



Contents lists available at ScienceDirect

Computers & Geosciences

journal homepage: www.elsevier.com/locate/cageo

Visualization of A-Train vertical profiles using Google Earth

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ARTICLE INFO

Article history:

Received 6 July 2007

Received in revised form

27 July 2008

Accepted 4 August 2008

Keywords:

Vertical geospatial data

A-Train

Giovanni

CloudSat

Earth remote sensing

KML

KMZ

COLLADA

Google earth

ABSTRACT

Online tools, such as those pioneered by Google Earth (GE), are changing the way in which scientists and the general public interact with three-dimensional geospatial data in a virtual environment. However, while GE provides a number of features to facilitate geospatial data visualization, there is currently no readily available method for rendering vertical geospatial data derived from Earth—viewing remote sensing satellites as an orbit curtain seen from above. Here, a solution (one of many possible) is demonstrated to render vertical profiles of atmospheric data from the A-Train satellite formation in GE, using as a proof-of-concept data from one of the instruments—the NASA CloudSat satellite. CloudSat carries a nadir-viewing Cloud Profiling Radar that produces data revealing the vertical distribution of cloud characteristics along the satellite track. These data are first rendered into a long vertical image for a user-selected spatial range through the NASA Goddard Interactive Online Visualization ANd aNalysis Infrastructure (GIOVANNI) system (<http://giovanni.gsfc.nasa.gov/>). The vertical image is then chopped into small slices representing 15 s of satellite time (~103 km long ground distance). Each small piece, as a texture, is fed into a generalized COLLABorative Design Activity (COLLADA) three-dimensional (3-D) model. Using the satellite orbit coordinates, the repeated 15 s “3-D model slices” are spliced together to form a vertical “curtain” image in Keyhole Markup Language (KML) format. Each model slice is geolocated along the CloudSat orbit path based on its size, scale and angle with the longitude line that are precisely calculated on the fly. The resulting vertical cloud data can be viewed in GE, either transparently or opaquely, superimposed above the Earth’s surface with an exaggerated vertical scale. Since CloudSat is just a part of the A-Train formation, the full utility of this tool can be explored within the context of the A-Train Data Depot (ATDD, <http://disc.gsfc.nasa.gov/atdd/>) and the corresponding Giovanni instance (http://disc1.sci.gsfc.nasa.gov/daac-bin/G3/gui.cgi?instance_id=atrain). The latter portal allows scientists and the general public to access and visualize complex A-Train datasets without having to delve into data formats specific to a given mission.

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1. Introduction

Google Earth (GE) combines satellite imagery, aerial photography, and map data to make a three-dimensional (3-D) interactive image of the world. People can then discover, add and share information about any subject

that is geolocated. The virtual globe represented by GE allows the user to “fly” from space down through layers of progressively higher resolution data sets and hover above any point on the Earth’s surface. GE then displays information relevant to that location from a vast number of sources. Its original purpose was to use the Earth itself as an organizing metaphor for digital information. Now, the GE virtual globe is changing the way scientists interact with geospatial data. A wide variety of information on the state of the planet, from toxic chemicals to the disease incidence rates, are becoming available to the public with just a few clicks of the mouse (Declan, 2006). With many applications moving from local machine-based environments to online web-based platforms with the emergence of new internet technologies, the virtual globe promises to play an increasingly important role in research, applications and the public’s daily life in the near future.

In the few years since its 2005 introduction, GE has found numerous applications, including climate change, weather forecasting,³ natural disasters (e.g., tsunamis, hurricanes), the environment,⁴ travel, history, presidential elections, mapping avian flu,⁵ online games and cross-platform view sharing. These applications primarily use two-dimensional (2-D) geospatial and socio-economic data to generate visualizations on virtual globe. For example, the NASA Goddard Space Flight Center (GSFC) Hurricane Portal is designed for viewing hurricanes by utilizing measurements from a variety of NASA satellite-based remote sensing instruments, including the Tropical Rainfall Measuring Mission (TRMM), the MODerate Resolution Imaging Spectroradiometer (MODIS), and the Atmospheric Infrared Sounder (AIRS). The Hurricane Portal (<http://disc.gsfc.nasa.gov/hurricane/>) provides visualizations of recent hurricanes (1998–present) in GE, as well as downloads of hurricane datasets to assist the science community in their research into tropical meteorology. For instance, atmospheric scientists may use real-time weather observations as visualized with GE’s fly-by feature to understand local weather systems and refine weather predictions (Declan, 2006). NOAA researchers display real-time weather information in GE alongside the landmarks and routes familiar to the general public.⁶ GE makes meteorological radar data and satellite images from NOAA, NASA and USGS more user friendly.

Apart from the CloudSat radar (Fig. 1) that in essence provides the vertical description of clouds, the A-Train formation includes several other instruments producing vertical profiles of various atmospheric parameters.

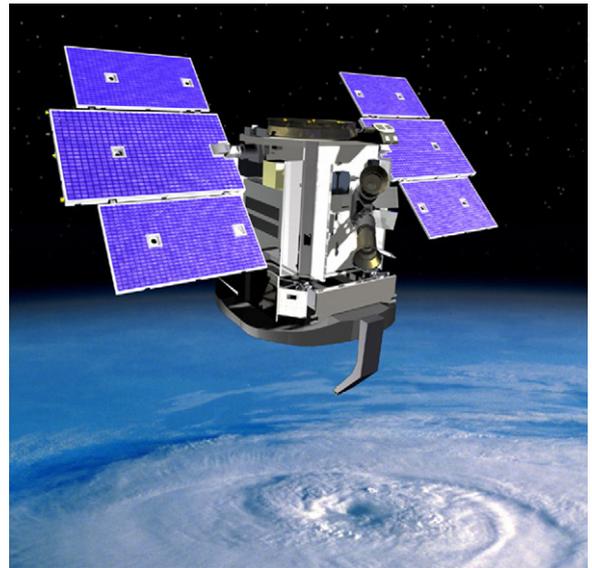


Fig. 1. Artist's rendering of CloudSat satellite. (Photo courtesy of NASA).

However, GE does not provide a simple solution for displaying this kind of vertical data. Using the method described in this paper, and CloudSat as a case study, we are able to transparently or opaquely display a “curtain” of high-resolution cloud parameters derived from CloudSat data and enable its visualization from all directions, including flying along the curtain. When viewed in the context of other related data sets (e.g., precipitation data), valuable insights into the nature of cloud processes can be gleaned by researchers and students.

There are indeed other methods for rendering orbit curtains. One is to process the geospatial data to produce a Keyhole Markup Language (KML) file that can render a 2-D curtain in GE directly. At the highest resolution, the curtain consists of many small rectangles, each of which represents the distance CloudSat satellite travels in 5 s. The problem with this method is that if the resolution is as high as the method discussed in this paper, the rendering and displaying speed in GE is unacceptably slow. To improve the rendering speed, the resolution has to be degraded to the point that the visualization is insufficient for use by scientists.

Geens (2006)⁷ first suggested displaying vertical images in GE with a very rough, inaccurate solution. No systematic scientific procedures are used to calculate the position, scale and rotation of the data along the satellite orbit in GE. Yamagishi et al. (2006) provided a tool to convert a seismic tomography model into KML files. The KML file used the method discussed above. Latitude, longitude and altitude data are provided using a seismic model for rendering the flat rectangle in GE (Chen et al., 2008). We also tried visualizing the vertical data via

³ Travis, M.S., Valliappa, L., 2006. Utilizing Google Earth as a GIS platform for weather applications. In: Proceedings of Lakshmanan 22nd International Conference on Interactive Information Processing Systems for Meteorology, Oceanography, and Hydrology. The 86th America Meteorological Society Annual Meeting, Atlantic, Georgia, USA. <http://ams.confex.com/ams/pdfpapers/104847.pdf>.

⁴ NIEES, 2007. Google Earth and other geobrowsing tools in the environmental sciences. <http://www.niees.ac.uk/events/GoogleEarth/index.shtml>.

⁵ Nature, 2006. Avian Flu. <http://www.nature.com/nature/multimedia/googleearth/index.html>.

⁶ NOAA, 2008. National Weather Data in GIS formats, <http://www.srh.noaa.gov/gis/kml/>.

⁷ Geens, S., 2006. Proof of concept: visualizing vertical data in Google Earth. http://www.ogleearth.com/2006/07/proof_of_concept.html.

rendering numerous flat rectangles on-the-fly in GE, but the rendering speed is unacceptable. Here, we proposed a systematic and accurate solution to fast visualize vertical geospatial data in GE with an impressive display.

2. CloudSat and other A-Train vertical data in Giovanni

The CloudSat mission, as a case study here, provides a direct measurement of the vertical structure of cloud systems, including radar reflectivity, cloud classification, optical depth, effective particle radius, the altitudes of cloud bases and cloud tops, as well as stacked cloud layers that have been unobservable by prior ground-based or satellite observations, and radiative fluxes (Stephens et al., 2002).

The primary CloudSat instrument is a 94 GHz, nadir-pointing Cloud Profiling Radar (CPR). The CPR has an instantaneous Field of View (FOV) of approximately 1.35 km wide by 1.7 km along the satellite subtrack. There are 125 vertical cloud “bins,” each one 240 m thick, from the surface up to 30 km (Durden and Boain, 2004). All Levels 0, 1, and 2 data products from the CloudSat mission are produced by the CloudSat Data Processing Center (DPC) at Colorado State University. CloudSat data products for Release 4 (R04) are available through the online ordering system in compressed (.zip) Hierarchical Data Format for Earth Observation System (HDF-EOS) 2.5 format using HDF 4.1r2.⁸

The Goddard Interactive Online Visualization AND aNalysis Infrastructure (GIOVANNI⁹) is a web-based interactive data analysis and visualization tool, used primarily for exploring many of NASA’s atmospheric datasets (Acker and Leptoukh, 2007). Giovanni provides on-line interactive multi-sensor data exploration, statistical analysis and downloading of subsetted data from multiple sensors, independent of the original file format. Giovanni version 3 is designed and implemented based on service- and workflow-oriented asynchronous architecture.¹⁰ Standard protocols, such as FTP, Open-source Network for Data Access Protocol (OPeNDAP),¹¹ WMS and WCS,¹² and Grid Analysis and Display System (GrADS) Data Server (GDS)¹³ are supported for remote data access

and transfer. The service-oriented architecture (SOA) requires that all data processing and rendering are implemented through standard web services, which increases the reusability, modularization, standardization and interoperability of the system components. This design makes possible clear separation of system infrastructure and the logic and algorithms of data processing/rendering. The asynchronous characteristic guarantees that more complex processing can be done without the limitation of the HTTP time-outs, and that web services in a process can be run in parallel. Real Simple Syndication (RSS) feeds are provided to alert a user when the product is available (Chen et al., 2008). Giovanni is a high-performance software system that is intrinsically extensible, scalable, and easy to work with.

A Perl script implements the automatic acquisition of the vertical image curtain from Giovanni. The script automatically produces the requested parameters file for the fixed temporal range in XML format according to user selected spatial range. In the case of CloudSat, one can choose which physical variable one wishes to view (either radar reflectivities, dBZ, or received echo powers, REP).

Table 1

Example of request parameters in XML format for producing the image curtain at Giovanni version 3.

```
<serviceSelection>swathTest</serviceSelection>
<instanceId>atrain</instanceId>
<binDir>/tools/gdaac/TS1/bin/G3</binDir>
<spatialConstraint>
  <geoBoundingBox>
    <south>28.100000</south>
    <north>36.100000</north>
    <west>-114.600000</west>
    <east>-116.800000</east>
  </geoBoundingBox>
</spatialConstraint>
<temporalConstraint>
  <interval>minutely</interval>
  <frequency>1</frequency>
  <startTime>2006-08-23T21:04:33Z</startTime>
  <longTime>2006 Aug 23</longTime>
  <endTime>2006-08-23T21:06:48Z</endTime>
</temporalConstraint>
.....
<datasetGroup>
  <dataset>
    <datatype>
      <datasetName>CloudSat.008</datasetName>
      <shortName>CloudSat</shortName>
      <version>87</version>
      <url>http://cloudsat.cira.colostate.edu/
dataSpecs.php?prodid=1</url>
    </datatype>
    <parameterSet>
      <parameter>
        <name>dBZ</name>
        <shortName>dBZ Reflectivity</shortName>
        <displayName>dBZ Reflectivity</displayName>
        <longName>dBZ Reflectivity</longName>
        <virtual>true</virtual>
        <unitsType>science</unitsType>
      </parameter>
    </parameterSet>
  </dataset>
</datasetGroup>
```

⁸ CloudSat, 2008. CloudSat Standard Data Products Handbook. Cooperative Institutes for Research in the Atmosphere, Colorado State University, Fort Collins, CO, USA. http://www.cloudsat.cira.colostate.edu/cloudsat_documentation/CloudSat_Data_Users_Handbook.pdf.

⁹ Giovanni, 2008a. The GES-DISC (Goddard Earth Sciences Data and Information Services Center) Interactive Online Visualization AND aNalysis Infrastructure version. <http://giovanni.gsfc.nasa.gov>.

¹⁰ Berrick, S., M. Butler, M., J. Farley, J., Hosler, J., L. Lighty, L., and H. Rui, H., 2006. Web services workflow for online data visualization and analysis in Giovanni. The Earth Science Technology Conference 2006—the 6th annual technology conference of NASA’s Earth Science Technology Office (ESTO), College Park, Maryland, USA. <http://esto.nasa.gov/conferences/ESTC2006/papers/a1p4.pdf>.

¹¹ Sgouros, T., 2004. OPeNDAP user guide version 1.14. <http://www.opendap.org/pdf/guide.pdf>.

¹² OGC, 2008. OGC implementing products, <http://www.opengeospatial.org/resource/products/>.

¹³ Doty, B., 1995. The Grid Analysis and Display System (GrADS) version 1.5.1.12. Center for Ocean–Land–Atmosphere Studies (COLA). <http://www.iges.org/grads/gadoc/index.html>.

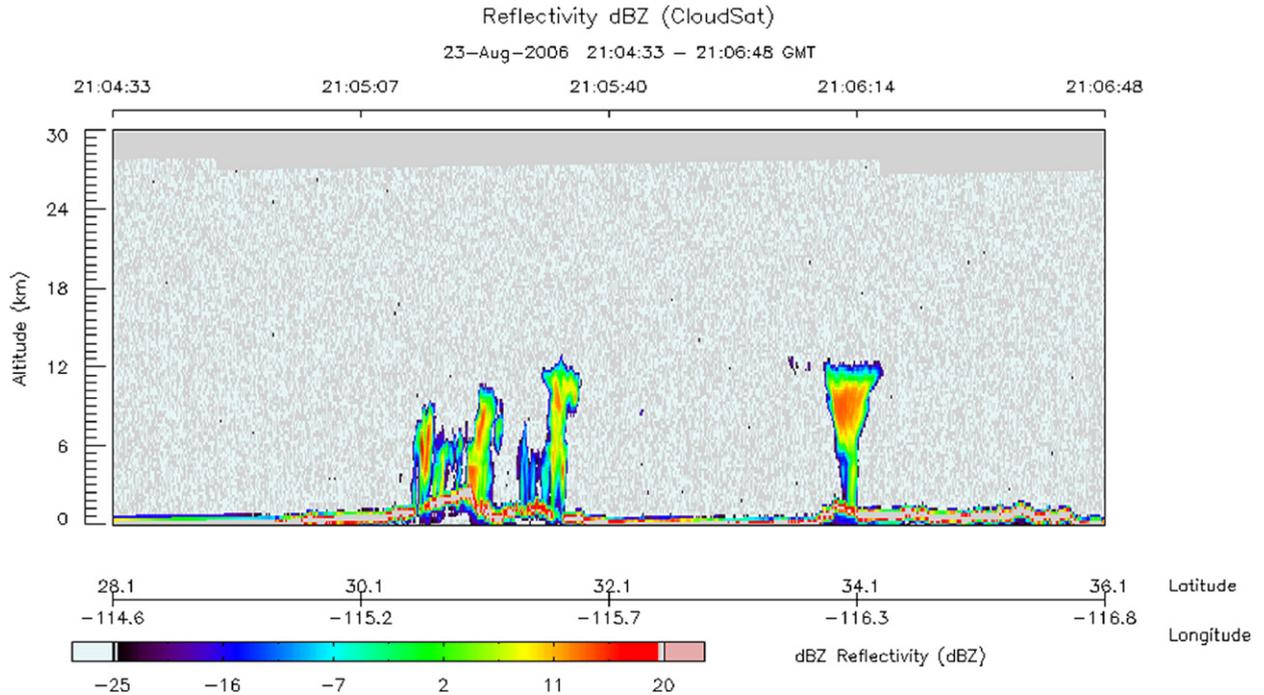


Fig. 2. Image curtain of cloud vertical profile produced by Giovanni version 3.

Table 1 illustrates the parameter details. Second, a workflow from Giovanni is invoked to transparently access the corresponding geospatial vertical data in HDF-EOS format. Finally, a series of procedures, including sub-setting, extracting, scaling, stitching and plotting, is used to output the data image curtain. Fig. 2 is an image curtain of CloudSat data produced by Giovanni.

At the time of this publication, the CloudSat previews through Giovanni and GE instances of the A-Train Data Depot (Savtchenko et al., 2008) include vertical profiles (“curtains”) of the radar reflectivities and the cloud water and ice content. Note, however, CloudSat is just one of the A-Train satellites and is used only as a case study here. The A-Train is a series of seven US and international Sun-synchronous satellites, all flying in tight formation, just minutes apart in very close orbital right ascension nodes (see Fig. 3). Detailed description of the A-Train formation is out of our scope here, but abundant information on its mission can be found from various references (Stephens et al., 2002). Our approach is in fact successfully applied to, and thus KML files are made available for, vertical profiles data from other A-Train instruments—MODIS, AIRS and CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation).

3. Visualization of A-Train vertical data in Google Earth

3.1. COLLADA model slices of the vertical profiles

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.¹⁴ Here, its 3-D features are used to represent geospatial vertical data to form an orbit curtain.

Google provides the SketchUp (v6)¹⁵ tool used to build a COLLADA 3-D template. SketchUp’s coordinate system (x, y, z) is mapped to that of GE (Latitude, Longitude, Altitude) in the template, starting with (0, 0, 0). Initially, $x = 103$ m (zooming out about 1000 scale of 103 km that is the ground distance passed by the satellite in 15 s along the orbit track), $y \approx 0$ and $z = 300$ m (zooming out 1000 scale of 300 km that is magnified 10 times of actual height of cloud for the impressive display effect). While we speak of a 3-D representation of the CloudSat data, we really mean a very thin ($y \approx 0$, essentially 2-D) curtain, placed vertically and perpendicular to the Earth’s surface (the x – z plane) in GE. When placed in GE, 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 GE and

¹⁴ Barnes, M. (Ed.), 2006. COLLADA—digital asset schema release 1.4.1 specification. Sony Computer Entertainment Inc., The Khronos Group Inc. http://www.khronos.org/files/collada_spec_1_4.pdf.

¹⁵ The Google Inc., 2007. Google SketchUp user guide. http://download.sketchup.com/GSU/pdfs/ug_sketchup_win.pdf.

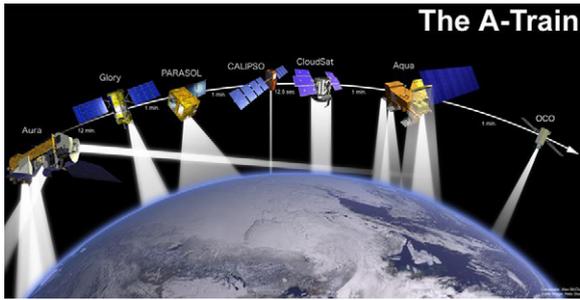


Fig. 3. Seven satellites comprising “A-Train” sequence of formation-flying satellites. Last satellite (EOS Aura) has a mean equator-crossing time only 23 min after first satellite (Orbiting Carbon Observatory, OCO, to be launched in 2008), allowing for near-simultaneous Earth remote sensing observations (Glory, to be launched in 2009). (Photo courtesy of NASA).

Table 2

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

```
<?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/20060823_21_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 0 109 0 0 -2.5 0 300 111.5 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>000101202010212111303202101313111212
</p>
          </triangles>
        </mesh></geometry></library_geometries>
        .....
      </COLLADA>
```

includes all related files required for displaying the curtain in GE. The KMZ file typically includes at least one KML file, image file(s), COLLADA model file(s), and a texture file. A *.dae COLLADA file extracted from the KMZ is the template, which will be positioned along the orbit track in KML to form the curtain. Table 2 is part of the COLLADA model file for defining the template. COLLADA model files as well as texture files will be automatically and repeatedly produced corresponding to the user-selected times and locations along the orbit track. A COLLADA model-based processing diagram (Fig. 4) shows the

procedure of visualizing A-Train vertical data in GE via Giovanni.

3.2. Welding the data orbit curtain

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 s intervals. Using these coordinates, a “Line-String” embedded in a “Placemark” in the KML file is built up, which is interpreted by GE as the orbit track. GE users can display the orbit track in whatever “style” they choose.

Giovanni produces minimum 45 s and maximum 1 h curtain images (in fact, there is no maximum limit, however, considering the processing speed related data volumes, maximum one hour is recommended). Given the rendering speed and accuracy of the orbit curtain in GE, 15 s is selected as the minimum temporal range whose corresponding spatial range is represented by each slice. A temporal range of 5 s was also tested; although the final orbit curtain is more accurate, the rendering speed in GE is too slow. The spatial range corresponding to 15 s temporal range, about 103 km, is used as a reference for selecting the x value in the COLLADA model.

In order to visualize the produced continuous images along the CloudSat orbit to form the orbit curtain, the continuous image is first chopped into small image slices. Each image slice represents the ground distance of 103 km past by satellite in 15 s along the orbit track. Then, each image slice is textured on the above COLLADA 3-D model template. All COLLADA model files are geolocated based on the set of spatial coordinates along the orbit track and stitched together one by one to form an orbit curtain finally. High-resolution cloud information and the relationship to other variables (such as precipitation) can be obtained by observing the curtain from all directions or flying along the orbit track.

Fig. 5 illustrates how to calculate the angle that is used in KML file to rotate and place the COLLADA model along the orbit track. The latitude direction (x -axis, along the forward direction of the satellite’s path) has a length of 103 m for every slice. The longitude direction (y -axis) is essentially zero for each slice (1.35 km is virtually negligible on a global scale). The altitude (z -axis) has a value of 300 m for each slice and is not displayed in Fig. 5 because of the z -axis is pointing to readers. After SketchUp builds the model on the x - z plane, GE assigns the default direction of the model to be along the x -axis as the vector OM . However, since the actual orbit direction is as the vector OP , the vector OM must be rotated to align with vector OP .

Angle α in Fig. 5 is defined as the angle between the vector ON (pointing North on the surface of the Earth) and the vector OP . Then, the angle required for rotating the model is

$$\beta = \alpha - 90$$

α is calculated using the coordinates (latitude, longitude) of two neighboring points (e.g., O and P) along on

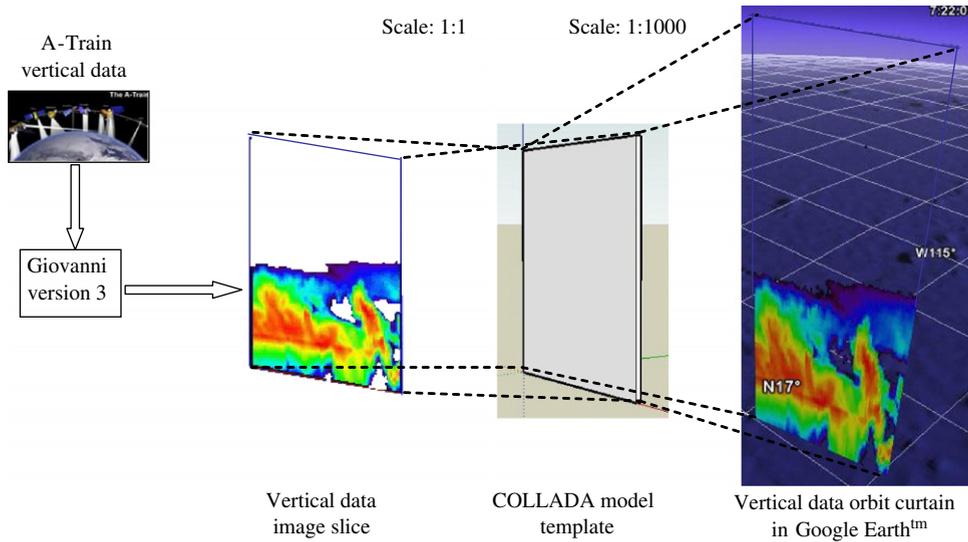


Fig. 4. Procedures of visualizing A-Train vertical data in Google Earth via Giovanni.

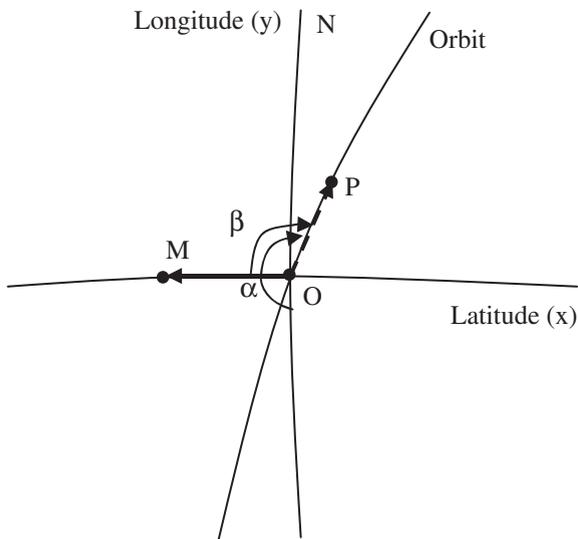


Fig. 5. Calculating bearing of orbit.

the orbit track, and d is defined as the distance of two neighboring points.

For point $O (lat_1, lon_1)$ and neighboring point $P (lat_2, lon_2)$, the calculation formula for angle α and distance d is as follows:

$$\begin{aligned} \tan_1 &= \tan(lat_1/2+\pi/4) \\ \tan_2 &= \tan(lat_2/2+\pi/4) \\ \Delta\theta &= \ln(\tan_2/\tan_1) \\ \Delta lat &= lat_2 - lat_1 \\ m &= \Delta lat / \Delta\theta \\ m &= \cos(lat_1) \text{ (if } \Delta\theta \text{ is near zero)} \\ \Delta lon &= lon_2 - lon_1 \\ \alpha &= a \tan_2(\Delta lon, \Delta\theta) \\ d &= \sqrt{\Delta lat^2 + m^2 \times \Delta lon^2} \times R \\ xScale &= d / X_{image} \end{aligned}$$

Table 3

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

```
<Placemark>
  <name>HourSlice_20060823_21_002</name>
  <description><![CDATA[]]></description>
  <Style id = 'default'></Style>
  <Model>
    <altitudeMode>clampToGround</altitudeMode>
    <Location>
      <longitude> -111.01514400</longitude>
      <latitude> 12.63987200</latitude>
      <altitude>0.000000</altitude>
    </Location>
    <Orientation>
      <heading> 257.85687765</heading>
      <tilt>0.000000</tilt>
      <roll>0.000000</roll>
    </Orientation>
    <Scale>
      <x> 1011</x>
      <y>1</y>
      <z>1000</z>
    </Scale>
    <Link>
      <href>models/20060823_21_002.dae</href>
    </Link>
  </Model>
</Placemark>
```

where d is the real distance between two points and is used for calculating the scale (represented by $xScale$) for zooming the image along the x -axis (represented by X_{image}) to fit the real orbit in the vector OP direction in GE. R is the radius of the Earth, 6371 km.

The above calculation accurately places the vertical image slices along the orbit track in GE through the KML file, image files, models and texture-mapping file. Table 3 is the KML code for one image slice with COLLADA model along the orbit track. The file "20060823_21_002.dae" is the COLLADA model file, which includes the vertical data image slice as its texture.

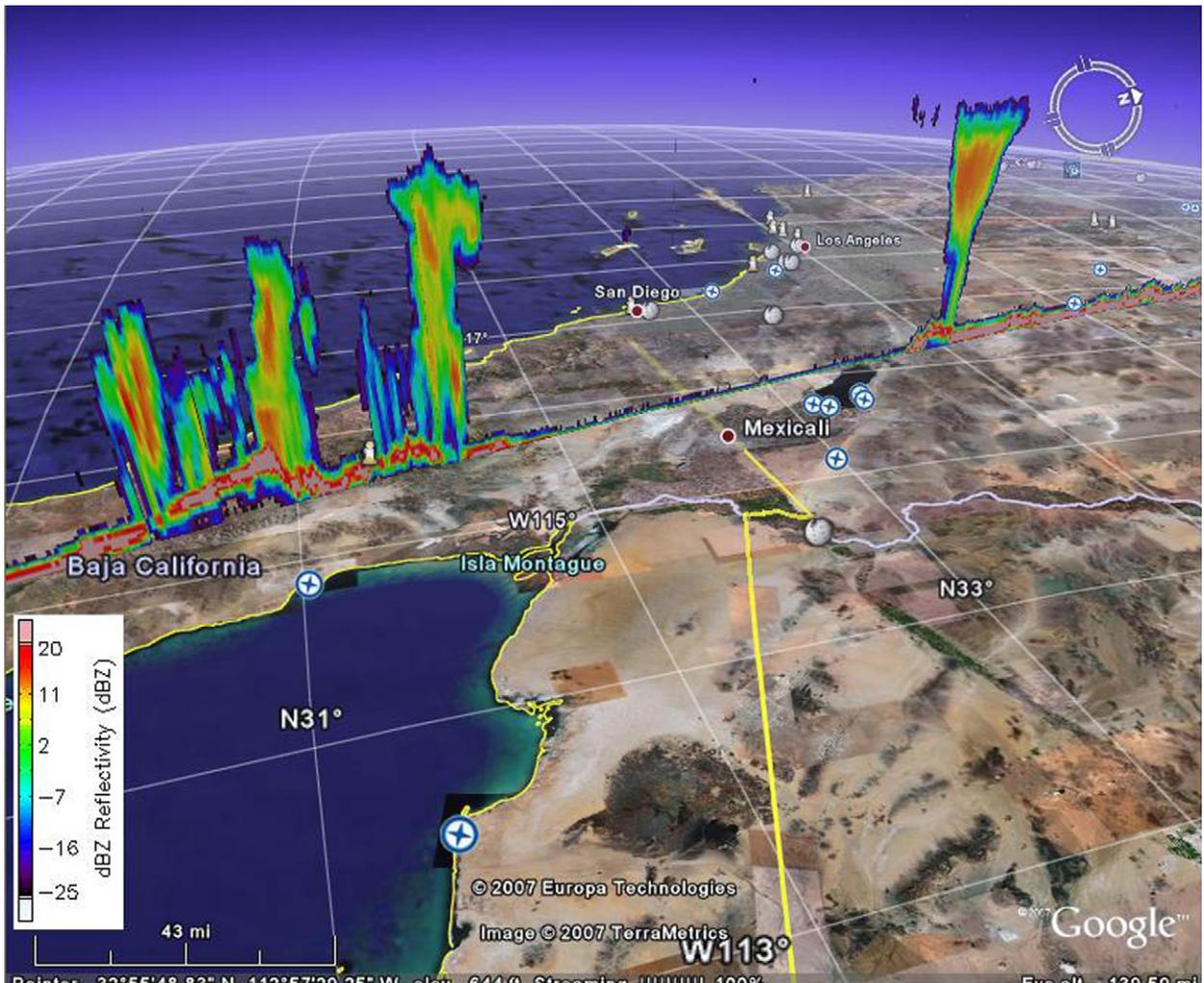


Fig. 6. Visualization of orbit curtain in Google Earth™ for vertical profile of cloud reflectivity from CloudSat mission.

A roughly 2 min (21:04:50–21:06:48, 08/23/2006) orbit curtain for cloud Radar Reflectivity (Unit: dBZ) from CloudSat is shown in Fig. 6. After users view the vertical data curtain either from their web browser or on GE, they can then download the corresponding data files from the ATDD.

Although the GE curtain contains high-resolution images along the CloudSat orbit (15 s intervals, corresponding to 103 km along the orbit track), the final KMZ file for 1 h of CloudSat data is very small, less than 1 Megabyte, which includes more than 240 images. The response speed of GE at this resolution is reasonably fast.

4. Integration with other atmospheric parameters

GE provides a very convenient platform for scientists to intercompare and integrate their geospatial products with other data. As an example, Fig. 7 combines 3 h rainfall data (displayed as a 2-D map across the Earth's surface) for

South China Storm on June 9, 2007 from the Tropical Rainfall Measurement Mission (TRMM) satellite with the vertical profile of cloud reflectivity data along a single CloudSat orbit in GE. The overlay of data shows the relationship between cloud cover and core rainfall areas of the storm. Scientists can use the data comparison to further their research, and the general public can get an understanding of the relationship between cloud cover and rainfall.

As the issue of global climate change becomes more serious, policy-makers are becoming more concerned about local environment issues and sudden natural hazards. The ATDD functionality presented here is yet another tool scientists can use to integrate socio-economic information together with geospatial data in a virtual globe environment to help policy-makers make better decisions and policies for improving people's lives. A good example is Hurricane Katrina. Using GE, all weather forecast information and near-real-time geospatial images can be integrated to display in a virtual globe environment to assist decision-makers.

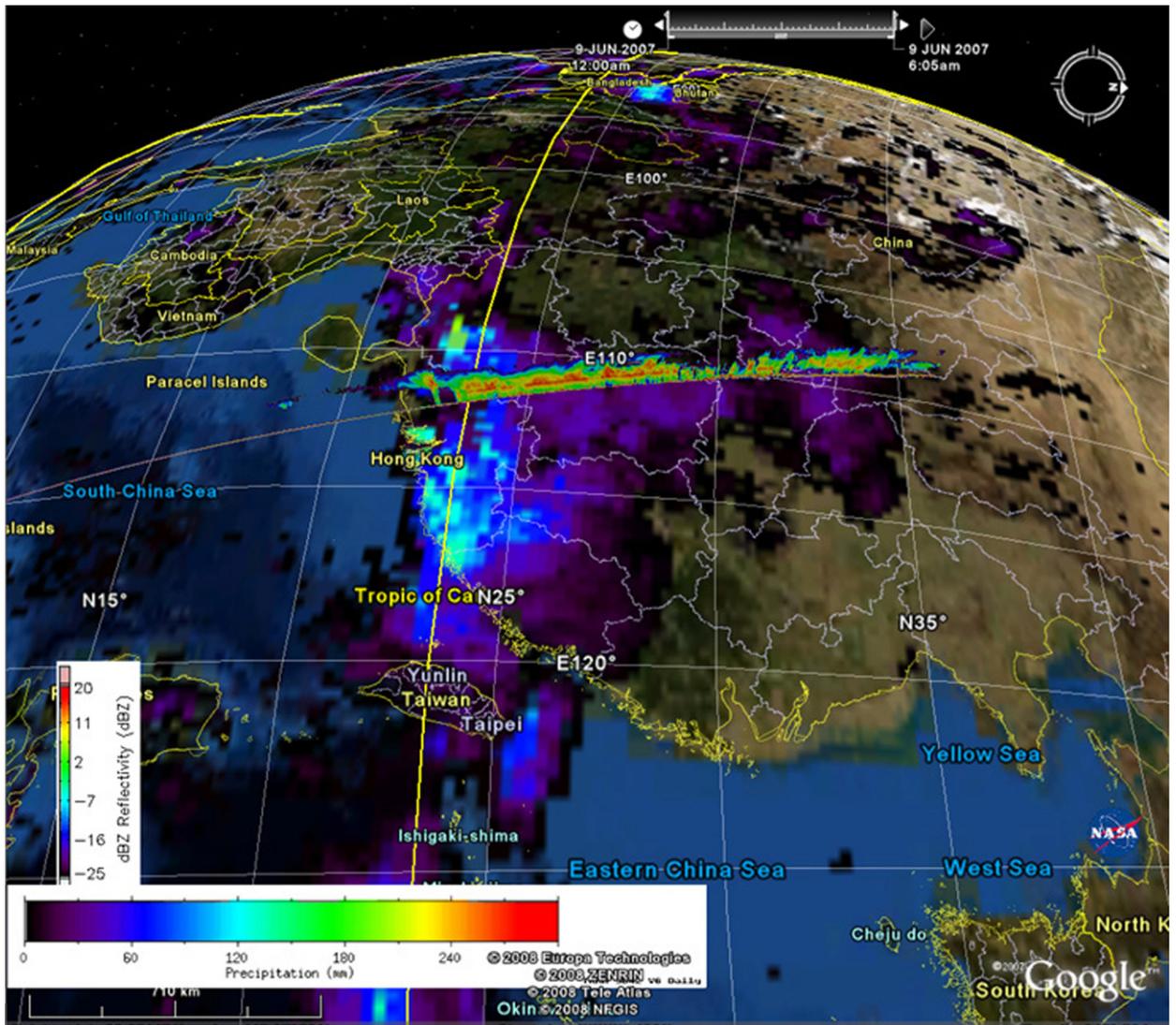


Fig. 7. Combination of cloud vertical profile from CloudSat with surface rainfall from TRMM for South China Storm on June 9, 2007.

5. Conclusions and future work

Ground-based geospatial data have been visualized and provided the general public and researchers through virtual globe servers such as Google Earth™ and Virtual 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 ATDD portal to preprocess geospatial data from CloudSat, this paper has demonstrated a method for visualizing high-resolution vertical cloud profiles along the satellite orbit in the form of a data curtain in GE. This method makes it possible to combine A-Train vertical data together with other geospatial data for scientific research and better understanding of the Earth's atmosphere. A key capability of the system is the ability to visualize and compare diverse, simultaneous data from different data sources, revealing new informa-

tion and knowledge that would otherwise have been hidden.

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 GE to facilitate scientific research and improve the daily life of the general public. Future work will focus on applying scientific research scenarios to virtual globes. The XML- and KML-oriented semantic workflow will play a key role in our future research.

Acknowledgements

The GES DISC is supported by the NASA HQ Science Mission Directorate's Earth-Sun System Division through ROSES 2005 NNH05ZDA001N-ACCESS. Author affiliated

with Center for Spatial Information Science and Systems, George Mason University has a cooperated agreement with GES DISC (Agreement no.: NNX06AD35A, Center Director: Dr. Liping Di).

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The authors would like to thank Dr. Steven A. Lloyd, Dr. Barry Schlesinger, and two anonymous reviewers for their detailed comments and corrections.

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