# COR SYSTEM FOR COSMIC RAYS TRAJECTORIES IN MAGNETOSPHERE SIMULATION

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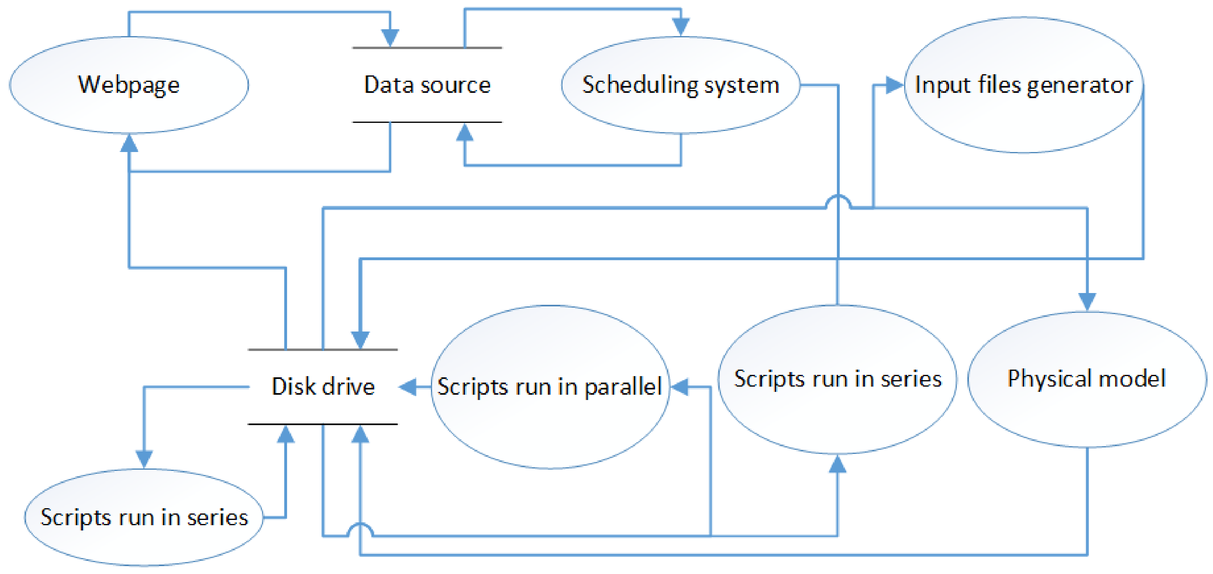
## Introduction

Cosmic rays are particles coming from space. The system COR (Cut-off rigidity) provides access for the wider scientific community to models of simulation of cosmic ray trajectories in the magnetosphere via a web interface. The system offers simulations of vertical directions or, from multiple nonvertical directions covering half sphere ($2\pi$ solid angle) with the center of the sphere in the point of interest. The simulation particle tracing is realized in combined internal (IGRF) and the external geomagnetic field (Tsyganenko 96 or Tsyganenko 05) covering the years 1968 to 2020. We call this Standard simulation module. There is also a module for simulation in an earlier period called the Historic simulation module that uses a couple of geomagnetic field approximations for the last two millennia (years from 0 to 1968) [1][2].

| Latitude | Longitude | Optimization | Duration |
|---|---|---|---|
| −60.15° | 287.79° | No | 14:04:31 |
| −60.15° | 287.79° | Yes | 09:12:33 |
| −10.05° | 287.79° | No | 05:05:36 |
| −10.05° | 287.79° | Yes | 04:24:15 |
| 40.21° | 287.79° | No | 14:11:44 |
| 40.21° | 287.79° | Yes | 10:28:57 |

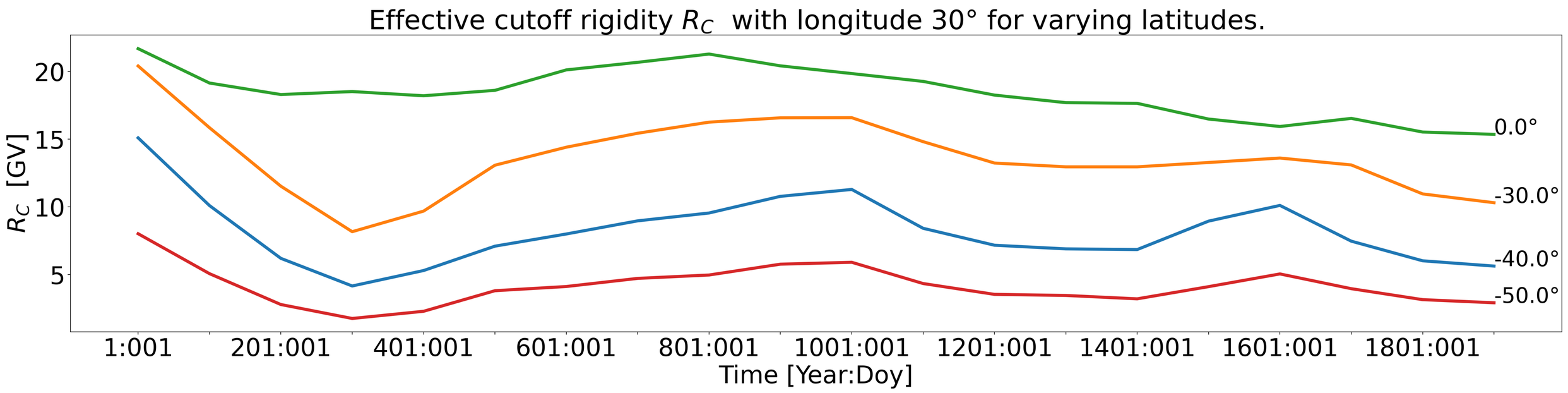
The table above shows the durations of simulations calculated using the system for selected points near the equator and further from it. There are also durations of simulations with starting rigidity optimization.

## System architecture



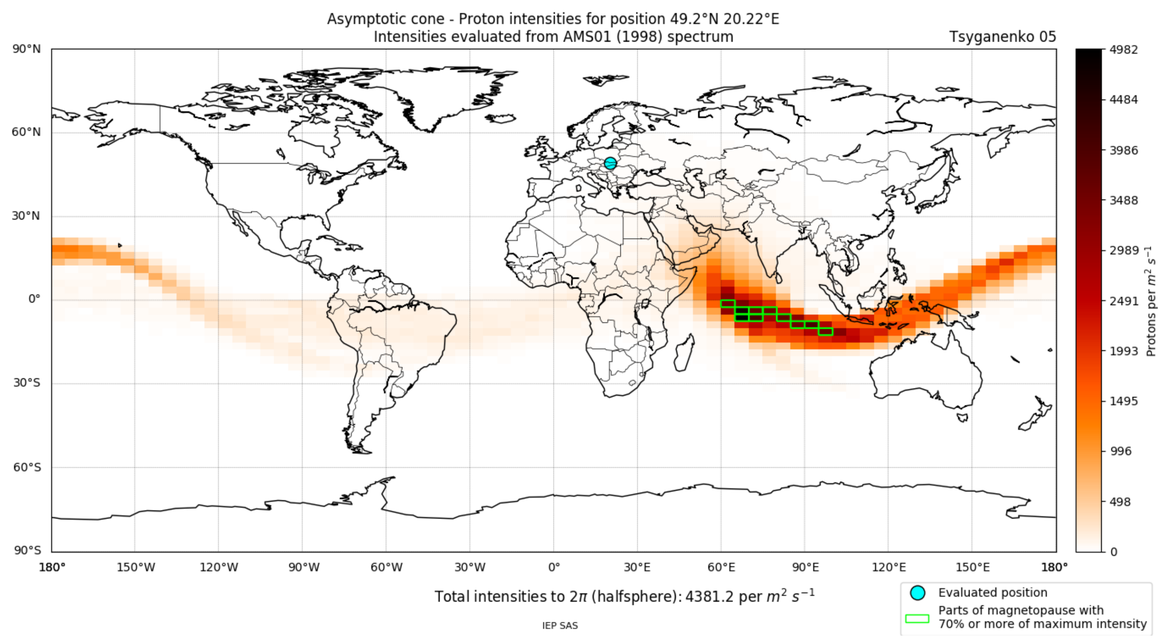

Two main parts of the system are the webpage and scheduling system. The webpage `cor.crmodels.org` is an interface for the user to interact with the system. Users can enter new requests for simulations, browse or download their results there. Anonymous users have access to limited functionality, they can only request single trajectory visualizations and browse existing results. Registered users can also request all types of possible simulations the system offers. There are also privileged users that can enter requests for long lasting simulations. The scheduling system reads requests from the data source and computes their results in a parallel environment. It also handles post processing of results and creation of visualizations.

## Development of a model for historical effective cutoff rigidity evaluation



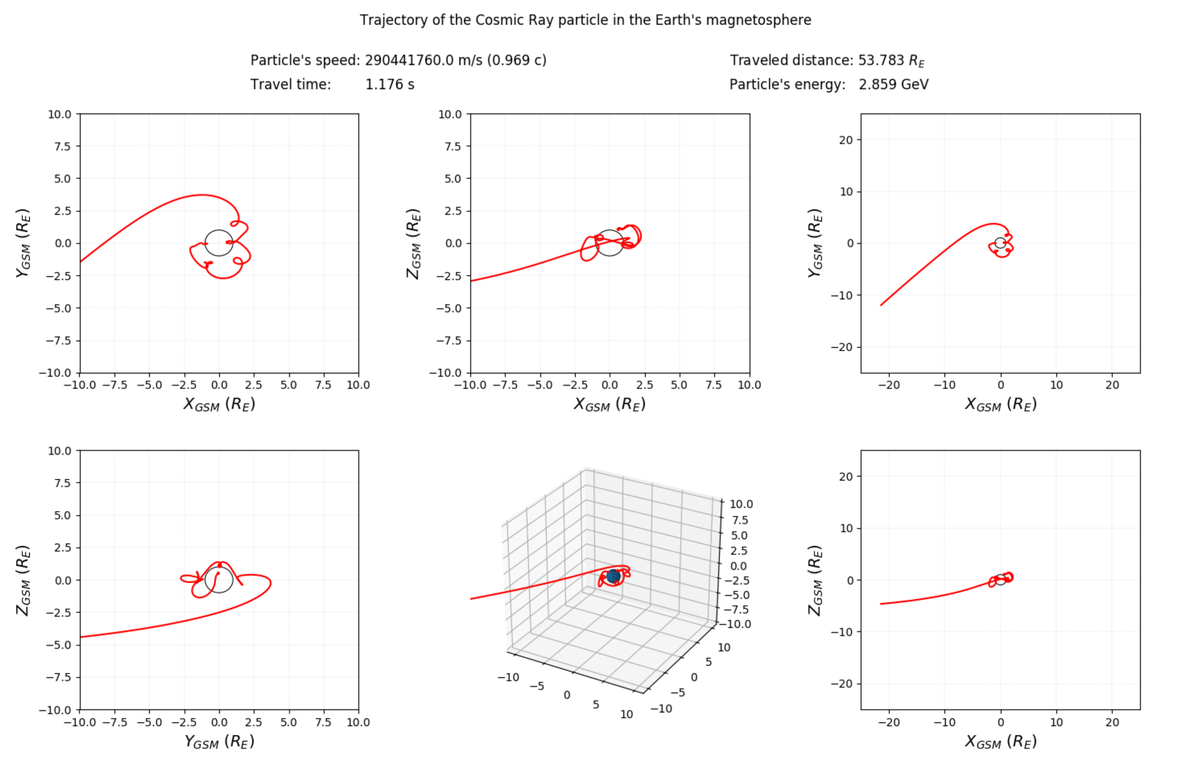

Long term changes of effective vertical cutoff rigidities at the longitudes 30° for selected latitudes of the southern hemisphere for years between 1 and 1901 CE. The time of calculation is 1st January 00:00 for each point in time. This visualization is an example of the COR historical simulations in the currently updated and improved module. The aim is to evaluate the transparency of the magnetosphere for cosmic rays in the last two millennia and consequences for $^{14}C$ dating.

## Visualization of the direction of cosmic ray arrivals and intensities in acceptance cone




This figure provides information on which directions most of the particles that landed on the surface of the atmosphere above the simulated point came from. The figure also shows the value of the number of protons that reach a given point.
The figure illustrates the multidirectional approach of cosmic ray trajectories in the Earth's magnetosphere.

## Visualization of cosmic ray particle trajectory




Example of the trajectory of a particle with energy 2.859 GeV (rigidity 3.68 GV) coming to a position with latitude 50° and longitude 0° coming from a direction from the zenith angle 10° and the azimuthal angle 70°. The used backtracking model is described in [3].

## References

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[2] K. Kudela and P. Bobik. "Long-Term Variations of Geomagnetic Rigidity Cutoffs". In: *Solar Physics* 224.1-2 (Oct. 2004), pp. 423–431. DOI: 10.1007/s11207-005-6498-9.

[3] Pavol Bobik et al. "A Back-Tracing Code to Study the Magnetosphere Transmission Function for Primary Cosmic Rays". In: *The Inner Magnetosphere: Physics and Modeling*. Ed. by Tuija I. Pulkkinen, Nikolai A. Tsyganenko, and Reiner H. W. Friedel. Vol. 155. Jan. 2005, p. 301. DOI: 10.1029/155GM32.