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NATURAL ENVIRONMENT RESEARCH COUNCIL

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

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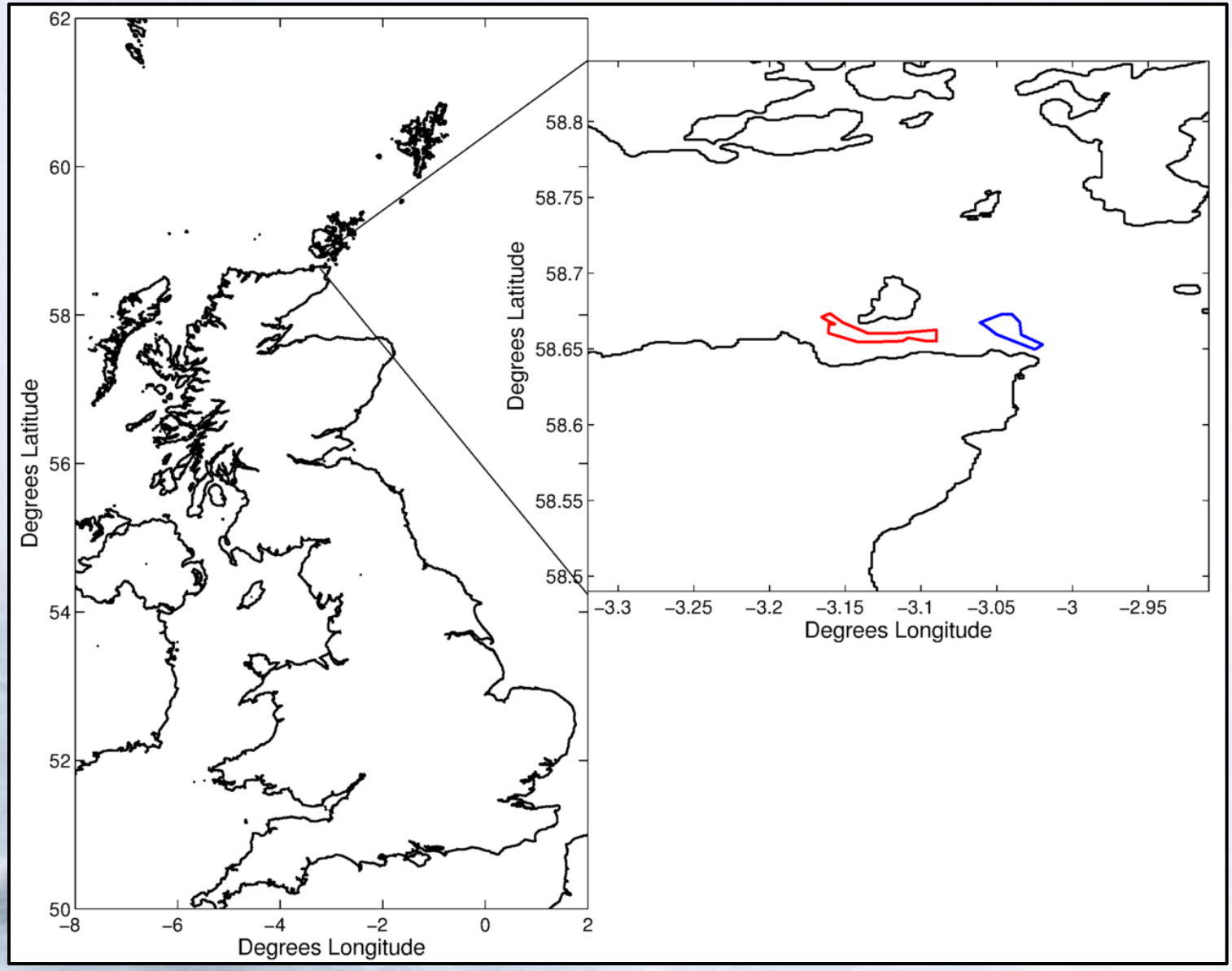
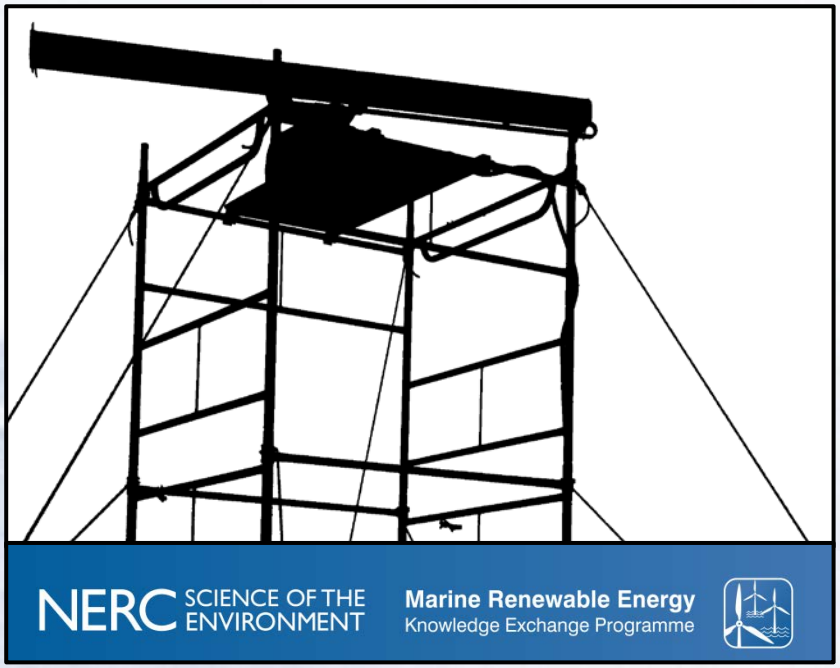
Tidal power in the Pentland Firth



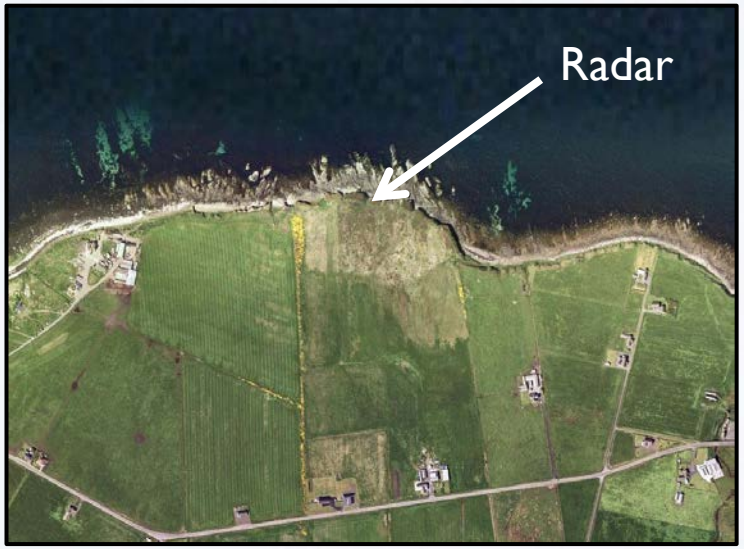
‘Pentland X’

- 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

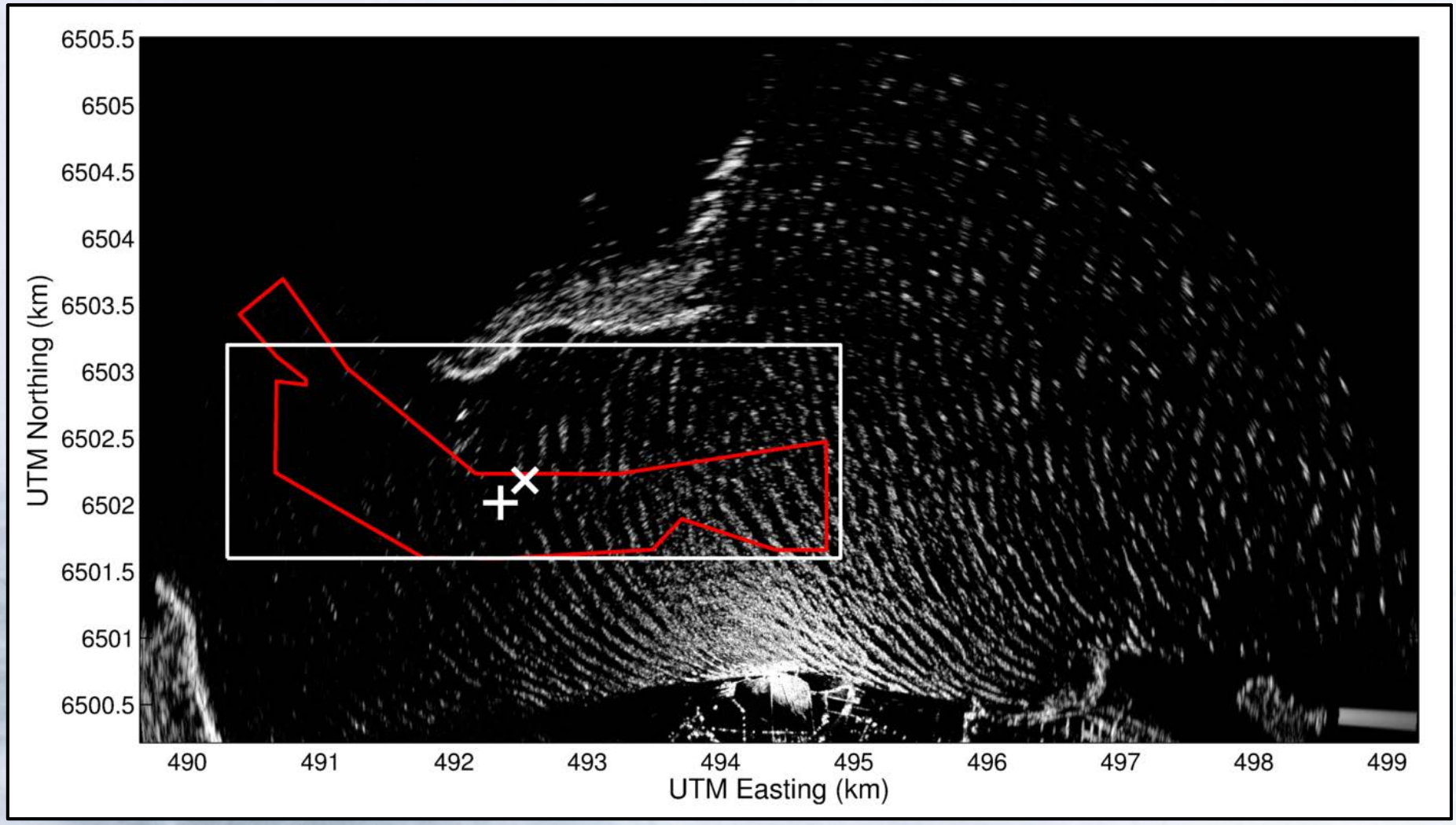


Field deployment

- 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

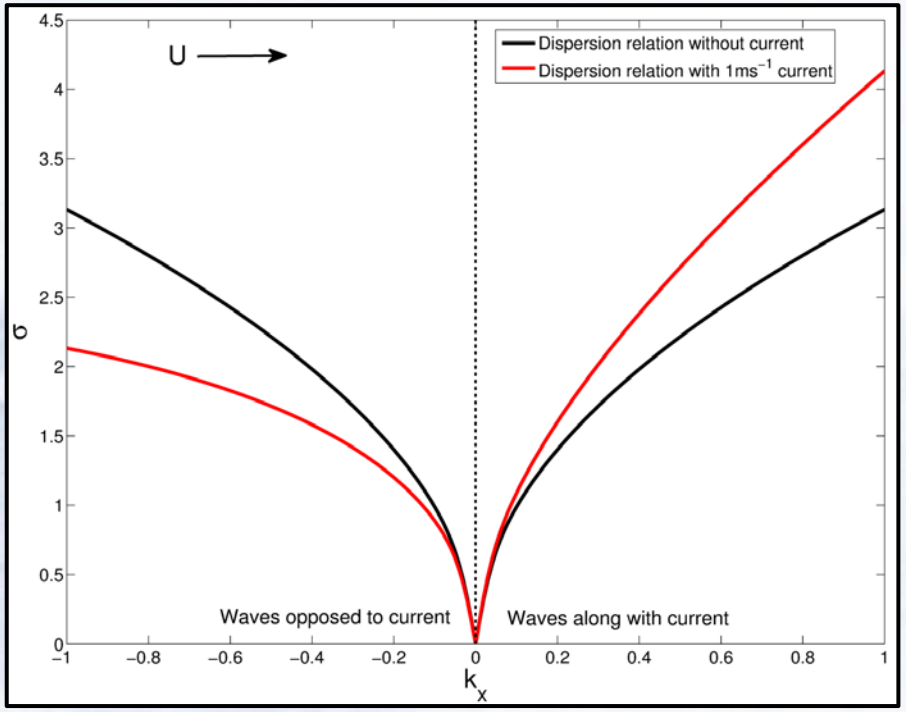


NOC current analysis

- 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



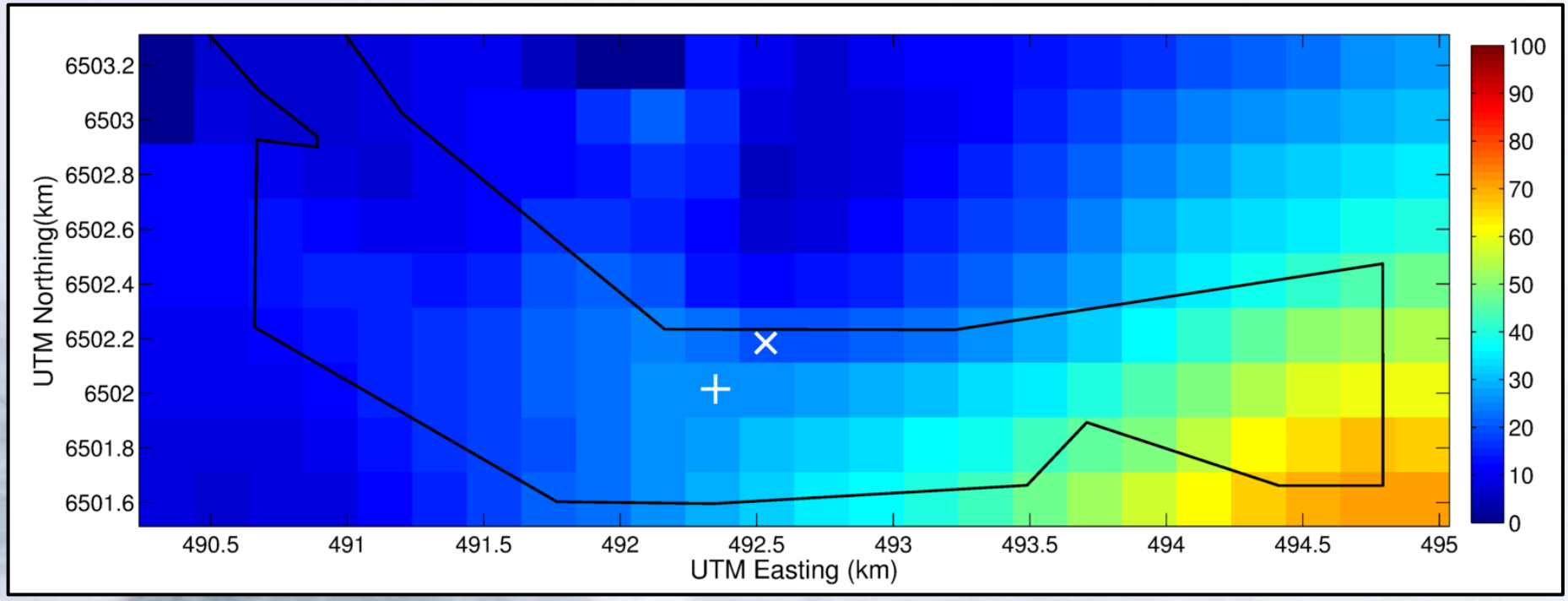
NOC current analysis

- 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

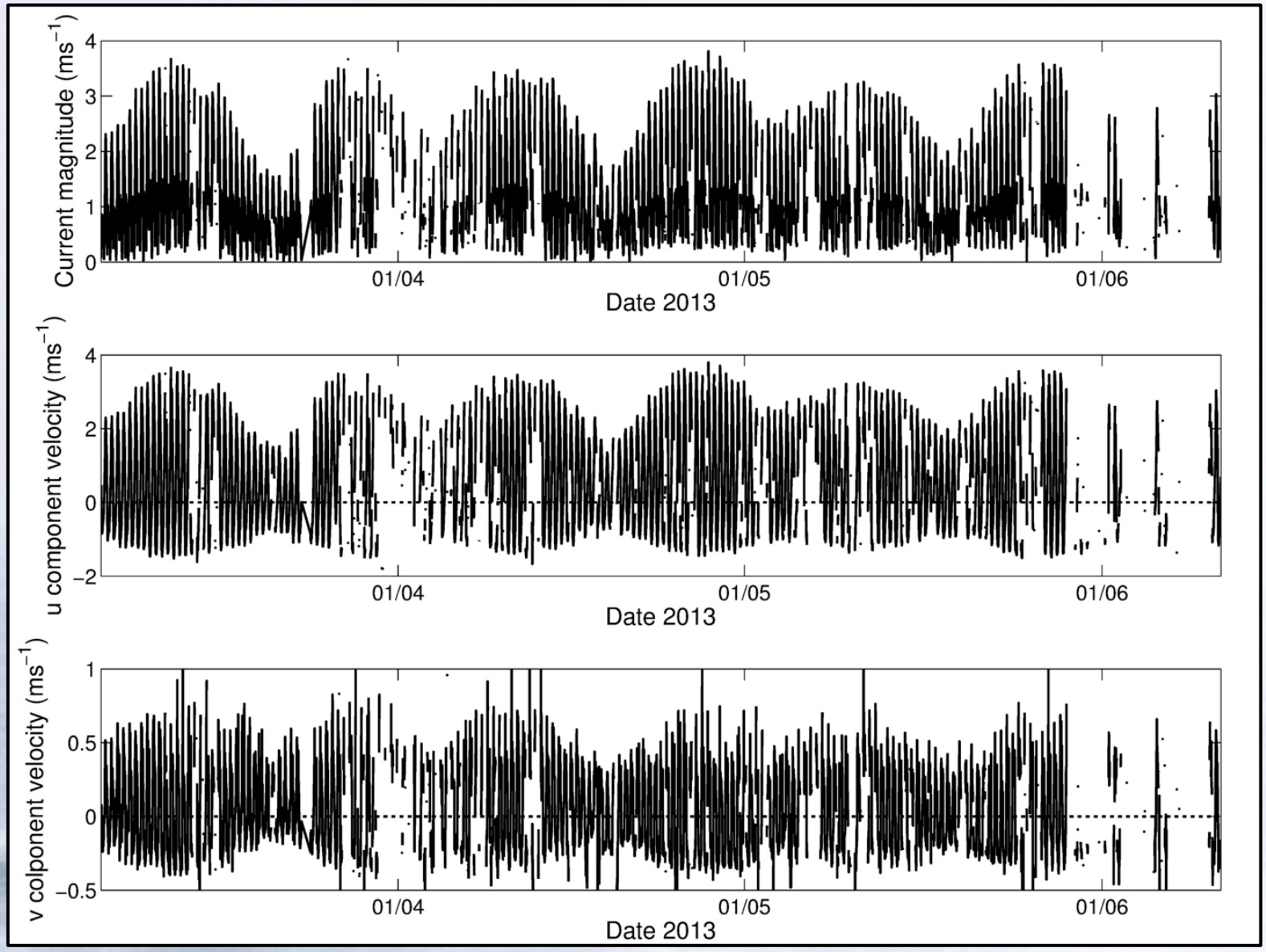
- Although currently post-processed we are close to trialling near-real-time processing on-site

NOC Quality Control

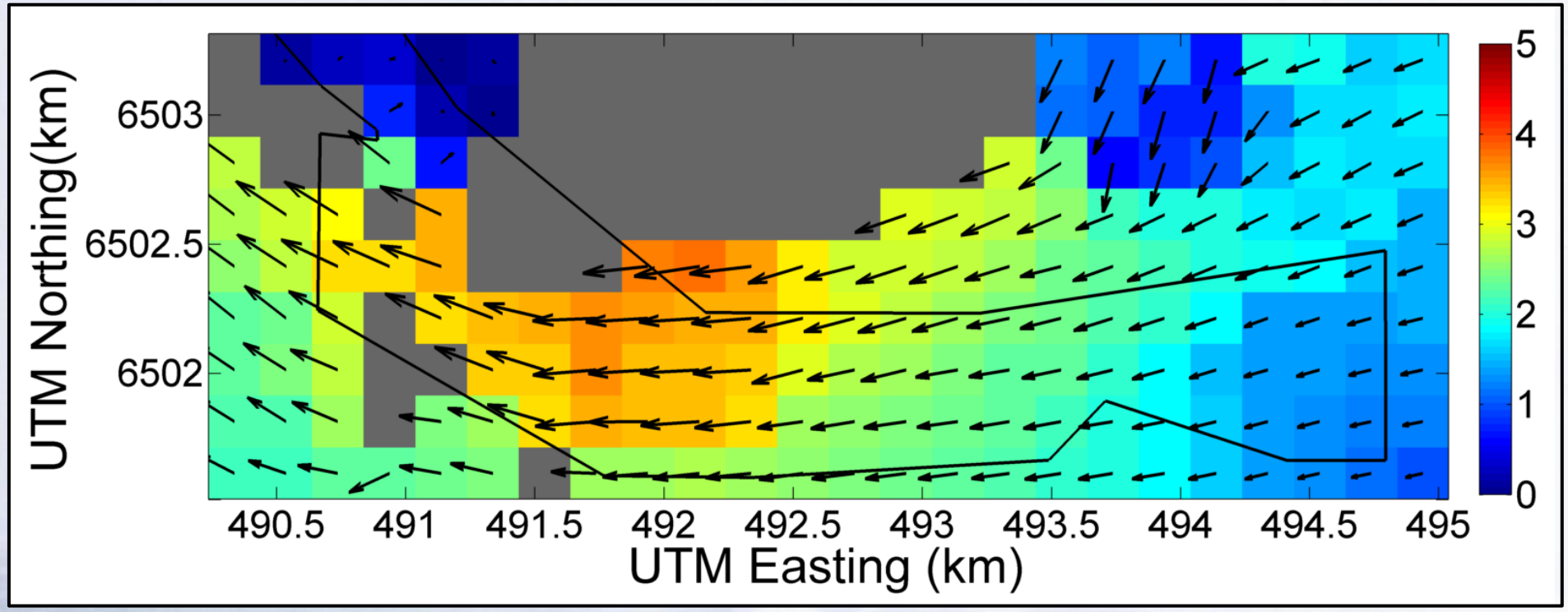
- Unique QC parameters calculated during the NOC current analysis routines
- Used to reject current vectors from poorly resolved wave spectra
- The consequence is a reduction in the current record length that varies across-site



Example Radar-derived time-series



Example radar-derived flow vectors (ebb)



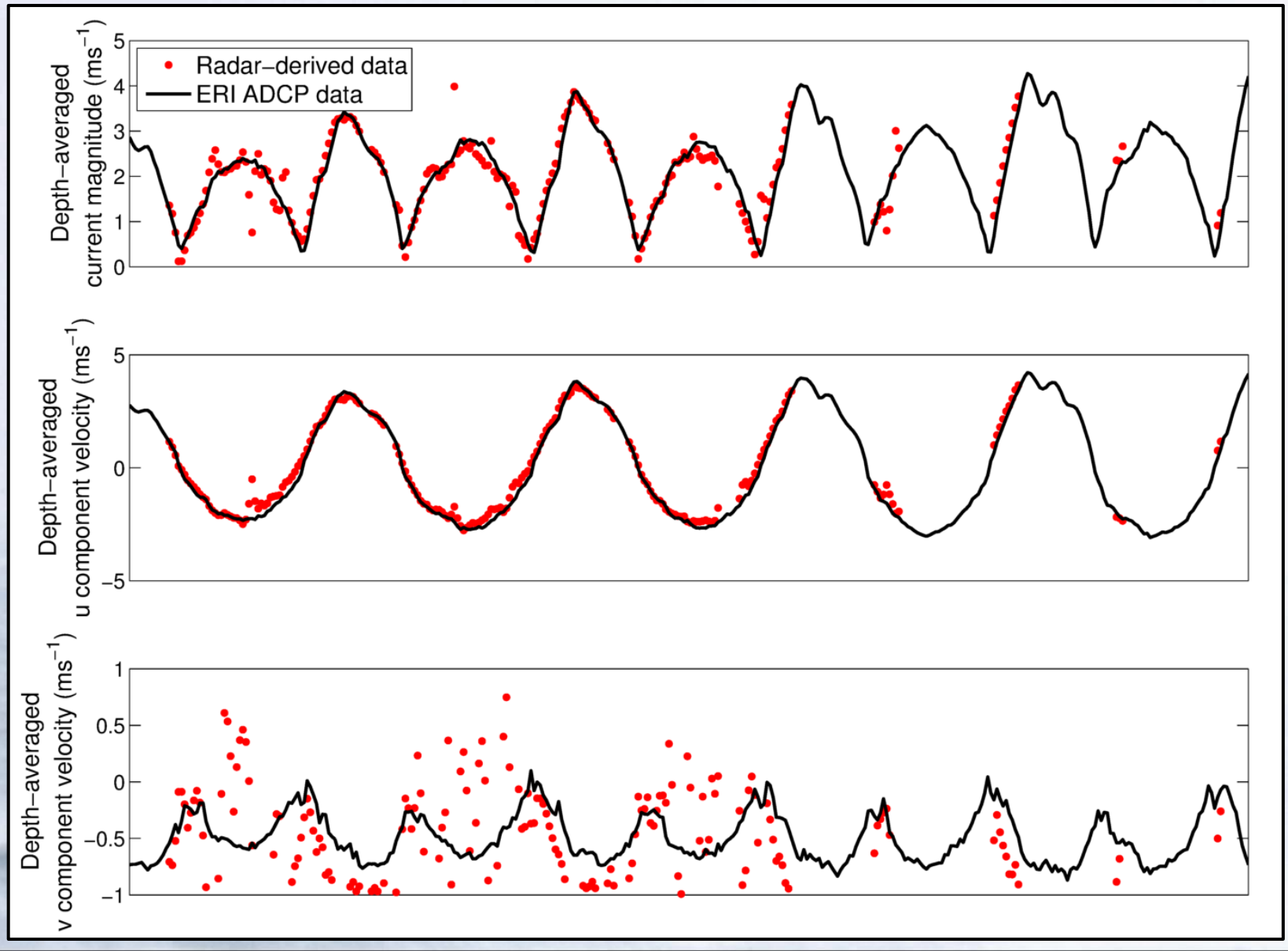
- Blanked areas show the activity of the QC routines
- The North-Western portion of the MeyGen lease tended to be sheltered from (predominantly Easterly) waves
- Data towards the North is degraded due to the presence of the Isle of Stroma

ADCP validation

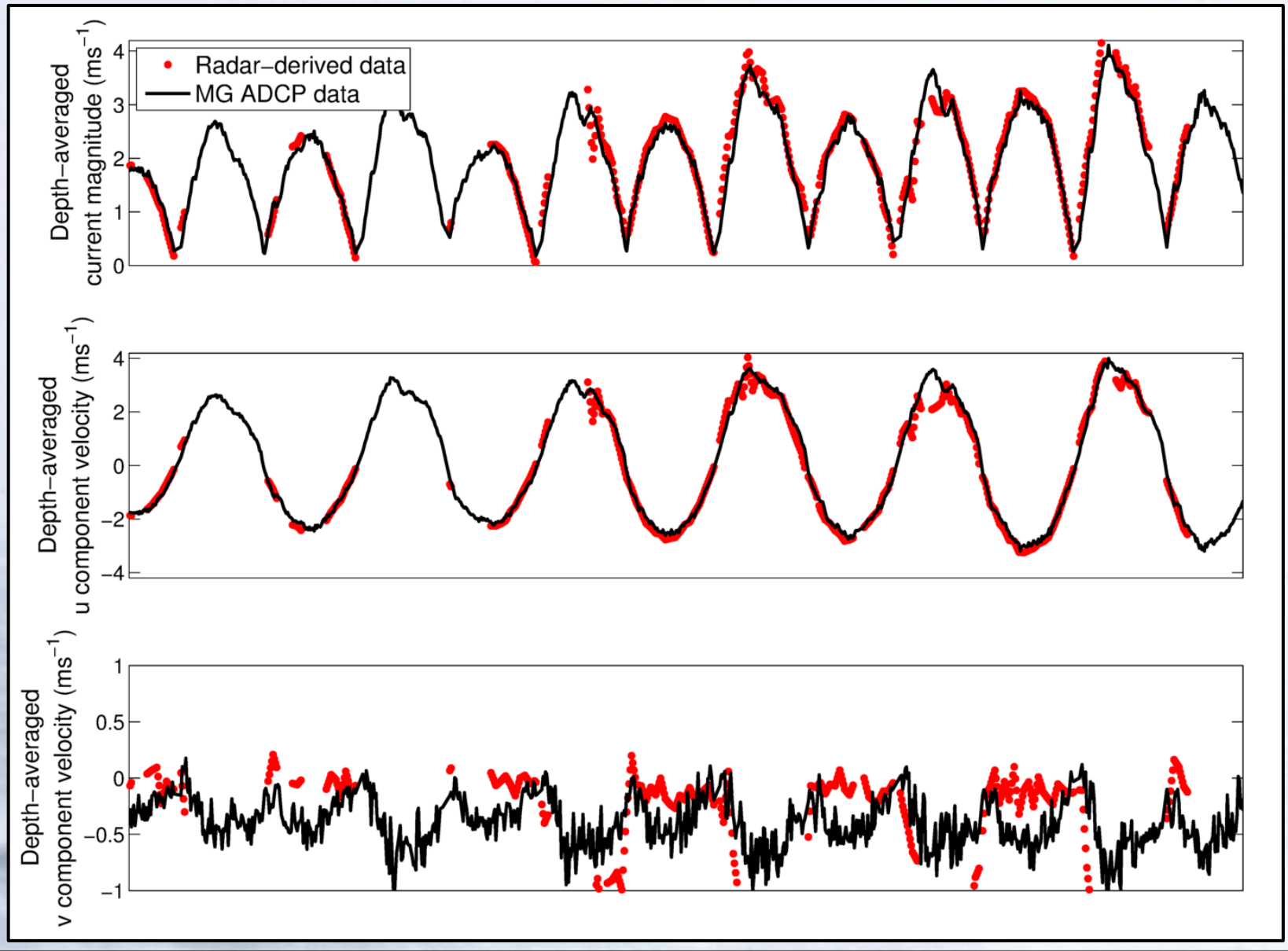
- Two ADCP surveys ('ERI' and 'MG') were used to validate the radar-derived currents
- At present there is no agreed relationship between the flow speed from X-band radar (i.e. what speed the waves 'feel') and its equivalent position in a depth profile.
- The current the waves feel must be some form 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.

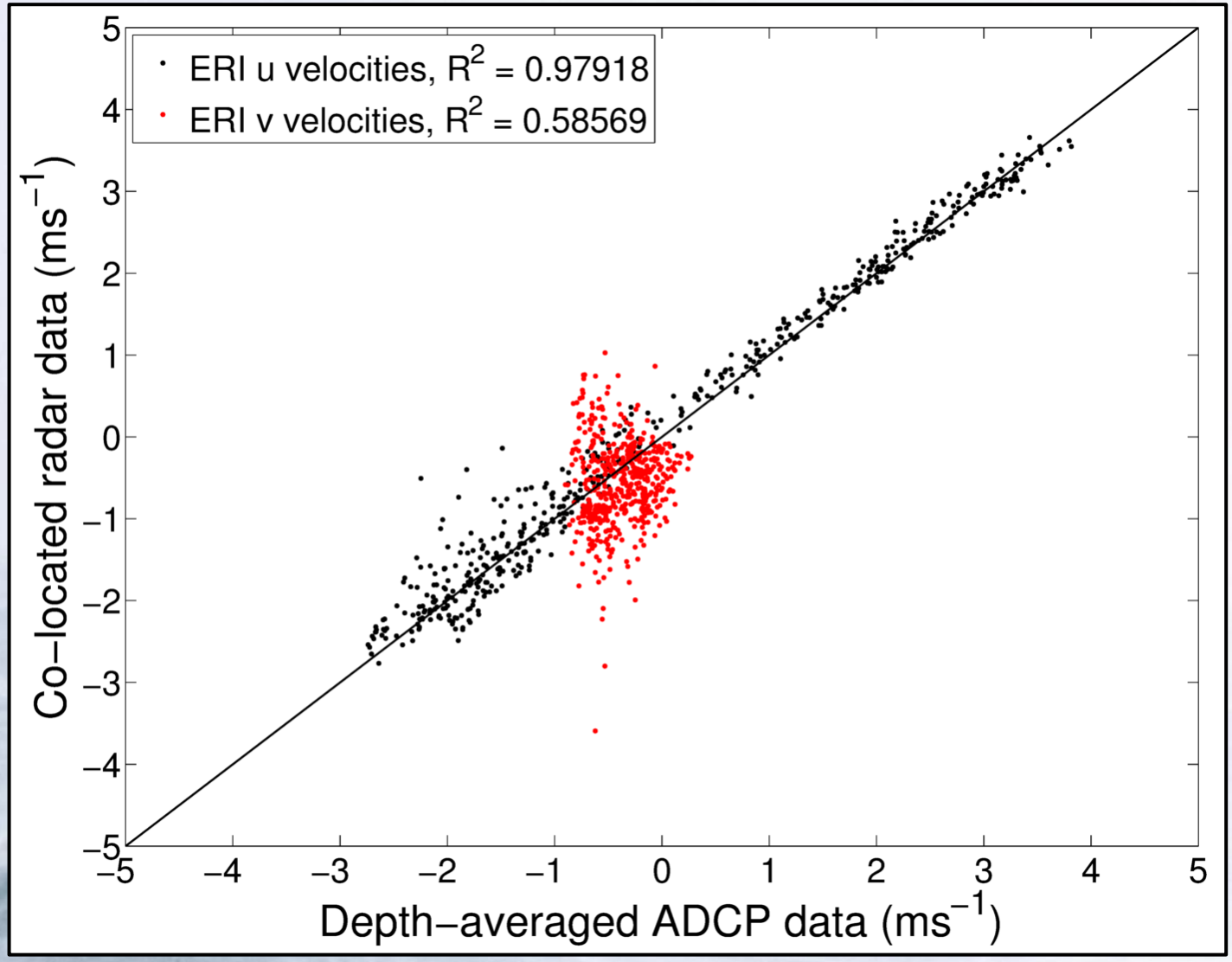
ADCP validation – ERI time-series



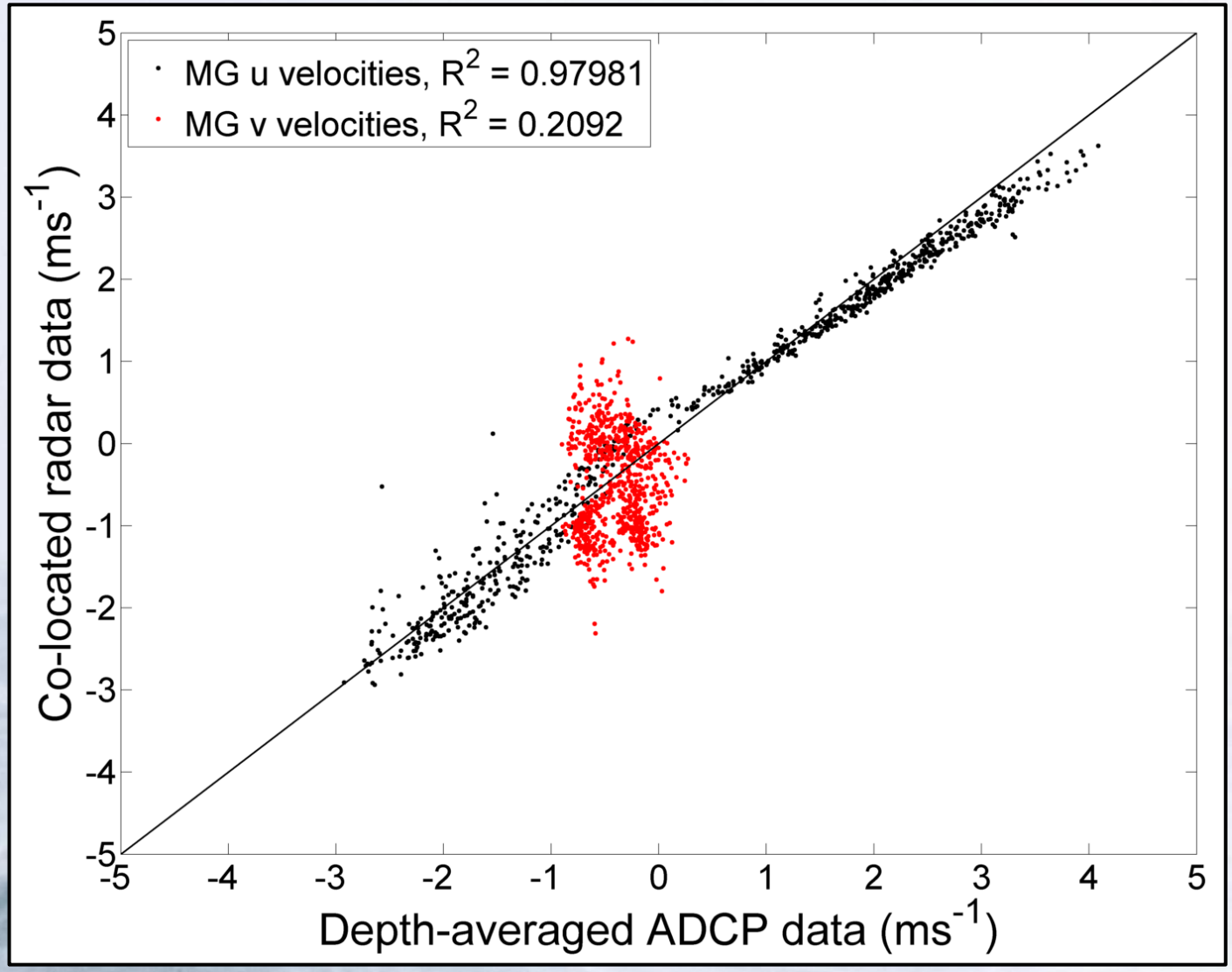
ADCP validation – MG time-series



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.

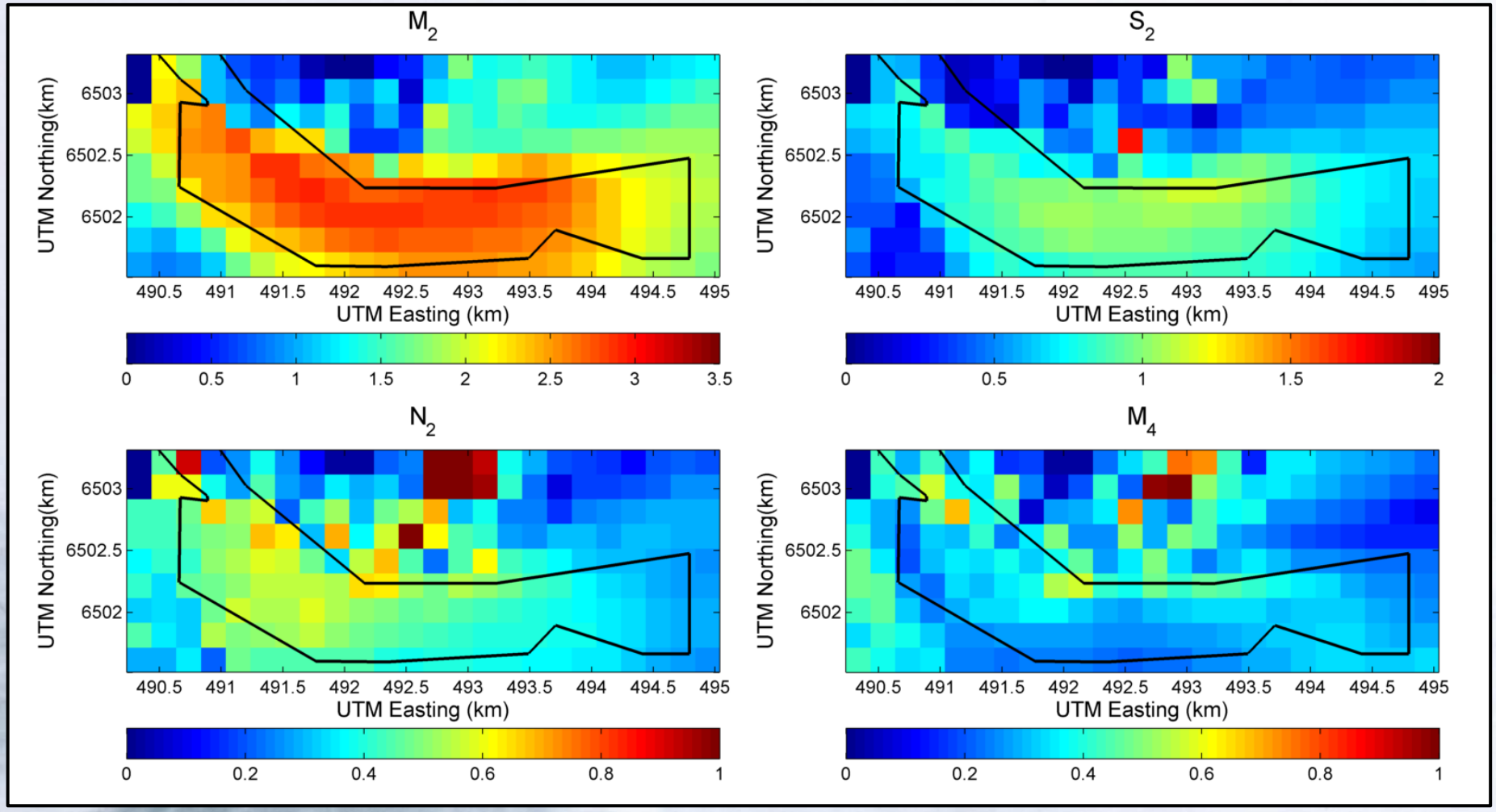
- NOC analysis based on 'UTide' – open source tidal harmonic analysis routine based on least-squares fitting of 40+ constituents and nodal coefficients. Works with 'gappy' data (essential!)

Tidal harmonic analysis – ADCP comparison

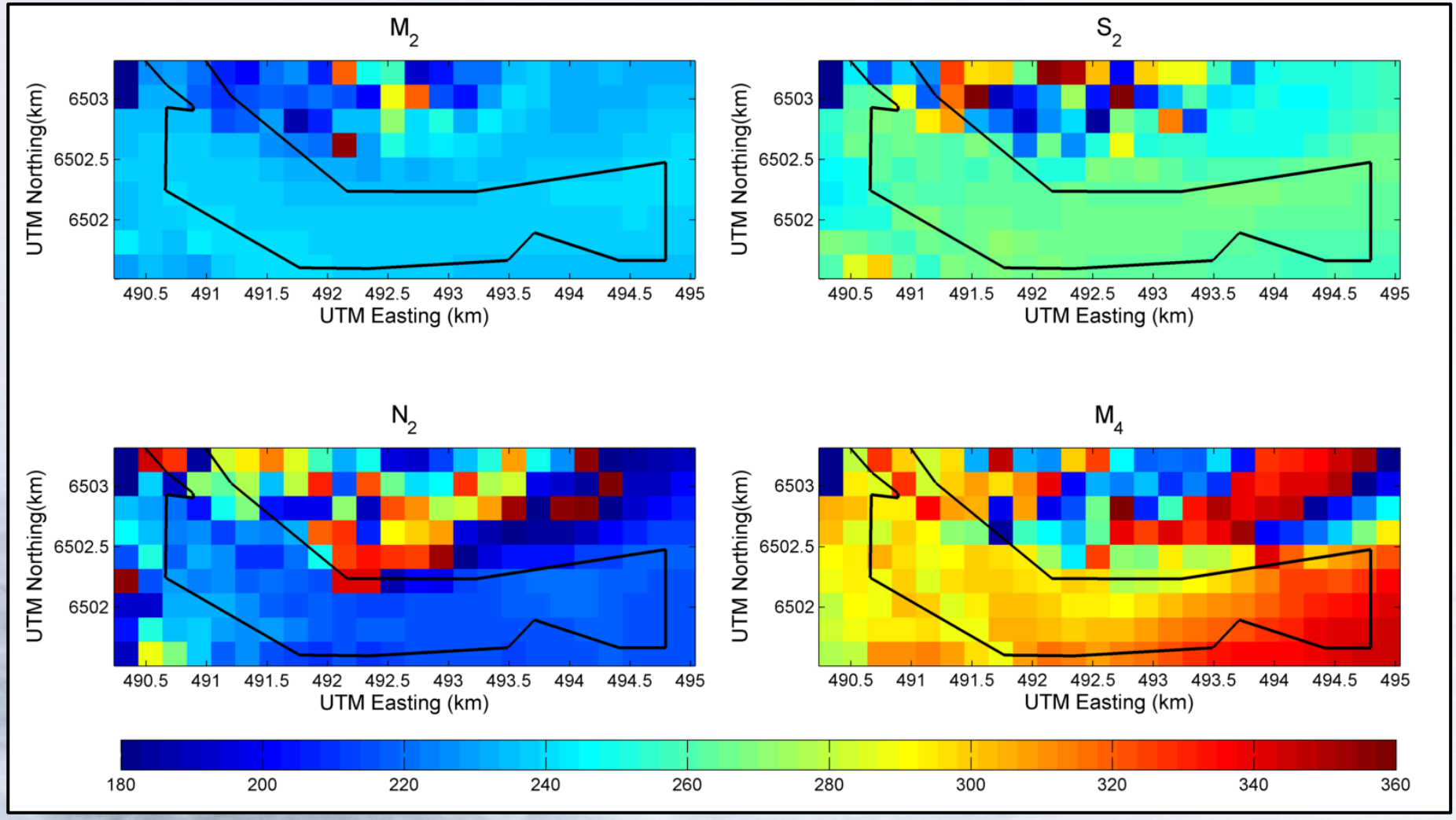
	ERI ADCP			Radar		
	A_{maj}, A_{min} (ms^{-1})	G (°)	E (%)	A_{maj}, A_{min} (ms^{-1})	G (°)	E (%)
M_2	2.66, -0.11	240	82.75	2.74, -0.04	236	75.70
S_2	1.01, -0.06	274	11.94	1.03, -0.14	263	10.83
N_2	0.47, 0.03	198	2.60	0.46, -0.23	186	2.69
M_4	0.26, -0.01	305	0.81	0.38, -0.054	296	1.45
U_{mean}, V_{mean}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

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Thank you for your attention

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