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Variability of atmospheric depth profiles

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Variation of profiles of atmospheric depth is studied based on the UK Met Office radiosonde data. The seasonal variation at different sites (Salt Lake City, USA; Mendoza, Argentina) is compared to daily variation within a given month in a season. Year-to-year variations of monthly average profiles are also presented. It is demonstrated that daily, local monitoring of the atmosphere is needed for precise shower reconstruction.

1. Introduction

Development of extensive air showers depends on the properties of the atmosphere itself, in particular on distribution of mass in the atmosphere. Since the atmosphere serves both as a target in which primary cosmic rays interact and the medium in which showers develop, as precise as possible knowledge of properties of the atmosphere is extremely important for studies of high energy cosmic rays. Therefore, the local distribution of air density along the shower path is of primary importance. In the fluorescence detection technique the longitudinal profile of shower development is reconstructed as a function of altitude above ground. To extract such important quantities like depth of shower maximum, X_{max}, an accurate conversion of the altitude into atmospheric depth is necessary.

The US Standard Atmosphere Model [1] is widely used in air shower simulation codes and in analyses of shower measurements. This model provides the temperature and pressure profiles at the northern hemisphere, for mid-latitude average atmosphere. The 1976 extension of the Model provides also the northern mid-latitude winter and summer atmospheric distributions. An important question is, however, how well does the US Standard Atmosphere Model approximate local conditions at the sites of air shower detectors, and what is the time variability of the local atmosphere? In other words, is the annual or seasonal average adequate for a particular day at a particular location? It is now well known [2, 3] that a good knowledge of atmospheric depth profiles is essential for precise shower reconstruction.

In this analysis we use the UK Met Office data [4] which contain temperature and pressure profiles measured by radiosondes at the stations located worldwide. A radiosonde, carried by a small balloon, typically reaches altitudes up to 20-30 km. At higher altitudes, the COSPAR International Reference Atmosphere (CIRA86) [5] is used, which provides temperature and pressure profiles at many latitudes at both hemispheres. In the following we present an analysis of data collected at the station in Salt Lake City (USA) and at the station in Mendoza (Argentina) located near the southern Pierre Auger Observatory site. The atmospheric depth at an altitude h is the integral of density of overlying air: $X(h) = \int_h^{\infty} \rho(h)dh$, where $\rho(p,T) = pM_{mol}/(RT)$ is the air density, p is the measured pressure, T - measured temperature, M_{mol} is the molar mass of air and R the universal gas constant.

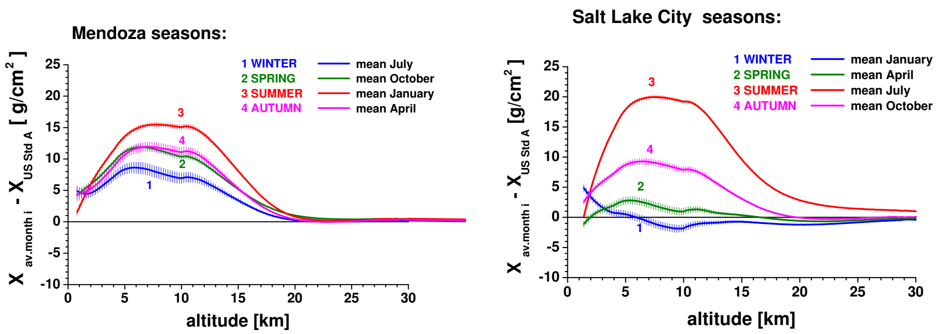

Figure 1. Average seasonal atmospheric depth profiles, relative to US Standard Atmosphere, at Mendoza (Argentina) and Salt Lake City (USA).

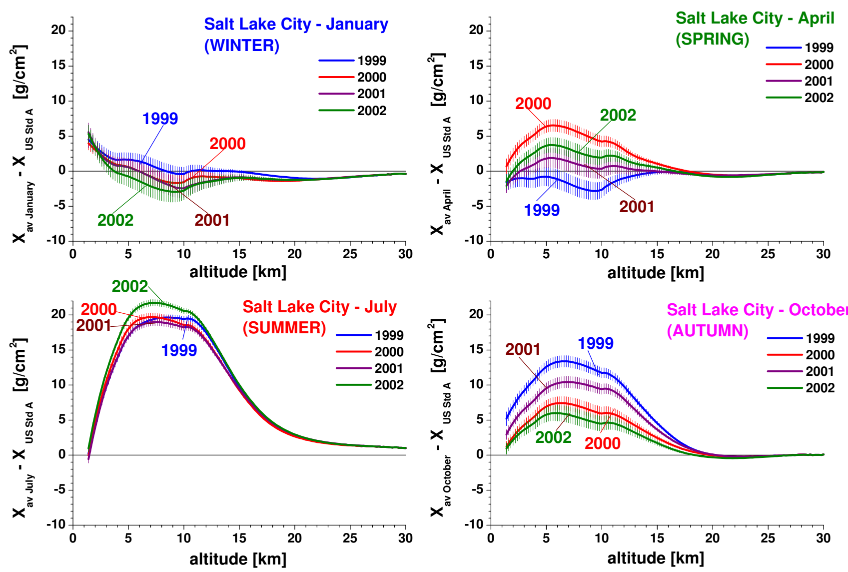

Figure 2. Year-to-year variability of monthly average profiles at Salt Lake City.

2. Seasonal variation of atmospheric profiles

Seasonal variations of the atmospheric depth profiles $X(h)$ for both sites analyzed (Mendoza and Salt Lake City) are shown in Fig.1. Differences of the average monthly profiles in four seasons, relative to the US Standard Atmosphere, are shown. One can see that seasonal profiles strongly depend on the site. In Salt Lake City the differences among seasons are much larger than in Mendoza. The seasonal profiles shown in Fig.1 are the four-year averages of the months shown. The average monthly profiles vary from year to year, as shown in Fig.2. The year-to-year variability of the average monthly profiles can reach 10 g/cm^2, as shown for April and October.

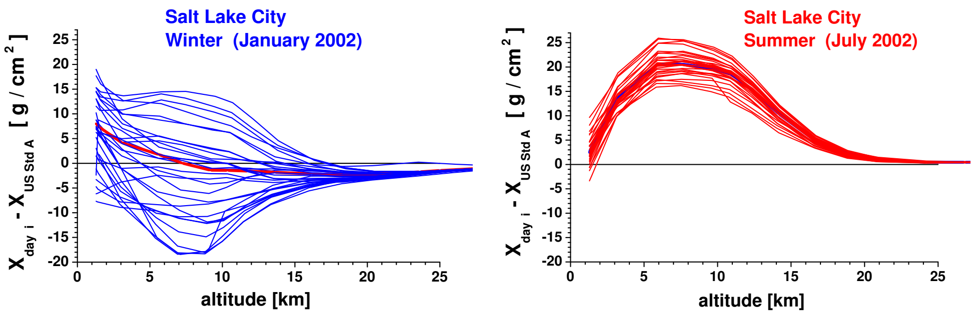

Figure 3. Daily variation of atmospheric depth profiles in winter and summer at Salt Lake City.

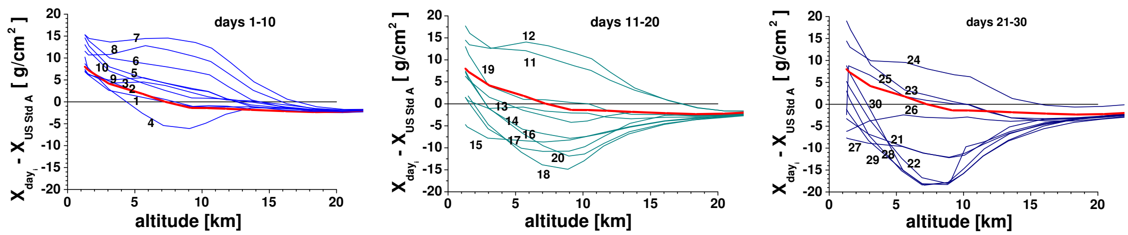

Figure 4. Profiles of individual days in January 2002 at Salt Lake City.

3. Day-to day variation within a month

Apart from the seasonal variation of the atmosphere, a strong variation is observed on the time scale of a day. In Fig.3 the differences of atmospheric depth profiles for individual days relative to the US Standard Atmosphere Model are presented for winter (January 2002) and summer (July 2002) at Salt Lake City. The range of profile variability is larger in winter than in summer. To examine closer this variability, the profiles of individual days of January 2002 are shown in Fig.4 with ten consecutive days shown in each panel. The numbers denote the date of each day. The four-year average of January is shown by the red heavy line.

One can note that the profiles of consecutive days differ typically by 3–5 g/cm^2, with profiles of neighboring days grouped together. Occasionally, a large change is observed from a day to a next one (e.g. days 12-13, days 18-19-20, days 22-23, etc.). Most of the daily profiles in the first decade of January lay above the monthly average, while in the rest of the month the profiles lay predominantly below the average. The character of the daily variability in other seasons and sites is very similar to that shown in Fig.3, but the range of variability is sometimes smaller. As an example, the daily profiles at Mendoza in winter and summer are shown in Fig.5.

The data presented in Figures 1–5 clearly demonstrate that taking into account the seasonal variation is not sufficient for precise shower reconstruction. The day-to-day variation within a month is equally important and should be accounted for.

4. Day-night variation

Observations of extensive air showers using the fluorescence technique are done only during nights. However, some of the balloon launching stations usually make balloon soundings during days only. A question therefore

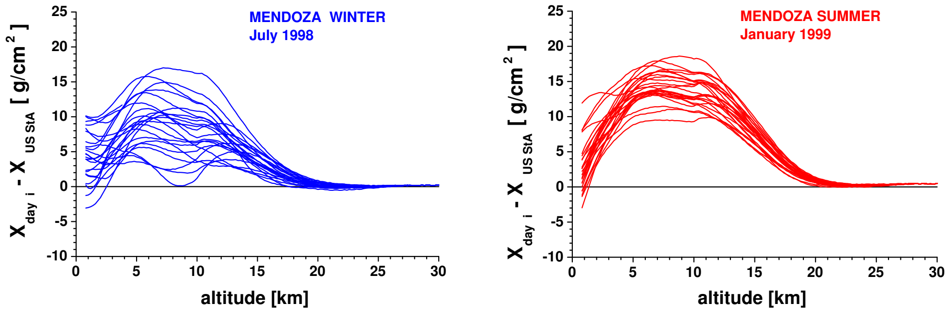

Figure 5. Daily variation of atmospheric profiles in winter and summer at Mendoza.

arises whether one can calculate accurately enough an atmospheric depth profile for the night, based on the radiosonde data collected during the day. The station at Salt Lake City routinely makes two radiosonde soundings during daytime (11.00 and 12.00 hrs) and two soundings during night (23.00 and 0.00 hrs). The day-night atmospheric variation can therefore be studied at Salt Lake City.

Using profiles of two consecutive days, an interpolation is made to get a "night interpolated" profile, which is then compared to the profile actually measured during that night. The standard deviation of the distribution of differences between measured and interpolated nightly profiles stay below ~ 3 g/cm^2. One can therefore conclude that the nightly profiles can be adequately determined from measurements done during neighboring days.

5. Summary

The profiles of atmospheric depth exhibit a seasonal variation of up to 10–20 g/cm^2, both at Mendoza and at Salt Lake City. The average monthly profiles vary year-to-year within a few g/cm^2. This variation is due to fluctuations of daily profiles. The day-to-day variation within a month is as important for shower studies as the seasonal variation: the ranges of the seasonal and daily variations are similar. Therefore, a daily local monitoring of the atmosphere is needed for precise shower reconstruction. The day-night variation, which reflects the day-to-day variation, is reasonably small.

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