Analysis of heavy precipitation events in Italy during the Fall 2014 using the GPM constellation

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Overview

Motivations

With the advent of the NASA/JAXA Global Precipitation Measurement (GPM) mission, a new era has started for precipitation monitoring. The first spaceborne dual-frequency precipitation radar (DPR), along with the advanced GPM Microwave Imager (GMI), onboard the GPM core satellite, are the reference instruments for precipitation retrieval from space. However, monitoring of the precipitation requires the full exploitation of the constellation of present (and future) satellites carrying cross-track and conically scanning passive microwave (PMW) radiometers orbiting around the globe, which has now reached its optimal configuration, ensuring a 3-hourly global coverage. To this purpose it is necessary to improve precipitation retrieval techniques, to test their ability to retrieve precipitation in all environmental and meteorological conditions, and to provide consistent estimates among the different sensors. The analysis of the accuracy and consistency of the PMW precipitation retrieval has become very challenging because of the characteristics of the different radiometers and because of the different approaches used for the precipitation retrieval itself.

Purpose of work

In this study, precipitation retrievals exploiting the available overpasses of PMW cross-track and conically scanning radiometers in the GPM era are used to verify and analyze the evolution of different precipitation systems occurred during the Fall 2014 in Italy. A comparison with dual-polarization radar observations at ground and with rain gauges is carried out to verify the ability of the different sensors to identify different precipitation areas and regimes, and correctly estimate the total precipitation in spite of the limited temporal sampling of PMW observations. This is particularly relevant in presence of complex orography, often found in proximity of coastal areas for the analyzed cases. However, the use of all available sensors is complicated by the different viewing geometry, spatial resolution, channel assortment, and by the use of different retrieval techniques. In this study we show that these aspects, as well as the limitations of the ground-based dataset used as reference and the methodology used to match the satellite estimate to the ground-based reference, significantly affect the results.

Methodology

PMW precipitation products

Two different PMW precipitation retrieval algorithms are used: one is the Cloud Dynamics Radiation Database algorithm (CDRD) [1] [2] [3], a physically-based Bayesian approach for conically scanning radiometers (i.e., the Special Sensor Microwave Imager and Sounder (SSMIS) on board the U.S. DMSP satellites); the other one is the Passive microwave Neural network Precipitation Retrieval algorithm (PNPR) [3] [4] for cross-track scanning radiometers (i.e., the Advanced Microwave Sounding Unit/Microwave Humidity Sounder (AMSU-A/MHS) on board the U.S. NOAA and the European MetOp-A/B satellites, and the Advanced Technology Microwave Sounder (ATMS) on board the NPP Suomi satellite). The CDRD and PNPR algorithms are used operationally within the EUMETSAT H-SAF program [5] (Satellite Application Facility on Support to Operational Hydrology and Water Management). For the seek of consistency among the different radiometers, the two algorithms are based on the same physical foundation, and use similar procedures for screening of not -precipitating pixels, for the estimate of the phase of the precipitation, and for the determination of a pixel-based quality index of the surface precipitation retrievals. In the analysis of the case studies, the NASA/JAXA GPM official instantaneous precipitation products are used for comparison.

In particular the Goddard PROFiling Algorithm (GPROF) Level 2A products [6] for SSMIS and MHS, and for the available overpasses of GMI and of the GCOM-W1 Advanced Microwave Scanning Radiometer 2 (AMSR2) (V03D-CLIM and V03B respectively), are used in conjunction with the CDRD and PNPR retrievals. The nominal resolution of the PMW precipitation products depends on the radiometer characteristics but it also changes depending on the algorithm used. Table 1 provides a summary of the declared "nominal" resolution of the PMW precipitation products used in this study.

Table 1: PMW products nominal resolution

	GPROF	CDRD/PNPR
SSMIS	44.2x27.5 km² (37 GHz)	15.5x13.2 km² (91 GHz)
AMSU-MHS	15x15 km²	Varying with the viewing scan angle (16 x 16 km² / circular at nadir to 26 x 52 km²).
AMSR-2	12x7 km² (36.5 GHz)	
ATMS		Varying with the viewing scan angle (16 x 16 km² / circular at nadir to 26 x 52 km²).
GMI	14x8.6 km² (36.5 GHz)	

Case Studies and Ground-based reference data

Different precipitation events have been analyzed occurred in the Fall 2014 mostly over the coastal areas of Italy and often strongly influenced by local topography. Two of them are presented in this study. The first case caused extensive floods, damages, and casualties on October 9-13, 2014 in Liguria (city of Genoa, 44.3°N, 9°E) and Piedmont regions (peak of registered precipitation 120 mm/hour and a total of 570 mm in 36 hours between 0400 UTC of October 9 and 1600 of October 10). The whole event was associated to a very intense lightning activity (i.e., 20,000 strokes were registered over the area of Genoa in 6 hours on October 9). The second case is a tropical-like cyclone in the Mediterranean (Medicane) developed in Southern Mediterranean on November 7, 2014, hitting the Eastern coast of Sicily (Catania) in the early morning of November 8. The Medicane development followed a series of heavy precipitation and flooding events in Sicily and Tuscany (November 5-6). The precipitation associated to the Medicane itself is much lower than what observed for the other cases, and associated to a weak lightning activity (with a total of 1200 strokes for the whole day, and only 40 strokes over the city of Catania, 37.5°N, 15.1°E).

Table 2: GPM constellation overpasses over Genoa area on 2014/10/11

		00:00-04:00				04:00-08:00				08:00-12:00				12:00-16:00				16:00-20:00				20:00-24:00			
SSMIS	F16					X									X										
	F17						X											X							
	F18									X								X							
MHS	MetOp-A									X		X								X					
	MetOp-B										X											X			
	NOAA18					X										X									
	NOAA19			X									X		X										
AMSR2	GCOM-W		X											X											
ATMS	NPOESS	X	X										X												
GMI	GPM	X								X															

Radar observations and raingauge measurements are used as ground reference. C- band dual-polarization radar observations have been made available by the Environmental Protection Agency of Piedmont region (ARPA Piemonte) (Bric and Settepani radars for the Liguria/Piedmont case) and by the Department of Civil Protection of Italy (DPC national weather radar mosaic for the Medicane case). Such observations are used to analyze the evolution of the precipitation structure at higher spatial and temporal resolution, and to verify the accuracy and consistency of the PMW retrievals obtained from the different sensors. Moreover, the lightning strokes registered by the Lightning NETwork (LINET) [7] during the events are used as further verification of the ability of PMW radiometers to correctly identify the most intense precipitation associated to the convection .

Ground-based data are averaged to match the PMW product nominal resolution. In the match–up procedure the antenna pattern at the ground is represented as a 2D Gaussian function with an elliptic horizontal section, whose variances in the cross-track and in the along-scan directions are defined by the IFOV of the MW channel corresponding to the nominal resolution of each precipitation product (see Table 1). The ellipse is defined taking into account its actual position and orientation along the scan and considering the orientation of the satellite orbit with respect to the surface at the time of the overpass.

PMW radiometers provide a very good temporal coverage of all events analyzed with at least one overpass available every two hours, except for the time frame between 21:00 and 24:00 UTC (an example is shown in Table 2). The best coverage is provided by SSMIS (on board three DMSP satellites) and AMSU/MHS (on board four MetOp and NOAA satellites), while ATMS, GMI (with improved sensing capabilities), and AMSR-2 (providing precipitation estimates at spatial resolution comparable to GMI) complete the constellation.

Results

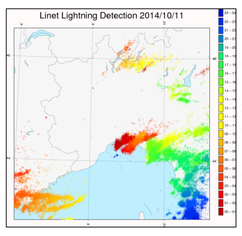

Fig. 1: LINET strokes registered in 24 hours on October 11, 2014 (colors refer to the strokes registered every hour); a total number of strokes around 80,000 in 24 hours was registered.

On October 11 a very intense convective cell affects the city of Genoa (44.4°N, 8.9°E) in the night and in the early morning (GMI, AMSR-2, ATMS, MHS, and SSMIS overpasses between 00:45 UTC and 05:07 UTC) and dissipates at mid morning (MHS overpass at 9:30 UTC). At the same time precipitation intensifies over Southern France and over the Ligurian Sea. In the afternoon (AMSR-2 overpass at 12:40 UTC) heavy thunderstorms affects Eastern Liguria and Northern Tuscany (SSMIS overpasses at 14:51 UTC and 18:01 UTC) until the time of the last available overpass (MHS overpass at 20:05 UTC).

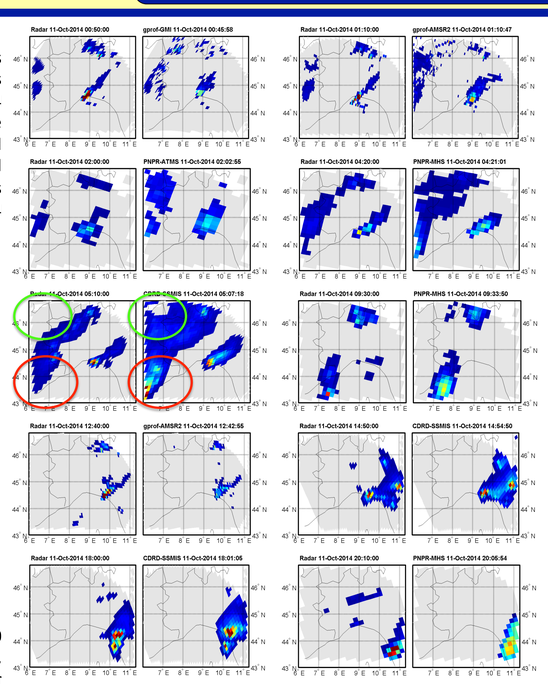

Fig. 2

Figure 2: Sequence of surface RR (mm/h) from 10 overpasses of PMW radiometers (SSMIS, AMSU/MHS, ATMS, GMI, AMSR-2) on October 11, 2014 and radar surface RR maps from the ARPA Piemonte averaged at the nominal resolution of the PMW precipitation products. Each two-figure panel shows the radar surface rainfall rate (RR) at the time closest to the satellite overpass, averaged at the nominal resolution of the corresponding satellite product (on the left), and the satellite precipitation rate (on the right).

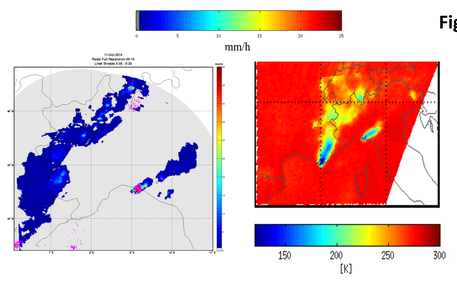

Fig. 3

Figure 3: Left panel: Radar surface RR (mm/h) at full resolution and LINET strokes (in magenta) registered in 20 minutes around the time of the SSIMS overpasses at 5:07 UTC; Right panel: TB at 150 GHz for the same overpass.

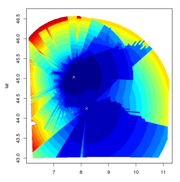

Fig. 4

Figure 4: Radar visibility map (color scale indicates heights in m)

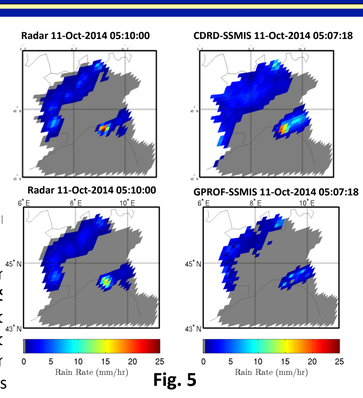

Fig. 5

Figure 5: Comparison between CDRD-SSMIS and GPROF-SSMIS with the radar estimates filtered through the visibility map and averaged to the nominal resolution of the two precipitation products (Table 1).

In Fig. 2 at 05:07 UTC CDRD-SSMIS depicts very well the convective cell over Genoa and shows heavy precipitation in Southern France (red circles), which is not present in the radar image, but finds correspondence in the intense lightning activity and in the low brightness temperatures at 150 GHz for the SSMIS overpass (Fig. 3). The discrepancies in the precipitation pattern found over the North-Western Italian border with France (green circles) and in Southern France (red circles) is mostly due to the poor radar visibility in this regions due to the Alps. This is confirmed by the radar visibility map (Fig. 4), showing that these areas are observed by the radar above 5000 m. By limiting the comparison with the radar to the region with visibility below 5000, m the agreement with the CDRD-SSMIS precipitation retrieval improves significantly (Fig. 5 top panels). For comparison the GPROF-SSMIS retrieval for the same overpass is shown (radar estimates averaged to the GPROF-SSMIS "nominal" resolution). The GPROF-SSMIS is able to better delineate the light precipitation areas while underestimates the precipitation over the city of Genoa.

Results are strongly dependent not only on the different spatial resolution and viewing geometry and channel assortment of the radiometers (affecting their ability to resolve the precipitation structure), but also on the approach used and the physical foundations behind the retrieval algorithms. These factors need to be carefully evaluated especially in validation activity where results are obtained on pixel-based match-ups with ground data.

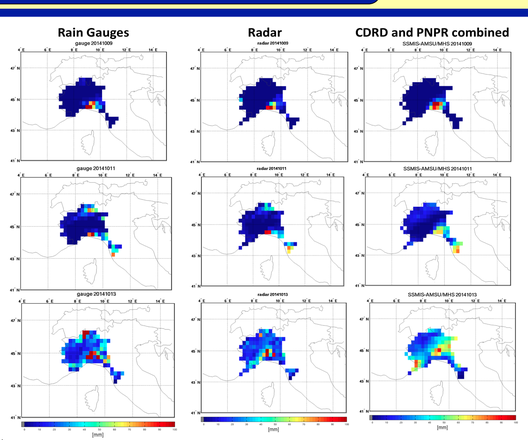

Figure 6: Daily precipitation from raingauges, radar, and combined PNPR and CDRD retrievals (for three days with significant amount of precipitation, October 9, 11, and 13, 2014).

In Fig. 6 daily precipitation obtained from the raingauges, the radar, and the combined PNPR and CDRD retrieval is shown. Only the area corresponding to the radar visibility lower then 5000 m and only pixels over land (where raingauges data are available) have been considered. The CDRD/PNPR maps are obtained from instantaneous precipitation estimates for all SSMIS and AMSU/MHS available overpasses for each day . All the data have been remapped on a regular grid at 0.25°x0.25° resolution. This comparison shows not only the good agreement between radar and rain gauges estimates, but also the ability of the PMW-only retrieval to give good results especially for extremely localized precipitation (October 9) and to delineate the light precipitation areas. It is also evident an overall overestimation of PMW retrieval due also to the low spatial resolution and temporal sampling of space-borne estimates with respect to ground-based observations.

The only available overpass of DPR during the October event is shown in Fig. 7. While ground radars were found in agreement with raingauges (not shown), DPR underestimates the peak of the precipitation, but is able to estimate precipitation where Bric radar is affected by beam blocking due to the Alps (i.e., 46°N 9°E).

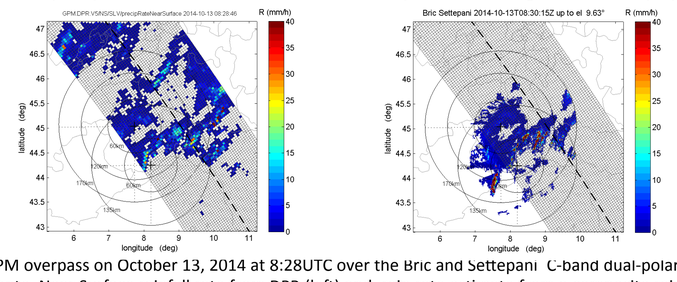

Figure 7: GPM overpass on October 13, 2014 at 8:28UTC over the Bric and Settepani C-band dual-polarization radars of ARPA Piemonte. Near Surface rainfall rate from DPR (left) and rain rate estimate from a composite rain algorithm from the ground-based radars (right).

Nominal vs. effective resolution?

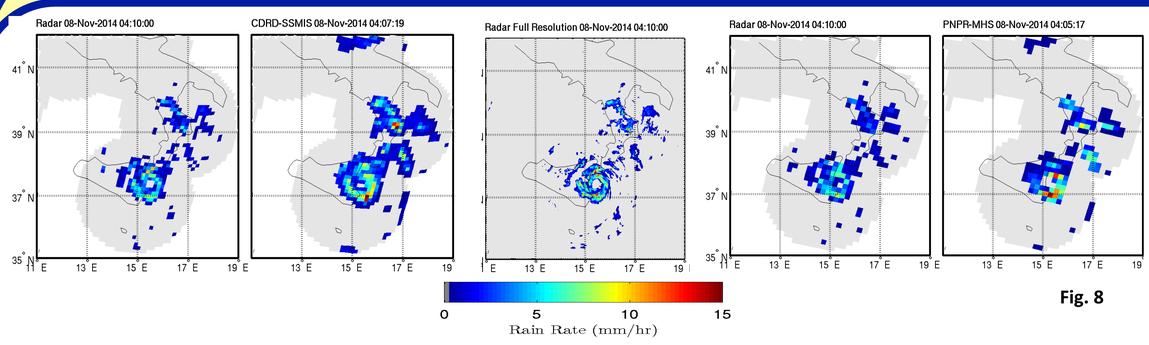

Fig. 8

Figure 8: Medicane case study on November 8, 2014, 4:05 UTC: surface rainfall rate from SSMIS (CDRD) and AMSU/MHS (PNPR) close-in-time overpasses and DPC national mosaic rainfall rate (mm/h) averaged at the nominal resolution of the PMW precipitation products (see Table 1). The radar estimate at full resolution is also shown for comparison (central panel).

Both algorithms capture quite well the structure of the cyclone, with the well defined eye and rain bands, and precipitation variability similar to what shown in the radar image at full resolution. Statistical scores shown in Table 3 tend to evidence the good agreement of both CDRD and PNPR with the radar precipitation estimates (with an overall overestimation). However, the pixel-based comparison evidences discrepancies between the radars and the radiometers also related to the different viewing geometry of the radiometers (close to nadir for AMSU/MHS overpass in this case, and slanted for SSMIS) and to the effective resolution of the precipitation product. The difficulty of adequately representing these effects in the match-up procedure with ground-based data significantly affects the results.

	CDRD	PNPR
POD	0.86	0.76
FAR	0.44	0.21
TS	0.51	0.63
ME	1.22	0.55
CC	0.61	0.65

Table 3: Statistical scores for the Medicane SSMIS (CDRD) and AMSU/MHS (PNPR) overpasses.

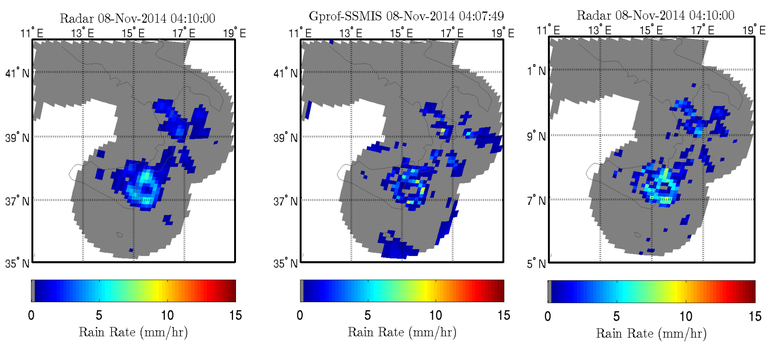

Figure 9: Comparison between GPROF-SSMIS precipitation (middle panel) with DPC national weather radar mosaic for the same overpass shown in Fig. 8. Left panel: radar precipitation averaged at GPROF-SSMIS "nominal" resolution (corresponding to the IFOV of the 37 GHz channel); Right panel : radar precipitation averaged at 91 GHz channel resolution.

The "nominal" resolution of GPROF-SSMIS product is lower than that of the CDRD-SSMIS product shown in Fig. 8. However, the precipitation structures and the eye of the Medicane seems to be very well defined in the GPROF-SSMIS product. The match-up of the ground-based radar (or raingauge) data with the PMW precipitation products is usually carried out at the "nominal" resolution of the satellite estimate. This does not always provide the best results. The "effective" resolution of PMW products can be different depending on the 3-D cloud structure and microphysical characteristics and on background surface conditions, and, therefore, on the PMW channels used in the retrieval process at the time of the overpass. In this case SSMIS seems to be able to capture the precipitation structure at much finer scale than the declared "product resolution". This is more evident when radar/radiometer match-ups at different resolutions are considered, as shown in left and right panel of Fig. 9.

A more complete analysis of the effect of different viewing geometry and resolution has been carried out for all the available overpasses of SSMIS, AMSU/MHS, and ATMS for all the days of the Liguria/Piedmont event (9-13 October, 2014). Statistical scores have been evaluated using high-quality ARPA Piemonte radar data as ground-reference averaged to the nominal resolution of each product (as in Table 1). For the match-up with GPROF-SSMIS the radar data have been averaged to two different resolutions (37 GHz and 91 GHz).

	CDRD SSMIS	GPROF-SSMIS 37 GHz	GPROF-SSMIS 91 GHz	PNPR AMSU/ MHS	PNPR ATMS
POD	0.77	0.54	0.60	0.77	0.59
FAR	0.44	0.22	0.28	0.46	0.33
CSI	0.48	0.47	0.49	0.46	0.46
HSS	0.62	0.61	0.63	0.59	0.60
ETS	0.45	0.44	0.46	0.42	0.43
ME	1.26	-0.95	-1.56	0.90	0.49
CORR	0.47	0.32	0.23	0.38	0.36
RMSE	5.61	3.21	5.37	5.29	4.51
SD	6.02	3.61	6.01	5.52	4.59
RMSE%	189.74	142.19	179.45	187.58	184.27

Table 4: Statistical scores for the 9-13 October event for SSMIS (CDRD and GPROF at 37 GHz and 91 GHz), AMSU/MHS (PNPR) and ATMS (PNPR) overpasses.

Conclusions

The study shows that exploiting all the available overpasses of the polar satellites carrying PMW radiometers it is possible to monitor and analyze the evolution of precipitation systems, also when they are strongly affected by the complex orography characterizing most of the Italian territory, or when they occur along the coast. In the comparison with ground-based radar data, some weaknesses in the PMW detection of light precipitation are evidenced, while the areas affected by the most intense precipitation are in general well identified. This can be particularly useful in areas showing very intense lightning activity and relatively low radar reflectivity, due to partial beam blocking. For this reason, in spite of their low spatial resolution and relatively poor temporal sampling, compared to ground-based observations, precipitation retrievals obtained from the frequent overpasses of the constellation of PMW radiometers in the GPM era represent a unique source of information about heavy precipitation systems, and offer great potentials for precipitation monitoring especially in regions of the globe where ground-based precipitation measurements are affected by complex orography or are not available at all. Moreover the availability of the first spaceborne dual-frequency precipitation radar (DPR), onboard the GPM core satellite, can offer a strong support as a reference instrument for precipitation retrieval providing consistency around the globe. In this study DPR observations show underestimations of the peaks of precipitation respect to ground-based radar, while they cover the lack of observations due to beam blocking.

However, the differences in the precipitation estimates found among the different sensors need to be carefully evaluated and possibly reconciled taking into account the characteristics of the radiometers, and the retrieval approaches used. The verification of PMW products using ground-based data as reference poses great challenges when the ground-based data are averaged to match the satellite product characteristics. Moreover, traditional statistical scores are not always successful in underlining potentials and weaknesses of the different PMW precipitation products. It is fundamental to adopt common advanced strategies both for ground-based data selection and processing and for validation procedures to be able to effectively compare different PMW precipitation products from the GPM constellation and provide the user community with useful information on their accuracy and consistency.

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Acknowledgments

This research has been supported by the EUMETSAT project "Satellite Application Facility on Support to Operational Hydrology and Water Management" (H-SAF), and by the EU FP7 project Earth2Observe.

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