The Influence of the Global Atmospheric Properties on the Detection of UHECR by EUSO on Board of the ISS

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Abstract

The Extreme Universe Space Observatory (EUSO) project is aimed to detect from space the Extensive Air Showers (EAS) produced by Ultra High Energy Cosmic Rays (UHECR) when entering the Earth's atmosphere, by the use of a telescope located on the International Space Station. The secondary particles in the shower produce fluorescence and Cherenkov light by interacting with the air molecules. The atmosphere influences the development and the detection of the EAS, and it is mandatory to know its characteristics at the place and time an EAS develops. Here we report on various aspects of basic atmospheric properties which can have a noticeable influence on the light production in the EAS and the light transport to the detector. By basic properties we mean pressure, temperature and composition as a function of altitude, geographical location and date. Since the EUSO telescope will be installed on the ISS, which has a revolution time of 92 minutes on an orbit inclined by 51.6 degrees, these global characteristics of atmosphere in the field of view of EUSO will change minute by minute. This variability with time and location and the consequences on the light production, transport and detection are emphasized.

1. Introduction

The "Extreme Universe Space Observatory - EUSO" will be the first Space mission dedicated to the Ultra High Energy Cosmic Rays (UHECR) and Neutrinos detection using the Earth's atmosphere as a huge detector. The aim of this note is to present some aspects of atmospheric parameters relevant for the study of the Extended Air Showers (EAS) produced by the UHECR.

2. Atmospheric Models

The US Standard Atmosphere 1976 models [1] are commonly used in the atmosphere community. Based on rocket and satellite data and perfect gas theory, the profiles of atmospheric densities, pressure, temperature are provided from sea

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level to 1000 km. The altitude resolution varies from 0.05 km at low altitudes to 5 km at high altitudes. The U.S. Standard Atmosphere Supplements includes tables of atmospheric parameters for five northern latitudes (15, 30, 45, 60, 75), for summer and winter conditions. The grid in latitude, longitude and time may be not precise enough for our purpose: using US Standard Atmosphere values as inputs, whatever the space-time location of the shower is, can lead to large systematic errors, in the UHECR energy determination or particle identification.

As far as we are concerned by the global properties and profiles such as pressure, temperature and the number densities of the main constituents, it seems better to use the empirical models recommended by the Committee for Space Research (COSPAR). These models are implemented with recent data and are based on the COSPAR International Reference Atmosphere CIRA-86, merged with the Mass-Spectrometer-Incoherent- Scatter (MSIS) model for the upper part of atmosphere. These empirical atmosphere models provide the profiles of the main constituents and properties from ground to 1000 km; it is based on 40 years of data of various types and is continuously updated. Neutral densities are given within a latitude, longitude and date grid, which can be easily accommodated to the EUSO trajectory for simulation purpose. Comparisons between US-Standard and NRLMISE-00 Model 2001 [2] density profiles from ground to 20 km have been performed, in order to check that the profiles of the US standard models can be reproduced with the data from NRLMSISE; the results show that profiles are consistent within 2.5% at all altitudes.

3. Nitrogen Number Density and Fluorescence Yield

The N_2 density is the most determinant parameter for the fluorescence yield. At ground level around earth and at a given date, it varies with the latitude: it is higher at the poles than near the equator. A longitudinal modulation also exists due to local time variation with respect to the sun. Considering the trajectory of the station, the variation of the nitrogen density can reach $\sim$10% in the EUSO field of view in a very short time.

During one day, the ISS performes fifteen rotations around the globe. In Fig. 1., the variation of the N_2 density at sea level is shown versus time corresponding to the ISS trajectory. Along the one day path of ISS around the earth (upper-left), the molecular nitrogen density varies according to the location, exhibiting an oscillating behaviour (upper-right); the maxima are for northern latitudes (in winter in this case), the smaller maxima for southern locations. The minima are for equatorial latitudes. One observes a longitudinal modulation for the maxima, while attenuated for southern locations; equatorial values do not exhibit strong variations with longitude. The amplitude of variations exceeds 10%. However since observations by EUSO will take place only at night, the variations expressed as a function of the local solar time (LST) (lower-left) show a

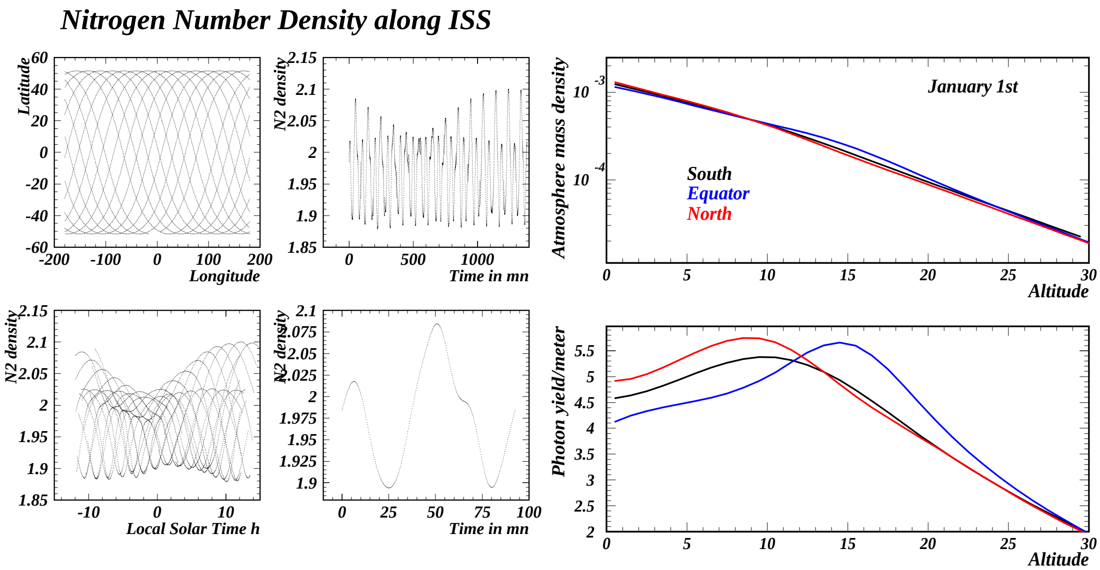

Fig. 1. Left: four plots showing the variation of the N_2 density (at sea level) versus time corresponding to the ISS trajectory (see text for details) Right: top : Atmosphere density as a function of altitude for 3 latitudes compatible with ISS trajectory; bottom: photon yield per metre as a function of altitude for the 3 locations using dry atmospheres and EUSO wavelength bandwidth.

smaller amplitude when limited by LST=0 + 4. At last the detailed variations for one revolution (92 minutes) as a function of time (lower-right) reveals the rapid variation with a 23 minutes period corresponding to of a revolution.

A complete calculation linking the fluorescence yield to the nitrogen density is in progress but not yet available. In order to give an idea of the influence of such variations on fluorescence yield, the photon yield as a function of altitude is presented on the right part of Fig. 1. for 3 locations corresponding to a maximum (south and north) and to a minimum (equator).

4. Atmospheric Mass Density and Primary Cosmic Ray Identification

The shower reconstruction is affected by the variations of the atmospheric conditions. This can lead to a misidentification of primary cosmic ray through X_{max} determination: a proton-like shower in winter can simulate a Fe-like shower in summer at a given place, as it has been illustrated by a study performed for the Auger observatory [3]. The same effect is expected to occur within less than 46 minutes which is the mean duration of a EUSO night counting time.

The shower development profile depends on the nature and energy of the incident particle and on the development of the shower according to the effective atmosphere encountered. Proton and Fe impinging at 60 degrees were simulated

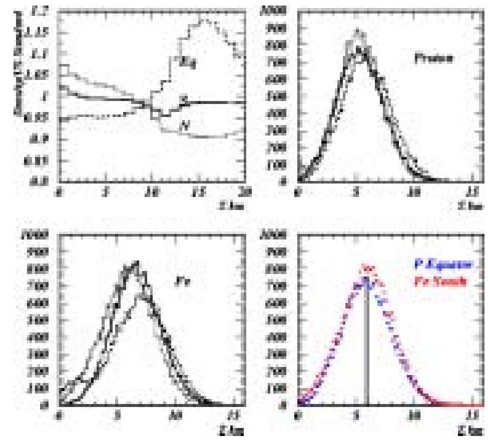

Fig. 2. EAS profiles as a function of altitude (see text for details).

and showers developed at different locations along the trajectory corresponding to one night of ISS flight. Atmospheric profiles of mass density and temperature where obtained from NRLMISE-00 for January 1st at night for 3 different realistic locations along ISS trajectory. Light yield profile was fixed for the different atmospheres and light transmission coefficient was fixed to 1. The results are shown in Fig. 2. On the upper left plot, the mass density profiles for the 3 chosen locations, normalized to US Standard profile are shown. For each location a sample of 10 showers with an energy of 5.10^{19} at zenith angle of 60 degrees are shown superimposed as a function of altitude in kilometer in upper-right (protons) and lower-left (Iron). The usual representation of showers in grammage is affected by the transformation to altitude. One can see on the lower-right plot that a situation where proton and Fe are overlapping, giving the same X_{max}, may exist. Since the showers are almost identical, the degeneracy cannot be resolved.

5. Conclusions

To be able to reconstruct the events detected by EUSO with a good accuracy, a good knowlegde of atmospheric conditions in the field of view of the telescope on board the ISS is mandatory.

6. References

1. http://nssdc.gsfc.nasa.gov/space/model/atmos/us_standard.html
2. Picone M. et al. http://nssdc.nasa.gov/space/model/atmos/nrlmsise00.html
3. Keilhauer B. et al. Auger Technical Note GAP-2002-022