HF radar wave measurement

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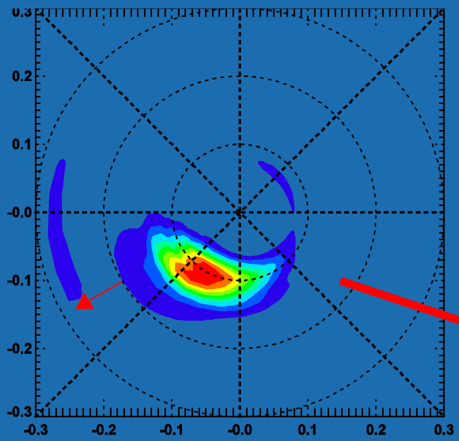
University of Sheffield and
Seaview Sensing Ltd

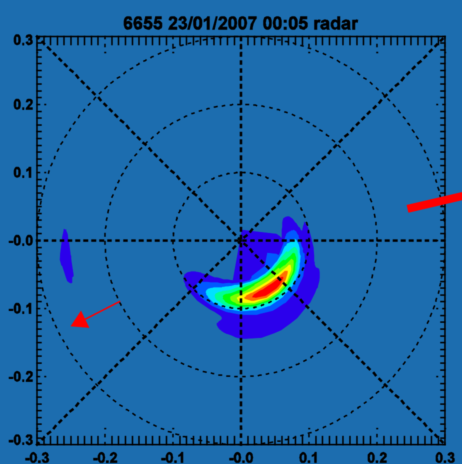
ROS2011, Lerici, Italy, October 2011

Spatial variability in waves in complex coastal environments

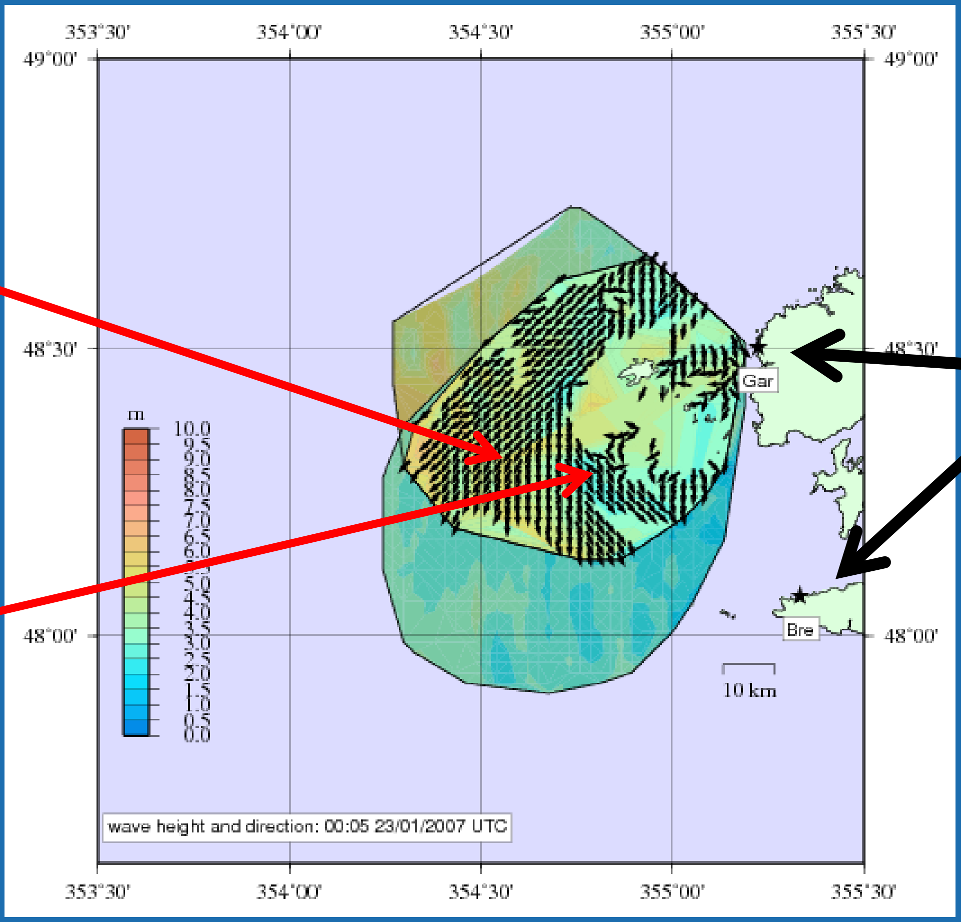
The University Of Sheffield.

SEAVIEW SENSING





Directional spectra



Wave Height and Direction

2 radar sites

Data kindly supplied by SHOM from their WERA system operated by Actimar

wind direction

Methods

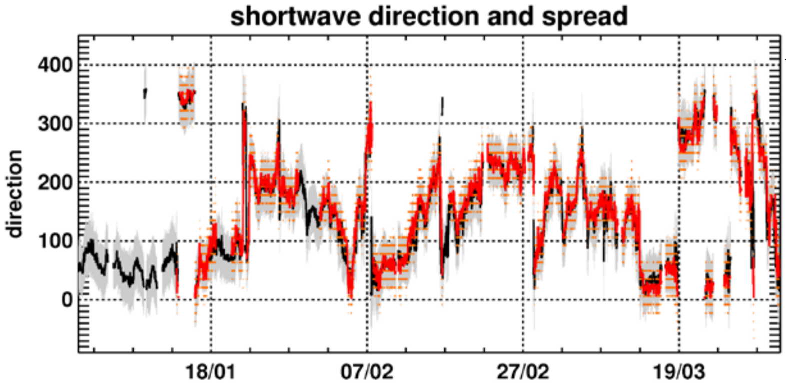
- Empirical estimates of waveheight and period from single radars;
- Short-wave direction using ML method;
- Integral inversion for directional spectrum S(**k**) to a radio-frequency dependent maximum ocean wave frequency (~0.2Hz at 6MHz, 0.38Hz at 25MHz) *~1min for 600 measurement cells*;
- Waveheight, period, direction etc determined from S(**k**) using standard methods, also including:

Wave power: $\rho g \int c_g(f) S(f) df$

Energy Period: $T_E = \dfrac{m_{-1}}{m_0}$ where $m_n = \int S(f) f^n df$

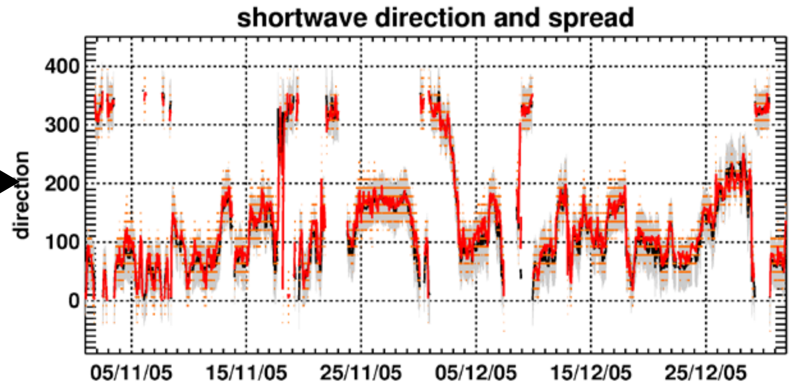
Short wave direction and spread

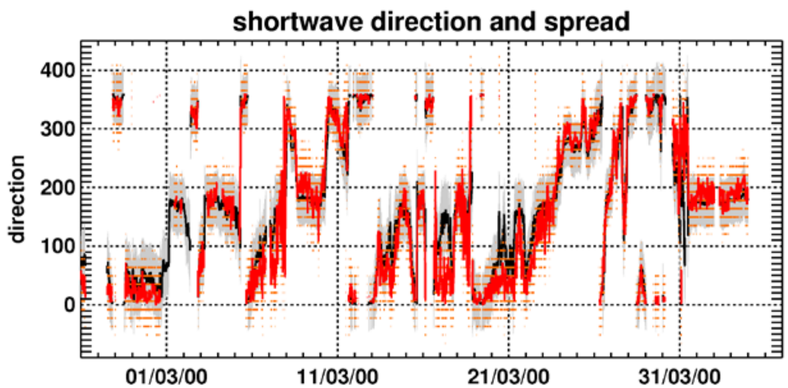
radar black line and gray shading; buoy red line and dashed shading



Celtic Sea, Pisces, 7-11MHz, 0.19-0.24Hz

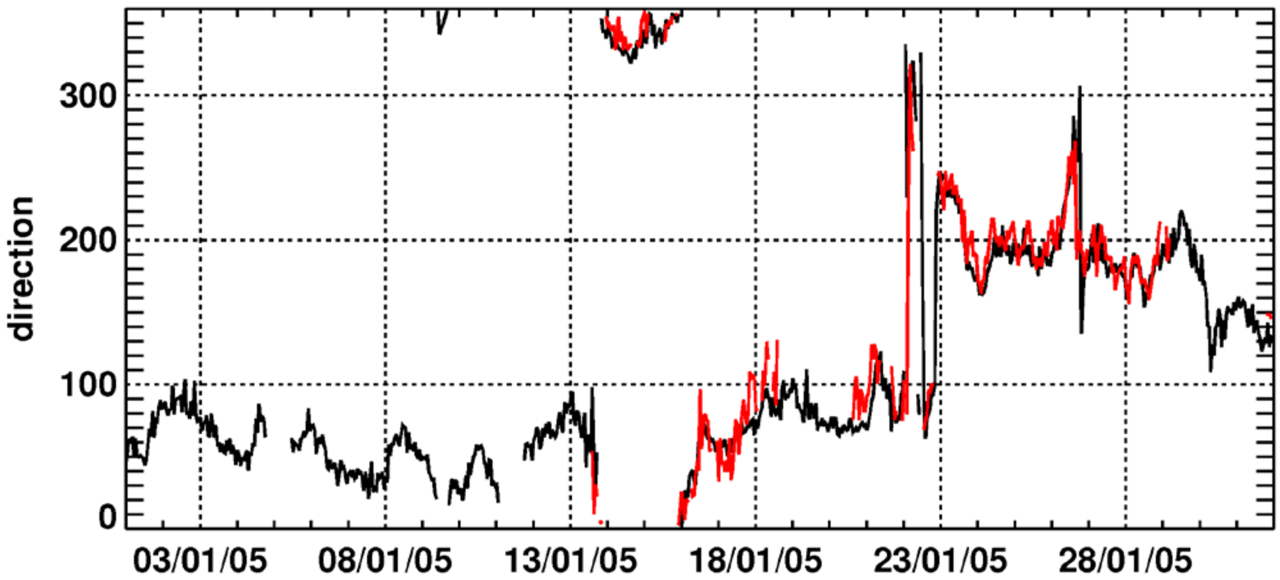
Liverpool Bay, WERA, 12-13MHz, 0.25-0.26Hz





Norway, WERA, 27MHz, 0.37Hz

Shortwave direction (used for wind direction estimation)



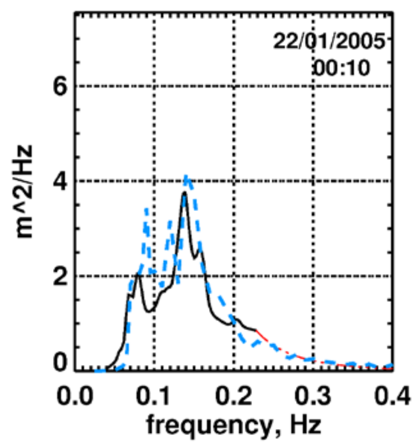
Pisces HF radar

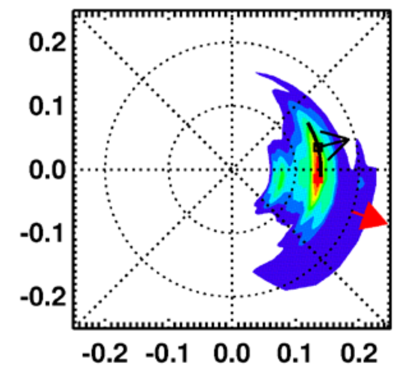
Directional waverider – buoy problem in early Jan

22/1/2005 00:00

frequency spectra

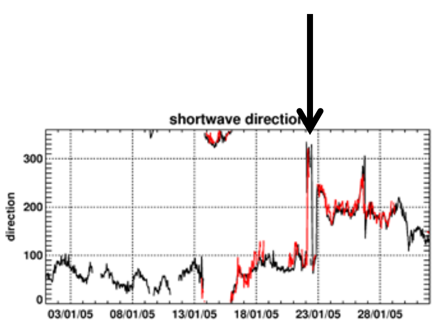
radar
buoy

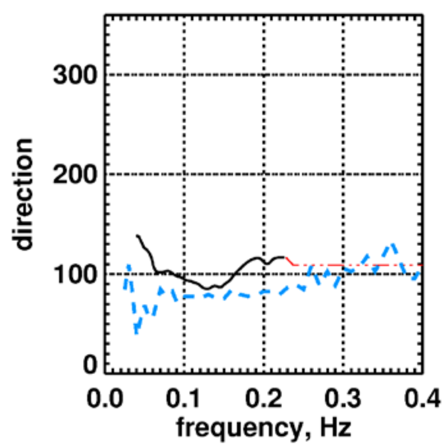


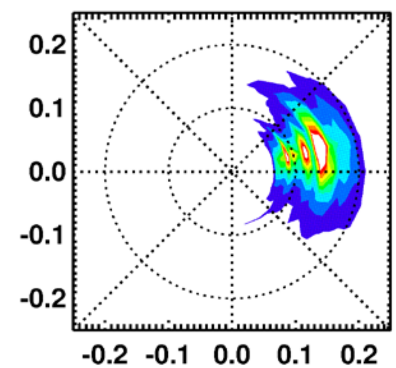


radar measured directional spectrum red arrow – wind direction, black arrow and arc - buoy peak direction and spread,

direction spectra





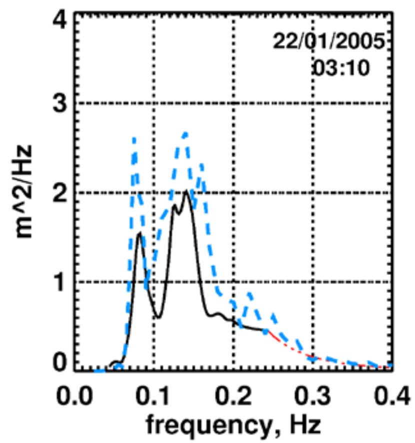


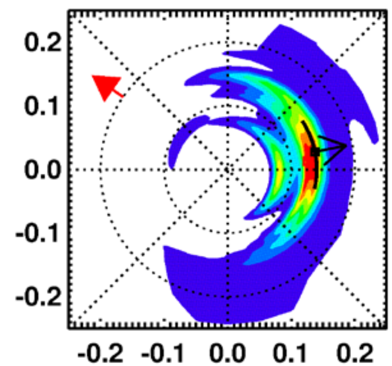
buoy directional spectrum using MLM. The radar and buoy directional spectra are scaled to the maximum in the radar spectrum.

22/1/2005 03:00

frequency spectra

radar
buoy





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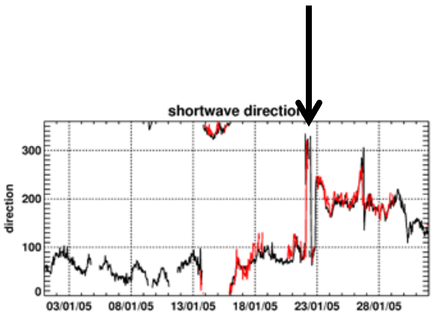

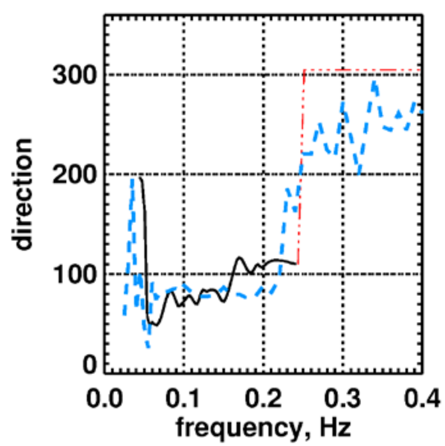

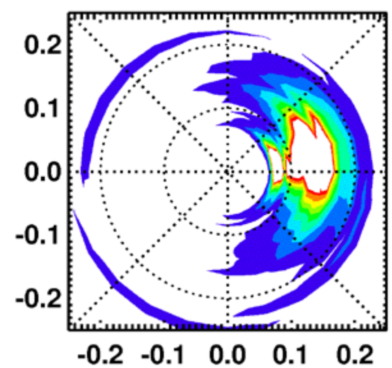

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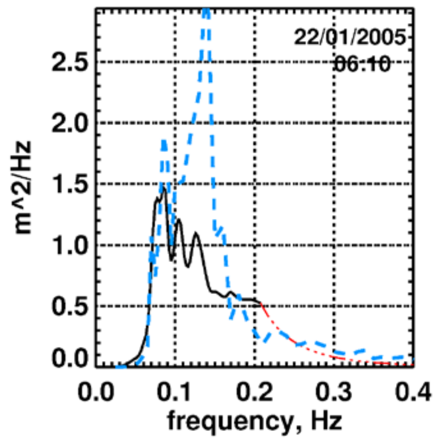
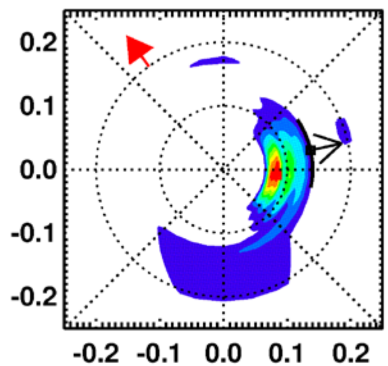
22/1/2005 06:00

frequency spectra

radar

buoy





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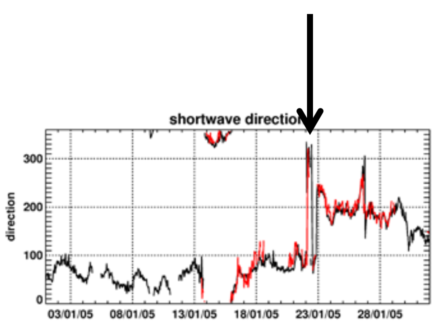
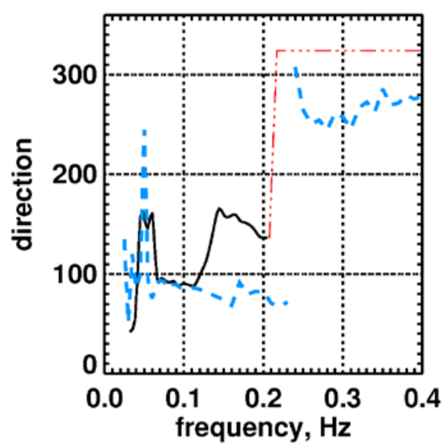
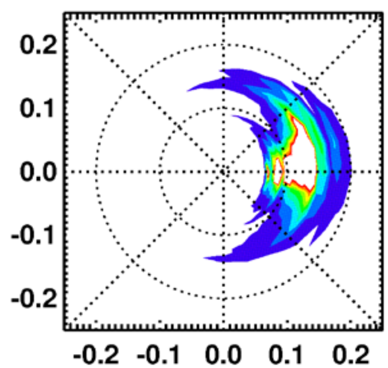




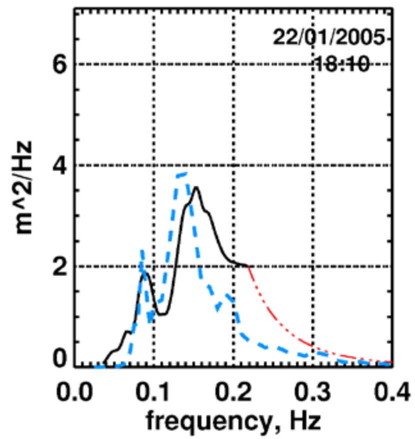


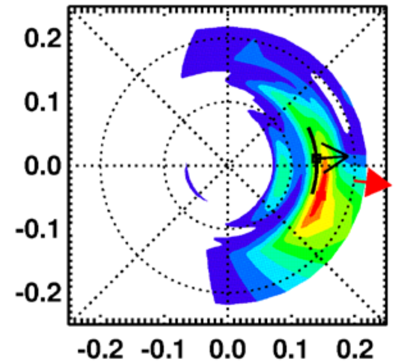
buoy directional spectrum using MLM. The radar and buoy directional spectra are scaled to the maximum in the radar spectrum.

22/1/2005 18:00

frequency spectra

radar
buoy





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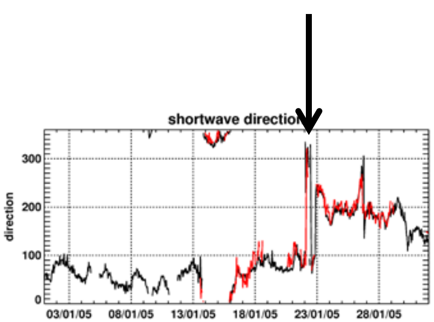
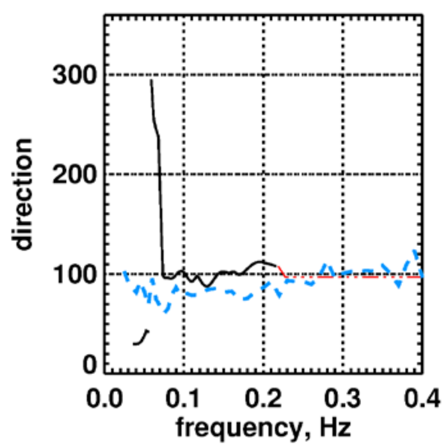
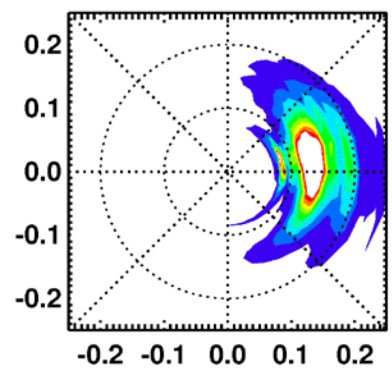




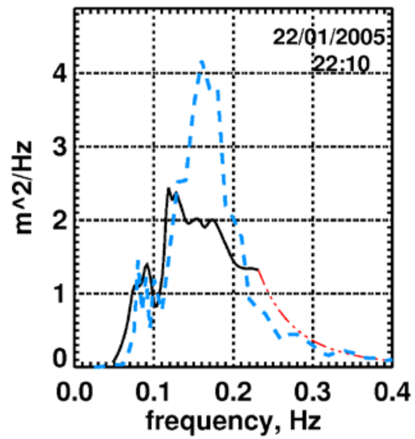


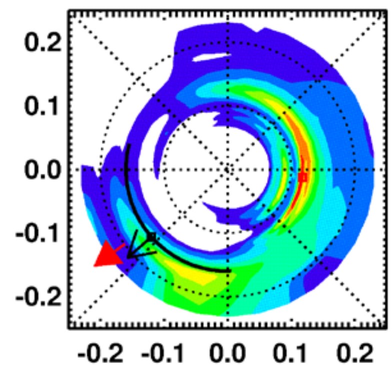
buoy directional spectrum using MLM. The radar and buoy directional spectra are scaled to the maximum in the radar spectrum.

22/1/2005 22:00

frequency spectra

radar
buoy





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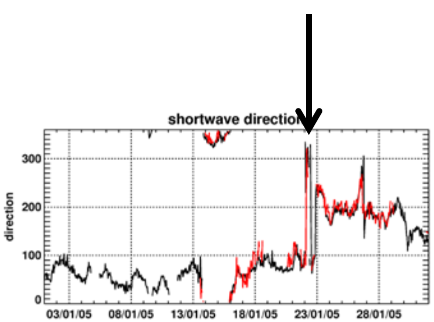
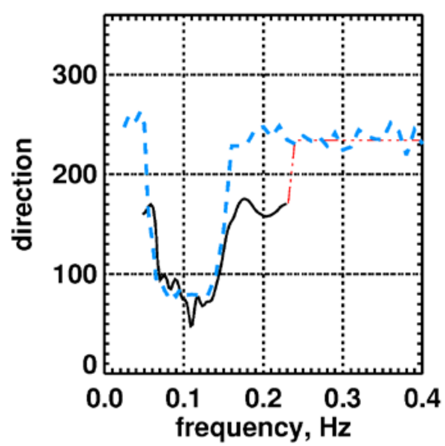
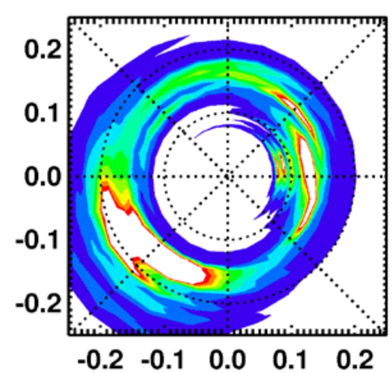
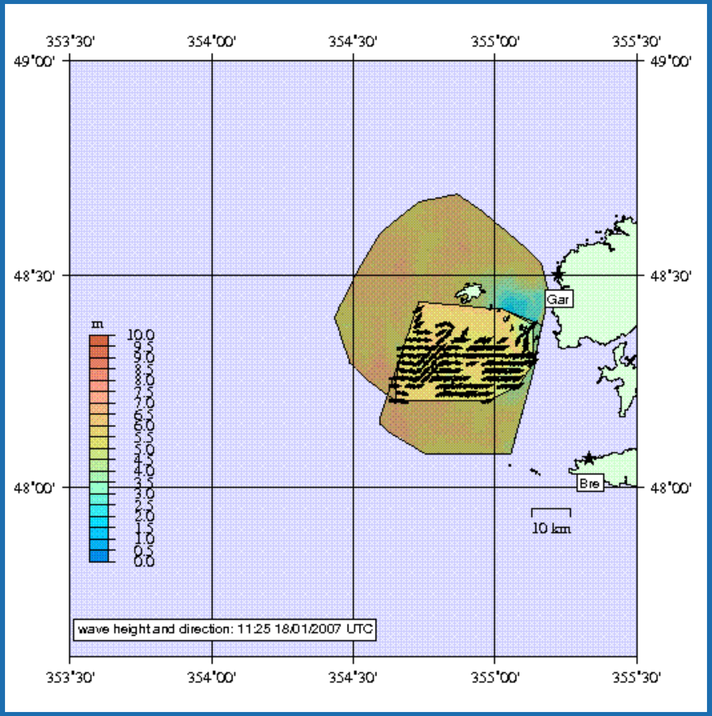


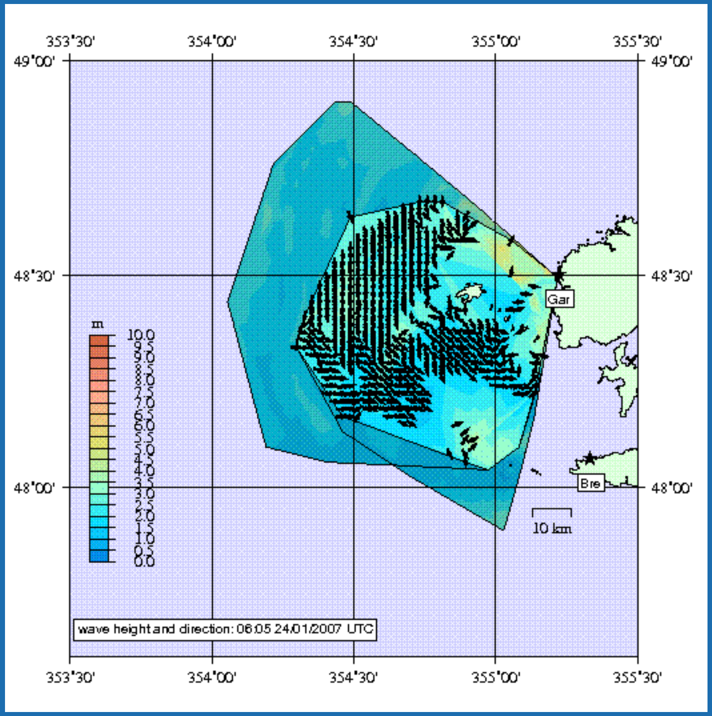




buoy directional spectrum using MLM. The radar and buoy directional spectra are scaled to the maximum in the radar spectrum.

Impact of high seas on coverage for wave measurement



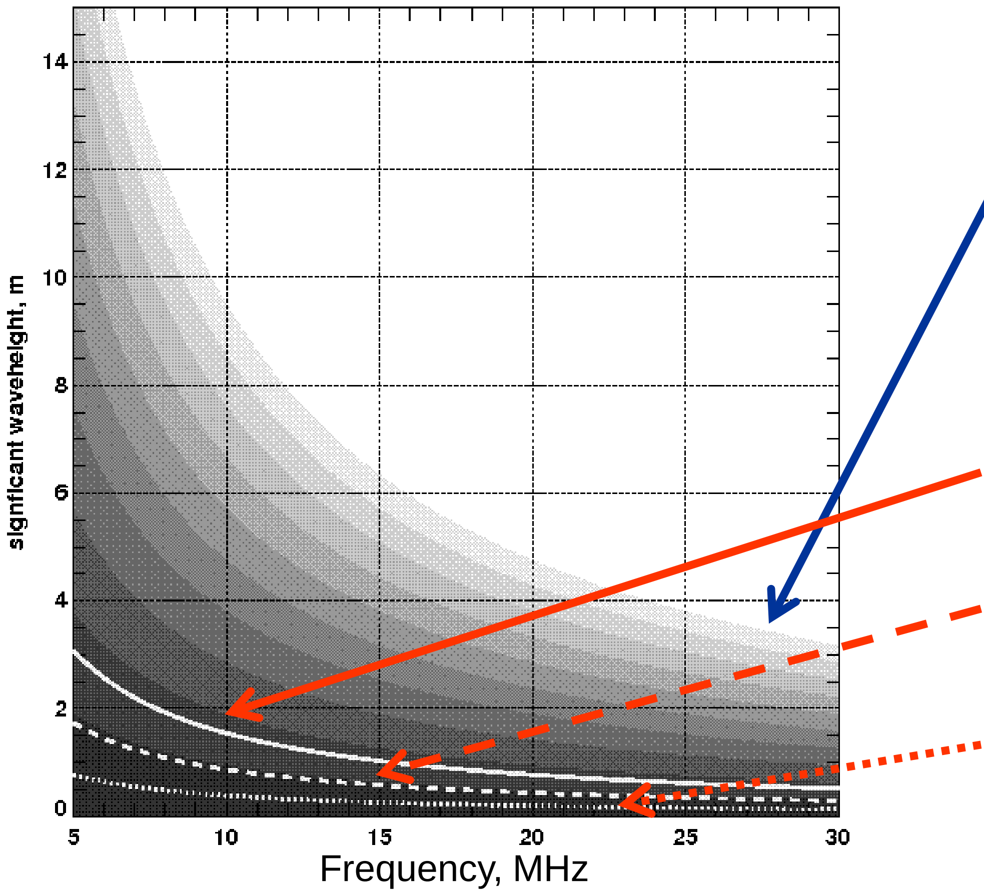


Data kindly supplied by SHOM from their WERA system operated by Actimar

high waves (usually shorter range)

moderate waves

Theoretical limitations



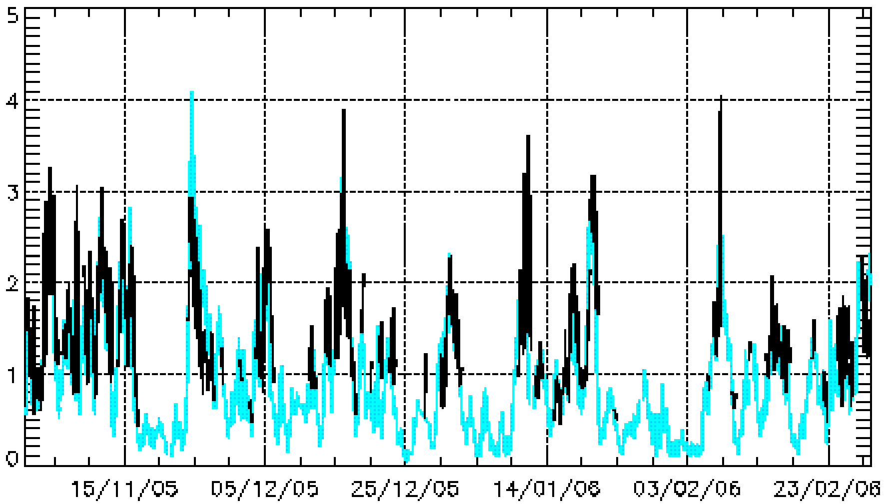
HF radar wave measurement works best in the darker regions so waveheight limited at high radio frequencies

with low waveheight limits for

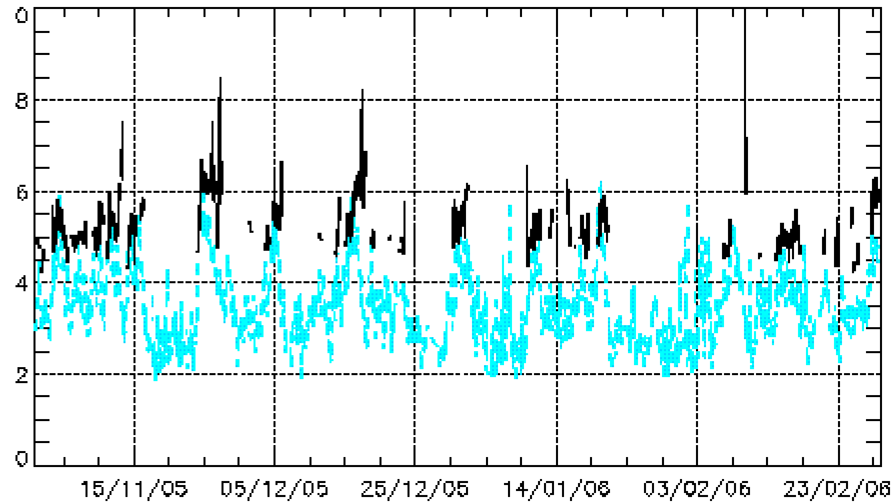
- accurate direction and frequency information (empirical)
- waveheight (spectral peak beyond inversion region)
- any wave or wind measurement (1st order Bragg waves not wind-driven)

The low waveheight limit: Liverpool Bay waves

waveheight



period

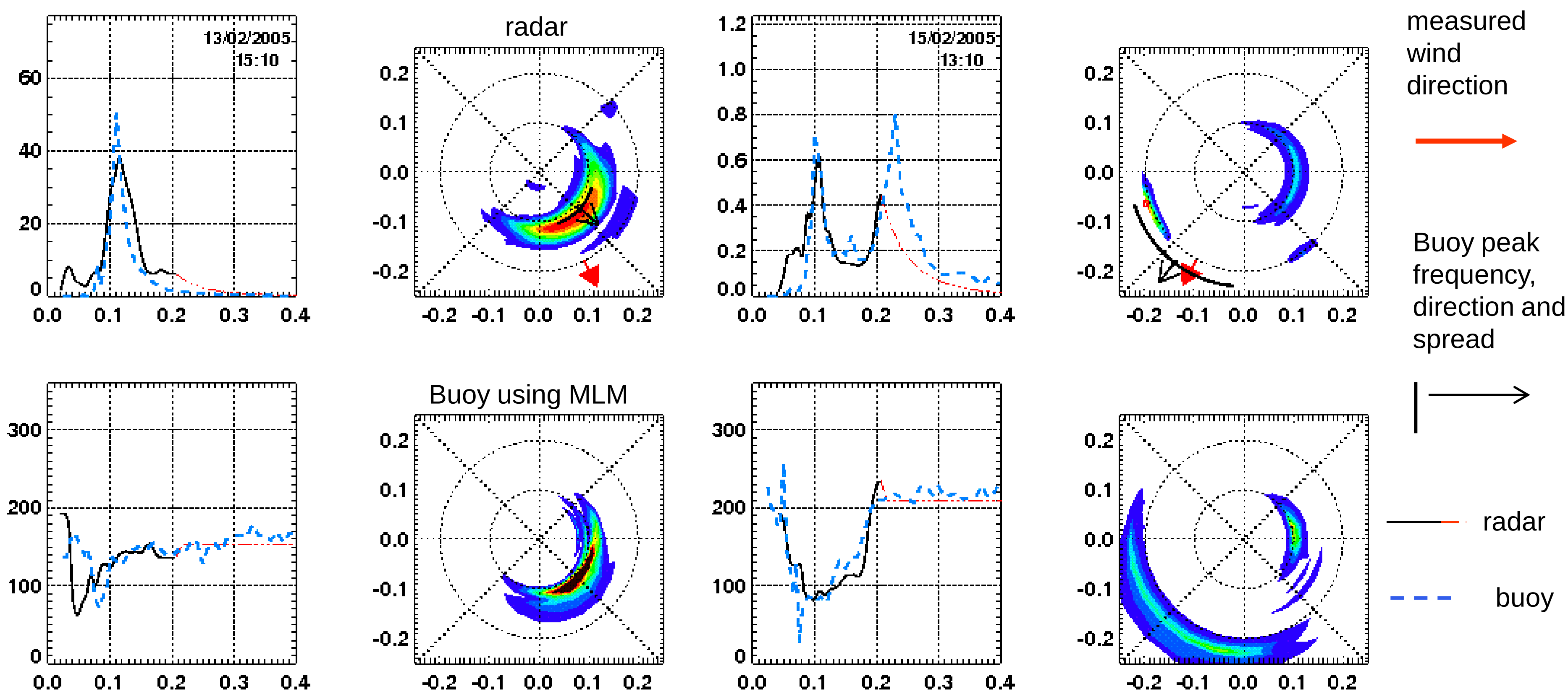


Data provided by NOC (Proudman Oceanographic Laboratory) from their WERA system

An example of a low wave environment measured at 12MHz. There is a radar (black) cut-off at 0.5-1m height and 4.5s period.

Spectral comparisons at low radio frequency <10MHz

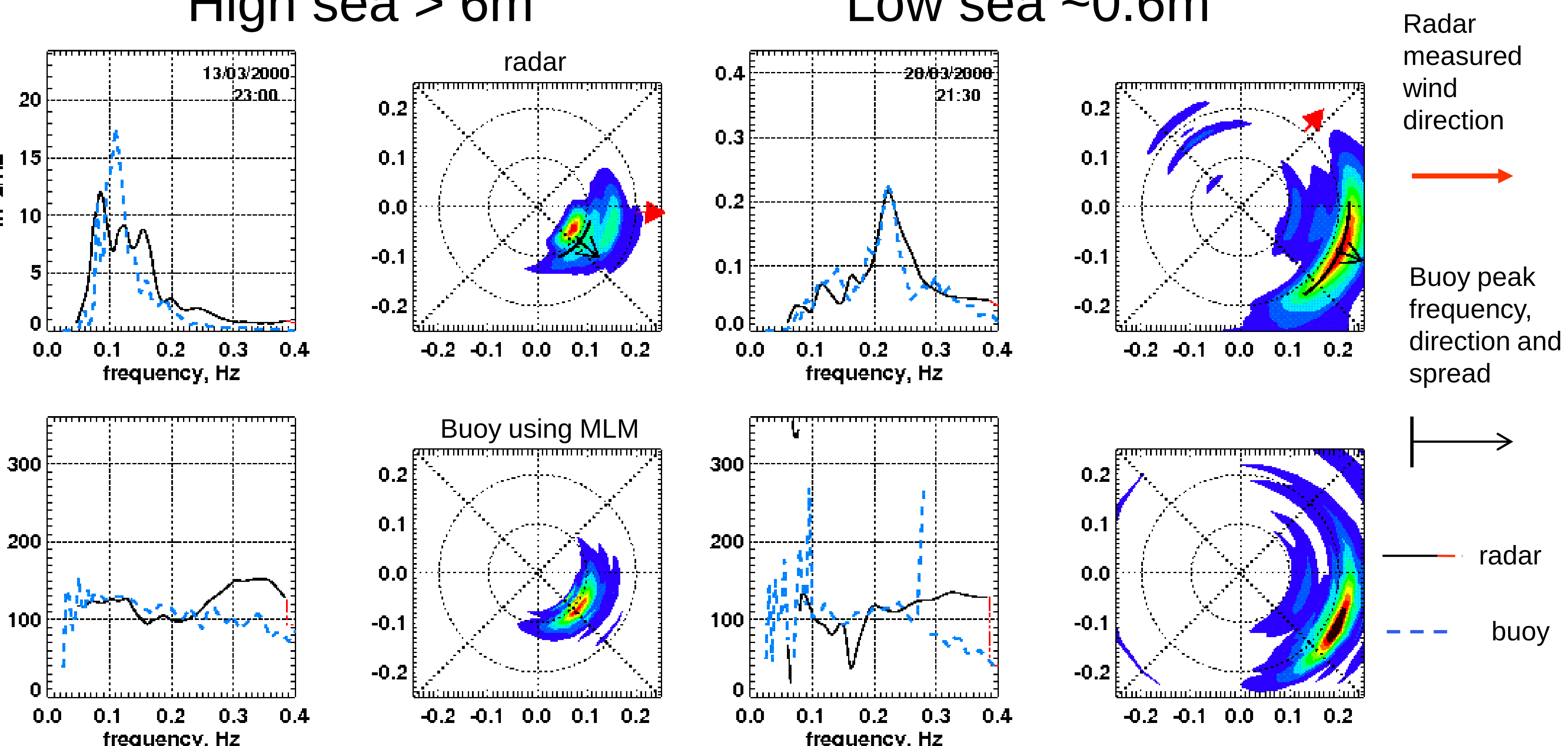
High sea ~5m   Low sea ~1m



Radar data provided by Neptune Radar Ltd from their Pisces system

Spectral comparisons at high radio frequency, 25MHz

High sea > 6m   Low sea ~0.6m

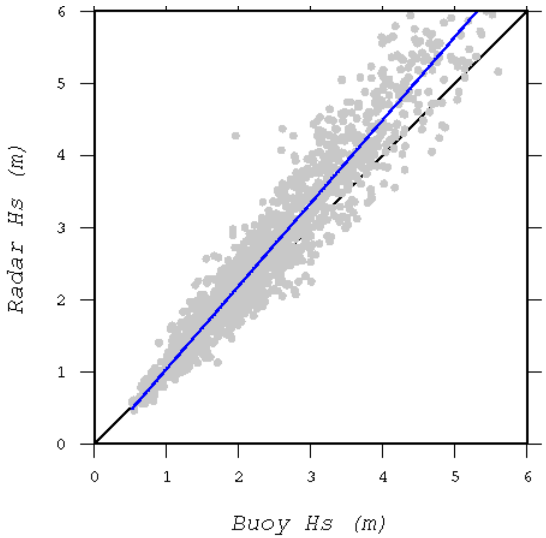


Data obtained during the EuroROSE experiment with a WERA system

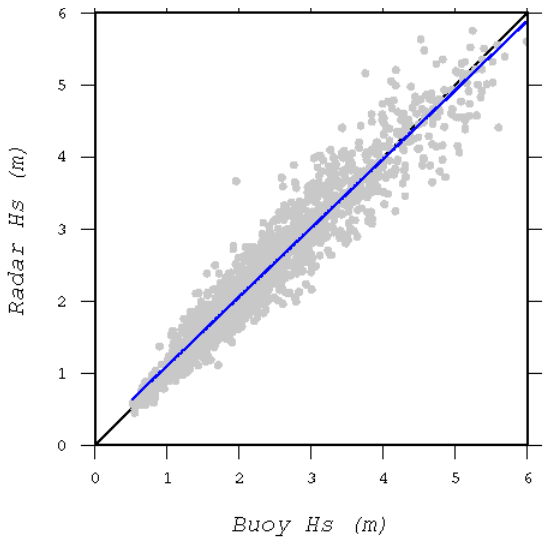
Improving performance in high seas

25MHz WERA waveheight comparisons

Using Barrick-Weber formulation of 2nd order spectrum

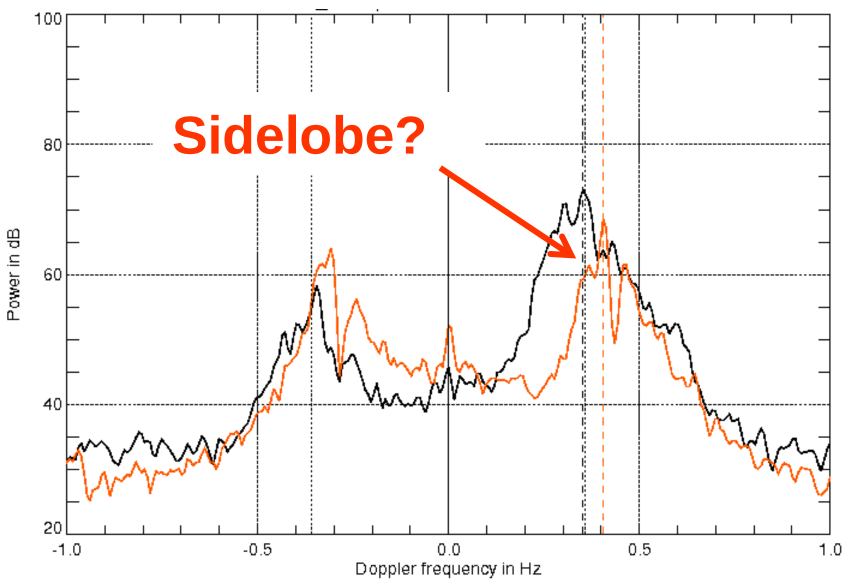


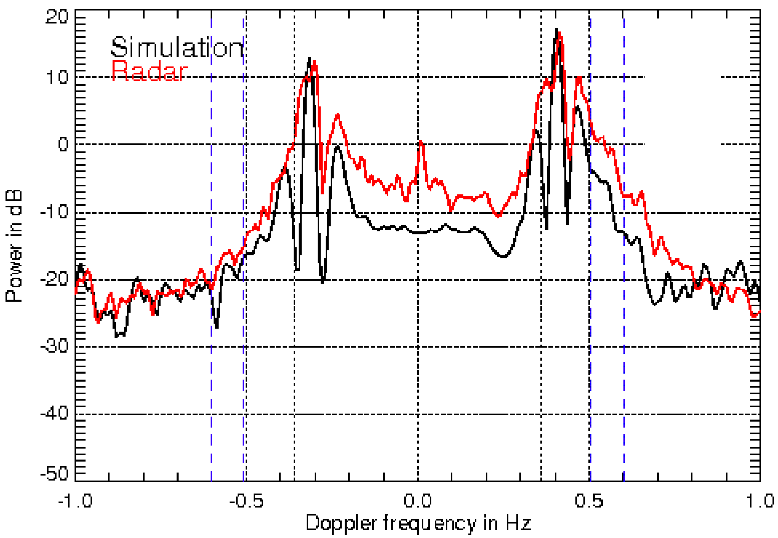
using approximation of Creamer et al / Janssen formulation of 2nd order wave spectrum.



We are working towards a full implementation

Impact of antenna sidelobes

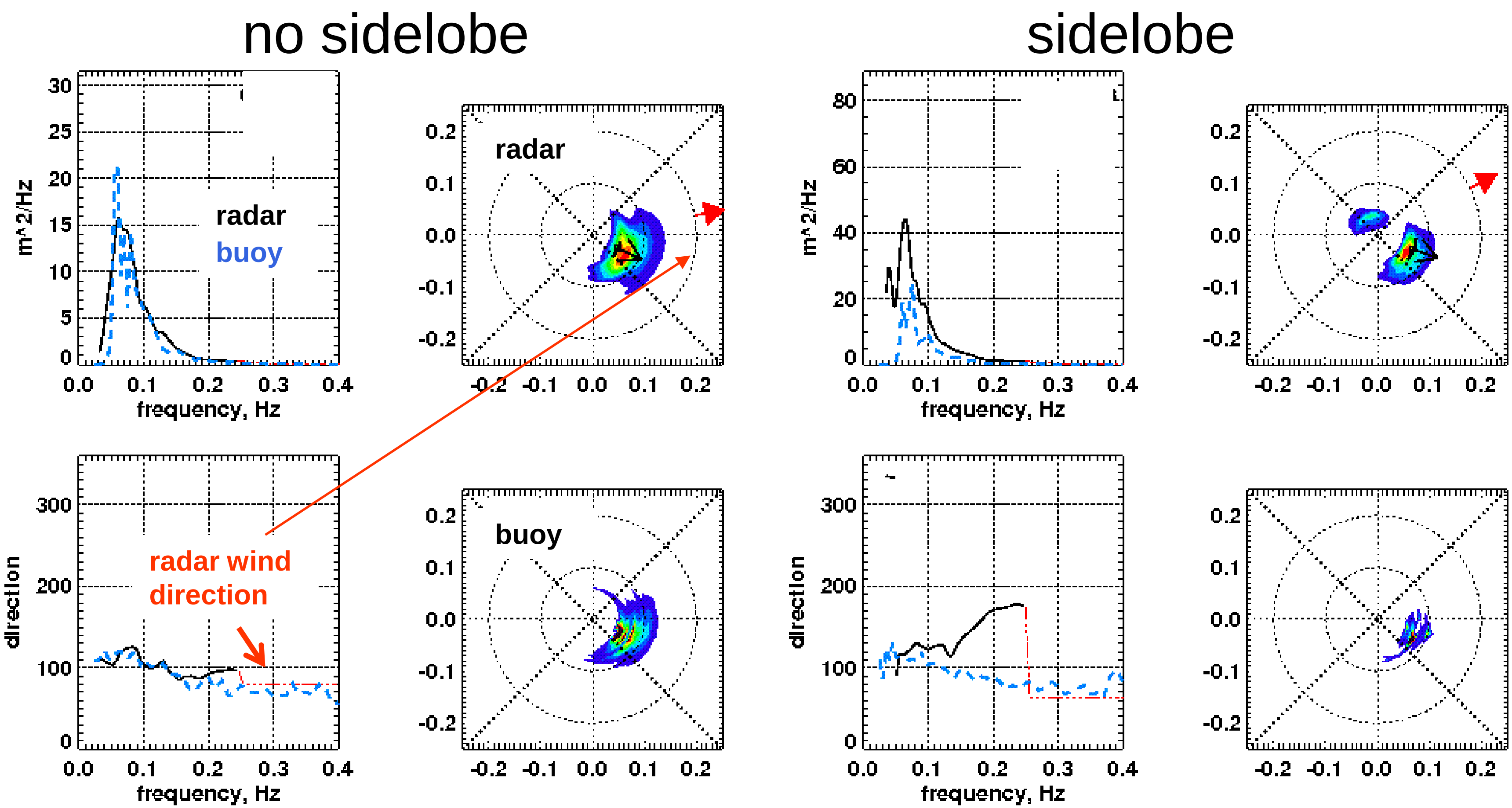




Red is doppler spectrum at buoy location, black at location which seems to be in the sidelobe.

Red is doppler spectrum at buoy location, black simulation using buoy data showing reduced 2nd order.

Impact of antenna sidelobes



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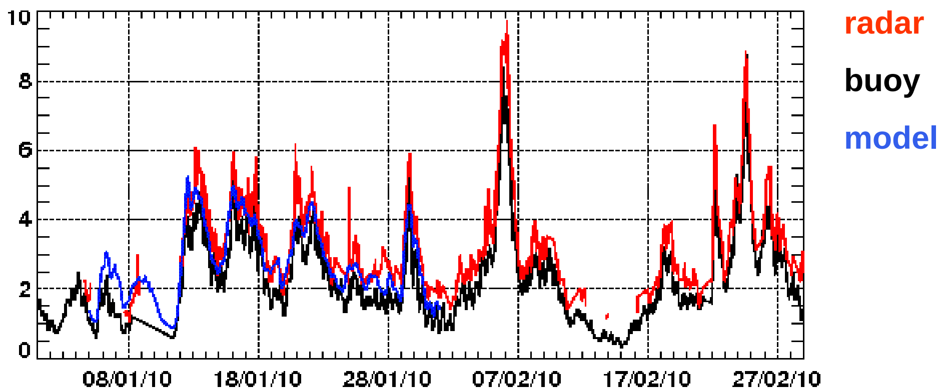
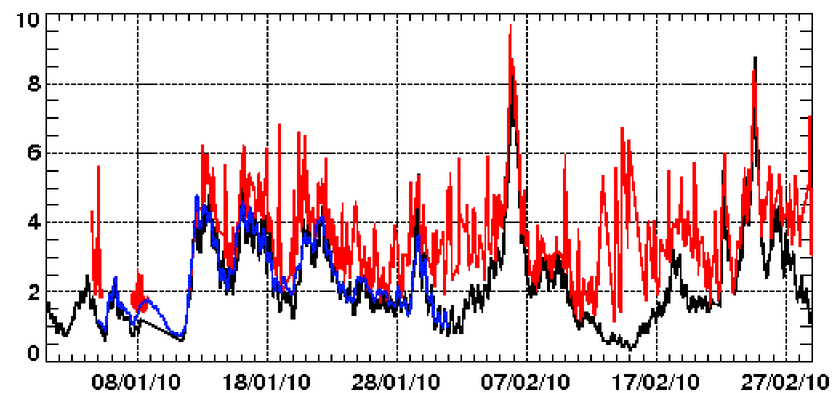
Impact of antenna sidelobes

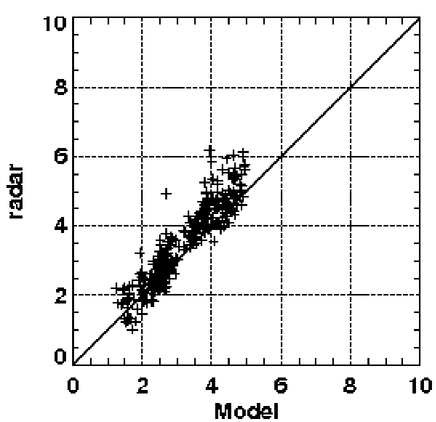
Data kindly supplied by SHOM from their WERA system operated by Actimar

no sidelobe

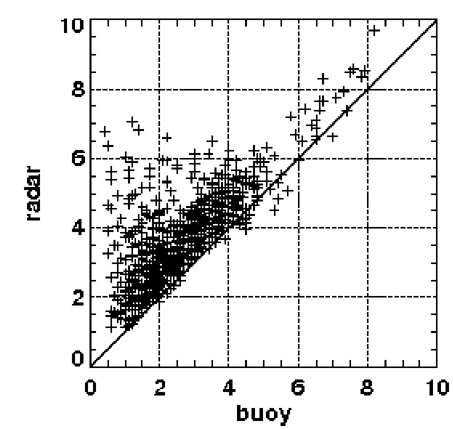


sidelobe





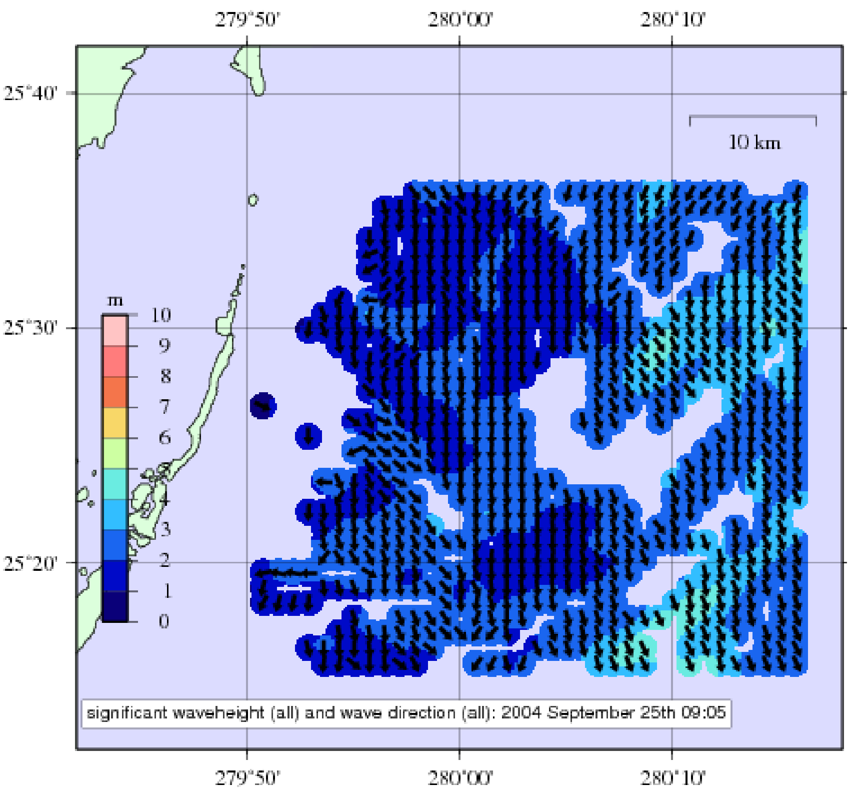
cell	Pair	N	ccf	mean,m	rms, m	si
1618	radar/buoy	653	0.95	0.74	0.86	0.17
	radar/model	312	0.93	0.31	0.54	0.14
	model/buoy	575	0.94	0.53	0.65	0.16
1987	radar/buoy	682	0.76	1.1	1.46	0.36
	radar/model	328	0.74	0.91	1.22	0.3
	model/buoy	575	0.95	0.15	0.36	0.33



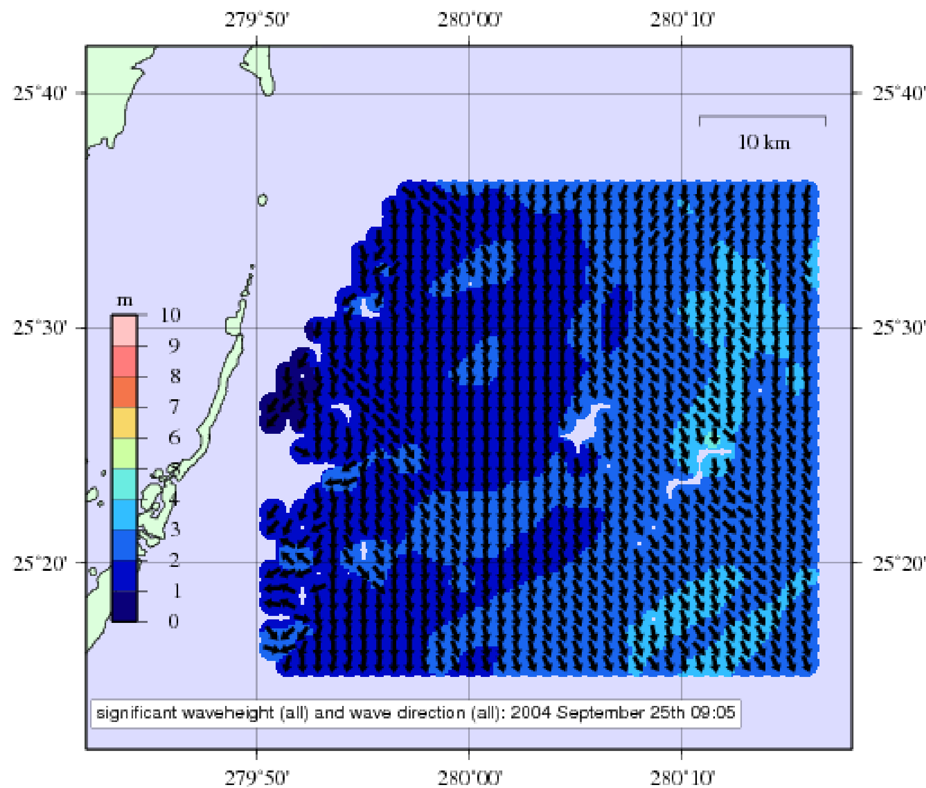
Need for longer averaging

25th September 2004 09:05

Data from Miami WERA



Data from the increased average



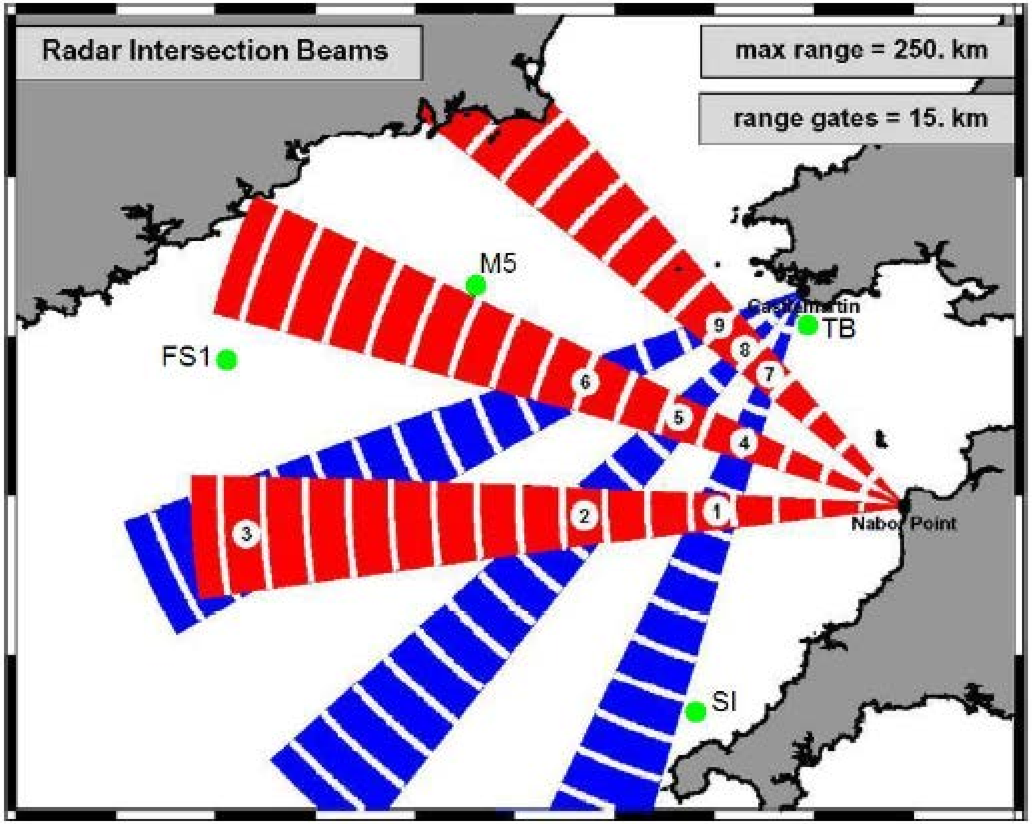
HF radar wave measurement - constraints

- High waveheights cannot be measured with high radio frequencies (needed for high spatial resolution and interference avoidance), aiming to extend waveheight range using Creamer et al/Janssen formulation, preliminary results encouraging, yet to be fully implemented.
- Low waveheights cannot be measured with low radio frequencies (needed for long range and high sea measurement).
- Range and coverage not fixed – depends on radio frequency, interference environment, shipping, waveheight.

Solution is to use a radar capable of operating over a range of radio frequencies with automated waveheight monitoring. Noise reduction and automatic clutter suppression also being developed.

- Phased-array radars need to maintain low sidelobe levels for good quality wave measurement.
- Averaging radar data over 20 minutes or more is needed **– now implemented on some systems.**

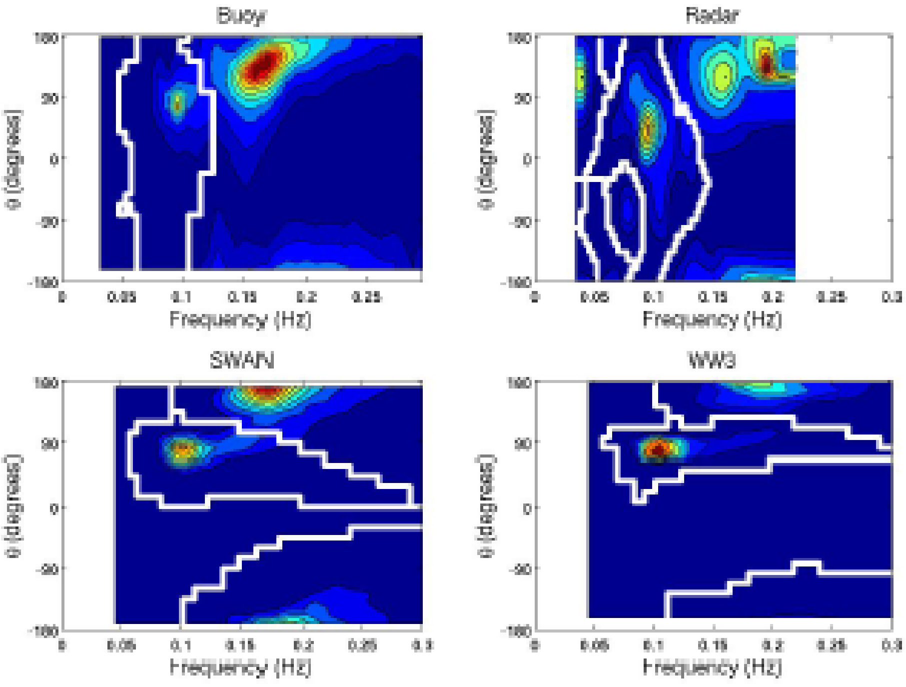
Data Assimilation of radar partitioned spectra – PhD work of Jennie Waters



Assimilation schemes used either mean or partitioned spectral parameters from
- buoy data at 4
- radar data at 4
- radar data at 1,2,4,5,6,7,8,9

Validated at buoys 4, TB, M5, FS1, SI

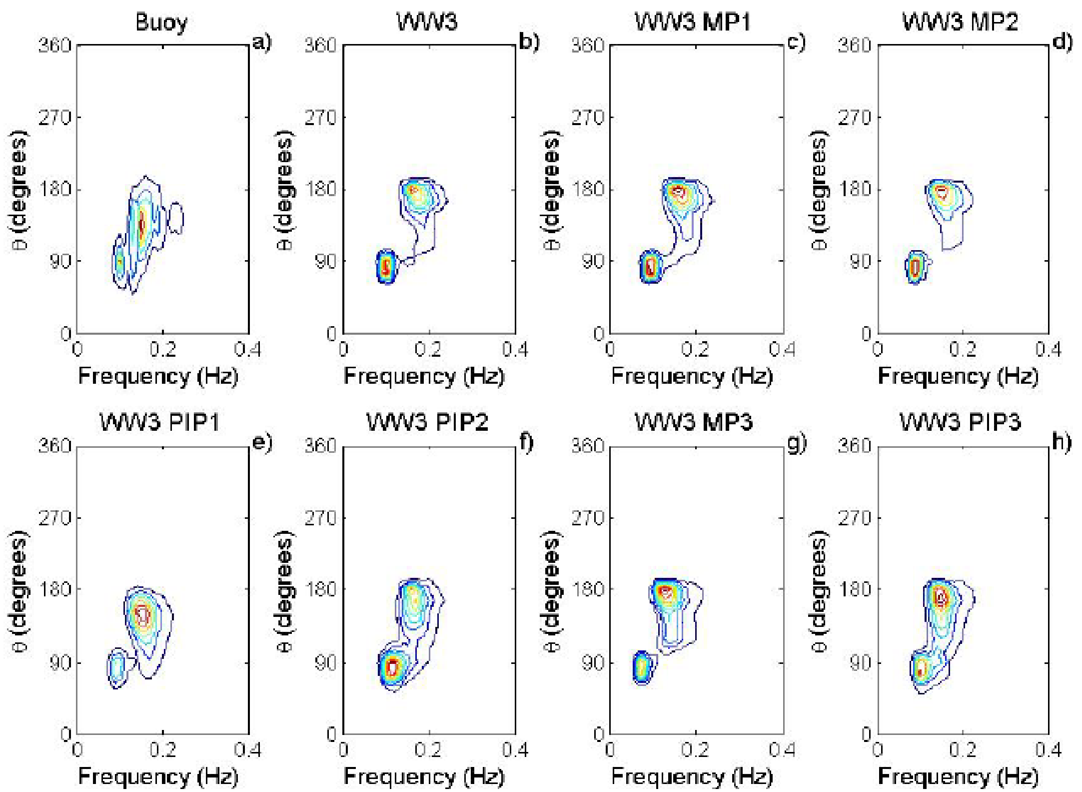
Data Assimilation of radar partitioned spectra – PhD work of Jennie Waters



Buoy, radar and model spectra are partitioned using steepest ascent method (Hasselmann et al, Voorrips et al, Hansen and Phillips) with criteria for combining and discarding partitions based on work of Hasselmann et al, Hansen and Phillips.

Partitions have to be cross-assigned for assimilation, sometimes difficult.

Data Assimilation of radar partitioned spectra – PhD work of Jennie Waters



Example showing impact on spectra of different assimilation schemes

Hs stats at M5

	Mean Error	RMSD	Correlation
M5 Loc			
No Assimilation	0.3079	0.5097	0.8693
Buoy MP1	0.2758	0.4346	0.9096
Radar MP2	0.2964	0.4738	0.9003
Buoy PIP1	0.2094	0.3528	0.9376
Radar PIP2	0.1835	0.3531	0.9266
All Radar MP3	0.0783	0.3848	0.9197
All Radar PIP3	0.0514	0.3253	0.9363

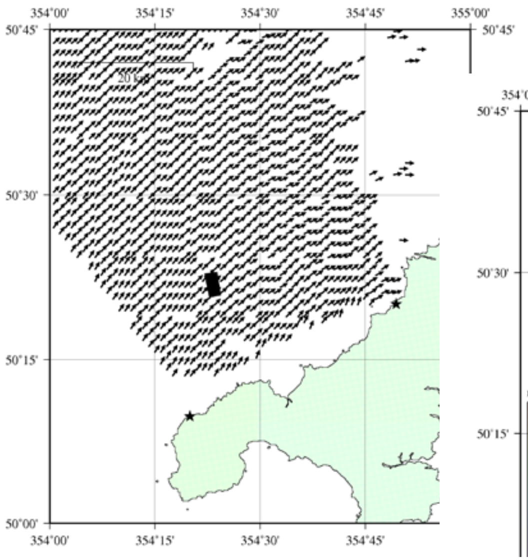
5th April 2011 12:00GMT from University of Plymouth WERA system

The University Of Sheffield.

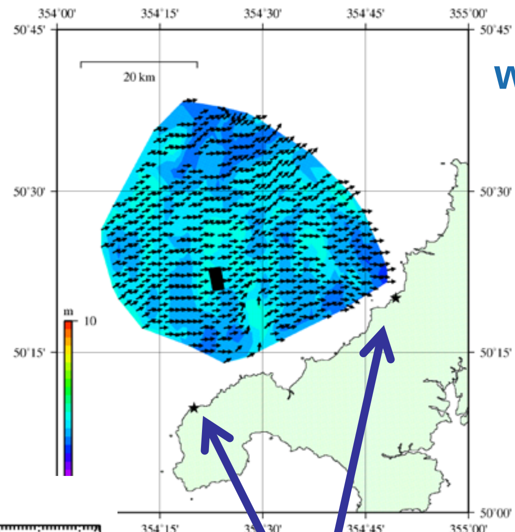
SEAVIEW SENSING

Arrows showing direction are plotted at every other measurement position for clarity.

wind direction

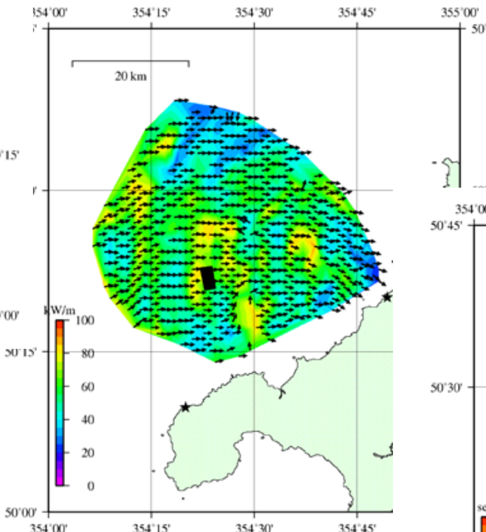


waveheight and mean direction

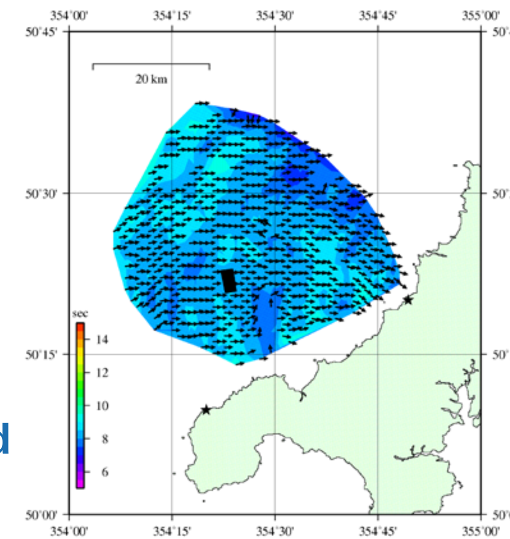


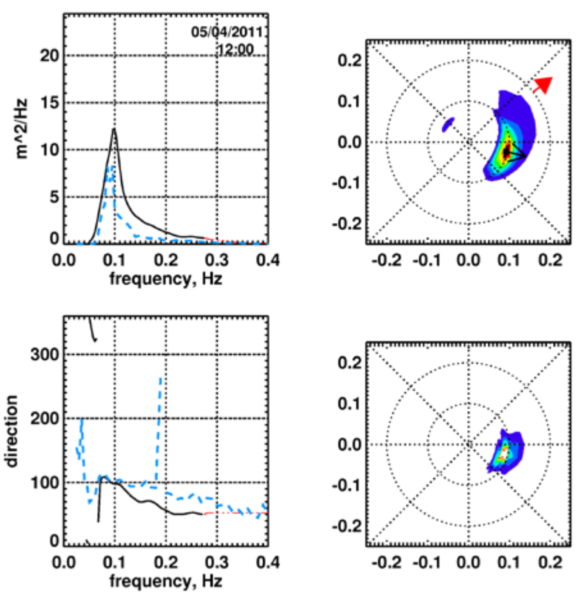
Radar sites

wave power and peak direction



energy period and peak direction



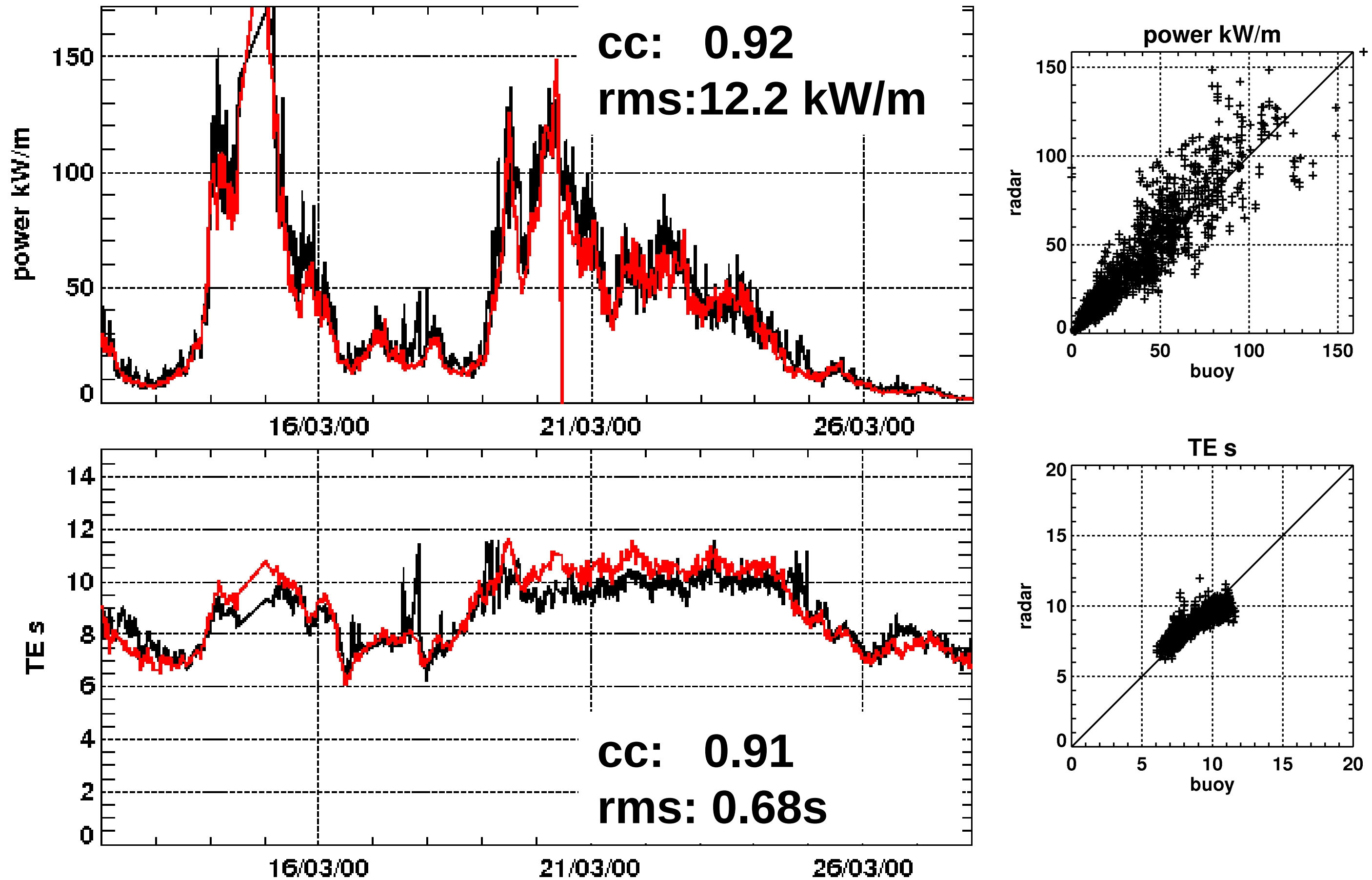


radar
buoy

Data kindly provided by Daniel Conley, University of Plymouth
Buoy data from Channel Coast Observatory

Norway 27MHz power comparisons

WERA
buoy

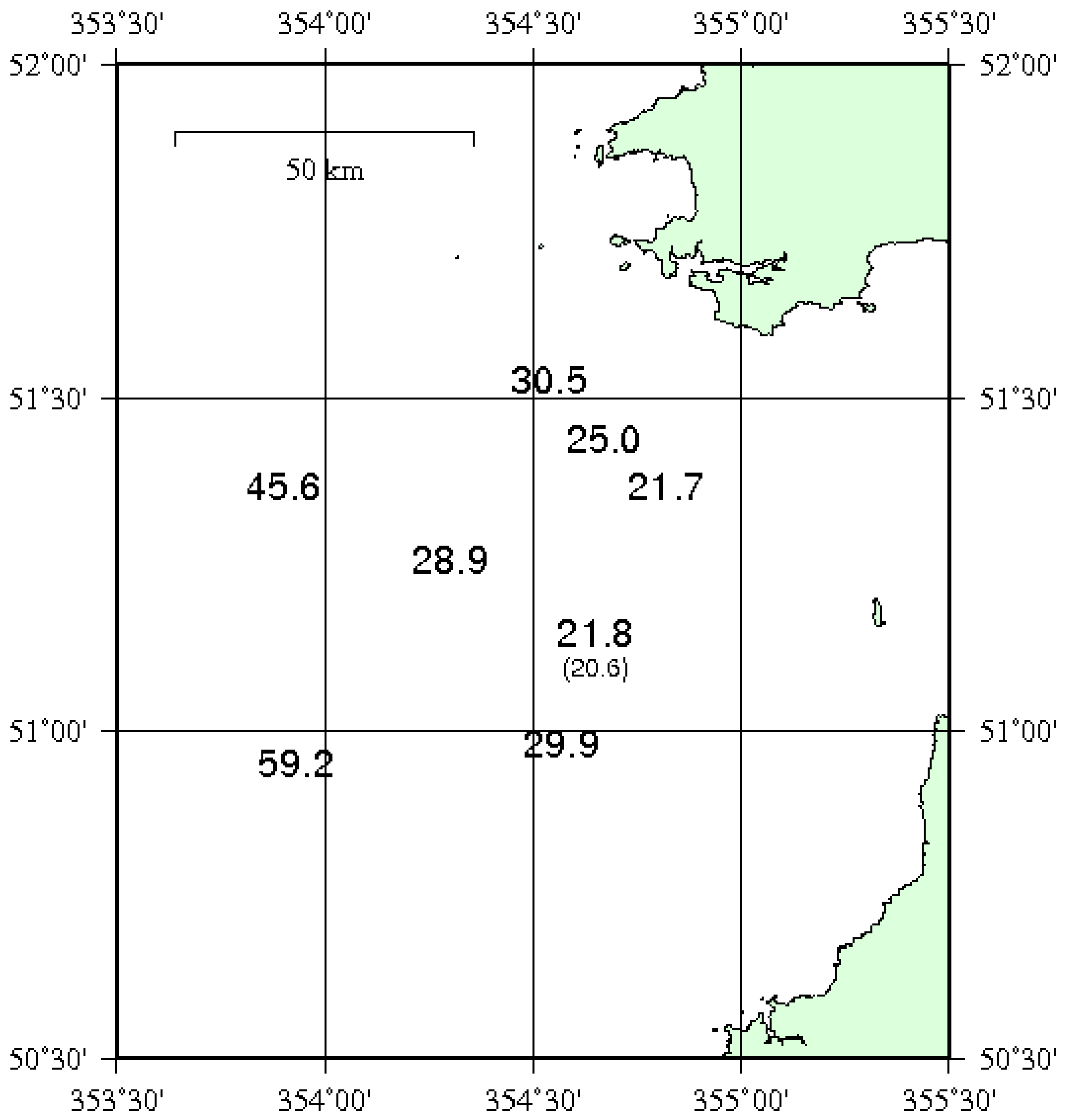


ROS2011, Lerici, Italy, October 2011

Spatial variation in 4 month average wave power kW/m

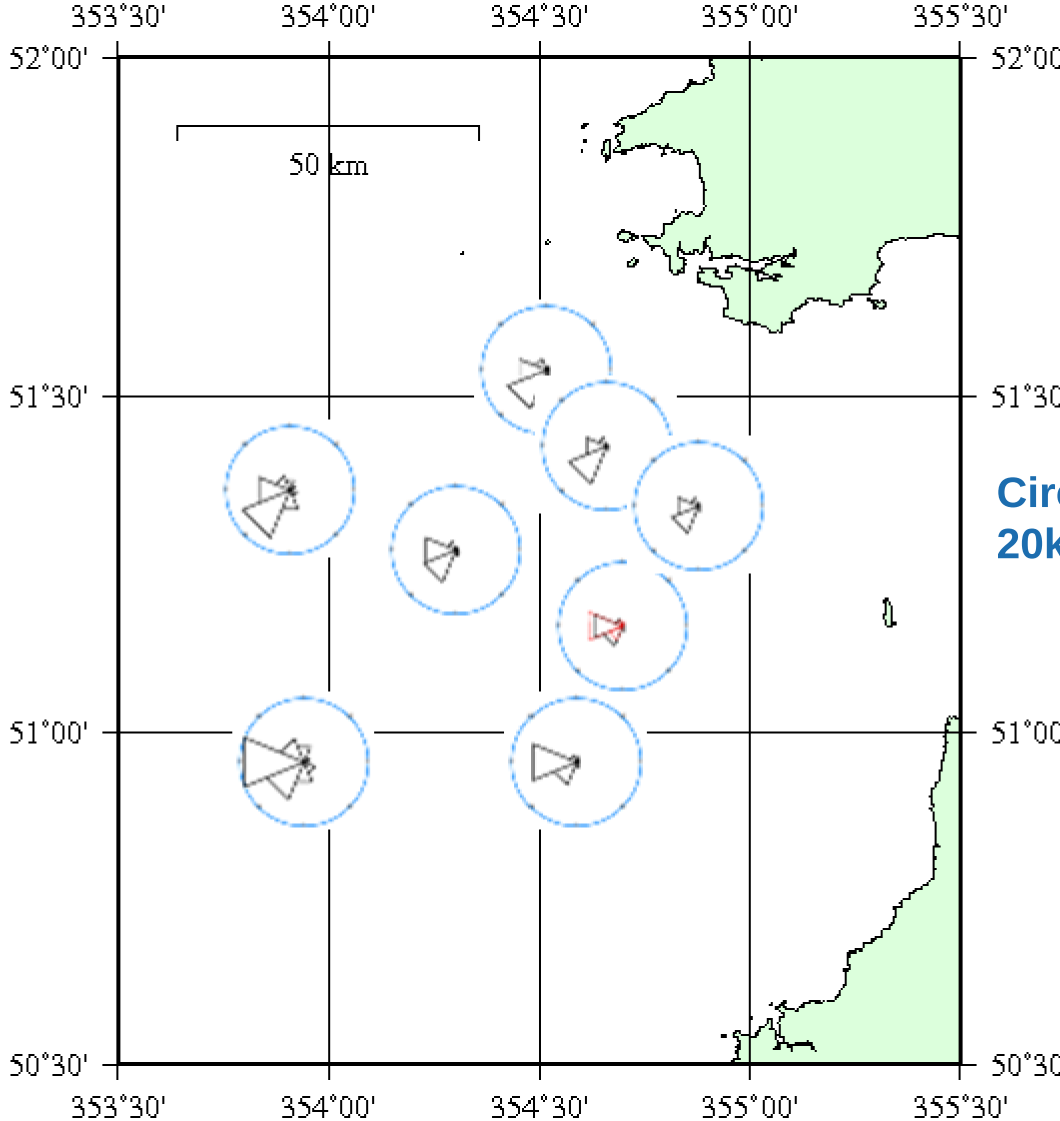
(buoy)

Neptune Radar Ltd Pisces, Celtic Sea data funded by DEFRA/Met Office. Cefas buoy.



Spatial variation in 4 month average directional distribution of wave power

(buoy)

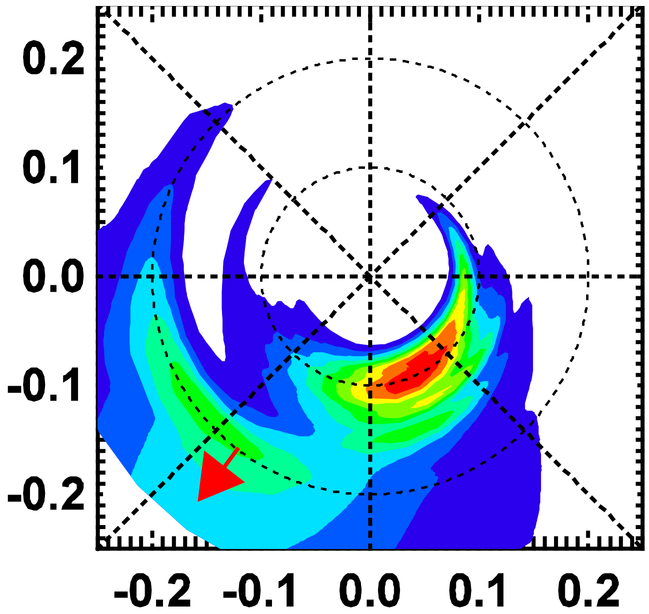


Circles: 20kW/m

Neptune Radar Ltd Pisces, Celtic Sea data funded by DEFRA/Met Office. Cefas buoy.

SUMMARY

- Clear evidence of spatial and temporal variability in wave properties;
- Long term measurements with wavebuoys can characterise the temporal variability (but sometimes fail and need weather windows for repair/recovery);
- Good quality data from HF radar can characterise the spatial and the temporal variability. Measurement limitations have been identified and are being addressed.



Thank you for your attention

Thanks to all who have provided and processed data for this work

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