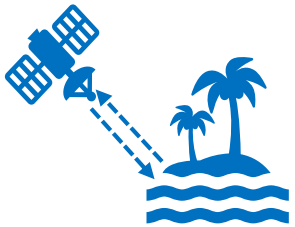
Coastal monitoring of sea state using airborne GNSS reflectometry

M. Moreno[(1)], M. Semmling[(1)], G. Stienne[(2)], W. Dalil[(2)], M. Hoque[(1)], J. Wickert[(3,4)], S. Reboul[(2)]

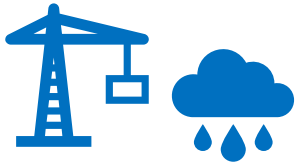
[(1)] Institute for Solar-Terrestrial Physics (DLR-SO), Neustrelitz, Germany
[(2)] Université Littoral Côte d'Opale (ULCO), Calais, France
[(3)] German Research Centre for Geosciences (GFZ), Potsdam, Germany
[(4)] Technische Universität Berlin, Germany

MOTIVATION

Considerable percentage of global **population** is **located** near to the **coastal zones**.



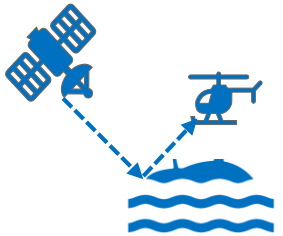
Satellite Altimetry achieves high accuracy in open sea but **less accurate** towards **coast**.



Coastal zones are dynamic areas **affected by natural** and **anthropogenic** forces.

Tide gauges allows to collect **in-situ data** that reminds **sparse** all over the **world.**

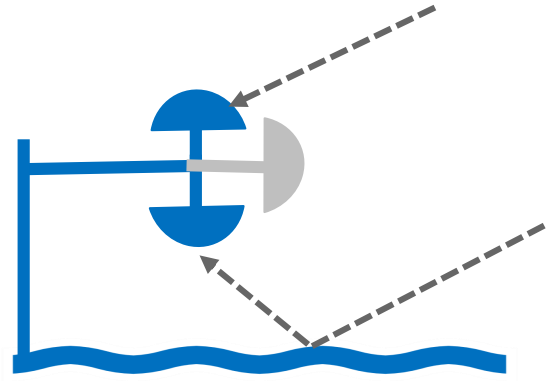
Sea state (sea level rise) impact considerably human activities increasing **risks** in **coastal areas**.



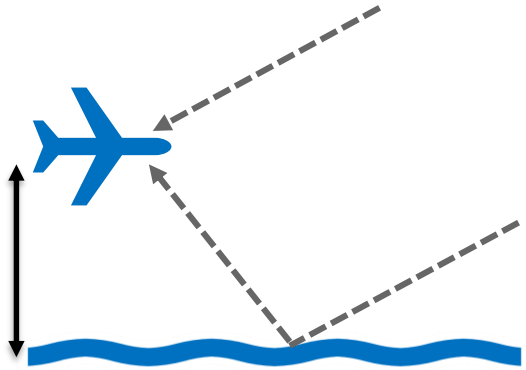
GNSS Reflectometry would **complement** altimetry and sea state **data in coastal zones.**

BACKGROUND

SEA STATE (LEVEL) MONITORING



- (Roussel et al., 2015)
- (Reinking et al., 2019)
- (Chen et al., 2019)
- (Hoseini et al., 2020)



- (Ruffini et al., 2003)
- (Yu et al., 2011)
- (Semmling et al., 2014)
- (Wang et al., 2021)

Setup

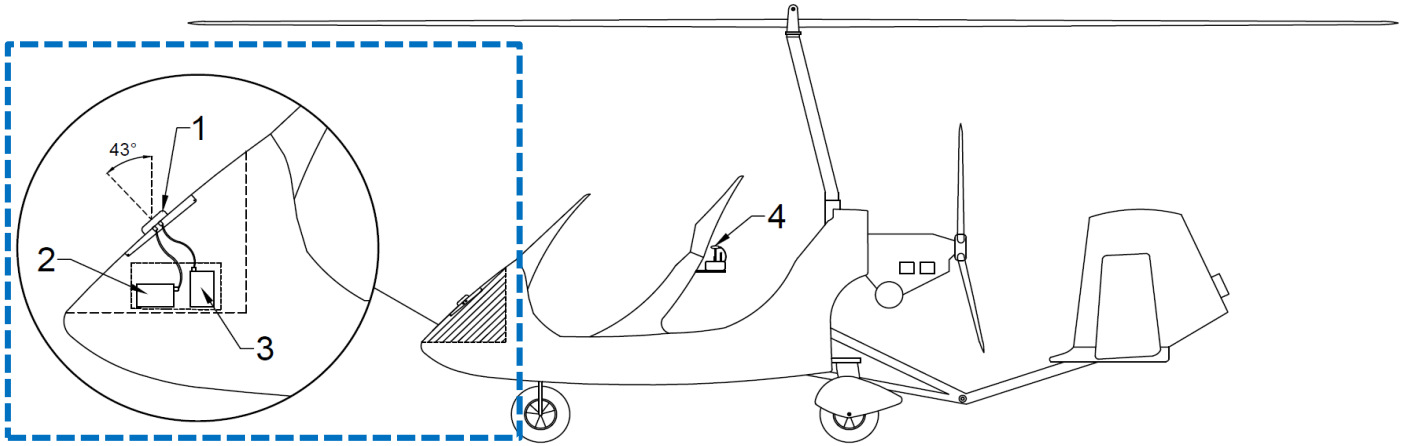
- Array of antennas (up-,down-, side–looking)
- High performance or low-cost antennas
- Medium and high altitude aircraft
- RHCP / LHCP

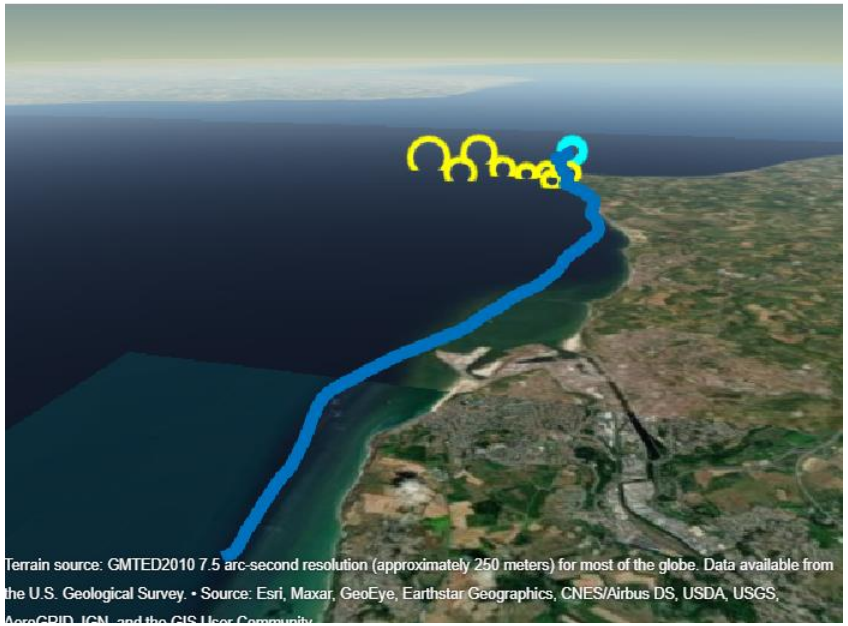
Observables

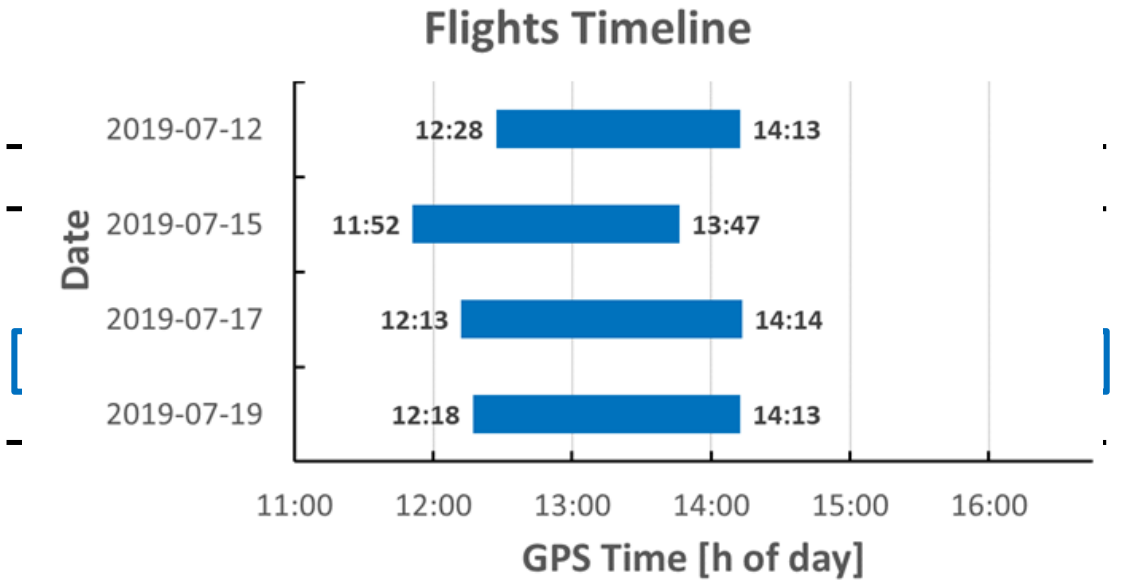
- Signal to noise Ratio (SNR)
- Code / Phase delay
- Polarimetric approach

EXPERIMENT SETUP

- Low-height aircraft (gyrocopter)
- (1) Dual-polarized antenna
- (2,3) Front-end receivers (LH/RH)
- (4) Flight control GPS+IMU

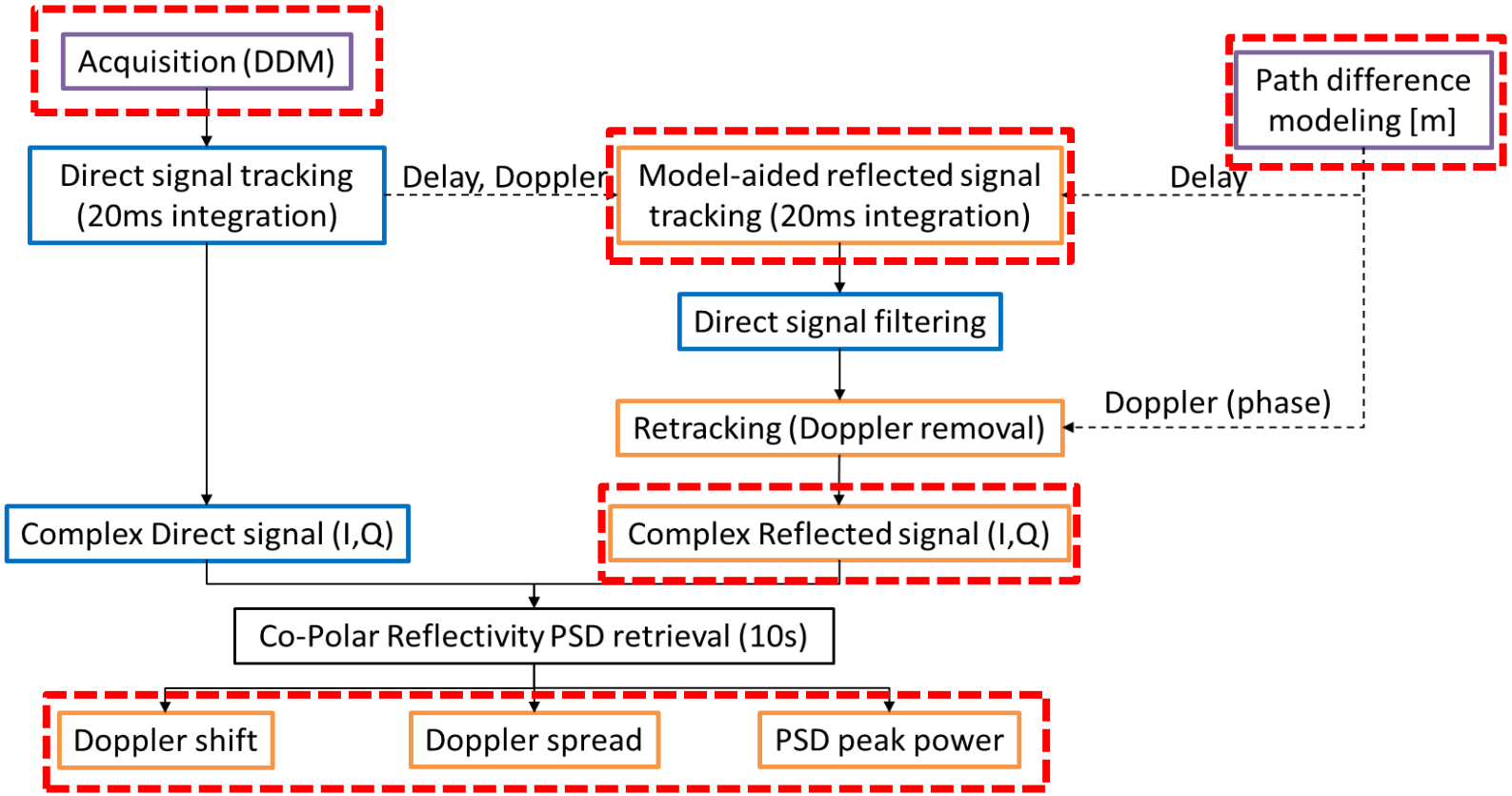


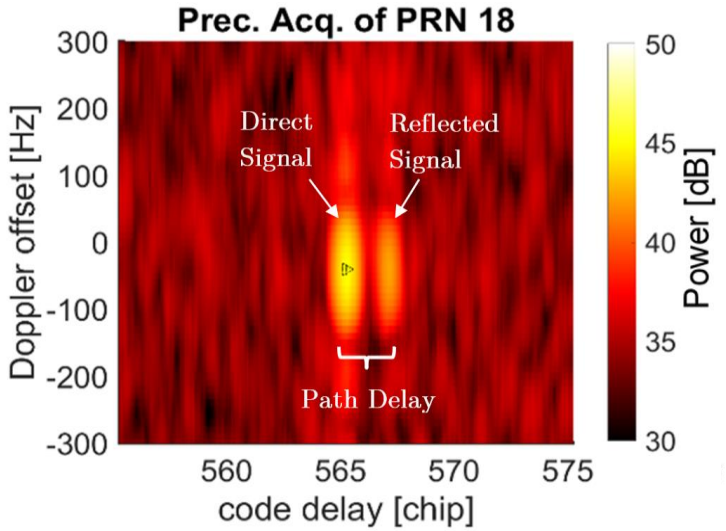




OBSERVABLES AND PROCESSING

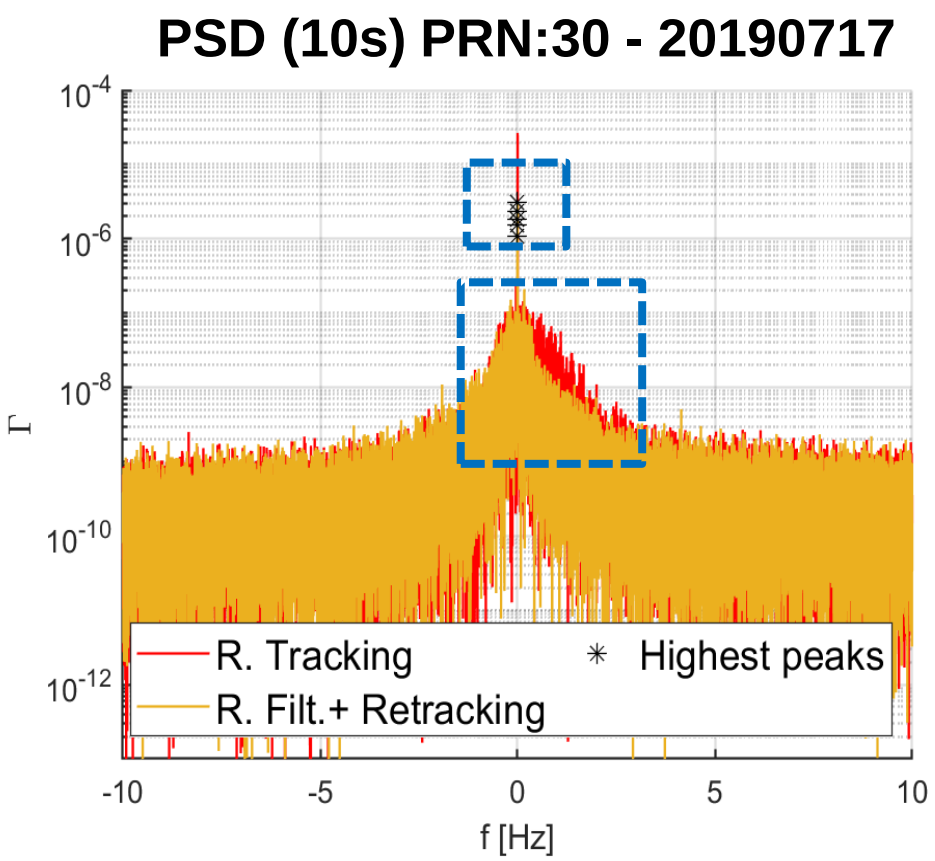
Observables: **Power** & **Doppler Shift**

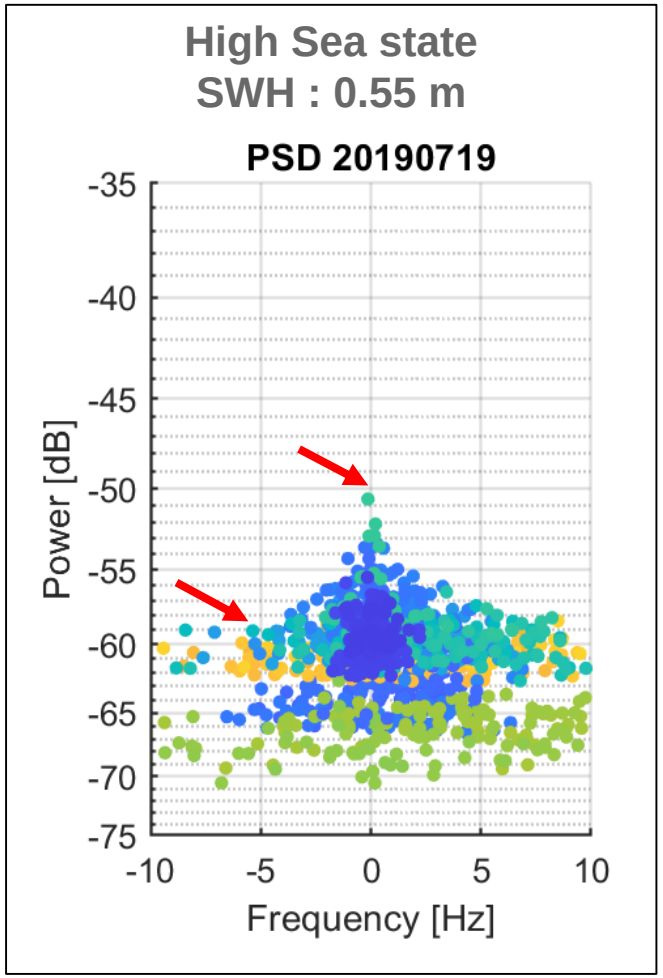


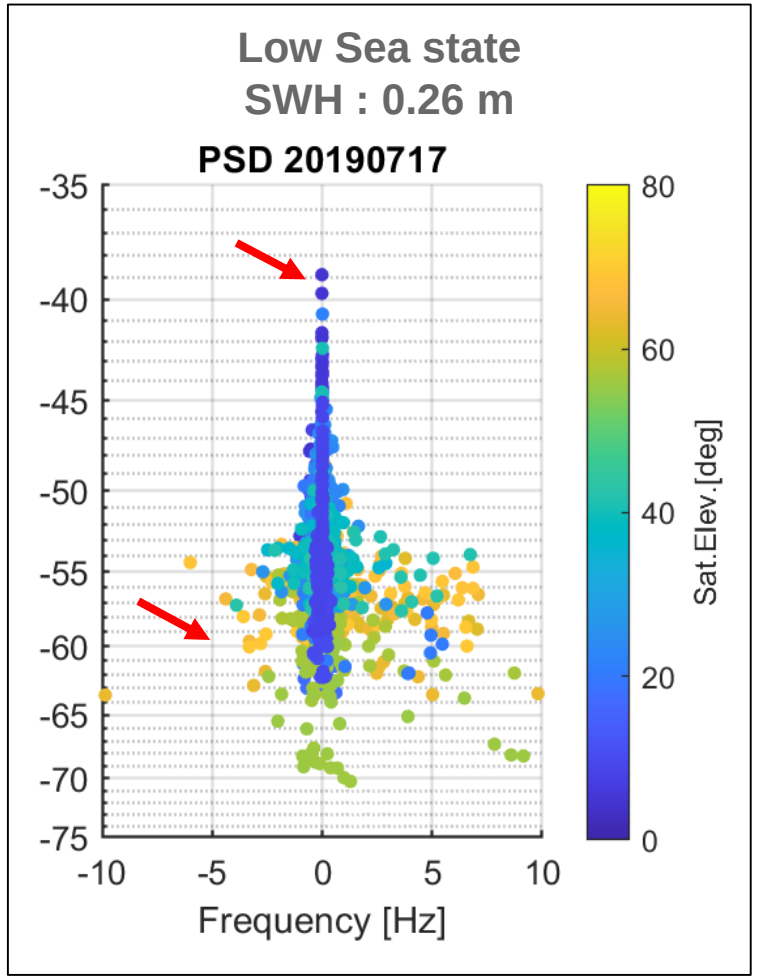


DOPPLER SHIFT ANALYSIS

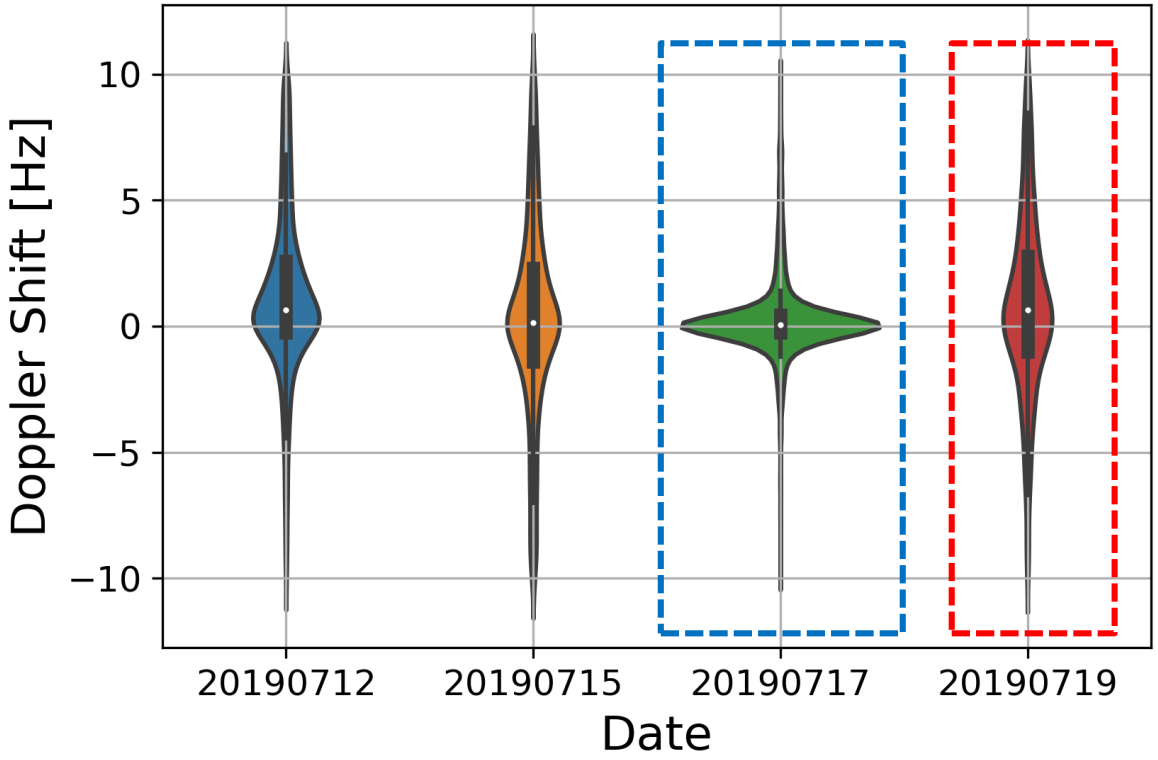
- **Observables**: **Power** & **Doppler Shift**







SEA STATE AND DOPPLER SPREAD (σ_f) CORRELATION



Doppler Spread : $\sigma_f^j = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(f_i - \mu)^2}$

σ_f dependency on:
Sea State (ss) and **Elevation (E)**

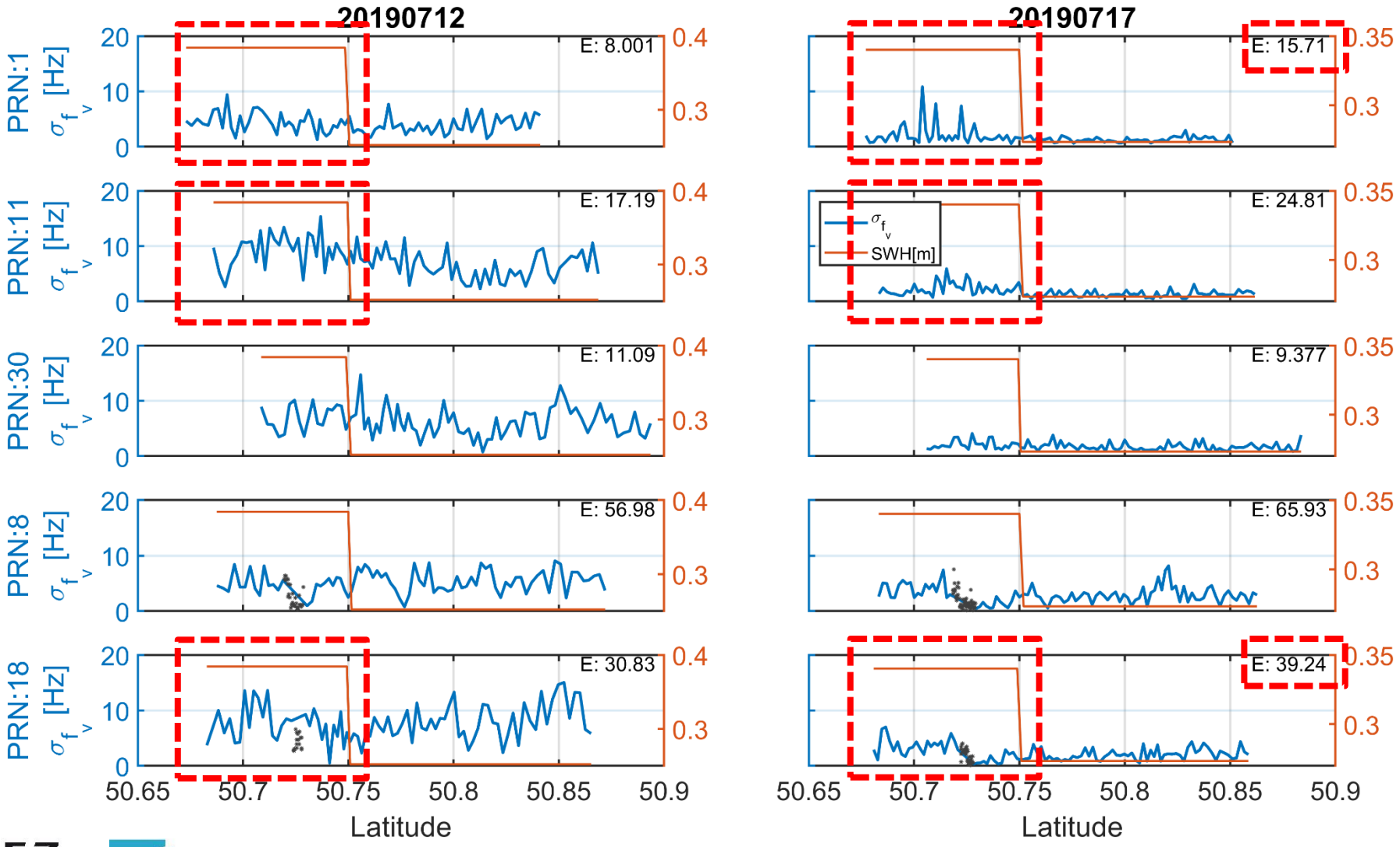
$Correlation\ (\sigma_f, ss)$		
Parameter	**E < 10°**	**E > 30°**
Wind Speed[1]	0.94	0.60
SWH[1]	0.85	0.56

[1] ERA5 Model (ECMWF)

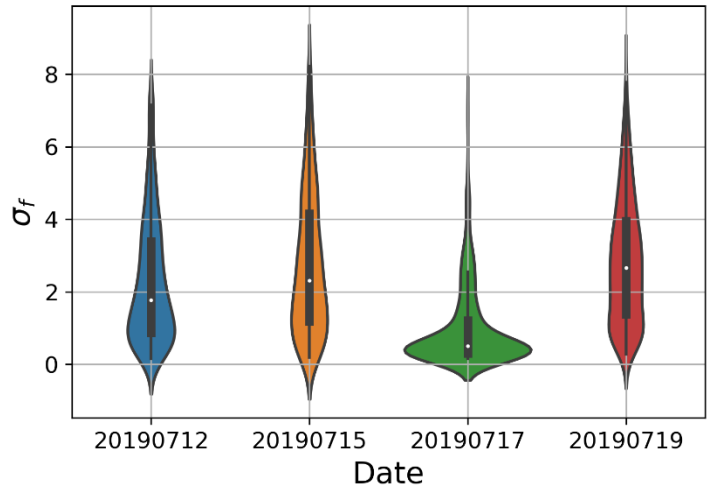
Reducing elevation dependency:

$$f_v = \frac{1}{\sin E} * \frac{d\varphi}{dt}$$

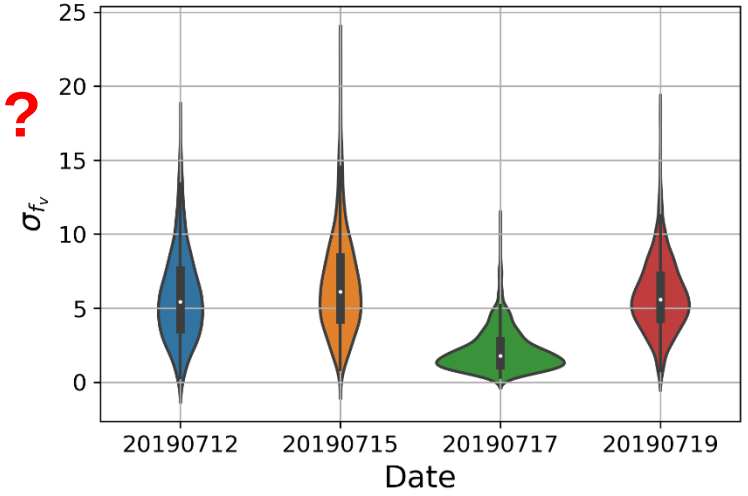
VERTICAL DOPPLER SPREAD (σ_{f_v}) COMPARISON

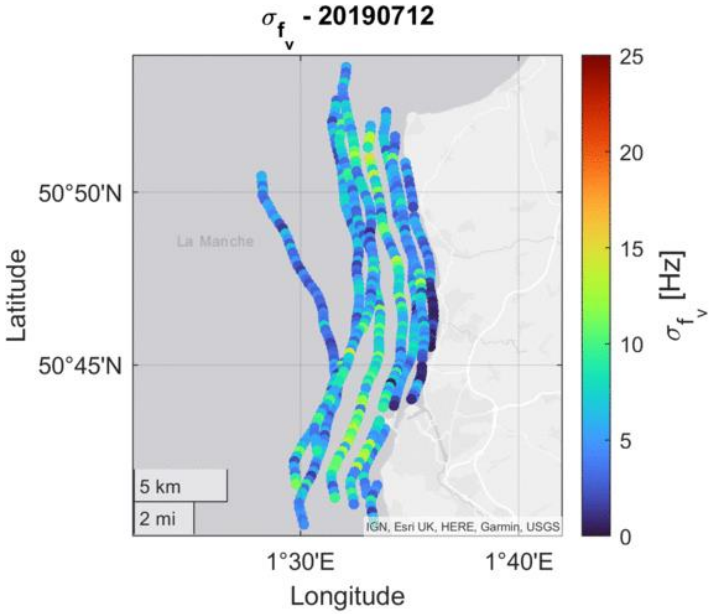


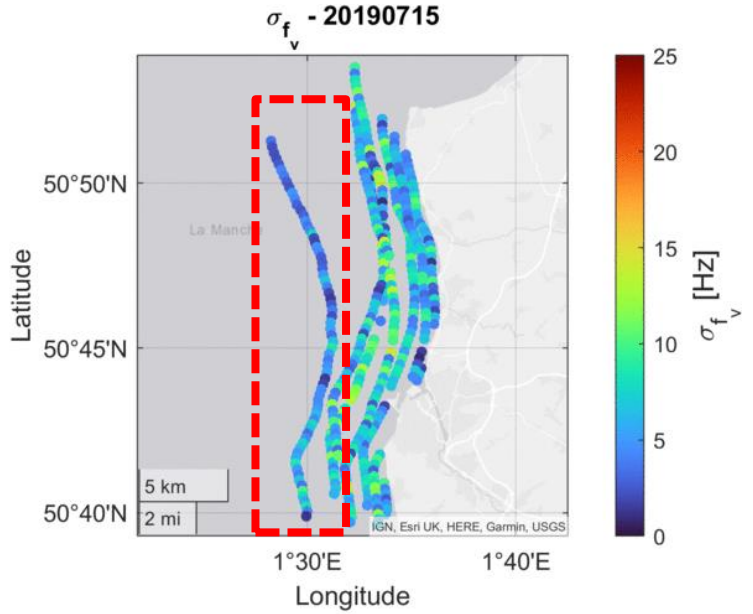
σ_f AND σ_{fv}

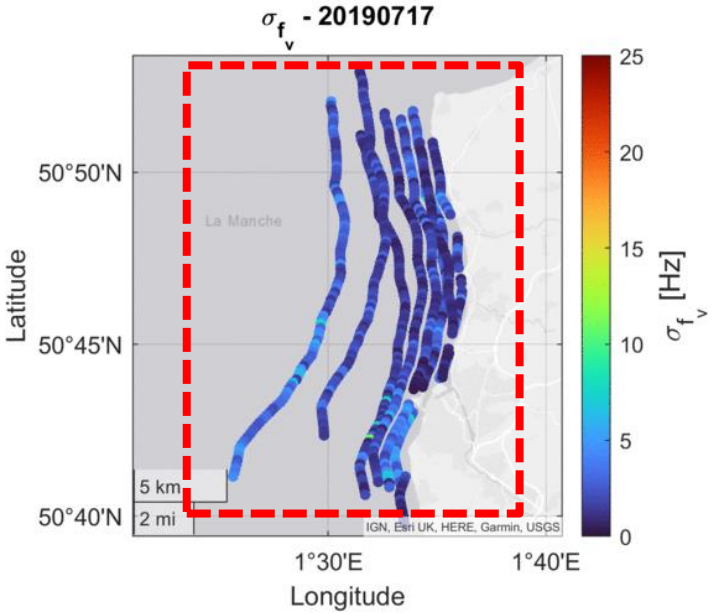


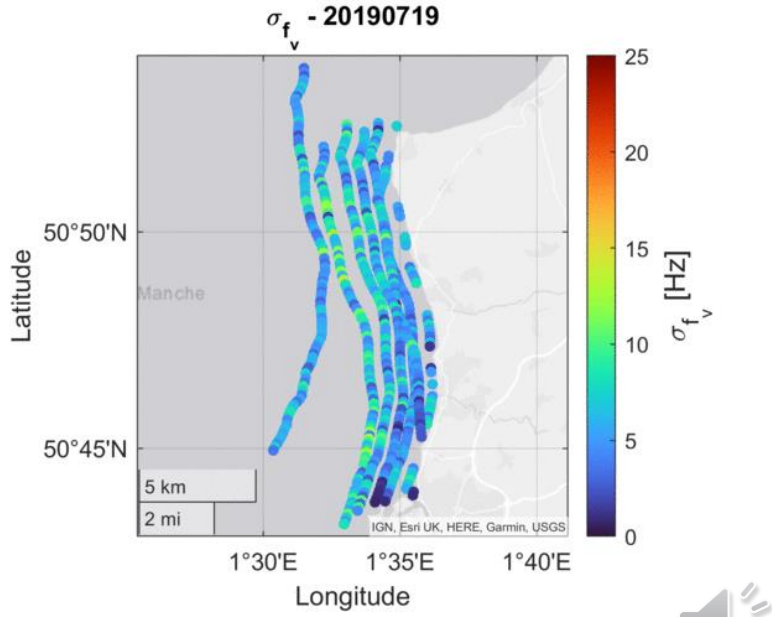
!?











CONCLUSIONS AND FUTURE WORK

The larger range in **Vertical Doppler Spread** (σ_{f_v}) is still under study. Initial analysis suggested that this behavior is due to the contribution not only from the specular zone but also from the **glistening zone (?)**

Slant Doppler spread presented a high degree correlation with respect to wind speed and significant wave height **but** also sensitive to the elevation angle changes.

The experiment setup and processing approach present a good performance and offers the possibility of monitoring the sea state in coastal areas. Further steps will consist on quantify **coherent altimetry** from Doppler spread (slant/vertical) analysis.

REFERENCES

- Nievinski, F. G., & Larson, K. M. (2014). Forward modeling of GPS multipath for near-surface reflectometry and positioning applications. GPS Solutions, 18 (2), 309–322. https://doi.org/10.1007/s10291-013-0331-y
- Chen, F., Liu, L., & Guo, F. (2019). Sea Surface Height Estimation with Multi-GNSS and Wavelet De-noising. *Scientific Reports*, *9*(1), 15181. https://doi.org/10.1038/s41598-019-51802-9
- 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
- Reinking, J., Roggenbuck, O., & Even-Tzur, G. (2019). *Estimating Wave Direction by Using Terrestrial GNSS Reflectometry*. https://doi.org/10.20944/preprints201904.0081.v1
- Roussel, N., Ramillien, G., Frappart, F., Darrozes, J., Gay, A., Biancale, R., Striebig, N., Hanquiez, V., Bertin, X., & Allain, D. (2015). Sea level monitoring and sea state estimate using a single geodetic receiver. *Remote Sensing of Environment*, *171*, 261–277. https://doi.org/10.1016/j.rse.2015.10.01
- Ruffini, G., Soulat, F., Caparrini, M., Germain, O., & Martin-Neira, M. (2003). *The GNSS-R Eddy Experiment I: Altimetry from Low Altitude Aircraft*.
- Semmling, A. M., Beckheinrich, J., Wickert, J., Beyerle, G., Schön, S., Fabra, F., Pflug, H., He, K., Schwabe, J., & Scheinert, M. (2014). Sea surface topography retrieved from GNSS reflectometry phase data of the GEOHALO flight mission. *Geophysical Research Letters*, *41*(3), 954–960. https://doi.org/10.1002/2013GL058725
- Wang, F., Yang, D., Zhang, G., Xing, J., Zhang, B., & Yang, L. (2021). Measurement of the Sea Surface Height with Airborne GNSS Reflectometry and Delay Bias Calibration. *Remote Sensing*, *13*(15), 3014. https://doi.org/10.3390/rs13153014

THANK YOU!

mario.moreno@dlr.de