National Scale Multi-Hazard Model Platform for Extreme Cyclone Impacts on Coasts and Infrastructure

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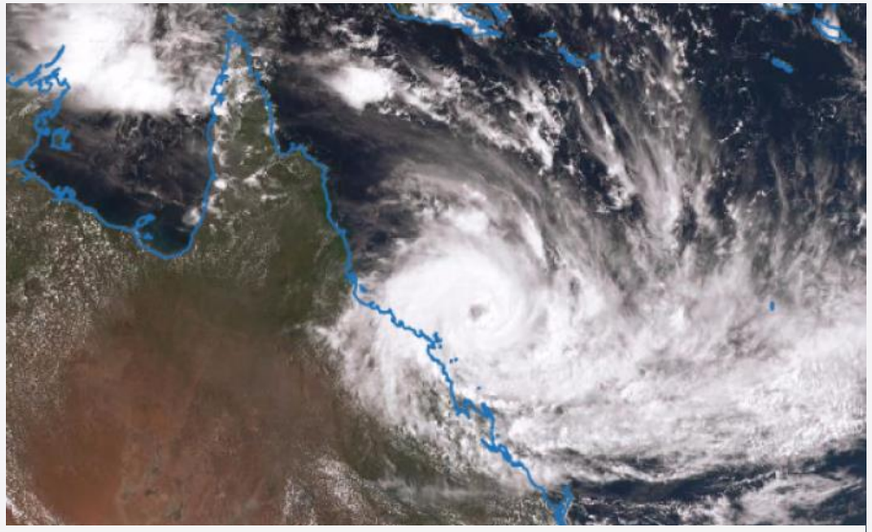
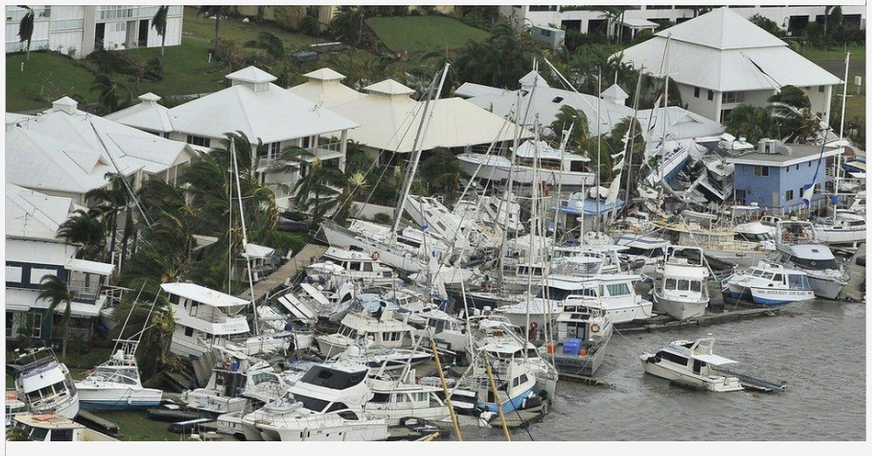
Presentation Outline

- Project Background
- Model System Framework
- Model Components
  - Synthetic cyclone tracks
  - Wind
  - Tide and storm surge
  - Inundation and hazard assessment
  - Rainfall
- Australian Cyclonic Storm Tide Hazard Dataset
- Latest Model Developments



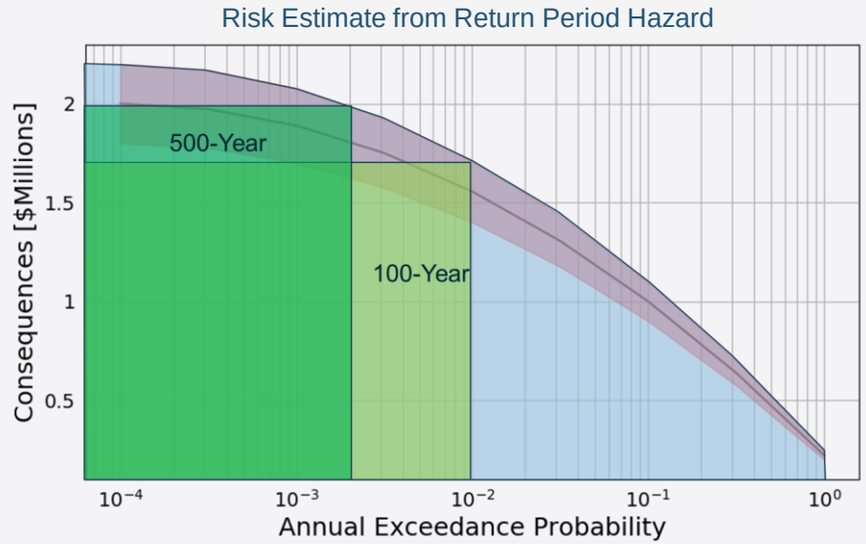
TC Debbie satellite image. Source: Bureau of Meteorology

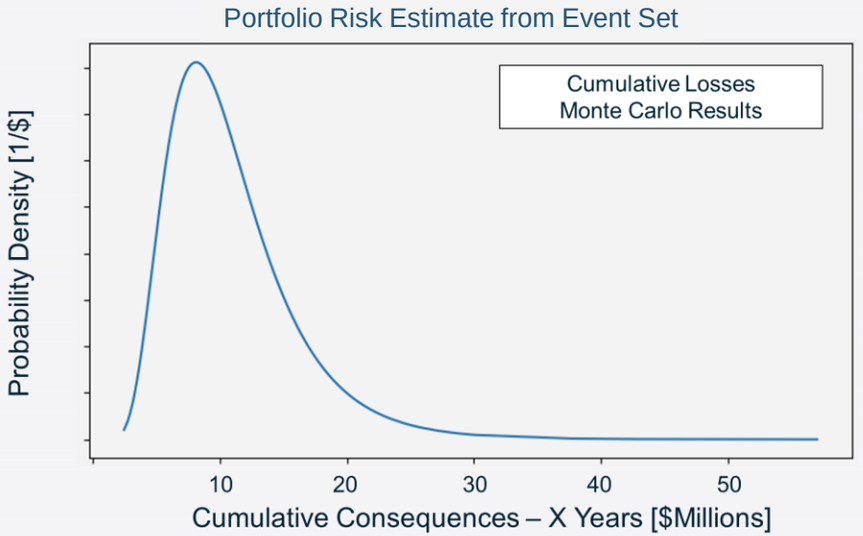


TC Yasi Impact Port Hinchinbrook Marina, Cardwell. Source: BBC

Project Background and Model Drivers

- Fundamental gap in quality of data and methods between:
  - Local/Regional scale high-resolution hazard assessments
  - Large scale hazard data sets
- Large scale cyclone hazard data sets had numerous problems
  - Australia's 3 major insurance companies have exceeded their natural catastrophe loss provisions between 8 and 9 years out of the last 10-years[1]
- Project Objective
  - *Approach coastal zone catastrophe modeling using coastal engineering and applied science methods*

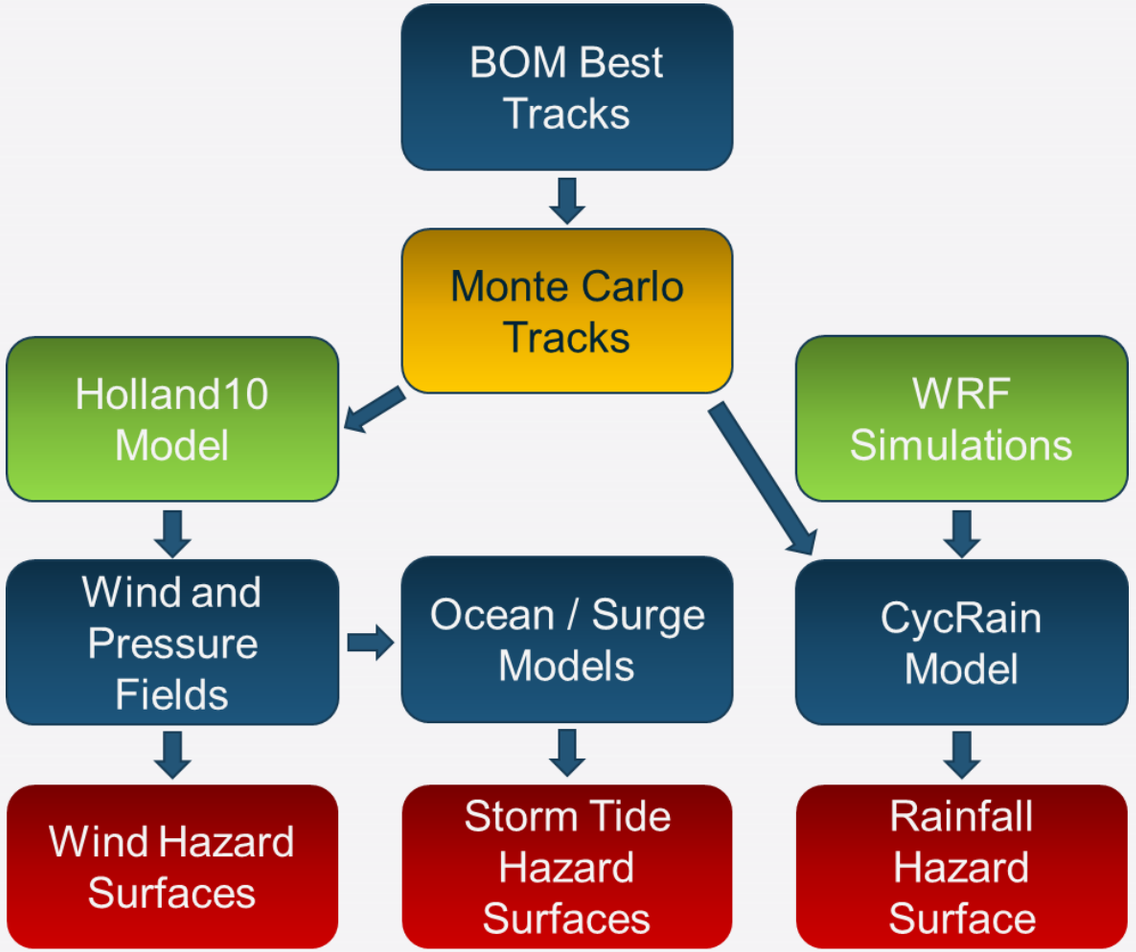




1. Source: SMH 2 Feb. 2017

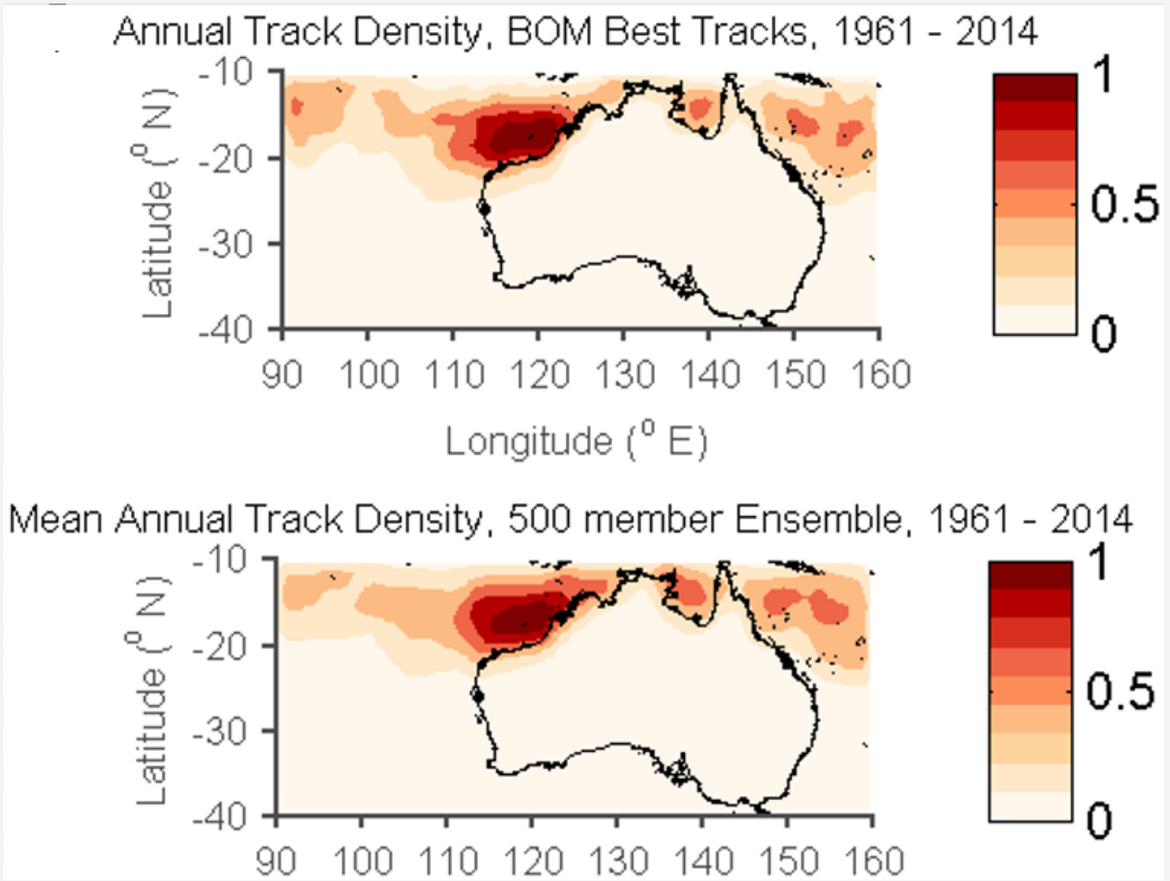
Model System: Overview

- Synthetic cyclone track model is key component of the system
- Common track data set applied across all model components to provide event based data of winds, storm tide inundation and rainfall
- Focus on adopting open source process models coupled with Baird's synthetic track model system



Model System: Synthetic Track Model

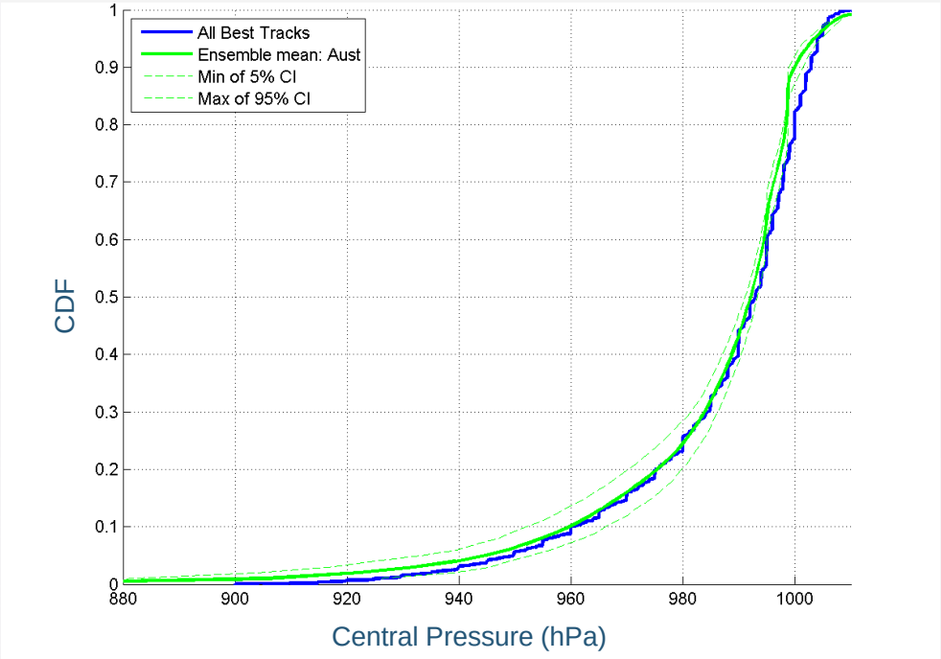
- Random walk model with conditional probability functions to simulate the evolution of cyclone tracks in time and space
  - Source terms are conditional rates of change in speed, heading and central pressure
- Model domain can cover entire cyclone basins
- Methods outlined in Taylor *et al* (2009) and Burston *et al* (2015)



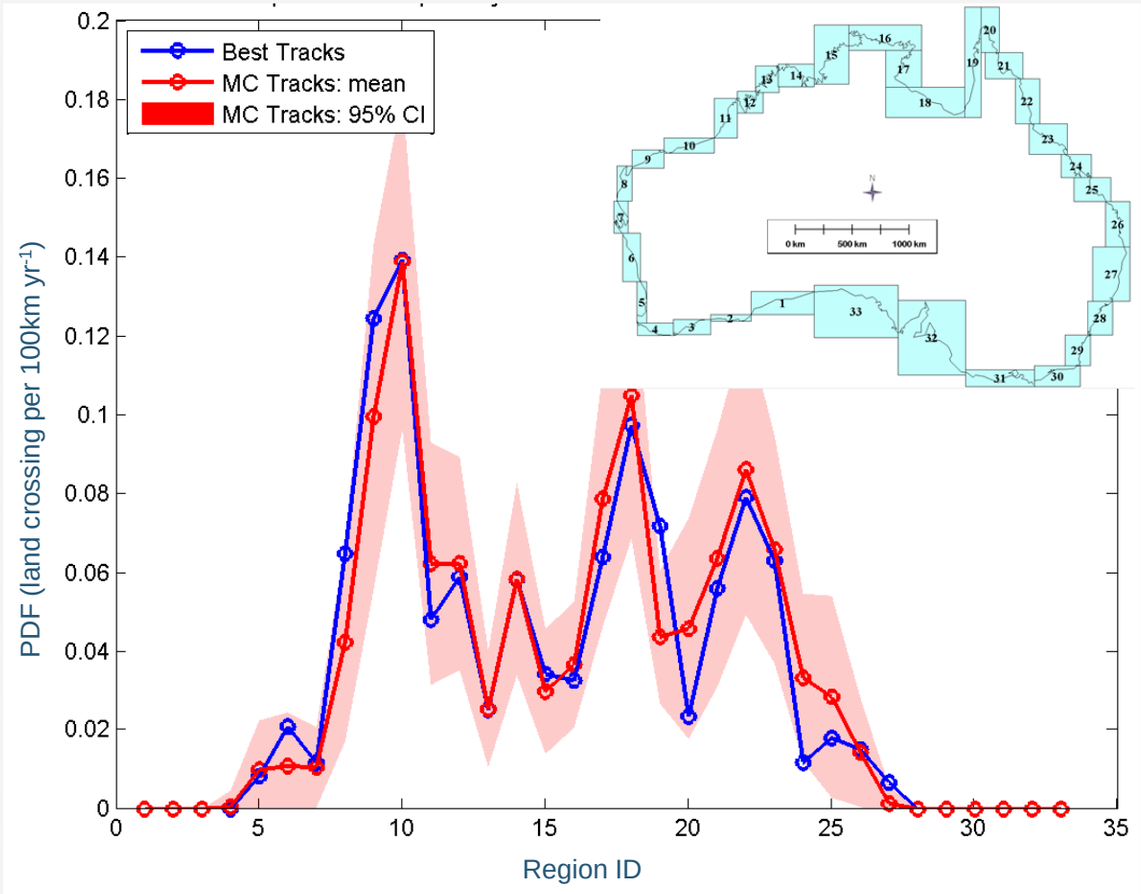
Model System: Synthetic Track Model Validation

- Model validation focused on independent variables that are not source terms

Best Track and Modeled Central Pressure



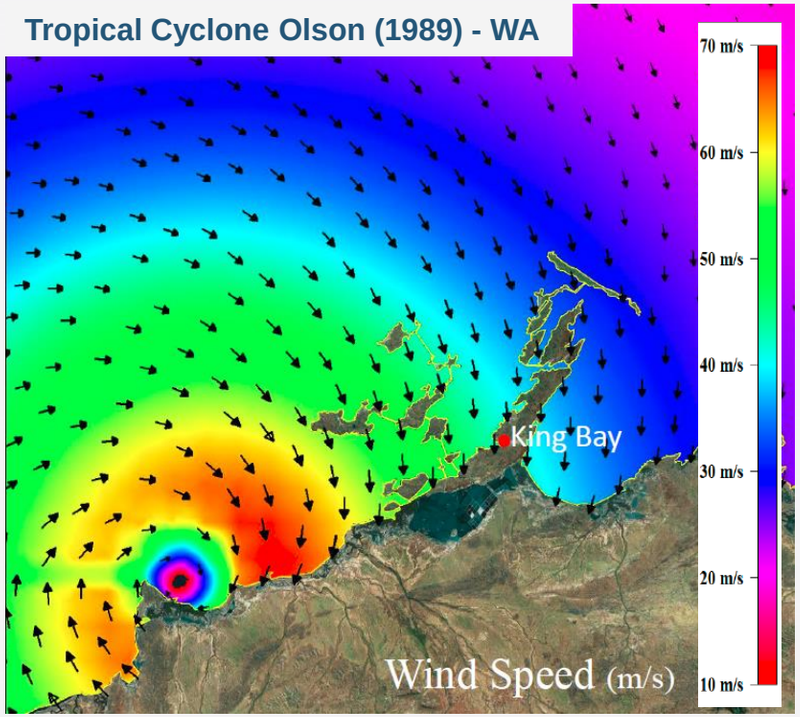
Frequency of Cyclone Landfall by Region



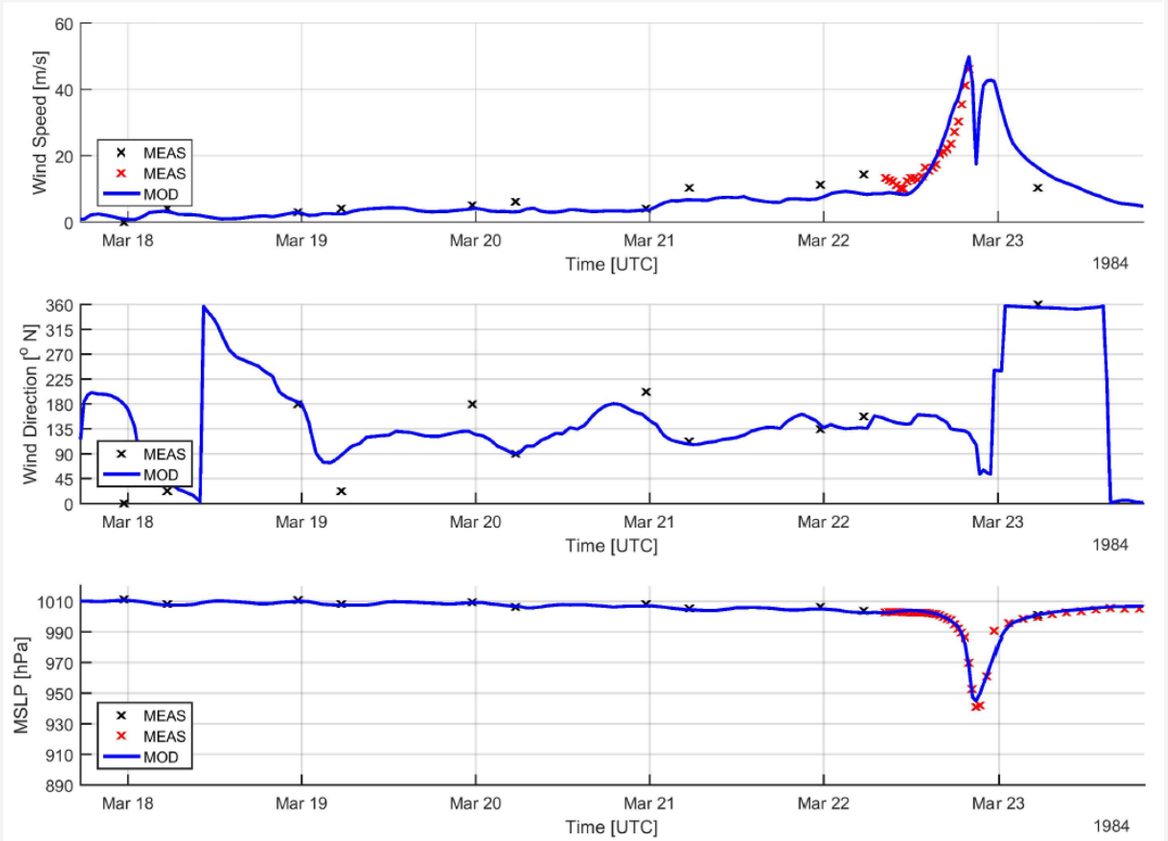
Model System: Parametric Wind Model

- Holland (2010) model including forward asymmetry and radius to gale force winds (R34)
- Inland decay and land friction accounted with parametric functions
- Model validated against long term wind measurements at key sites and Australian Wind Code (AS/NZS1170.2:2011)

Tropical Cyclone Olson (1989) - WA



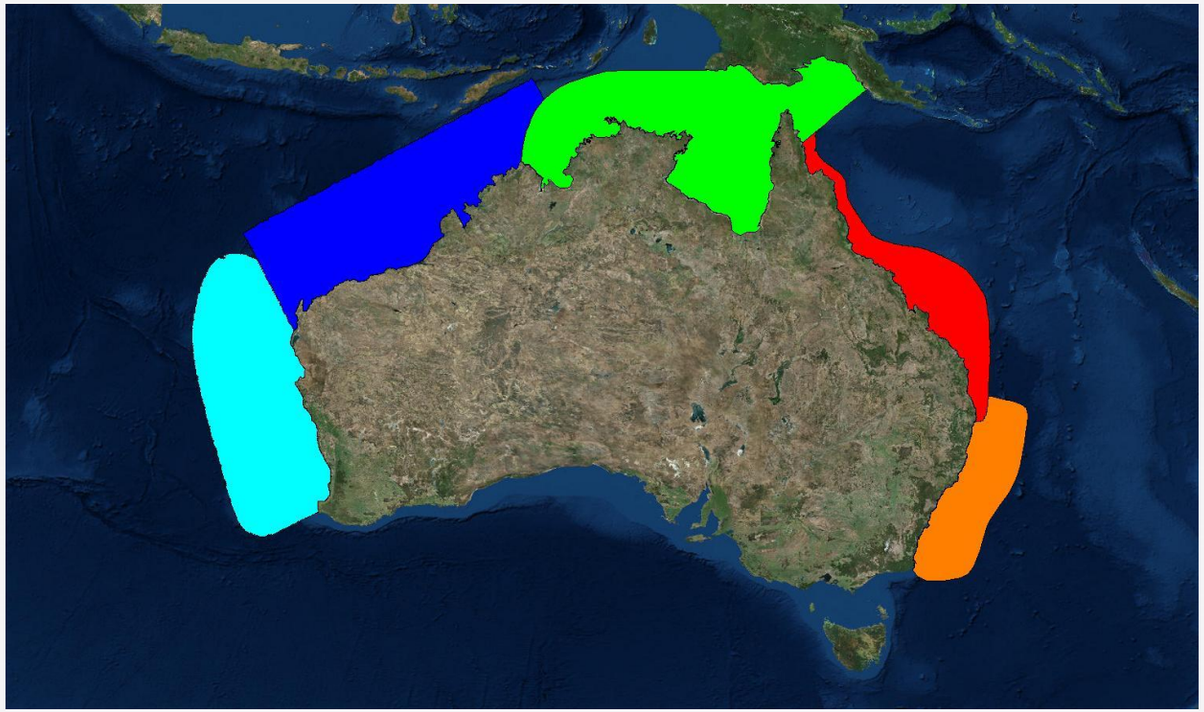
Tropical Cyclone Kathy (1984) - NT



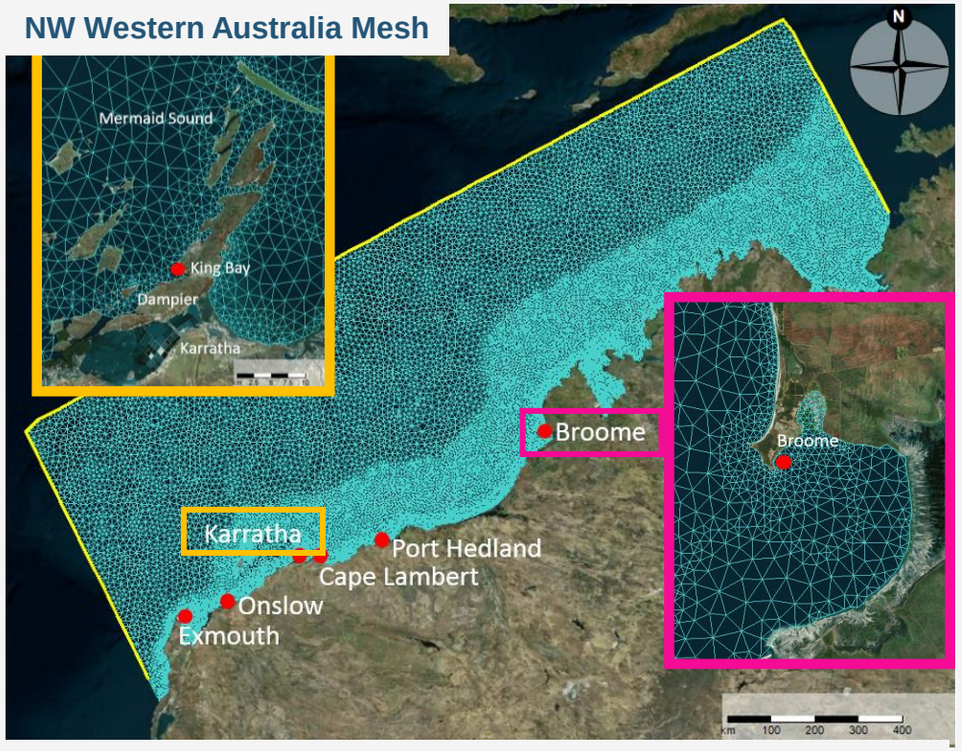
Model System: Tide and Storm Surge Model

- Integrated Delft-FM models

Delft FM Model System – Australian Cyclone Region



NW Western Australia Mesh

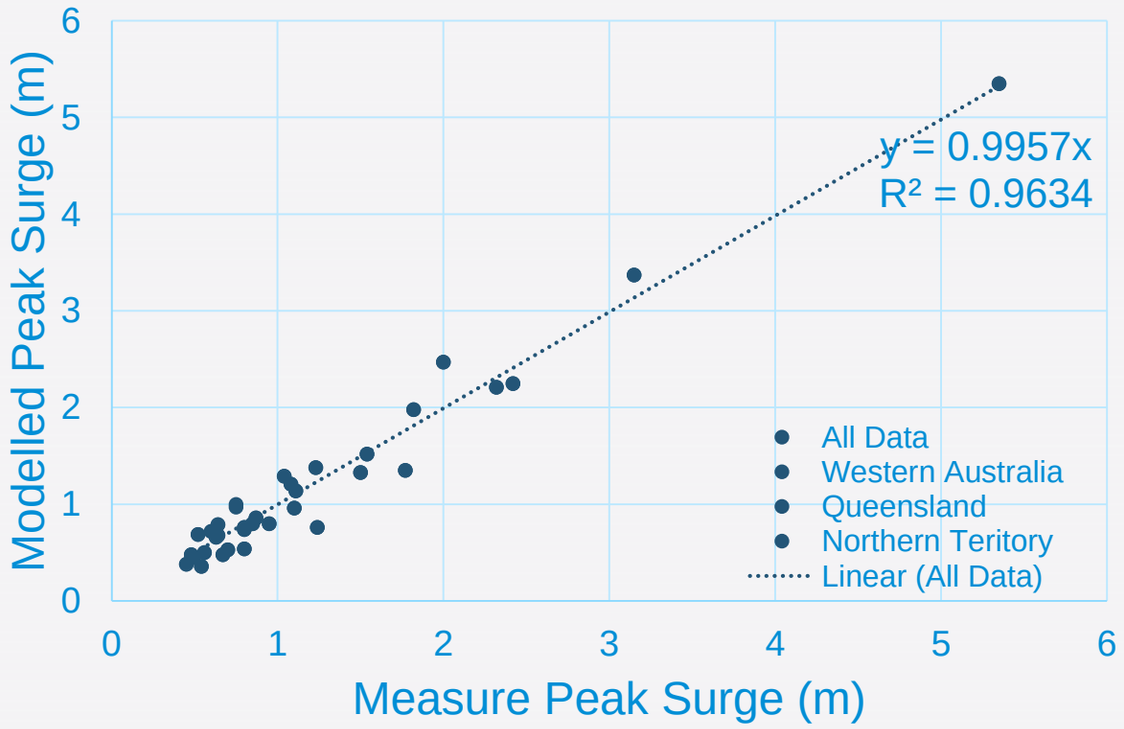


Tide Validation Metrics – 48 Standard and Secondary Ports

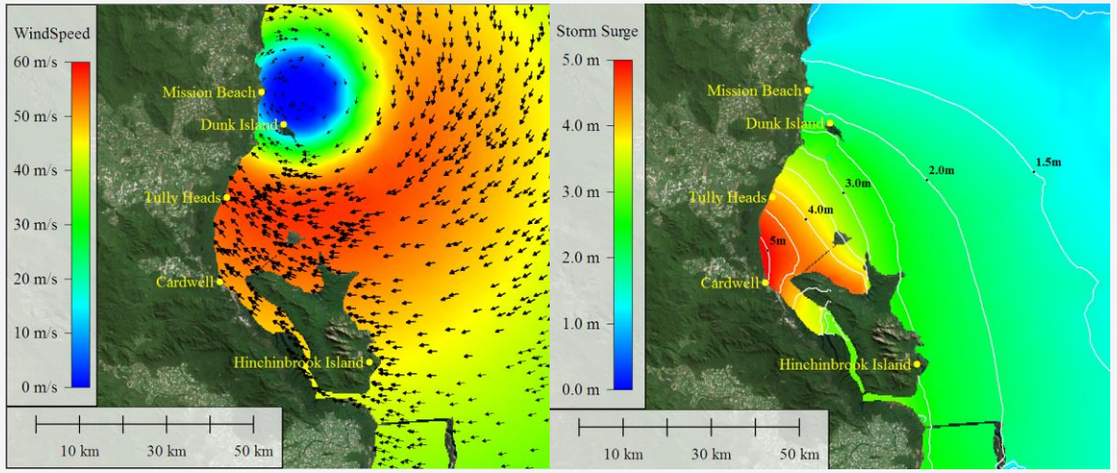
Sites = 48	Bias (m)	Model Skill	RMSE (m)
Mean	0.00	0.99	0.11
Std.	0.02	0.01	0.11
5%	-0.01	0.98	0.02
50%	0.00	1.00	0.08
95%	0.03	1.00	0.31

Model System: Storm Surge Model Validation

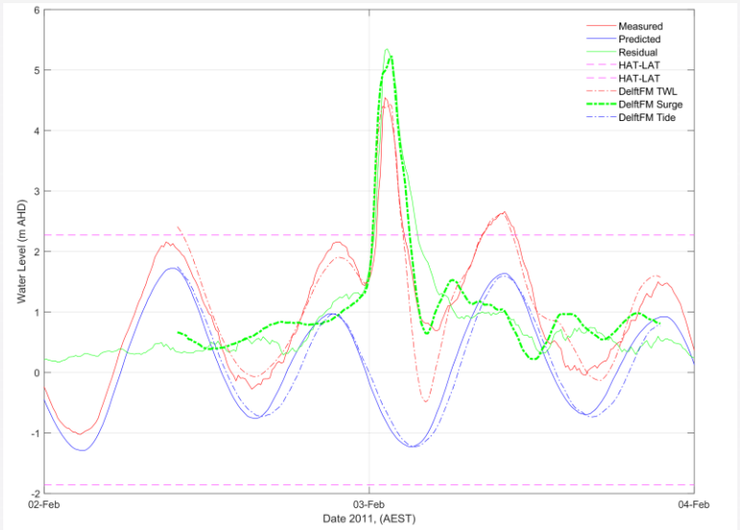
- Storm surge validated against available gauge data for over 30 events
- Wind drag coefficients at low wind speed examined – see Churchill *et al* (2017)



TC Yasi – Modeled Wind and Storm Surge

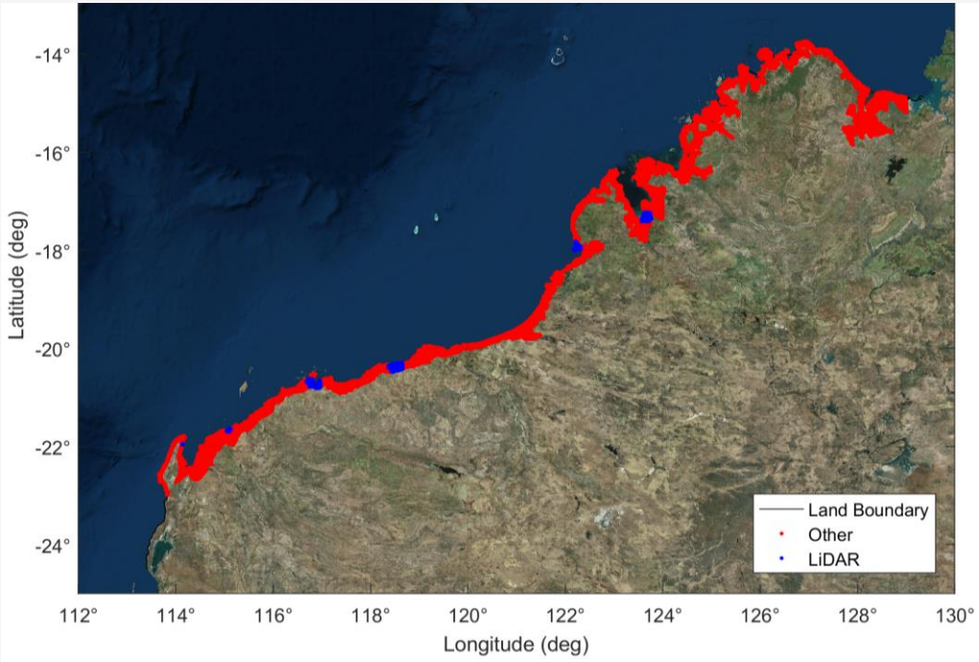


Cardwell Modeled and Measured Storm Tide and Surge

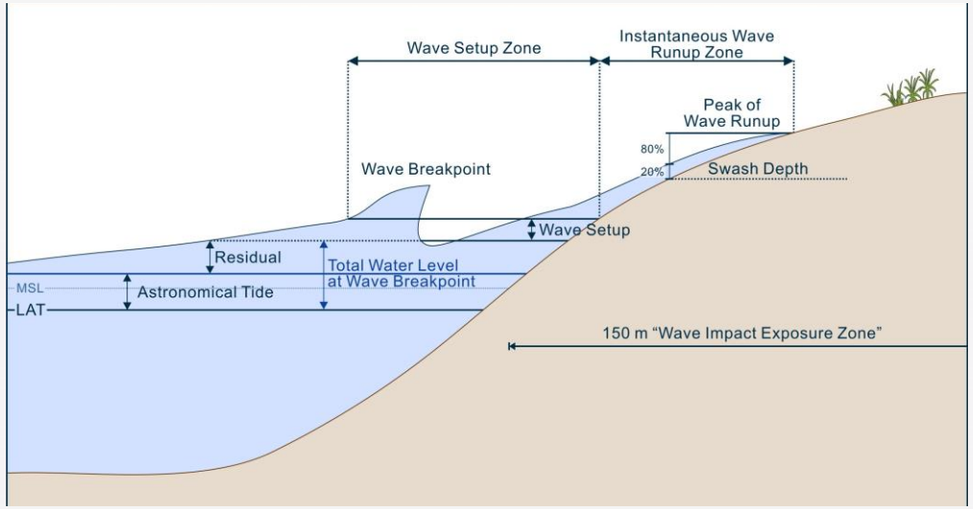


Model System: Inundation

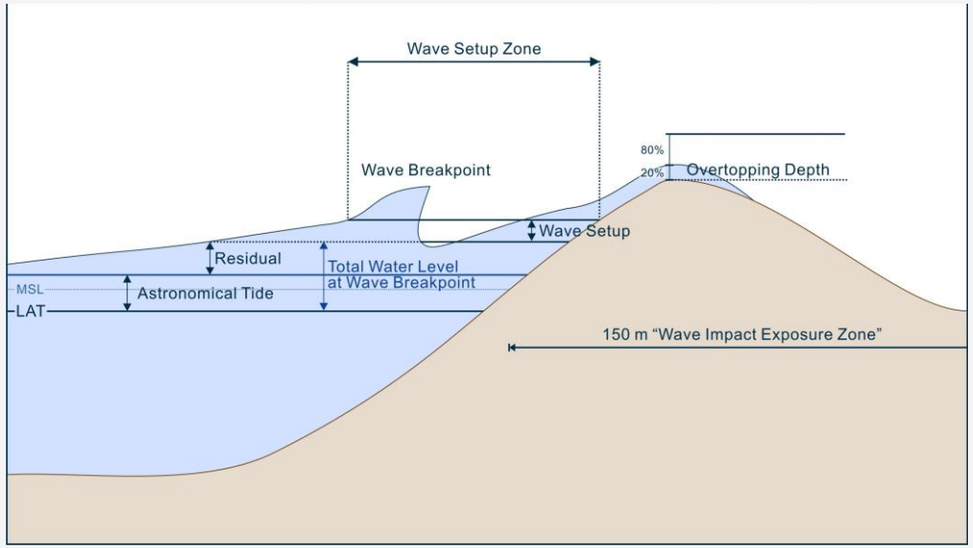
- GIS based solution which accounts for hydro-connectivity to the ocean
- 20 m resolution DEM developed across the whole of model area – LiDAR data covers most populated areas
  - ≈ 235 million points in DEM
- Wave contribution added to areas exposed to open coast



Swash Model – Full Dune



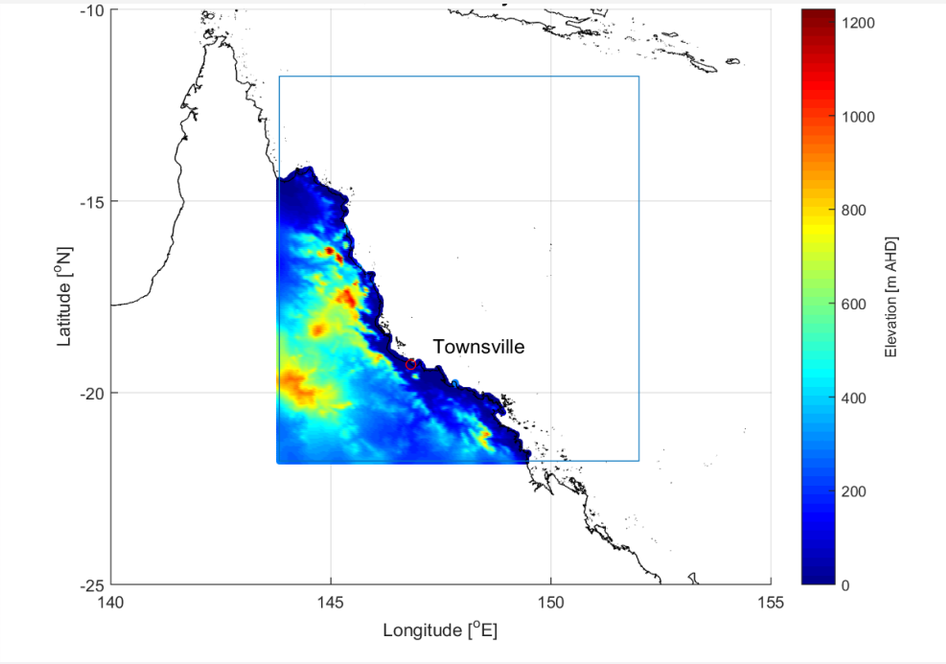
Swash Model – Overtopped Dune



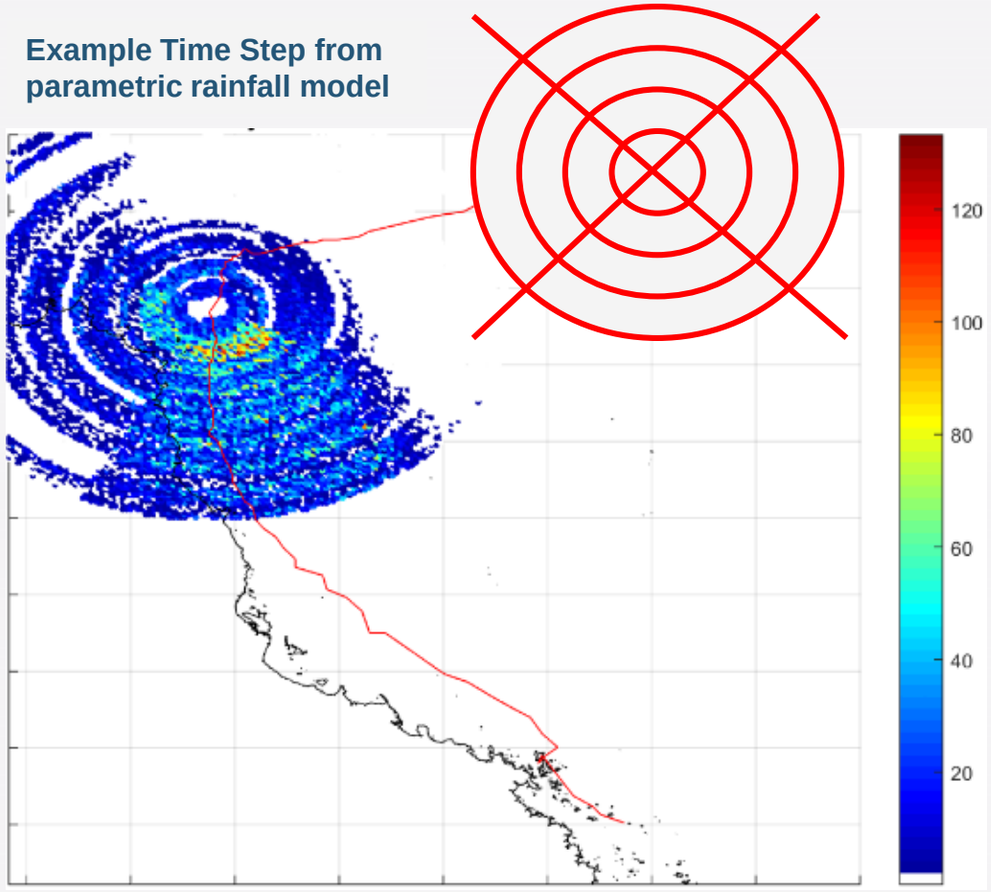
Model System: Rainfall

- Combined effects of rainfall run-off and elevated ocean water levels can significantly amplify flood impacts
- Parametric cyclone rainfall model for North Queensland (Burston et al, 2017) developed from hindcast WRF model data

North Queensland Rainfall Model Domain



Example Time Step from parametric rainfall model

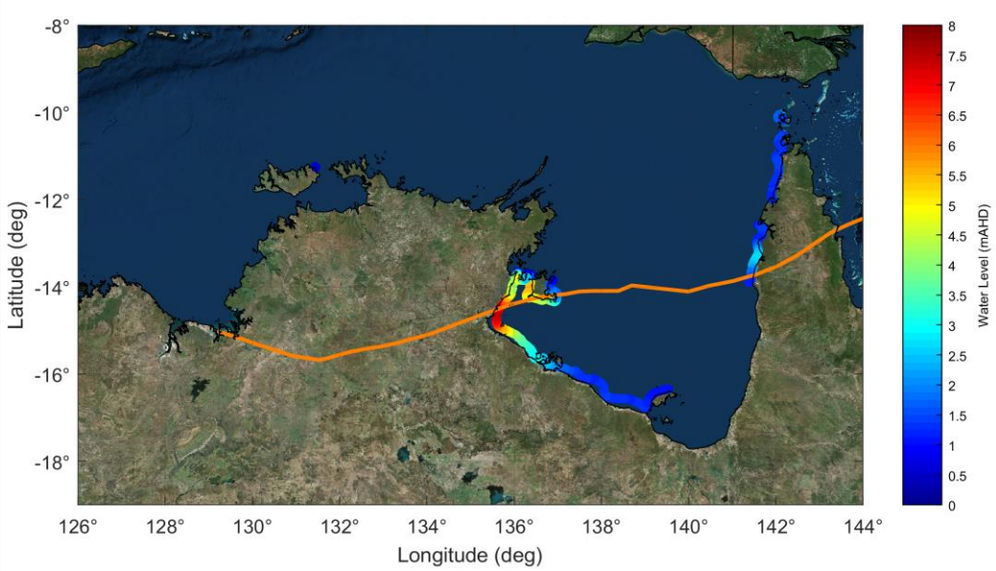


Model Validation	Peak Rainfall Intensity Ratio – Model: Australian Rainfall and Runoff			
ARI (yr)	10	20	50	100
Mean Ratio (8 sites)	1.05	0.98	0.94	0.93
Std. Dev	0.42	0.39	0.37	0.36

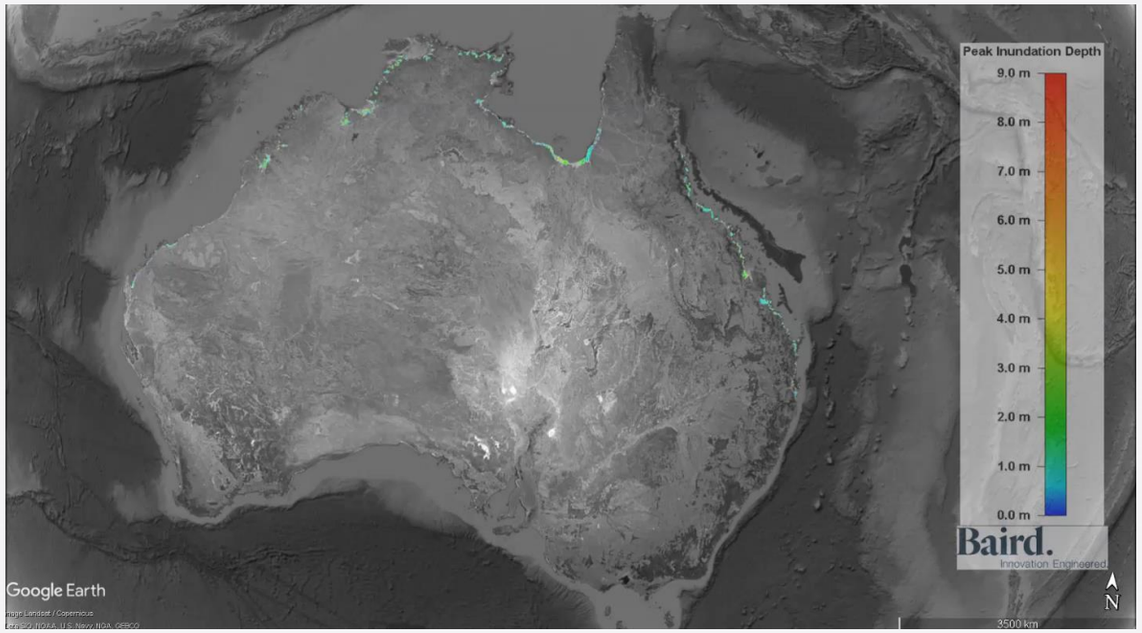
Australian Cyclonic Storm Tide Hazard Dataset

- Computed from simulation of ≈ 85,000 discrete events
- 10,000 year event set with spatial time series for all events:
  - Inundation extents and flood depths for events exceeding HAT
  - Data compiled into a range of data formats
  - Storm tide hazard estimates benchmarked against local hazard studies at 32 sites

Example TC Event Set Data

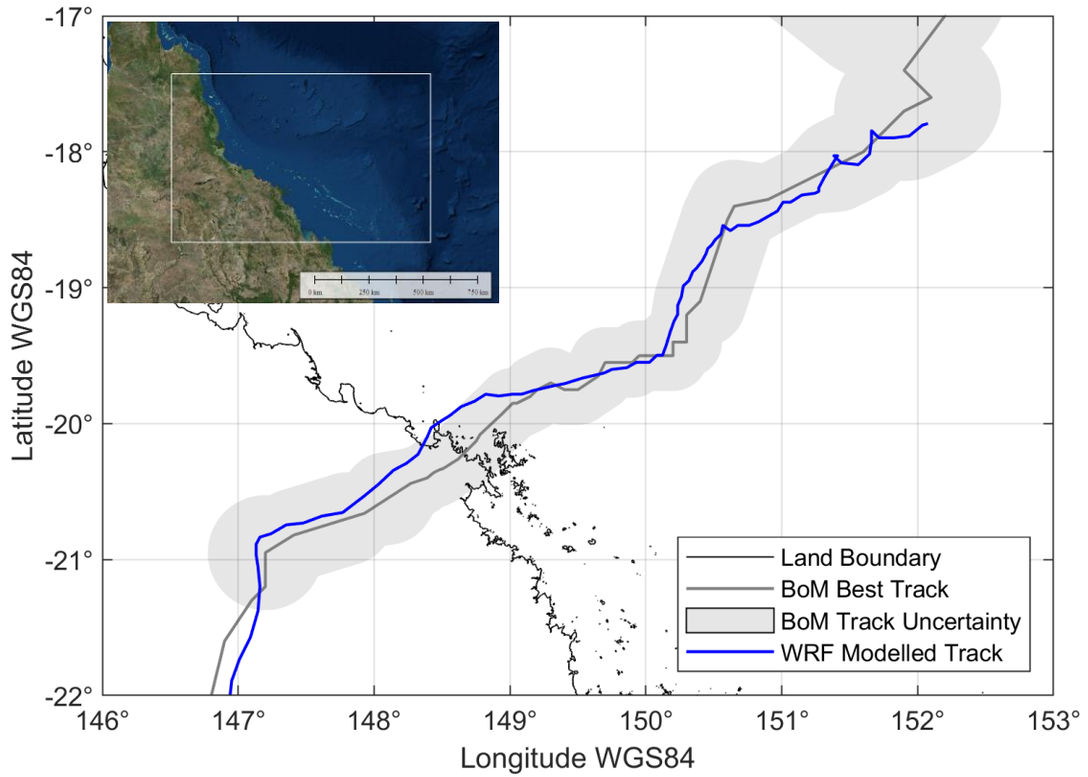


500-year ARI Inundation – Cairns, Darwin & Port Hedland

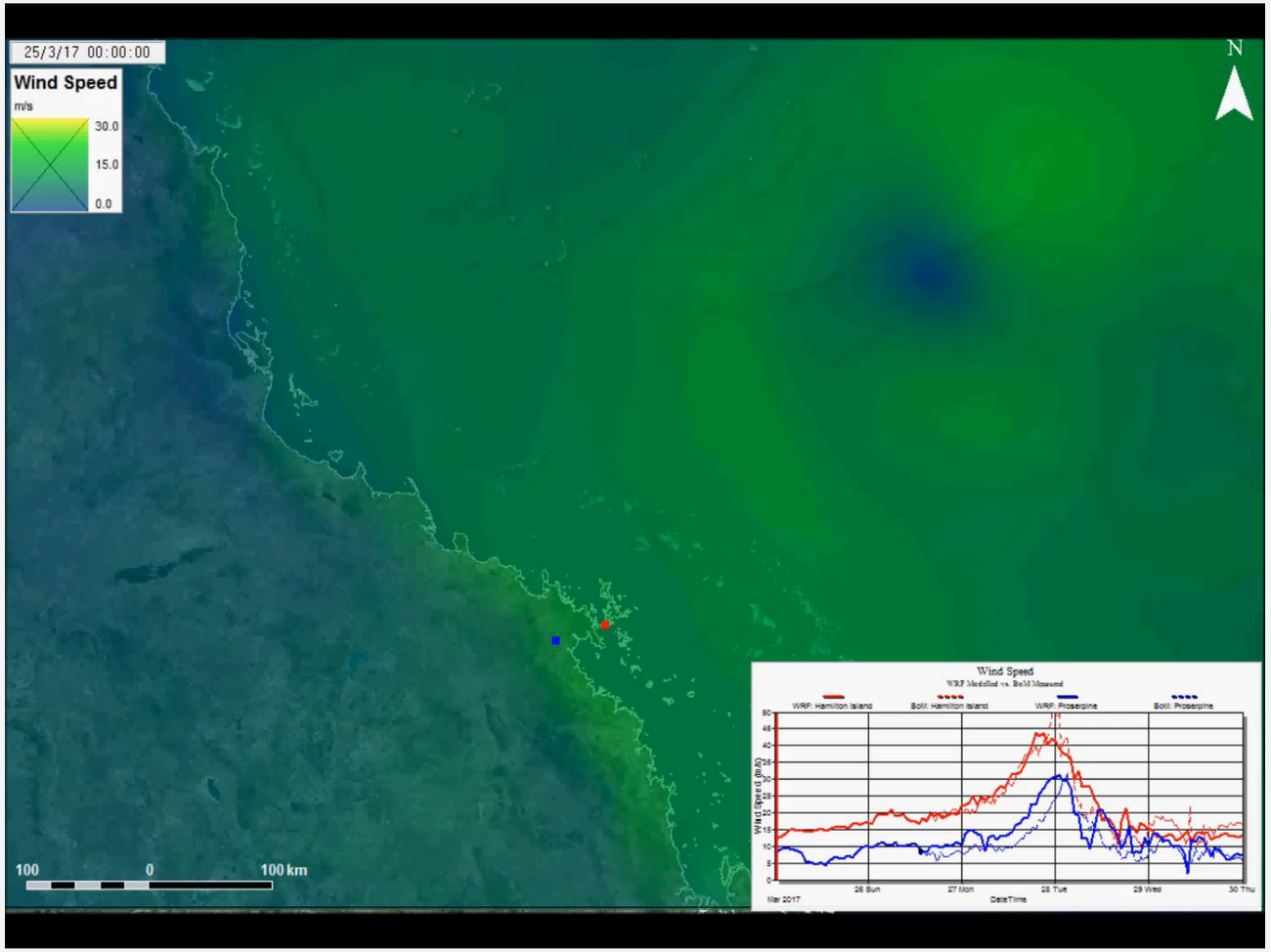


Latest Developments: Atmospheric Modeling of Cyclone Winds

- Parametric cyclone wind model have limitations, particularly when cyclones interact with land
- Example WRF Simulation TC Debbie (2017)
  - Spatial Resolution: 4km
  - Vertical Resolution: 36 Vertical Layers
  - Boundary Forcing: ERA5 (hourly)
  - Sea-Surface Temperature: ERA5 (hourly)
  - Microphysics: WSM 6-class graupel scheme
  - Planetary Boundary Layer: YSU Scheme



Tropical Cyclone Debbie (2017) – Modeled and Measured Wind



Latest Developments: Coupled Storm Tide and Rainfall Inundation

- Severe inundation impacts often from combined effects of local rainfall in addition to elevated ocean water levels
- Coupled storm tide and rainfall model developed for North Queensland using TELEMAC-SS model presented in Kelly *et al* (2018)

Cairns Mesh

Inundation from Storm Tide and Rainfall - Cairns

Summary and Conclusions

- A large scale multi-hazard cyclone model system has been demonstrated on a national scale
- Validation completed for all components of the model
  - Storm tide hazard estimates benchmarked against a large sample of local and regional storm tide studies
- Data set has been adopted for regional hazard planning and insurance pricing
  - Also adopted as input data for local scale hazard and engineering studies
- Further development areas:
  - Climate change impacts
  - Hydraulic modeling of inundation from ocean inundation and rainfall
  - Process based wind and/or atmospheric modeling to address limitations of parametric models

Darwin Inundation Depth Hazard – 500 yr ARI

References

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