Atmos. Chem. Phys. Discuss., 12, 31187–31204, 2012
www.atmos-chem-phys-discuss.net/12/31187/2012/
doi:10.5194/acpd-12-31187-2012

Atmospheric Chemistry and Physics Discussions

Investigation of diurnal patterns in vertical distributions of pollen in the lower troposphere using LIDAR technique

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Received: 6 September 2012 – Accepted: 20 November 2012 – Published: 5 December 2012

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Published by Copernicus Publications on behalf of the European Geosciences Union.

Abstract

The diurnal patterns in pollen vertical distributions in the lower troposphere were investigated by the LIDAR remote sensing technique. Meteorological and pollen concentration data was measured at the surface using a Burkard 7 day recording volumetric spore sampler. An aerosol extinction coefficient and depolarization ratio of 532 nm was obtained from LIDAR measurements in spring (4 May–2 June) 2009 in Gwagnju, Korea. Depolarization ratios from 0.08 to 0.14 were observed only in daytime (09:00–17:00 local time (LT)) during high pollen concentration days from 4 to 9 May. Vertical distributions in the depolarization ratio with time showed a specific diurnal pattern. Depolarization ratios, which varied from 0.08 to 0.14, were measured near the surface in the morning. High depolarization ratios were detected even up to 2.0 km between 12:00 and 14:00 LT but subsequently were observed only close to the surface after 17:00 LT. Low values of depolarization ratios (≤ 0.05) were detected after 18:00 LT until next morning. During the measurement period, the daily variations in the high depolarization ratios close to the surface showed good agreement with those in surface pollen concentrations, which implies that high depolarization ratios can be attributed to high pollen concentrations. The diurnal characteristics in high values of depolarization ratios were closely associated with turbulent transport, which can be caused by increasing temperature and wind speed and decreasing relative humidity. Continuously measured diurnal and vertical characteristics of pollen data can be further used to enhance the accuracy of the pollen-forecasting model via data assimilation studies.

1 Introduction

Pollen, a form of biogenic air pollution, is a common cause of allergy-related diseases such as asthma, rhinitis, and atopic eczema (Lewis et al., 1983; Esch and Bush, 2003). In the industrialised countries of central and northern Europe, up to 15 % of the population is sensitive to pollen allergens (WHO, 2003). It also can play a role as

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an atmospheric pollutant by decreasing visibility during main pollen seasons. According to previous studies (Beggs, 2004; D'Amato and Cecchi, 2008; Shea et al., 2008), these negative effects of airborne pollens are becoming increasingly problematic as climate change rapidly progresses. In order to understand and predict temporal and spatial characteristics of these pollens, various models have been developed (Andersen, 1991; Giner et al., 1999; Laaidi, 2001; Adams-Groom et al., 2002; Gioulekas et al., 2003; Laaidi et al., 2003; Water et al., 2003; Vázquez et al., 2003). These forecasting models utilized pollen concentration data observed by in situ aerobiological monitors near the surface ollen (Frøsig and Forbundet, 2003; Severova and Polevova, 1996; Porsbjerg et al., 2003; Rantio-Lehtimäki and Matikainen, 2002). However, there is convincing evidence that long-range transported pollen can significantly enhance pollen concentrations at both the surface and elevated altitudes of the receptor sites so that it may affect temporal and spatial characteristics of the pollens. Especially in these cases, temporally and vertically resolved pollen data are expected to enhance the forecasting capability of the model.

Raynor et al. (1973) and Hart et al. (1994) reported that the vertical distributions in pollen abundance are highly associated with meteorological conditions through vertically resolved tower sampling. Since the maximum height of their sampling was limited to 108 m, these tower-based studies had difficulties investigating the diffusion of pollens up to the top of the planetary boundary layer and beyond. The experimental data collected by aircraft sampling indicate that the presence of substantial pollen concentrations at greater heights supports the hypothesis of recurring meteorological conditions favouring vertical and long distance transport of pollens (Mandrioli et al., 1984). Although many types of investigations, including airborne and tower-based measurements, have been performed to understand the dispersion and physical behavior of either long- or short-range transport of pollen grains (Raynor et al., 1975; Mandrioli et al., 1984; Hjelmroos, 1991; Sofiev et al., 2006), the data obtained from these studies can only be used to understand the physical characteristics for limited cases of pollen events, owing to the lack of continuous airborne measurements and limited height cov-

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erage of tower-based measurements (Raynor et al., 1974). Therefore, continuous information regarding the vertical distribution of pollen abundance is of clear benefit in the investigation of pollen dispersal and transport.

Anthesis and pollen release are influenced by the circadian patterns associated with air temperature, relative humidity, and wind speed (Kasprzyk, 2006). Daily temperature and relative humidity act as significant factors influencing the release of pollens into the ambient air (Bartková-Ščevková, 2003). Pollen transport, dispersal, and atmospheric concentration are also mainly affected by meteorological factors (Damialis et al., 2005; Sofiev et al., 2006). However, few studies have investigated pollen vertical distribution in conjunction with meteorological data. Therefore, in order to understand and predict pollen release, dispersal, and transport, it is necessary to measure pollen vertical distribution and meteorological variables simultaneously.

The main goal of this study is to understand vertical characteristics and diurnal patterns of pollen via 24-h LIDAR measurements at an urban site for a one-month period when pollen release is most active. To identify relation of pollen to depolarization ratio by LIDAR, we analysed surface pollen and PM_{10} concentrations and sun/sky radiometer data. The relative humidity, wind speed, and temperature were also employed to investigate the relationship between diurnal patterns in vertical pollen distribution and these meteorological factors.

2 Measurements

At the campus of Gwangju Institute of Science and Technology (GIST), polarization LIDAR measurements were carried out using the depolarization LIDAR system (DPL) of Korea Polar Research Institute (KOPRI) during May 2009, which is main pollen season in Korea (Park et al., 2009). DPL is located at 35.13 latitude and 126.50 longitude at an elevation of 53 m above mean sea level (MSL). The DPL has a high power (170 mJ), 10 Hz pulse repetition rate, Nd:YAG (532 nm) laser transmitter, and a two-channel receiver using a 20-cm diameter telescope. With LIDAR, the total linear depolarization ratio (δ, the ratio of the returned laser powers in the planes of polarization orthogonal and parallel to that transmitted) and aerosol extinction coefficient (α) were measured: the signals comprise the sum of aerosol and molecular backscatter signals. The LIDAR backscatter depolarization technique is widely used in atmospheric research because of its ability to distinguish dust from non-dust particles (Noh et al., 2007, 2008, 2012). In the presence of anthropogenic aerosols, the depolarization ratio, which is used as a criterion in the determination of aerosol's sphericalness, shows values smaller than 0.05, while that of Asian dust ranges from 0.10 to 0.30 (Sakai et al., 2003; Noh et al., 2007, 2008).

Column-integrated aerosol optical depth (τ) at 440 nm and the Ångström exponent (440–870 nm, Å) were measured with the polarized version of the CIMEL 318-1 Sun/sky radiometer (Holben et al., 1998) at the same site where we carried out the LIDAR measurements. Those parameters were retrieved using the AERONET algorithm (Dubovik and King, 2000). Detailed information on the cloud-screening and data-retrieval processes can be found in Dubovik and King (2000) and Smirnov et al. (2000). In this study, we use daily mean level 2.0 data, which can be downloaded from the AERONET site (http://aeronet.gsfc.nasa.gov). The daily number of pollen grains in the atmosphere was monitored by a Burkard 7 day recording volumetric spore sampler, situated on the rooftop of Gwangju Bohoon hospital, where the building is located 1.0 km away from LIDAR site, at a height of 2 m above the rooftop and at an altitude of 85 m above MSL. Hourly meteorological data such as relative humidity, wind speed, and temperature and PM_{10} concentrations were measured at the Gwangju local meteorological administration, which is located 5-km away from the LIDAR site. Radiosonde observations, conducted four times (03:00, 09:00, 15:00, 21:00 LT) a day by the Korean Meteorological Administration (KMA) at Gwangju airport (located about 10-km away from the LIDAR observation site), provided the vertical profiles of relative humidity and temperature.

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3 Relation of pollen to the depolarization ratio

Figure 1 shows temporal variations in the aerosol extinction coefficient (α) and depolarization ratio (δ) measured by the LIDAR for the period 4–9 May 2009. Figure 1a shows continuous observation of high δ values up to an altitude of 1.5–2.0 km and aerosols stayed within the mixing height. δ in Fig. 1b shows different vertical patterns from those of α in Fig. 1a. δ, ranging from 0.08 to 0.14, was measured near the surface between 09:00 and 10:00 LT. These δ values were measured up to the altitude of 2.0 km, close to the top of the boundary layer during the daytime between 12:00 and 14:00 LT while the altitude range, where high δ was observed, lowered and these δs were no longer detected after 17:00 or 18:00 LT. This unique diurnal pattern in vertical distributions of δ's was repeatedly observed over the six consecutive days we took measurements. The large value of δ indicates the dominance of non-spherical aerosols within the measurement area. In general, Asian dust and sea-salt induce a large value of δ at this measurement site. In Asian dust events, diurnal patterns in vertical distributions of δ show generally good agreement with those of αs. However, diurnal patterns in vertical distributions of the depolarization ratio in this study, as shown Fig. 1b, were different from the typical patterns observed during Asian dust events.

The surface PM_{10} data and sun/sky radiometer data were analyzed to identify non-spherical particle types that were thought to increase the δs during the measurement period. Figure 2 shows hourly variations in the surface PM_{10} concentration and aerosol optical depth (τ) at 440 nm and Ångström exponent(Å) in the wavelength interval range of 440 to 870 nm measured by sun/sky radiometer for the period 4–31 May. PM_{10} concentration rapidly increased up to 100 µg m^{-3} until 10 May, when τ and Å ranged from 0.28 to 0.91 and from 1.12 to 1.44, respectively. In northeast Asia, during the Asian dust period, PM_{10} concentration and τ tend to increase, whereas Å shows values smaller than 1.0 (Murayama et al., 2001). In Fig. 2, however, PM_{10} concentration does not seem to be related with δ, which varies only during daytime. In addition, this increase in δ is thought not to be effected by Asian dust events because of high Å values rang-

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ing from 1.20 to 1.43 for the period May 4-9. Thus, based on the Å data as well as disagreement in diurnal pattern of vertical distribution of δ with those of α, the diurnal and vertical characteristics of δ shown in Fig. 1b can be hardly attributed to Asian dust. Additionally, given the geometrical location of the measurement site (50-km away from the coastline) and the repetitive diurnal and vertical patterns in the observed δs, it is also less likely that sea-salt had dominant contributions to the increased δ only during the daytime.

Therefore, we attempted to identify relationship between increased δ and pollen, which was once identified as one of the causes of increasing δ according to a previous study by Sassen (2008). Figure 3 shows daily pollen concentrations for the periods of 4–9 and 24–31 May. Among the six-day period with large δ values, high surface pollen concentrations were observed ranging from 1216 to 1952 m^{-3} for the period from 4 to 7 May even though they were 346 and 220 m^{-3} on 8 and 9 May, respectively, which were still larger than those on other measurement dates from 10 to 31 May. In Fig. 4, δ did not increase for the period 24–31 May when the pollen concentration was observed to be lower than 100 m^{-3}. The enhanced δs in Fig. 1b could be attributed to the increased pollen concentration observed for the period 4-9 May owing to the non-spherical shapes of pollen grains.

4 Effects of meteorological conditions on diurnal and vertical patterns

Alba et al. (2000), Jato et al. (2000), Käpylä (1984) and Bartková-Ščevková (2003) found that the temperature, the hours of sunshine, and the wind speed positively affect the atmospheric concentration of pollen. Alternatively, rainfall and humidity during the pollination periods tend to decrease pollen concentrations. Figure 5 shows the hourly mean relative humidity, wind speed, and temperature for the period 4–9 May. δ in Fig. 1b varied from 0.08 to 0.14 between 09:00 and 12:00 LT, for which 60–80 % of relative humidity decreased to less than 20 % and the temperature reading of 15 °C at 09:00 LT increased to above 25 °C by around 13:00 LT. Between 16:00 and 09:00 LT

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when δ was less 0.05, relative humidity increased and its maximum value was observed at dawn whereas there was a decreasing trend of temperature. Although mean wind speeds were 3.1 and 2.8 ms^{-1} on 4 and 8 May, respectively, which are lower than those on other dates, an increasing trend of temperature was maintained during the daytime on those two days. In the present study, when temperature and humidity met these pollen-releasing conditions, pollen concentration increased, as shown in Fig. 3, thereby inducing depolarization scattering by non-spherical shapes of pollens. In other words, during the daytime, δ increased because of increased pollens concentrations.

In the present study, the altitude range where the pollen was observed varied significantly between 09:00 and 18:00 LT, as shown in Fig. 1b . Pollen started to be observed only near the surface around 09:00 LT, up to 2 km around 13:00 LT and again only near the surface around 18:00 LT for 6 days in row. This sort of diurnal pattern in vertical distributions of pollen is thought to be related with their short or long travel distance characteristics. Most of the pollen grains injected into the air will fall close to their source and only a few, termed the "escape fraction" (Gregory, 1978), will be carried long distances. Gregory (1978) reported that only 10 % of total pollens released into the air can be dispersed long distance by vertical transport. According to Mandrioli et al. (1984), vertical movement of atmospheric particles takes place by turbulent transport. Turbulent transport, widely considered in problems related to air pollution, occurs via turbulence formation by the vertical movement of air mass within the boundary layer when the surface level is heated by sunrise. Thus, atmospheric particles are vertically mixed by this turbulent transport.

Vertically resolved relative humidity and temperature as shown in Fig. 6 support our assertion that the diurnal pattern in vertical distribution of pollens observed in this study is induced by turbulent transport. The data at 09:00 LT show that vertical movement of pollen is limited owing to inversion layer formed near the surface with high relative humidity. On the contrary, vertical pollen movement took place via turbulent transport, which occurred as a result of the unstable atmospheric conditions with insulated air that is formed by the rate at which the temperature fell at 15:00 LT.

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5 Conclusions

In this present study, we utilised the LIDAR depolarization ratio and meteorological data to observe diurnal patterns in vertical distributions of pollen. Based on LIDAR measurements, depolarization ratios by the pollens were observed to range from 0.08 to 0.14, which are explicitly larger than those of anthropogenic aerosols. Pollens were dispersed up to 2.0 km in altitude with increased temperature, wind speed and decreased relative humidity conditions. However, the height of the pollen layer rapidly decreased at the late afternoon when wind speed and temperature decreased and relative humidity increased.

The diurnal variabilities and the vertical structures of pollens observed in this study can be utilised as reference for those seeking to separate pollens from mineral dust particles for space borne sensors such as Cloud-Aerosol LIDAR and Infrared Pathfinder Satellite Observations (CALIPSO). Moreover, the continuously measured diurnal and vertical characteristics of pollen data can be further used to enhance the accuracy of the pollen forecasting model via data assimilation studies.

Acknowledgements. This work was funded by the Korea Meteorological Administration Research and Development Program under Grant CATER 2012-7080. This work was partly supported by the project "Reconstruction and observation of components for the Southern and Northern Annular Mode to investigate the cause of polar climate change (PE12010)" of Korea Polar Research Institute. Sungkyun Shin is supported by the Global Ph.D. Fellowship program which is sponsored by the National Research Foundation of Korea.

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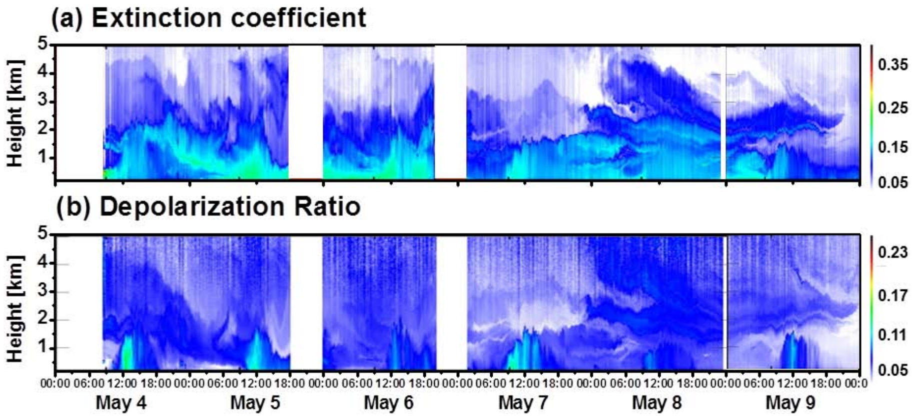

Fig. 1. Time-altitude plot of the extinction coefficient **(a)** and depolarization ratio **(b)** at 532 nm measured from 00:00 LT on 4 May to 24:00 LT on 9 May 2009.

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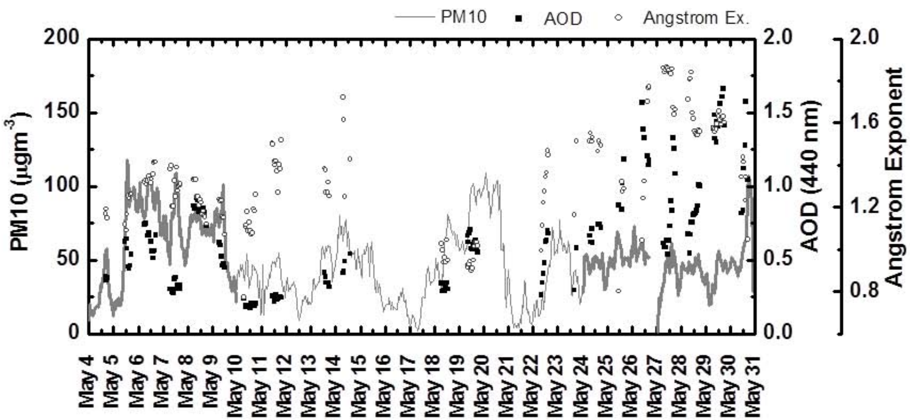

Fig. 2. Hourly averaged PM_{10} concentration from 4 to 31 May 2009. The period from 4 to 9 May and 24 to 31 May indicated by a thick gray line. Aerosol optical depth at 440 nm (dark square) and Ångström exponent (open circle) measured by the AERONET sun/sky radiometer.

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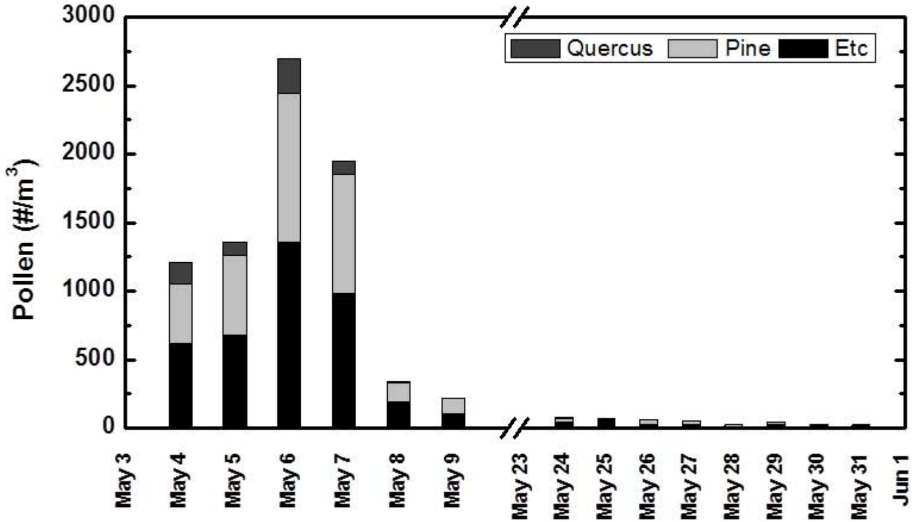

Fig. 3. Daily distribution of pollen counts from 4 to 9 May and 24 to 31 May at Gwangju, Korea.

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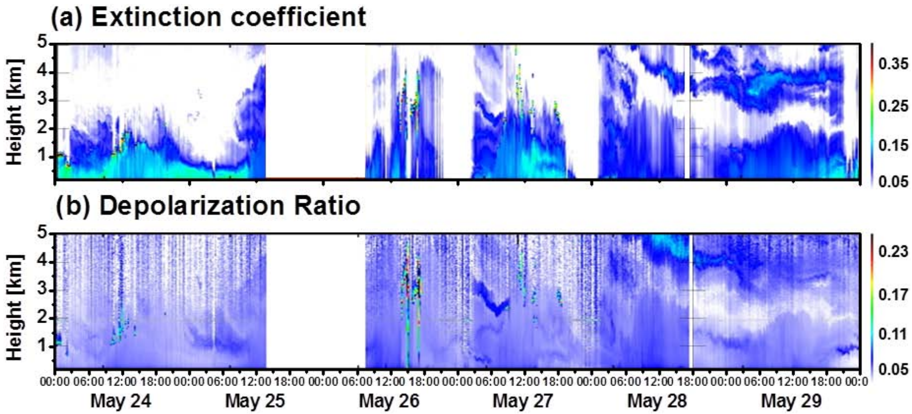

Fig. 4. Time-altitude plot of the extinction coefficient **(a)** and depolarization ratio **(b)** at 532 nm measured from 00:00 LT on 24 May to 24:00 LT on 29 May 2009.

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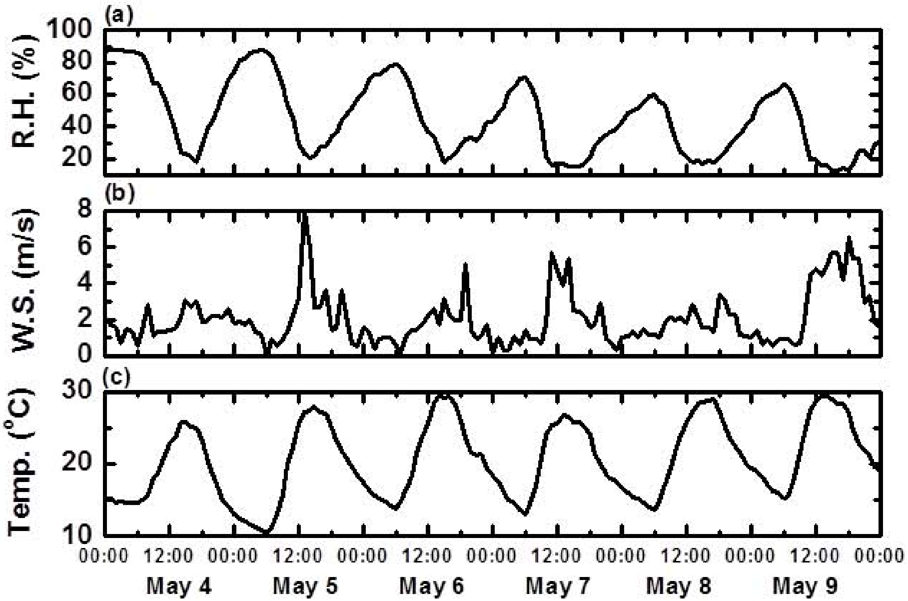

Fig. 5. Hourly averaged meteorological data observed from 00:00 LT on 4 May to 24:00 LT on 9 May 2009. **(a)** Relative humidity, **(b)** wind speed, and **(c)** temperature.

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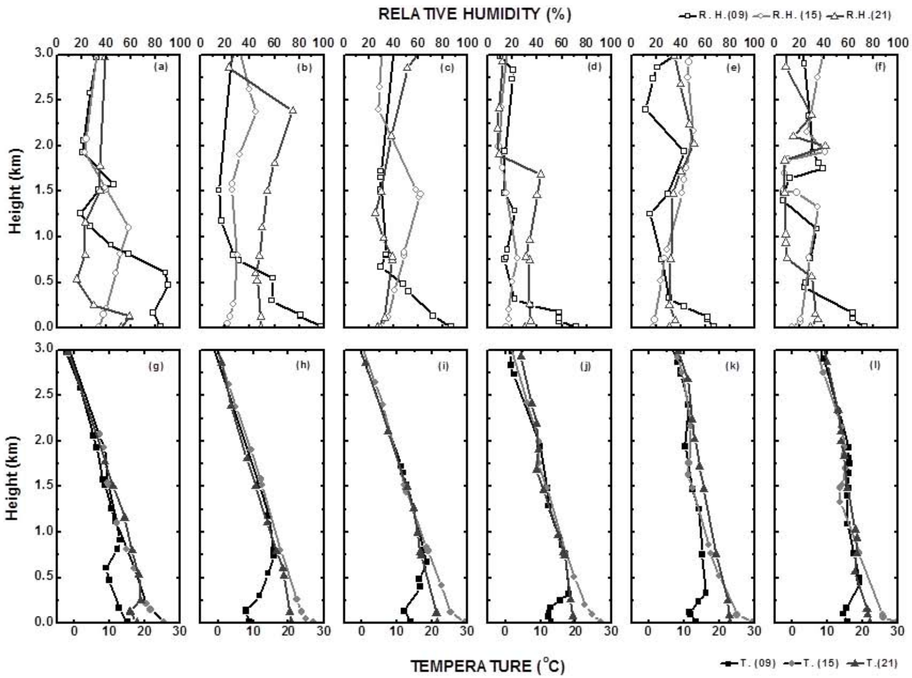

Fig. 6. Radiosonde data on 4 May **(a, g)**, 5 May **(b, h)**, 6 May **(c, i)**, 7 May **(d, j)**, 8 May **(e, k)**, and 9 May **(f, l)**. Relative humidity observed on 09:00 LT (open square), 15:00 LT (open circle) and 21:00 LT (open triangle). Relative humidity observed on 09:00 LT (closed square), 15:00 LT (closed circle) and 21:00 LT (closed triangle)

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