Visualization of NASA Campaign Mission Vertical Profiles Using Google Earth

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***Abstract*--Google Earth, as the pioneer of Virtual Globes, is changing the way in which professionals acquire, assess, organize, manage, share, visualize, and utilize three-dimensional geospatial data in a virtual environment for scientific research. Google Earth is also changing how the public interacts with virtual globes to facilitate their daily life. Keyhole Markup Language (KML) is the key technology making this change possible. NASA campaign missions have collected large volumes of vertical profiles of the atmosphere for various experiments and validation of instruments to be loaded on satellites. This paper describes design and implementation of two solutions to visualizing those vertical profiles in Google Earth for facilitating the validation and testing of the instruments. The first is to read and process the scientific data into images by using Interface Description Language (IDL). Then, COLLAborative Design Activity (COLLADA) model is used to process and render these images in the form of three dimension. Finally, KML files are produced—the vertical profiles are visualized in the form of vertical curtains in Google Earth. The second way is to read the data values directly from the vertical profiles and use them to produce KML files that visualize the vertical profiles as vertical curtains in Google Earth. The vertical curtain is composed of a large number of small rectangles. The first way produces a high-resolution curtain quickly, but the positions of the vertical curtain in Google Earth are not accurate. For the second way, the positions of the vertical curtain can be very accurate in Google Earth, but the resolution is low and the speed is slow. Examples are given for both solutions.**

Keywords: Atmosphere; Campaign Mission; Vertical Profile; KML; KMZ; COLLADA; Google Earth

I. INTRODUCTION

Google Earth integrates imagery from satellites, airplanes and ground maps data to form a virtual environment of our planet. Both professionals and the general public can virtually explore the world, discover sites and data of interest, and publish and share their own data with great ease. Via this virtual globe platform, people can quickly and freely fly virtually from space down through layers of progressively higher resolution data sets and hover above any point on the Earth's surface. Google Earth then displays information relevant to that location from a vast number of sources. Google Earth was designed and implemented with the purpose of using the Earth itself as a tool for organizing and displaying digital information. Now, Google Earth is changing the way in which professionals and the public interact with any Earth-related data. With a few clicks of the mouse, people can get a huge amount of information of interest. With the maturity of Web 1.0 and the emergence of Web 2.0 and 3.0, online Web-based platforms and applications are becoming mainstream in the information technology era. Virtual Globes, such as Google Earth and Microsoft Virtual Earth, will be playing increasingly important roles in scientific research and applications and people's daily lives in the near future [1].

NASA campaign missions have collected large volumes of vertical profiles of the atmosphere for various experiments and validation of satellite instruments. One mission is CALIPSO-CloudSat validation mission. CALIPSO is an acronym for Cloud Aerosol Lidar and Infrared Pathfinder Satellite Observation. Those mission flights in July and August 2006 are intended to validate CALIPSO and CloudSat, which have already been launched.

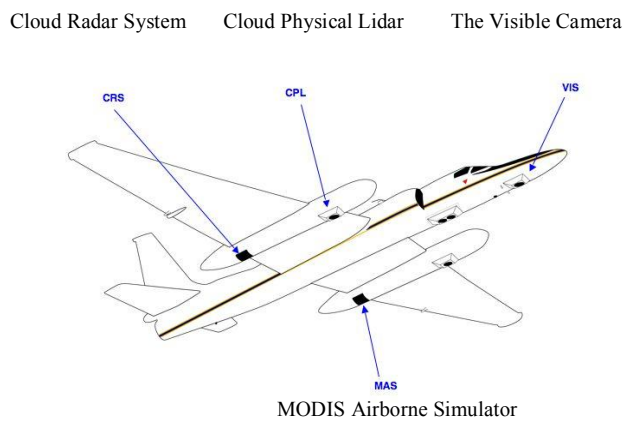

Figure 1 The Aircraft ER-2 and its payloads [5]

Figure 1 is the aircraft whose payload for the validation mission includes the Cloud Physical Lidar (CPL), the Cloud Radar System (CRS), the MODIS Airborne Simulator (MAS), and a visible camera (VIS) [5]. CPL is primarily used to validate the CALIPSO lidar, while CRS mainly validates the CloudSat radar. The focus here is on processing vertical profiles of cloud characteristics derived from CPL. The vertical profiles are visualized as a vertical curtain in Google Earth. A "curtain" of high-resolution cloud parameters derived from CPL can be displayed transparently or opaquely and visualized from all directions, including along the flight track. Visualizing the vertical profiles from aircraft CPL and CloudSat satellite for the same time provides for easy,

straightforward comparison of cloud vertical profiles from different instruments. Scientists thus glean valuable insights into the nature of cloud processes.

Two methods are introduced for rendering orbit curtains from vertical profiles derived in campaign missions. One is to directly use geospatial data values to generate KML files that are rendered into two-dimensional vertical curtains in Google Earth. Another way is based on the Collaborative Design Activity (COLLADA) model. Both ways have advantages and disadvantages. Details will be discussed in the following sections.

Since the re-release of Google Earth in 2005, it has been used for many scientific applications, for example, volcano observatory, real-time monitoring of campaign missions, climate change, weather forecasting, hurricanes, tsunamis, avian flu, and pollution. Most of those applications visualize only horizontal data and the results of analyzing it in Google Earth [2][3]. The public uses Google Earth to preview places of interest to them, plan travel routes, and share their imagery and related information. However, few scientific applications process the vertical profiles of the atmosphere collected in campaign missions, especially comparing data on the same physical phenomena from different instruments in a unified virtual platform. Chen, et al. (2009) introduced how to render vertical profiles from A-Train satellites in Google Earth.

II. VERTICAL PROFILES FROM CAMPAIGN MISSIONS

Many field campaign missions calibrate and validate instruments loaded on different satellite platforms, for example, the Tropical Composition Cloud and Climate Coupling (TC4) mission, the Cloud and Land Surface Interaction (CLASIC) mission, and the Aura Validation Field Campaign. We select and process the vertical profiles from the CALIPSO-CloudSat validation mission, in a CALIPSO-CloudSat Validation Experiment (CC-VEX). CC-VEX has two overarching goals: a) establish sensitivity and calibration for CloudSat-CALIPSO orbital coordination; b) initial microphysical validation – A-Train simulation. The planned flights of CC-VEX in July and August 2006 are intended to validate the launched CALIPSO and CloudSat satellites. The Cloud Physical Lidar (CPL) is the primary validation tool for CALIPSO lidar, while, the Cloud Radar System (CRS) is a primary validation tool for Cloud radar [5].

The CPL is a backscatter lidar designed to operate simultaneously at three wavelengths: 1064, 532, and 355nm. It is designed to provide multi-wavelength measurements of cirrus and subvisual cirrus clouds, and of aerosols with high temporal and spatial resolution. The CPL utilizes state-of-the-art technology with a high repetition rate, a low pulse energy laser, and photon-counting detection. The vertical resolution of the CPL measurements is fixed at 30 m; the horizontal resolution can vary but is typically about 200 m. These vertical and horizontal resolutions are the highest resolution on which the vertical profiles in Google Earth are based. The data products are time-height cross-section images, cloud and aerosol layer boundaries, cloud optical depths, aerosol layers, planetary boundary layer (PBL), and extinction profiles.

CPL was designed for loading on the NASA ER-2 aircraft but it can be adapted to other platforms. The ER-2 usually flies at an altitude of about 20 km. There, the onboard instruments are above 94% of the earth's atmosphere, so ER-2 instruments can function as spaceborne instrument simulators. ER-2 provides a unique platform for atmospheric profiling, particularly for active remote sensing instruments such as lidar. Lidar profiling from the ER-2 platform is especially valuable because the cloud height structure, up to the limit of signal attenuation, is unambiguously measured. The fundamental CPL data product is a time-height cross-section image of the atmosphere [6].

The vertical data profiles from CPL collected on August 11, 2006 are selected for processing and visualization in Google Earth. The data reflect the attenuated backscatter in 532nm of the cloud. The data are stored in the eXternal Data Representation (XDR) format, which has the extension file name *.xdr). Figure 2 shows the data in .gif format. An Interactive Description Language (IDL) program processes the vertical data to an image.

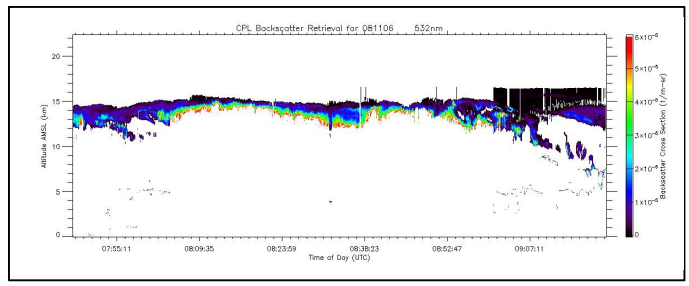

Figure 2 The image of vertical profile derived from CPL, representing the attenuated backscatter in 532 nm.

III. VISUALIZATION OF CAMPAIGN MISSION VERTICAL PROFILES IN GOOGLE EARTH

Two approaches to visualizing vertical profiles are proposed and implemented. One way uses the COLLADA model. A COLLADA model template is designed. Vertical data are first processed into images. Then, the images are chopped into small pieces and put on the COLLADA model template as texture. COLLADA models are embedded into the KML files that are finally visualized in Google Earth. In the other way, values of the vertical data are used to generate small rectangles that can be displayed vertically in Google Earth in the KML format.

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 the spatial range selected by the user. For CloudSat, one can choose which physical variable one wishes to view (either radar reflectivities, dBZ, or received echo powers, REP). Then, 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. Figure 2 is an image curtain of CloudSat data produced by Giovanni.

A. COLLADA model-based visualization

COLLADA provides a schema for exchanging digital assets among graphic software and applications based on open standards and XML. The COLLADA schema supports all the features that modern three-dimensional (3D) interactive applications need. Its choice of XML offers many of the benefits of the eXtensible Markup Language [7]. Its 3D features are used here to visualize geospatial data to form an orbit curtain.

From the image produced by the IDL program in section 2, three steps are needed to visualize the vertical profiles in Google Earth:

1) Design and create a COLLADA model template that can be visualized in Google Earth
2) Cut the image into small slices and put the slices on the COLLADA model template as texture
3) Position COLLADA models continuously along the flight track in Google Earth.

Given the display resolution and rendering speed in Google Earth, the model template is designed to represent 15 seconds of ER-2 vertical profiles. The flying speed of the ER-2 is about 200m/s. So the x value of the model template in Google Earth is 300m, which represents 3km. To make the 3D model template very thin, so it looks like a curtain, the y value is set to close to zero. The z value is based on the altitude at which ER-2 flies and is set to 200m in Google Earth, which represents 2km. Thus, the (x, y, z) of the model template are respectively 300m, 0.01m, and 200m in SketchUp coordinate space. Google's SketchUp tool is used to create the model template. In Google Earth, the x value is mapped to the distance that ER-2 flew in 15 seconds, and the z value is mapped into the altitude at which ER-2 flies. The vertical profiles are processed into an image that is cut into many small slices. Each of the image slices is put on the model template as texture to build up a 3D COLLADA model. So, many 3D COLLADA models are produced. Those models can be embedded into a KML file and visualized in Google Earth. Table 1 shows part of the 3D COLLADA model in XML format.

TABLE 1. PART OF THE COLLADA MODEL DESIGNED FOR REPRESENTING VERTICAL RPOFILES

```
<?xml version="1.0" encoding="utf-8"?>
<COLLADA xmlns="http://www.collada.org/2005/11/COLLADASchema" version="1.4.1">
… …
    <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 0 300 0 0 -0.5 0 200 300.5 0 200</float_array>
                <technique_common>
                    <accessor source="#mesh1-geometry-position-array" count="4" stride="3">
                        <param name="X" type="float"/>
                        <param name="Y" type="float"/>
                        <param name="Z" type="float"/>
                    </accessor>
                </technique_common>
            </source>
            <source id="mesh1-geometry-normal">
                <float_array id="mesh1-geometry-normal-array" count="6">0 -0.0254 0 0 0.0254 0</float_array>
                <technique_common>
                    <accessor source="#mesh1-geometry-normal-array" count="2" stride="3">
                        <param name="X" type="float"/>
                        <param name="Y" type="float"/>
                        <param name="Z" type="float"/>
                    </accessor>
                </technique_common>
            </source>
            <vertices id="mesh1-geometry-vertex">
                <input semantic="POSITION" source="#mesh1-geometry-position"/>
            </vertices>
            <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>
……
</COLLADA>
```

To position the 3D models in Google Earth, two factors need to be considered. One is the latitude and longitude for each model in Google Earth. The other is the direction in which the models are placed—along the flight track. The resolution of the data profiles from a Campaign Mission is one second in temporal range and 30m vertical by 200m horizontal in spatial range. Because each model represents 15 seconds of data profiles, the latitude, longitude, and flight direction can easily be read from the whole set of data profiles at intervals of 15 seconds, given the start time of the data profiles. According to the available latitude, longitude, flight direction, and a series of 3D models, we produced a KMZ file (*.kmz) that visualizes the vertical profiles in the form of a vertical curtain in Google Earth. The KMZ file includes a KML file (*.kml), a texture mapping file (*.txt), a series of image slices (*.gif or *.png), and a series of 3D COLLADA models (*.dae). The Placemark and Timespan KML features are used to create the KML file. Placemark is used to organize the models, and Timespan is used to display the temporal range of the vertical curtain. Figure 3 displays the implemented vertical curtain in Google Earth.

Although the vertical curtain contains high-resolution images along the flight track (at15-second intervals, corresponding to 3km along the flight track), the final KMZ file for half hour of vertical data from CPL is small, less than 1 Megabyte, including 120 images, 120 COLLADA 3D models. The display speed in Google Earth is reasonably fast.

B. Data values-based visualization

The KML specification provides many features that can be used directly to store and organize binary data values. Some of those features are Point, LineString, LinearRing, Polygon, and MultiGeometry. They render vertical data in the form of a vector in Google Earth. The binary data of the vertical profiles are read to produce the KML file [4]. The KML specification

also provides some special features that make it possible to visualize different levels of detail in data as the user zooms in and out in Google Earth, for example, Regions, LatLonAltBox, and Lod. It is very useful for improving the display speed for big volumes of vertical profiles [8].

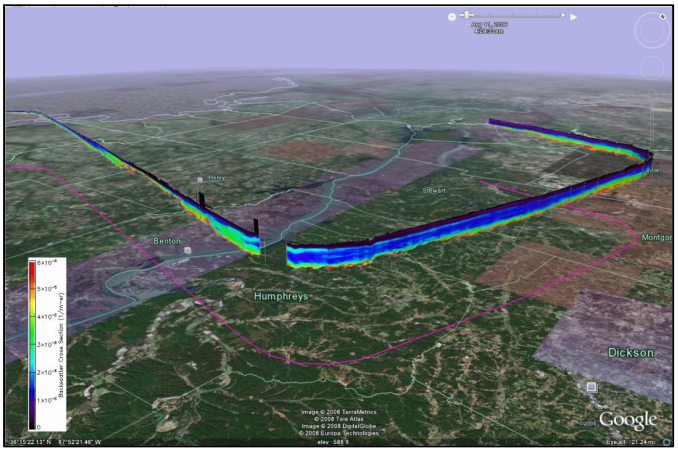

Figure 3 The COLLADA model-based vertical curtain representing the vertical profiles from Campaign Mission CC-VEX (CPL backscatter retrieval in 532nm on Aug. 11, 2006)

Considering the big volumes of the vertical profiles and the speed of rendering the vertical curtain based on the final KML file in Google Earth, we designed and implemented the KML files from high resolution to low resolution in three levels. The highest temporal resolution derived from the processed vertical profiles is one second. The highest spatial range is 200m in the direction of flight (horizontal). The vertical resolution is 30m. So, the highest resolution of the vertical profiles is 200m by 30m.The area of 200 by 30m is displayed as a vertical rectangle by using KML features. The complete vertical curtain consists of numerous small rectangles. A 256-color palette is used to express the data value. The color palette and the data value of the point determine the color of the rectangle. Those rectangles with missing or zero data values are made transparent. The resolution of the middle level is 2 seconds in time and 400m by 60m in space. The resolution in the bottom level is 3 seconds in time and 600m by 90m in space. When the resolution is higher, the size of the file is bigger, and the speed of rendering it in Google Earth is slower. The sizes of the files for different resolutions are, respectively, more than about 20, 5, and 2 Megabytes from high resolution to low resolution. The KML file with the lowest resolution is displayed by default if the user wants to view these vertical profiles in Google Earth. With Zooming in will display, the KML file with higher resolution in place of the KML file with low resolution. Figure 4 shows the vertical curtain in Google Earth produced from the highest resolution data values,

IV. VIRTUALLY COMPARING VERTICAL PROFILES FROM THE A-TRAIN AND CAMPAIGN MISSIONS

Google Earth provides a virtual unified platform that scientists can use to integrate and compare related geospatial data products. The vertical profiles from CPL of the CC-VEX Campaign Mission and VFM (Vertical Feature Mask) of CALIPSO of the A-Train were compared for the same day, 2006 August 11 for the same track. Figure 5 illustrates the comparison. The pink line is the flight track for both airplane and satellite. The two legends respectively for vertical curtains from Campaign Mission and A-Train satellite are helping users identify and compare these two kinds of vertical products. The CPL was designed to validate the lidar sensor loaded at the CALIPSO satellite. This work will facilitate the validation with its improvement. Current comparisons are not so straightforward, and conclusions cannot easily be drawn from them. We are trying to improving the vertical curtain from the Campaign Mission to increase the scientific applicability of our solution.

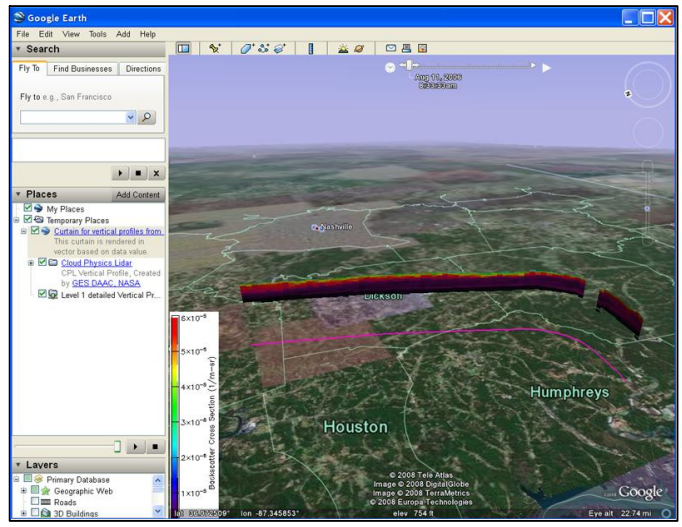

Figure 4 The binary data value-based vertical curtain rendered in the highest resolution in Google Earth. The vertical profiles are from Campaign Mission CC-VEX (CPL backscatter retrieval in 532nm for Aug. 11, 2006)

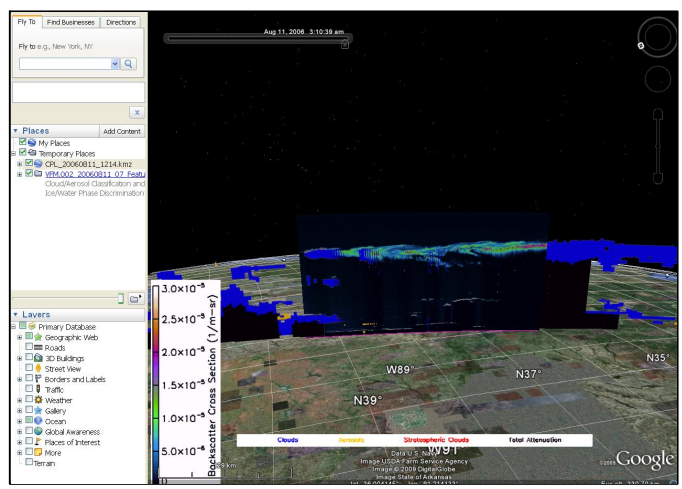

Figure 5 Comparison of the vertical curtains from CPL of CC-VEX of Campaign Mission and CALIPSO of A-Train on Aug. 10, 2006.

V. CONCLUSIONS

Use of Google Earth as a web-based online virtual platform is becoming an increasingly popular approach among scientists researching geospatial phenomena and the general public for easily using the geospatial data. This paper has discussed how to process and display vertical profiles from the Campaign Mission in Google Earth. Two different ways were

introduced. In one, based on the COLLADA 3D model, vertical profiles are first processed into images, and a COLLADA model template is designed. Then, the images are divided into small slices on the COLLADA model templates to form a series of models. Finally, a KML file is created to organize the models together along the flight track and display them in Google Earth. In the other, the binary data value vertical profiles from KML features are directly used to form small vertical rectangles. The collection of many small vertical rectangles forms the vertical curtain of the vertical profiles in Google Earth.

Given the large volume of data, the vertical curtain can be designed and displayed at three levels of spatial resolution: 200m by 30m, 400m by 60m, and 600m by 90m and three intervals of time: 1, 2 and 3 seconds. By default, the curtain with the lowest resolution is displayed when a user first wants to view the vertical curtain of some vertical profiles. Zooming-in in Google Earth replaces the current curtain with one of higher resolution. This method improves the speed of producing a curtain in Google Earth and makes it possible to combine A-Train vertical data together with other geospatial data for scientific research and better understanding of our planet.

Virtual, visual Google Earth comparison of the vertical profiles derived from different observation instruments facilitates scientists' research and makes it easier for both professionals and the public to understand complicated atmospheric phenomena. A key capability of our method is the ability to reveal new information and knowledge by visualizing and comparing simultaneous data from different data sources, In the near future, we will improve the vertical curtain for vertical profiles from the Campaign Mission so that the comparison between profiles from airplane and satellites will be more fruitful.

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