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Research Article

Heavy rainfall in central Viet Nam in December 2018 and modification of precipitation analysis at VNMHA

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Abstract: On 9 December 2018, a heavy rainfall event occurred in central Viet Nam, and at Da Nang, a record–breaking rainfall of 972 mm was observed in 24 hours. The operational precipitation analysis at the Viet Nam Meteorological and Hydrological Administration (VNMHA) on the day considerably underestimated the intense rains. We checked causes of underestimation and modified the precipitation analysis by revising the use of observation data from Automated Weather Stations (AWS) and meteorological radar data. Since the cloud top height of the precipitation system was not high, satellite precipitation estimates using Himawari–8 data drastically underestimated intense rains around central Viet Nam. GSMaP on the day detected the intense rains to a certain extent, and their rainfall estimates (GSMaP_MVK and GSMaP_NOW) were applied to precipitation analysis as alternative satellite estimates. The revised precipitation analysis showed much better representation of the precipitation system. Verification of three precipitation estimates (Himarari–8, GSMaP_MVK, and GSMaP_NOW) against AWS observation was conducted. GSMaP products clearly outperformed precipitation estimates by Himawari-8, though their standard product (GSMaP_MVK) was better than the real time version (GSMaP_NOW).

Keywords: Heavy rainfall; JICA; GSMaP; Nowcast; Precipitation analysis; Himawari–8.

1. Introduction

In Viet Nam, meteorological disasters occur every year. In particular, disasters by heavy rains often cause the greatest damage, and improvement of nowcasting and forecasting of intense precipitation is a key issue for disaster prevention and mitigation. Since June 2018, a bilateral cooperative project between the Japan International Cooperation Agency (JICA) and the Viet Nam Meteorological and Hydrological Administration (VNMHA) for "Strengthening capacity in Weather Forecasting and Flood Early Warning System in the Social Republic of Vietnam" has been conducted. This project is related to S–band radars that were installed at Hai Phong (Phu Lien) and Vinh in September 2017 by another JICA grant aid project. The Japan Meteorological Business Support Center (JMBSC) has been participating in the project as a main contributing organization of Japan. The project scopes are divided into four output targets: 1) surface meteorological observation; 2) radar maintenance and products; 3) weather forecasting; and 4) regional weather dissemination. More detailed reviews of the JICA project are given by [1].

One of the main targets of the JICA project is the quantitative precipitation estimation (QPE). Good QPE is attained by qualified networks of rain gauges and radars, and satellite data are used for supplementary information for filling data sparse areas as on the sea. QPE is important for disaster prevention/mitigation through detection of heavy rainfall areas. The application includes the very short–range forecast of precipitation, input of hydrological models, and verification of numerical weather prediction.

On 9 December 2018, a heavy rainfall event occurred in central Viet Nam, and at Da Nang, a record–breaking rainfall of 972 mm was observed in 24 hours. The operational precipitation analysis at VNMHA on the day considerably underestimated the intense rains. As the output 3 activity in the JICA project, we modified the precipitation analysis by revising the use of observation data from Automated Weather Stations (AWS) and meteorological radars. Since the cloud top height of the precipitation system was not high, satellite precipitation estimates using Himawari–8 data drastically underestimated intense rains around central Viet Nam. We applied GSMaP rainfall estimates to the precipitation analysis as alternative data for satellite estimates.

The organization of this paper is as follows. In Section 2, a heavy rainfall event in central Viet Nam on 9 December 2018 is introduced. In Section 3, operational precipitation analysis at VNMHA is introduced and modification of the analysis using AWS and radar data is described. In Section 4, application of GSMaP is shown. Verification of GSMaP and Himawari–8 satellite estimates of precipitation against AWS observation. Summary and concluding remarks are given in Section 5.

2. Heavy rainfall event in central Viet Nam on 9 December 2018

On 9^{th} December 2018, a heavy rainfall event occurred in central Viet Nam, and at Da Nang, a record–breaking rainfall 972 mm was observed in 24 hours from 01 local standard time (LST) of December 9^{th} (18 UTC of December 8^{th}). Figure 1a shows three–hour rainfalls at Da Nang from 12 UTC December 8^{th} to 18 UTC December 10^{th}. The highest period of the heavy rainfall was from 18 UTC December 8^{th} to 15 UTC December 9^{th}. Observed 6–hour precipitation by SYNOP stations for 00 to 06 UTC of December 9^{th} is indicated by Figure 1b.

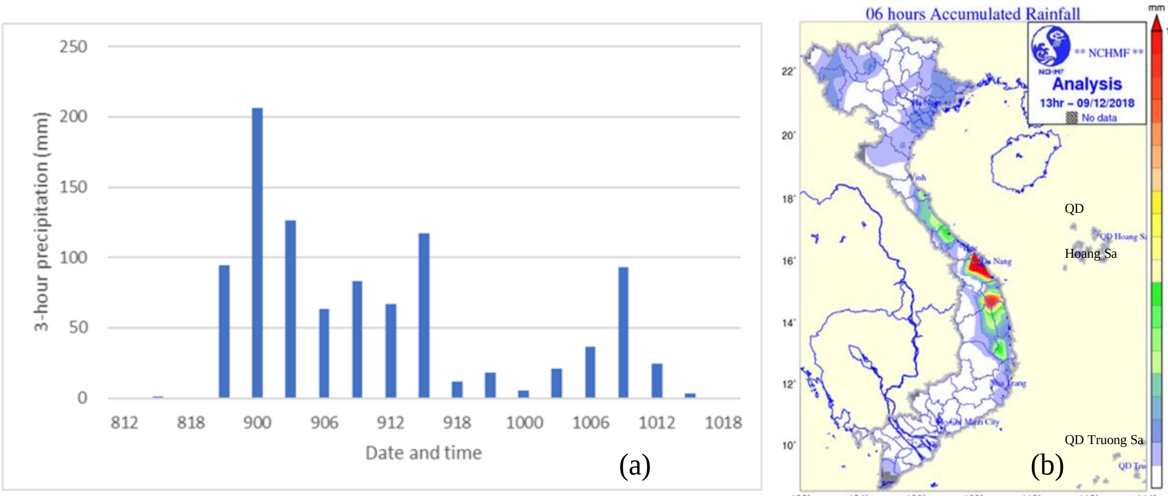


Figure 1. (a) Observed 3–hour rainfalls at Da Nang from 12 UTC 8^{th} to 18 UTC 10^{th}, December 2018; **(b)** Observed 6–hour precipitation at SYNOP stations for 00 to 06 UTC of December 9^{th}.

This heavy rainfall occurred in a typical heavy rainfall situation in Viet Nam, relating to the northeasterly cold surge at the surface (Figure 2a). At 700 hPa level (Figure 2b), southeasterly moist air was lifted over the cold surge, suggesting abundant water vapor convergence in the lower troposphere.

Geostationary satellite (Himawari–8) images on the day suggested that this event was not brought by deep convection but mainly by the warm rain process, because the cloud top height of the rainfall system was not high (Figure 2c).

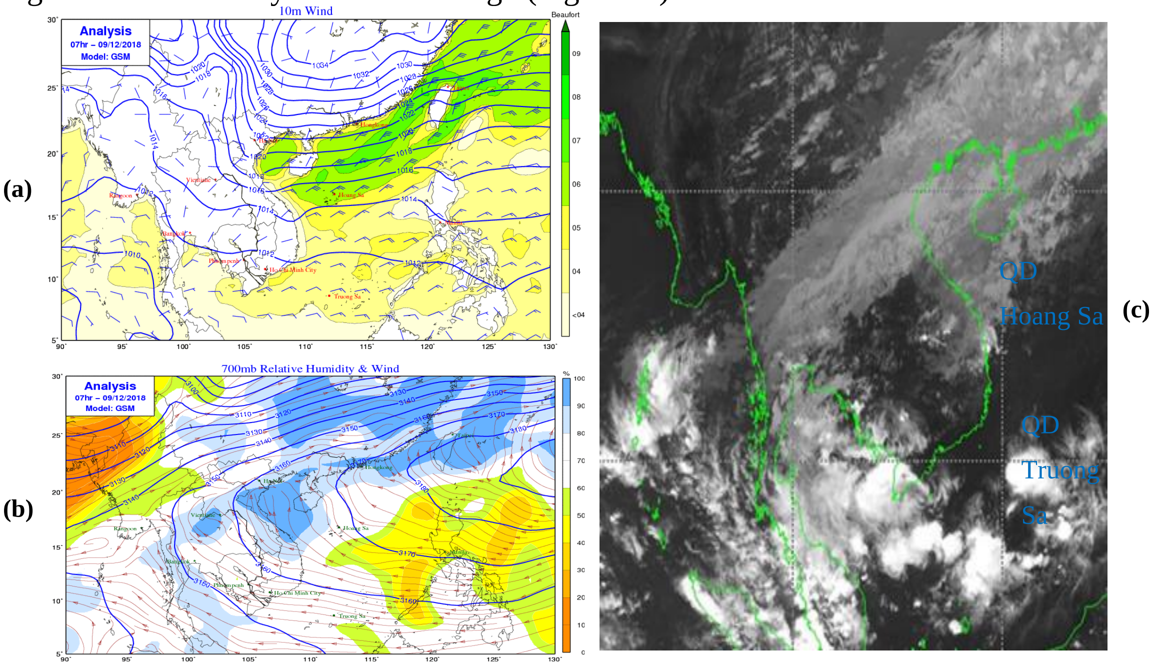


Figure 2. (**a**) Global analysis at 00 UTC 9 December 2018 by JMA. Mean sea level pressure and surface wind; (**b**) Relative humidity and wind at 700 hPa; **(c)** Infrared image by geostationary satellite (Himawari–8) at 00 UTC 9 December 2018.

3. Precipitation analysis at VNMHA

In VNMHA, 176 manned observatories (SYNOP) observe 6–hour accumulated rain at four times (00, 06, 12, 18 UTC) a day, and the rains are interpolated to 5 km grids to produce a rainfall map (Figure 1c). Since August 2018, a 3–hour accumulated rainfall map has been produced at the National Center for Hydro–Meteorological Forecasting (NCHMF) as a real time precipitation analysis, using observations from rain gauge data at about 1,100 AWS stations (Figure 3a) and precipitation estimates by meteorological radars (Figure 3b) and satellite. For details of meteorological radar observations at VNMHA [2].

Two kinds of precipitation analysis ("Mean" and "Max") are produced at NCHMF. In "Mean", a priority order of data, AWS, radar and satellite, is prescribed, and precipitation amount at each analysis grid (5 km resolution) is determined by higher priority data source in order among the available data (e.g., a mean value of AWS precipitation is taken first if AWS rain gauge data are available). In "Max", the maximum value of the available data is selected.

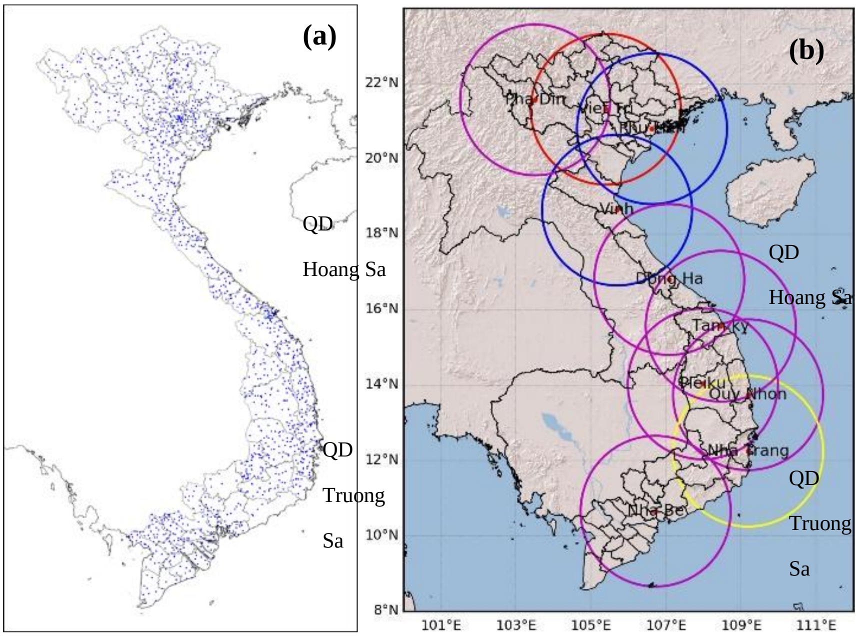


Figure 3. (**a**) AWS stations of VNMHA; (**b**) Meteorological radars of VNMHA (as of 2019). Purple circles represent Vaisala radars, blue circles as Japan Radio Company (JRC) radars, red circle as Thompson radar and yellow circle as Enterprise Electronic Corporation (EEC) radar.

4. Modification of precipitation analysis

Figure 4 is the precipitation analysis of 9 December 2018 that produced by NCHMF in operation on that day. Despite the intense rain observed by SYNOP (Figure 1b), no intense precipitation was analyzed over central Viet Nam. We checked three components of the precipitation analysis (AWS, radar, and satellite).

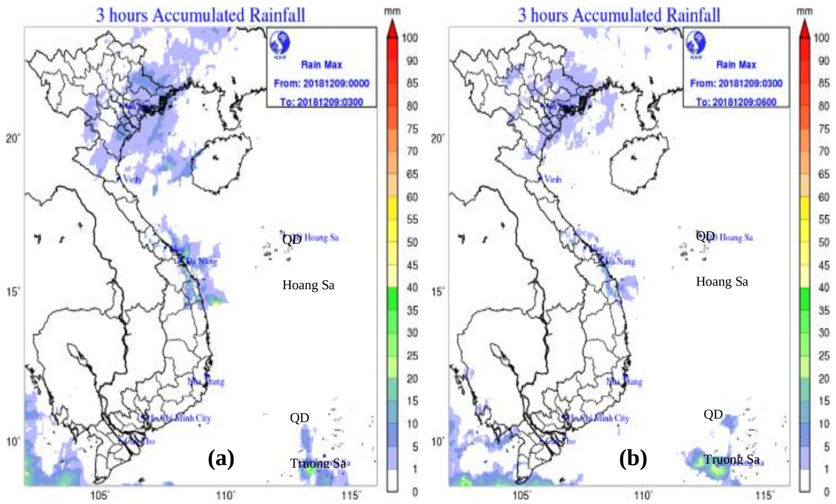


Figure 4. Precipitation analysis at VNMHA on 9th December 2018: **(a)** For 00 to 03 UTC; **(b)** For 03 to 06 UTC.

4.1. AWS observation

Figure 5 shows three–hour precipitation observed by AWS on 9th December 2018. For 00–03 UTC, seven AWS stations (Cau Lau, Cam Le, Hoi An, Da Nang, Thanh Binh, Trang Bom, Tay Thuan), and for 03–06 UTC, six stations (Cau Lau, Hoi An, Tam Ky, Thanh Binh, Ho Nui Mot, Duy Son) detected intense rains above 80 mm. Errors were found in the treatment of AWS observation data in real time operation of precipitation analysis at NCHMF on the day. The errors were in data transfer and storing methods for AWS stations coming from different projects, and were fixed after the event.

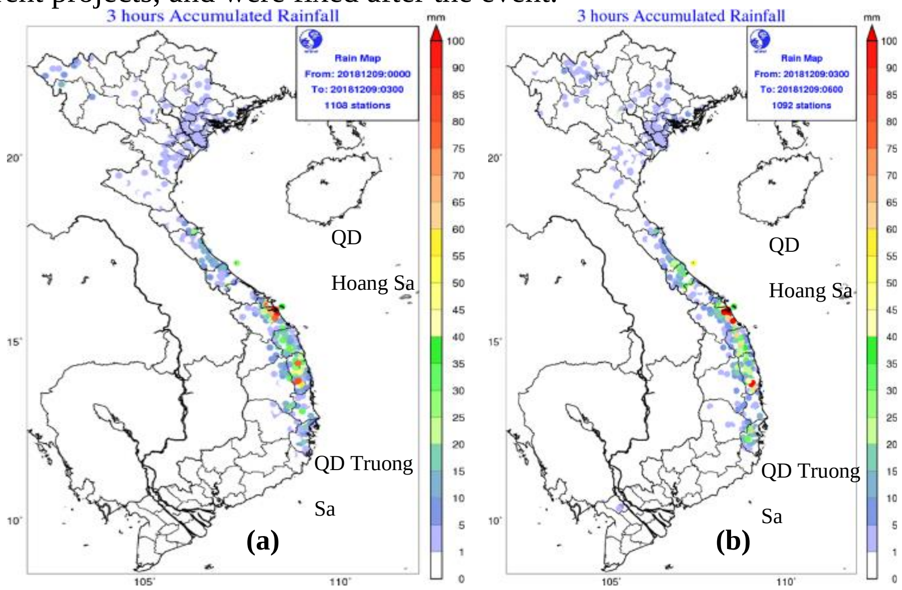


Figure 5. Three–hour precipitation observed by AWS on 9 December 2018: **(a)** for 00 to 03 UTC; **(b)** for 03 to 06 UTC.

4.2. Radar estimation

Figure 6 shows three–hour precipitation estimated from weather radars of VNMHA on 9th December 2018. The estimation is produced by Aero–Meteorological Observatory (AMO) of VNMHA from the radar reflectivity composite map using the Z–R relationship of

$$Z=200*R^{1.6} \quad (1)$$

Here, Z is the radar reflectivity factor in $mm^6\ m^{-3}$ and R the rain rate in mm. This relationship is based on the observation of raindrop size distribution [3].

In the radar composite map used for the operation on the day, data from Vinh radar were not used (Figure 7a). Actually, the Vinh radar was operated on the day, and its data were archived by the JICA team member. We added the data to the composited map (Figure 7b). Figure 8 is three-hour precipitation estimated from radars including Vinh. Precipitation areas near Vinh appeared, however, precipitation around central Viet Nam is not necessarily very strong.

Two C–band weather radars of VNMHA at Dong Ha and Tam Ky are located at east coastal areas of central Viet Nam and there are mountain areas in the west. Since their antennas' altitudes are low (about 40 m above the mean sea level), terrain shielding occurs for low elevation angle (0.5 degree) in the west side semicircle as shown in Figures 9–10. As for other factors, adjustment for attenuation by precipitation in C–band radars may be insufficient. There is room for reconsidering in the Z–R relationship, because when the warm rain process is dominant small size raindrop particles relatively increase compared with the intense rain case with the ice phase.

Figure 10 shows modified three–hour precipitation analysis using AWS data, radar data including Vinh radar and satellite estimated rainfall on 9 December 2018. Compared with the original analysis (Figure 4), improvement is distinct in the representation of rainfall areas in central Viet Nam, however, precipitations over the sea are likely still insufficient as suggested by the satellite image (Figure 2c).

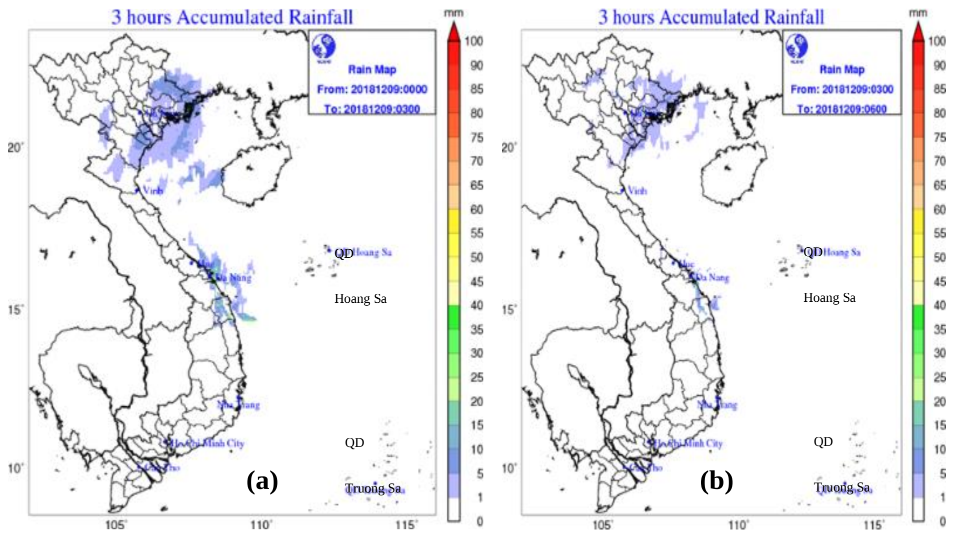


Figure 6. Radar estimated rainfall from reflectivity composite map on 9 December 2018; (a) For 00 to 03 UTC; (b) For 03 to 06 UTC.

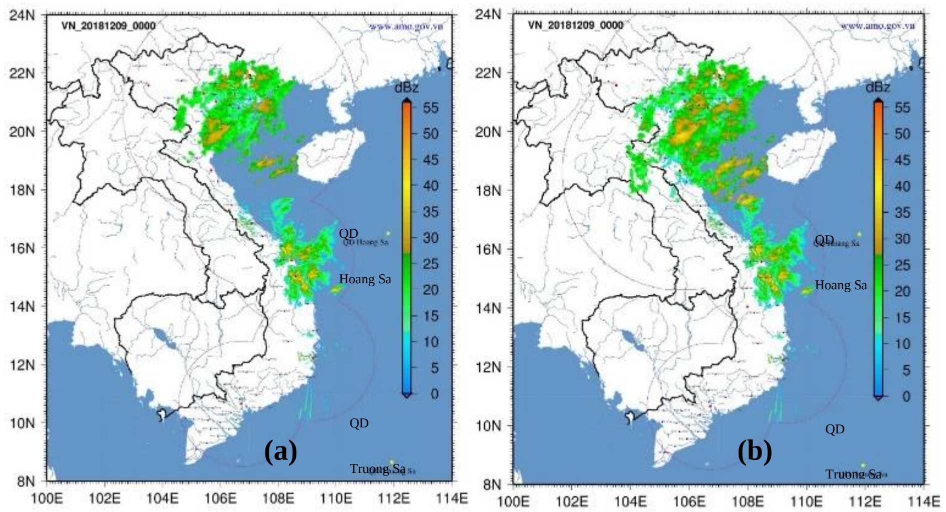


Figure 7. (a) Radar reflectivity composite map at 00 UTC, 9 December 2018; **(b)** Same as a) but with Vinh radar data.

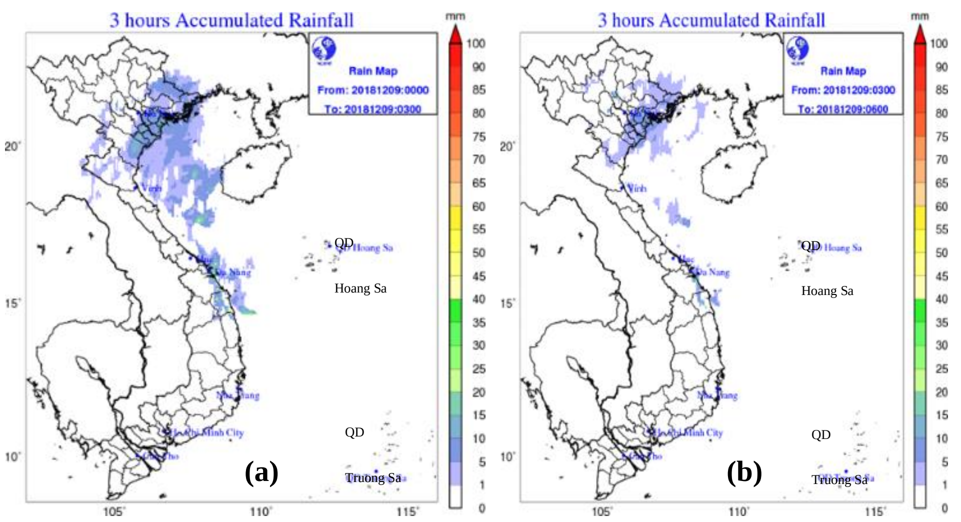


Figure 8. Radar estimated rainfall from reflectivity composite map on 9 December 2018 with Vinh radar data: **(a)** For 00 to 03 UTC; **(b)** For 03 to 06 UTC.

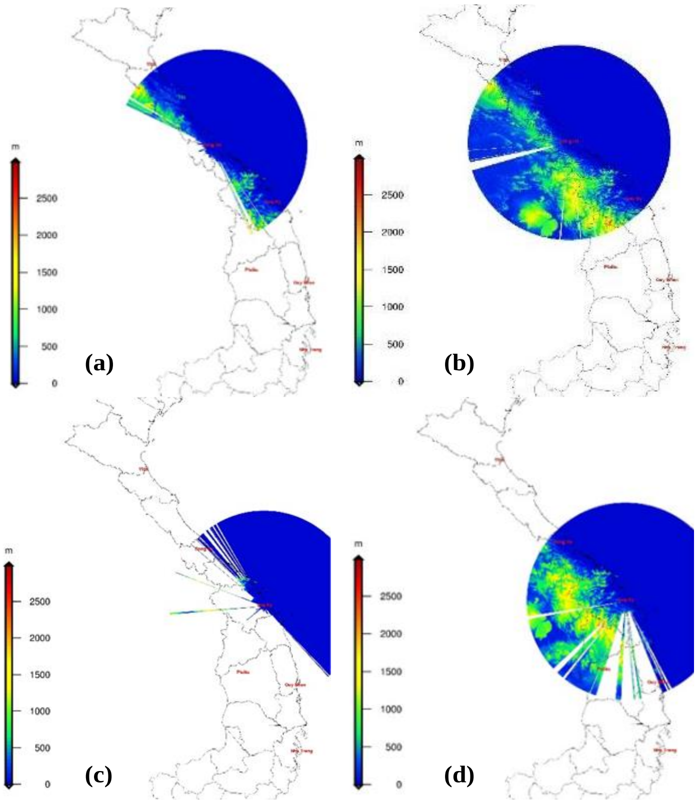


Figure 9. Terrain shielding at Dong Ha radar: **(a)** Elevation angle 0.5 degree; **(b)** Elevation angle 1.0 degree; **(c)** Same as Figures 9a but for Tam Ky radar; **(d)** Elevation angle 1.0 degree.

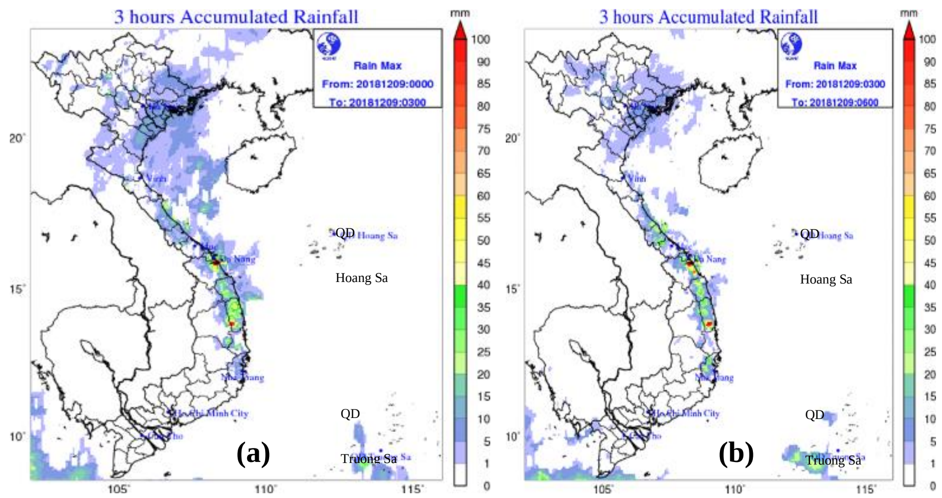


Figure 10. Modified three–hour precipitation analysis with AWS data and Vinh radar data on 9 December 2018: **(a)** For 00 to 03 UTC; **(b)** For 03 to 06 UTC.

4.2. Satellite rainfall estimation

Figure 11 shows three–hour precipitation estimates from the Himawari–8 satellite processed by AMO on 9 December 2018. Estimated rainfall intensity around central Viet Nam is very weak.

AMO uses relationship between cloud top brightness temperature (TBB) and rainfall intensity R (Figure 12a):

$$R = 1.1183*10^{11} exp(-3.6382*10^{-2} T_{BB}^{1.2}) \quad (2)$$

This relationship is based on statistics between TBB observed by the GOES satellite and radar–estimated rainfall over north America [4]. As shown in Figure 2c, cloud top height of the precipitation system near central Viet Nam on the day was not high. Indeed, its TBB by infrared image was around –4 °C (Figure 12b), which corresponds to only 1.2 mm/h in the rain rate by Eq. (2). Rainfall estimates based on brightness temperatures by a geostationary satellite have a limit in accuracy, because it does not observe the rain directly but is a statistical relationship.

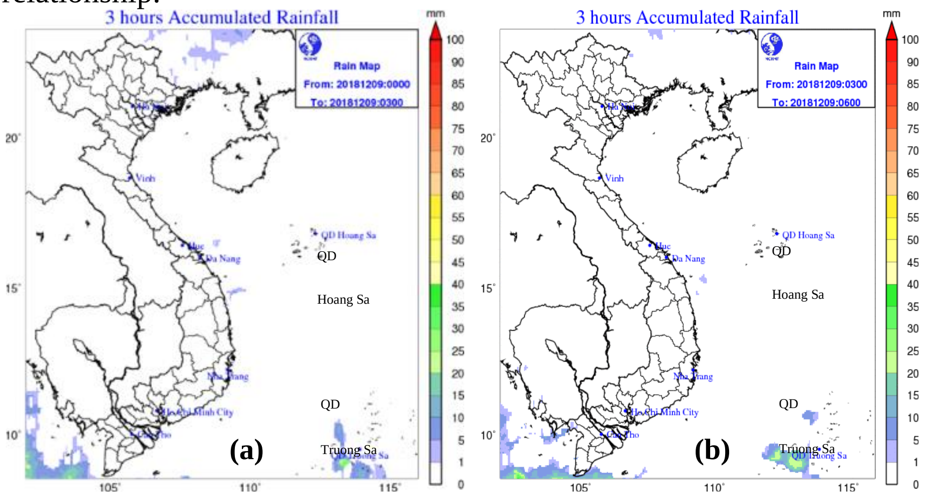


Figure 11. Estimated rainfall from satellite (Himawari–8) on 9 December 2018: **(a)** for 00 to 03 UTC; **(b)** for 03 to 06 UTC.

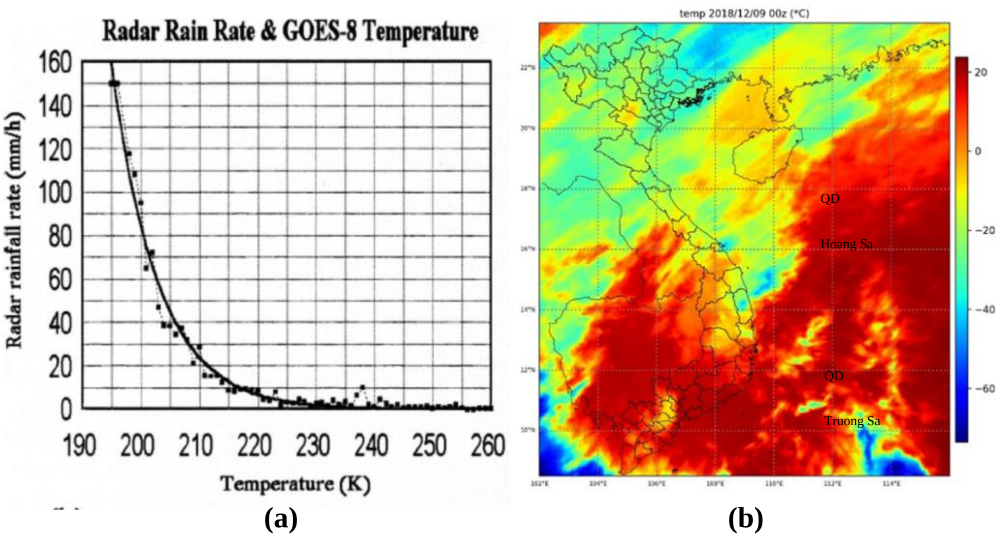


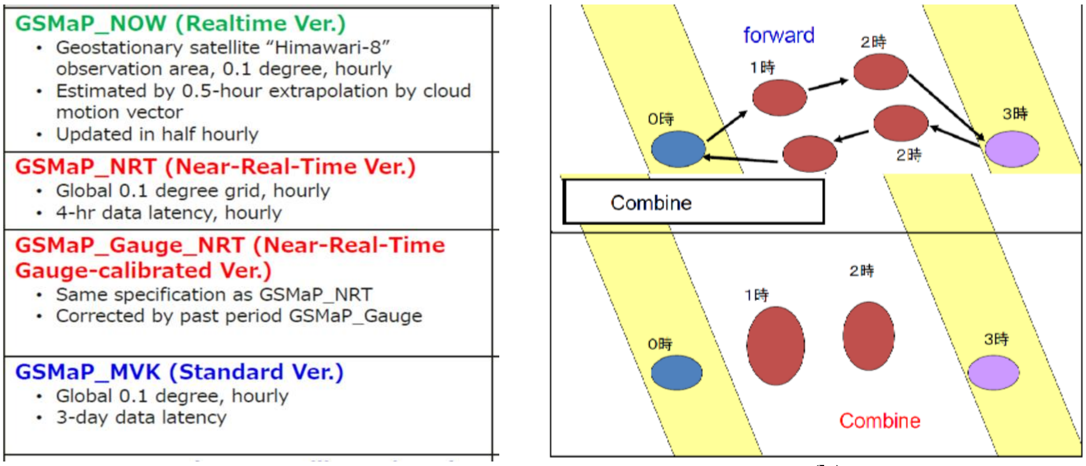
Figure 12. (a) Relationship between TBB and rainfall rate by Vicente et al. (1998); **(b)** T_{BB} observed by Himawari–8 at 00 UTC 9 December 2018, corresponding to Figure 2c.

5. Application of GSMaP estimated rain

5.1. GSMaP

GSMaP is the rainfall estimate operated by the Earth Observation Research Center (EORC) of the Japan Aerospace Exploration Agency (JAXA) based on satellite observations. Main source to observe rainfall is microwave radiometer data from Global Precipitation Measurement (GPM) satellites [5–7]. As shown in Figure 13a, operational GSMaP products are classified to several kinds according to their latencies. Standard product is GSMaP_MVK, whose latency is about 3 days. Since observation frequency of satellite microwave data is about three hourly at each targeted point, in GSMaP_MVK, precipitation rates at no observation times are estimated by combining forward and backward extrapolations with observation data immediately before and after the analysis times. Extrapolations are conducted using horizontal winds based on cloud motion vectors (AMVs) by the geostationary satellite (Figure 13b).

GSMaP_NRT and GSMaP_NOW are products more focused on promptness. In GSMaP_NRT, the rain rate is estimated by forward extrapolation only using observation data immediately before for the near real time operation. In GSMaP_NOW, to provide the results at real time, the rain rate is estimated every 30 min based on extrapolation of GSMaP_NRT at immediately before and available satellite data at the analysis time.



(a) (b)

Figure 13. (a) Classification of operational GSMaP data [6]; **(b)** Conceptual diagram of rain estimation by GSMaP_MVK [7].

5.2. GSMaP on the Da Nang heavy rainfall event

GSMaP detected the intense rains over central Viet Nam on 9th December 2018 up to a point. Figure 14 shows hourly rainfall estimates by GSMaP_MVK for 01 to 06 UTC of 9th December 2018. Rainfall intensity is strong at 02 and 05 UTC, when microwave data are available. At other times, rainfall rates are relatively weak due to interpolation (combination of forward and backward extrapolations).

Figure 15 is hourly rainfall intensity and accumulated rainfall amount at a grid point near Da Nang (16.04N, 108.21E) for 8th to 10th December by GSMaP_MVK. The accumulated rain amount is still underestimated, however, in maximum, 200 mm/h hourly rainfall intensity and 600 mm accumulated precipitation were estimated at another point (14.53N, 108.8E) in central Viet Nam (figure not shown).

In the viewpoint of real time disaster prevention, accuracy of GSMaP_NOW is more important. Figure 16 is hourly rainfall estimation by GSMaP_NOW corresponding to Figure 14. Here, the hourly rainfall amount was calculated by a sum of two 30 min rainfall intensities. Compared with GSMaP_MVK, there is a time lag in GSMaP_NOW in the timing of intense rains, which is attributable to the forward extrapolation used in GSMaP_NOW.

As shown in Figures 14 and 16, the hourly rainfall intensities by GSMaP fluctuate depending on available microwave data, however, the three–hour accumulated rainfall amount is likely usable to precipitation analysis because the GPM satellite microwave observation is generally available three hourly. Figure 17 shows three–hour rainfall estimates for 9th December 2018 by GSMaP_MVK and GSMaP_NOW corresponding to Figure 11. The rainfall system around central Viet Nam is much well represented compared with the Himawari–8 satellite estimates.

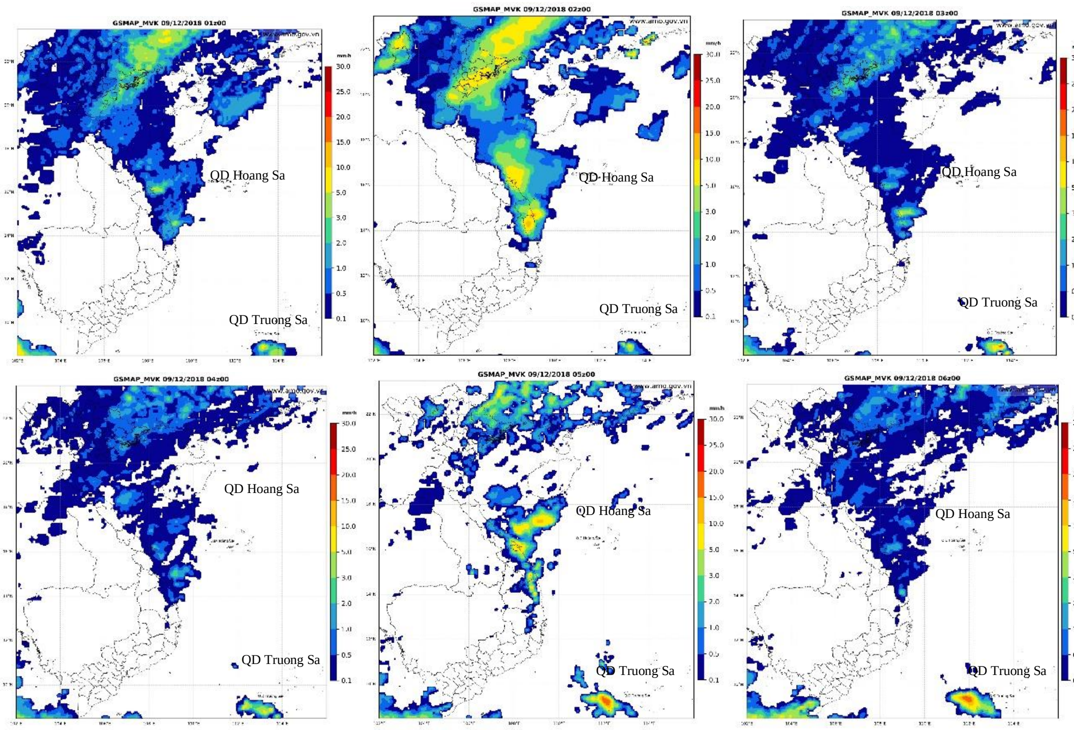


Figure 14. Hourly rainfall estimation by GSMaP_MVK for 01 to 06 UTC 9 December 2018.

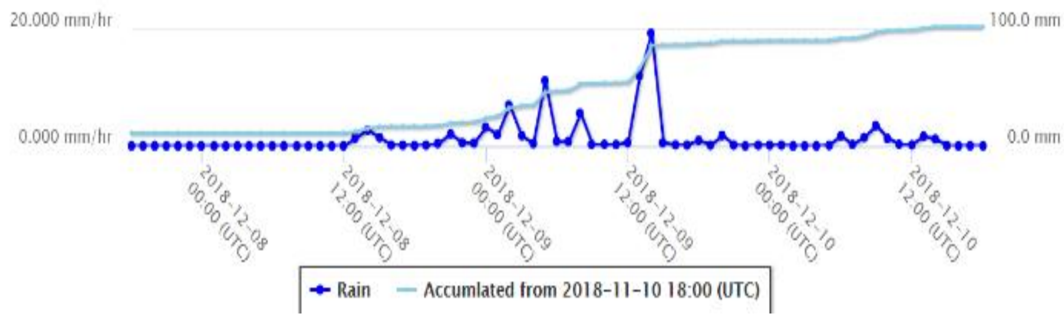


Figure 15. Hourly rainfall intensity (blue) and accumulated rainfall amount (light blue) at a point near Da Nang (16.04N, 108.21E) for 8th to10th Dec 2018 by GSMaP_MVK.

Figure 18 shows the modified 3–hour precipitation analysis using GSMaP data on 9 December 2018 corresponding to Figure 10. Here, satellite estimation by Himawari-8 was replaced by GSMaP data, and both AWS data and Vinh radar data are used in addition. Both figures with GSMaP_MVK and GSMaP NOW are seemingly much better than the original analysis (Figure 4) and improved from that using the Himawari–8 estimated rain (Figure 10).

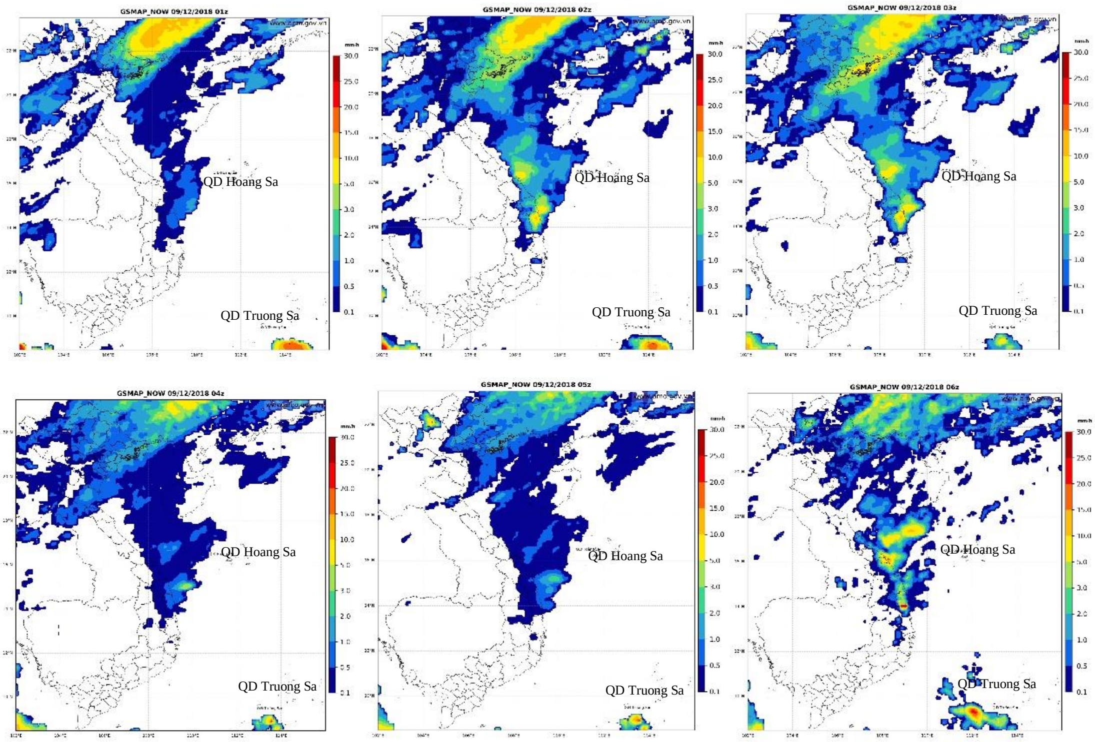


Figure 16. Hourly rainfall estimation by GSMaP_NOW for 01 to 06 UTC 9 December 2018.

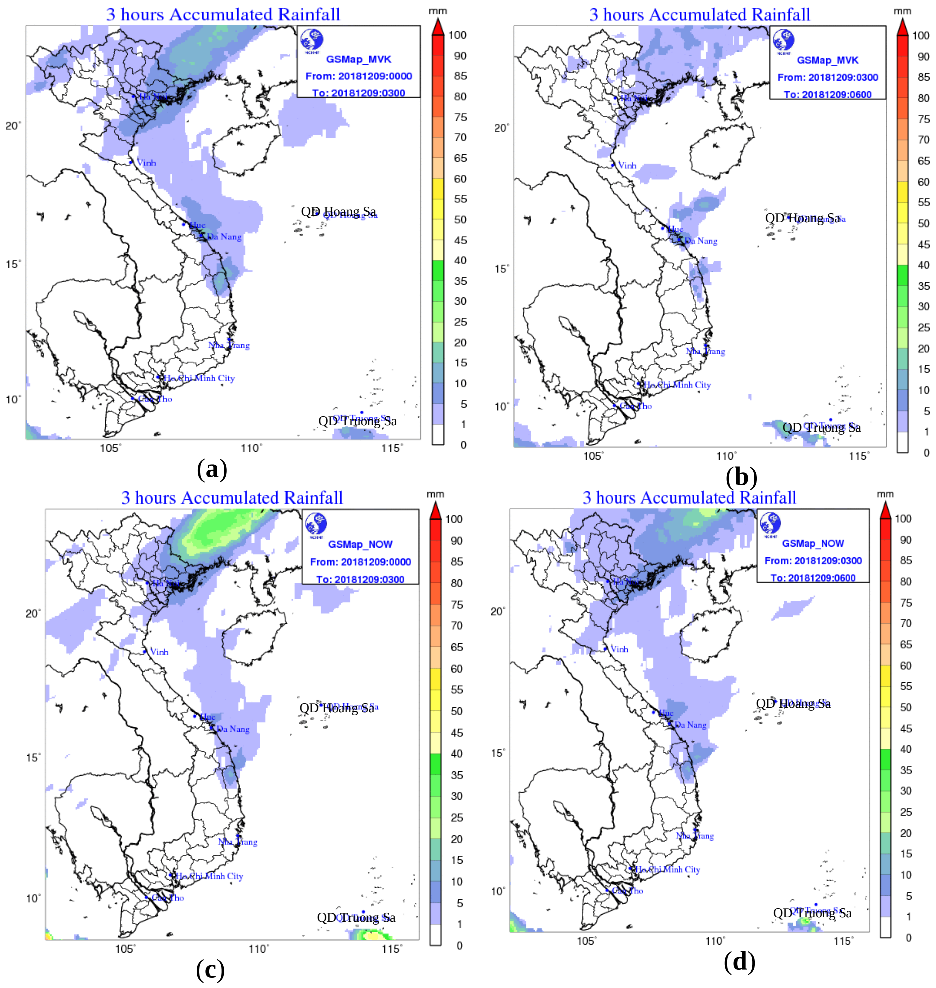


Figure 17. Three–hour rainfall estimation for 9 December 2018: **(a)** 00–03 UTC by GSMaP_MVK; **(b)** 03–06 UTC; **(c)** 00–03 UTC by GSMaP_NOW; **(d)** 03–06 UTC.

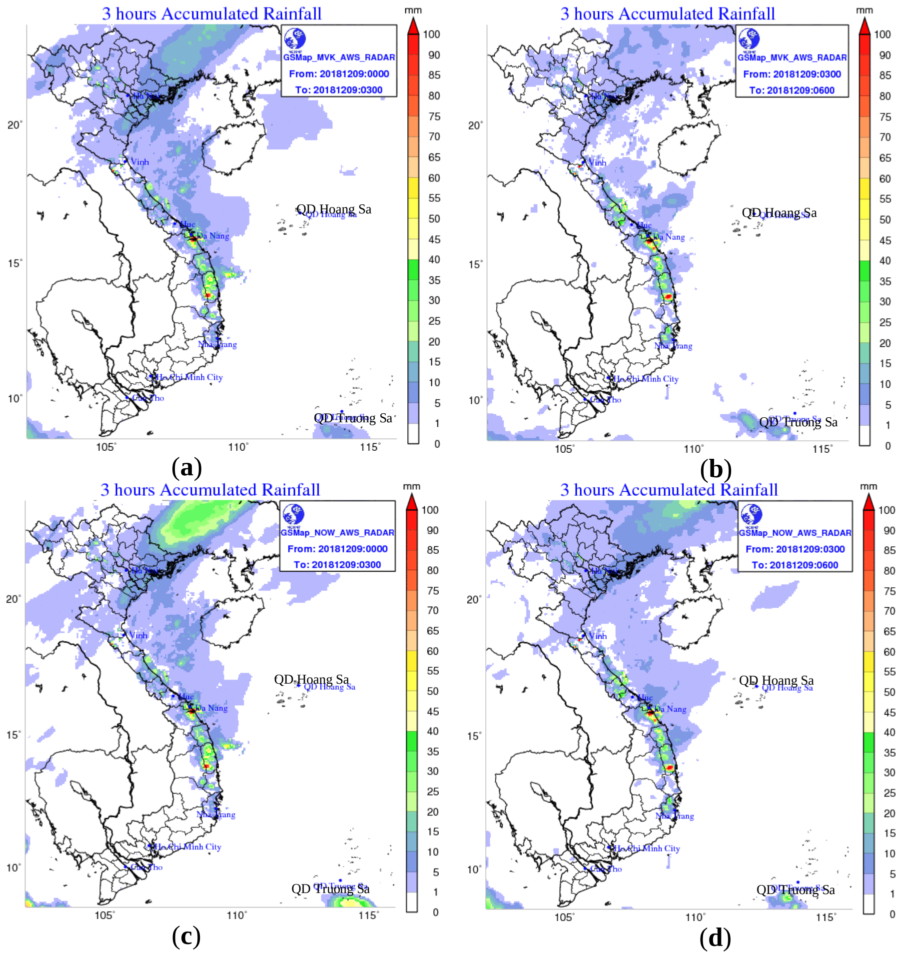


Figure 18. Modified precipitation analysis for 9 December 2018 using AWS and Vinh radar data with GSMaP data: **(a)** 00 to 03 UTC with GSMaP_MVK; **(b)** 03–06 UTC; **(c)** 00–03 UTC by GSMaP_NOW; **(d)** 03–06 UTC.

5.3. Verification

We verified the rainfall estimates by GSMaP_MVK, GSMaP_NOW and Himawari–8 on 9th December 2018 against AWS observations. Figure 19 shows scatter diagrams of the three estimates against AWS rains for 3–hour accumulated precipitation for 00 to 03 UTC. Here, verification was done with 5 km grids of precipitation analysis over the land. As suggested by Figures 11–12, Himawari–8 (Figure 19c) drastically underestimates intense rains, while both GSMaP_MVK and GSMaP_NOW express intense rains up to a point. Figure 21a shows threat scores of the three estimates. Threat scores of Himawari–8 are almost zero for thresholds over 3 mm per 3 hours. GSMaP_MVK is better than GSMaP_NOW, but both GSMaP estimates notably outperform the Himawari–8 for this period.

Figures 20 and 21b indicate results of the same verification of 3–hour rains for the whole day (00 to 24 UTC) of 9th December. In scatter diagrams, GSMaP sometimes overestimated rains, while no intense rains are seen in Himawari–8. The tendency of threat scores is almost the same as for 00–03 UTC. Himawari–8 drastically underestimates intense rains, and though GSMaP_MVK is better than GSMaP_NOW, both GSMaP estimates clearly outperform Himawari–8.

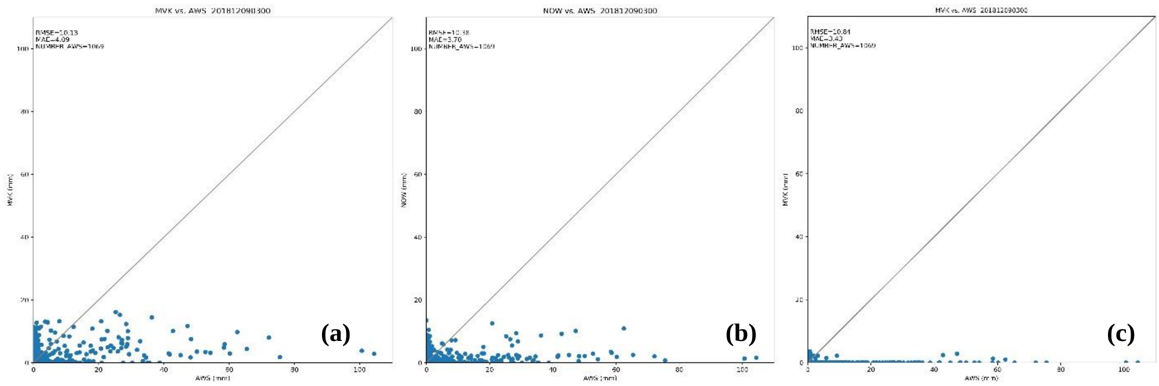


Figure 19. (a) Scatter diagram between GSMaP_MVK (vertical axis) and AWS (horizontal axis) for 3–hour precipitations on 9th December 2018 (00–03 UTC); **(b)** Same as in a) except for GSMaP_NOW; **(c)** Same as in a) except for Himawari–8.

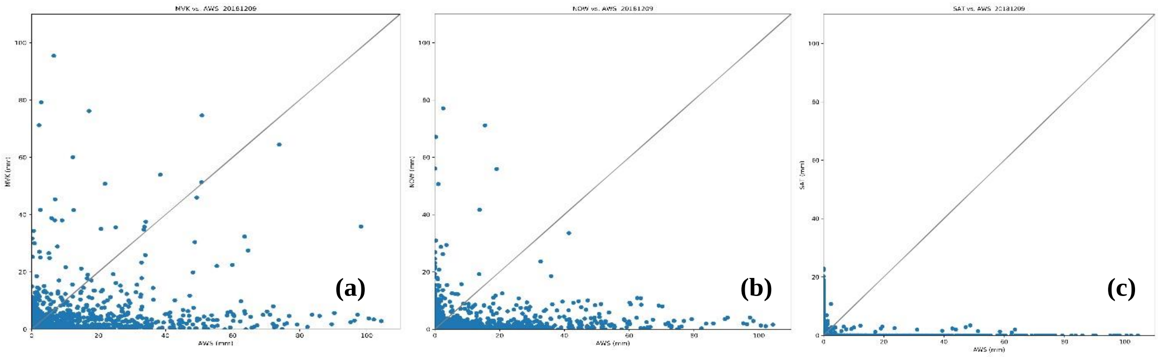


Figure 20. (a) Scatter diagram between GSMaP_MVK (vertical axis) and AWS (horizontal axis) for 3–hour precipitations on 9th December 2018 (00–24 UTC; eight 3–hour precipitations); **(b)** Same as in a) except for GSMaP_NOW; **(c)** Same as in a) except for Himawari–8.

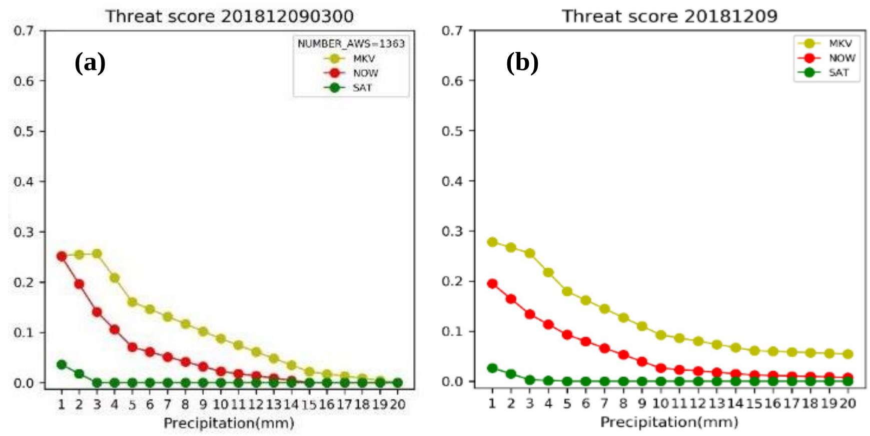


Figure 21. Threat scores of GSMaP_MVK (light green) GSMaP_NOW (red) and Himawari–8 (green) 3–hour precipitations for 00–03 UTC against AWS observation: **(a)** For 3–hour precipitations on 9 December 2018 (00–03 UTC); **(b)** Same as in (a) but for 00–24 UTC.

6. Summary and concluding remarks

We checked the quality of the operational precipitation analysis at VNMHA for the case of a heavy rainfall event in central Viet Nam in December 2018. The precipitation analysis was modified by revision of the use of observation data from AWS and additional radar data at Vinh, and application of GSMaP data. The revised precipitation analysis showed much better representation of the heavy precipitation system.

Comparison and verification of GSMaP data and Himawari-8 estimated rains against AWS observation were conducted. GSMaP distinctively outperforms precipitation estimates by Himawari-8, though their real time version (GSMaP_NOW) is inferior to the standard product (GSMaP_MVK). It is recommended to use GSMaP_NOW for real time operation for disaster prevention and to use GSMaP_MVK for verification of NWP to cover a shortage of AWS and radar data.

NCHMF started operational use of GSMaP data for their precipitation analysis in October 2019. Validation of the operational application of GSMaP is given by a separate paper [8].

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