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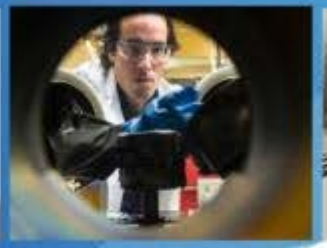


Seasonal Trends of Soiling on Photovoltaic Systems

Leonardo Micheli[a,b], Daniel Ruth[a], Matthew Muller[a]

a) National Renewable Energy Laboratory, Golden, CO, USA.
b) Colorado School of Mines, Golden, CO, USA.

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Introduction

Soiling stations: common way to quantify soiling.

➔ Consist of two reference cells (or modules).

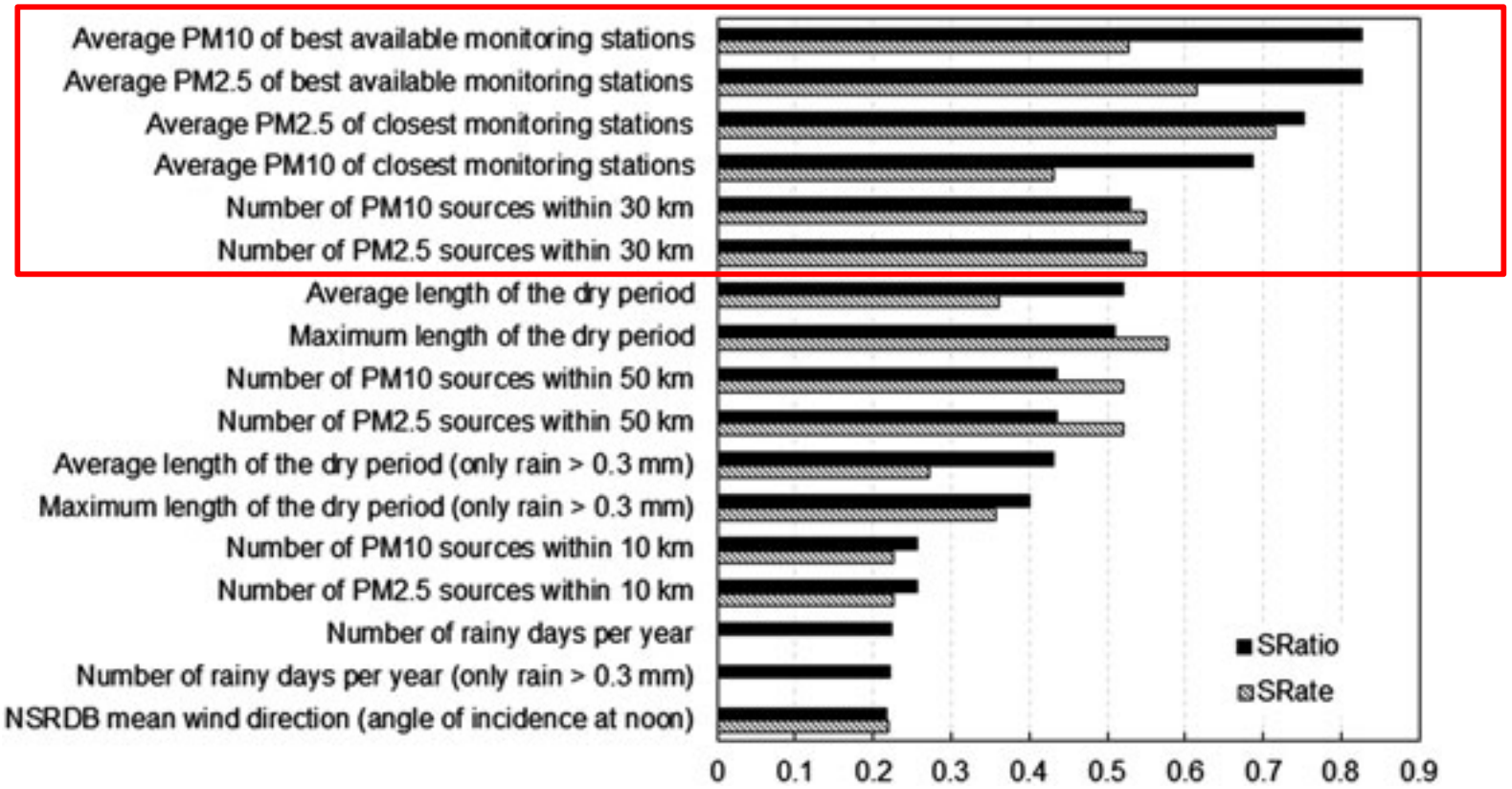
$$\boldsymbol{daily\ Soiling\ Ratio} = \frac{I_{sc\_Soiled}}{I_{sc\_Control}}$$

(Avg. of 12PM and 1PM data, only POA irradiance > 500 W/m^2)

daily SRatio = 1 at clean conditions,
daily SRatio < 1 in soiling conditions.

Introduction

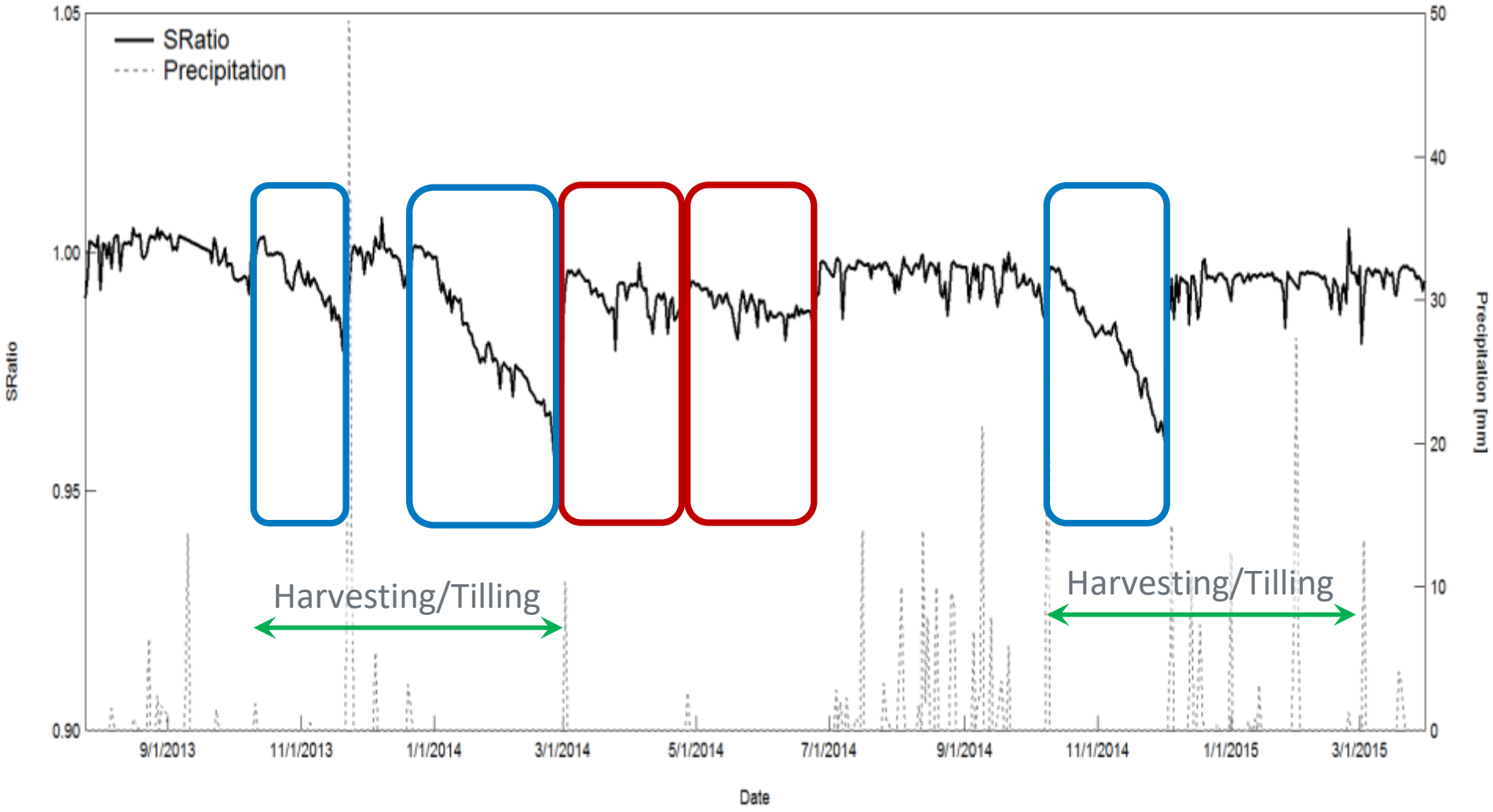
Particulate matter (i.e. concentration of particles suspended in air) has the best correlation with Sratio for long time periods (> 6 months) in the USA [1].



Parameters with the highest coefficient of determination when related to soiling ratios and soiling rates.

[1] L. Micheli and M. Muller, Prog. Photovoltaics Res. Appl. **25**, 291 (2017).

Introduction: Motivation



The identification of seasonal patterns is essential to determine the **most adequate cleaning schedule**.

Introduction: Aim

- Providing an instrument to quantify the seasonal soiling.
- Investigating, with a systematic approach, the seasonal soiling occurring at 15 different sites over a 12-month period.
- Analyzing the causes of seasonal soiling.

Introduction: Definition of seasonal soiling

Colwell [2], using the term "**contingency**," defined **seasonality** as the degree to which time and states statistically dependent on each other.

Our aim is identifying how much **soiling can vary in one year** ("variability") and which factors are driving these changes.

[2] R.K. Colwell, Ecology 55, 1148 (1974).

Introduction: Classification of seasonality

"Seasonality Index" (SI): parameter introduced in 1981 to describe the degree of variability in monthly rainfall through one year [3].

SI	Class
< 0.2	Very equable
≥ 0.2 and < 0.4	Equable, but with a definite wetter season
≥ 0.4 and < 0.6	Rather seasonal with a short drier season
≥ 0.6 and < 0.8	Seasonal
≥ 0.8 and < 1.0	Markedly seasonal, with a longer drier season
≥ 1.0 and < 1.2	Most rain in 3 months or less
≥ 1.2	Extreme, almost all rain in 1–2 months

[3] R.P.D. Walsh and D.M. Lawler, Weather **36**, 201 (1981).

Quantifying the seasonal soiling: Soiling Variability Index

"Seasonality Index" has been adapted to describe the variability of soiling across a 12-month period and renamed as **"Soiling Variability Index" (SVI).**

$$SVI(site) = \frac{\sum_{m=1}^{12} \left| S_m(m) - \left(S_{m\_sum} / 12 \right) \right|}{S_{m\_sum}}$$

With the **monthly soiling metric (S_m)** being:

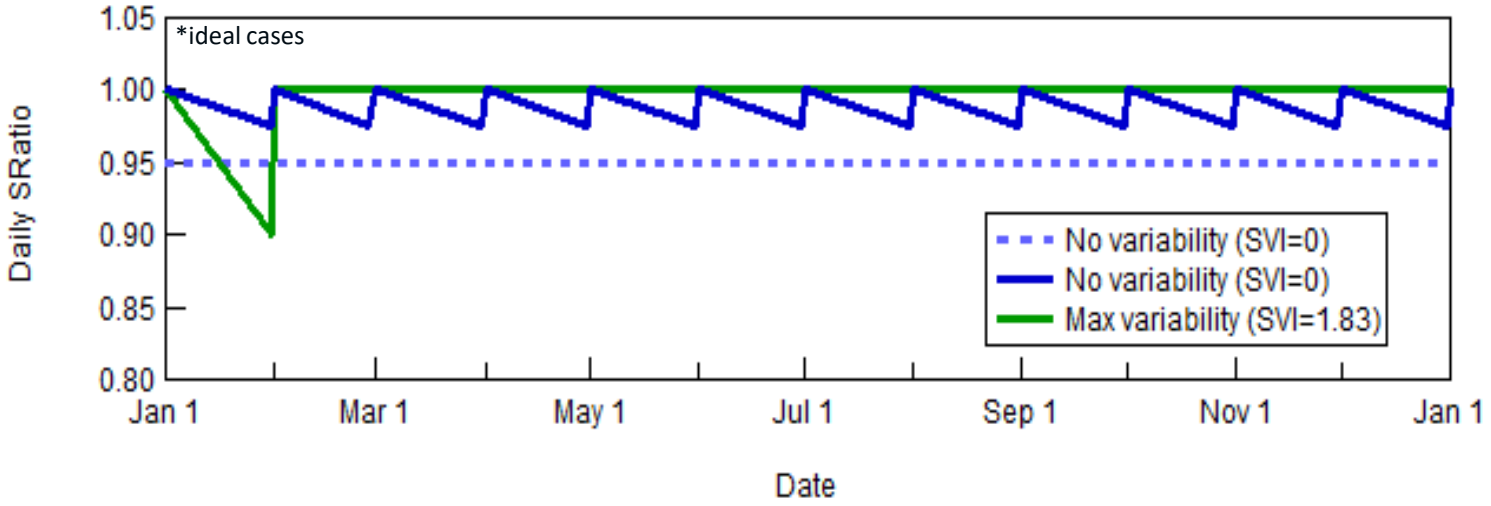
$$S_m(m) = \sum_{d=1}^{n_d} \left(1 - dailySRatio(d) \right)$$

S_m is 0 if no soiling occurred; otherwise, it is always greater than 0.

Quantifying the seasonal soiling: Soiling Variability Index.

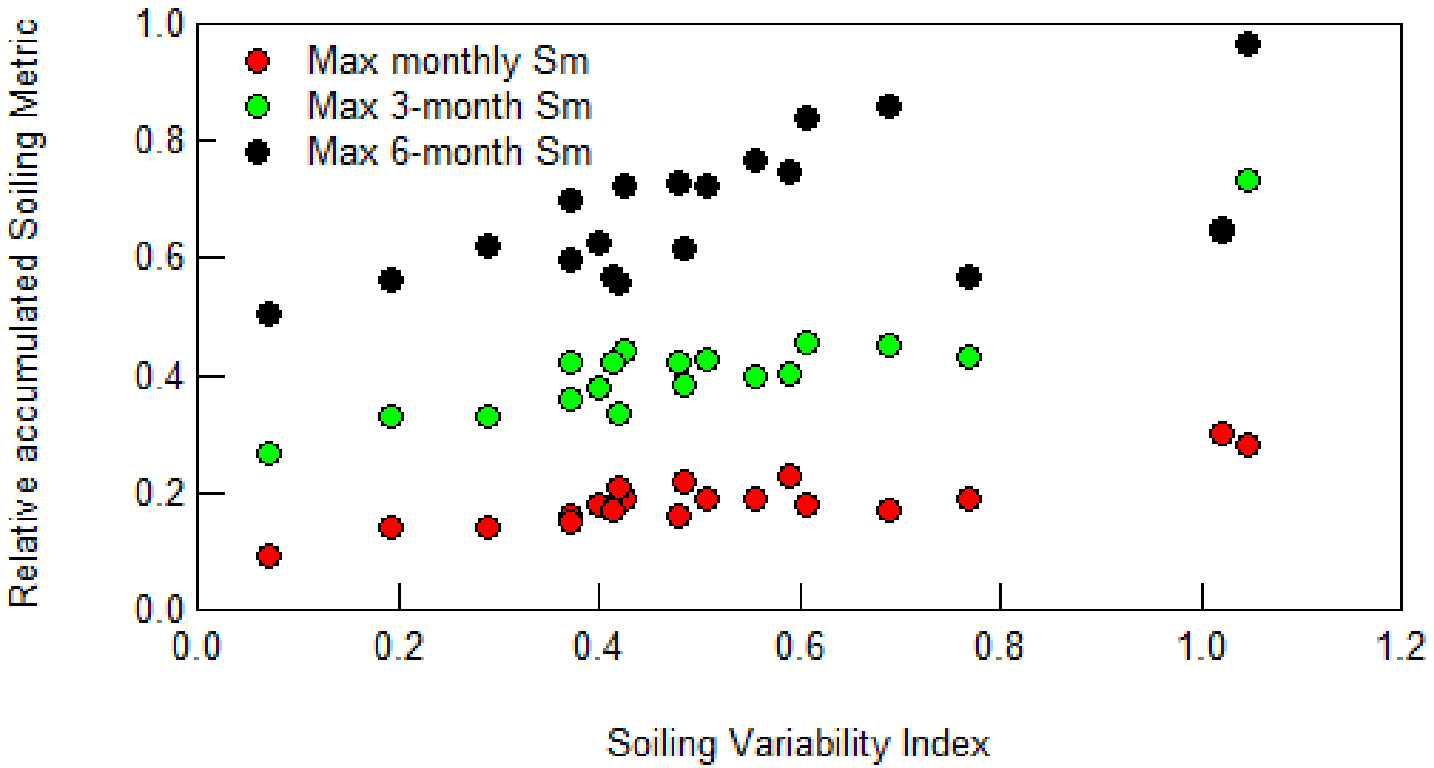
As for the **Seasonality Index**,

- the **Soiling Variability Index** varies
  - from 0 (**no variability**: same soiling occurring any month)
  - to 1.83 (**max variability**: all soiling accumulated in 1month)



- No correction has been made to balance the different number of days among the various months.

Soiling Variability Index: Results



Parameter	Description	R^2 (%)
Max monthly S_m	Max S_m registered in one month	73
Max 3-month S_m	Max S_m when three consecutive months are considered	82
Max 6-month S_m	Max S_m when six consecutive months are considered	37

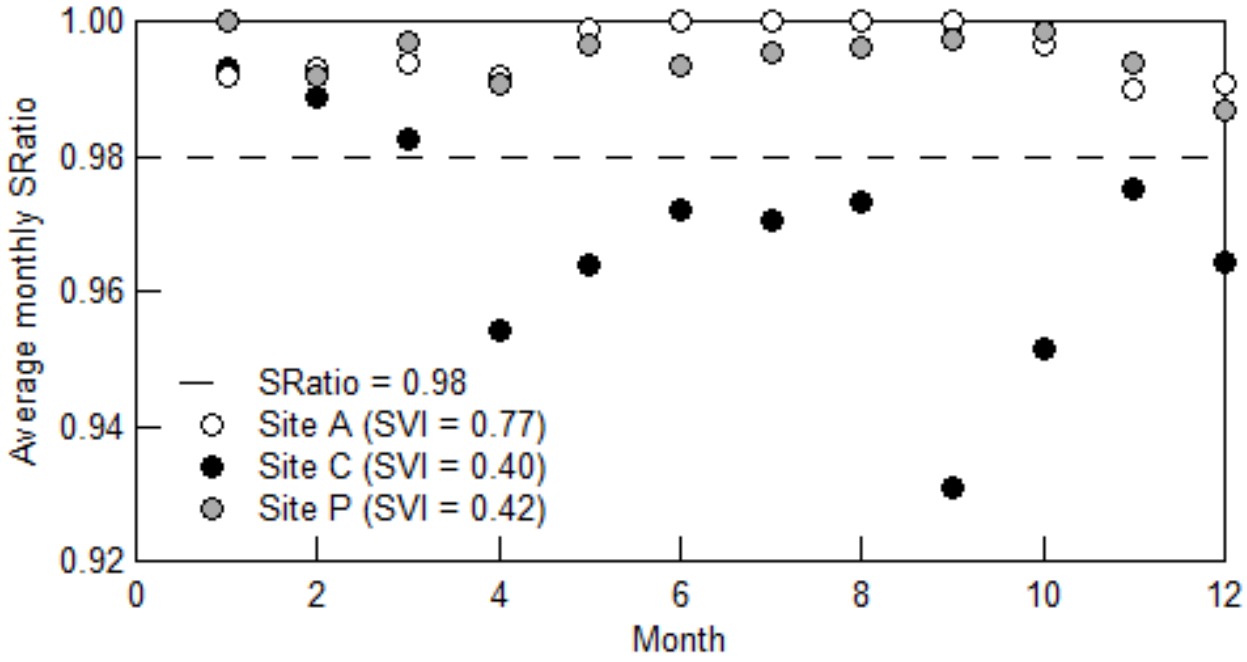
SVI can be used to determine high soiling seasons occurring within a 12-month period.

Soiling Variability Index : Classification

The analyzed datasets fall into five categories:

SVI	Class	Soiling profile
< 0.2	Seasonal variability in soiling not present or negligible.	Losses are equally distributed during the year: about 50% of the losses recorded in 6 months.
≥ 0.2 and < 0.4	Limited seasonal soiling.	0% to 70% of their soiling losses occurring in 6 months.
≥ 0.4 and < 0.6	Non-negligible impact of seasonal soiling.	70% to 80% of the total losses occur in 6 months.
≥ 0.6 and < 0.8	High variability in soiling.	Most of the losses occur in 3 to 4 months and 85% to 90% of soiling is experienced in 6 months.
≥ 1.0	Extreme variability.	Almost all the losses (> 95%) occur in 6 months.

Soiling Variability Index vs. Soiling Ratio



Site A: SRatio > 0.99, SVI = 0.77.

Site C: SRatio = 0.97, SVI = 0.40.

Site P: SRatio = 0.99, SVI = 0.42.

Both the SVI and the annualized SRatio must be considered.

Causes of seasonal soiling: Motivation

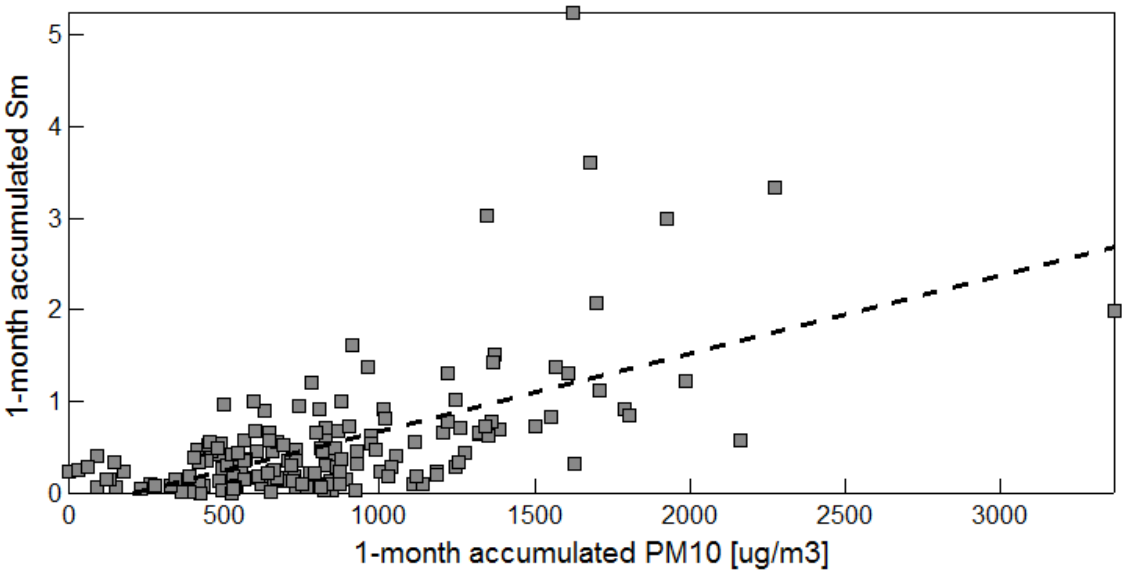
Seasonality is generally determined using
multi-year datasets.

Lacking such long soiling datasets,
the prediction of seasonal soiling relies on identifying its correlation with other more widely available parameters.

The investigation here is limited to **PM_{10} data**.

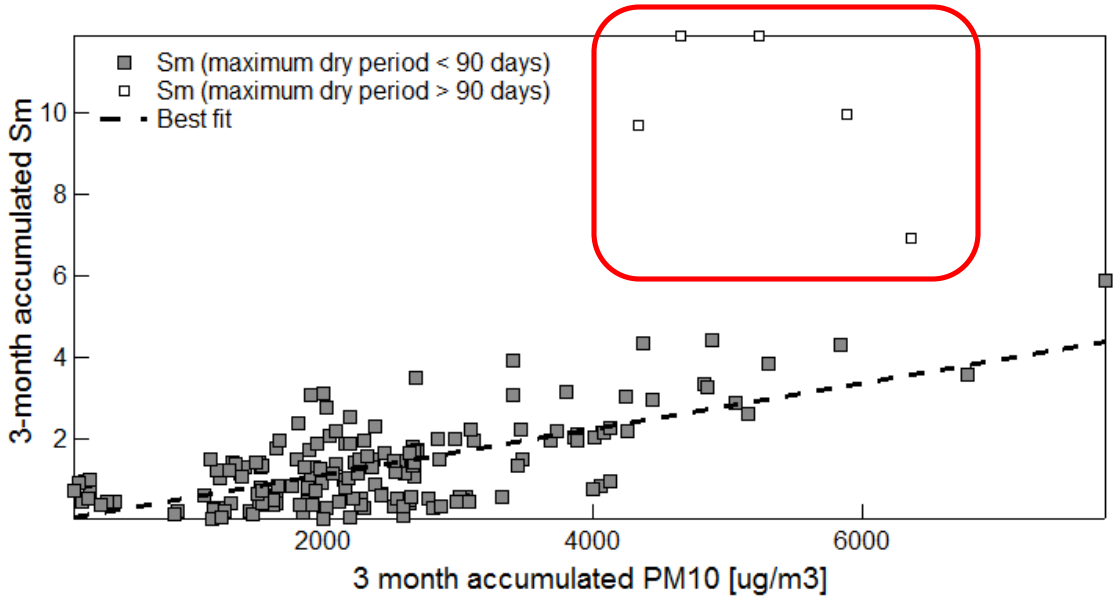
Causes of seasonal soiling: Particulate Matter

- **R^2 of 0.39** if the monthly accumulated daily losses compared against the accumulated daily PM_{10} concentrations.



- **R^2 of 0.47** if monthly data are replaced with data accumulated in three consecutive months.

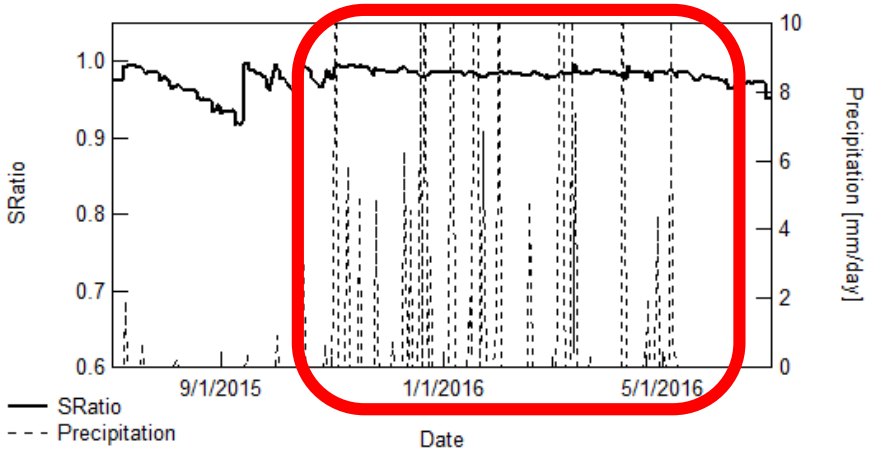
- **R^2 of 0.63** if data occurring for dry periods longer than 90 days are removed.



Causes of seasonal soiling: Particulate Matter

Lower R^2 between SRatio and PM_{10} compared to our previous study:

- the variability of other parameters (e.g. rainfall) is more relevant for short than for longer time periods [4,5].

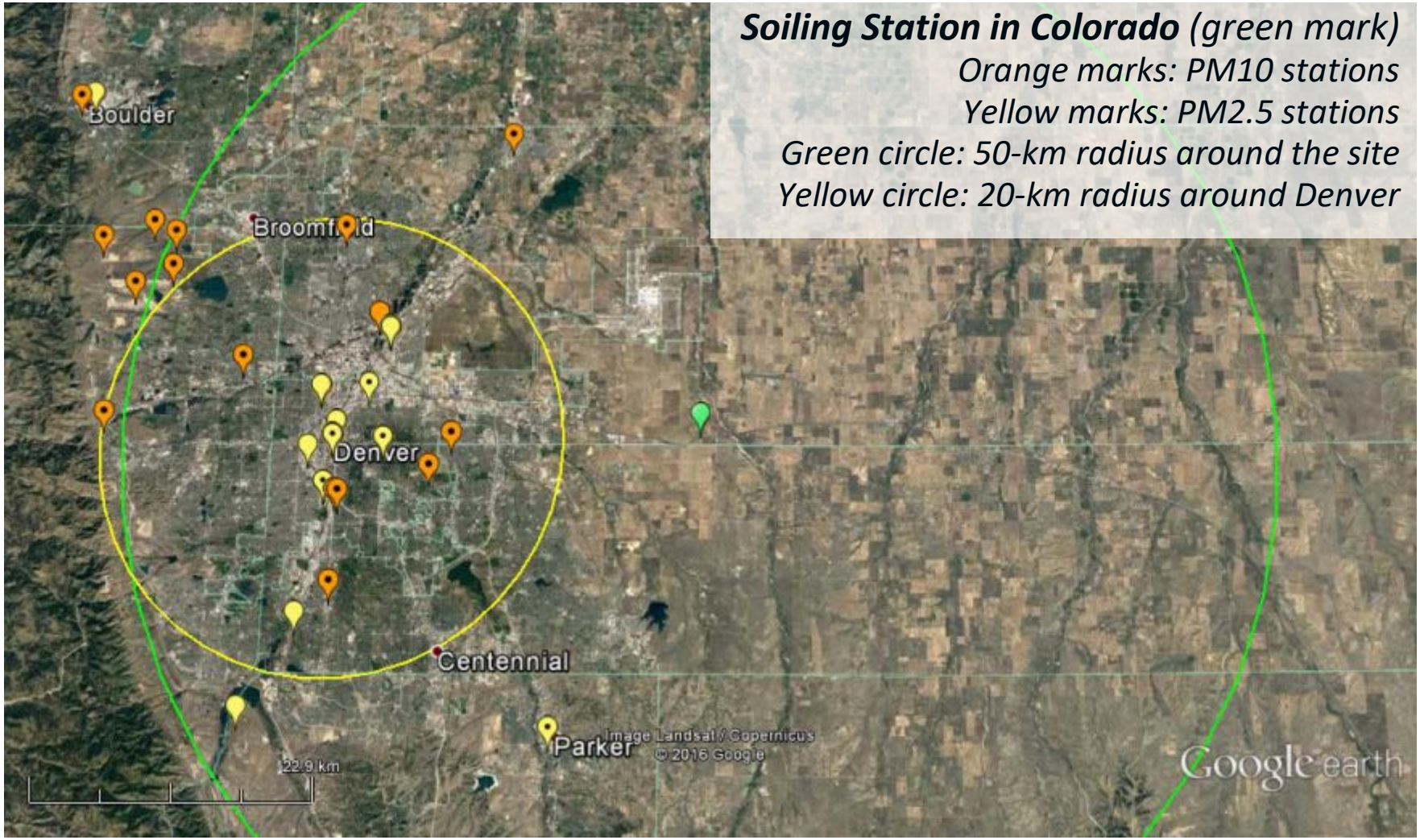


- daily PM10 registered by the EPA monitoring stations are discontinue and require an appropriate data process.
- the EPA monitoring stations might not be able, in some cases, to register the local seasonal PM10 trend of a site.

[4] L. Boyle, H. Flinchpaugh, and M. Hannigan, Aerosol Sci. Technol. **50**, 380 (2016).

[5] B. Guo, W. Javed, S. Khan, B. Figgis, and T. Mirza, in *ASME 2016 10th Int. Conf. Energy Sustain. Collocated with ASME 2016 Power Conf. ASME 2016 14th Int. Conf. Fuel Cell Sci. Eng. Technol.* (2016), pp. 1–8.

Causes of seasonal soiling: Particulate Matter



Source: 39.75685 & -104.62025. Google Earth, 12/30/16. 01/19/17.

Conclusions

Initial results of an investigation on seasonal PV soiling, using data from 15 stations in the USA.

- **Seasonal variability index** (SVI) introduced to quantify the seasonal behavior of soiling over a 12-month period.
- SVI used to **classify the sites** depending on the number of months in which most of the soiling losses occurred.
- SVI cannot distinguish high or low soiling sites.
- Correlations among monthly soiling and pollution data have **lower accuracy** that those reported for longer-term data. Results **enhanced if three month periods** are considered.

Thank you!

Leonardo Micheli
Leonardo.Micheli@NREL.gov

More on NREL soiling project on the thursday 10.30-12.00 Poster Session:

Lin Simpson, NREL Efforts to Address Soiling on PV Modules (**e-poster**)

Micheal Deceglie, Quantifying Year-to-Year Variations in Solar Panel Soiling from PV Energy-Production Data (**K39**)

Leonardo Micheli, A Unified Global Investigation on the Spectral Effects of Soiling Losses of PV Glass Substrates: Preliminary Results (**K52**)

Matthew Muller, A Method to Extract Soiling Loss Data From Soiling Stations with Imperfect Cleaning Schedules (**L4**)

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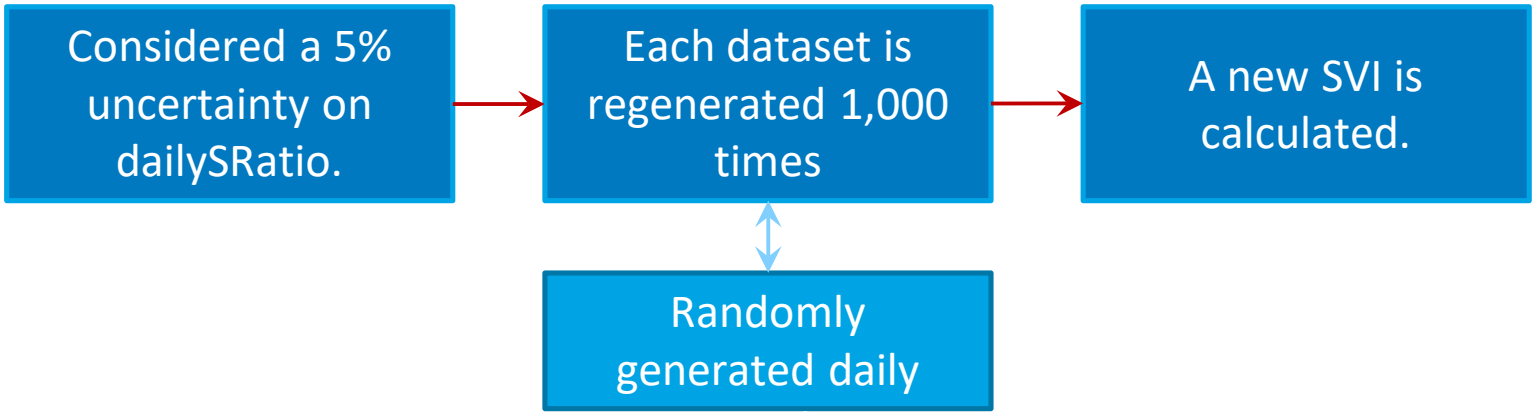
Soiling Variability Index: uncertainty

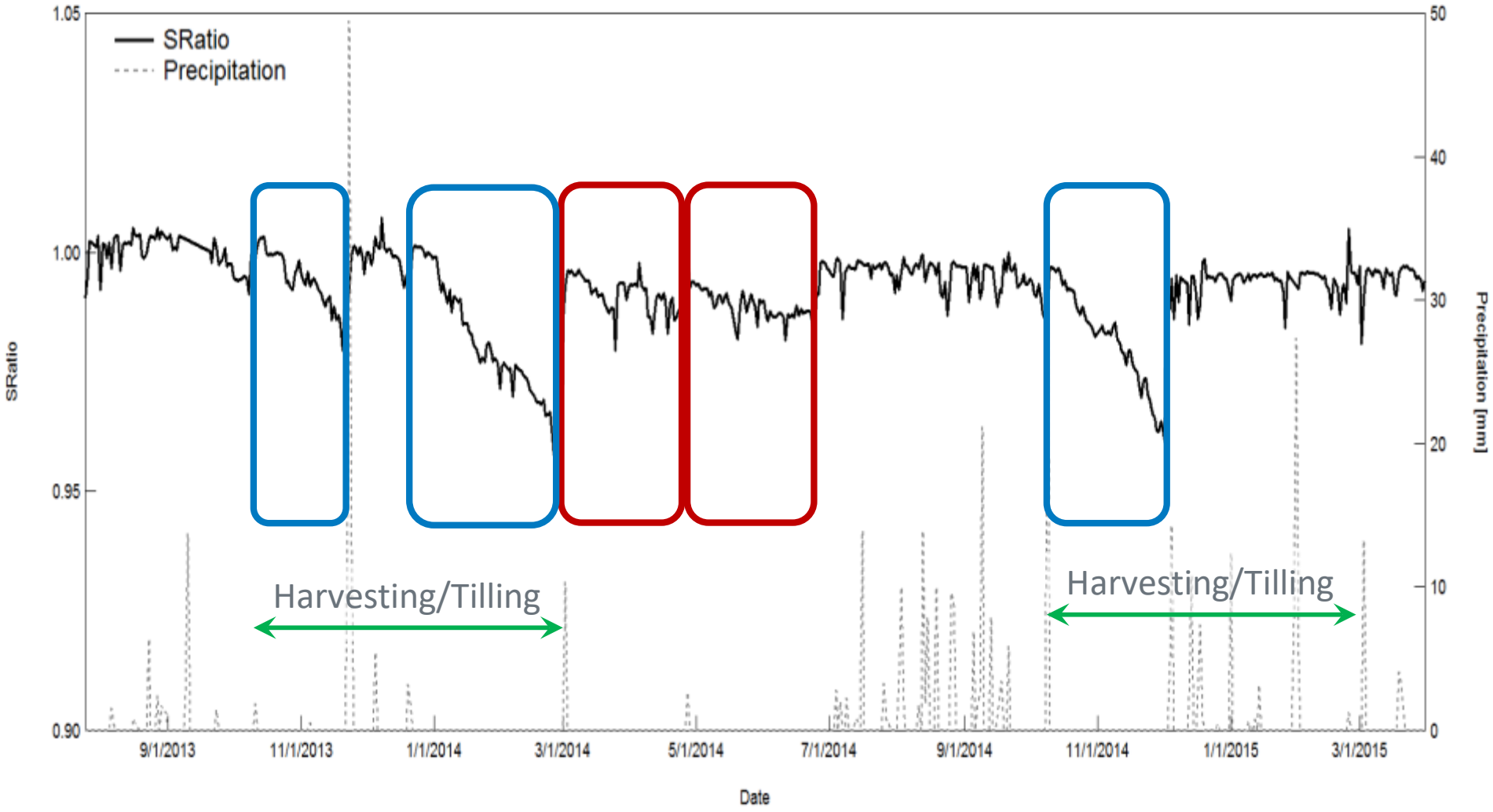
Monte Carlo computation:

the uncertainty can be particularly significant for low soiling ratio sites.



The uncertainty on SVI tends to increase with the soiling ratios, ranging from values of 1% to 42%.

Introduction: Motivation



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