ACCURATE: Influence of Aerosol and Cloud Layers on Infrared Laser Occultation Signals for Sensing of Greenhouse Gases

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ACCURATE (Atmospheric Climate and Chemistry in the UTLS Region And climate Trends Explorer) is a new climate satellite mission concept enabling simultaneous measurement of profiles of greenhouse gases, thermodynamic variables and wind from Low Earth Orbit (LEO) satellites. The measurement principle applied is a combination of the new LEO-LEO infrared laser occultation (LIO) and the well-studied but not yet flown LEO-LEO microwave occultation (LMO) technique (Fig. 1).

1 Mission Concept

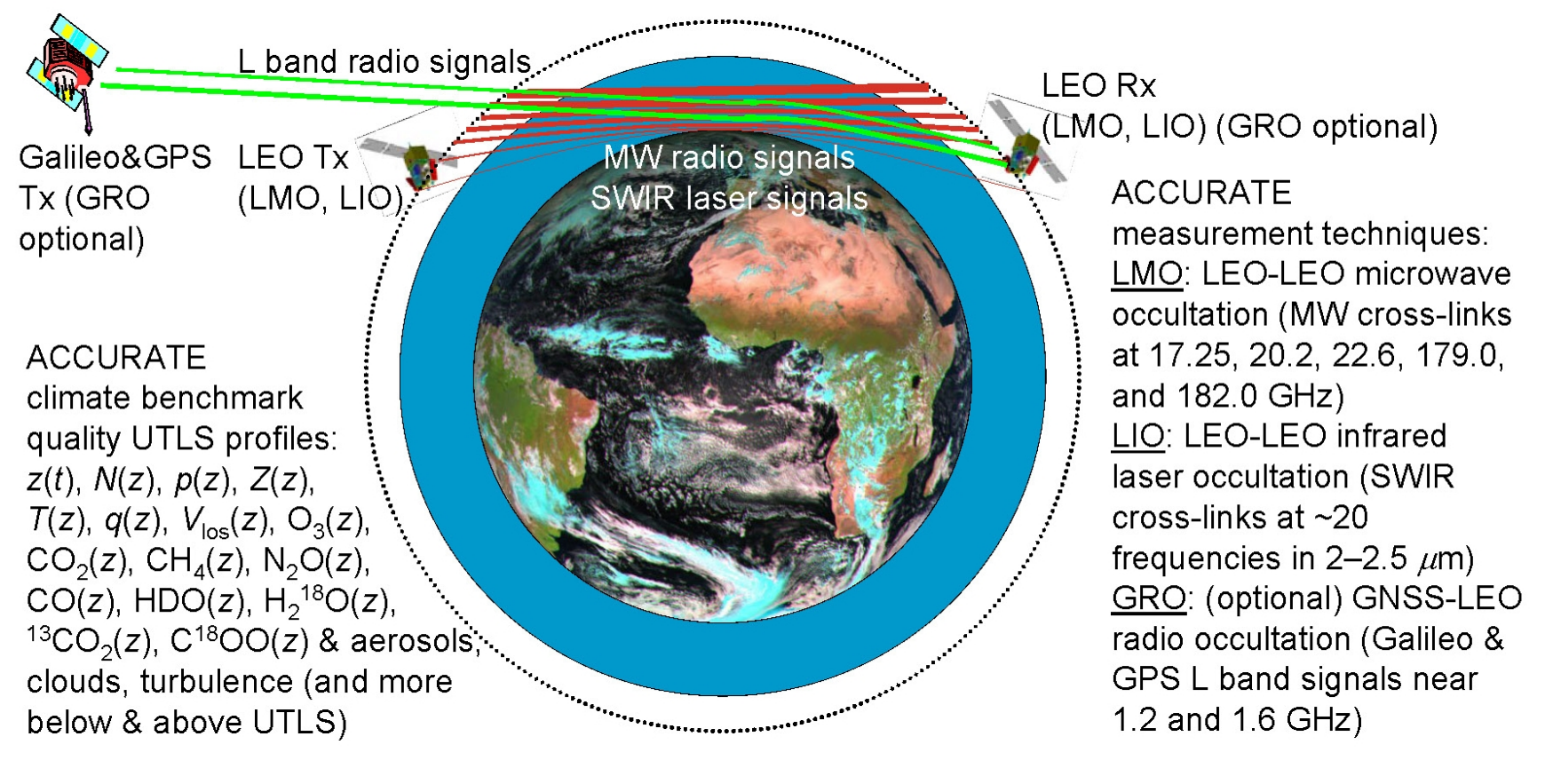


Fig. 1: Schematic view of the ACCURATE technique

The LMO and LIO techniques applied by ACCURATE enable measurements of phase delay / Doppler shift and amplitudes / transmissions. From these measurements, profiles of trace gases, line-of-sight wind, aerosols, scintillation strength and cloud layering (from LIO) as well as pressure/geopotential height, temperature and humidity (from LMO) can be retrieved within the UTLS (Upper Troposphere / Lower Stratosphere). High vertical resolution and accuracy combined with long-term stability are characteristic for the occultation technique.

2 The New LIO Technique

ACCURATE is the first mission applying LIO, which uses carefully selected nearly monochromatic short-wave infrared laser signals in the range between 2-2.5 μm. These signals are sensitive to various trace species in the Earth's atmosphere. A set of thirteen channels was gathered which is absorbent for six greenhouse gases (H_2O, CO_2, CH_4, N_2O, CO, O_3) and four isotopes ($^{13}CO_2$, $C^{18}OO$, HDO, $H_2^{18}O$). Associated to this set six adjacent reference channels are chosen for which the atmosphere is nearly transparent regarding molecular absorption. Subtracting the log-transmission of a reference channel from the one of an absorption channel corrects the transmission from unwanted background influences of the atmosphere.

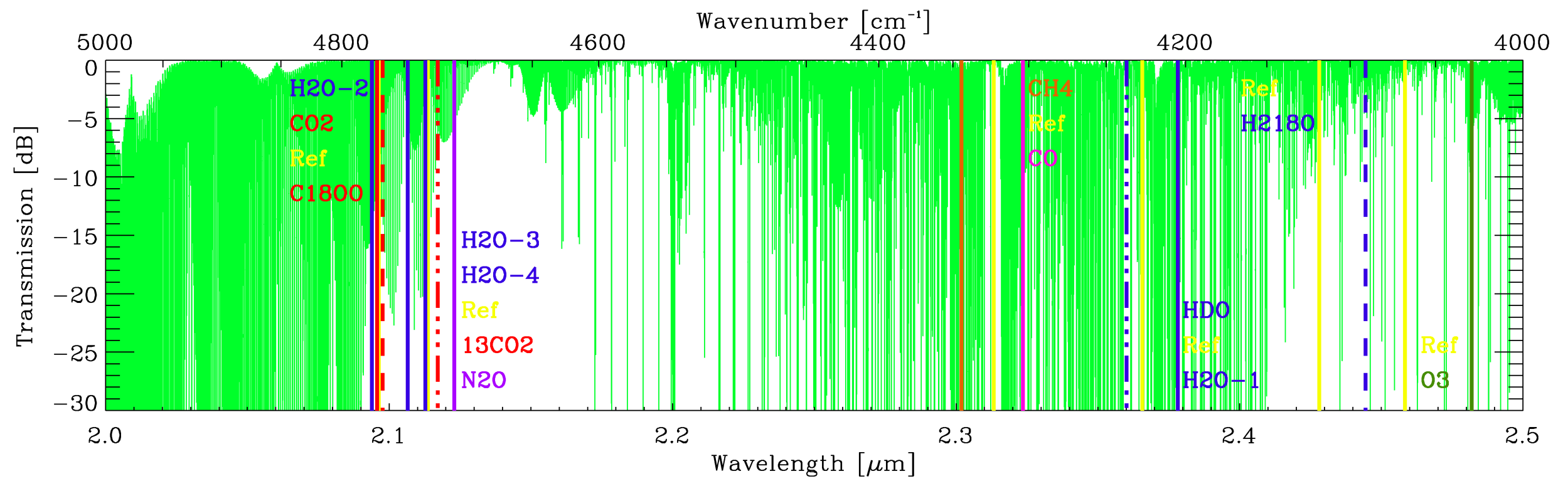
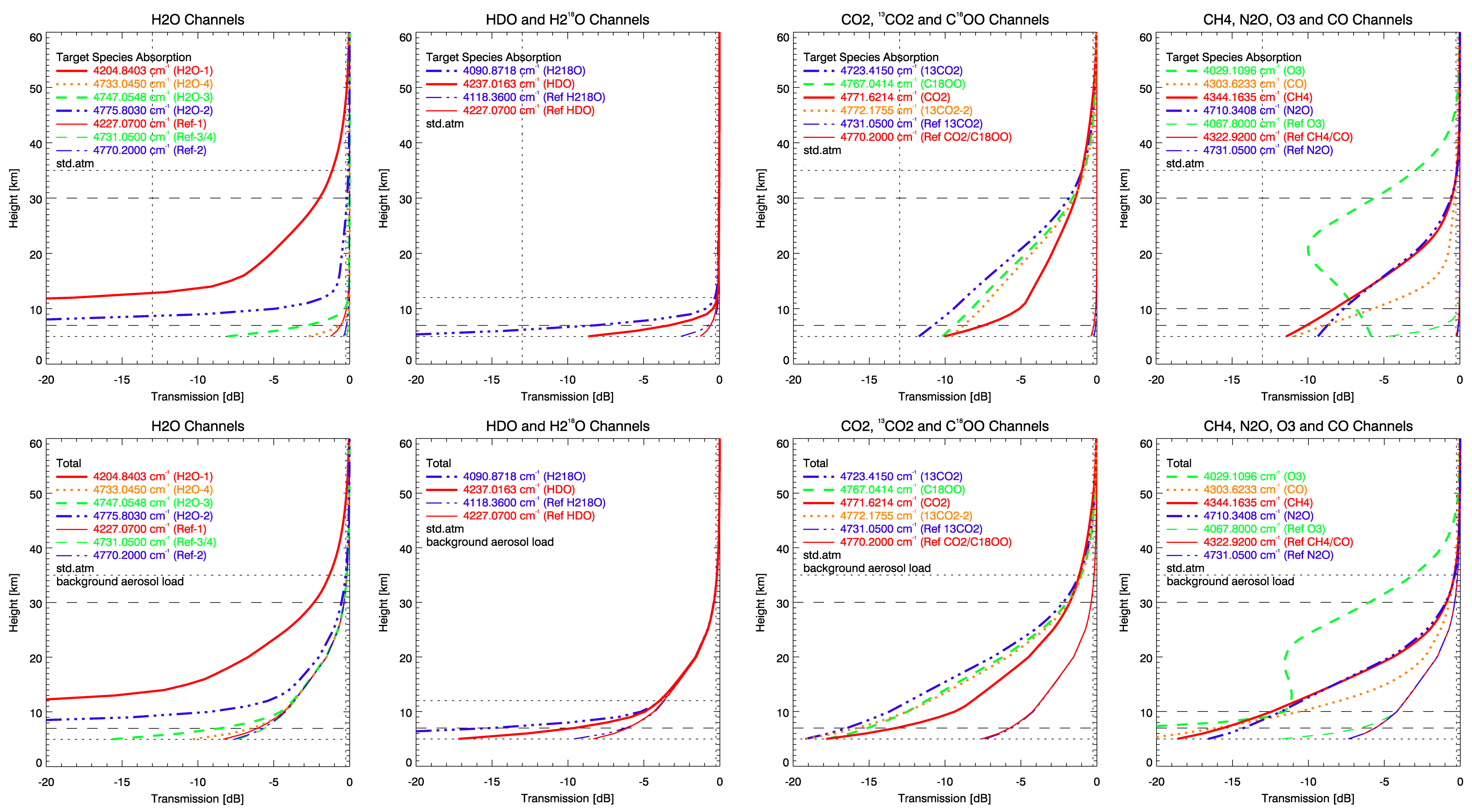


Fig. 2: Tx-to-Rx transmission spectrum over the ACCURATE spectral range for a tangent height of 15 km (top panel). Transmission profiles accounting for the main absorbing species only (middle panels) and total transmission profiles (bottom) for the ACCURATE channels. All data produced using RFM [RFM08] and HITRAN [HIT08].



3 Retrieval Performance Estimation

Initial estimation of the LIO retrieval performance shows that greenhouse gases can be retrieved within the UTLS region accurate to less than 1-5%, wind to less than 2m/s. The high accuracy of the retrieval results and the high vertical resolution (1-2 km) underline the enormous potential of LIO to monitor climate and chemistry variability and change.

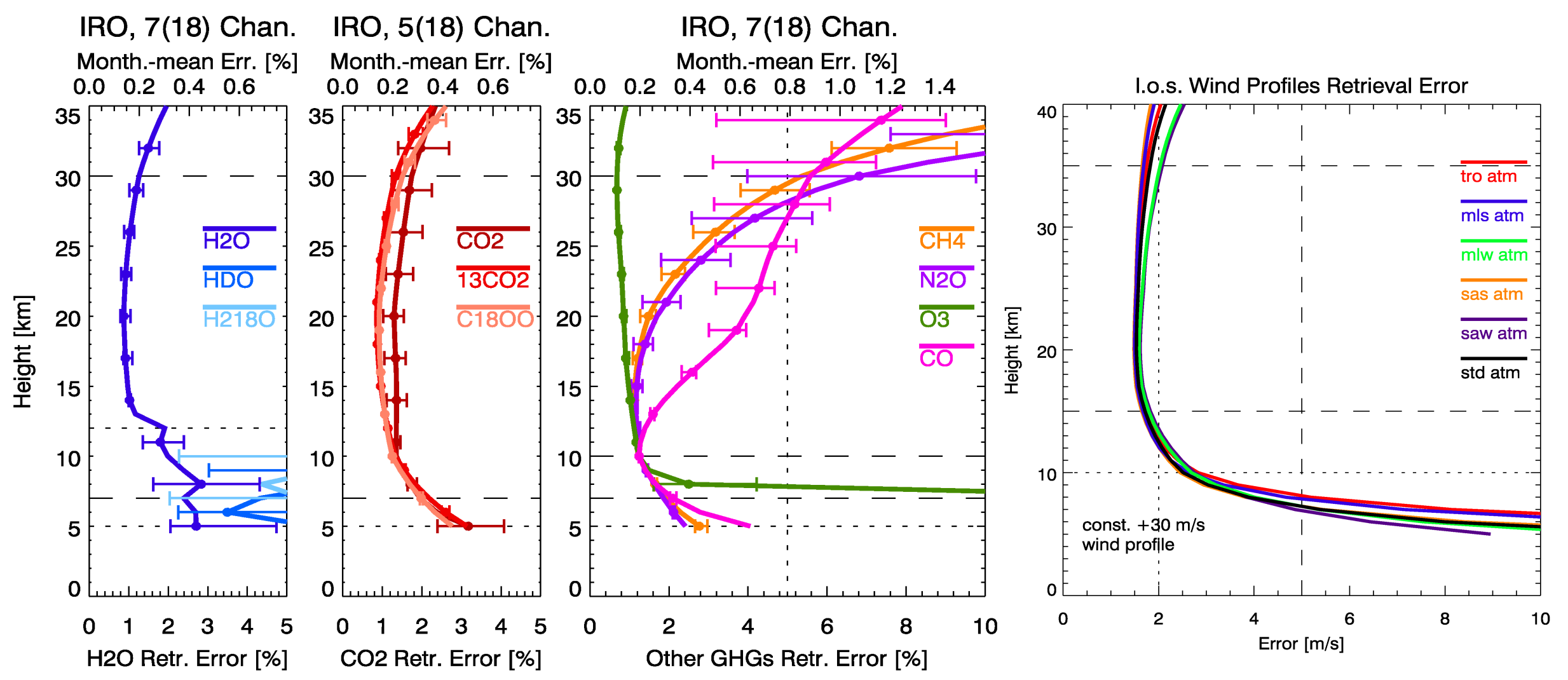


Fig. 3: Retrieval performance estimates for water and isotopes (left), CO_2 and isotopes (mid-left), other greenhouse gases (mid-right) and line-of-sight wind (right). Horizontal and vertical dotted/dashed lines mark target/threshold requirements. Horizontal bars indicate variation within the 6 FASCODE (incl. U.S. standard) atmospheres.

4 Influences of Aerosol and Clouds

The influence of aerosols and clouds on the transmission of LIO signals was assessed by using the EGOPS [EG07] software. For this purpose new routines based on parameterization models simulating their influence were implemented. The results regarding cloud layers were compared to corresponding results from libRadtran [LIB09].

4.1 Aerosol

A latitude-height dependent climatology for the aerosol extinction coefficient ε at 1020 nm and for the Ångström exponent α was developed from SAGE II measurements [SAGE07]. α defines the wavelength dependency of ε (Eq. 1) and allows to determine ε at arbitrary wavelengths (Fig. 4) if ε_{λ_0} is known. Examples for resulting aerosol extinction losses are shown in Fig. 6.

$$\epsilon\left(\lambda\right) = \epsilon_{\lambda_0}\left(\frac{\lambda_0}{\lambda}\right)^{\alpha} \quad Eq.1$$

$\varepsilon(\lambda)$ ... *aerosol extinction coefficient*
ε_{λ_0} ... *aerosol extinction coefficient at reference wavelength*
λ ... *wavelength*
λ_0 ... *reference wavelength*
α ... *Anström exponent*

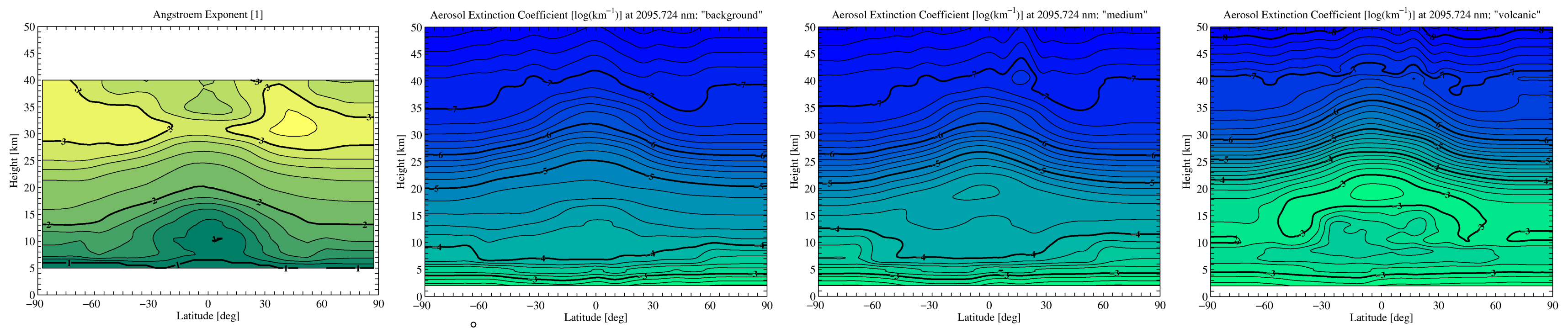


Fig. 4: Left panel: Climatology of Ångström exponent α. Other panels: Aerosol extinction coefficient ε; climatologies for background, medium and volcanic aerosol load at 2095.724 nm (sensitive to CO_2 absorption).

4.2 Clouds

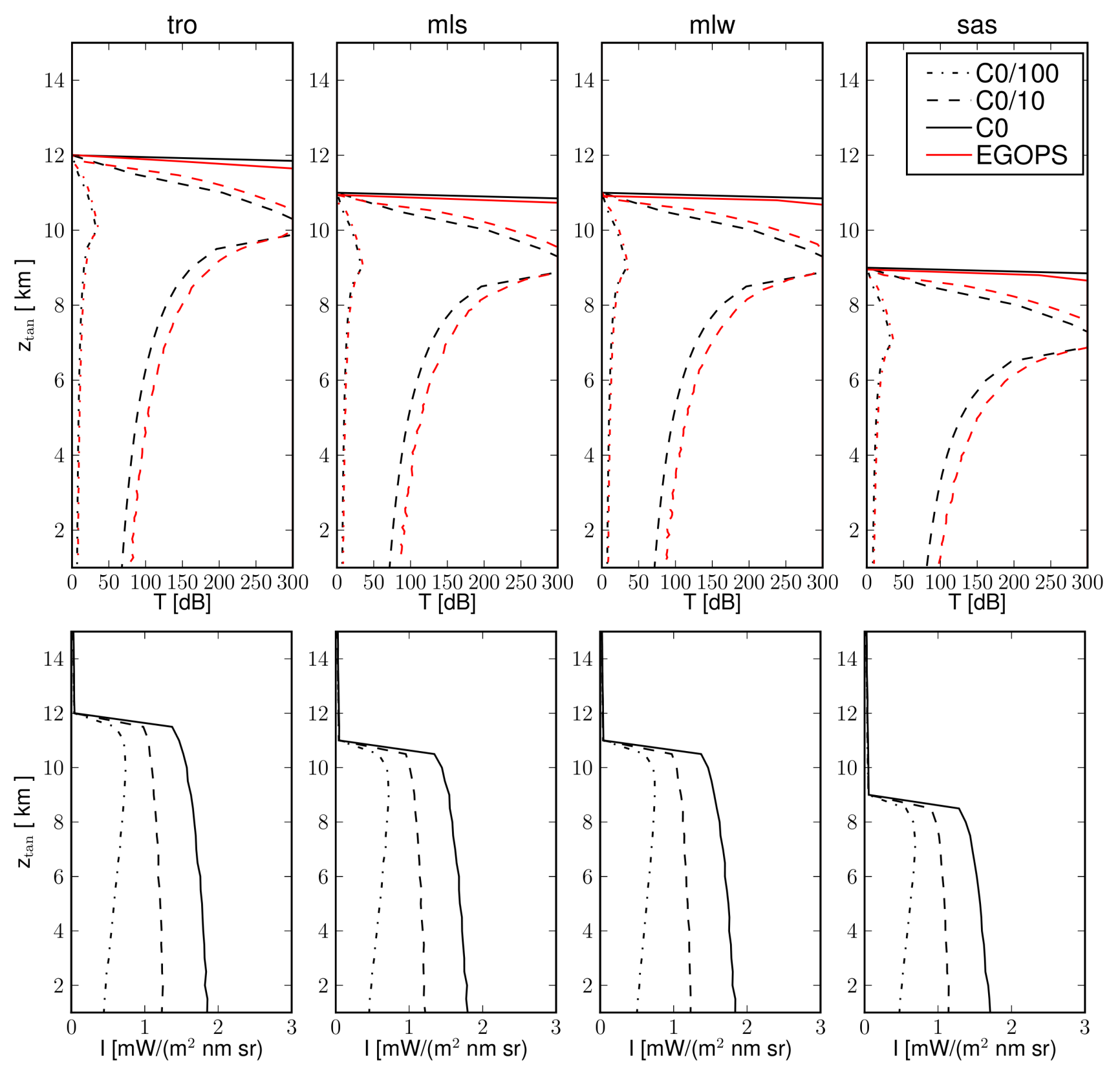
The influence of clouds is modeled based on a parametrization of the effective particle radius [WYS98a, WYS98b] and the extinction due to liquid and ice water clouds, respectively (Eq.2, Eq.3) [HU93,KEY02]. Studies are performed for a set of typical simple cloud shapes assuming constant effective radii for ice and liquid water cloud particles as well as realistic vertical cloud profiles (ECMWF data). Atmospheric background are the FASCODE atmospheres. The EGOPS intensity loss profiles are compared with 1D-spherical simulations of libRadtran [CLE08], which additionally allows to assess the radiance due to cloud scattering into direction of the receiver. Focus of the studies lies on thin/sub-visible cirrus clouds, since these are the ones which allow some penetration of infrared signals, provided that the extinction loss is less than about 20 dB (see Fig.5, Fig.6). For opaque clouds the focus is on profiling cloud layers.

$$\beta_{LWC}\left(\nu\right) = \left[a\left(\nu\right) {r_{eff}}^{b(\nu)} + c\left(\nu\right)\right]\mathrm{LWC} \quad Eq.2$$

$$\beta_{IWC}\left(\nu\right) = \left[\sum_{n=0}^{3} a_n\left(\nu\right)\frac{1}{{r_{eff}}^{n}}\right]\mathrm{IWC} \quad Eq.3$$

$\beta_{LWC}(\nu)$ ... *extinction coef. liquid water clouds*
$\beta_{IWC}(\nu)$ ... *extinction coef. ice water clouds*
ν ... *frequency*
$a(\nu)$, $b(\nu)$, $c(\nu)$ ... *parametrization set by [HU93]*
$a_n(\nu)$ ... *parametrization set by [KEY02]*
r_{eff} ... *effective radius*
LWC, IWC ... *liquid and ice water content*

4.3 Results



Water Content C_0 [g/m^3]				Height/Thickness [km]			
tro	mls	mlw	sas	tro	mls	mlw	sas
0.05	0.05	0.05	0.05	10.0/1.6	9.0/1.6	9.0/1.6	7.0/1.6

Tab. 1: Definition of cirrus cloud characteristics [GRA04].

Investigation on simply shaped cirrus clouds show some transmission through thin/sub-visible cirrus (Fig. 5, top). The thickness, height and water content were adapted from [GRA04] (see Tab. 1). The effective radius is kept constant at 10 μm. Comparison with libRadtran shows good agreement of the simulation results (Fig. 5, top). libRadtran also provides the radiation of the sun into the receiver due to scattering. The radiance decreases for decreasing ice water content (Fig. 5, bottom). Liquid water clouds block the signals (see Fig. 6, left columns). Aerosol induces no significant performance-degrading loss even for volcanic loads (Fig. 6, right columns).

Fig 5: Intensity loss profiles (T [dB]) of simple cirrus clouds for three different constant ice water contents; EGOPS results (top, black lines) are compared with libRadtran (top, red lines). Profiles of scattered radiance towards the receiver [mW/(m² nm sr)] from libRadtran (bottom); four FASCODE atmospheres are shown.

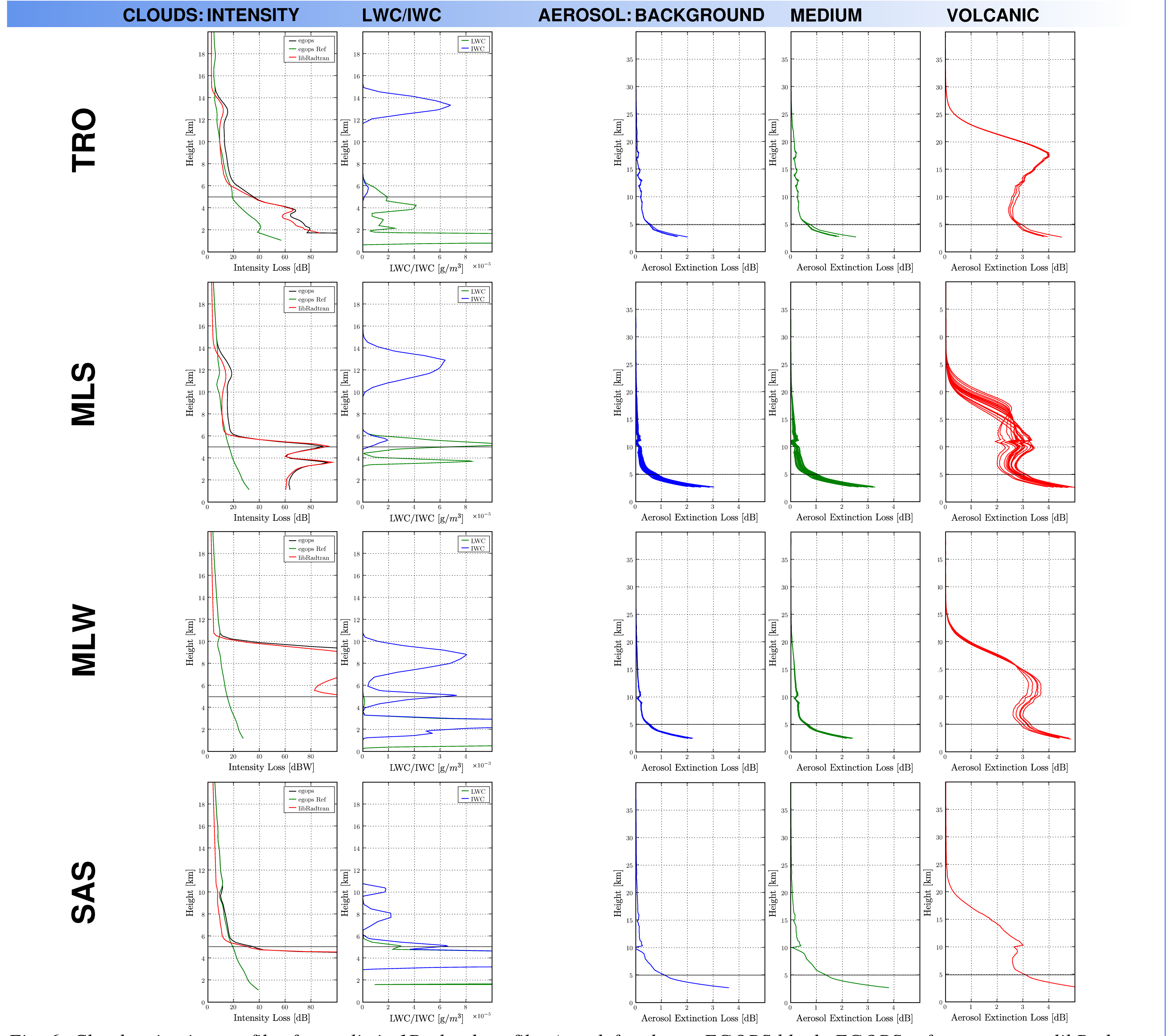


Fig. 6: Cloud extinction profiles for realistic 1D cloud profiles (two left colums; EGOPS black, EGOPS reference green, libRadtran red) and aerosol extinction loss profiles (three right colums); four FASCODE atmospheres are shown, channel is 2095.724 nm.

References and Acknowledgments

References: [RFM08] www.atm.ox.ac.uk/RFM/; [HIT08] www.cfa.harvard.edu/HITRAN/; [EG07] Kirchengast, G., et al., Tech. Rep. ESA/ESTEC-4/2007, Wegener Center&IGAM, Univ. of Graz, Austria, 2007; [SAGE07] www.sparc.sunysb.edu/html/RefData.html; [WYS98a] Wyser, K., Atmos. Research, 1998, Vol. 49, p. 213-234; [WYS98b] Wyser, K., J. Climate, 1998, Vol. 11, p. 1794-1802; [HU93] Hu, Y.X., and Stamnes, K., J. Climate, 1993, Vol. 6, p. 728-742; [KEY02] Key, J.R., and Yang, P., and Baum, B.A., and Nasiri, S.L., J. Geophys. Res., 2002, Vol. 107, Nr. D13; [CLE08] Emde, C., libRadtran: www.libradtran.org, www.bmayer.de/mystic.html; [GRA04] Gradinarsky, L., et al., Tech. Rep., Chalmers Univ. of Tech., Göteborg, Sweden, 2004.

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