

VISUALIZATION OF NASA A-TRAIN VERTICAL DATA ON GOOGLE EARTH™

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ABSTRACT:

Google Earth is becoming a popular browser for online geographic-related data and information. It integrates satellite imagery, aerial photography, digital map data, and social-economic data to make a virtual three dimensional interactive template of our living planet. The Keyhole Markup Language, promoted by Google Inc., offers easy and convenient interfaces for people publishing, sharing and integrating their data and information that has a geospatial element on Google Earth. A new solution is proposed here to integrate NASA A-Train vertical data with Google Earth for promoting the scientific and public use of A-Train data. The vertical data are from the A-Train constellation satellites CloudSat, CALIPSO, and Aqua. The NASA Goddard Earth Science Data Information Service Center (GES DISC) Interactive Online Visualization ANd aNalysis Infrastructure (GIOVANNI) A-Train system is first used to produce the image curtain based on user inputted interested spatial/temporal range and other physical parameters. A COLLADA (COLLABorative Design Activity) model is devised for visualizing image curtain on Google Earth. Using COLLADA models and satellite orbit coordinates, an orbit curtain model is designed and implemented in KML. The orbit curtain model is made from repeated COLLADA models. The finished KML file can be rendered, transparently or opaquely, on Google Earth to visualize the vertical data from A-Train. The research bridges the science and data with scientists and the general public in a popular way. Also, synergistic visualization, sharing and discovery of the knowledge over massive diverse simultaneous geospatial data become possible.

1. INTRODUCTION

NASA A-Train satellite constellation is a carefully planned formation flying, consisting of seven missions -- three Earth Observing System (EOS) missions, three Earth System Science Pathfinder (ESSP) missions, and one French Centre National d'Etudes Spatiales (CNES) mission flying in close proximity. This formation flying allows for "synergy – meaning that more information about the condition of the Earth is obtained from the combined observations than would be possible from the sum of the observations taken independently" (NASA, 2003). In the order of time, the A-Train seven missions are Orbiting Carbon Observatory (OCO), Aqua, CloudSat, CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation), PARASOL (Polarization and Anisotropy of Reflectances for Atmospheric Science coupled with Observations from a Lidar), Glory and Aura. "The value of the formation flying is that the whole is greater than the sum of its parts" (NASA, 2003). Figure 1 illustrates the A-Train satellite constellation.

Google Earth is facilitating people to discover, add, and share information about any subject that has a geographical element via its virtual template of the world. Although, the original purpose of Google Earth is to use the Earth itself as an organizing metaphor for digital information, now, Google Earth virtual globe is changing the way in which scientists and general public interact with the geospatial data in a virtual environment. The best merit of Google Earth is the ease with which the user can zoom into street level from the global, user can add and share their data, and use can find others' data.

Therefore, there is renewed hope that all sorts of information on the state of the planet will become available to all with a few moves of the mouse (Butler, 2006). Our research is just to promote the utilization of NASA vertical profiles of atmospheric data via Google Earth.

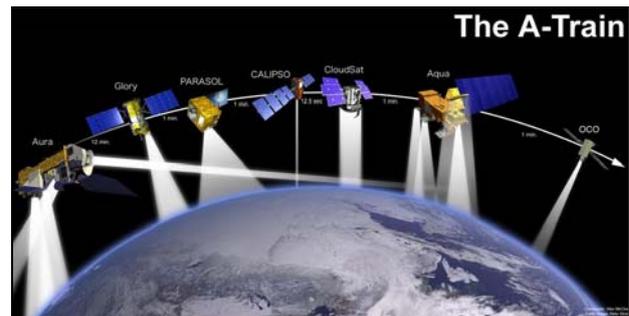


Figure 1. The A-Train satellite constellation

Since 2006, Google Earth has been used in many fields, including climate change, weather forecasting, natural disasters (e.g. tsunami, hurricane), the environment, educations, and cross-platform view sharing. These applications primarily process geospatial two-dimensional (2D) data and socio-economic data to generate visualization in Google Earth, for example, NASA Goddard Space Flight Center Hurricane Portal(Leptoukh 2006) provides viewing and studying of

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hurricanes by utilizing measurements from remote-sensing instruments, including TRMM (Tropical Rainfall Measuring Mission), MODIS (MODerate Resolution Imaging Spectroradiometer), and AIRS (Atmospheric Infrared Sounder). The portal displays most of the past hurricanes on Google Earth and provides data download of the hurricanes to assist science communities in future research and investigations in tropical meteorology. David Whiteman, an atmospheric scientist at NASA's GSFC, is using Google Earth's fly-by feature to understand local weather systems and trying to use real-time observations to refine the prediction of weather. NOAA researchers prefer that real-time weather information is displayed on Google Earth alongside the landmarks and routes in which the general public is interested. Google Earth makes meteorological radar data and satellite images, e.g. from NOAA, NASA and USGS, more useful and user friendly (Butler, 2006).

However, only few are related to discuss how to render vertical geospatial data on Google Earth. Geens (2006) first suggested displaying vertical data on Google Earth with a very rough, inaccurate solution. It is just a proof-of-concept that vertical data can be displayed on Google Earth. There is no systematic procedures are introduced. However, of most importance for rendering vertical data on Google Earth is how to accurately curve vertical data images along the curving orbit on the surface of Google Earth. This paper proposes detailed solutions. Yamagishi et al. (2006) provided a tool to convert a seismic tomography model into KML files. The KML file contains latitude, longitude and altitude data that are provided using a seismic model. The numerous small rectangles will be rendered on Google Earth to form the vertical data curtain for displaying the vertical data while KML file is opened on Google Earth.

This paper proposes an innovative solution to render NASA A-Train vertical profiles of atmospheric data on Google Earth. The vertical profiles include data from CloudSat, CALIPSO, Aqua/MOIDS and Aqua/AIRS. The NASA Goddard Earth Science Data Information Service Center (GES DISC) Interactive Online Visualization ANd aNalysis Infrastructure (GIOVANNI) A-Train system is first used to produce the vertical data image based on specified temporal range and physical parameters. A COLLADA (COLLABorative Design Activity) model is designed to visualize vertical data image on Google Earth. Using COLLADA models and satellite orbit coordinates calculated based on temporal data, an orbit curtain model is designed and implemented in KML. The orbit curtain model is made from repeated COLLADA models. The finished KML file can be rendered, transparently or opaquely, on Google Earth to visualize the vertical data derived from NASA A-Train satellite constellation.

2. NASA A-TRAIN VERTICAL DATA

NASA Earth Observing System (EOS) is helping to improve our understanding of the Earth as an integrated system. The GES DISC is committed to bringing the satellite imagery derived from EOS, program information, and other resources to professional scientists and the general public alike. The geospatial data from EOS include 2D mapped data and 3D data with the vertical dimension in atmosphere. This paper focuses on describing the visualization of 3D vertical data from A-Train on Google Earth.

Although there are seven missions in A-Train satellite constellation, only data from three missions – CloudSat,

CALIPSO and Aqua, are integrated into Google Earth for possible synergistic scientific research. Five data products from three missions are processed. All data are first processed through the GES-DISC Giovanni version 3 A-Train system, then integrated and visualized on Google Earth as orbit curtain plot. Our research related three missions and five data products are as following:

The CloudSat mission, the first to collect cloud-related data from space was launched by NASA on April 28, 2006, and has been collecting data since June 2, 2006. The data directly describes the cloud vertical profile, including the cloud bases and the elusive hidden layers. The CloudSat profile provides a 3D view of the vertical structure of clouds from the top of the atmosphere to the surface, and the radar observations are processed into estimates of water and ice content with 500m vertical resolution (Partain *et al.*, 2006). The key instrument at CloudSat is a 94-GHz, nadir pointing, Cloud Profiling Radar (CPR). It collects vertical profiles of cloud from its 705-km sun-synchronous orbit. The data products are made available in the Hierarchical Data Format for Earth Observation System (HDF-EOS) format (CSU, 2007).

1. Radar reflectivity (unit: dBZ) from standard level 1B data product (1B_CPR.008);
2. Received echo power from standard level 1B data product (1B_CPR.008);
3. Radar-only ice water content from standard level 2B data product (2B_CWC_RO.008);
4. Radar-only liquid water content from standard level 2B data product (2B_CWC_RO.008).

The CALIPSO mission employs an innovative set of instruments to explore our atmosphere and to study the aerosols and thin clouds that play a major role in regulating earth's weather, climate, and air quality. It collects data and information about the vertical structure of clouds and aerosols unavailable from other earth-observing satellites. From space, CALIPSO globally surveys the seasonal and geographical variations of cloud and aerosol profiles and physical properties. CALIPSO has a unique capability to collect information about the vertical structure of clouds and aerosols and how these structures overlap (NASA 2005). Three co-aligned, near-nadir viewing instruments are loaded on CALIPSO:

1. a 2-wavelength polarization-sensitive lidar
2. an imaging infrared radiometer (IIR)
3. a high-resolution wide field camera (WFC)

The lidar profiles provide information on the vertical distribution of aerosols and clouds, cloud particle phase, and classification of aerosol size. IIR provides medium spatial resolution nadir viewing images offering information on the size of cirrus cloud particles and infrared emissivity. The WFC digital camera collects daytime high spatial resolution imagery that is used to ascertain cloud homogeneity, aid in cloud clearing, and provide meteorological context (NASA 2006).

AIRS and MODIS-Aqua also provides vertical profiles of quantities such as atmospheric temperature, H₂O saturation, and of H₂O vapor. AIRS is a high spectral resolution spectrometer with 2378 bands in the thermal infrared and 4 bands in the visible. The ranges have been selected to allow determination of atmospheric temperature with an accuracy of 1°C in layers 1km thick, and humidity with an accuracy of 20% in layers 2km thick in the troposphere. AIRS measurements of the Earth's atmosphere and surface allow scientists to improve

weather predictions and observe changes in Earth's climate (NASA, 2008a).

MODIS, a key instrument aboard Aqua and Terra, also provides 3D vertical data. It has a viewing swath width of 2,330 km and views the entire surface of the Earth every 1 to 2 days. Its detectors measure 36 spectral bands between 0.405 and 14.385 μm , and it collects data at three spatial resolutions: 250 m, 500 m, and 1000 m. Many of the MODIS data products describe features, including 3D features of the land, oceans, and atmosphere, which will improve our understanding of global dynamics and processes occurring on the land, in the oceans, and in the lower atmosphere (NASA, 2008b).

3. GIOVANNI AND PROCESSING OF THE VERTICAL DATA

NASA GES DISC facilitates science and applications research by, in consultation with its users, applying cutting-edge information technology to the development of new tools and data services. Giovanni is one such tool that is a Web-based interactive data analysis and visualization system, used primarily for exploring NASA atmospheric and precipitation datasets. It allows on-line interactive data exploration, analysis, and downloading of data subsets from multiple sensors, independent of the underlying file format. With the rapidly increasing volume of archived atmospheric and precipitation data from NASA missions, Giovanni enables users easily to manipulate data and facilitate scientific discovery.

The Giovanni version 2 (Giovanni, 2008a) provides capabilities including area plots, time plots, Hovmöller plots, ASCII output, image animation, two parameter inter-comparisons, two parameter plots, scatter plots (relationships between two parameters), and temporal correlation maps for most of atmospheric and participation data hosted at GES DISC. Giovanni version 3 (Giovanni, 2008b) (*i.e.*, G3) offers many new and more advanced functions, such as vertical data profiling, vertical cross-sections, and zonal averaging. The newest function is producing multi-instrument vertical plots beneath the A-Train track. G3 provides a useful platform for the efficient utilization of both 2D and 3D geospatial data.

G3 uses a service- and workflow-oriented asynchronous architecture. FTP and HTTP-based scientific data networking software, such as OPeNDAP and GrADS Data Server (GDS), are used to enable G3 to transparently access and transfer local and remote scientific data. Service-oriented architecture (SOA) requires that all data processing and rendering be implemented through standard Web services. This dramatically increases reusability, modularization, standardization, and interoperability of the system components. This design makes possible clear separation between the system infrastructure and the logic and algorithms for data processing and image rendering. The workflow-oriented management system enables users to easily create, modify, and save their own workflows. This asynchronicity guarantees that more complex processing without the limitation of HTTP time-outs is possible, and that Web services in a process can run in parallel. Finally, G3 is intrinsically extensible, scalable, easy to work with, and high performance (Giovanni, 2008b).

The A-Train Data Depot (ATDD) (Savtchenko, *et al.* 2008) is the first instance of the use of G3 for processing and analyzing geospatial data derived from the A-Train satellite constellation.

The A-Train orbital configuration enables synergistic scientific measurement using data from several different satellites. The data can be processed together to obtain comprehensive and combined information that can address scientific problems more comprehensively than is possible with data from any single satellite dataset. At present, vertical data from three of the seven satellites of the A-train – CloudSat, CALIPSO, and Aqua – are processed using G3.

Users can launch a G3 web-based Graphical User Interface (GUI) to input spatial and temporal criteria to produce a Curtain Plot image. The GUI lists all of the available parameters which users can customize to their specific requirements. When the user selects the input parameters from the GUI, the user interface software creates an XML representation of the inputs, and initiates execution of the appropriate workflow. For the asynchronous case, when the workflow processing is complete, the URL of the resultant product (usually an image) is available. When the processing is fast and appears to be synchronous, the result will be directly returned to the user, usually via the Web browser (Berrick, *et al.* 2006).

The following geospatial vertical data products are processed in G3 to produce image curtain plot, to reveal different physical phenomena with different physical parameters:

1. The standard level 1B data product 1B-CPR (version 008) from CloudSat for vertical profiles of clouds, which indicates such cloud characteristics as reflectivity and Received Echo Powers.
2. The standard level 2B data product 2B-CWC from CloudSat for vertical profiles of ice water content and liquid water content.
3. Lidar Level 2 Vertical Feature Mask (version 001) data products from CALIPSO for high-resolution vertical profiles of clouds and aerosols, which can be used to classify clouds and aerosols and to distinguish ice and water phases.
4. MODIS vertical data from Aqua for vertical profiles of atmospheric temperature and H₂O temperature in Kelvin.
5. AIRS vertical data from Aqua for vertical profiles of atmospheric temperature, H₂O temperature, and H₂O vapor in Kelvin.

A Perl script automatically acquires the vertical data image curtain. First, the script produces the requested parameters file in XML format for the temporal range selected and input by the user. Table 1 is part of example of the requested parameters in XML format. In the parameters file, the temporal range and the specific satellite orbit model are used to calculate the spatial range. Other parameters depend on the relevant physical variable, e.g. Radar Reflectivity or Received Echo Powers. Second, the parameters file is used to invoke a workflow from G3 to transparently access the vertical data in HDF-EOS format. Finally, a series of procedures such as sub-setting, extracting, scaling, stitching, and plotting is used to output the Curtain Plot image. Figure 2 shows the image curtain for received echo power of cloud from CloudSat in ATDD.

```
<serviceSelection>swathTest</serviceSelection>
<instanceId>atrain</instanceId>
<binDir>/tools/gdaac/TS1/bin/G3</binDir>
<spatialConstraint>
  <geoBoundingBox>
    <south> 2.04369200 </south>
    <north> 37.33200900 </north>
```

```

<west> 108.43485300 </west>
<east> 116.87484000 </east>
</geoBoundingBox>
</spatialConstraint>
<temporalConstraint>
<interval>minutely</interval>
<frequency>1</frequency>
<startTime>2008-03-07T05:55:02Z</startTime>
<longTime>2008 Mar 07</longTime>
<endTime>2008-03-07T05:56:31Z</endTime>
</temporalConstraint>
.....
<datasetGroup>
<dataset>
<datatype>
<datasetName>CloudSat.008</datasetName>
<shortName>CloudSat</shortName>
<version>8</version>
<url>http://cloudsat.cira.colostate.edu/dataSpecs.php?
prodid=1</url>
</datatype>
<parameterSet>
<parameter>
<name>REP </name>
<shortName> ReceivedEchoPower </shortName>
<displayName>ReceivedEchoPower </displayName>
<longName> ReceivedEchoPower </longName>
<virtual>true</virtual>
<unitsType>science</unitsType>
</parameter>
</parameterSet>
</dataset>
</datasetGroup>
    
```

Table 1. Example of requested parameters in XML format

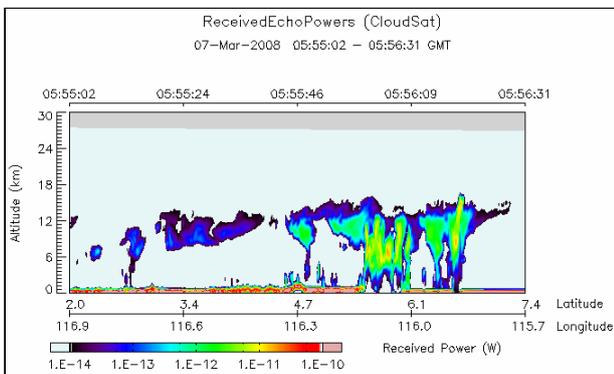


Figure 2. Image curtain for received echo power of cloud from CloudSat produced by Giovanni version 3

4. VISUALIZATION OF THE VERTICAL DATA IN GOOGLE EARTH

Of most importance is the XML-compatible KML (Keyhole Markup Language) promoted by Google Inc. The KML offers very easy and convenient user application interfaces for people finding, publishing and sharing any data and information that has a geospatial element on Google Earth. In this section, we introduce how KML organizes data, what is COLLADA model and how to use it to render vertical data image produced by G3 on Google Earth. Figure 3 is simple diagram showing the

procedures of visualizing vertical data on Google Earth from HDF-EOS files to orbit curtain plot.

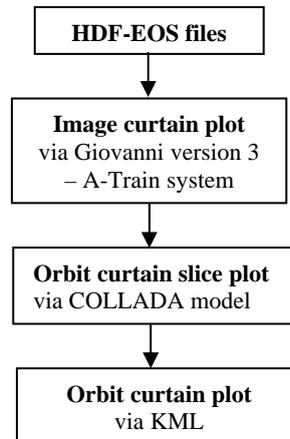


Figure 3. Procedures of visualizing vertical data on Google Earth

4.1 Data organization and visualization on Google Earth

Keyhole Markup Language (KML) proposed by Google Inc. is an XML-compliant markup language. KML can be used to represent, organize, store, manage, serve and visualize 2D and 3D geospatial data on Google Earth. General users can easily integrate and publish their geospatial data of personal interested in Google Earth. Data providers can also release their data products via KML on Google Earth.

The KML file specifies a set of features, such as Document, Folder, Placemark, Icon, LineString, LinearRing, Polygon, MultiGeometry, 3D Models, GroundOverlay, ScreenOverlay, NetworkLink and Textual descriptions. Every geospatial data element, regardless of form (point, line strings, polygons, geometries, images, and 3D models), always has corresponding longitude, latitude and altitude information. Other data can make the view of geospatial data more specific, such as scale, tilt, heading, and style. The KML also provides time features, such as TimeSpan and TimeStamp, which are very important for visualization of a massive historical archive of geospatial data. Geospatial data can be nicely organized via KML specific tags in KML files (Google, 2008).

4.2 COLLADA 3D model and its application to vertical data

COLLADA is a COLLABorative Design Activity for establishing an open standard, XML-based digital asset schema for interactive 3-D applications. The COLLADA schema supports all the features that modern 3-D interactive applications need, and its choice of XML offers many of the benefits of the eXtensible Markup Language. Here, its 3-D features are used to represent geospatial vertical data to form an orbit curtain.

The Google Inc. provides the SketchUp (v6) tool used to build COLLADA 3D model. SketchUp's coordinate system (x, y, z) is mapped to that of Google Earth (Latitude, Longitude, Altitude) in the model, starting with (0,0,0). We designed a COLLADA model as a template to render the vertical data. The template is with x=103m, y=0m and z=300m. While we speak

of a 3D representation of the CloudSat data, we really mean a very thin ($y \approx 0$, essentially 2D) curtain, placed vertically and perpendicular to the Earth's surface (the x-z plane) in Google Earth as the "texture." The x and z values are calculated based on the 15 seconds flying distance of satellite and the real height of cloud. When placed on Google Earth, the curtain will be a vertical plane roughly along a meridian of longitude (x-axis, running North-South), very thin (y-axis, corresponding to a 1.35-km wide CloudSat observation) and arising vertically from and normal to the Earth's surface as the atmospheric altitude (z-axis).

The finished curtain can be exported from SketchUp as a KMZ file, which is in a .zip format supported by Google Earth and includes all related files required for displaying the curtain in Google Earth. The KMZ file typically includes at least one KML file, image file(s), COLLADA file(s), and a texture file. A *.dae file extracted from the KMZ is the template, which will be positioned along the orbit track to form the curtain. Table 2 is part of the COLLADA file for defining the texture. COLLADA images as texture files will be automatically and repeatedly produced corresponding to the user-selected times and locations along the orbit track.

```
<?xml version="1.0" encoding="utf-8"?>
<COLLADA
xmlns="http://www.collada.org/2005/11/COLLADASchema" version="1.4.1">
  <library_images>
    <image id="cloudsat_data-image"
name="cloudsat_data-image">
      <init_from>../images/20080307_05_002.gif</init_from>
    </image>
  </library_images>
  .....
  <library_geometries>
    <geometry id="mesh1-geometry" name="mesh1-geometry">
      <mesh>
        <source id="mesh1-geometry-position">
<float_array id="mesh1-geometry-position-array" count="12">0 0 0 103 0 0 -2.5 0 300 105.5 0 300</float_array>
          </source>
          .....
          <triangles material="cloudsat_data" count="4">
            <input semantic="VERTEX" source="#mesh1-geometry-vertex" offset="0"/>
            <input semantic="NORMAL" source="#mesh1-geometry-normal" offset="1"/>
            <input semantic="TEXCOORD" source="#mesh1-geometry-uv" offset="2" set="0"/>
            <p>0 0 0 1 0 1 2 0 2 0 1 0 2 1 2 1 1 1 3 0 3 2 0 2
1 0 1 3 1 3 1 1 1 2 1 2 </p>
          </triangles>
        </mesh></geometry></library_geometries>
        .....
      </COLLADA>
```

Table 2. Part of the COLLADA model for defining the model and its texture

4.3 Rendering vertical data image on Google Earth via COLLADA models

Before building up orbit curtain, the spatial coordinates (latitude and longitude) of the orbit are calculated as the set of positions of the CloudSat satellite corresponding to the temporal range selected by the user at fixed, 15-second intervals. Giovanni produces one high-resolution image curtain for user requesting temporal range. The minimum required temporal range is 45 seconds, the maximum recommended range is one hour considering the rendering speed in Google Earth. Given the rendering speed and accuracy of the orbit curtain in Google Earth, 15 seconds is selected as the minimum temporal range for image slice whose corresponding spatial range is represented by each model slice. A temporal range of 5 seconds was also tested; although the final orbit curtain is more accurate, the rendering speed on Google Earth is too slow. The 15-second temporal range corresponds about 103 km in spatial range that is used as a reference for selecting the x value in the COLLADA model. The whole image curtain produced by Giovanni is chopped into smaller 15-second images. Each smaller, 15-second image curtain is placed on the x-z plate of the COLLADA model template as the texture, and the finished COLLADA model slices are positioned along the satellite orbit track to form the orbit curtain on Google Earth. Figure 4 is the implemented orbit curtain on Google Earth corresponding to the image curtain in Figure 2.

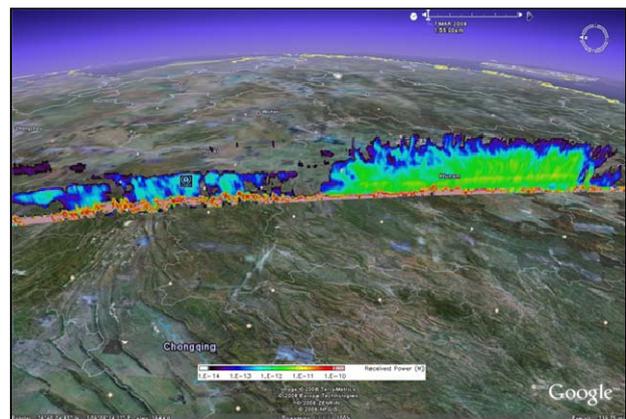


Figure 4. Implemented orbit curtain in Google Earth corresponding to the image curtain in Figure 2.

Table 3 is the KML code for one image slice along the satellite orbit track. The file "20080307_05_002.dae" is the COLLADA file, which includes the vertical data image slice as its texture.

```
<Placemark>
  <name>HourSlice_20080307_05_002</name>
  <description><![CDATA[]]></description>
  <Model>
    <altitudeMode>clampToGround</altitudeMode>
    <Location>
      <longitude> 116.66890700 </longitude>
      <latitude> 3.01061100 </latitude>
      <altitude>0.000000</altitude>
    </Location>
    <Orientation>
      <heading> 257.98490910 </heading>
```

```

<tilt>0.000000</tilt>
<roll>0.000000</roll>
</Orientation>
<Scale>
<x>809</x>
<y>1</y>
<z>1000</z>
</Scale>
<Link>
<href>models/20080307_05_002.dae</href>
</Link>
</Model>
</Placemark>
    
```

Table 3. Example of KML codes for one slice of image curtain on orbit curtain

5. CONCLUSIONS

Two dimensional mapped geospatial data have been visualized and provided the general public and researchers via Google Earth. However, vertically resolved atmospheric data are not as easily available, and are often archived in formats that are difficult for the average user to decode. By using the Giovanni A-Train system to preprocess vertical geospatial data from CloudSat, CALIPSO and Aqua missions of A-Train constellation, this paper has demonstrated a new method for visualizing high-resolution vertical profiles of atmosphere along the satellite orbit in the form of a data curtain on Google Earth. The COLLADA and KML standards are followed to create the 3D COLLADA model and produce the KML file that finally visualizes vertical geospatial data on Google Earth. This method makes it possible to combine vertical data together with other geospatial data for scientific research and better understanding of our planet. A key capability of the system is the ability to visualize and compare diverse, simultaneous data from different data sources, revealing new information and knowledge that would otherwise have been hidden. The implementation is released online and can be accessed at the website <http://disc.gsfc.nasa.gov/googleearth/>.

In the future, we will overlay more vertical data with multiple curtains to compare and visualize different physical parameters from the A-Train constellation. Also, additional research results derived from geospatial data will be integrated into Google Earth to facilitate scientific research and improve the daily life of the general public. Future work will focus on applying scientific research scenarios to Google Earth. The XML- and KML-oriented semantic workflow will play a key role in our future research.

REFERENCES

Berrick, S., Butler, M., Farley, J., Hosler, J., Lighty, L., and Rui, H., 2006. Web services workflow for online data visualization and analysis in Giovanni. *NASA ESTO – Earth Science Technology Conference*, Jun. 27-29, College Park, MD, USA.

Butler, D., 2006. Virtual Globes: The web-wide world. *Nature*, Vol. 439, pp776-778, February 16.

CSU, 2007. CloudSat Standard Data Products Handbook. Cooperative Institutes for Research in the Atmosphere, Colorado State University, Fort Collins, CO, USA.

Geens, S., 2006. “Proof of concept: visualizing vertical data in Google Earth”. http://www.ogleearth.com/2006/07/proof_of_concep.html (accessed 10 Sep. 2007).

Giovanni, 2008a. GES DISC Giovanni Version 2, *NASA GES DISC*, <http://daac.gsfc.nasa.gov/techlab/giovanni/> (accessed 10 Mar. 2008)

Giovanni, 2008b. GES DISC Giovanni Version 3, *NASA GES DISC*, <http://daac.gsfc.nasa.gov/atddd/> (accessed 6 Apr. 2008).

Google, 2008. “KML 2.2 Reference (Beta)”, *The Google Inc.* http://code.google.com/apis/kml/documentation/kml_tags_beta1.html (accessed 12 Apr. 2008).

Leptoukh, D., S. Braun and G. Vicente, 2006. Multisensor Studies of Hurricanes From Space: Storm Structure, Environment, and Impacts I, *EOS Trans. AGU*, 87 (52), Fall Meet. Suppl., Abstract A12-A.

NASA, 2003. NASA Facts: formation flying: the afternoon “A-Train” satellite constellation, FS-2003-1-053-GSFC. *NASA GES DISC*, <http://www.gsfc.nasa.gov> (accessed 10 Sep. 2007).

NASA, 2005. NASA Facts: CALIPSO: Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations, FS-2005-09-120-LaRC. *NASA LaRC*, <http://www.nasa.gov> (accessed 2 Oct. 2007).

NASA, 2006. Cloud – Aerosol LIDAR Infrared Pathfinder Satellite Observations (CALIPSO): data management system and data products catalog, *NASA LaRC*.

NASA, 2008a. Atmospheric Infrared Sounder, *NASA GES DISC*, <http://disc.gsfc.nasa.gov/AIRS/instruments.shtml> (accessed 11 Mar. 2008).

NASA, 2008b. MODIS Web, *NASA GES DISC*, <http://modis.gsfc.nasa.gov/data/> (accessed 15 Mar. 2008).

Savtchenko, A., R. Kummerer, P. Smith, A. Gopalan, S. Kempler, and G. Leptoukh, 2008. A-Train Data Depot - Bringing Atmospheric Measurements Together, *IEEE Trans. Geosci. Remote Sensing*, to be published in Special Issue IGARSS'07.

Partain, P. T., D. L. Reinke, and K. E. Eis, 2006. A Users Guide to CloudSat Standard Data Products. *AGU Fall Meeting*, Dec. 11-15, San Francisco, CA, USA.

Yamagishi et al., Integration of geophysical and geochemical data, *EOS Trans. AGU*, 87(52), Fall Meet. Suppl., Abstract IN11A-1142, 2006.

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