Overview of National Aeronautics and Space Agency Langley Atmospheric Radiation Measurement Project Cloud Products and Validation

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Introduction

To complement the wide array of instruments taking measurements from the surface at various Atmospheric Radiation Measurement (ARM) Program sites, the ARM program sponsors analysis of satellite data to provide estimates of top-of-atmosphere radiative fluxes and column-integrated cloud properties over large domains centered on each surface site. With validation from ground-based or aircraft borne instrumentation, satellite-derived datasets can be a valuable asset in climatic studies and complement surface-based measurements. National Aeronautic and Space Agency (NASA) Langley Research Center (LaRC) has provided Geostationary Operational Environmental Satellite (GOES) satellite-derived cloud and radiation datasets, spanning a period of several years, covering the central United States. More recently these retrievals have been expanded to cover a wider variety of locations and satellites. Retrievals covering the continental United States using GOES-10 and 12 have been initiated, as well as retrievals over Europe (Meteosat Second Generation), Asia (Feng-Yun-2; FY2C), the Pacific Ocean and Australia (Multi-functional Transport Satellite; MTSAT-1R). In addition, data from polar orbiting satellite, such as the National Oceanic and Atmospheric Administration (NOAA) series, Tropical Rainfall Measurement Mission, Aqua, and Terra are also analyzed.

This paper provides a summary and status of the products for various domains, summarizes the content of our online database, and describes web-based tools to access satellite imagery and cloud products. It also provides summaries and examples of validation studies. Particular attention will be focused on

measurements from the Marine Stratus Radiation Aerosol and Drizzle (MASRAD) Intensive Observation Period (IOP) to validate retrievals in marine areas.

Methodology

The GOES satellite-derived cloud and radiation datasets originally placed in the ARM Archive, covering various IOPs, and spanning a period of several years were derived using the Layered Bispectral Threshold Method (LBTM; Minnis and Smith 1998). LBTM is a 2-channel method that uses visible (VIS; 0.65 μm) and infrared (IR; 11 μm) channels to match observed radiances to theoretical calculations. Advances in the retrieval methodology have led to the development of the Visible Infrared Solar-Infrared Split Window Technique (VISST). VISST is a 4-channel model-matching method for plane parallel clouds, Minnis et al. (1995, 1998). It utilizes parameterization of theoretical radiance calculations for 7 water and 9 ice crystal size distributions, Minnis et al. (1998), to match observations to theoretical model calculations. Several additional inputs are required to facilitate satellite retrievals. Atmospheric profiles derived from Rapid Update Cycle, Aviation Model, or European Center for Medium range Weather Forecasting analyses are used for skin temperature, cloud height calculation, and humidity profiles. Surface type is based on the International Geosphere-Biosphere Program 10-minute resolution surface map, remapped to an albedo representation. Clear-sky reflectance, and ice and snow masks developed for the Clouds and the Earth's Radiant Energy System (CERES) program are used for additional surface characterization. Narrowband-to-broadband flux conversion functions developed from correlations of coincident CERES broadband and GOES narrowband fluxes are used to compute broadband shortwave and longwave fluxes.

Data and Domains

Cloud and radiation products are derived using VISST from GOES, MTSAT-1R, FY2C, NOAA Advanced Very High Resolution Radiometer (AVHRR), and Terra and Aqua Moderate Resolution Imaging Spectroradiometer (MODIS) covering the Southern Great Plains (SGP), Tropical Western Pacific (TWP), and North Slope of Alaska (NSA) ARM sites along with the ARM mobile facility deployments at Pt. Reyes, California and Niamey, Niger. The domain definition, temporal coverage and types of product datasets available for each domain are listed in Table 1.

Table 1. ARM domain and available products from NASA LaRC.

DOMAIN	COVERAGE	PRODUCTS VISST	PRODUCTS LBTM	GIF IMAGERY
SGP: (Half Hourly) GOES EAST & WEST (4km):	42N-32N, 105W – 91W	Jan, 1998 – Present	Jan, 1996 – Aug, 2003	Jan, 1996 – Present
NSA: (available overpasses) AVHRR, MODIS (1km)	74N-64N, 165W-140W	Sep, Oct 2004, MPACE IOP		Jan, 1996 – Present
TWP: (Hourly) GMS-5, GOES-9, MTSAT-1R	10N – 20S, 120E- 180E	May, 2003 - Present	Jun, 1999 – Apr, 2003	Jan, 1998 – Present
MANUS: (Hourly) GOES-9, MTSAT-1R	3N-12S, 135E-160E	May, 2003 - Present		Jan, 2005 - Present
NAURU: (Hourly) GOES-9, MTSAT-1R	3N-17S, 155E-180E	May, 2003 - Present		Jan, 2005 - Present
DARWIN: (Hourly) GOES-9, MTSAT-1R, FY2C	5S-17S, 125E-136E	May, 2003 - Present TWPICE IOP		Jan, 2005 - Present
Pt. REYES: (Half Hourly) GOES-10 (4 km)	50N-25N, 135W-115W	Mar, 2005 - Sep, 2005		Mar, 2005 - Present
NIAMEY: (Hourly) METEOSAT (3 km)	25N-0N, 20W-15E	Feb, 2005- Present		Feb, 2005- Present

Satellite Retrieved Products

Pixel Level

VISST-derived pixel-level products, retrieved at instrument pixel resolution provide cloud microphysical and radiation properties derived from the pixel radiances. Each cloudy pixel is analyzed and assigned a phase (water, super-cooled water, or ice). The VISST pixel-level products are summarized in Table 2. In contrast to the VISST, which explicitly determines phase, particle size, and optical depth, the LBTM assumed a particle size and estimated phase based on the temperature alone. No pixel-level LBTM data are available and nighttime cloud amounts and heights were not very reliable (Khaiyer et al. 2002) because only the IR channel is used. The VISST uses several infrared channels to detect clouds at night (e.g., Trepte et al. 2005). For researchers interested in matching satellite data to surface or aircraft measurements, the high spatial resolution VISST results would be the preferred product.

Table 2. VISST pixel-level cloud products.	
0.65 µm Reflectance	Skin Temperature
1.6 µm Reflectance	Optical Depth
3.7 µm Temperature	Effective Radius/Diameter
6.7 µm Temperature	Liquid/Ice Water Path
10.8 µm Temperature	Cloud Effective Temperature
12 or 13.3 µm Temperature	Cloud Top Pressure
Broadband Albedo	Cloud Effective Pressure
Broadband Infrared	Cloud Bottom Pressure
Infrared Emittance	Cloud Top Height
Cloud Mask	Cloud Effective Height
Cloud Phase	Cloud Bottom Height
Pixel Latitude	Pixel Longitude

Gridded Products

In order to provide continuity for past cloud product users, the data stream includes gridded averages of VISST products that mimic the 0.5° x 0.5° LBTM products currently in the XDC for the SGP domain. These gridded files include the LBTM-like products, as well as the additional cloud and radiation products that are obtainable from VISST. Gridded cloud products are calculated either by cloud height (low, mid, high, total) or by phase (water, ice, super-cooled). LBTM datasets currently in the XDC should remain, but users are encouraged to use VISST datasets when they are available. The VISST gridded product for March 2000 covering the SGP domain has recently been added to the ARM archive with data from other months and domains to follow

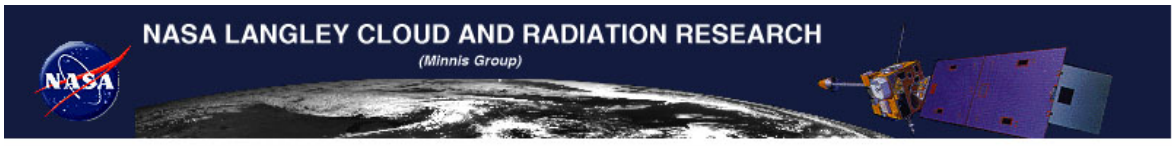
Surface-Site and IOP Products

The surface site and aircraft products consist of the means of pixel-derived quantities whose center locations fall within a 10 or 20-km radius circle of a particular surface site or the weighted mean of the 4 nearest pixels to an aircraft flight track (8 pixels for standard deviation). These data are useful for quick comparisons of satellite-derived quantities with surface or aircraft measurements. During IOP's, cloud products are generally available at higher temporal resolution (every 15 minutes depending on availability) from the geostationary satellites (e.g. GOES, geostationary meteorological satellite (GMS), MTSAT-1R) and from available overpasses from sun synchronous satellite (e.g. AVHRR, MODIS). Data are available for many ARM IOPs and from IOPs sponsored by other programs

Data Access and Web Tools

LaRC maintains an online database and website (http://www-pm.larc.nasa.gov) to access historical and near real-time VISST results for a variety of regions and IOPs. The database includes a multi-year time series of site-specific averages including more than 100 cloud and radiative parameters, pixel-level gif images of retrieved properties, and binary pixel-level retrievals for selected regions. This site has web-

based data browsers and tools to access satellite imagery and derived cloud products, see Figure 1. The user has the option to select the domain, single or multi-panel images, or time series animations of the products. Additional tools allow the user to retrieve data or plot cloud products over the ARM surface sites or along IOP aircraft flight tracks. Examples of these data extraction tools are shown in Figure 2. Using these tools the user can select up to four cloud products for plotting with the additional option of selecting either a 10 or 20 km radius for ground sites. The plots are generated in both GIF and postscript format with a link to the data in ASCII format. The user can download the ASCII data and investigate it with their application of choice. Additional tools are available to display aircraft flight tracks overlaid on coincident satellite or VISST products. Dedicated web pages have been developed for each IOP and provide links to these datasets and tools.



User Warning, Please read !

Site Map:

Minnis Group Homepage

Viewers/Tools:

NOAA AVHRR Viewer
MODIS Viewer
MID-Atlantic NEXRAD
ARM-SGP NEXRAD
Angles Viewer
Plot RUC Sounding
Satellite Overpass Predictor

Field Experiments:

TWP-ICE 2006
MASRAD Pt. Reyes
MIDCIX 2004
MPACE 2004
INTEX-NA
ATReC 2003
THORPEX
CRYSTAL
ARM SGP
CLAMS

Satellite Imagery And Cloud Products Page

Real-time and Historical Cloud Product Loops: The cloud products are derived with VISST/SIST algorithm. Select a domain from the table below to access the real-time (blue cells) and archived products. Java applet (JV applet) may not work on some Mac browsers, then use non-java version.

GOES WEST	GOES EAST	GOES-09	MTSAT-1R	NOAA 15/16/17 and MSG
West CONUS non-java JV applet	East CONUS non-java JV applet	NAURU JV applet	NAURU JV applet	ARM-NSA JV applet
MERGED CONUS non-java JV applet		MANUS JV Applet	MANUS JV Applet	EUROPE JV Applet
ARM-SGP JV Applet	ARM-SGP JV Applet	DARWIN JV applet	DARWIN JV applet	WESTERN EURO JV Applet
ARM-NSA JV applet	COVE JV applet	TWP JV Applet	TWP JV Applet	ARM-NIAMEY JV Applet
Monterey JV applet	ATReC/AIRS JV applet			ATReC/AIRS
	CRYSTAL JV applet			NSA MPACE
	OHIO JV applet			TWP

Real-time and Historical Satellite Imagery Loops: The links from the table below provides access to the real-time (blue cells) and historical loops from several GEO satellites.

Mid-West (SGP) JV applet	North East JV applet	Mid-Atlantic JV applet	South East JV applet	CONUS JV applet
East Pacific G-12 JV applet	Full Disk G-10 JV applet	TWPICE MTSAT-1R JV applet	TWPICE FY2C JV applet	TWPICE MTSAT-1R & FY2C JV applet
Pacific/West JV applet	Florida JV applet	TWP GOES-9 JV applet	GMS-5 TWP	PACS EPIC
ATReC GOES-12 JV applet	AVHRR CONUS	MODIS CONUS	AVHRR NSA	MASRAD JV applet

Check the Notes on using java applets in browsers from Tom Whittaker for any difficulty of displaying the images on your browser.

Figure 1. NASA LaRC Cloud Products Website.

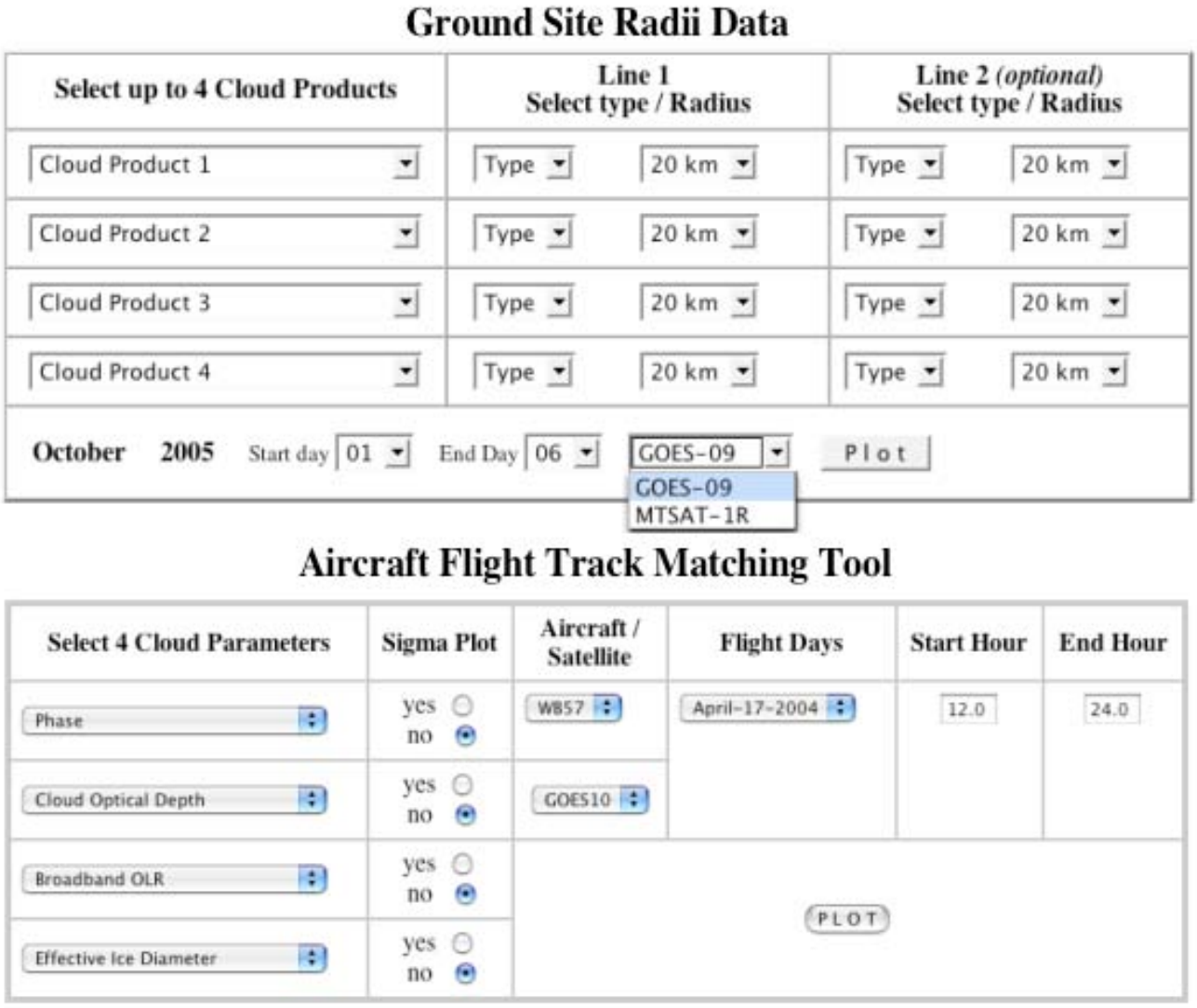


Figure 2. Ground site and Aircraft flight track matched data extraction tools.

Comparison of MASRAD Satellite and Surface Derived Cloud Properties

LaRC analyzed GOES-10 multi-spectral images for March through September 2005 covering the domain bounded by 25°-50°N, 115°-135°W in support of the MASRAD field mission. The satellite images and VISST derived cloud products are available from our website. The deployment of the ARM Mobile Facility to Pt. Reyes presented an opportunity to observe marine area clouds with surface based instruments. The climate is this area is heavily influenced by a semi-persistent stratus cloud deck and subsequent on-shore flow.

The pseudo-color image from September 1, 2005, shown in Figure 3, illustrates the extent of the off shore stratus deck. This image was generated using GOES-10 observed visible, infrared, and solar-

infrared radiances to represent red, green, and blue. These images are useful for identifying water clouds (red to pink), ice clouds (light blue to white), and areas of clear land or ocean. The clouds observed in this scene are primarily water clouds with the exception of the contrails that are visible in the upper left quadrant of the image. The amount of cloud coverage for this area is diurnally influenced. As shown in Figure 4, the VISST derived cloud fraction over Pt. Reyes peaks near 7:30 a.m. local time, which agrees with local observations. To access the accuracy of the VISST cloud base height retrievals, comparisons were done with ARM Mobile Facility ceilometer derived cloud base heights. This comparison was limited to VISST determined single-phase water clouds. As seen in Figure 5, the agreement between the VISST and ceilometer derived mean cloud base height is very good. The comparison of hourly observations shows that the agreement is generally good with VISST overestimating, as expected. The comparison between VISST and Microwave Radiometer (MWR) derived liquid water path were facilitated by linear regression, as shown in Figure 6. The regression shows that they compare fairly well with a correlation coefficient of 0.67 and a bias of 27.7 g/m^2. The bias is due to the overestimation of the liquid water path in comparison to the MWR.

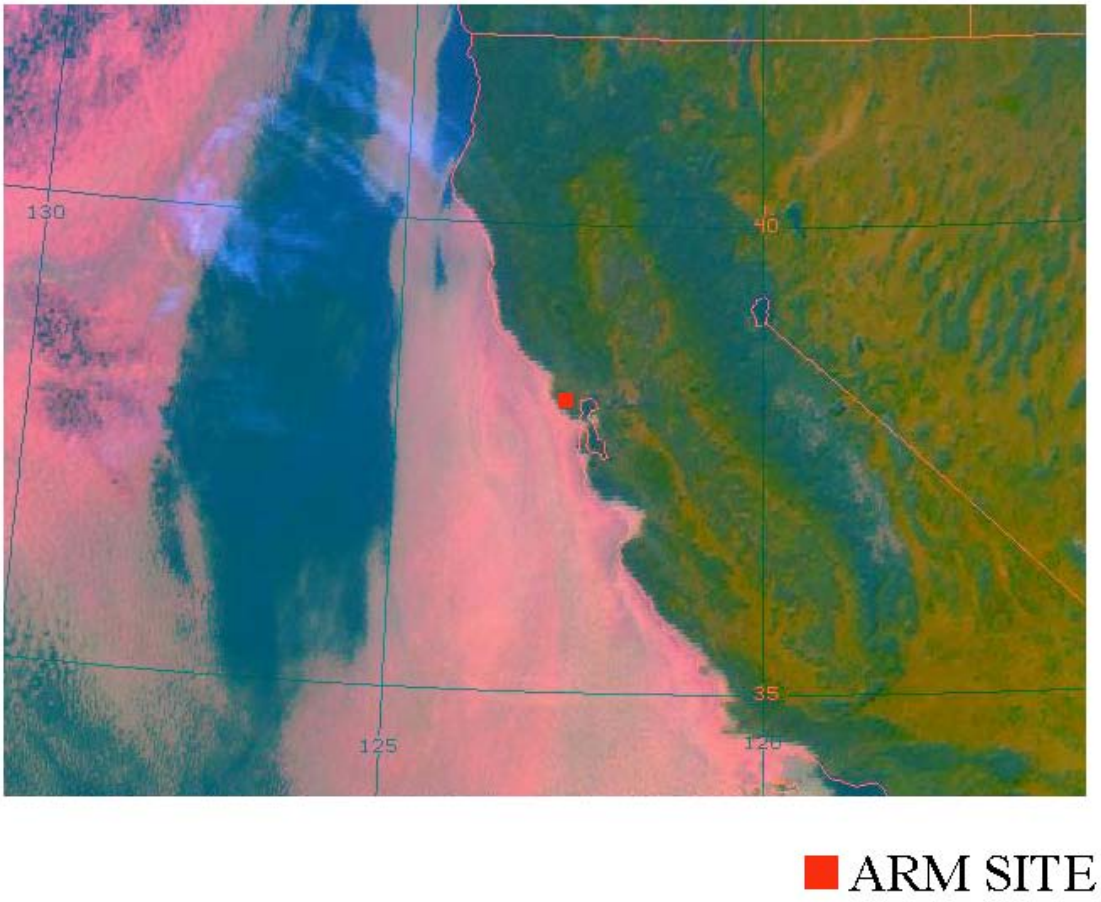


Figure 3. September 1, 2005 GOES-10 pseudo-color image.

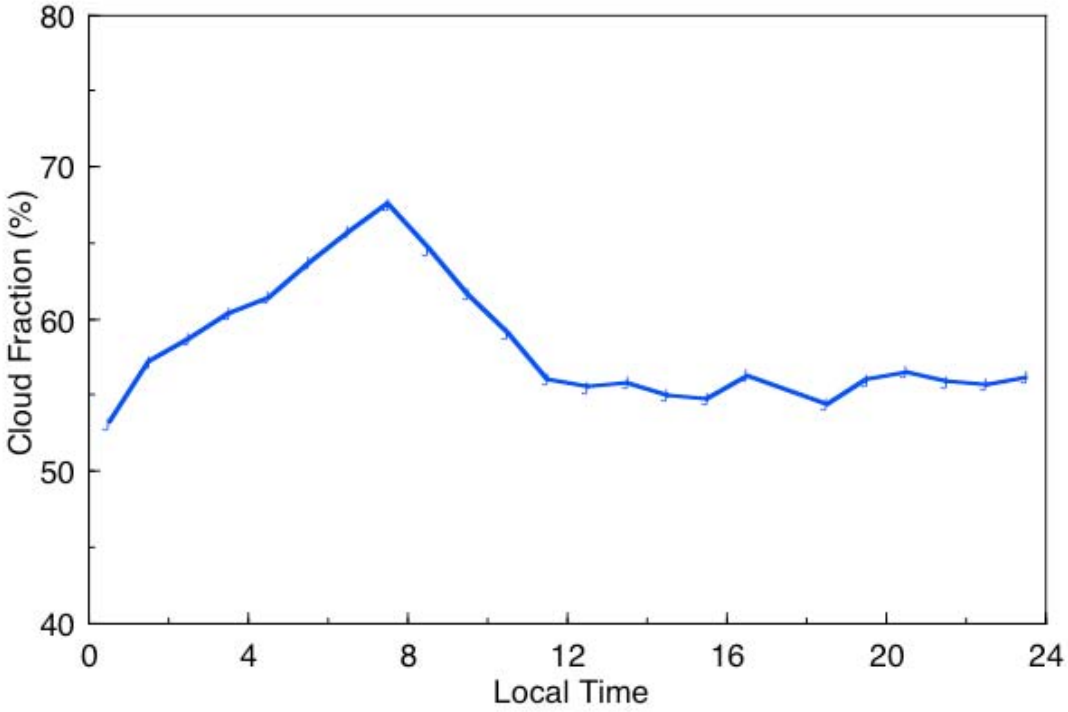


Figure 4. Pt. Reyes cloud cover diurnal cycle.

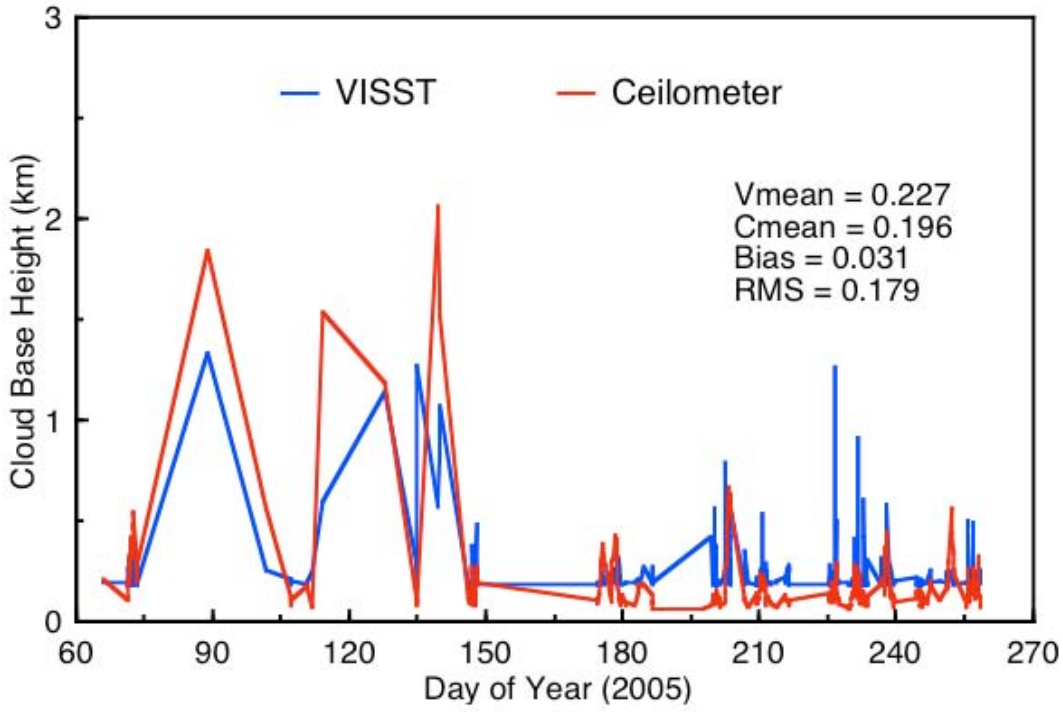


Figure 5. Comparison of VISST and ceilometer cloud base heights.

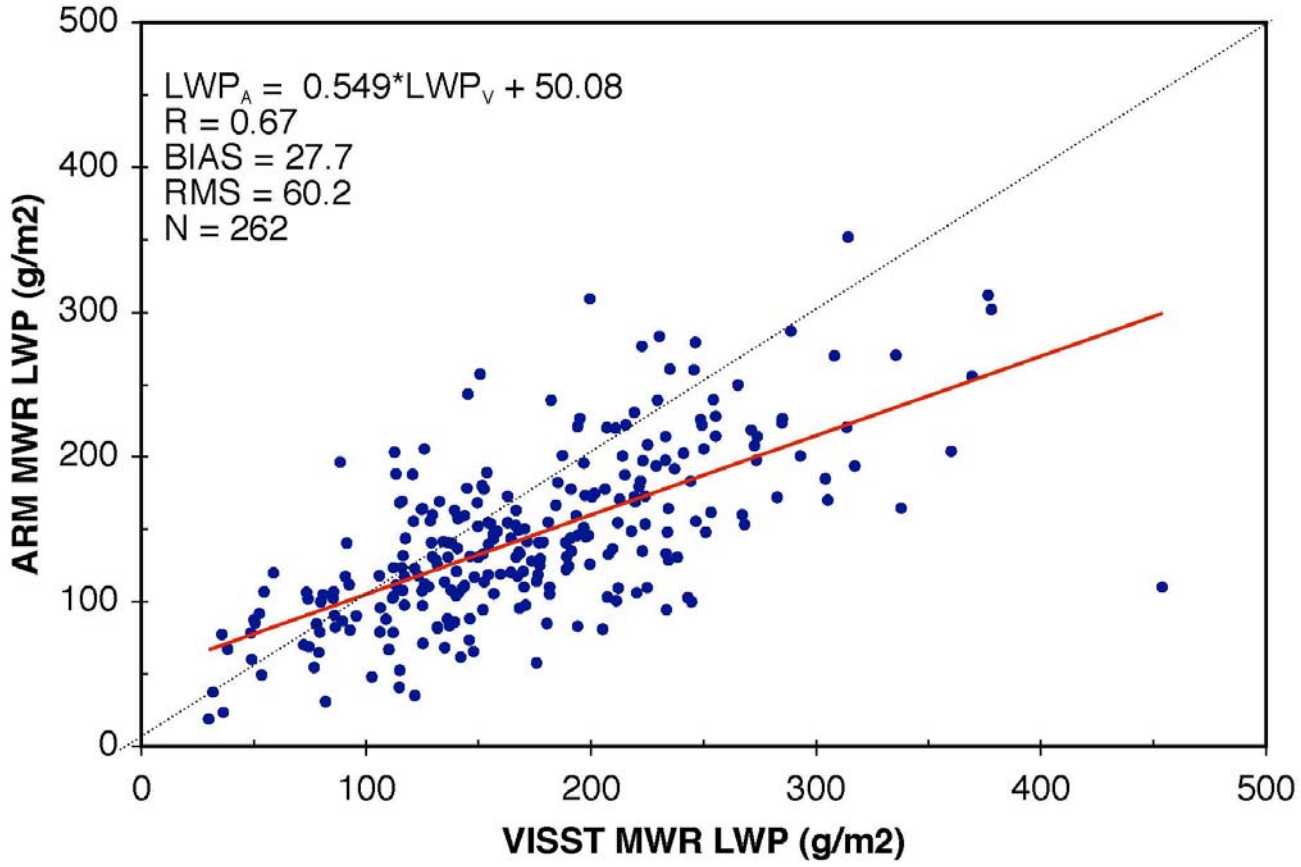


Figure 6. Comparison of VISST and MWR derived liquid water path.

Summary

Cloud and radiation products derived from GOES, GMS, AVHRR, MODIS, FY-2C, and MTSAT-1R satellite have been developed for ARM over several domains and IOP campaigns such as Tropical Warm Pool International Cloud Experiment, Mixed-Phase Arctic Cloud Experiment, & MASRAD. These products are available from the Langley website and the ARM data center. Measurements from the ARM surface sites provide valuable datasets for improving satellite algorithms. As new algorithm improvements are implemented (i.e. multi-layer detection, calibration, etc.), products will be reprocessed and updated. Several tools have been developed to provide easy access to these data. New tools for enhanced accessibility are under development and will be placed online when they become available.

Acknowledgments

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