Retrieval of tropospheric ozone columns from SCIAMACHY limb-nadir matching observations

EGU 2012-48, AS 3.10, XY74

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1) Introduction and aim

The retrieval of tropospheric ozone from satellite instruments is still a great challenge due to the difficulties in separating tropospheric ozone from stratospheric ozone, which accounts on average for 90% of the total ozone columns.

A number of methods have been used to retrieve tropospheric ozone from satellite observations, including methods using a residual approach, pioneered by Fishman and Larsen (1987), where the tropospheric ozone columns was derived by subtracting the Stratospheric Column Ozone (SCO) from the Total Column Ozone (TCO). This approach has undergone several modifications over the years. Some other techniques that have been used to retrieve tropospheric ozone include, convective cloud differential techniques (Ziemke et al., 2006), solar backscattered UV spectra (Liu et al., 2010) using the optimal estimation technique (Rodgers, 2000).

The retrieval of tropospheric ozone from SCIAMACHY using the limb-nadir matching technique is a residual approach and would be of great importance to improving our understanding of the processes controlling tropospheric ozone abundances on local, regional and global scales.

2) Schematics of SCIAMACHY limb-nadir matching observations

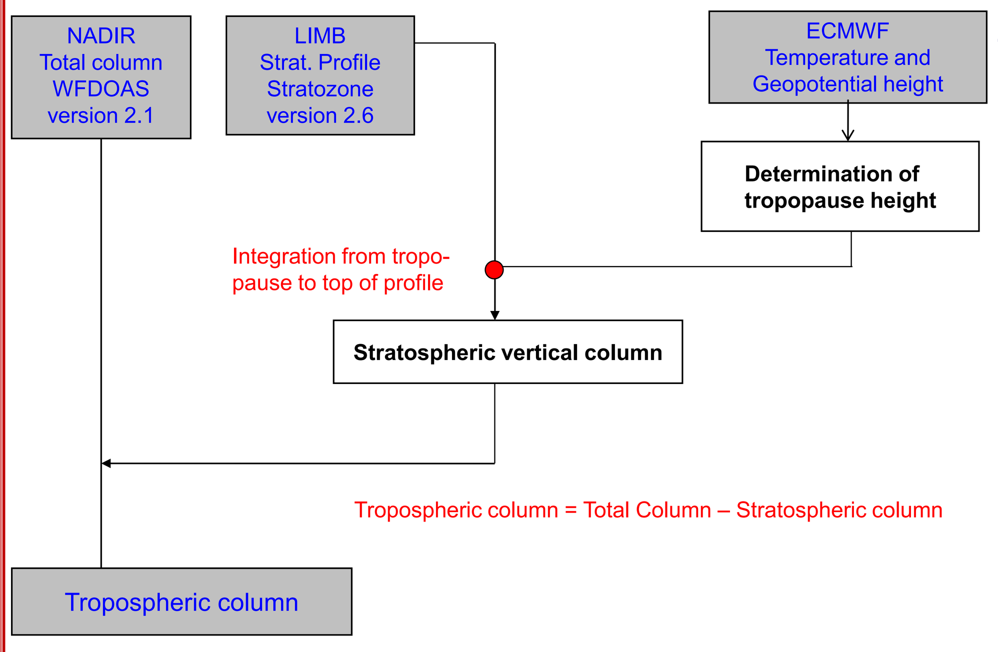

Figure 1: Illustration of the limb-nadir matching technique

Features:

- Stratospheric ozone columns derived from the stratospheric ozone profiles using ozone triplet method (Sonkaew et al., 2009)
- Total ozone columns derived from nadir ozone profiles using the weighting function DOAS (WFDOAS) techniques (Coldewey-Egbers et al., 2005)
- Tropopause height determined from ECMWF reanalysis data
- Tropospheric ozone column is obtained by subtracting the stratospheric ozone columns from the total ozone columns

3) Methodology

Stratospheric ozone profile retrieval (Ozone triplet method)

$$I_N(\lambda_K, TH_i) = \frac{I(\lambda_K, TH_i)}{I(\lambda_K, TH_{ref})}$$ Tangent height normalization

Chappuis triplet

$$I_{Chap}(TH_i) = \frac{I_N(602nm, TH_i)}{\sqrt{I_N(525nm, TH_i) \times I_N(672nm, TH_i)}}$$

Constructing retrieval vector of Hartley + Chappuis band

$$Y_{ret} = (I_N(\lambda_1, TH_{\lambda_1,1}), \ldots, I_N(\lambda_1, TH_{\lambda_1,N_{\lambda_1}}), \ldots, I_{Chap}(TH_{Chap,1}), \ldots, I_{Chap}(TH_{Chap,N_{Chap}}))^T$$

Total ozone column retrieval (WFDOAS)

$$\ln\frac{I_{obs}}{F_{obs}} = \ln\left(\frac{I}{F}\right)_{mod} + \frac{d\ln\left(\frac{I}{F}\right)}{dTOZ}\bigg|_{mod}(TOZ_{fit} - TOZ_{clim}) + \frac{d\ln\left(\frac{I}{F}\right)}{dT}\bigg|_{mod}(T_{fit} - T_{clim}) + \ldots + Pol$$

Radiation transfer model

Determination of tropopause height (thermal tropopause)

WMO criterion using lapse rate definition

$$\left(\frac{\partial T}{\partial Z}\right)_{i+(1/2)} = \left(\frac{T_{i+1} - T_i}{Z_{i+1} - Z_i}\right)$$

Determination of the lowest level that fulfils: $\left(\frac{\partial T}{\partial Z}\right)_{i+(1/2)} \geq -2Kkm^{-1}$ & $\left(\frac{\partial T}{\partial Z}\right)_{i-(1/2)} < -2Kkm^{-1}$

Tropopause height is set at $$Z_{TP} = Z_{i-(1/2)} + \frac{\gamma_{TP} - \left(\frac{\partial T}{\partial Z}\right)_{i+(1/2)}}{\left(\frac{\partial T}{\partial Z}\right)_{i+(1/2)} - \left(\frac{\partial T}{\partial Z}\right)_{i-(1/2)}} Z_{i+(1/2)} - Z_{i-(1/2)}$$ where $\gamma_{TP} = -2Kkm^{-1}$ is the threshold value of the thermal criterion

Determination of tropopause height (dynamic tropopause)

The vertical temperature gradient is replaced by the potential vorticity, the hydrostatic form of PV in z coordinate is given by

$$P = \frac{1}{\rho}(f\kappa + \nabla \times v).\nabla\theta$$

Tropopause height is set at

$$Z_{TP} = Z_{i-(1/2)} + (Z_{i+(1/2)} - Z_{i-(1/2)})\frac{P_{TP} - P_{i-(1/2)}}{P_{i+(1/2)} - P_{i-(1/2)}}$$

Features

- Combination of thermal (*WMO criterion*) and dynamic (*PV > 3.0 x 10^{-6} m^2 K $kg^{-1}s^{-1}$*) tropopause
- Thermal tropopause between 0° and 20° latitude
- Dynamic tropopause at latitudes higher than 30°
- Weighted mean between 20° and 30° latitude

4) Results: Validation of tropospheric ozone columns

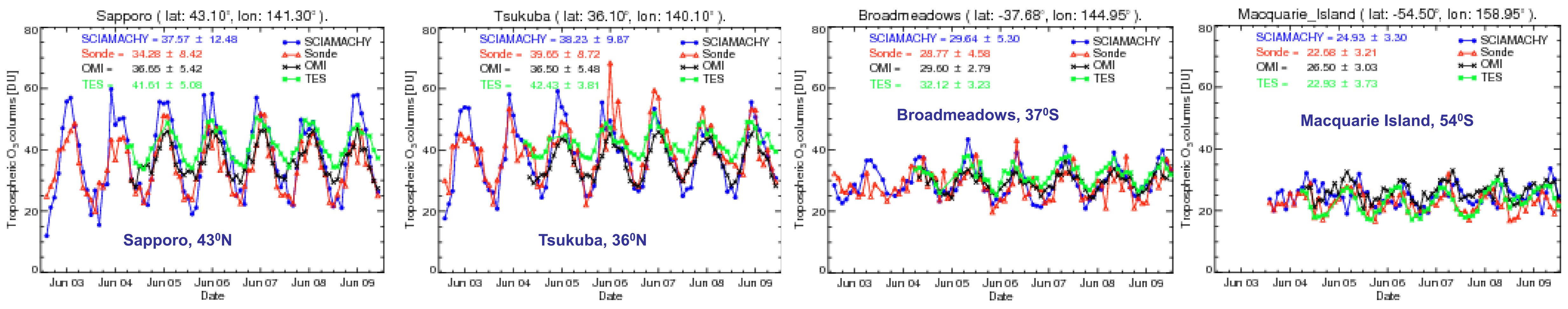

Figure 2: Comparison time series of tropospheric ozone monthly mean in Dobson Units (DU) between SCIAMACHY in blue and ozonesondes in red, OMI in black, TES in green over Tsukuba, Sapporo, Broadmeadows and Macquire Island.

Features:

- Strong seasonal cycle depicted mostly in the northern mid-latitudes by all instruments
- Less scatter in the linear plot
- All four instruments agree quite well in the mid latitudes

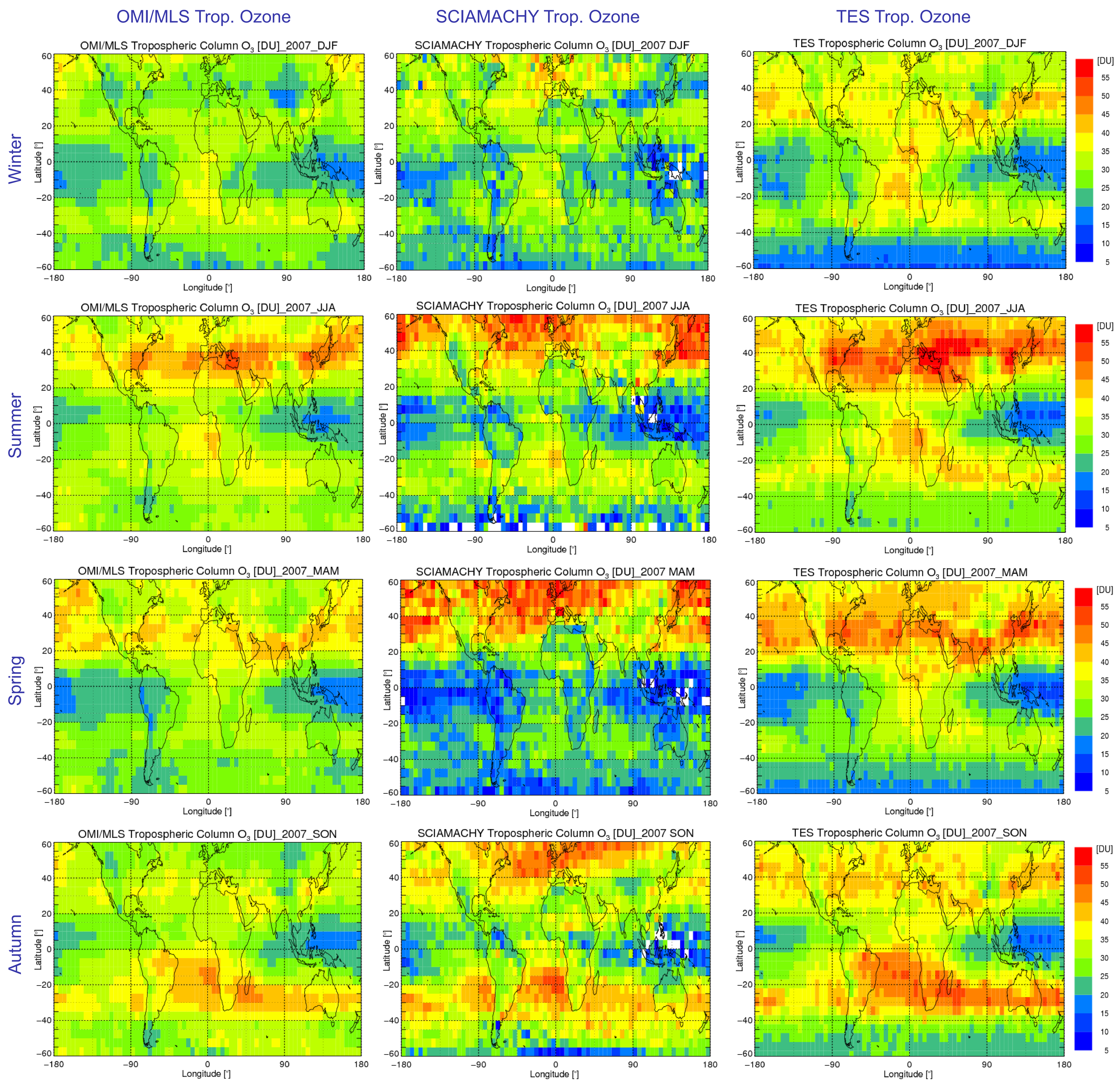

Figure 3: Tropospheric ozone distributions in Dobson Units from left to right OMI/MLS, SCIAMACHY and TES and from top to bottom DJF, JJA, MAM and SON in 2007

- The seasonal distribution of tropospheric O_3 in both hemispheres shows good correlation with its precursors
- All three satellite instruments show similar pollution features in some regions
- Observed regional difference, which may be due to difference in retrieval algorithm and overpass time
- Low ozone values at the western pacific during boreal spring observed by all three instruments
- Tropospheric ozone pollution features shown by SCIAMACHY are similar to those of TES, OMI/MLS values are lower in some regions

5) Possible error sources

- Clouds effect, which is supposed to be a major source of error on tropospheric ozone retrieval, including, albedo effect, increase in-cloud absorption and shielding effect was handled using two cloud algorithms (SemiAnalytical CloUd Retrieval Algorithm (SACURA) and SCIAMACHY ClOud Detection Algorithm (SCODA))
- Cloud free pixels were considered in the computation of stratospheric ozone columns and 10 % threshold was allowed in the determination of total ozone columns
- Error in stratospheric ozone column from the different error parameters (albedo, aerosol, temperature, pressure, tangent height) introduce about 15-20% error in tropospheric ozone retrieval
- The different error sources (total ozone columns, stratospheric ozone columns, tropopause height) lead to typical errors of about 5 – 25% or even more in extreme cases in tropospheric ozone columns

6) Summary and conclusions

- Comparisons of tropospheric O_3 columns with ozonesondes observation show good overall agreement (incl. seasonal cycle)
- Comparisons of tropospheric O_3 columns with other satellite observations show good agreement only with some regional deviations
- Observed differences with the ozonesonde instruments are within the estimated errors

Acknowledgements

This work was funded in parts by the German Aerospace DLR project SADOS (FKZ 50EE1105), by ESA through the SCIAMACHY Quality Working Group and by the University and State of Bremen, Germany. SCIAMACHY is jointly funded by Germany, the Netherlands and Belgium.

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