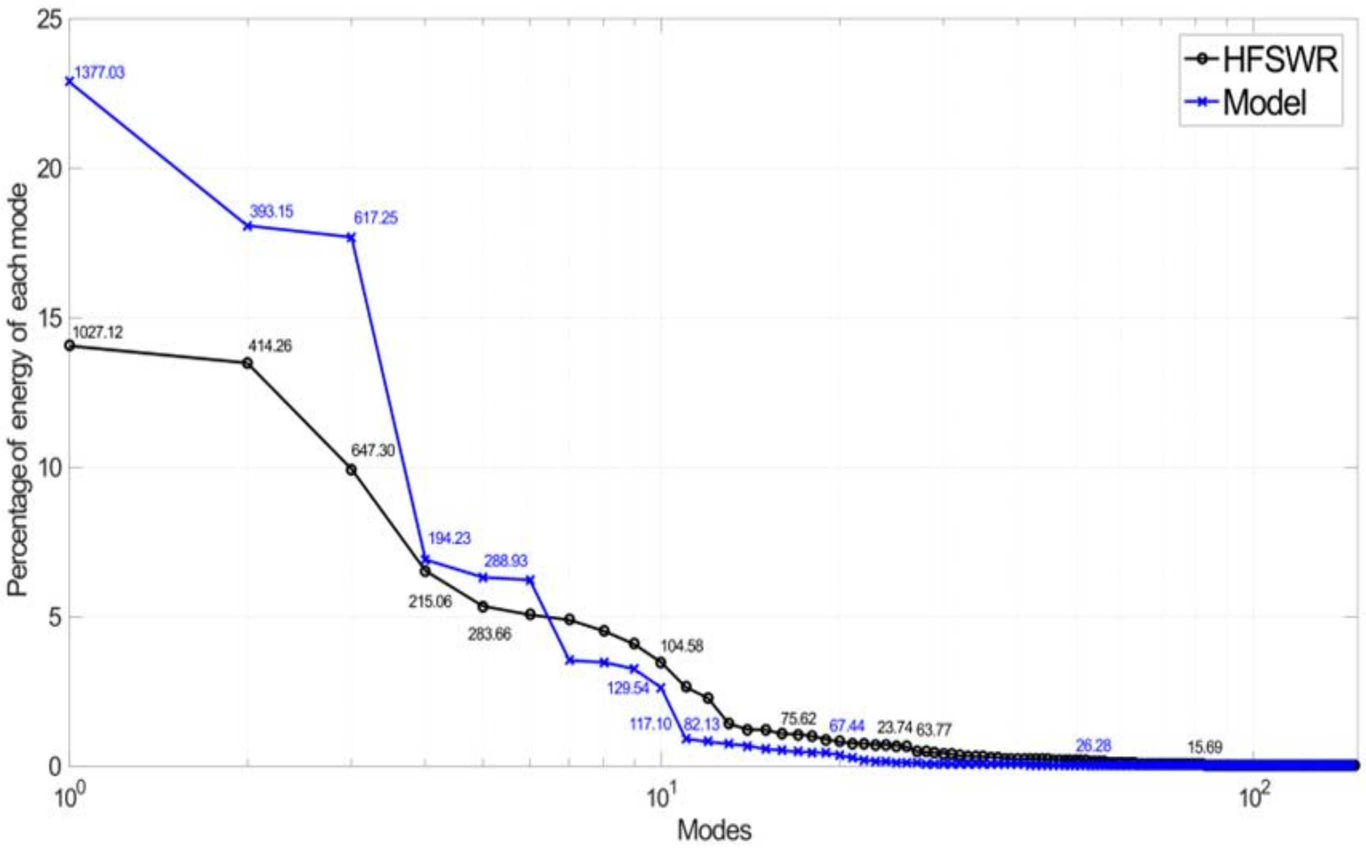
1. **Formulate the Koopman Operator K**: Arrange sequential data snapshots into matrices Z_1 and Z_2 , where $Z_2 = \boldsymbol{K} Z_1$.
2. **Apply Singular Value Decomposition (SVD)**: Decompose Z_1 as $Z_1 = U\Sigma V^*$
3. **Compute Reduced Koopman Operator**: Use $\widetilde{K} = U^* Z_2 V \Sigma^{-1}$.
4. **Eigen Decomposition**: Decompose $\widetilde{K}$ to find eigenvalues Λ and eigenvectors W.
5. **Calculate DMD Modes**: $\Phi = Z_1 V \Sigma^{-1} W$, where Φ represents the dynamic modes.

DMDSP – Sparsity-Promoting Dynamic Mode Decomposition, Mihailo R. Jovanovic, Peter J. Schmid, Joseph W. Nichols, Physics of Fluids 26, 024103 (2014)

Key Findings

- Residual Current Dynamics in the UGoT

- **Dominant Modes**: Key temporal modes identified at 1027.12, 647.3, and 414.26 hours, which capture the primary dynamics of residual currents at sub-monthly to monthly scales.
- **Resonance Properties**: Additional shorter periods (215.06 and 173.09 hours) reveal resonant characteristics, likely unique to the UGoT, adding complexity to the residual current variability.
- **Environmental Influence**: These periodic structures reflect the impact of regional environmental factors on the temporal behavior of currents in the UGoT.



Key Findings

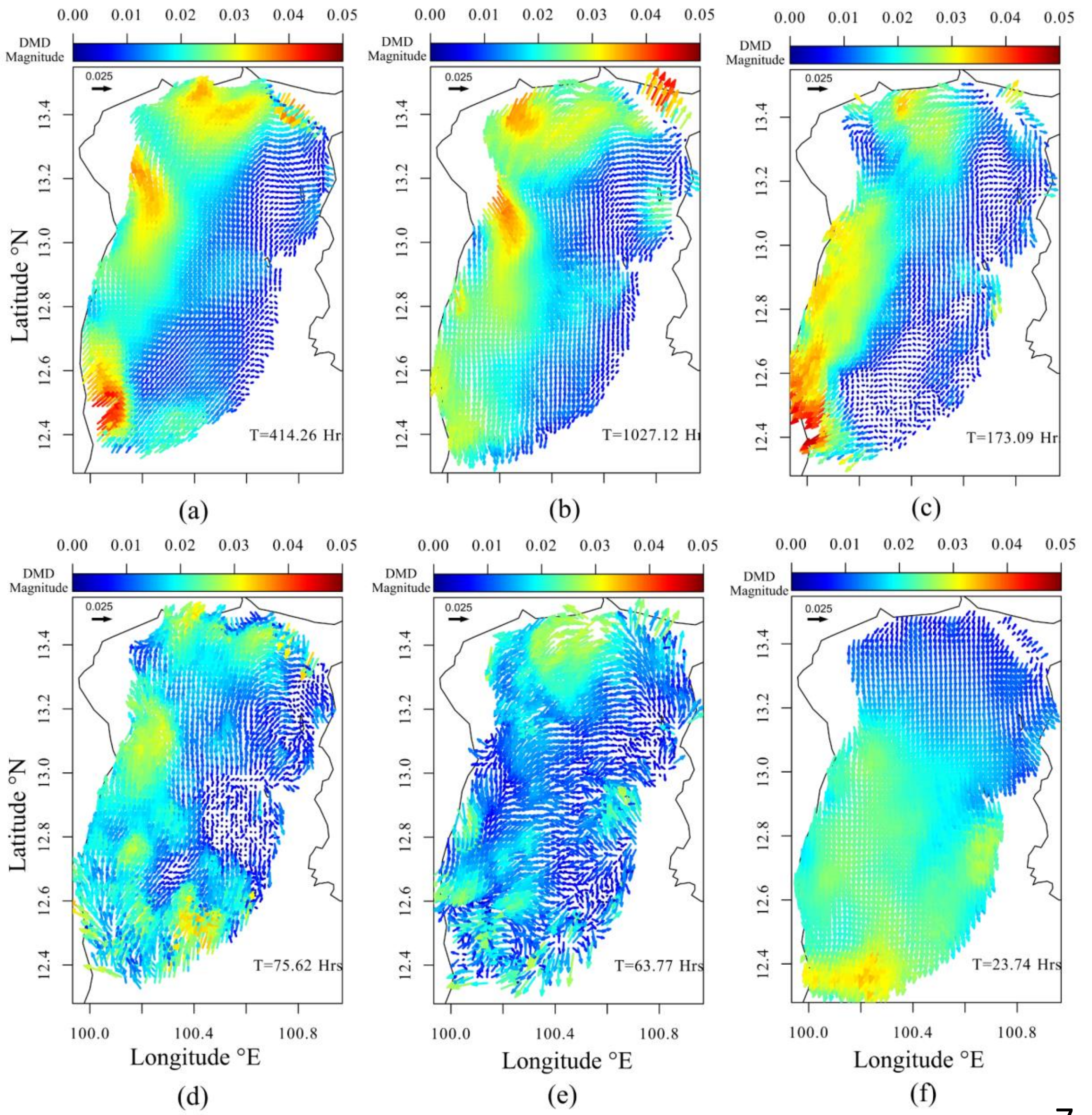
• Residual Current Dynamics in the UGoT

- **Dominant Modes:** Long-period modes (1027.12 and 414.26 hours) show strong residual currents along the northern and western UGoT coastlines, indicating a wind-driven pattern, with weaker currents on the eastern shore.

- **Resonance Mechanisms:** Shorter-period modes (e.g., 75.62, 63.77, and 23.74 hours) display resonance effects, particularly along the north-south and east-west axes. Notably, the 23.74-hour mode is most intense in the southern UGoT, demonstrating distinct spatial variability.

- **Wind Influence:** The spatial distribution of these modes suggests that coastal topography and wind play key roles in shaping UGoT circulation patterns

- **Wind-Driven Dominance:** Findings show that wind-driven flow is the primary force affecting residual currents in the UGoT, due to its limited spatial dimensions which inhibit geostrophic effect.

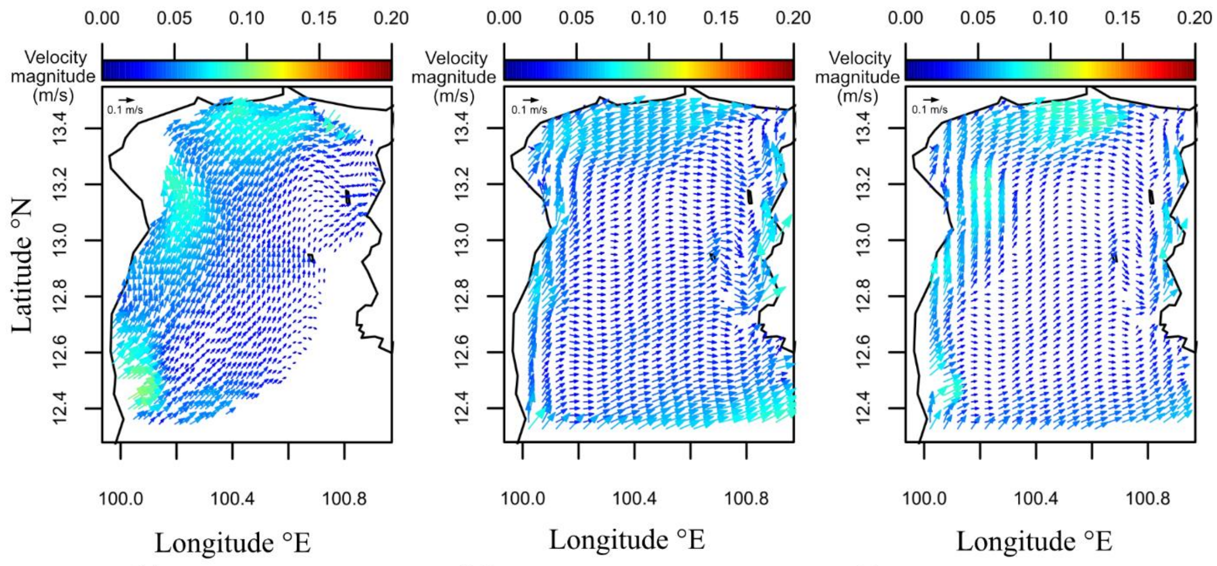


Applications and Broader Implications

- Impact of Data-Driven Forecasting on Coastal Management

- Reconstruct residual currents in the UGoT using DMD modes to capture key dynamics while minimizing error
- Accuracy Improvement: Error decreases as more modes are added.
- Best Results: 16 modes achieve highest accuracy, with 6.5% error for HFSWR data and 2.2% for simulated data.

Number of DMD modes	Error	
	HFSWR data	Simulated data
2 modes	51.70%	64.20%
4 modes	23.10%	24.20%
8 modes	10.90%	16.20%
16 modes	6.50%	2.20%



(a) Two modes-Obs. (b) Two modes-Sim. (Only Scaling) (c) Two modes-Sim. (Scaling plus biases)

Scaling and bias correction methods also help reconstruction quality

Improved reconstruction enhances understanding of UGoT current patterns.

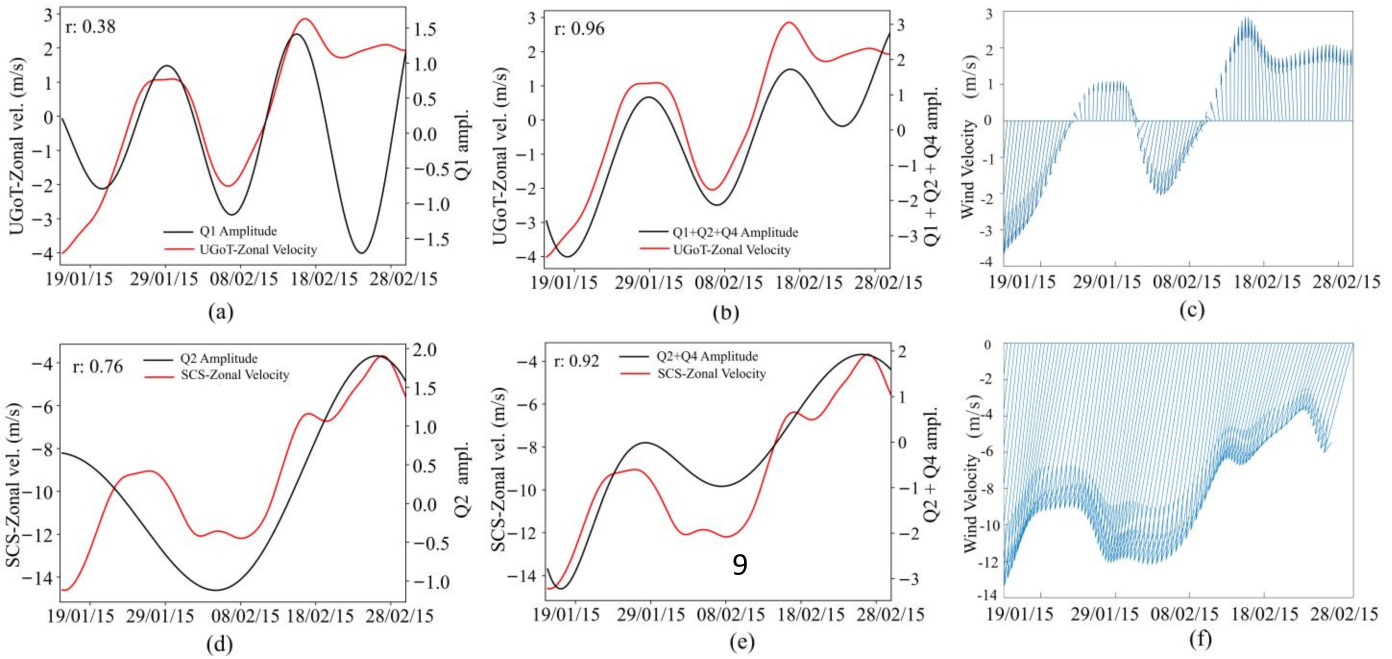
Supports more reliable forecasting and informed decision-making for coastal planning

Applications and Broader Implications

- Impact of Data-Driven Forecasting on Coastal Management

Wind Correlation with DMD Modes

- High Correlation (>0.9): Combined amplitudes of DMD modes show strong correlation with zonal wind patterns in the UGoT and South China Sea (SCS).
- Individual Mode Correlations:
  - 414.26-hour Mode : Driven primarily by zonal winds in the UGoT.
  - 1027.12-hour Mode : Influenced by SCS zonal winds.



Wind forcing data from NCEP highlights the potential for using wind data to predict DMD modes and, by extension, residual currents in the UGoT

Applications and Broader Implications

- Extending the Model for Future Projections

•**Climate Change Projections:** Leverage GeoMIP and SSP (Shared Socioeconomic Pathways) data to explore potential changes in residual currents under diverse future climate scenarios.

•**Historical Baseline**:

Use historical data to benchmark and understand changes relative to past climate patterns.

•**Future Emission Pathways**:

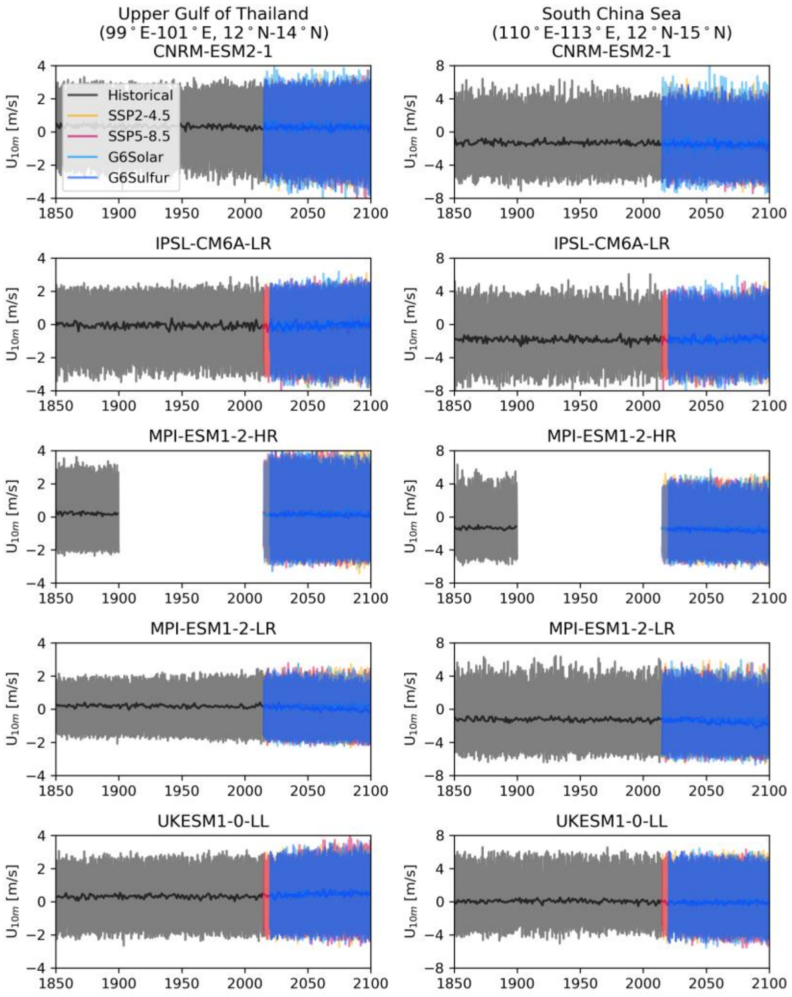
SSP245: A moderate emissions scenario, representing a world with medium climate action.

SSP585: A high emissions scenario, simulating extreme climate conditions for robust stress-testing

•**Geoengineering Scenarios**:

G6solar: Simulates the effects of reduced solar radiation to explore cooling impacts.

G6sulfur: Models the impact of adding aerosols, reflecting climate intervention strategies.



Utilizing wind data from GeoMIP, SSP, and CMIP climate scenarios allows us to explore the potential impacts of future climate conditions on residual current structures. By integrating these diverse scenarios, we enhance our predictive capability, enabling us to forecast changes in current patterns and strengthen preparedness for a range of climate outcomes.

Conclusions

- Advancing Ocean Prediction for Sustainable Management

Enhanced Understanding

Identified key dynamics of residual currents influenced by wind and seiche patterns.

Ecosystem Resilience

Helps in managing nutrient transport, sediment movement, and pollution dispersion for sustainability.

Predictive Capability

Validated model enhances prediction accuracy for complex coastal current behaviors, especially when integrating climate projections using GeoMIP data

Disaster Preparedness

Supports early detection of hazardous current patterns and enhances preparedness for future climate-induced changes.

Future Directions

Plans to expand the model to incorporate more climate scenarios and apply it to other coastal regions, supporting proactive adaptation strategies.

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