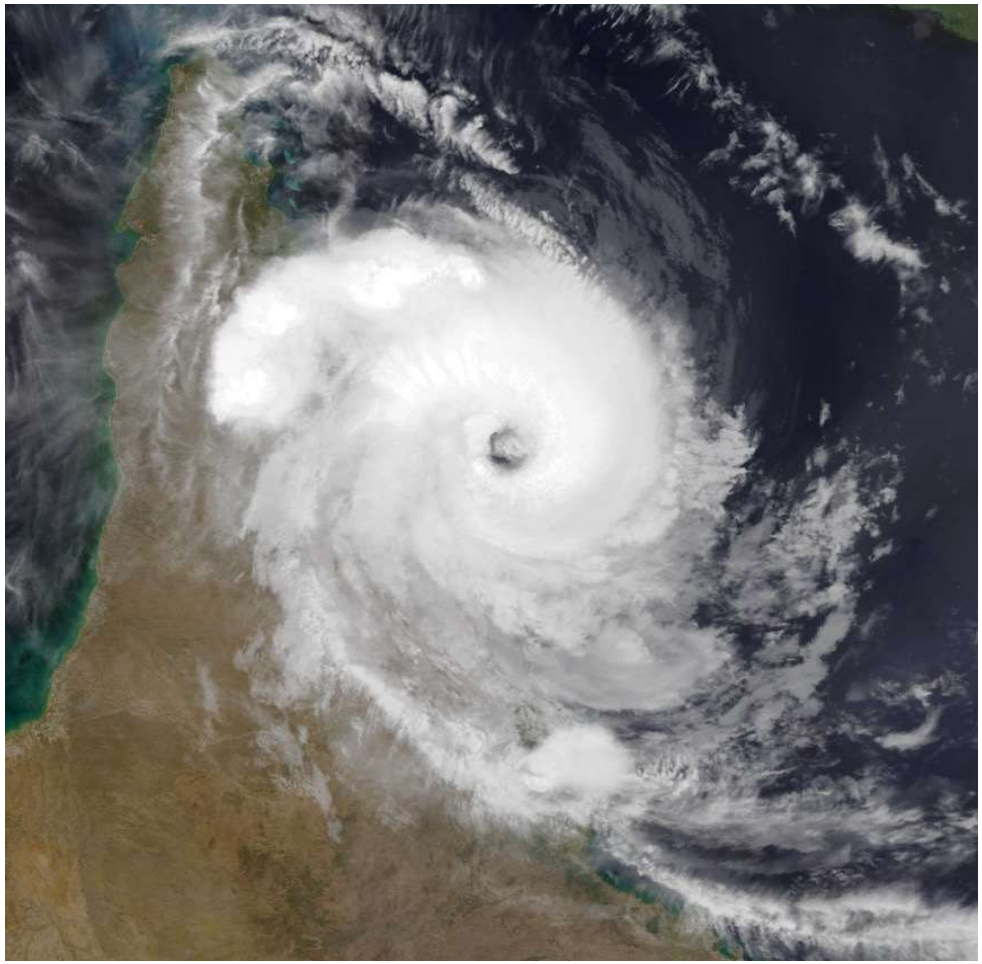


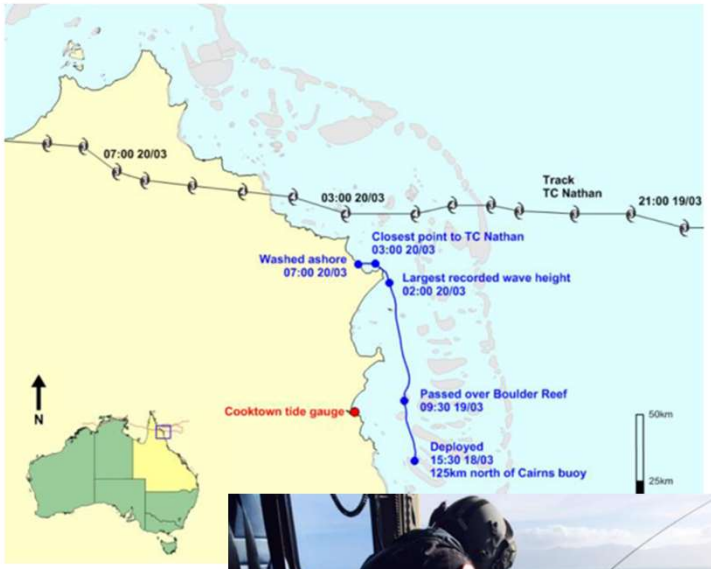
Wave-by-wave data from GPS-based buoys - spikes and spirals

Paul H. Taylor
School of Earth and Oceans
The University of Western Australia

With - Kosuke Sando & Hugh Wolgamot at UWA
Daryl Metters at Queensland Gov. Hydraulics Lab

BOB's bash with Tropical Cyclone Nathan 2015

- BOB (DWR-G 0.4m)
  - GPS based directional buoy
  - Deployed from a helicopter
- Statistics
  - Peak Hmax: 9.60 m
  - Peak Hm0: 5.34 m
- Passing over Boulder Reef (9:30 18/03)
  - ~ 5 m depth
- Previous publications
  - BOB's bash with TC Nathan (DSITI, 2015)
  - Monitoring and Modelling Extreme Wave Conditions during Tropical Cyclone Nathan (Boswood et al., 2017)



Datawell BV
oceanographic instruments

From:
https://datawell.nl/products/directional-waverider-dwr-g4/

TIDE BEYOND THE NUMBERS
THE UNIVERSITY OF WESTERN AUSTRALIA

Directional Waverider DWR-G4 0.4 m diameter

Sensor	single GPS (not differential)	
Periods	heave	1.6 s to 100 s
	direction	1.6 s to 100 s (free-floating)
		1.6 s to 20 s (moored)
Precision	0.01 to 0.02 m, all directions (1σ) (excluding GPS antenna pitch and roll motion)	
Calibration	not required ever	
Exclusion	GPS signals do not penetrate through water, occasional data gaps may occur	
Exclusion	measurements fail at position changes greater than 100 m in less than 100 s, e.g. when used free floating or towed at constant velocities greater than 1 m/s.	

Note : spike / loss of signal behaviour is different vertically and horizontally

Measured wave data: motion in heave, north + west

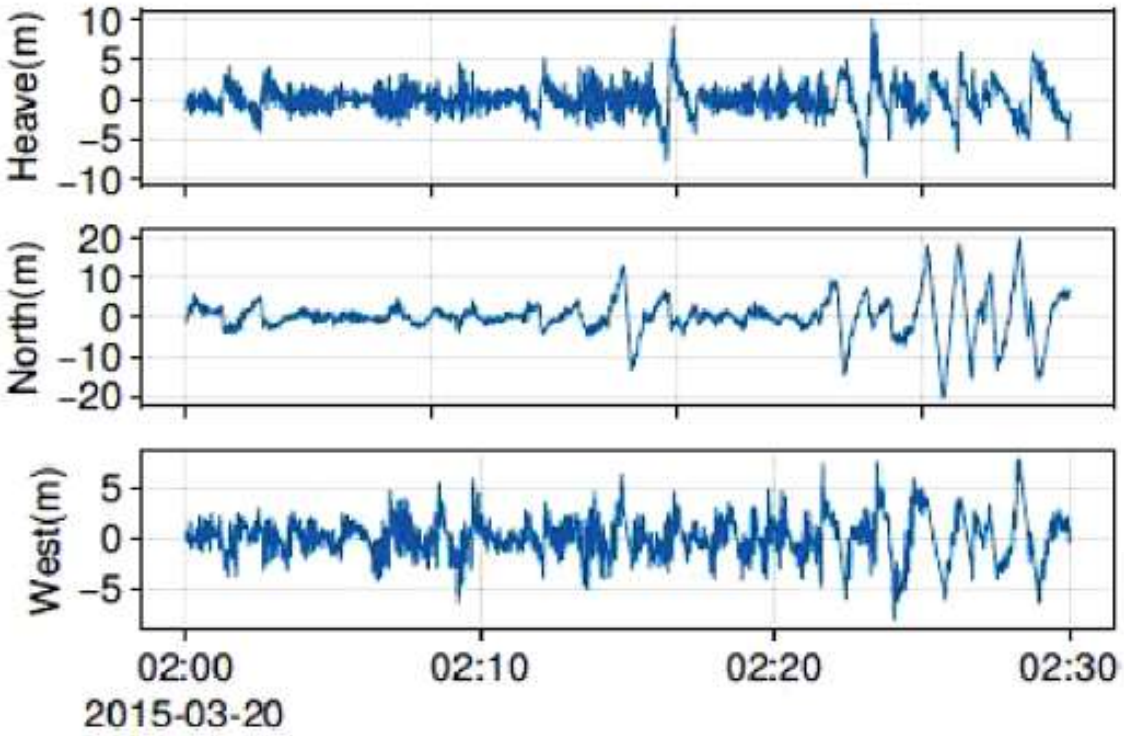
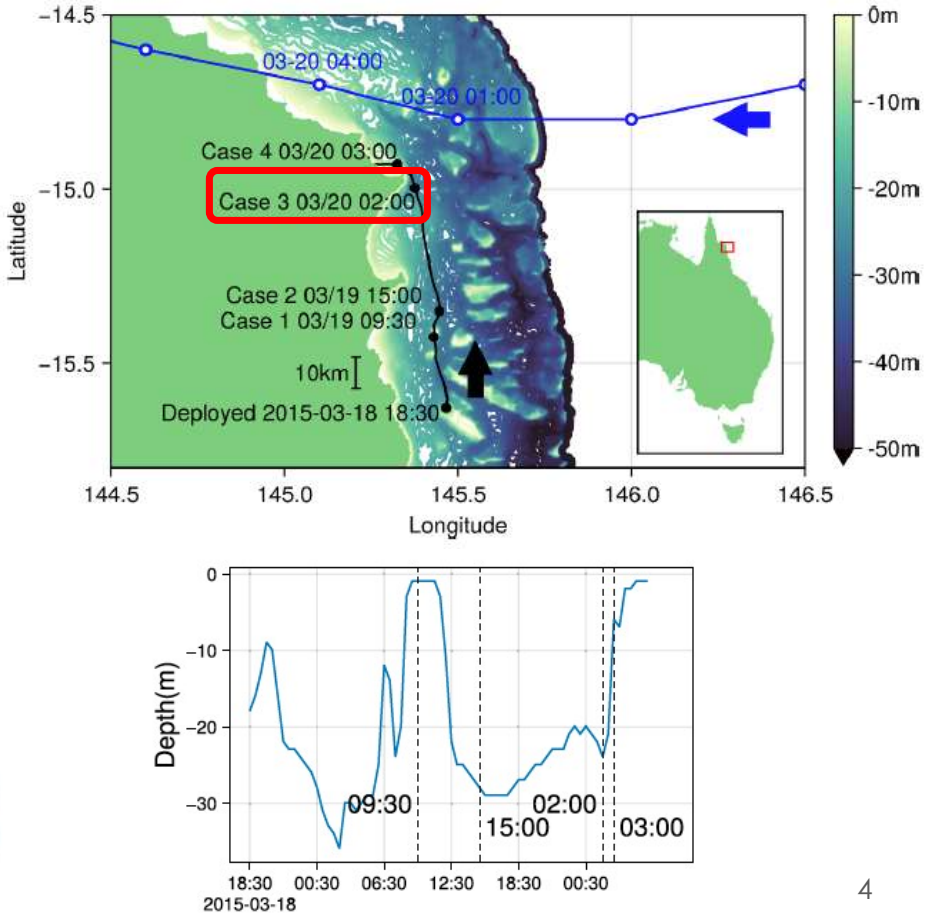


Fig. 3. Measured displacement of heave, north, and west direction. The largest wave height was recorded during this 30 min segment beginning from 2015/03/20 2:00AM.

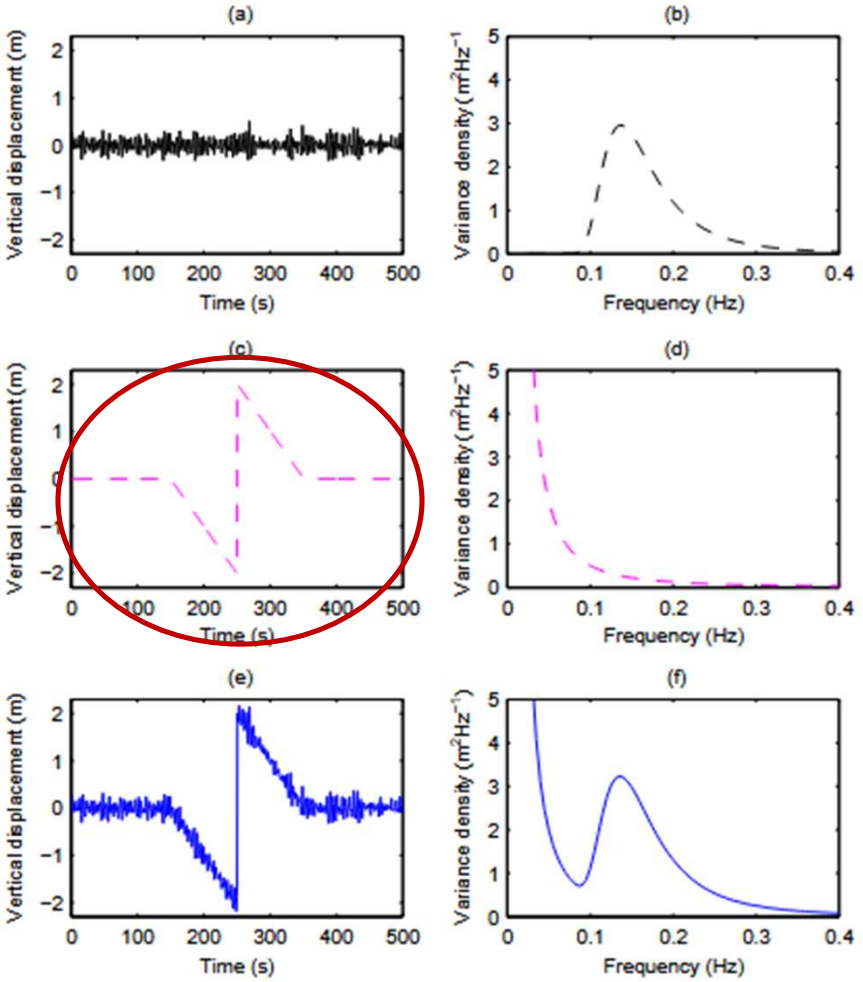


Previously published material and modelling of spikes

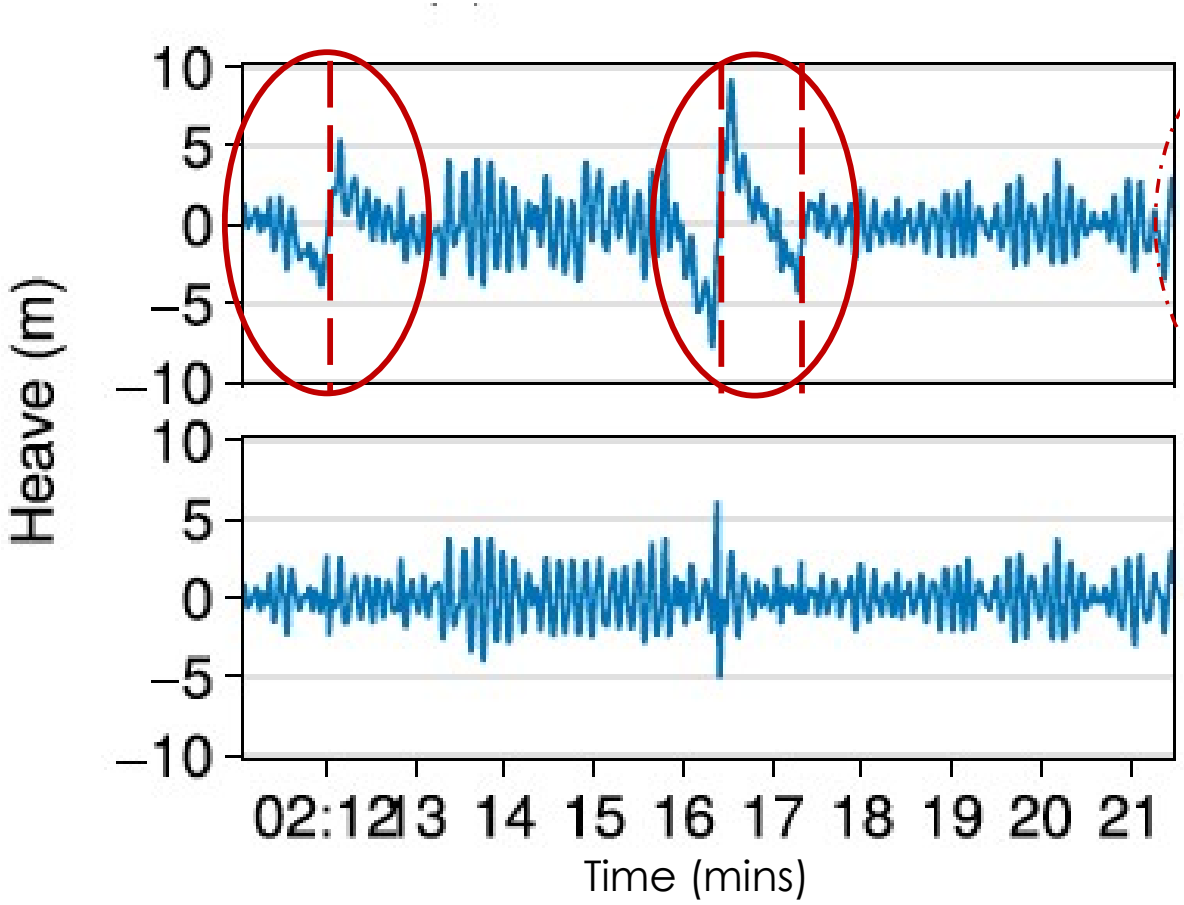
Spikes in GPS buoys reported by Björkqvist (2016) and Boswood (2017)

– Assumed **Sawtooth shape** based spectral correction by Björkqvist

- not applicable for wave-by-wave analysis
- model has room for improvement



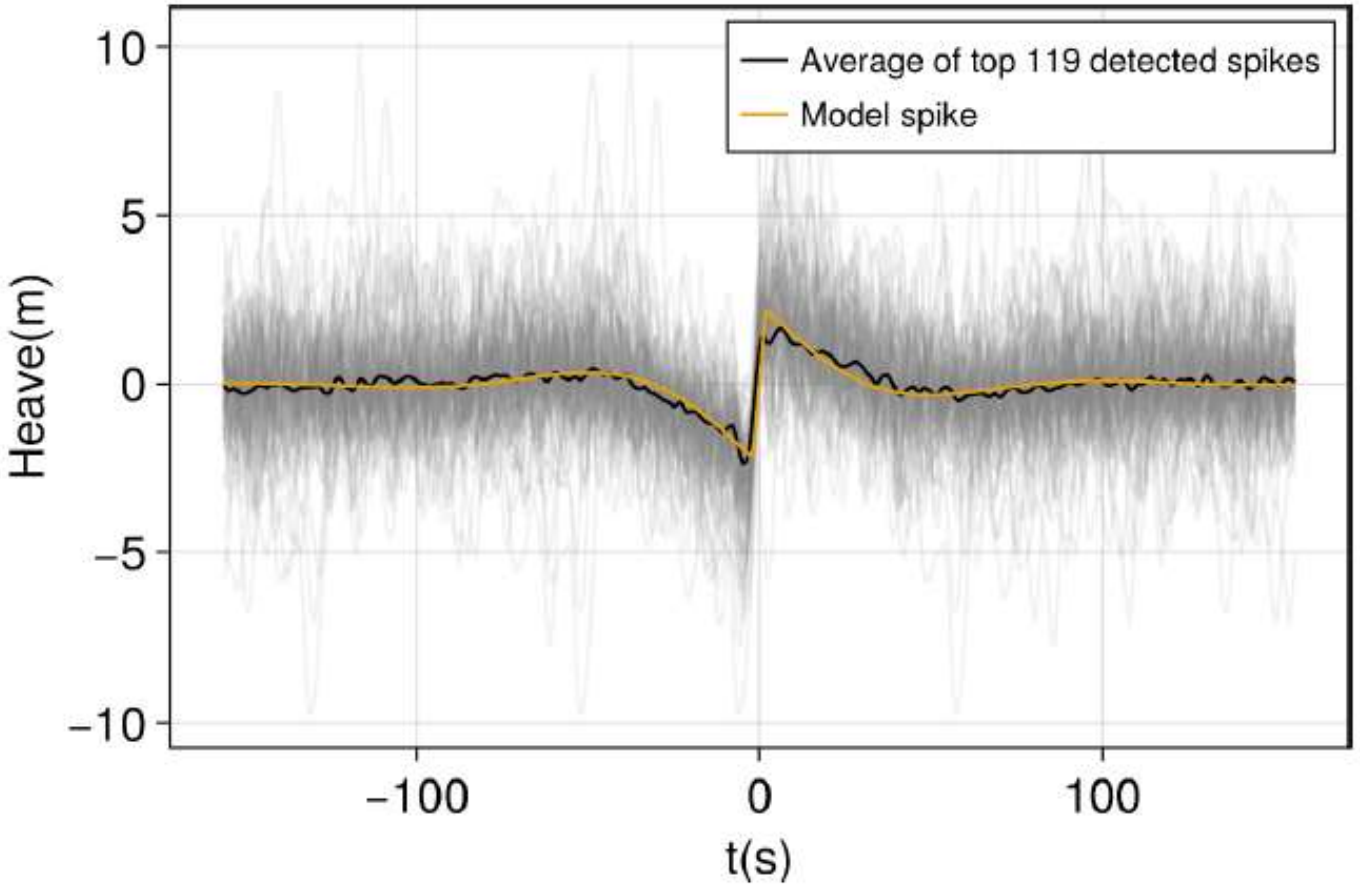
Vertical spikes in heave motion



3 spikes here in 9 mins, 2 overlap
Each spike damages ~ 1.5 mins

Can we remove the spikes
AND
recover the whole signal ?

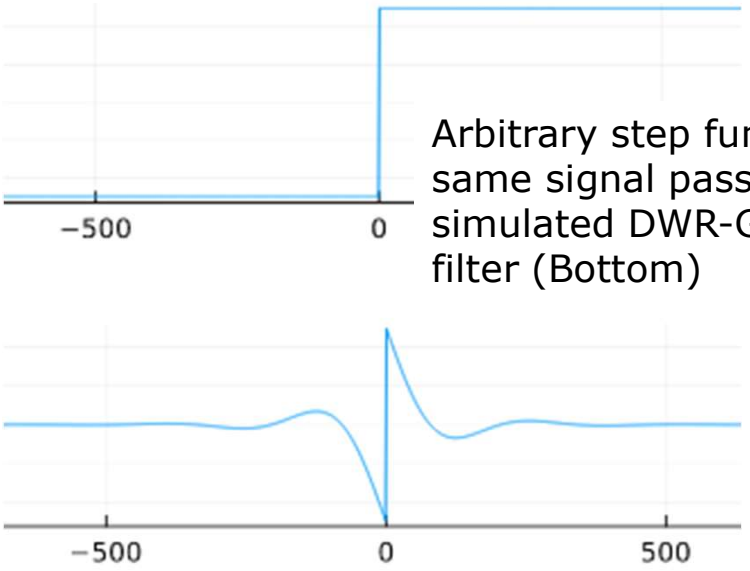
Spikes have a characteristic shape – not a saw tooth



Improved understanding and model of spikes

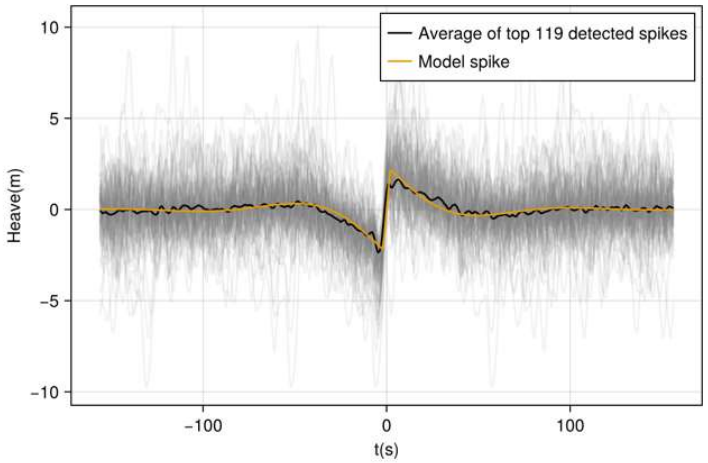
Theory: whenever GPS signal is lost, the discontinuity creates a "jump". Hardwired high-pass (100s) filter removes the shift in m-s-l level but leaves behind a residual spike.

Proposed spike model: step function through high pass filter (quasi-step response)



Arbitrary step function (Top), same signal passed through simulated DWR-G4 high-pass filter (Bottom)

Average shape of 119 detected spikes (Black) and model spike (Orange) ->



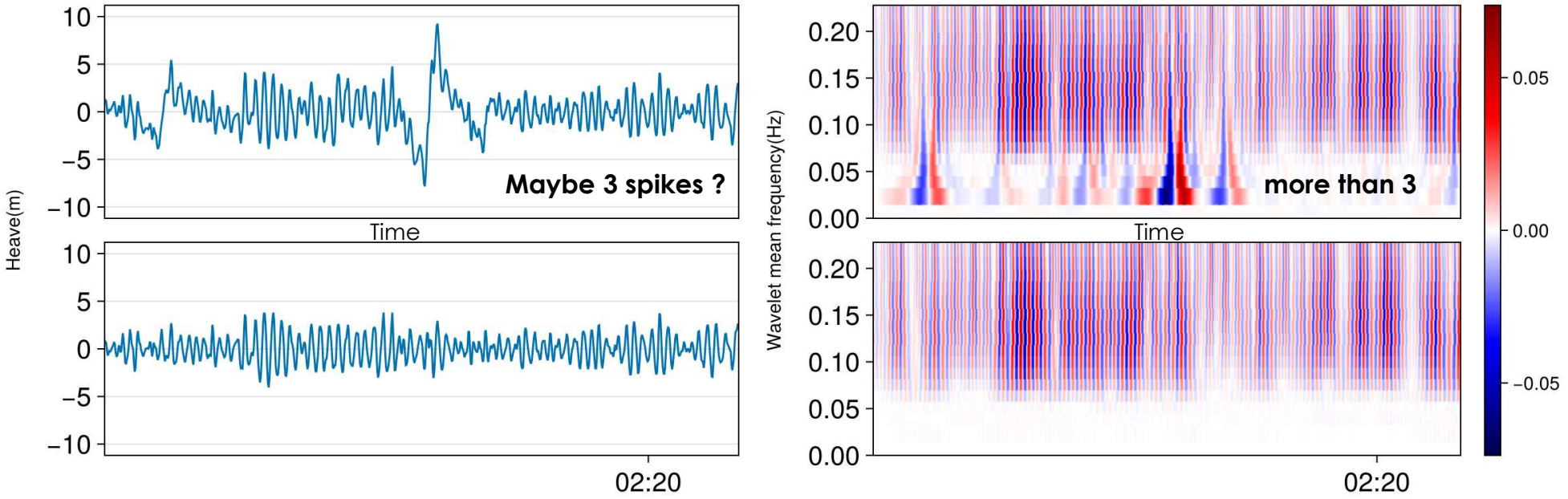
De-spiking methodology

With the shape of a model spike identified

use a wavelet transform method in MATLAB using Symlet 4 wavelets (chosen to match spike form)

1. Use convolution with model spike to estimate spike location
   - Large value in convolution -> possible spike
2. Estimate spike parameters (size, precise location, loss duration)
   - Use wavelet transform of signal to feed into the cost function
3. Remove spike by best-possible subtraction from original signal
4. Repeat 1-3 until number of expected spikes reached
5. High pass filter to remove residual low frequency artefact

De-spiking results – using Symlet 4 wavelets in MATLAB



Raw (Top) and de-spiked (Bottom) heave motion at 2:00 when BOB recorded largest wave

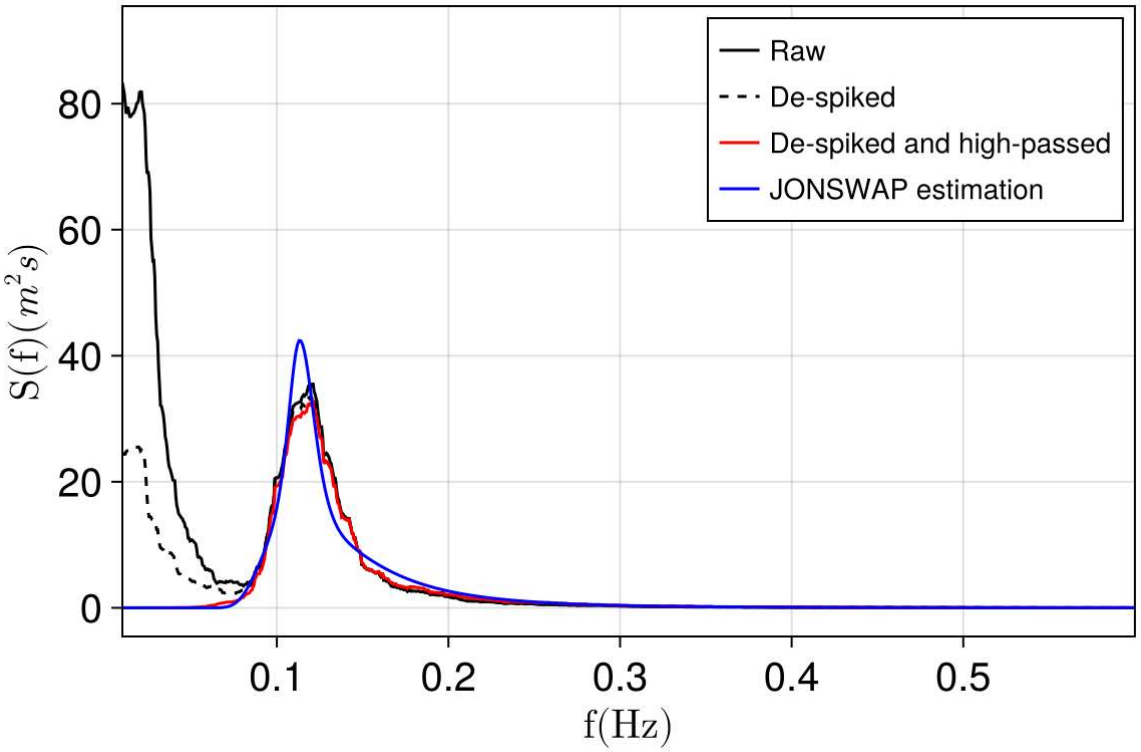
Left - time signals; Right - wavelet transforms

De-spiking results

- **Bulk statistics** – for most severe interval
  - Peak Hmax: 9.60 m **-> 8.06 m**
  - Hm0: 5.34 m **-> 5.00 m**

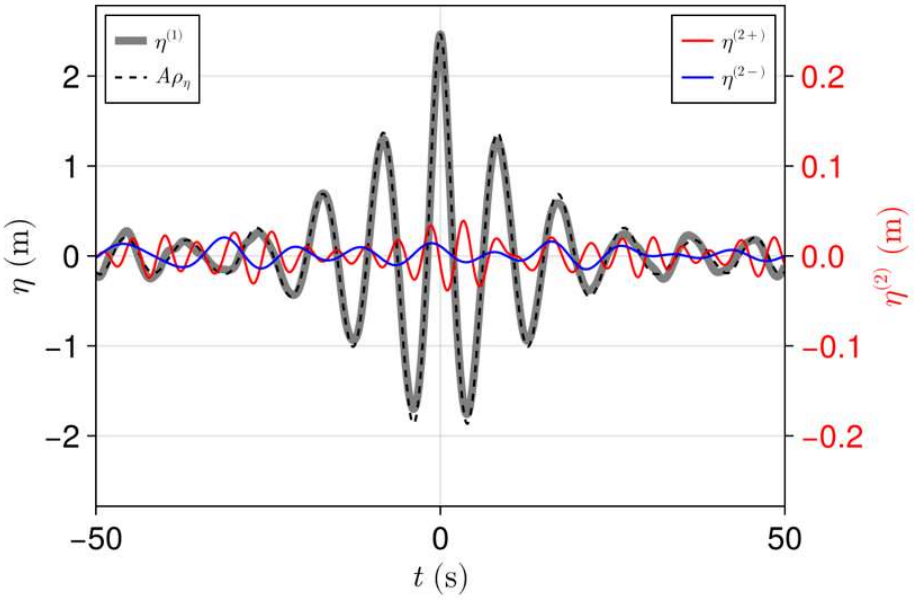
- Spectrum
  - Large reduction <0.07 Hz
    due to de-spiking and high pass filter

–What about wave shapes?



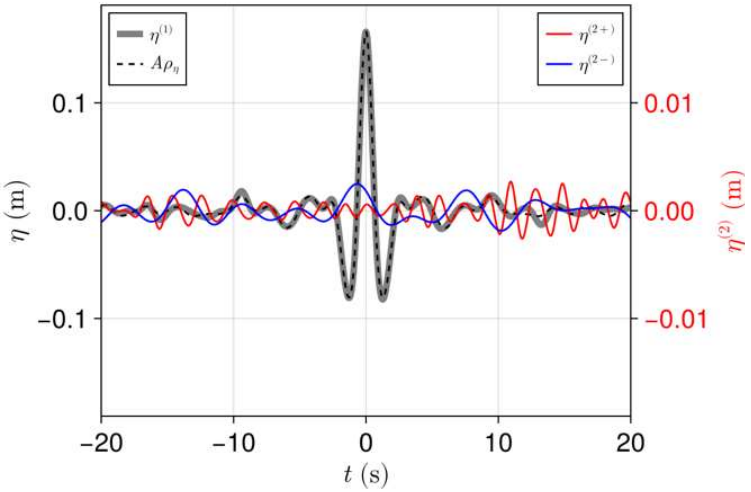
What is NewWave?

- Linear model for the average shape of large waves at sea (Tromans,1991)(Bocotti, 1983)
  - Based on stats of extremes in a linear random Gaussian process (Lindgren, 1970)
  - Scaled auto-correlation function of the measurement

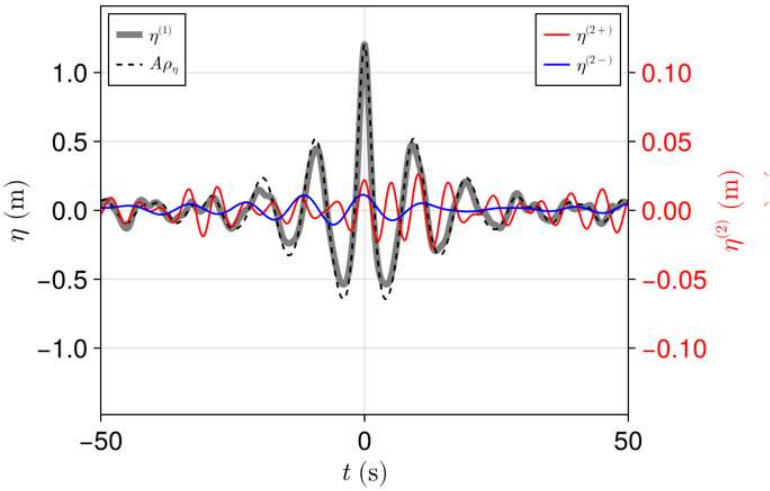


Average shape of linear waves from top 30% crest and troughs in solid grey line.
Scaled autocorrelation function (NewWave) in dotted black line. @2:00AM 20/03 (largest wave)

NW as viable model in shallow waters (vert)



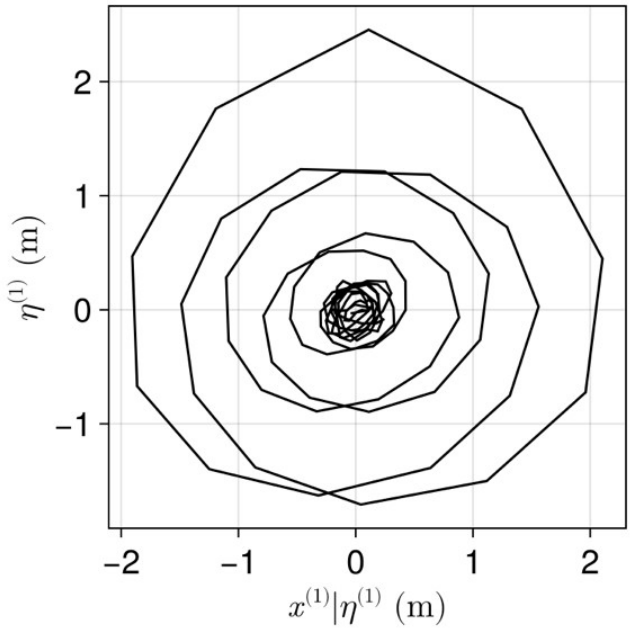
9:30 19/03 (Boulder Reef) d=1~5m



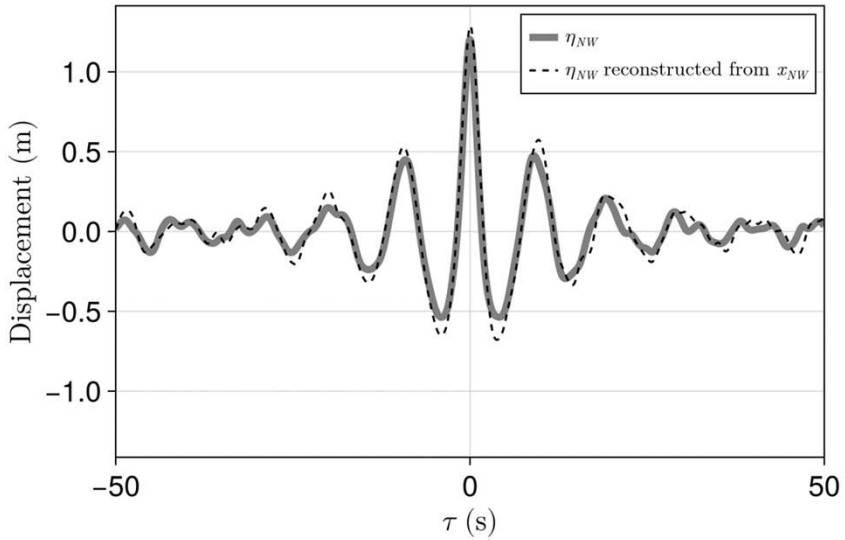
3:00 20/03 (closest to TC) d=6m

NewWave works well for linear term even in very shallow water and locally steep waves
($k_p d$ ~0.59) ($k_p H_s$ ~0.24)

Validation of NW linear components
- average motion of buoy in a large wave crest



Trajectory of horizontal motion
in a vertical NW
- elliptic **spiral** -> linear motion



3:00 20/03 (closest to TC) d=6m

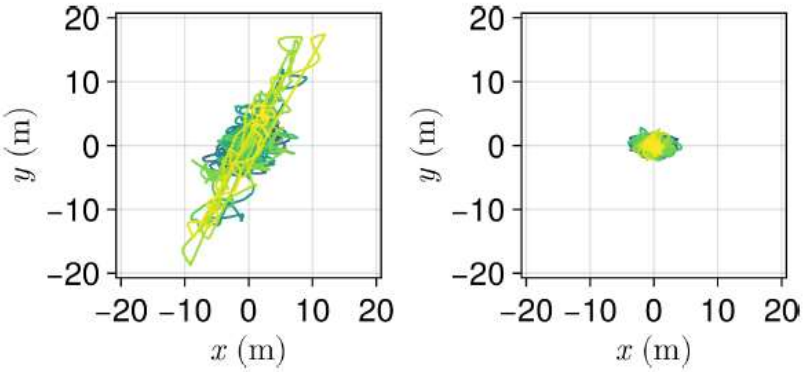
Vertical NewWave profile (grey), also reconstructed from horizontal NewWave profile (dotted black) using linear wave theory
- a **check of buoy motion**

Conclusions

- New approach to de-spiking raw data from DWR-G4
  - based on spike identification with wavelets
  - can recover entire time history of vertical motion

- NewWave in shallow water
  - A good model for steep waves in water depth $k_p d > 0.5$

Future work
Gaps in horizontal motion are much harder to treat
- application of ML methods?



Recently published :

Sando K., Taylor P.H., Wolgamot H., Chen L., Metters D.

Wave-by-wave analysis, spike removal, and NewWaves in GPS buoy data near the Great Barrier Reef in tropical cyclone Nathan

Ocean Engineering 336 (2025) 121808