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Validation of satellite solar irradiance estimates: separating clear-sky and cloud effect

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3. Centre for Energy, Environment and Technological Research CIEMAT

15th BSRN Scientific Review and Workshop
19.07.2018 Boulder, USA

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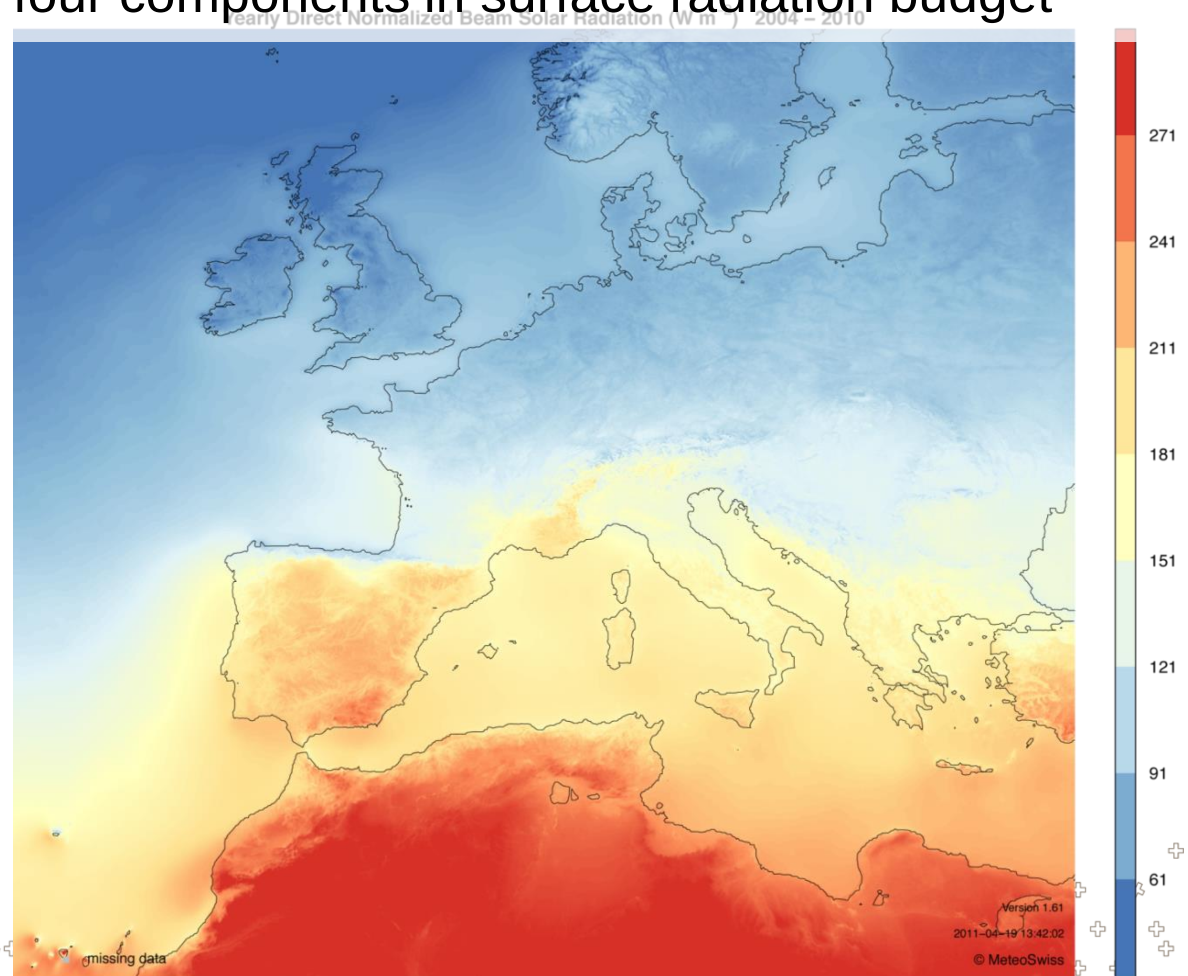
1. Introduction
2. Clear-sky estimates
3. All-sky estimates
4. Conclusions

Motivations

introduction

Solar radiation estimates obtained from satellite data:

1. Climate: one of four components in surface radiation budget



Yearly Direct Normalized Beam Solar Radiation (Wm^{-2}) 2004-2010
from HelioMont (Stöckli, 2013)
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Stöckli, R. (2013), The HelioMont Surface Solar Radiation Processing, *Scientific Report MeteoSwiss*, *93*, Editor: Federal Office of Meteorology and Climatology MeteoSwiss

Motivations

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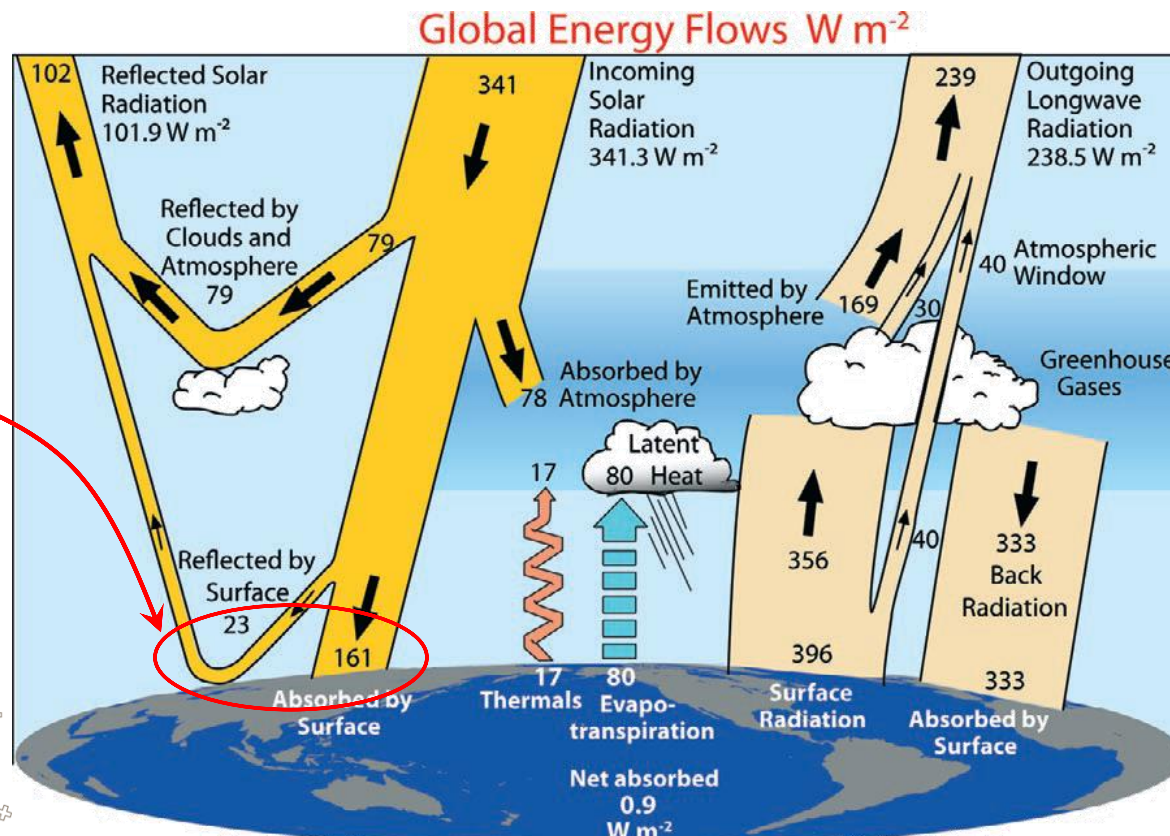

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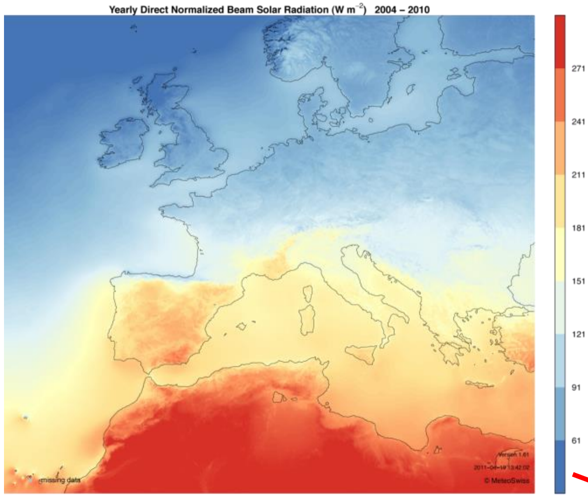

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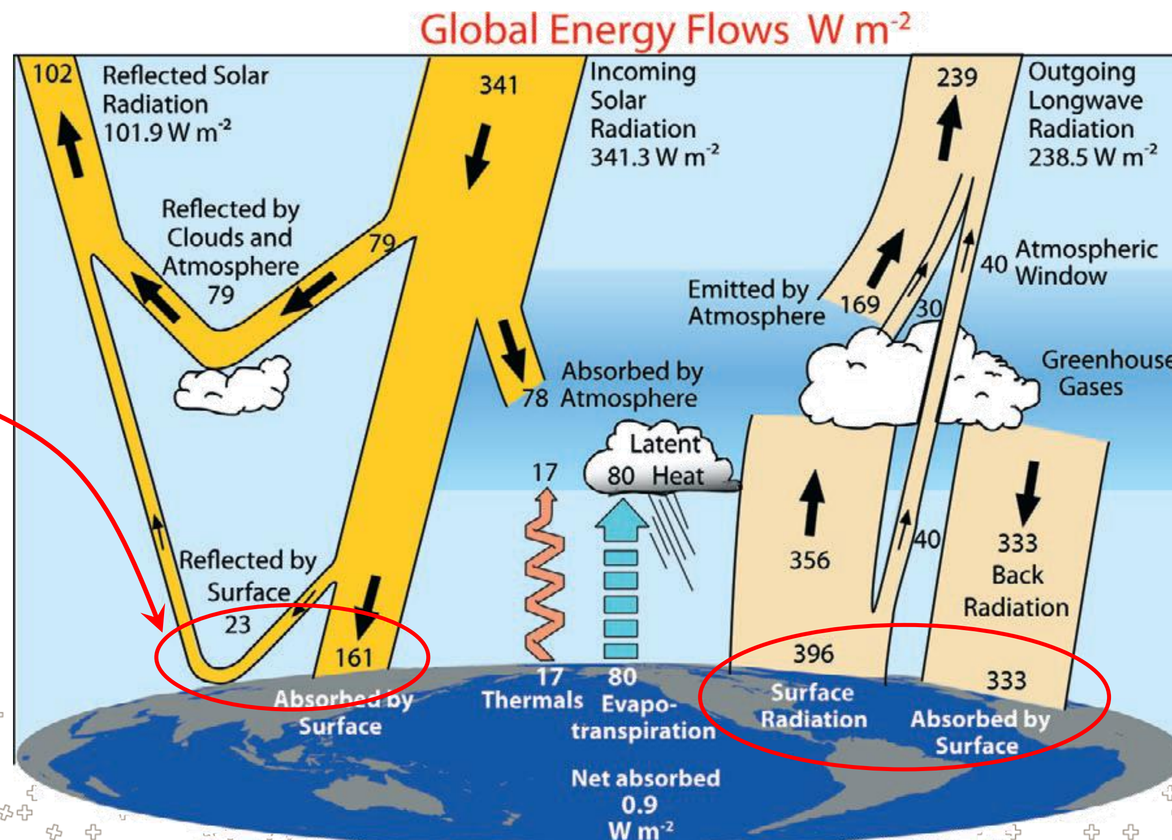

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Motivations

Solar radiation estimates obtained from satellite data:

1. Climate: one of four components in surface radiation budget
2. Solar energy: used for large-scale solar resources maps
   - Details concerning orographic influence on solar radiation
   - High resolution climatological cloud patterns on large areas
   - Explicit separation in solar radiation components (direct / diffuse)

Motivations

Solar radiation estimates obtained from satellite data:

1. Climate: one of four components in surface radiation budget
2. Solar energy: used for large-scale solar resources maps

Useful only if satellite radiation estimates reasonably close to “truth”

- Assess uncertainties in satellite estimates of solar radiation using high accuracy ground-based data as reference
- Look into radiation component uncertainty (direct irradiance) instead of global radiation (global irradiance)

Best way to evaluate agreement between satellite estimates and reference measurements?

Background

General scheme for radiation estimates

both sides should be tested separately

Clear-sky estimates

Radiative transfer model (RTM → LUT)

Non-trivial input:

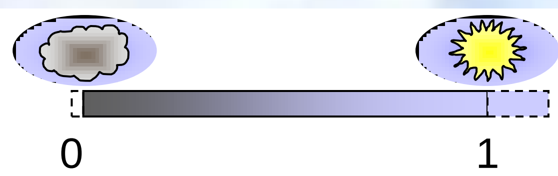
- **Aerosol** (**AOD**, SSA, α, …)
- Surface Albedo (satellite)
- Water vapor column (ECMWF)
- O3 (ECMWF)

Cloud modification factor

Cloud macrophysical information (e.g., satellite VIS & IR imagery)

Typically:

- Cloud cover
- Cloud brightness } ~ COD
- Cloud depth



physics understood
as good as input

physics limited in model
empirical and quite crude

Background

Solar zenith angle ✓

Clear-sky estimates

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Non-trivial input:

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- Surface Albedo (satellite)
- Water vapor column (ECMWF)
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✗

Altitude ✓

Cloud modification factor

Cloud macrophysical information (e.g., satellite VIS & IR imagery)

Typically:

Aerosols ← various DB ✓

- Cloud cover
- Cloud brightness
- Cloud depth

} ~ COD

Surface albedo ← sat ✓

$H_2O + O_3$ ECMWF ← sat ✓

Background

Cloud modification factor can be verified only if clear-sky in good agreement

Cloud modification factor

Cloud macrophysical information (e.g., satellite VIS & IR imagery)

Typically:

- Cloud cover
- Cloud brightness
- Cloud depth

} ~ COD

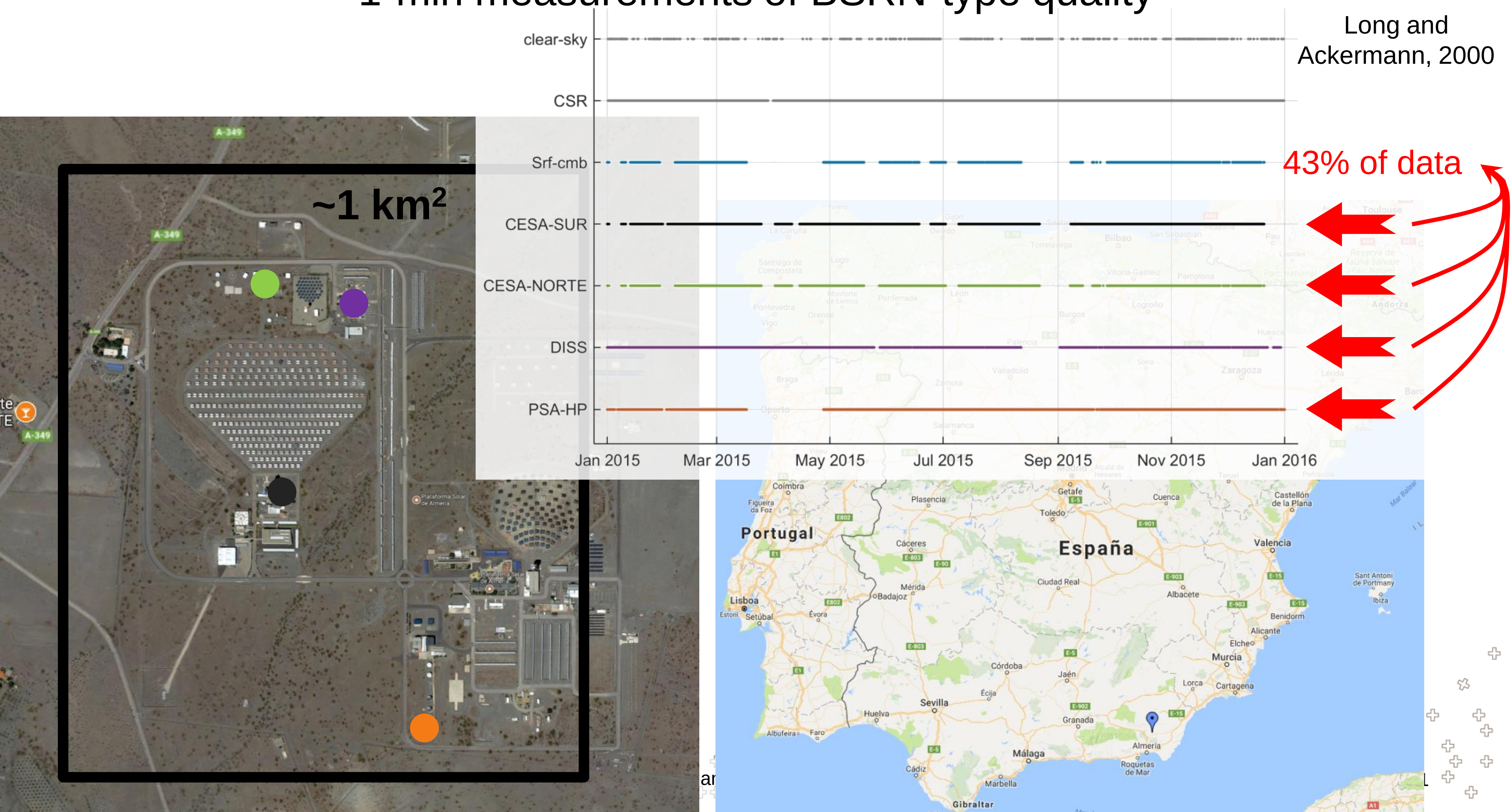
Data & data availability

data

PSA allows using a combination of 4 pyrheliometers for full year (2015)

DNI measurements spread on about 1 MSG SEVIRI pixel (visible)

1-min measurements of BSRN-type quality

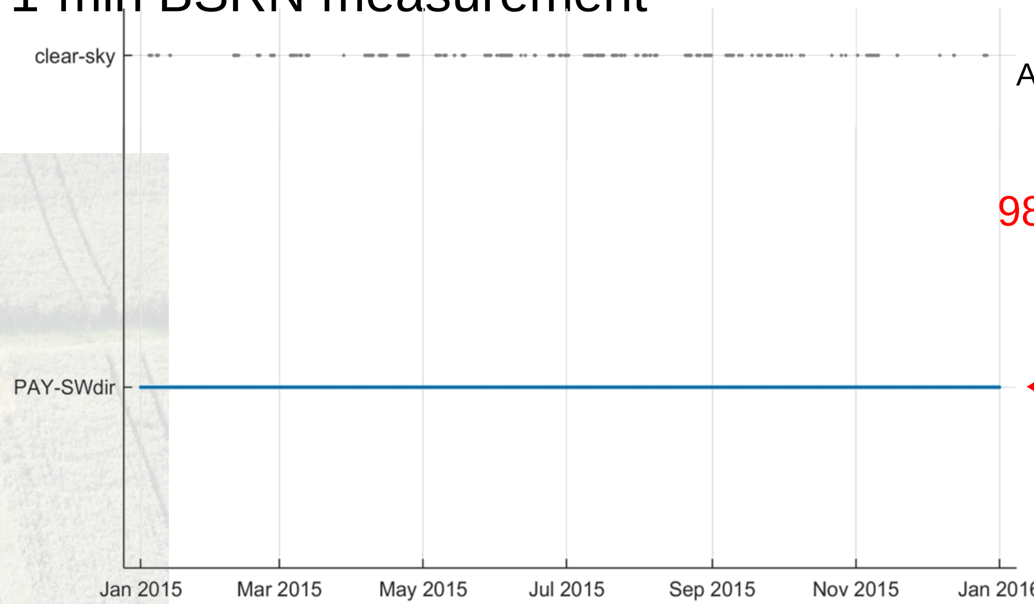


Data & data availability

data

Payerne allows confirmation of PSA results with data from station with climatic conditions significantly different from arid Spain desert

1-min BSRN measurement



Long and Ackermann, 2000

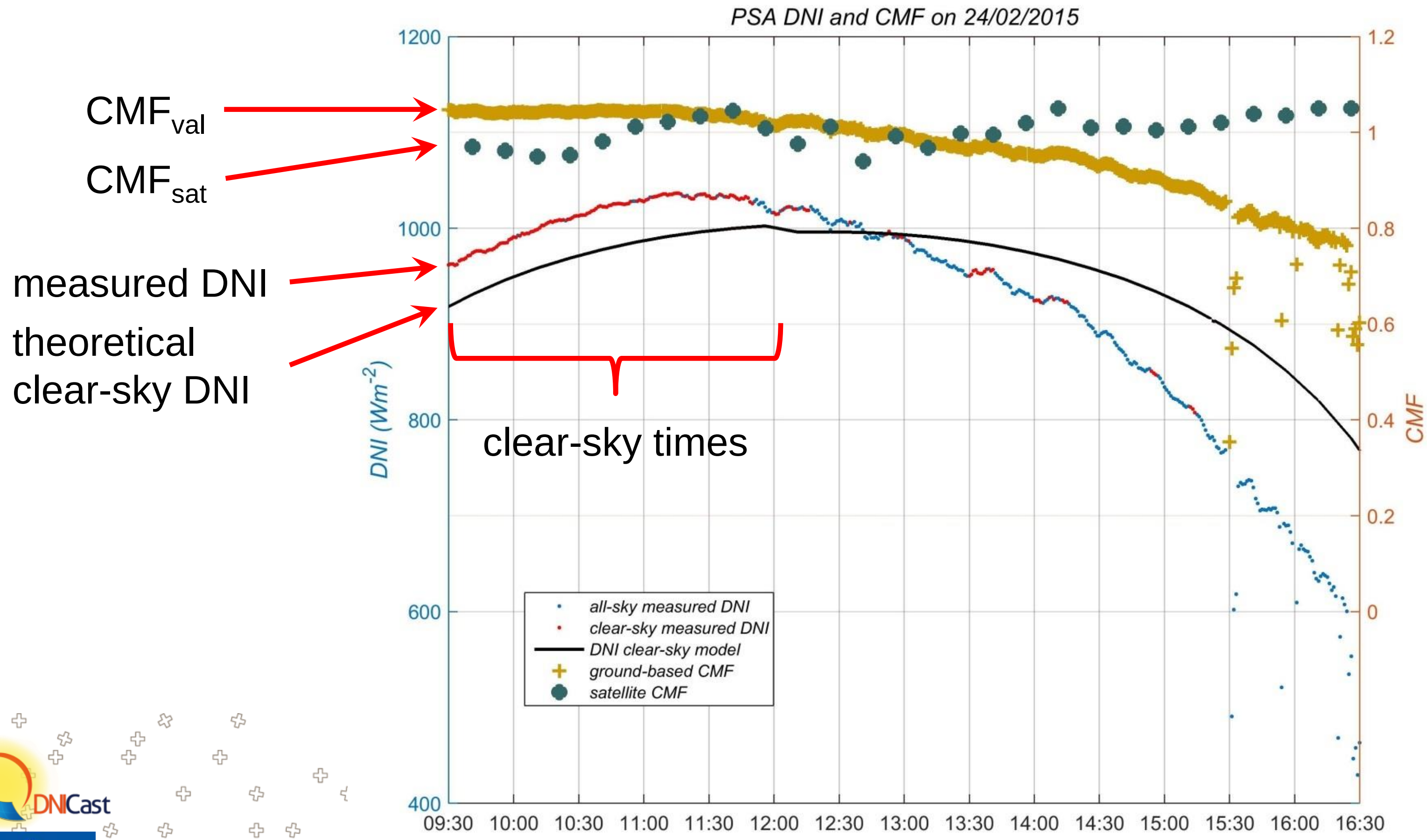
98% of data

Radiation and CMF

data

Satellite information → CMF_{sat} compared to $CMF_{val} = \frac{I^{meas}}{I^{th}_{cs}}$

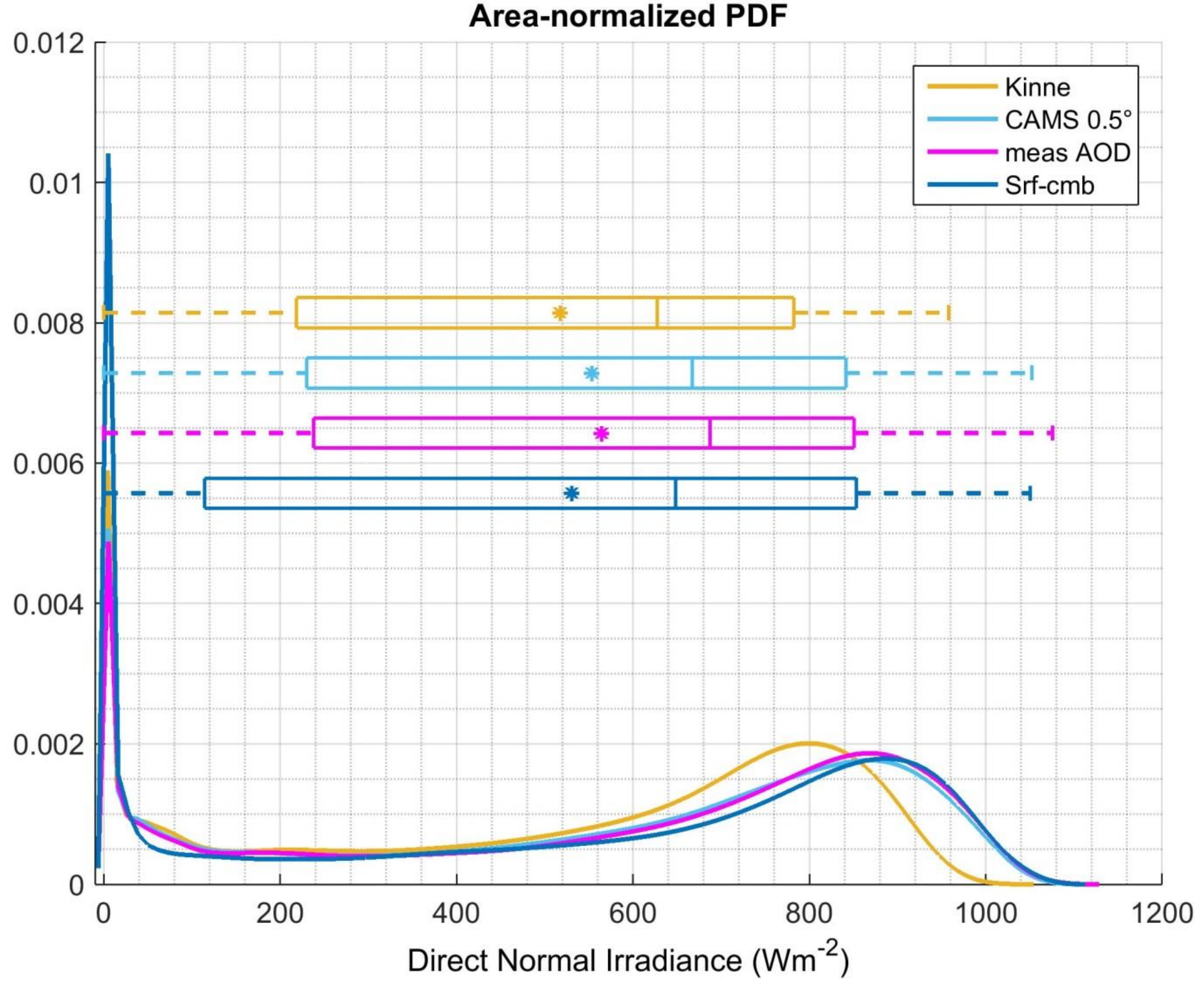
At clear-sky times radiation theoretical prediction can be compared with data.



Probability density function

all-sky estimates

- Using averages or medians to compare ground-based all-sky DNI measurements to satellite corresponding estimates suggests aerosol climatology by Kinne et al. (2006) is best



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Probability density function

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Similar PDF for all ground-based measurements → same for their average

Estimates using measured AOD: extremely close to measurements

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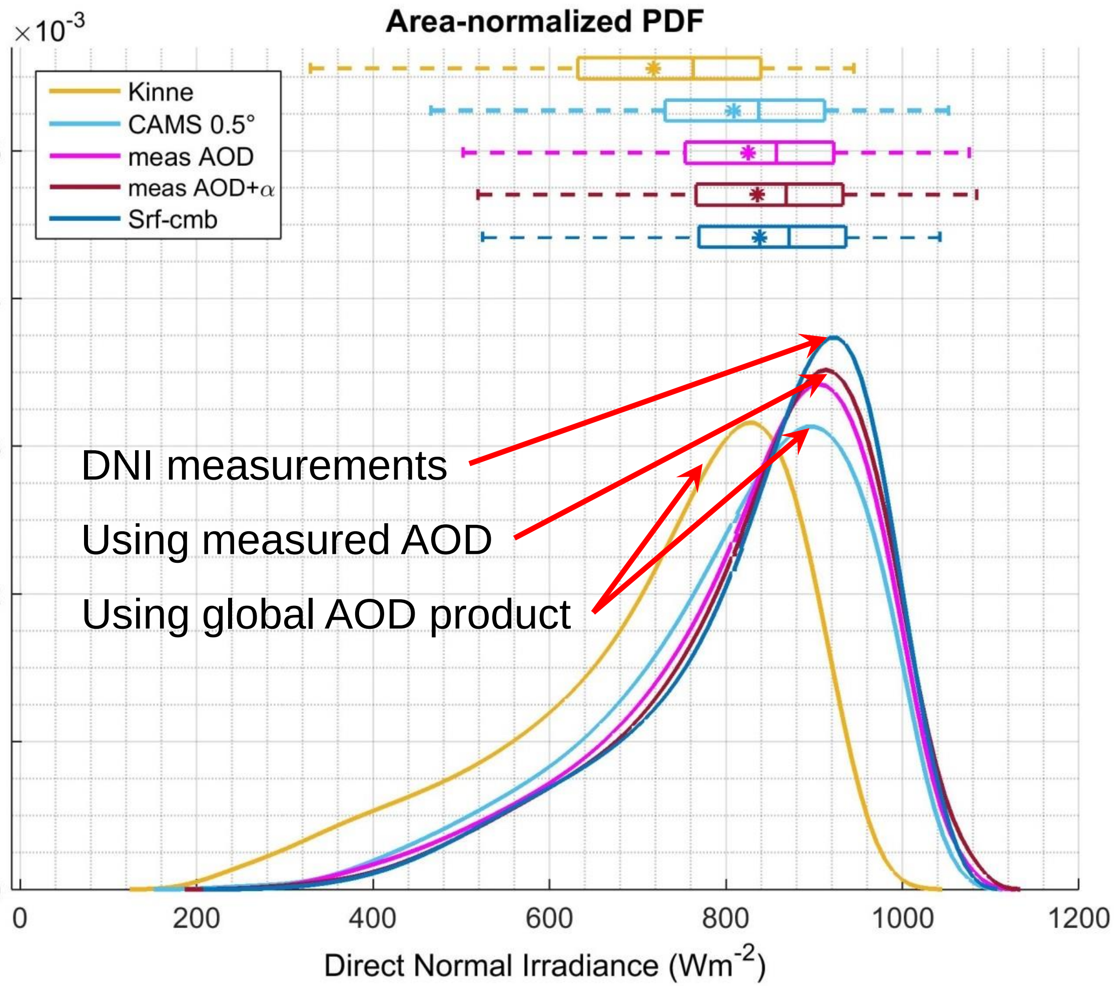

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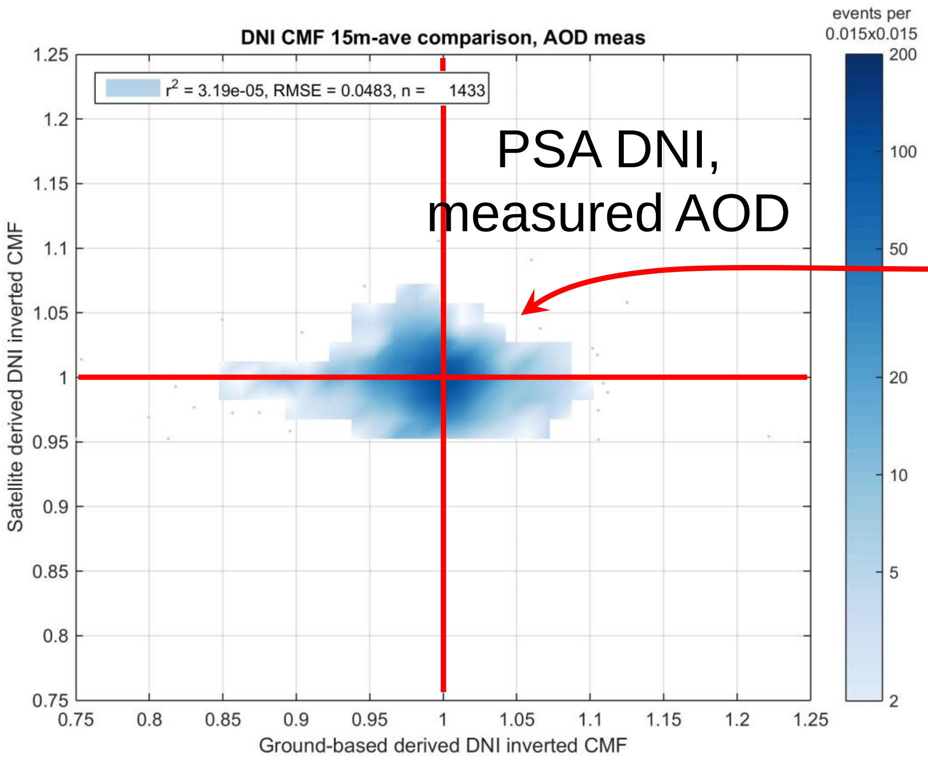
Inverse CMF distributions

clear-sky estimates

Validating CMF for clear-sky



For clear-sky, one expects CMF_{sat} vs CMF_{val} to be a blob centered on (1,1)

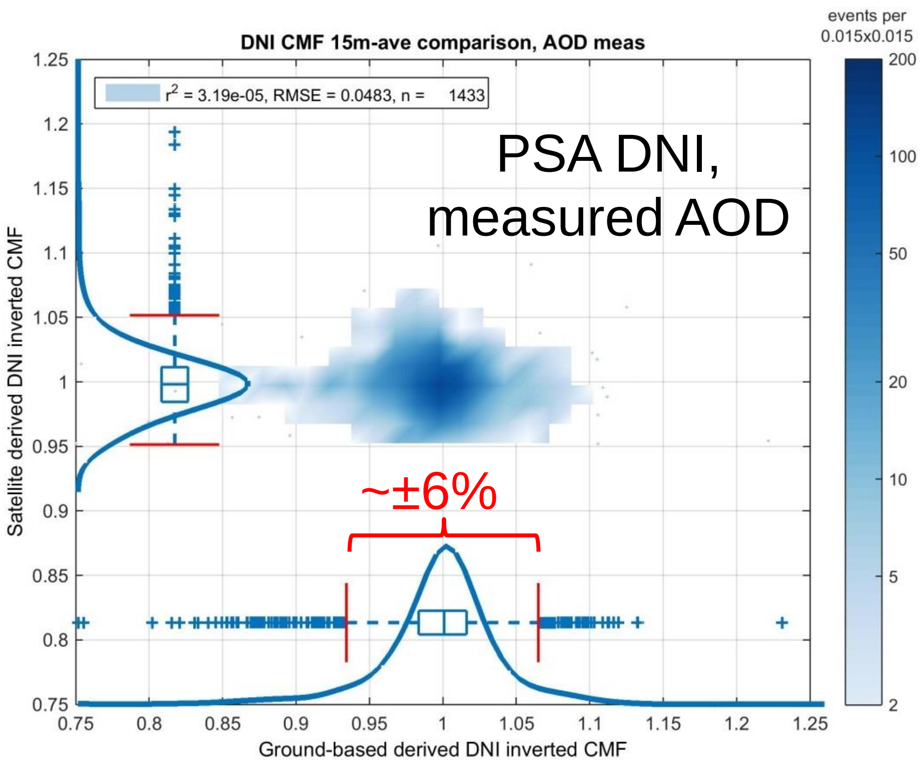
Inverse CMF distributions

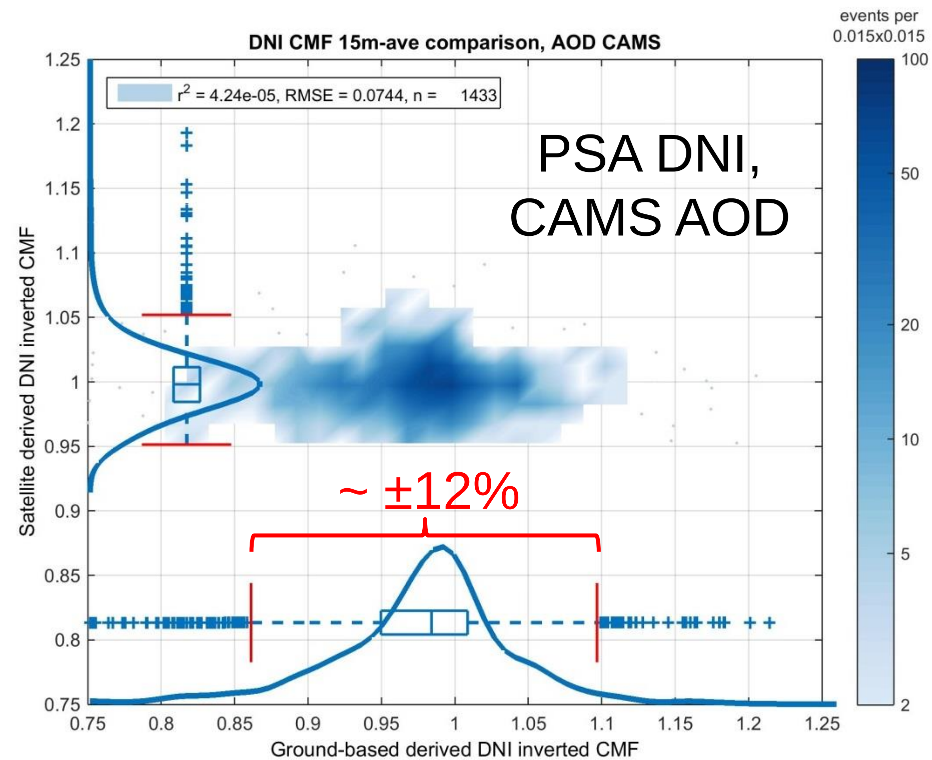
clear-sky estimates

Validating CMF for clear-sky (should be =1) gives information on uncertainty of clear-sky estimates → uncertainty in aerosol input

$$\frac{1}{\mathrm{CMF}_{cs}^{val}} = f\left(I_{cs}^{th}, I_{cs}^{meas}\right) = \frac{I_{cs}^{th}}{I_{cs}^{meas}}$$

$$\sigma^2(f) = \frac{\sigma^2\left(I_{cs}^{th}\right)}{\left(I_{cs}^{meas}\right)^2} + \overbrace{\left(\frac{I_{cs}^{th}}{I_{cs}^{meas}}\right)}^{\sim 1}{}^2 \overbrace{\frac{\sigma^2\left(I_{cs}^{meas}\right)}{\left(I_{cs}^{meas}\right)^2}}^{(\sim 1.5\%)^2}$$





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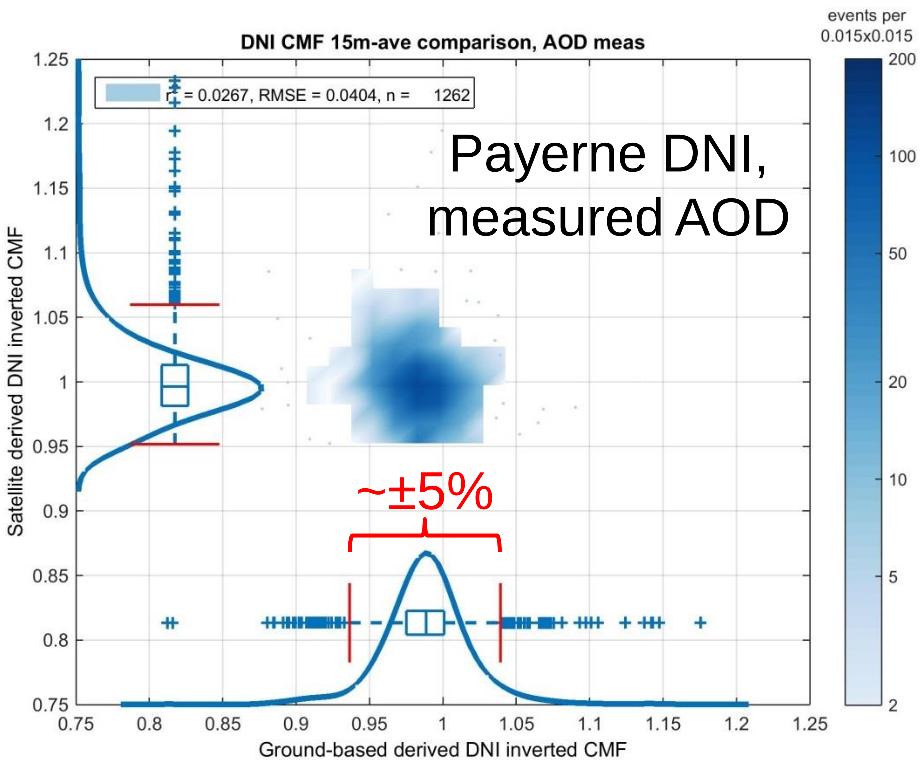

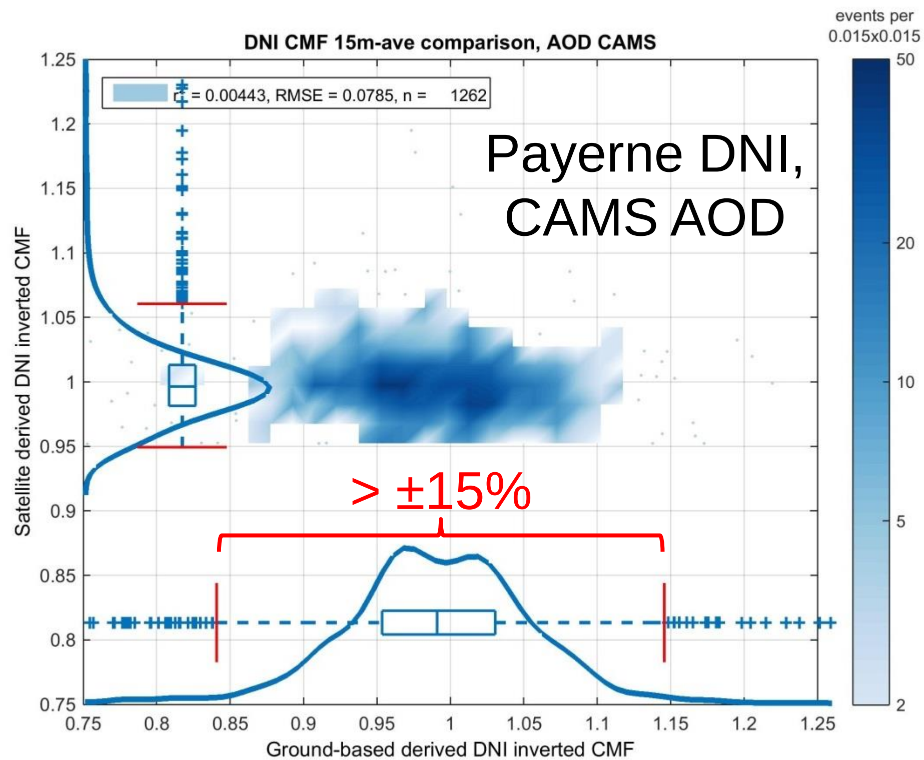

Inverse CMF distributions

clear-sky estimates

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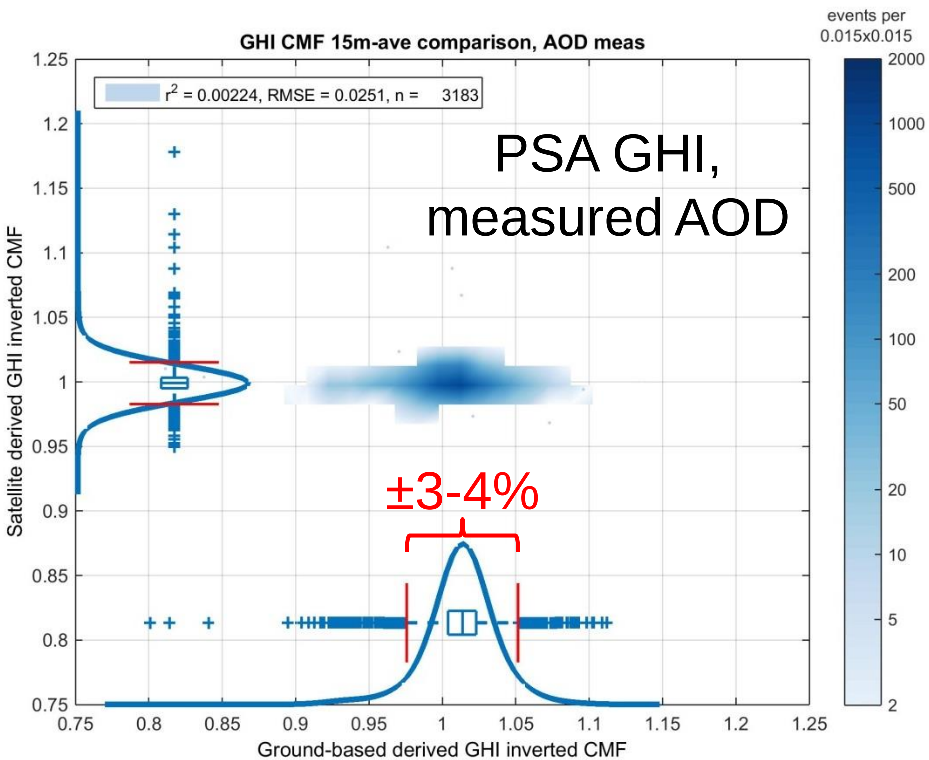
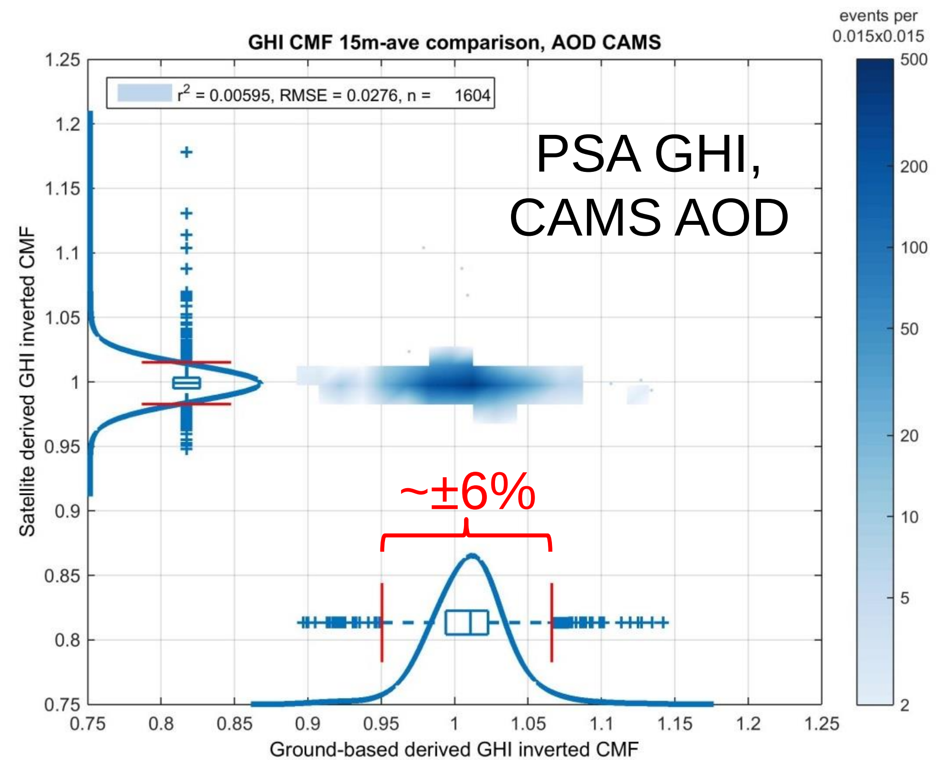
Results for GHI are significantly better ← compensation between AOD effects on direct and diffuse component





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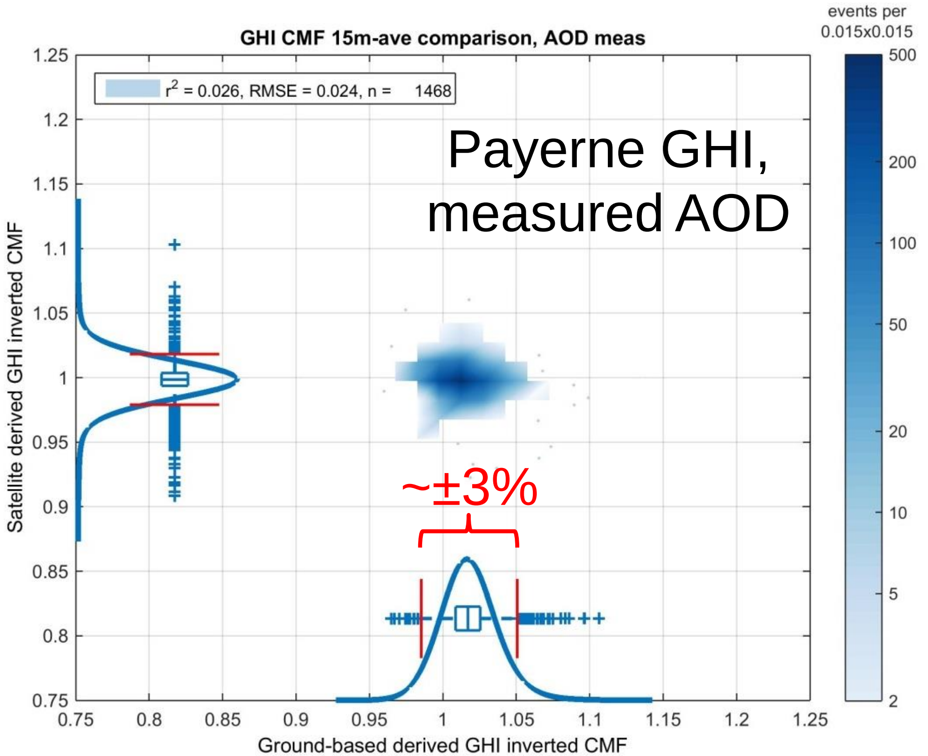
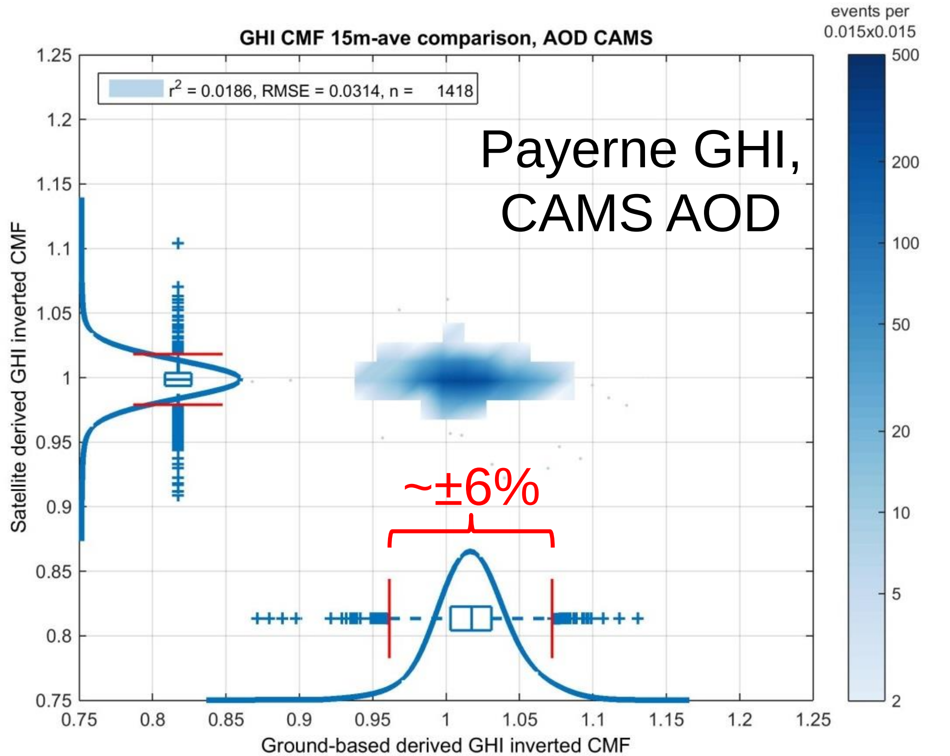




Conclusions (intermediary, part 1)

Clear-sky situations:

- Model performing well with main uncertainty from AOD input
- Using measured AOD allows agreement within about 2–3 times measurement uncertainty
  - Measured AOD: DNI ~ –1% bias, uncertainty: ~ ±6%

    GHI ~ +1% bias, uncertainty: ~ ±3%
- Using global AOD product
  - Kinne climatology → strong DNI underestimation (do not use)
  - CAMS AOD product: DNI ~ –3% bias, uncertainty: ~ ±15%

    GHI ~ +1% bias, uncertainty: ~ ±5%
  - Unsolved issue with CAMS / MACC: constant quality over time?

Probability density function

all-sky estimates

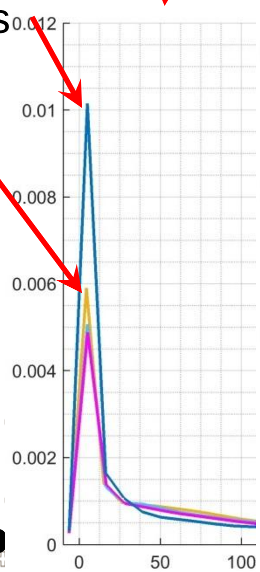
Similar PDF for all ground-based measurements → same for their average

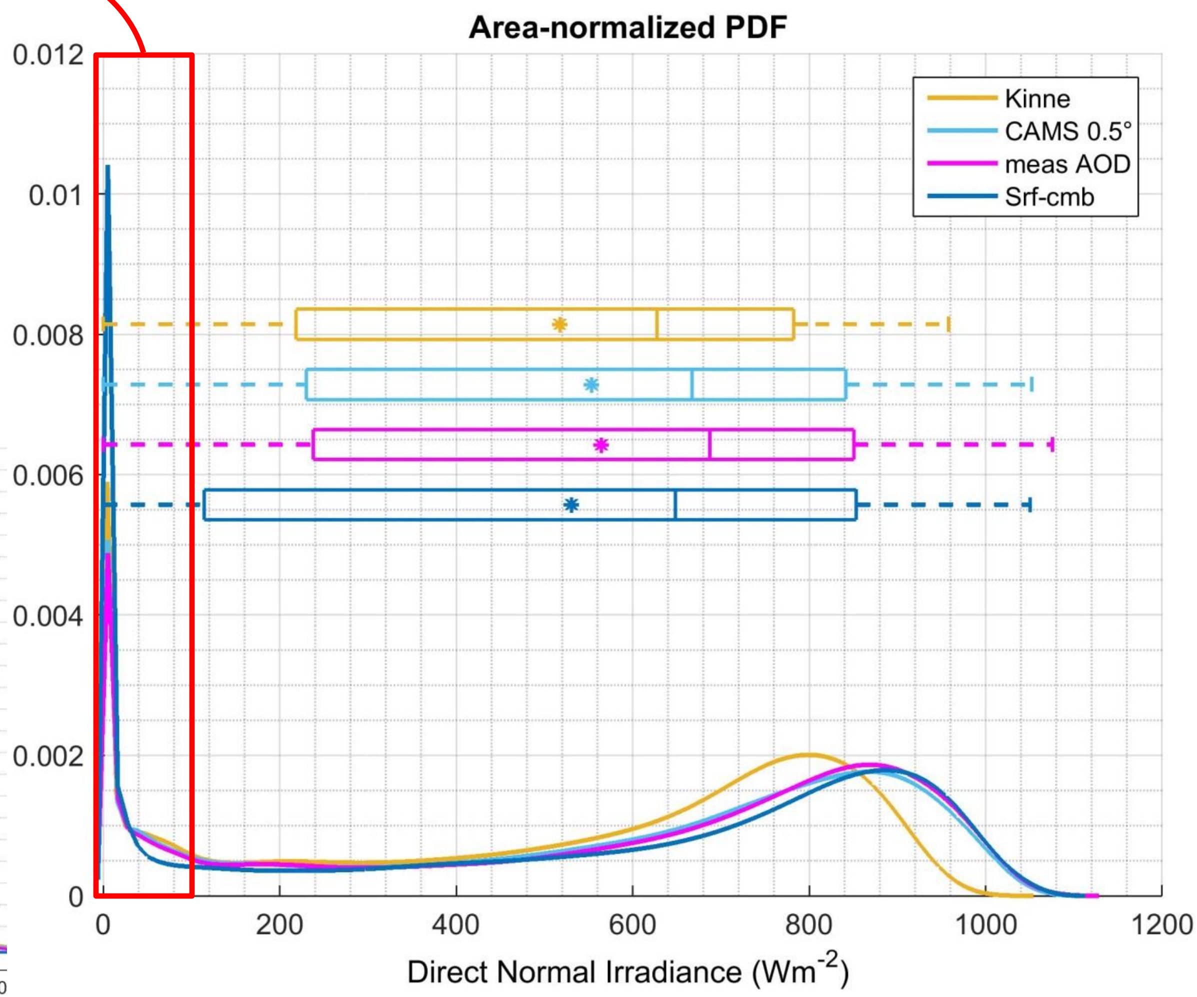
Satellite estimates: significant underestimation of (almost-)zero-DNI events

- Strong effect on 1st quartile
- "Compensate" for Kinne AOD overestimation

DNI measurements

DNI estimates





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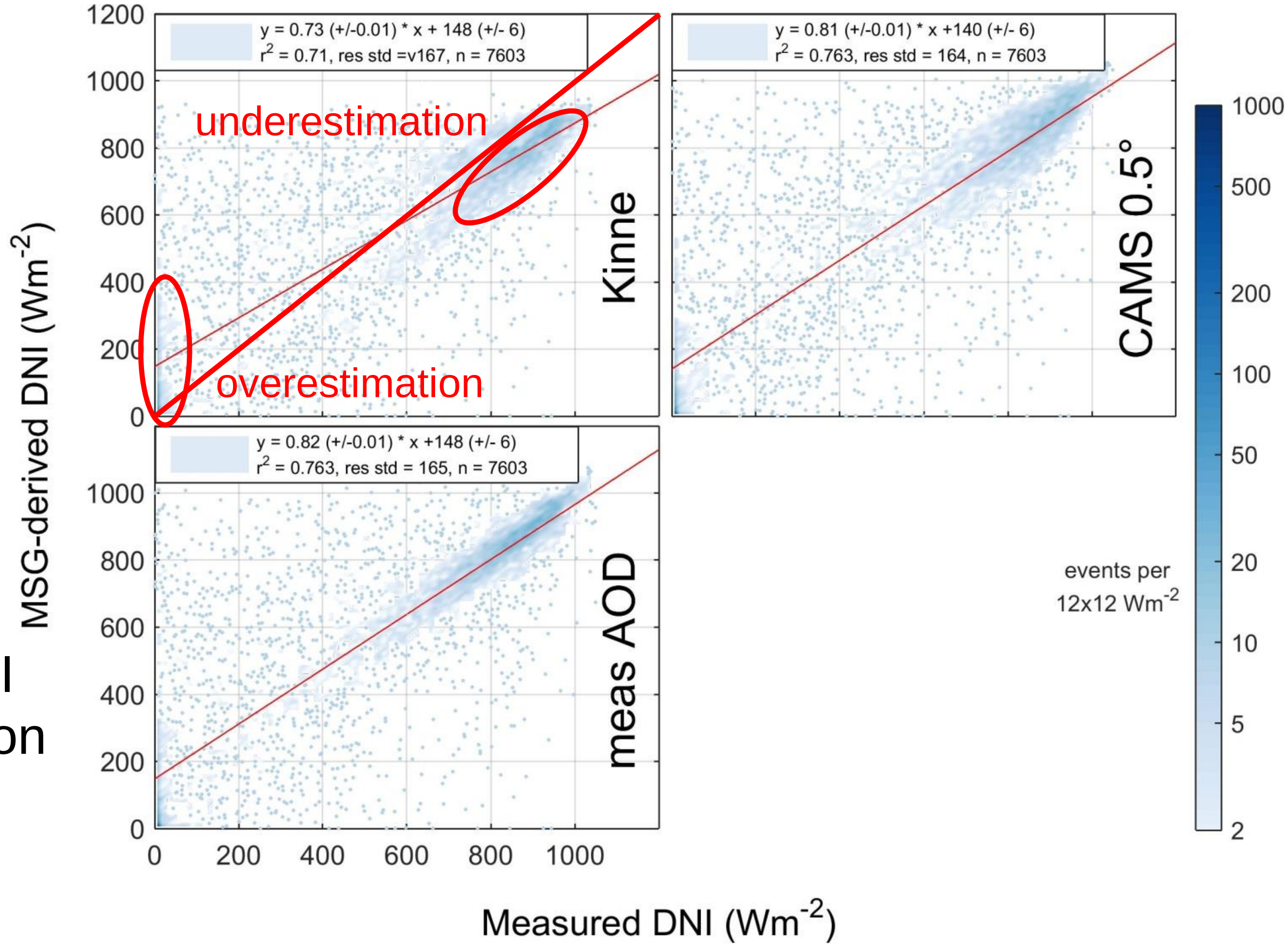
DNI comparison

all-sky estimates

- Kinne agrees better on average, but CAMS better event by event
- Significant scatter



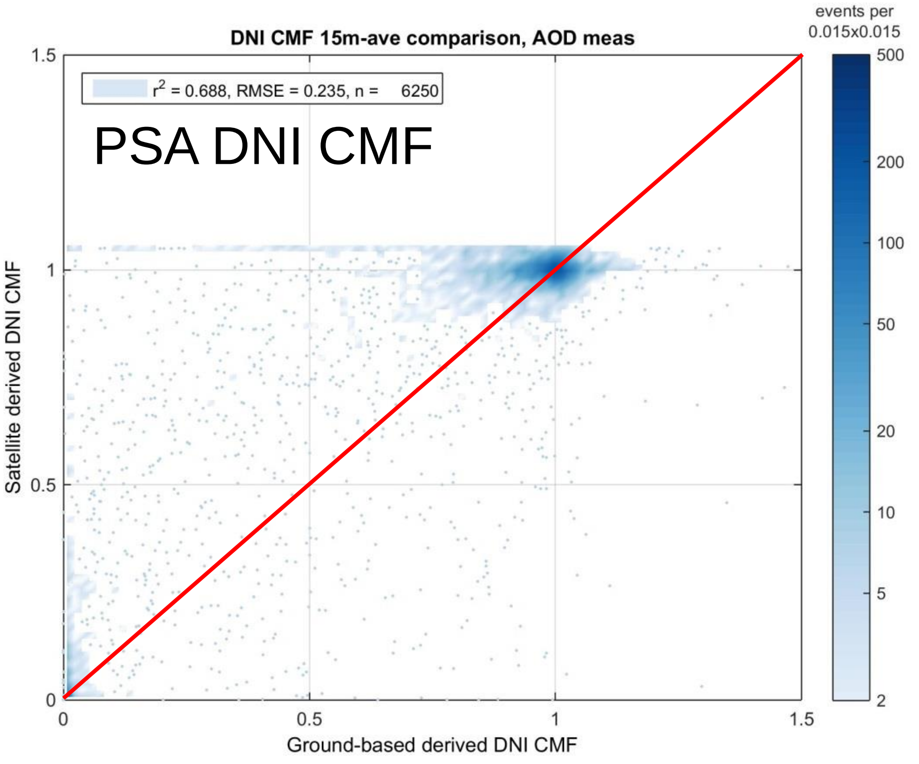
PSA DNI comparison

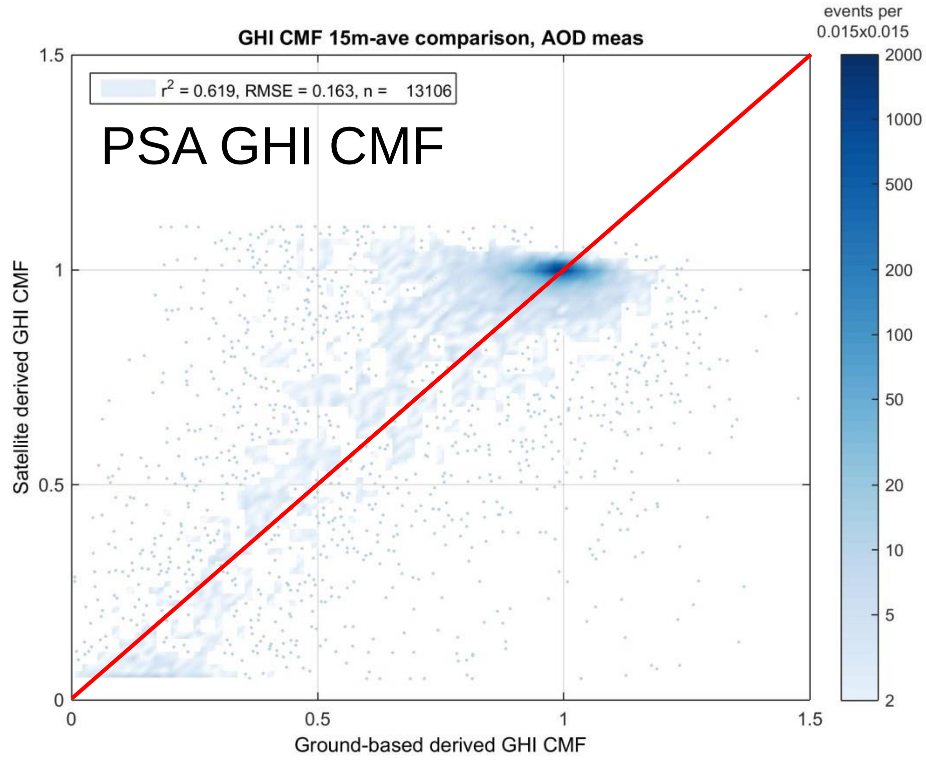
CMF comparisons

all-sky estimates

Satellite CMF determination for DNI & GHI is empirical with limited physical understanding

Issues in empirical algorithm going beyond spatial and temporal variability for both DNI and GHI (may be specific to HelioMont)





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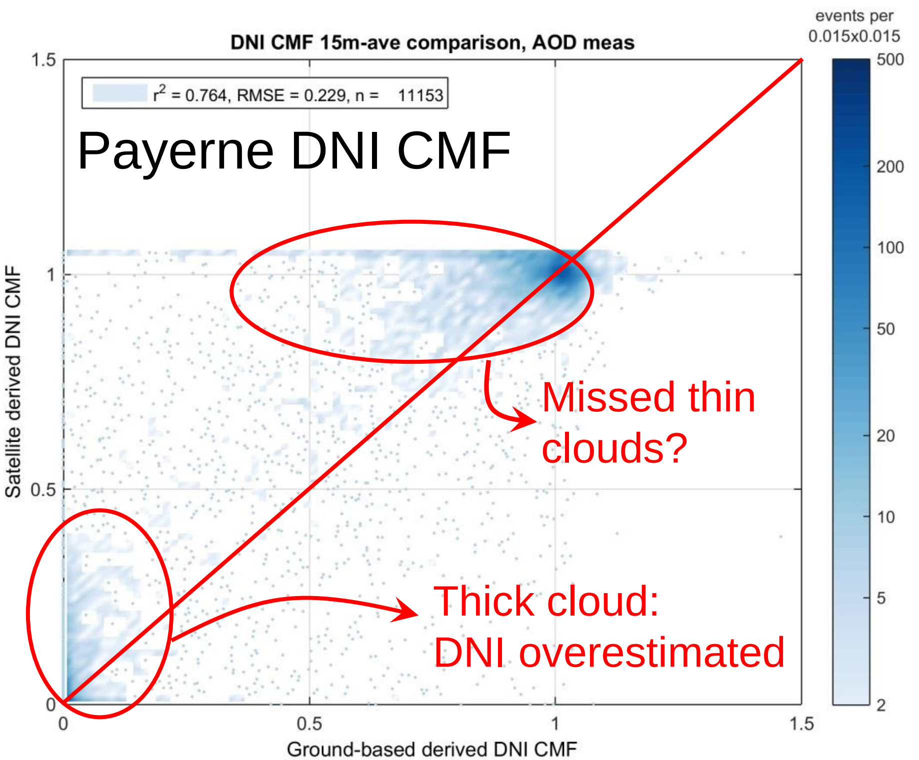
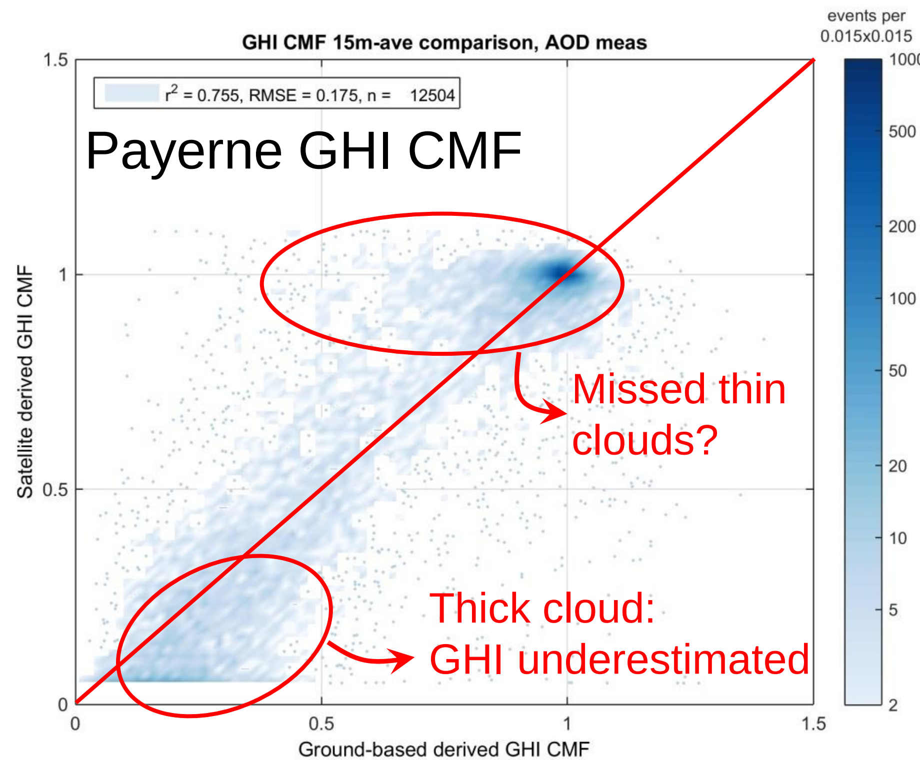




Conclusions

All-sky situations:

- Issues remain to be solved in satellite-based CMF determination
  - Thick clouds: DNI overestimation / GHI underestimation
  - Thin clouds missed?
- Optimism: issues identified, roadmap for solving them can be set!

Separately validating clear-sky irradiance and cloud effect provides better understanding of satellite irradiance estimation performance

- Spatial / temporal averaging → reduction cloud-induced scatter in comparisons between area satellite estimates and point ground-based measurements, 1-hour averaging satisfactory over MSG pixel

Thank you

? / !

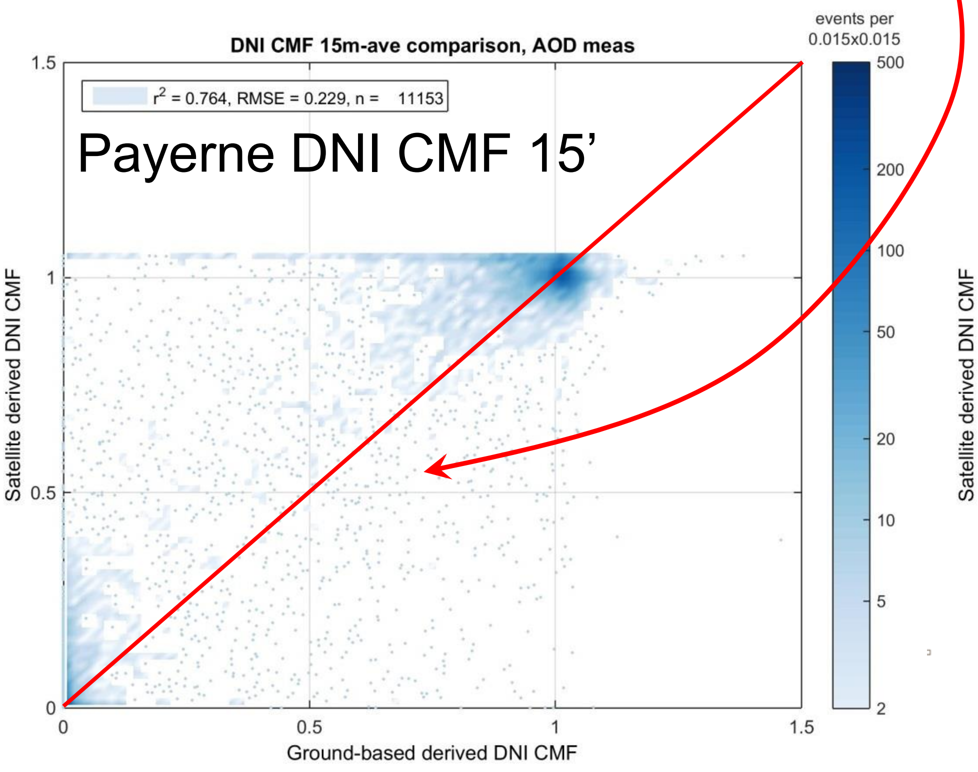
L. Vuilleumier, Meyer, A., R. Stöckli, S. Wilbert and L. F. Zarzalejo (2018). Validation of Direct Normal Irradiance from Meteosat Second Generation, manuscript in preparation.

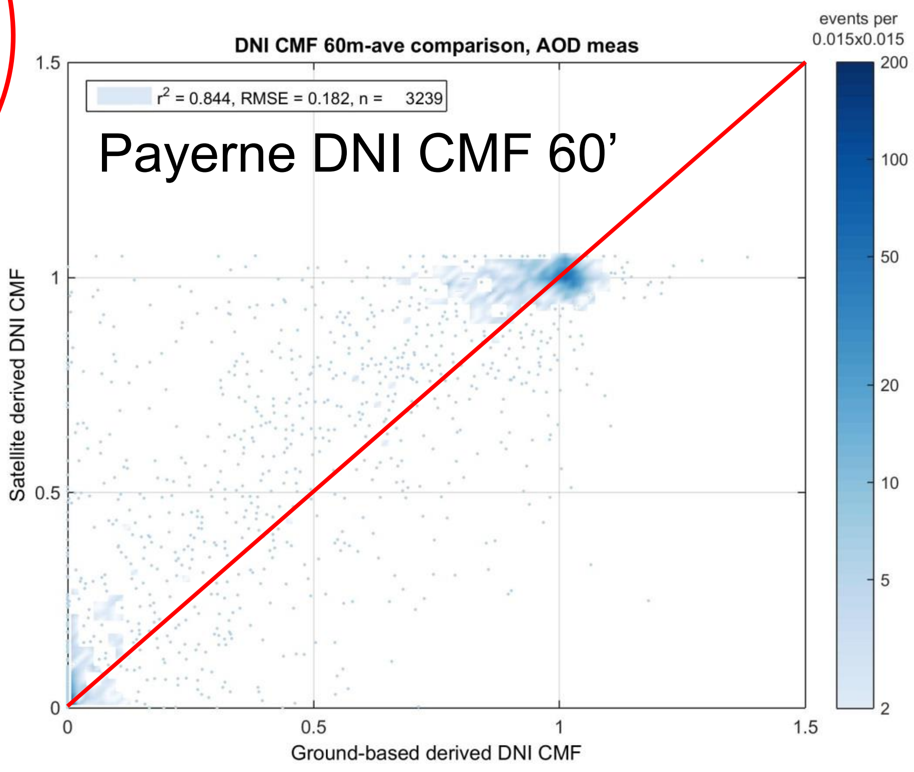
CMF comparisons

all-sky estimates

Satellite CMF determination for DNI & GHI is empirical with limited physical understanding

Have you notice there is some scatter?

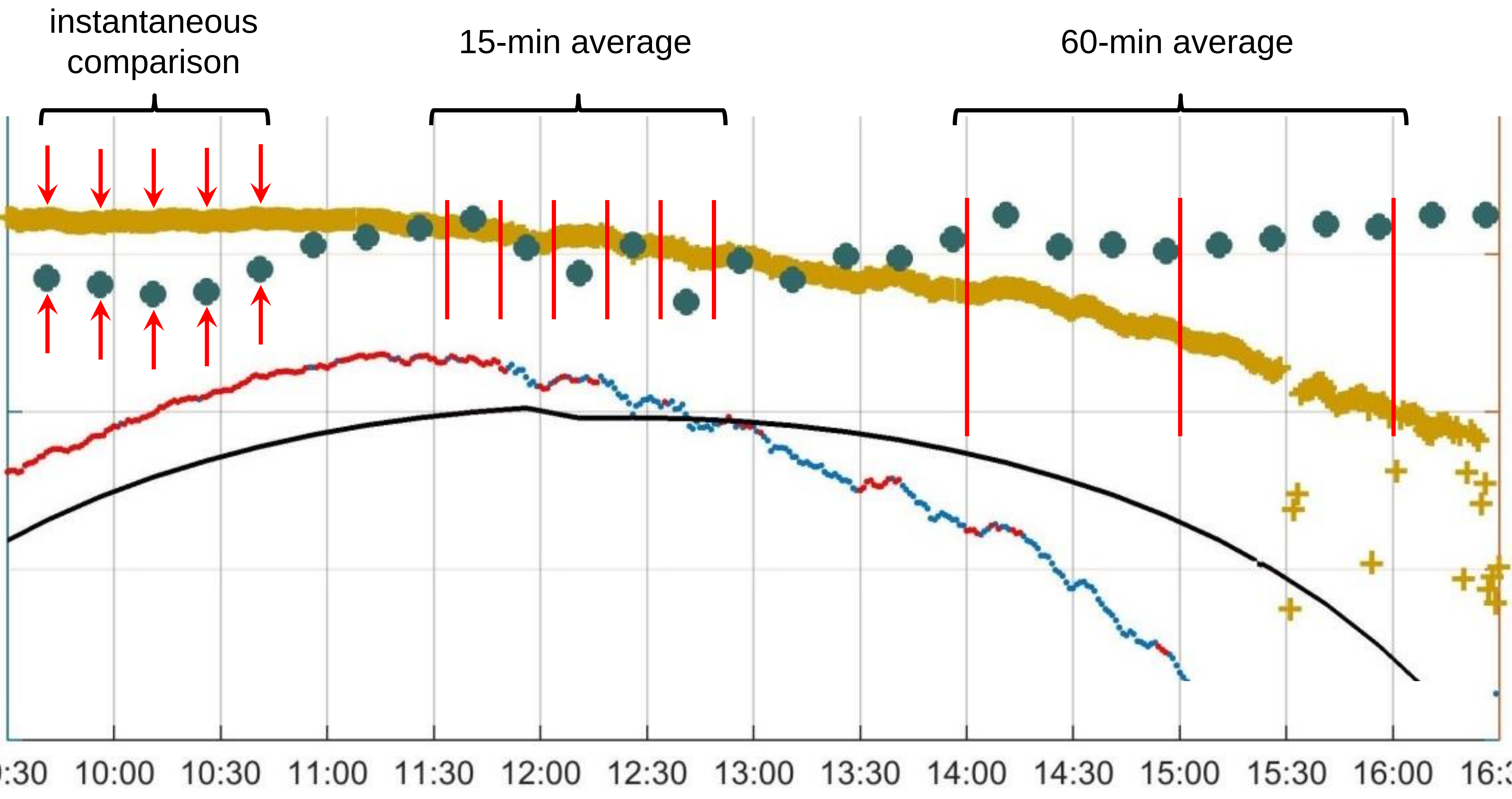




DNI spatial and temporal averaging

all-sky estimates

Computing r^2 and RMSE of CMF comparisons for different temporal and spatial averaging (single vs. 4-instrument average at PSA)



DNI spatial and temporal averaging

all-sky estimates

- Temporal & spatial averaging increase correlation and decrease RMSE
- At 1-hour temporal averaging, very small difference between PSA with and without spatial averaging

1-hour averaging satisfactory for point-to-area comparison in cloud effect

temporal averaging →

			instantaneous	15-min.	60-min.
Correlation (r^2)	**PSA**	all instruments	0.667	0.708	0.789
		single instrument	0.640	0.699	0.788
	PAY	single instrument	0.718	0.764	0.844
RMSE	**PSA**	all instruments	0.237	0.217	0.181
		single instrument	0.249	0.219	0.178
	PAY	single instrument	0.255	0.229	0.182

nearly equal

↑ spatial averaging

increase

nearly equal

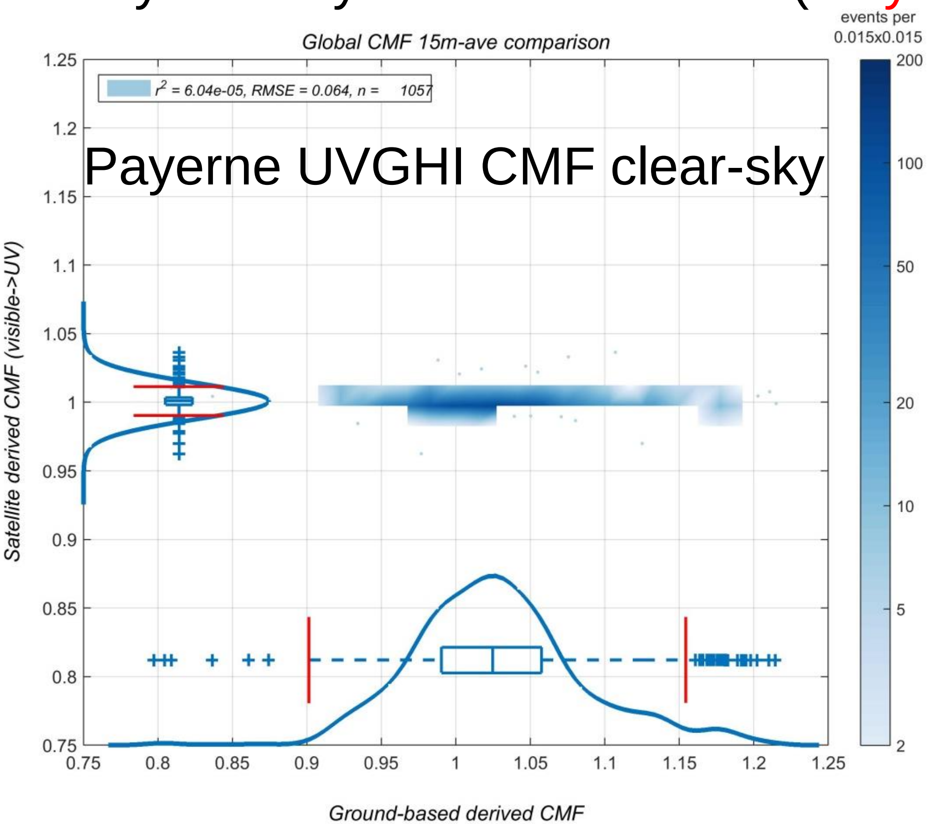
↑ spatial averaging

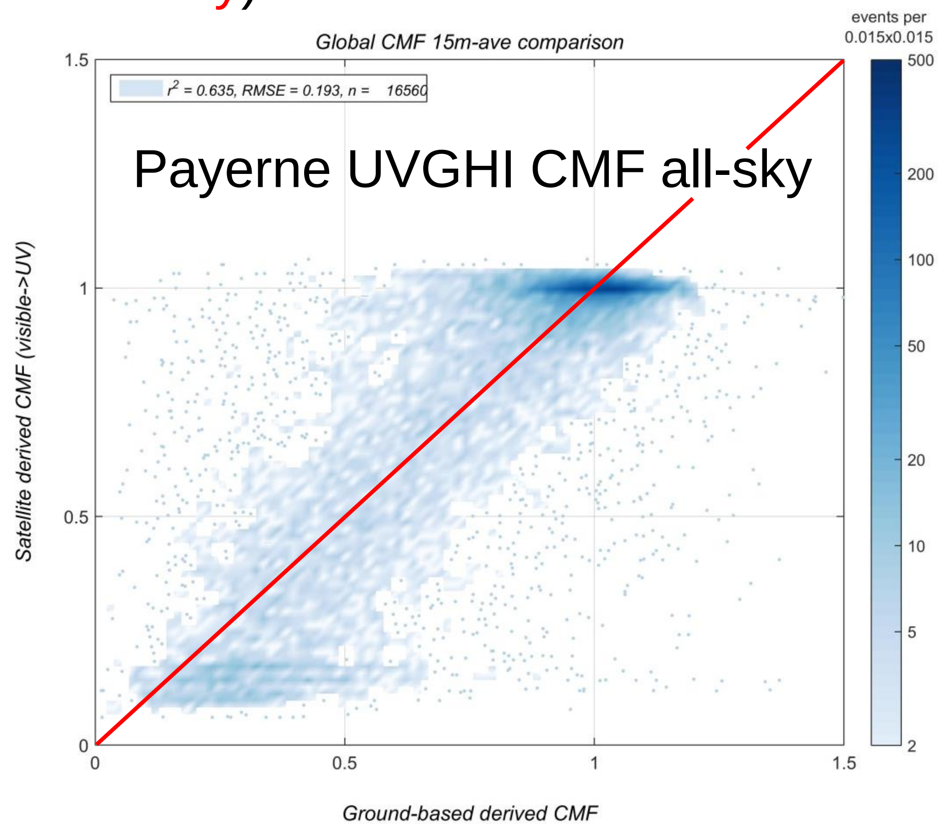
decrease

Outlook

- More stations → finding spatially homogenous?
- More years → stability over time
- More understanding → can we verify hypothesis on current issues

By the way how is it for UV ? (very preliminary)





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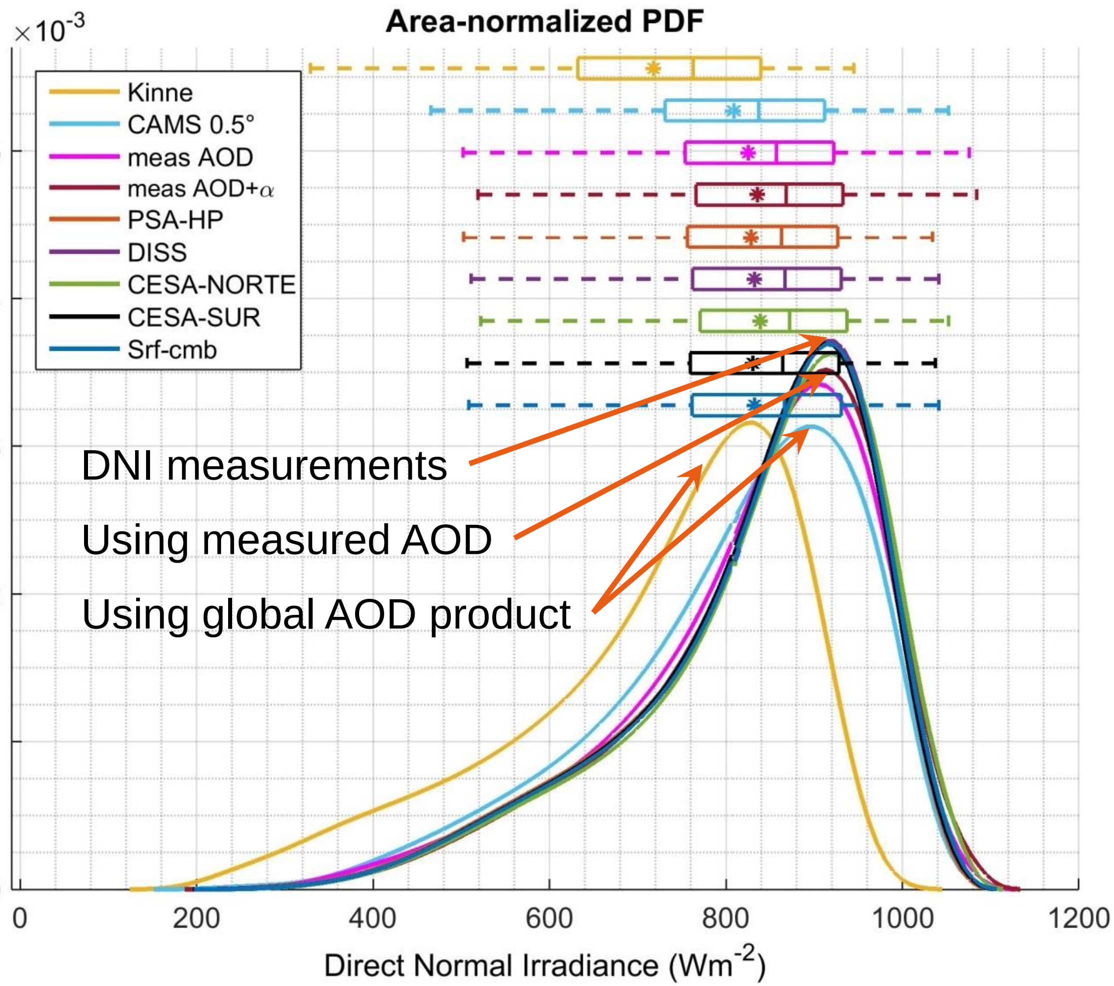

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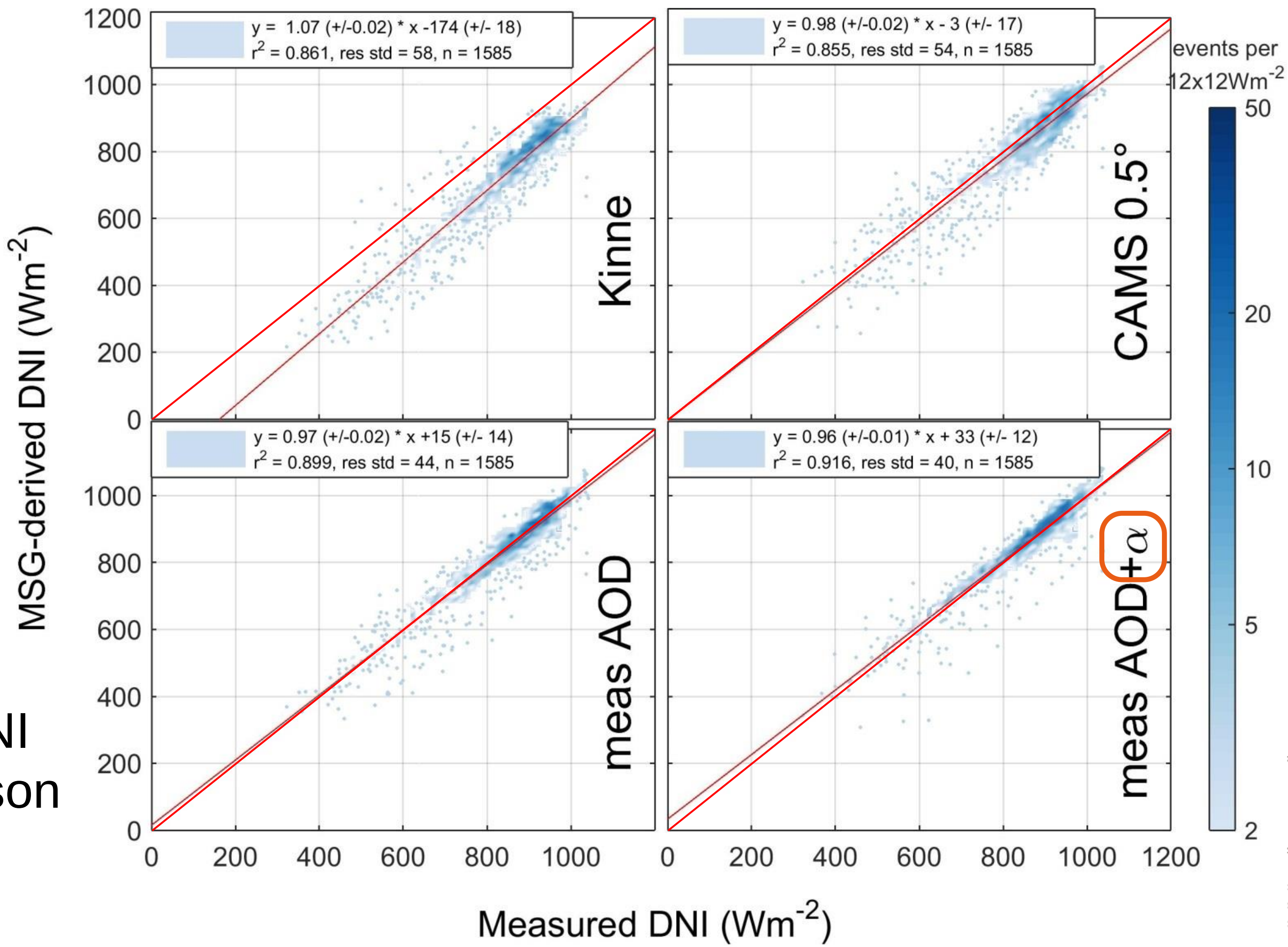
DNI comparison

clear-sky estimates

The understanding of physics processes and the high measurement accuracy allow deep tests of aerosol influence on radiation:



At limit: effect of AOD wavelength dependence

PSA DNI comparison

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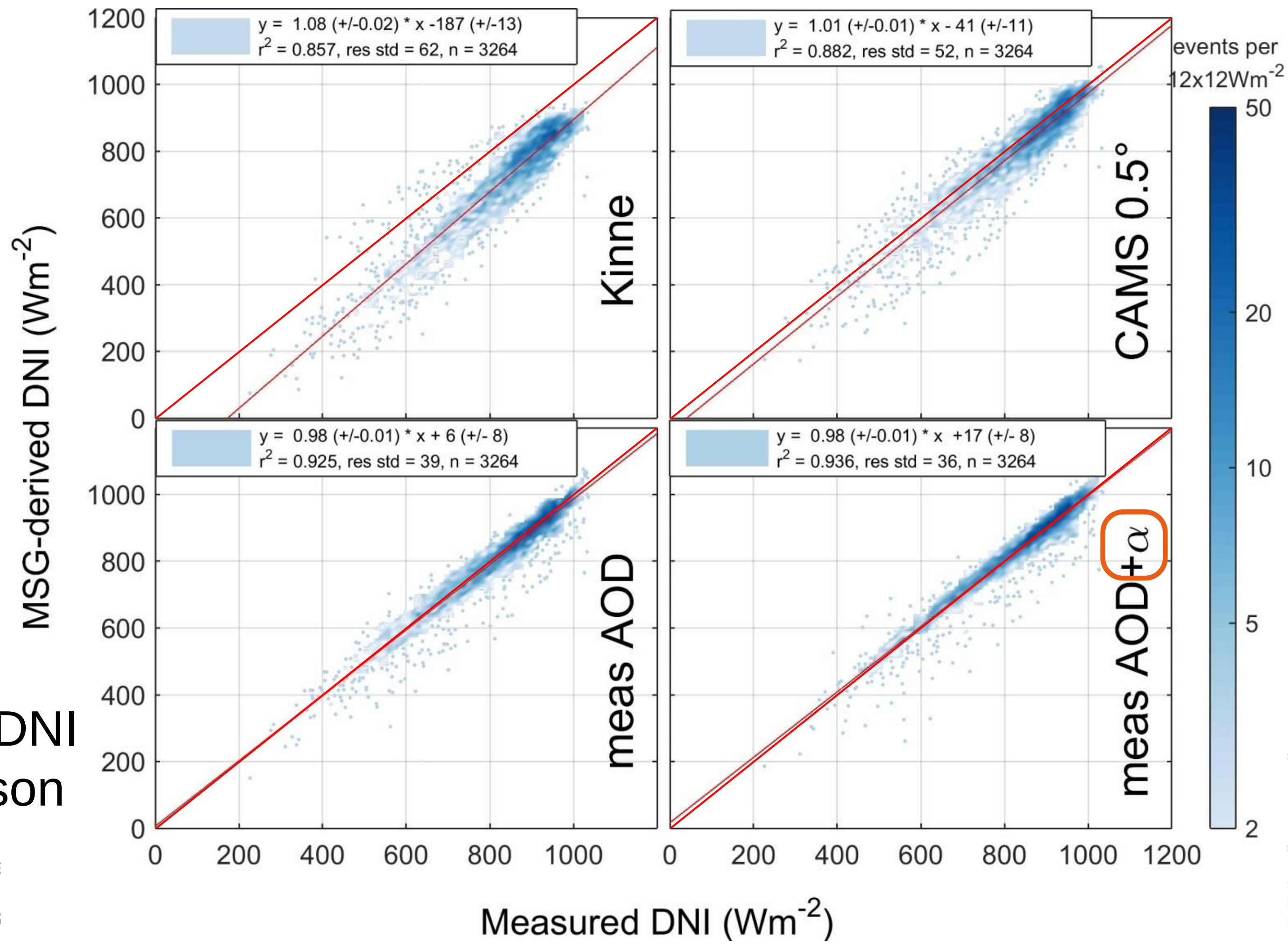

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Payerne DNI comparison

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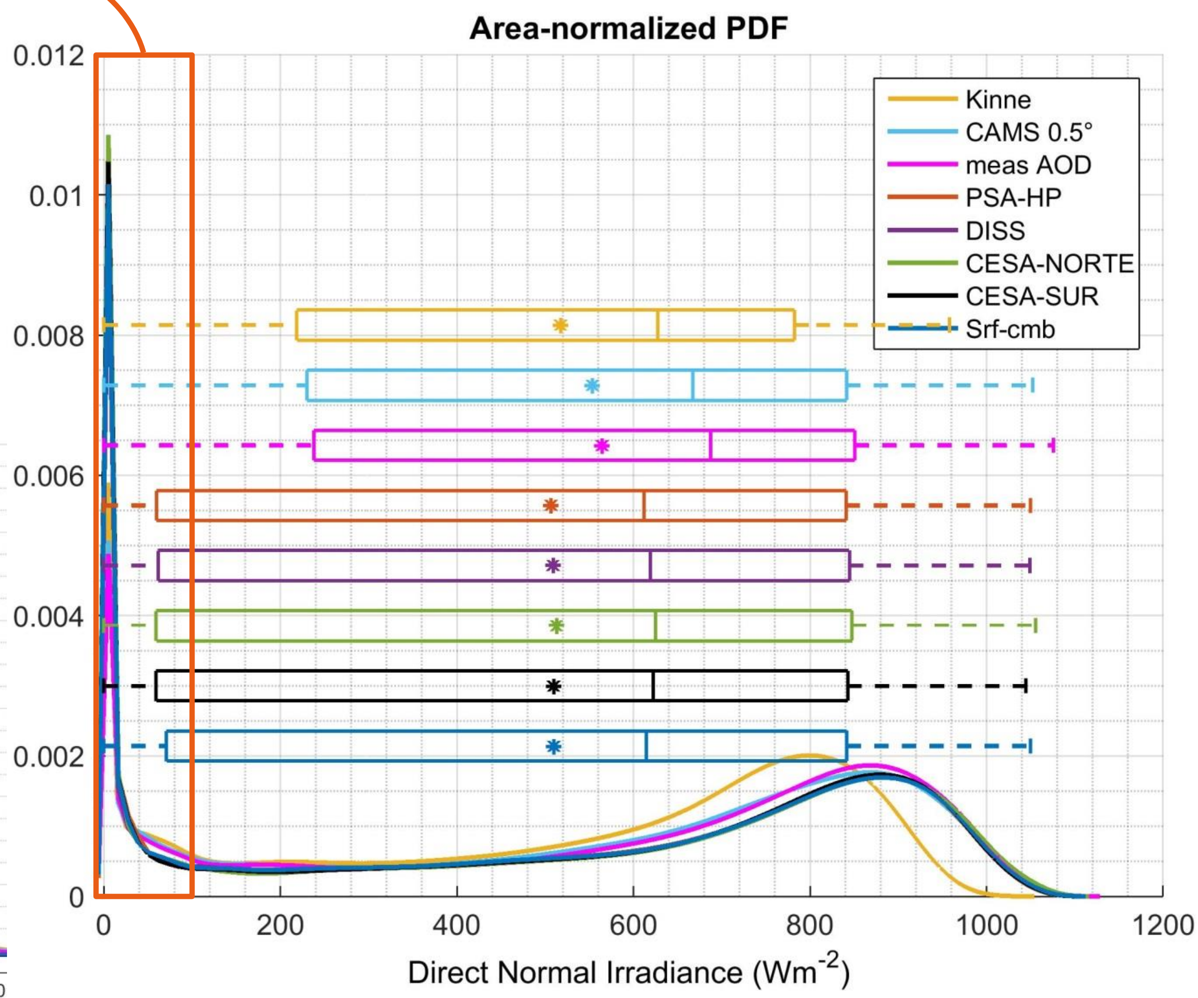

DNI measurements

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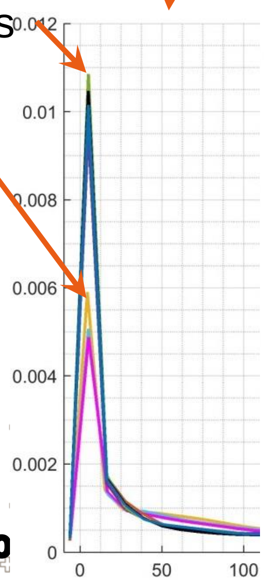

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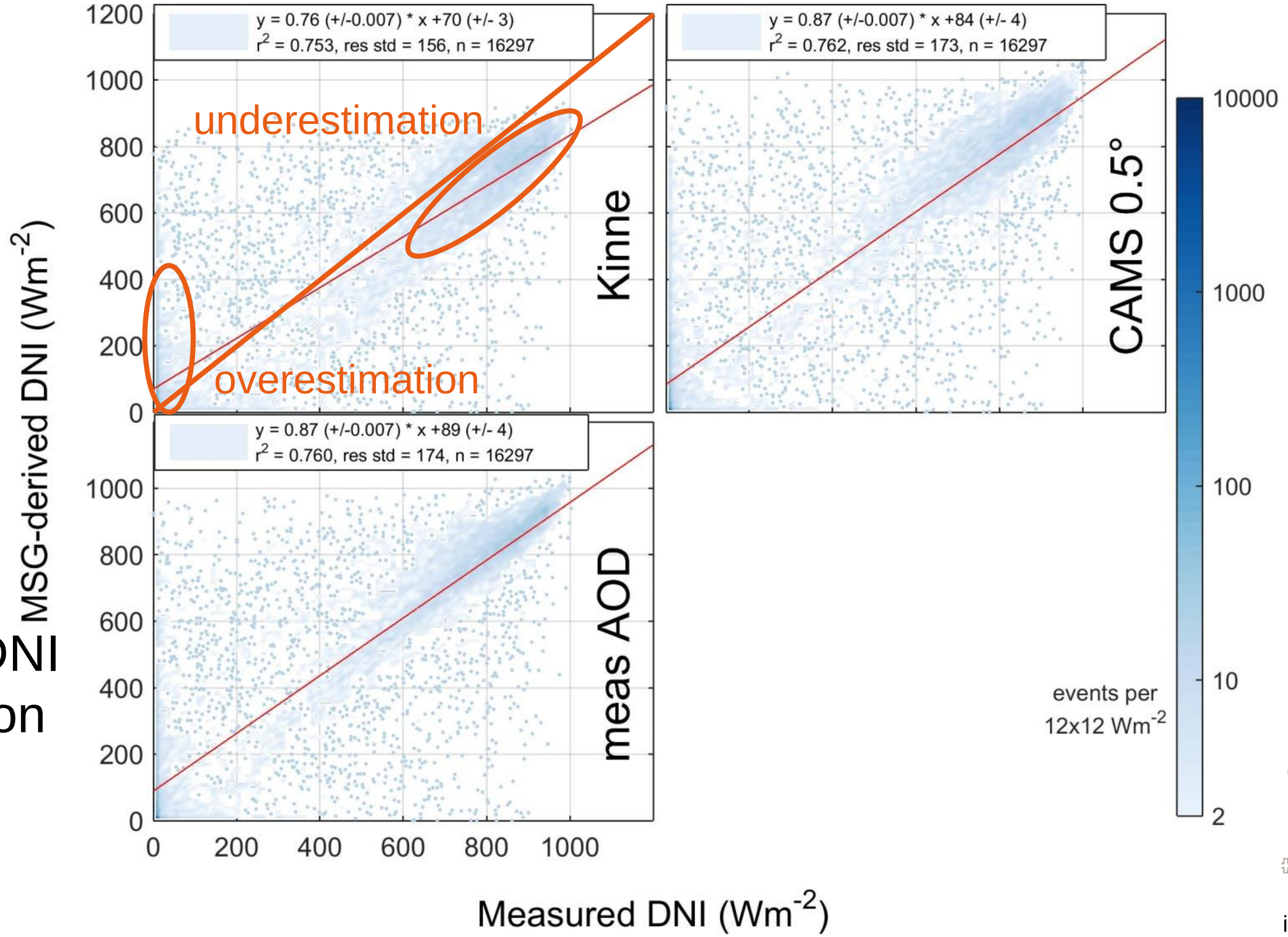

Payerne DNI comparison

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↑ spatial averaging — increase

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