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## Solar occultations observed by VIMS-IR: What haze and methane profiles reveal about Titan's atmospheric dynamics and climate.

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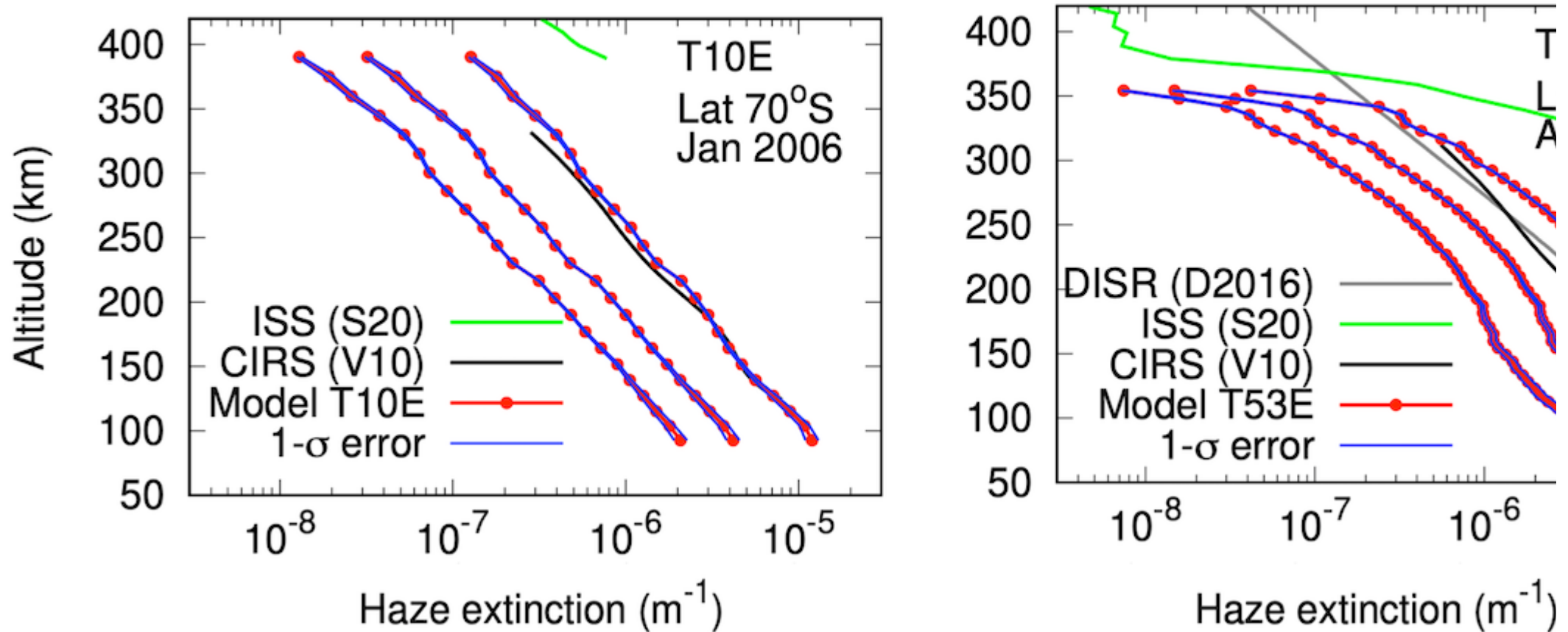
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Titan, the largest satellite of Saturn, has a dense atmosphere mainly composed of nitrogen and methane at a percent level. These two molecules generate a complex prebiotic chemistry, a global haze, most of the cloud cover and the rainfalls which model the landscape. Methane sources are located in liquid reservoirs at and below the surface and it sink is the photodissociation at high altitude. Titan's present and past climates strongly depend on the connection between the surface sources and the atmosphere upper layers. Despite its importance, very little information is available on this topic.

In the last two decades, the observations made by the Cassini orbiter and the Huygens probe have greatly improved our knowledge of Titan's system. The surface, haze, clouds, and chemical species can be studied and characterised with several instruments simultaneously. On the other hand, some compounds of its climatic cycle remain poorly known. This is clearly the case of the methane cycle, which is, however, a critical component of Titan's climate and of its evolution.

We reanalysed four solar occultations by Titan's atmosphere observed with the infrared part of the Visual Infrared Mapping Spectrometer (VIMS) instrument. These observations were already analysed (Bellucci et al., 2009, Maltagliati et al., 2015), but here we used significantly improved methane spectroscopic data. We retrieved the haze properties (not treated previously) (Figure 1) and the mixing ratios of methane (Figure 2), deuterated methane, and CO in the stratosphere and in the low mesosphere.



**Figure 1** : Haze extinction as a function of altitude, retrieved for the four observations, at wavelengths  $0.884 \mu\text{m}$  (channel #97),  $1.540 \mu\text{m}$  (channel #137) and  $2.199 \mu\text{m}$  (channel #177). The extinction profiles retrieved by Seignovert et al. (2021) with Cassini/ISS, at wavelength  $338 \text{ nm}$  (CL-UV3 filters), are shown with green lines (labelled "S2020"). Those from Vinatier et al. (2010) or Vinatier et al. (2015), scaled at the wavelength  $1 \mu\text{m}$ , are shown with black lines ("V2010" or "V2015"). The profiles in cyan ("RP83"), are the extinctions retrieved by Rages & Pollack (1983) at  $30^\circ\text{N}$  in August 1981 (wavelength  $0.5 \mu\text{m}$ ). The differences in the detached haze altitudes between VIMS-IR ( $L_s = 26^\circ$ ), Cassini/ISS ( $L_s = 14.8^\circ$ ) and Voyager 2/ISS ( $L_s = 18^\circ$ ) are their dates while the detached is falling down (West et al. (2018); Seignovert et al. (2021)). The grey line shows the haze profile by Doose et al. (2016) with DISR in 2005 at  $10^\circ\text{S}$  (labelled "D2016").

1.5%). However, this is consistent with previous results obtained with CIRS. Features in the methane vertical profiles clearly demonstrate that there are interactions between the methane distribution and the atmosphere circulation. We find a layer rich in methane at 165 km and at 70°S (mixing ratio  $1.45 \pm 0.1\%$ ) and a dryer background stratosphere (1.1 – 1.2%). In absence of local production, this reveals an intrusion of methane transported into the stratosphere, probably by convective circulation. On the other hand, methane transport through the tropopause at global scale appears quite inhibited. Leaking through the tropopause is an important bottleneck of Titan's methane cycle at all timescales. As such, it affects the long term evolution of Titan atmosphere and the exchange fluxes with the surface and subsurface reservoirs in a complex way.