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Tropopause and Cirrus Clouds Tops Heights

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Abstract

Cirrus clouds have recently garnered much attention due to their important role and impact on the atmospheric radiative balance. This stresses the need for active remote sensing such as lidar, whose capability to perceive high and optically thin cirrus makes it one of the most accurate systems for cirri study. The dynamic range of backscatter lidar signals enable to measure the altitude as well as the evolution of cirrus clouds in real time. By means of the retrievals profiles of the cirrus clouds parameters derived from lidar (light Detection and Ranging) system, particularly of those close to the upper troposphere, it is possible to analyze the evolution of tropopause layer using the top of cirrus clouds present as a tropopause tracer. A random selected dataset of 80 diurnal tropopause cirrus clouds collected during 2001-2006 were analyzed in order to estimate tropopause height and its temporal evolution with the altitude of the cirrus tops. We present here the preliminary results of the comparison between the cirrus top altitudes measured by lidar and the tropopause altitudes derived from rawinsonde data. Results show that cirrus tops can be viewed as tropopause tracers with an accuracy close to 1km.

Key words: diurnal tropopause cirrus, lidar, tropopause.

Resumen

Las nubes cirrus han atraído recientemente mucha atención debido a su importante rol e impacto en el balance radiativo de la atmósfera. Esto resalta la necesidad de mejorar las mediciones de la atmósfera, a través de por ejemplo, la detección remota que proveen los sistemas lidar (acrónimo del inglés: light Detection and Ranging), con una excelente capacidad para detectar nubes altas y delgadas con mucha precisión. El rango dinámico del lidar de retrodifusión permite analizar la altitud así como la evolución de nubes cirrus en tiempo real. Mediante los perfiles de retrodifusión obtenidos a partir de los cirrus detectados y particularmente de los cirrus de la alta troposfera, es posible analizar la evolución de la tropopausa por medio del análisis del tope de los cirrus, utilizándolos como trazadores de la tropopausa. En el presente trabajo se analizaron 80 casos de cirrus de la tropopausa diurnos, elegidos en forma arbitraria, detectados durante el período 2001-2006, con el objetivo de estimar la altura de la tropopausa y su evolución temporal. Esta contribución presenta los primeros resultados preliminares de la comparación de las alturas detectadas por medio de un sistema lidar local y las alturas de la tropopausa obtenidas a partir de radiosondeos locales. Los resultados muestran que estos cirrus pueden considerarse como trazadores de la tropopausa, con un error típico inferior a 1 km.

Palabras clave: *cirrus diurnos de la tropopausa, lidar, tropopausa.*

1. Introduction

Understanding the physics and chemistry of the processes involved in the upper troposphere-lower stratosphere (UTLS) region, as well as troposphere-stratosphere exchange (STE), has become one of the major scientific and technical challenges for the next years due to the strong evidence that the Earths climate is changing (IPCC, 2007). The UTLS is a critical region for understanding climate: the dynamical, radiative and chemical connections between the troposphere and the stratosphere are a topic of great importance that must be understood in order to advance in the understanding of global climate change.

Cirrus clouds play a significant role in the energy budget of the earth-atmosphere system by their effects on the transfer of radiant energy through the atmosphere (Hansen *et al.*, 1997), and they are critical to understanding feedback processes that regulate or modulate the climate response to forcing. Moreover, the presence of cirrus and subvisual cirrus clouds in the neighborhood of the tropopause (tropopause cirrus clouds), and thus in the UTLS region, is one of the subjects with particular interest in the current research on climate change due to their influence in the dehydration of the air entering into the upper troposphere and lower stratosphere region. In addition the cirrus clouds may perturb chlorine chemistry and play an important role in ozone chemistry at midlatitudes, similar to the role played by polar stratospheric clouds at higher latitudes. Several observations have shown the decrease of the ozone concentration in presence of cirrus clouds at tropical and middle latitudes (Reichardt, 1999)

The tropopause is recognized as a key feature of the atmospheric structure at all latitudes; i.e., polar, mid-latitudes and tropics. This layer can be viewed as the transition zone between the turbulently mixed troposphere and the more stable stratified stratosphere (Hoinka, 1998), affecting both the dynamics and the chemistry. An overall understanding both of the UTLS and of STE is dependent on our ability to quantify and describe tropopause structures and their evolution in time (e.g.: Holton *et al.*, 1995; Shepherd, 2002; Stohl *et al.*, 2003; Seidel and Randel, 2006). For this purpose, reliable quantitative information on transport properties between these two regions, as well as temperature structure and trends among others parameters, is required.

One of the most important achievements of the lidar systems, related to dynamic processes and climatology of the UTLS, is the capability to obtain in real time the altitudes of the layers they detect, providing data of their different atmospheric components (Campbell, 2007). In this sense, one of the direct applications of the lidar is to provide unique information simultaneously about the geometrical and optical properties of the cirrus clouds.

The cirrus clouds appear below the tropopause, especially in the tropics (Beyerle *et al.*, 1998) and they have been observed also above the local tropopause at mid-latitudes (Goldfarb *et al.*, 2001) and polar regions (Formenti *et al.*, 1999). Therefore, monitoring tropopause cirrus clouds height and its evolution might be considered to be a new alternative, highly accurate way, including a high temporal resolution to study the tropopause height: tropopause cirrus clouds can be viewed as tropopause tracers. To avoid possible, unwanted inclusion of altocumulus, i.e., of water clouds, we restricted the present campaign to clouds with a cloud base height lg 6 km, a criterion that coincides with the definition of cirrus clouds given by the International Coordination group on Laser Atmospheric Studies (ICLAS): cirrus clouds derived from lidar measurements are layers of particles above 6 km situated in an air mass with temperature of -25°C or colder which in addition display a large temporal and spatial variability.

The backscatter lidar system located at Buenos Aires (34.6°S, 58.5°W) used here, operates at 532 nm, with a great dynamic range, starting from 50 m above the ground up to 20 km in daytime and up to 27 km in nighttime.

The aim of the present work is to compare tropopause altitude derived from rawinsonde and 80 lidar profiles measured over Buenos Aires during 2001-2006.

2. Data and methodology

In a general scheme, a lidar can be classified in accordance with the interaction that the laser light suffers with the atmosphere in two kinds: elastic scattering lidar and inelastic scattering lidar. First type includes the phenomena in which the laser radiation is scattered by atoms, molecules, aerosols or particles on the air, without changing its wavelength. The inelastic scattering in contrast, is related with those others phenomena in which the wavelength of the scattered radiation change. Here the energy of the incident photon is quite different from the scattered photon. In elastic scattering, the physical size of the particle determines the type of the scattering. If the particles are atoms or molecules, the scattering is known as Rayleigh scattering. If the size of the particles is comparable to that of the laser wavelength, the scattering is called Mie scattering. In an elastic scattering lidar the analysis of the received signal is made taking into account these two types of scattering.

The elastic scattering allows locating, in direction and distance, zones with changes in the atmospheric structure like gradients of density, humidity, height of mixing ratio layer, pollutant, etc. This work considered only data from elastic case. The elastic backscatter lidar used for the present work is located in Villa Martelli near Buenos Aires and is based on Nd: YAG laser transmitter (Continuun-Surelite II) which delivers around 300 mJ by pulse at 532 nm with a 10 Hz pulse rate, 5 ns pulse duration, with a tilt angle less than 0.6 mrad. A dual telescope receiver is used to handle the large signal dynamic range. An 8.2 cm diameter Cassegrain telescope covers the range between 50 m to 6 km, while a 50 cm diameter Newtonian telescope covers from 500 m up to 28 km. A field of view less than 1.2 mrad is normally used for both telescopes. The lidar was operated at a fixed off-zenith angle of typically 2.5° to avoid the unwanted impact of specular reflection by falling, horizontally oriented ice crystals. In order to improve the system for future measurements, two interference filters at 532 nm and 1064 nm were added to reduce the radiometric background during daytime. The 8.2 cm diameter telescope has now two channels at 532 nm Photomultiplier (PTM) and 1064 nm Photodiode (PD), while the 50 cm diameter telescope has three channels: 532 parallel, 532 perpendicular and 1064 nm. The optical part of the detection channel implemented on the 50 cm diameter telescope is based on two optical elements. On one side, a dichroic mirror is used to separate the two probing wavelengths (R = 95% in 532 nm and T = 85% in 1064 nm) (Lavorato *et al.*, 2004). On the other side, depolarizer unit is used to separate the polarized parallel beam from the perpendicular one at 532 nm. The 1064 nm signal is focused and sent onto a PD detector by a fiber optic link. The fiber optic is coupled directly to a photodiode (YAG-100-Quantum efficiency = 50% at 1064nm). A large band and high gain photomultiplier amplify the electrical signal, which is sent to the analog to digital converter and data acquisition unit.

After detection by high gain-low noise PMTs and PD at 1064 nm, the lidar signal is low-pass filtered with a 1-2 MHz cut-off frequency filter in order to eliminate radio frequency interference. The analogue to digital converter is a 10 bits/25 MS/s numerical oscilloscope. Such system allows to measure daily lidar signals with a quite good signal to noise ratio in absence of low level cloudiness, pollutants or aerosols.

3. Results and Discussion

With the purpose to study the tropopause height, only the high resolution lidar signal is taken into account, which corresponds to a logarithmic scale plot for the electric pulse. These signals are mathematically processed in three stages in order to correct the range of the scale, filtering the noise and obtain the best signal to noise ratio. The final lidar signal is averaged with more than 500 shot laser. By adjusting the slope of the high resolution signal up to the point where the cirrus ends, it is possible to detect the tropopause height as the altitude of the last point of the cirrus clouds signal (Klett, 1981; Fernald, 1984). This technique should be considered a graphic method to detect the tropopause height with a confidence interval of about 500 meters.

The present analysis uses the conventional tropopause height as given by the World Meteorological Organization (WMO). This is defined as the lower boundary layer of an atmospheric layer in the upper troposphere in which the temperature lapse rate is less than 2 °C/km and this layer has to be at least 2 km thick (WMO, 1992). This definition, defined as the thermal tropopause and used in the operational rawinsonde profiles retrievals, actually reflects dynamical disturbances to the temperature profile like jet streams or upper-level fronts, resulting in multiple temperature inversions in the UTLS (Shapiro, 1980) that can lead to tropopause folding and mixing of stratospheric and tropospheric air (Hoinka, 1998). Due to the ambiguity of the thermal tropopause definition with respect to the different processes involved in both hemispheres (Shepherd, 2002) which are also used to define it, e.g., chemical tropopause and dynamical tropopause, it should be noted that when we refer to tropopause, the Extratropical Tropopause Layer (ExTL) as explained in Bischoff *et al.* (2007) is considered (Lakkis and Canziani, 2009): the tropopause is a layer which, at midlatitudes can be as much as 6 km thick.

Once obtained the tropopause height from the lidar profiles, the values were compared with those derived from the rawinsondes. Figure 1 (a-c) shows the complete procedure and comparison with rawinsonde data.

Following the criteria applied in figure 2, we analyze a set of 80 tropopause cirrus cloud signals from 2001-2006. The profiles collected correspond to diurnal signals. Each event represents a certain number of profiles for a specific year, month, day and time period (in UTC hours) compounded by instantaneous and periodical measurements. Figure 3 displays the scatterplot of the tropopause cirrus clouds tops heights.

As the cirrus dataset analyzed over Buenos Aires are 80% located below, but near the top of the troposphere (figure 3), the altitude of the cirrus top can be taken as representative of the tropopause height. Moreover, the tropopause height, calculated using the Klett's method (1981) is more accurately determined when the signal is clear enough to show not only the end of the cirrus but also the change of the lapse rate of the processed signal, which corresponds to a lower stratospheric signal. In this case, cirrus clouds occur in a boundary layer between the troposphere-stratosphere, corresponding to the transition zone. Thus monitoring the temporal evolution of the cirrus top, it is possible to obtain a proxy of the tropopause evolution in real time. Such cirrus can be defined as tropopause cirrus.

a
b
c

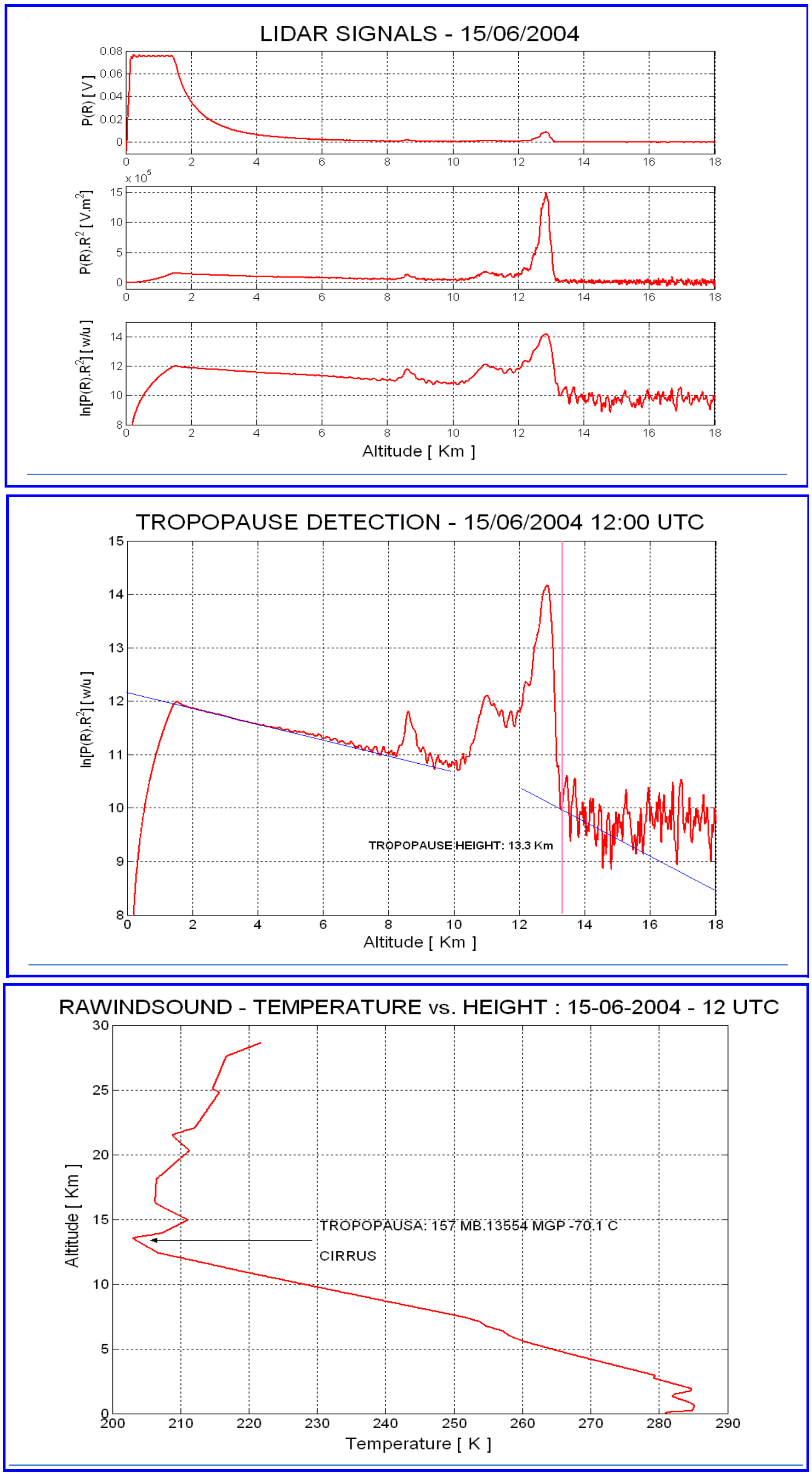

Fig. 1: (a) Example of high resolution lidar signal filtered and amplified; (b) Linear regression of the signal slope to calculate tropopause height compared with (c) tropopause height from rawinsonde data (SMN) for June 6, 2004.

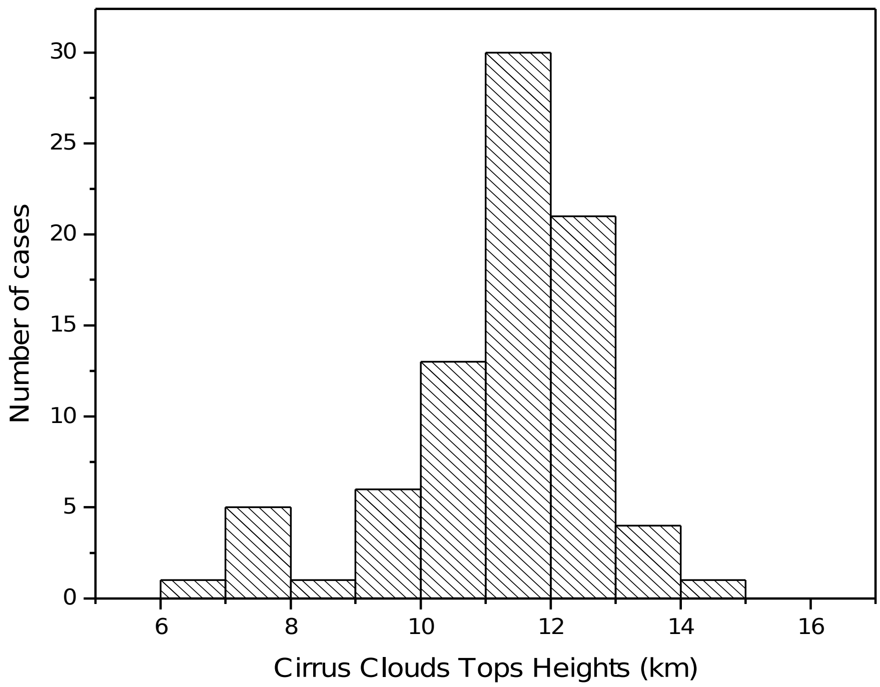

Fig. 2: Distribution of tropopause cirrus tops heights.

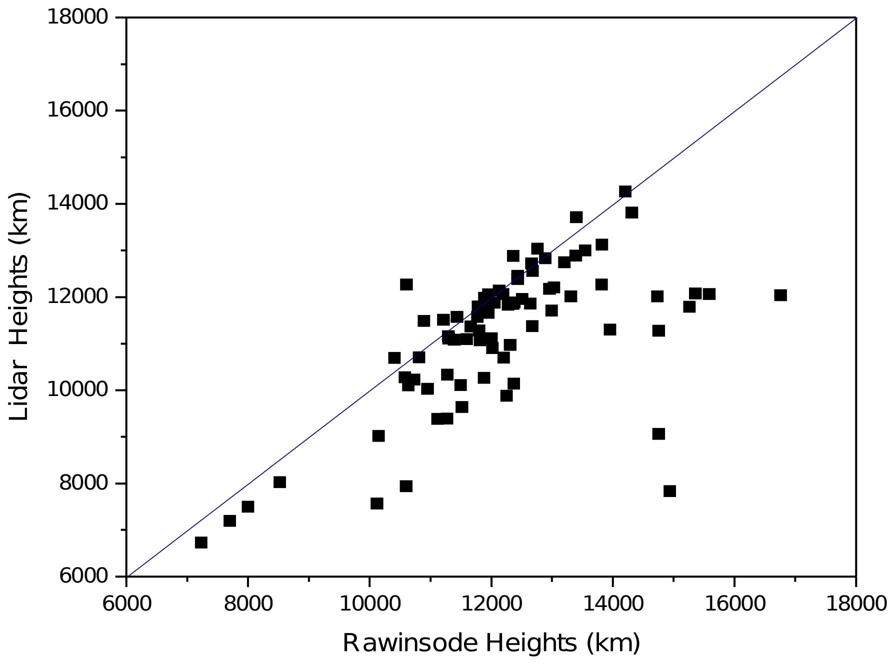

Fig. 3: Tropopause cirrus clouds tops heights evolution compared with tropopause heights derived from rawinsonde.

In order to evaluate the differences between the two comparable datasets, distance (ε) in km between cloud top and the tropopause altitude derived from rawinsonde data was calculated. Figure 4 displays the values. Note that only for a very few cases the absolute value of ε is greater than 2 (with a |ε| mean of 960 m and standard deviation of 1397 m), meaning that almost all the cirrus clouds heights are located below the tropopause with value differences less than 2 km. Moreover, the plot shows that the 65% of all the dataset analyzed displays a value of $|\varepsilon| \leq 1$ km. Therefore, by means of the lidar system it is possible to detect the tropopause height with an accuracy of order lower than 1 km.

The analysis of the plot also shows that even when the cirrus clouds are mostly located below the tropopause, there are some cirrus with tops above the layer. Even when these clouds are not relevant in the present analysis due to their rather low frequency, they can contribute to our knowledge about their role in the local dynamics processes, especially in the stratosphere-troposphere exchange processes. Further analysis involving a dataset with a wide number of cirrus clouds detected could confirm this hypothesis.

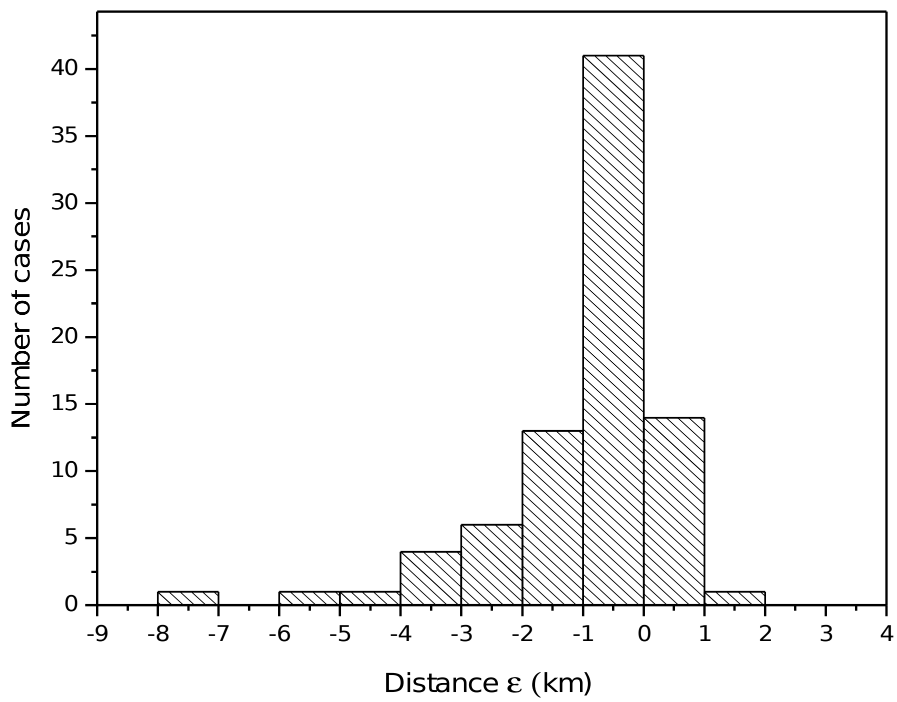

Fig. 4: Distance ε measured as km, between cloud top and the tropopause heights.

4. Conclusion

In this study a lidar system located in Buenos Aires was used in order to study cirrus clouds. These clouds located in the upper troposphere can provide insights about the tropopause layer. In this sense, we analyzed the cirrus tops heights detected by the lidar and tropopause heights derived from the local rawinsonde.

The analysis reveals that the cirrus clouds are usually located at 10-14 km, near the tropopause layer. Moreover, 80% of these cirrus have their tops height below but very close to the transition layer (figure 3). By means of the value it is possible to note that cirrus clouds tops are located close to the tropopause with heights in the range [-8, 2] km, with positive (negative) values corresponding to cloud-top altitudes above (below) the tropopause. Moreover, more than 70% of all the dataset are located stuck right under the tropopause with a confidence interval near 1 km (figure 4). Therefore, monitoring tropopause cirrus clouds height and its evolution might be considered to be a new alternative, highly accurate way, including a high temporal resolution to study the tropopause height: tropopause cirrus clouds can be viewed as tropopause tracers.

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