Advances in Predictive Modelling of Extreme Weather Events

PIANC New Technologies Seminar

9-10 May, 2019

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Presentation Outline

- Forecasting extreme weather impacts
  - Human safety
  - Infrastructure impacts leading to disruption in export supply chains

- Summary of predictive tools available for extreme weather events

- Case Study: Tropical Cyclone Veronica
  - Event and impacts
  - High resolution predictive modelling applied to NWS

- The Future
 - Next generation predictive modelling
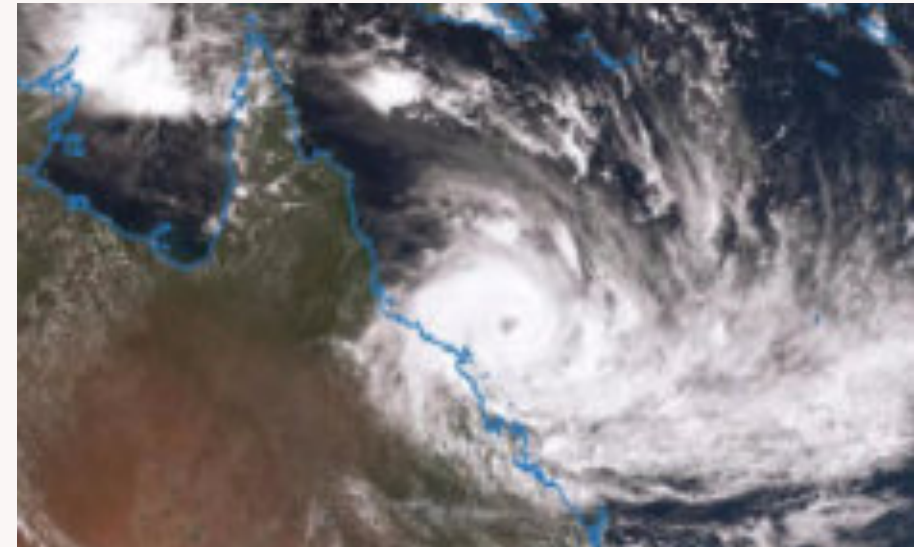
TC Debbie satellite image. Source: Bureau of Meteorology

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

Cyclone Forecast and Warnings – Australia

- Bureau of Meteorology is the designated forecast agency. Adopts a two level cyclone warning system:
  - Cyclone Watch: Gales 24-48 hours
  - Warning Zone: Gales within 24 hrs
- State agencies then issue further advice for potentially affected communities
  - DFES (WA)
    - **Blue Alert**
      Get Ready for a cyclone. You need to start preparing for cyclone weather.
    - **Yellow Alert**
      Take action and get ready to shelter from a cyclone. You need to prepare for the arrival of a cyclone.
    - **Red Alert**
      Take shelter from the cyclone. You need to go shelter immediately.
- Local governments may be responsible for evacuation maps
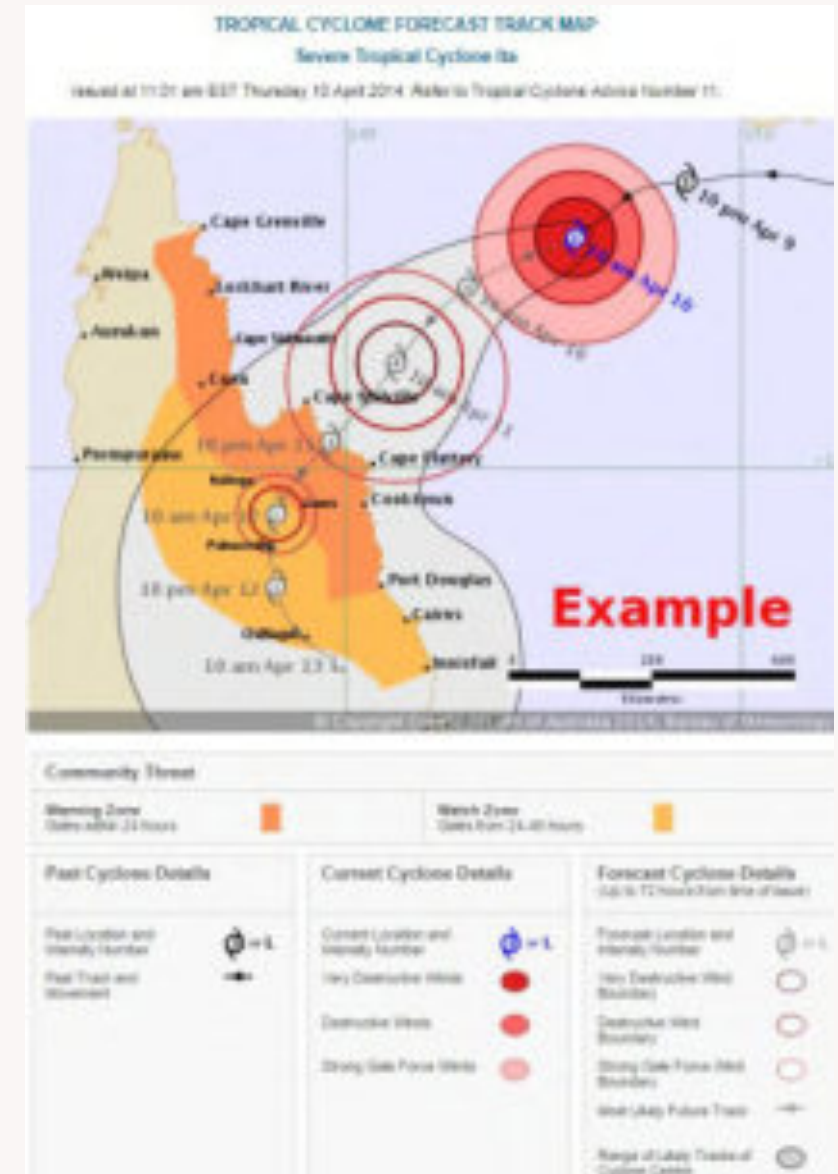
Cyclone Forecast and Warnings – Australia

- Forecasts and tools are under continual development
  - BoM's Meteye
  - ECMWF (European Centre for Medium-Range Weather Forecasts) available on public platforms
- Predictive systems for wave and storm tide impacts have been researched and developed but limited operations:
  - *Qsurge* project undertaken by Griffith University Centre for Coastal Management
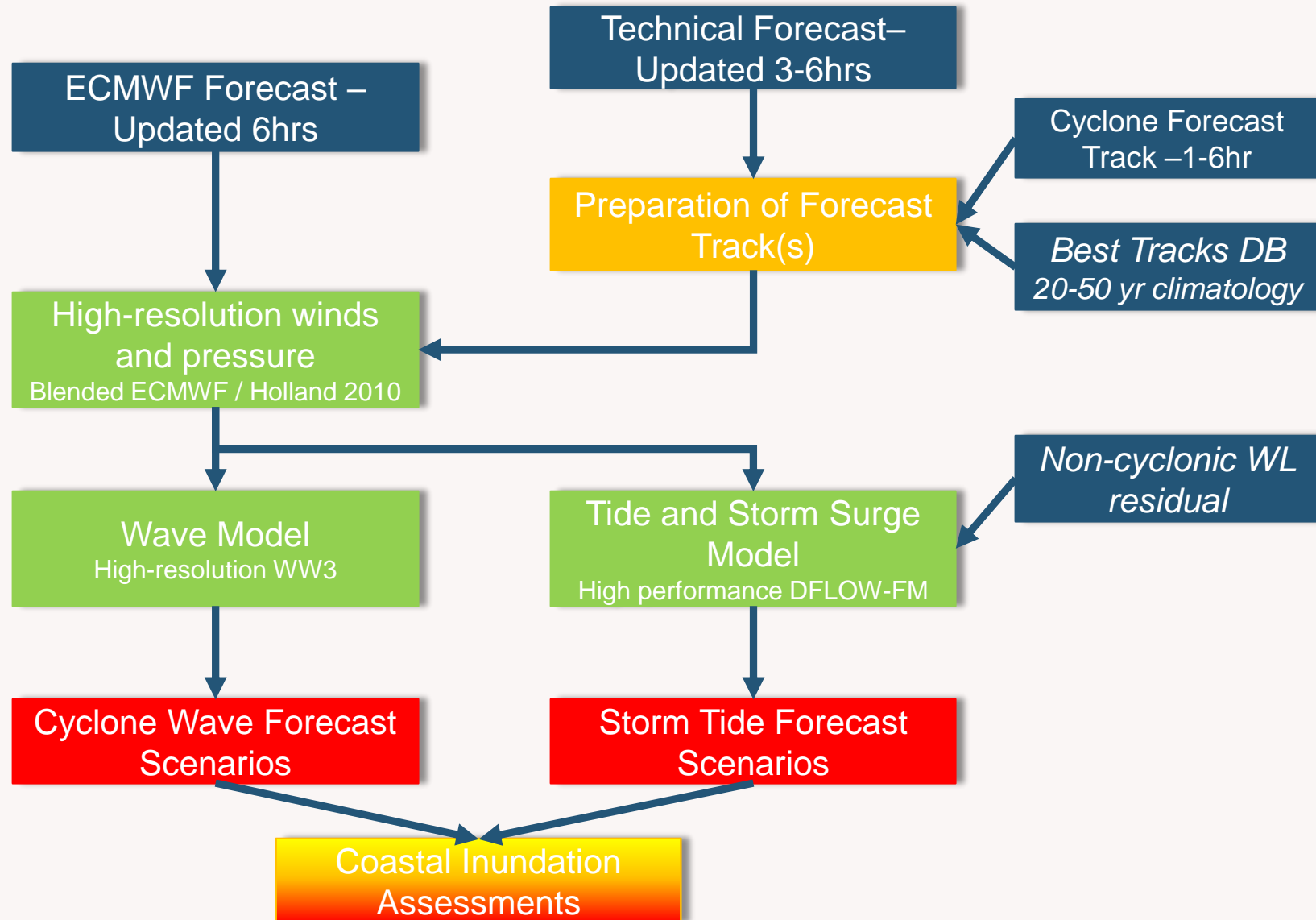 - AI and Machine Learning projects are also being undertaken
    https://www.forgov.qld.gov.au/storm-tide-forecasting

Cyclone Forecast and Warnings – Australia
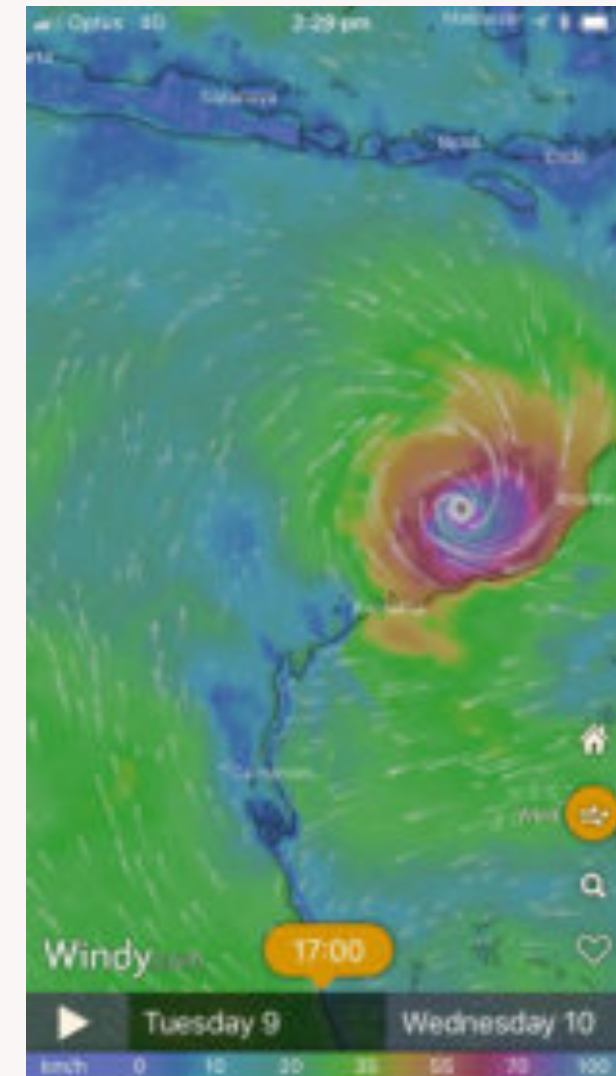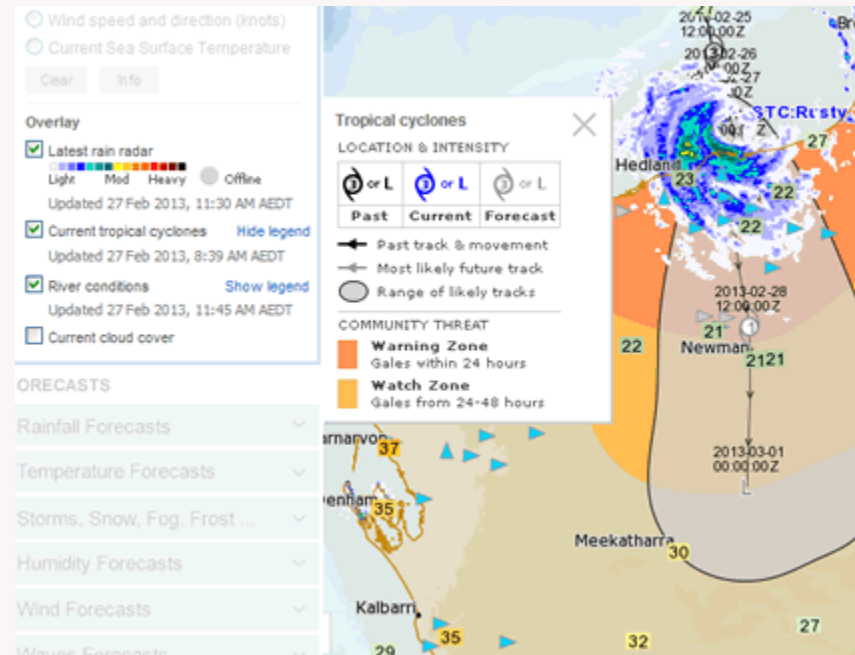
- Accuracy of forecasts are improving, but accuracy is variable between events – BoM (2016)
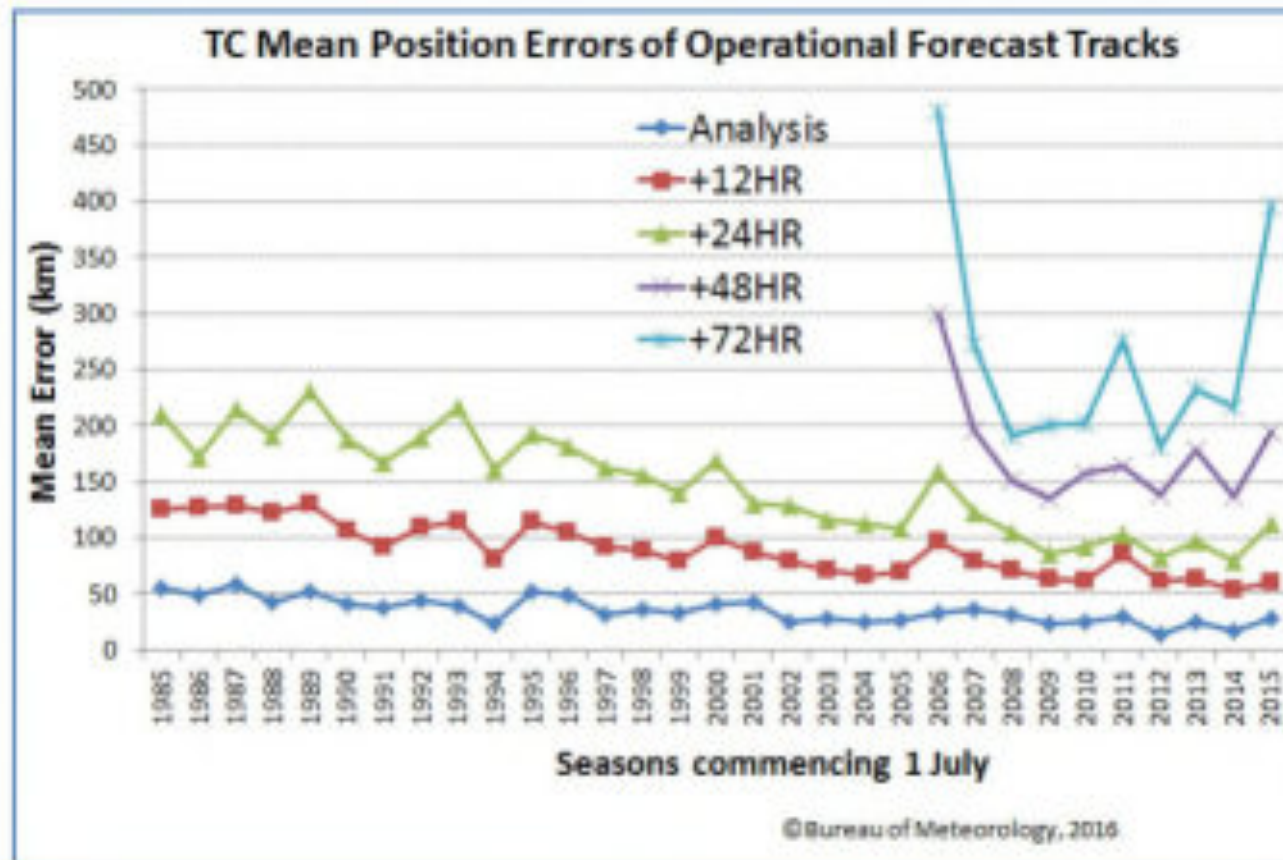
Development of a Process Based Forecast Model

- Developments in cloud computing result in process based forecast modelling being more feasible

- Model system components developed from national scale hazard model
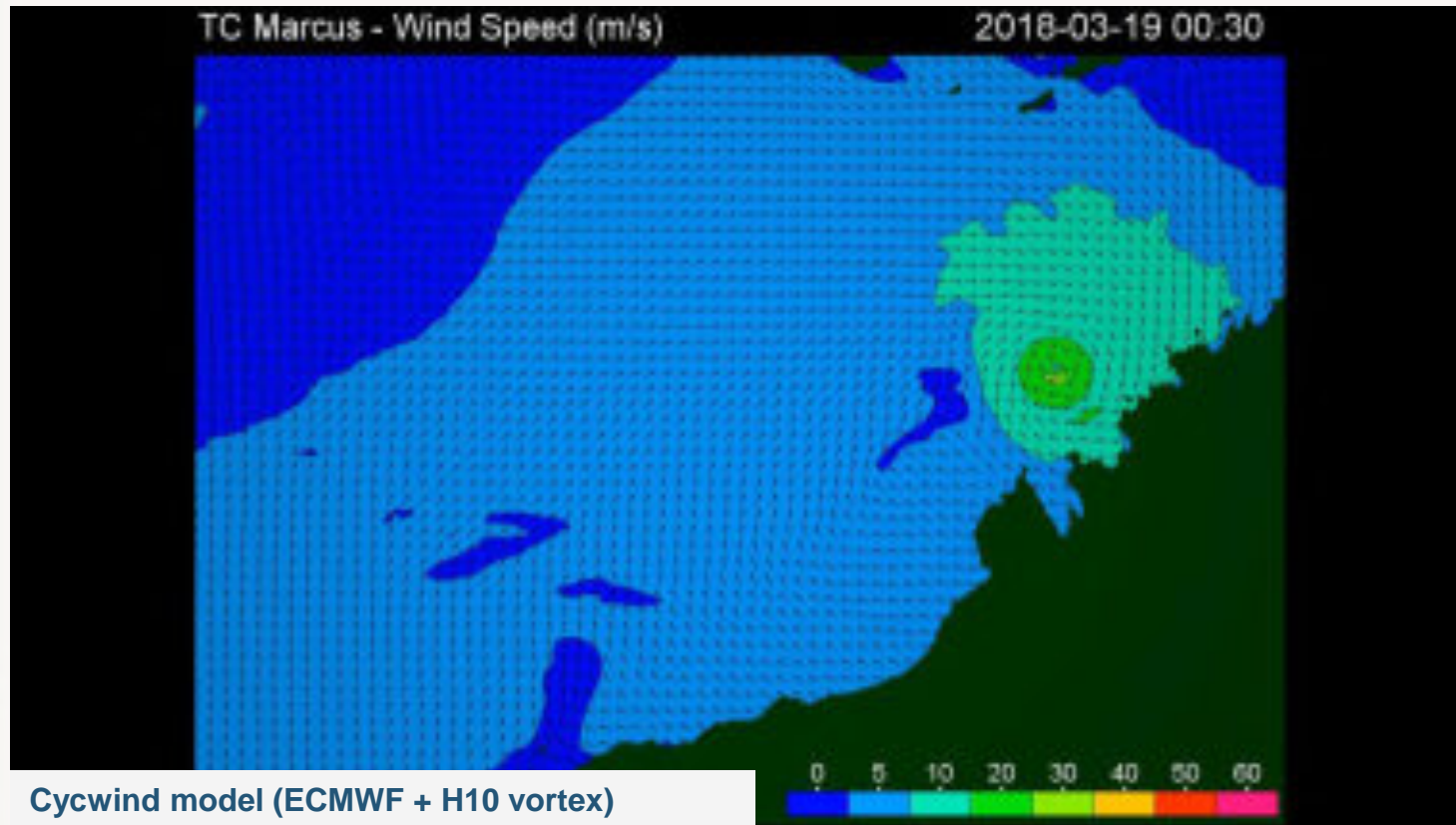
- Run on Azure cloud system

ECMWF Forecast – Updated 6hrs

Technical Forecast– Updated 3-6hrs

Cyclone Forecast Track –1-6hr

Preparation of Forecast Track(s)

Best Tracks DB 20-50 yr climatology

High-resolution winds and pressure
Blended ECMWF / Holland 2010

Non-cyclonic WL residual

Wave Model
High-resolution WW3

Tide and Storm Surge Model
High performance DFLOW-FM

Cyclone Wave Forecast Scenarios

Storm Tide Forecast Scenarios

Coastal Inundation Assessments

Track Forecast Data

- Detailed track, intensity and scale data in BoM's Technical Forecast

- Typically issued 1 to 1.5 hrs after forecast period

- Retrieved automatically from BoM's operational data system via ftp

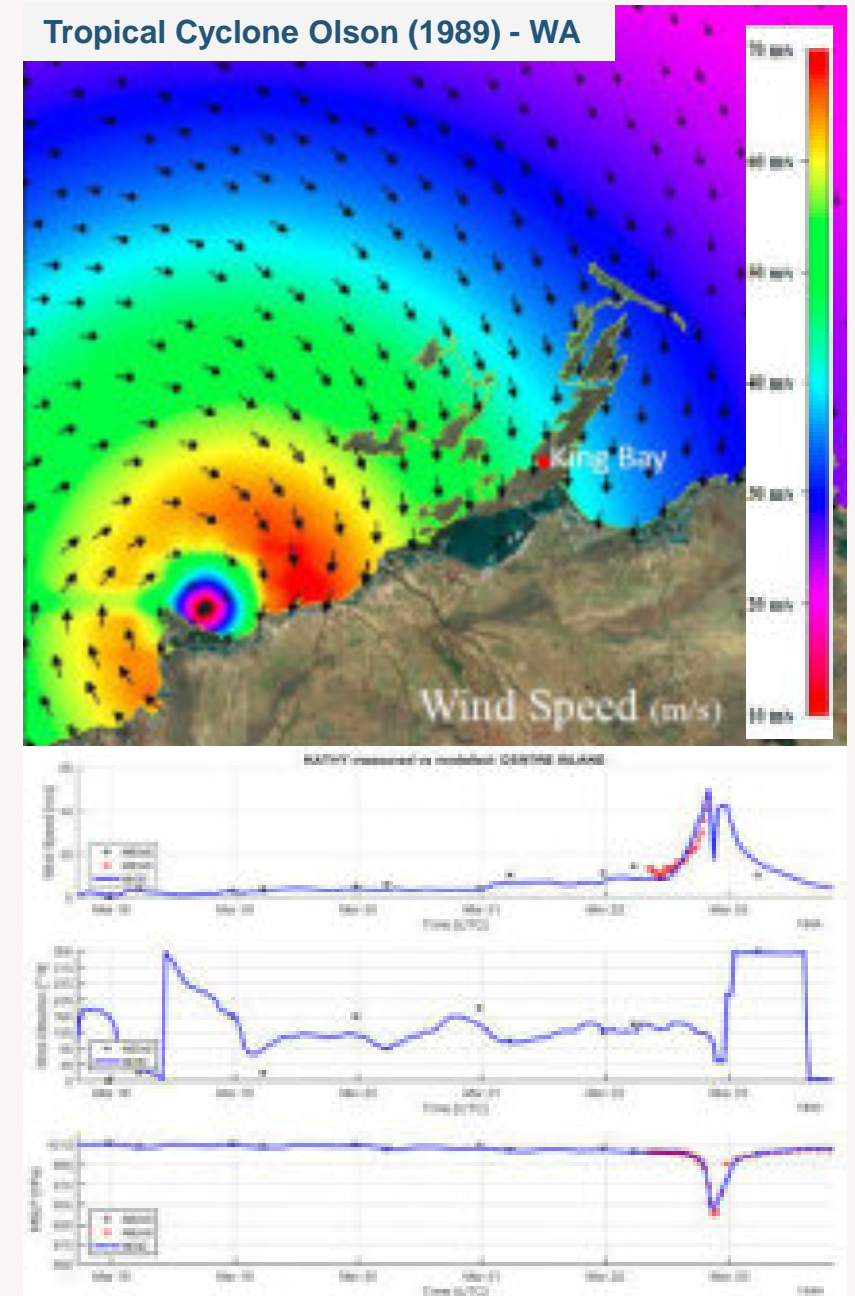- Climatology database / user input is required to inform missing data

Cyclone Wind Model –*Cycwind*

Cycwind model (ECMWF + H10 vortex)
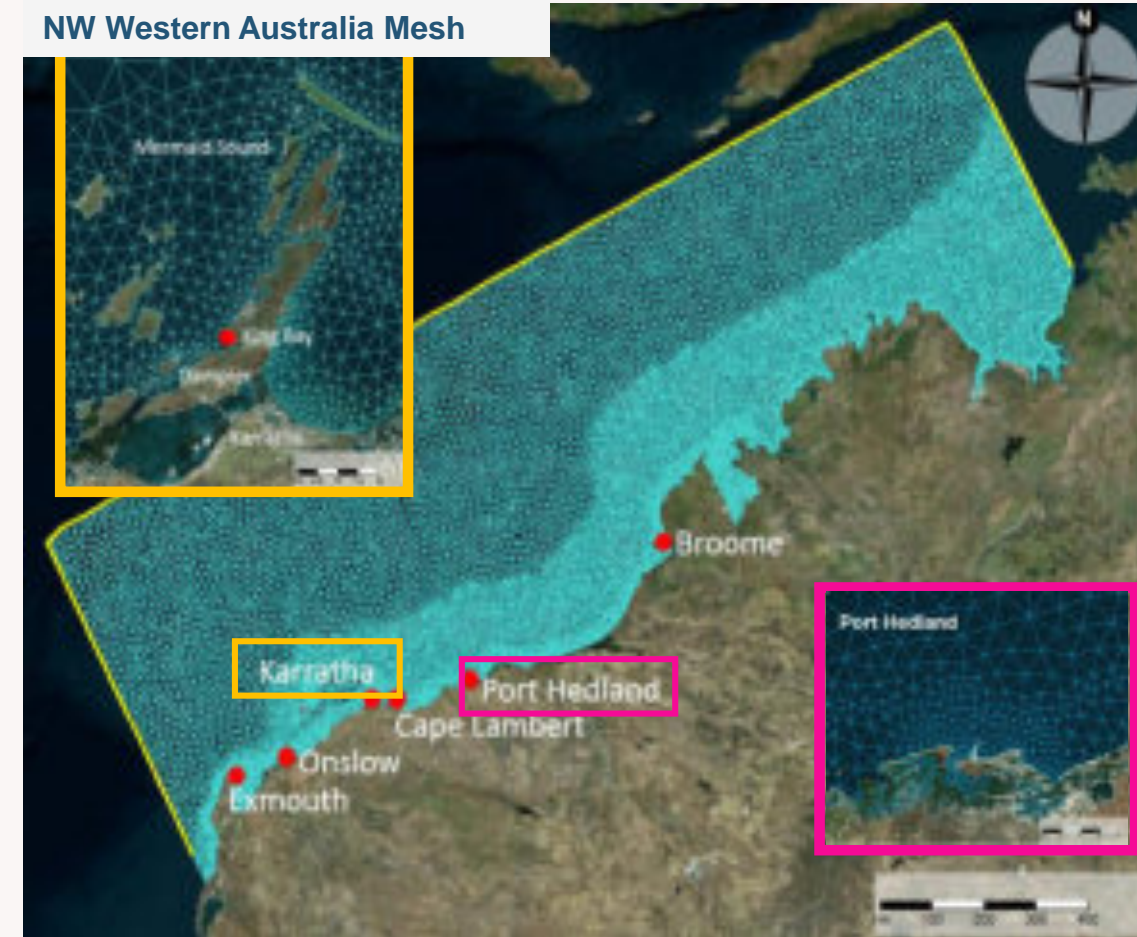

Tropical Cyclone Olson (1989) - WA

Hydrodynamic Model System

- Integrated Delft-FM models

- AHO charted contours and survey data for bathymetry + other survey data sets

Delft FM Model System – Australian Cyclone Region


NW Western Australia Mesh

Tide Model – Delft FM

- Model is one of the most accurate published numerical models for tides across the NWS – used on over 30 government and industry projects.

- Generally predicted tidal water levels within +/- 0.1 m

Tide Validation Metrics – 48 Standard and Secondary Ports
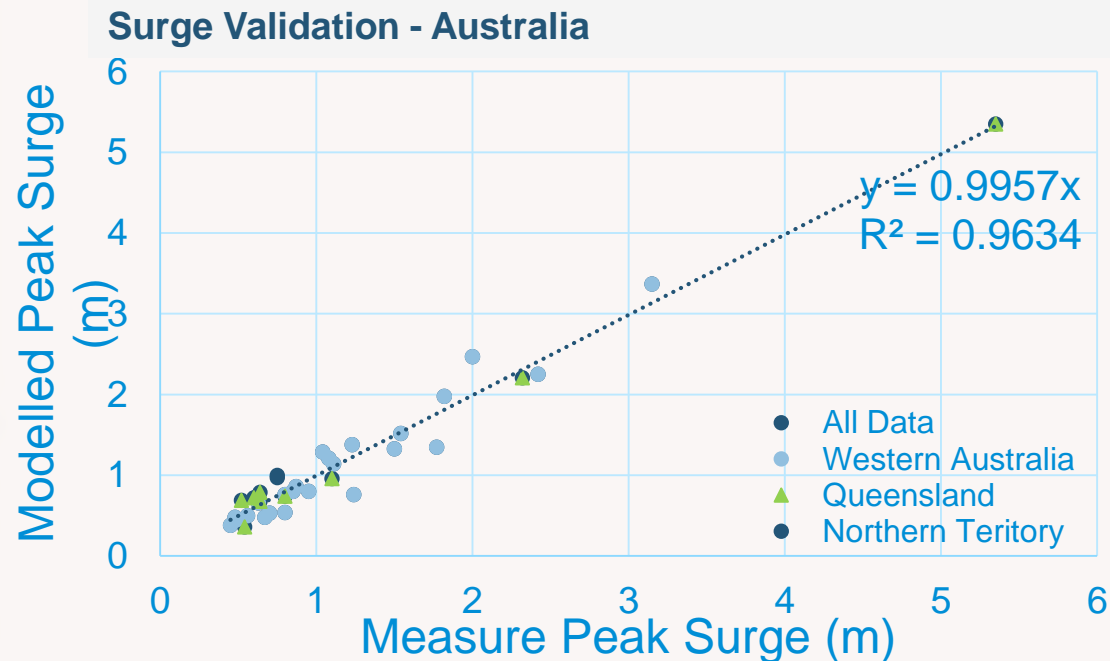
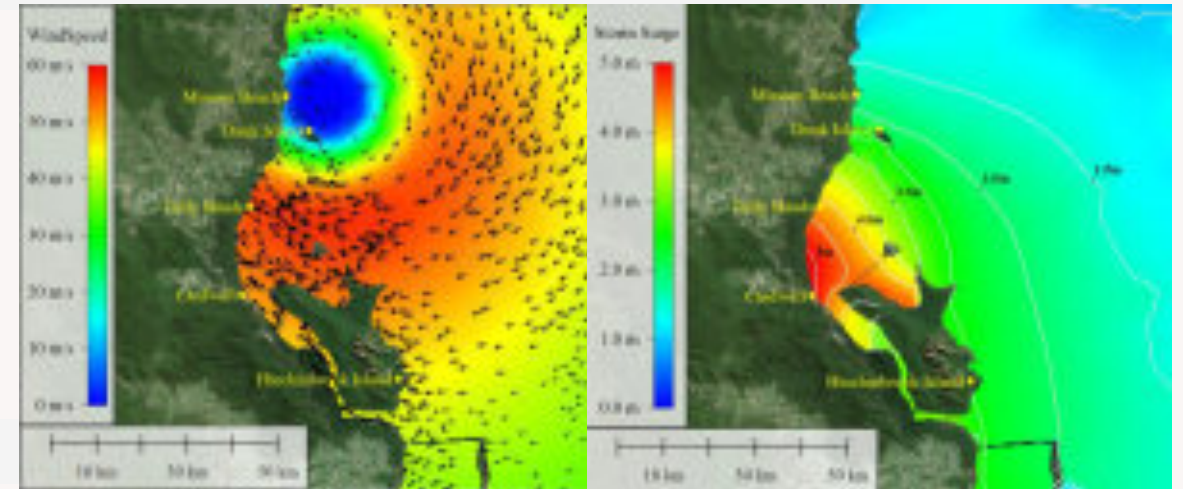| Sites = 48	Bias (m)	Model Skill	RMSE (m)
Mean	0.00	0.99	0.11
Std.	0.02	0.01	0.11
5%	-0.01	0.98	0.02
50%	0.00	1.00	0.08
95%	0.03	1.00	0.31
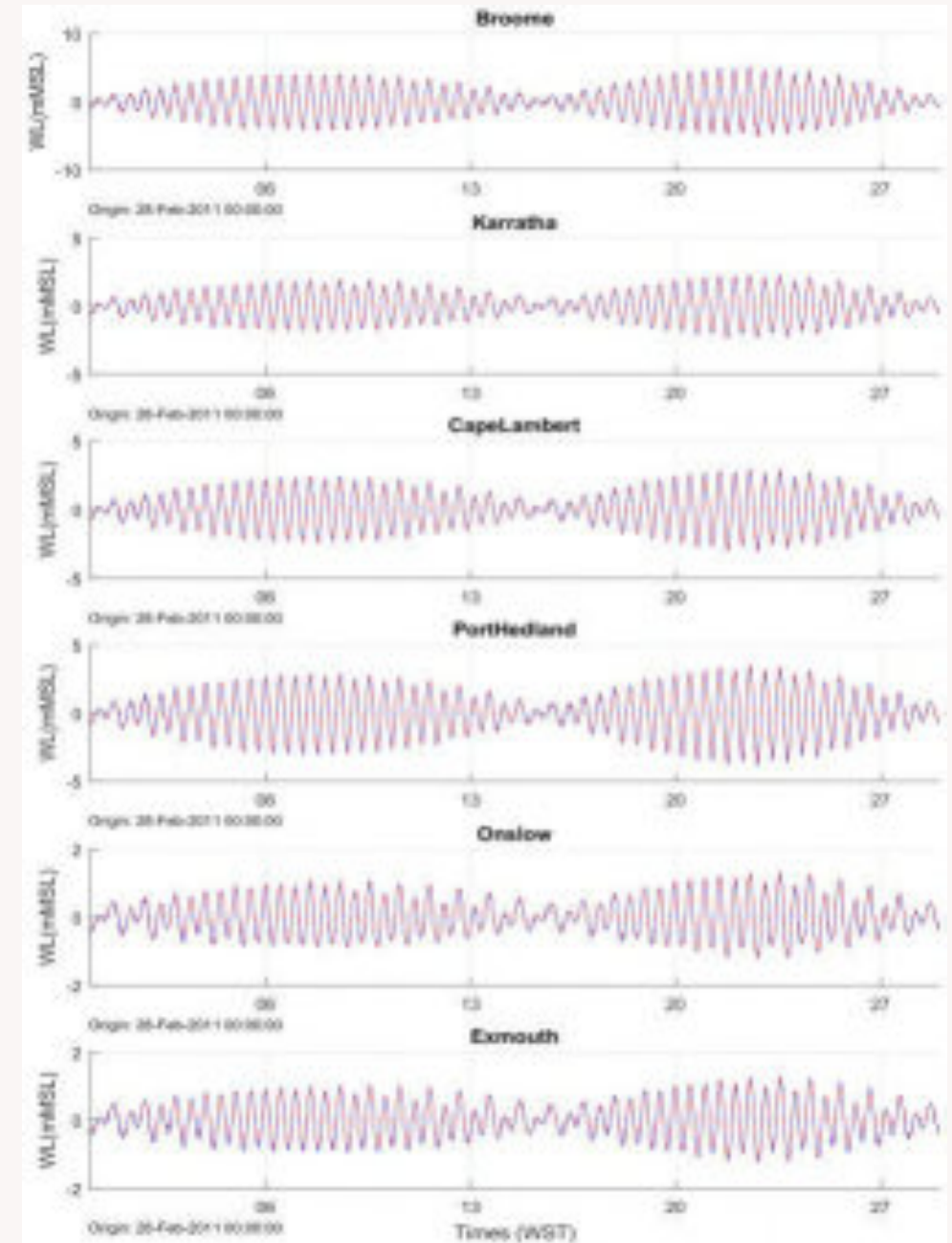
Surge Model – Delft FM

- Baird's model has been validated to over 30 reliable tide gauge measured storm surge data points around Australia including severe Category 5 events

- Validated at Port Hedland for numerous events, including similar track to TC Veronica

- Model accuracy: +/- 10% of measured surge

Surge Validation - Australia

$y = 0.9957x$
$R^2 = 0.9634$

- All Data
- Western Australia
- Queensland
- Northern Teritory

TC Yasi – Modeled Wind and Storm Surge

Cardwell Modeled and Measured Storm Tide and Surge
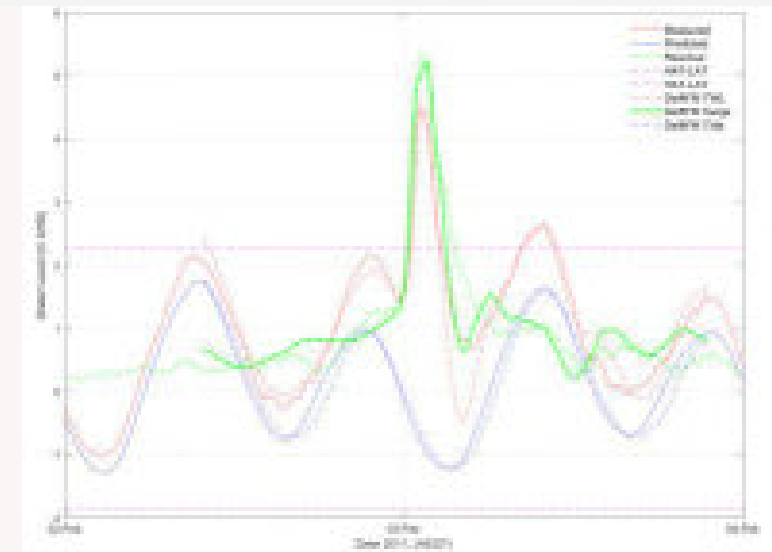
GIS Hydro-connected Inundation

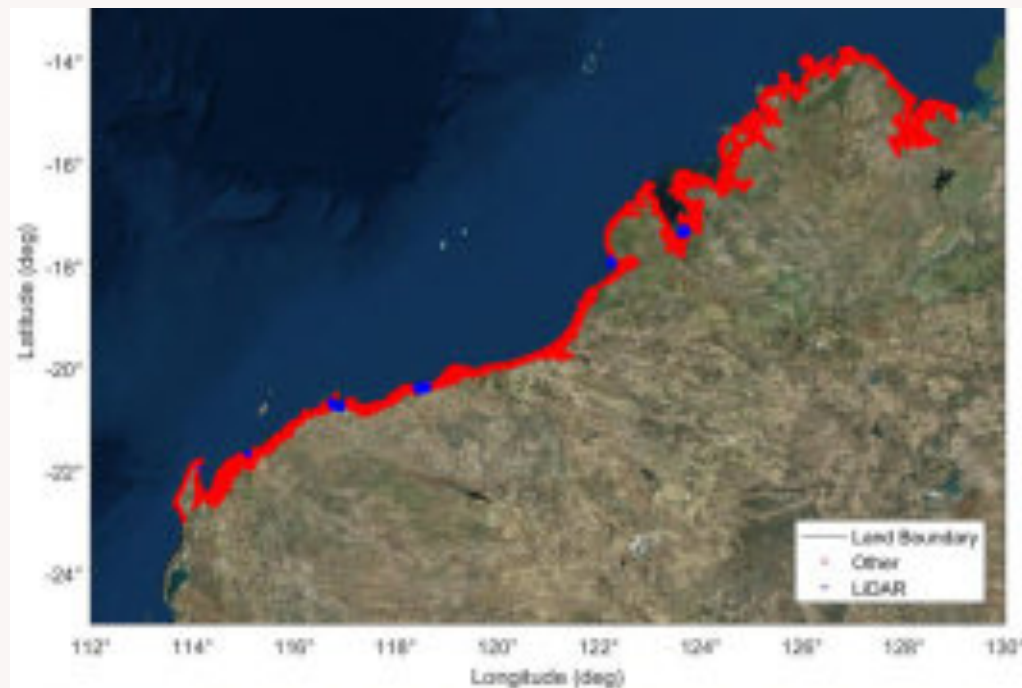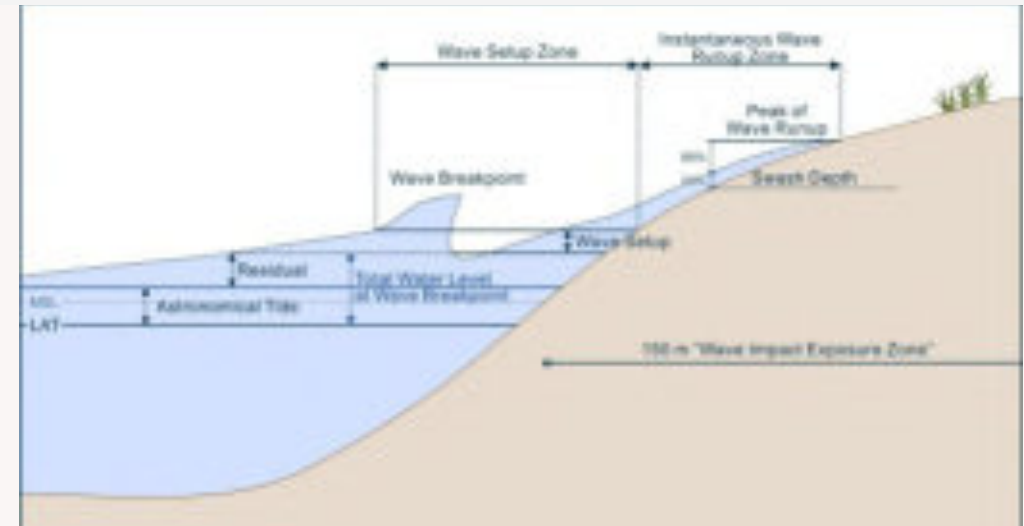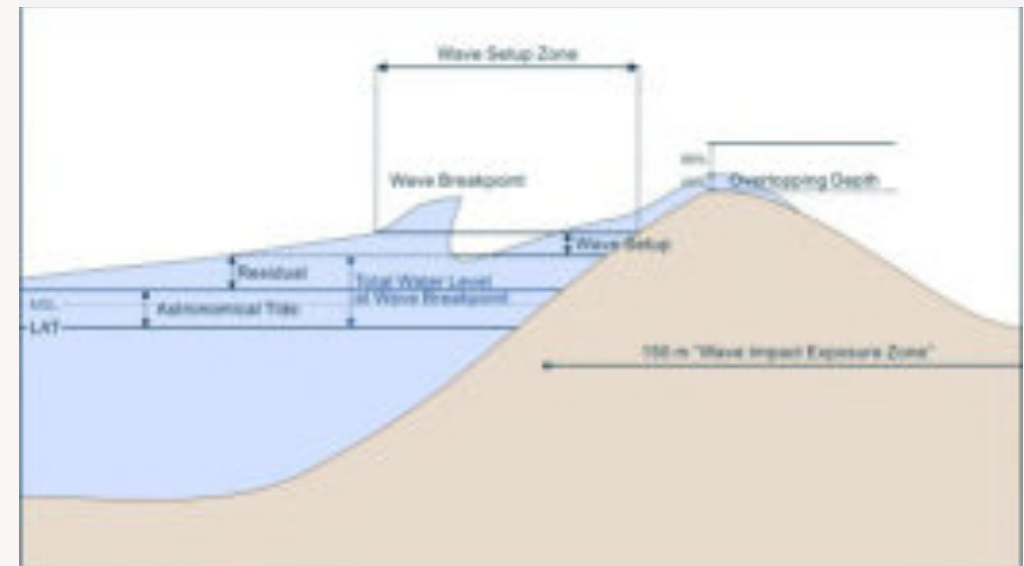- GIS based solution which accounts for hydro-connectivity to the ocean

- 20 m resolution DEM developed across the whole of model area – LiDAR data covers most populated areas
  - ≈ 235 million points in DEM
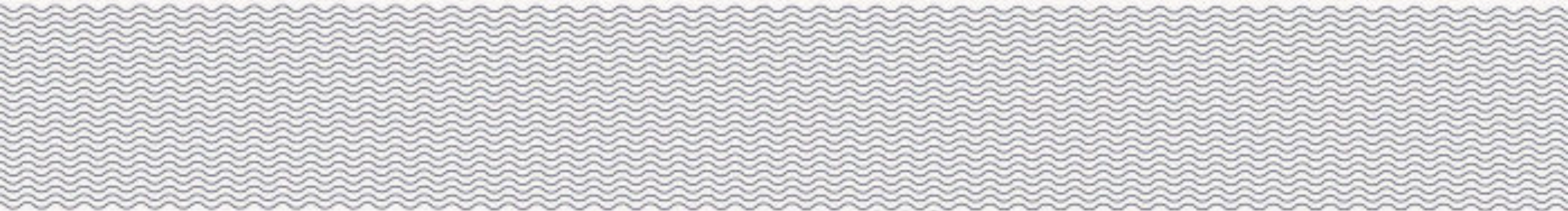
- Wave contribution added to areas exposed to open coast

Swash Model – Full Dune

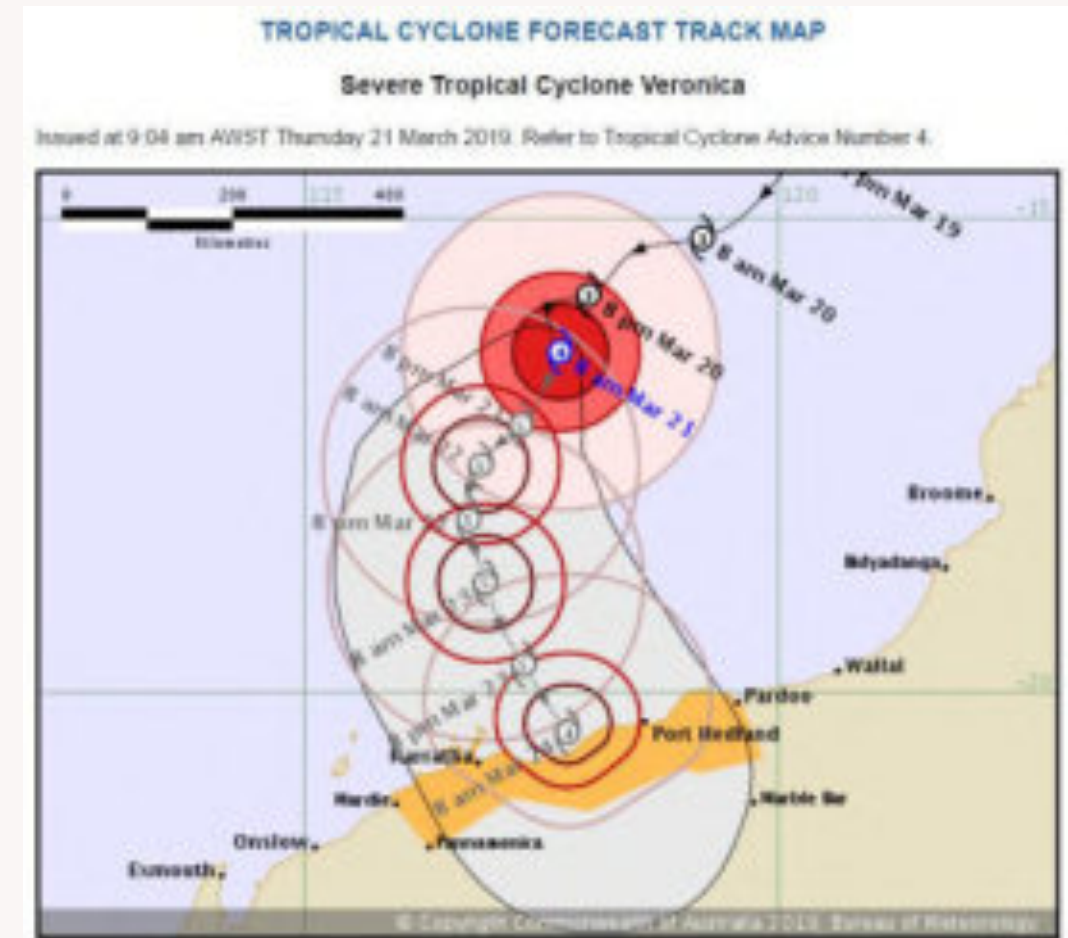**Swash Model – Overtopped Dune**

Case Study - Tropical Cyclone Veronica

Event Development

- Bureau of Meteorology issues Weekly Tropical Cyclone Note on Tuesday 19 March identifying:
    - *A tropical low, north of Western Australia's Kimberley, is forecast to track west-southwest over the next few days and is likely to develop into a cyclone either Wednesday or Thursday. There is potential for the system to impact the Pilbara coast later in the week.*

- Tropical low developed over 19 and 20 March, reaching Category 1 Cyclone on Wednesday 20 March and rapidly intensified over 12 to 24 hrs

- Tropical Cyclone Advice 4 issued @ 09:04 WST (see right) on 21 March 2019, provided a forecast with a high likelihood of the system crossing the Pilbara coast to the west of Port Hedland at Category 4 +

- Cyclones crossing the coast to the west of Port Hedland are particularly severe given the like hood of large storm surge in combination with strong winds, waves and rainfall. The 'design cyclone' for Port Hedland is a track very similar to Tropical Cyclone Advice 4

- The predicted landfall of TC Veronica coincided with the second largest tides of the year occurring on 24 March 2019

- BHP Marine engaged Baird on 21 March 2019 to provide regular updates on TC Veronica, particularly flooding impacts on Port Hedland

TROPICAL CYCLONE FORECAST TRACK MAP

Severe Tropical Cyclone Veronica

Issued at 9:04 am AWST Thursday 21 March 2019. Refer to Tropical Cyclone Advice Number 4.

Potential Impact – Public Warning

- At 16:00 WST on 22 March, Department of Fire and Emergency Services and the Town of Port Hedland issue a major flood alert for Port Hedland warning of risk 7.9 m AHD (11.8 m CD) storm tide (tide + surge)

- This is would be a catastrophic event beyond anything experienced within the Port Hedland region within recorded history (post 1900)

**Port Hedland 1939 ≈ 5.7 m AHD**
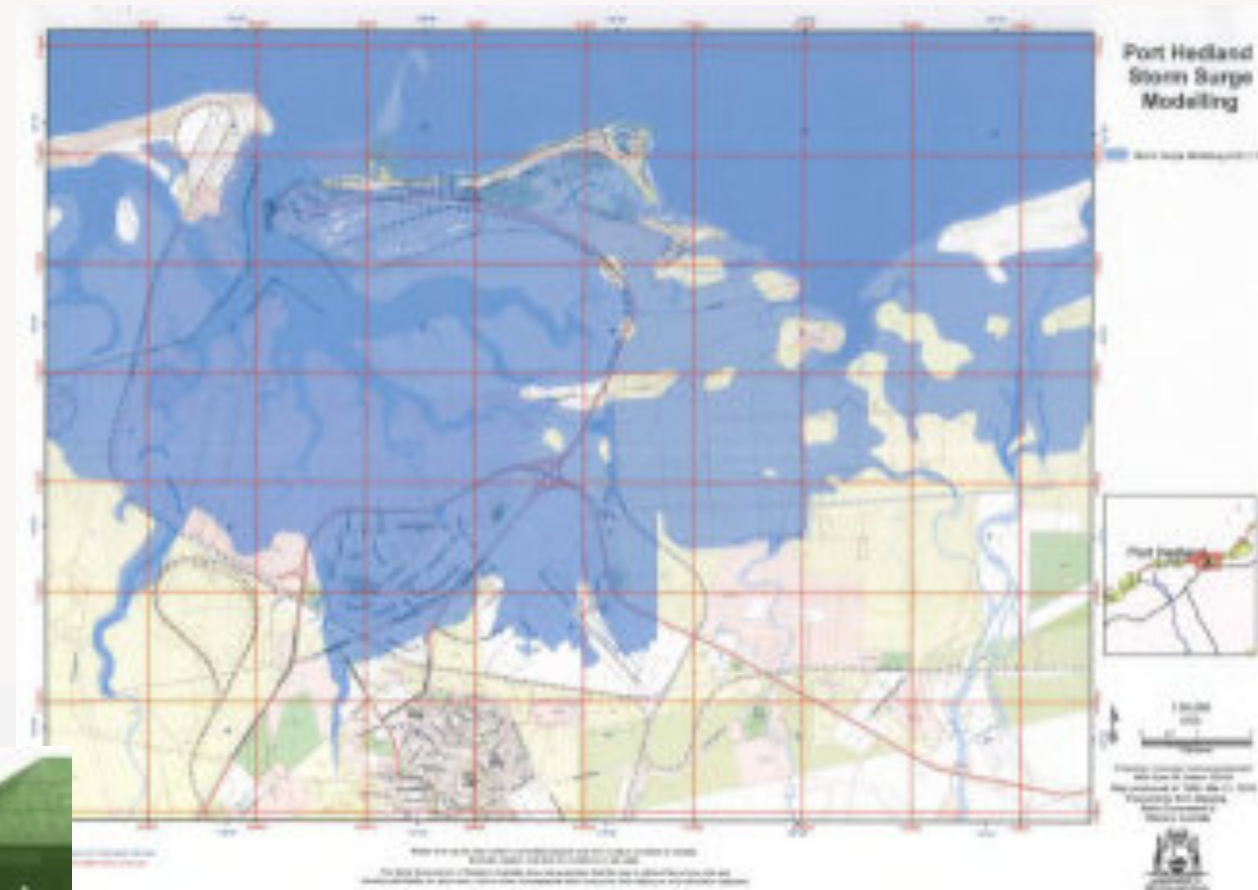
# Event Track
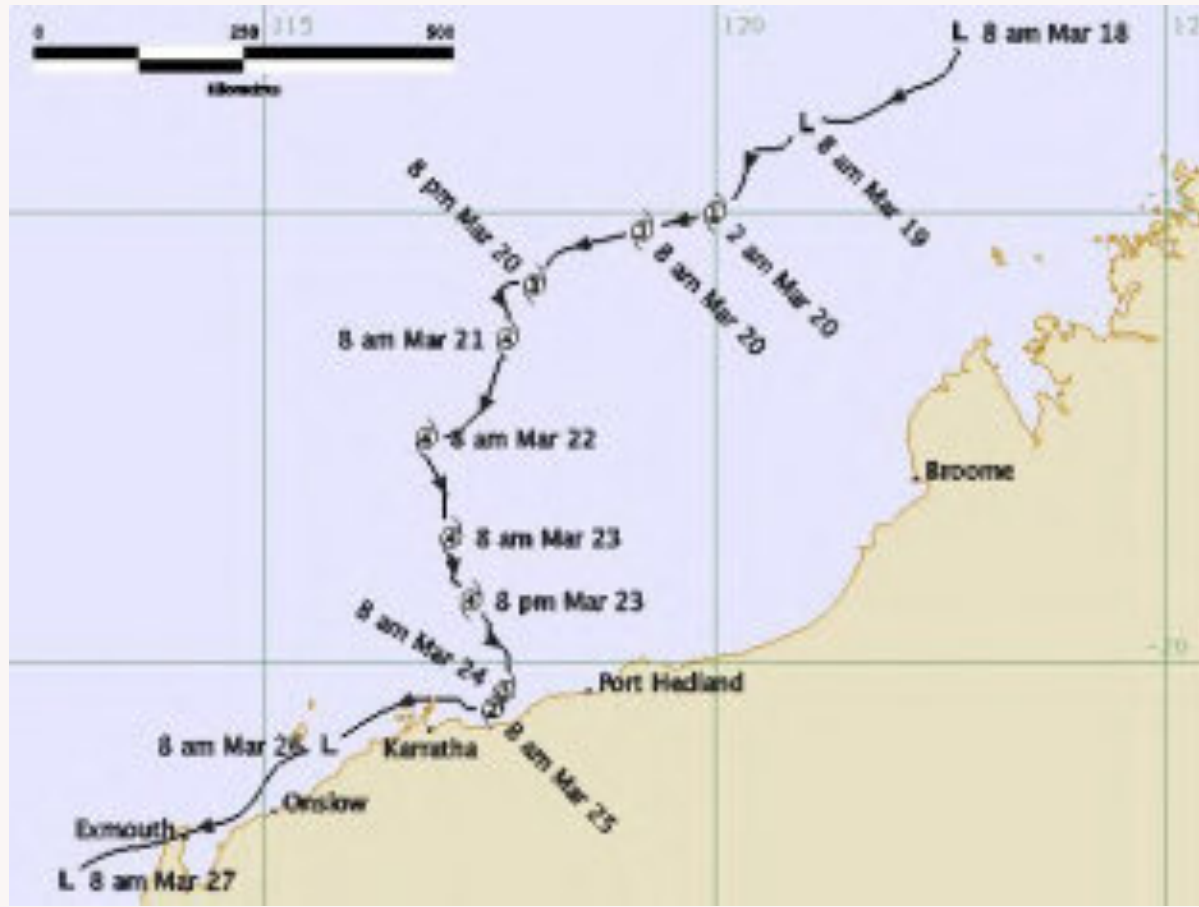
Operational Data

- System pulls operational data from a range of sources including:
    - Operational cyclone track data from Bureau of Meteorology (Technical bulletin data)
    - Real time weather observations from Bureau of Meteorology
    - Real time data from our client's metocean monitoring system (only for their exclusive use)
    - Forecast wind data sets from a range of agencies (ECMWF, NOAA, BoM)

Operational Data Sites on NWS Utilised for a Client
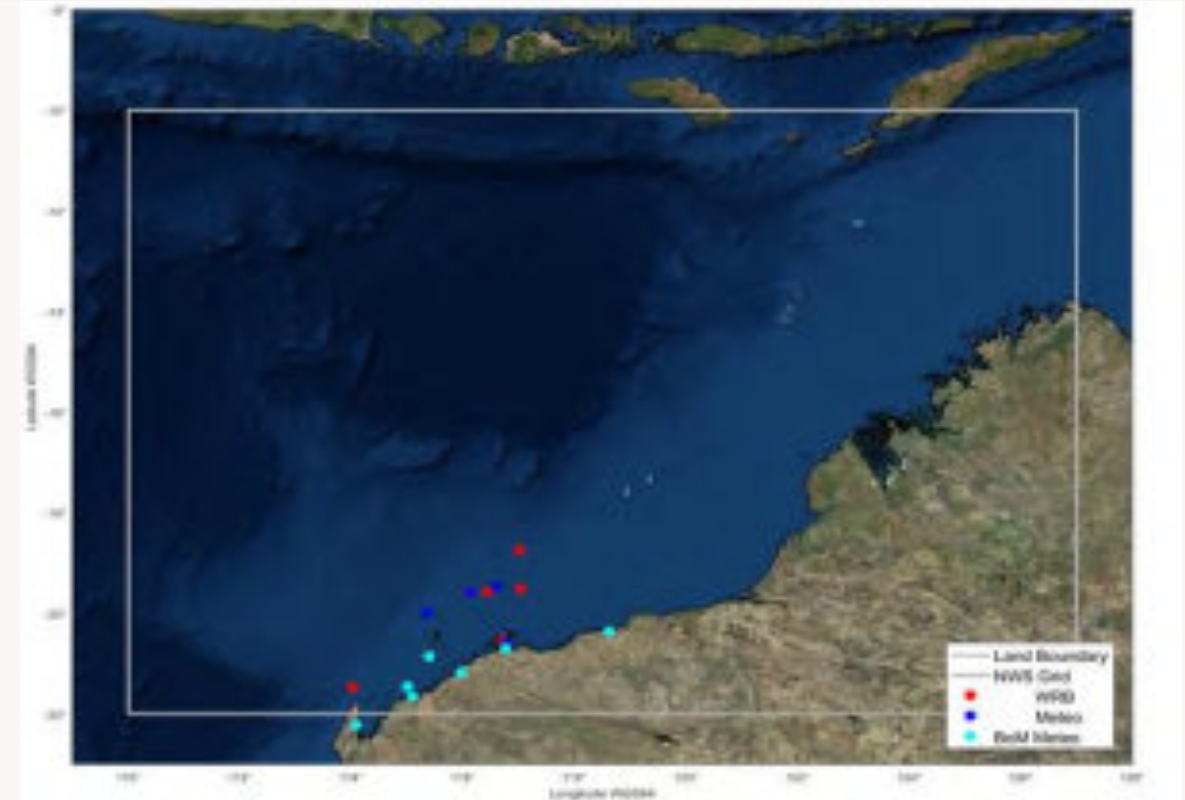
Forecast / Nowcast Winds

- System track over 1-12 hours well described by ECMWF forecast

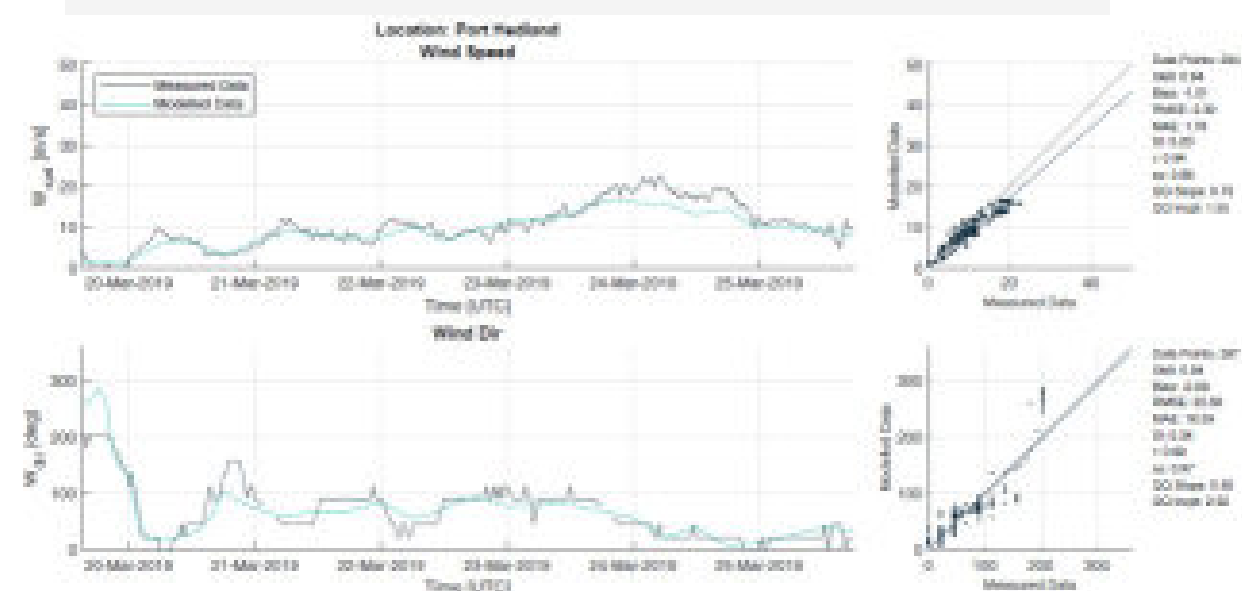- Vortex enhancement better described intensity and winds within 200 km of the eye.
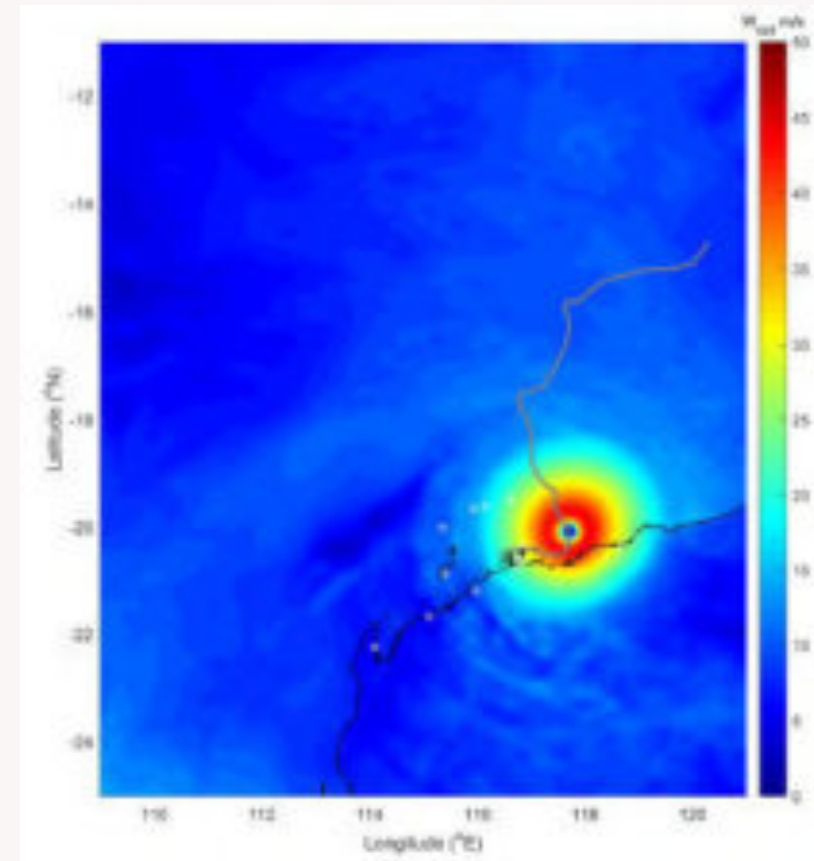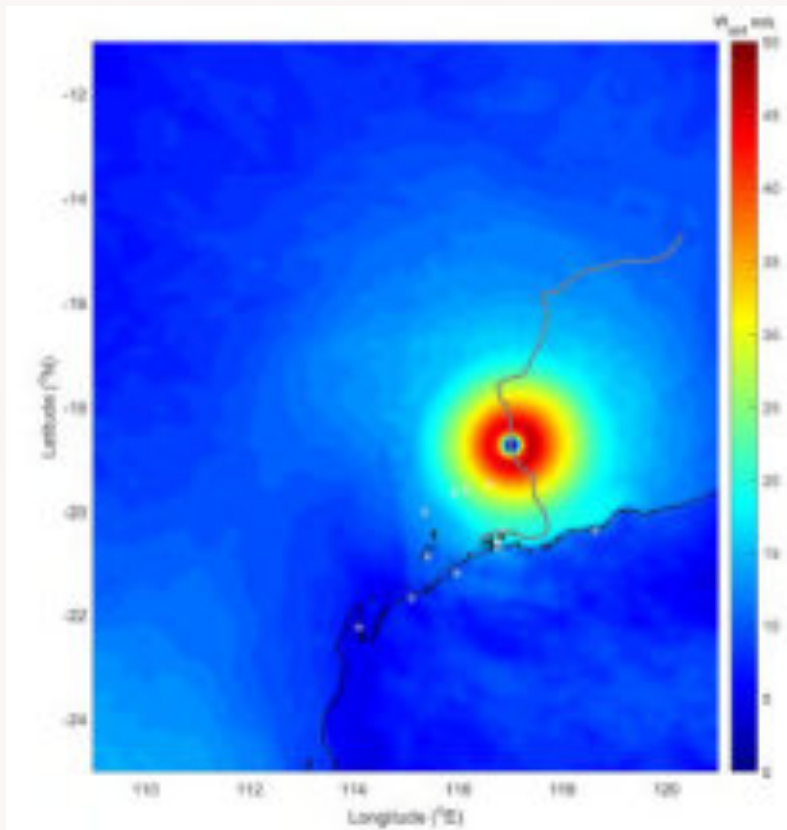
Forecast / Nowcast Winds

- Offshore and Coastal winds generally well described around the whole storm radius

Cycwind – ECMWF 6 hr Nowcast + Holland (2010) Vortex

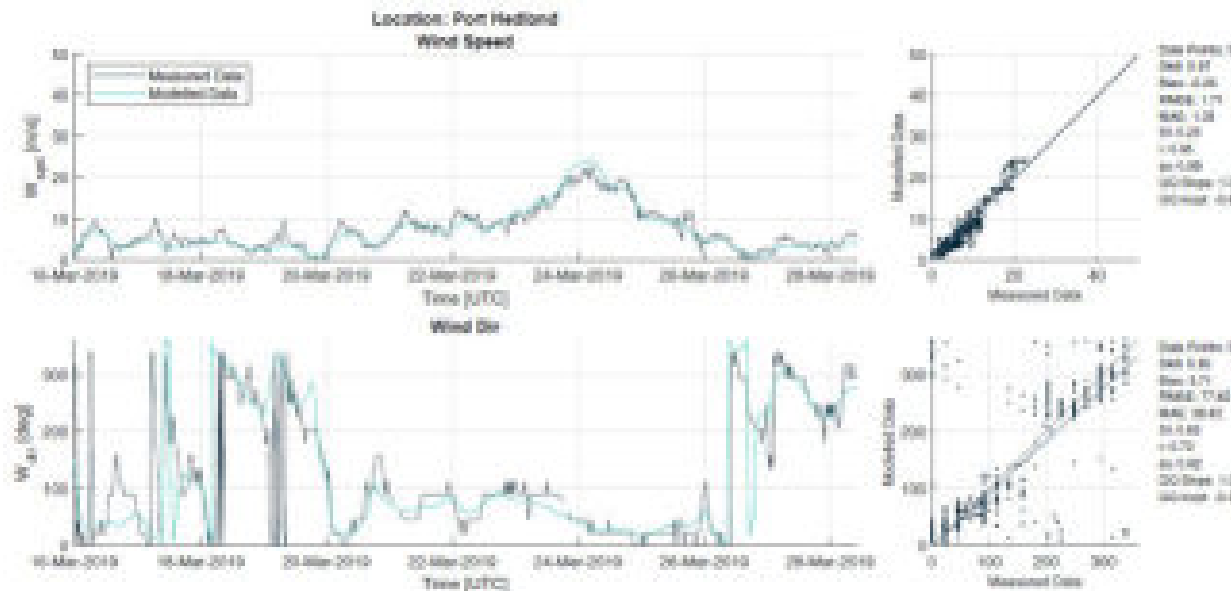**ECMWF – 6 hr Nowcast**

Forecast / Nowcast Winds

- Offshore and Coastal winds generally well described around the whole storm radius

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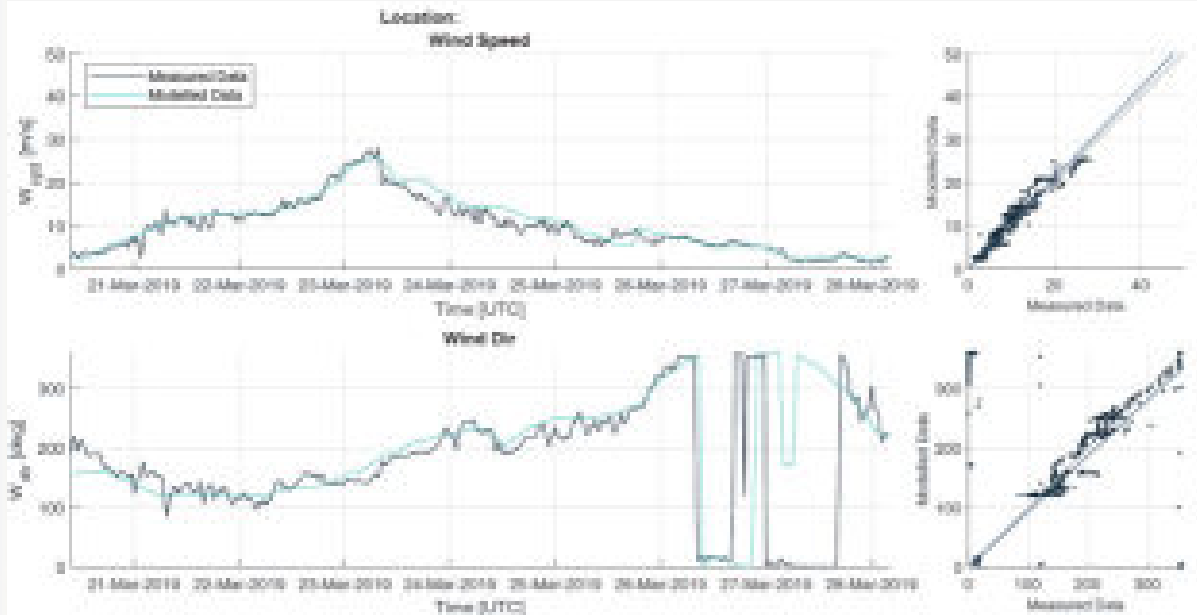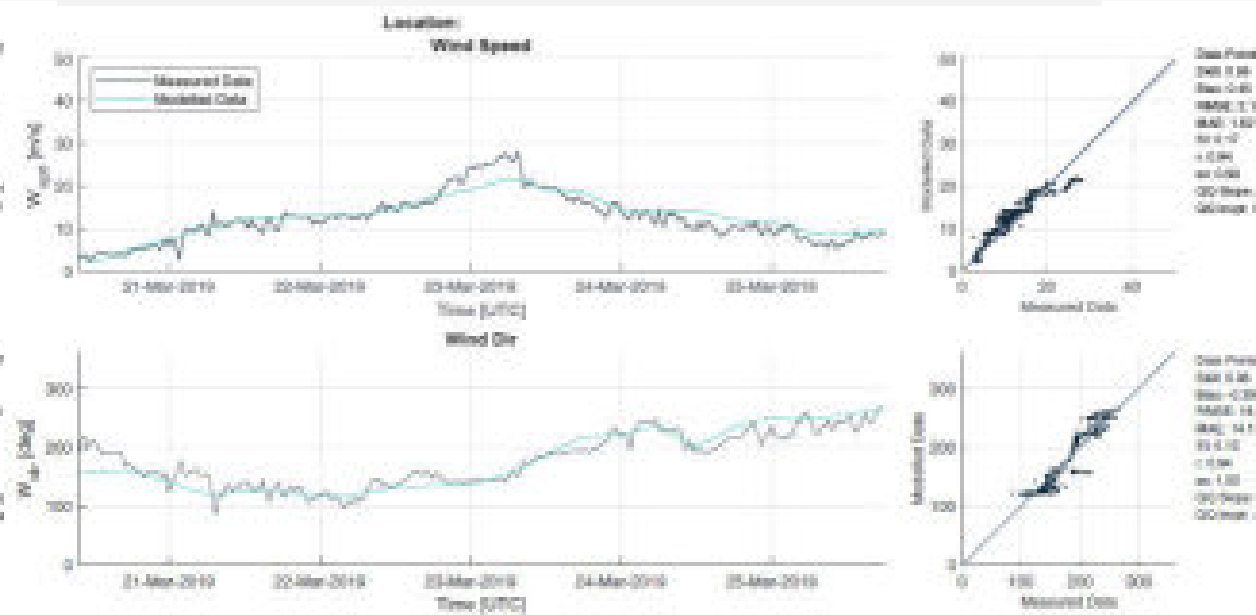
ECMWF – 6 hr Nowcast

Storm Tide Forecast Bulletin's: TC Veronica

- Issued 3-4 times per day

- Present current forecast and observed data with predictions

- Storm tide forecast presented for current forecast as well as severe scenarios for Port Hedland within forecast track accuracy
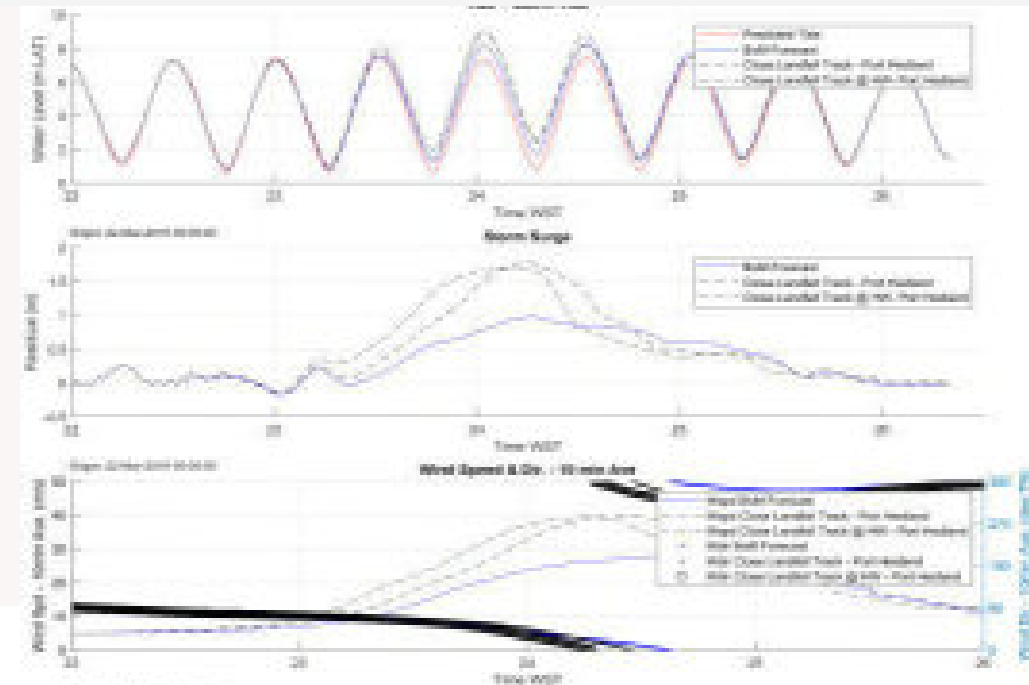
Storm Surge Forecast – Models Output

Real Time Data Summary – Department of Transport

2.82

Forecast Summary: Issued @ 04:42 WST, 22 March 2019

Storm Tide Prediction – Port Hedland

Based on BoM track forecast

- Tide level exceeding HAT is likely due to large tides and cyclone track being west of Port Hedland
- Current forecast track has peak water level near 8.0 m LAT - +0.5 m HAT
- If the track shifted 0.4 deg east at landfall which is within the track uncertainty, storm surge could exceed 2 m, and water level exceed 9 m LAT. This is an extreme storm tide.
- Storm tide is highly sensitive to phase of track and tide and needs to be reviewed with each forecast bulletin
- At 04:00 22/3/2019, positive surge of 0.3 to 0.4 m observed at Port Hedland

Forecast Scenarios 23 March 2019

- On 22 and 23 March, forecast impact on Port Hedland increased significantly:
  - Forecast on 22 March was most likely to be severe, but flood levels significantly mitigated by storm surge being coincident with low tide. However, risk of much larger flood if forecast cyclone speed changed.
  - On 23 March, forecast impact worsened, track close to Port Hedland and more uncertainty in track timing as the track was not increasing in speed as expected

- Storm surge prediction:
  - Best Track Forecast: 8.7 m CD
  - High risk of extreme water level exceeding 10 m CD depending on track and tide phasing

- Storm surge forecast summary:
  - *The current (05:39 WST 23 March) TC Veronica forecast track is the most severe event to impact on Port Hedland in achieved records, and the current track would exceed the 1939 cyclone for wind, rainfall, wave and storm tide hazard.*
  - *Current track has the cyclone crossing the coast to the west of Port Hedland near low water, significantly reducing the peak water levels. Ensemble modelling has been completed for the eye crossing the coast +/- 5 hrs from current track which would make peak surge coincident with high tide.* **In those scenarios, peak water levels inside Port Hedland harbour are expected to exceed 10 m LAT.**
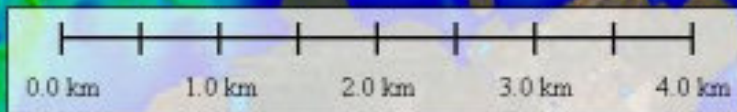
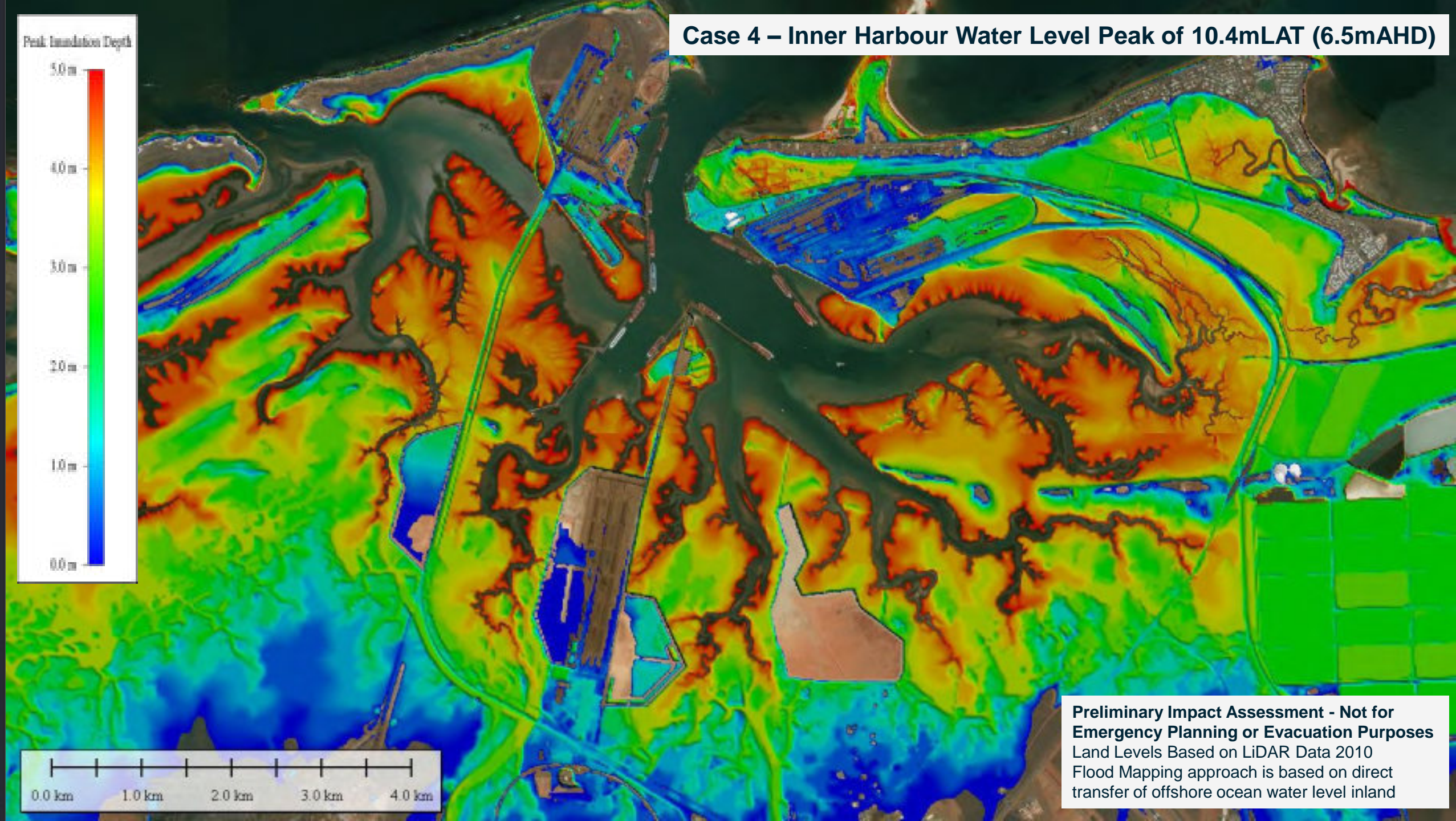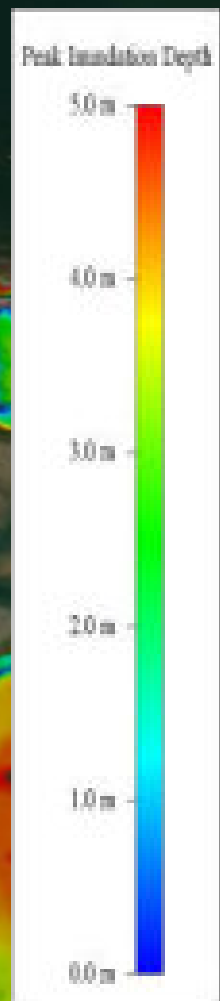

Forecast @ 06:26 WST 23/03/2019
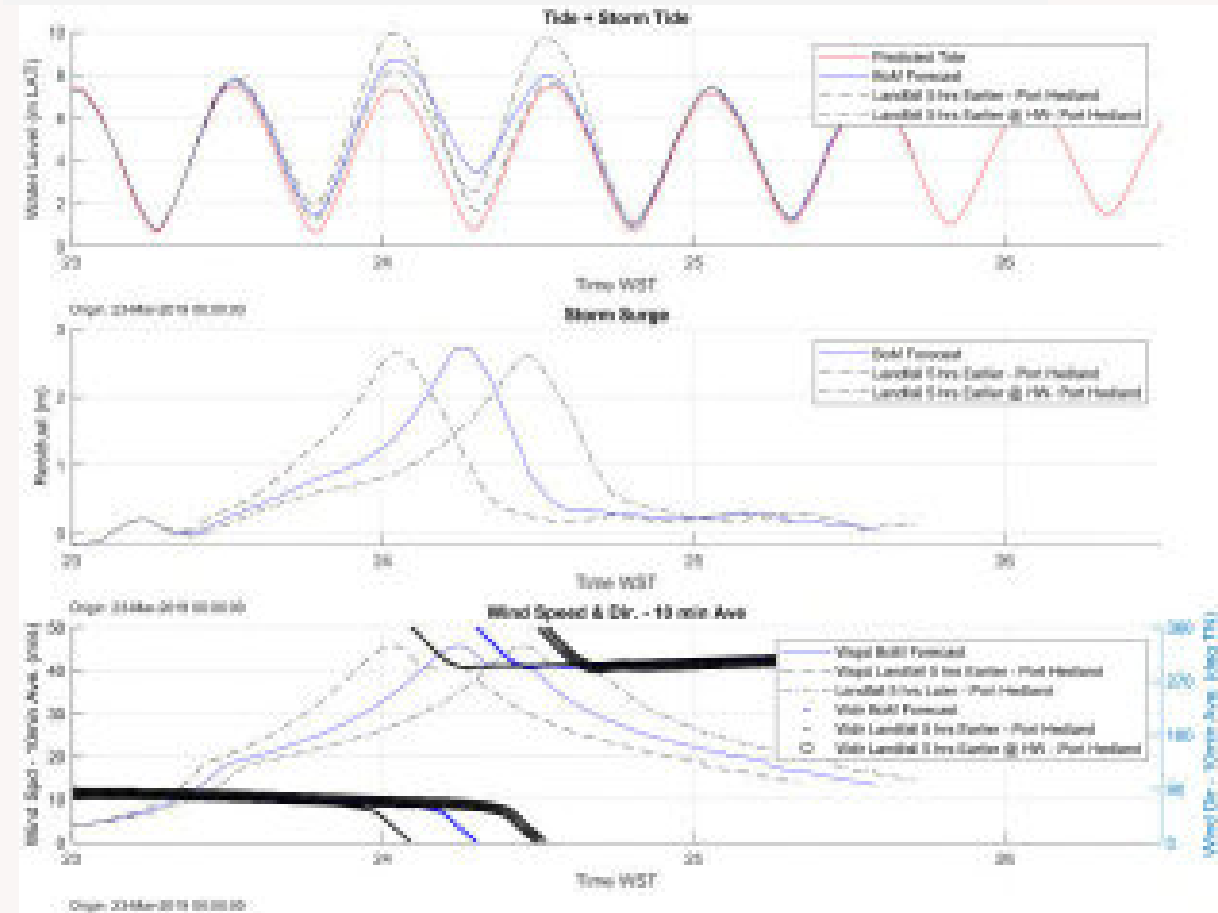
Flood Mapping Cases – Prepared 23 March 2019

- Flood Depth is shown for the peak inundation depth associated with 4 scenarios (Case 1 -4)

- Mapping has been undertaken in GIS with a DTM using a hydro-connectivity algorithm.

- Open Coast water levels have 1.2m additional water level due to wave setup based on PH CVS (Cardno, 2010)

- Maps can be applied based on observed peak water levels from the Port Hedland Inner Harbour (https://www.transport.wa.gov.au/imarine/port-hedland-tide.asp)

Case	Inner Harbour	Open Coast
1	4.8 m AHD	6.0 m AHD
2	5.5 m AHD	6.7 m AHD
3	6.0 m AHD	7.2 m AHD
4	6.5 m AHD	7.7 m AHD

Case	Inner Harbour	Open Coast
1	8.7 m LAT	9.9 m LAT
2	9.4 m LAT	10.6 m LAT
3	9.9 m LAT	11.2 m LAT
4	10.4 m LAT	11.6 m LAT

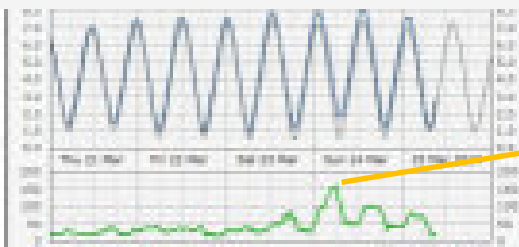Case 4 – Inner Harbour Water Level Peak of 10.4mLAT (6.5mAHD)

Peak Inundation Depth
5.0 m
4.0 m
3.0 m
2.0 m
1.0 m
0.0 m

0.0 km   1.0 km   2.0 km   3.0 km   4.0 km

24 March 2019 – What Happened?

- TC Veronica weakened and slowed in track on 24 March
- Slow movement contributed to significant weakening in the southeast quadrant
- Offshore data around 06:00 WST 24 March indicated weakening trend

Operational Track
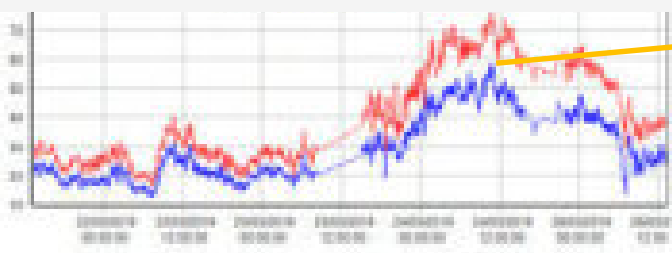

Forecast @ 18:19 WST 23/03/2019

Baird Operational Model Validation with Nowcast Data

- Port Hedland Forecast

  - Modelled Peak Surge ≈ 1.5 m, agreed with Berth 2 gauge from DoT

  - Modelled peak wind (10 min avg) 30 m/s, PPA from Port Hedland Tower: 30 m/s (58 kts)

  - Modelled Peak Water Level: 8.4 m LAT, agreed with Berth 2 gauge from DoT of 8.3 m LAT
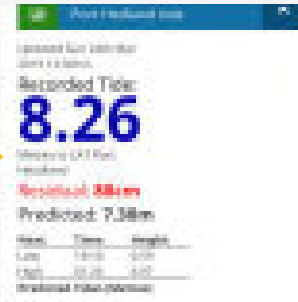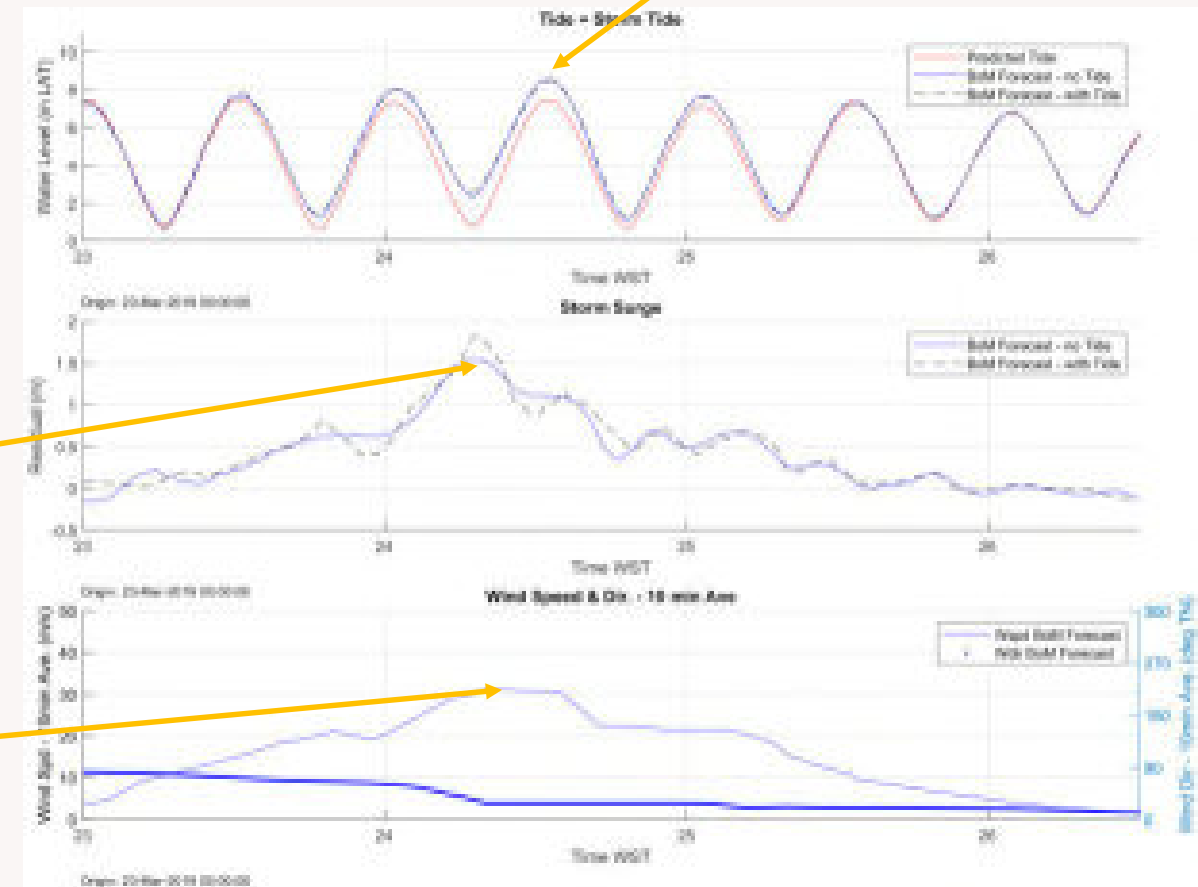
Operational Model @ 03:32 WST 25/03/2019
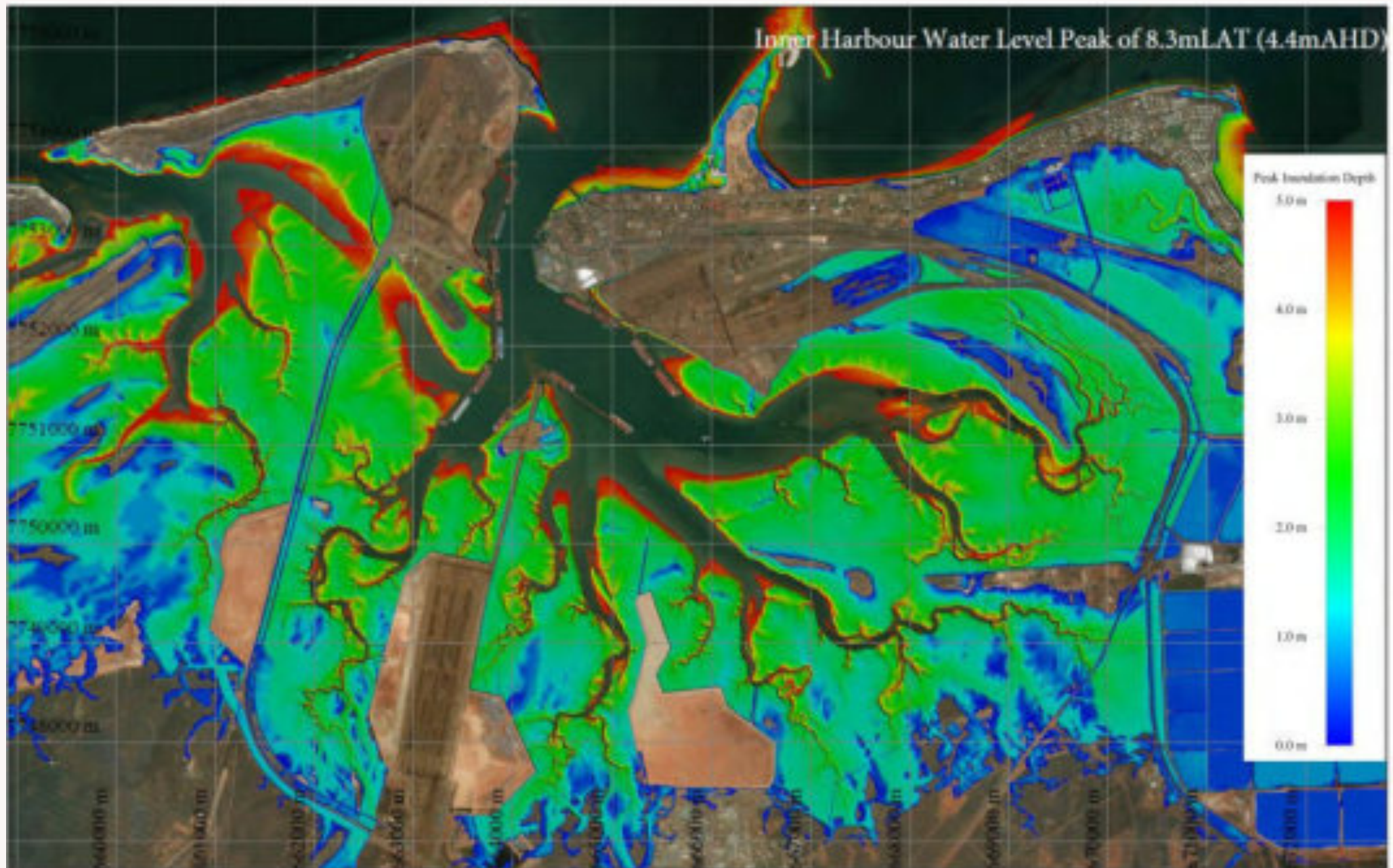
Measured Surge (DoT, Berth 2)

Measured Wind Port Hedland Tower (PPA)

Inner Harbour Water Level Peak of 8.3mLAT (4.4mAHD)

Peak Inundation Depth
5.0 m
4.0 m
3.0 m
2.0 m
1.0 m
0.0 m

0.5 km   1.5 km   2.5 km   3.5 km   4.5 km

Preliminary Impact Assessment – Not for Emergency Planning or Evacuation Purposes
Land Levels Based on LiDAR Data 2010
Flood Mapping approach is based on direct transfer of offshore ocean water level inland
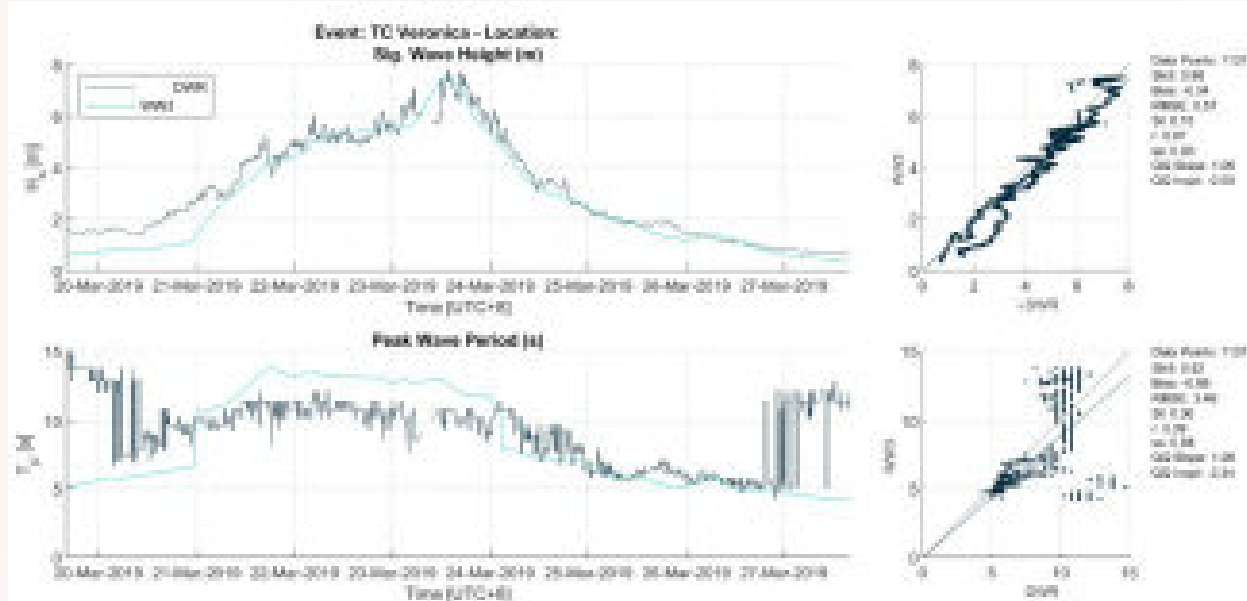
Forecast / Nowcast Waves

- High resolution WW3 model validated for 10 cyclone events over last 15-years
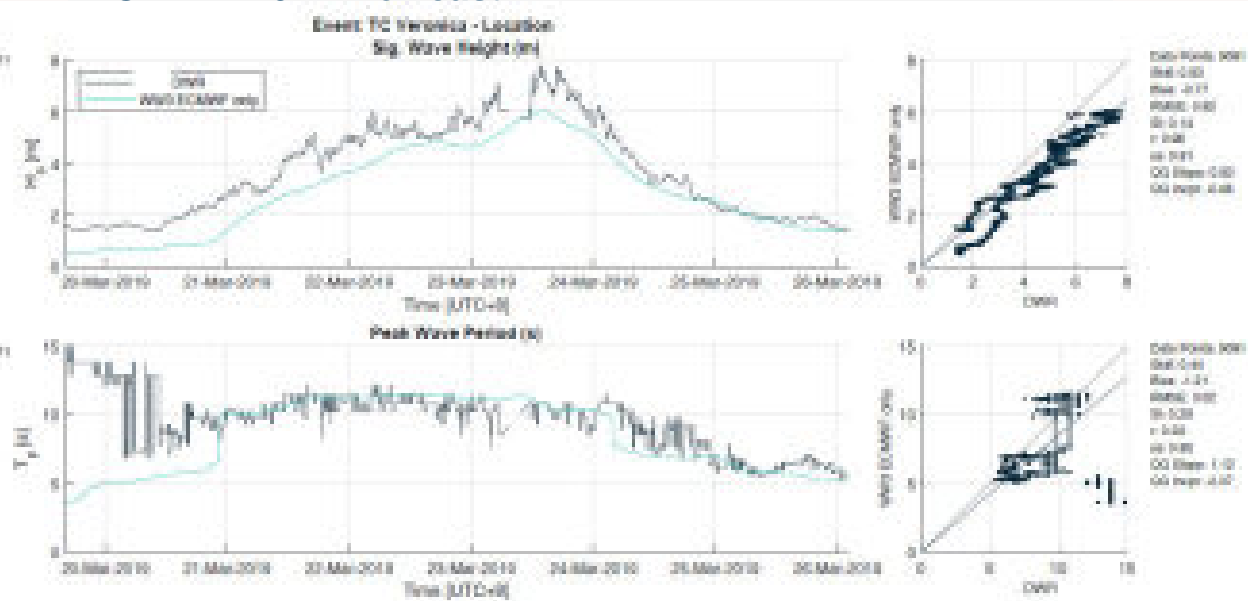
Forecast / Nowcast Winds

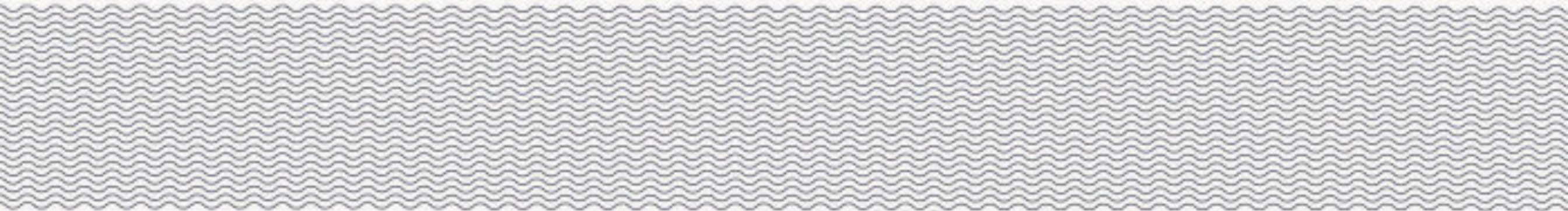- Offshore and Coastal winds generally well described around the whole storm radius
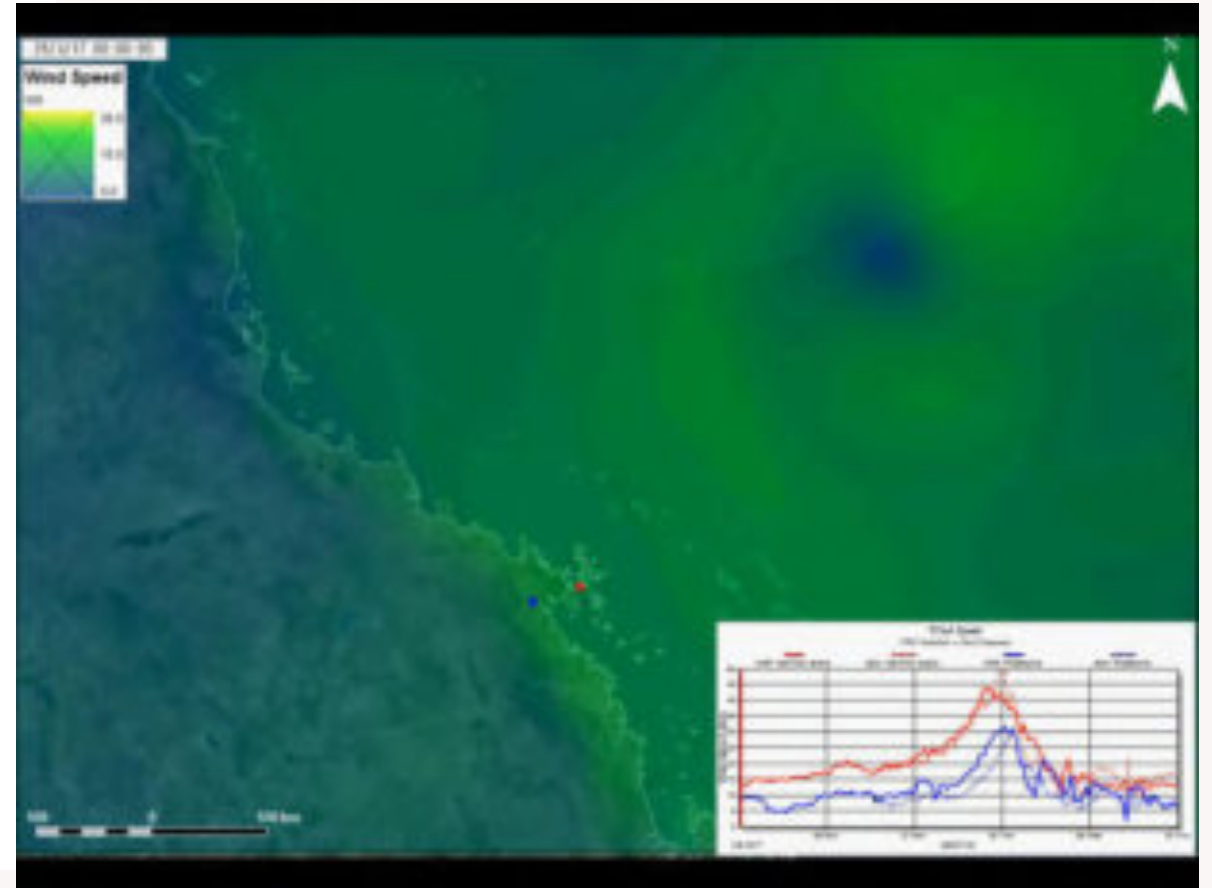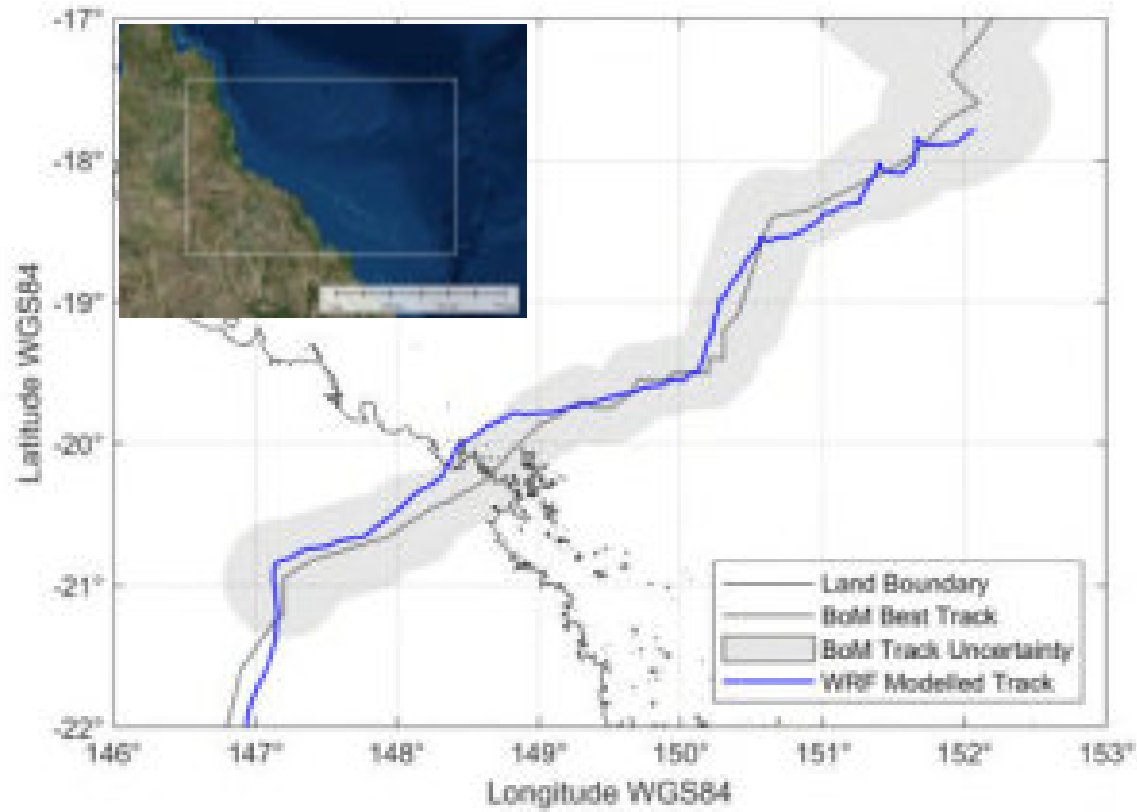
Cycwind – ECMWF 6 hr Nowcast + Holland (2010) Vortex

ECMWF – 6 hr Nowcast

Emerging Technologies

WRF modeling of cyclone events

Extreme event combined flooding - Cairns

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