Tropical Rainfall Measuring Mission (TRMM) Precipitation Data and Services for Research and Applications

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ABSTRACT

Precipitation is a critical component of the Earth's hydrological cycle. Launched on 27 November 1997, TRMM is a joint U.S.-Japan satellite mission to provide the first detailed and comprehensive data set of the four-dimensional distribution of rainfall and latent heating over vastly under-sampled tropical and subtropical oceans and continents (40° S - 40° N). Over the past 14 years, TRMM has been a major data source for meteorological, hydrological and other research and application activities around the world.

The purpose of this short article is to inform that the NASA Goddard Earth Sciences Data and Information Services Center (GES DISC) provides TRMM archive and near-real-time precipitation data sets and services for research and applications. TRMM data consist of orbital data from TRMM instruments at the sensor's resolution, gridded data at a range of spatial and temporal resolutions, subsets, ground-based instrument data, and ancillary data. Data analysis, display, and delivery are facilitated by the following services: (1) Mirador (data search and access); (2) TOVAS (TRMM Online Visualization and Analysis System); (3) OPeNDAP (Open-source Project for a Network Data Access Protocol); (4) GrADS Data Server (GDS); and (5) Open Geospatial Consortium (OGC) Web Map Service (WMS) for the GIS community. Precipitation data application services are available to support a wide variety of applications around the world. Future plans include enhanced and new services to address data related issues from the user community. Meanwhile, the GES DISC is preparing for the Global Precipitation Measurement (GPM) mission which is scheduled for launch in 2014.

1. Introduction

Precipitation is a critical component of the Earth's hydrological cycle. Launched on 27 November 1997, the National Aeronautics and Space Administration (NASA) Tropical Rainfall Measuring Mission (TRMM) is a joint U.S.-Japan satellite mission to provide the first detailed and comprehensive data set of the four-dimensional distribution of rainfall and latent heating over vastly under-sampled tropical and subtropical oceans and continents (40° S - 40° N). Over the past 14 years, TRMM has been a major data source for meteorological, hydrological and other research and application activities around the world. For example, major achievements in fundamental new information on the synoptic climatology of tropical rainfall and weather systems are summarized in the 2006 National Research Council assessment report:

- Detailed vertical profiles of precipitation and latent heating
- Quantitative determination of the relative contributions of stratiform and convective precipitation
- Description of the fine-scale structure of rainfall systems that can be determined from the Precipitation Radar (PR) data, and
- Documentation of lightning and convection relationships over land and ocean.

There are five instruments onboard the TRMM satellite and four of them are used for precipitation (Table 1). Standard TRMM products from the Visible and Infrared Scanner (VIRS), the TRMM Microwave Imager (TMI), and PR are archived at and distributed from the NASA Goddard Space Flight Center (GSFC) Earth Sciences Data and Information Services Center (GES DISC). The Lightning Imaging Sensor (LIS) data products are archived at the NASA Global Hydrology Resource Center (GHRC). In

63 addition to these four instruments, data products from the Clouds and Earth's Radiant
64 Energy System (CERES) are archived at the Atmospheric Science Data Center (ASDC)
65 at the NASA Langley Research Center.
66 In August 2001, the TRMM satellite was boosted from 350 km to 402.5 km to
67 extend its lifespan by reducing the consumption rate of the fuel used to maintain its orbit
68 altitude. As of this writing, TRMM is still in operation and has continually collected data.
69 Since 1997, more than 14 years of TRMM data have been collected. This article is to
70 inform that the GES DISC provides free, quasi-global, archive and near-real-time
71 precipitation products and services for research and applications.
72
73 **2. TRMM Product Overview**
74 TRMM data products archived at and distributed from the GES DISC are
75 organized as the following three categories: (1) orbital products (also known as swath
76 products); (2) gridded products; and (3) other TRMM related products, consisting of
77 TRMM ancillary products, ground-based instrument products, TRMM and ground
78 observation subsets, and field experiment products. Table 2 lists raw and calibrated
79 satellite swath data, as well as geophysical swath products derived from VIRS, TMI, PR,
80 and combined TMI/PR, such as 2A12 TMI hydrometeor profiles, 2A23 radar rain
81 characteristics, 2B31 combined rainfall profile, etc. LIS science data contain orbital
82 lightning products distributed by GHRC. Table 3 contains monthly gridded products from
83 single or multiple instruments, spatially and temporally averaged, and a daily gridded
84 product. For example, 3A25 provides global rain rate from PR alone. The collection of
85 these monthly products allows inter-comparison to understand precipitation biases and

uncertainty. Two multi-satellite precipitation products, the 3-hourly and monthly TRMM Multi-Satellite Precipitation Analysis (TMPA) products (3B42, 3B43), are the most popular because of their high spatial and temporal resolutions. The daily product derived from 3B42 is also popular for those who do not want high temporal resolution products.

Table 4 lists other TRMM-related products. The NOAA National Centers for Environmental Prediction (NCEP)/Climate Prediction Center (CPC) globally-merged (60° S – 60° N), half-hourly, 4-km infrared brightness temperature data (equivalent blackbody temperatures, merged from several geostationary satellites around the globe) are an ancillary product not only for precipitation algorithm development, but also for providing background information for TRMM and other meteorological event case studies. Data from ground-based instruments provide radar data products from 10 TRMM project-affiliated ground stations in the tropical and sub-tropical regions. Table 4 also describes subsets from (a) ground validation Coincidence Subsetted Intermediate data (CSI), consisting of a single volume scan (VOS) when the satellite nadir is within a specified distance from a ground validation site, or a gridded field associated with a VOS which is coincident with a satellite overpass; (b) gridded subsets of orbital data products derived from VIRS, TMI and PR; and (c) collection of TRMM satellite instrument scan data when the satellite nadir is within a specified distance from a ground validation or experiment site. These value-added subsets facilitate TRMM ground validation and other research activities, because users do not need to download the entire original orbital data and perform the subsetting task themselves.

The TRMM field campaign program was designed to provide independent ground truth for use in algorithm development for TRMM satellite measurements.

TRMM field campaigns employ ground-based radars, rain gauge networks, and aircraft measurements from NASA DC-8 and ER2, with instrumentation similar to TMI and PR. TRMM field campaigns consist of TExas-FLorida UNderflight (TEFLUN A) and TEFLUN B, Large-scale Biosphere-Atmosphere Experiment in Amazonia (TRMM-LBA), Kwajalein Experiment (KWAJEX), South China Sea Monsoon Experiment (SCSMEX), Convection And Moisture EXperiment (CAMEX) , and Tropical Ocean Global Atmospheres/Coupled Ocean Atmosphere Response Experiment (TOGA COARE) .

3. TRMM Precipitation Data Services

Providing TRMM data services is very important for expediting research and applications and maximizing the societal benefits from the TRMM mission. Using remote sensing products can be a daunting task due to a number of problems, such as data format conversion, large data volume, lack of software, etc. Value-added data services can reduce data processing time and thus increase the time spent on scientific investigations and applications. New users are more likely to evaluate and use TRMM products if user-friendly data services are provided. Since TRMM was launched, several data services (Table 5) have been developed and/or applied at the GES DISC. In particular:

1) *Mirador.* Mirador (Fig. 1) is designed to facilitate data searching, accessing and downloading. Mirador consists of a search and access Web interface developed in response to the search habits of data users. It has a drastically simplified, clean interface and employs the Google mini appliance for metadata keyword searches. Other features include quick response, data file hit estimator, Gazetteer (geographic search by feature

name capability), and an interactive shopping cart. Value-added services include several data format conversions and spatial subsetting for a number of popular products.

2*) Giovanni TOVAS*. To enable scientific exploration of Earth science data products without going through complicated and often time consuming data processing steps (i.e., data downloading, data processing, etc.), the GES DISC has developed the GES-DISC Interactive Online Visualization ANd aNalysis Infrastructure (Giovanni), based on user support experience and in consultation with members of the user community. The TRMM Online Visualization and Analysis System (TOVAS) is the first member of the Giovanni family. Giovanni is characterized with the capabilities for quick data search, subset, analysis, display, and download. In short, Giovanni can allow access to data products without downloading data and software. For example, Fig. 2a is a rainfall map of the near-real-time TRMM Multi-Satellite Precipitation Analysis (TMPA-RT, or 3B42RT) generated from TOVAS, showing that Typhoon Morakot dumped record rains on southern Taiwan during 8 – 9 August 2009 on Google Earth. Over the years, TOVAS has proven to be very popular with users for online accessing of TRMM and other precipitation data products. TOVAS will continue to evolve to accommodate the Global Precipitation Mission (GPM) data and the expected increase in multi-sensor data product inter-comparisons.

3*) Other data services*. Users of TRMM products can benefit from several other data services listed in Table 5. The TRMM read software developed at the GES DISC can read in all TRMM standard products and write out user-selected parameter arrays and other data in flat binary or ASCII files. The Orbit Viewer Tool for High-resolution Observation Review (THOR), developed by the Precipitation Processing System (PPS) at

155 the GSFC, is a convenient stand-alone tool to visualize all TRMM standard products.
156 Figure 2b is an example of using Orbit Viewer THOR to plot a 3-D 10 dBZ isosurface
157 from the first space-borne precipitation radar, showing an intensifying tropical cyclone,
158 Giovanna, near the east-northeast of Madagascar in Indian Ocean at 1200 UTC on 11
159 February 2012. The Simple Subset Wizard (SSW) tool allows spatial subsetting and
160 provides outputs in NetCDF and ASCII. REVERB is a tool that allows keyword, spatial
161 and temporal search. The GrADS Data Server (GDS, formerly known as GrADS-DODS
162 Server) is a stable, secure data server that provides subsetting and analysis services across
163 the internet and provides a convenient way for GrADS users to access TRMM data. The
164 core of GDS is the Open Source Project for a Network Data Access Protocol (OPeNDAP,
165 also known as Distributed Oceanographic Data System or DODS), which provides
166 remote access to individual variables within data sets in a form usable by many tools,
167 such as Interactive Data Viewer (IDV), McIDAS-V, Panoply, Ferret, and GrADS. The
168 Open Geospatial Consortium (OGC) Web Map Service (WMS) provides map depictions
169 over the network via a standard protocol and enables clients to build customized maps
170 with data coming from different networks.
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172 **4. TRMM application services**
173 TRMM mission societal benefits have been realized through the use of data
174 services for precipitation applications, such as flood monitoring, often requiring near-
175 real-time precipitation data services support. The GES DISC provides such support
176 through various means: (1) near-real-time precipitation product access through ftp, GDS,
177 and WMS; (2) daily global and regional maps of current conditions for monitoring

precipitation and its anomaly around the world; (3) various tools and services in Section 3; (4) Crop Explorer of the U.S. Department of Agriculture's Foreign Agricultural Service (USDA FAS); and (5) GES DISC Hurricane Portal that provides near-real-time monitoring services and imagery archive for the Atlantic basin. Customized application software can be developed to directly access data via ftp, GDS, and WMS. For example, monthly total rainfall from 3B43 is provided to the NASA Earth Observations (NEO) via WMS. To provide a simple and quick way to monitor global droughts and floods, we routinely generate global and regional maps of rainfall accumulation, rainfall anomaly, and normalized anomaly (anomaly/climatology), ranging from 3-hourly to 90 days. The maps are updated daily. With the services described in Section 3, subsets can be produced from several popular TRMM products as well as conversion from HDF to NetCDF and ASCII formats. We have developed several value-added products to expedite TRMM applications, such as two daily products derived from 3B42 and 3B42RT (the near-real-time version of 3B42) and an accumulated rainfall product from 3B43. With TOVAS, customized analysis, visualization and data can be obtained from the built-in functions, such as latitude-longitude maps, time series, Hovemöller diagrams, etc. Further analysis using other software can be done with customized data downloaded from TOVAS.

The USDA FAS, in collaboration with the GES DISC, is routinely using near-real-time global satellite-derived precipitation data (i.e. 3B42RT) to monitor crop condition around the world. This project is unique, being the first of its kind to utilize satellite precipitation data in an operational manner. Satellite precipitation products are produced by NASA via a semi-automated process and made publicly accessible from the USDA FAS' Crop Explorer Web site. Monitoring precipitation for agriculturally

important areas around the world greatly assists the USDA FAS to quickly locate regional weather events, as well as help improve crop production estimates. Figure 3 is an example of the TRMM near-real-time product (3B42RT) in USDA Crop Explorer. Figure 3a contains a global map for selecting a region of interest and Fig. 3b is a sample of 10-day accumulated rainfall derived from 3B42RT in southern Africa and its percent normal (normalized anomaly).

In addition to applications at the GES DISC, TRMM data have been used in a wide variety of activities around the globe. Applications reported by TRMM users range from meteorology and hydrology to other areas as well, such as, a development of a rainfall-based crop insurance product for developing countries, a study on environmental causes of diabetes using rainfall as an effect on crop moisture and toxins, an early warning system for mosquito-borne diseases, etc.

5. Future Plans

Future plans include new and enhanced data services to address user needs and support applications. Meanwhile, the GES DISC is preparing for the GPM era. Scheduled for launch in 2014, GPM consists of a core observatory which serves as a reference standard to a constellation of research and operational microwave sensors to provide uniformly calibrated precipitation measurements around the globe every 2-4 hours for research and applications. As of this writing, three types of scientific data products will be generated: near-real-time products, research products, and outreach data products. The near-real-time and outreach products will be created within short time spans to meet the particular needs of their end users. The research products are full data products of

research quality. With an increasing number of instruments and improved spatial and temporal resolutions and coverage, it is expected that GPM data volume will greatly exceed that of TRMM. Nonetheless, the GES DISC will continue to provide the existing data services for GPM and in the meanwhile, to develop services for improving data accessibility and discovery, as well as addressing new issues arising from the user community.

For Further Reading:

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284 **TRMM Data Services URLs:**
285 Mirador: http://mirador.gsfc.nasa.gov/
286 TOVAS: http://disc2.nascom.nasa.gov/Giovanni/tovas/
287 LIS: http://thunder.msfc.nasa.gov/
288 GES DISC Precipitation Product and Service Portal:
289 http://disc.sci.gsfc.nasa.gov/precipitation
290 TRMM Data FAQ: http://disc.sci.gsfc.nasa.gov/additional/faq/precipitation_faq.shtml
291 TRMM read software:
292 http://disc.sci.gsfc.nasa.gov/precipitation/additional/tools/trmm_readHDF.shtml
293 Orbit Viewer THOR:
294 http://pps.gsfc.nasa.gov/tsdis/THOR/release.html
295 Simple Subset Wizard (SSW): http://disc.gsfc.nasa.gov/SSW/
296 REVERB: http://reverb.echo.nasa.gov/reverb/
297 GrADS Data Server: http://disc2.nascom.nasa.gov/dods/
298 OPeNDAP: http://disc.sci.gsfc.nasa.gov/services/opendap/TRMM/trmm.shtml
299 OGC Web Map Service: http://disc.sci.gsfc.nasa.gov/services/ogc_wms

TRMM Field Experiments:

http://disc.sci.gsfc.nasa.gov/additional/additional/faq/precipitation_faq.shtml#TRMM_field

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

Year of Tropical Convection (YOTC)-Giovanni System:

http://disc.sci.gsfc.nasa.gov/YOTC/yotc_gs

Giovanni: giovanni.gsfc.nasa.gov

Current conditions:

http://disc.sci.gsfc.nasa.gov/agriculture/additional/tools/current_conditions.shtml

USDA FAS Crop Explorer: http://www.pecad.fas.usda.gov/cropexplorer/mpa_maps.cfm

TRMM Extreme Event Archives:

http://trmm.gsfc.nasa.gov/publications_dir/extreme_events.html

TRMM Project: http://trmm.gsfc.nasa.gov/

NASA GPM Project: http://pmm.nasa.gov/

FIGURE CAPTIONS:

Figure 1. Mirador homepage where users can search, access, and download TRMM data.

Figure 2. Examples of TRMM data services. a): A Google Earth screen shot of the near-real-time 3-hourly precipitation product (3B42RT). The rainfall map was generated from TOVAS, showing the record rains dumped by Typhoon Morakot on southern Taiwan between 8-9 August 2009. b): A 3-D plot of the 2A25 10 dBZ isosurface from the first space-borne precipitation radar, showing an intensifying tropical cyclone, Giovanna, near the east-northeast of Madagascar in Indian Ocean at 1200 UTC on 11 February 2012.

Figure 3. The TRMM near-real-time product (3B42RT) in USDA FAS Crop Explorer. a): A global map for selecting a region of interest and b): a sample of 10-day accumulated rainfall (left panel) in southern Africa and its percent normal (right).

331 Table 1. TRMM precipitation related instruments

Instrument Name	Description
Visible and Infrared Scanner (VIRS)	5 channels (0.63, 1.6, 3.75, 10.8, and 12 um); spatial resolution: 2.2 km (pre-boost) and 2.4 km (post-boost); swath width: 720 km (pre-boost) and 833 km (post-boost).
TRMM Microwave Imager (TMI)	5 frequencies (10.7, 19.4, 21.3, 37, 85.5 GHz); spatial resolution: 4.4 km (at 85.5 GHz, pre-boost) and 5.1 km (at 85.5 GHz, post-boost); swath width: 760 km (pre-boost) and 878 km (post-boost).
Precipitation Radar (PR)	13.8 GHz; spatial resolution: 4.3 km (pre-boost) and 5.0 (post-boost); swath width: 215 km (pre-boost) and 247 km (post-boost).
Lightning Imaging Sensor (LIS)	Spatial resolution: 3-6 km; swath coverage: 600 x 600 km. LIS data are archived at the NASA Global Hydrology Resource Center.

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334 Table 2. Standard TRMM Version 7 orbital data products (time coverage: 12/1997 –
335 present).

Product Name	Description
1A01: VIRS Raw Data (VIRS)	Reconstructed, unprocessed VIRS (0.63, 1.6, 3.75, 10.8, and 12 um) data
1A11: TMI Raw Data (TMI)	Reconstructed, unprocessed TMI (10.65, 19.35, 21, 37, and 85.5 GHz) data
1B01: Visible and Infrared Radiance (VIRS)	Calibrated VIRS (0.63, 1.6, 3.75, 10.8, and 12 um) radiances at 2.4 km resolution over a 833 km swath
1B11: Microwave Brightness Temperature (TMI)	Calibrated TMI (10.65, 19.35, 21, 37, and 85.5 GHz) brightness temperatures at 5 to 45 km resolution over a 878 km swath
1B21: Radar Power (PR)	Calibrated PR (13.8 GHz) power at 5 km horizontal, and 250 m vertical, resolutions over a 247 km swath
1C21: Radar Reflectivity (PR)	Calibrated PR (13.8 GHz) reflectivity at 5 km horizontal, and 250 m vertical, resolutions over a 247 km swath
2A12: Hydrometeor Profile (TMI)	TMI Hydrometeor (cloud liquid water, prec. water, cloud ice, prec. ice) profiles in 28 layers at 5.1 km (at 85.5 GHz) horizontal resolution, along with latent heat and surface rain, over a 878 km swath
2A21: Radar Surface Cross-Section (PR)	PR (13.8 GHz) normalized surface cross-section at 5 km horizontal resolution and path attenuation (in case of rain), over a 247 km swath
2A23: Radar Rain Characteristics (PR)	Rain type; storm, freezing, and bright band heights; from PR (13.8 GHz) at 5 km horizontal resolution over a 247 km swath
2A25: Radar Rainfall Rate and Profile (PR)	PR (13.8 GHz) rain rate, reflectivity, and attenuation profiles, at 5 km horizontal, and 250 m vertical, resolutions, over a 247 km swath
2B31: Combined Rainfall Profile (PR,	Combined PR/TMI rain rate and path-integrated attenuation at 5 km horizontal, and 250 m vertical, resolutions, over a 247 km

TMI)	swath
LIS Science Data*	Orbital lightning products. Spatial resolution: 3-6 km

*Available at the NASA Global Hydrology Resource Center (GHRC)

337 Table 3. Standard TRMM gridded data products.

Data Product	Description	Time Range
3A11: Monthly 5 x 5 degree oceanic rainfall	Rain rate, conditional rain rate, rain frequency, and freezing height for a latitude band from 40° N to 40° S, from TMI	1997-12 to present
3A12 : Monthly 0.5 x 0.5 degree mean 2A12, profile, and surface rainfall	0.5 x 0.5 degree gridded monthly product comprising mean 2A12 data and calculated vertical hydrometeor profiles, as well as mean surface rainfall for a latitude band from 40° N to 40° S	1997-12 to present
3A25: Monthly 5x5 degree and .5x.5 degree spaceborne radar rainfall	Total and conditional rain rate, radar reflectivity, path-integrated attenuation at 2, 4, 6, 10, 15 km for convective and stratiform rain; storm, freezing, and bright band heights, and snow-ice layer depth for a latitude band from 40° N to 40° S, from PR	1997-12 to present
3A26: Monthly 5 x 5 degree surface rain total	Rain rate probability distribution at surface, 2 km, and 4 km for a latitude band from 40° N to 40° S, from PR	1997-12 to present
3A46: Monthly 1 x 1 degree SSM/I Rain	Global rain rate from SSM/I	1998-01 to 2009-09
3B31: Monthly 5 x 5 degree combined rainfall	Rain rate, cloud liquid water, rain water, cloud ice, grauples at 14 levels for a latitude band from 40° N to 40° S, from PR and TMI	1997-12 to present
3B42: 3-Hourly 0.25 x 0.25 degree merged TRMM and other satellite estimates	Calibrated IR merged with TRMM and other satellite data for a latitude band from 50° N to 50° S	1998-01 to present
3B42 Daily: Daily 0.25 x 0.25 degree merged TRMM and other satellite estimates	Daily TRMM and other satellite rainfall Estimates derived from 3B42 for a latitude band from 50° N to 50° S	1998-01 to present
3B43: Monthly 0.25 x 0.25 degree merged TRMM and other sources estimates	Merged 3B42 and rain gauge estimates for a latitude band from 50° N to 50° S	1998-01 to present
3H12: Monthly 0.5 x 0.5 degree heating profile	Monthly oceanic heating maps at 19 layers for a latitude band from 40° N to 40° S, from TMI	1997-12 to present
3H25: Monthly 0.5 x 0.5 degree spectral	Monthly heating maps at 19 layers for a latitude band from 40° N to 40° S,	1997-12 to present

latent heating profile	from PR rain	
3H31: Monthly 0.5 x 0.5 degree convective stratiform heating profile	Monthly heating maps at 19 layers for a latitude band from 40° N to 40° S, from surface convective rainfall rate and surface stratiform rainfall rate.	1997-12 to present

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340 Table 4. Other TRMM related products

Product	Description
NCEP/CPC Global Merged IR	Globally-merged (60°N - 60°S) pixel-resolution IR brightness temperature data (equivalent blackbody temps), merged from all available geostationary satellites (GOES, METEOSAT, GMS/MTSAT). Associated Satellite ID files are available via ftp. (2002-02 to present)
Ground-based instruments	Ground-based instrument (radar data) products from 10 TRMM project ground stations
Subsets	Ground Validation Coincidence Subsetted Intermediate Data (CSI): the single volume scan when the satellite is nearest or a gridded field associated with a volume scan (VOS) which is coincident with a satellite overpass
	Gridded subsets of orbital data products derived from VIRS, TMI, and PR
	Satellite Coincidence Subsetted Intermediate Data (CSI): Collection of Instrument Scan data when TRMM satellite passes over a Ground Validation or Experiment Site
Field Experiments	Ground truth for use in algorithm development for TRMM satellite measurements. The data archived at GES DISC include KWAJEX, LBA, SGP97, SGP99, SCSMEX, TEFLUNA, TEFLUNB, TOGA COARE, and TRMM LBA.

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344 Table 5. TRMM data services

Service	Description
Mirador	Mirador (from Spanish, *a place providing a wide view*) is a Google-based data archive search interface that allows searching, browsing, subsetting, format conversion, and ordering of Earth science data at NASA GES DISC.
TOVAS	TRMM Online Visualization and Analysis System: A member of The GES-DISC Interactive Online Visualization ANd aNalysis Infrastructure (Giovanni), which is the underlying infrastructure for a growing family of Web interfaces that allows users to analyze gridded data interactively online without having to download any data.
TRMM read software	Read in a TRMM HDF data file and write out user-selected scientific data set (SDS) arrays and vertex data (Vdata) tables as separate flat binary files.
Simple Subset Wizard	A simple spatial subset tool that allows spatial subsetting; outputs are in NetCDF or ASCII.
REVERB	Refine your granule search with the NASA-developed Earth Observing System (EOS) Clearinghouse (ECHO) next generation Earth Science discovery tool.
GrADS Data Server	Stable, secure data server that provides subsetting and analysis services across the internet. The core of GDS is OPeNDAP (also known as DODS), a software framework used for data networking that makes local data accessible to remote locations.
OPeNDAP	The Open Source Project for a Network Data Access Protocol (OPeNDAP) provides remote access to individual variables within data sets in a form usable by many tools, such as IDV, McIDAS-V, Panoply, Ferret, and GrADS.
OGC Web Map Service	The Open Geospatial Consortium (OGC) Web Map Service (WMS) provides map depictions over the network via a standard protocol, enabling clients to build customized maps based on data coming from a variety of distributed sources.

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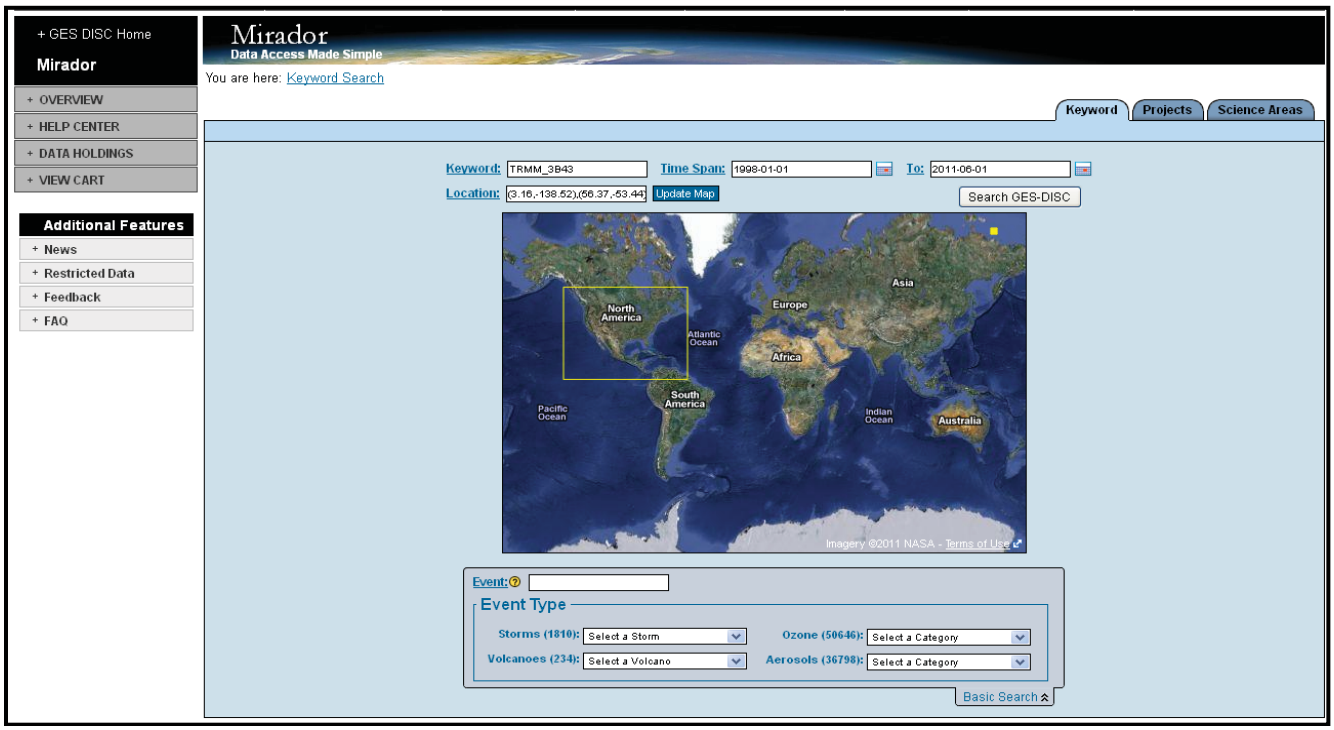

Figure 1. Mirador homepage where users can search, access, and download TRMM data.

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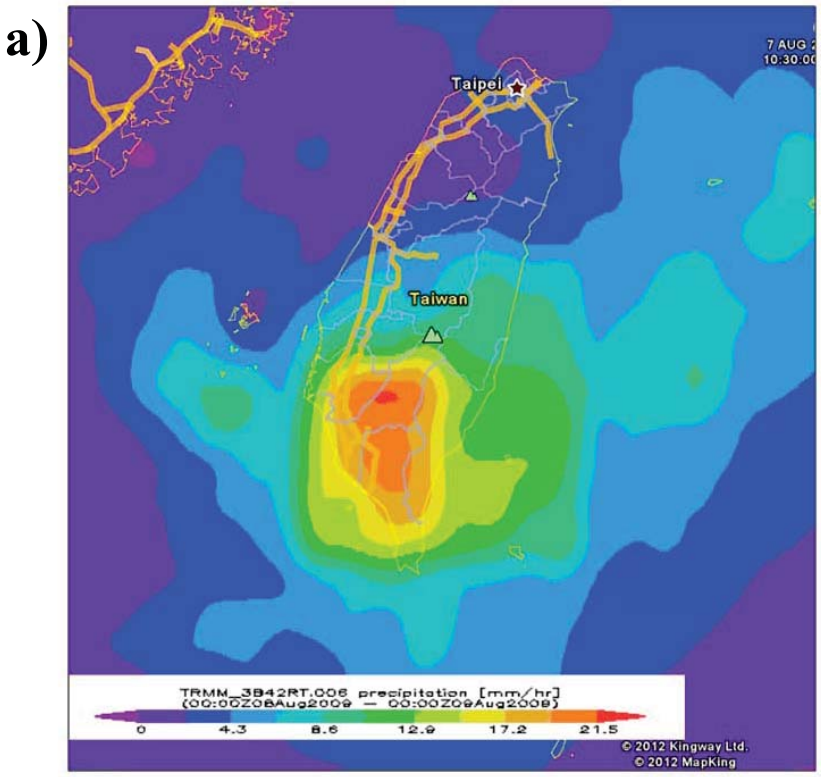

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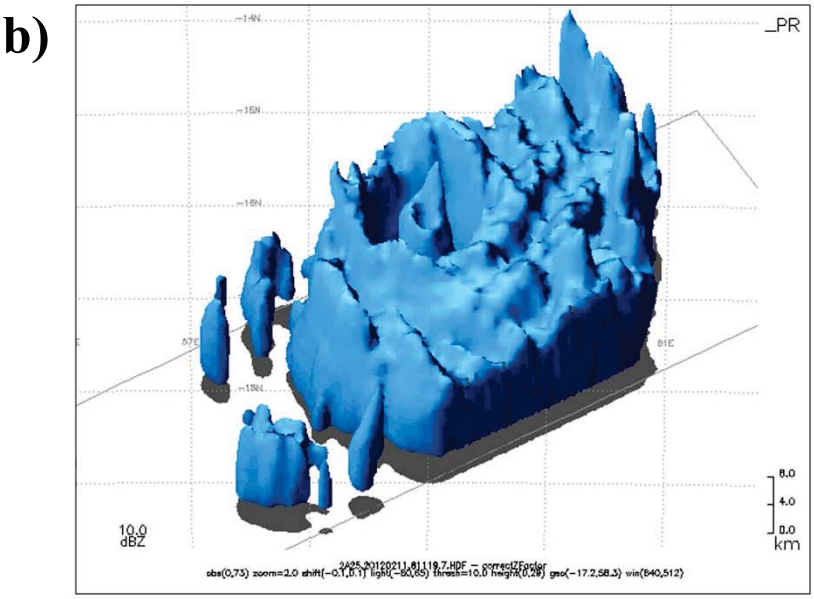

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356 Figure 2. Examples of TRMM data services. a): A Google Earth screen shot of the near-
357 real-time 3-hourly precipitation product (3B42RT). The rainfall map was generated from
358 TOVAS, showing the record rains dumped by Typhoon Morakot on southern Taiwan
359 between 8-9 August 2009. TOVAS provides quick data search, subset, analysis,
360 visualization, and download capabilities for popular near-real-time and archive

precipitation products. b): A 3-D plot of the 2A25 10 dBZ isosurface from the first space-borne precipitation radar, showing an intensifying tropical cyclone, Giovanna, near the east-northeast of Madagascar in Indian Ocean at 1200 UTC on 11 February 2012.

a)

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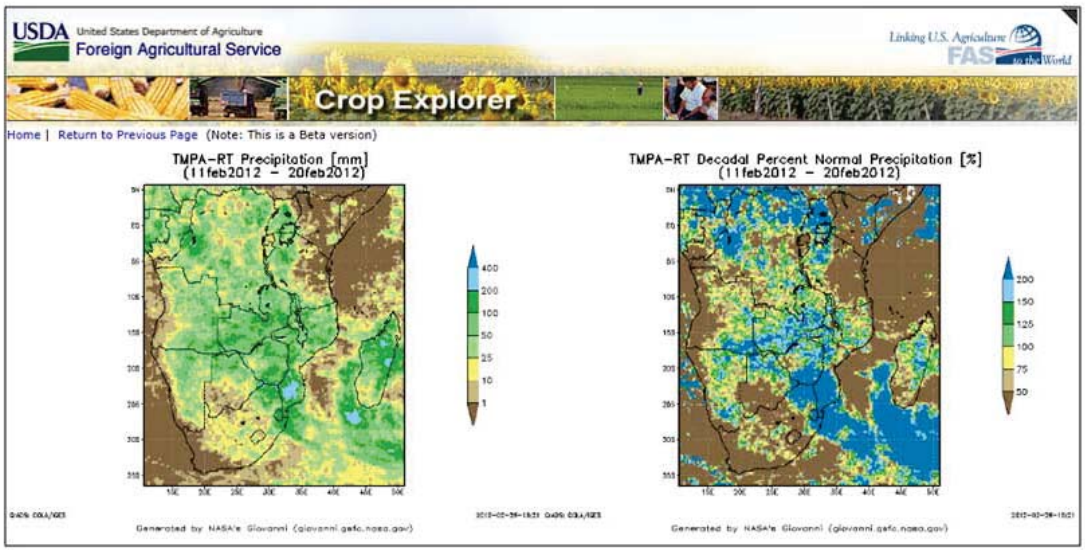
b)



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367 Figure 3. The TRMM near-real-time product (3B42RT) in USDA FAS Crop Explorer. a):
368 A global map for selecting a region of interest and b): a sample of 10-day accumulated
369 rainfall (left panel) in southern Africa and its percent normal (right).

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