P- 41

Lidar and Satellite observations of Cirrus Climatology over a tropical station, Gadanki, India

M. Krishnaiah*[1],Padmavathikulkarni[2],Y. Bhavani Kumar[2] and H.Kuze[1]

[1]Center for Environmental Remote Sensing (CEReS), Chiba University, Chiba 263-8522, Japan.

[2]National Atmospheric Research Loboratory (NARL), Gadanki, India

Abstract

A state of the art Nd.YAG lidar system established over a tropical station, Gadanki (13.5 N,79.2 E), India is in operation since 1998.Using this system regular observations of upper troposphere clouds, aerosols at stratospheric heights and atmospheric temperatures in the range from 30-80 km were made. Data collected using the polarization lidar during the period 1998-2004 are selected for systematic investigation and presentation. Several tropical cirrus cloud structures have been identified with low to moderate ice content. Occasionally thin sub visible clouds in the vicinity of tropical tropopause have been identified. Lidar observations clearly show occurrence of cirrus clouds over this station with varying thickness. Cirrus observations made using MODIS satellite are compared with lidar data for systematic statistical study of cirrus climatology.

1. Introduction

Cirrus clouds are globally distributed high altitude (6-18 km) thin, wispy clouds and generally found in the region of upper troposphere and lower stratosphere. As they play a significant role in the radiative balance of Earth atmosphere system[1)], both hydrologically[2)] and radiatively[3)], a clear understanding of their properties at different geographical locations is highly essential for climate modeling studies. The MODIS instrument on the Terra and Aqua Spacecraft is used for global observations of cirrus clouds. A channel centered near 1.38 μm was selected to measure cirrus. Cirrus clouds are observed over many areas in particular, abundant over the western Pacific, the Bay of Bengal as well as the Inter-Tropical Convergence Zone (ITCZ) in the eastern Pacific Ocean where convection is most active.[4)] Local climatologies can also be built using ground-based lidar data for a particular location. The objective of this paper is to construct a cirrus cloud statistics using the monostatic Nd: YAG lidar measurements, and compare with MODIS data for the observations made over a tropical station located at National Atmospheric Research Laboratory (NARL), Gadanki (13.5ºN, 79.2º E), India.

2. Method of data analysis

2.1 Lidar data set and cirrus observations

The lidar system installed at NARL (Previously NMRF) by CRL, Japan is in operation since 1998 and system description, measurements and analysis are discussed elsewhere.[5)] The seven-year dataset has been used to study cirrus cloud using ground-based polarization lidar during 1998-2004. During this period the lidar has been operated for 636 nights. Measurements were taken only during cloud free nights. The criterion for the detection of cirrus cloud is identified as the region where the scattering ratio is greater than 1.5 in either of the two channels.[4)] Figure 1 shows the two different nights of cirrus detection with single layer and multiple layers. Single layer cirrus shows the observation of cloud at 21:04 LT and after some time the cloud was not observed and again appeared. Other appeared. Other night figure shows two-layered cirrus cloud where one layer appeared at an altitude of 12

*Permanent affiliation: Department of Physics, Sri Venkateswara University, Tirupati, India.

km and another layer at 15 km. (b) represent the temporal variation of backscatter ratio (*R*) and volume depolarisation (*D*) as function of altitude for two night observations made on 8-9 May and 11-12 November 1998 respectively.

Figure 2 shows the cirrus occurrence frequency obtained as the ratio of cirrus detection time versus the total measurement time. During 1998-2004, the histogram shows more nightly measurements in all the months from January to June and November to December. The reason for this is that there are fewer or no low-level clouds or deep convective clouds during these periods, as fewer measurements during monsoon months due to thick clouds.

2.2. Radiosonde data

Since there is no co-located radiosonde observation facility at Gadanki during the period of observation, the temperature measurements are taken from radiosonde flights conducted by India Meteorological Department (IMD), Chennai (80.2°E, 13.1°N; 120 km southwest to Gadanki). Usually radiosondes are launched at Chennai twice a day once at 05:30 LT (00GMT) and again at 17:30 LT (12 GMT). For the background atmospheric temperature at the cloud heights, we have used 05:30 LT measurements, since the time of this launch is closer to the lidar observational period. Here, we have considered the cold point tropopause for identifying the tropopause height. The average tropopause height during 1998- 2004 was 16.5 km with a temperature -79.5ºC.

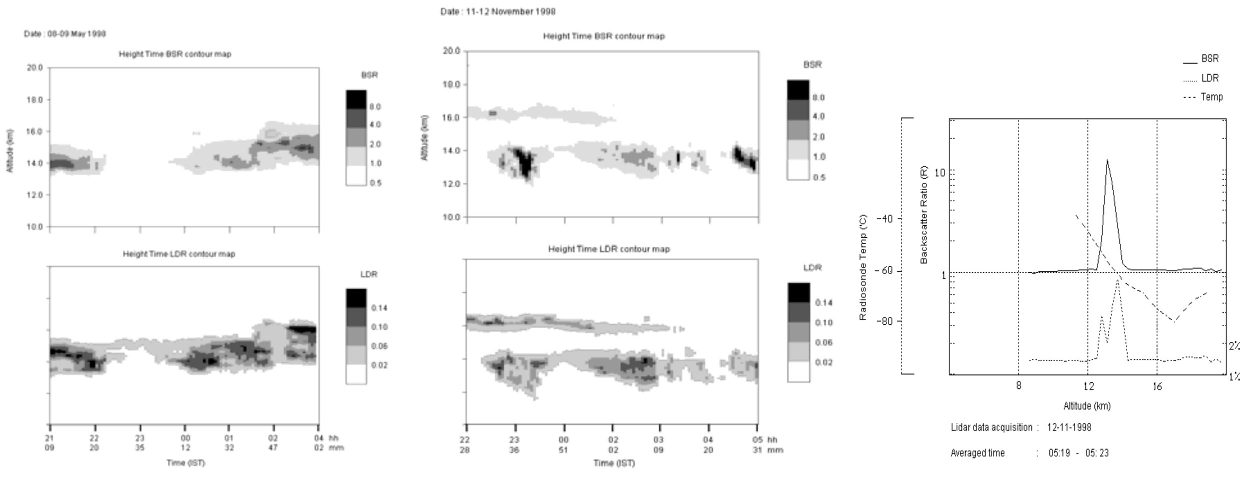

Fig.1 Cloud backscatter ratio (*R*), volume depolarisation (*D*), and radio sonde temperatures.

3. MODIS data description

The Moderate resolution Imaging Spectroradiometer (MODIS) is the primary imager on the Earth Observing Systems Terra platform. The Terra satellite is in a sun-synchronous near polar orbit of 705 km and views the entire surface of the earth every one to two days. The MODIS data are generally processed into different levels from level 1 (radiances or brightness temperature), level 2 (derived geographical data products) and level 3, which is daily, eight-day, and monthly mean products generated globally at a 1°-1° latitude-longitude grid resolution. MODIS is the first satellite instrument with capability of the 1.375-μm channel for cirrus cloud study because of strong water vapor absorption at this wavelength, and little upwelling radiance from low clouds or the surface which could reach the satellite. Here for cirrus detection MOD08_L3, level 3 Terra platform cloud data products are used. It is a level 3 MODIS girded atmosphere monthly product. The MODIS Cloud Product combines infrared and visible techniques to determine cirrus reflectance. Atmospheric monthly mean and annual mean high cloud reflectance are used in this study.

4. Results and cloud properties statistics

4.1 Interannual and interseasonal occurrence statistics

The interannual and interseasonal variability of cirrus cloud has been studied using ground based LIDAR during 1998-2004. Interannual observations showed significant enhancement in percentage of occurrence of cirrus during 2001 and less occurrences during 2002. Figure 2a shows a histogram of lidar observed interannual and interseasonal cirrus statistics. The cloud variation can be understood with reference to monsoon conditions and the year is accordingly divided into four seasons viz., winter (December, January and February), pre-monsoon (March, April and May), monsoon (June, July and August) and post-monsoon season (September, October and November). The lidar observed interseasonal statistics show higher occurrence during monsoon period. Similar interannual statistics are obtained with the recently available MODIS terra dataset and are shown in figure 3b and 3c

4.2 Cloud base and top height statistics & Cloud thickness statistics

The distribution of cloud top height shows the strength of the tropical convective processes. Figure 2b shows the analysis of frequency of occurrence of cirrus cloud base (dashed) and cloud top (solid) heights derived from lidar data from 1998-2004. The line Tp is the average tropopause height taken from radiosonde. The average cold point tropopause (cpt) height is 16.6 km, which varies from 15.6-18.0 km.

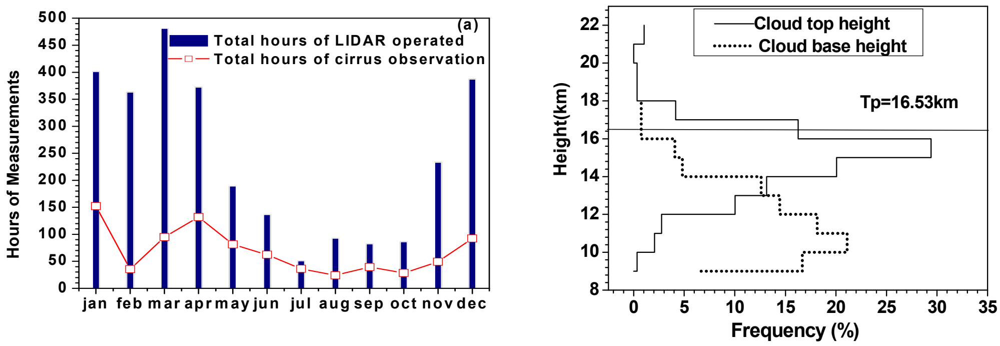

Fig. 2 Number of hours of cirrus observed and frequency of cloud base and cloud top heights.

4.3. Cirrus reflectance over India using MODIS data

Monthly-mean, high-clouds reflectance images are obtained over the latitude range of 5°S- 40°N and the longitude range of 60°E-100°E from January to December 2001. The images are gray color coded in such a way that maximum value corresponds to a reflectance value of 0.3 and dark gray corresponds to reflectance value of 0,

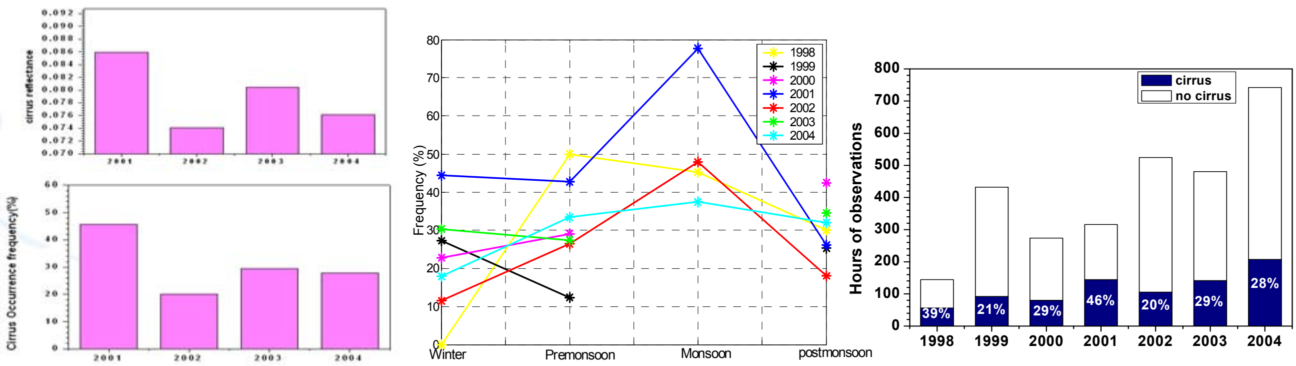

Fig. 3 Comparison of cirrus occurrence and interannual and interseasonal frequency statistics.

indicating no cirrus. For January image, a small amount of high clouds are observed over our site but still few amounts during February, March and April images. In the month of May image (before the monsoon season) high clouds start forming; large amounts of high clouds with significant reflectance values are seen during the monsoon periods (June, July, August). Images during monsoon periods show the high cloud reflectance over the Bay of Bengal, which increases dramatically due to the solar heating of the water surface. For months September to December again the reflectance decreased significantly in comparison with the June image. This is true even during the other years.

5. Discussion and conclusions

An attempt has been made in this paper to relate the cirrus occurrence statistics with lidar and MODIS data. There are different physical processes in the formation and dissipation of tropical thin cirrus. Two mechanisms for the formation of thin cirrus are 1) Dissipation of optically thick cumulonimbus outflow anvils leaves behind an optically thin layer of small ice crystals; 2) in-situ nucleation of ice crystals near the tropopause occurs due to homogeneous freezing of sulfuric acid haze particles. Either slow, synoptic-scale uplift or shear-driven turbulent mixing may generate the super saturation required in the second mechanism. The enhancement in cirrus reflectance during the monsoon period is mainly due to large amount of cumulonimbus anvil outflow. Most of the clouds formed in this region are mainly generated by the first mechanism, as the deep convective activities play the major role in the formation of cirrus in this region. Because of less convective activity during 2002 which leads to droughts of the Indian monsoon, could be one of the possible reasons for the lesser amount of cirrus during 2002 observed by both lidar and MODIS. The distribution of cloud top height clearly shows the strength of the tropical convective processes and how the tropopause served as a barrier to the anvil generated cirrus. Stronger convective systems (defined as having colder cloud tops) correspond to higher cirrus tops which are observed during most of the cases in our observations. The maximum cloud base height frequency at 10 -12 km which signifies the detrainment type of cirrus and a small percentage of occurrence of cloud base within the tropopause vicinity are the cirrus clouds generated by the in-situ mechanism. Hence sorting cirrus properties and the evolution depend on the strength of the convective sources. Hence we can infer much of the cirrus clouds, which are generated in this site, are of detrainment type, which will appear much below the tropopause and are closely associated with the deep convection.

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