Measuring soiling impact on solar power plants & their application for monitoring CSP and PV plants

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Suntrace GmbH – a member of DORNIER GROUP

Suntrace joined the Dornier Group, which offers all relevant engineering services for energy, infrastructure and mobility

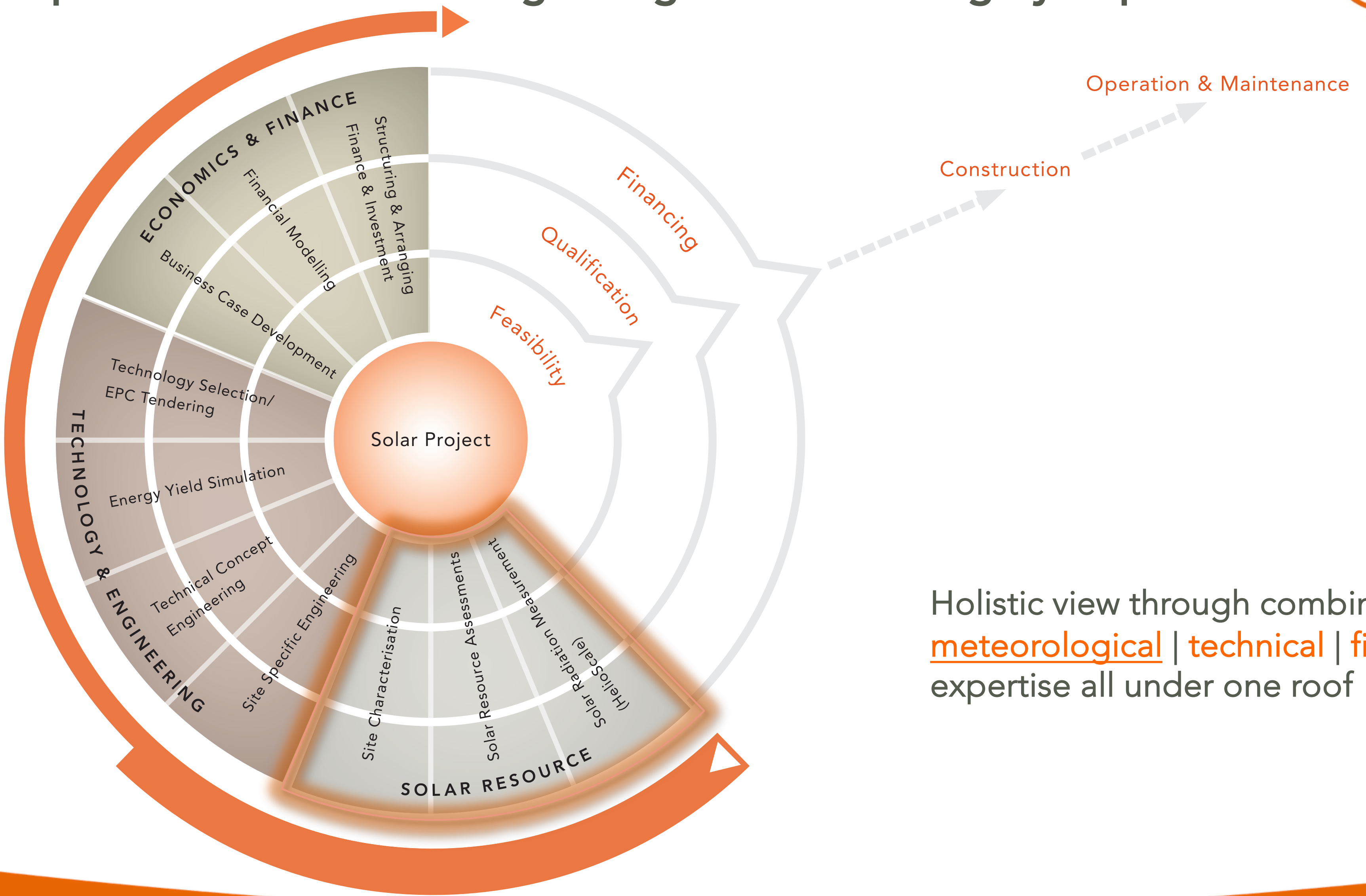
Several infrastructure areas require good knowledge of soiling on site

DORNIER GROUP

Overhead functions

VPC	DORNIER	conwico	encotec	suntrace
Energy	Water	Energy	Energy	Renewables
Storage	Mobility	Water	Real estate	
Environment	Real estate	Environment	Renewables	
E- Mobility	Aviation			
Waste Mana.				
Water Treat.				
Design & Engineering	Consulting & Engineering	EPC Business	O&M, Erection, Commissioning	Consulting

Suntrace strongly experienced in site characterization of solar plants: Effects of soiling recognized to be highly important



Holistic view through combining meteorological | technical | financial expertise all under one roof

Agenda

1. Soiling: an issue for all solar technologies
2. Examples from application of AVUS sensors
3. Comparison with HelioScale Soiling Assembly for CSP and PV
4. Results from HelioScale Soiling Assembly for PV sites in various climates
5. Effect of soiling on energy yield of CSP and PV plants
6. Recommendations for monitoring soiling during project development & plant operations

The value of soiling measurements

Project Development

- Performance prediction
- Better knowledge of plant operational costs (demand of water, maintenance costs,…)
- site specific soiling intensity and characteristics (type of dust, particle sizes, annual cycle …)

→ Optimization of investment:

→ Site-specific design

→ cleaning strategy

soiling assessment

Operation & Maintenance

- Optimize real-life cleaning strategy (frequency, technique, demand water/detergents…)
- Reduce operational cost
- Performance prediction
- Adjust predictive maintenance

Main Effects of Soiling on Solar Energy

- Soiling of CSP mirrors affects the heat production of solar thermal power plants

- Soiling of PV panels directly affects the power output of PV modules

- Soiling depends on several external conditions → environmental factors:
    a) Material properties and composition of soil/dust (natural/lime/ash etc.)
    b) Particle characteristics: density, shape, weight, composition, chemistry and charge
    c) Homogeneity of the dust particle distribution
    d) Rain / cleaning cycles
    e) Humidity
    f) Wind direction, wind speed

source: Sarvar et al. (2013)

Requirements for soiling measurements during site qualification

Good estimation of average soiling rates throughout the year

- Site specific
- Accurate
- Ideally low maintenance needs

For designing effective and cost efficient cleaning systems for a site ideally also the characteristics of the dust are analyzed

- Type of dust
- Particles sizes
- Chemistry – stickiness etc.

How to measure soiling impact on …

a) CSP	b) PV
• **Reflectometers** (D&S or pFLEX)	• **HelioScale Soiling Assembly**
• DLR-TraCS	• PV modules reg. cleaned / dirty
• **ISE-AVUS**	• K&Z DustIQ
• **HelioScale Soiling Assembly**	

Reflectometers of D&S 15R-RGB and ISE/PSE/pFlex for monitoring soiling on CSP mirrors

- Portable, manual reflectivity instruments in combination with exposed mirror samples

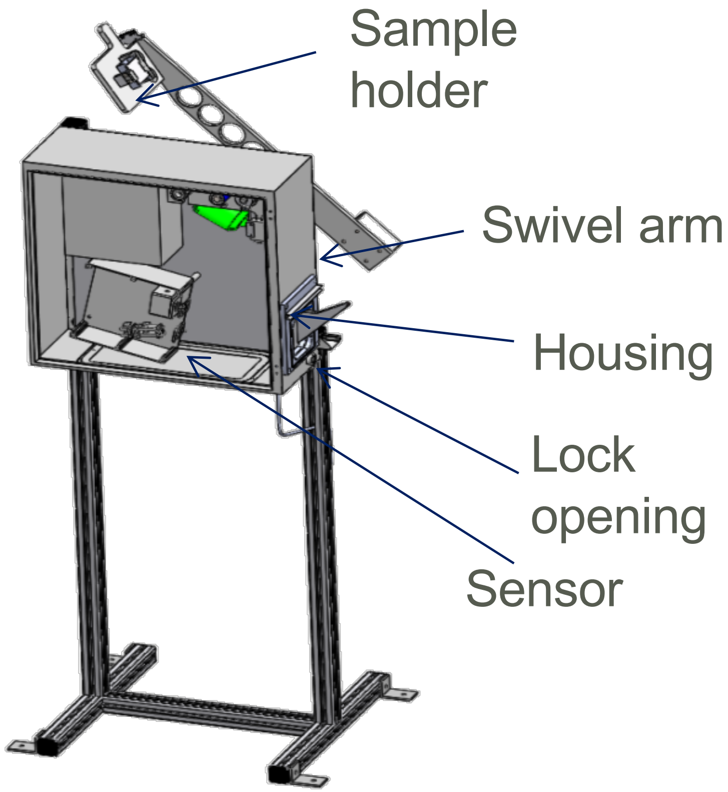
DLR TraCS

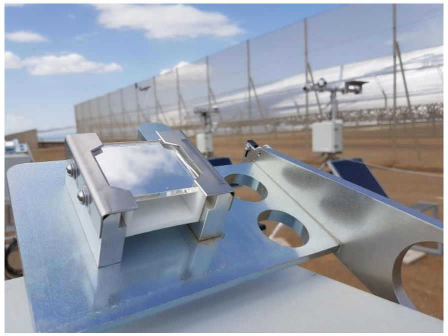
Automatic instrumentation measuring reflectivity of mirror sample indirectly

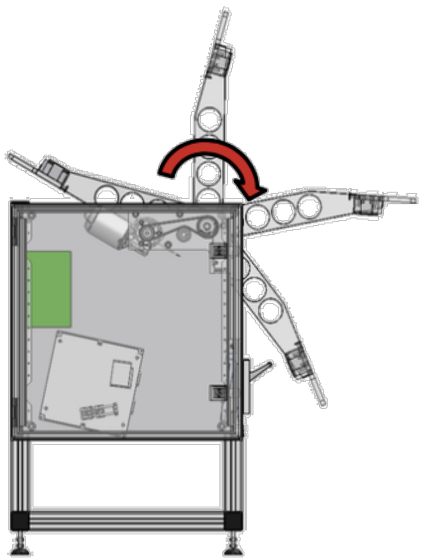
→ Using two pyrheliometer, one pointing on sample mirror, the other pointing on the sun (reference)

Fraunhofer ISE/PSE AVUS: a device for continuous measurement of reflectivity & collecting dust probes

Automatic instrumentation measuring reflectivity of a mirror sample **directly**







source: Heimsath et al. (2017)

Advantages of the AVUS device

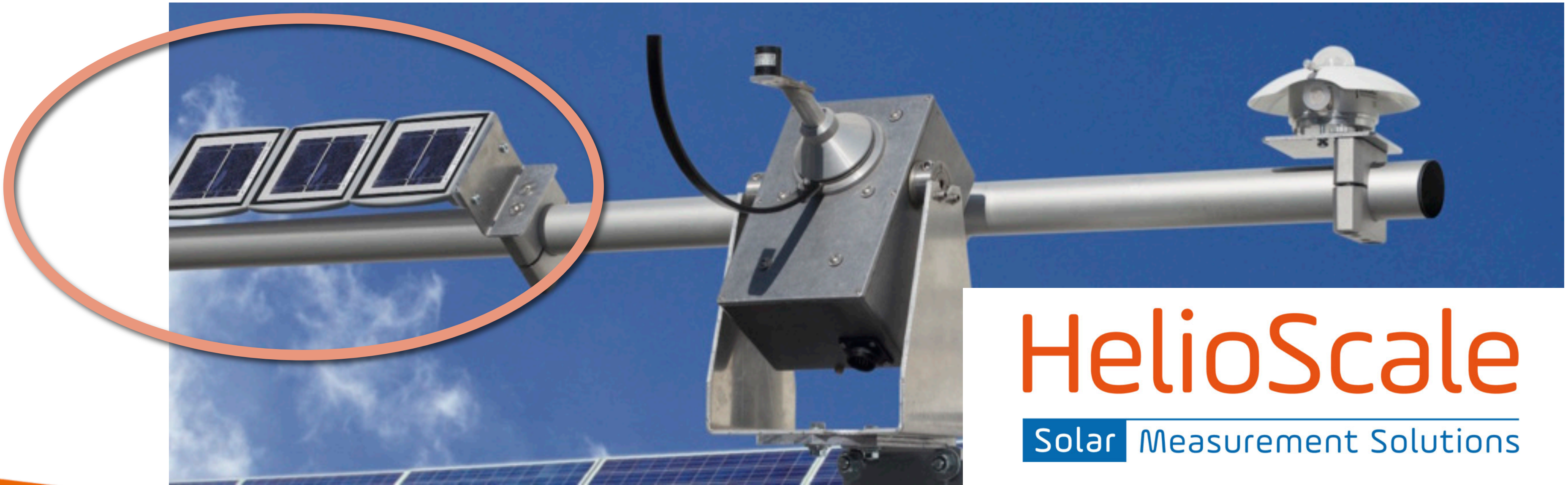
- Fully automatic
- **Quasi-continuous measurements** with variable time resolution
- **Mirror exposition adjustable** either at 30°, 45°, 60° or 75° for best representation of expected mirror angles
- **Very low maintenance**: only for exchanging the exposed mirror sample after several weeks
- Low power consumption
- Results:
  - reflectance, cleanliness and soiling rate
  - Soiling archive → soiled mirror samples can be sent to lab for further analysis including physical / chemical characterisation (e.g. particle size, chemistry, composition) of dust
- Also of value for very detailed analysis for PV

source: Heimsath et al. (2017)

HelioScale Soiling Assembly (HSA): the ideal solution for soiling of PV plants – robust, specific, cost-effective

Redundant operation of PV reference cells of same model:
1st cell very well cleaned as reference, 2nd cleaned as expected in plant, 3rd never

- Fulfilling the standard **IEC 61724-1** Photovoltaic system performance "Measurement method 1 – max power reduction due to soiling"
- **Easy to install and control** as an add-on to our solar measurement stations
- All sensors present the **same characteristics** regarding temperature, reflection and degradation → direct inter-comparison is possible.



HelioScale
Solar Measurement Solutions

Methodology

Mirror/CSP: Cleanliness = reflectance soiled / clean

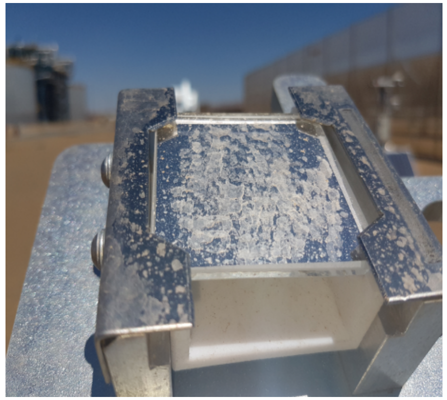
Reference Cell/ PV: Cleanliness = irradiance soiled / clean

Soiling loss = 1 – Cleanliness

Soiling rate = change of soiling loss / time

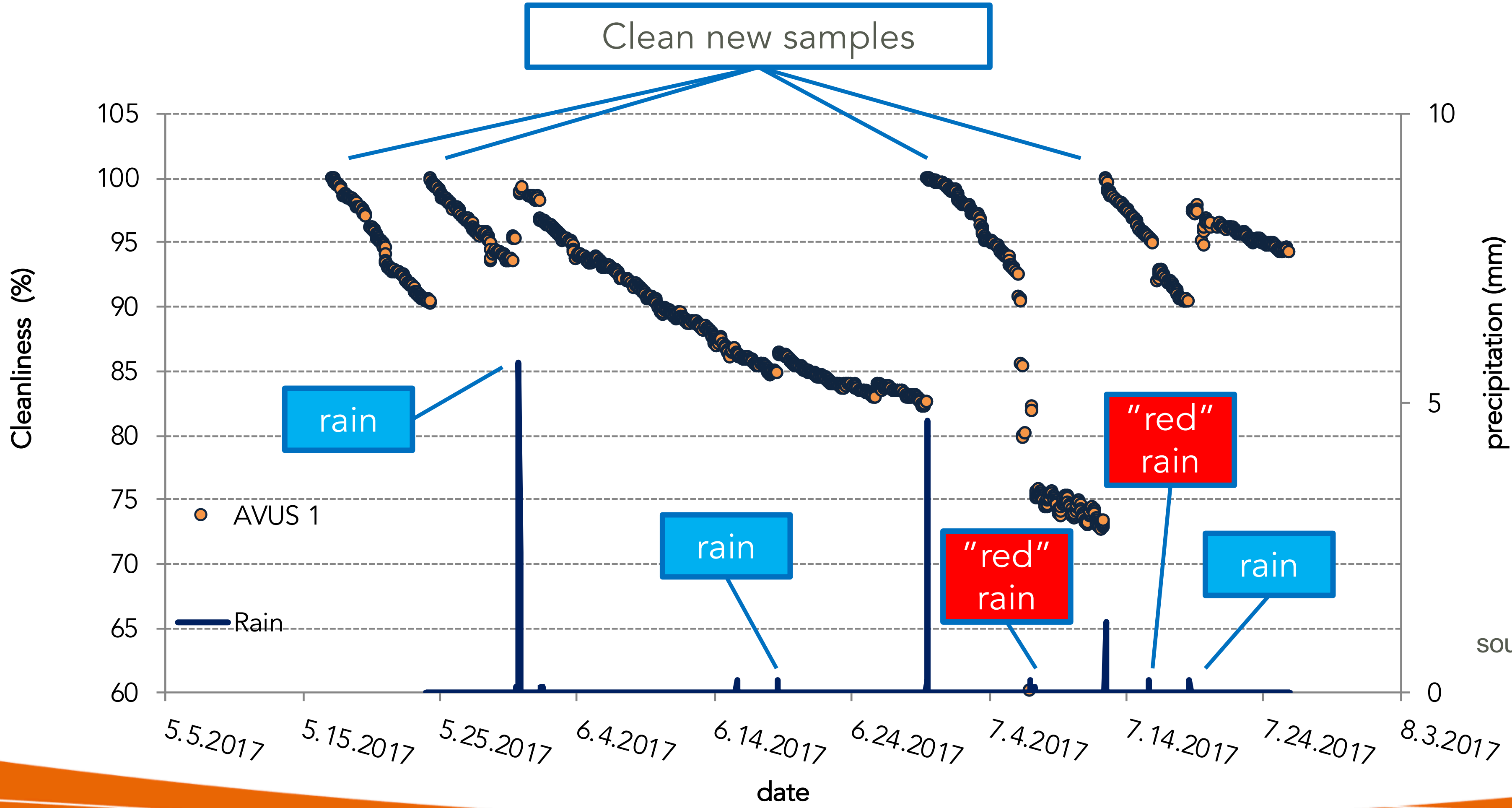
AVUS: Example in South Spain

Andasol 3 near Guadix (Granada) May 2017 – May 2018



AVUS field testing

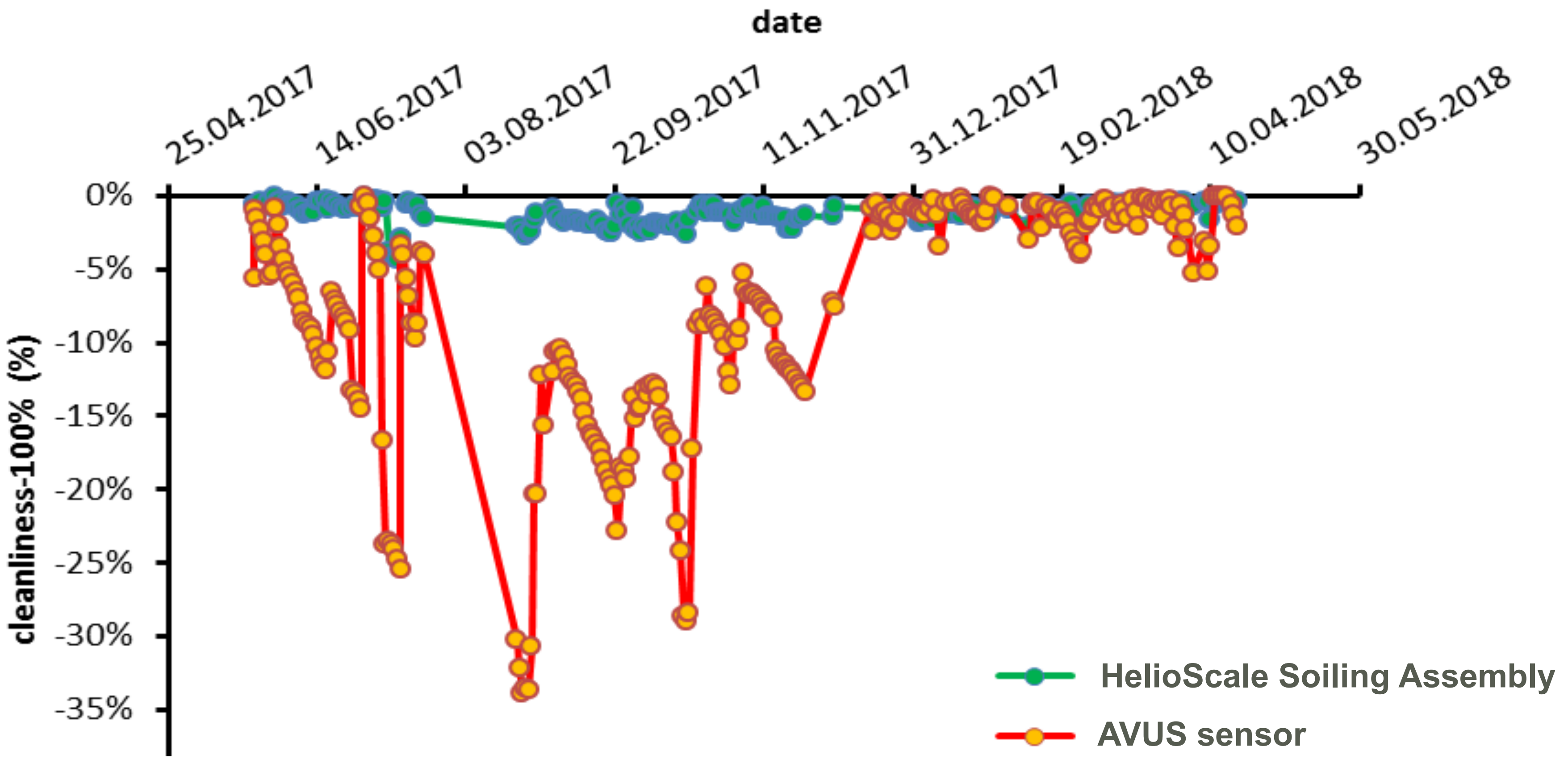
Example results AVUS1 - cleanliness



Continuous soiling, positive and negative rain events

source: Heimsath et al. (2018)

Comparison of AVUS sensor with HelioScale Soiling Assembly: measurement period over 1 year

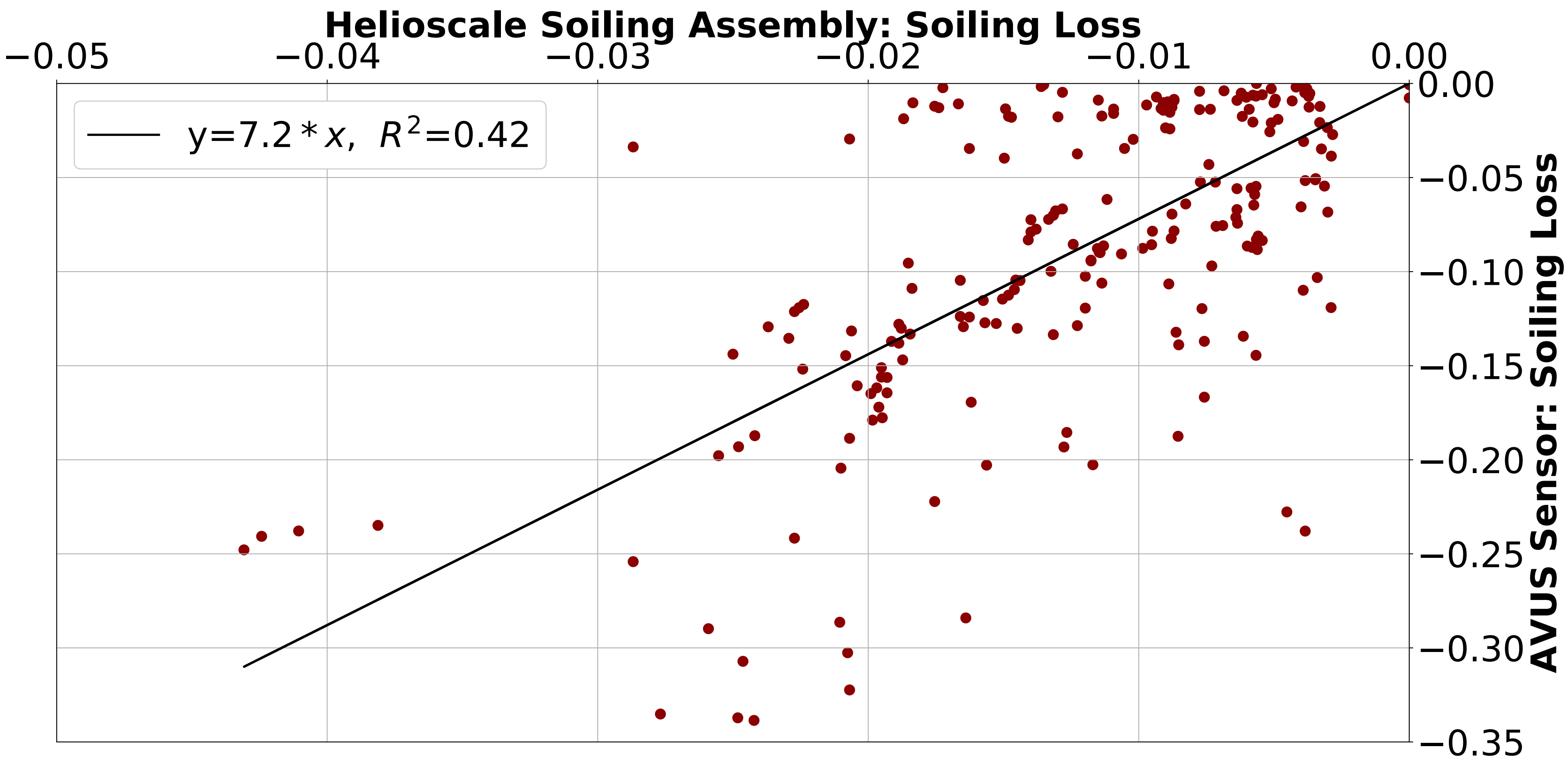


source: Heimsath et al. (2018)

AVUS sensor: maximum soiling loss of -35%

Helioscale Soiling Assembly: maximum soiling loss of -5%

AVUS sensor reacts 7x more sensitive to soiling



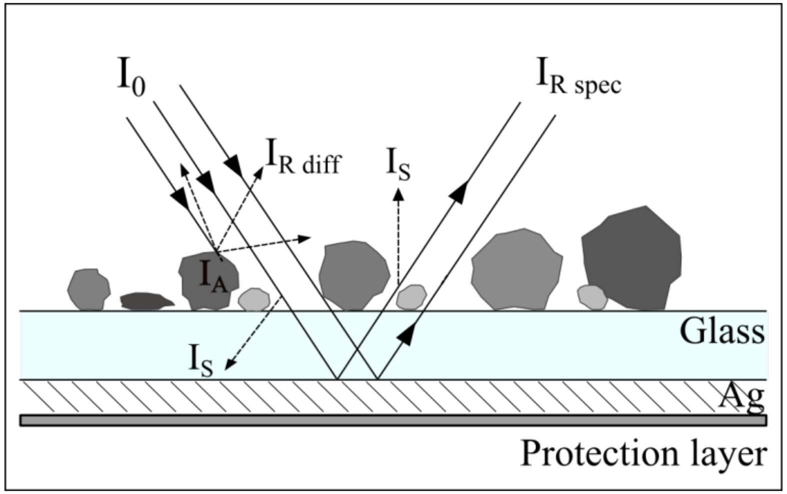
RMSE= 0.06

- Mirror reflectivity for CSP suffers much more under soiling than PV
- HSA shows moderate correlation to more precise AVUS soiling results

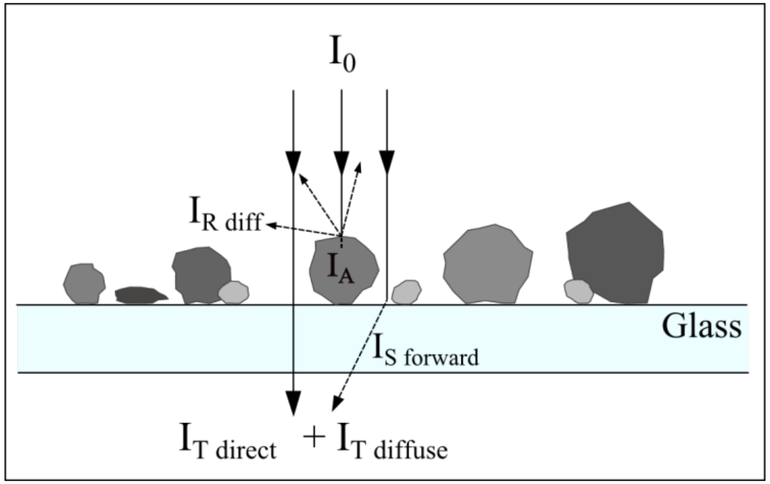
→ For CSP preferably use AVUS, for PV use HSA!

Soiling: an issue for all solar technologies

e.g. CSP: Glass-silver mirror



PV: Glass transparent cover



Optical losses occur due to diffuse reflection, scattering, absorption

CSP:

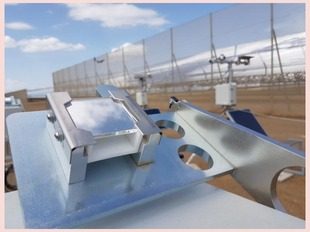
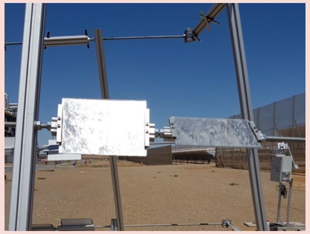
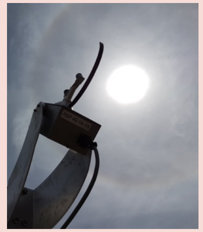
- 2 passages through soiling layer
- 1 passage through (soiled) absorber tubes glass cover
- Most forward scattered light is lost

PV:

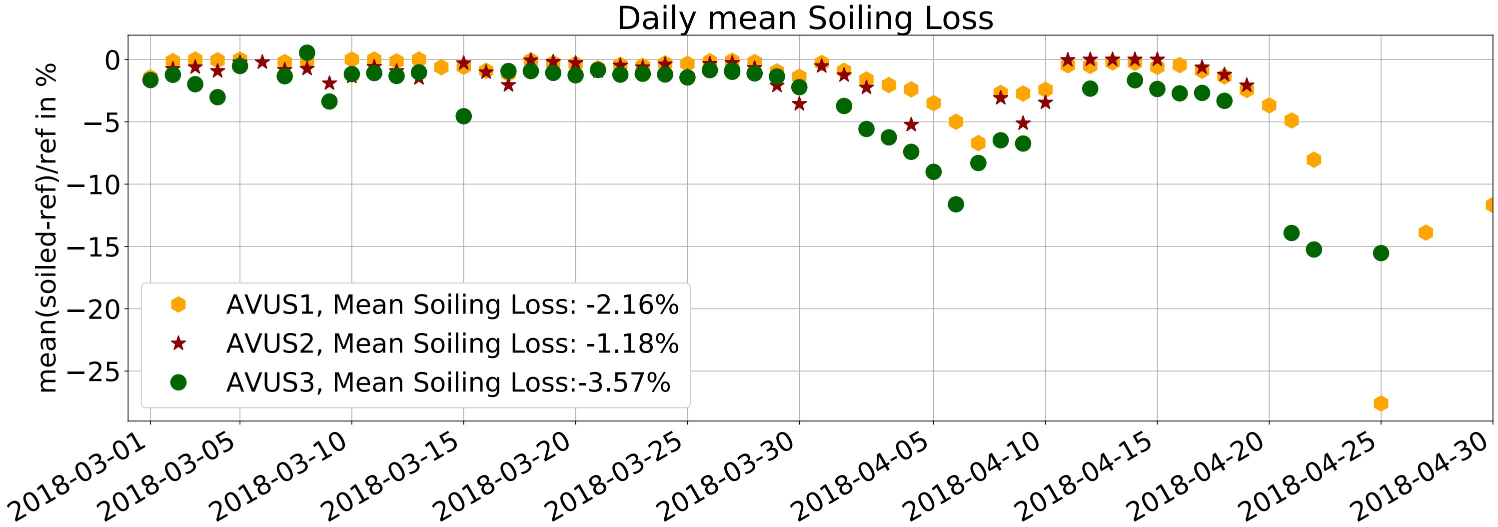
- 1 passage through the (soiled) glass cover
- Most forward scattered light is NOT lost

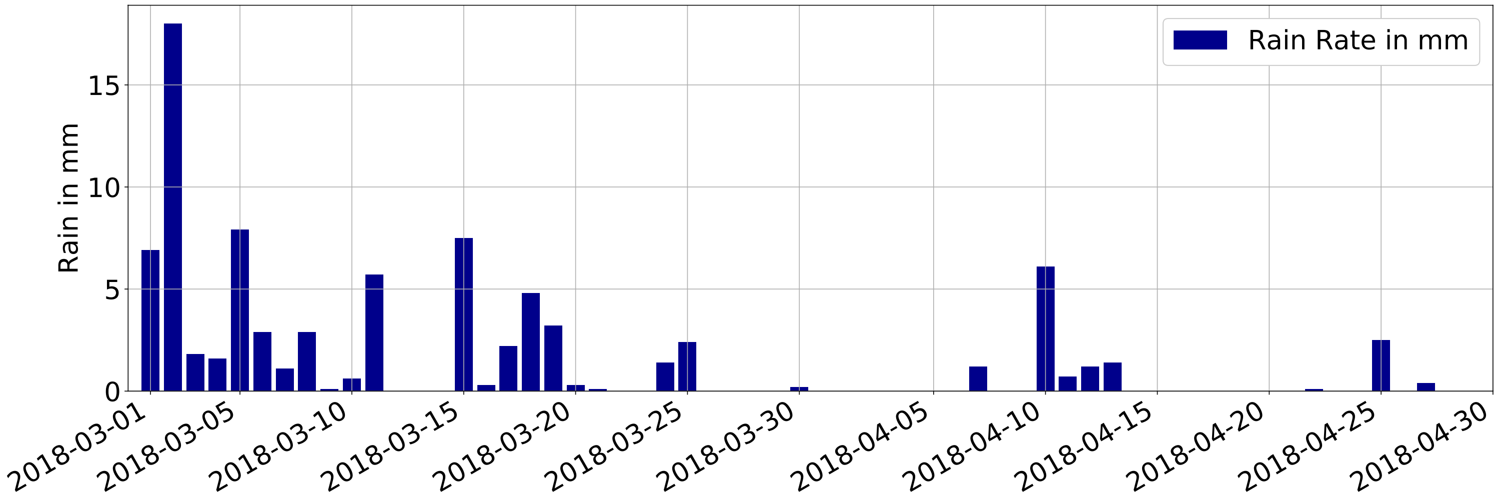
source: Bellmann (2017)

Comparison of daily soiling rates for different measurement principles at CSP plant Andasol 3

				derived from soiling of radiometers	
HS Soiling Assembly	AVUS Sensor	Static Mirror Samples (30º)	Moving mirror on tracker	Pyrheliometer	RSP
					
0.06%	0.39%	0.5%	0.18%	0.11%	0.03%

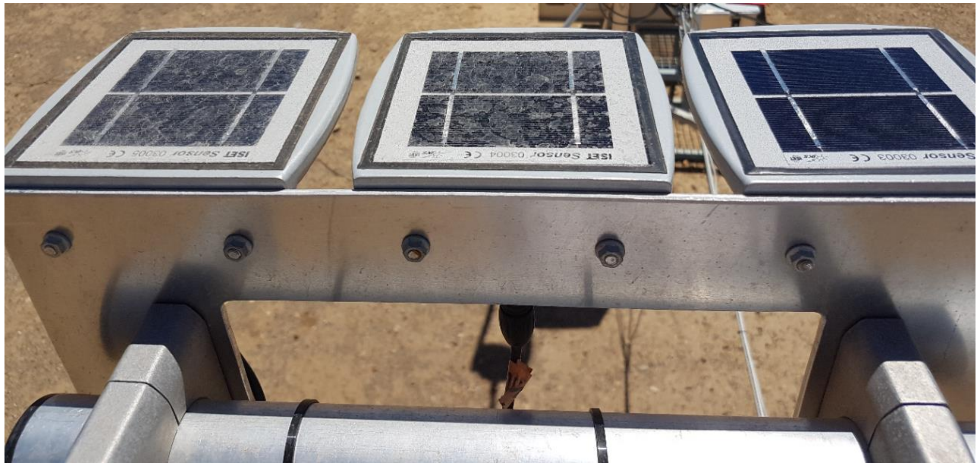
Soiling can differ strongly within one plant:
> factor 3 difference observed within < 2 km distance!





Results from HelioScale Soiling Assembly for PV sites in various climates

suntrace

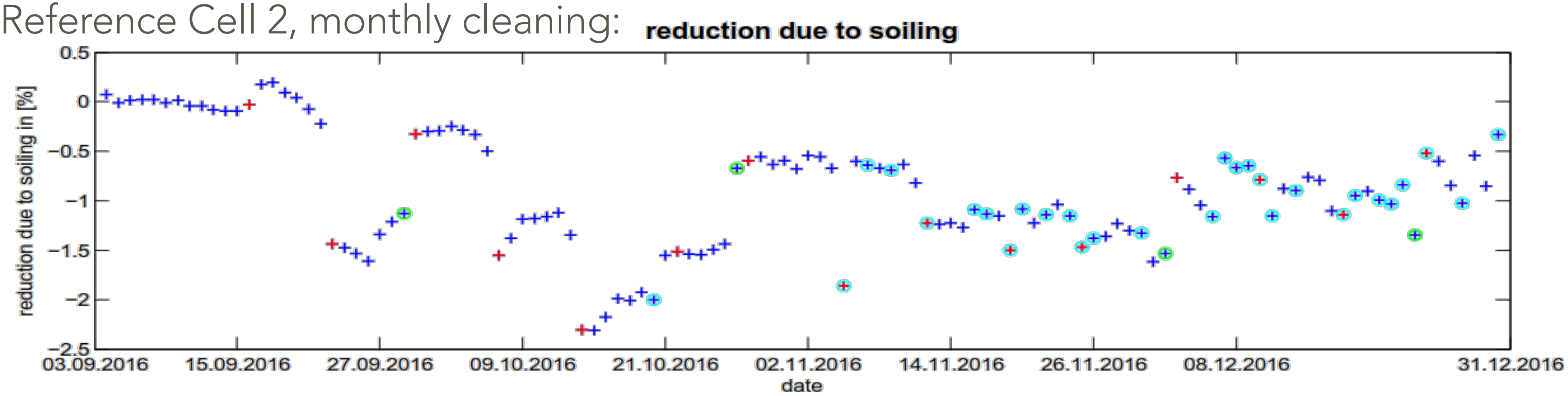


Soiling measurement results for various location and climate: Europe / South America

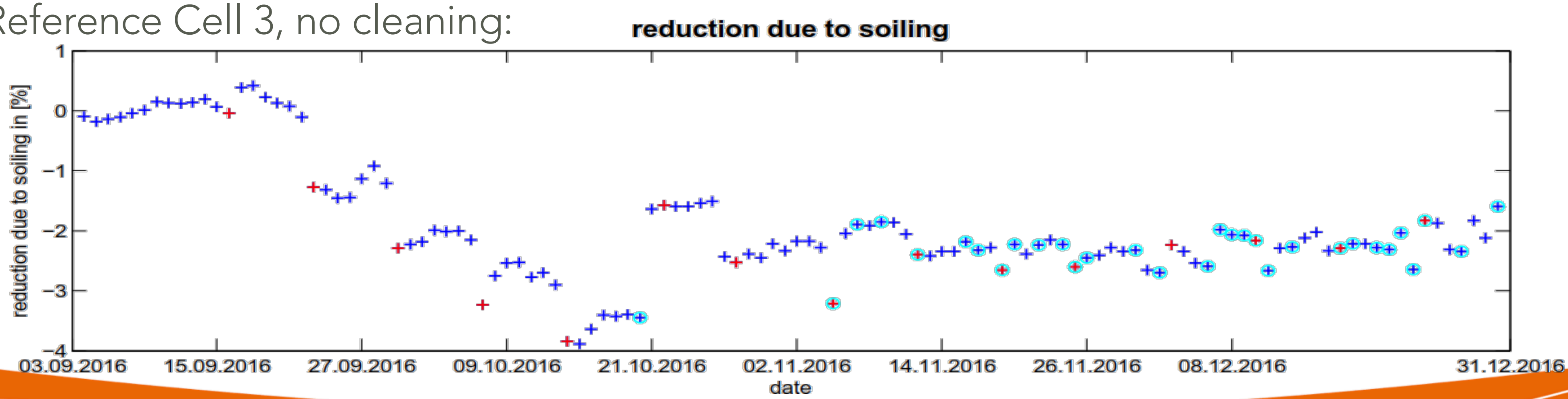
Continent	Region/ Country	Climate	Time frame measurem. campaign	Cleaning frequency RefCell2	Daily soiling rate	
					RefCell2	RefCell3
Europe	Southwest Europe	Dry Climate: Semi Arid (Mediterranean)	2017-05 to 2018-05	different	**0.05%**	0.10%
South America	Chile	Dry Climate: Semi Arid (Mediterranean)	2015-03 to 2019-02	monthly	**0.14**	0.07

Moderate soiling at PV plant in subtropical Southern Africa

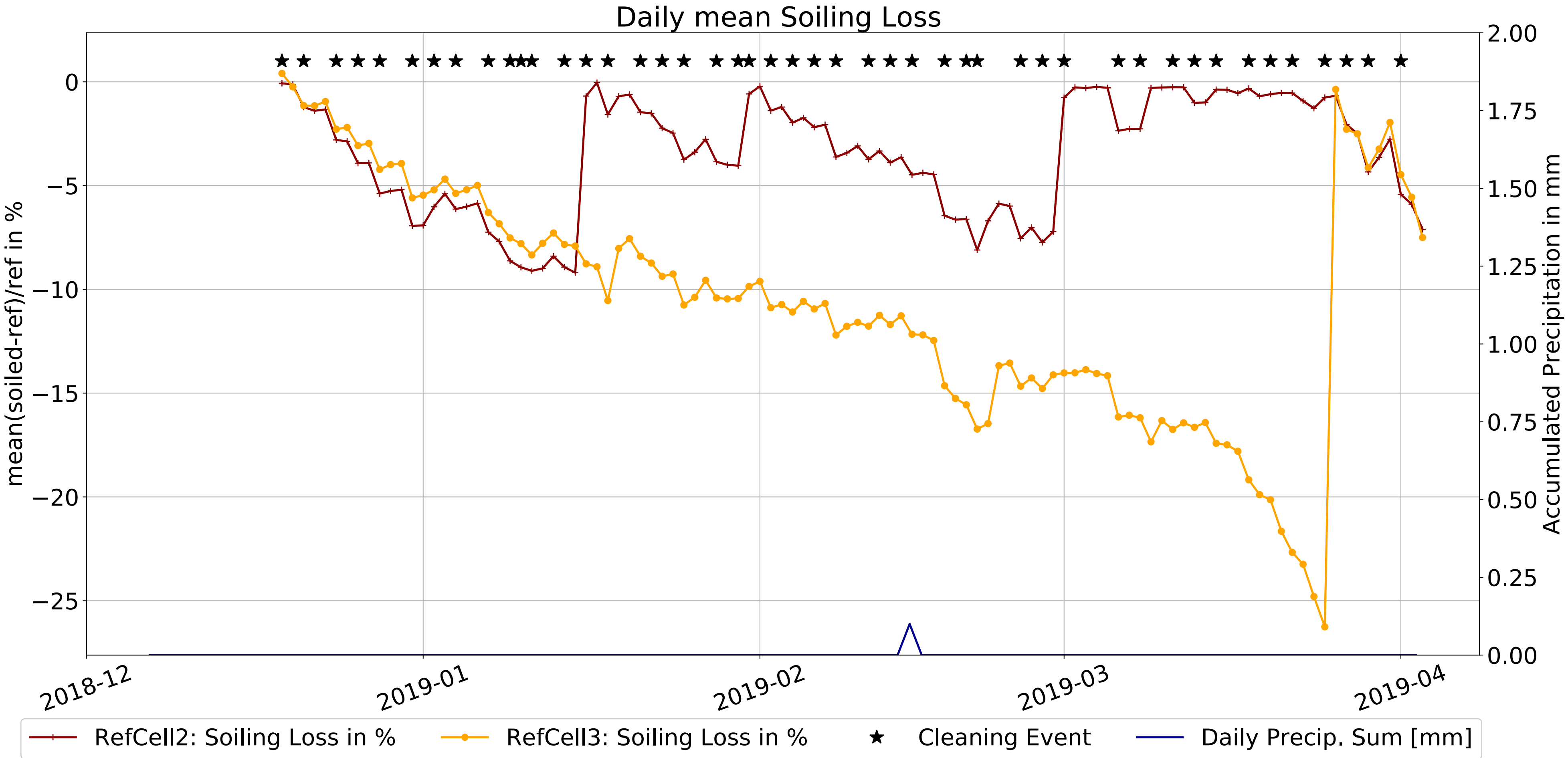
Reference Cell 2, monthly cleaning:



Reference Cell 3, no cleaning:



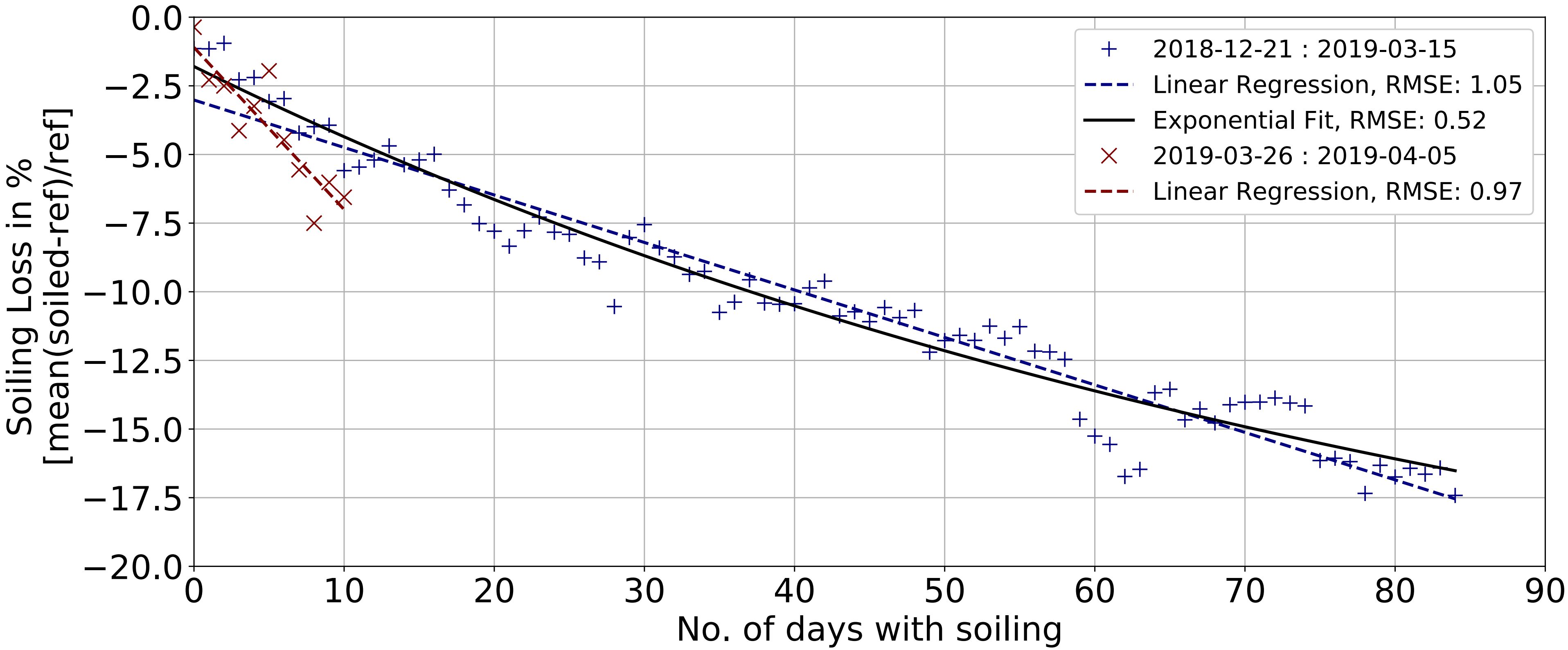
Severe soiling for a PV site in subtropical Northern Africa



- Daily soiling rate on Reference Cell 2: 0.36%
- Daily soiling rate on Reference Cell 3: 0.28%

Saturation effects reduce the soiling process

e.g. Reference Cell 3 for station subtropical Africa



- soiling of reference cells follow an exponential dependency due to saturation effects
- until a soiling loss of around 10% is reached, linear soiling rate is a good approximation

→ daily soiling rate of reference cell 3 is in general lower than reference cell 2

Soiling measurement results for various location and climate: Africa

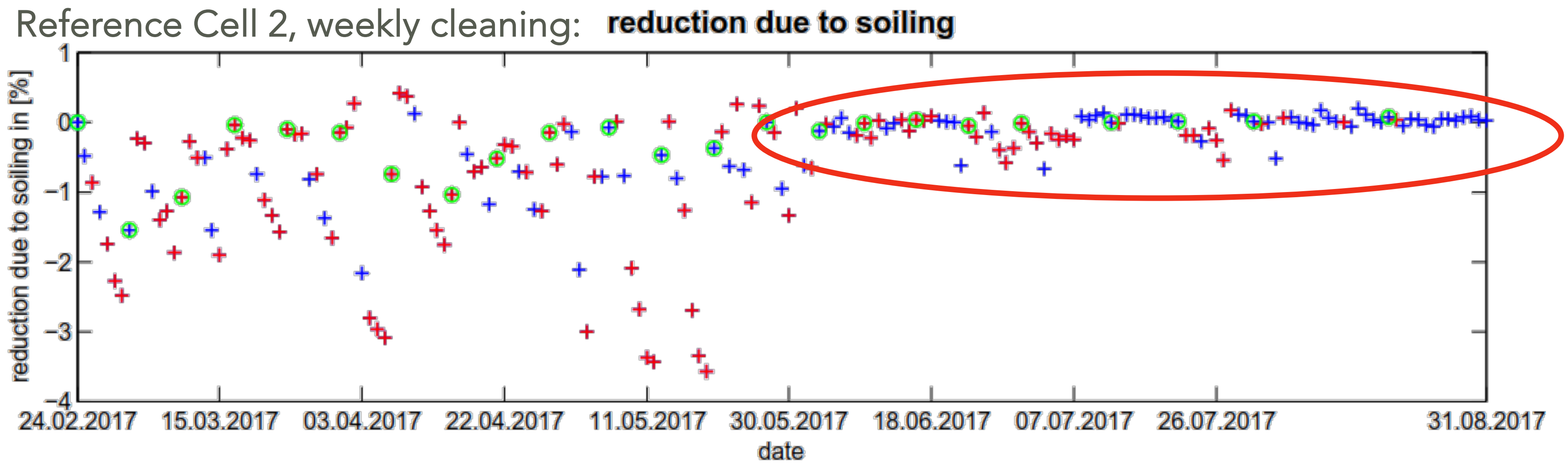
Region	Climate	Time frame measurem. campaign	Cleaning frequency RefCell2	Daily soiling rate	
				RefCell2	RefCell3
Subtropical Southern Africa	Dry climate: Semi arid (steppe)	2016-09 ongoing	monthly	**0.09%**	0.04%
Subtropical Northern Africa	Dry climate: Semi arid (steppe)	2018-12 ongoing	monthly	**0.36%**	0.28%
Subtropical East Africa	Dry climate: Arid (desert)	2018-02 to 2019-01	monthly	**0.24%**	0.21%
Subtropical East Africa	Humid Equatorial Climate: Long Dry Season (steppe)	2018-02 to 2019-01	monthly	**0.34%**	0.35%

Soiling measurement results for various location and climate: Asia

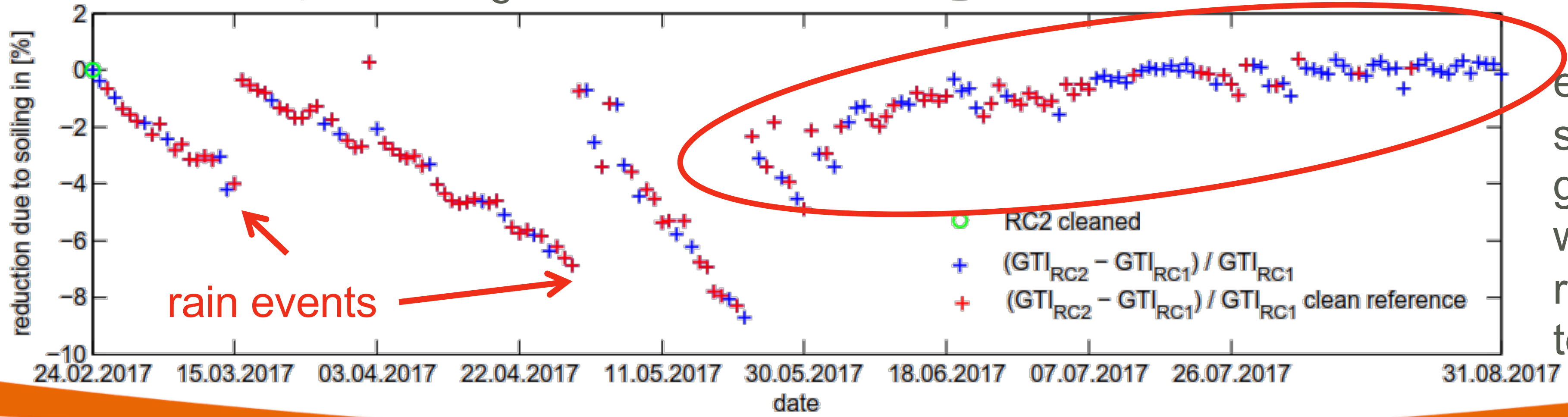
Region	Climate	Time frame measurem. campaign	Cleaning frequency RefCell2	Daily soiling rate	
				RefCell2	RefCell3
South Asia	Dry Winter (Steppe)	2017-03 to 2018-02	weekly	**0.22%**	0.19%
South-East Asia (Bangladesh)	Humid Equatorial Climate: Short Dry Season (Tropical savanna/monsoon)	2017-06 ongoing	monthly	**0.18%**	0.17%
South-East Asia (Vietnam)	Humid Equatorial Climate: Long Dry Season (Tropical savanna/monsoon)	2017-10 ongoing	monthly	**0.06%**	0.04%
South-East Asia (Vietnam)	Humid Equatorial Climate: Long Dry Season (Tropical savanna/monsoon)	2017-10 ongoing	monthly	**0.01%**	-

Severe soiling in South Asia with dry winter, but good self-cleaning during rainy season

Reference Cell 2, weekly cleaning:

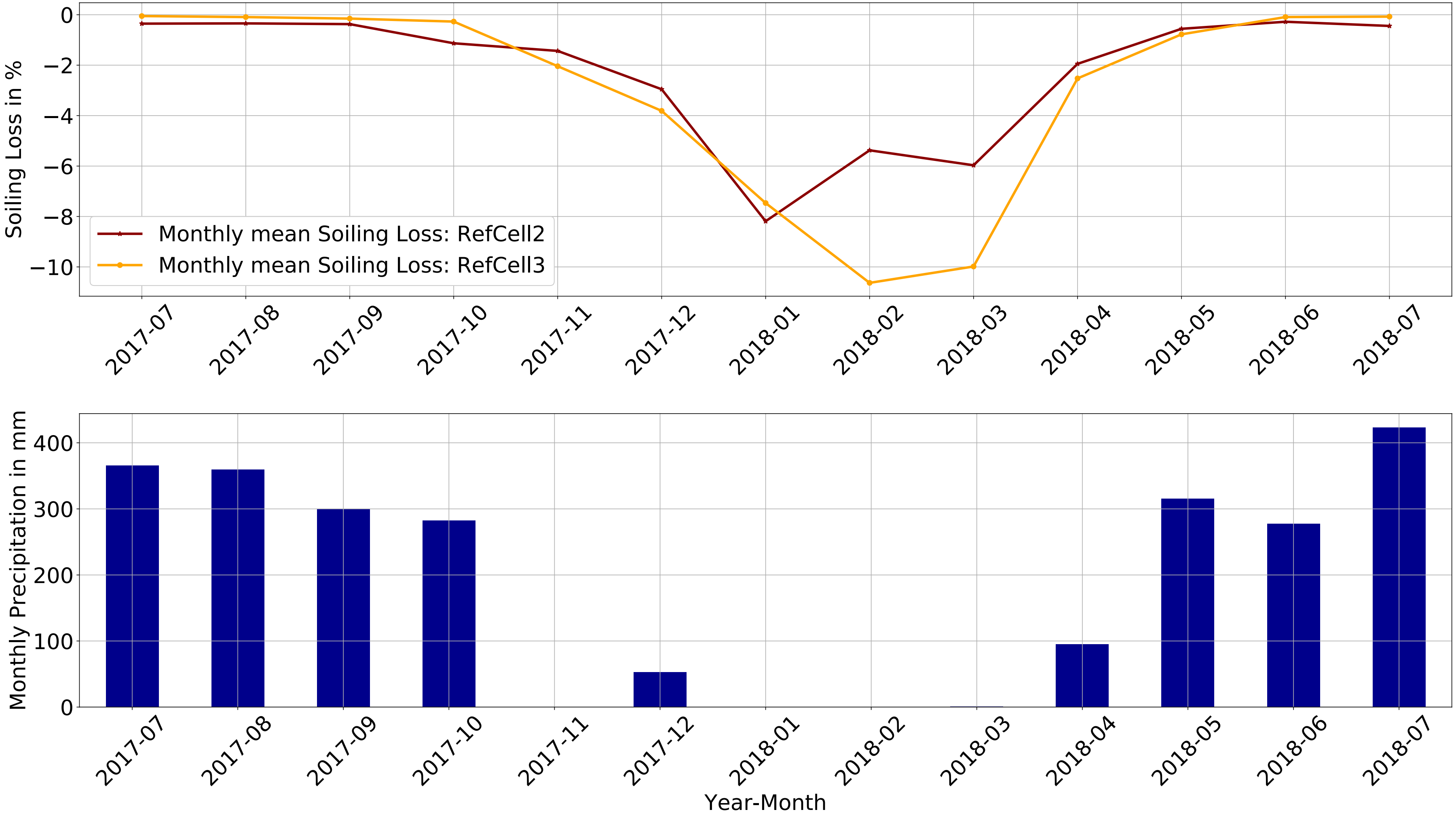


Reference Cell 3, no cleaning:

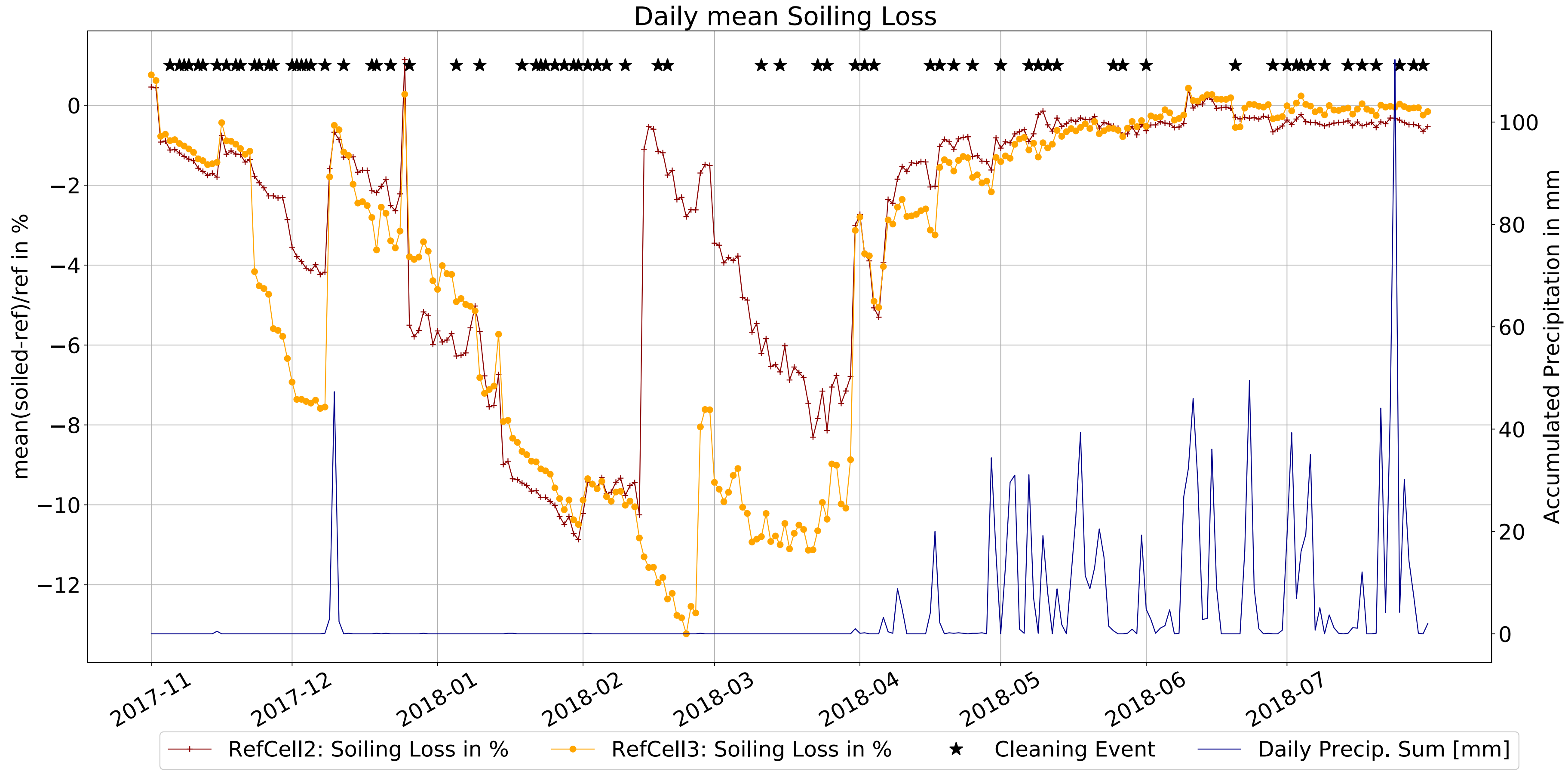


even strongly soiled refCell3 gets cleaner with sustained rain from day to day!

Seasonal variability over one year in South-East Asian monsoon climate



Dry season in more detail



- Soiling loss increased to >12% in February 2018.
- Mean Daily soiling rates in dry season up to 0.4%
- Soiling more intense than in Vietnam (Mean daily soiling rate around 0.06%)

Effects of soiling on energy yield of a 100 MW CSP plant

Total OPEX might be approximately 5 M€

Assume annual contribution of cleaning activities to OPEX to be 20%

→ ca. 1 M€ only cleaning expenditures

→ For each 1% reduction of cleaning costs, 10 k€ saved by measures like

  - Less frequent cleaning, but then when good effects can be achieved
  - Less water use
  - Less or cheaper detergents

→ Reduction of cleaning costs in the order of 10% to 20% can be achieved

Assume annual energy production (AEP) of a 100 MW CSP plant: 400 GWh

- at an electricity price of 70 EUR / MWh
- annual earnings around 28 Mio. EUR

Thus, yield increase of only 0.1% leads to +28 k€ higher earnings each year!

Effects of soiling on energy yield of 100 MW_{AC} PV plant

Averaged soiling loss of up to -0.4% per day observed at sites in arid sunny regions

→ soiling loss after 1 month already 12%, or

→ 6% on average assuming approx. linear decrease

Even at -0.1% soiling loss per day, typically -3% yield loss after 1 month without cleaning.

Example for 100 MW_{AC} PV plant:

GHI yearly avg.	AEP	Average soiling losses per year	Tariff	Non-delivered Energy (oportunity cost)
1000 kWh/m²/a (e.g. Germany)	100 GWh	-1.5% => -1.5 GWh	50 €/MWh	-75 k€/year
1500 kWh/m²/a (e.g. Vietnam)	150 GWh	-3% => -4.5 GWh	40 €/MWh	-180 k€/year
2000 kWh/m²/a (e.g. Mexico)	200 GWh	-6% => -12 GWh	30 €/MWh	-360 k€/year

→ Each cleaning cycle costs ca. 25 k€– assuming non-automate nor mechanical cleaning sufficient water and work efforts of 4 Pd/MWp.

Findings & recommendations concerning soiling for solar project development

- PV soiling rates at some sites <<-0.1% per day, but as high as -0.4% per day in arid regions; observed total efficiency losses due to soiled PV panels up to -25% in dry climate!
  e.g. 100 MW_{AC} plant only 1% additional soiling leads to annual yield deficit of 0,7 Mio€
- CSP affected 7-10 x more by soiling than PV
  e.g. 100 MW CSP-plant only 1% add. soiling leads to annual yield deficit of 3,4 Mio€

Take soiling serious as it has highly relevant cost implications – but several ways to optimize!

- **Measure soiling during site qualification:**

AVUS ideal device to monitor soiling for CSP plants.

- But its particle sampling function might also be of value for deeper analysis of soiling for PV.
- Costs effective solution for an optimized OPEX: AVUS ca. 20 k€ and pFLEX ca. 12 k€

Helioscale Soiling Assembly is the preferred device to quantify soiling rates primarily for PV:

- Very cost effective: <2500 € additional investment to station, only +80 € monthly for analysis
- Proven in several measurement campaigns worldwide for World Bank, IFC and industry
- In agreement with IEC 61724-1

Due to correlation with CSP-soiling rates, HelioScale device also useful for estimating soiling for CSP projects.

For due diligence of plants – especially in regions known for strong soiling, banks & investors can make soiling measurements obligatory to accept taking the risk!

Findings & recommendations concerning soiling for plant operations

- Soiling might change from the observations during project development:
  - lots of dust during & shortly after construction,
  - ground conditions may be better or have worsened due to plant implementation.
- Optimize cleaning methods & times for increasing profits:
  - more yield from better cleaned modules & mirrors
  - lowering costs by cleaning efficiently at the most favourable times and
  - improving cleaning methods based on better knowledge of site-specific soiling characteristics
- Solution is to continue observing soiling during plant operation
  - Use HelioScale Soiling Assemblies for PV and AVUS + pFLEX sensors for CSP plants; for huge PV plants consider also adding an AVUS sensor for analysing dust type.
  - We observed 3 different soiling rates within 2 km distance, therefore wise to follow IEC 61724-1:2017 Class A requirement of installing multiple soiling stations at larger plants:

System size (AC)	Number of stations
< 5 MW	1
5 MW - 40 MW	2
40 MW - 100 MW	3
100 MW - 200 MW	4

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