30TH INTERNATIONAL COSMIC RAY CONFERENCE

Application of radiosonde data to VERITAS simulations

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Abstract: The atmosphere is a vital component of the detector in an atmospheric Cherenkov telescope. In order to understand observations from these instruments and reduce systematic uncertainties and biases in their data it is important to correctly model the atmosphere in simulations of the extensive air showers they probe. The Very Energetic Radiation Imaging Telescope Array System (VERITAS) consists of 4 such telescopes located at the Whipple Observatory in Southern Arizona. Daily radiosonde measurements from the nearby Tucson airport allow an accurate model of the atmosphere for the VERITAS experiment to be constructed. Comparison of the radiosonde data to existing atmospheric models is performed and the expected effects on the systematic uncertainties are summarised here.

Introduction

An atmospheric Cherenkov telescope relies on detecting the faint flashes of light given off when the energetic particles created in an extensive air shower (EAS) travel faster than the speed of light in the medium of air. The number of Cherenkov photons generated and the angle they are emitted at depends on the refractive index of the air – which itself is a complicated function of pressure, temperature, water vapour content and wavelength – but can be approximated as being proportional to the air density [1].

A radiosonde (at its most basic level) transmits temperature, pressure and humidity readings. When floated on a weather balloon these instruments can construct a profile of the atmosphere up to altitudes of $\sim$ 30 km. Twice a day radiosonde measurements are taken from Tucson International Airport, about 40 miles north of the Whipple Observatory where the VERITAS telescopes are located. The values of the readings from the measurements made at midnight allow us to construct a profile of the atmosphere relevant to the night time observations of the VERITAS experiment.

Simulations of the extensive air showers causing Cherenkov light generally use a model approximation to describe the density profile of the atmosphere. This study aims to examine how well the various standard atmospheric models that are available describe the atmospheric density profile in the area local to the VERITAS experiment at $-110^{\circ}57^{'}07.^{''}77$ longitude, $31^{\circ}41^{'}19.^{''}6$ latitude. There are four standard models [3] that are of particular relevance to this latitude

- US Standard Atmosphere 1976 (US76). This is a profile representing the idealised, steady-state atmosphere for moderate solar activity based on the work of the U.S. Committee on Extension to the Standard Atmosphere (COESA). This is the default atmospheric model used by many EAS simulation packages.
- Tropical profile. This is an annual average of radisonde reading measured at a number of sites in longitude and at a common latitude of 15 degrees north.
- Mid-latitude summer profile. This is an average of readings taken at sites with a latitude of 45 degrees north in the month of July.
- Mid-latitude winter profile. As for the Mid-latitude summer profile, but an average of readings taken in the month of January.

These model profiles will be compared to the radiosonde readings to see which, if any, accurately reflect the atmospheric conditions for the Tucson region.

Density as a function of altitude

The density as a function of altitude for these models are plotted in figure 1 along with the midnight radiosonde readings taken for all of 2004. It is clear from this that none of the models can be said to accurately reconstruct the density profile across the entire year, but in the region of greatest interest for the production of Cherenkov light (most of the shower development will occur somewhere between 10 and 20 km in altitude) the spread in values is bounded by the mid-latitude winter and the tropical model profiles. Data for other years also match these findings. Figure 2 plots the density value for the radiosonde 15000 Pa isobar reading ($\sim$ 14 km altitude) by date, it is clear that, whilst there is some day-to-day spread due to weather fronts, there is a strong seasonal trend to the density values.

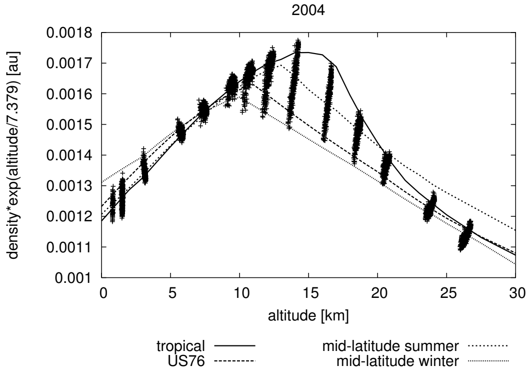

Figure 1: The density of the atmosphere as a function of altitude for the Tucson region during 2004. Also plotted are the density-altitude profiles for a number of models: a) tropical (line), b) US76 (dashed), c) mid-latitude summer (dotted), d) mid-latitude winter (small dots).

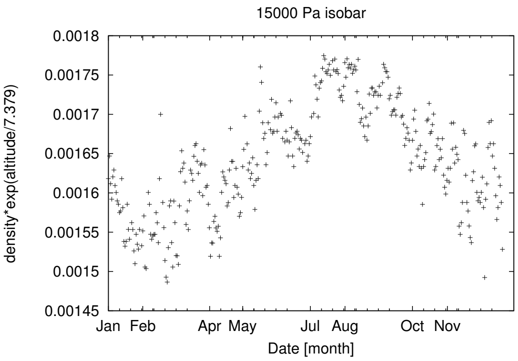

Figure 2: The density values for the 15000 Pa isobar taken from figure 1 and plotted by day.

Cherenkov light pool lateral photon density profile

The index of refraction is the important factor for Cherenkov radiation: it defines the threshold energy that particles need for emission, the angle of emission and the number of photons generated. As stated earlier, the index of refraction can be approximated as being proportional to the air density. As we saw in the previous section, there is quite a variation in the atmospheric density profile during the course of a year which will in turn have repercussions on the amount of Cherenkov light generated for Imaging Atmospheric Cherenkov Telescopes (IACTs) to detect. To study the different scenarios simulations of 100 GeV primary gamma-ray showers were generated using CORSIKA with the modtran profiles parameterised in the bernlohr package [2]. Figure 3 shows the density of 200-700 nm Cherenkov photons that will reach the ground from 100 GeV primary gamma ray air showers for the tropical (representative of a Tucson summer), mid-latitude winter (representative of a Tucson winter) and US76 atmosphere (representative of the default profile used in simulations). In the central 125 m of the light pool (i.e. the relatively constant region before the shoulder) there is an average 18% less Cherenkov light reaching the ground with the tropical model atmosphere than with the mid-latitude winter one. The difference between the mid-latitude winter and US76 models is a more modest 6.4% for the same region. Similar statements can be made for showers produced by primaries of different energies.

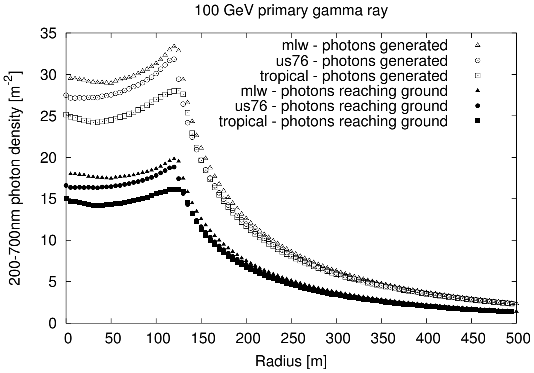

Figure 3: The lateral density profile of Cherenkov photons produced for three different atmospheric models. The triangles are for the mid-latitude winter (mlw) profile, the circles for the U. S. Standard (us76) profile and the squares for the tropical profile. The open markers represent the total number of Cherenkov photons generated and the filled markers are the actual density of photons on the ground after atmospheric attenuation has been accounted for. The wavelength range for the Cherenkov photons is from 200 to 700 nm. Error bars are smaller than the point size.

Effective collection area dependence on model atmosphere

Shown in figure 4 are effective collection area curves for the tropical and US76 model atmospheres. The detector simulation was made with the GrISU[1] package for a 12 m IACT. Below the region where the effective area becomes efficient a clear separation of the effective area curves is apparent, but at higher energies the curves become indistinguishable. This is very easy to understand since close to the hardware trigger threshold the system is very sensitive to the amount of light in the Cherenkov light pool. A shower in the tropical model atmosphere, having a smaller Cherenkov photon density at the ground, is less likely to trigger the telescope until there are sufficient photons (i.e. from more energetic showers) in the light pool that fluctuations no longer become the dominant effect in whether the system triggers or not. Once the energy of the showers, hence Cherenkov photon density, is above that regime the difference in Cherenkov photon density becomes irrelevant for triggering the telescope. So if software cuts ensure that any analysis is well above the hardware threshold, then there should be little to no difference in the calculation of integral fluxes from sources. The difference in the Cherenkov light density between atmospheric profiles will still play a part in the analysis of IACT data, however, since the $size$ parameter, which is a measurement of the amount of light in an image and relates to the energy of the primary particle, will still have a systematic shift between the atmospheric models. This systematic shift will in turn lead to a bias in the energy estimate for a recorded event that will complicate any spectral analysis and lead to an error in the spectral index and differential flux constant determined for a source.

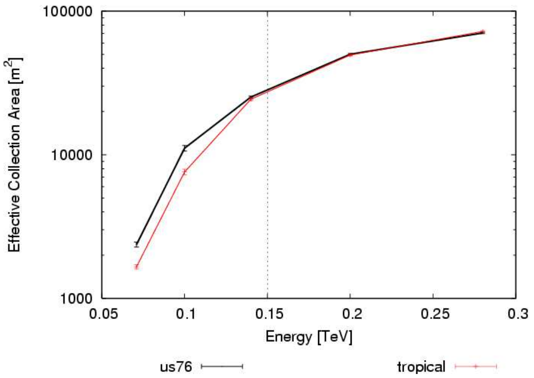

Figure 4: The effective collection of a 12 m class IACT for the tropical and US76 model atmosphere profiles.

Conclusions

Measurements of the atmospheric conditions in the region around the VERITAS experiment have been compared to standard atmospheric models. There is no fixed atmospheric model that can fit all of the seasonal changes in the Tucson area and the

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[1] http://www.physics.utah.edu/gammaray/GrISU/

bounds provided by the models show that as much as an 18% difference in the lateral Cherenkov photon density across the year. This difference in the Cherenkov light yield has implications for low energy events, below the system threshold, and in spectral analyses. Studies are continuing to assess the systematic uncertainties caused by changes in the atmospheric conditions.

Acknowledgements

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