Cloud Effects on Solar Actinic Radiation: Evaluation of Satellite-Aided RTM Calculations with Airborne HALO Measurements

05.07.2022 I Arthur Kremer[1], Birger Bohn[1], Rabindra Palikonda[2], William L. Smith, Jr.[3]

(1) Forschungszentrum Jülich, IEK-8 Troposphere, Jülich, Germany
(2) Science Systems and Applications, Inc., Hampton, USA
(3) NASA Langley Research Center, Hampton, USA

ATMOSPHERIC AND EARTH SYSTEM RESEARCH WITH HALO · DFG · SPP 1294

JÜLICH Forschungszentrum

Chemistry-transport models (CTM) rely on accurate predictions of actinic flux densities based on clouds predicted by NWP

- Clouds have a crucial influence on actinic flux densities

⇒ highly variable in their temporal and spatial evolution

Can the CTM be improved by using globally available cloud products from satellites?

- Satellites provide reliable horizontal information on cloud presence but limited vertical information on cloud properties

How well do the satellite cloud products perform in predicting actinic flux densities used in a RTM?

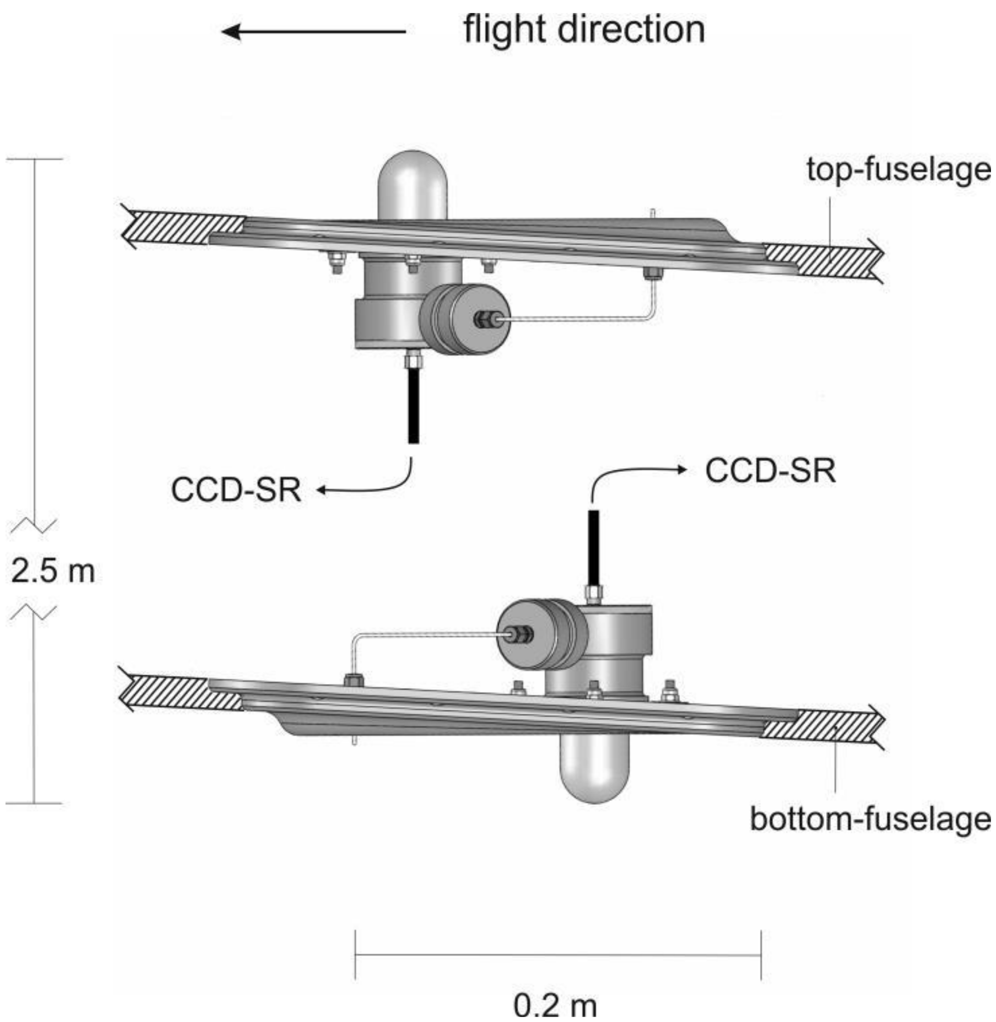
- Pilot study by Ryu et al. in 2016

⇒ Relatively small sample size and only UV region investigated

High Altitude and Long range research aircraft (HALO)
Photo: Andreas Minikin

⇒ Evaluation of libRadtran model simulations with data from aircraft measurements from several HALO missions

Measurement of actinic radiation with Charge-Coupled Device (CCD) spectroradiometers on-board HALO

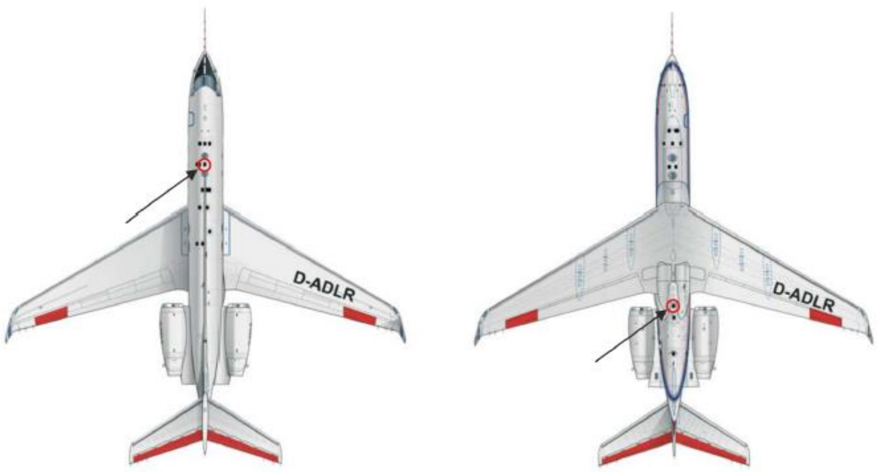


CCD:

- Spectrum: 280 – 650 nm
- Sampling: Δt ~ 1s

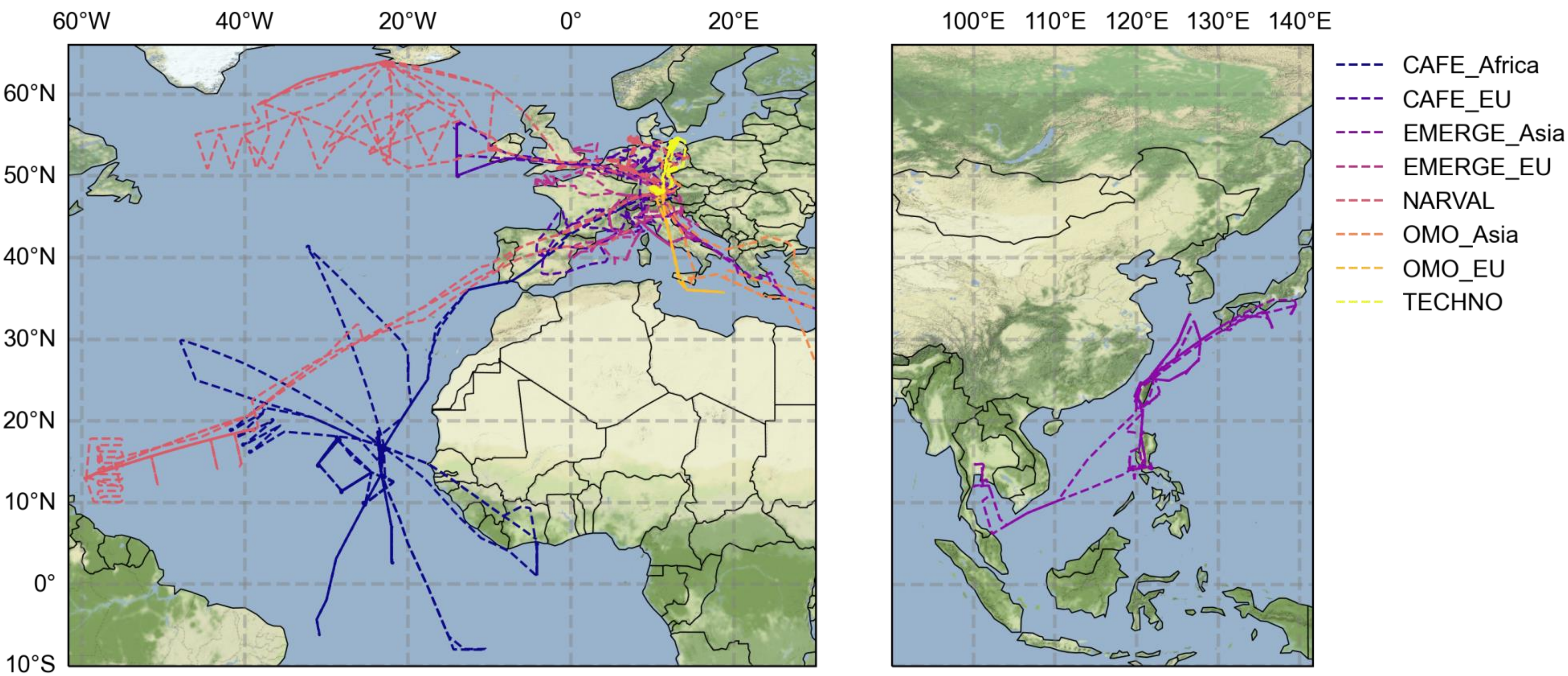
HALO:

- Speed: ~ 270 m/s
- Altitude: ~15 km
- Flight duration: ~10 h



Taken from Lohse 2015

HALO flight route overview of photochemical campaigns



1D radiative transfer calculations (libRadtran) based on satellite observations

Surface albedo

- MODIS (Terra/Aqua)
- Global product (MCD43A3)
- Δx: 500 x 500 m
- Δt: 16-Day mean
- Land only, Ocean filled

Aerosol optical depth

- MODIS (Terra/Aqua)
- Global product (MOD08_D3)
- Δx: 1° x 1°
- Δt: 8-Day mean

Ozone column

- Satellite composite
- Global product (MSR-2)
- Δx: 1° x 1°
- Δt: 12-Hourly

Cloud products

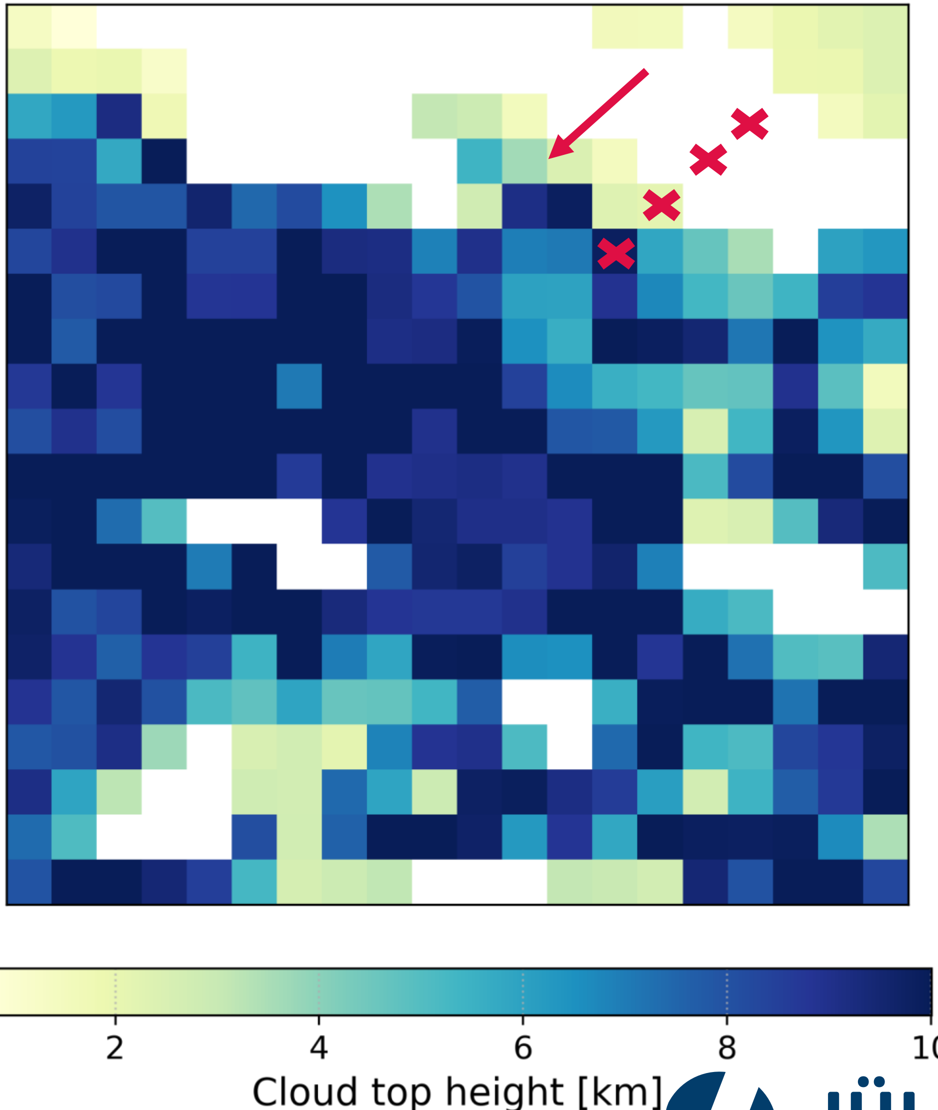
- Global product (NASA SatCORPS)
- Reprocessed for each individual flight
- Δx: ~ 3-6 km (depending on geost. satellite)
- Δt: ~15 min
- Cloud optical depth, cloud top/cloud effective height, liquid/ice water content, cloud phase, no info on vertical phase only cloud top, effective radius

Cloud parametrization

- Liquid clouds: Mie-Theory
- Ice clouds: Baum et. al. 2014

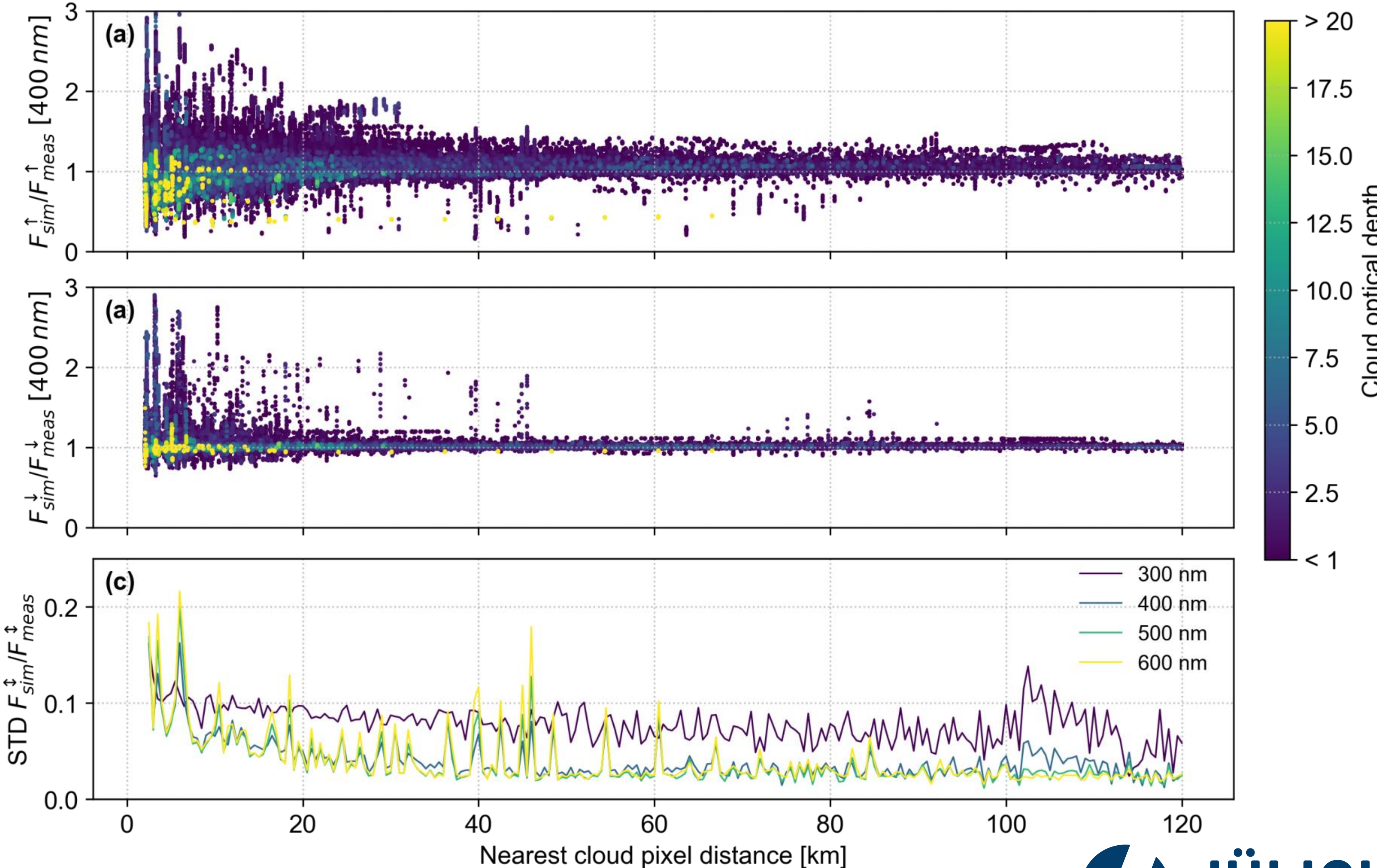
Downsampling of aircraft measurements

- Per-Pixel downsampling of in-situ measurements
- ~15-20 seconds time steps



JÜLICH Forschungszentrum

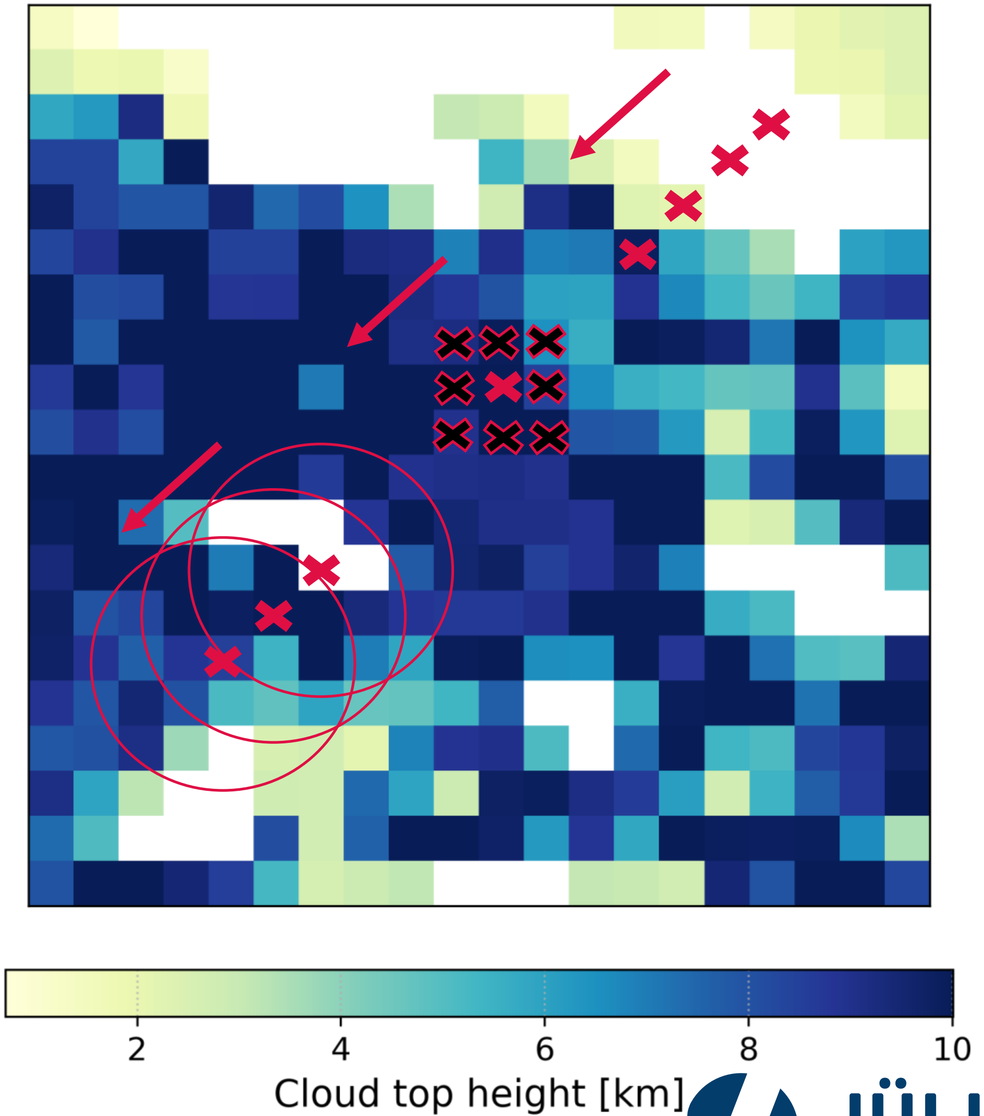
Clear sky based simulations depending on cloud distance



JÜLICH Forschungszentrum

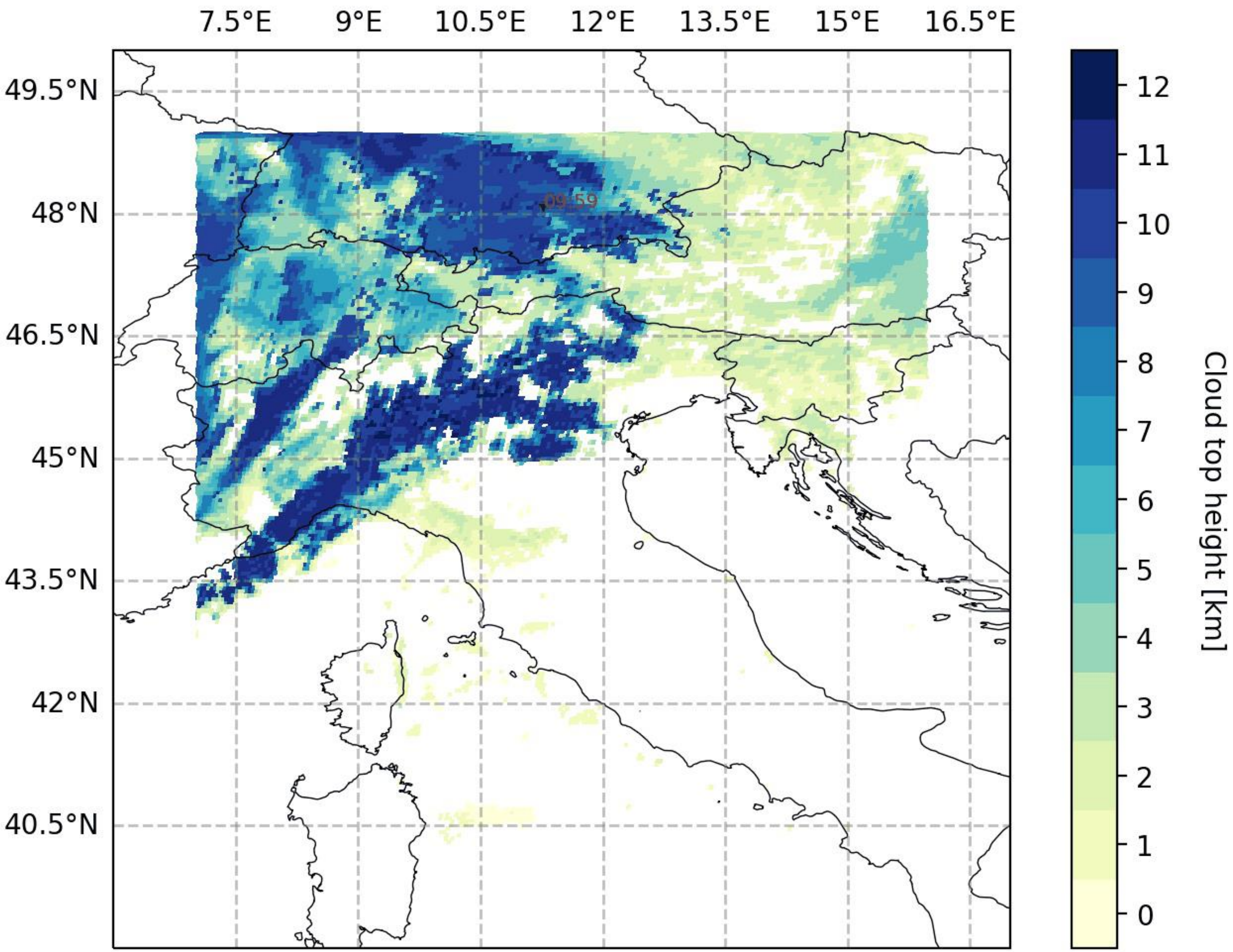
Retrieval of cloud properties along flight routes

- Per-Pixel downsampling of in-situ measurements
- Cloud property retrieval:
  - Per pixel
  - Nearest (3x3 Pixel)
  - Mean over radius (20 km)
  - Weighting within radius (20km)
- Introduction of cloud fraction (weight clouds closer to HALO higher)

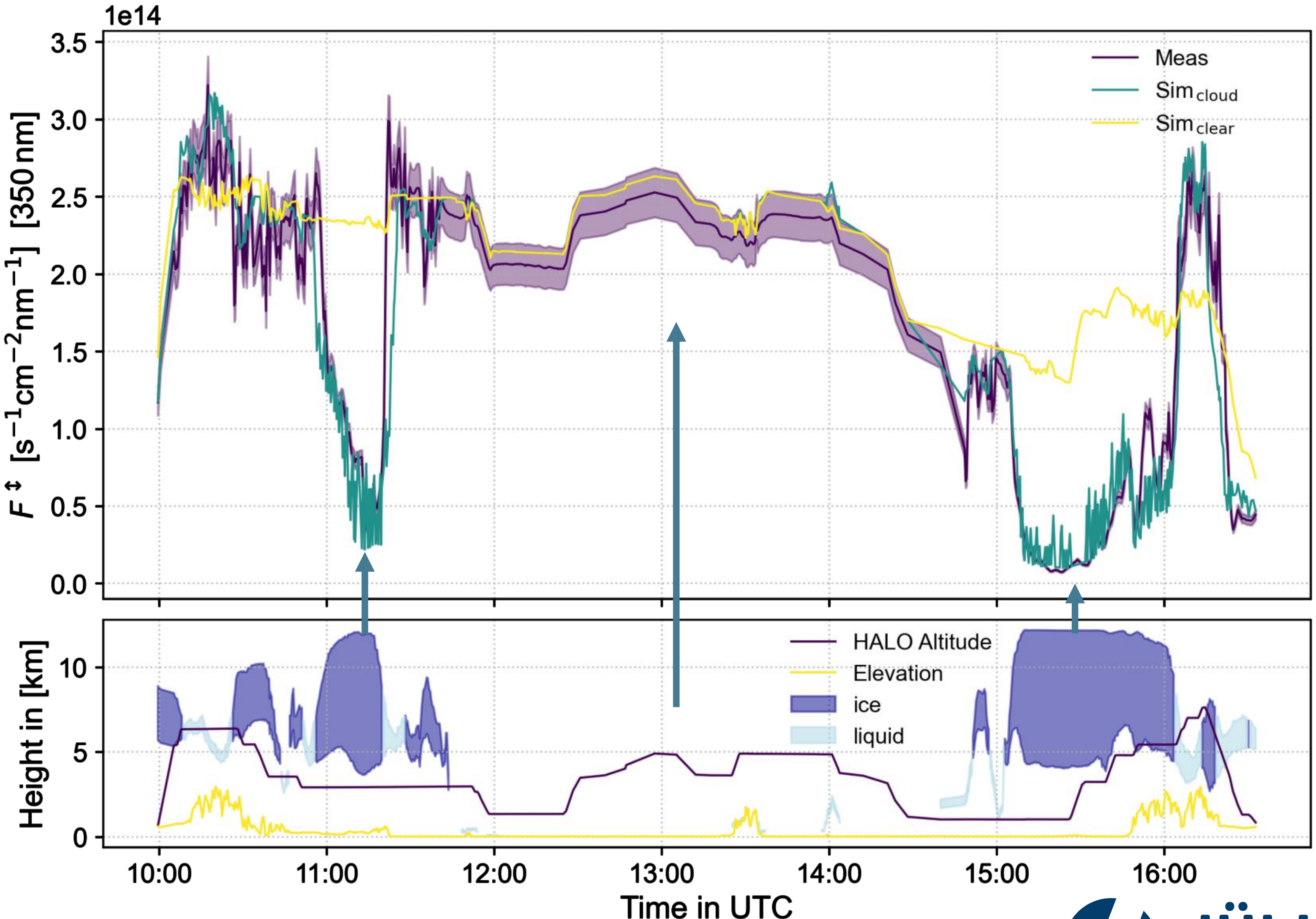


Preliminary results for the EMeRGe-EU mission in 2017

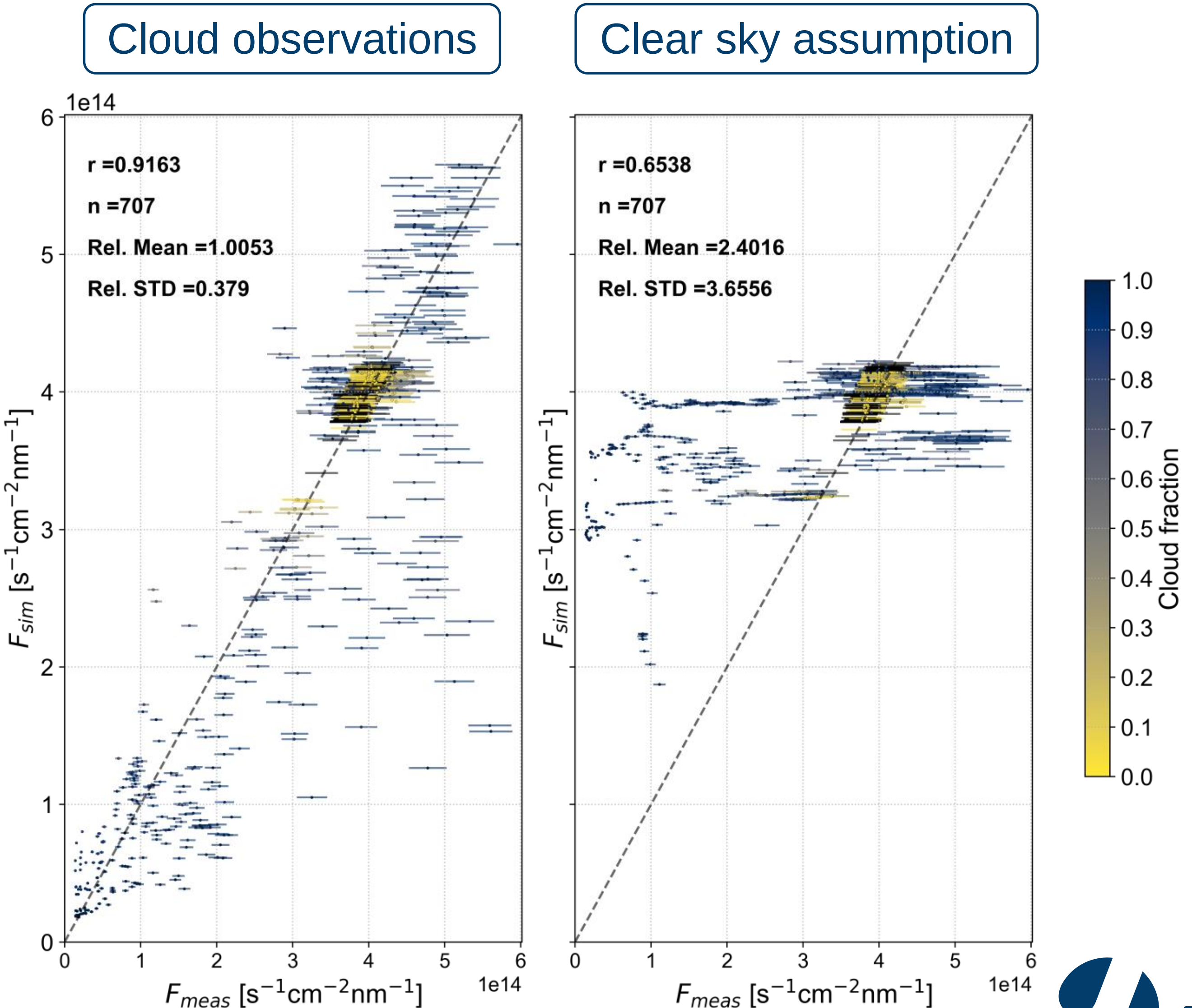
Cloud top height / EMeRGe-EU flight 11.07.2017



Simulated total actinic flux density / EMeRGe-EU flight 11.07.2017



Simulated total actinic flux density / EMeRGe-EU flight 11.07.2017

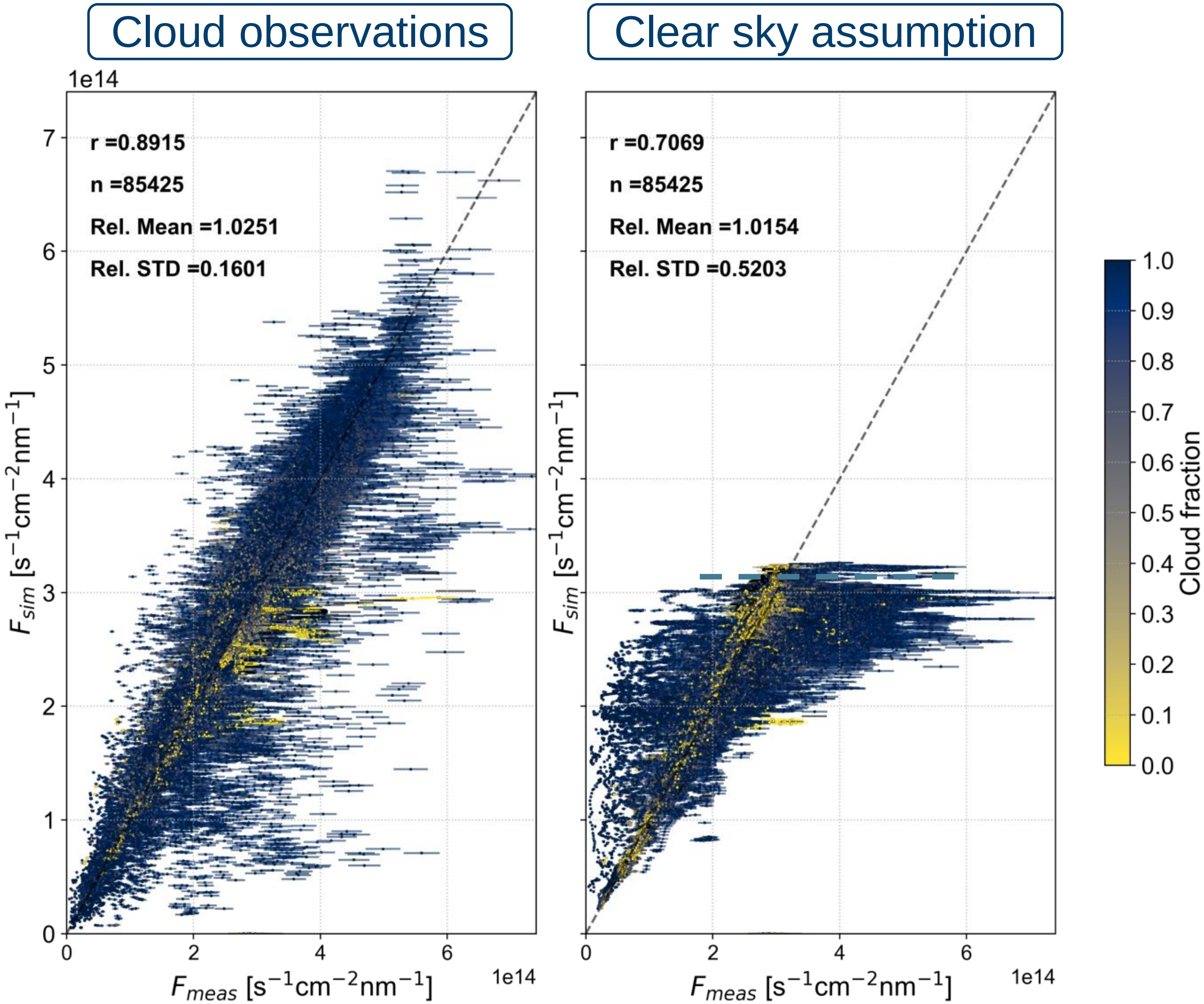


JÜLICH Forschungszentrum

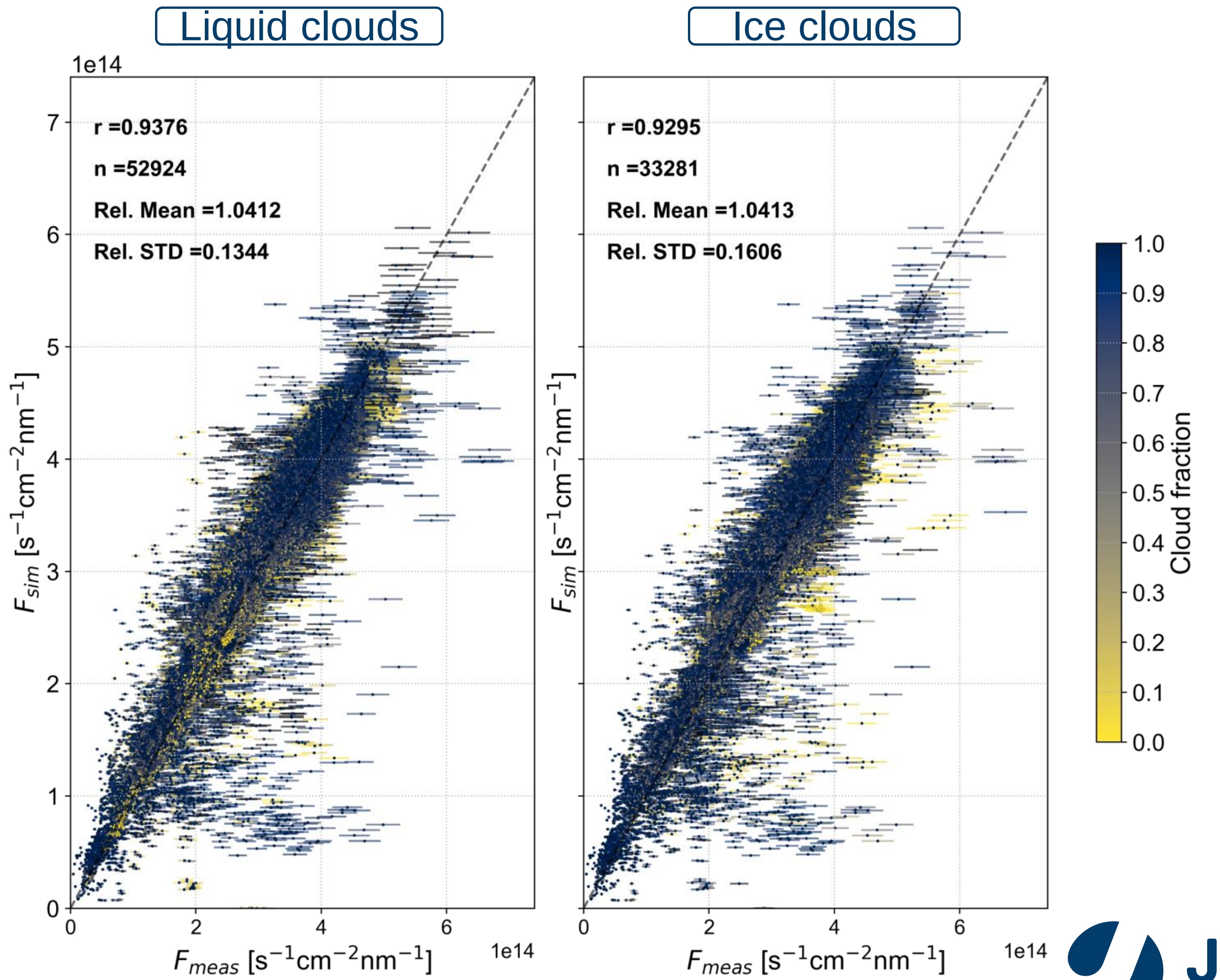
Preliminary results for ALL available missions

Simulated total actinic flux densities - all flight mission (350 nm)

- Cloud impact visible in large under- and overestimations
- "Upper limit" of clear sky simulations
- **Improved agreement using satellite observations of clouds**



Simulated total actinic flux densities – liquid and ice clouds (350 nm)



JÜLICH Forschungszentrum

Interpolation of cloud products along flight routes

- Rapidly evolving cloud structures not captured with satellite imagery ($\Delta t < 15$min)
- Flight passages through clouds not well reproduces (limit of satellite retrieval)

⇒ Limitation of 1-D approach (by averaging over a larger area)

Inclusion of clouds leads to general improvement of simulated actinic flux densities

- Mie-Theory & ice cloud parametrization from Baum et. al (2014) show good agreement for large dataset

⇒ Compare to simpler parametrizations and all liquid/ice cloud approaches

Outlook: Investigate aircraft-cloud position relation, impact of land surfaces and individual campaigns

Goal: Chemistry-transport model case study based on satellite observations

References

- Ryu, Y.-H., et al. (2017), Improved modeling of cloudy-sky actinic flux using satellite cloud retrievals, *Geophys. Res. Lett.*, 44, 1592–1600.
- Emde, C., et al. (2016), The libRadtran software package for radiative transfer calculations (version 2.0.1). Geoscientific Model Development, 9 (5), 1647–1672.
- Minnis, P., et al. (2011), CERES Edition-2 Cloud Property Retrievals Using TRMM VIRS and Terra and Aqua MODIS Data—Part I: Algorithms. IEEE Transactions on Geoscience and Remote Sensing, 49 (11), 4374–4400.
- Schaaf, C., Wang, Z. (2015), MCD43A3 MODIS/Terra+Aqua BRDF/Albedo Daily L3 Global - 500m. NASA LP DAAC. https://doi.org/10.5067/MODIS/MCD43A3.006
- Van der A, R. J., Allaart, M. A. F., and Eskes, H. J. (2015), Multi-Sensor Reanalysis (MSR) of total ozone, version 2. Dataset. Royal Netherlands Meteorological Institute (KNMI), https://doi.org/10.21944/temis-ozone-msr2
- Platnick, S., et al. (2015), MODIS Atmosphere L3 Daily Product. NASA MODIS Adaptive Processing System, Goddard Space Flight Center, USA: https://dx.doi.org/10.5067/MODIS/MOD08_D3.061
- Baum, B. A., Yang, P., Heymsfield, A. J., Bansemer, A., Merrelli, A., Schmitt, C., and Wang, C.: Ice cloud bulk single-scattering property models with the full phase matrix at wavelengths from 0.2 to 100 µm, J. Quant. Spectrosc. Radiat. Transfer, special Issue ELS-XIV, 2014.
- Zhonghai Jin, Yanli Qiao, Yingjian Wang, Yonghua Fang, and Weining Yi, "A new parameterization of spectral and broadband ocean surface albedo," Opt. Express 19, 26429-26443 (2011)

Extras

1D radiative transfer calculations (libRadtran) based on satellite observations

Atmospheric parameters

- Trace gas, temperature & pressure profiles
- Ozone column
- Aerosols
- Liquid/Ice clouds
- Surface properties
- Wind speed
- ...

⇒ Absorption properties
⇒ Parametrizations
⇒ Aerosol & cloud physics

Optical properties

Profiles of:

- Extinction coefficient
- Single scattering albedo
- Scattering phase functions/matrix
- Reflectance function

Satellite observations

⇒ RTE SOLVER

Radiation quantities

- Radiances/stokes vector
- Irrandiance
- Actinic flux densities

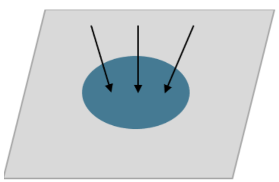
Postprocessing

Radiation quantities

- Calibrated radiances/stokes vector
- Irradiance
- Actinic flux densities
- Brightness temperature
- ...

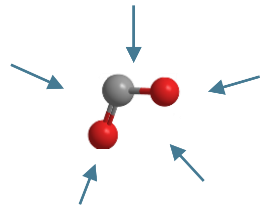
Adapted from Emde et al. 2016

Actinic flux density



- Irradiance: (net) radiation flux incident on a (horizontal) surface

$$E = \int_0^{2\pi} \int_0^{\frac{\pi}{2}} I(\theta,\varphi) \cos\theta \sin\theta \, \mathrm{d}\theta \, \mathrm{d}\varphi$$



- Actinic flux: radiation flux spherically integrated (isotropic)

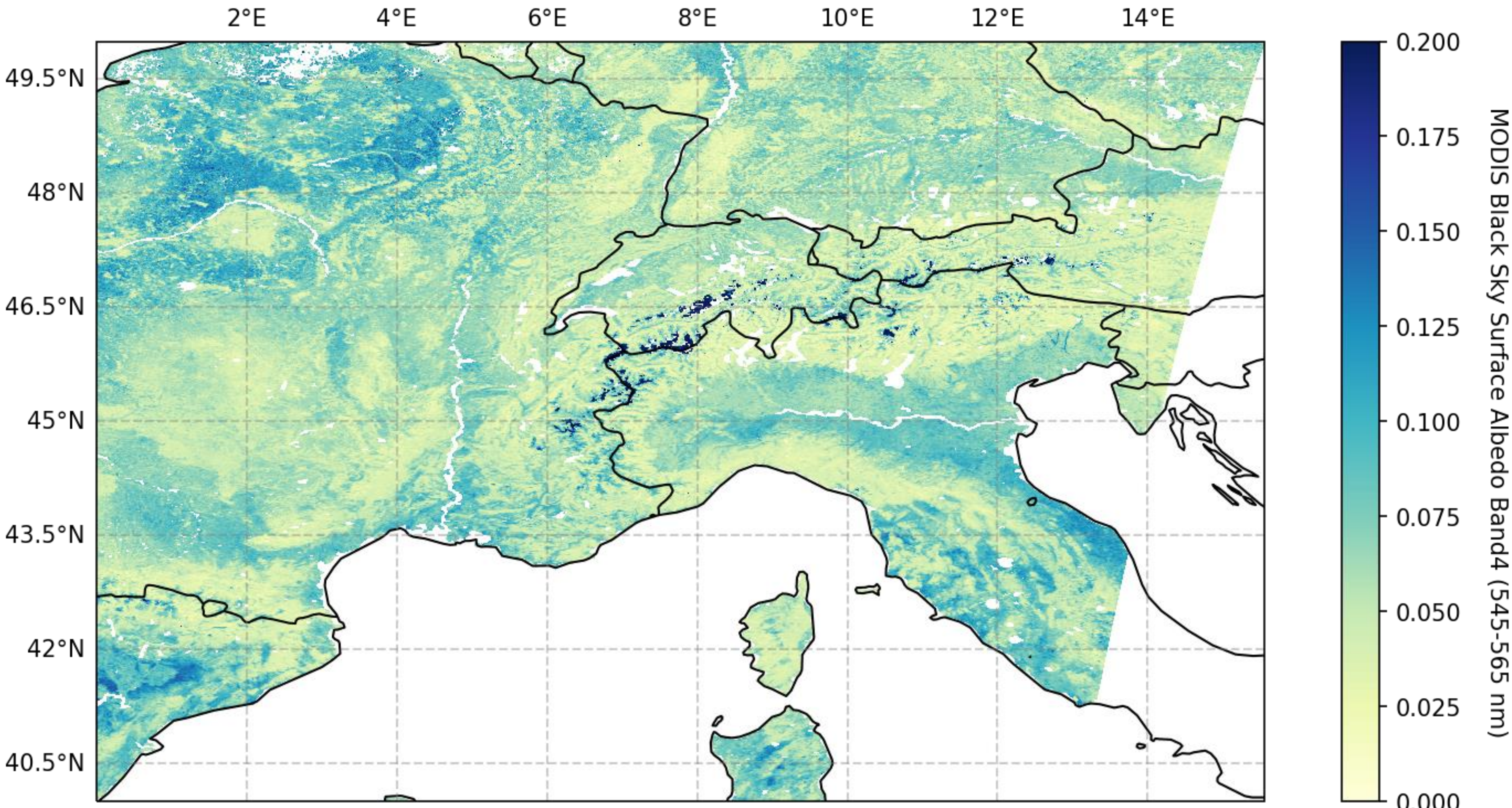
$$F = \int_0^{\pi} \int_0^{2\pi} I(\theta,\varphi) \sin\theta \, \mathrm{d}\varphi \, \mathrm{d}\theta$$

Page 20

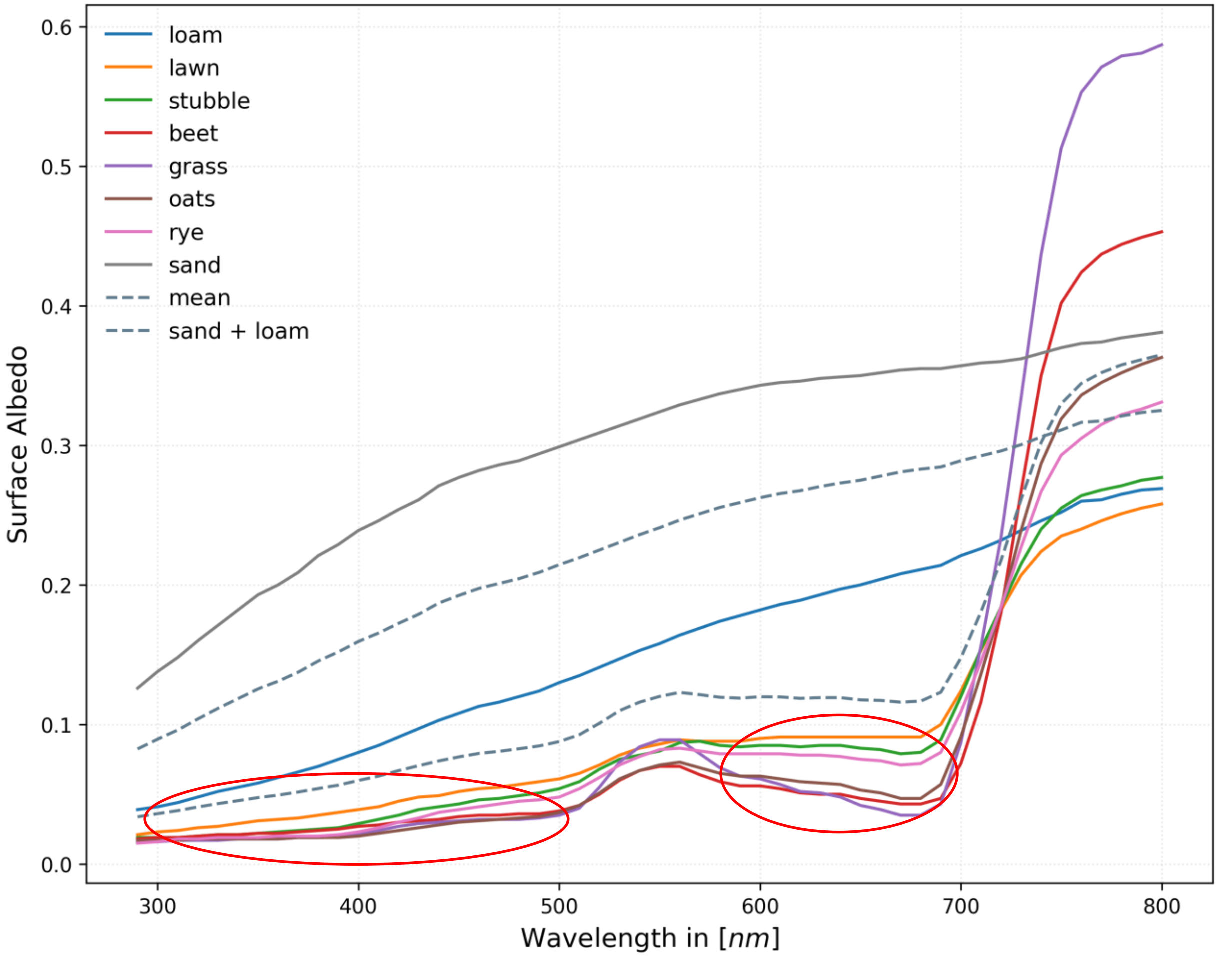
Interpolation of albedo products originating from satellite measurements along the flight tracks of HALO aircraft

- Global Albedo product (MODIS: Terra/Aqua, ~500 m x 500 m):
  - 16-Day mean ground albedo (4 MODIS Bands used (620-670nm, 841-876nm, 459-479nm, 545-565nm) for land only

Highly resolved MODIS tile, no albedo retrieval over water surfaces



Narrow band MODIS albedo to spectral albedo conversion

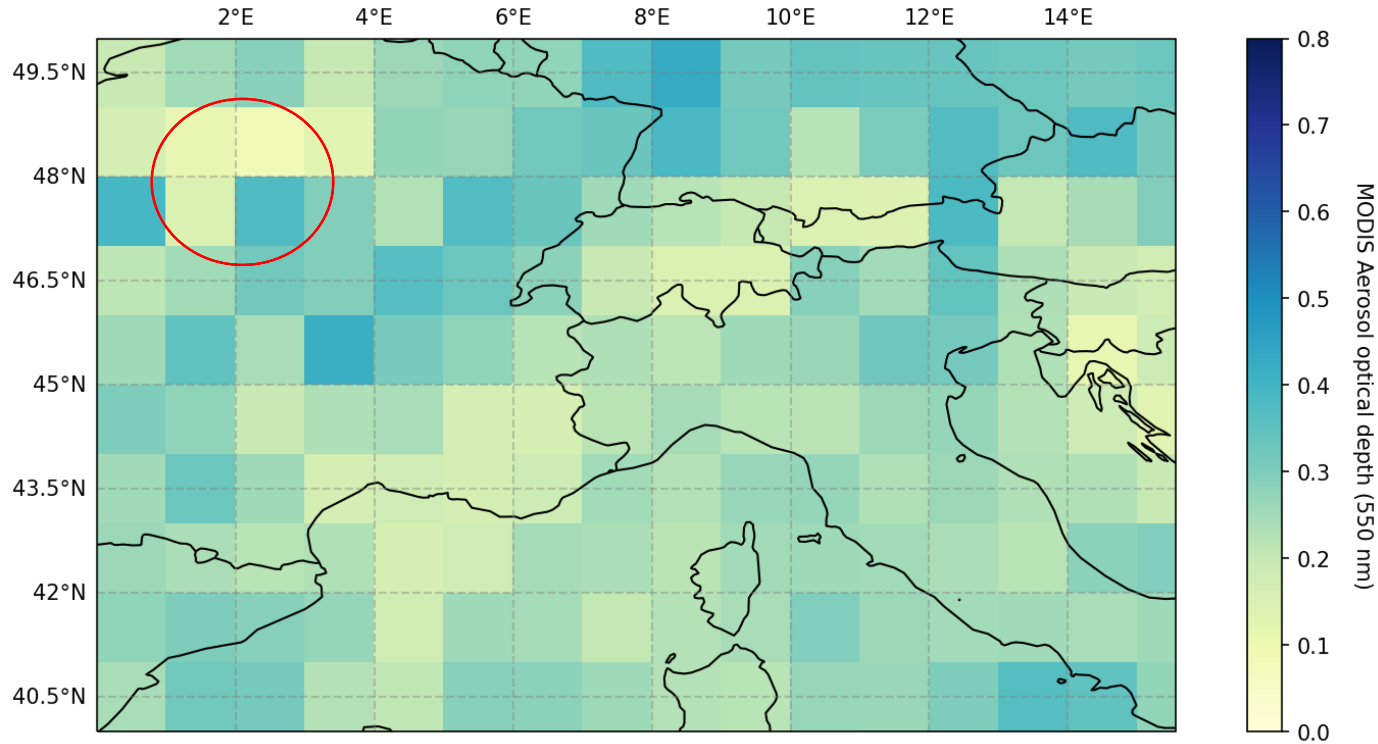


$$\begin{pmatrix} MODIS\ Band3 \\ MODIS\ Band4 \\ MODIS\ Band1 \end{pmatrix} = a \begin{pmatrix} grass\ 460nm \\ grass\ 550nm \\ grass\ 650nm \end{pmatrix} + b \begin{pmatrix} sand + loam\ 460nm \\ sand + loam\ 550nm \\ sand + loam\ 650nm \end{pmatrix} + c \begin{pmatrix} mean\ 460nm \\ mean\ 550nm \\ mean\ 650nm \end{pmatrix}$$

JÜLICH Forschungszentrum

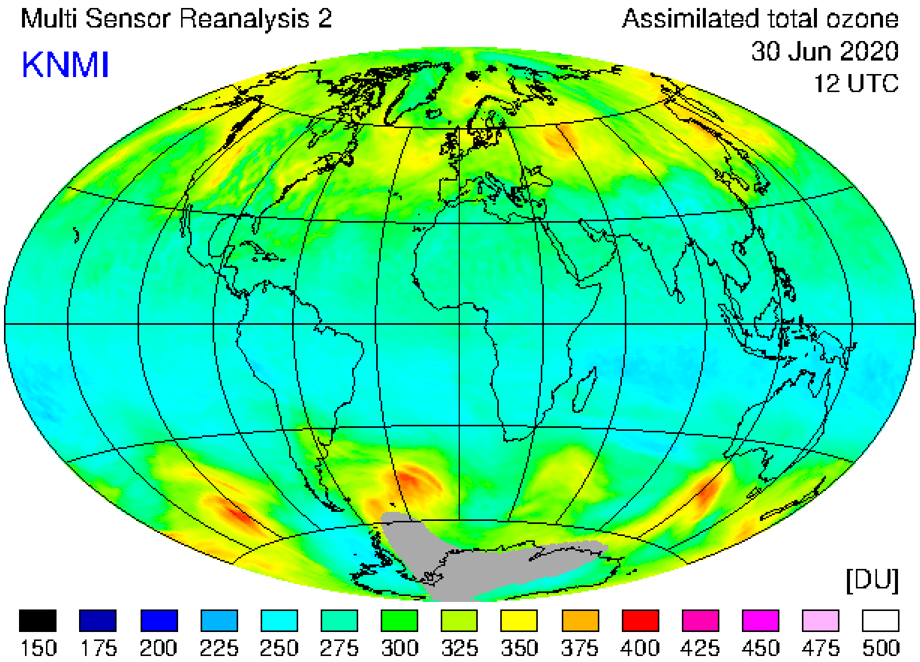
Interpolation of aerosol products originating from satellite measurements along the flight tracks of HALO aircraft

- Global Aerosol (MODIS: Terra/Aqua, ~ 1° x 1°):
  - 8-Day averages of column integrated aerosol optical thickness (land and ocean)



Interpolation of ozone column products originating from satellite measurements along the flight tracks of HALO aircraft

- Global Ozone Column (MSR-2, ~ 1° x 1°)
  - 12-hourly data of total assimilated ozone columns



Taken from temis.nl

JÜLICH Forschungszentrum