3D Visualisation of continuous, multidimensional, meteorological Satellite Data

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Abstract

Ten years of earth observation by the MIPAS instrument aboard the European environmental satellite Envisat [1] led to a considerable amount of measurement and processed data, which has to be managed and visualized by powerful and flexible software tools. This paper gives an overview about new concepts, tools and methods for the 3D visualisation of continuous, multidimensional, meteorological Satellite Data, which are realised with WISA (Wissenschaftliches Informations-system für die Atmosphärenforschung – Scientific Information System for atmospheric Research). A major goal of the visualisation is the recognition of correlations between different trace gas concentrations (e.g. ozone, chlorine nitrate, chlorofluorocarbons, etc.) and the visualisation of trace gas distributions where the main focus was laid on the polar areas.

1. Introduction

Envisat was launched in 2002 with 10 instruments aboard and at eight tons. It is the largest civilian earth observation mission which ended in 2012. One of the instruments was MIPAS, the Michelson Interferometer for Passive Atmospheric Sounding, which measures atmospheric emissions [2]. The final processing of the MIPAS measurement data, performed by IMK (KIT Institute for Meteorology and Climate Research), leads to a huge amount of vertical concentration profiles for more than 30 atmospheric trace gases. The Envisat data is captured continuously along a given satellite orbit which covers the whole earth's surface. Figure 1 shows two single orbits, each of them requires 100 minutes and is repeated after 36 days (left side) and the earth coverage of Envisat/MIPAS for September, 2002, using small blue lines for about 32.000 datasets.

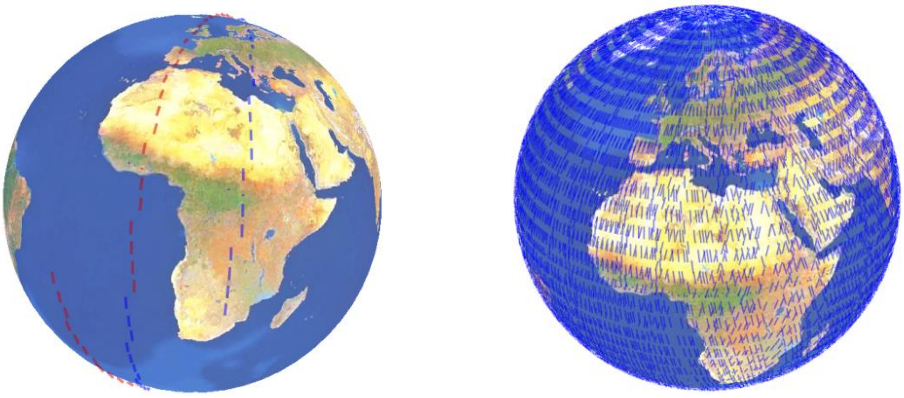

Figure 1: two single orbits and the earth coverage of Envisat/MIPAS data.

Each dataset consists of several trace gas profiles with values at given heights and references a geographic location on earth. In order to show several trace gas profiles in parallel for a selected orbit or area, the use of the most common 2D diagram types, which are used mostly in meteorological publications, are not appropriate. For this reason, a new concept and new methods were developed, which are presented in this article.

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2. The Envisat/MIPAS Data Structure

MIPAS delivered datasets which are related to a geographical location and to different altitudes. The number of altitudes and their values depend on the actual configuration of the instrument. The given altitudes can vary between 5 and 150 km, the vertical step size may be at least 3 km. The final processing of the MIPAS data corrects the real sloped vertical dataset, caused by the continuing flight of the satellite, to a vertical profile with a singular geographical location. Figure 2 shows the dataset given by MIPAS, and the processed *DataSet3D* element. Each *DataSet3D* element consists of a bundle of trace gases at several altitudes. If a value is not available for a given altitude, the position is marked with ‘NaN’ (Not a Number).

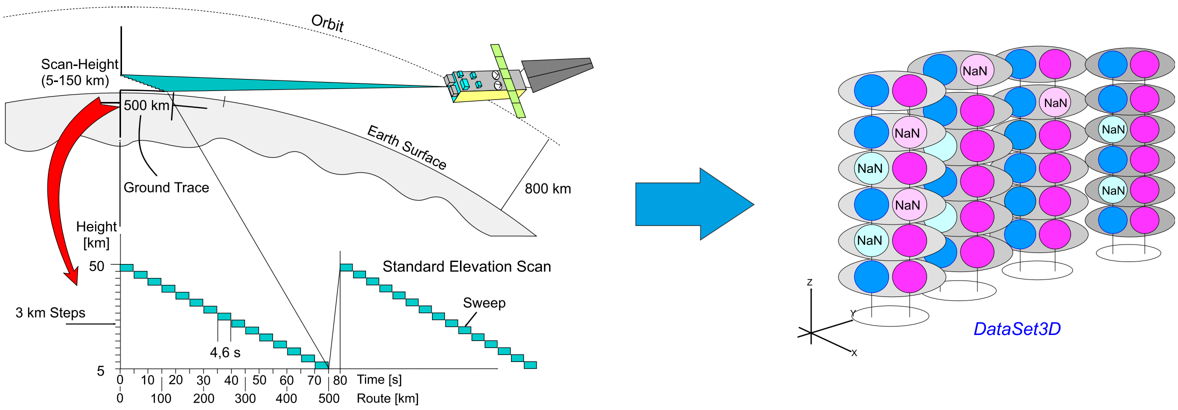

Figure 2: Structure of MIPAS data, during generation and after processing

3. Requirements for the Visualisation

In order to achieve an effective visualisation of measurement data, application-specific requirements must be fulfilled. The following aspects represent some of the most important requirements:

- Simple and fast selection of desired datasets with the use of extended search facilities.
- Visualisation of real data, i.e. no automatic approximation or interpolation to perceive slight visual differences, too, and to recognise data anomalies.
- Numerous interactive tools are needed to adapt the visualisation to the user’s needs, e.g. colours, views, distances, sizes, proportions
- The feasibility to interactively select each trace gas profile contained in the selected dataset for visualisation and comparison.

4. Related Work: Visualisation of multidimensional Data Sets

Most publications about this subject comprise the use of traditional visualisation techniques for the visualisation of a given complex data set, like Parallel Coordinates, Scatterplot Matrices, etc., combined with automatical data analysis approaches. Multidimensionality is regarded as the join of different data (attributes) with a geographic location [3]. The location is mostly bounded to 2D and the third dimension is omitted or regarded being constant. Furthermore, the majority of given data does not change continuously. This allows the use of traditional 2D charts for multiple attributes without spatiotemporal animations.

There are only a few concepts in 3D visualisation for multidimensional data. One well-known concept is the use of surfaces overlaid with a colour map, which is able to visualise two parameters. Other promising approaches can be found at [7] where net diagrams are used in 3D for relatively small time series or a 3D approach at [5] for chemical data sets.

5. Why not using common Charts in 2D?

There are several 2D chart types which promise to show multidimensional data. This is true for a single multidimensional dataset. But when a number of multidimensional datasets must be visualised simultaneously, important information is lost in most cases due to the lack of a third dimension (local or temporal). This problem could be overcome by applying a 3D scene or an animation concept. Additionally, 3D scenes can be easily enriched with visualisation effects like shading, perspectives, etc.

The following 2D chart types can be basically used for multidimensional datasets: point and line diagrams, Kiviat graphs (net diagrams) which use colours and line thicknesses to distinguish the data (dimensions), bar charts, histograms, pie charts (circle graphs), and data jacks. Stick figures are an option, which use colours, line thicknesses and angles between the extremities. Stick figures seemed to be a very worthwhile approach for the given datasets, because they are used mostly for multidimensional big data sets. Finally, *Parallel Profiles*, developed by [4], which makes anomalies in profile arrays directly visible, can be used in 3D to exploit the rendering effects and to show their geographic location.

6. Satellite Data Visualisation by moving 2D Diagrams to 3D

Based on the structure of the processed data, the idea was developed to use common 2D charts for each height of a *DataSet3D* element and move them into 3D space. In this way, new 3D structures can be used to oppose a trace gas profile (e.g. ozone) to another one (e.g. chlorine nitrate) to visualise correlations, gradients and distributions. Figure 3 shows some common diagram types realised in WISA to visualise the data. In this article, the use of bar charts, circle and line diagrams, scatter plots, stick figures, and *Parallel Profiles* is presented. All of them can be considerable enriched using spatial and/or temporal animation which is realised in WISA, too.

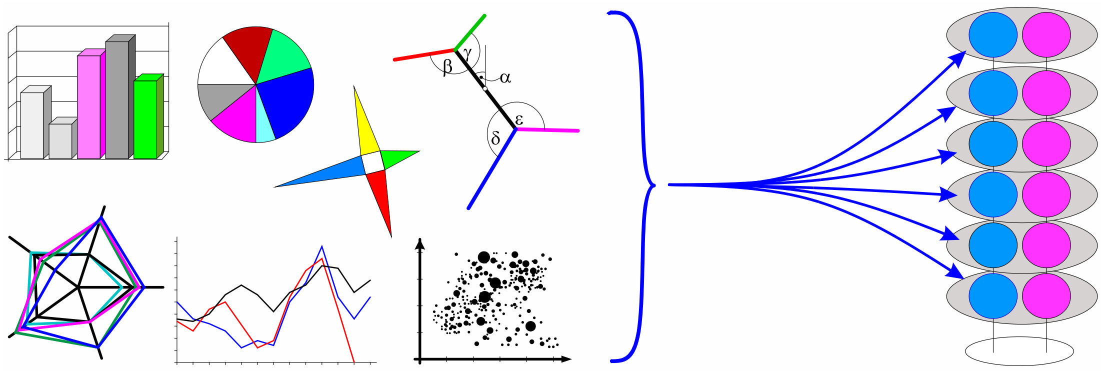

Figure 3: The use of common 2D charts in 3D to visualise DataSet3D elements

Using 2D diagrams in 3D is much more than adding a third dimension to flat charts. The desired information about trace gas distributions and profiles can only be retrieved when the user has the option to interactively modify graphical attributes (colours, lines, etc.) and the 3D scene. Furthermore, the use of volume and surface elements is necessary to render the scene and all profiles must be able to be hidden or shown to identify adjacent profiles.

7. The WISA Software System

The management component allows clients to connect to the database server for the administration of users, groups, projects, and MIPAS data. The administrative and meta data of MIPAS is hosted in the database whereas the basic MIPAS data is located on a file system associated to a processing cluster. The processing of the trace gases is performed in a separate processing environment and the results (trace gas profiles) are stored in the WISA database to allow dedicated, fast and flexible access for the visualisation (figure 4). The visualisation component offers tools for searching, selecting and visualising the trace gases interactively. A data preparation takes place to map the profiles to common altitudes within the *DataSet3D* elements. The visualisation of *DataSet3D* elements can be performed for both, the 2D and 3D space. For every chart type, an own viewer component exists for 2D and 3D. It provides chart-specific functionalities and is added to a base viewer frame offering common manipulation tools for e.g. zooming, rotating of the elements or the whole scene, and animation. Additional tools allow the configuration of background world maps, a coordinate system, or using a 2D or 3D grid. Finally, it is possible to generate JPEG images of the visualisation scene.

WISA is mainly written in Java (plus Java3D, JDBC), several scripts (UNIX shell, Perl) exist for managing the start-up configuration and the separated start of Java VMs as sub processes for 3D Viewers to avoid storage problems with fixed Java VM sizes.

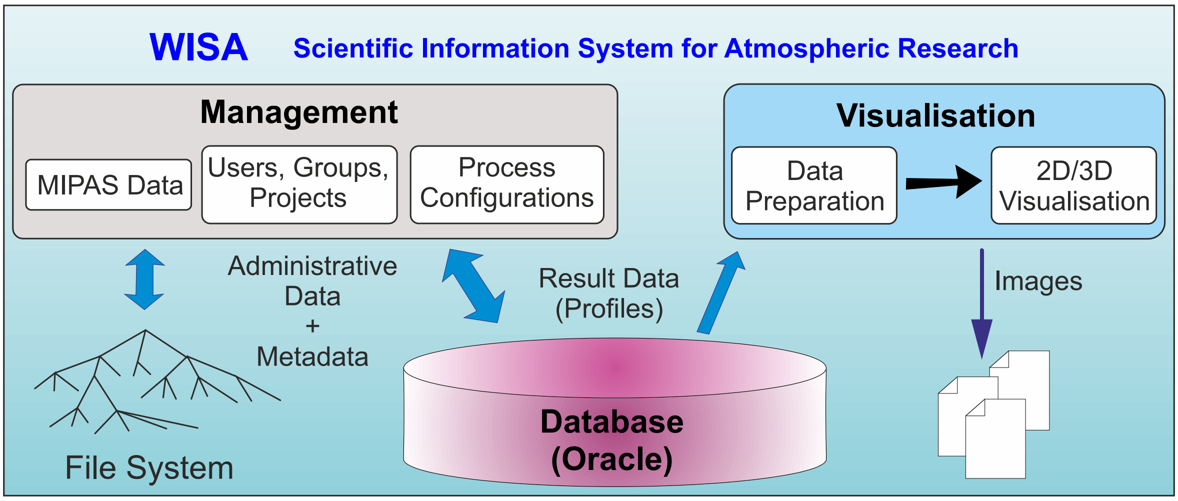

Figure 4: The WISA software system

8. The Visualisation Workflow

The first step is the selection of desired result profiles. The user can search for the results of whole cycles (all orbits within 36 days, see section 1), or one or several orbits or parts of them. Figure 5 shows the *Profile Retrieval Tool* with selected *DataSet3D* elements (red circles) of 2 chosen orbits.

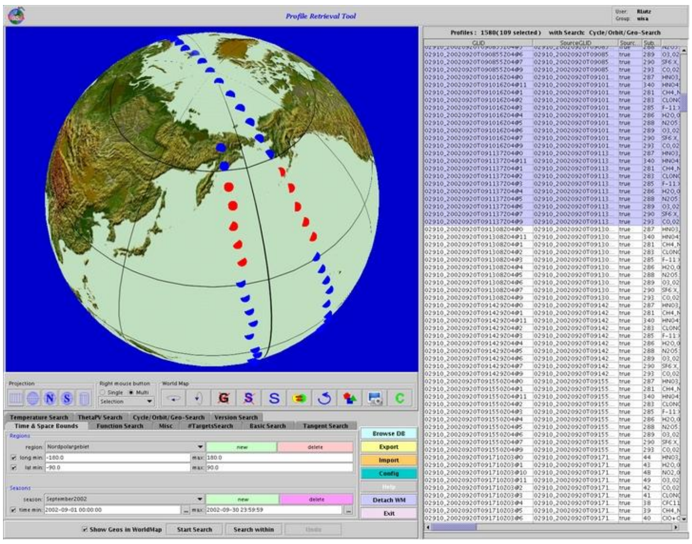

Figure 5: The WISA Profile Retrieval Tool for the selection of trace gas profiles

The selection can be visualised for all given chart types. In order to increase visualisation performance, the data can be reduced to the most interesting altitude range. The user can interactively switch between a flat world map and a spherical globe view.

9. Results

In order to compare the visualisation results of each viewer, one dedicated orbit was chosen which contains several trace gas profiles. Each representation of a trace gas profile can be faded out in order to improve the visibility of correlations between selected profiles.

9.1. Simple Diagram types – Bar Charts, Circle Diagrams, Line Graphs, Scatter Plots

Depending on the chart type, some optimisations had to be performed in order to get a fast and manageable software tool and a good visualisation result:

- **Bar Chart:** The first approach was the use of Java3D box primitive to represent the bars. It turned out that rendering of the box primitive is really slow. Hence, the cube primitives were replaced by Java3D surfaces with additional boundary lines for a better visibility (figure 6). Furthermore, profiles are often covered totally or partly by other profiles of the scene. To overcome this problem, the profiles can be ordered arbitrarily.
- **Line Graph:** The trace gas profiles were mapped to polylines and surface boundaries, which can be arranged in a circle, side by side (figure 6) or one above the other.

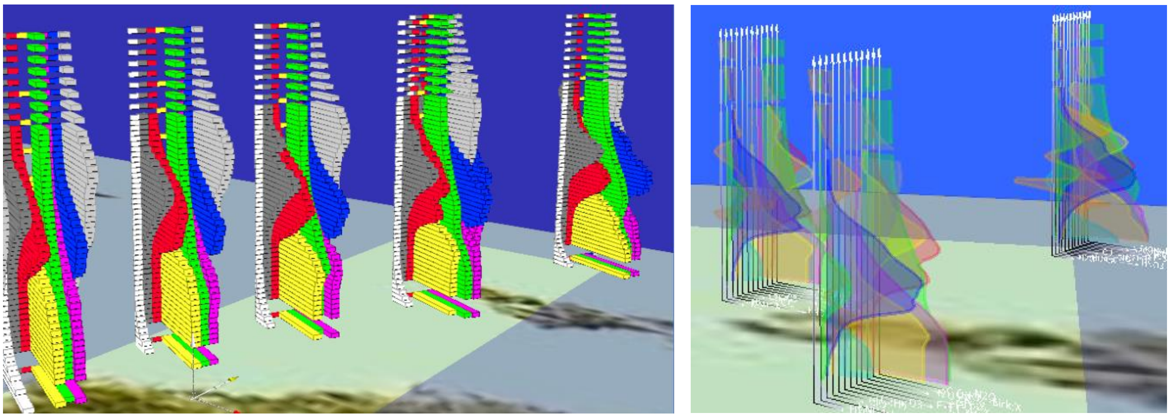

Figure 6: visualization of a part orbit with bar charts (left side) and with line graphs ordered in parallel with surfaces (right side)

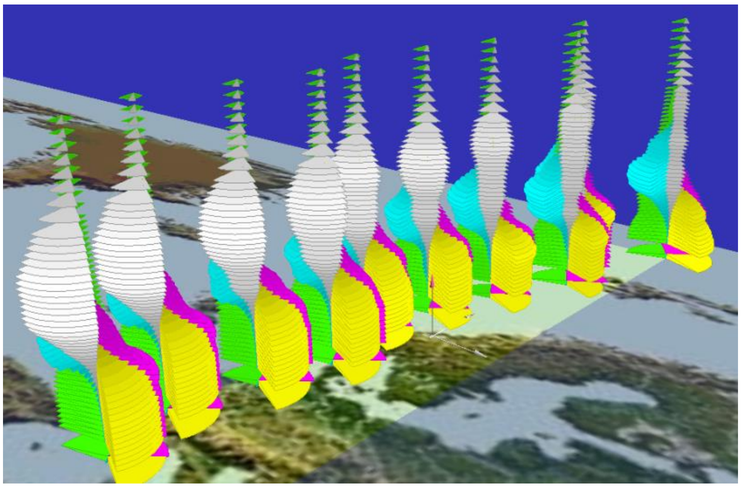

Figure 7: visualization of a part orbit with circle diagrams (pie charts, flat form)

- **Circle diagram:** Four alternatives are realised, which can be chosen at start-up. Either the upper and bottom surfaces are parallel like the segments of a pie chart or they have a flat end. Furthermore, either the sizes of the segments or their radiuses are proportional to the dimension of their trace gas values (figure 7).
- **Scatter plot:** Each altitude value of a profile is represented by a point, rather than creating a whole scatter plot on the given area. The simple Java3D sphere and box primitives were used to represent the points. Three trace gases can be visualised using the three geometric dimensions, i.e., the sphere will be deformed to an ellipsoid. A fourth trace gas profile can be shown when the resulting elements are superimposed with colours which are mapped to the trace gas values (figure 8).

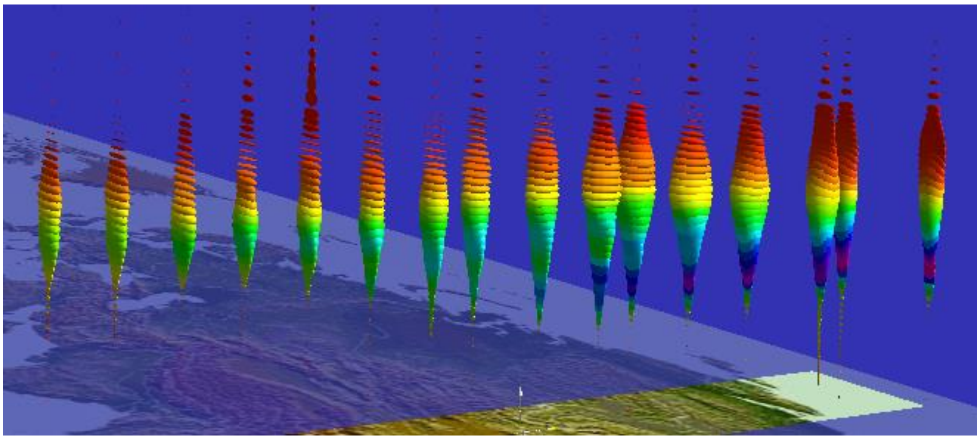

Figure 8: a part orbit visualized with scatter plots

Each diagram type can generally be used to visualise the trace gas profiles in order to show distributions along an orbit for a given area. Changes of profile gradients can be recognized easily. The tests showed that each diagram type has its advantages and disadvantages depending on the amount of profiles and *DataSet3D* elements which should be visualised.

The simplest and fastest element is offered by the scatter plot type. Since Java3D sphere elements can be rendered very fast, the scatter plot type can be used for a big data amount like data for a whole satellite cycle. Figure 9 shows the ozone distribution on the northern hemisphere for several orbits on the flat world map and on the globe. Approximately 40.000 spheres are used for this scene. At the North Pole, the low concentration of ozone can be recognised very well (ozone hole?).

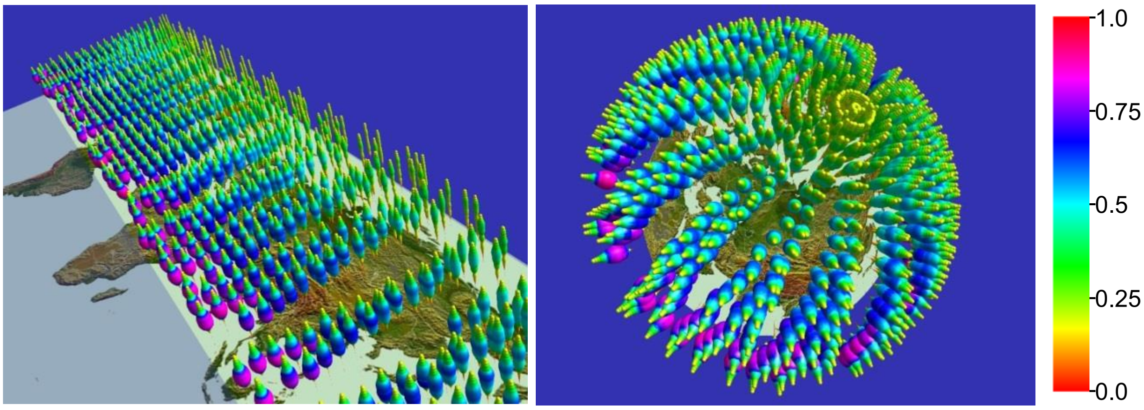

Figure 9: the distribution of ozone in the northern hemisphere using the scatter plot type

9.2. Stick Figures

Picket and Grinstein introduced this method already in 1988 to identify correlations between closely spaced data sets with five dimensions. They applied the stick figures while testing different figures manually to get a result [6]. The method aims at the creation of textured patterns which help to recognise structures. For WISA, the stick figures have been extended for a better maintenance.

Within WISA, stick figures are used in 2D and in 3D. The figure is built of two arms and legs connected to a body. The extremities are positioned with an angle relative to the body. The trace gas values can be mapped to the angle, the element colour, the length and thickness of the element. Considering all the attributes, 18 stick figure variants can be derived. They are all implemented in the software and the user can switch from one variant to another to determine the best visualisation.

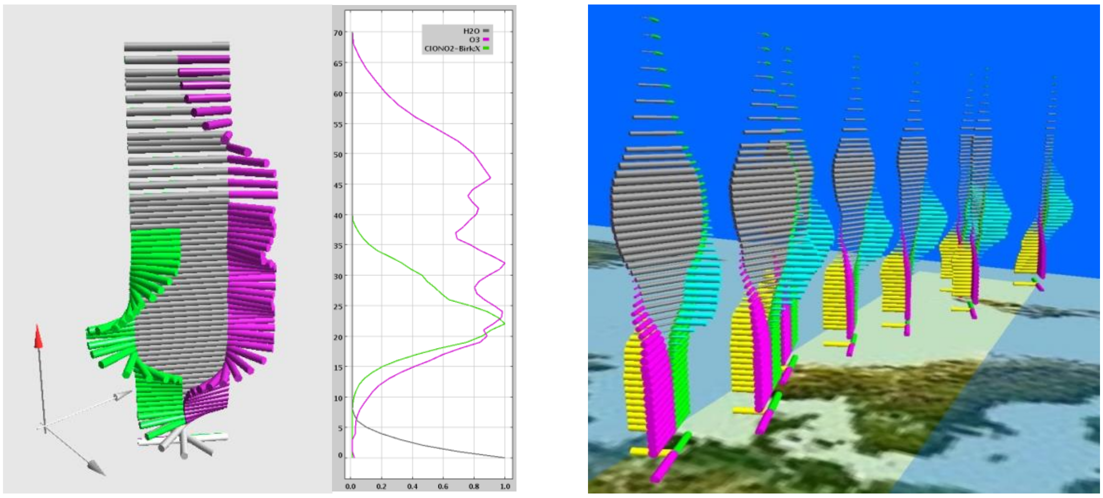

Figure 10: Stick Figures; a) functionality, the corresponding line plot, and b), the 3D scene;

Figure 10a) shows a *DataSet3D* element with three trace gas profiles represented by the stick figure type to show its functionality, and the corresponding line diagram. The body (grey) represents H2O, the left arm (magenta) ozone and the left leg chlorine nitrate (green). The values are only mapped to the angles between the extremities and between the body and the local coordinate system. Figure 10b) shows the stick figure scene with profile values mapped by length, thickness and extremity angles (fixed body angle). The tests showed that stick figures are a good way to identify correlations when the body is fixed and the same values are mapped on length and/or thickness and/or angles of one extremity. In so doing, 4 trace gas profiles can be compared easily.

9.3. Parallel Profiles

This concept, developed by [4], is based on visualisation effects which arise when equidistantly ordered profiles are resized and/or stretched. The standard approach is shown by figure 11: at first the profiles are ordered (a). Then they are moved and stretched (b, c) to the final arrangement (d). Note: for a clear identification of the behaviour of the profiles, the values are normalised.

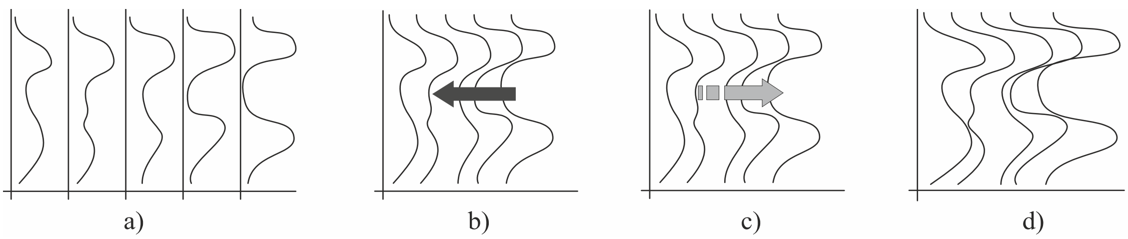

Figure 11: Parallel Profiles; positioning, moving, stretching the profiles, and the final result

Figure 12 shows a given orbit starting and ending at the equator and passing the North Pole. The left side shows the profiles for ozone overlaid with the colour map of ozone to emphasise the interesting areas (maximum ozone concentration at the equator, minimal concentration at the pole). The right figure shows the same profiles overlaid with the colour map for chlorine nitrate.

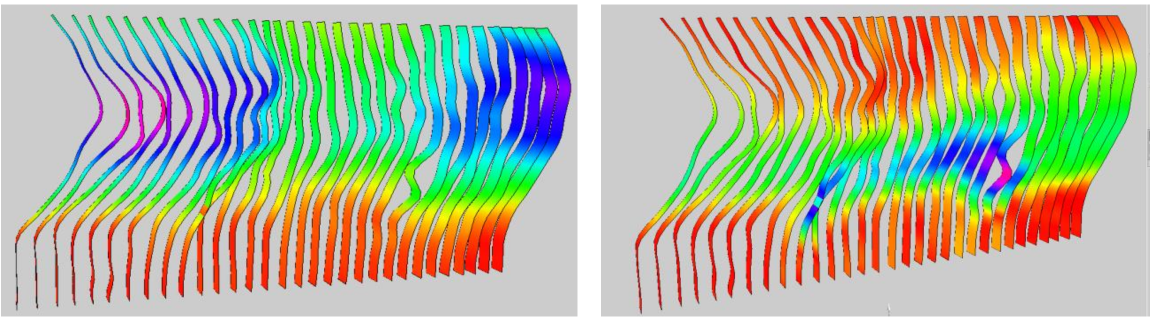

Figure 12: Parallel Profiles; 3D scene with profiles for ozone with colour maps for ozone (left –hand side) and chlorine nitrate (right-hand side)

10. Conclusions

The use of 2D charts is a reasonable option for the visualisation of structured 3D datasets. Although the presented approach is tailored towards the given Envisat/MIPAS data structure, it can be used for other arbitrary scenarios, too. The main advantages are the utilisation of 3D features like rotation, zooming, shading as well as a simple identification of the geographical locations. Furthermore, the functionality offered by the WISA tool, e.g. modifying all graphical attributes and the selection of each chart type, is a basic key for a good and successful visualisation.

Disadvantages may be the need for computer power and big main storage for the Java3D scenes and perhaps the unfamiliarity of many users with the interactive use of the viewers.

In order to improve the identification of temporal and spatial distribution changes for selected orbits or geographical areas, animation concepts must be applied to the given approaches in 2D and in 3D, which are already realised in the WISA system.

References

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