Introduction to QSAS

prepared by Eugen Sorbalo
Jacobs University Bremen

9 February 2012

The following exercise[1] demonstrates the QSAS capabilities to:
- import and export data
- plot data
- use basic math operations and plug-ins
- perform a Minimum-Variance Analysis (MVA)

QSAS [2] is a science analysis software for space plasmas provided by the United Kingdom Cluster Science Centre. It was initially designed for the Cluster mission, which comprises 4 satellites flying at separations of ∼100s km to 10000 km. Later the software was adapted to the Double Star (two Cluster-type satellites) and Themis (five satellites) missions. Currently QSAS can process data from any mission, if these are provided either in CEF or CDF format.

This demonstration will shows the first steps in QSAS: importing data and visualizing magnetic field data from the Champ satellite and some basic computations. The functionality of QSAS can be extended with the help of plug-ins. The basic usage of two plug-ins is presented: computation of the POMME6 model and subtraction of it from the measurements, and the Minimum-Variance Analysis plug-in, which is used to compute the field-aligned currents.

[1] This document and associated data are also made available online, through http://www.faculty.jacobs-university.de/jvogt/sci/satdat/musat-swarm/

[2] It can be downloaded from: http://www.sp.ph.ic.ac.uk/csc-web/QSAS/

1 Overview of QSAS

QSAS (Queen Mary Science Analysis System) was programmed in Nokia's QT framework and can be used on Window, Linux and Mac systems. The binary packages, as well as source code can be obtained from the Cluster Science Center: `http://www.sp.ph.ic.ac.uk/csc-web/QSAS` .

On launching the QSAS (or QSAS.bat) script the QSAS Main Window (see figure 1), containing a Working List of Data Objects, will appear. Any imported or new produced data will appear in this window. There are also some frequently used constants. New constants can be added later.

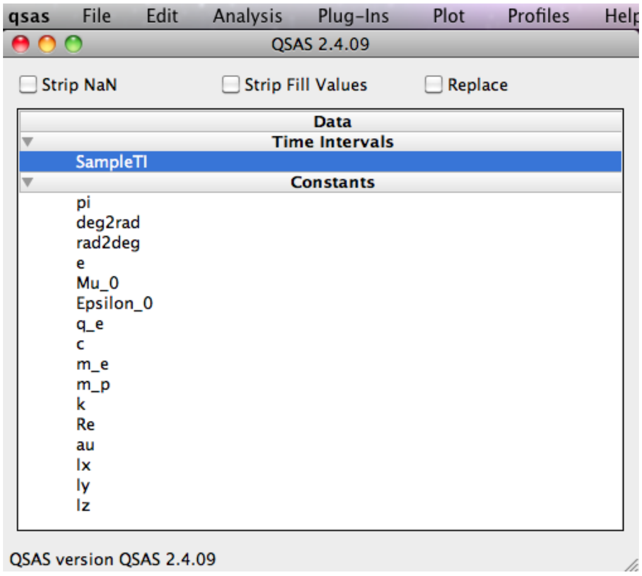

Figure 1: The main window of QSAS in Mac OS

2 Importing data

QSAS supports natively two data types: ASCII CEF (Cluster Exchange Format) and binary CDF (Common Data Format). Cluster Active Archive (CAA) provides the data for all Cluster instruments in both formats. Data from Themis and Champ missions are available only in CDF format. Various other data formats can be converted into either CEF or CDF using the *Qtran* conversion tool [3].

In this example we shall use the Champ's vector magnetic field in the North-East-Center (NEC) frame:
`CH-ME-2-FGM-NEC+2009-06-04-23-59-59.140-1_51.cdf`
This file has been downloaded form the *Information System and Data Center* in Potsdam [4]. In order for QSAS to understand properly Champ's CDF files, the metadata of the CDF needs to be "corrected". This is done by creating a helper

[3] Available at `http://www.sp.ph.ic.ac.uk/csc-web/Qtran/qtran_welcome.html`
[4] `http://isdc.gfz-potsdam.de/index.php`

file, which is placed in the same folder as data files. The content of the helper file, `CH_VEC_B_TOTAL.qat`, is as follows:

```
START_VARIABLE = VEC
   FRAME = "vector>nec_xyz"
   REPRESENTATION_1= "x", "y", "z"
   HELPER_FILE = "CH_VEC_B_TOTAL.qat"
   UNITS = "nT"
   LABLAXIS = "B_champ"
   SI_CONVERSION = "1.e-9>T"
END_VARIABLE = VEC

START_VARIABLE = GEO_ALT
   HELPER_FILE = "CH_VEC_B_TOTAL.qat"
   UNITS = "km"
   SI_CONVERSION = "1.e3>m"
   LABLAXIS = "Alt above ref sphere"
END_VARIABLE = VEC

START_VARIABLE = GEO_LAT
   HELPER_FILE = "CH_VEC_B_TOTAL.qat"
   UNITS = "deg"
   SI_CONVERSION = "1.0 >degree"
   LABLAXIS = "Geographic latitude"
END_VARIABLE = VEC

START_VARIABLE = GEO_LON
   HELPER_FILE = "CH_VEC_B_TOTAL.qat"
   UNITS = "deg"
   SI_CONVERSION = "1.0 >degree"
   LABLAXIS = "Geographic longitude"
END_VARIABLE = VEC

START_VARIABLE = B_TOTAL
   DEPEND_0 = GPS_TM
   HELPER_FILE = "CH_VEC_B_TOTAL.qat"
   UNITS = "nT/100"
   SI_CONVERSION = "1.e-11>T"
END_VARIABLE = B_TOTAL

START_VARIABLE = GPS_TM
   FIELDNAM = "GPS_TM"
   UNITS = "s"
   HELPER_FILE = "CH_VEC_B_TOTAL.qat"
END_VARIABLE = GPS_TM
```

The data file can be opened by choosing **File** → **Open Data File** and then finding the above CDF file. A dialog will open as is shown in the figure 2. In the upper left box, **Variables**, is a list of time series of data contained in the CDF file. A specific variable is imported into the Working List by either double-clicking on it or selecting it and clicking on **Get Data**. The upper right box shows the metadata of the CDF file. The information is obtained by double-clicking on a specific attribute. The lower panel allows selecting only a range of data to be imported in the work list. Time tags are obtained by checking **Get time for subsetting**. In this example we select the range 2009-06-05 13:38:10.140 to 18:44:05.140. The variables of interest for this study are `GEO_LAT`, `GEO_LON`, `GEO_ALT` and `VEC`, which represent the latitude, longitude and the altitude above a reference sphere of the Champ satellite and the measured magnetic field vector in the NEC frame, respectively. The dialog is closed by clicking on the **Dismiss** button.

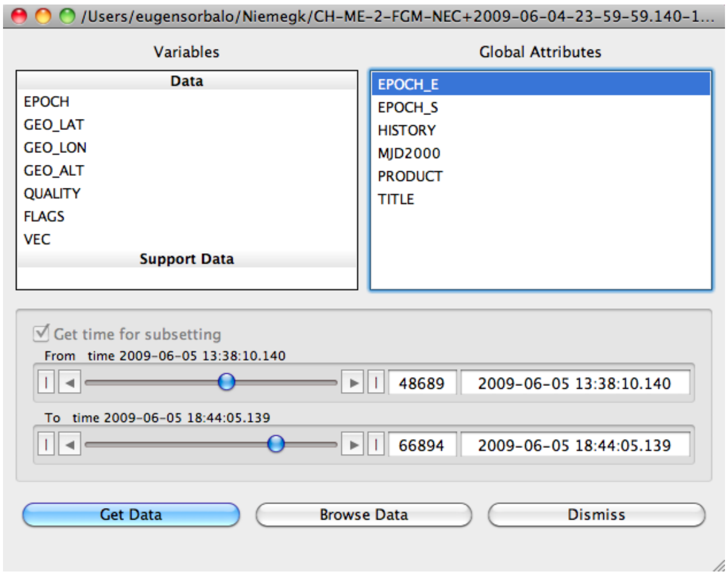

Figure 2: Open Data File dialog

The above variables appear now in the working list. A variable's values and metadata (information about the variable, such as units, description or label axis) can be seen by double-clicking on the variable, or right-click and choosing **Browse Object** from the menu. A **Object Editor** window will pop-up, as is shown in the figure 3 left. The time is chosen using the scroll bar at the top. Values are shown in the bottom left panel. The **Attributes** panel shows the associated metadata. Some metadata here appeared from the helper file, which was discussed above.

A metadata content can be seen by double clicking on it. The **Metadata Editor** window will open (figure 3 right). The information can be edited by clicking on **Allow Editing**. In our example we see that the variable `GEO_ALT` is given as *Altitude above a reference sphere*, given by the attribute `INFO`, where the reference sphere is specified by the attribute `REFRADIUS` , whose value were 6371.2 km, and the units were specified by the attribute `UNITS`.

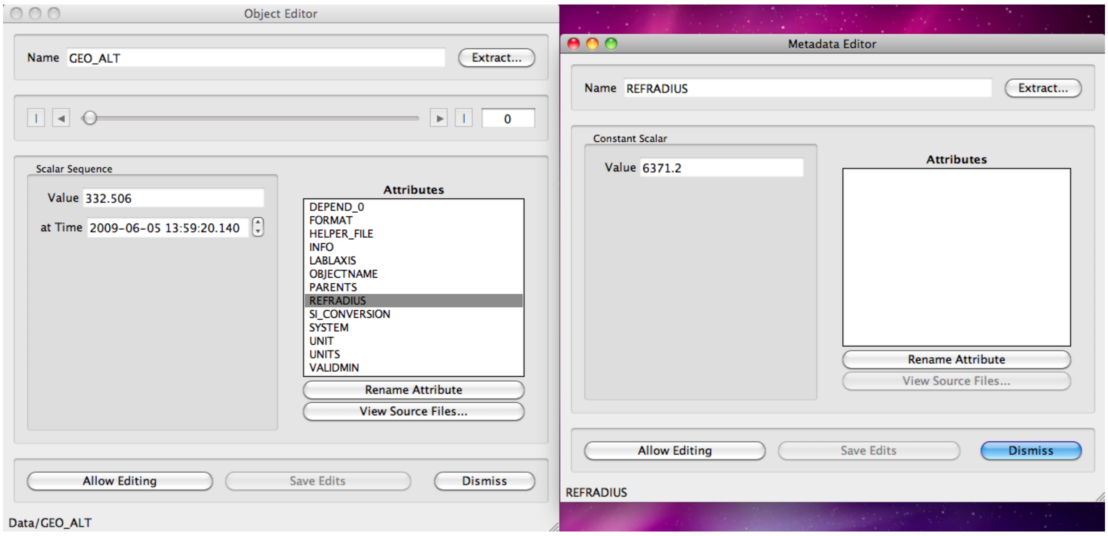

Figure 3: Object editor and metadata editor

3 The first plot

QSAS supports many types of plots. Here is shown a way to plot a time series of satellite's position and measured magnetic field. The **Plot** window (figure 4) is started by choosing **Plot Layout** in the **Plot** menu.

Setting variables to plot is as easy as *drag-and-drop*. We drag-and-drop the variable `GEO_LAT` into the white box at the left of the **Plot** window. QSAS uses the metadata of the variable to automatically determine the type of the plot and other settings. We notice that QSAS automatically created the **Frame 1** and **Panel 1** sections (see figure 5). The former describes the *time* or the *x axis*. The latter is a *y axis*, which is linked to the *x axis*.

Drag-and-drop `GEO_ALT` and `VEC` variables onto **Frame 1** to complete the fig-

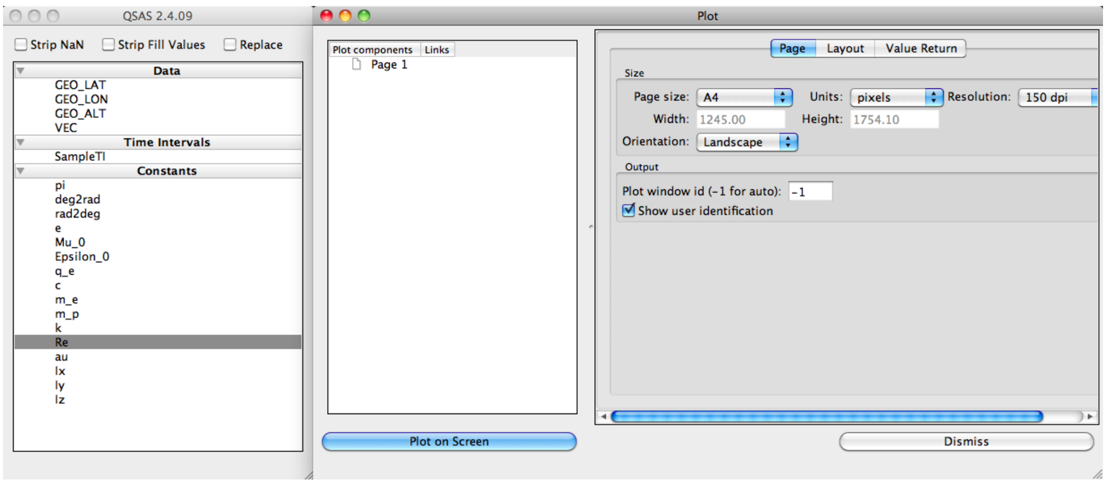

Figure 4: The **Plot** window.

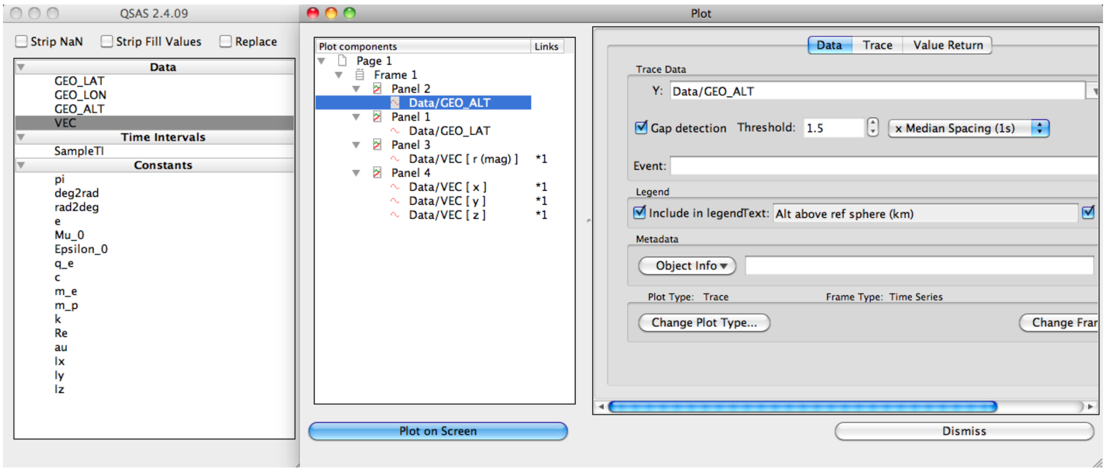

Figure 5: The **Plot** window with two scalar and one vectorial variables.

ure 5. Three panels were created automatically for the new items, although all variables use the same time frame. QSAS also recognized the vector and placed its three components into one panel, while the amplitude of the vector was placed in another. The plot is generated by clicking on the **Plot on Screen button**. The result is shown in the figure 6.

The **Plot** window can be closed by clicking on the **Dismiss** button. However, the entire plot configuration (variables, labels, ranges, etc) are not discarded until QSAS is not closed.

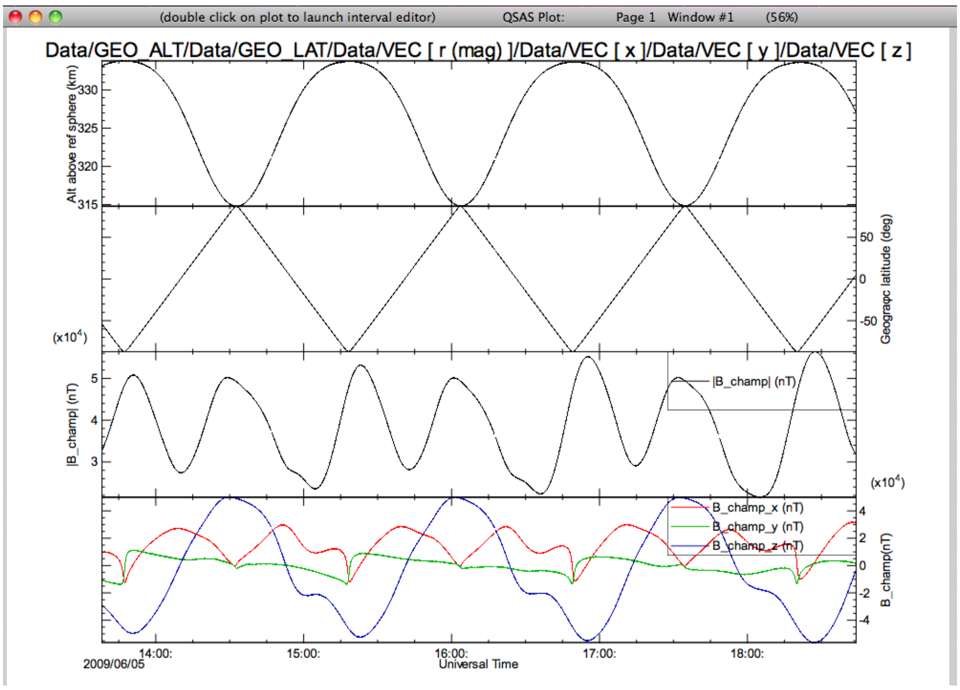

Figure 6: The **Plot** window with two scalar and one vectorial variables.

4 Exporting data

QSAS allows exporting variables into CEF, CDF or ASCII tabular files, which can be later imported by MatLab, IDL or other software for further processing. This is accomplished by selecting the menu **File** → **Write Data File**, after which the **Export** dialog appears (see figure 7). The variables can be *dragged and dropped*

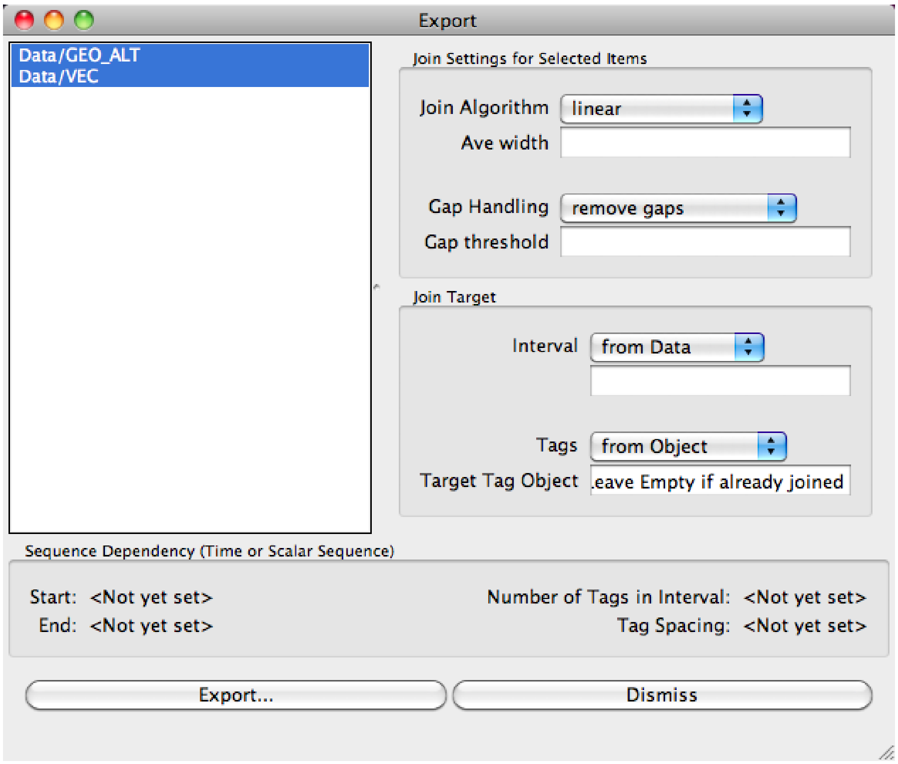

Figure 7: The **Export** window.

from the working list into the upper left box of the dialog. The parameters on the right are related to the time joining of series of data. The joining is needed here because the data files assume that measurements from multiple instruments are done simultaneously (or at least bear the same time tag). Indeed, here is an excerpt from the export of variables to an ASCII tab delimited file:

```
!EPOCH                             GEO_LON             GEO_ALT

Start_data = 18206 ! Data records to follow
2009-06-05 13:38:10.140            43.4211             333.106
2009-06-05 13:38:11.140            43.4262             333.108
2009-06-05 13:38:12.140            43.4313             333.111
```

If the variables are known to have already same time tags, then the parameters on the right can be left at their default. After clicking on the **Export...** button, the **Write File** dialog opens, which asks for the file format and the path.

5 Simple math

QSAS has extensive data analysis capabilities. These can be found in the **Analyis** and **Plug-Ins** menus (see figure 8). The latter is discussed in the following section. In this simple example we will obtain sin(GEO_LAT), which is the scaled z component of the position vector of the satellite in the ITRF frame. For this we go to the menu **Analysis** → **Simple Maths** → **Trig**. A dialog opens, as shown in the figure 9. In such type of dialogs of QSAS, input variables and parameters

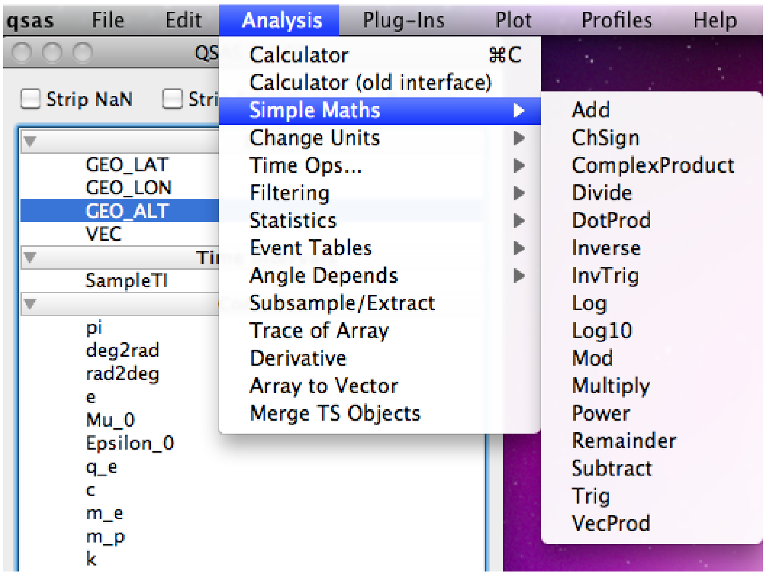

Figure 8: The **Analysis** menu shows basic operations on data.

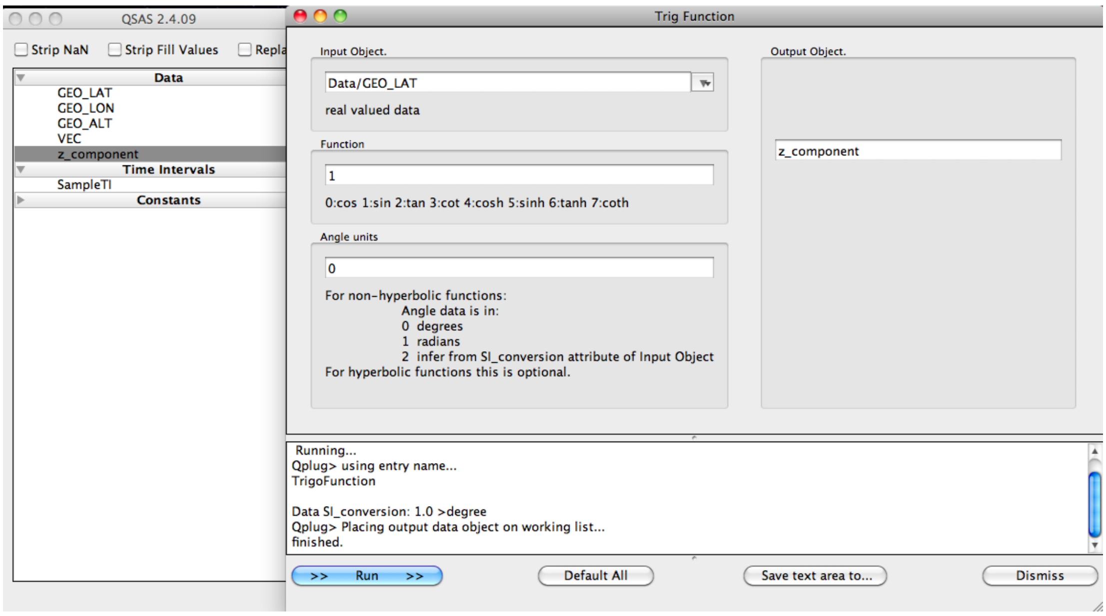

Figure 9: Basic trigonometric operations on data.

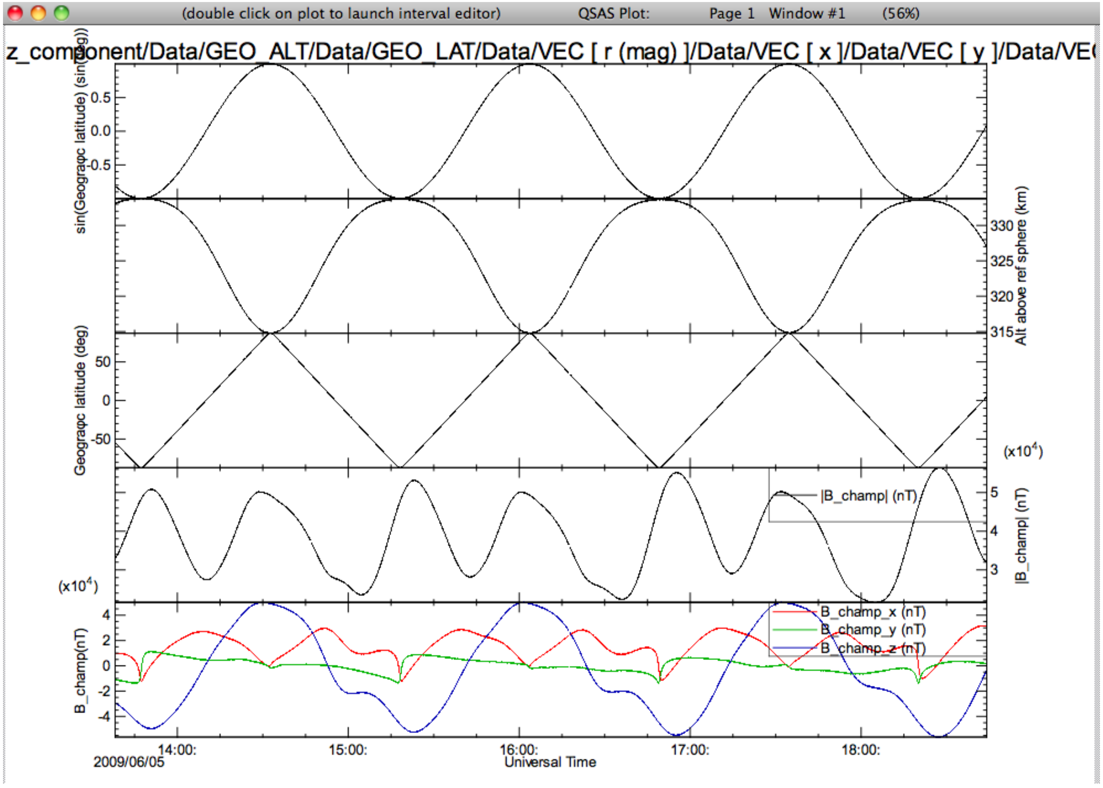

Figure 10: The result of taking *sin* from the geographic latitude of the satellite. Compare the first and the third panels.

are always on the left, while the names for the output variables are given on the right. Possible warnings and errors are shown in the lower text area.

The `GEO_LAT` variable can be brought to the **Input Object** by drag-and-drop. The **Function** is set to 1 (sinus) and the **Angle units** box is set to 0. Here we named the **Output object** as `z_component`. The computation started after clicking on **Run**. The result is best seen on the plot, where we dropped the output variable onto the **Frame 1**. It is shown in the first panel of the figure 10, where the third panel indicates the latitude.

6 Plug-ins

The functionality of the QSAS can be further extended through custom plug-ins. These are written in the C++ language and can be added to QSAS at any time, without reinstalling the entire software. QSAS distribution comes already with a number of plug-ins, ranging from coordinates rotation and the computation of the Tsyganenko model to the Fast Fourier Transform and wavelets analyses. In this section the use of two plug-ins is exemplified: the computation of the POMME-6 model and the Minimum Variance Analysis.

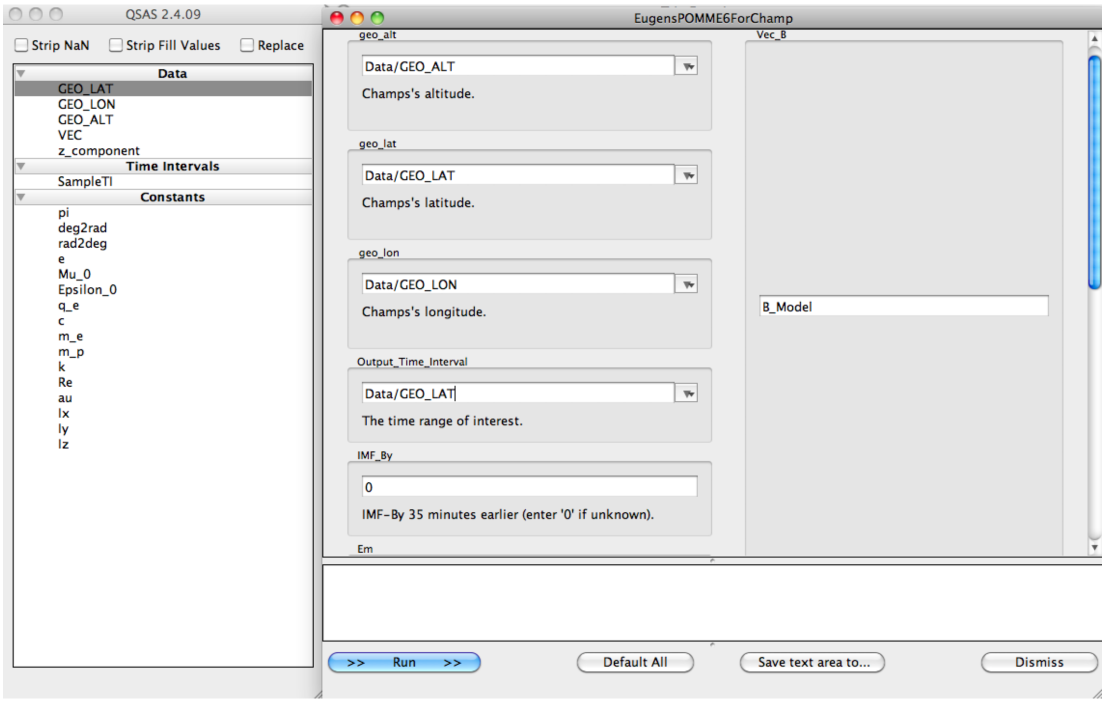

Figure 11: The *eugen_pomme6_champ* plug-in, which computes the POMME 6 model based on coordinates of Champ.

6.1 POMME-6 model

POMME-6 is the sixth generation of the Potsdam Magnetic Model of the Earth. The plug-in `eugen_pomme6_champ` was created from the provided C code[5]. The plug-in accepts satellite's positions and a number of parameters, which model the external field, and outputs the modeled magnetic fields at those positions. In this example we use this plug-in to show the existence of *field-aligned currents* (FACs) at higher latitudes.

It is started from the menu **Plug-Ins** → **Analysis** → **eugen_pomme6_champ**. The dialog (see figure 11) is similar to the one that was used to compute a trigonometric function above. The input parameters and variables are on the left, while names of output variables are on the right. We enter `GEO_ALT`, `GEO_LAT` and `GEO_LON` to their respective place in the dialog and one of this variables into the **Output Time Interval** field. A variable caries time tags with it, so it is possible to enter a time series variable, where a time interval variable is requested. Then the interval is the entire time span of the given variable. For this exercise we shall leave other parameters to their defaults, which signifies that we consider the modeled field produced by the internal sources only. After clicking on **Run** and waiting a short time, the variable `B_Model` appears in the working list.

The difference between the measured data and the modeled magnetic field is computed using **Analysis** → **Simple Maths** → **Subtract**. In the two fields we

[5]available at `http://www.geomag.us/models/pomme6.html`

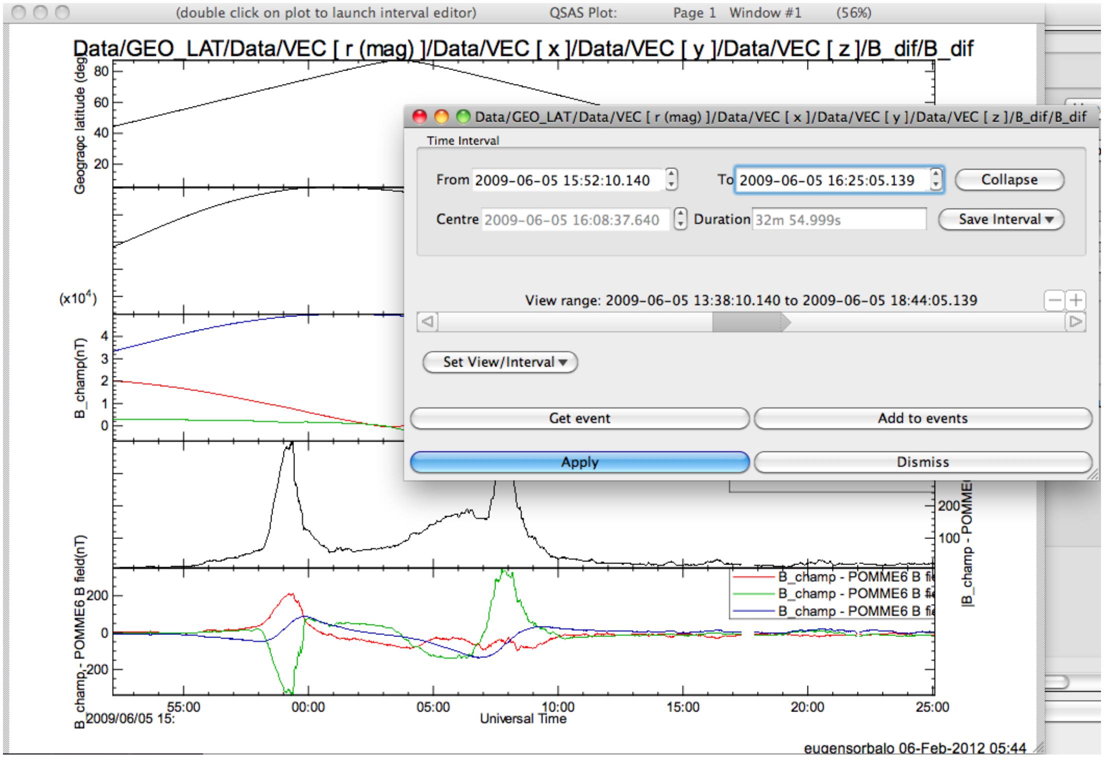

Figure 12: Time zooming-in.

enter VEC and B_Model variables, whereas the output variable we name B_dif. Finally we open the **Plot** window and drop the subtracted variable onto **Frame 1** [6].

QSAS allows a simple way to zoom-in the time axis of the plot. A double click of the mouse anywhere on the plot will open a dialog as shown in the figure 12. We use this dialog to zoom into the time interval 15:58:20 – 15:59:00, which corresponds to one of FAC regions and B_dif was monotonically growing. We save the time interval by clicking on the **Save Interval** button, choosing **Save Interval to WL...** and typing FAC_interval as the name of the variable in the working list. We shall use this time interval in the next plug-in.

6.2 Minimum Variance Analysis

It is well known that at the sharp discontinuities the normal component of the magnetic field does not change its value. This was the starting point for an analysis which looks for the component / projection of the magnetic field which changes the least when a satellite crosses a discontinuity. FACs at auroral latitudes are not physical discontinuities in the strict sense. Still, they are usually modeled as infinite sheets of currents, which implies that the normal component of the magnetic field should be zero. In this example we shall use the **Minimum Variance**

[6]**Delete plots:** unwanted panels or traces can be removed by right-clicking on them and clicking on **Delete**.

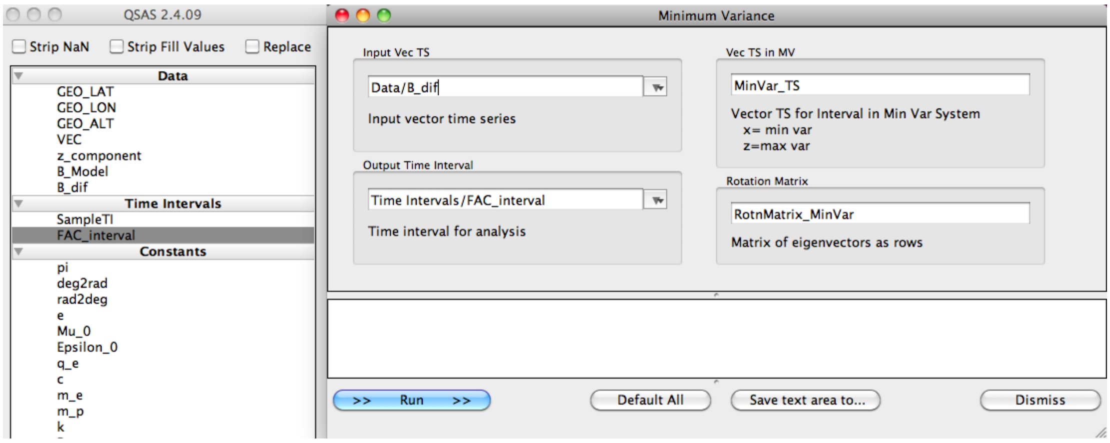

Figure 13: The **Minimum Variance** plug-in.

plug-in to obtain the component of the magnetic field B_t which is tangential to the current sheet. Then the current density j_z is proportional to $(\Delta B_t/\Delta r_n)/\mu_0$, where Δr_n is the progress of the satellite in the direction normal to the current sheet, and μ_0 is the magnetic constant.

The plug-in is accessible from the main menu of QSAS, **Plug-Ins** → **Analysis** → **Minimum_Variance** (see the figure 13). In the **Input Vec TS** we drop `B_dif`, which is the difference between the measured and the modeled magnetic field. For the **Output Time Interval** the previously saved `FAC_interval` is used. This time interval is characterized by having monotonically increasing field with components having almost constant slopes. This hints us to the fact that there might be only one current sheet with only one normal orientation. Indeed, that can be seen in the direct result of the plug-in, which besides returning some variables, also shows a graphic window that displays hodograms in the new reference system (see figure 14). The new system is formed by the direction of the maximum and minimum change of the field, whereas the third direction is orthogonal to the first two. In our case the direction of minimum change is the normal to the current sheet. Hodograms show the tip of a vector as it is measured in time. Notice in the figure 14 that the normal component of the magnetic field almost does not change, but the tangential field changes by more than 200 nT.

The plug-in returns also two variables:

Vec TS in MV is the input vector rotated into the new reference system, where the z axis points to the direction of maximum change;

Rotation Matrix is the rotation matrix between the input and MVA reference systems.

7 Save/Restore workspace

The work can (and should) be saved at any time. QSAS allows to save the variables from the working list and the plot configuration on the hard drive. For

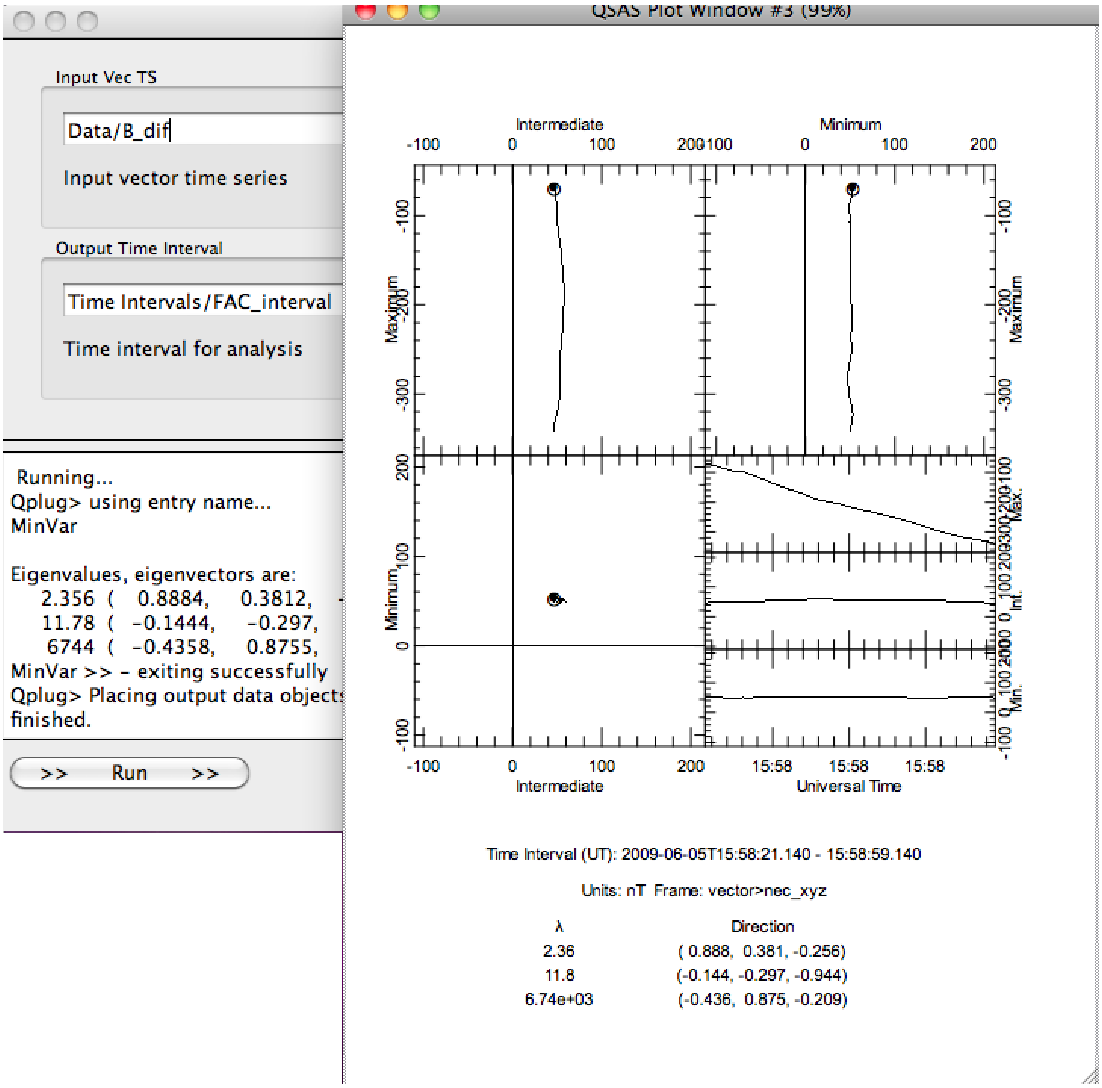

Figure 14: The graphical result of the **Minimum Variance** plug-in.

this, we click on **File** → **Save Session As...**. In the dialog we create the folder `Niemegk_champ.qss`, select this folder and click on **Save**. The session can be restored later by choosing **File** → **Restore Session**.