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General **I**onosphere **V**isualisation and **E**xtraction from a **M**odel for the **E**iscat Svalbard Radar

by

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Version 1.1

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Abstract

An ionospheric model is presented which was recognised to accurately reproduce ionospheric observations with EISCAT at auroral latitudes. This model is used to predict ionospheric structures in the polar region above Svalbard for the time scheduled for the first observations of ESR. A MATLAB routine is provided which allows for extracting altitude profiles of various ionospheric parameters, for use in experiment preparation of ESR.

Introduction

This report presents a MATLAB-based routine developed for visualising and extracting results of numerical ionospheric characteristics resulting from runs of an ionosphere transport model developed at CESR-CNRS-UPS since 1992; this routine is intended for being used for ESR experiment preparation, in particular by the GUISDAP users, but can also be used in independent studies.

The numerical model was issued from the Blelly and Schunk (1993) study of transport equations for the ionosphere, and their various level approximations, from the standard 5-moment approximation (plus the Fourier's law), up to the bi-maxwellian based 16-moment approximation. Blelly and Schunk (1993) showed that, for normal ionospheric conditions, the so-called 8-moment approximation (solving the continuity, momentum, energy and heat flow equations for each species) is a good-enough level of approximation, while for studying anisotropies the 16-moment approximation is the most robust model.

Since this comparative study, the 8-moment model was first compared with results from auroral zone observations with EISCAT. In order to perform the comparison, it was necessary to define one of the most important input to the model, i.e. the electron heat flow at the top of the ionosphere. Blelly and Alcaydé (1994) showed that such a parameter can be inferred from EISCAT observations, simply by adjusting the topside electron temperature profile with the relationship between the heat flow and the electron temperature given by Blelly and Schunk (1993). Robineau et al. (1995) and Blelly et al. (1995) showed that using these inferred topside heat flow, and realistic production and energy deposition from EUV solar fluxes, they were able to quantitatively reproduce the global structure of the observed ionosphere, for quiet-time conditions and for magnetospheric disturbances as well. Also the model was extended for representing realistic E- and F-region chemistry, and also for being able to treat the electron transport with a kinetic exhaustive model; initial results were presented by Diloy et al. (COSPAR, Hamburg, 1994), and a more complete description of the model is being submitted for publication in Annales Geophysicae by Diloy et al. (1995).

In a recent IRI News-Letter Bilitza (1994) underlines the fact that IRI is not yet fully adapted for auroral-zone or polar-cap/cusp latitudes; in addition IRI does not provide "minor constituents" concentrations, velocities and temperatures. The availability of the 8-moment model gives therefore opportunities of providing a tool for predicting ionospheric conditions, including minor ions, in an hopefully realistic manner. It was thought that such predictions could be helpfull for getting « typical » ionospheric profiles for specific conditions, such as solar minimum in the polar-cap, which conditions will likely occur at the time of initial EISCAT Svalbard Radar operations in 1996. Blelly et al. recently presented at COSPAR, Hamburg-FRG, such forecasts for the ionosphere above SVALBARD in 1996 (Blelly et al., 1995).

In the first Section, the model is briefly presented; Section 2 lists the main characteristics of the two runs (near-winter and near-summer conditions) with the various parameters and indices defining the run conditions. In the third section, the MATLAB routines are described in short, and the final section describes the format of the binary files provided with the program for independent use.

Model description.

The ionosphere is formed by the Ionization of the neutral species (essentially O, O_2, N_2) by the absorption of solar UV and EUV radiations. However the resulting ions, namely O^+, O_2^+, N_2^+, do not necessarily remain the main ionospheric ions due to the chemical and charge exchange reactions which occur between these ions, the electrons and the neutral atmosphere. As an example, NO^+ is the major ion in the E and F_1 regions although NO is a minor atmospheric constituent. So, only an ionospheric model taking into account the complete chemistry between the ions, the electrons and the neutral species can give an accurate representation of the E and F regions.

Furthermore, the dynamic motions of the ionospheric plasma are very important in the understanding of the terrestrial ionosphere, particularly at high latitude where large energy inputs very often occur, of magnetospheric origin. Classical transports terms are the diffusion of ions in response to gravity, pressure gradients, motions of the neutral atmosphere and the presence of convective electric fields; transport effects of magnetospheric origin are due to field-aligned currents or particle precipitations, and corresponding downwards electron heat flows, but also effects of convection electric field perturbations.

This study is based on an 8-moment fluid approximation of Boltzmann's equation (Schunk, 1977). The resulting set of equations projected along the magnetic field line allows the determination of the density, velocity, temperature and heat flow of each species. However, the electron density and velocity are solved assuming charge neutrality and ambipolar flow. This set of equations was solved in the altitude range probed by the EISCAT-VHF radar (200-1600 km). It has already been proved that this model correctly reproduce the observed ionospheric structures above 200 km with a reduced set of ions (O+ and H+) and a simplified scheme of chemistry (Blelly et al., 1995; Robineau et al., 1995).

This model was recently extended down to the E-region (lower limit at ~100 km) which requires to take into account other species (ions and neutrals). The E-region is dominated by the molecular ions O_2^+, NO^+ and N_2^+ while the F-region is dominated by the atomic ions O^+, H^+ and N^+ which dominate above the f2-peak. In the chemistry reactions, the needed concentrations of the main atmospheric constituents (O, H, N, N_2, O_2) are provided by the MSIS 86 model (Hedin, 1987), while the neutral nitric oxide NO, which is not provided by MSIS, is consistently provided by solving its continuity and diffusion (momentum) equations.

Various kinds of energy inputs are included in this model, i.e. solar EUV heating and magnetospheric energy inputs. Two kinds of magnetospheric energy input are considered, the first one is the electron and ion precipitations which have an important effect at the lower altitude and are modelled with the empirical formulation of Hardy et al. (1987), and the second one is the downwards topside electron heat flow, which can be provided by Incoherent Scatter observations, as shown with EISCAT data by Blelly and Alcaydé (1994).

Furthermore, this model is coupled with a kinetic transport code of suprathermal electrons which provides the production and heating resulting from the solar UV and EUV, and particle precipitation energy inputs (Lilensten et al., 1989).

In the model used for this report, the ionospheric plasma is assumed to be composed of six ions (O^+, H^+, N^+, $N_2{}^+$, NO^+, $O_2{}^+$) and electrons. Each atomic ion is consistently described by its complete set of moments in the 8-moment approximation (namely, concentration, field aligned velocity component, temperature and field-aligned heat flow component). The molecular ions ($N_2{}^+$, NO^+, $O_2{}^+$) are assumed to have equal mean velocity and temperature; these ions are treated as a "mean heavy ion" in the determination of the higher moments (velocity and temperature); however their continuity equation (concentration) is separately solved for each molecular ion. Finally, in each case, the collision terms include the resonant and non-resonant collisions terms between all charged species (ions and electrons) and neutrals.

Finally, the heat flow of the molecular ions is neglected, due to their weak thermal conductivity. As a consequence, the molecular ions are solved by using a simplified fluid approximation, namely the five moment approximation. A complete description of the set of equations can be found in the paper of Blelly and Schunk (1993). A full description of the chemistry included in the model and the corresponding references is given by Diloy et al. (1995).

The model use the MSIS model (Hedin et al., 1987) for providing the neutral atmosphere parameters for photo-electron and electron precipitation production and energy losses, and for computing the ion-neutral collision frequencies. Also the Hedin et al. (1988) neutral wind model is used for computing the relative drifts between ions and neutrals, and the resulting momentum and energy frictional effects. Finally the model makes use of the Hardy et al. (1987) empirical model of integral energy flux and number fluxes for electron precipitation. These models need various parameters such as the geographic/geomagnetic co-ordinates, the solar flux intensity (F10.7 indices), the magnetospheric activity (Ap indices), the day of the year and the UT time. All these parameters are listed in the following section.

In this first version 1.1 of MATLAB **giveme** routine, two sets of model results are provided, one for near-winter, the second for near-summer conditions, as can be forecasted for ESR latitudes in the 1996 period (i.e. deep solar minimum, F10.7=70 Jansky); 24 hour-runs are provided, for normal quiet conditions.

In a future version of the program (version 2.x), additional data sets will be provided, including EISCAT KST data sets, and « events » data set, providing for example large ExB events for which it is anticipated that NO+ ions and O+ ions present large differential temperatures. Version 2.x should be available for mid-1995.

Finally, it is also planed to run the 16-moment model for providing cases of anisotropies in the O+ and NO+ ion temperatures (Version 3.x of **giveme**, which is planned for autumn 1995).

Model runs conditions.

The main parameters entering in the model runs are given in the following table:

	Winter 1996	**Summer 1996**
Date (yy-mm-dd)	96-01-21	96-05-20
F10.7	70	70
<F10.7>	70	70
Ap	5	5
Geo-Lat	78.15	78.15
Geo-Long	16.03	16.03
Time of the run (U.T.)	00:00 - 24:00	00:00 - 24:00
Time Step in the DATA (minutes)	10	10
Altitude Range (km)	100-2000	100-2000

MATLAB « giveme » routine and model data description.

Here are some indications of how installing and running the MATLAB routine.

- Place all the m.files in a MATLAB-recognised path
- Place the two binary files in an appropriate directory
- Modify lines 8 and 9 in the m-file "open_files.m" in order to adequately modify the complete path and the variable name to your environment for allowing the program to find them:
  l.8: path_data='/u/alcayde/giveme_1.1/data/'
  l.9: filename=[[path_data 'winter_1996']]; [path_data 'summer_1996']];
- under MATLAB prompt, type **giveme** and hit **<Return>**

The program displays in a first 4-panel figure the standard IS parameters (Ne, Te, Ti & Vi) in colour plates (Colour-Panel figure, figures 1a for winter 1996 ,and the alternative data set, i.e. summer 1996, figure 1b); in a second figure are drawn altitude profiles of electron and major ions densities, temperatures and B// velocities (i.e. e-, NO+, O+ & H+, figure 2). A Command Window then open (figure 3).

In addition, you can define your own plotting routine for any favourite plot you wish: if you name it « personal_plot.m » in your MATLAB workspace, a 4rth window will be open and your favourite plot will be drawn after the figure 2 plot for each command you enter in the Command Window.

Within the Command Window, the User is invited to:
- switch the data set (Summer/Winter);
- display profiles for wanted times in the 24-period:

* either by actions on "hour" and "minute" sliders which allow precise time selections,
* or by selecting events in the Colour-Panel figure making easy to select a particular period;

•end the program and exit: in that case the two first figures (as well as the user's figure, if any) are kept alive for eventual printing.

All operations are driven by the mouse. Once the program is ended, the MATLAB workspace is left with the last selected (HH,MM) profile, with all the model results, which values can be used for additional plotting or saving for later use.

The MATLAB variables are described in the following table (S.I. Units); variable names between brackets are temporary abridged names used by **giveme** which should be used for personal plots in user-figure 4.

altitude		altitude	[km]
n_electr		e- Concentration	[m-3]
t_electr	(te)	e- Temperature	[K]
q_electr	(qe)	e- Heat Flow	[W.m-2]
n_O__ion	(n1)	O+ Concentration	[m-3]
v_O__ion	(v1)	O+ Velocity	[m.s-1]
t_O__ion	(t1)	O+ Temperature	[K]
q_O__ion	(q1)	O+ Heat Flow	[W.m-2
n_H__ion	(n2)	H+ Concentration	[m-3]
v_H__ion	(v2)	H+ Velocity	[m.s-1]
t_H__ion	(t2)	H+ Temperature	[K]
q_H__ion	(q2)	H+ Heat Flow	[W.m-2]
n_N__ion	(n3)	N+ Concentration	[m-3]
v_N__ion	(v3)	N+ Velocity	[m.s-1]
t_N__ion	(t3)	N+ Temperature	[K]
q_N__ion	(q3)	N+ Heat Flow	[W.m-2]
n_N2_ion	(n4)	N2+ Concentration	[m-3]
n_NO_ion	(n5)	NO+ Concentration	[m-3]
n_02_ion	(n6)	02+ Concentration	[m-3]
v_M2_ion	(vm)	M2+ Velocity	[m.s-1]
t_M2_ion	(tm)	M2+ Temperature	[K]

The following additional parameters are also provided in the MATLAB workspace:

Year		
Month		
Day		
Hour		
Minute		
Second		
Geoglon	Geographic Longitude	(deg)
Geoglat	Geographic Latitude	(deg)
F107ins	F10.7 index	(Janski)
F107ave	< F10.7> index	(Janski)

Apindex	Ap index		
Enorth	Convection E-field North		(mV.m-1)
Eeast	Convection E-field East		(mV.m-1)
No__Cira	n(O)	CIRA	(m-3)
Nh__Cira	n(H)		
Nn__Cira	n(N)		
Nn2_Cira	n(N2)		
No2_Cira	n(O2)		
Tn__Cira	Tn	CIRA	(K)

where M2 stands for N2+, O2+ or NO+ (which temperature and velocities are assumed to be equal in the model).

Warnings:

The program needs to write in your local disc two temporary files, of names **"user_wrksp.mat"** and **"scratch_gvm.mat"**. If you have personal files with the same name in your local disc, you should rename them, or change the names in the **giveme** program !

Thus **giveme** needs write permissions on your local disc.

One of these files is used for saving your workspace and restoring it when you exit the **giveme** program: this only becomes **effective when you click "Stop & Exit"** in the Command Window.

Binary data structure

The binary files "winter_1996" and "summer_1996" which are provided in a binary 32-bit, direct access format: the data structure is organised according to the following structure.

The files contain consecutive logical blocks:

Each block contains:
- a header of : **2** x **nco** 32-bits words
- a matrix of : **nli** x **nco** 32-bits words

nli and **nco** are two variables which are defined in the header as:
- **nli = header (1)** (number of altitudes in the model)
- **nco = header (2)** (number of vector variables in the model)

The total size of each record will thus be (nli+2) x nco 32-bits words; in the files provided with **version 1.1**, nli = 96 and nco = 35.

The header and the matrix are named hdr and dat in MATLAB syntax and are given in the following table for any use independent of **giveme** (see the routine "extract_data.m" for additional information, regarding units in particular and missing parameters).

header vector

hdr(1)	=	nli
hdr(2)	=	nco
hdr(3)	=	Year
hdr(4)	=	Month
hdr(5)	=	Day
hdr(6)	=	Hour
hdr(7)	=	Minutes
hdr(8)	=	Seconds
hdr(9)	=	time step
hdr(10)	=	geographic long.
hdr(11)	=	geographic latit.
hdr(12)	=	geomagnetic long.
hdr(13)	=	geomagnetic latit.
hdr(14)	=	MLT (hours)
hdr(15)	=	F10.7
hdr(16)	=	<F10.7>
hdr(17)	=	Ap
hdr(18)	=	Kp
--------		
hdr(24)	=	E-North
hdr(25)	=	E-East
--------		

data matrix

data(:, 1)	=	Altitude
data(:, 2)	=	O+ Concentration
data(:, 3)	=	H+
data(:, 4)	=	N+
data(:, 5)	=	N2+
data(:, 6)	=	NO+
data(:, 7)	=	O2+
data(:, 8)	=	O+ Velocity
data(:, 9)	=	H+
data(:,10)	=	N+
data(:,11)	=	Molecular Velocity
data(:,12)	=	Electron Velocity
data(:,13)	=	O+ Temperature
data(:,14)	=	H+
data(:,15)	=	N+
data(:,16)	=	Molecular Temper.
data(:,17)	=	Electron Temper.
data(:,18)	=	O+ Heat flow
data(:,19)	=	H+
data(:,20)	=	N+
data(:,21)	=	Electron Heat flow
data(:,22:nco)	=	Working variable

Conclusion

The model, and the « **giveme** » MATLAB routines allow for extracting altitude-time colour panels of the « standard » IS parameters, namely Ne, Te, Ti and Vi (B-aligned), and altitude-profile plots of these parameters plus additional parameters (such as H+ and NO+ concentrations, temperatures and velocities) for User selected U.T. time. The MATLAB workspace is left with all these parameters, plus additional ones, as MATLAB vectors.

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Figure Caption

Figure 1: Time-altitude colour plot of, from top to bottom, the electron concentration, the electron temperature, the ion temperature and the B-aligned ion velocity for ESR simulation in **winter 1996** (**figure 1a**) and **summer 1996** (**figure 1b**); one of these figures is displayed according to the user's choice in the **giveme** command window (figure 3).

Figure 2: Altitude profiles of electron and some ion concentrations (left panel), temperatures (middle panel) and velocities (right panel) for a user selected time; the parameters plotted in this figure among other will be left in your workspace when you click to end the program (see figure 3).

Figure 3: **giveme** command window which allows changing the data set, the time of the altitude profile display and exiting **giveme** for getting a set of parameters as vector variables in your MATLAB workspace.

Figure 4: example of a user-defined figure with a specific plot of the altitude profile of the electron heat flow (**qe**, in the temporary **giveme** abridged name), at the same time as the one selected by the user for figure 2.

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Availability:

The model binary files, this document in a PostScript format and the **giveme** M.Files are compressed in the file: **giveme.ver.1.1.tar.Z** which you can get by ftp through the Eiscat Web server:

http://seldon.eiscat.no/index.html

Subsequent versions of giveme will be made available through the Web server; the paper version will be only printed once, and subsequent versions (PostScript format) will only be available through the Web.

Comments on successful installation and reports on "bugs" are welcome at the following addresses:

Denis.Alcayde@cesr.cnes.fr
Pierre-Louis.Blelly@cesr.cnes.fr

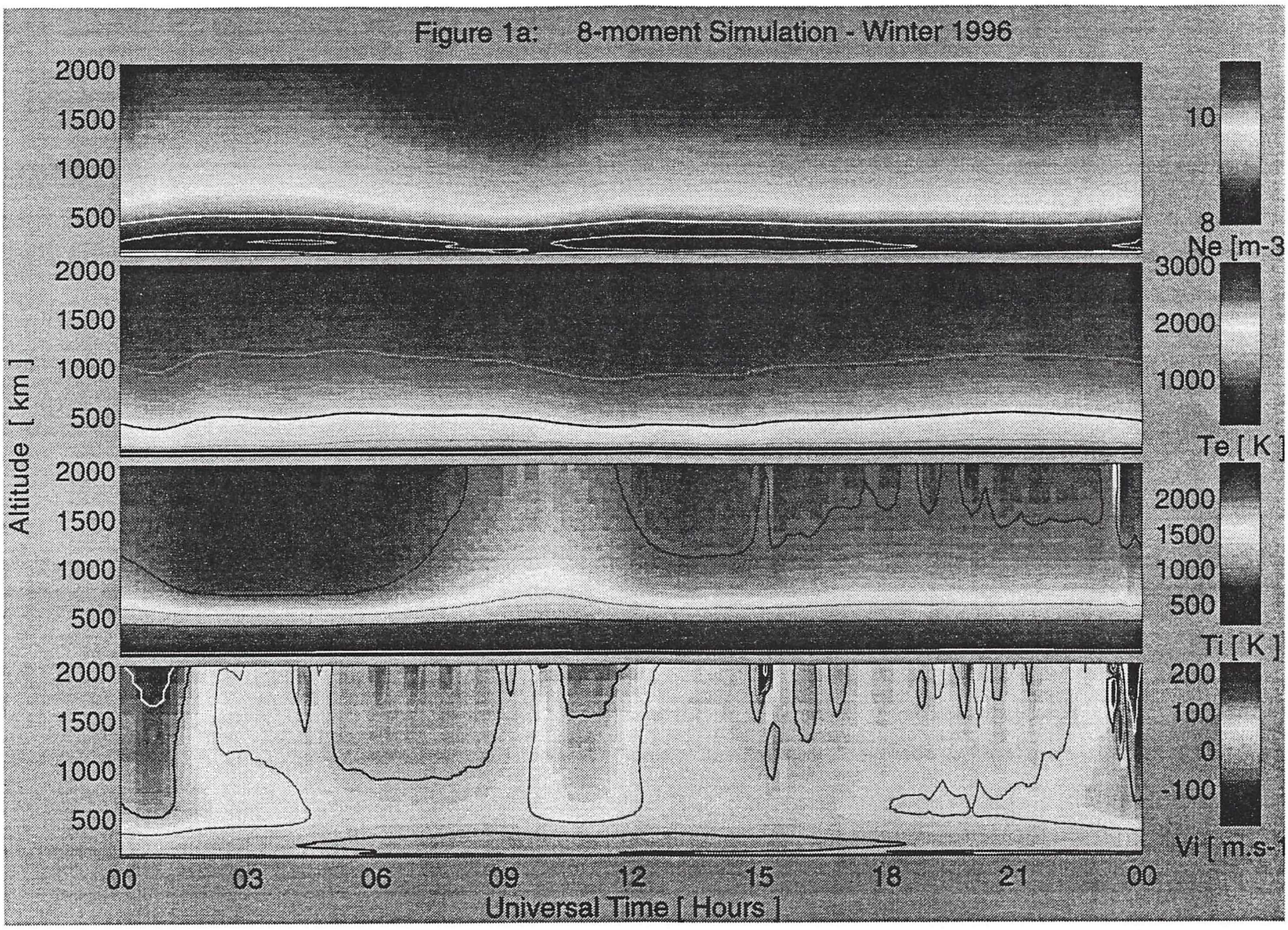

Figure 1a: 8-moment Simulation - Winter 1996
Altitude [km]
2000
1500
1000
500
Ne [m-3
10
8
Te [K]
3000
2000
1000
Ti [K]
2000
1500
1000
500
Vi [m.s-1
200
100
0
-100
00
03
06
09
12
15
18
21
00
Universal Time [Hours]

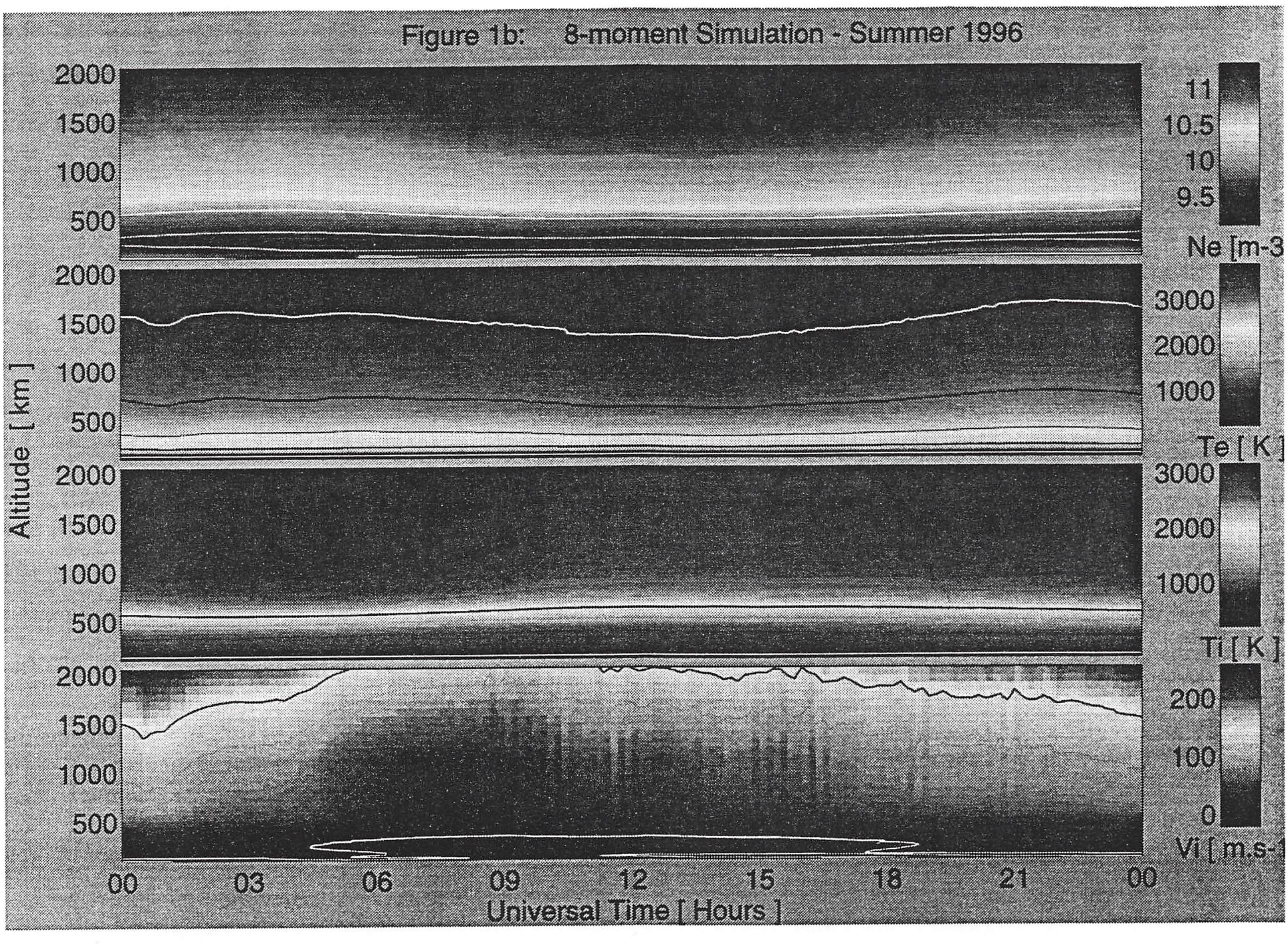
Figure 1b: 8-moment Simulation - Summer 1996
Altitude [km]
2000
1500
1000
500
11
10.5
10
9.5
Ne [m-3
3000
2000
1000
Te [K]
Ti [K]
200
100
0
Vi [m.s-1
00
03
06
09
12
15
18
21
Universal Time [Hours]

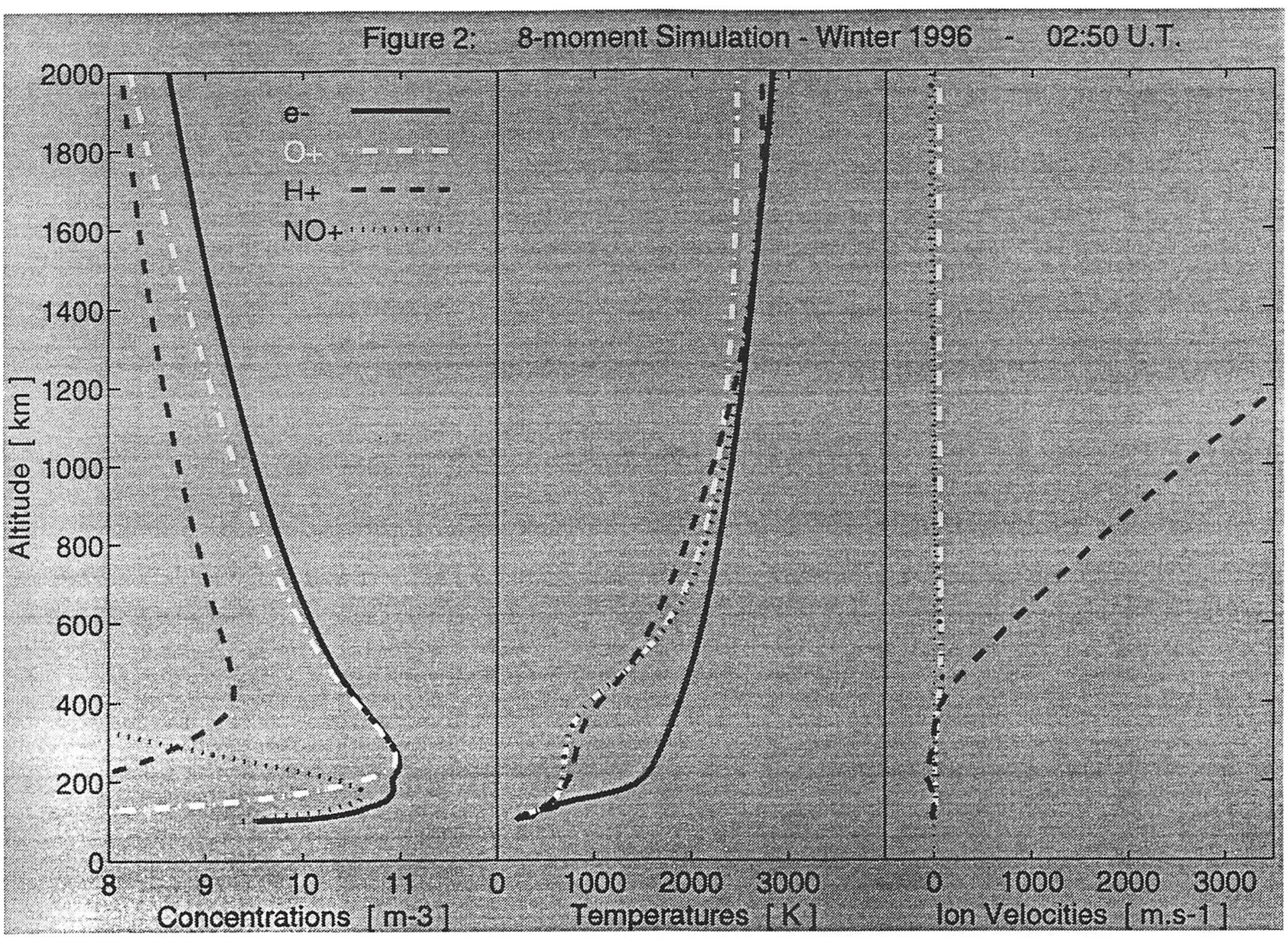
Figure 2: 8-moment Simulation - Winter 1996 - 02:50 U.T.
Altitude [km]
e-
O+
H+
NO+
Concentrations [m-3]
Temperatures [K]
Ion Velocities [m.s-1]
0
200
400
600
800
1000
1200
1400
1600
1800
2000
8
9
10
11
0
1000
2000
3000
0
1000
2000
3000

Figure 3:

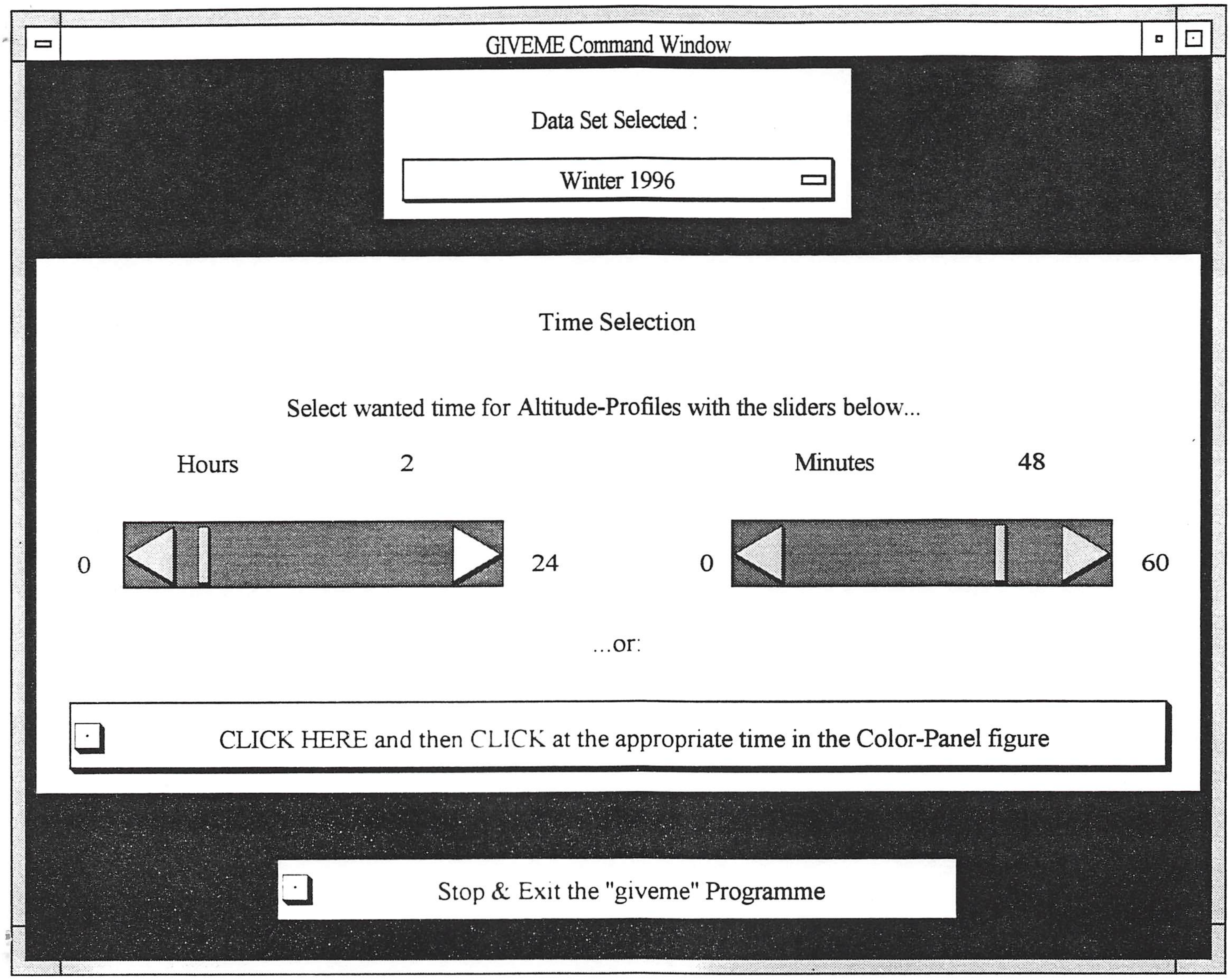
GIVEME Command Window
Data Set Selected :
Winter 1996
Time Selection
Select wanted time for Altitude-Profiles with the sliders below...
Hours
2
Minutes
48
0
24
0
60
...or:
CLICK HERE and then CLICK at the appropriate time in the Color-Panel figure
Stop & Exit the "giveme" Programme

Figure 4: Personal Plot