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Descending cirrus associated with planetary scale disturbance: An observational study from lidar, radiosonde and reanalysis data

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ABSTRACT

The impact of planetary scale disturbances on cirrus clouds in the vicinity of the cold point tropopause is examined by using a ground based lidar over Chung-Li (24.5°N, 121.1°E), Taiwan, from July to September 2009. An interesting feature of descending cirrus case is observed between 21 and 28 July 2009, and height from 16 to 8 km. Investigation shows the presence of planetary scale waves for about 6–12 days and found that during the cold phase of these waves, the descending cirrus clouds were observed. Global ERA-Interim reanalysis data along with radiosonde observations show the enhancement of relative humidity with respect to water (ice) in the lower (upper) troposphere during the observed periods of descending cirrus clouds. Analysis at the 350 K isentropic surface shows that low values of Ertel's potential vorticity correspond to high specific humidity over the Taiwan and the surrounding areas. The westward propagating planetary wave, emerging for about 6–12 days with a horizontal wavelength of about 4000–7000 km and horizontal and vertical phase speeds of about 4.5 m s^{-1} and 1.4–2.1 cm s^{-1} respectively, is one of the factors for the observed descending cirrus. A case study presented here provides some insights into the relationship between atmospheric wave disturbances and cirrus cloud structure.

1. Introduction

Cirrus clouds can trap longwave, reflect shortwave radiation, and thus have a strong and complex influence on the Earth's radiation budget (Sassen, 2002; Sassen et al., 2008). Due to lack of in-situ measurements for the formation of cirrus, the broad radiative properties of cirrus and their impacts on the climate system and feedback processes are not well understood (Stephens, 2005 and references therein). The net radiative effect of cirrus depends on their formation height, thickness, and microphysical properties such as the shape and size of the ice crystals (Das et al., 2011). These clouds in the tropical tropopause layer (TTL) are also of research interest due to their role in the hydration/dehydration of the air in the upper troposphere and lower stratosphere (UTLS) region (Cotton et al., 2011). In spite of their importance, the cirrus cloud parameterization is poor in the global climate models because of their transient nature, complex morphology and lack of measurements of the conditions controlling the formation of cirrus (Kärcher and Lohmann, 2002).

Various dynamical processes control the generation, maintenance and disappearance of cirrus clouds in the vicinity of tropopause (VOT) (Fujiwara et al., 2009). Jensen et al. (1996) proposed two mechanisms for the formation of tropical cirrus clouds: (i) the outflow from cumulonimbus anvils and (ii) in-situ condensation causing the air to become supersaturated. Several studies have shown that the upper tropospheric waves (may be formed by the organized cumulus clouds) can affect the large-scale temperature distribution (causing the cold anomaly) in the VOT and strongly influence the formation and maintenance of cirrus clouds in the tropics (Potter and Holton, 1995; Boehm and Verlinde, 2000; Immler et al., 2008; Fujiwara et al., 2009). These waves can cover a wide range of wavelengths. The spatial range can be from a planetary scale to a few hundreds of meters, while the temporal period ranges from about a few days to a day (Tsuda et al., 1994). The sub-tropical wave activities like the Brewer–Dobson circulation can also affect the cirrus cloud formation (e.g., Eguchi and Kodera, 2007). Recently, Eixmann et al. (2010) investigated the dynamical coupling between the Rossby wave and the cirrus cloud occurrence over a mid-latitude station, Kühlungsborn (54.1°N, 11.8°E). Such studies have greatly improved our understanding about the dynamical process in determining the cloud structure (temporally and

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spatially variable). However, the investigation of cirrus properties and their generative mechanisms confined usually to the tropical region with only limited investigations over the subtropical region such as Taiwan. As an active remote sensing instrument, the ground-based lidar is one of the useful tools to quantify the cirrus cloud properties with high vertical and temporal resolutions. In this study, we attempt to understand the wave dynamics that can influence the generation, maintenance and disappearance of cirrus clouds in the VOT. The investigations are based on about 3 months observation (July–September 2009) over Chung-Li (24.5°N, 121.1°E), Taiwan. This study gives an insight on the temporal fluctuations of the cirrus cloud properties caused by the interaction with atmospheric waves. The organization of the paper is as follows: Section 2 is about the description of the experimental details and data collected for the present study, followed by results and discussion in Section 3, and finally, Section 4 is the summary and the concluding remarks.

2. Experimental method and data analysis

2.1. Lidar measurement

The data collected from a ground based lidar system installed at the National Central University (NCU), Chung-Li (hereafter NCU lidar) has been utilized for this work. The lidar transmitter system has a 30 Hz Nd:YAG laser emitting at 532 nm, with pulse energy of about 40–60 mJ, pointing to the zenith of atmosphere. The reception of signals is through a Newtonian telescope of a diameter of 45 cm and a field of view of 0.5 mrad. Two photo-multiplier tubes (PMTs) measure the backscattered signals in two mutually perpendicular channels. The outputs of PMTs recorded by using a multi-channel transient recorder (Licel TR40-160), which has a 12-bit resolution at 40 MHz sampling rate with 16 k trace length combined with 250 MHz photon counting system. The measurements are in a vertical and temporal resolution of 7.5 m and 1 min, respectively. A narrowband interference filter centered at 532 nm with full width at half maximum (FWHM) of 3 nm is used in front of beam splitter cube to suppress the background signals. The transmitting laser beam overlaps with the receiver field of view at about 1.6 km. The lidar operated during the nighttime only, as the daytime measurements are limited due to the solar light. The system description, calibration, and algorithm are described in Das et al. (2009) and the references therein.

The backscattering ratio, BR (z) expressed as

$$BR(z) = \frac{\beta_c(z) + \beta_{air}(z)}{\beta_{air}(z)} \quad (1)$$

where $\beta_c(z)$ and $\beta_{air}(z)$ denotes the clouds and atmospheric gases backscatter coefficient at the laser wavelength and at a distance z, respectively.

The BR of background atmosphere over the observational site, Chung-Li is about 1.05 at 20 km (Chiang et al., 2007). The BR of cirrus clouds is usually high. In this work, to define the cirrus cloud height, the value of BR $\geq$ 1.5 is considered so that the observation made is only for the cirrus clouds not from any fluctuating BR/signals. The threshold value of BR considered from the long-term data analysis of the cirrus clouds over Chung-Li. The base and top height of cirrus cloud is defined as: cloud-base is the height (above 8 km) where the value of BR $\geq$ 1.5 (i.e., a strong vertical gradient in the BR) and this value of BR must continue for another 16 successive intervals of height range ($\approx$7.5 m $\times$ 16 = 120 m). The cloud-top height is where BR $\leq$ 1.5 (above the cloud base height).

2.2. Radiosonde observation

The vertical profile of temperature, wind, pressure and humidity are obtained from the radiosonde measurement, which are carried out twice daily at local time 08:00 and 20:00 LT (LT=08 h+GMT) by the Central Weather Bureau using the standard Vaisala module RS-92 at a nearby station, Banqiao (25°N, 121.2°E). Generally, the radiosonde can reach up an altitude of ~25–35 km, depending upon the local meteorological conditions. The error and accuracy in temperature and relative humidity measured by radiosonde may be due to (i) the sensor coating used, (ii) accuracy of the calibration model and references, (iii) solar radiation errors caused by solar heating of sensors, and (iv) time-lag error caused by slow sensors response at low temperature. The temperature sensors are of capacitive wire type and have an accuracy of 0.2 °C below 100 hPa, 0.3 °C between 100 and 20 hPa and above which it have 0.5 °C. The humidity sensors are thin-film capacitor type and have an accuracy of 5% relative humidity. Detailed accuracy assessment and correction of Vaisala RS-92 radiosonde can be found in Miloshevich et al. (2006) and reference therein and datasheet can be found on the website www.vaisala.com.

In this study, we have considered the cold point tropopause (CPT) to define the tropopause, since the CPT tropopause indicates the strong temperature gradient as well as the sharp relative humidity change. The temperature and relative humidity are the two crucial factors considered for the cloud studies. The CPT is the height of the coldest point of the sounding in the troposphere, i.e., the level where the minimum temperature occurs.

2.3. NOAA interpolated Outgoing Long-wave Radiation (OLR)

The Outgoing Long-wave Radiation (OLR) is considered as a proxy of the convection. The lower value of OLR indicates the region of maximum cloud cover in contrast to the higher being the cloud free region. This is because the OLR emitted from the lower height clouds or from the surface is higher than the high, cold or deep convective clouds. We used the NOAA interpolated OLR to quantify the convection. This data is the real-time observations from the NOAA satellite and downloaded from the website http://www.esrl.noaa.gov/psd/data/gridded/data.interp_OLR.html. The daily mean OLR data are gridded for 2.5° × 2.5° spatial resolution. Detailed description of the NOAA interpolated OLR data set is in Liebmann and Smith (1996). Less than 220 Wm^{-2} is used to indicate the presence of deep convection (Das et al., 2011 and references therein).

2.4. ERA-Interim data

Radiosonde observation provides the measurement of temperature, relative humidity and wind but over a single location. To have the spatial coverage of these meteorological parameters including the Ertel's potential vorticity, the ERA-Interim reanalysis data are used. The ERA-Interim (Dee et al., 2011) is the latest global atmospheric reanalysis produced by the European Centre for Medium-Range Weather Forecasts (ECMWF). The spatial and temporal resolutions of the ERA-Interim reanalysis data are 1.5° × 1.5° and every 6 h respectively and the data are downloaded from the website http://data-portal.ecmwf.int/data/d/interim_daily/levtype=pl/. The data are available at different pressure and isentropic levels. In the ERA-Interim, there is a bias correction in temperature and relative humidity. Detail bias correction, accuracy and limitation of the ERA-Interim reanalysis data are in Dee et al. (2011) and comprehensive documentation is available in the website http://www.ecmwf.int/publications/newsletters.

3. Results and discussion

3.1. Lidar observation of cirrus

In this work, the cirrus cloud observation for about 3 months from July to September 2009 is considered. Fig. 1a shows