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SATELLITE PRECIPITATION OBSERVATIONS AND ITS APPLICATIONS TO GEOGRAPHY

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Abstract Nowadays, space-based data and information is one of the essential tools to understand Earth's environments and its changes related to the global warming. In particular, satellite precipitation information is being widely used for both applicational and scientific purposes. Global Satellite Mapping of Precipitation, or GSMaP is a global precipitation mapping product generated by using multiple satellite sensors, and its utilizations are spreading in various fields. GSMaP data has a high affinity with geography, and can be overlay with other information by utilizing Geographical Information System (GIS) tools. In addition to downloading the GSMaP data and using it locally, the GSMaP information can be handled on the Google Earth Engine. There are some Google Earth Engine apps using GSMaP, and some of them are for geography education. Moreover, real-time rainfall information by GSMaP is valuable to offer current status of globe in terms of rainfall, and there are some educational tools using GSMaP in combination with advanced technology, such as augmented reality.

Keywords: satellite data, rainfall, precipitation, application, education

1. Introduction

Satellite observation is an essential factor to understand global-scale environmental phenomena such as responses to the climate change since it can provide information wide coverage, homogeneous accuracy, and constant spatio-temporal intervals. Recently, various geophysical variables are available by using some kinds of space instruments aboard satellites; aerosols, clouds, precipitation, water vapour, carbon dioxide, soil moisture, sea surface temperature, land cover, elevation, and so on.

Especially, spaceborne precipitation information (*i.e.*, rainfall and snowfall) has been widely used for applicational and practical purposes as well as scientific purposes since precipitation is fundamental information for our daily lives. The application fields are not only for weather monitoring and disaster management, but also for agricultural insurance, food security, climate monitoring, marine domain awareness, public health, educations, hydropower etc. There are some satellite products of global precipitation, and the Global Satellite Mapping of Precipitation (GSMaP) is one of them (Kubota *et al.* 2020).

GSMaP provides hourly precipitation map with spatial resolution of 0.1 degree × 0.1 degree latitude/longitude grid box. The GSMaP products can be divided into some types as shown in Table 1. The real-time products as GSMaP_NOW and GSMaP_Gauge_NOW achieve better latency as a few minutes but the accuracy is not as good as other products, while standard products

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as GSMaP_MVK and GSMaP_Gauge take almost three days to be provided, but the accuracy is better compared with the near-real-time and real-time products. Therefore, users can select the suitable dataset in terms of latency and accuracy.

Table 1 GSMaP products

	Product name		Latency	Update interval
	satellite basis	adjusted by rain gauges		
Standard product	GSMaP_MVK	GSMaP_Gauge	Three days	Hourly
Near real time product	GSMaP_NRT	GSMaP_Gauge_NRT	Four hours	Hourly
Real time product	GSMaP_NOW	GSMaP_Gauge_NOW	A few minutes	Every 30 minutes

The quality of GSMaP products has been improved by updating the algorithms. The new version of GSMaP was released in December 2021, and the major updates were described in Kubota *et al*. (2022). In terms of the availability of long-term data record, GSMaP products except real-time products (*i.e.*, GSMaP_NOW and GSMaP_Gauge_NOW) provide hourly precipitation rate since March 2000. Therefore, more than 22 years of global precipitation dataset from GSMaP is available. It should be noted that the long-term GSMaP data record has been updated by being reprocessed with the latest algorithms. Therefore, long-term GSMaP data with the latest algorithms enables statistical approach, such as scientific research on global climate, providing climatological view of global precipitation distribution including over the oceans, and statistical detection of extreme precipitation (*i.e.*, heavy precipitation or drought).

This study firstly reviews the characteristics of GSMaP data in terms of its algorithms, focusing on some points important for users. Next, some applicational utilizations of the GSMaP data are described by introducing some practical use cases in geographic fields.

Section 2 describes the characteristics of GSMaP dataset by briefly introducing the algorithms. Section 3 shows various applications and some use cases in geographic area.

2. Overview of the GSMaP Data Characteristics

In the GSMaP algorithm, multiple satellite sensors are used to generate an hourly precipitation map. For various applications, it is crutial for users to be able to use data with as few missing values as possible. GSMaP is a mapping-type product rather than orbit-based data by filling in gaps using multiple observations in the algorithm, so that utilizations have been widely spread. In this section, essence of the GSMaP algorithm is reviewed following to Kubota *et al*. (2020), especially in terms of data characteristics that users should understand to use it more effectively.

The GSMaP algorithm mainly consists of an algorithm for retrieving precipitation from passive microwave (PMW) sensors (the PMW algorithm, Kubota *et al.* 2007; Aonashi *et al.* 2009) and an algorithm for estimating precipitation from both PMW sensors and infrared (IR) radiometer data (the PMW-IR combined algorithm, Ushio *et al.* 2009). Previous studies suggested that the precipitation amount (Masunaga *et al.* 2019) and precipitating area (Hirose *et al.* 2016) estimated by the PMW-IR combined algorithm caused the GSMaP algorithm to produce overestimates compared with those made by the PMW algorithm.

In addition to the PMW algorithm and PMW-IR combined algorithm, there is an algorithm to adjust the precipitation estimation based on satellite sensors to ground-based observations (the gauge adjustment algorithm, Mega *et al*. 2019). Global unified gauge-based analysis of daily precipitation (Chen *et al*. 2008) provided by Climate Prediction Center (CPC) of National Oceanic and Atmospheric Administration (NOAA) is used in the GSMaP gauge adjustment algorithm. The NOAA/CPC conducts quality checks of the collected raingauges and generates a gridded dataset based on the raingauge information.

Moreover, some ancillary information supporting the GSMaP precipitation rate are also available, such as observation time flag, satellite information flag, and reliability flag. In particular, the reliability flag shows reliability of precipitation estimation in GSMaP at each pixel as any one of ten levels (10 being the best and 1 the worst) by considering its algorithm characteristics (Yamaji *et al*. 2021). The reliability flag was developed by requests from applicational users, so that the information can be useful for users even those who are not familiar with the details in algorithms.

3. GSMaP Applications in Geography

As described in the previous section, GSMaP data is provided as a mapping-type product (*i.e.*, gridded dataset) by using multiple satellite sensors and filling in the gap area that would result from using a single sensor. The advantage of GSMaP data, such as global gridded dataset and provision of precipitation which varies both spatially and temporally, has a high affinity with geography. This section reviews some utilizations of GSMaP in geographic field.

Synergetic use with the Geographic Information System (GIS)

The GSMaP data can be displayed through a webpage called "JAXA GLOBAL RAINFALL WATCH", and the graphical user interface is as shown in Fig. 1. Users can easily monitor the rainfall anywhere (60°S–60°N) and anytime (since March 2000 until current) after opening the website.

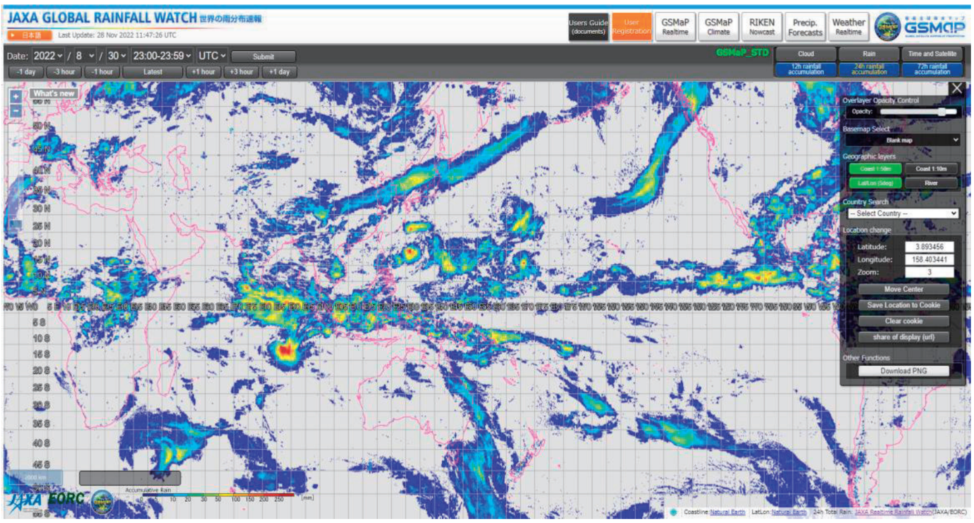

Fig. 1 Graphical user interface of the GSMaP website "JAXA GLOBAL RAINFALL WATCH".

From the analysis of the pageview number of GSMaP webpage, it is found that user-kindly interface using geographical maps triggers increasing of data utilizations. Figure 2 presents a timeseries of the pageview number from September 2013 to October 2022, and suggests that the number of pageview was significantly increased in June 2018 when the GSMaP website was majorly updated. User interface of the website has been improved as the major updates, adding some functions to select the country/regions or latitude/longitude of center location to be displayed, and to change the opacity of GSMaP precipitation layer to recognize the location shown from base map, and so on. Note that the pronounced peaks were found in July 2020 and August 2021 because many public users accessed GSMaP website to see some specific extreme heavy rainfall events in Asia. Thus, space-based global precipitation data can be more convenient when combined with geographical information such as base map and coastline.

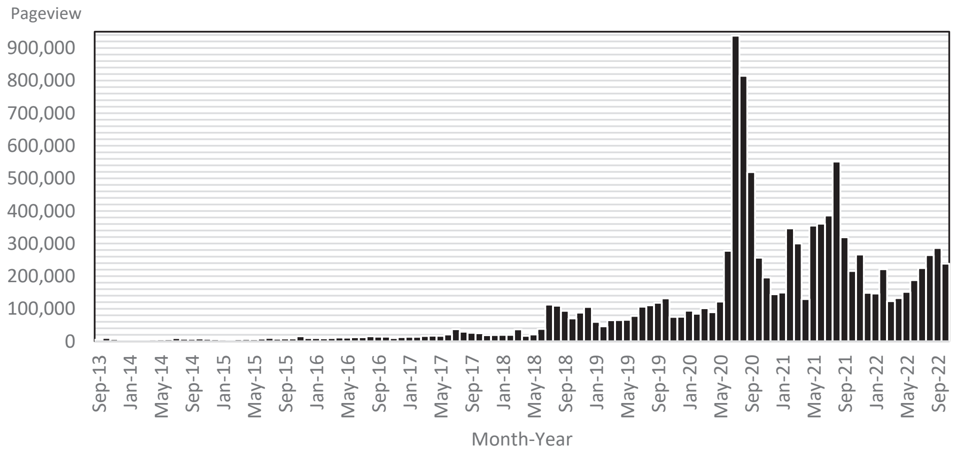

Fig. 2 Timeseries of monthly pageview number of the GSMaP website "JAXA GLOBAL RAINFALL WATCH" from September 2013 to October 2022.

The GSMaP data in hourly, daily, and monthly basis can be also freely downloaded by the data distribution service connected with the website mentioned above, so that users can overlay the rainfall data with other information (*e.g.*, user's own data) on any GIS software, as well as other analysis tools.

As mentioned earlier, GSMaP data is available since March 2000, and 22-year climatological statistics (*i.e.*, annual mean, monthly mean, and percentile values) are also provided together with hourly precipitation data updated operationally. Operational meteorological and hydrological agencies in the Asia-Pacific regions use GSMaP data for operational monitoring of weather, detecting extremely heavy rain or droughts, validating the model predictions with GSMaP, etc.

Google Earth Engine and its application to geographic educations

In addition to downloading the GSMaP data and using it locally, the long-term GSMaP information can be handled on a platform of Google Earth Engine. There are some Google Earth Engine apps using GSMaP including for geography education. Users, even elementary school students, can use satellite dataset by their own.

Recently, each elementary school student uses each one personal computer (PC) to learn Information and Communication Technology (ICT) skills as promoted in Japan's Global and Innovation Gateway for All (GIGA) School Program. JAXA provides apps on the Google Earth Engine using monthly GSMaP rainfall data to support the study to learn global rainfall climatology.

Figure 3 presents the interface of the app using GSMaP, showing typical precipitation differences between winter and summer over Japan region. Figure 3a indicates precipitation along the coastline of Japan Sea whereas Fig. 3b shows heavy convective rainfall especially over the western Japan. Students can select two months to display the precipitation and compare the differences on the web-based platform.

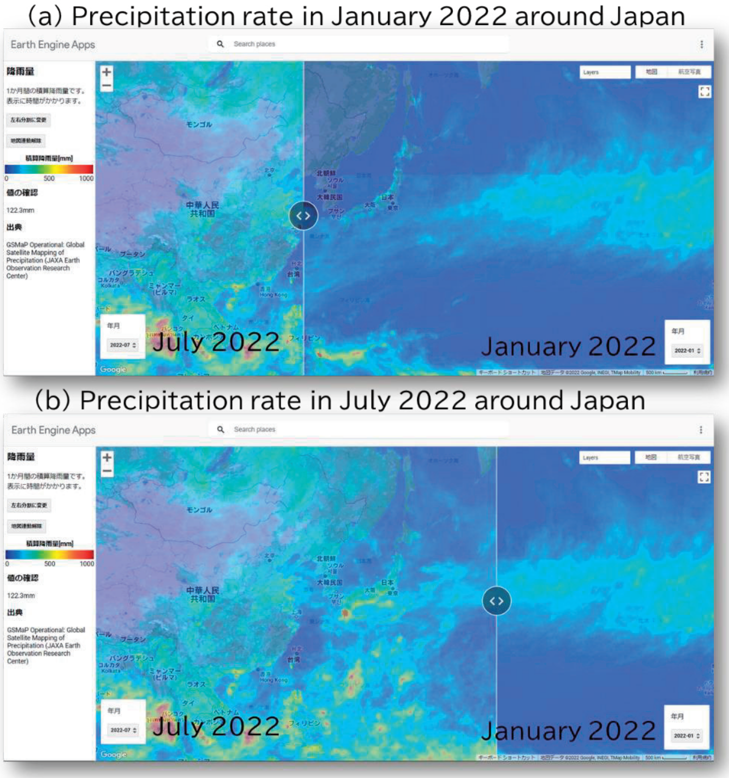

Fig. 3 Graphical user interface of the app using GSMaP on the Google Earth Engine platform.

Educational tools in combination with advanced visualization technology

Recently, some private companies are using GSMaP data to develop educational tools and services for educations. For example, Hobonichi, a Japanese private company, uses GSMaP realtime rainfall imagery to show the Earth's current status on a globe in combination with Augmented Reality (AR) technique, called "Hobonichi Globe". When we view the Hobonchi globe with a smartphone or tablet, some geophysical variables including GSMaP rainfall can be seen in realtime basis.

Hence, GSMaP data has been used in combination with GIS tool or platforms, which further expand the base of data utilization. This paper mainly focused on the geography educations but other use cases are seen in case study collection book (JAXA 2022).

4. Summary

GSMaP is a mapping-type precipitation product generated by filling in gaps using multiple observations in the algorithm. This paper reviews the major characteristics of GSMaP algorithms, which are important to be understood by users.

- There is a variety of GSMaP products; the standard product with three-days latency, the near-real-time product with four-hours latency, and the real-time product with a few minutes latency. Basically, latency and quality/accuracy are trade-offs. There are also gauge-adjusted products for each.
- Precipitation is estimated by the PMW algorithm and PMW-IR combined algorithm. Previous studies reported that precipitation amount and area estimated by the PMW-IR combined algorithm caused overestimates compared with those made by the PMW algorithm.
- Some ancillary information supporting to use the GSMaP precipitation rate are available, such as reliability flag.

The global precipitation information by GSMaP has a high affinity with geography, and there are some applicational utilizations of the GSMaP data related to geography.

- GSMaP data can be overlay with other information (*e.g.*, user's own data) by utilizing Geographical Information System (GIS) tools, as well as other analysis tools.
- In addition to downloading the GSMaP data and using it locally, the GSMaP information can be handled on the Google Earth Engine, so that some users are able to quickly analyze the data without downloading it to their local environment.
- There are some Google Earth Engine apps using GSMaP for geography education, which enables users even elementary school students to handle satellite dataset.
- Moreover, real-time rainfall information by GSMaP is valuable to offer current status of globe in terms of rainfall, and some private companies have developed educational tools or services using GSMaP in combination with advanced visualization technology, such as augmented reality.

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(*: in Japanese with English title)