IL NUOVO CIMENTO Vol. 29 C, N. 5 Settembre-Ottobre 2006
DOI 10.1393/ncc/i2006-10010-6

Multiparametric advanced research tool for meteo satellites data interfacing with space observation of ultra high energy cosmic rays

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(ricevuto il 28 Febbraio 2006; revisionato il 6 Luglio 2006; approvato il 10 Luglio 2006)

Summary. — To approach the study of the cosmic rays in the energy range $E > 10^{20}\,\mathrm{eV}$, the upper end of the spectrum observed to date, with a large statistical significance (10^3 events/year), and hence address the solution of several astrophysical and cosmological problems related to their existence and behaviour, a new generation of experiments will probably have to be conceived and realised. They will be based on the observation and measurements of cosmic rays from space. The extremely low rate of these events ($\sim$ 1 event/(century $\times$ km^2 $\times$ sr)) imposes a very large effective area to be monitored, of the order of $10^5\,\mathrm{km}^2$, as an observational requirement to meet the target statistics. The Extreme Universe Space Observatory (EUSO) mission has been proposed as the precursor of this new generation of experiments. Its approach consists in fact in looking downwards to the Earth atmosphere by means of a large field-of-view telescope accommodated aboard an orbiting satellite. The fluorescence strike produced by a cosmic ray through the atmosphere will be recorded by the detector, which will reconstruct the kinematical and dynamical features of the primary cosmic ray. The atmosphere acts therefore as an active target for the detectable event. A strategic tool for the success of EUSO as well as for all the experiments of its category will be a correct and detailed atmospheric sounding system, in order to monitor the atmospheric parameters within the field-of-view of the telescope. Beside an on-board measurement by means of dedicated devices such an infrared camera (IR) and possibly a LIDAR (LIght Detection And Ranging) coupled to the main instrument, the Atmosphere Sounding will take advantage from the continuous observation of the atmospheric parameters given by the orbiting meteorological satellites.

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Their databases have thus to be interfaced to the experimental data and used picking-up the relevant data according to the space and time coordinates corresponding to each triggered event. The present work outlines a software module (MARVIN-Multiparametric Advanced Research tool for Visualisation In the Network) able to build-up such an interface, and shows a preliminary implementation of it, using a sample of existing satellites and ISCCP meteorological data collection. It has been developed during the phase A study of the EUSO mission but is general enough to be adapted to different missions observing the Earth atmosphere from space.

PACS 92.60.-e – Properties and dynamics of the atmosphere; meteorology.
PACS 95.75.-z – Observation and data reduction techniques; computer modeling and simulation.
PACS 98.70.-f – Unidentified sources of radiation outside the Solar System.
PACS 13.85.-t – Hadron-induced high- and super-high-energy interactions (energy $> 10\,\mathrm{GeV}$).

1. – Introduction

The observation and characterization of Ultra High Energy Cosmic Rays (UHECR) production represents one of the major challenges of the astroparticle physics. Its scientific interests go from the traditional field of the cosmic-ray physics to the field of particle physics, since the energy of the primary particle interaction occurs in an energy range which exceeds by two orders of magnitude the largest energy achievable in the Large Hadron Collider, LHC, the largest particle accelerator in the world, whose operation is scheduled to begin in 2007. The field of high-energy astronomy will take advantage of such measurements as well, thanks to the possibility of tracing back the position of the UHECR source. The bending power of the interstellar magnetic field is in fact unable, according to the existing predictions, to reshuffle the particle direction at primary energy $> 10^{20}\,\mathrm{eV}$, in such a way that one can identify the position of the cosmic-ray source within a fiducial region of the order of a degree within the sky.

The energy spectrum of the UHECR, their nature in terms of primary particles, the existence of compact sources for them and even the study of the particle interaction features are unsolved problems which rise the scientific interest of a continuously expanding community of researchers.

The existence of cosmic rays up to $10^{20}\,\mathrm{eV}$ has been a well-established fact for more than forty years. Since when they were firstly observed, only a small number of them have been measured, of the order of 20 [1]. The reason for that is that a very steep energy spectrum determines their rate to diminish very rapidly. Only 1 event/(century $\times\,\mathrm{km}^2 \times$ sr) reaches the Earth at an energy $E > 10^{20}\,\mathrm{eV}$. Such a low rate implies that a very large detection area is required in order to collect a large statistics of events in a reasonable amount of time. The existing experiment relying on very large arrays of ground-based detectors [2] plans to equip an area of $\sim 3500\,\mathrm{km}^2$ with an acceptance of the order of 1 sr, and represents probably a limit to the size of ground-based experiments, due to the complexity for such a huge detector to be handled, from the technological, logistic and managerial points of view. The observational approach of EUSO is a different one, which has been recognised as the most promising one for the next generation of UHECR experiments.

A space telescope with a large field of view around the optical axis, and looking downwards to the atmosphere from the typical distance of orbiting satellites ($\sim 400\,\text{km}$ for the International Space Station ISS, for example) has an instantaneous aperture of the order of $\lesssim 10^6\,\text{km}^2$ when pointing exactly to the Nadir. The experimental approach proposed for an orbiting telescope of the EUSO category relies on the possibility of detecting the fluorescence signal emitted by the cosmic ray when hitting the atmosphere and resolving its position and direction, as well as measuring the energy of the primary cosmic ray and possibly its nature in terms of elemental composition. Any UHECR hitting the Earth atmosphere is in fact a light source to the extent that it determines the development of a particle shower growing to a maximum size of $> 10^{10}$ charged particles that excite the nitrogen molecules of the air that will on their turn decade with a $2.2\,\text{ms}$ lifetime emitting isotropically UV fluorescence photons. As the atmosphere is relatively transparent to such a radiation, it can be detected and studied by the space-time signal induced in the detector sensors. The light emission being proportional to the number of emitting particles in the shower, the recorded signal allows to reconstruct the shower features and hence finally the primary particle. A detailed description of the observational approach can be found elsewhere [3]. As it is obvious from what has been said, the knowledge of the atmosphere transparency in the UV range, its attenuation power as well as its mapping, in terms of cloud topology and height, within the instantaneous field of view observed by the telescope is mandatory both for the calibration of the recorded signal and for the calculation of the instantaneous acceptance from which one can derive the duty cycle of the experiment. The energy calibration and the signal reconstruction depends on the knowledge of the target where the shower develops and of the path to the detector, *i.e.* of the atmosphere locally where the event occurs and its transparency to the UV signal. A detailed analysis of the possible distortion introduced by the atmospheric parameters variability is outside the scope of this work and can be found elsewhere [4, 5]. The coupling of a steerable LIDAR (LIght Detection And Ranging) system to the main telescope has been considered as the best solution to handle the problem. The composition as well as the transparency of the atmosphere will be recorded by the LIDAR, shooting a well calibrated and controlled UV-light beam (Ultra Violet) toward the region where a trigger has occurred (steerable device). The LIDAR is however a narrow-field device, unable to give an overall view of the detection sensitivity within the whole field of view, with the purpose of measuring the experimental acceptance and hence the effective duty cycle of the observation, essential quantities to compute the observed flux and therefore to normalise the energy spectrum. A large field device is needed as well, therefore. In the EUSO case, an InfraRed camera IR, mounted on board the ISS and coupled to the main telescope has been envisaged, but also an off-line interfacing with the existing databases of meteorological observation provided continuously by the orbiting meteo satellites will be required. The data coming from those satellites, specifically devoted to the measurements of cloud coverage, optical thickness and environmental parameters in the altitude range of few kilometres from the Earth surfaces, where the extended air showers produced by UHECR are expected to reach their maximum development, will in fact complement and eventually cross-check the on board measurements. ISCCP [6] database([1]) represent actually a very good example of meteo data collection with a full coverage of the Earth surface and a refreshing time of few hours, being thus fully compatible with the expected rate of change of the basic atmospheric parameters needed for an overall survey of the

([1]) ISCCP stands for International Satellite Cloud Climatology Program.

field of view of the space telescope. The overall amount of cloud coverage and topology both in terms of cloud height and optical depth, cannot be in fact expected to change very fast within the field of view of an instrument like the EUSO telescope. The velocity of an orbiting satellite (ISS velocity is of 7 km/s, for instance), ensures that the atmosphere is seen at each passage as a static scene, well depicted, at each position of the orbit, by the meteo satellite data taken with their typical refreshing time.

The software module MARVIN (*M*ulti-parametric *A*dvanced *R*esearch tool for *V*isualisation *I*n the *N*etwork), described in this work, accomplishes essentially two roles:

a) The first one is to build and update a proprietary database (DB) accessing a preselected list of public databases of meteo satellites data, picking-up, when available, the relevant environmental parameters, according to the experimental requirements of an experiment like EUSO.

b) The second one is to interface the experimental data (EUSO data in the specific implementation) with the existing parameters of the DB. A position and a time are given to a web interactive search module: the existing data are downloaded from the DB, according to a list of atmospheric sounding parameters selected at search time with different possible levels of detail and therefore of database accessing complexity.

Section **2** describes the overall architecture of the software tool, whereas sects. **3** and **4** are devoted to the description of the modules performing the two major tasks. Finally sect. **5** summarises the possible application and the expected improvements of MARVIN.

2. – The overall architecture of MARVIN

The goal of MARVIN is to represent a tool for the physics research analysis to get the situation of the atmospheric parameters at the time of a given triggered event, in the position where the event occurred, picking them out from the existing meteo satellite data. Such data will be interfaced to the physically relevant information recorded by the experiment, which is typically an ultrahigh energy cosmic-ray experiment of the EUSO category, accommodated on board an orbiting vehicle such as the ISS or a free-flying satellite. The MARVIN architecture consists therefore of two main modules:

– A proprietary database [7] where the relevant data coming from the weather satellite are collected, according to a data format suitable for the processing by means of an interactive search module;

– A web-based interactive search module [8], which will be able to extract from the database the relevant data according to user-defined selection criteria.

Figure 1 shows the MARVIN module overall data flow.

The reason for having a proprietary database is mainly based on the need to use only a relatively small fraction of the information given by several different satellites, each with a different scientific objective, different data format and possibly different data content. The proprietary DataBase building module extracts the data from the original single satellite databases, interfaces them with our architecture and fills the data base record according to a uniform internal format.

Several advantages are connected to the use of a web-based search module:

Once the search module architecture is defined, the software residing on a master web site is continuously maintained by a system administrator, which specifically

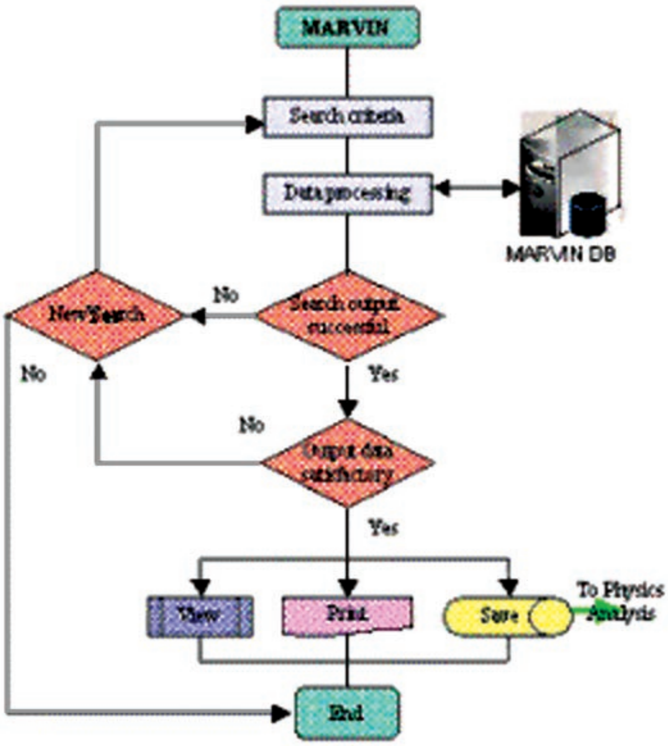

Fig. 1. – MARVIN data flow.

– Updates the database with the new data coming from the interfaced satellites.

– Enlarges the database, upon request of the users, adding those new satellites which start taking data.

– Upgrades the search module software that will be released in a transparent way vis-à-vis the clients, possibly dispersed all-around the world. The user interface will just be the search module form.

3. – The proprietary database of atmospheric data

The meteorological satellite databases provide several atmospheric parameters retrieved by the data collected during the continuous observation of the Earth (Geostationary and Polar satellites). Some of them are relevant for the analysis of UHECR events detected by a space-based telescope: the module described in this section is devoted to building and updating a proprietary DB obtained picking-up the values of the atmospheric parameters selected in particular according to the experimental requirements of a space experiment devoted to UHECR study through the fluorescence detection induced by extended air showers, as EUSO is.

The DB was created by using Microsoft SQL Server DBMS and consists of a set of correlated archives of data extracted from meteorological satellites observation [9], as listed in fig. 2.

EUSO — DAY — VIS

	Satellite	Reflected solar energ	Wind	Hurricanes/storms	Vegetation	Clouds over Land	Clouds over Sea	Radiating energy	Land reflected energ	Cloud reflected ener	Reflecting power	Water vapour	Ocean color scale	Image
GEOSTATIONARY	METEOSAT	•												•
	MSG		•		•	•	•							•
	GOES	•		•				•	•					•
	GMS-5	•							•	•				•
	MTSAT	•	•			•	•		•	•				•
	FENG-YUNG 2				•	•	•				•	•	•	•
	GOMS		•	•		•	•							•
	INSAT-2-3C *		•	•										•
POLAR	NOAA-15-17	•			•	•	•		•	•	•	•		•
	METOP		•			•	•						•	•
	METEOR-3					•	•							•
	FY-1 & FY-3				•	•	•				•	•	•	•

DAY — IR

Satellite	Thermal radiation	Cloud temperature	Land temperature	Sea water temp.	Humidity	Ice/Snow	Clouds over Snow	High altitude clouds	Low altitude clouds	Water Vapour	Ozone	Land reflected energ	Cloud reflected ener	Fire	Volcanic clouds	Image
METEOSAT	•	•	•	•												•
MSG		•	•				•	•	•	•	•					•
GOES	•	•	•								•					•
GMS-5	•	•	•	•								•	•			•
MTSAT	•	•	•	•				•	•	•		•	•		•	•
FENG-YUNG 2		•	•	•						•				•		•
GOMS		•	•	•					•							•
INSAT-2-3C *																•
NOAA-15-17		•	•	•		•	•	•	•			•	•			•
METOP		•	•	•	•		•	•	•	•	•					•
METEOR-3		•	•	•	•	•	•	•	•		•					•
FY-1 & FY-3		•	•	•			•	•	•	•				•		•

DAY — WV; IR; WV; Space resolution at Nadir (km)

Satellite	WV: Thermal radiation	WV: Wind	WV: Water Vapour	WV: Image	IR: Thermal radiation	IR: Cloud temperature	IR: Land temperature	IR: Sea water temp.	IR: Clouds	IR: Image	WV: Thermal radiation	WV: Image	VIS	IR	WV
METEOSAT	•			•	•	•	•	•		•	•	•	2,5	5,0	5,0
MSG				•						•		•	1 - 3	3,0	3,0
GOES				•						•		•	1,0	4,0	
GMS-5			•	•						•		•	1,25	5,0	5,0
MTSAT		•		•					•	•		•	1,0	4,0	
FENG-YUNG 2			•	•						•		•	1,25	5,0	5,0
GOMS				•						•		•	1,25	6,25	
INSAT-2-3C *				•						•		•	2,0	8,0	
NOAA-15-17	•		•	•		•	•	•	•	•		•	1,1	4,0	
METOP		•	•	•		•	•	•	•	•		•			
METEOR-3				•						•		•			
FY-1 & FY-3			•	•		•	•	•		•		•			

Fig. 2. – List of satellites considered for the DB and their available parameters.

For this first release other datasets have been considered as support in case of absence of information: ISCCP [6] (International Satellite Cloud Climatology Project) and MODIS (Moderate Resolution Imaging Spectroradiometer) on Terra, Aqua satellites [10]. Despite of the fact that the ISCCP and MODIS archives use the same file format HDF (Hierarchical Data Format), they arrange the data in a different way including different parameters. Therefore two specific procedures (*jobs*) were created to suitably process the data during the downloading phase; possible errors are pointed out to a specified Marvin operator.

Every parameter from the included datasets is referred to areas of fixed dimensions and to a time period that are characteristic of each original source. ISSCP for instance, collects data from different meteorological satellites, processes them retrieving the mean values computed mapping the Earth surface in a grid of equal area boxes (squared at Equator latitude and a fixed size of 280 km along the latitude direction), and updates them daily every three hours.

Marvin arranges its data according to the standard organization of SQL Server DBMS [11], *i.e.* through tables where each row (*record*) represents the data from a single observation and each column (*field*) refers to a data property. Virtual tables, called *views*, enable the user to see the internal organization of the data without occupying any extra memory space. There is a table for each dataset included in the DB (fig. 3). Theoretically the number of tables can be infinite, while there exists a limit for the number of columns. Figure 4 shows the list of all objects the DB consists of (tables, views, . . .).

4. – The search module

The search module interfaces the EUSO data with the existing atmospheric parameters of the DB.

It has been developed on the web in order to be accessed by all participants in the experimental project. It is protected by a username and a password in order to restrict its use to a controlled list of registered users. This module was developed by using Microsoft ASP server-side (Active Server Pages), JavaScript and VBScript languages.

Two different subjects are allowed to interact with the module: the user and the system administrator. Only the second one can directly control and manage the database and all accounts of the application.

The graphic interface helps the operator to interact with the search section. The

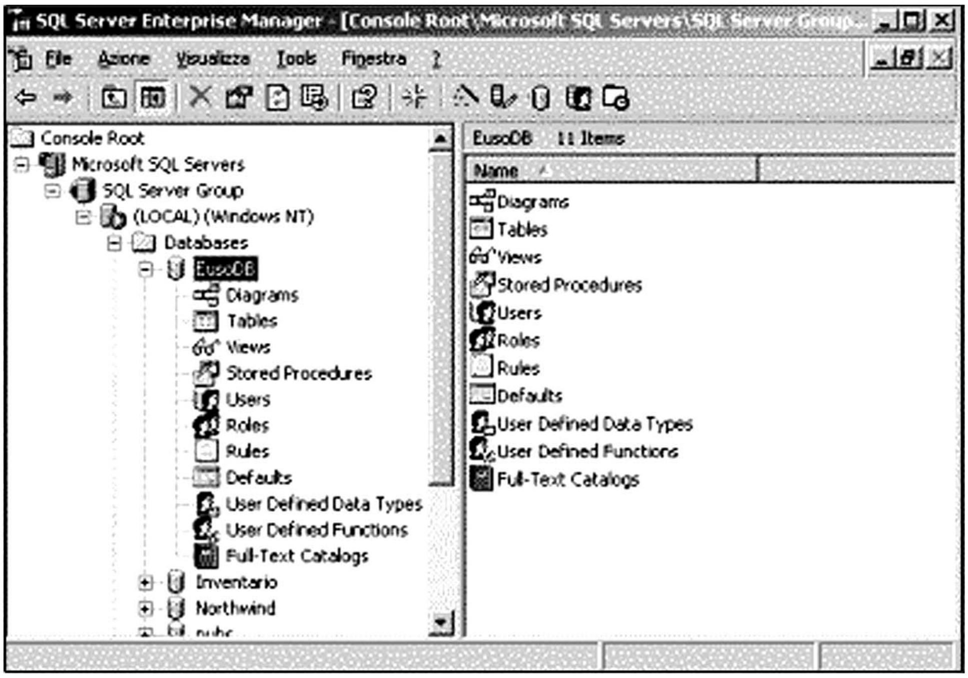

Fig. 3. – The proprietary DB structure in SQL Server Enterprise Manager.

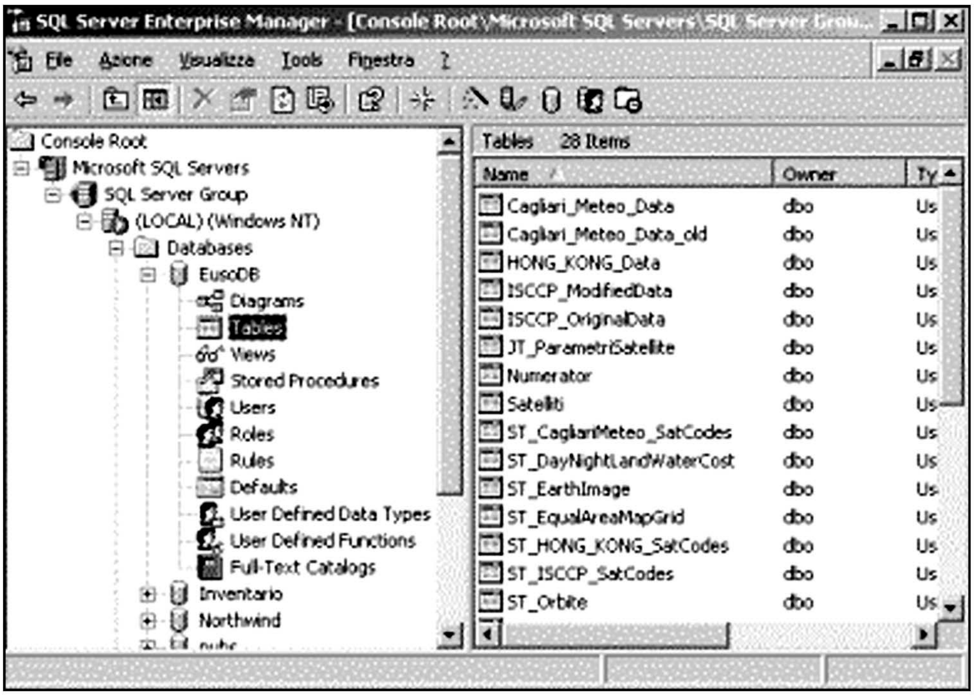

Fig. 4. – Tables of the DB data in SQL Server Enterprise Manager.

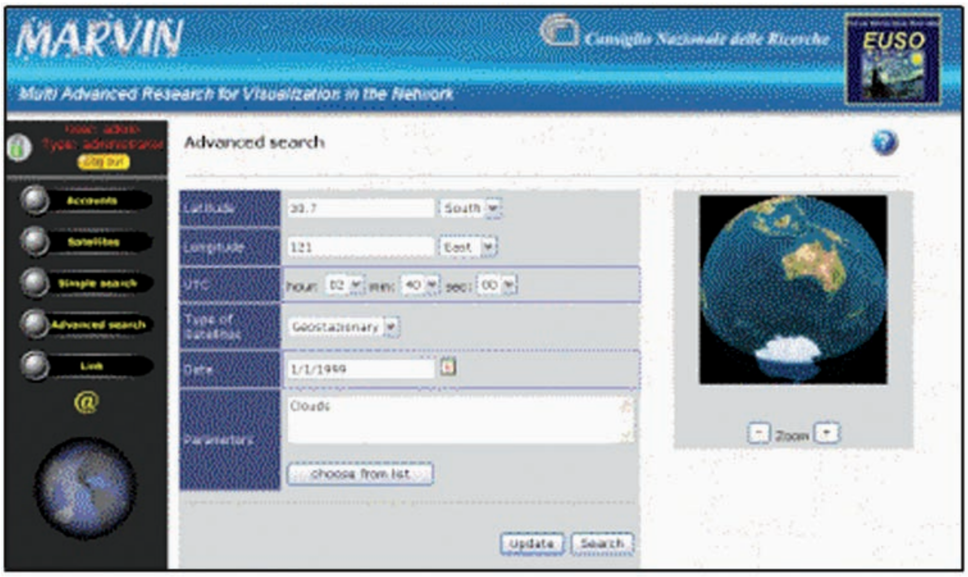

Fig. 5. – The Advanced Search section.

introductory dialog mask introduces for example to the basical function choice through selection buttons:

- user and password declaration (*Log* in button),

- get satellite information (*Satellites* button)

- choice the search method (*Simple/Advanced Search* Button)

- connect to the main web sites related to the client project (EUSO in the pilot case).

From the DB, by means of the search sections, a user can get the meteorological information on a pre-selected geographical area of interest at a given selected time.

Two different types of searches are possible: *Simple Search* and *Advanced Search*.

The *Simple Search* provides as a result the list of the satellites that were monitoring the region of interest at the required time (time of triggered event), with the possibility to visualize all available meteorological parameters, sorted out from a predetermined list. The user is asked to insert just the geographic coordinates (latitude and longitude), the UTC (Universal Time Coordinates) and the date of the observation. The *Advanced Search* allows also picking out the type of satellite (polar or geostationary) and focusing the search to a given parameter, out from a fixed list of relevant atmosphere sounding features (figs. 5, 6).

Both sections can be independently activated, but the *Advanced Search* can be also accessed via the *Simple Search*. In any case the zone selected by its coordinates is displayed on a devoted graphic area on the screen and can also be zoomed.

In both cases the results are visualized, saved in a file and/or printed.

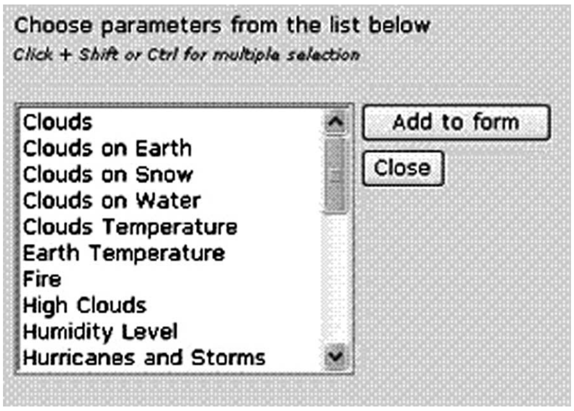

Fig. 6. – Some of the available atmospheric parameters.

5. – Conclusion and future improvements

In this paper the first release of the software module MARVIN has been presented. It is a useful tool that serves to collect and to provide a suitable set of meteorological parameters from public data archives of the orbiting weather satellites. Its main objective is to support the data analysis in space research on ultrahigh energy cosmic-rays physics, taking the EUSO project as a prototype of this new kind of experiments in astroparticle physics.

It can be used both for simulation purposes and for the real data analysis, either providing the basic atmospheric parameters at the event generation time or retrieving them in a given position and at a given time, as for example those of a recorded trigger.

The expected improvements needed to use it in a real context as for example that of the EUSO experiment, is to develop an interface to the event data structure, in such a way to be fed by the real event time and position, both interactively on an event by event basis, but also in batch mode for a collection of recorded event in a running period.

The amount and accuracy of information can be obviously improved by considering more data sources and more datasets, in a sort of ordinary maintenance work. For example enlarging the set of satellites used in order to enrich the database information, including the orbiting satellites that will be launched for specific atmosphere study purposes. The collaboration of the satellite operators will for sure improve the knowledge of the data source, allowing to obtain more detailed information with respect to those available using a public access mode.

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