Assessing prospects of sub-daily radar-observations to improve the understanding of soil- and vegetation dynamics.

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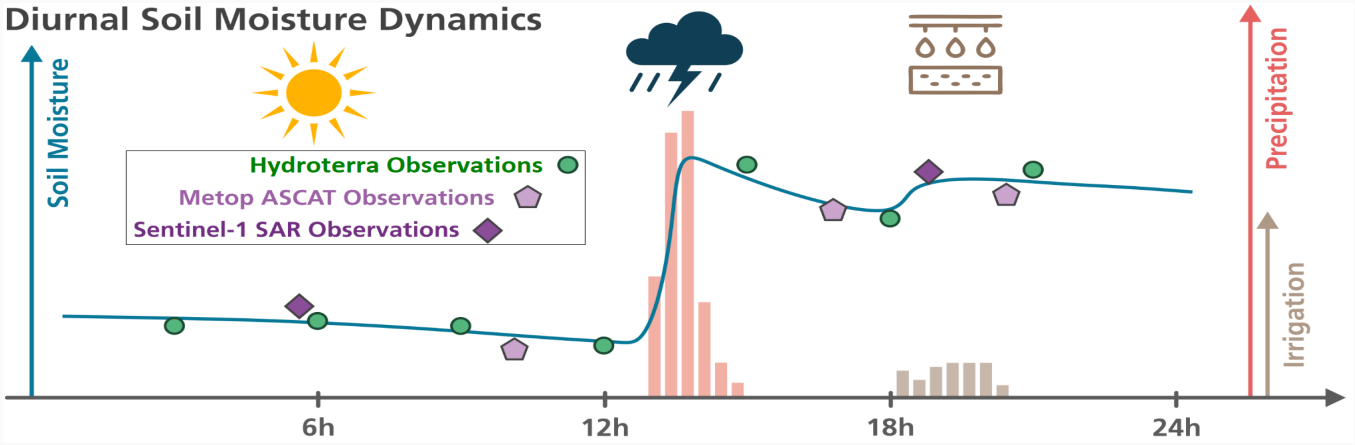
Motivation

- ESA Earth Explorer 10 mission candidate **"Hydroterra"**
  - Geo-synchronous C-band SAR system providing observations at
    - high spatial resolution (below 100m - 1km)
    - high temporal resolution (hourly)

    to be used for soil-moisture, vegetation and rainfall retrievals.

- How to assess the mission requirements?
  How to demonstrate the added-value of such measurements?

  ⇒ perform a **Closed-loop experiment**
  1) simulate "Hydroterra-like" datasets
  2) perform retrieval-experiments with the simulated datasets

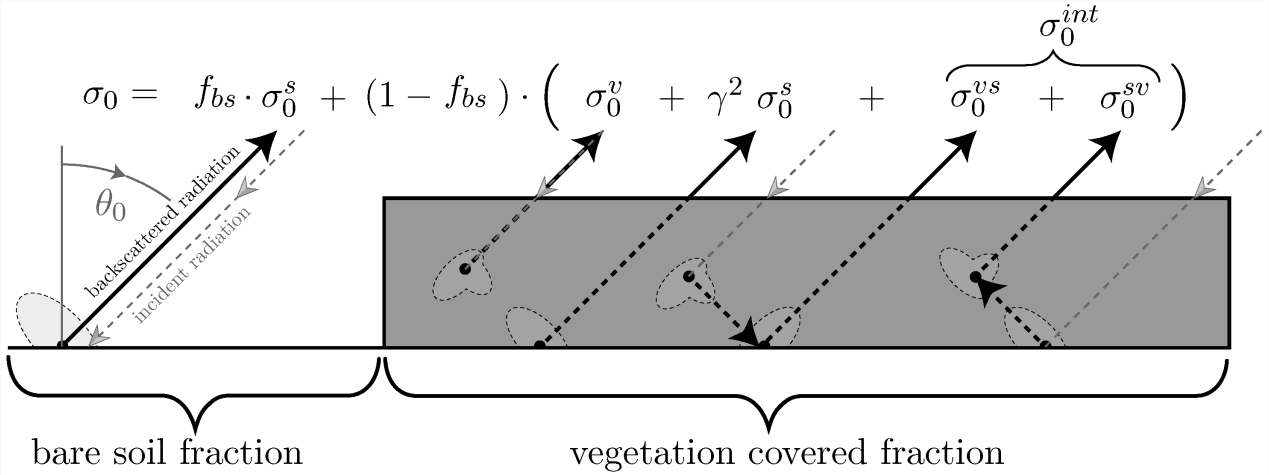


Simulation of σ_0 measurements at high temporal resolution

Forward simulation - A 2-step procedure

1) For each site, a radiative-transfer model (RT1 [1]) is optimized to represent Sentinel-1 data at 500m, spatial resolution
   - using auxiliary soil-moisture and LAI datasets from SURFEX-ISBA [3] simulations
   - both constant and temporally varying model parameters are estimated via nonlinear regression that minimizes $\chi^2 = \sum_{time,\theta_0} \left((\sigma_0^{S1} - \sigma_0^{model})^2 \right)$

2) σ_0 measurements at hourly intervals are simulated using obtained model-parameters and SURFEX-ISBA simulations



Forward Simulation Example

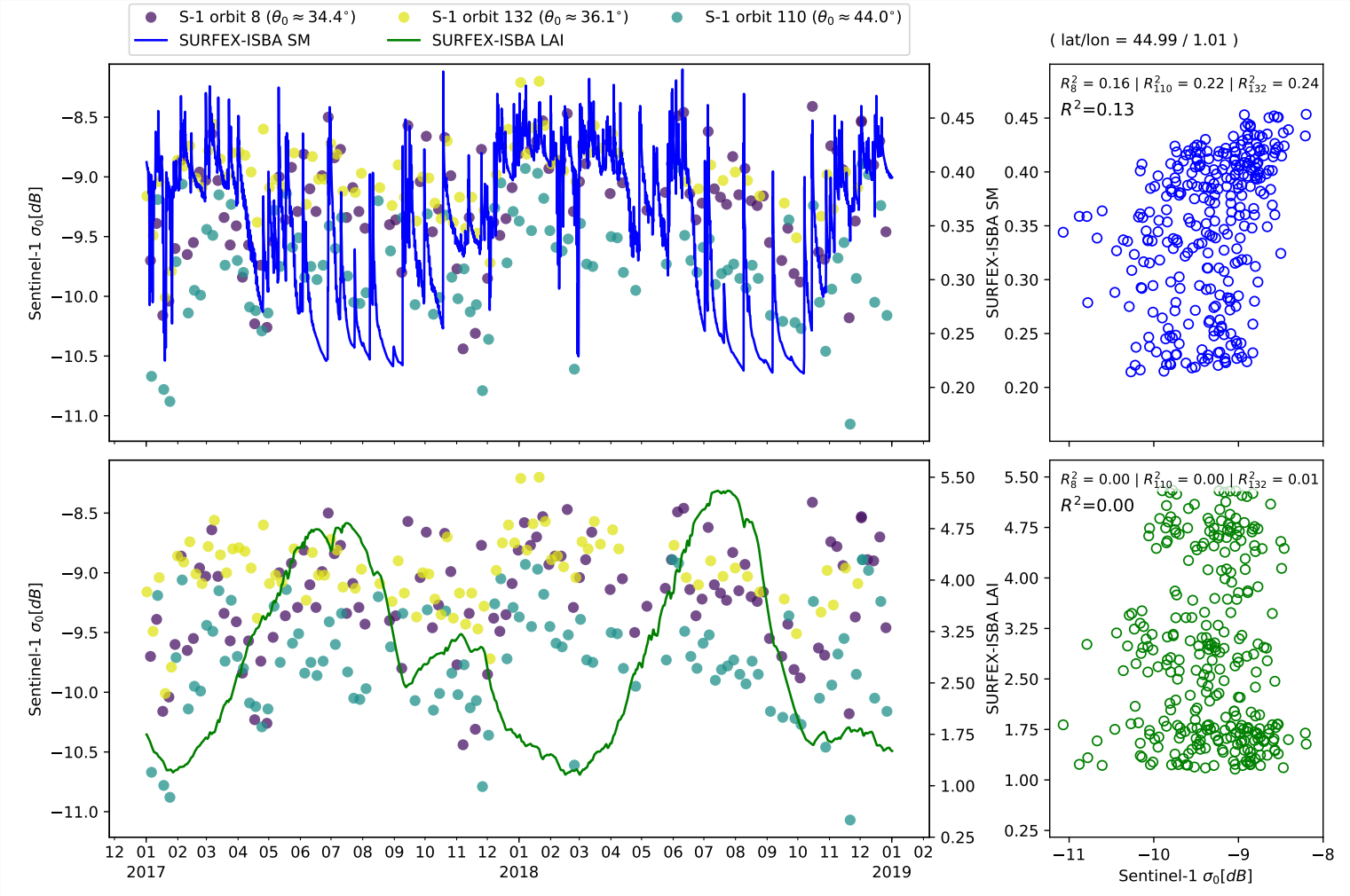
Forward simulation

- Within the selected RT1 model parametrization [1, 2], the following variables are estimated for each site individually:
  - single-scattering albedo (ω) of the vegetation-coverage
  - "effective" bare-soil fraction (*bsf*)
  - a directionality parameter of the soil-scattering BRDF
  - a constant factor to scale SM input-timeseries

$\Rightarrow$ How well can the temporal dynamics of Sentinel-1 data be represented via a radiative-transfer model? [1]
  - using **only** soil-moisture and LAI as dynamic variables
  - allowing additional (slowly varying) temporal variations in the single-scattering albedo ω
  - allowing an individual *bsf* estimate for each satellite-orbit

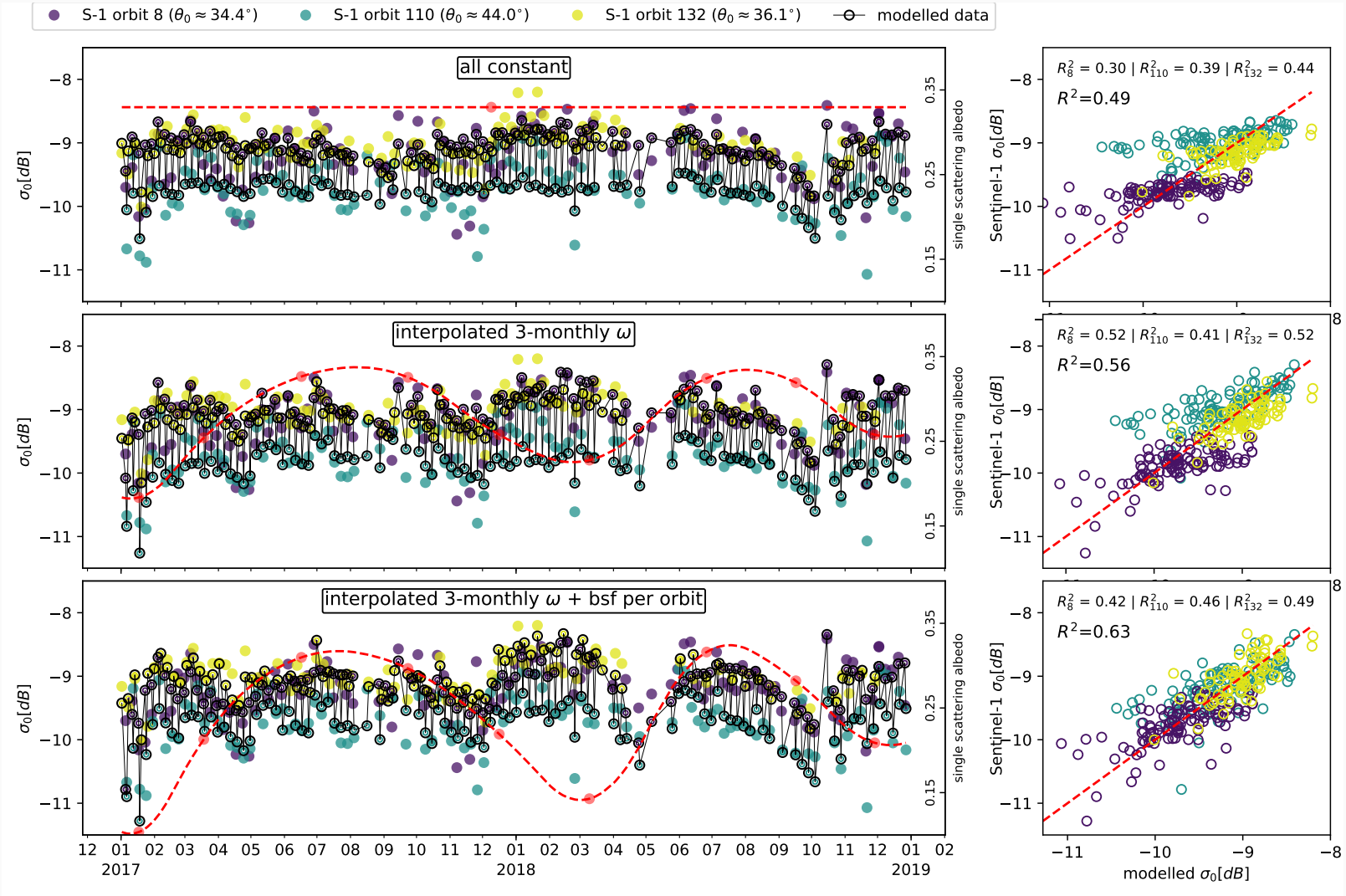
[1] Note that by allowing high-frequency variations in the model-parameters a perfect fit can of course always be obtained. However the resulting parameter-timeseries would show a high variability since it ingests all representation-errors between the used datasets. Furthermore an extrapolation to hourly timestamps would not be directly possible.

Forward simulation - Input datasets



Sentinel-1 σ_0 timeseries alongside the auxiliary SM and LAI datasets used in the presented model-parameter optimization (South-western France, lat/lon = 44.99/1.01)

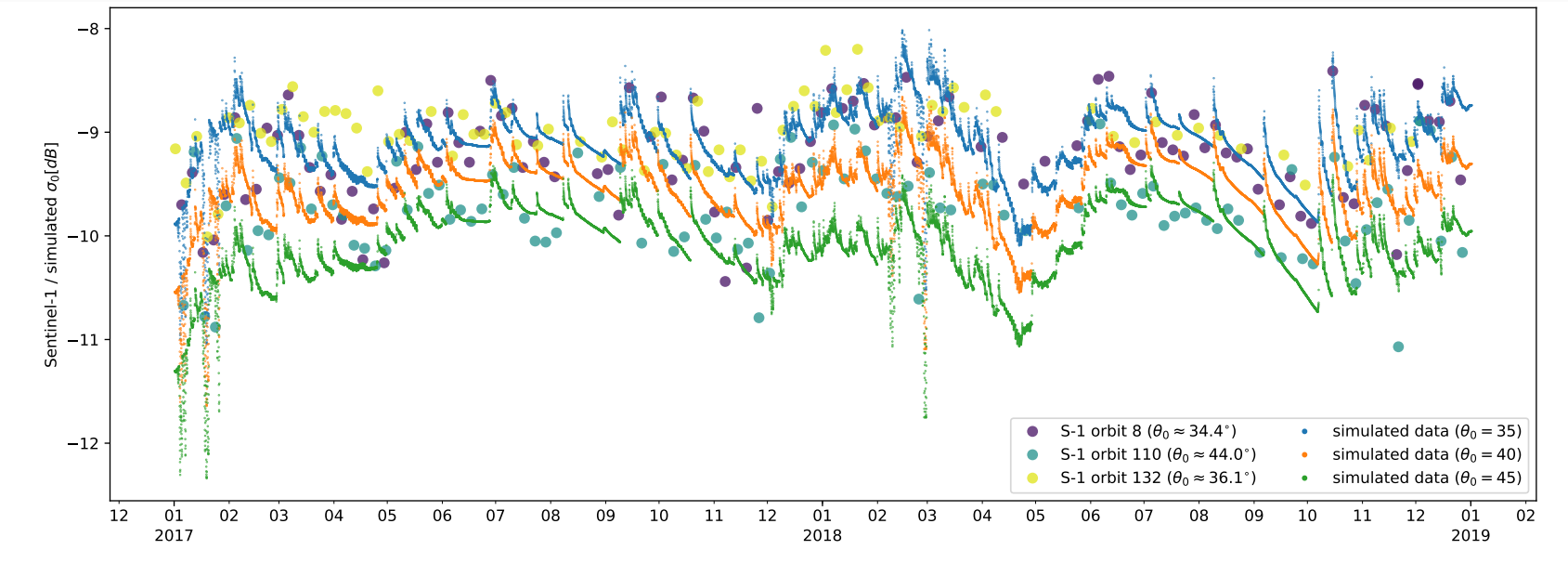
Forward simulation - Calibration performance



Sentinel-1 vs. modelled σ_0 timeseries for different parametrization complexities

Forward simulation - Simulated data

- once a suitable parametrization has been selected, the RT1-model can directly be used to simulate σ_0 timeseries at different incidence-angles and temporal resolutions

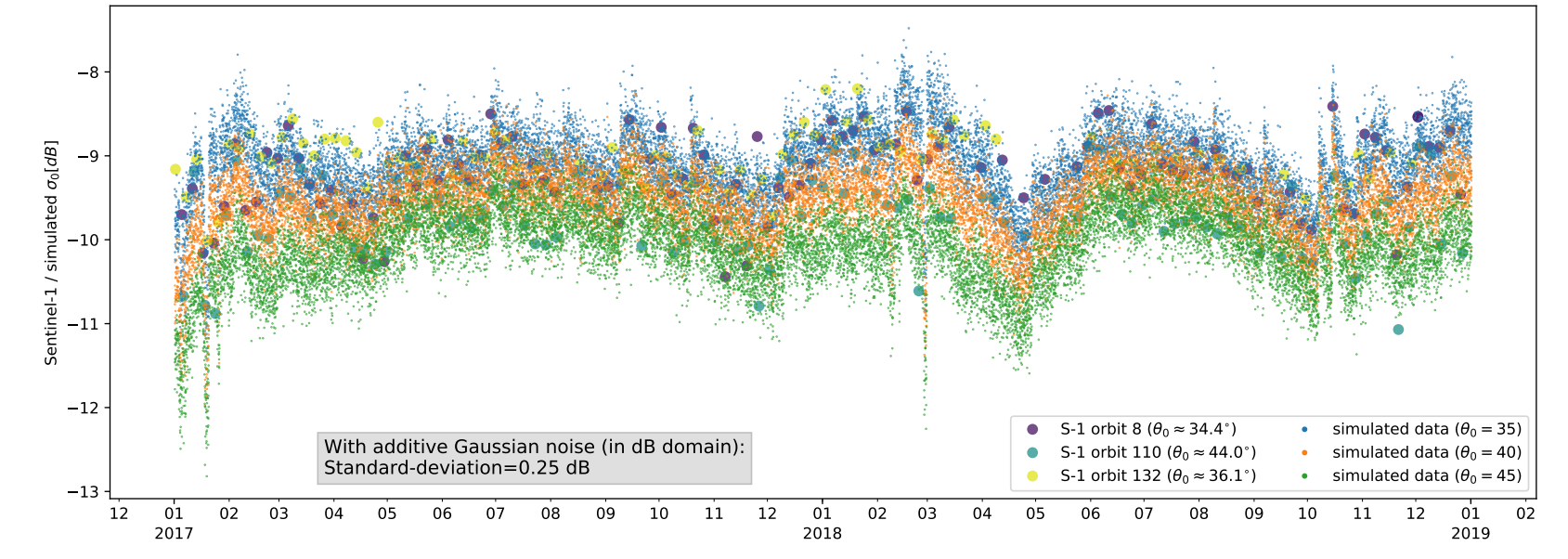


Simulated σ_0 at hourly intervals using 3-monthly ω and const. bsf parametrization [2]

[2] The spikes visible in Jan. 2017 and Feb. 2018 stem from soil-freezing events since the used SURFEX-ISBA SM dataset separates liquid from frozen soil water content. Since this actually represents the expected behavior, the affected dates have not been masked.

Forward simulation - Simulated data

- to simulate more realistic data, different noise-levels are added as additive Gaussian noise in the dB domain



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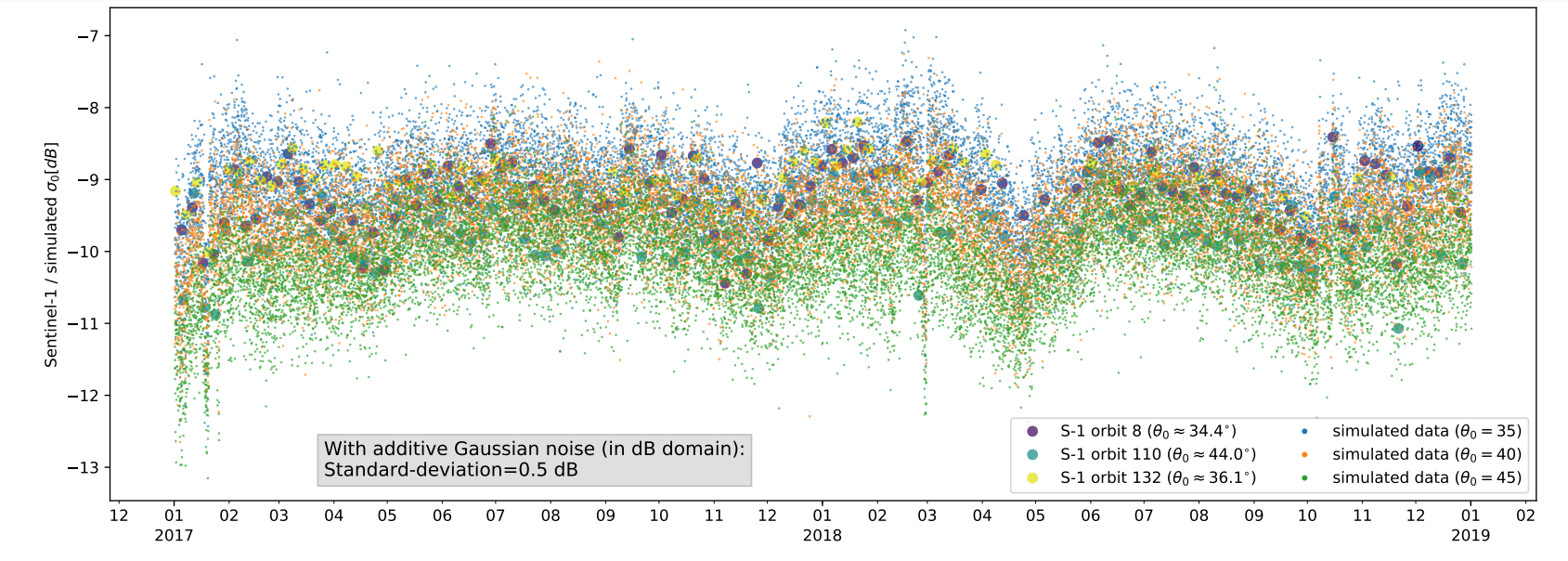

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A Closed Loop Experiment

Closed Loop Experiment - questions

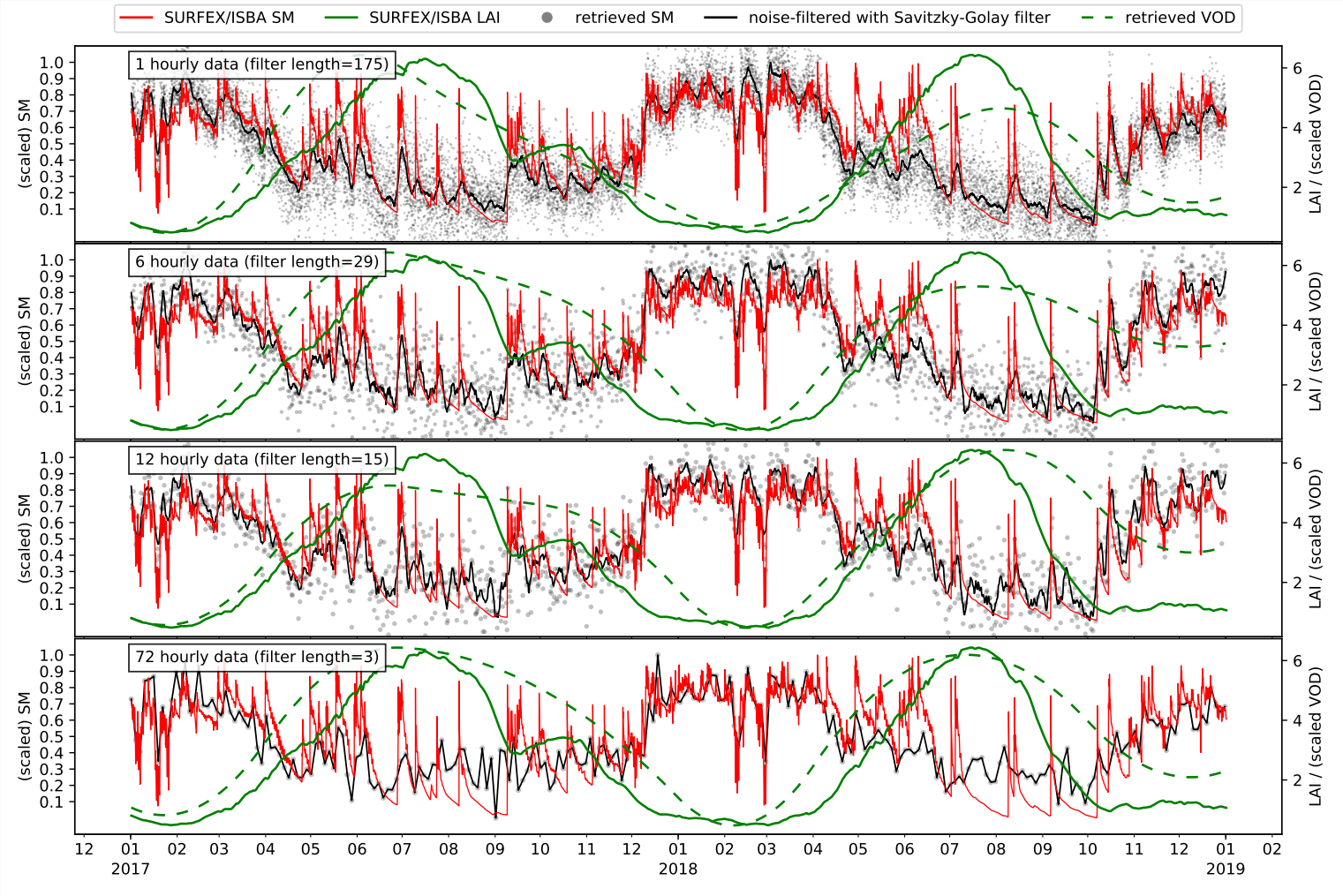
Now, the simulated datasets are used to perform a retrieval of both soil- and vegetation parameters, trying to address the following questions:

- What is the impact of temporal sampling?
- Is it feasible to separate soil- and vegetation temporal dynamics from a single incidence-angle σ_0 dataset?
- How is the retrieval performance affected by the absence of auxiliary information on the vegetation-dynamics?
- What noise-level is acceptable to obtain meaningful retrieval-performance short-term / long-term temporal dynamics
  - under different vegetation-coverage densities
  - how to properly correct for noise in the retrieved SM timeseries?

$\Rightarrow$ The following slides show some re-fit results

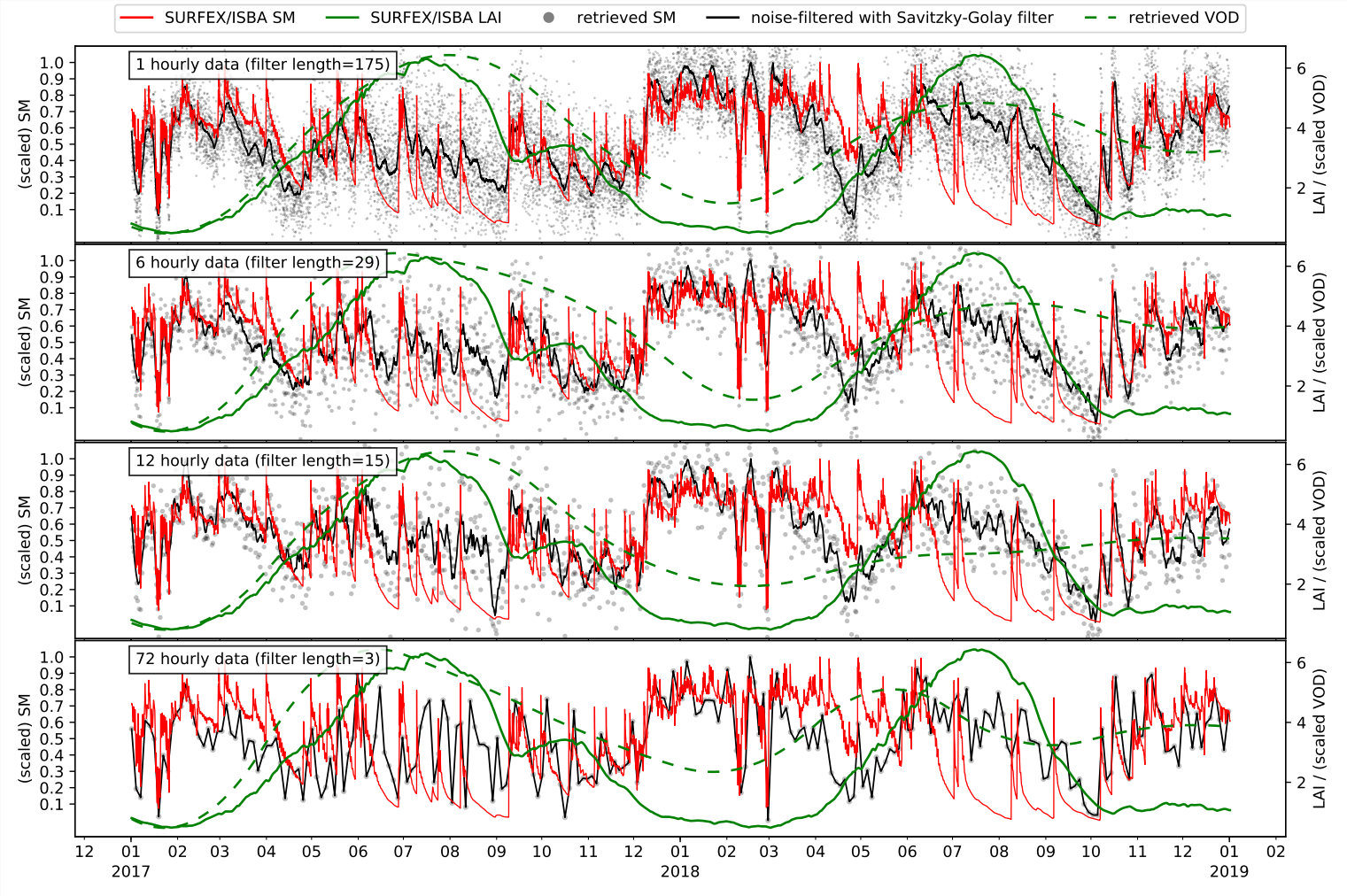
- at 1-6-12-72 hourly sampling of the simulated dataset
- using different noise-levels (0.25dB and 0.5dB)
- with/without a-priori knowledge on ω timeseries
- using 3-monthly interpolated seasonality for VOD-retrieval ($\propto$ LAI)

Closed Loop - Inversion of simulated dataset



Retrieved SM and VOD at $\theta_0 = 40^\circ$ and $\sigma_{noise} = 0.25$dB
with a-priori knowledge of auxiliary ω timeseries

Closed Loop - Inversion of simulated dataset



Retrieved SM and VOD at $\theta_0 = 40°$ and $\sigma_{noise} = 0.25$dB without auxiliary information [3]

[3] Note that while short-term variations (e.g. anomalies) are still well represented in the high-temporal resolution datasets, long-term variations of soil- and vegetation can no longer be separated properly once the vegetation has reached a certain density.

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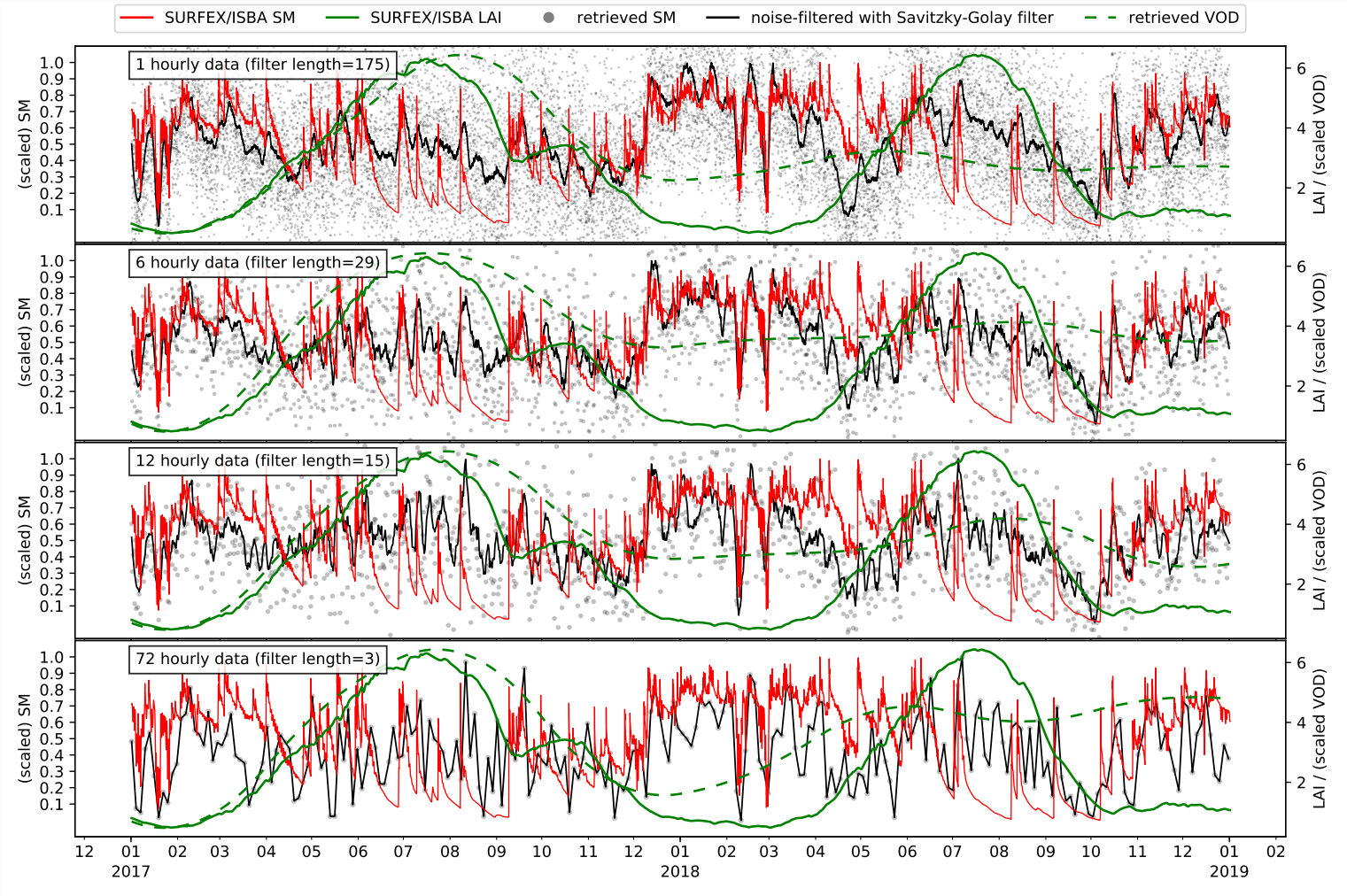

Retrieved SM and VOD at $\theta_0 = 40°$ and $\sigma_{noise} = 0.5$dB without auxiliary information [3]

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Conclusion / Outlook

- high temporal resolution allows application of more sophisticated noise-removal techniques in the temporal domain

  $\Rightarrow$ can be used to compensate radiometric resolution

- good understanding of factors influencing the measured signal is crucial for disentanglement of soil- and vegetation dynamics

  $\Rightarrow$ what are feasible auxiliary datasets that can be used to mimic those dynamics (e.g. LAI, NDVI, EVI, etc.) ?

Further work is planned on:

- optimizing the "calibration $\rightarrow$ simulation$\rightarrow$ retrieval" cycle to come up with a robust model parametrization
- assessing the performance of derived products (e.g. rainfall retrievals using SM2Rain algorithm [4])
- utilization of simulated interception and irrigation datasets
- application of the experiment on larger areas with diverse landscapes

References

[1] Quast, R.: RT1 python module: https://github.com/TUW-GEO/rt1 (https://doi.org/10.5281/zenodo.3745590)

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Rainfall estimation from in situ soil moisture observations at several sites in Europe: an evaluation of SM2RAIN algorithm.
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