

Mapping and analysis using multisource oceanic satellite data and google earth engine

Yan Kang¹, and Jun Wang^{2,*}

¹Institute of Land and Urban-Rural Development, Zhejiang University of Finance and Economics, 310018 No.18, Xueyuan Street, Hangzhou, Zhejiang, China

²College of Mechanical and Electrical Engineering, China Jiliang University, 310018 No.258, Xueyuan Street, Hangzhou, Zhejiang, China

Abstract. Ocean satellite observation because of its large coverage area and high frequency observation become ever more important data and information source with global climate changing, ocean resources protecting and oceanic engineering projects implementing. Oceanic satellite data characteristically include multi-physical parameters, are the product of multi-level processing and are multi-sourced data. Therefore, oceanic satellite data often have different manifestations making the understanding and use of these data challenging, and there is an urgent need for a flexible platform to share the data and merge different kinds of the data information. Here we use Google Earth Engine that make these data easily understandable and a fully synthesized and comprehensive visualization. Then the key techniques for creating 2D and 3D visualizations of oceanic satellite data using KML and Google Earth are detailed in this paper. As an example, multi-sourced satellite data including horizontal distribution and vertical profiles of Typhoon Morakot in August 2009 are combined on Google Earth with three-dimensional visualization. We have extended this research and developed a web service system based on an oceanic satellite visualization data model to dynamically display different types of the oceanic satellite data on Google Earth.

1 Introduction

Zcanner (COCTS) and Coastal Zone Imaging (CZI) on board HY-1A and HY-1B satellites are being applied to the oceanic environment research fields, and shows great potential for various applications, such as coastal water quality monitoring, fishery resources protection, development and utilization of fishery resources, coastal engineering and oceanography. Three series of ocean remote sensing satellites are already planned: the ocean color satellite series HY-1, the ocean dynamic satellite series HY-2, and the comprehensive ocean satellite series HY-3 in China^[4]. With the rapid increasing of the ocean satellite data and information, there is an urgent need for a flexible platform to share the data and merge different kinds of the information.

* Corresponding author: wangjun8762103@sina.com

With the development of computer systems and software, it is now possible to rapidly acquire and analyze large satellite data sets online. Google Earth has become a cult web product since its release in June, 2006. Using this web-based tool, users can fly around the globe and zoom in on both natural features and access the whole world's information as added by other users^[5]. Due to its capability of providing a virtual 3D platform for visualizing and synergizing earth science data, Google Earth now plays an increasingly important role in many scientific research fields, and is changing the way that scientists interact with the geospatial data. Google Earth lowers the entry barrier for both scientists and people with little GIS experience by sharing and viewing multiple large data sets on a virtual globe. At present, Google Earth is being used in many fields, for example climate change, weather forecasting, natural disasters (e.g. tsunami, hurricane), the environment, travel, nature and geography, illustrating history, presidential elections etc.^[9]. Keyhole Markup Language (KML) can be utilized to present and display geospatial data on Google Earth, Google Maps, Google Maps for mobile, and Microsoft Virtual Earth as well as many other digital mapping platforms. Shi and Meng^[3] integrated and interoperated multiple theme data on the basis of Google Earth. Chen et al.^[1,2,5,6,9] have used KML and KMZ to visualize and synergize NASA earth science data on Google Earth since 2007. NASA Goddard Earth Science (GES) Data and Information Service Center (DISC) has developed many tools for visualizing 2D, 3D and 4D Earth science data on Google Earth on their website <http://disc.sci.gsfc.nasa.gov/>. NOAA researchers also display real-time weather information in Google Earth familiar to the general public. Duncan et al.^[9] displayed 3D seismicity with Google Earth. Also, Yamagishi et al.^[10] have developed a visualization system for multidisciplinary geosciences data, which visualizes seismic tomographic models, geochemical datasets of rocks, and geomagnetic field models by exploiting Google Earth technologies. The Alaska Volcano Observatory remote sensing group has developed Keyhole Markup Language (KML) tools that are used to display satellite data for volcano monitoring and forecast ash cloud movement on the website <http://ge.images.alaska.edu/>.

We have extended this research and developed a web service system based on an oceanic satellite visualization data model to dynamically display different types of the oceanic satellite data on Google Earth. The different types of satellite data and visualization data model used in this system are introduced. Then, the details of the key techniques for 2D and 3D visualization of oceanic satellite data on Google Earth are described. Finally, as an example, multi-source satellite data including the horizontal distribution and vertical profiles during Typhoon Morakot in August 2009 are combined on Google Earth with three-dimensional visualization as an application example of the oceanic satellite data web mapping service system.

2 Oceanic satellite data and visualization data model

2.1 Oceanic satellite data introduce

Three type's oceanic satellite data are used in this paper for example, which cover the most types of the current oceanic satellite remote sensing products. One is the satellite remote sensing data of the ocean color and temperature in the upper ocean layer with a horizontal distribution and continuous values. The second are the satellite remote sensing data from sea surface winds, with a horizontal distribution and vector values. The third is the satellite remote sensing data of the vertical structure of clouds, with a vertical profile distribution.

The ocean color and temperature data were obtained from the State Key Laboratory of Satellite Ocean Environment Dynamics (SOED) of the Second Institute of Oceanography (SIO) in China. Ocean color data such as the chlorophyll concentration data can be retrieved

from spectral water-leaving radiances received by the satellite ocean color remote sensor with very high sensitivity^[8]. The sea surface temperature was retrieved by the radiances received by the sensor at two thermal infrared bands. Cloud cover is one of the most important factors cause missing daily ocean color and temperature data. Because of the larger cloud coverage area during the course of a single day, especially during the typhoon season, the average monthly ocean color and temperature data is used to avoid the cloud cover affect. Each average monthly ocean color and temperature data has two separately formatted data files, the grid data file (Level-3B) with the spatial resolution of 1.825km, and the contour line file (Level-4A). The ranges of the ocean color and temperature data are from 14°N to 42°N for latitude, and from 105°E to 130°E for longitude since 1999. These data currently are available to the public by application from the China SOED.

The QuikSCAT Level 3 data in Hierarchical Data Format (HDF) was downloaded from the NASA Jet Propulsion Laboratory (JPL) website <http://podaac.jpl.nasa.gov/quikscat/>. The QuikSCAT Level 3 product is the generic, gridded product and can easily be manipulated to fit the exact requirements necessary for multiple scientific uses. These products contain ascending and descending pass data, and are produced as a global grid of 1440 pixels in longitude by 720 pixels in latitude (0.25° grid). The following parameters are available for both the ascending and descending passes: wind speed, wind velocity (u and v components), wind speed squared, number of counts, and time in fractions of a day, rain probability, and rain flag.

Launched by NASA on April 28, 2006, the CloudSat satellite, records the vertical profiles of clouds. These vertical profiles provide a 3D view of the vertical structure of clouds from the top of the atmosphere to the surface. All data products from the CloudSat mission are produced by the CloudSat Data Processing Center (DPC) at Colorado State University. CloudSat data products as compressed (.zip) files are available through an online ordering system in Hierarchical Data Format for the Earth Observation System (HDF-EOS) 2.5 format. The Goddard Interactive Online Visualization ANd aNalysis Infrastructure (GIOVANNI) is a web-based interactive data analysis and visualization tool and used primarily for exploring many of NASA's earth science datasets^[7]. and can be used to visualize and download HDF, KMZ format CloudSat data. A-Train along CloudSat Track instances implements the automatic acquisition of the vertical image curtain. It automatically produces the images and HDF and KMZ format data according to user requested parameters file for a fixed temporal range and selected spatial range.

The Tropical Rainfall Measurement Mission (TRMM) satellite data are produced from the Visible Infrared Scanner (VIRS), TRMM Microwave Imager (TMI), and Precipitation Radar (PR) instruments. The products provide the tropical rainfall-related physical parameters: rain rates, 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. TRMM data are available through an instance of GIOVANNI-TRMM Online Visualization and Analysis System from website <http://disc2.nascom.nasa.gov/Giovanni/товas/>.

2.2 Oceanic satellite data visualization model

Oceanic satellite data often have different manifestations due to different sources, different physical parameters, and different levels of data processing. In order to better display the data, an oceanic satellite data visualization data model was first established. As compared to the land, oceanic phenomena usually have larger scales, and shorter time intervals. Therefore, the temporal information is essential in oceanic satellite visualization data models.

The design of Oceanic satellite visualization data models, on the one hand need to consider the means to truly reflect oceanic environmental information from data, on the other

hand the temporal or time information needs to be carefully considered. An oceanic satellite visualization data model was designed based on full understanding of the characteristics of various types of oceanic satellite data for a fully synthesized and comprehensive visualization of multi-source oceanic satellite data. The ocean satellite data not only contains two-dimensional plane grid data, but also 3D vertical data. The oceanic satellite visualization data model includes scalar field and vector fields which consist of point, line, surface and volume four entities, the time or temporal properties are the essential attributes of each field or entity.

Table 1. Relationship between oceanic satellite visualization model and KML element.

Oceanic satellite data	Visualization data model		KML element	
Ocean color Level 3B and TRMM data	Scale field		Feature	Overlay
Ocean color level 4A data	Vector field	Line	Geometry	Line String
Ocean surface wind		point		Point
CloudSat data		Area volume		Polygon Model

Table 1 shows the relationship between oceanic satellite data, visualization data model and KML element. Ocean color satellite level 3B data are the grid data (raster data) usually expressed by scalar field. Ocean color level 4A data are the contour data, ocean surface wind data are the point data with wind speed and director information, and CloudSat data are 3D vertical data which all are express by vector field, for example, point, line, area and volume. Time information is essential for all fields.

3 Visualization of oceanic satellite data on google earth

KML is a file format used to display geographic data on an Earth browser such as Google Earth, Google Maps, and Google Maps for mobile. KML uses a tag-based structure with nested elements and attributes, which is based on the XML standard. KML has been used as a standard of the Open Geospatial Consortium (OGC). In this paper, the oceanic satellite data firstly abstract to visualization data model according to table 1, and then are converted to KML through the following ways:

- (1) The thematic image files such as the ocean color and temperature data, which can be in most common raster image formats, are contained in a separate directory and the KML file which are combined using the “zip” utility to put both into a KMZ archive. The Google Earth viewer can read such an archive and display the combined KML and image information.
- (2) Different KML icon tags and image templates for different classes of points are used to make the Google Earth viewer for visualizing wind velocity and direction.
- (3) CloudSat data are rendered along a vertical image for a user-selected spatial range through GIOVANNI system. The vertical image is then chopped into small slices, and as a texture is fed into a generalized COLLADA 3D model. Along the satellite orbit coordinates, the 3D models are spliced together to form a vertical “curtain” image in KMZ format ^[5].

3.1. Visualization of ocean color and temperature satellite data

We have developed web service software to convert the ocean color and temperature data with Level-3 and Level-4A to KMZ files and display them on Google Earth online. The ocean color and temperature data include sea surface temperature (SST), chlorophyll concentration (CHL), suspended sediment concentration (SSC), water transparency (SDD), diffuse

attenuation coefficient at 490nm (KD3), normalized water-leaving radiance at 490nm (LW3) and aerosol optical thickness at 865nm (TAU), etc.

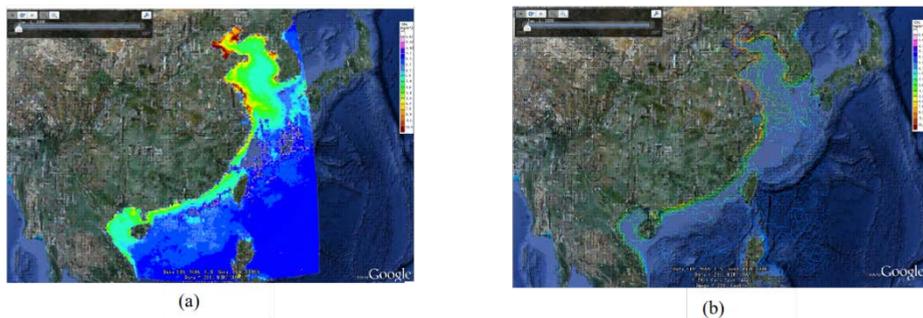


Fig. 1. (a) Visualization of the Chlorophyll concentration data on Google Earth (a) monthly averaged Level-3B data from January to December in 2006 (b) Visualization of Chlorophyll concentration data on Google Earth monthly average Level-4A data from January to December in 2006. (Data geography range latitude from 14°N to 42°N, longitude from 105°E to 130°E).

Such as Figure.1. Figure.1 (a) is the Level-3B data of the monthly averaged chlorophyll concentration from January to December in 2006 on Google Earth. Figure.2 (a), the KML `<href>` tag is a WMS request that is necessary for WMS to acquire and process the Level-3B image data and the KML `<LatLonBox>` tag defines the size of the image that will be displayed. Figure.1 (b) is the visualization of Chlorophyll concentration monthly average L4A data from January to December in 2006 on the Google Earth. In the Figure.2 (b) the KML tags `<LineString>` as the sub-tag of tag `<MultiGeometry>` directly read the ocean color remote sensing Level-4A data values into the KML file as the values of the KML tags and its properties. Finally, the ocean color and temperature satellite data can be visualized on Google Earth via KML file.

3.2 Visualization of satellite wind vector data

The sea surface wind velocity and direction for wind vector data have been converted to KML and displayed on Google Earth. The wind icon templates and the range of wind velocity are shown in table 2. QuikSCAT level 3 wind vector data are 0.25°X0.25° grid data. Figure.4 is the KML file example of the wind vector data. The KML `<href>` tag is a suitable wind template image according to the wind velocity selected from table 2. The `<LatLonBox>` tag defines the range of the template that will be displayed. The 0° direction for QuikSCAT level 3 wind vector data is eastward, while it is the northward for the Google Earth as shown in Figure. 3 (a). Therefore, if the direction of the wind vector is α , the rotated angle should be $\alpha-90$, and the `<rotation>` tags is $\alpha-90$. For each grid, the attributes of the wind vector data are organized and managed, and finally exported out as a KML Zipped (KMZ) file. It usually includes a KML file and image files at the minimum. The KML file determines the spatial coordinates, the level of zooming out, and the number of degrees of rotation needed to accurately visualize each point position and wind direction in Google Earth. The image files are the maps using the wind template showed in table 2.

Currently, two dimension satellite data for ocean color and temperature and wind vector are integrated into Google Earth for visualization online. When the user clicks the KMZ button in the website, a request is sent to the server, and a KMZ file is returned to the Google Earth for display as shown in Figure. 5. Also, the user can download the KMZ file to the local computer and open it by Google Earth.

```
<?xml version="1.0" encoding="UTF-8"?>
<kml xmlns="http://earth.google.com/kml/2.2">
<Document id="SAT_2006_4A_CHL">
  <name>SAT_2006_4A_CHL</name>
  <Snippet></Snippet>
  <Folder id="FeatureLayer0">
    <name>SAT_2006_1_4A_CHL</name>
    <TimeSpan>
      <begin>2006-01</begin>
      <end>2006-02</end>
    </TimeSpan>
    <Snippet></Snippet>
    <Placemark>
      .....
      <styleUrl>#LineStyle00</styleUrl>
      <MultiGeometry>
        <LineString>
          <tessellate>1</tessellate>
          <extrude>0</extrude>
          <altitudeMode>
            clampToGround
          </altitudeMode>
          <coordinates>
            127.977844, 14.115019, 0.000000
            .....
            129.313507, 14.118393, 0.000000
          </coordinates>
        </LineString>
      </MultiGeometry>
    </Placemark>
  </Folder>
  .....
<ScreenOverlay>
  <name>CHL Legend</name>
  .....
</ScreenOverlay>
</Document>
</kml>
```

Fig. 2. KML samples of Level 3B and Level-4A. (a) KML sample of L3B data KML. (b) KML sample of L4A data.

3.3 Visualization of vertical profile satellite data

At present, remote sensing vertical profile data are primarily extracted from satellites of CloudSat, CALIPSO, and Aqua. The A-train instance of GIOVANNI system can produce curtain plot images, HDF and KMZ files via the Web browser by the interface listing all available parameters that users can customize to their specific requirements.

The CloudSat vertical profile KMZ data includes KML file and many slices curtain images as 3D Collada model template texture. Collada can be used to establish open, standard, XML-based 3D applications, and then the Google Earth can display 3D Collada models. The CloudSat firstly is cut into 10 seconds data slices, and then these slices are used as texture of vertical Collada model templates which are created via Google's SketchUp tool [5,6]. This method is used to create the orbit curtain of the vertical profile data of CloudSat, CALIPSO, AIRS, and MODIS-Aqua. The <Folder>, <Document>, <Placemark> and <NetworkLink> tags are used to organize and manage the data, and finally exported out as a KML Zipped (KMZ) file. The KMZ file includes a KML file, image file(s), model file(s), and a texture

file. Figure. 6 shows the example of the curtain of the cloud reflectivity (dBZ) from the CloudSat satellite on Google Earth.

Table. 2. Wind Icon template.

Wind Template	Wind Speed Range (units: m)
	<0.7
	0.3-1.5
	1.5-3.3
	3.4-5.4
	5.5-7.9
	8.0-10.7
	10.8-13.8
	13.9-17.1
	17.2-20.7
	20.8-24.4
	24.5-28.4
	>28.4

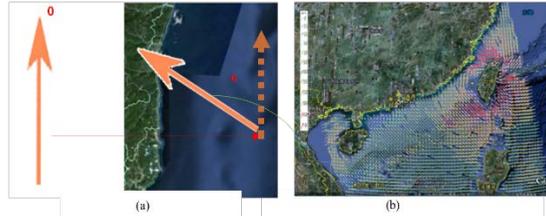


Fig. 3. Example of placing the wind template on Google Earth.

```
<?xml version="1.0" encoding="UTF-8"?>
<kml xmlns="http://earth.google.com/kml/2.2">
<Document id="SAT_2006_4A_CHL">
  <name>SAT_2006_4A_CHL</name>
  <Snippet></Snippet>
  <Folder id="FeatureLayer0">
    <name>SAT_2006_1_4A_CHL</name>
    <TimeSpan>
      <begin>2006-01</begin>
      <end>2006-02</end>
    </TimeSpan>
    <Snippet></Snippet>
    <Placemark>
      .....
      <styleUrl>#LineStyle00</styleUrl>
      <MultiGeometry>
        <LineString>
          <tessellate>1</tessellate>
          <extrude>0</extrude>
          <altitudeMode>
            clampToGround
          </altitudeMode>
          <coordinates>
            127.977844, 14.115019, 0.000000
            .....
            129.313507, 14.118393, 0.000000
          </coordinates>
        </LineString>
      </MultiGeometry>
    </Placemark>
  </Folder>
  .....
  <ScreenOverlay>
    <name>CHL Legend</name>
    .....
  </ScreenOverlay>
</Document>
</kml>
```

Fig. 4. The KML of QuikSCAT level 3 wind vector data.

4. Integrated visualization of multiple oceanic satellite data on google earth

The ocean environment is known to be a very complex system. Many oceanic phenomena therefore reflect the comprehensive variation in the ocean environment. For example, a typhoon is the result of the interaction of the atmosphere and ocean. Combining the multiple

satellite data together is more vivid and intuitive using Google Earth as a three-dimension display platform. Google Earth provides a very convenient and practical platform for ocean scientists, researchers and the general public interested in the ocean to compare and integrate their own geospatial ocean products with other data.

As an example, figure.7 shows the combination of the chlorophyll concentration, rainfall, wind vector and the vertical profile of cloud reflectivity data during the typhoon Morakot on August 7, 2009. The maximum height of the clouds is about 15km and the substantial convective activity can be seen within the vertical structure of the typhoon. The integrated visualization of multiple satellite data shows the relationship between the cloud structure, chlorophyll concentration, sea surface wind and rainfall areas during the typhoon. The near-real-time ocean satellite data and thematic information can be integrated to display in a virtual globe environment to assist decision-makers to make better decisions and policies for improving marine management and marine production. In addition, the general people can understand more easily how the ocean remote sensing data can reveal the variation of the marine environment.



Fig. 5. Interface of ocean satellite data web service.

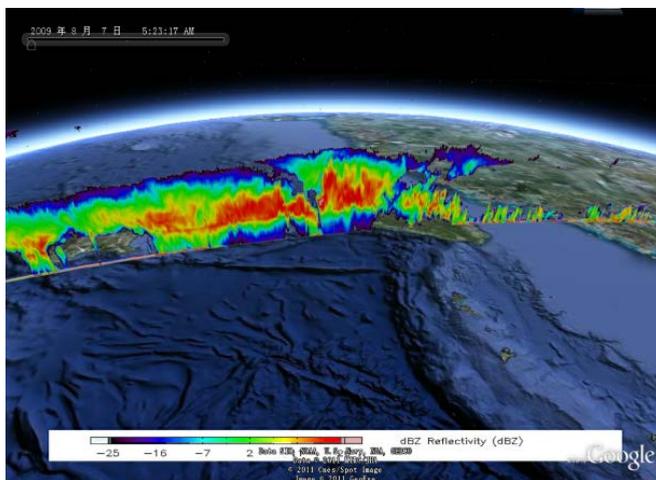


Fig. 6. Visualization of orbit curtain for cloud reflectiity (dBZ) from the CloudSat satellite on Google Earth.

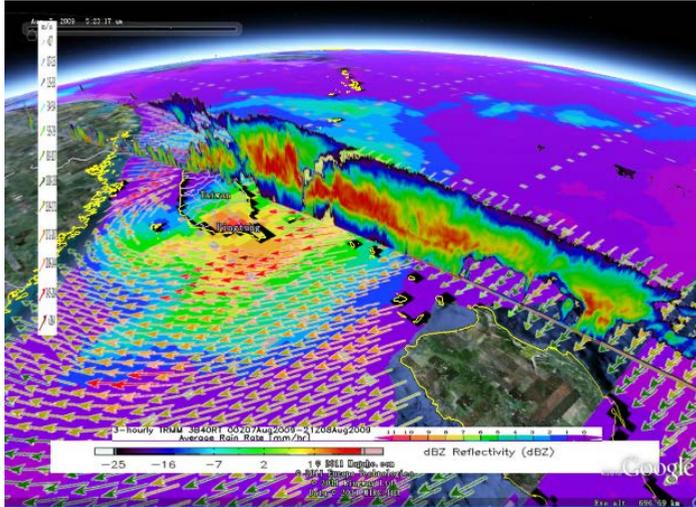


Fig. 7. Integration of CloudSat cloud reflectivity vertical profile data, QuikSCAT level 3 wind vector data, with three hours rainfall data from TRMM on 07 August, 2009, typhoon Morakot.

5 Conclusions

In this paper, a web service converting the datasets of different types of oceanic satellite data into KML or KMZ files was developed, one that provides web applications for users and enabling them to download and display both horizontally distributed and vertical profiles of oceanic satellite data on Google Earth. Two dimensional satellite ocean color and temperature data are converted to KML or KMZ files with proper control parameters and then directly offered to Google Earth for visualization. Using the twelve templates according to wind speed, the sea surface wind vector data from QuikSCAT satellite are converted to KMZ files, and visualized on Google earth. Using the KMZ files from the NASA GIOVANNI web site, the vertical profile data of cloud reflectivity from the CloudSat satellite and three hour rainfall data from TRMM satellite are also visualized on Google earth. Finally, as an example, mutli-satellite data including the horizontal distribution and vertical profiles collected during Typhoon Morakot during August 2009 are combined on Google Earth with three-dimensional visualization. The advantage of this solution is that data access and processing are transparent and independent of the platform, data format, and application requirements.

Using Google Earth to visualize 2D and 3D data is becoming more widely applied for geospatially related satellite data. NASA and NOAA are a few pioneer organizations using online geospatial data accessing and processing services to visualize the 2D and 3D data on Google Earth. Based on Google Earth, all past and near-real-time data and information about the ocean from satellites and in-situ stations can be integrated for scientists, professionals and other individuals. Google Earth also can be used with these data for public, national ocean applications with valuable societal benefits. Virtual globes are emerging as the next generation framework for sharing data, information and knowledge, collaborating in scientific research, and educational visualization in many disciplines.

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