The 1921 Shark Bay Tropical Cyclone: Understanding the Extreme Storm Surge and its Implications

https://www.sharkbayvisit.com.au/top-10

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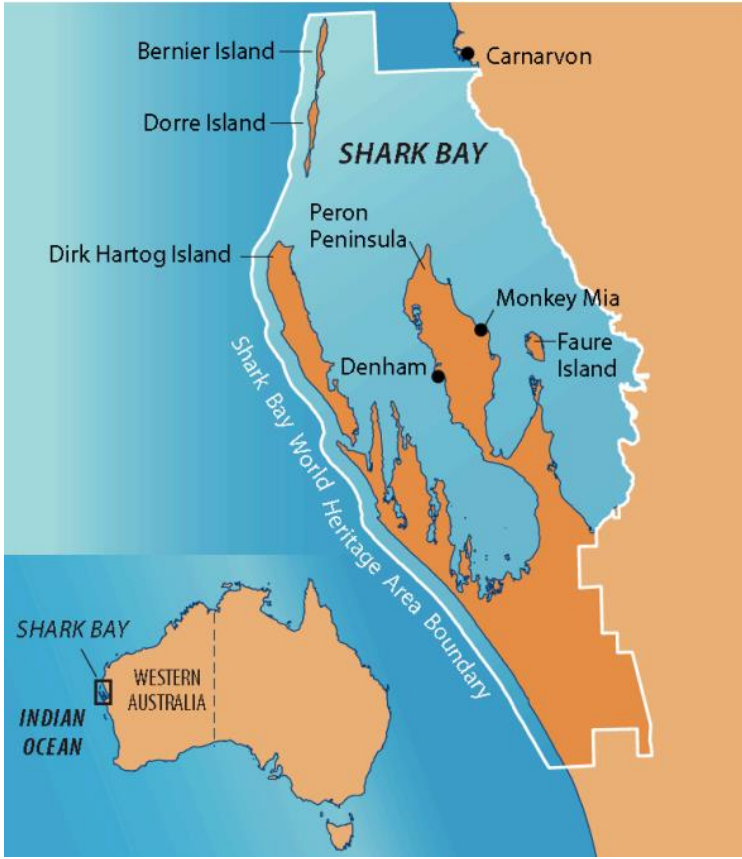
Baird.
Innovation Engineered.

Overview

- Motivation
  - About Shark Bay
- Historical Evidence
- Modelling
- Implications for Risk Management



https://www.sharkbay.org/publications/brochuresmaps/Map

Motivation - Paleoreconstruction

- Combine multidisciplinary knowledge to construct multiple lines of evidence for risk
- Uncover expanded data source to test our assumptions
- Explore the possible beyond known datasets

Shark Bay

World Heritage Area: world's most diverse seagrass assemblage

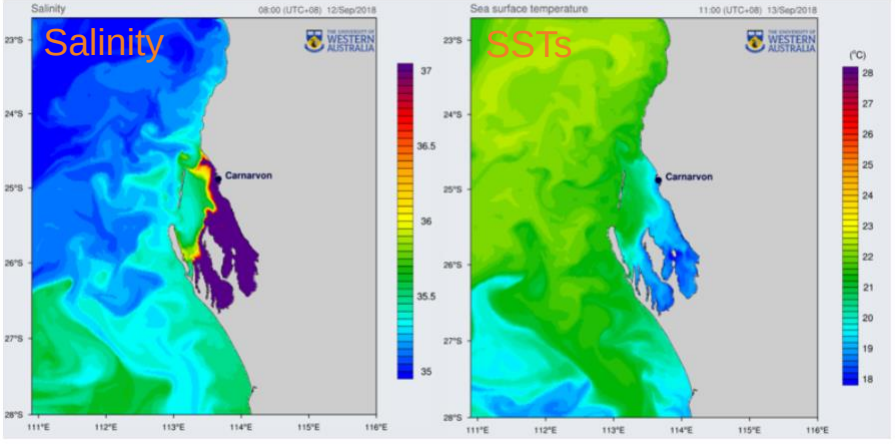
- Dugongs, dolphins, turtles, stromatolites
- Tourism
- Commercial fishery

Already threatened by rising SSTs

State Library of WA

Physical Environment

- Shallow bathymetry with N-S orientation
- SSTs and salinity affected by the ecosystem
- Tides: mixed diurnal and semi-diurnal
- Extensive coastal plain with sand ridges



Source: WAMSI

Shark Bay Tropical Cyclones: What We Already Know

Shark Bay (26° S) has marginal exposure to TCs

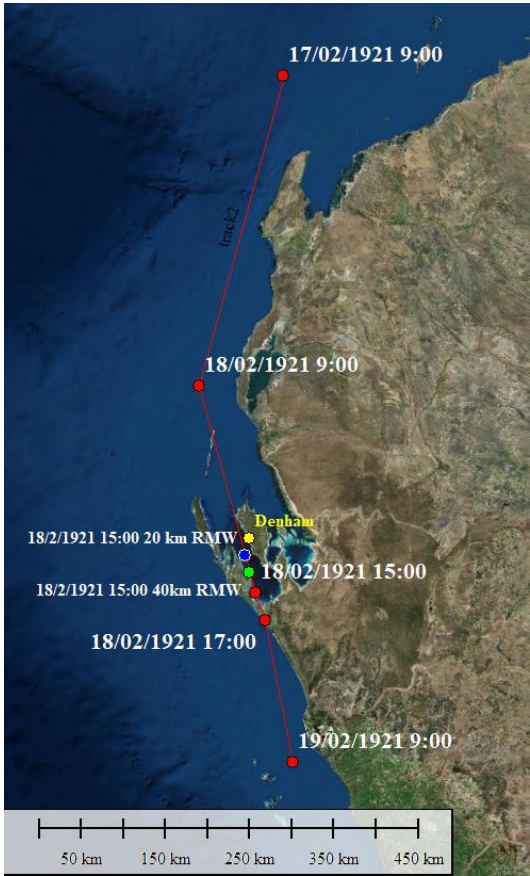
Paleo Evidence: Severe TC frequency of 190 – 270 years over the Holocene, based on parallel shell ridges (Nott 2011).

Recent Events: TC Hazel (1979), TC Herbie (1988)
Storm surge > 2 m at Denham

1921 TC track: BOM archive records a min Pc of 989 hPa
~ Cat 1 - 2

But was it?

1921 TC BOM Best Track: 989 hPa?



1921 Tropical Cyclone: Further Historical Evidence

Coincided with the 1921 Australian Census collection.

Observed Inundation:

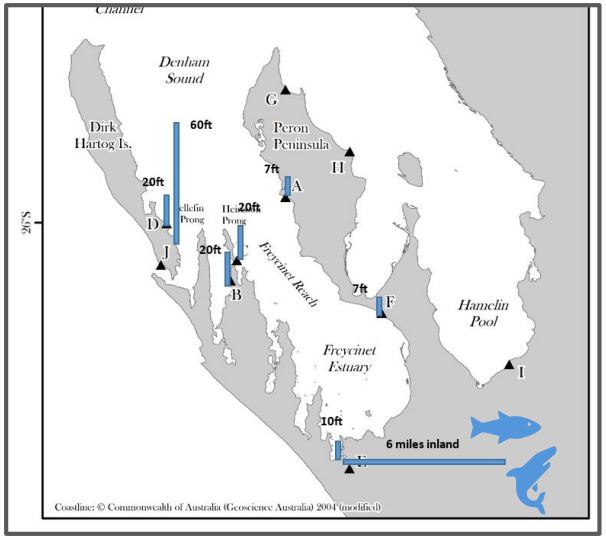
- 2.1 -3.0 m at Denham
- 6.1 m at Useless Inlet
- 2.1 m at the southern end of Freycinet Reach

Overland flow left sharks and fish stranded up to 10 km inland.

Ship groundings, flooding, and altered coastal geomorphology.

Long Lasting Impacts:

- Saltwater inundation of Denham's freshwater wells
- Pearling industry in decline
- Seagrass ecosystem



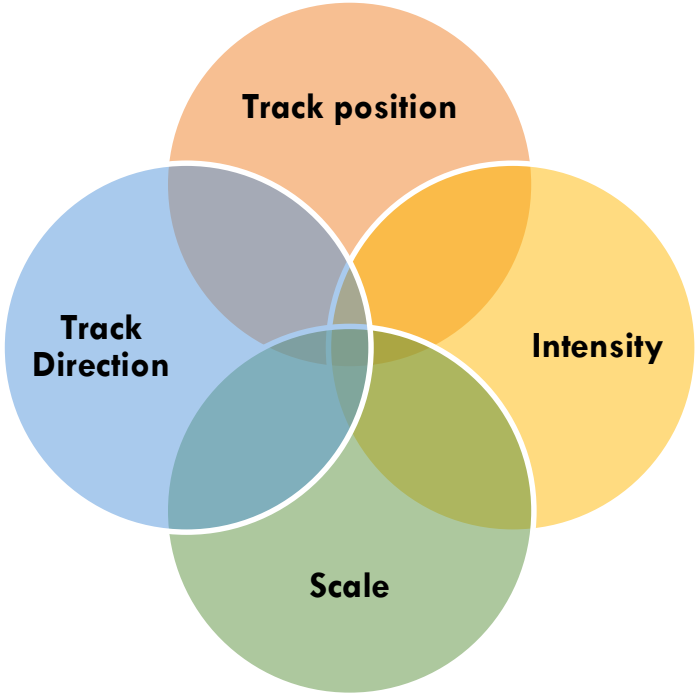
1921 TC: Observed inundation around Shark Bay.

Sources: SROWA, Trove.

1921 Tropical Cyclone: Inverse Modelling Problem

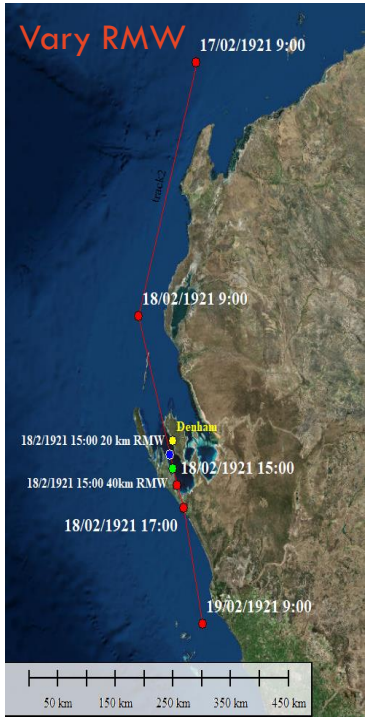
Aims: Given the sensitivity of storm surge to TC track and parameters:

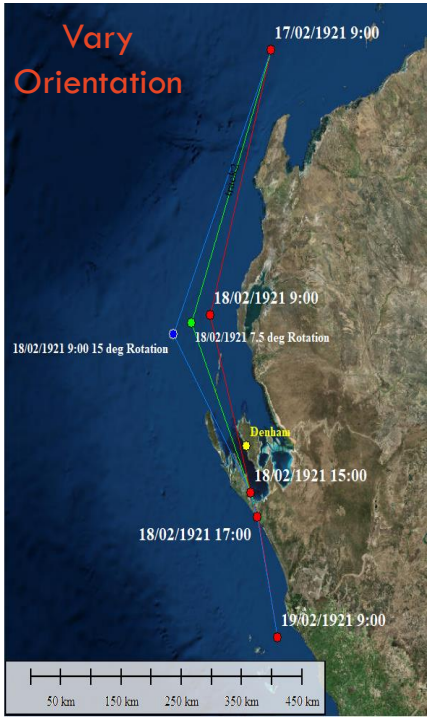
- Can we replicate the historical observations of elevated water levels and inundation?
- What is the likely set of TC track and parameters that resulted in the historical inundation observations?
- What does this tell us about the likely intensity/category of the 1921 TC?

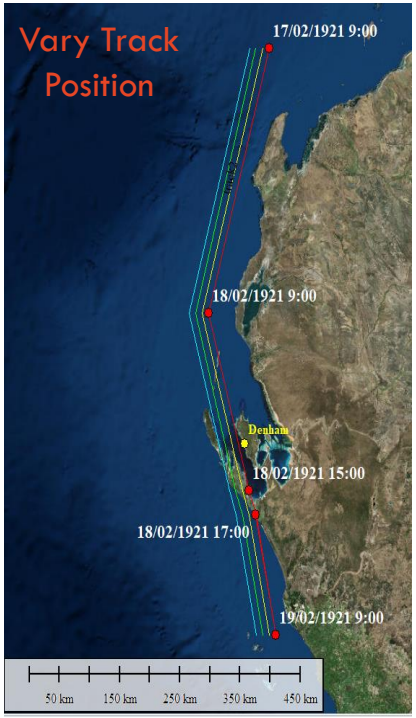


1921 TC: Numerical Modelling Approach

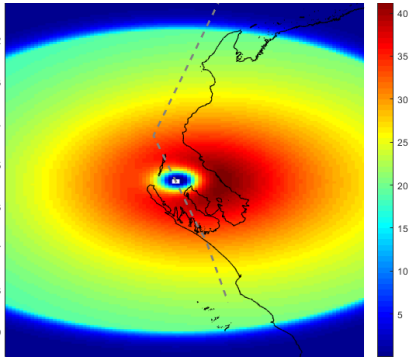
225 model runs varying the BOM Best Track using cyclonic parametric wind speed/pressure model





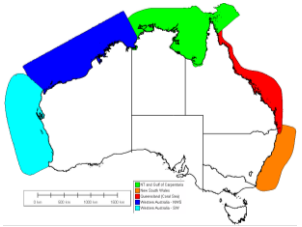


Pc [hPa]	RMW [km]	Orientation at landfall [°N]	Track position [relative to Best Track]
989	65	165	**0**
975	40	172.5	0.1 °W
960	20	180	0.2 °W
945			0.3 °W
930			0.4 °W



1921 TC: Holland (2010) wind field

1921 TC: Ocean Modelling Set-Up

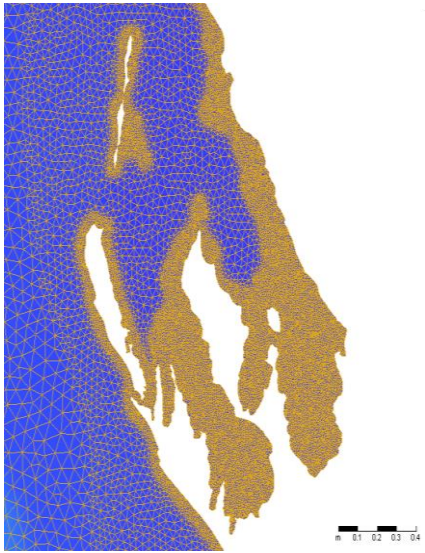


Delft-FM SW WA Australia ocean model (Baird)

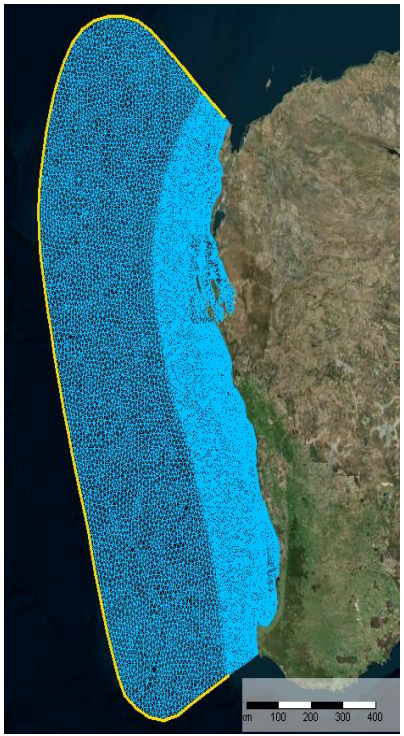
- Unstructured 2D-vertical hydrodynamic model
- **Resolution**: max 1 km bt -10 m contour and coast
- **Bathymetry**: Aust Navy Electronic Navy Charts.
- **Tidal Boundaries**: TOPEX-8 tidal constituents
- **Tidal Calibration**: 9 Standard Ports over 1 yr

  MAE = <0.02 m
- **Storm Surge Validation**: 35 historical TC storm surge events over Australian region, replicating measured peak tidal residuals

  Linear fit = 0.9957 (R^2 = 0.96)
- Ocean waves not considered (yet)



Baird's SW WA Delft-FM ocean model



Burston, J.M., Taylor, D.R., Dent, J.M. & Churchill, J.W. 2017. Australia-wide Tropical Cyclone Multi-hazard Risk Assessment. Proceedings of the Australasian Coasts and Ports Conference, June 2017. Cairns, Australia.

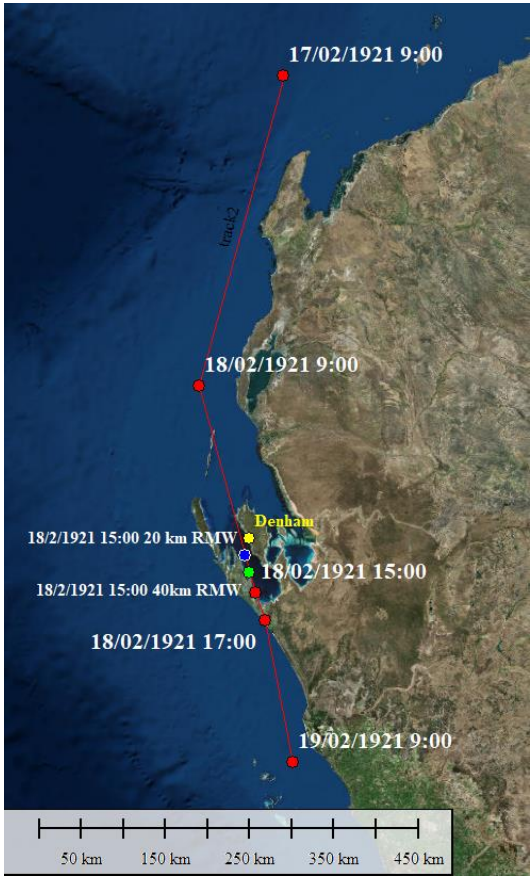
1921 TC: Numerical Modelling Results

BOM Best Track does not replicate observed storm surge

Peak Storm Tide [m AHD]

Location	BOM Best Track	Observation
Denham	0.86 m	2.1 -3.0 m
Point of Landfall	1.28 m	~2.1 m

1921 TC BOM Best Track: 989 hPa?



1921 TC: Numerical Modelling Results – Simulation Set

Marked variability in peak storm surge in response to TC parameters

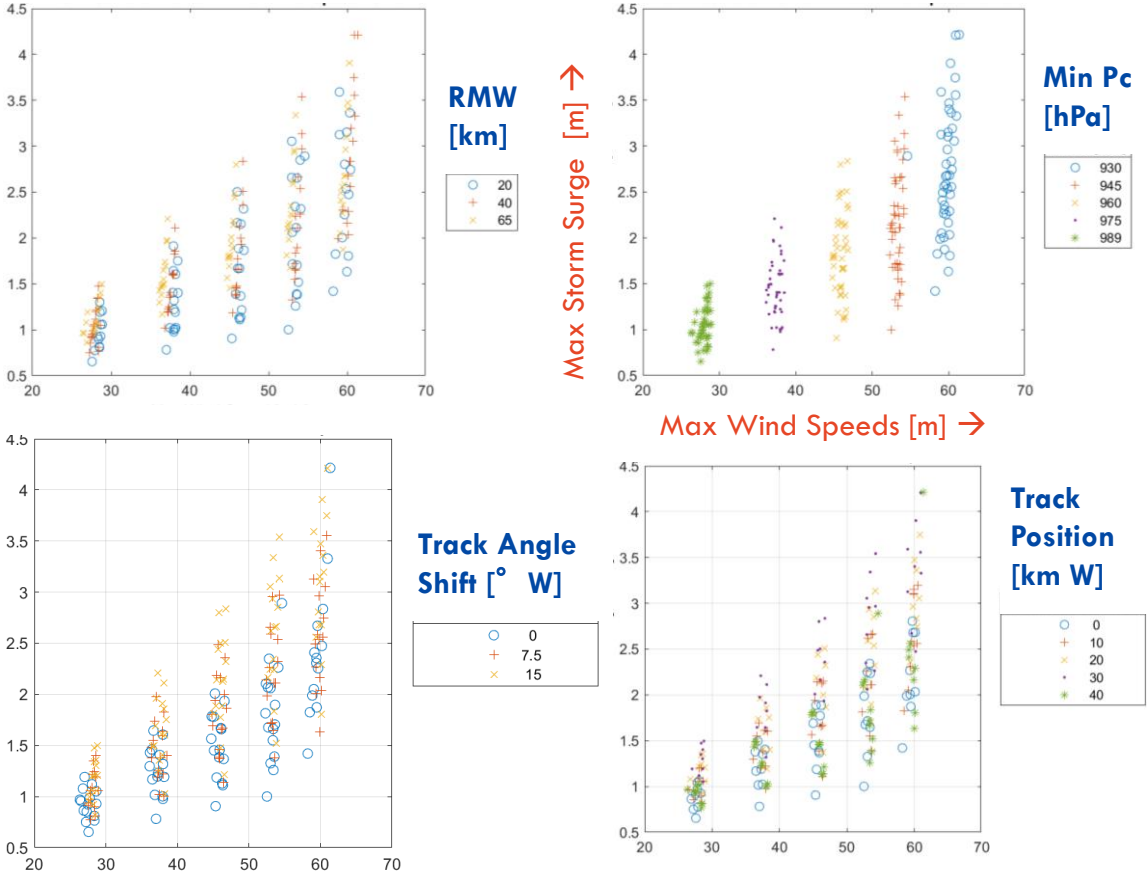
Denham

Among 225 ensemble members:

– ranges from 0.6 to 4.3 m

Even for same Pc (eg 930 hPa):

– Range is 1.4 to 4.3 m



1921 TC: Numerical Modelling Results – Simulation Set

Of the 225 ensemble set:

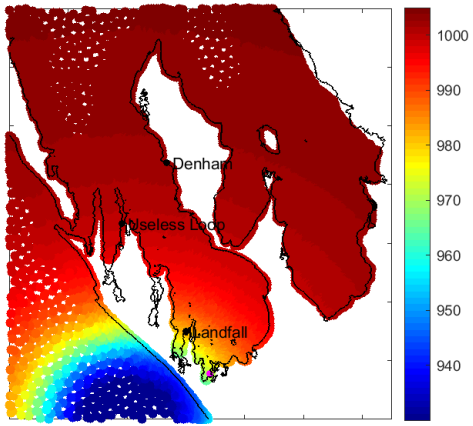
- **29** satisfy the constraints of the historical observations at Denham
  - peak winds from NE and >33 m/s, peak water level at spring tide > 2.1 m
- **5** satisfy the additional constraints of peak storm tide > 4 m at Useless Loop and at the south end of Shark Bay

1921 TC was likely a Cat 4 to marginal Cat 5

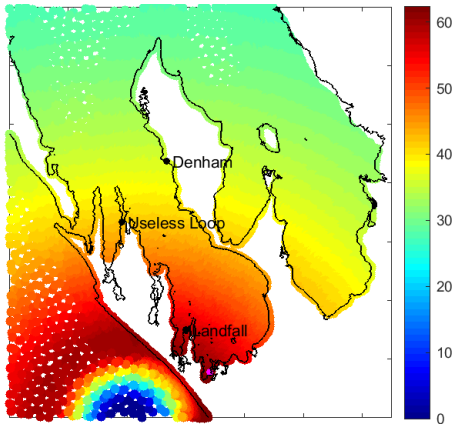
					Peak Surge (m)		
RUNID	Pc (hPa)	Shift (km)	Rotation (deg N)	RMW (km)	Denham	Shark Bay	Useless Loop
115	930	40	15	20	3.3	4.1	5.2
164	945	20	15	30	3.1	4.2	4.3
165	930	20	15	30	3.7	5.0	5.0
180	930	20	7.5	30	3.2	4.5	4.3
195	930	20	0	40	2.5	4.2	6.5

1921 TC: Numerical Modelling Results – Run 180

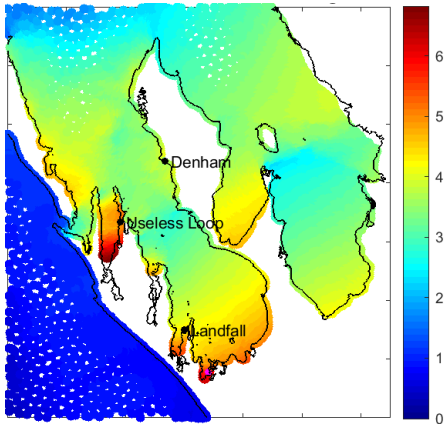
Central Pressure [hPa]



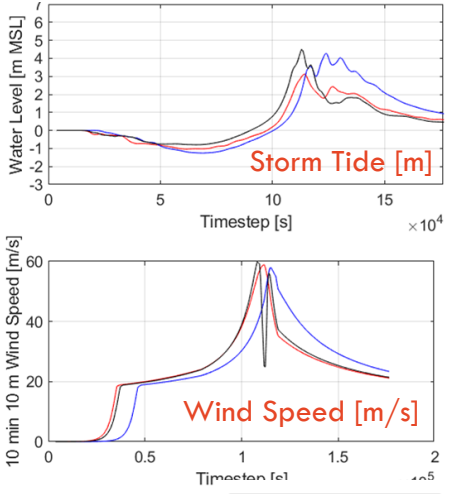
10-min 10 m Wind Speed [m/s]



Peak Storm Tide [m AHD]

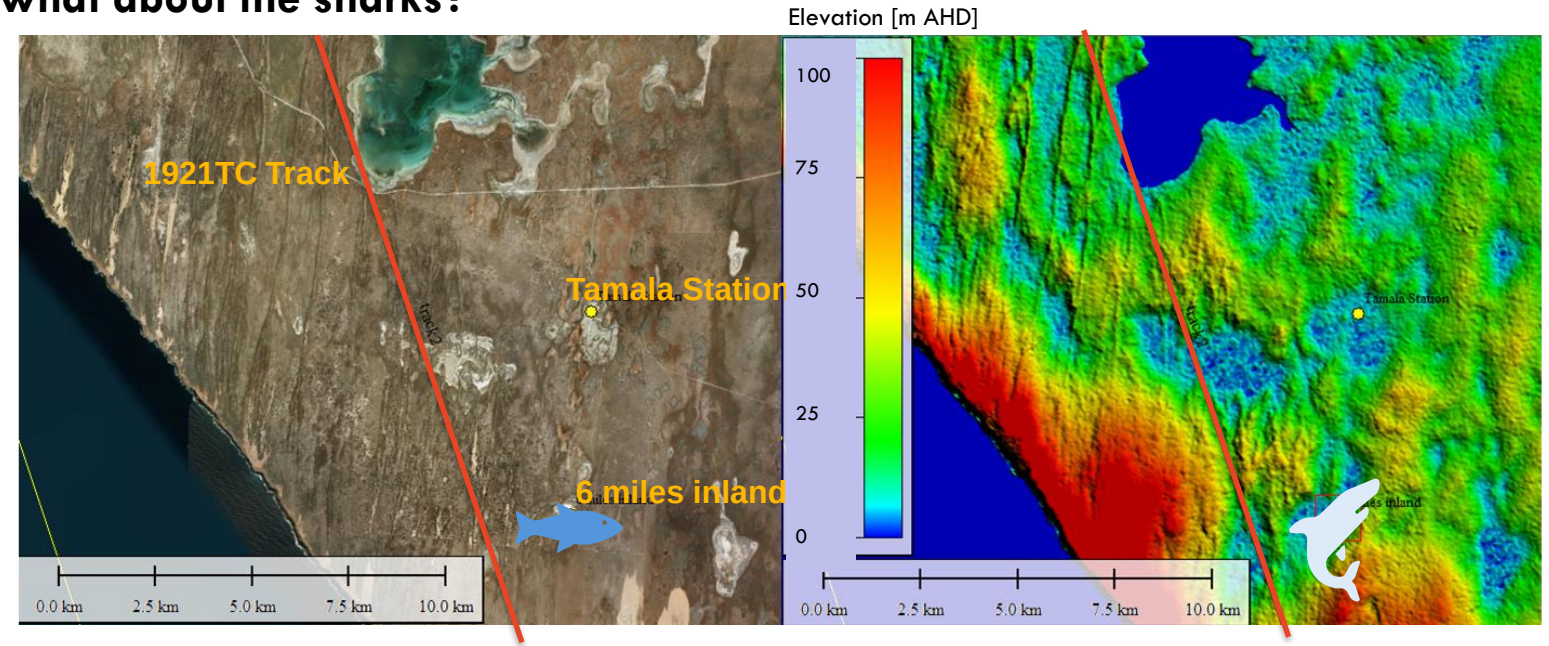


Time Series Profiles



1921 TC: Overland Flow

So what about the sharks?



Satellite imagery at STRM topography (30 m resolution) surrounding Tamala Station.

Contextualising the Risk

Current Planning Levels for Denham:

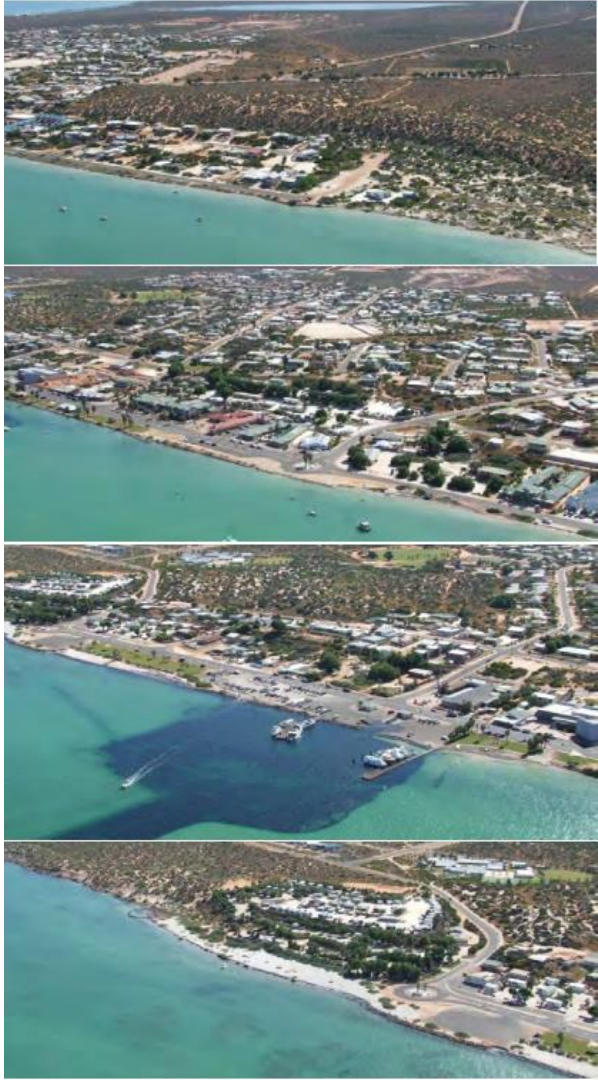
- 100 yr ARI for existing development:
  3.6 m AHD (incl 0.9 m SLR) = 2.7 m AHD (ex SLR)
- 500 yr ARI for new freehold development:
  4.2 m AHD (incl 0.9 m SLR)) = 3.3 m AHD (ex SLR)

1921 TC: 3.0 m AHD storm tide

- Is the planning level underestimated?
- Is the emergency evacuation level sufficient?

Shark Bay Ecosystem – Environmental Management Challenge

- Threat to seagrass assemblage, stromatolites and marine mammals already threatened by rising SLR and SSTs



Shire of Shark Bay, 2012. Local Planning Scheme No3 – District Zoning Scheme.
M.P. Rogers and Associates. 2014. Denham Inundation Levels Storm Surge Modelling Report. On behalf of: Shire of Shark Bay. R558 Rev0. December 2014.

Denham is quite flat!

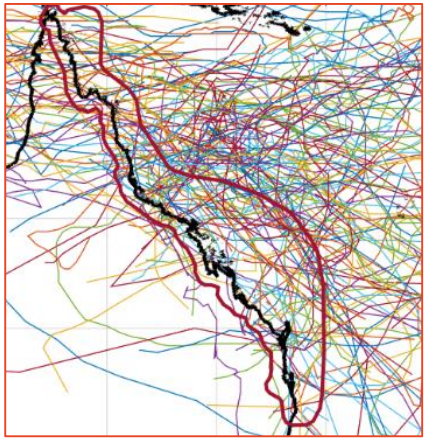
Image - WACoast: Gozzard (2012)

Implications for Hazard Models

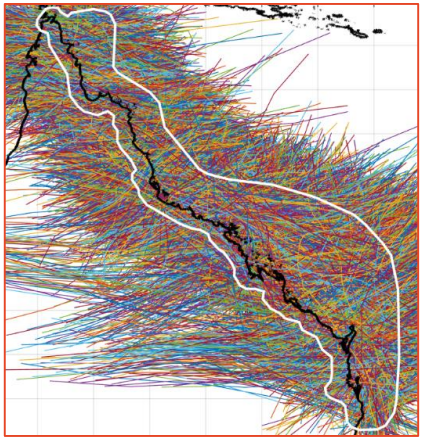
Stochastic hazard models are built on underlying distribution of the climatology typically over the satellite era:

- Genesis locations
- Track locations, forward speed and direction
- Intensity and scale parameters

1. What does this mean on the margins?
2. Can we test by expanding the TC climatology underpinning the synthetic tracks?



Coral Sea – 54 years BOM tracks



10 000 yr Monte Carlo tracks

Burston, JM, Taylor, DR & Churchill, JW. 2015. Stochastic tropical cyclone modelling in the Australian region: An updated track model. Coasts and Ports 2015. Auckland

Take Aways

1. Multidisciplinary paleoclimate studies add value to current risk understanding
2. Do we have sufficient appreciation of our current risk?
3. How many more Cat 5s can we uncover? In Australia and across the globe.