Evaluation of drivers of the 2025 harmful algal bloom event in South Australia

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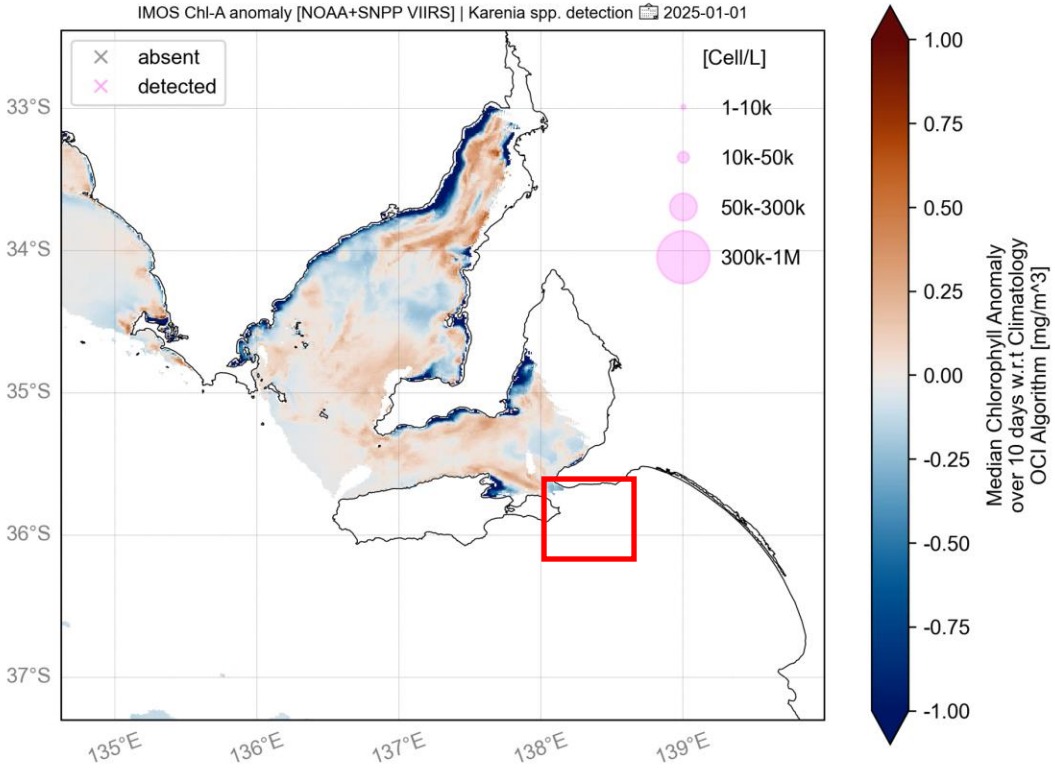
A preliminary investigation into bloom initiation

Global review of HAB-*Karenia* drivers

Focused on two coastal regions with contrasting exposure to suspected drivers

Data-driven approach using existing observational and modelled datasets

Key gaps and next steps



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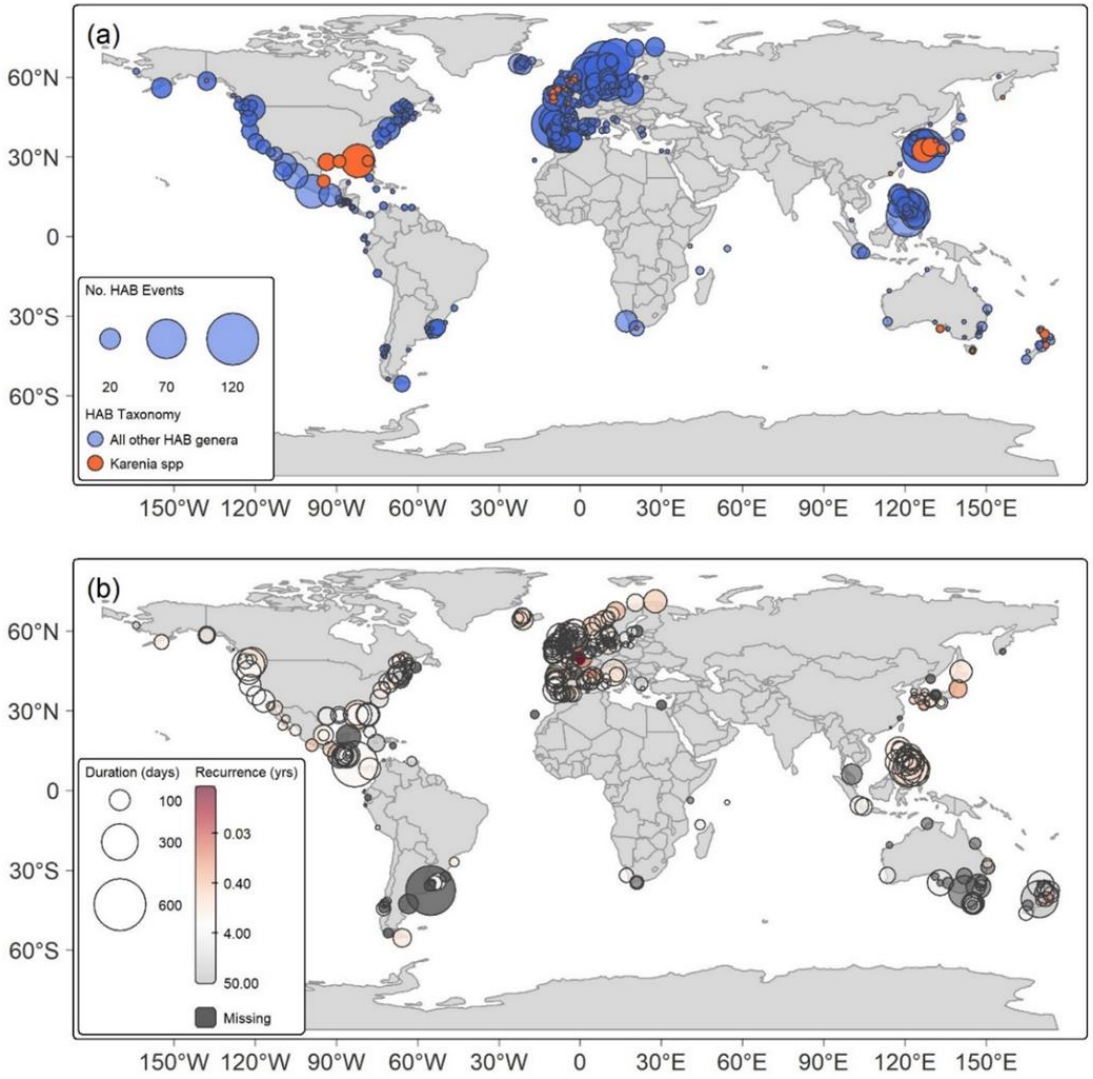
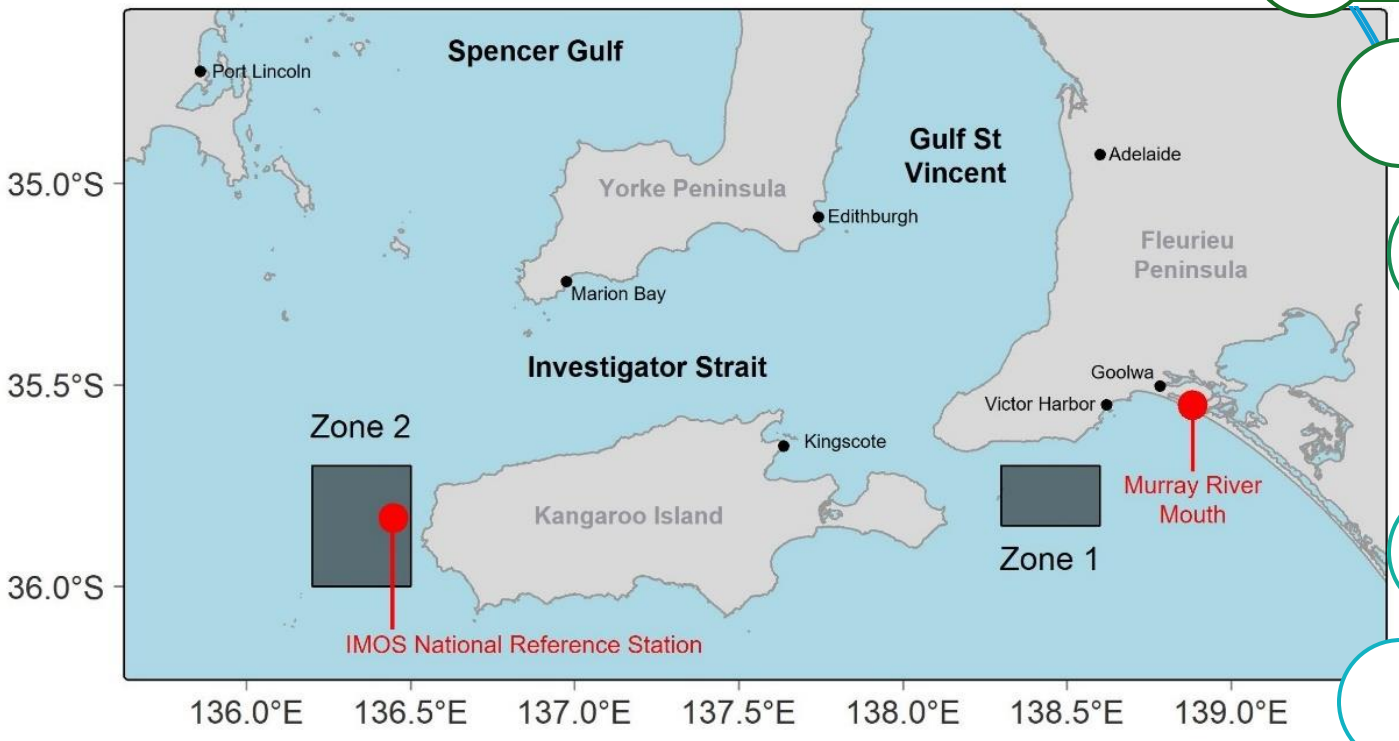
Global HAB-*Karenia* Drivers



- **HABs occur when conditions, nutrients & species traits align — shaped by geography and climate**
- **Ocean/coastal circulation & geography** (upwelling, retention)
- **Stratified, calm & warm waters**
- **Nutrient inputs** (land & ocean sources)
- **Climate variability & change** (marine heatwaves, storms/rainfall)
- **Species can take advantage different drivers/conditions**
- **No single cause** (multiple drivers & favourable conditions)

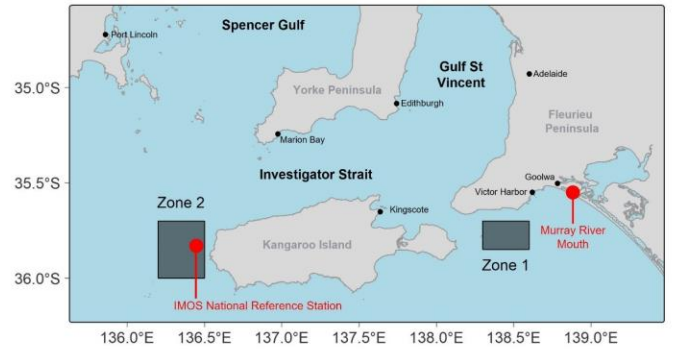
HAB events, occurrence, duration and recurrence as reported in the Harmful Algal Event Database (HAEDAT) - Intergovernmental Oceanographic Commission (IOC) -UNESCO

HAB Drivers Approach

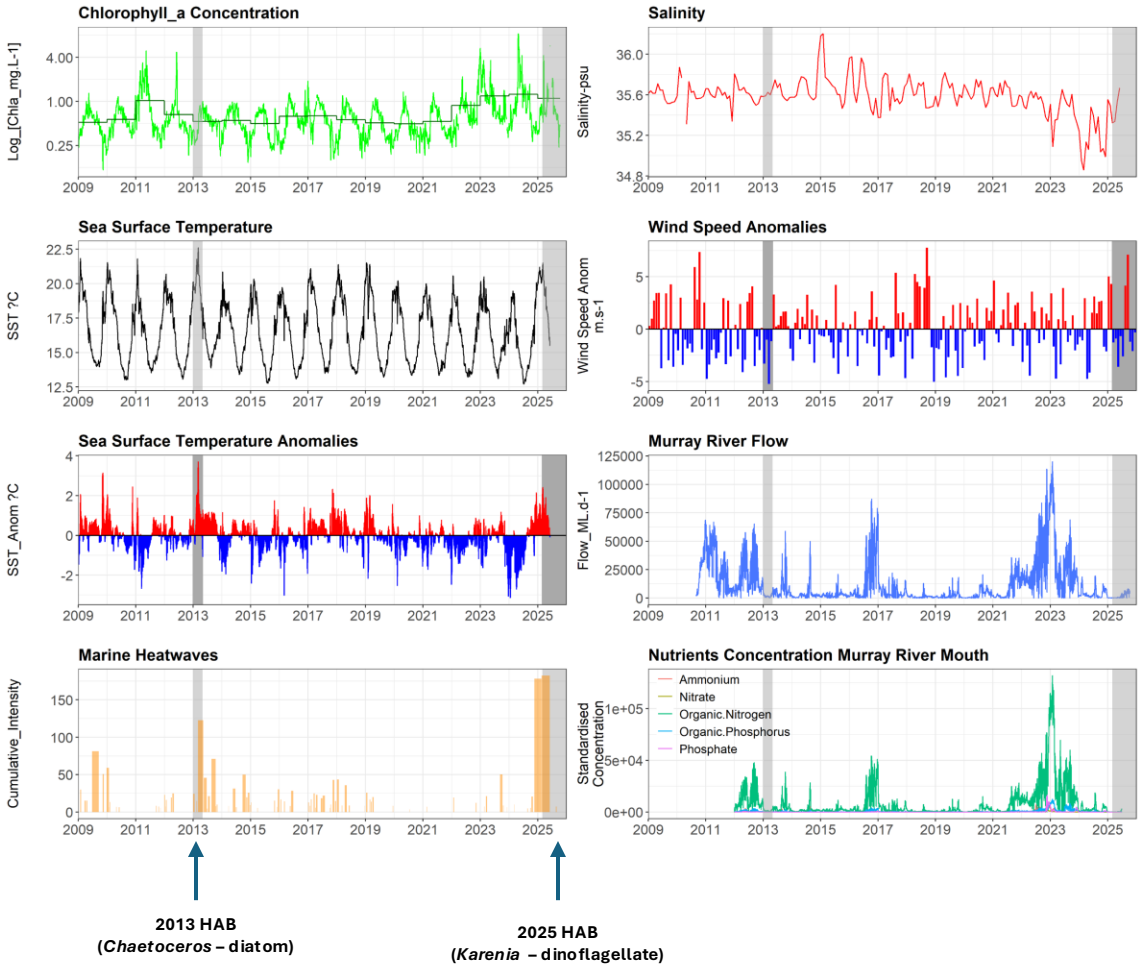


- **Used long-term environmental datasets (satellite + in situ observations 16 years – 2009 to 2025)**
- **Compared two regions with different conditions:**
- **Zone 1** –HAB origin (river + upwelling impact, no *in situ* observations)
- **Zone 2** –Offshore shelf (upwelling impact, sustained observations)
- **Compared 2025 HAB with 2013 HAB event** (*Chaetoceros*)
- **Identify which conditions were unusual before each bloom**
- **Consistent with global HAB studies:** compare baseline vs extreme years

Environmental Data



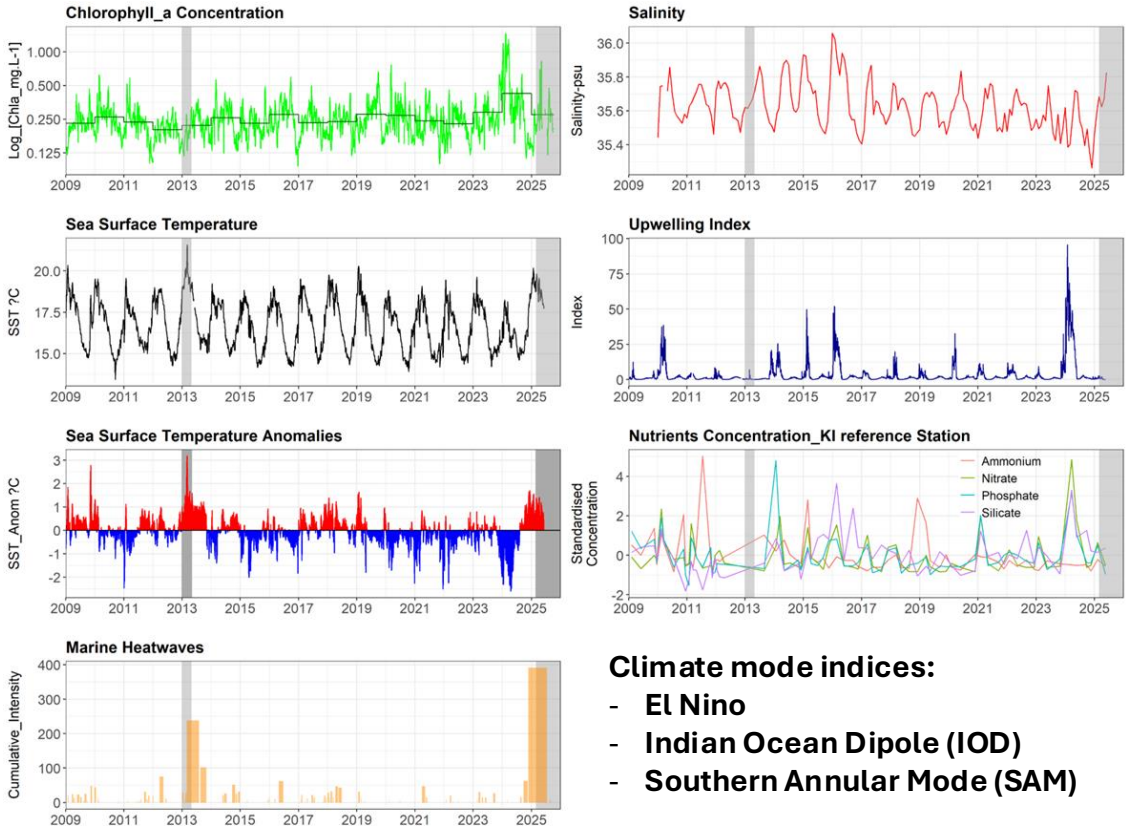
Zone 1



2013 HAB
(*Chaetoceros* – diatom)

2025 HAB
(*Karenia* – dinoflagellate)

Zone 2



Climate mode indices:

- **El Nino**
- **Indian Ocean Dipole (IOD)**
- **Southern Annular Mode (SAM)**

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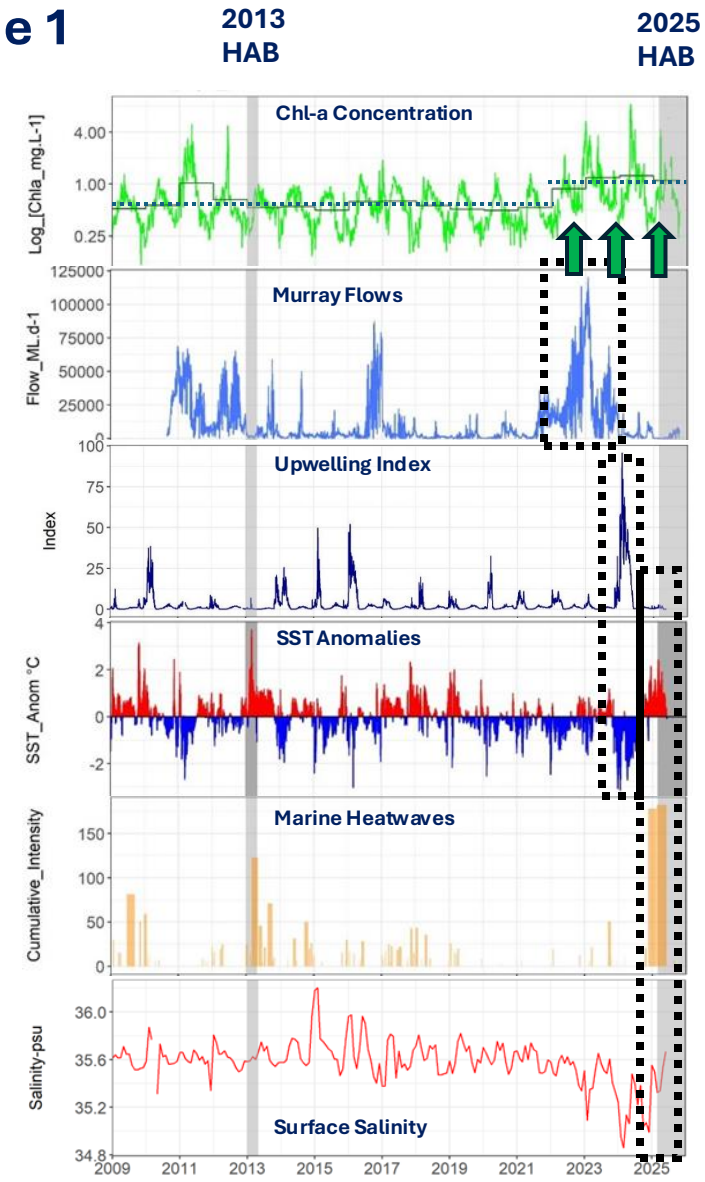
Potential preconditioning-drivers HAB Drivers

Zone 1



3 years elevated Chl-a (sustained nutrient enrichment)

2022/23 Murray River flooding

2023/24 record upwelling

2024/25 very weak upwelling

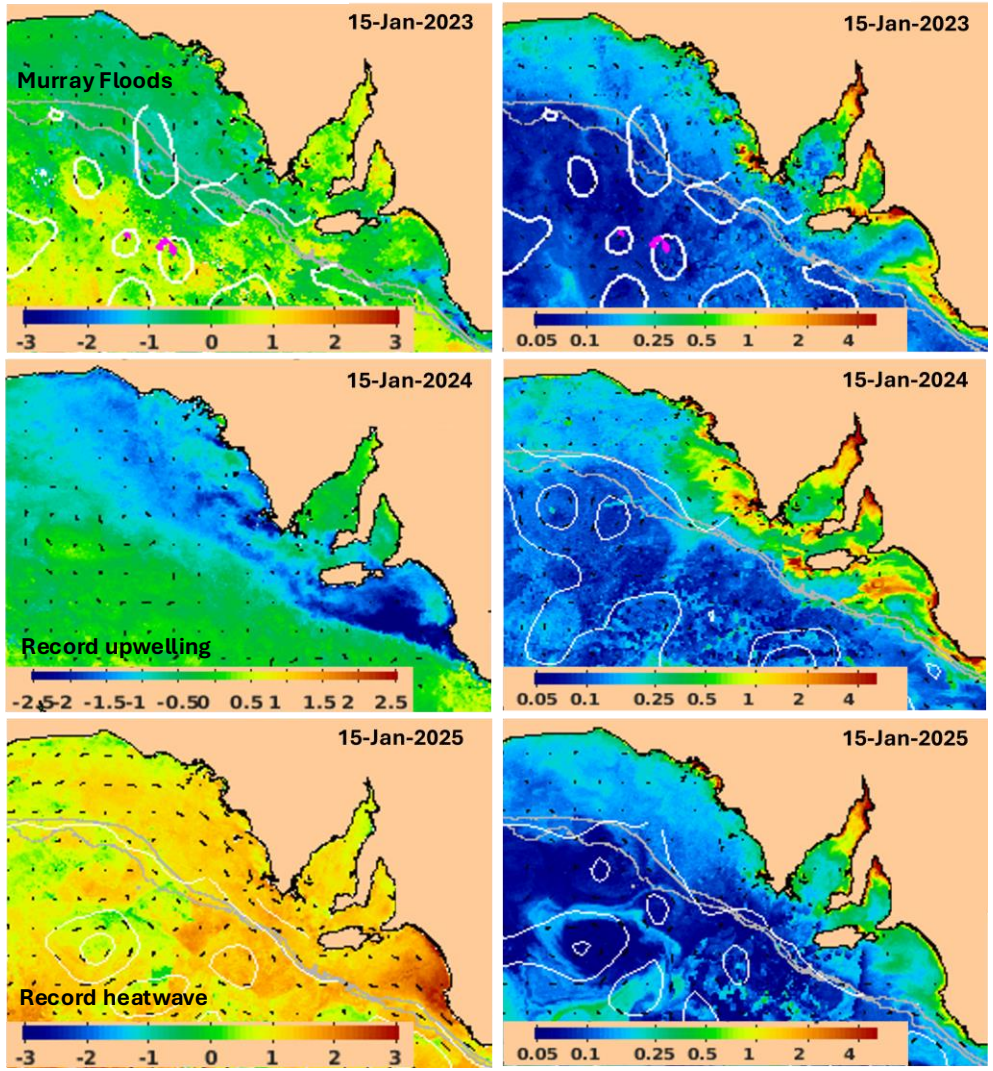
Mid-2024 warm SST intensified

Mid-2024 extreme marine heatwave (~10 months)

Mid-2023 to end 2024, low salinity, indicative of high stratification

SST anomaly

Chl-a -anomaly



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Summary

- **No evidence for a single dominant driver or definitive causal pathway**
- **Prolonged environmental preconditioning** over several years, including elevated phytoplankton biomass and nutrient availability in the bloom origin region
  - 2023 River Murray flood (highest discharge in ~70 years)/record-strength coastal upwelling 2023–24
  - not aligned directly with bloom onset, suggesting a preconditioning rather than triggering role
- **Bloom development and intensification** occurred during an unprecedented marine heatwave
  - calm conditions, reduced wind mixing, and enhanced water-column stratification likely favoured motile dinoflagellates such as *Karenia*
- **Resident *Karina* species** including *K. cristata*, have been present at low abundance in SA waters for at least a decade
  - The 2025 event likely reflects rapid proliferation of a resident assemblage under favourable conditions, rather than introduction of new species
- **Compared with the 2013 SA HAB event** the 2025 bloom was preceded by stronger and more prolonged environmental preconditioning
- **Consistent with global HAB research** attribution remains complex and uncertain
  - relative importance of individual drivers, and whether all were necessary for bloom development, remains unresolved

Gaps and Challenges

Single unprecedented event

- only one major *Karenia* bloom to analyse (2025)
- unclear if drivers are typical - or rare convergence of conditions
- many global *Karenia* systems have multi-decadal bloom records

Limited knowledge of *K. cristata*

- largest and most extensive documented *K. cristata* event worldwide
- species-specific preferences unknown
- may differ from better-studied *Karenia* species

Multi-species assemblage

- complex, temporally shifting assemblage of at least five *Karenia* species
- uncertainty in species-specific environmental tolerances

Bloom origin and population source

- processes by which a *Karenia* population first grew to bloom densities
- origin, conditions that triggered growth and bloom spread and maintenance uncertain

Data gaps

- limited in situ nutrients/stratification data at bloom origin
- reliance on satellite and modelled datasets
- analysis qualitative – quantitative work needed
- new moorings/sensors now deployed for future events

Conclusions

- **Bloom development and persistence likely reflects interacting drivers**, including:
  – prolonged regional nutrient enrichment and elevated productivity,
  - marine heatwave-driven stratification and calm conditions,
  - site-specific physical conditions,
  - *Karenia*-specific biological traits and ecological interactions

- Alternatively, short-term physical conditions immediately prior to bloom detection (e.g. stratification and low wind mixing) may have been the proximate triggers, with earlier processes acting as background environmental preconditioning

- **scale of the event unprecedented and dominance of *K. cristata* mark it as a significant and relevant global HAB event**

- Next steps:
  - **Apply detailed statistical & ecosystem modelling analyses** (quantitative vs qualitative)
  - **Strengthen observing & modelling systems** - assist with recovery planning/forecasting
  - **Develop early warning and risk assessment frameworks**