# The determination of cloud top height using hyperspectral measurements in the oxygen A-band

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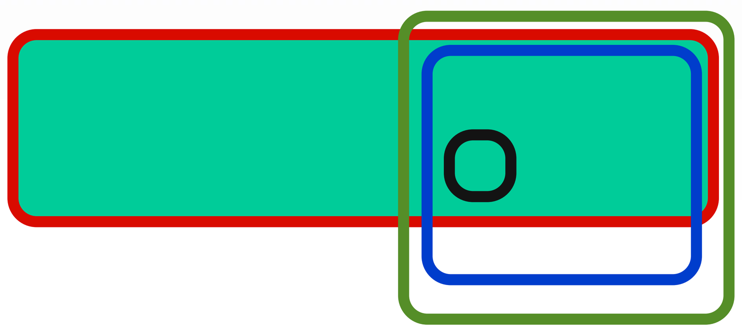
## Introduction

The information on the aerosol and cloud top height (CTH) is of importance for a number of applications including climate change studies, weather observation, aviation safety and volcanic ash hazard. In most of cases the cloud top height is obtained from the thermal infrared (TIR) observations (e.g., at 11 and/or 12 microns). The thermal infrared methods are quite accurate in identifying the position of cloud tops. However, they may fail for thin aerosol layers and also they are not capable to give information on the cloud structure beneath the upper cloud in case of common multi-layered cloud systems (e.g., the thick Stratocumulus cloud with thin Cirrus cloud above). This poster presents the capabilities of the CTH retrieval using the top-of-atmosphere spectral reflectance measurements in the oxygen A-band located around 761nm. The method is less sensitive to thin Cirrus clouds and gives primarily the position of the lower thick cloud deck. The TIR method can provide the CTH for the upper layer and the O2 absorption method then gives the CTH position for the lower cloud assuming the 2-layer system in the retrieval process. The retrieval method presented here was applied to the hyperspectral GOME and SCIAMACHY measurements. It can be applied to the measurements in the oxygen A-band performed by current and future radiometers, imagers, and polarimeters such as 3MI of the EUMETSAT Polar System – Second Generation dedicated to aerosol and cloud characterization (Marbach et al., 2013).

| | GOME ERS-2 | SCIAMACHY ENVISAT | GOME-2 METOPs | TROPOMI S-5 p |
|---|---|---|---|---|
| LT | 10h30 | 10h00 | 9h30 | 13h30 |
| Global coverage | 3 days | 6 days | 1.5 days | 1 day |
| Time span | 1996 - 2010 | 2002 - 2012 | 2007 - 2021 | 2015 - 2022 |
| Swath | 960 km | 1000 km | 1920 km | 2600 km |
| Spectral coverage | 290-800 nm | 240-2400 nm | 290-800 nm | 270-775 nm + SWIR |
| Spectral resolution | 0.38 nm | 0.44 nm | 0.48 nm | 0.25-0.55 nm |
| Polarization channels | 3p | 6p | 15(s,p) | --- |

*Table 1: The satellite instrumentation capable of the spectral top-of-atmosphere reflectance measurements in the oxygen A-band.*



GOME (320 x 40 km)
SCIAMACHY (60 x 40 km)
GOME-2 (80 x 40 km)

TROPOMI (7 x 7 km)
1.8 x 1.8 km $O_2$ A-band

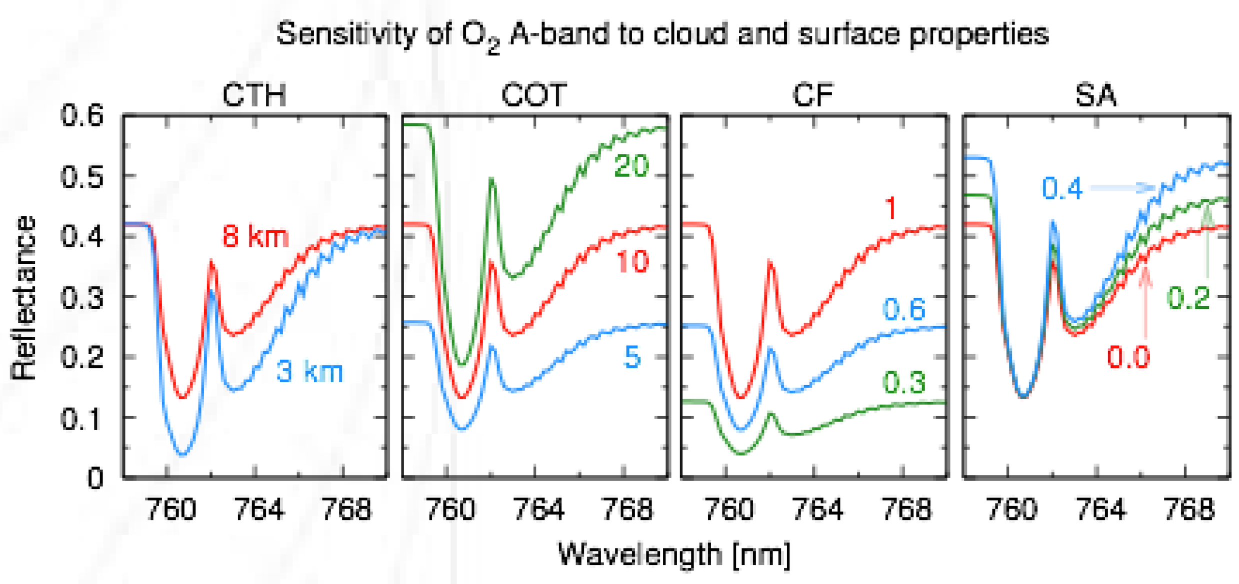
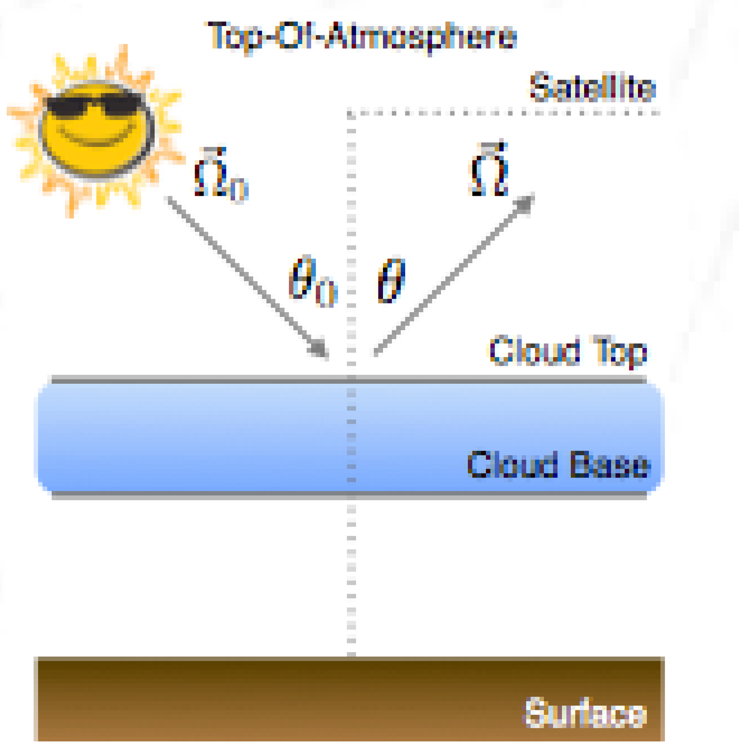



*Figure 1: Sensitivity of top-of-atmosphere spectral reflectance to the variation of the cloud top height, cloud optical thickness, cloud fraction, and surface albedo. The calculations have been performed with the software package SCIATRAN (Rozanov et al., 2014).*




$$R_{TOA}(\lambda) = R_a(\lambda) + T_1(\lambda)\, R_b(\lambda)\, T_2(\lambda)$$

$$R_b(\theta,\theta_0) = R_\infty(\theta,\theta_0) - t\, K_0(\theta)K_0(\theta_0) + \frac{A\, t^2 K_0(\theta)K_0(\theta_0)}{1 - A\,(1-t)}$$

$$t = \frac{1}{\alpha + 0.75\,\tau\,(1-g)}$$

*Figure 2: The geometry of the problem and main equations*

## The error in the derived CTH

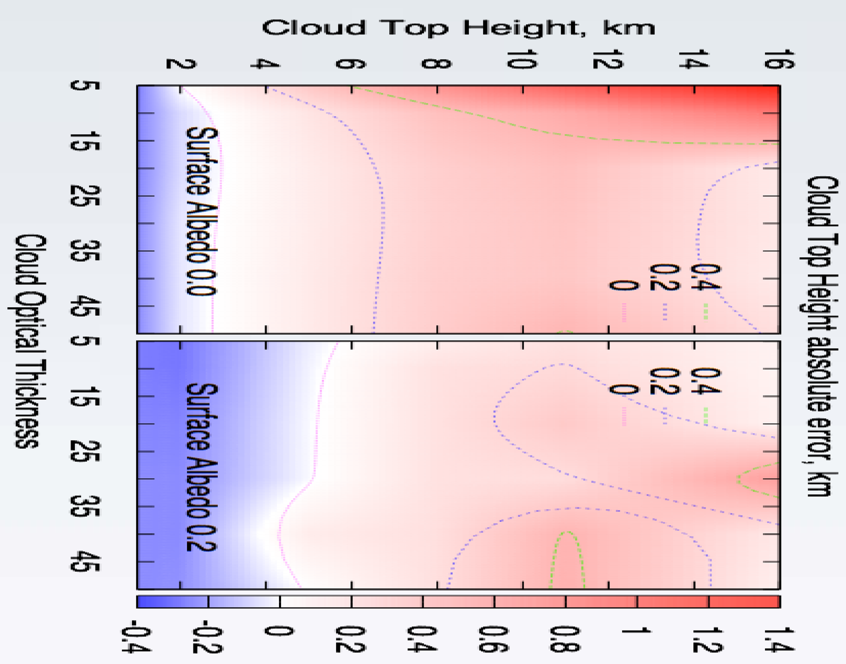



*Figure 3: The error in the retrieved cloud top height as the function of cloud optical thickness and cloud top height for the Lambertian surace albedo of 0.0 and 0.2 . The results are obtained using the synthetic measurements derived using SCIATRAN (Rozanov et al., 2014).*

## The retrievals with different algorithms

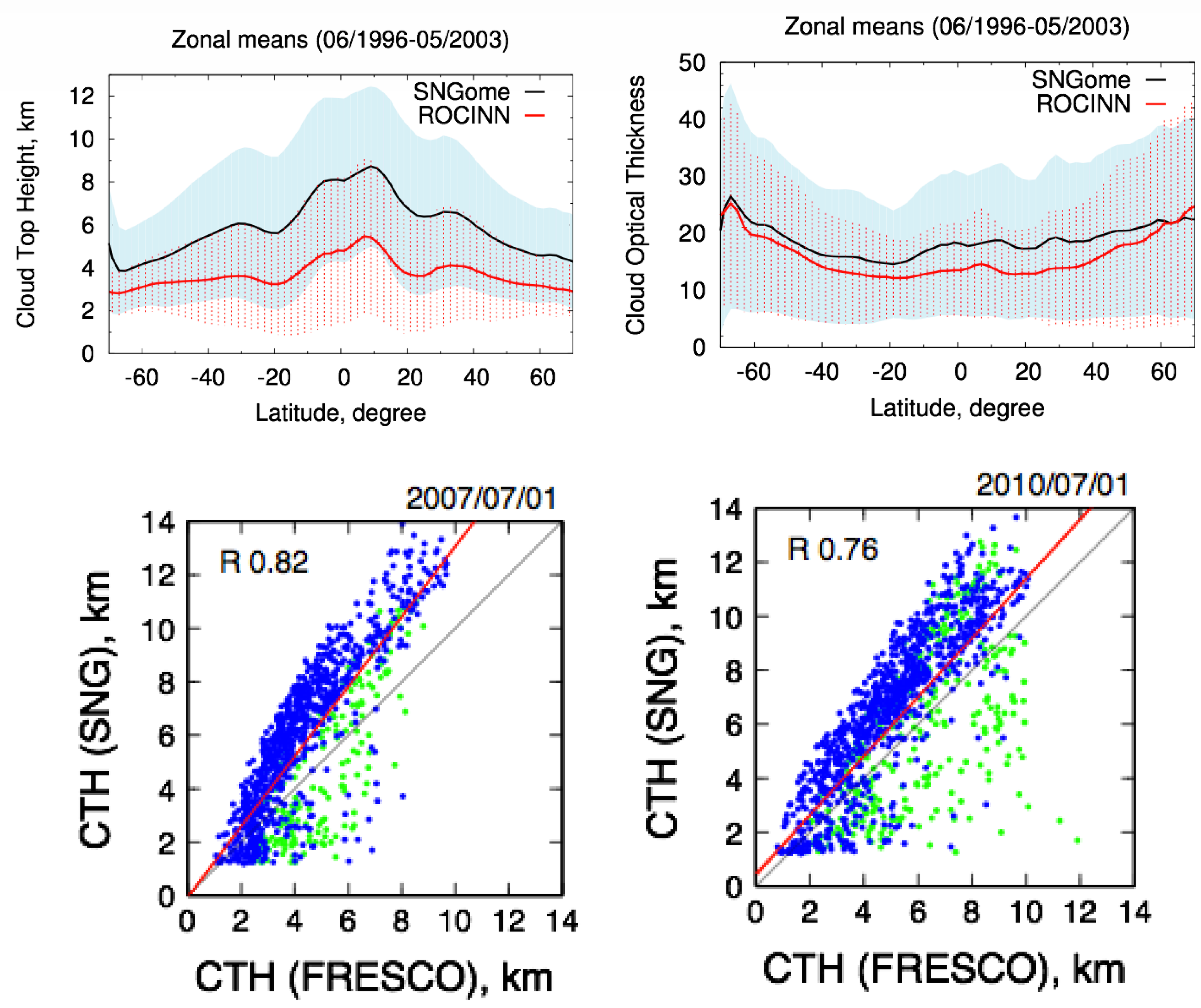



*Figure 4: The comparison of retrievals performed using the SNGome (Uni Bremen), ROCINN (DLR) , and FRESCO (KNMI) algorithms. The differences are due to different forward models. The blue color is for the underlying ocean surfaces, green – for land surfaces.*

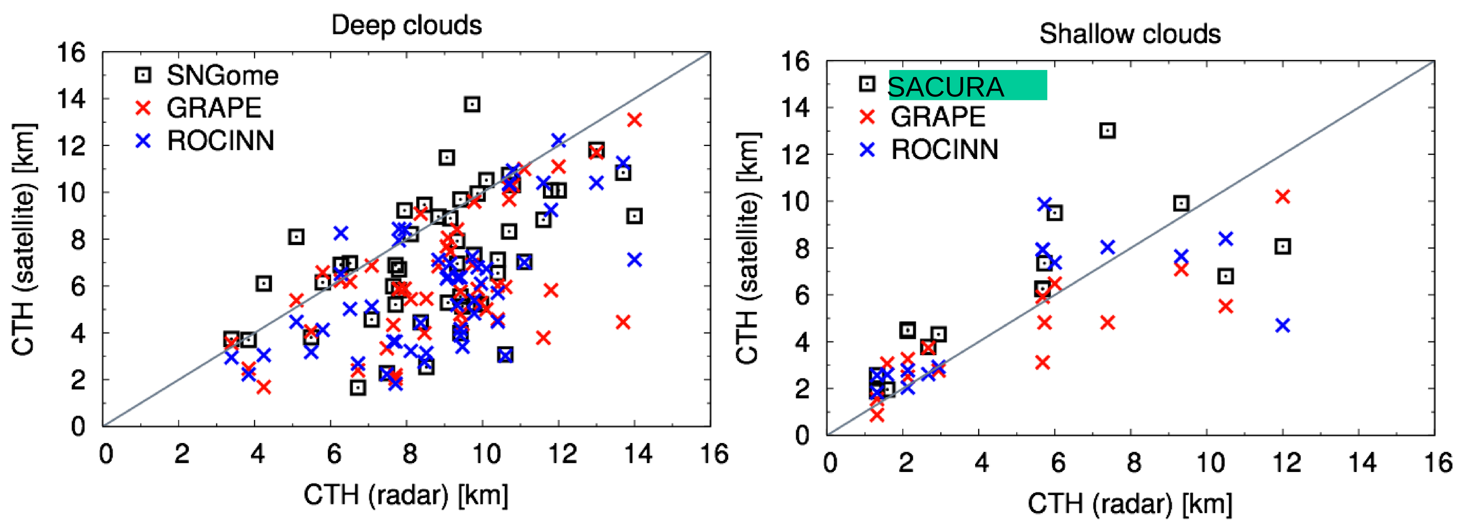



*Figure 5: Global cloud top height retrievals using SNGome/SACURA and ROCINN oxygen A-band algorithms as compared to the ground radar measurements. The results for the retrievals based on TIR measurements (GRAPE (Poulsen et al., 2011)) are given by the blue crosses. Generally, the retrieved CTH for all algorithms is too low as compared to the radar (Lelli et al., 2012).*

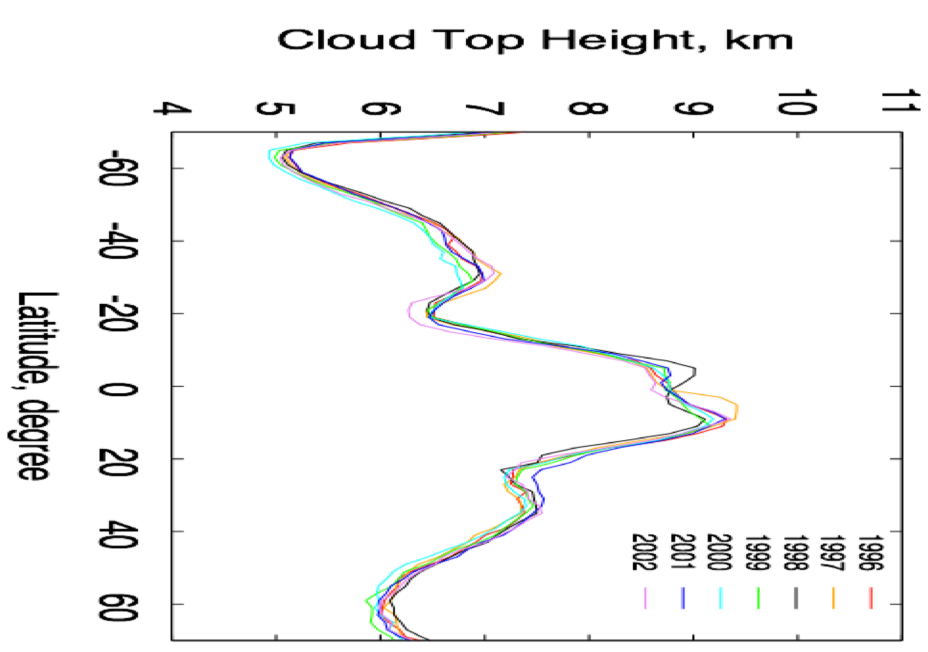
## Inverse problem solution

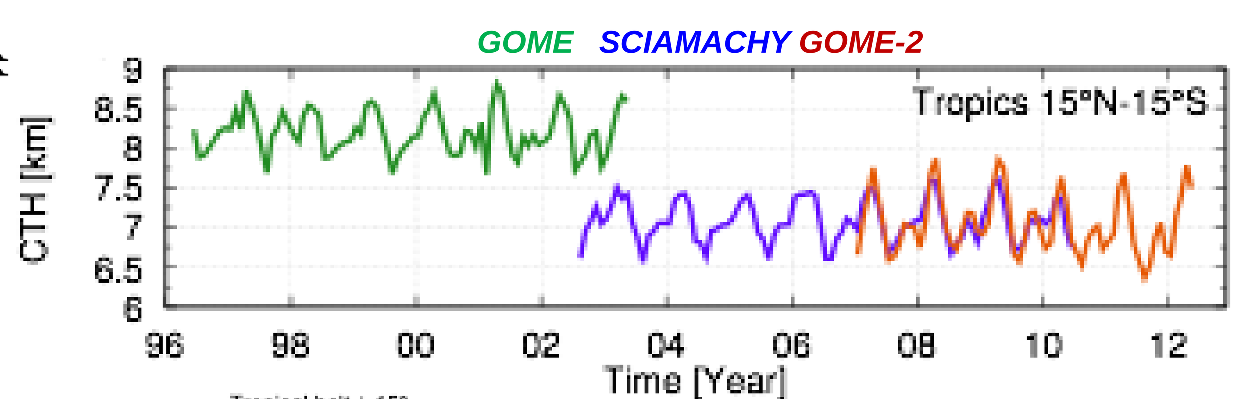
$$\frac{\pi\,\vec{I}}{\cos\theta_0\,\vec{E}_0} = \mathrm{CF}\,\vec{R}_{cl} + (1-\mathrm{CF})\,\mathrm{SA}$$

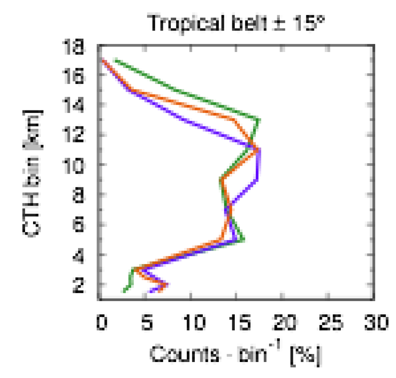
$$\underset{k}{\mathrm{minimize}}\left\| \vec{R}_{cl} - \vec{R}(h_k,l_k) - \frac{\partial \vec{R}(h_k,l_k)}{\partial h}\cdot(h-h_k) - \frac{\partial \vec{R}(h_k,l_k)}{\partial l}\cdot(l-l_k) \right\|^2$$

- ➡ 758 nm Cloud Optical Thickness
  Cloud Spherical Albedo
- ➡761 nm Cloud Top Height
  Cloud Geometrical Thickness
- ➡ 67 spectral points
- ➡ Reflectances normalized to R(758 nm)
- ➡ Effective single scattering albedo in the oxygen A-band value is found (Yanovitskij, 1997)

## Global cloud top height retrievals

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