Advances and challenges in simulating the Great Barrier Reef environment with a fine-resolution near-real-time modelling system

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Outline

- Environmental Modelling System
- GBR NRT application
- RECOM to traverse scales
- DEnKF and eDICE to constrain the model
- Web delivery and communication
- Conclusions
Environmental Modelling System

- 3-D Hydrodynamics, sediment transport, biogeochemistry, optics model, carbon chemistry, coral models
  - More than 100 state variables hourly per every grid cell
  - $2389 \times 510 \times 50 = 60\,919\,500$ grid cells in GBR 1 km model
  - Increasingly Near-Real-Time (NRT) mode of applications
eReefs

- Information system for GBR

- Integrated hydrodynamic, sediment transport, and biogeochemical models
  - BoM ACCESS-R and OceanMaps models at the surface and ocean boundaries
  - Observations and stats between flow, load and climatology at the river and ocean boundaries

- Near-real-time simulation building up an archive of hind-cast data
Nested models to traverse spatial scales
RECOM to resolve small-scale features

http://research.csiro.au/ereefs/
Web interface to set up and run RECOM
http://research.csiro.au/ereefs/
<table>
<thead>
<tr>
<th>Run ID</th>
<th>Run Name</th>
<th>Model Name</th>
<th>Run Start</th>
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Showing 1 to 10 of 48 model runs
Complex modelling system with many sources of uncertainty

- Expert knowledge to select processes

- Observations to constrain parameters and state variables
  - MODIS, IMOS, GBRMPA Marine Monitoring Program (MMP)

- Data-assimilation strategy – subdivide and conquer
  - Expert knowledge to tune hydrodynamics
  - Emulators to estimate parameters of the sediment transport model
  - DEnKF to assimilate data into biogeochemical model
➢ Emulators are fast and cheap surrogates of complex models
  o Run order of magnitude faster than the original model
  o Reduced accuracy of the prediction
Sequential assimilation of observations

\[ S = \text{Model}(t, p) \]

Observation
Sequential assimilation of observations

\[ S = \text{Model}(t, p) \]

\[ S' = \text{Emulator}(t, p) \]
Sequential assimilation of observations

\[ S = \text{Model}(t, p) \]
\[ S' = \text{Emulator}(t, p) \]
eDICE – emulation and Data assimilation in Computationally Expensive models

➢ Takes the model to be a black box with known inputs and outputs

➢ Reduces temporal complexity through the sequential handling of the problem

➢ Reduces structural complexity via hierarchical structuring of the dependencies between variables

➢ Reduces spatial complexity via decomposition into truncated set of basis functions (SVD)
Mean Absolute Error (MAE), RMSE and Willmott-index of the simulated TSS records at observation sites (GBRMPA MMP)

➢ The distribution of the simulated suspended sediment on GBR, in general, is consistent with observations.
➢ The quality of the calibrated model varies across the GBR region and with time.

*Margvelashvili et al., 2016 Emulator-assisted data assimilation in complex models. Ocean Dynamics 66(9)*
**DEnKF to assimilate remote sensing data into the biogeochemical model**

Remote-sensing reflectance (RSR) simulated by in-water optical model to be compared to observed RSR

<table>
<thead>
<tr>
<th></th>
<th>RSR</th>
<th>Chl a</th>
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<tr>
<td>Model</td>
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Forecast error halved by using simulated RSR instead of the Chl a estimated from the remote sensing data.
Welcome to eReefs

eReefs is a platform that provides a picture of what is currently happening on the reef, and what will likely happen in the future.

Dive in

- Visualisation and open access to raw data and data products
- Updates on recent and ongoing developments
- Shared scripts to process and analyse data
- eReefs data platform to host different types of data from a range of agencies
  - Use of models to support ecologically relevant targets.
  - Gaining end-user trust and support.
Key advances and achievement

- The relatively seamless NRT implementation of a fine-resolution integrated hydrodynamics, sediment transport, biogeochemistry, and optical models
- Open web-delivery of model outputs serving multiple visualisation products by different organisations and facilitating diverse use cases.
- Use of models to support ecologically relevant targets.
- Gaining considerable end-user trust and support.
- RECOM web nesting
- eReefs data platform
- DEnKF, eDICE applications
- Optical model (*Baird et al.*, 2016)
- Carbon chemistry model (*Mongin et al.*, 2016)
Challenges

- Characterisation and communication/visualisation of uncertainty.
- Making RECOM a smoother experience, less prone to crashing.
- Data assimilation.
- Building in or linking in more ecology.
- Simulation of physical and especially bgc processes in buoyant surface films.
- Transitioning to new Finite Volume model and expanding the domain.
- Emulators to speed complex water quality models.
- **Delivery of data and information.**
- Online community of practitioners to facilitate uptake of knowledge
- Integrating real-time modelling products across scales and disciplinary domains
Acknowledgements

- eReefs project
- Whitsundays project
Models simulation of Chl $a$. b. the models representation of simulated Chl $a$ as observed by MODIS OC3M. c. MODIS observed OC3M Chlorophyll. D. MODIS observed MIM Chlorophyll.
Modelled TSS (blue) vs observations (red)

Margvelashvili et al., 2016 Emulator-assisted data assimilation in complex models. Ocean Dynamics 66(9)
• Visualisation and open access to raw data and data products
• Updates on recent and ongoing developments
• Shared scripts to process and analyse data
• eReefs data platform to host different types of data from a range of agencies
eReefs 1km GBR model
(simulated true colour e.g. simulating satellites view)

Sequential assimilation of observations

\[ S = \text{Model}(t, p) \]

\[ S' = \text{Emulator}(t, p) \]
Challenges

✓ Virtual laboratory for a modelling community
  • Distributed
  • Real-time
  • Online community of practitioners
Mass balance

Concentration of particulate or dissolved material

\[
\frac{\partial}{\partial t} (C \cdot \varphi) + \frac{\partial}{\partial z} \left[ \varphi \left( U - \nu \frac{\partial}{\partial z} \right) C \right] = 0
\]

- Solid and liquid fluxes across water and sediments

\[
F^s = \frac{Q^s}{\rho^s} \quad F^w = -U^c \bigg|_{z = z\text{ int}} + \frac{\varepsilon Q^s}{\rho^s}
\]

- Sediment thickness

\[
\frac{\partial z_{\text{int}}}{\partial t} = -(F^s + F^w)
\]
https://research.csiro.au/cem/projects/
Model ensemble

Basis functions

Decomposition \[ m-\langle m \rangle \approx a_1 f_1 + a_2 f_2 \mid_{t=t_i} \]

\[ m-\langle m \rangle \approx b_1 h_1 + b_2 h_2 \mid_{t=t_{i+1}} \]

Propagator

Data assimilation (eDICE)
Simulated sediment concentration (blue) vs observations. Both model and observations are passed through the low-pass filter.

vs observations (red)
Probability maps for TSS to exceed 2 mg/L (bottom plots) and difference between these maps (on the top plot)
Simulated mean euphotic depth (bottom plots) and difference between baseline and fluff-layer scenarios (on the top plot)