Development of a Backscatter-Lidar Forward-Operator

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1. Motivation

- Aerosols and trace gases become more and more important for numerical weather and climate prediction
- Amongst other models, the **COSMO-ART** system is capable to simulate the transport and evolution of **A**erosols and **R**eactive **T**race gases
- Famous applications for that skill are simulations of a volcanic eruption or several saharan dust events

- Validation of such simulations is a demanding task
- Particle analyzers are precise but measure locally
- Lidar (**Li**ght **D**etection **A**nd **R**anging) systems allow the detection of atmospheric profiles remotely
- Using lidar data to validate aerosol simulations requires a common measurement variable

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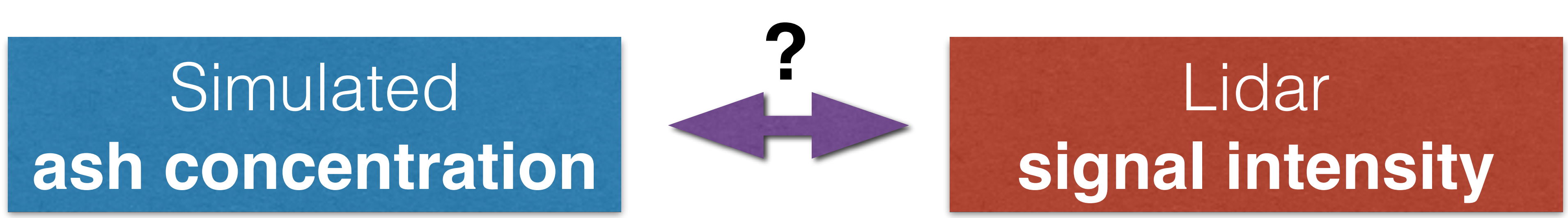

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Model | Lidar

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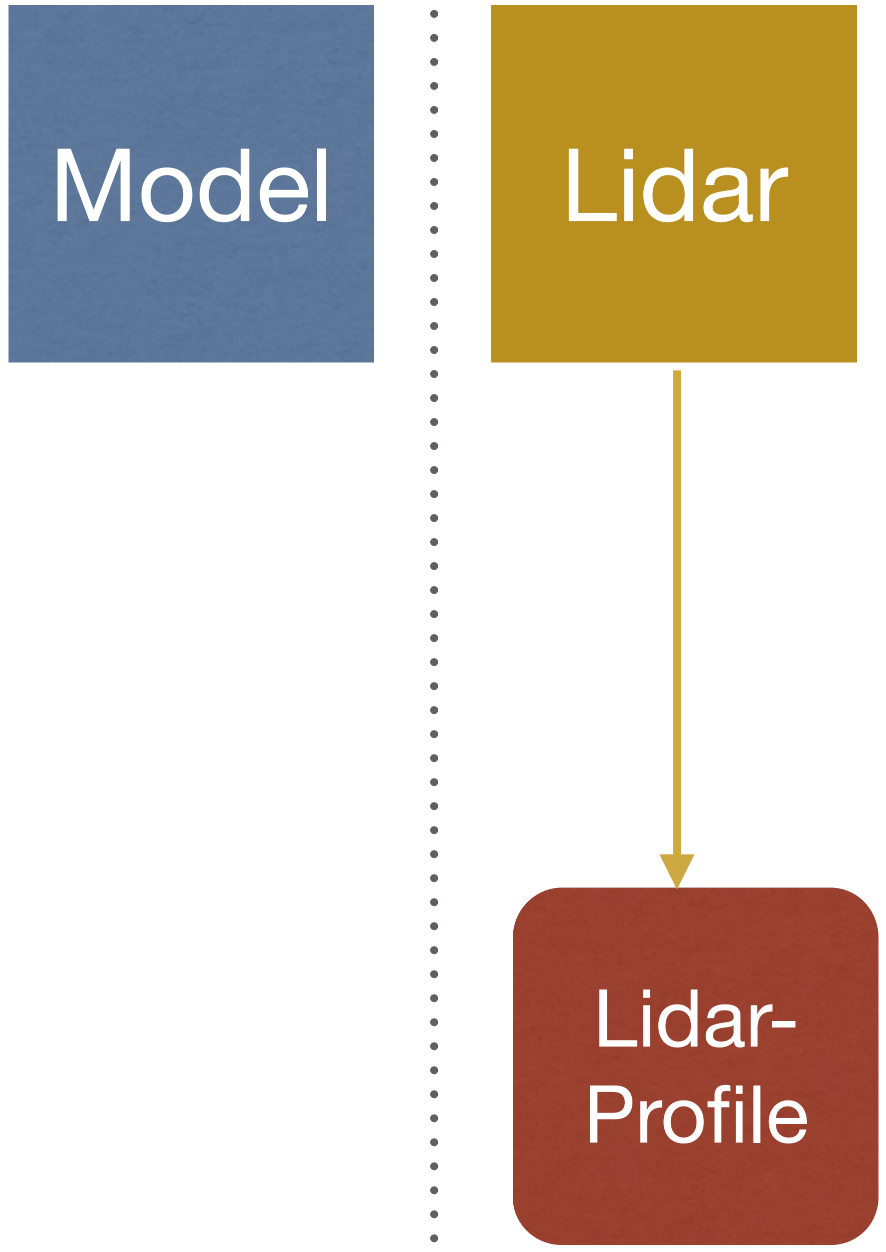

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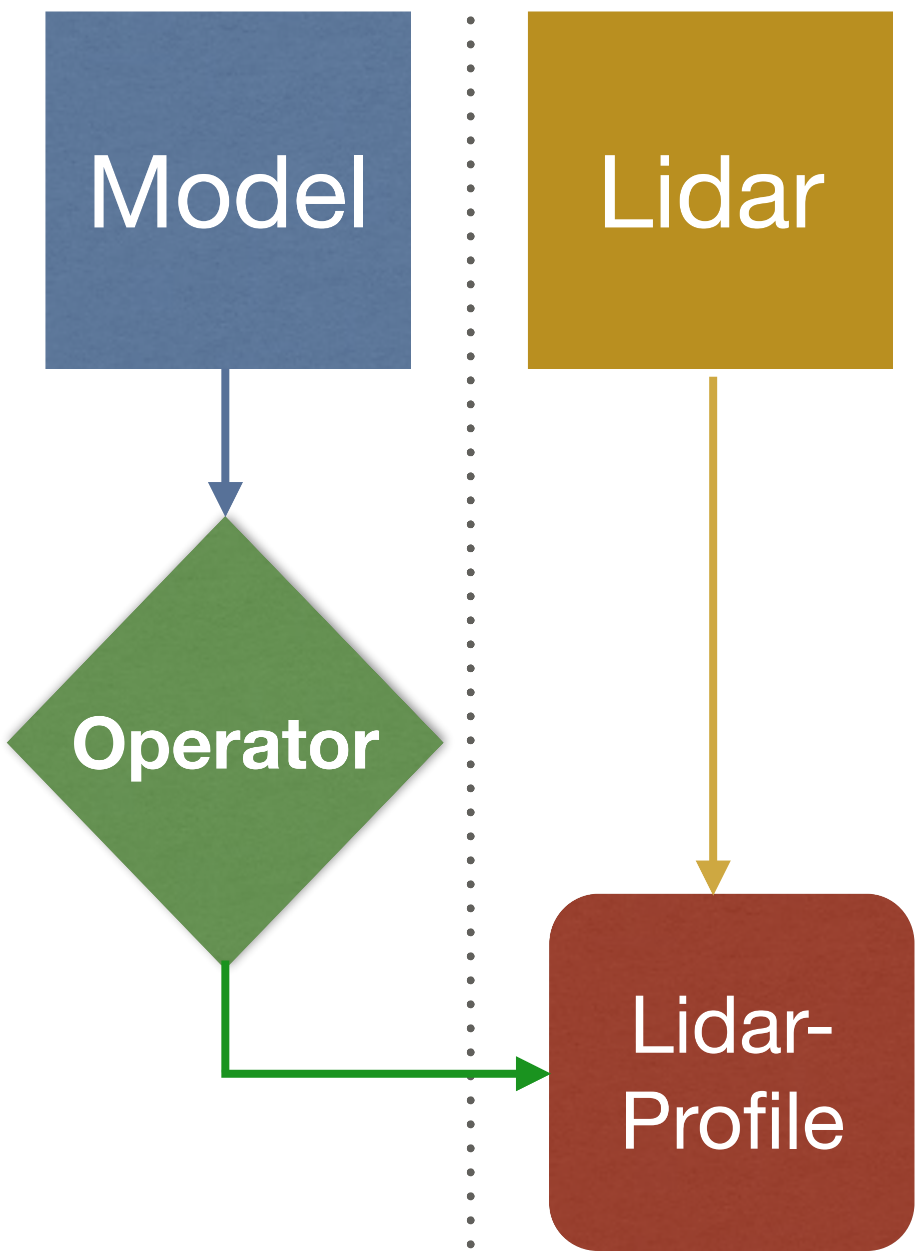
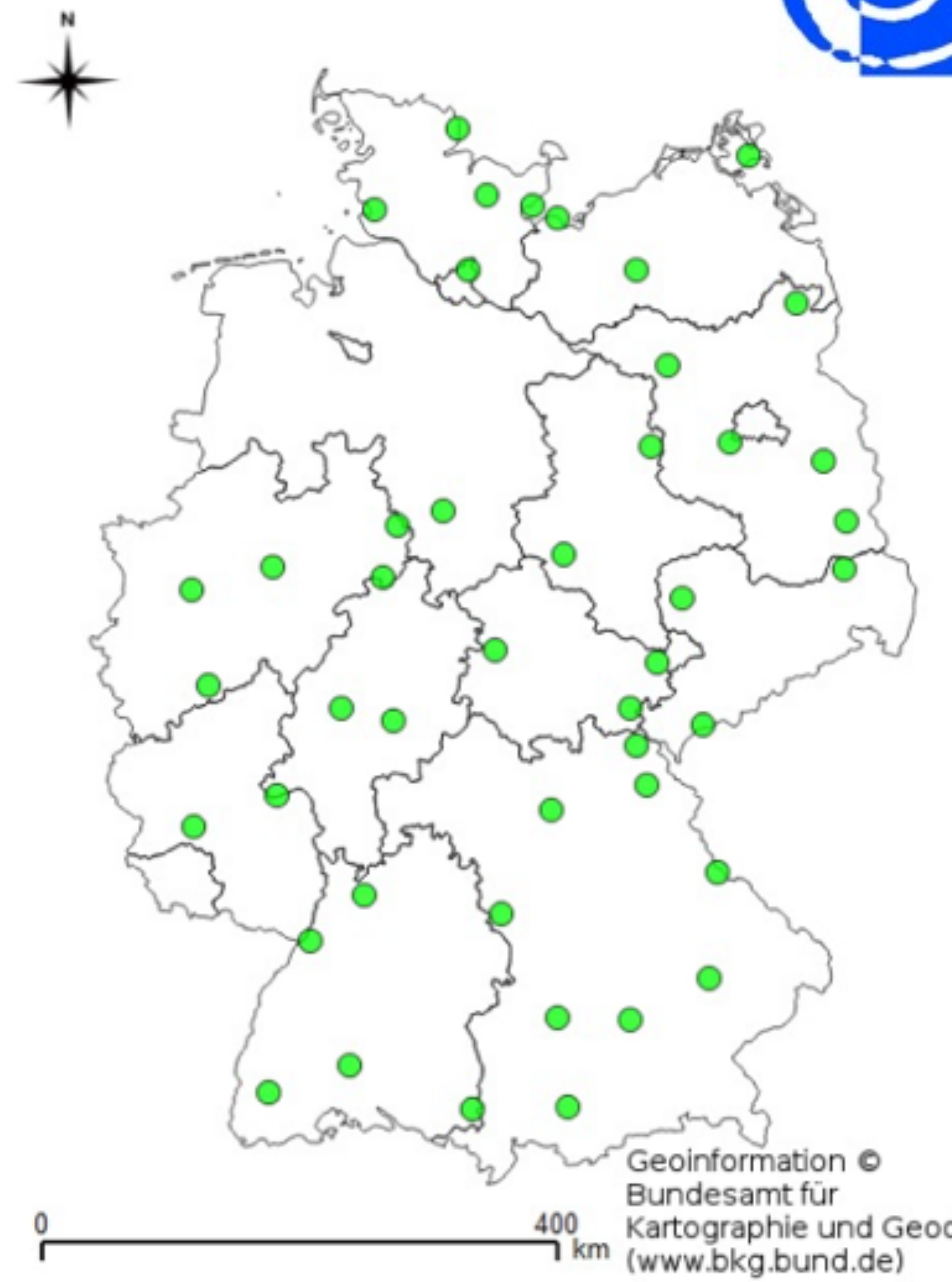


- Many weather services maintain lidar networks to survey clouds
- These so-called „**ceilometers**“ are also sensitive to aerosols
- In Germany, we have about 50 ceilometer stations operating
- Vertically-pointing instruments

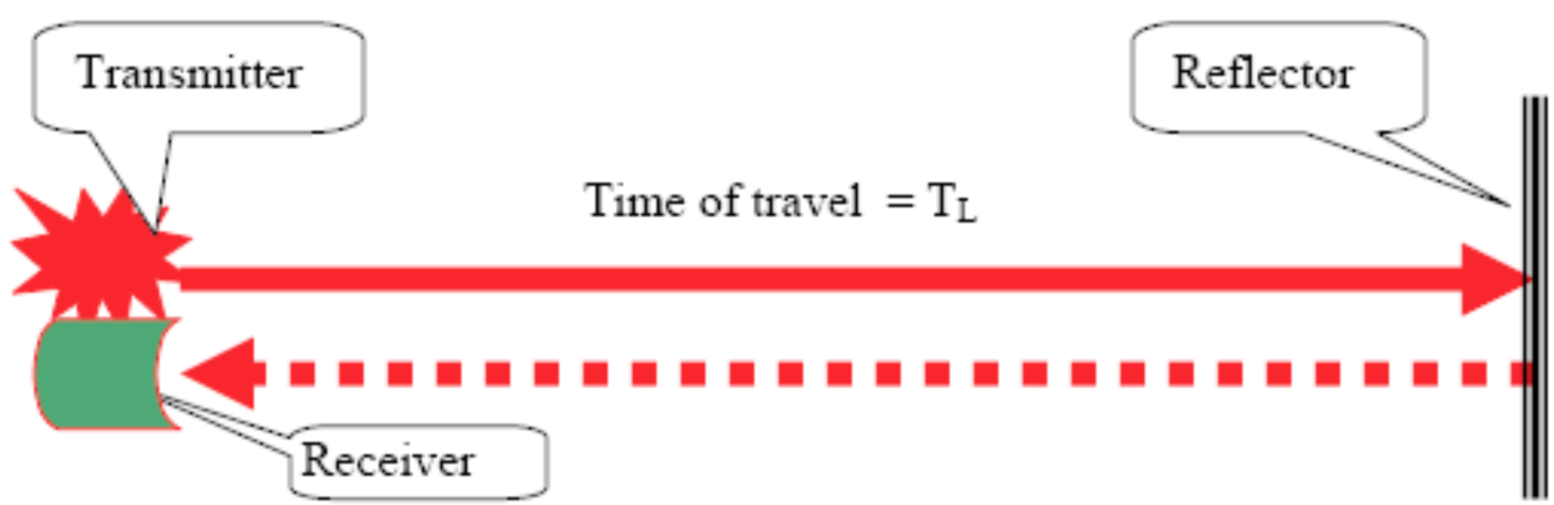
Jenoptics



J. Strohbach

2. Lidar forward operator

- Lidar is an acronym for „**Li**ght **D**etection **A**nd **R**anging“
- Lidars emit electromagnetic waves and measure/ analyze the signal which is scattered back
- By run-time measurements, the signal can be allocated to a distance



http://home.iitk.ac.in

- The „Lidar equation“ is a mathematical description for the **lidar measurement**:

$$N_{\mathrm{rec}}(r) = N_{\mathrm{t}}\, \eta\, O(r)\, \Delta h(r)\, \frac{A_T}{r^2}\, \beta_\lambda(r)\, e^{-2\int\limits_0^r \alpha_\lambda(r')\, \mathrm{d}r'}$$

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Calculated Signal

Lidar properties (depending on reference lidar)

Atmospheric properties (need to be calculated)

- The major task of the forward operator is to calculate the extinction coefficient *α(r)* and the backscatter coefficient *β(r)*

- The extinction and backscatter coefficients of a volume depend on the number density and the scattering cross-section of each aerosol / gas species *i*

$$\alpha(r) = \sum_{i=1}^{n} \alpha_i(r) = \sum_{i=1}^{n} N_i(r)\, \sigma_{\mathrm{ext},i,\lambda}(r)$$

$$\beta(r) = \sum_{i=1}^{n} \beta_i(r) = \sum_{i=1}^{n} N_i(r)\, \sigma_{\mathrm{bsc},i,\lambda}(r)$$

- While the number-density *N(r)* is a model variable, the scattering cross-sections *σ* have to be calculated by the operator

3. Case study

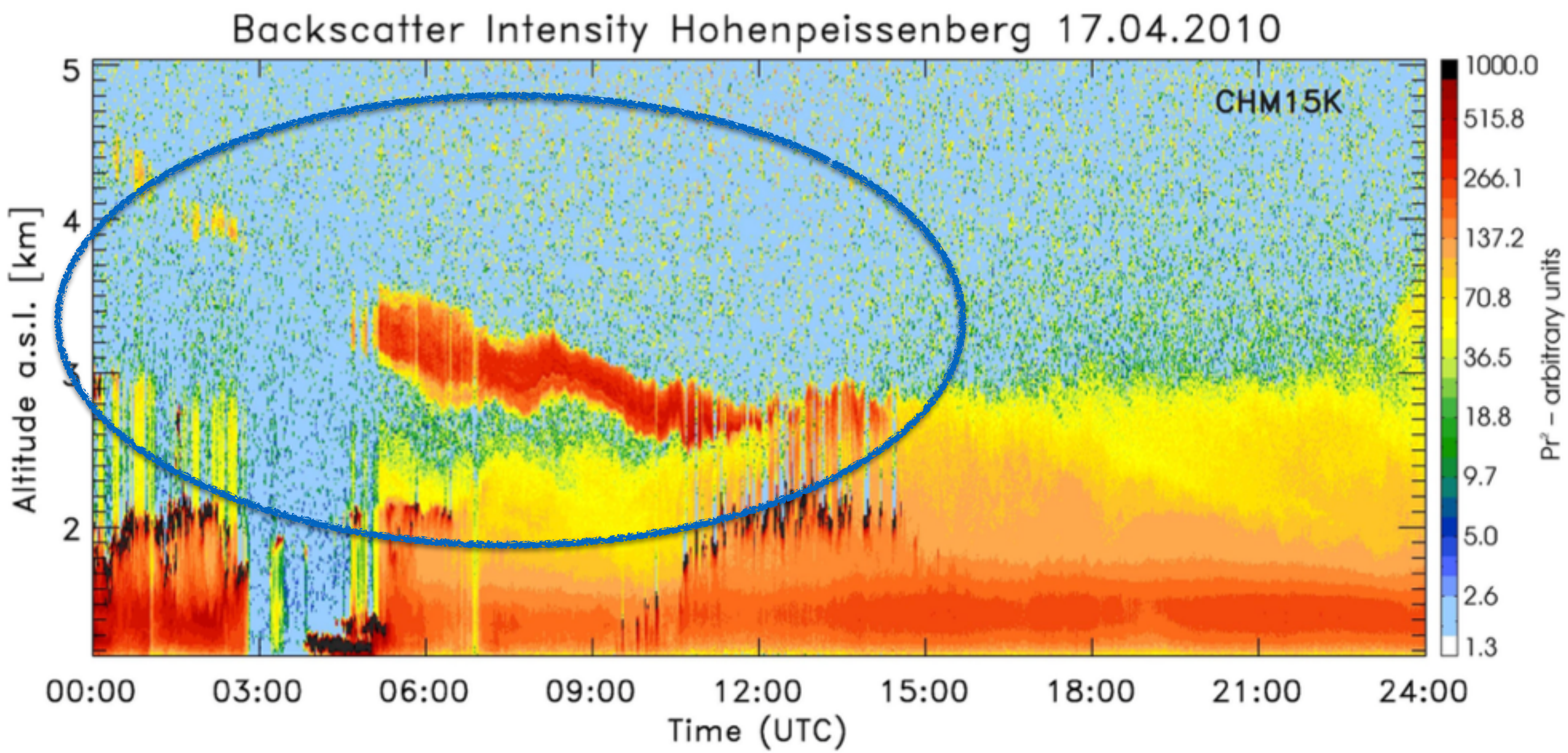
- In 2010, the volcano Eyjafjallajökull, Iceland, erupted; ash was transported to Europe

- Due to missing information about the spatial distribution of ash, the air space was closed for several days

- DWD and KIT were the first to set-up COSMO-ART for an ash-transport simulation

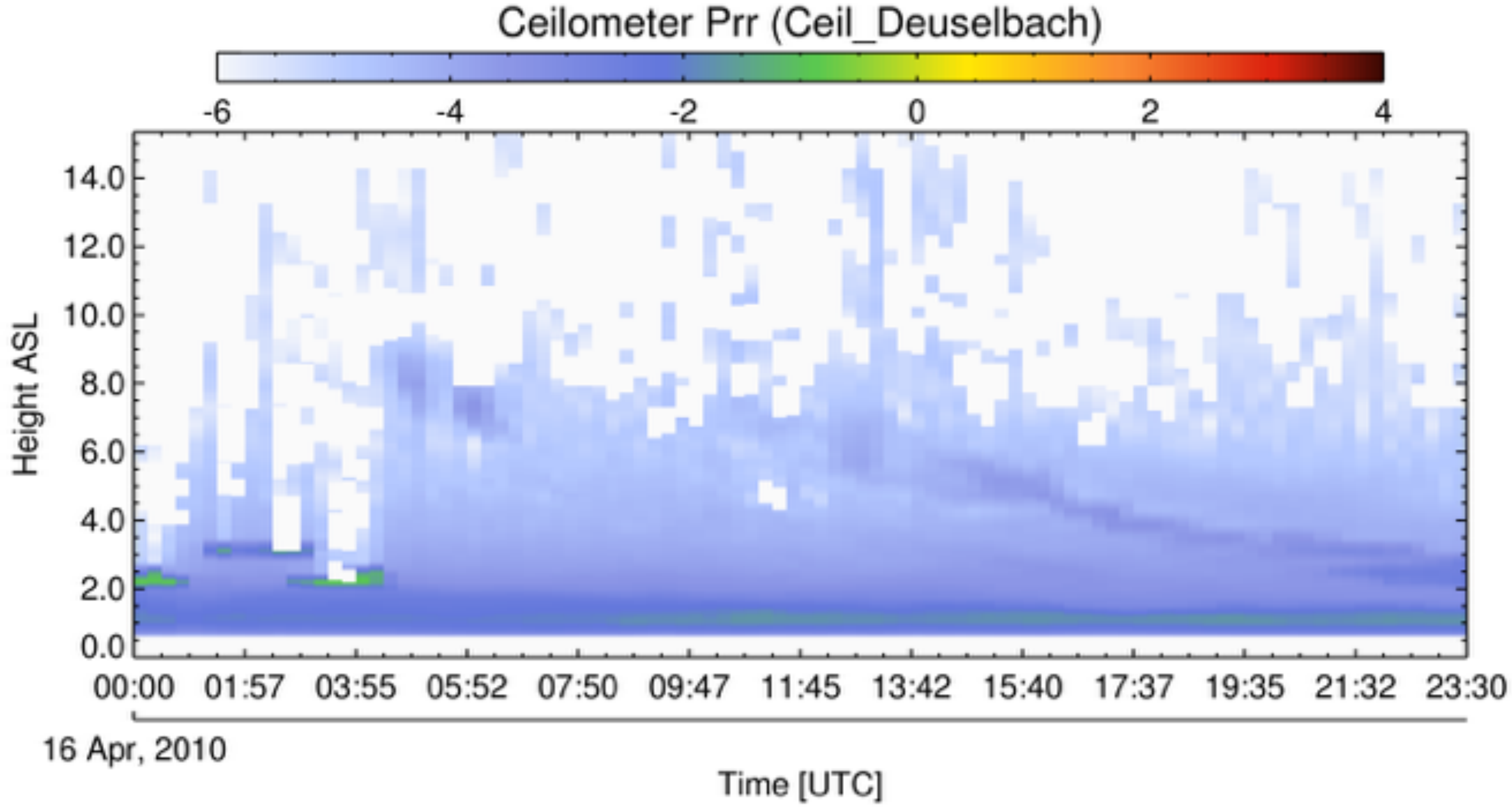
www.boeckel.de

- The volcanic ash layers have also been found in ceilometer measurements:



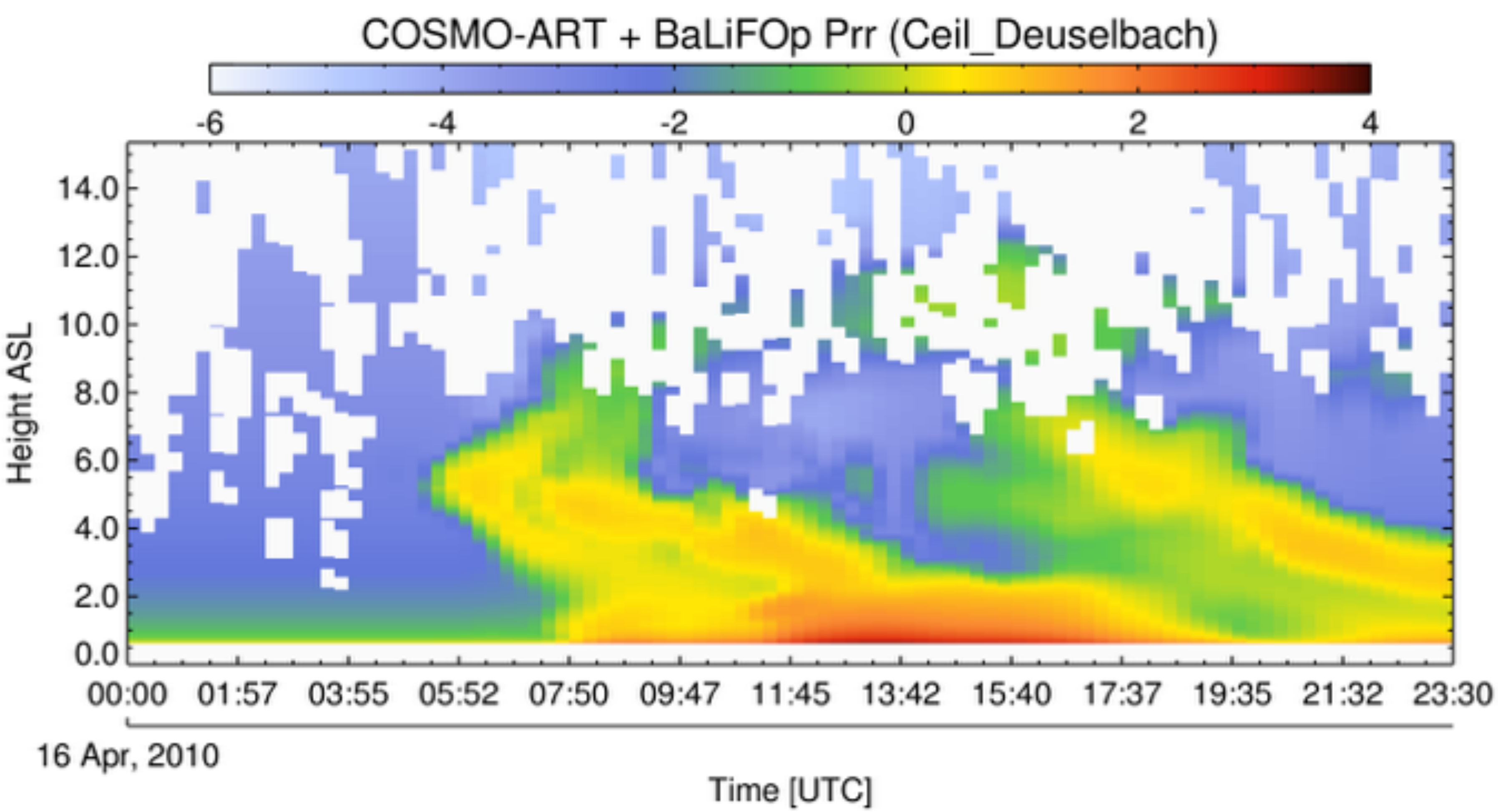
Flentje et al, 2010

- To compare the ceilometer data with COSMO-ART + forward-operator, we had to:
    - Rescale ceilometer data to fit the time- and height-levels of COSMO-ART
    - Filter invalid ceilometer measurement values
    - Extract common measurement periods and height-levels
    - Guess ceilometer calibration parameters (η)

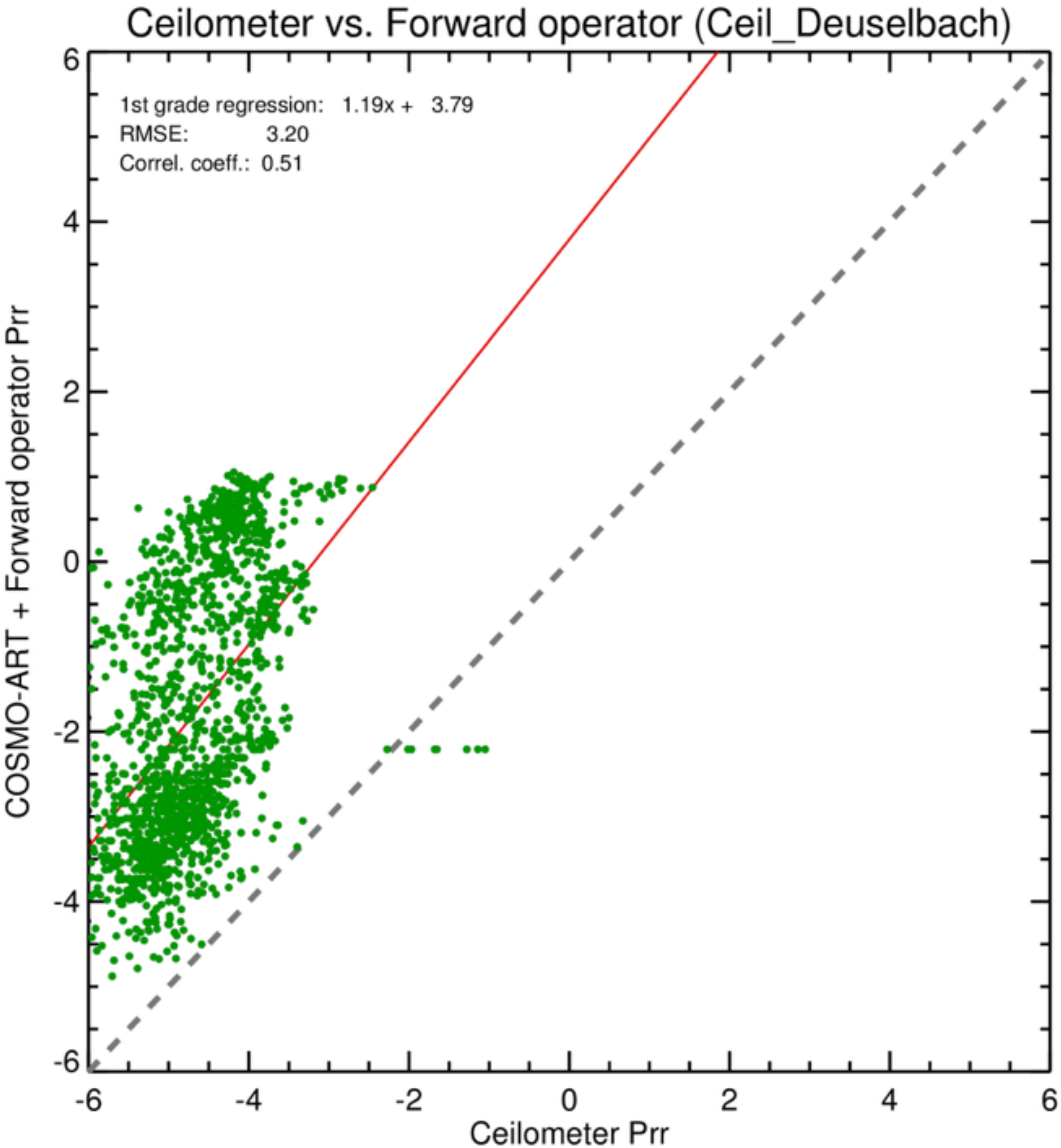


Ceilometer measurement

Comparison 1:
Deuselbach
(West-Germany)



COSMO-ART Forward Operator



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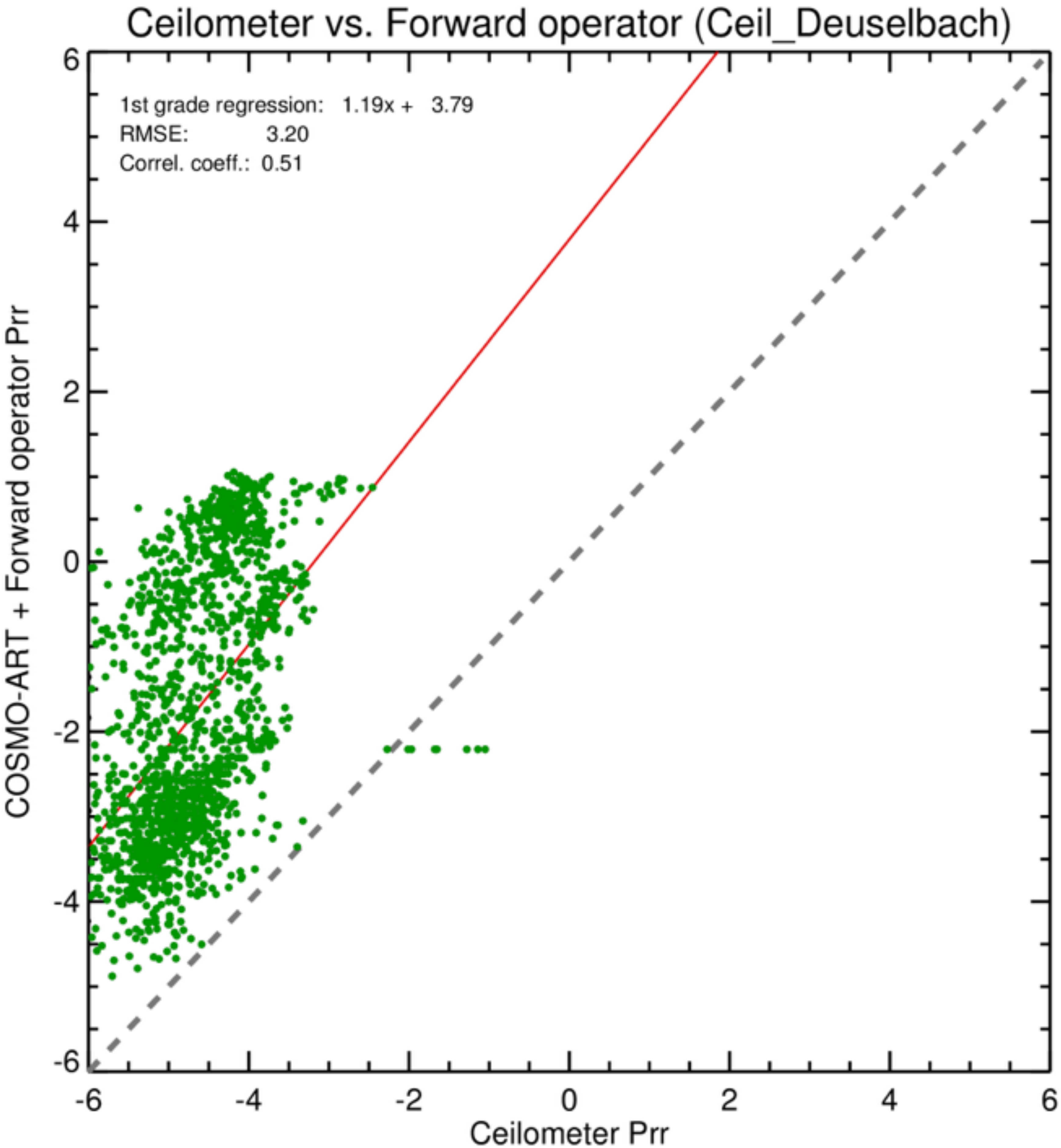

Comparison 1:
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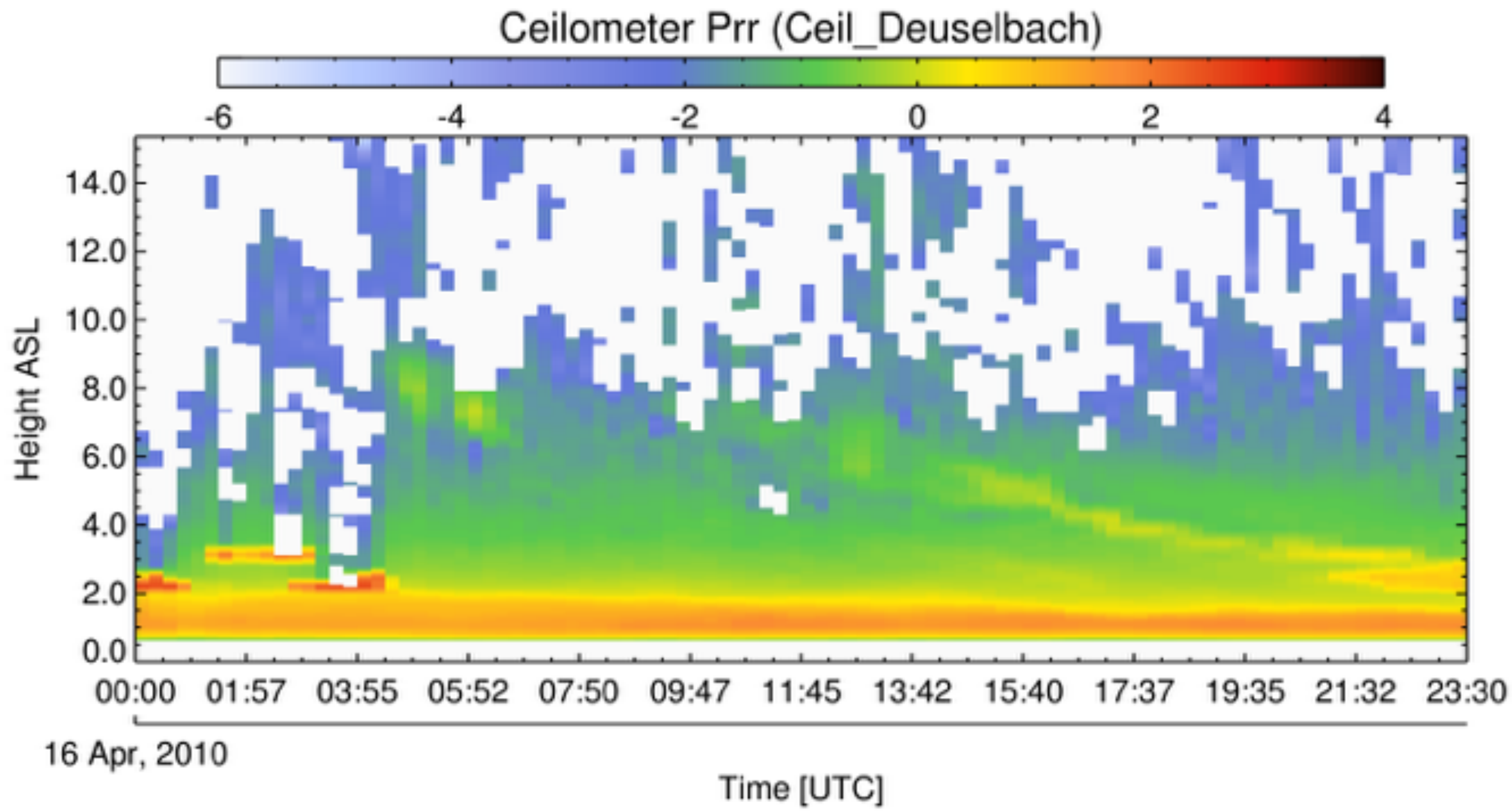
It looks like the COSMO-ART +operator overestimate the signal by a factor of about 10^3



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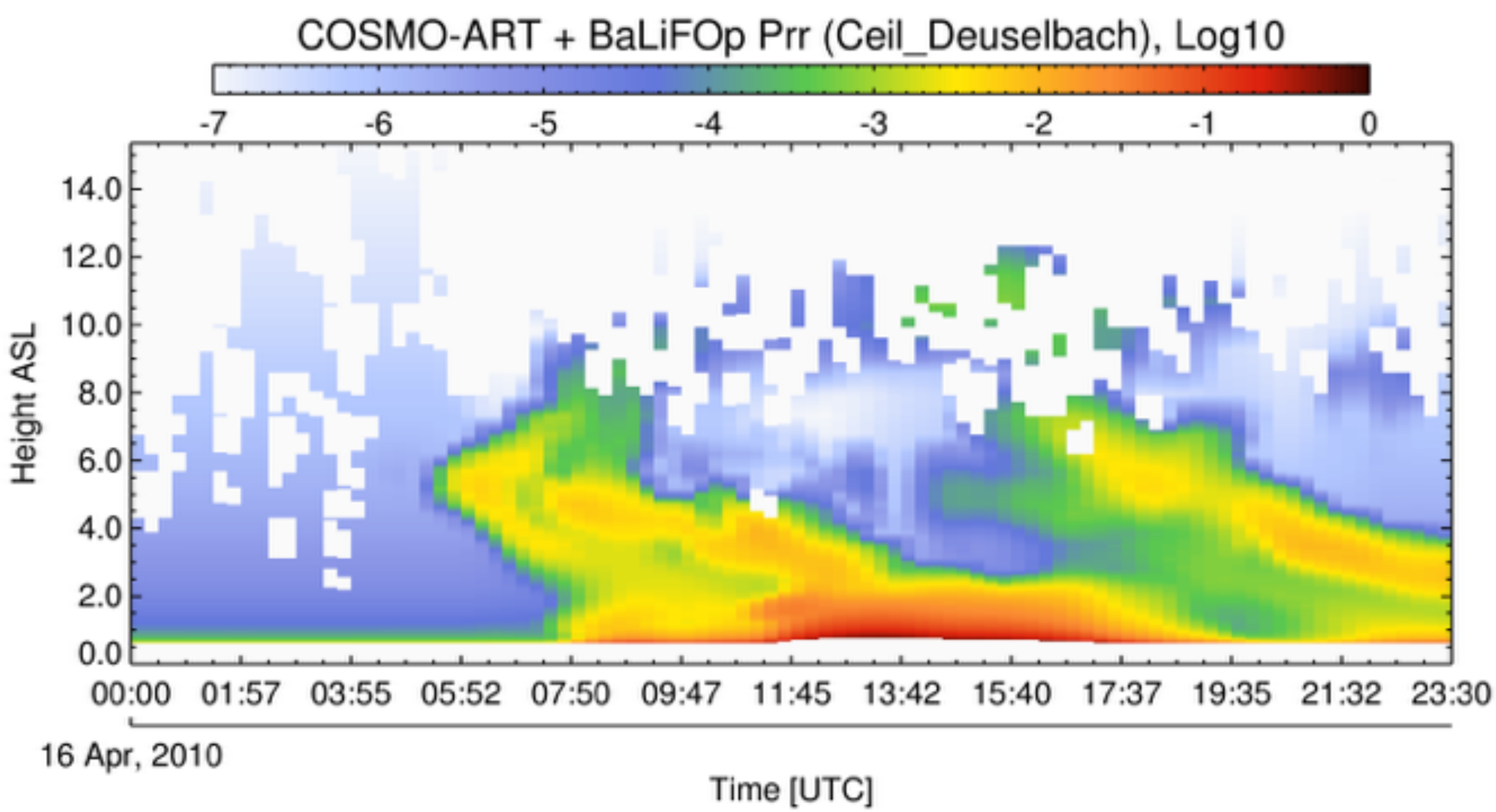
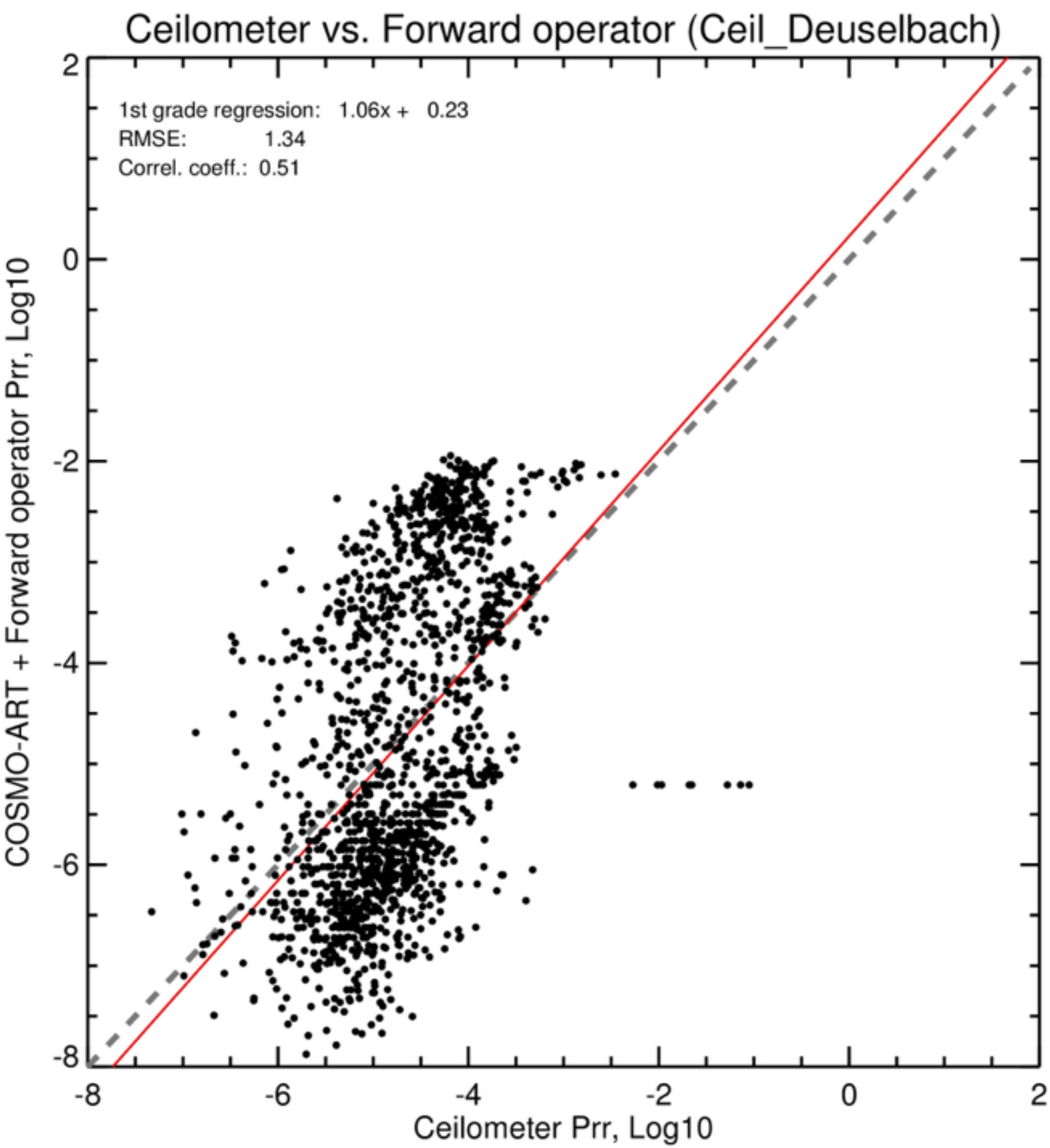
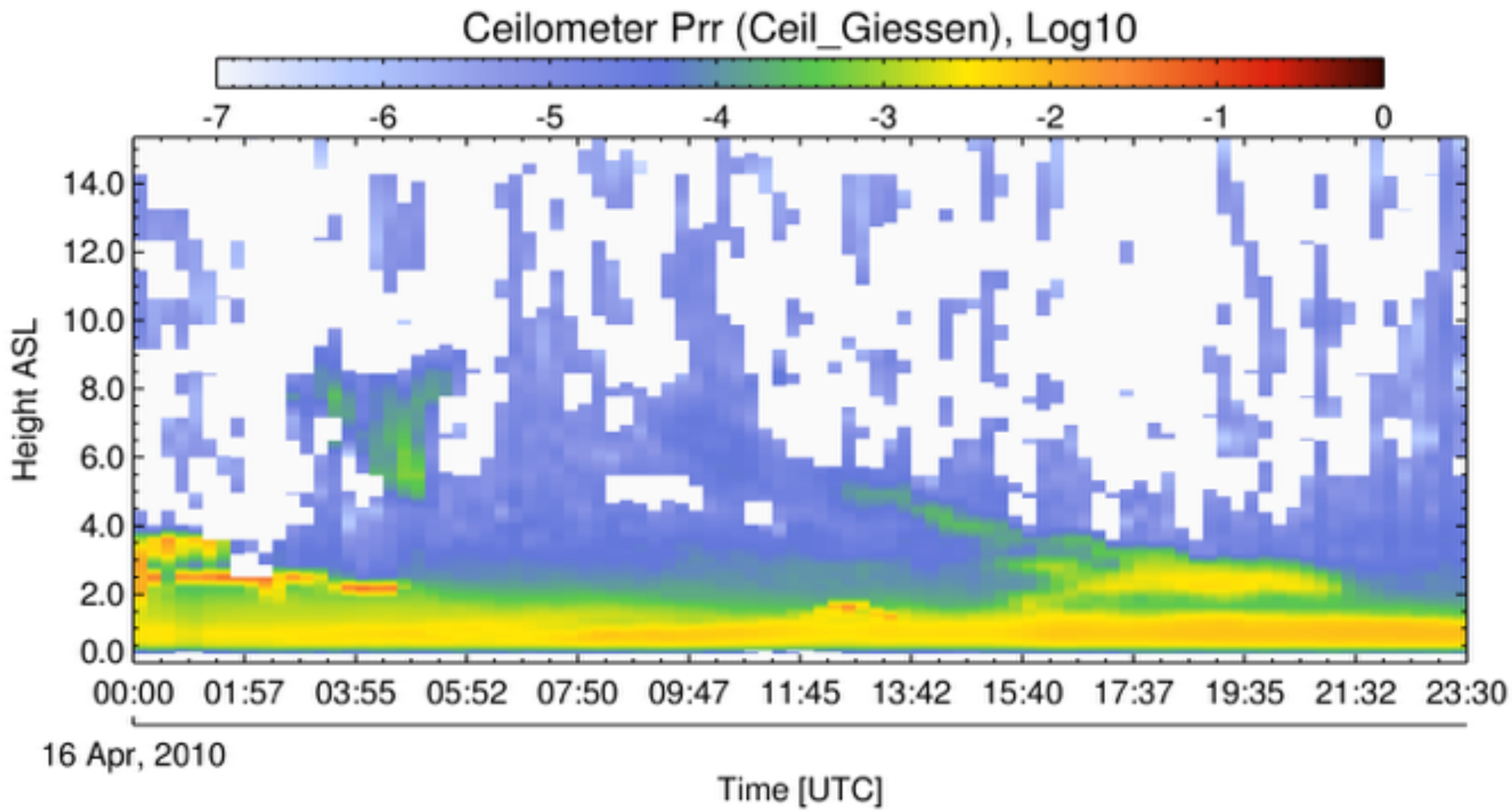


COSMO-ART + Forward Operator (**divided by 1000**)



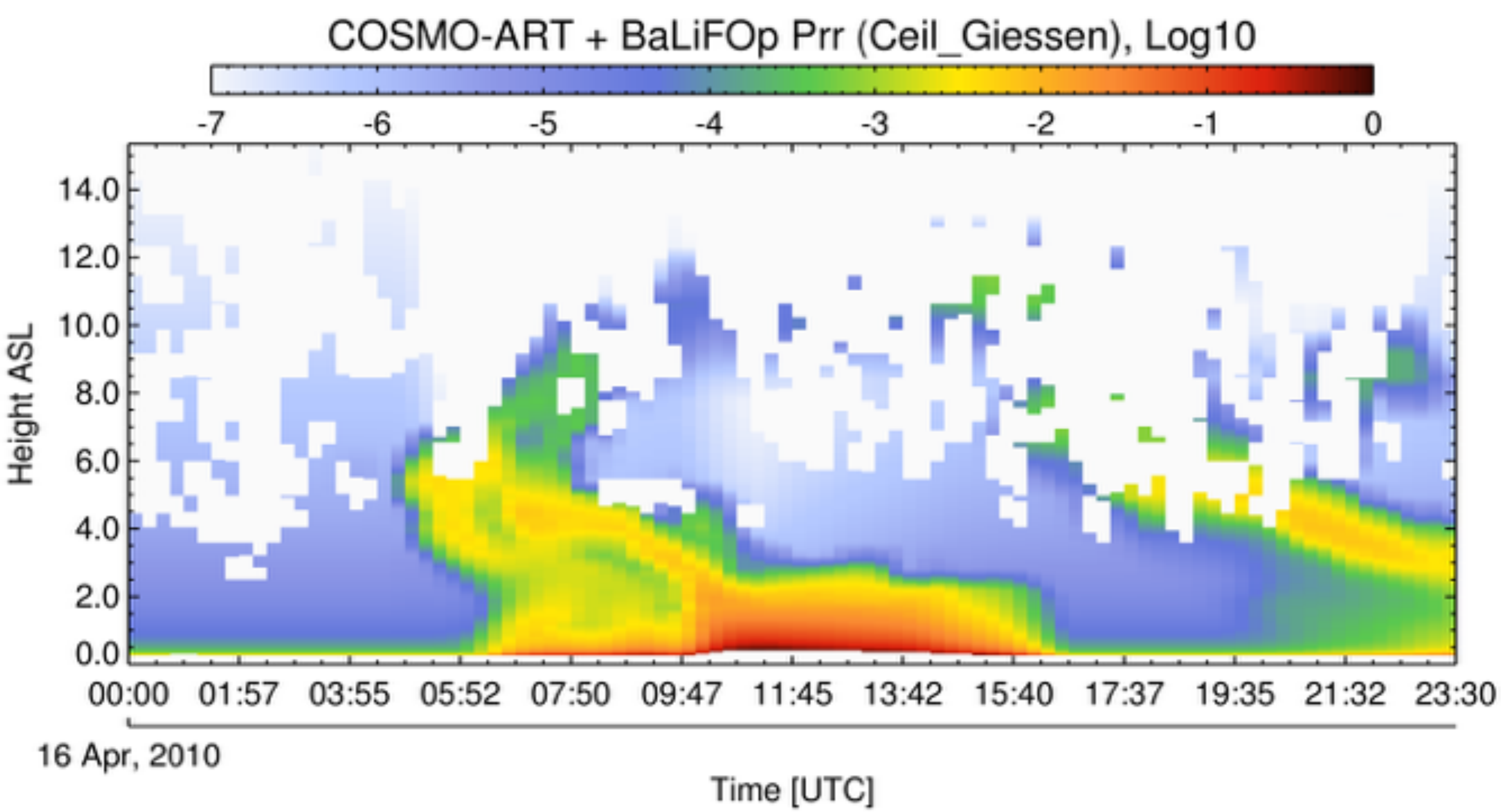
Comparison 1:
Deuselbach
(West-Germany)

- If we apply our correction, the values seem to fit very well
- The offset may be explained by wrong values for the calibration**...**



Ceilometer measurement

Comparison 2:
Giessen
(Central-Germany)



COSMO-ART
\+ Forward Operator
(**divided by 1000**)

4. Summary

- A backscatter-lidar forward-operator was developed and applied to COSMO-ART output for a case study

- Differences were obtained between COSMO-ART + BaLiFOp and Ceilometer measurement:

    1. An average difference of factor 1000 (may be caused by missing calibration coefficients or by wrong initialization of the model)

    2. A „ghost cloud“ (maybe explained by strong attenuating layers near ground, or by errors in the dynamics of the model)

- A **qualitative** comparison shows a temporal shift of the cloud arrival which must be related to the dynamics in the model

- To estimate the **quantitative** error, we need calibrated ceilometer data and more aerosol information (next case-study: Saharan-dust events in 2014)

- We can also use the forward operator to compare the model simulation with more powerful research lidar systems

Thanks for your attention!!

Further questions? Send me an e-Mail:
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