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

2   Research and Applications

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16   **ABSTRACT**

17   Precipitation is a critical component of the Earth's hydrological cycle. Launched

18   on 27 November 1997, TRMM is a joint U.S.-Japan satellite mission to provide the first

19   detailed and comprehensive data set of the four-dimensional distribution of rainfall and

20   latent heating over vastly under-sampled tropical and subtropical oceans and continents

21   (40° S - 40° N). Over the past 14 years, TRMM has been a major data source for

22   meteorological, hydrological and other research and application activities around the

23   world.

24   The purpose of this short article is to inform that the NASA Goddard Earth

25   Sciences Data and Information Services Center (GES DISC) provides TRMM archive

26   and near-real-time precipitation data sets and services for research and applications.

27   TRMM data consist of orbital data from TRMM instruments at the sensor's resolution,

28   gridded data at a range of spatial and temporal resolutions, subsets, ground-based

29   instrument data, and ancillary data. Data analysis, display, and delivery are facilitated by

30   the following services: (1) Mirador (data search and access); (2) TOVAS (TRMM Online

31   Visualization and Analysis System); (3) OPeNDAP (Open-source Project for a Network

32   Data Access Protocol); (4) GrADS Data Server (GDS); and (5) Open Geospatial

33   Consortium (OGC) Web Map Service (WMS) for the GIS community. Precipitation data

34   application services are available to support a wide variety of applications around the

35   world. Future plans include enhanced and new services to address data related issues

36   from the user community. Meanwhile, the GES DISC is preparing for the Global

37   Precipitation Measurement (GPM) mission which is scheduled for launch in 2014.

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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.

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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

86   uncertainty. Two multi-satellite precipitation products, the 3-hourly and monthly TRMM

87   Multi-Satellite Precipitation Analysis (TMPA) products (3B42, 3B43), are the most

88   popular because of their high spatial and temporal resolutions. The daily product derived

89   from 3B42 is also popular for those who do not want high temporal resolution products.

90   Table 4 lists other TRMM-related products. The NOAA National Centers for

91   Environmental Prediction (NCEP)/Climate Prediction Center (CPC) globally-merged

92   (60° S – 60° N), half-hourly, 4-km infrared brightness temperature data (equivalent

93   blackbody temperatures, merged from several geostationary satellites around the globe)

94   are an ancillary product not only for precipitation algorithm development, but also for

95   providing background information for TRMM and other meteorological event case

96   studies. Data from ground-based instruments provide radar data products from 10

97   TRMM project-affiliated ground stations in the tropical and sub-tropical regions. Table 4

98   also describes subsets from (a) ground validation Coincidence Subsetted Intermediate

99   data (CSI), consisting of a single volume scan (VOS) when the satellite nadir is within a

100   specified distance from a ground validation site, or a gridded field associated with a VOS

101   which is coincident with a satellite overpass; (b) gridded subsets of orbital data products

102   derived from VIRS, TMI and PR; and (c) collection of TRMM satellite instrument scan

103   data when the satellite nadir is within a specified distance from a ground validation or

104   experiment site. These value-added subsets facilitate TRMM ground validation and other

105   research activities, because users do not need to download the entire original orbital data

106   and perform the subsetting task themselves.

107   The TRMM field campaign program was designed to provide independent

108   ground truth for use in algorithm development for TRMM satellite measurements.

109 TRMM field campaigns employ ground-based radars, rain gauge networks, and aircraft

110 measurements from NASA DC-8 and ER2, with instrumentation similar to TMI and PR.

111 TRMM field campaigns consist of TExas-FLorida UNderflight (TEFLUN A) and

112 TEFLUN B, Large-scale Biosphere-Atmosphere Experiment in Amazonia (TRMM-

113 LBA), Kwajalein Experiment (KWAJEX), South China Sea Monsoon Experiment

114 (SCSMEX), Convection And Moisture EXperiment (CAMEX) , and Tropical Ocean

115 Global Atmospheres/Coupled Ocean Atmosphere Response Experiment (TOGA

116 COARE) .

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118 **3. TRMM Precipitation Data Services**

119   Providing TRMM data services is very important for expediting research and

120 applications and maximizing the societal benefits from the TRMM mission. Using remote

121 sensing products can be a daunting task due to a number of problems, such as data format

122 conversion, large data volume, lack of software, etc. Value-added data services can

123 reduce data processing time and thus increase the time spent on scientific investigations

124 and applications. New users are more likely to evaluate and use TRMM products if user-

125 friendly data services are provided. Since TRMM was launched, several data services

126 (Table 5) have been developed and/or applied at the GES DISC. In particular:

127   1) *Mirador.* Mirador (Fig. 1) is designed to facilitate data searching, accessing

128 and downloading. Mirador consists of a search and access Web interface developed in

129 response to the search habits of data users. It has a drastically simplified, clean interface

130 and employs the Google mini appliance for metadata keyword searches. Other features

131 include quick response, data file hit estimator, Gazetteer (geographic search by feature

132   name capability), and an interactive shopping cart. Value-added services include several

133   data format conversions and spatial subsetting for a number of popular products.

134   2) *Giovanni TOVAS*. To enable scientific exploration of Earth science data

135   products without going through complicated and often time consuming data processing

136   steps (i.e., data downloading, data processing, etc.), the GES DISC has developed the

137   GES-DISC Interactive Online Visualization ANd aNalysis Infrastructure (Giovanni),

138   based on user support experience and in consultation with members of the user

139   community. The TRMM Online Visualization and Analysis System (TOVAS) is the first

140   member of the Giovanni family. Giovanni is characterized with the capabilities for quick

141   data search, subset, analysis, display, and download. In short, Giovanni can allow access

142   to data products without downloading data and software. For example, Fig. 2a is a

143   rainfall map of the near-real-time TRMM Multi-Satellite Precipitation Analysis (TMPA-

144   RT, or 3B42RT) generated from TOVAS, showing that Typhoon Morakot dumped

145   record rains on southern Taiwan during 8 – 9 August 2009 on Google Earth. Over the

146   years, TOVAS has proven to be very popular with users for online accessing of TRMM

147   and other precipitation data products. TOVAS will continue to evolve to accommodate

148   the Global Precipitation Mission (GPM) data and the expected increase in multi-sensor

149   data product inter-comparisons.

150   3) *Other data services*. Users of TRMM products can benefit from several other

151   data services listed in Table 5. The TRMM read software developed at the GES DISC

152   can read in all TRMM standard products and write out user-selected parameter arrays and

153   other data in flat binary or ASCII files. The Orbit Viewer Tool for High-resolution

154   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.

171

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

178   precipitation and its anomaly around the world; (3) various tools and services in Section

179   3; (4) Crop Explorer of the U.S. Department of Agriculture's Foreign Agricultural

180   Service (USDA FAS); and (5) GES DISC Hurricane Portal that provides near-real-time

181   monitoring services and imagery archive for the Atlantic basin. Customized application

182   software can be developed to directly access data via ftp, GDS, and WMS. For example,

183   monthly total rainfall from 3B43 is provided to the NASA Earth Observations (NEO) via

184   WMS. To provide a simple and quick way to monitor global droughts and floods, we

185   routinely generate global and regional maps of rainfall accumulation, rainfall anomaly,

186   and normalized anomaly (anomaly/climatology), ranging from 3-hourly to 90 days. The

187   maps are updated daily. With the services described in Section 3, subsets can be produced

188   from several popular TRMM products as well as conversion from HDF to NetCDF and

189   ASCII formats. We have developed several value-added products to expedite TRMM

190   applications, such as two daily products derived from 3B42 and 3B42RT (the near-real-

191   time version of 3B42) and an accumulated rainfall product from 3B43. With TOVAS,

192   customized analysis, visualization and data can be obtained from the built-in functions,

193   such as latitude-longitude maps, time series, Hovemöller diagrams, etc. Further analysis

194   using other software can be done with customized data downloaded from TOVAS.

195   The USDA FAS, in collaboration with the GES DISC, is routinely using near-

196   real-time global satellite-derived precipitation data (i.e. 3B42RT) to monitor crop

197   condition around the world. This project is unique, being the first of its kind to utilize

198   satellite precipitation data in an operational manner. Satellite precipitation products are

199   produced by NASA via a semi-automated process and made publicly accessible from the

200   USDA FAS' Crop Explorer Web site. Monitoring precipitation for agriculturally

201   important areas around the world greatly assists the USDA FAS to quickly locate

202   regional weather events, as well as help improve crop production estimates. Figure 3 is an

203   example of the TRMM near-real-time product (3B42RT) in USDA Crop Explorer. Figure

204   3a contains a global map for selecting a region of interest and Fig. 3b is a sample of 10-

205   day accumulated rainfall derived from 3B42RT in southern Africa and its percent normal

206   (normalized anomaly).

207   In addition to applications at the GES DISC, TRMM data have been used in a

208   wide variety of activities around the globe. Applications reported by TRMM users range

209   from meteorology and hydrology to other areas as well, such as, a development of a

210   rainfall-based crop insurance product for developing countries, a study on environmental

211   causes of diabetes using rainfall as an effect on crop moisture and toxins, an early

212   warning system for mosquito-borne diseases, etc.

213

214   **5. Future Plans**

215   Future plans include new and enhanced data services to address user needs and

216   support applications. Meanwhile, the GES DISC is preparing for the GPM era. Scheduled

217   for launch in 2014, GPM consists of a core observatory which serves as a reference

218   standard to a constellation of research and operational microwave sensors to provide

219   uniformly calibrated precipitation measurements around the globe every 2-4 hours for

220   research and applications. As of this writing, three types of scientific data products will

221   be generated: near-real-time products, research products, and outreach data products. The

222   near-real-time and outreach products will be created within short time spans to meet the

223   particular needs of their end users. The research products are full data products of

224   research quality. With an increasing number of instruments and improved spatial and

225   temporal resolutions and coverage, it is expected that GPM data volume will greatly

226   exceed that of TRMM. Nonetheless, the GES DISC will continue to provide the existing

227   data services for GPM and in the meanwhile, to develop services for improving data

228   accessibility and discovery, as well as addressing new issues arising from the user

229   community.

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284   **TRMM Data Services URLs:**

285   Mirador: http://mirador.gsfc.nasa.gov/

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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/

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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

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307   Giovanni: giovanni.gsfc.nasa.gov

308   Current conditions:

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

315   **FIGURE CAPTIONS:**

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

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319   Figure 2. Examples of TRMM data services. a): A Google Earth screen shot of the near-

320   real-time 3-hourly precipitation product (3B42RT). The rainfall map was generated from

321   TOVAS, showing the record rains dumped by Typhoon Morakot on southern Taiwan

322   between 8-9 August 2009.   b): A 3-D plot of the 2A25 10 dBZ isosurface from the first

323   space-borne precipitation radar, showing an intensifying tropical cyclone, Giovanna, near

324   the east-northeast of Madagascar in Indian Ocean at 1200 UTC on 11 February 2012.

325

326   Figure 3. The TRMM near-real-time product (3B42RT) in USDA FAS Crop Explorer. a):

327   A global map for selecting a region of interest and b): a sample of 10-day accumulated

328   rainfall (left panel) in southern Africa and its percent normal (right).

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330

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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333
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

336   *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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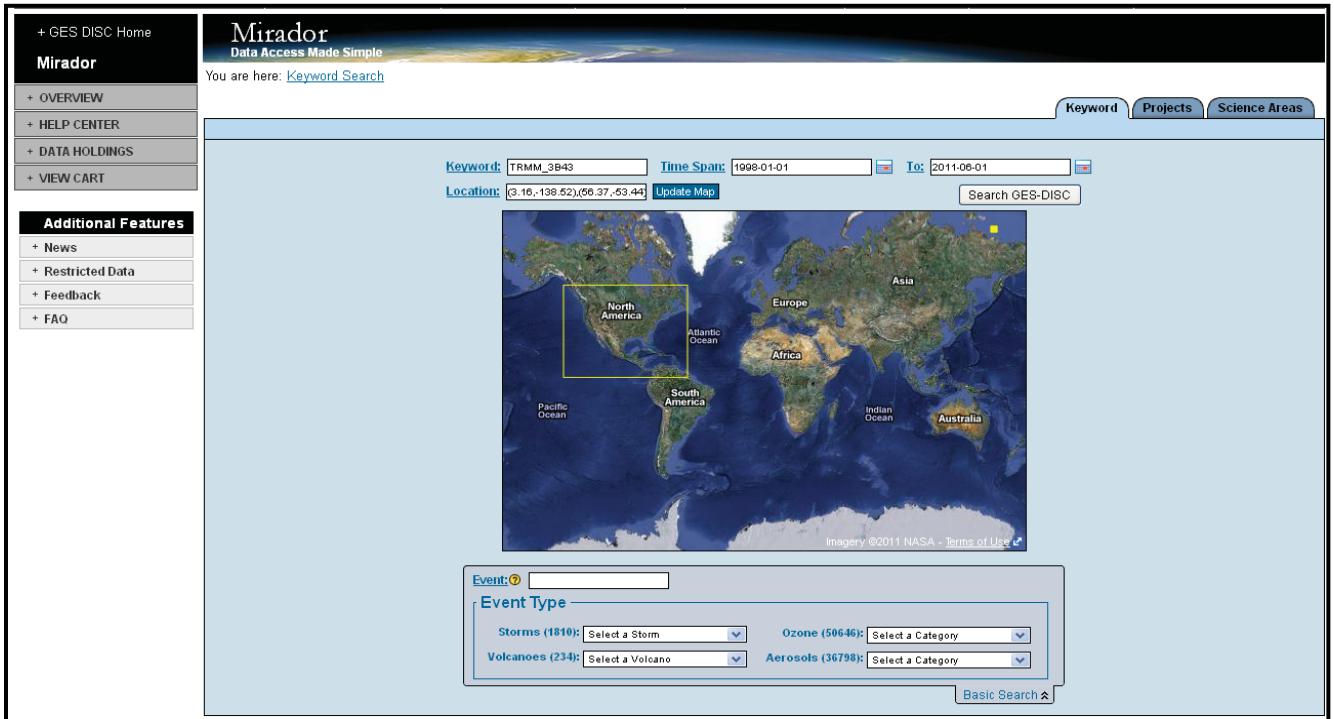
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350   Figure 1. Mirador homepage where users can search, access, and download TRMM data.
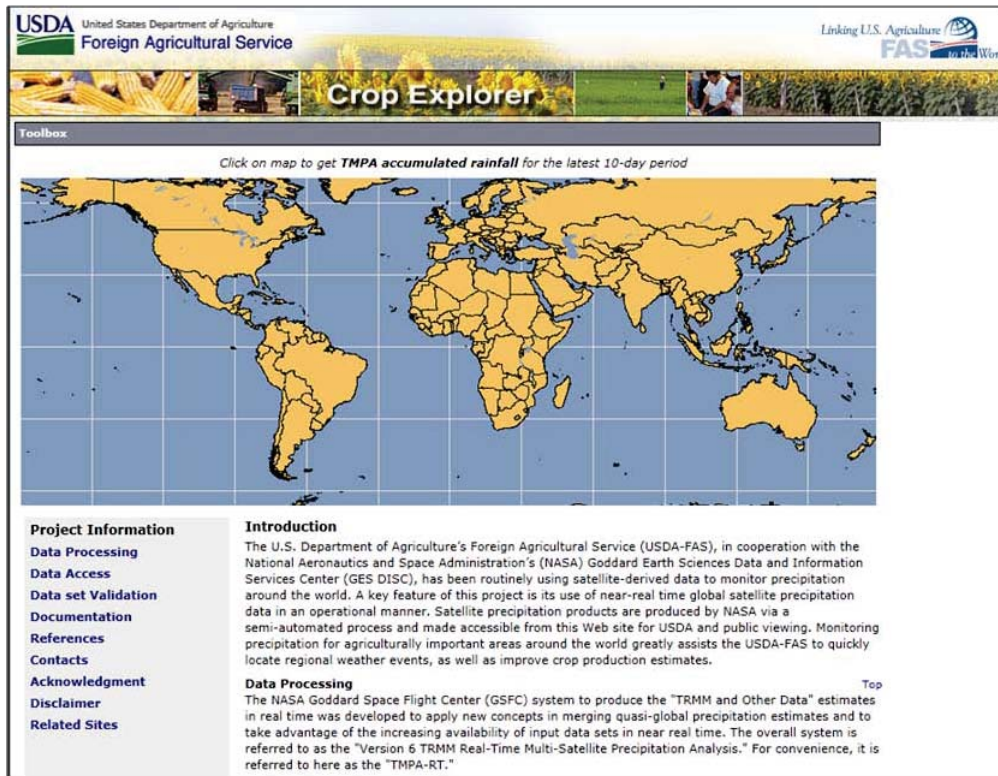351
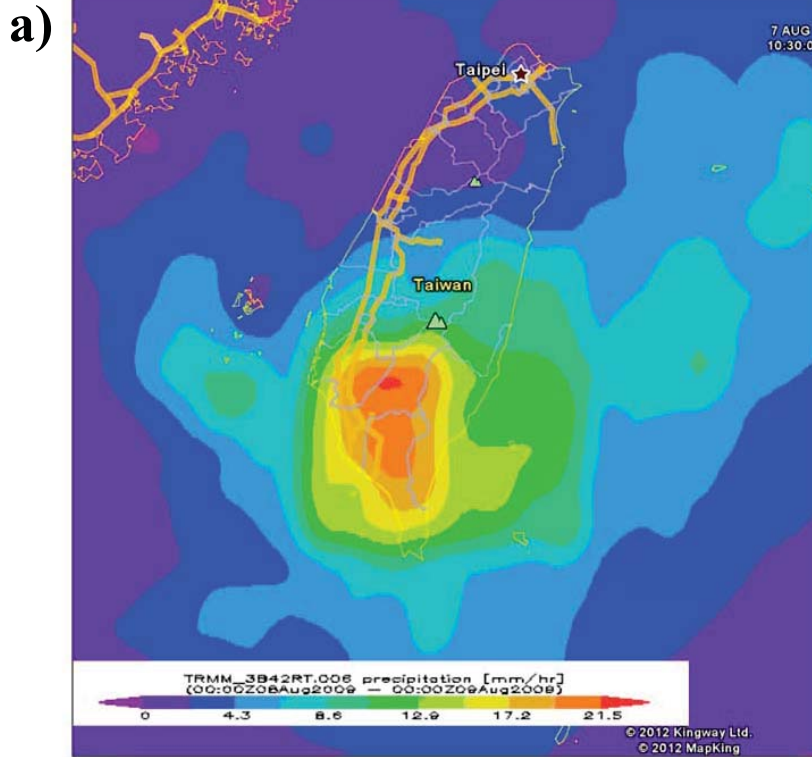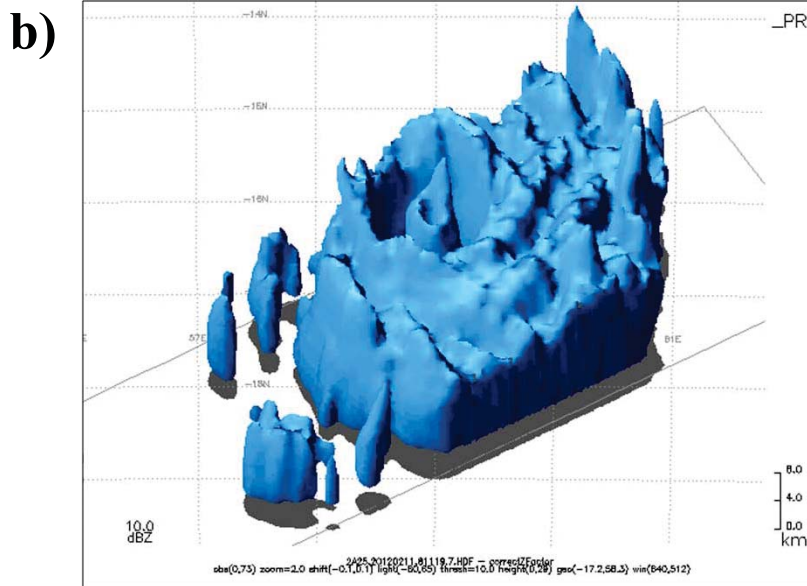
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356 Figure 2. Examples of TRMM data services. a): A Google Earth screen shot of the near-
357 real-time 3-hourly precipitation product (3B42RT). The rainfall map was generated from
358 TOVAS, showing the record rains dumped by Typhoon Morakot on southern 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
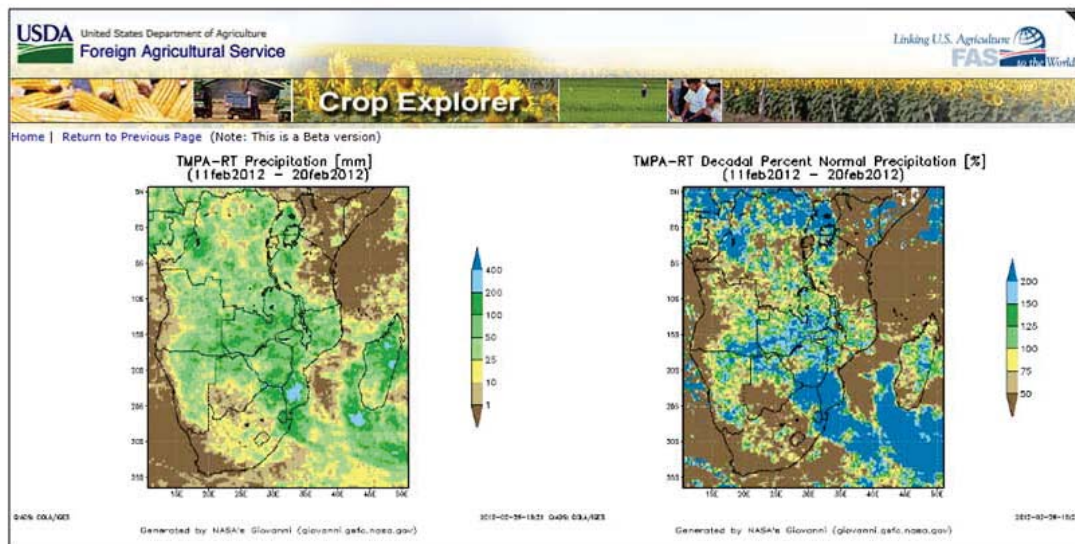
361   precipitation products. b): A 3-D plot of the 2A25 10 dBZ isosurface from the first space-
362   borne precipitation radar, showing an intensifying tropical cyclone, Giovanna, near the
363   east-northeast of Madagascar in Indian Ocean at 1200 UTC on 11 February 2012.
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a)

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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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