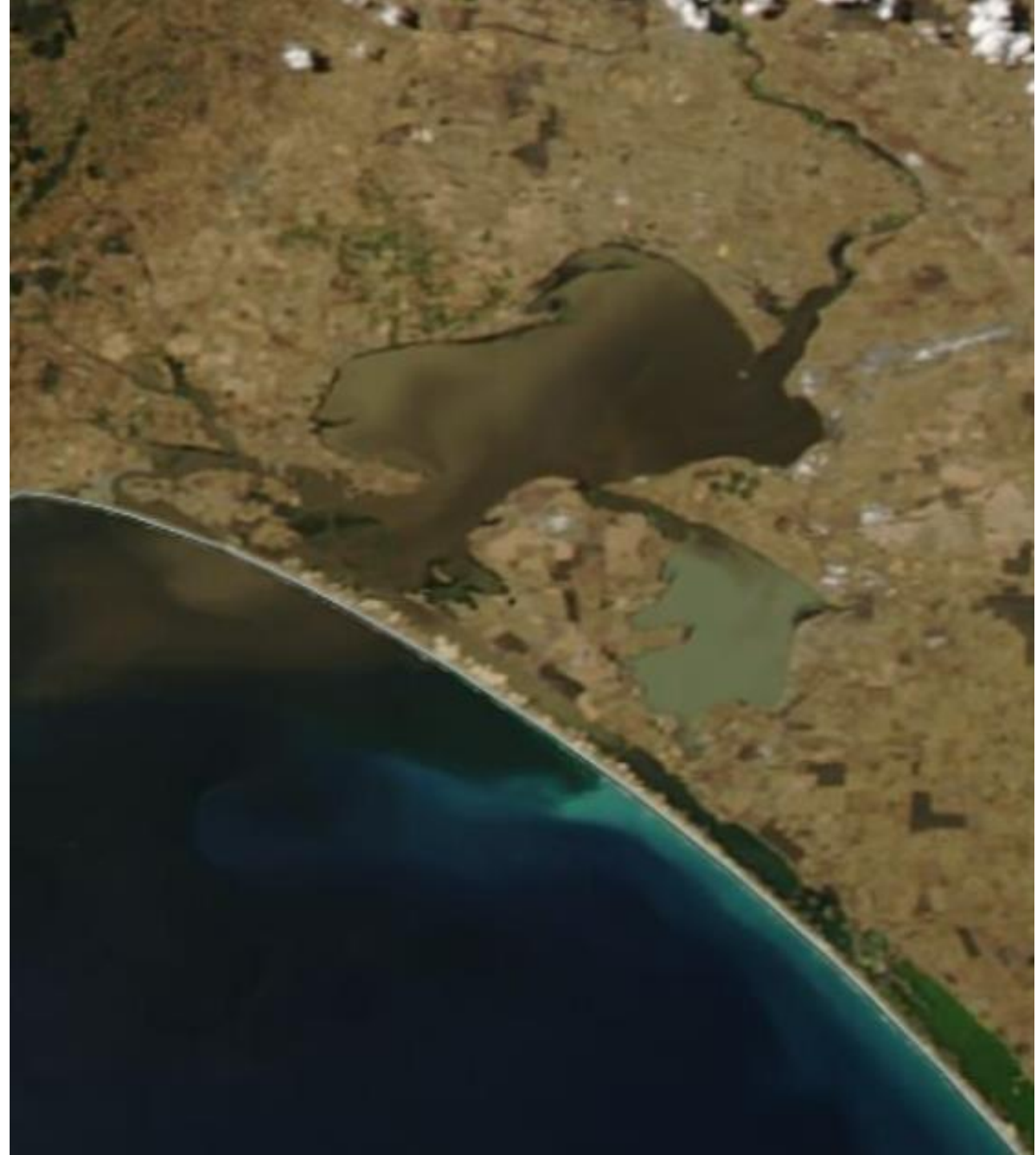




Hydrodynamic / biogeochemical / optical modelling of algal blooms.

Mark Baird, Albertina Dias, Lachlan Phillips,
Darren Engwirda, Chaojiao Sun, Jim
Greenwood and Emlyn Jones | 2-June-2026



Acknowledgement of Country

Palawa and
Muwinina people of
Nipaluna / Hobart

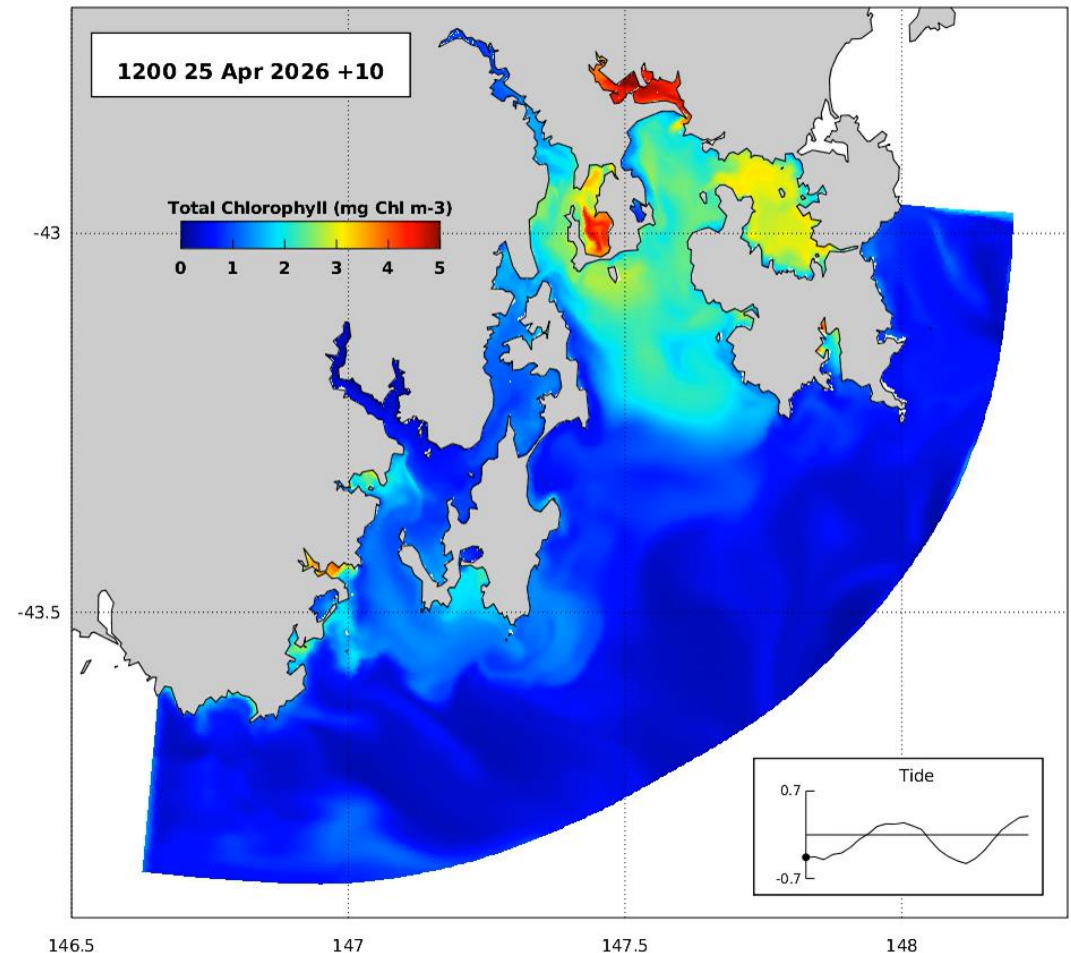


Value of hydrodynamic / biogeochemical modelling for HAB blooms

- Hindcast to better understand environmental conditions that lead to algal blooms.
- Scenarios to understand impact of management strategies.
- Sensitivity analysis to understand limits to prediction of HABs.
- Climate downscaling projections to quantify future risk of algal blooms.



Total Chlorophyll (average 0 - 12m)





Coastal modelling platform - Environmental Modelling Suite EMS:

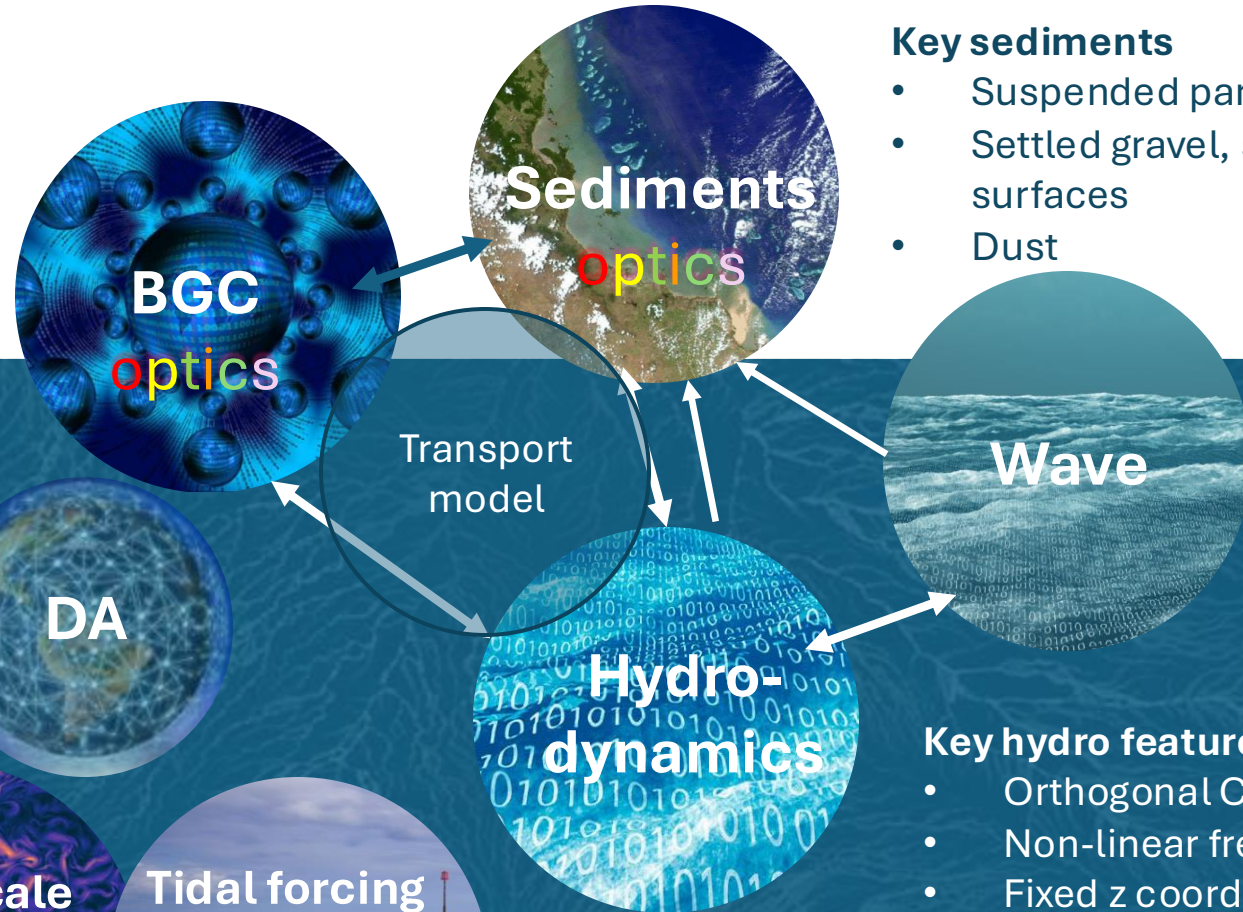
hydrodynamics, waves, sediment transport, biogeochemistry, ocean **optics**, plankton dynamics and data assimilation.

Key BGC features:

- Nutrient cycling, particles and water
- Phytoplankton and zooplankton
- Labile and refractory detritus

Unique features:

- seagrass, macroalgae and corals in sediment zone
- Spectrally resolved **optics** model, including remote-sensing reflectance

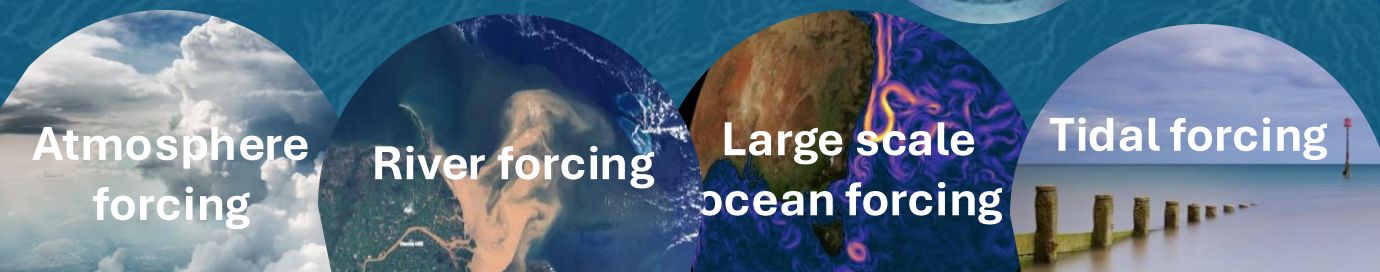


Key sediments

- Suspended particles (silt and mud)
- Settled gravel, silt, mud and sand surfaces
- Dust

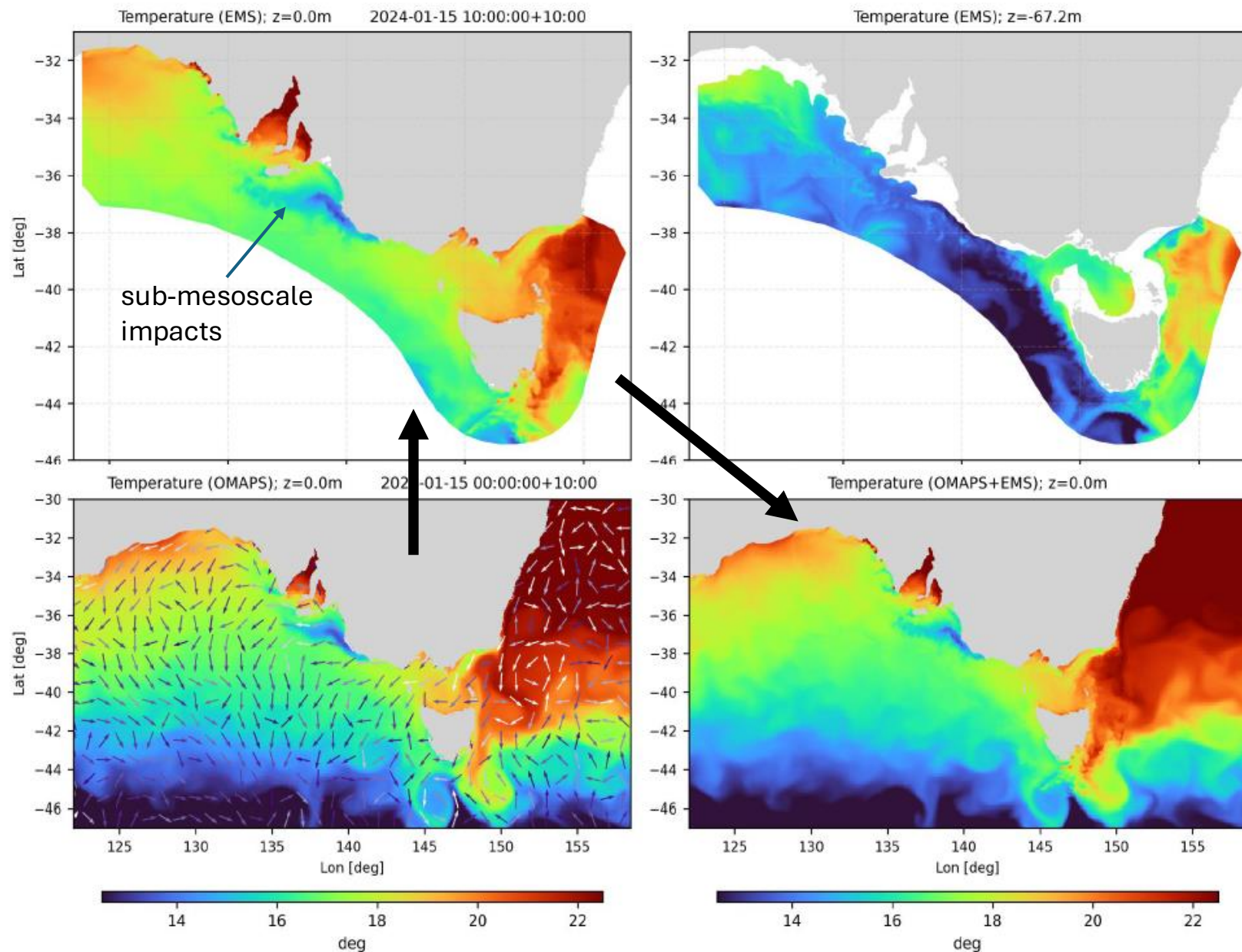
Key hydro features

- Orthogonal Curvilinear grid
- Non-linear free surface - tides
- Fixed z coordinates + Wetting/drying



Shelf-scale hydrodynamic modelling

- Shelf-scale modelling that transitions from 10 km on a structured grid (OceanMaps) to a 2 km unstructured grid with coastal process (sub-mesoscale / shelf edge circulation, rivers, tides, wave-flow interaction).
- Enables further nesting to Gulf models, tracer simulations, climate downscaling etc.





Proposed Karenia modelling – summary

Increasing sophistication:

1. Population dynamics based on environmental condition suitability.

Proposed Karenia modelling – summary

Increasing sophistication:

1. Environmental condition suitability.
2. Single-species population dynamics.

Example of single-species modelling.

- Species-specific temperature-dependence
- Shear stress modulated mortality.
- Transport using particle tracking.

Biophysical HAB Forecasting of *Karenia mikimotoi* in Western Scotland

1 PHYSICAL HYDRODYNAMIC MODEL (FVCOM)

Inputs

- Atmospheric forcing (WRF)
- Tides (OTIS)
- Ocean boundary (NEA-ROMS)
- River discharge / freshwater inputs

Simulates

- 3D Currents
- Sea level
- Temperature
- Salinity
- Turbulent mixing

2 BLOOM DETECTION & INITIALIZATION

Observations

- Satellite chlorophyll / color
- In situ HAB cell counts

3 LAGRANGIAN PARTICLE TRACKING

- Initialize virtual particles (HAB cells)
- Advection using archived FVCOM currents
- Include diffusion and vertical motion
- Track transport pathways to coast / farms

4 BIOLOGICAL MODEL (Individual-Based)

Processes Included

- Temperature-dependent growth
- Mortality
- Aggregation & sinking

5 HAB FORECAST / RISK OUTPUT

Products

- Bloom transport pathways
- Timing of coastal arrival
- Relative bloom intensity
- High-risk aquaculture areas

Forecast horizon: 1–5 days

BIOLOGICAL MODEL EQUATIONS

1. Cell Concentration Equation

$$\frac{\partial C}{\partial t} = \mu(T)C - K - C\gamma$$

Where:

- C = cell concentration (cells L^{-1})
- $\mu(T)$ = temperature-dependent growth rate (d^{-1})
- K = empirical mortality coefficient (d^{-1})
- γ = shear-dependent aggregation term (m^{-1})

2. Temperature-Dependent Growth

$$\mu(T) = 2.5 \times 10^{-7} e^{1.1(T - 12.7)} - 11.8$$

Where: T = water temperature ($^{\circ}C$)

3. Shear / Aggregation Term

$$\gamma = \frac{\epsilon}{7.5 \sqrt{\rho}}$$

Where:

- ϵ = turbulent dissipation rate ($m^2 s^{-3}$)
- ρ = kinematic viscosity of seawater ($m^2 s^{-1}$)

The biological model is solved offshore using FVCOM physical fields and particle trajectories.

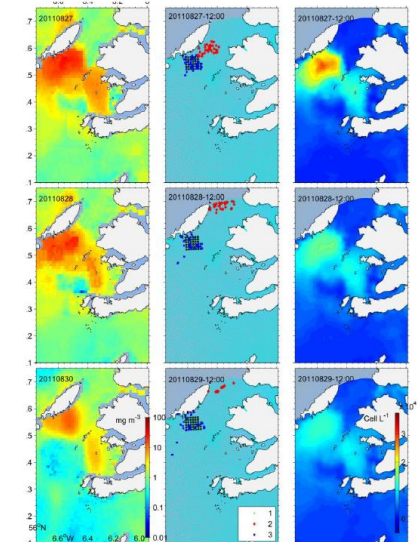


Figure. Satellite observations of Chlorophyll-A concentrations (CHL-A MODIS_MERIS_L4-RAN-OBS merged MyOcean product, 0.01 mg m⁻³) during the *K. mikimotoi* event August 2011 (column a). Three snapshots of the Lagrangian tracking of forty neutrally buoyant VPs released from the surface (3, red) and near-bottom (2, blue). Initial VP positions are shown with black circles (1) (column b). *K. mikimotoi* bloom modelling results are shown in the right hand column (c) as the concentration of cells (cells L⁻¹) in the upper layer.

Source: Aleynik et al. (2016)

Proposed Karenia modelling – summary

Increasing sophistication:

1. Environmental condition suitability.
2. Single-species population dynamics.
3. Simple biogeochemical (BGC) modelling (NPZD) + radiative transfer optical model (Rrs).
4. Complex BGC modelling + benthic communities, sediment processes.
5. BGC-modelling + species-specific behaviours such as life-cycles.

Example of single-species modelling.

- Species-specific temperature-dependence
- Shear stress modulated mortality.
- Transport using particle tracking.

Biophysical HAB Forecasting of *Karenia mikimotoi* in Western Scotland

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- Bloom transport pathways
- Timing of coastal arrival
- Relative bloom intensity
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Forecast horizon: 1-5 days

BIOLOGICAL MODEL EQUATIONS

1. Cell Concentration Equation

$$\frac{dC}{dt} = \mu(T)C - K - \gamma C^2$$

Where:

- C = cell concentration (cells L^{-1})
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- γ = shear-dependent aggregation term (m^{-1})

2. Temperature-Dependent Growth

$$\mu(T) = 2.5 \times 10^{-7} e^{(T - 10)^2 / 10}$$

Where: T = water temperature ($^{\circ}C$)

3. Shear / Aggregation Term

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Where:

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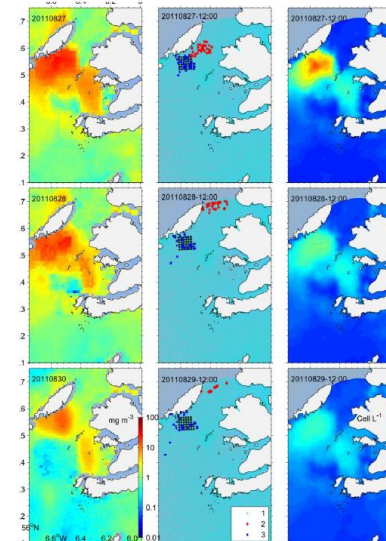


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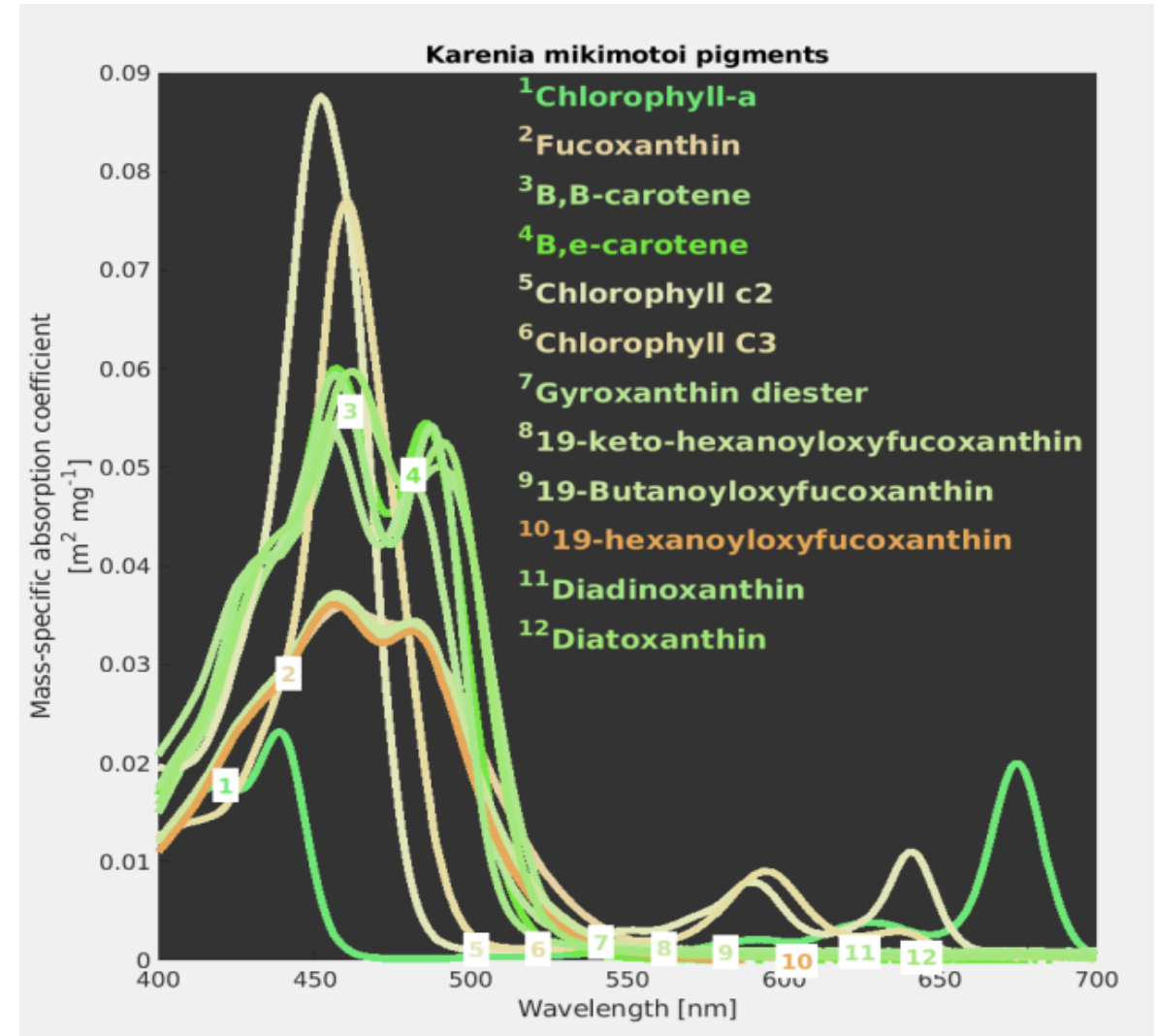
Source: Aleynik et al. (2016)



Karenia bio-optical modelling - pigments

Karenia will be uniquely parameterised by:

- Using the mass-specific absorption coefficients of the 12 pigments in the photosystems.
- Ratios of accessory pigments to Chl-a
- Considering cell size / volume and intracellular pigment concentrations to calculated absorption (see next slide).
- Individual cell growth and pigment synthesis rates.
- Spectrally-resolved passive fluorescence.



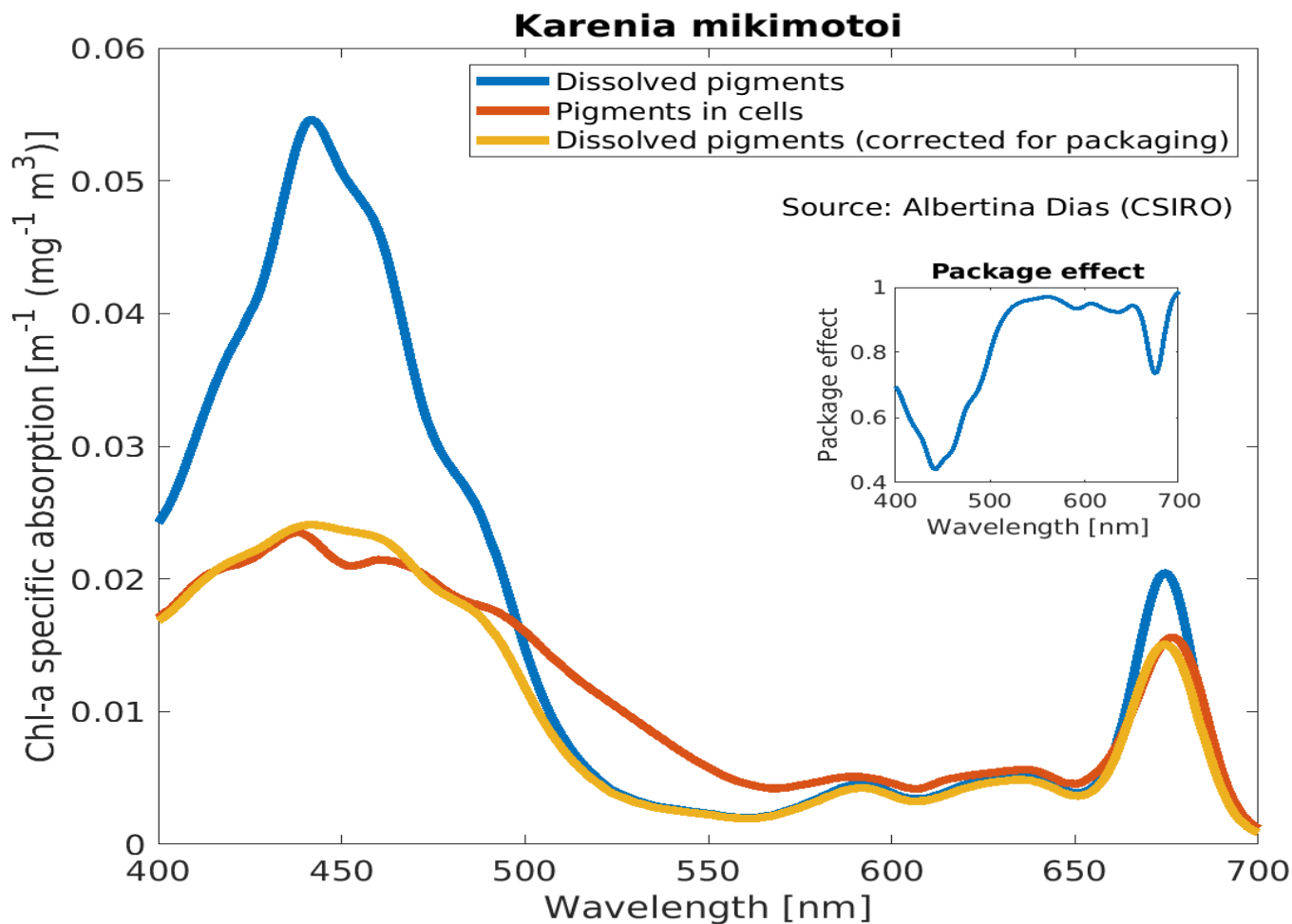


Karenia bio-optical modelling – absorption

Chlorophyll-specific absorption

(a^*_{Chl}) can be determined by:

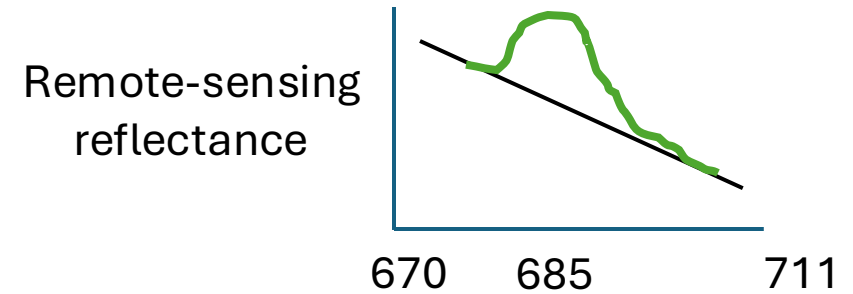
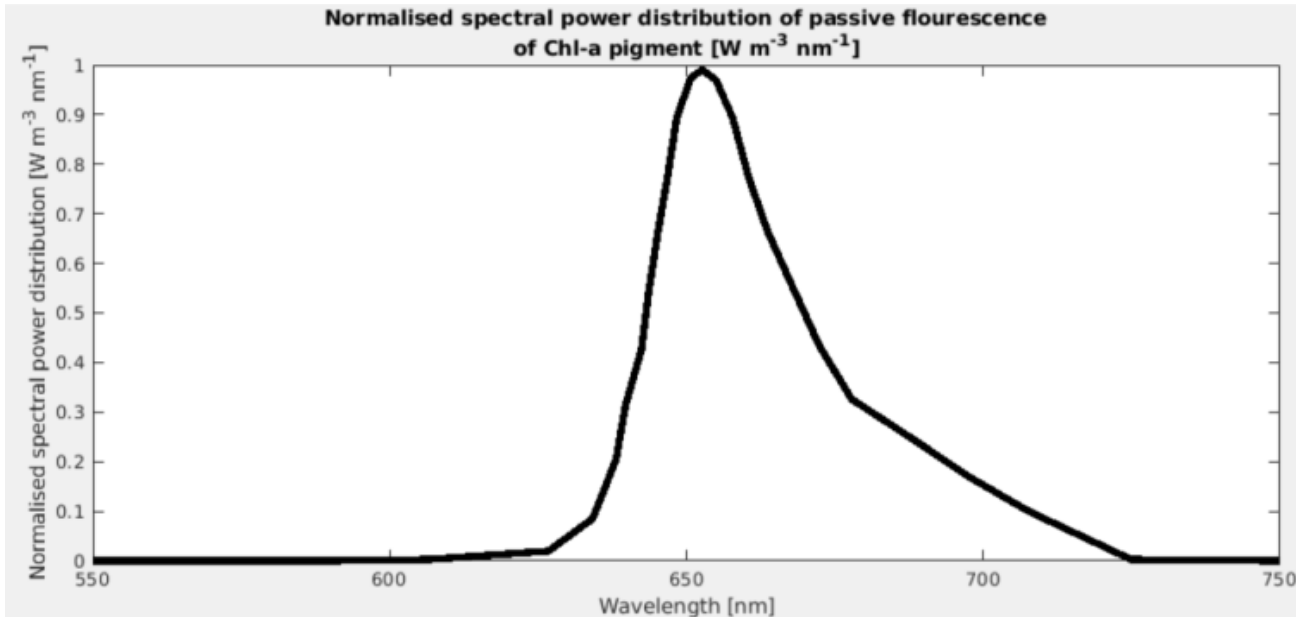
- The sum of mass-specific coefficients pigments multiplied by their pig: Chl-a ratio (i.e. dissolved pigments).
- In-situ measurement of the absorption of a population of cells divided by the Chl-a conc.
- The sum of mass-specific coefficients pigments multiplied by their pig: Chl-a ratio, multiplied by the package effect.





Karenia bio-optical – passive fluorescence

- One approach to remote-sensing Karenia is using normalised Fluorescence Line Height.
- Predict energy of passive fluorescence by cells as a function of photosystem state and incident light.
- Spectral distribution determined by pigments.



NASA Karenia algorithm looks for an anomalously high R_{685} due to passive fluorescence:

$$Chl_{Karenia} = R_{686} - \left(685 - \left(670 - \left(\frac{41}{R_{711} - R_{670}} \right) R_{670} \right) / \left(\frac{41}{R_{711} - R_{670}} \right) \right)$$

Using the Red Band Difference Algorithm to Detect and Monitor a *Karenia* spp. Bloom Off the South Coast of Ireland, June 2019

Catherine Jordan^{1,2*}, Caroline Cusack², Michelle C. Tomlinson³, Andrew Meredith⁴, Ryan McGeady^{2,5}, Rafael Salas², Clynton Gregory¹ and Peter L. Croot¹



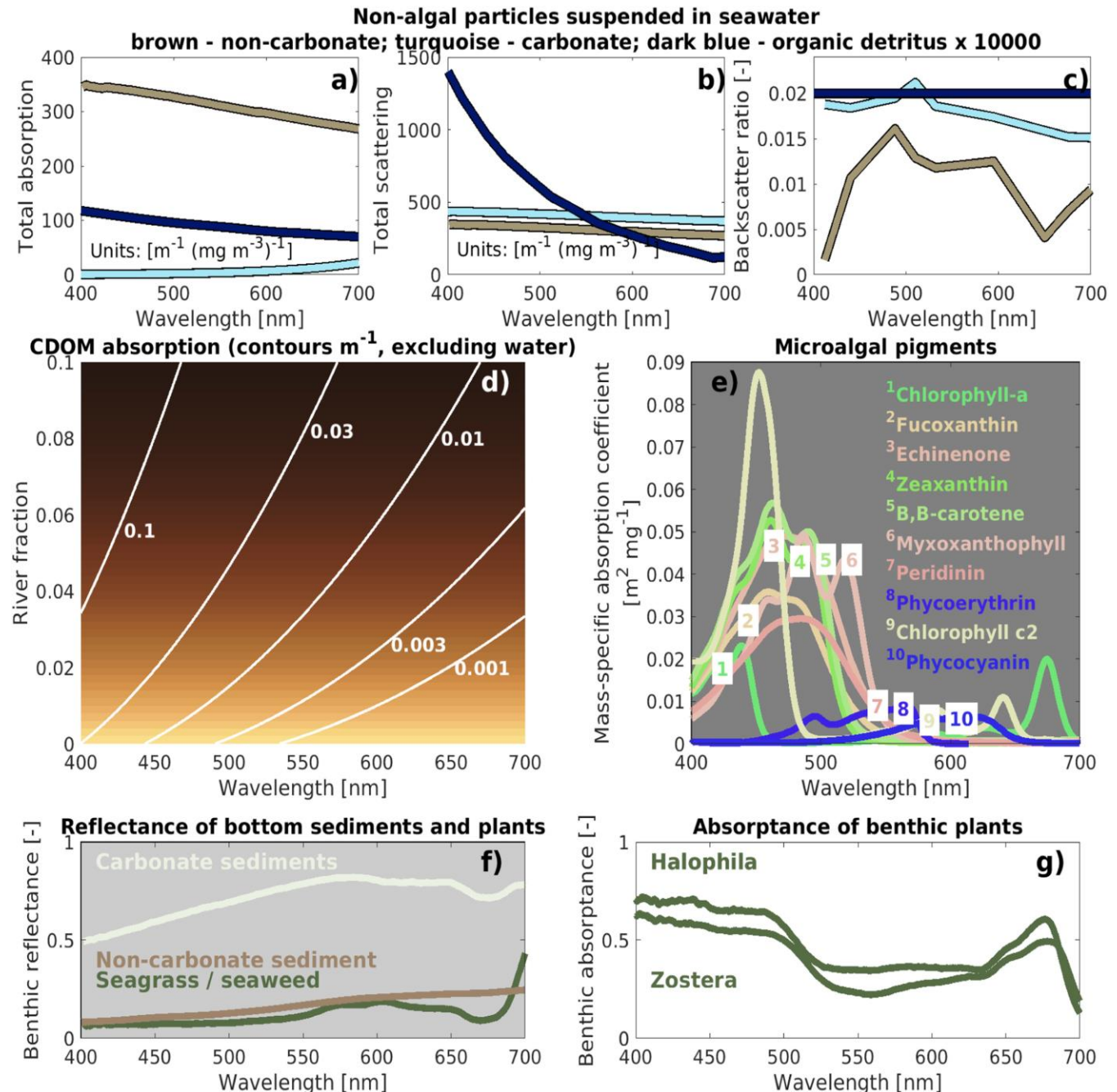
Optical modelling

- Represents spectrally-resolved scattering and absorption of water, CDOM, plankton, detritus, inorganic particles and benthic substrates.



Corbett et al. Remote Sens. 2025, 17, 1711.

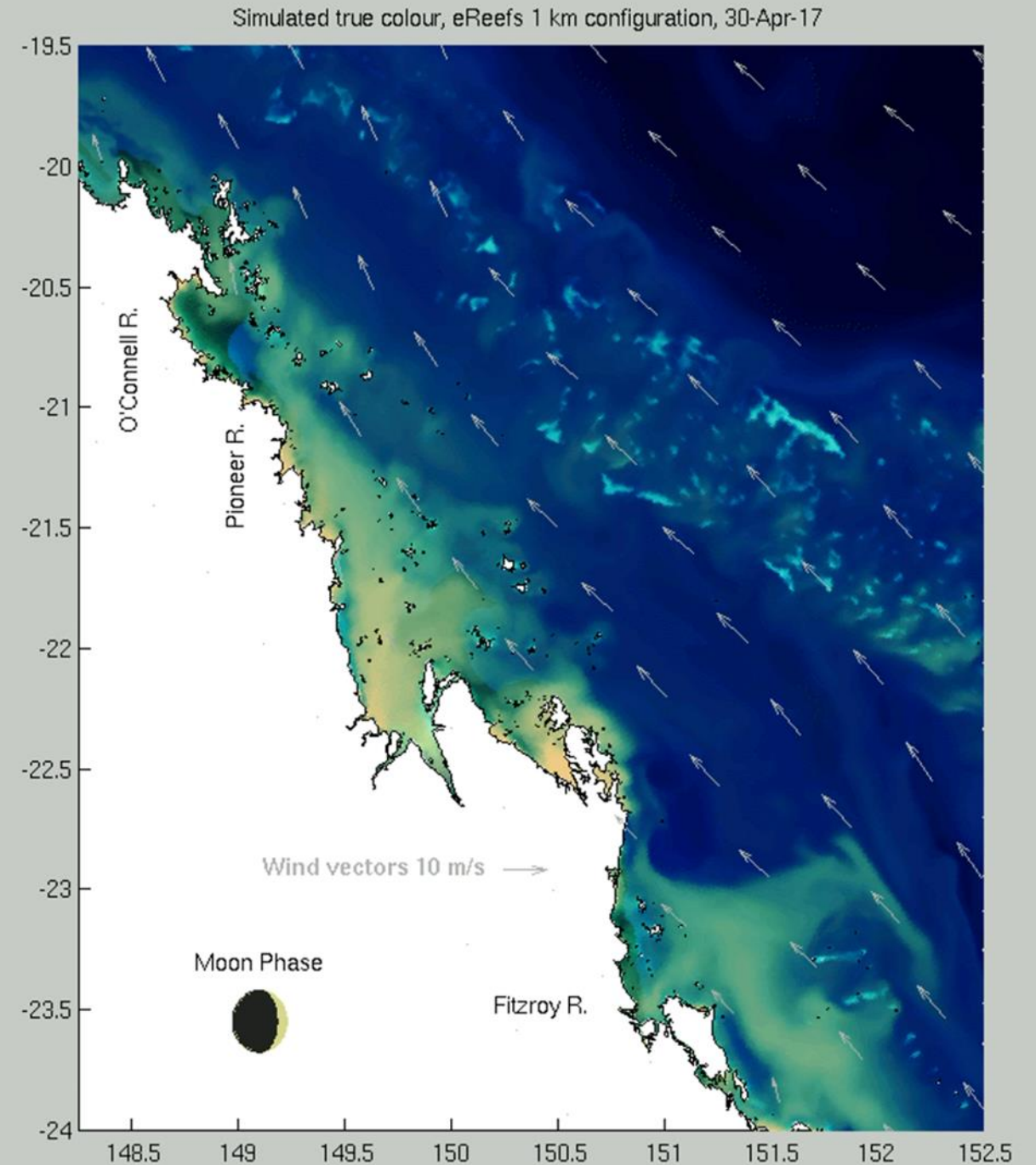
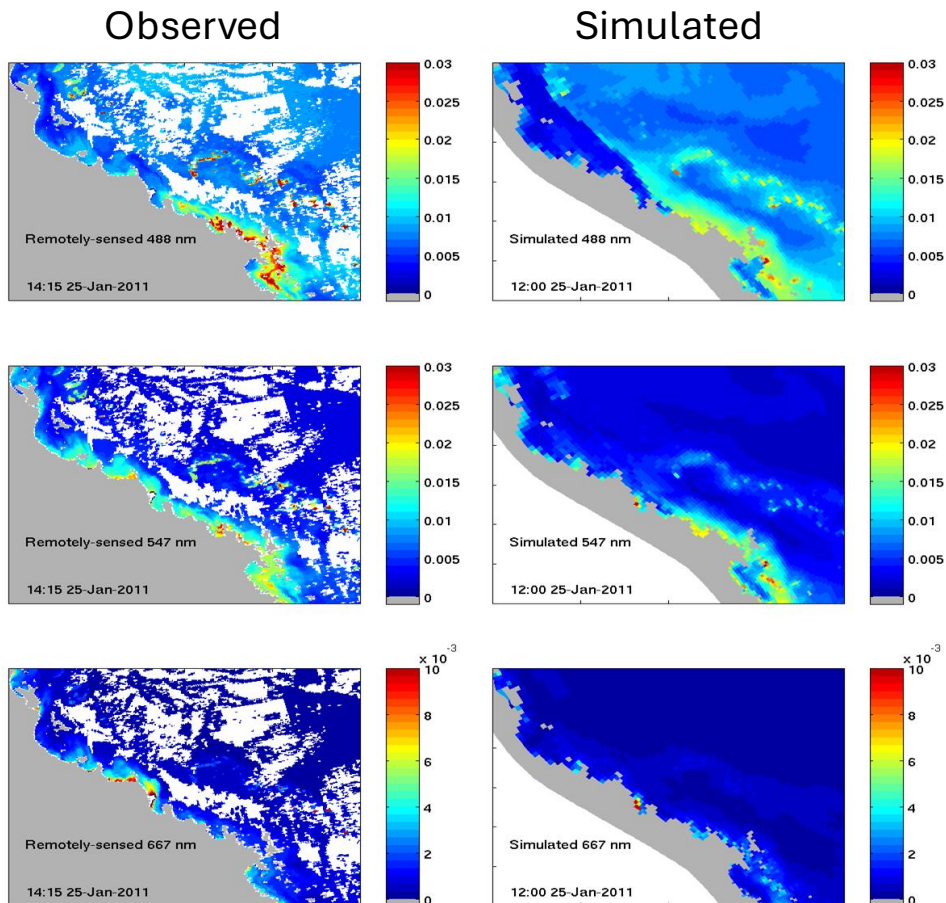
OFFICIAL





Optical modelling

- Calculates light field and remote-sensing reflectance using a 3-stream radiative transfer model (direct and diffuse downwelling and diffuse upwelling).

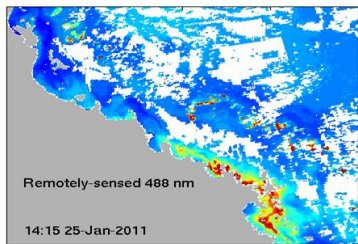




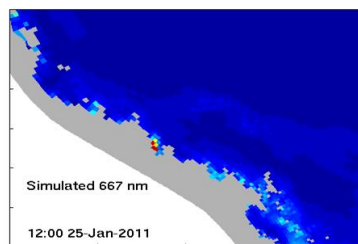
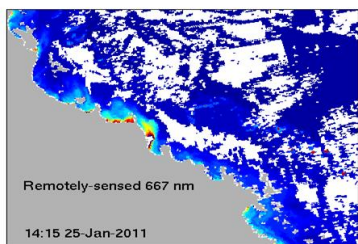
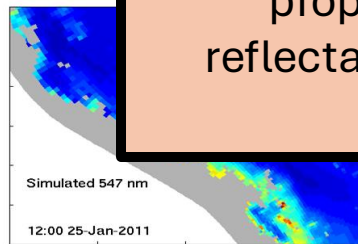
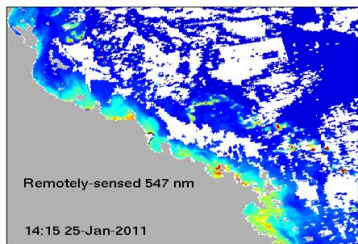
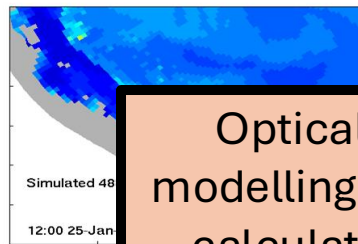
Optical modelling

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Observed

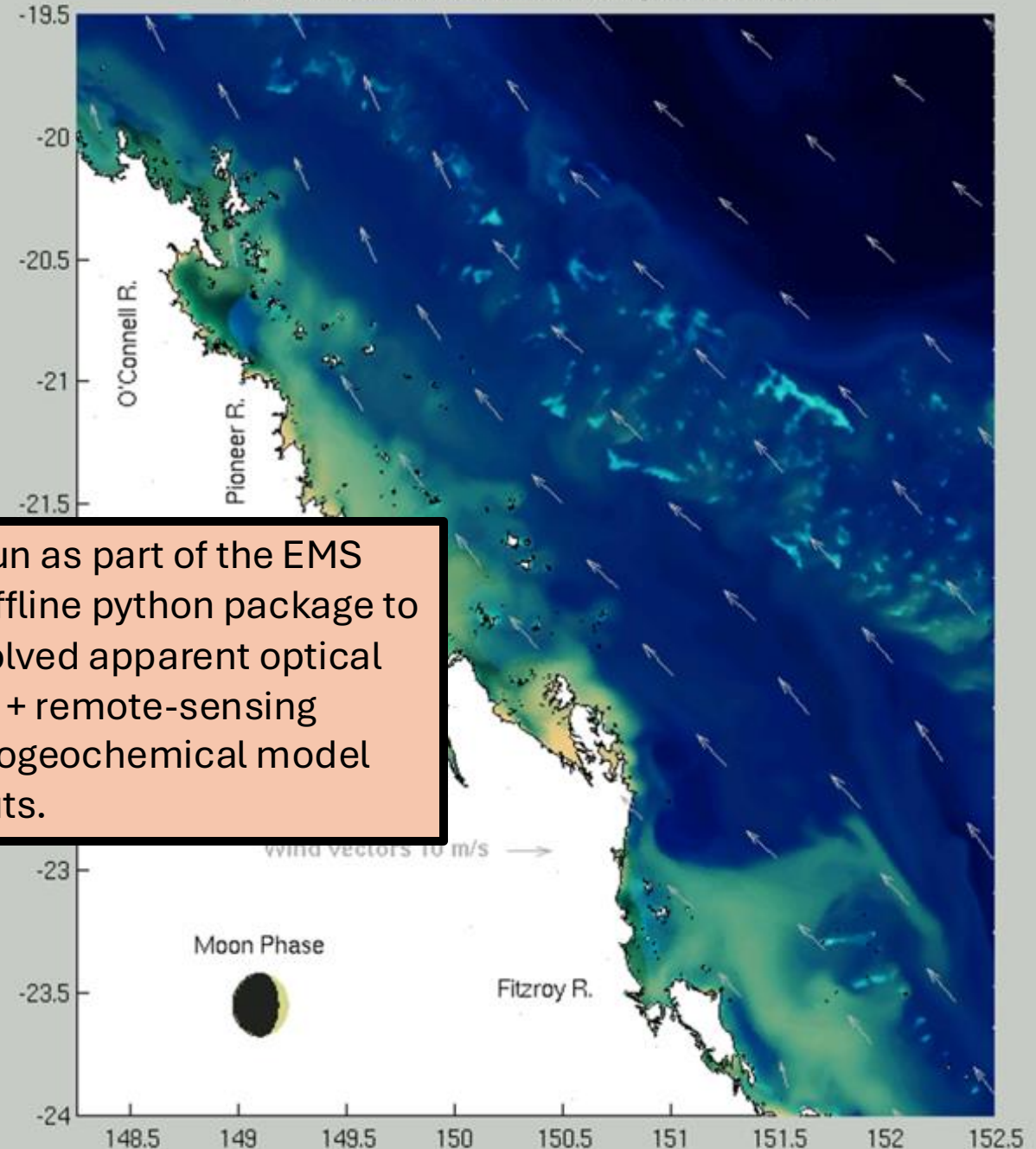


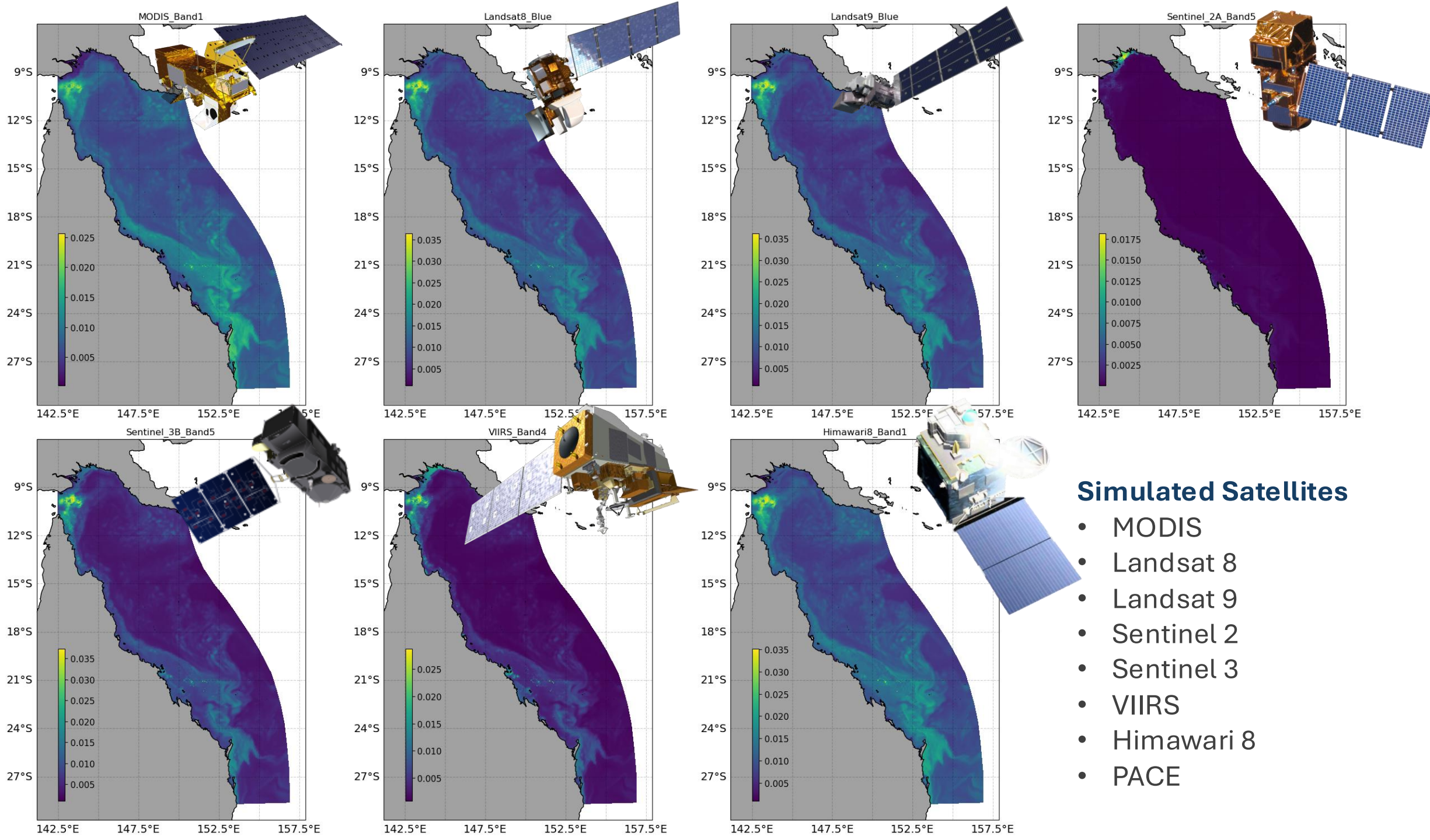
Simulated



Optical model can be run as part of the EMS modelling suite, or as an offline python package to calculate spectrally-resolved apparent optical properties (light field + remote-sensing reflectance) from any biogeochemical model outputs.

Simulated true colour, eReefs 1 km configuration, 30-Apr-17



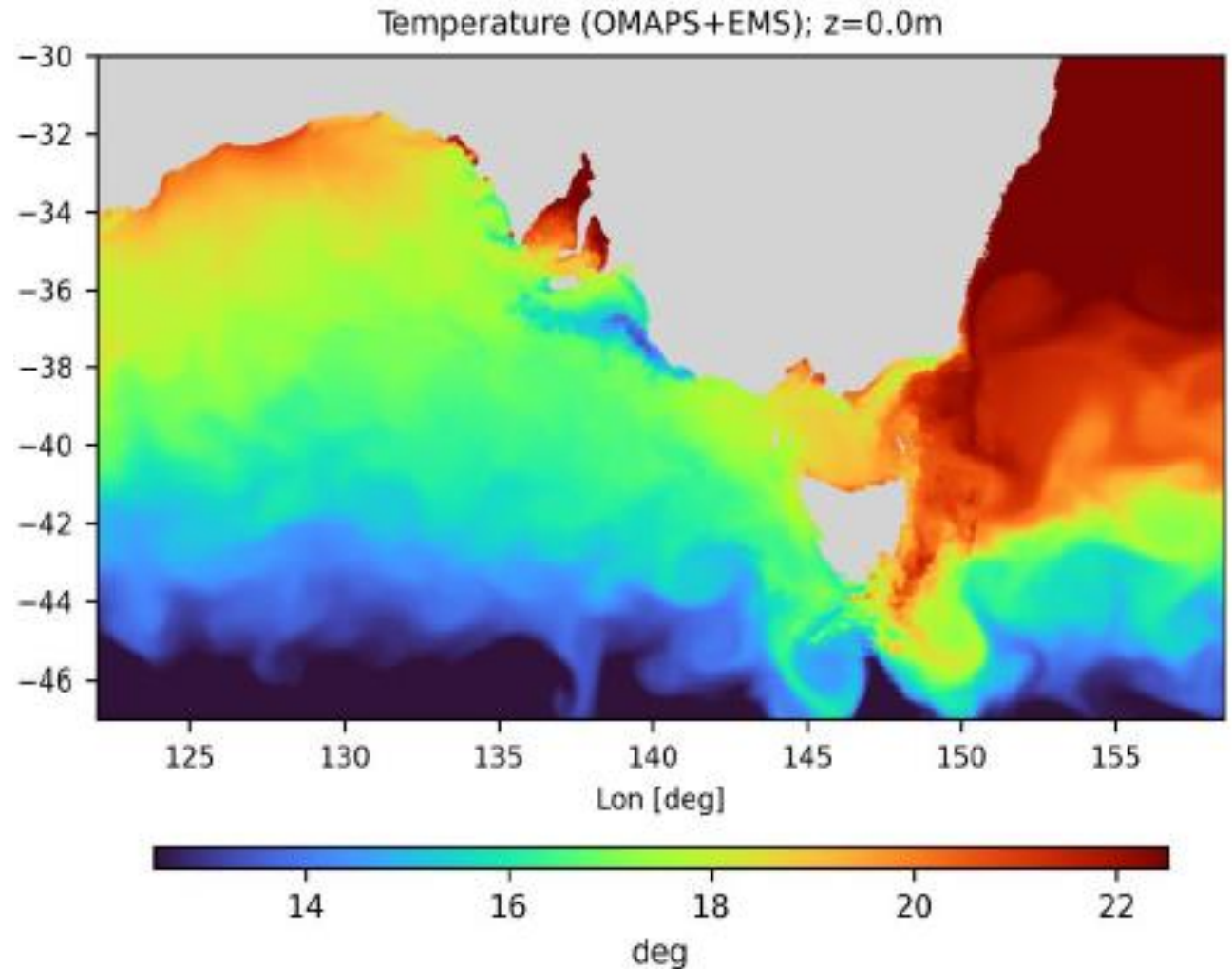


Simulated Satellites

- MODIS
- Landsat 8
- Landsat 9
- Sentinel 2
- Sentinel 3
- VIIRS
- Himawari 8
- PACE

Summary

- CSIRO / SARDI coupled hydrodynamic - biogeochemical modelling will provide a nesting capability between large scale oceanography / climate and gulf scale.
- Biogeochemical / Karenia modelling will focus on bloom attribution and prediction capabilities.
- Emphasis in optical modelling will be model assessment against satellite products and improve synergy with remote-sensing based machine learning modelling systems.



Particulate Backscattering Ratio as an Indicator of Changing Particle Composition in Coastal Waters: Observations From Great Barrier Reef Waters

Monika Soja-Woźniak¹ , Mark Baird¹, Thomas Schroeder², Yi Qin³, Lesley Clementson¹ , Brett Baker⁴ , David Boadle⁴, Vittorio Brando⁵ , and Andy D. L. Steven²

