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## TREPS, a tool for coordinate and time transformations in space physics



V. Génot<sup>a,\*</sup>, B. Renard<sup>b</sup>, N. Dufourg<sup>c</sup>, M. Bouchemit<sup>a</sup>, N. Lormant<sup>b</sup>, L. Beigbeder<sup>d</sup>, D. Popescu<sup>d</sup>, J.-P. Toniutti<sup>d</sup>, N. André<sup>a</sup>, F. Pitout<sup>a</sup>, C. Jacquy<sup>a</sup>, B. Cecconi<sup>a</sup>, M. Gangloff<sup>a</sup>

<sup>a</sup> IRAP, Université de Toulouse, CNRS, UPS, CNES, Toulouse, France

<sup>b</sup> AKKA, Site Andromède, 7 Bd Henri Ziegler, 31700 Blagnac, France

<sup>c</sup> CNES, 18 Av. Edouard Belin, 31400 Toulouse, France

<sup>d</sup> GFI, 1 Av. Général Eisenhower, 31100 Toulouse, France

### ABSTRACT

We present TREPS (Transformation de REpères en Physique Spatiale) an online tool to perform coordinate transformations commonly used in planetology and heliophysics. It is based on SPICE kernels developed by NASA/NAIF. Its usage is straightforward, with a 4-step process, including various import/export options. Interoperability with external services is available through Virtual Observatory technology which is illustrated in a use case.

### 1. Introduction

Comparing planetary/heliophysics vector data from heterogeneous sources often implies to homogenise their reference frame. It is generally a tedious, if not complex, task for data analysts when they are confronted to the need for such transformations. NASA's Navigation and Ancillary Information Facility (NAIF, <http://naif.jpl.nasa.gov/>) provides fully tested (public domain) libraries to do just that. These libraries (the SPICE information system) are available in various computer languages, are directly implemented in specific operation and analysis software, and are also integrated in general public tools like 3DView (<http://3dview.cdpp.eu>, Génot et al., 2018) or Cosmographia (<http://naif.jpl.nasa.gov/naif/cosmographia.html>). However these software and tools are generally multi-purpose and complex. A simple, friendly, and focused tool, exclusively devoted to coordinate transformations, was missing in the planetary and heliophysics communities. The CDPP (<http://www.cdpp.eu>) therefore designed TREPS (Transformation de REpères en Physique Spatiale <http://treps.cdpp.eu>) with this aim. This paper explains the architecture of the tool, its 4-step usage, and lists the reference frames considered. Finally, two use cases are described, to demonstrate TREPS integrates interoperability and can be connected to companion tools through Virtual Observatory (VO) technology.

### 2. TREPS architecture and usage

TREPS is easily accessible via a user friendly interface in a browser

window; it is coded in Javascript (Ext-JS). The transformation themselves are done via web-service calls to the companion tool 3Dview (orbitography and data visualization, Génot et al., 2018) which makes use of SPICE kernels internally; these calls are transparent to the user.

More generally reference frames can be linked to instruments or planetary boundaries (such that LMN for magnetopause studies). At present these frames are not taken care of in TREPS. The complete list of reference frames handled by TREPS is available in the Help/About TREPS Tool.

The workflow in TREPS consists in four steps: first the user loads his/her quantity to be transformed, second he/she chooses the source and target reference frames and, optionally, the time base and the vector definition, then the transformation is realized and the result can be visualized, and finally exported. Import/export can be done with SAMP (Simple Application Messaging Protocol), a standard protocol designed by IVOA (International Virtual Observatory Alliance). Technically SAMP is activated by opening a hub to which databases and tools can connect. Tools like Topcat (Taylor, 2005), Aladin (Bonnarel et al., 2000) or Cassis (Cassis team) embeds a SAMP hub. Practically the user can send vector data from a database to TREPS, perform the transformation then send the result to a third visualization or analysis tool; in this process no file needs to be uploaded/downloaded.

Time transformations are also possible from/to different formats such as: ISO8601 in several representations for day, month, year, etc, time stamps (number of sec. Since 1970), decimal year, user defined patterns (multiple options), epoch time and TT2000 for CDF format, DDTIME for

\* Corresponding author.

E-mail address: [vincent.genot@irap.omp.eu](mailto:vincent.genot@irap.omp.eu) (V. Génot).

CDPP/DD server. The targeted time format must be specified in the Exported Time Format setting at Step 3 in the TREPS workflow.

Let us now describe TREPS steps in detail.

### 2.1. Step 1

The home page of TREPS (Fig. 1) is the place where the source data must be uploaded, either from a local file (it can be dragged and dropped directly in the squared box encompassed by a dashed line in Fig. 1), or an URL, or via SAMP, or via manual edition. The right part of the page displays help for the different functionalities, general references on coordinate transformations, as well as information on underlying web-services. On Fig. 1 the help displays information on the types of files that are accepted by TREPS in Step 1: they comprise tabular ASCII, VOTable, CDF and NetCDF files. Once the source data are chosen, via whatever means, the data are loaded which brings the user to Step 2.

### 2.2. Step 2

In Step 2 the window changes if data are correctly loaded (Fig. 2). Time appears in yellow while the 3 components of vectors appear in red/green/blue. In case the Source file contains more than a single vector, or a mix of scalar and vector quantities, the user must choose which column represents the x/y/z component respectively (this is the “edit mode”); for self-describing CDF or NetCDF TREPS automatically recognizes arrays of dimension three and displays them as vectors. If the file is in ASCII with 3 columns TREPS will directly highlight the columns in red/green/blue. The user can add/remove selected vectors with the corresponding buttons in the ‘Vectors Definition’ window. The time format is recognized and displayed in “Time field”. At this step the user must enter important information: the Source and Destination coordinate systems (or leave them blank if the aim is only to perform time transformation, see below), and whether the vector is a position or not. In case it is a position, as the centres of the ‘Source system’ and of the ‘Destination system’ may differ, the transformation must include the associated translation. If the user wants to perform time format transformation only, the selection of ‘Source system’ and ‘Destination system’ is not mandatory. Once this is

done the system is ready to proceed to the transformation itself and then to Step 3.

### 2.3. Step 3

In Step 3 the resulting transformation is displayed either as a grid result (i.e. similarly to the coloured vector representation in Step 2) or as a plot as it is illustrated in Fig. 3. Source and destination vectors are plotted and individual components can be selected. At this stage the user has to choose how the transformed vector must be exported. The exported time format must be specified as well as the file format itself. Source and destination vectors can be gathered in the exported file. If the user wants to use SAMP to send the transformed vector to companion tools the export format must be VOTable (standardized XML).

### 2.4. Step 4

Finally the export operation is performed on Step 4 (Fig. 4). The resulting file can be simply downloaded on the user disk. Alternatively a SAMP hub can be activated (for instance with TOPCAT, see Génot et al., 2014 for more details on how to use SAMP). A first click on the ‘Send (via SAMP) to ...’ button will ask the user to connect the TREPS page to the hub. After accepting, if the VOTable format has correctly been chosen as export format at Step 3, then the resulting file may be broadcasted to all tools connected to the SAMP hub.

## 3. Science cases

TREPS can be used as a standalone tool to transform vector/position files as shown in Section 2. However its possibilities are greatly enhanced when it is part of a data analysis workflow. As an illustration, we propose here the first necessary steps to analyze Titan’s flow-induced magnetosphere (Bertucci et al., 2008). The aim of this science case is to obtain, and subsequently visualize, the magnetic field measured by Cassini in Titan centered reference frame, TIIS (Titan Interaction System). The (+x) axis of the TIIS is aligned with the direction of ideal co-rotation, whereas the (+y) axis points from Titan to Saturn. The (+z) axis completes the

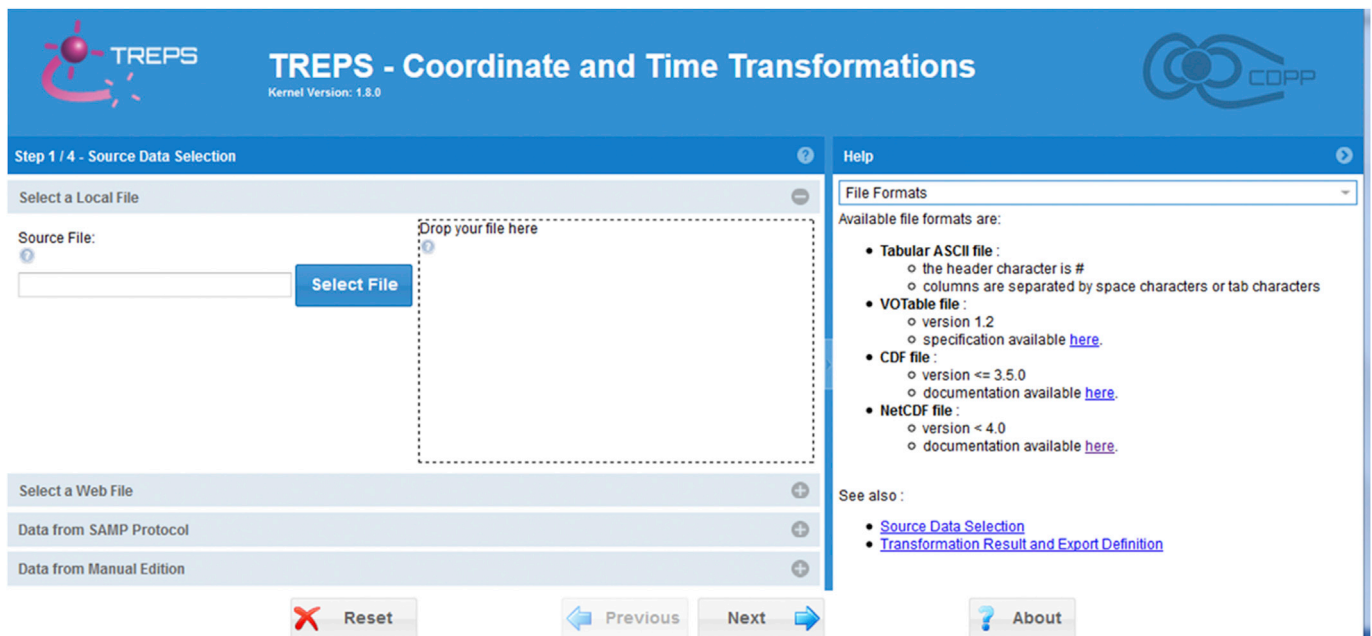


Fig. 1. TREPS welcome interface where source data selection is realized (Step 1, see text).

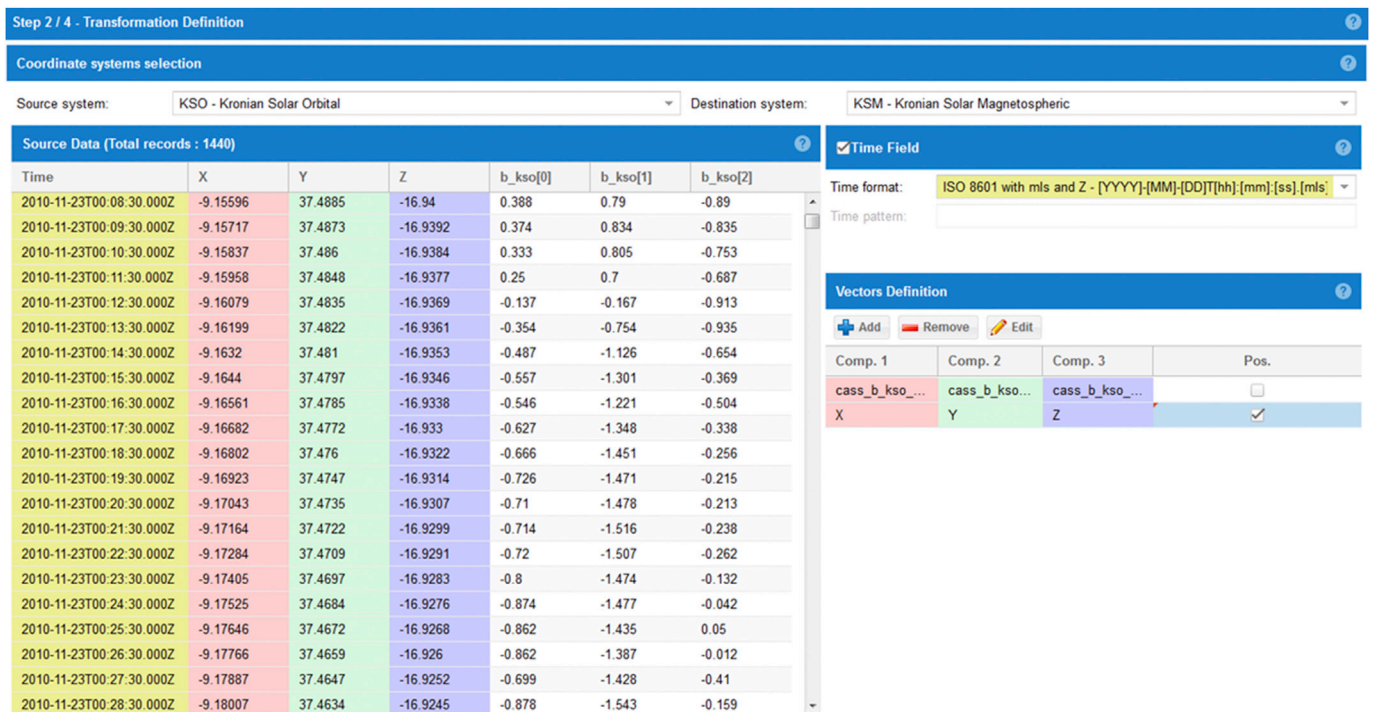


Fig. 2. TREPS interface at Step 2 (see text). Two vectors are recognized in the loaded file as can be seen in the Vector Definition window; the one displayed in colour on the left corresponds to a position vector (X, Y, Z) hence the box ‘Pos.’ must be ticked by the user on the bottom right.

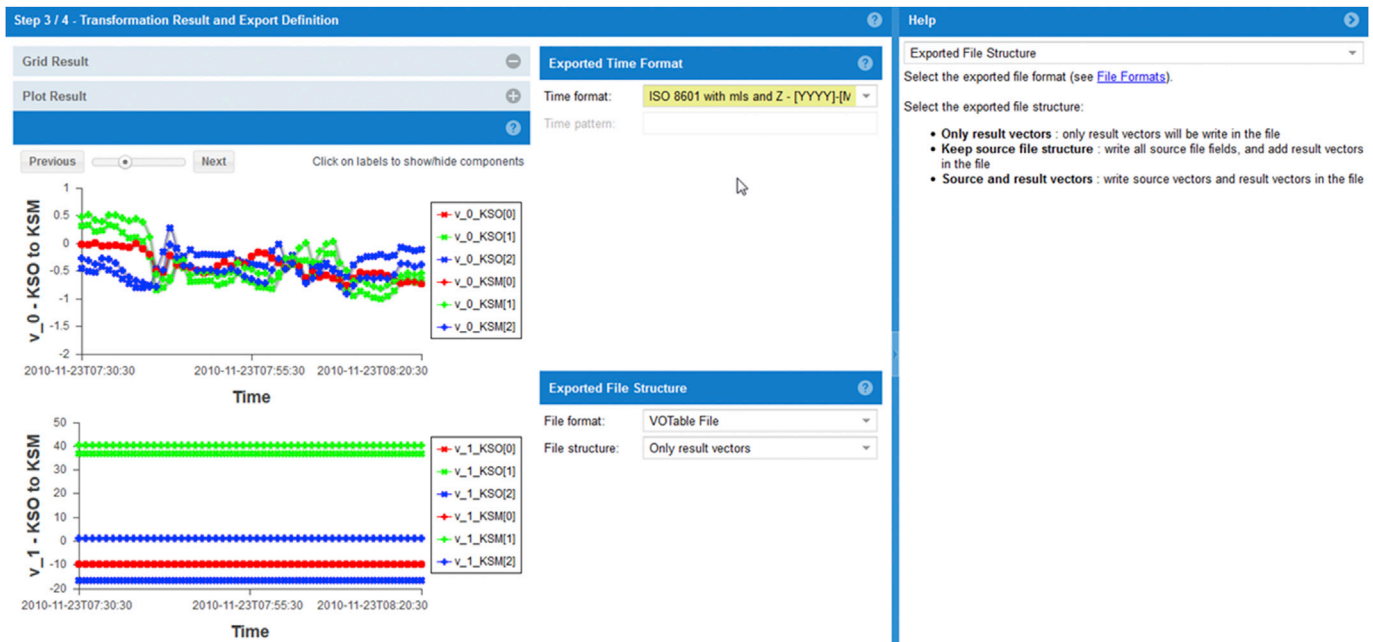


Fig. 3. TREPS interface at Step 3 (see text). The two vectors defined at Step 2 have been transformed and are plotted in separate windows. Original and transformed components are overlotted.

right-handed coordinate system, pointing northward (i.e., it is approximately parallel to Saturn’s magnetic moment/rotation axis). We use data from NASA/PDS as they are archived in the CDPP data analysis tool AMDA (Automated Multi Dataset Analysis <http://amda.cdpp.eu/>). It should be noted that AMDA holds a collection of time tables, or event lists, shared by all users, and among them a list of (83 among the 127 close flybys of the mission) Titan’s fly-bys by Cassini (3 h interval centered on the closest approach). The science case is conducted in accordance with the following steps: the user logs in AMDA (or uses guest

access), opens the Cassini data tree and chooses the MAG instrument. The user opens a SAMP hub (by launching TOPCAT or other means) and connects AMDA (connector button at the bottom right part of the desktop) and TREPS (Step 1, Data from SAMP protocol) to the hub. In the AMDA download interface the magnetic field dataset at 1 min resolution in the KSO coordinate frame is selected together with the time table “List\_of\_Cassini\_Titan\_flybys”. Internally a file containing all magnetic field records for the 83 (flybys) times 3 h of data is produced. Via SAMP, the user then sends this file directly to TREPS and, because it is already

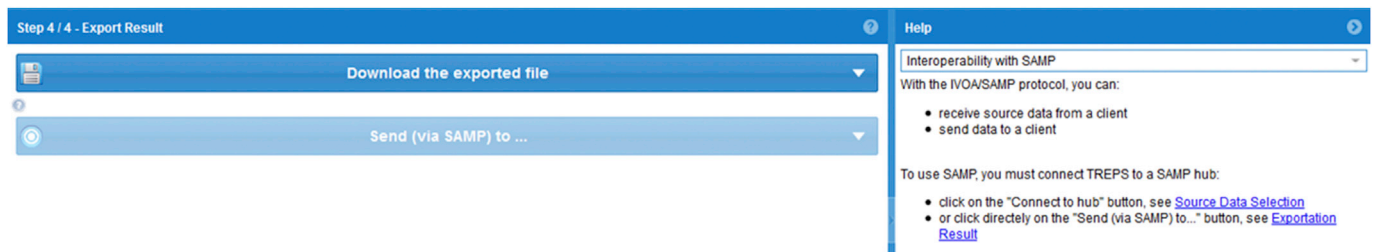


Fig. 4. TREPS interface at step 4 (see text).

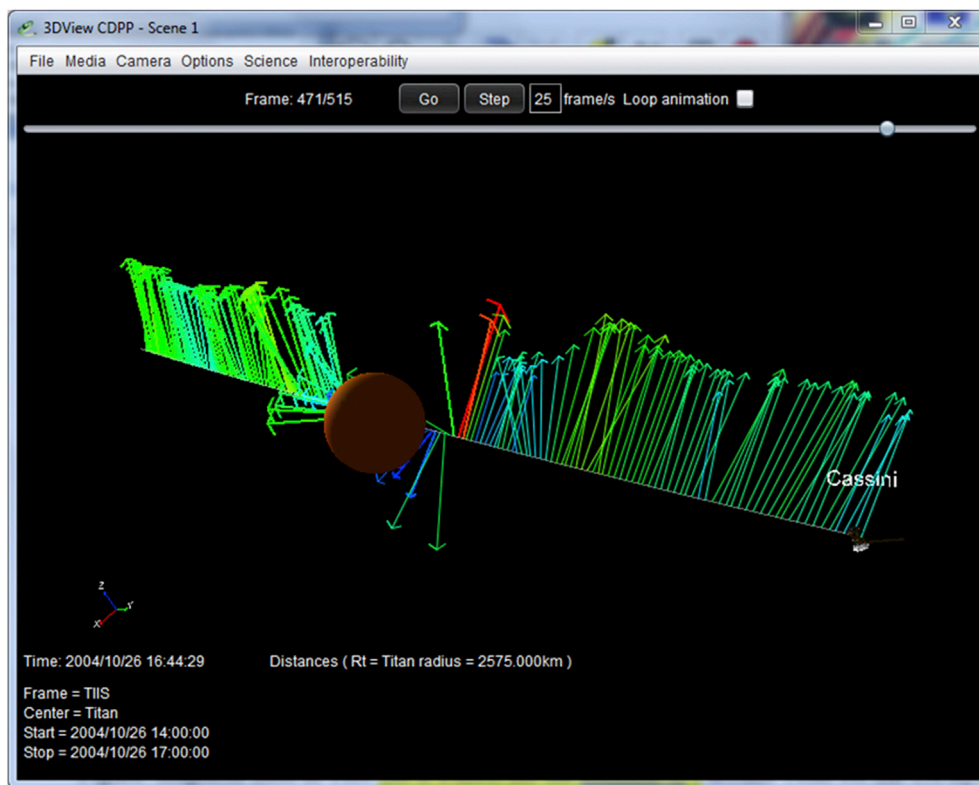


Fig. 5. Magnetic field vector around Titan for the TA flyby (3 h on the 26/10/2004) visualized in the 3DView tool (scene is in TIIS coordinate system). The colour and the length of the arrows both code the field amplitude (colour scale: blue to red). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

connected to the hub, all fields are automatically filled (Step 2). The user chooses KSO as “Source system” and TIIS as “Destination system”. Hitting the Next button performs the KSO→TIIS transformation. At Step 3 the user can prepare the way he/she wants to export the data. Selecting VOTable (an XML format practical for machine to machine exchange) it is then possible, on Step 4, to ‘SAMP’ the transformed data back to AMDA, or alternatively to push them to TOPCAT or 3DView for further analysis or visualization (as illustrated on Fig. 5), respectively. A broad survey of Titan’s flybys have been conducted in Simon et al. (2013). They made use of TIIS magnetic field as the starting point of their analysis to study the influence of the field draping on the structure of the induced magnetosphere. In the paper it is further demonstrated that a new coordinate system eliminating the influence of a rotation of the induced magnetosphere around the corotation direction is more appropriate for the analysis. However this new system makes use of the specific orientation of Saturn’s field at each flyby and cannot be implemented in a systematic way in TREPS for the moment.

Another science case combining AMDA, 3DView and TREPS is presented in Génot et al. (2014). It shows how to transform magnetic field vector, measured by the THEMIS C spacecraft orbiting the Moon and

available on the AMDA database, from the archived GSE (Earth-centered) coordinate system to the LSE (Moon-centered) coordinate system. The transformed vector is then sent to the 3D visualization tool 3DView to be displayed and manipulated in context.

#### 4. Conclusion

This paper shows the main functionalities of a web-based coordinate transformation tool, TREPS, designed and developed by the French Plasma Physics Data Centre (CDPP). The usage is simplified by a step by step approach and associated documentation. The transformations are based on the well referenced SPICE libraries from NASA/NAIF. The simplicity of the tool makes it an ideal software for students in planetary and heliophysics with very few IT prerequisites; it is also very convenient for the general space physics scientist who often has to work in multiple coordinate systems. Connections to the outside world is possible via the virtual observatories (IVOA) standards, namely SAMP and VOTable. Future developments will take care of additional coordinate systems, at the same time they are added in the companion tool 3DView which holds the SPICE libraries.

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