Marine radar derived current vector mapping at a planned commercial tidal stream turbine array in the Pentland Firth

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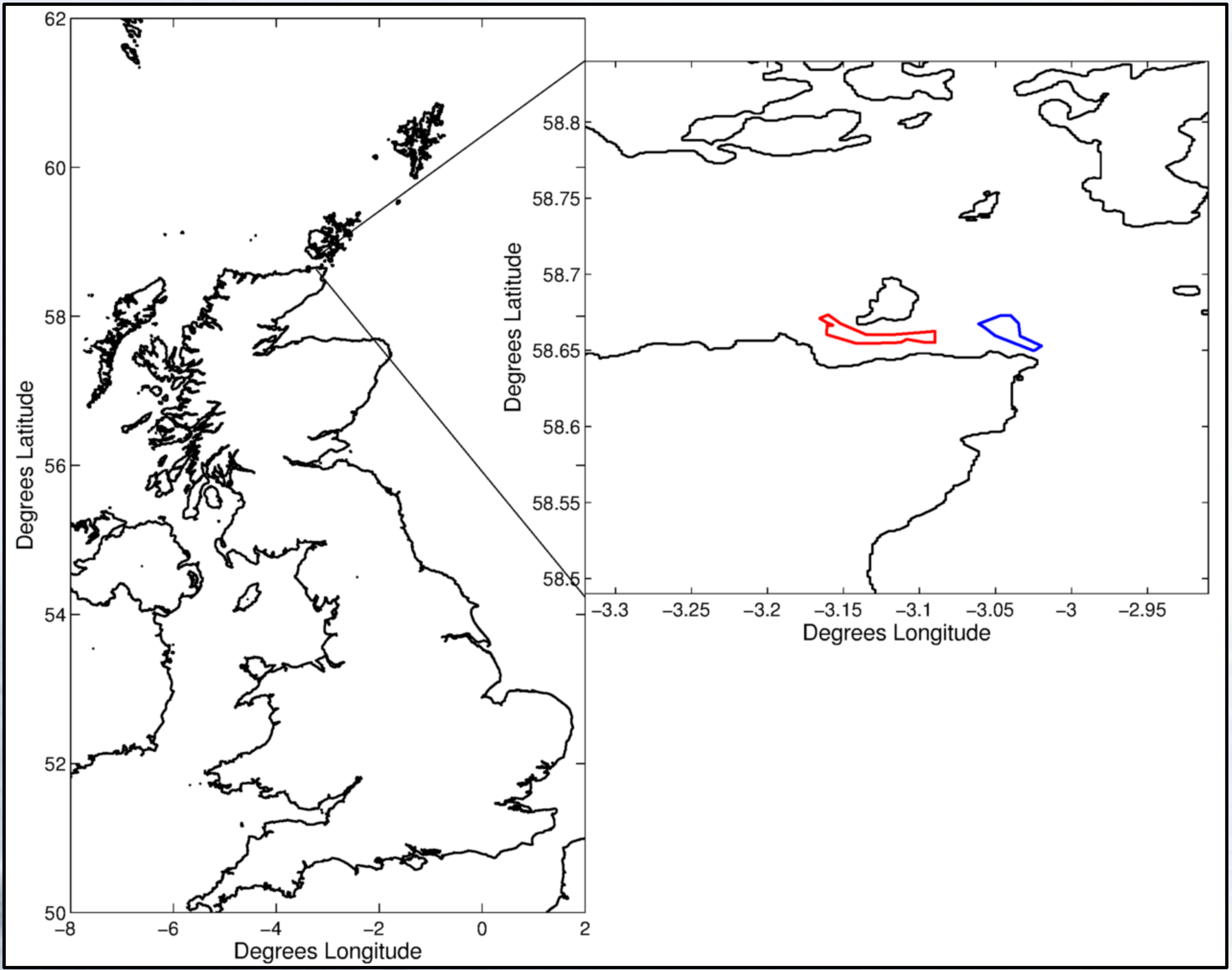
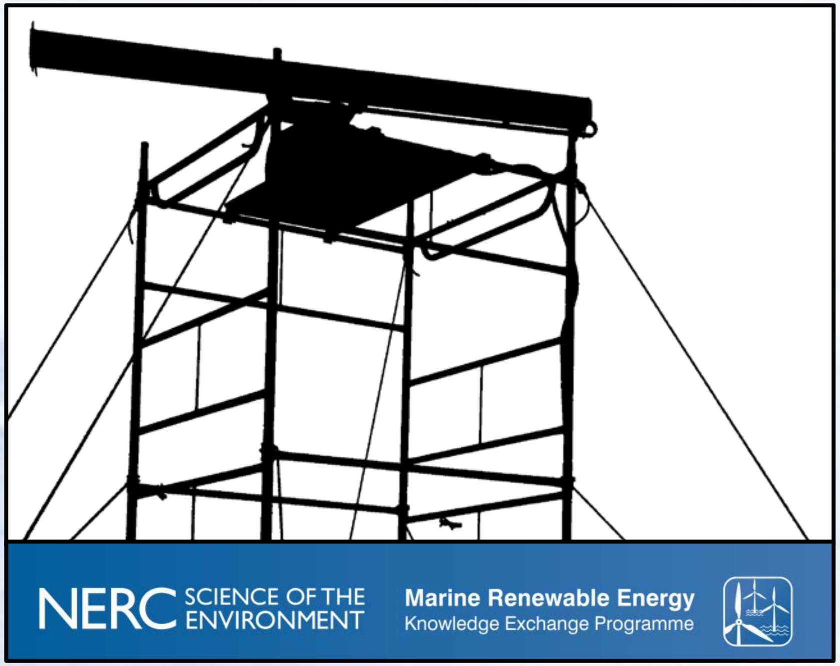
Tidal power in the Pentland Firth



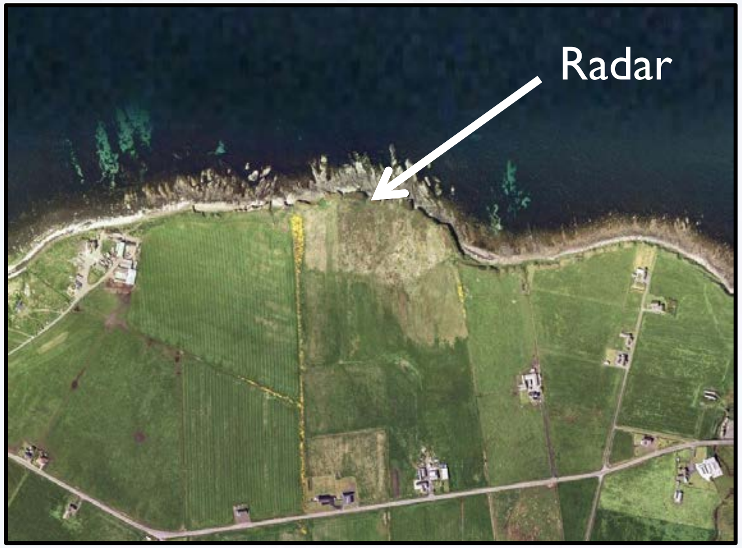
‘Pentland X’

- A NERC MRE KEP project was set up between the NOC and MeyGen to help provide expertise in state-of-the-art X-band Radar oceanography and apply it to the MeyGen lease area in the Pentland Firth
- The primary aim was to showcase the state-of-the-art in radar oceanography to augment MeyGen’s understanding of the hydrodynamics of the Inner Sound of Stroma
- Flow profile data from two in-situ ADCP surveys (ERI and MeyGen) were provided to validate radar-derived currents

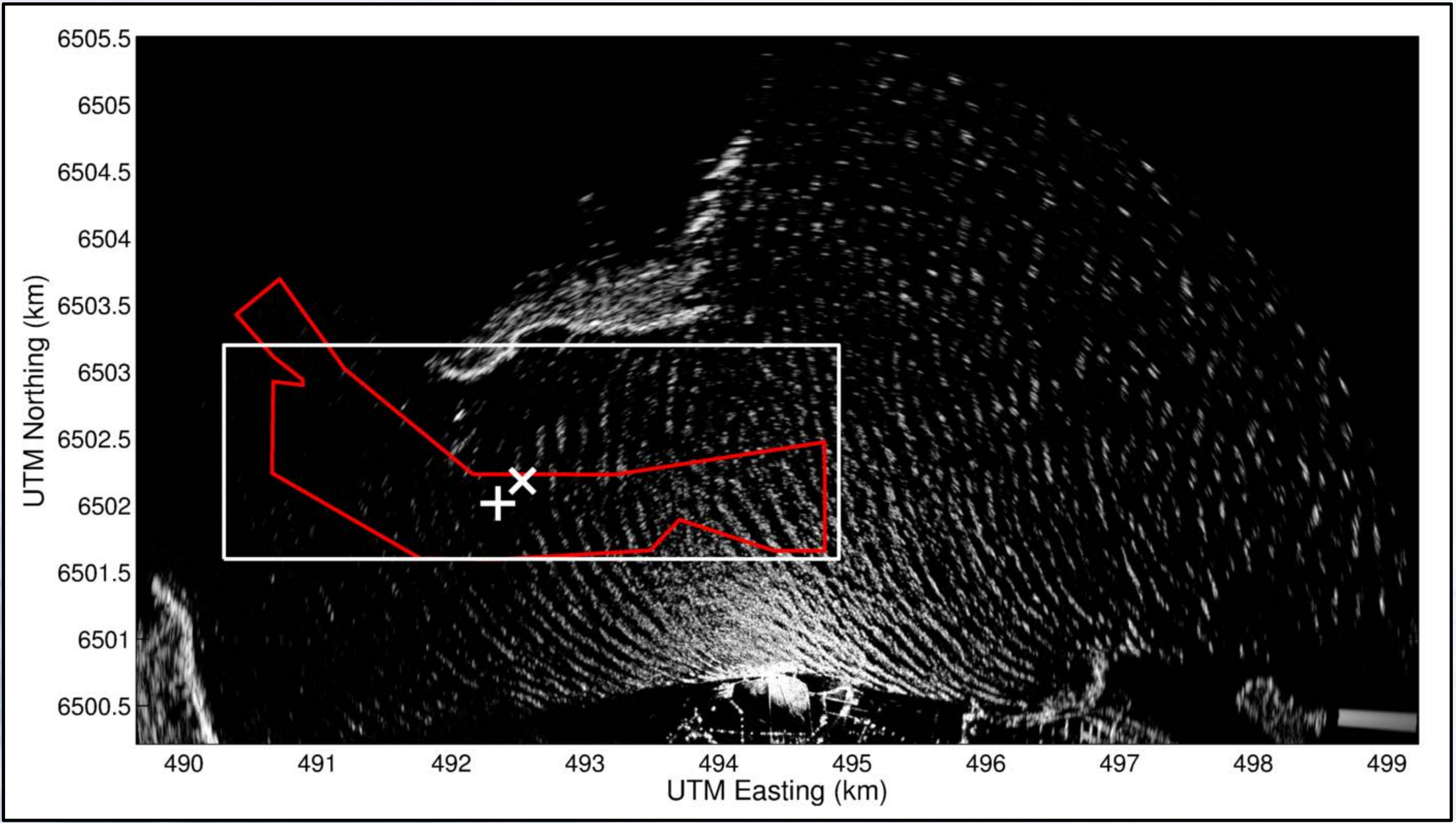


Field deployment

- Ran between March and June 2013 (91 days)
- Kelvin Hughes Nucleus3000 series with 2.4m HH antenna rotating once every 2.5s
- Recording 5 minutes of data (128 images) every 20 minutes
- Antenna mounted on scaffold (~12m above MSL) with equipment housed in wooden enclosure
- Equipment run off batteries with generator used for charging only – significantly reduced fuel and maintenance costs
- Raw radar images stored to disk and retrieved for post-processing
- ~1Tb per month



Raw radar data

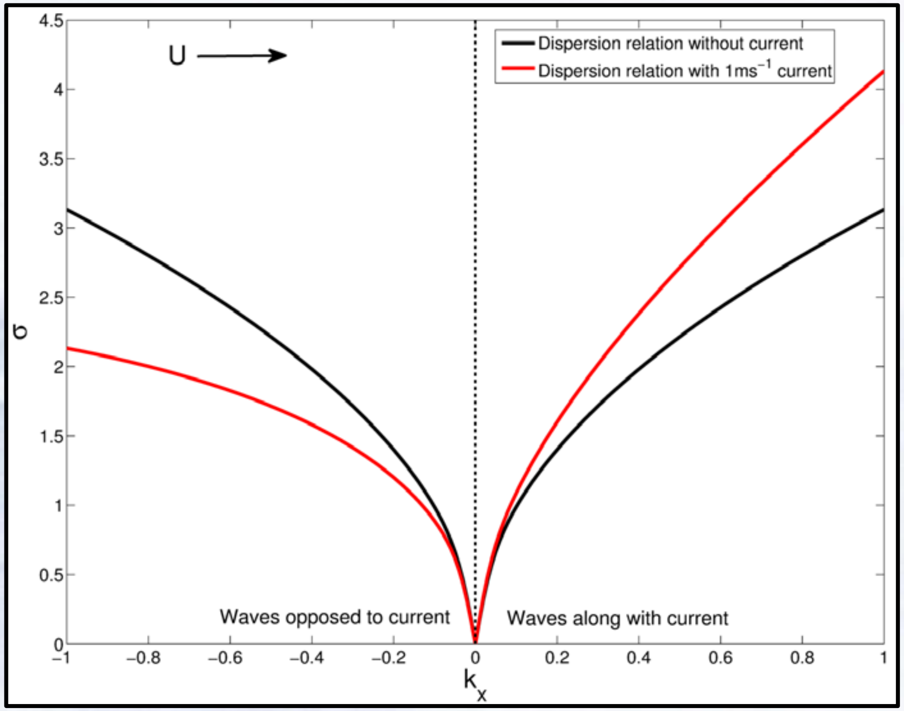


NOC current analysis

- Performs a spectral analysis of sea clutter to determine the Doppler shift of surface waves from an underlying mean current.
- The two-dimensional Doppler-shifted wave parameters are then used to perform an inversion of the wave dispersion relation to solve for the underlying current vector
- NOC analysis also calculates the effective depth (h) using a similar method

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

- Critically, a good spread of k and σ needs to be resolved from wave images to get a lock on the magnitude and direction of the current
- Quality of currents is proportional to quality of wave images



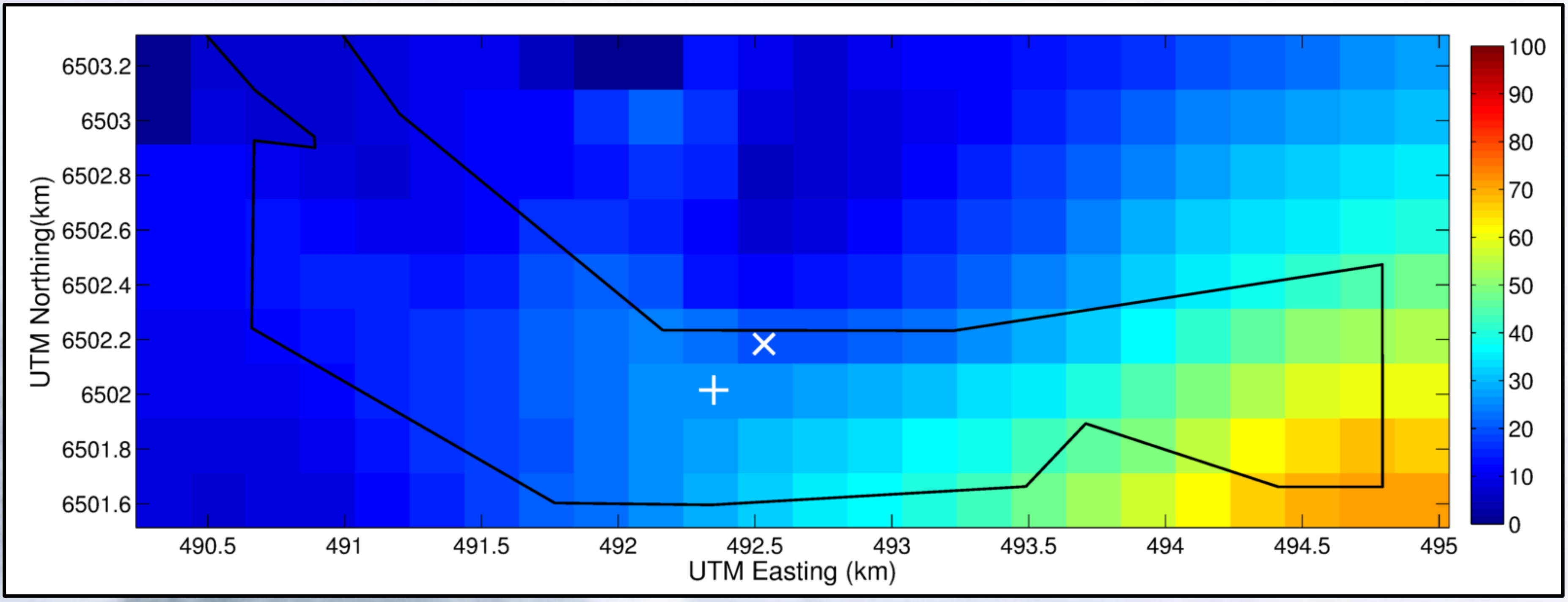
NOC current analysis

- The analysis works on the assumption of wave spectral homogeneity across a grid cell (200m across)
- Analysis box shifted step-wise across the survey area
- Calculated currents are therefore an **area measurement** representing conditions across an entire grid cell
- Sub-grid-scale effects (e.g. turbulent eddies, shear-zones) are therefore unaccounted for by the analysis
- Must be taken into account when comparing point (e.g. ADCP) measurements with those derived from radar images

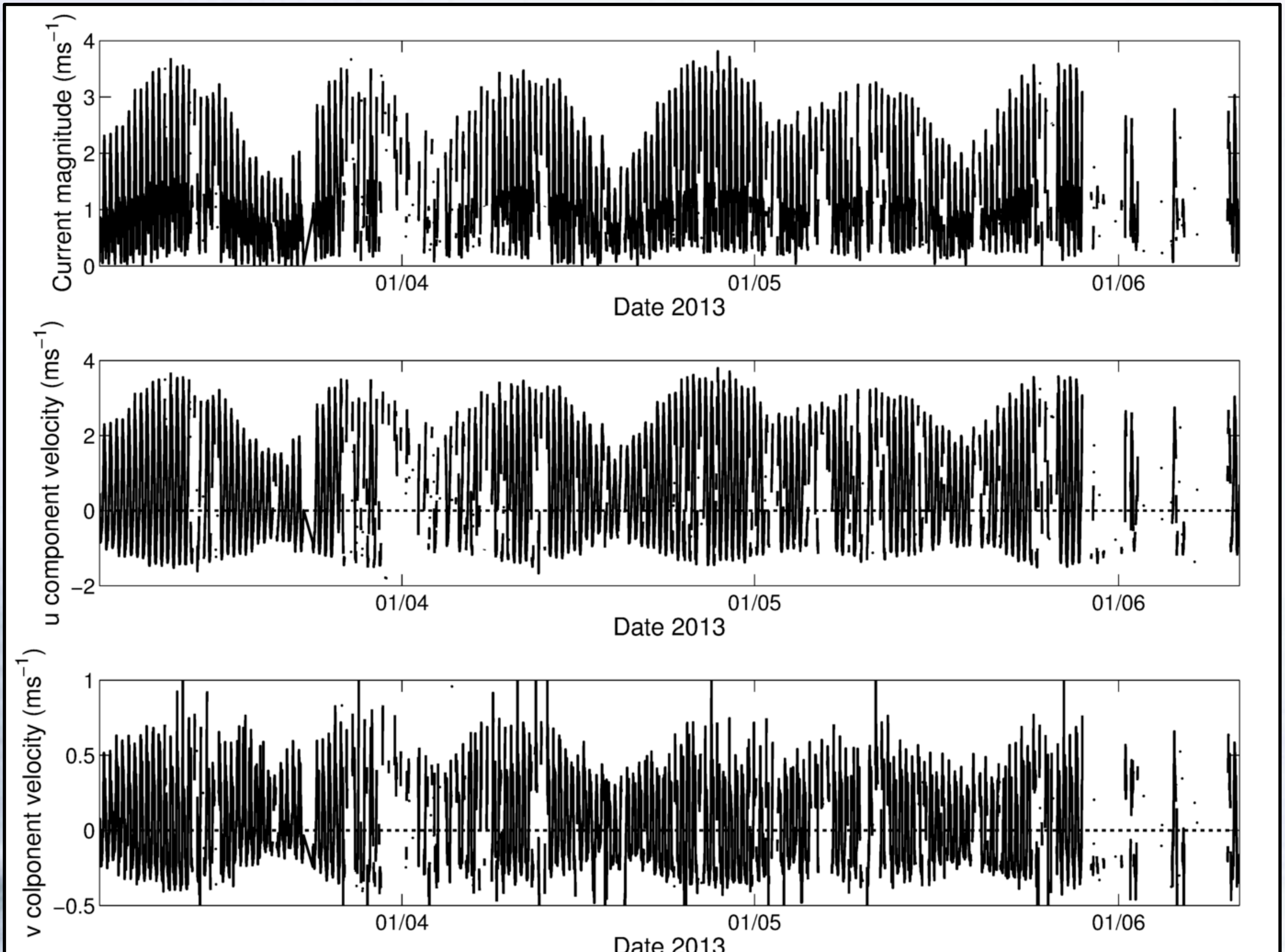
- Although currently post-processed we are close to trialling near-real-time processing on-site

NOC Quality Control

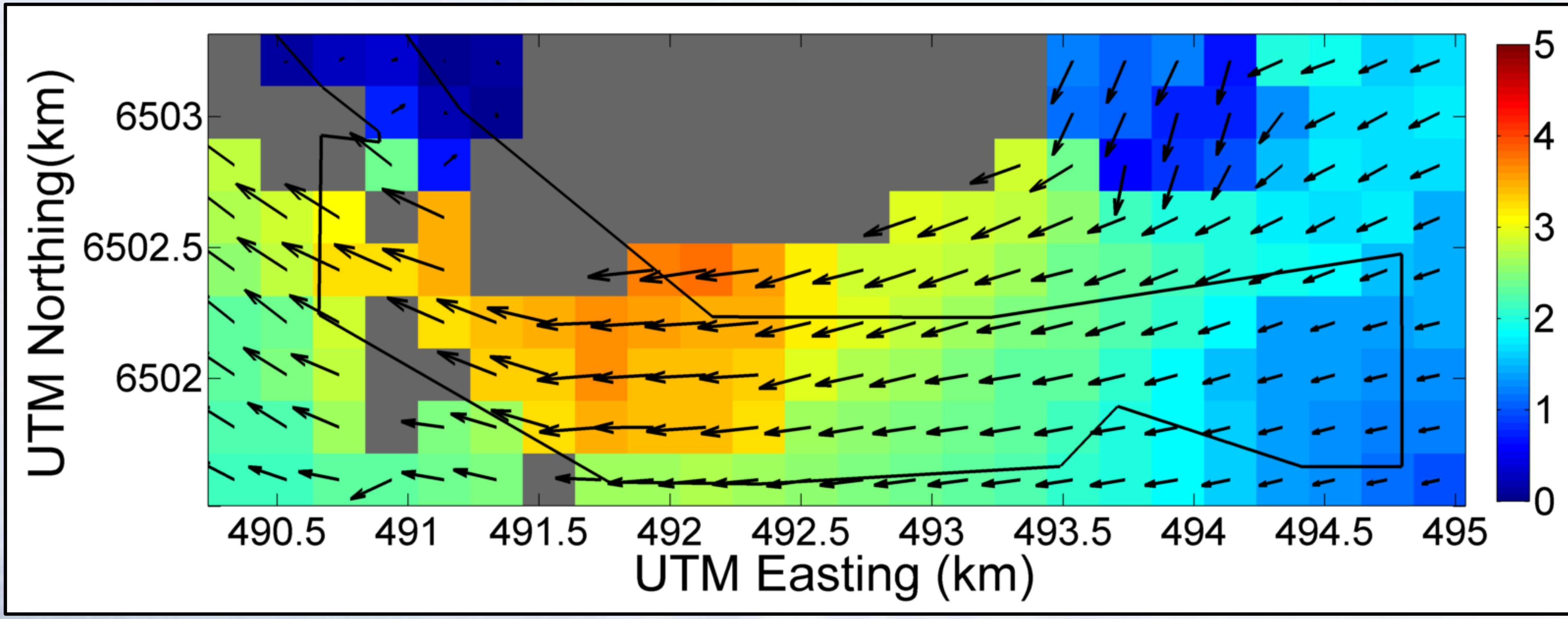
- Unique QC parameters calculated during the NOC current analysis routines
- Used to reject current vectors from poorly resolved wave spectra
- The consequence is a reduction in the current record length that varies across-site



Example Radar-derived time-series



Example radar-derived flow vectors (ebb)



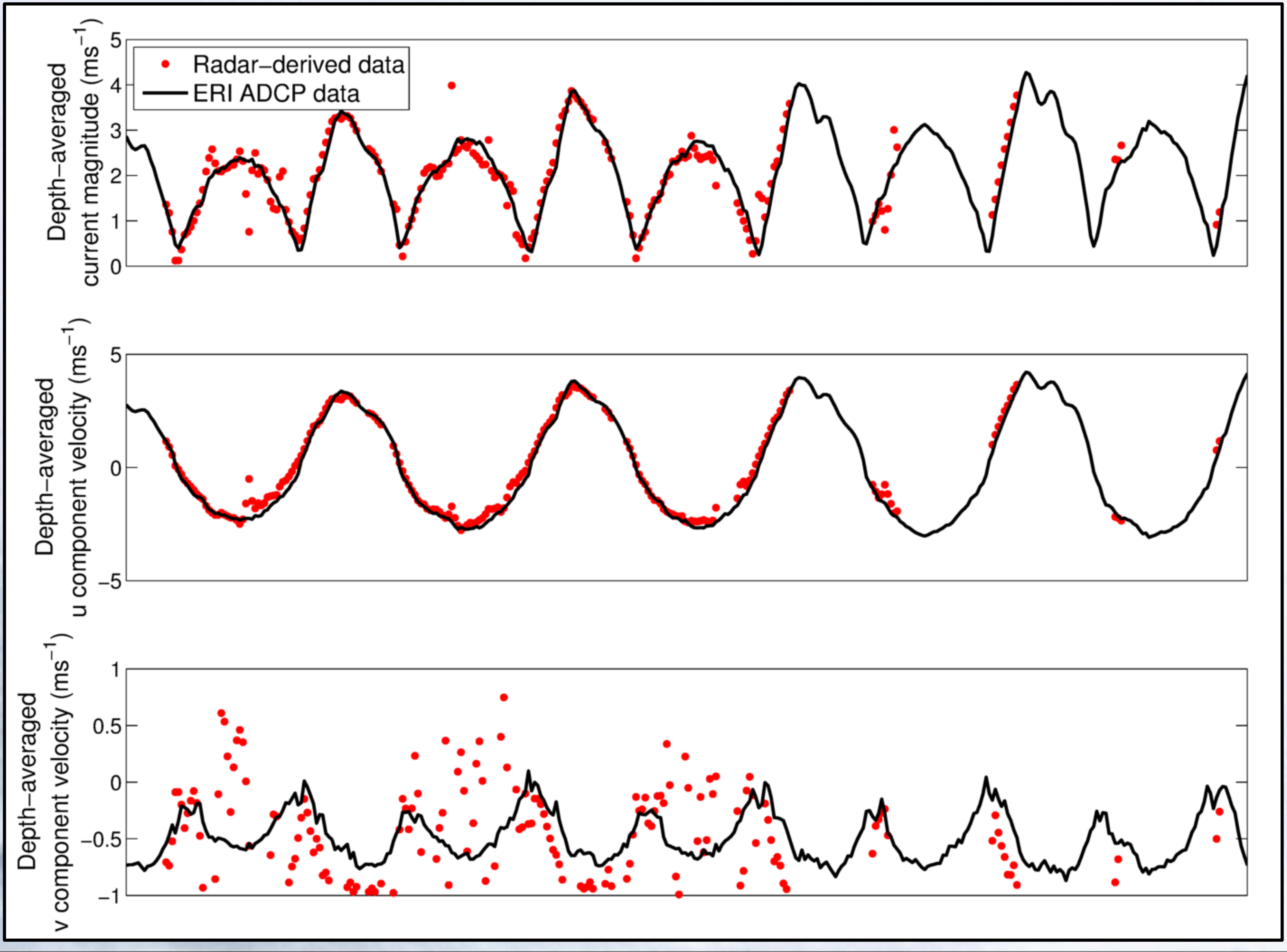
- Blanked areas show the activity of the QC routines
- The North-Western portion of the MeyGen lease tended to be sheltered from (predominantly Easterly) waves
- Data towards the North is degraded due to the presence of the Isle of Stroma

ADCP validation

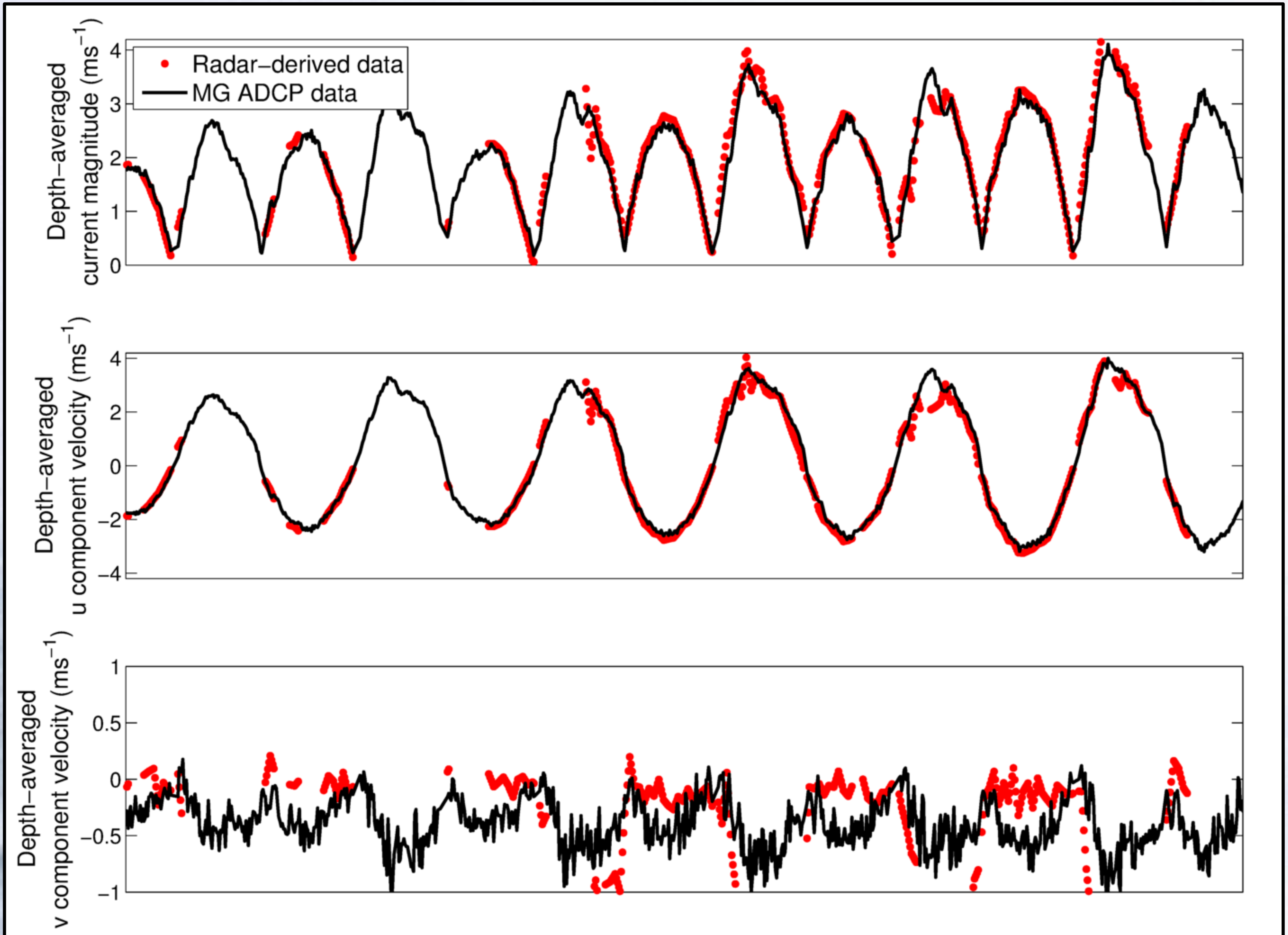
- Two ADCP surveys ('ERI' and 'MG') were used to validate the radar-derived currents
- At present there is no agreed relationship between the flow speed from X-band radar (i.e. what speed the waves 'feel') and its equivalent position in a depth profile.
- The current the waves feel must be some form of an integral over the effective depth – as the waves are long enough to reach the bed, this is therefore likely to be close to the depth-averaged flow speed.
- Therefore the depth-average from the ADCP flow profiles was used to compare to the radar-derived current speeds.

- It is important to note that *there is no 'like-for-like' comparison possible* – the ADCPs and the radar make two very different forms of measurements. The comparison therefore relies on the sea-state over a radar grid cell.

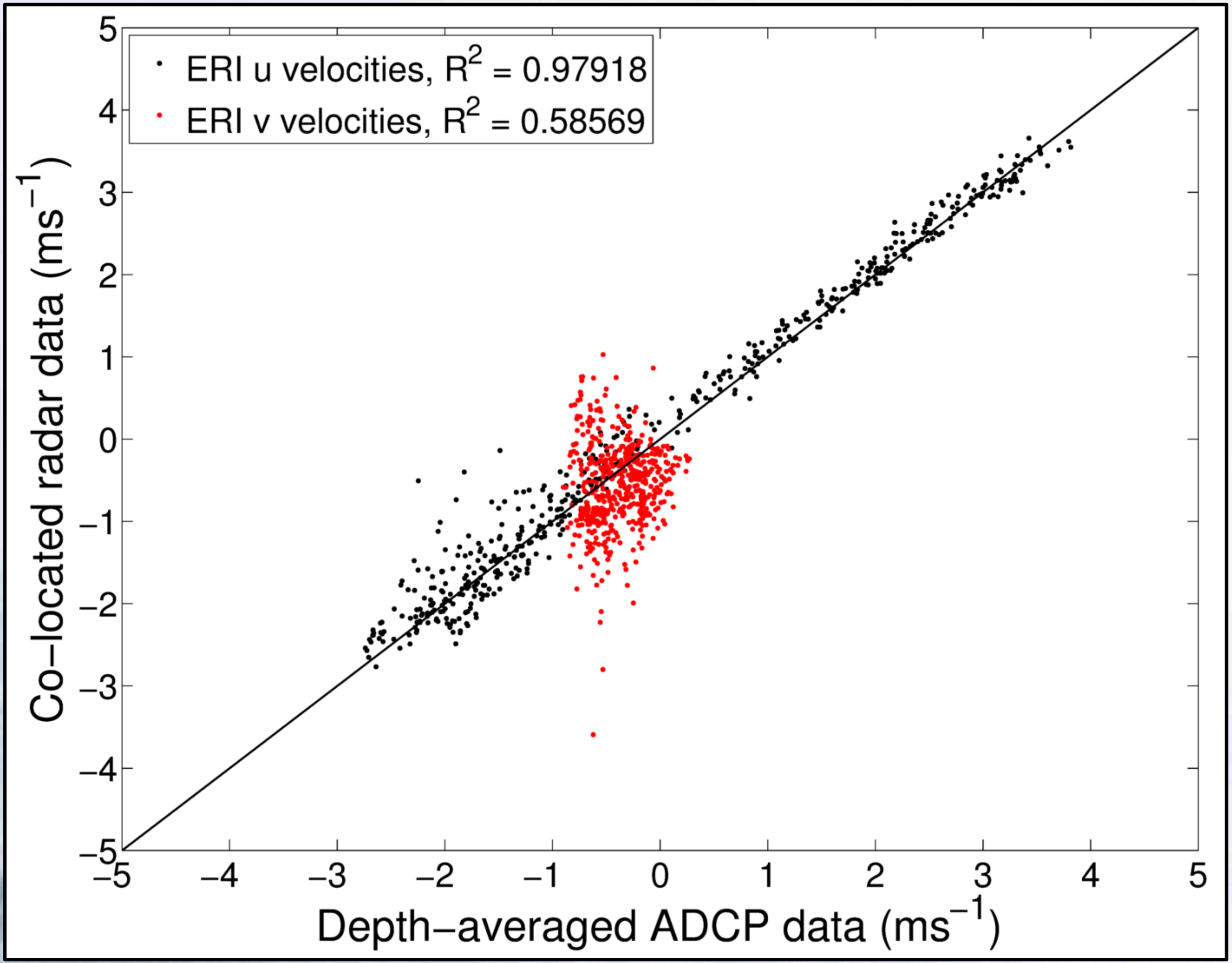
ADCP validation – ERI time-series



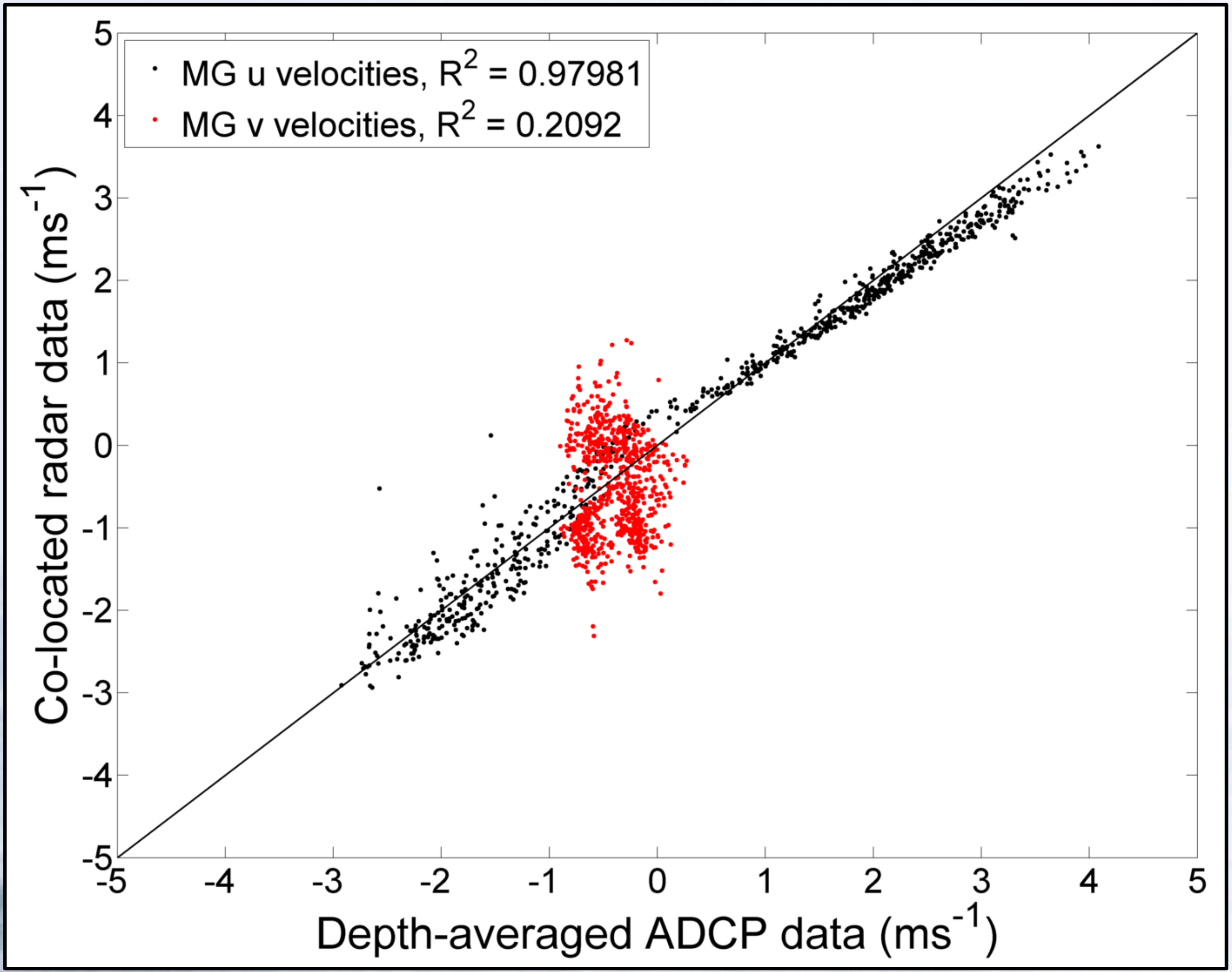
ADCP validation – MG time-series



ADCP validation – ERI data



ADCP validation – MG data



Tidal harmonic analysis

- Possible to undertake harmonic analysis of the radar-derived time-series at each point in the survey grid
- Although there is 91 days of data, QC reduces the record length considerably across much of the survey area
- The resolution of harmonic constituents requires record lengths of the order of the constituent period
- The resulting harmonic constituents are therefore not suitable for predictive purposes but the top diurnal and semi-diurnal constituents are sufficiently resolved to be used for comparative purposes.

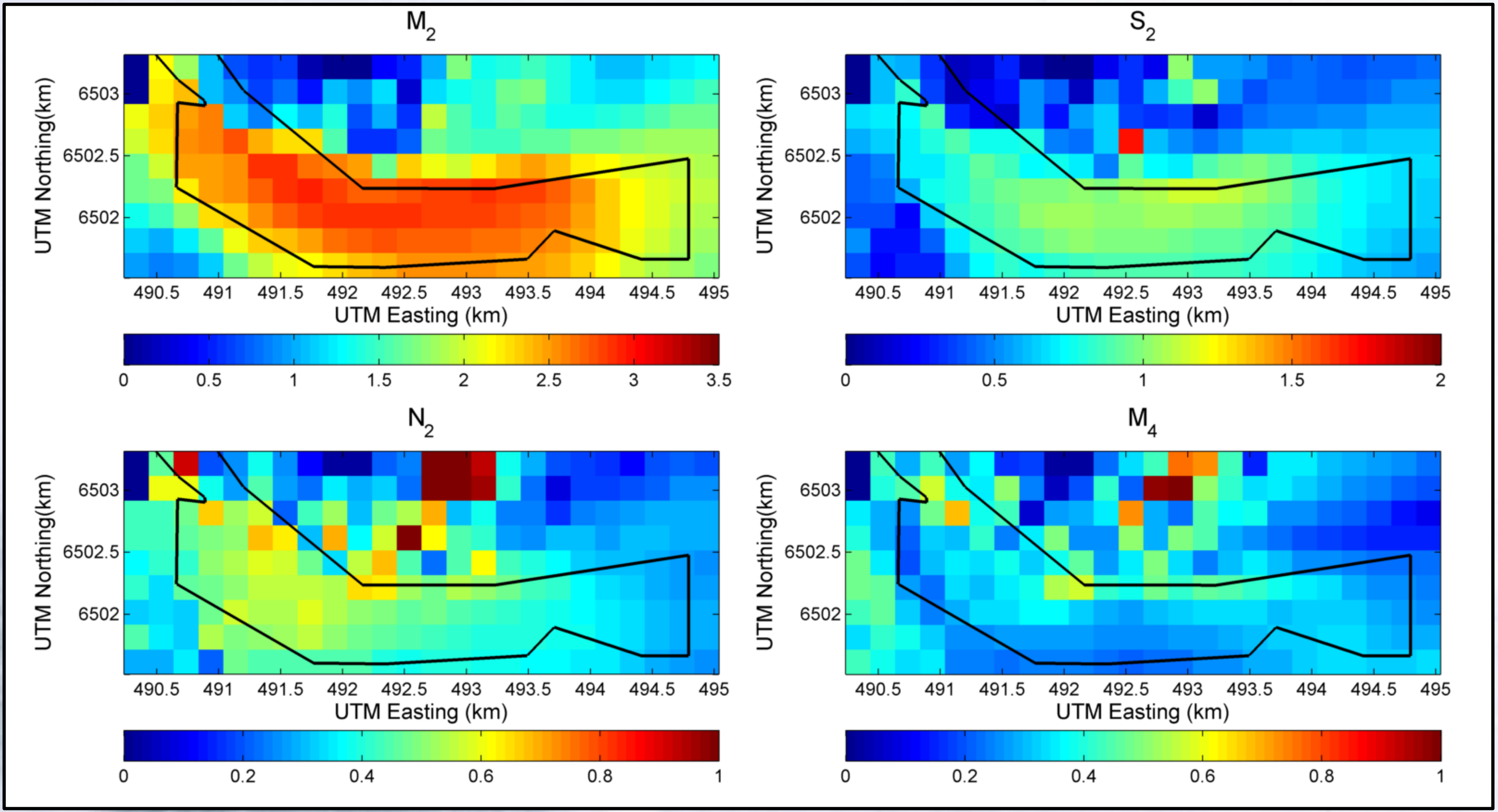
- NOC analysis based on 'UTide' – open source tidal harmonic analysis routine based on least-squares fitting of 40+ constituents and nodal coefficients. Works with 'gappy' data (essential!)

Tidal harmonic analysis – ADCP comparison

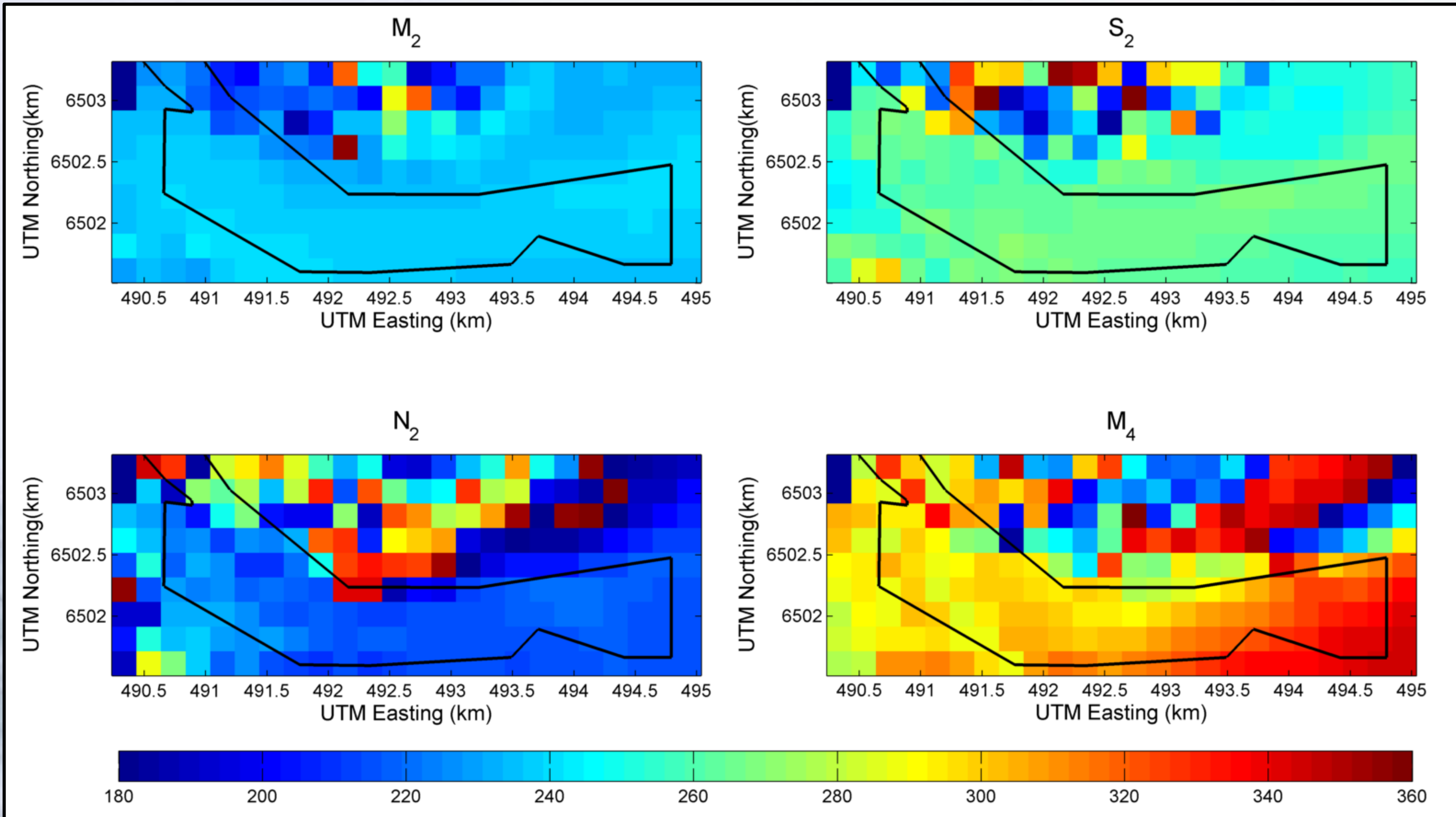
	ERI ADCP			Radar		
	A_{maj}, A_{min} (ms^{-1})	G (°)	E (%)	A_{maj}, A_{min} (ms^{-1})	G (°)	E (%)
M_2	2.66, -0.11	240	82.75	2.74, -0.04	236	75.70
S_2	1.01, -0.06	274	11.94	1.03, -0.14	263	10.83
N_2	0.47, 0.03	198	2.60	0.46, -0.23	186	2.69
M_4	0.26, -0.01	305	0.81	0.38, -0.054	296	1.45
U_{mean}, V_{mean}	0.29, -0.43			0.099, -0.64		
Var (%)	98.3			94.8		
E_4 (%)	98.1			90.7		

	MG ADCP			Radar		
	A_{maj}, A_{min} (ms^{-1})	G (°)	E (%)	A_{maj}, A_{min} (ms^{-1})	G (°)	E (%)
M_2	2.81, -0.08	238	89.33	2.85, -0.08	238	82.03
S_2	0.68, -0.007	264	5.17	1.03, -0.03	266	10.67
N_2	0.57, -0.03	218	3.64	0.49, -0.013	213	2.41
M_4	0.24, -0.007	303	0.63	0.29, -0.008	295	0.83
U_{mean}, V_{mean}	0.19, -0.38			0.12, -0.52		
Var (%)	97.9			97.28		
E_4 (%)	98.77			95.94		

Tidal harmonic analysis - Amplitudes



Tidal Harmonic analysis – Phases



Conclusions

- X-band marine radar can provide complimentary information to traditional, in-situ surveys of MRE resource
- The area-wide surveys, if run for a sufficient length of time, can provide valuable information on the spatial variation of tidal harmonics
- Radar surveys could provide a valuable tool to help plan the deployment of (costly) in-situ measurements to maximise the yield of useful data and avoid the cost of redundant surveys

- The validation is excellent and lends confidence to the accuracy of the dataset
- The confidence in ADCP validation allows the dataset to be used to cross-validate coastal area hydrodynamic models of the MeyGen site

- MeyGen are currently using the dataset to help de-risk turbine placement ahead of the installation of their operational demonstration array later this year

NERC SCIENCE OF THE ENVIRONMENT

National Oceanography Centre
NATURAL ENVIRONMENT RESEARCH COUNCIL

Thank you for your attention

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