

# ESABASE2 - Atmosphere/Ionosphere

## Software User Manual

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## Document Information

### I. Release Note

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### II. Revision History

Version	Date	Initials	Changed	Reason for Revision
0.1	2009-08-03	KR	All	Split from common ESABASE2 handbook.
0.2	2009-09-22	KR	Chap. 2.1 – 2.4	Added geometry, Atmosphere chapters
0.3	2009-09-29	KR	Chap. 2.5 – 2.7	Added Ionosphere chapters
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1.0	2009-11-25	KR	All	Reviewed and finalised.
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### III. Distribution List

Institution	Name	Remarks
ESTEC	Gerhard Drolshagen	
ESTEC	Jon Sørensen	
diverse	n/a	ESABASE2 licensees

#### IV. List of References

- /1/ K. Ruhl, K. Bunte, ESABASE2/Framework software user manual, R077-230rep, ESA/ESTEC Contract 16852/02/NL/JA "PC Version of DEBRIS Impact Analysis Tool", etamax space, 2009
- /2/ ESABASE2 homepage, <http://www.esabase2.net/>
- /3/ SWENET, ESA's Space Weather European Network, since 2004, <http://www.esa-spaceweather.net/swenet/>
- /4/ ESABASE User Manual, ESABASE/GEN-UM-070, Issue 1, Mathematics & Software Division, ESTEC, March 1994
- /5/ J. Borde, G. de Sabbathier, Atomic Oxygen software user manual, S413/NT/19.94, ESA/ESTEC Contract 9558/91/NL/JG " Development of improved Atomic Oxygen analysis tool", Matra Marconi Space, May 1994
- /6/ J. Borde, G. de Sabbathier, Review and Implementation of Atmosphere and Wind Models, Technical Note 1, S413/NT/18.94, Matra Marconi Space, February 1994
- /7/ B. R. Bowman, W. K. Tobiska, F. A. Marcos, C Valladares, The JB2006 empirical thermospheric density model, Journal of Atmospheric and Solar-Terrestrial Physics 70 (2008), p. 774-793
- /8/ J.M. Picone, A.E. Hedin, D.P. Drob, and A.C. Aikin, NRL-MSISE-00 Empirical Model of the Atmosphere: Statistical Comparisons and Scientific Issues, J. Geophys. Res., doi:10.1029/2002JA009430
- /9/ International Reference Ionosphere homepage, <http://iri.gsfc.nasa.gov>
- /10/ K. Rawer, W. R. Piggott, Development of IRI-90, Advances in space research, Pergamon Press, New York, Volume 10(11), 1990

## V. Glossary

Term	Description
Application	ESABASE application such as e.g. the "Debris" or the "Sun light" application.
Eclipse	Eclipse is an open source community whose projects are focused on providing an extensible development platform and application frameworks for building software. For detailed information refer to <a href="http://www.eclipse.org/">http://www.eclipse.org/</a> .
ESABASE	Unix-based analysis software for various space applications. For details refer to the ESABASE User Manual /4/.
ESABASE/Debris	ESABASE framework and the debris and meteoroid flux and damage analysis application.
ESABASE2	New ESABASE version running on PC-based Windows platforms (to be distinguished from the "old" Unix-based ESABASE).
Geometric(al) (analysis)	Flux and damage analysis of a full geometric model.
Georelay	object pointing keyword: tracking of a GEO satellite.
non-geometric(al) (analysis)	Flux and damage analysis of a plate, which can be specified as a randomly tumbling plate or an oriented plate.
STEP	Acronym which stands for the Standard for the Exchange of Product model data.

## VI. List of Abbreviations

Abbreviation	Description
GUI	Graphical User Interface
JVM	Java Virtual Machine
NASA	National Astronautics and Space Administration
OCAF	Open CASCADE Application Framework (contains the ESABASE2 data model)

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## 1 Introduction

ESABASE2 is a software application (and framework) for space environment analyses, which play a vital role in spacecraft mission planning. Currently, it encompasses Debris/Meteoroid, Atmosphere/Ionosphere, Sunlight and Contamination/Outgassing analyses; with this, it complements other aspects of mission planning like thermal or power design.

The application grew from ESABASE2/Debris, an application for space debris and micro-meteoroid impact and damage analysis, which in turn is based on the original ESABASE/Debris software developed by the European Space Agency. ESABASE2 adds a modern graphical user interface enabling the user to interactively establish and manipulate three-dimensional spacecraft models and to display the selected orbit. Analysis results can be displayed by means of the colour-coded surfaces of the 3D spacecraft model, and by means of various diagrams.

The development of ESABASE2 was undertaken by etamax space GmbH under the European Space Agency contract No. 16852/02/NL/JA. The first goal was to port ESABASE/Debris and its framework/user interface to the PC platform (Microsoft Windows) and to create a modern user interface.

From the start, the software architecture has been expressively designed to accommodate further applications: the solvers outlined in the first paragraph were added, and more modules like radiation are to follow.

ESABASE2 is written in Fortran 77, ANSI C++ and Java 6. The GUI is built on top of the Eclipse rich client platform, with 3D visualisation and STEP import realised by Open CASCADE. Report and graphs are based on the JFreeReport/JFreeGraph libraries.

This user manual is the **Atmosphere/Ionosphere handbook**. It complements the Framework user manual /1/, which explains the common functionality of all solvers (e.g. Debris, Sunlight, Atmosphere/Ionosphere, or COMOVA).

## 2 Atmosphere/Ionosphere Solver

Atomosphere and Ionosphere solver are similar in scope, as they both evolved from the Atomic Oxygen (AtomOx) application within the original ESABASE, which is concerned with particles (mostly O<sub>1</sub>) that accumulate on the surfaces of a spacecraft.

In the following sections, the functionalities of the Atmosphere and Ionosphere solvers are described:

- *Geometry Additions*: Additions to a spacecraft geometry relevant for both Atmosphere and Ionosphere solvers.
- *Atmosphere chapters*:
  - *Atmosphere Input*: Describes the input editor for Atmosphere.
  - *Atmosphere Analysis*: How to make an Atmosphere run.
  - *Atmosphere Results*: How to interpret the results of an Atmosphere run.
- *Ionosphere chapters*:
  - *Ionosphere Input*: Describes the input editor for Ionosphere.
  - *Ionosphere Analysis*: How to make an Ionosphere run.
  - *Ionosphere Results*: How to interpret the results of an Ionosphere run.

### 2.1 Geometry Additions

Atmosphere and Ionosphere rely mostly on the common spacecraft geometry description. There is no dedicated Atmosphere/Ionosphere page in the geometry wizard; however, some pages are of special significance:

- *Material Page*: Both solver uses settings from the material page.
- *Meshing Page*: Positive/negative sides and meshing recommendations for Atmosphere/Ionosphere.

The following subsections cover these Wizard pages.

## 2.1.1 Material Page

Materials are specified for the surfaces of shapes (see /1/). Please take care to assign only materials which contain the necessary attributes for Atmosphere and Ionosphere, as shown in the lower part of the figure below.

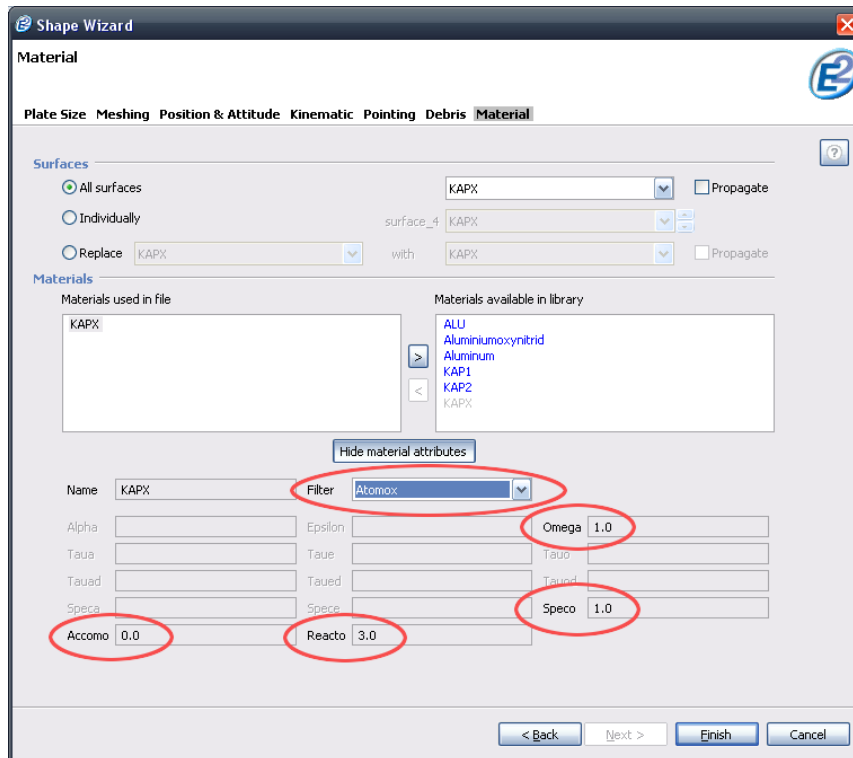


Figure 2.1: Geometry editor, Material page, Atmosphere/Ionosphere

In particular, these attributes are:

		range	default	no	full
• <i>omega</i> :	atmospheric absorptivity	0..1	1	0	1
• <i>speco</i> :	specularity ratio for reflection of atmosphere	0..1	0	0	1
• <i>accomo</i> :	accomodation ratio for particles of the atmosphere	0..1	1	0	1
• <i>reacto</i> :	reactivity of the material, defining the erosion rate, in microns/10 <sup>20</sup> atoms/cm <sup>2</sup> (which is equivalent to 10 <sup>24</sup> cm <sup>3</sup> /atom)	0.. ∞	0	0	∞

## 2.1.2 Meshing page

Although the meshing page (shown below) is the same for all solvers, the effects of the settings may vary.

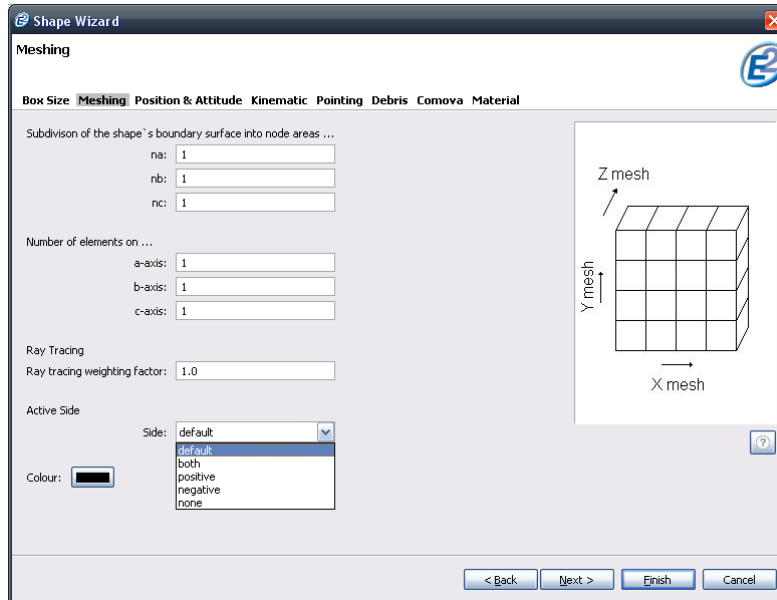


Figure 2.2: Geometry editor, Meshing page

Subdivision of surfaces (i.e. "surface nodes") are not supported by Atmosphere or Ionosphere. We recommend using the "Number of elements on" settings for finer meshing.

Regarding active sides: Atmosphere/Ionosphere results always comprise both sides of an element (the solver sums them up). For volumes, this is uncritical, because only one side is ever affected. For surfacic shapes (e.g. plate), we recommend choosing only one active side, because the results can otherwise not be correctly assigned to an element side.

And with this, the geometry file is ready, and we can move to the input editor.

## 2.2 Atmosphere Input

Besides the materials specified in the spacecraft geometry file, a global Atmosphere input file provides input parameters to the solver. The Atmosphere input editor is divided into 4 tabs, as shown below in Figure 2.3:

- *Environment and Analysis*: Parameters used for both geometric and non-geometric analyses.
- *Geometric*: Parameters used only for geometric analyses, i.e. using a spacecraft geometry.
- *Non-geometric*: Parameters used only for non-geometric analyses, i.e. using an in-orbit oriented plate instead of a spacecraft geometry.
- *Model Display*: A model display analysis provides atmosphere and wind characteristics such as number density and temperature from the models.

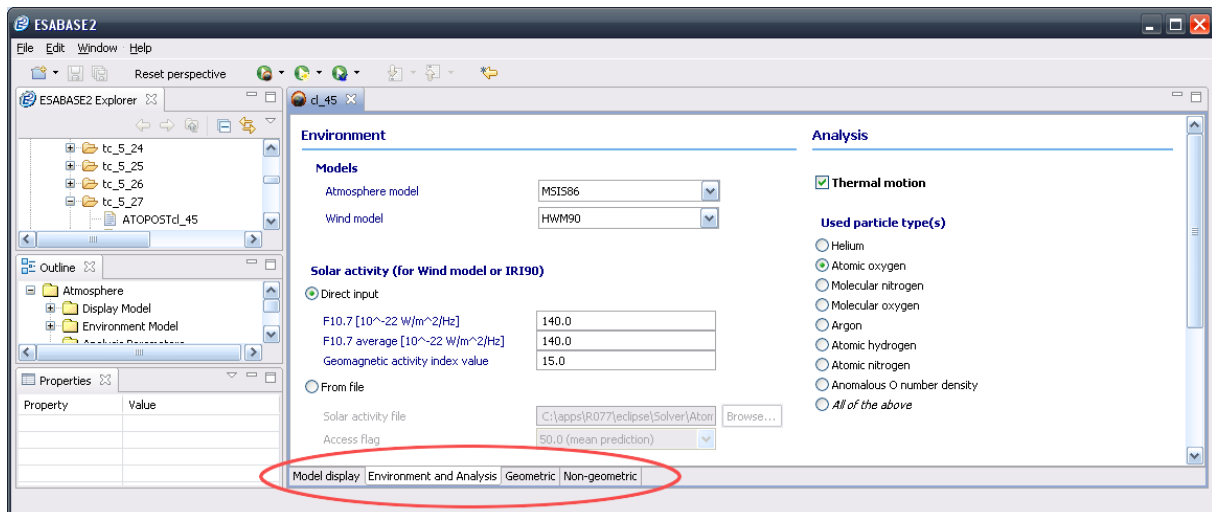


Figure 2.3: Atmosphere input editor

## 2.2.1 Environment and Analysis Tab

The environment and analysis tab describes the environment that the spacecraft is moving in. It has two sections, which are shown in the following figure:

- *Environment*: Defines the atmosphere and wind models, and the solar activity.
- *Analysis*: Defines which particle types to be included in the analysis, and whether to consider thermal motion.

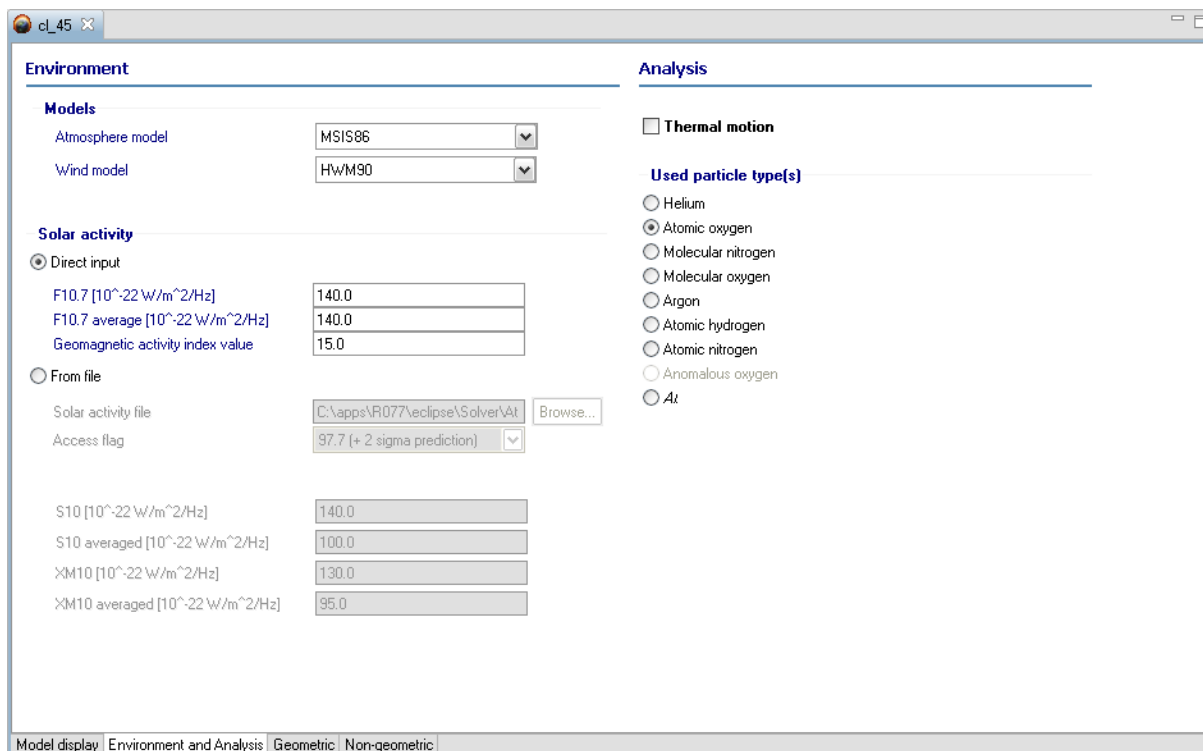


Figure 2.4: Atmosphere input editor, Environment and Analysis tab

### 2.2.1.1 Environment

The atmosphere environment is described by the following factors:

- *Atmosphere model*: Describes the atmospheric conditions, in particular thermospheric temperature, density and composition for altitudes of 85 to 2500 km. Several models are selectable.
- *Wind model*: Describes the wind conditions. Currently two Models are selectable. By selecting one Atmosphere can consider the influence of wind in different altitudes.

- *Solar activity*. Describes the perturbations caused by solar activity of the Sun. This activity is essential for the behaviour of the selected atmosphere and wind model.

#### 2.2.1.1.1 Atmosphere Models

You can select among the following atmosphere models:

- *MSIS86 thermosphere model*. "Mass Spectrometer Incoherent Scatter" is a semi-empirical model of thermospheric temperature, density and composition. It was released in 1986.
- *NRLMSISE00*. This model is an update of the MSIS86 model released by the U.S. Naval Research Laboratory (NRL). It is based on data of Mass Spectrometer and Incoherent Scatter radar. In addition it is Extended from the ground to the space. It was released in 2000.
- *MET thermosphere model*. "Marshall Engineering Thermospheric" describes the neutral atmosphere between 90 and 2500 km altitude. Internally, it uses the Jacchia 70 model to compute the atmospheric density.
- *DTM atmosphere model*. "Drag Temperature Model" is a 3D thermospheric model developed in terms of spherical harmonics from satellite drag data covering a time period of almost two solar cycles. It covers altitudes from 200 to 1200 km.
- *JB2006*. „Jacchia-Bowman thermospheric density model“ is based on the CIRA72 (Jacchia 71) model. New solar indices have been used for the solar irradiances in the extreme and far ultraviolet wavelengths. New exospheric temperature and semiannual density equations were created to represent the major thermospheric density variations. Temperature correction equations were also developed for diurnal and latitudinal effects, and finally density correction factors have been included for model corrections required at high altitudes (1500- 4000 km). It was released in 2006.

Further information about MSIS86, MET and DTM are contained in /6/; NRLMSISE00 is described in Fehler! Verweisquelle konnte nicht gefunden werden. and JB2006 is described in /7/.

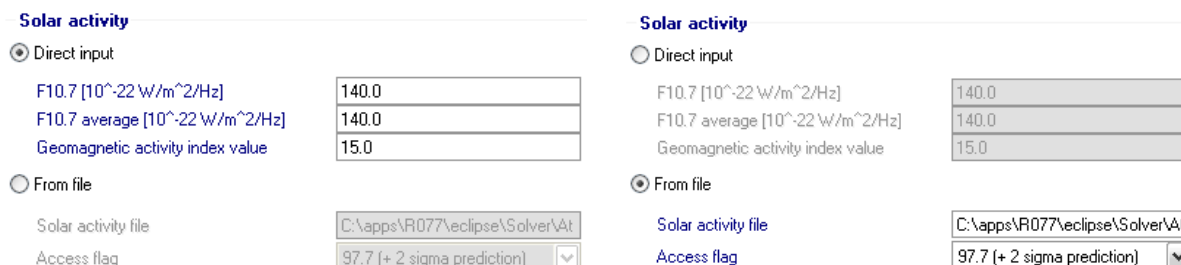
#### 2.2.1.1.2 Wind models

Wind models are optional ("None" being one of the options). The available models are:

- *HWM90 wind model*. "Horizontal Wind Model" is an empirical model of diurnal variations in the upper thermosphere. It covers altitudes from 100 to 850 km.
- *HWM93 wind model*. This model is an update of the HWM90 wind model. It now covers altitudes from 0 to 850 km.

### 2.2.1.1.3 Solar activity

Solar activity consists of particles and radiation from the sun, which causes changes in the atmosphere. The figure below shows available solar activity parameters.



**Figure 2.5:** Atmosphere input editor, Environment and Analysis tab, Solar activity

You have the choice between two modes of input: Direct and from a file.

In the direct input, the following parameters are available (see e.g. SWENET /3/ for values occurring during your mission time):

- *F10.7 cm flux*: The F10.7 index is a daily measure of the noise level generated by the sun at a wavelength of 10.7 cm at the earth's orbit. The range is from 0.0 to 300.0 and a default value is 150.0.
- *F10.7 cm flux, averaged*: It is the 3-month average of the F10.7 cm daily flux.
- *Geomagnetic activity index (Ap)*: The Ap index is a measure of the general level of geomagnetic activity over the globe for a given (UT) day. The range is from 0.0 to 400.0 and a default value is 15.0.

Your second option is to provide a solar activity file; this is meant only for expert users. Within such a file, monthly variations of the solar activity can be considered. Access flag (see figure above) refers to the percentile column to be taken from the file: mean predictions, 2.3 percentile or 97.7 percentile.

For illustration, the figure below shows the [SOLAR9407.DAT](#) file delivered together with ESABASE2.

SOLAR9407 Solar activity inputs for upper atmospheric models [Ref EL54(54-94)]  
 (a) From Jan 1983 to July 1994, mean monthly real values are taken  
 (b) From Aug 1994 onwards, long range estimates are taken  
 Of current solar cycle for 50% F10P7, BEST ESTIMATE is taken

year	TIME month	10.7CM SOLAR FLUX F10P7			GEOMAGNETIC INDEX AP		
		percentile			percentile		
		97.7%	50%	2.3%	97.7%	50%	2.3%
1983.0004	1	142.3	142.3	142.3	16	16	16
1983.0836	2	122.6	122.6	122.6	27	27	27
1983.1670	3	118.8	118.8	118.8	23	23	23
1983.2504	4	118.9	118.9	118.9	24	24	24
1983.3336	5	137.1	137.1	137.1	20	20	20
1983.4170	6	138.6	138.6	138.6	16	16	16
1983.5004	7	125.0	125.0	125.0	12	12	12
1983.5836	8	124.4	124.4	124.4	16	16	16
1983.6670	9	109.0	109.0	109.9	14	14	14
1983.7504	10	112.4	112.4	112.4	17	17	17
1983.8336	11	92.5	92.5	92.5	21	21	21
1983.9170	12	93.4	93.4	93.4	15	15	15
1984.0004	1	116.1	116.1	116.1	13	13	13
1984.0836	2	140.6	140.6	140.6	17	17	17
1984.1670	3	122.0	122.0	122.0	21	21	21
1984.2504	4	128.7	128.7	128.7	25	25	25
1984.3336	5	128.3	128.3	128.3	17	17	17
1984.4170	6	100.3	100.3	100.3	15	15	15

Figure 2.6: Atmosphere input editor, SOLAR9407.DAT solar flux file

Further below in the Environment and analysis tab, you can specify additional solar activity parameters (only if the JB2006 model is used).

S10 [10 <sup>-22</sup> W/m <sup>2</sup> /Hz]	<input type="text" value="140.0"/>
S10 averaged [10 <sup>-22</sup> W/m <sup>2</sup> /Hz]	<input type="text" value="100.0"/>
XM10 [10 <sup>-22</sup> W/m <sup>2</sup> /Hz]	<input type="text" value="130.0"/>
XM10 averaged [10 <sup>-22</sup> W/m <sup>2</sup> /Hz]	<input type="text" value="95.0"/>

Figure 2.7: Atmosphere input editor, Environment and Analysis tab, Solar activity

In addition to the traditional 10.7-cm flux (F10.7) that is a proxy for solar Extreme Ultraviolet (EUV) irradiances, a new solar irradiance index (S10.7) and a new proxy (M10.7) have been developed for use in empirical thermospheric density models. A proxy is a substitute for a distinctly different energy input while an index expresses the activity level of an energy input.

These three solar indices and proxies above best represent the complex interaction between the solar emission source (photosphere, chromosphere, corona) with the irradiances' penetration into the thermosphere (unit optical depth in the middle and lower

thermosphere) and the length of time for energy transfer between thermospheric layers (thermal process of molecular conduction or kinetic process of molecular diffusion).

The following four parameters are only used by JB2006 model.

- *S10*: The S10.7 index accounts for the majority of the daily density variability with a 1-day lag, is reported in units of F10.7, is the chromospheric EUV energy between 26-34 nm as measured by the SOHO SEM instrument, and is deposited above 200 km.
- *S10 (averaged)*: It is the 81-day average of the previously described S10 index.
- *XM10*: The M10.7 proxy accounts for the next significant factor of the daily density variability with a 5-day lag and is the Mg II core-to-wing ratio reported in units of F10.7. It is used as a substitute for the FUV Schumann-Runge Continuum (SRC) energy dominated by the 145-165 nm range that has a unit optical depth in the lower thermosphere and is the main source of thermospheric molecular oxygen dissociation that is not historically included in Jacchia and MSIS-type models.
- *XM10 (averaged)*: It is the 81-day average of the previously described XM10 index.

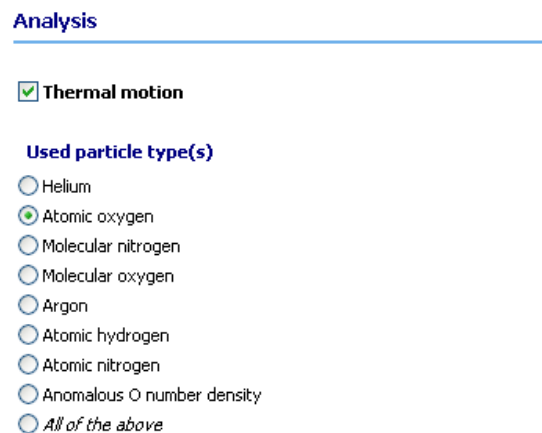
Further information about the four proxies and indices used in JB2006 can be found in *171*.

### 2.2.1.2 Analysis

In the Analysis section, you can define output parameters for the Atmosphere analysis.

- *Thermal motion*: Whether particles undergo thermal motion.
- *Used particles types*: Which particle types are to be considered.

The figure below shows the Analysis section in the Atmosphere input editor.



**Figure 2.8:** Atmosphere input editor, Environment and Analysis tab, Analysis

When thermal motion is activated, the particles do not move in straight lines, but undergo jittery motions due to thermal effects. The effect is that e.g. the side of a box can be affected by a "wavy" particle trajectory.

Typical particle types that can affect the geometry in the thermosphere are helium (He), atomic oxygen ( $O_1$ ), molecular nitrogen ( $N_2$ ), molecular oxygen ( $O_2$ ), argon (Ar), atomic hydrogen ( $H_1$ ), atomic nitrogen ( $N_1$ ), anomalous O number densities, or all of the previously mentioned.

Depending on the selected model one or all of the valid particle types can be selected.

	MSIS86	NRLMSIS 00E	MET	DTM	JB2006
Helium	x	x	x	x	-
Atomic oxygen	x	x	x	x	-
Molecular nitrogen	x	x	x	x	-
Molecular oxygen	x	x	x	x	-
Argon	x	x	x	-	-
Atomic hydrogen	x	x	x	-	-
Atomic nitrogen	x	x	-	-	-
Anomalous oxygen	-	x	-	-	-
All	x	x	x	x	x

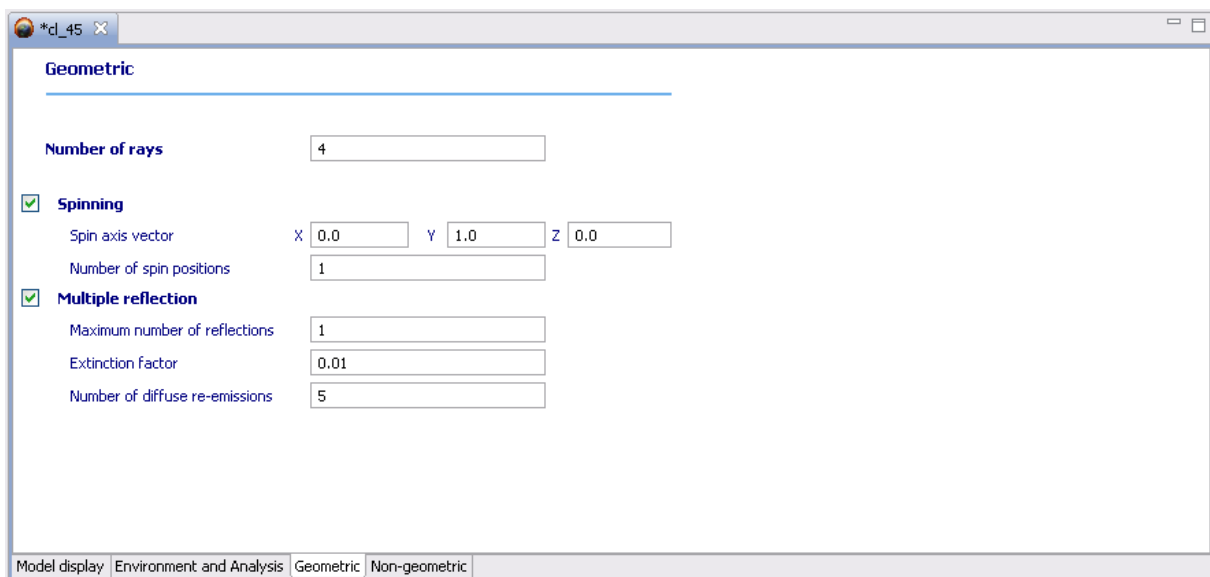
**Table 2.1:** Selectable particle types for the atmosphere models

*Please note:* At high altitudes (> 500 km), hot atomic oxygen or ionized oxygen can become appreciable for some ranges of subroutine inputs, thereby affecting drag on satellites and debris. These species are grouped under the term "anomalous oxygen", since their individual variations are not presently separable with the drag data used to define this model component.

## 2.2.2 Geometric Tab

The geometric tab, pictured below, is relevant for the geometric analysis only and features the following parameters:

- *Number of rays*: Used for raytracing algorithm that calculates the flux
- *Spinning*: Whether the spacecraft is spinning around an axis (e.g. in velocity direction).
- *Multiple reflection*: Whether a reflection of a particle shall be considered or not (possibly multiple times). The behaviour depends on the material properties selected for the surfaces (see 2.1)



**Figure 2.9:** Atmosphere input editor, Geometric tab

### 2.2.2.1 Number of Rays

This is a very simple parameter. Increasing the number of rays improves the accuracy of the models, e.g. by averaging over extreme effects of one ray. A lower number improves the performance of the analysis run. If only one ray is set, the ray is fixed from the centre of the element and the thermal motion is not considered. If several rays are emitted, the emission points are sampled at random on the element surface. Especially for analysis with multiple reflection switched on the number of rays should be increased.

### 2.2.2.2 Spinning

Determines whether the spacecraft is spinning, and around which axis. While this would normally be a S/C geometry property, it is included here because it is only used in the Atmosphere/Ionosphere solvers.

The number of spin positions determines the S/C alignment positions to be analysed: 1 means the S/C has always the same position.

### 2.2.2.3 Multiple Reflection

When multiple reflection is activated, a ray is not only analysed when hitting a surface, but the ray reflection is further followed.

- *Maximum number of reflections* is a threshold above which the ray is no longer reflected. If it is set to 0 no reflection is performed, but the absorbed fluxes and fluencies are computed. The larger this number is set the longer the analysis need. 10 is the default value.
- The *extinction factor* defines the stop criteria (in 100% of direct impacting flux) to stop the multiple reflection for that ray. The smaller this value is set the more multiple reflection will be analysed.
- The *number of diffuse re-emissions* is the number of rays that result from the diffuse part of re-emission. For each hitting ray, part of the flux is absorbed and the re-emitted part is separated in one specular ray and *n* diffuse rays. The material settings (see 2.1) are essential for the behaviour of the geometry. If it is set to 0 no diffuse reflection is performed.

### 2.2.3 Non-Geometric Tab

Similar to the geometric tab, the non-geometric tab shown below allows you to define parameters for the non-geometrical Atmosphere analysis, which works on a simple plate instead of a full spacecraft geometry.

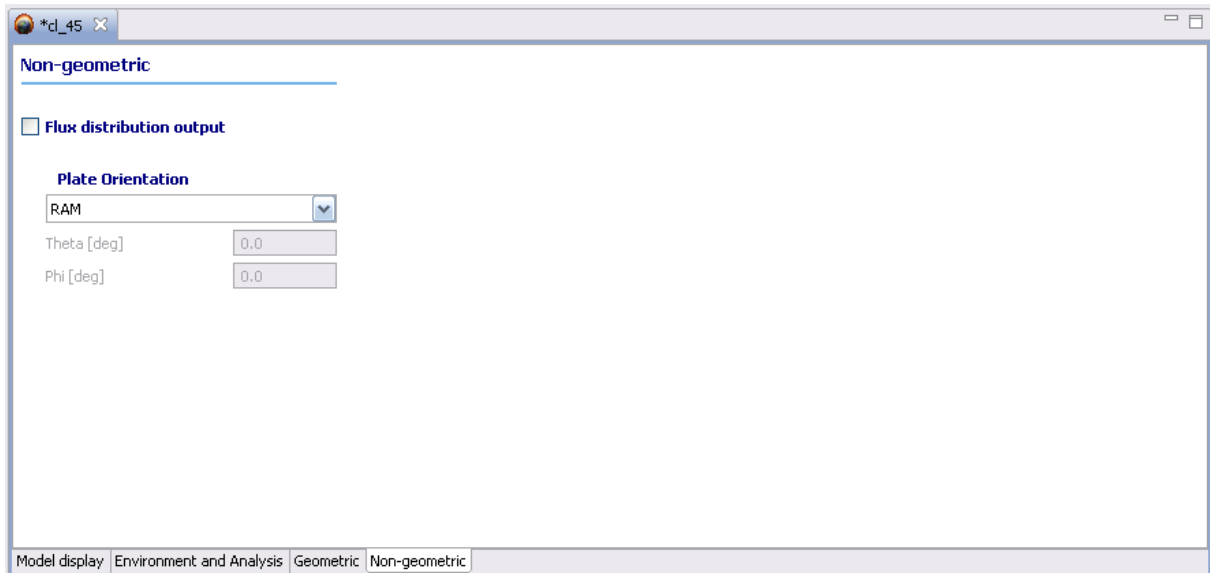


Figure 2.10: Atmosphere input editor, Non-geometric tab

If the Flux distribution output is selected, the flux distribution versus angle with the plate normal will be computed at each orbital point. The results are available as 2D plot in the 2D-result tab of the result file (see 2.4.2).

Plate orientation is the direction that the plate is looking at. Possible options are:

- *SUN*: Plate is always facing the sun.
- *EARTH*: Plate is always facing the earth.
- *RAM*: Plate is always facing the velocity direction.
- *USER*: You can define theta and phi yourself. Theta is the angle between the plate normal and the Z axis of the satellite frame. The satellite frame axes are defined as (XYZ orthogonal system):

X = velocity axis  
 -Z = opposite to Earth  
 Y = completes the right handed coordinate system

Phi is the angle between the projection of the normal on the XY plane of the satellite frame and the X axis of the satellite frame. Example for the RAM direction: theta = 90° phi = 0°.

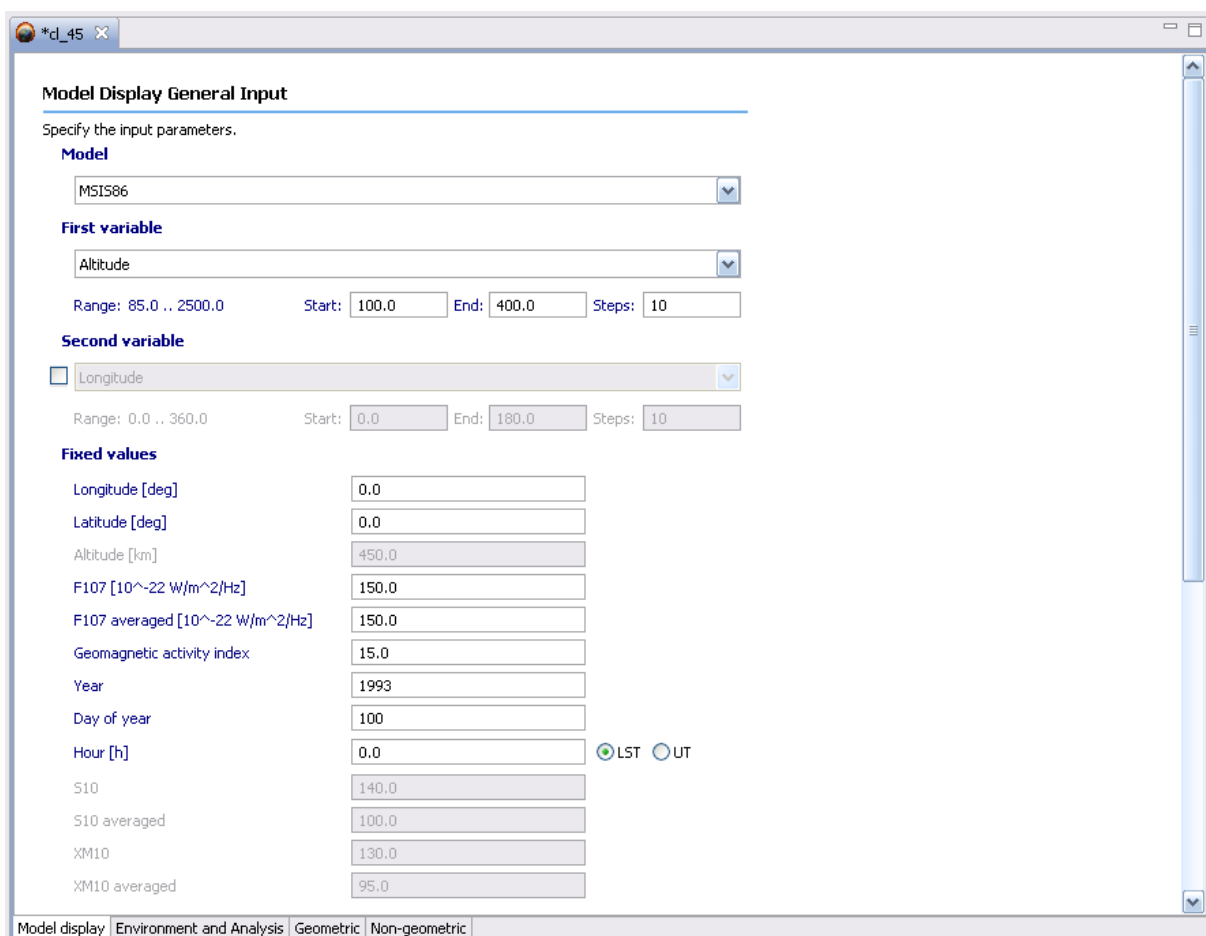
## 2.2.4 Model Display Tab

In the model display tab, you can specify the parameters for a model display analysis, which provides you with characteristics of the different atmosphere and wind models in tabular and graph form.

The tab contains two sections: Input and output parameters.

### 2.2.4.1 General Input

The picture below shows the input parameters of the Atmosphere model display.



**Figure 2.11:** Atmosphere input editor, Model display tab, General input

Input parameters are splitted into the 4 sections:

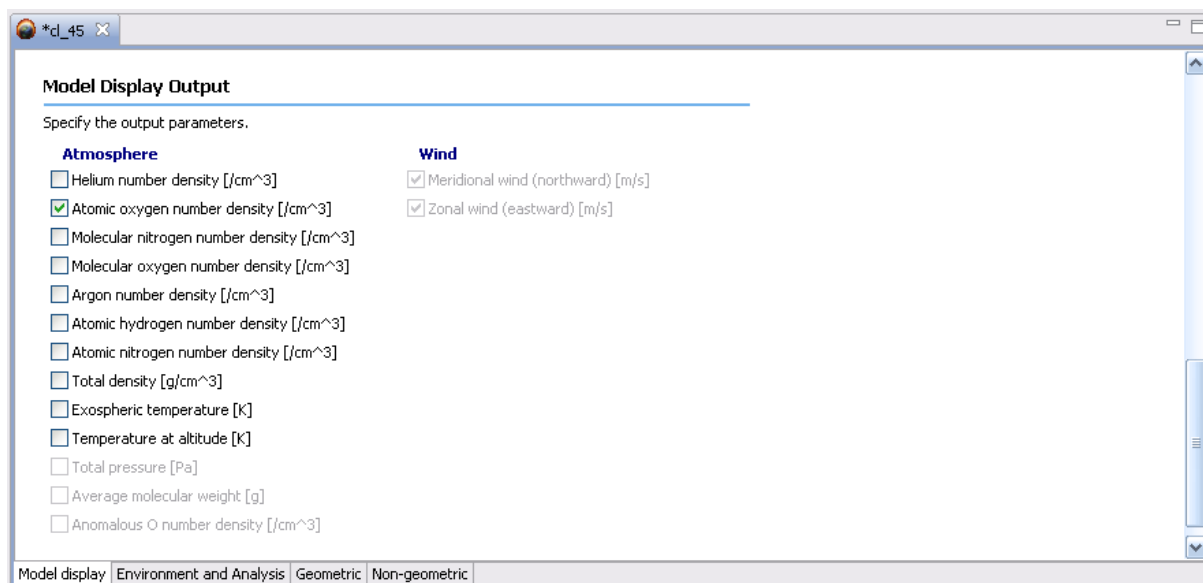
- *Model*: The atmosphere or wind model to use, see 2.2.1.1.
- *First variable*: The first variable of the model display.
- *Second variable*: Optional second variable; if activated, a 3D plot is generated instead of a 2D plot.
- *Fixed values*: The remaining values remain non-variable.

The following parameters (of which up to 2 are variable, the rest fixed) must be specified:

- *Longitude, Latitude, Altitude*: The "position of spacecraft" assumed for the purposes of the model display.
- *Solar activity (F10.7 cm Flux, F10.7 cm Flux (averaged), Geomagnetic activity index (Ap))*: See environment and analysis tab, section 2.2.1.1.3.
- *Year*: to be analysed year, in format YYYY.
- *Day of Year*: to be analysed day (of the year) between 1 and 365.
- *Hour*: to be analysed time (in hour) can be specified as local solar time (LST) or universal time (UT).
- *S10, S10 (averaged), XM10 and XM10 (averaged)*: See environment and analysis tab, section 2.2.1.1.3.

## 2.2.4.2 Output

Output parameters are split into Atmosphere and Wind parameters, as shown in the figure below.



**Figure 2.12:** Atmosphere input editor, Model display tab, Output

The availability of the parameters depends on the chosen Atmosphere or Wind model. For every selected output parameter, a 2D or 3D plot is generated.

The following table gives you the available Atmosphere output parameters.

	MISIS86	NRLMISE00	MET	DTM	JB2006	HWM90	HWM93
Helium number density	X	X	X	X	-	-	-
Atomic oxygen number density	X	X	X	X	-	-	-
Molecular nitrogen number density	X	X	X	X	-	-	-
Molecular oxygen number density	X	X	X	X	-	-	-
Argon number density	X	X	X	-	-	-	-
Atomic hydrogen number density	X	X	-	-	-	-	-
Anomalous oxygen number density	-	X	-	-	-	-	-
Total density	X	X	X	X	X	-	-

Exospheric temperature	X	x	x	x	x	-	-
Temperature at altitude	X	x	x	x	x	-	-
Total pressure	-	-	x	-	-	-	-
Average molecular weight	-	-	x	-	-	-	-
Meridonal wind	-	-	-	-	-	x	x
Zonal wind	-	-	-	-	-	x	x

**Table 2.2:** Available Atmosphere output parameters for different models

The available Atmosphere parameters have the following meaning:

- *Number density:* Gives the number of specific particles per cm<sup>3</sup> at the given position and time.
- *Temperature:* Gives the temperatures of the exosphere and the temperature of the given altitude.
- *Total pressure:* Gives the pressure at given position and time,
- *Average molecular weight:* Gives the average molecular weight of the particles at given position and time.
- *Meridonal wind:* Gives wind speed from south to north.
- *Zonal wind:* Gives wind speed from west to east.

## 2.3 Atmosphere Analysis

The atmosphere analysis is started by selecting the right side of the Atmosphere/Ionosphere Run button, and selecting the appropriate analysis type, as depicted below.

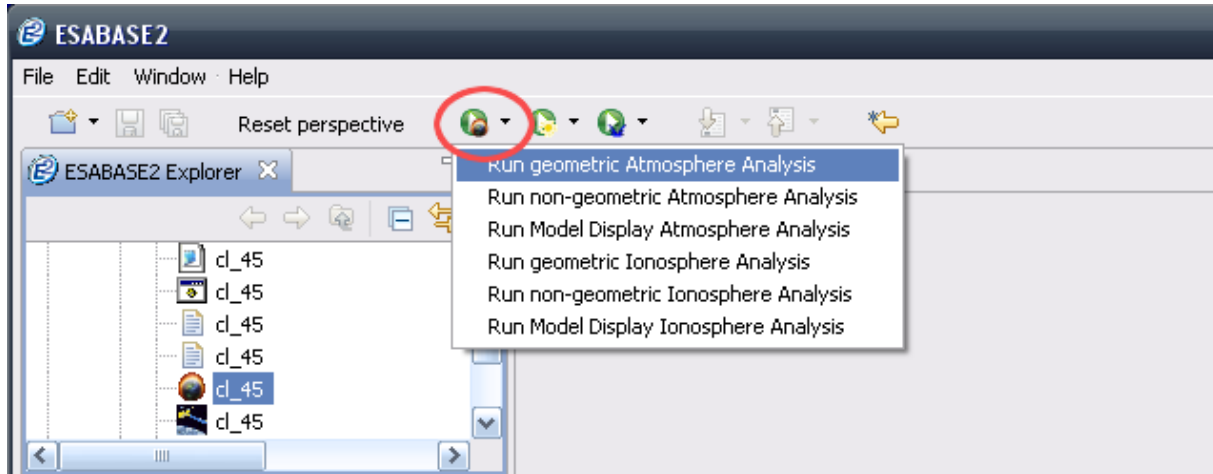


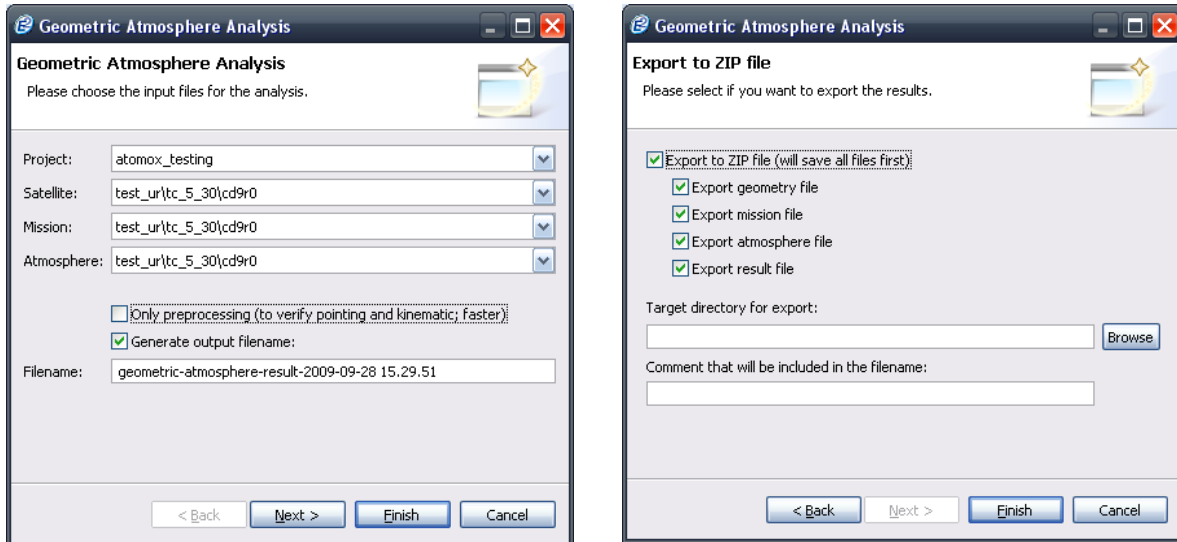
Figure 2.13: Atmosphere analysis, Run button

Corresponding to the tabs in the Atmosphere input editor, the following analysis types are available:

- *Geometric Atmospheric Analysis*. Uses a spacecraft geometry.
- *Non-geometric Atmosphere Analysis*. Uses an oriented plate.
- *Model Display Atmosphere Analysis*. Pre-runs some analysis parameters.

### 2.3.1 Atmosphere Geometric Analysis

When you press "Run Geometric Atmosphere Analysis", the Run wizard shown in the figure below will be opened.



**Figure 2.14:** Atmosphere analysis, Geometric, Run wizard

On the first page, you select the project from the workspace to work in. The next three lines specify the geometry file, the mission file, and the Atmosphere input file to be used.

With the first checkbox below, you can choose to run pre-processing only to confirm the validity of the spacecraft pointing and kinematics; no actual Atmosphere results will be produced in that case.

The second checkbox and the textfield below are for defining the name of the output file. We recommend to always use a fitting name, because the listing files (to be found in the [ListingFiles](#) directory within the project) will be named in kind.

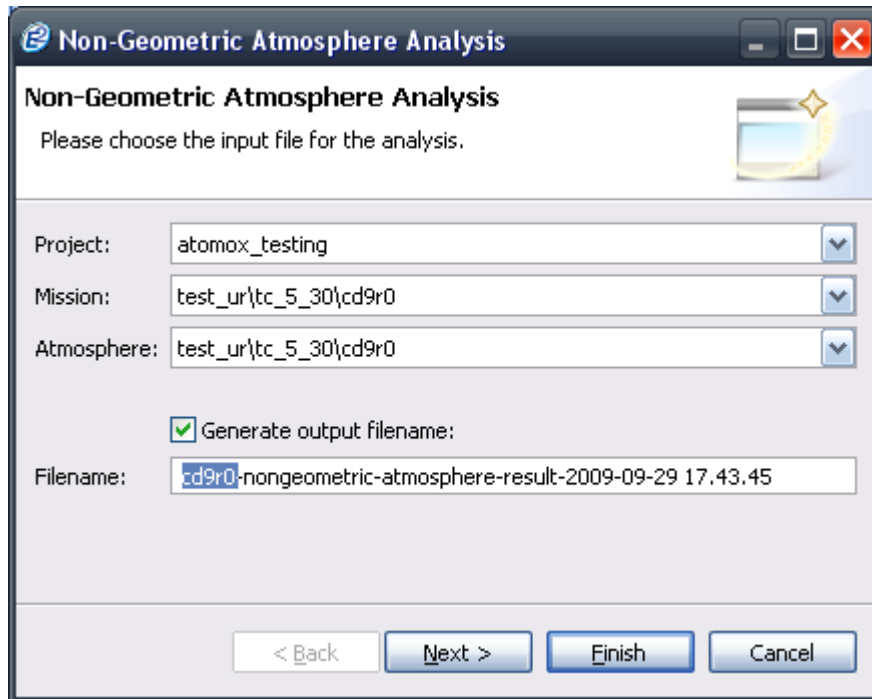
On the second page, the possibility exists to package the result file together with the input files into a ZIP archive. Normally, the result file will be saved into the project. A consolidated ZIP file, saved into a directory of your choice (see first textfield) can e.g. be sent to your colleagues.

A comment (see second textfield) can also be included to the ZIP file.

Press the "Finish" button to start the analysis. When it has finished, the result file will be shown in the Atmosphere result editor (see section 2.4).

### 2.3.2 Atmosphere Non-Geometric Analysis

The non-geometric Atmosphere analysis is a simpler version of the geometric analysis, as shown in the figure below.



**Figure 2.15:** Atmosphere analysis, Non-geometric, Run wizard

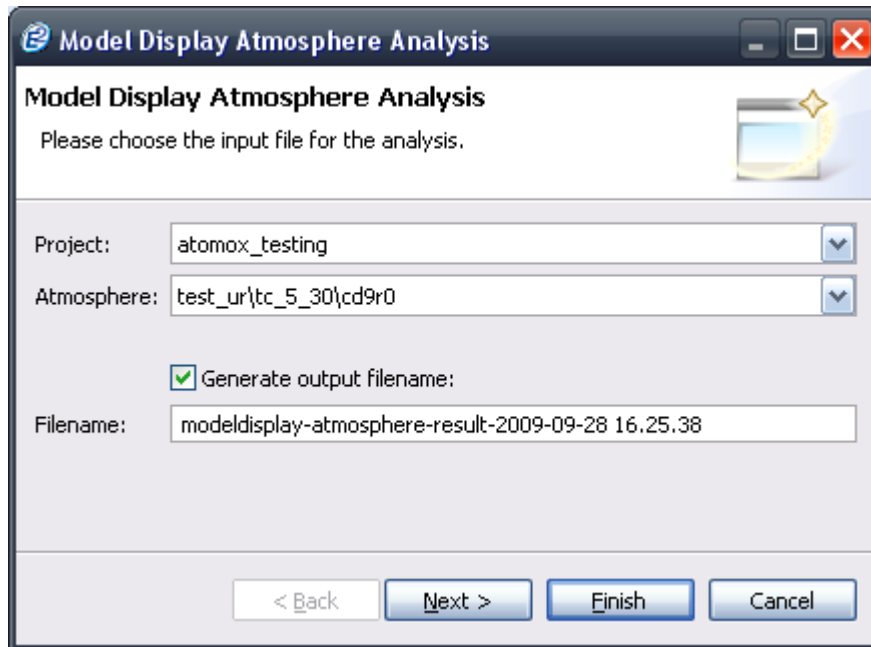
Select the project, and from it, the mission and Atmosphere input file; then select a name for the result file.

Again, the second page provides the possibility to save the results in a ZIP file.

Upon pressing "Finish", the non-geometric analysis will be started, and the result file will be shown in the Atmosphere result editor (see section 2.4).

### 2.3.3 Atmosphere Model Display Analysis

The Atmosphere model display analysis is even simpler than the non-geometric analysis, as shown in the screenshot below.



**Figure 2.16:** Atmosphere analysis, Model display, Run wizard

Project and Atmosphere input file are the only analysis parameters, together with the name of the result file. The "Finish" button will execute the analysis, and the Atmosphere result editor will show the result file.

## 2.4 Atmosphere Results

Whether running a geometric, a non-geometric or a model display analysis, an Atmosphere result file will always be created, and opened in the Atmosphere result editor pictured below.

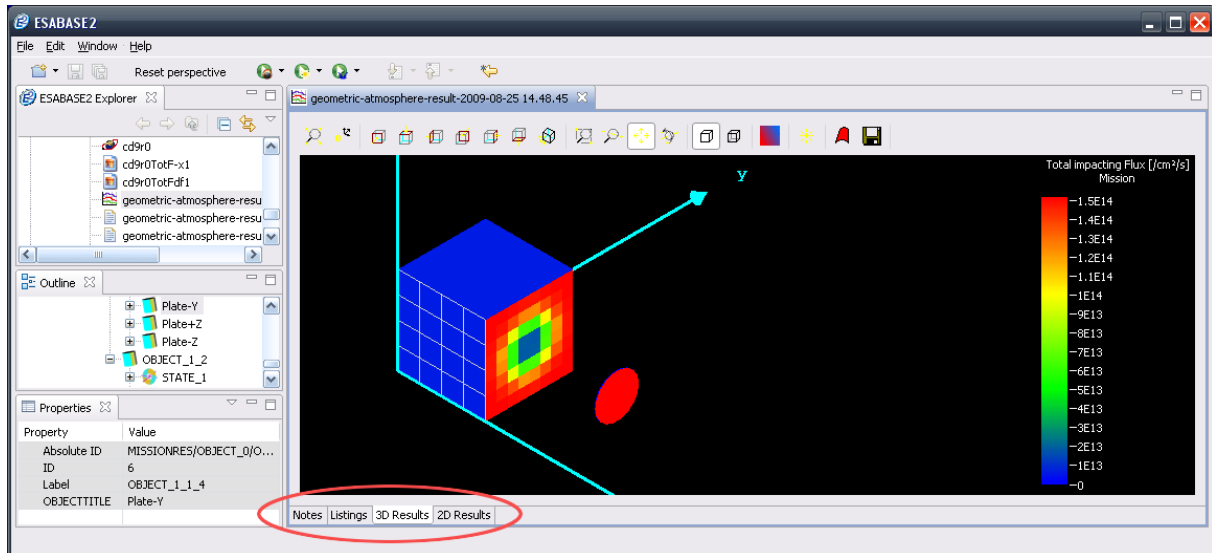


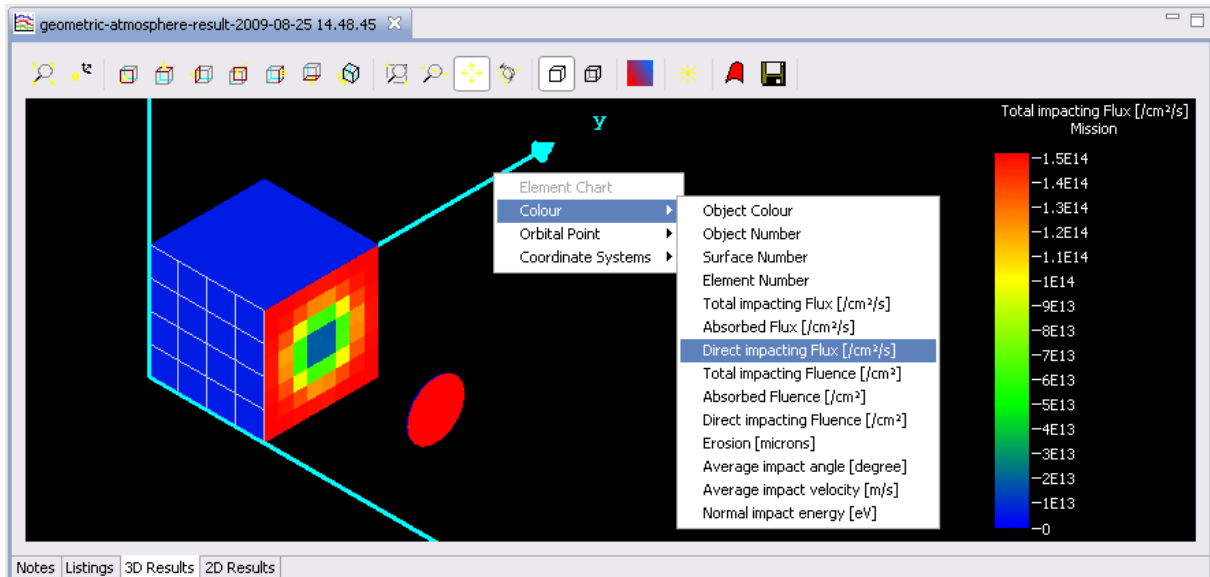
Figure 2.17: Atmosphere result editor

The result editor has four tabs which show different aspects of the result file.

- *3D Results*: Show the atmospheric and wind effects on the spacecraft surface.
- *2D Results*: Graphs and reports of atmospheric effects over the mission time.
- *Listings*: The Atmosphere listing files, in the form produced also by the original ESABASE/Atomox.
- *Notes*: A tab for your own notes, e.g. in preparation to sending the result file to a colleague.

## 2.4.1 3D Results Tab

The 3D result tab shown in the figure below provides a view on the spacecraft geometry, overlaid with the atmospheric effect of your choice.



**Figure 2.18:** Atmosphere result editor, 3D results tab

In order to adjust the view, rightclick into the black area in the editor; a context menu will open with the following top-level choices:

- *Colour*: The atmospheric effect to be viewed on the spacecraft model.
- *Orbital Point*: Whether to see the effects on the entire mission, or on a specific orbital point (the latter with the appropriate pointing).
- *Coordinate Systems*: Which coordinate systems to add to the view.
- *Element chart* (only when an element has been selected): Shows atmospheric effects over orbital points in a 2D graph.

### 2.4.1.1 Colour

The colour choice determines the atmospheric effect that is shown on the surface (and pictured numerically in the colorscale to the right of the editor).

The following colour choices are possible:

- *Object colour, Object number, Surface number, Element number.* The identifiers already used in the geometry file.
- *Total impacting Flux:* This is the total flux of particles hitting the element on direct hits and after multiple reflections, in particles/cm<sup>2</sup>/second.
- *Absorbed Flux:* This is the flux absorbed by the element, that is to say, the product of the total impacting flux by the absorptivity ratio of the element (see 2.1).

Note: The multiple reflection has to be activated for the computation of absorbed flux. If the multiple reflection is not activated (max. number of reflection = 0), then the absorbed flux is set to zero.

- *Direct impacting Flux:* This is the flux due to direct impacts. If the multiple reflection is not activated, it is equal to the total impacting flux.
- *Total impacting Fluence:* It is the integration over time of the total flux crossing the surface in particles/cm<sup>2</sup>.
- *Absorbed Fluence:* It is the integration over time of the absorbed flux that is absorbed by the surface.
- *Direct impacting Fluence:* It is the integration over time of the direct flux that is crossing the surface.
- *Erosion:* The erosion is the product of the total impacting fluence by the material reactivity coefficient (see 2.1).
- *Average impact angle:* Gives you the average angle of the impacting particles relative to the element surface (not the normal) in degrees.
- *Average impact velocity:* Gives you the average velocity of the impacting particles in m/s.
- *Normal impact energy:* Gives you the energy in electron-volts (eV) that is caused by the impacting particles. It is calculated with the particle mass and the average impacting velocity.

Please note that results always comprise both positive and negative sides of the elements; viewing each side separately is not possible.

### 2.4.1.2 Orbital point

The "Orbital Point" menu entry allows you to view each analysed orbital point, the entire mission, or an orbital arc. The default is to view the entire mission.

### 2.4.1.3 Coordinate Systems

The "Coordinate Systems" menu entry is for enabling and disabling coordinate systems within the 3D view to facilitate axis orientation. The following choices are possible:

- No coordinates
- Global coordinate system (centered)
- Global coordinate system (in one corner)
- Global and local coordinate systems

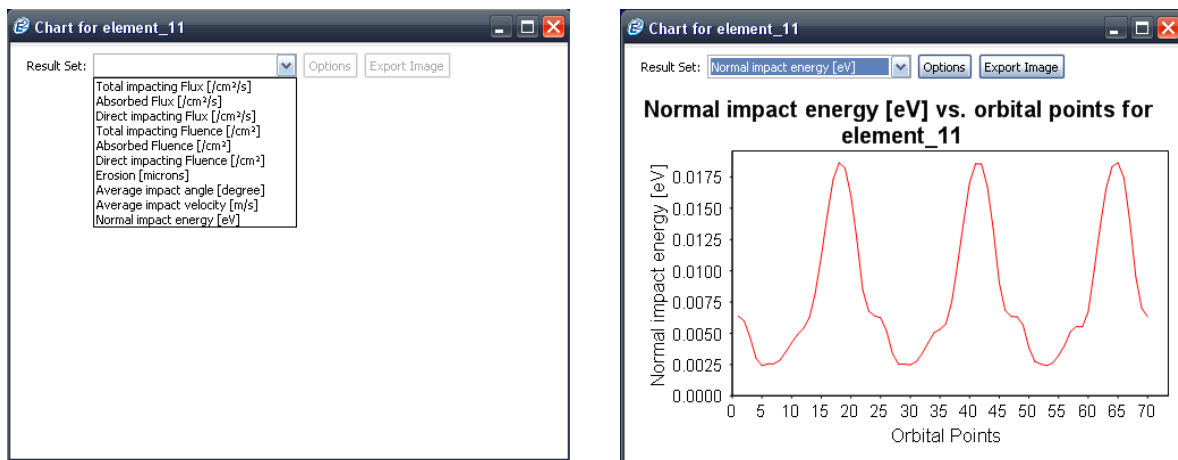
The last option will look very crowded for large models.

### 2.4.1.4 Element Chart

The 2D results (see next section) show atmospheric effects over time for the entire spacecraft. With element charts, you can see the effects over orbital points on a single element of the 3D model.

To select an element, hold the Shift key and leftclick on a element on the model. It will be marked with a gray border, and the Outline and Properties view on the left of the application window will show the marked element.

Rightclick anywhere in the result editor and the context menu will open; this time, the "Element Chart" option will be enabled. Click it and a new window will pop up, initially not showing any graph, as shown in the figure below.



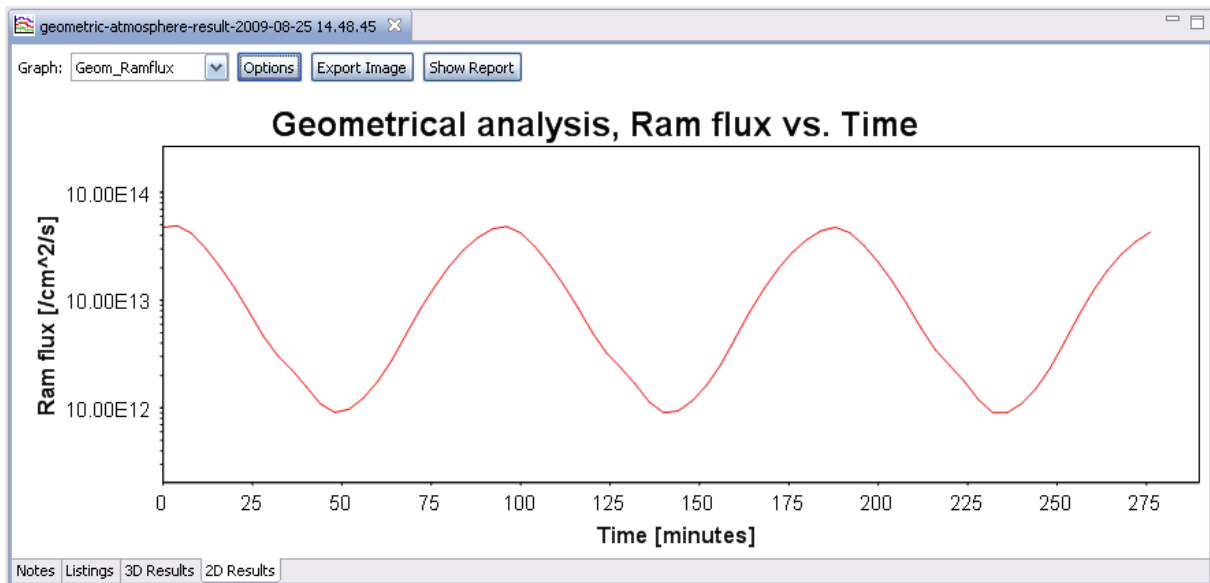
**Figure 2.19:** Atmosphere result editor, 3D results tab, Element chart

At the top, a combobox provides the different possible parameters (the same as for the 3D model, see section 2.4.1.1). Once you have selected one entry, a graph such as shown in the right figure above will be displayed.

The x axis of the graph is always composed of the orbital points (divided unto the mission time), while the y axis corresponds to the atmospheric effect chosen in the combobox.

## 2.4.2 2D Results Tab

Similar to the Element Chart in section 2.4.1.4, the 2D Results tab shows the atmospheric effects on the spacecraft geometry in a 2D graph, as shown in the screenshot below.



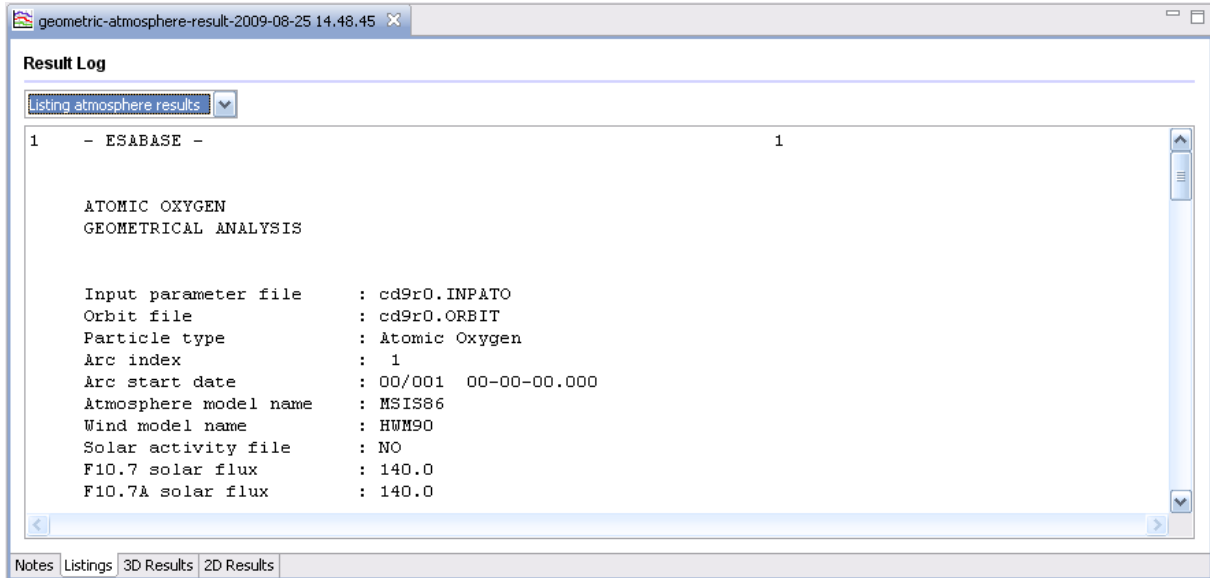
**Figure 2.20:** Atmosphere result editor, 2D results tab

In the combobox to the top left of the editor, you select the entity to be displayed; the graph then changes to show this entity vs. the mission time. The three buttons to the right of the combobox server the following purposes:

- The "Options" button allows you to adjust various parameters of the graph.
- The "Export Image" button is used to save the graph as PNG or JPG image.
- The "Show Report" buttons opens a new window with the graph contents in both tabular and graph form in a format ready to print.

### 2.4.3 Listings Tab

Users of the original ESABASE/Atomox can use the Listings tab to view the LIS files they are familiar with, as shown in the figure below.



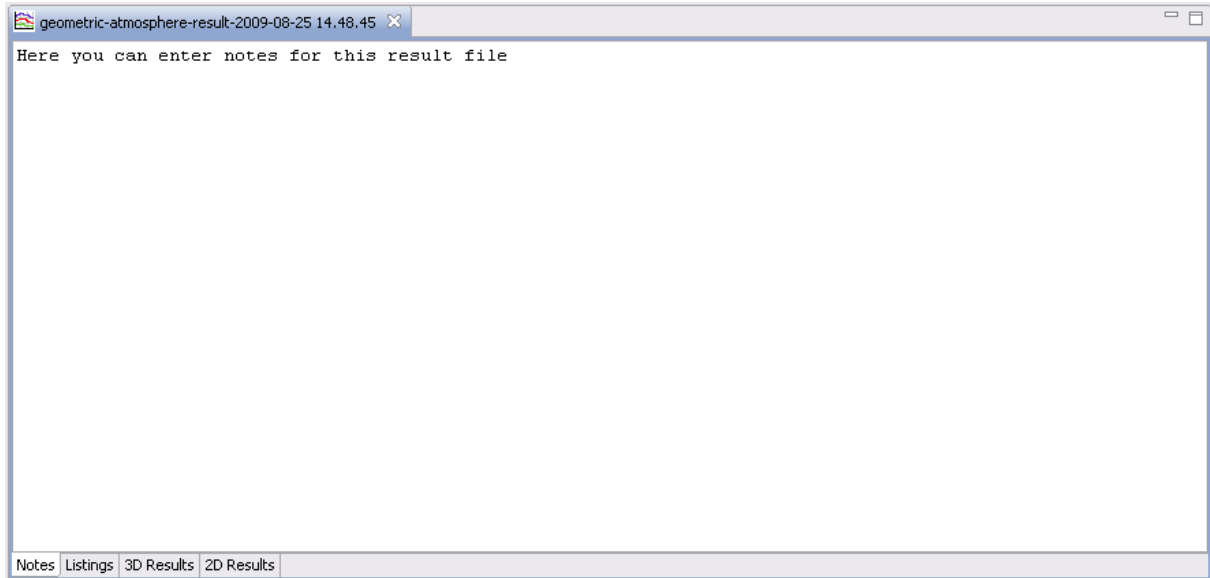
**Figure 2.21:** Atmosphere result editor, Listings tab

The combobox to the top left shows the available report types; upon selecting one, the text area in the middle is updated immediately.

Apart from the Listings tab, the LIS files are saved in the project under the `Listing-Files` directory under the same name as the result file (but with different file ending). It is for this reason that we recommend running the Atmosphere analysis with a dedicated output file.

## 2.4.4 Notes Tab

In the Notes tab depicted below, you can enter any text as notes pertaining the present result file.



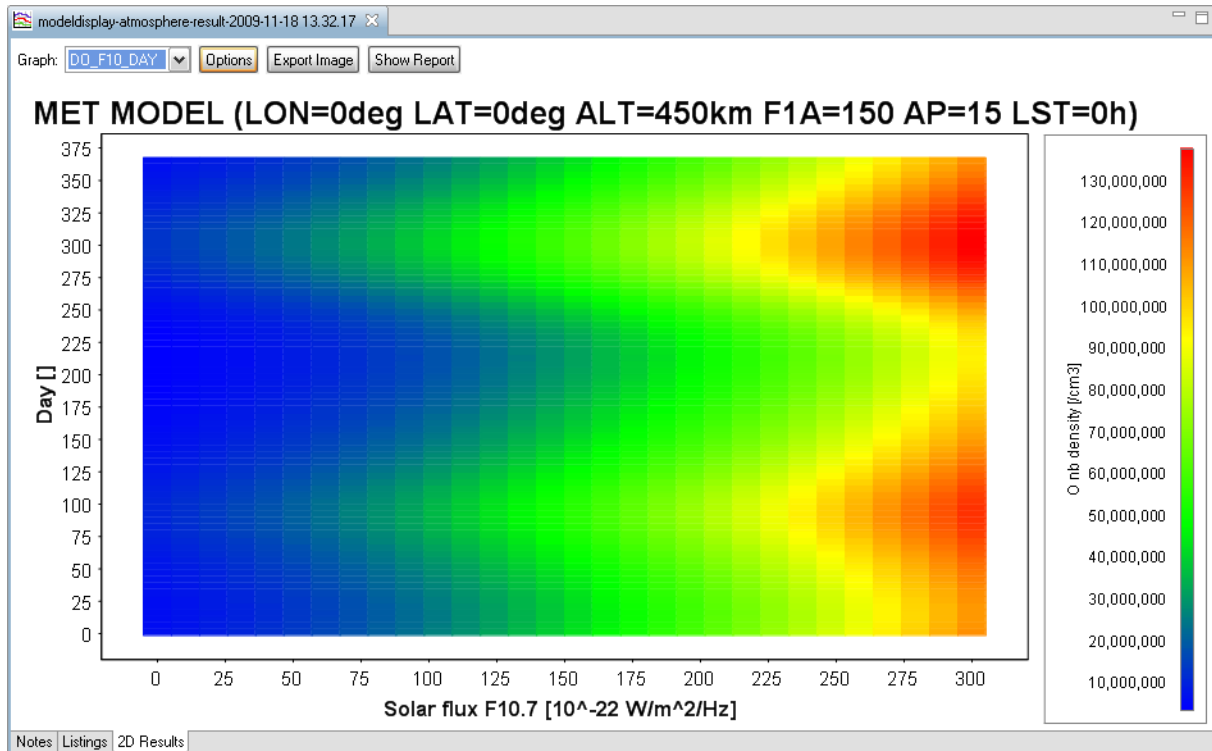
**Figure 2.22:** Atmosphere result editor, Notes tab

Like all other settings, the notes will be saved and are available when you (or a colleague) open the result file again.

## 2.4.5 Model Display

When the Atmosphere analysis was a model display, the 2D Results tab will show either a line or a contour plot, as depicted in the figure below.

- One variable will produce a line plot.
- Two variables will produce a contour plot.



**Figure 2.23:** Atmosphere result editor, 2D results tab, Model display

Options for both plot types are identical to the standard 2D Results graph as described in section 2.4.2.

## 2.5 Ionosphere Input

Ionosphere analyses are quite similar to Atmosphere analyses. They use different input and output parameters but the procedure of producing an analysis is mostly the same.

We begin with the Ionosphere input editor, which is divided into 4 tabs, as shown below in Figure 2.24 below:

- *Environment and Analysis*: Parameters used for both geometric and non-geometric analyses.
- *Geometric*: Parameters used only for geometric analyses, i.e. using a spacecraft geometry.
- *Non-geometric*: Parameters used only for non-geometric analyses, i.e. using an in-orbit oriented plate instead of a spacecraft geometry.
- *Model Display*: A model display analysis provides ionosphere characteristics such as number density and temperature from the models.

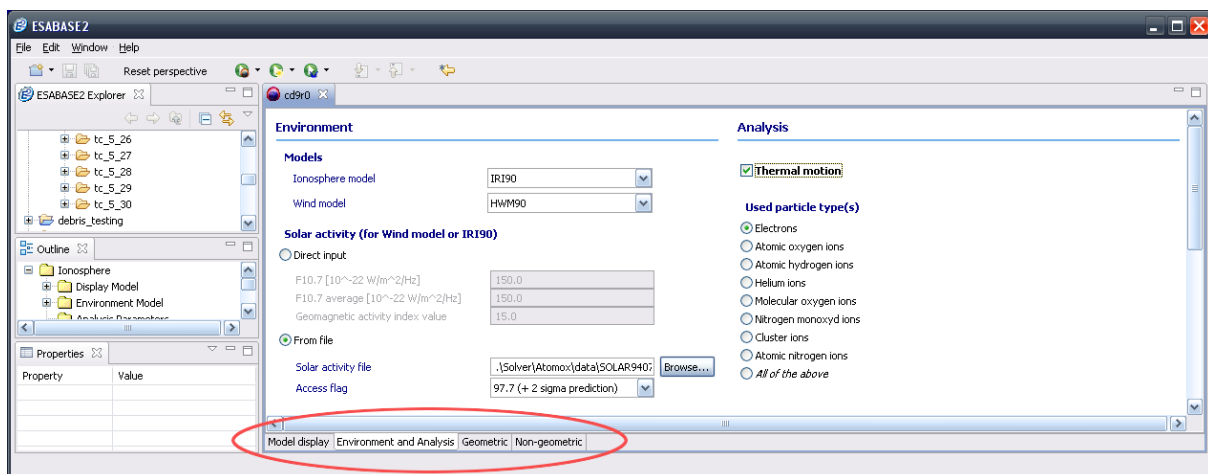


Figure 2.24: Ionosphere input editor

## 2.5.1 Environment and Analysis Tab

The environment and analysis tab describes the environment that the spacecraft is moving in. It has two sections, which are shown in the following figure:

- *Environment*: Defines the ionosphere and wind models, and the solar activity.
- *Analysis*: Defines which particle types to use, and whether to consider thermal motion.

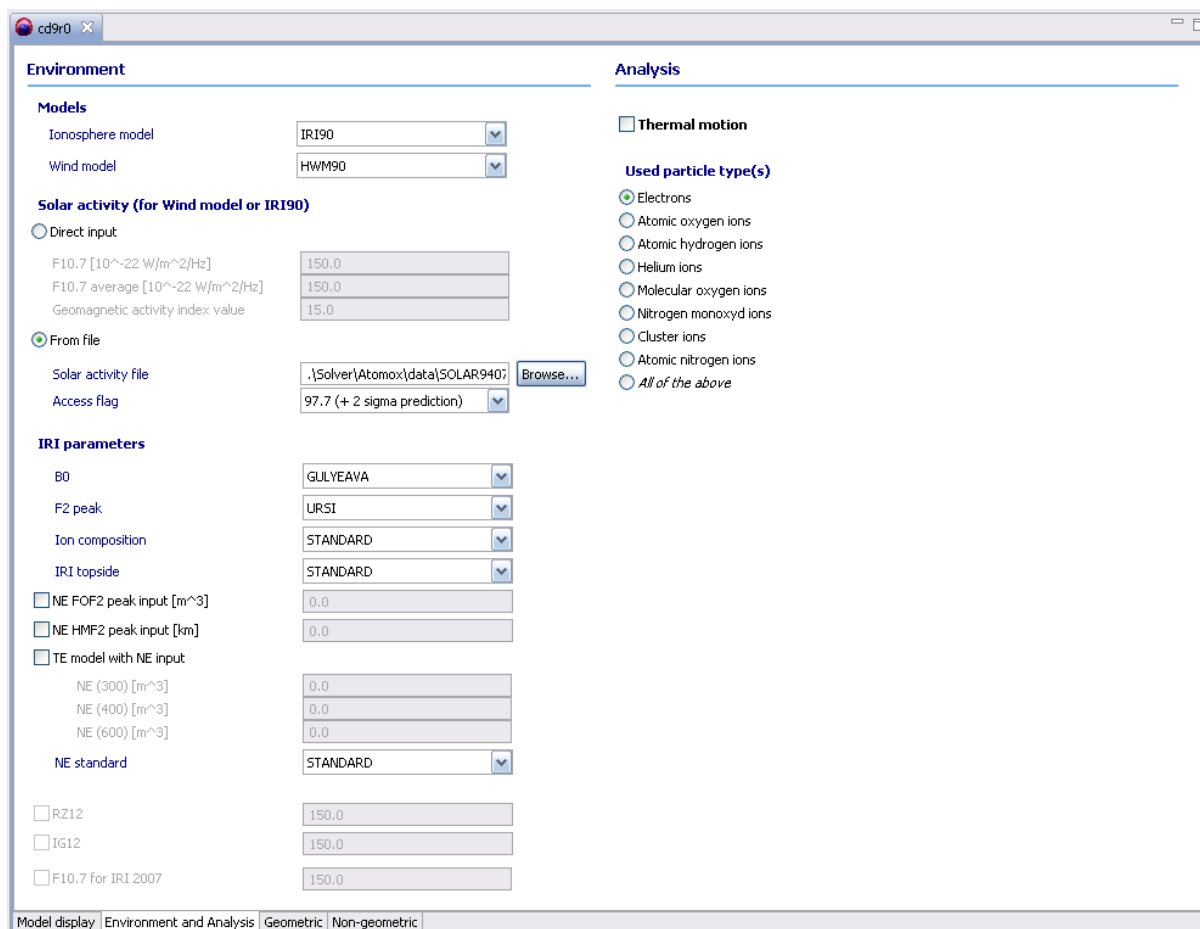


Figure 2.25: Ionosphere input editor, Environment and Analysis tab

### 2.5.1.1 Environment

The ionosphere environment is described by the following factors:

- *Ionosphere model*: Describes the ionospheric conditions that depend on several parameters described later on. Currently two models are selectable.
- *Wind model*: Describes the wind conditions. By selecting one Ionosphere can consider the influence of the wind. Like in Atmosphere, 2 models are selectable.
- *Solar activity*: Describes the perturbations caused by solar activity.

#### 2.5.1.1.1 Ionosphere Models

You can select among the following ionosphere models:

- *IRI90*: "International Reference Ionosphere", released in 1990. For given location, time and date, IRI provides monthly averages of the electron density, electron temperature, ion temperature, and ion composition in the altitude range from 50 km to 2000 km. Additionally parameters given by IRI include the Total Electron Content (TEC), the occurrence probability for Spread-F and also the F1-region, and the equatorial vertical ion drift.
- *IRI2007*: Is the updated version of the IRI90 model. It includes more data sources which improve the model.

Further information about IRI90 and IRI2007 can be found in /6/ and /9/.

#### 2.5.1.1.2 Wind models

The wind models are the same as for Atmosphere, see section 2.2.1.1.2.

#### 2.5.1.1.3 Solar activity

Solar activity settings are the same as for Atmosphere (see section 2.2.1.1.3), except that the S10, S10 averaged, XM10 and XM10 averaged are not used and thus not present.

In addition, this section is only used by the wind models and the IRI90 model. If the IRI2007 model is selected, the solar activity is specified by the parameters RZ12, IG12 and F10.7 for IRI2007 at the end of the Environment and Analysis tab.

#### 2.5.1.1.4 IRI Parameters

The IRI models can process up to eleven further input parameters. Changing them is only recommended for advanced users. All others are advised to use the default values or be referred to /10/.

- *B0*: Specify whether you want to use TABLE values or GULYEAVA. GULYEAVA is the default selection.
- *F2 peak*: Specify whether you want to use CCIR or URSI. URSI is the default selection.
- *Ion composition*: Specify whether you want to use STANDARD or DANILOV. STANDARD is the default selection.
- *IRI topside*: Specify whether you want to use Standard or IRI79. Standard is the default selection.
- *NE foF2 peak input*: Specify whether you want to use a fix F2 peak density input and the value for F2 peak density in /m<sup>3</sup>. It is also possible to specify the F2 plasma frequency foF2 in MHz instead of F2 peak density. The value is disabled by default, which means that the value is calculated internally.
- *NE hmF2 peak input*: Specify whether you want to use a fix F2 peak height input and the value for F2 peak height in km. The value is disabled by default, which means that the value is calculated internally.
- *TE model with NE input*: If this option is selected, you have to specify the electron density at 300, 400 and 600 km altitude. Otherwise the standard TE model is used (default).
  - *NE(300)*: Electron density (in /m<sup>3</sup>) at 300 km altitude.
  - *NE(400)*: Electron density (in /m<sup>3</sup>) at 400 km altitude.
  - *NE(600)*: Electron density (in /m<sup>3</sup>) at 600 km altitude.
- *NE standard*: Select here whether the standard or Lay-functions shall be used for NE. Standard is the default selection.

In addition, IRI 2007 has the following (optional) parameters:

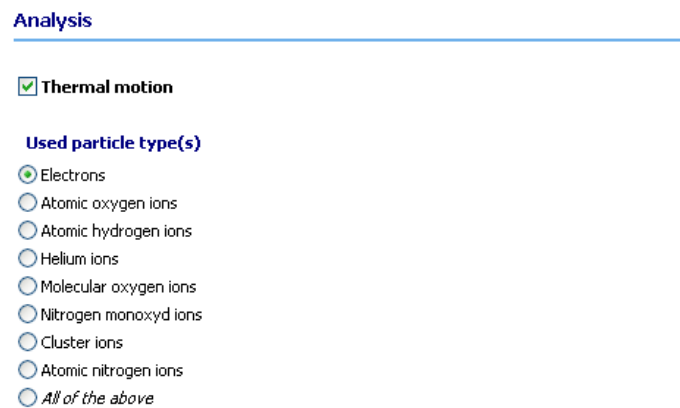
- *RZ12*: This is the sunspot number. Its range is 0.0 to 400.0.
- *IG12*: This is an ionospheric index. Its range is -50.0 to 400.0.
- *F10.7 cm flux for IRI 2007*: This is separated from the F10.7 cm flux under solar activity because the IRI2007 model has fixed files to consider the variation of the F10.7 parameter. If the parameter is disabled, IRI2007 uses fixed files unlike IRI90 where the user has to specify his own file under solar activity.

### 2.5.1.2 Analysis

In the Analysis section, you can define output parameters for the Ionosphere analysis:

- *Thermal motion*: Whether particles undergo thermal motion.
- *Used particles types*: Which particle types are to be considered.

The figure below shows the Analysis section in the Ionosphere input editor.



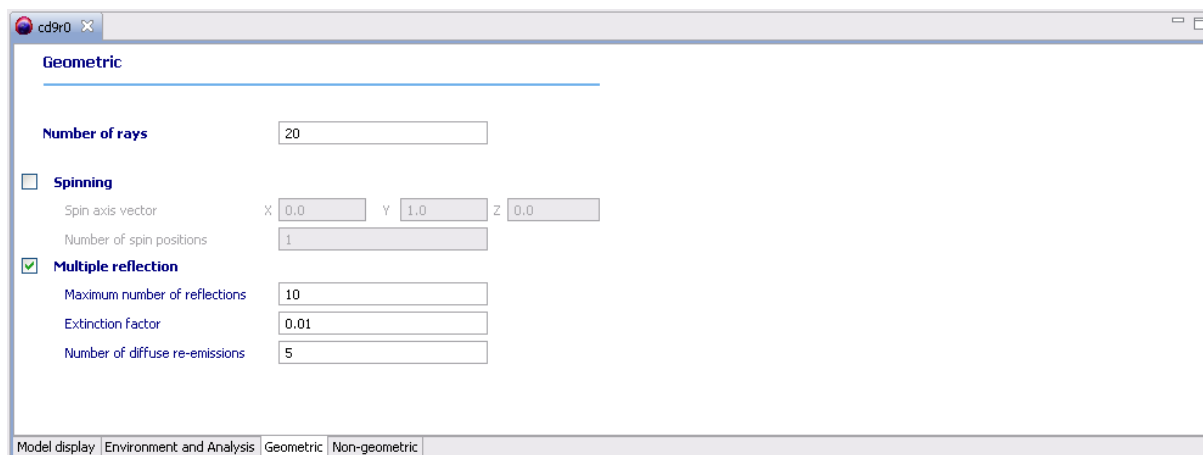
**Figure 2.26:** Ionosphere input editor, Environment and Analysis tab, Analysis

As in Atmosphere, thermal motion makes the straight raytracing rays consider the jitter effects of thermally induced molecular effects.

Typical particle types of the ionosphere that can be considered are electrons, atomic oxygen ions, atomic hydrogen ions, helium ions, molecular oxygen ions, nitrogen monoxyd ions, cluster ions, atomic nitrogen ions, or all of the previously mentioned.

## 2.5.2 Geometric Tab

The geometric tab, pictured below, is relevant for the geometric analysis only and features the same parameters as in the Atmosphere input editor.



**Figure 2.27:** Ionosphere input editor, Geometric tab

For a description of the parameters, please see section 2.2.2.

### 2.5.3 Non-Geometric Tab

The non-geometric tab shown below allows you to define parameters for the non-geometrical Ionosphere analysis, which works on a simple plate instead of a full spacecraft geometry.



**Figure 2.28:** Ionosphere input editor, Non-geometric tab

The parameters are the same as for the Atmosphere input editor, see section 2.2.3.

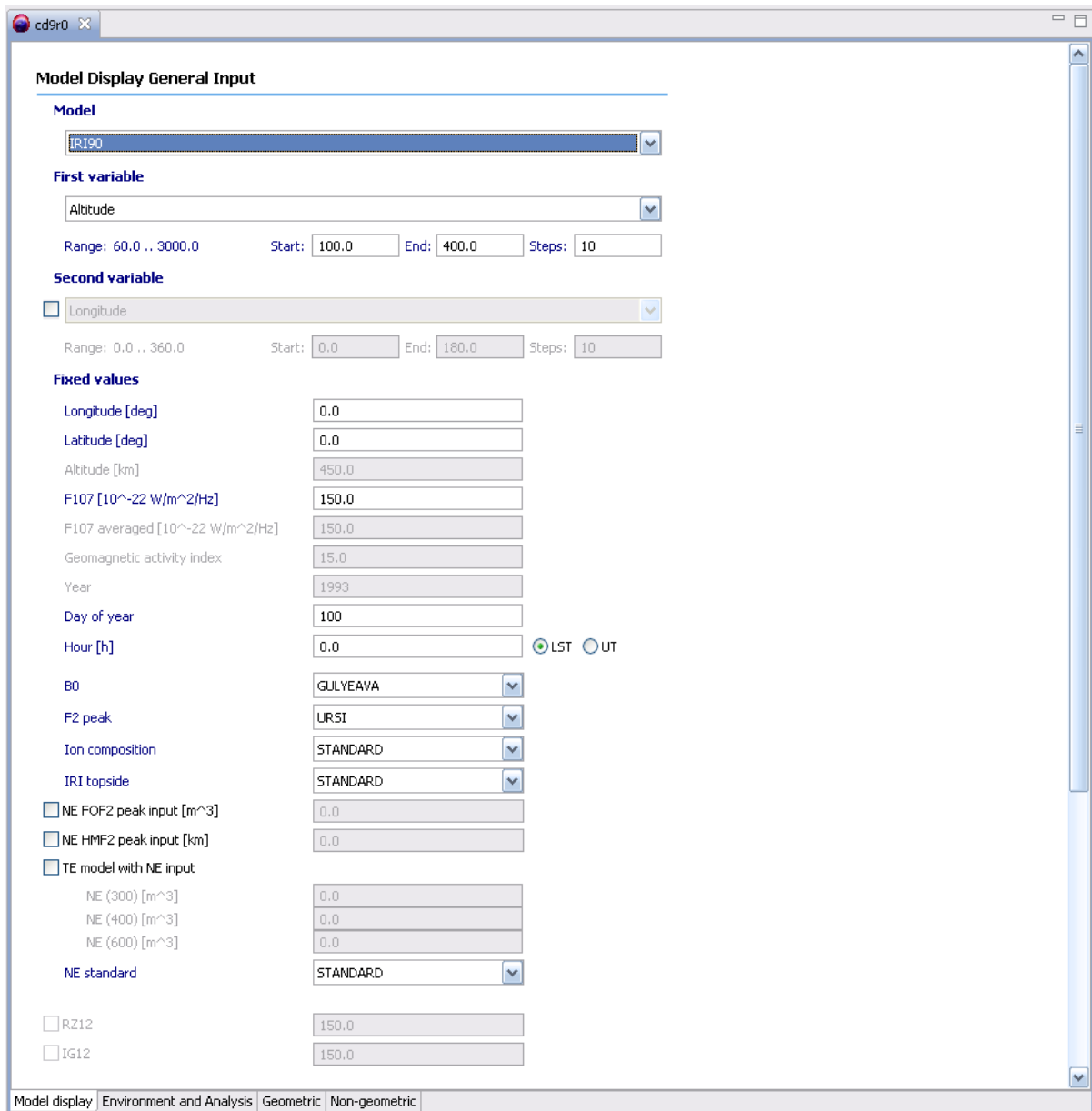
## 2.5.4 Model Display Tab

In the model display tab, you can specify the parameters for a model display analysis, which provides you with characteristics of the different ionosphere and wind models in tabular and graph form.

The tab contains two sections: Input and output parameters.

### 2.5.4.1 General Input

The picture below shows the input parameters of the Ionosphere model display.



The screenshot shows a software window titled "cd9r0" with a tab labeled "Model Display General Input". The interface is divided into several sections:

- Model:** A dropdown menu set to "IRI90".
- First variable:** A dropdown menu set to "Altitude". Below it, a range of "60.0 .. 3000.0" is shown, along with input fields for "Start: 100.0", "End: 400.0", and "Steps: 10".
- Second variable:** A dropdown menu set to "Longitude". Below it, a range of "0.0 .. 360.0" is shown, along with input fields for "Start: 0.0", "End: 180.0", and "Steps: 10".
- Fixed values:** A list of parameters with corresponding input fields:
  - Longitude [deg]: 0.0
  - Latitude [deg]: 0.0
  - Altitude [km]: 450.0
  - F107 [10<sup>-22</sup> W/m<sup>2</sup>/Hz]: 150.0
  - F107 averaged [10<sup>-22</sup> W/m<sup>2</sup>/Hz]: 150.0
  - Geomagnetic activity index: 15.0
  - Year: 1993
  - Day of year: 100
  - Hour [h]: 0.0
  - Time zone: Radio buttons for "LST" (selected) and "UT".
  - B0: GULYEAVA
  - F2 peak: URSI
  - Ion composition: STANDARD
  - IRI topside: STANDARD
  - NE FOF2 peak input [m<sup>3</sup>]: 0.0
  - NE HMF2 peak input [km]: 0.0
  - TE model with NE input:
    - NE (300) [m<sup>3</sup>]: 0.0
    - NE (400) [m<sup>3</sup>]: 0.0
    - NE (600) [m<sup>3</sup>]: 0.0
  - NE standard: STANDARD
  - RZ12: 150.0
  - IG12: 150.0

At the bottom of the window, there are four tabs: "Model display", "Environment and Analysis", "Geometric", and "Non-geometric". The "Model display" tab is currently selected.

Figure 2.29: Ionosphere input editor, Model display tab, General input

Input parameters are splitted into the 4 sections:

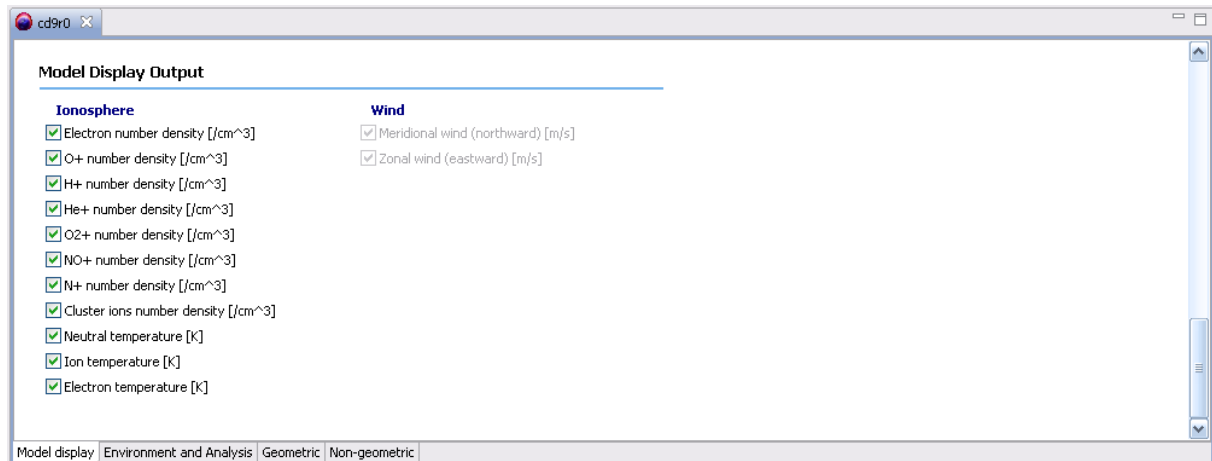
- *Model*: The ionosphere or wind model to use, see sections 2.5.1.1.1 and 2.5.1.1.2.
- *First variable*: The first variable of the model display.
- *Second variable*: Optional second variable; if activated, a 3D plot is generated instead of a 2D plot.
- *Fixed values*: The remaining values remain non-variable.

The following parameters (of which up to 2 are variable, the rest fixed) must be specified:

- *Longitude, Latitude, Altitude*: The "position of spacecraft" assumed for the purposes of the model display.
- *Solar activity (F10.7 cm Flux, F10.7 cm Flux (averaged), Geomagnetic activity index (Ap))*: See environment and analysis tab, section 2.5.1.1.3.
- *Year*: To be analysed year in Format YYYY.
- *Day of Year*: To be analysed Day (of the year) between 1 to 365.
- *Hour*: To be analysed time (in hour) can be specified as local solar time (LST) or universal time (UT).
- *IRI parameters (B0, F2 peak, Ion composition, IRI topside, NE foF2 peak input, NE hmF2 input, TE model with NE input, NE standard)*: See environment and analysis tab, section 2.5.1.1.4.
- *IRI2007 parameters (RZ12, IG12, F10.7 for IRI 2007)*: Again, see environment and analysis tab, section 2.5.1.1.4.

## 2.5.4.2 Output

Output parameters are split into Ionosphere and Wind parameters, as shown in the figure below.



**Figure 2.30:** Ionosphere input editor, Model display tab, Output

The availability of the parameters depends on the chosen Ionosphere or Wind model. More than one is selectable.

Ionosphere output parameters are:

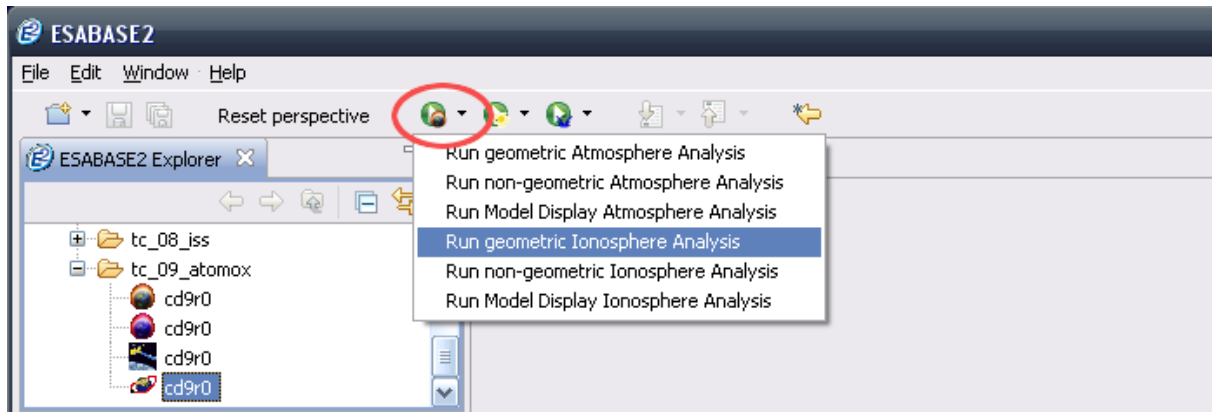
- Number density (in  $1/\text{cm}^3$ ) for:
  - Electrons
  - $\text{O}^+$ : Atomic oxygen ions
  - $\text{H}^+$ : Atomic hydrogen ions
  - $\text{He}^+$ : Helium ions
  - $\text{O}_2^+$ : Molecular oxygen ions
  - $\text{NO}^+$ : Nitrogen monoxyd ions
  - $\text{N}^+$ : Atomic nitrogen ions
  - Cluster ions
- Temperature (in K):
  - Neutral temperature is the temperature of the neutral gas.
  - Ion temperature is the average temperature of ions.
  - Electron temperature is the average temperature of electrons.

Wind output parameters (in m/s) are:

- Meridional wind: Wind speed from south to north.
- Zonal wind: Wind speed from west to east.

## 2.6 Ionosphere Analysis

The ionosphere analysis is completely analogous to the atmosphere analysis, and started by the Atmosphere/Ionosphere Run button pictured below.

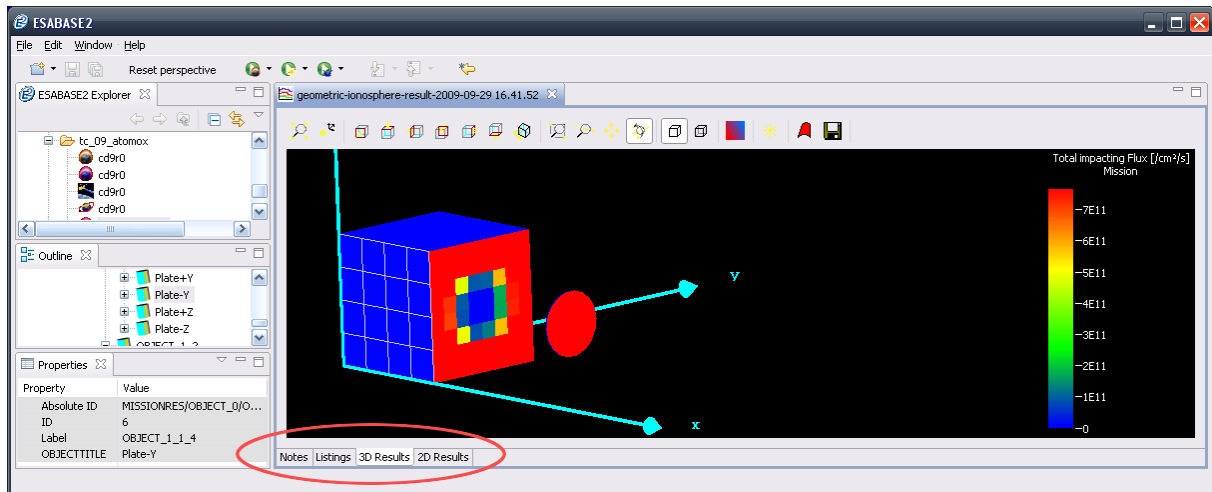


**Figure 2.31:** Ionosphere analysis, Run button

See section 2.3 for geometric, non-geometric, and model display analyses.

## 2.7 Ionosphere Result

Whether running a geometric, a non-geometric or a model display analysis, an ionosphere result file will always be created, and opened in the Ionosphere result editor pictured below.



**Figure 2.32:** Ionosphere result editor

Handling of the Ionosphere result editor is completely analogous to the Atmosphere result editor, see section 2.4.