Interactive Visualization of Atmospheric Data for Eruption Events

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ABSTRACT

We present our approach to interactive visualization and analysis of atmospheric data for eruption events. The proposed approach combines traditional and novel data processing and visualization techniques. We interpolate trajectories to enable nesting detailed and high resolution motion fields using low resolution trajectory information (a combination of a long-trajectory adjustment with spatio-temporal interpolation). An interactive GPU-based probing technique implemented in a geometry shader enables a user specified geometric shape to be tested for intersection with all trajectories. Only the trajectories passing through the probe are displayed. We implemented our approach using GPU-parallelism and new features in OpenGL 4.4 shaders to achieve interactive frame rates.

Index Terms: I.3.3 [COMPUTER GRAPHICS]: Picture/Image Generation—Display algorithms; I.3.6 [COMPUTER GRAPHICS]: Methodology and Techniques—Graphics data structures and data types

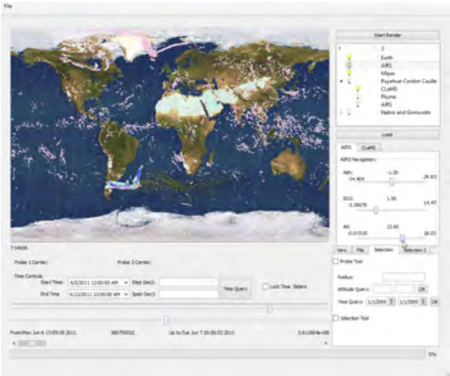

Figure 1: The developed tool.

1 INTRODUCTION

2014 IEEE Scientific Visualization Contest [1] provides a challenging visual data analysis application scenario. We have developed an interactive visualization tool (Figure 1) that provides a simple (single window) and effective Qt-based user interface for interactive data analysis. We take advantage of new OpenGL 4.4 features and shader programming to move some of the data processing into the OpenGL pipeline. This supports real-time GPU-based techniques, including user interaction techniques for data processing (aggregation, selection, manipulation, interpolation, intersection, and filtering) and visualization techniques. The vertex shader calculates data dependent color and opacity values. The fragment shader calculates lighting at the individual fragment level. The geometry shader is used for vertex culling and generation of data constructs while supporting probing and user interactions (MIPAS data). Two user controlled data probes enable interactive data selection and filtering by using set operations (intersection, union, complement) on the subsets of data selected by individual data probes.

2 DATA PROCESSING

We address the data size and complexity by using a combination of CPU- and GPU-side data processing to implement novel interpolation and intersection test techniques. The developed interpolation technique can interpolate trajectories at any location not given in CLaMS data sets. This enables nesting detailed and high resolution motion fields (e.g., narrow plumes) using low resolution trajectory information (e.g., CLaMS). The technique consists of two modules, the along trajectory adjustment (ADJUSTT) and the spatio-temporal interpolation (SPATIOT). We use motion information (spatial translations) from the nearest 9–16 CLaMS points (adjusted in time and space using ADJUSTT to match the time of the detection) and then spatially interpolate the translation information to the un-gauged location under consideration based on its relative location to the nearest CLaMS points. We used the technique to: *1)* Advect an artificially simulated plume consisting of five points injected at the center and perimeter of the volcano opening every one hour. *2)* Correct AIRS positions due to the different acquisition times and reconstructed the 12 hour full scan at any desired time (this also enabled assignment of Z attribute to AIRS data). *3)* Separate detections that belong to certain eruption (ADJUSTT for MIPAS and both ADJUSTT and SPATIOT for AIRS data sets).

ADJUSTT determines the position of any CLAMS point in between its successive 3-hours positions using a 2nd degree polynomial by using the spatial coordinates shift as response and the difference in time $dt < 3$ hours as predictor (Figure 2a).

SPATIOT determines the motion vector during a certain period at any un-gauged location (i.e., not available in CLaMS data) by interpolating the corresponding shifts of the nearest CLaMS points (in time and space) to the un-gauged location. The spatial interpolation implemented is based on the inverse distance weighted principle [3] in which closer points are given much higher weights (Figure 2b).

The intersection test determines whether a trajectory passed through a search distance from the volcano during eruption or not. For example, in order to find MIPAS seed points that belong to a certain volcano we first select all corresponding CLaMS positions that fall within the eruption periods of the volcano and then test if these positions crossed the volcano search distance (i.e., radius). For that reason, the minimum distance from the volcano to a trajectory is found in a rapidly converging approach (Figure 3).

The search distance is 0.5 degrees and the eruption times are two periods for Puyehue-Cordón Caulle eruption ([360460800, 360892800] or [361065600, 361238400]) and one period for Nabro eruption ([361238400, 362502000]). ADJUSTT determines the nearest point (NP) position along the trajectory and the intersection time (passage time) to trim the trajectory before reaching the volcano position (selects plume-only CLaMS point).

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3 VISUALIZATION

We use the five specified tasks [1] to elaborate on the techniques we developed and to provide answers to the questions posed.

Task 1: Initial data integration and browsing

In order to solve the problem of integrating multiple datasets into a unified framework, we developed a tool to give the user the freedom to load and unload entire datasets or subsets specific to a volcanic eruption (Figure 4).

Visual encodings (color and opacity) are updated in real time in the vertex shader and can be manipulated by the user through the use of attribute sliders (Figure 5).

Time-dependent data are handled by using two time sliders to select data for viewing within a specified time period, or to create a sliding time window for animation by locking the two sliders together. Time slider ranges are specified by the loaded data or through user input.

For clutter reduction, we developed an interactive GPU-based probing technique [2]. The user specifies a 3D geometric shape, a probe. This shape is used in the geometry shader to test for intersection with all trajectories. Only the trajectories passing through the probe (intersecting with the shape) are displayed. The probe can be moved or resized to change the data query parameters. An additional time query can be added to the probe to filter only trajectories that pass through the probe within a specified time interval. This is very useful in linking detections to eruption events.

Another way to help the user to efficiently browse through and explore data is by using the AIRS data as a sliding culling plane for other datasets.

Task 2: How can MIPAS detections be linked to eruption events?

We visualize the temporal evolution of eruption events through mapping MIPAS detections to their corresponding trajectories from CLAMS data. This mapping can be done both on the GPU and on the CPU. Our GPU-based probing technique can filter out MIPAS detections whose corresponding trajectories intersect the probe during the time of eruption. Intersection tests on the GPU assume linear interpolation between CLAMS points. On the CPU, a second degree polynomial was used for interpolation and intersection tests with eruption location excluding all points that cannot be mapped back to the volcano location and time. Visualizing the CPU-generated MIPAS plume along with the GPU-selected detections provides context and reveals the correctness of our interactive GPU method (Figure 6).

We use the same probing method and the CPU-generated plume to separate the Nabro eruption plume while masking out aerosol detections that were already present from Grimsvötn eruption. As a result, we get an animation of both plumes representing the two eruptions together (Figure 7). An altitude view reveals the different altitude ranges in which each plume exists.

Task 3: What does AIRS add to the overall picture?

Comparing our generated MIPAS plumes with raw AIRS data reveals mineral dust clouds, especially in the Sahara desert in North Africa. For a more accurate comparison between the two instruments, we needed to correct AIRS data through time to account for different acquisition times in AIRS data. Again, we developed both CPU (Figure 8) and GPU (Figure 9) implementations.

Our GPU-based AIRS tracking technique uses a time-regular synthetic plume that we created through spatio-temporal interpolation of CLAMS data. Given the regularity of this plume, an efficient nearest neighbor search is performed in the geometry shader to map each AIRS point to its nearest neighbor's location at the time step specified by the time slider. However efficient, this GPU technique has limited accuracy. We generated a more accurate AIRS plume on the CPU through mapping each AIRS point to the nearest neighborhood in CLAMS trajectories and performing spatio-temporal interpolation as described Section 2. This also helped us pinpoint the vertical extent of AIRS detections and generate a 3D cloud for it.

Task 4: How did the eruption of Puyehue-Cordón Caulle affect air traffic?

Our three-dimensional time-corrected AIRS plume makes it easy to identify dangerous corridors in the southern hemisphere at any point in time. In addition, our simulated plume overlaid on corrected AIRS data provides more complete picture of the spatio-temporal evolution of the volcanic plume. We extended our probing technique (Figure 10) by providing the user with a second interactive probe. Only the trajectories flowing through the two probes are displayed. We can place our second probe on of the AIRS plume to display trajectories flowing through it from the volcano. We can also place our second probe on any part of the Toulouse, Darwin, or Wellington advisory centers covered regions to observe detections coming from the volcano to that region (Figure 11).

Task 5: How did Nabro aerosol enter the stratosphere?

We matched each point in our generated plumes and in CLAMS trajectories to the corresponding $tropo1$ and $tropo2$ tropopause values. These values were then passed to the geometry shader as vertex attributes. Trajectories in which at least one point traversed the first tropopause are displayed while those who never cross it are filtered out. Trajectory segments in which traversal occurs are shown in red (Figure 12). We also add the point generated from the MIPAS plume and only those points that exceed $tropo1$ altitudes are displayed. We can hence rule out the hypothesis that Asian Monsoon circulation is the sole pathway into the stratosphere since we can see multiple other locations where aerosol detections entered it.

We can also explore how the locations with high gradients match the trajectories penetrating the tropopause. This can give confidence on using the potential temperature to determine uplfit regions and can be used as the second methodology for tropopause height estimation (Figure 13).

4 CONCLUSION

We have created a unified framework and the corresponding tool to address the challenges of the 2014 IEEE Scientific Visualization Contest [1] visual data analysis application scenario. The emphasis is on interactivity and use of modern GPU shader capabilities to achieve real-time performance. Our probing technique can be generalized to any logical combination of probes to select subsets of trajectories which help identify regions of interest. Our spatio-temporal interpolation technique is an efficient tool that has been implemented for plume nesting and time-space correction tasks. In addition, it can be used for domain filling studies. In the future, we will focus more on interactive matching and tracking of detections through spatio-temporal interpolation on the GPU. This requires an efficient hierarchical data structure to store trajectories in GPU memory and to speed up nearest neighbor search to achieve interactive frame rates. Improving the accuracy of the GPU AIRS tracking technique is another promising direction for future research.

REFERENCES

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[2] M. ElShehaly, D. Gračanin, M. Gad, H. G. Elmongui, and K. Matković. Poster: StreamProbe: A novel GPU-based selection technique for interactive flow field exploration. In *Proceeding of the IEEE VIS 2014 Conference*, 9–14 Nov. 2014. To appear.

[3] D. Shepard. A two-dimensional interpolation function for irregularly-spaced data. In *Proceeding of the 1968 23rd ACM national conference*, 517–524, 1968.

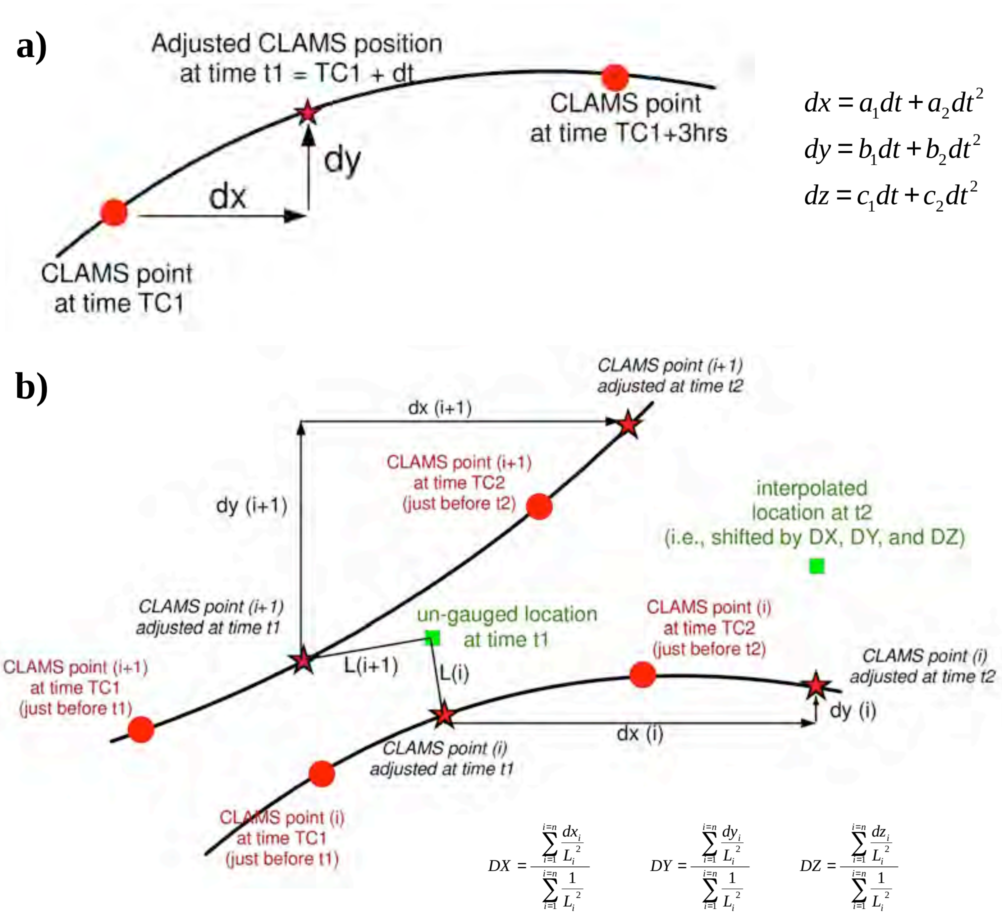


Figure 2: Data processing: the spatio-temporal interpolation technique. **a) ADJUSTT**: a_1, a_2, b_1, b_2, c_1, c_2 are pre-calculated at every CLaMS position using least squares and added as new attributes to CLaMS data sets. Three position (the current position and the subsequent two positions) are used in the least squares to pre-determine the coefficients at each clams position on the regular 3-hours CLaMS scale. **b) SPATIOT**: n is the number of nearest neighborhood CLaMS points used in the interpolation (recommended n = 5–16, 9 is used).

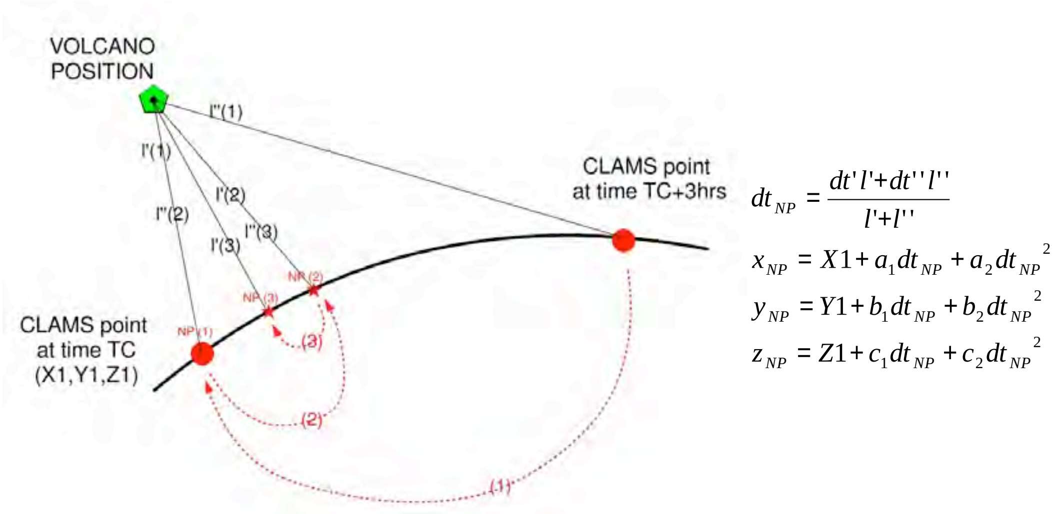
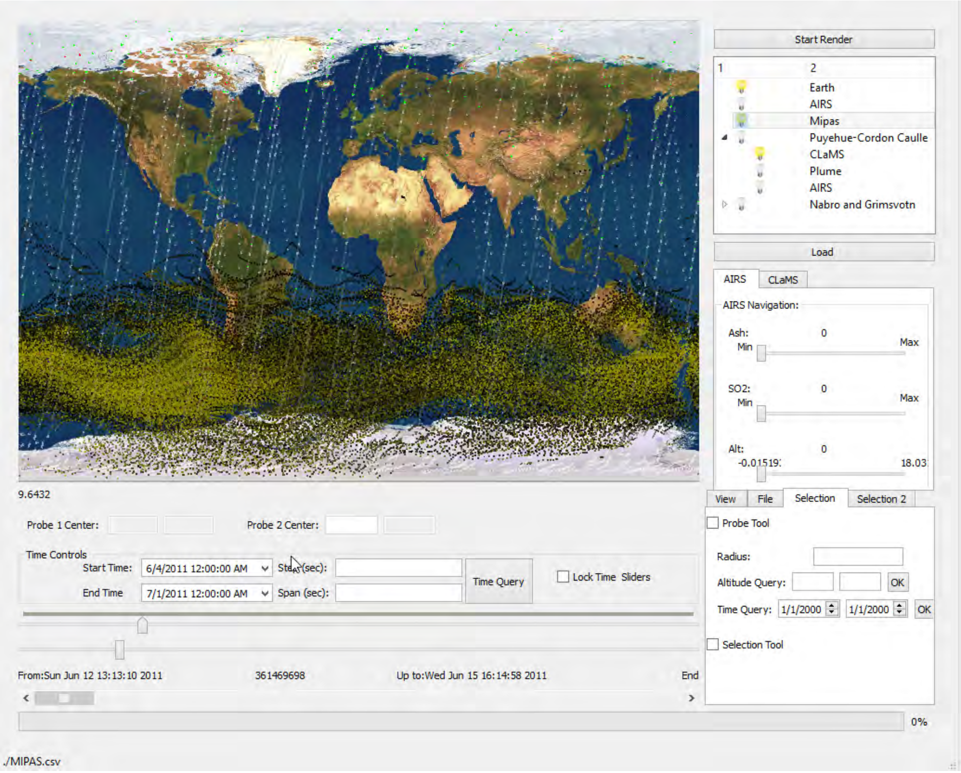


Figure 3: Data processing: the intersection test. NP stands for nearest point to the volcano on the trajectory, dt' is time from the first CLaMS point to the dash-location, dt'' is the time from the first CLaMS point to the double-dash-location. The approach stops when the difference between x' in successive trials is less than 0.0001 degrees. If the calculated shortest distance is less than the search distance (eruption circle), then it can be concluded that this trajectory passed through the volcano eruption.



AIRS Navigation:

Ash: 0 Min Max

SO2: 0 Min Max

Alt: 0 -0.01519: 18.03

9.6432

Probe 1 Center:

Probe 2 Center:

Time Controls

Start Time: 6/4/2011 12:00:00 AM

End Time 7/1/2011 12:00:00 AM

Step (sec):

Span (sec):

☐ Lock Time Sliders

☐ Probe Tool

Radius:

Altitude Query:

Time Query: 1/1/2000 1/1/2000

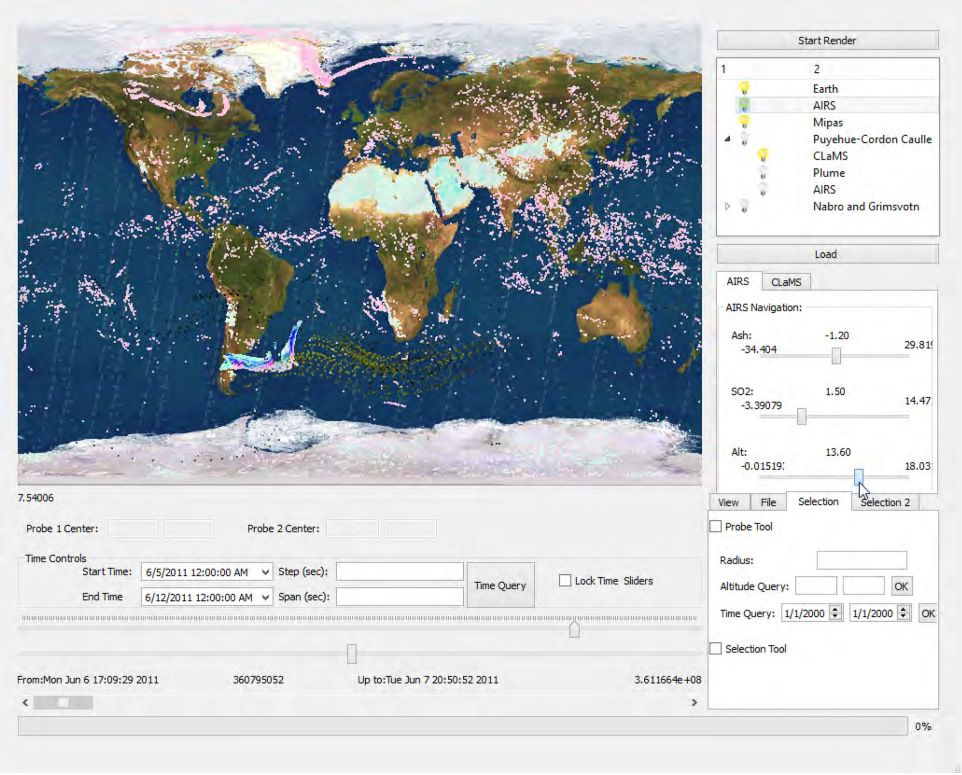
☐ Selection Tool

From:Sun Jun 12 13:13:10 2011 361469698 Up to:Wed Jun 15 16:14:58 2011

0%

./MIPAS.csv

Figure 4: Task 1: Visual encoding for MIPAS and CLaMS data.



AIRS Navigation:

Ash: -1.20 -34.404 29.81

SO2: 1.50 -3.39079 14.47

Alt: 13.60 -0.01519: 18.03

7.54006

Probe 1 Center:

Probe 2 Center:

Time Controls

Start Time: 6/5/2011 12:00:00 AM

End Time 6/12/2011 12:00:00 AM

Step (sec):

Span (sec):

☐ Lock Time Sliders

☐ Probe Tool

Radius:

Altitude Query:

Time Query: 1/1/2000 1/1/2000

☐ Selection Tool

From:Mon Jun 6 17:09:29 2011 360795052 Up to:Tue Jun 7 20:50:52 2011 3.611664e+08

0%

Figure 5: Task 1: Attribute sliders for the visual encoding of AIRS data.

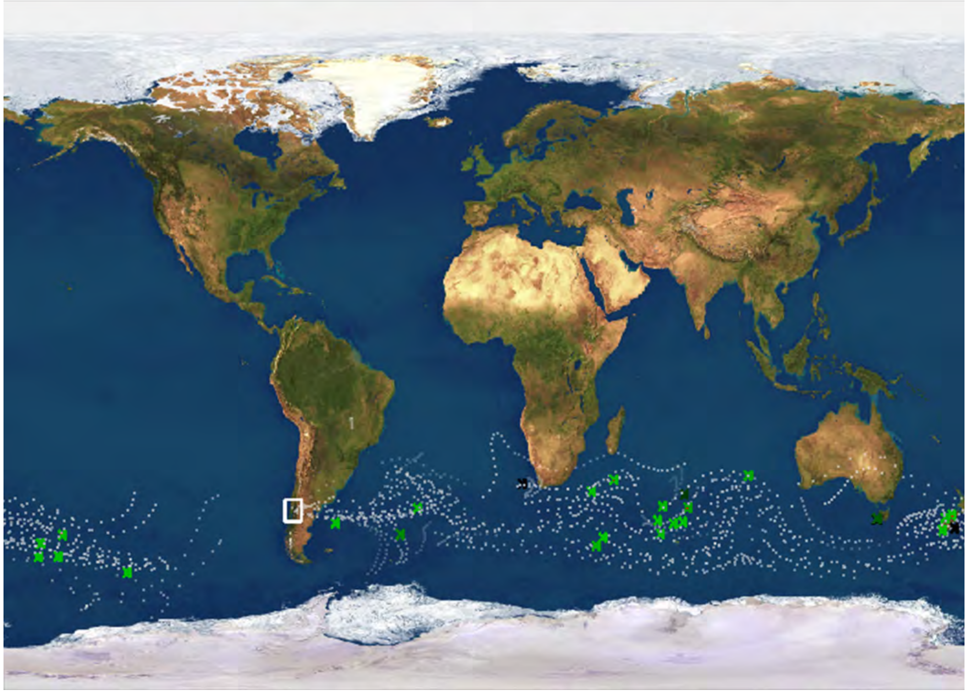


Figure 6: Task 2: Temporal evolution of MIPAS detections for Puyehue-Cordón Caulle eruption (overlayed on CLaMS trajectories).

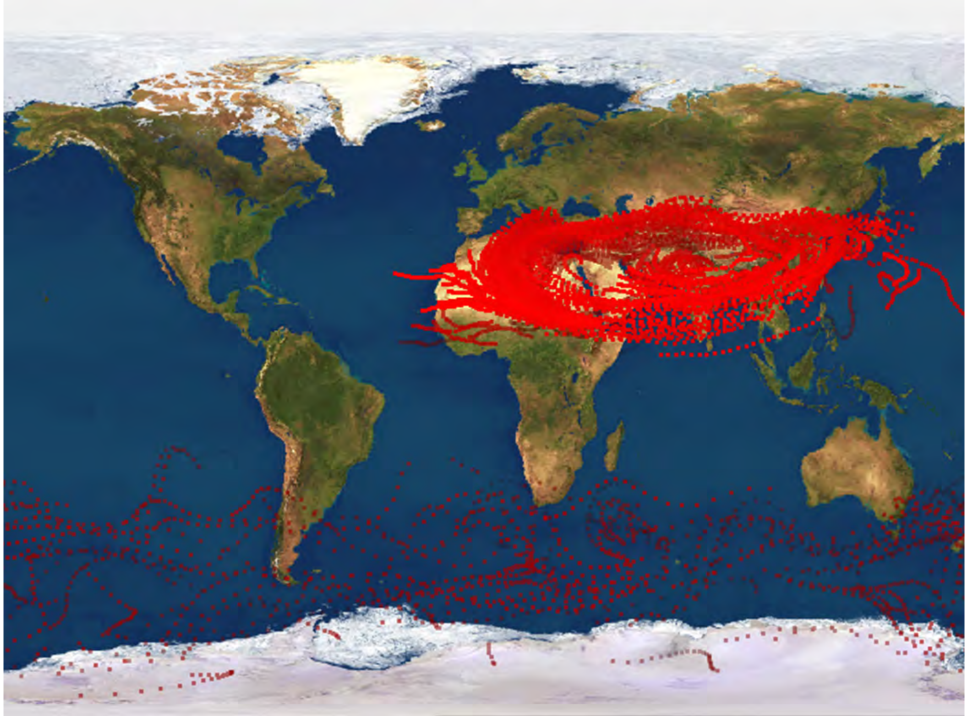


Figure 7: Task 2: Visualization of Puyehue-Cordón Caulle and Nabro eruptions with masking of Grimsvötn eruption.

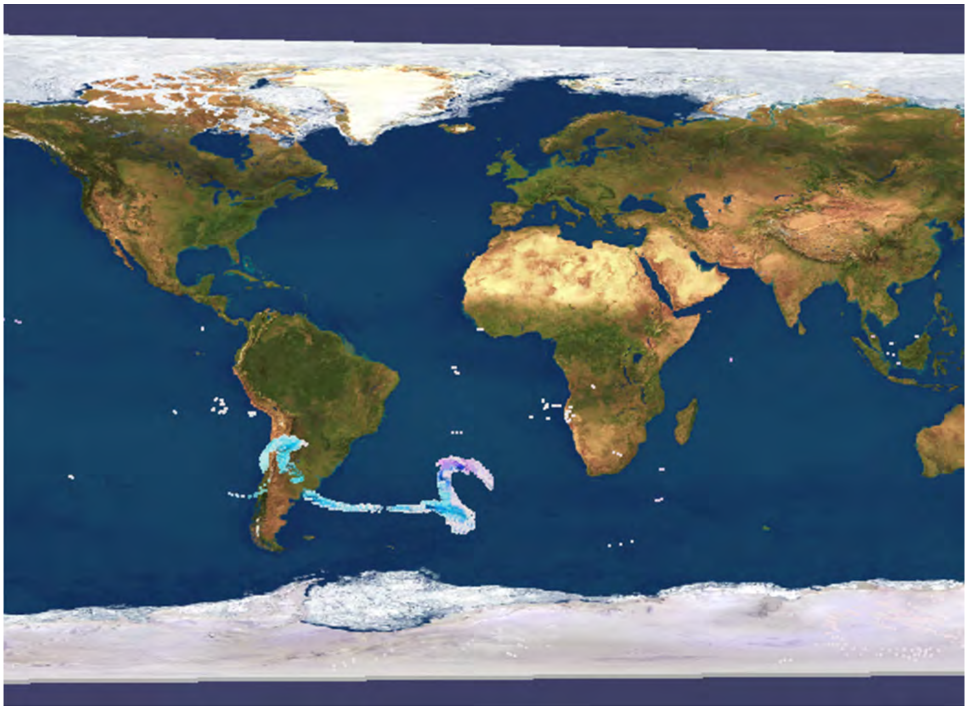


Figure 8: Task 3: CPU corrected AIRS data.

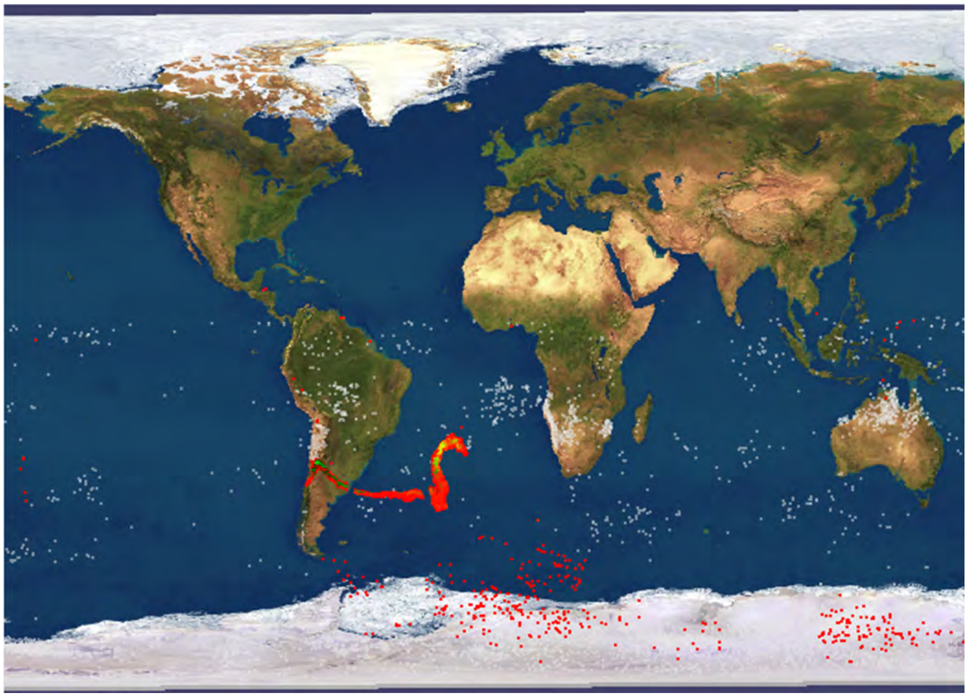
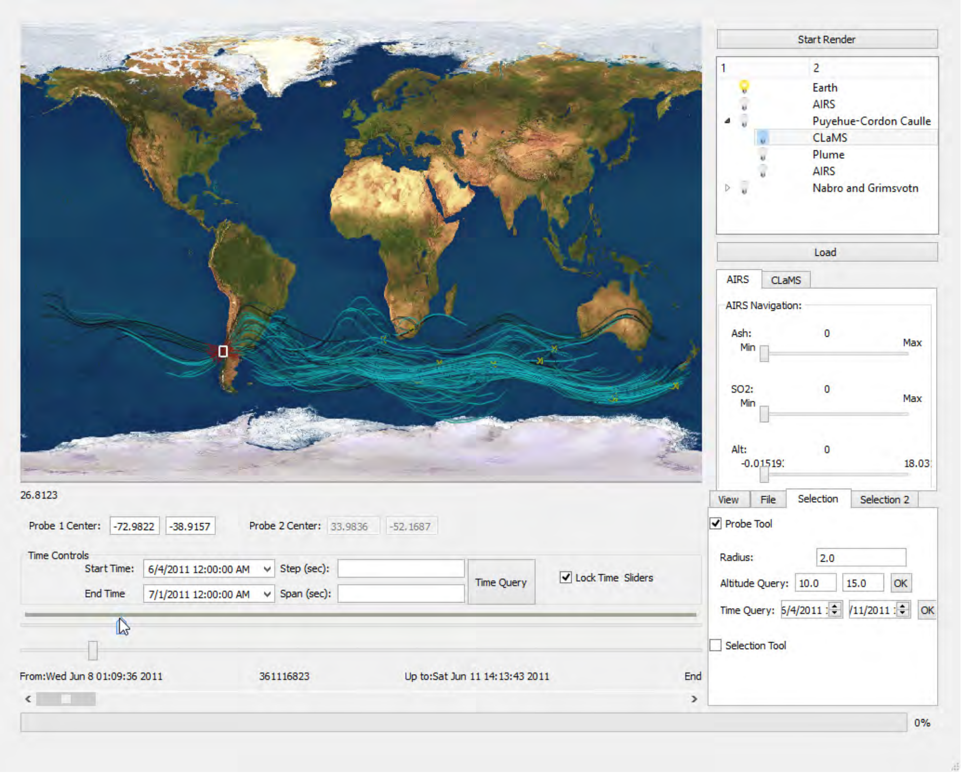


Figure 9: Task 3: GPU corrected AIRS data.



Earth
AIRS
Puyehue-Cordon Caulle
CLaMS
Plume
AIRS
Nabro and Grimsvotn

AIRS Navigation:
Ash: 0 Min Max
SO2: 0 Min Max
Alt: 0 -0.01519: 18.03

26.8123

Probe 1 Center: -72.9822 -38.9157
Probe 2 Center: 33.9836 -52.1687

Time Controls
Start Time: 6/4/2011 12:00:00 AM
End Time 7/1/2011 12:00:00 AM
Step (sec):
Span (sec):
☑ Lock Time Sliders

From:Wed Jun 8 01:09:36 2011
361116823
Up to:Sat Jun 11 14:13:43 2011

☑ Probe Tool
Radius: 2.0
Altitude Query: 10.0 15.0
Time Query: 5/4/2011 /11/2011
☐ Selection Tool

0%

Figure 10: Task 4: Single probe — selecting the source of the eruption of Puyehue-Cordón Caulle.

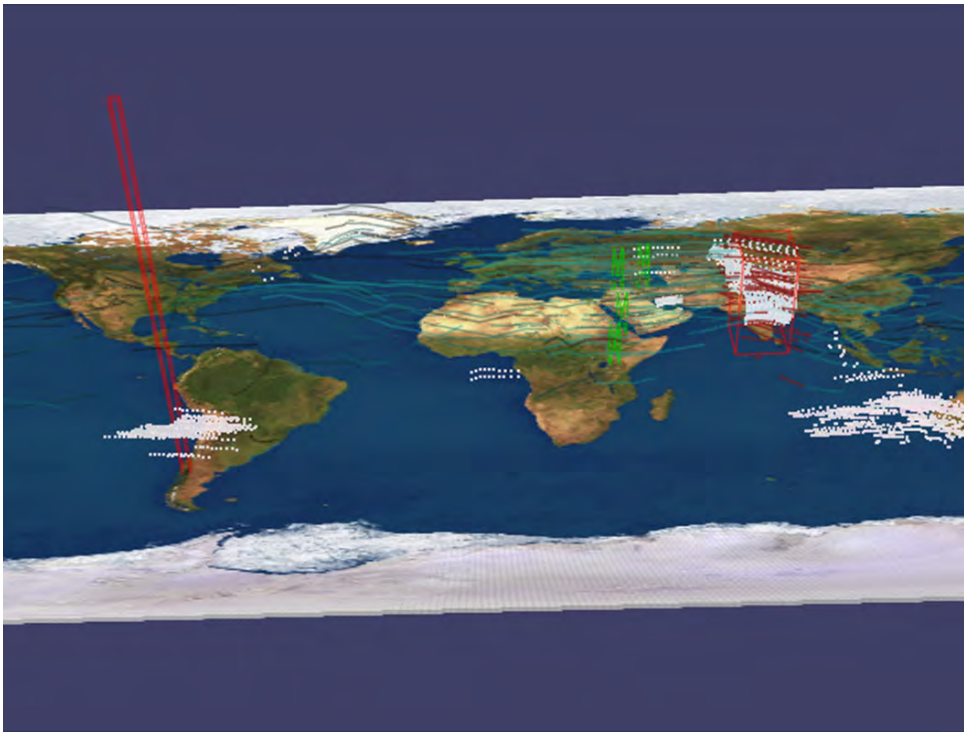


Figure 11: Task 4: Two probes — selecting the source of the eruption of Puyehue-Cordón Caulle and the affected area (destination).

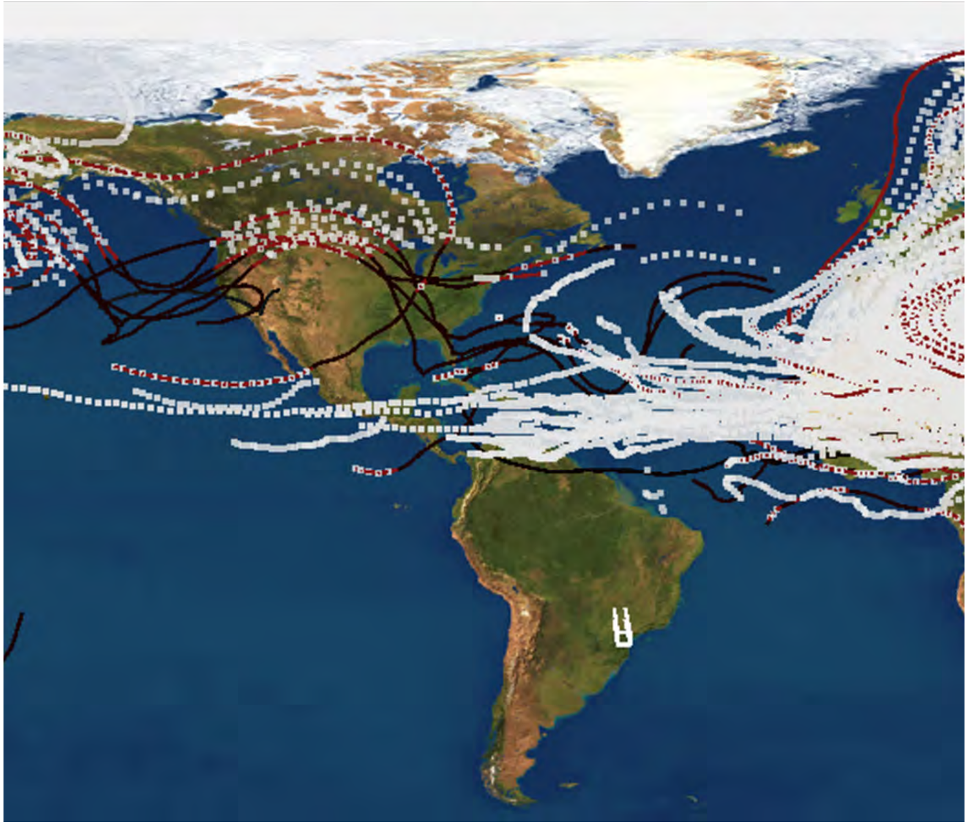


Figure 12: Task 5: Trajectories in the tropopause (red) and below the tropopause (black).

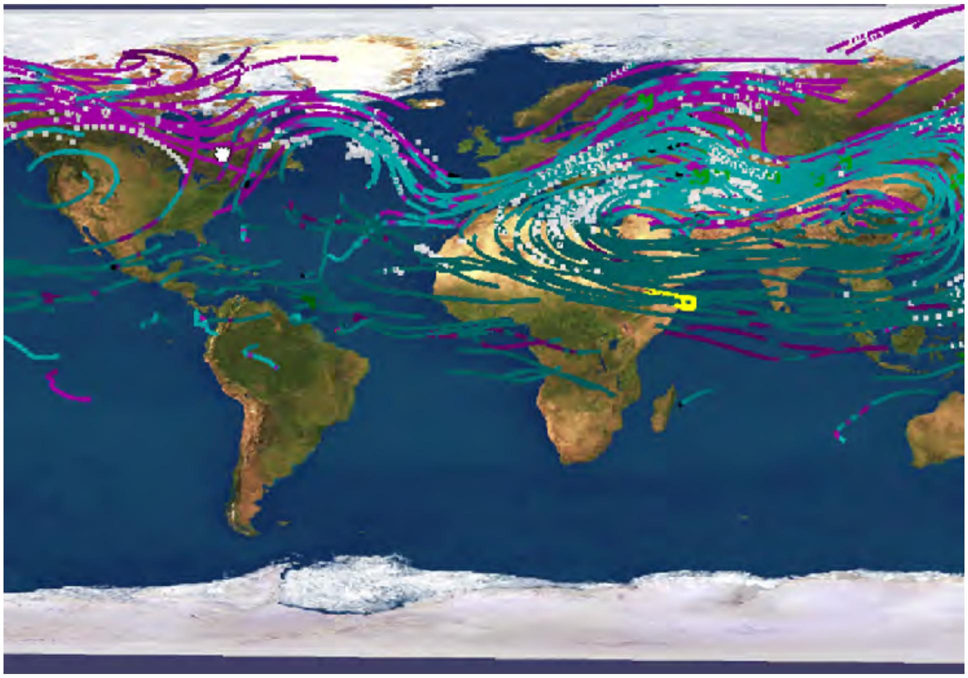


Figure 13: Task 5: Vertical transport and temperature gradient. Red indicates high positive gradient and blue high negative gradient.