
# Explainable Multimodal Spatiotemporal Learning for Two-Week HAB Forecasting

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# Motivation

## The Threat of HABs

**Harmful Algal Bloom (HAB)** are caused by excessive algae growth (i.e., **> 50000 cells/L**), some of which produce toxins that are harmful to marine life and human health.

- Environmental Impact
  - Marine life mortality
  - Water quality
- Economic Consequences
  - Fish farm closure
  - Tourism decline

# Challenges in Current Methods

## Limitations

**Manual water sampling**

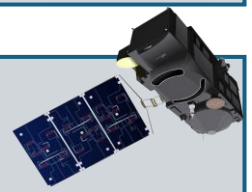
- Low frequently: weekly or monthly
- Sparse in space
- Labor-intensive and costly

**In-situ sensors**

- High-frequent data
- Fixed location: limited spatial coverage

**Remote sensing**

- Weather-dependent: cloud-induced missing data
- Near-global converge but irregular temporal availability



## Practical requirements

**Cross-domain HAB drivers**

- Non-linear interactions among biological, optical, and physical processes

**Multi-week forecasts**

- Early warnings usable by managers
- Deploy response measures (public advisories, equipment adjustments)

*Caballero, C. B., Martins, V. S., Paulino, R. S., Butler, E., Sparks, E., Lima, T. M., & Novo, E. M. (2025). The need for advancing algal bloom forecasting using remote sensing and modelling: Progress and future directions. Ecological Indicators, 172, 113244.*
*Goodrich, S., Canfield, K. N., & Mulvaney, K. (2024). Expert insights on managing harmful algal blooms. Frontiers in Freshwater Science, 2, 1452344.*

# Problem Statement

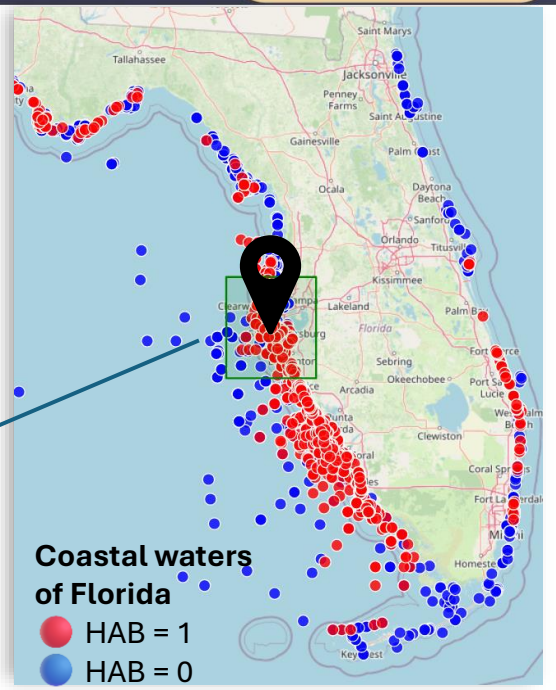
**How can multimodal spatiotemporal learning be leveraged to provide reliable multi-horizon HAB forecasts (1–14 days ahead) that are operationally useful for early-warning and management decisions?**

Given: 10-day multimodal historical data $\mathcal{X}_{t-10:t}$
Predict: HAB alert $y_{t+k}$ for multiple horizons $H \in \{1, \dots, 7, \dots 14\}$ .

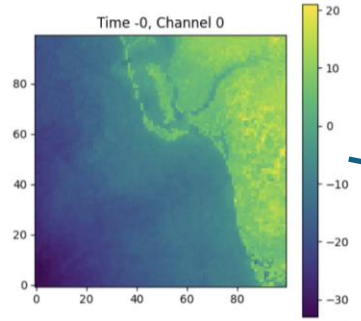
# Multimodal Data Fusion

**Multimodal sources differ in scale, resolution, temporal frequency, and noise.**

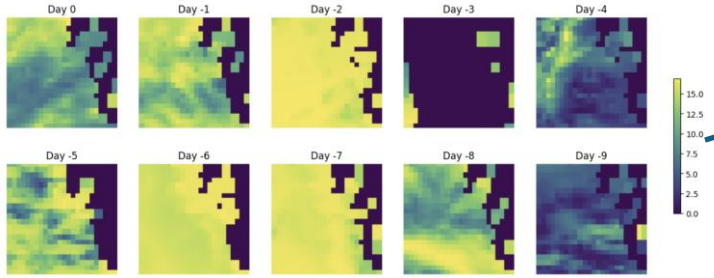
- **HABSOS water sampling records**
- **GEBCO Bathymetry**
- **Satellite data (MODIS-Aqua, Terra)**
  - Bands: chlorophyll-a, remote sensing reflectance, photosynthetically available radiation (PAR) , sea surface temperature (SST), etc.
- **HRRR meteorology**
  - Multi-variables (wind, temp, rain, cloud)
  - Instantaneous vs accumulated

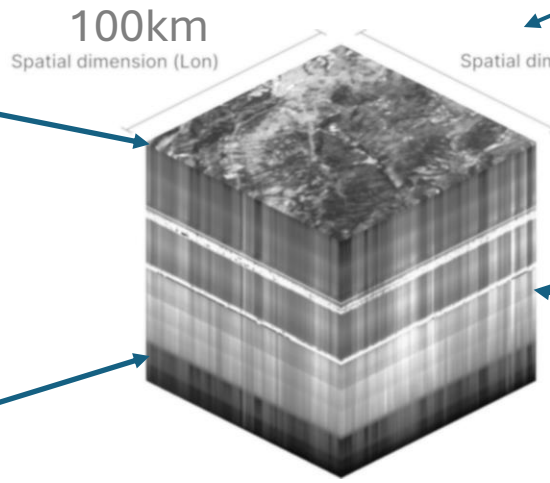



Bathymetry

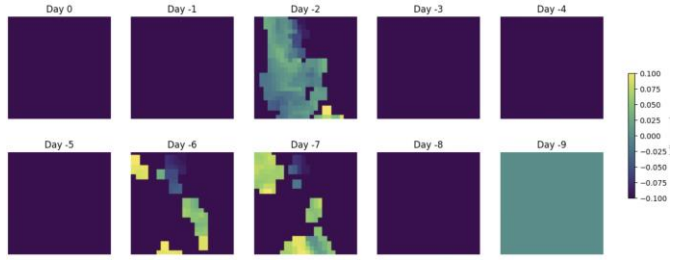



PAR



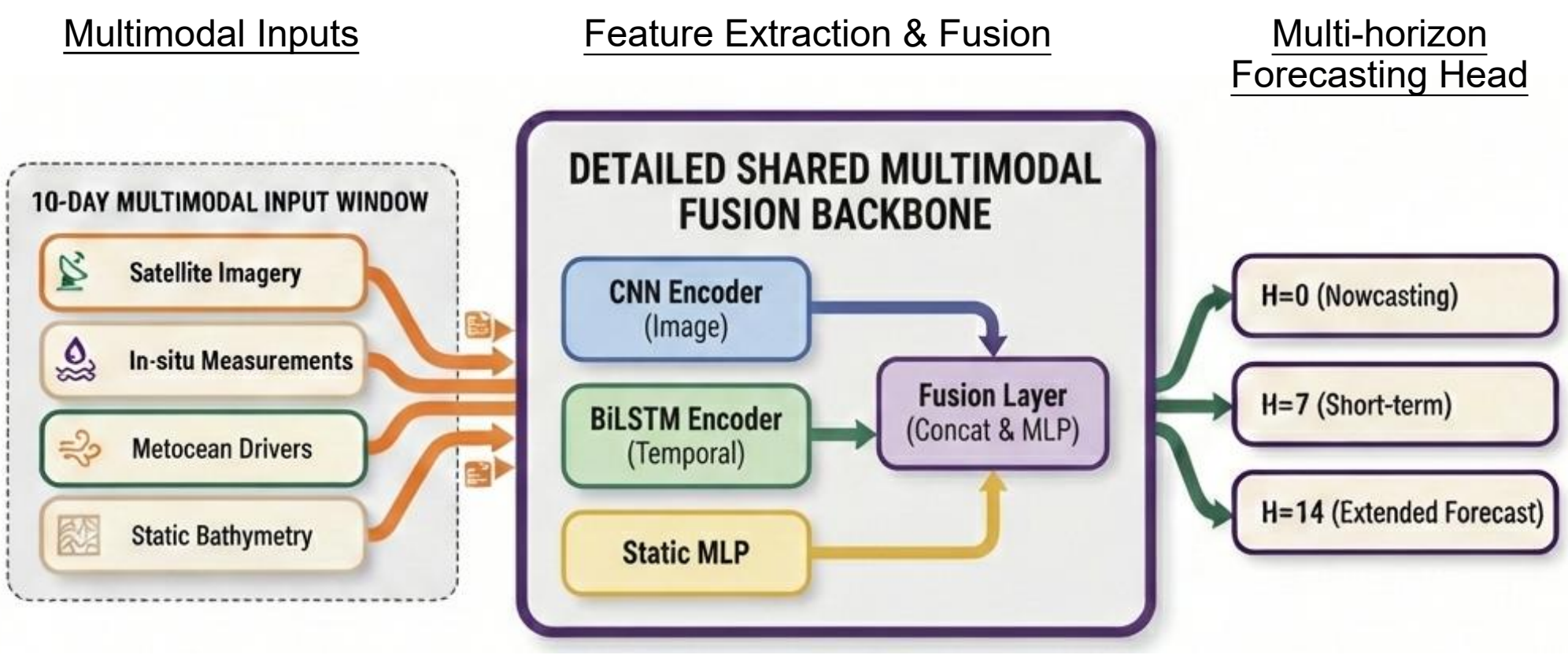




Mult-spectral Image

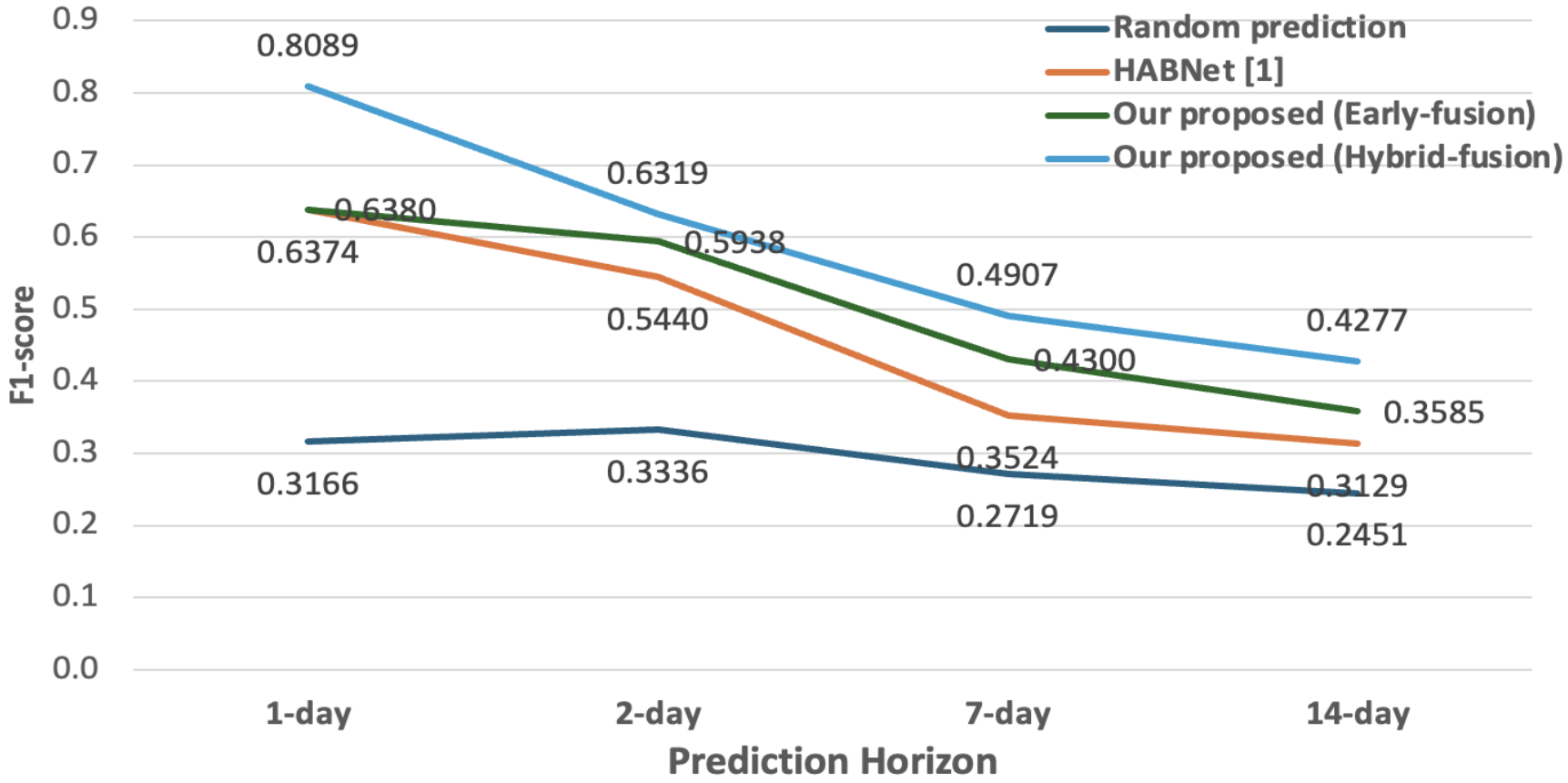



Rain

# Proposed Framework Overview

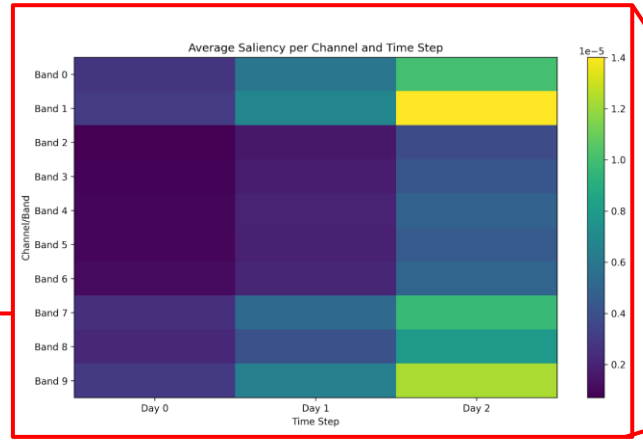


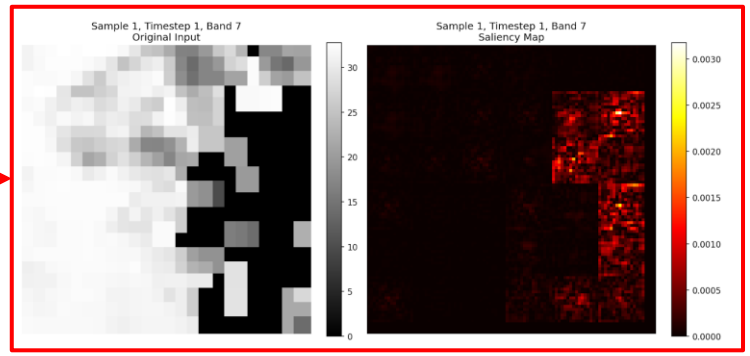
# Experimental Results

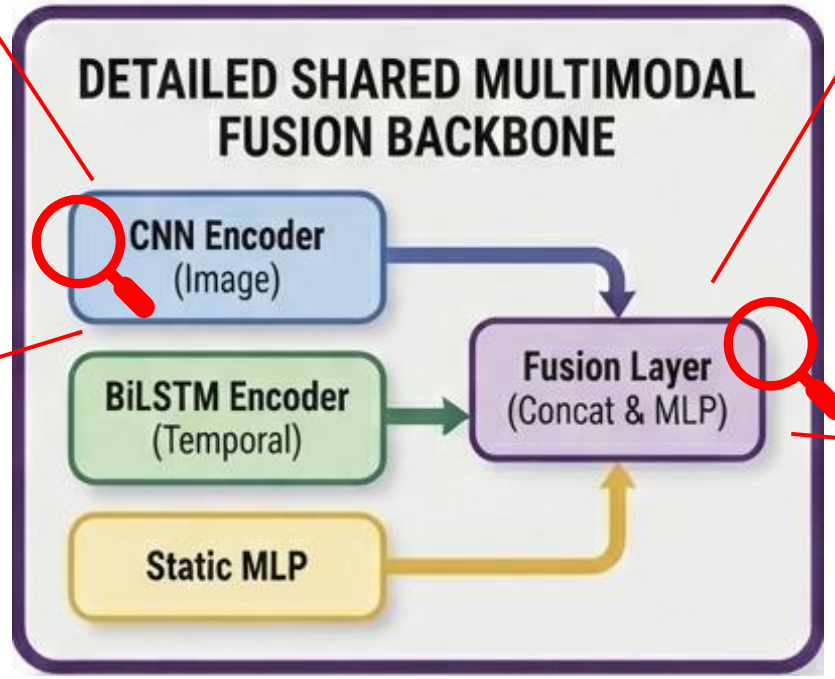


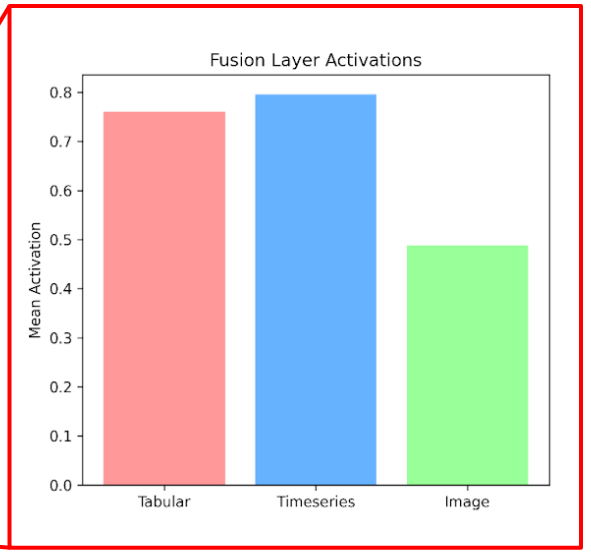

*Hill, P. R., Kumar, A., Temimi, M., & Bull, D. R. (2020). HABNet: Machine learning, remote sensing-based detection of harmful algal blooms. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 13, 3229-3239.*

# Visualizing Explainability



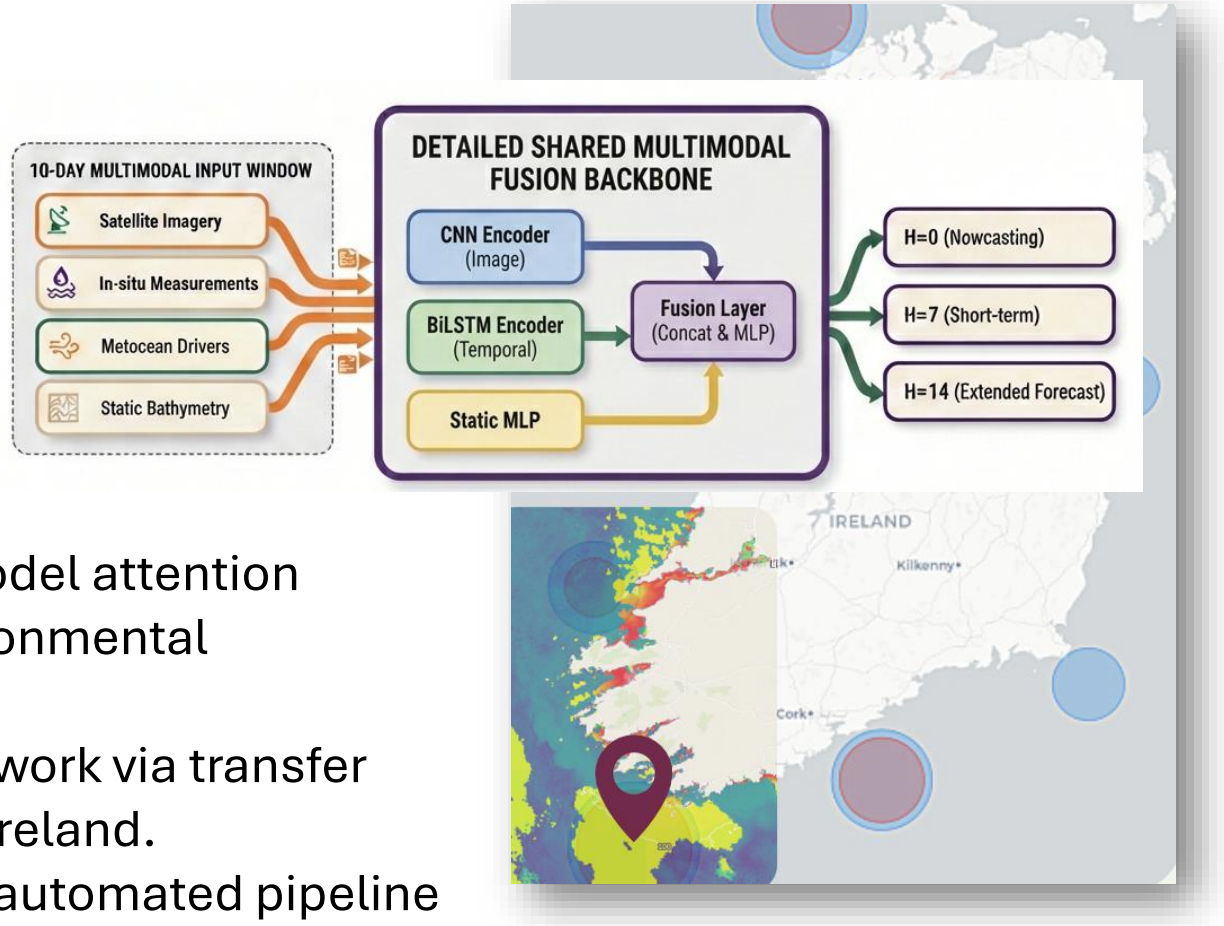



# Key Contributions

- **Integrated Multimodal Framework**
- **Robust 14-Day Forecasting**
- **Bridging "Black-box" Gap**




# Future Work

- **Actionable Explainability:** Translate model attention weights into actionable reports for environmental stakeholders
- **Scaling to Irish Water:** Adapt the framework via transfer learning to diverse coastal sites across Ireland.
- **Real-Time Deployment:** Implement an automated pipeline for live monitoring and early-warning delivery.

# Thanks for your attention!

# Questions are welcome.

**HABShield**: Online Multimodal Spatio-Temporal, LLM-Enhanced, Explainable AI Detection System for Harmful Algal Bloom Alerts

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