Validation of Marine Radar's Multi-Directional Wave Retrieval Capabilities

[1]Björn Lund, [1]Hans C. Graber, [2]Hitoshi Tamura, and [3]Clarence O. Collins III

[1]Rosenstiel School of Marine and Atmospheric Science, University of Miami

[2]Naval Research Laboratory, Stennis Space Center

[3]Yokohama Institute for Earth Sciences, Japan Agency for Marine-Earth Science and Technology

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Outline

- Motivation / Demonstrate Marine Radar Wave Retrieval's Strengths (and Acknowledge Weaknesses)
- Data Overview / ITOP Field Experiment
- Methodology / Advanced Shipboard Marine Radar Wave Retrieval
- Results / Multi-Directional Radar Wave Measurements and WW3 Model Validation

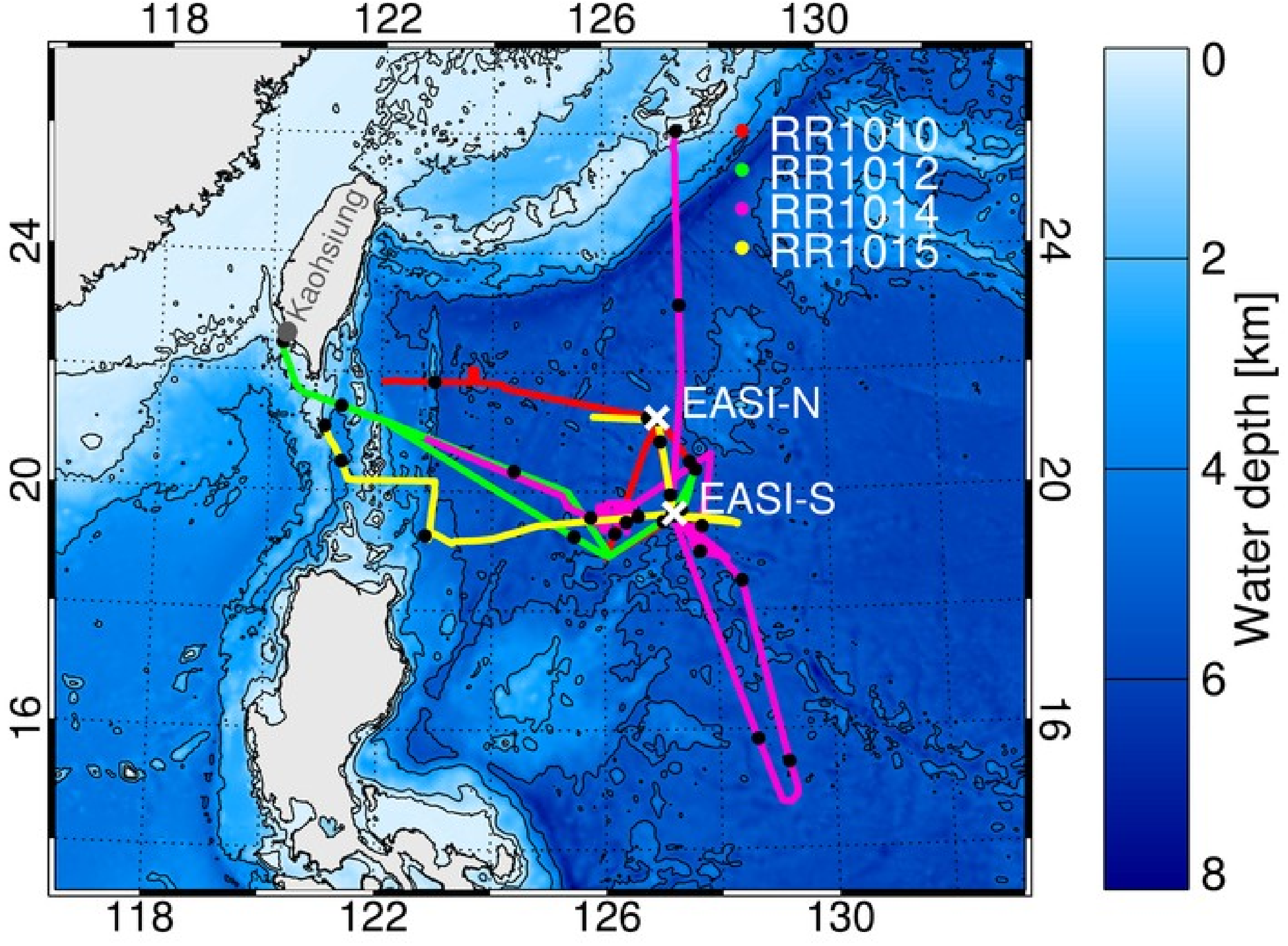
Motivation

- Marine X-band radar (MR) wave spectra based on spatio-temporal backscatter measurements
- Technique's advantages over traditional buoy point measurements:
  - MR spectra resolve multi-directional seas directly without use of a model function (e.g. MLM)
  - Measurement periods of 1-2 min allow sea state changes on short temporal scales
- Disadvantages: Wave energy estimate requires calibration and “modulation transfer function”
- Goal of this study: Demonstrate MR's strength in terms of multi-directional wave retrieval

ITOP Experiment

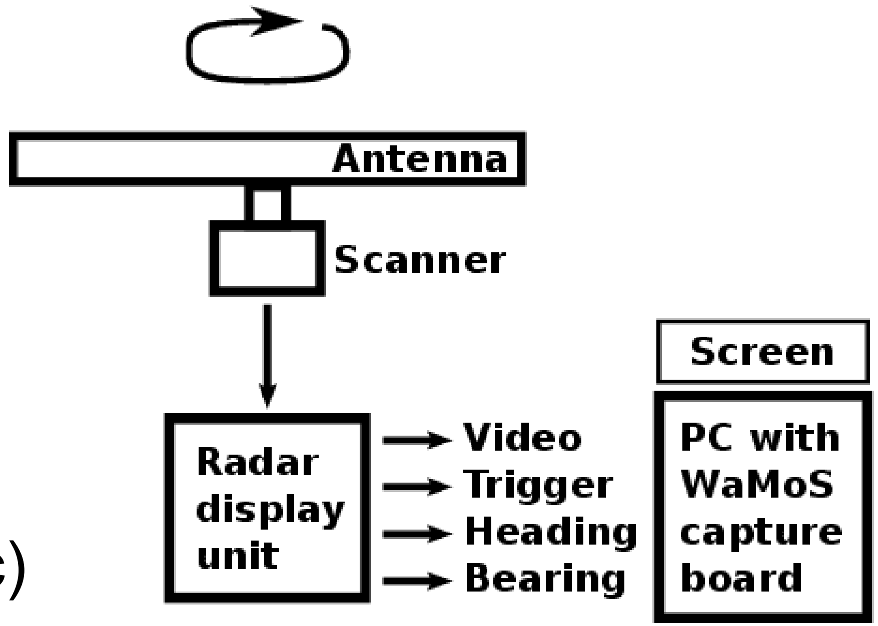
Impact of Typhoons on the Pacific (ITOP), western Pacific, 2010.

R/V Roger Revelle cruise tracks and EASI–ASIS wave buoy locations:



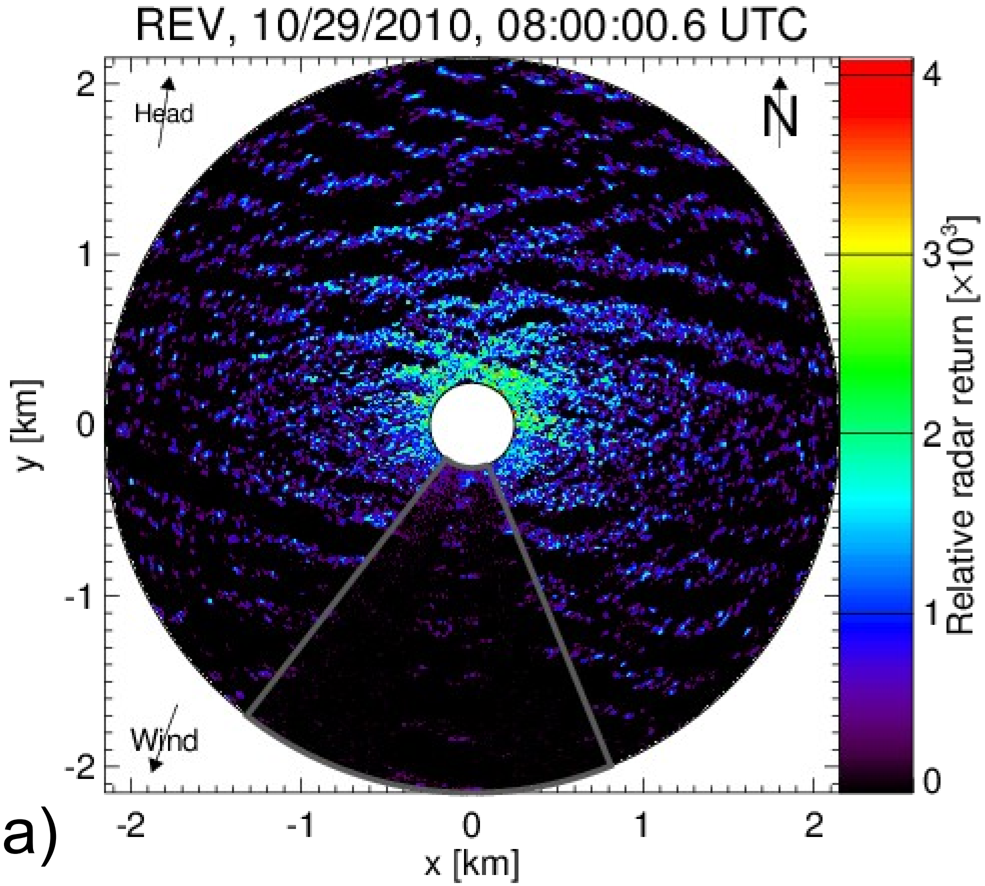
ITOP Experiment

(a) MR image example,
(b) R/V Roger Revelle with EASI–ASIS buoy,
(c) MR hardware diagram:



(c)

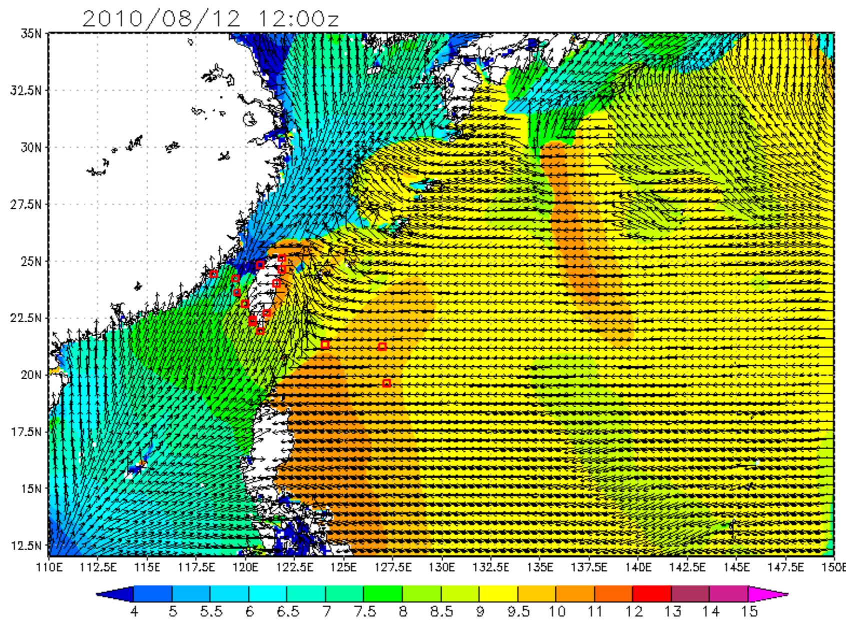
(b)



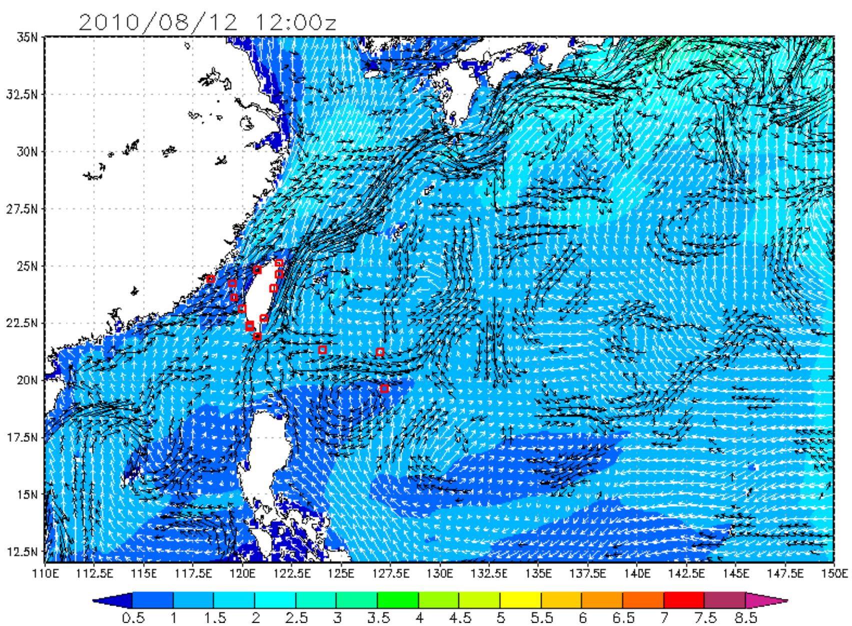
(a)

WW3 and EASI Reference Data

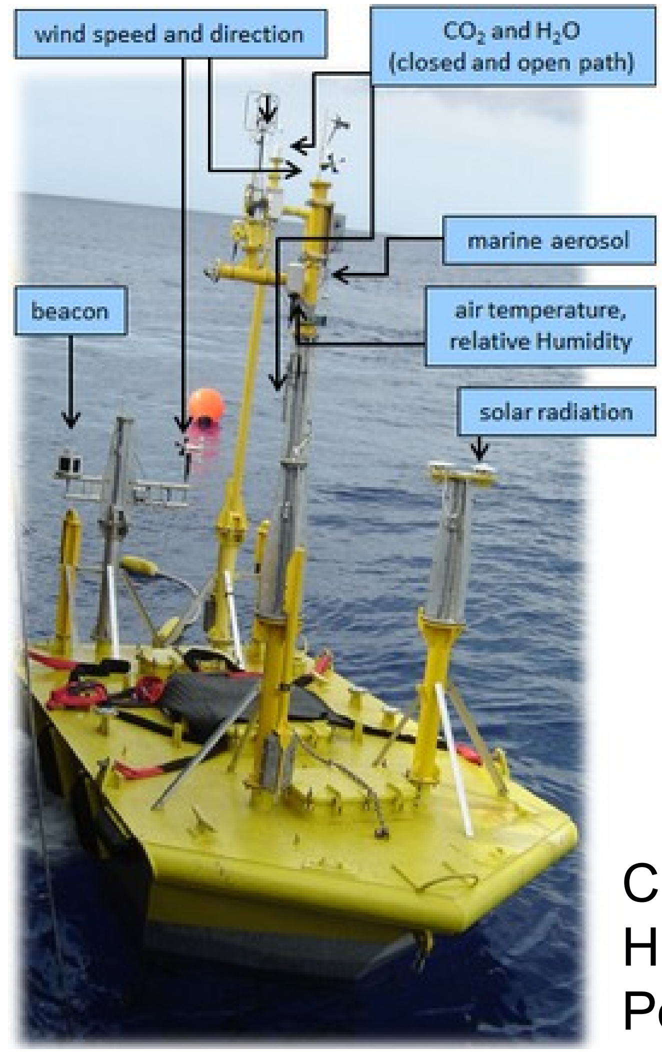
(a) EASI wave buoy, WW3 (b) H_s and (c) T_p for study area:



(c)



(b)



(a)

Credit: Henry Potter

Methodology

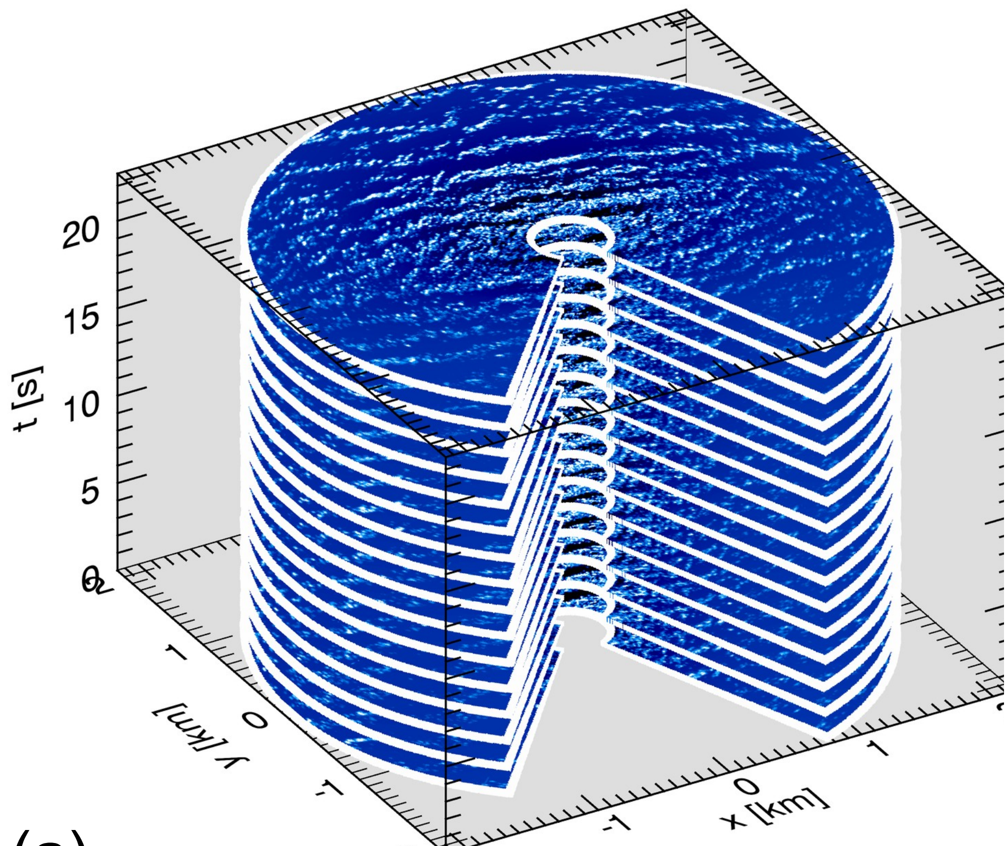
Steps to obtain a 2D wavenumber spectrum:

(1) Radar image sequence → FFT → 3D wavenumber-freq. spectrum

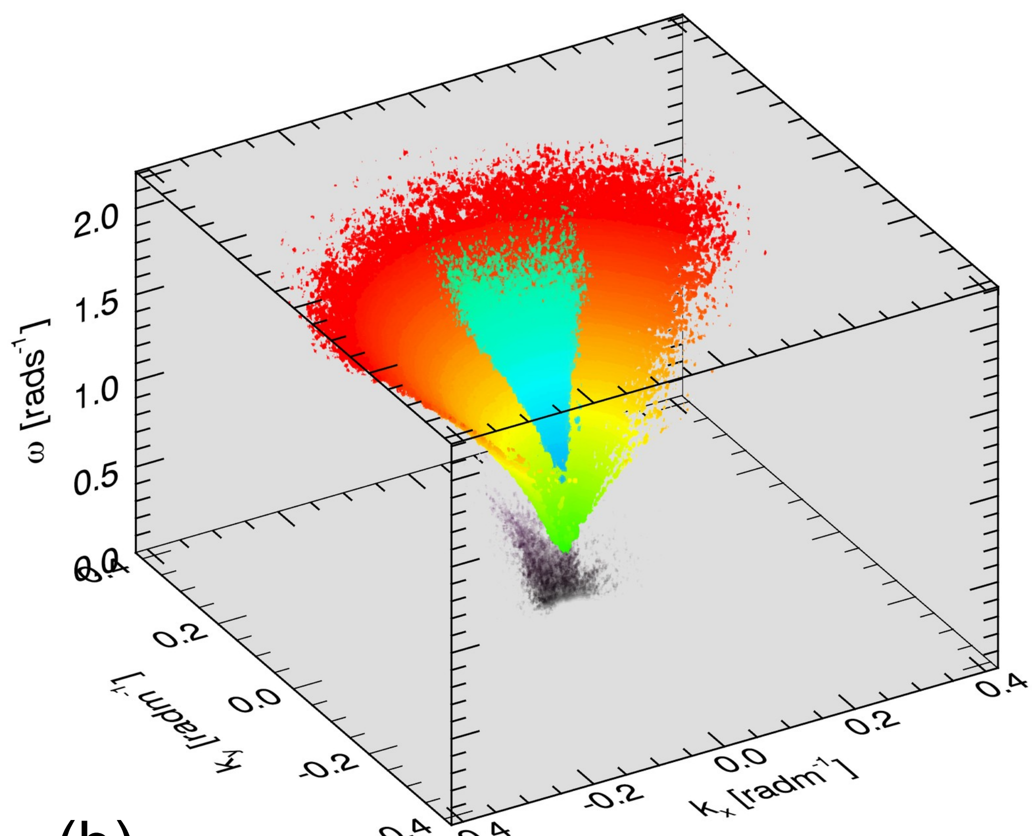
(2) Near-surface current fit (Young et al. 1985, Senet et al. 2001)

(3) Dispersion filtering, freq.-integration, MTF (Nieto-Borge et al. 2004)

Marine radar image sequence (a) and corresponding 3D spectrum (b):



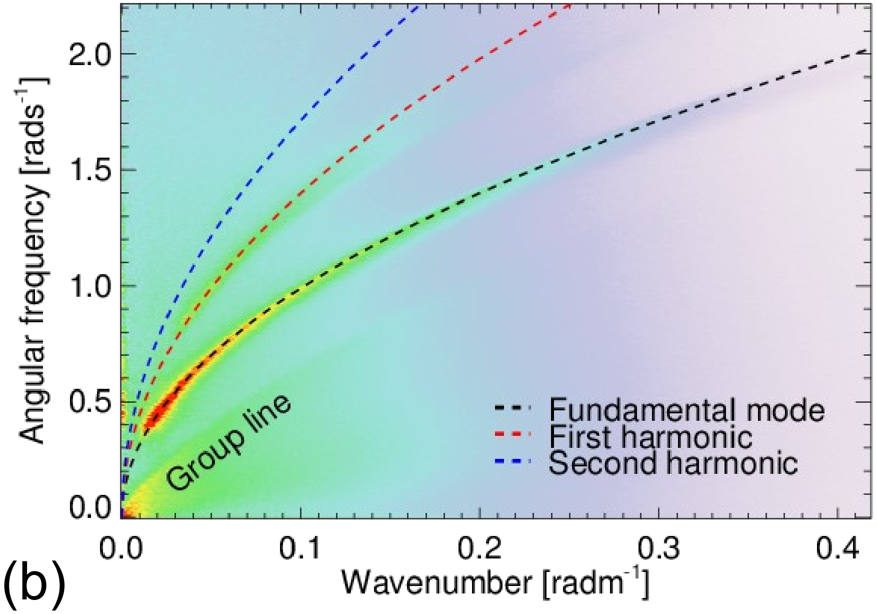
(a)



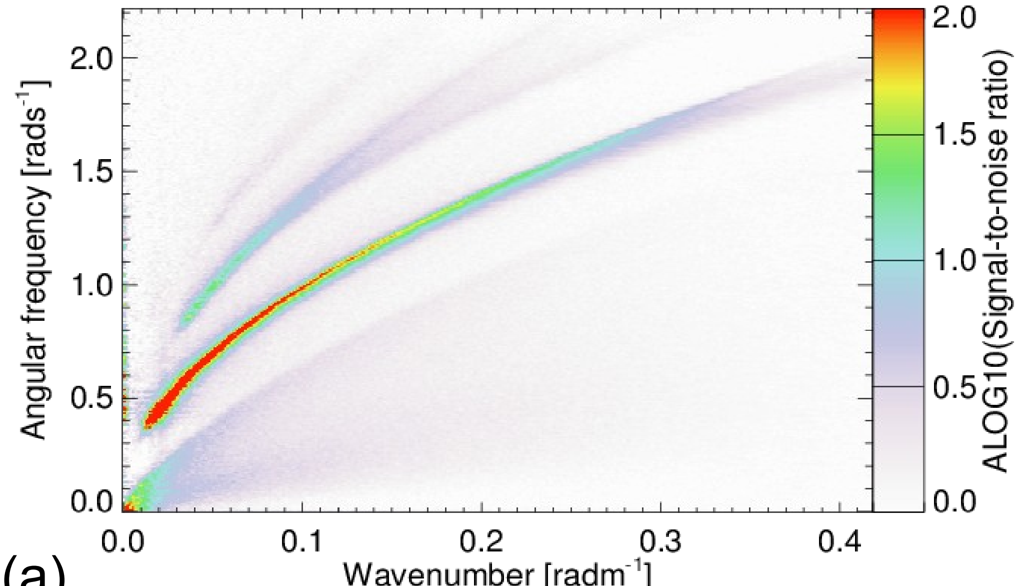
(b)

Advancements

(1) Analysis over whole radar field of view → Eliminates results' dependency on azimuth (Lund et al. 2014)
(2) Near-surface current “calibration” for shipborne data (Lund et al. 2015)
(3) Use of signal-to-noise ratio (a) versus power (b) → Clear distinction of wave signal from background noise
(4) Wavenumber-dependent current fit (Lund et al. 2015, submitted) → Dispersion filter accounting for vertical current shear



(b)

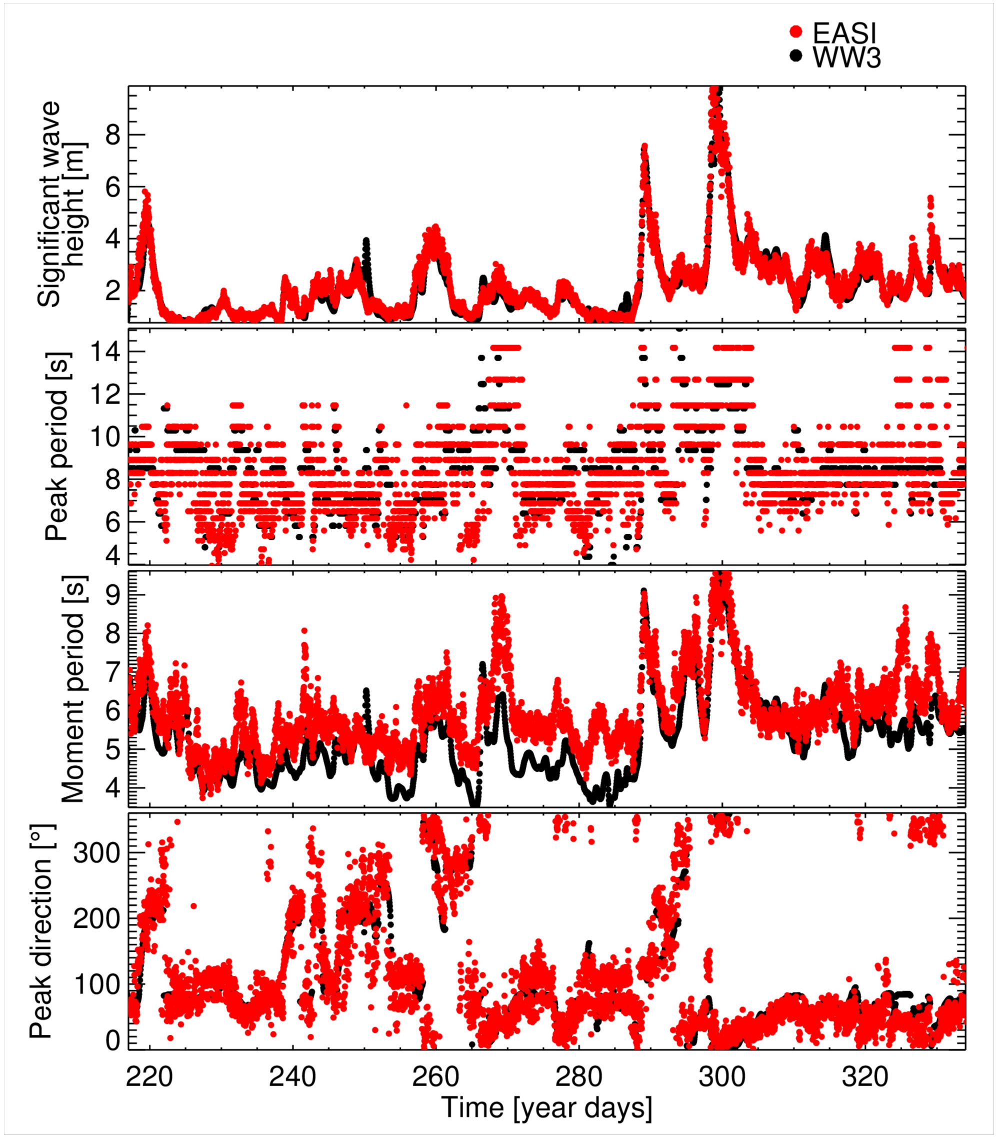


(a)

WW3 Model Validation

Time series and comparison statistics of EASI-N wave measurements and WW3 model results:

	r	Bias	RMS	σxy
Hs [m]	0.94	-0.15	0.49	0.46
Tp [s]	0.60	-0.19	1.76	1.75
Tm0 [s]	0.85	-0.73	0.96	0.62
Θp [°]	0.76	-2.67	46.75	46.67

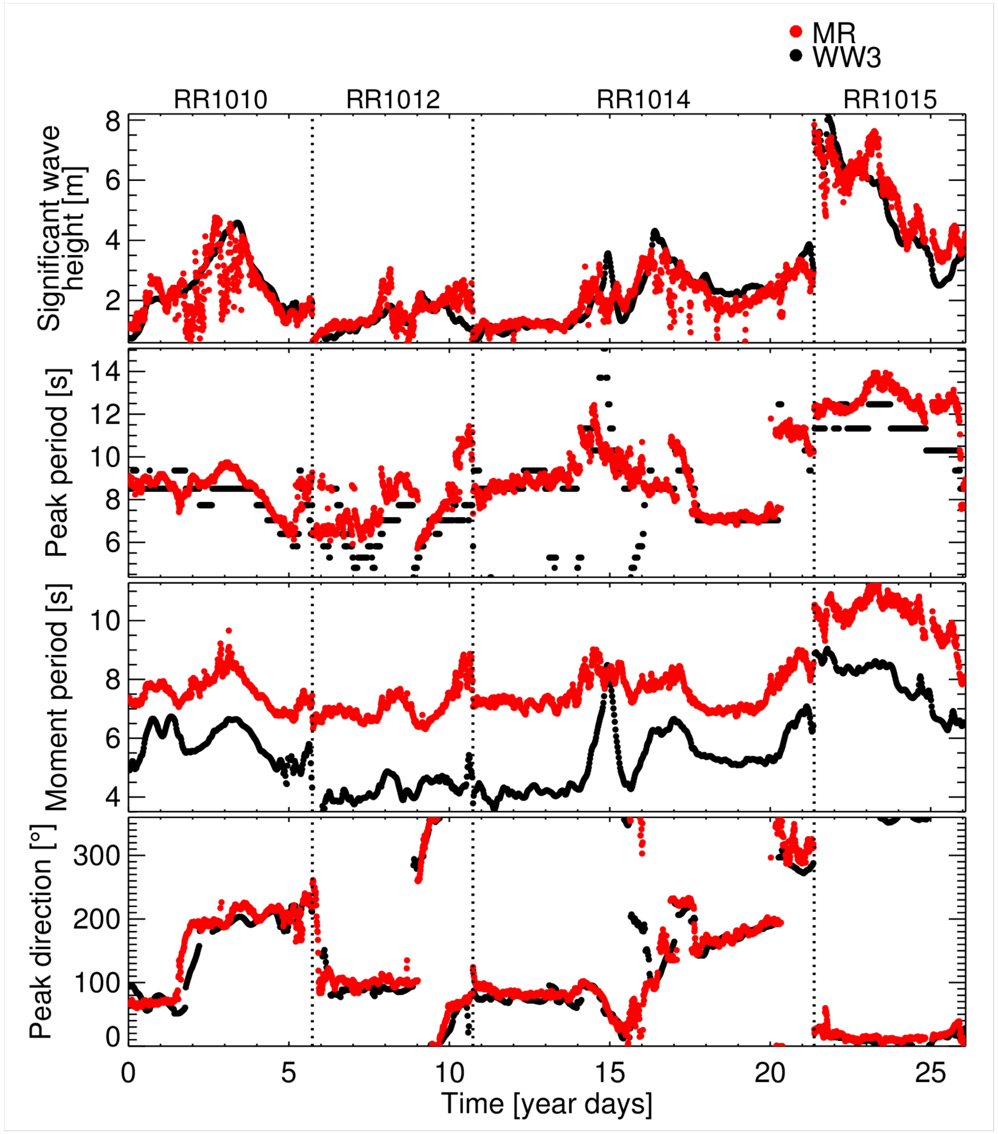


For a validation of EASI wave results, cf. Collins et al. (2014)

MR–WW3 Comparison

Time series and comparison statistics of MR wave measurements and WW3 model results:

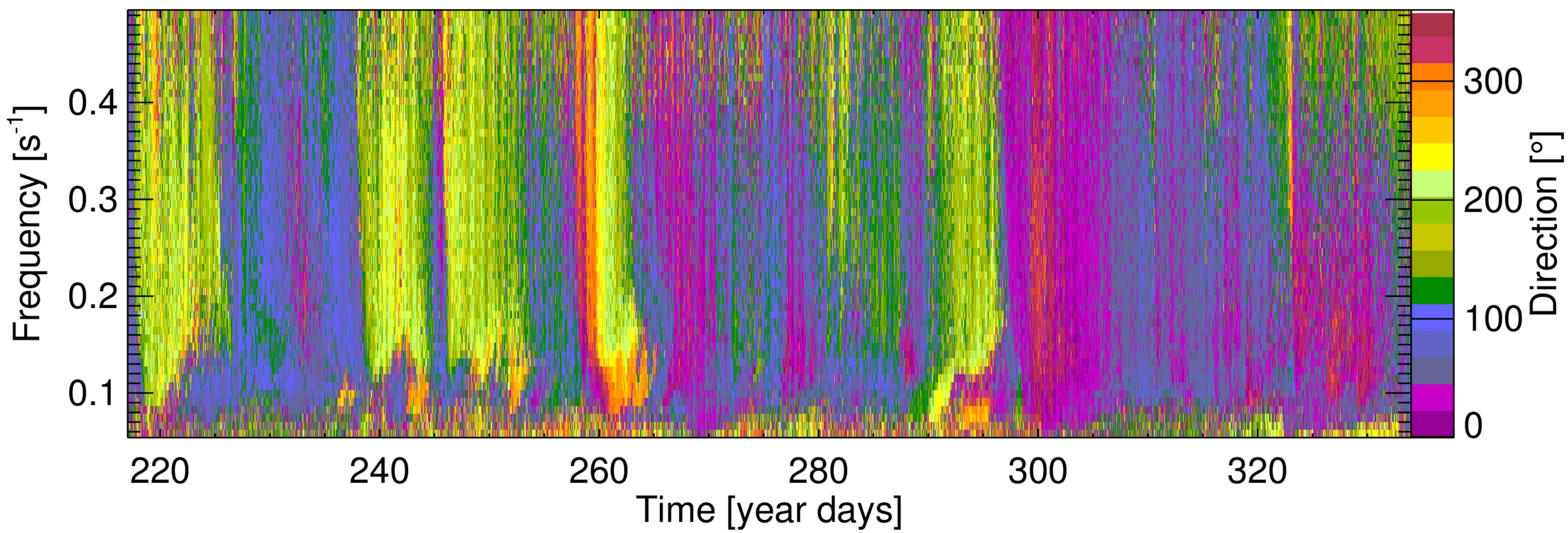
	r	Bias	RMS	σxy
Hs [m]	0.91	0.00	0.65	0.65
Tp [s]	0.80	-0.63	1.40	1.26
Tm0 [s]	0.86	-2.28	2.39	0.71
Θp [°]	0.90	-8.09	31.93	30.89



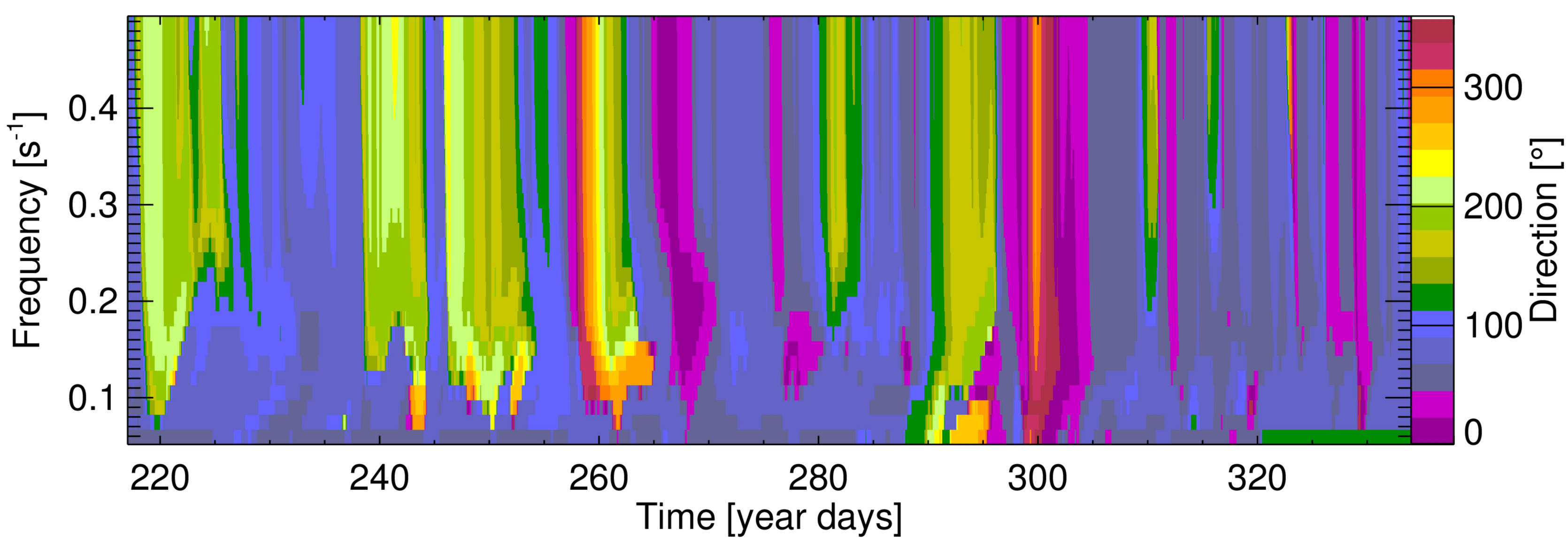
Note: Heavy rain negatively affected MR wave height estimates

EASI vs. WW3 Mean Direction

EASI:

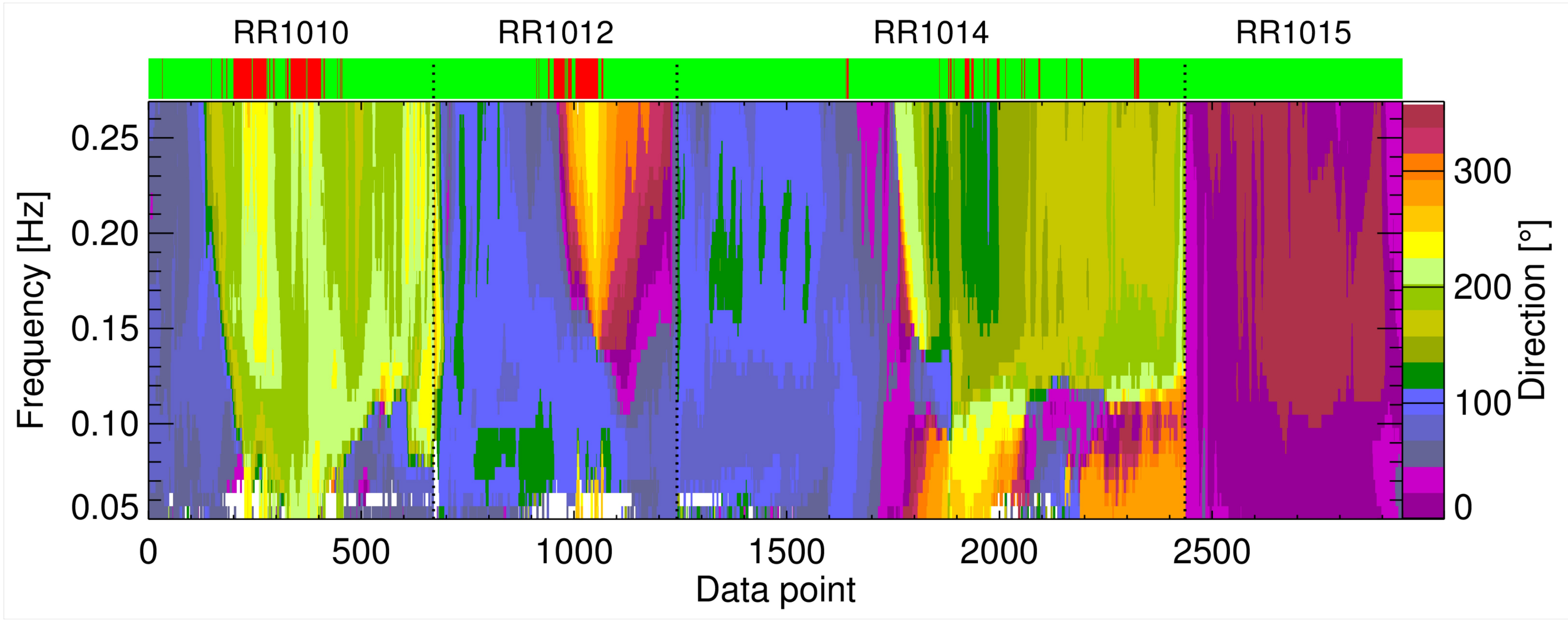


WW3:

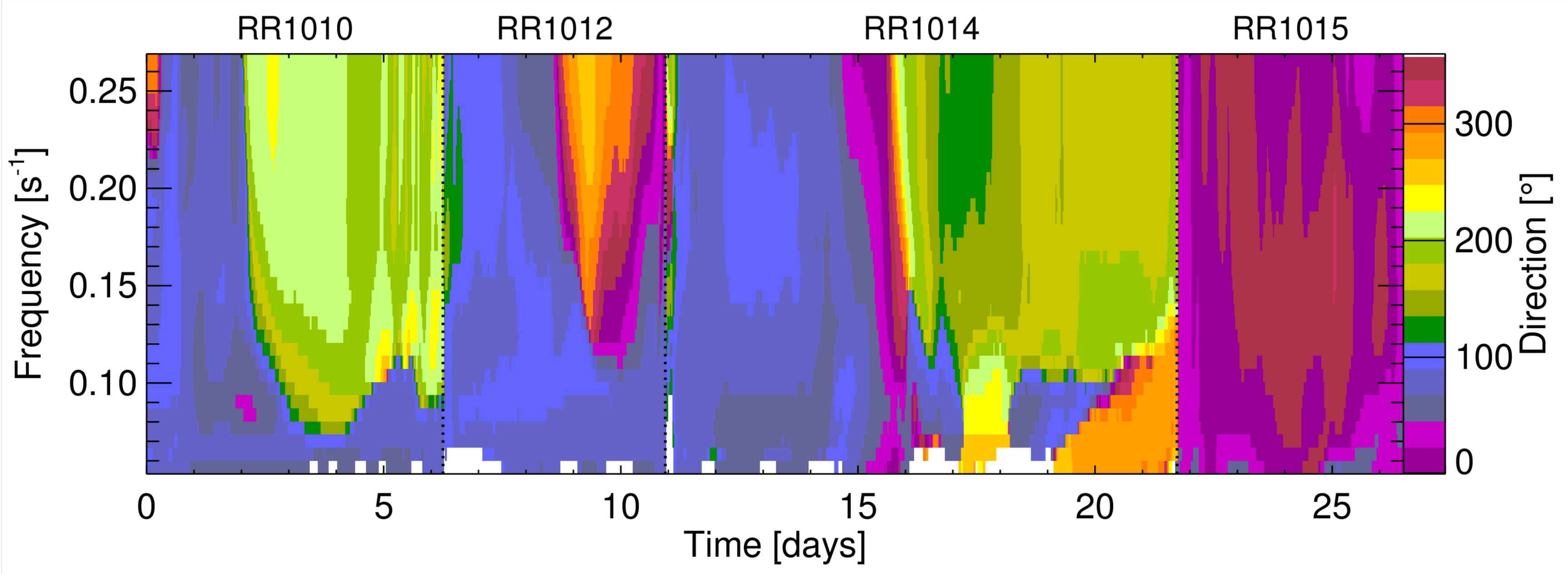


MR vs. WW3 Mean Direction

MR:

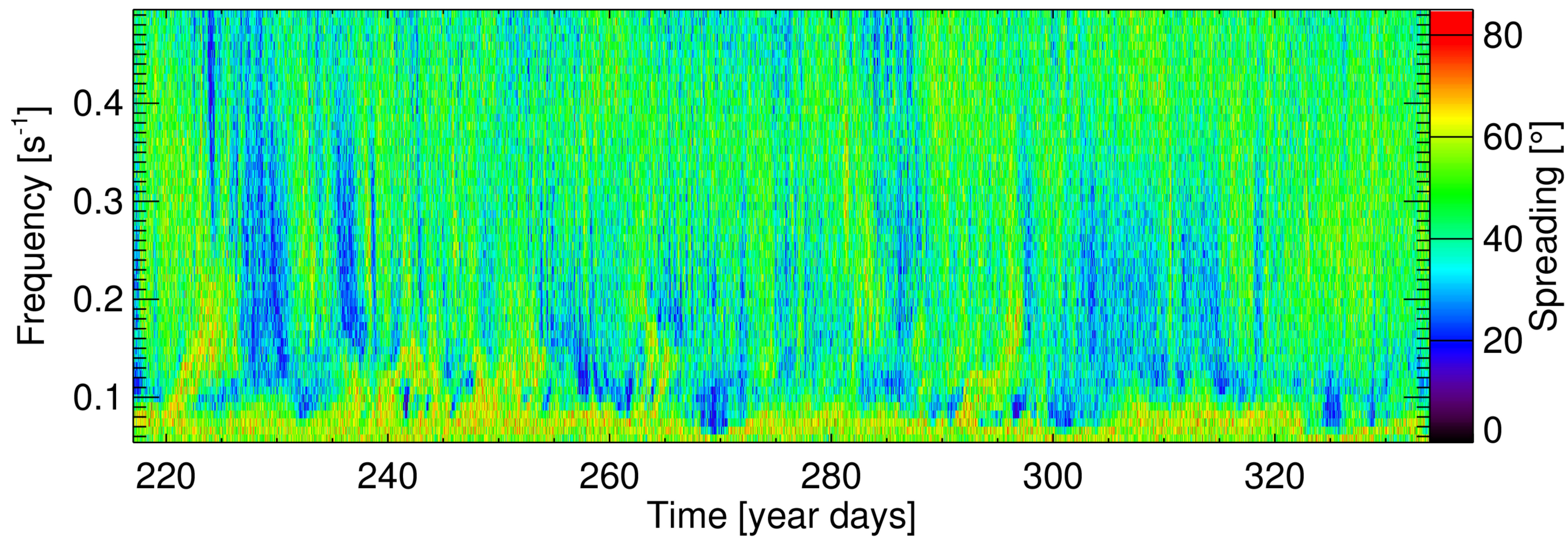


WW3:

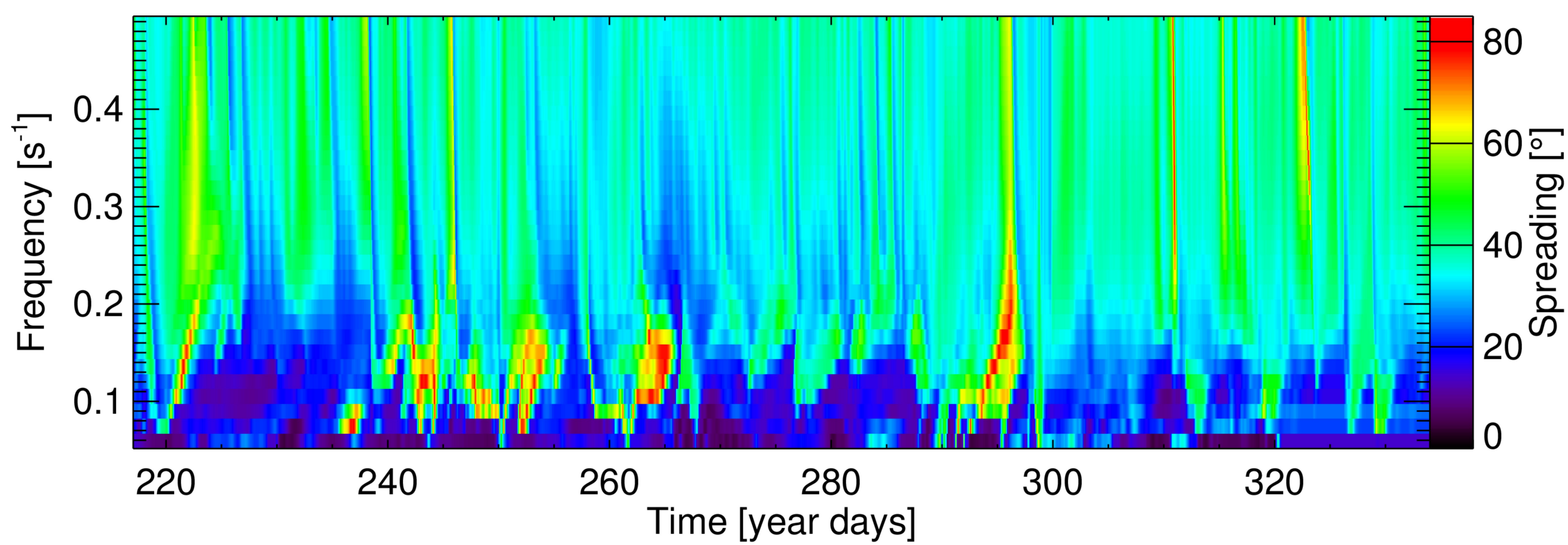


EASI vs. WW3 Spreading

EASI:

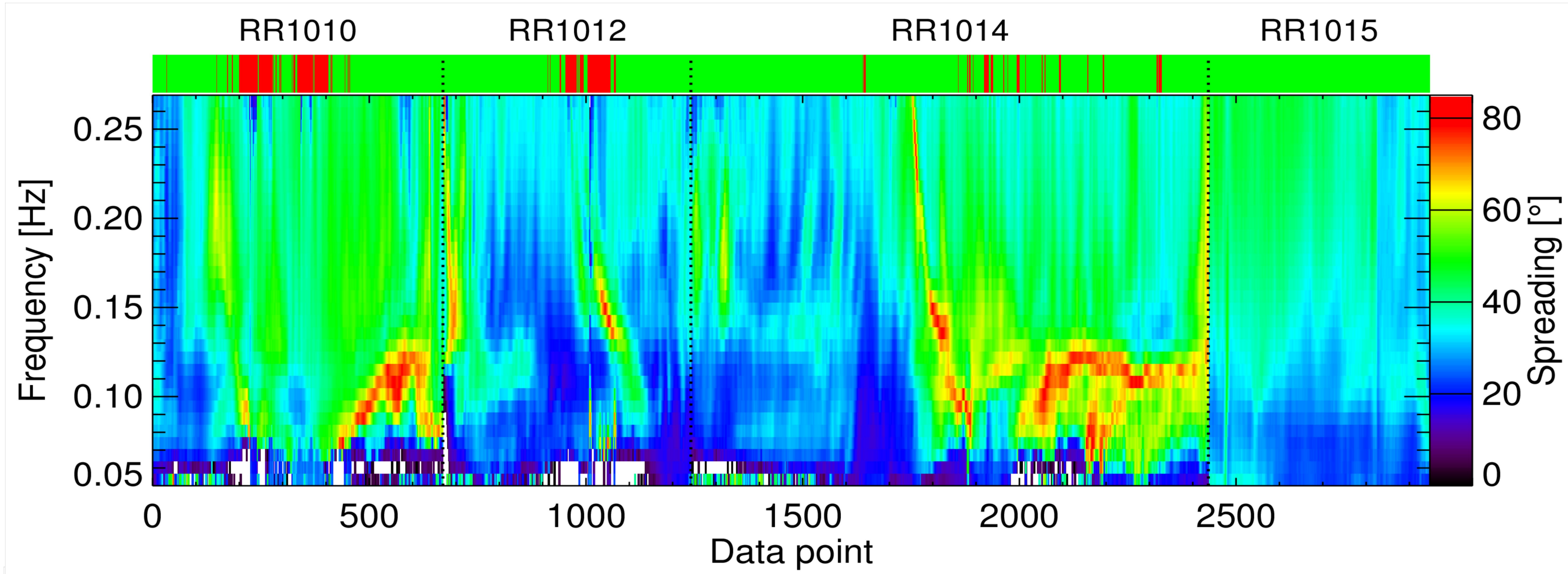


WW3:

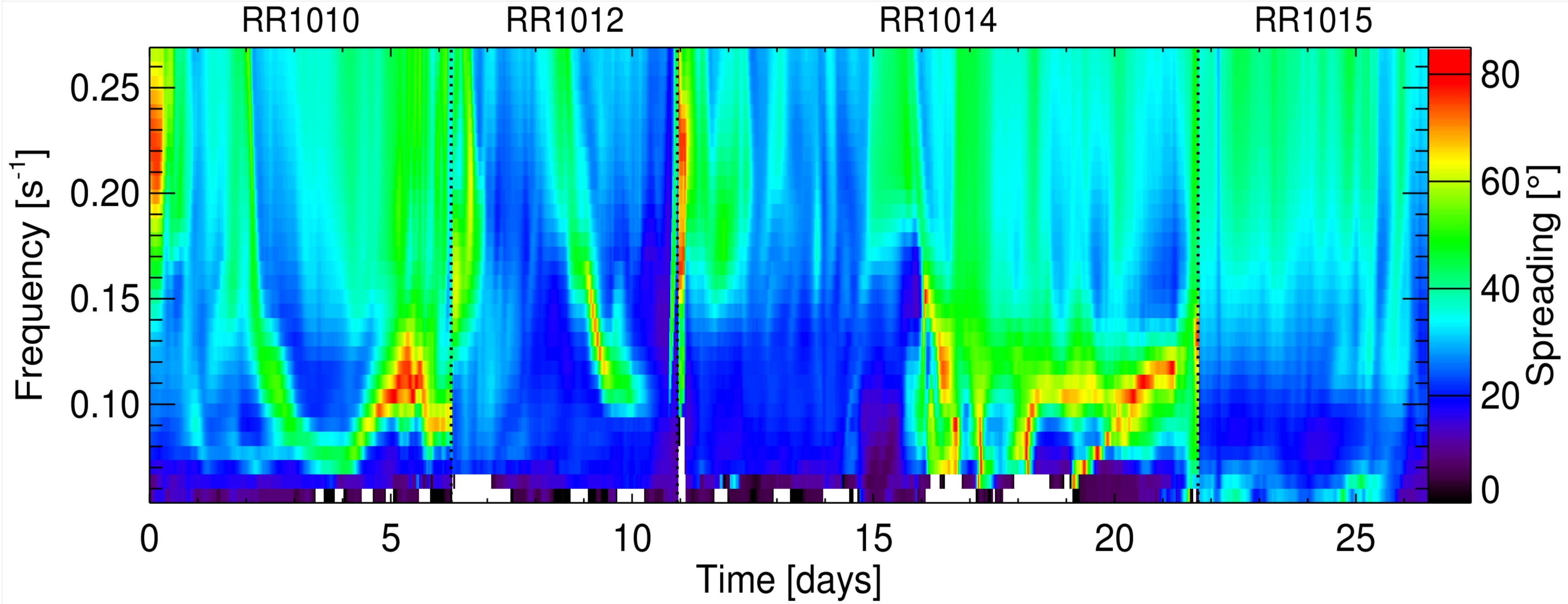


MR vs. WW3 Spreading

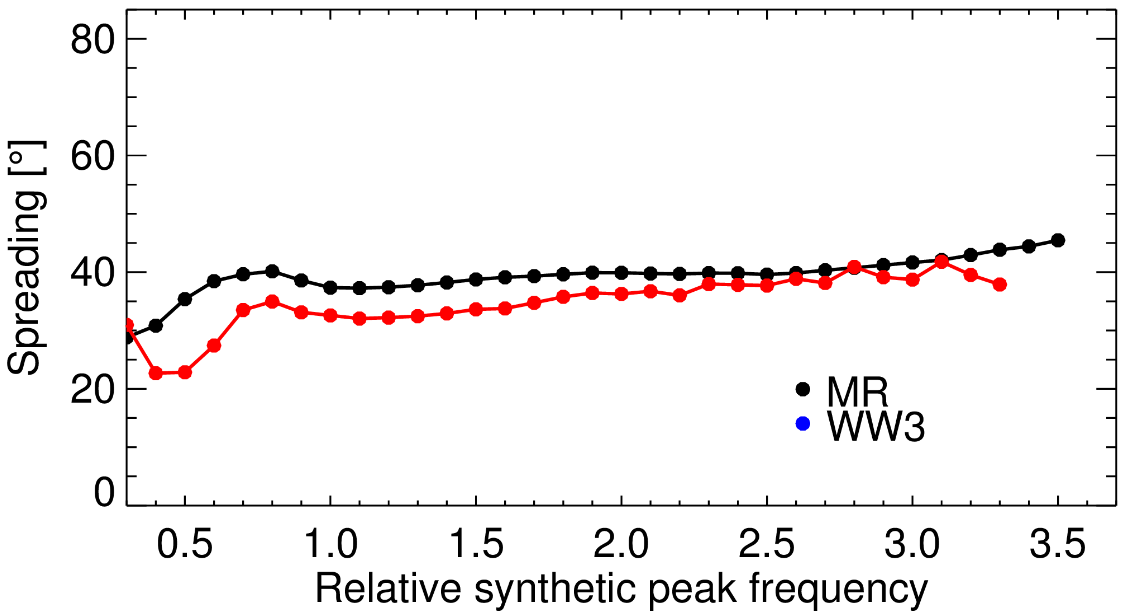
MR:

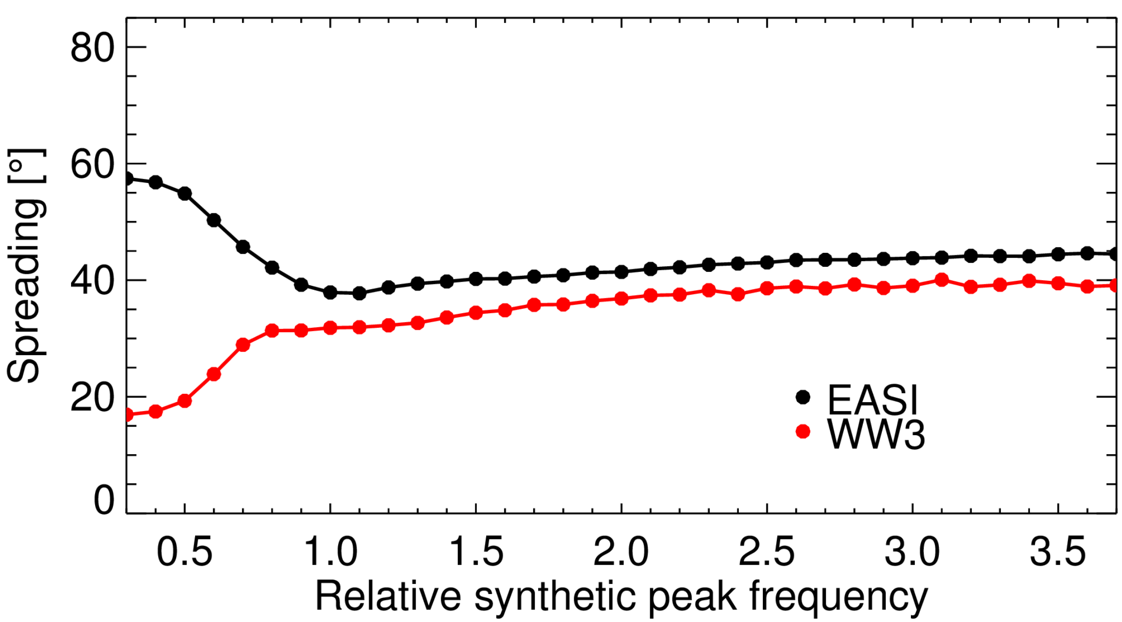


WW3:



Mean Spreading

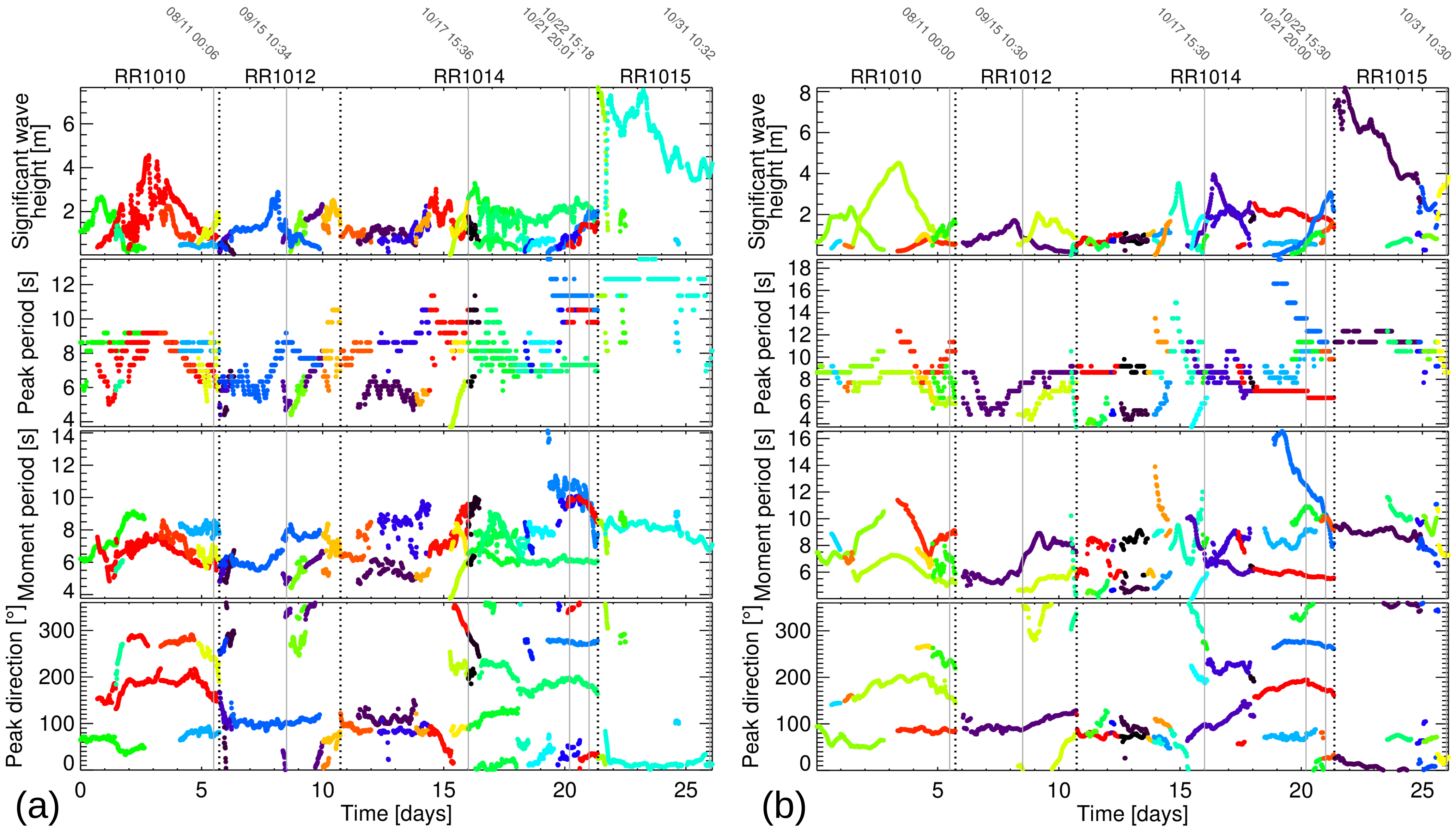




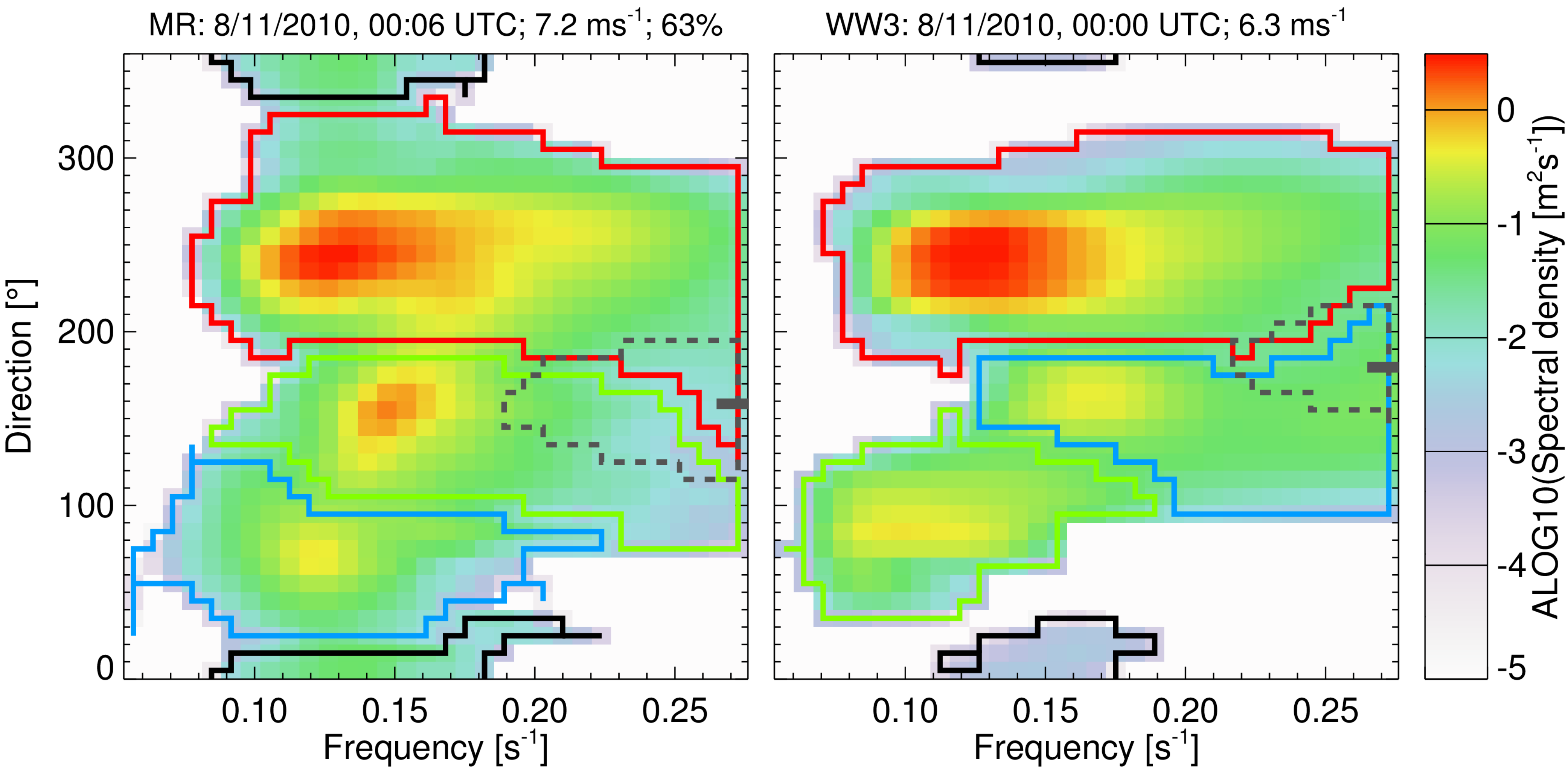
- Synthetic peak frequency function of mean period (Rogers and Wang, 2007)
- ITOP measurements dominated by swells and mixed seas → Metric includes multiple wave systems
- Long low-amplitude wave measurements by buoys problematic due to weak acceleration
- Noise in surface elevations causes positive bias in spread (Kuik et al., 1988)

Spectral Partitioning

MR (a) and WW3 (b) spectral partitioning based on Hanson and Phillips (2001).

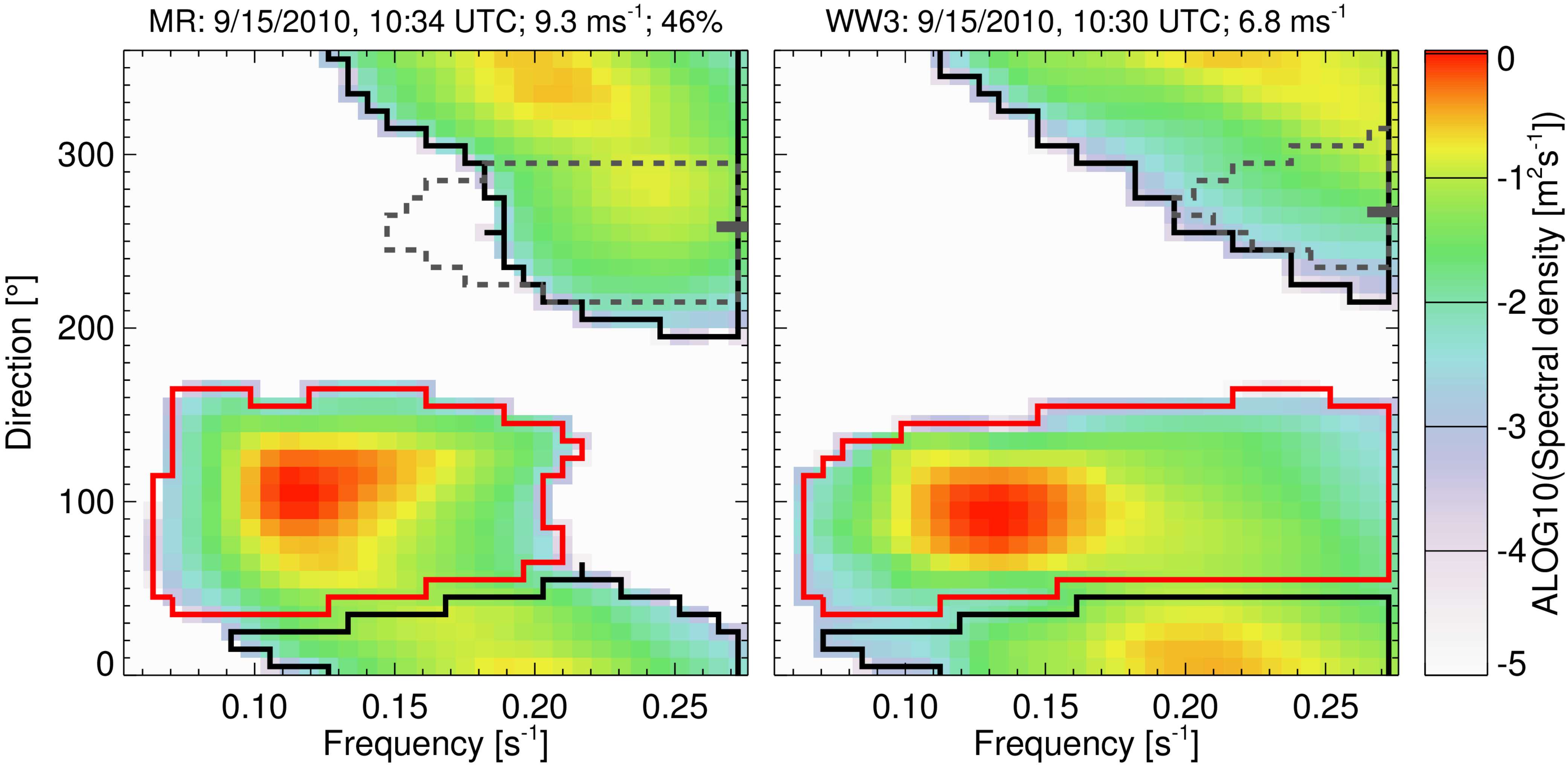


Partitioning Example 1



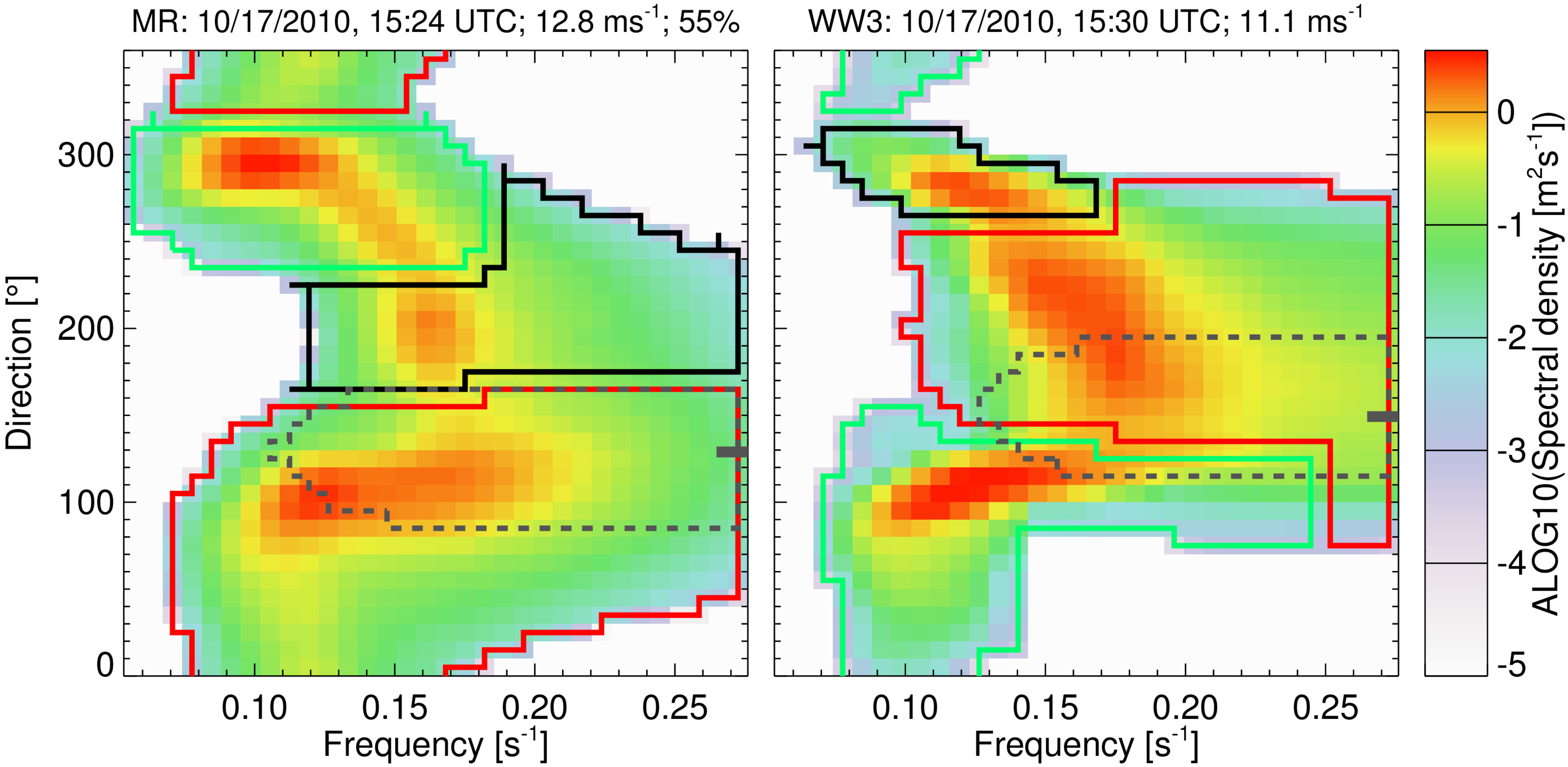
Black border corresponds to least energetic, red to most energetic partition. Gray dashed line marks wind sea (Donelan, 1985).

Partitioning Example 2



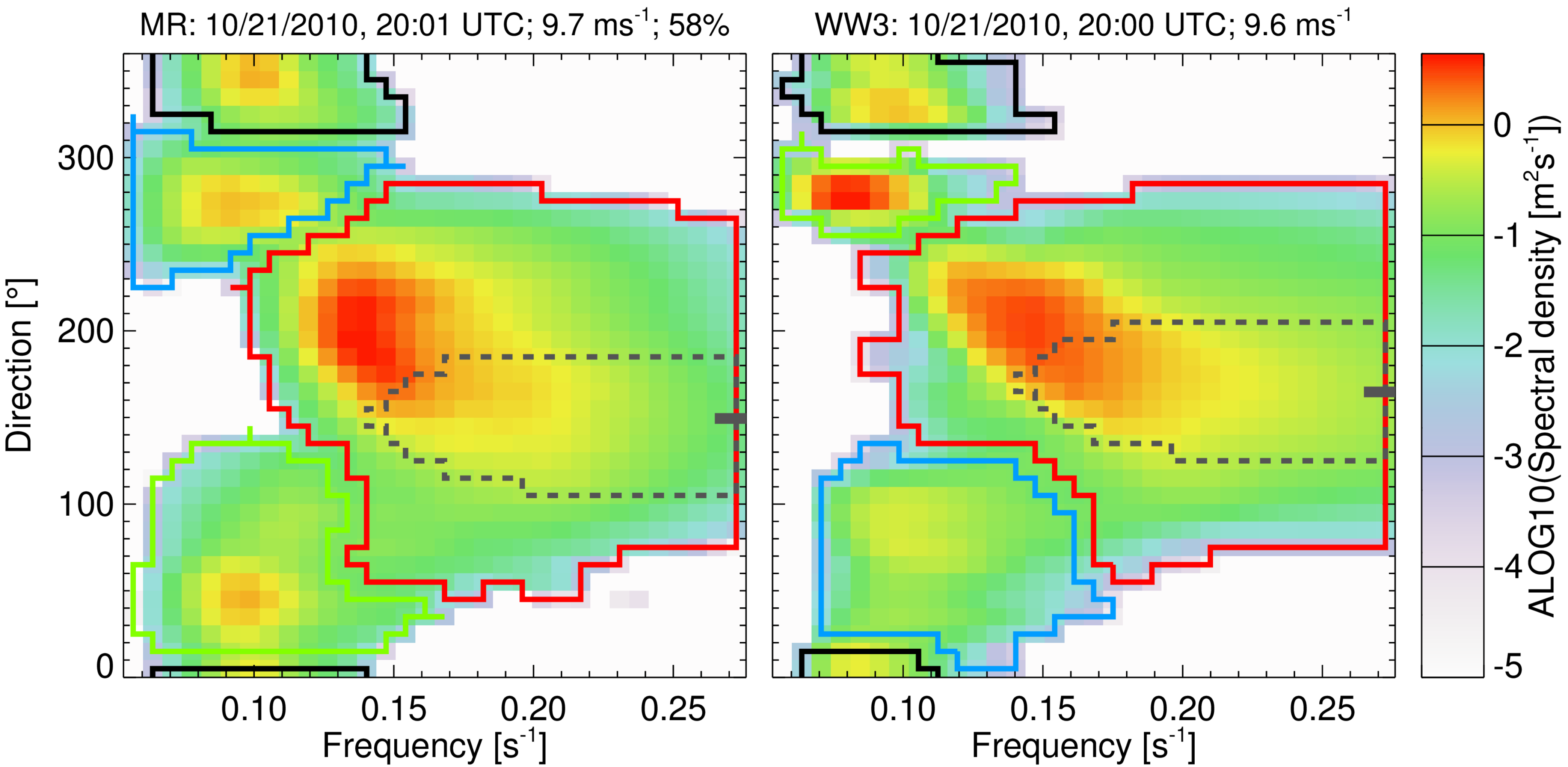
Black border corresponds to least energetic, red to most energetic partition. Gray dashed line marks wind sea (Donelan, 1985).

Partitioning Example 3



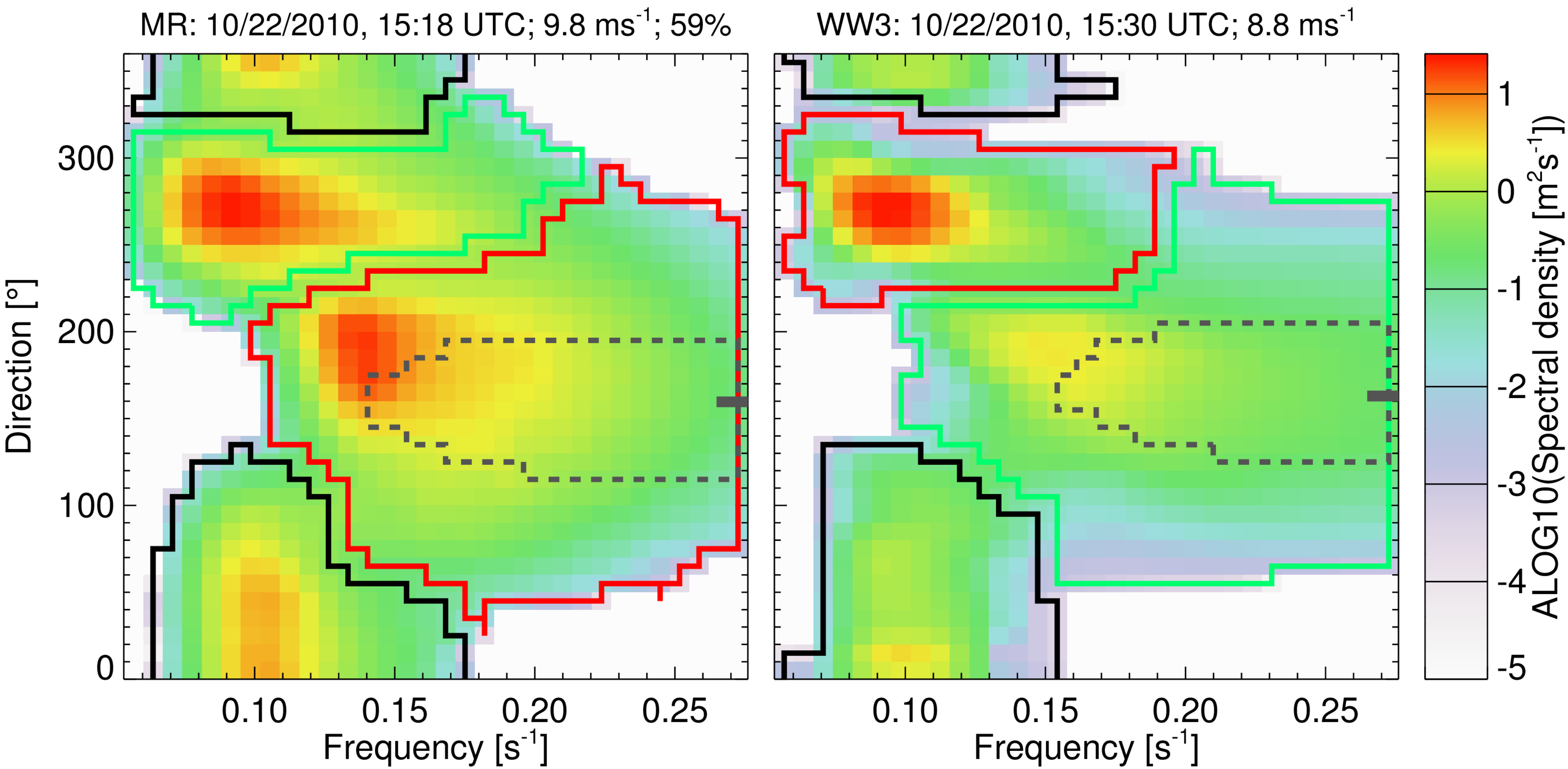
Black border corresponds to least energetic, red to most energetic partition.
Gray dashed line marks wind sea (Donelan, 1985).

Partitioning Example 4



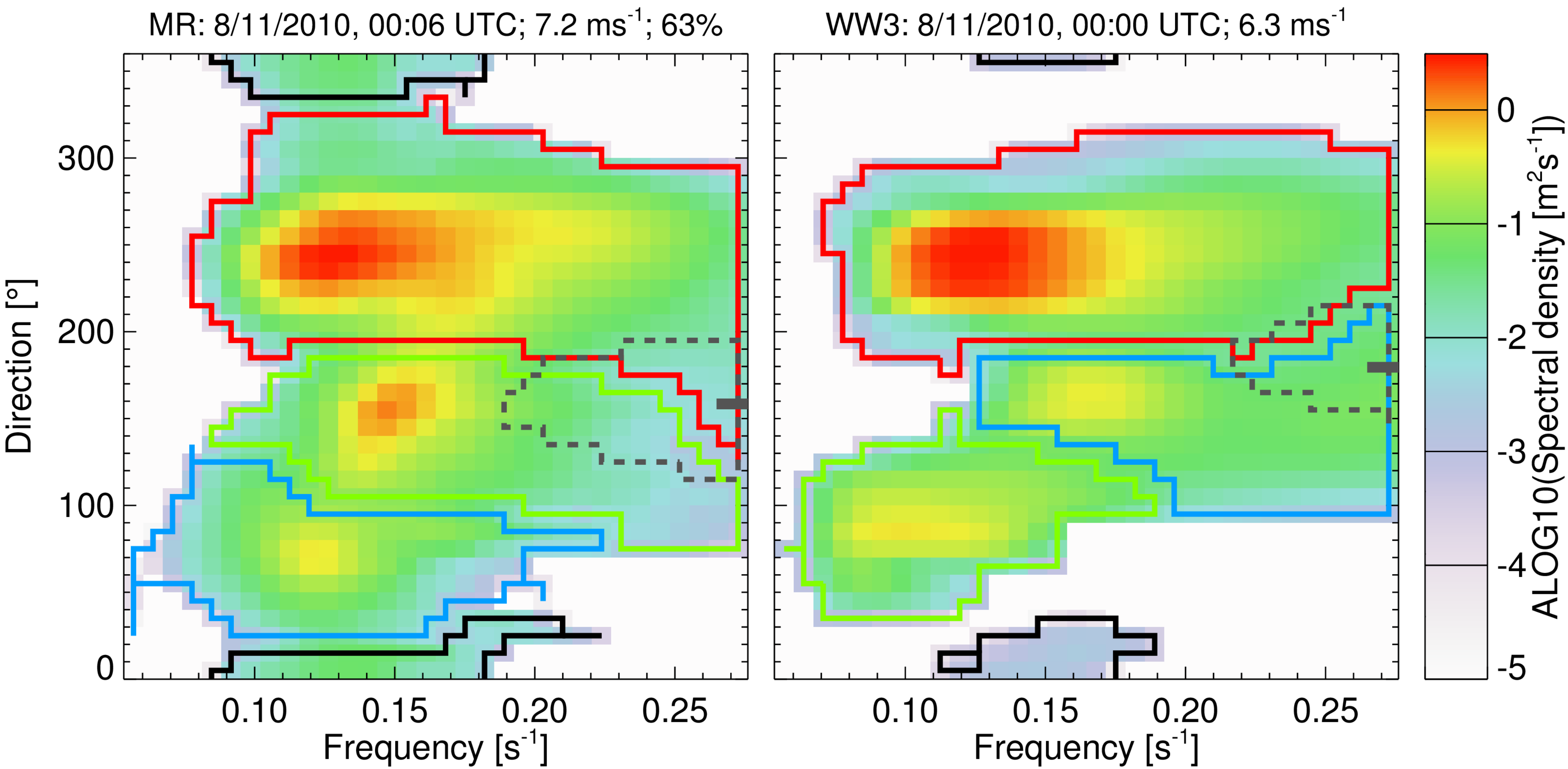
Black border corresponds to least energetic, red to most energetic partition.
Gray dashed line marks wind sea (Donelan, 1985).

Partitioning Example 5



Black border corresponds to least energetic, red to most energetic partition.
Gray dashed line marks wind sea (Donelan, 1985).

Partitioning Example 6



Black border corresponds to least energetic, red to most energetic partition. Gray dashed line marks wind sea (Donelan, 1985).

Summary

- Validated WW3 peak wave and directional parameters with EASI buoy measurements
- MR and WW3 peak wave parameters compare well (but bias in mean period indicates MTF shortcomings)
- Good qualitative agreement regarding spreading and mean direction
- Used spectral partitioning to track multi-directional wave systems, demonstrated excellent MR–WW3 agreement
- Future work / outlook:
  - Improve existing empirical MTF
  - Explore alternatives to SNR-based MR significant wave height estimates (e.g. exploit shadowing)

Acknowledgements

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Publications:

- Lund, B.; Collins III, C. O.; Graber, H. C.; Terrill, E. & Herbers, T. H. C: Marine radar ocean wave retrieval's dependency on range and azimuth. Ocean Dynam., 2014, 64, 999-1018
- Lund, B.; Graber, H. C.; Hessner, K. & Williams, N. J.: On shipboard marine X-band radar near-surface current "calibration". J. Atmos. Oceanic Technol., 2015, 32, 1928-1944
- Lund, B.; Graber, H. C.; Tamura, H.; Collins III, C. O. & Varlamov, S. M.: A new technique for the retrieval of near-surface vertical current shear from marine X-band radar images. Manuscript submitted for publication, 2015