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Assessing Storm Tide Hazard for the North-West Coast of Australia using an Integrated High-Resolution Model System

J. Churchill, D. Taylor, J. Burston, J. Dent

September 14, 2017, Presenter Jim Churchill

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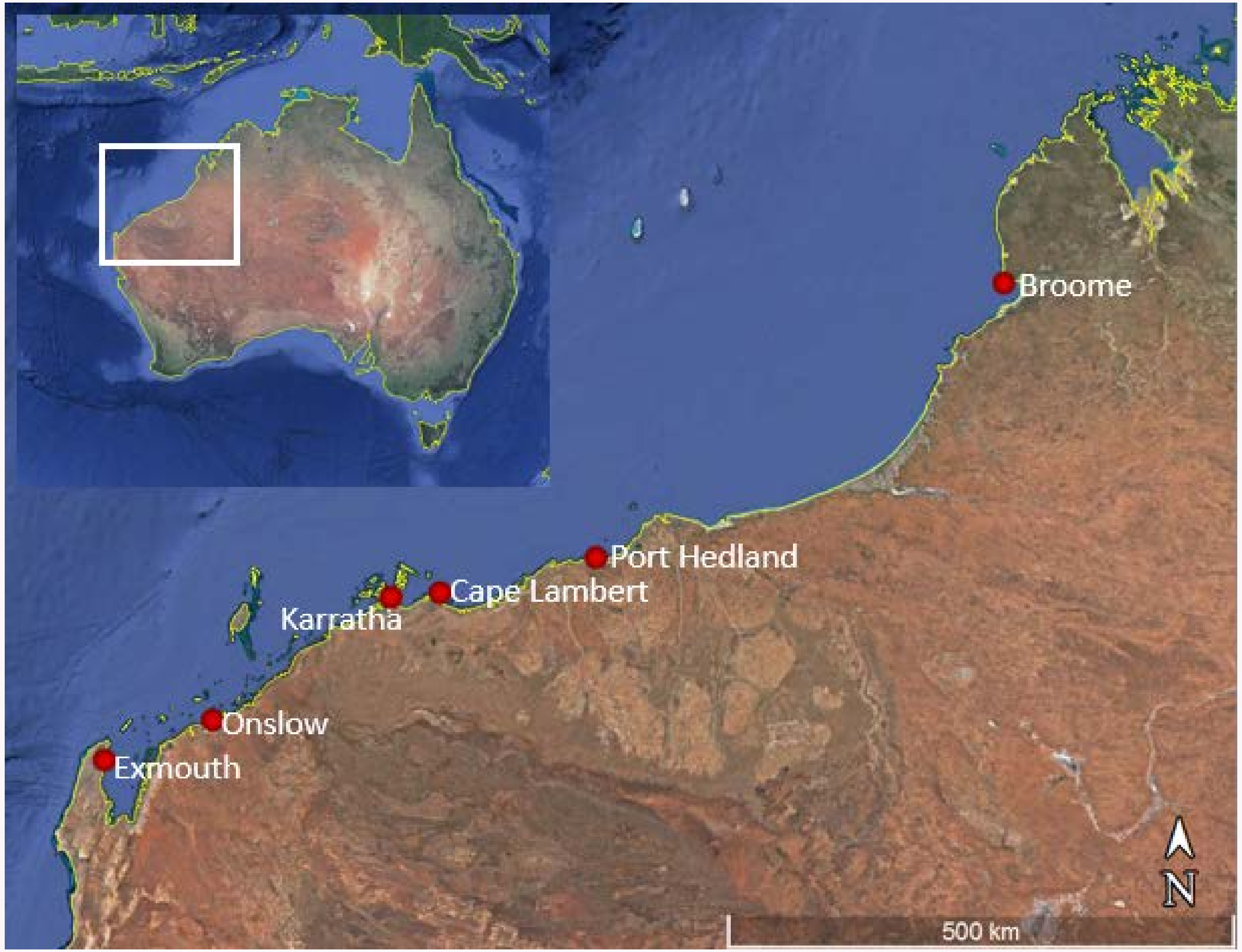
1st International Workshop on Waves, Storm Surges and Coastal Hazards. Liverpool UK

Overview

- Motivation - Storm Tide Hazard
- Methodology for Hazard Assessment
  - Synthetic Cyclone Track Database
  - Hydrodynamic Model
  - Validation to Historical Data
  - Monte Carlo production cases
- Study Outputs
  - Extreme Value Analysis
  - Inundation Mapping
- Modelling Sensitivities

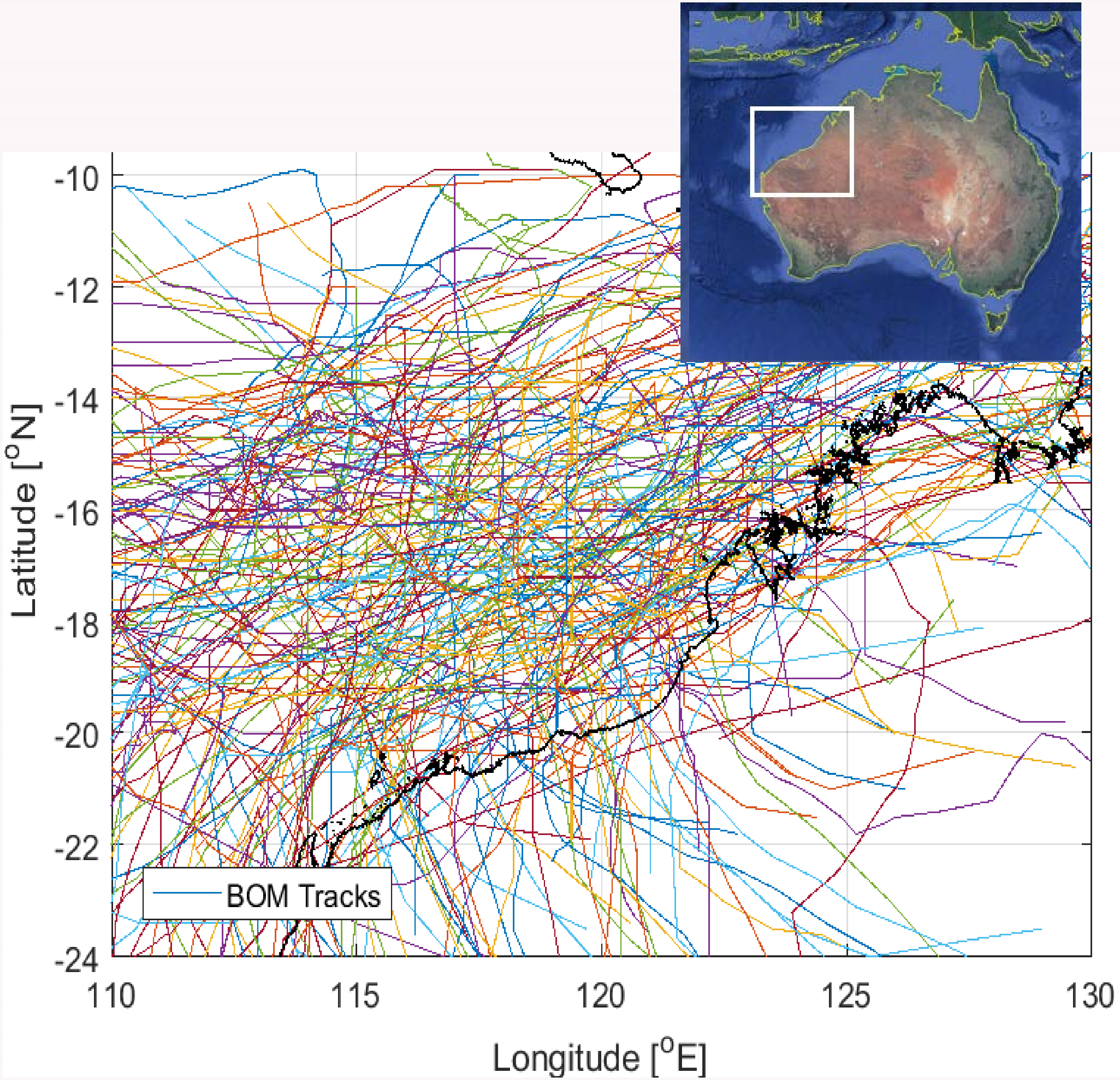
Motivation

- Location Context
  - North west coast of Australia
  - Significant oil and gas reserves
  - Major ports servicing the resources sector
  - Small Coastal communities
- Storm Tide Levels
  - Infrastructure Design
  - Safety Requirements
  - Planning Regulations
  - Emergency Planning



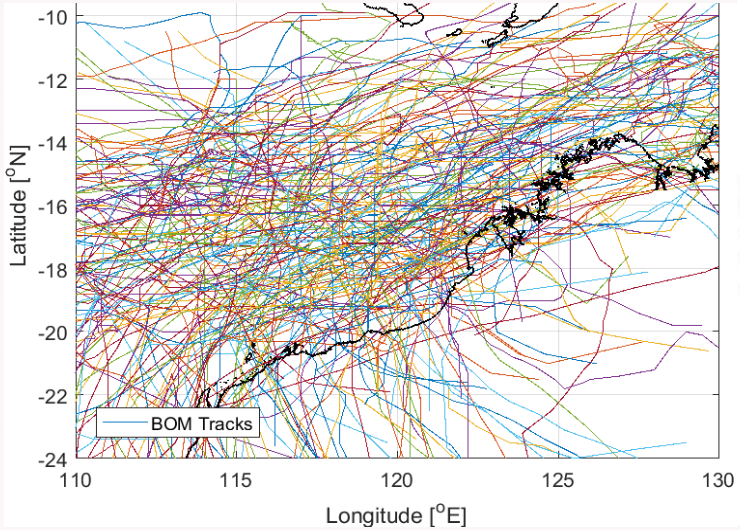
Methods

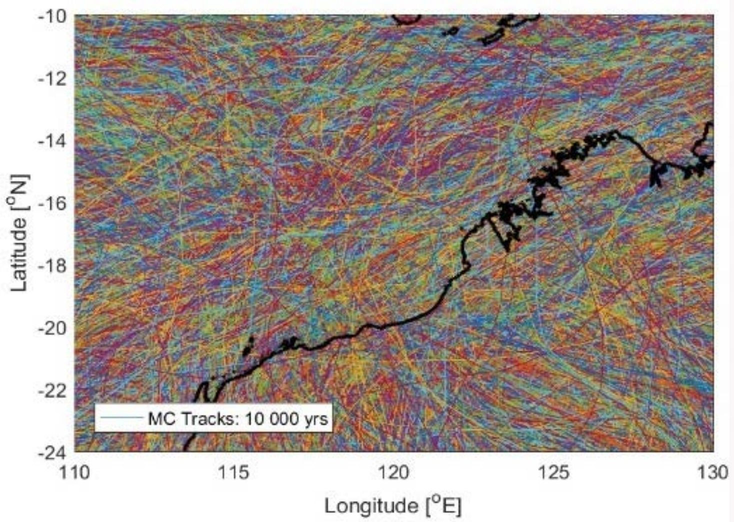
- Metocean Setting
  - Highest incidence of Tropical Cyclones in Australian region
  - Large tide range
- Historical Data
  - Relatively short historical measured data record available ~30yrs
  - Australian Bureau of Meteorology ‘best tracks’ database of TC dating back 40 – 50 years

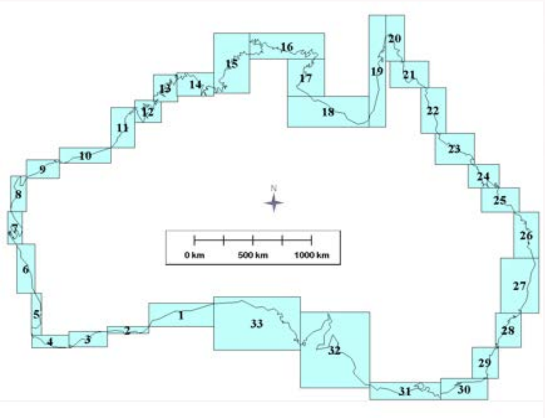


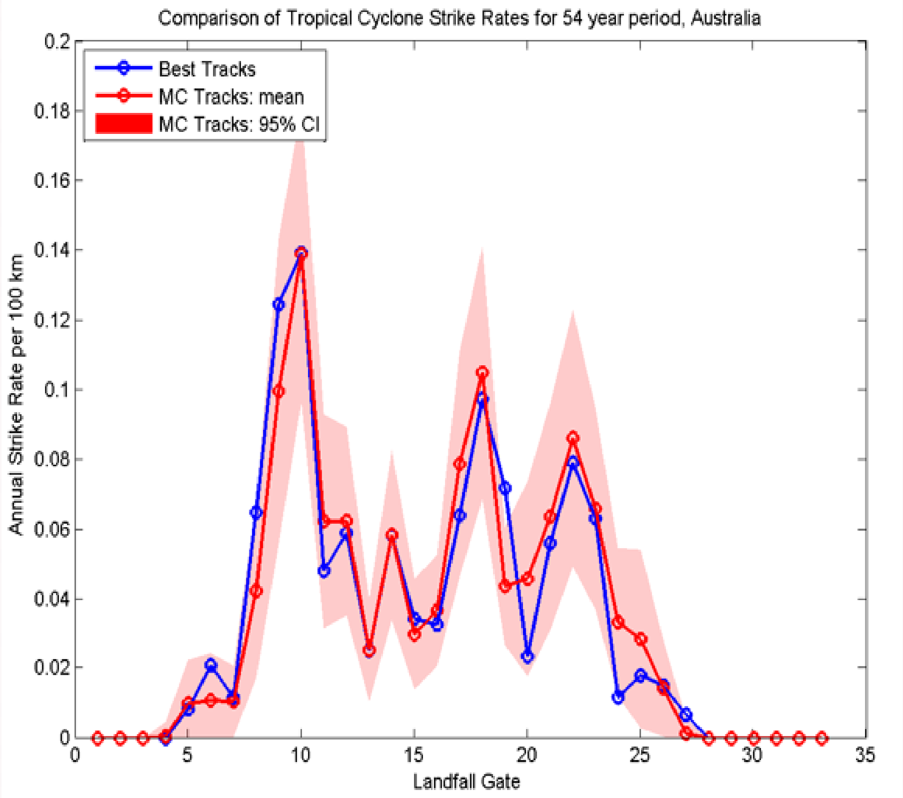
Cyclone Track Database

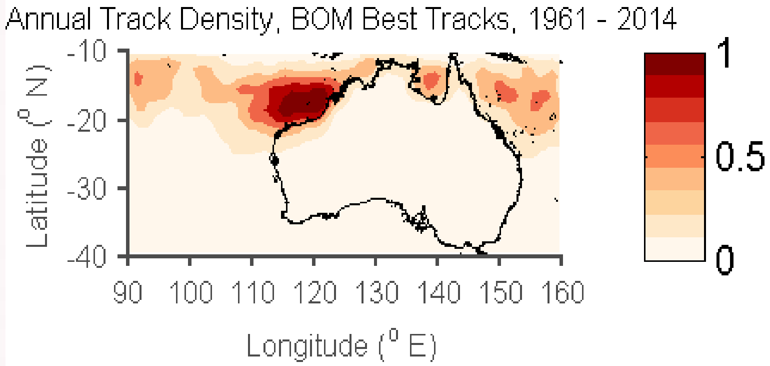
- Synthetic Tracks
  - Cyclone track database of over 28,000 events representing 10,000yr data set
  - Developed from satellite era track data
  - Synthetic Landfall rates validate well to historical landfall rates (Burston et al 2015, 2017)

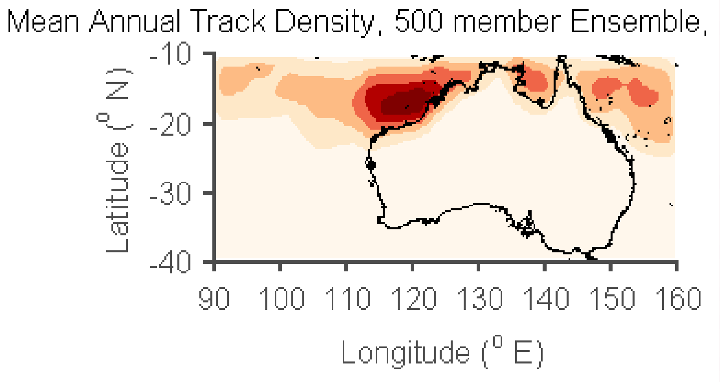






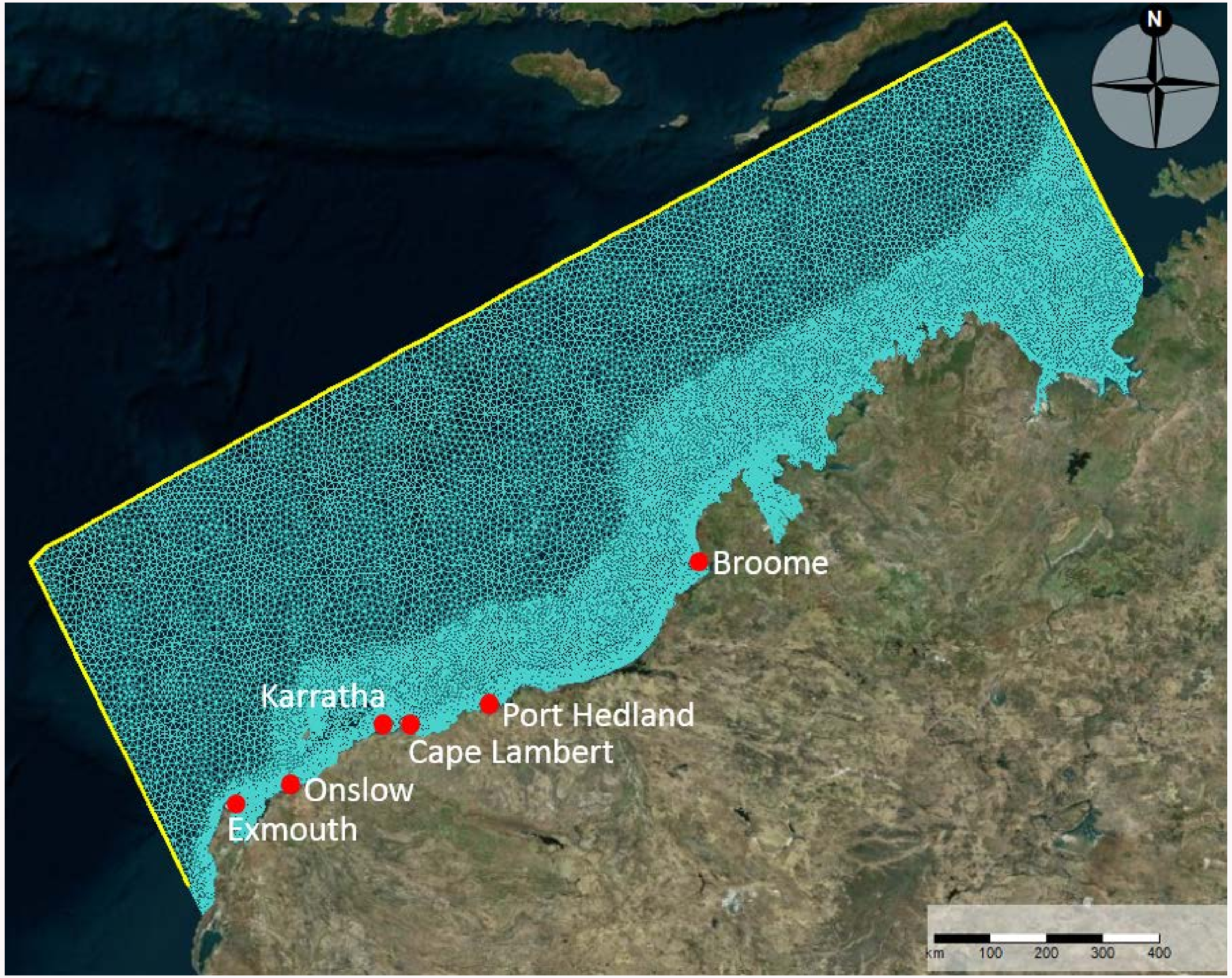






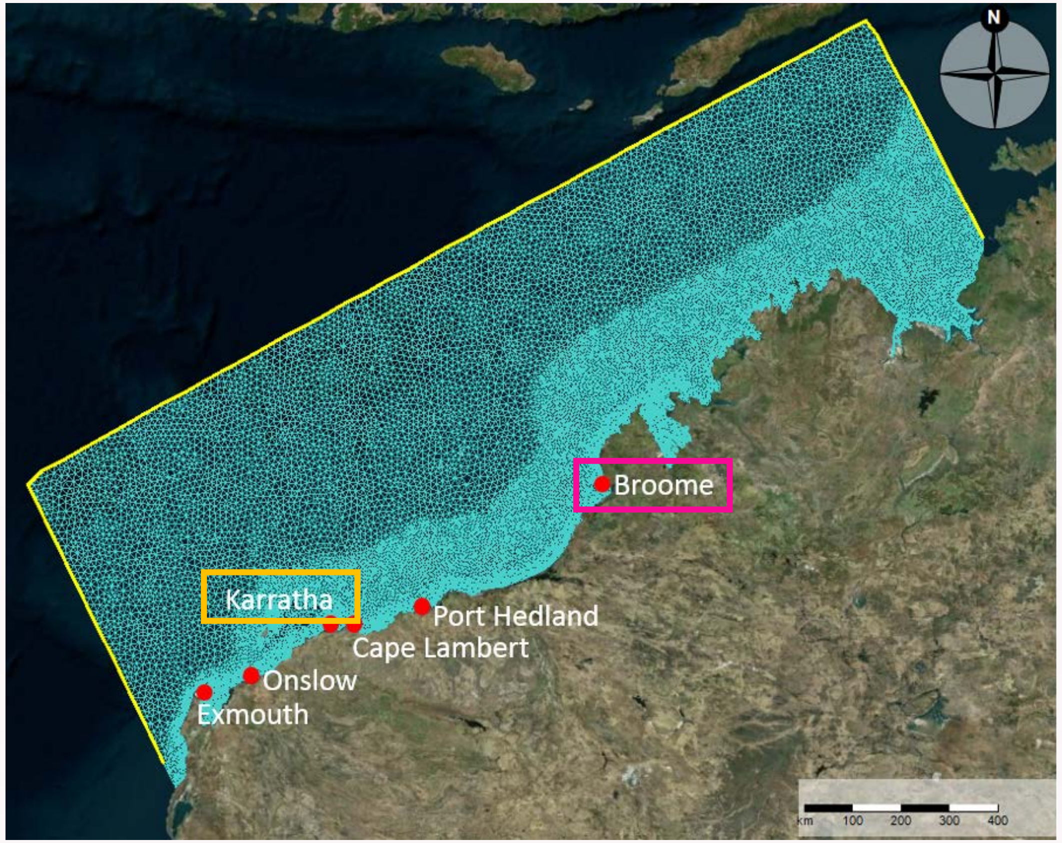
Hydrodynamic Model

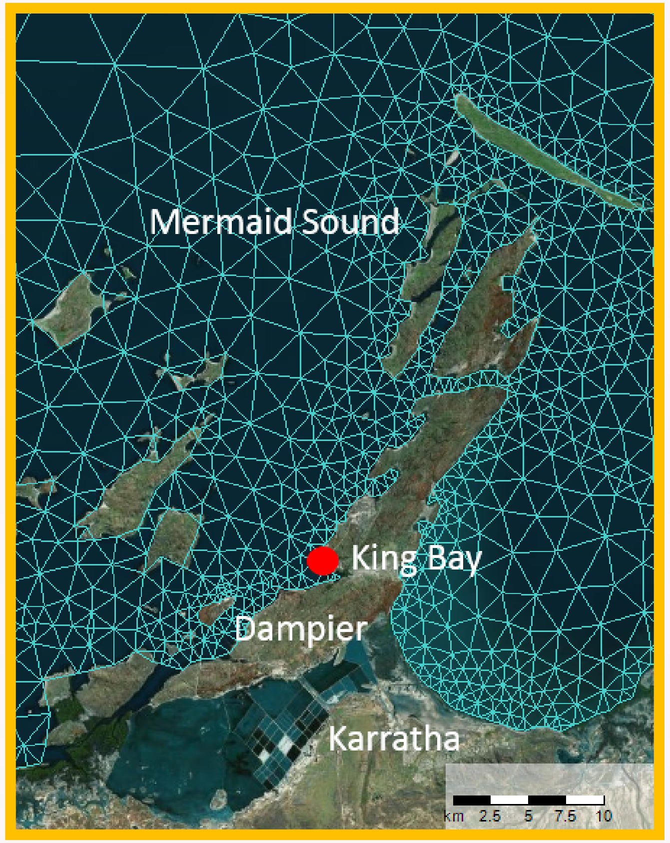
- Hydrodynamic model established using Delft3D Flexible Mesh Suite (Delft3D FM 2017)
- 2D model unstructured mesh ≈ 90,000 elements
- The model extends across 2000 km of the northwest coast of Australia and offshore up to 800 km
- Bathymetry compiled from survey data hydrographic charts, nearshore LiDAR and regional DTM's
- Offshore boundaries forced by TOPEX - 14 tidal constituents

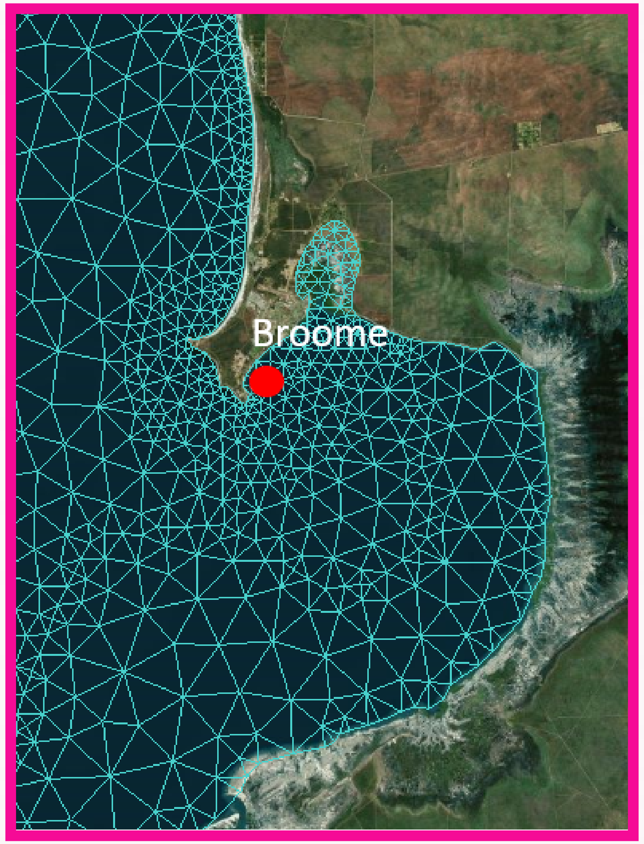


Hydrodynamic Model

- Increasing resolution from the offshore to nearshore areas.
- Approximately 4000 reporting locations in the model at 1km intervals along the 10m depth contour



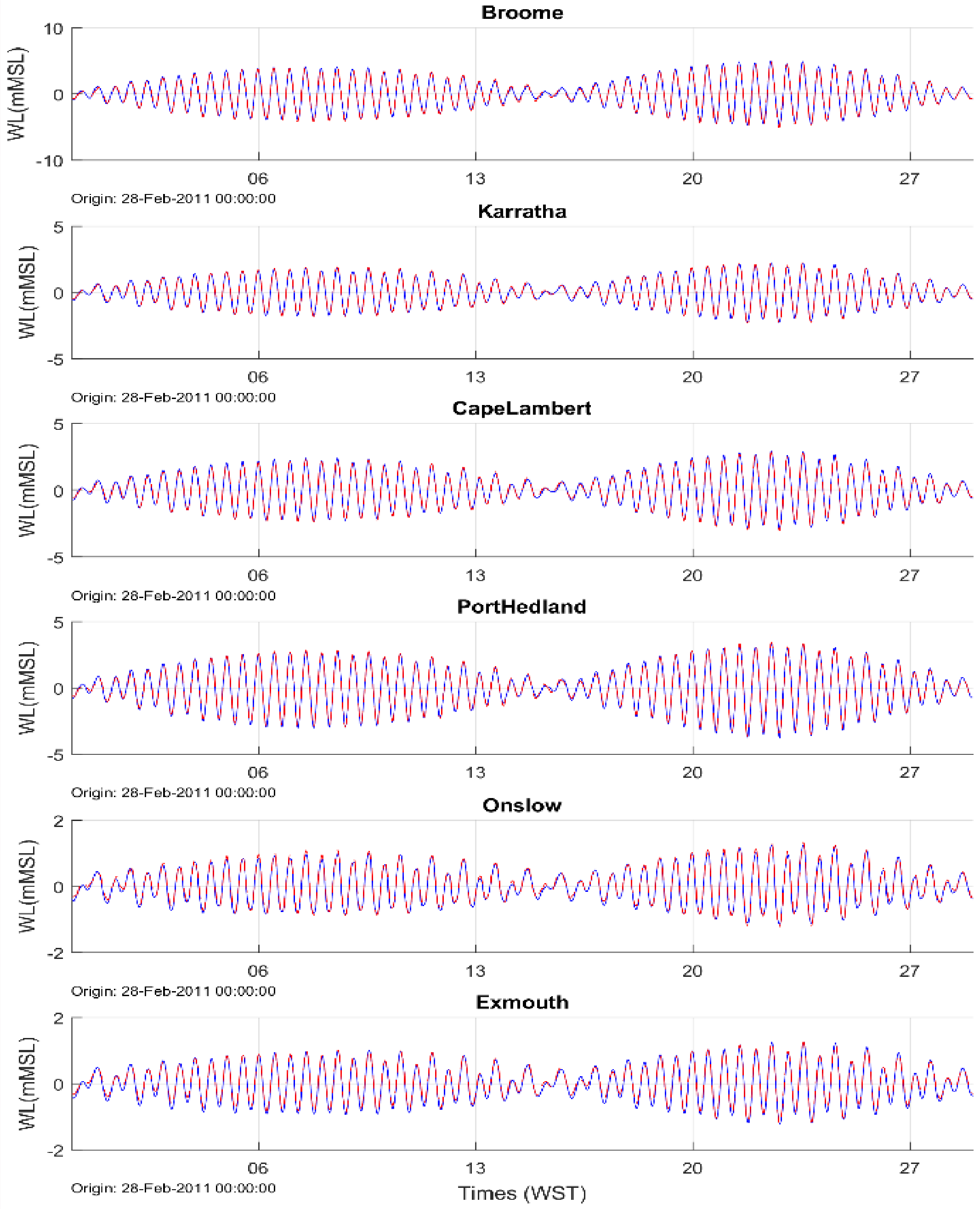




Hydrodynamic Model Validation

- Validation of the hydrodynamic model to one full year (2011) predicted and measured astronomical tide shows very good agreement to water level amplitude and phase
- Comparison of top eight constituents across the six sites shows very good validation to the predicted amplitude and phase

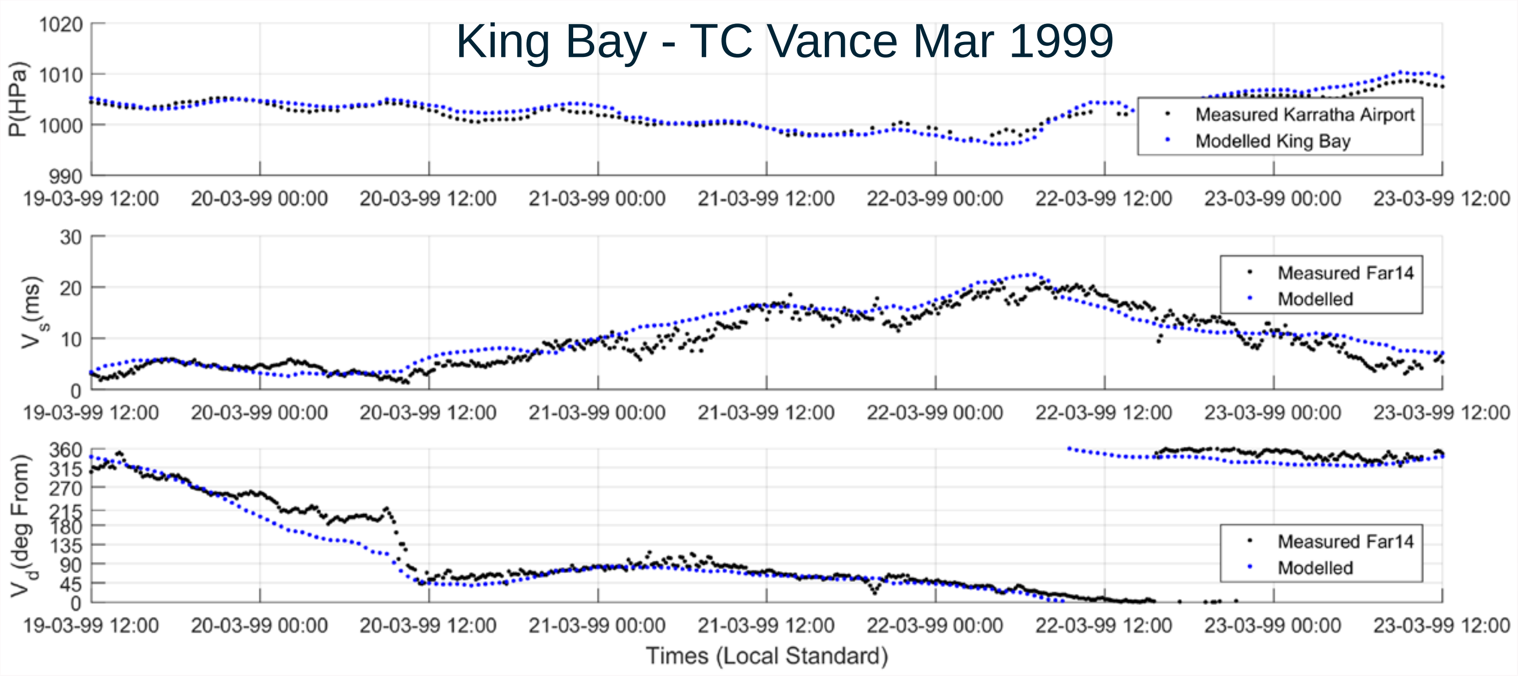
Location	Bias (m)	Skill	RMS error (m)
Broome	-0.029	0.997	0.206
Cape Lambert	-0.008	0.998	0.119
Exmouth	0.003	0.991	0.102
Port Hedland	0.000	0.998	0.128
Onslow	0.008	0.991	0.100
King Bay Karratha	0.004	0.997	0.102

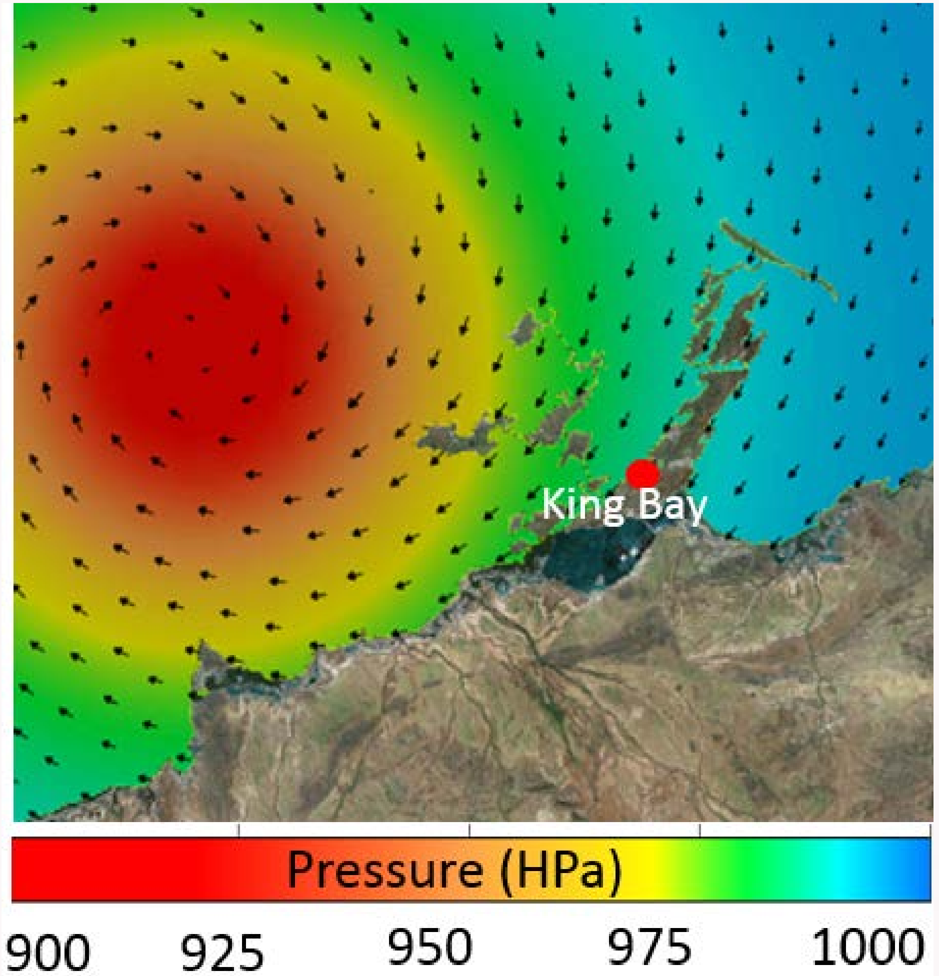


Water level: Predicted = Blue Modelled = Red

Modelled Wind and Pressure Fields

- Cyclonic wind and pressure fields generated for historical events through Baird Australia’s *Cycwind* program.
- *Cycwind* combines a Holland et al. (2010) vortex model blended into Climate Forecast System Reanalysis (CFSR) regional scale atmospheric fields
- Regular grid 0.05° extends across entire northwest Australia (approx. 5km)

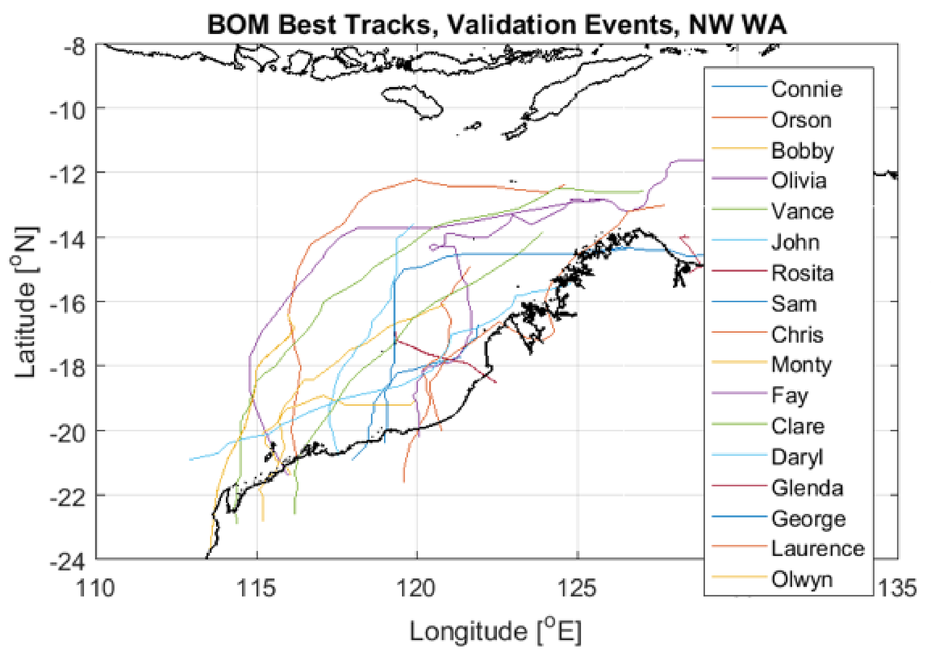


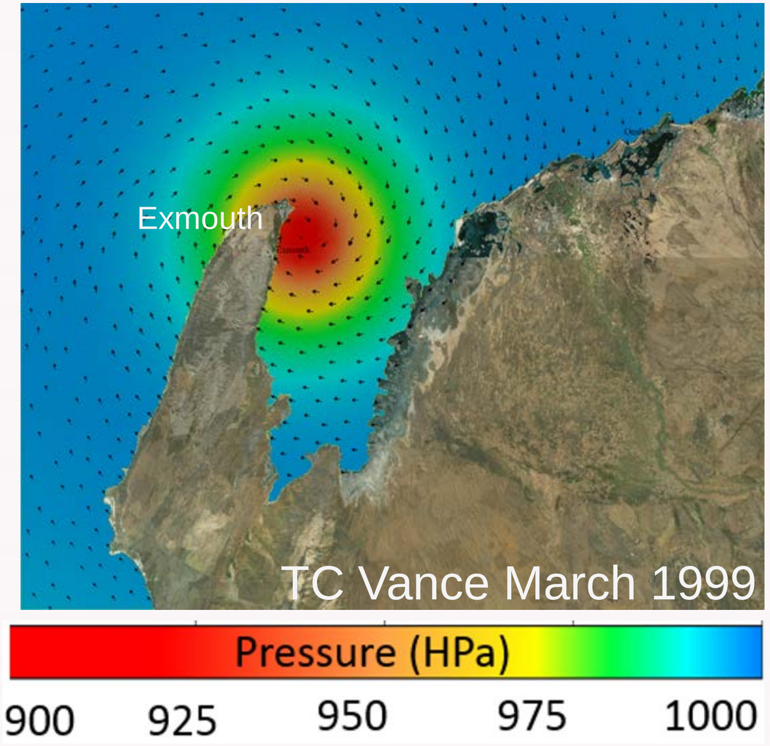


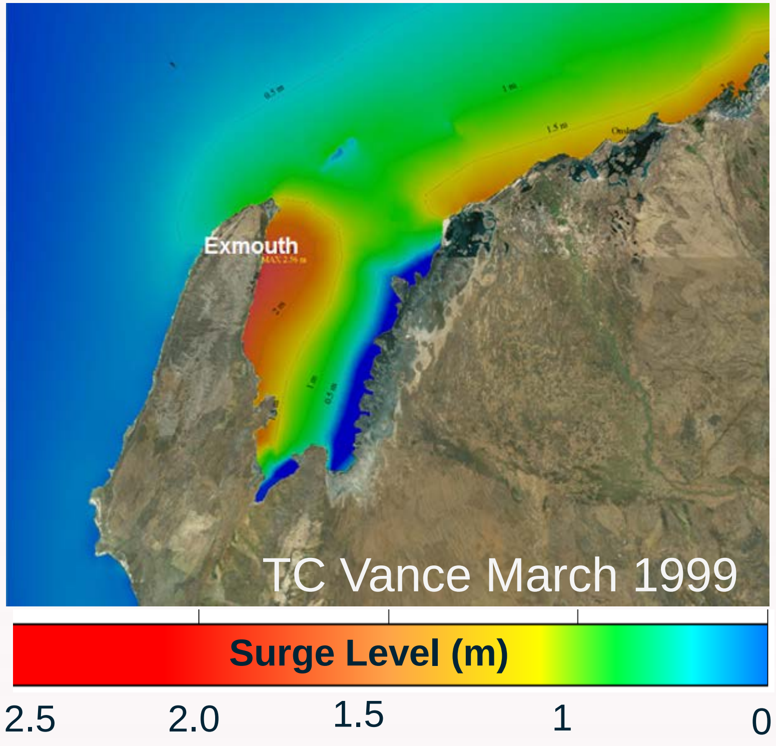
TC Orson at Karratha, 22 April 1989 0930UTC

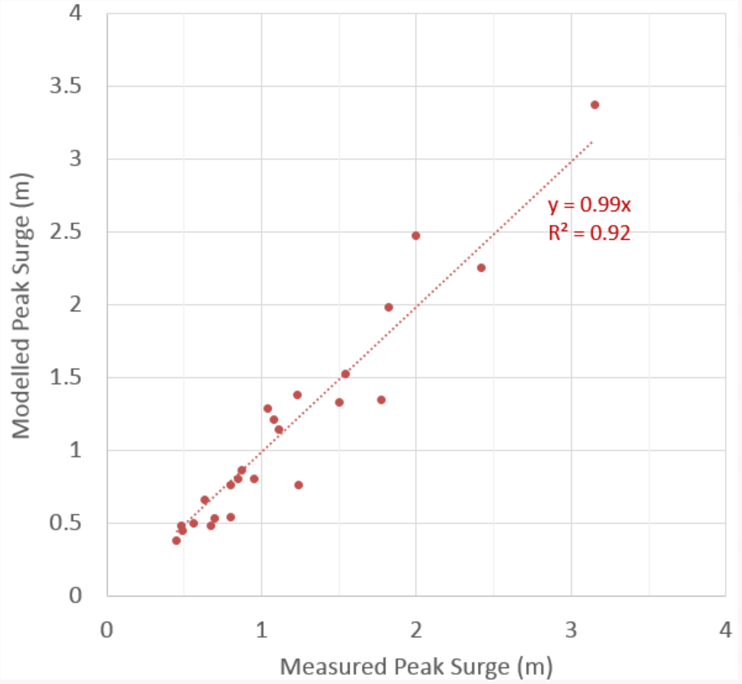
Validation events – Cyclone Cases

- 18 historical cyclones post 1985 were developed for validation of the hydrodynamic model
- Model replicates measured peak tidal residuals well with a linear fit of 0.99 ($R^2 = 0.92$).



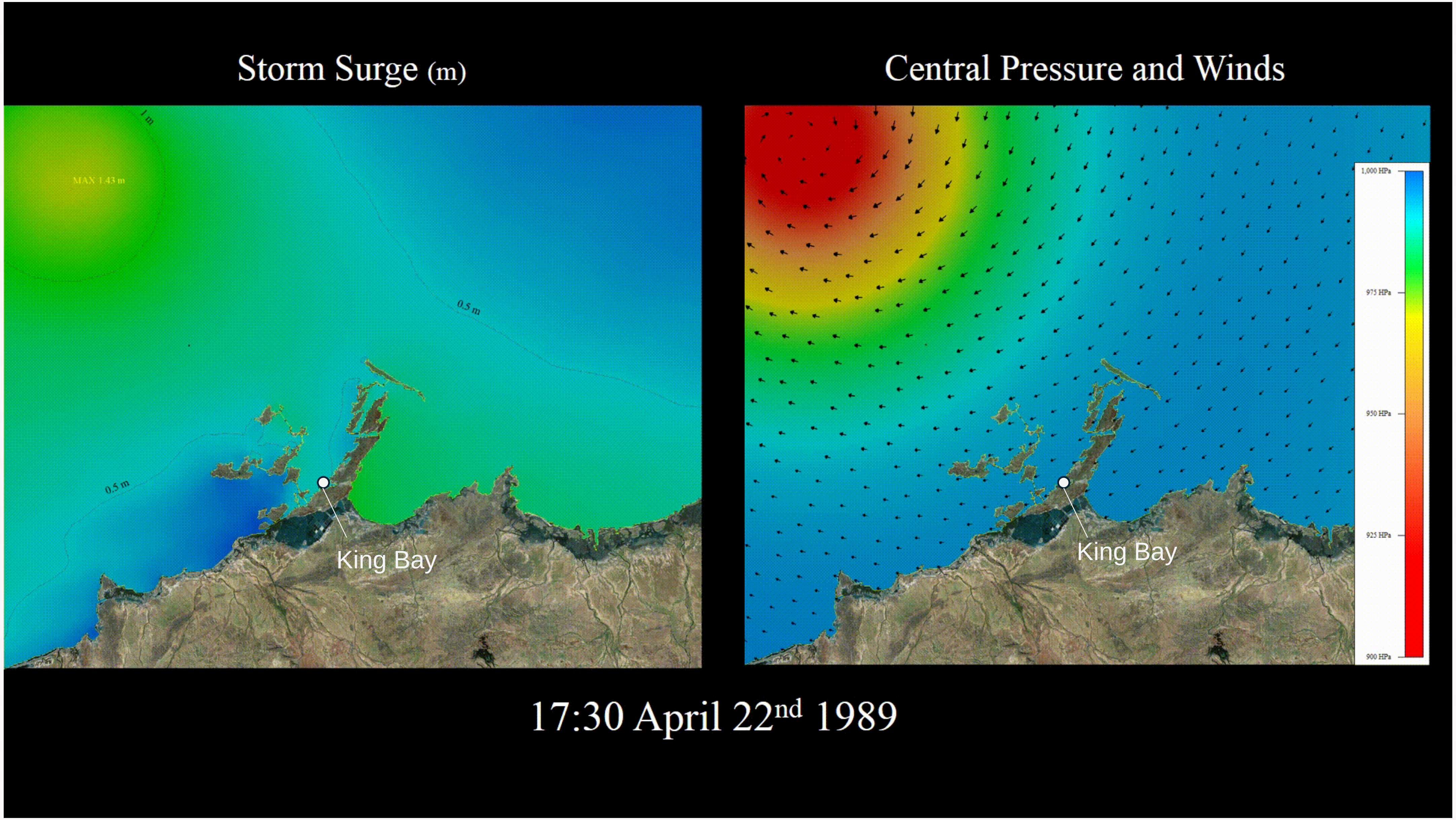






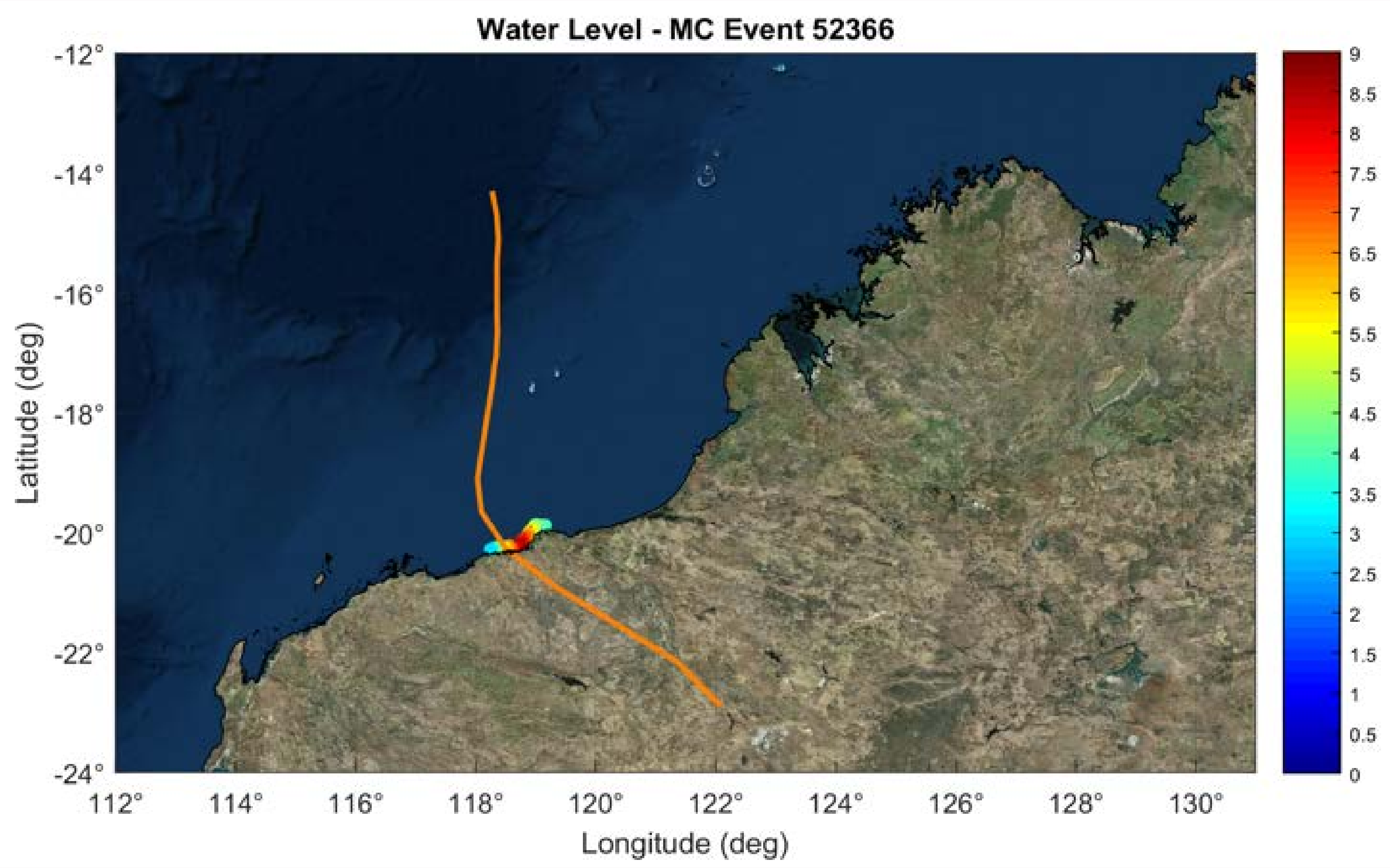
Measured and modelled peak surge values

TC Orson 1989 – King Bay Karratha



Production Cases – Synthetic Cyclones

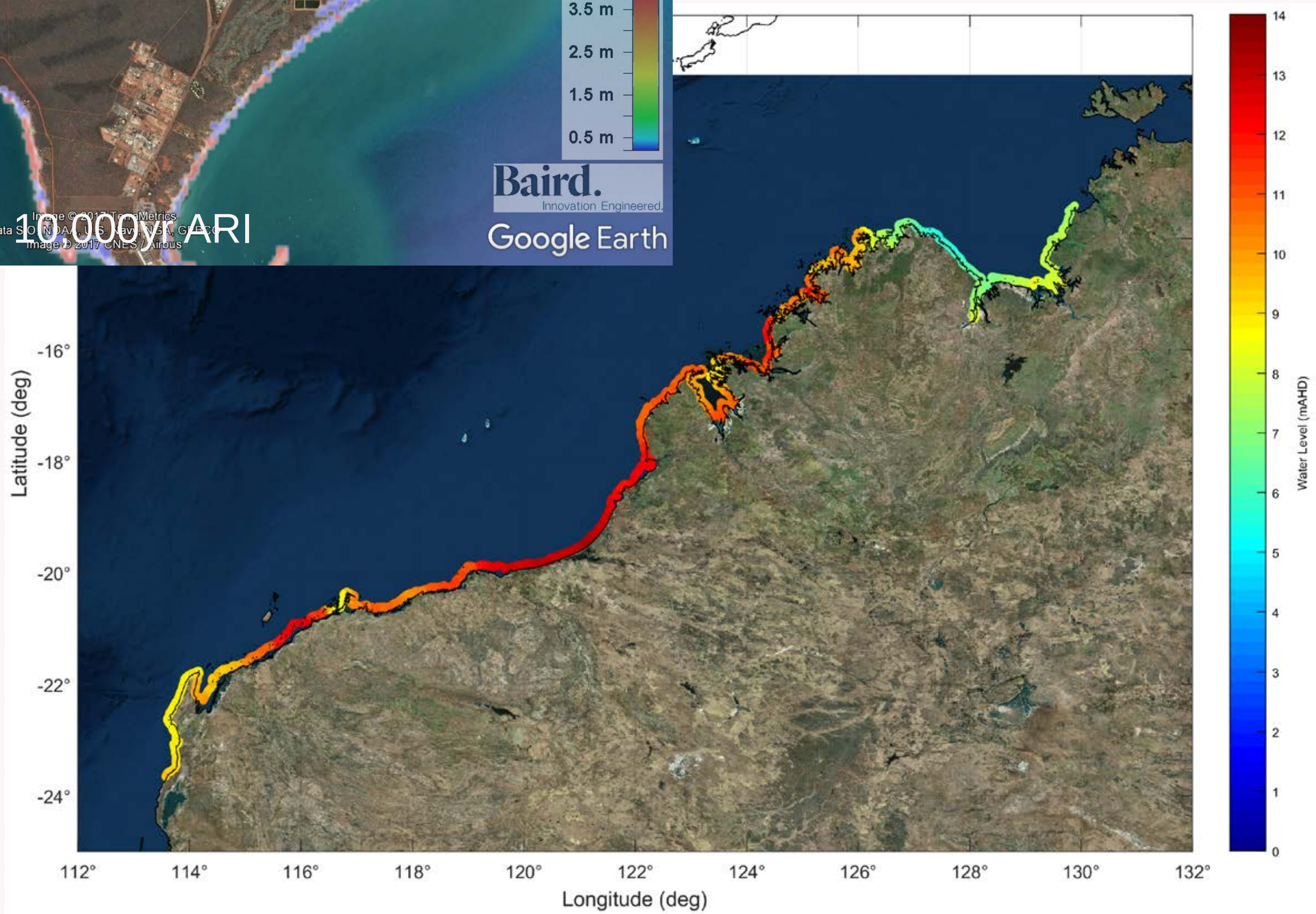
- The calibrated wind (*Cycwind*) and hydrodynamic model (D-Flow FM) used to model cyclone track model to assess over 28,000 synthetic cyclone tracks
- All model cases were run at a fixed water level of MSL to optimise model run time
- Simulations performed using the Microsoft Azure™ cloud computing platform requiring over 50,000 CPU (SU) hours
- Time series storm surge outputs were extracted from the approximately 4000 reporting locations along the coast and combined linearly with concurrent astronomical tide.



Storm tide water level (above AHD) from the event causing the highest storm tide (MC 52366) in the WA event set

Data Analysis

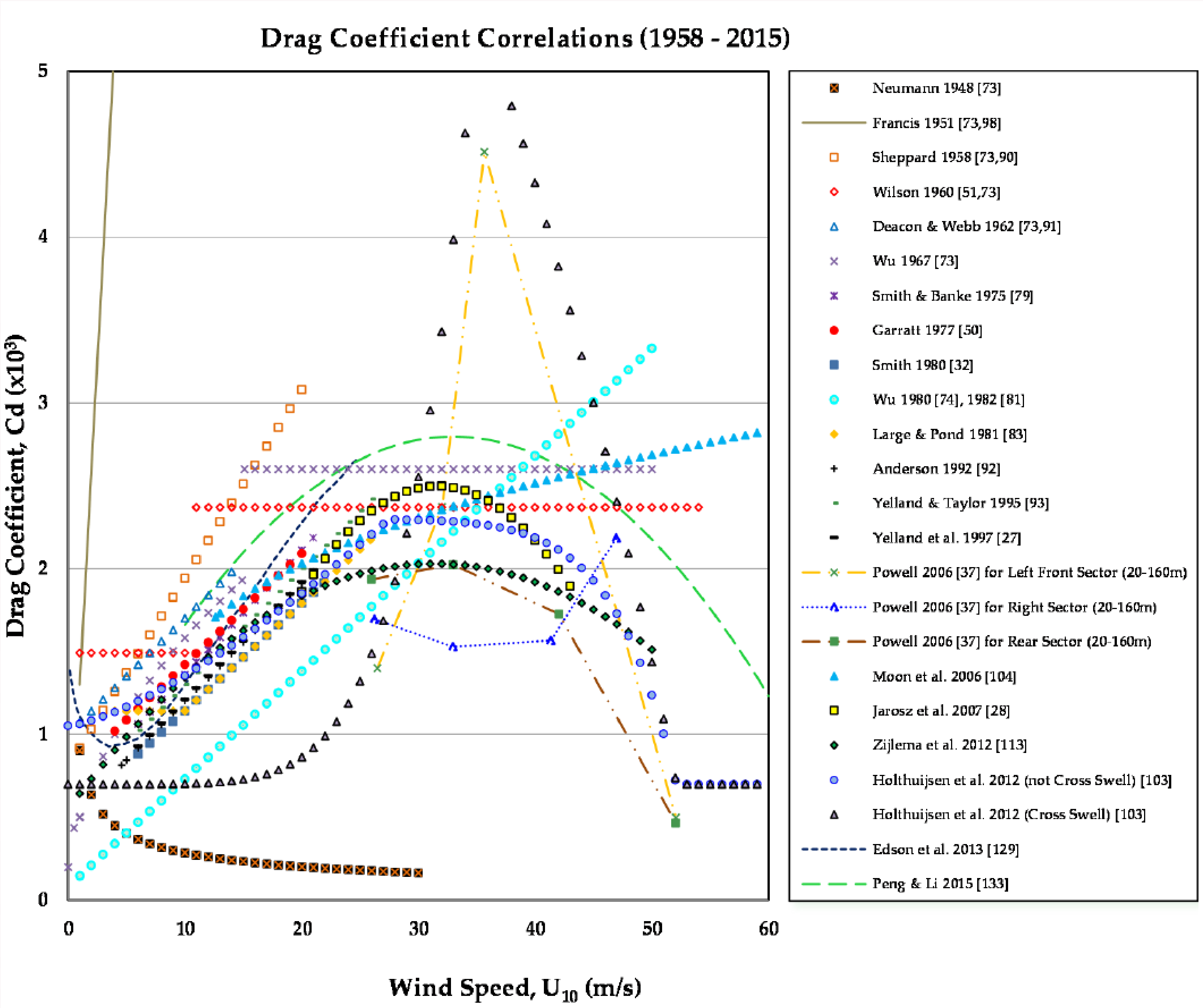
- Estimates of the ARI storm tide values for the reporting locations along the coast using Extreme Value Analysis
- The resulting high-resolution storm tide outputs (≈ 1 km resolution) were applied to an inundation mapping algorithm to spatially estimate storm tide inundation to a 20 m resolution
- Empirical wave exposure model applied to estimate additional wave inundation effects on the open coast



Modelled storm tide hazard along the northern WA coastline relative to AHD for the 500 year ARI

Wind Drag

- The selection of appropriate limits for wind drag coefficients at high wind speeds is well established
- At the lower end of wind speed, there is nearly an order of magnitude variation in published wind drag coefficients



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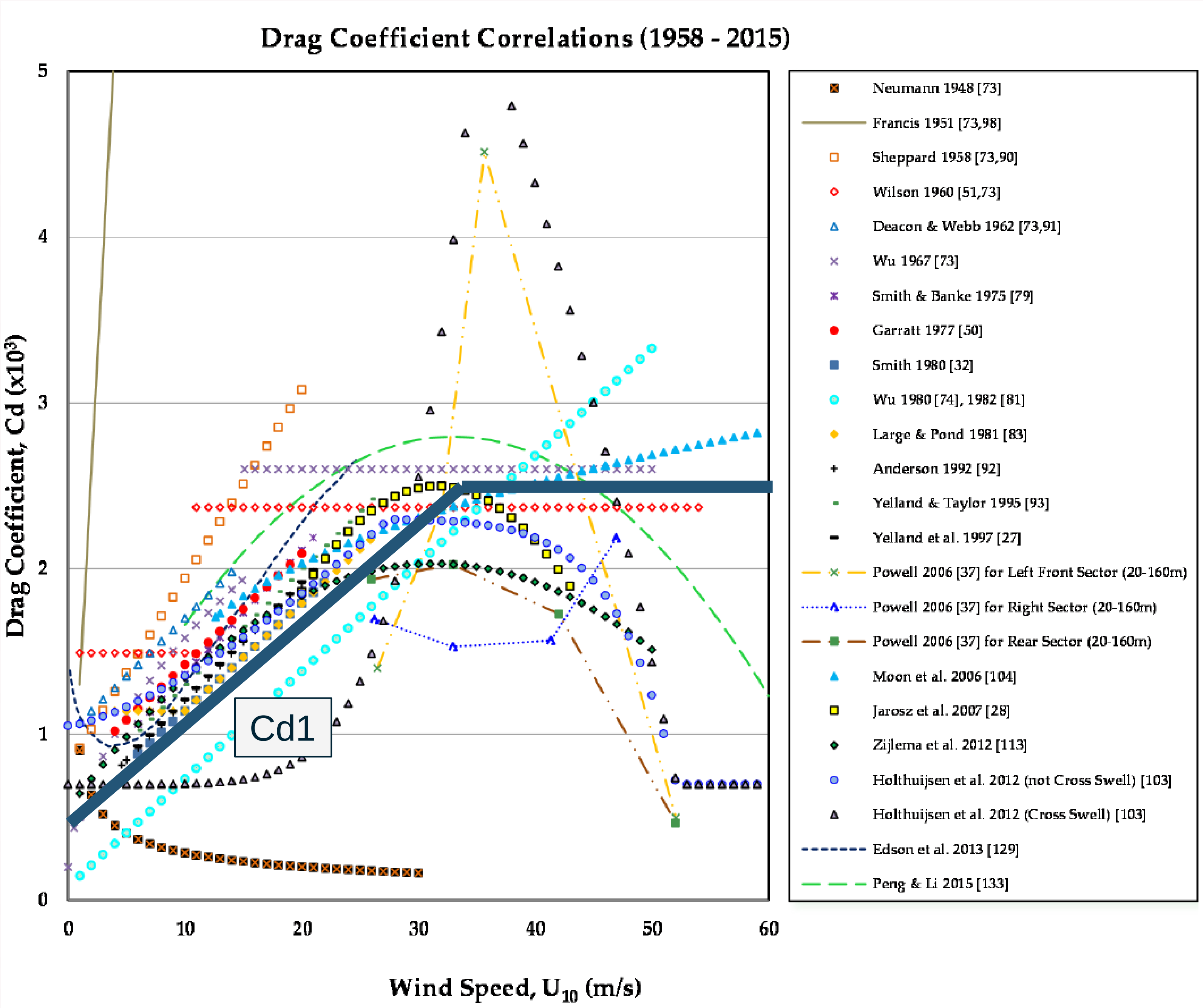

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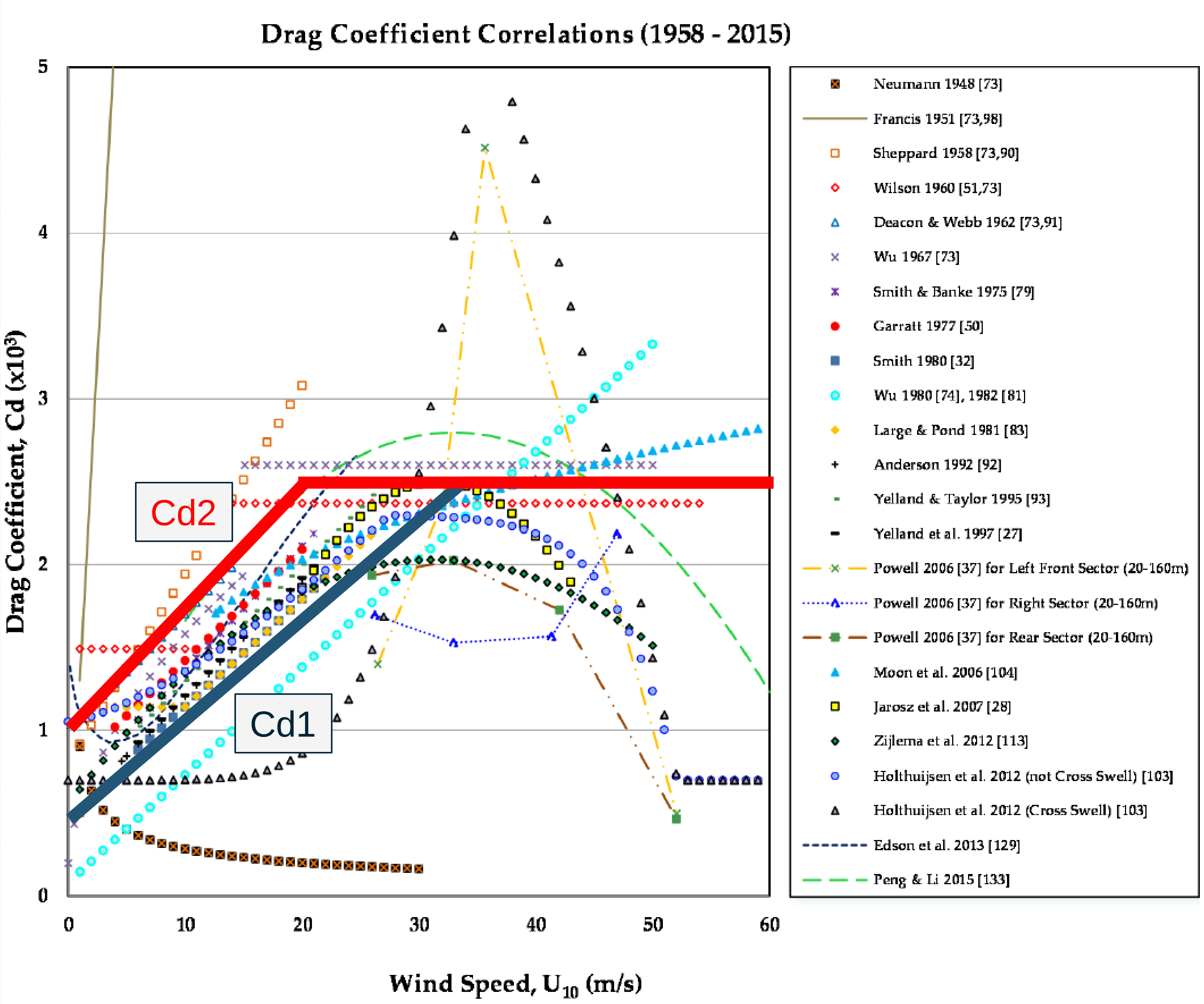

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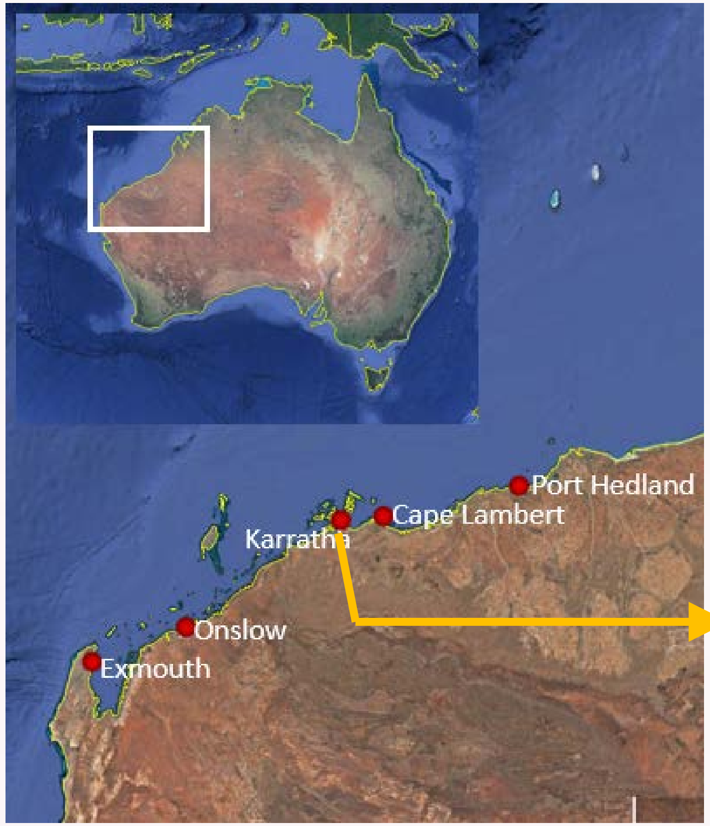
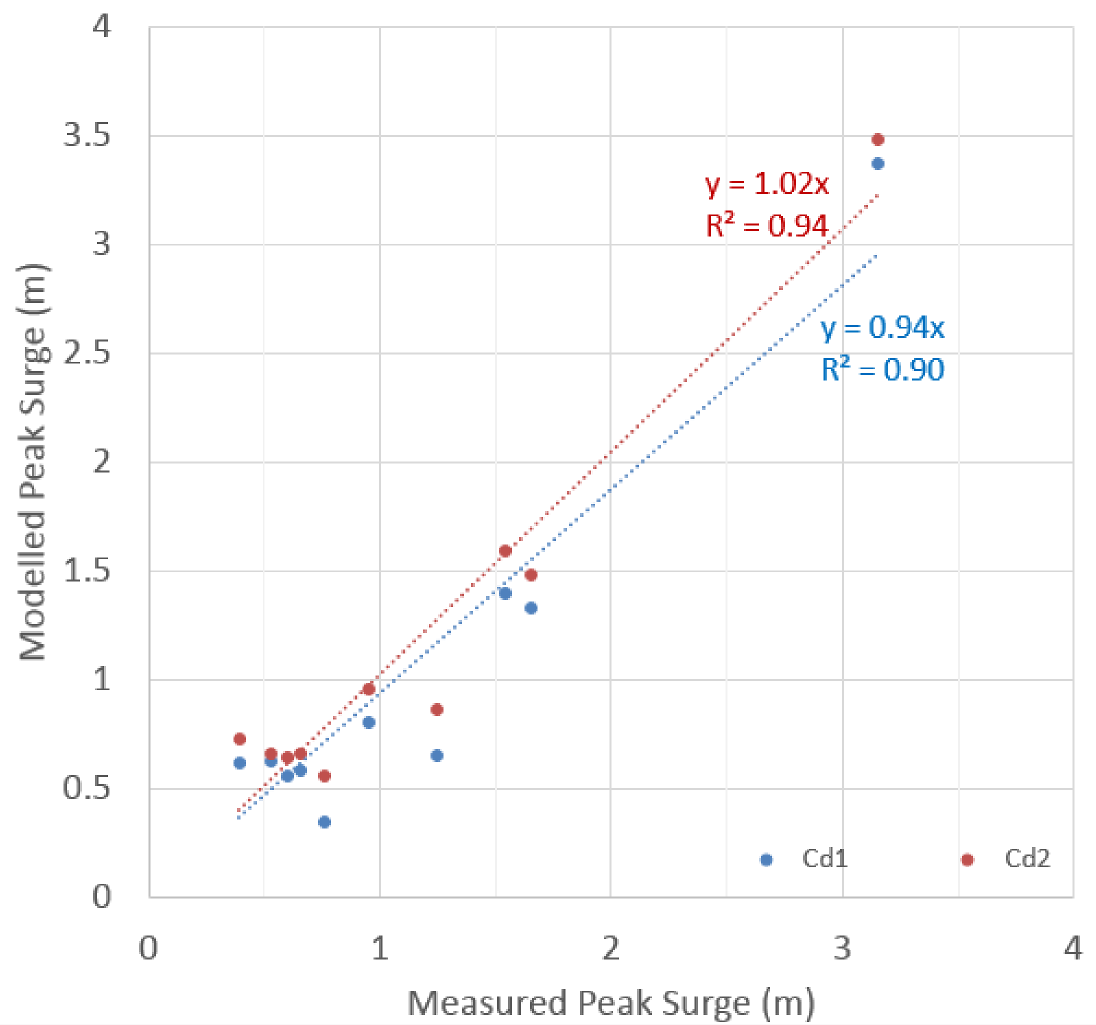
Sensitivity – Wind Drag Coefficients

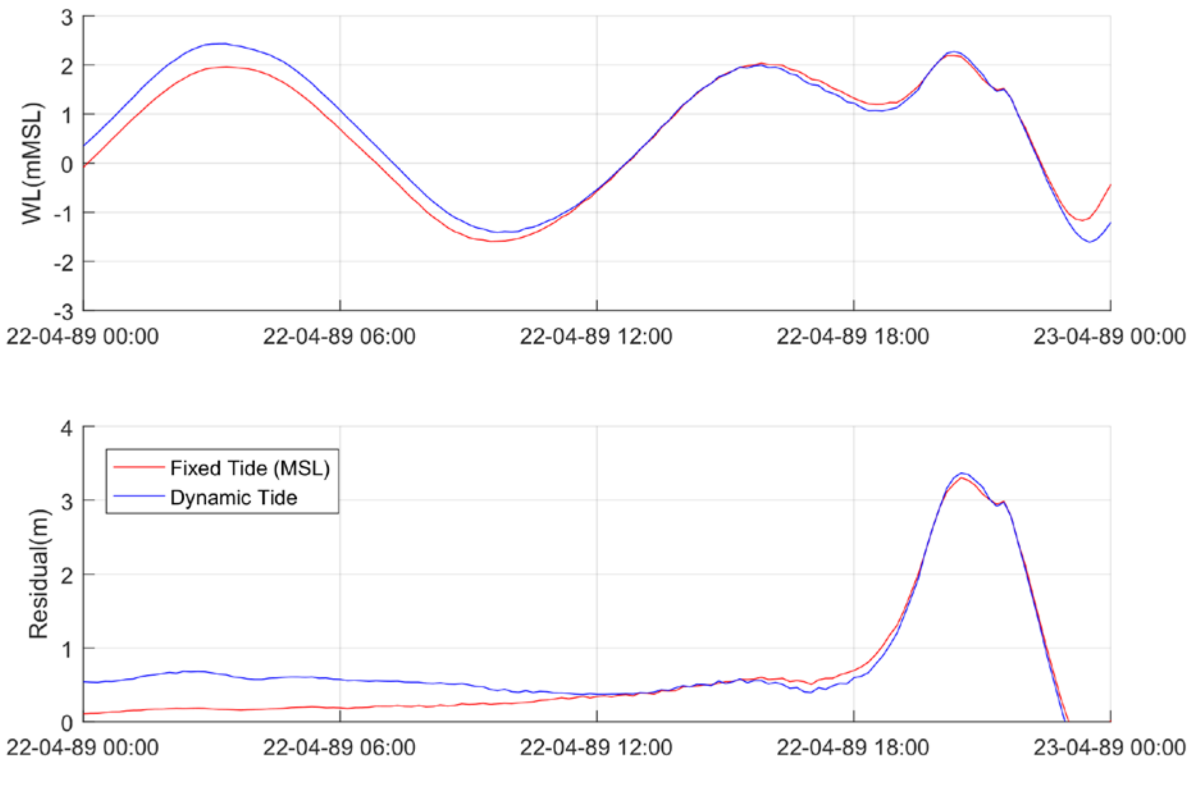
- Cd based on the upper limit values <30 ms^{-1}
- Applied to 10 events impacting Mermaid Sound region, improves agreement to measured





Sensitivity – Simulations with Varying Tide Level

- The influence of the tide level on the storm surge level was examined for three cyclone cases in Mermaid Sound
- Model scenario with time varying tide compared against a model scenario with tide fixed at MSL.
- Dynamic tide level can make a small difference to the resultant surge values
- Overall variation in peak water levels is relatively small

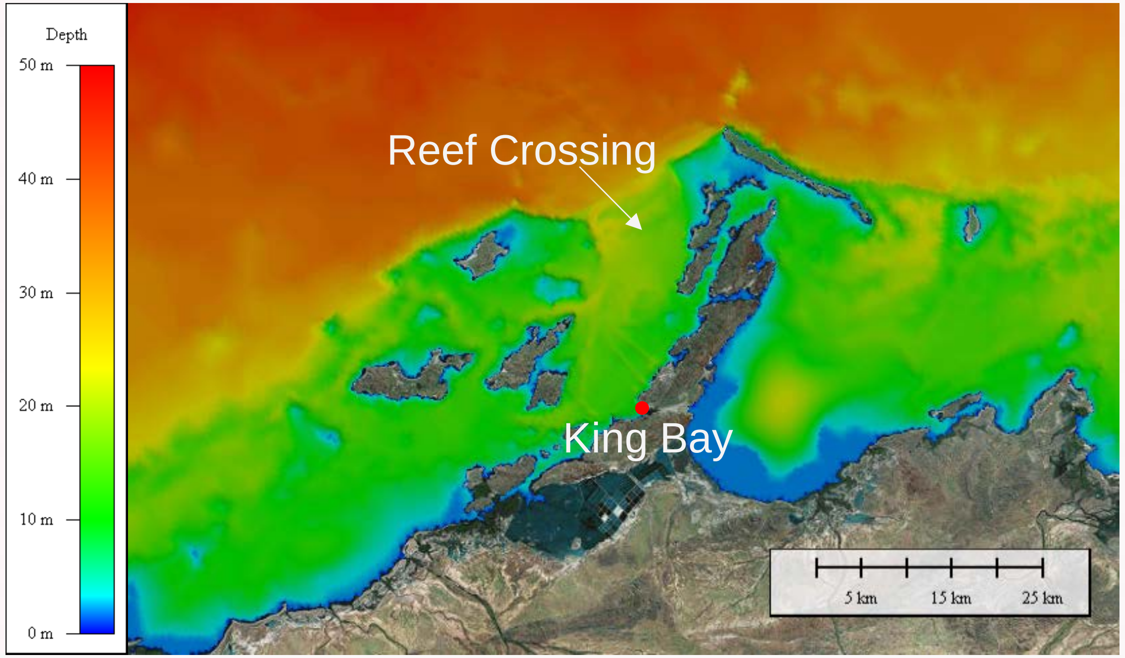


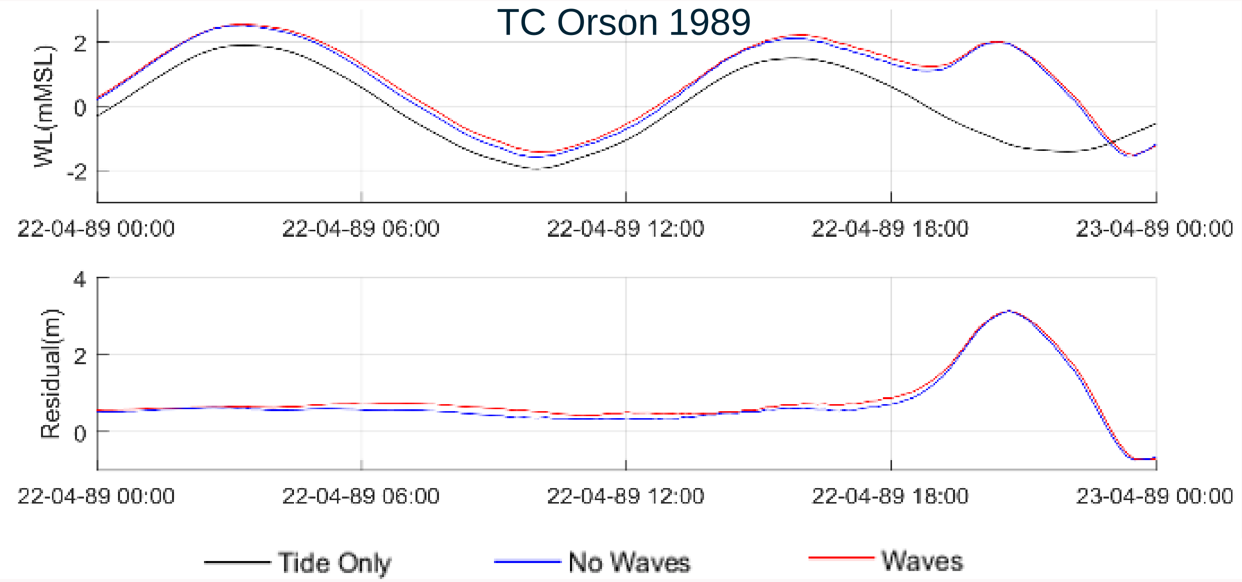
TC Orson 1989 - modelled water level for dynamic tide and fixed tide.

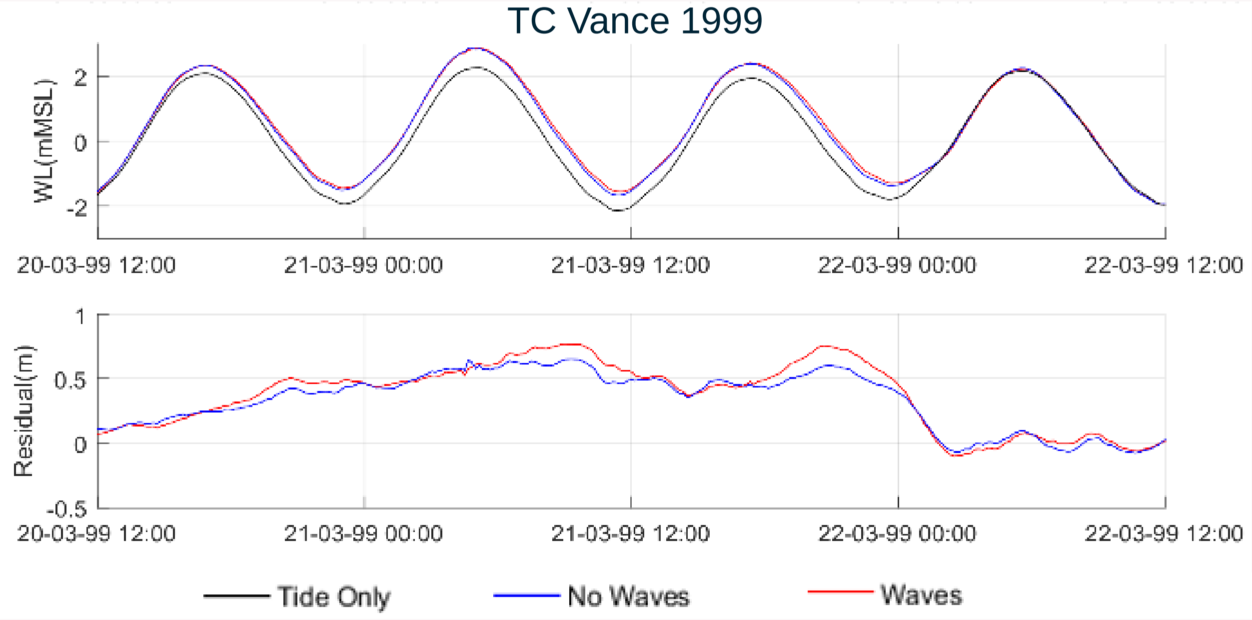
Cyclone Name	Residual Peak		Water level Peak	
	Dynamic	Fixed	Dynamic	Fixed
Orson 1989	3.37	3.31	2.26	2.18
Vance 1999	0.66	0.74	2.78	2.58
Olwyn 2015	0.43	0.40	1.82	1.83

Sensitivity – Joint Waves

- Joint wave simulations modelled for the cyclones affecting Mermaid Sound, via a Delft3D Flow-Wave-Flow model consistent with DFLOW model
- Storm surge levels are increased through the lower ebb tide, however at the higher water level there is negligible difference

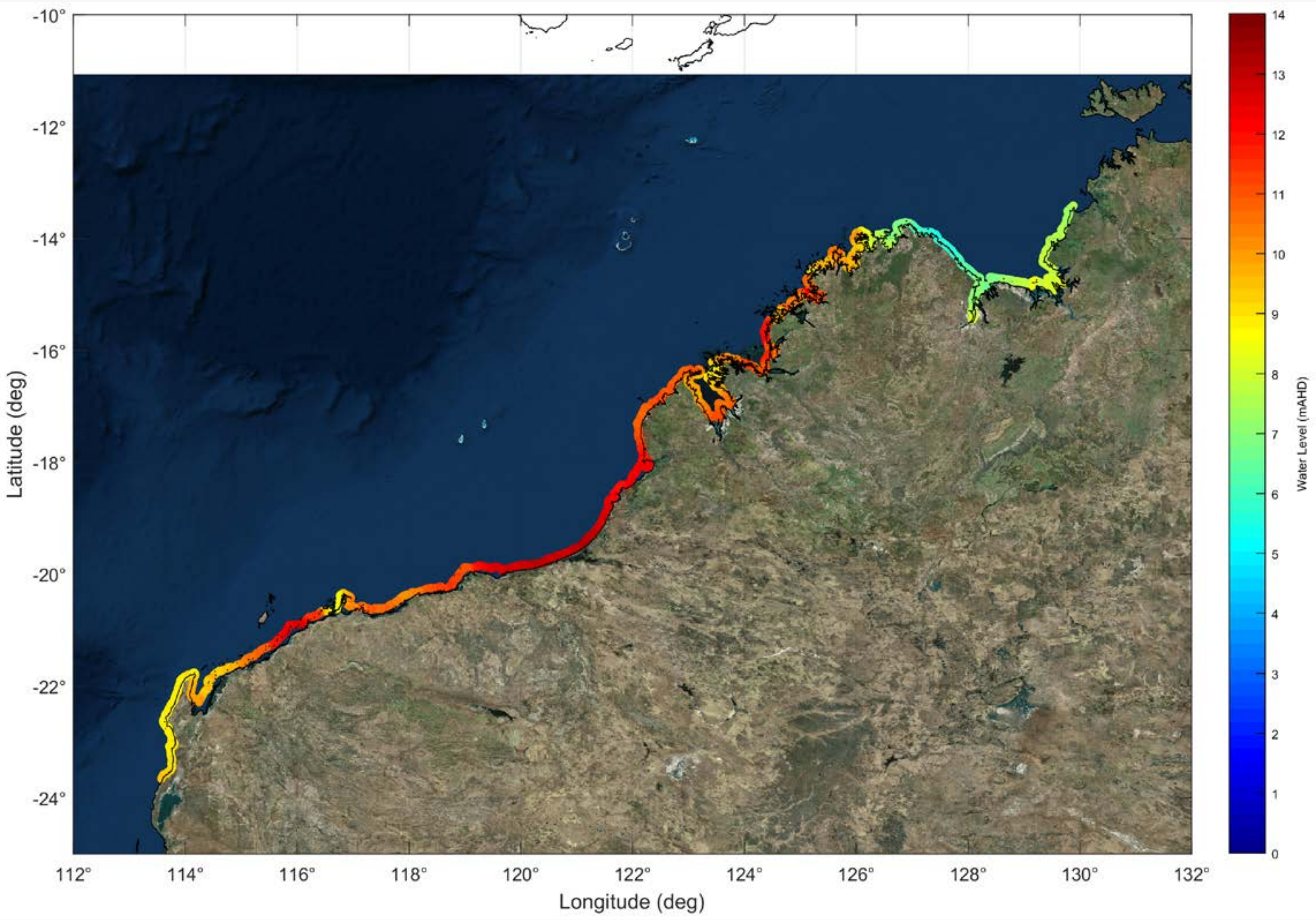






Conclusions

- D-FM Flow model developed for the northwest Australia region validated to astronomical tide and historical storm surge events
- Model adopted for over 28,000 synthetic cyclone cases to develop estimates of long term storm tide for the region.
- Results have been applied to determine storm surge inundation risk
- Applications such as coastal planning and infrastructure hazard assessment.
- Investigations of model sensitivities on storm surge for
    - wind shear stress,
    - dynamic tide vs fixed tide level (MSL).
    - joint occurrence wave conditions



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