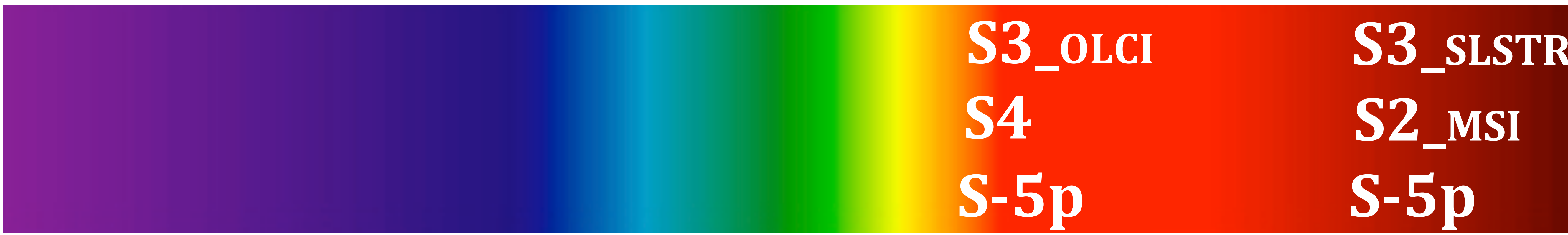
(Part 1)
Algorithm development

Profile of effective droplet radius
Ice optical thickness and effective radius
Aerosol-contaminated clouds
0.67, 0.87, 1.24, 1.6, 2.1 μm



(Part 2)
Verification of Aerosol and Cloud for Sentinel-5 Precursor

755-775 nm
Aerosol layer height
Cloud top height
Cloud optical thickness

Credits

IUP Bremen

L. Lelli, L. Mei, V.V. Rozanov, M. Vountas,
A.A. Kokhanvosky, M. Jaeger, J.-P. Burrows

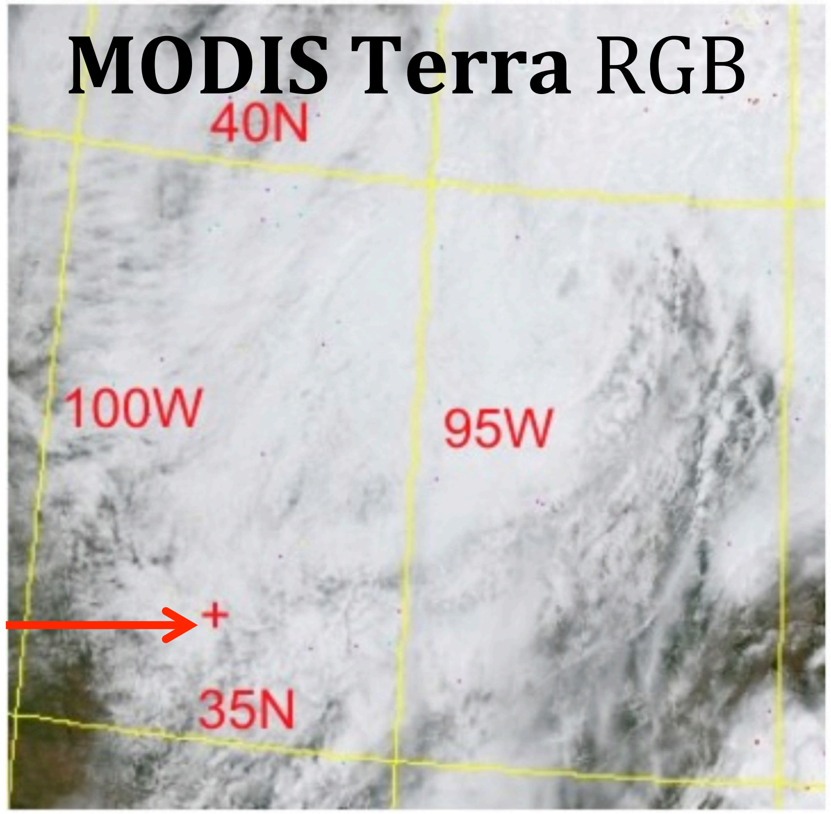
DLR Oberpfaffenhofen

S. Gimeno-Garcia, R. Lutz, D. Loyola

KNMI De Bilt

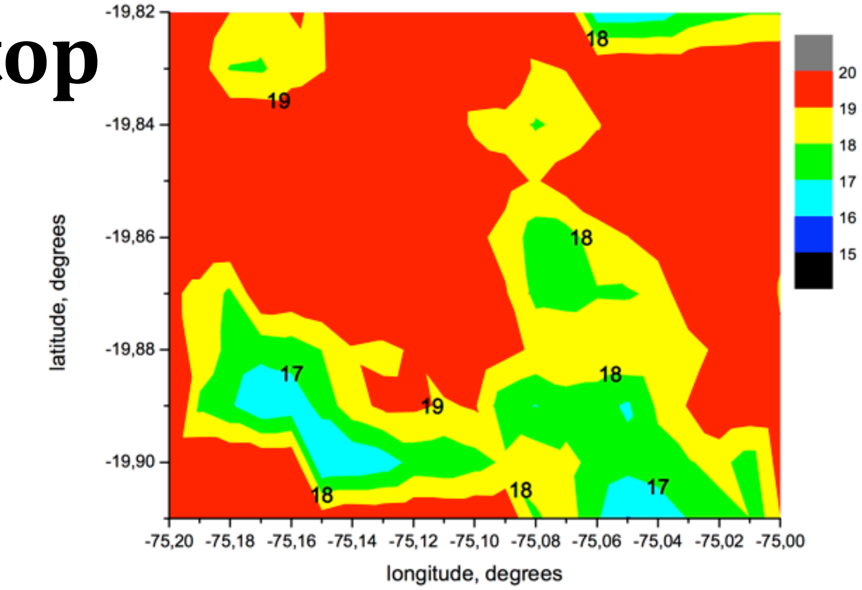
A.F.J. Sanders, M. Sneep, O. Tuinder

Profile of effective cloud droplet radius

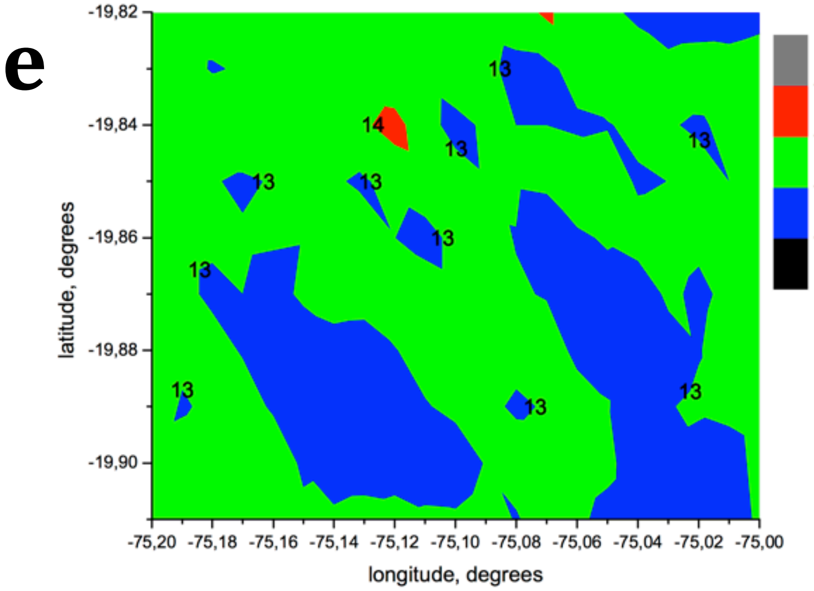


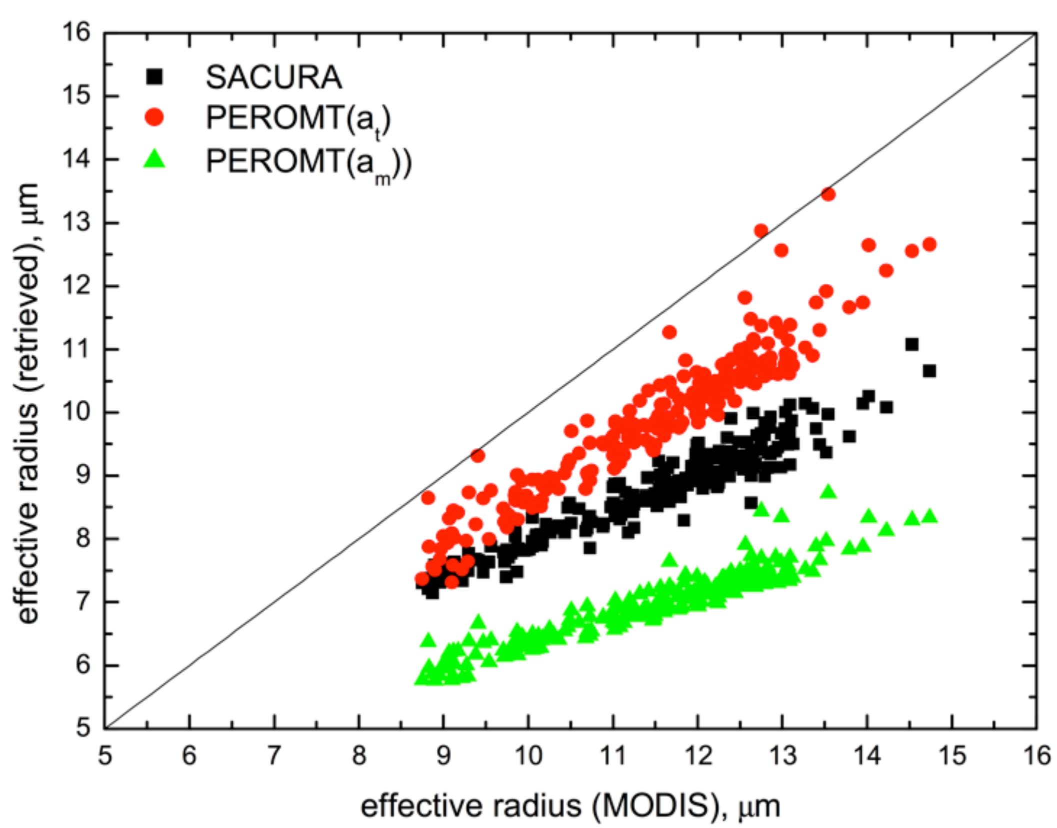
ARM site

Cloud top

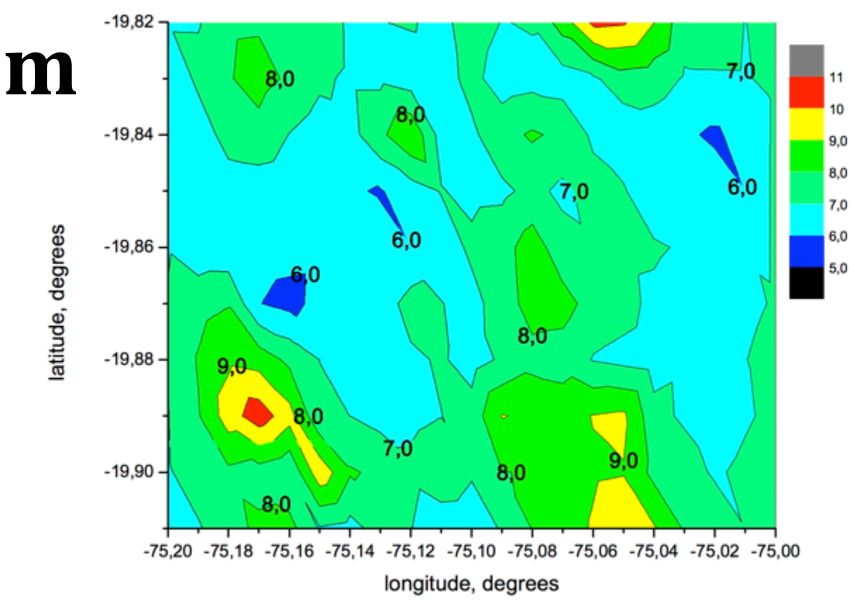


middle



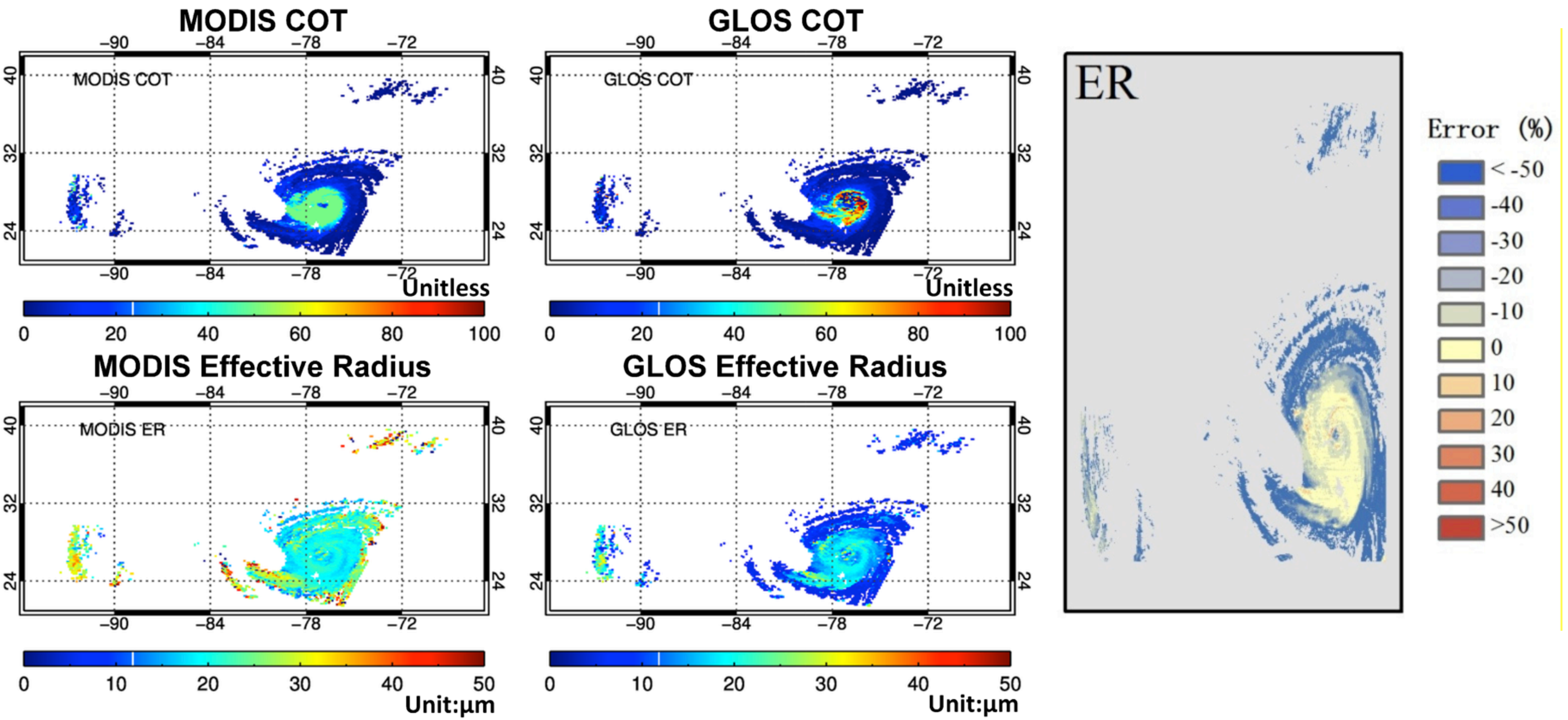


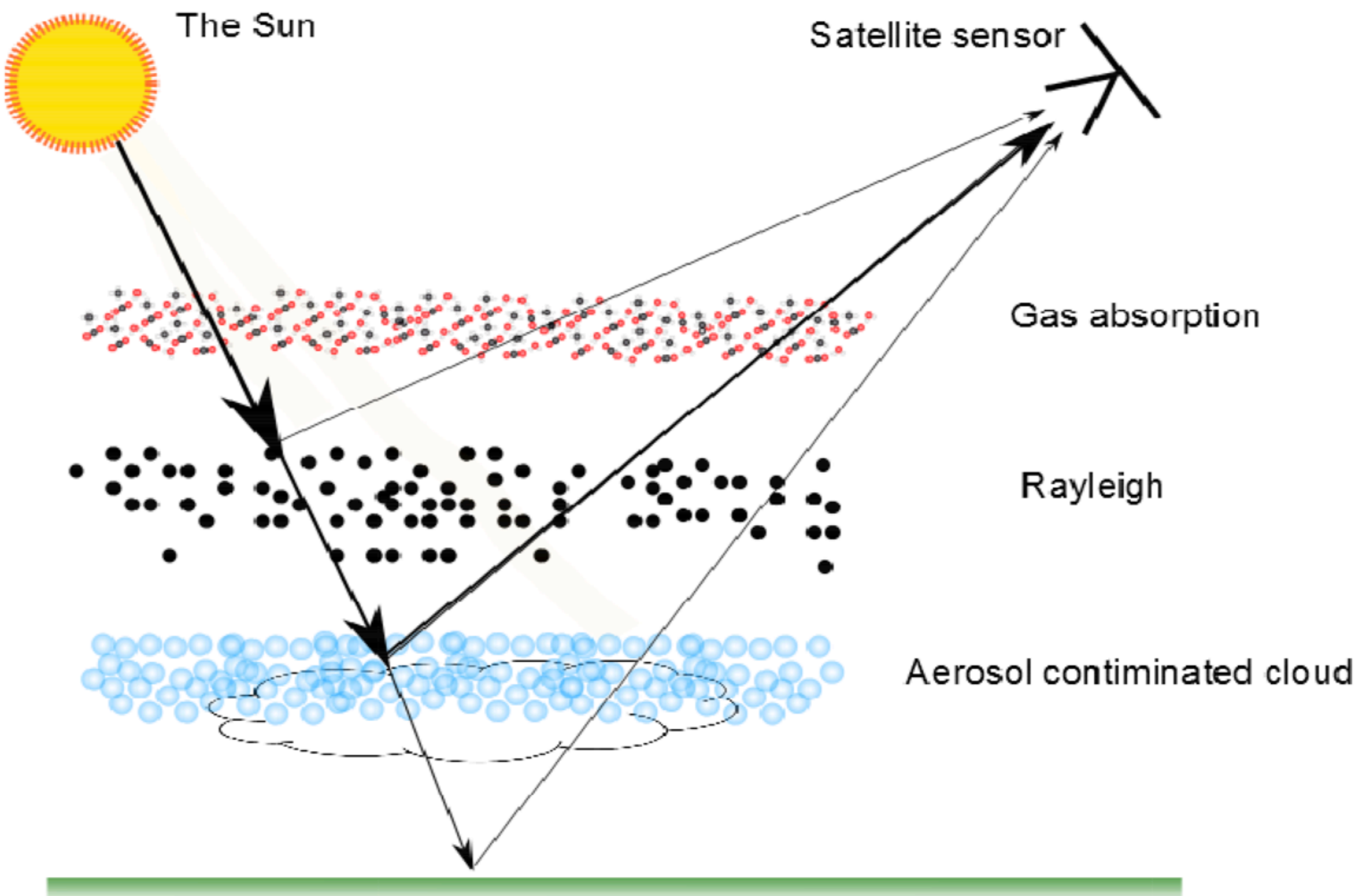
bottom



Ice optical thickness and radius

MODIS Collection 06



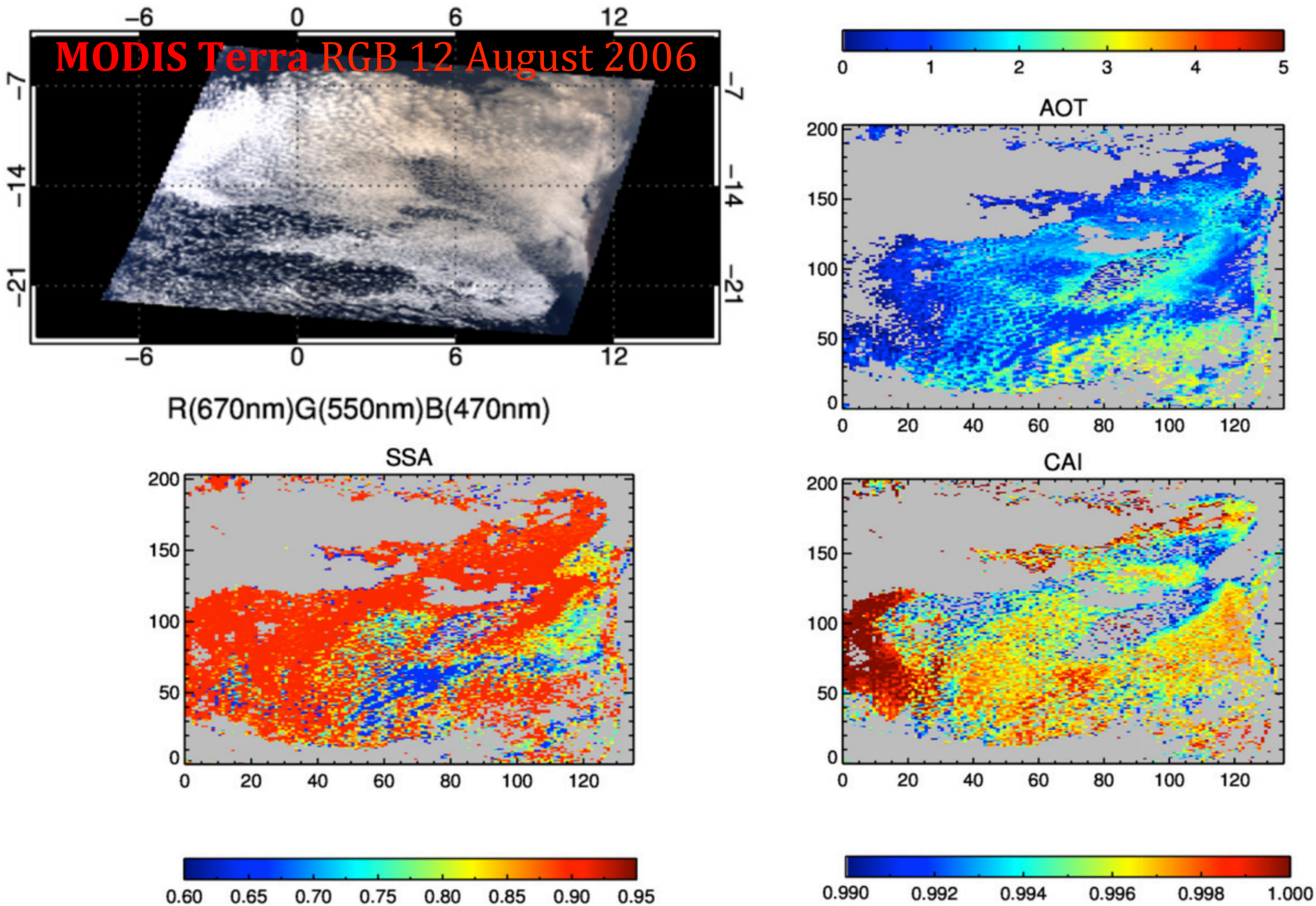


Cloud regarded as a *block* of pure water droplets and aerosol particles

Cloud Absorbing Index

$$\mathrm{CAI} = \frac{\tau_{\mathrm{cloud}} + \omega_{\mathrm{aer}}\,\tau_{\mathrm{aer}}}{\tau_{\mathrm{cloud}} + \tau_{\mathrm{aer}}}$$

Aerosol-contaminated clouds



Goals of aerosol verification for TROPOMI on Sentinel-5 precursor

Assess feasibility of using the oxygen A-band to retrieve height of aerosol layers and applicability to various aerosol types.

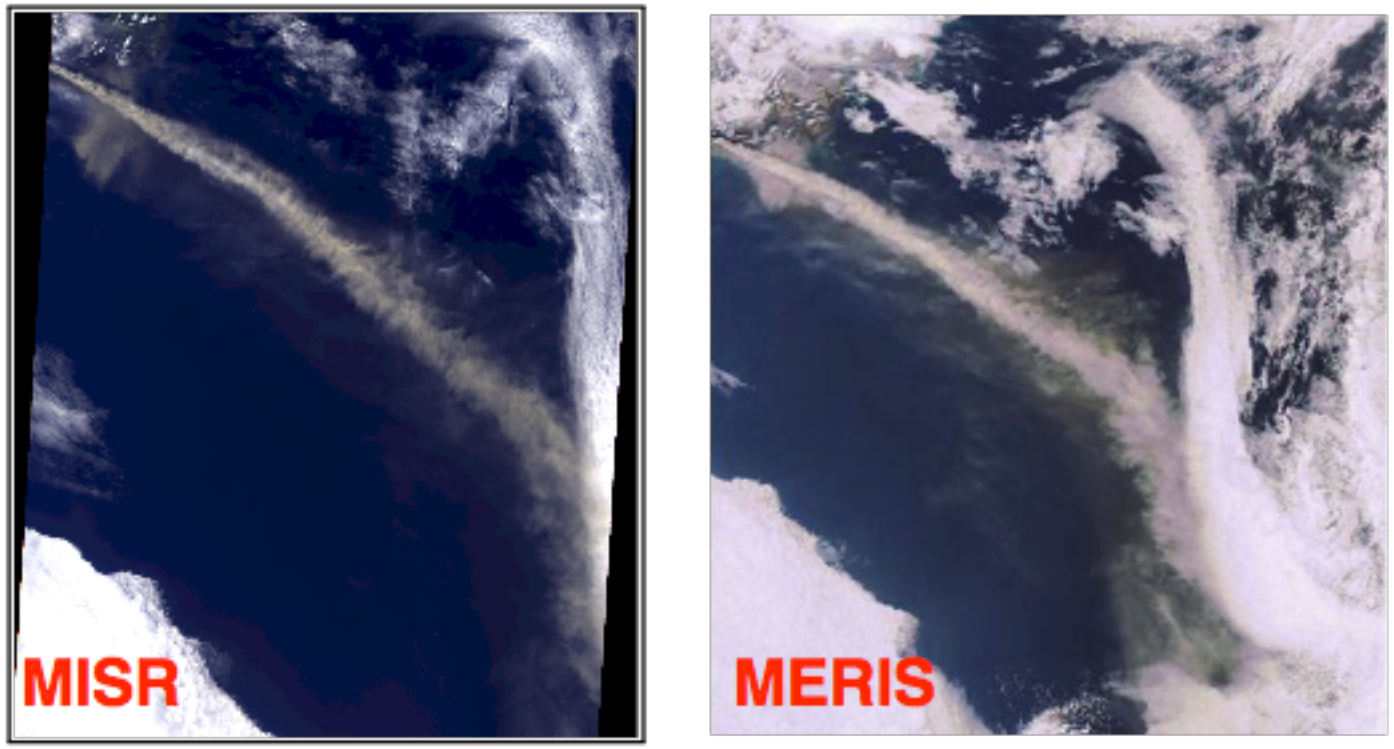
Algorithms (O_2A-band 755-775 nm)

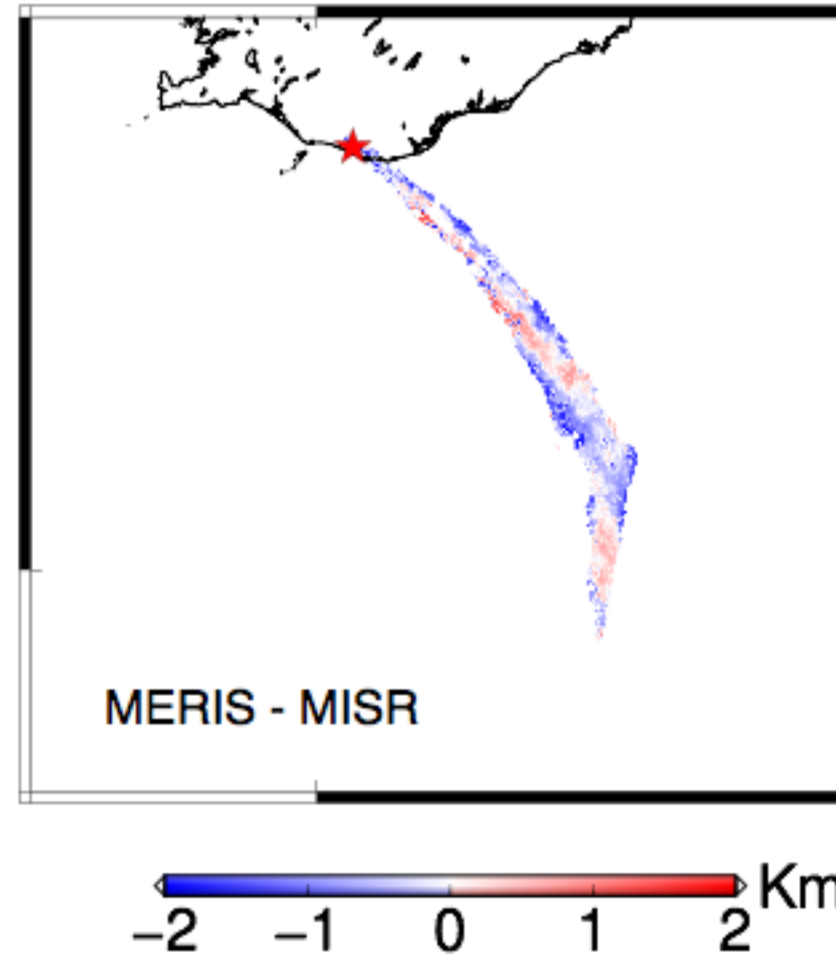
- **Prototype**: **DISAMAR (KNMI)**
  Aerosol model: H-G with g = 0.7 and SSA = 0.95
  Profile parameterization: elevated scattering layer with assumed geom. thickness
  2-parameter retrieval: AOT and aerosol layer height

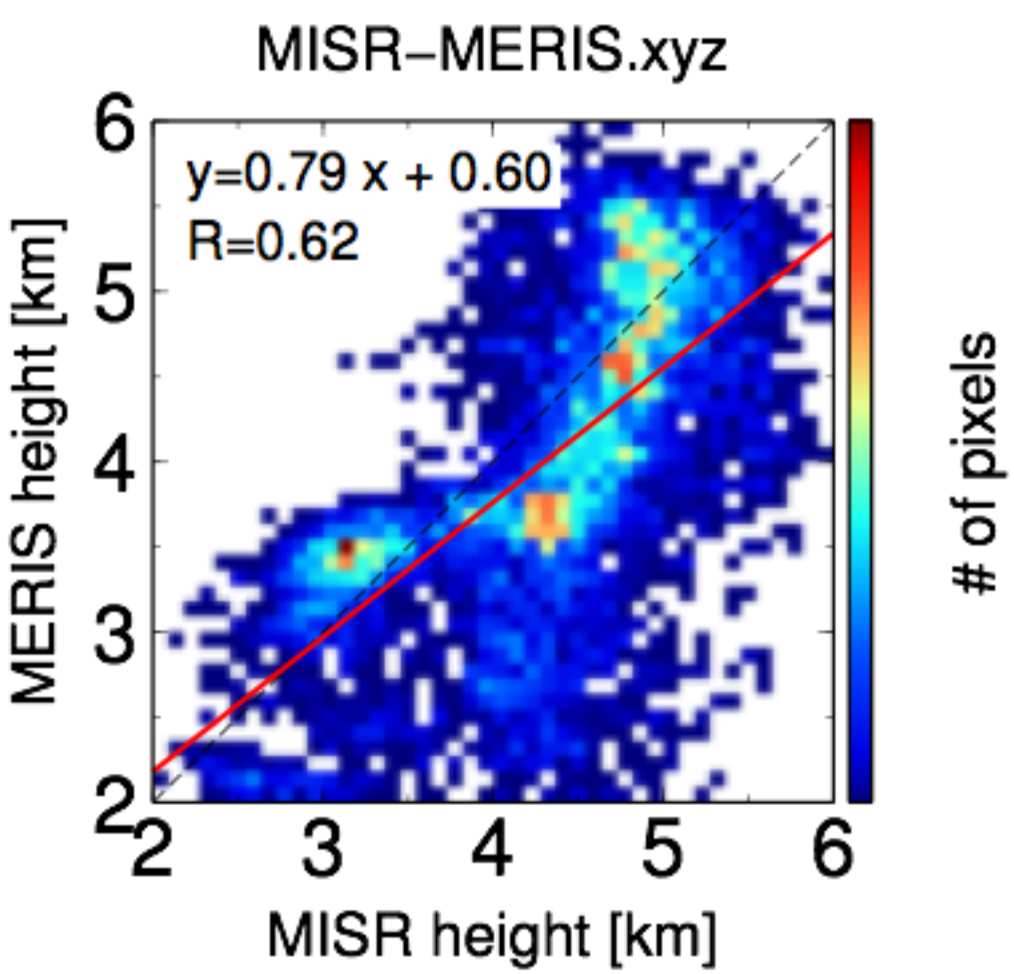
  See poster 31 (and paper on S-5p special issue on AMT):
  Sanders, A.F.J. et al.: "Operational aerosol products for Sentinel-5 Precursor: Aerosol Layer Height and UV Aerosol Index"

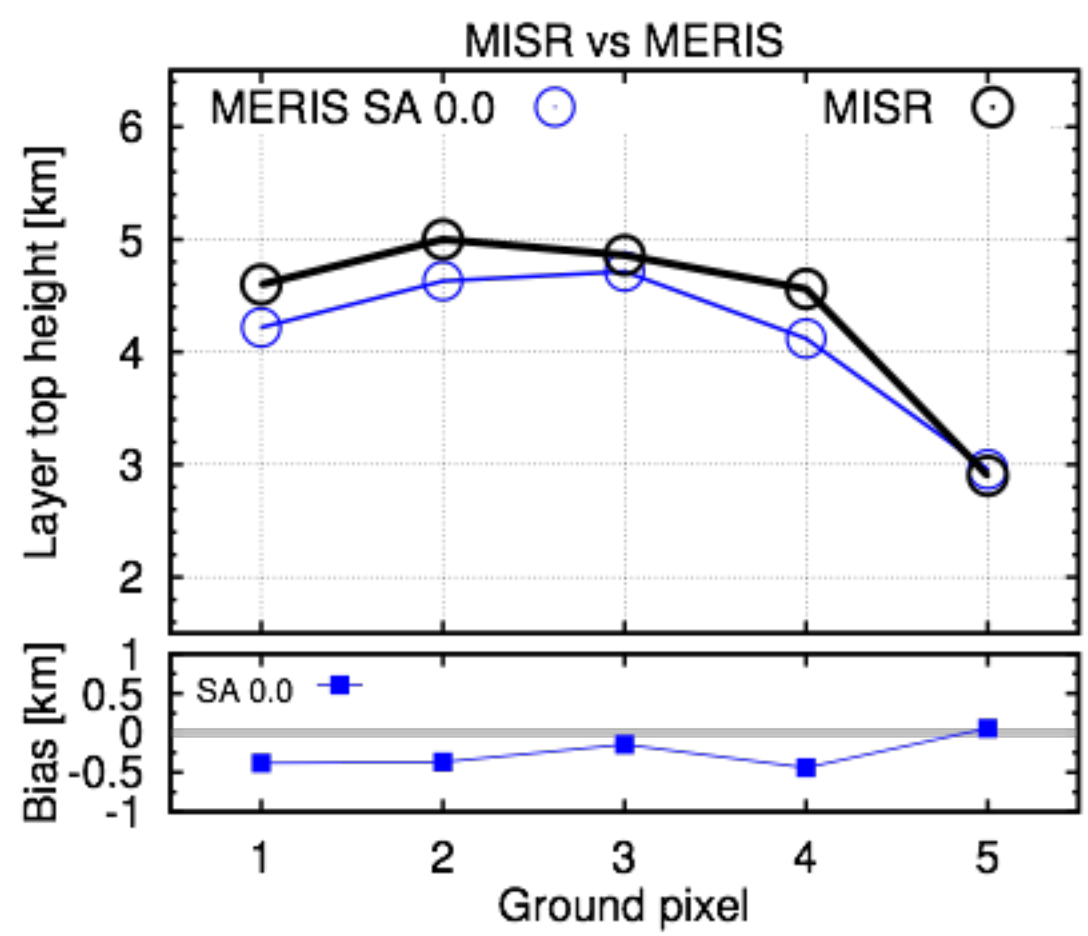
- **Verification**: **SACURA and (planned) SCIATRAN-OE (IUP-Bremen)**
  Heritage of cloud retrieval, based on analytical parameterization of RT in the geometric optics limit.
  Aerosol model: Mie, AERONET climatology (Dubovik, 1996; Muñoz, 2002)

Eyjafjallajökull 7 May 2010

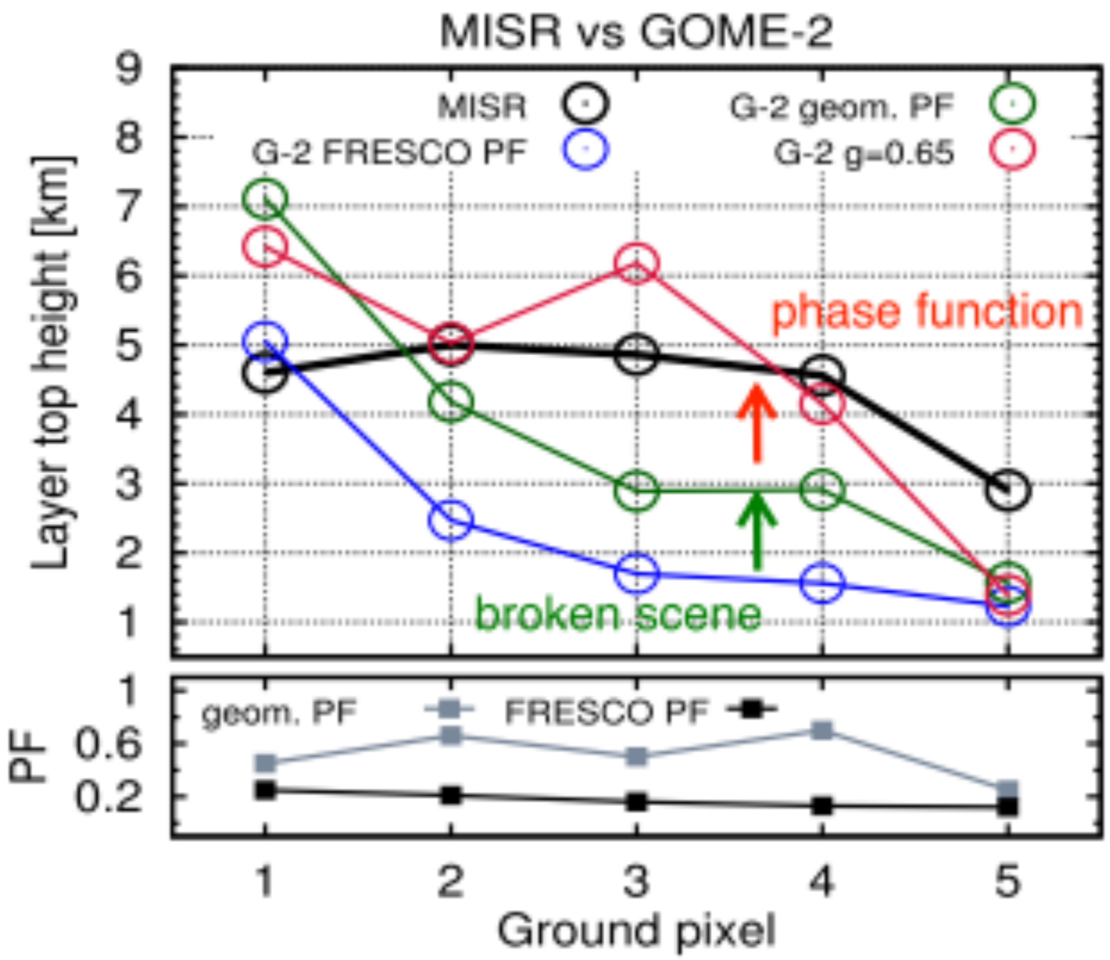


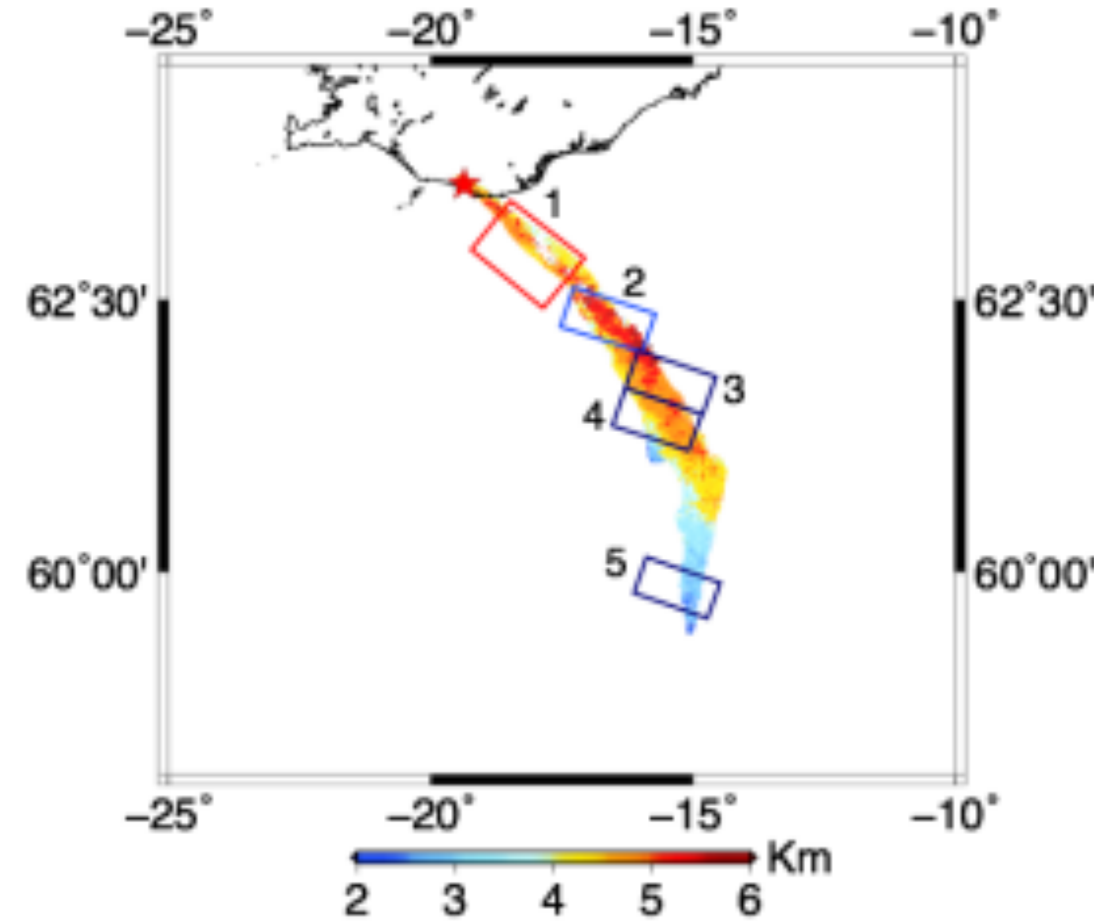


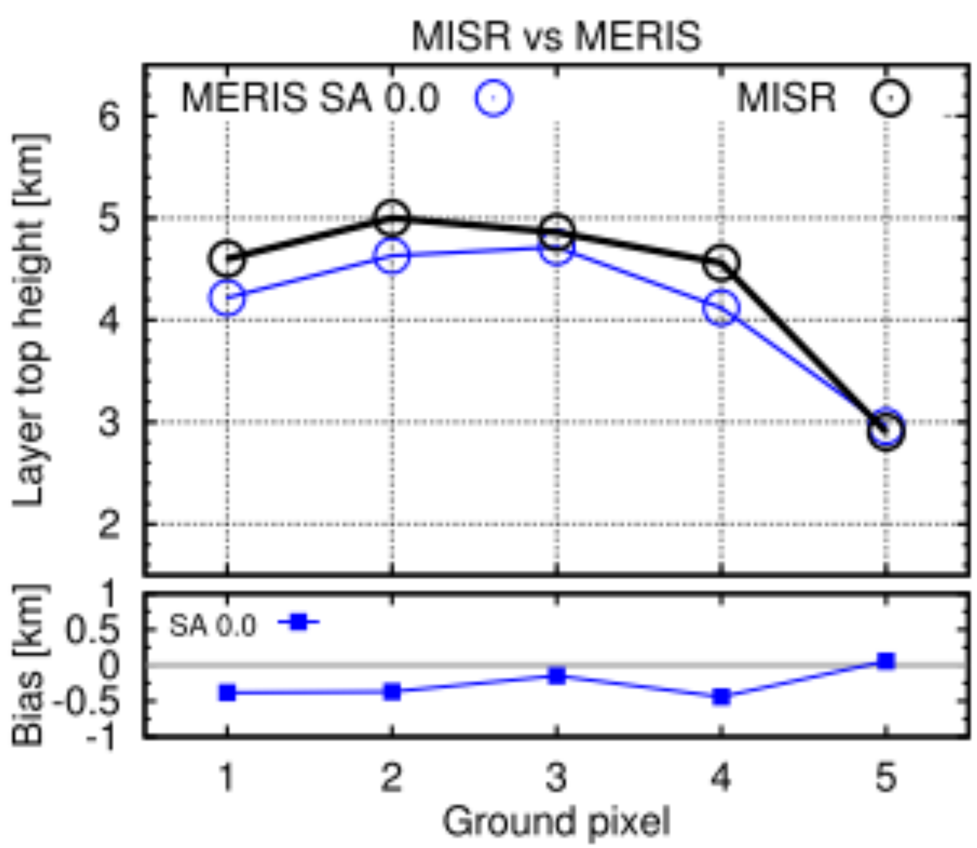


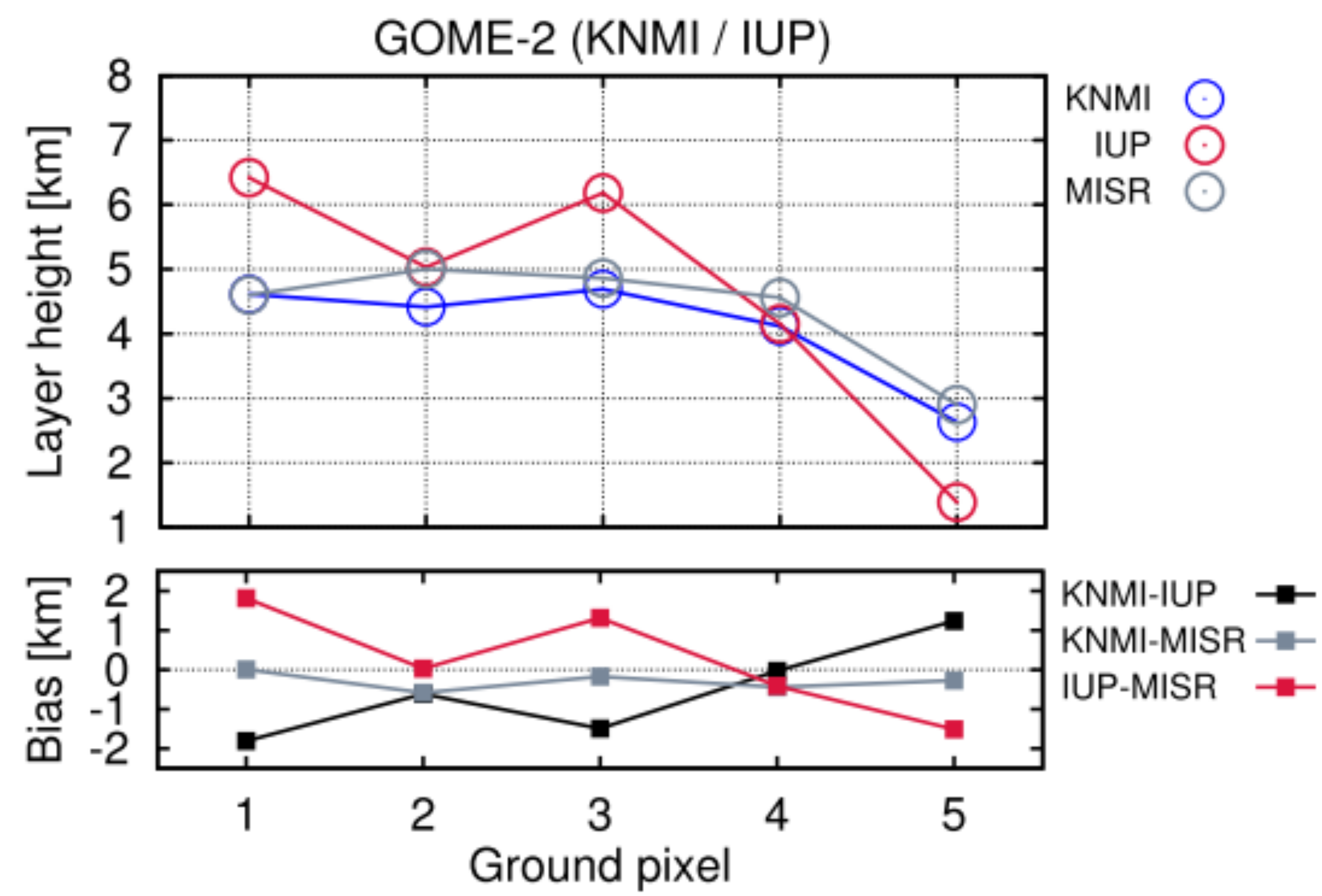


Eyjafjallajökull 7 May 2010









Goals of cloud verification for TROPOMI on Sentinel-5 precursor

Assess biases in
- **Cloud height** with clouds as scattering instead of ideal Lambertian layers
- **Cloud optical thickness / albedo**

Algorithms (O_2A-band 755-775 nm, IPA Marshak et al., 1995)

- **Prototype** (Lambertian & Scattering)**: ROCINN (DLR)**
  Retrieval of Cloud Information using Neural Networks
  (Loyola et al., 2007, 2010)

- **Verification** (Scattering): **SACURA (IUP-Bremen)**
  Semi-Analytical CloUd Retrieval Algorithm
  (Rozanov and Kokhanovsky, 2004; Lelli et al., 2012)

- **Additional** (Lambertian): **FRESCO (KNMI)**
  Fast Retrieval Scheme for Clouds from the O_2A-band
  (Koelemeijer et al., 2001; Wang et al., 2008)

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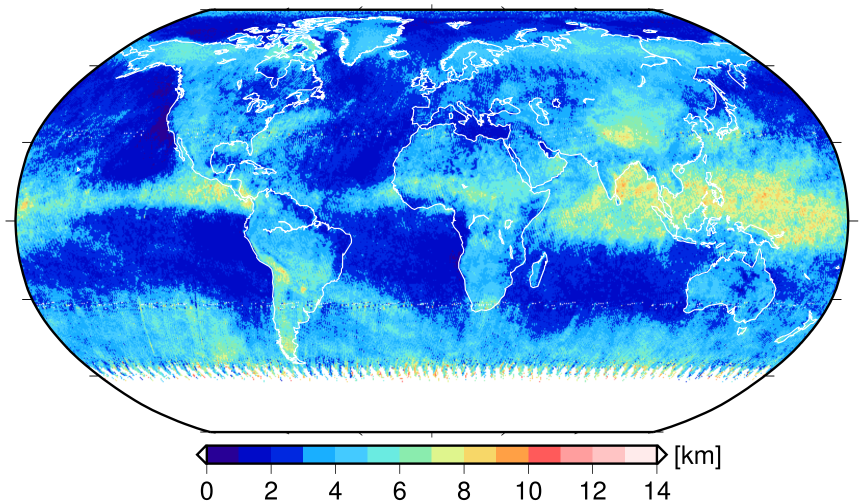
Example: GOME-2 Cloud height, July 2009

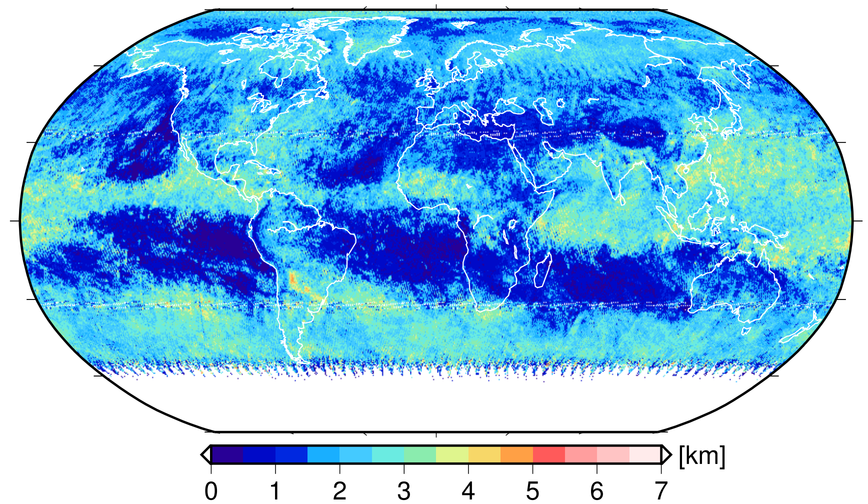
Mean CH

1-σιγμα CH

GOME−2 November 2009 CTH ROCINN (DLR)

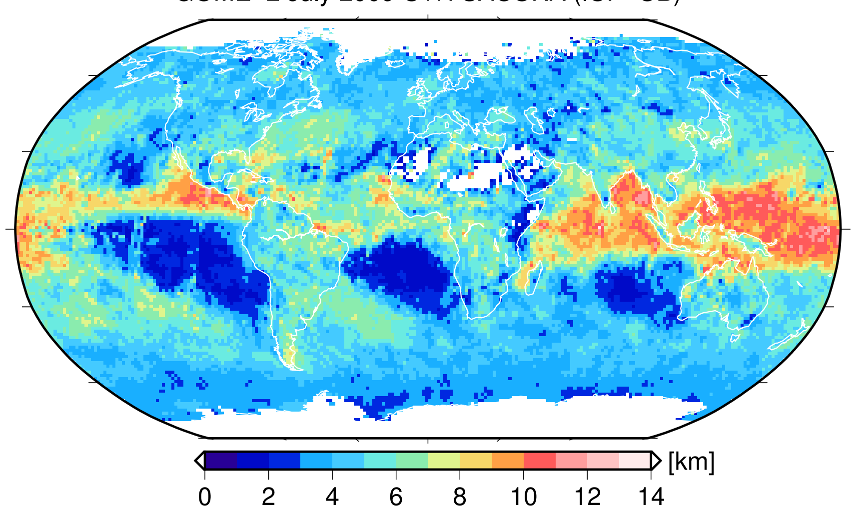


GOME−2 November 2009 CTH STDV ROCINN (DLR)

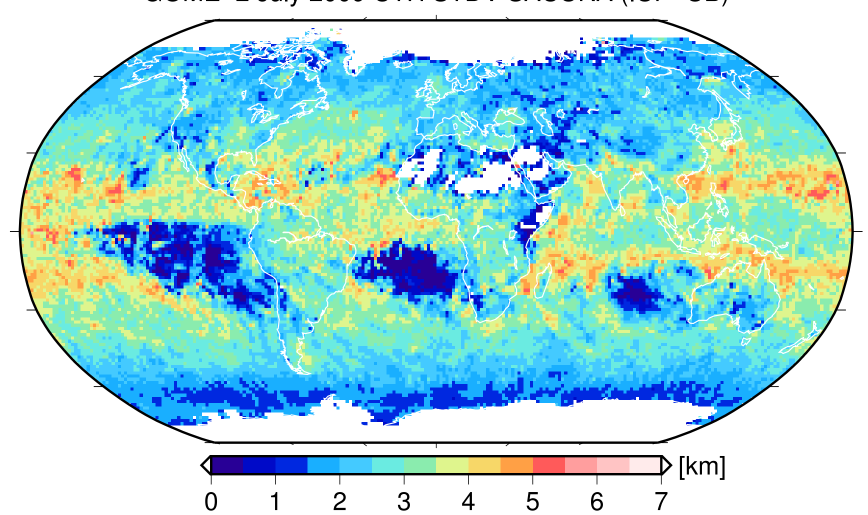


ROCINN Lambertian
3.73 ± 1.62 km

GOME−2 July 2009 CTH SACURA (IUP−UB)

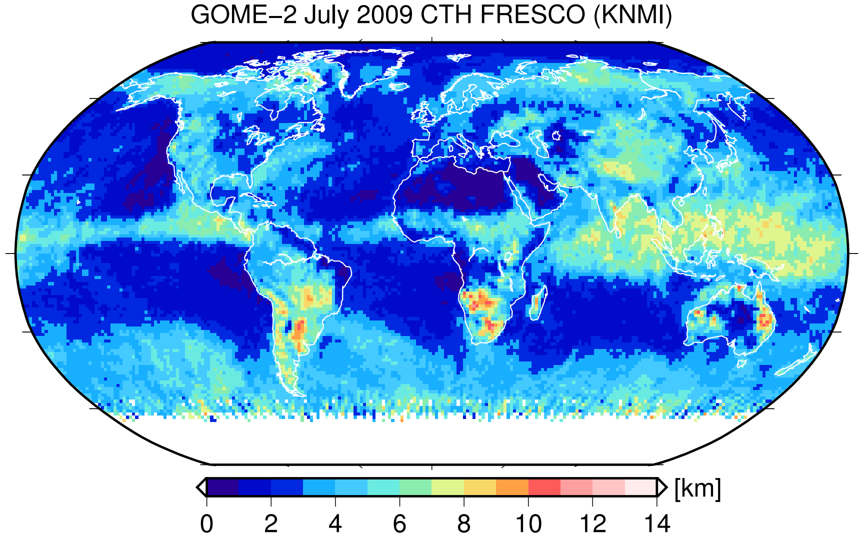


GOME−2 July 2009 CTH STDV SACURA (IUP−UB)

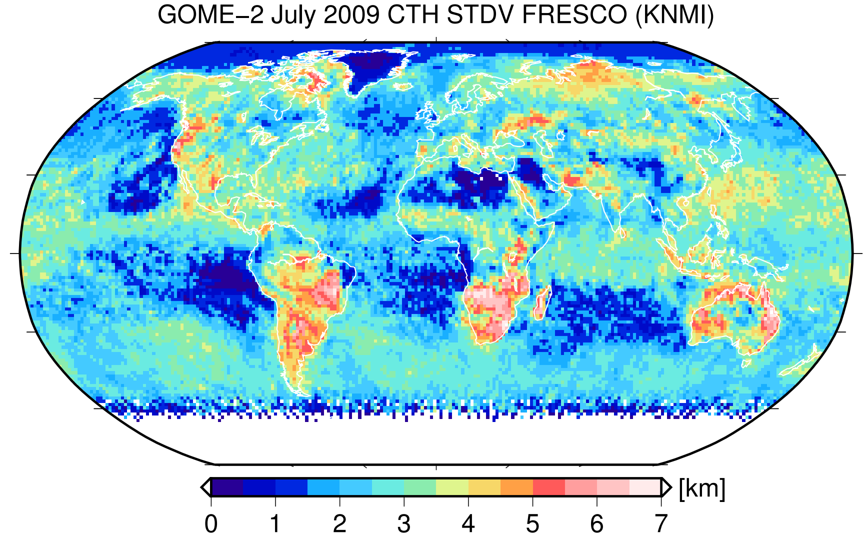


SACURA scattering
5.21 ± 2.02 km

GOME−2 July 2009 CTH FRESCO (KNMI)

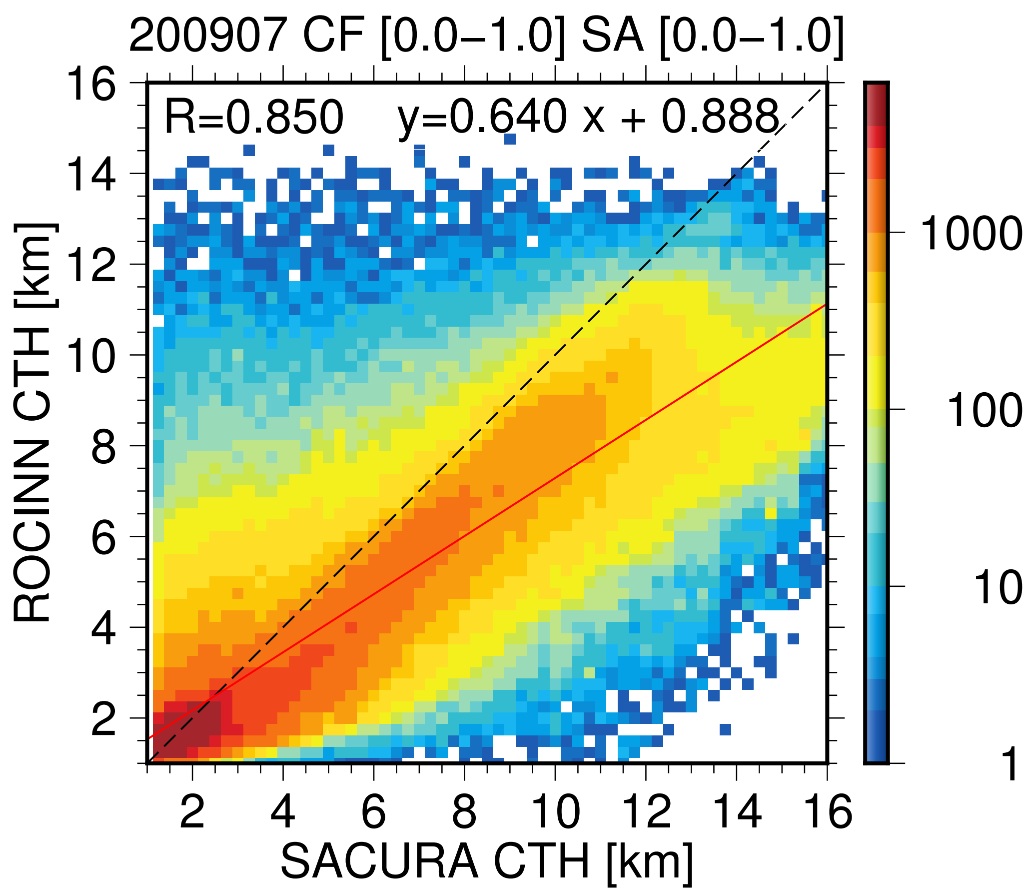


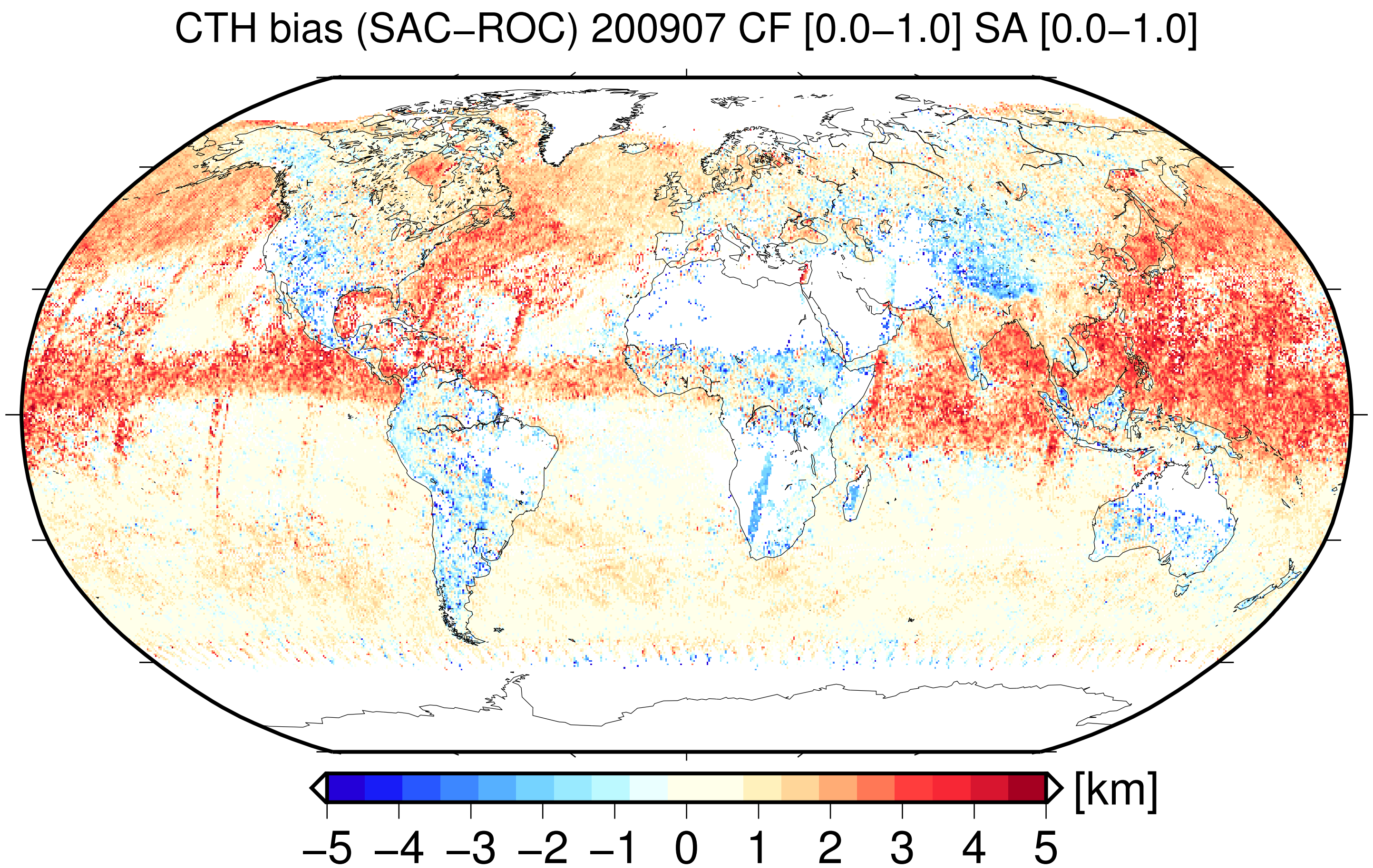
GOME−2 July 2009 CTH STDV FRESCO (KNMI)

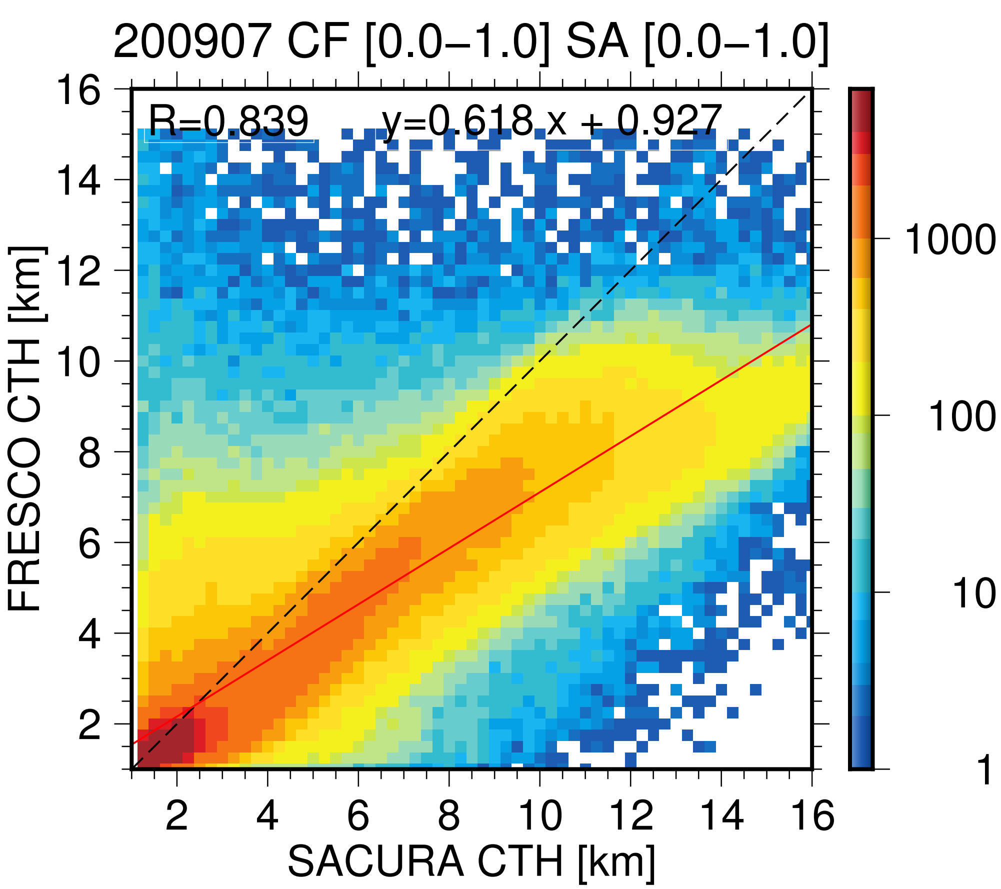


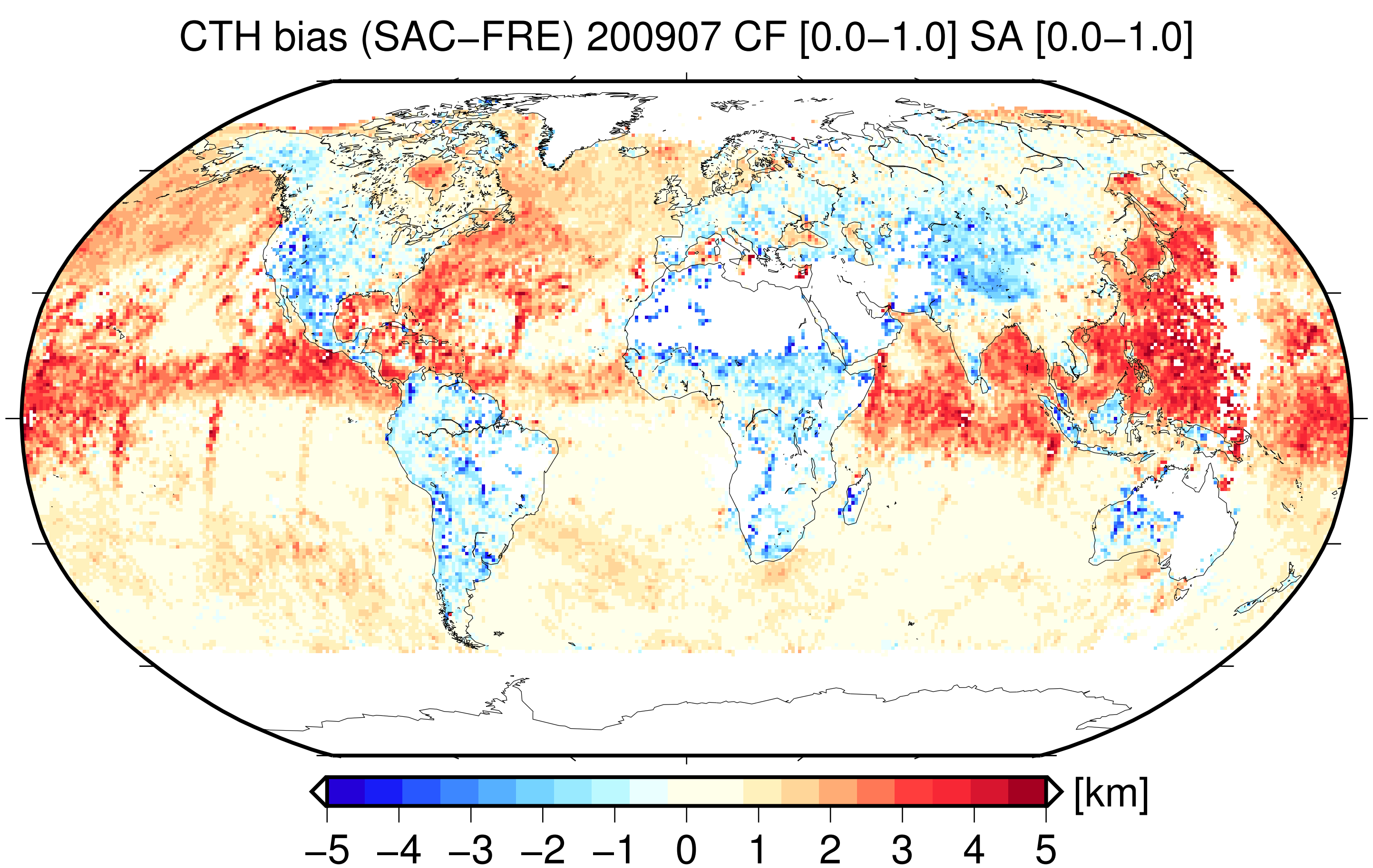
FRESCO Lambertian
3.60 ± 1.77 km

SACURA (scattering) – ROCINN / FRESCO (Lambertian)

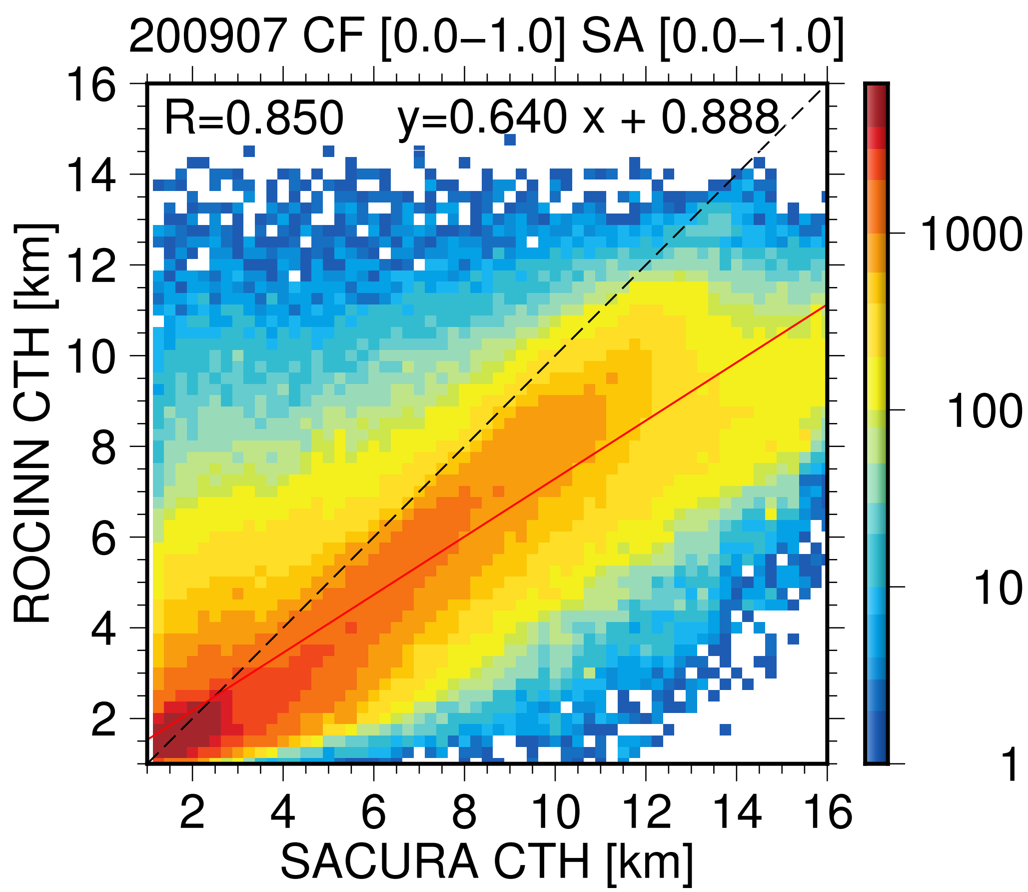


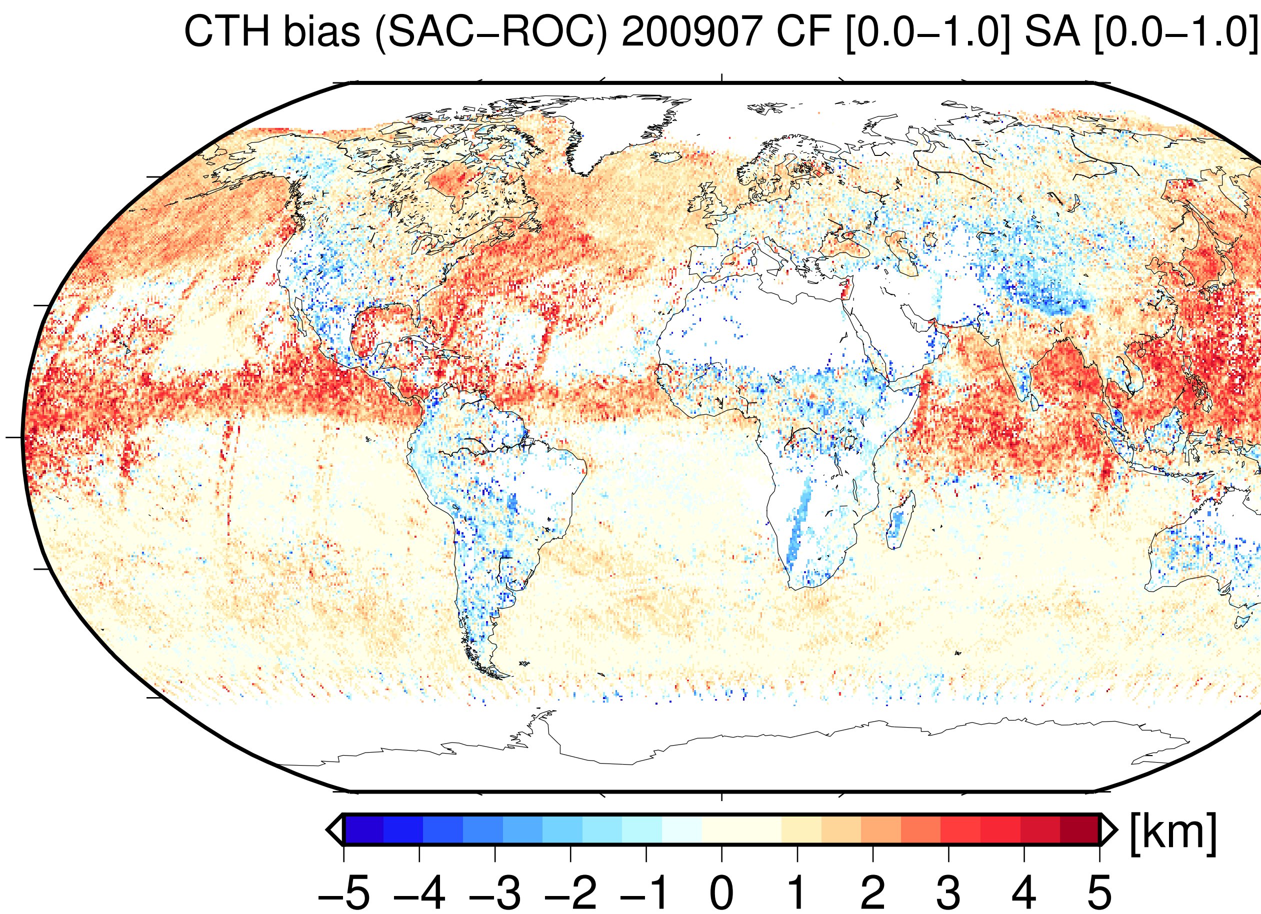


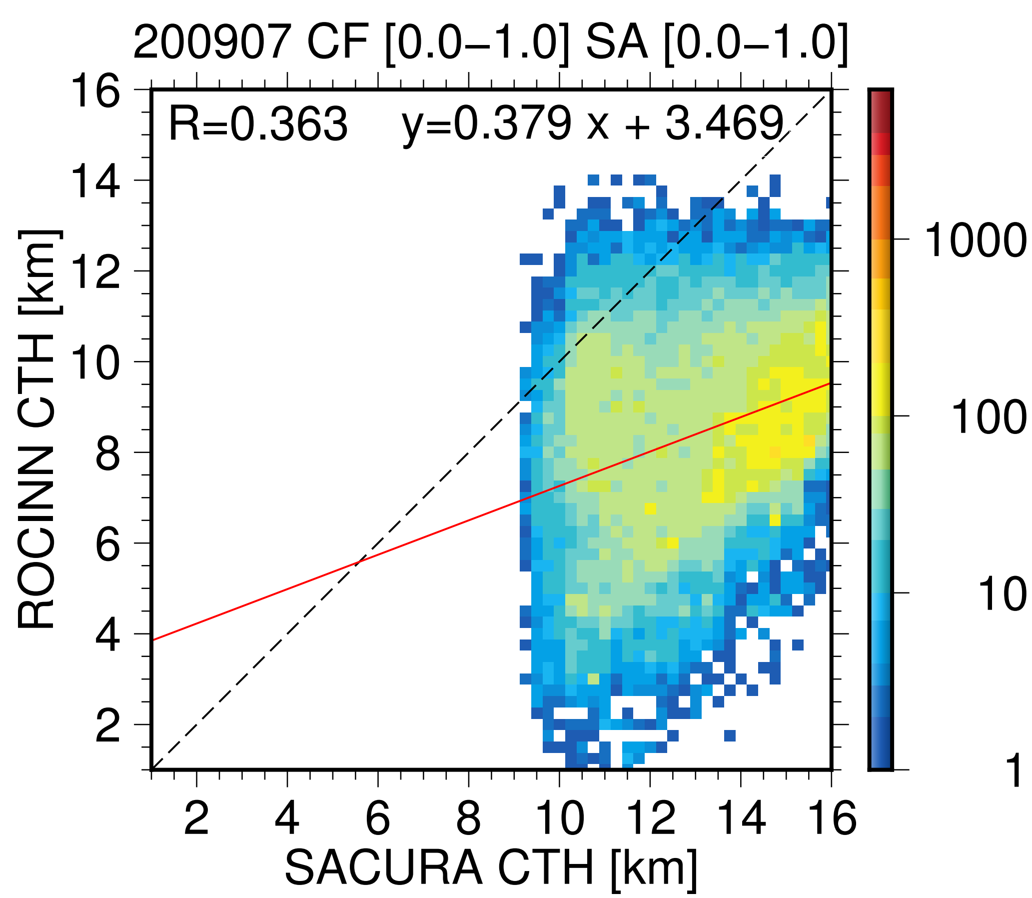


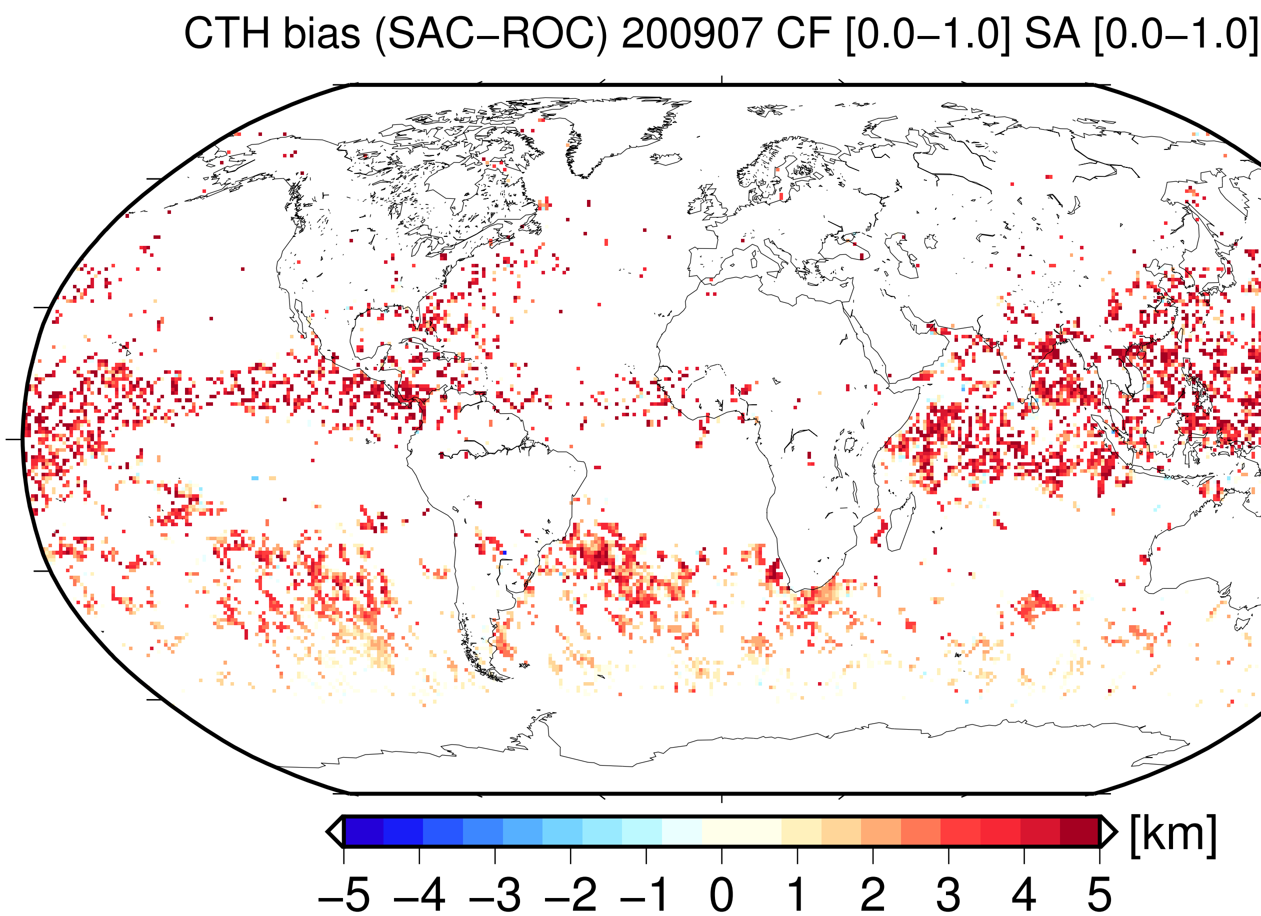


Multi-layer clouds



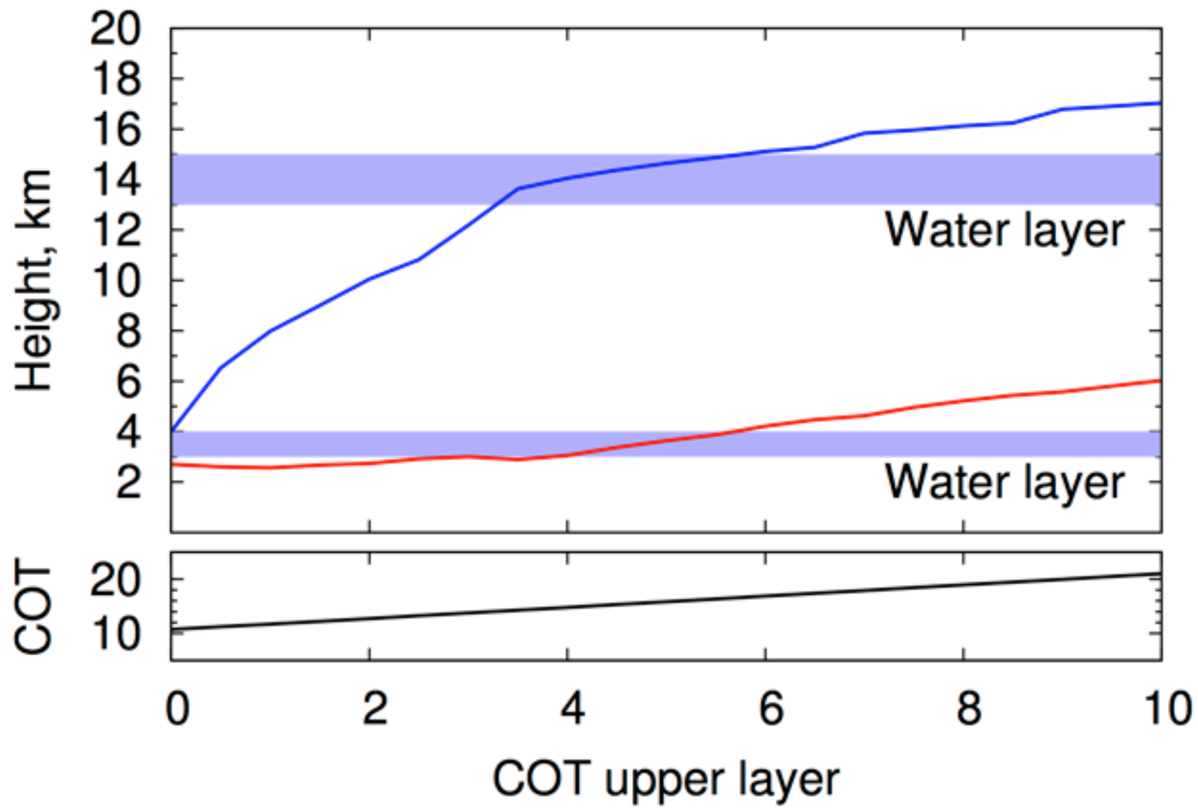


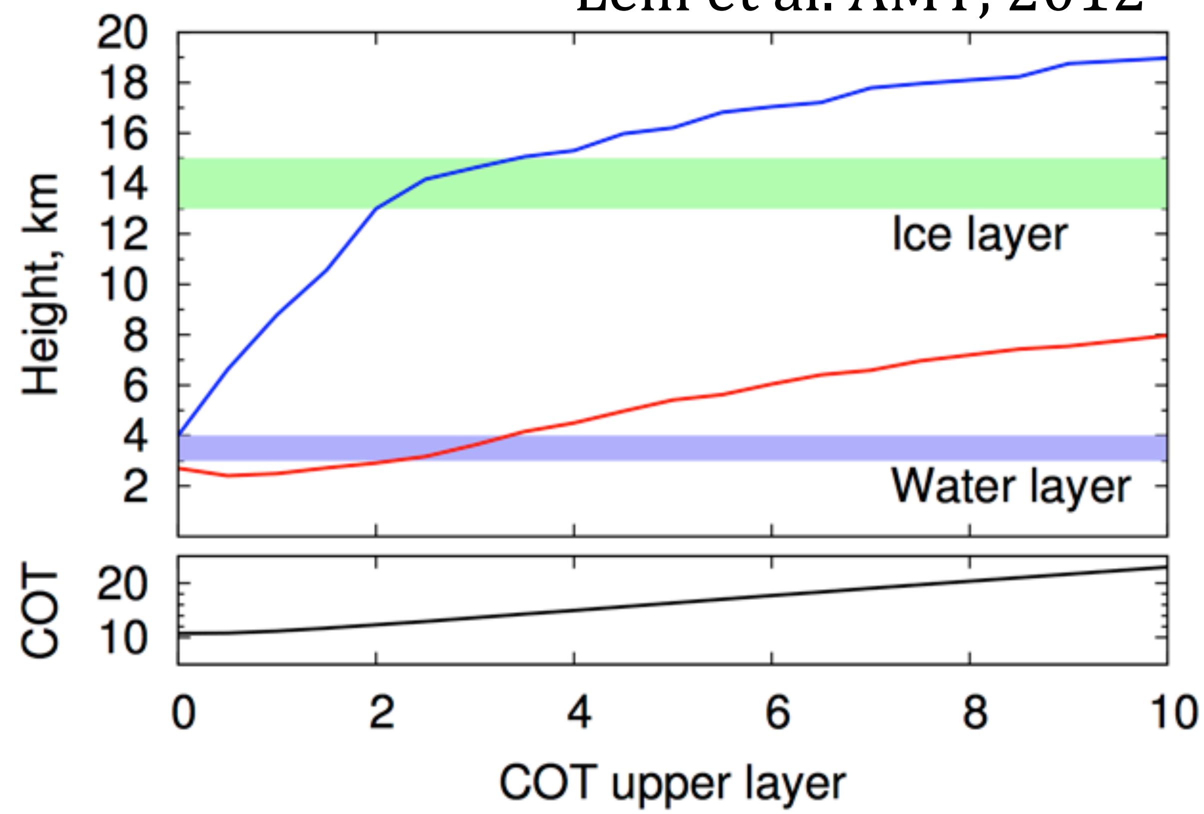


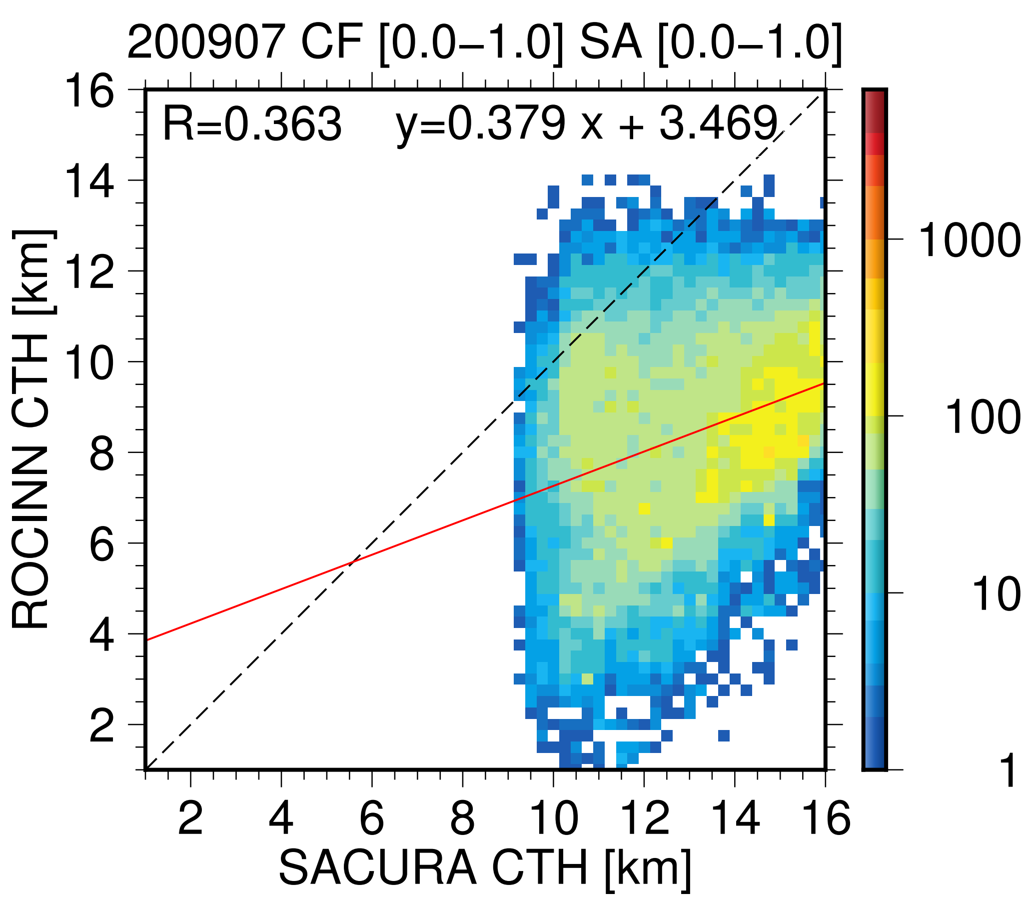


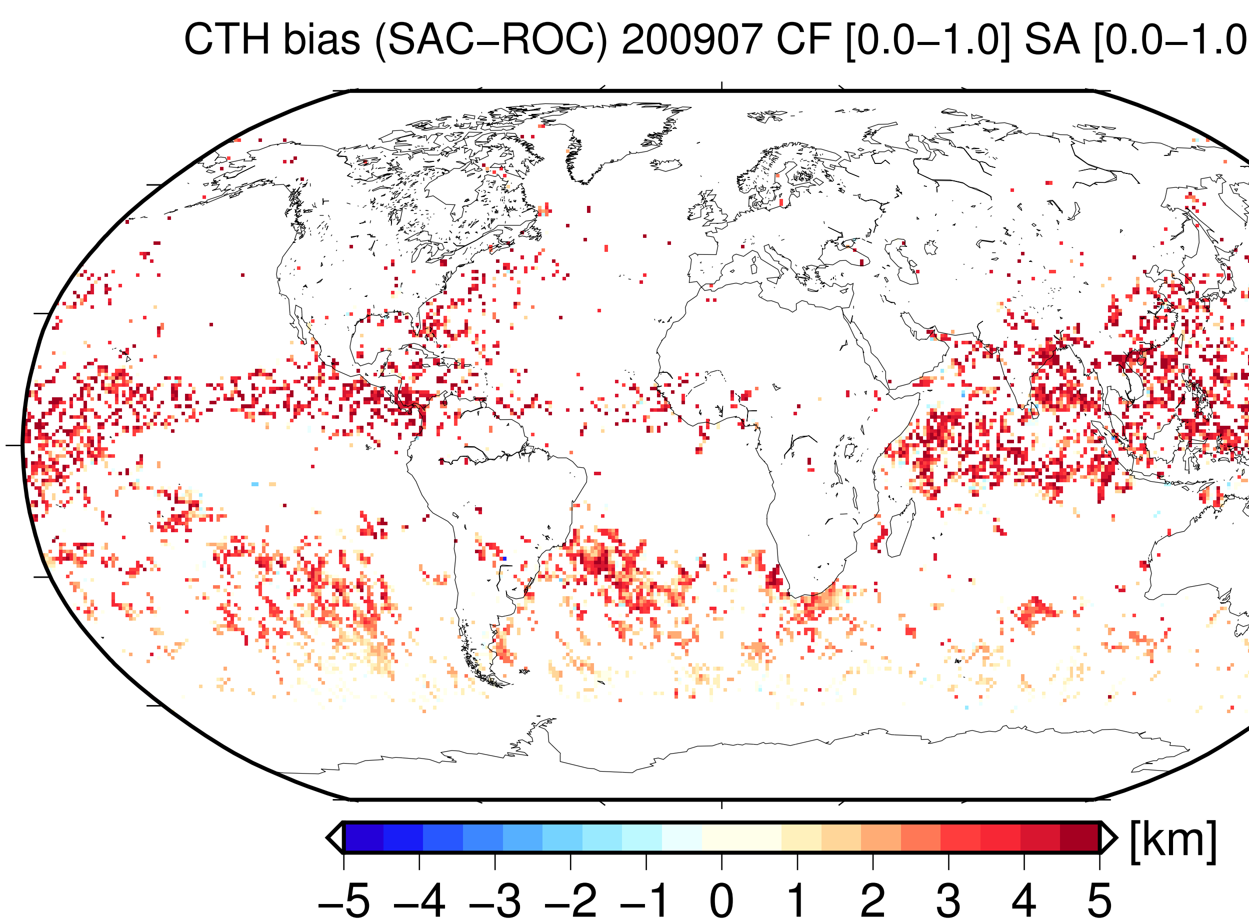
Multi-layer clouds

Lelli et al. AMT, 2012









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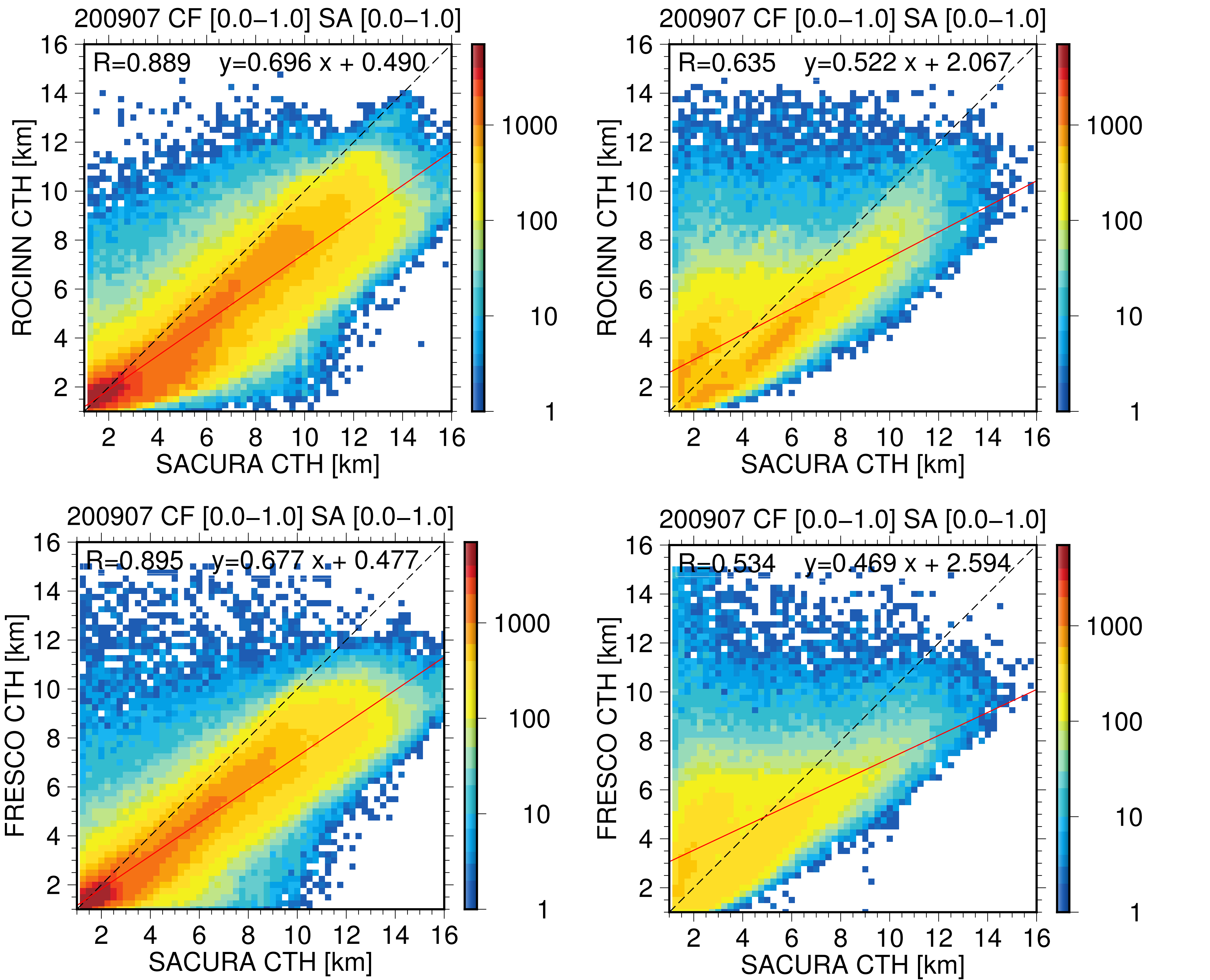
ROCINN vs SACURA vs FRESCO: land / water

WATER

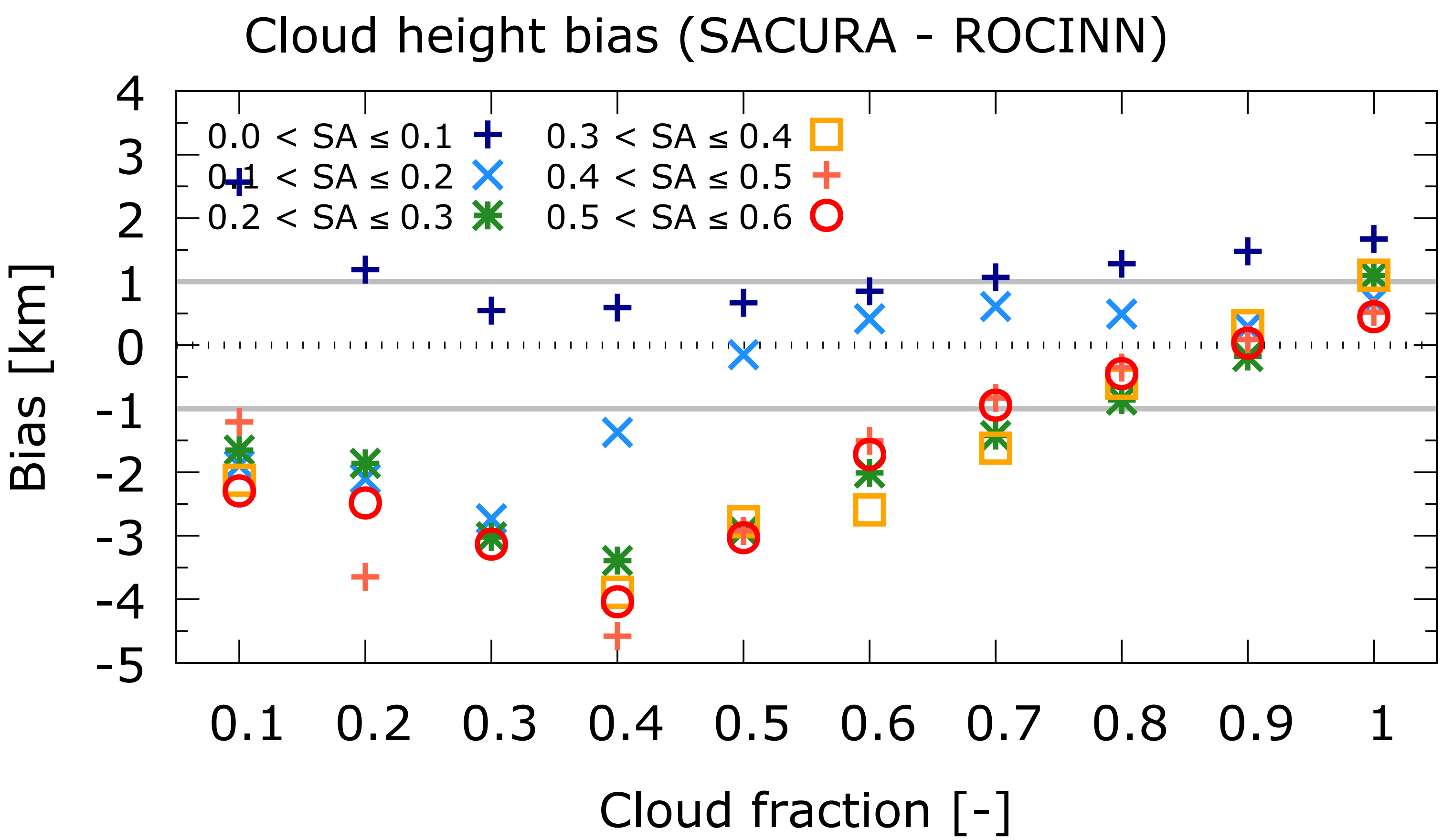
LAND

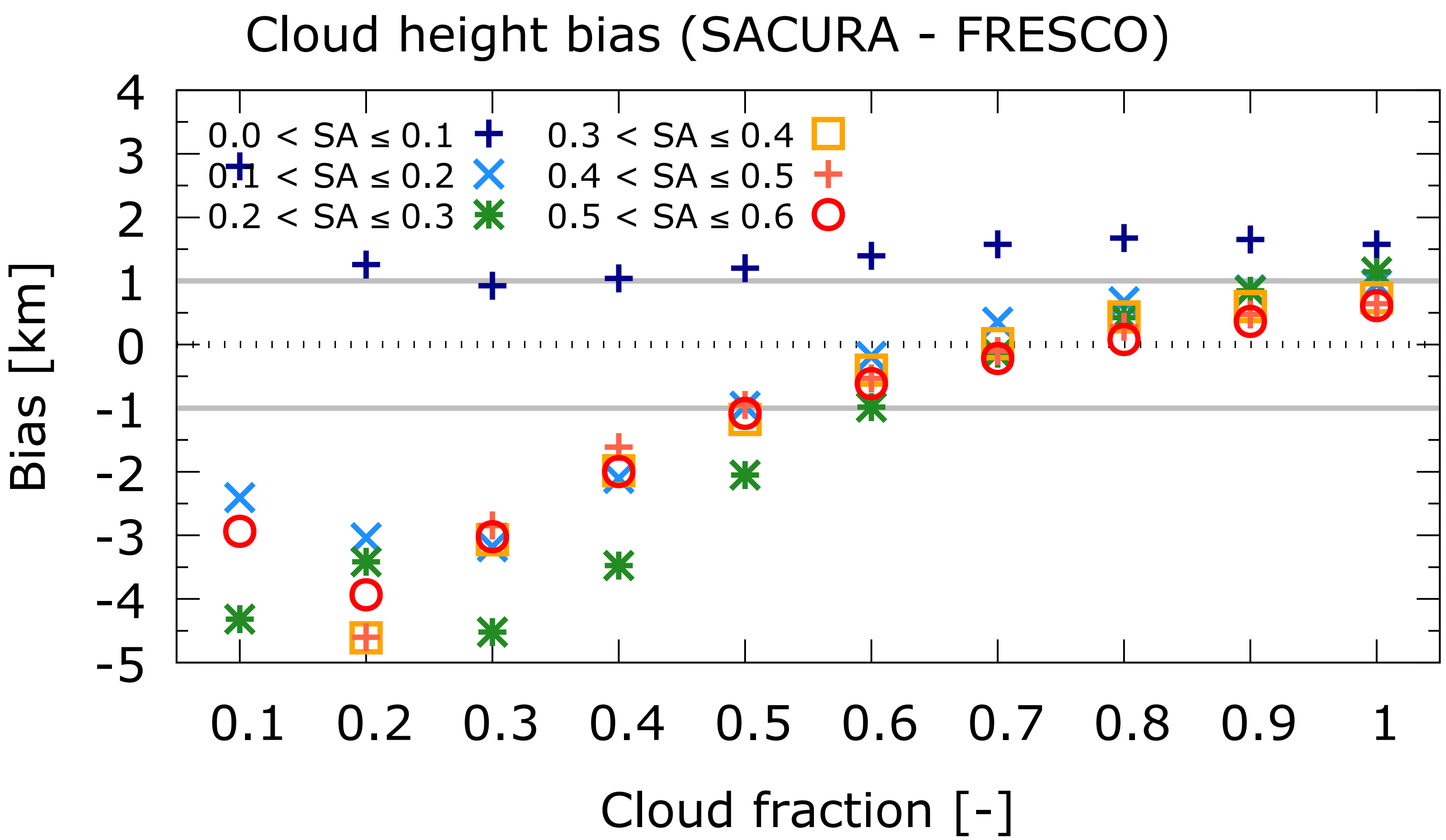
ROCINN

FRESCO

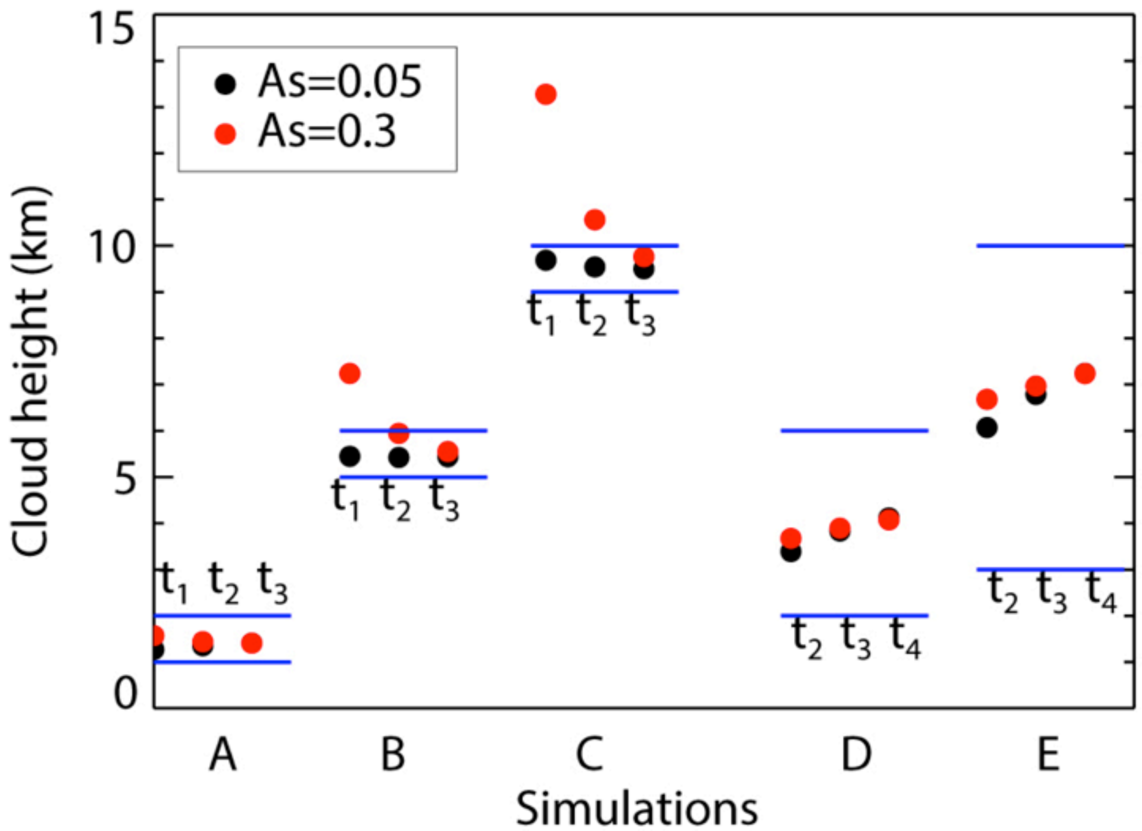


Dependency on cloud fraction and surface albedo





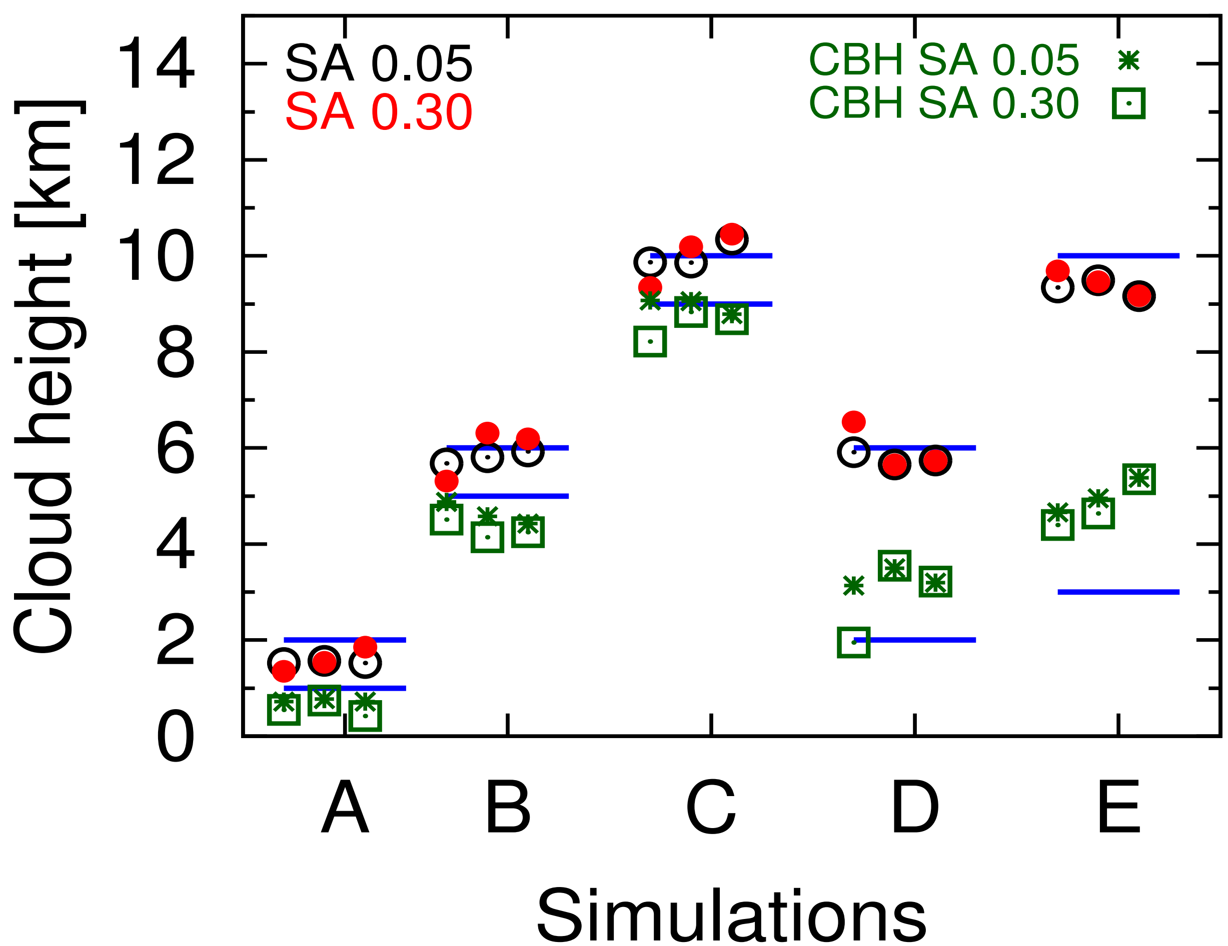
Synthetic: FRESCO, SACURA



FRESCO Lambertian

Fig. 2, p. 1336 from "Evaluation of SCIAMACHY Oxygen A band cloud heights using Cloudnet measurements"

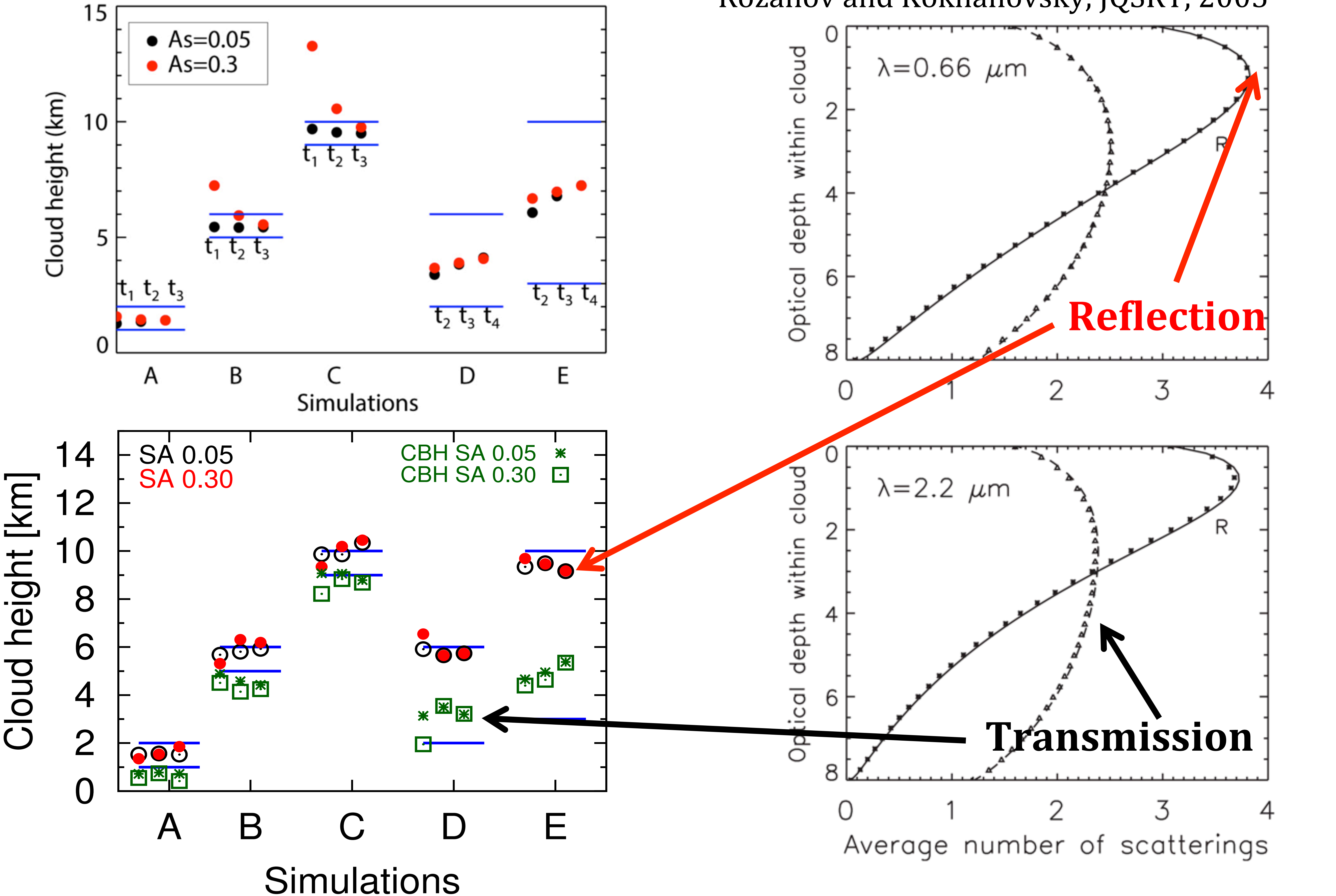
Wang and Stammes (AMT, 2014)
(see also Poster 86)



SACURA Scattering

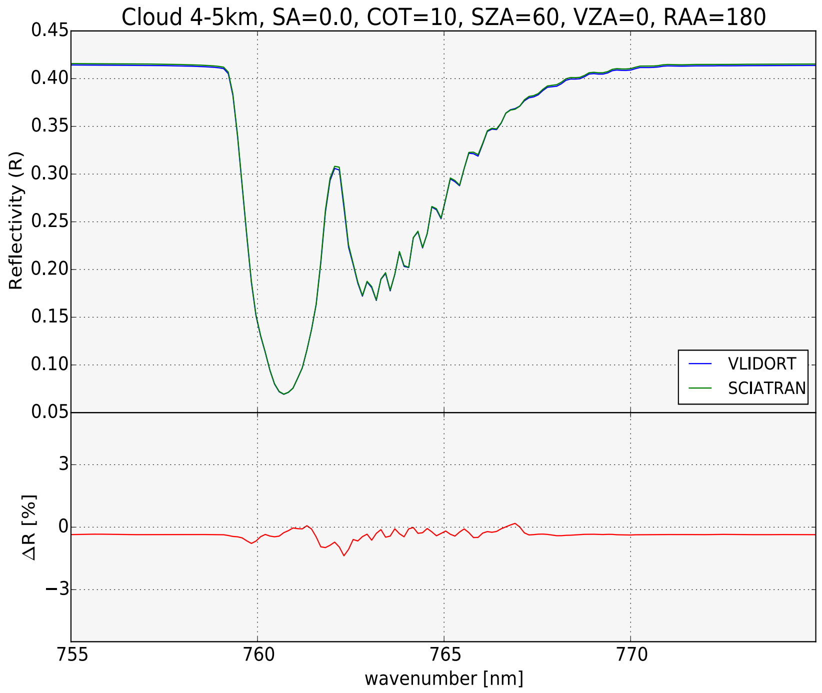
Synthetic: FRESCO, SACURA

Rozanov and Kokhanovsky, JQSRT, 2005



Optical closure: SCIATRAN, VLIDORT

Surface albedo 0.0

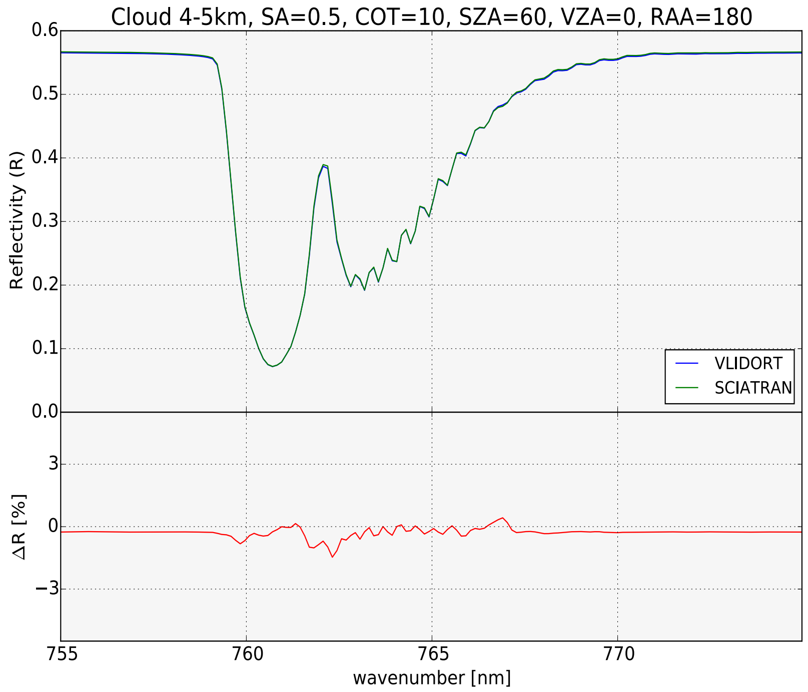


Mie scattering cloud, optically thick 10, placed at 4-5 km

Residuals for Stokes I (and Q) systematic < 0.5%

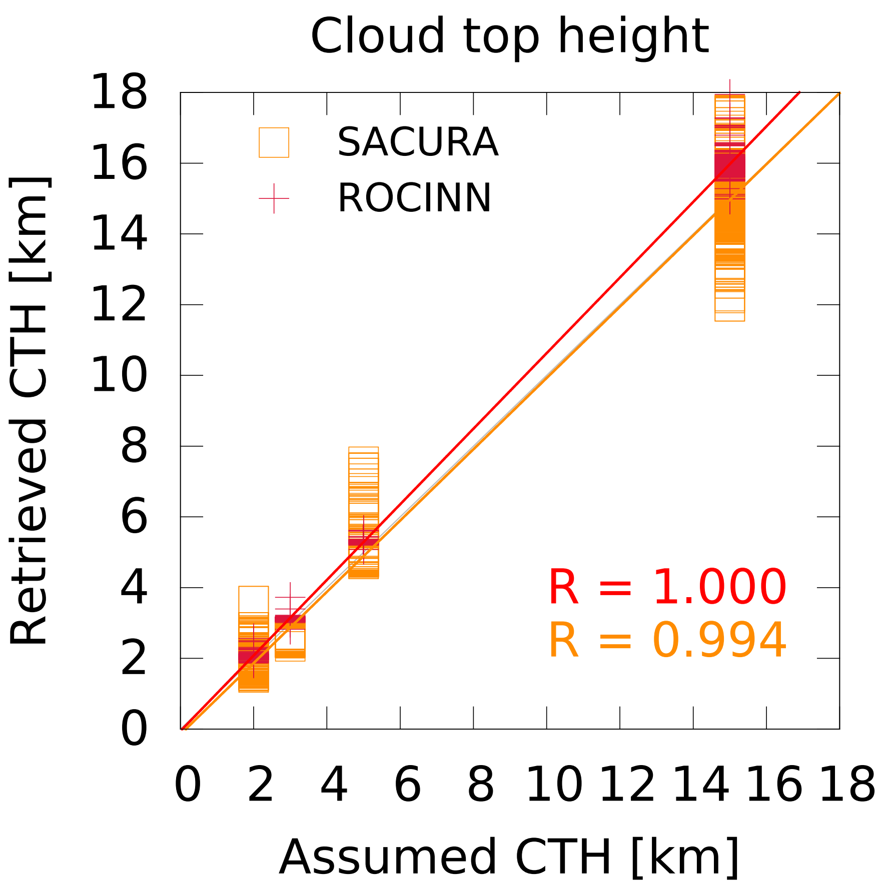
Generation with SCIATRAN of a synthetic cloud data set for permutation of significant geophysical parameters (157760 spectra)

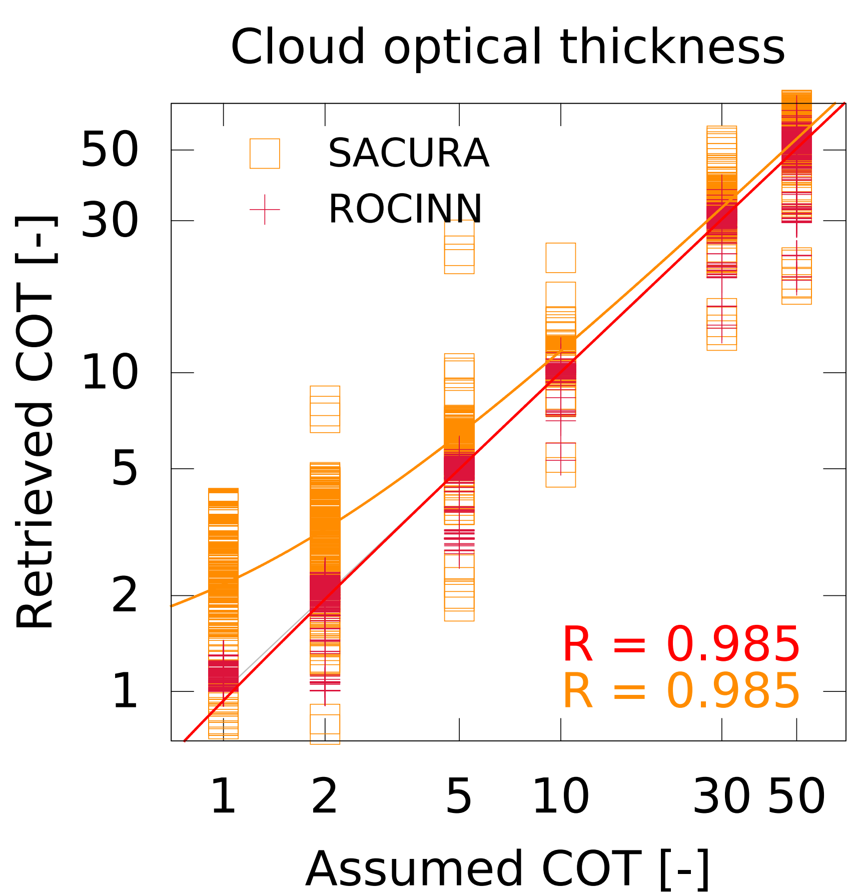
Surface albedo 0.5



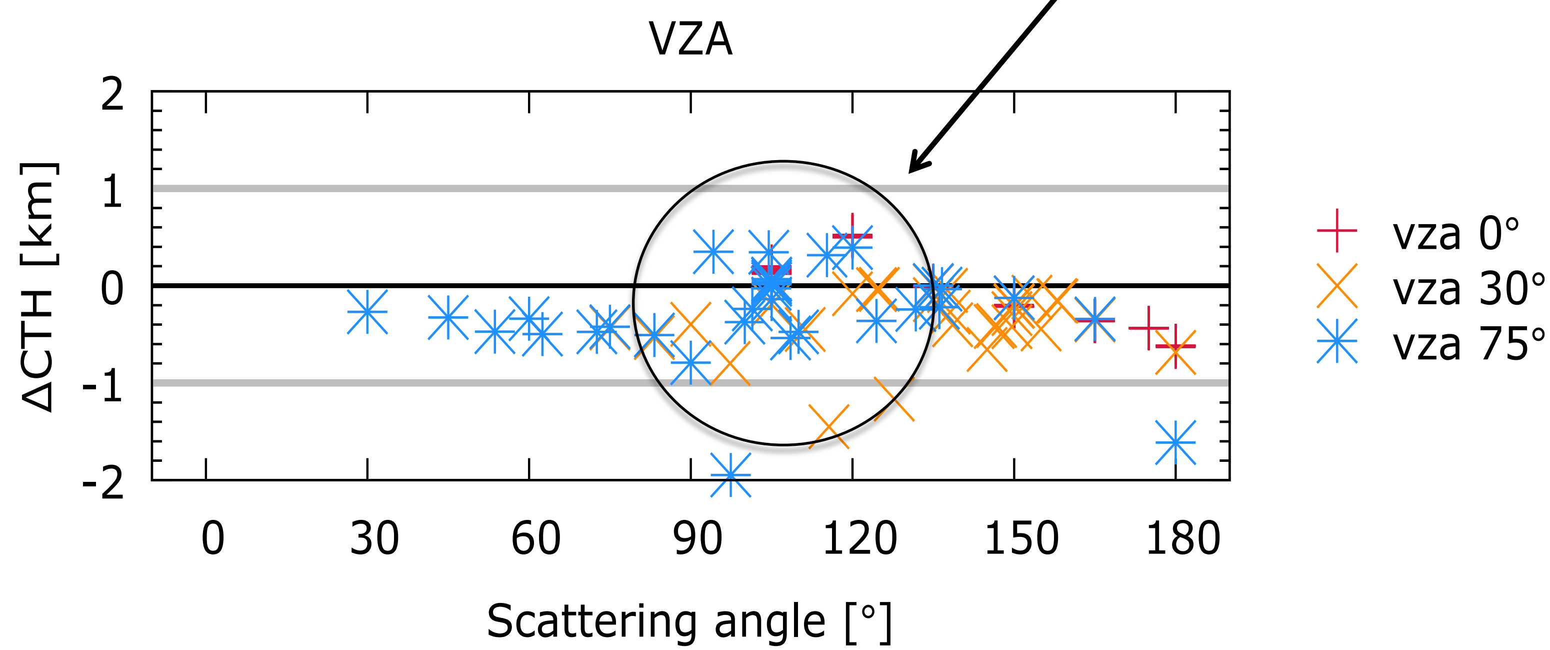
***Parameter* [unit]**	***Value***
Surface albedo [-]	0, 0.2, 0.4, 0.6, 0.8, 1.0
Cloud bottom height [km]	1.0, 4.0, 9.0
Cloud top height [km]	2.0 – 15.0, with 1.0 km step
Cloud optical thickness [-]	1.0, 2.0, 5.0, 10.0, 30.0, 50.0
Solar zenith angle [deg]	0, 5, 15, 30, 45, 60, 75
Viewing zenith angle [deg]	0, 5, 15, 30, 45, 60, 75
Relative azimuth [deg]	0, 45, 90, 135, 180

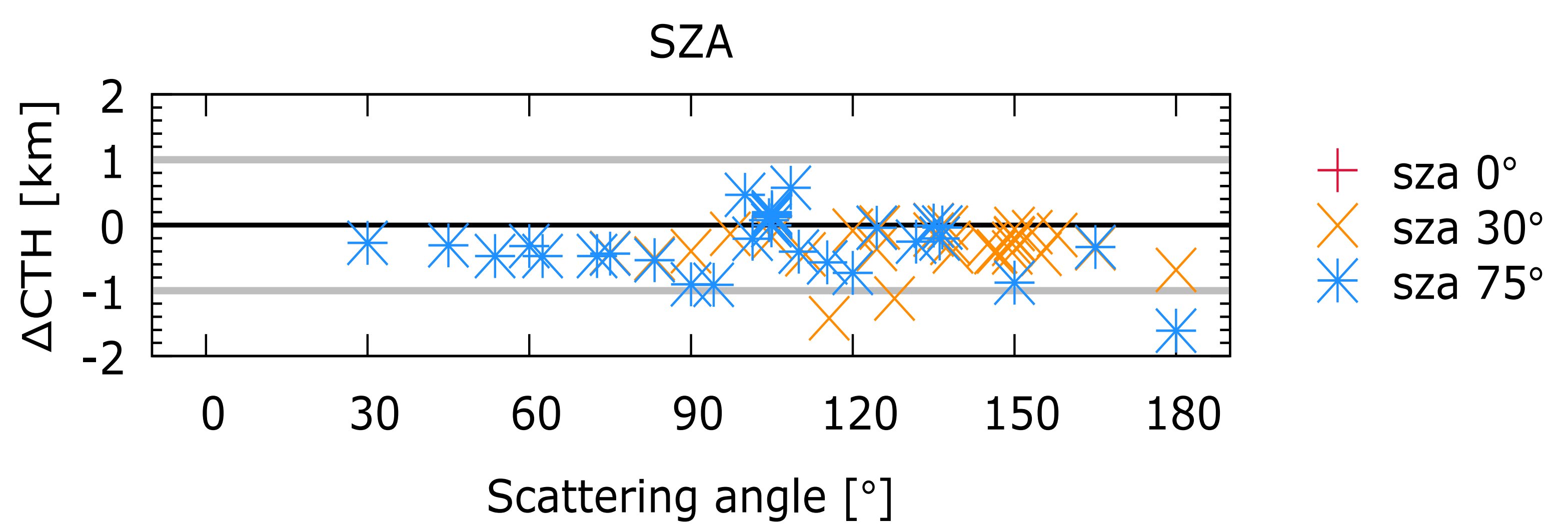
Synthetic: ROCINN scattering, SACURA





Different cloud microphysics between forward and inverse





Conclusions

- Altitude of **elevated aerosol layers** can be retrieved
- With a **Lambertian** cloud model, cloud altitude is **underestimated**
- **Multi-layer** scenes are interpreted as **lower single-layer** clouds
- With a **scattering** cloud model, information on cloud **bottom altitude** becomes available from the O_2A-band
- **Cloud fraction** plays little role in the retrieval of cloud-top height, given surface albedos < 0.2
- Biases in cloud-top height can be mitigated when using **synergistic** information from the **SWIR**

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- Biases in cloud-top height can be mitigated when using **synergistic** information from the **SWIR**

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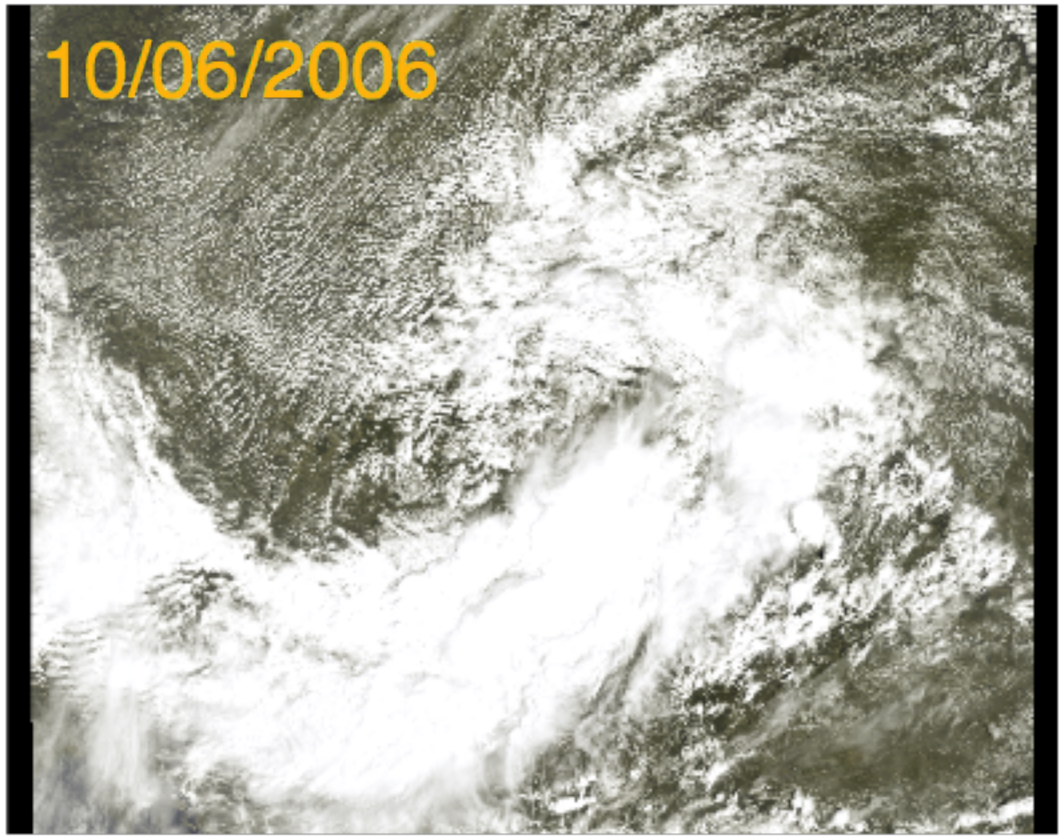
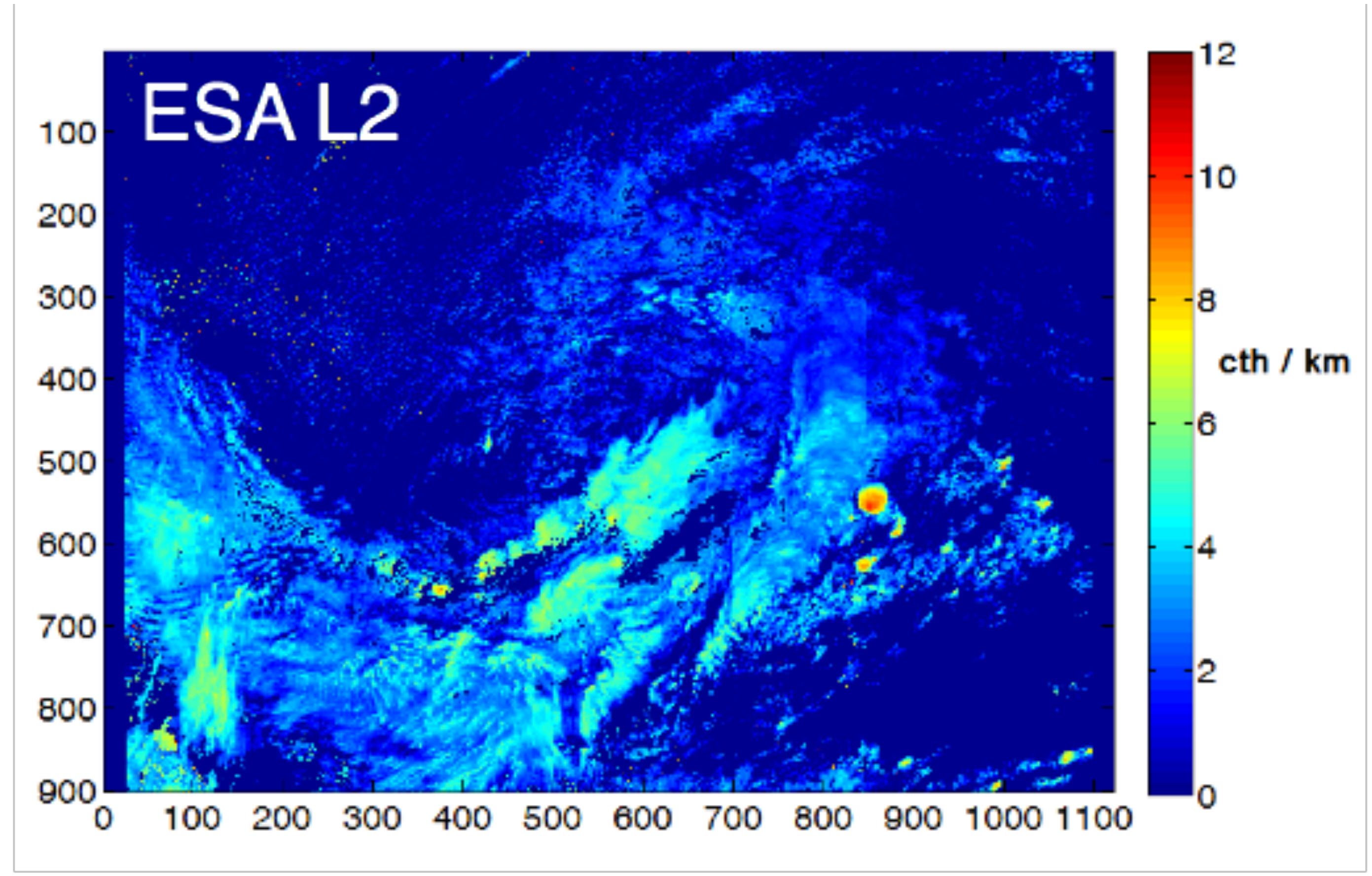
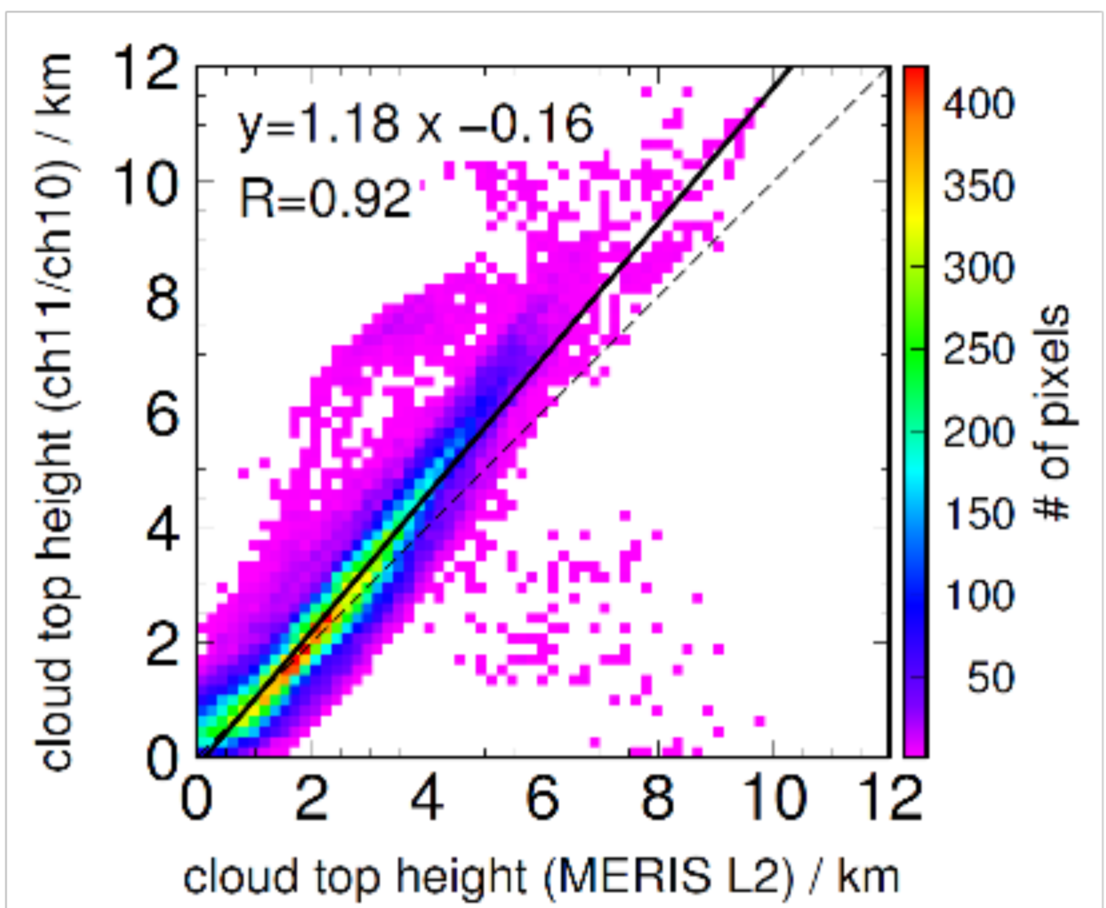
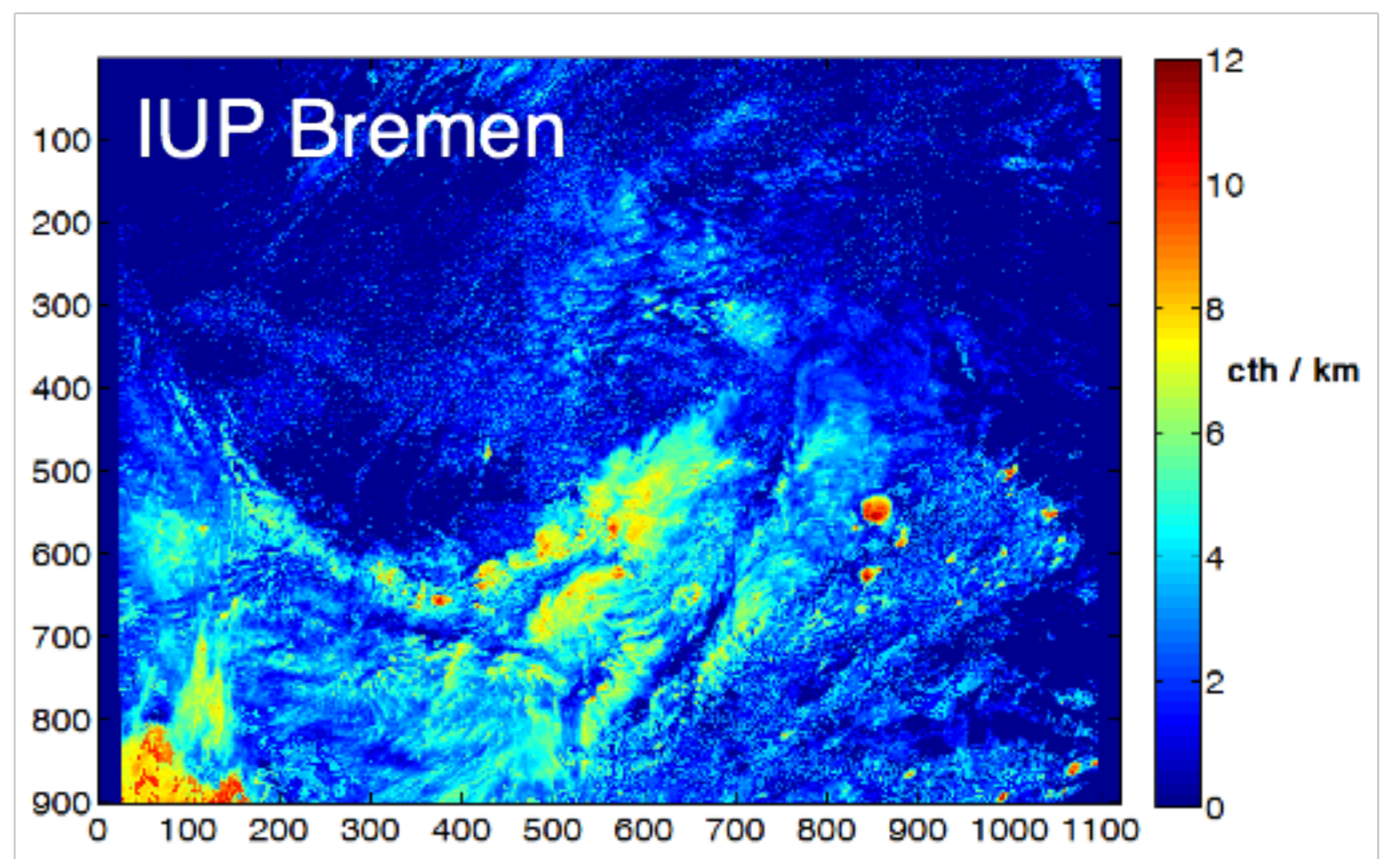
Back-up slides

MERIS smile-corrected cloud top height







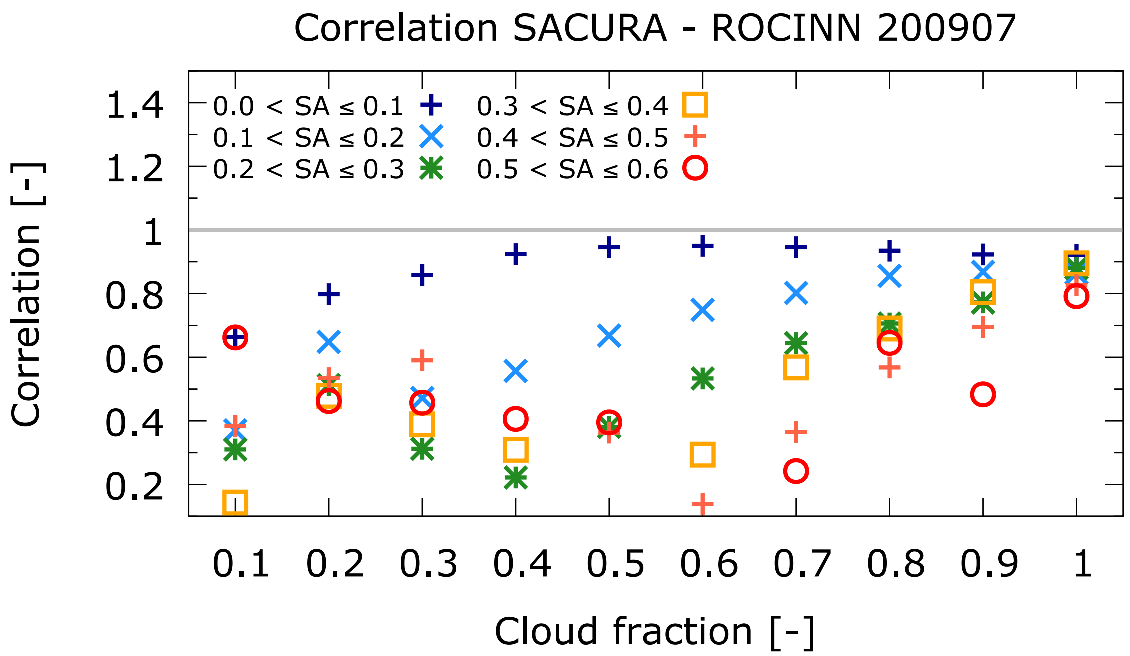


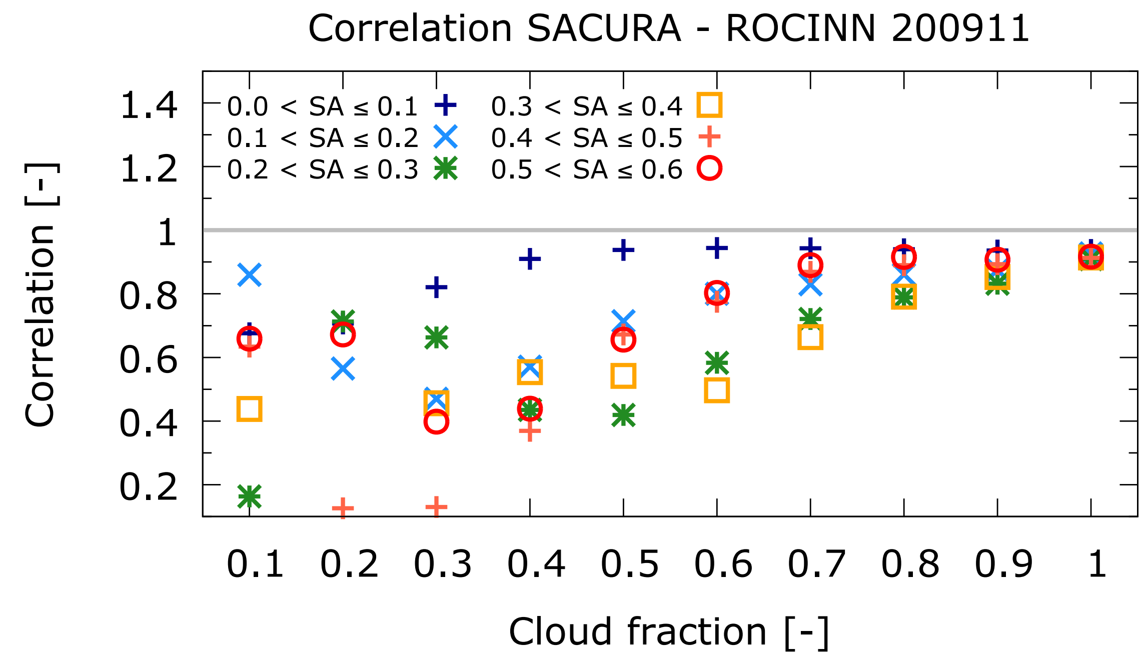
Correlations

ROCINN

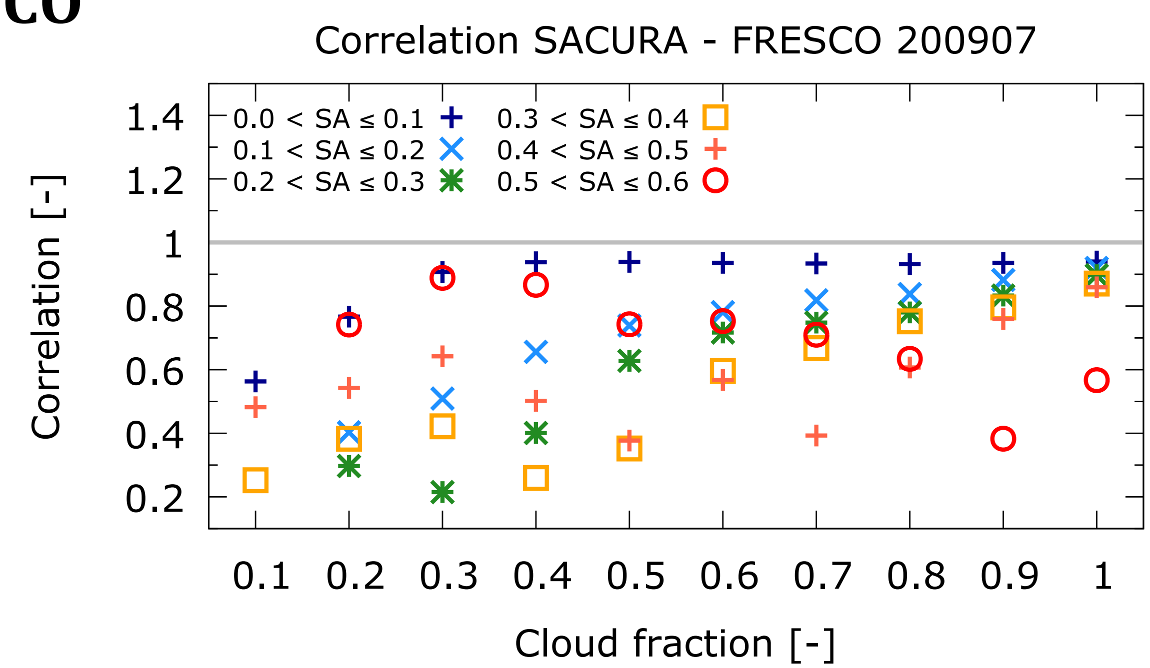
July 2009

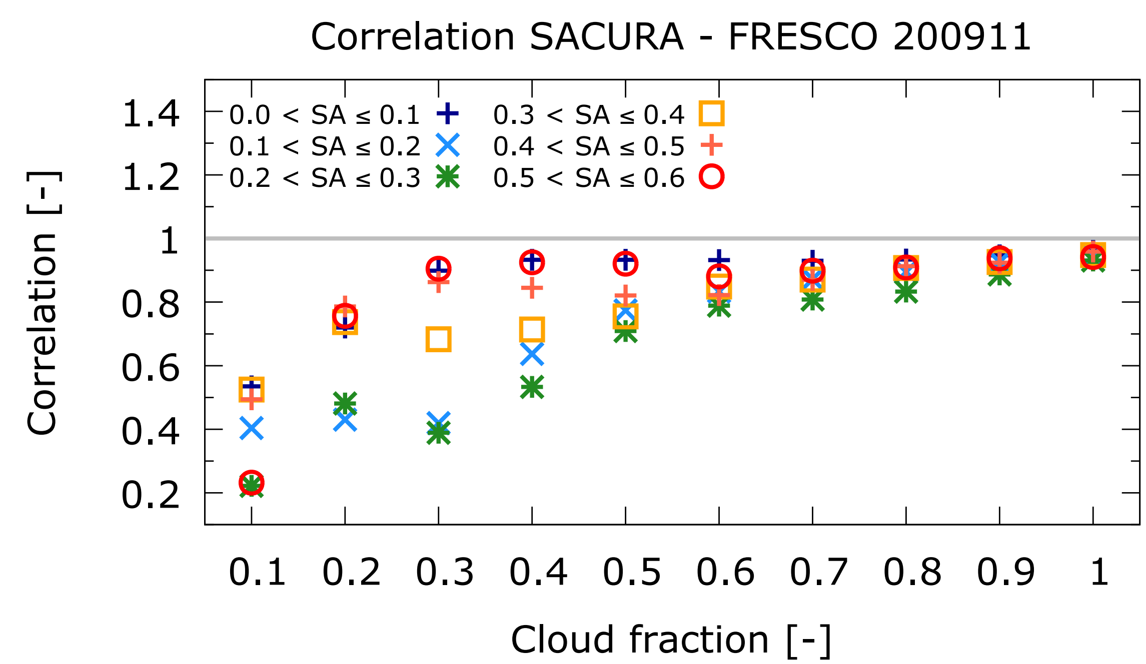
November 2009





FRESCO





Average number of photon scatterings (<N>) for reflection and transmission and single scattering albedo for a 2-layer cloud system in the oxygen A-band (761 nm)