Long-term records of cirrus cloud properties for climate understanding

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Cirrus clouds are key features of the climate system due to their ubiquity. Changes in their micro- and macro-physical properties can have profound impacts on the Earth's atmosphere. Cirrus clouds are sensitive to changes in small- and large-scale dynamical forcing, upper tropospheric moisture and temperature, and the abundance and properties of upper tropospheric aerosols. In addition, changes in other clouds types (contrail cirrus, convective clouds) are expected to influence the occurrence and properties of cirrus clouds. Due to the poor representation of cirrus clouds in Global Climate Models (GCMs), robust signatures of the response of cirrus clouds to above-mentioned changes are not available. However, synergy of ground-based, airborne and satellite observations can shed light on the changing properties of cirrus clouds and its impact on the Earth's climate.

Recent satellite observations from SAGE II and CALIPSO have shown that the aerosol load in the upper troposphere and lower stratosphere (UTLS) region has increased by a factor of 2-3 since late 90's (*Vernier et al.,* 2015) resulting in the formation of an Asian Tropopause Aerosol Layer (ATAL) within the Asian Summer Monsoon region. Several studies have suggested that increase in anthropogenic sulphate and carbonaceous particles may possibly shift the freezing mechanism from homogeneous to heterogeneous freezing resulting into thinner cirrus clouds (a process called Negative Twomey effect). In this context, this study attempts to investigate such responses using observations from ground-based lidars, CALIPSO and SAGE II over ASM region. Long-term (from 1998-2013) lidar observations over a tropical station in Southern India shows a statistically significant increase in the fraction of sub-visible cirrus clouds (optical thickness less than 0.03) by 9%. Segregation into seasonal trends revealed that this response was noticed only during June to August period which could be possibly linked to ATAL. Trend-analysis using historic SAGE-II aerosol extinction profiles at 525 and 1020 nm wavelengths also shows an increasing trend in the anomaly in occurrence frequency of aerosol events at 16 km altitude while a decreasing trend is observed in case of aerosol-cloud mixture which are mostly influenced by sub-visible cirrus clouds. To understand the mechanisms involved in such responses, in-situ measurements of size distribution and number concentration of ice-crystals carried out during Balloon measurement campaigns of Asian Tropopause Aerosol Layer (BATAL) which held in Hyderabad, India during 2017 are also used.

Key words: Cirrus clouds, ATAL, lidar, trends.