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Midlatitude cirrus cloud investigations from ground-based lidar and ERA-5 re-analysis

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Cirrus as high-altitude clouds are formed at the highest layers of the troposphere, usually at the altitude range 5,000 – 14,000m. Cirrus clouds are composed mainly by asymmetric ice crystals, which are formed during the freezing process of the water vapor at the regions of very low temperature. In global scale, over land, their frequency of occurrence ranges between 28 and 42%, depending on the geographic location and season.

Cirrus clouds are classified with respect to optical thickness into four major classes; thick cloud ($\tau > 3$), opaque cirrostratus ($0.3 < \tau < 3$), transparent or thin cirrus ($0.03 < \tau < 0.3$), and subvisible cirrus ($\tau < 0.03$). Another classification of cirrus comes from their origin; in-situ and liquid origins.

This cloud type plays a key role in the Earth's radiation budget. In general, cirrus has a net warming effect (21 W/m^2), due to the warming LR and cooling caused by SR reflection. However, difficulties to investigate optically very thin cirrus clouds with satellite observations, don't allow to have the whole picture of the cirrus radiative forcing. Local investigations, engaging ground-based lidar measurements enable the detection of cirrus clouds of optical depths down to 10^{-3} and hence a better quantification of the effect of the thin clouds.

In this study, we have investigated the cirrus cloud geometrical properties, during the period 2020 – 2023, based on the nocturnal measurements of the high-resolution Rayleigh/Mie lidar at the Observatory of Haute Provence (OHP) in France (43.9°N, 5.7°E). The analysed parameters are the top/base/mid- cloud heights, mid-cloud altitude and geometrical thickness .

Coincident meteorological parameters Data, such as mid-cloud temperature and relative humidity are provided by ERA-5 (climate reanalysis produced by ECMWF).

Clouds are then considered as cirrus based on the following criterias: In-cloud temperature must be as lower than −25 °C, the Scattering Ratio SR, must be above its average plus three times its

standard deviation in the 17–19 km altitude range.

Multivariate analysis combining the principal component analysis and cluster methods are used to classify cirrus cloud with respect of their geometrical properties. Overall results of these analysis indicate three major cirrus cloud classes; mid-troposphere thin cirrus, thick upper-troposphere cirrus and thin-tropopause cirrus. These cirrus classes have different geometrical thickness and mid-cloud altitude. These classes differ also in terms of meteorological parameters, such as relative humidity and In-cloud temperature.

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