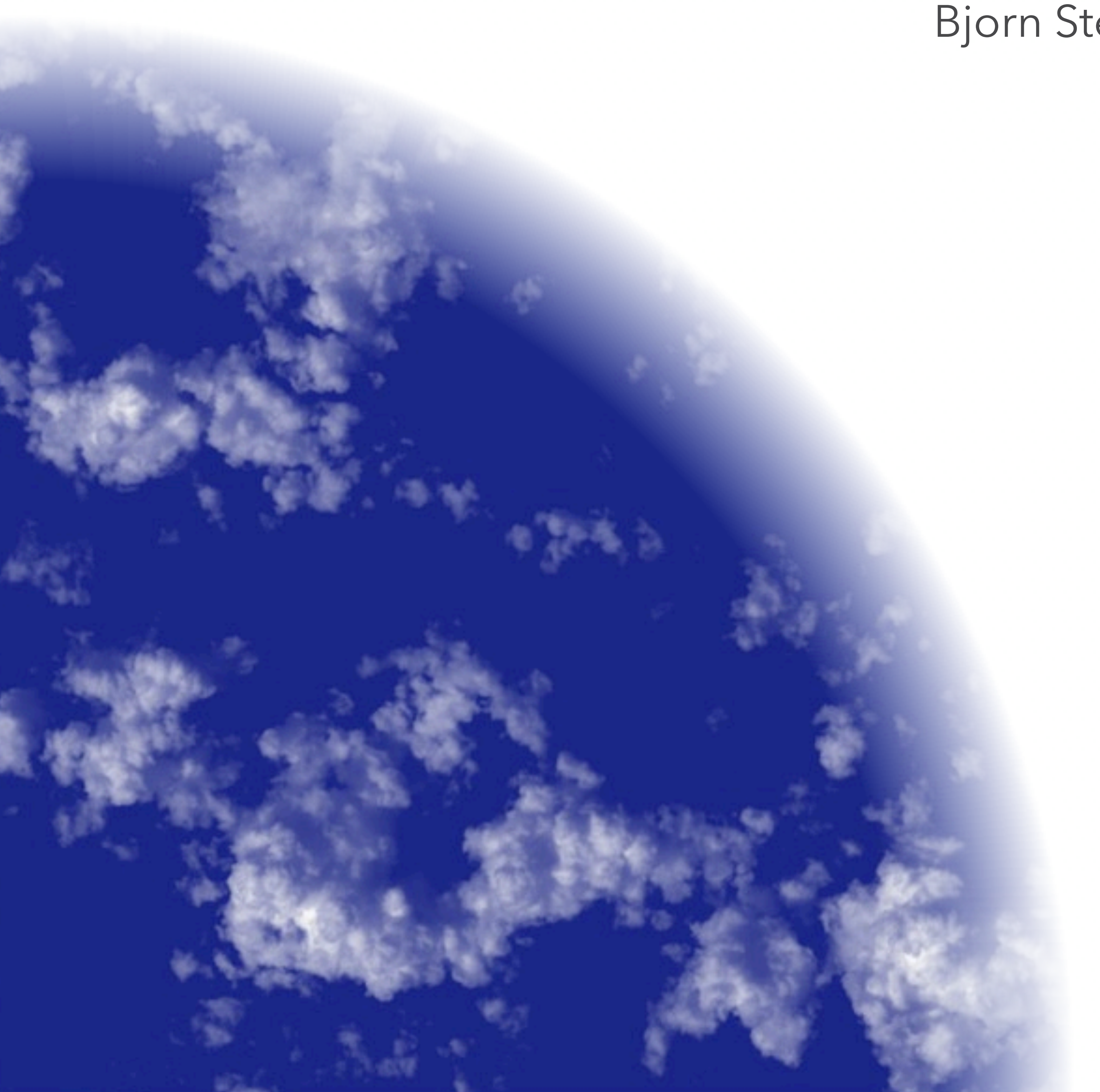
Thin, thinner, clear-sky.

- A closer look at optically thin clouds in the trades

Theresa Mieslinger[1, 2] [theresa.mieslinger@mpimet.mpg.de]

Bjorn Stevens[2], Tobias Kölling[2], Manfred Brath[1], Martin Wirth[3], and Stefan A. Buehler[1]

CERES Spring 2021 Science Team Meeting
13 May 2021



2 Max-Planck-Institut für Meteorologie

3 DLR Deutsches Zentrum für Luft- und Raumfahrt

1 Universität Hamburg

The (cloudy) trades in the global context

What we know and what we don't know

- Lack of observations and understanding of shallow cumulus clouds leads to a large inter-model spread in climate sensitivity [Bony et al., 2015]
- Climate models as well as LES commonly underestimate the cloud cover, while overestimating cloud brightness [Nam et al., 2012; Nuijens et al., 2015; Klein et al., 2016]
- Observations largely disagree on the cloud cover in the trades [Stevens et al., 2019]

How cloudy are the trades?

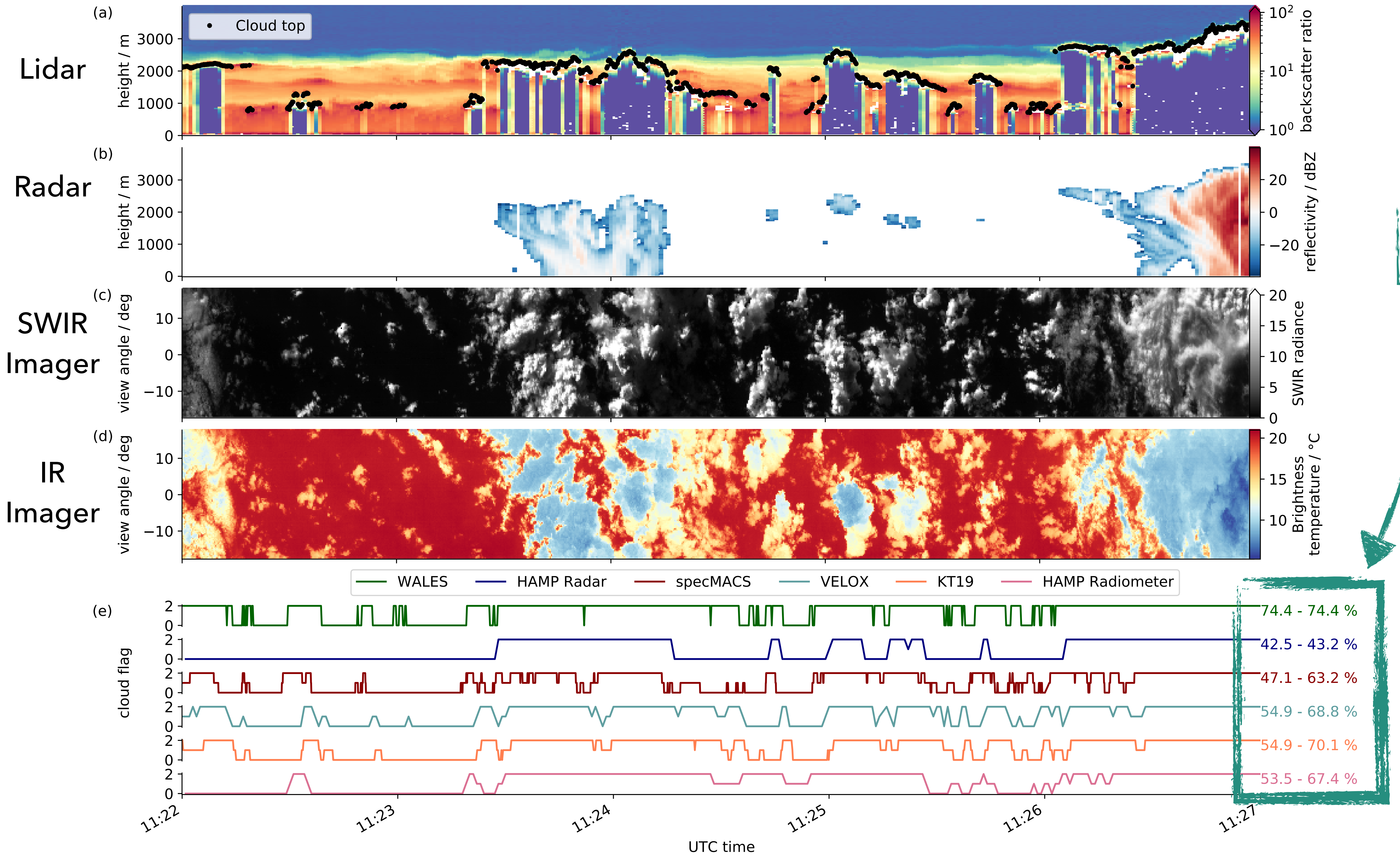
Do small clouds matter
in terms of their radiative effect?

30°N

Image credit: NASA Worldview (08 Feb 2021)

30°S

The issue with cloud fraction estimates



5 minutes of aircraft observations

Data from the EUREC4A field campaign:

Cloud fraction estimates differ by a factor of 2 between observation methods.

Possible reasons:

- data resolution
- applied thresholding tests
- wavelength and resulting sensitivity to clouds

Figure: from Konow et al., 2021 (in preparation)
Cloud information from different instruments during a HALO research flight on 05.02.2020. Panel (a) shows the lidar backscatter ratio at 1024 nm. (b) shows cloud radar reflectivity, (c) a horizontal view on the cloud field from an imager at 1.6~µm, and (d) from an IR imager (7.7~µm and 12~µm). Panel (e) shows a scalar cloud mask product along the flight path from six instruments.

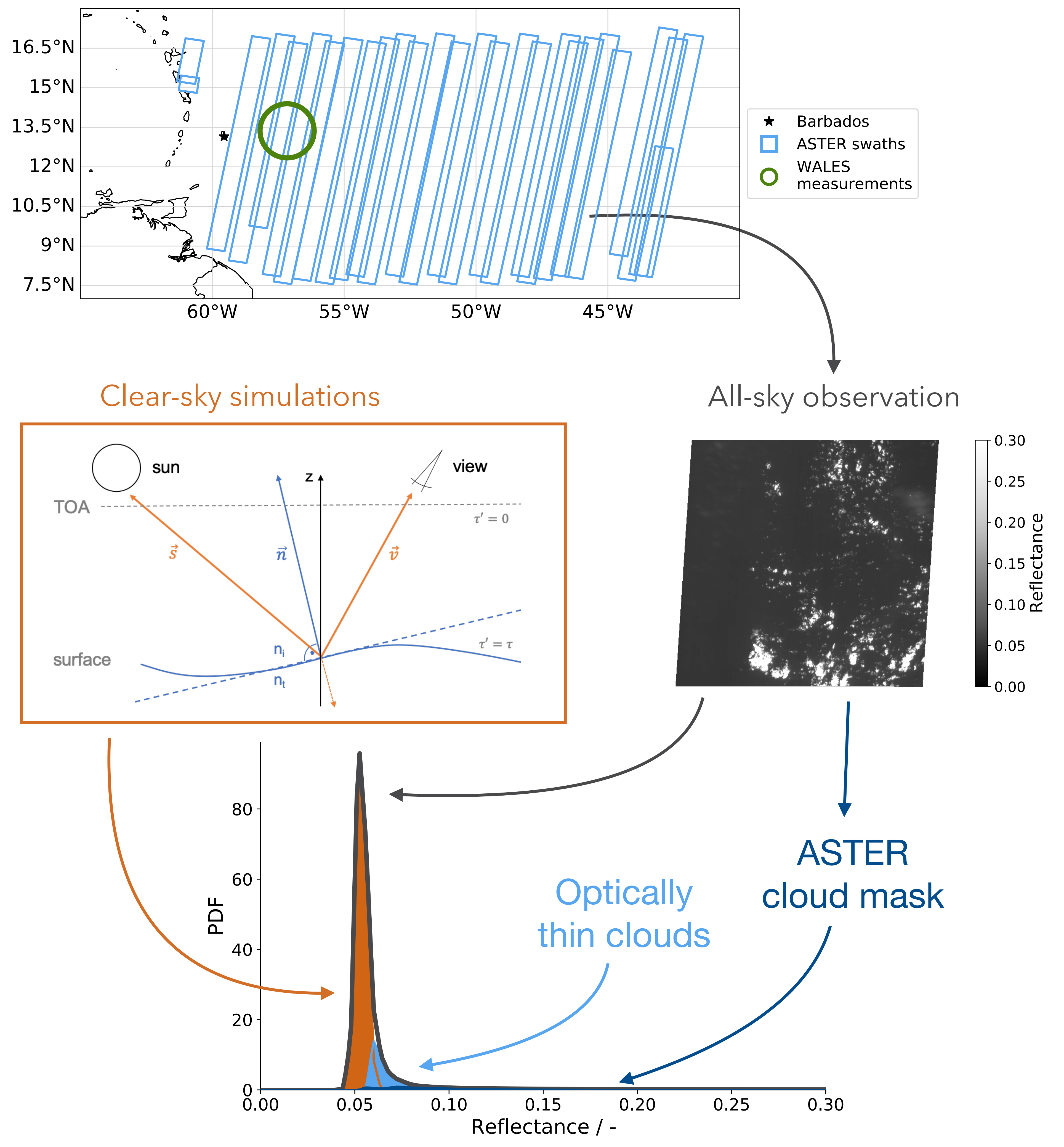
Our approach on quantifying clouds

We develop a method to quantify the total cloud cover in ASTER satellite images from a clear-sky perspective.

1 We use high spatial resolution satellite images from ASTER

2 We run radiative transfer simulations to identify the clear-sky contributions to an observed all-sky observation

3 Knowing the clear-sky part, we can investigate the remaining cloud-related contributions.



Our approach on quantifying clouds

We develop a method to quantify the total cloud cover in ASTER satellite images from a clear-sky perspective.

1 The Advanced Spaceborne Thermal Emission and Reflection Radiometer ASTER

- Imager on board TERRA
- high spatial resolution of 15 m pixel in the VNIR bands.
- We use the band 3 reflectance at 0.807 µm and derive an ASTER cloud mask following Werner et al., 2016.
- EUREC4A dataset: 412 images in 27 overpasses between 11 Jan and 19 Feb 2020

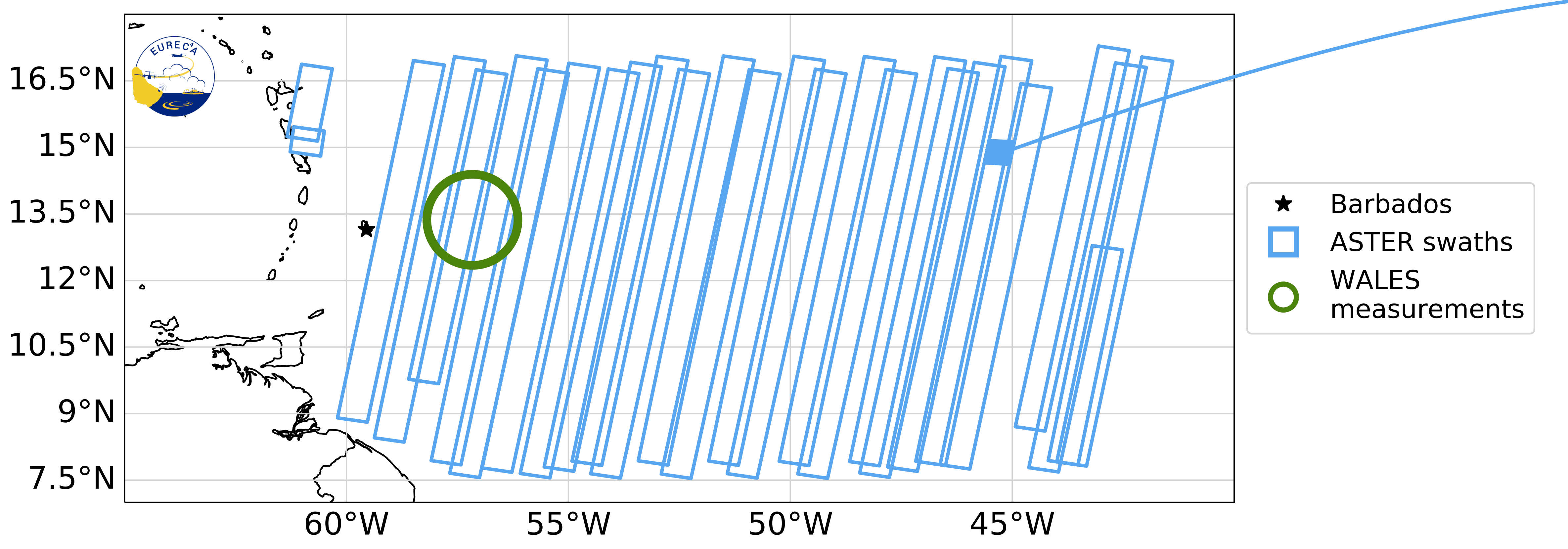


Figure left: ASTER dataset during EUREC4A with 412 images (60km x 60km) recorded on 27 days in January and February 2020. WALES lidar measurements are available from HALO's research flights predominantly on the circular path shown in green from 13 flight days between January 22 and February 15.

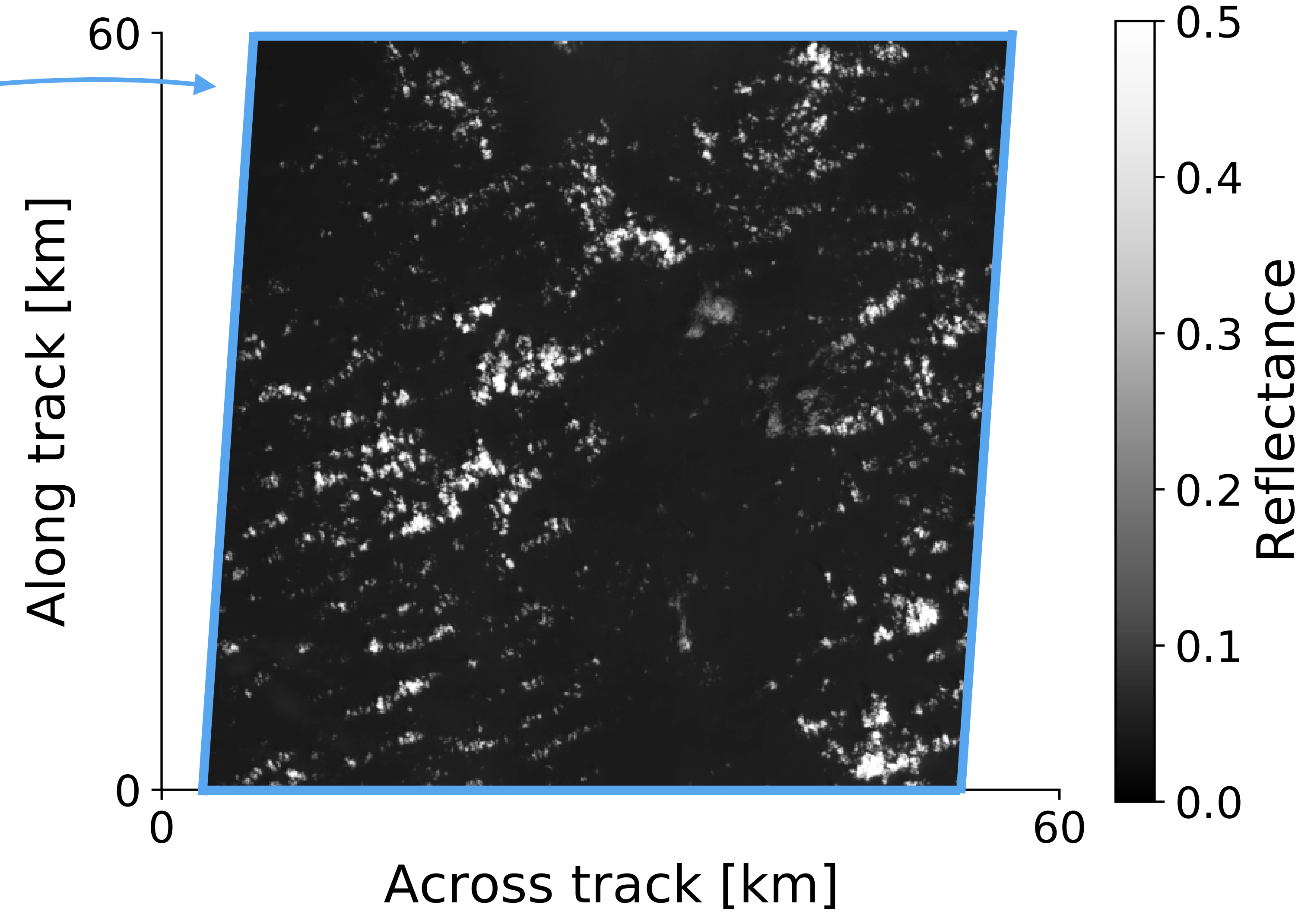


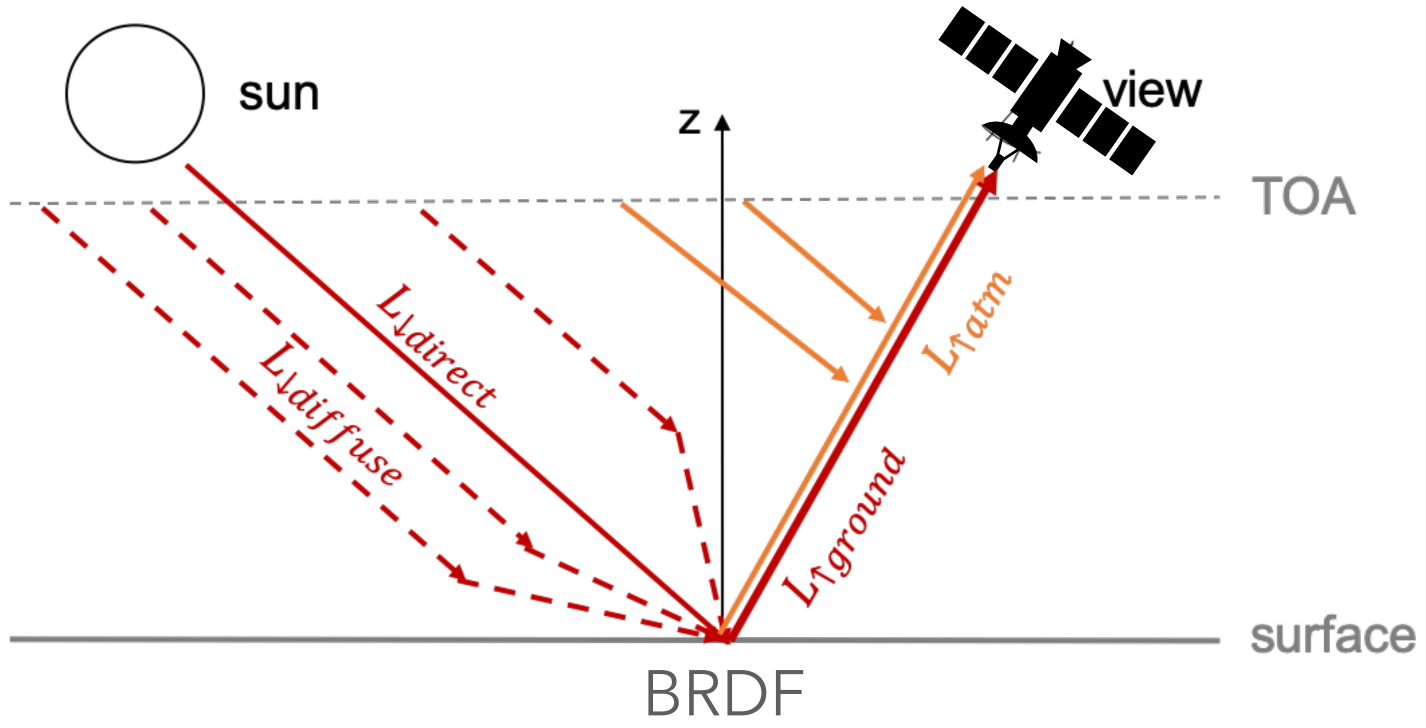
Figure right: ASTER sample image recorded in the visual near-infrared range at 0.807 µm and at 15 m pixel resolution

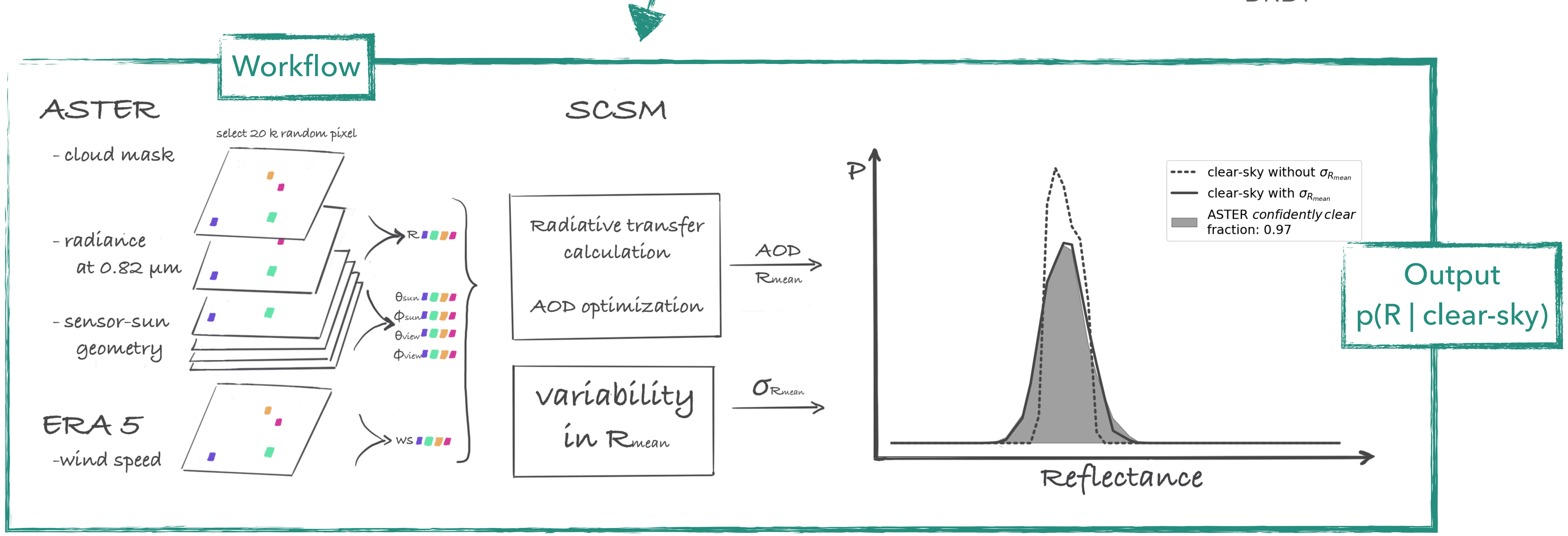
Our approach on quantifying clouds

We develop a method to quantify the total cloud cover in ASTER satellite images from a clear-sky perspective.

2 We build a simplified clear-sky model (SCSM)

including a surface parameterisation and single scattering events in the atmosphere and simulate the clear-sky reflectance distribution to an ASTER observation [Stamnes et al., 2017; Cox and Munk, 1954].





Our approach on quantifying clouds

We develop a method to quantify the total cloud cover in ASTER satellite images from a clear-sky perspective.

3 Knowing the clear-sky part, we can investigate the remaining cloud-related contributions consisting of areas detected by common cloud masking algorithms and those undetected areas related to optically thin clouds.

Advantage of this approach

- clear/cloudy decision not needed for individual pixels
- We can derive cloud cover and expected cloud reflectance directly from the PDFs

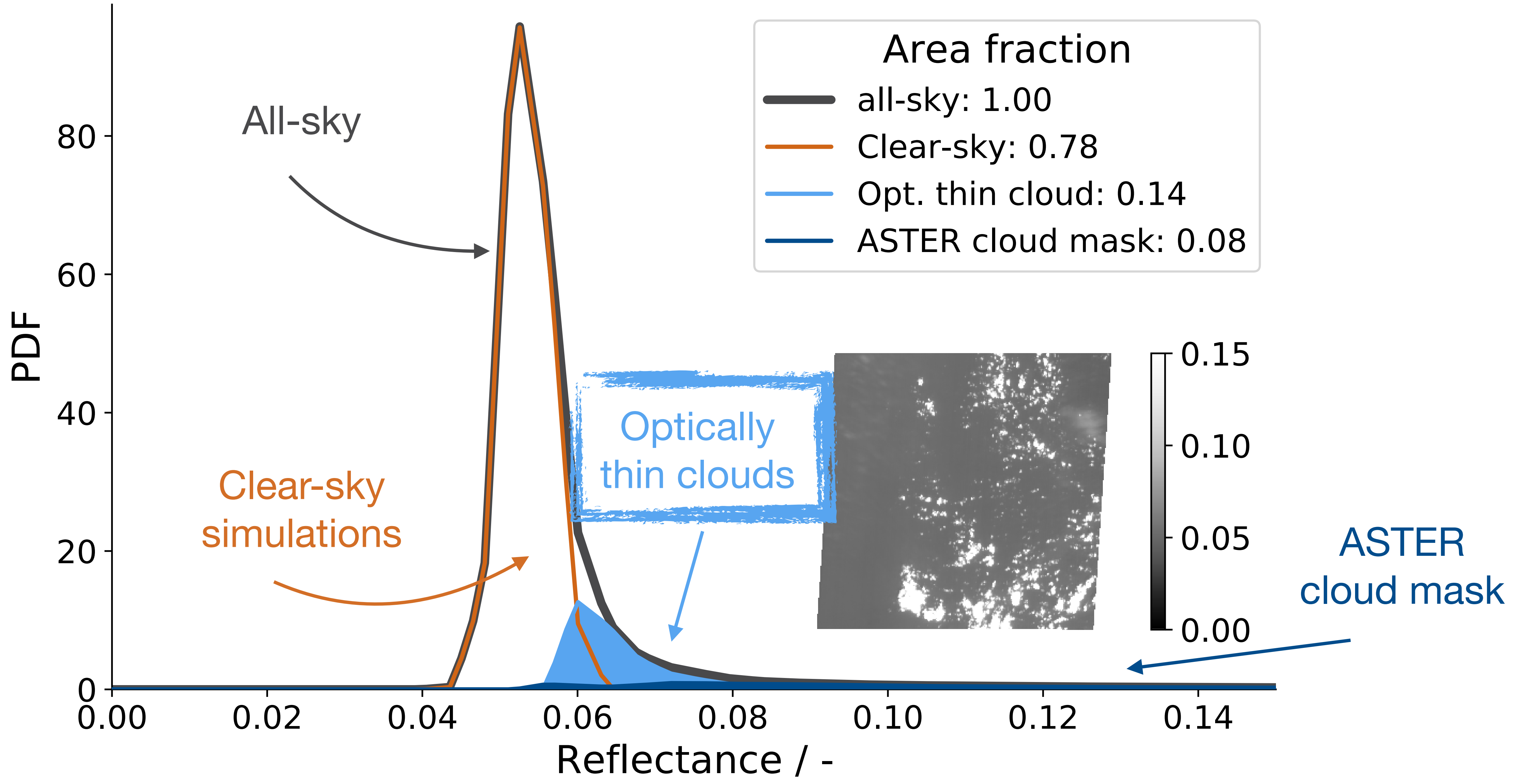
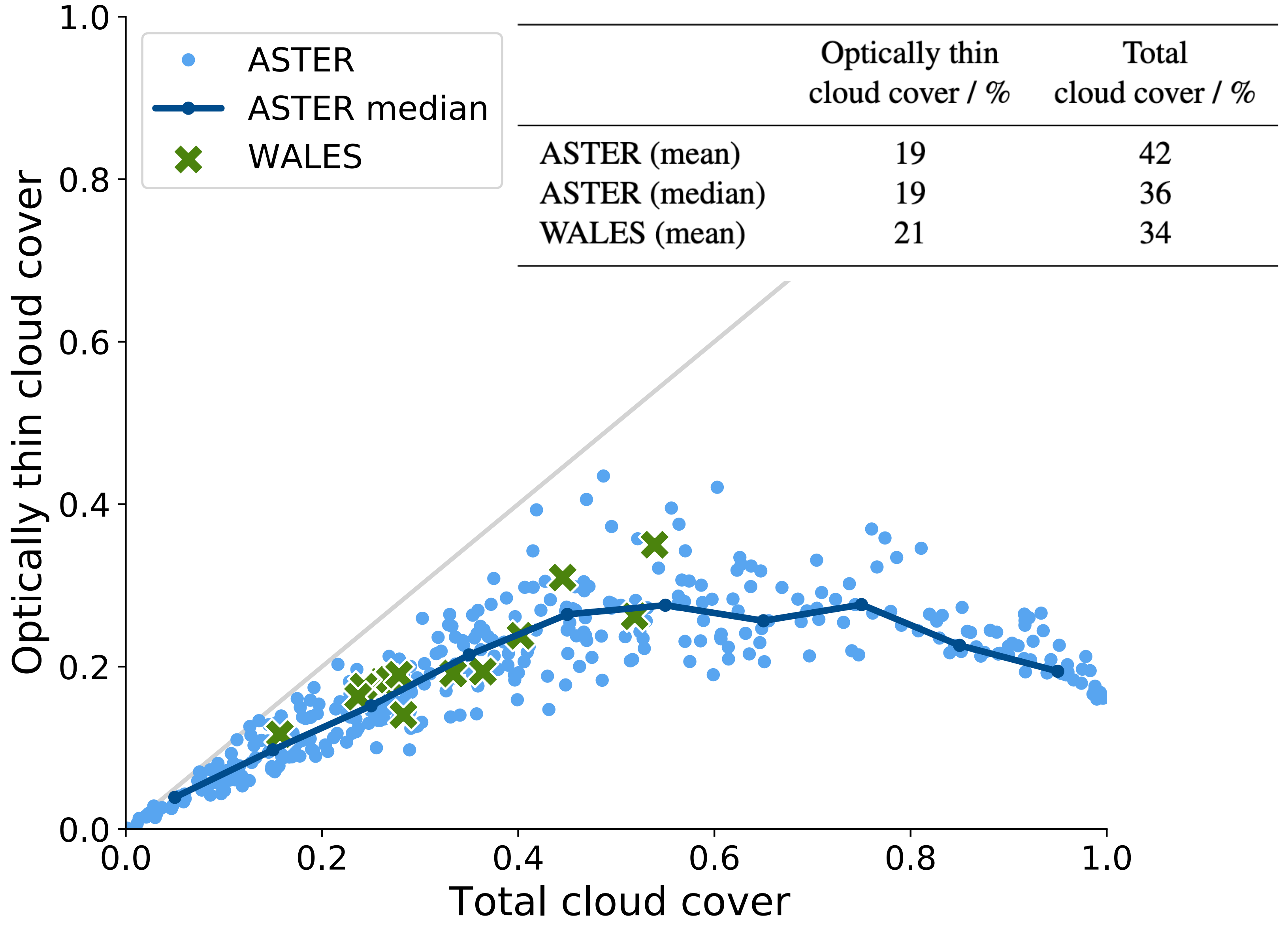


Figure: Reflectance distribution corresponding to the ASTER observation shown in the inset figure recorded on 31 January 2020,14:08:05 UTC. The information from the simulated clear-sky probability distribution is translated to the all-sky observations. We derive the combined probability distribution of clear-sky reflectance pixels and subtract the clear-sky and the ASTER cloud mask distributions from the all-sky to get the reflectance distribution that we attribute to optically thin clouds.

The contribution of optically thin clouds to the total cloud cover and cloud reflectance

The ASTER cloud-mask underestimates the total cloud cover by a factor of 2.

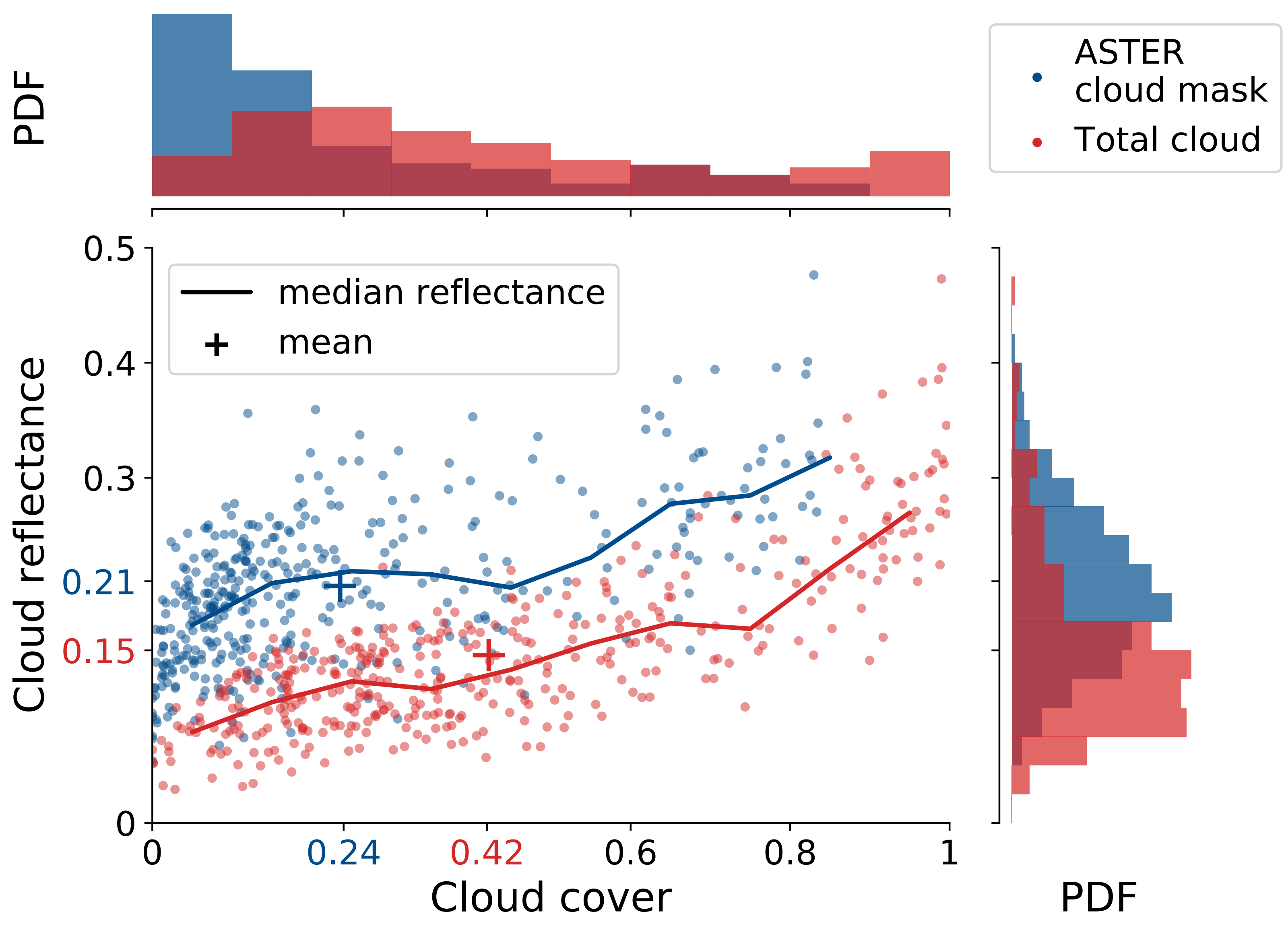
The known “too few, too bright” bias in models might be even higher than assumed so far.



	Optically thin cloud cover / %	Total cloud cover / %
ASTER (mean)	19	42
ASTER (median)	19	36
WALES (mean)	21	34

Figure right: Expected cloud reflectance corresponding to the ASTER cloud mask (blue) and the derived total cloud cover including optically thin clouds (red) from 395 ASTER images. The median cloud reflectances are given by the lines and the dataset averages are visualised by the “+” marker and the respectively coloured tick labels. The frequency distributions of cloud cover and cloud reflectance are shown in the panels on the top and right respectively.

Figure left: Change in optically thin cloud cover with total cloud cover, i.e. the combination of clouds detected by the ASTER cloud mask and undetected optically thin clouds. The blue markers correspond to values derived from 395 ASTER images with the dark blue line following along the median values. The green markers correspond to daily-averaged cloud cover estimates from WALES lidar measurements. Optically thin clouds are those with a derived cloud optical thickness below 2.



Implications for aerosol-cloud interaction studies

- Indirect aerosol effects:
  - aerosols can increase the cloud's life time and thus lead to a positive correlation between AOD and cloud cover [Albrecht, 1989]
  - aerosols can increase the cloud brightness (Twomey effect) [Twomey, 1989]

- The positive correlation in optically thin cloud cover and detected clouds in the current study suggests that part of the proposed sensitivity of cloud cover to AOD might reflect a high bias in clear-sky estimates that is interpreted as high AOD.

- Increasing cloud brightness with higher AOD likely increases the probability of undetected and optically thin clouds identified in the current study to cross the detection threshold of common cloud masking schemes.

Undetected optically thin clouds
can cause artificial correlation between AOD and cloud cover

Implications for cloud radiative effect estimates

What happens if the clear-sky signal is contaminated by optically thin clouds?

Cloud radiative effect:

$$CRE = F_{\mathrm{ALL}} - F_{\mathrm{CLEAR}}$$

CRE bias due to optically thin clouds:

$$\Delta CRE = \frac{CRE_{\mathrm{CLEAR+OTC}} - CRE_{\mathrm{CLEAR}}}{CRE_{\mathrm{CLEAR}}} \rightarrow \Delta\mathrm{CRE} = -32\ \%$$

Undetected optically thin clouds can lead to an underestimation of the cloud radiative effect

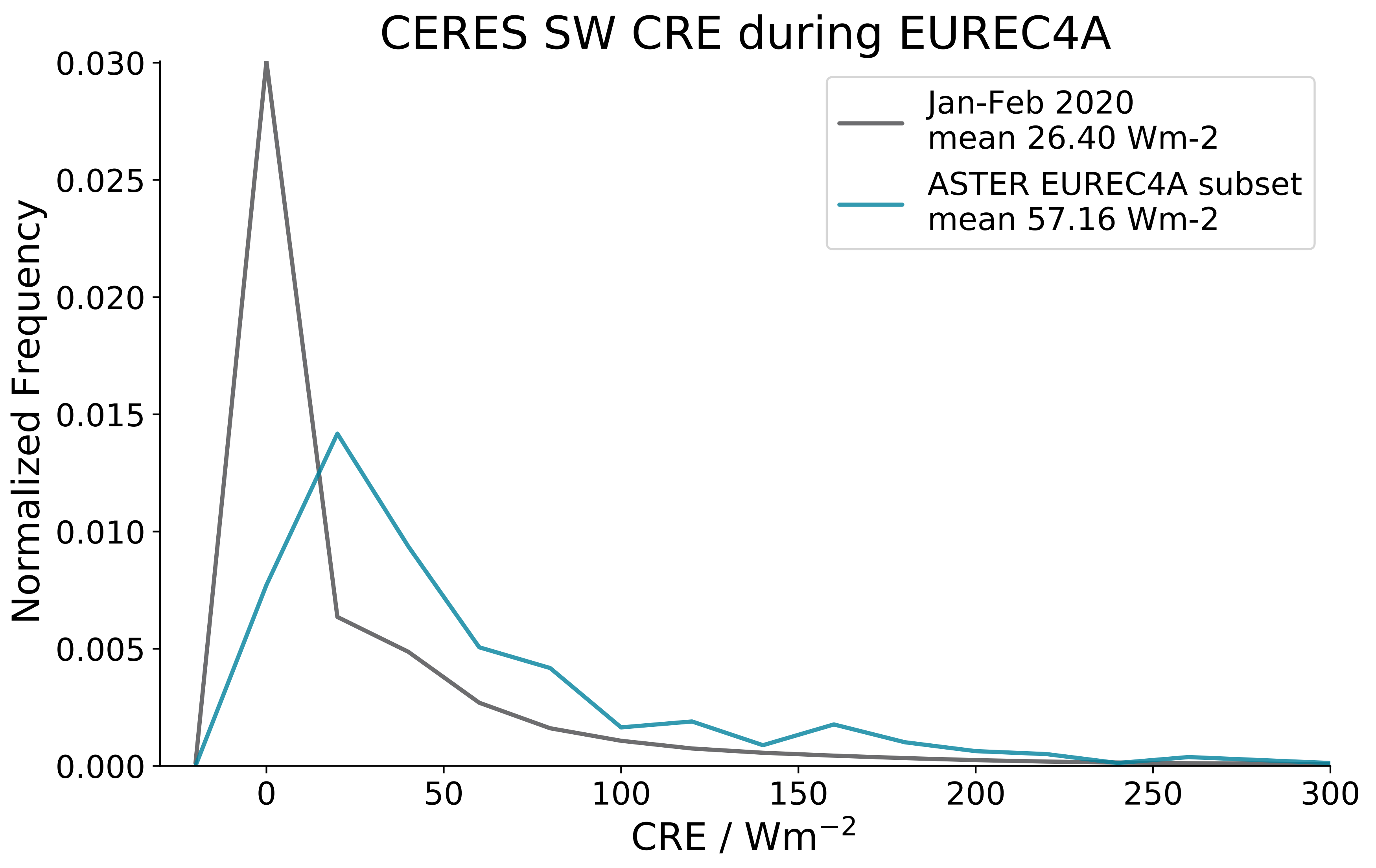
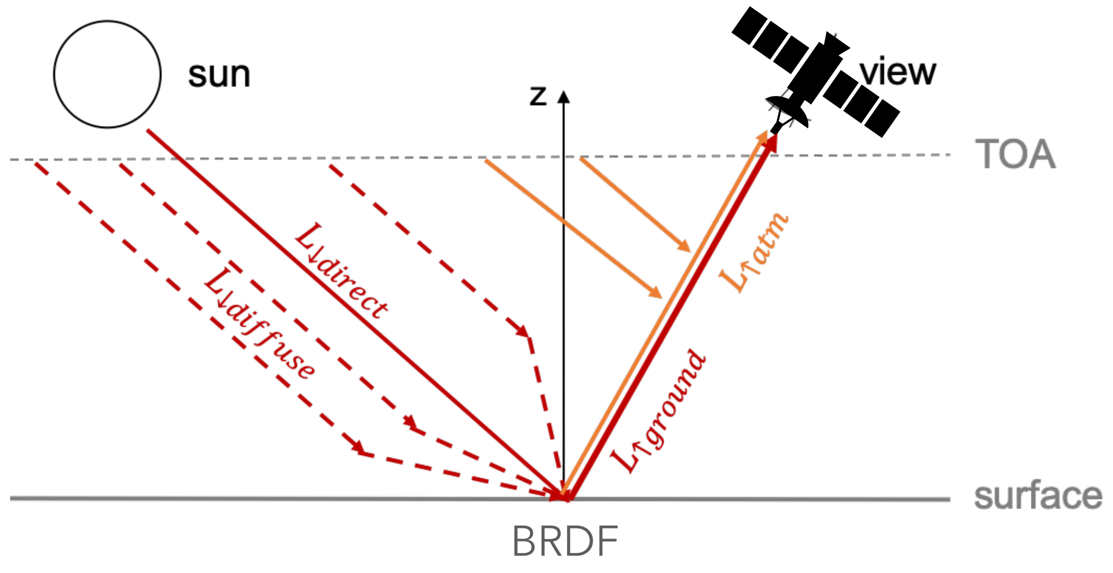
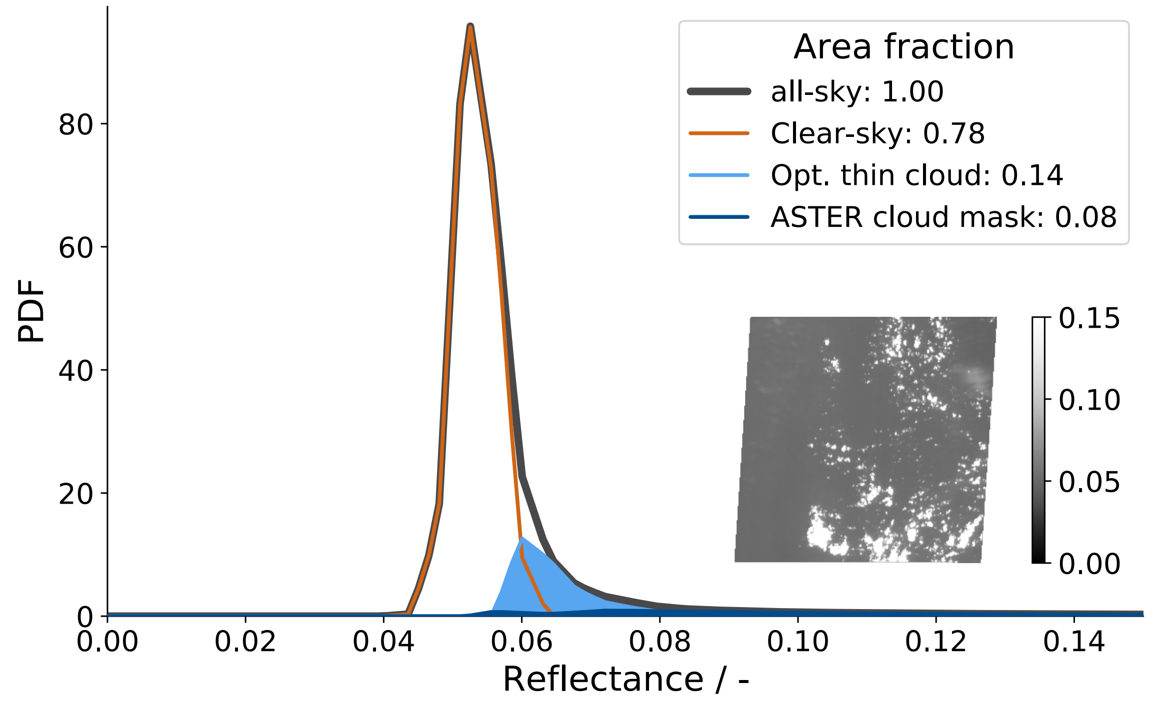


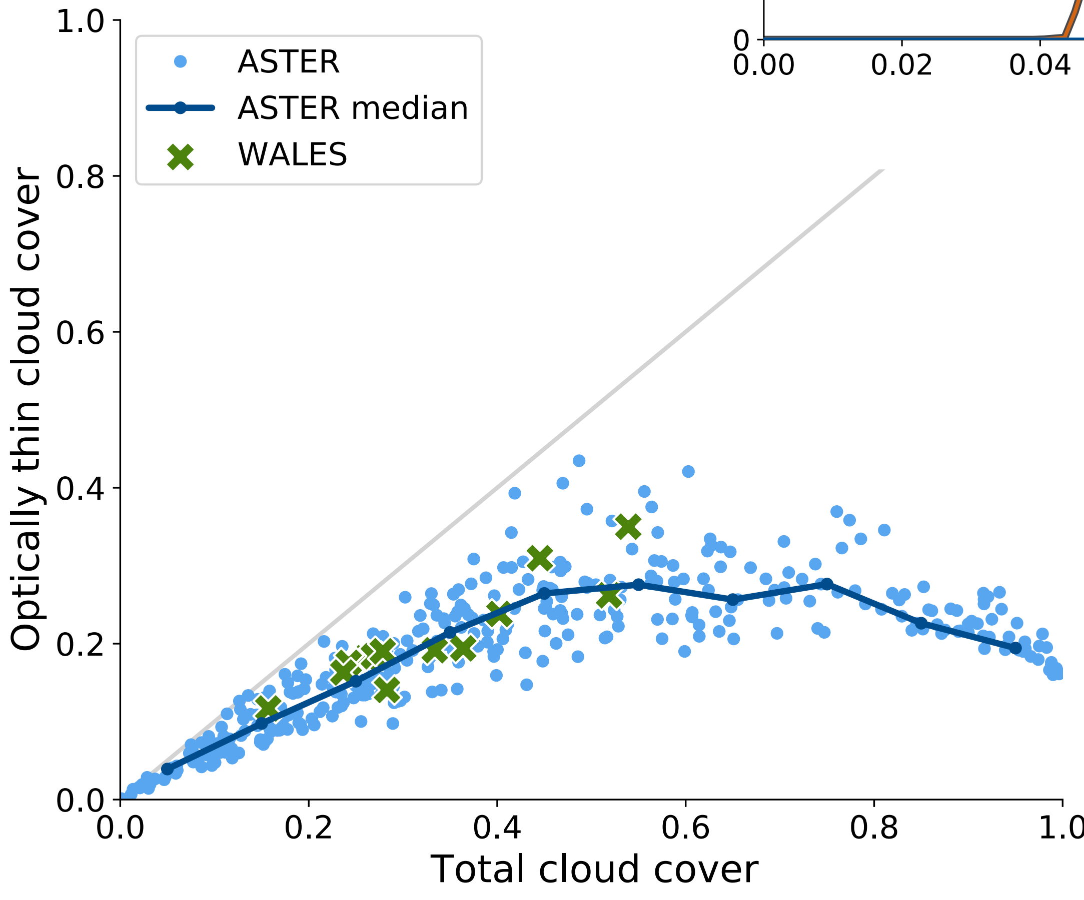
Figure 1: CERES (hourly SYN1deg) short-wave cloud radiative effect estimates for January and February 2020 in the area of the EUREC^{4}A field campaign. The grey line corresponds to all time steps, while the blue shows ASTER - CERES collocations that are only during daytime.

Summary and Conclusion

- We develop a new method to describe the total cloud cover including optically thin clouds in trade wind cumulus cloud fields.
- We find that the cloud cover derived from common satellite cloud masking algorithms underestimates the total cloud cover by a factor of 2.
- Our analysis suggests that the known underestimation of trade wind cloud cover and simultaneous overestimation of cloud brightness in models is even higher than assumed so far.
- Undetected optically thin clouds might lead to an underestimation of the cloud radiative effect and cause artificial correlations in aerosol-cloud cover interaction studies.







Thank you for listening!