Importance of Atmospheric Model in Shower Reconstruction

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Abstract

The influence of an atmospheric model on shower reconstruction is studied. In the fluorescence detection technique, one of the key measurements is the depth of shower maximum in the atmosphere, X_{max}. The altitude corresponding to X_{max} depends considerably on distributions of atmospheric pressure and temperature, used in the shower reconstruction. In this paper, measured atmospheric profiles at different geographic locations are compared to the US Standard Atmosphere model. A study of the atmospheric effect in shower reconstruction as a function of shower inclination and energy is done. Seasonal variations of atmosphere are shown to affect considerably the X_{max} determination.

1. Introduction

The atmosphere serves both as a target and a part of an extensive air shower detection system. The main parameter governing the shower development is the amount of traversed air. 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. An accurate conversion of the altitude into grammage of air traversed is necessary in order to extract such important quantities like depth of shower maximum, X_{max}. In addition, light attenuation in the atmosphere depends on the air density distribution, making the detailed knowledge of the atmosphere even more important.

The US Standard Atmosphere model [5] is widely used in air shower simulation codes and in analysis of shower measurements. It has been shown [4] that the time variation of the atmosphere can be significant, so that the actual distribution of the atmospheric density can differ considerably from the model one. In this paper, we study profiles of the atmosphere density in northern and southern hemispheres and compare them to the US Standard Atmosphere.

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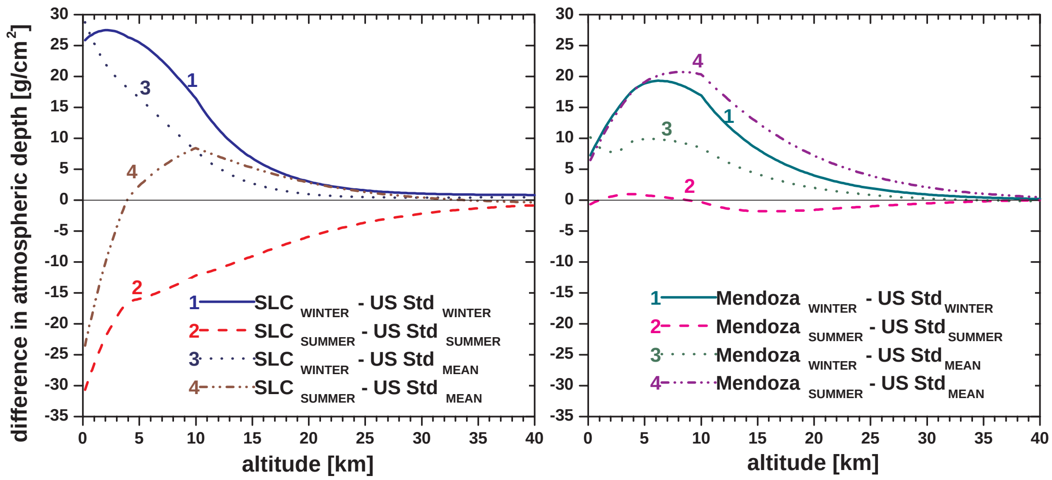

Fig. 1. Comparison of measured atmospheric depth to the US Standard Atmosphere at Salt Lake City (SLC) and Mendoza.

2. Measurements of atmospheric profiles

The atmospheric depth at an altitude h is the integral of density of overlying air: $X(h) = \int_h^\infty \rho(h)dh$. Since the air density is not measured directly, it must be inferred from the ideal gas law based on measurements of pressure p and temperature T: $\rho(p,T) = pM_{mol}/(RT)$, where M_{mol} is the molar mass of air and R is the universal gas constant. The pressure and temperature profiles are measured by radiosondes suspended to small balloons. The balloons typically reach altitudes between 20 and 30 km and provide temperature and pressure readings at predefined standard pressure levels.

The US Standard Atmosphere model (with the 1966 Supplement) provides the temperature and pressure profiles at the northern hemisphere, for mid-latitude winter and summer, as well as average atmosphere. At the southern hemisphere, e.g. at the southern Auger Observatory in Argentina, the US Standard Atmosphere model may not be appropriate. The COSPAR International Reference Atmosphere (CIRA86) [2] provides temperature and pressure profiles at altitudes above 20 km at many latitudes at both hemispheres. However, most of air shower development takes place at altitudes smaller than 20 km, so the CIRA86 model is not sufficient for air shower studies.

We use the UK Met Office data [1] which contain the temperature and pressure profiles measured by radiosondes at a number of locations worldwide, including Salt Lake City (USA) and Mendoza (Argentina), which are near the northern and southern Pierre Auger Observatory sites. Averages over several years of measurements in winter (January at Salt Lake City, July at Mendoza) and summer (July and January, respectively) were used for comparison with winter,

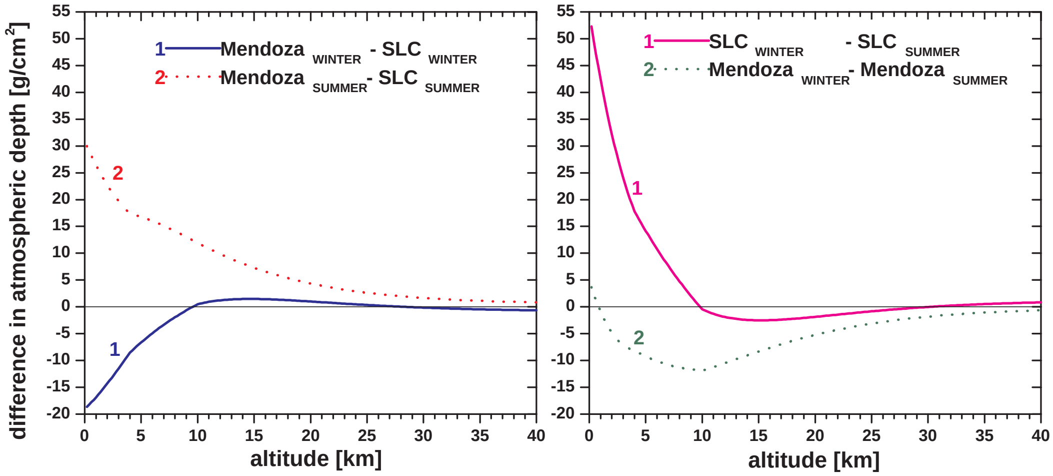

Fig. 2. Comparison of measured winter and summer atmospheric depth at Salt Lake City (SLC) and Mendoza, and seasonal variation at both sites.

summer and annual average US Standard Atmosphere model.

3. Comparison of atmospheric models

The BADC data were used to derive a parameterization of the atmosphere analogous to that used in the CORSIKA shower simulation package [3], i.e. separate fits to atmospheric depth in altitude ranges 0-4, 4-10, 10-40, 40-100 and above 100 km. Since the BADC radiosonde data cover altitudes below about 30 km, at higher altitudes the CIRA86 data were used. Differences in atmospheric depth versus altitude between actual measurements (BADC data) and US Standard model are shown in Figure 1 for Salt Lake City (SLC) and Mendoza. Seasonal variations of the atmosphere in Salt Lake City do not quite follow the US Standard Atmosphere model: the difference between measured and model atmospheric depth reaches ± 30 g/cm^2 at low altitudes. It is interesting to note that the US Standard Atmosphere model happens to describe the actual atmosphere in Mendoza much better than in Salt Lake City.

Figure 2 shows a comparison of the SLC and Mendoza measured atmospheres as well as their seasonal variations. The profiles of the atmosphere at these sites are clearly very different, both in winter and in summer.

Since the seasonal variations of the atmospheric profiles seem to be rather large, it is important to check their influence on shower reconstruction. A set of shower simulations were performed using CORSIKA for proton- and iron-induced showers at various energies and zenith angles. Differences in altitudes of shower maximum, using winter and summer atmospheres, were found. These differences were rescaled by the average difference in shower maximum altitude between proton and iron showers in order to see how important they are. The results are

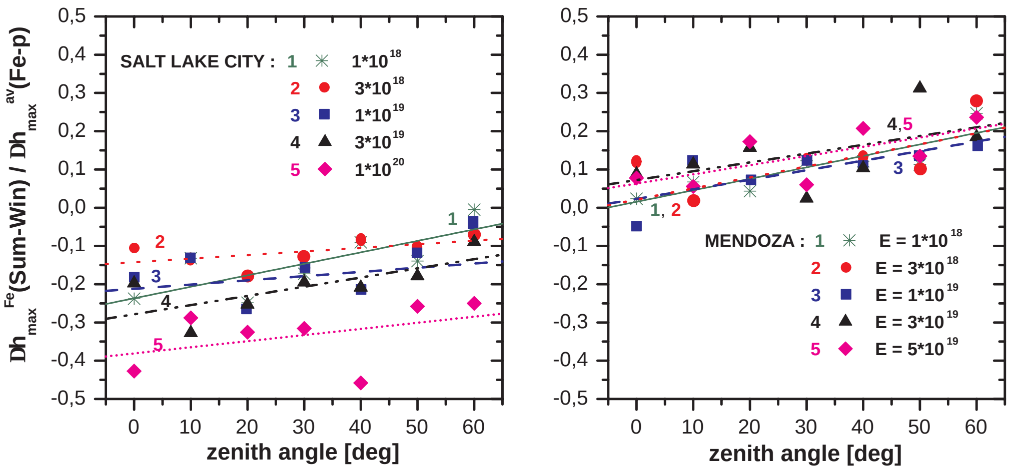

Fig. 3. Seasonal differences in shower maximum altitude of iron-initiated showers relative to average iron-proton difference in altitude of shower maximum.

shown in Figure 3. It is seen that the effects due to seasonal variations can be as large as 40% of the iron-proton difference, and are different in Salt Lake City and in Mendoza.

4. Conclusion

Atmospheric profiles actually measured in Salt Lake City and in Mendoza were compared to the US Standard Atmosphere model. Large differences between the data and the model are observed. The seasonal variation of the data differs significantly from that assumed in the model. A clear conclusion emerges: a *global* atmospheric model is not satisfactory for use in extensive air shower studies. Instead, atmospheric profiles *measured* as locally as possible should be used. Since local measurements are available for each month, they should be used to follow the seasonal variations of the atmosphere as closely as possible. Even daily variations of the atmospheric properties should be accounted for.

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1. http://badc.nerc.ac.uk/data/radiosglobe/radhelp.html
2. http://nssdc.gsfc.nasa.gov/space/model/atmos/cospar1.html
3. Heck D. et al. 1998, Report FZKA 6019, Forschungszentrum Karlsruhe
4. Keilhauer B. et al.,Auger Notes GAP2002-022,GAP2003-009; these proceedings
5. http://nssdc.gsfc.nasa.gov/space/model/atmos/us_standard.html