Title: Analysis of the SMAP Daily Soil Moisture Time Series through Power Spectrum-Adjustment Methods Utilizing Additional Datasets

Abstract:

Soil moisture (SM) analyses and assessments hold significance for numerous applications in the fields of hydrometeorology and agriculture. Throughout history, flux tower sites have been a primary source of data for observationally-based SM examinations and evaluations of land-atmosphere interaction. However, these monitoring stations are not evenly distributed worldwide. One of the ways in which the comprehensive understanding of how land and atmosphere interact can be improved is by incorporating remotely sensed SM observations.

The Soil Moisture Active Passive (SMAP) satellite is one of the satellite resources which closely aligns with in-site observations. However, the remote sensing nature of SMAP data means that it is prone to unpredictable random distortions. Since variations in SM tend to follow a fundamental Markov process, they typically display a specific "red noise" pattern of variability. On the other hand, satellite data that incorporates random fluctuations exhibits a more uniform "white noise" pattern at higher frequencies, which contrasts with the anticipated red noise pattern. Furthermore, gaps in SMAP data are not randomly distributed; due to its orbital characteristics, the satellite experiences regular instances of missing data during its 8-day orbital cycle, differing depending on the orbital pass. This introduces additional anomalies in the power spectrum, performed through examining correlations in the time series data, leading to recurring spikes at intervals of 8, 4 (half of 8), 2 and 2/3 (one-third of 8), and 2 days (one-fourth of 8). These spectral spikes become broader due to small variations in the satellite's orbit. To make the satellite data most effective for assessing land-atmosphere interactions, which tend to rely on estimates of covariability of SM with other environmental variables, it is crucial to minimize the impact of random distortions and systematic missing data.

A technique for adjusting the power spectrum, and thus the time series, of SM has been developed to minimize the influence of orbital harmonic spikes in the gridded Level 3 (L3) SMAP dataset. This is achieved by fitting a catenary function to the power spectrum between the harmonic spikes and then removing their influence. The adjusted spectrum is then aligned with soil moisture data from the surface layer, collected from sites within the AmeriFlux network (in-situ flux tower data). These sites demonstrate relatively minimal distortion and exhibit SM power spectra that closely resemble those generated by offline land surface models (LSMs), which are free of random noise by nature. Using validated spectral data from gridded LSM-based datasets, an improved global L3 SMAP dataset is being generated that accounts for noise and harmonic effects. This presentation will showcase the outcomes of this technique in enhancing SMAP data and its temporal correspondence with observational data.

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INTRODUCTION

Process chains in **land-atmosphere (LA)** interactions connect soil moisture (SM) to surface fluxes, partly controlling the evaporation of accumulated precipitation under varying environmental conditions. Given the uneven global distribution of observationally-based flux tower data, satellite products present an excellent opportunity to analyze SM and assess LA interaction studies.

The **Soil Moisture Active Passive (SMAP)** satellite most closely aligns with in-situ observations. However, the stochastic random noise in SMAP can affect the accuracy of coupling estimates. Notably, the missing data in SMAP are patterned rather than random. These patterns are due to its 8-day repeating polar orbit, which influences data availability based on location. This study introduces a method to ***estimate and remove noise from SMAP time series***. This aims to enhance the quantification of how soil moisture influences global turbulent surface fluxes of sensible heat (SH) and latent heat (LE).

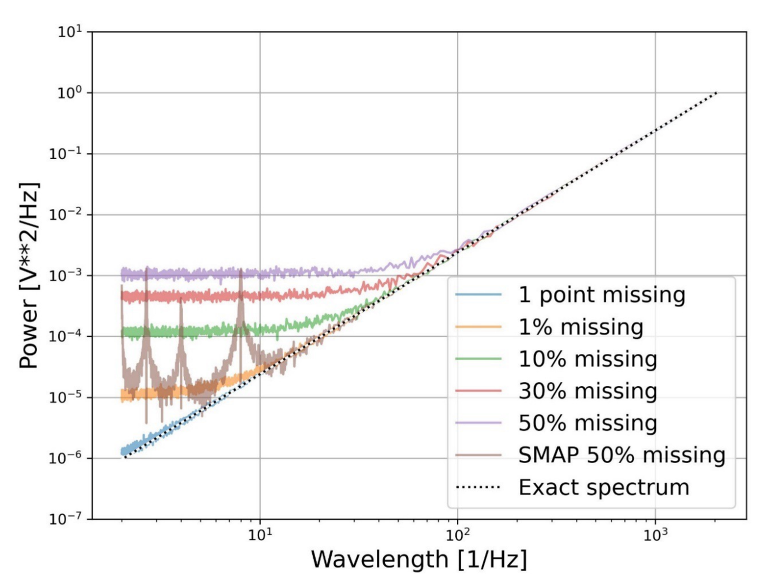
METHODOLOGY

Hypothesis: The ***Power Spectrum – Adjustment*** technique can be applied to SM from SMAP L3 to **identify and remove noise**.

The steps of our methodology include:

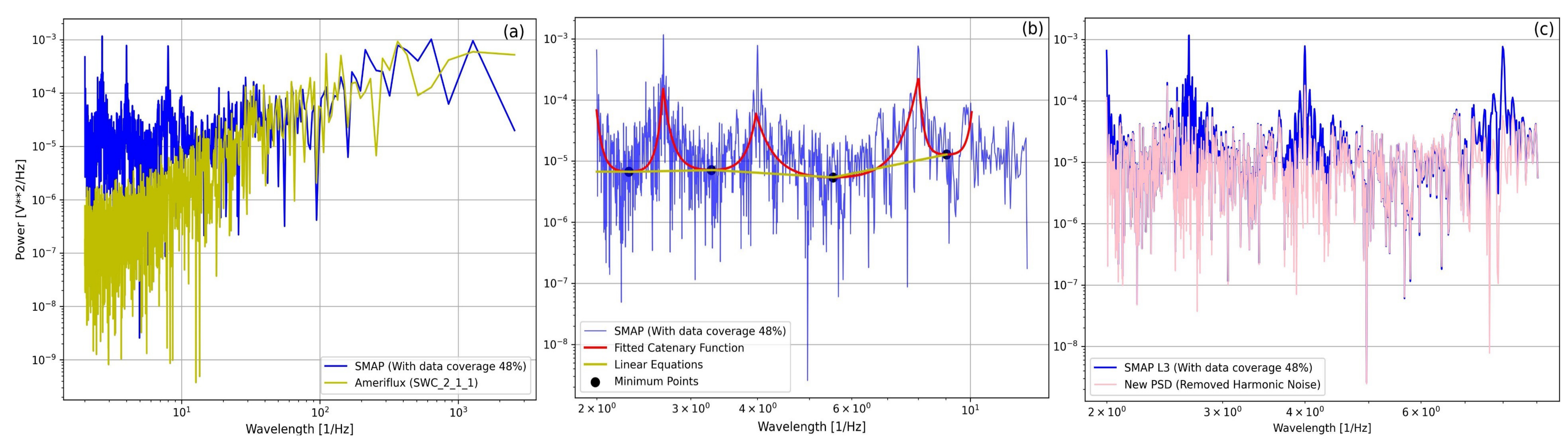
- Calculate Power Spectrum Density (PSD) based on **Lagged Autocovariance** (works with missing data)

Contrasted with an idealized time series constructed of superposed waves, SMAP's PSD displays a notable deviation at higher frequencies, influenced by the proportion of missing data. Additionally, it exhibits spikes at wavelengths corresponding to 8, 4 (8/2), 2 2/3(8/3), and 2 (8/4) days, representing **orbital harmonics**. This pattern reveals SMAP's unique 8-day orbital cycle, which varies based on geographical location.



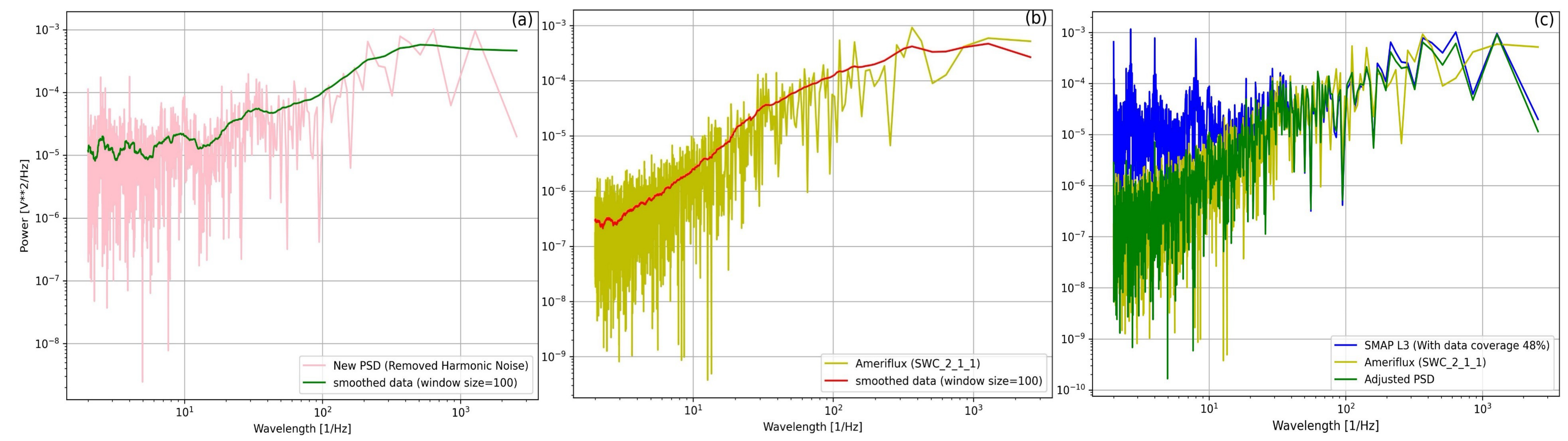
Power spectrum density for different fractions of random missing data. SMAP 50% missing PSD has a pattern of **1-0-1-1-0-1-0-0.**

- Remove the **Harmonic Noise** in PSD by ***Fitting Catenary Curves***



(a) PSD for SMAP L3 and Ameriflux from 2015 to 2022 in ARM Southern Great Plains – Lamont, (b) fitted catenary to PSD and lines connected minimum points of each curve, (c) new PSD in which harmonic noise is removed by dividing lines to fitted catenary.

- Remove the **White Noise** by Adjusting to ***Flux Tower PSD***

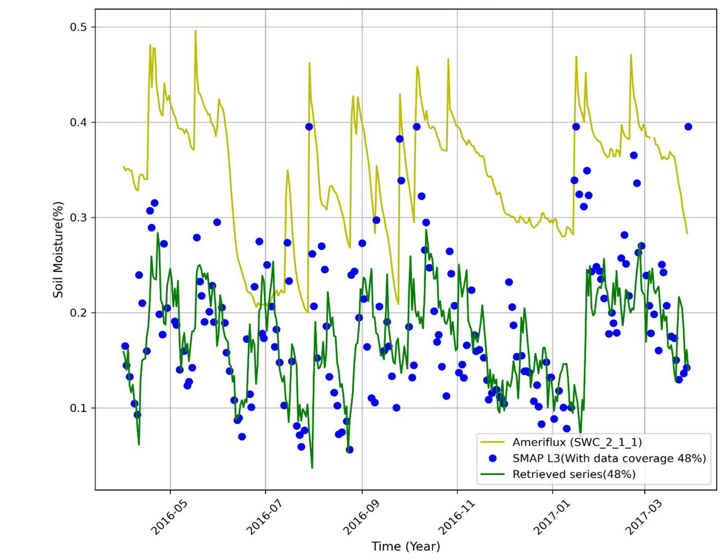


Removed harmonic noise PSD for (a) SMAP L3 and (b) Ameriflux with their smoothed spectra also plotted Adjusted PSD (c) in which white noise is removed by dividing smoothed removed harmonic noise PSD to smoothed Ameriflux PSD and then removed harmonic noise PSD divided by this ratio.

METHODOLOGY (Continued)

38% of PSD is removing >>> Harmonic Noise
78% of PSD is removing >>> White Noise

- Get phases using **"Slow" Fourier Transform** (SFT) (Fitting Sine & Cosine to the Time Series)
- Retrieve the time series using the **Backward Fourier Transform**

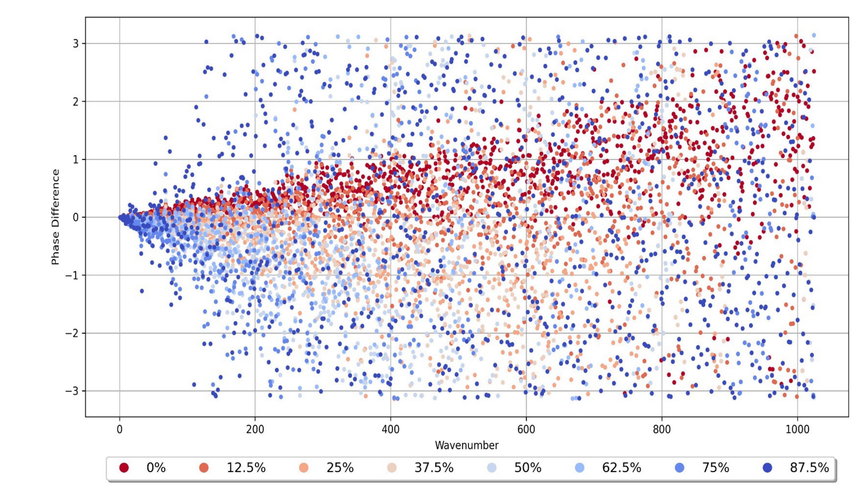


Daily soil moisture time series for SMAP L3, Ameriflux, and retrieved SMAP from 2016-04 to 2017-03 in ARM Southern Great Plains – Lemont.

RESULTS AND FINDINGS

- The proposed method is an efficient way to ***identify and remove the noise*** from time series with missing values.
- When phases are retrieved from SFT, in some frequencies, these phases and the real one have differences between –π and π.

Phase Difference (Actual-SFT) for different percentages of missing data.



- Therefore, the lack of ability to get phases lead to ***less variability at higher frequency***, and **dry-downs cannot be predicted accurately**.
- ***Checking day-to-day variation*** of invented series with SMAP L3 and Ameriflux shows that there is no improvement in retrieved time series because it is not possible to get phases at some frequencies.

Lags	Fraction of common sign between retrieved and Ameriflux	Fraction of common sign between complete and retrieved series and SMAP L3
1	0.52	0.53
2	0.52	0.53
3	0.53	0.52
4	0.54	-----
5	0.55	0.53
6	0.57	0.58
7	0.56	0.58
8	0.57	0.59

The table shows how many times the sign of day-to-day changes matches between the complete and invented series.

FUTURE WORKS

- Identify an improved method for phase retrieval
- Extend this method to additional in-situ locations
- Develop a worldwide, gridded, noise-reduced SMAP L3 product
- Compute metrics to assess the coupling between the retrieved SMAP L3 and surface fluxes
- Apply a new method to find a noise-free coupling index such as the linear correlation between noisy time series of SMAP L3 and surface fluxes
- Apply this method across various locations

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