living planet symposium | VIENNA 23–27 June 2025

FDR4LDYN

Preserving and Harmonising ERS C-Band Scatterometer Backscatter Data for Long-Term Land Surface Applications

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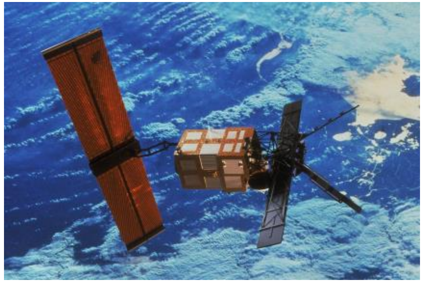
1. TU Wien | 2. TU Delft | 3. ESA-ESRIN | 4. Earth Observation Data Centre (EODC)

C.02.02 Heritage Missions and Long Time Data Series | Room 0.96/0.97 | 27 June, 08:30–10:00

European C-Band Scatterometer Series

#LPS25



ERS ESCAT

Frequency: 5.3 GHz
Polarisation: VV

Resolution: 25/50 km
Daily coverage: < 40 %

Satellites:
ERS-1: 1991–2000
ERS-2: 1995–2011

MetOp ASCAT

Frequency: 5.255 GHz
Polarisation: VV

Resolution: 15-25 km
Daily coverage: 82 %

Satellites:
MetOp-A: 2006–2021
MetOp-B: 2012–ongoing
MetOp-C: 2018–ongoing

MetOp-SG SCA

Frequency: 5.355 GHz
Polarisations: VV + VH + HH

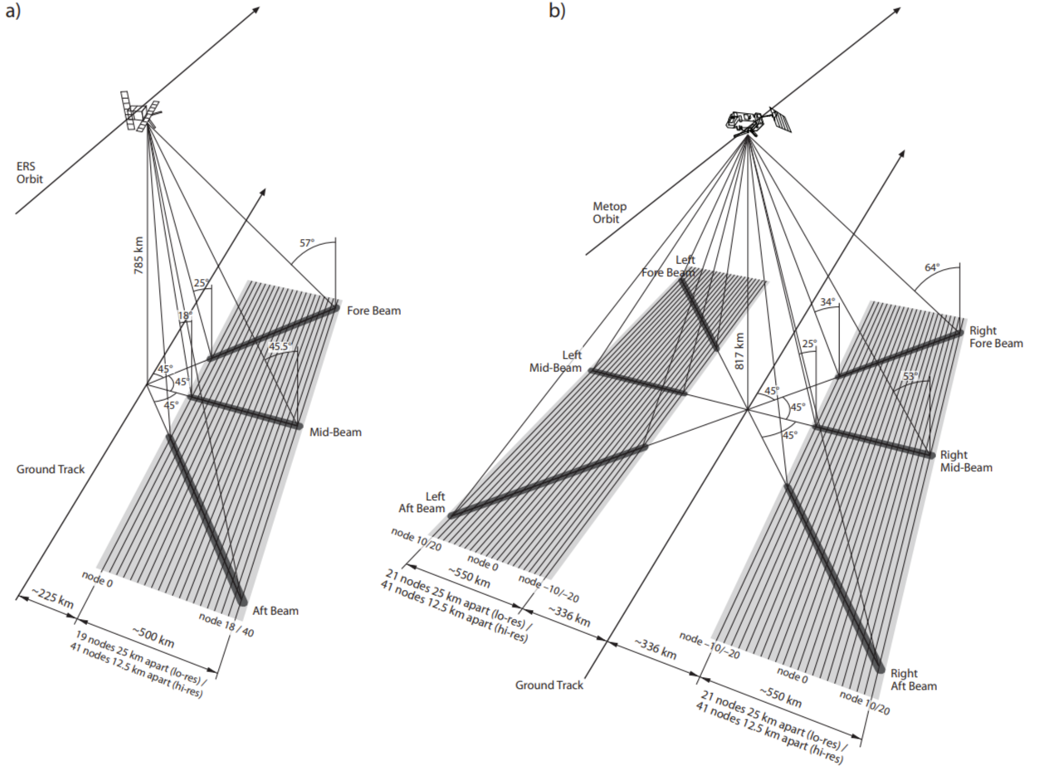
Resolution: ~ 12.5 km
Daily coverage: ~ 88 %

Satellites:
MetOp-SG-B1: launch 2026
MetOp-SG-B2: launch 2032
MetOp-SG-B3: launch 2039

Image credits: ESA, ESA/AOES Medialab, ESA–P. Carril

Comparable Measurement Principles

ERS ESCAT



MetOp ASCAT

Figure taken from Reimer (2014)

Introduction

- Scatterometer observations provide **radiometrically stable** and **well-calibrated** measurements with **high global coverage**
- Continuous data collection extends **40+ years** with SCA
- No products currently leverage long-term observation history

➡ Fundamental **D**ata **R**ecords **for L**and **Dyn**amics = **FDR4LDYN**
(2024 – 2027)

Objectives

- Prepare **ERS-1/2** C-band scatterometer (ESCAT) backscatter, slope and curvature data for interoperability with **current** ASCAT and **future** SCA missions

- Support **scientific research** and **operational applications** by collaborating with EUMETSAT

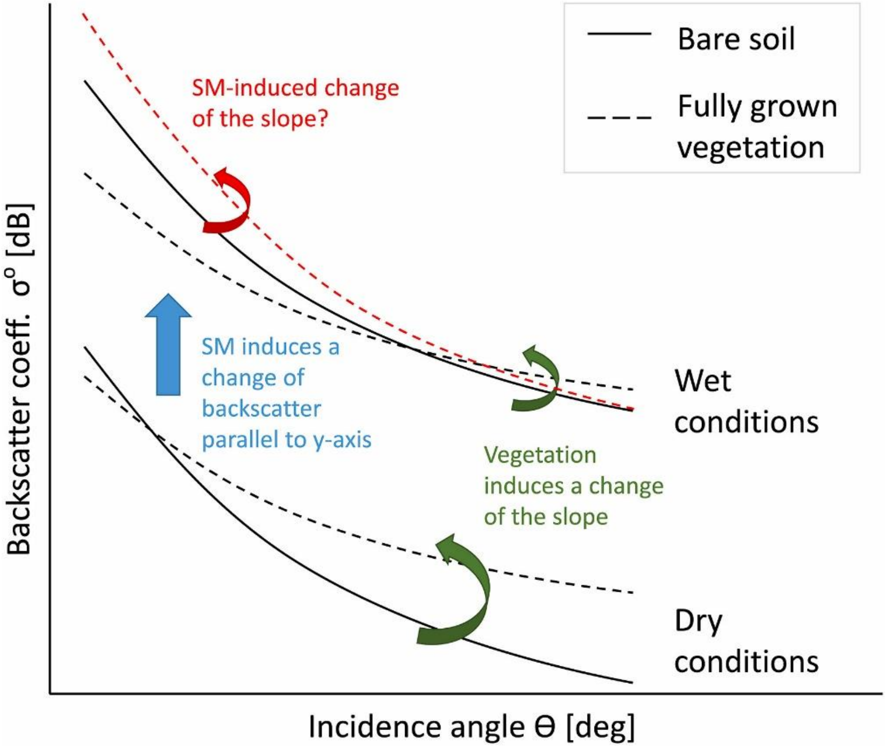


Figure taken from Greimeister-Pfeil (2022)

Scientific Use Cases

Soil moisture

Vegetation monitoring

Surface water and flood dynamics

+ climate change studies, cryospheric research, etc.

Image credits: Pixabay/M_wie_Moehre, Pixabay/Tom, Pixabay/Tri Le

Activities and Results

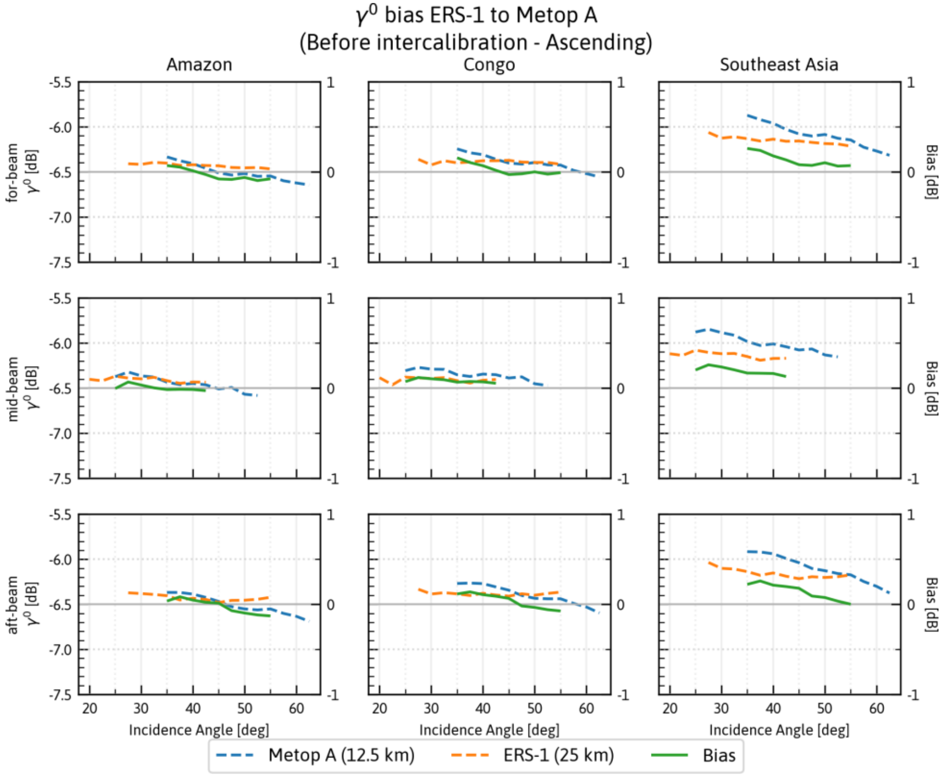
1. Quality assessment
2. Inter-calibration with ASCAT
3. Synthetic ESCAT experiment
4. **Azimuthal correction + Uncertainty estimates**
5. **Slope/ curvature variants**
6. **Normalised backscatter**
7. *Demonstration of scientific potential*

- **Resulting products:**
  - **backscatter, slope, curvature** (including quality flags)
  - slope/curvature variants and local slopes
  - yearly azimuth reference polynomials and yearly uncertainty estimates

Example Activity 1

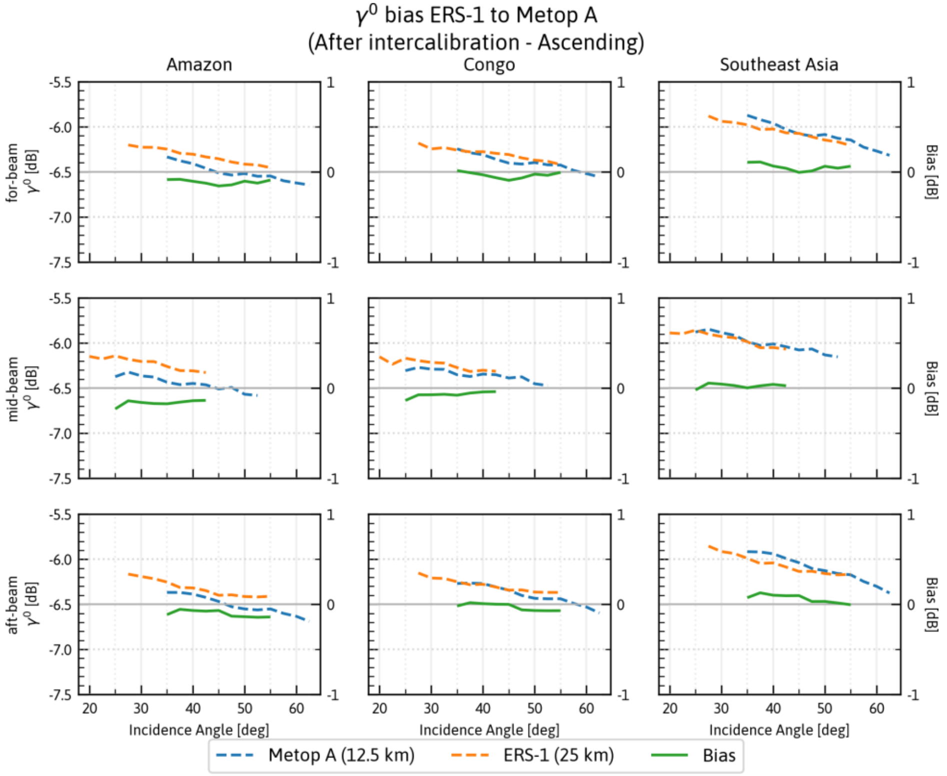
- **Inter-calibration with MetOp ASCAT:**
  - correct breaks and trends
  - harmonise measurements between fore/mid/aft beams
  - calibrate ESCAT measurements to ASCAT to ensure interoperability

Inter-Calibration with MetOp ASCAT



Before inter-cal

Inter-Calibration with MetOp ASCAT

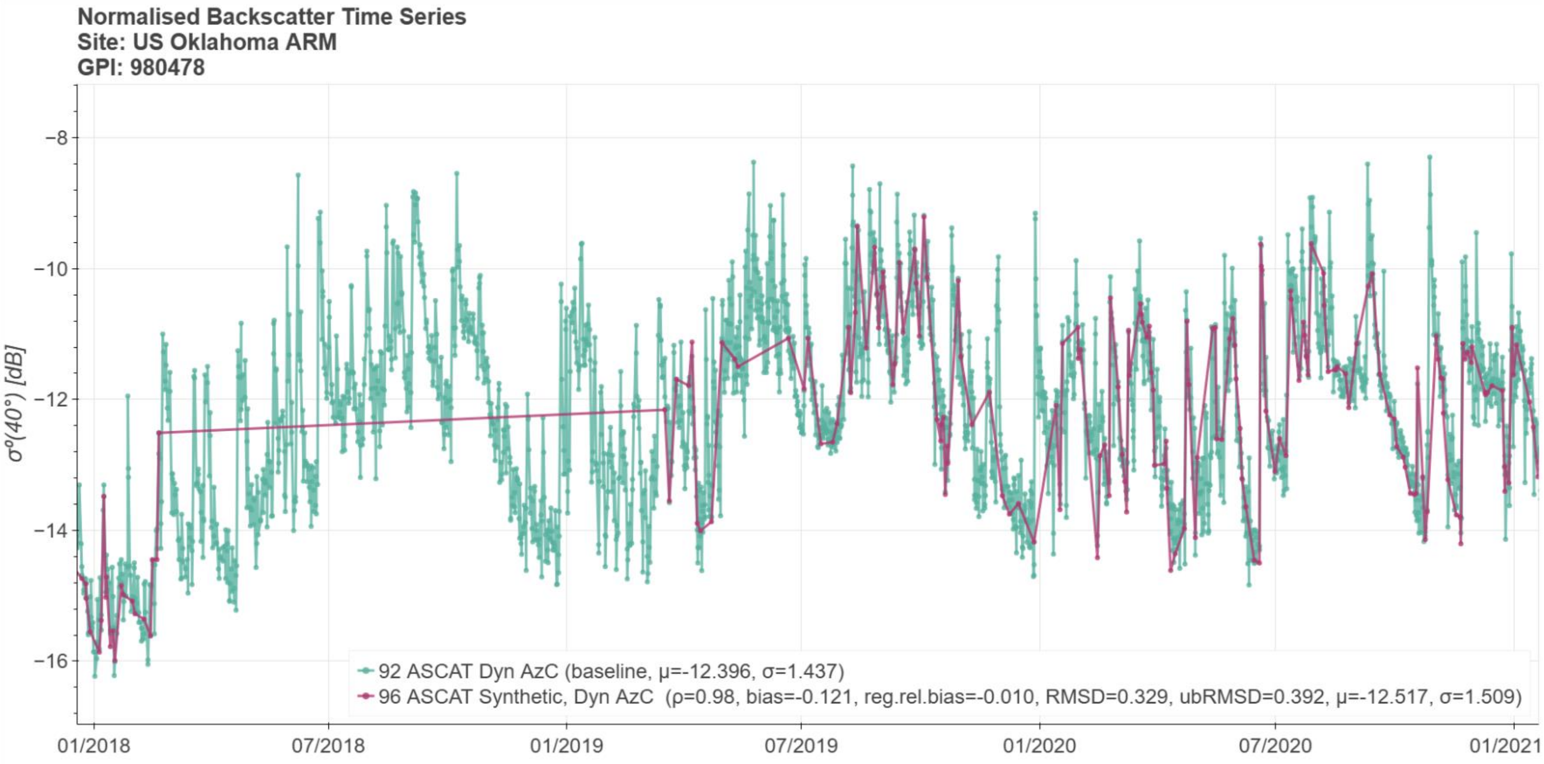


After inter-cal

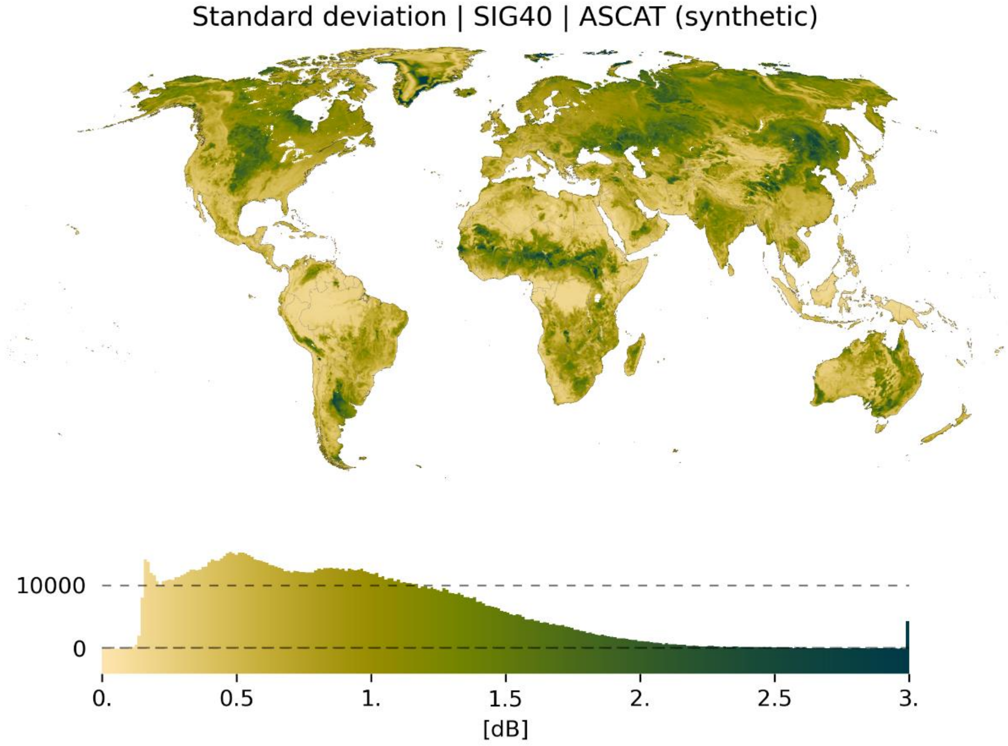
Example Activity 2

- **Synthetic ESCAT experiment:**
  - understand the implications of coarse temporal resolution and data gaps
  - subsample ASCAT time series to mimic ESCAT temporal sampling
  - compare original ASCAT with subsampled ASCAT

Synthetic ESCAT Experiment

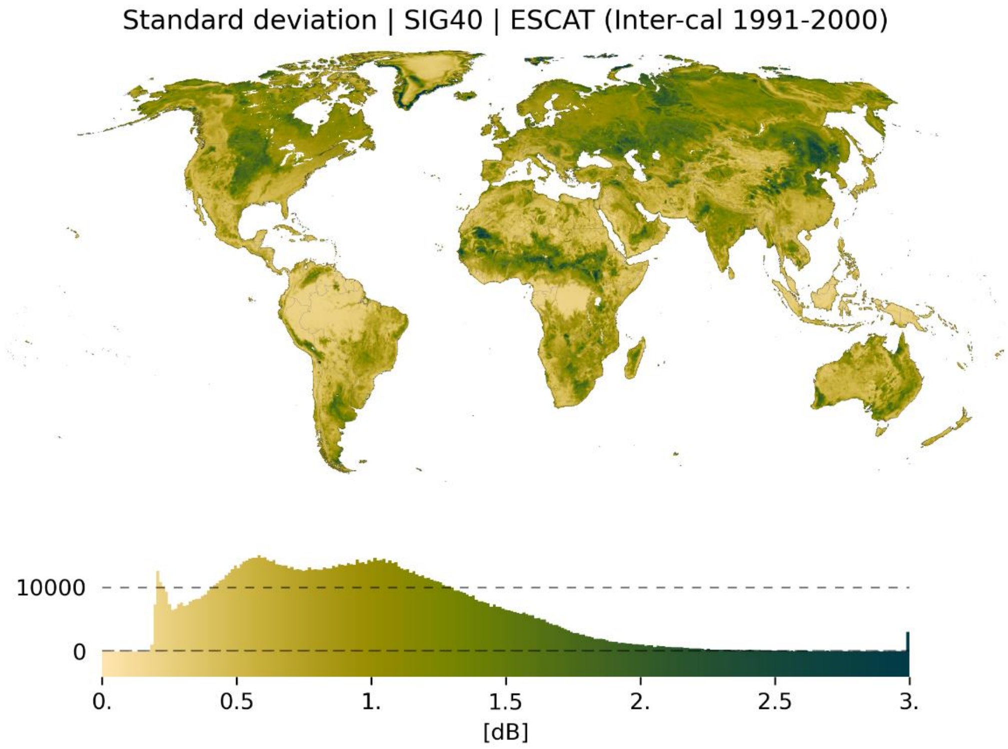


Synthetic ESCAT Experiment



Synthetic ESCAT

Synthetic ESCAT Experiment



Original ESCAT

Outreach

- Website: https://fdr4ldyn.project.tuwien.ac.at/
  - stay informed with our **newsletter**
- Jupyter notebooks
  - clear, practical guides for accessing the FDR4LDYN data records
  - directly experiment with your own analyses
- Python packages

In a Nutshell

- Leverage **ERS heritage** data for interoperability with **current** ASCAT and **future** SCA missions
- Prepare for a **40+ years** scatterometer backscatter data record for **land applications** serving **diverse user communities**
- **Main activities** along the way:
  - inter-calibration and interoperability
  - azimuthal correction and uncertainty estimation
  - alternative methods to retrieve slope and curvature estimates

QUESTIONS & ANSWERS

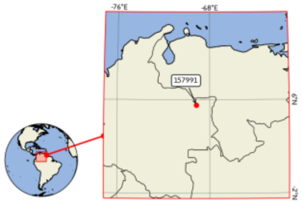
References and Credits

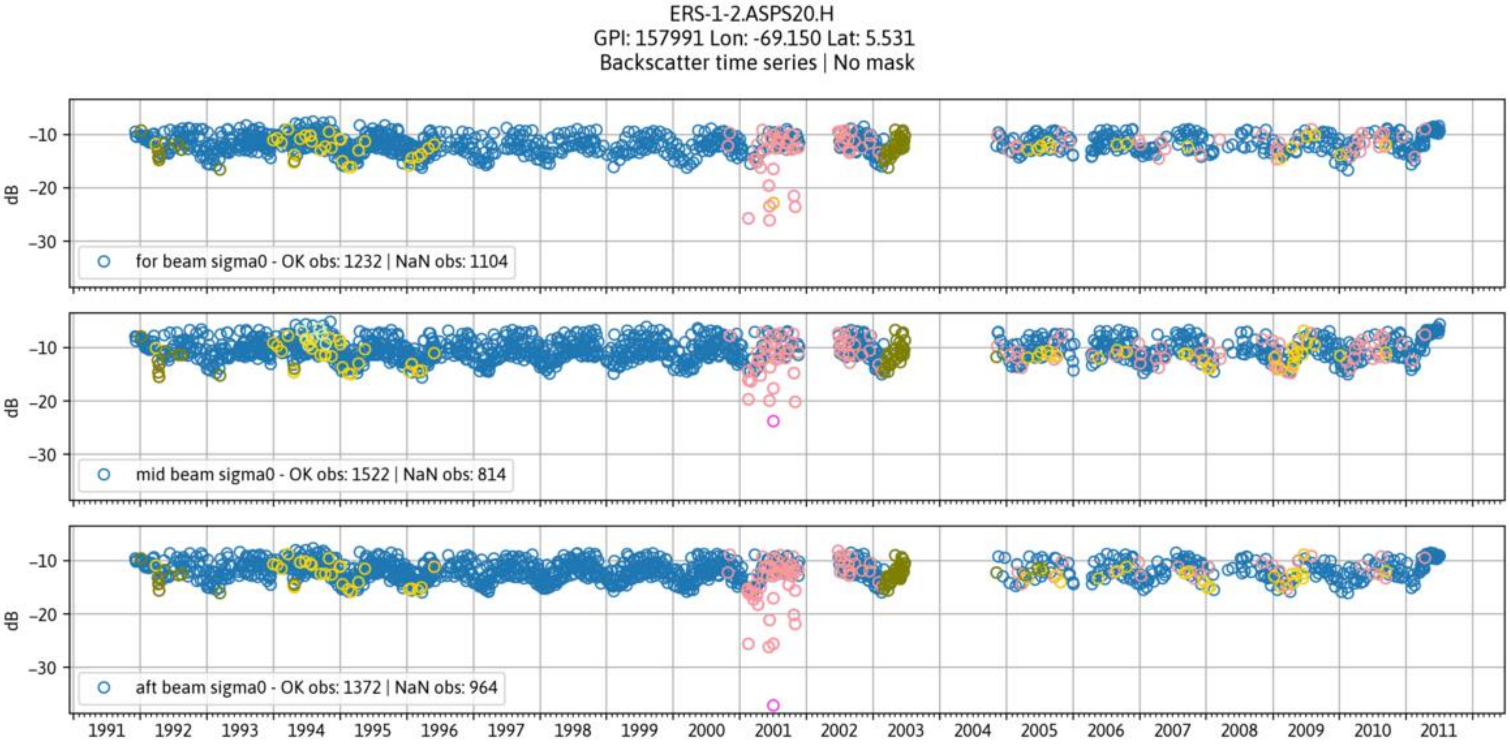
#LPS25

- Reimer, C., “Calibration of space-borne Scatterometers: Towards a consistent climate data record for Soil Moisture Retrieval,” Vienna University of Technology, Department of Geodesy and Geoinformation, Austria, 2014. doi: https://doi.org/10.34726/hss.2014.25022.
- Greimeister-Pfeil, I., Wagner, W., Quast, R., Hahn, S., Steele-Dunne, S., and Vreugdenhil, M., “Analysis of short-term soil moisture effects on the ascat backscatter-incidence angle dependence,” Science of Remote Sensing, vol. 5, p. 100 053, 2022. doi: https:// doi.org/ 10.1016/ j.srs.2022.100053.
- Bartalis, Z., Scipal, K., and Wagner, W., “Azimuthal anisotropy of scatterometer measurements over land,” IEEE Transactions on Geoscience and Remote Sensing, vol. 44, no. 8, pp. 2083–2092, 2006. doi: 10.1109/TGRS.2006.872084.
- Lindorfer, R., “Azimuthal anisotropy in ASCAT backscatter measurements,” Technische Universität Wien, Vienna, Austria, 2024. doi: https://doi.org/10.34726/hss.2024.120220.
- Frantzen, P., Steele-Dunne, S. C., Quaife, T., Vreugdenhil, M., Hahn, S., and Wagner, W., “Improved Estimation of Temporal Dynamics in the ASCAT Backscatter-Incidence Angle Relation Using Regularization,” IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, vol. 18, pp. 13 457–13 471, 2025. doi: 10.1109/JSTARS.2025.3572306.

- Images have been used from ESA’s multimedia library and Pixabay.com.
- Icons have been used from Flaticon.com.

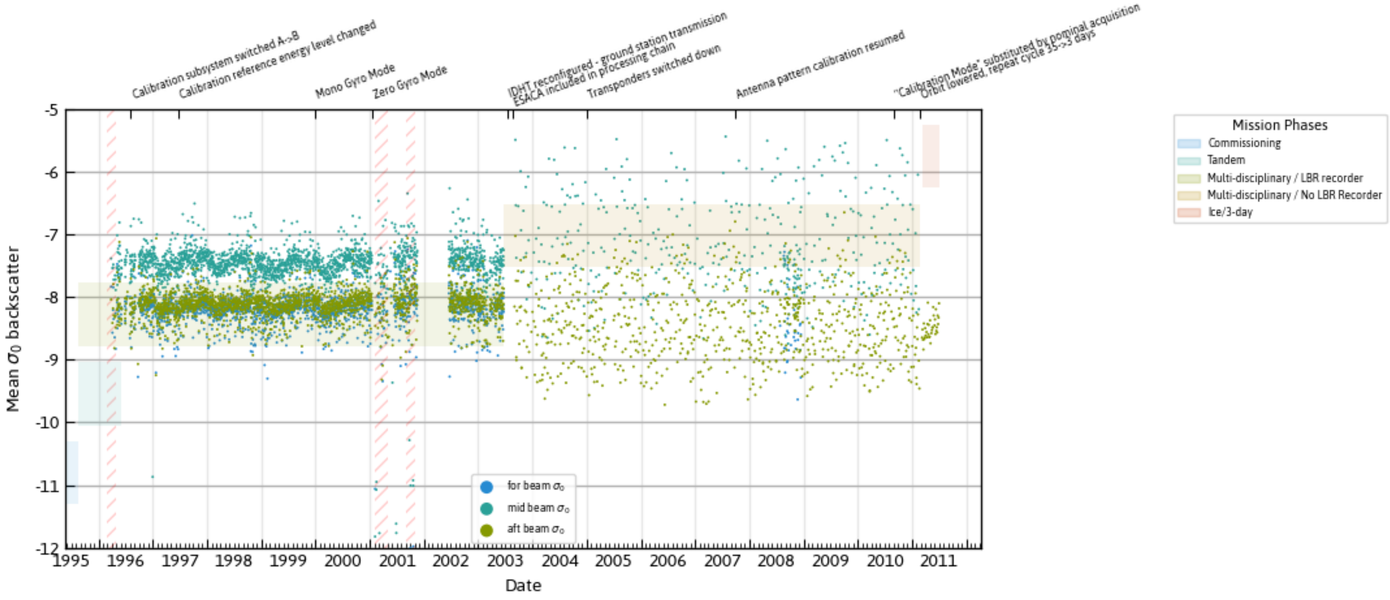
Appendix A: Quality Checking



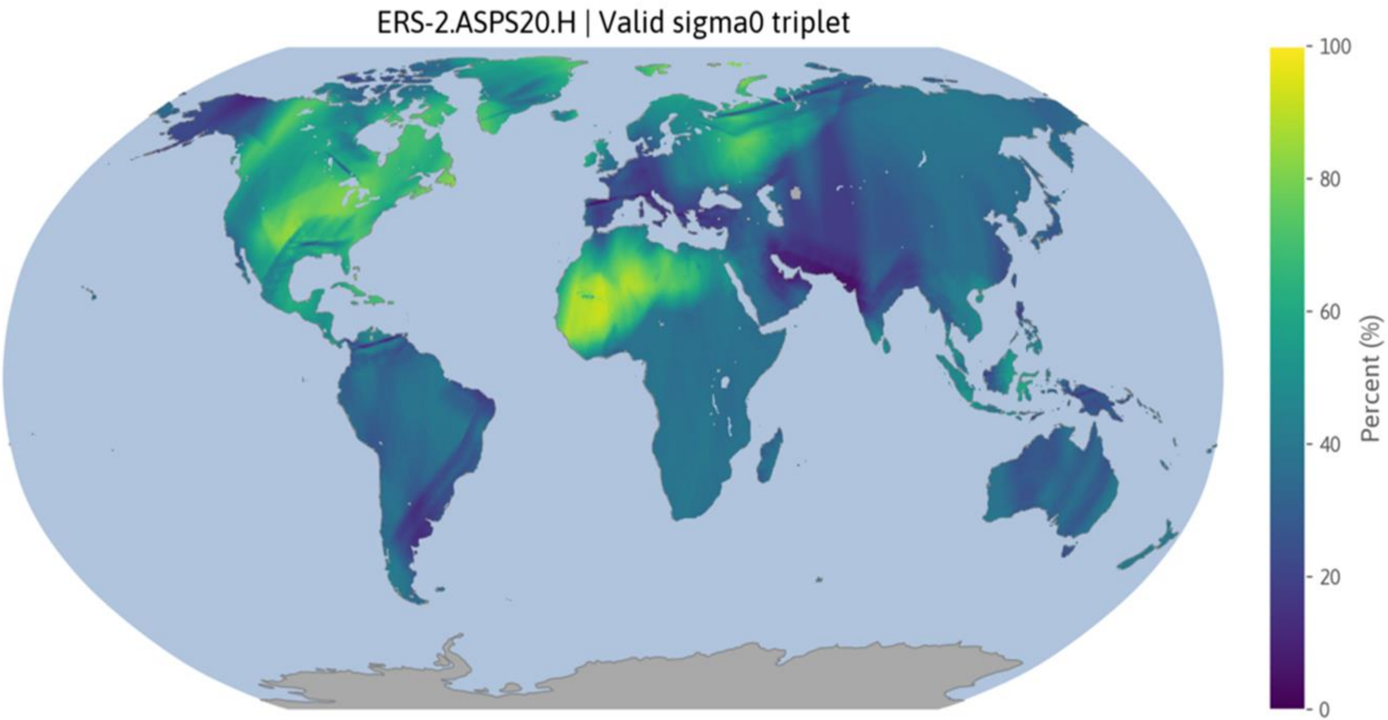


Appendix A: Quality Checking

Periods with anomalous backscatter-incidence angle relationships
in at least two azimuth configurations
ERS-2 25km
(Calibration region: Congo)



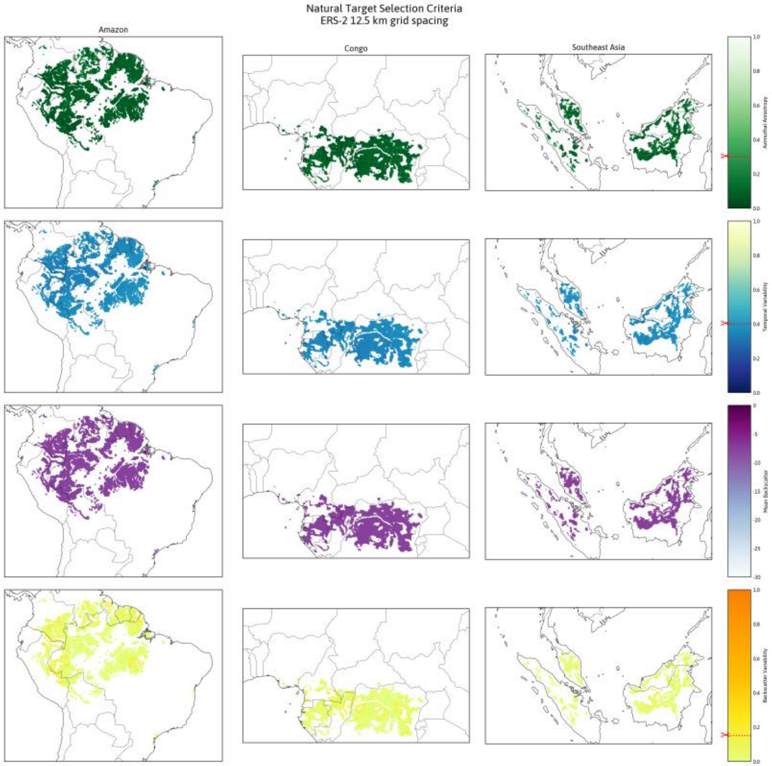
Appendix A: Quality Checking



Appendix B: Inter-Calibration with ASCAT

- Adapt methodology from Reimer (2014):
  - use **Amazon** and **Congo rainforests** as reference regions
    - azimuth isotropy (< 0.2 dB for ASCAT, < 0.3 dB for ERS)
    - temporal stability (< 0.4 dB)
    - spatial homogeneity (< 0.15 dB)
  - reserve **Southeast Asia** for validation
  - month-wise **intra-calibration** of sensor beams
  - use **Metop-A** as a reference for inter-calibration of ERS
  - calibrate in **gamma-nought** rather than sigma-nought

Appendix B: Inter-Calibration with ASCAT



Appendix B: Inter-Calibration with ASCAT

- Normalise σ^0 to 40° incidence angle (per month, per azimuth configuration)
- Remove seasonal effects (subtract daily climatology and add back long-term mean)
- Un-normalise and convert to γ^0
- Fit reference polynomial for each region and orbit direction

$$\overline{\gamma^0}(L_T, \theta) = B_0(L_T, 40°) + B_1(L_T, 40°)\cdot(\theta - 40°)$$

- Calculate deviation between measured and expected backscatter

$$C_{IAS}(L_T, t_i, \theta, \phi_j) = \gamma^0(L_T, t_i, \theta, \phi_j) - \overline{\gamma^0}(L_T, \theta)$$

- Model deviations as function of incidence angle for each month

$$\overline{C_{IAS}}(L_T, t_i, \theta, \phi_j) = C_0(L_T, t_i, 40°, \phi_j) \text{ (Metop)}$$

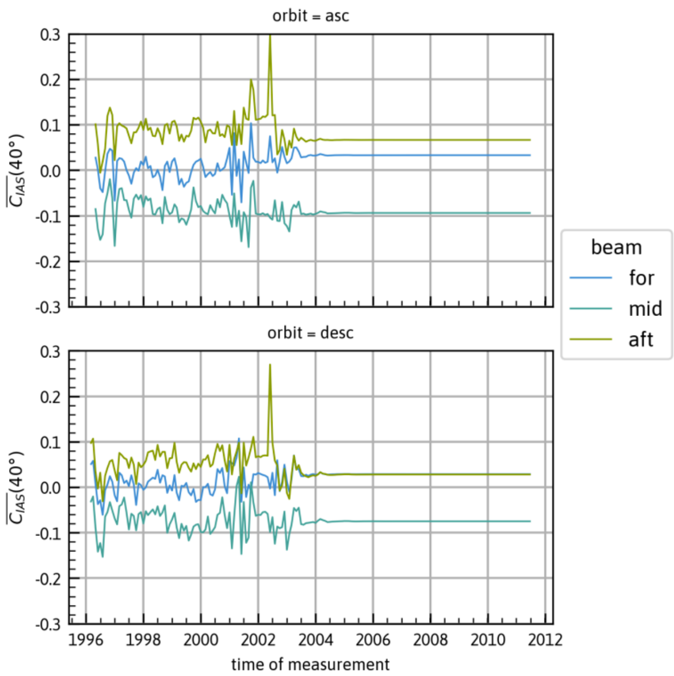
$$\overline{C_{IAS}}(L_T, t_i, \theta, \phi_j) = C_0(L_T, t_i, 40°, \phi_j) + C_1(L_T, t_i, 40°, \phi_j)\cdot(\theta - 40°) \text{ (ERS)}$$

- Compute weighted average of correction coefficients from both regions
  - weights harmonic sum of MSEs of $\overline{\gamma^0}(L_T, \theta)$ and $C_{IAS}(L_T, t_i, \theta, \phi_j)$
- Apply correction coefficients to backscatter as γ^0 and convert back to σ^0

$$\gamma^0_{intra}(L, t_i, \theta, \phi_j) = \gamma^0(L, t_i, \theta, \phi_j) - \overline{C_{IAS}}(t_i, \theta, \phi_j)$$

Appendix B: Inter-Calibration with ASCAT

Global $\overline{C_{IAS}}(40°)$ evolution (right swath)
ERS-2 25 km



Appendix C: Synthetic ESCAT Experiment

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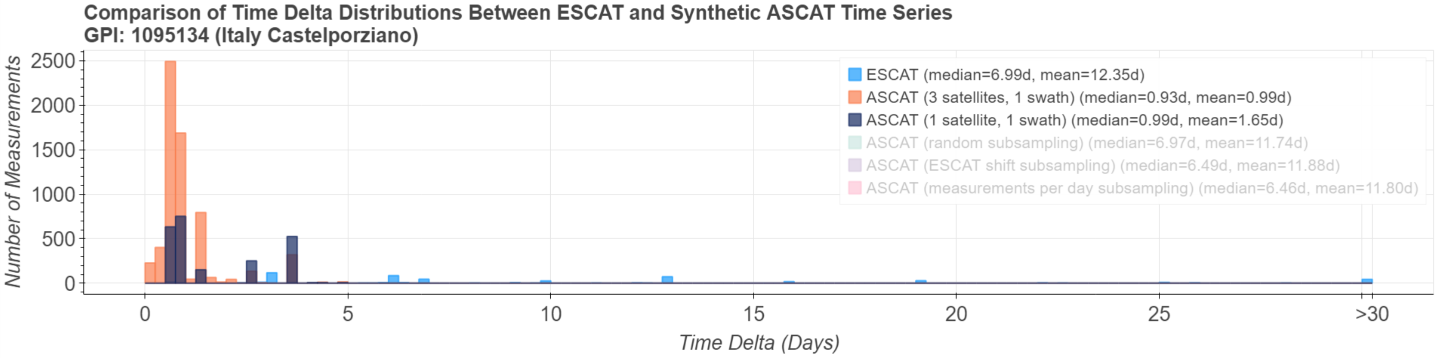
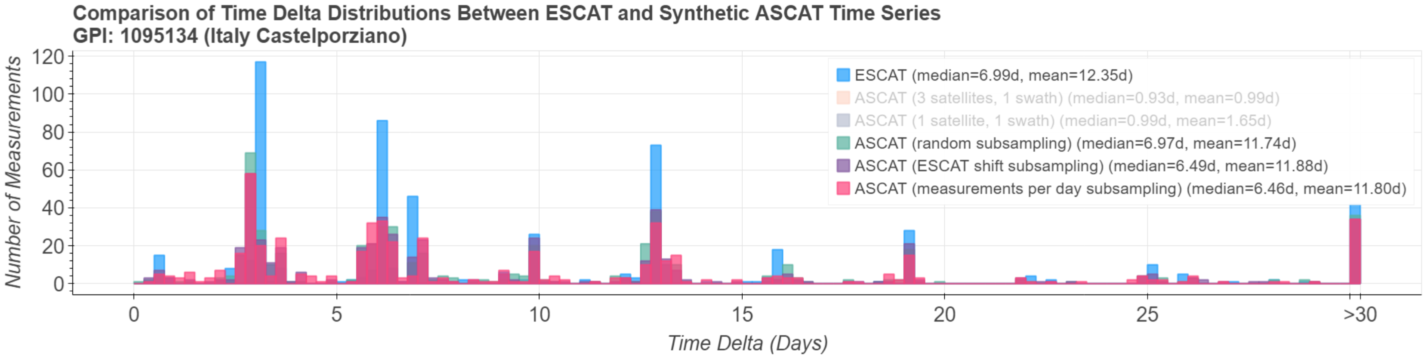
- **Subsampling process:**
  - remove left swath data and limit incidence angle range to match ESCAT
  - shift ESCAT time series by 15 years
  - match as many ESCAT timestamps as possible to ASCAT timestamps with maximum-cardinality matching Hopcroft–Karp algorithm

Appendix C: Synthetic ESCAT Experiment





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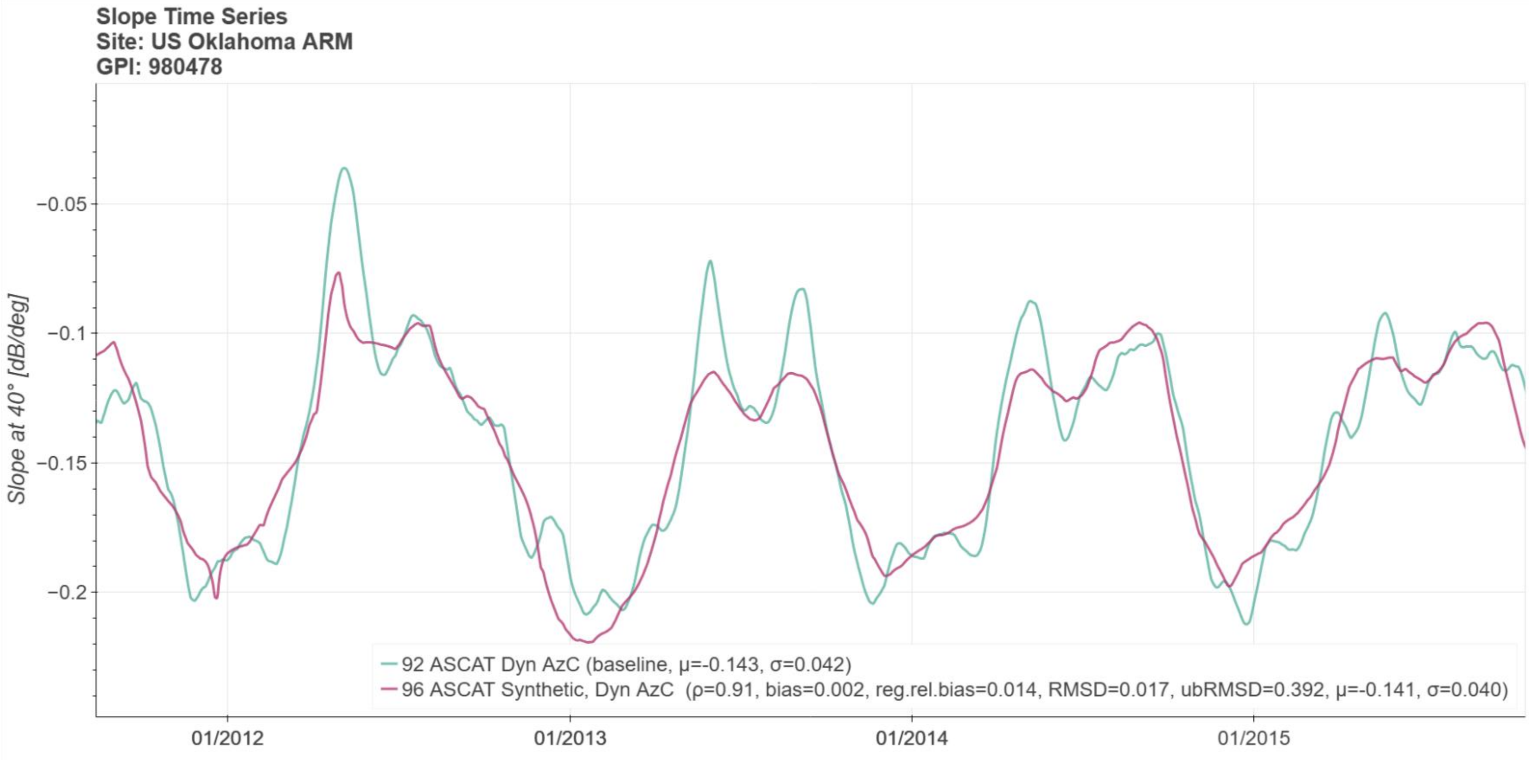

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Appendix D: Azimuthal Correction

- **Update azimuthal correction:**
  - yearly correction polynomials (land cover change, RFI, strong point scatterers)
  - switch to fixed reference azimuth angle (right swath, mid beam)

Appendix D: Azimuthal Correction

Driving mechanisms of azimuthal anisotropy:

- sloping surface backscattering targets with a predominant slope orientation
- corner reflectors with a predominant orientation
- resonant Bragg scattering

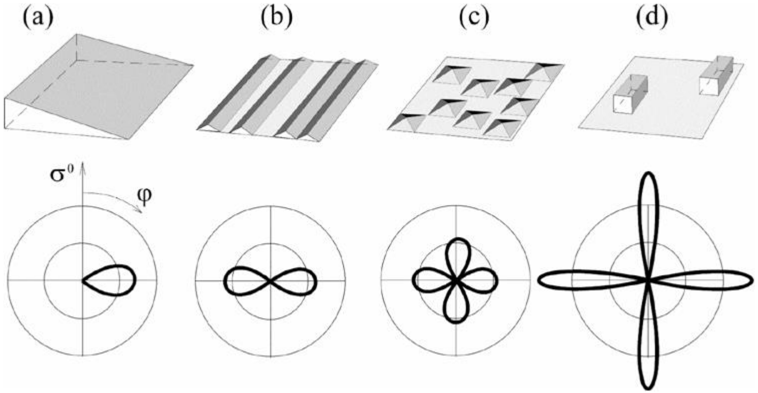


Figure taken from Bartalis et al. (2006)

Appendix D: Azimuthal Correction

- Azimuthal anisotropy is considered noise for most land surface applications:
  - underlying geophysical variable does not depend on viewing geometry
- But:
  - can be an indicator of changes in land cover or surface roughness

➡ **Publication as dedicated data record**

Appendix D: Azimuthal Correction

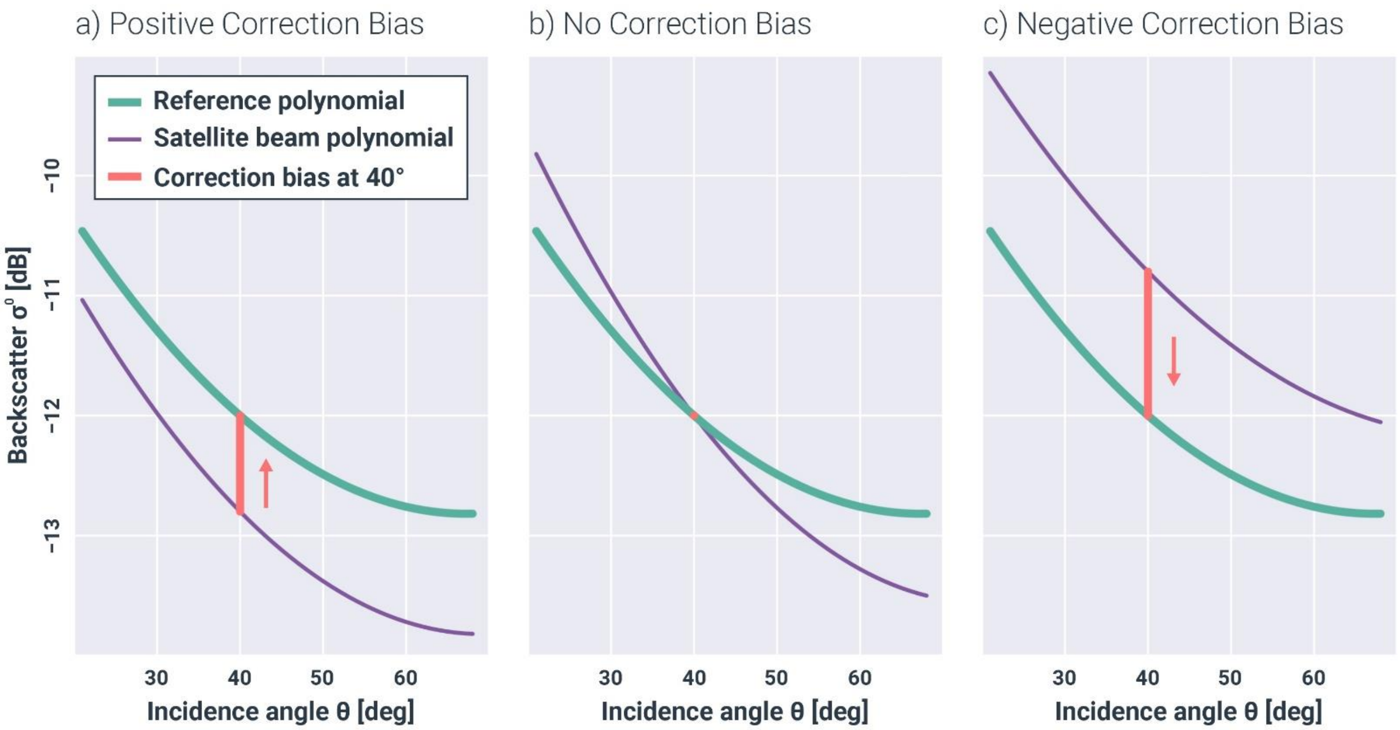
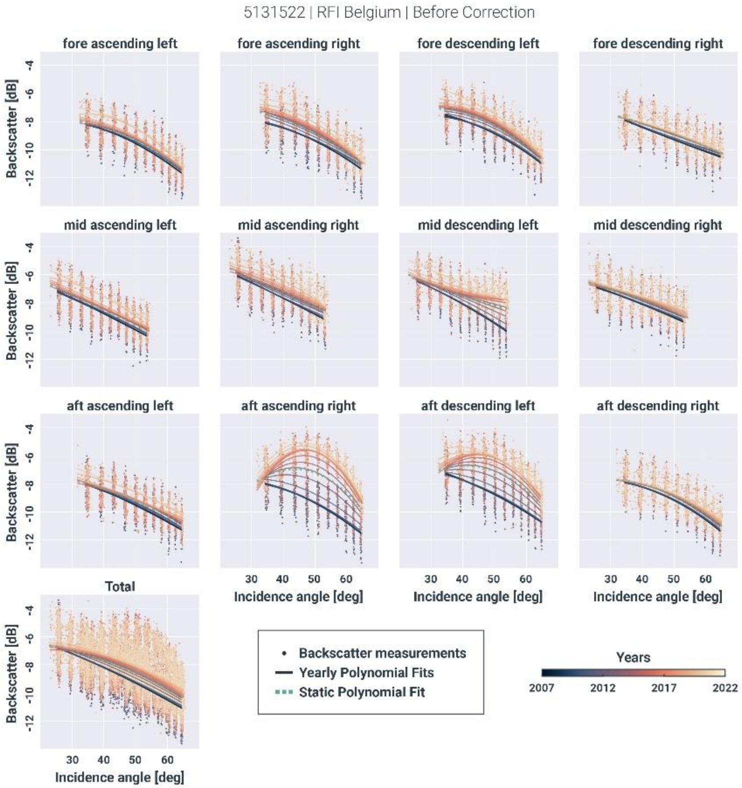


Figure taken from Lindorfer (2024)

Appendix D: Azimuthal Correction



Example:
strong point scatterer before correction

Figure taken from Lindorfer (2024)

Appendix D: Azimuthal Correction

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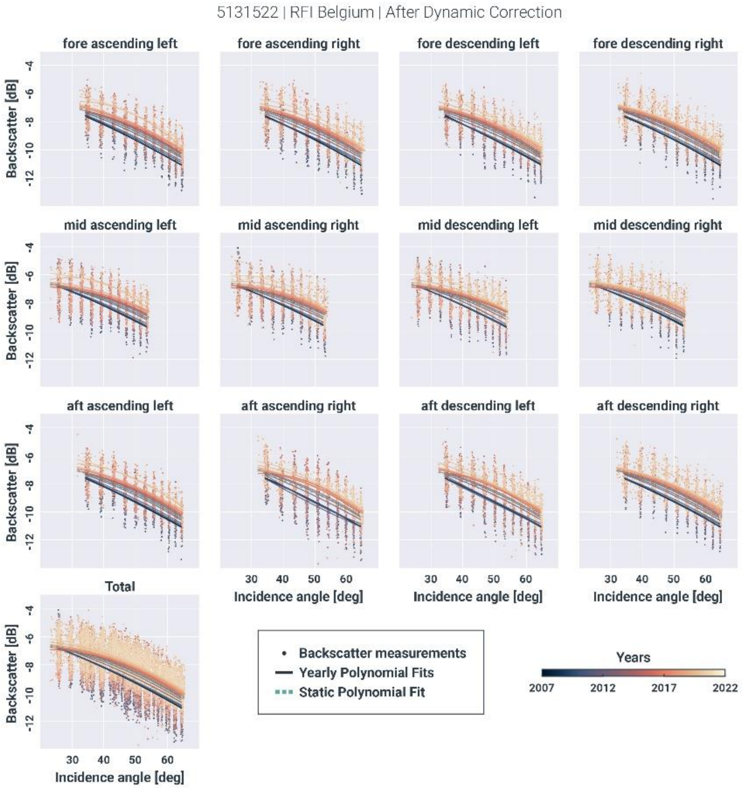

Example:
strong point scatterer after correction

Figure taken from Lindorfer (2024)

Appendix E: Uncertainty Estimation (ESD)

#LPS25

- Estimated standard deviation (ESD) = estimation of noise in σ^0
  - starting point of error propagation in TU Wien soil moisture retrieval
  - indicator of (residual) azimuthal effects
- ESD is derived from the difference between fore beam σ^0 and aft beam σ^0
  - computed before and after azimuthal correction
- Yearly calculation to explore temporal dynamics

➡ **Publication as dedicated data record**

Appendix E: Uncertainty Estimation (ESD)

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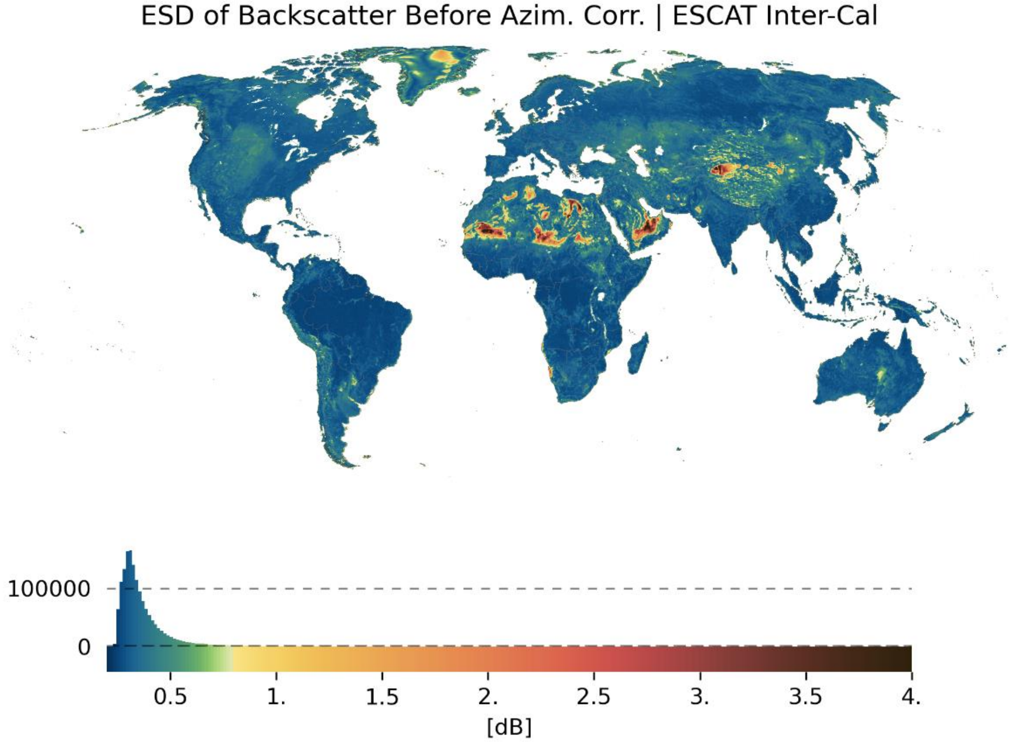

Appendix E: Uncertainty Estimation (ESD)

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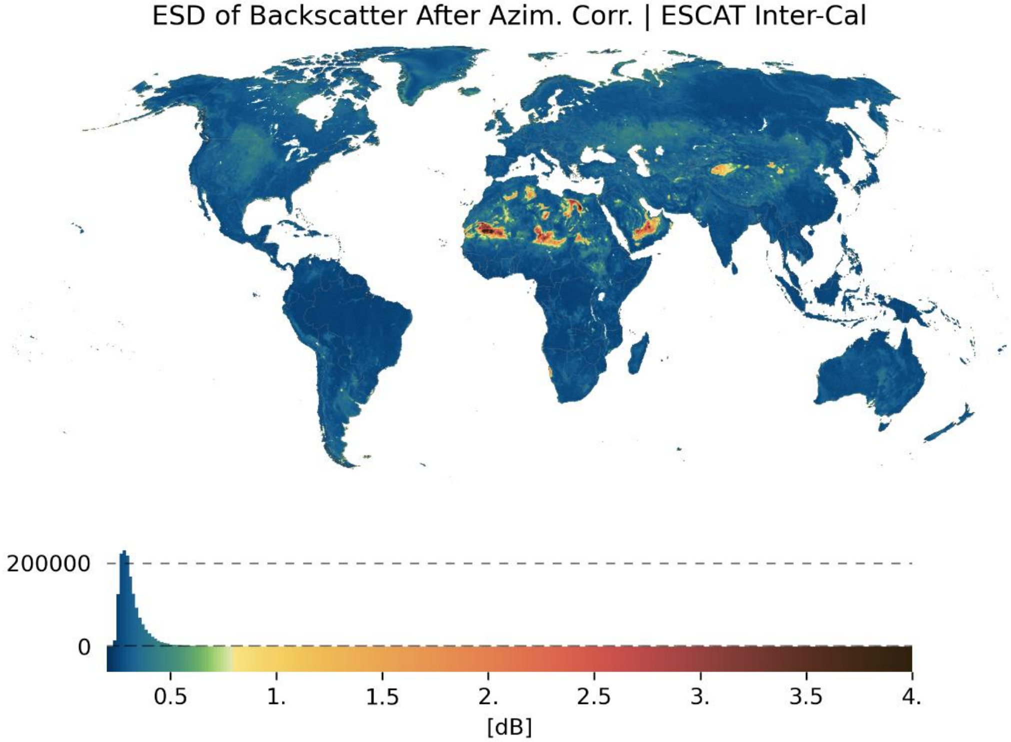
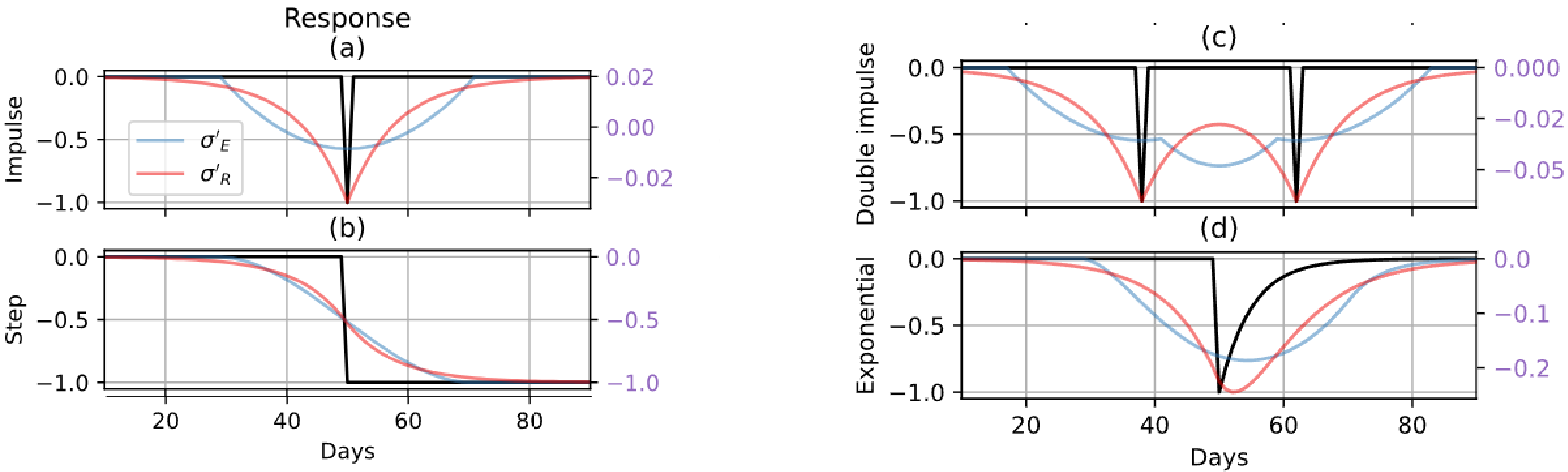


Appendix F: Alternative Slope/Curvature

- Current approach: kernel smoother method
- Empirical Bayesian approach:
  - simultaneous **correction** of dynamic (yearly) and **estimation** of aggregate (climatology) slope/curvature
- Regularisation approach:
  - mitigates potential artefacts introduced by kernel smoother method
  - captures changes in slope/curvature **at the right time**

Appendix F: Alternative Slope/Curvature



black: impulse | blue: kernel smoother | red: regularisation method

Figure taken from Frantzen et al. (2025)