This is to describe the major changes taken in the Cosmos.uv5.13.

1 Bug fixes

1. An endless loop in the Lund Fritiof code was pinpointed which occurred for low energy (near 5 GeV) particles (with the help by Dr. C.S.Zhang). This takes place very rare so that such an interaction is discarded now. I hope this is the last endless loop in the entire Cosmos code.

2. If the user puts the injection height of the primary very high ($\gg$1000 km), `Reverse=0` and (`KEminiObs` low (say <10 GeV) and/or the zenith angle of the primary large), some particles are directed to outer space and arithmetic overflow takes place. (If the user uses non-zero `Reverse`, the overflow does not take place; but this can be used only for limited purpose.) The bug is corrected by introducing a new atmosphere described in the next section.

2 New atmosphere

So far the user couldn't change the structure of the atmosphere. The atmosphere was expressed with different analytic formulas below and above 11.2 km. The structure starts deviating from a plausible model over 30 km and almost unrealistic over 50 km. It attenuates too fast, although it is expected not harmful for normal applications. We compare the new and old atmosphere in Fig.1.

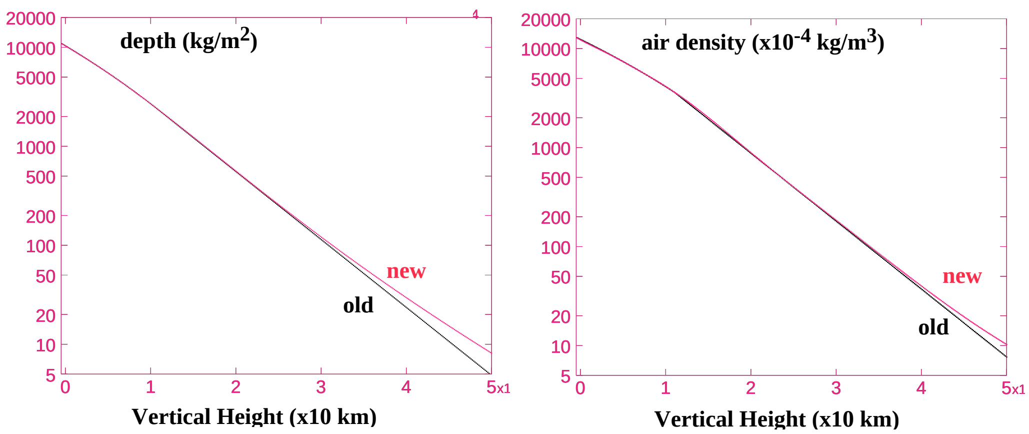

Figure 1: Comparison of old (black) and new (red) atmosphere. Left–height vs atmospheric depth. Right– height vs atmospheric density.

In the new treatment, we use a number of segments to represent the atmosphere and smoothly connect them by cubic spline functions. This will need a little bit more time for processing but the user can change the model to see the effect of the atmospheric structure. In the current version, the user can choose the old or new atmosphere; this must be decided before making the library.

- If the user wants to use the old one, he/she must define `ATMOSPHERE 0` in *Cosmos*/`cosmos/Zcondc.h`. The bug noted in section1, item2 still remains in this case.

- If the user wants to use the new one he/she must define `ATMOSPHERE 1` in *Cosmos*/cosmos/Zcondc.h (default).

2.1 Making a new atmosphere

- We must prepare a table like below:

```
# height(m)   Temp(K) Press(hP)        density(kg/m3)
#-------------------------------------------------------------------
      -400   290.75      1062.6             1.2729
      -200   289.45      1037.5             1.2487
        0     288.15      1013.25            1.2250
       3.d3    268.659    7.0121e2         9.0925e-1
       6.e3    249.187    4.7217e2         6.6011e-1
       11.1e3  216.65       223.46            0.35932
       20.0e3  216.65        55.293           8.891e-2
       32.2e3  228.756        8.6314          1.3145e-2
       47.4e3  270.65         1.1022          1.4187e-3
       51.0e3  270.65         7.0458e-1       9.0696e-4
       72.0e3  214.263        3.8362e-2       9.2374e-5
       ...
```

  A template which is used in the current model is located in *Cosmos*/Data/Atmos/stdatmos1.d.

  The pressure actually dose not appear in any part of current Cosmos. The temperature (in Kelvin) is also not used directly in the current Cosmos but the user may need it for generating fluorescence scintillation light. The user can know the temperature as a function of the vertical height by

  `temp=cvh2temp(height)`

  where height is the double precision vertical height in m.

- If the table is prepared, you may place it in *Cosmos*/Data/Atmos/ or wherever you like.

- To use it, you may give the path to the file in the second group of the namelist parameter as `AtmosFile='xxxx'` .

- To check the new atmosphere, you may go to *Cosmos*/Util/Atmos, and use the following two:

  – `make -f atmosd.mk` to make an executable `a.out`.

  – Feed the namelist to `a.out` like

    `a.out < param`

    and you will see a table with some additional fields such as `a, d0, cumd, H`. They are used internally in the further calculations (See Appendix; cumd is the thickness of the atmosphere).

  – `make -f atmosd2.mk` will create another `a.out` to which you may also feed the namelist data.

    This will show a large table interpolated by cubic splines. The last two fields are the height and density computed from the depth and should basically the same values as the first two columns. The third and forth fields are $d\rho/dz$ and $d^2\rho/dz^2$, respectively, which are used when a curvature of the Earth must be considered while track following.

    The atmosphere above 1000 km is essentially vacuum and we treat it quite conventionally so that the program can run without overflow or something else.

  – `atmosd2.f` can be used for the old atmosphere, too. In that case, you need not feed the namelist data to `a.out`.

- NOTE: In default, Cosmos.uv5.13 or later will use the new atmosphere. However, the user need not specify the table by `AtmosFile`. If it is kept blank (default), Cosmos uses an internally stored table which is the same one as *Cosmos*/Data/Atmos/stdatmos1.d. (The user may, off course, specify it by `AtmosFile`).

- NOTE: If the user gives `AtmosFile` and use the script for Distributed job over a number of workstations, the path may have to be the absolute path.

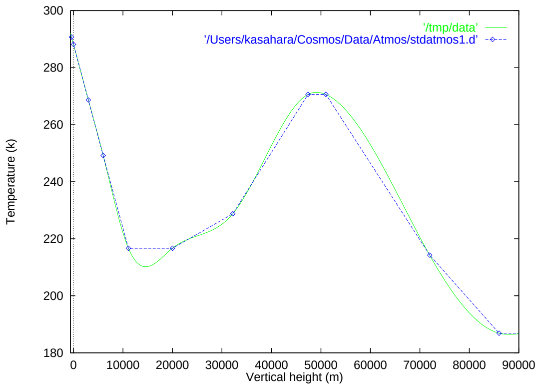

Figure 2: Segmented atmosphere and cubic spline smoothing

Figure 2 shows raw data for segmented atmosphere and cubic spline smoothing. for height vs temperature.

3 Appendix

To make cubic spline coefficients, we assume the following behavior of the atmosphere.

The scale height, H, is expressed by

$$
\begin{aligned}
H &= H_0 + a(z - z_0) \qquad (1)\\
&= kT/mg \qquad (2)
\end{aligned}
$$

in each segment, where z is the vertical height. We neglect height dependence of gravitational acceleration g, and the average mass of air molecules, m. We also assume

$$T(z) = T_0 + b(z - z_0) \qquad (3)$$

in each region. We can first get b, and then a by $a = dH/dz = k/mgb$. H at a nodal point, z, is obtained as $H(z) = kT(z)/mg$. The density is given by

$$
\begin{aligned}
\rho &= \rho_0 \left[1 + \frac{a(z - z_0)}{H(z_0)}\right]^{(-1-1/a)} \quad (a \neq 0) \qquad (4)\\
&= \rho_0 \exp(-\frac{z - z_0}{H_0}) \quad (a = 0) \qquad (5)
\end{aligned}
$$

The amount of air between given heights, z_1 and z_2 is computed by

$$d = d_0(f_d(z_2) - f_d(z_1)) \qquad (6)$$

where

$$
\begin{aligned}
f_d(z) &= (1 + \frac{a(z - z_0)}{H(z_0)})^{-1/a} \quad (a \neq 0) \qquad (7)\\
&= \exp(-\frac{z - z_0}{H}) \quad (a = 0) \qquad (8)
\end{aligned}
$$

where $d_0 = \rho_0 H(z_0)$.