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AIRBORNE SYSTEM FOR COASTAL SEA STATE ESTIMATION USING GNSS-REFLECTOMETRY

G. Stienne[1], M. Moreno[2], M. Semmling[3], S. Reboul[1], J. Wickert[2,4]

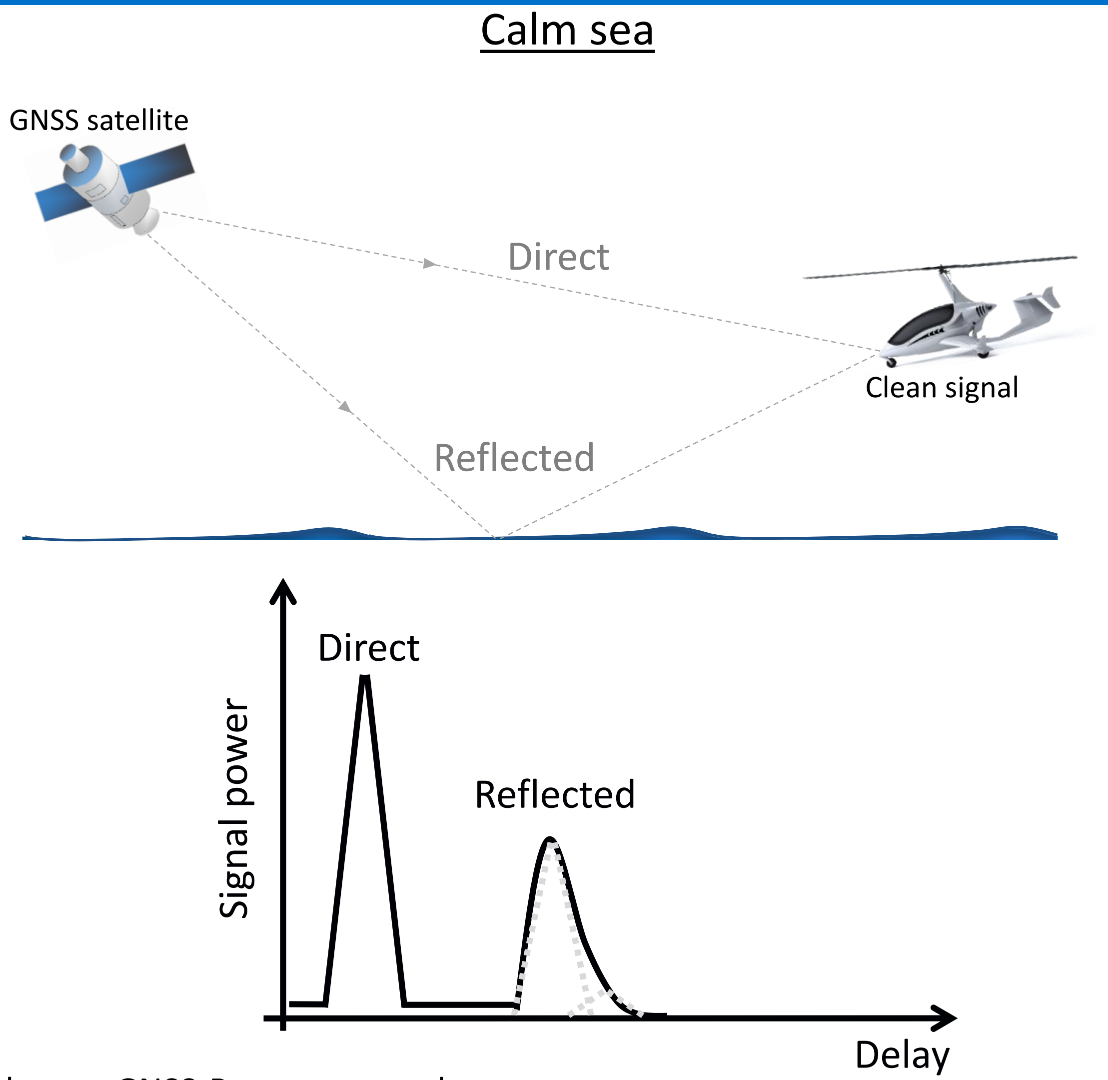
[1] Laboratoire d'Informatique, Signal et Image de la Côte d'Opale, Université du Littoral Côte d'Opale (ULCO), Calais, France.

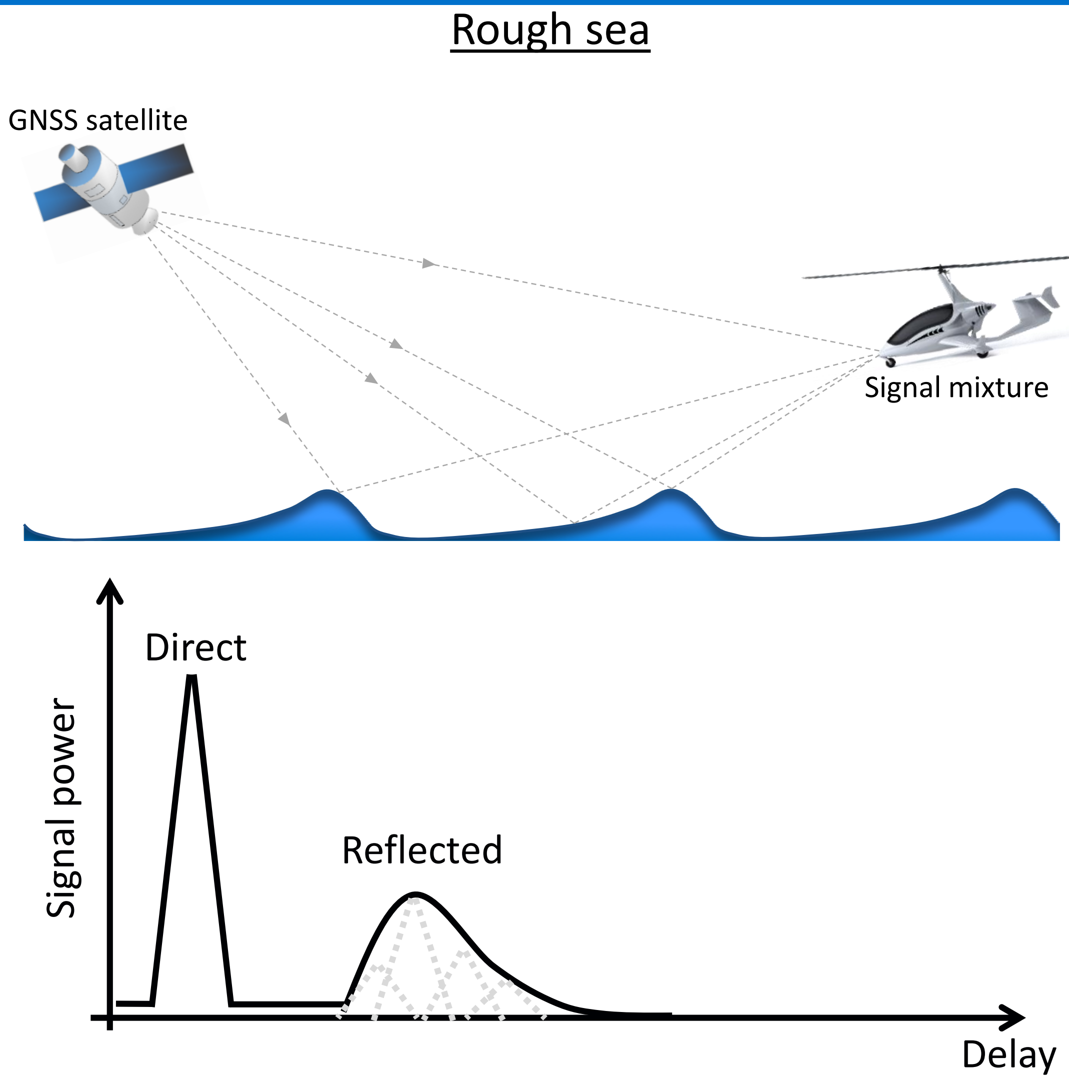
[2] Technische Universität Berlin (TUB), Germany.

[3] Institute for Solar-terrestrial Physics (DLR-SO), Neustrelitz, Germany.

[4] German Research Centre for Geosciences (GFZ), Potsdam, Germany.

Concept





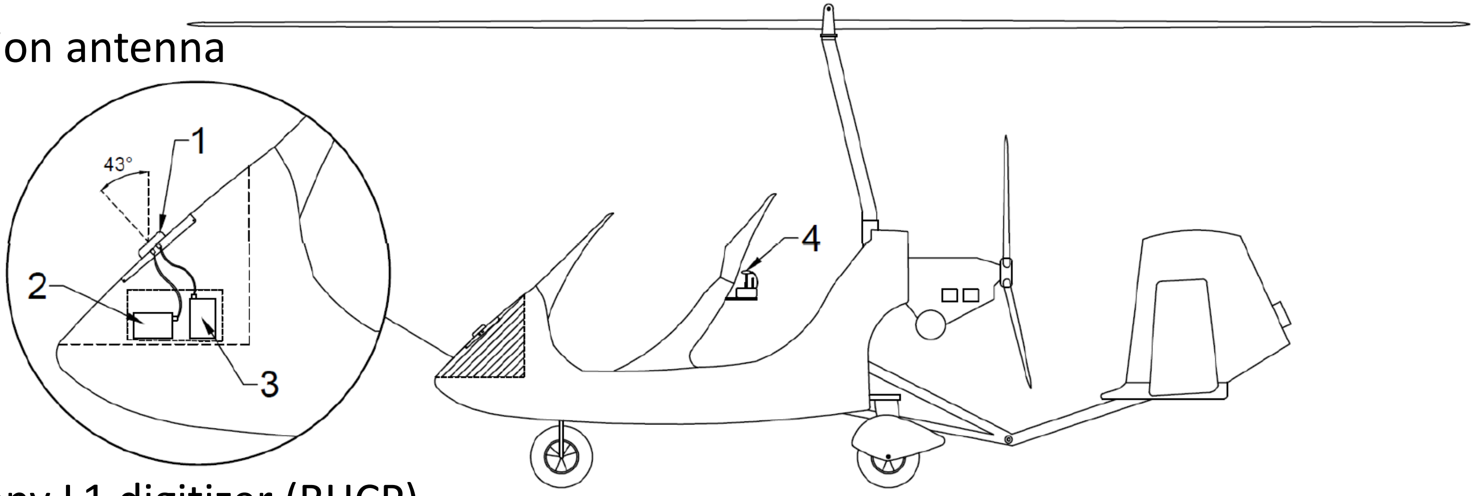
On coherent GNSS-R sea state study:

Alonso-Arroyo, A., Camps, A., Park, H., Pascual, D., Onrubia, R., & Martin, F. (2015). Retrieval of Significant Wave Height and Mean Sea Surface Level Using the GNSS-R Interference Pattern Technique: Results From a Three-Month Field Campaign. IEEE Transactions on Geoscience and Remote Sensing, 53 (6), 3198–3209. https://doi.org/10.1109/TGRS.2014.2371540

Hoseini, M., Semmling, M., Nahavandchi, H., Rennspiess, E., Ramatschi, M., Haas, R., Strandberg, J., & Wickert, J. (2020). On the Response of Polarimetric GNSS-Reflectometry to Sea Surface Roughness. IEEE Transactions on Geoscience and Remote Sensing, 1–12. https://doi.org/10.1109/TGRS.2020.3031396

Hardware

1- Dual-polarization antenna



2- Syntony L1 digitizer (RHCP)
3- Syntony L1 digitizer (LHCP)

4- Drone board sensors (INS, GPS, barometer)

- Average gyrocopter height during the experiments: 780m.
- Average gyrocopter speed: 95km/h.
- Drone board sensors: determination of the gyrocopter attitude and position.
- Only the Right Handed Circular Polarization signals (direct and reflected) have been used in this work.

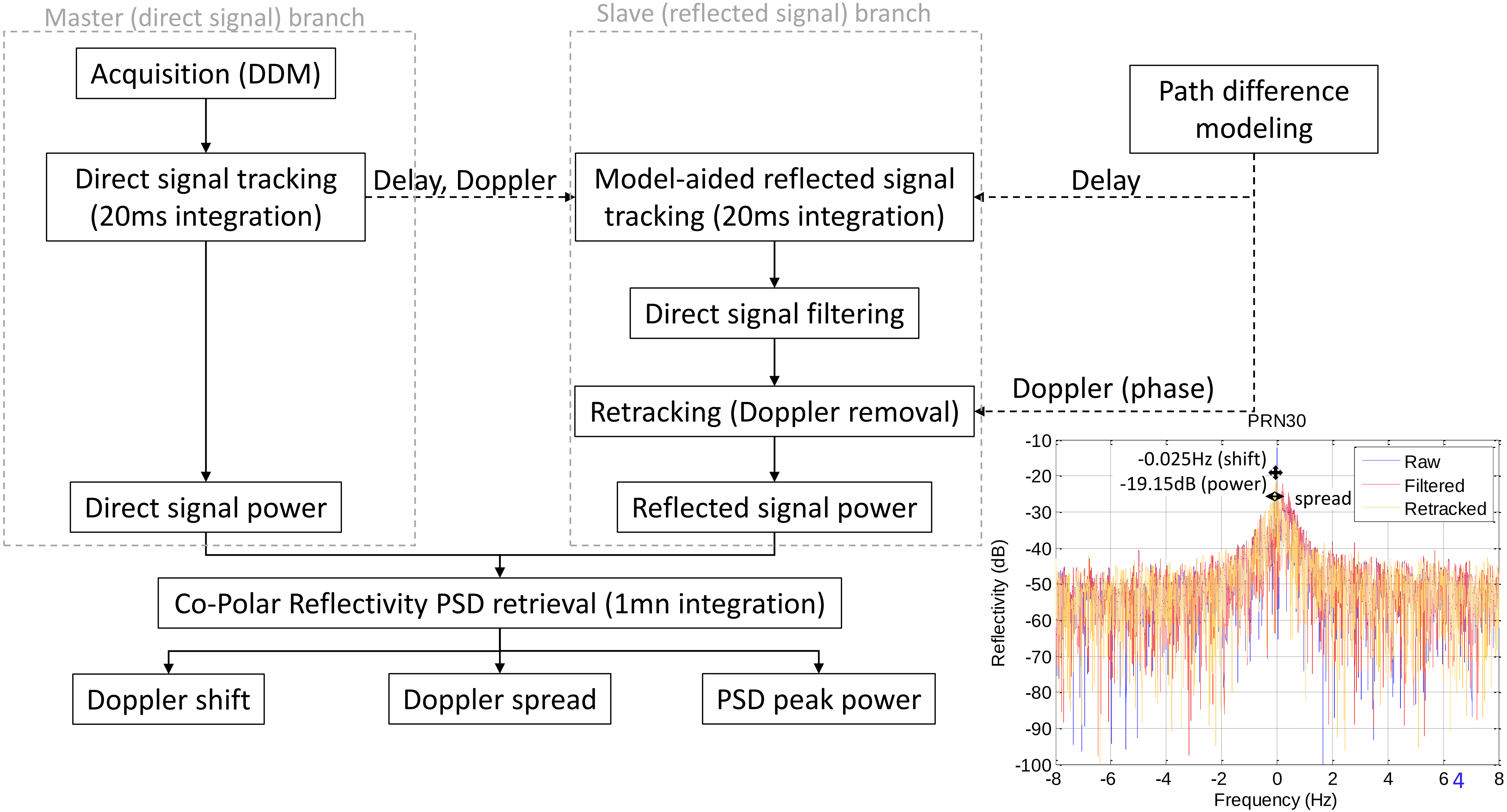
On the software processing of raw digitized GNSS-R signals:

Kucwaj, J.-C., Reboul, S., Stienne, G., Choquel, J.-B., & Benjelloun, M. (2017). Circular regression applied to GNSS-R phase altimetry. Remote Sensing, 9. https://doi.org/10.3390/rs9070651

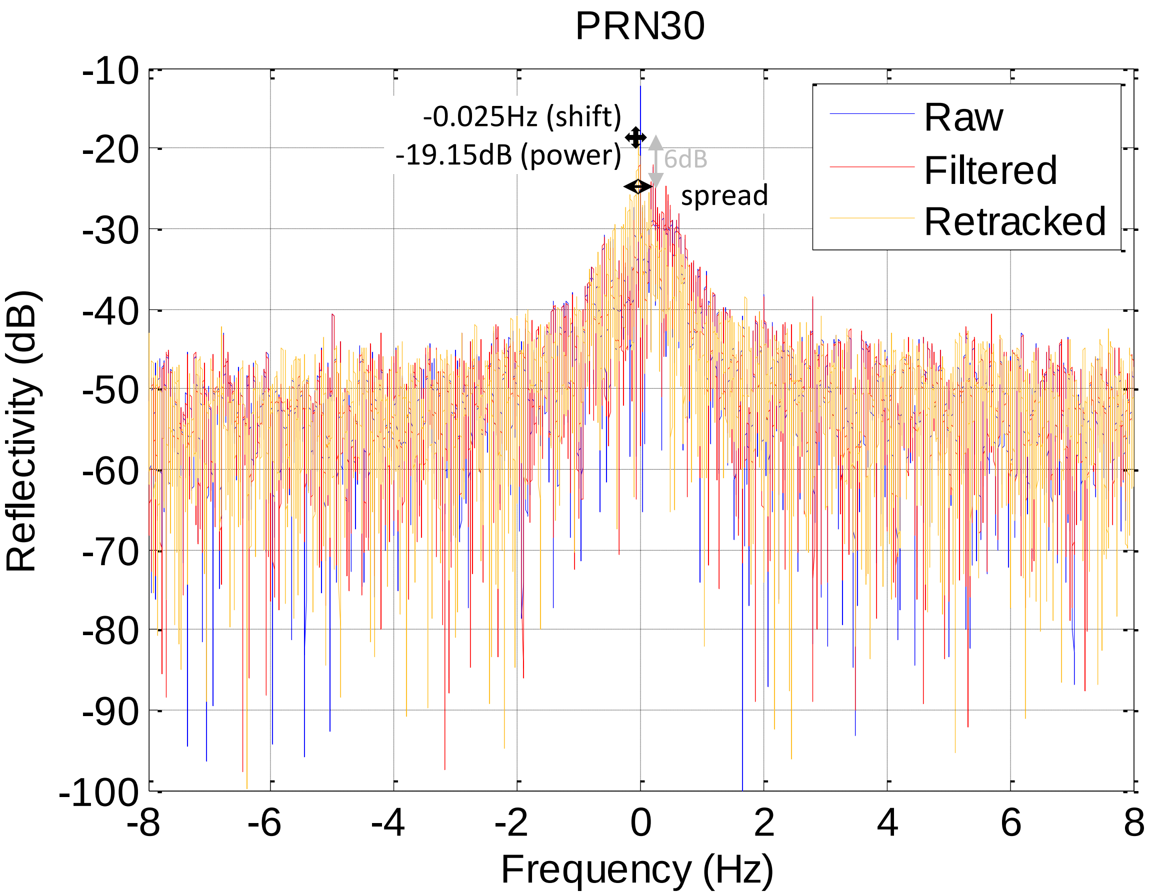
On a similar airborne GNSS-R setup:

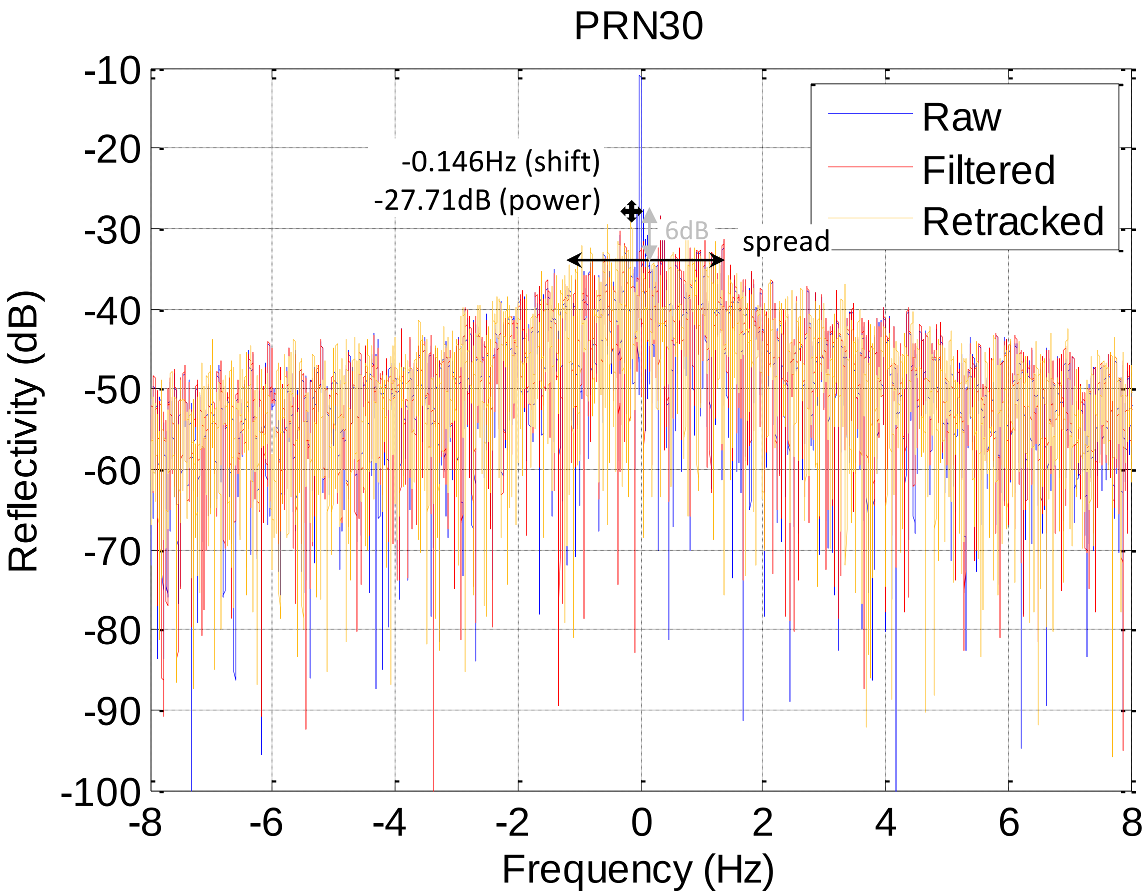
Semmling, M., Wickert, J., Schön, S., Stosius, R., Markgraf, M., Gerber, T., Ge, M., & Beyerle, G. (2013). A zeppelin experiment to study airborne altimetry using specular Global Navigation Satellite System reflections. Radio Science, 48, 427–440. https://doi.org/10.1002/rds.20049

Signal processing



Reflectivity PSD



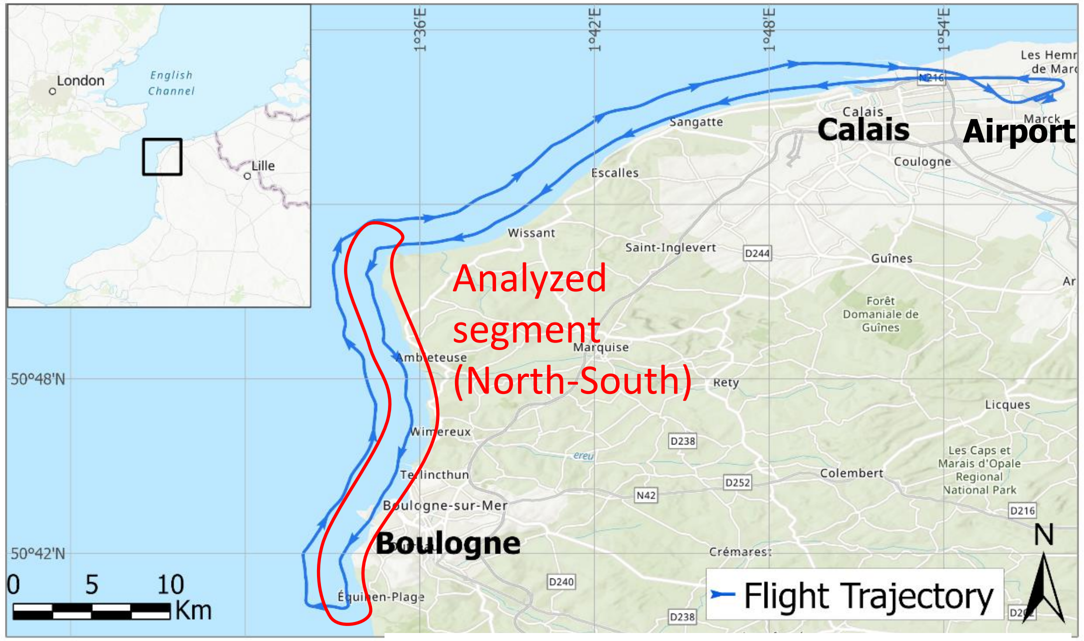


Sharper, higher Power Spectral Density, with lower shift: indicative of a calmer sea

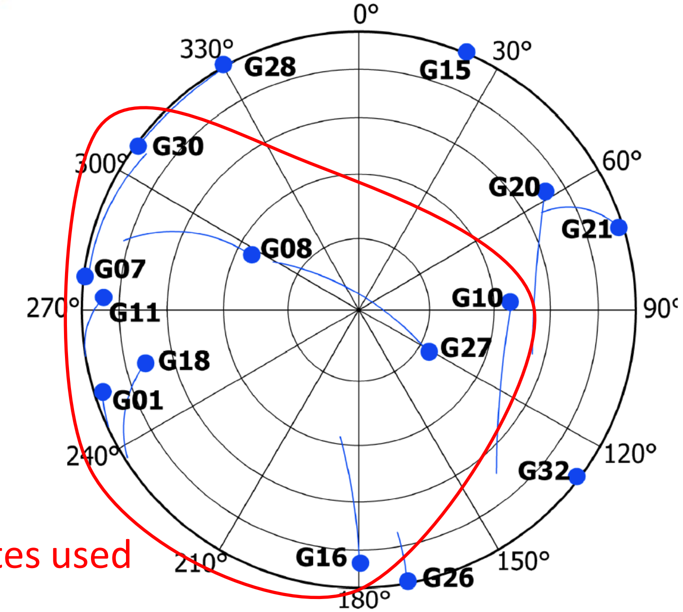
Wider, lower Power Spectral Density, with larger shift: indicative of a rougher sea

Experimentation

The experimentation took place in July 2019, over the English channel. The same trajectory was repeated, with various wind and sea state conditions.



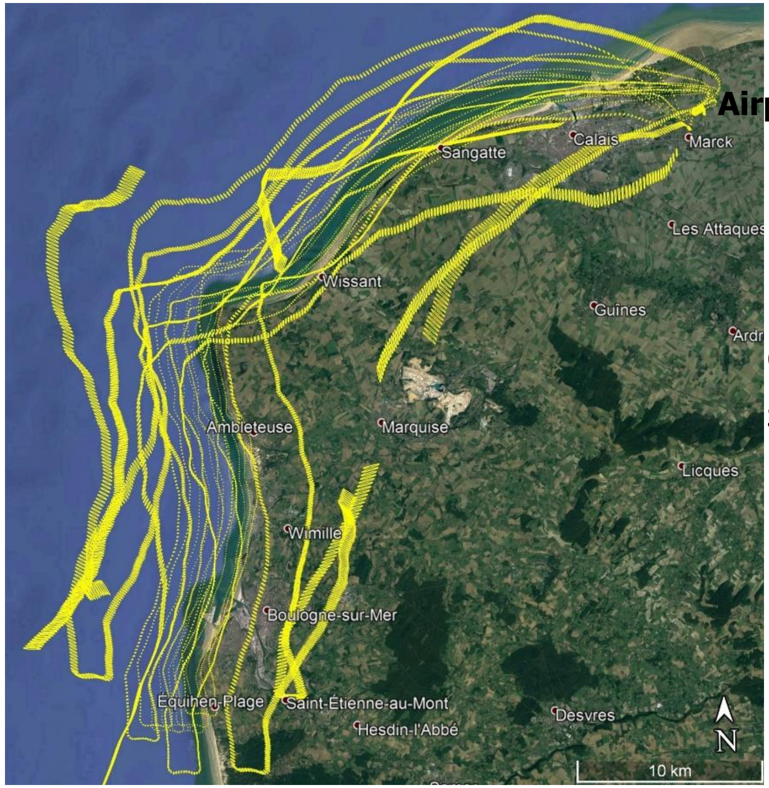
GPS skyplot (similar for 3 out of 4 flights, shifted on July 15)



Datasets

Space resolution:

Configuration	Elevation (°)	First Fresnel zone major axis (m)
Minimum	5	950
Regular	30	70
Maximum	85	25



First Fresnel zones (all visible satellites) displayed every 6 seconds

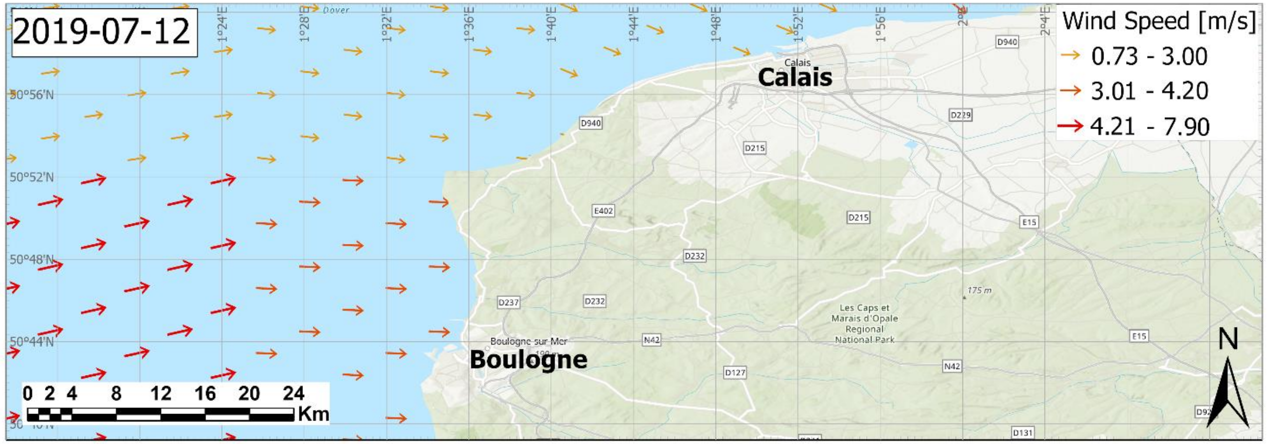
Time resolution:

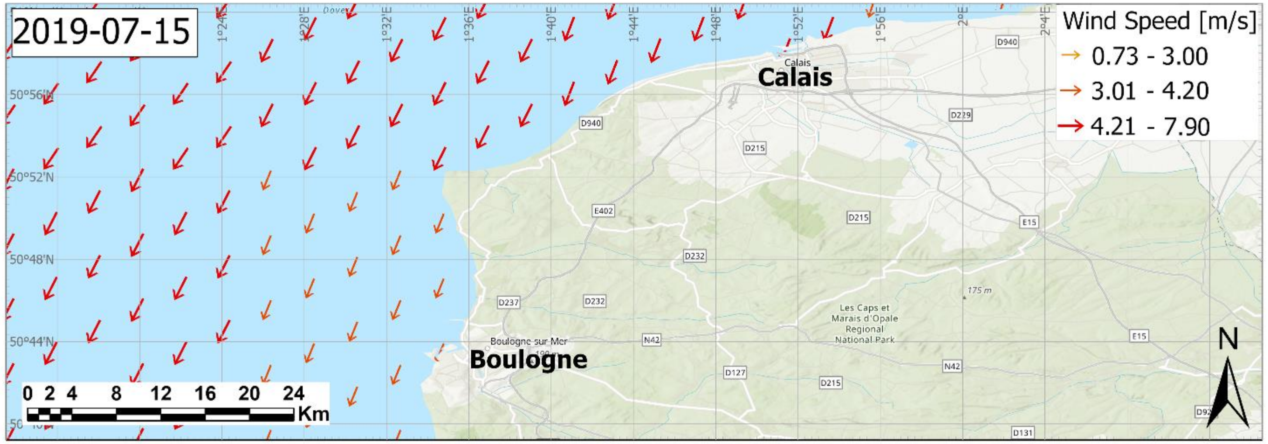
- Data lvl0 (data bits): 16.368MHz sampling
- Data lvl1 (I and Q): every 20ms
- Data lvl2 (PSD): every minute

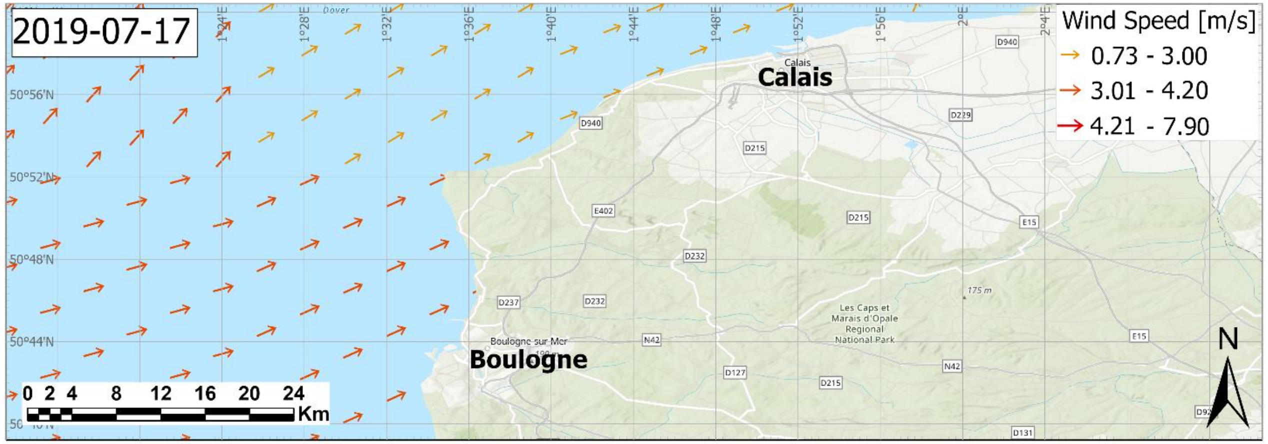
Wind speeds and directions, Significant Wave Heights: ERA5 data

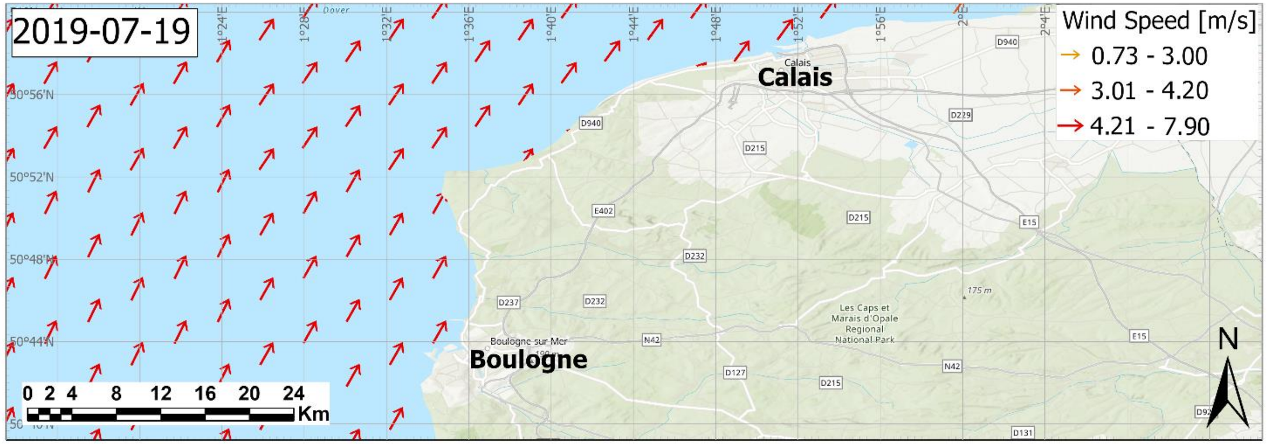
Date	Wind speed (m/s)	Wind direction (°)	SWH (m)	Flight duration (min)	RHCP data size (GB)	N-S segment duration (min)
2019-07-12	5.49	117	0.30	105	12.64	16
2019-07-15	4.29	67	0.58	115	13.80	14
2019-07-17	2.29	204	0.26	121	14.56	20
2019-07-19	6.50	240	0.55	115	13.80	23

Wind speeds and directions



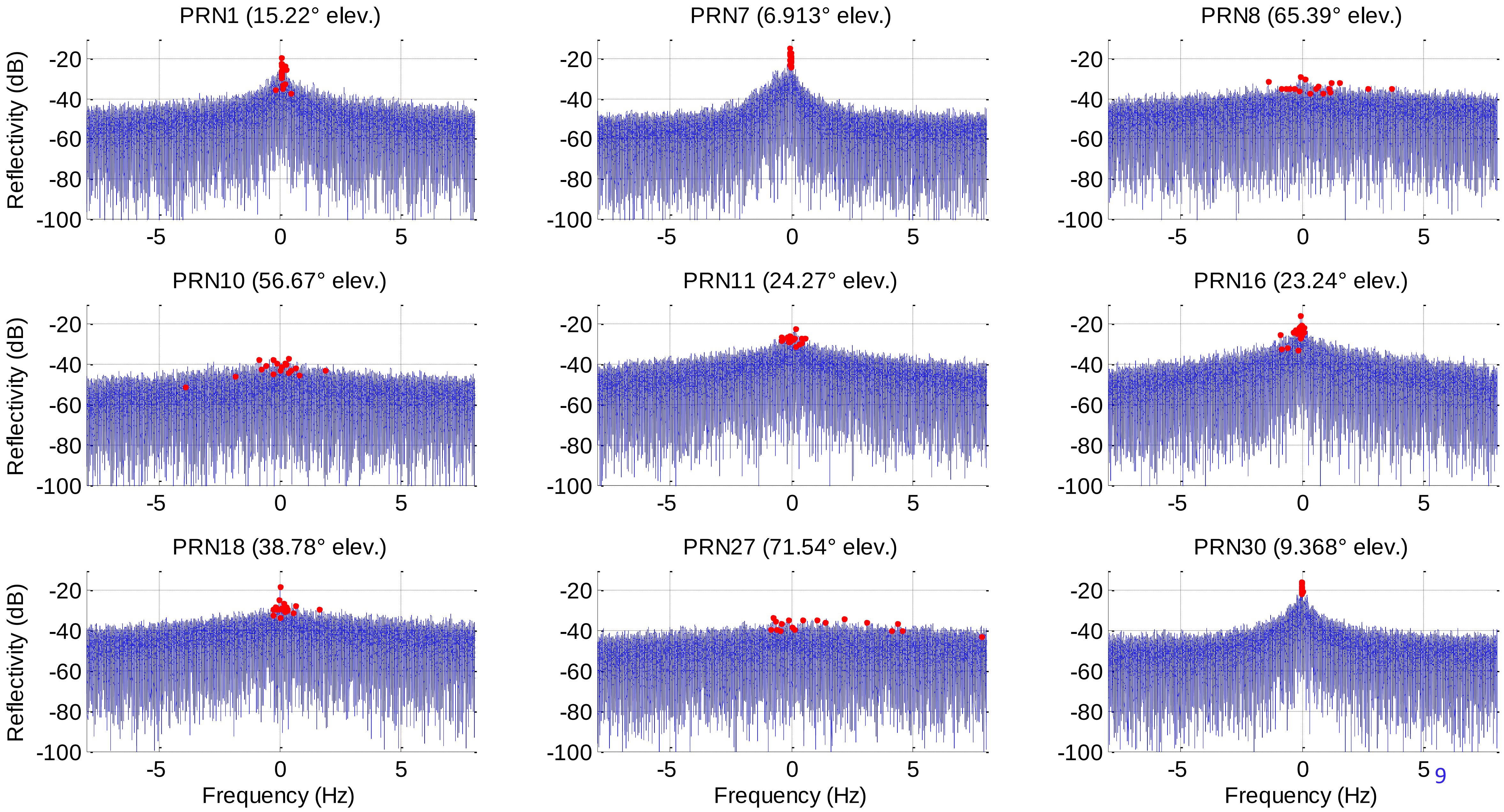




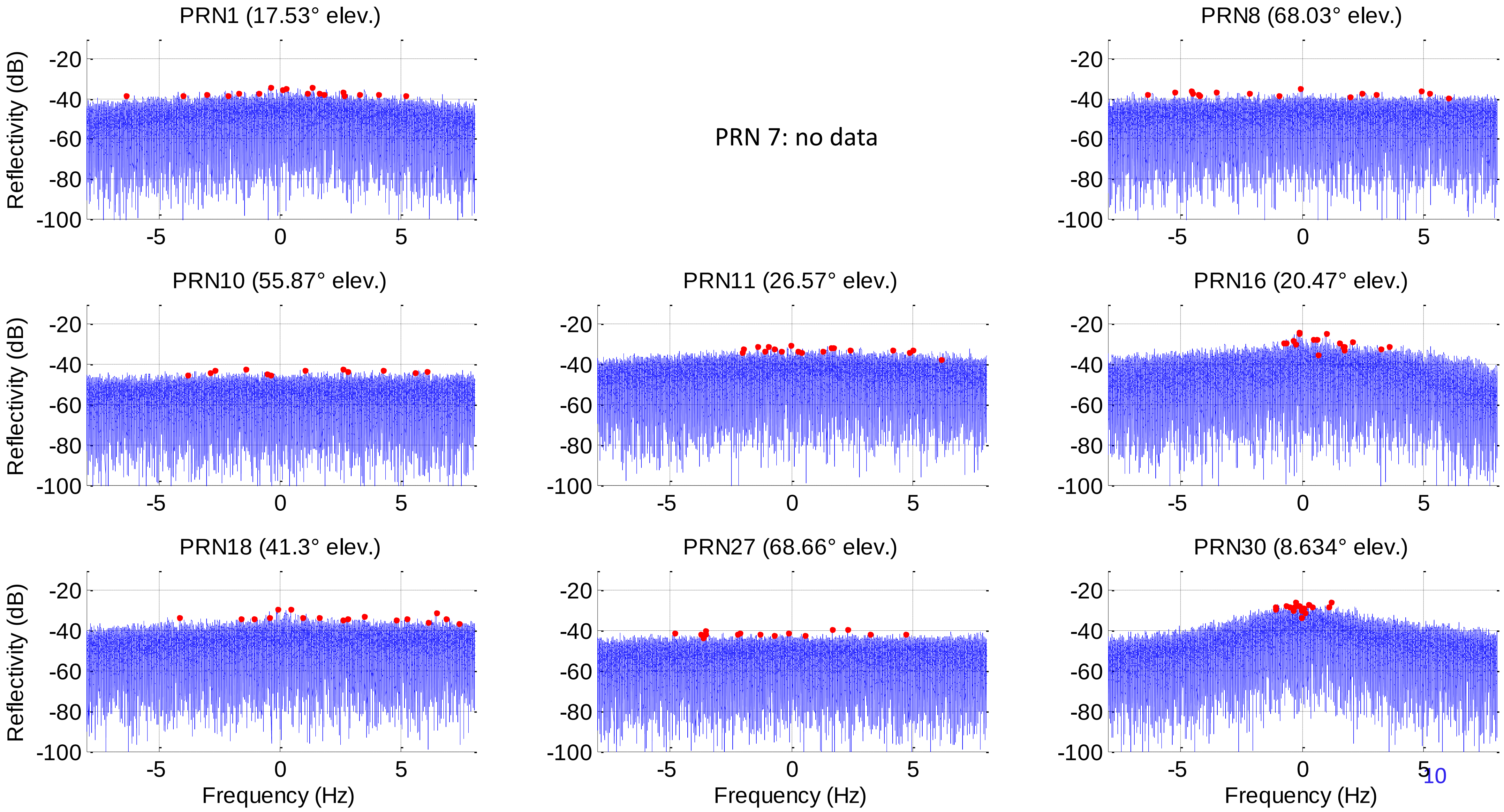


Source: ECMWF ERA5 model - https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era5

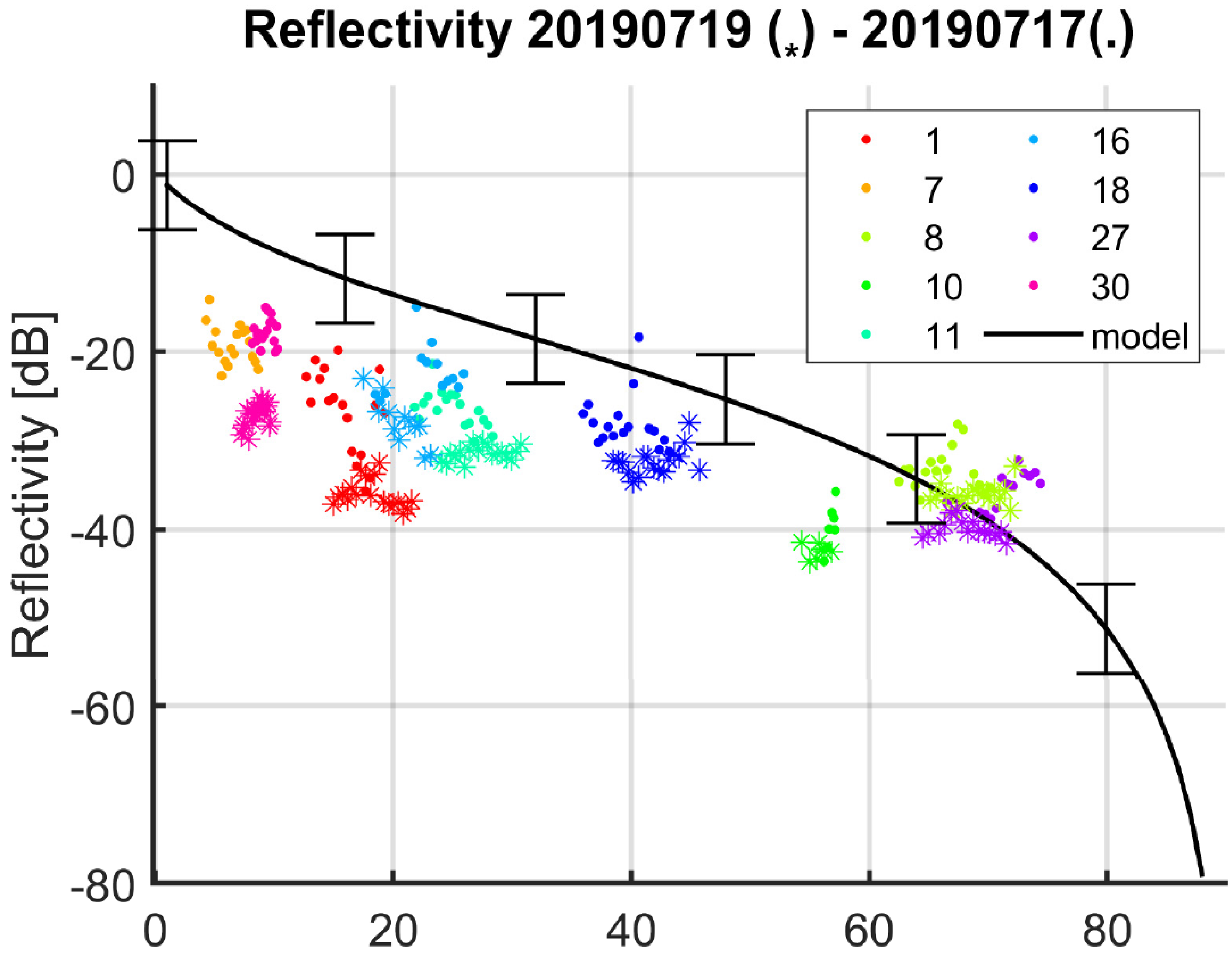
Reflectivity PSD: July 17 (each minute)



Reflectivity PSD: July 19 (each minute)



Reflectivity: observation vs model – July 17 and 19

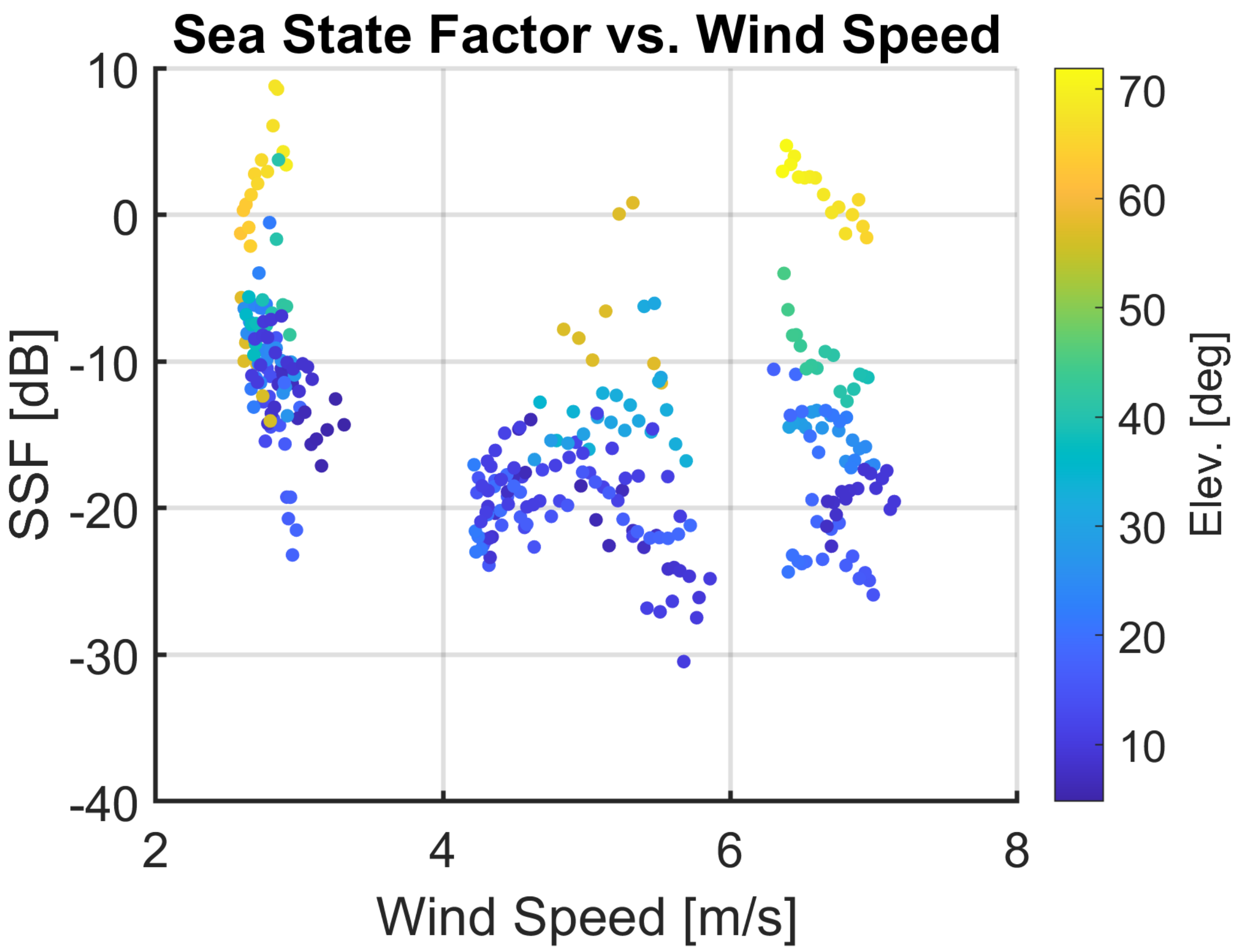


The displayed reflectivity model considers a flat sea surface.

The difference between the observed and the modeled reflectivity can thus be linked with the sea state and be used to define a « Sea State Factor ».

PRN 10 reflections were very close to the coast and some of the corresponding observations were removed accordingly.

Sea State Factor vs Wind Speed (all days)



At similar elevations, the Sea State Factor globally increases (in absolute value) with the wind speed.

At high elevations, the reflected signal is generally barely visible, and the reflectivity power peaks are at the noise level (-50 to -40 dB).

Correlation coefficient	Sea State Factor (Elevation < 10°)	Sea State Factor (10° < Elevation < 30°)	Sea State Factor (Elevation > 30°)
Wind Speed	-0.7346	-0.4639	-0.1221
SWH	-0.5066	-0.3775	-0.0007

Doppler shift spreading

The spreading of Doppler shifts have been studied by computing the standard deviation (STD) of their one minute observations over the considered North-South segment.

The spreading increases with both the wind speed (or Significant Wave Height) and satellite elevation.

Date	Doppler shift STD (Elevation < 10°)	Doppler shift STD (10° < Elevation < 30°)	Doppler shift STD (Elevation > 30°)	Wind speed (m/s)	Wind direction (°)	SWH (m)
2019-07-12	0.2909	1.8742	4.2486	5.49	117	0.30
2019-07-15	0.4437	2.2183	No data	4.29	67	0.58
2019-07-17	0.0174	0.2041	1.2998	2.29	204	0.26
2019-07-19	0.7181	2.0394	4.9026	6.50	240	0.55

Correlation coefficient	Doppler shift STD (Elevation < 10°)	Doppler shift STD (10° < Elevation < 30°)	Doppler shift STD (Elevation > 30°)
Wind Speed	0.9421	0.6395	0.6080
SWH	0.8530	0.6061	0.5691

Conclusions, perspectives

- Conclusions
  - Highly space and time resolved airborne remote sensing of the sea.
  - Good correlation between the reflectivity spectral spread and the sea roughness, particularly at low elevations.
  - Lower correlation when using the reflectivity power, which might be linked with the antenna gain pattern (not taken into account).
- Perspectives
  - LHCP signals study
  - South-North segment study, impact of the wind/waves direction?
  - Further improvement of the time resolution (up to 50Hz)