An Inversion Method for Extraction of Low Wind Speed from HF Radar Backscatter

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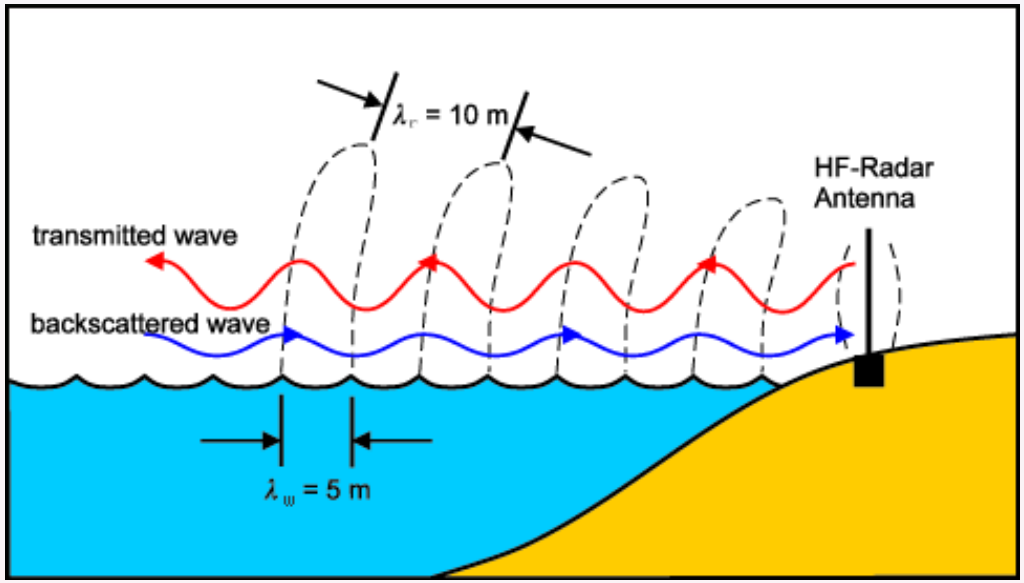
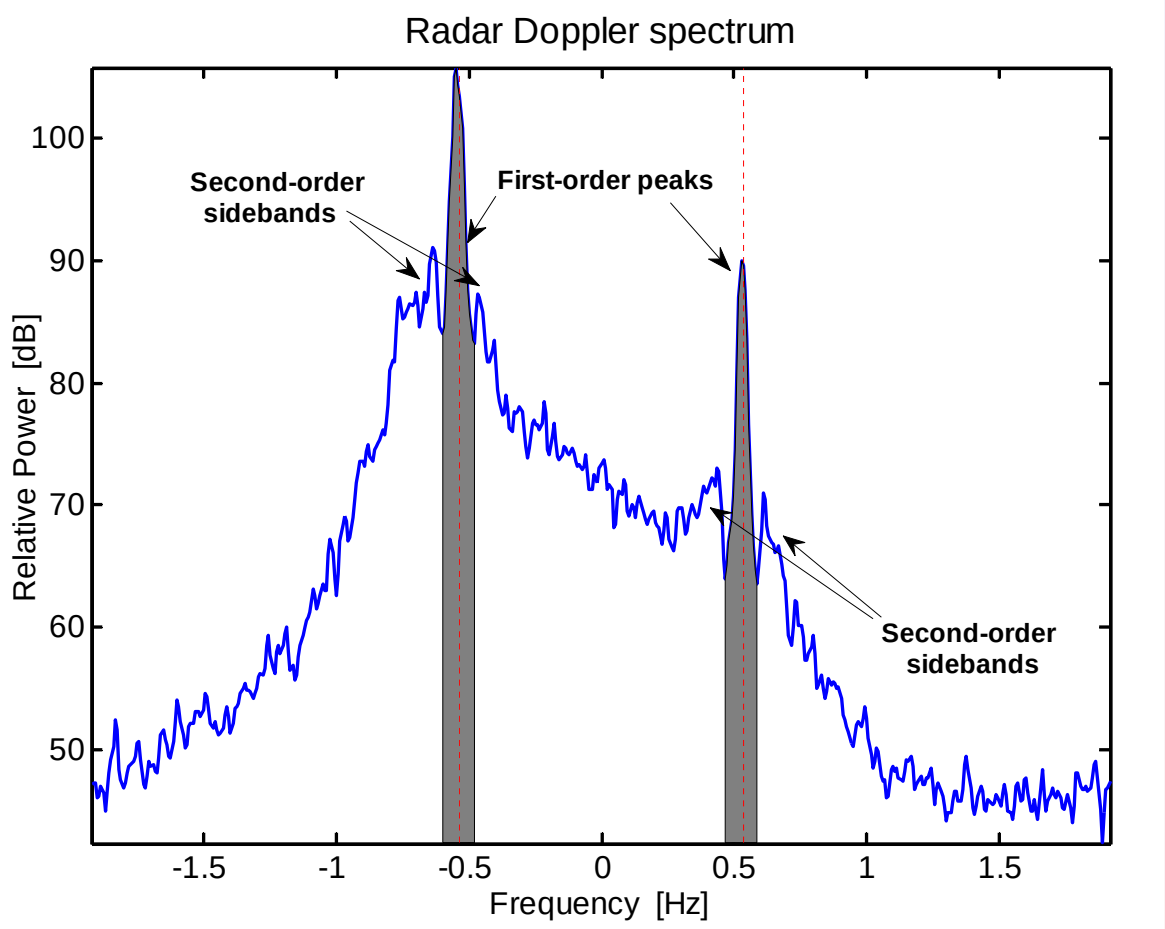


Bragg Scattering

Resonant ocean wavelength is half of radio wavelength: $\lambda_w = \lambda_r/2$

HF Radar Basics

An example of HF radar Doppler spectrum



- First-order backscatter due to Bragg scattering
- The second-order sidebands due to the interaction with longer ocean waves

Previous work on wind speed inversion

Wind speed derived from radar second-order sidebands

Method

- Radar second-order sidebands$\rightarrow$ ocean wave power spectra (H_S and f_P) $\rightarrow$ Wind speed

Limitations

- It is only valid in the pure wind sea (the presence of swell might overestimate wind speed)
- The SNR of the second-order sidebands is nearly 20-40 dB lower than that of first-order peaks, which reduces the range of wind speed measurement

New method for wind speed inversion

Wind speed derived from radar first-order backscatter

Method

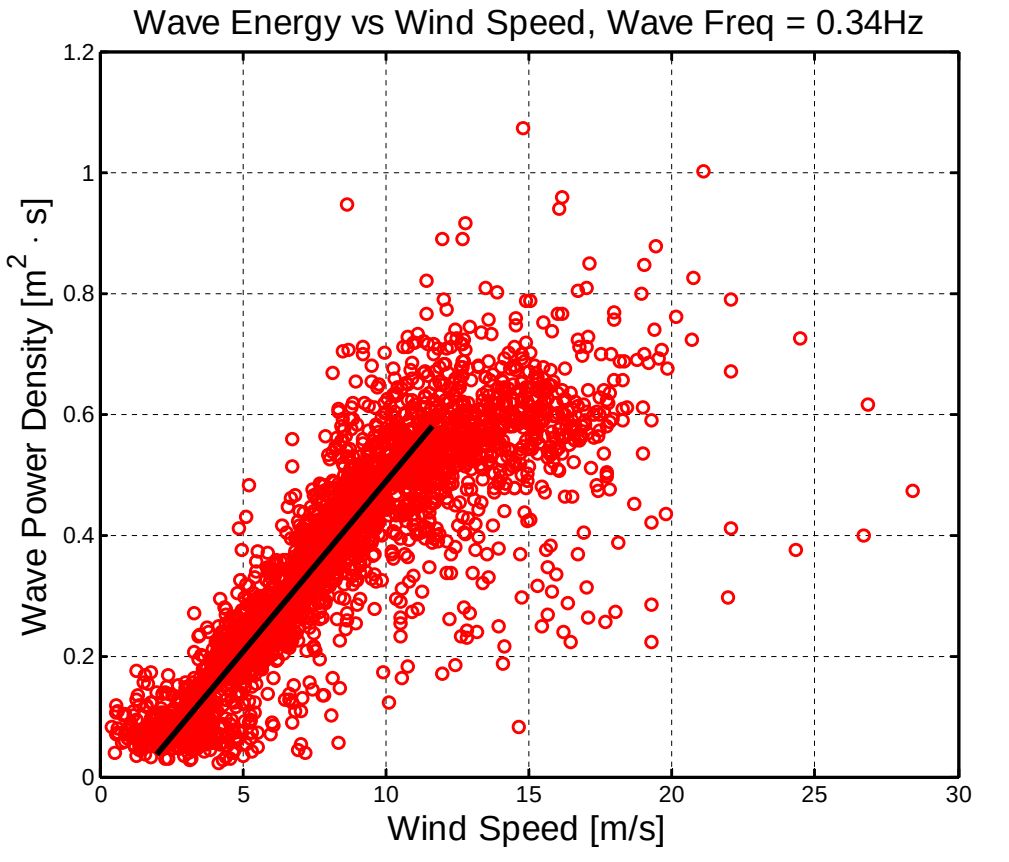
- Radar first-order peaks→ Information of Bragg resonant waves→ Wind speed

Principles

1. The power of radar first-order peaks represents the energy scattered by the Bragg resonant waves along the radio beam.
2. Signature of Bragg waves indicates the local wind conditions (Based on the HIPOCAS[a] WAM data analysis)

[a] (HIPOCAS) HIndcast of dynamic Processes of the Ocean and Coastal AreaS of europe

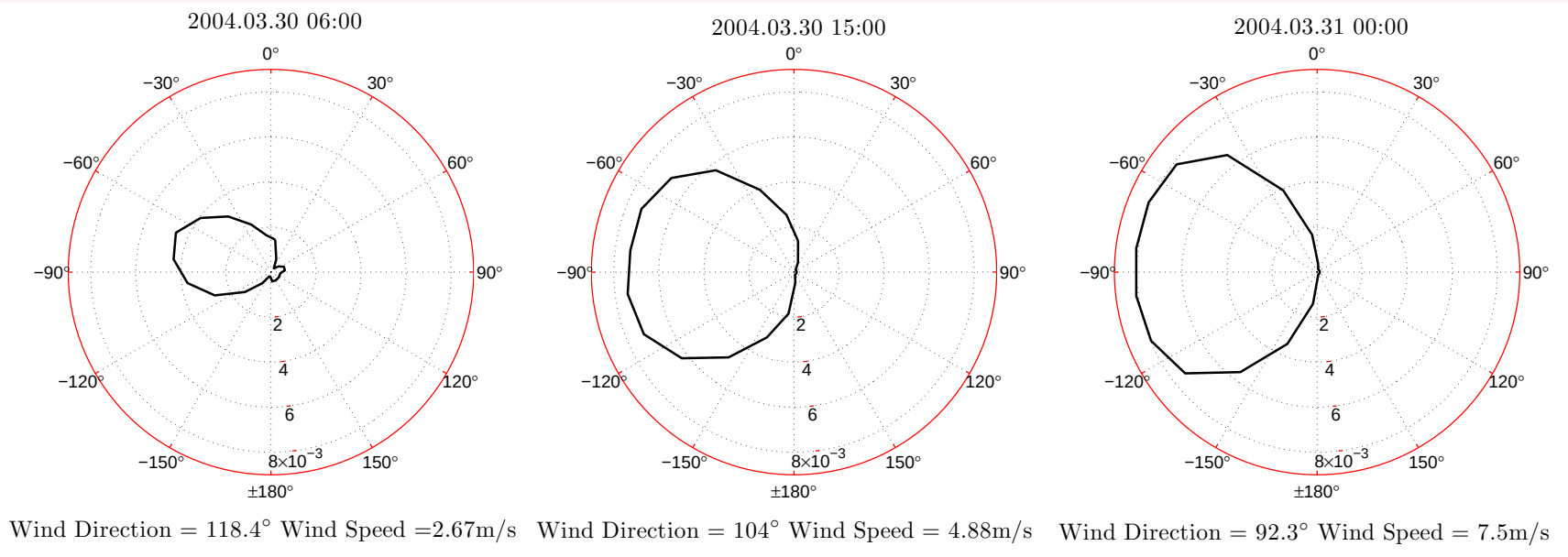
- Integrated wave power density at Bragg wave frequency vs. local wind speed (WAM data, 2004)



$f_{\text{Bragg}} = 0.34$ Hz, corresponding $f_{\text{Radar}} = 11.1$ MHz

- Bragg wave directional distribution varies with wind speed

Time	03/29 21:00	03/30 06:00	03/30 15:00	03/31 00:00	03/31 09:00
Wind speed (m/s)	0.87	2.67	4.88	7.5	11.3
Wind direction (°)	224.9	118.4	104	92.3	98



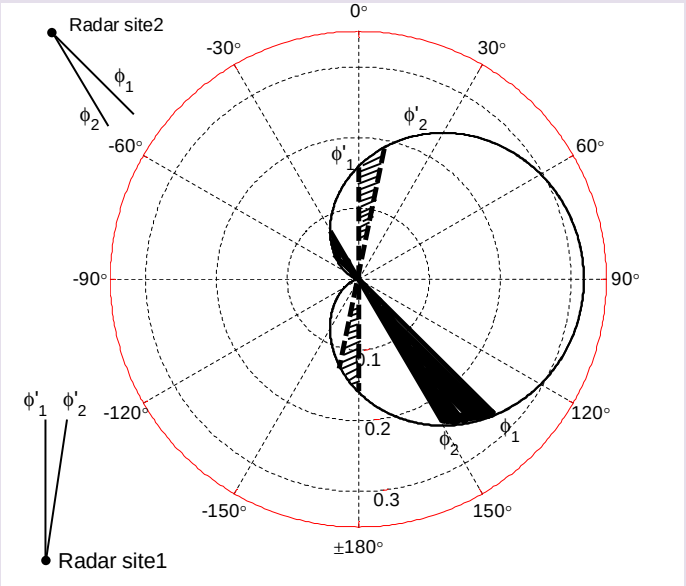
Wind Direction = 118.4° Wind Speed =2.67m/s Wind Direction = 104° Wind Speed = 4.88m/s Wind Direction = 92.3° Wind Speed = 7.5m/s

Neural Network implemented for wind speed inversion

Data set and neural network structure

Input data set

Wave pattern and radio beams



$\sigma_1(\pm f_{\text{Bragg}})$ and $\sigma'_1(\pm f_{\text{Bragg}})$

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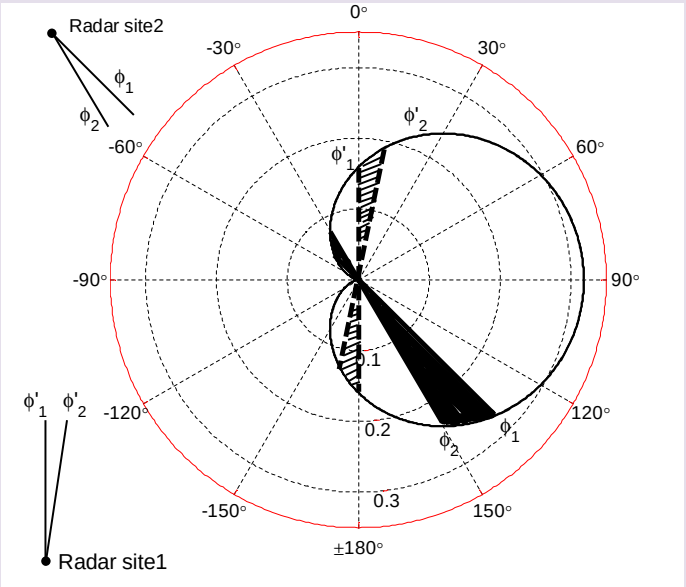
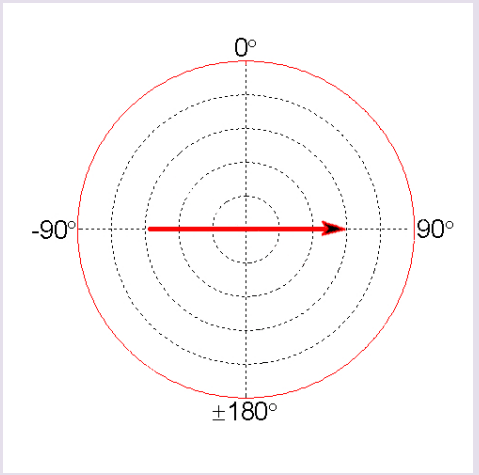


$\sigma_1(\pm f_{\text{Bragg}})$ and $\sigma_1'(\pm f_{\text{Bragg}})$

Target data

In-situ wind data



U_{10}

$\cos\theta$

$\sin\theta$

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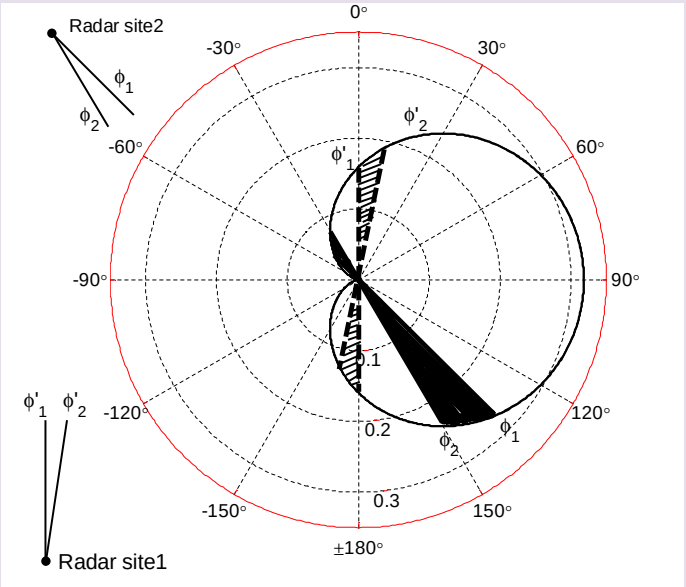
Data set and neural network structure

Input data set

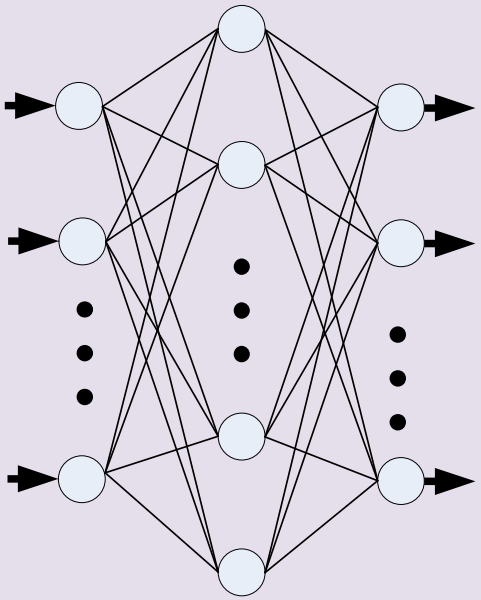
Wave pattern and radio beams



$\sigma_1(\pm f_{\text{Bragg}})$ and $\sigma_1'(\pm f_{\text{Bragg}})$

Neural Network

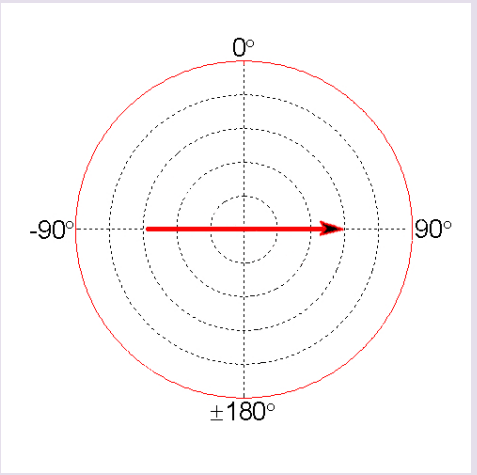
Network type : BP



3-layer network

Target data

In-situ wind data



U_{10}

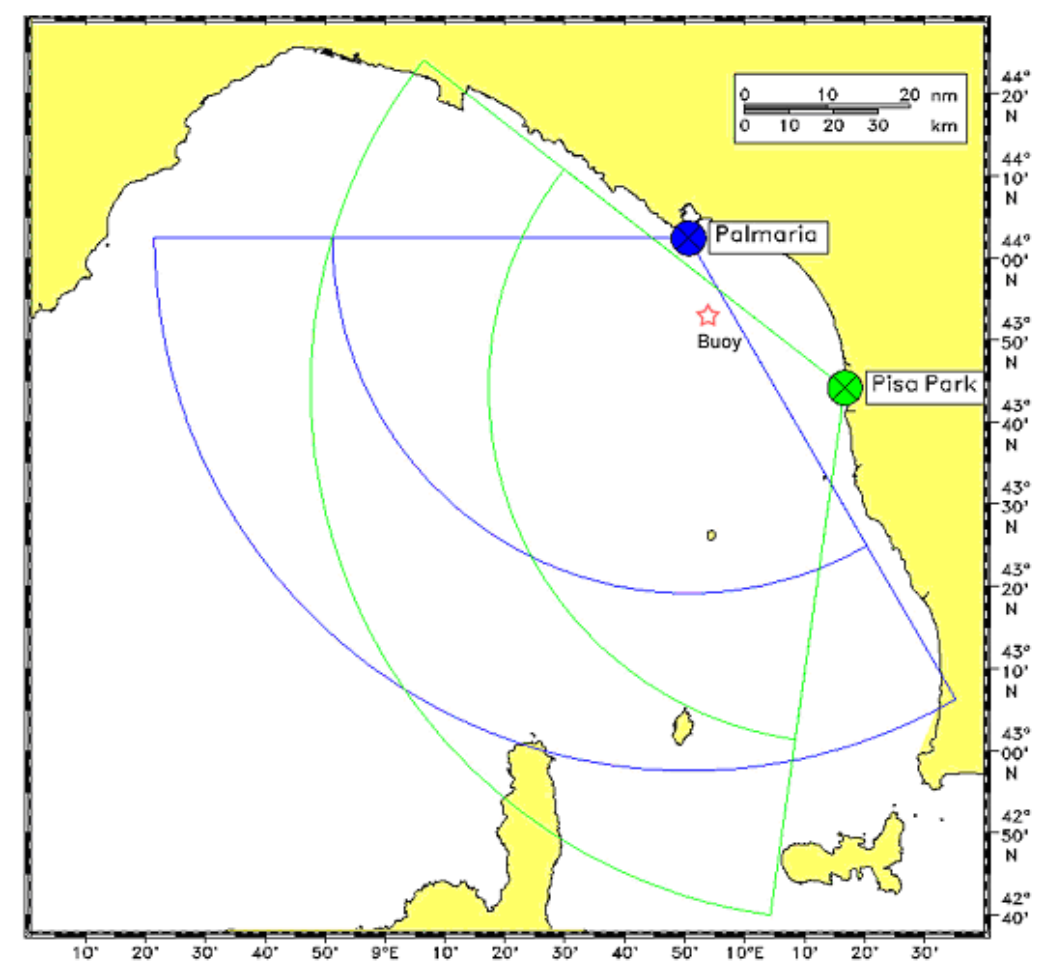
$\cos\theta$

$\sin\theta$

Ligurian Sea experiment(2009)

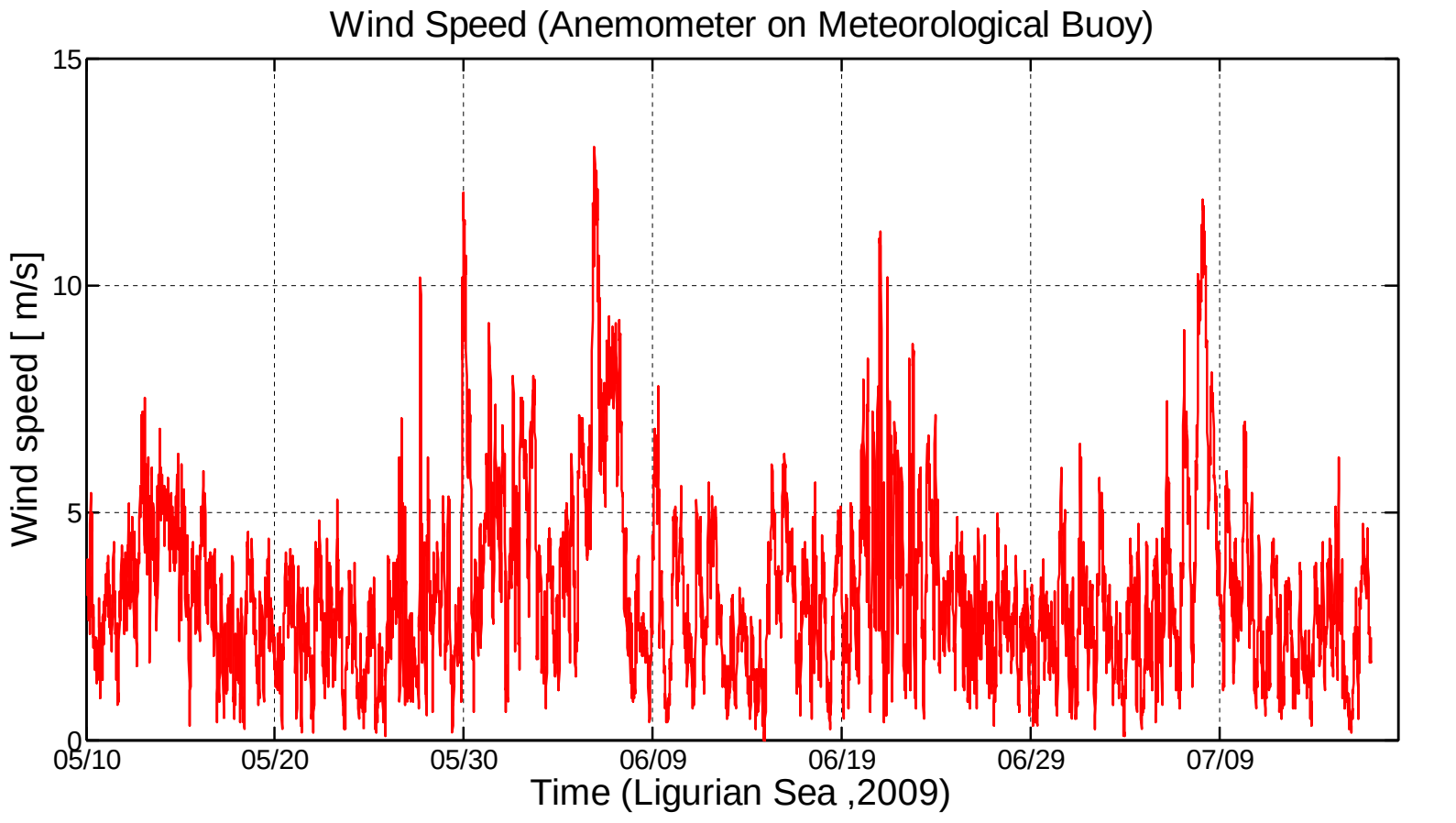
Radar sites and meteorological buoy (in-situ wind measurement)

- Radar frequency: $12 \sim 13$ MHz
- Radar coverage: up to 120 km



In-situ wind measurement at the sea surface

Statistics of the wind speed record

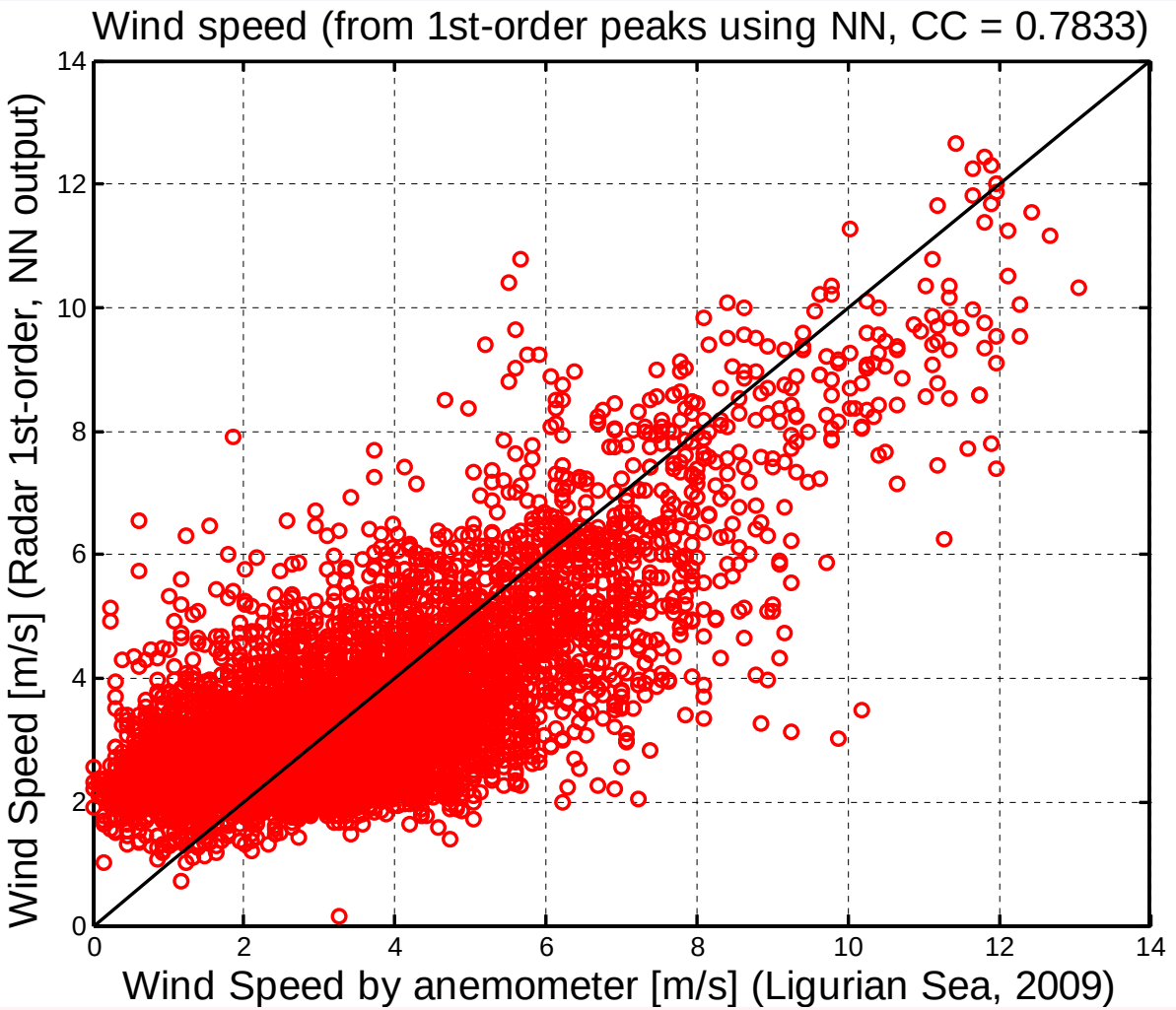


Wind speed range (m/s)	$0 < U \leq 3$	$3 < U \leq 5$	$5 < U \leq 10$	$U > 10$
Percentage (%)	48.1	33	17.23	1.67

Wind speed is low during the experiment (81% lower than 5 m/s)

Wind speed inversion using neural network

Performance of the new method



Scatter plot of wind speed (NN output and in-situ measurement)

- RMS error analysis

RMS Error for wind speed inversion (m/s)			
Wind speed U		NN method	Conventional method
$U > 3$		1.36	2.21
$0.1 < U \leq 3$	46.3%	1.13	3.64
$3 < U \leq 10$	50.2%	1.34	2.16
$U > 10$	1.67%	2.13	4.19

Conclusions and Outlook

Conclusion

1. The new method can derive low wind speed from radar first-order backscatter up to 12 m/s
2. Compared to the conventional method, the new method reduces the RMS error by a factor of 1.5 to 2

Outlook

- The algorithm will be extended to the other grid points on the radar map for the wind speed field inversion

Thank you for attention!

Test points of the HIPOCAS WAM data

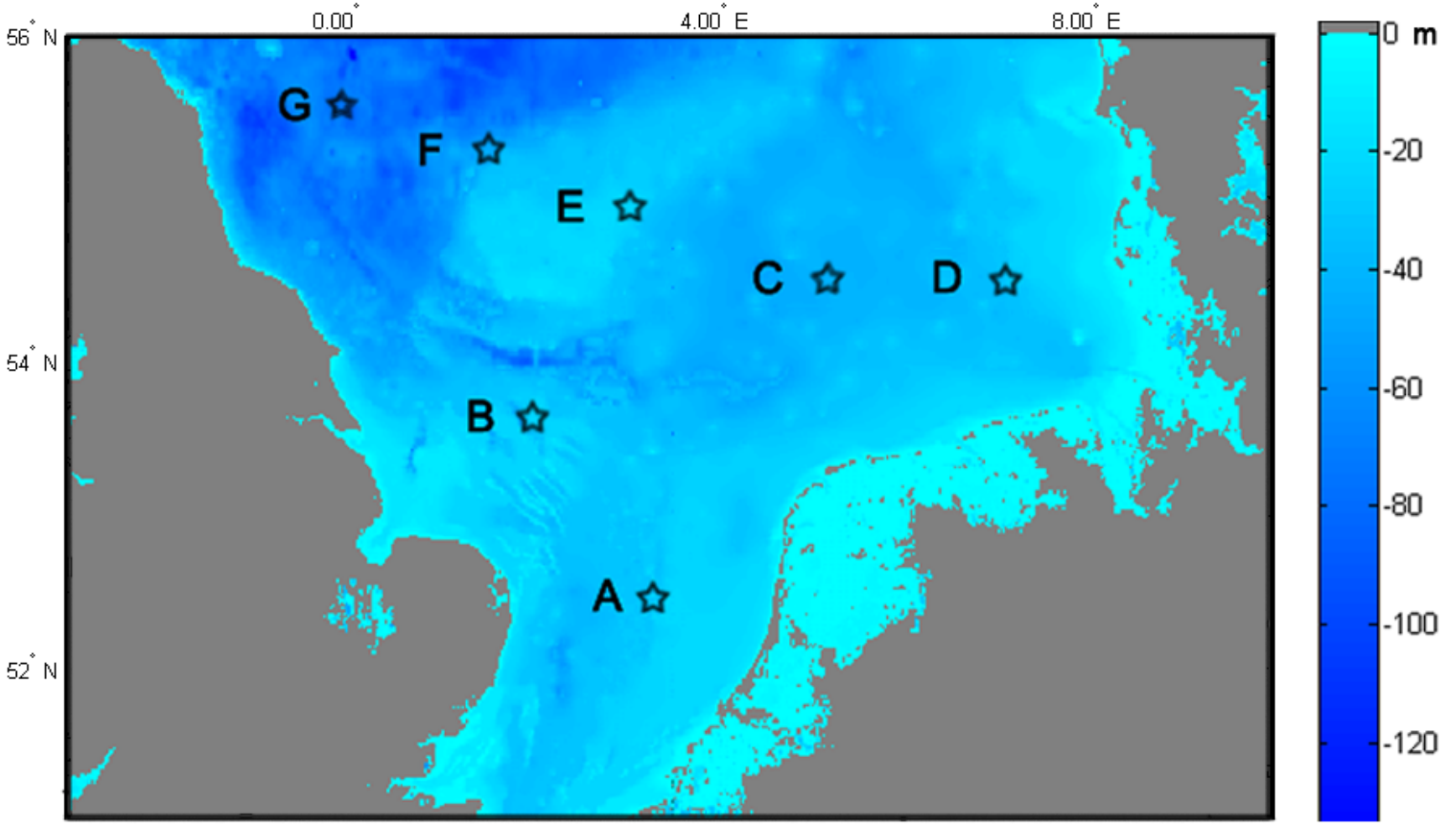
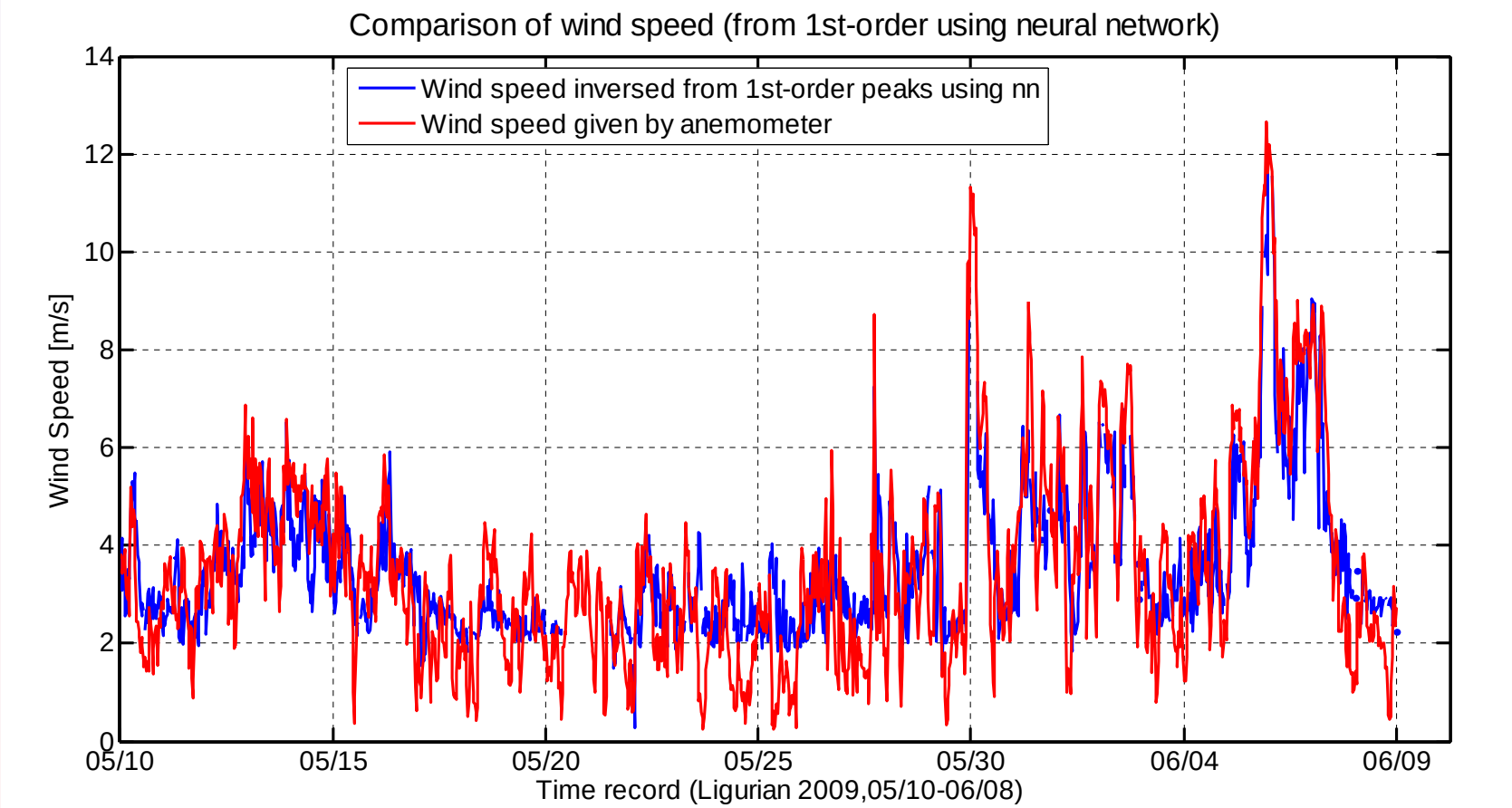


Figure:

Comparison of wind speed measurement



Wind field derived using neural network