Passive microwave precipitation retrieval: potentials, challenges, and future perspectives within H-SAF

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H-SAF PMW precipitation products at ISAC-Rome

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National Research Council of Italy (CNR)
Rome, Italy

Precipitation products in H-SAF

- **H-SAF aims at providing precipitation products based on remote sensing techniques with the accuracy and at the spatial and temporal scales useful *mainly* to operational hydrology and water management**
  - Passive microwave (PMW) retrieval techniques
  - Combined IR/MW retrieval techniques
  - Derived cumulated rainfall

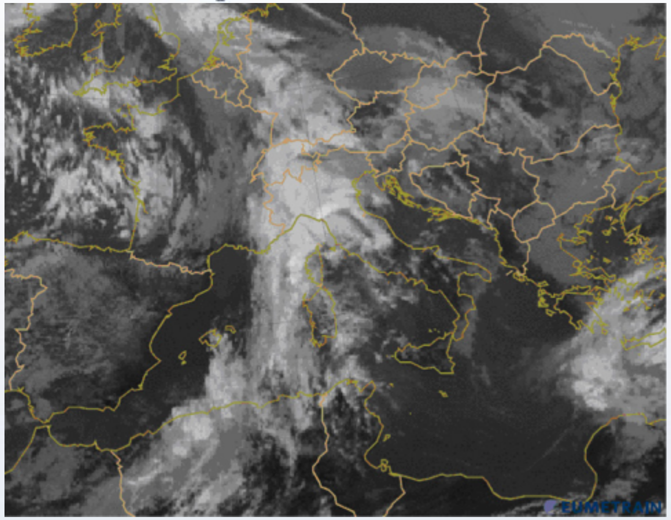
Precipitation retrieval from PMW observations within H-SAF

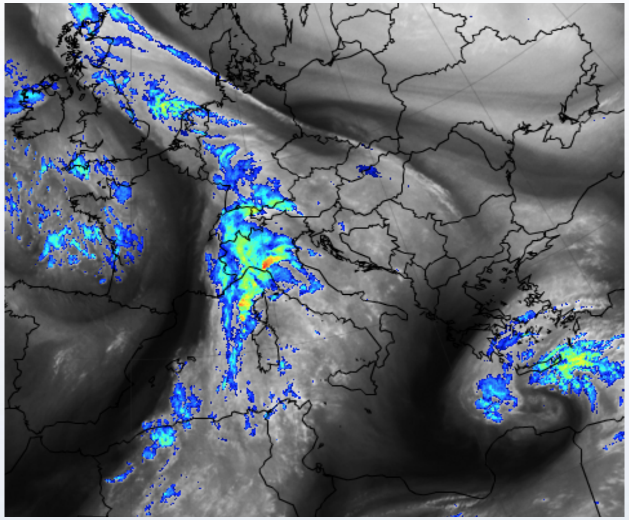
Potentials: PMW radiometers (conically and cross-track scanning) offer the most complete set of satellite based observations to retrieve surface precipitation due to the ability of MW radiation to penetrate precipitating clouds and interact with its liquid and iced hydrometeors.

Challenge: Achieve **consistency** and **accuracy** of passive microwave precipitation retrievals from the different sensors orbiting around the globe

Future perspectives: Full exploitation of *all* overpasses of present and future satellites carrying cross-track and conically scanning PMW radiometers, which has now reached its optimal configuration with the NASA/JAXA GPM, and exploitation of the GPM core satellite

VIS/IR vs. PMW observations





October 25, 2011, 12:00 UTC: MSG IR 10.8 µm image (left), and MSG water vapor image at 6.2 µm + enhanced IR product (right) (EUMeTrain).

GEO satellites: High temporal-spatial resolution

- Signal originates from the cloud top;
- Basic assumption is that cloud-top properties are related to cloud height (or thickness for VIS), which in turn is related rainfall rate
  - Colder (deeper) or brighter (thicker) cloud are associated with heavier rain
  - Warmer or darker clouds are associated with light or no rain
- Reasonable assumption for convective clouds
- Poor assumption for
  - stratiform clouds (warm, but wet)
  - cirrus clouds (cold, but rain-free)

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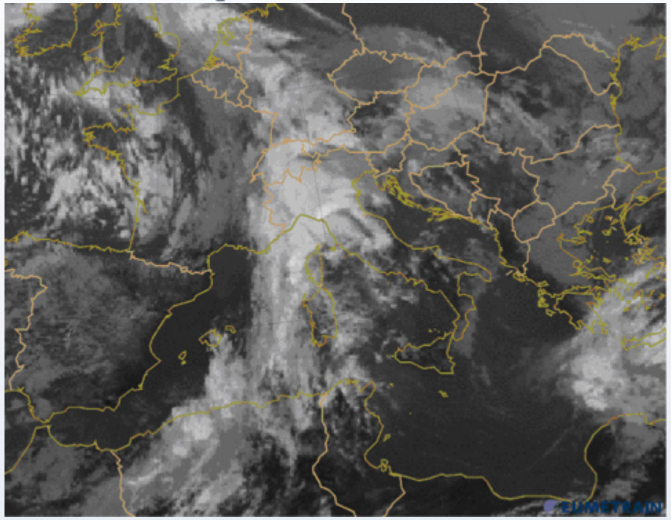
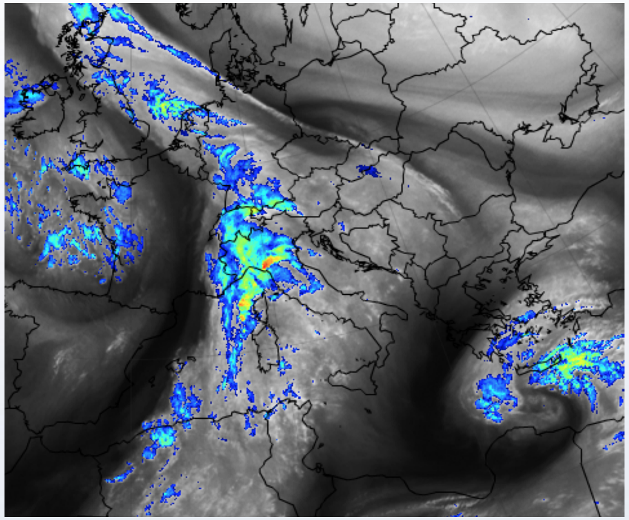
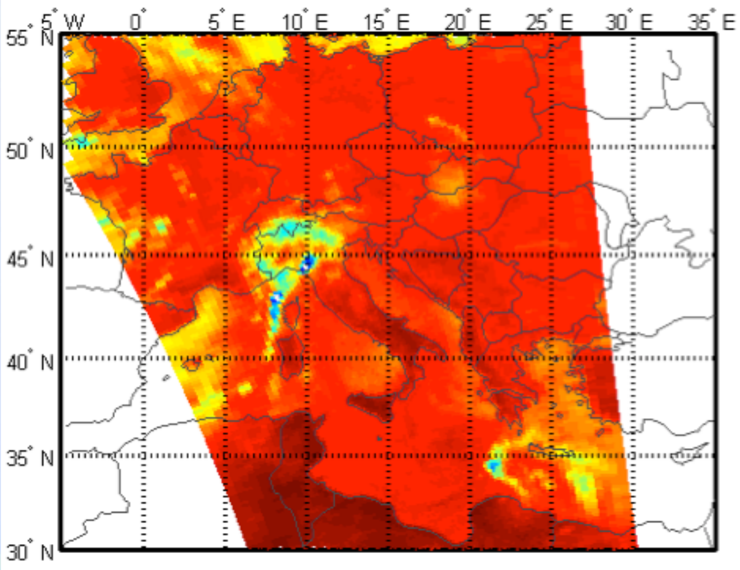
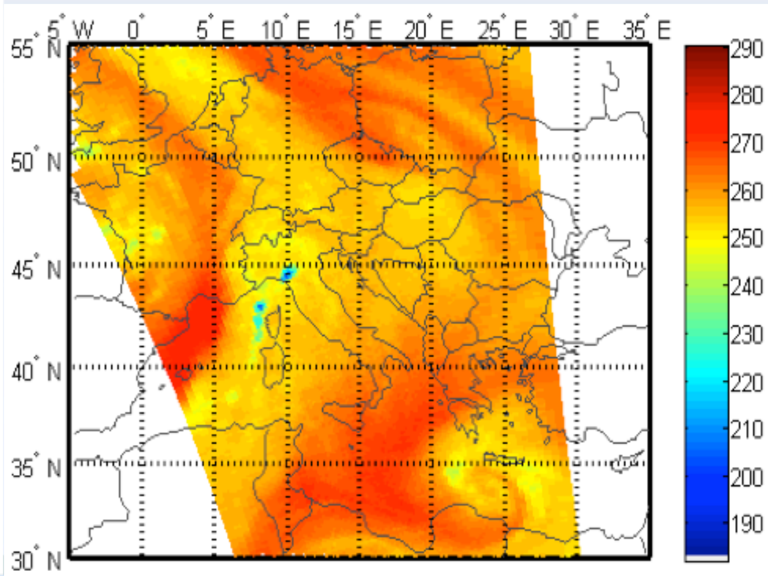
VIS/IR vs. PMW observations





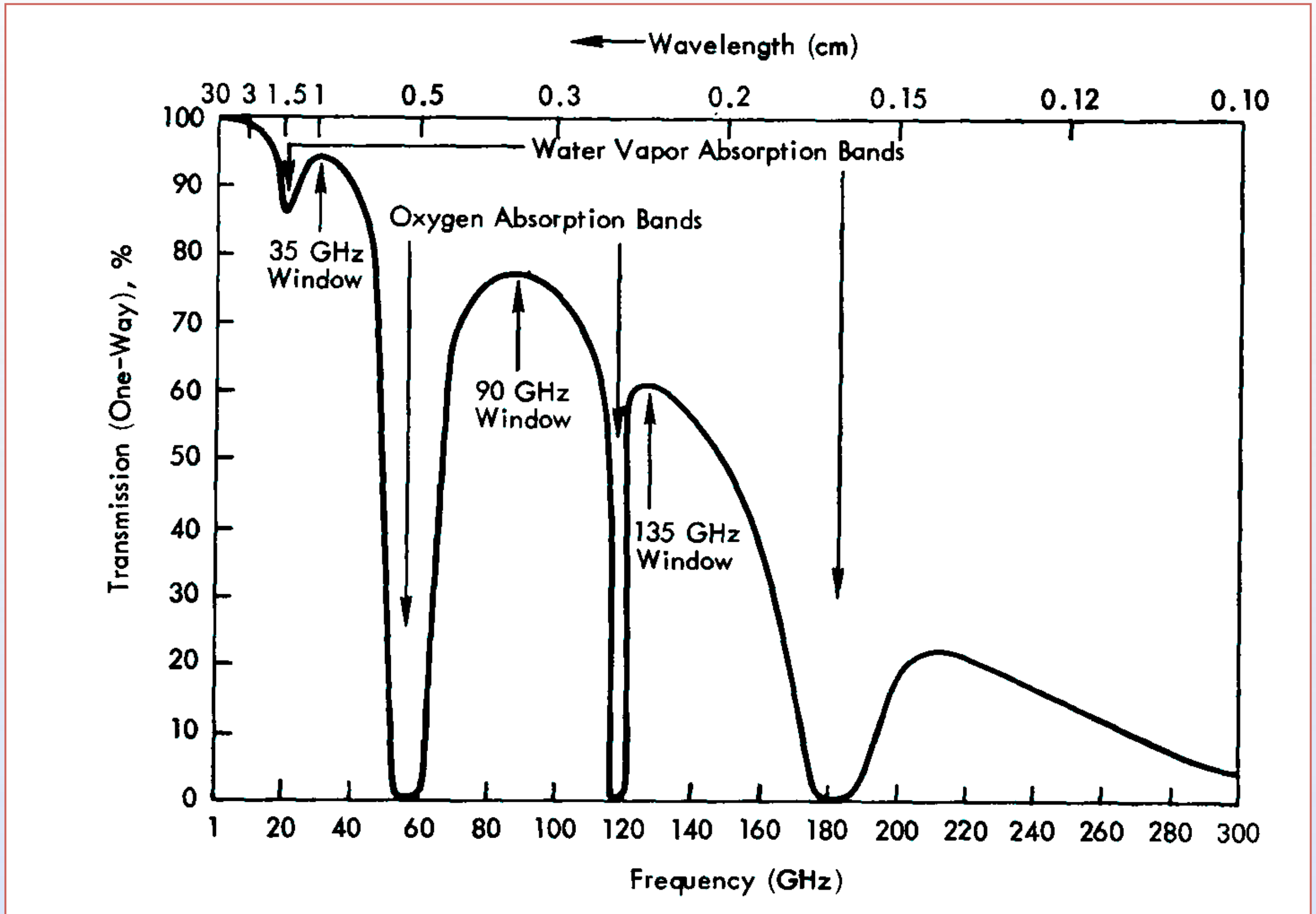
October 25, 2011, 12:00 UTC: MSG IR 10.8 µm image (left), and MSG water vapor image at 6.2 µm + enhanced IR product (right) (EUMeTrain). **GEO satellites: High temporal-spatial resolution**





October 25, 2011, 11:44 UTC: MHS (NOAA 19) TB (K) at 150 GHz (left) and TB (K) at 183.31±3 GHz WV band (right). **LEO satellites: low spatial resolution and temporal sampling**

Passive MW Radiometry



Percentage trasmission through the Earth´s atmosphere along the vertical direction, under clear-sky conditions. *[Adapted from Ulaby et al, 1981]*

- Microwave region: 1-200 GHz (30-0.15 cm)
- **Uses the same principles as thermal emission remote sensing**
- Multi-frequency/ multi-polarization sensing
- **Weak energy source so need large IFOV and wide bands (LEO)**

PMW (LEO) Precipitation Simplified Theory/Basis

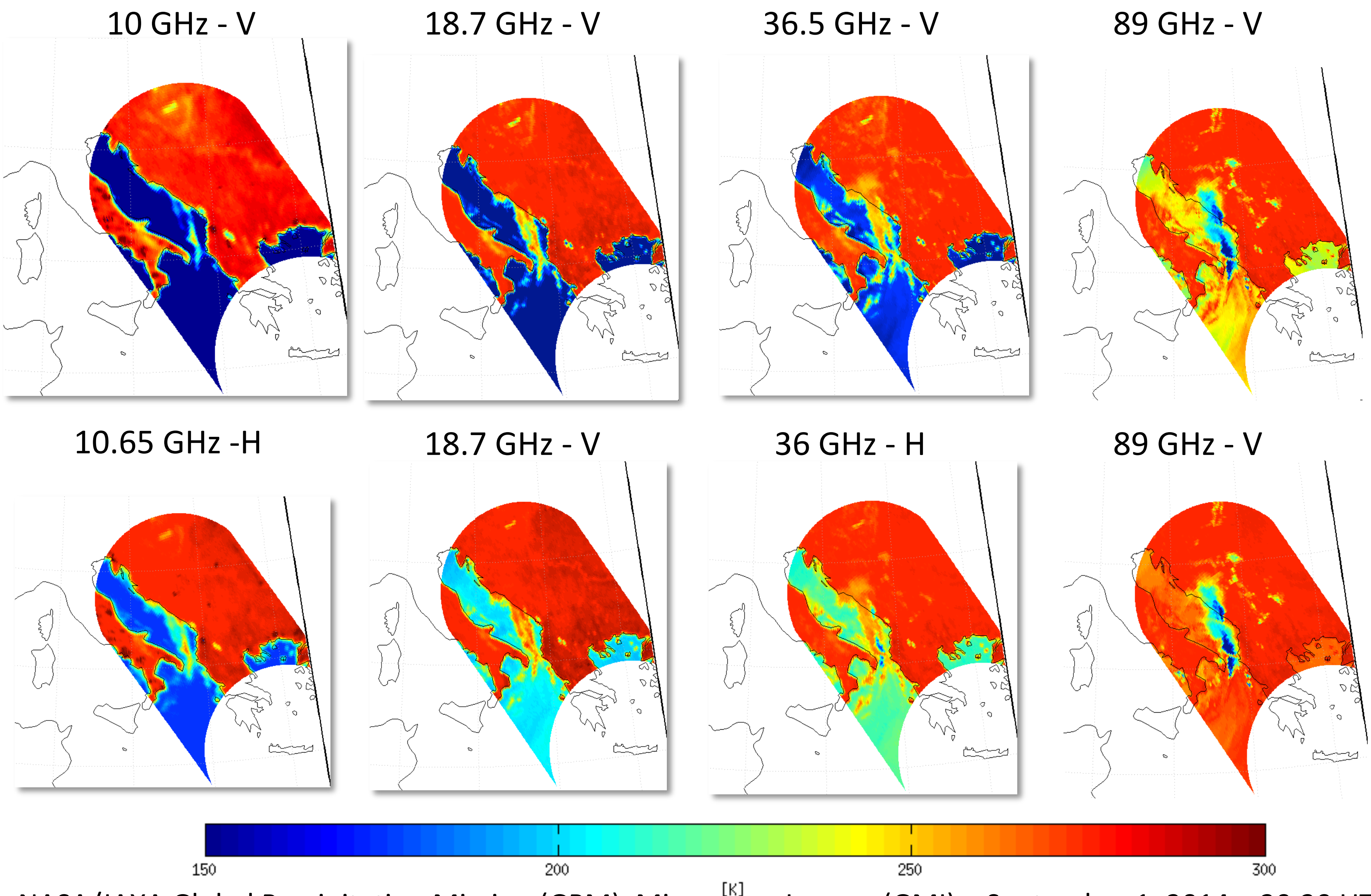
Emission: water in clouds emits radiation, can be seen against a radiatively cold background (i.e. oceans).

- Rainfall rates are related to the magnitude of the resulting brightness temperature difference (low frequencies)
- **Strength**: Sensitive to clouds with little or no ice
- **Weakness**: must know terrestrial radiances without cloud beforehand; generally applicable over oceans but not land

Scattering: ice in clouds scatters (warm) terrestrial radiation downward, producing cold areas in imagery.

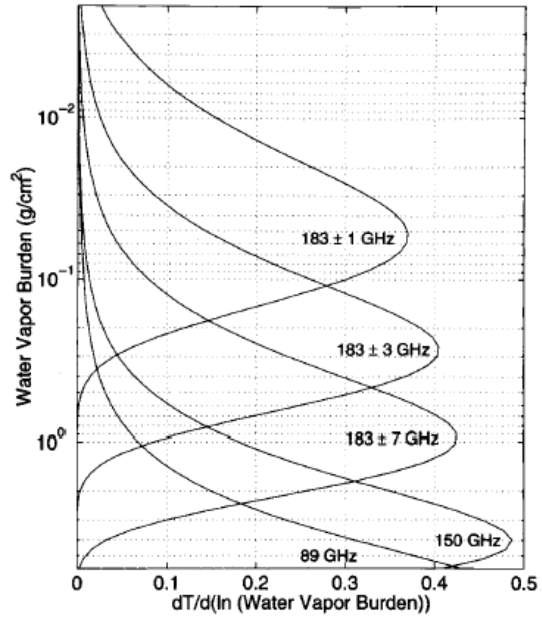
- Rainfall rates are related to the magnitude of the resulting brightness temperature depression (high frequencies).
- **Strength**: can be applied to high-frequency channels where surface effects are not detected: works over both land and ocean
- **Weakness**: poor at detecting precipitation clouds with little or no ice (e.g. warm rain, orographic clouds, light rain over land)

Example of multichannel PMW observations

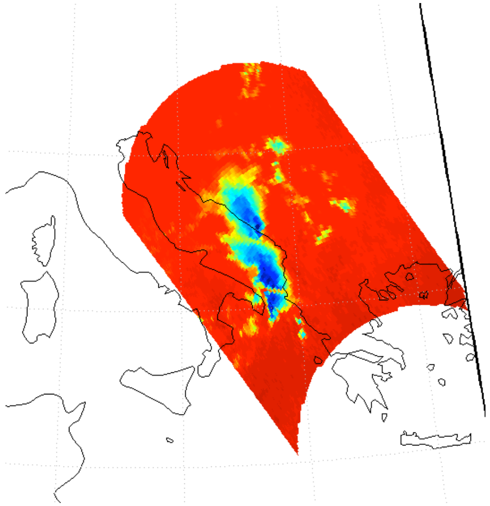


NASA/JAXA Global Precipitation Mission (GPM) Microwave Imager (GMI) – September 1, 2014 – 20:20 UTC

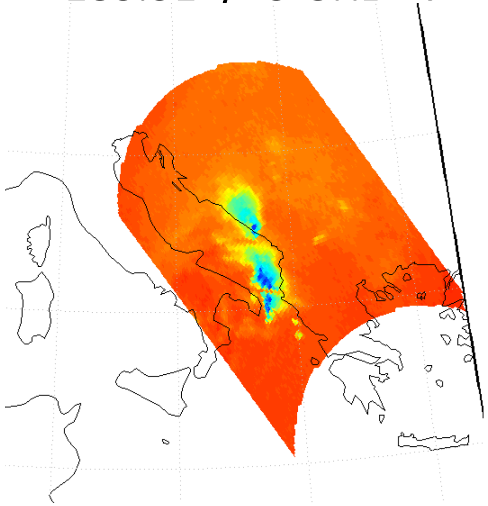
Example of multichannel PMW observations



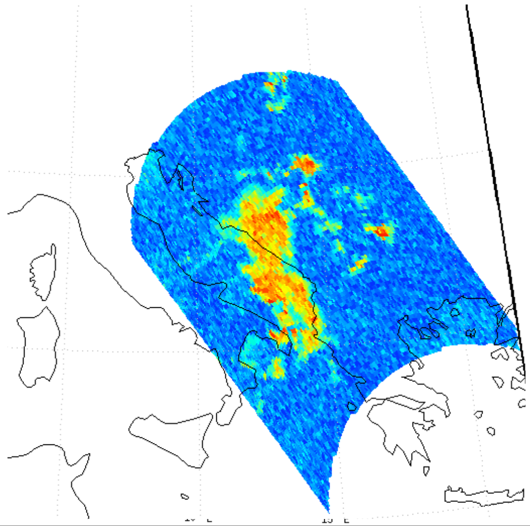
165.5 GHz - V



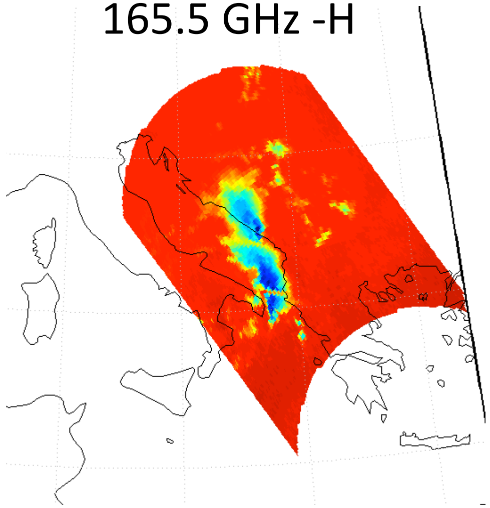
183.31+/- 3 GHz - V



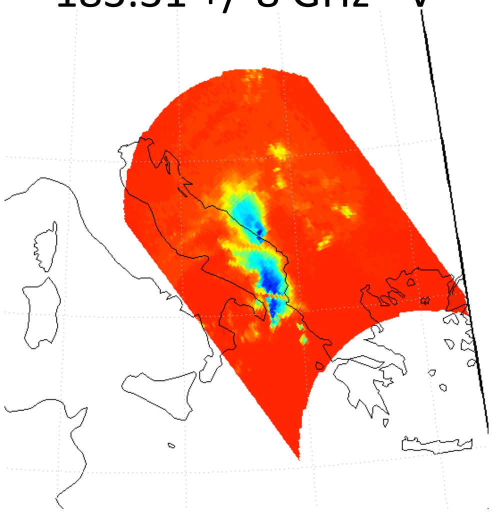
165.5 GHz – V-H

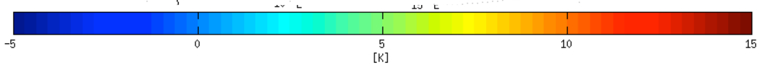


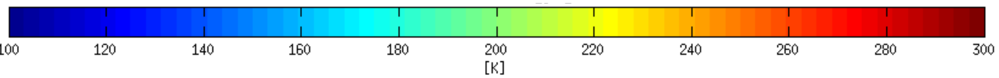
165.5 GHz -H



183.31 +/-8 GHz - V







NASA/JAXA Global Precipitation Mission (GPM) Microwave Imager (GMI) – September 1, 2014 – 20:20 UTC

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Support to Operational Hydrology and Water Management

Potentials

of PMW retrieval of precipitation

PMW radiometers (conically and cross-track scanning) offer the most complete set of satellite based observations to retrieve surface precipitation due to the ability of MW radiation to penetrate precipitating clouds and interact with its liquid and iced hydrometeors

Higher confidence in:

- Identification of different types of precipitation (deep convective, convective, stratiform)
- Retrieve convective precipitation due to the correlation between the upper portion of the cloud (high density ice) and rainfall;
- Stratiform and warm rain over ocean
- Stratiform rain over land in specific environmental conditions (contrast between surface and cloud)

Less confidence in:

- Oropgraphic precipitation (with warm-topped clouds);
- Light precipitation at high latitudes (low moisture and temperature conditions)
- Snowfall and/or with presence of snow/ice at the ground
- Warm rain over land (no confidence);

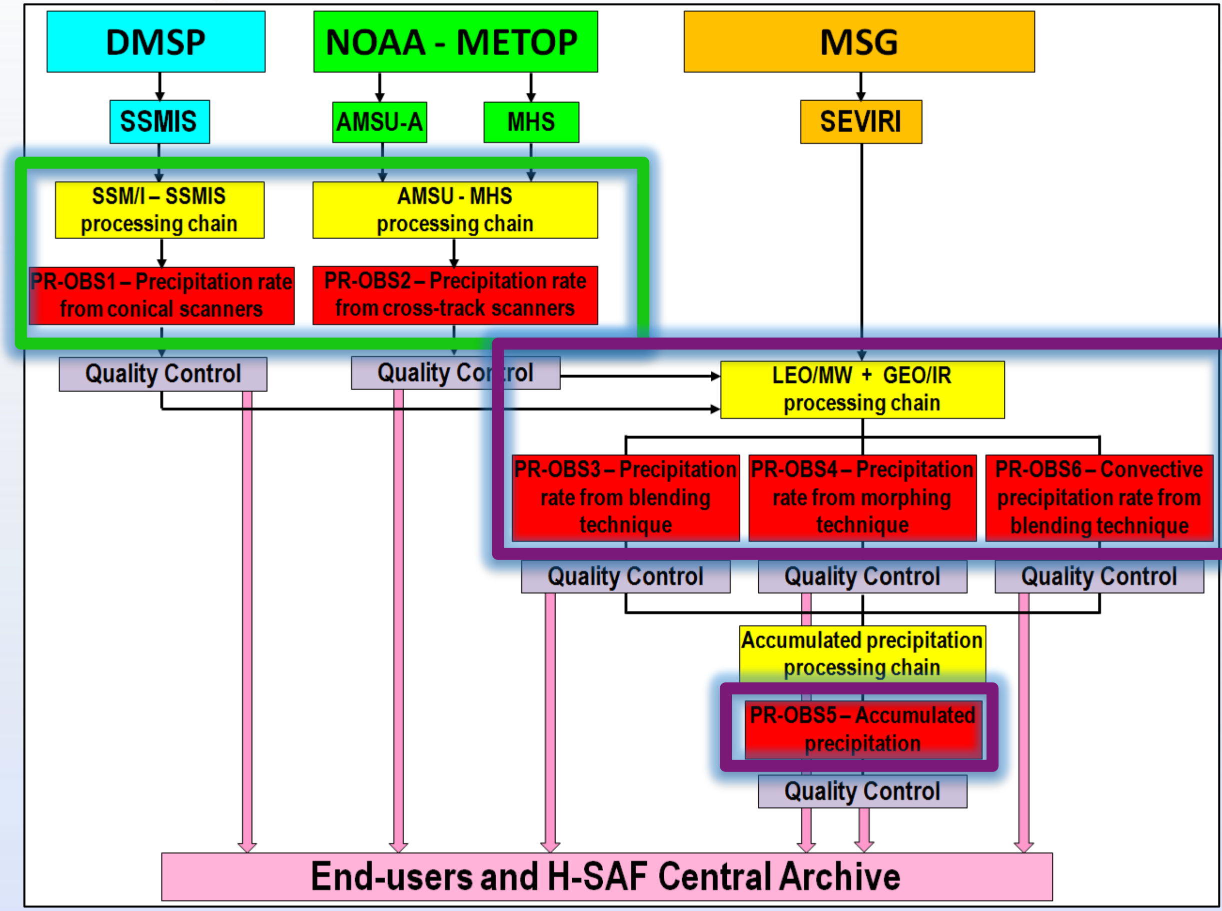
Combination of MW estimates and IR observations

For precipitation monitoring and hydrological applications one solution is to combine LEO MW estimates and GEO IR observations to benefit from physical robustness of MW and space/time resolution of IR. In remote areas (high latitudes, polar regions) only LEO MW observations can be used.

- Physical Robustness:
  - Microwave radiances are sensitive to cloud microphysical structure and it is related to rainfall (in most cases)
  - IR/VIS data reflect cloud-top conditions only and thus are more weakly related to actual rainfall rates over a wider range of conditions than MW radiances.
- Space/Time Resolution
  - IR/VIS data are available at 4 km/1km resolution (MSG) on geostationary platforms, allowing looks in many locations every 15 minutes
  - MW instruments are presently restricted to polar-orbiting platforms, limiting views to 2 per day per satellite at most latitudes—more suitable for larger scales in time and space-need to use constellation of satellites

Current Precipitation Products

Mugnai et al., 2013, NHESS



Current H-SAF precipitation product generation chain

All precipitation products are generated routinely at the CNMCA, Italy [CNMCA also manages the Data service for all H-SAF products].

The use of IR/MW blending/morphing techniques for monitoring of precipitation at high temporal and spatial resolution is subject to **accuracy, consistency,** and ***high temporal sampling*** of retrievals from PMW observations.

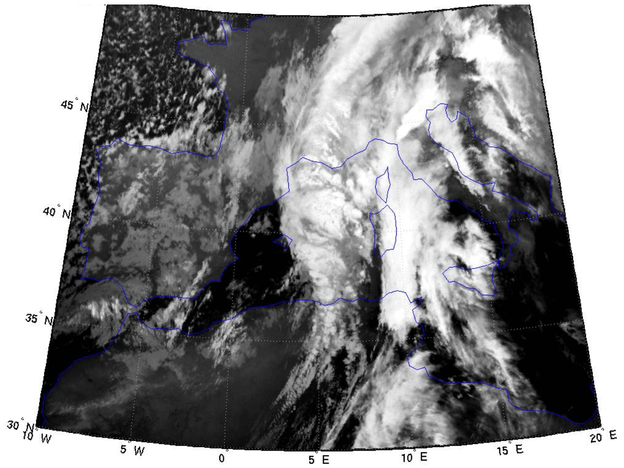
Why is consistency important?

Southern Tuscany (Grosseto area)
Devastating Flood on 11-12 November 2012

Very intense and persistent storm;
Max Acc. Precip exceeding:

- 177 mm/3 hr
- 270 mm /12 hr
- 400 mm / 72 hr

SEVIRI IR Ch09 (10.8 µm)



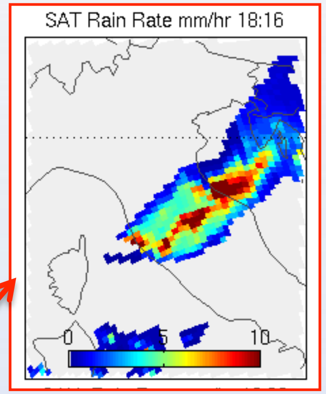
RR from Conical-scanning

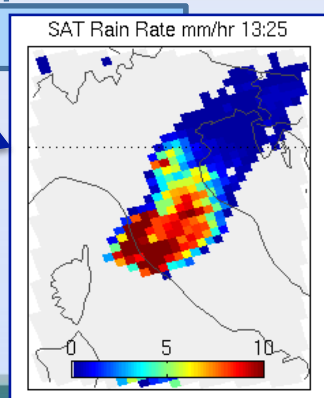
2012 Nov 11:

- H01 F-17 05:16
- H01 F-16 05:25
- H01 F-18 07:26
- H01 F-17 16:15
- H01 F-16 17:51
- H01 F-18 18:27
- H02 N19 01:26
- H02 N18 02:09
- H02 MetOp 09:34
- H02 N19 12:53
- H02 N18 13:56
- H02 MetOp 19:26

2012 Nov 12:

- H01 F-17 05:12
- H01 F-18 07:14
- H01 F-17 16:04
- H01 F-16 16:42
- H01 F-18 18:16
- H02 N19 01:15
- H02 N18 01:58
- H02 MetOp 09:23
- H02 N19 12:42
- H02 N18 13:25





RR from Cross-track scanning

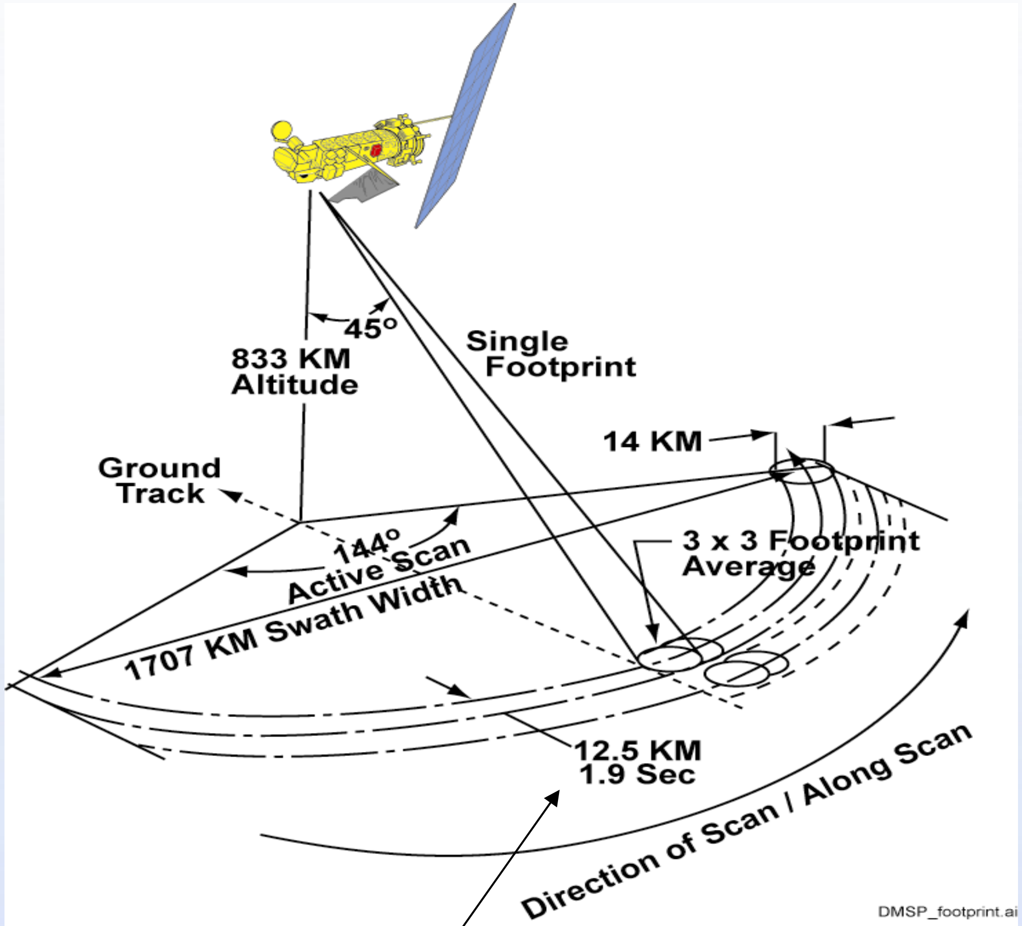
SSMIS (SSM-I) *conical scanning*

- DMSP F-16 F17 F18 (F19) Spacecraft
- Launched October 2003

- 24 Channels (19-183 GHz)

•Added 150 and 183 GHz channel capabilities for high latitude precipitation and snowfall

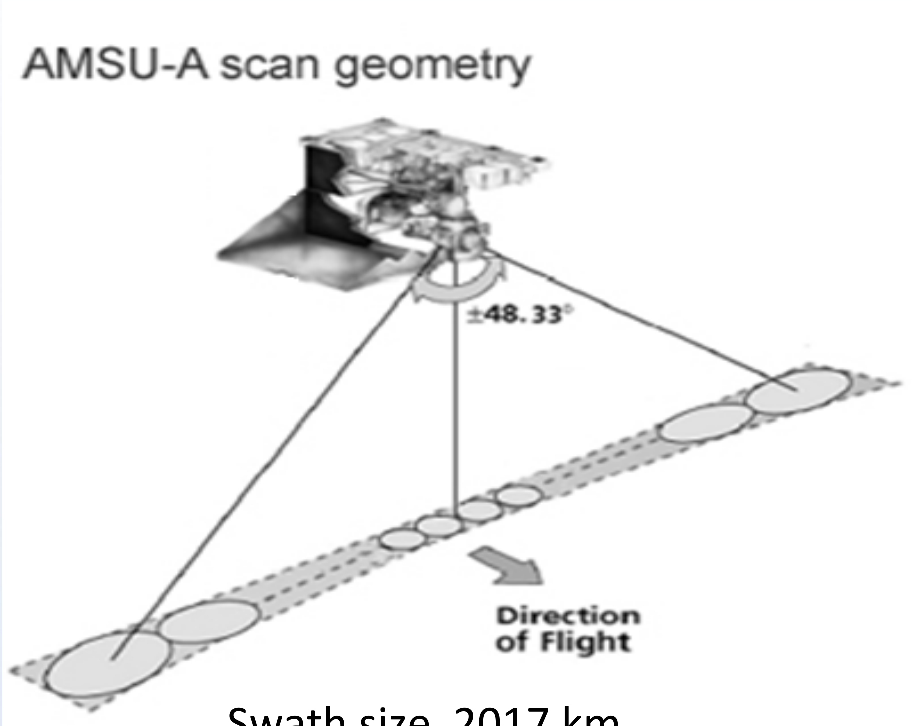
•IFOV size with channel frequency (max ≅13 km)
•Sampling Freq. 12.5 km



1700 km swath

AMSU-A/MHS – *Cross-track scanning*

AMSU-A NOAA 18-19/MetOp A-B (817/833 km)		MHS NOAA 18-19/MetOp A-B (817/833 km)
	Channel Frequency (GHz)	Channel Frequency (GHz)
1	23.8	89
2	31.4	157
3	50.3	183.311±1
4	52.8	183.311±3
5	53.596±0.115	183.311±7
6	54.4	
7	54.94	
8	55.5	
9	57.29	
10	57.29±0.217	
11	57.29±0.3222±0.048	
12	57.29±0.3222±0.022	
13	57.29±0.3222±0.01	
14	57.29±0.3222±0.0045	
15	89	



Swath size 2017 km

IFOV: 48 km (AMSU-A) or 16 km (MHS) at nadir
Sampling Freq. 16 km

Development of H01 (operational)

H SAF Support to Operational Hydrology and Water Management

Precipitation rate from SSMIS

(Sanò et al., 2013, Casella et al., 2013, IEEE , Mugnai et al., 2013 , NHESS)

CDOP-1	Initial Version	H01	Bayesian retrieval algorithm based on the use of a [**Cloud Dynamics and Radiation Database (CDRD) approach**] built over Europe/Mediterranean Basin Spatial resolution: 30 km
	Ver. 1.7 Delivered **Dec. 2012** **Operational July 2013**	H01	• Higher spatial resolution ≅ **12.5 km** • Use of additional dynamical-meteorological constraints in the Bayesian physically-based retrieval: −reduction the retrieval *ambiguity*; −categorization of the CDRD to speedup retrieval procedure; • Improvement of the **screening procedures** • **Quality flag** and **indication of phase**
CDOP-2	Ver. 1.8 **delivered March 2014**	H01	Extension to MSG Full Disk Area (*exp. op. 2014*) • New database for Africa and Sothern Atlantic • New Screening over Arid Land

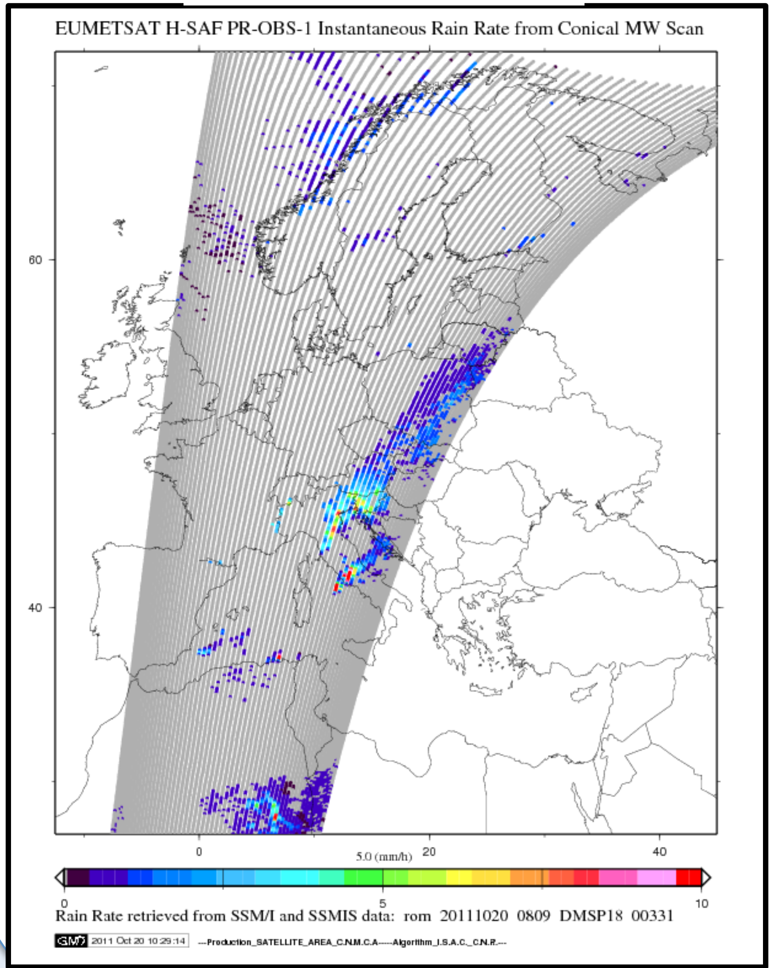
Development of H01 (operational)

H SAF Support to Operational Hydrology and Water Management

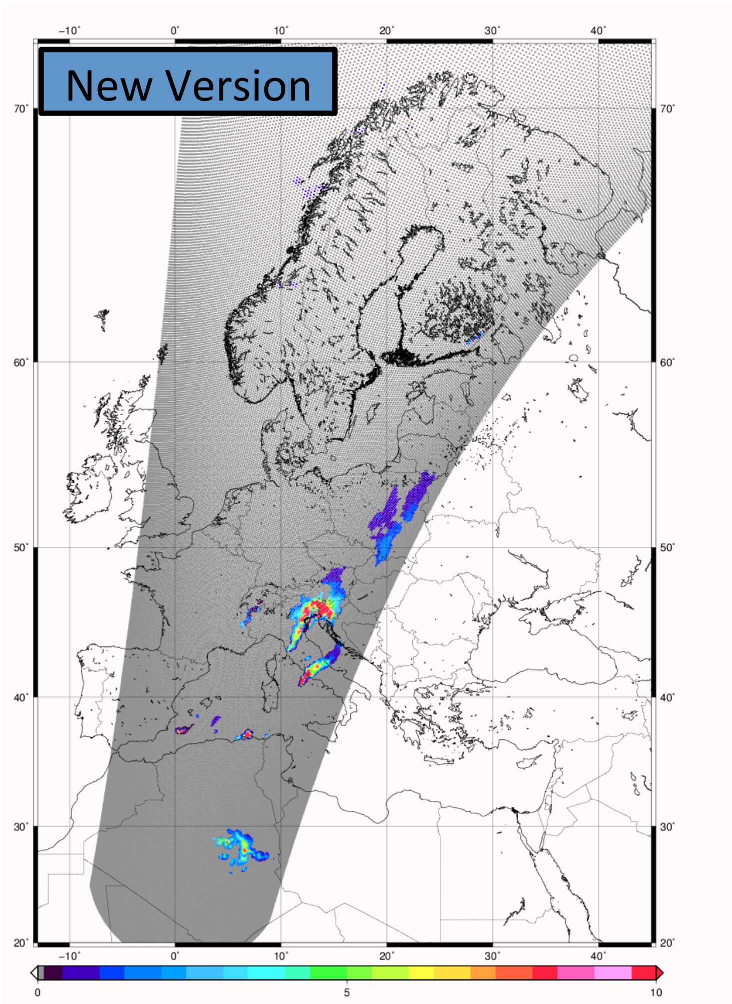
Precipitation rate from SSMIS

(Sanò et al., 2013, Casella et al., 2013, IEEE , Mugnai et al., 2013 , NHESS)

30 km horiz. resol.



12.5 km horiz. Resol.



Rome, Italy
Flash Flood
20 Oct 2011

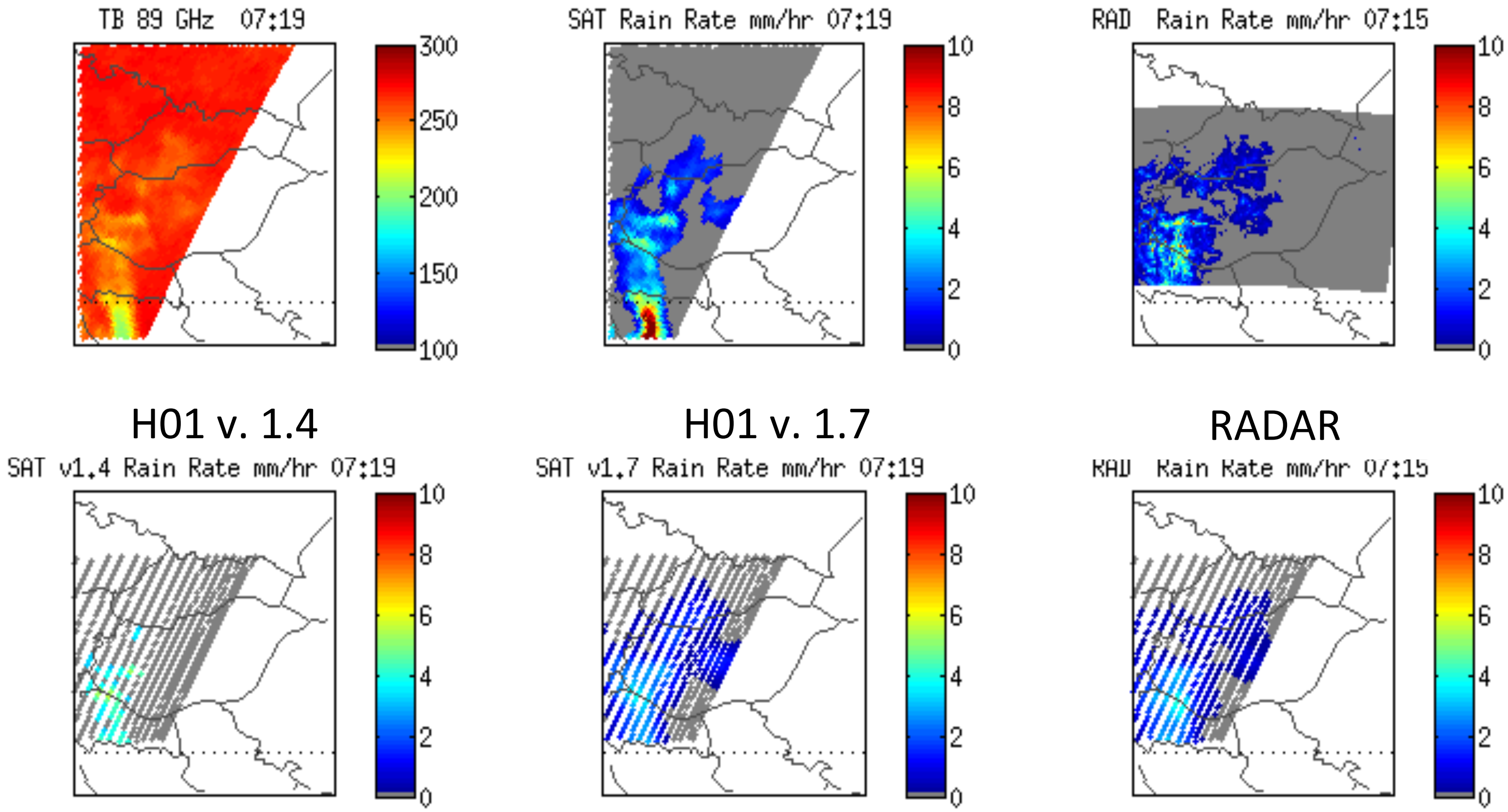
8:09 UTC
SSMIS F18

Development of H01 (operational)

Precipitation rate from SSMIS

(Sanò et al., 2013, Casella et al., 2013, IEEE , Mugnai et al., 2013 , NHESS)

HUNGARY 1 December 2009 – light rain



H SAF

Support to Operational Hydrology and Water Management

Development of H02 (operational)

Precipitation rate from AMSU/MHS

(Mugnai et al., 2013, NHESS, Sanò et al., 2013, IEEE, Sanò et al., 2014, AMTD)

ISAC

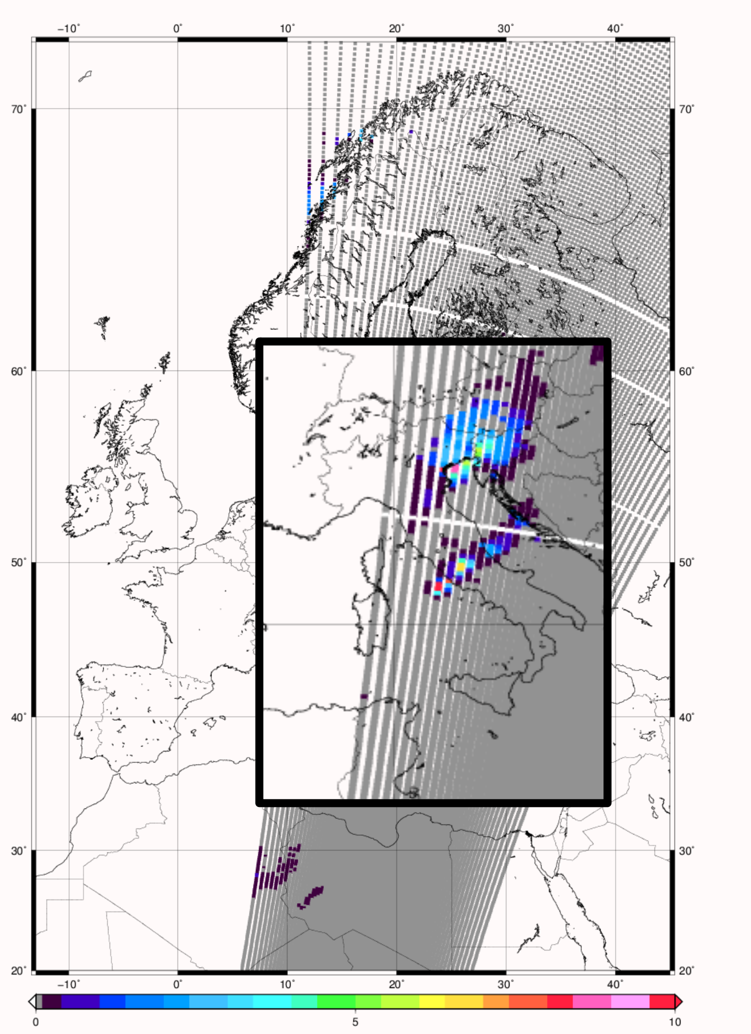
CDOP-1	Initial Version	H02	**Neural Network algorithm** trained with a global CRD: not optimized for Europe/Mediterranean area; using different CRM than H01 (Surussavadee and Staelin, 2008)
	Ver. 2.4 Delivered **Dec. 2012**	H02A	• Generation of a **new** neural network algorithm, based on **same physical foundation as H01**: – *Representativeness* for Europe/Mediterranean basin – Harmonize products from cross-track and conical MW scanners GAUGES 9.00UTC • **Unique ANN for all background conditions;** • **Geographical and seasonal factors;** • **Correction of corrupted channels** [i.e., MetOp-A, AMSU-A Channel 7 (54 GHz)] • Identification of frozen background surface; • **Quality flag** and **indication of phase**
CDOP-2	Ver. 1 Delivered **March 2014**	H02B	Extension to Full Disk Area (*exp. op. 2014*) • Generation of new database for Africa and Southern Atlantic • New screening algorithm for Arid land (desert) • New ANN for the African database

Development of H02 (operational)

Precipitation rate from AMSU/MHS

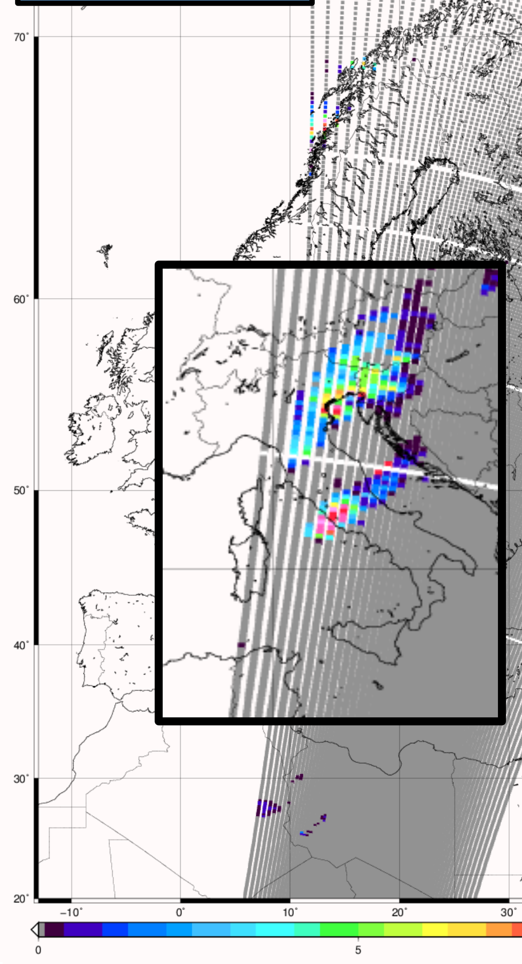
(Mugnai et al., 2013, NHESS, Sanò et al., 2013, IEEE, Sanò et al., 2014, AMTD)

ANN from Global database

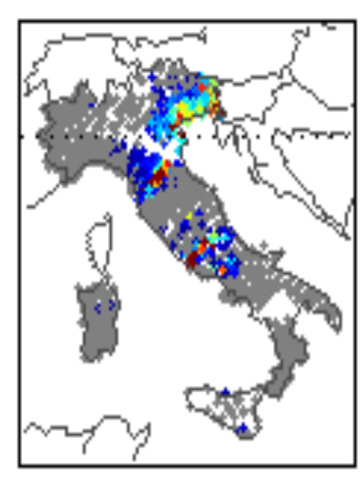


New ANN from H-SAF area database

New Version



GAUGES 9:00UTC

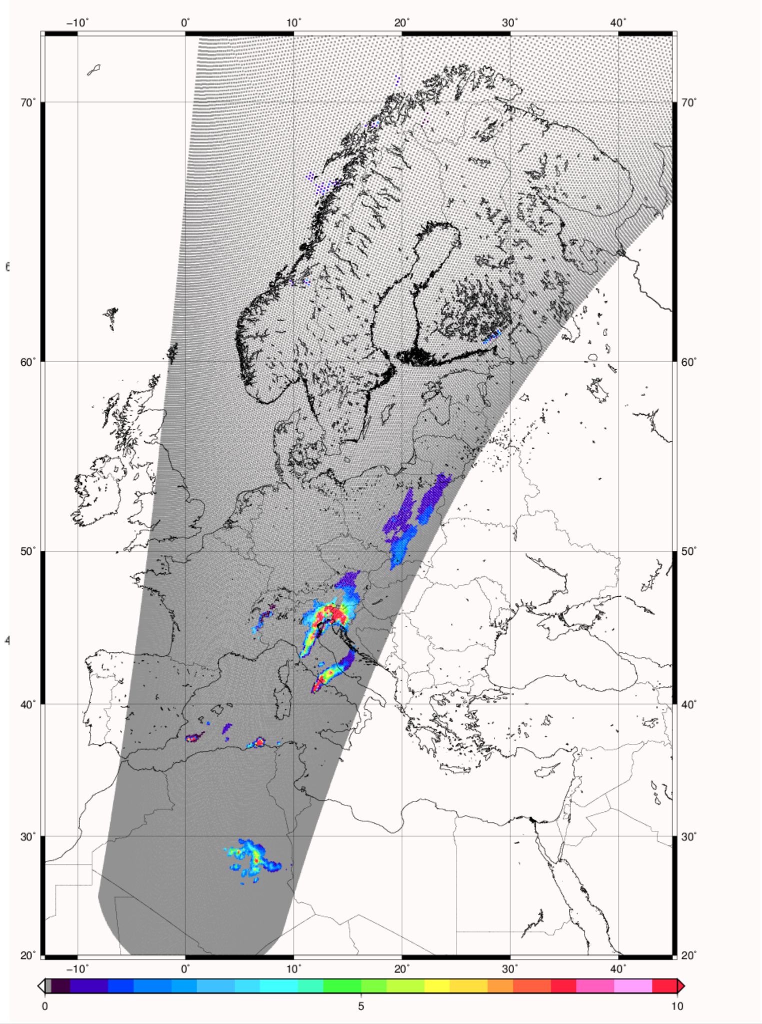


ıe, Italy
ı Flood
ct 2011

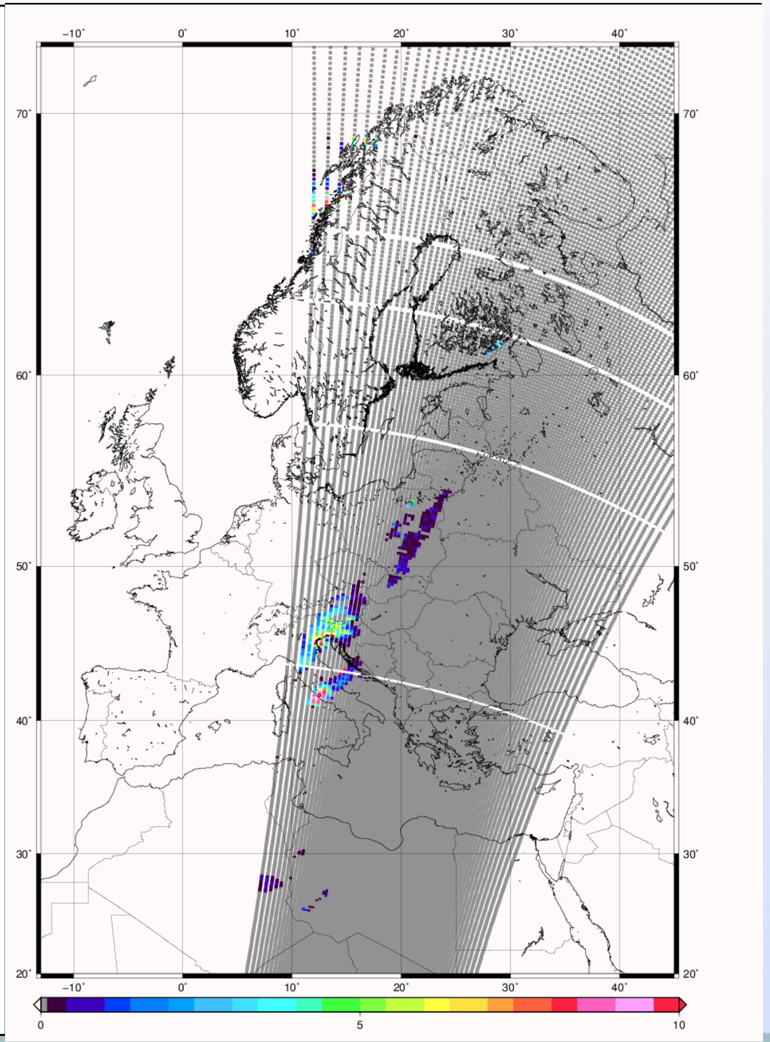
20 UTC
etOp-A
ΜSU/MHS

Consistency between retrievals from cross-track and conical scanning radiometers

CDRD (new H01) SSMIS 8:19 UTC



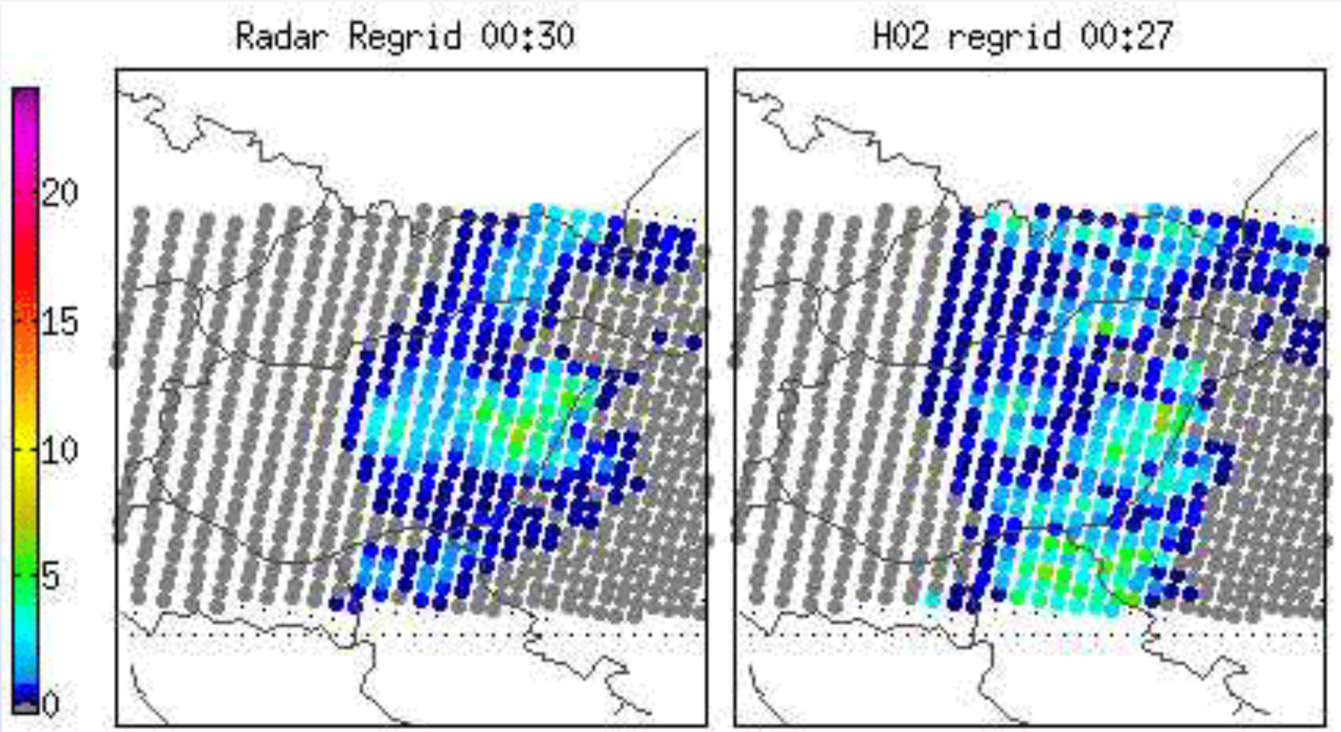
PNPR (new H02) AMSU/MHS 8:30 UTC



ROME FLOOD
20/10/2011

Consistency between retrievals from cross-track and conical scanning radiometers

Hungary July 07, 2011

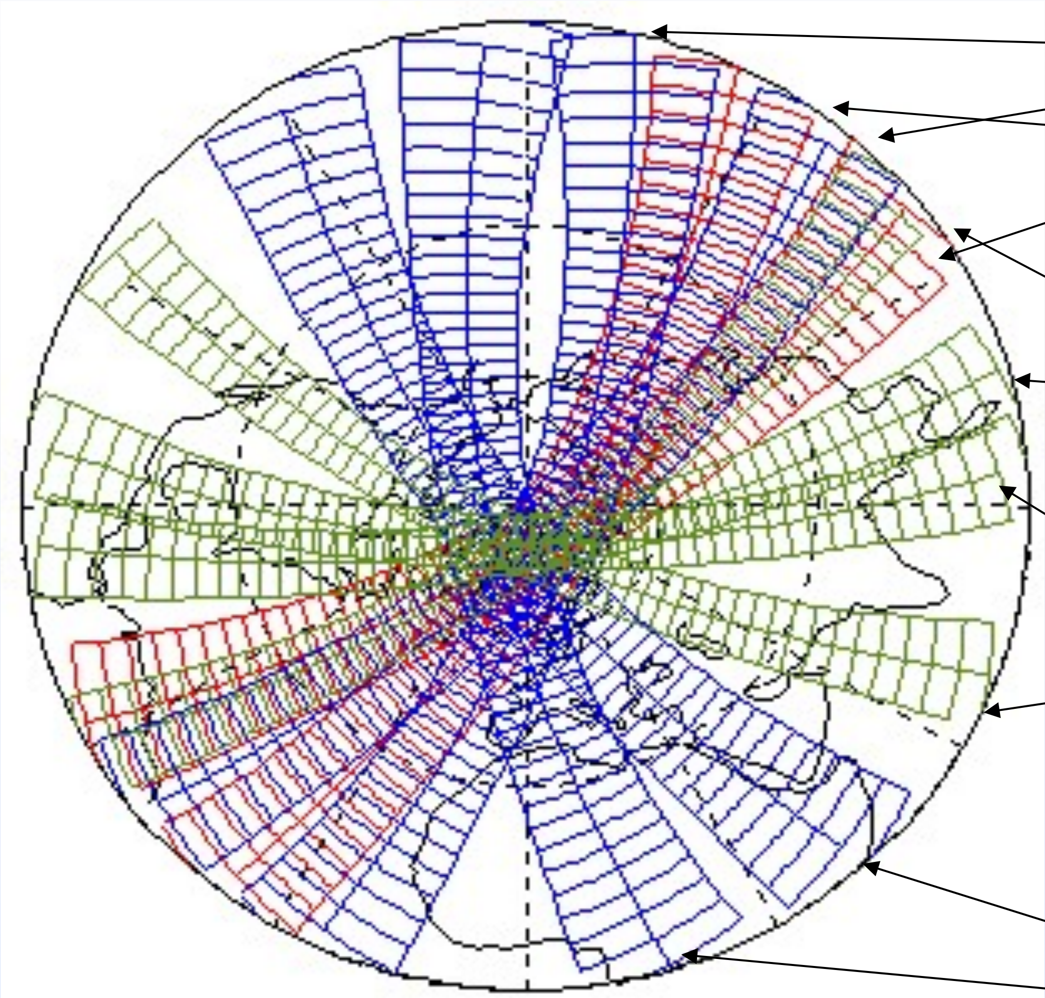


Future perspective:

Higher temporal sampling

- Full exploitation of *all* overpasses of present and future satellites carrying cross-track and conically scanning PMW radiometers, which has now reached its optimal configuration with the NASA/JAXA GPM (number of satellites, GPM core satellite)

3-hr Coverage by MW/LEO satellites currently used operationally in Hsaf



NOAA-18 (ECT 15:23 asc)
(AMSU-A , MHS)

MetOp-A (ECT 9:30 desc)
(AMSU-A , MHS)

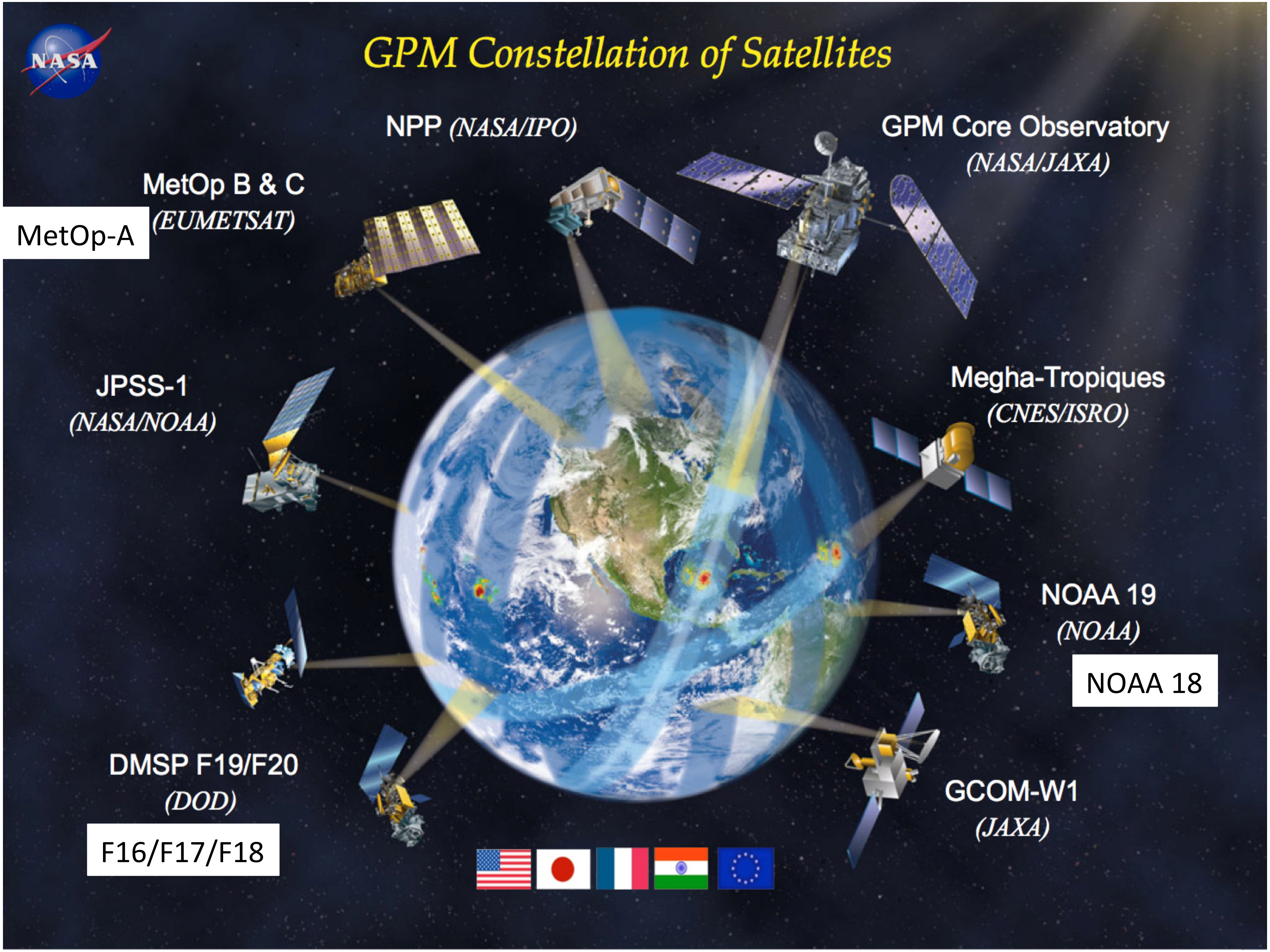
MetOp-B (LST 9:30 desc)
(AMSU-A , MHS)

DMSP-17 (ECT 5:49 desc)
(SSMIS)

DMSP-18 (ECT 8:06 desc)

DMSP-16 (ECT 5:22 desc)
(SSMIS)

NOAA-19 (ECT 13:39 asc)
(AMSU-A , MHS)


GPM Constellation of Satellites
NASA
NPP (NASA/IPO)
GPM Core Observatory
(NASA/JAXA)
MetOp B & C
(EUMETSAT)
MetOp-A
JPSS-1
(NASA/NOAA)
Megha-Tropiques
(CNES/ISRO)
NOAA 19
(NOAA)
NOAA 18
DMSP F19/F20
(DOD)
F16/F17/F18
GCOM-W1
(JAXA)

NASA-JAXA GPM Core Observatory

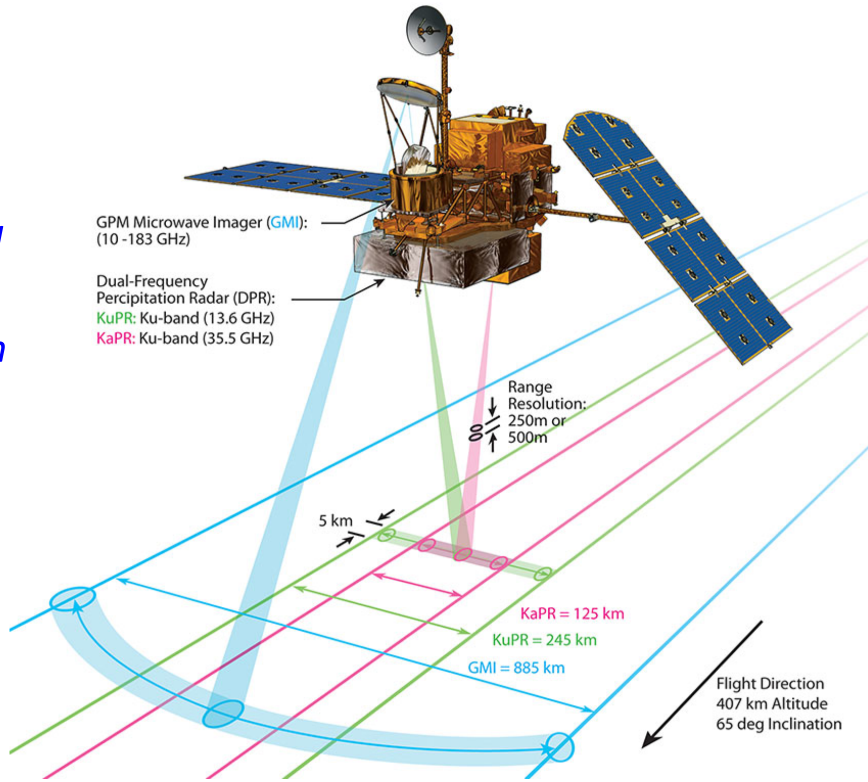
GPM Core Observatory Measurement Capabilities

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 light rain & snow detection*
- *Improved signals of solid precipitation over land (especially over snow-covered surfaces)*
- *4-point calibration to serve as a radiometric reference for constellation radiometers*



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*

Passive Microwave Sensor Characteristics in the GPM Era

Constellation microwave sensor channel coverage

V – Vertical Polarization   H – Horizontal Polarization

Channel	6 GHz	10 GHz	19 GHz	23 GHz	31/36 GHz	50-60 GHz	89/91 GHz	150/166 GHz	183/190 GHz
SSMIS			19.35 V/H	22.235 V	37.0 V/H	50.3-63.28 V/H	91.65 V/H	150 H	183.31H
MHS							**89**	**157**	**183.311** **190.311**
AMSU-A				**23.8**	**31.4**	**50.2-58**	**89**		
AMSR-2	6.925 V/H	10.65 V/H	18.7 V/H	23.8 V/H	36.5 V/H		89.0 V/H		
GMI		10.65 V/H	18.70 V/H	23.80 V	36.50 V/H		89.0 V/H	165.5 V/H	183.31 V
ATMS				**23.8**	**31.4**	**50.3-57.29**	**87-91**	**164-167**	**183.31**

Mean Spatial Resolution (km)

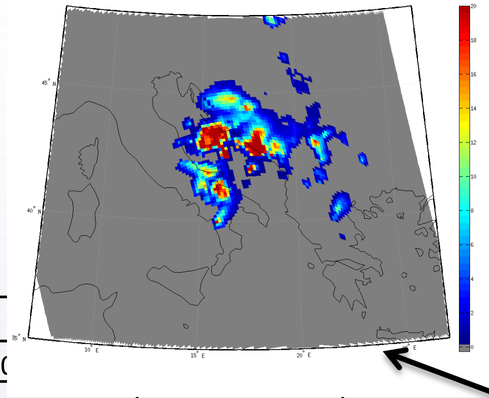
Channel	6 GHz	10 GHz	19 GHz	23 GHz	31/36 GHz	50-60 GHz	89/91 GHz	150/166 GHz	183 GHz
SSMIS			**59**	**59**	**36**	**22**	**14**	**14**	**14**
MHS							**17**	**17**	**17**
AMSU-A				**48**	**48**		**48**		
AMSR-2	**56**	**38**	**21**	**24**	**12**		**5**		
GMI		**26**	**15**	**12**	**11**		**6**	**6**	**6**
ATMS				**74**	**74**	**32**	**16**	**16**	**16**

H SAF

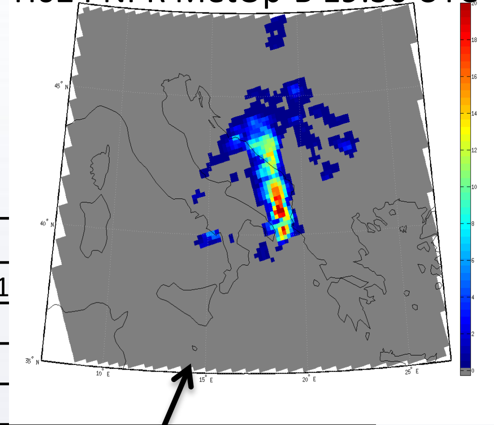
Support to Operational Hydrology and Water Management

Flood in Gargano – Italy
1 September 2014

H01 CDRD F16 15:02 UTC



H02 PNPR MetOp-B 19:36 UTC

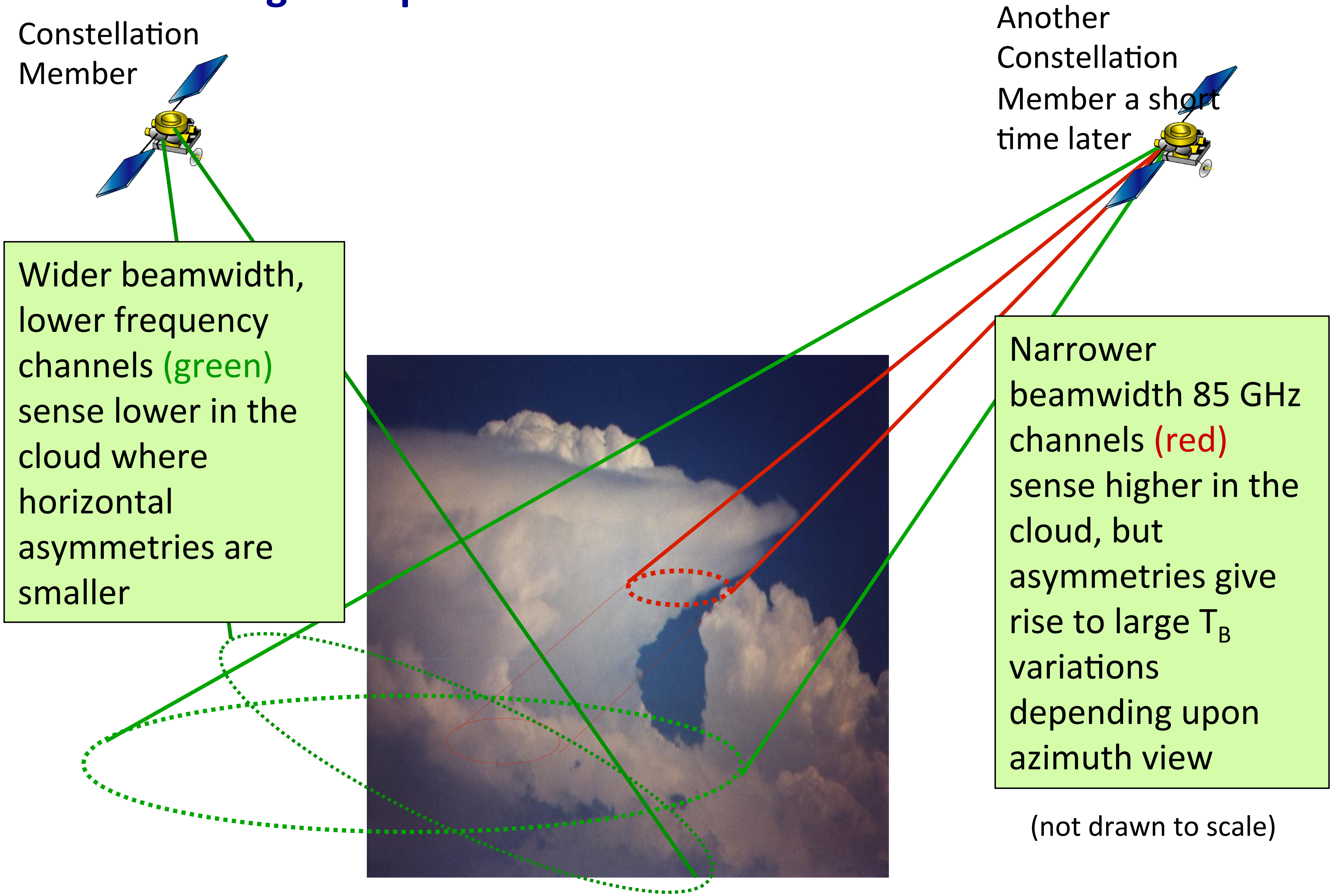


		00:00-04:00	04:0		00	1	
SSMIS	F16	X			X		
	F17		X		X		
	F18						
MHS	MetOp-A			X			X
	MetOp-B			X		X	
	NOAA18	X			X		
	NOAA19	X			X		
AMSR2	GCOM-W	X		X			
ATMS	NPOESS	X		X X	X		
GMI	GPM			X		X	
		X / X X / X X	X	X / X / X / X X	X X / X / X X	X / X X	X

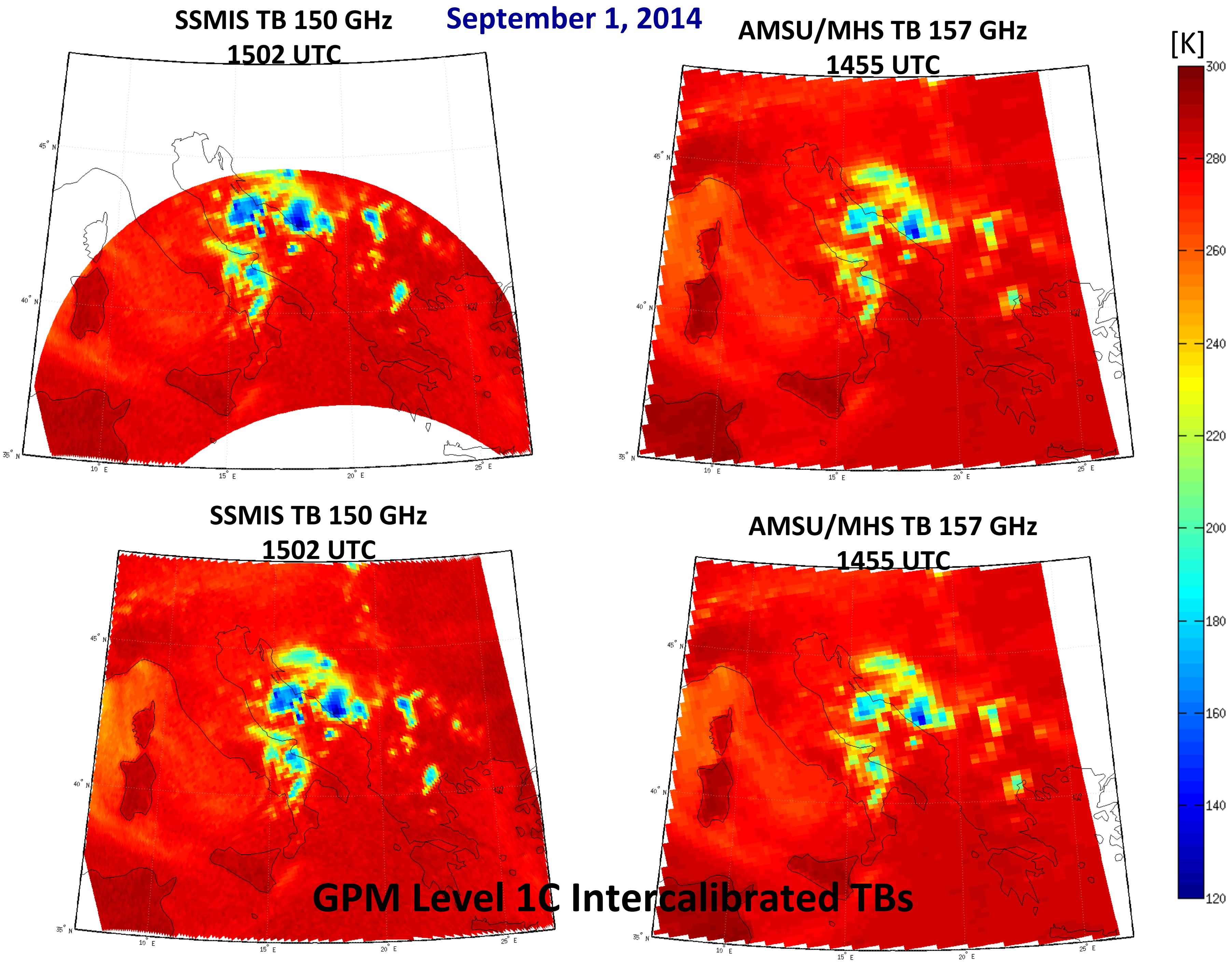
GPM Observations from Non-Sun-Synchronous Orbits filling gaps between those of polar orbiters at fixed time of the day

Different center frequencies, viewing geometry, effect of beam filling, and spatial resolution must be reconciled

Combining Multiple PMW sensors at Short Revisit



(not drawn to scale)


SSMIS TB 150 GHz
1502 UTC
September 1, 2014
AMSU/MHS TB 157 GHz
1455 UTC
SSMIS TB 150 GHz
1502 UTC
AMSU/MHS TB 157 GHz
1455 UTC
[K]
300
280
260
240
220
200
180
160
140
120
GPM Level 1C Intercalibrated TBs

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H-SAF

PMW Products in development during CDOP-2 and proposed changes for exploitation of GPM

	Area	Original Description	Proposed Changes
H17	Full MSG Disk	CDRD based Bayesian retrieval with SSI for SSMIS	CDRD based Bayesian retrieval for **GCOM-W1 AMSR-2**
H18	Full MSG Disk	CDRD based ANN algorithm with SSI for AMSU/MHS	CDRD based ANN algorithm for **NPP Suomi ATMS**
H19	Full MSG Disk	CDRD based Bayesian algorithm for GMI	CDRD based **ANN algorithm for GMI** and use of DPR as additional input
H20	Global (65 S – 65 N)	ANN trained using GMI and DPR global coincident observations over a minimum of one year time period	
H21	Full MSG Disk	High frequency MW delineation of cloud areas with new development of hydrometeors: Input: AMSU-B/MHS	
H22	Full MSG Disk	Snowfall intensity Input: AMSU-B/MHS	

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No-cost proposal

"H-SAF and GPM: precipitation algorithm development and validation activity"

Approved by the NASA PMM Research Program

- The goal is to contribute toward the establishment of a long term collaboration between EUMETSAT H-SAF and GPM on the following aspects:
  - ***precipitation retrieval algorithm development***, through a fruitful interaction on several critical aspects of interest both to H-SAF and GPM (**ISAC-CNR, CNMCA**);
  Scientific coordinator: Giulia Panegrossi (ISAC-CNR)
  - ***validation activity***, through the connection between the well established H-SAF product validation (**DPC, IMGW, and PPVG)** and hydrological validation ((**IMGW**) programs and the Ground Validation/Calibration activity of GPM**;**
  Scientific Coordinator: Silvia Puca (DPC)
- **Active participation of H-SAF to GPM EM phase and beyond:**
  - Daily download of "Europe" subset of GPM products
  - Analysis of case studies and validation over Europe of GPM products
  - Algorithm development for all GPM constellation of radiometers;

H-SAF/GPM proposal

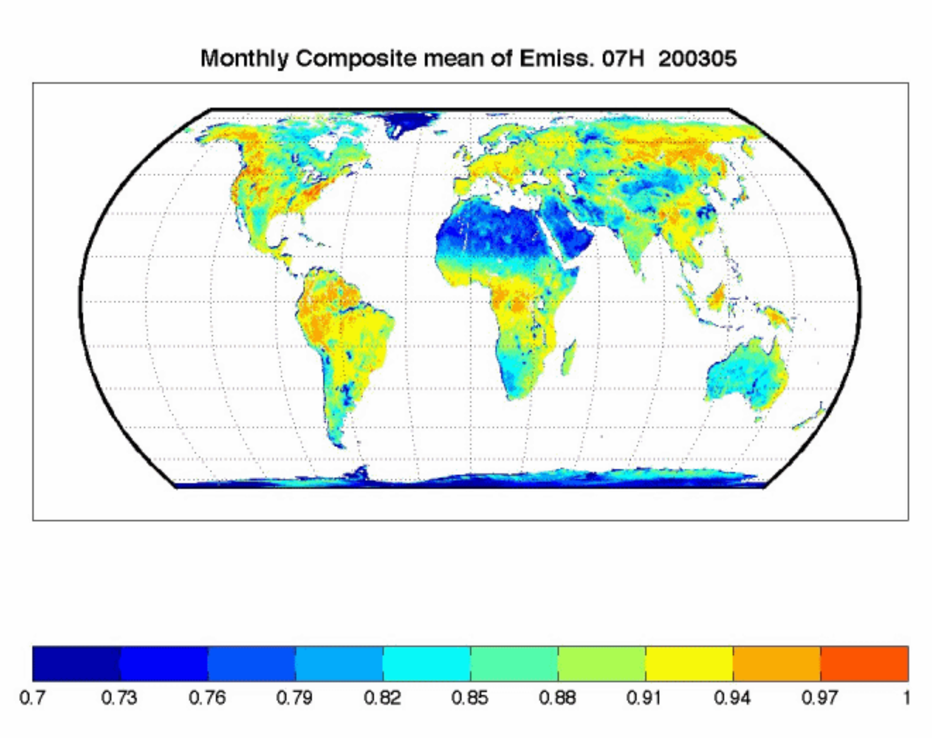
Precipitation retrieval algorithm development

It will benefit from interaction on several aspects of interest to H-SAF *and* GPM

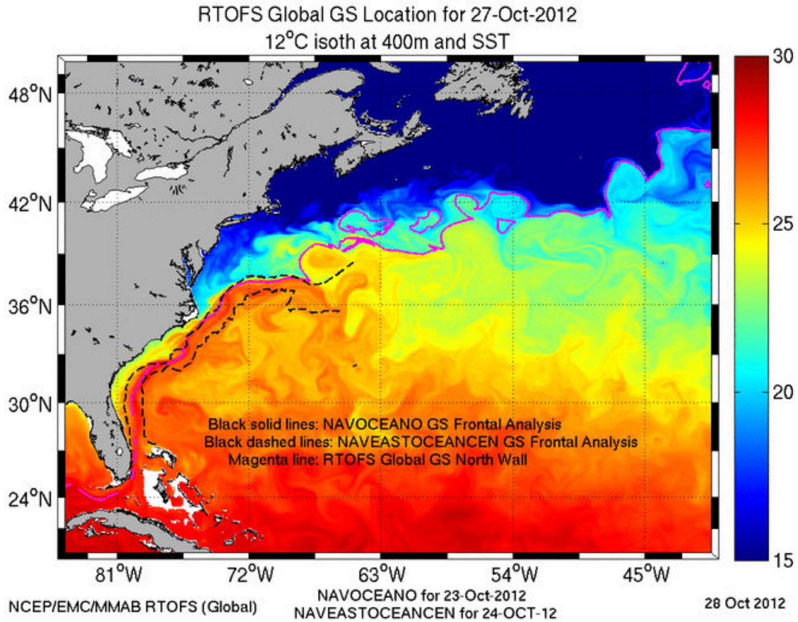
- **Background surface characterization** (surface emissivity and SST or Skin Temperature), snow/ice, vegetation, soil moisture, etc.) both in the database and at time of observation
- **Ambiguity** in the interpretation of MW multichannel TB: use of ancillary data to guide retrieval towards the solution: going towards use of satellite data?
- **Verification of consistency** of precipitation detection and retrieval from different sensors of the GPM constellation.
- **Detetection/retrieval of precipitation (solid and liquid) at high latitutdes**

  Correct parameterization of scattering properties of iced hydrometeors (shape, DSD, density); critical for snowfall and light stratiform rain retrieval relying on high frequency channels (sensitive to low density ice crystals)
- **Account for orography**

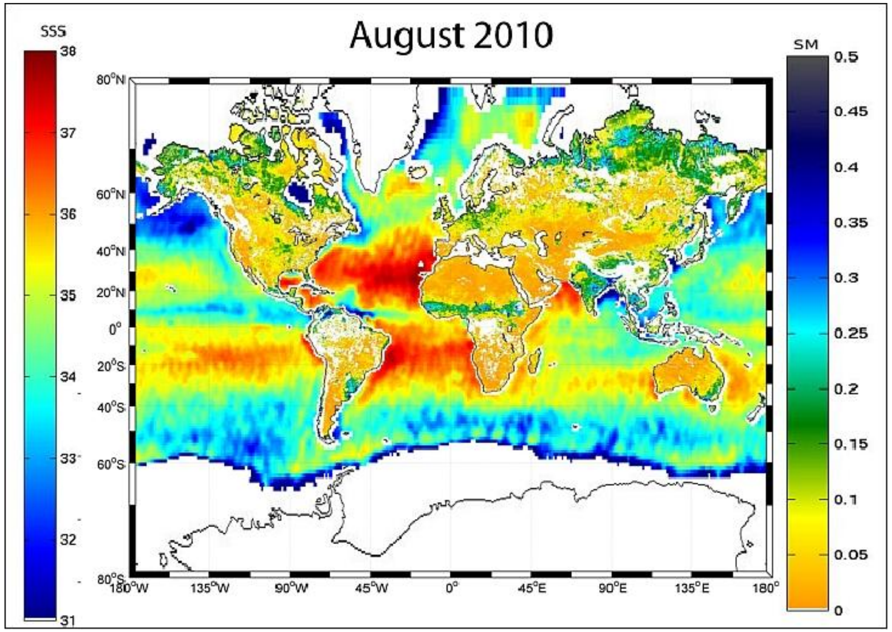
Background surface characterization



Land surface emissivity map from AMSR_E
(Image Credit: NOAA Crest CenterAMSR-E data)



Sea surface temperature (°C) with ~26-degree isotherm (dash line) on Oct. 27, 2012. Image (Credit: NOAA/NCEP/EMC/MMAB/RTOFS).



SMOS global map of Sea Surface Salinity (SSS) and Soil Moisture (SM) combining global measurements acquired in August 2010. The SSS data have a spatial resolution of 1º x 1º (Credit ESA)

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Conclusions

PMW radiometers (conically and cross-track scanning) offer the most complete set of satellite based observations to retrieve surface precipitation

Global monitoring of the precipitation requires the full exploitation of all overpasses of present and future satellites carrying cross-track and conically scanning PMW radiometers (proposed H-SAF **new products for ATMS, AMSR-2, and GMI**)

- Better space-time coverage through international partnership
- High spatial resolution (DPR & GMI on Core Observatory)

Next-generation precipitation products need constellation **of intercalibrated radiometric measurements (GPM Level 1C?)**

Development and improvement of H-SAF PMW precipitation products need **collaboration** (PMM Science Team, other SAF's, etc.);

Feedbacks from users and validation activity are crucial to the delivery of high quality products.

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Thank you!

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ISAC

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