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Design Tropical Cyclone Wind and Waves for North Western Australia

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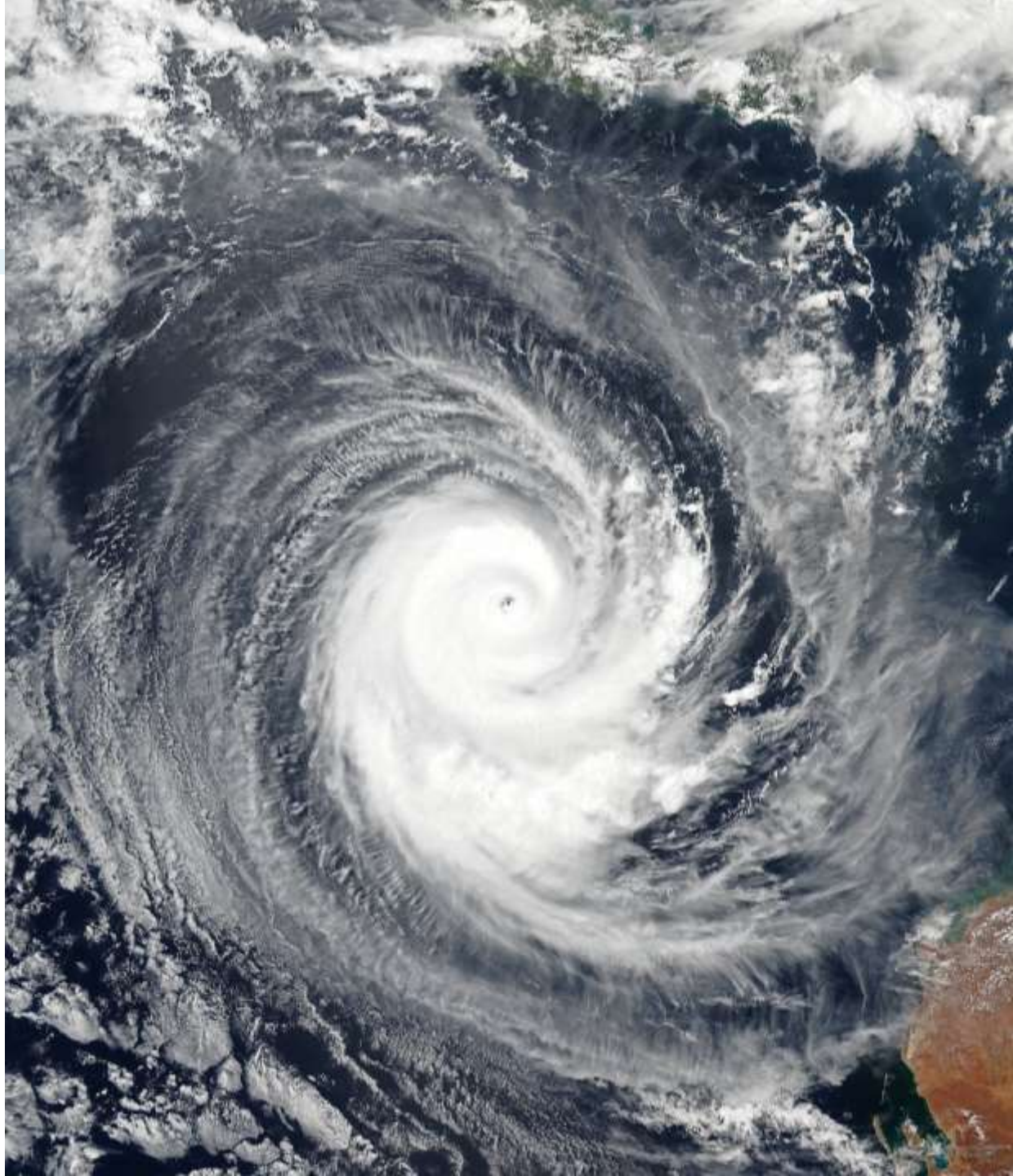
Motivation

- Project for Woodside Energy Ltd – we gratefully acknowledge their support
- Determine 1 in 10,000 year winds and waves (and currents) for Tropical Cyclones (TCs) on the North West Shelf
- Reliable observational record too short for direct analysis
  - ~40 years for position
  - ~15 years for intensity, structure
- Hence, require a synthetic track approach – here, 100 000 years



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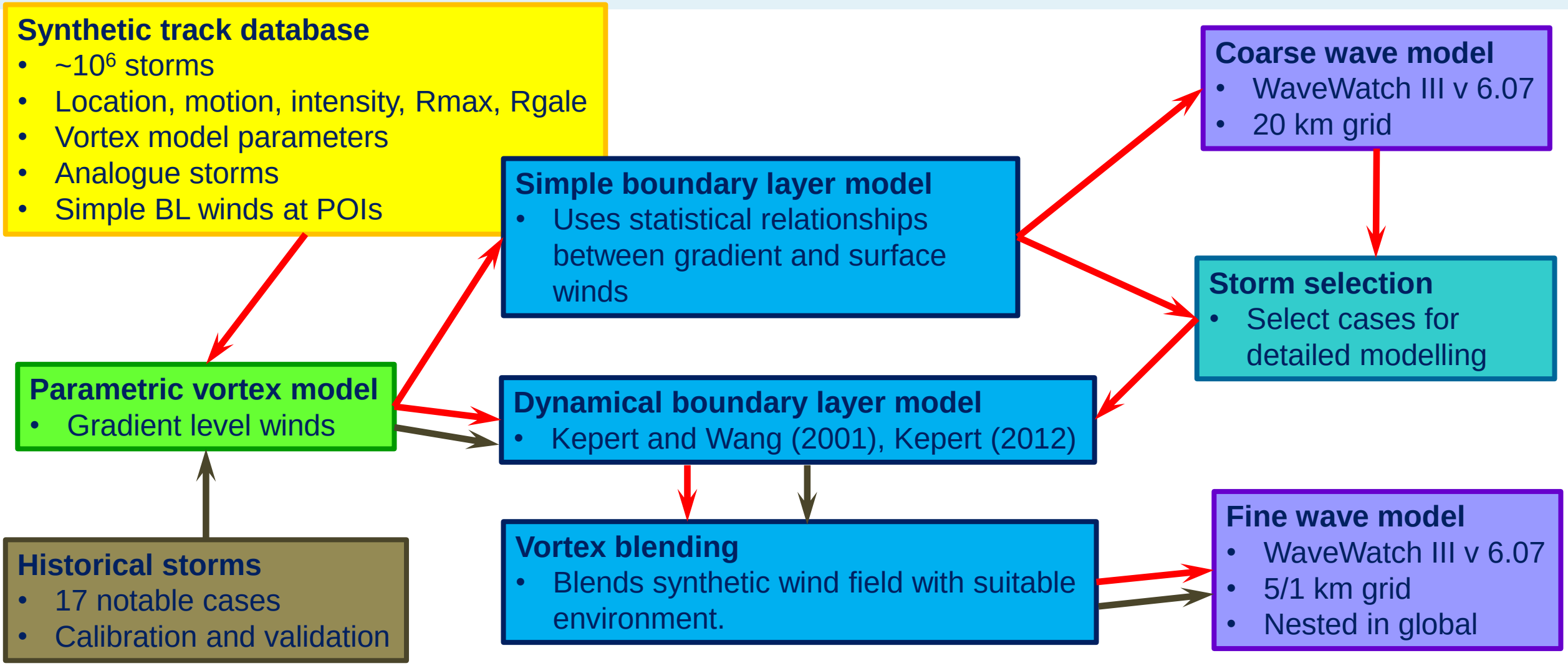
Project components



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Synthetic Tracks

Genesis:

- Randomly samples genesis times and locations
- Seasonal cycle of genesis frequency
- Seasonal cycle of genesis location
- Trained on AustBT, 1979 – present, genesis redefined to be first occurrence of 15 m/s or stronger

Motion:

- Multivariate autoregressive model
- Trained on AustBT / IBTraCS, 1979 – present
- Mean and covariances calculated on a 3x1 degree grid, 80E – 180E, 3S – 30S
- Incorporates beta-effect on motion

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Synthetic Tracks

Intensity:

- Maximum wind speed
- Univariate autoregressive model
- Trained on AustBT, post – July 2003
- Intensity tendency modelled as function of potential intensity deficit, storm motion, location
- Potential intensities (PI) calculated by Emanuel theory using ERA-I, seasonal cycle
- Over-land model similar, assumes PI = 20 m/s

Structure:

- log(Rmax) and log(Rgale)
- Univariate autoregressive models, trained on AustBT, July 2003 – present
- Tendencies depend on intensity, latitude, Rgale (for Rmax)

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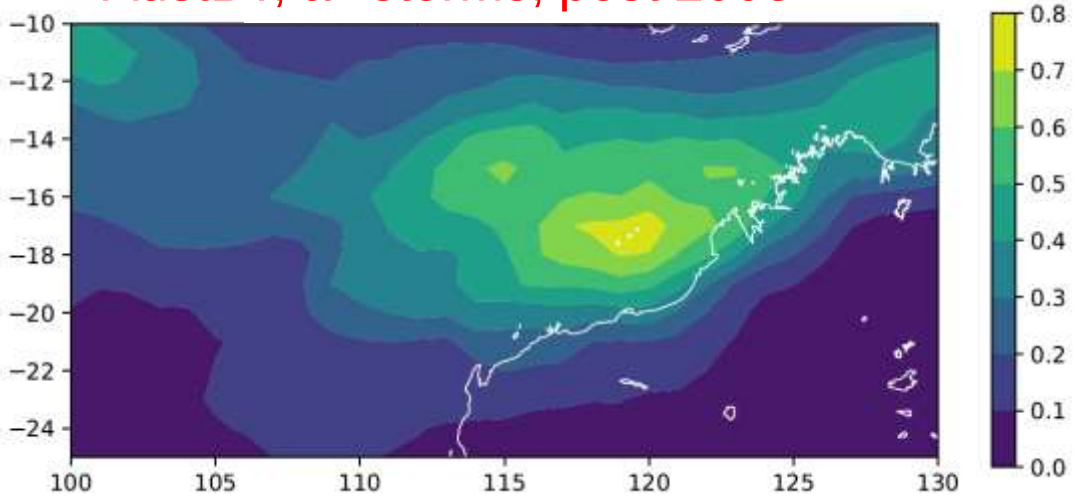
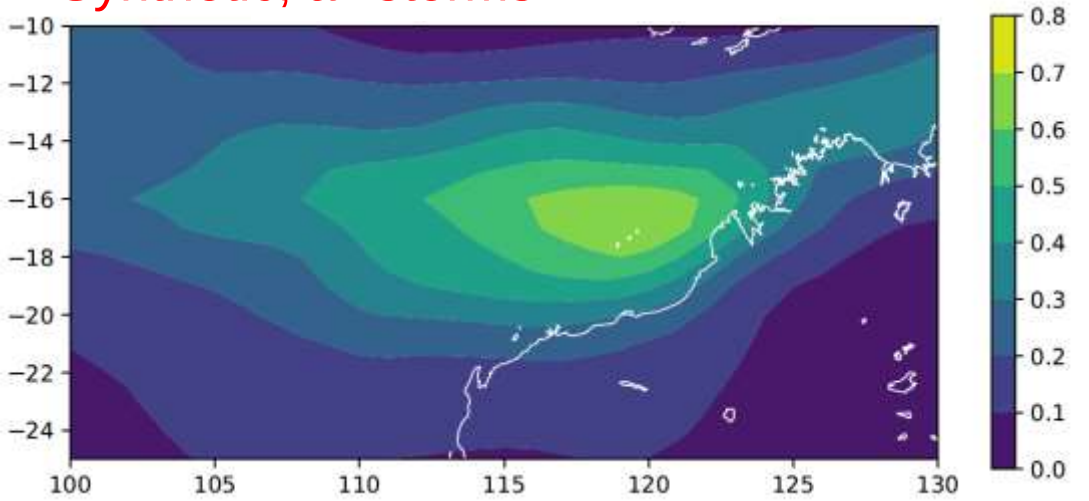
Synthetic Track Verification – Broadscale

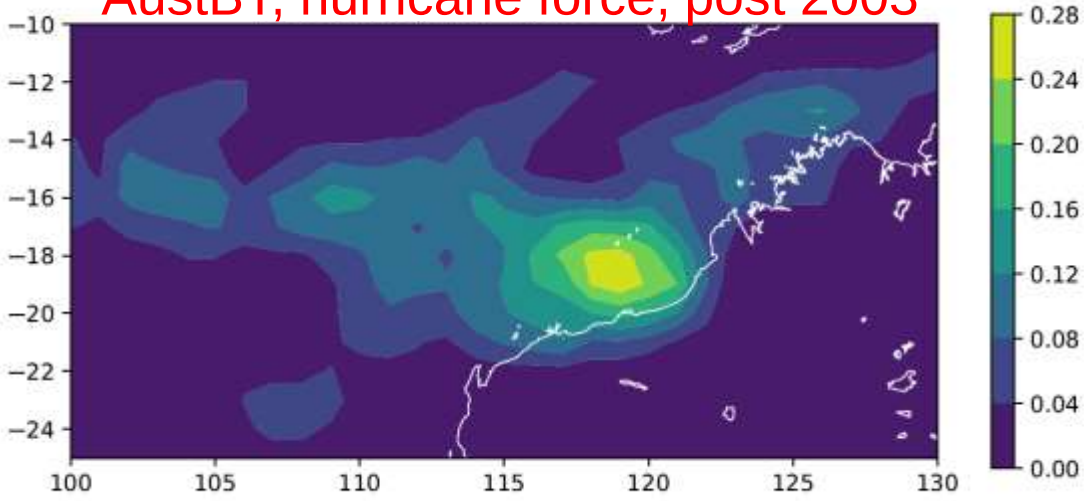
AustBT, all storms, post 2003



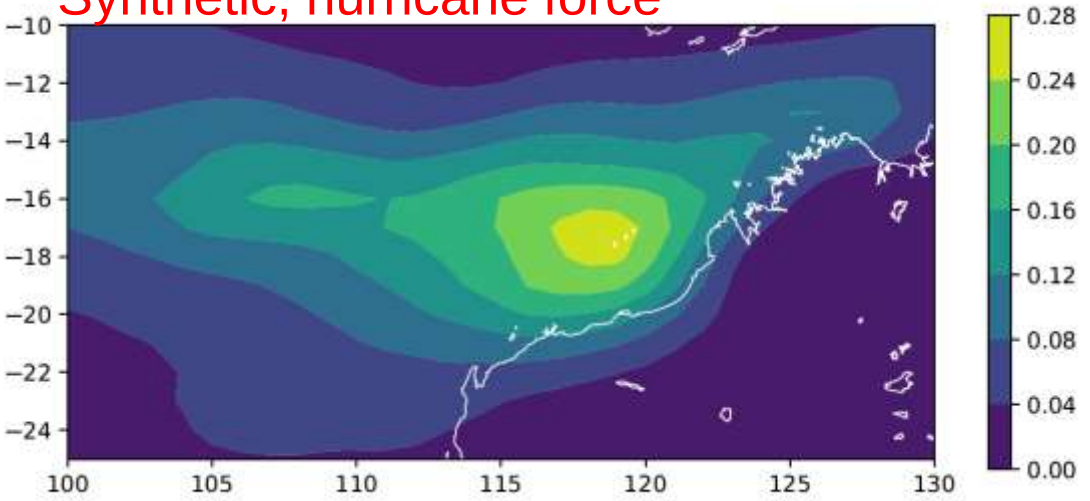
Synthetic, all storms



AustBT, hurricane force, post 2003



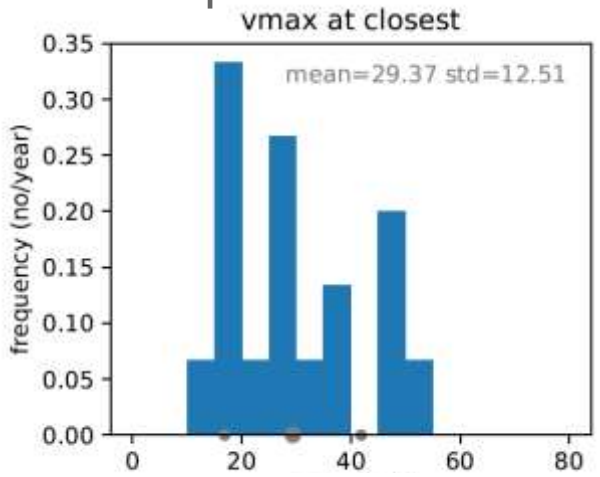
Synthetic, hurricane force



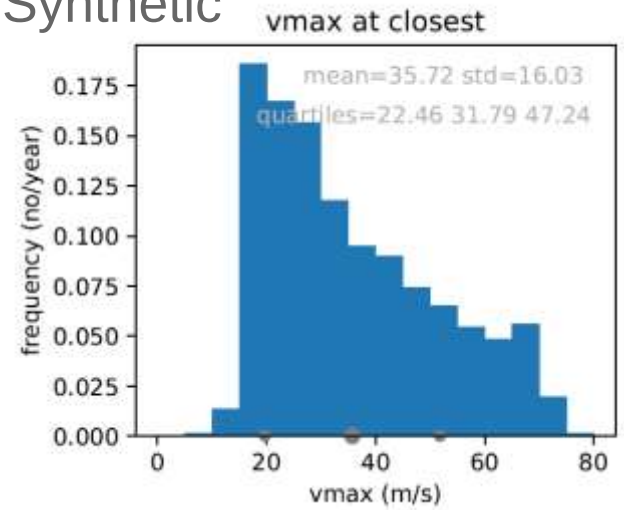
Synthetic Track Verification – Local

Storms within 200 km of a North West Shelf location

Aust BT post-2003



Synthetic



Storms per year

	All	Gale+	Storm+	Hurr+	50+
AustBT (post 2003)	1.20	0.93	0.73	0.40	0.07*
Objective reanalysis (post 1989)	1.25	1.19	0.89	0.59	0.15*
Synthetic	1.15	1.04	0.78	0.54	0.24

*Caution: very little data

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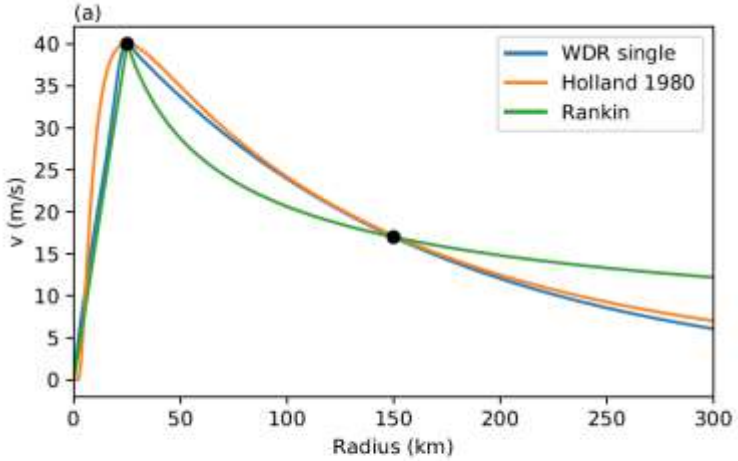
Tropical Cyclone Parametric Profile

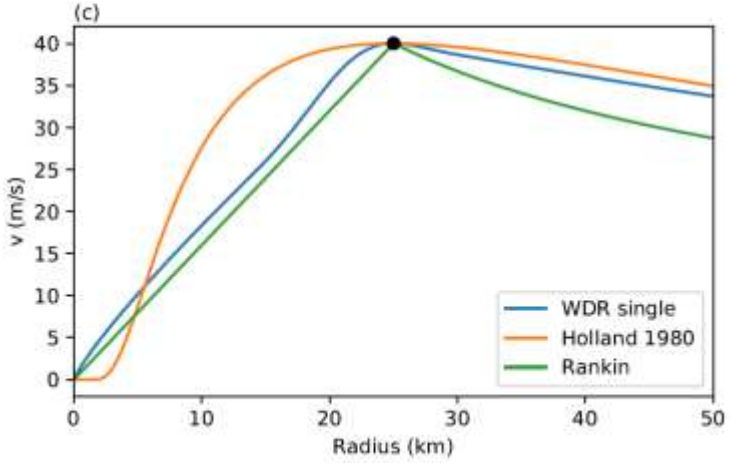
- Willoughby et al. (2006)
- Based on 493 aircraft reconnaissance profiles in N Atlantic
- Parameters:
  - Intensity Vmax
  - Rmax
  - Two outer length scales
  - Relative weight of length scales
- Pros:
  - Based on lots of observations
  - Most realistic profile available
- Cons:
  - More difficult to fit
  - Less familiar to users

Fitting the Willoughby et al. (WDR) profile

- Synthetic database or best track include surface Vmax, Rmax, Rgale
- Need to fit 5 parameters for gradient level winds
- Surface Vmax is adjusted to gradient level by inverting simple wind model
- Rmax is unchanged
- Outer structure parameters derived from Rgale as maximum likelihood estimate, using climatological distribution from WDR
- Central pressure and other wind radii obtained analytically

Three profiles, same Vmax, Rmax, Rgale

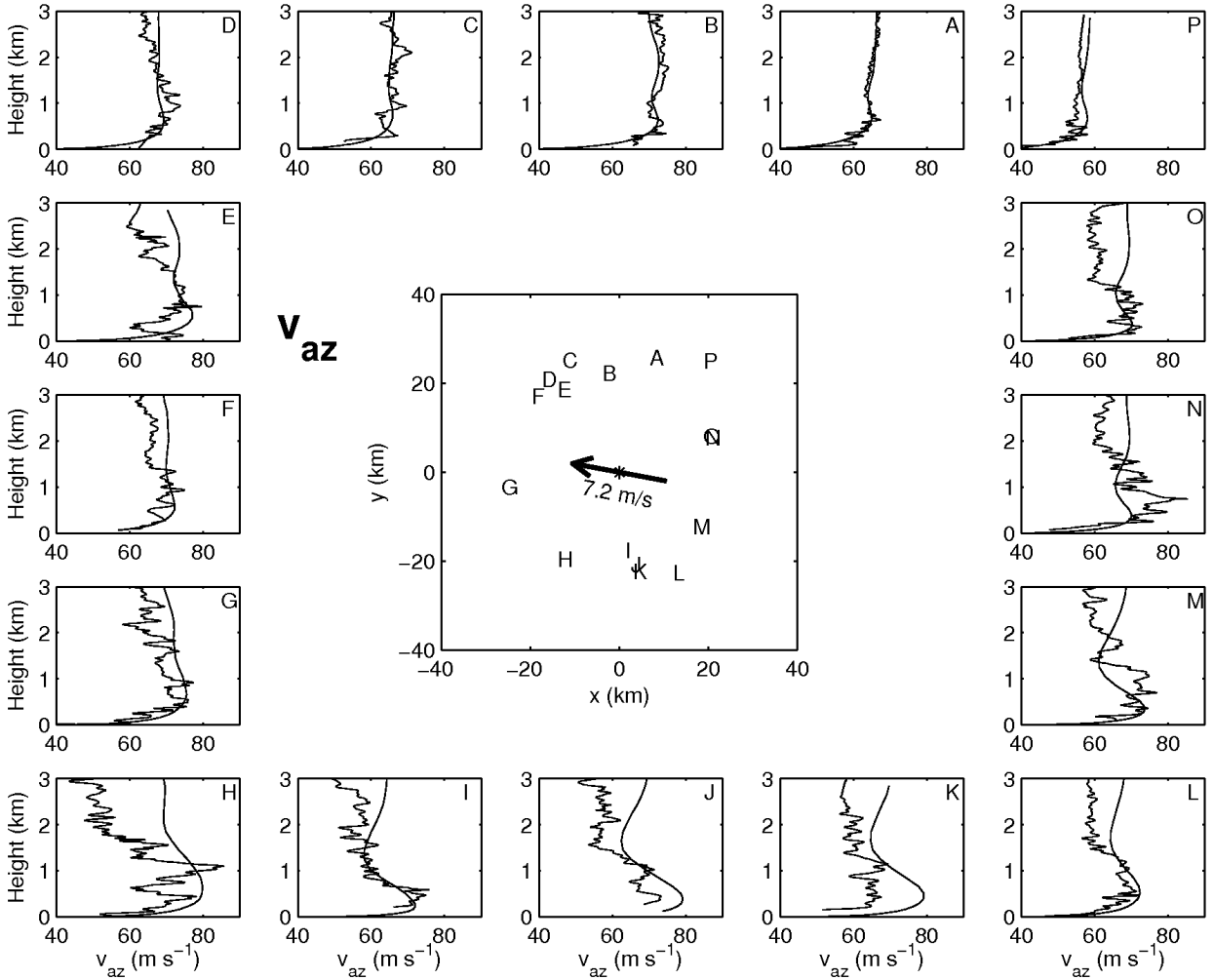




Dynamical boundary layer model

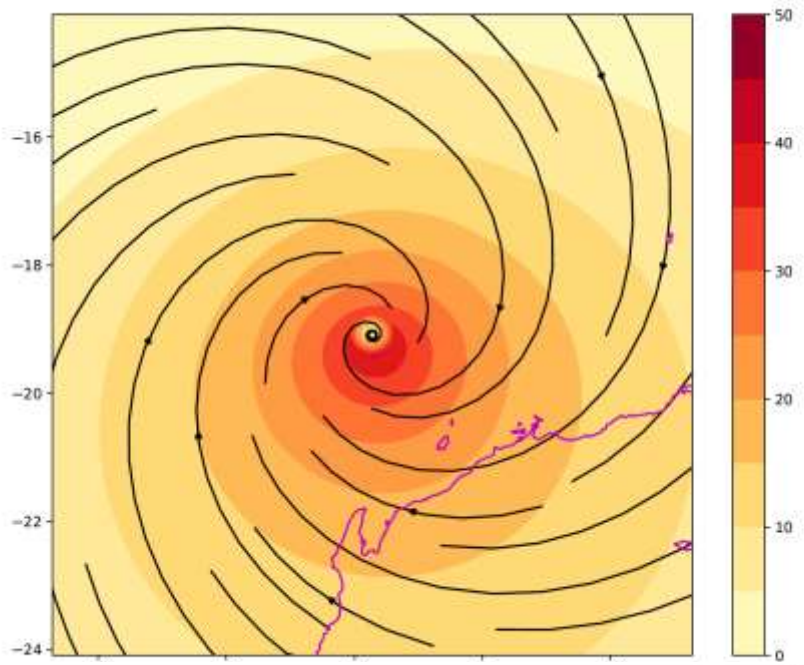
- Kepert and Wang (2001), Kepert (2012)
- Finds steady-state solution to dynamical equations, given imposed gradient wind field (or pressure field)
- Previously used for theoretical and observational studies
- Incorporates modern knowledge on drag coefficient and turbulence parameterization
- Sped up for this project by starting the simulation from the solution to the linear model of Kepert (2001)

Hurricane Georges (1998) eyewall
Dropsonde observations vs model simulations

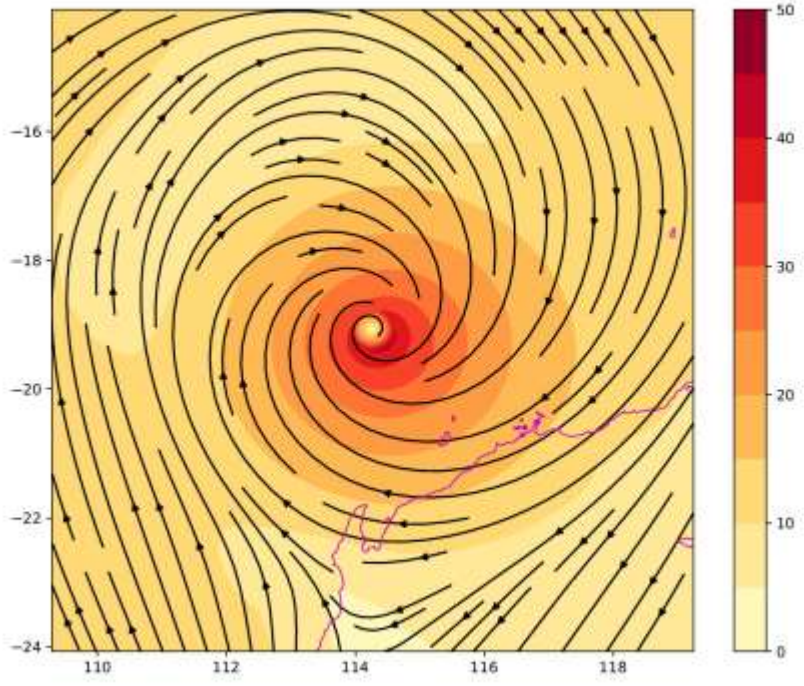


Simple boundary layer model

- Estimates surface winds from gradient level winds using a statistical model
- Trained on dynamical model output
- Uses a spatially-varying wind reduction factor dependent on storm structure
- Predictors: intensity, motion, Rgale
- Spatial wind fields (e.g. for coarse wave model)
- Time series of winds at POIs for all storms in synthetic database



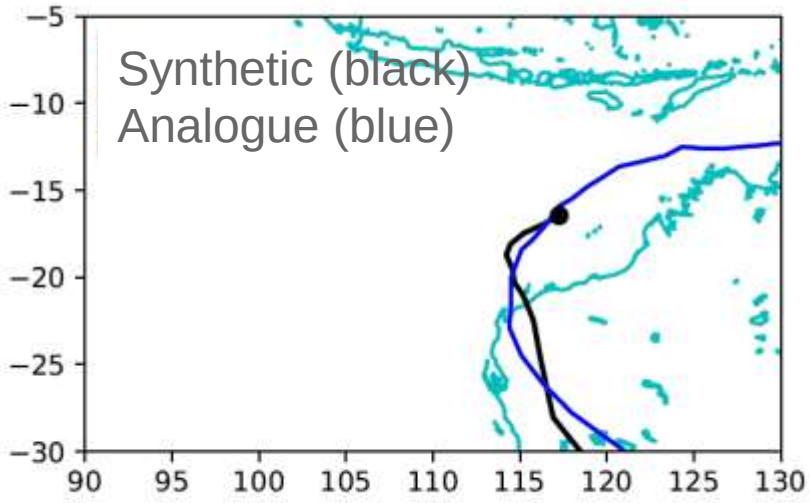
Simple model

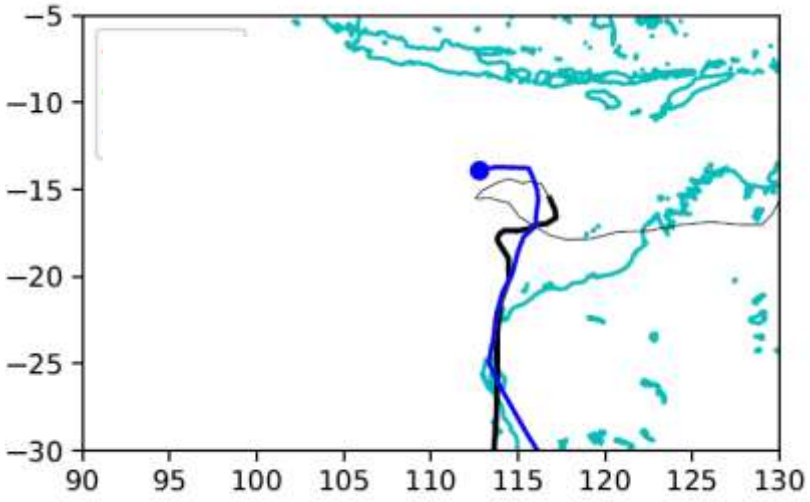


Full model, blended with ERA-I environment

Merging with the environment

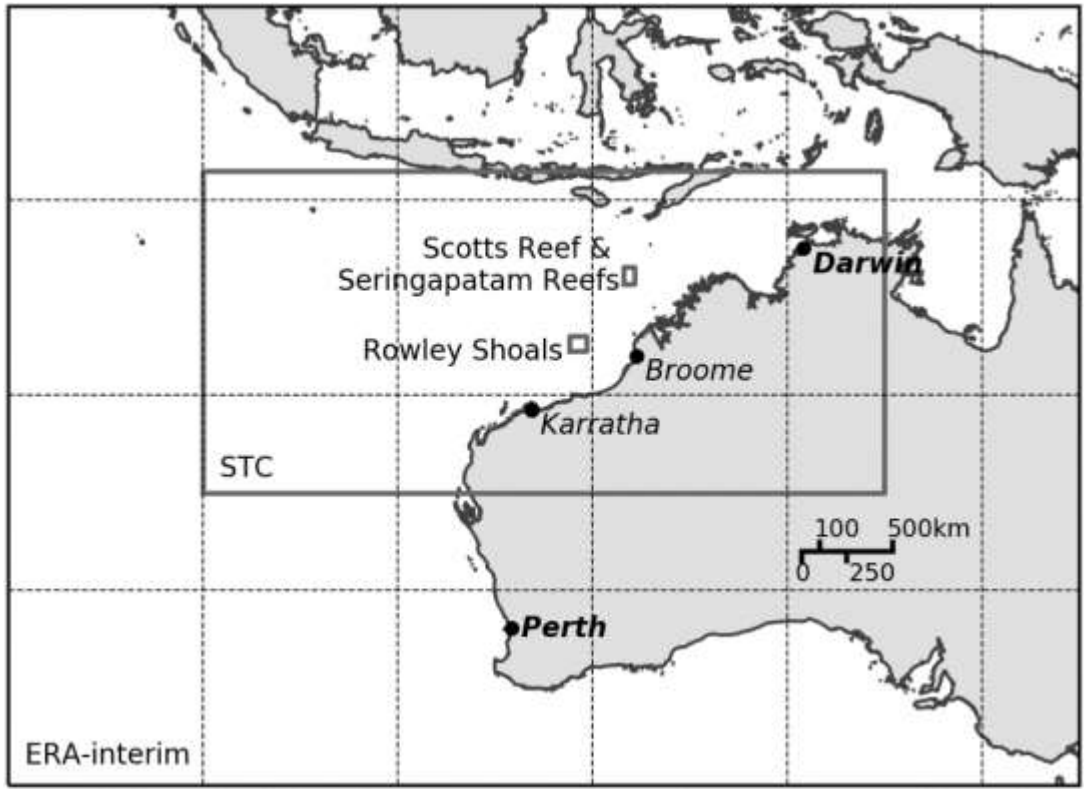
- For each synthetic storm and each POI, find an analogue real storm with a similar track
- Match is over a given period around closest approach to a point of interest
- Time can be stretched, compressed or even (rarely) reversed
- Synthetic wind field is blended into ERA-I reanalysis at corresponding times, with real storm filtered out





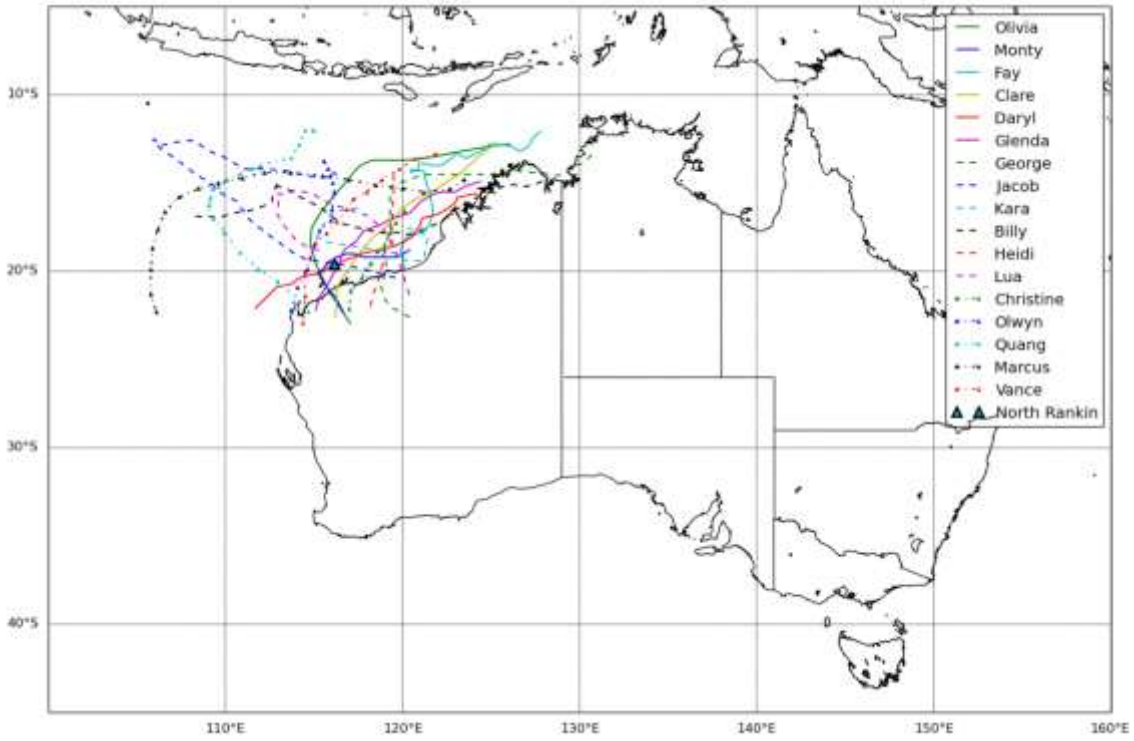
Wave model

- WAVEWATCH III v 6.07
- 0.05° spatial resolution with dedicated 0.01° grids around two reef areas
- 5° directional resolution, frequency range 0.035 – 0.5 Hz
- Source terms
  - ST4 (TEST471F with $\beta_{max} = 1.43$)
  - ST6 (default)
- Boundary conditions from global wave model
- Also coarse-resolution version (0.2° spatial, 10° direction, same frequencies)



Historical storms – calibration and validation

- 17 historical events from 1999 - 2018
- TC track details from Australian Best Track database (thanks to WA for some reanalysis)
- Gradient winds used exactly the same process as synthetic tracks
- Surface winds derived using fully dynamic three-dimensional boundary layer model blended into ERA-I environment



Wave model verification

- Observations provided by Woodside
- Verification focused on
  - Peak wind speed
  - Significant wave height
  - Swell significant wave height
  - Wind-sea significant wave height
- Wind sea and swell are defined by a cut-off wave period of 9 seconds
- Best source terms found to be ST4(471f)

		ST4 (471f)		ST6	
	Mean observed max (m)	MAE (m)	Bias (m)	MAE (m)	Bias (m)
H_S	4.29	0.66	-0.09	0.67	0.1
$H_{S\ SWELL}$	3.15	0.70	0.08	0.79	0.3
$H_{S\ SEA}$	2.99	0.51	-0.40	0.64	-0.53

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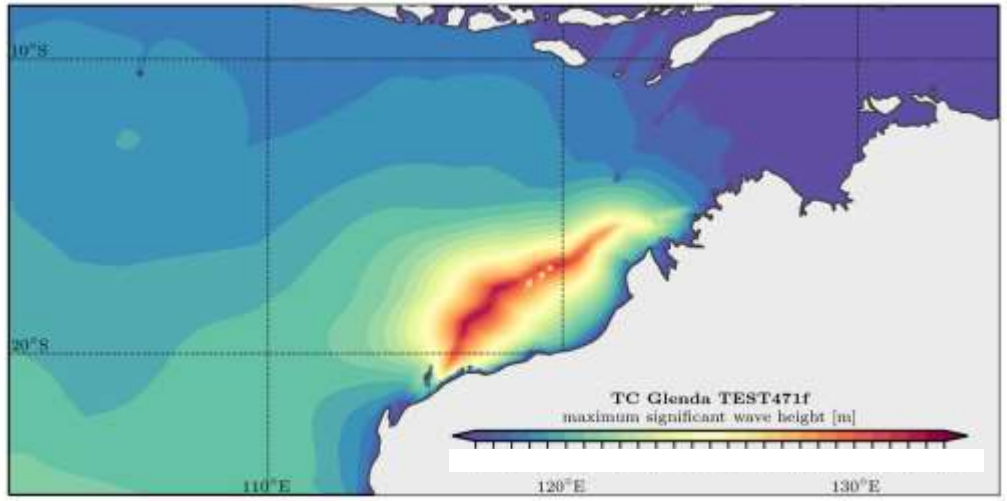
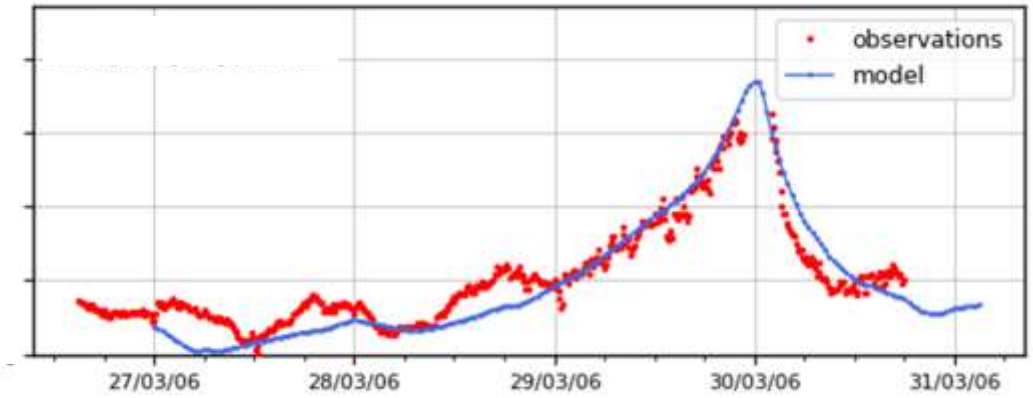
TC Glenda

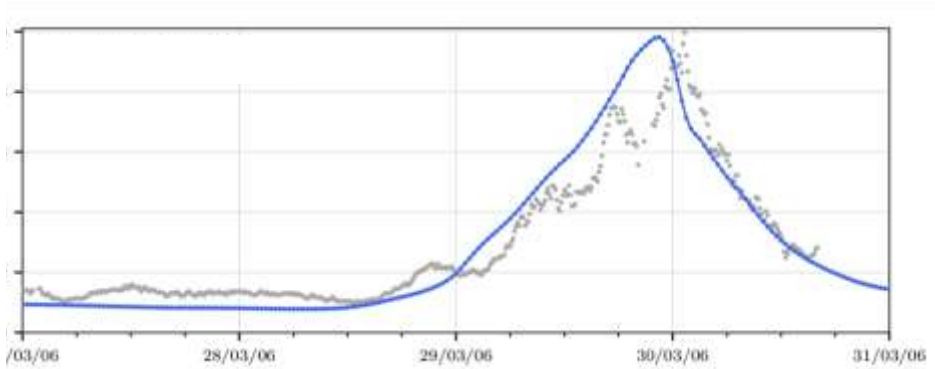
Hs total



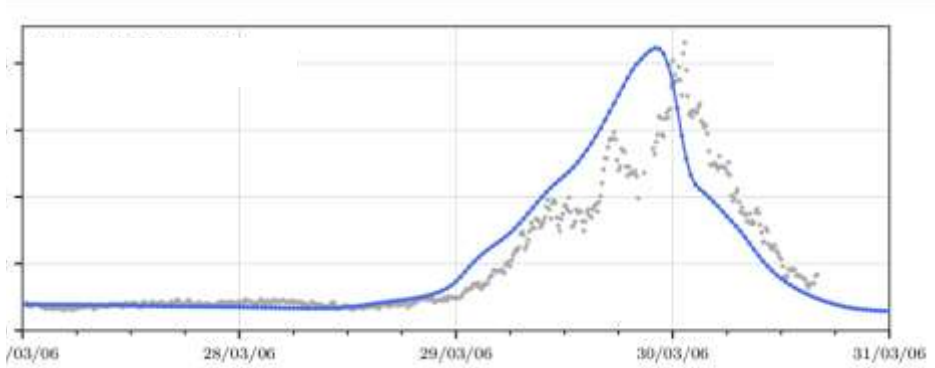
Wind speed



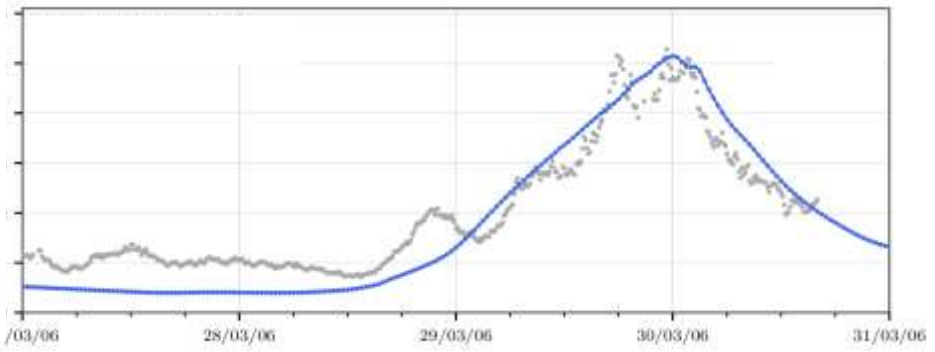
Hs total



Hs swell



Hs wind-sea



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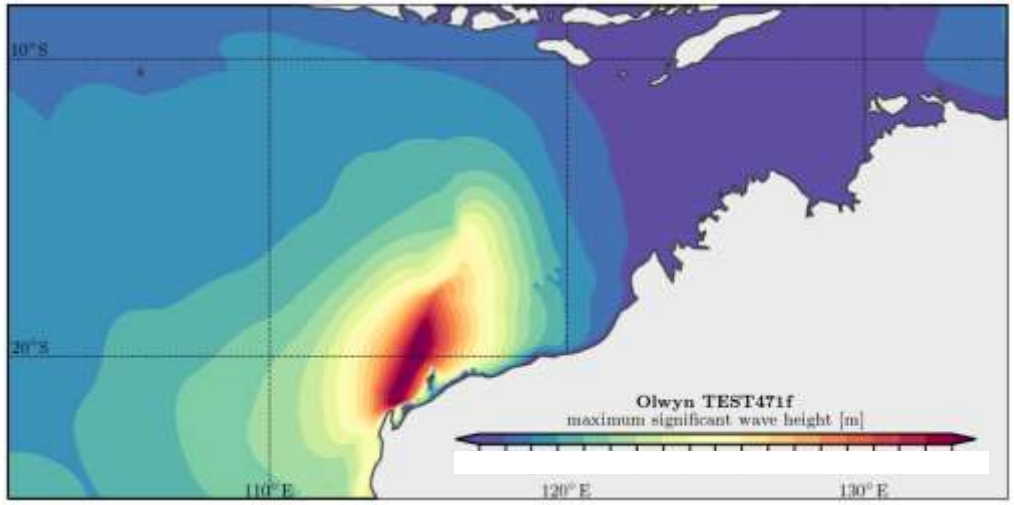
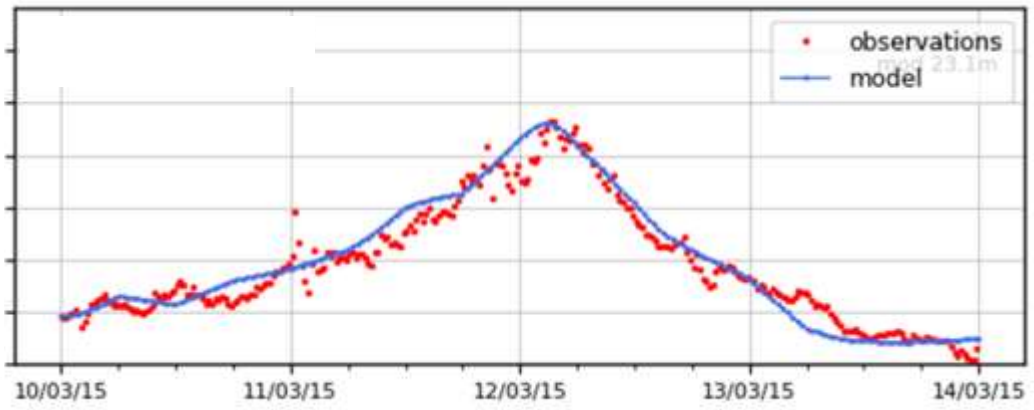
TC Olwyn

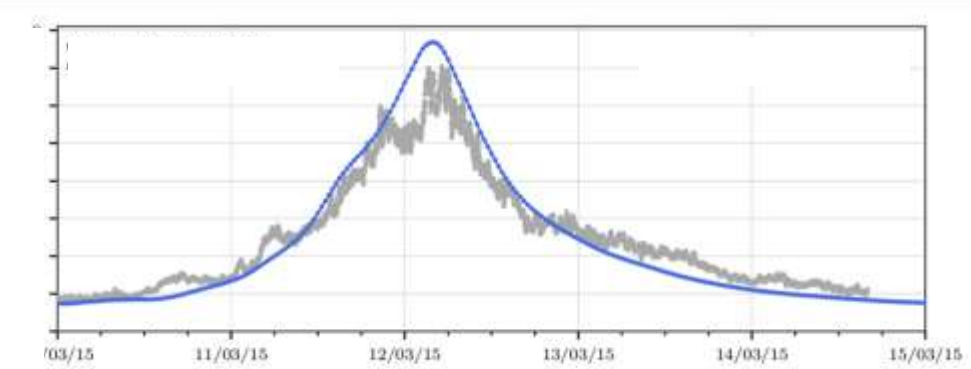
Hs total



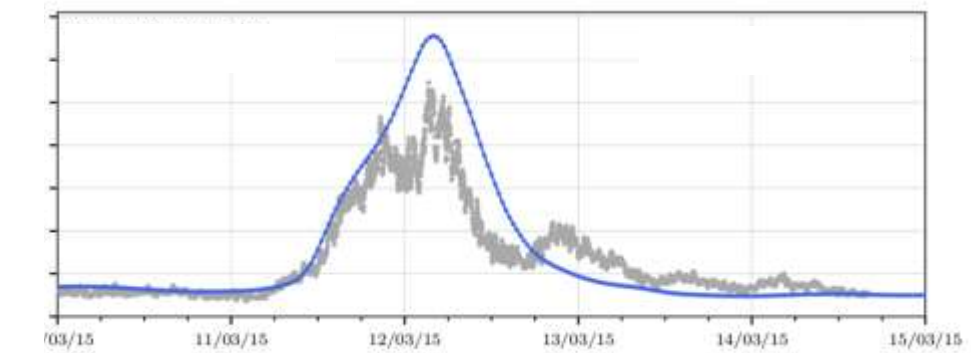
Wind speed



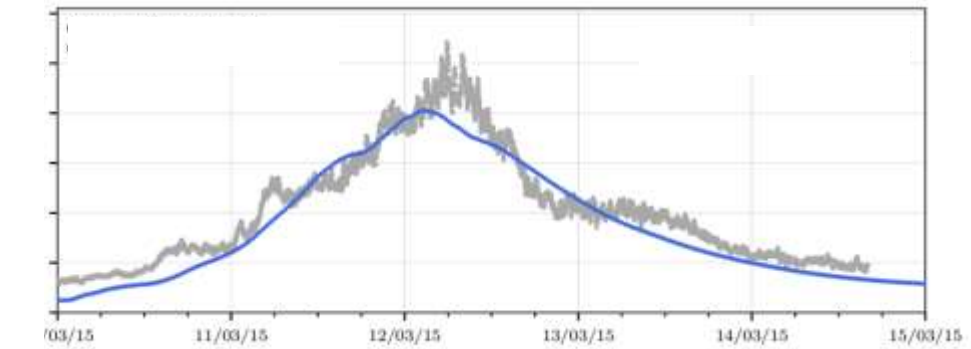
Hs total



Hs swell



Hs wind-sea



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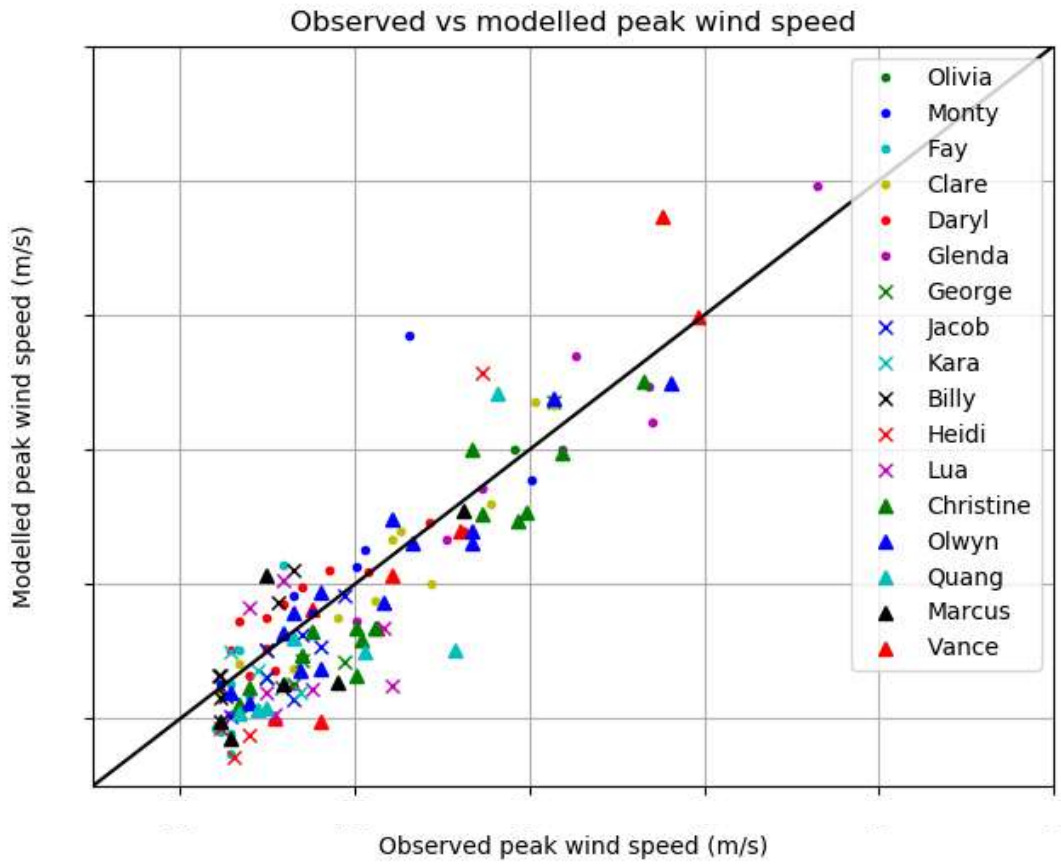
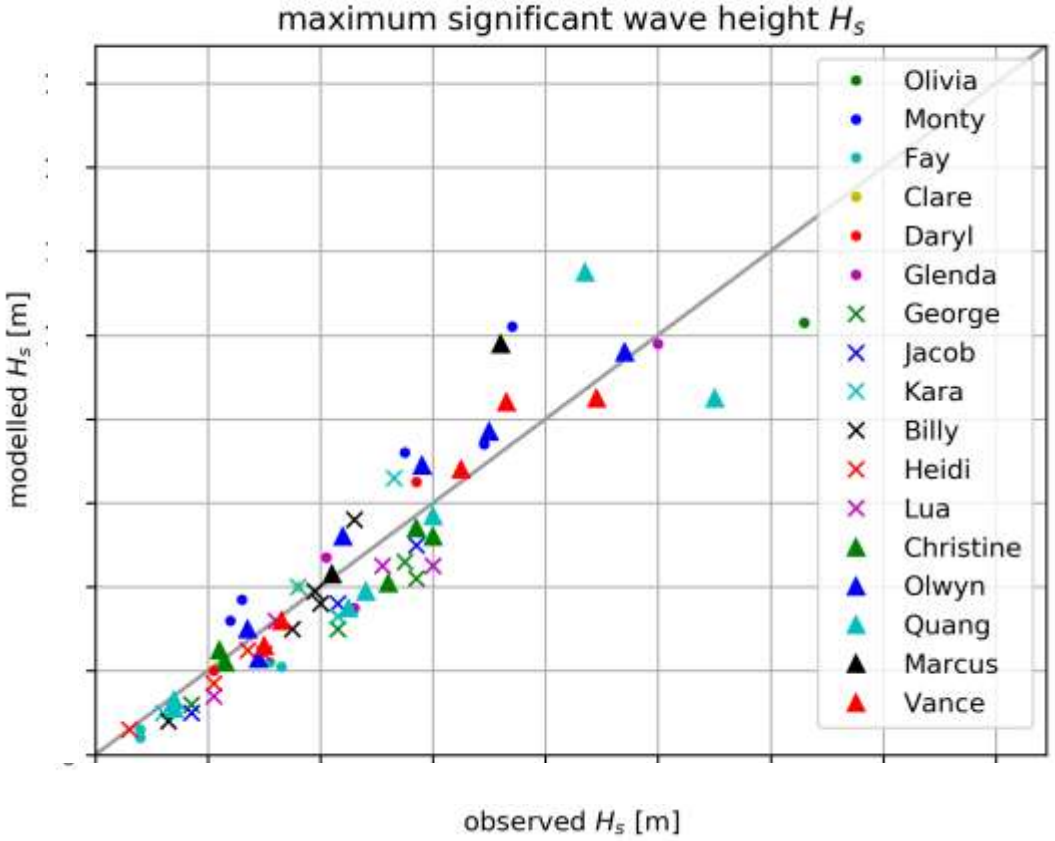
Historical storms verification – summary





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Summary

- 100 000-year synthetic track database
- Simple and dynamical boundary layer wind models
- Environmental blending
- Wave model, coarse and fine resolutions
- Simple wind and wave models for storm selection, complex ones for final runs
- Wind and wave models validated on 17 historical storms
- Acknowledge financial and subject-matter expert support from Woodside Energy Ltd