Innovative Wave Transformation Algorithm for Improved Short-term Wave Forecasting

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Presentation Outline

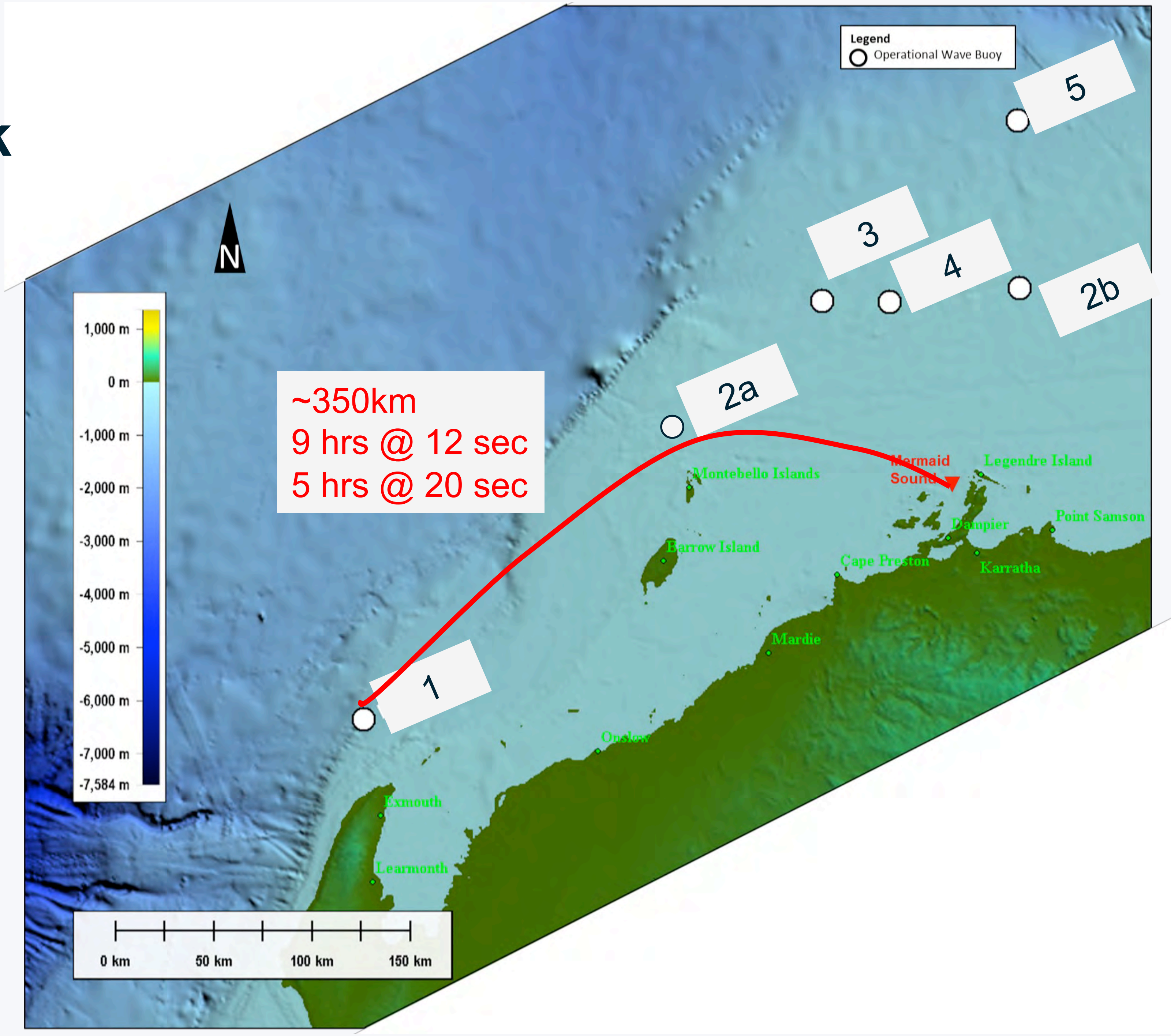
- Project Background
- Offshore Buoy Network
- Recap of the Spectral Wave Transformation Method
- Advances to the Transformation Method
- Amalgamation of Multiple Transformations
- Nearshore Swell Forecasting Performance
- Operational Implementation

Development Background

- Requirement for accurate short-term operational forecasts of swell conditions
- Availability of high frequency real-time measurements with relatively extensive spatial coverage
- Requirement to integrate one or any combination of offshore buoys and provide redundancy to the forecasts
- Requirement to produce directional wave spectra at nearshore locations

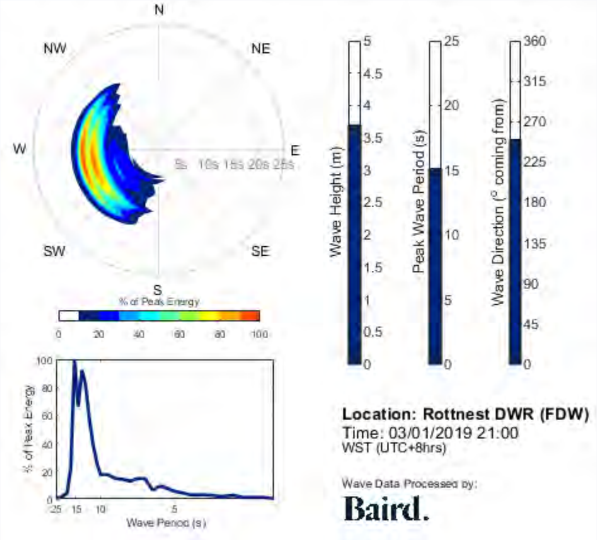
Offshore Buoy Network

- Five offshore buoys
- Seasonal configuration
- Distances from Mermaid Sound between ~100 to 350km; or 1.5 to 9+ hrs propagation time

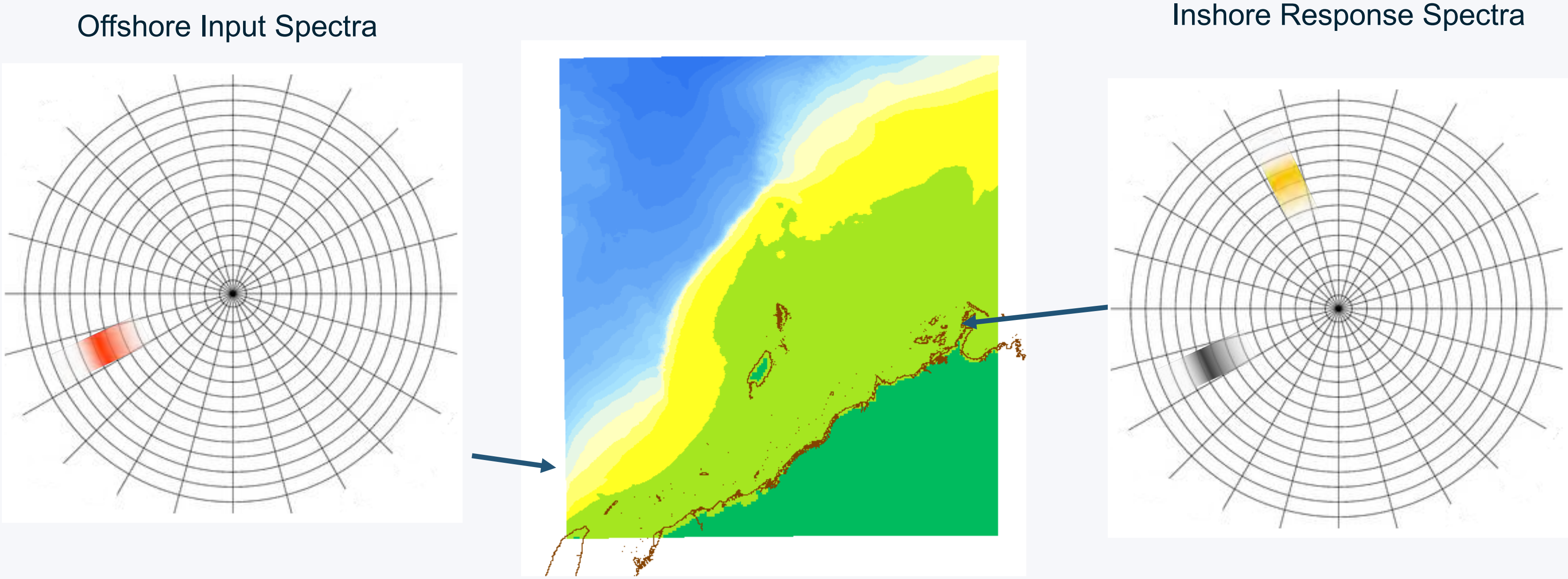


Recap of the Wave Transformation Method

- Spectral Wave Transformation
  - Data in: $S(f,\theta)$
  - Transfer: $\Delta S(f,\theta)_{i,j}$
  - Data out: $\sum [\Delta S_{i,j} \times S_{i,j}] = S_{inshore}(f,\theta)$
- Equivalent validation to high-resolution 3rd generation spectral wave model
- Extensively applied

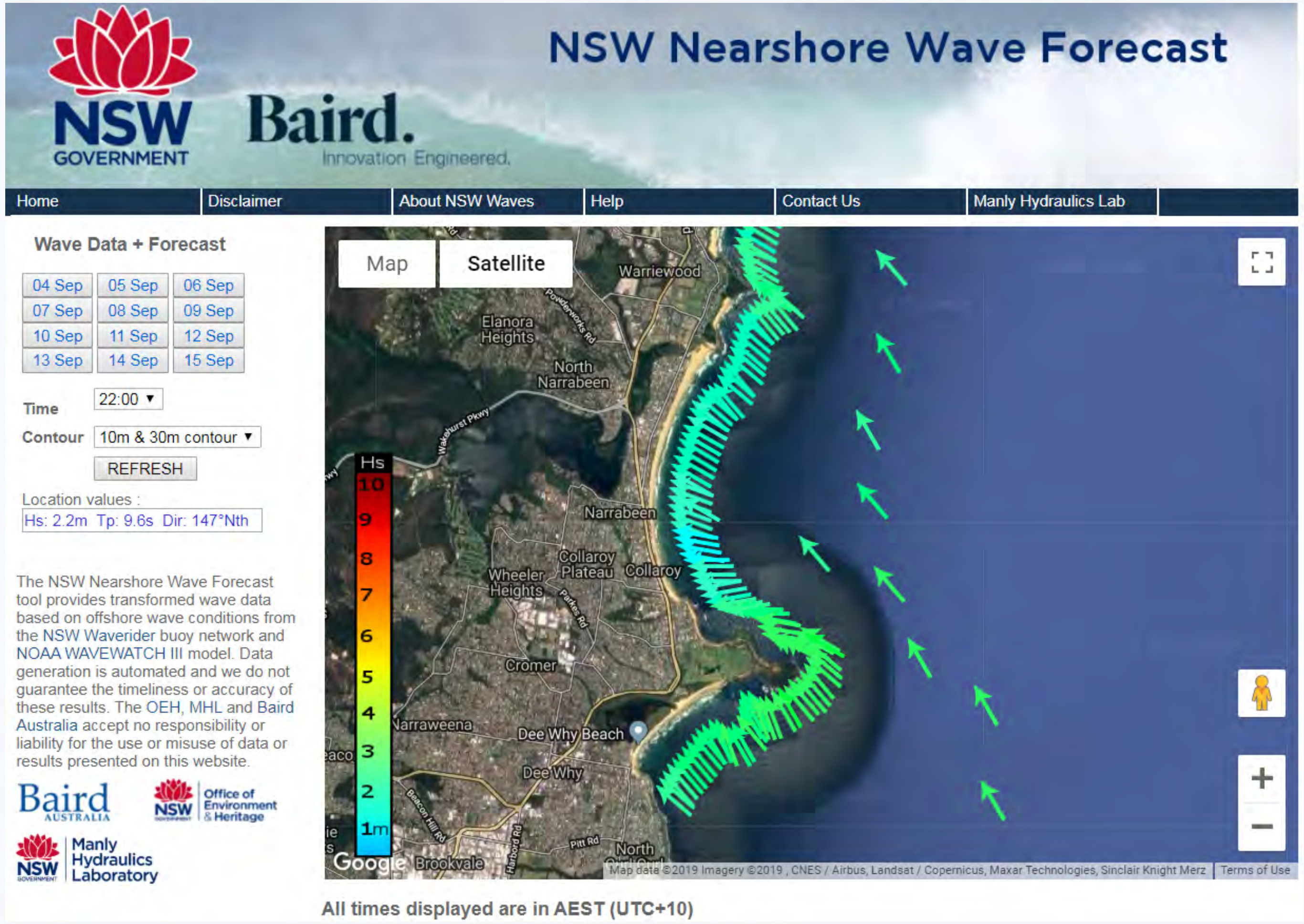


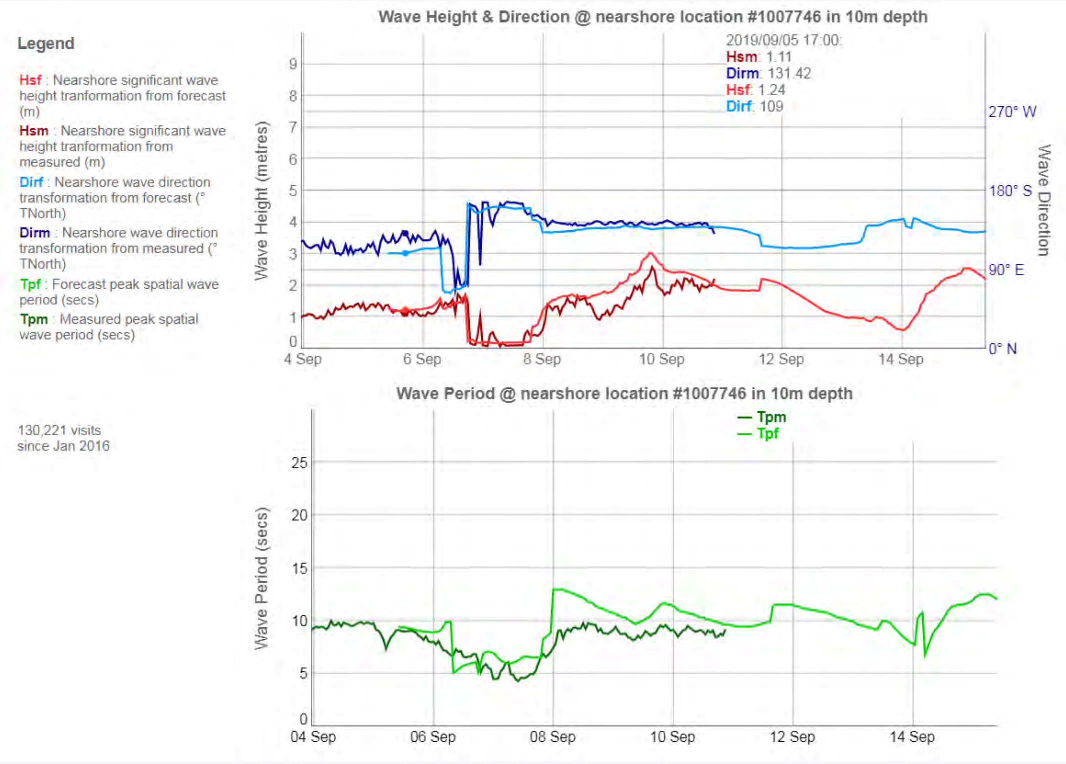
Schematic of Spectral Transformation



NSW Nearshore Wave Forecast

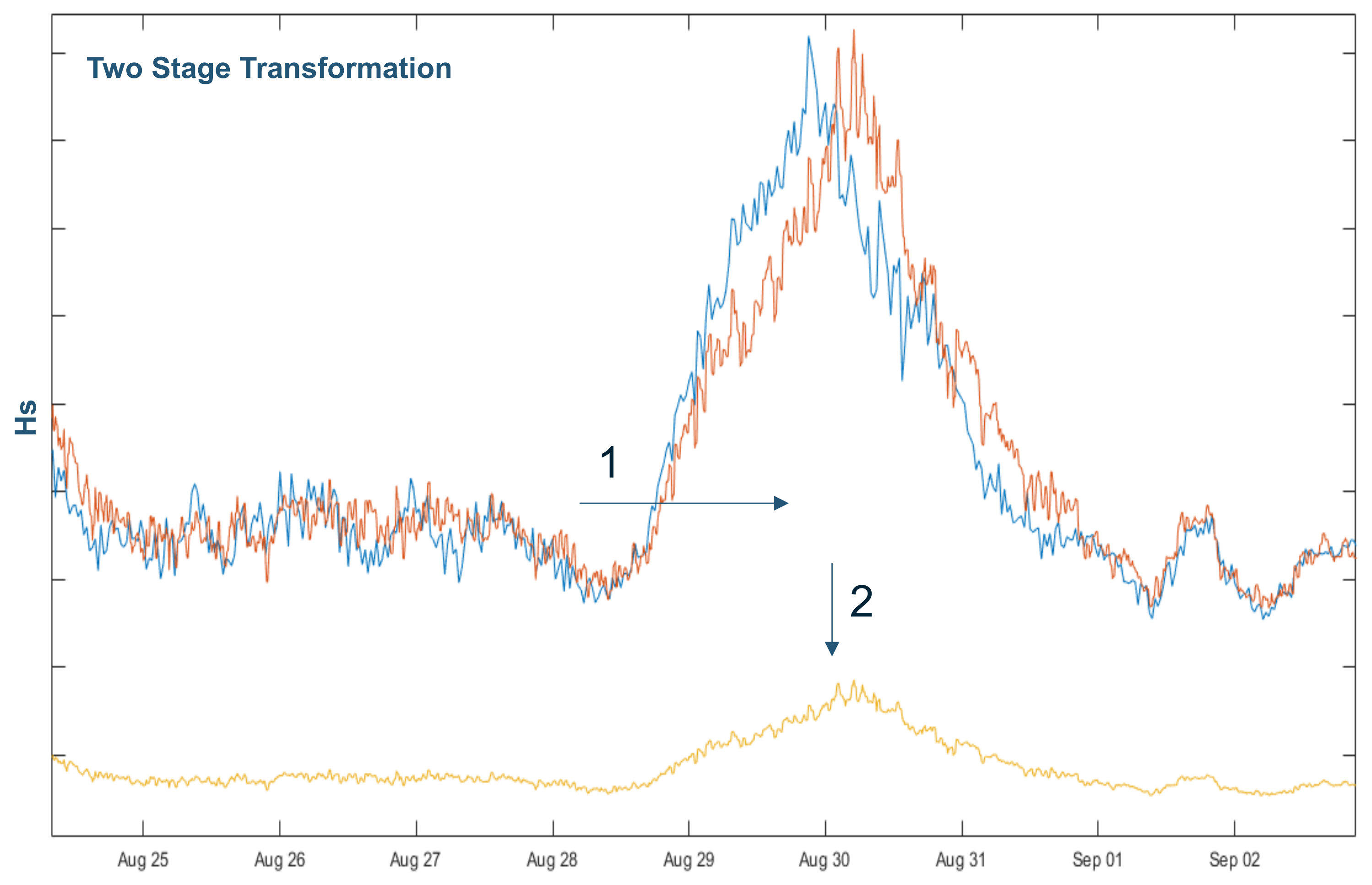
http://www.forecast.waves.nsw.gov.au





Advances to the Transformation Method
Propagation Time

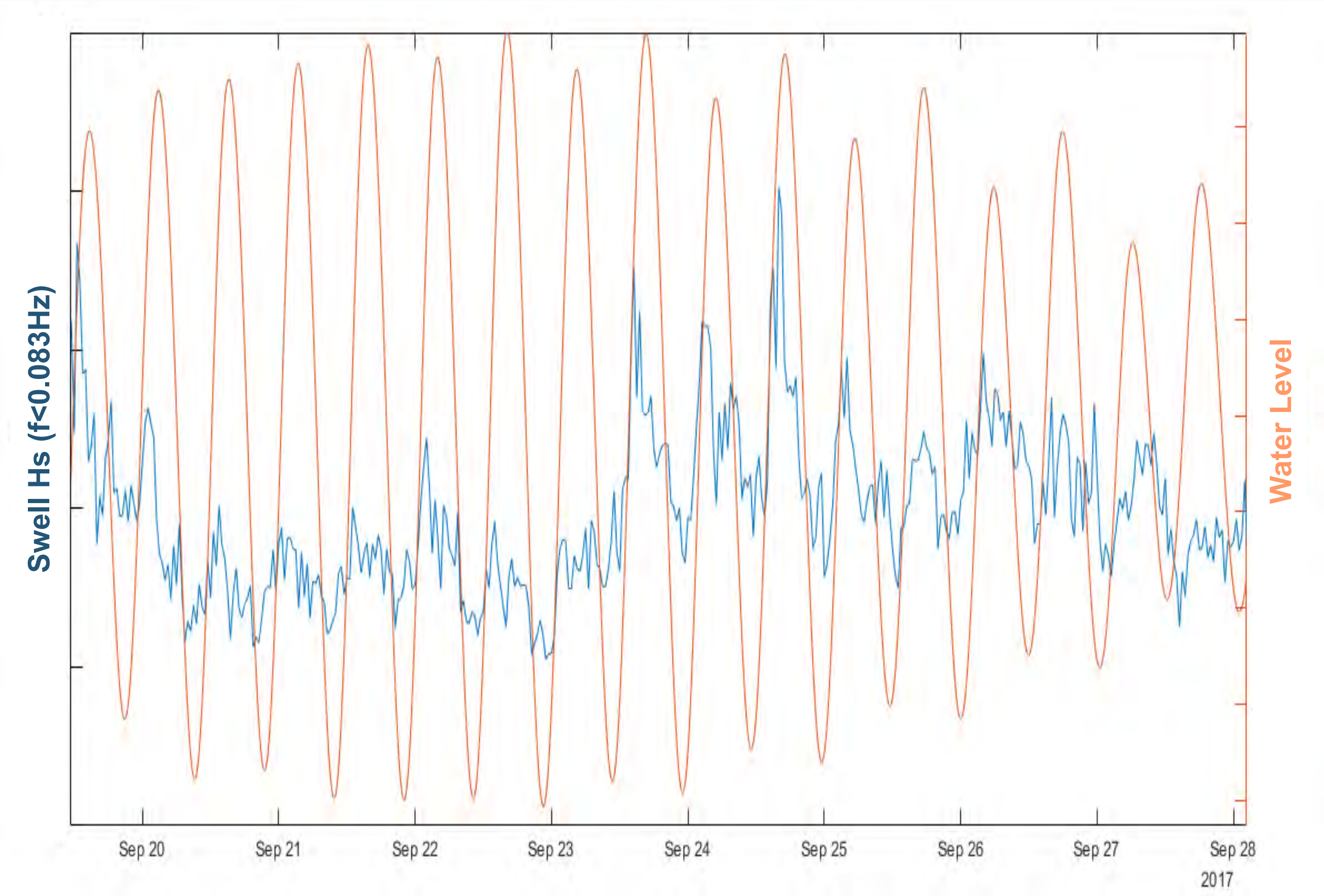
- Frequency dependent swell propagation needs to be taken into account to ensure correct phasing of the forecast
- Non-stationary wave scheme with ‘short peak’ time series boundary conditions
- Creates a two stage transformation
  1. Propagate forward in time
  2. Apply energy transform



Advances to the Transformation Method
Tidal Hydrodynamics

- Clear tidal signal present in the measured inshore swell condition
- Requires inclusion of water level and tidal currents
- Important for long period swell propagating across shallow water

Mermaid Sound Swell



Advances to the Transformation Method
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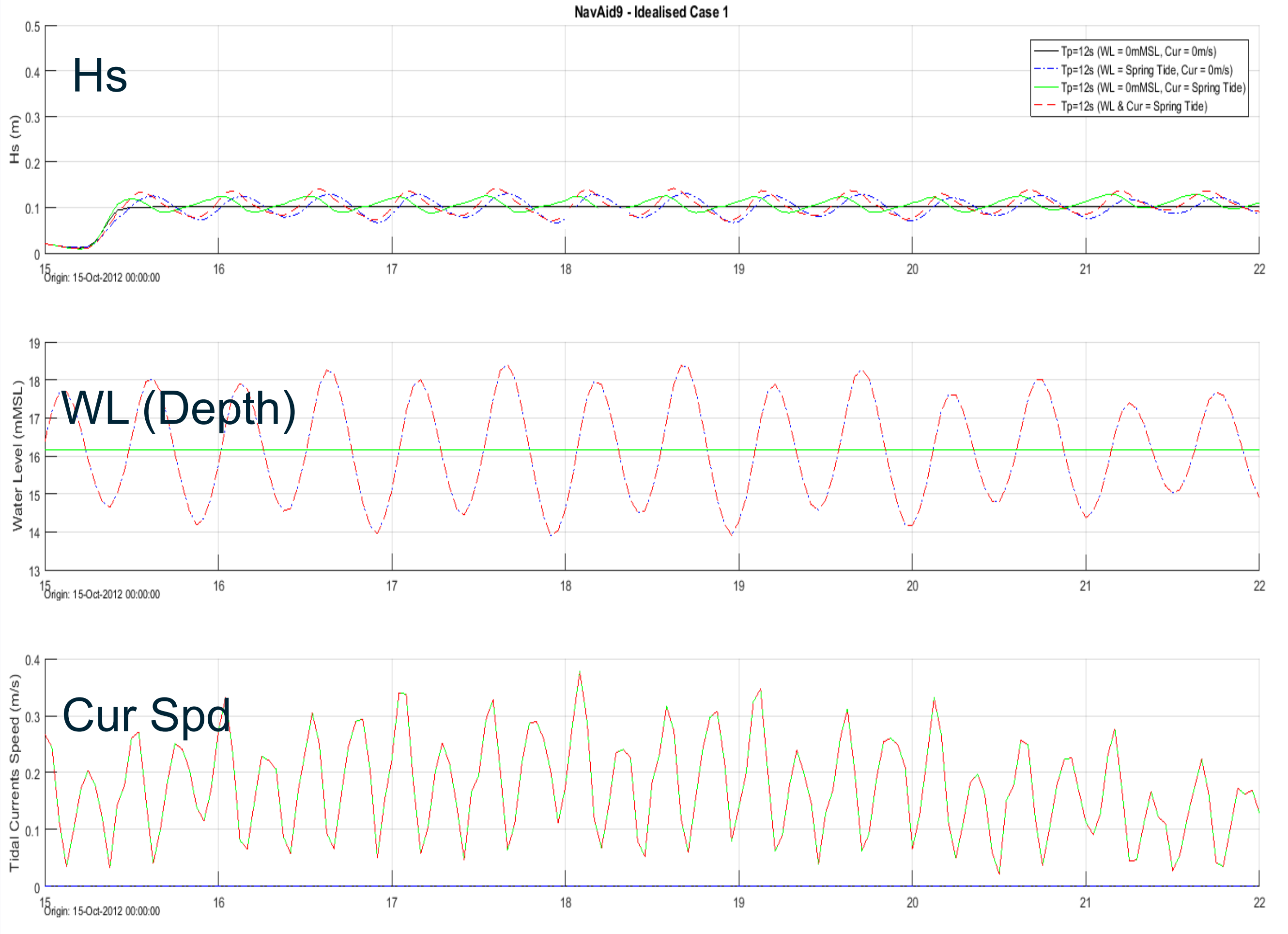
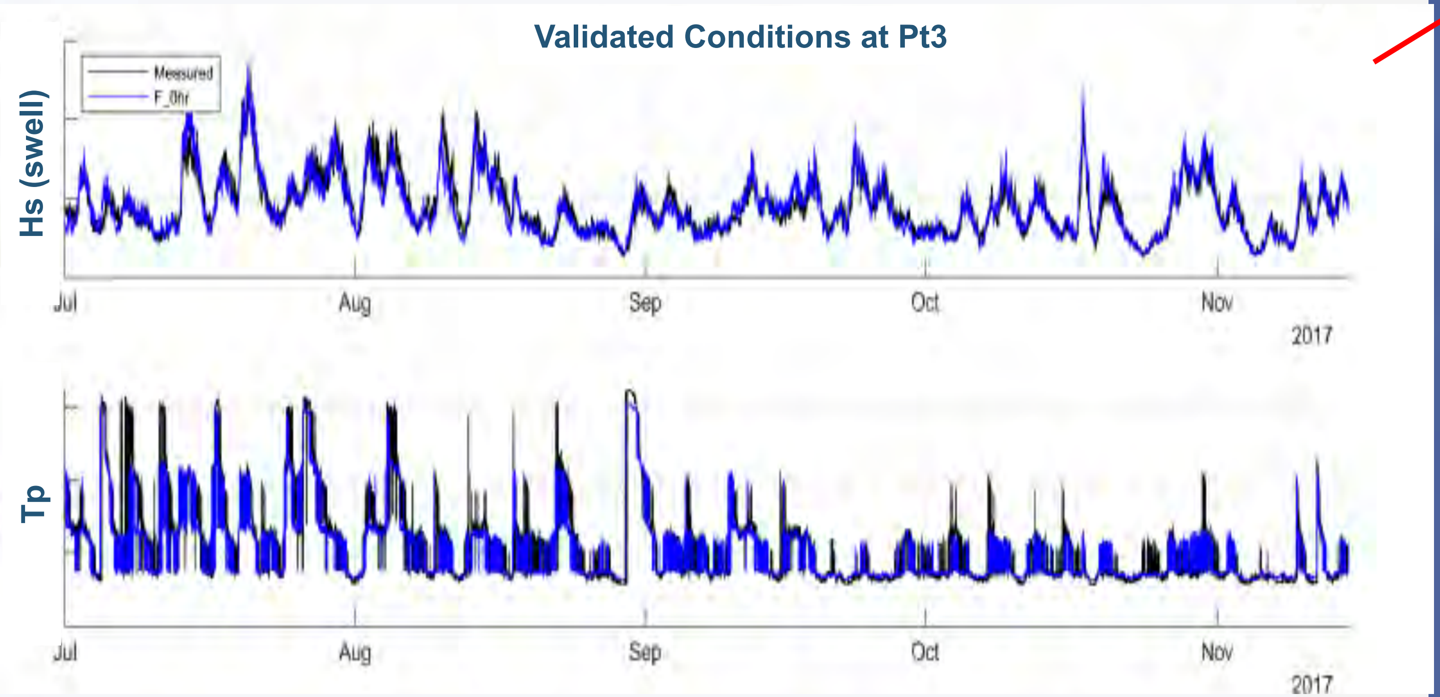
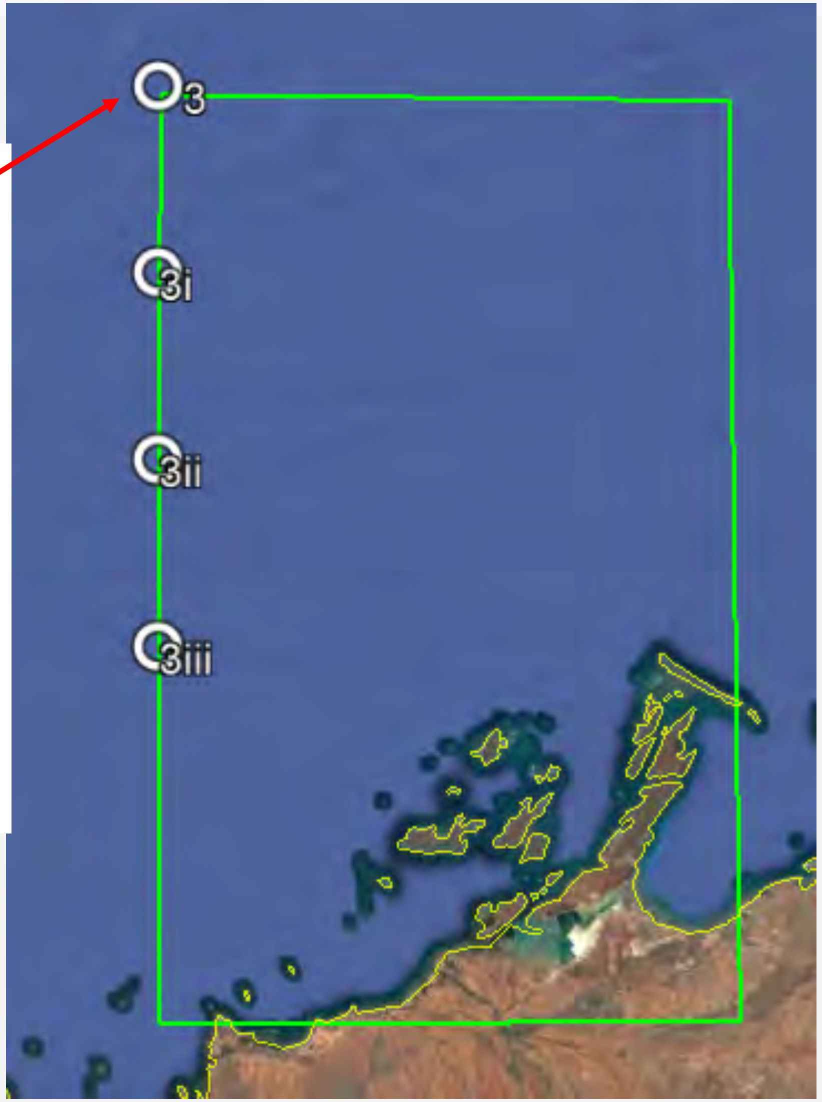
Influence of Hydrodynamics on generic swell case



Advances to the Transformation Method
Matrix Boundary Conditions

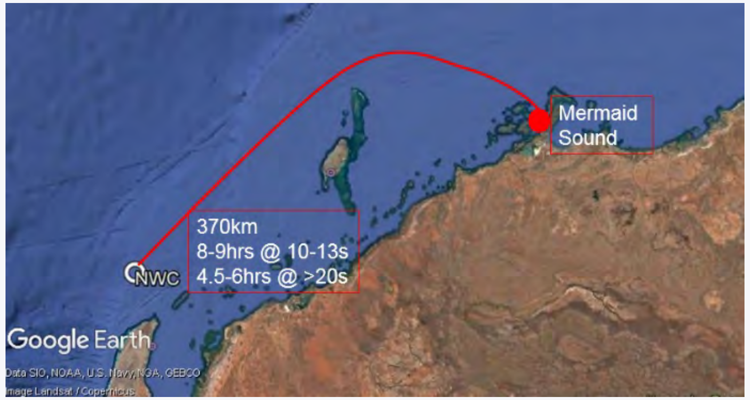


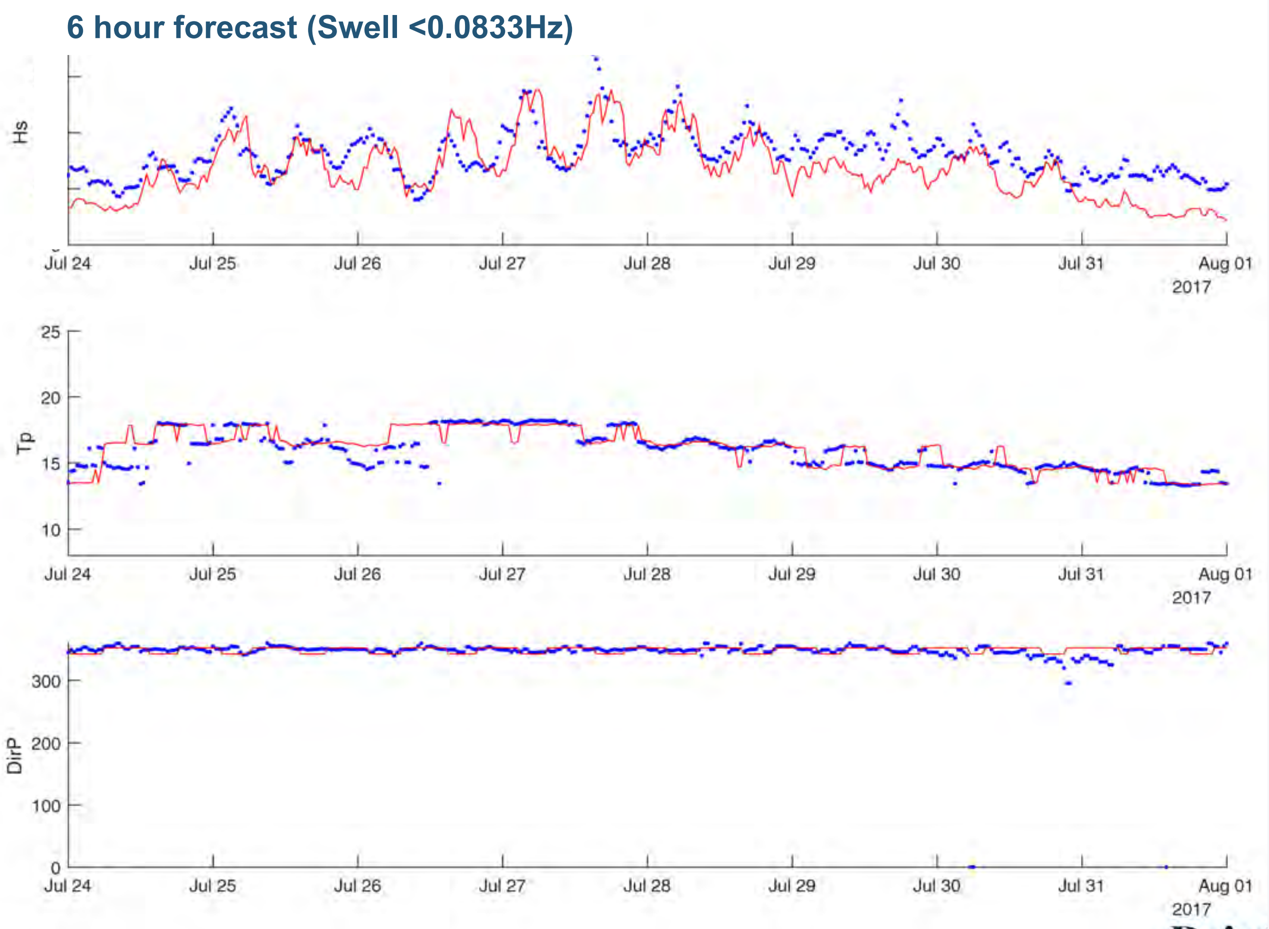


- Optimised through iterative solver

Performance of Transformation Method

- Good validation for long period low magnitude swell (ranging Hs 0.1 to 0.4m inshore)
- Magnitudes and phasing of swell peaks well captured
- Some underestimation of 'trailing' swell as peak period drops through 15s



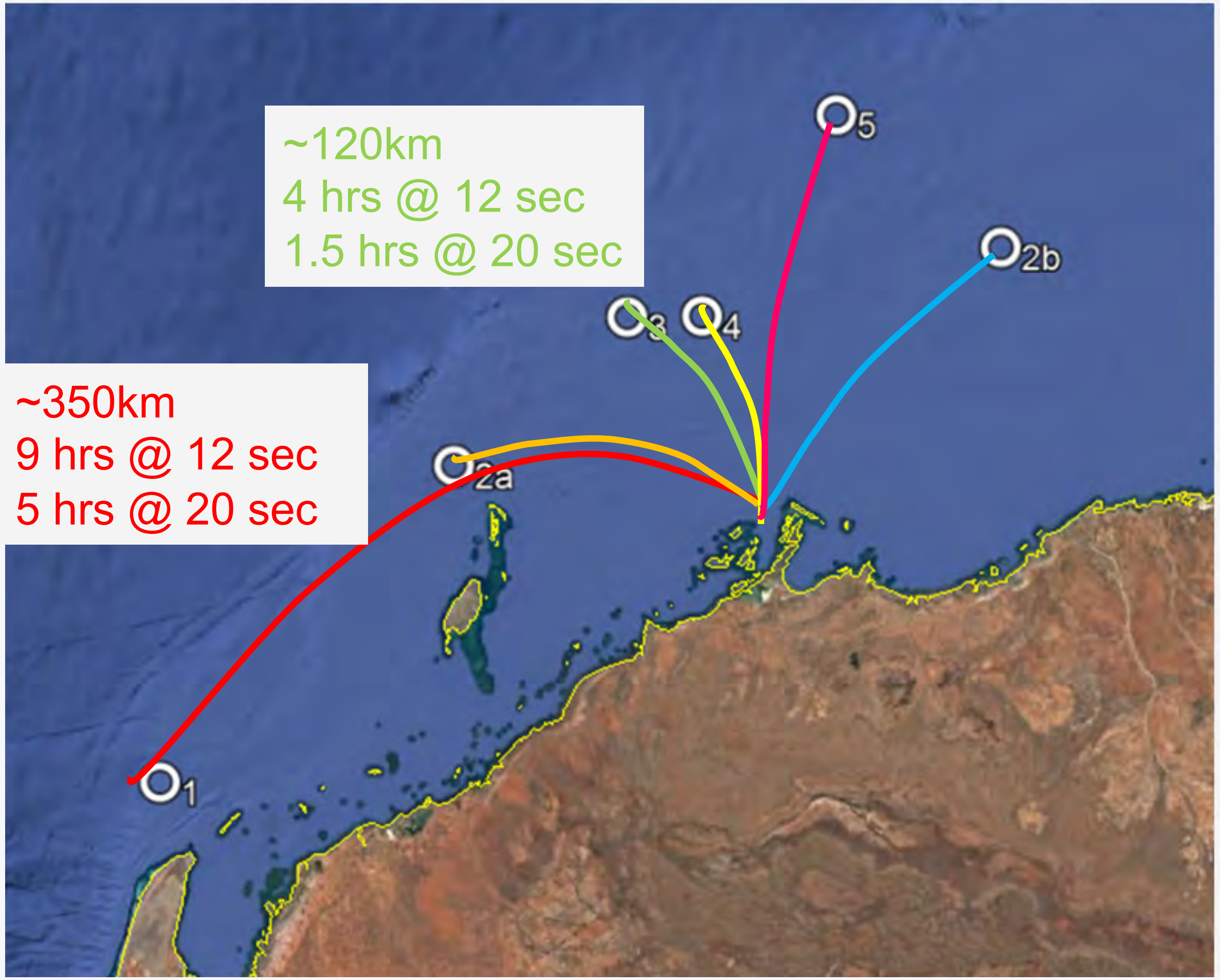


Validation Metrics: Mermaid Sound – Swell (<0.0833Hz) – 2 winter seasons

Forecast	Error Statistics				
	MS	Bias	MAE	RMSE	R
1 hour	0.88	-0.01	0.02	0.02	0.84
2 hour	0.88	-0.01	0.02	0.02	0.84
3 hour	0.85	-0.01	0.02	0.02	0.76
4 hour	0.82	-0.01	0.02	0.03	0.70
5 hour	0.82	-0.01	0.02	0.03	0.71
6 hour	0.82	-0.01	0.02	0.03	0.71

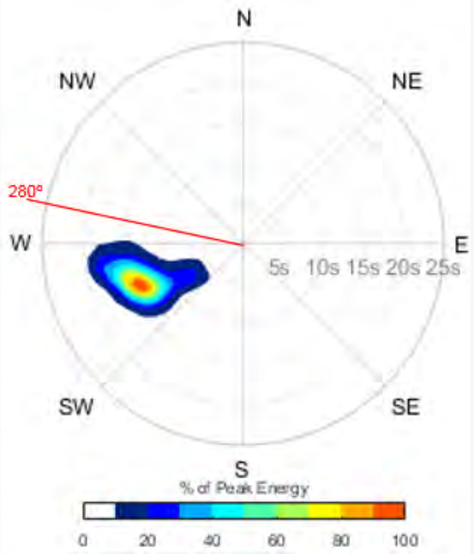
Combining Multiple Transformations

- Considerations:
  - Each buoy is well suited to capture different directional range and forecast horizon
  - Want to ensure best performing transformations are contributing to the forecast
  - Allow for redundancy

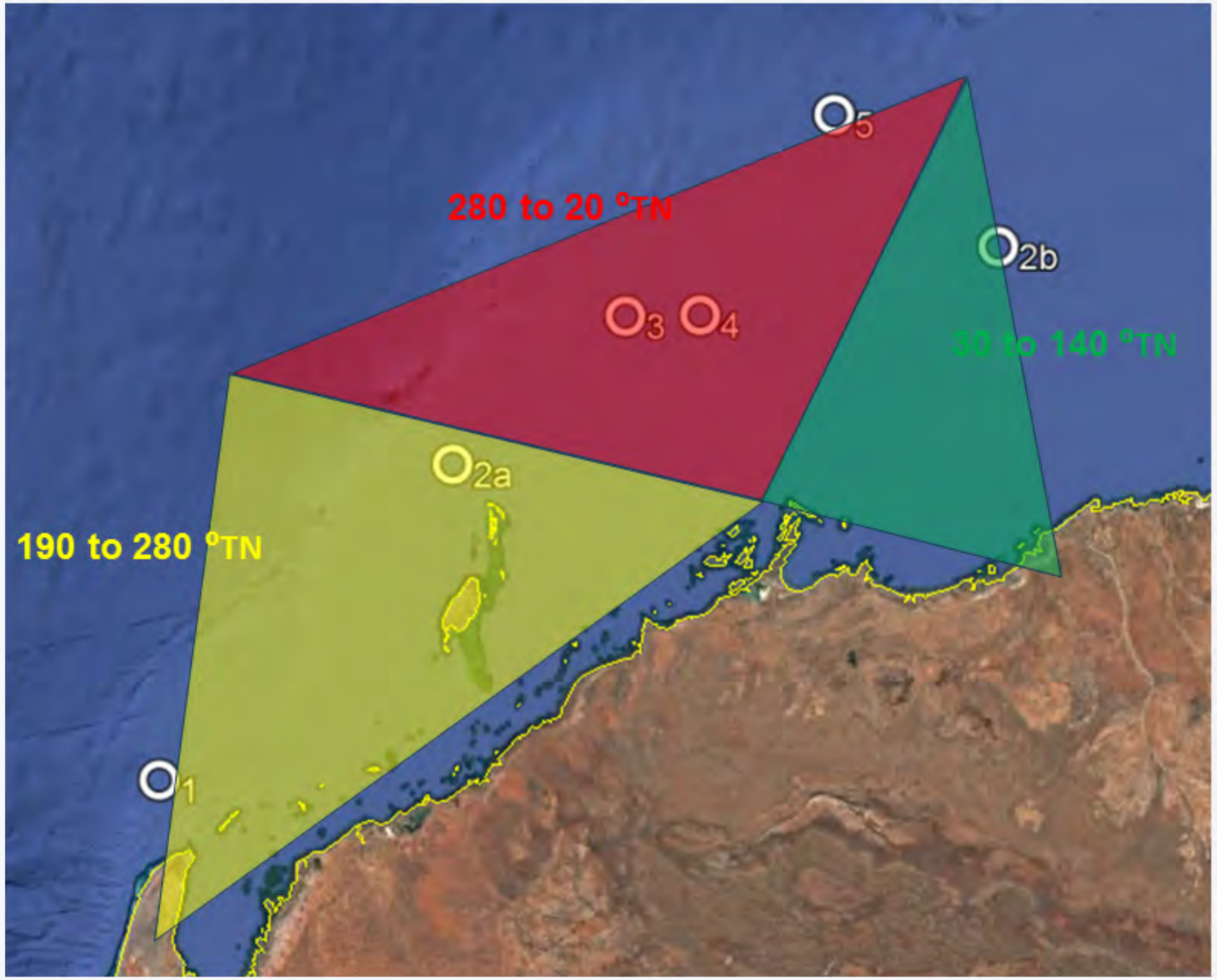


Combining Multiple Transformations

- Approach:
  - Complete transformation in directional sectors
  - Valid for NWS as winter swells are directionally unique 99% of swell energy arrives from directions <280°TN

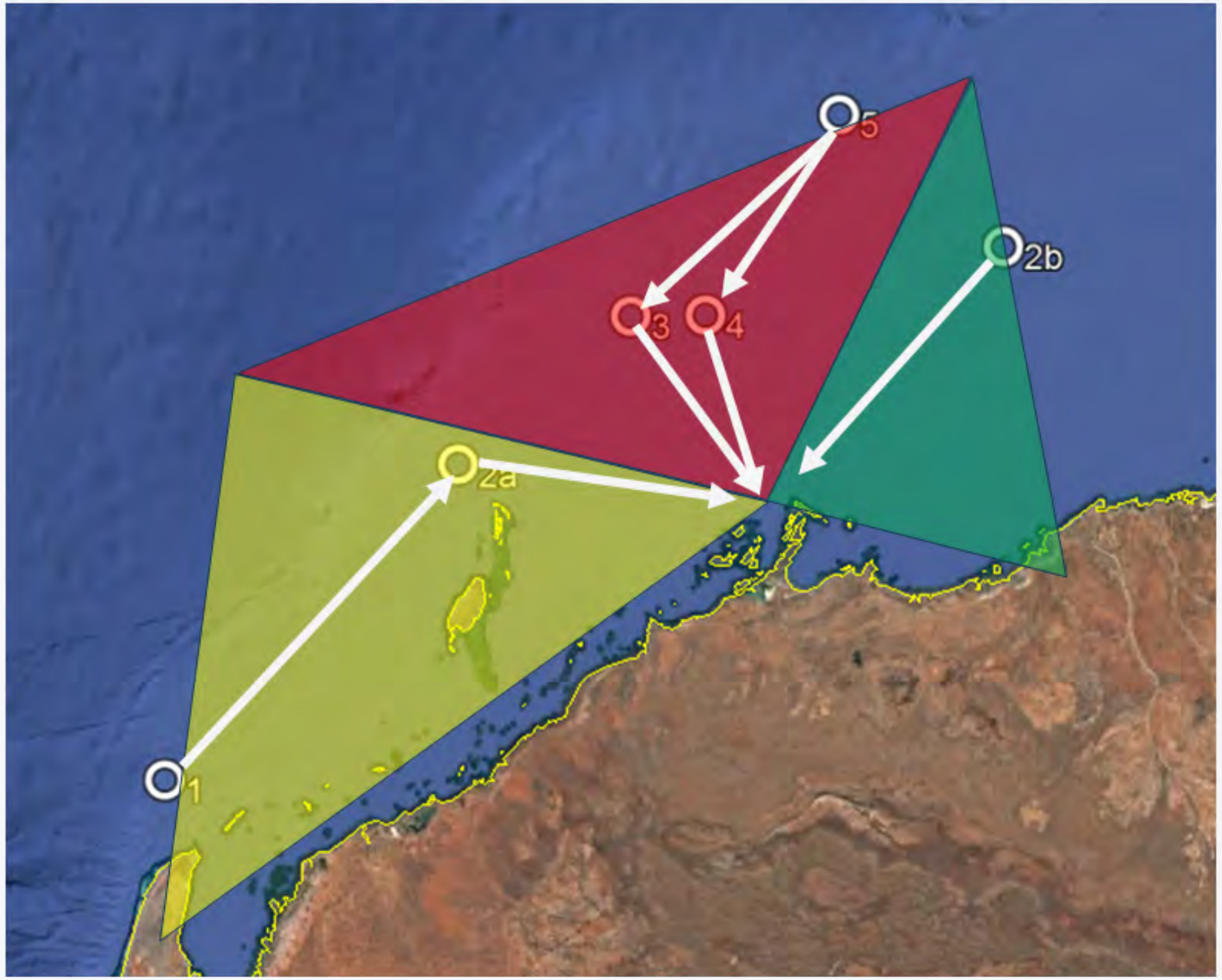


Weighted average winter swell spectra



Combining Multiple Transformations

- Approach:
  - Develop intermediate transformations to extend observed record at more inshore buoys
  - Hierarchy of transformations in each sector (provides redundancy)
  - Sum of transformations from each directional sector



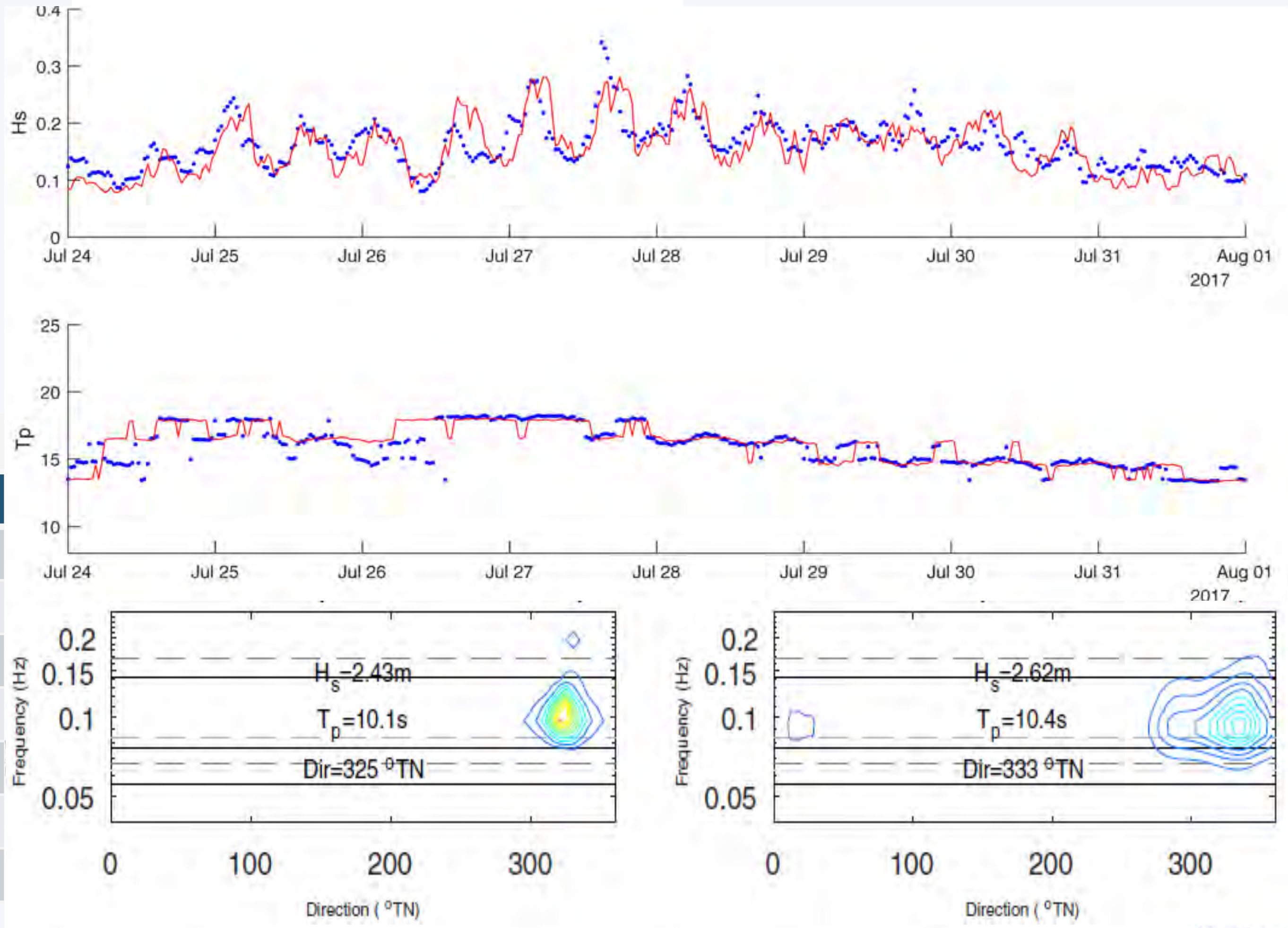
Performance of Multiple Forecast Combination

- Very good validation for long period low magnitude swell (ranging Hs 0.1 to 0.4m inshore)
- Magnitudes and phasing of swell peaks well captured
- Reasonably replicates the inshore directional spectrum

Validation Metrics: Mermaid Sound – Swell (<0.0833Hz) – 2 winter seasons

Forecast	Error Statistics				
	MS	Bias	MAE	RMSE	R
1 hour	0.91	-0.01	0.02	0.03	0.88
2 hour	0.91	-0.01	0.02	0.03	0.88
3 hour	0.91	-0.01	0.02	0.03	0.88
4 hour	0.92	-0.01	0.02	0.03	0.88
5 hour	0.92	-0.01	0.02	0.03	0.88
6 hour	0.92	-0.01	0.02	0.03	0.88

6 hour forecast (Swell <0.0833Hz)



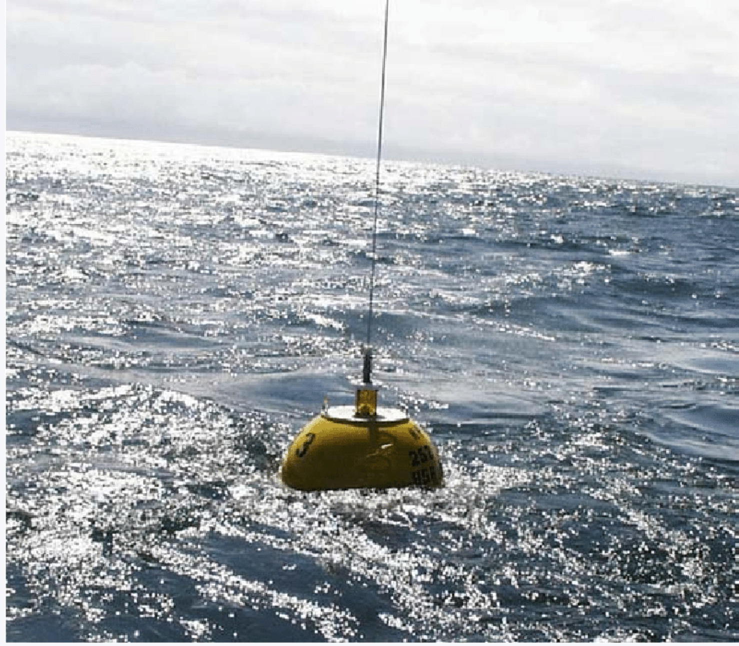
Operational Implementation

- Equivalent validation to high-resolution 3rd generation spectral wave model in fraction of the time
- Availability of real-time nearshore measurements allows bias correction to be calculated in real-time:
  - Simple bias correction using t=0hr forecast
  - Multiple linear regression of comparisons over previous 6 hours

Bias Corrected 1 to 6 hour forecast (Swell <0.0833Hz)

Forecast	Error Statistics				
	MS	Bias	MAE	RMSE	R
1 hour	0.95	-0.01	0.02	0.02	0.89
2 hour	0.94	-0.01	0.02	0.02	0.88
3 hour	0.94	-0.01	0.02	0.02	0.84
4 hour	0.94	-0.01	0.02	0.03	0.81
5 hour	0.94	-0.01	0.02	0.03	0.80
6 hour	0.94	-0.01	0.02	0.03	0.80

Conclusions



- Spectral transfer method has proven applicable for short-term forecasting of nearshore swell conditions across large distances with the following advancements:
  - Inclusion of swell propagation time
  - Inclusion of tidal hydrodynamics
- Able to forecast multiple swell modes for +1 hr to +6 hr forecast horizon
- Fast computation time allows implementation within a real-time monitoring network for regular forecast updates
- Availability of nearshore real-time data provides basis for bias correction to be calculated in real-time to improve accuracy of the physics based transformation

Thank You

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