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Making NASA Precipitation Information Accessible to the Public

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ABSTRACT:
All of the data collected by NASA satellites are freely available to the public on the web, however many end-users do not know how to access and utilize the data. Rainfall data from NASA's Tropical Rainfall Measuring Mission (TRMM) can be obtained from a variety of sources, and there are also many tools that can be used for data analysis. A thorough search and investigation of an assortment of websites was performed. The websites were then evaluated for their ease of access, quality of TRMM data tools, and availability of data and image downloads, especially Google Earth files. Complete educational modules were created, explaining in detail each website and how to navigate through them to obtain images and data. The modules, in Power Point format, include descriptions, screenshots, graphics, and Google Earth snapshots to demonstrate use of the online tools. Following these educational modules, case studies with question and answer sheets were created to show the use of these free, online tools for real-life and real-time problems. The goal of these modules and Case Studies is to teach the public how to utilize these available TRMM tools for personal use, research, education, and decision making activities. This is especially important for countries that are not equipped with their own tools to obtain this hydrological data.

Monitoring Rainfall

Everyday, somewhere around the globe, rain is falling. This rain is necessary for a multitude of reasons, including for agriculture, for ecosystems, and as a part of the water cycle. However, heavy rainfall can be catastrophic, causing flooding and landslides, killing hundreds of people and animals, and destroying millions of dollars of property and crops. Heavy rainfall is also associated with severe weather events like thunder storms, tornadoes, and hurricanes or typhoons. Monitoring and studying rainfall can help us to better understand rainfall and can improve forecasting of these events. In addition, observing these events in real time will help decision makers to warn and evacuate people, which can save hundreds of lives each year.

Rainfall can be measured and monitored from the ground using instruments like rain gages and Doppler radar. However, this is only useful for locations that have these instruments. There are vast remote locations where we cannot obtain rainfall data as easily and readily as we can over currently monitored land. This includes areas over oceans and countries with

insufficient monitoring tools. Hence, remote sensing from satellites has emerged to help us gain insight into global rainfall. The TRMM satellite was especially built for this reason.

TRMM and its Instruments

The Tropical Rainfall Measuring Mission (TRMM) is a joint mission between the United States (NASA) and Japanese (JAXA) space agencies, and was designed to monitor and study tropical rainfall. TRMM collects data between 35°S and 35°N, and adds composite data from TRMM and other satellite and meteorological data to extend the range from 50°S to 50°N. It travels 403 km over the atmosphere, making 16 orbits a day every 92.5 minutes (Figure 1). TRMM is the first satellite mission to establish global distribution of rainfall on earth's surface. It provides a 4-D (3-D plus time) distribution of rainfall and latent heating, by using five instruments (TRMM NASA).

The Precipitation Radar (PR) is the first spaceborne instrument to provide three-dimensional maps of storm structure and provide quantitative rainfall measurements over ocean and land. It has a 247 km swath width by 5 km instantaneous field of view (Figure 1). The PR can provide vertical profiles of rain and snow from the surface to 20 km, and can detect rain as little as 0.7 mm per hour. It can separate out rain echoes for vertical samples 250 m looking straight down. The PR is a low energy use instrument, only using 224 Watts of power to take measurements. A radar frequency about three times higher than that of ground radar provides good resolution and higher quality images. The PR is important because it provides 3-D maps of storm structure, including intensity, rain distribution, storm depth, and the height where snow melts to become rain (TRMM NASA).

In addition to the PR, the TRMM Microwave Imager (TMI) is another instrument aboard TRMM. TMI is a passive microwave sensor whose objective is to measure rain rate over the ocean. This is important because we do not have a lot of measurements of rainfall over oceans, due to the size and inaccessibility of the ocean compared to land. It can quantify water vapor, cloud water, and rainfall intensity by measuring the amounts of microwave energy emitted by the earth and the atmosphere at five different frequencies. TMI uses Planck's radiation law (how much energy a body radiates given its temperature) as the basis of calculations to determine rainfall rates, because each surface emits a different amount of microwave energy which can be measured. Oceans appear about 50% colder than they actually are, raindrops reflect their actual temperature, and land emits 90% of its real temperature. Hence, rain over oceans appears much warmer than its surroundings, and can be recorded. Rain over land is harder to measure due to similar temperatures. However, the high frequency microwaves are scattered when ice is present in raining clouds, which reduces the signal and contrasts the rain against the warm land. TMI has an 878 km swath width by 5.1 km field of view (Figure 1), (TRMM NASA).

The Visible InfraRed Sensor (VIRS) is the third instrument in the rainfall package. VIRS senses outgoing radiation from earth, detecting rainfall. It measures radiation emitted from Earth in five spectral regions, from visible to infrared (0.63 to 12 µm), using an 833 km swath width by 2.4 km field of view (Figure 1). In order to detect rainfall, VIRS uses the intensity of radiation in the spectral regions to determine brightness or temperature of the source. When the sky is clear, the temperature will equal that of Earth, and when it is cloudy, the temperature will equal that of the cold cloud tops. The cold cloud tops will indicate cloud heights and hence the presence of rain. By comparing two infrared channels at 10.8µm and 12.0µm, clouds can be differentiated. High clouds are positively correlated with convective precipitation, and high cirrus clouds are not associated with precipitation. By combining this data with that of TMI and PR, a

relationship between cloud tops and precipitation monitored from space can be made. VIRS also ties TRMM measurements with those of Polar Orbiting Environmental Satellites (POES) and Geostationary Operational Environmental Satellites (GOES). It acts as a transfer standard to compare with these other measurements and obtain a more accurate measurement of rainfall (TRMM NASA).

In addition to these three instruments, TRMM has an instrument called Cloud and the Earth's Radiant Energy System (CERES). This instrument is part of a series of five satellite CERES missions to create a 15 year history of energy budget and cloud data for climate analysis. It measures energy at the top of the atmosphere and estimates energy within the atmosphere. The final instrument is the Lightning Imaging Sensor (LIS). LIS detects and locates lightning (TRMM NASA).

These instruments on the TRMM satellite have allowed us to collect global rainfall data, improving our knowledge of the global distribution of rainfall, especially over the oceans. TRMM provides us with an understanding of the global distribution of vertical profiles of precipitation from space and hence furthers our understanding of the interactions between the ocean, atmosphere, and land which affect global rainfall and climate. In addition, its data improves modeling of tropical rainfall processes and their influence on global circulation and enhances predictions of rainfall and its variability at various time scales (TRMM NASA, TRMM JAXA). All of this information about the TRMM satellite and its instruments has been compiled into a PowerPoint presentation.

The data products produced by the three precipitation recording instruments (PR, TMI, and VIRS) include rain rate and rain accumulation. Rain rate is the amount of rain over time, in this case recorded as mm/hr. This is recorded as a 3 hour, daily, and monthly product. Rain accumulation is the total amount of rain that falls in an area. TRMM measures this in mm, and is recorded for daily and monthly periods. Using the monthly accumulated rainfall measurements, rainfall anomalies can be found. An anomaly can be found by using rainfall climatology, which is the normal amount of rainfall per month averaged over several years for a specific location. Comparing the actual amount of precipitation to this "normal" number will reveal the abnormal precipitation conditions for that area, called an *anomaly*.

The data collected from TRMM (like data from other NASA satellites) is free for public use, and is used for an assortment of research, analysis, and decision making activities. This includes the analysis and tracking of hurricanes and typhoons and global flood and landslide monitoring. TRMM data is available in near real-time form and also archived form (1998 to present). Although the data exists online, many people do not know where and how to access it. Teaching people about these resources can solve this problem. Hence, we developed a series of educational modules to present the TRMM websites to the public. The modules provide a clear, easy to understand explanation of the websites, how to navigate around them, and what data sets and images they can provide. Furthermore, we created two Case Studies based on current precipitation events to offer examples of how these sites can be applied to real life studies.

Compiling Websites with TRMM Tools

In order to educate others about the websites that use TRMM data, it was first necessary to identify and then understand how to use these sites. Using Google as the primary search engine, multiple searches we made looking for "tools using TRMM data". Each website that was found was thoroughly explored. Careful consideration was made to examine the quality and type of TRMM tools that were included on the sites. The sites were evaluated on a variety of

topics in order to validate their usefulness (Table 1). Websites were assessed for ease of access, or how user friendly it is to navigate around the site. This also includes how straightforward the site is for a user to understand and figure out. In addition, the type of TRMM data that can be accessed from the sites was examined, whether it was near real-time (current) data and/or archived previous data. Some websites included already prepared images and maps using TRMM data, whereas others allowed the user to customize and build their own images, and do analysis on them. Finally, the websites were evaluated on whether the data could be downloaded, especially downloads in the form of Google Earth files (KML or KMZ) and GIS files. Google Earth was chosen because it seems to be the best mapping program available. The free GIS programs available are not as easy to use and do not have many features included.

Now that the most useful TRMM tools websites were found, they could be compiled into a presentation to share with the public. A PowerPoint presentation was made that provides a short background on the TRMM satellite, its applications, and all of the tools that were found online for TRMM data. This presentation explains how to navigate and operate the websites using screen shots of the sites, along with text, arrows, and boxes to highlight important features (Figure 2). For the websites that have downloadable Google Earth links, screen shots of Google Earth are also included to demonstrate what it would look like with the TRMM data (Figure 3).

Description and Evaluation of Websites

TRMM NASA (http://trmm.gsfc.nasa.gov)

Out of the nine websites examined, one of the best sites was the TRMM NASA website. This website is NASA's home TRMM site, which includes information about the mission, its instruments, and its data. The TRMM NASA website is updated daily, providing real-time, current data, including rain rate, rain accumulation, flood potential, average rainfall over the last 30 days, and rainfall anomalies for the last 30 days. Hence, this site is especially valuable for current precipitation issues. For example, it provides current flood and landslide potential maps, pointing out areas at risk for these events. In addition, TRMM NASA has archived hurricane images, beginning in 1998. One of the best features of this site is that there are a variety of Google Earth downloads available. For most of the resources on the site, there is a link to download into Google Earth, which allows the user to do analysis. This includes average rainfall, rainfall anomalies, rainfall accumulation, and flood potential.

TRMM JAXA (http://www.eorc.jaxa.jp/TRMM/index_e.htm)

TRMM JAXA is the Japanese Space Agency's home page for TRMM. It, too, provides information about the TRMM mission and its instruments. The most useful feature of this site is the ability to visualize maps using different TRMM data, like PR, TMI, and VIRS rain rates. This ranges from near real-time images from all of the instruments, to latent heat maps, to monthly rainfall data. Moreover, it devotes a section to tropical cyclones. This includes the monitoring of current cyclones and a database of previous cyclones. Finally, TRMM JAXA has a Google Earth Lab, where the user can request current KML files of cyclones, sea surface temperatures (SSTs), rainfall, radar, typhoons, and hurricanes.

Giovanni (http://daac.gsfc.nasa.gov/giovanni/)

Giovanni is a NASA-based program that stands for GES-DISC (Goddard Earth Sciences Data and Information Services Center) Interactive Online Visualization ANd aNalysis Infrastructure. Giovanni allows users to generate visualizations of Earth science data without

downloading it. Giovanni has a whole instance devoted to TRMM data, and is by far the most customizable TRMM tool of all of the websites. It enables users to generate lat-lon maps, time series, Hovmöller diagrams, and animations, using different temporal and spatial scales. The user can create plots of specific areas, by either clicking and dragging a selection box or imputing lat-lon values. Also, it has data for 3 hour, daily, weekly, and monthly TRMM rain rate and rain accumulation. In addition, the user can create anomaly and normalized anomaly maps. Most of the data available are archived since 1998, and some of the instances have near real-time data as well. One of the best features of this tool is the ability to download data as HDF, NetCDF, ASCII, and KMZ files offered in the new system at the top of the page.

Hurricane Analysis Tool (http://disc.sci.gsfc.nasa.gov/daac-bin/hurricane_data_analysis_tool.pl)

The Hurricane Analysis Tool is a NASA tool that is most useful when looking at hurricanes, typhoons, and tropical cyclones. It allows the user to generate maps and animations of an affected area. The Hurricane Analysis Tool can overlay TRMM daily rain rate data (3B42) and TMI sea surface temperatures, as well as QuickSCAT (Quick Scatterometer, satellite over oceans) Winds, NCEP (National Center for Environmental Prediction, headed by NOAA) winds and sea level pressure, and merged IR data. Not all of these data are up to date, which makes some of the data only useful for retrospective analysis. The data and maps generated cannot be downloaded.

SERVIR (http://www.servir.net/)

Spanish for "to serve", SERVIR is a website designed to help improve decision-making in the Central America and Africa. It is a Regional Visualization and Monitoring System that works to integrate satellite information, forecast models, and direct observations for environmental monitoring. Using the resources in SERVIR, a user can monitor natural disasters such as floods, fires, earthquakes, volcanoes, and tropical storms. The site provides applications to create maps and visualizations to overlay events, alerts, predictions, and other data. SERVIR uses TRMM data for monitoring of precipitation, and provides premade images and analysis of certain weather events, like 2010 Tropical Storm Agatha.

SERVIR was the least user-friendly website examined. It is naturally a Spanish website with an option for English, however not all of the Spanish is translated in the English version. This could cause problems for people who cannot understand Spanish. Also, the site is confusing to navigate through and to access data. SERVIR has a few mapping programs: Map Maker, Map Viewer, and SERVIR Viz. The data within these programs does not seem to be up to date, which is important for current events and decision making. However, these maps can be exported to KML files and loaded into Google Earth.

NASA Earth Observations (NEO) (http://neo.sci.gsfc.nasa.gov/Search.html)

NASA Earth Observations, or NEO, provides datasets from a multitude of satellite instruments for the ocean, atmosphere, energy, land, and life. Within the atmospheric dataset, there is the total rainfall from TRMM. NEO allows the user to access maps of monthly accumulated rainfall from 1998 to the current last month. The user is able to download the image in a variety of forms, one being into Google Earth. NEO also has an option to "Analyze this image" where the user can perform web-based analysis on one to three images. Here, they can select specific areas, select the modes of analysis, chose a file size, and download the file to

their desktop. When the user has chosen all of those features, they can zoom, probe, print, and create a histogram of the image. The features on NEO are helpful for monthly rainfall analysis.

Global Precipitation Analysis (GPCP) (http://precip.gsfc.nasa.gov/)

The Global Precipitation Climatology Project (GPCP) is a project whose goal is to develop a better understanding of global precipitation. GPCP uses data from rain gage stations and satellites (including TRMM) to estimate global monthly rainfall from 1979 to present. This website provides users with real-time global maps of rain rate, a weekly animation of rain rate, and downloadable near real-time, 3 hourly, and monthly data. The data and images on this site using solely TRMM data do not differ from the images on the TRMM NASA website. However, the maps from 1979 to present use other rainfall data as well, like rain gauge and surface rainfall measurements, which can be used for climatology studies.

Remote Sensing Systems (RSS) (http://remss.com)

This website provides datasets from several satellite instruments, including the TMI sensor on TRMM. TMI provides numerous types of data, including SST, surface wind speed, atmospheric water vapor amount, cloud liquid water amount, and rain rate, which are all presented on this site. RSS gives the user pre-rendered (not real-time) and dynamic data images globally. It has data in a variety of temporal scales, including daily, 3-day, weekly, and monthly data. The data is all up to date and current, as well as archived since 1997. The user can download data as a binary file, but not as KML/KMZ.

University of Utah PMM Science (http://trmm.chpc.utah.edu/)

The University of Utah uses TRMM data for precipitation research. It is based off of NASA's Precipitation Measuring Mission (PMM), whose goal is to measure rainfall globally. This includes TRMM and will include GPM (Global Precipitation Measurement, to be launched in 2013). They classify different precipitation systems based on global distribution, and display statistics, maps and animations of the distribution. In addition, they discuss different climatology features of precipitation. Finally, they have compiled the top 100 storms of heavy rainfall, thunderstorms, and tower clouds seen by TRMM. The database includes data and images of the storm events. Data can be downloaded, but no Google Earth downloads are available.

Applying These Tools to Recent Events

The nine tools listed above provide TRMM precipitation products for visualizing and analyzing precipitation events. With these tools, rainfall episodes can be monitored and used to make predictions of resulting problems. Some of these tools also provide flooding and landslide potential maps. Recently, Tropical Storm Agatha hit Central America with heavy rains which resulted in the deaths of 180 people (Associated Press, 2010). In addition, south central China experienced an exceptional drought, followed by weeks of heavy rainfall focused in southeastern China, which also killed over 300 people in total (CNN Wire Staff, 2010). Using websites with TRMM data and tools, these events can be investigated so that in the future, appropriate warnings can be made and lives can be saved.

Case Studies were created of these two events to show users how to utilize TRMM online tools for real life, real time problems. The Case Studies contain both a PowerPoint presentation of images and descriptions of the events, along with a written document teaching the user how to

generate the images and use the web tools. The document contains a worksheet with step by step instructions for creating and accessing each image in the PowerPoint, and questions with their appropriate responses for analyzing the event at the end of the document. These Case Studies were designed to demonstrate how researchers, educators, students, and decision makers can obtain important, near real-time information about environmental issues and then analyze the event in order to take appropriate action such as issuing alerts to the public.

Tropical Storm Agatha's Affects on Guatemala, May 2010

On May 29, 2010, the first tropical storm of the 2010 Eastern Pacific season emerged near Central America. The storm, named Agatha, made landfall on the Mexico-Guatemala border on the morning of May 29, 2010. Agatha was a slow-moving system, which allowed for an excess of 20 inches (510 mm) of rain to fall over El Salvador, Nicaragua, and Guatemala. It dissipated on May 30, leaving 180 people dead as a result of flooding and landslides and even a sinkhole from the intense rainfall.

To visualize the storm, users can start with the Hurricane Analysis Tool, and generate an animation of the storm to view its track and the cloud structure as it moved from the eastern Pacific towards the Mexico-Guatemala border (Figure 4). Users can also obtain True Color Images of the area using MODIS Rapid Response (http://rapidfire.sci.gsfc.nasa.gov/), and import them into Google Earth. A True Color Image provides a visual representation of the earth that can include features such as hurricanes, pollution, and other events. Here, the user can overlay the storm track obtained from a Tropical Cyclone Model Archive (http://www.tropicalatlantic.com/models/data.cgi?archive=1). Also, to see a vertical cross section of the clouds, the user can use Giovanni's A-Train instance to generate CloudSat 3D reflectivity images over Central America, and import them into Google Earth. With these images, the user can see what the storm looked like and how it moved.

To visualize the rainfall, there are many already made images on the TRMM NASA and TRMM JAXA sites. These images include Precipitation Radar (PR) vertical cross sections, rain accumulation, and rain rate by TMI and PR. They cannot be analyzed or downloaded, just used to observe the storm. Giovanni provides the user with the most customizable images. Using the TOVAS/TRMM instance, the user can create maps of rain rate and rain accumulation over Guatemala. A sample of such plot is shown in Figure 5 for May 29 to May 30, which shows rain rate over Guatemala. In addition, users can make time series and Hovmöller plots (Figure 6) for user selected areas to see when and where the rain peaked in its intensity. Some of these maps can be downloaded into Google Earth for further exploration and analysis.

The heavy rainfall from Agatha caused major flooding and landslides in Guatemala. If someone was investigating this event while it was occurring, then the NASA TRMM Global Flood and Landslide Monitoring resource could be incredibly helpful to point out areas where flooding or landslides are likely to occur. However, the data is not archived, so it is not useful after the event. The SERVIR website provides analysis of some types of natural disasters in Central America, such as hurricanes, volcanic eruptions, and earthquakes. The SERVIR analysis of Agatha includes many maps of river flooding (Figure 7A). The site also compiled a landslide risk map for May 29 in Guatemala (Figure 7B). These maps and analysis show the affects of Agatha on Guatemala.

From Drought to Flood: Southern China 2010

Since September 2009, south central China has been experiencing drought conditions, with 60% less rainfall than normal (PhysOrg.com). Affected provinces include Sichuan, Chongqing, Guizhou, Guangxi, and Yunnan. Normal amounts of rainfall are determined using climatology, which is defined as the average weather conditions over a period of time. In this case, the average amount of precipitation was found over some time period, to obtain the "normal" amount that is expected monthly in China. Comparing the actual amounts of precipitation to this "normal" number will show the abnormal precipitation conditions. The dry conditions in south central China have left millions short of drinking water, and an expected US$2.5-billion worth of crop failure. Meteorologists have said that in some areas, this drought was the worst in 100 years (Nature.com).

In order to visualize the drought conditions, Giovanni can be used to create anomaly maps using TRMM rainfall data. An anomaly map from September 2009 to March 2010 shows that areas in southern China were receiving way less than normal amounts of rain (Figure 8). Also, there are some drought monitors available online, from NCDC, UCL, and the Dartmouth Flood Observatory (Figure 9). These monitors have maps of China and point out areas that are currently or are predicted to experience drought conditions. The categories of drought range from weak to extreme, and the monitor maps display China as being in extreme.

Beginning in May, southeastern China was relieved of the drought when heavy rainfall covered ten provinces. The rainfall caused significant flooding and landslides, which killed over 300 people and left over 100 people missing. Millions of people were evacuated and hundreds of thousands of homes were destroyed (Xiang, 2010). The heavy rainfall continued to fall in June, which is during China's monsoon summer season. Southern China has received over a meter of rainfall since the rain began in May.

Looking at a rainfall anomaly is also helpful when an area experiences a lot of excess rain. In this case, the user can generate a map using Giovanni, for May and June 2010 and see the huge amount of rain above normal (0) that fell (Figure 10). A rainfall anomaly map can also be found on the TRMM NASA site, however it displays anomalies for the last 30 days, so is only helpful after the event. The user can also look at the normalized anomaly on Giovanni, which is the percent variance from normal.

In order to see exactly how much rain fell, where, when, and at what rate, Giovanni can be used to generate these plots. The user can create maps of the southern China area, looking at rain rate and rain accumulation from May to June. By making a time series, the user can see what day received the most rain, in this case June 19 (Figure 11). The rain rate map can be imported into Google Earth and can be used for further analysis, like pointing out which provinces receives the most intense rain that could have resulted in landslides and flooding.

Knowing that the most intense rain occurred on June 19, the user can use MODIS Rapid Response to find images of China during the storm. The images can then be imported into Google Earth. Using Giovanni to generate CloudSat 3D cross section images of that day, the user can see what the clouds looked like vertically. Overlay this on the MODIS imagery in Google Earth and there is the structure of the storm that day (Figure 12). Also, the user can use the Hurricane Analysis Tool to create an animation of the storm to see its extent and its movement.

The consequences of the ongoing rainfall were flooding and landslides which destroyed, damaged, and killed property and people. TRMM NASA offers a real time flooding and landslide potential monitor, which can be useful during the event. For solely flooding, the

Dartmouth Flood Observatory provides global flood analysis. Zooming in on south China, there is a flooding map that highlights the rivers and lakes that flooded. The Poyang Lake in the province of Jiangxi was especially flooded, as seen in the map (Figure 13). This can be verified by looking at MODIS Rapid Response images before and after the rainfall events. It may take some time to find images where there are no clouds blocking the view because MODIS cannot see through cloud cover. The difference between the lake before and after the rainfall is extreme, and the flooding is obvious (Figure 14).

Discussion

Monitoring precipitation globally is an ongoing challenge. However, the TRMM satellite offers a way to observe and record tropical rain rate and rain accumulation around the globe. People can use this free data for research and decision making easily once they know what tools are available online and how to use them. The various educational modules and Case Studies were created to enable users to use these tools to access precipitation, flooding, and landslide maps, and analyze severe precipitation events. The goal of these educational modules is to provide easy, step by step, instructions to learn about datasets and tools offered online. Eventually, the aim is to use these educational modules and Case Studies for the NASA Applied Sciences Program Satellite Training (http://arset.gsfc.nasa.gov/) activities to be conducted at universities and government centers to educate students, teachers, researchers, professionals, and decision makers about these tools.

One of the most important features of these tools is that TRMM precipitation data are available globally. Not all countries have the funding and resources to collect and analyze rainfall information using monitor observations. Because TRMM data are global and freely available, they can be used by countries in the tropics, such as in Central America and Africa. These countries do not have many weather stations but they are affected by severe precipitation events, like Guatemala was during Tropical Storm Agatha.

In addition, these tools are free and easy to use. As long as the user has access to the internet, all of the tools can be accessed. Also, the tools were evaluated for data downloads to perform analysis of precipitation information. After thorough searching and investigation of free data mapping software, it was concluded that Google Earth is currently the best and most useful tool for visualizing the TRMM datasets available. Among the other software evaluated were free GIS programs: ArcGIS Explorer, Quantum GIS, and DIVA-GIS. NASA World Wind and SERVIR Viz were also examined. Google Earth was the easiest to download and use. Moreover, five out of the nine TRMM tools websites have KML or KMZ files to download into Google Earth (Table 1). None of the sites had downloadable GIS files, like shapefiles, and therefore they could not be visualized with ArcGIS like tools.

Furthermore, most of the TRMM data is available near real-time, in three hour blocks. This means that every three hours precipitation data is updated for an accurate record of rain rate. The TMPA-RT (TRMM Real-Time Multi-Satellite Precipitation Analysis, Real Time) is a real-time multi-satellite dataset which uses TRMM data along with other satellite data to make an estimate of rain rate over the globe. Many of the sites, including Giovanni and the TRMM NASA and JAXA sites, provide near real-time data and maps for TRMM.

The goal is that TRMM data will be used for more research projects and weather prediction. For decision makers around the world, this free data can aid them in warning and alerting the public about potential dangerous conditions due to excessive or insufficient rainfall. Landslide and flood monitoring is being improved, as well. The combination of rainfall

information and disaster monitoring can allow professionals to evacuate where necessary and hopefully save hundreds of lives from human tragedies due to flash floods and landslides.

In the near future, these educational modules will be presented to professional and educational groups. They will also be distributed online for the public to access at http://arset.gsfc.nasa.gov. In addition to these presentations on precipitation information, other modules would be created in the future for additional satellite data and tools, such as land-use.

TRMM has the first spaceborne radar and only records data from 35ºN-35ºS, so it is very limited in its measurements. The launch of GPM (Global Precipitation Measurement) will provide the next generation of global rainfall, snow, and ice measurements. This mission will cover the entire globe and will use passive and active sensors to advance the monitoring of global precipitation, further the understanding of Earth's water and energy cycles, and improve weather prediction, modeling, and forecasting (GPM NASA). The modules created for TRMM will be very helpful for GPM and other future satellites, showing the public websites to visit in order to access free, useful data and tools.

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References

Associated Press. 2010. Death Toll from Tropical Storm Agatha Climbs to 180 as Central America Struggles to Recover. FOXNews.com. Fox News. http://www.foxnews.com/world/2010/06/01/death-toll-tropical-storm-agatha-climbs-central-america-struggles-recover/.

Castillo, Moises. 2010. Pacific Tropical Storm Agatha Hits Guatemala, Mexico; Landslides Kill 12. Cleveland OH Local News, Breaking News, Sports & Weather, http://www.cleveland.com/world/index.ssf/2010/05/pacific_tropical_storm_agatha.html.

China Drought Leaves Millions Short of Water. 2010. PhysOrg.com. http://www.physorg.com/news188032826.html.

CNN Wire Staff. 2010. More than 200 Dead in China Flooding. CNN.com. CNN. http://www.cnn.com/2010/WORLD/asiapcf/06/25/china.flood.deaths/index.html.

Dartmouth Flood Observatory. Dartmouth College. http://www.dartmouth.edu/~floods/index.html.

GIOVANNI. GES DISC: Goddard Earth Sciences, Data & Information Services Center. NASA. http://daac.gsfc.nasa.gov/giovanni/.

Global Drought Monitor. http://drought.mssl.ucl.ac.uk.

GPM NASA. GPM: Global Precipitation Measurement. NASA. http://gpm.gsfc.nasa.gov/.

Global Precipitation Analysis. GPCP. NASA. http://precip.gsfc.nasa.gov/.
Hurricane Data Analysis Tool. GES DISC: Goddard Earth Sciences, Data & Information Services Center. NASA. http://disc.sci.gsfc.nasa.gov/daac-bin/hurricane_data_analysis_tool.pl.
HYSPLIT - Hybrid Single Particle Lagrangian Integrated Trajectory Model. Air Resources Laboratory. NOAA. http://ready.arl.noaa.gov/HYSPLIT.php.
Llana, Sara M. 2010. Tropical Storm Agatha Floods Kill 150, Cause Giant Sinkhole in Guatemala City. The Christian Science Monitor. http://www.csmonitor.com/World/Americas/2010/0601/Tropical-Storm-Agatha-floods-kill-150-cause-giant-sinkhole-in-Guatemala-City.
Lott, Neal. NCDC: Worldwide Weather and Climate Events. NCDC: National Climatic Data Center. NOAA. http://www.ncdc.noaa.gov/oa/reports/weather-events.html.
MODIS Rapid Response System. NASA. http://rapidfire.sci.gsfc.nasa.gov/.
NASA Applied Sciences Program Satellite Training. NASA. http://arset.gsfc.nasa.gov/.
NEO: Welcome to NASA Earth Observations. http://neo.sci.gsfc.nasa.gov/Search.html.
Precipitation Measurement Missions. PMM Home. NASA. http://pmm.gsfc.nasa.gov/.
Qiu, Jane. 2010. China Drought Highlights Future Climate Threats. Nature.com. Nature News. http://www.nature.com/news/2010/100511/full/465142a.html.
SERVIR - Sistema Regional De Visualización Y Monitoreo. http://www.servir.net/.
Tropical Cyclone Model & Best Track Archive. Tropical Atlantic: Information About Atlantic Hurricanes. http://www.tropicalatlantic.com/models/data.cgi?archive=1.
TRMM JAXA. TRMM: Tropical Rainfall Measuring Mission. JAXA. http://www.eorc.jaxa.jp/TRMM/index_e.htm.
TRMM NASA. TRMM: Tropical Rainfall Measuring Mission. NASA. http://trmm.gsfc.nasa.gov/.
University of Utah PMM Science. University of Utah. http://trmm.chpc.utah.edu/.
Watts, Jonathan. 2010a. China Sends Emergency Food to Drought-stricken Provinces. The Guardian. http://www.guardian.co.uk/environment/2010/mar/25/china-drought-emergency-food.
Watts, Jonathan. 2010b. China Devastated by Floods. The Guardian. http://www.guardian.co.uk/world/2010/jun/20/china-devastated-floods.
Xiang, Zhang. 2010. South China Floods Toll Rises to 235. English.news.cn. http://news.xinhuanet.com/english2010/china/2010-06/25/c_13369707.htm.

Tables and Figures:

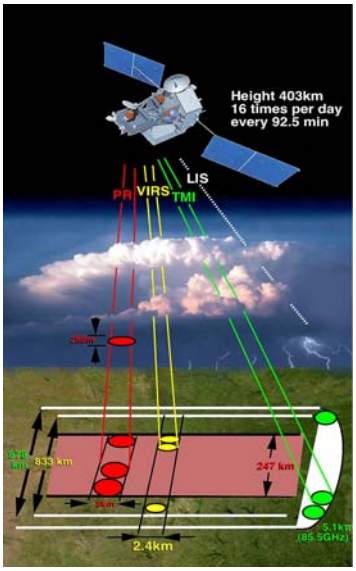

Figure 1: Graphic of the TRMM satellite, including the instruments and their field of view and swath widths (TRMM NASA).

Table 1: Evaluation of websites with TRMM tools.

	TRMM NASA	TRMM JAXA	Giovanni	Hurricane Analysis Tool	SERVIR	NEO	GPCP	RSS	U of Utah
User Friendly	♦	♦	♦	♦		♦	♦	♦	♦
Near Real-Time Data	♦	♦	♦		♦	♦	♦	♦	
Archived Previous Data	♦	♦	♦	♦	♦	♦	♦	♦	♦
Prepared Images	♦	♦			♦	♦	♦	♦	♦
Customizable Images		♦	♦	♦	♦	♦		♦	
Analysis Tools			♦			♦			
Data Downloads	♦	♦	♦	♦	♦	♦	♦	♦	♦
Google Earth Downloads	♦	♦	♦	♦		♦			
GIS Downloads									

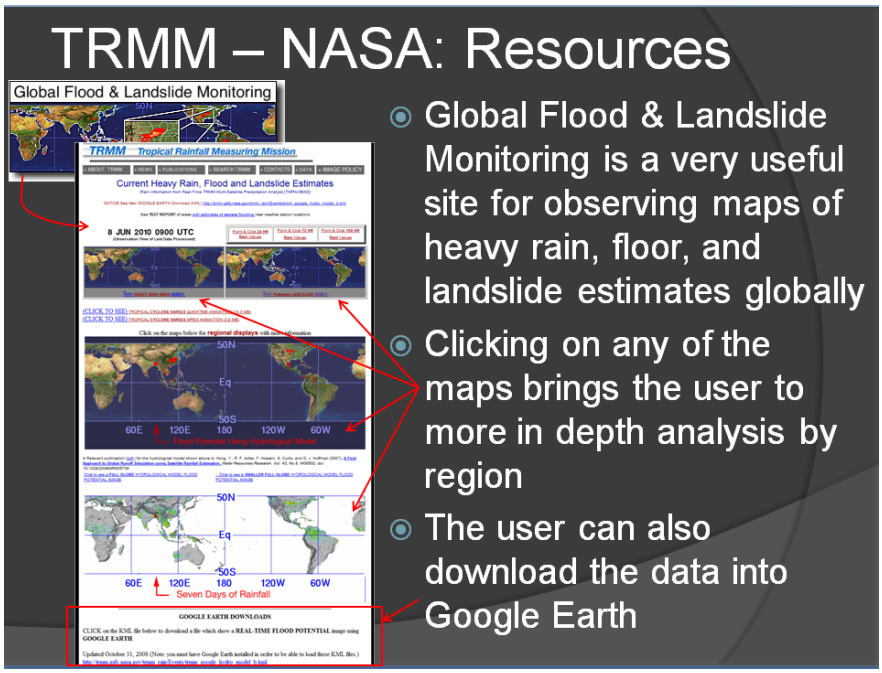

Figure 2: Sample slide from the TRMM Tools PowerPoint. The slides include screen shots, text, arrows, and boxes highlighting important features of the website, especially where to find the TRMM tools.

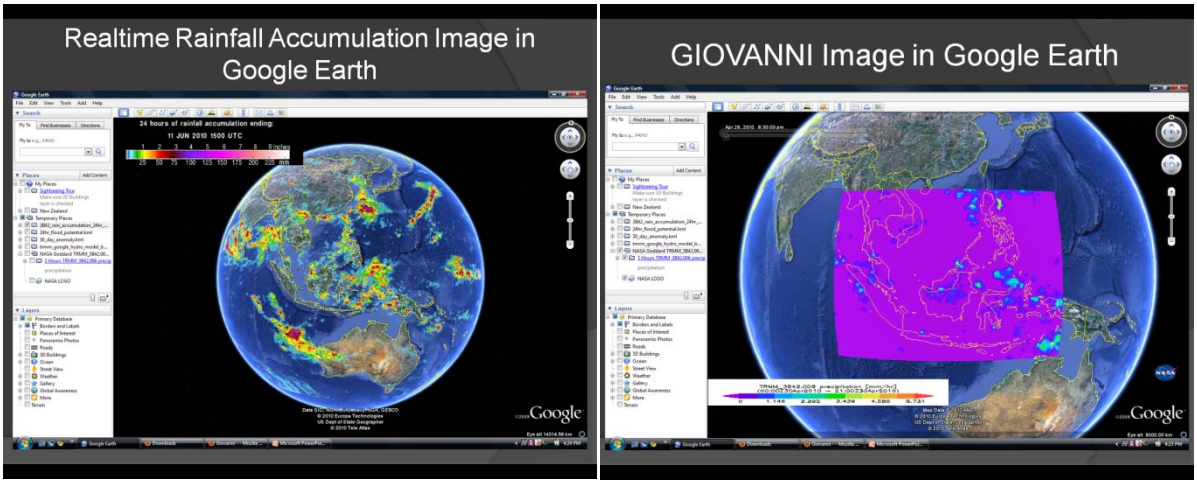

Figure 3: Examples of TRMM Tools in Google Earth

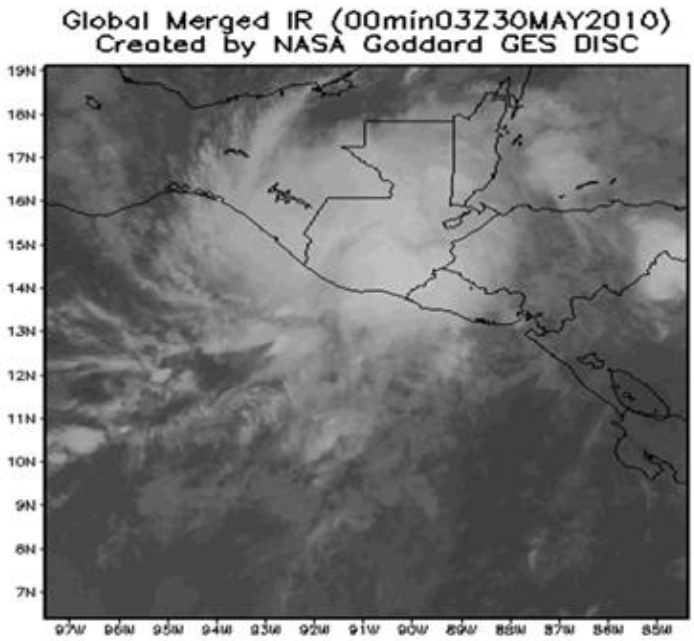

Figure 4: Merged Infrared image of Tropical Storm Agatha over Guatemala created with the Hurricane Analysis Tool.

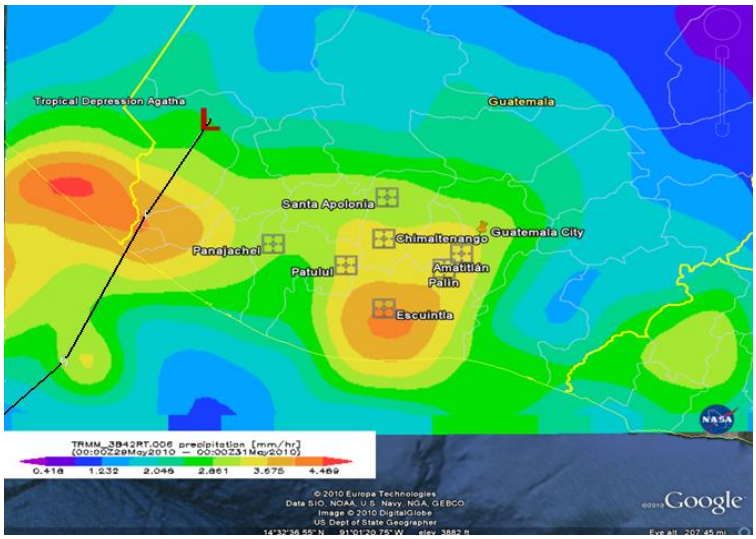

Figure 5: An image of rain rate from May 29 to May 30, 2010 over Guatemala generated using Giovanni. The image was downloaded into Google Earth, and cities with reported landslides are labeled. The storm track of Agatha is labeled as the black line on the left.

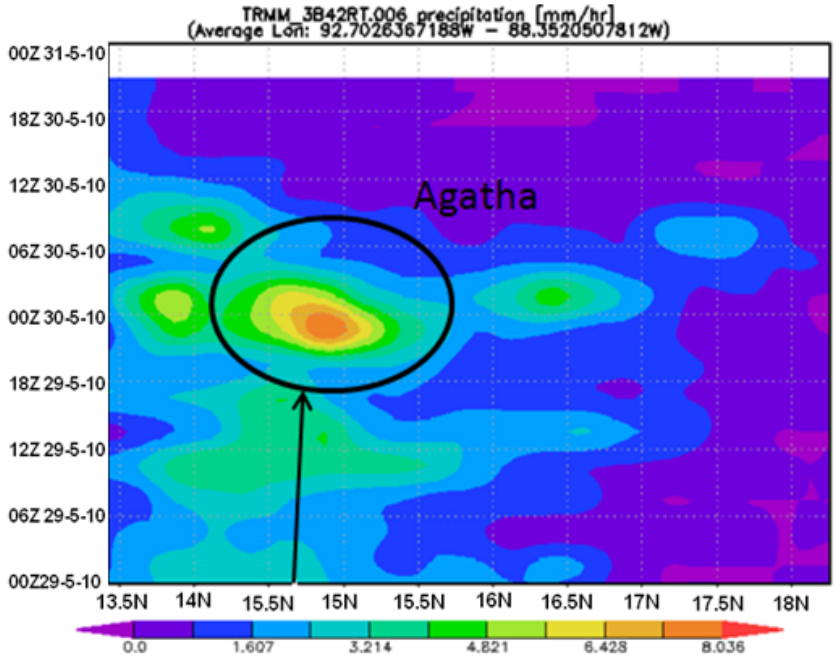

Figure 6: A Hovmöller diagram showing the areas that received the highest rain rate between May 29 and May 30. The arrow points from the latitude of Guatemala City, and points to the date and time that received the highest rain rate. The highest rain rate occurred over Guatemala City on May 30, 2010 around 00Z.

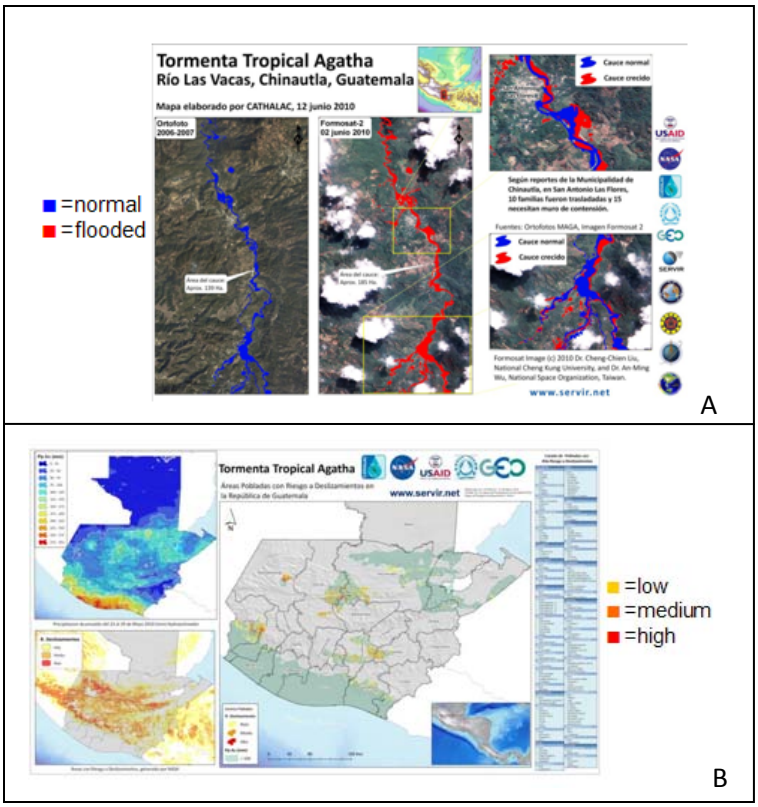

Figure 7: Agatha's affects on Guatemala, as analyzed by SERVIR. A) shows imagery and analysis of a flooded river, as seen in red. B) shows landslide risks for Guatemala on May 29, 2010.

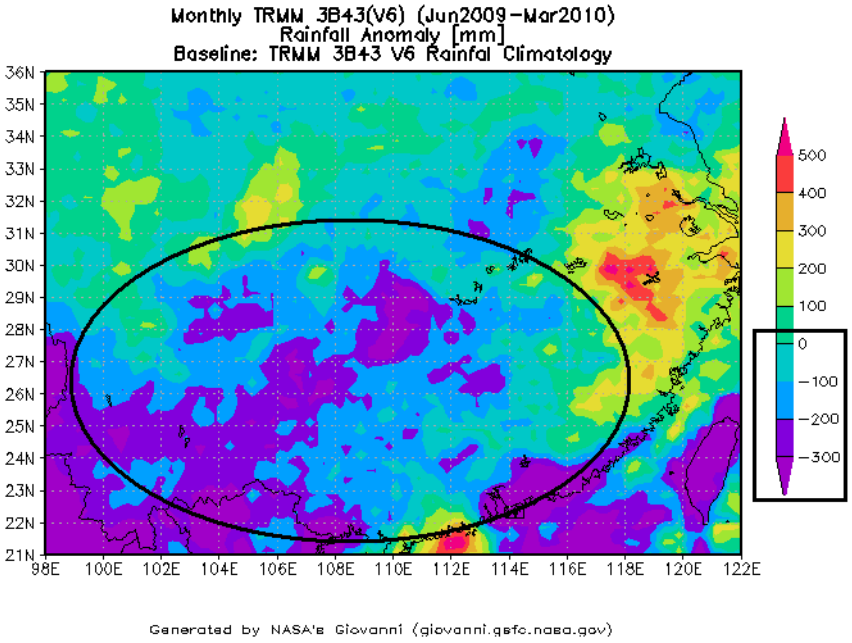

Figure 8: Rainfall anomaly map of southern China from June 2009 to March 2010. The south central region is highlighted to show the drastic negative rainfall anomaly of this region, demonstrating the lack of precipitation in this area causing an exceptional drought.

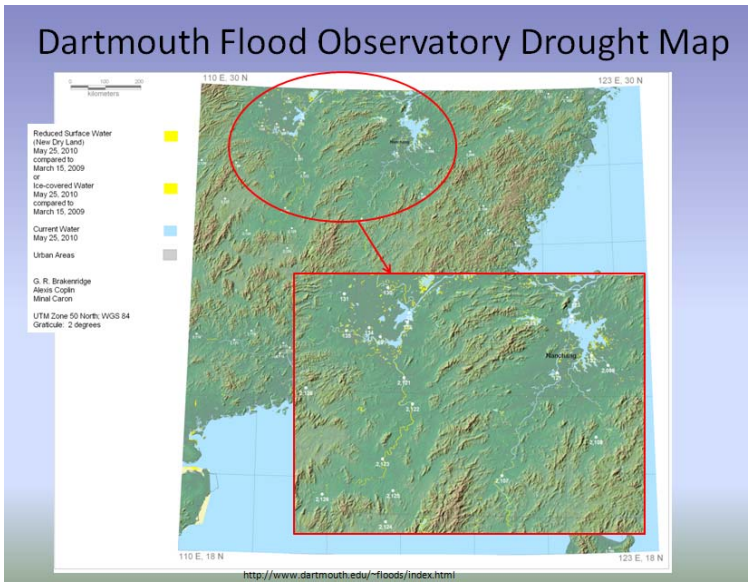

Figure 9: A drought map created by the Dartmouth Flood Observatory, showing rivers and lakes with reduced surface water in yellow.

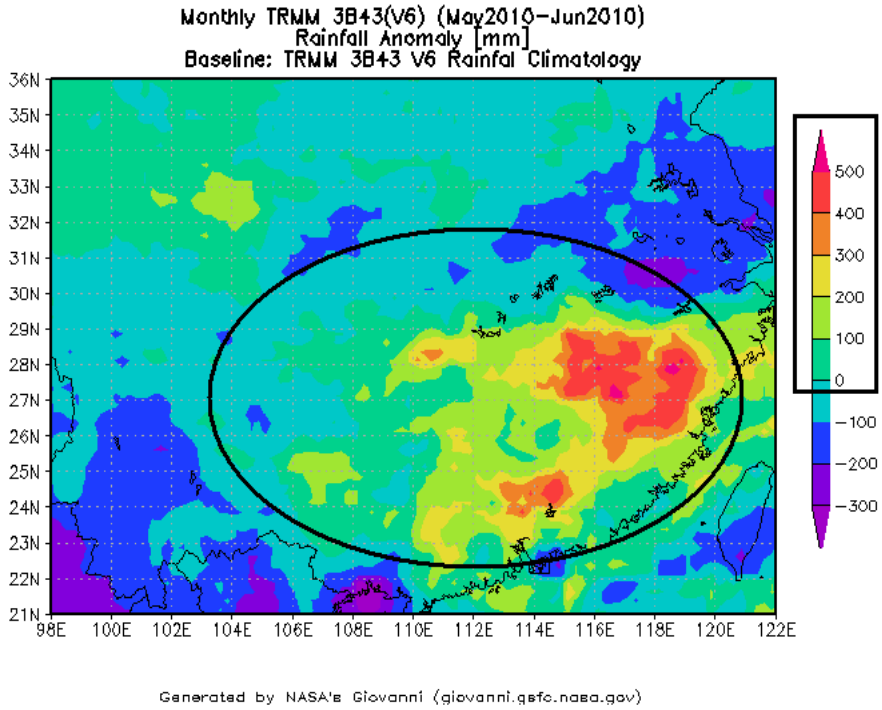

Figure 10: Rainfall anomaly from May to June 2010 of southern China. Southeastern China is highlighted to show the huge positive rainfall anomaly, or the enormous amount of rainfall above normal that fell during these two months.

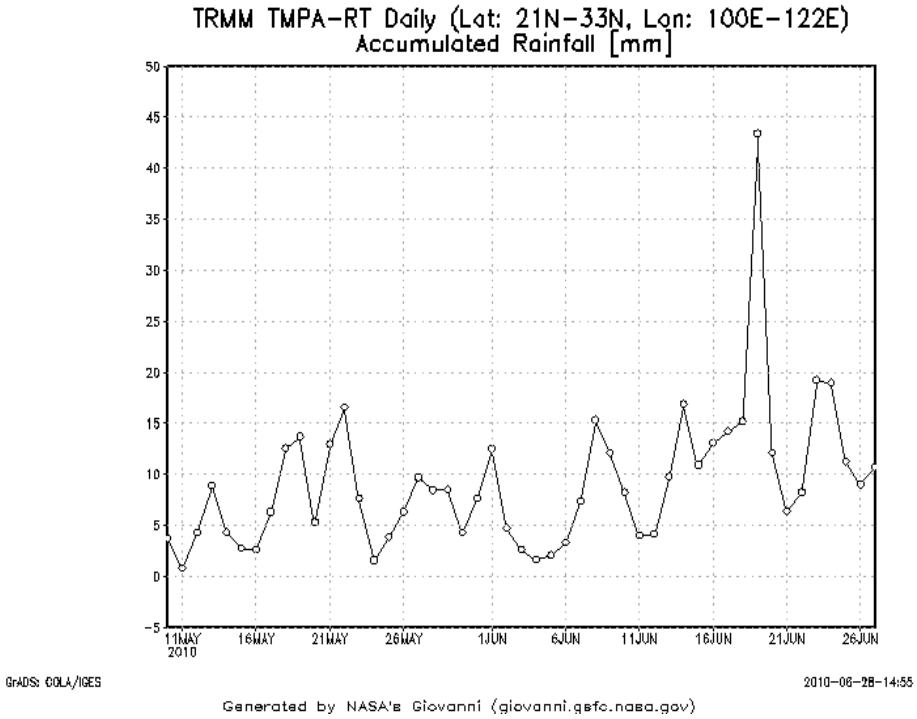

Figure 11: A time series of the accumulated rain over southern China from May 11 to June 26, 2010. The highest peak displays the day that received the most rain, June 19.

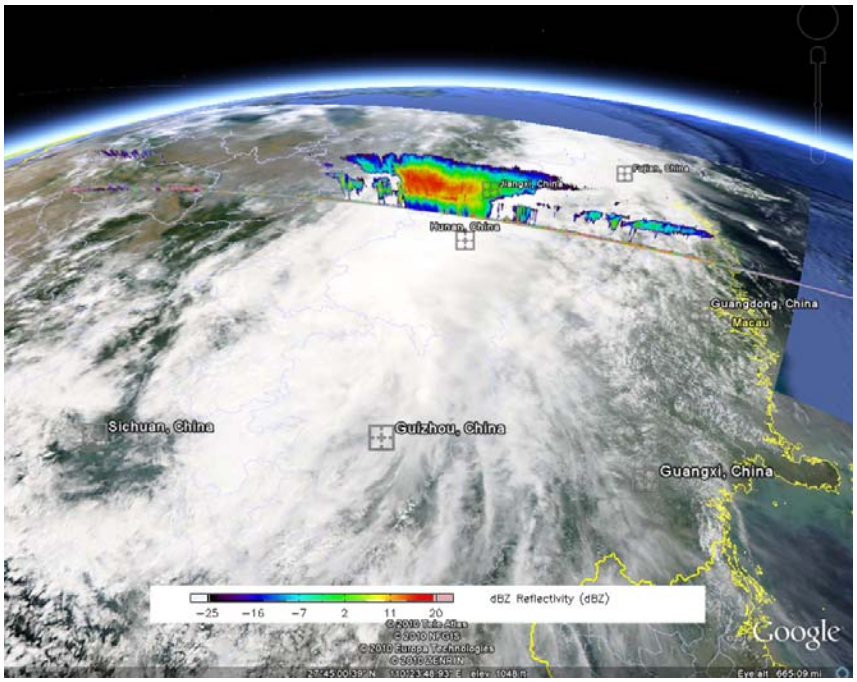

Figure 12: MODIS Rapid Response imagery of China on June 29, 2010 in Google Earth. CloudSat 3D vertical cloud cross section is overlaid on top of the image to visualize the storm structure that day.

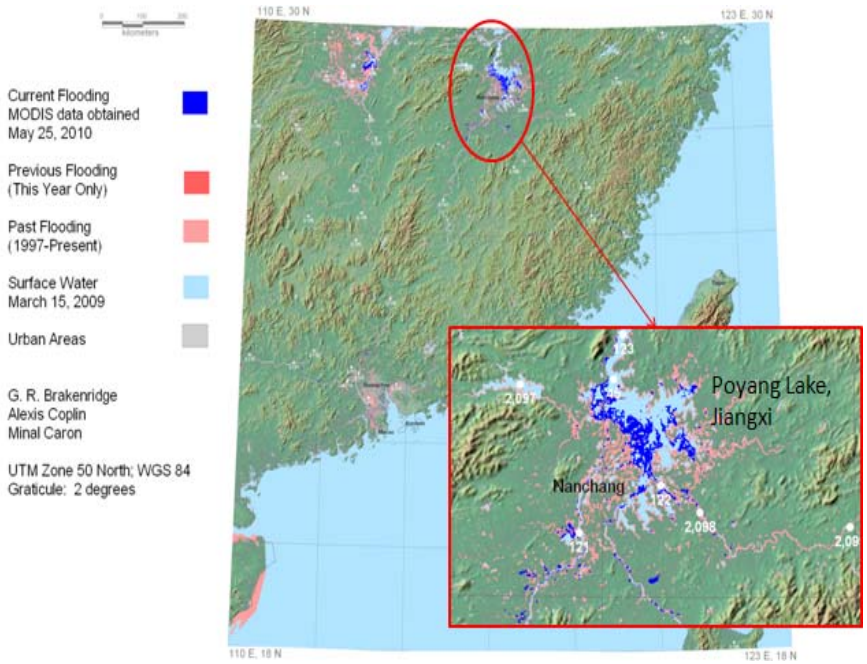

Figure 13: Flooded areas of southeast China recorded by the Dartmouth Flood Observatory. Areas in dark blue show flooded regions, like the Poyang Lake.

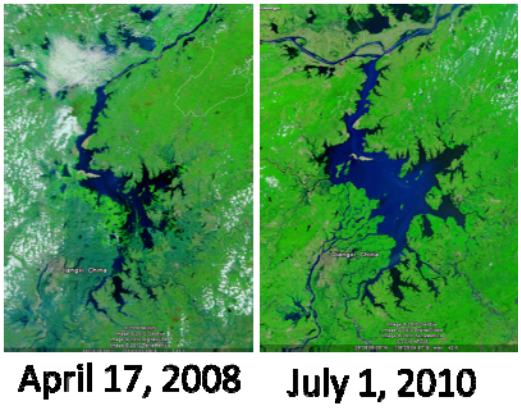

Figure 14: MODIS Rapid Response imagery of China in Bands 7-2-1, showing the extensive amount of flooding in China. The left map shows what the lake looks like normally, from April 17, 2008. The right map shows an image of the lake after the heavy rainfall events of May and June 2010, displaying the extensive flooding.