Satellite rainfall estimation during the GPM era

Daniel Vila

Centro de Previsão de Tempo e Estudos Climáticos/Divisão de Satélites e Sistemas Ambientais (CPTEC/DSA)

Why measure precipitation?

Precipitation is a key component of the Earth's energy and water cycle

- Through evaporation and condensation energy is redistributed through the atmosphere and across the Earth's surface

Water is vital to life on Earth

- Less than 1% of all water on Earth is available to us as freshwater

Water is fundamental to our economic and social wellbeing

- We depend upon water; too much or too little can be disastrous

Surface & Satellite Observing Systems

	Instrument	Temporal	Spatial	Notes
Surface	Gauges: accumulation	Variable	Point	Temporal scale dependent upon observation frequency
Surface	Gauges: Tipping Bucket	Quantised	Point	Quantisation of bucket (0.1 or 0.2 mm or 1/100”) and data logger
Surface	Distrometers	Instantaneous	Point	Individual drop measurements
Surface	Micro rain radar	Instantaneous	Point	30 vertical levels
Surface	Weather radar	Instantaneous	Radial	Remapped radial measurements of dBZ
Satellite	Visible imagery	Cloud top	1-4 km	Intermittent (LEO) 15 min sampling (GEO)
Satellite	Infrared imagery	Cloud top	1-4 km	Intermittent (LEO) 15 min sampling (GEO)
Satellite	Passive Microwave Imagers	Column	5-25 km	Intermittent sampling (LEO) Resolution = frequency dependent
Satellite	Passive Microwave Sounders	Column	16-48 km	Intermittent sampling (LEO) Resolution = frequency/scan position depen.
Satellite	Active Microwave (radar)	Instantaneous	5 km	80 vertical levels; Intermittent sampling (LEO)

Observations have different spatial/temporal characteristics

Current precipitation-capable systems

Low Earth Orbit	#		Vis/IR	PMW-I	PMW-S	AMW
NOAA/MetOp	**4**	**US/Europe**	√		√	
DMSP	**4**	**US**	√	√	√	
GPM	1	US/Japan		√		√
GCOM-W1	1	Japan		√		
CloudSat	*1*	*US*				√
Megha-Tropiques	*1*	*France/India*		x	√	
Geostationary						
GOES	**2 (+1)**	**US**	√			
MTSAT	**1 +1**	**Japan**	√			
Meteosat	**2 (+2)**	**Europe**	√			

PMW-I Passive Microwave Imager
PMW-S Passive Microwave Sounder
AMW Active Microwave (radar)

Other systems such a MODIS and even Landsat may also be used

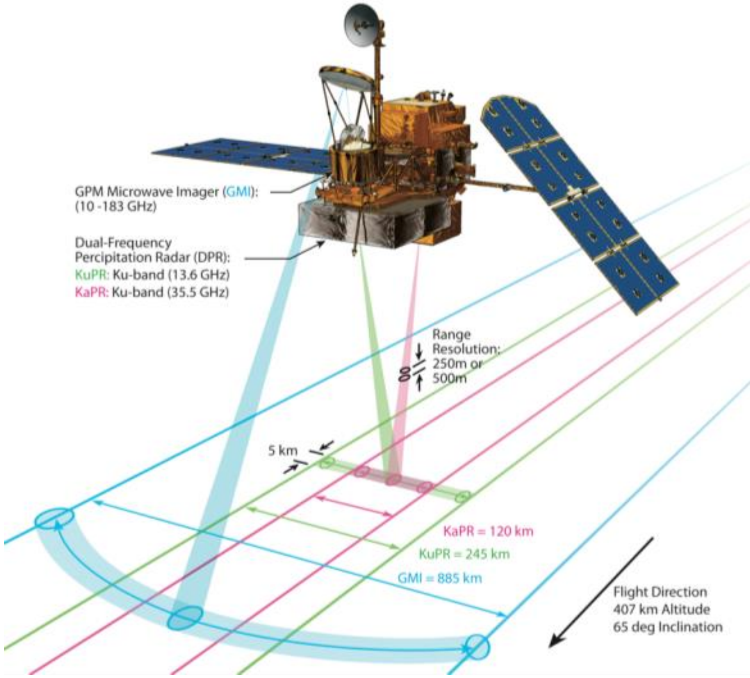
NOTE: Other satellite systems exist, but data are not readily available

What is GPM ?

The Global Precipitation Measurement (GPM) mission essentially comprises of two key components:

- ***The Core Observatory*:**
  - A joint NASA/JAXA satellite launched 28 February 2014 to provide high quality measurements of precipitation
  - Comprises of two high-quality instruments for precipitation measurements
- ***The international constellation:***
  - multiple, international satellites/sensors to provide temporal /spatial coverage necessary for global precipitation studies
  - A total of 11 satellites/sensors are currently available, including those from the US, Europe, Japan and France/India

GPM Core Observatory



Orbit 407 km; 65° inclination; 3-yr life, 5+ yr fuel

GPM Microwave Imager (GMI)

- passive microwave radiometer
- precipitation over 880 km swath
- spatial resolution up to ~5 x 5 km

Dual-frequency Precipitation Radar (DPR)

- KuPR similar to TRMM, KaPR added for GPM
- 3D structure, PSD, intensity and distribution
- spatial resolution to 5 km horiz.; 250 m vert.

	KuPR	KaPR
Frequency	13.597, 13.603 GHz	35.547, 35.553 GHz
Min. detectable rainfall rate	0.5 mmh^{-1}	0.2 mmh^{-1}
Data Rate	< 109 kbps	< 81 kbps
Mass	< 472 kg	< 336 kg
Power Consumption	< 446 W	< 344 W
Size	2.5 × 2.4 × 0.6 m	1.2 × 1.4 × 0.7 m

GMI Frequencies	GMI Polarizations
10.65 GHz	V/H
18.7 GHz	V/H
23.8 GHz	V
36.5 GHz	V/H
89 GHz	V/H
166 GHz	V/H
183.31 GHz	Va/Vb (±3 & ±7)

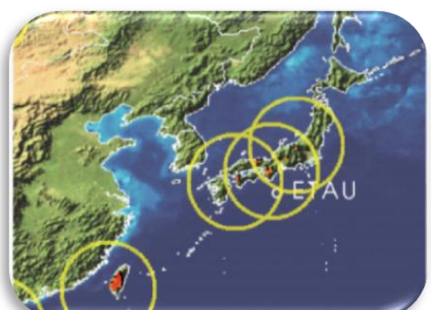
GPM science: application goals

Science Objectives:

- New reference standards for precipitation measurements from space
  - Active and passive microwave sensors
- Improved knowledge of water cycle variability and freshwater availability
  - Accurate description of space-time variability of global precipitation
- Improved numerical weather prediction skills
  - Better instantaneous precipitation information and error characterization
- Improved climate prediction capabilities
  - Better knowledge of latent heat, precipitation microphysics, and surface water fluxes
- Improved predictions for floods, landslides, and freshwater resources
  - Better hydrological modeling & high-resolution precipitation data via downscaling

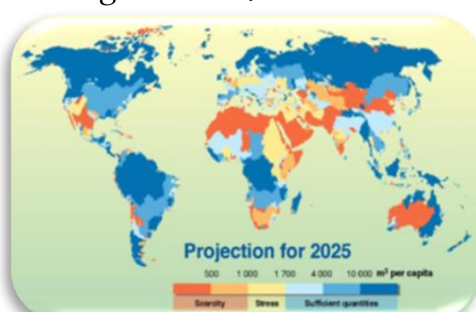
Societal Benefits:

Floods and Landslides

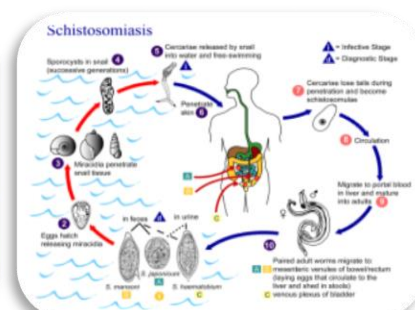


Extreme Events

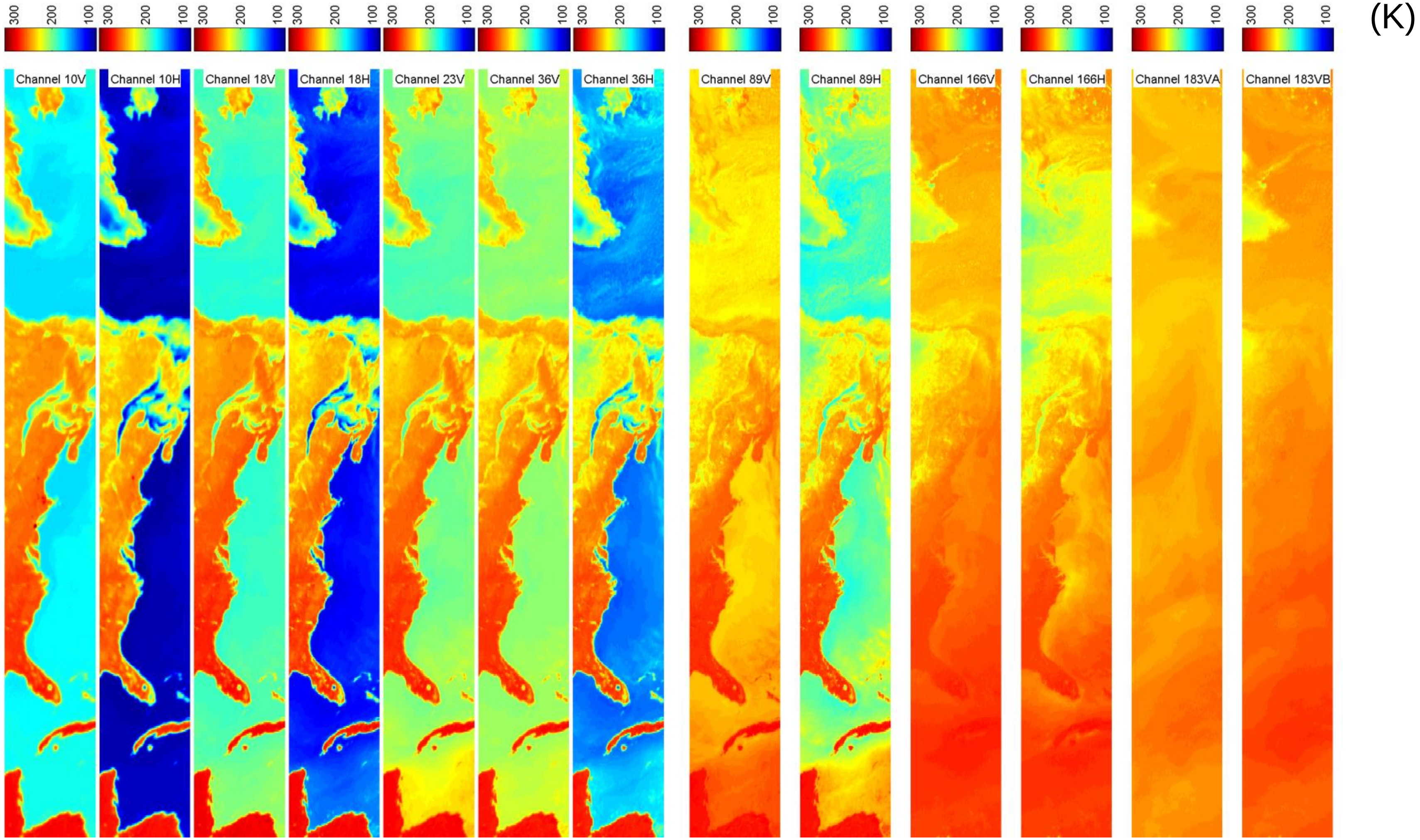
Freshwater Availability/ Agriculture/Famine



World Health

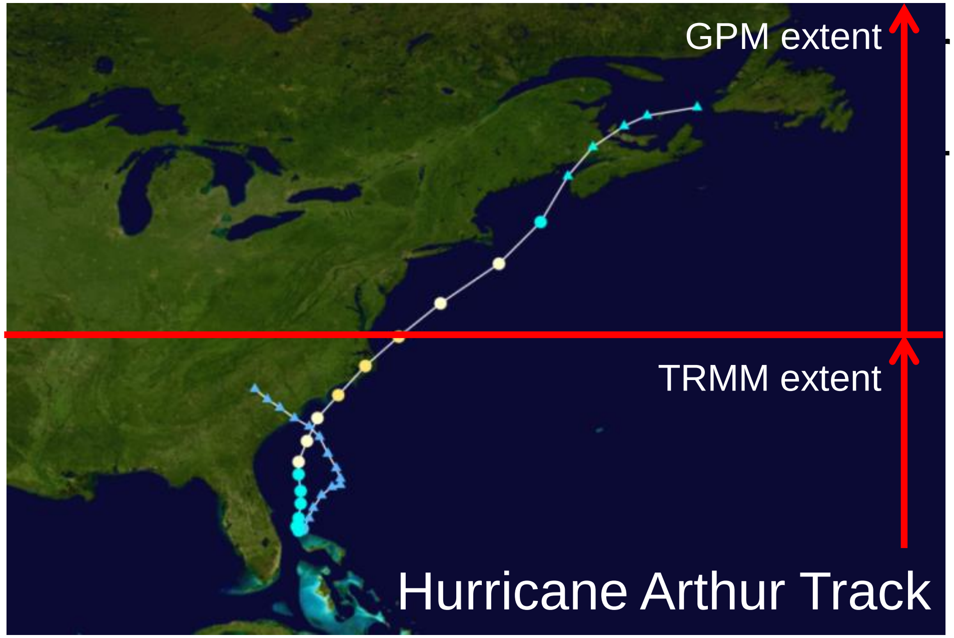


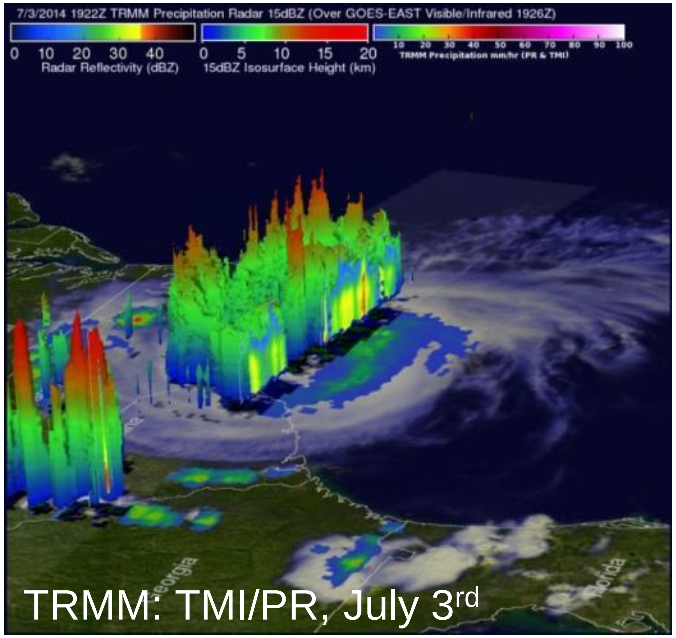
GPM Microwave Imager – 13 channels



First clear-air GMI brightness temperature data. The 10 to 89 GHz channels show the contrast between the *warm* land and *cold* ocean. The 166 and 183 GHz channels, increasingly sensitive to ice, clouds, and water vapor, are used to detect and estimate light rain and falling snow.

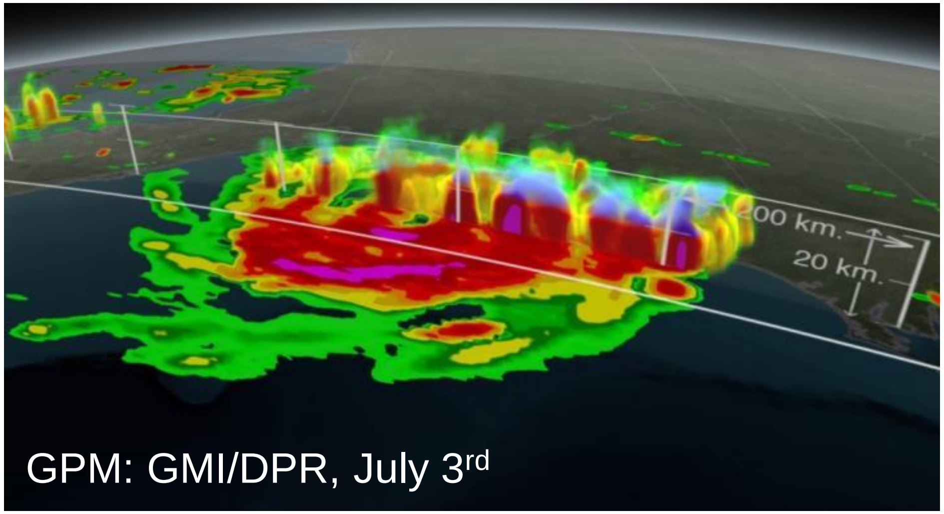
Hurricane Arthur (Atlantic Ocean, 3 July 2014)



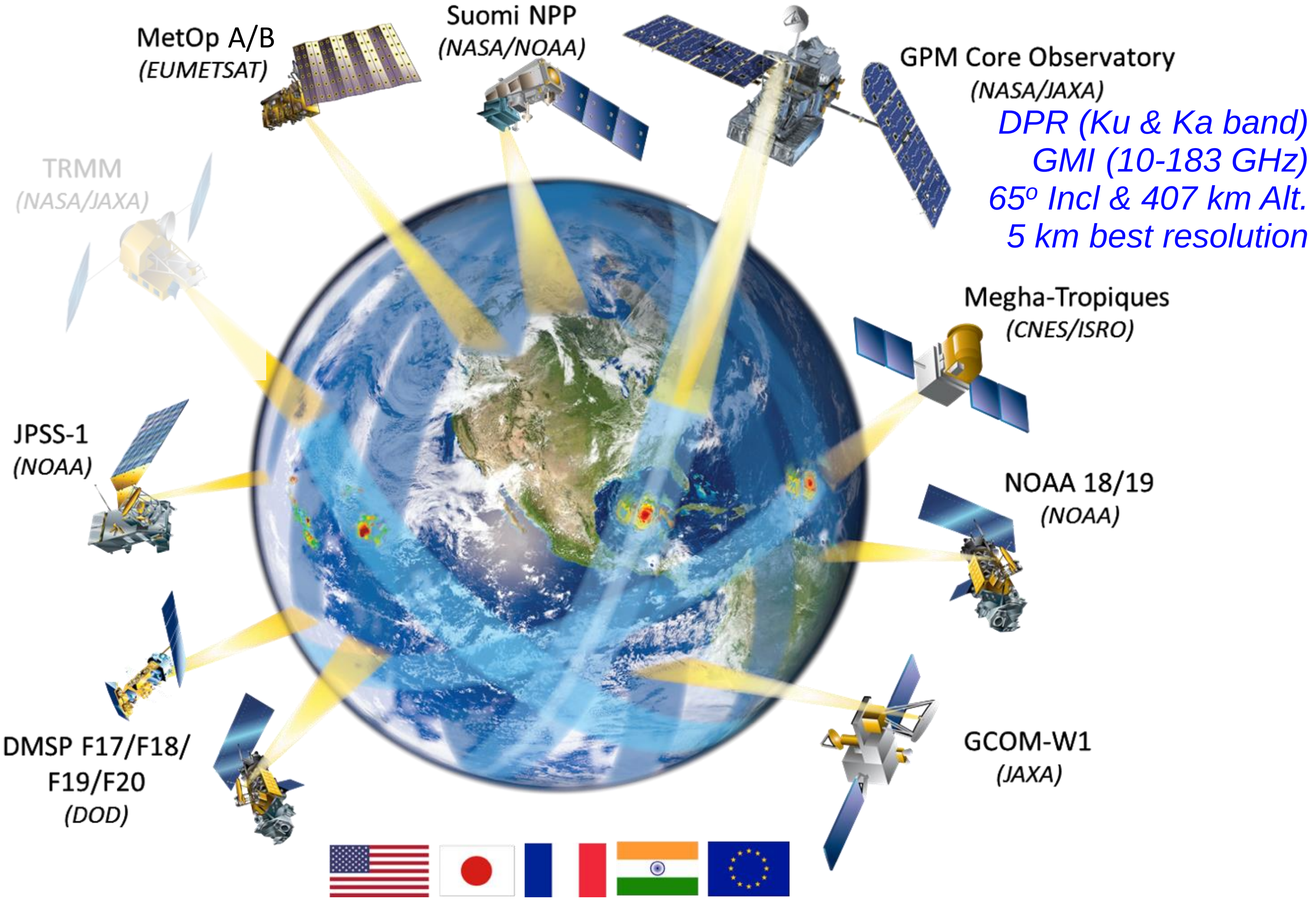


http://en.wikipedia.org/wiki/Hurricane_Arthur#mediaviewer/File:Arthur_2014_track.png

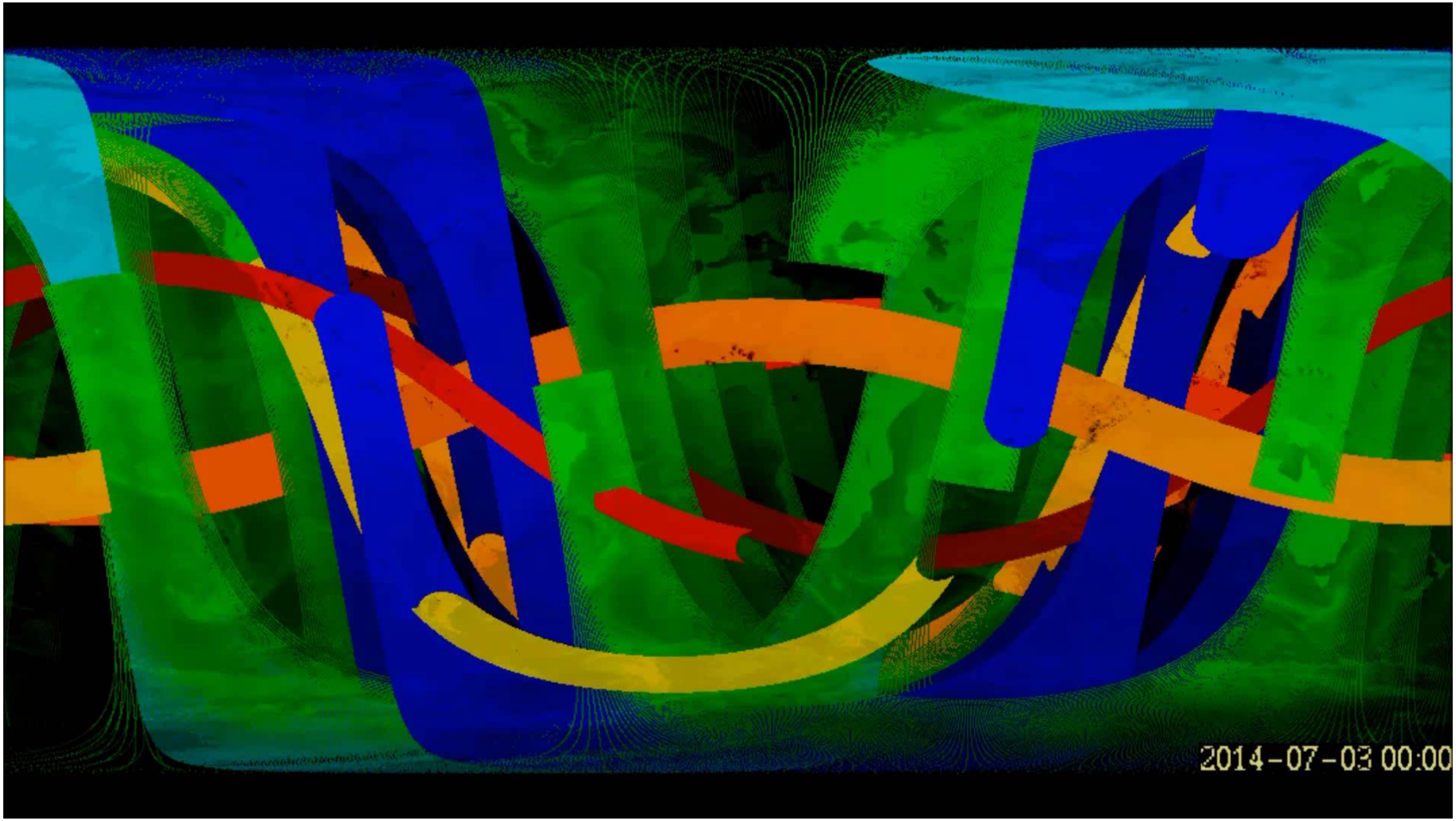
GPM is able to view storms as they transition to extra-tropical systems at higher latitudes



GPM Constellation

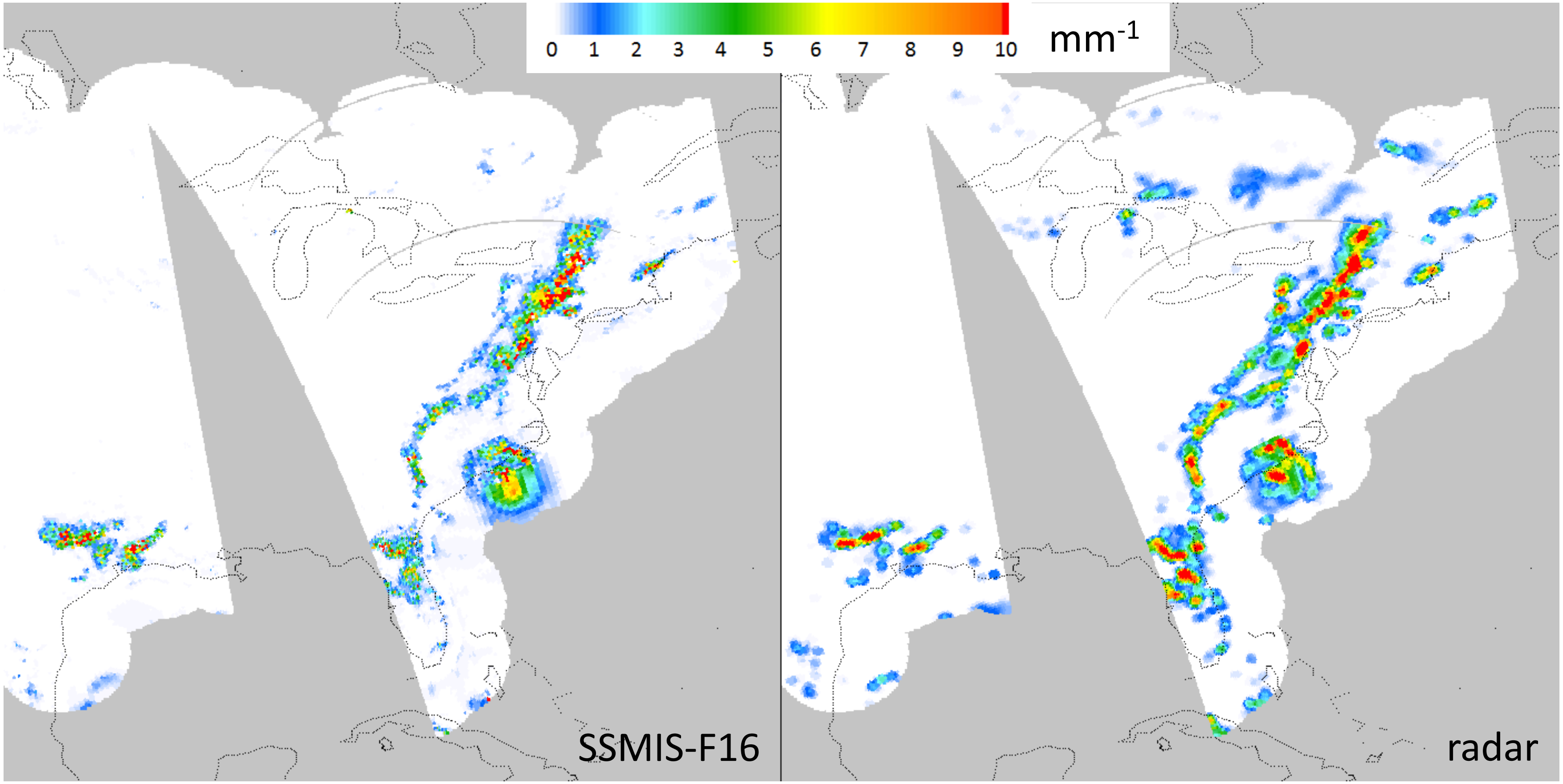


GPM constellation



MHS – MetOp/NOAA; AMSR2 – GCOM-W; SSMIS – DMSP; SAPHIR – MT; GMI – GPM; TMI - TRMM

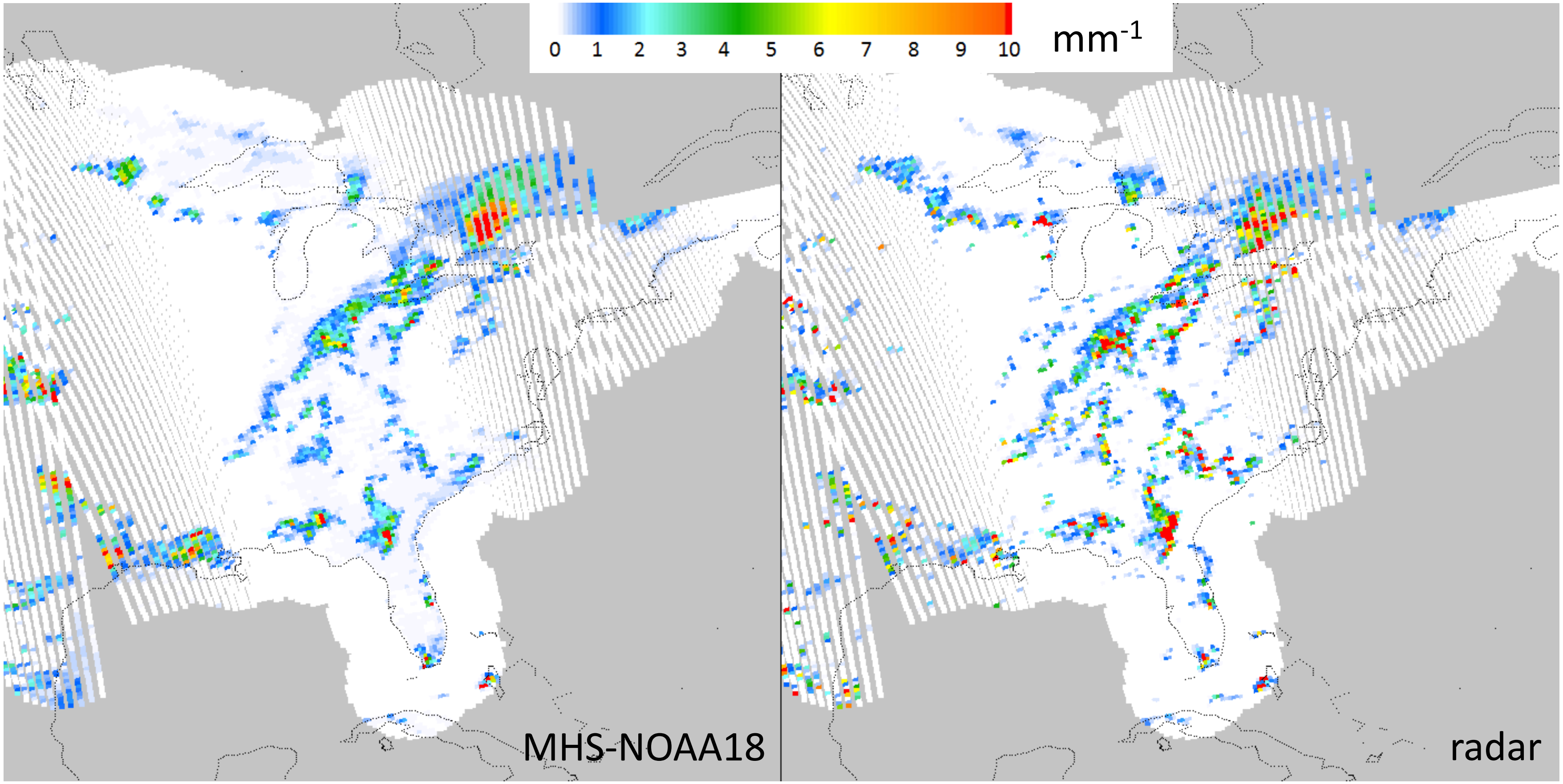
SSMIS (F16) retrieval (GPROF)



3 July 2014: Hurricane Arthur

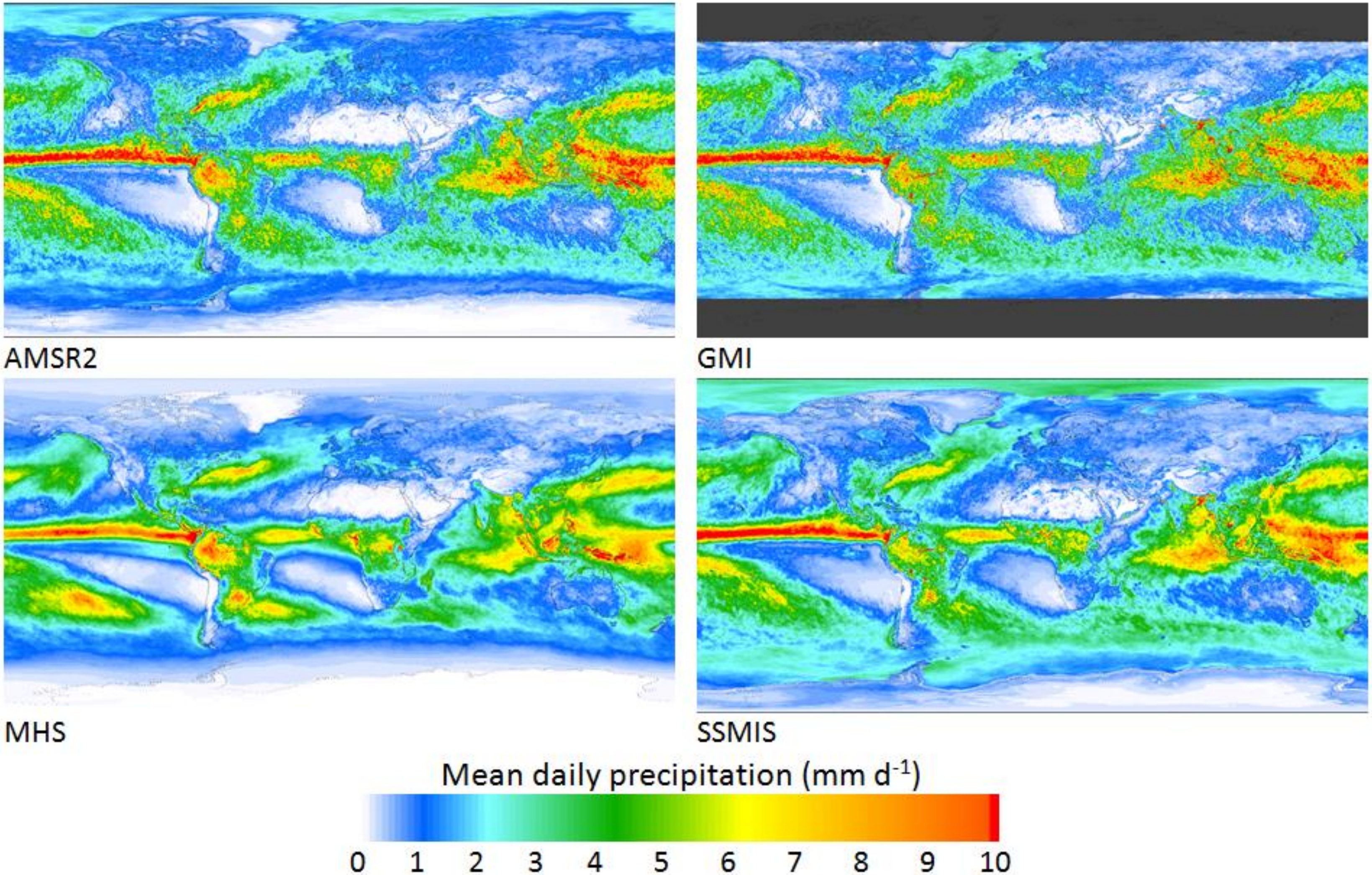
The SSMIS retrieval resolution is at the size of the 37 GHz footprint – but sampled at 12.5 x 12. 5 km: over land reliance on high frequency channels (higher resolution?)

MHS (NOAA18) retrieval (GPROF)

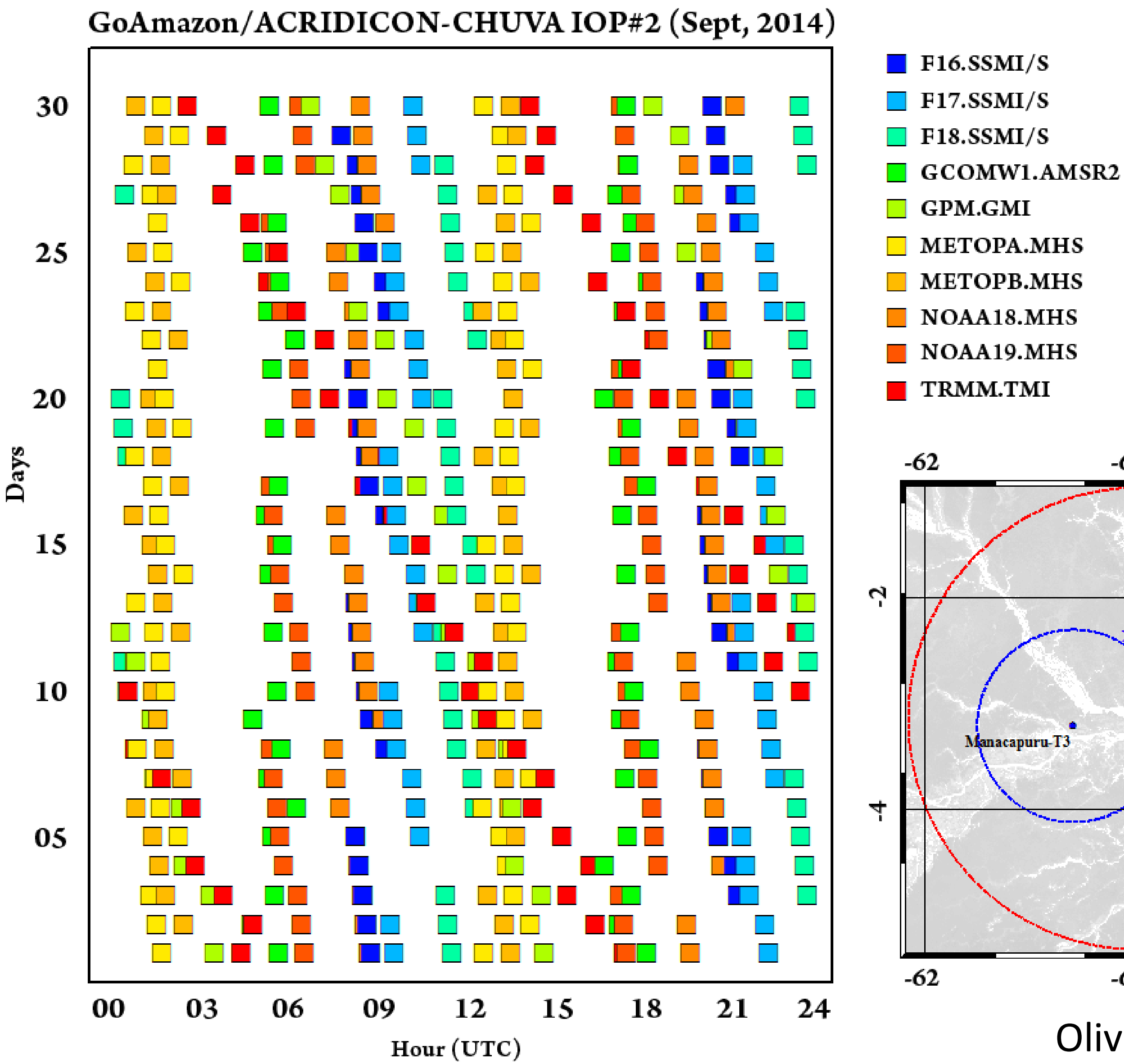


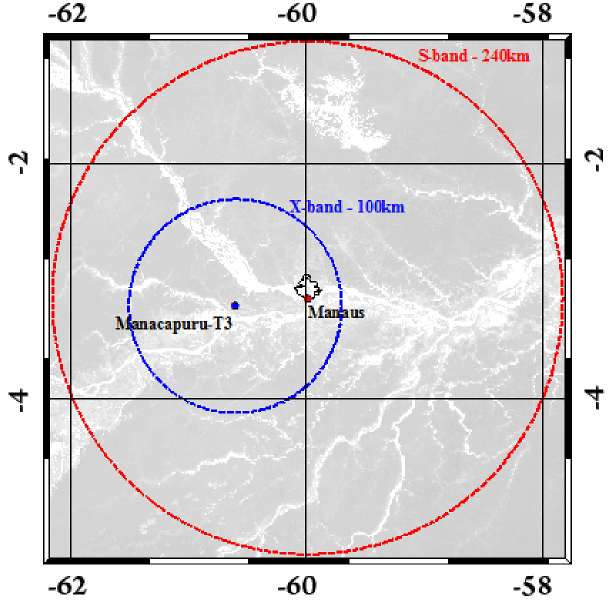
Cross-track retrievals are comparable at identifying and quantifying precipitation, even at the coarse-resolution edge-of-scan footprints

Mean Annual Global Estimates



Preliminary results of GPROF2014 and IMERG for Amazon-Brazil



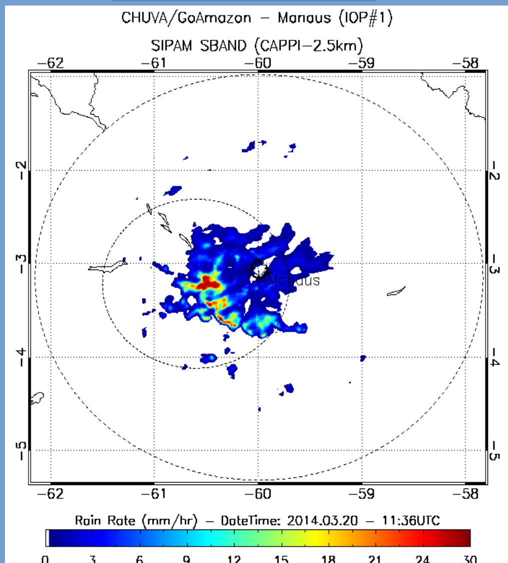


Oliveira R. – PhD Student

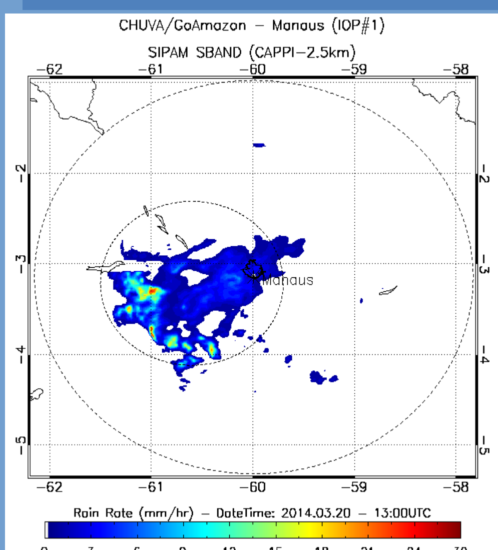
2014.03.20

S-Band radar

11:36 UTC

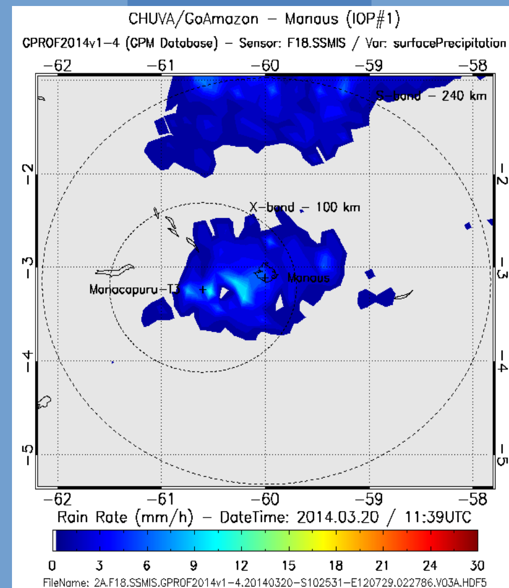


13:00 UTC

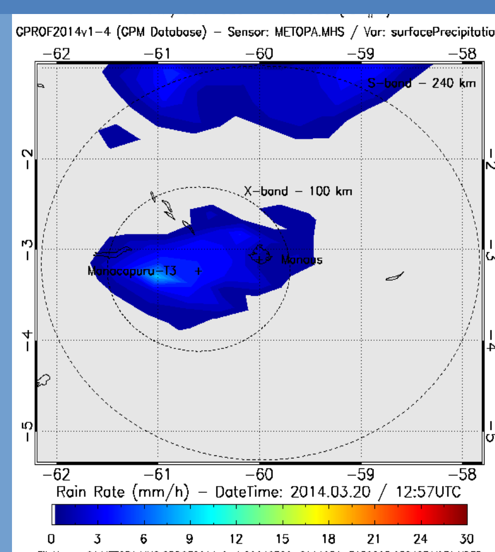


GPROF2014

11:39 UTC

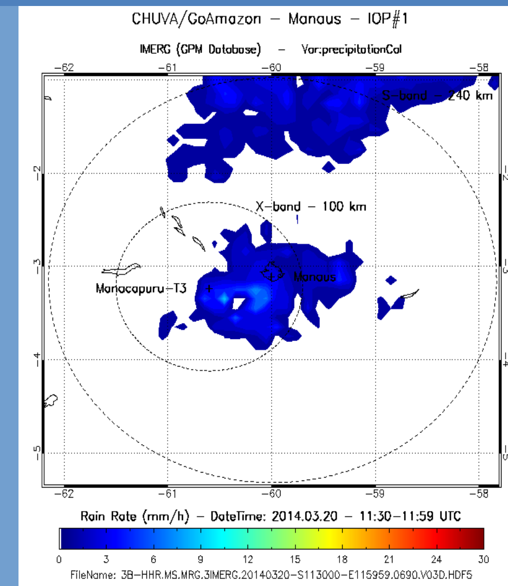


12:57 UTC

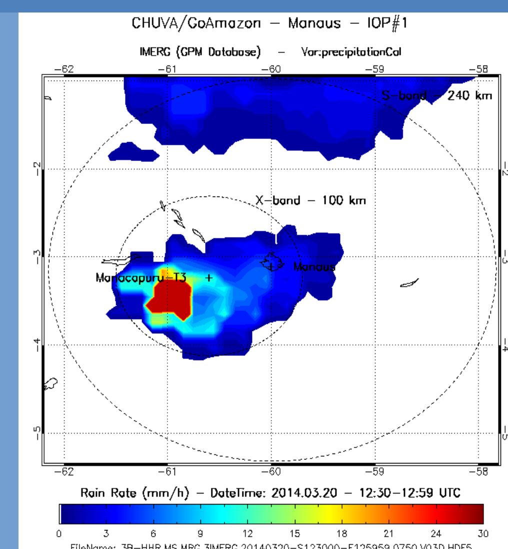


IMERG HHR - V03D

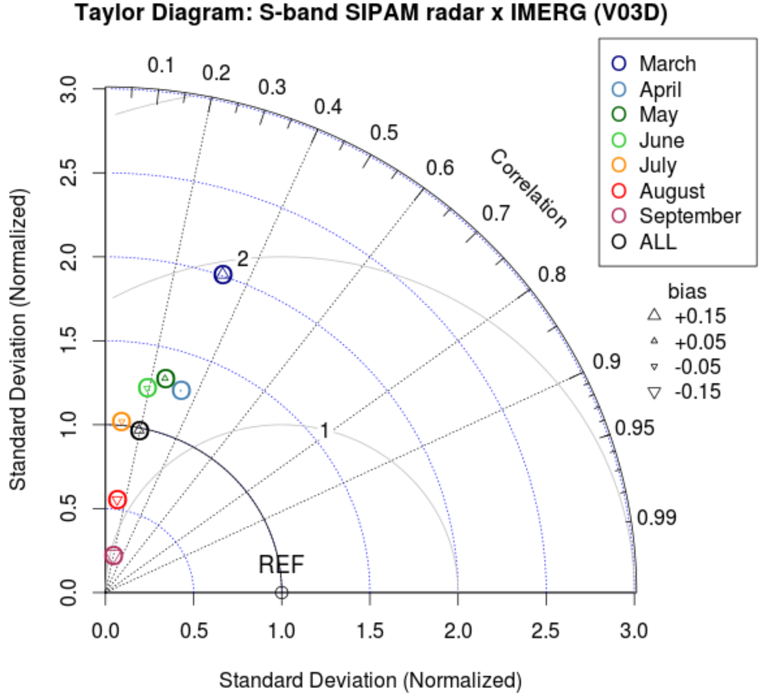
11:30 - 12:00 UTC

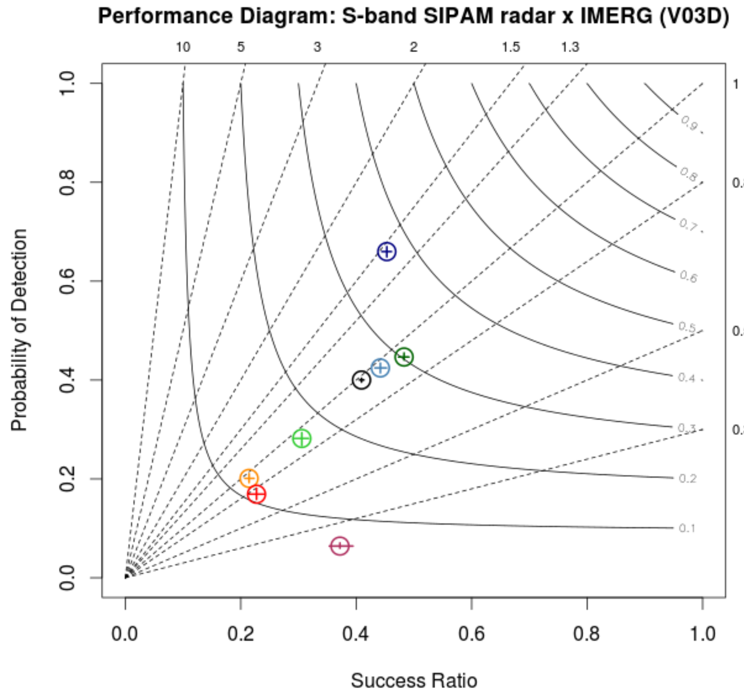


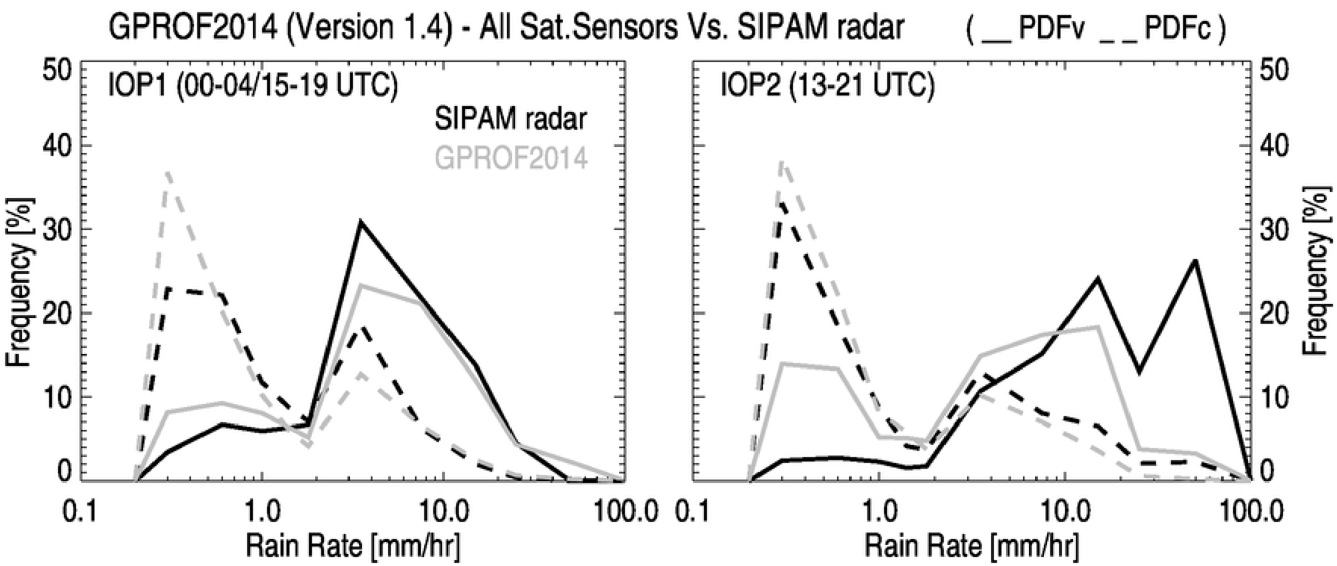
12:00 - 12:30 UTC



SIPAM vs. IMERG



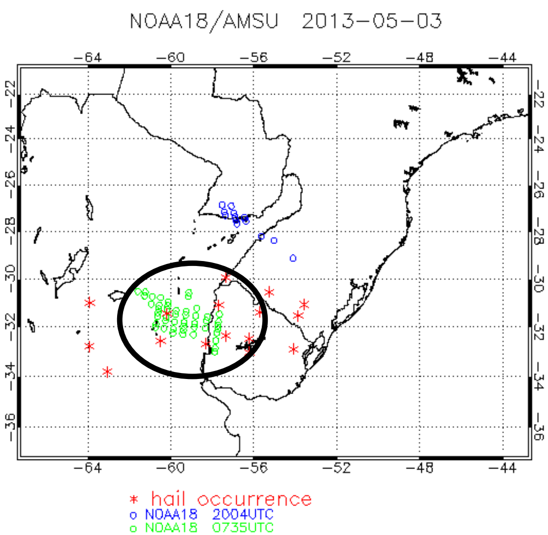


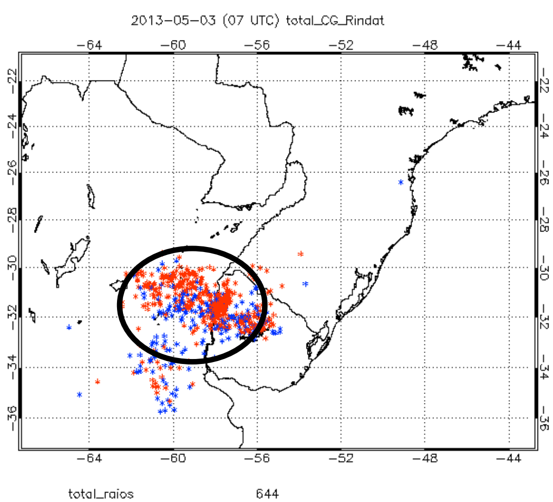


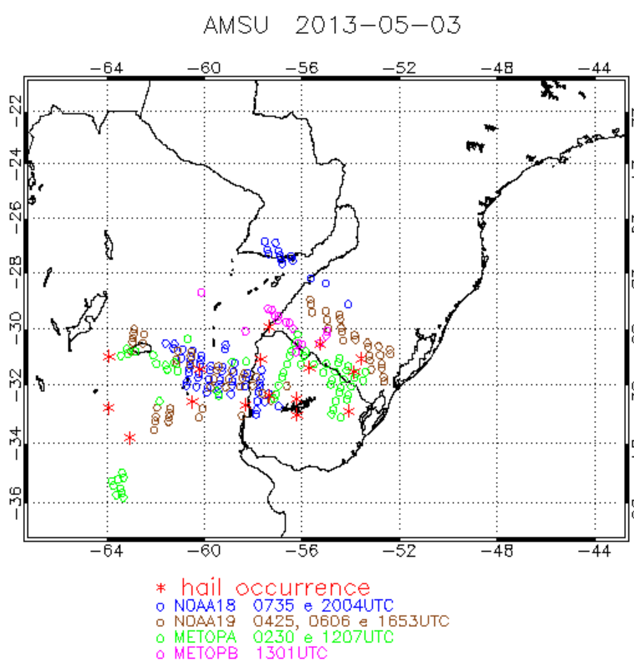
Algoritmo de detecção de granizo utilizando o Advanced Microwave Sounding Unit (AMSU)

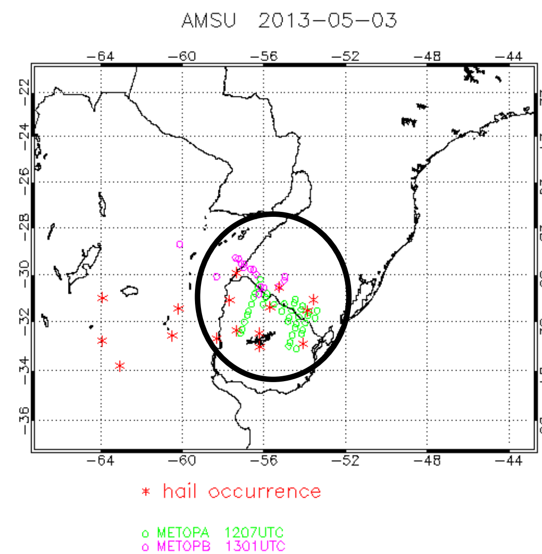
O algoritmo é baseado em simples limiares de temperaturas de brilho

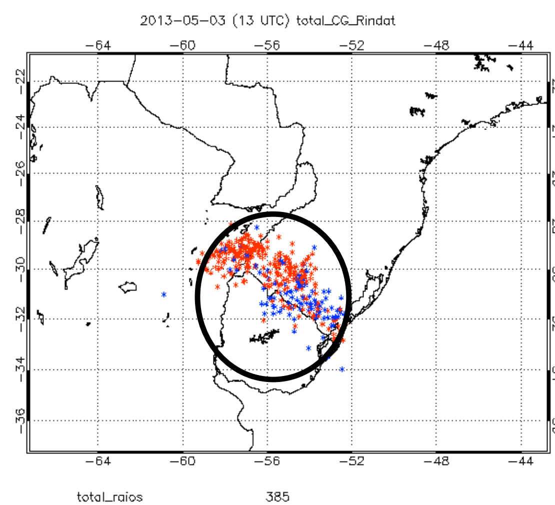
Tb_ch5 (89GHz)= 228.219;
Tb_ch6(150GHz)=206.950;
Tb_ch7(183±1GHz)=211.154;
Tb_ch8(183±3GHz)=204.628;
Tb_ch(183±7GHz)=200.500K











ROLE OF GPM GROUND VALIDATION

Pre-launch algorithm development & post-launch product evaluation

- Refine algorithm assumptions & parameters
- Characterize uncertainties in satellite retrievals & GV measurements

"Truth" is estimated through the convergence of satellite and ground-based estimates

Three complementary approaches:

- *Direct statistical validation (surface):*

  - Leveraging off operational networks to identify and resolve first-order discrepancies between satellite and ground-based precipitation estimates

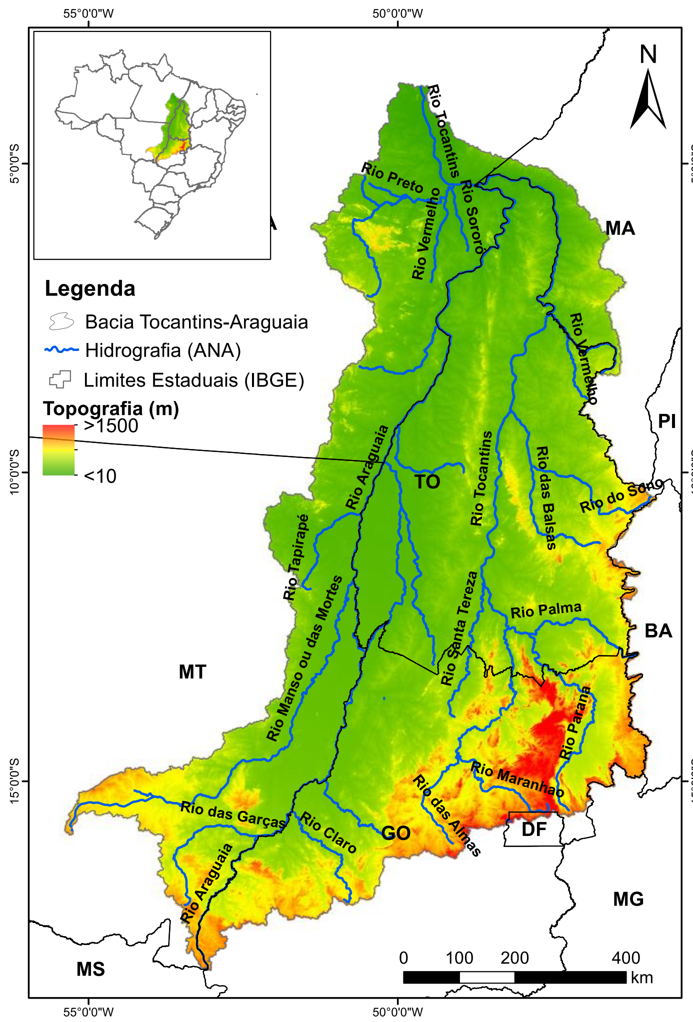
- *Physical process validation (vertical column):*

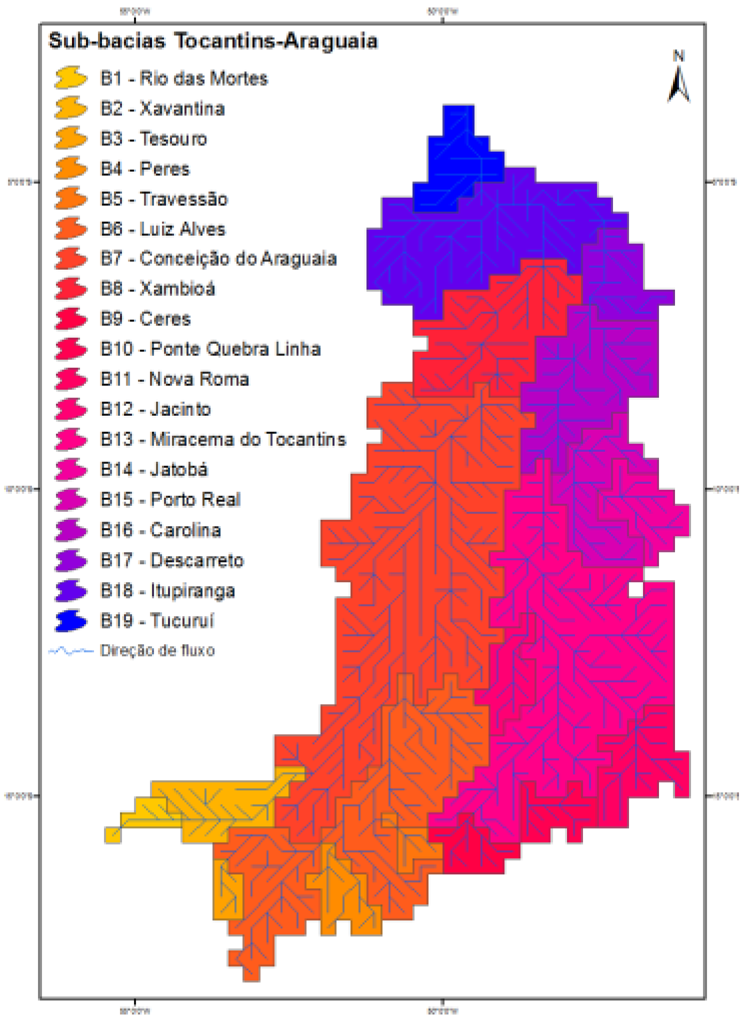
  - Cloud system and microphysical studies geared toward testing and refinement of physically-based retrieval algorithms

- *Integrated hydrologic validation/applications (4-dimensional):*

  - Identify space-time scales at which satellite precipitation data are useful to water budget studies and hydrological applications; characterization of model and observation errors

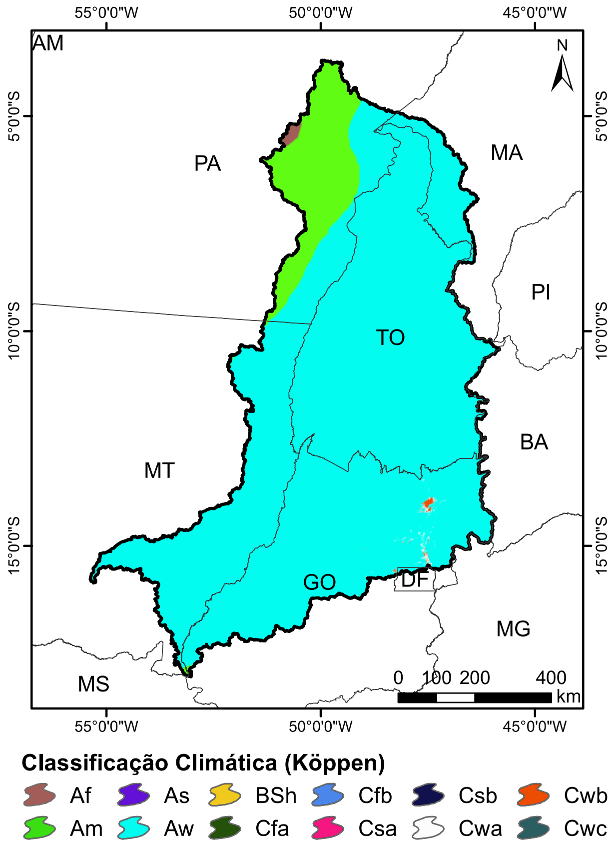
Evaluation of satellite rainfall estimates on hydrological modeling of Tocantins-Araguaia basin



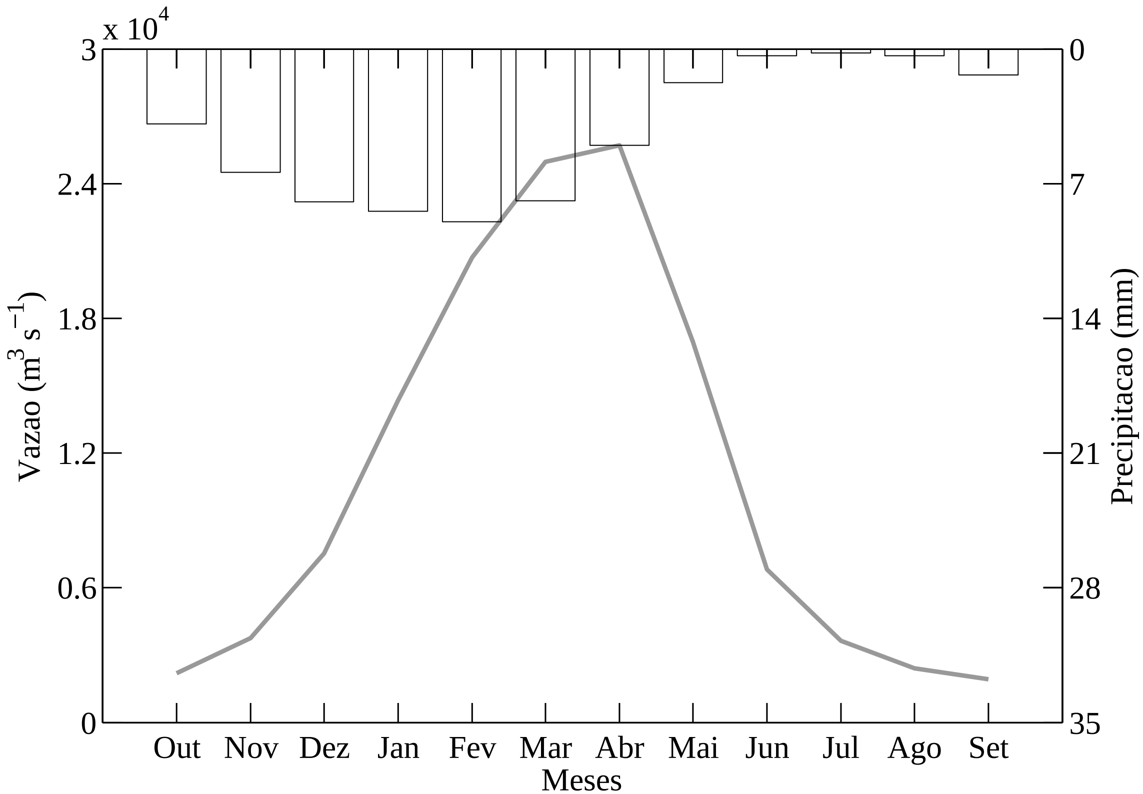


Localization of Tocantins river basin
Area: ~800,000 km^2

Evaluation of satellite rainfall estimates on hydrological modeling of Tocantins-Araguaia basin



Regimes climáticos (Alvares et al., 2013)

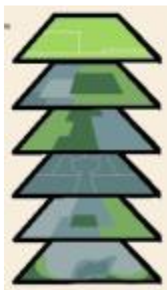


Mean rainfall and discharge at Tocantins-Araguaia basin (Estação Tucuruí; 2000-2011)

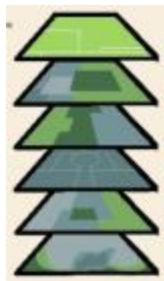
SREM2D

(Hossain & Anagnostou (2006))

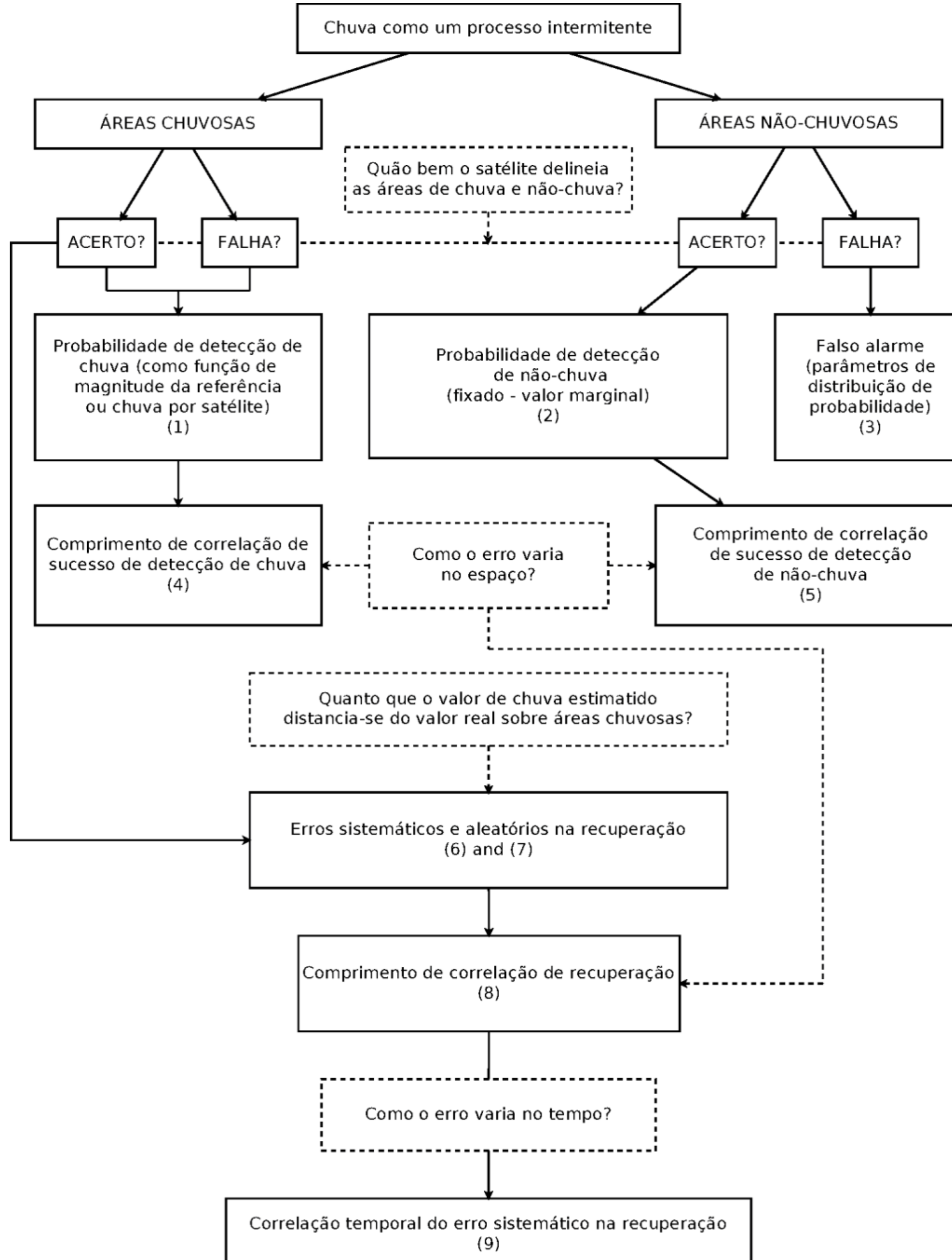
Série de tempo
Estimativa de precipitação por satélite



Série de tempo
Dados de referência, maior precisão (pluviômetros, radar)



Estimativa satélite	Referência: **Chuva**	Referência: **Não-chuva**
Chuva	Na (acerto)	Nb (falha)
Não-chuva	Nc (falha)	Nd (acerto)



Implementação SREM2D

Entrada

Algoritmos de estimativa de precipitação por satélite

Parâmetros

Métricas SREM2D inversa

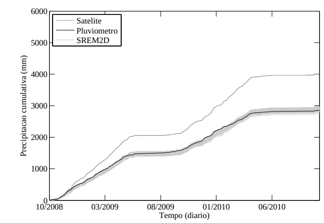
(9 métricas)

Processamento

SREM2D

Saída

Precipitação por Conjuntos



Entrada

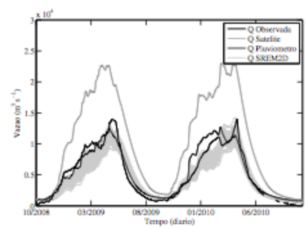
Precipitação por Conjuntos

Processamento

MHD-INPE

Saída

Vazão simulada por Conjuntos



Métricas de desempenho

Razão de Excedência (ER)

Razão de Incerteza (UR)

Propagação do erro

Erro Médio Absoluto relativo (rMAE)

Raiz Erro Quadrático médio relativo (rRMSE)

Fator de Propagação MAE

Fator de Propagação RMSE

Modelo hidrológico distribuído (MHD-INPE)

(RODRIGUEZ, 2011;
SIQUEIRA JÚNIOR et al.,2014)

A estrutura do MHD-INPE é composta por quatro módulos:

✧**Balanço de água no solo;**

✧**Evapotranspiração:**

Eq. Penman-Monteith

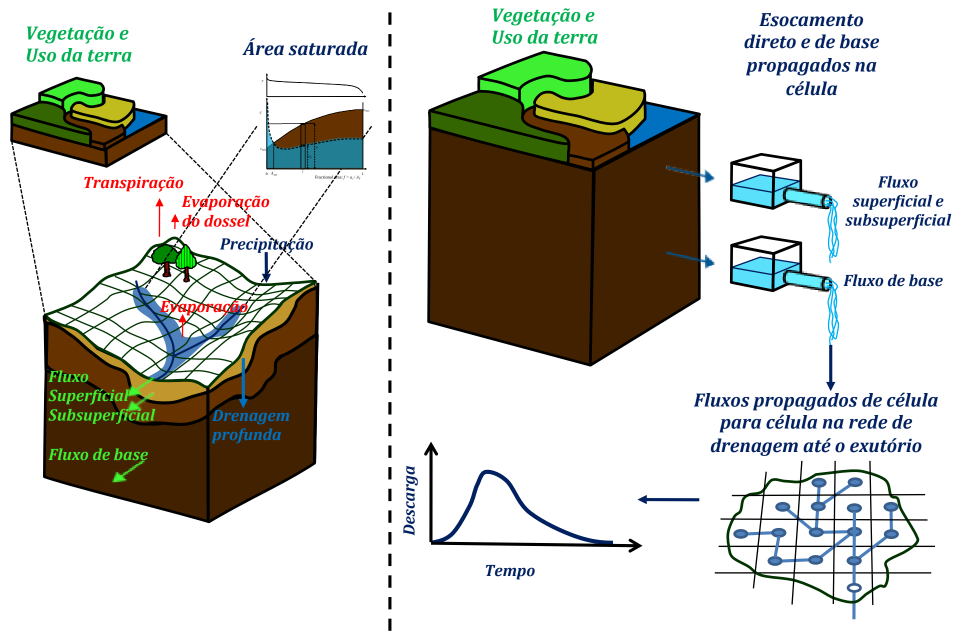
✧**Escoamentos:**

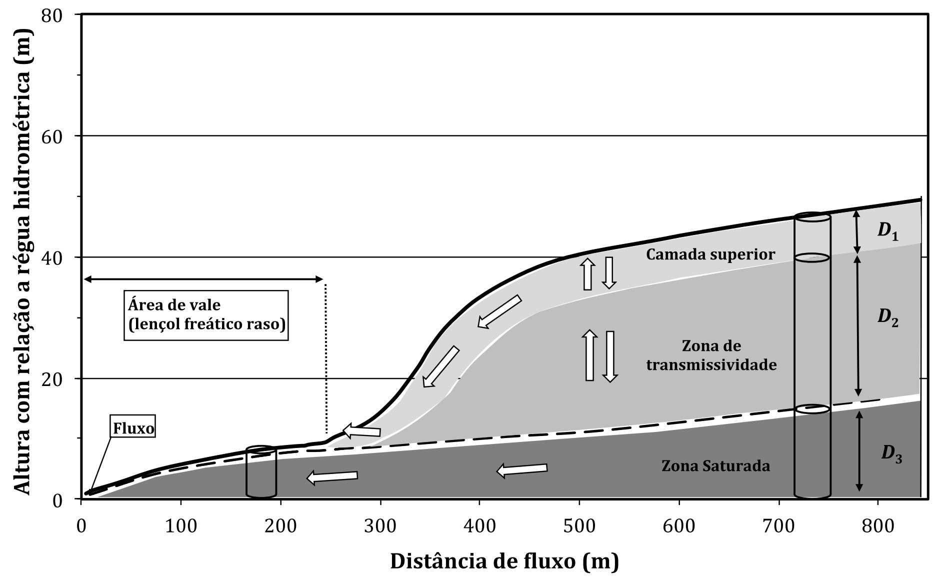
Superficial;

Sub-superficial;

Subterrâneo.

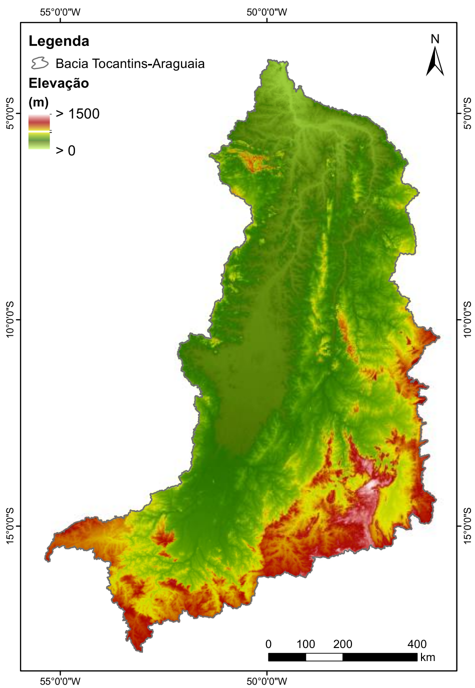
✧ **Escoamento na rede de drenagem**





Implementação do MHD-INPE

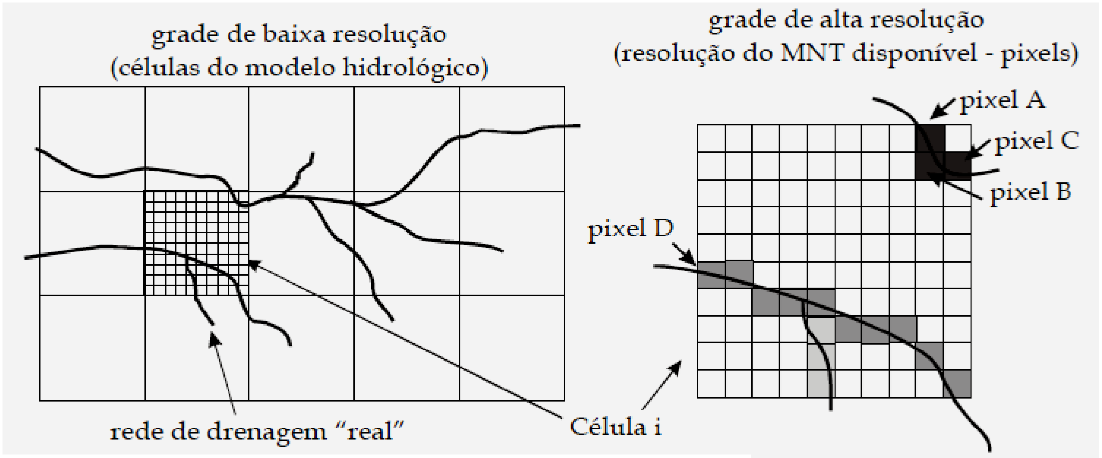
Bacia do Tocantins-Araguaia
Res. espacial 0,25º x 0,25º (total 1008 células)
Res. temporal diária
Calibração: 01/01/2000 a 14/10/2008
Verificação: 15/10/2008 a 14/10/2011

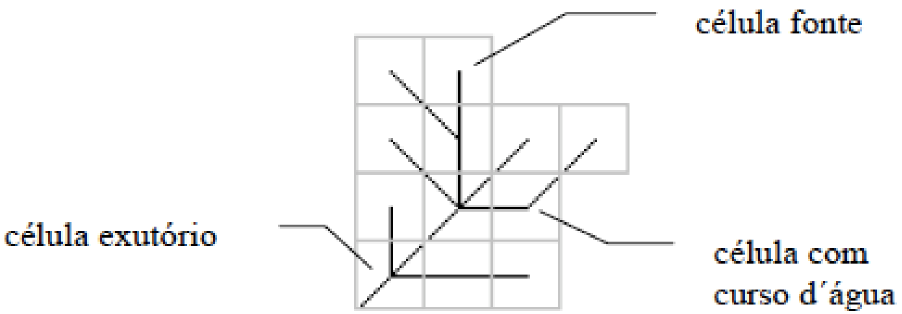


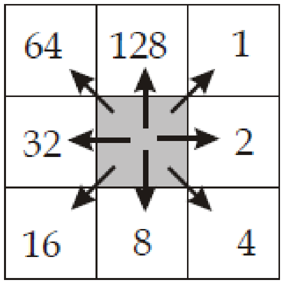
Modelo Digital de Elevação

- **Rede de drenagem**

  Rosim et al. (2008)

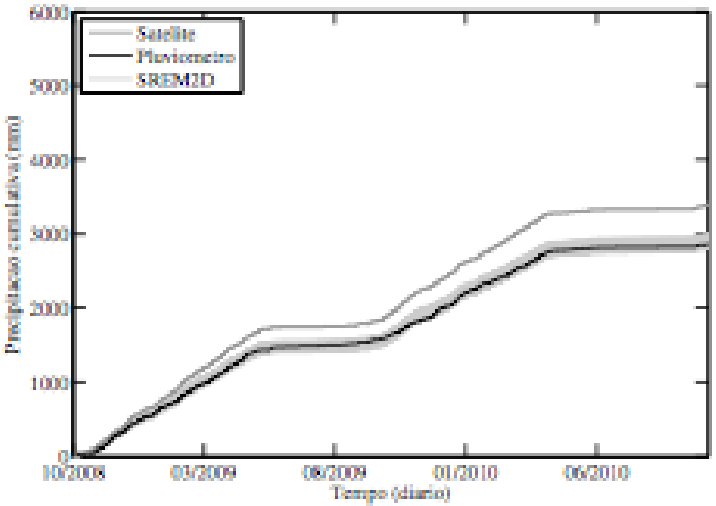




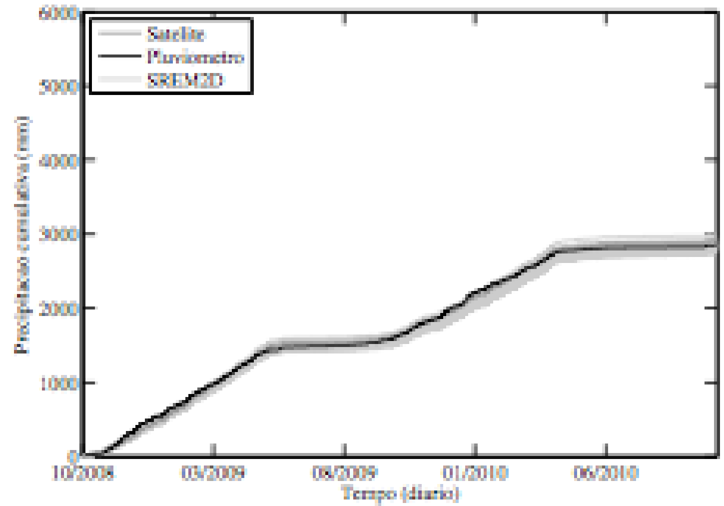


Discretização da bacia em células e a rede de drenagem
Fonte: Paz e Collischonn (2001)

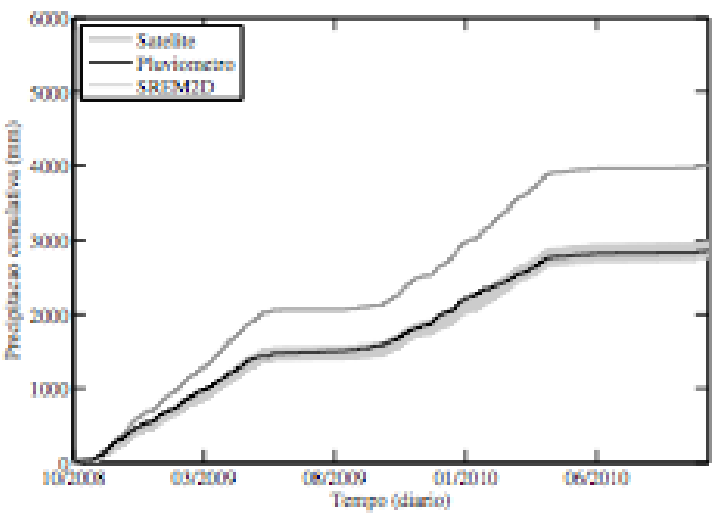
Conjuntos (100 membros)



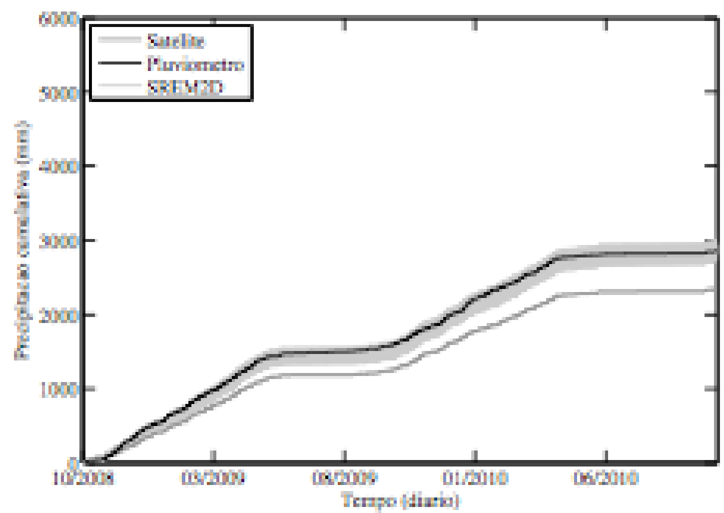
(a) CMORPH



(b) 3B42RT

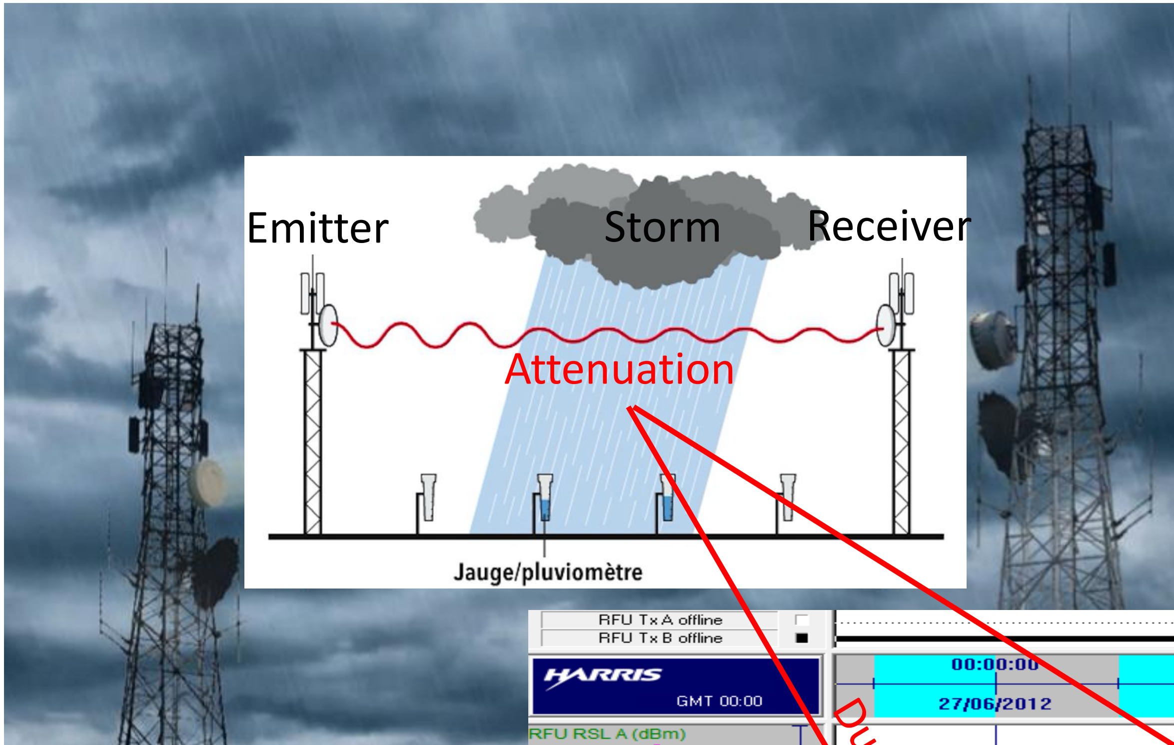


(c) HYDROE



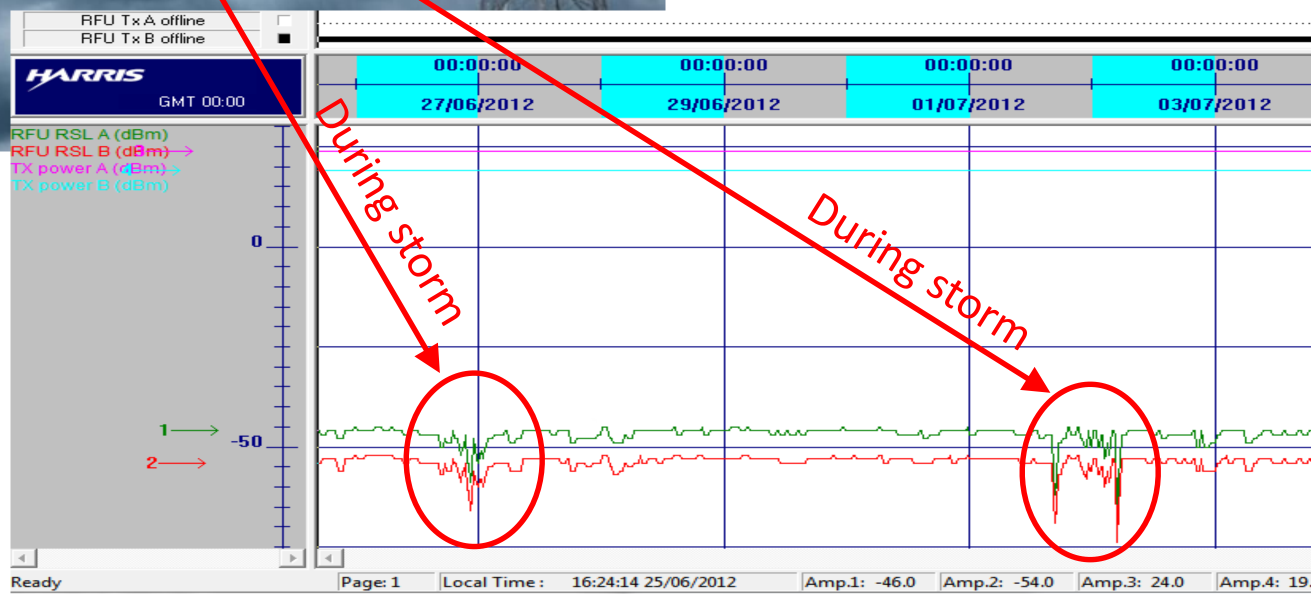
(d) GSMAP

Remote rainfall from cell phone antenna : ***Principle***



Rainfall attenuates the microwave signal between telecom towers.

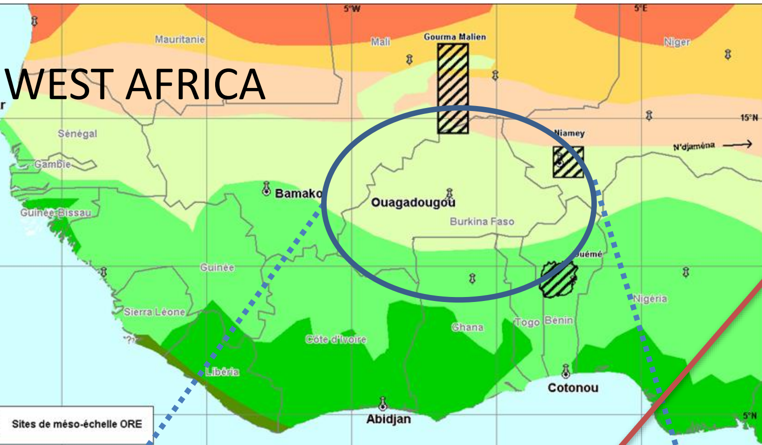
Typical Rainfall signature in reception data record from telecom operator

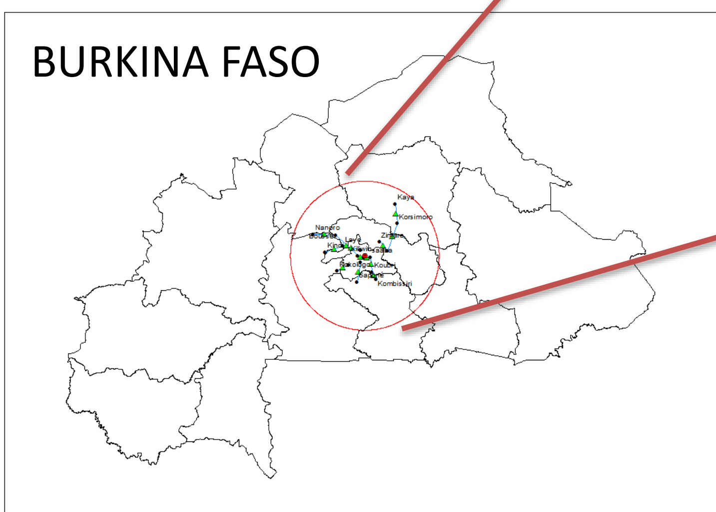


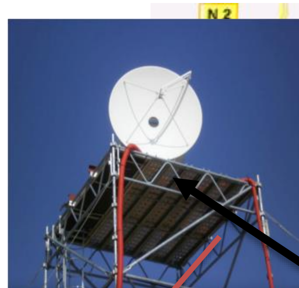
Courtesy of Telcel Faso

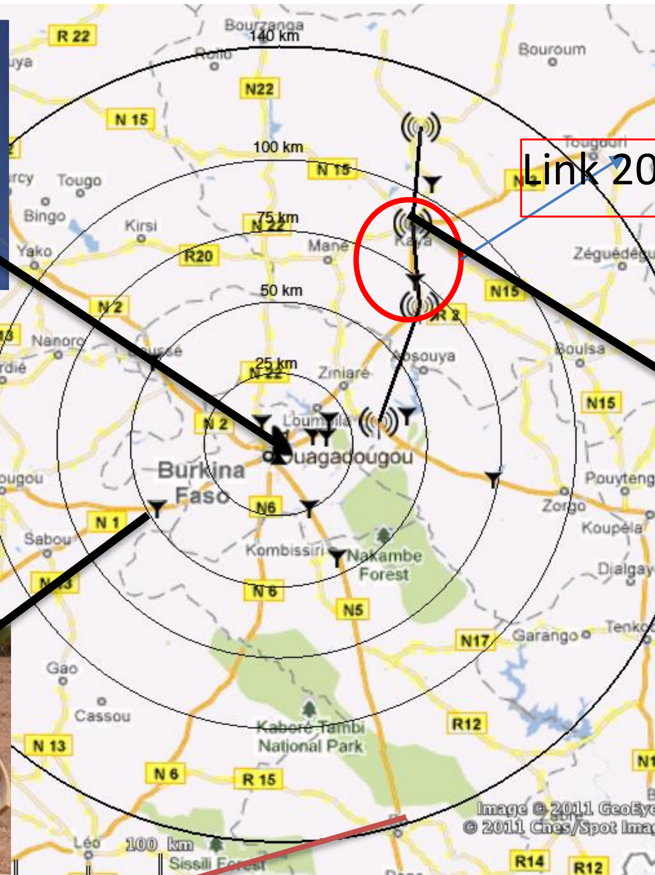
Based on Megha-Tropiques GV network

ISRO-CNES
megha-tropiques









	Dist(Km)	Freq	polar
Radar Xport	135	9.4GHz	H/V
Korsimoro/Kaya	29	7GHz	H
Rain gauges	17 with 0.5mm resol/400cm2		

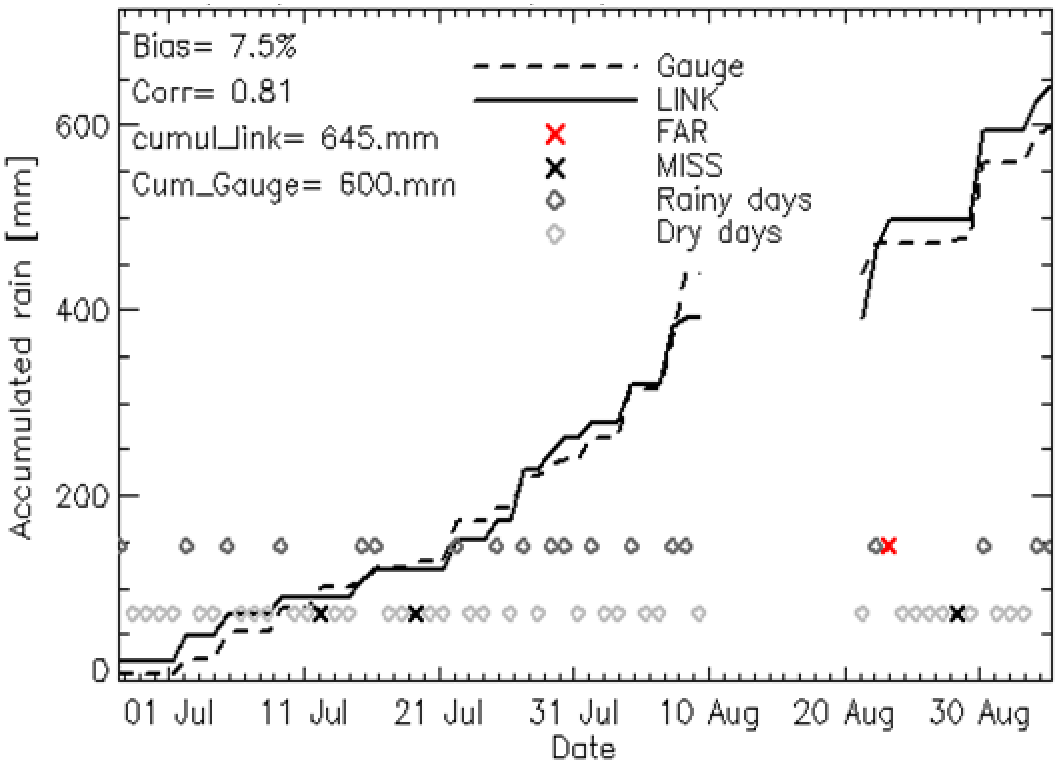
Doumounia et al, 2014 , GRL

Remote rainfall from cell phone antenna : ***First results in Africa***

2 - Quantification

- **Excellent agreement with the rain gauge (correlation 0.8 for the whole season)**
- **Probability of detection = 95 %**
- **Better or as good as satellite rainfall products !**
- **Very Low overall bias**
- **But RMSE ~ 40%**

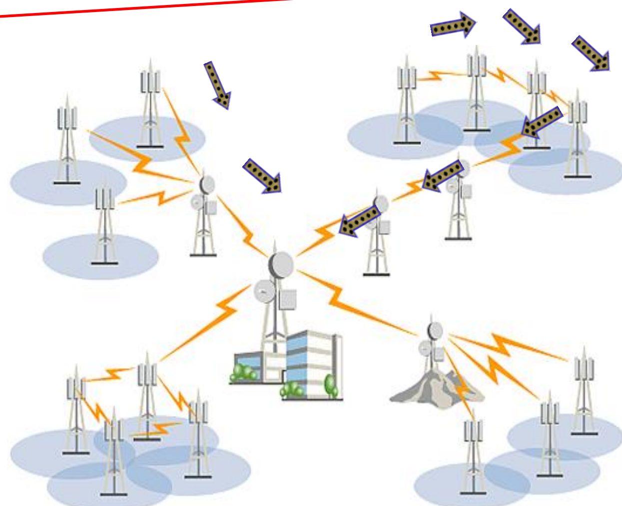
Rain Gauge VS Link Rainfall accumulations
Ouagadougou, 2012

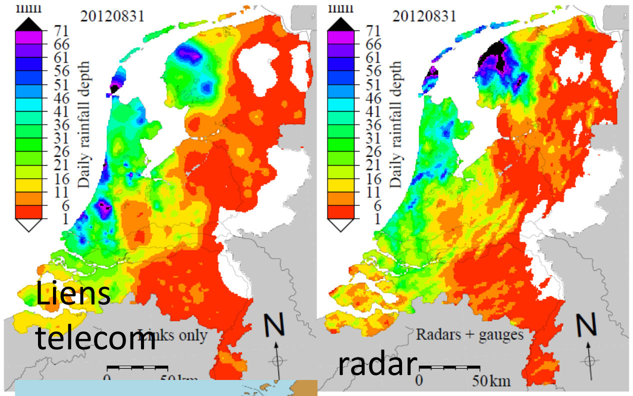


Let's test it Campinas !!

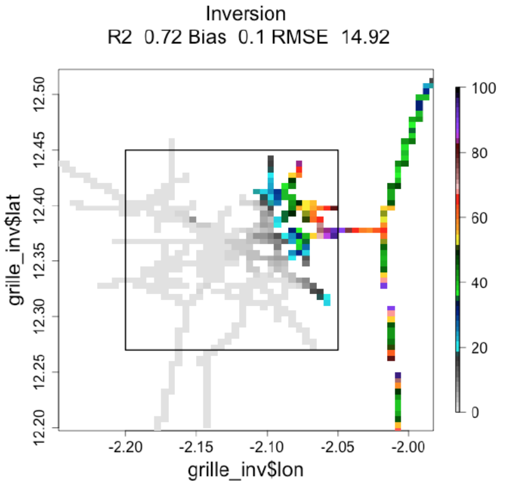
with SOS CHUVA data for validation

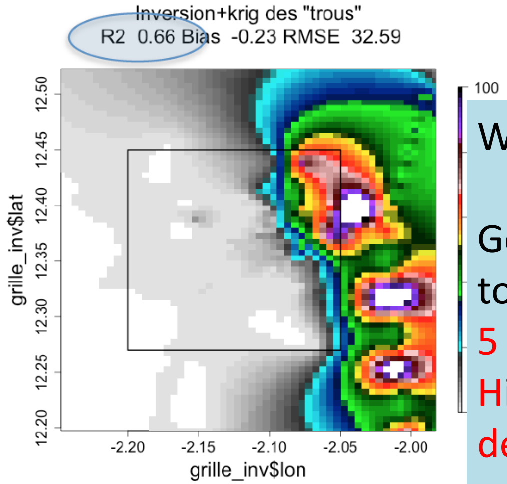
Advantage :
High RES :
Dense networks of MWlinks available ~free of charge for science !!!





cf The Netherland KNMI

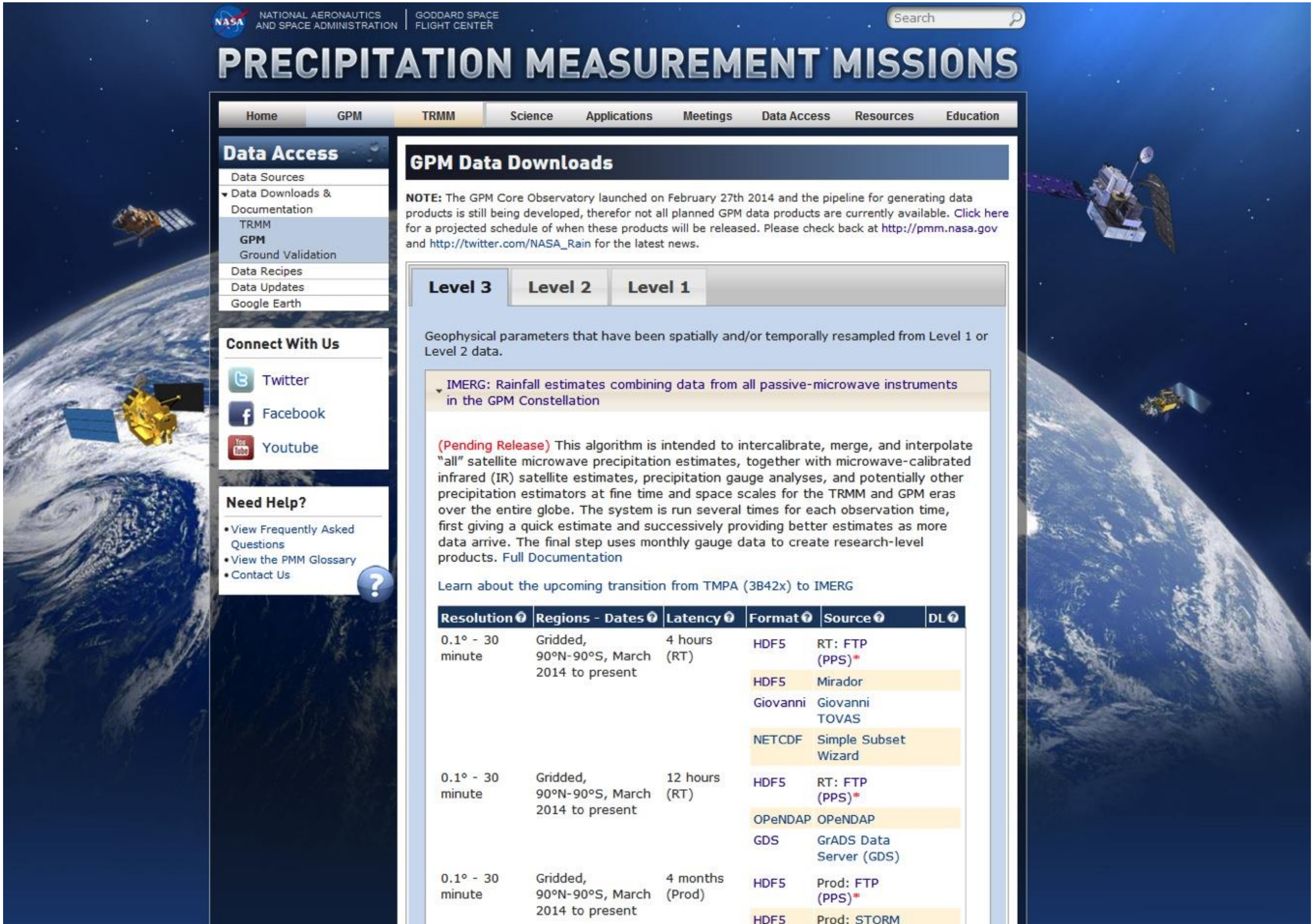




World Bank Projet in Burkina Faso / Mali

Generate high resolution Rain fields over a town for flood forecast
5 minutes time step
High resolutuion in town because of high density

Data Access (http://pps.gsfc.nasa.gov)



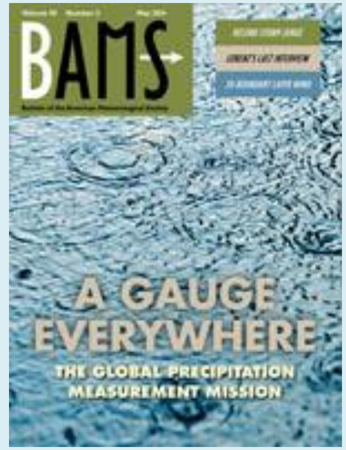
More information on the GPM mission

http://gpm.nasa.gov

http://www.nasa.gov/gpm

Twitter: NASA_Rain

Facebook: NASA.Rain



The Global Precipitation Measurement Mission
A.Y. Hou, R.K. Kakar, S. Neeck, A. A. Azarbarzin, C.D. Kummerow, M. Kojima, R. Oki, K. Nakamura, T. Iguchi. **May 2014.**