9B.3 DYNAMICALLY UPDATED ENVIRONMENTAL SATELLITE DATA IN GOOGLE EARTH: AN APPLICATION TO TROPICAL METEOROLOGY

J. Turk[1], S. Miller[2], J. Hawkins[1], K. Richardson[1]

[1]Naval Research Laboratory, Marine Meteorology Division, Monterey, CA
[2]Cooperative Institute for Research in the Atmosphere (CIRA), Colorado State University, Fort Collins, CO

1. INTRODUCTION

[1]One of the main challenges facing current and future environmental satellite systems (e.g, the future National Polar Orbiting Environmental Satellite System (NPOESS)) is reaching and entraining the diverse user community via communication of how these systems address their particular needs. A necessary element to meeting this challenge is effective data visualization: facilitating the display, animation and layering of multiple satellite imaging and sounding sensors (providing complementary information) in a user-friendly and intuitive fashion. In particular, virtual globes (Google Earth, Virtual Earth, World Wind, Arc Explorer, among others) have features which are desirable for dissemination of a wide range of satellite data types. In this manuscript, we utilize multiple satellite datasets to demonstrate how these features can be exploited to effectively visualize the meteorological evolution of tropical cyclones.

2. KEY FEATURES OF GOOGLE EARTH

The Naval Research Laboratory (NRL) has maintained a World Wide Web-based tropical cyclone website (TC-Web) with a diverse selection of near-realtime geostationary and low Earth orbiting satellite imagery for active tropical storms, including as an extensive image archive going back to 1997. To facilitate the display, animation and layering of geolocated satellite with other observational datasets in a user-selective fashion, the TC-Web data processing stream was adapted for display within Google Earth.

Google Earth has key features which are desirable for dissemination of a wide range of environmental satellite image products. The first is the concept of data layering. An ideal way to present multiple types of satellite datasets is to present them to the user as multiple layers. Figure 1 depicts an example from Hurricane Felix, as it was approaching landfall in Mexico on 3 September 2007. While not apparent when zoomed in at this altitude, the multi-colored region actually indicates individual surface wind vector retrievals (each is an individual placemark) from the WindSat polarimetric radiometer during the overpass of the Coriolis satellite at 2254 UTC (the color indicates wind speed; the associated image overlay legend is not shown). The interpretation of these data is greatly enhanced by layering the wind barb placemarks on top of nearby-time visible imagery (or infrared at night) from the Geostationary Operational Earth Satellite (GOES-12 positioned at 75°W longitude). A close-up view is shown in Figure 2, where both the cloud top structure and the wind barb locations and directions are more readily apparent. Selecting each placemark presents a popup balloon providing additional information.

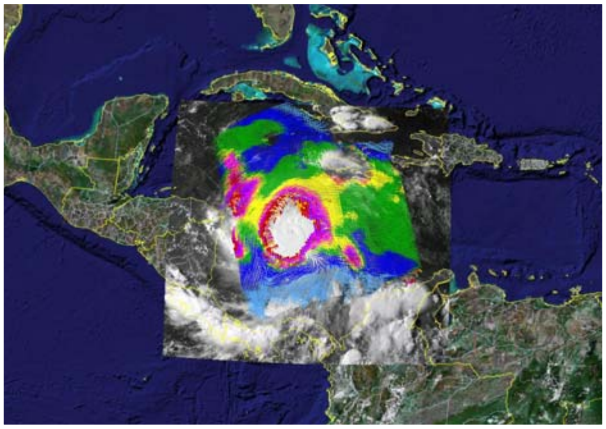

Figure 1. Surface wind vectors retrieved from the Coriolis/WindSat satellite overpass of Hurricane Felix near 2254 UTC on 3 September 2007, overlaid on top of nearby time visible imagery from the GOES-12 geostationary satellite.

Other key features of Google Earth define how, where, and when the satellite data are displayed (or animated), and how often the datasets are refreshed. Since environmental satellite data are available with a variety

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[1] *Corresponding author address*: Dr. Joe Turk, Naval Research Laboratory, Marine Meteorology Division, Monterey, CA 93943 US. joe.turk@nrlmry.navy.mil.

of horizontal spatial resolutions (e.g., 4-km infrared imagery on geostationary imagers to 250-meter visible imagery from the Moderate Resolution Imaging Spectroradiometer (MODIS) instruments on EOS-Aqua and Terra), the imagery is tiled at a very small size (e.g., 256 pixels on a side). This allows low-bandwidth users to efficiently view and animate a sequence of imagery while zoomed at a high altitude, whereas high-bandwidth users can take full advantage of the native, fine-scale imagery resolution when zooming in to lower altitudes, which automatically triggers downloads of higher resolution image tiles. In operational settings, dynamically updated network links can refresh the most recent satellite after receipt of new data. Geographical regions can be used such that datasets are downloaded (and can appear and/or disappear) only when the user navigates their viewing location to the region of interest.

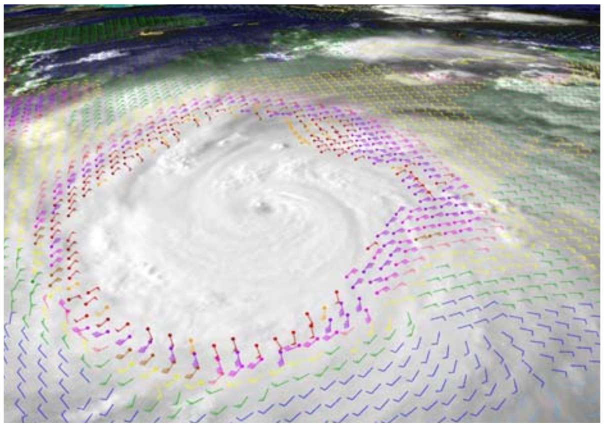

Figure 2. A close-up view of Figure 1, where the hurricane cloud structure is apparent, as well as individual wind barbs (color coded by intensity). Each wind barb placemark can be interrogated for more information.

3. TROPICAL CYCLONE APPLICATIONS

To conceptualize how environmental satellite data would be utilized within a virtual globe, we present a demonstration from the 2007 hurricane season. To effectively present both a large and diverse set of satellite and other data to a user, the data should be organized by some key feature. In the case of a tropical cyclone (TC), the TC track history is an ideal feature to follow the evolution of the storm throughout its genesis, intensification, and in some cases, landfall. Since TC positions are routinely updated every six hours by operational tropical forecasting centers worldwide, they can be used to subset the data into time intervals. In Figure 3, the track of Tropical Cyclone Sidr in the Indian Ocean is shown between 11-15 November 2007. Each six-hour position update is a time-tagged placemark icon, which brings up a list of all satellite datasets during this six-hour interval, and a list of upcoming satellite overpasses (Figure 4). Knowledge of the upcoming satellite overpass times is valuable to forecasting agencies, for planning the update time of their warnings and other advisory messages. Each dataset is available as a Keyhole Markup Language (KML) hyperlink to data stored on a server, allowing the user to select which data to layer. The remapping of these satellite data follows the hurricane track, enabling the user to view, animate, and layer individual satellite data, and further combine this with other data layers (surface reports, buoy data, surface winds, ground radars, webcams, etc.) at various stages of the hurricane lifecycle. Geostationary satellite data, with its sub-hourly time refresh cycle, are well-suited for animation in Google Earth (through the use of TimeSpan tags), which smoothly animate the image sequence over a time interval. Figure 5 depicts the visible imagery from the Meteosat-7 geostationary satellite, subsetted and tiled over the TC location on 15 November 2007.

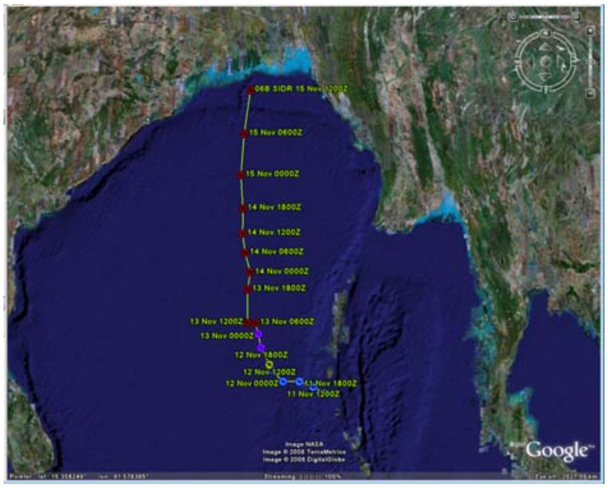

Figure 3. Storm track of Tropical Cyclone Sidr in the Indian Ocean between 11-15 November 2007. Each position placemark can be interrogated for additional information on storm intensity and nearby-time satellite data products.

As shown, geostationary satellite data provide the spatial and temporal repeat cycle needed to follow the time evolution of tropical cyclones and other rapidly-intensifying weather events. In recent years, the successful launch of advanced research satellite/sensor systems such as the joint United States/Japan Tropical Rainfall Measuring Mission (TRMM, launched in 1997) and the NASA CloudSat satellite (2006) have deployed the first spaceborne radar systems. The Precipitation Radar (PR) onboard TRMM provides vertical profiles (250-meter vertical resolution) of precipitating clouds (i.e, sensitive to precipitation-sized rain drops) from the 402-km orbit altitude of TRMM. CloudSat, while providing a similar vertical resolution, orbits at a higher orbit (800 km) and transmits at a higher frequency (94 GHz), which is sensitive to much smaller cloud drops, but is also adversely affected by attenuation of larger, precipitation-sized drops. Together, these spaceborne radar sensors provide the capability to gather information on the 3-dimensional structure of rain and clouds, and are well-suited to layer and combine with visible, infrared and passive microwave satellite imagery. While a full description of the diverse set of environmental satellite data types is beyond the scope of this manuscript, we present two examples below in Figures 6 and 7.

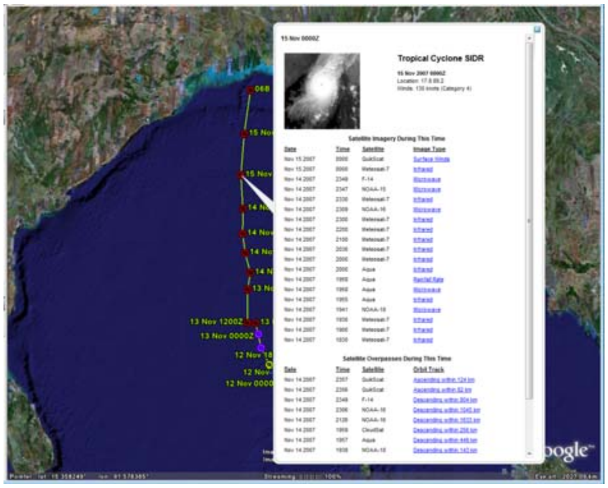

Figure 4. Example popup balloon from Figure 3, revealing storm intensity warnings for a six-hour period ending at 00 UTC on November 15. A list of nearby time satellite datasets and upcoming low Earth orbiting satellite overpass times is provided, where each available satellite (or other) dataset during this time is a KML hyperlink (blue text), which subsequently opens up as a temporary dataset when selected.

Figure 6 depicts a vertical radar reflectivity profile in Google Earth from an overpass of the CloudSat satellite at 2000 UTC on 14 November 2007. Since the image is stretched in the vertical for viewing purposes, the thin gray vertically oriented shading indicates the actual 20-km altitude. Since CloudSat flies in formation with the Earth Observing System (EOS) Aqua satellite, the radar profile is layered on top of 1-km resolution infrared imagery from the MODIS imager onboard the Aqua satellite. Generally, infrared (or visible) imagery primarily provide information about the tops of clouds. When viewed from a tilted view angle in Google Earth, the radar profile provides the user with a glimpse of the vertical cloud structure underneath the cloud tops. In this situation, there is a long line of high-altitude cirrus clouds that overly the clouds below, and obscure the view of the cyclone's circulation from the MODIS data alone. In this situation, passive microwave imagery from the Advanced Microwave Scanning Radiometer (AMSR-E), also onboard Aqua, would have better depicted the lower-altitude cloud structure and cyclone eye position (not shown).

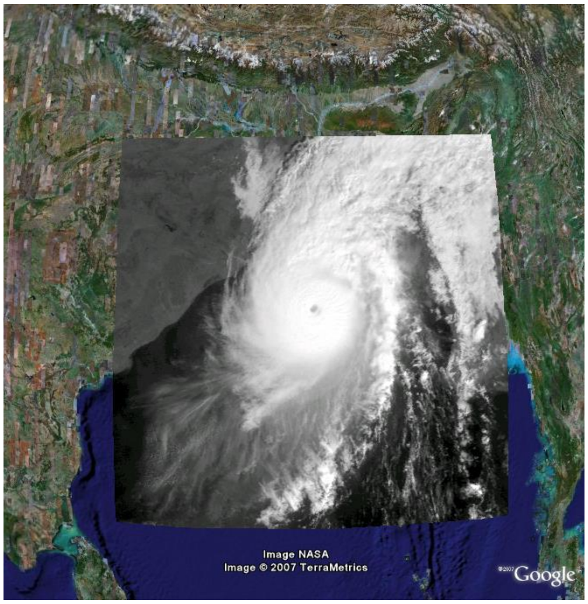

Figure 5. Close-up of Meteosat-7 visible imagery as Tropical Cyclone Sidr approaches landfall in Bangladesh.

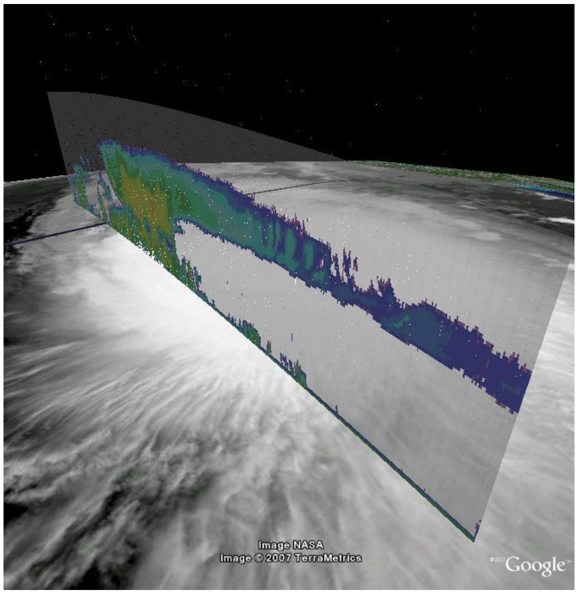

Figure 6. Vertical radar profile from the radar onboard the NASA CloudSat satellite, at 2000 UTC on 14 November 2007, overlaid on top of infrared imagery from the MODIS sensor onboard EOS-Aqua. In this depiction, the Earth is tilted up to best reveal the vertical structure, which is artificially stretched in the vertical for viewing purposes. The vertical grayscale shading indicates the actual 20-km altitude.

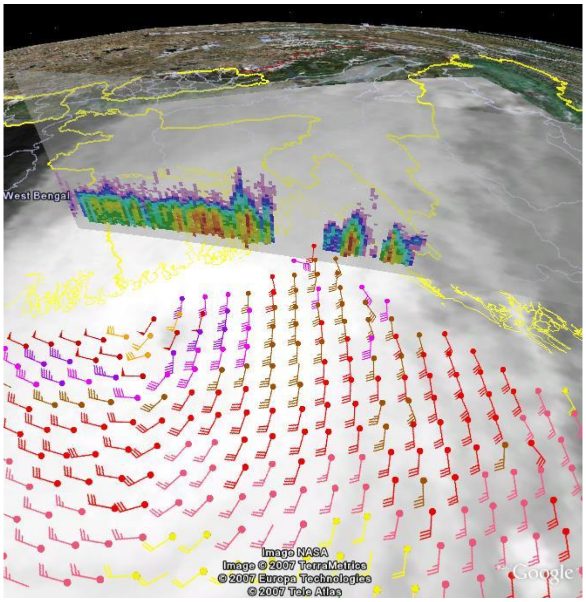

Figure 7. Vertical radar profile from the Precipitation Radar (PR) onboard the TRMM satellite at 1301 UTC on 15 November 2007, overlaid on top of nearby-time infrared imagery from the Meteosat-7 geostationary satellite. Colored wind barbs represent surface wind vectors retrieved from a nearby-time (1227 UTC on 15 November 2007) overpass of the NASA QuikScat satellite. In this depiction, the Earth is tilted up to best reveal the vertical structure, which is artificially stretched in the vertical for viewing purposes. The vertical grayscale shading indicates the actual 20-km altitude.

Figure 7 depicts an overpass of the TRMM satellite at 1301 UTC on 15 November 2007, as the cyclone was nearing landfall. Similar vertical shading indicates the actual 20-km altitude. The vertical radar profile from the PR is shown, layered on top of nearby-time infrared imagery from the Meteosat-7 satellite, and then subsequently overlaid with surface wind vectors from an overpass of the NASA QuikScat satellite at 1227 UTC on 15 November 2007. These three products together (geostationary imagery providing the large scale view of the cloud top structure, PR providing a glimpse of the vertical precipitation structure underneath, and QuikScat providing further information on surface wind speed and direction), condense a high level of data and information content down into one single depiction. Furthermore, the user can navigate around the tropical storm from different view locations and tilt angles, thereby exploiting the 3-dimensional nature of the TRMM PR data. The passive microwave imagery from the TRMM Microwave Imager (TMI) could also be shown in place of the Meteosat-7 imagery (not shown) to better reveal the horizontal rain locations and structure.

4. CONCLUSIONS

Virtual globes provide a effective framework for efficiently demonstrating meteorological, oceanographic and weather and climate concepts to not only forecasters and meteorologists, but to students and the public audience. Several key features of Google Earth, such as region subsetting, multiple levels of detail, refreshable network links, layering and animation capabilities, are ideal for visualization of environmental satellite data. With their emphasis upon geolocated data, virtual globes represent the next evolution beyond the traditional browser; for this reason they are often referred to as “geobrowsers”.

In this manuscript, we have demonstrated how virtual globes such as Google Earth can effectively combine layers environmental satellite data for tropical meteorological applications. However, the methodology developed here is easily adaptable to other types of weather and geophysical events, especially events with rapid onset and evolution (e.g., fires, volcanoes, convective storm outbreaks, etc.). Numerical forecast model output (numerical weather prediction and climate models) could be further added as an additional layer to bring together forecasts with actual observations. Future efforts are geared towards these virtual globe applications so as to best capitalize upon the capabilities of today’s (and future) environmental satellite systems.

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References

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