Space and time partitioning for efficient uncluttered scientific visualization

Iason Nikolas, *Student Member, IEEE*, Konstantinos Moustakas, *Member, IEEE*

Abstract— In this paper, a visualization approach on data from satellites related to volcanic eruptions is presented. In particular, the data that were processed were provided by the Simulation Laboratory Climate Science and the Institute of Energy and Climate Research (at Julich Research Center, Germany, JARA) through IEEE Scientific Visualization Contest 2014 site. The presented implementations contain both general and data specific methods. Cluttering was the main problem we had to deal with. Efficient partition has been implemented through octrees space partitioning, while time partitioning was achieved using time windows. The algorithms we develop to correlate data to each time window confirmed visually for their correctness. Also an important factor for better understanding is related to the visual encodings that were chosen.

Index Terms—Scientific Visualization, visual analitics, volcanic eruption

1 Initial data integration and browsing

1.1 What visual encodings do you choose for the different data modalities?

MIPAS: In MIPAS modality, the main visual encodings used are color and shape. In the first version spheres are placed in every detection position. The color of the spheres has been selected based on detection type. For aerosol detection type green color has been chosen, while for ash, ice and clear detections, brown, blue and white respectively as illustrated in Figure 1. In the second version of MIPAS visualization only aerosol and ash detections have been visualized. Furthermore, different kinds of shapes indicate the origin of each particle. The method which is used to detect each particles origin will be disused in the next section. The shapes used are cubes for Grimsvoth event, spheres for Puyehue and cylinders for Nabro event. A screenshot of this implementation is shown in Figure 2.

AIRS: For AIRS modality, quads extracted from the data are placed on corresponding earth locations. In order to render only useful data only those quads that their value surpass a threshold are visualized That way we effectively visualize streams of SO^2 and ash measurements. SO^2 streams colored green while ash streams colored brown. In Figure 3a we see ash steam emitted from Puyehue mountain just some hours after eruption event is shown. Also in Figure 3c SO^2 steam is visualized after Nabro eruption.

CLaMS: CLaMS modality is visualized using polylines. Polylines are trimmed trajectories based on a time window the user has chosen. Polylines color is a gradient of blue to white indicating time. Also a white semi-transparent sphere is placed on seed point position, in order to indicate particle location, at measurement time. Figure 4 shows CLaMS trajectories and there seed points that belong to one day time window from 06 to 07 of June.

Tropopause: Both first and second tropopause are visualized by rendering a surface around the Earth that the corresponding altitude has been given in each point. The color that is used to emphasize different tropopause altitudes is a gradient of four colors. Black, blue, yellow and red colors have been mapped to scales less than five, five to ten, ten to fifteen and more than fifteen kilometers of altitude. Also transparency given to the surface so user can identify the corresponding measurements location. The first tropopause is well defined in every point on the Earths' surface and can be shown in Figure 5. The second tropopause though, exists only in some specific areas were double tropopause condition is valid as can be seen in Figure 6.

- *Iason Nikolas is with University of Patras. E-mail: iason.nikolas@ece.upatras.gr*
- *Konstantinos Moustakas is with University of Patras. E-mail: moustakas@ece.upatras.gr*

1.2 How do you handle time-dependent data?

Time window: All data we have to process contain a time field which means they are time-dependent. Time-dependent data are visualized using a time window, which the user can define providing the initial and final dates. This way, when the user presses the corresponding button to see each modality, only data that lie inside the selected time window will be displayed.

Gradient color: In CLaMS data, color is also indicative of time as mentioned before. In particular a several color interpolations has been used to map time of each particle to position. When trajectories had to be visualized based on respective MIPAS detections the gradient of the chosen colors was brown to red for ash detections and green to white for aerosol detections. A gradient of two colors is used to give a moving effect to the trajectories, indicating the direction of the moving particle. A bright color is used for the head of the polyline when a smoother and less shiny for the tail, giving the illusion of movement to the user as shown in Figure 8. Usually a sphere is added to the head of polyline.

Animation: Whats' more time-dependency of the data handled with a sequence of frames. A couple of animations has been created to show sequence of consecutive time windows. Each frame contains the data of a six hour time window and lasts for half a second. That way motion of particles can be visualized and be more comprehensive.

1.3 How do you cope with cluttering due to the amount of data available?

First of all we filtered out non informative data. Especially in MIPAS case, "clear" and "ice" detections were discarded due to lack of relative information with our case scenario. However the main cluttering problem stems from CLaMS trajectories. The factors that helped us to surpass this problem are the following.

3D representation: Spherical representation instead of map(plane) representation makes data look more sparse and clear due to the 3D representation instead of 2.5D. In an attempt to provide the user the ability to distinguish different particles easier, size had to be scaled accordingly and altitude had to be stretched.

Time window: In each frame data that do not belong on the respective time window have been filtered out. Especially on CLaMS trajectories the method which is used to decide which part of the trajectory will be rendered is as follows. At first we find the time of the trajectory set's seed point and we compare it with the window's limits. If the seed point's time lies inside the time window, with an extra 3-day margin, then we trim the trajectory part that corresponds

Table 1: Viewport Interaction style.

Mouse and Key Interaction	
Mouse Click and Hold	Translate, Rotate, Pan, Zoom.
Button 1	Rotate Camera (Actor) around focal point (origin).
Button 2	Camera Pan / Actor Translate.
Button 3	Camera Zoom / Actor Scale.
Key **e**	Exit application.
Key **f**	Fly to picked point.
Key **p**	Perform Pick operation.
Key **r**	Reset camera.
Key **s**	Solid Actor appearance.
Key **w**	Wireframe Actor appearance.

to this window's time (preferably 6 hour window) and we render it. The aforementioned three day margin was chosen empirically so that the continuity of the data would be highlighted, while simultaneously the cluttering would be avoided. Using larger margins, trajectories that came from anterior and posterior periods of time would clutter the scene. Also, as we step away from the seed points' locations the accuracy of the rendered trajectories is reduced, resulting in strange appearance and disappearance of trajectories during animation time. On the other hand using smaller margin only a part of the trajectories that are located close to seed points would be rendered resulting in discontinuity between frames.

1.4 How do you help users to efficiently browse through their data?

The interface of our program is shown in Figure 7. We use several widgets that help users browse through data efficiently. Moreover users can interact with the view-port using the mouse and keyboard to control the viewing angle.

Widgets: Date-time edit widget enables user to set initial and final date of time window hes interested in. There is an axes widget on bottom left corner of view-port showing the axes orientation. A compass widget located on top right corner of view-port pointing to north pole and giving user the ability to tilt camera. With balloon widget user can mouse over each volcano to see its name.

View-port interaction: The user can interact with the view-port through mouse and keyboard as mentioned before. The interaction style is described in Table 1. In case of animations users can change the viewing angle and play the video as many times they wish without reloading their data.

2 How can MIPAS detections be linked to eruption events?

Our method to assign MIPAS detections to eruption event is as follows: First of all two octrees are built, the first one contains volcano positions and the second one all MIPAS point detections. Then we read CLaMS data and for each trajectory, if seed points time belongs to time window selected by the user, then we go back in time to the initial trajectory point and using the volcanoes octree we decide on the eruption event of each trajectory. Then a sphere, cube or cylinder is rendered at CLaMS seed position (which is same as MIPAS position) based on volcano event Grimsvotn, Puyehue, Nabro respectively. Then we use the MIPAS octree to assign MIPAS detection to each trajectory. The color selected for each shape object based on MIPAS point detection and is the same as described in the previous section. In figure Figure 2 a screen shot of this implementation is shown.

2.1 How can the temporal evolution of eruption events be visualized?

Temporal evolution is visualized using animations. A couple of animations have been created using MIPAS and CLaMS data with the following method. Initially an octree is built based on MIPAS points and one based on volcano positions as stated in previous paragraph. That way CLaMS trajectories mapped to MIPAS detections and eruption events is the same as previous. The main difference from the previous static picture is that in this case we use a fixed six hour time window corresponding to one frame. The overall period of animation is defined by the user. Videos included in this report show a one month period after each event, when each frame lasts half a second. The first video emphasizes detection type by giving to trajectories a gradient color from brown to red for ash detection and a gradient color from green to white for sulfate aerosol detection. By watching this video its noticeable the fact that ash particles tend to be in the center of the vortices that mold in north hemisphere. A screenshot of this example is shown in Figure 9

2.2 How can the Grimsvotn and Nabro eruptions be separated?

Grimsvotn and Nabro eruptions are separated using volcanoes octree. Looking back in time through CLaMS trajectories and finding the initial point of each trajectory and the closest volcano to this. Then we assumed that this is the volcano that the trajectory belongs to. Mapping each eruption event to a different shape as done before, failed to represent the origin of each trajectory on an animation. In order to make the second animation which emphasize on the volcano events that each particle belongs to, we had to reconsider. For trajectories that assigned to Grimsvotn event a gradient color from dark green to light green selected, when for Puyehue eruption brown to red gradient has selected and for Nabro ultramarine to light blue. Screen shot of this video can be seen Figure 10. Watching this video particles from all volcanoes can be easily distinguished. Impressing is the fact that after some days particles from Puyehue eruption were detected on the northern hemisphere mixed with Grismvotn and Nabro particles.

3 What does AIRS add to the overall picture?

The great benefit of AIRS measurements is that provides continuous data, whereas MIPAS consist of point measurements. Also AIRS gives us at the same time both ash and SO^2 measurements at each point location, while in MIPAS data only the most dominant detection exists in every point. For example using AIRS we can see SO^2 steams emitted from Puyehue volcano as shown in Figure 3b. In this case if just the MIPAS data were used, the ash detections will suffocate the SO^2 detections compared to Figure 3a. However there is not an altitude field on AIRS data, so we tried to give them altitude based on MIPAS detections. For each quad that its value passes our threshold we found the closest MIPAS point with same detection type as the quad and we render that quad at his location with MIPAS point altitude. That technique is not as much informative as we expected to. One reason is the sparse nature of MIPAS detections so a lot of quads take altitude from the same MIPAS point. The second reason is that there is not high deviation of altitude between detections. In Figure 11 AIRS data that are given MIPAS altitude can be seen.

4 How did the eruption of Puyehue-Cordon Caulle affect air traffic?

In an attempt to see how the Puyehue event affected air traffic a third animation has been created. In this video ash particles that emitted from Puyehue volcano are shown from the time that event started till one month later. During this period of time ash particles passed above Australia making hundreds of flights to be canceled. With a closer look to that video vortexes that are created can be spotified. Those vortexes were created mainly close to southern pole, but in some cases as someone can see in Figure 12 they were created above south part of Australia.

References

[1] Kitware, Inc. *The Visualization Toolkit User's Guide*, March 2010.

[2] P. A. KOLERS and M. V. GRUNAU. Shape and color in apparent motion. In *Vsion Res '91*, volume 16, pages 329–335, 1975.

[3] M. Levoy. *Display of Surfaces from Volume Data*. PhD thesis, University of North Carolina at Chapel Hill, 1989.

Fig. 1: MIPAS data are colored based on detections type that measured at 6th of June 2011.

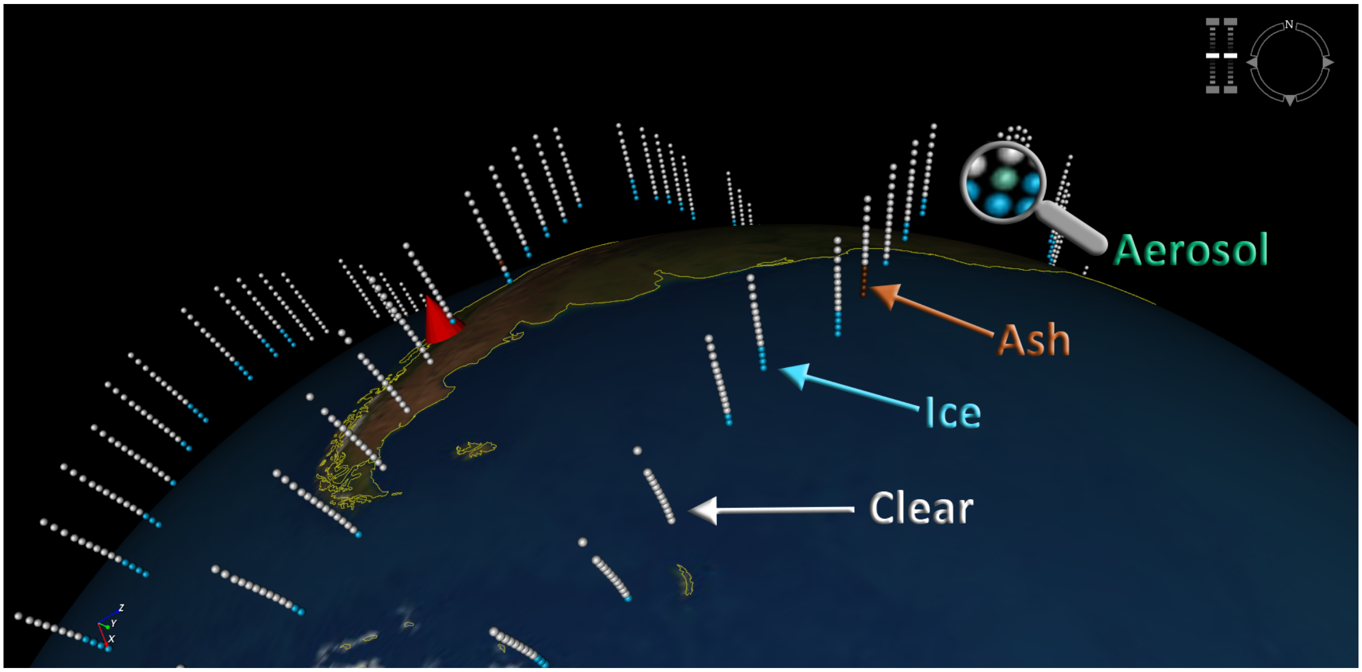
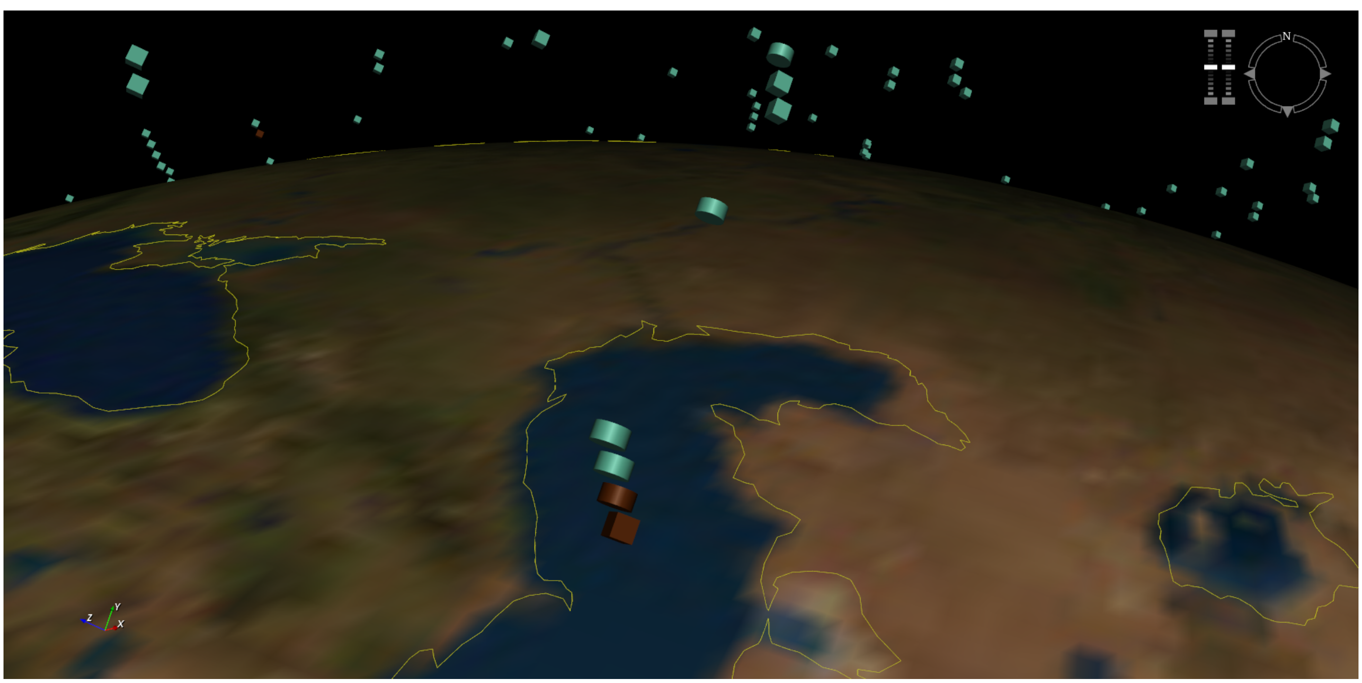


Fig. 2: Ash and aerosol MIPAS detections which shape was assigned, based on its volcano origin. To identify each particles origin CLaMS trajectories are used.



(a) AIRS ash detectons, six hours after Puyehue mountain started injecting gas into the southern hemisphere.

(b) Using AIRS data we can see SO^2 detections that came from Puyehue event.

(c) AIRS SO^2 detecton at 14^{th} of June the day that Nabro volcano erupted.

Fig. 3: AIRS data detections after Puyehue and Nabro eruptions

Fig. 4: The color that assigned to CLaMS trajectories is based on time. A gradient color from blue to white has been used. Also white transparent spheres indicates seed points locations.

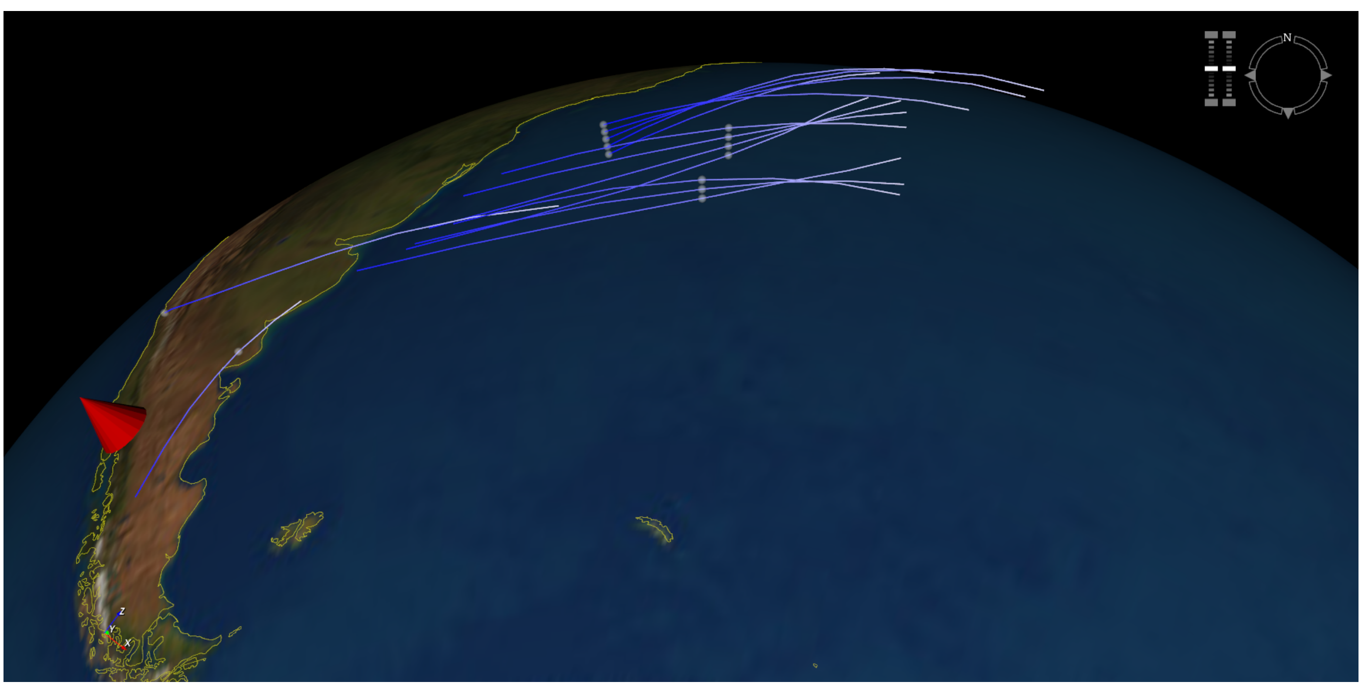


Fig. 5: First tropopause is defined everywhere. Color is based on altitude, also transparency added.

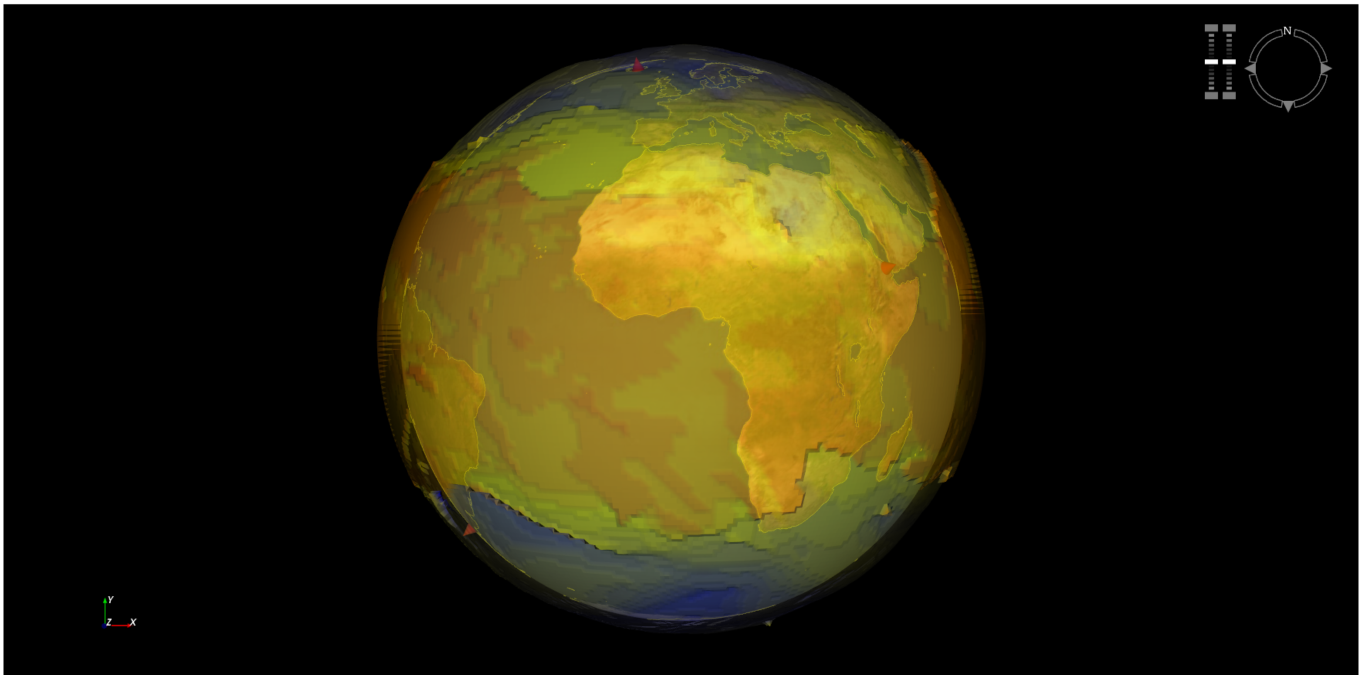


Fig. 6: Second tropopause is defined only at locations where there actually is a double tropopause condition. Colors maped to altitude, also transparency added.

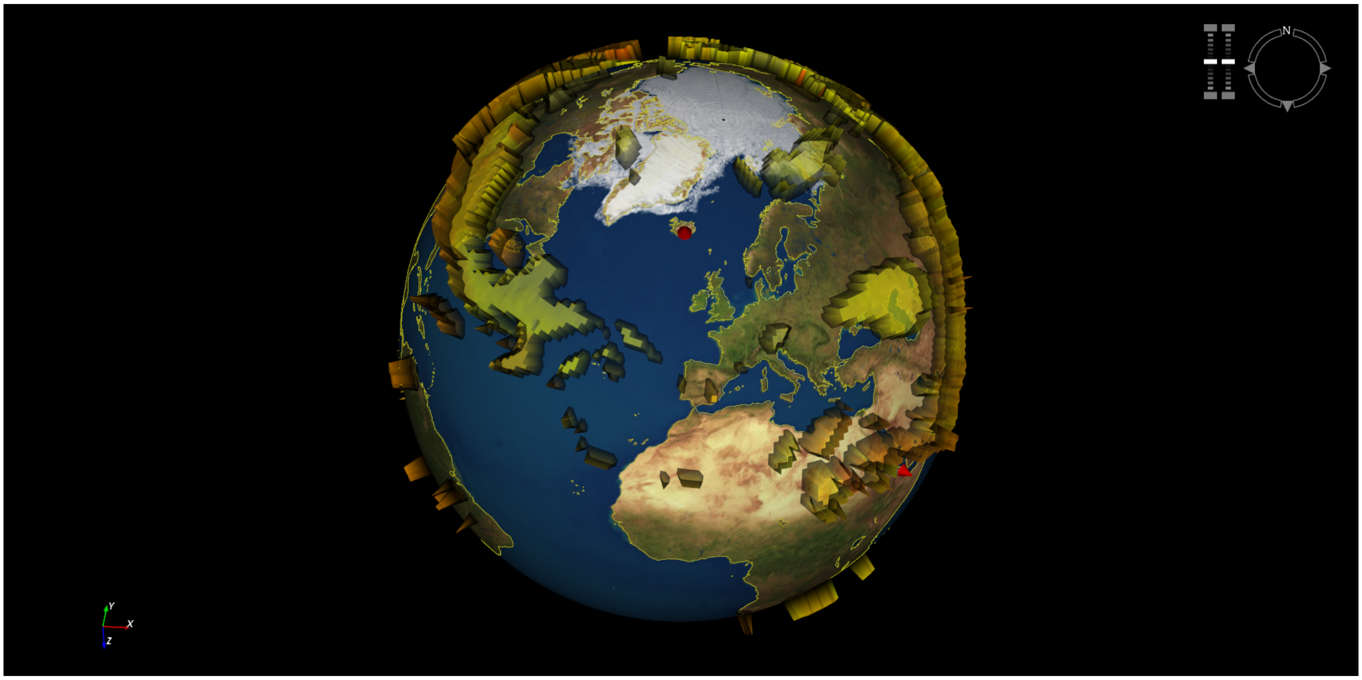


Fig. 7: Programs interface showing widgets used to help users browse their data.

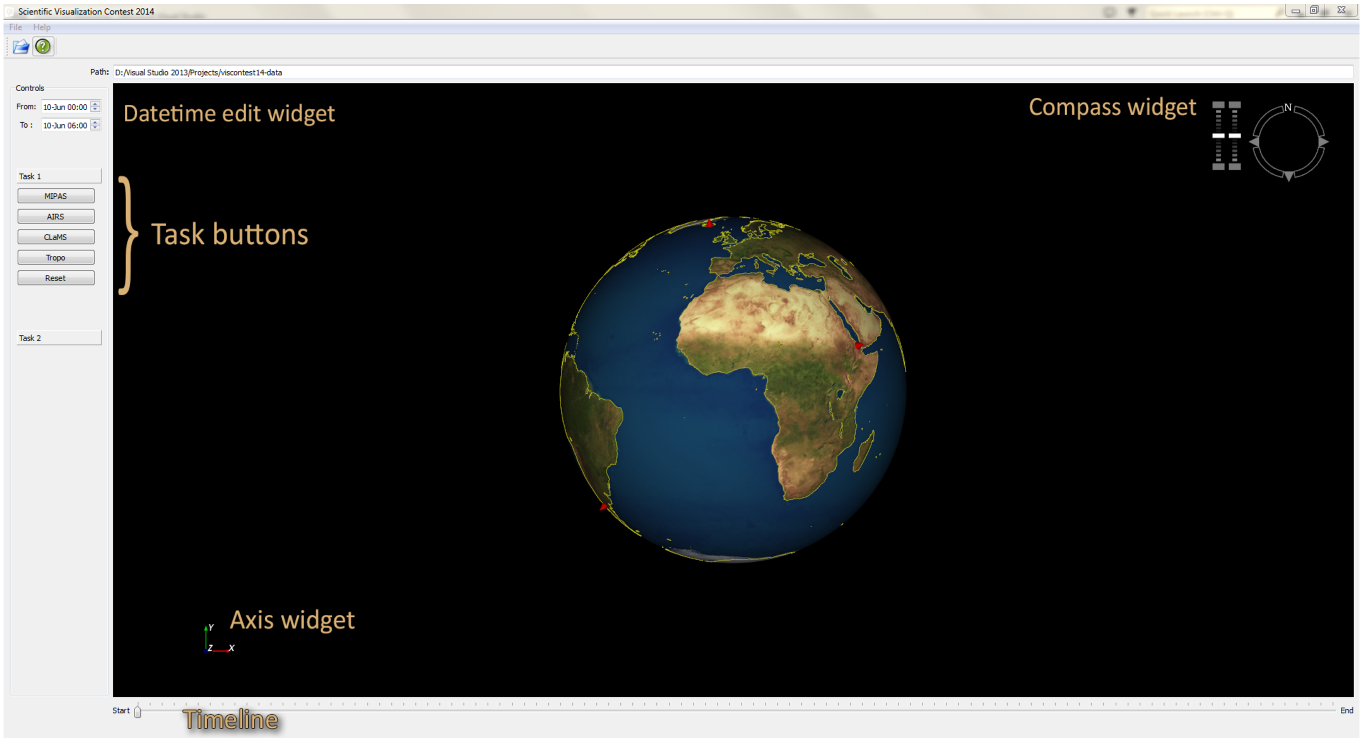


Fig. 8: A gradient color from brown to red has assigned to CLaMS to illustrate moving effect. Spheres has been placed on head of each trajectory.

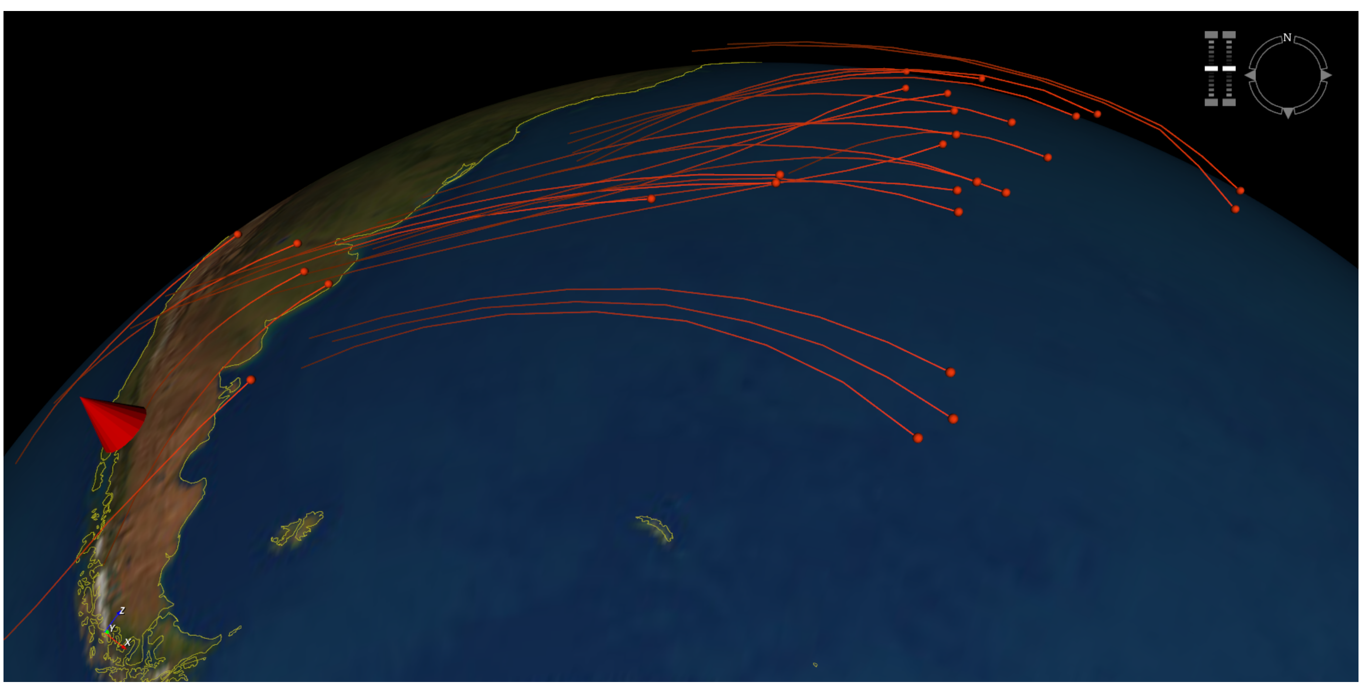


Fig. 9: CLaMS trajectories of northern hemisphere that colored based on respected MIPAS detections. Ash particles tend to be in the center of the vortices.

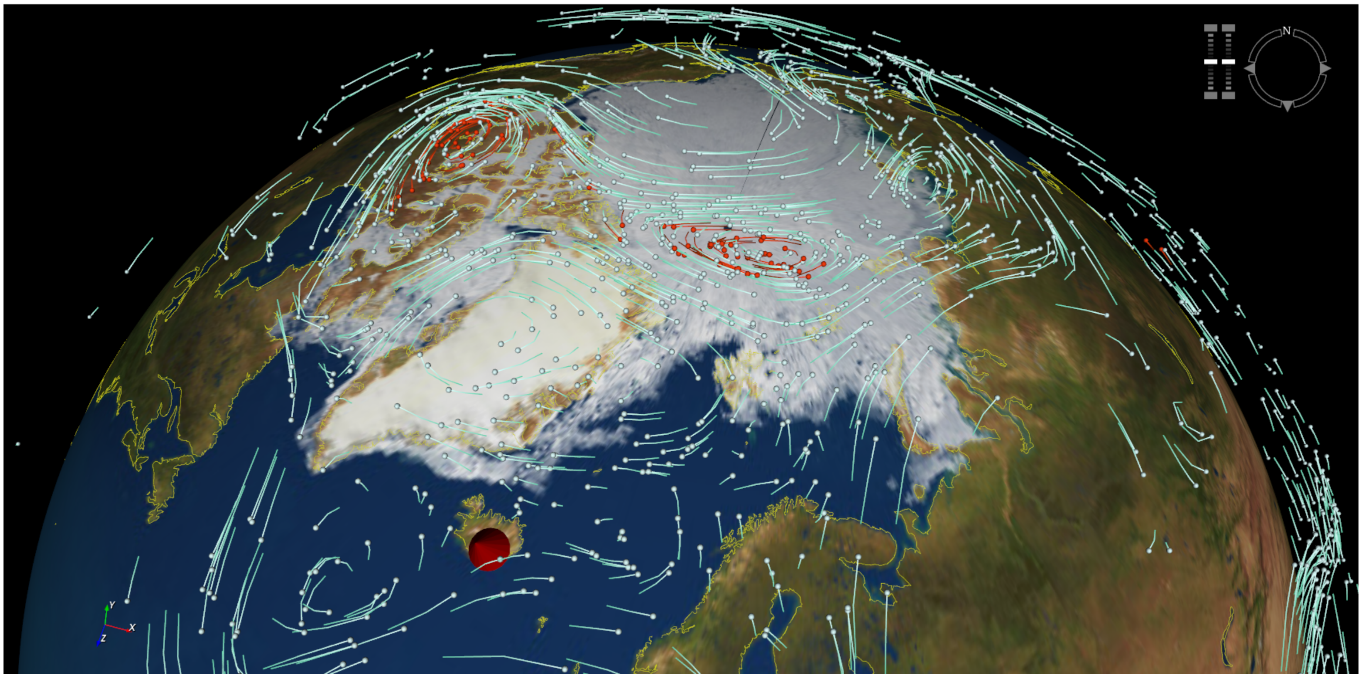


Fig. 10: CLaMS trajectories colored based on volcano event they came from.

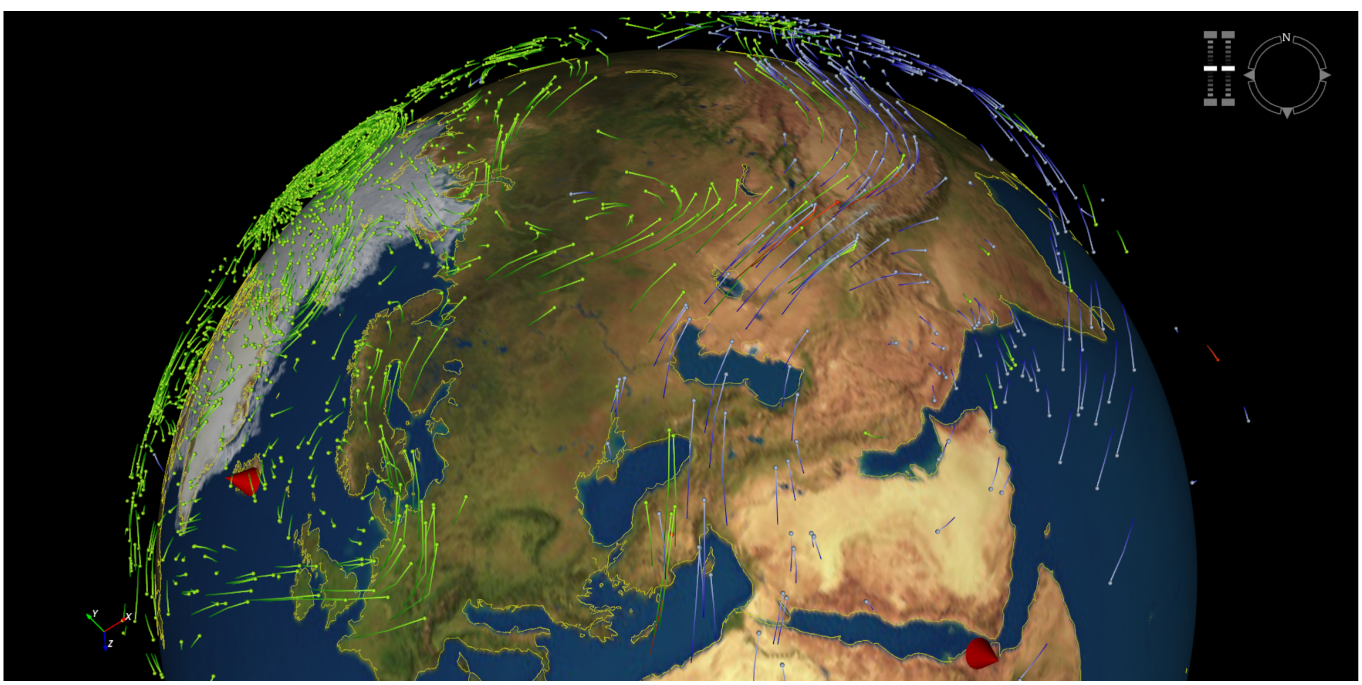


Fig. 11: AIRS data from ash detections that given MIPAS respective detection altitude.

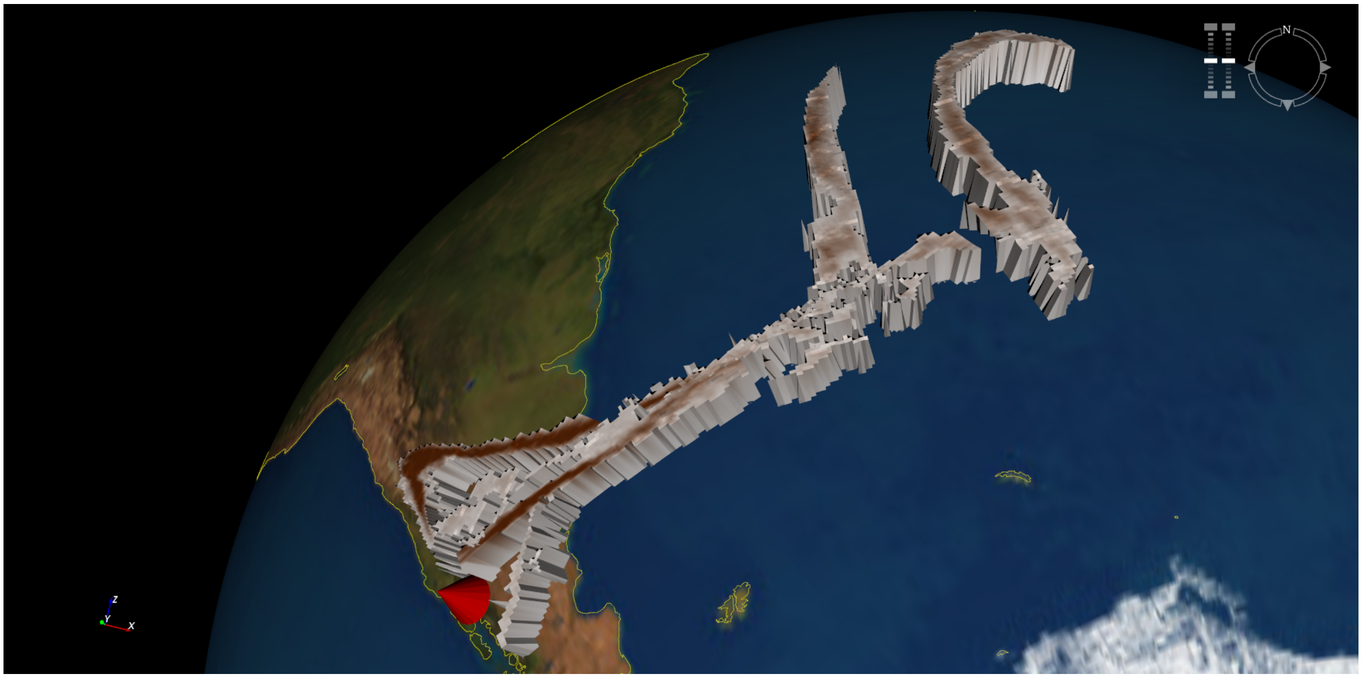


Fig. 12: AIR traffic of southern pole. One week after Puyehue event, a vortex has been mold above Australia.