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Comparison of Rainfall Data Accuracy from Fengyun Satellite, GSMaP, and Weather Radar in Semarang City, Indonesia: A Case Study of 11–15 March 2024

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Background Indonesia



Indonesia, located within the equatorial belt and influenced by both the Asian–Australian monsoon system and the Intertropical Convergence Zone (ITCZ), exhibits highly dynamic atmospheric conditions (Ariska et al., 2024).

Accurate, near-real-time precipitation information is essential for early warning, emergency response, and urban flood management.

Purpose

- 1.To validate rainfall data from C-band weather radar and weather satellites against actual rainfall observations.
- 2.To analyze the rainfall dynamics in the Semarang area, Central Java.
- 3.To identify heavy rainfall events in Semarang City, Central Java.



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Meteorology

This study applies a quantitative precipitation analysis using multiple observation sources, including the Automatic Rain Gauge (ARG), Weather Radar, and satellite-based QPE (Fengyun-4B, Himawari-9, and GSMaP). The methodology consists of the following steps:

Data Collection

Rainfall data were collected from ARG stations distributed across Semarang City. Complementary datasets from radar and satellite observations (FY-4B, Himawari-9, GSMaP) were also obtained to ensure spatial coverage.

Data Processing

The recorded rainfall data from the ARG were downloaded from the data logger, checked for missing values, and validated against radar and satellite data.

Spatial and Temporal Analysis

Daily rainfall accumulation was visualized spatially to identify rainfall distribution patterns during the flood event period. Temporal trends were analyzed to compare rainfall peaks among ARG, radar, and satellite observations.

Validation and Comparison

Quantitative comparisons were performed between ground-based (ARG) and remotely sensed (radar and satellite) rainfall estimates to assess accuracy and bias. Correlation and error metrics such as RMSE and correlation coefficient (R) were calculated.

Instruments

Automatic Rain Gauge (ARG)

Measures rainfall automatically using battery power.

- **Sensor:** collects rainfall.
- **Logger:** records data.

Provides real-time rainfall information for BMKG monitoring.

Weather Radar

Mode System:

- Doppler, Dual-Polarization

Operating Frequency Range:

- 5430 – 5750 MHz (C-Band)

Typical Operational Range:

- 200 km / 600 km

Standard Radar Meteorological Product:

- PPI, MPPI, RHI, CAPPI, Pseudo-CAPPI, MCAPPI, MAX, VCUT, MVCUT, EHT

Meteorological Satellites

Observe clouds and precipitation globally.

- **FY-4B:** cloud and convection analysis.
- **Himawari-9:** real-time visible & IR imagery.
- **GSMaP:** global rainfall estimation.

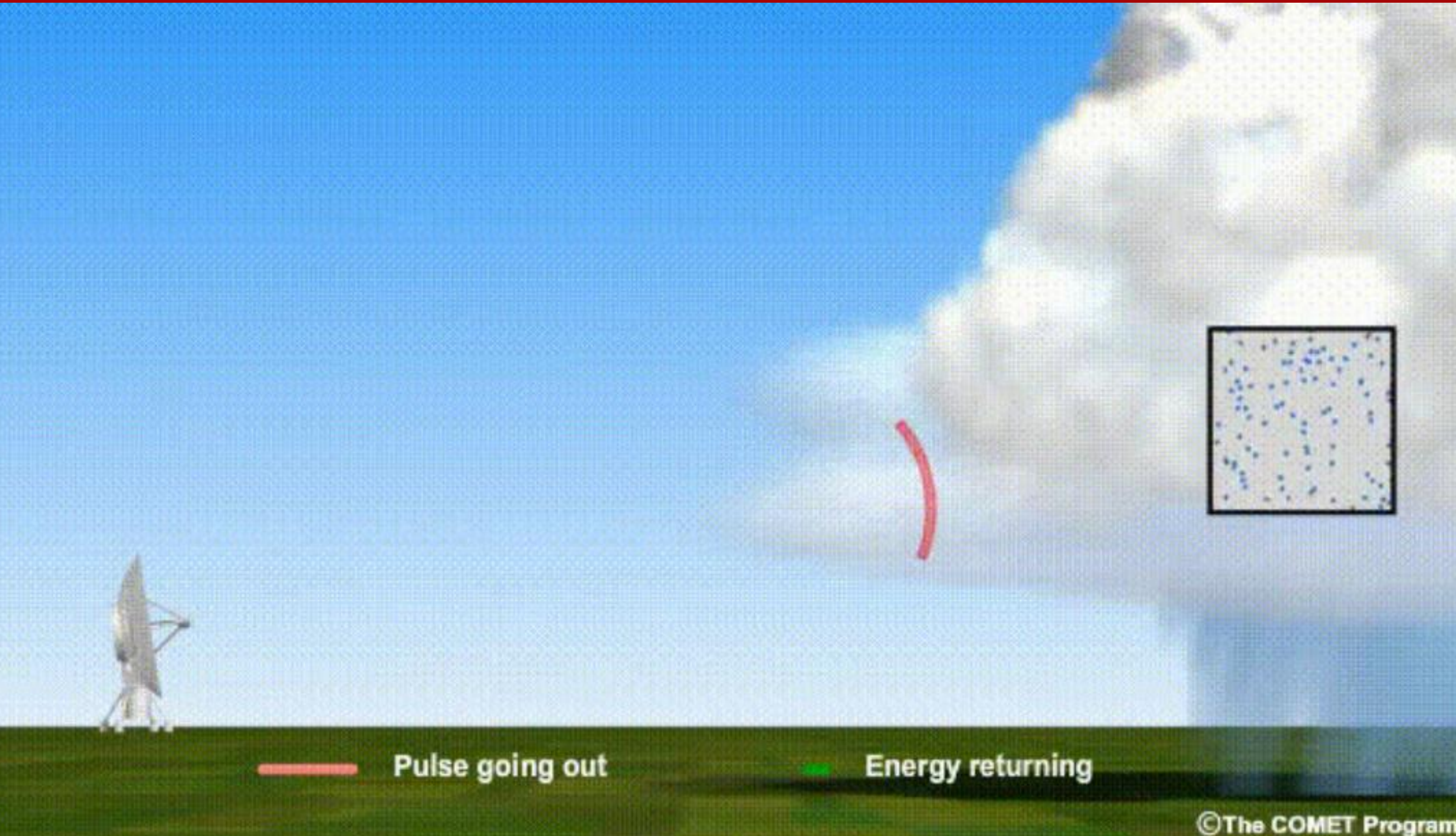
Complements radar and ARG for accurate monitoring.

Automatic Rain Gauge (ARG)



The Automatic Rain Gauge (ARG) functions as an automatic rainfall measuring instrument that records the amount of precipitation over a specific period using a battery as its power source. This device helps BMKG obtain rainfall data without the need to station observers in certain areas. The ARG consists of two main components: the ARG Sensor, which collects and measures rainfall, and the ARG Logger, which calculates and records the rainfall data.

Principles of Weather Radar Observation



RADAR → Radio Detecting and Ranging

Radar emits electromagnetic waves → the waves hit a target → and receive the backscattered energy.

The backscattered energy depends on:

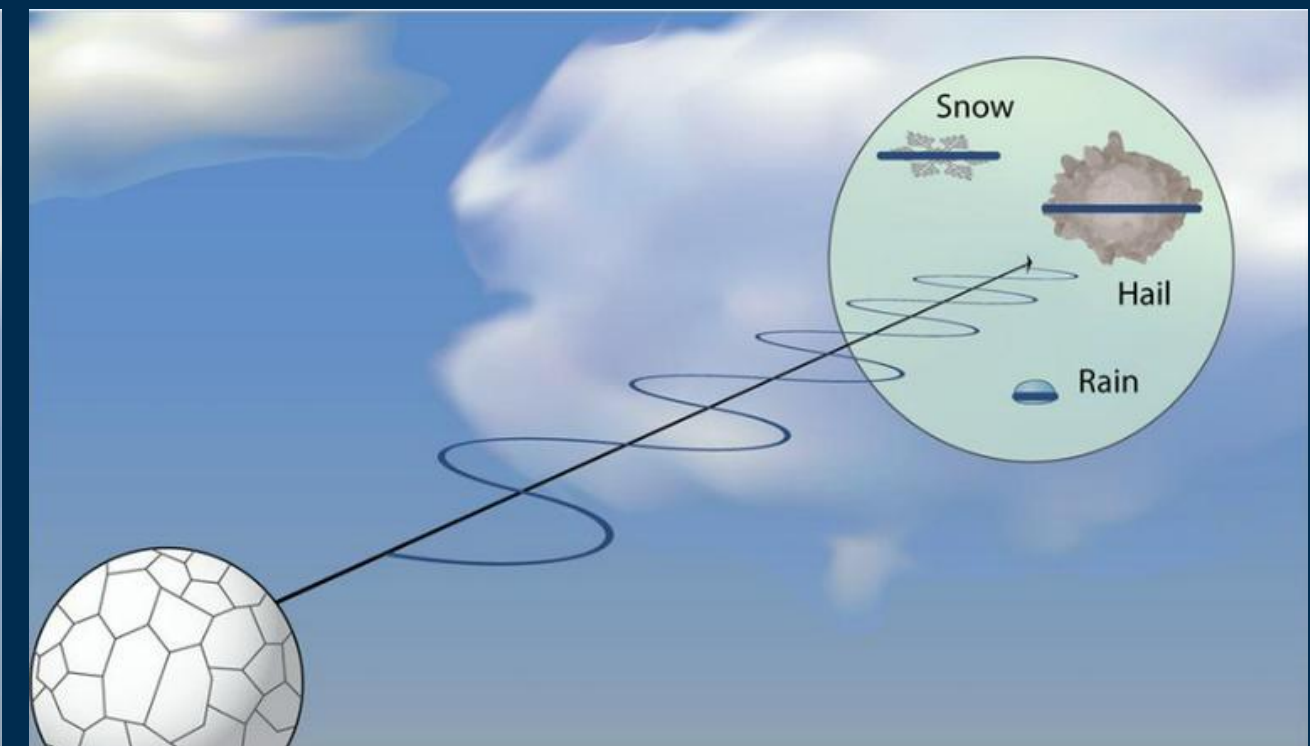
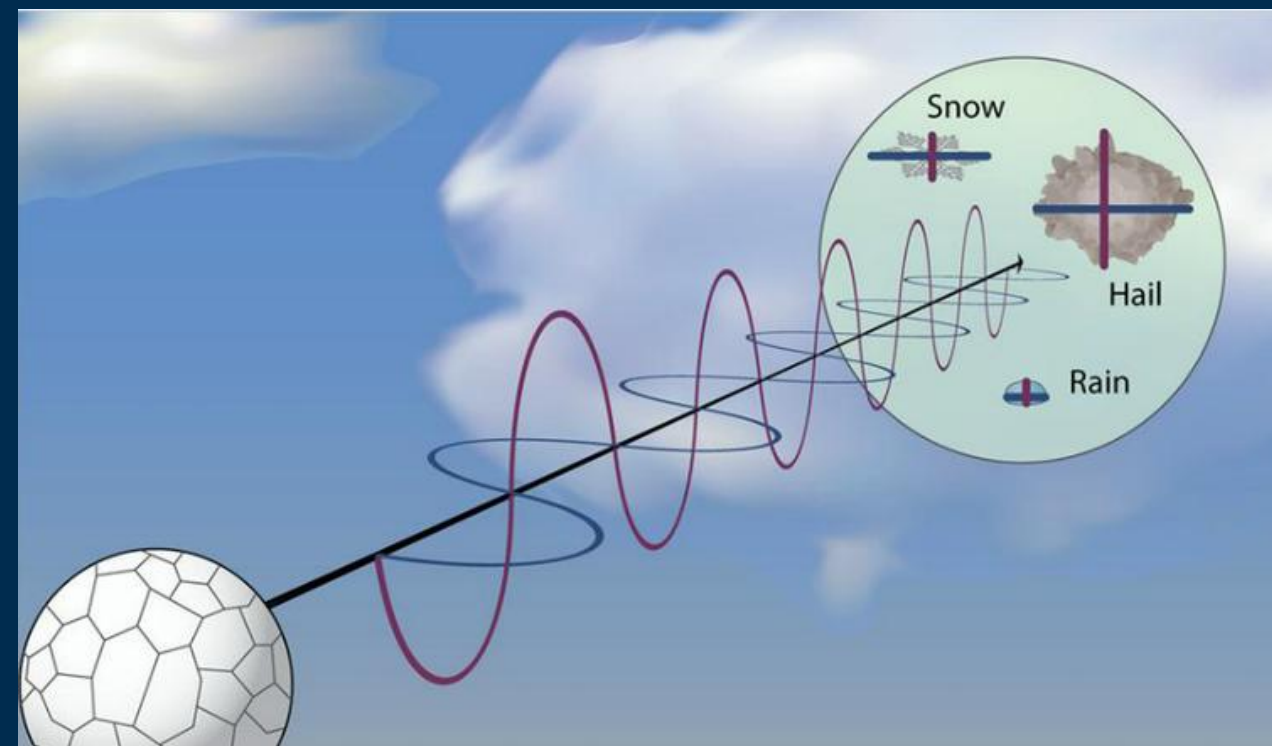
- Particle size
- Particle concentration
- Particle phase (liquid, mixed)
- Particle shape (spherical, flattened)



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Principles of Weather Radar Observation



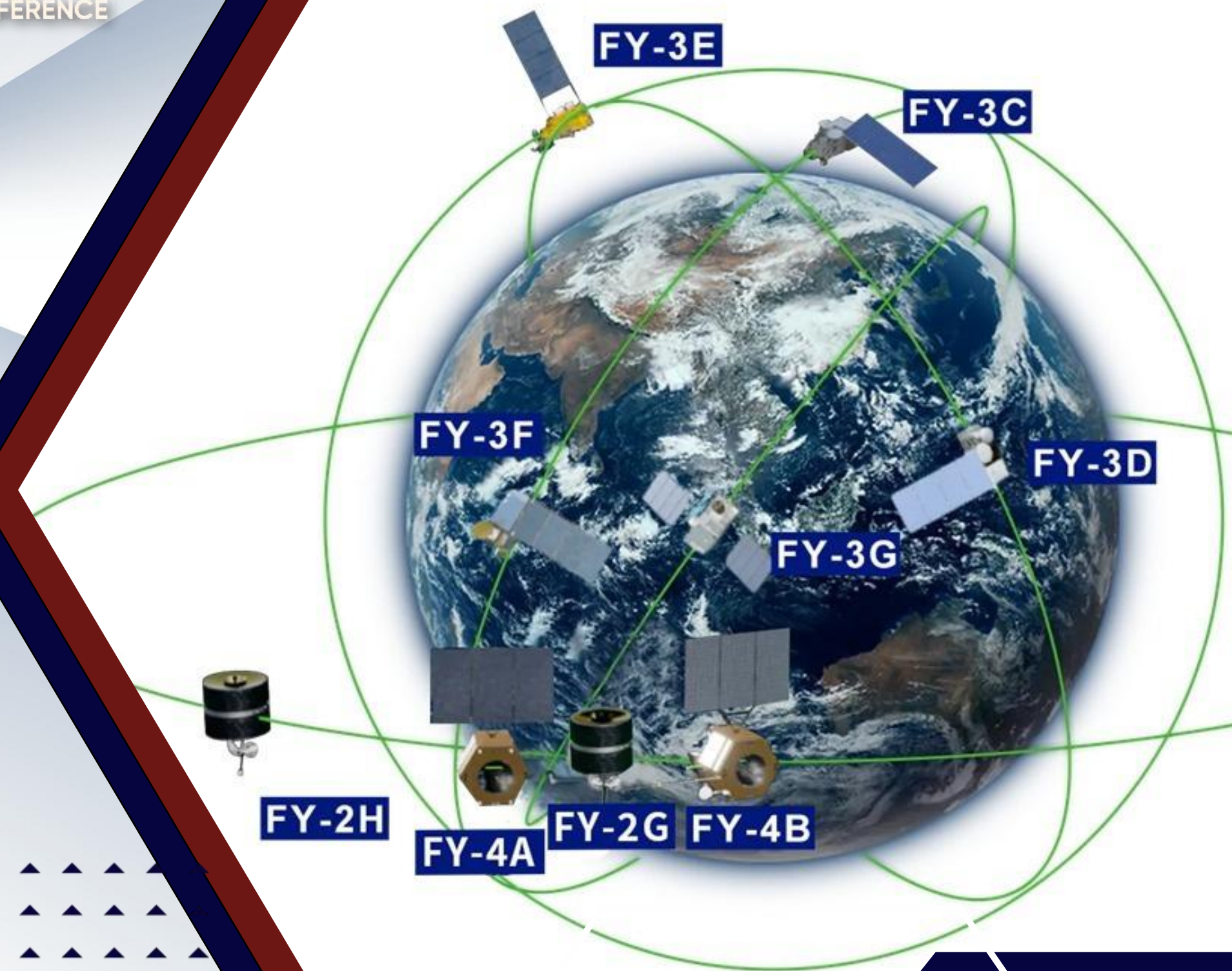
Source: http://research.atmos.ucla.edu/weather/C110/Documents/tmp/basic_wxradar/navmenu.php_tab_1_page_2_0_0_type_text.htm



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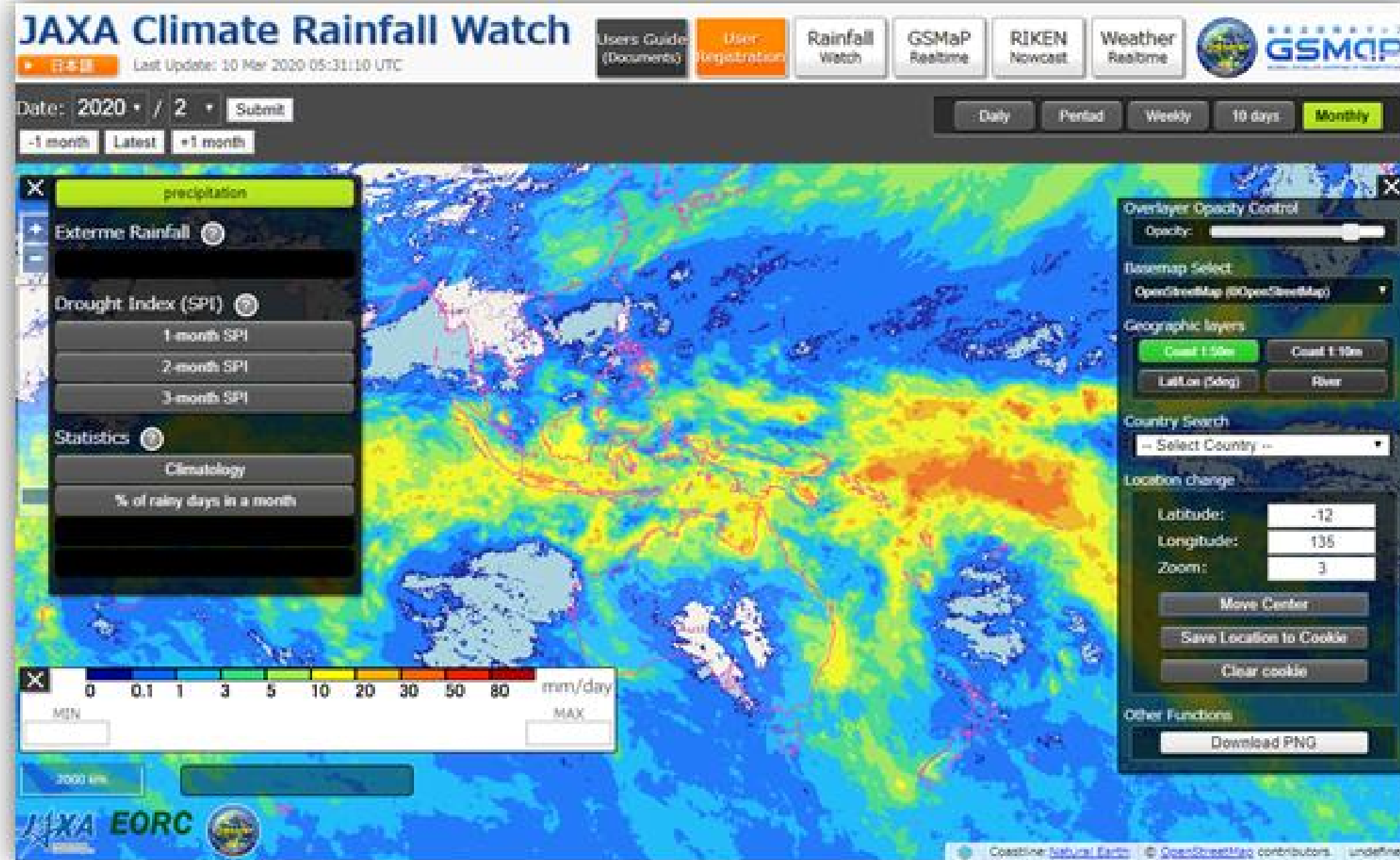
FY4B is the first operational meteorological satellite in China's second-generation geostationary meteorological satellite series. It works alongside FengYun-4A, FengYun-2H, FengYun-2G, and FengYun-2F to form China's geostationary meteorological satellite observation network, gradually replacing Fengyun-2.. FengYun-4B carries four main payloads: the Advanced Geostationary Radiation Imager (AGRI), the Geostationary Interferometric Infrared Sounder (GIIRS), the Rapid Imaging Instrument (GHI), and the Space Environment Monitoring Package (SEP). AGRI features 15 channels.



Fengyun 4B

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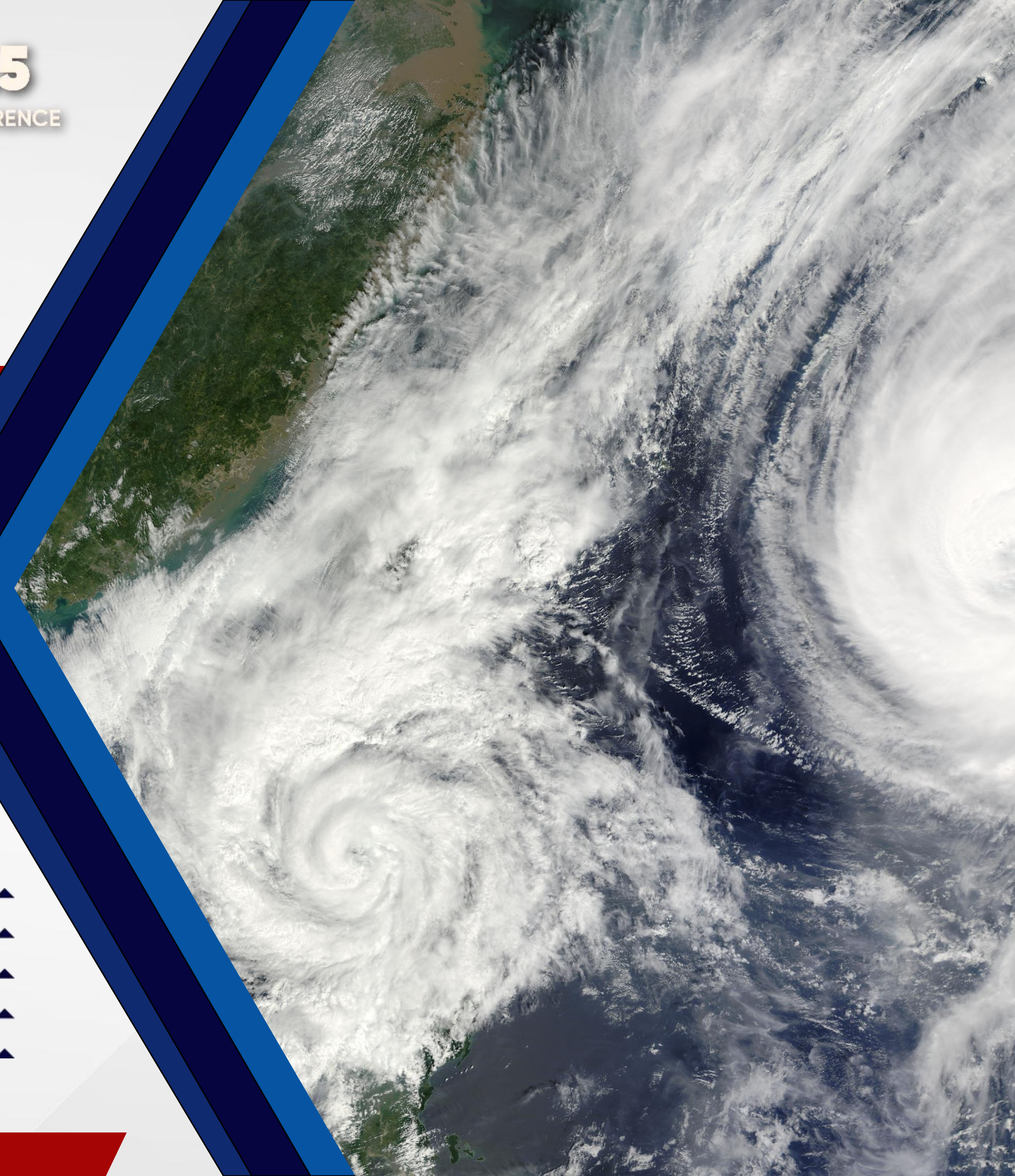
GSMap (Global Satellite Mapping of Precipitation) is a global precipitation dataset developed by the **Japan Aerospace Exploration Agency (JAXA)** aimed at providing high spatiotemporal resolution rainfall estimates by integrating data from multiple meteorological satellites.



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Study Case Analysis Semarang City





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Background Semarang

The rainfall dynamics in Semarang City, Central Java, are strongly influenced by both local and regional meteorological conditions. Irregular changes in rainfall patterns often lead to various hydrometeorological problems, such as tidal flooding, river flooding, and waterlogging due to extreme rainfall events.

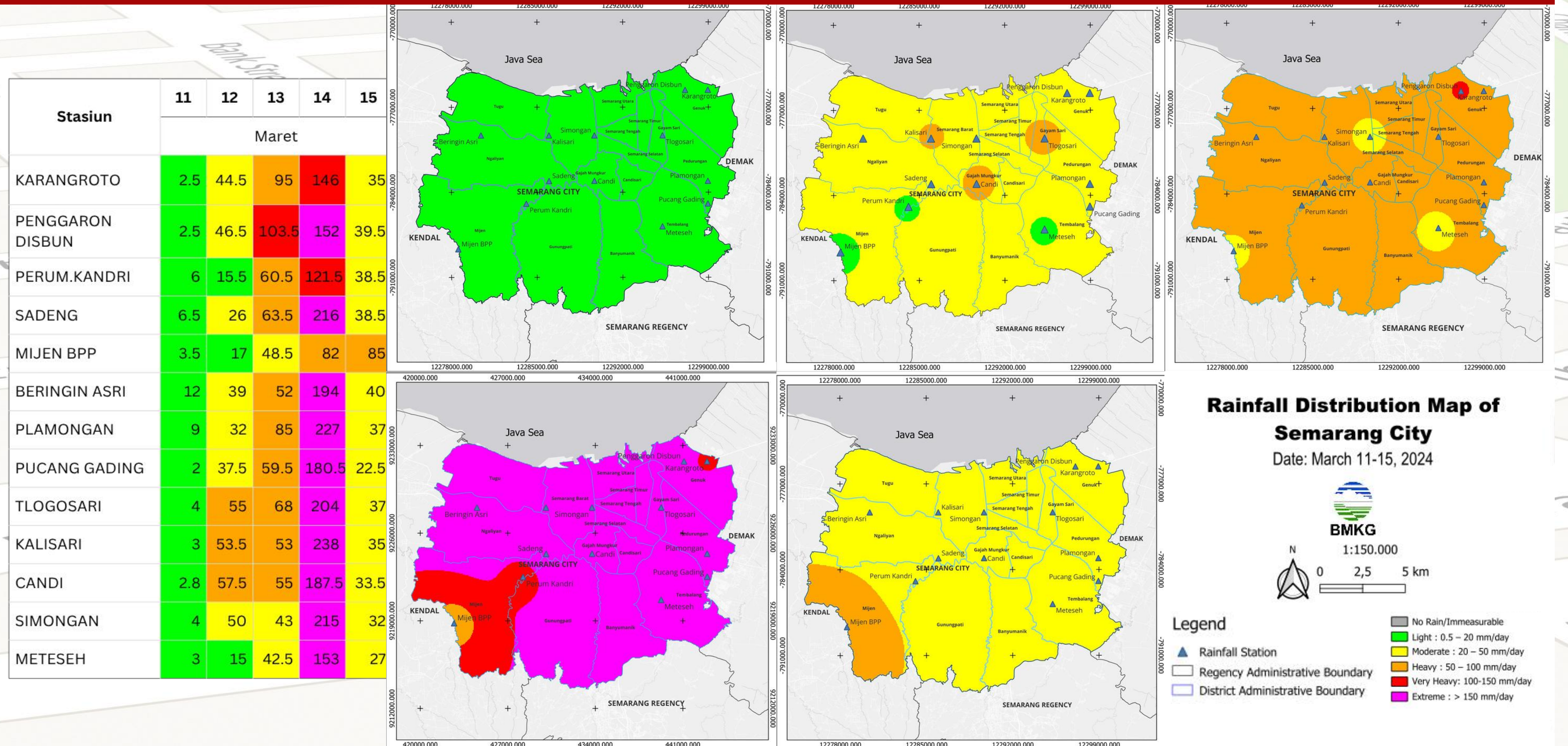
Research on rainfall dynamics in the northern coastal region of Central Java remains very limited. Most existing studies rely on data from rain gauge stations, which are unevenly distributed, or on satellite-based precipitation data, which often have limited accuracy at the local scale.

The Semarang C-Band Weather Radar became operational in 2024, and therefore, its data have not yet been utilized or processed for research purposes particularly for rainfall validation, understanding rainfall dynamics, and identifying heavy precipitation events.

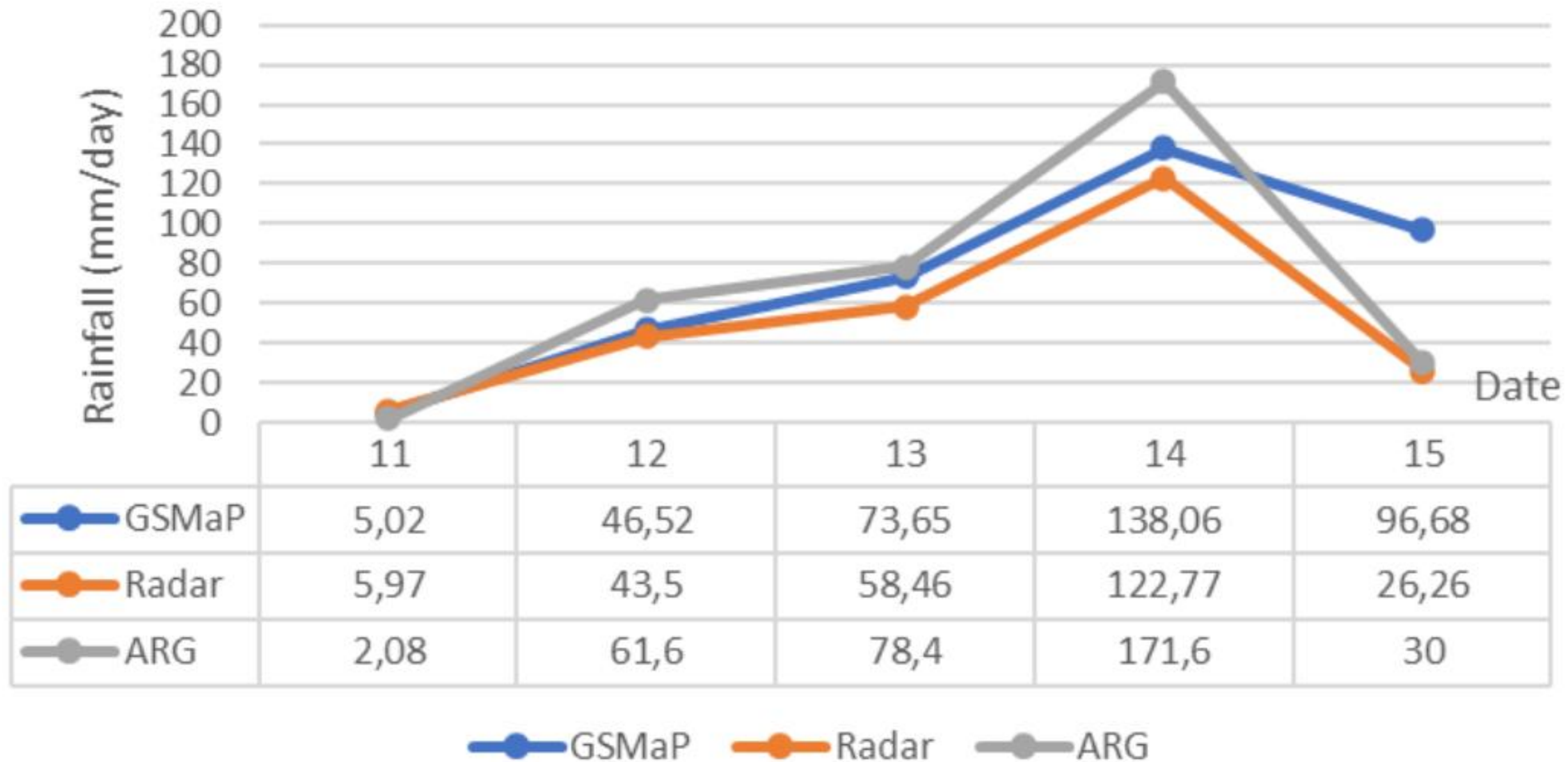


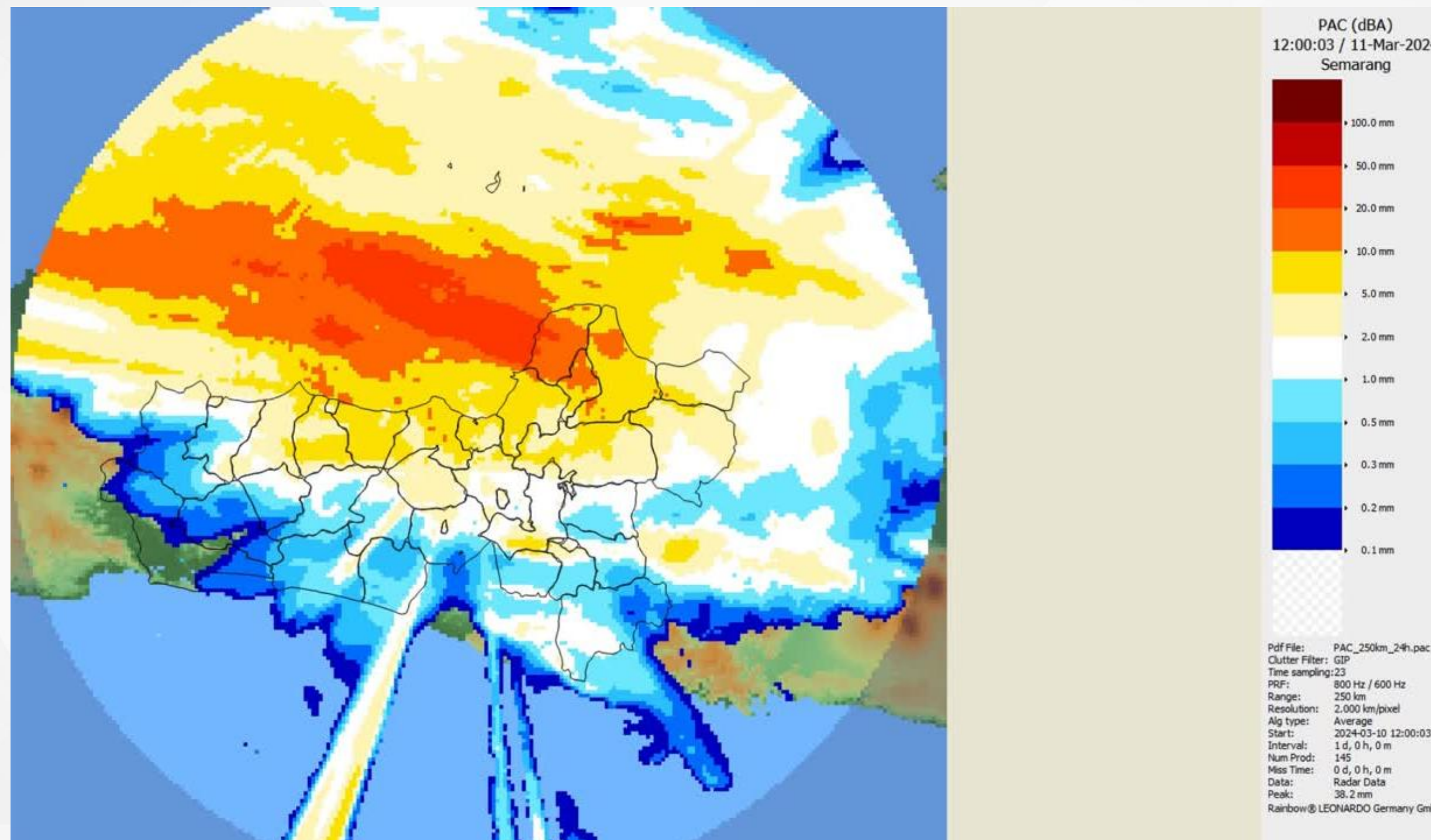


Spatial Distribution of Rainfall During the Flood Period (11–15 March 2024) (in Semarang City, Central Java)



Comparison of Satellite-Based Rainfall During the Flood Period (11–15 March 2024) (in Semarang City, Central Java)

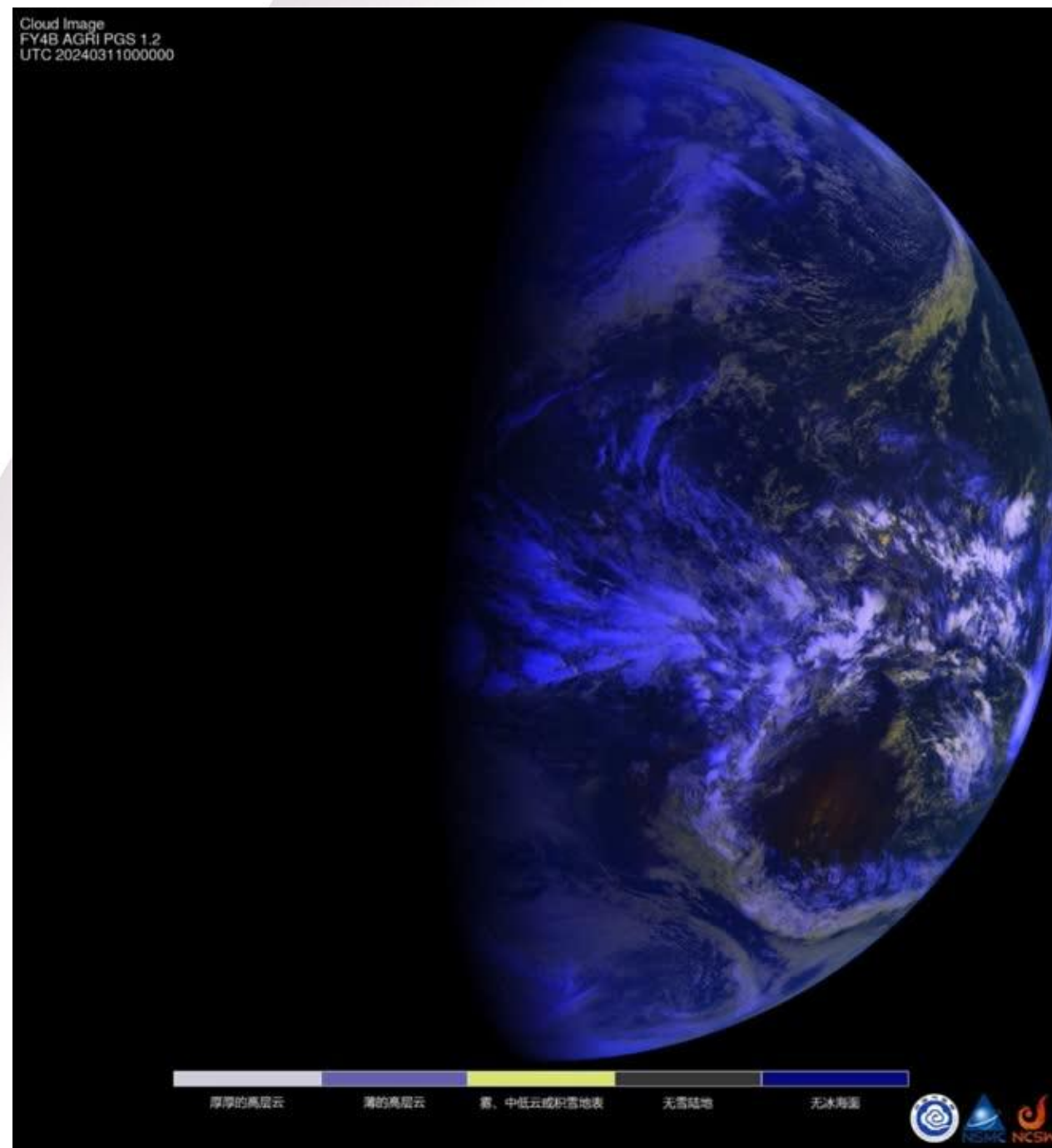




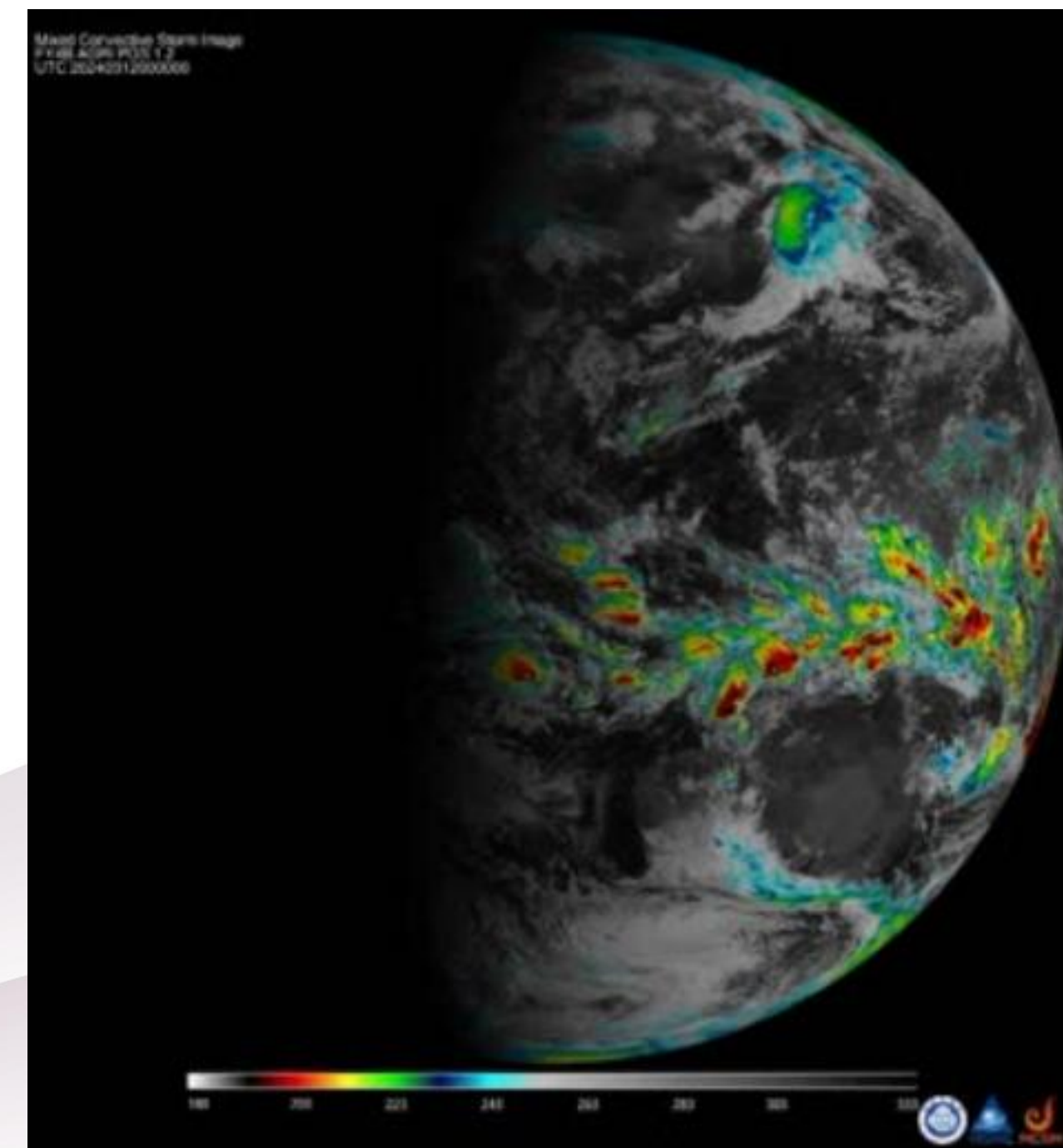


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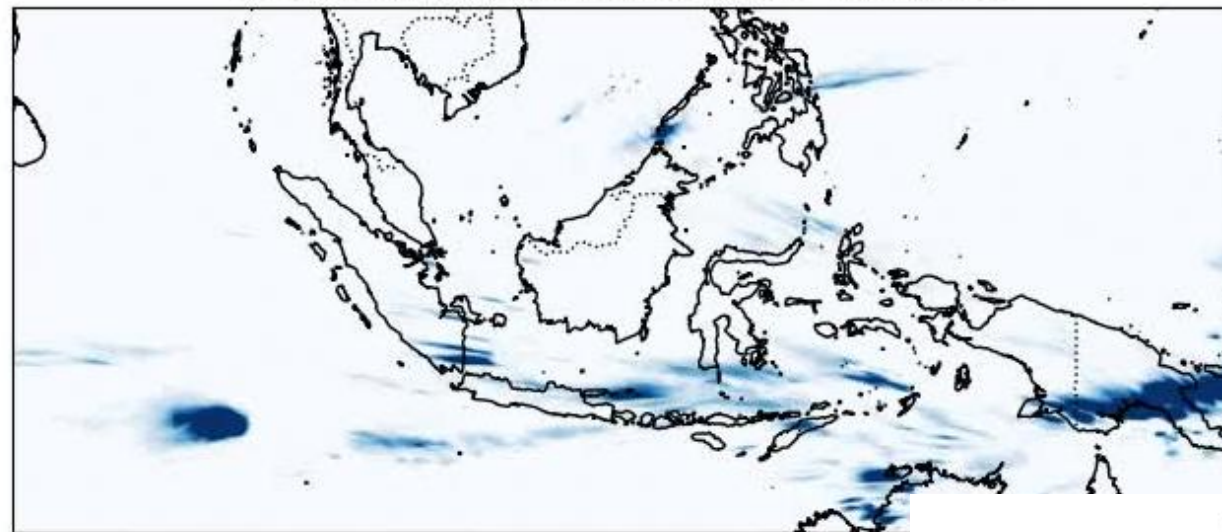
Cloud Image



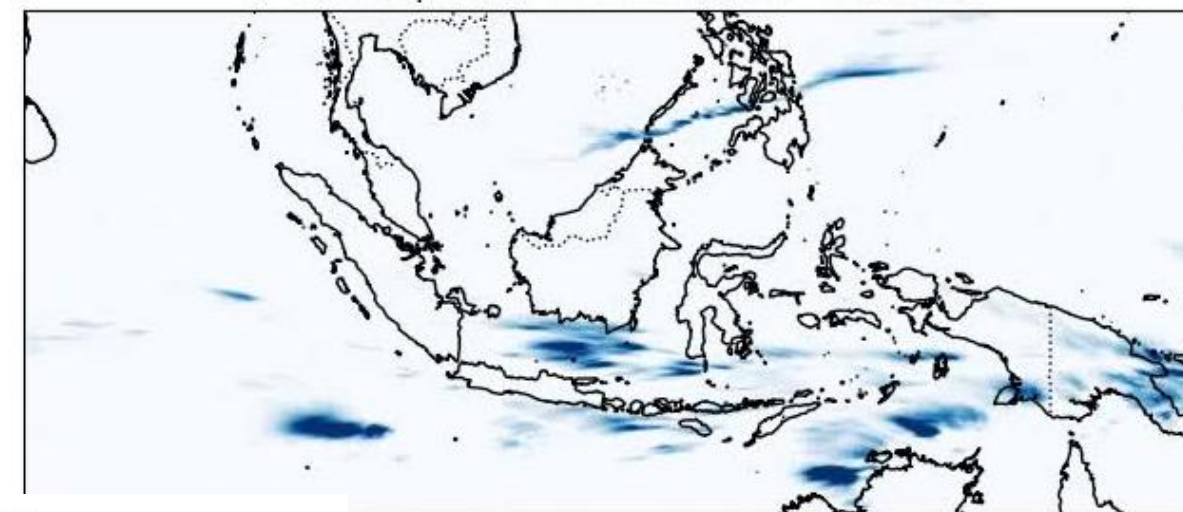
Sandwich Image

Fengyun-4B (FY-4B) Satellite Content (11–15 March 2024)

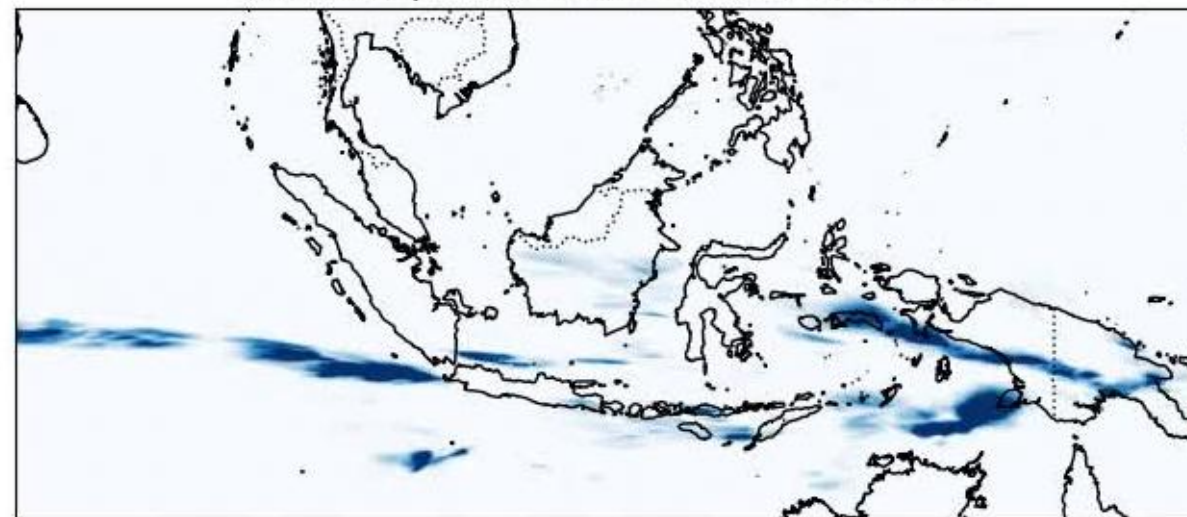
FY-4B Precipitation 11 March 2024 - 03:00 UTC



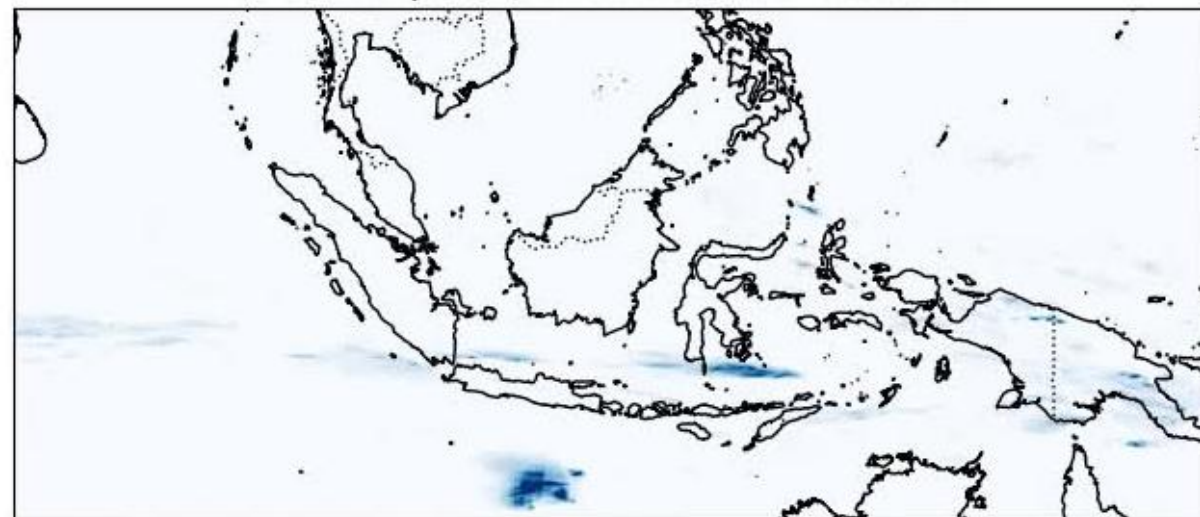
FY-4B Precipitation 12 March 2024 - 03:00 UTC



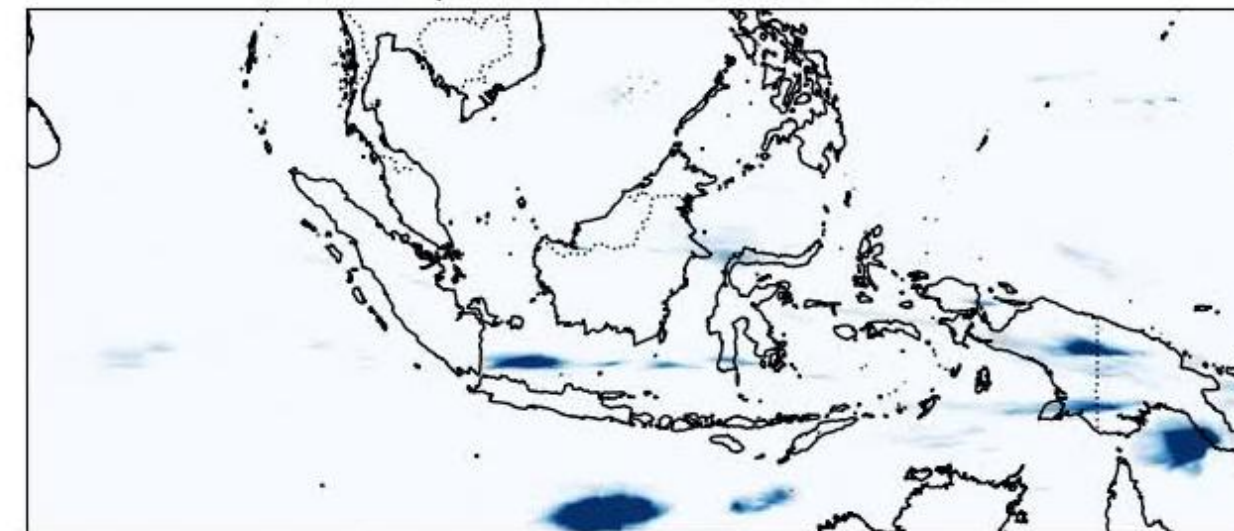
FY-4B Precipitation 13 March 2024 - 00:00 UTC



FY-4B Precipitation 14 March 2024 - 06:00 UTC



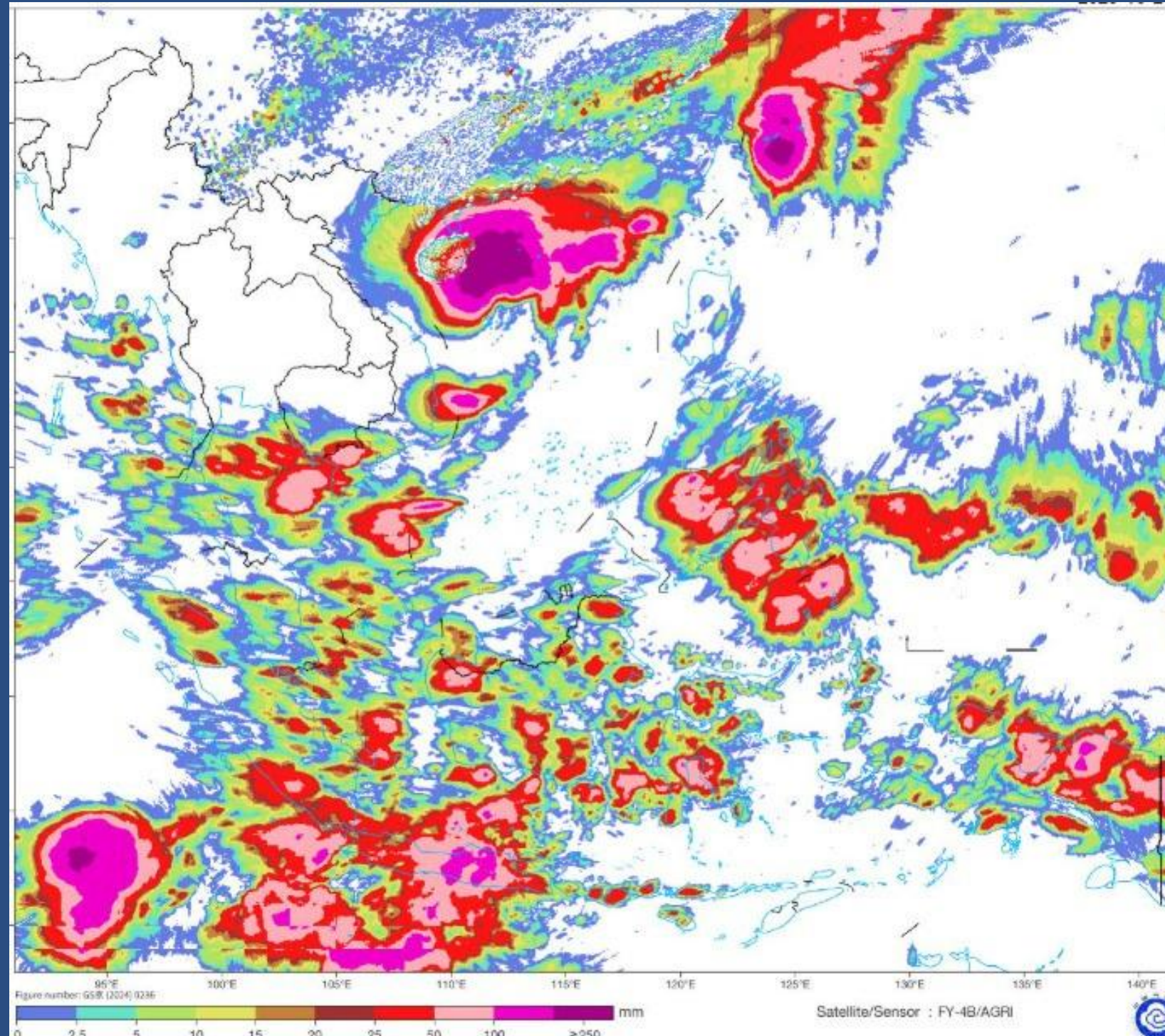
FY-4B Precipitation 15 March 2024 - 03:00 UTC





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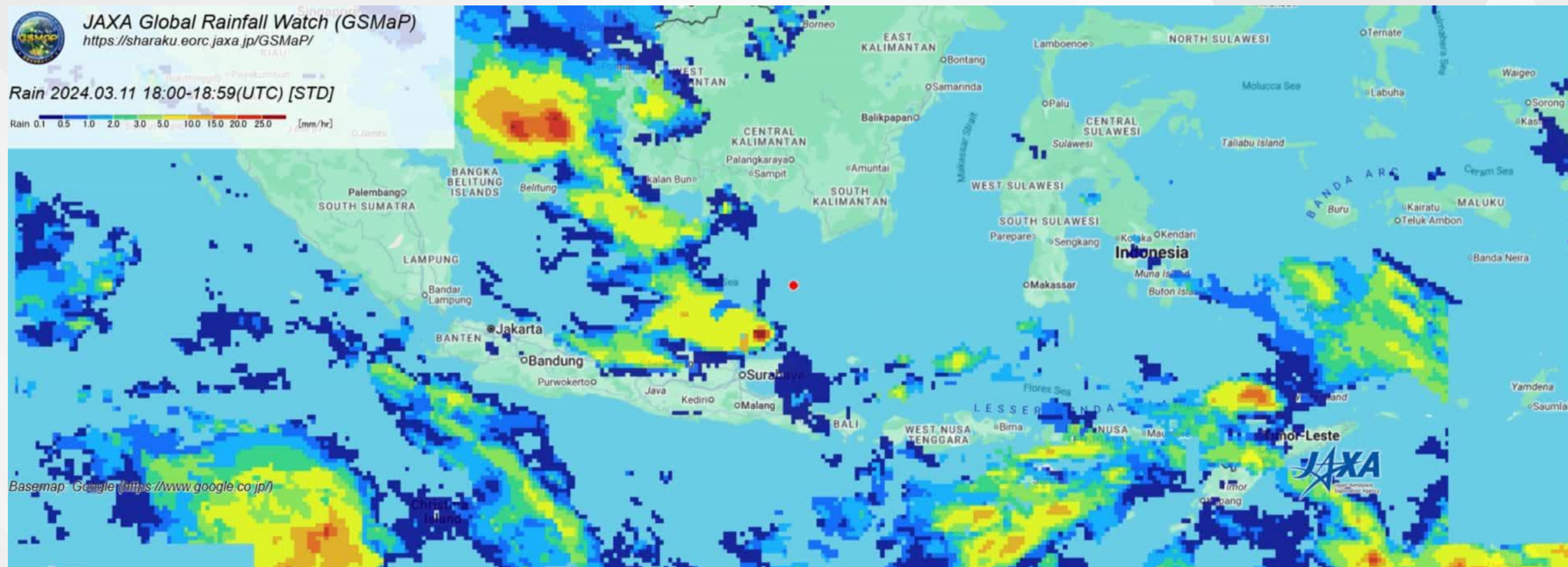


24H Quantitive Precipitation Estimation FY4B



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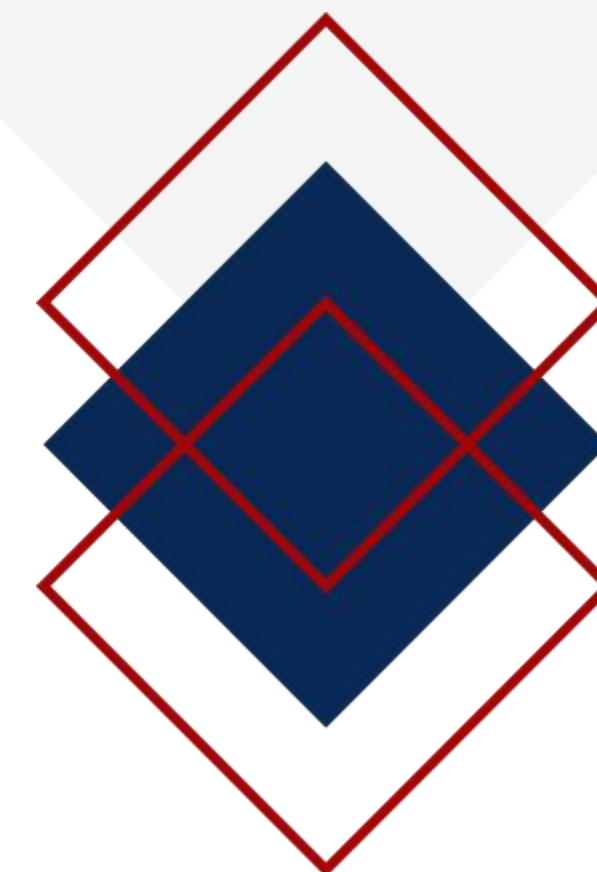
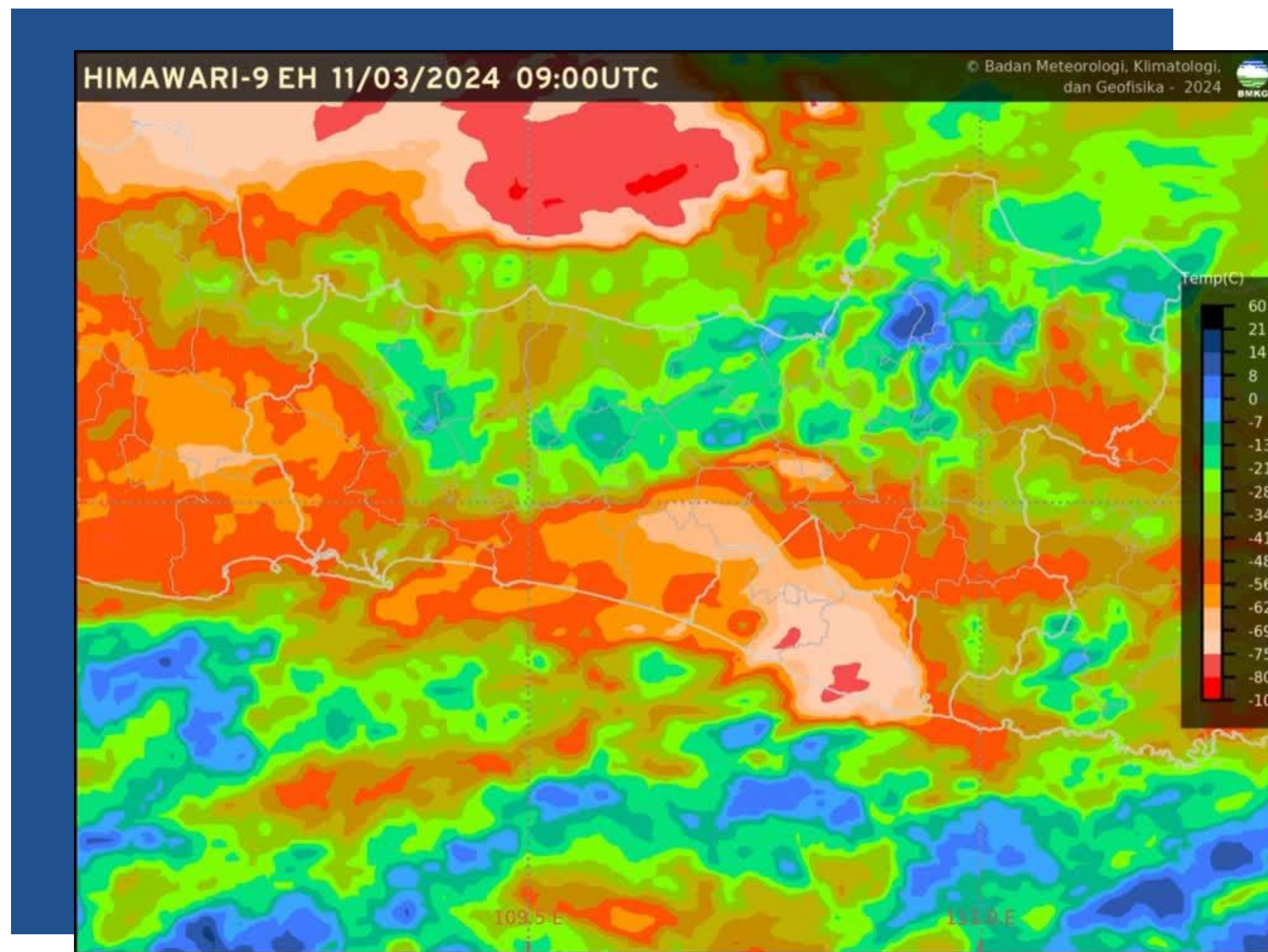


GSMAP SATELLITE CONTENT (11-15 MARCH 2024)



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Himawari-9 Satellite Content (11–15 March 2024)



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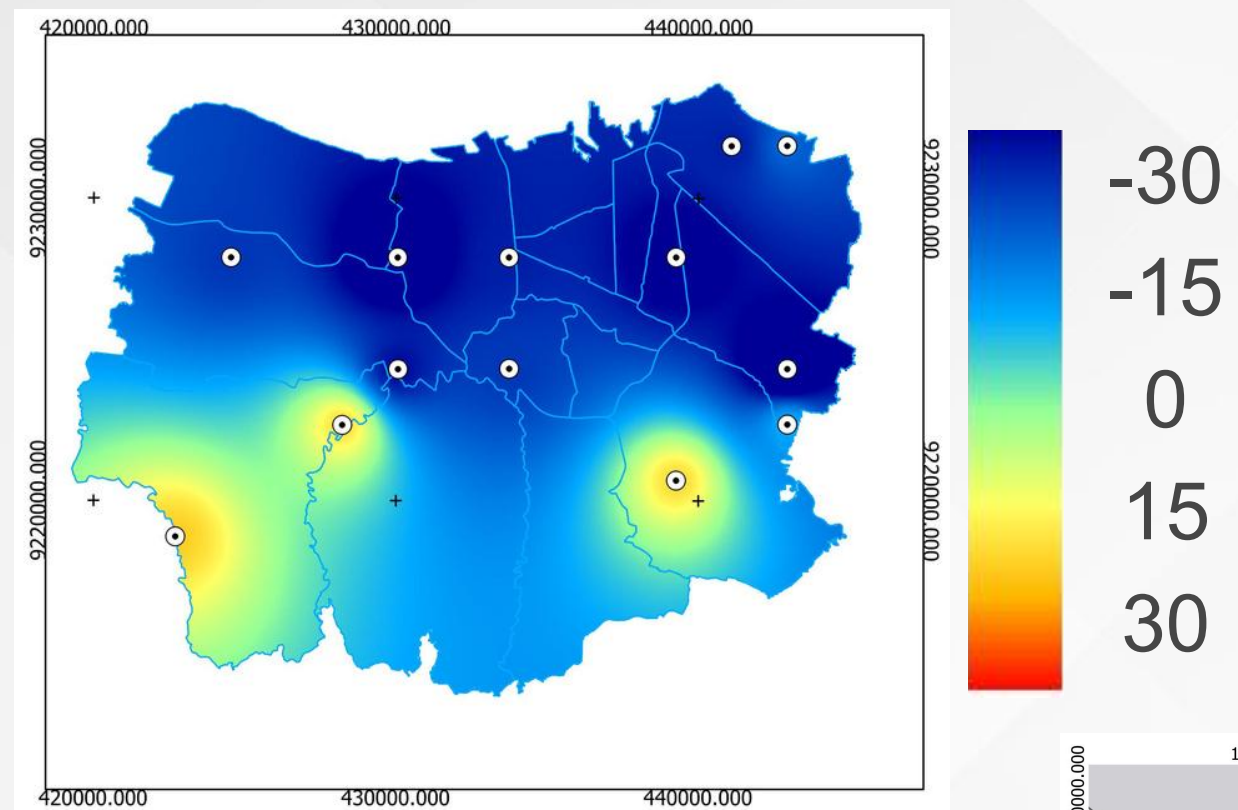
Comparison Table with GSMaP

Rain Gauge Station Name	Bias	R	RMSE
KARANGROTO	964	69	3,853
PENGGARON DISBUN	544	69	3,864
PERUM KANDRI	2,584	49	4,929
SADENG	414	41	6,951
MIJEN GPP	2,704	-1	6,003
BERINGIN ASRI	684	37	6,298
PLAMONGAN	-376	50	6,836
PUCANG GADING	1,384	49	5,748
TLOGOSARI	64	46	6,166
KALISARI	-226	38	7,727
CANDI	698	43	5,935
SIMONGAN	544	36	7,162
METESEH	2,614	40	5,958
SUMURPANGGANG	6,624	-25	7,937

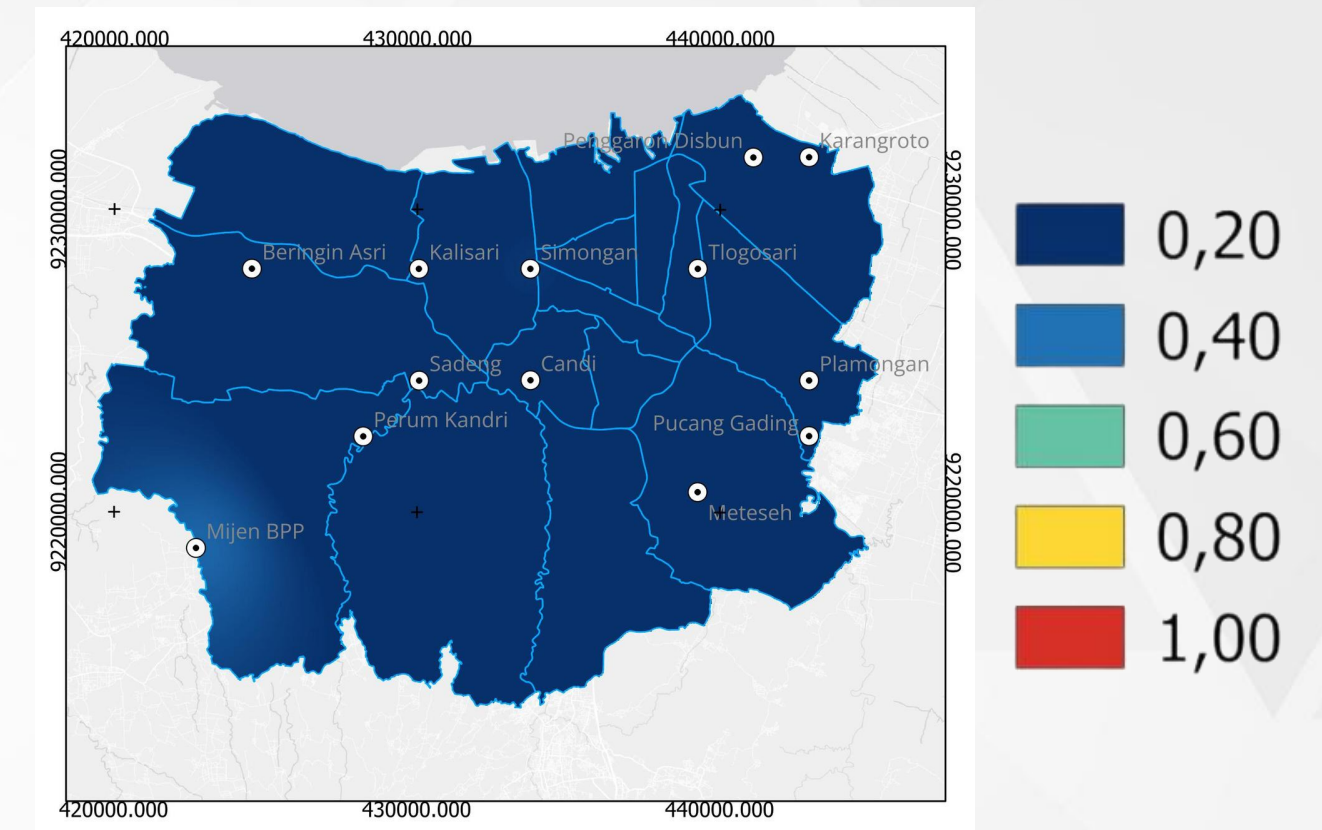
Comparison Table with Radar

Rain Gauge Station Name	Bias	R	RMSE
KARANGROTO	-1,403	19	6,013
PENGGARON DISBUN	-1,823	21	6,232
PERUM KANDRI	217	-5	5,922
SADENG	-1,953	-16	9,303
MIJEN GPP	337	-37	6,139
BERINGIN ASRI	-1,683	-20	8,481
PLAMONGAN	-2,743	-6	9,470
PUCANG GADING	-983	-7	7,794
TLOGOSARI	-2,303	-10	8,648
KALISARI	-2,593	-19	10,243
CANDI	-1,669	-14	8,154
SIMONGAN	-1,823	-22	9,436
METESEH	247	-17	7,302
SUMURPANGGANG	4,257	-28	6,045

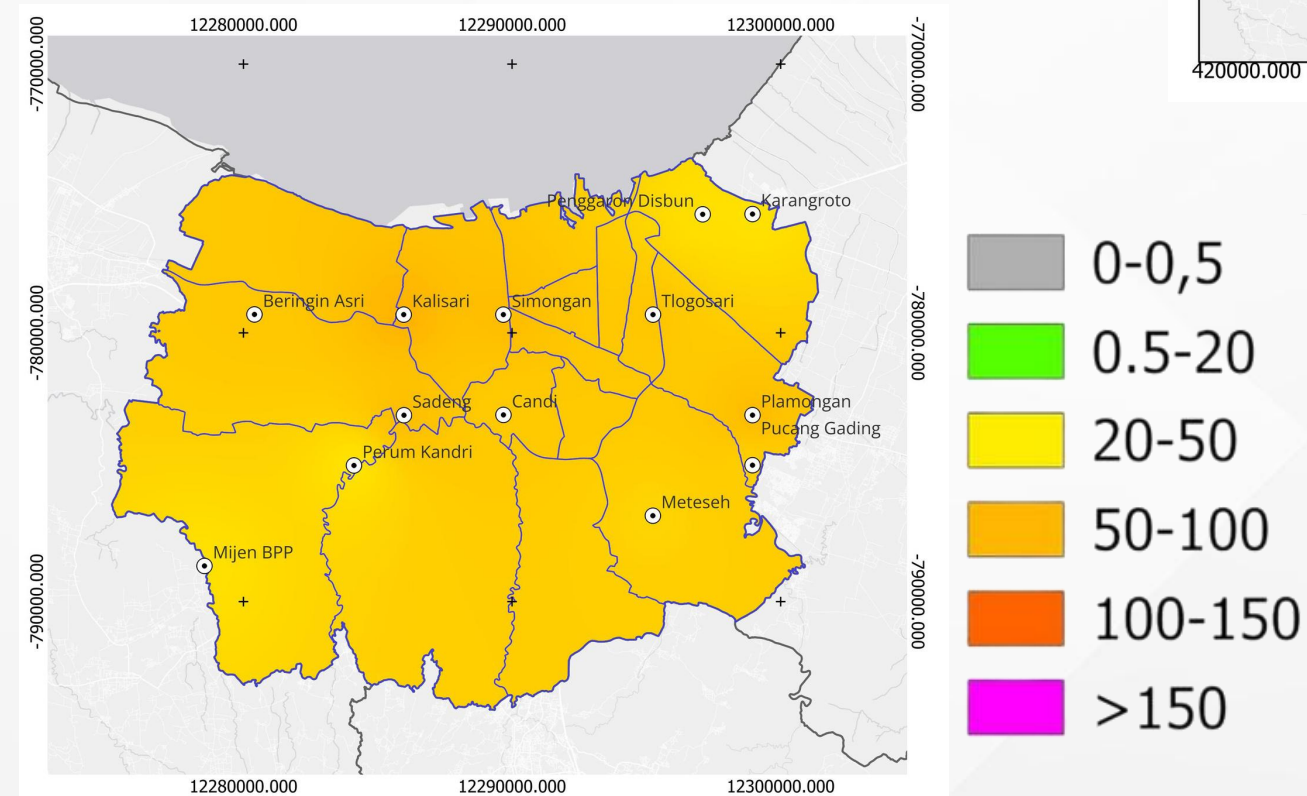
Comparison between GSMaP and Weather Radar



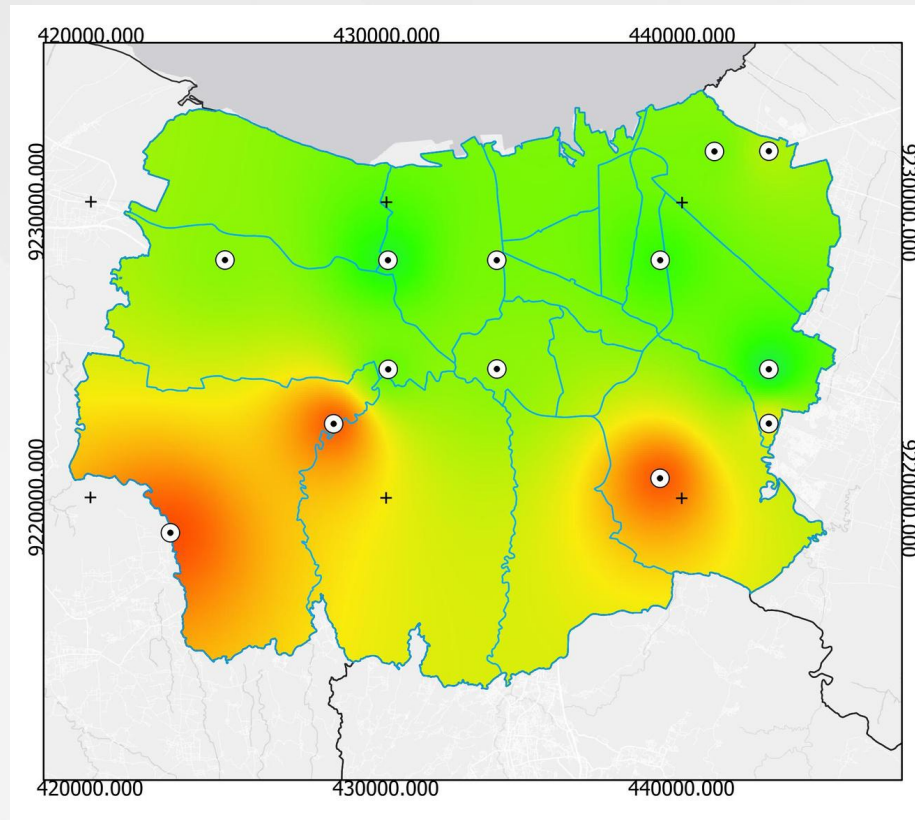
a. Bias



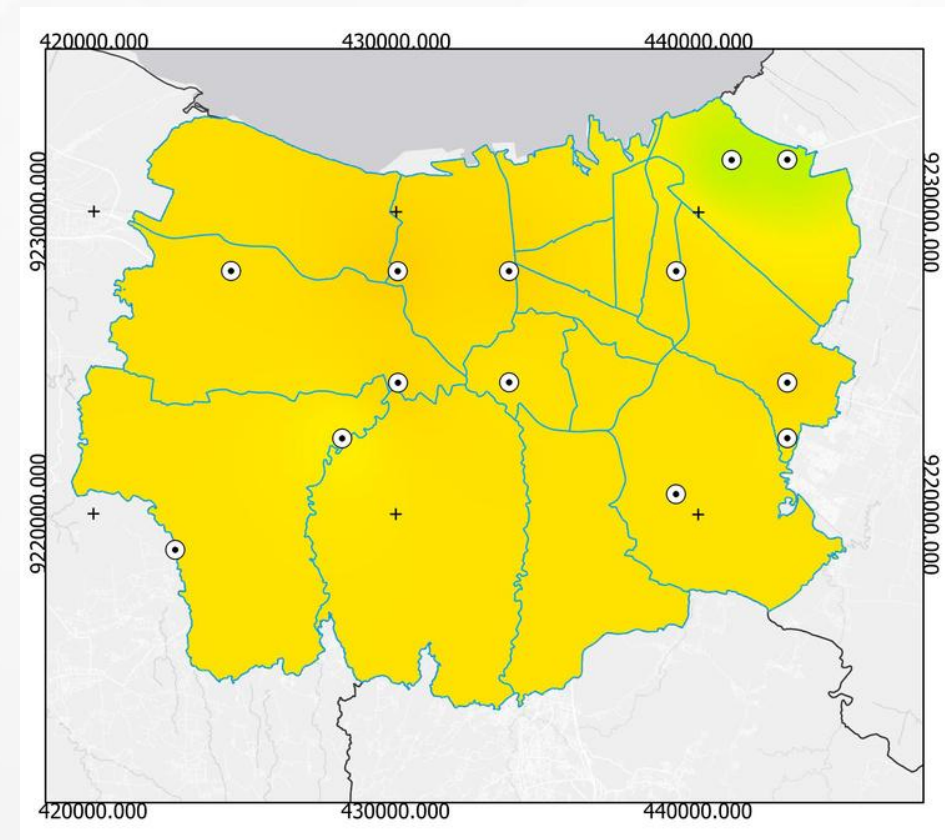
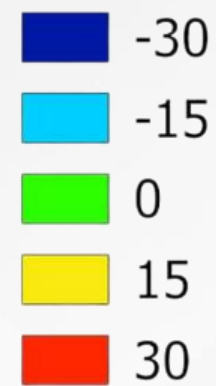
b. Correlation Coefficient (R)



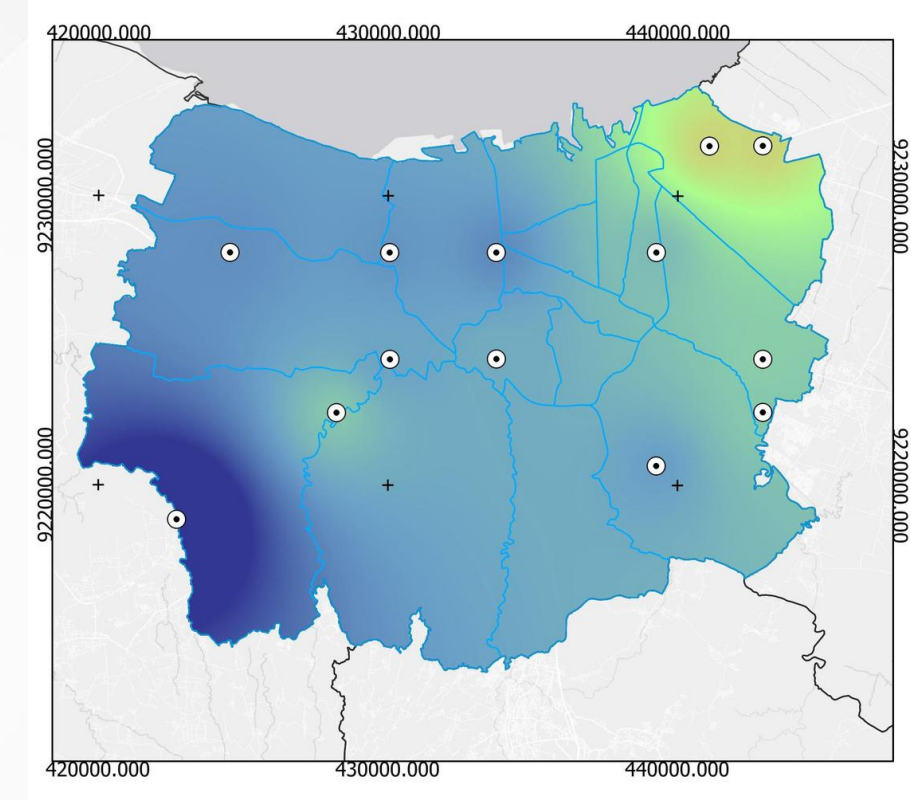
c. RMSE (mm)



a. Bias



c. RMSE (mm)



b. Correlation Coefficient (R)





The map displays the administrative divisions of Semarang City and its surrounding areas. The city itself is highlighted in yellow, while the surrounding districts are in light blue. The map includes labels for various districts and regencies, as well as the Java Sea to the north. The map is color-coded to distinguish between the city, districts, and surrounding regencies.

Java Sea

KENDAL

DEMOK

SEMARANG CITY

SEMARANG REGENCY

Districts and Areas:

- Tugu
- Beringin Asri
- Ngaliyan
- Sadeng
- Perum Kandri
- Gunungpati
- Banyumanik
- Tembalang
- Meteseh
- Pucang Gading
- Plamongan
- Hedurungan
- Gayam Sari
- Tlogosari
- Karangroto
- Genuk
- Penggaron Disbun
- Semarang Utara
- Semarang Timur
- Semarang Tengah
- Semarang Selatan
- Gajah Mungkur
- Candi
- Candisari
- Mijen
- Mijen BPP

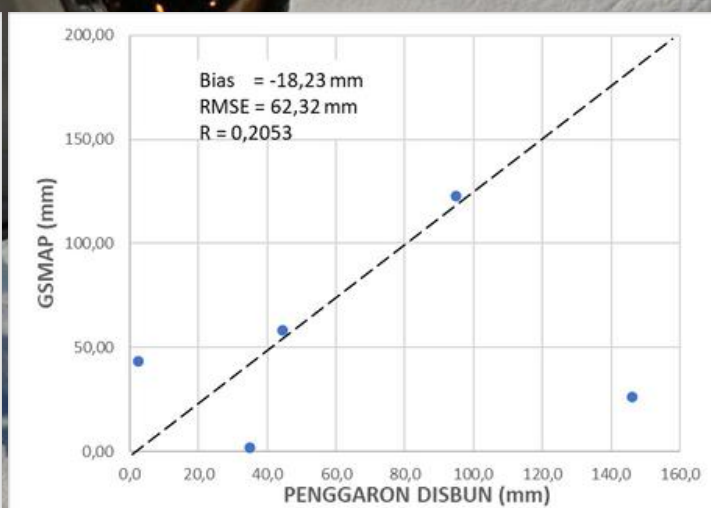
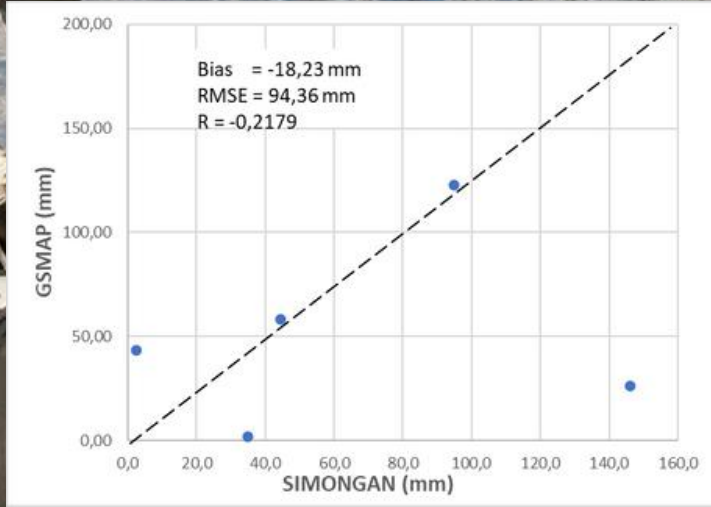
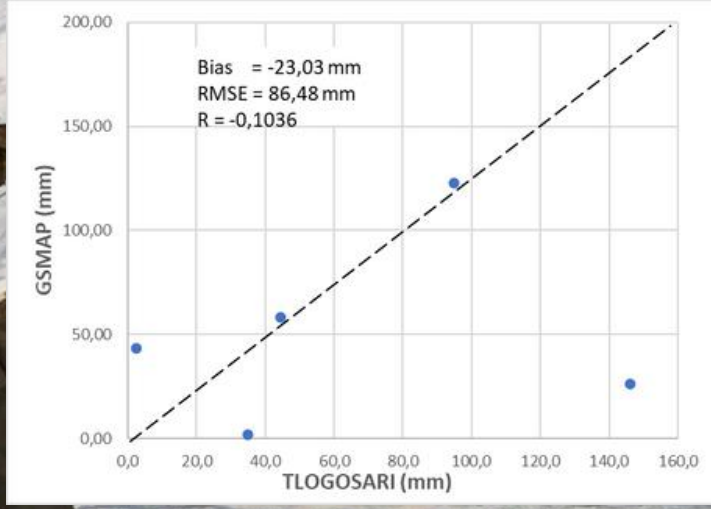
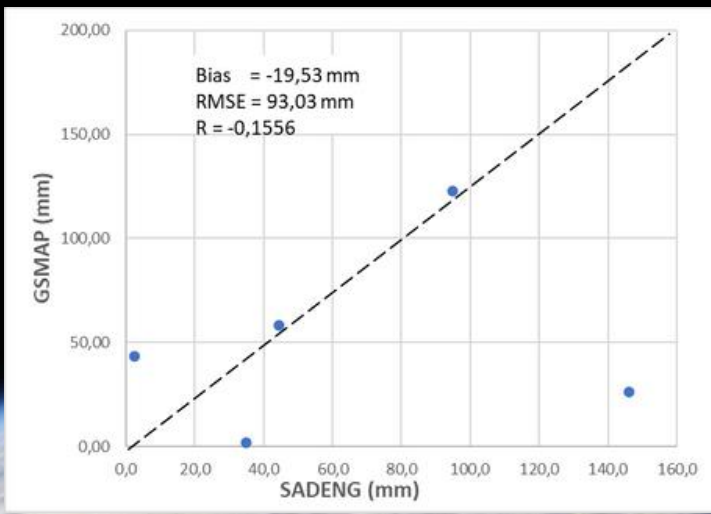
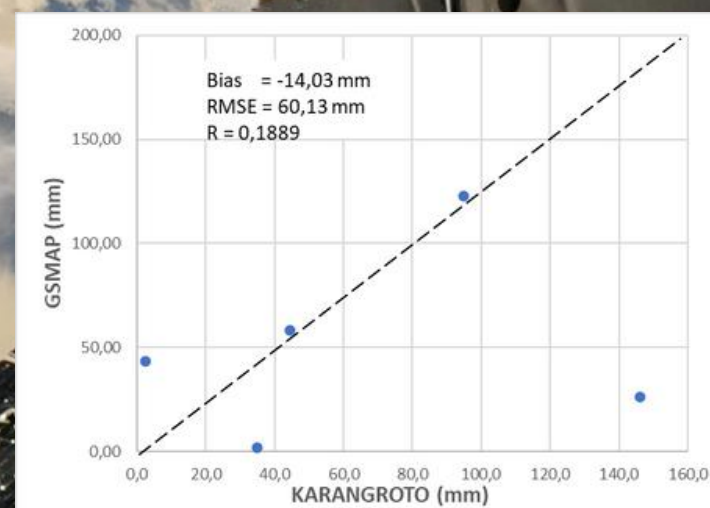
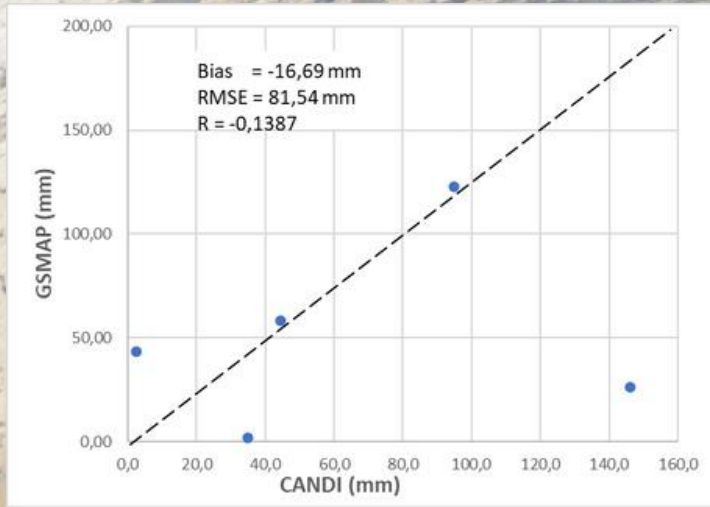
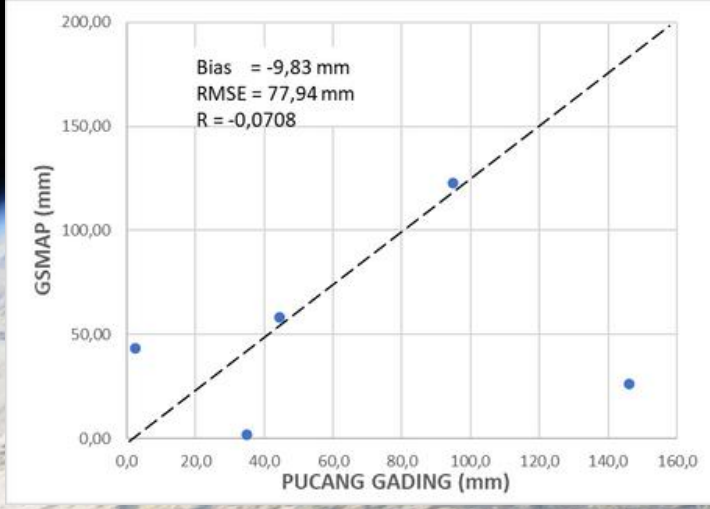
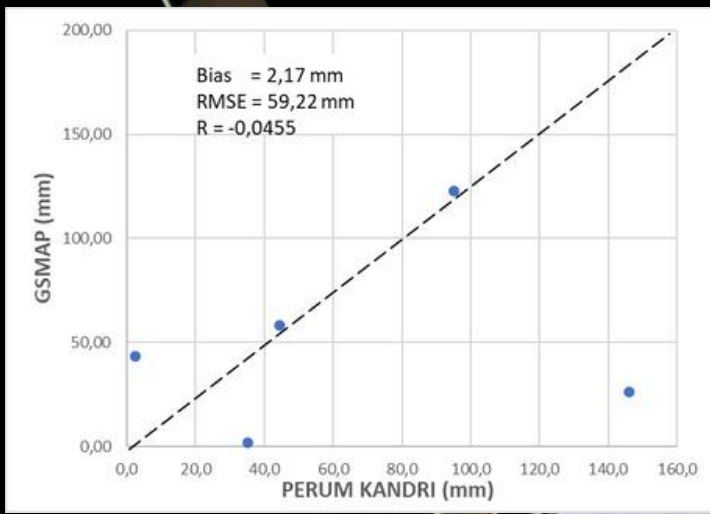
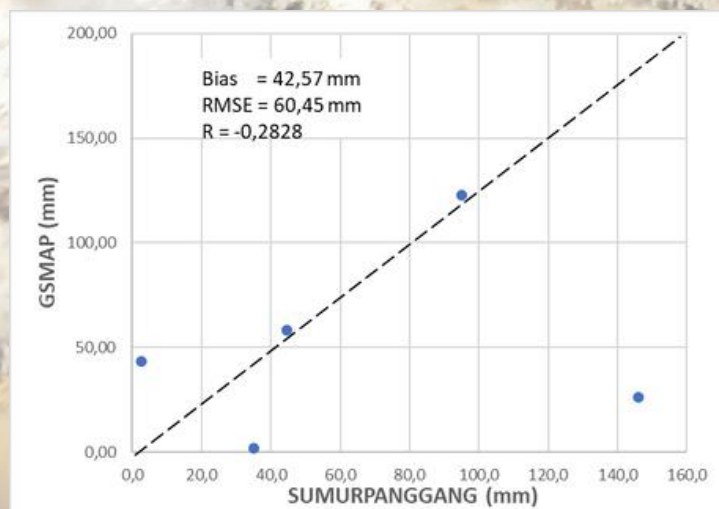
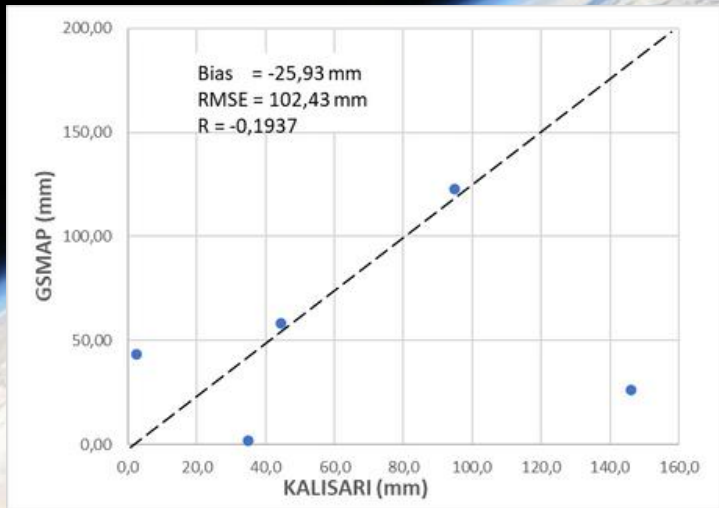
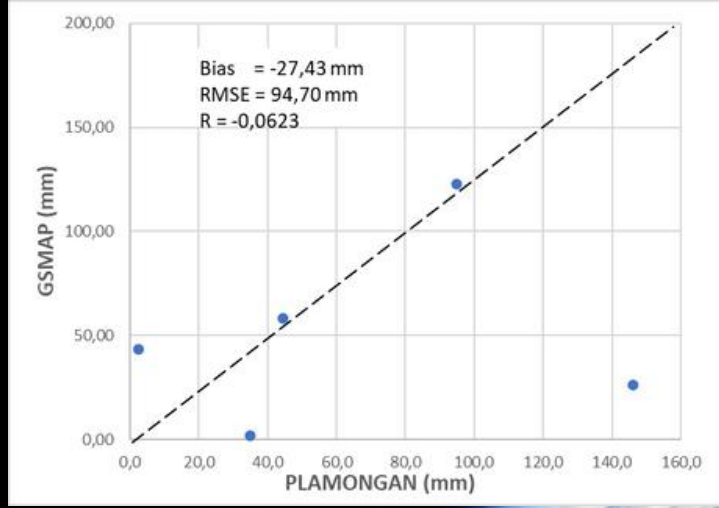
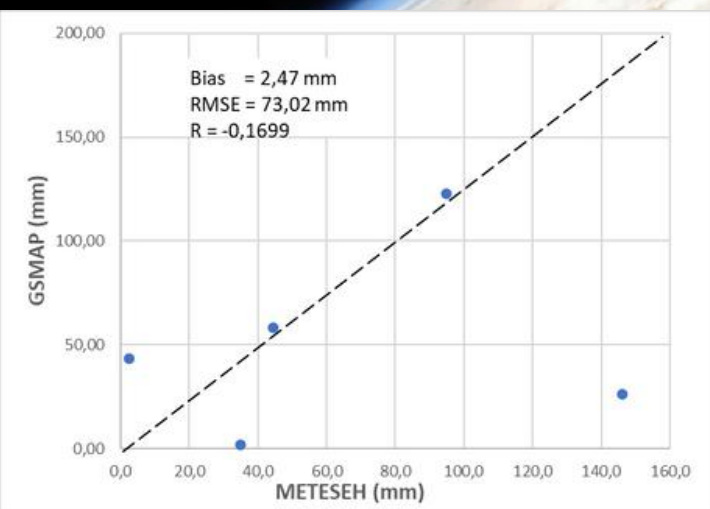
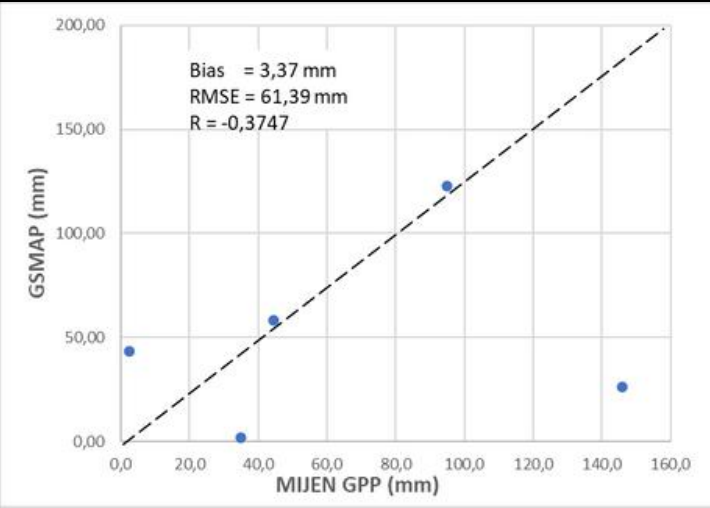
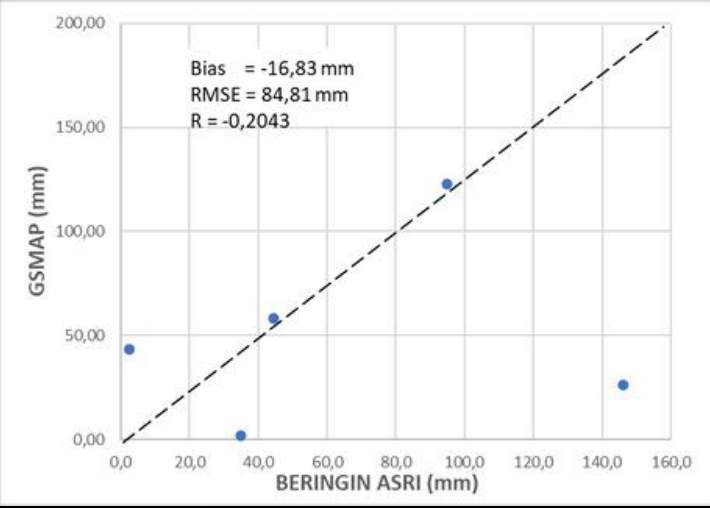
c. Himawari



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Scatter Plot of C-Band Weather Radar Data and AWS/ARG





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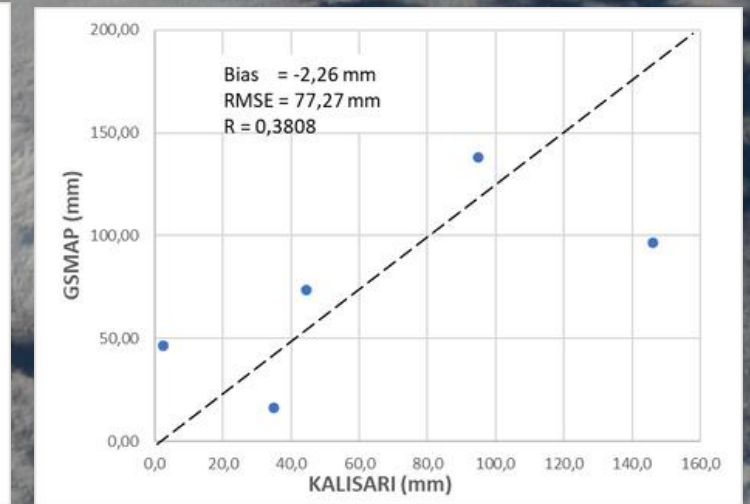
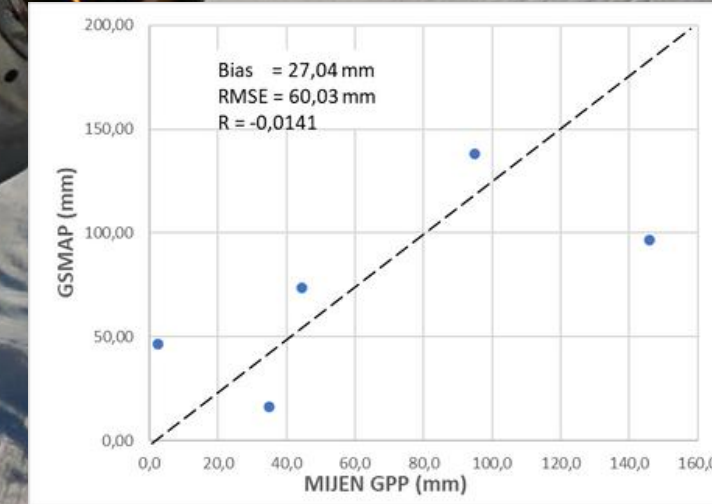
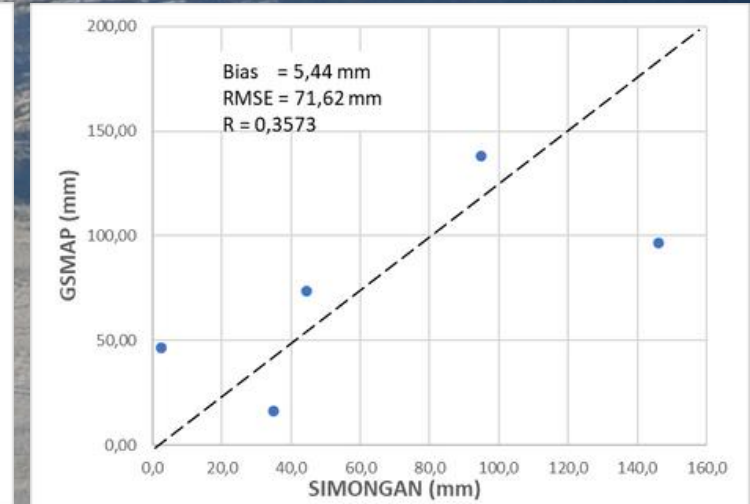
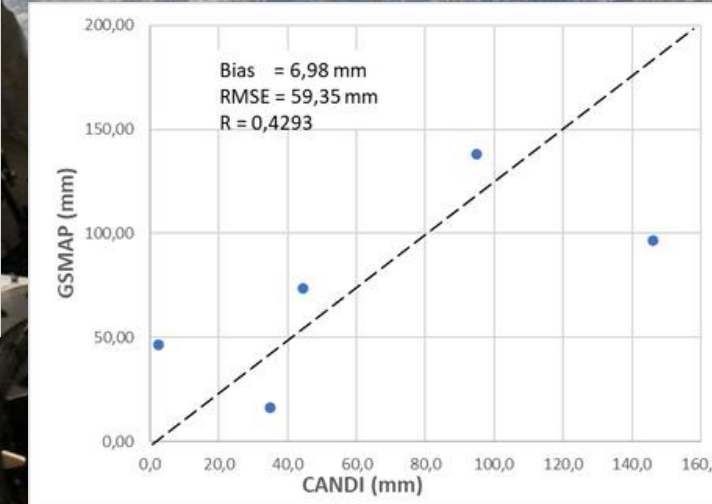
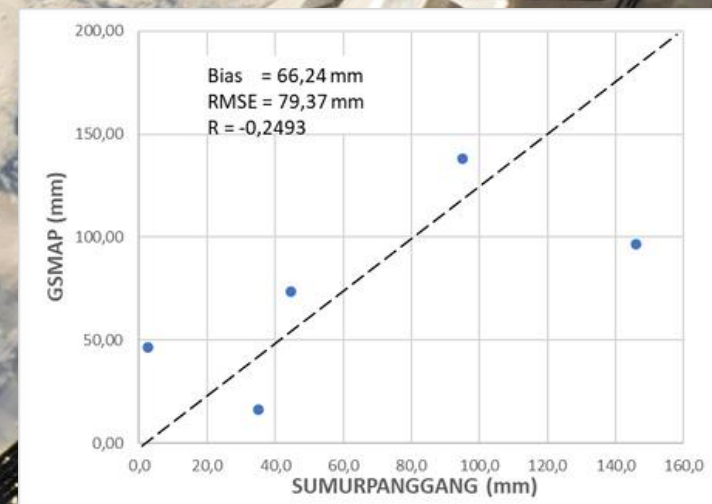
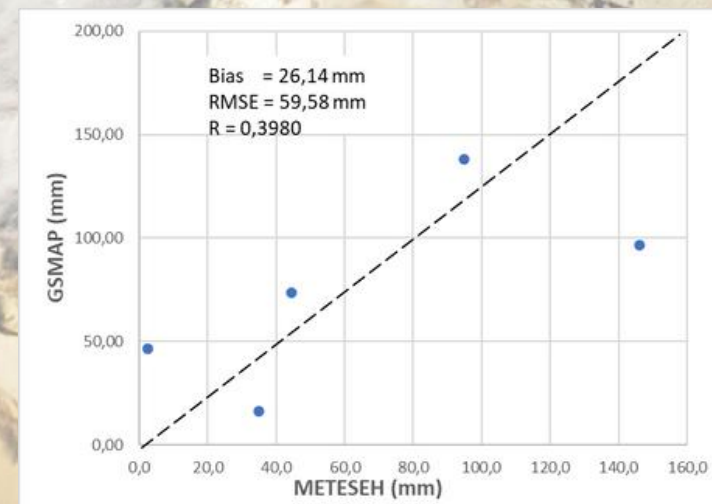
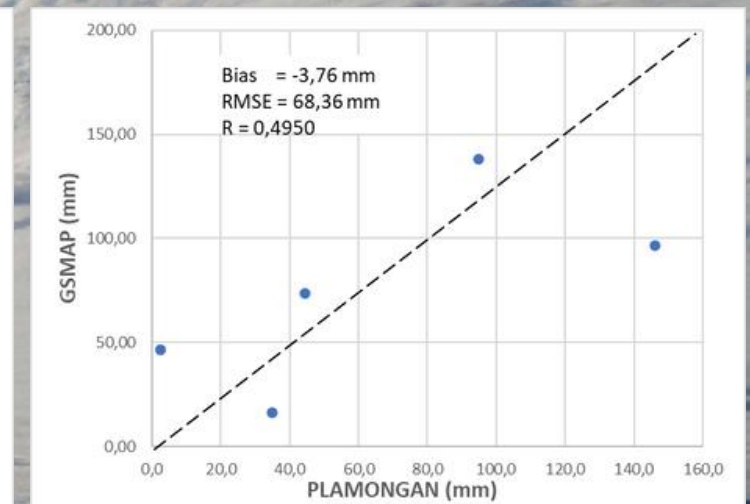
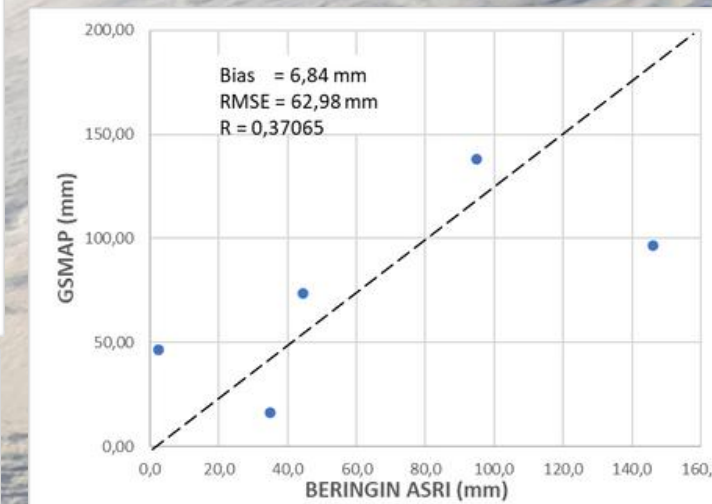
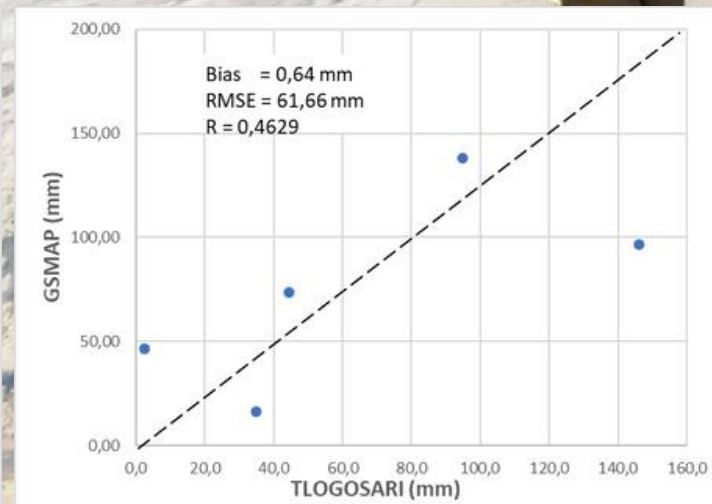
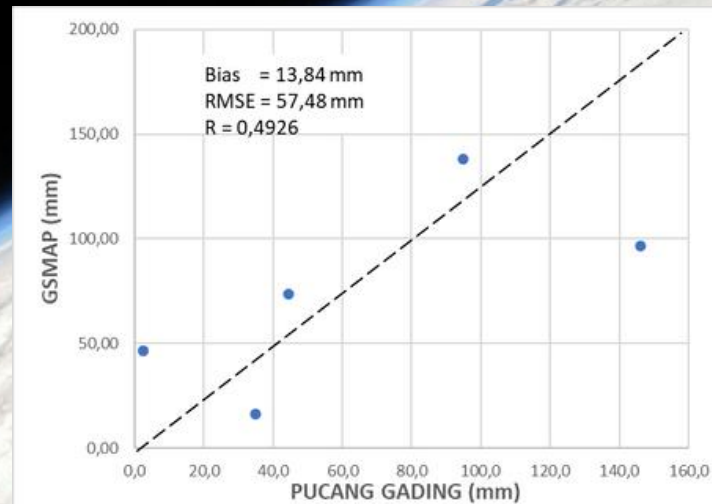
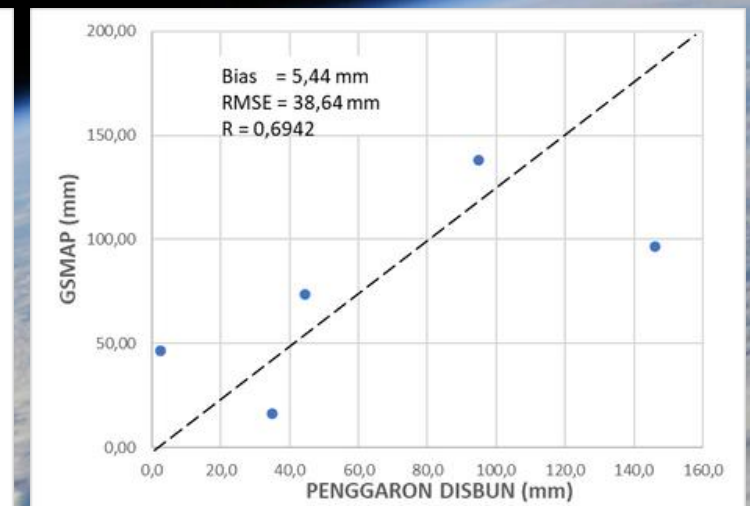
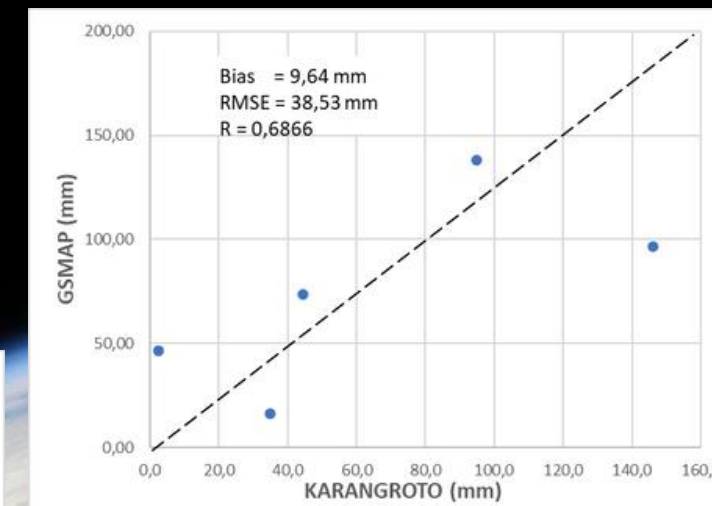
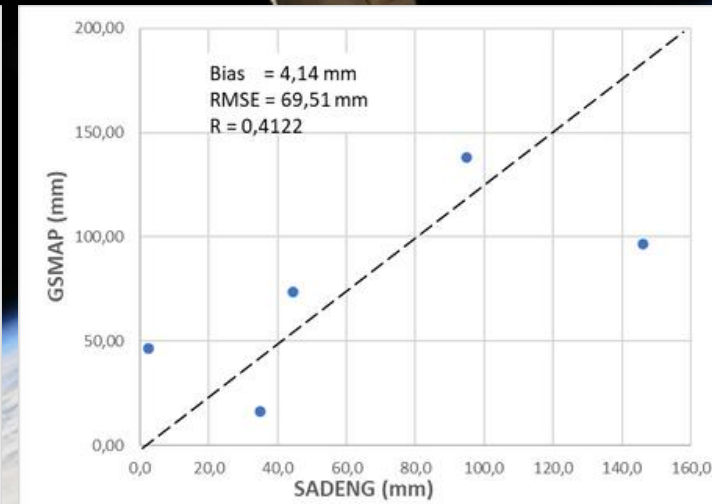
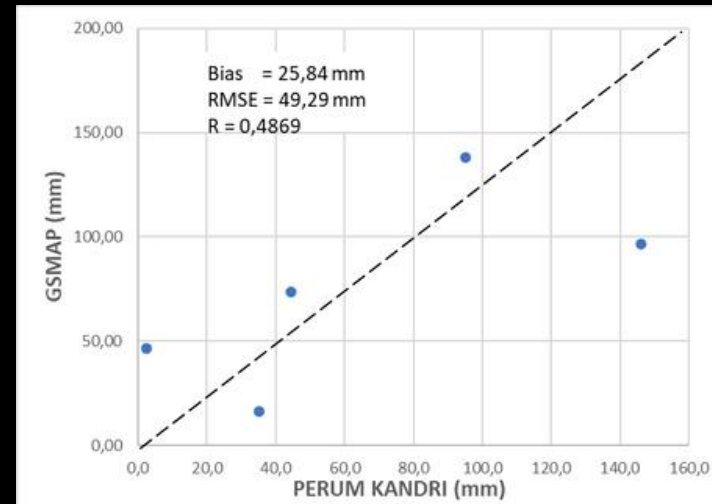
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Scatter Plot of **C-Band Weather Radar Data and AWS/ARG**

The positive bias value indicates that, in general, the weather radar tends to slightly overestimate rainfall compared to AWS/ARG measurements. The relatively high RMSE value shows a fairly wide variation of errors, especially at moderate to high rainfall intensities. This can be seen from the data points that deviate from the ideal line at rainfall greater than 50 mm, where the radar sometimes records higher or lower values than AWS. The concentration of data points near the ideal line at light to moderate rainfall (<30 mm) indicates a fairly good agreement between the radar and AWS/ARG observations.



GSMaP Satellite Data and AWS/ARG





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Scatter Plot of **GSMaP Satellite Data** and **AWS/ARG**

GSMaP tends to provide higher rainfall estimates compared to AWS observations. In other words, GSmAP shows an overestimation tendency. This may be caused by limitations in the GSmAP algorithm in correcting thin cloud effects, its coarser spatial resolution compared to point-based AWS observations, or the influence of local topography and atmospheric conditions around Semarang that are not fully captured by the satellite system. In addition, the obtained Root Mean Square Error (RMSE) value is relatively large, indicating a significant deviation or estimation error between the two data sources. This error is more evident during moderate to heavy rainfall events (>50 mm), where GSmAP often produces values considerably higher than those observed by AWS/ARG.





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Conclusion

- **The validation results comparing rainfall observations from field data (AWS/ARG) with C-Band Weather Radar and GSMaP satellite data show varying performance across different locations. In general, the bias and RMSE values presented in the table indicate that the C-Band Radar demonstrates better accuracy than GSMaP, both in terms of lower bias and more stable RMSE values.**
- **Overall, the validation results reveal that the C-Band Weather Radar is more accurate and consistent than GSMaP in estimating local rainfall. GSMaP tends to show overestimation in most locations, with higher RMSE values compared to the radar. Nevertheless, GSMaP still holds potential as an alternative data source due to its wide spatial coverage. However, its use for hydrometeorological analysis requires bias correction or calibration with field data (AWS/ARG) to ensure more representative and accurate results.**
- **Strengthening the use of Fengyun satellites will improve disaster preparedness, aviation safety, and national resilience**



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