Remote Sensing of Precipitation
From Space

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☐ References:


Objectives

- Introduce you and give examples of the three prime instrument types for measuring precipitation from space
- Give you an overview of the Tropical Rainfall Measuring Mission (TRMM) and the Global Precipitation Measurement (GPM) mission
- Provide you some examples of how measurements from space can be used
- Provide some simple, high level, scenarios for how remote sensed precipitation data can be used by planners, managers, etc.
Topics for Presentation

- Introduction to how one measures precipitation from Space
- Illustration of how a radiometer can be used for measurement
- The TRMM Precipitation Radar (PR) designed by CRL (NICT), project managed by NASDA (JAXA), and built by Toshiba
- Examples of the three prime instrument types for precipitation measurement
- The joint U.S. ± Japan Tropical Rainfall Measuring Mission (TRMM)
- The U.S.-Japan led international Global Precipitation Measurement (GPM) mission
- Uses for precipitation data for officials involved with environmental monitoring and protection
Instruments Useful for Precipitation Measurement from Space

Visible and Infrared instruments
- These use visible channels to see the target of interest
- Use various infrared (essentially "heat") to see the target of interest

Microwave Radiometers
- Basically receivers of various frequencies at particular signal polarization that receive the emissions from objects
- All matter radiates electromagnetic energy
- A material may absorb or reflect energy incident to it
- A key to precipitation retrievals is to have a good blackbody
  - Blackbody an ideal material that absorbs all incident radiation, reflecting none
  - This is used as a reference against which radiation spectra of real bodies at the same physical temperature are compared
- Radiometry is a measurement of this electromagnetic radiation

Radar
- Active instrument that transmits particularly frequencies
- Receives the returned (reflected) signal and uses attenuation from the scattering to help establish what was viewed
- Frequency chosen and power used help establish radar sensitivity
Radar Transmission

TRMM Radar

Transmits 616 watts
400 km

Light precipitation
5 km across
250 meter high
TRMM Radar

Received Power

$8 \cdot 10^{-14}$ watts
Precipitation Sources of Scattering of Radar Signal

 Courtesy of JAXA
How Radiometer works

Absorbed and Emitted by O\textsubscript{2}, H\textsubscript{2}O

Absorbed and Emitted

Reflected

Reflected

\(\epsilon \sim 0.5\)

\(\epsilon \sim 0.9\)

Transmitted

Emitted

Scattered by Particles and Absorbed

Emitting

Anvil Ice

Hail Grable

Large Drops

Small Drops

Absorbed

Reflecting

Ocean

Land
I will show some examples of how each of these three instruments see precipitation and associated parameters.

Each instrument has a particular view and adds some information.

I will use three of the instrument from TRMM which mission I will examine after I show the instrument examples.

This is only a very brief overview of remote sensing of precipitation from space and the examples while useful are certainly not meant to be complete.
TRMM Satellite Overflight
Supertyphoon Melor (T0918)

2 October 2009 at 9 AM local time (1 Oct 2312 UT)

♦ One day earlier, Typhoon Melor completed a period of explosive intensification from category 1 to category 4 winds.

♦ One-minute sustained winds increased from 65 to 120 knots (121 to 223 km h⁻¹).

♦ Intensification of just 30 knots (56 km h⁻¹) in a day would have qualified as rapid intensification.

♦ One week later, Typhoon Melor struck Japan on 8 October 2009 as a category 1 typhoon.
True Color Visible Image of Melor from MODIS

Supertyphoon Melor (T0918), Category 5 with 135 kt (250 km h⁻¹) sustained winds. Observed by MODIS on NASA TERRA, 5 October 2009 1500 UT.
Visible brightness of cloud tops (TRMM VIRS).

Gravity waves

Direction of the morning sun

Convective Cell

North
West + East
South

Circular cloud top formed by air gushing out of the top of the typhoon's eyewall

(14.21°Lat, 151.24°Lon) ±2.0°
Cloud Height from VIRS

Cloud top height from infrared (TRMM VIRS)

Direction of surface wind rotation (cyclonic = counterclockwise)

2 High-altitude outflow plumes rising like steam from 2 steam locomotives' smokestacks

Convective Cell

Temp. (K) | Height (km)
---|---
265 | 6
246 | 9
228 | 11.5
209 | 14.5
190 | 17

(14.21°Lat, 151.24°Lon) ±2.0°

100 km
Column Ice Mass from TMI 89 GHz
>25 mm h⁻¹ Surf Rain Rate (TRMM PR)
Surface Rain Rate from TMI

> 25 mm h\(^{-1}\) Surf Rain Rate (TRMM PR)

TMI’s swath extends beyond PR swath (shown in color), but TMI fails to detect small-scale heavy precipitation (> 25 mm h\(^{-1}\)) in eyewall (shown in white).
Surface Rainfall Rate
(TRMM Precip Radar)
Surface Rainfall Rate
(TRMM Precip Radar)

- Outer eyewall
- Inner eyewall
- Eye

Scale: 50 km
Surface Rainfall Rate
(TRMM Precip. Radar)

A ring of four hot towers in the outer eyewall (green and blue)

Updraft locations based on 10-km High Ice Precipitation (TRMM Precip. Radar)
TRMM

- A joint U.S. ± Japanese mission to measure precipitation in the tropical area 35N ± 35S
- Launched from Tanegashima in November of 1997
- **U.S. provided**
  - Spacecraft
  - Command and control of satellite and instruments
  - Rain related Instruments: TRMM Microwave Imager, Visible/Infrared Scanner (VIRS), Lighting Imaging Scanner (LIS)
- **Japan provided**
  - The first precipitation radar (PR) ever in space (designed by CRL)
  - HIIA launch vehicle
  - Launch services
- **TRMM is currently in the 13th year of a nominal 3 year mission**
- Perhaps the best example of U.S.-Japan remote sensing cooperation
- Perhaps the best example of project management and science
TRMM Being Built
TRMM Mission Overview and Launch

Play O_Launch_new
TRMM Orbit from Space

Play: O_Orbit_new
TRMM Instrument On-orbit Scanning

Height 403km
16 times per day
every 92.5 min

247 km

2.4 km

5.1 km

(85.5 GHz)

9 km

978 km

933 km

540 m

PR, VIRS, TM, LIS
GPM Mission Concept

Unify and advance precipitation measurements from space to provide next-generation global precipitation products within a consistent framework

Low Inclination Observatory (40°)
- GMI (10-183 GHz)
  (NASA & Partner, 2014)
- Enhanced capability for near-realtime monitoring of hurricanes & midlatitude storms
- Improved estimation of rain accumulation

GPM Core Observatory (65°)
- DPR (Ku-Ka band)
- GMI (10-183 GHz)
  (NASA-JAXA, LRD 2013)
- Precipitation physics observatory
- Transfer standard for inter-satellite calibration of constellation sensors

Partner Satellites:
- GCOM-W1
- DMSP F-18, F-19
- Megha-Tropiques
- MetOp, NOAA-19
- NPP, JPSS (over land)

Coverage & Sampling
- 1-2 hr revisit time over land
- < 3 hr mean revisit time over 91% of globe

Key Advancement
- Using an advanced radar/radiometer measurement system to improve constellation sensor retrievals
Validating Precipitation Retrievals

- Precipitation retrievals from space has many uncertainties
- Validating such retrievals with ground data is an important aspect of any mission
- Ground radars and raingauges are an important part of the validation process
- In GPM a major goal is to narrow the differences between precipitation measurements from space and ground
- To focus on certain aspects of precipitation (e.g. cloud microphysics, snow, etc) GPM has and will have a number of field campaigns
- So, GPM while a space mission is investing a large amount of many in ground validation efforts
Physical Validation: Field Campaigns (2010-2012)

- **Pre-CHUVA**: GPM-Brazil & NASA field campaign targeting warm rain retrieval over land, Alcântara Launching Center, 3-24 March 2010.

- **Light Precipitation Validation Experiment (LPVEx)**: CloudSat-GPM light rain in shallow melting layer situations, Helsinki Testbed & Gulf of Finland, Sept-Oct 2010.

- **Mid-Latitude Continental Convective Clouds Experiment (MC3E)**: NASA-DOE field campaign at DOE-ASR Central Facility in Oklahoma, Apr-May 2011

- **High-Latitude Cold-Season Snowfall Campaign**: GPM-Environment Canada campaign on snowfall retrieval, Ontario, Canada, Jan-Feb 2012
Direct Statistical Validation

Identify systematic regional or regime issues

Geometrically matches ground and spaceborne radar volumes (TRMM PR used as pre-launch proxy for GPM DPR)

Horizontal/vertical cross-section comparisons

Volume statistics on radar reflectivity

Surface rain-rate comparison

Radar reflectivity comparison

± Systematic regime variability in reflectivity between space and ground radars can be detected with existing operational networks

± Stable PR supports ground radar calibration

± Scalable and Platform-Adaptive Matching Software available as open source

(In use in Korea, Taiwan, Australia, & Europe)

Surface rain-rate comparison

± Compare satellite rain products with NOAA National Mosaic & QPE (NMQ) data at 0.01° resolution updated every 5 min.

± Integrate satellite rainfall data into NMQ

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Japan University Presentation 2010

June, 2010
Identify space-time scales at which satellite precipitation data are useful to water budget studies and hydrological applications

- Characterization of uncertainties in satellite and ground-based (radar, dense gauge networks) rainfall estimates over a broad range of space/time scales
- Characterization of uncertainties in hydrologic models and understanding propagation of input uncertainties into model forecasts
- Assessing performance of satellite rainfall products in hydrologic applications over a range of space-time scales
- Using data from synergistic missions (e.g. SMOS, SMAP, GRACE) to refine hydrologic model parameters and improve predictions driven by GPM input data

Joint field campaign with NOAA HMT-SE under planning for 2013
International Participation in GPM GV

(Pre-launch algorithm development and post-launch product evaluation)

Active Collaborations
- Argentina (U. Buenos Aires)
- Australia (BOM)
- Brazil (INPE)
- Canada (EC)
- Ethiopia (AAU)
- Finland (FMI)
- France (CNRS)
- Germany (U. Bonn)
- Israel (Hebrew U. Jerusalem)
- Italy (CNR-ISAC)
- Italy (Sapienza U. Rome)
- South Korea (KMA)
- Spain (UCLM)
- United Kingdom (U. Birmingham)

Projects under Development
- Germany (MPI)
- Spain (Barcelona)
- India (ISRO)
- Taiwan
Many scientists are directly involved with the issues of developing precipitation retrievals both from space and ground.

Precipitation data is an important input source for many other:
- Hydrologists
- Environmentals
- City planners
- Disaster monitors/planners

Following images provide some examples of how precipitation data is used rather than how retrievals are made.
Tornadic Thunderstorms-1 May 2010
(PR/VIRS)
Hurricane Watching from Space
Multiple Overflights of Hurricane Isabel

- Hurricane Isabel (2003) 8 to 16 September 2003
- The TRMM Precipitation Radar observed the eyewall of Hurricane Isabel six times as it developed over the Atlantic Ocean.
- This is a high number of overflights considering that the typical TRMM radar revisit time in the tropics is 3 days.
- Wind intensity varied from category 2 to 5.
- The TRMM radar permits the vertical and horizontal structure of the hurricane to be studied.
Vertical Information on Isabel

TRMM Precipitation Radar
Along-track vertical cross section of precipitation rate

Category 2
Category 4
Category 4
Category 5
Category 4
Category 3

Decay
Intensification

40 km

Eye
Eyewall
Rain Bands
09 March 1998

The TRMM satellite observes the 3D structure of this squall line traveling east over Florida.

TRMM data products provide different information on time scales of a year, a day, or instantaneously.

This squall line produced millions of dollars of damage from large hail, tornados, flooding, and strong winds.

Estimating the surface precipitation of such an intense system is difficult because ground clutter affects the radar and horizontal emission variability affects the passive microwave instrument.

But such information vital for disaster planners, government, etc.
TMI Surface Rain Rate ±Mar 9, 1998
Surface Rain Rate:

- 2 inch (50 mm)
- 1 inch (25 mm)
- 0.5 inch (13 mm)
- 0.1 inch (2.5 mm)

Intense convective cell producing 5 cm of rain per hour.

The Precipitation Radar has 5 km resolution.
Height of Heavy Precipitation

feet  km
39k  12
29k  9
10k  3

40dBZ height

Lightning Flash
GIS packages are an important tool for planners, monitors, and scientists.

It is likely that some time during your careers that you will be using such tools.

They allow the layering of different types of data often on spatial grids.

The Precipitation Processing System has been producing TRMM data (and will produce GPM data) in GIS compatible formats.

- Used by disaster monitoring centers
- Used by UN global change researchers and monitors

Next example shows how GIS can be used in a monitoring role.
Hurricane Monitoring with GIS and Precipitation Information

Hurricane Jeanne making landfall in Florida, USA

Sept. 26, 2004

TMI surface rainfall rate (color)

Coastline, Highways, and Cities
GIS and Precipitation

Hurricane Jeanne making landfall in Florida, USA

Sept. 26, 2004

TMI surface rainfall rate (transparent color)

GlobalMapper TerraServer (grayscale)
Flood Potential Global Map 18 May 2010 - TRMM
Flood Potential East Asia-18 May 2010
MODIS Overflight of Iceland Volcano Eruption April 16-17, 2009

The Eyja volcano erupted on 20 March 2009. It began erupting again on 14 April 2009 and has continued to do so through late May.

Commercial aircraft did not fly over Europe from 14-20 April 2009, due to volcanic ash.

NASA's MODIS instrument on the AQUA and TERRA spacecrafts observes the visible flow of ash.

MODIS can also detect invisible amounts of smaller aerosols generated from the ash.

Met offices provide wind speed and wind direction information often also from satellites

Information needed both for safety and environmental impact

Because of aerosols volcanoes have impact on both general weather and precipitation (particles often cause raindrops not to coalesce)
MODIS-Volcano Eruption

Eyja Volcano, Iceland
MODIS 17 April 2010
Some possible scenarios for people who have jobs in environmental and/or disaster agencies
Heavy rain in forested areas

Tennessee Flooding
26 Apr – 3 May 2010
Suppose you had just received the previous satellite based precipitation image

Suppose that the area that you were monitoring and had to make recommendations for evacuation, HPHUJHQF\ FRYHUDJH\ HWF\ ORRNHG\ OLNH\ WK on the next page

Action: What would you recommend, evacuation??

Question: What are the key issues here based on the precipitation and terrain
Suppose you had just received the previous satellite-based precipitation image.

Suppose that the area that you were monitoring and had to make recommendations for evacuation, HPHUJHQF\ FRYHUDJH\ HWF\ ORRNHG\ OLNH\ WK on the next page.

Action: What would you recommend, evacuation??

Question: What are the key issues here based on the precipitation and terrain?
Deforested Local Area-Scene
Actual Situation from the images

- 2-3 May 2010, there was heavy rain and flooding in Tennessee.
  - In some places 490 mm of rain was recorded.
  - Flooding killed 20 in Tennessee. [Wikipedia]

- 18-25 May 2009, there was heavy rain and flooding over Haiti.
  - TRMM satellite estimated ≥500 mm of rain during this period.
  - Floods and landslides killed ~2000 people in Haiti. [Wikipedia, Dartmouth]