Soiling in CSP: modeling and forecasting from weather inputs

German Aerospace Center (DLR), Plataforma Solar de Almería, Spain

Fabian Wolfertstetter, Stefan Wilbert, Natalie Hanrieder, Lothar Keller, Sergio Gonzalez Rodriguez, Bijan Nouri

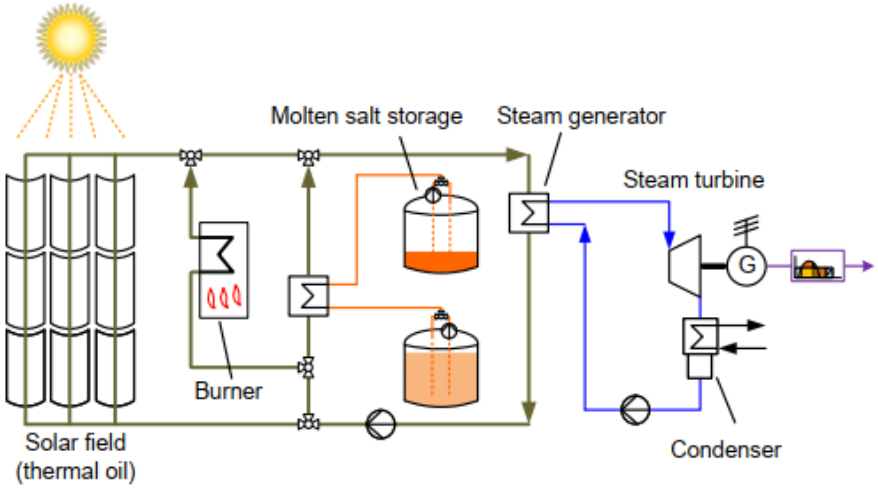
fabian.wolfertstetter@dlr.de

+34 950611877

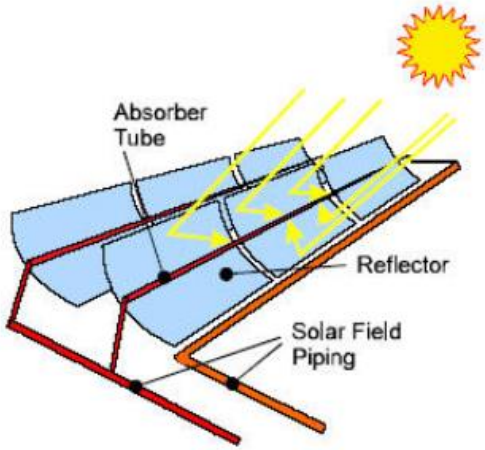
Outline

- Intro and short summary of PV-CSP-soiling comparison
- Measurements and sites
- Empirical soiling model: architecture, training and validation
- Soiling rate forecasting with dust transport models
- Summary and outlook

Concentrating Solar Power

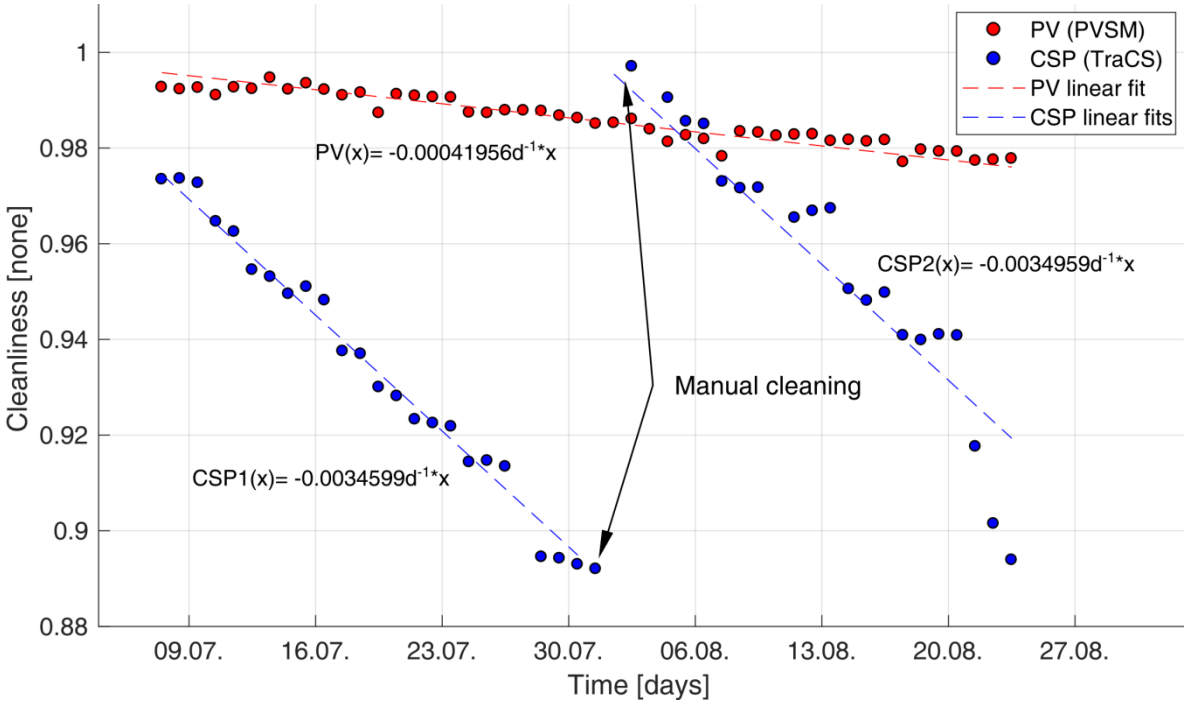


- Concentration of direct sunlight with mirrors to achieve high temperatures
- Provision of electricity (turbine cycle), process heat, desalination
- Cost effective **thermal storage** option
- **Grid stabilizing** effect thanks to turbine
- CSP uses only **direct component** of solar irradiation (=> soiling impact higher as in PV)



Images property of: Torresol energy, MASEN, SolarPACES, [T]

Comparison of soiling PV - CSP



→ CSP soiling rate approx. **8-9 times higher** than PV (0.35%/d and 0.04%/d)

→ Assumption: same surface densities on both technologies

Soiling on a more global scale?

- Direct measurement of soiling is expensive and time consuming
- Project developers require more global data for site selection

Questions:

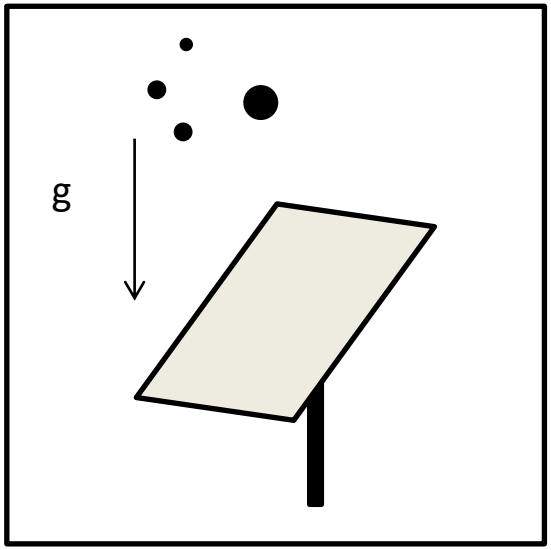
- Is it possible to derive a soiling model and validate it with local measurement data?
- Can this model be transfered to a more global scale?

Measurement sites used in this study

Soiling model

Aim: predict soiling rate on solar mirrors from other weather data.
Test and validate with measurement data

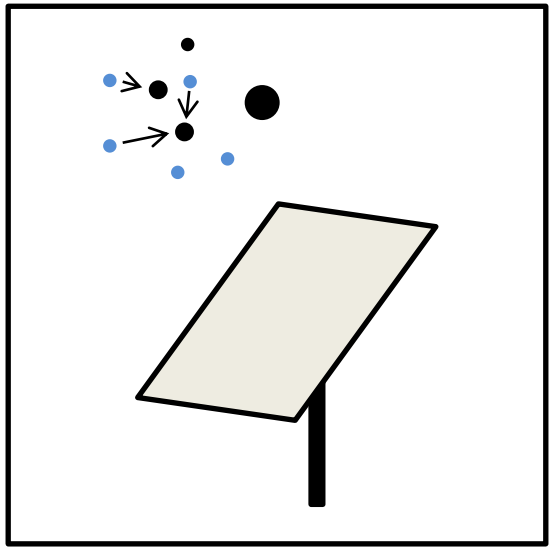
Sedimentation



- Gravitation

$$v_{S,p} = \frac{g\ {d_p}^2(\rho_{Aerosol} - \rho_{Luft})}{18\ \eta_{Luft}}$$

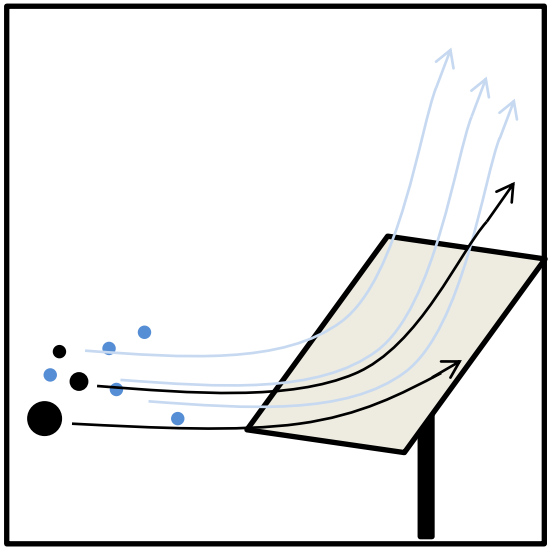
Brownian motion



- Thermal motion

$$v_B = a_{Brown}\ u_{Wind} \left(\frac{\nu_{Luft}}{D_B}\right)^{-\gamma}$$

Impaction



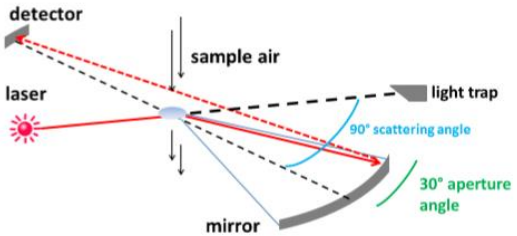
- Air stream/wind

$$v_{Im} = a_{Im} \cdot \frac{\sigma_{Ausrichtung}\ u_{Wind}}{1 + \exp(-f_{Im} \cdot (St - 1))}$$

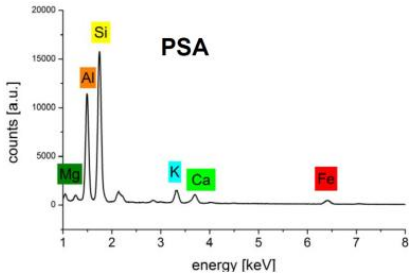
Also considered:
Rebound, resuspension, rain washing, cementation, mirror/panel orientation

Soiling model: input data

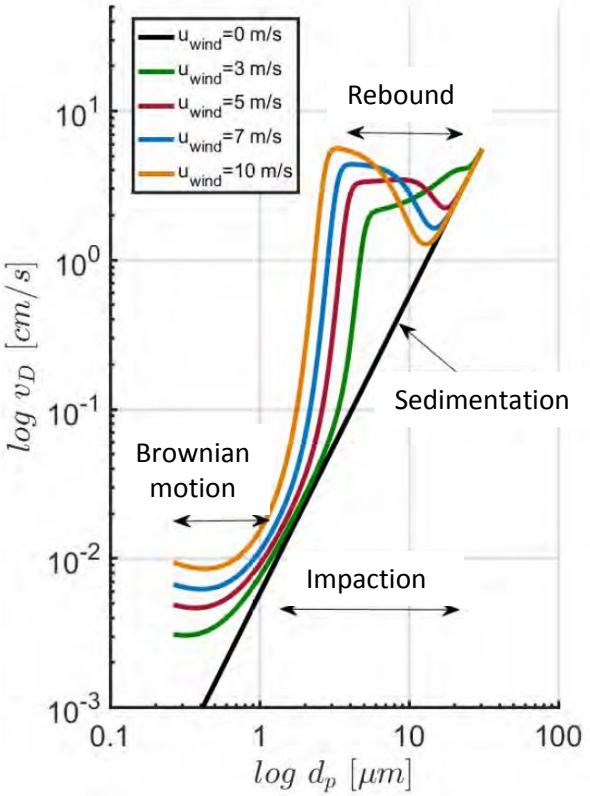
- Model is trained with a long term measurement dataset from PSA containing:
  - Aerosol particle number concentration from 0.25 µm - 30 µm
  - Wind, relative Humidity, rain, irradiance, dew, temperature, atmospheric pressure, etc.



Optical particle counter



Soil properties



Visibility

Flysand

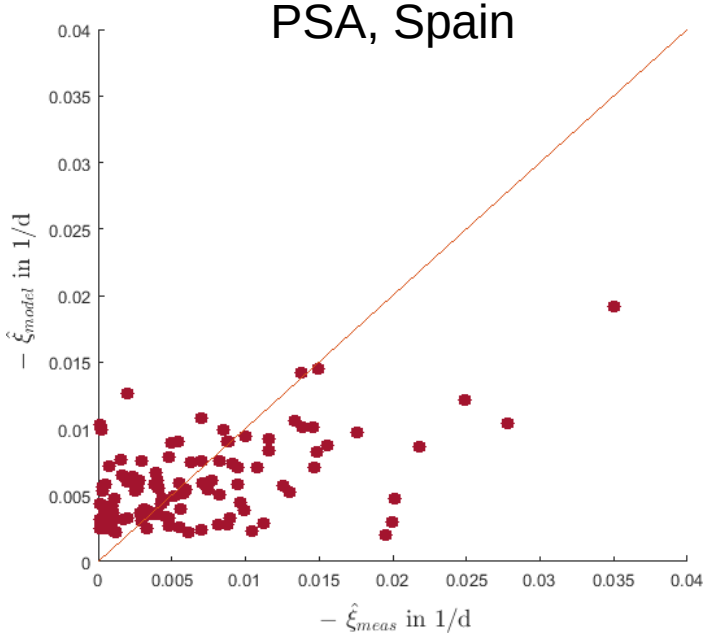
3D Wind, rain, temperature

Soiling model performance

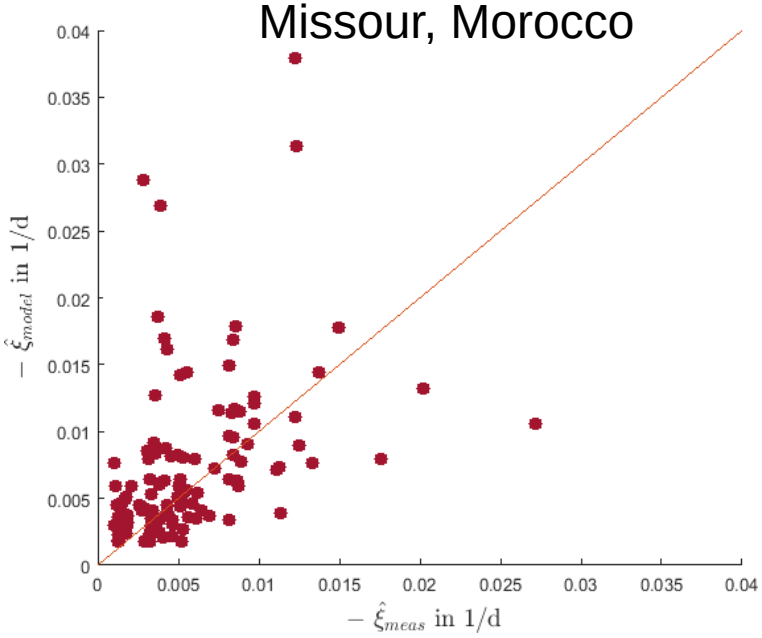
- Model validated for two sites
- RMSE = 2 x soiling rate measurement accuracy
- Bias = 0.5 x soiling rate meaurement accuracy
- Heavy soiling days (>1% daily loss) can be identified with 90% accuracy

	Bias ($\cdot\ \%/d$)	RMSE ($\%/d$)
PSA Training Set	0.08	0.43
PSA Test Set	0.11	0.44
Missour	0.09	0.46

PSA, Spain



Missour, Morocco



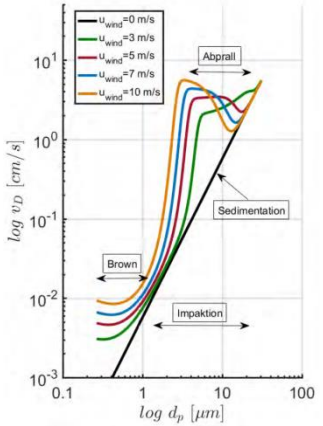
Soiling and condensation model applied to CSP solar field – DLR Report, WASCOP H2020 project D3.2, 2018, to be published online on www.wascop.eu,

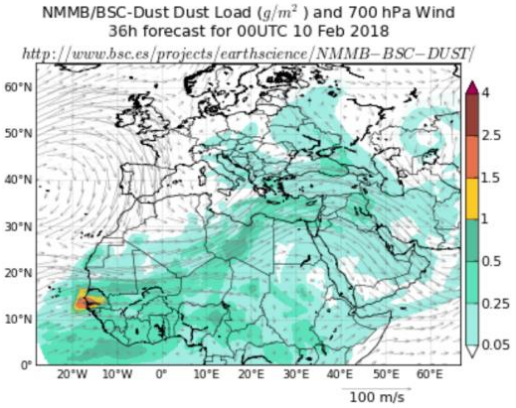
Outlook: Soiling rate map and forecast

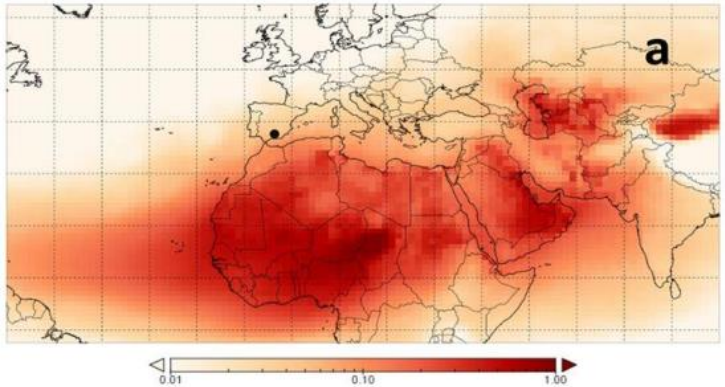
Activities within the solwatt project (https://solwatt.eu/) in collaboration with BSC:

- Couple the CSP soiling model with BSC atmospheric dust transport model
  - => soiling rate forecast of 72 hours
  - => soiling rate map from reanalysis of historical dust model data

- Not yet covered: Transfer of CSP soiling to PV soiling possible?







References

[W4] Wolfertstetter et al, „Soiling and Condensation model applied to CSP solar field“, WASCOP project report 3.2, 2018, http://wascop.eu/wp-content/uploads/2018/06/WASCOP_deliverable_3.2_final_plainText.pdf

[Wi] **Wilbert**, S.: *Determination of Circumsolar Radiation and its Effect on Concentrating Solar Power.* PhD thesis, Technische Hochschule Aachen, 2014.

[W1] **Wolfertstetter**, F.*: Effects of soiling on concentrating solar power plants.* PhD thesis, Technische Hochschule (RWTH) Aachen, 2016

[K] **Knisely**, B., S. V. **Janakeeraman**, J. **Kuitche** . G. TamizhMani: *Validation of Draft International Electrotechnical Commission 61853-2 Standard: Angle of Incidence Effect on Photovoltaic Modules.* Arizona State University, Photovoltaic Reliability Laboratory, 2013.

[L] **Laven**, P.: *MiePlot - A computer program for scattering of light from a sphere using Mie theory & the Debye series.* Computer Program, 2017.

[Wa] **Wagner**, R., T. **Ajtai**, K. **Kandler**, K. Lieke, C. Linke, T. Müller, M. Schnaiter . M. Vragel: *Complex refractive indices of Saharan dust samples at visible and near UV wavelengths: a laboratory study. A*tmospheric Chemistry and Physics, 12(5):2491–2512, mar 2012.

[F] **Figgis**, B.: *PV Soiling: Qatar Perspective.* DEWA Soilingworkshop 2016*, 2016*

[T] THERMVOLT Systemvergleich von solarthermischen und photovoltaischen Kraftwerken für die Versorgungssicherheit Schlussbericht 01.11.2014 - 30.06.2016

[B] Bellmann, P., Oct. 2017, „**Investigation of soiling on mirror and glass samples with regard to power losses in CSP and PV technologies**“, Diploma thesis, University of Dresden

[Sc] Schüler, David, et al. "The enerMENA meteorological network–Solar radiation measurements in the MENA region." AIP Conference Proceedings. Vol. 1734. No. 1. AIP Publishing, 2016.

[W2] Wolfertstetter F, Wilbert S, Dersch J, Dieckmann S, Pitz-Paal R, Ghennioui A. Integration of Soiling-Rate Measurements and Cleaning Strategies in Yield Analysis of Parabolic Trough Plants. ASME. J. Sol. Energy Eng. 2018

[W3] Wolfertstetter, F., Pottler, K., Alami, A., Mezrhab, A., & Pitz-Paal, R. (2012). A novel method for automatic real-time monitoring of mirror soiling rates. SolarPACES 2012.

[FG] A. Fernández-García, F. Sutter, L. Martínez-Arcos, C. Sansom, F. Wolfertstetter, C. Delord, Equipment and methods for measuring reflectance of concentrating solar reflector materials, Solar Energy Materials and Solar Cells, Volume 167, 2017

[S] Schüler, David, et al. "The enerMENA meteorological network–Solar radiation measurements in the MENA region." AIP Conference Proceedings. Vol. 1734. No. 1. AIP Publishing, 2016.

Soiling measurement setup at PSA

PV reference cells

PV panels SCC comparison

TraCS for 4 mirrors

transmission measurement (tubes)

PV panels

TraCS for 4 mirrors

rain

Optical particle counter

visibility

wind