Underway Ship Radar Observations of Wind Wave Directional Spectra

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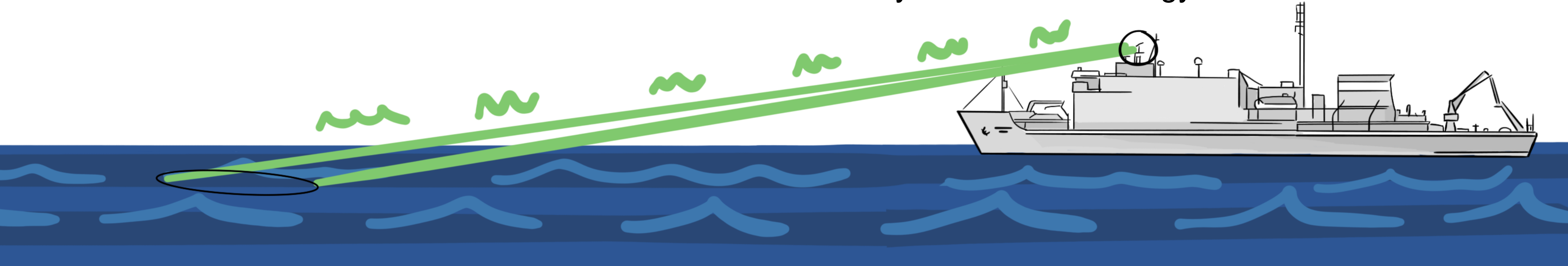


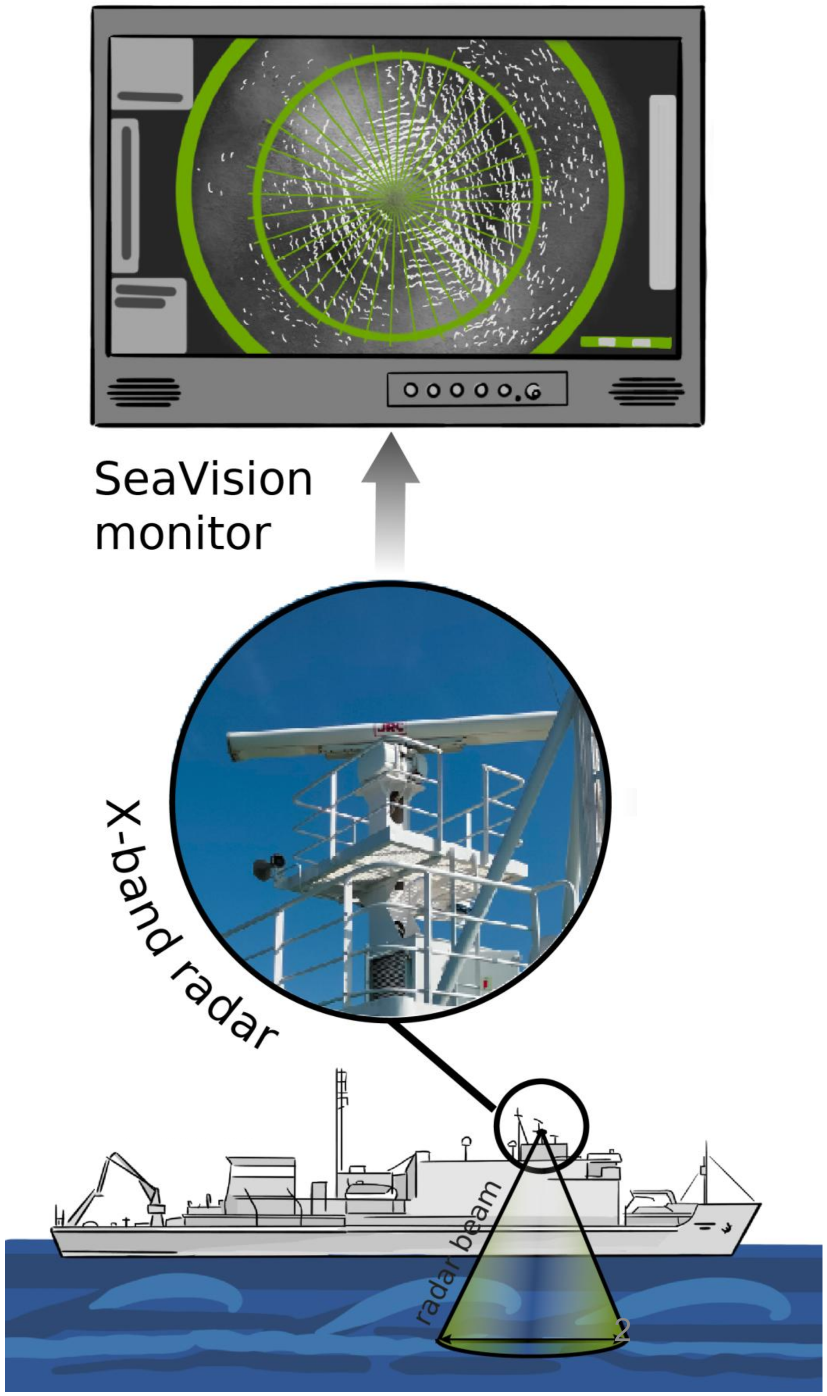
Motivation

Satellite data — global but need validation

Buoy networks — reliable but sparse

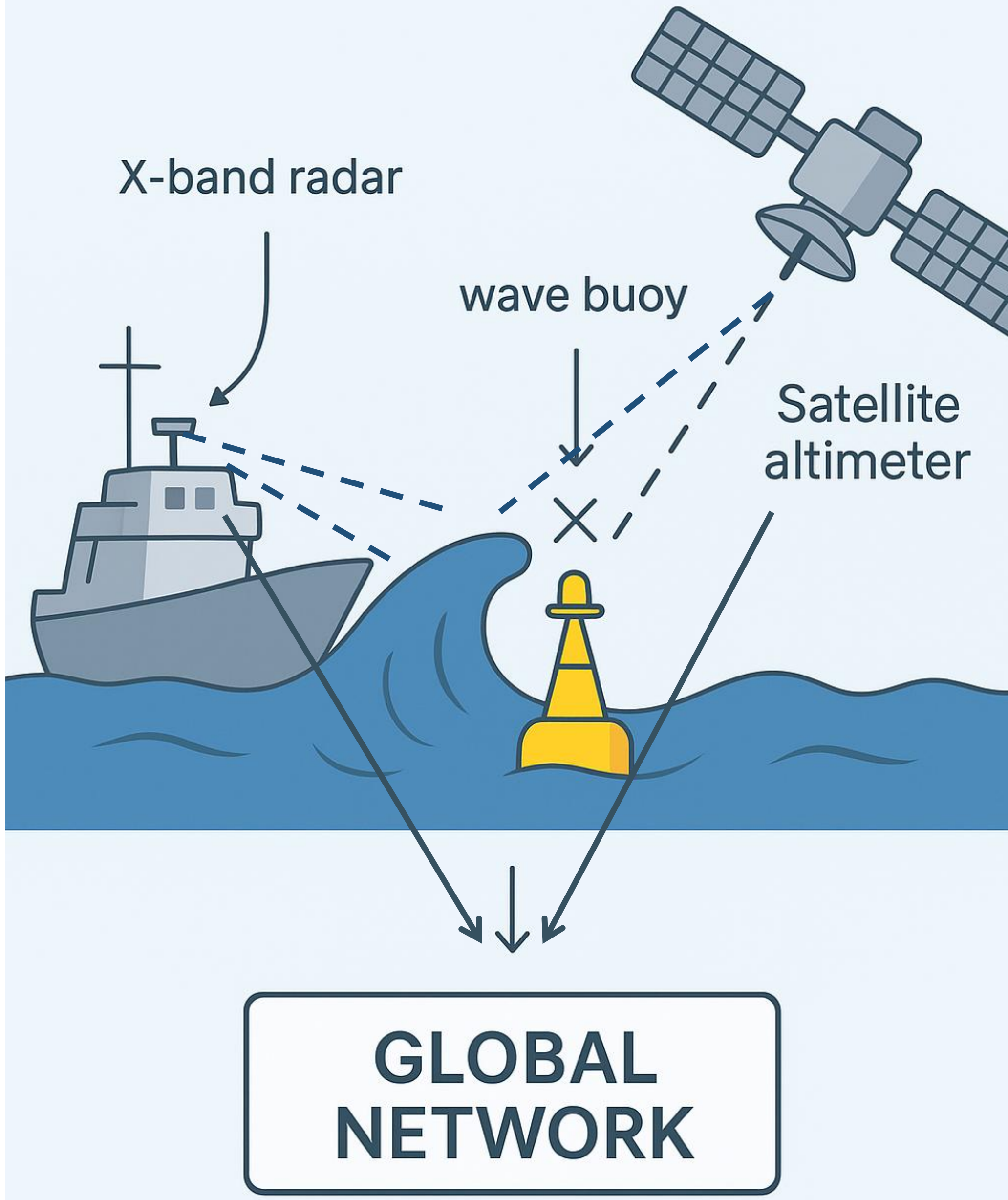
Models — require validation and assimilation

*Adapted **ship radars** for dual mode can provide directional spectra and potentially form a new global observational network like VOS*

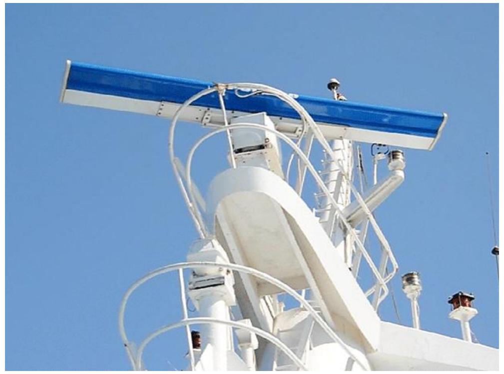


Study Objective

- Evaluate the retrieval of directional spectra from X-band radar for different conditions and radar characteristics
- Compare radar-derived spectra with independent measurements and model
- Adapt processing for the moving reference frame of a ship
- Assess potential for assimilation into models

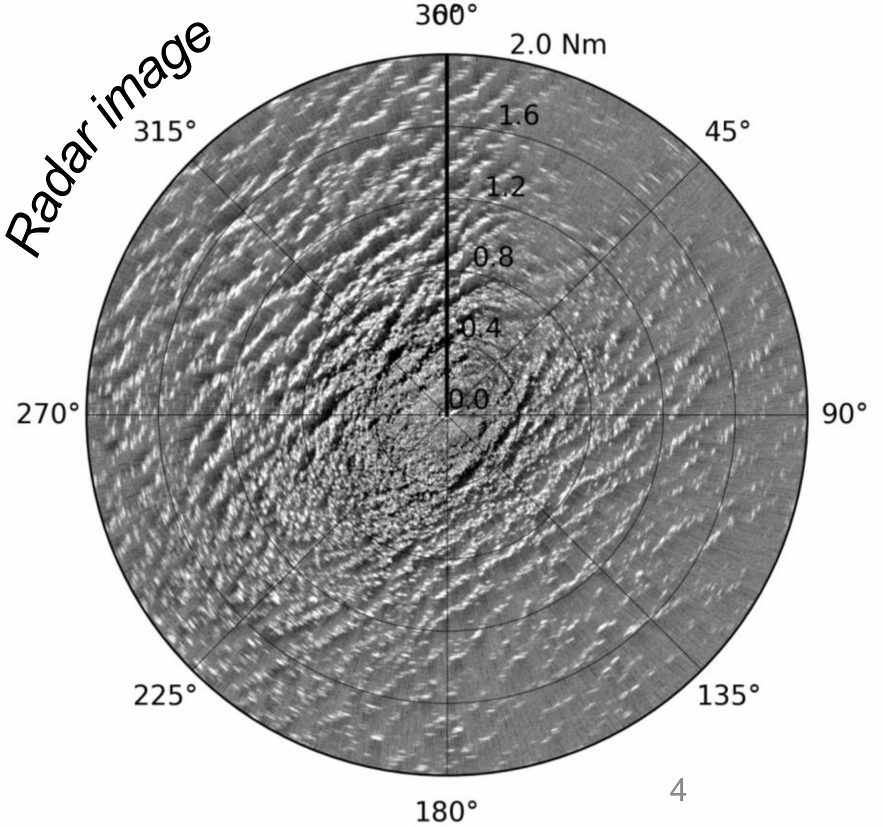


Instrumentation – X-band radar



Polarization	HH
Frequency	9410 ± 30 MHz
Impulse power	10/25 kW
Antenna rotation speed	24/28
Min impulse duration	70-80 ns (~10 m)
Width and height of radiation pattern	0.8° and 20° / 1° and 24°
Max recording distance	7680 m (~4 Nm)
Size of recording image	4096 x 4096
Range of image values	0-256

Radar antenna is located at height ~25-30 m above sea level



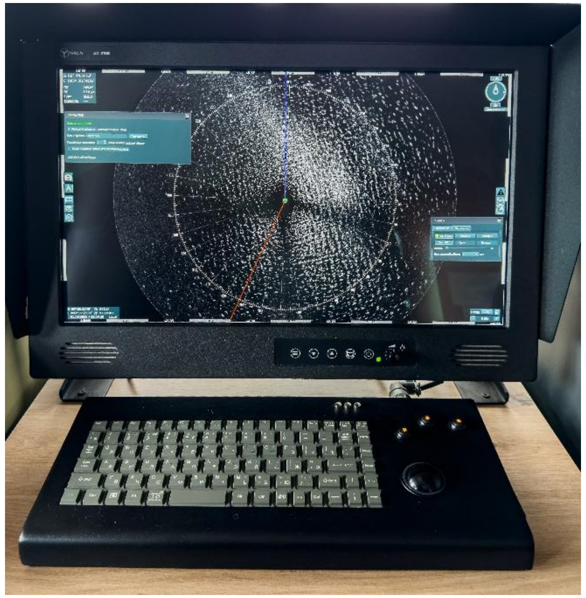
Instrumentation – SeaVision system

LAG

GPS

GYRO

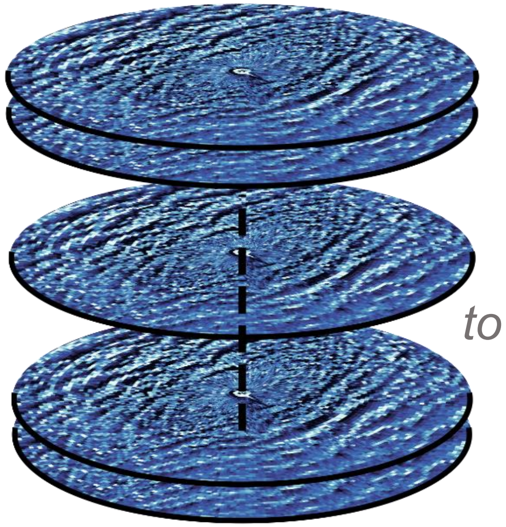
AIS



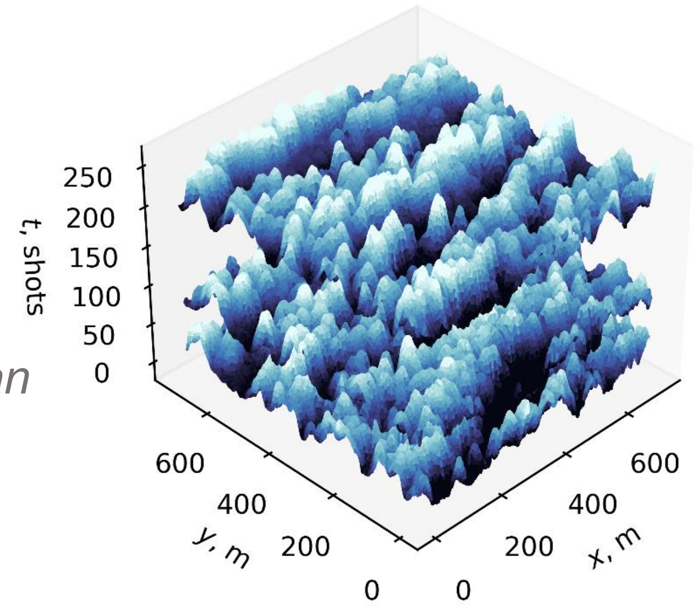
Monitor on the captain's bridge

Frequency of analog-to-digital conversion	80 MHz
Size of one image	16.4 Mb
Number of images to processing	256 (~10 minutes)
Frequency of data updating	every antenna turn
SWH accuracy	+- 0.4 m
Peak period accuracy	+- 0.5 s
Peak direction accuracy	+- 10°

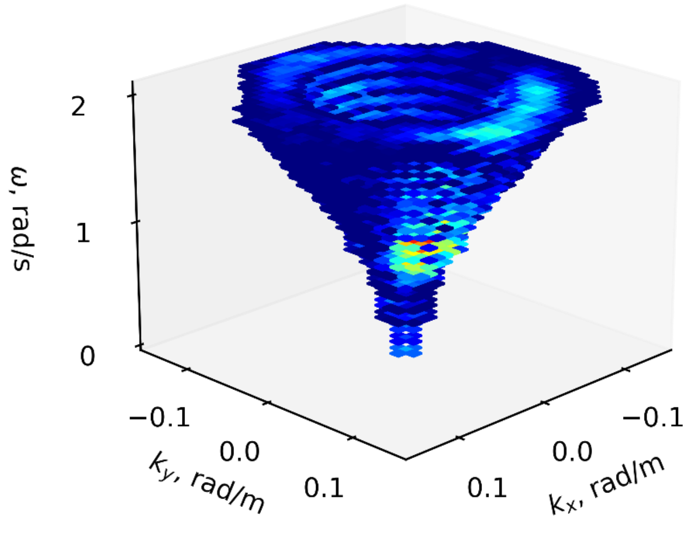
Radar Data Processing



to Cartesian



FFT



Sequence of 256 radar images

Square segments 720x720 m

Dispersion shell* in 3D wave spectrum

Estimation of the position of the dispersion curve

$$\omega = \sqrt{gk} + \mathbf{k} \cdot \mathbf{V}$$

where ω – frequency, **k** – wave vector, g – gravity acceleration, **V** – radar speed relative to still water

*Young, I. R., Rosenthal, W., & Ziemer, F. (1985). A three-dimensional analysis of marine radar images for the determination of ocean wave directionality and surface currents. *Journal of Geophysical Research: Oceans*, *90*(C1), 1049-1059.

Converting spectrum to stationary frame

In moving frame

$$\omega = \sqrt{gk} + \mathbf{k} \cdot \mathbf{V}$$

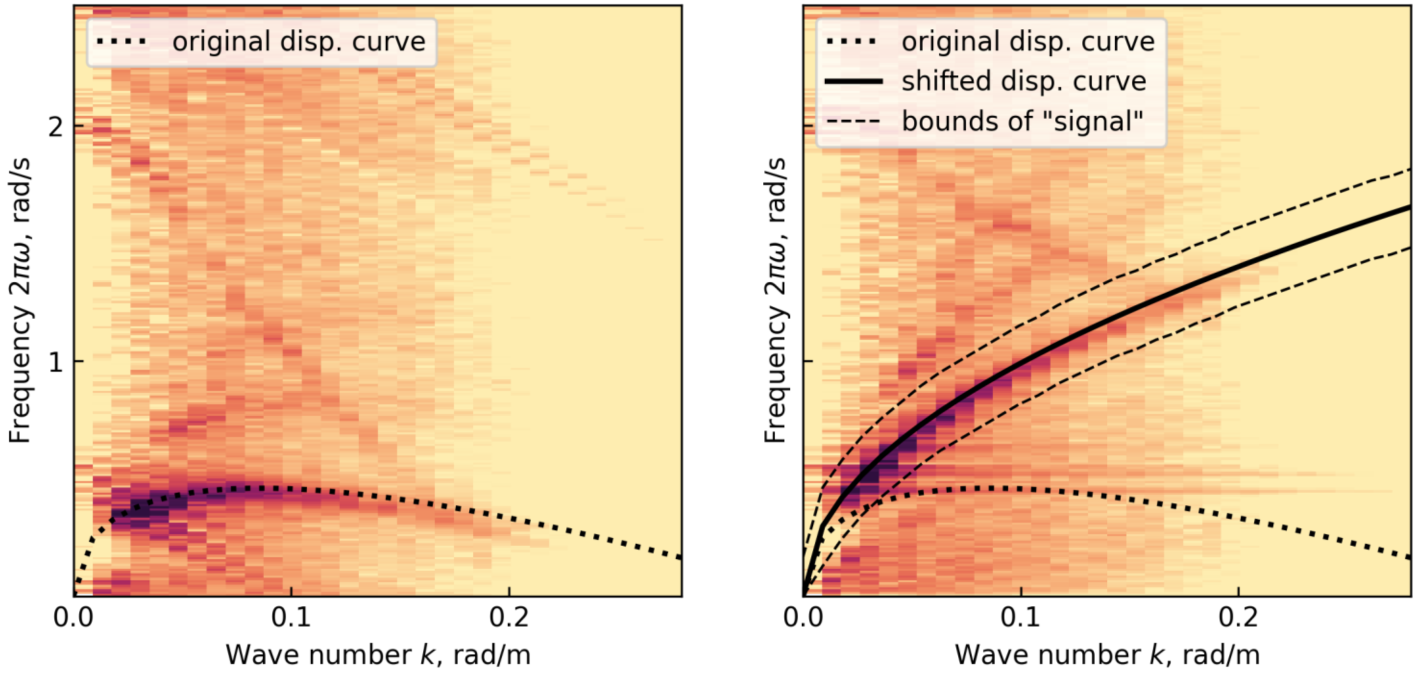
In stationary frame

$$\omega = \sqrt{gk}$$

Signal-to-noise ratio*

$$SNR = \frac{\int_{signal} S(\omega,k)k^{-1.2}dkd\omega}{\int_{noise} S(\omega,k)dkd\omega}$$

$$H_s = A + B\sqrt{SNR}$$ where A, B – calibration coefficients



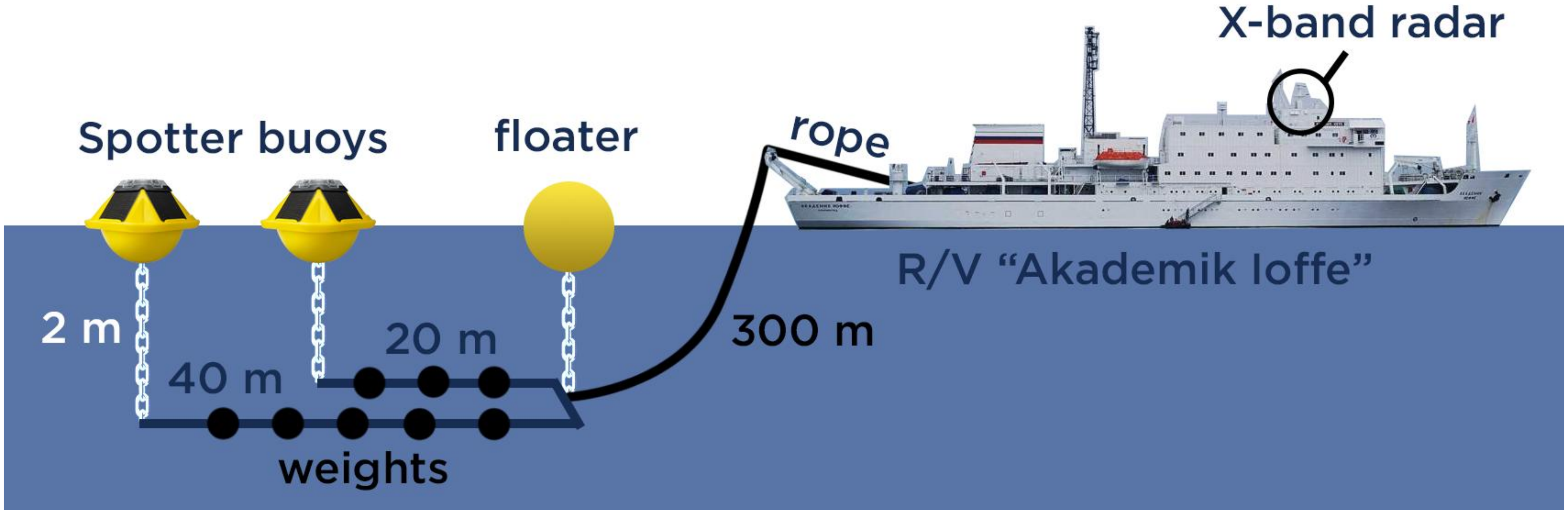
S(ω, k) spectrum before and after conversion

Algorithm was tested at speed to 9 m/s

*Nieto Borge, J., G. R. RodrÍguez, K. Hessner, and P. I. González, 2004: Inversion of Marine Radar Images for Surface Wave Analysis. *J. Atmos. Oceanic Technol.*, **21**, 1291–1300.

Instrumentation – Spotter buoys

- Station experiment: the ship is drifting
- Spotter buoys are deployed from the side, attached to ropes
- Buoys remain in “free” water for ~30 minutes, unaffected by ship motion



The beginning of station with Spotters

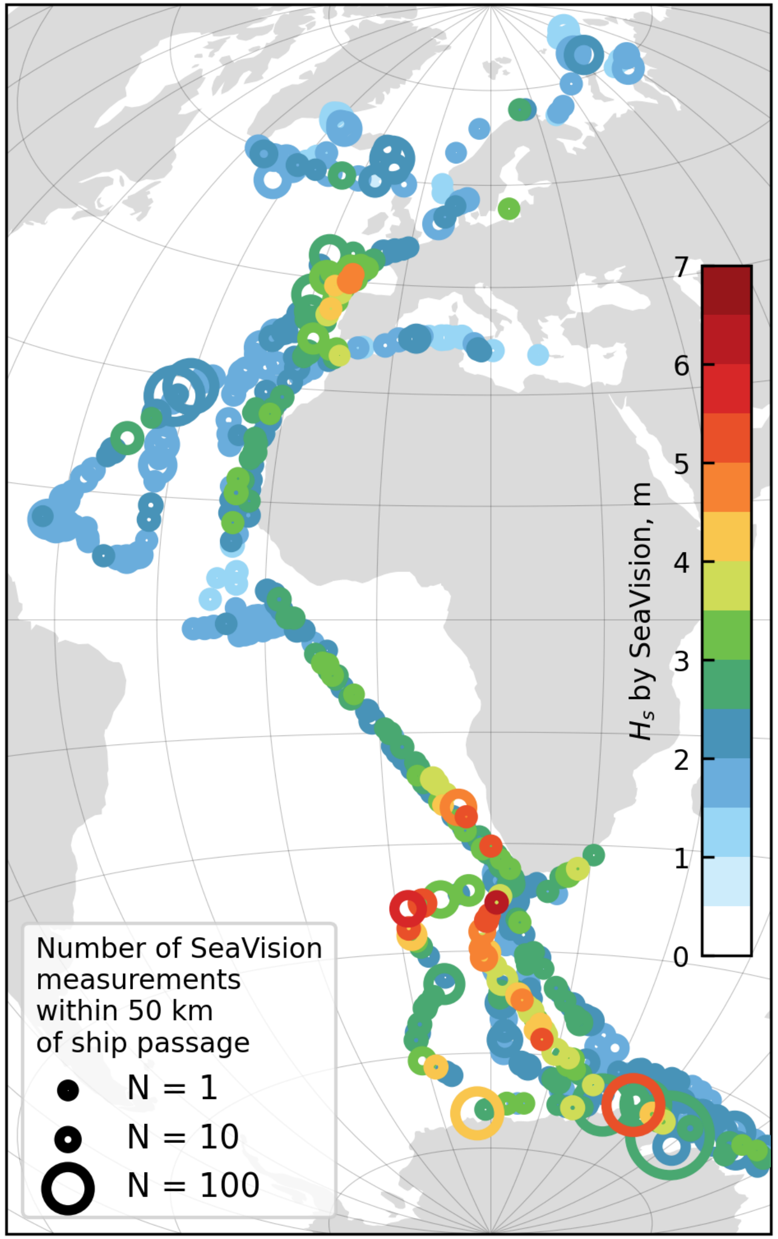
Data overview

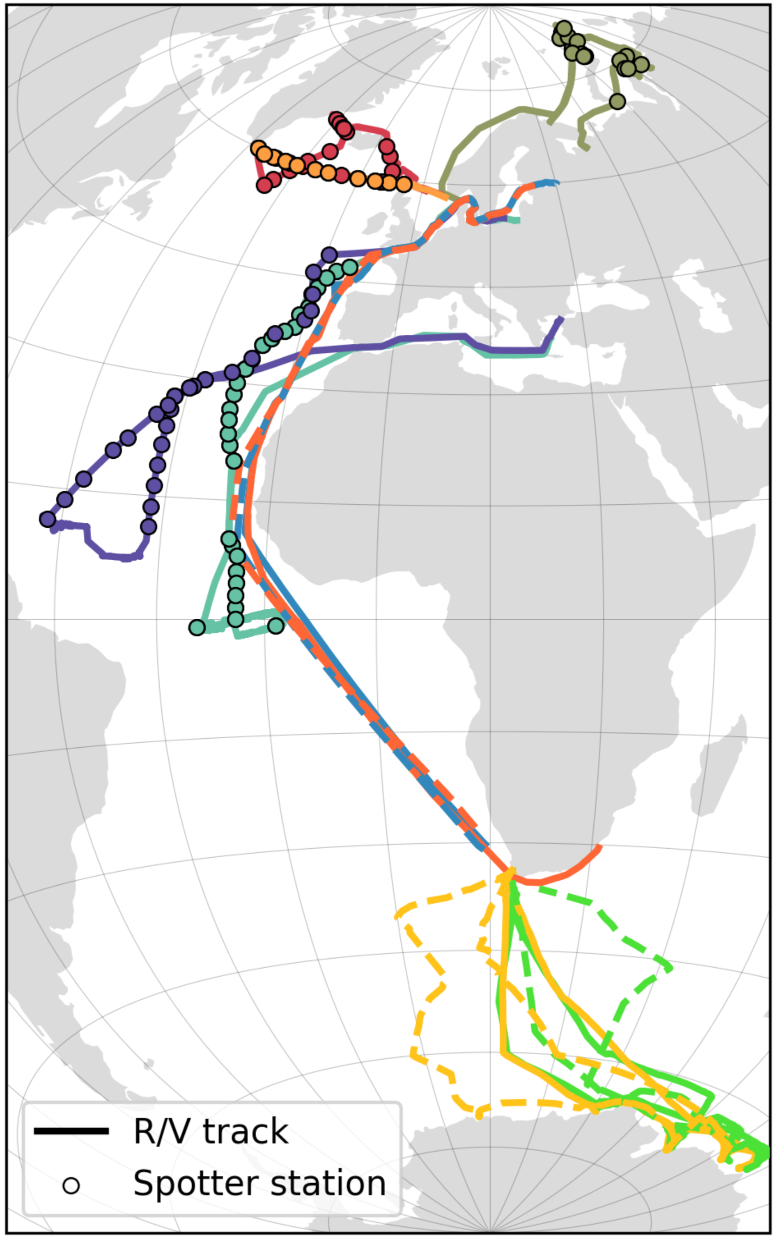
7 cruises since 2020

109 stations with Spotter

3956 collocations with altimeters (200 km)

1348 hours of measurements

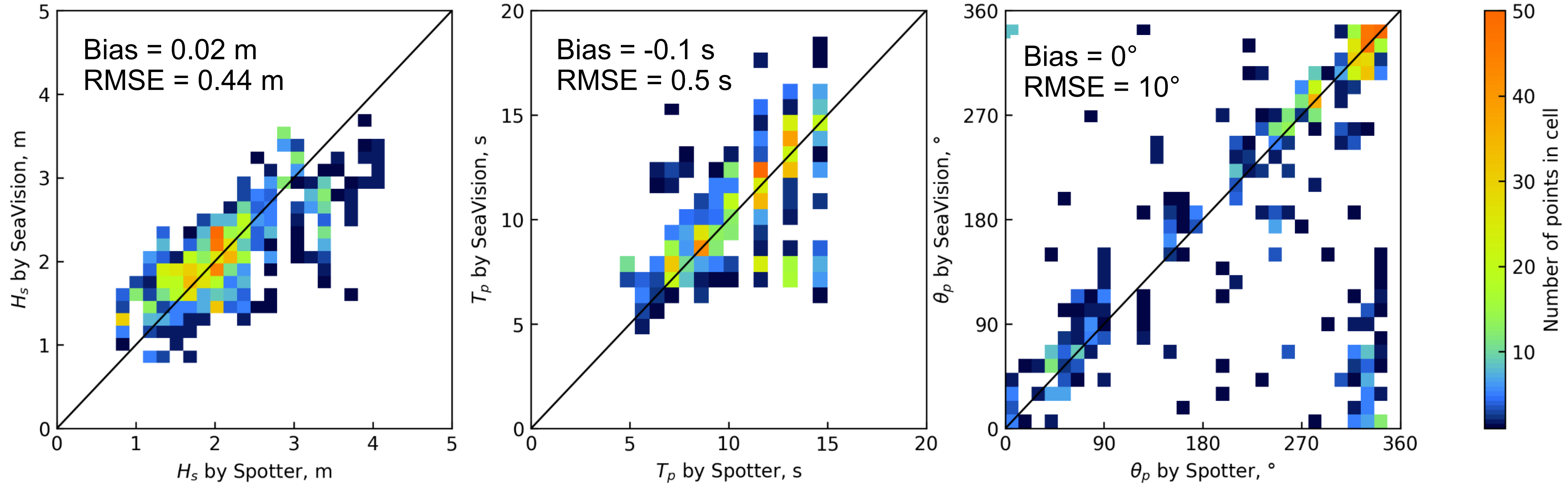


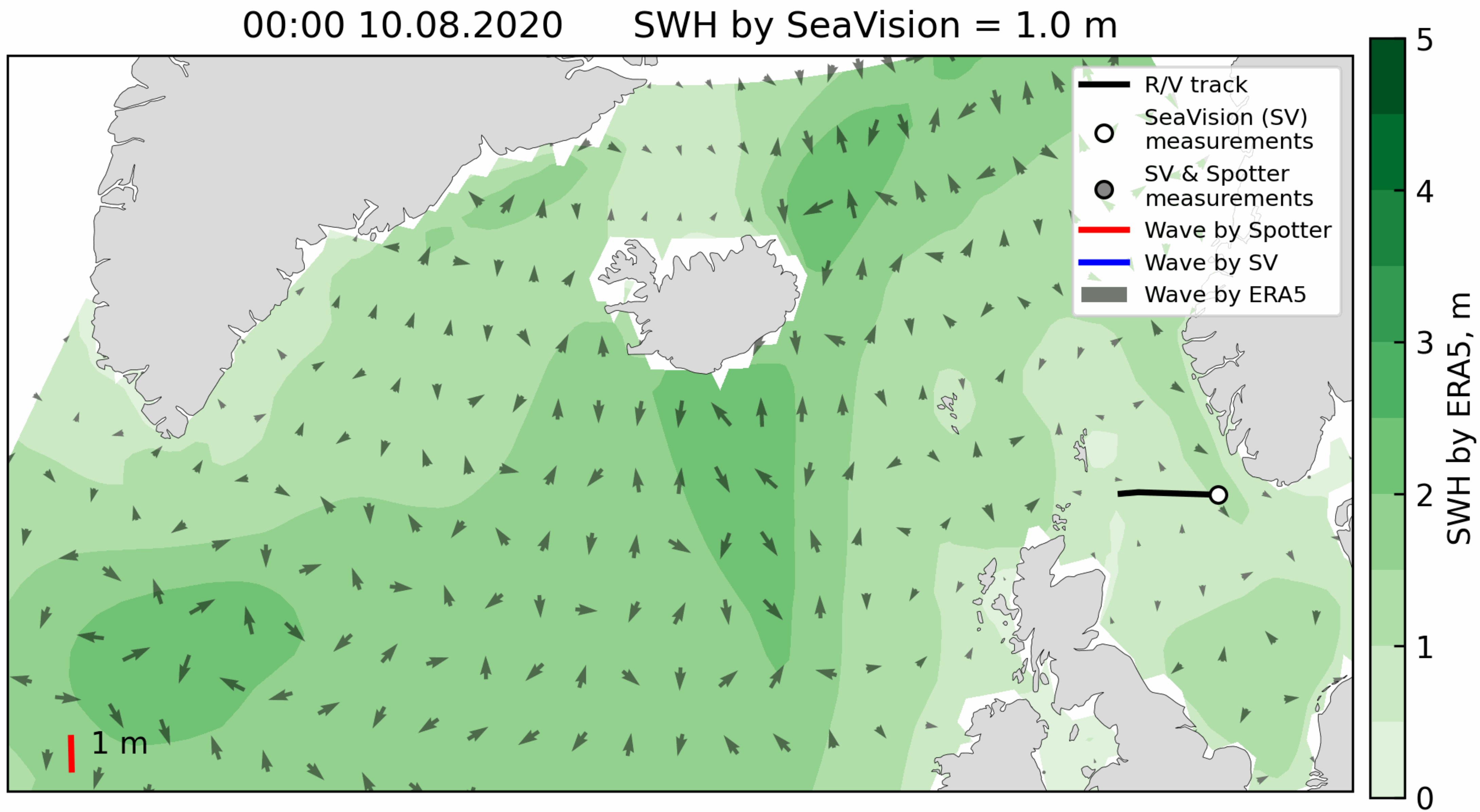


Validation

Simultaneous buoy and radar measurements were conducted at 109 stations, lasting from 30 minutes to 8 hours

These time series were divided into 1174 segments to increase the sample size



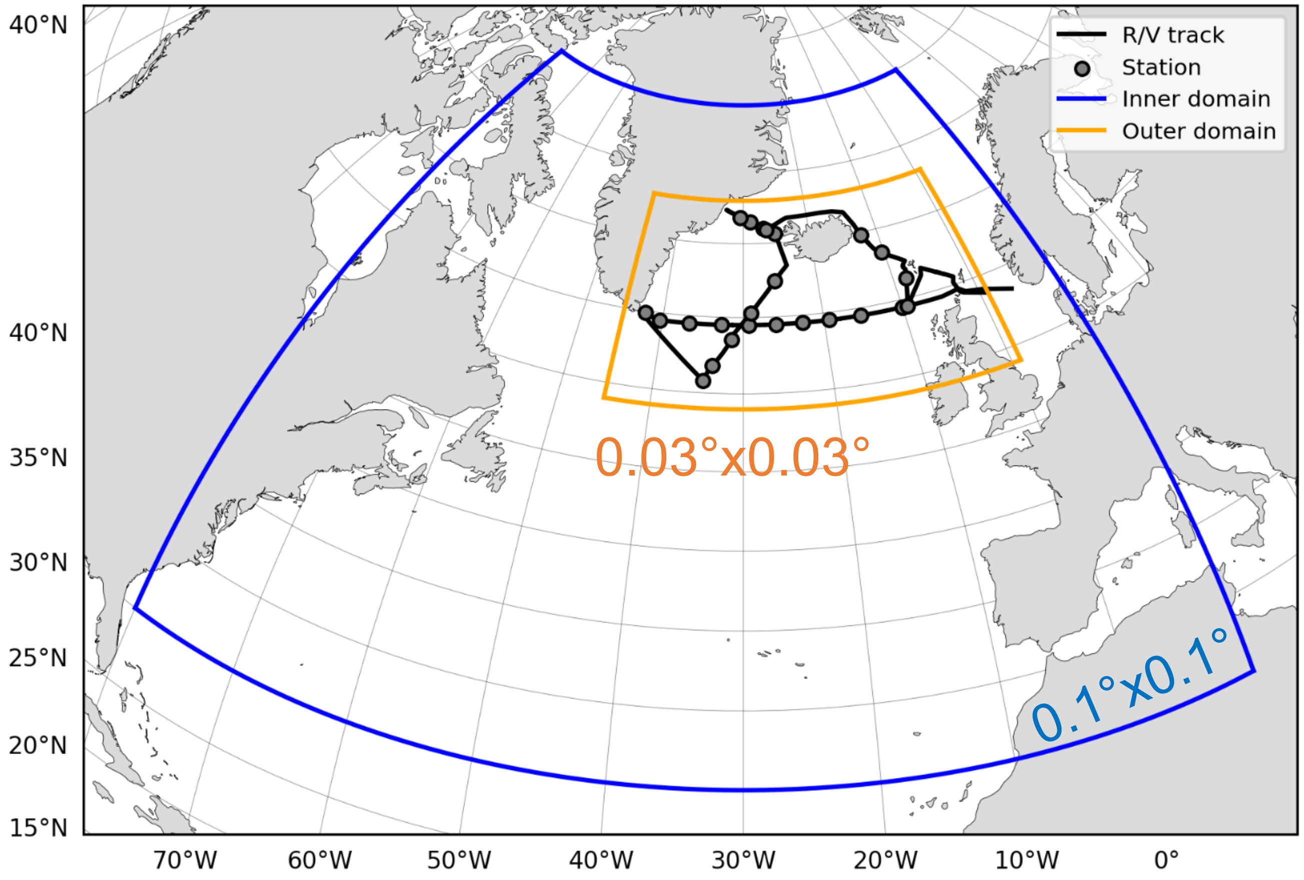


Wave parameters obtained by the route of the North Atlantic expedition in 2020

WW3 modeling

Cruise	ASV50
Region	North Atlantic polygon
Grid type	Regular, nested grid
Outer domain spatial resolution	30°-75°N and 80W-10E 0.1°x0.1°
Inner domain spatial resolution	54°-68°N and 45°W-1°E 0.03°x0.03°
Time coverage	01.08.20 - 06.09.20

ASV50 cruise to the North Atlantic

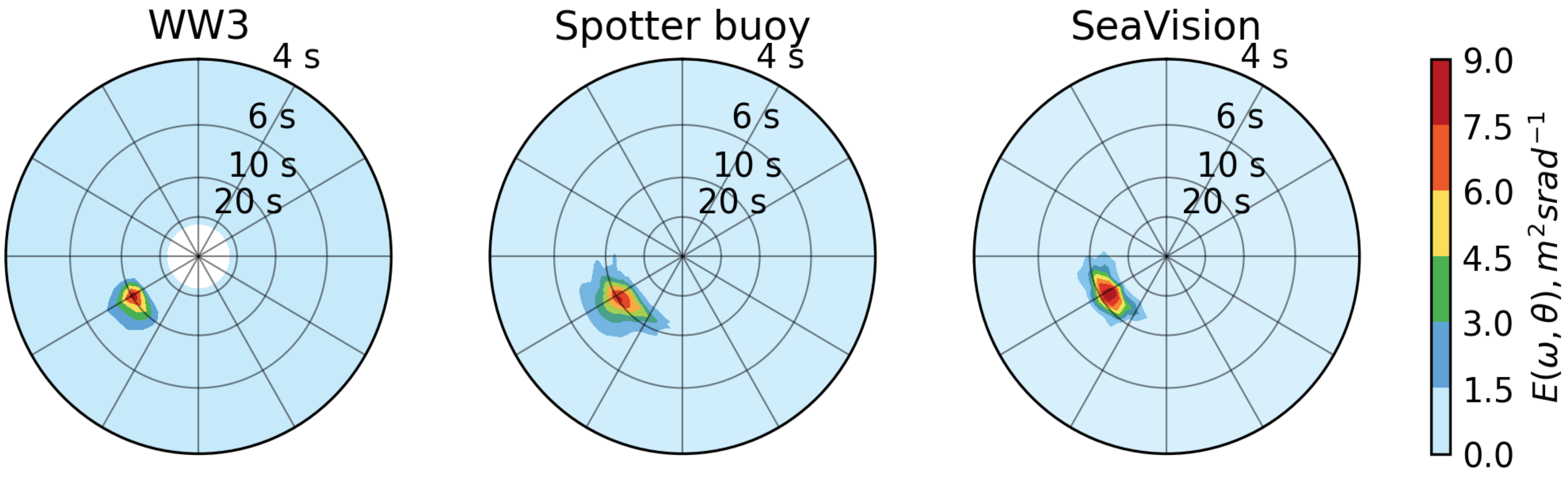


Directional spectra was calculated for every station (1-h time resolution)

Directional spectra

The Extended Wavelet Directional Method* was used to reconstruct the directional spectra from Spotter buoys data

30 Aug 2020 11:00 UTC (Hs ~ 2.1 m)



*Peláez-Zapata, D., V. Pakrashi, and F. Dias, 2024: Ocean Wave Directional Distribution from GPS Buoy Observations off the West Coast of Ireland: Assessment of a Wavelet-Based Method. *J. Atmos. Oceanic Technol.*, **41**, 749–765.

Directional spectra

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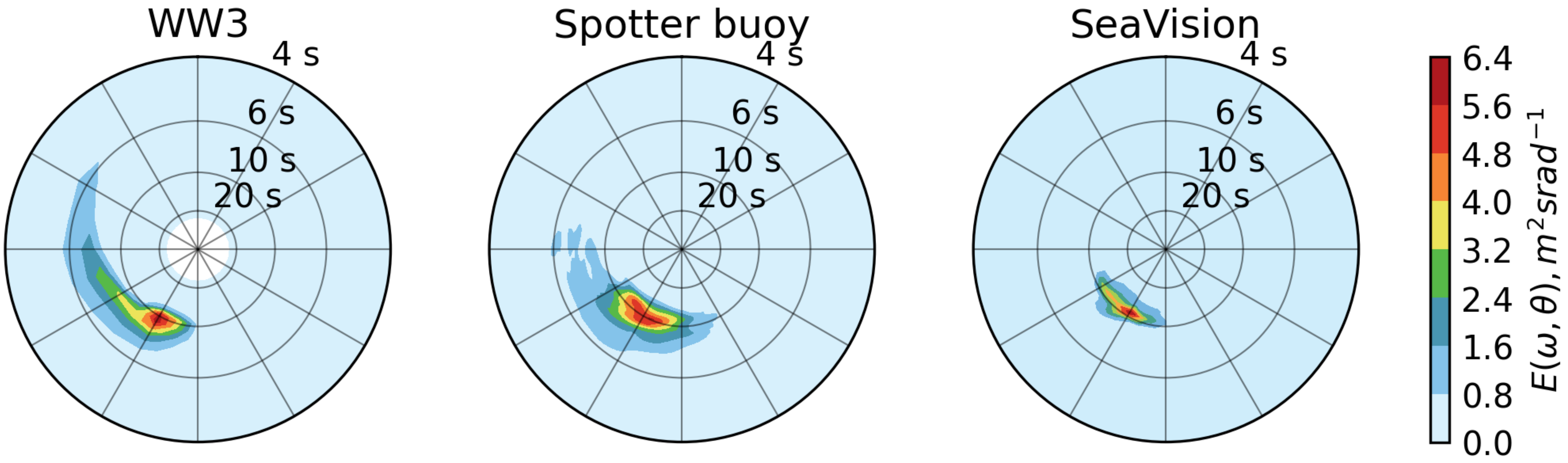
2 Sept 2020 13:00 UTC (Hs ~ 2.7 m)

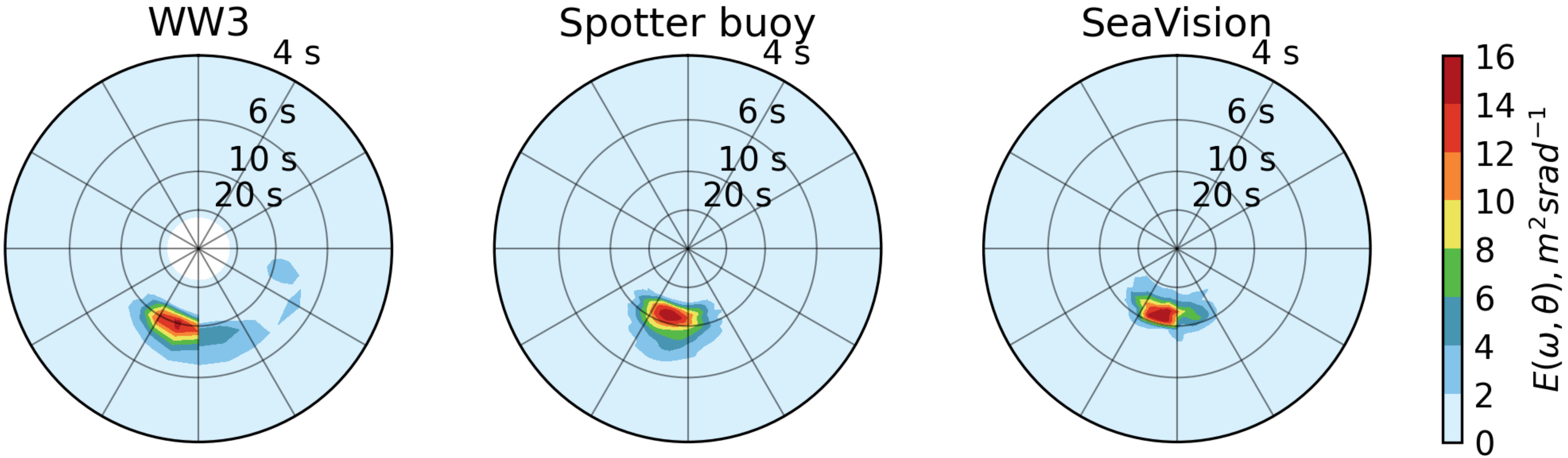


*Peláez-Zapata, D., V. Pakrashi, and F. Dias, 2024: Ocean Wave Directional Distribution from GPS Buoy Observations off the West Coast of Ireland: Assessment of a Wavelet-Based Method. *J. Atmos. Oceanic Technol.*, **41**, 749–765.

Directional spectra

The Extended Wavelet Directional Method* was used to reconstruct the directional spectra from Spotter buoys data

5 Sept 2020 00:00 UTC (Hs ~ 4.4 m)



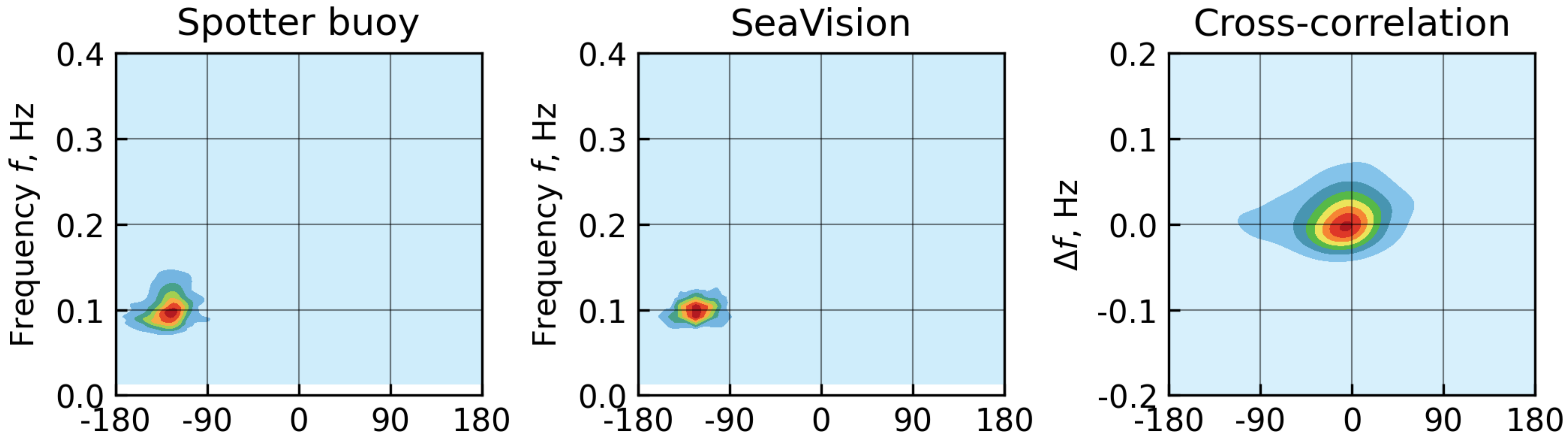
*Peláez-Zapata, D., V. Pakrashi, and F. Dias, 2024: Ocean Wave Directional Distribution from GPS Buoy Observations off the West Coast of Ireland: Assessment of a Wavelet-Based Method. *J. Atmos. Oceanic Technol.*, **41**, 749–765.

Cross-correlation

Cross-correlation for normalized $E_1(\omega, \theta)$ and $E_2(\omega, \theta)$:

$$C(m,n) = \sum_i \sum_j E_1(i,j) \cdot E_2(i-m, j-n)$$

Good agreement



Cross-correlation

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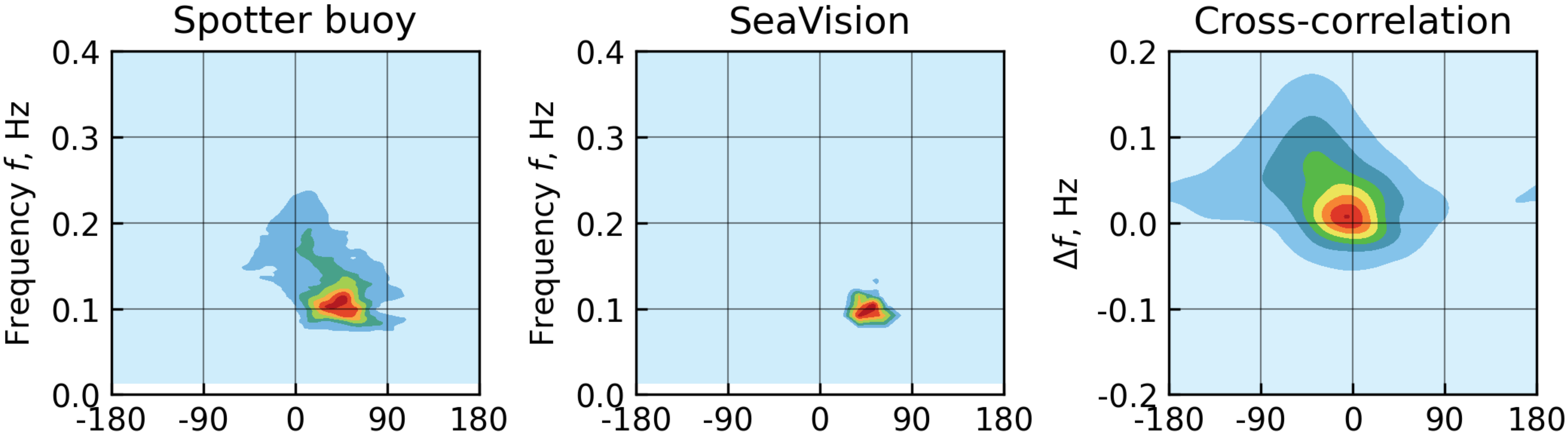
High-frequency part is not reproduced



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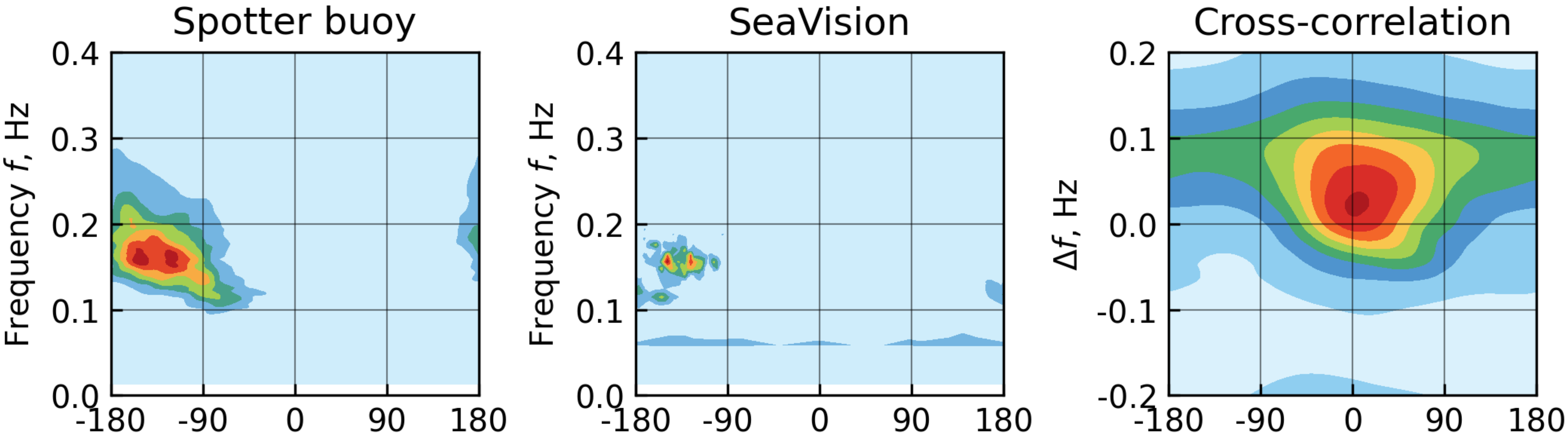
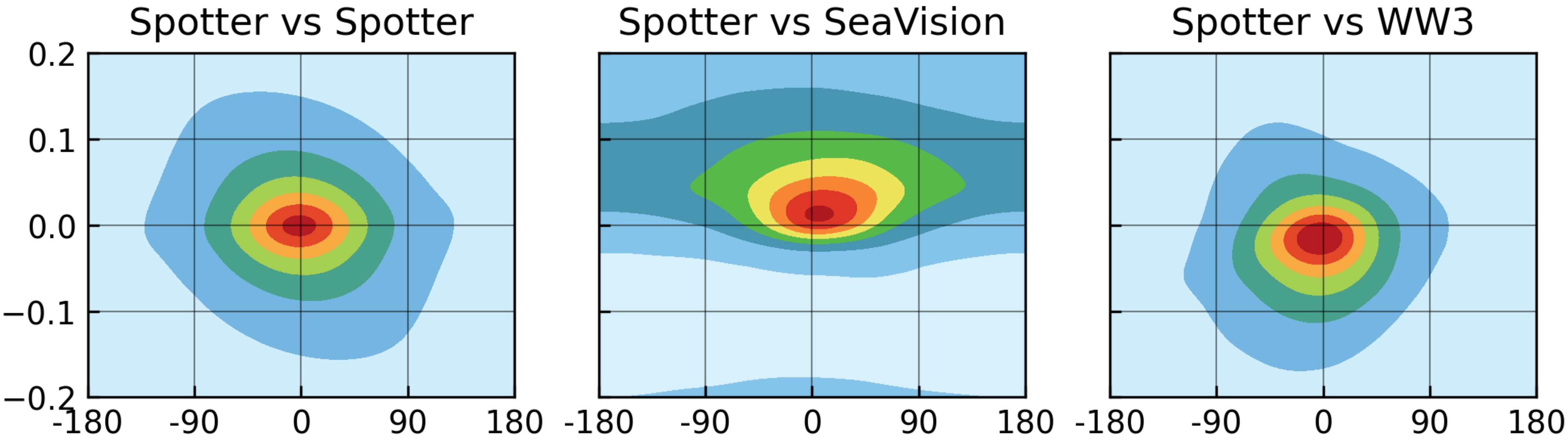
Radar spectrum narrower than buoy



Cross-correlation sum

A cross-correlation was calculated for all station and averaged after that



Auto correlation (average shape)

SeaVision give more narrow spectra

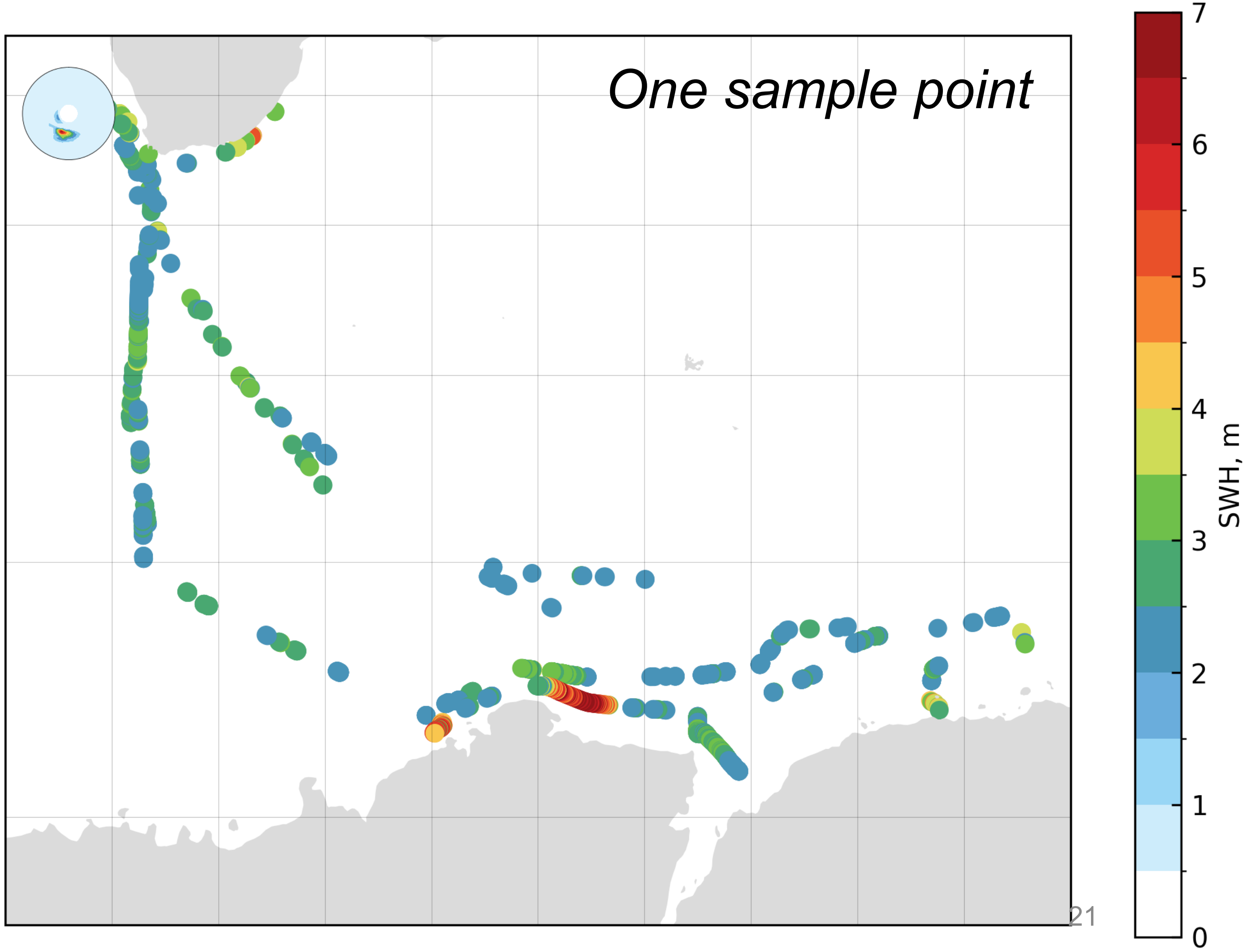
WW3 slightly overestimates the frequency

On-the-way measurements

AF50 was 4-month expedition in the Southern ocean

We did on-the-way short under-satellite measurements and long during storms and in marginal zone

We can update spectrum in near real-time mode



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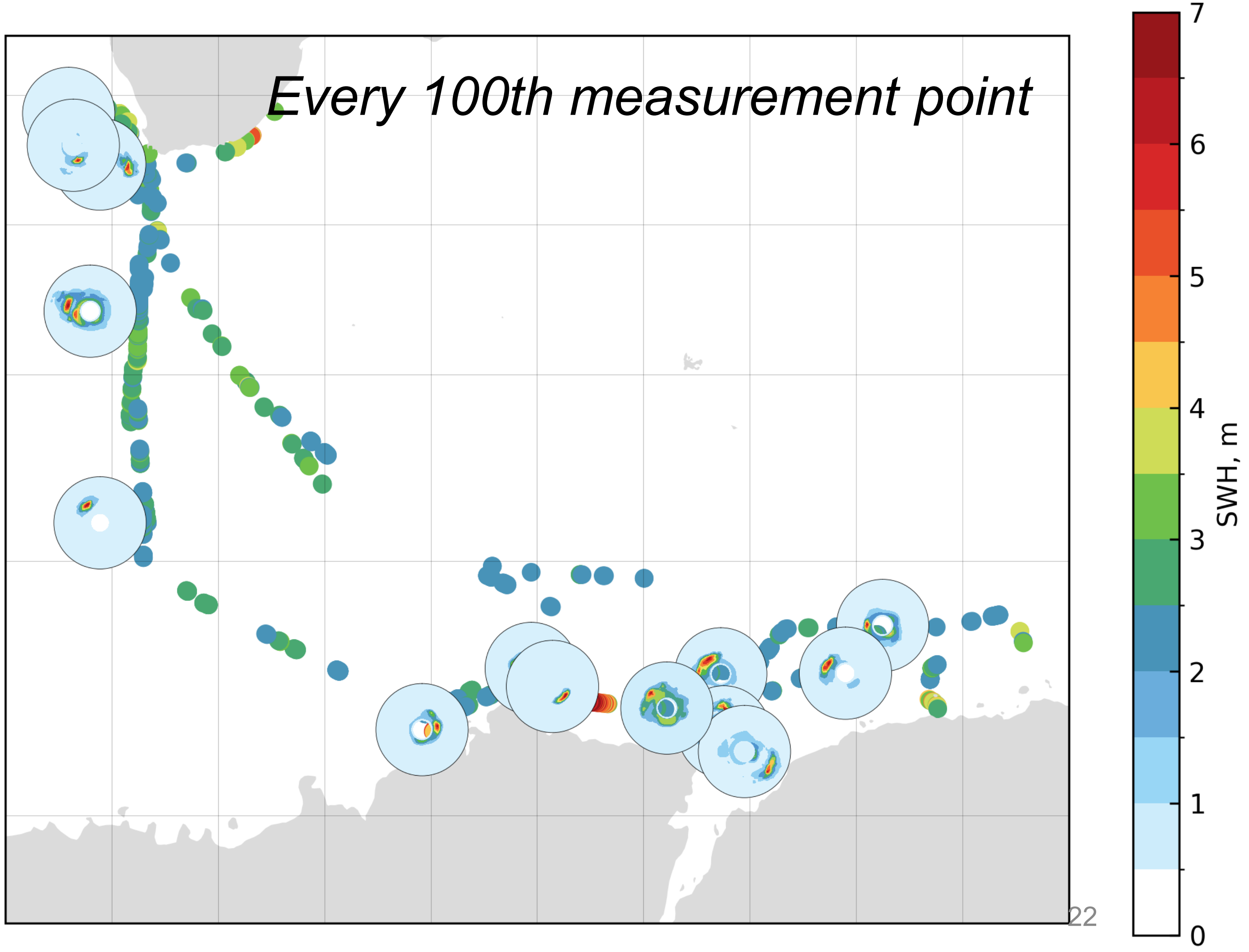

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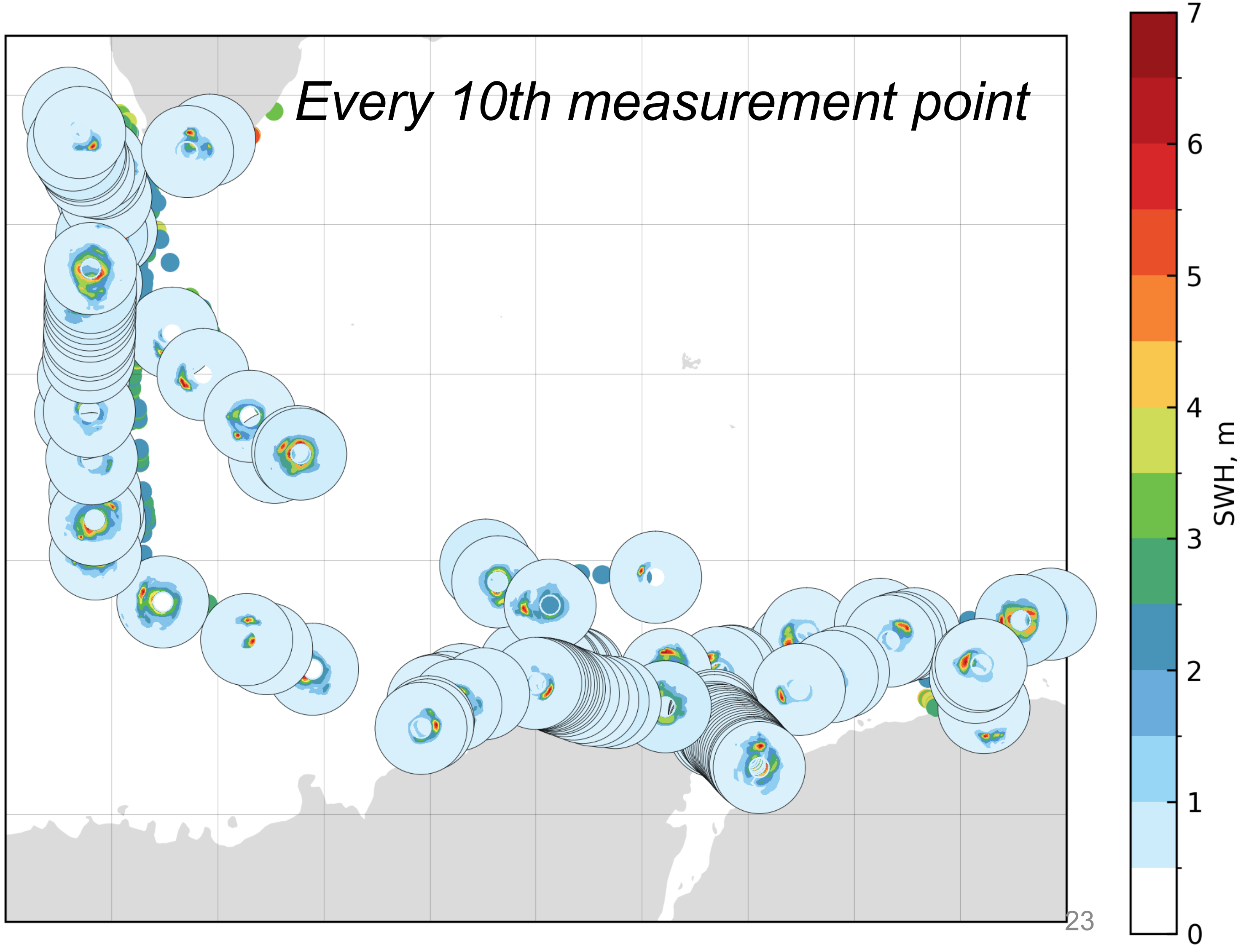

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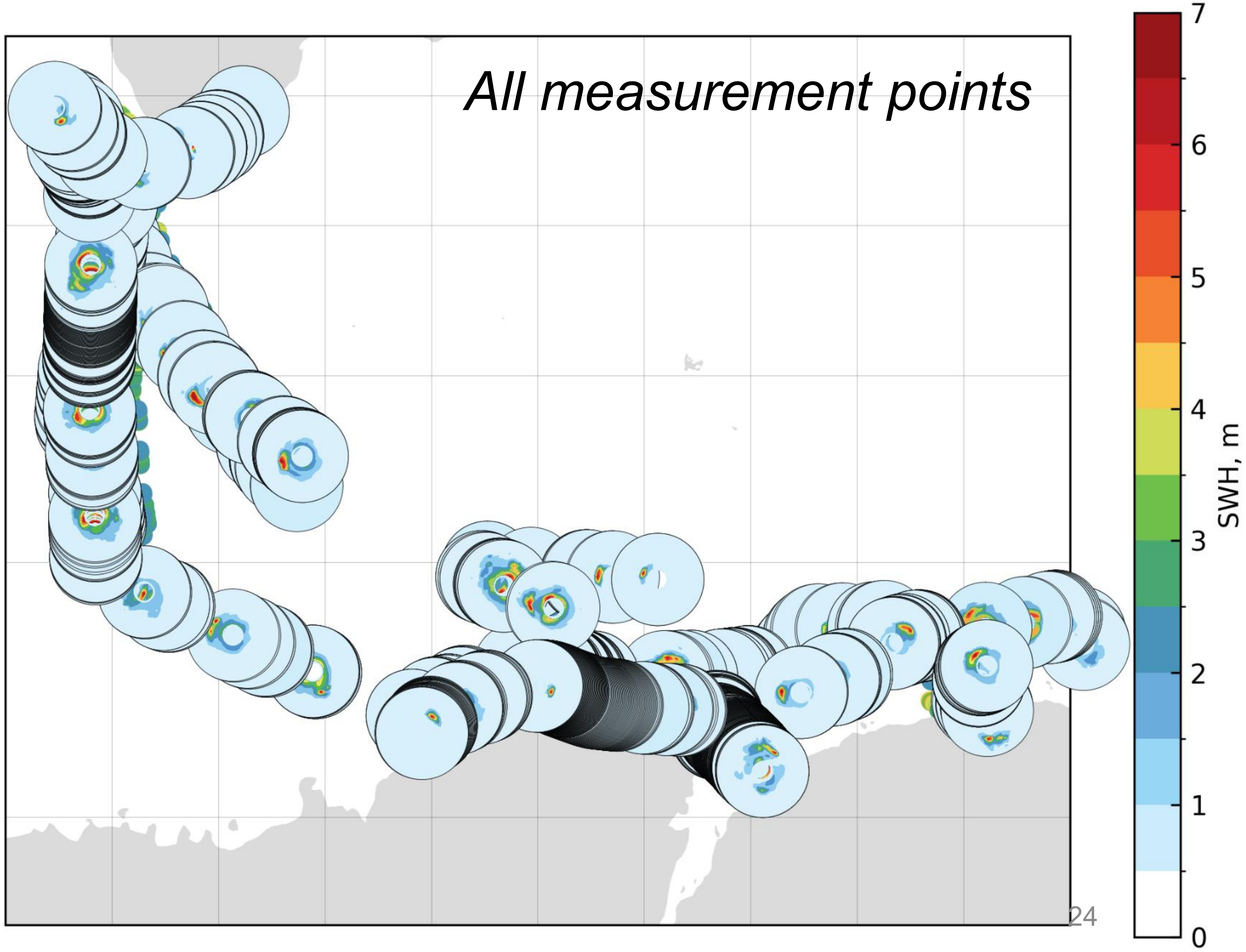
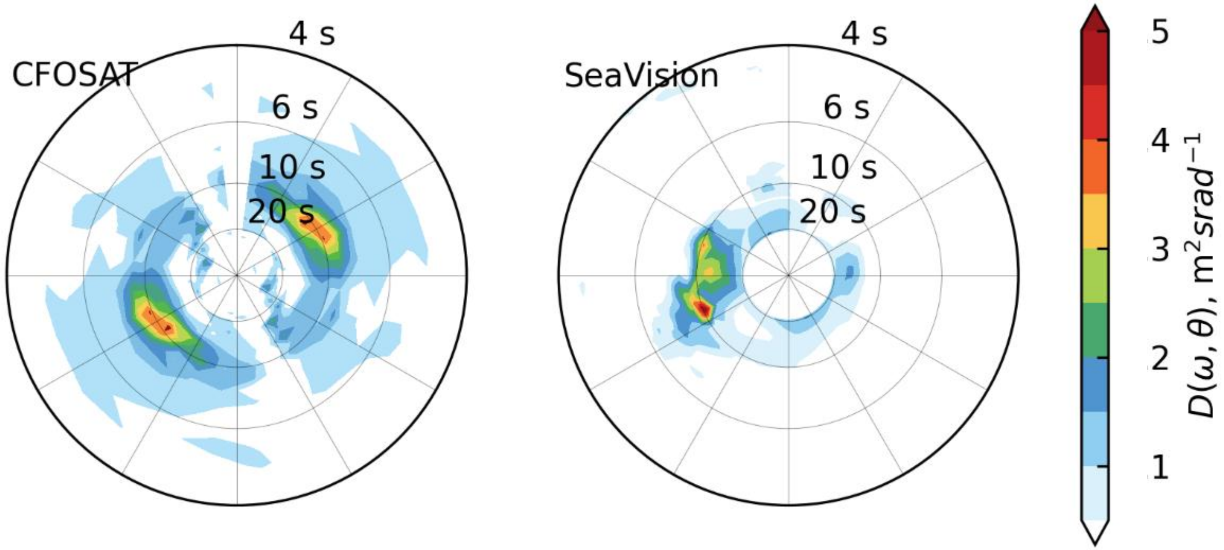
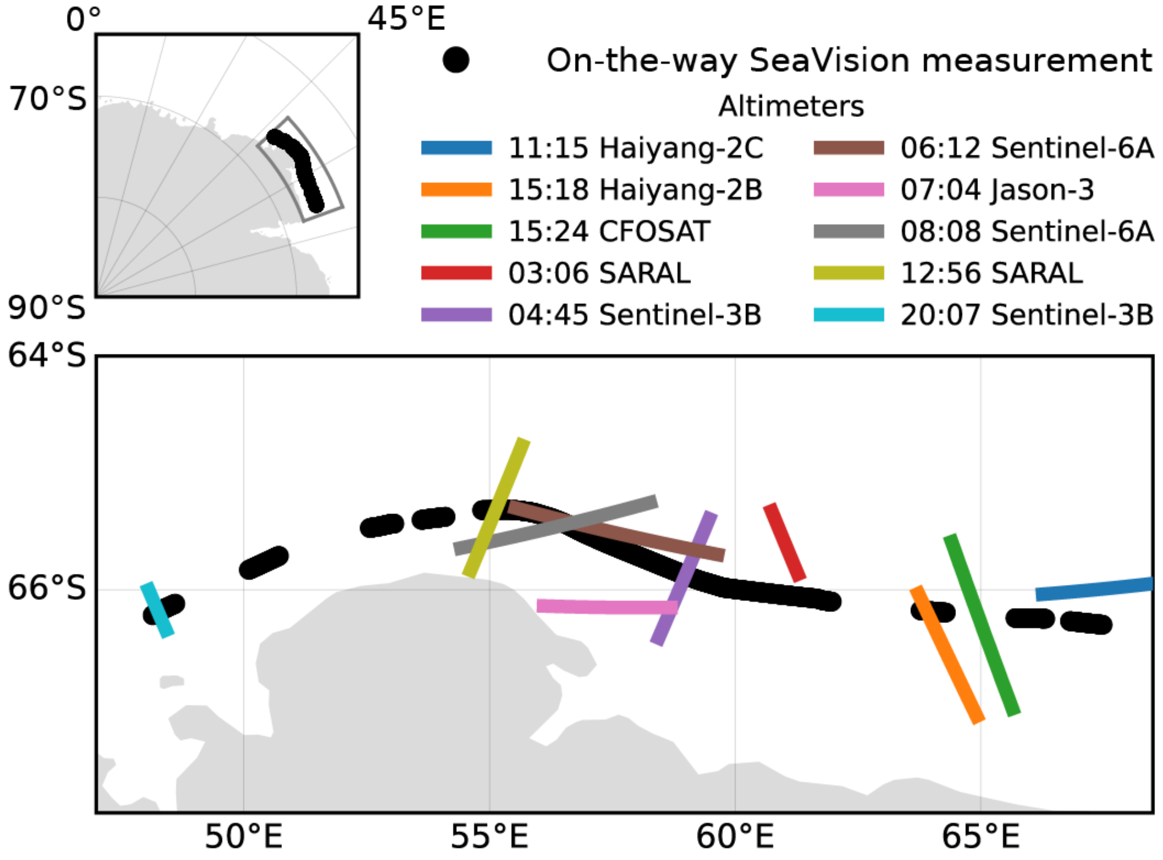


CFOSAT data

For many collocation points with satellites only few points was with CFOSAT, which also provided directional spectra



Reconstructed spectra 7 Mar 2024 UTC 15:24



On-the way SeaVision measurements 7-8 March 2024 near Antarctica

Conclusions

- Shipborne radar successfully retrieves directional spectra in both drift and underway modes
- Good agreement with buoys, models, and satellite data
- Cross-correlation confirms consistency in spectral shape and direction, but
- SeaVision tends to obtain narrower spectra than buoy and model

Future work

- Tune the modulating transfer function (MTF)
- Test sensitivity of algorithm for MTF, dispersion shell width, other parameters

Our “fleet”

Actual and planned for the end of 2025

The work was founded by RSF 23-77-30001

Thank you for your attention!