Reading the waves

Improving remotely-sensed wave height measurements with X-band radar

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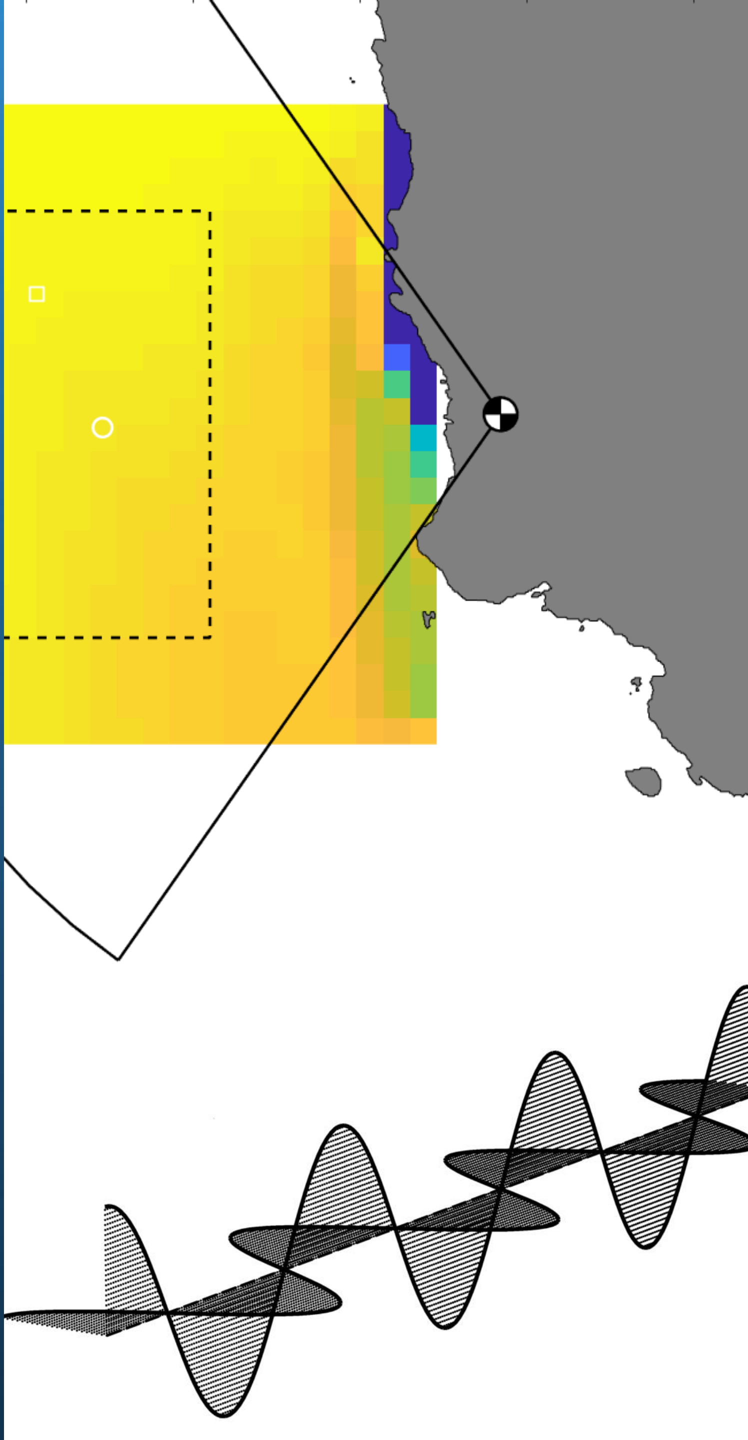
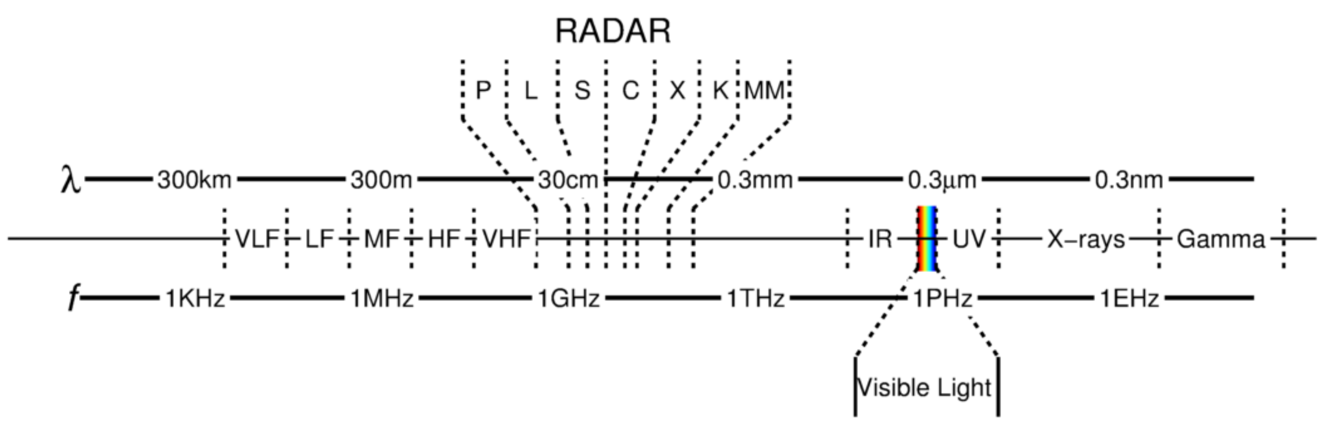
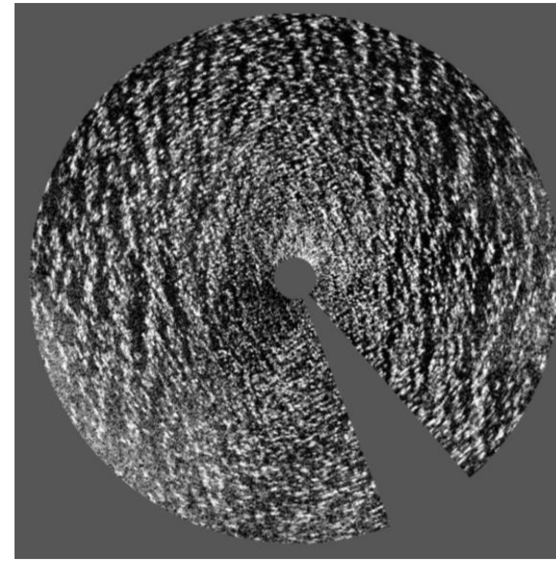


X-band radar remote sensing: an overview

- Radar (Radio detection and ranging) is a tool designed for the detection and measurement of objects and physical phenomena at a distance from a transceiver
- The simplest form of radar consists of a pulse of radio frequency energy emitted from a transmitting ('TX') antenna, the 'echo' of which is then 'listened' for by a receiving ('RX') antenna. The time taken for this echo to be measured determines its range.
- 'X-band' radar occupies the centimetric / GHz band of the E-M spectrum, with a radio wavelength of ~3cm and a frequency of ~9.4GHz

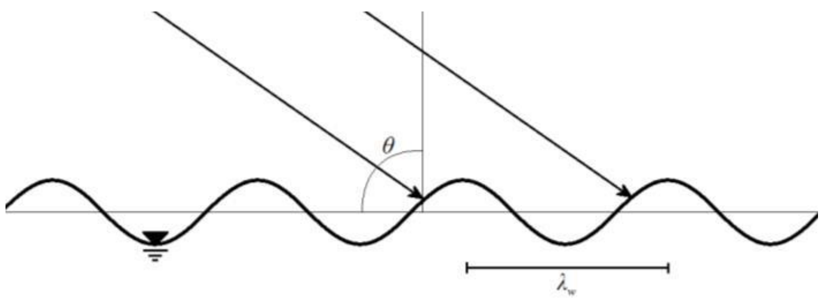


X-band radar remote sensing: an overview



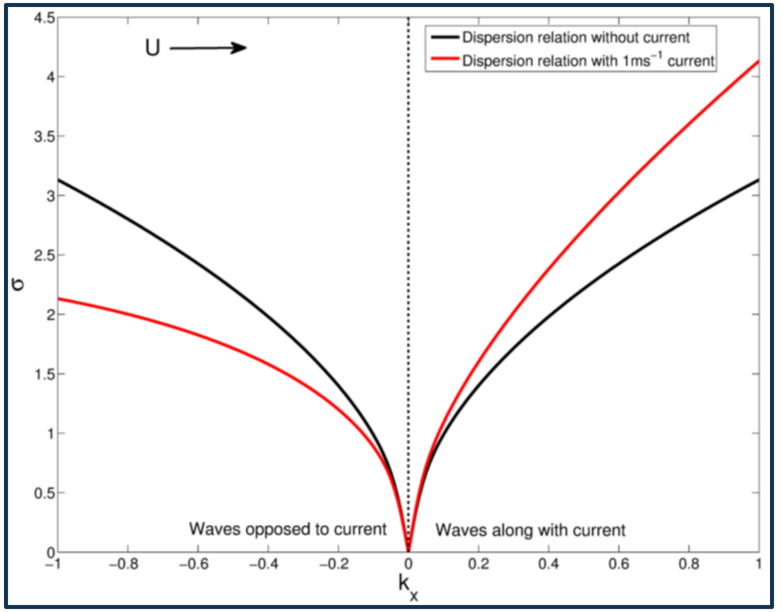
- X-band radar microwaves produce a Bragg resonant response when illuminating ocean surface ripples that satisfy the condition:

$$\lambda_w = \frac{n\lambda_r}{2\cos\theta}$$



- Wind-generated ripples of this length (~1.5cm) are modulated by larger waves (wind sea, swell), producing the phenomenon known as Sea Clutter

X-band radar remote sensing: an overview



Surface waves are **Doppler shifted** by ocean currents (e.g., tides) and **slow down** in **shallowing water**. The theory that links all of this is the **dispersion relation**

$$\sigma = \sqrt{gk \tanh kh} + (Uk \cos \emptyset)$$

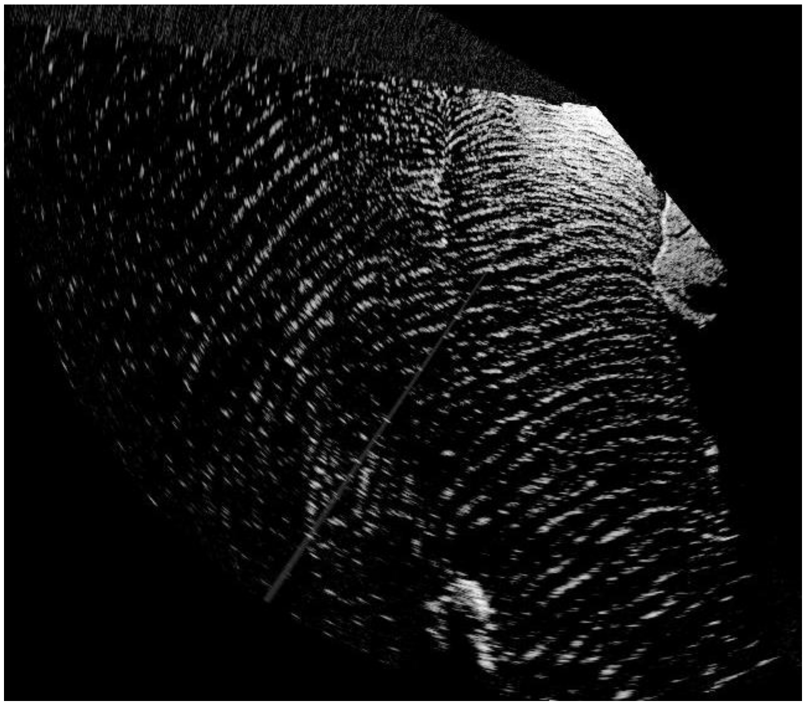
Wave inversion techniques aim to resolve ***h*** and ***U*** using estimates of wave properties ***k*** and ***σ***, derived from **spectral analysis** of **sea clutter imagery**

X-band radar remote sensing: an overview

Caveats:

- **Must be able to 'see' waves** in order to measure anything – minimum wind speed, wave height and wave direction across radar beam
- Imaging mechanism complex and can be affected by a multitude of physical phenomena
- **Maximum depth set by wavelength of waves** – must 'feel' the bottom. In practice this is ~ 1/4λ
- **Currents are surface-skewed** with an average depth dependent on surface wavelength.
- Spectra from image analysis **must be calibrated** with a modulation transfer function (MTF) to estimate surface power spectral density.

Radar-model fusion for high-resolution resource mapping (RAWMapping)

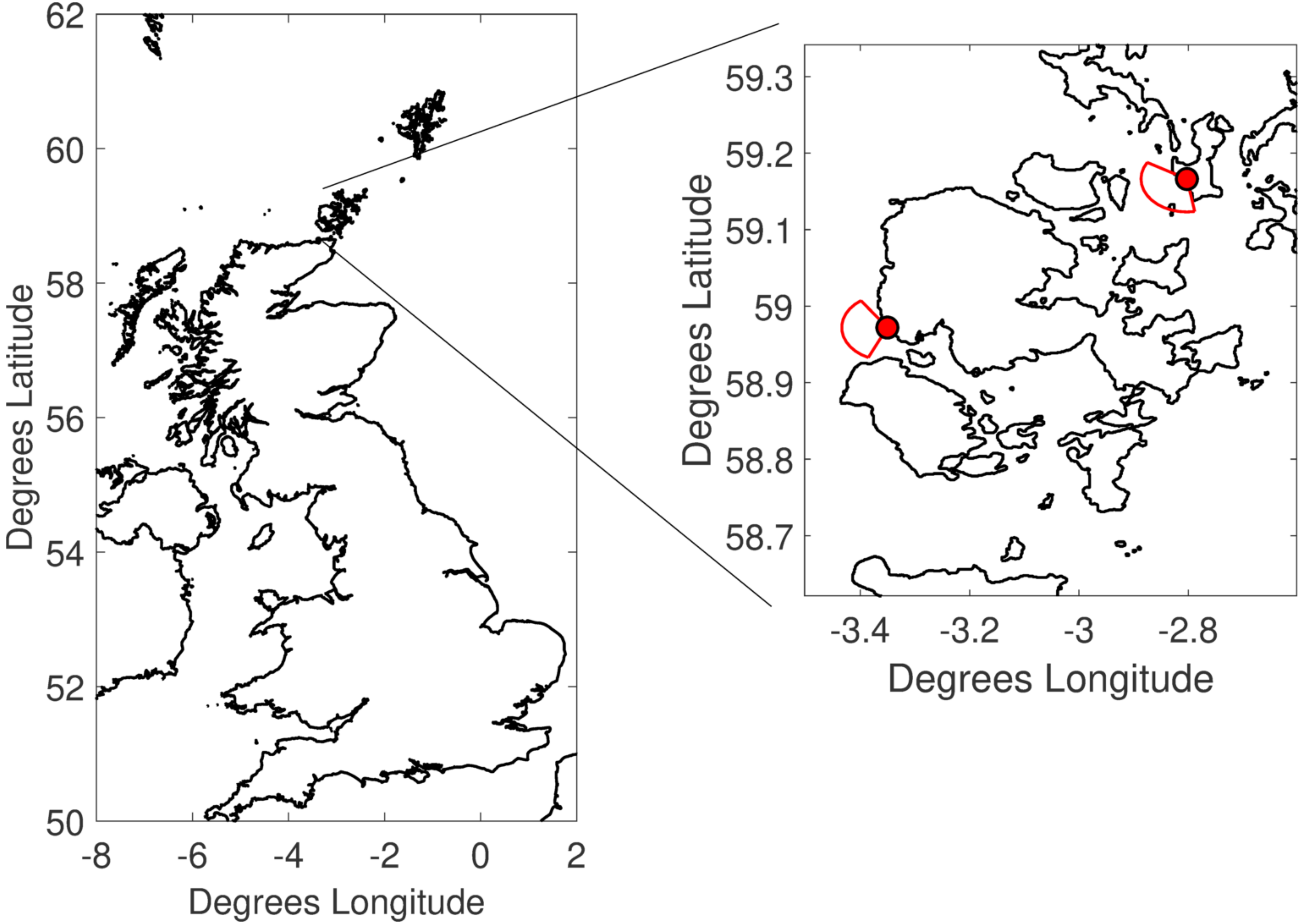


- NERC Innovative Monitoring project Jan 2018 to Dec 2019
- Aimed to improving remotely-assessed measurements of Hs for O&M purposes in high energy, dynamic coastal environments.
- Traditional in-situ measurements unreliable in high-energy flows
- Existing COTS radar methods unsuitable for such inhomogeneous environments

EMEC ORKNEY THE EUROPEAN MARINE ENERGY CENTRE LTD

JBA consulting

openhydro™ a DCNS energies company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-3.2
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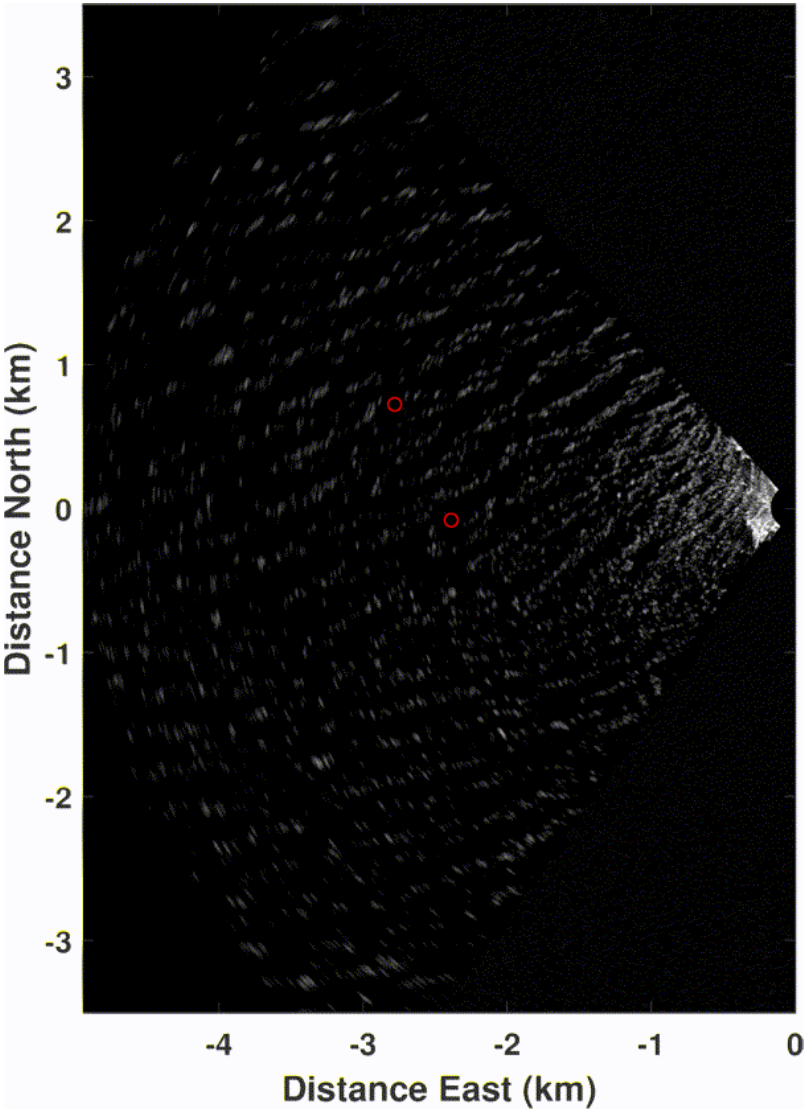
-2.8
Degrees Latitude
Degrees Longitude

Radar installation

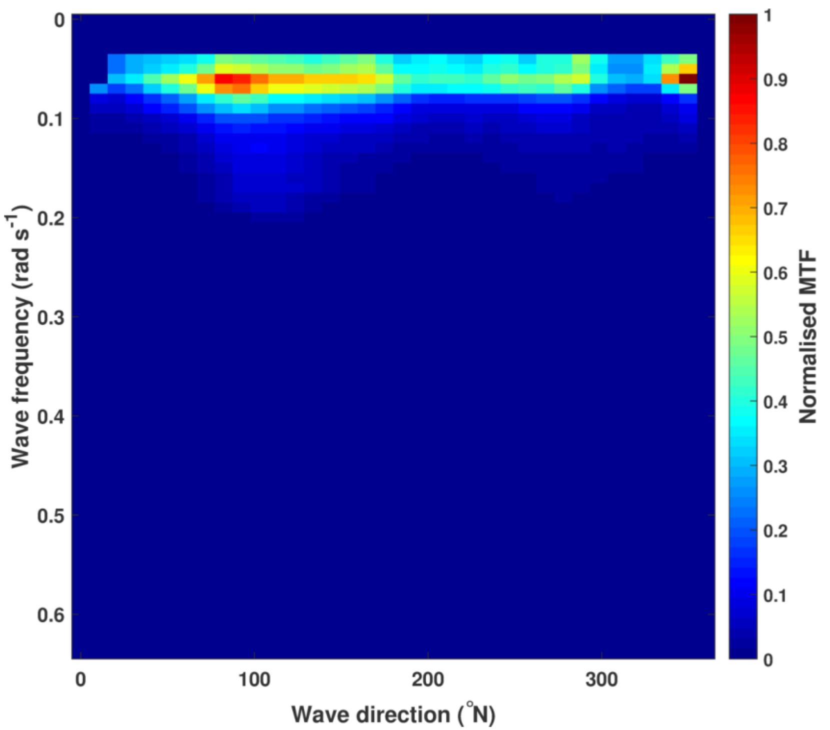
- 10kW Furuno X-band radar mounted on top of EMEC's substation at Billia Croo
- Approx. 6m above MSL
- 2.5s rotation time
- 4.8km range, 7.5m pixel resolution, 128 image stacks
- OceanWaveS 'WaMoS II' radar computer used to digitise radar imagery

Project data



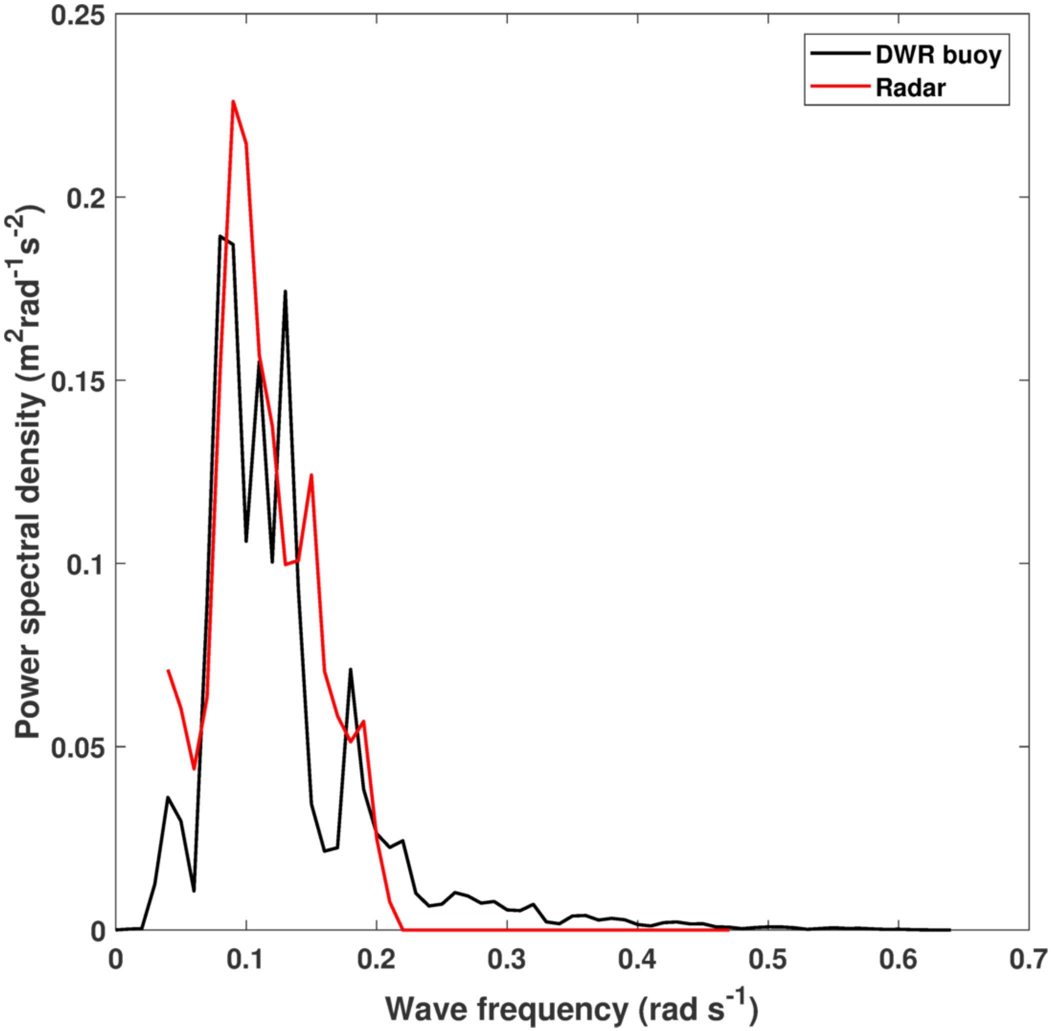
- Radar imagery collected throughout 2019 – apprx. 4Tb
- Two permanently-wired Datawell DWR wave buoys within radar range (red circles)
- Bathymetry of the area taken from the EMODnet harmonised DTM
- Analysis set chosen as 582 sets of 128 images in early May 2019
- Encompassed a 5m Hs wave event and variable sea conditions inbetween

Modulation Transfer Function (MTF)



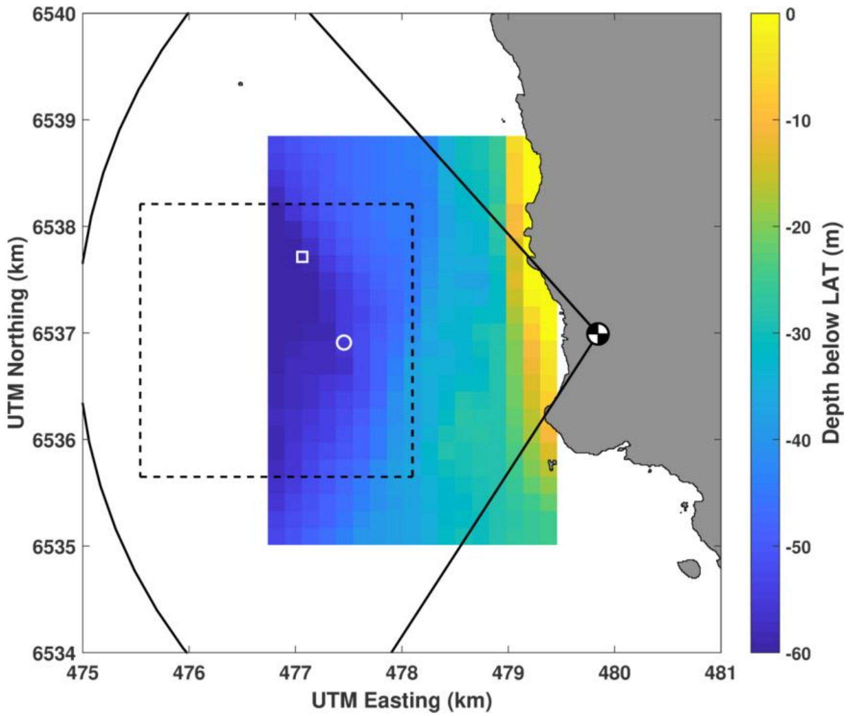
- Directional spectra calculated from radar imagery (image spectra) not representative of ocean surface power spectral density
- Need a function to convert – an MTF
- Calculated by comparing image spectrum filtered using the dispersion relation with 2D spectra from wave buoys
- MTF is radar/site specific and changes with time (magnetron physical degradation)

Wave spectra



- Resulting wave spectra from the radar range from very good to very bad depending on imaging conditions
- Due to the imaging mechanism low and high-frequency ‘cut-offs’ present
- Rain, low-wave / wind days and vessels parked in the analysis box all contribute to bad recordings

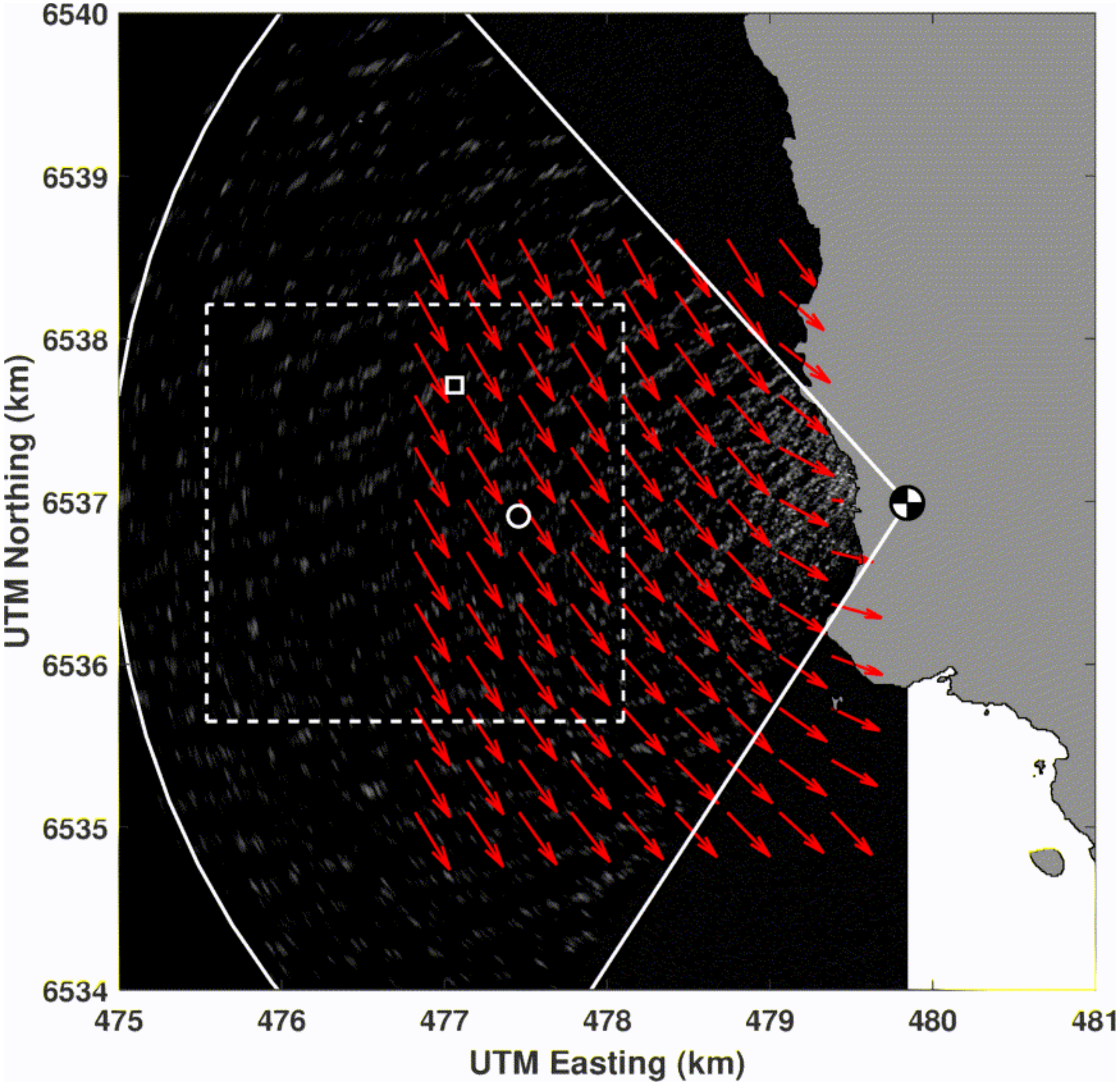
SWAN model set-up



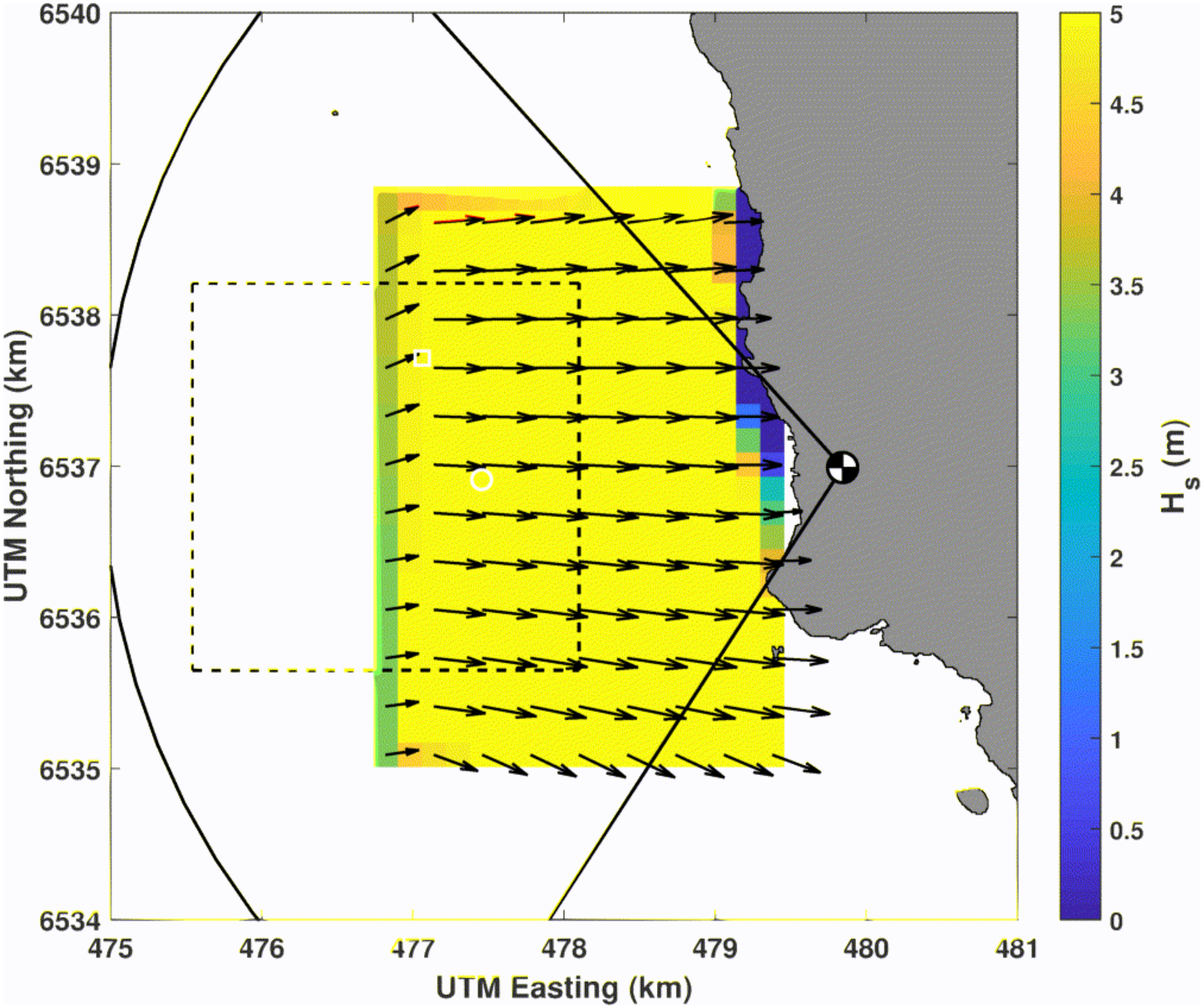
- Depth from EMODnet Harmonised DTM
- Boundary conditions constant around open boundary
- No wind (assume wind sea captured in radar-derived spectra) or tidal elevation changes (MWL=0)
- Run in 'stationary' mode – reaching convergence for each radar record in isolation

- Largely 'standard' physics set-up (Triads, Wave Breaking, Diffraction, Whitecapping)

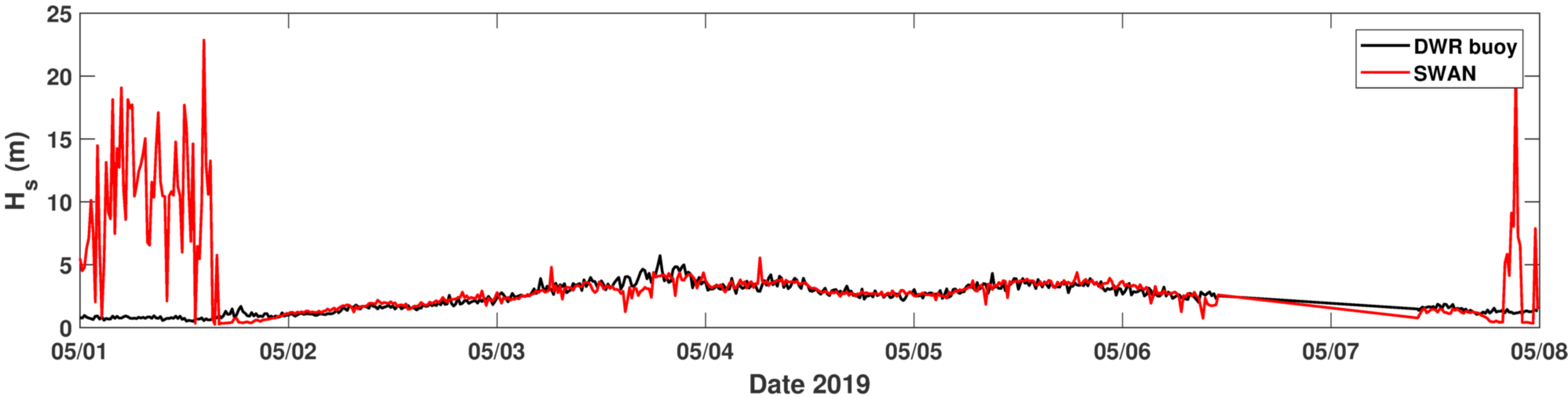
SWAN model set-up

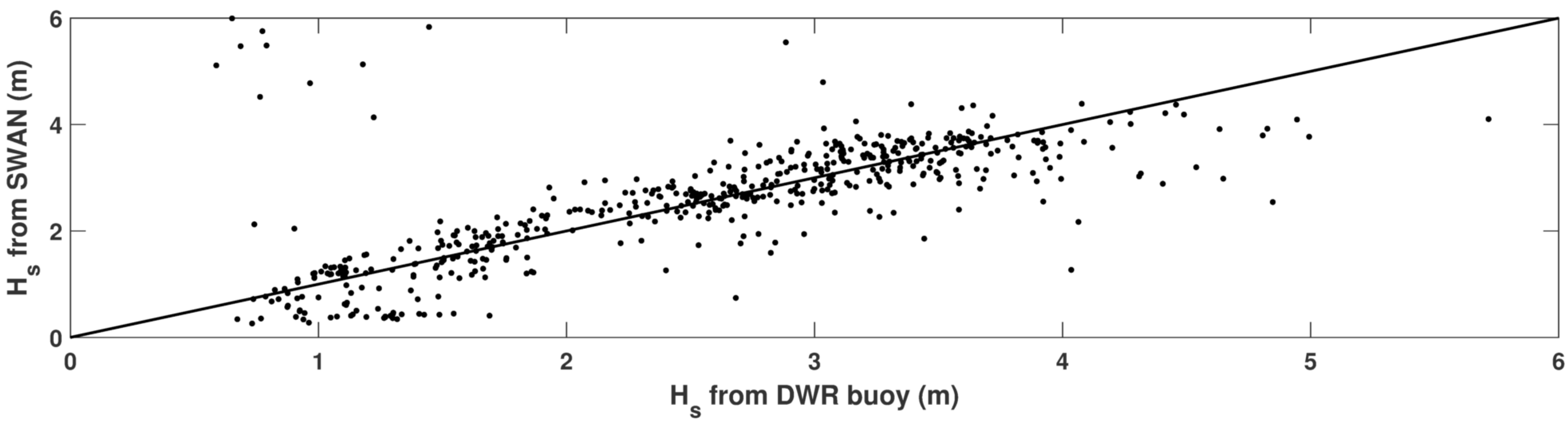


SWAN results

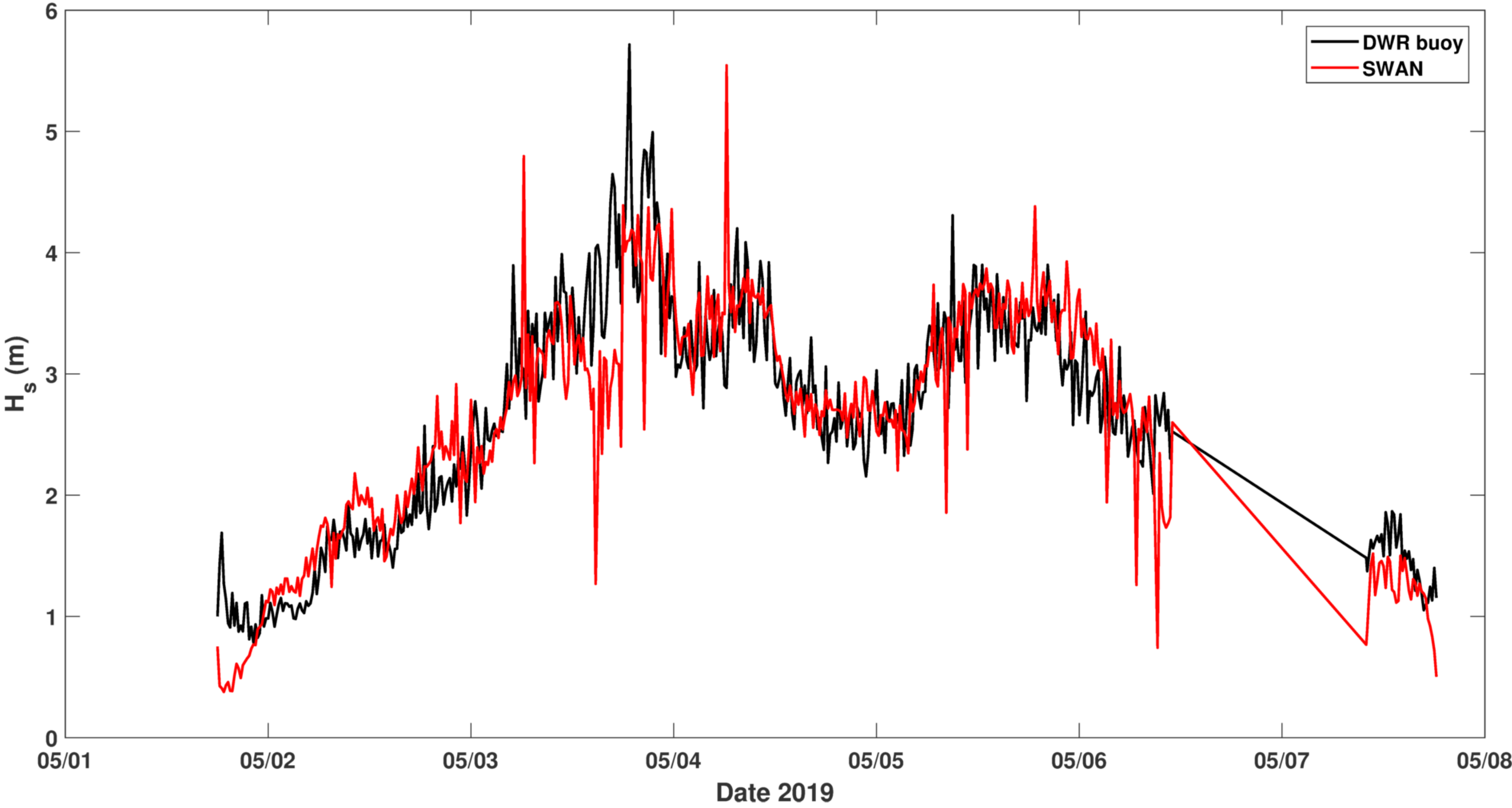


Significant wave height

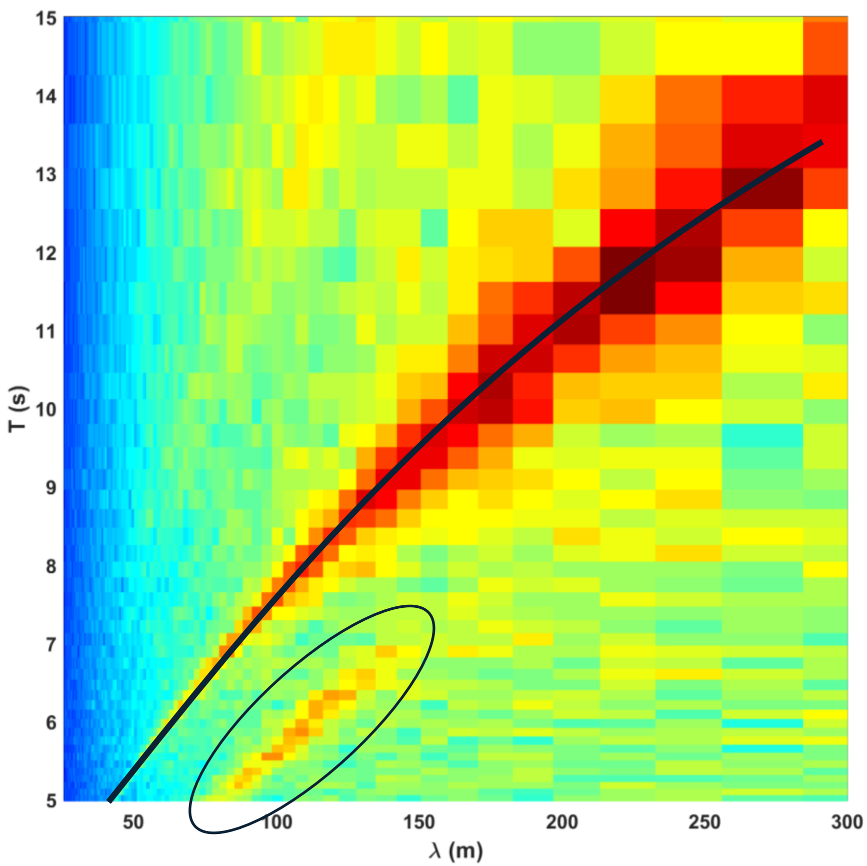




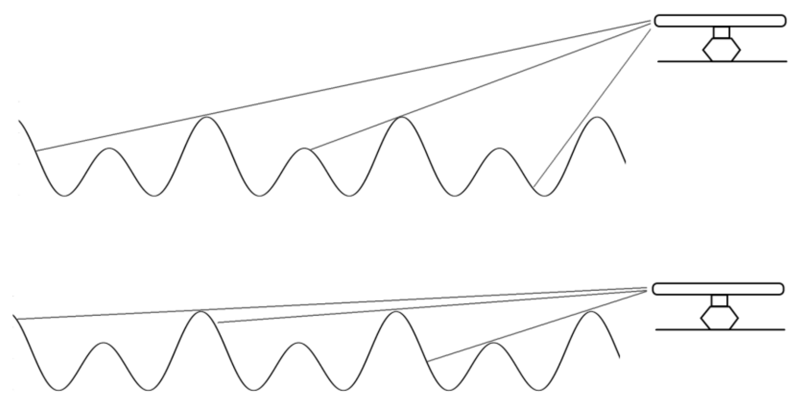
Significant wave height



‘Shadowing’ problem at Billia Croo



- Band of energy in image spectra at ~2x wavelength of principal dispersion shell
- Effect of imaging mechanism? Or consequence of site set-up?
- Current theory is ‘shadowing’ from low elevation angle and large waves at Billia Croo



Conclusions

- First time successfully forcing a 3rd generation wave model with radar-derived data products
- Model is ‘garbage in – garbage out’, need robust QC routines to filter out bad radar data (rain, low wind / clutter, presence of vessels)
- Site not ideal but borne of necessity – need to apply the system to better radar data (high elevation) and more non-homogeneous wave conditions

National Oceanography Centre

Thanks for listening