Coastal sediment transport modelling and observational needs

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Outline

- Why care about sediment transport?
- Key sources of model uncertainty
- Data needs and DAS
- Case studies
  - Mecosed
  - Sedsim
- Future directions – funding needs
Why care about sediment transport?

- Dredging
- Coastal erosion
- Planning and maintenance of coastal infrastructure
- Impacts on GBR
- Contaminant transport
- Water quality compliance

Green & Goughanowr, 2003
Key sources of model uncertainty

- Unknown processes and parameters
  - Wide range of sediment properties
  - Settling influenced by flocculation
  - Resuspension influenced by consolidation and biota
  - Turbulent BBL of water sediment mixtures

- Stochastic forcing, boundary and initial conditions

- Numerical approx and simplifying assumptions

- Observation errors
Data needs

➢ To set up and run a pilot model
  • Initial conditions
  • Boundary conditions
  • Hydrodynamic/Wave Forcing

➢ To improve the pilot model
  • Calibration/assimilation data

➢ Issues
  • Collecting all data underpinning pilot model can take months
  • Poor quality of assimilation data
Mecosed

3D coastal sediment transport model

-Coupled to CSIRO EMS modelling suite
-Tailored to bgc model requirements
-Coastal and shelf scale applications
-Best performance with fine sediments
-NRT to annual time-scales
Initial conditions: seabed gravel, sand and mud deposits (Mars database)
Initial conditions: global perspective

http://instaar.colorado.edu/~jenkinsc/dbseabed/
Issues with seabed maps

- Uneven coverage of coastal regions/estuaries
- A lot of coastal data can still be scattered across different institutions/programs/DBs
- Lack of motivation to populate a single centralised DB on an ongoing basis
- Not all data accessible directly through the web
Boundary conditions: Oceans and catchments

Ocean boundary:
- Observed concentrations of TSS (e.g. inferred from RS data)
- Nesting into larger model

Options for setting river inputs:
- Directly measured river TSS concentrations
- TSS calculated from monitored turbidity
- Catchment sediment generation models (e.g. SedNet, Source)
- Statistical models (e.g. LRE)
Boundary conditions: River loads from monitoring programs

Issues

- TSS measurements are usually infrequent and may not resolve flow events
- Observational data may not be immediately available for nowcasting models
- Turbidity data can be high-frequency but TSS/turbidity relationships are often strong and linear, but change geographically and may change with time
- Monitoring upstream of the tidal limit misses inputs from the lower catchment; observations within the tidal estuary are difficult to interpret as loads
- Anthropogenic effects dominate around much of the Australian coast due to damming of river systems and entrapment of sediment. This means that catchment models are often not sufficient and estuarine sediment flux also needs to be monitored.
Boundary conditions: River loads from models

Process-based models (e.g. SedNet):
- Allow evaluation of scenarios and predictive runs
- Often designed to operate on different time-scales than marine models (e.g. annual) and may not be reliable on shorter time-scales
- Impose additional data requirements

Statistical models (e.g. LRE):
- Can provide a more accurate match to observational data
- Simpler implementation
- Limited scenario capability

There is substantial (>100%) uncertainty in predicted river inputs either way.
Forcing data

Hydrodynamics
- Bluelink shelf scale model (~10 km resolution)
- Ribbon model - a prototype NRT coastal model
- eReefs - stepping stone towards coastal NRT hydrodynamic products around Australia

Waves
- AUSWAVE model, adapted from the WAVEWATCH III
- Driven by ACCESS winds
- Runs on global (1.0°), regional (0.5°) and Australia (0.125°) domains as used in ACCESS

Potential issues
- Wetting/drying, tidal modulation of waves, wave/current coupling
Data-model fusion

Bayesian inference
- Posterior $\sim$ Likelihood x Prior

MCMC/PF machinery to sample from the posterior

MCMC/PF intractable with complex fine-resolution models
- Dimensionality too high ($\sim 10^5$)
- The model too slow (hours and days to run)

The remedy
- Suboptimal schemes (e.g. variational and KF based techniques)

Issues
- Typically poor quality of coastal sediment data
- Insufficient research into coastal data assimilation
Fitzroy Estuary & Keppel Bay

- Turbid macrotidal environment
- Significant loads of nutrients and sediments from catchments
- Concerns with the potential impact on GBR
- Altered land use practices with unknown effects on the marine side
DICE: Data Assimilation In Computationally Expensive Models

- Experimental technique for data assimilation based on dimension reduction and emulation of complex models (Margvelashvili & Campbell, 2012)

- Key ingredients
  - Singular Value Decomposition (SVD) to reduce dimensionality
  - Gaussian Process Modelling (GPM) to speed up simulation
  - Sequential MC to sample posterior

- Recent applications of emulators to ocean models
  - Polynomial chaos approximation to emulate 3d bgc model (Mattern et al., 2012)
  - Neural-network batch emulation of a coastal ocean model (van der Merwe 2007, Frolov, 2009)
Data assimilating model

Model RMS Error. Green line is a control run with no data assimilation. Red and blue lines correspond to 30 and 60 % observation errors, respectively.

Samples from the posterior distribution of the model parameters
Mean RMS error of the surface TSS

Normalized RMS error of the estimated suspended sediment concentration for scenarios with satellite data (left plot) and synthetic data (right plot). The model error is normalized by the measurement error.
SEQ monthly EHMP data

- Several thousand samples over the 4 year period
- Each sample is a point snapshot of a complex 3D field evolving with time
- Both model and observations have errors
- Observation errors
  - Point sample up-scaling
  - NTU to TSS conversion
  - Stochastic nature of TSS

http://www.healthywaterways.org/ehmphome.aspx
Model vs observations

![Graphs showing model vs observations for different regions like Logan and Brisbane.](image)
Observational needs

- Readily available complete set of data to underpin pilot model development and calibration:

- **Initialisation data**
  - Further development and consolidation of *benthic habitat maps* around the Australian coast
  - To identify cyclic and event-driven changes to habitat pattern, repeat (could be random time interval) high resolution baseline studies with accurate positioning (± 0.5 m) are required

- **Forcing data**
  - Readily available coastal *hydrodynamic/wave forcing data* on the national scale to drive sediment/biogeochemistry/ecosystem models (e.g. the e-Reefs project and its upscaling to national level).

- **Input from catchments**
  - Daily *catchment loads for major rivers* around Australian coast based on NRT models and observations [LRE and other GAMs, dyn-SedNet, turbidity monitoring].

- **Assimilation data**
  - Suspended and benthic sediment data to assimilate into models at adequate assimilation frequency and resolution (e.g. remote sensing, gliders, moorings, monthly monitoring, sensor networks, etc).
Future model developments

- Near-Real-Time (NRT) monitoring and modelling capability
  - NRT model is important by itself but also as a data integration tool capable of creating digital environments for scenario simulations

- Research into DAS and uncertainty of coastal models
  - The capacity to uptake and to use efficiently high quality data sets is often hampered by the deficiency of the corresponding data assimilation schemes and the lack of science behind the coastal data assimilation. Manual “trial-and-error” calibration of models against large volumes of data is inefficient and unproductive.

- Research into emulators (statistical surrogates) of complex models to speed up simulations and fill-up the gap between complex models and managers
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Sedsim

Quantitative Prediction of Future Coastal Change
Environmental processes considered in Sedsim

- Sea level rise and fluctuation
- River flow
- Tidal currents
- Wind-induced currents
- Wave height, period, direction
- Extreme events/Storm
- Ocean currents
- Carbonate growth
- Organic growth
- Coastal Dunes
- Slope failure gravity flow
Issues

• Value of coasts?
• Historical/geological change
• Understanding causes of change – long period – short period
• Background data
• Predicting change
• Testing predictions of change
Value of Coasts

• One third of the world's population live in the coastal zone (<100 km from the shoreline), which comprises an area of only 4% of the total land surface. (UNEP, 2006)

• 70% of the coastlines between 30° N and S are built on, this is projected to rise to 81-95% by 2032. (GRID-Arendal report to the United Nations Environment Programme (UNEP) (2011))

• The world coastline extends over 350,000-1,000,000 km (depending on mapping resolution)

• Australian residential buildings exposed to both inundation and shoreline recession associated with sea level rise have a national replacement value of $51 - $72 billion ($2008) (DCCEE, 2011)

• 187,000 to 274,000 (DCC, 2009) (DCCEE, 2011) buildings at risk, respectively. ACCARNSDISCUSSIONPAPER–NODE1COASTALSETTLEMENTS - The Economic Value of Natural and Built Coastal Assets - 2012
Data distribution issues (iSeabed)
Predicted Wind-Induced Current Changes
floods? seasons?
wet in winter
dry in summer

Total average annual discharge is small and decreases from N to S

The IOD has a annual discharge of about 40,000 gigaL which is less than 1% of the Amazon River annual discharge.
Temperature and salinity vary from N to S with a maximum range which could reach 8° C. Low salinity combined with extreme temperature can be lethal to reef organisms and other carbonate-producing marine organisms.
Reef and non-reef carbonate growth

Major controls modeled by Fuzzy rules:

- Water depth
- Tidal currents
- Salinity level
- Turbidity/sedimentation rate
- Water temperature
- Substrate types
- Exposed to moderate – high circulation
- Others

Fuzzy Logic: A useful way of converting qualitative information into quantitative rules
Carbonate example rules

Reef building

Will form in warm water, within normal salinity ranges, in moderate to fast currents, in most tidal ranges, not on land, within the photic/neritic zone, with little sediment input and away from rivers.

“Pelagic”: foraminifera, molluscs

Will accumulate in open waters, in medium-deep water (foraminifera) or shallow water (molluscs), away from river mouths, where sediment input is very low, surface waters are temperate to warm, nutrient levels are moderate to low, and the ocean floor is above carbonate compensation depth.
Carbonate Offneria Sp. example rules

# 1. Bank-crest biotope – Offneria sets
on-rudist-bank  carbdist  0.0  1.0  10.0  0.0
highexposure    expo     0.0  0.0  1.0  1.0
shallow         depth    0.0  0.0  0.0  1.0  5.0  1.0  10.0  0.5  15.0  0.0
rise            valley   -1.0  1.0  0.0  0.0
offneria-temp   temp     15.0  0.0  18.0  0.5  26.0  1.0  28.0  1.0  33.0  0.0

# Offneria growth rates ~75m per 1 Ma = 0.000075 m/year
offneria_growth  growth  0.0  0.0  0.000075  1.0

# 1. Bank-crest biotope - Offneria rules
# initiation
carbonate1 = offneria_growth = shallow and highexposure and offneria-temp and rise
# Continuation
carbonate1 = offneria_growth = shallow and offneria-temp and on-rudist-bank and highexposure
Carbonate **Glossomyophorus/Agriopleura** example rules

# 2. Lagoon and back bank - Glossomyophorus/Agriopleura sets

<table>
<thead>
<tr>
<th>off-rudist-bank</th>
<th>carbdist</th>
<th>0.0</th>
<th>0.0</th>
<th>2000.0</th>
<th>0.5</th>
<th>4000.0</th>
<th>1.0</th>
<th>6000.0</th>
<th>1.0</th>
<th>8000.0</th>
<th>0.5</th>
<th>10000</th>
<th>0.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>lagoon_depth</td>
<td>depth</td>
<td>0.0</td>
<td>0.0</td>
<td>5.0</td>
<td>1.0</td>
<td>10.0</td>
<td>1.0</td>
<td>25.0</td>
<td>0.5</td>
<td>40.0</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

# Glossomyophorus growth rates

~45m per 1 Ma = 0.000045 m/year

| glossomyophorus_growth | growth | 0.0 | 0.0 | 0.000045 | 1.0 |

# 2. Lagoon and back bank - Glossomyophorus/Agriopleura rules

```plaintext
carbonate2 = glossomyophorus_growth = lagoon_depth and off-rudist-bank
```

#
Climate change projections

Special report of regional climate change from CSIRO

- Local mean sea level, Rainfall, Sediment load, Outflow, Cyclone intensity and Frequency, Wind velocity, Wave height, CO₂ concentration.

- Climate change scenarios
  1. Moving towards the lowest energy climate possible.
     Lowest rainfall, lowest sediment load, lowest outflow, highest salinity, and lowest oceanographic conditions, minimum sea level rise.
  2. Moving towards highest energy climate possible.
     Highest rainfall, highest sediment load, highest outflow, lowest salinity, and highest oceanographic conditions, maximum sea level rise.
Predicting Change – Beach replenishment

Terschelling Island, NL

1994 - 1997

Brighton Beach, SA
Estuarine Changes

Modelling coastline change of the Darss-Zingst peninsula with SEDSIM

Sinking Coasts – Geosphere, Ecosphere and Anthroposphere of the Holocene Southern Baltic Sea

Michael Meyer
Jan Harff
Chris Dyt
Open-file reports on climate change impacts on seabed sediment transport

Research Highlights

CSIRO Reports for climate change impacts on seabed sediment transport

- NW regions report (zone 1 & 2) download file size: 14 Mb
- N region report (zone 3) download file size: 3 Mb
- NE/E regions report (zone 4 & 5) download file size: 38.5 Mb
- SE regions report (zone 6) download file size: 2 Mb
- S/SW regions report (zone 7, 8 & 9) download file size: 15 Mb

Conferences & Papers List since 2005

- APPEA - 2005 - Seabed sediment transport and offshore pipeline risks in the Australian Southeast
- Coasts & Ports - 2005 - Preliminary Study of seabed sediment transport in SE Region, Australia
- ISOPE - 2006 - Wind-driven water circulation and its impact on seabed sediment transport in the Australian Northeast
- AAGP - 2006 - Climate change impact on seabed sediment deposition in SW Region, Australia
- Coasts & Ports - 2007 - Climate change impact on seabed sediment deposition in SW Region, Australia
- APPEA - 2008 - Climate change impact on NW Shelf seabed evolution and its implication for offshore pipeline design
- GSA - 2008 - Predicting seabed change as a function of climate change over the next 50 year in the Australian Southeast
- IASWS - 2008 - Mutligrain seabed sediment transport modelling for Southwest region, Australia
- Coast to Coast - 2008 - Climate change impact on seabed sediment transport in the Australian Exclusive Economic Zone
- Marine and Freshwater Research - 2009 - Mutligrain seabed sediment transport modelling for the south-west Australian Shelf

National Research Flagships

Wealth from Oceans
Morphological change in next 50 years under **low-energy** climate for all Australia
Ningaloo to Dampier reefs change in next 50 years comparison between scenarios

Controlling factors:
- El Nino circulation pattern
- Rapid salinity increase

Stationary climate

Low-energy climate

High-energy climate

Erosion Accretion
-2 -1E-05 1E-05 2
Ningaloo to Dampier reefs change in next 50 years comparison between scenarios

Stationary climate

Destruction of 70% of the reefs

Controlling factors:
• increasing impact of wave power
§ and extreme events

High-energy climate
Morphological change in next 50 years comparison between low and high energy

38% increase of seabed morphological activity under high-energy climate
increase of erosion and accretion between Dampier and Exmouth
more accretion on the outer-shelf from Jurien Bay to Kalbarri
Talk outline

- Value of coasts?
- Historical/geological change
- Understanding causes of change – long period – short period
- Background data
- Predicting change
- Testing predictions of change
Morphological change in next 50 years under high-energy climate for all Australia.
What are data? - Interpolation/extrapolation

Interpolation/extrapolation issues

- Preservation of data resolution
- Adaptive search radii
- Directional searching
- Anthropogenic artifacts
- Weighting metric
- Statistical performance
- Validation of interpolation

A Competent Interpolator of Marine Substrates Data

C.J. Jenkins, J.A. Goff 2006
Repeat sampling

1994 - 1997

Observed: 2.37 m

Modelled: 2.16 m

0.5 1.0 1.5 2.0 m
Talk outline

• Value of coasts?
• Historical/geological change
• Understanding causes of change – long period – short period
• Background data
• Predicting change
• Testing predictions of change
• Politics of change
• Call for concerted international effort
Stakeholders

- Coastal states
- Coastal communities
- Insurance companies
- Lawyers
- Planners
- Marine industry
- Developers
- Geological/Geotechnical community
- Military
Future Directions – Funding needs

a) real-time coastal impact prediction tool - ? one day before cyclone - ? during Pacific/Indian Ocean tsunami warning
b) baseline studies from 500 m behind the shoreline to storm wave base
c) frequent replicate sampling at ‘the same’ location to test models
d) seagrass and mangrove ecology and modification of the hydraulic regime
e) coastal dune numerical modelling integrated in coastal morphodynamics
f) carbonate coastal morphodynamics including growth/dissolution
g) inverse modelling – to do this we need fast objective/cost functions and probably an experimental design approach.
h) adaptive grids for engineering-scale predictions within large coastal models


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