The SLANT Option of the Air Shower Simulation Program CORSIKA

D. Heck

Institnut für Kernphysik

Forschungszentrum Karlsruhe

in der Helmholtz-Gemeinschaft

Wissenschaftliche Berichte

FZKA 7082

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D. Heck

Institut für Kernphysik

Forschungszentrum Karlsruhe GmbH, Karlsruhe
2004

Abstract

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This report describes the action of the *SLANT* option of the extensive air shower simulation program CORSIKA. The introduction of skew planes perpendicular to the shower axis is described. Their spacing corresponds with the slant depth binning along the shower axis. All particles crossing a skew plane are counted in the respective longitudinal particle distribution bin. Their energy deposited between two adjacent skew planes is summed up in the respective energy deposit longitudinal distribution bin.

Zusammenfassung

Die SLANT-Option des Luftschauer-Simulationsprogramms CORSIKA

Dieser Bericht beschreibt die Wirkungsweise der *SLANT*-Option des Programms CORSIKA zur Simulation ausgedehnter Luftschauer. Die Einführung von schrägen Ebenen senkrecht zur Schauerachse wird beschrieben. Ihre Abstände entsprechen den Bins der Tabelle für die 'schräge Eindringtiefe' (slant depth) entlang der Schauerachse. Alle Teilchen, die eine schräge Ebene kreuzen, werden in dem entsprechenden Bin der longitudinalen Teilchenverteilung gezählt. Ihre Energie, die zwischen zwei benachbarten schrägen Ebenen deponiert wird, wird in dem entsprechenden Bin der longitudinalen Energy-Deposit-Verteilung aufaddiert.

Contents

1 Introduction

The standard version of the air shower simulation program CORSIKA [1] is designed for showers with nearly vertical incidence as observed by the KASCADE experiment [2] where the main interest concentrates on the the particles arriving at the detector level. For more fundamental studies the longitudinal shower development can be followed by CORSIKA in vertical bins by counting all particles crossing horizontal layers (particle distribution) and summing up their energy deposited between two consecutive horizontal layers (energy deposit distribution). The vertical spacing of these horizontal layers is arranged in a manner to represent equal increments in the mass overlay.

Since several years CORSIKA is applied for many other experiments and the requirements have been extended to more horizontal or even upward going showers. Especially in the P. Auger experiment [3] the longitudinal development along the shower axis can be measured with the fluorescence telescopes. Moreover experiments observing the fluorescence from space like EUSO [4] or OWL [5] need the development of the particle numbers and their energy deposit along the shower axis rather than the development in vertical direction.

In the simulation the development along the vertical depth is calculated with high simplicity: Once at the beginning the layer altitude table is established according to the equal increment in mass overlay. For each particle track the starting and ending altitudes are compared with the height of the vertical binning and for all passed layers the corresponding particle numbers are incremented. The energy deposited between the layers is added up in the energy deposit tables.

In the SLANT option these horizontal layers are replaced by skew planes perpendicular to the shower axis and arranged in a spacing which corresponds to a regular increment in the penetrated atmospheric mass thickness along the shower axis. Each time a shower particle crosses such a skew plane it is counted for the longitudinal particle distribution, and the energy deposited between two adjacent skew planes is added up to obtain the longitudinal energy deposit distribution. Calculating the passage through skew planes needs not only the altitude of the particle, but also the x and y coordinates in horizontal direction and the direction cosines of the shower axis, which prolongates the calculation time.

The CORSIKA User's Guide [6] describes how to extract the *corsika.f* Fortran file with the SLANT option from the *corsika.cmz* rsp. *corsika.car* file.

2 Geometry Definitions

The geometry and the quantities which are necessary for the SLANT option are explained in Fig. 1. The shower starts with the zenith angle θ at the atmospheric border at the upper right corner and, moving downwards, reaches the observation level at the lower left corner. Drawn are some of the skew planes perpendicular to the shower axis by short lines. As the atmospheric density increases with decreasing altitude, the
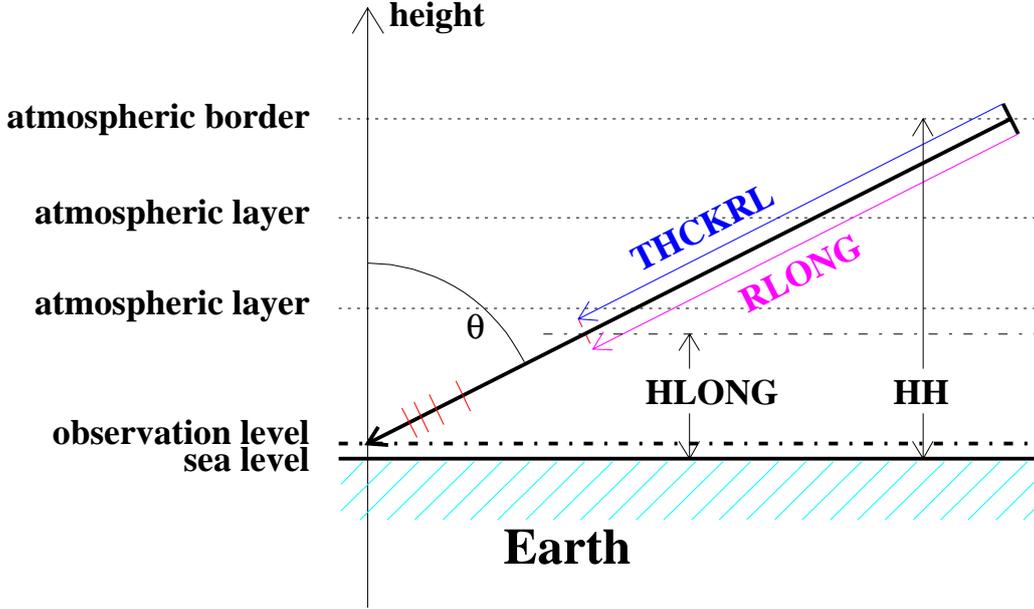
Figure 1: Geometry definitions of slant thickness in planar atmosphere.

distances between the skew planes are decreasing with increasing distance from the shower starting point. For each skew plane its altitude (HLONG) of the crossing with the shower axis is kept in a table as well as the distance (RLONG) from the atmospheric border to the crossing point and the penetrated slant depth (THCKRL). The index counting of these arrays starts at the atmospheric border.

In CORSIKA the origin of the coordinate **h** (altitude) is at sea level, while the origin of the horizontal coordinates **x** and **y** is defined by the point of first interaction[1]. To detect the passage of a particle through a skew plane **i**, its position along the shower axis

$$r = x \cdot \sin(\theta) \cdot \cos(\phi) + y \cdot \sin(\theta) \cdot \sin(\phi) - h \cdot \cos(\theta) + r_{Loff} \tag{1}$$

before and after the transport step must fulfill the condition

$$r_{before} < RLONG(i) < r_{after} \quad . \tag{2}$$

The angles θ and ϕ are the zenith and azimuth angles of the primary particle at its starting point. The offset r_{Loff} is calculated from the condition that the primary particle at the starting point must fulfill eq. 1 with r = 0, x = 0, and y = 0, which gives

$$r_{Loff} = h \cdot \cos(\theta) \quad .$$

The products $\sin(\theta) \cdot \cos(\phi)$ and $\sin(\theta) \cdot \sin(\phi)$ depend only on the primary's direction and are constants for a shower (denoted in the program by STHCPH and STHSPH).

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[1]The coordinate origin is placed at the starting point of the primary particle if TMARGIN is set .true. by the input keyword TSTART.

3 The SLANT Routines

Several routines in CORSIKA are available for the calculations which are necessary to get the longitudinal shower development along the slant depth. They are described in the following subsections. Moreover the routines COORIN (standard version) rsp. COOINC (CURVED option [7]) contain longer program blocks which deal with the calculation of the necessary arrays of HLONG, RLONG, and THCKRL. Their description is included in these subsections.

3.1 *COORIN*

This subroutine normally is called after the first interaction to calculate the offset in x and y for each observation level in a manner that by the corrections $x - x_{off}$ rsp. $y - y_{off}$ the coordinates refer to the crossing point of the shower axis through the observation level under consideration. The additional programming calculates STHCPH, STH-SPH, and the distance offset r_{Loff}. The specified bin width THSTEP of the penetrated mass thickness is used to get the values of the HLONG array with the help of the function *HEIGH* (which gives the height value for a specified mass overlay)

$$\text{HLONG(i)} = HEIGH(\ i \cdot \text{THSTEP} \cdot \cos(\theta)\ )\ .$$

Finally the array RLONG is calculated using the geometrical relation of the starting altitude HH and the actual altitude HLONG by

$$\text{RLONG(i)} = (\text{HH} - \text{HLONG(i)})/\cos(\theta)\ .$$

Special care is taken for those particles which travel above the shower axis and hit the observation level far away on the downstream side. Their energy deposit is collected in a last energy deposit bin which extends to the double of the total penetrated mass thickness along the shower axis.

For an effective and time-saving calculation of the shower development along the slant axis several additional arrays are filled by COORIN. Each of the 5 atmospheric layers is subdivided in 100 bins with equidistant height decrements to get the distance values PATH1(j) along the slant path which correspond with the 500 height bins. For each of these distances the array elements of the local density RHOSLT(j) and of the appropriate slant depth TSLANT(j) are calculated. The latter array is used in the function *THCKSI* to determine the penetrated mass thickness between the start point of the track and the passage of the next skew plane (rsp. the passage of the last skew plane and the point where the particle track ends) to determine the precise energy deposit to be added up in the corresponding bin of the energy deposit distribution.

3.2 *COOINC*

For the CURVED option [7] the routine *COOINC* performs essentially those calculations which are done by *COORIN* in the standard version.

Compared with *COORIN* the sequence of the calculations is modified: First the arrays HLAYS(k), RHOS(k), and THICKS(k) are established which give the apparent height, the density, and the penetrated mass thickness at the crossing point of the shower axis with the atmospheric layer **k** (now a sphere with constant altitude above the curved Earth surface). For the penetrated mass thickness THICKS(k) the function *DGAUSS* is used to integrate the density from the starting point along the shower axis in the CURVED system to the crossing point at the atmospheric layer **k**. These values are needed to fill the arrays PATH1(j), RSLANT(j), and TSLANT(j). The function *THCKSL* is used to calculate TSLANT(j). Finally the arrays THCKRL(i), RLONG(i), and HLONG(i) are filled employing the function *PATHSI* for the calculation of RLONG(i).

3.3   *DGAUSS*

The function *DGAUSS* is an integration routine taken from the CERN MATHLIB library and described in Ref. [8]. In the CURVED option [7] it is employed by the routine *COOINC* and the function *THCKSL* for integrating the penetrated mass thickness along the shower axis. The sensities along the shower axis are obtained by *RHOSL.*

3.4   *LBIN*

For given particle coordinates the function *LBIN* determines the longitudinal bin number of the particle position. An additional argument gives the lowest bin number which is used as starting value for the sequential search with increasing bin numbers.

3.5   *PATHSI*

In the CURVED option [7] the function *PATHSI* determines the path length as function of the penetrated matter along the shower axis normal to the skew planes. It is assumed that the shower starts at the atmospheric border. By a simple search algorithm applying the repeated bisectioning of the search interval the index **j** is determined for which TSLANT(j) comes closest below the penetrated matter. The final value of the path length is obtained by interpolating the table PATH1(j) between **j** and **j** + 1 according to the increment of the table TSLANT(j) in this index interval.

3.6   *RHOSL*

For the CURVED option [7] the function *RHOSL* gives the density of the atmosphere along the shower axis. This function is called from *COOINC* and from *THICKSL*

3.7 *THCKSI*

The function *THCKSI* determines the penetrated mass thickness for a given total path length along the shower axis. By a simple search algorithm applying the repeated bisectioning of the search interval the index **j** is determined for which PATH1(j) comes closest below the given path length. The final value of the penetrated matter is obtained by interpolating the table TSLANT(j) between **j** and **j** + 1 according to the increment of the table PATH1(j) in this index interval.

3.8 *THCKSL*

In the CURVED option [7] the function *THCKSL* calculates the penetrated mass thickness along the shower axis between the starting point at the atmospheric border and the end point at a given height employing the function *DGAUSS* [8].

4 Combination of *SLANT* with *UPWARD* Option

Combining the *SLANT* option with the *UPWARD* option the geometry is changing if the primary particle is moving upward with a zenith angle $\theta > 90^\circ$. Fig. 2 shows this situation. In principle all the routines used for the standard case are taken over nearly unchanged. Only the altitude of the starting point (to be defined by the keywords FIXHEI or FIXCHI in the CORSIKA input file) and the position of the observation
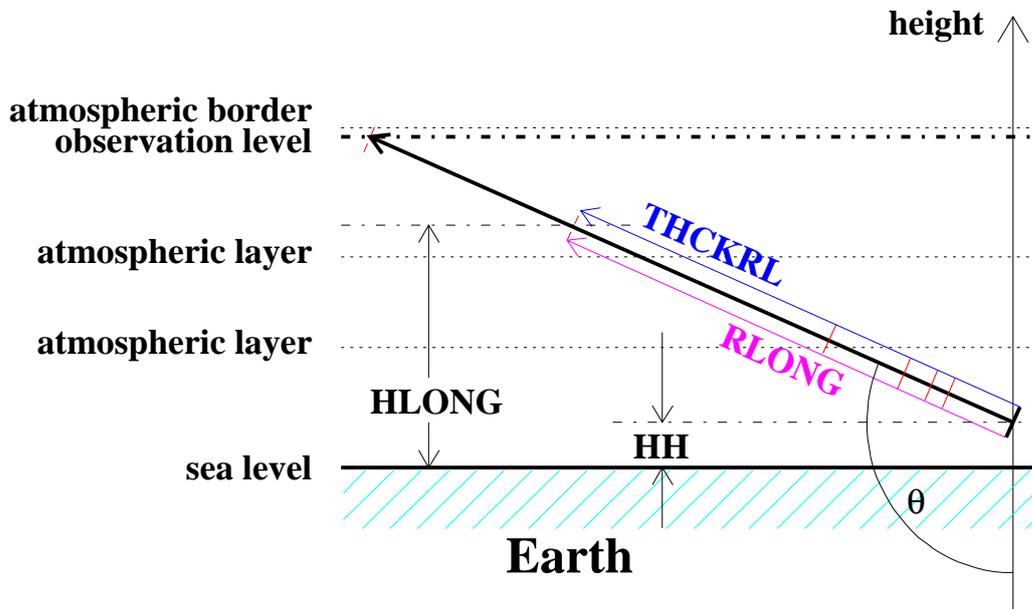

Figure 2: Geometry definitions of slant thickness in planar atmosphere for an upward going shower.

level at the atmospheric border make the difference. This case is checked by the sign of the $cos(theta)$ which becomes negativ for upward going showers.

5 Final Remarks

Using the SLANT option all the longitudinal output tables of CORSIKA refer to the *slant* depth instead to the *vertical* depth, which is also made visible in the header lines of the longitudinal output tables for a clear interpretation of the longitudinal tables. All other features of the longitudinal tables are more or less unchanged.

The combination of the options UPWARD with SLANT is not yet supported in the CORSIKA version 6.200 (released Oct. 2004), but will be available with the next major release after Dez. 2004.

6   References

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