VISUALIZATION OF EARTH SCIENCE DATA USING GOOGLE EARTH™

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ABSTRACT:

With Google Earth being widely used by the general public and professionals, Virtual Globes are revolutionizing the way in which scientists conduct their research and the general public uses geospatial-related data and information. NASA Goddard Earth Science Data and Information Service Center (GES DISC) developed a service-oriented online scientific data analysis system to provide customable online analysis to huge volumes of two-dimensional and three-dimensional atmospheric scientific data. In this paper, Google Earth and Keyhole Markup Language (KML) are used to cooperate with GES DISC online system to enhance the visualization and visualized analysis of Earth science data. In this paper, general solutions to visualizing Earth science data in Google Earth are proposed and illustrated in details and implemented. A new method is proposed for visualizing vertical satellite data in the form of vertical orbit curtain in Google Earth. The visualization of Earth scientific data and their visualized synergy in Google Earths enables easy and straight synergistic research based on a virtual platform, advancing collaborative and globalized scientific research.

1. INTRODUCTION

NASA Goddard Earth Science (GES) Data and Information Center (DISC) did some researches related to "Virtual Globes", such as NASA World Wind (NASA, 2009a), Google Earth (Google Inc., 2009), Microsoft Virtual Earth (Microsoft Corp., 2009), and ESRI ArcGIS Explorer (ESRI, 2009). Virtual Globes usually integrate satellite imagery, aerial photography, and digital map data to create and enhance a three-dimensional interactive virtual template of our planet. Users of such virtual globe systems can then discover, add, and share geolocation-related data and information. These environments also enable researchers to conveniently collaborate and share their research projects and results. There is renewed hope that every sort of information on the state of the planet, from the levels of toxic chemicals to the incidence of disease, will become available to all with a few moves of the mouse (Butler, 2006). With the emergence of Web 2.0 and 3.0, research and applications are moving from local machine-based environments to online web-based platforms. Thus, virtual globes are recognized as an important trend in geoscience research and applications. For this reason, Google Earth was selected to enhance the research value of Earth science data at NASA GES DISC.

Since 2006, virtual globes have been used for various research fields and applications, such as global climate change, weather forecasting, natural disasters (e.g. tsunamis, hurricanes), environment conservation, travel, nature, people and culture, history illustration, avian flu, online game, etc. Most of researches and applications involved two dimensional geospatial data and socio-economic data. They are displayed in a virtual globe using geographic elements. Lots of Google Earth-related scientific research can be found in latest three years meetings including American Geophyisical Union (AGU), Association of American Geographers (AAG), American Meteorological Society (AMS) and Geological Society of America (GSA) (Bailey, 2009). In this paper, we integrated one of most popular Virtual Globes -- Google Earth and KML with web-based online analysis system to enhance research value of Earth science data.

2. GES DISC ONLINE ANALYSIS SYSTEM AND EARTH SCIENCE DATA

NASA GES DISC facilitates science and applications research by 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 current Giovanni version 3 (Giovanni, 2009) (*i.e.*, G3) provides many new and more advanced functions than Giovanni version 2. G3 provides a useful platform for the efficient utilization of both two-dimensional (2D) and three-dimensional (3D) geospatial data. G3 was designed and implemented based on a service- and workflow-oriented asynchronous architecture. Service-oriented architecture (SOA) requires that all data processing and rendering be implemented through standard Web services. This greatly 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. The 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 extensible, scalable, easy to work with, and high performance (Giovanni, 2009). GES DISC developed many instances based on G3. Each instance is a separated,

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independent online analysis system for processing specific data with specific scientific purpose. Figure 1 is a typical web interface of Giovanni instance.

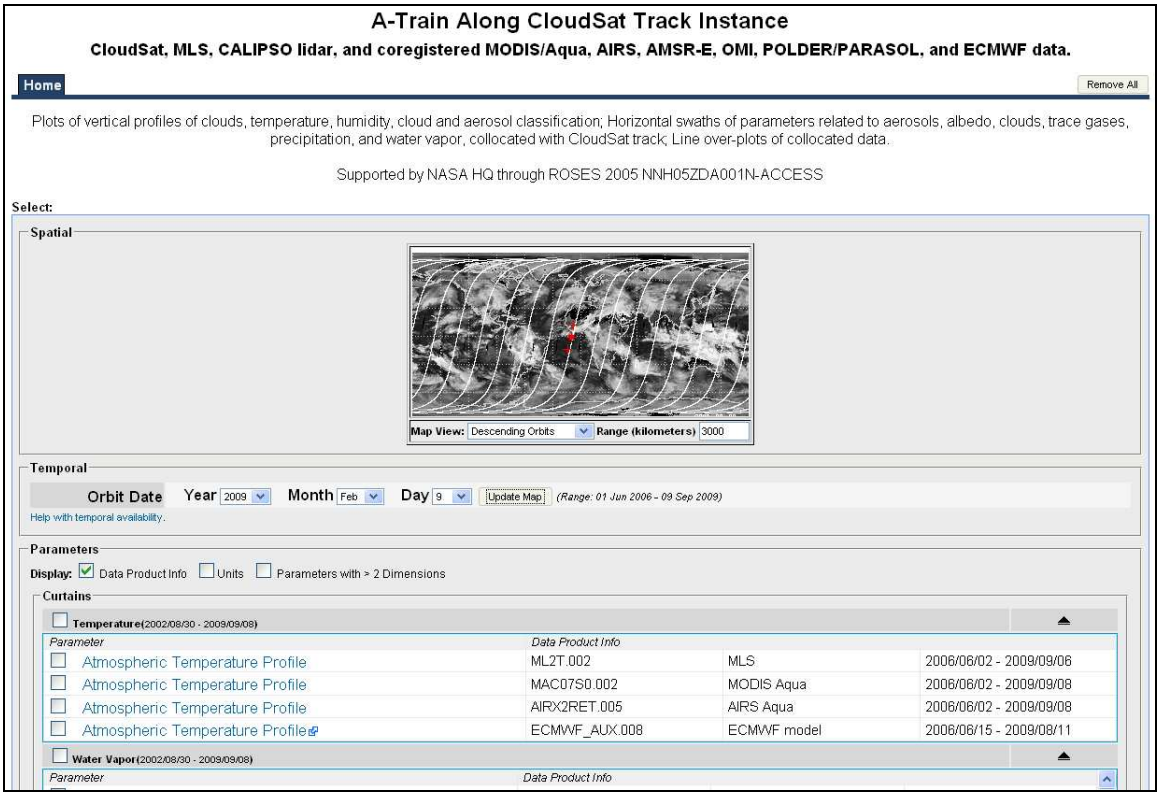

Figure 1. The online GUI of Giovanni online analysis system

The mission of GES DISC is to bring satellite imagery derived from Earth Observation System (EOS), program information, and other resources to professional scientists and general public alike. The EOS provides both 2D and 3D geospatial data that are being processed by G3. Here, we visualized these data and their analyzed results in Google Earth to augment their scientific value.

The following kinds of 2D Earth science data are processed and available for online analysis via Giovanni at GES DISC:

1. The Tropical Rainfall Measurement Mission (TRMM) Gridded Level 3 daily and monthly satellite data products. These products are from the Visible Infrared Scanner (VIRS), TRMM Microwave Imager (TMI), and Precipitation Radar (PR) instruments, describing some tropical rainfall-related core physical parameters: rain rate; rain frequency; mean surface rainfall; combined calibrated rainfall; rain rate probability distribution; vertical hydrometeor profiles; cloud liquid water; rain water; cloud ice; and convective/stratiform heating (NASA, 2009b).
2. The Atmospheric Infrared Sounder (AIRS) data products from Aqua satellite. AIRS/Aqua products describe global coverage data that describe atmospheric temperature and humidity, land and sea surface temperatures, clouds, and radioactive energy flux[9]. The gridded Level 3 2D daily and monthly physical retrieval standard products are processed and analyzed via Giovanni and visualized in Google Earth (NASA, 2009c).
3. AIRS and MODIS data from Aqua satellite. AIRS product AIRX2RET.005 is used to analyze 3D atmospheric temperature profile, H_2O saturation mass mixing ratio (gm/kg dry air) and H_2O vapor mass mixing ratio (gm/kg dry air). MODIS product
3. The Moderate Resolution Imaging Spectroradiometer (MODIS) data from Aqua and Terra satellite. MODIS daily and monthly level 3 data products are processed at GES DISC and the latitude-longitude map of many physical parameters derived from the products are processed by Giovanni and displayed in Google Earth.
4. The Ozone Monitoring Instrument (OMI) data from Aura satellite, focusing on measurements of atmospheric chemistry. The OMI daily level 3 global 0.25°x0.25° gridded products version 3 are processed at GES DISC and displayed in Google Earth.

The following three-dimensional data products derived from A-Train satellite constellation are processed and visualized in Google Earth (Chen, 2008).

1. Two kinds of Data products from CloudSat satellite: standard level 1B data and standard level 2B data. CloudSat is to help learn the vertical characteristics of cloud from space. The data are direct descriptions of the cloud vertical profile. Four physical parameters from those two data products are available and processed: a) Radar reflectivity (unit: dBZ) from data product (1B_CPR.008); b) Received echo power; c) Radar-only ice water content; and d) Radar-only liquid water content.
2. Lidar Level 2 Vertical Feature Mask (VFM) data products from Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO). The CALIPSO collects data and information about the vertical structure of clouds and aerosols unavailable from other earth-observing satellites.

MAC07S0.002 is used to analyze 3D atmospheric temperature profile (Kelvin) and H_2O Dew point temperature profile in Kelvin.

The above 2D and 3D data products are first analyzed and processed in Giovanni system, then, visualized in Google Earth.

3. VISUALIZATION OF 2D AND 3D DATA PRODUCTS

Keyhole Markup Language (KML) is used to organize and visualize data in Google Earth. Generally, there are three kinds of methods can be used to organize and visualize geospatial data via KML.

1. Using binary values of geospatial data in KML file. Binary values can be stored and organized into such KML elements as Point, LineString, LinearRing, Polygon, MultiGeometry. Some Earth science-specific software, such as OGC Web Coverage Service (WCS), Thematic Realtime Environmental Distributed Data Services (THREDDS), and NASA GES DISC Giovanni can be used to access and tailor user required data and directly return results in binary format.

2. Using image in the format of png, jpeg, gif. Geospatial data can be easily depicted in the format of image, such as png, jpeg, and gif. The images can be embedded into KML file by using KML elements, for example, PhotoOverlay, ScreenOverlay, and GroundOverlay. Some Earth science-specific software, for example, THREDDS, OGC Web Map Service (WMS), and Giovanni can process geospatial data and output results in the format of image. We used this way to visualize Earth science data in Google Earth.

3. Using 3D models that can be modeled based on binary values and/or images, both of which can be provided via the above two methods separately. The model is a COLLADA (COLLAborative Design Activity) model supported by Google's SketchUp tool and Google Earth. 3D data are processed using this method to produce the orbit curtain plot in Google Earth.

3.1 Processing and visualizing 2D Earth science data

Giovanni is used to first process 2D data. We proposed and implemented an OGC standard compatible WMS in Giovanni. Giovanni is responsible for acquiring and pre-processing data, then, WMS is responsible for processing and outputting data in the format of image. The outputted images are embedded into KML file and finally visualized in Google Earth.

The following 2D data products are processed and visualized in Google Earth, including Level 3 monthly, daily and 3-hour TRMM data, monthly and daily AIRS/Aqua data, monthly MODIS/Terra and MODIS/Aqua data, monthly OMI data (Ozone Monitoring Instrument)/Aura, SeaWiFS data (Sea-viewing Wide Field-view Sensor) and others. KML works as the intermediate media for integrating the processed data and images with Google Earth. The images are produced on-the-fly via Giovanni WMS. Figure 2 is a demonstration of the visualization of Column Amount Ozone from 2D OMI/Aura data products.

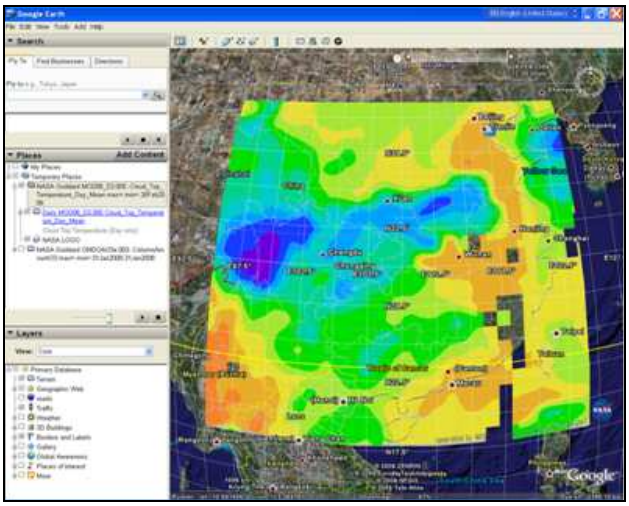

Figure 2. Visualization of 2D Earth science data in Google Earth (OMI/Aura daily 0.25˚ x 0.25˚ Column Amount Ozone (DU))

Table 1 is part of example of the KML file for 2D TRMM data. In KML file is embedded a WMS request that will be activated and return image while user opens the KML file in Google Earth™.

Table 1 KML file for integrating TRMM 3B43 data product

```
<kml xmlns="http://earth.google.com/kml/2.0">
 <Folder>
  <name>NASA TRMM_3B43_V6 2007-12-01</name>
  <description>The TRMM data images in Google Earth are
served via OGC WMS by NASA GES DISC.</description>
   <visibility>1</visibility>
   <open>1</open>
    <GroundOverlay>
     <name>2007-12-01</name>
     <Icon>
      <href>
<![CDATA[http://g0dup05u.ecs.nasa.gov/cgi-
bin/wms_ogc?SERVICE=WMS&VERSION=1.1.1&REQ
UEST=Getmap&layers=bluemarble,TRMM_3B43_V6_
MONTHLY&BBOX=-180,-50,180,50&TIME=2007-12-
01&format=png&transparent=true&WIDTH=1500&HEI
GHT=800]]> </href>
     </Icon>
     <LatLonBox>
       <north>50</north>
       <south>-50</south>
       <east>180</east>
       <west>-180</west>
     </LatLonBox>
     <TimeStamp>
       <when>2007-12-01</when>
     </TimeStamp>
    </GroundOverlay>
 </Folder>
</kml>
```

3.2 Processing and visualizing 3D vertical data

We introduced a new way to visualize 3D Earth science data. The 3D data mainly are atmospheric vertical profiles that represent the characteristics of cloud, aerosol, H_2O, and atmospheric temperature, which are considerably different from 2D data.

Giovanni A-Train instance is first used to process all kinds of 3D data to produce three kinds of images: data image, color bar image, and vertical scale image. Via the GUI of Giovanni, user may input spatial and temporal ranges and select desired physical parameters. The GUI lists available parameters to help users customize their specific requirements. Then, a new method was proposed and applied to the data image to visualize it in Google Earth, and color bar image and vertical scale image are separately visualized in Google Earth.

COLLAborative Design Activity (COLLADA) (COLLADA, 2009) is a XML-compatible standard for building three-dimensional applications. It is supported by Google Inc. and COLLADA 3D models can be visualized via KML in Google Earth. According to A-Train satellite flight parameters, we designed and built a 3D model as a template for visualizing vertical Earth science data. Table 2 is part of the COLLADA model codes.

Table 2. A COLLADA 3D model with image 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/20090214_18_001.png</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 0 300 108 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>
```

The model template covers about 103m horizontal distance in the direction of satellite flying that spends about 15 seconds. So, the data image in a spatial range is chopped into small pieces with same horizontal distance flying in each 15 seconds and putted on the model template as texture repeatedly. The procedure produces a series of models that are used to form KML file. Exactly placing the series models along the satellite orbit track is a critical step for visualizing the vertical profiles in Google Earth. Based on the 15-second interval, we designed an algorithm to calculated latitude and longitude of the point where the left-bottom corner of the model be placed. We also designed an algorithm to calculate the angle between longitude and the orbit track, so we can place the models in a specific angle to make sure that the models are visualized along the orbit track. The visualization component for 3D data regularly does: a) designing an image slice template and chopping data image into series of image slices; b) designing a COLLODA model template; c) texturing COLLADA model template with image slices to repeatedly produce series of COLLADA models; d) Calculating positions (latitude & longitude) in Google Earth for each model, where the left-bottom corner of each model is placed in Google Earth; e) Calculating the angle between latitude and orbit track that decides in which direction the model is placed. Finally, we can get a KMZ file that is able to be opened in Google Earth and produce an orbit curtain (Chen, 2009). Table 3 is part of KML codes including one model slice. Figure 3 demonstrates part of the orbit curtain of cloud radar reflectivity (unit: dBZ) from CloudSat satellite.

Table 3. Example of KML codes with one model slice

```
<Placemark>
  <name> HourSlice_20090214_18_001</name>
    <description><![CDATA[]]></description>
      <Style id='default'></Style>
      <Model>
        <altitudeMode>clampToGround</altitudeMode>
        <Location>
          <longitude>-64.12197900</longitude>
          <latitude> 22.091977</latitude>
          <altitude>0.000000</altitude>
        </Location>
        <Orientation>
          <heading> 257.59190965</heading>
          <tilt>0.000000</tilt>
          <roll>0.000000</roll>
        </Orientation>
        <Scale>
          <x>808</x>
          <y>1</y>
          <z>1000</z>
        </Scale>
        <Link>
          <href>models/20081012_05_001.dae</href>
        </Link>
    </Model>
</Placemark>
```

4. INTEGRATION OF GOOGLE EARTHS-BASED DATA VISUALIZATION WITH GIOVANNI SYSTEM

The visualization components for 2D and 3D data products have been integrated into the Giovanni system. Figure 4 shows the integration. Through the Giovanni GUI, users can directly download KMZ files and view them in Google Earth after they view data images in Web browsers.

The orbit curtain plot in Google Earth can be overlaid with other Earth science products, available in Google Earth, for synergistic analysis and application in the uniform platform – Google Earth.

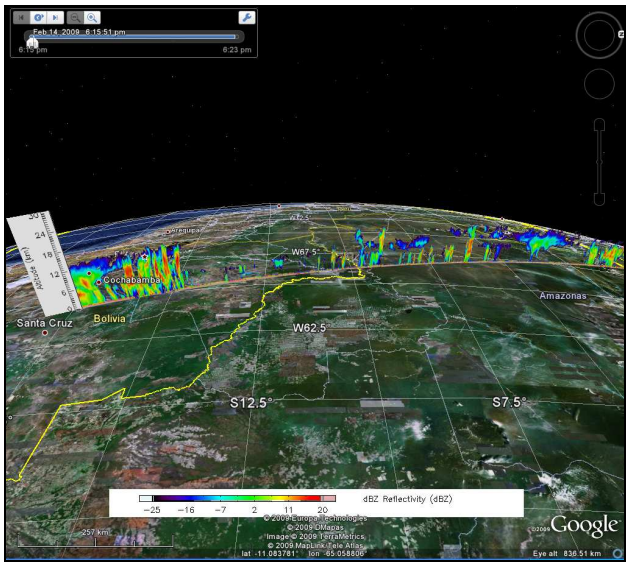

Figure 3. The orbit curtain of CloudSat 3D data in Google Earth

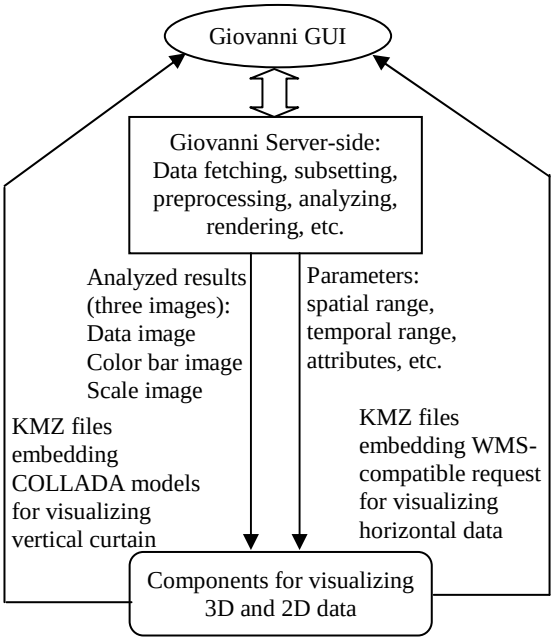

Figure 4. Integrating data visualization with Giovanni system

5. CONCLUSION

Three ways to visualizing Earth science data in Google Earth are proposed and discussed in the paper. After introducing NASA GES DISC 2D and 3D Earth science data and its online analysis system – Giovanni, two of ways are designed and implemented to visualize analyzed results outputted from Giovanni. An OGC WMS standard compatible Web Map Server is implemented in Giovanni system to accept data and parameters from Giovanni internally and output images. The outputted images are processed and embedded in KML file for visualizing in Google Earth. Most of 2D data are visualized in this way. A new COLLADA model-based way is proposed and implemented to visualize 3D vertical data. The 3D vertical data is first processed in Giovanni system to output three images: data image, color bar image and scale image. Then, a 3D visualization component takes these three images as input and finally outputs a KMZ file that visualizes 3D vertical data as a vertical orbit curtain in Google Earth. A diagram illustrates how to integrate the Google Earth-based visualization component with Giovanni system. The integrated system has been released online and can be accessed at the website http://disc.gsfc.nasa.gov/googleearth/. These general solutions can be applied to most geospatial data to integrate them into Google Earth for collaborative and synergistic scientific research and applications.

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Giovanni, 2009. The GES-DISC (Goddard Earth Sciences Data and Information Services Center) Interactive Online Visualization ANd aNalysis Infrastructure version 3. 2007 from http://daac.gsfc.nasa.gov/atdd/ (accessed 8 Sep 2009).

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NASA, 2009c. Atmospheric Infrared Sounder. http://disc.gsfc.nasa.gov/AIRS/instruments.shtml, 2008.