Determination of atmospheric attenuation from ground measurements

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Content

- Introduction

- 4 approaches for ground based extinction determination
  - 3 measurement methods (involving modelling)
  - 1 model based on clear sky DNI
  - Inter-comparison

- Outlook

Extinction

- **Beer-Bouguer-Lambert law (monochromatic)**

$$\boxed{I(x) = I_0 \exp(-\beta_e x)}$$

- Usually, β_e IS NOT measured → Another variable might be used → MOR
  MOR is measured for traffic purposes
  -roads, airports

- **Def.:** MOR = Path after which a luminous flux from an incandescent lamp @ color temperature of 2700 K, is reduced to 5% of its original value (WMO, CIMO Guide).

Koschmieder Equation

$$\mathrm{MOR} \approx -\ln 0.05 / \beta_{e,550nm}$$

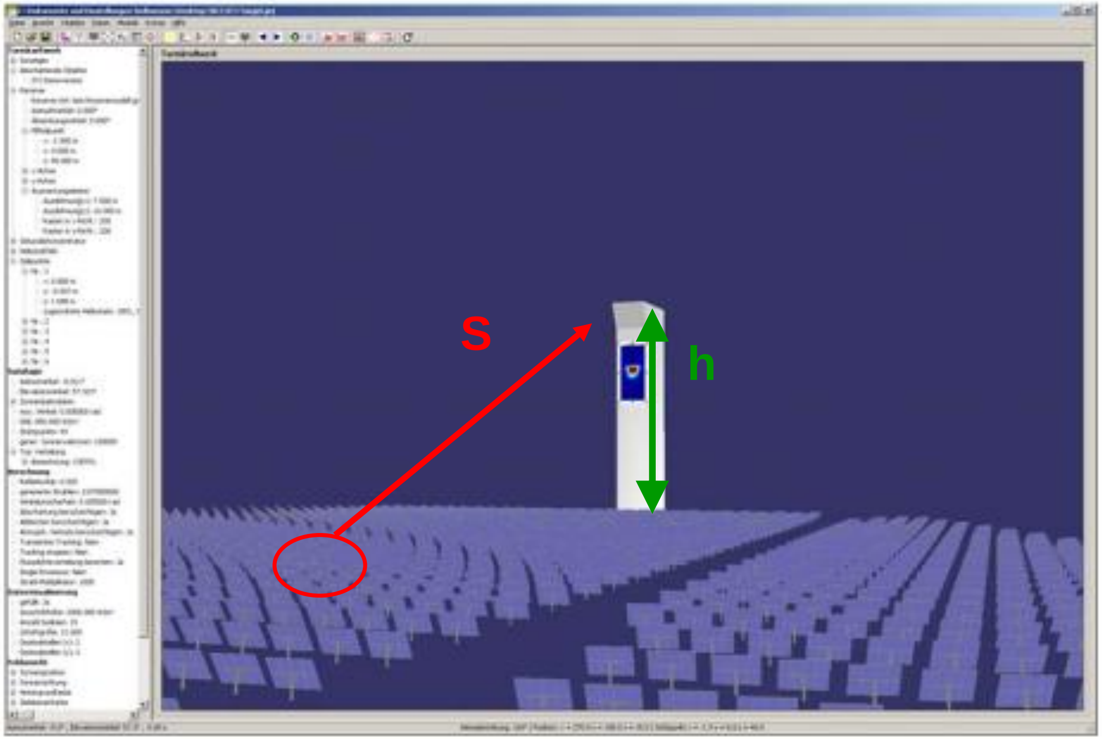
- 2011: MOR used as extinction information in solar resource assessment
  - Is this a good idea?

State of the art in 2011

- In raytracing tools the case hazy or clear was selected for whole evaluation based on MOR (or estimation)

→**Most sophisticated option 2011:**
MOR + Pitman & Vant-Hull transmittance model (1982)

based on calculations with atmospheric model LOWTRAN3 by Vittitoe & Biggs for 12 atmospheric conditions



→Input parameters

- Tower height h = 200m
- Slant range S
- Water vapor density ρ
- Site elevation H = 500m
- Scattering coefficient β_s at λ=550nm

Pitman & Vant-Hull model: drawbacks

Scattering coefficient β_s typically not known

- P&V often not used
- Or MOR measured and Koschmieder equation is applied without detailed investigation by users

Physical simplifications

- Variation of solar spectrum not included
- Exponentially decreasing aerosol density with height
- Only rural aerosol type

=> investigate MOR sensors in more detail

Measurement options (PSA)

2. Optec LPV- 4

1. Vaisala FS11

1. MOR measurements with FS11 + ABC (corr.)

2. MOR measurements with LPV4 + ABC (corr.)
   Long path visibility sensor, > 500 m
   Diagonal measurement path possible

3. Grimm particle counter EDM 164

5. Degreane TR30

3. Particle counters + libRadtran based correction
   - Size dependent aerosol concentration, rel. hum, pressure, temperature

4. Model based on clear sky DNI

(5. MOR measurements with TR30)
(6. DNI from ground and top of tower)
(7. LIDAR)

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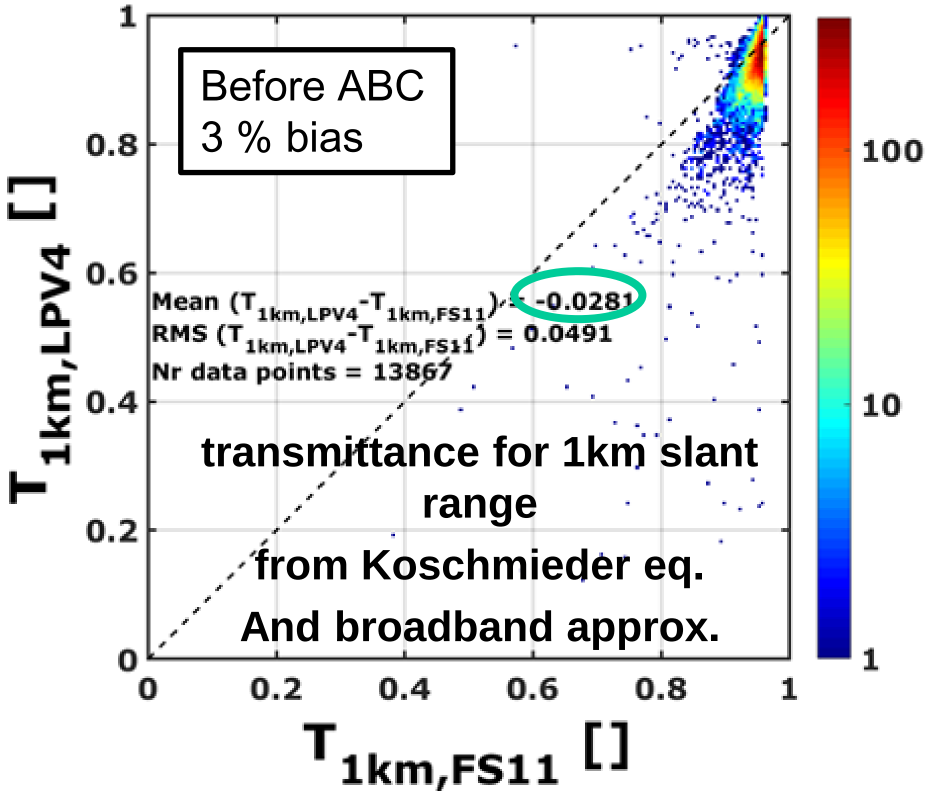
Approaches 1 & 2: FS11 and LPV4

Vaisala FS11 scatterometer (NIR, no absorption)

Optec LPV-4 transmissometer (532 nm)



1 year processed data from PSA

10 min time resolution

bias of ~2% occurs also for P&V model if used with (MOR + Koschmieder) input

Hanrieder, N., S Wilbert, R Pitz-Paal, C Emde, J. Gasteiger, B Mayer, and J. Polo. 2015. "Atmospheric extinction in solar tower plants: absorption and broadband correction for MOR measurements." *Atmos. Meas. Tech.* no. 8:3467-3480. doi: 10.5194/amt-8-3467-2015.

Approaches 1 & 2: FS11 and LPV4 + ABC

Vaisala FS11 scatterometer
(NIR, no absorption)

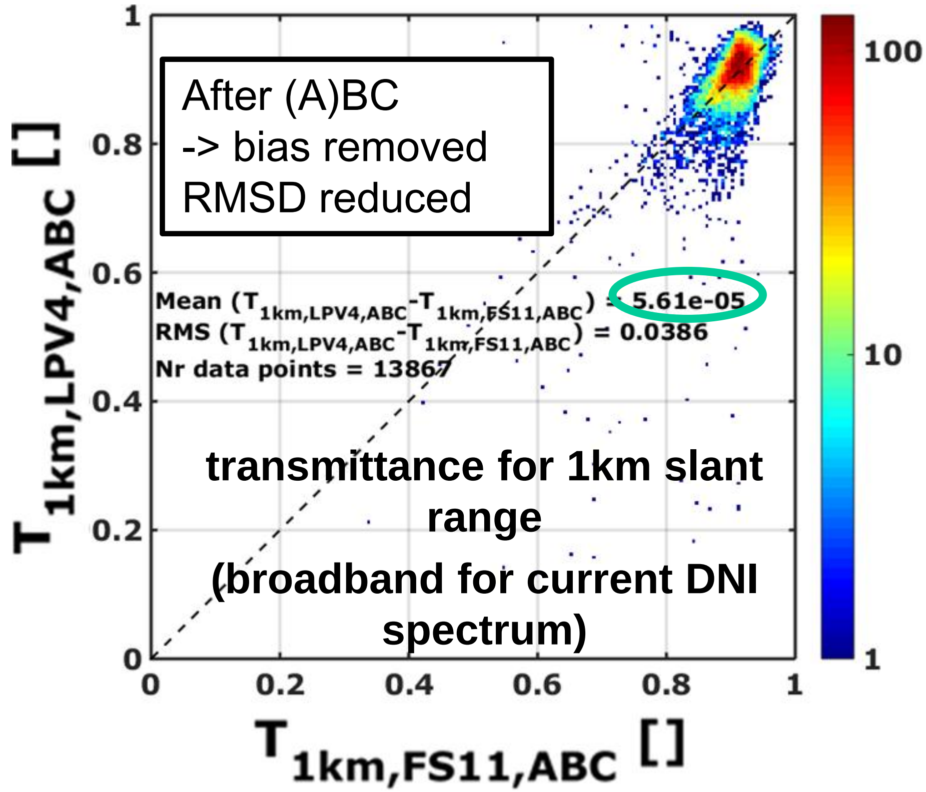
Optec LPV-4 transmissometer

(532 nm)

libRadtran

Absorption & Broadband Correction (ABC)

ABC correction for LPV4 small



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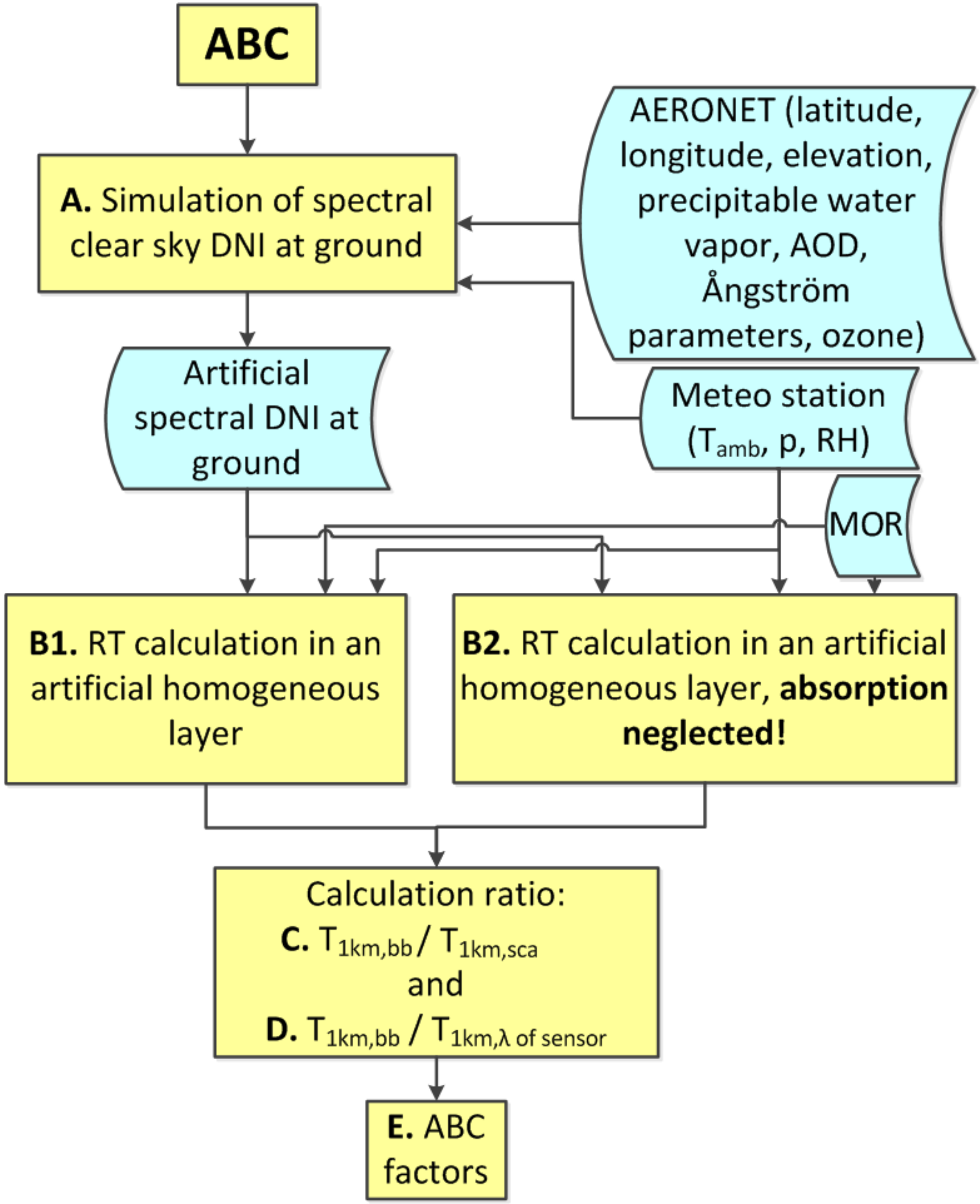
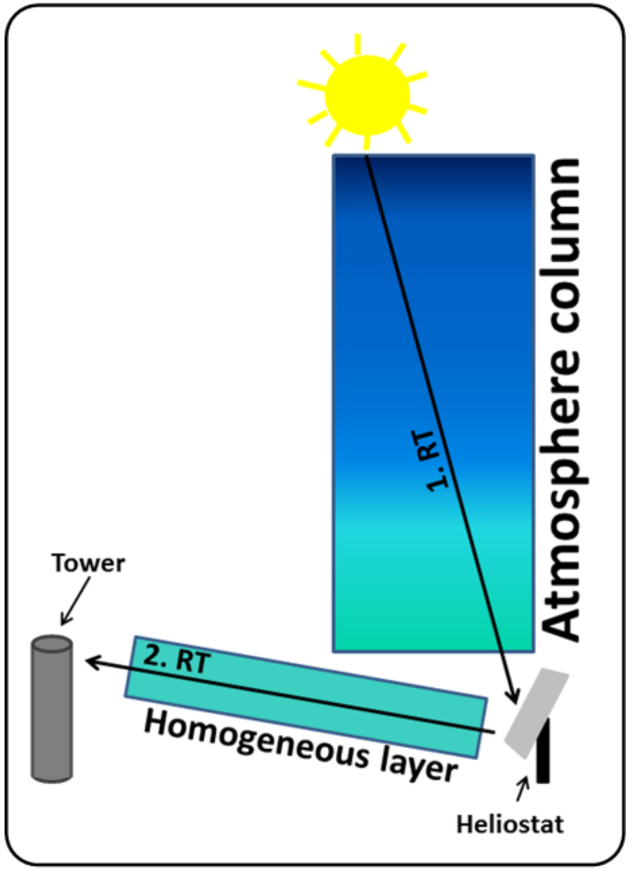
Absorption & Broadband Correction (ABC)





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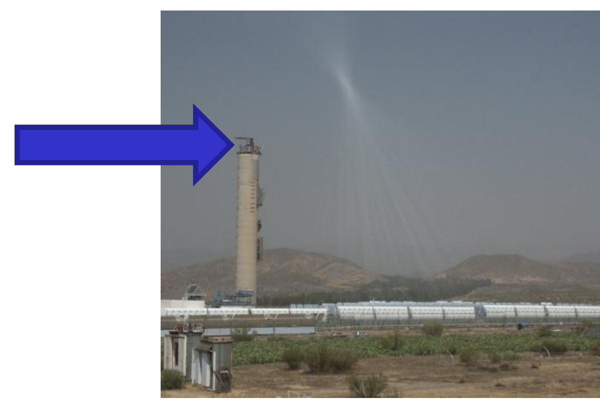
Assumption of constant β_e in the lowest ~100m

- FS11 and EDM164 measurements from ~1m
- Compared to ~90 m at PSA
    - 1 year data

- No systematic difference found, bias close to 0
- Deviations (RMSD, bias) close to what has been observed when instruments where used directly next to each other
- Assumption ok for PSA
- For other sites?



Approach 3: particle counter

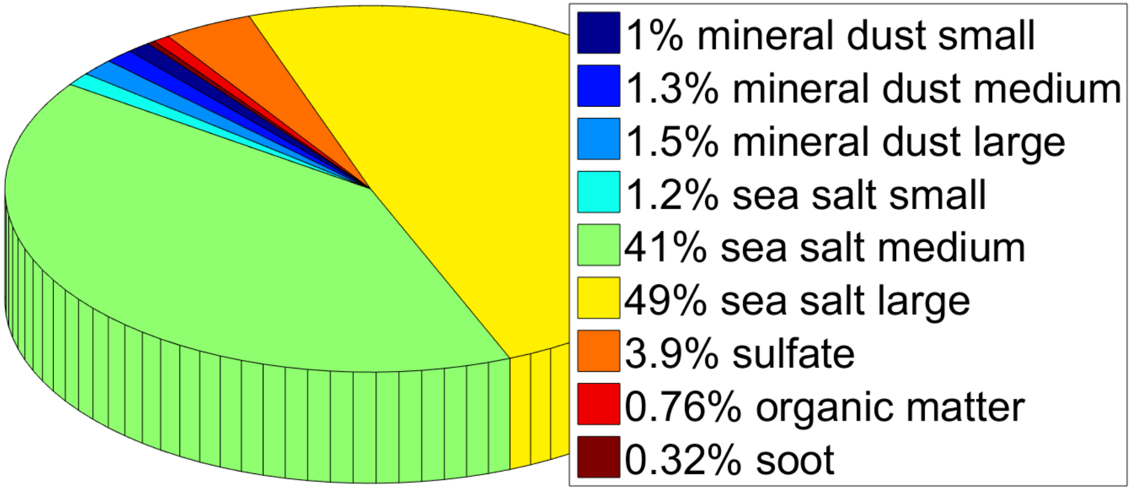
Use measurements of particle counter (Grimm EDM164) to derive transmittance

31 particle size channels (0.25 µm to 32 µm)

libRadtran

Challenges - assumptions about:

- Aerosol mixture
- Small particles (<0.25µm diameter) which are not detected by EDM164
- Particle shape
- …



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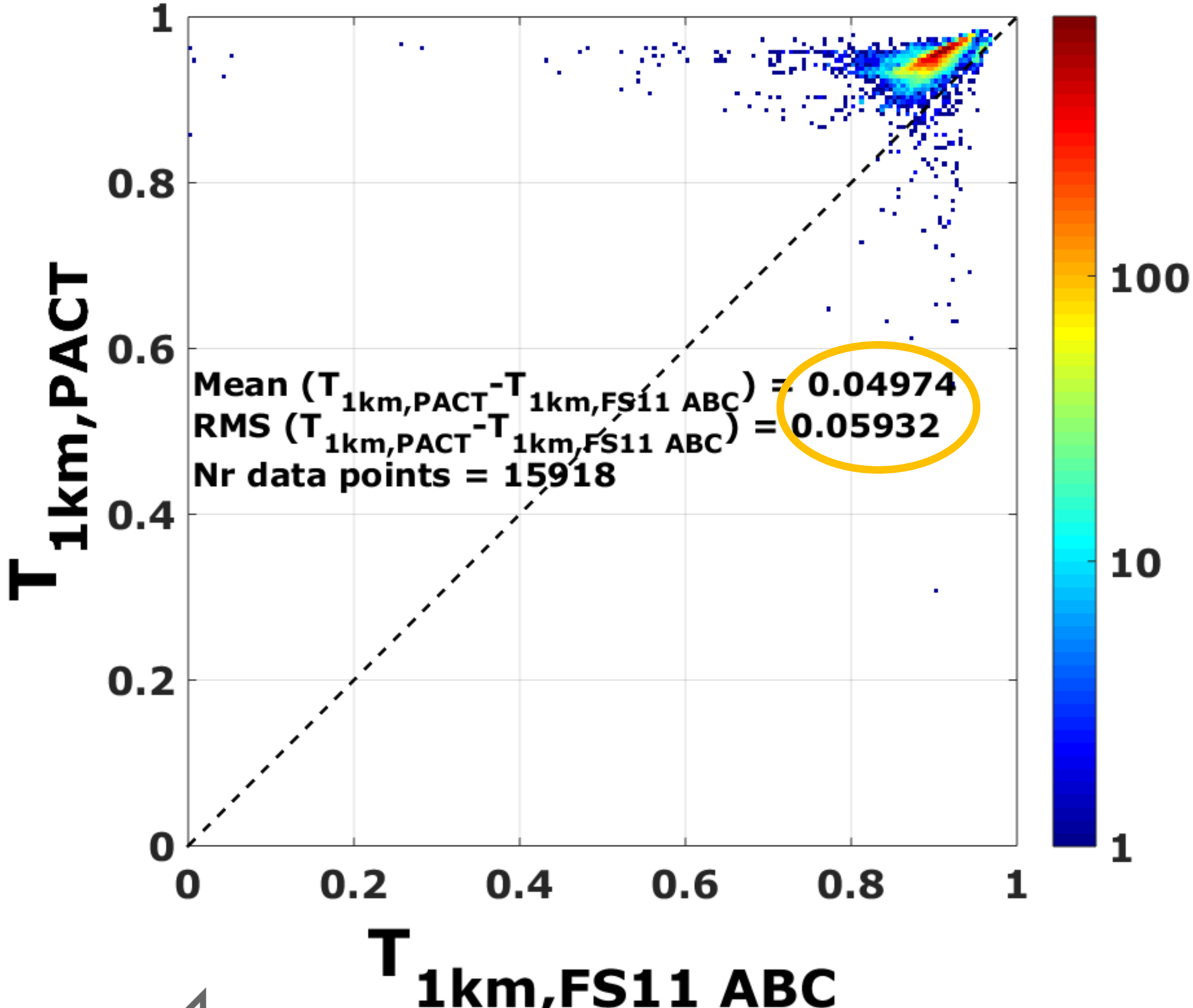
To be published in Hanrieder, 2016. Dissertation RWTH.

Approach 3: Results – Particle counter



- **Reference data set:**
    - 1 year ABC corrected FS11 data
    - 10min resolution
- **5% bias**
- **explainable by inlet characteristics of EDM164 and assumptions**

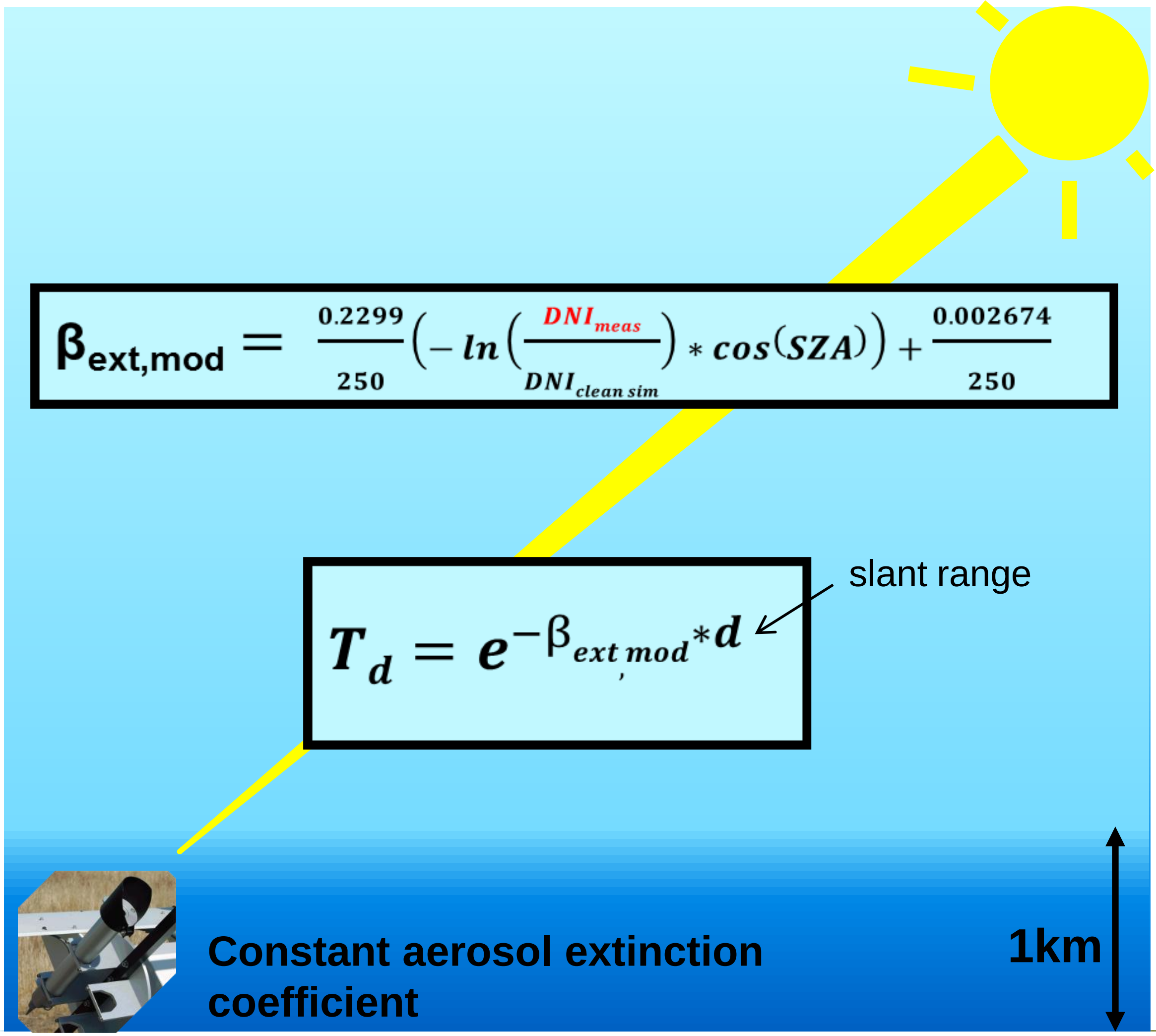
Approach 4: based on Sengupta & Wagner extinction model

Compare clear sky DNI measurement
to
clear sky DNI for one fixed atmosphere without aerosol

=> Estimate of AOD

Assume that aerosol height profile is known
=>extinction coefficient close to ground

Simple assumption:
Aerosol ext. coef. constant in 1^{st} 1km above ground, zero above



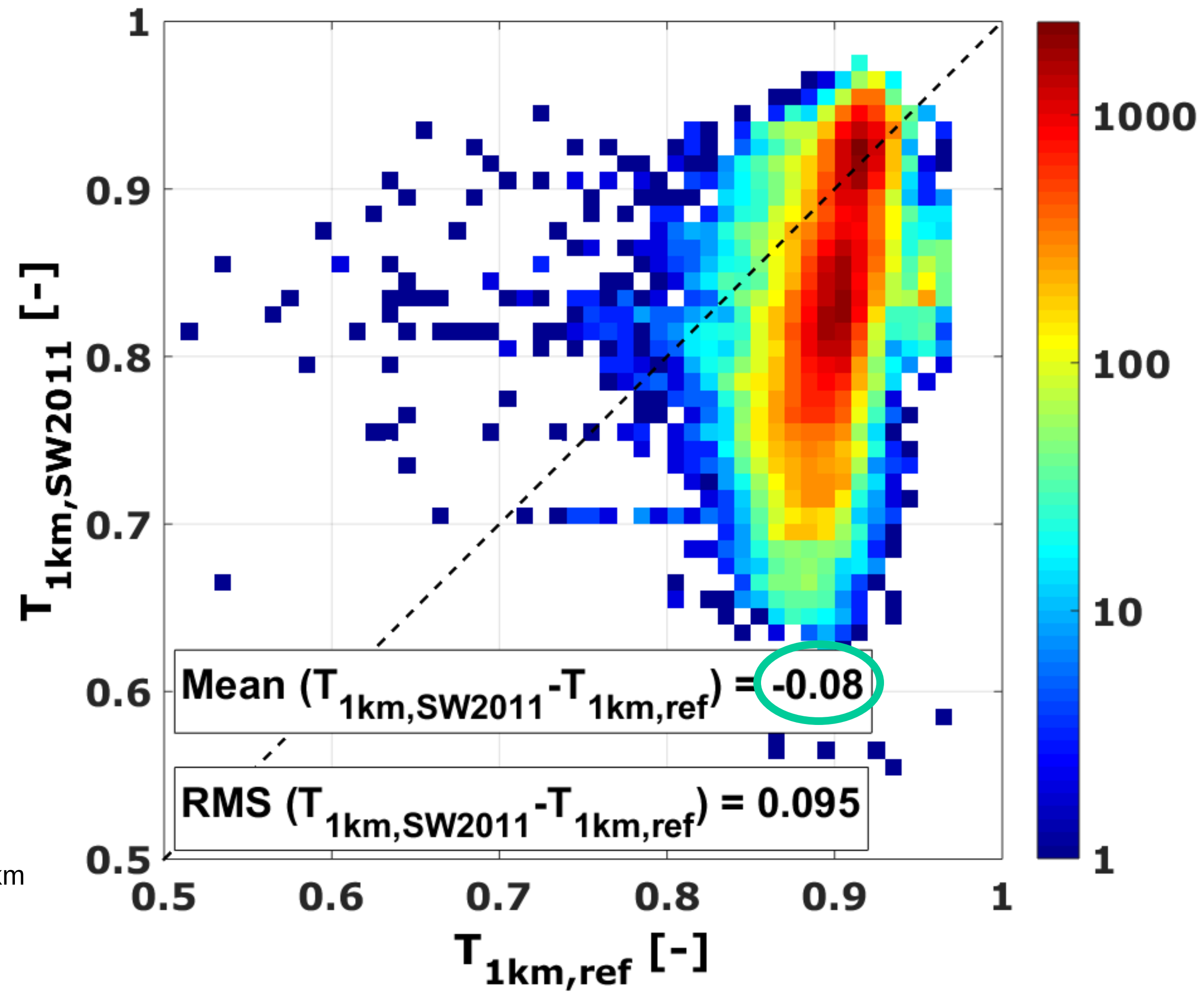
Sengupta, M., Wagner, M., 2011: “Impact of aerosols on atmospheric attenuation loss in central receiver systems”. SolarPACES conference, Granada, Spain.

Approach 4: Results – original Sengupta model

1. Test of original model
- with measurements @ PSA

2. Model enhanced by
- LUT for water vapor content
- Site specific model creation for PSA using appropriate
  - aerosol type
  - altitude

Reference data set:
1 year ABC corrected FS11 T_{1km}
1min resolution



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Hanrieder, N., M Sengupta, Y. Xie, S Wilbert, and R Pitz-Paal. 2015. Modelling Beam Attenuation in Solar Tower Plants Using Common DNI Measurements. Presentation at ICEM, at Boulder, CO, USA. (submitted to Solar Energy)

Approach 4: Results – enhanced Sengupta model

Comparison of “new” model to measurement @ PSA

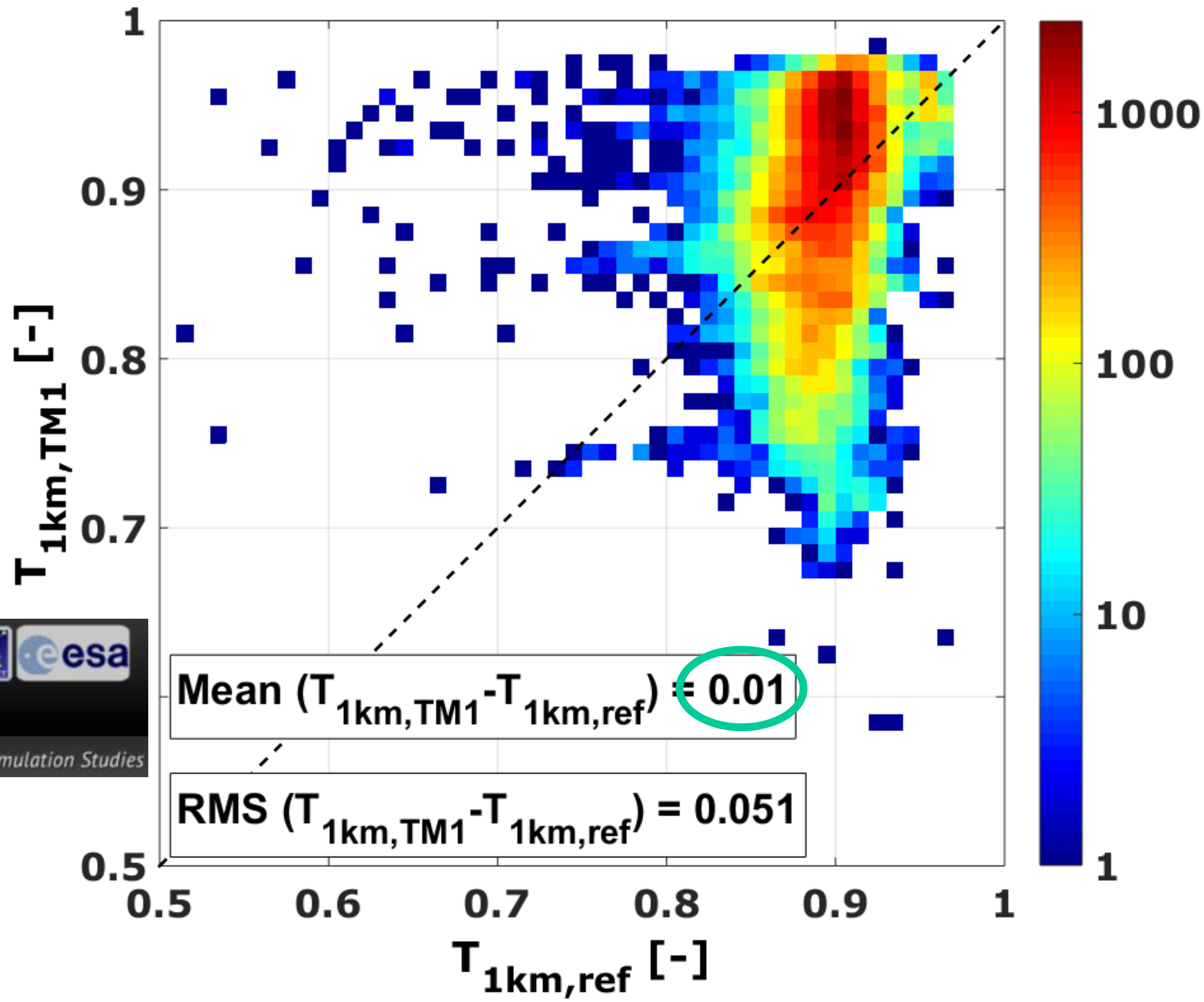
Aerosol height profile:
1st km over ground constant
-> 1% bias

Other height profiles:
Shettle and Fenn: 5% bias
LIVAS profile: 3.5% bias

LIVAS

Lidar Climatology of Vertical Aerosol Structure for Space-Based Lidar Simulation Studies

Reference data set:
1 year ABC corrected FS11 T_{1km}
1min resolution



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Conclusion

- Extinction measurements are possible with commercially available instruments if appropriate corrections are applied (ABC)
  - Without corrections bias of ~3% between FS11 and LPV4 for T_{1km} occur
    => removed by ABC
  - LPV4 good if special infrastructure and personnel requirements fulfilled
  - FS11 even for remote stations
  - Warning: Other apparently similar sensors might not be usable

- A method with a particle counter is implemented (but 5% bias)

- Modelling beam attenuation in solar tower plants using DNI measurements is possible at PSA
  - Validation of enhanced model 2015 shows bias of 1% at PSA
  - Selection of height profile is important

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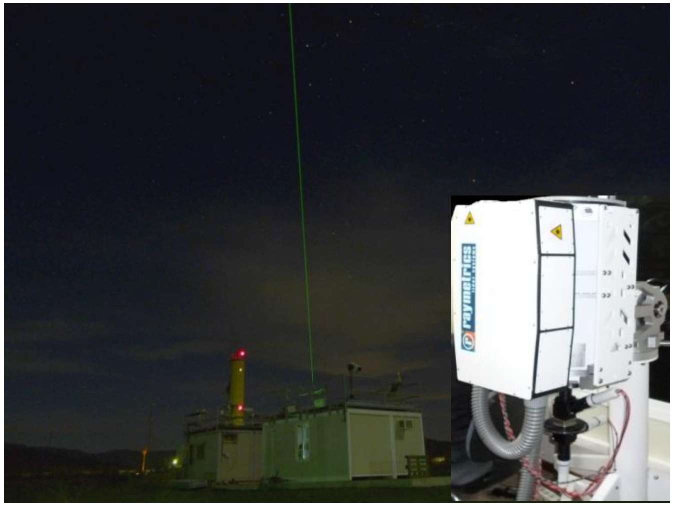
Outlook

What can be expected for other climates?

Is the ext. coef. in the lowest 100m constant at other sites?
And in the lowest 200m?

Does the enhanced Sengupta model also work at other sites?
Include boundary layer heights? (Elias et al., 2015)

→ FS11 data from 2 desert sites in Morocco
→ LIDAR measurements for lowest 300 m @ PSA and ???
→ Evaluation of 2 pyrheliometer method



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Thank you for your attention

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