SUMMER SCHOOL ALPBACH 2010

Remote Sensing of Clouds and Precipitation from Space

Daniele Casella

Istituto di Scienze dell'Atmosfera e del Clima (ISAC)

Consiglio Nazionale delle Ricerche CNR, Roma, Italy

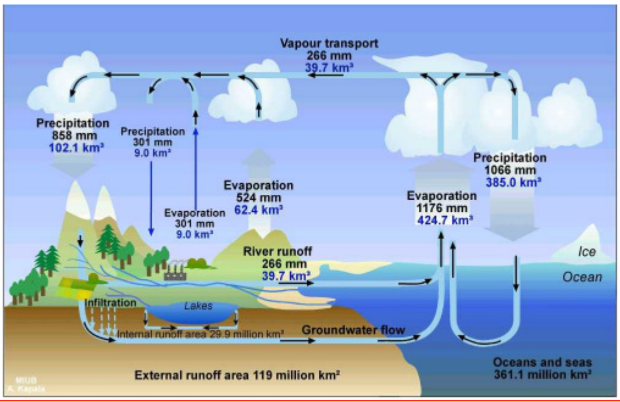
daniele.casella@artov.isac.cnr.it

Outline

- **Scientific Justification – Precipitation & Cloud Dynamics**
- **Present Space Missions**
  - **GEO**
    - Meteosat Second Generation (MSG)
  - **LEO**
    - Tropical Rainfall Measuring Mission (TRMM)
    - DMSP -- Special Sensor Microwave Imager Sounder (SSMIS)
    - METOP & NOAA -- Advanced Microwave Sounding Unit (AMSU)
    - EOS AQUA – Advanced Microwave Scanning Radiometer (AMSR-E)
    - CloudSat
- **Future Space Missions**
  - Meteosat Third Generation (MTG)
  - Global Precipitation Measurement (GPM) Mission
  - Post-EPS
  - EarthCARE

Scientific Justification

- **_Water Cycle_**
  - Precipitation is a major component in driving atmospheric and hydrological circulation
  - Water cycle estimates are uncertain – closure?



Knowledge of global precipitation is crucial for understanding weather and climate at all scales

Scientific Justification

- **_Earth's Energy Balance Model Updated_**
  - Adjustments of "back radiation" and latent heating

"In our analysis, the biggest uncertainity an bias comes from the downward longwave radiation. This source of uncertainty il likely manly from clous."

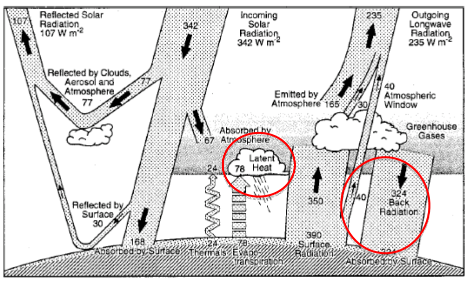
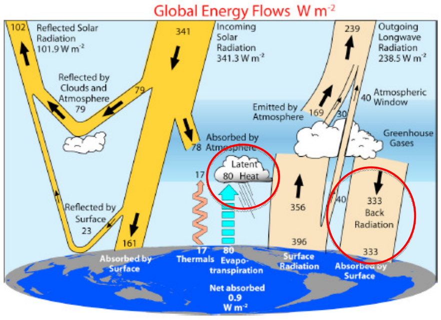


FIG. 7. The earth's annual global mean energy budget based on the present study. Units are W m^{-2}.

Kiehl and Trenberth, 1997



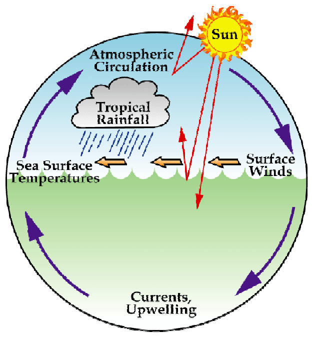
Trenberth et al, 2009.

Scientific Justification

TREND IN RATE OF GLOBAL WATER CYCLE?

OPEN ISSUE:

Establish existence (or absence) of trend in rate of global water cycle -- acceleration would lead to faster evaporation, increased global average precipitation, & general increase in extremes, particularly droughts & floods

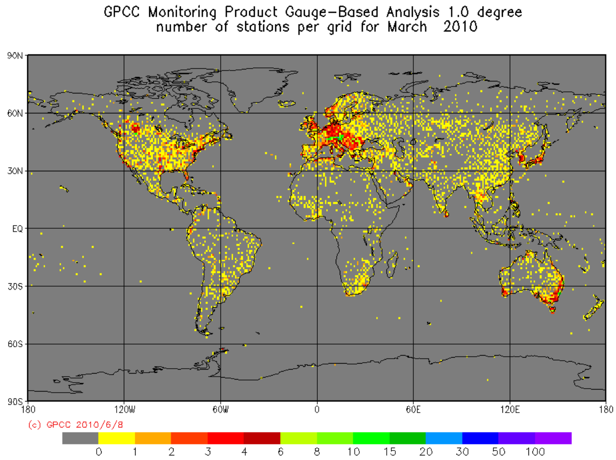


Scientific Justification

- **Meteorology and Weather Forecasting**
  - Quantitative precipitation estimates and forecasts are inaccurate
  - Assimilation of variables directly related to the formation of precipitation and to the water cycle leads to an improvement in precipitation forecasting
- **Climate Diagnostics and Prediction**
  - Large uncertainties in model precipitation estimates
  - Large uncertainties in observational precipitation estimates
- ***Hydrology***
  - Ground based precipitation measurement networks are insufficient – heterogeneous, inconsistent and sparse
- ***Oceanography***
  - Oceanic circulation is influenced by freshwater from runoff and surface precipitation
  - Runoff estimates and precipitation estimates are inadequate

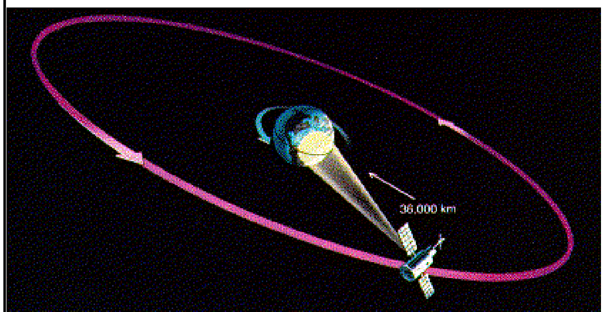
Scientific Justification

- ***Why from Space?***
  - Conventional observations lack **coverage** and often accuracy and representativeness



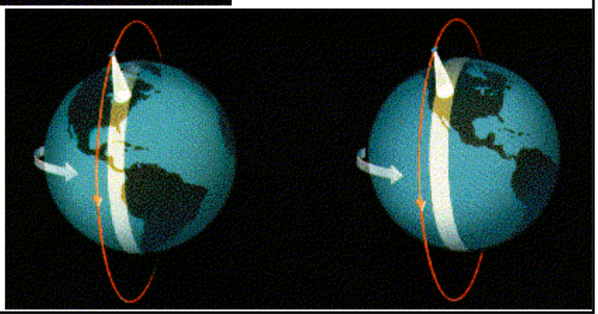
Satellites are the only viable means of providing global observations

GEO vs LEO Orbits

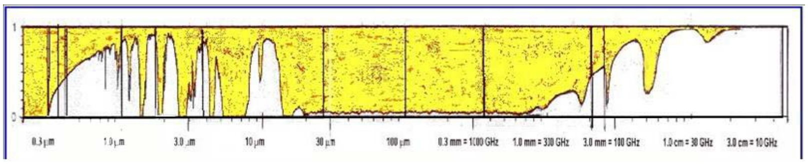


GEOSYNCHRONOUS EARTH ORBIT (GEO) SATELLITES

LOW EARTH ORBIT (LEO) SATELLITES



Wavelengths for satellite remote sensing of clouds and precipitation



Visible

Lidar, sensing of cirrus, water vapour and areosols

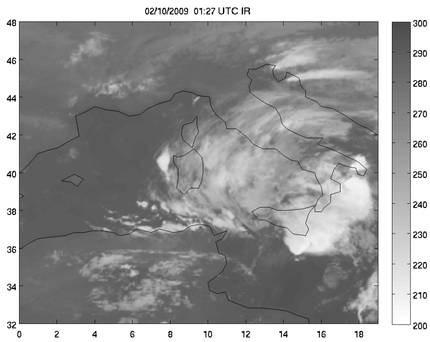
Infrared

- Good coverage spatial and temporal
- Radiation from cloud top

Microwaves

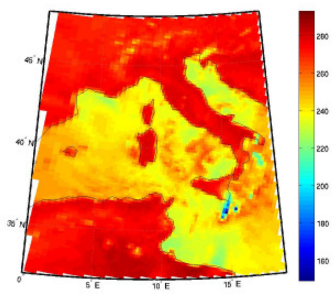
- Active and Passive radiometers
- Coarse spatial and temporal coverage
- More information on clouds and precipitation

WHY SPACE-BORNE MICROWAVE (MW) RADIOMETERS?



Meteosat IR image - October 02, 2010 01:27 UTC

X = 2 π 10 μm/ 10.8 μm ~ 2 π

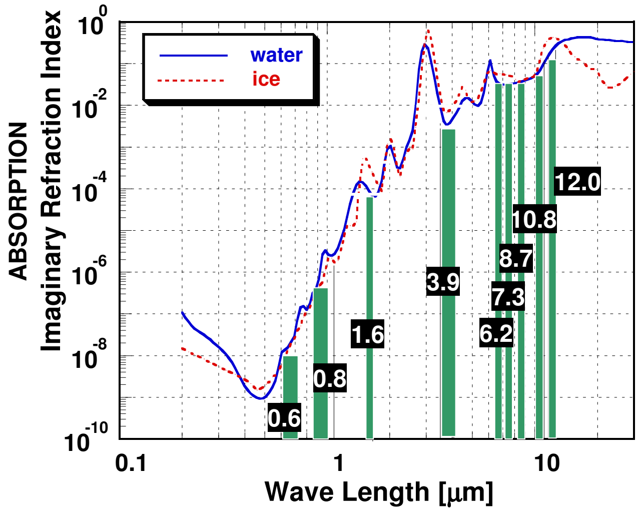


Corresponding AMSU microwave observations @ 89 GHz - October 02, 2010 01:24 UTC

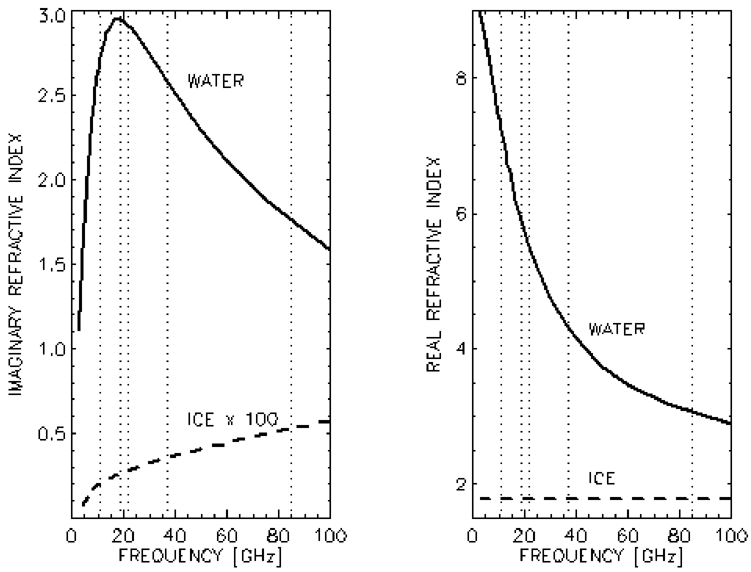
X = 2 π 10 μm/ 3 cm ~ 2 10^{-3}

Two Factors:
- Refractive Index
- Mie Size Parameter x = 2πr / λ

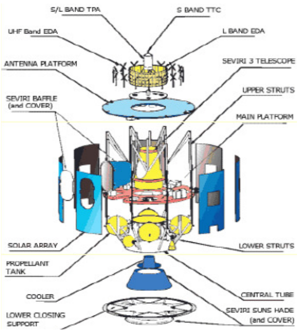
WATER & ICE IMAGINARY REFRACTIVE INDEX (VIS-IR)

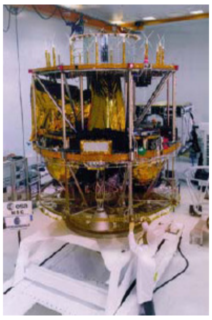


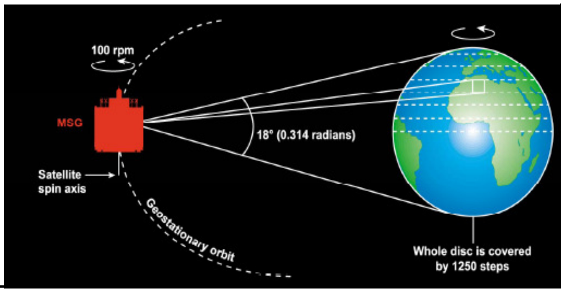
WATER & ICE REFRACTIVE INDEX (MW)



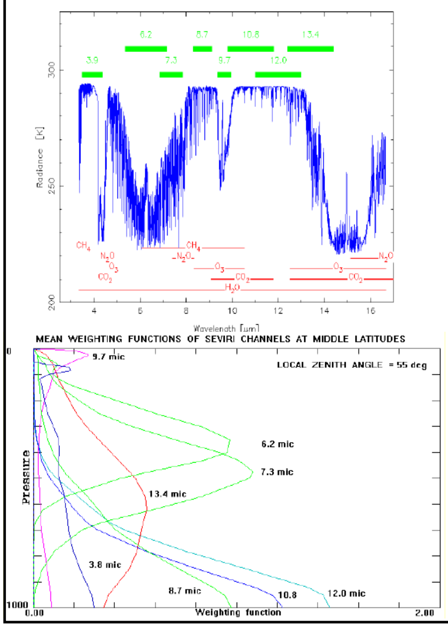
METEOSAT SECOND GENERATION (1)







METEOSAT SECOND GENERATION (2)



Spinning Enhanced Visible and Infrared Imager (SEVIRI).

Channel	USE
0.6 and 0.8 µm	Cloud detection, scene identification, cloud tracking, aerosol observation, vegetation monitoring. Heritage from AVHRR
1.6 µm	Discriminates between snow and cloud, ice and water clouds. Aerosol information. Heritage from ATSR
3.9 µm	Low cloud and fog detection, Measurement of land and sea surface temperature at night. Spectral band broadened towards higher wavelength to improve signal-to-noise ratio. Heritage from AVHRR
6.2 and 7.3 µm	Upper- and mid-tropospheric water vapour, Cloud and water vapour tracking, Height allocation of semitransparent clouds
8.7 µm	Quantitative information of thin cirrus clouds, Discriminates between ice and water clouds. Heritage from HIRS
9.7 µm	Ozone radiances as input to NWP. Experimental channel used for tracking ozone patterns representative of wind motion in the lower stratosphere. Monitoring of evolution of total ozone field
10.8 and 12.0 µm	Measurement of earth surface and cloud top temperatures, Detection of cirrus and inference of total precipitable WV over sea.
13.4 µm	Split window channels from AVHRR Improvement of height determination of transmissive cirrus clouds, Temperature information from lower troposphere (cloud free areas) for instability assessment. Known from GOES VAS instrument.

broadband HRV (High Resolution Viible)

METEOROLOGICAL PRODUCTS FROM MSG

Product	Content	Applications & Users
High Resolution Wind Vectors from HRVIS	Wind vectors at high resolution	Nowcasting
Automatic Satellite Image Interpretation	Cloud images with text and objective attributes overlays	Nowcasting
Air Mass Advection	Advected air mass parameter fields	Nowcasting
Cloud Mask and Cloud Amount	Presence of clouds, snow or sea-ice	Nowcasting
Cloud Top Temperature/Height	Cloud top temperature and height in pressure units	Nowcasting
Cloud Type (including fog)	Cloud type identification (including fog), ice/water cloud discrimination	Nowcasting
Convective Rainfall Rate	Precipitation intensity for convective clouds	Nowcasting Hydrology
Precipitating Clouds	Identification of clouds likely to produce precipitation	Nowcasting
Rapid Developing Thunderstorms	Identification of rapidly developing thunderstorms	Nowcasting
Layer Precipitable Water	Layer precipitable water in cloud free areas	Nowcasting
Total Precipitable Water	Total precipitable water in cloud free areas	Nowcasting
Stability Analysis Imagery	Multispectral coloured imagery, enhanced to visualise instability	Nowcasting

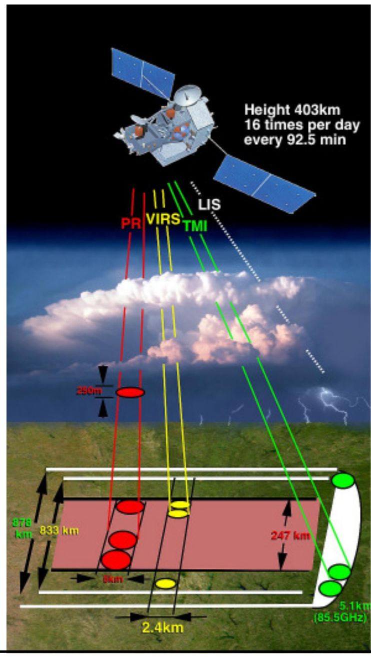
NASA / JAXA Tropical Rainfall Measuring Mission (TRMM)

TRMM satellite:
- Launch : November 27, 1997
- Orbit : 35° inclination @ 350 km alt.
- Boosted to 403 km in August 2001
- Life : 1997 – Present

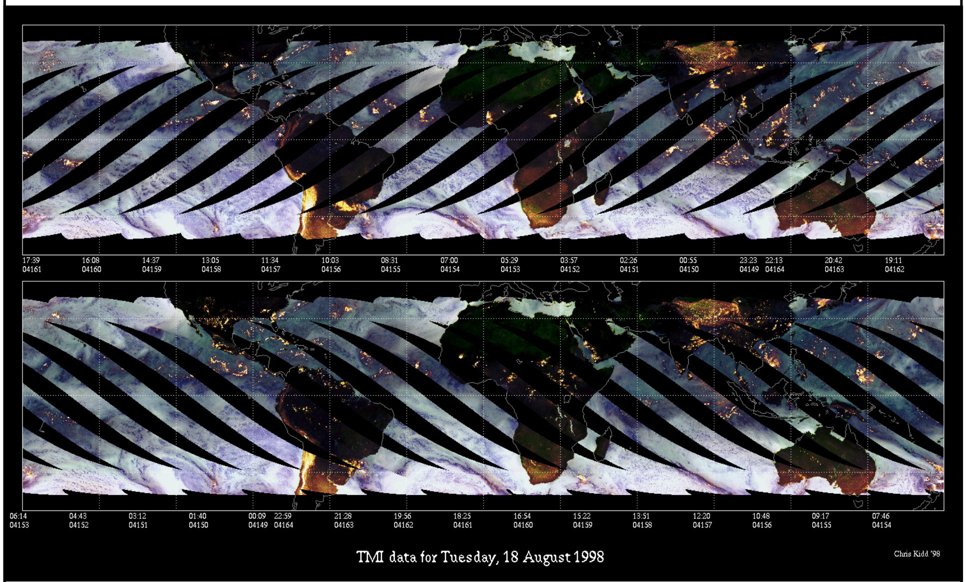
LIS:
- Resolution : 4-7 km (storm scale res.)
- Field of view : 600 km x 600 km
- Each point is observed for 90 sec
- CG & IC Lightning (no discriminat.)

TMI:
- Freq. : 10.65, 19.35, 21.3, 37, 85.5 GHz
- Resolution : 47 - 5.5 km
- Sampling Frequency : 15 hours

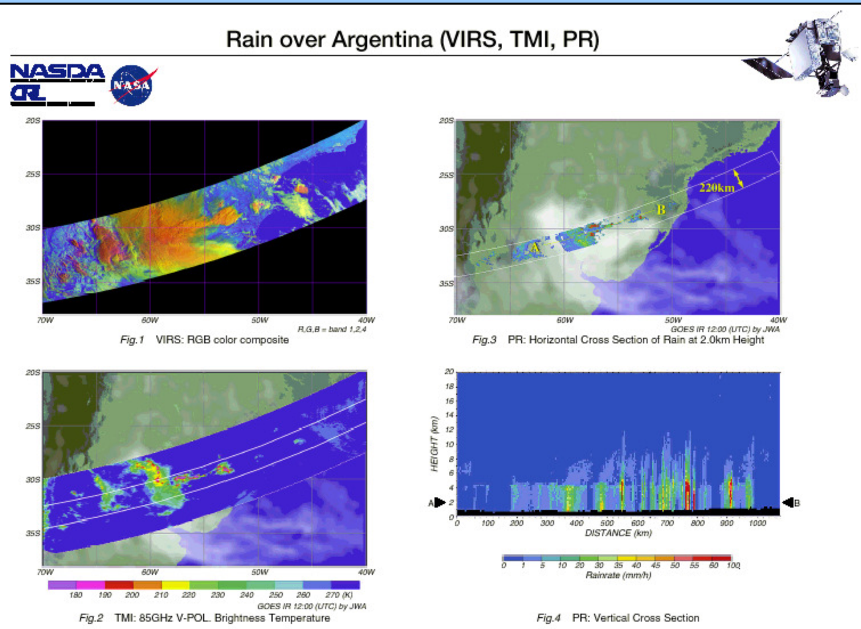
PR:
- Ku-band : 13.8 GHz
- Horiz. Res. : 4.5 km
- Vert. Res.: 250 m
- Sampling Frequency : 50 hours



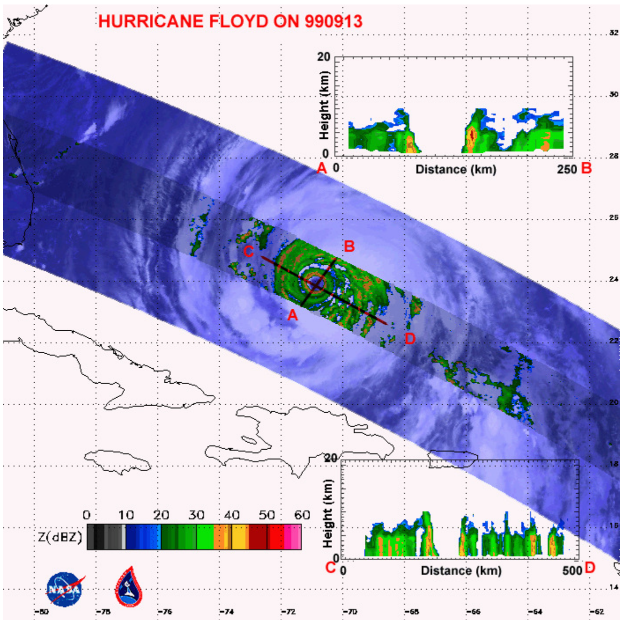
TMI Daily Earth Coverage



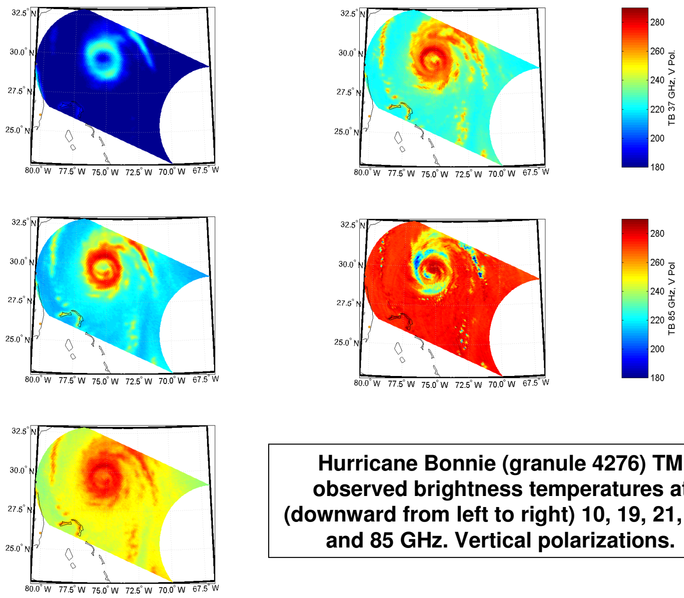
TRMM VIRS-TMI-PR Corresponding Observations



TRMM Precipitation Radar (PR)

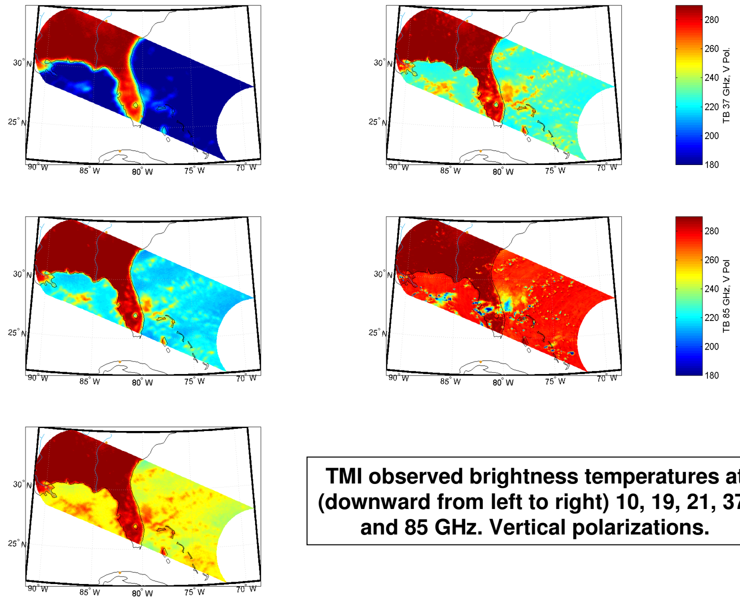


TMI INSTANTANEOUS



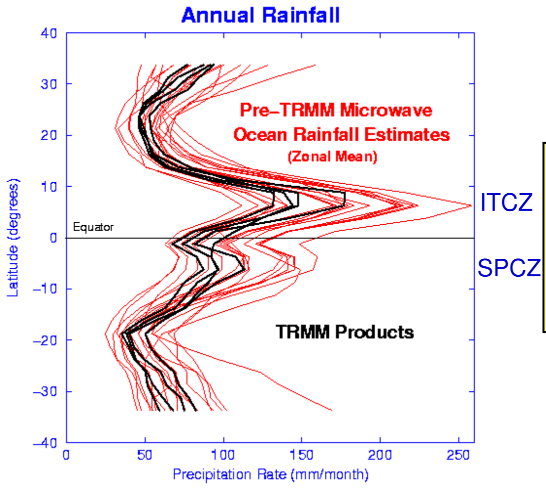
Hurricane Bonnie (granule 4276) TMI observed brightness temperatures at (downward from left to right) 10, 19, 21, 37, and 85 GHz. Vertical polarizations.

TMI INSTANTANEOUS



TMI observed brightness temperatures at (downward from left to right) 10, 19, 21, 37, and 85 GHz. Vertical polarizations.

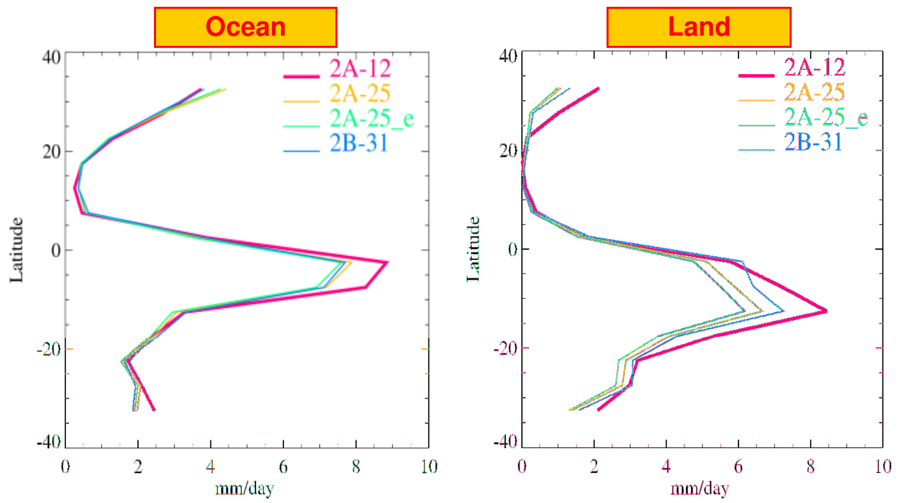
TRMM vs. SSM/I Annual Rainfall Estimates



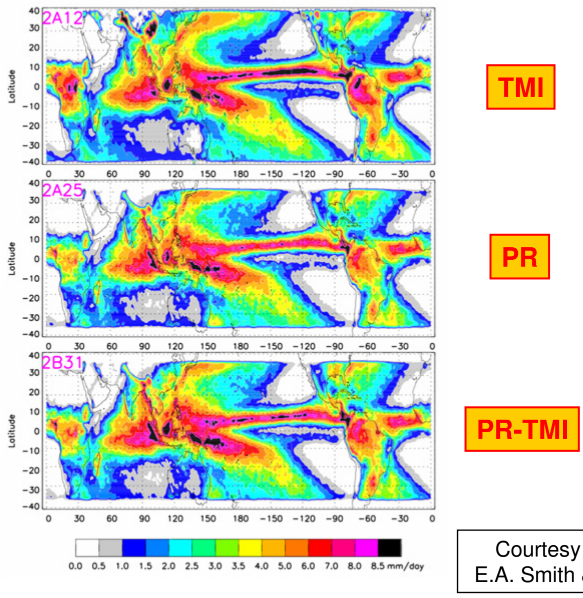
Annual rainfalls as function of latitude. The plots represent the rainfall estimates as obtained by different algorithms and from different sensors.

[Courtesy of Dr. C.Kummerow]

Zonal-Monthly Mean Surface Rainrates from TRMM Algorithms (Feb'98 --- 5 deg latitude bands) (V6)



Horizontal Distributions of Mean Rainrate (mm day-1) for 8-year (1998-2005) TRRM Measurements

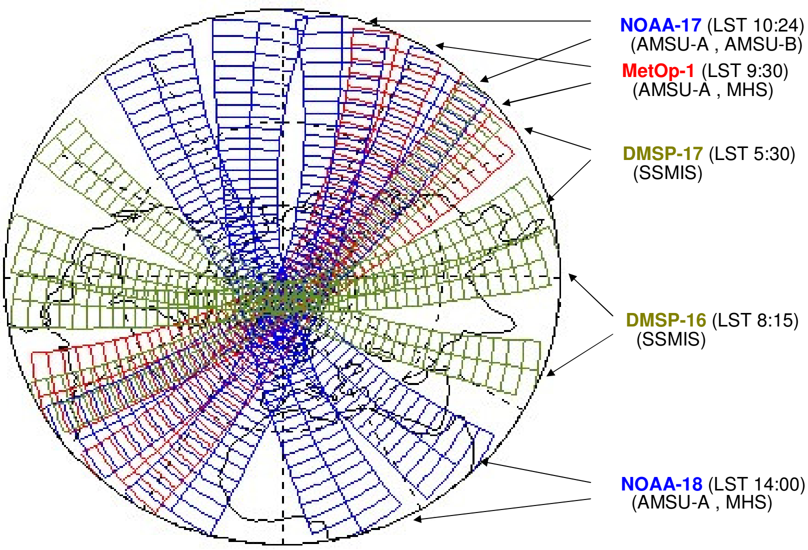


Courtesy of Drs.
E.A. Smith & S. Yang

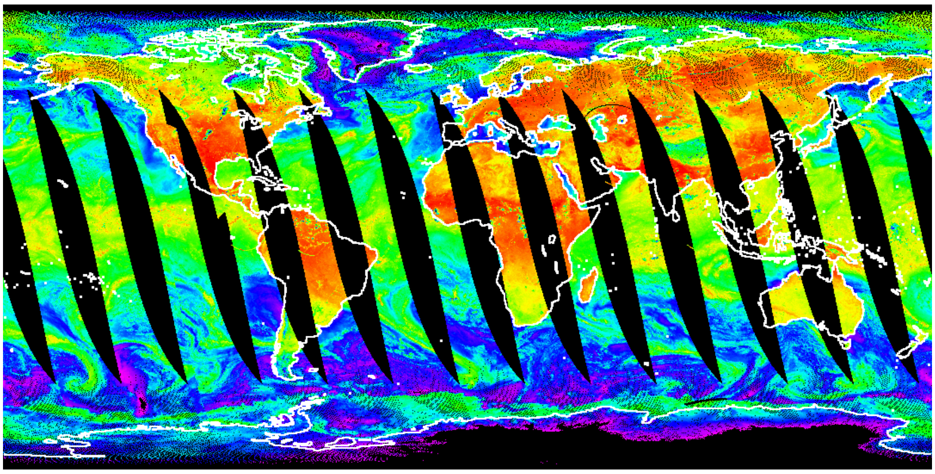
TRMM Limitations

- Tropical measurements only (35° S – 35° N)
- Limited life-time (1997 – ?)
- Coarse sampling frequency (depending on latitude)
  - TMI: 1 sample / 15 h
  - PR: 1 sample / 50 h

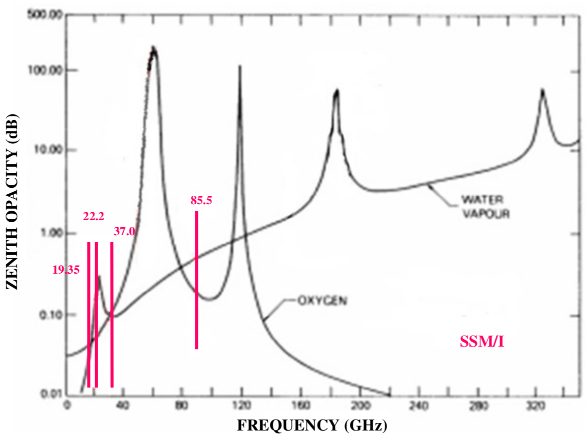
3-hr Coverage by Operational MW/LEO Satellites

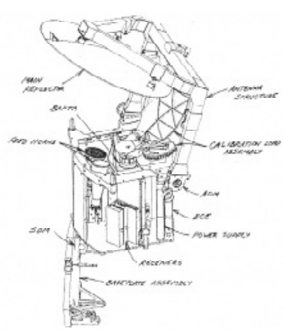


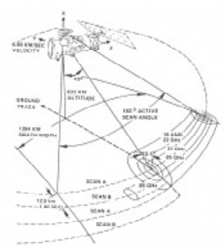
SSM/I DAILY EARTH COVERAGE: 85 GHz H – ASC.



Special Sensor Microwave/Imager (SSM/I)

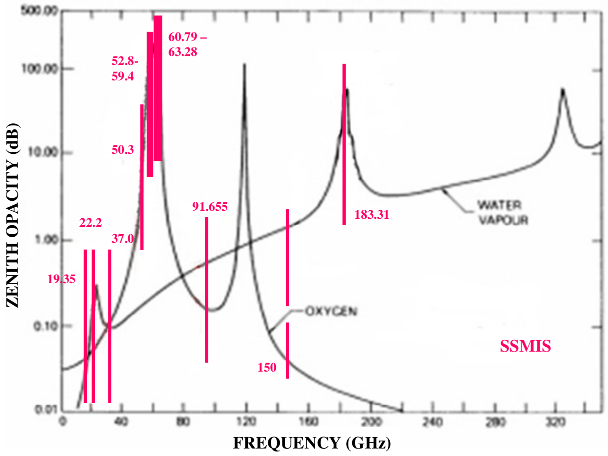


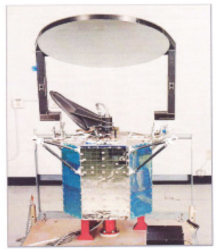


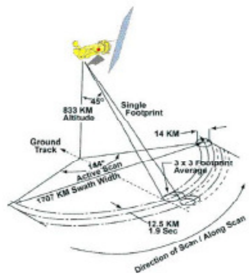


SSM/I	Special Sensor Microwave - Imager
Satellites	**DMSP F 8, 10, 11, 13, 14 and 15**
Status (Sept 2005)	**Operational** – Utilisation period: 1987 to ~ 2007
Mission	Multi-purpose MW imager
Instrument type	4-frequency, 7-channel MW radiometer
Scanning technique	Conical: 53.1° zenith angle, swath 1400 km – Scan rate: 31.9 scan/min = 12.5 km/scan
Coverage/cycle	Global coverage once/day
Resolution (constant)	Changing with frequency, consistent with an antenna diameter of 61 x 66 cm

Special Sensor Microwave Imager Sounder (SSMIS)

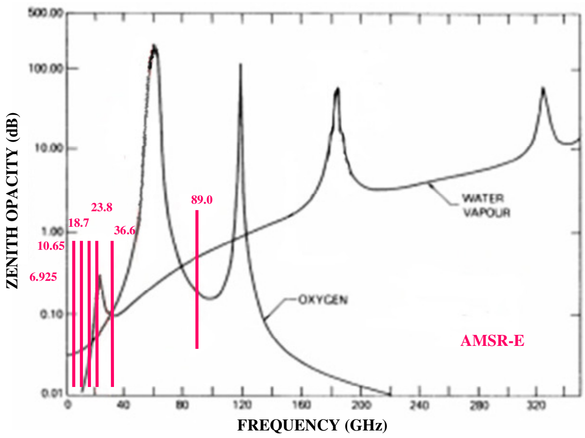


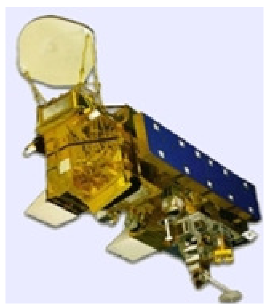




SSMIS	Special Sensor Microwave – Imager/Sounder
Satellites	DMSP F 16 and DMSP S 17 to 20
Status (Sept 2005)	**Operational** – Utilisation period: 2003 to ~ 2015
Mission	Multi-purpose MW imager with temperature/humidity sounding channels for improved precipitation rate
Instrument type	21-frequency, 24-channel MW radiometer
Scanning technique	Conical: 53.1° zenith angle, swath 1700 km – Scan rate: 31.9 scan/min = 12.5 km/scan
Coverage/cycle	Global coverage once/day
Resolution (constant)	Changing with frequency, consistent with an antenna diameter of 61 x 66 cm

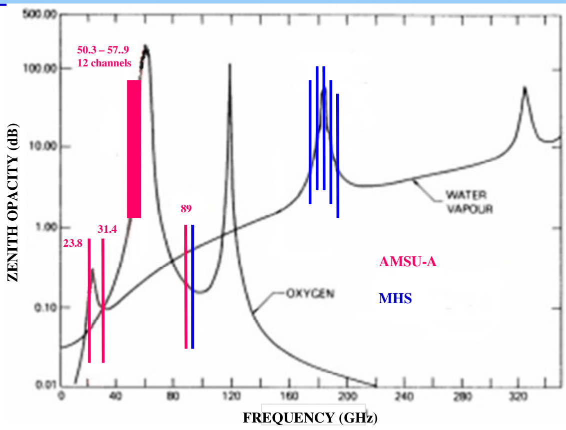
Advanced Microwave Scanning Radiometer (AMSR-E)

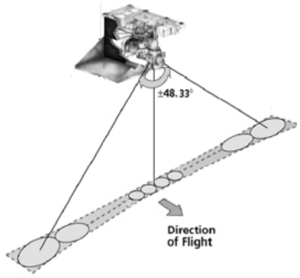




AMSR-E	Advanced Microwave Scanning Radiometer for EOS
Satellites	EOS-Aqua
Status (May 2008)	**Operational** - Utilisation period: 2002 to ~ 2009
Mission	Multi-purpose MW imager
Instrument type	MW radiometer with 6 frequencies / 12 channels
Scanning technique	Conical: 55° zenith angle; swath: 1450 km - Scan rate: 40 scan/min = 10 km/scan
Coverage/cycle	Global coverage once/day
Resolution	Changing with frequency, consistent with an antenna diameter of 1.6 m
Resources	Mass: 314 kg - Power: 350 W - Data rate: 87.4 kbps

Advanced Microwave Sounding Unit (AMSU-A, AMSU-B, MHS)





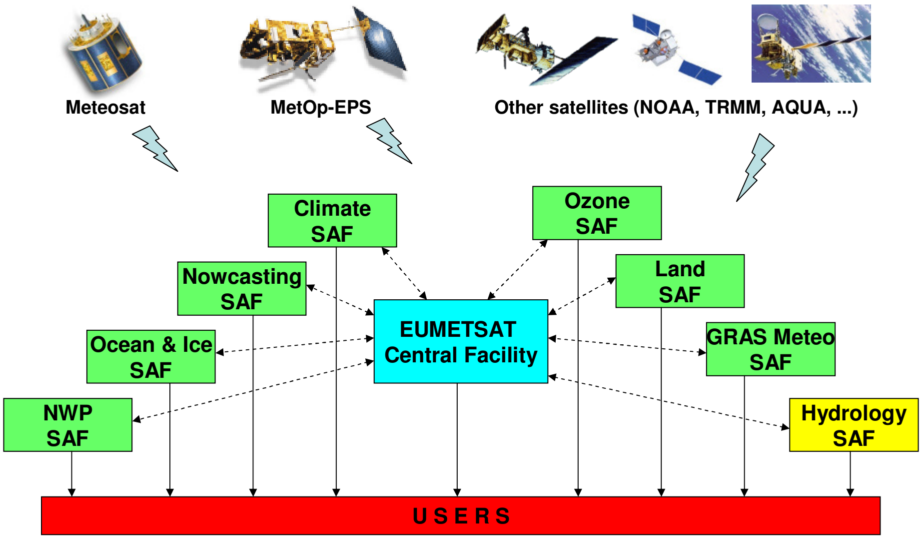
AMSU-A	Advanced Microwave Sounding Unit - A
Satellites	**NOAA 15 to 19 - Metop 1 to 3**
Status (Sept 2005)	**Operational** – Utilisation period: 1998 to ~ 2012 on NOAA, 2006 to ~ 2020 on MetOp
Mission	Temperature sounding in nearly-all-weather conditions. Also precipitation rate
Instrument type	15-channel MW radiometer
Scanning technique	Cross-track: 30 steps of 48 km ssp, swath 2250 km - Along-track: one 48-km line each 8 s
Coverage/cycle	Near-global coverage twice/day
Resolution (s.s.p.)	48 km IFOV

AMSU-B	Advanced Microwave Sounding Unit - B
Satellites	**NOAA 15 to 17**
Status (Sept 2005)	**Operational** – Utilisation period: 1998 to ~ 2007
Mission	Humidity sounding in nearly-all-weather conditions. Also precipitation rate
Instrument type	5-channel MW radiometer
Scanning technique	Cross-track: 90 steps of 16 km ssp, swath 2250 km - Along-track: one 16-km line each 8/3 s
Coverage/cycle	Near-global coverage twice/day
Resolution (s.s.p.)	16 km IFOV

MHS	Microwave Humidity Sounder
Satellites	**NOAA 18 to 19 - MetOp 1 to 3**
Status (Sept 2005)	**Operational** - Utilisation period: 2005 to ~ 2012 on NOAA, 2006 to ~ 2020 on MetOp
Mission	Humidity sounding in almost all-weather conditions. Also precipitation rate
Instrument type	5-channel MW radiometer
Scanning technique	Cross-track: 90 steps of 16 km ssp, swath 2170 km - Along-track: one 16-km line each 8/3 s
Coverage/cycle	Near-global coverage twice/day
Resolution (s.s.p.)	16 km IFOV

EUMETSAT's Satellite Application Facilities (SAF's)

Decentralized elements of the EUMETSAT Application Ground Segment



http://www.eumetsat.int/Home/Main/What_We_Do/SAFs/index.htm?l=en

Objectives of H-SAF

The Satellite Application Facility on Support to Operational Hydrology and Water Management (H-SAF) objectives are:

H SAF

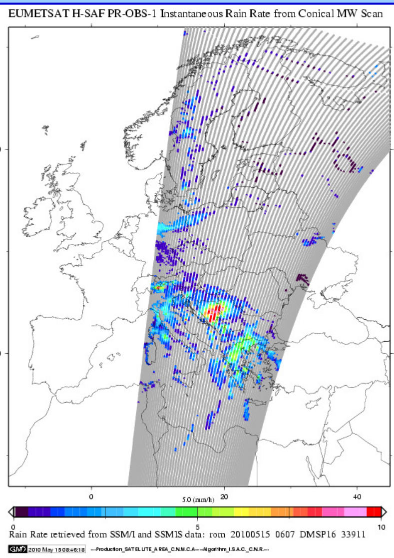
- to provide **new satellite-derived products**:
  - precipitation (liquid, solid, rate, cumulate)
  - soil moisture (at surface, in the roots region)
  - snow parameters (cover, melting conditions, water equivalent);
- to perform independent **validation** of the usefulness of the new products for hydrological applications.

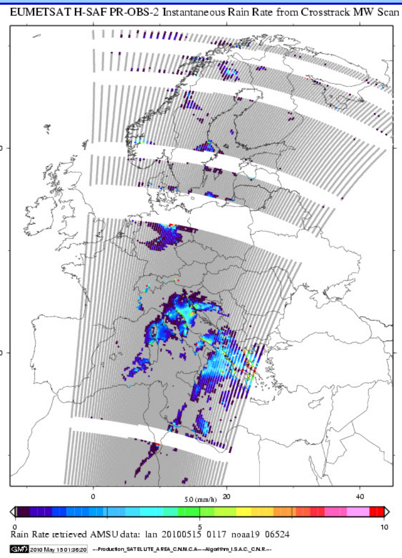
H-SAF Precipitation Products

Code	Acronym	Product name	Responsible of the algorithm
H-01	PR-OBS-1	Precipitation rate at ground by MW conical scanners (with indication of phase)	Italy, CNR-ISAC
H-02	PR-OBS-2	Precipitation rate at ground by MW cross-track scanners (with indication of phase)	Italy, CNR-ISAC
H-03	PR-OBS-3	Precipitation rate at ground by GEO/IR supported by LEO/MW	Italy, CNR-ISAC
H-04	PR-OBS-4	Precipitation rate at ground by LEO/MW supported by GEO/IR (with flag for phase)	Italy, CNR-ISAC
H-05	PR-OBS-5	Accumulated precipitation at ground by blended MW and IR	Italy, CNMCA
H-06	PR-ASS-1	Instantaneous and accumulated precipitation at ground computed by a NWP model	Italy, CNMCA

All precipitation products are operationally generated at the
- Centro Nazionale di Meteorologia e Climatologia Aeronautica (CNMCA) [Note: CNMCA also manages the Data service for all H-SAF products].

H-SAF : Precipitation Products





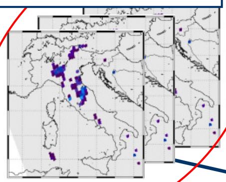
PR-OBS-1:
CDRD Bayesian Algorithm & SSM/I – SSMIS

PR-OBS-2:
Neural Network Algorithm & AMSU – MHS

http://www.meteoam.it/modules.php?name=hsaf

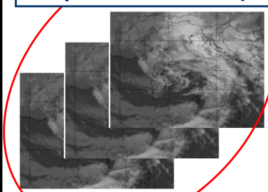
How the Rapid Update algorithm works

Rain intensity maps from PMW data



AT TIME t…

MSG- SEVIRI IR brightness temperatures at 10.8 µm

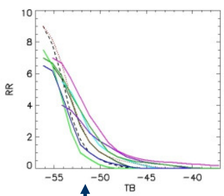


The RU allows to compute **instantaneous rain intensities at the ground at the geostationary time-space scale** (Turk et al. 2000, Torricella et al. 2007).

based on a **blended MW-IR** technique that correlates, by means of the **statistical probability matching**, brightness temperatures measured by the IR geostationary sensors and PMW-estimated precipitation rates at the ground

Extract space and time coincident locations from IR and MW data for each grid box

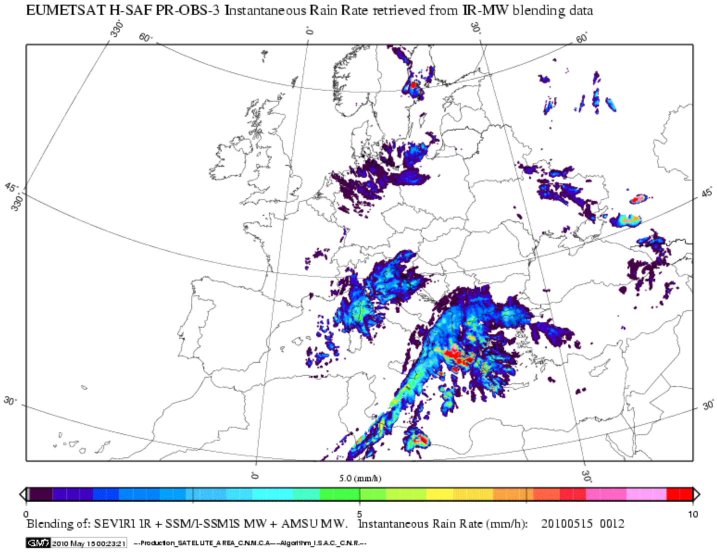
Create dynamical geolocated statistical relationships RR-T_b



Assign RR at every IR pixel

Produce instantaneous rain intensity maps at the geostationary time/space resolution

H-SAF : Precipitation Products



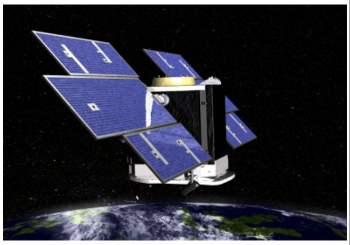
PR-OBS-3:
NRL Blending Algorithm & MW (SSM/I – SSMIS + AMSU – MHS) + IR (SEVIRI)

http://www.meteoam.it/modules.php?name=hsaf

CloudSat Mission Overview

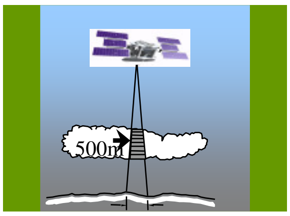
Salient Features

First 94 GHz (w band) radar space borne system
Co-manifested with CALIPSO on Delta II launch vehicle
Flies in formation with the EOS Constellation
Launch date: 28 April 2006
Partnership with DoD (on-orbit ops), DoE (validation) and CSA (radar development)
PI-mode: Prof. Graeme Stephens, Colorado State University



Science

Measure the vertical structure of clouds and quantify their ice and water content
Improve weather prediction and clarify climatic processes.
Improve cloud information from other satellite systems, in particular those of Aqua
Investigate the way aerosols affect clouds and precipitation
Investigate the utility of 94 GHz radar to observe and quantify precipitation, in the context of cloud properties, from space

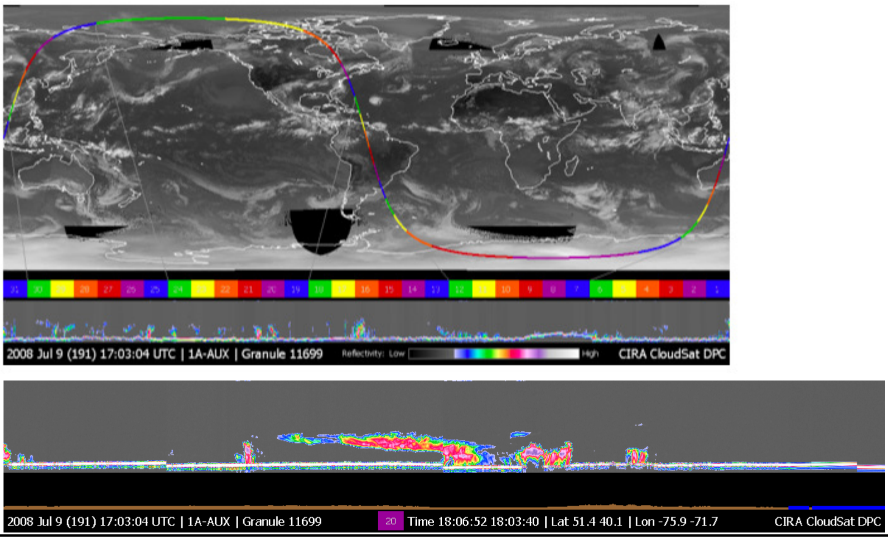


~1.8 km

- Nadir pointing, 94 GHz radar
- 3.3µs pulse ➔ 480m vertical res, over- sampled at ~240m
- 1.4 km horizontal res.
- Calibration better than 2 dBZ
- Sensitivity ~ -28 dBZ (-31 dBZ)
- Dynamic Range: 80 dB

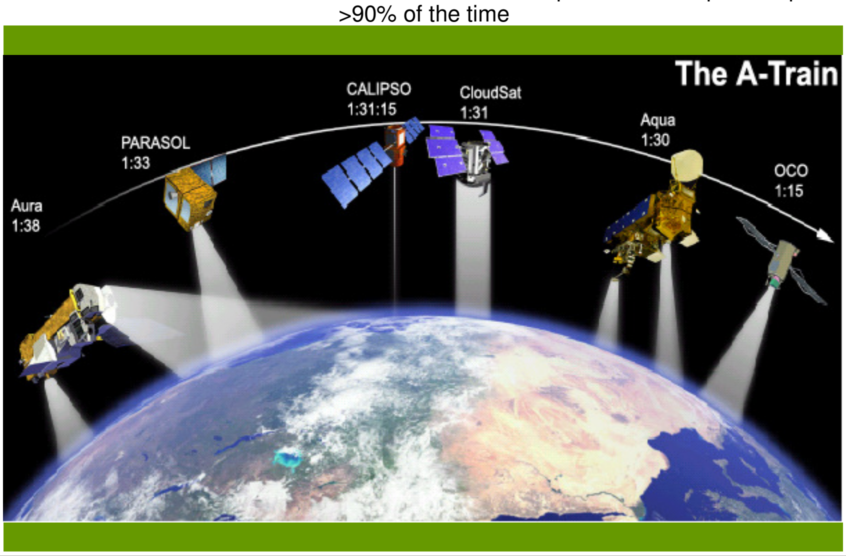
CloudSat Product

Example of CloudSat quicklook product, available online within 3-8 hours from observation.
The lower panel is from segment 20 in the upper panel over Montreal

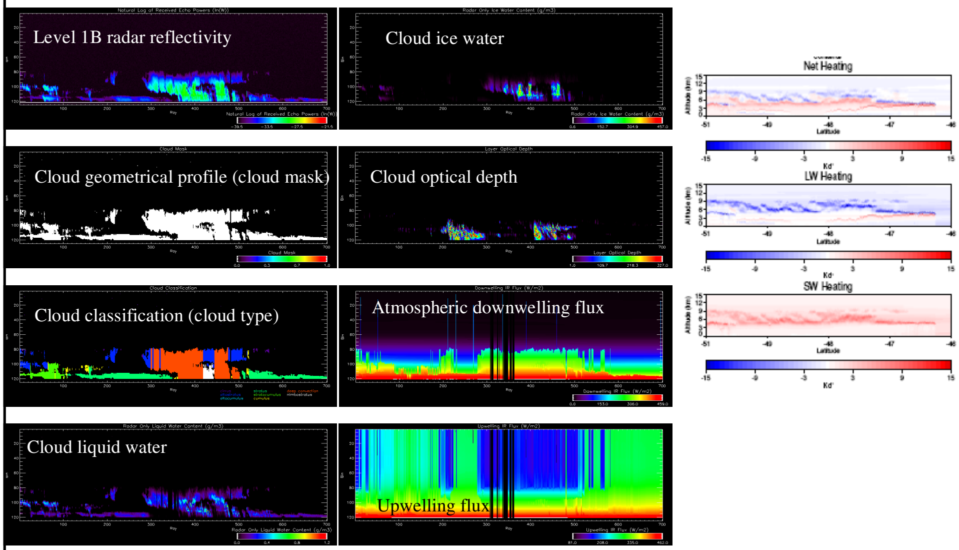


The A-Train

CloudSat flies in close formation with CALIPSO in the A-Train Constellation of satellites
CloudSat and CALIPSO have maintained a ~15-sec separation overlap of footprints >90% of the time

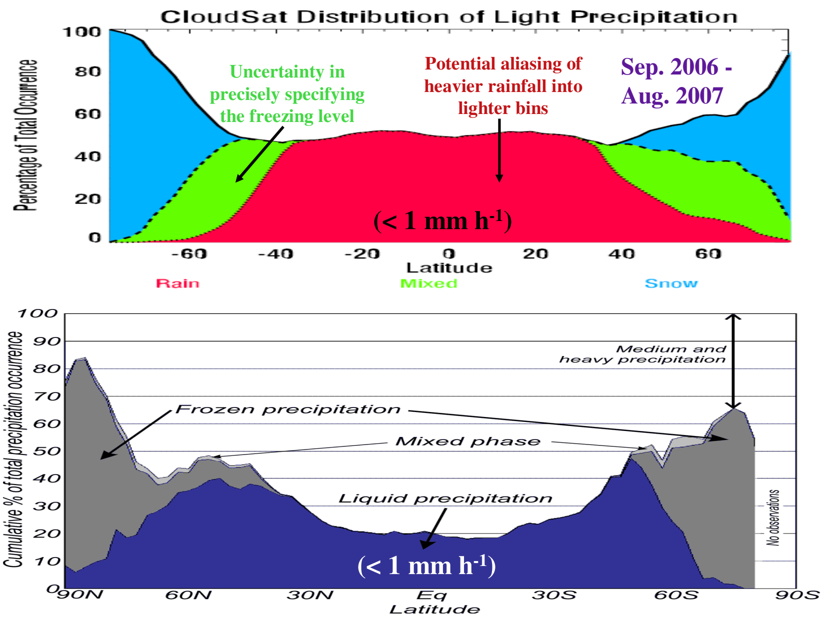


Cloudsat Standard Products



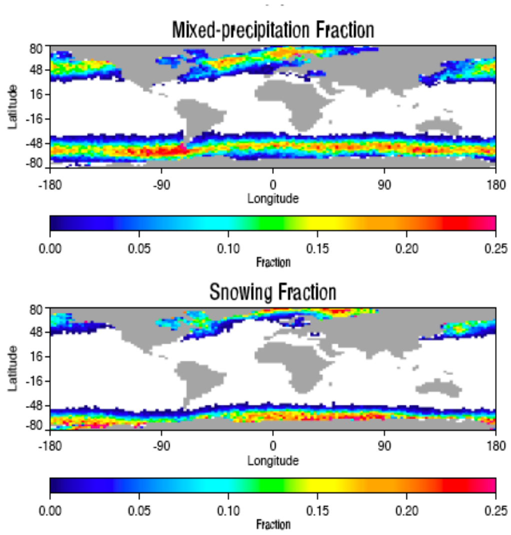
These CloudSat Level 1/2 standard products
are all available online

Comparison With COADS Statistics



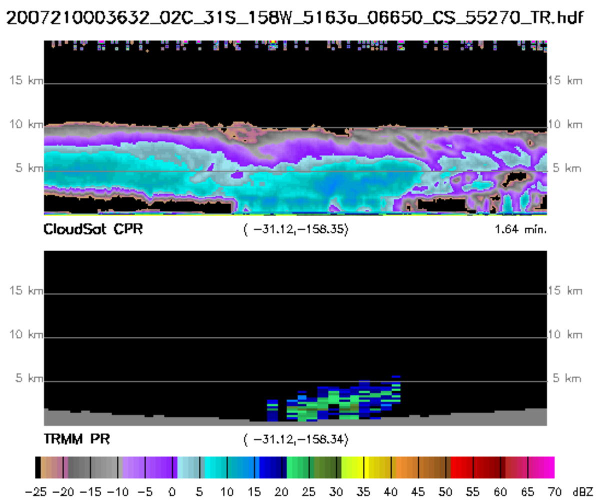
Derived from the ship-based Comprehensive Ocean-Atmosphere Data Set (COADS)

Snowfall Detection



Sep. 2006-Aug. 2007

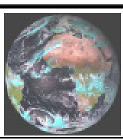
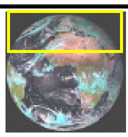
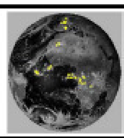
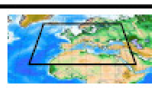
CloudSat – TRMM Radar Comparison



Future Missions

- Meteosat Third Generation
- Global Precipitation Measurement (GPM) Mission
- Post-EPS
- EarthCARE

Meteosat Third Generation

				
FDHSI / FDSS BRC = 10 min.	HRFI / RSS BRC = 2.5 min.	Lightning Detection Continuous Bkg = 60 sec.	IR Sounding with 0.625 cm-1 BRC = 60 min. RSS = 15 min.	UV-VIS-NIR BRC = 60/30 min. 30°W - 45°E [@40°N] & 30°N - 65°N, FOV of 5°NS x 55°EW + Sahara Vicarious Cal.
Solar channels: SSD=1 km IR channels: SSD=2 km	Solar channels: SSD=0.5 km IR channels: SSD=1 km	Goal SSD=5 km at SSP Threshold 10 km at 45°N	Spectral Bands: 1600-2175 cm^{-1} 700 - 1210 cm^{-1} SSD = 4 km	Spectral Bands: UV: 305 - 400 nm VIS: 400 - 500 nm NIR: 750 - 775 nm SSD = 8 km
SNR >20 in VIS NEdT=0.1 – 0.2 K All channels 0.5 – 1K for FA 3.8 and 8.7 µm	SNR = 12 in VIS 0.2 K @ 3.8 and 10.5 µm	DE = 90% at 45°N DE = 70% elsewhere day/night	See next slide for NEdT template update	SNR ~ 100 - 2500

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 (sounders over land only)

Coverage & Sampling

- 1-2 hr revisit time over land
- < 3 hr mean revisit time over 90% of globe

Key Advancement

Using an advanced radar/radiometer measurement system to improve constellation sensor retrievals

For more information: http://pmm.gsfc.nasa.gov/ NASA Contact: Dr. Arthur Y. Hou (arthur.y.hou@nasa.gov)

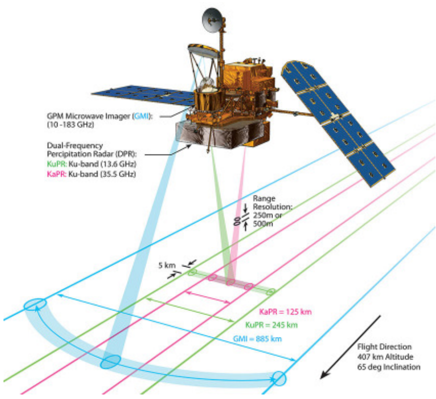
GPM Core Instruments

Dual-Frequency (Ku-Ka band) Precipitation Radar (DPR):

- *Increased sensitivity (~12 dBZ) for light rain and snow detection relative to TRMM*
- *Better measurement accuracy with differential attenuation correction*
- *Detailed microphysical information (DSD mean mass diameter & particle no. density) & identification of liquid, ice, and mixed-phase regions*

Multi-Channel (10-183 GHz) GPM Microwave Imager (GMI):

- *Higher spatial resolution (IFOV: 6-26 km)*
- *Improved sensitivity to light rain*
- *Improved signals of solid precipitation over land (especially over snow-covered surfaces)*
- *4-point calibration for nonlinearity removal and backup calibration reference during hot load anomalies*



Combined Radar-Radiometer Retrieval

- *DPR & GMI together provide greater constraints on possible solutions to improve retrieval accuracy*
- *Observation-based a-priori cloud database for constellation radiometer retrievals*

DPR Instrument Characteristics

Item	KuPR at 407 km	KaPR at 407 km	TRMM PR at 350 km
Antenna Type	Active Phased Array (128)	Active Phased Array (128)	Active Phased Array (128)
Frequency	13.597 & 13.603 GHz	35.547 & 35.553 GHz	13.796 & 13.802 GHz
Swath Width	245 km	120 km	215 km
Horizontal Reso	5 km (at nadir)	5 km (at nadir)	4.3 km (at nadir)
Tx Pulse Width	1.6 μs (x2)	1.6/3.2 μs (x2)	1.6 μs (x2)
Range Reso	250 m (1.67 μs)	250 m/500 m (1.67/3.34 μs)	250m
Observation Range	18 km to -5 km (mirror image around nadir)	18 km to -3 km (mirror image around nadir)	15km to -5km (mirror image at nadir)
PRF	VPRF (4206 Hz±170 Hz)	VPRF (4275 Hz±100 Hz)	Fixed PRF (2776Hz)
Sampling Num	104□112	108□112	64
Tx Peak Power	> 1013 W	> 146 W	> 500 W
Min Detect Ze (Rainfall Rate)	< 18 dBZ (< 0.5 mm/hr)	< 12 dBZ (500m res) (< 0.2 mm/hr)	< 18 dBZ (< 0.7 mm/hr)
Measure Accuracy	within ±1 dB	within ±1 dB	within ±1 dB
Data Rate	< 112 Kbps	< 78 Kbps	< 93.5 Kbps
Mass	< 365 kg	< 300 kg	< 465 kg
Power Consumption	< 383 W	< 297 W	< 250 W
Size	2.4×2.4×0.6 m	1.44 ×1.07×0.7 m	2.2×2.2×0.6 m

* Minimum detectable rainfall rate is defined by $Ze=200 R^{1.6}$ (TRMM/PR: $Ze=372.4 R^{1.54}$)

GMI Instrument Characteristics

Frequency	*Beam NEDT Req. (K)*	*Expected* NEDT (K)*	*Expected Beam Efficiency (%)*	*Expected Cal. Uncertainty (K)*	*Resolution (km)*
10.65 GHz (V & H)	*0.53*	*0.53 K*	*91.4*	*1.04*	*19.4 x 32.2*
18.7 (V & H)	*0.61*	*0.60*	*92.0*	*1.08*	*11.2 x 18.3*
23.8 (V)	*0.82*	*0.45*	*92.5*	*1.26*	*9.2 x 15.0*
36.5 (V & H)	*0.52*	*0.45*	*96.6*	*1.20*	*8.6 x 14.4*
89.0 (V & H)	*0.65*	*0.46*	*95.6*	*1.19*	*4.4 x 7.3*
165.5 (V & H)	*1.72*	*0.93*	*91.9*	*1.20*	*4.4 x 7.3*
183.31±3 (V)	*1.72*	*0.99*	*91.7*	*1.20*	*4.4 x 7.3*
183.31±7 (V)	*1.72*	*0.93*	*91.7*	*1.20*	*4.4 x 7.3*

Data Rate: ~30 kbps
Power: 162 Watts
Mass: 166 kg
** Analysis data as of May 2010*

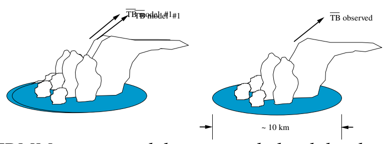
Deployed Size: 1.4 m x 1.5 m x 3.5 m
Antenna Size: 1.2 m
Swath: 885 km
Resolution and swath for GMI on Core

Next-Generation Global Precipitation Products

- Intercalibrated constellation radiometric data reconciling differences in center frequency, viewing geometry, resolution, etc.
  - Converting observations of one satellite to virtual observations of another using non-Sun-synchronous satellite as a transfer standard
  - GMI employs an encased hot load design (to minimize solar intrusion) and noise diodes for nonlinearity removal to attain greater accuracy & stability
  - International working group (NASA, NOAA, JAXA, CONAE, CMA, EUMETSAT, CNRS, GIST, & universities) in coordination with WMO/CGMS GSICS
- Unified precipitation retrievals using a common cloud/hydrometeor database constrained by DPR+GMI measurements from the GPM Core Observatory

Optimally matching observed T_b with simulated T_b from an a priori cloud database

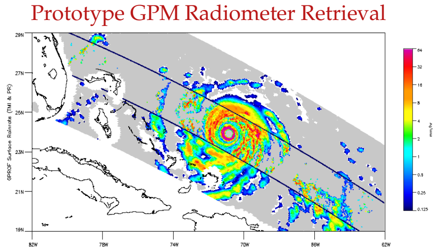
Simulated T_b *Observed T_b*



TRMM uses a model-generated cloud database

GPM uses a DPR/GMI-constrained database

Prototype GPM Radiometer Retrieval



Comparison of TRMM PR surface rain with TMI rain retrieval using an cloud database consistent with PR reflectivity and GMI multichannel radiances

International Collaboration on GPM Ground Validation

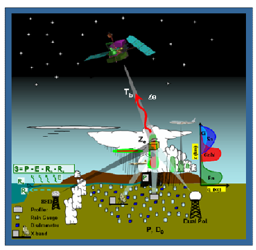
- *Joint field campaigns*
- *National networks and other ground assets (radar, gauges, etc.)*
- *Hydrological validation sites (streamflow gauges, etc.)*

Active Projects

- 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)

Proposals in Development

- Cyprus (CMS)
- Germany (MPI)
- Spain (Barcelona)
- India (ISRO)
- Taiwan



4th International Workshop for GPM Ground Validation hosted by the Finish Meteorological Institute, 21-23 June 2010, Helsinki, Finland

Post-EPS Microwave Imager (MWI)

- MWI – Ocean, Land, Ice : 8 channels (1.4 ÷ 89 GHz)
- MWI – Precipitation : 20 channels (10.65 ÷ 183.31 ± 2.0 GHz)
- MWI – Clouds : 20 channels (36.5 ÷ 664 ± 4.2 GHz)

Post-EPS Microwave Imager (MWI) - Precipitation

Channel name	Frequency [GHz]	Bandwidth [MHz]	Stability [MHz] All TBC	Utilization	Priority
MWI-4	10.65	100	50	Heavy precipitation over sea	2
MWI-5	**18.7**	**200**	**50**	**Precipitation over sea**	**1**
MWI-6	23.8	400	50	Total column water vapor over sea	2
MWI-7	**36.5**	**1000**	**50**	**Precipitation over sea and (marginally) land**	**1**
MWI-8	**50.3**	**200**	**10**	**Precipitation over sea and land including drizzle, snowfall, height and depth of the melting layer**	**1**
MWI-9	**52.610**	**400**	**10**		**1**
MWI-10	**53.24**	**300**	**10**		**1**
MWI-11	**53.750**	**300**	**10**		**1**
MWI-12	**89.0**	**4000**	**100**	**Precipitation (sea & land) & snowfall**	**1**
MWI-13	**100.49**	**4000 (TBC)**	**100 (TBC)**	**Precipitation over sea and land**	**1**
MWI-14	**118.7503±2.00**	**1000**	**10**	**Precipitation over sea and land including light precipitation and snowfall,**	**1**
MWI-15	**118.7503±1.6**	**400**	**10**		**1**
MWI-16	**118.7503±1.4**	**400**	**10**		**1**
MWI-17	**118.7503±1.20**	**400**	**10**	**height and depth of the melting layer**	**1**
MWI-18	166.9	1425	100	Quasi-window, water-vapor profile, precipitation over land, snowfall	2
MWI-19	**183.31±8.4**	**3000**	**100**	**Water vapor profile and snowfall**	**1**
MWI-20	**183.31±6.1**	**1500**	**100**		**1**
MWI-21	183.31±4.9	1500	100		2
MWI-22	**183.31±3.4**	**1500**	**100**		**1**
MWI-23	183.31±2.0	1500	100		3

Earth Cloud Aerosol and Radiation Explorer

EarthCARE has been defined with the specific scientific objectives of quantifying **aerosol-cloud-radiation** interactions so they may be included correctly in **climate** and numerical **weather forecasting** models to provide:

- Vertical profiles of natural and anthropogenic **aerosols** on a global scale, their radiative properties and interaction with clouds.
- Vertical distribution of atmospheric **liquid water and ice** on a global scale, their transport by clouds and radiative impact.
- **Cloud** overlap in the vertical, **cloud-precipitation** interactions and the characteristics of **vertical motion** within clouds.
- The profiles of atmospheric **radiative** heating and cooling through a combination of retrieved aerosol and cloud properties.

EarthCARE

SPACE SEGMENT

Payload:
- Backscatter Lidar (ATLID)
- Cloud Profiling Radar (CPR)
- Multi-Spectral Imager (MSI)
- Broad-Band Radiometer (BBR)

Platform

MISSION PARAMETERS

Orbit:
- Sun-synchronous
- Altitude 450.8 or 443.8 km
- Local time 10:30 descending node
- Repeat cycle 11days (15+4/11) or 31 days (15+12/31)

Launch date: Mid 2011

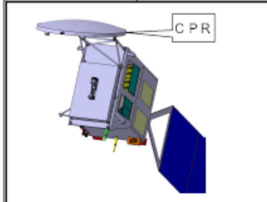
Mission life: 2 years (+1 yr or 15 % additional Propellant)

LAUNCH VEHICLE OPTIONS
- PSLV
- DNEPR
- SOYUZ

GROUND SEGMENT
- CDAE in Kiruna
- MSCE at ESOC
- PAE in ESRIN and Japan

Cloud Profiling RADAR

ESA 6th EarthExplorer Mission



EarthCARE Satellite (ESA)
Orbit : Sun-synchronous Polar
Instruments
- Cloud Profiling RADAR (JAXA/NICT)
- Atmospheric LIDAR (ESA)
- Multi-spectral Imager (ESA)
- Broadband Radiometer(ESA)

Launcher
- TBD

Satellite Operation (ESA)

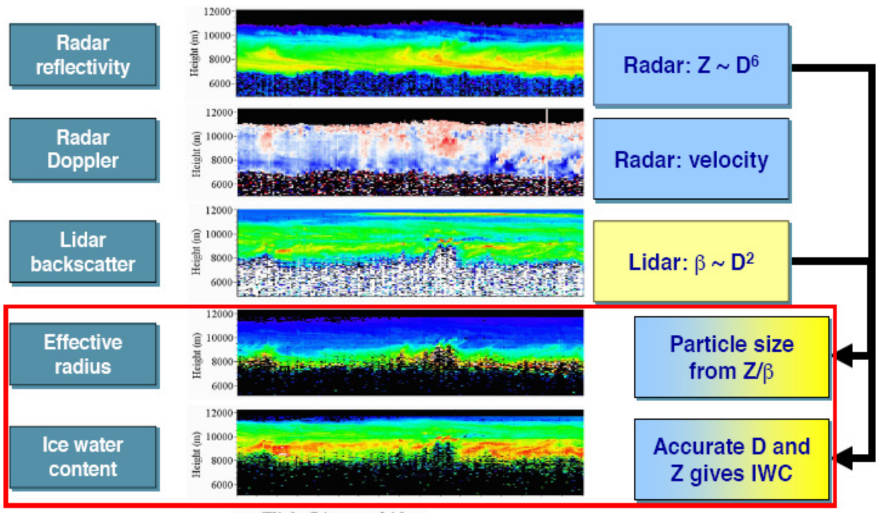
NICT(JAPAN); National Institute of Information and Communications Technology

Joint Development of JAXA/NICT

Cloud Profiling RADAR(CPR)

- Specification
  - 94GHz Doppler RADAR
  - Measurement Height -0.5 ~ 20km
  - Vertical Resolution 500m[sample100m](V)
  - Dynamic Range : -35dBZ~+21dBZ
  - Field of View:850m
  - Doppler measurement: -10 ~ +10 m/s
  - Doppler Accuracy: <1 m/s
  - Radiometric accuracy; <2.7dBZ
- Physical charastristics
  - size 2500x2700x1300 [mm] (stow), 2500x2700x3550 [mm] (deploy)
  - Main reflector diameter: 2.5m
  - Mass: 216kg TBD
  - Power: 300W TBD
  - Max data rate: 240kbps TBD

EarthCARE



Thank You !

Principle of observing precipitation from GEO

- From LEO:
  - use is made of atmospheric windows (typical: 10, 19, 37 and 90 GHz)
  - Polarization diversity is needed for surface roughness and observation on land
- From GEO:
  - 10-km resolution would require Ø 15 m at 90 GHz and 35 m at 37 GHz
  - Polarization diversity is impractical (zenith angle unfavourable and variable)
  - Use of higher frequencies is needed; absorption bands to be exploited.

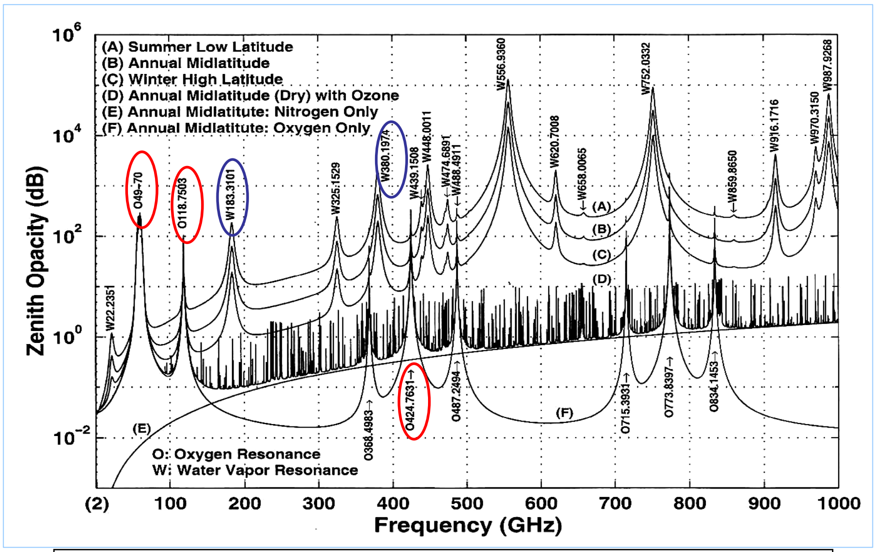
Resolution (at s.s.p.) versus frequency and antenna size for GEO imaging

Antenna Ø	37 GHz window	54 GHz O_2 band	89 GHz window	118 GHz O_2 band	183 GHz H_2O band	220 GHz window	340 GHz window	380 GHz H_2O band	425 GHz O_2 band	683 GHz window
1 m	353 km	242 km	147 km	112 km	73 km	59 km	38 km	35 km	31 km	19 km
2 m	176 km	121 km	73 km	56 km	36 km	30 km	19 km	18 km	16 km	9.6 km
3 m	118 km	81 km	49 km	37 km	24 km	20 km	13 km	12 km	10 km	6.4 km
4 m	88 km	60 km	36 km	28 km	18 km	15 km	9.5 km	8.8 km	7.8 km	4.7 km

A 3-m antenna provides 10-km resolution at least at the highest frequencies.
Absorption bands do not require polarization diversity, and shield-out surface.

Atmospheric Spectrum in the MW / Sub-MM Range

(Klein and Gasiewski, 2000)



Preferred bands

for O_2 (temperature) : 50-56 GHz, 118 GHz, 425 GHz - for H_2O : 183 GHz, 380 GHz

NEXRAD in Space (NIS)

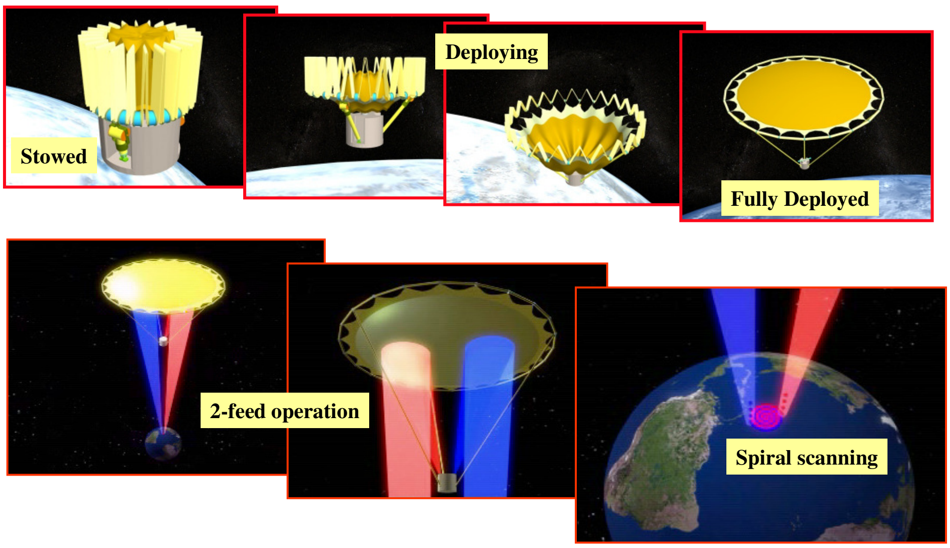
- **First-generation geostationary (GEO) orbiting radar for monitoring hurricanes and convective storms at hourly frequency throughout their life cycles.**
- **Ka-band (35 GHz) Doppler spiral-scan radar:**
  - **12 km horiz-res ; 0.3 km vert-res ; 5 dBZ sensitivity**
- **Large but light-weight, scanning, deployable antenna reflector**
- **Recovery of 4D dynamics (from Doppler signals) and 4D microphysics (from reflectivity, vertical velocity, and degree of polarization observations).**

Mission Concept under study for technology development by UCLA & NASA/JPL (funded by NASA)

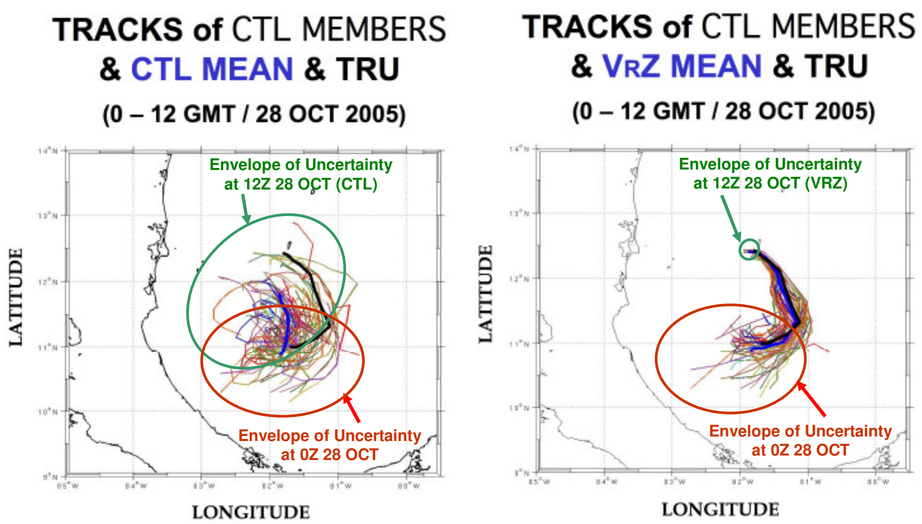
NIS Design and Performance Parameters

Frequency (GHz)	35
Range Resolution (m)	300
Horizontal Resolution (km)	12 (nadir), 14 (4°)
Disk Coverage (km)	5300
Pulse Compression Sidelobes (dB)	-30
Antenna Aperture (m)	28
Beamwidth (deg.)	0.02
Minimum Detectable Reflectivity (dBZ)	5
Doppler Precision (m/s)	0.3

Schematics of NIS Deployment & Operation



Ensemble Experiment for Hurricane Beta (60 members)



NIS radar will be able to acquire 4D dynamical and microphysical information.
Assimilation studies indicate improved hurricane forecasts.

References

- J. T. Kiehl, Kevin E. Trenberth Earth's Annual Global Mean Energy Budget Bulletin of the American Meteorological Society 1997 78:2, 197-208
- Kevin E. Trenberth, John T. Fasullo, Jeffrey Kiehl Earth's Global Energy Budget Bulletin of the American Meteorological Society 2009 90:3, 311-323