# Introduction of Global Satellite Mapping of Precipitation (GSMaP)

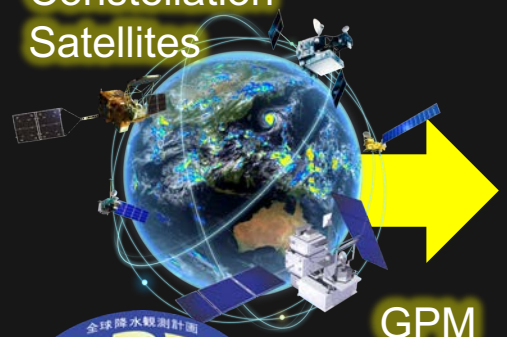
Tomoo Ushio, Hitoshi Hirose (University of Osaka)

Nao Yoshida, Takuji Kubota (JAXA)

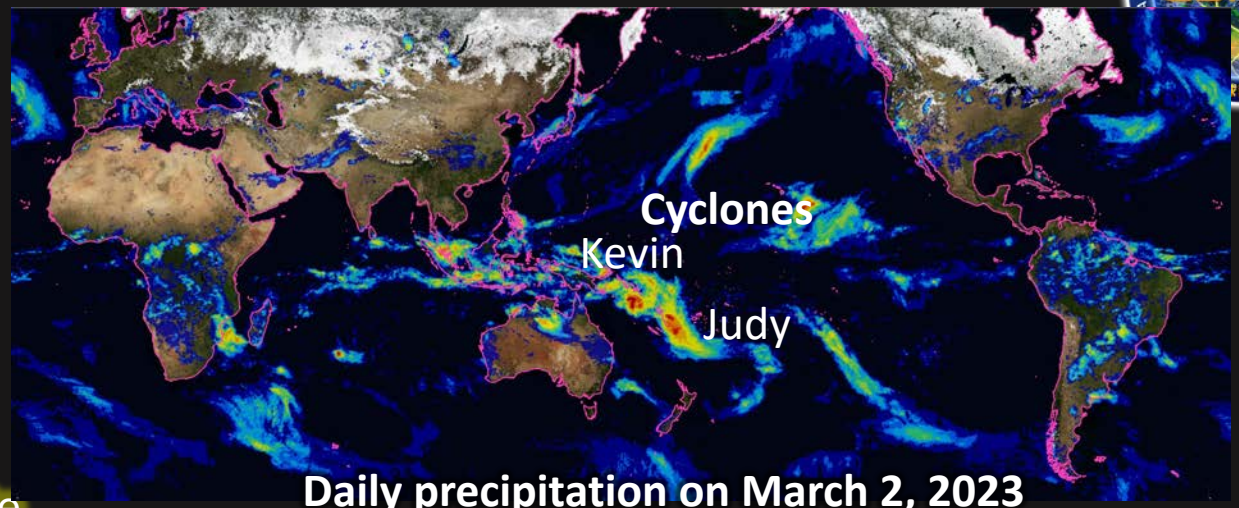
# Satellite-based global rainfall map:

GSMaP
GLOBAL SATELLITE MAPPING OF PRECIPITATION

GPM Constellation Satellites



GPM Core Satellite



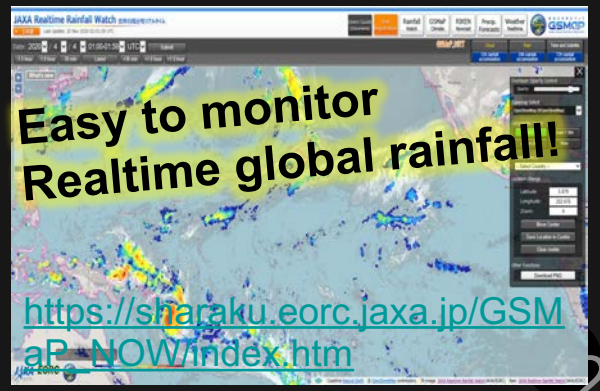
Daily precipitation on March 2, 2023

- **Hourly global** rainfall data
- Spatial resolution: about **11x11km**
- Various version such as **real-time for monitoring** or **long-term gauge-adjusted for climatological purposes**

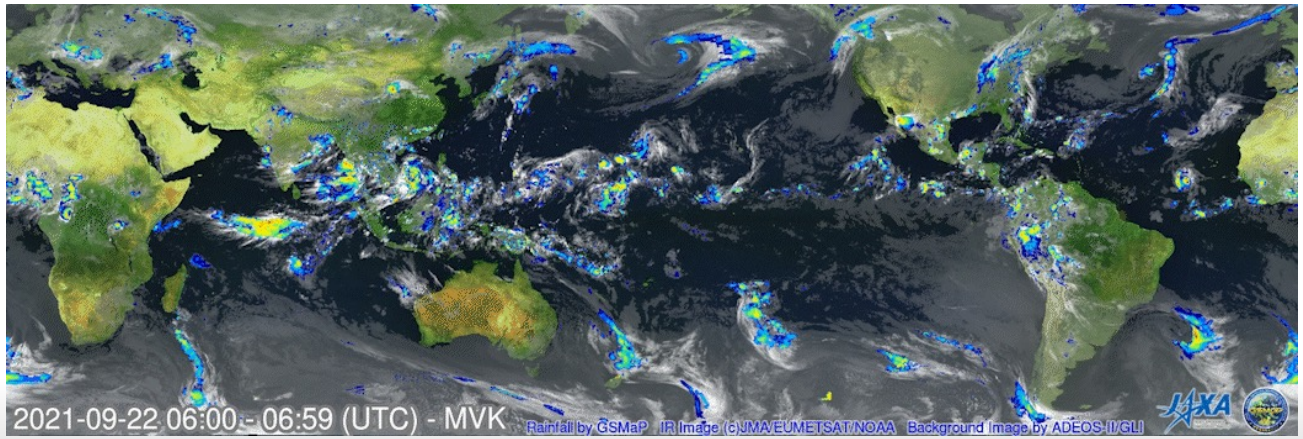
**12,271**
**registered users**
**from 150**
**countries/regions**
(as of Oct. 2023)
**+ website users**
(not registered)


## The unique advantage of GSMaP

- Space-based rainfall observations allow us to capture the rainfall even in the area lack of ground-based observations.
- Rainfall can be measured globally, continuous and same interval, and consistent accuracy.
- Open and freely available via web-based GUI, FTP site and data analysis cloud platforms (ex. GEE)
- Long-term archive data for more than 25 years (since 1998)



# Various application fields





Climate monitoring

WMO extremes monitoring

Weather Monitoring/ forecasts

Asia-oceania met services

Water-related disasters

Flood analysis and predictions by disaster management offices

Agriculture

Flood security and insurance for farmers

Energy

Hydropower development planning

Public health

Researches on infectious diseases

Educations

Educational tools

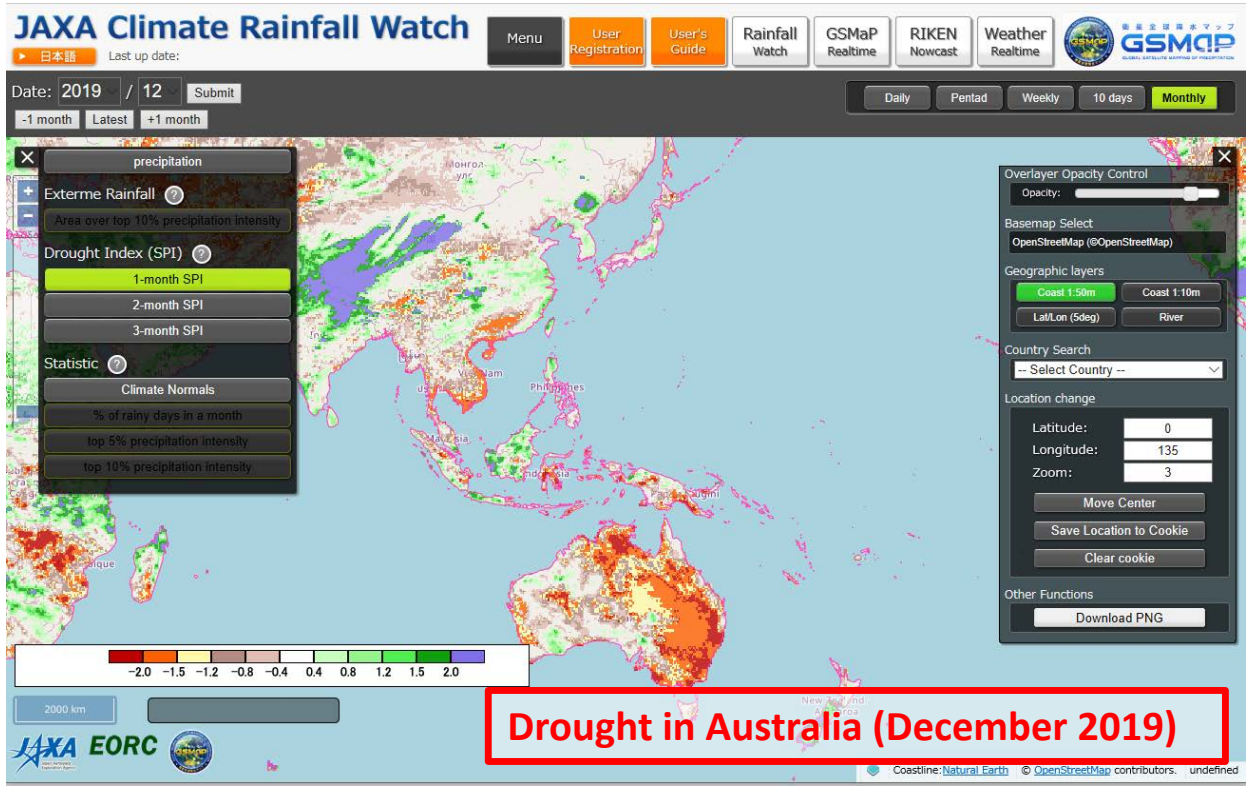
**Use cases are collected in the book “Case studies demonstrated by TRMM/GPM/GSMaP”**

https://www.eorc.jaxa.jp/GPM/doc/data_utilization/latest_jireishu_e.pdf

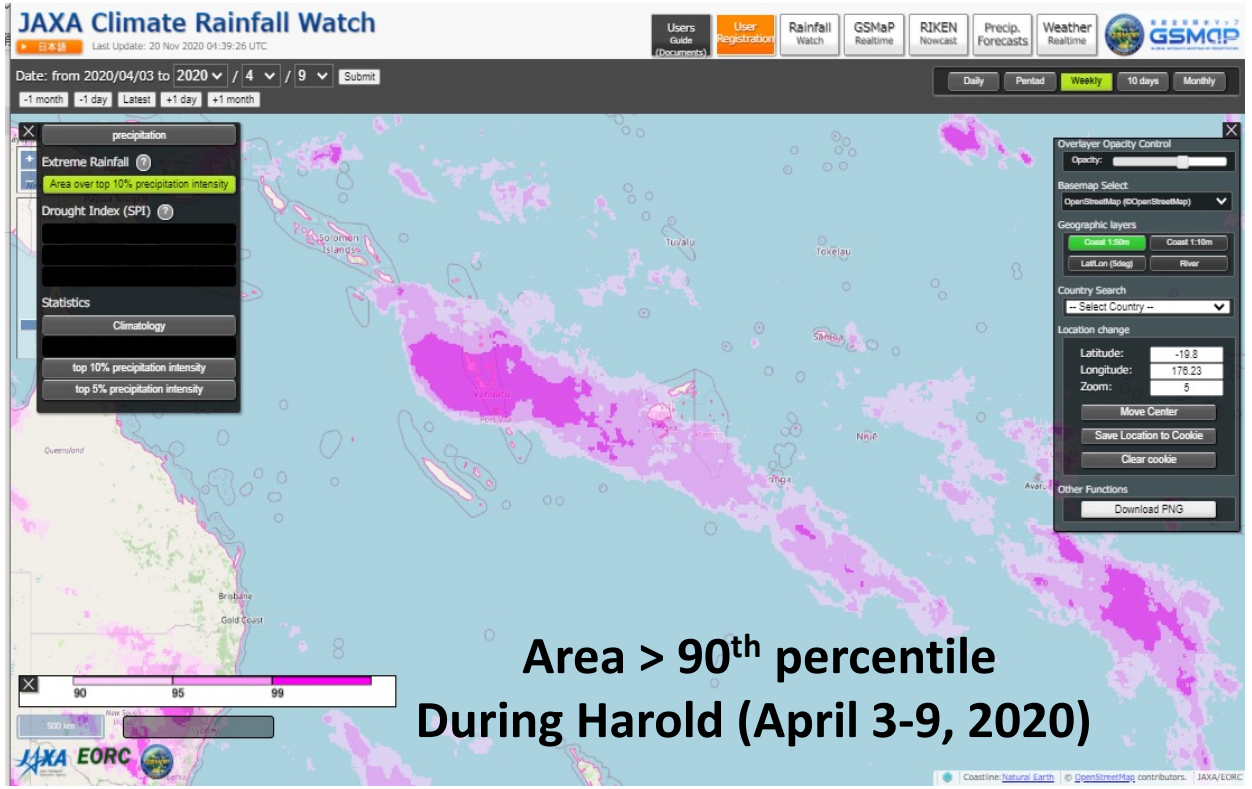
# Drought and Heavy Rainfall Monitoring

We started to operate a website "**JAXA Climate Rainfall Watch**", which provides information about **extreme drought and heavy rainfall** over the world based on the GSMaP statistics.

Displaying accumulated rainfall in some temporal scale (daily, pentad, weekly, 10-days and monthly) and 20-year climate normal.



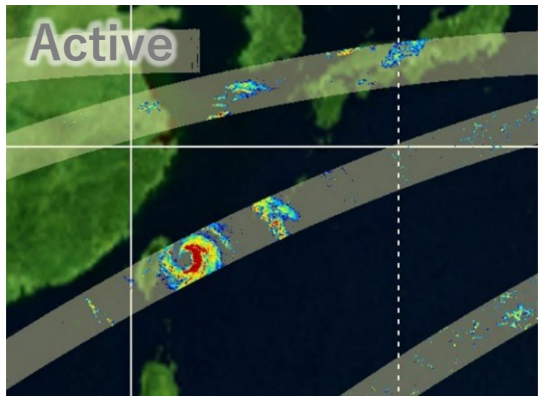

Drought in Australia (December 2019)

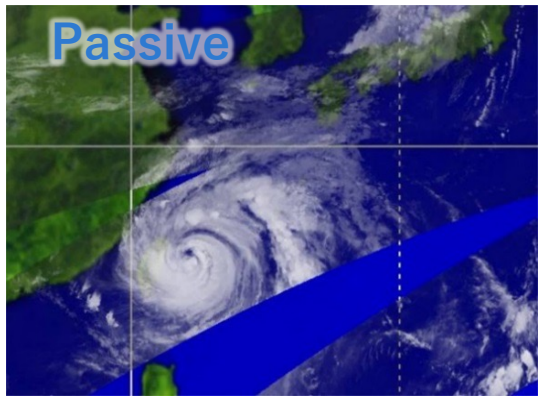


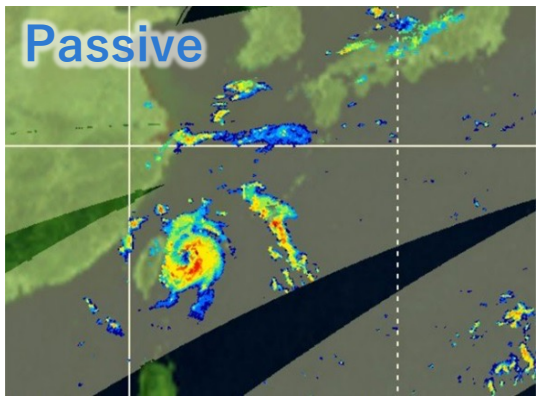

Area > 90th percentile
During Harold (April 3-9, 2020)

**Graphical User Interface of the "JAXA Climate Rainfall Watch" website**
**(https://sharaku.eorc.jaxa.jp/GSMaP_CLM/)**

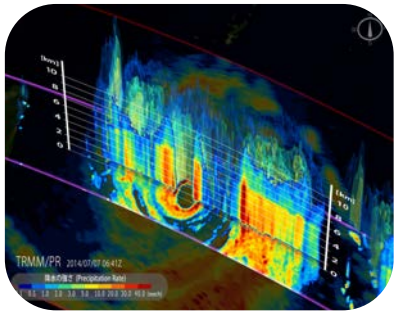
# Features of sensors



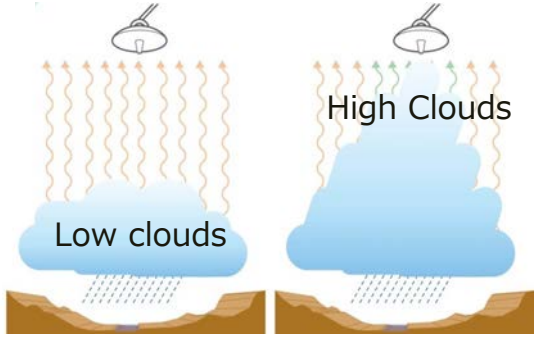



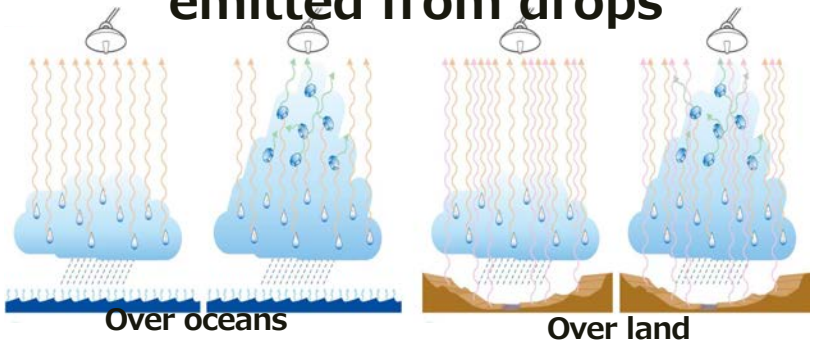

## Directly observe vertical structure of precipitation


## Measure cloud top temperature




## Measure microwave radiation emitted from drops




## Precipitation Radar

e.g., GPM/DPR

- Actively emit pulse and measure the echoes reflected back from drops.
- Can detect vertical distributions of precipitation but narrow swath.
- There is only one precipitation radar in operation over the world, developed by Japan.

## Infrared Imager

e.g., Himawari/AHI

- Measure cloud top temperature.
- Cannot directory observe precipitation.

## Microwave Radiometer (Imager/Sounder)

e.g., GPM/GMI

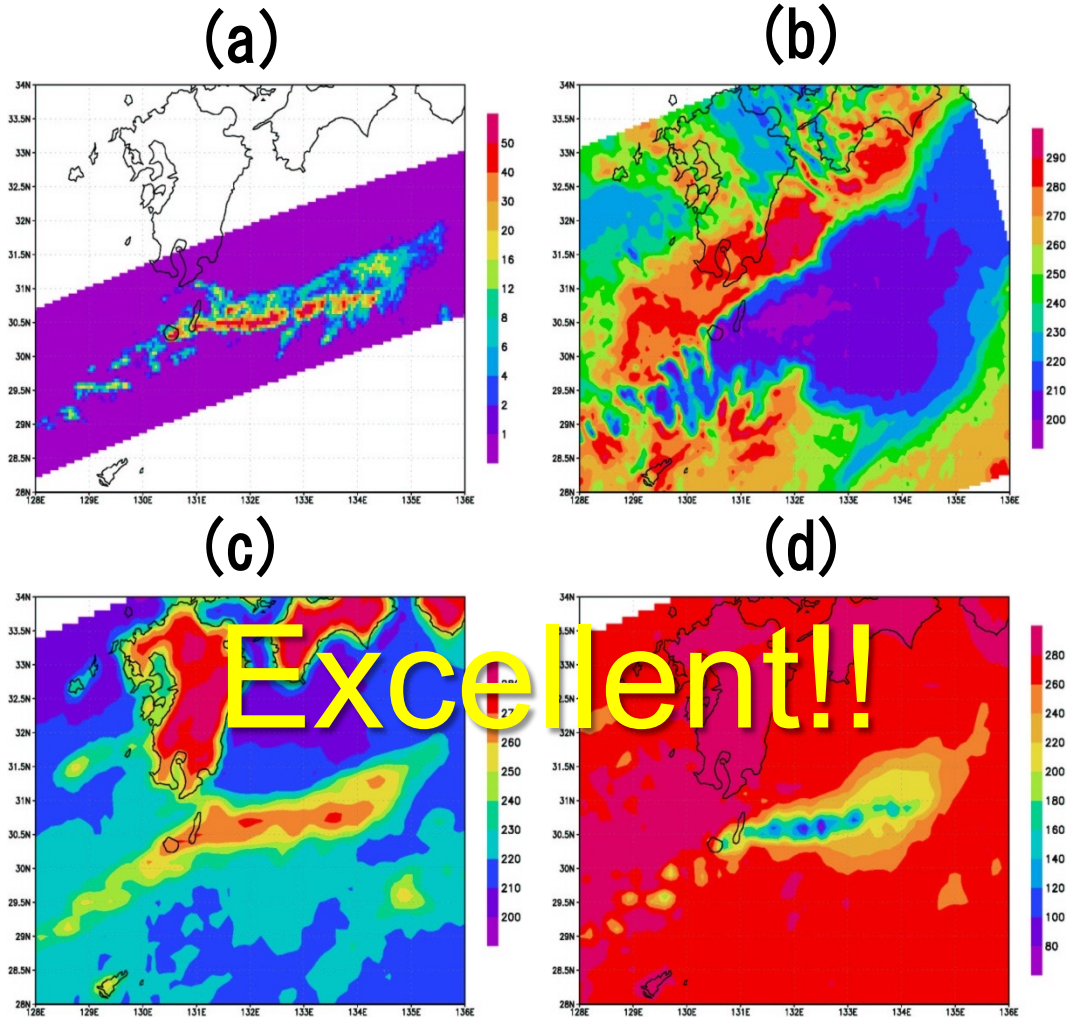
- Measure intensity of microwave radiation that is constantly emitted from raindrops.
- Can estimate spatial distributions of precipitation with wider swath
- There are many microwave radiometers in operation.

# Precipitation characteristics observed by the space borne sensors

(a) Precipitation radar
- Back scattering from rain drops
- High accuracy
- Narrow swath width

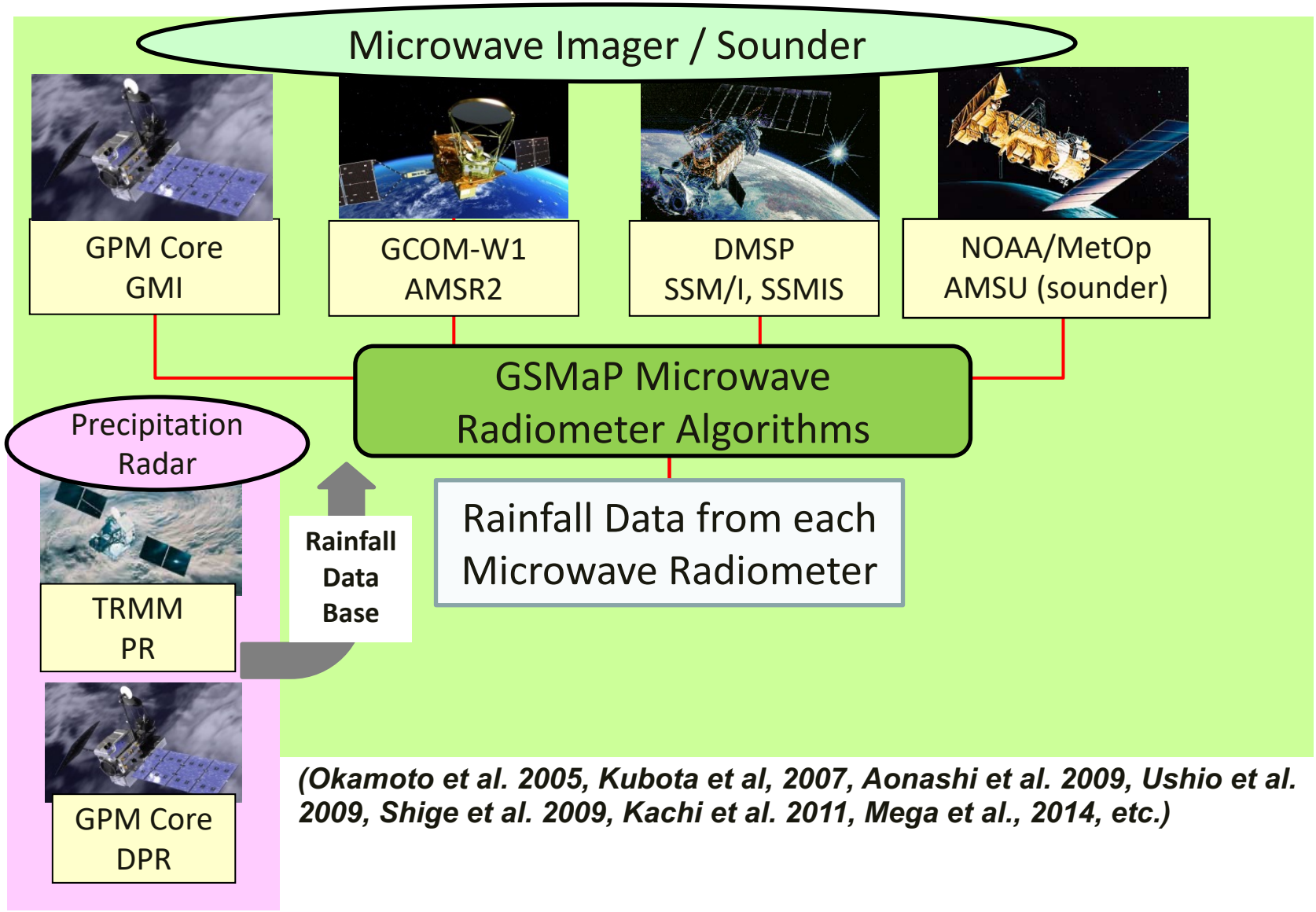
(b)Infrared radiometer：
- Cloud top information
- Not related to surface precipitation rates

(c)Microwave radiometer(19GHz)：
(d)Microwave radiometer(85GHz):
- Directly measures the emission from precipitation particularly in low frequencies




It is important to combine the data from different frequencies to retrieve precipitation

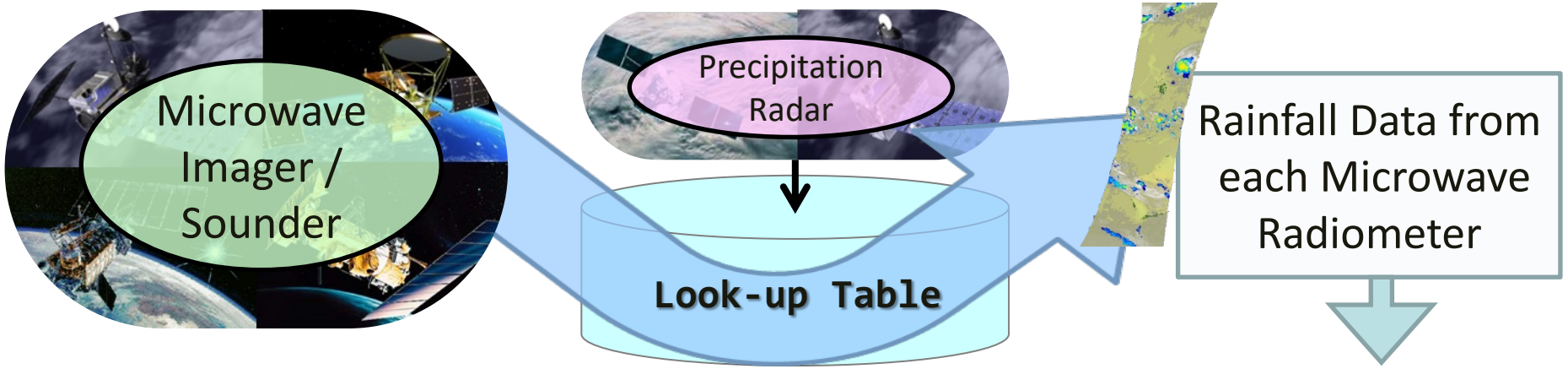
# Overview of GSMaP Algorithm

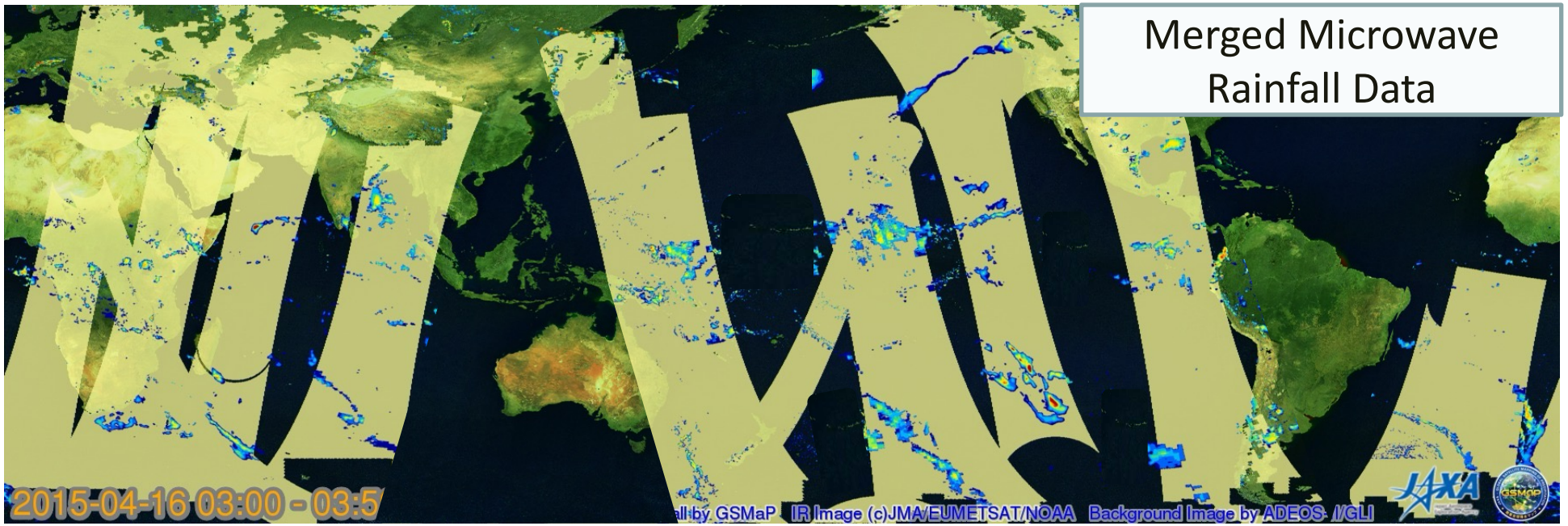



*(Okamoto et al. 2005, Kubota et al, 2007, Aonashi et al. 2009, Ushio et al. 2009, Shige et al. 2009, Kachi et al. 2011, Mega et al., 2014, etc.)*

# Simplified explanation of Algorithm

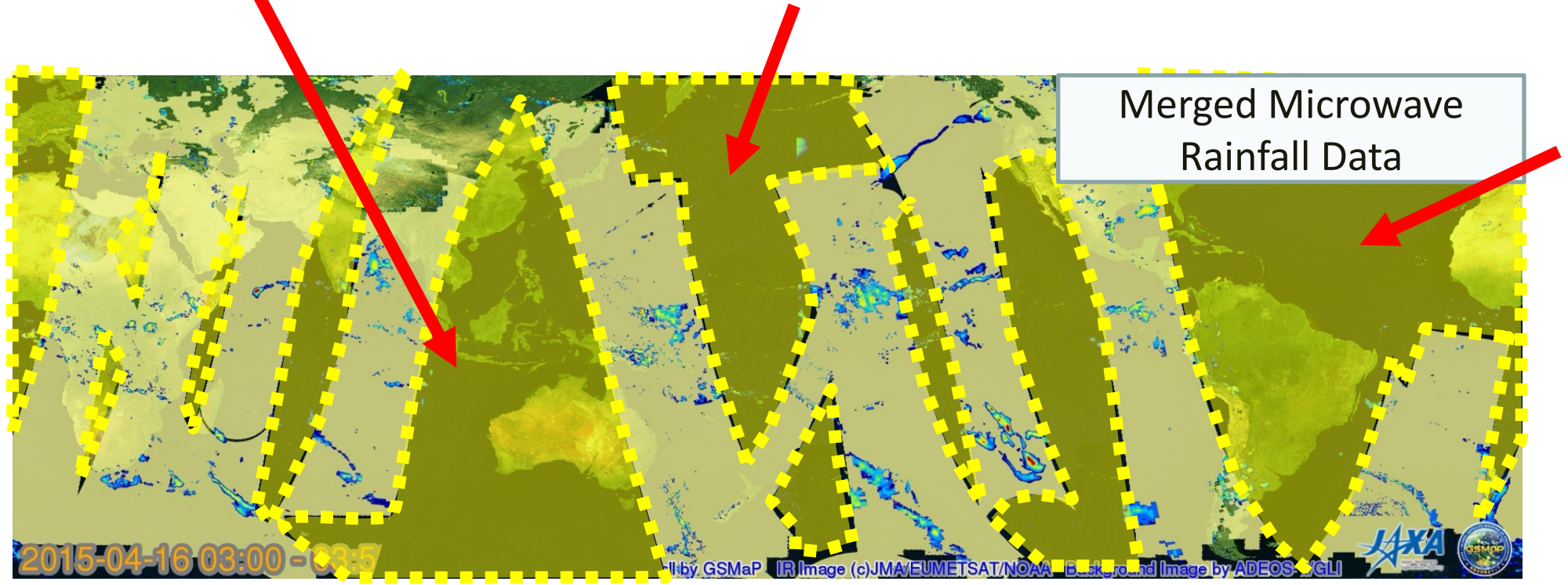
*(Aonashi and Liu 2000, Kubota et al. 2007, Aonashi et al .2009)*



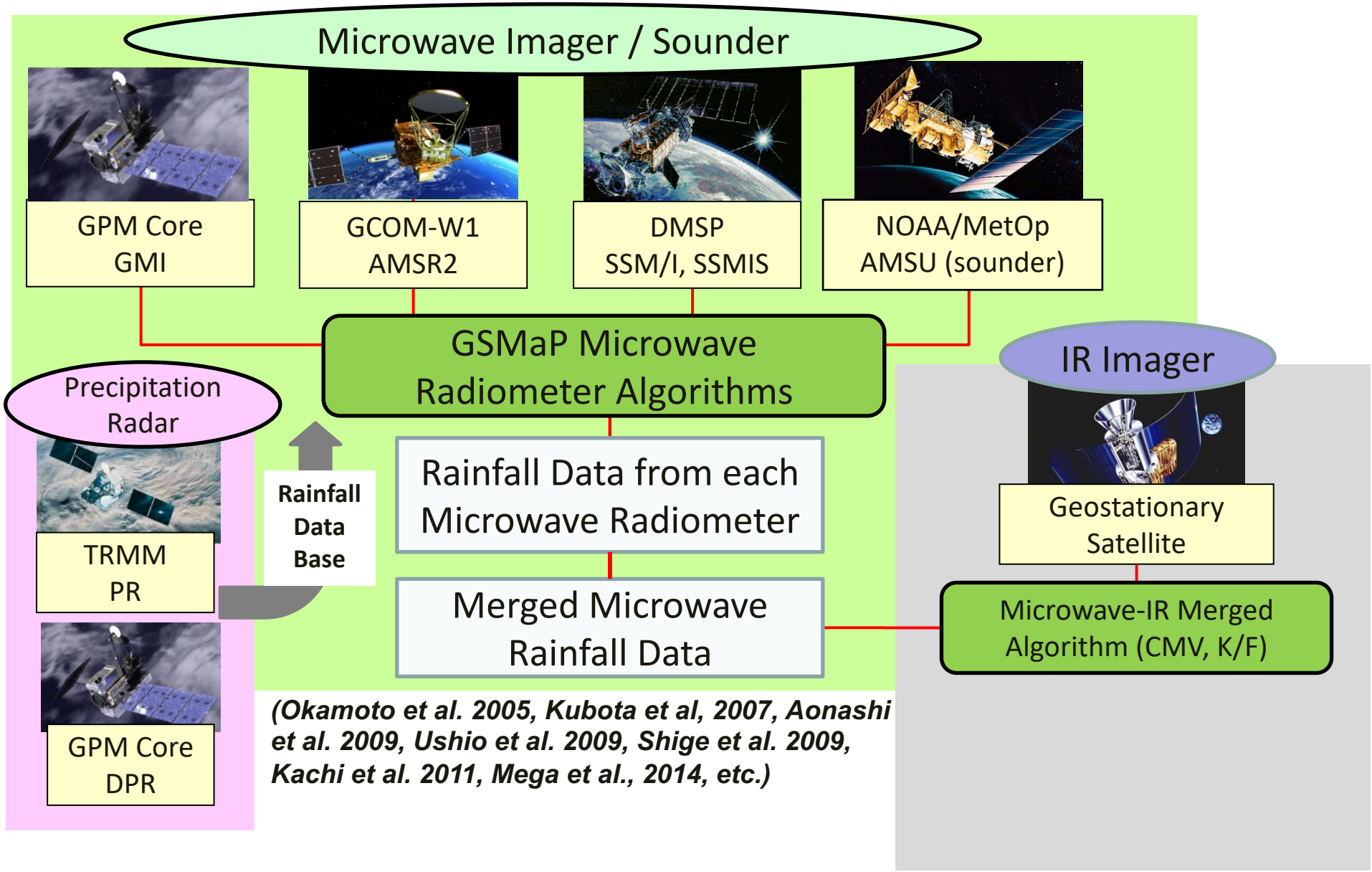
# Simplified explanation of Algorithm

Some area cannot be covered with merged microwave rainfall data in one hour...




Yellow color indicates an area observed by microwave imager and sounder.

# Overview of GSMaP Algorithm



# Approaches for the Global Rainfall Map

- IR-based Approach (ex. GPCP)
  - Uses mainly direct conversion of the brightness temperature at IR wavelength to precipitation rate
  - Generally, the lower temperature, the higher rain rate
  - It is generally true. However, it is also well known that the IR-based rainfall estimation sometimes has large error.

- Moving Vector Approach (ex. CMORPH)
  - Propagate the rainy pixels with the atmospheric motion vector
  - Advantage: Relatively high score
  - A possible main source of error is that the advection vector is the only process that describes the temporal variation of the precipitation process.

# GSMaP approach - Hybrid approach -

- Combination of the moving vector and IR Tb type method
  - We have decided to combine each method (sampling from both world).

  That is…..
  1. Propagates the rainy pixels on the moving vector derived from the successive IR images
  2. And then, optimally estimates the rain rate from the brightness temperature at IR wavelength

- What is the best way to realize this?
  - Global precipitation mapping is a sequential process.
  - So, the Kalman filter is the best way to do this.

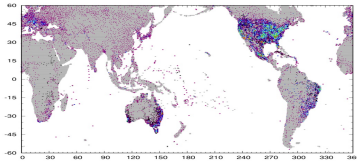
GSMaP

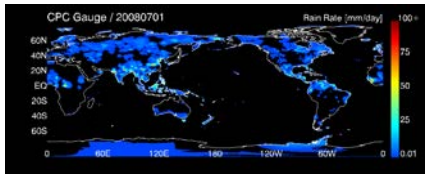
- Kalman filter approach
  - Refine precipitation rate on Kalman gain after propagating the rain pixel
  - The Kalman gain is determined from the database on the relationship between the IR Tb and surface rain rate.

# GSMaP algorithm flow

CPC Global Daily Gauge

Daily/0.5 deg.






MWR data

GSMaP

Geo-IR image

Atmospheric Motion Vector

Kalman Filter

GSMaP_NRT and Now

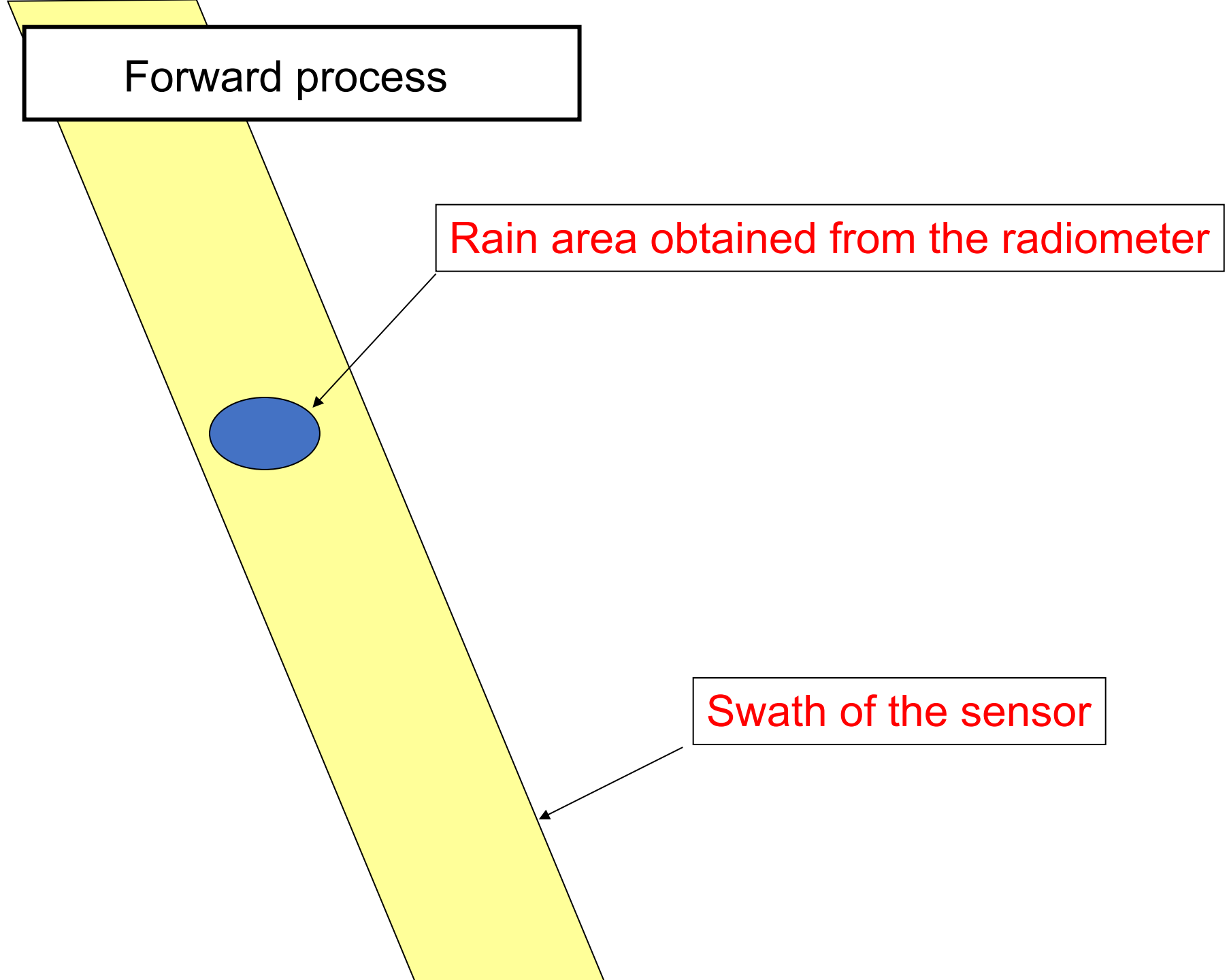
Kalman Filter for smoothing

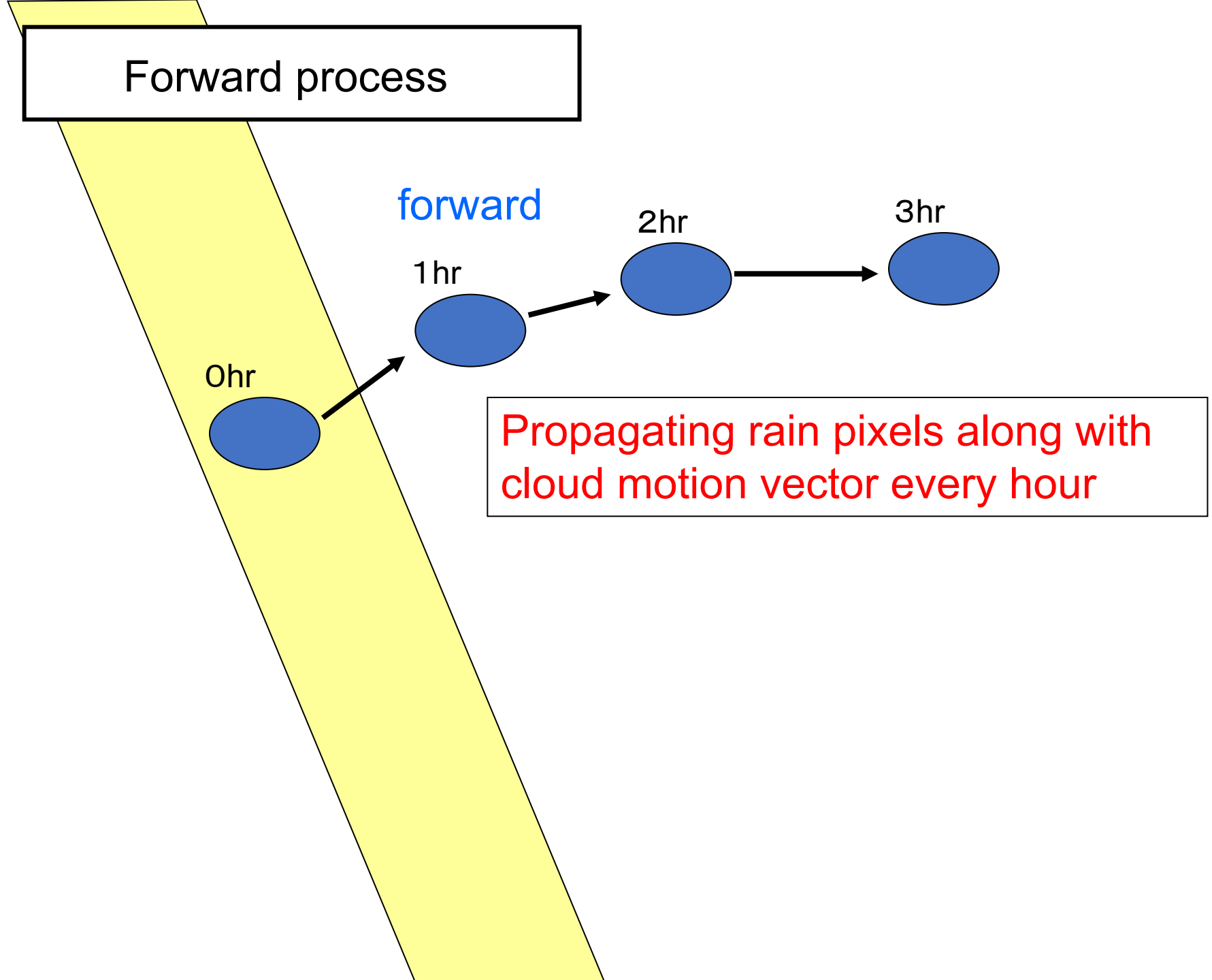
GSMaP_Gauge_NRT

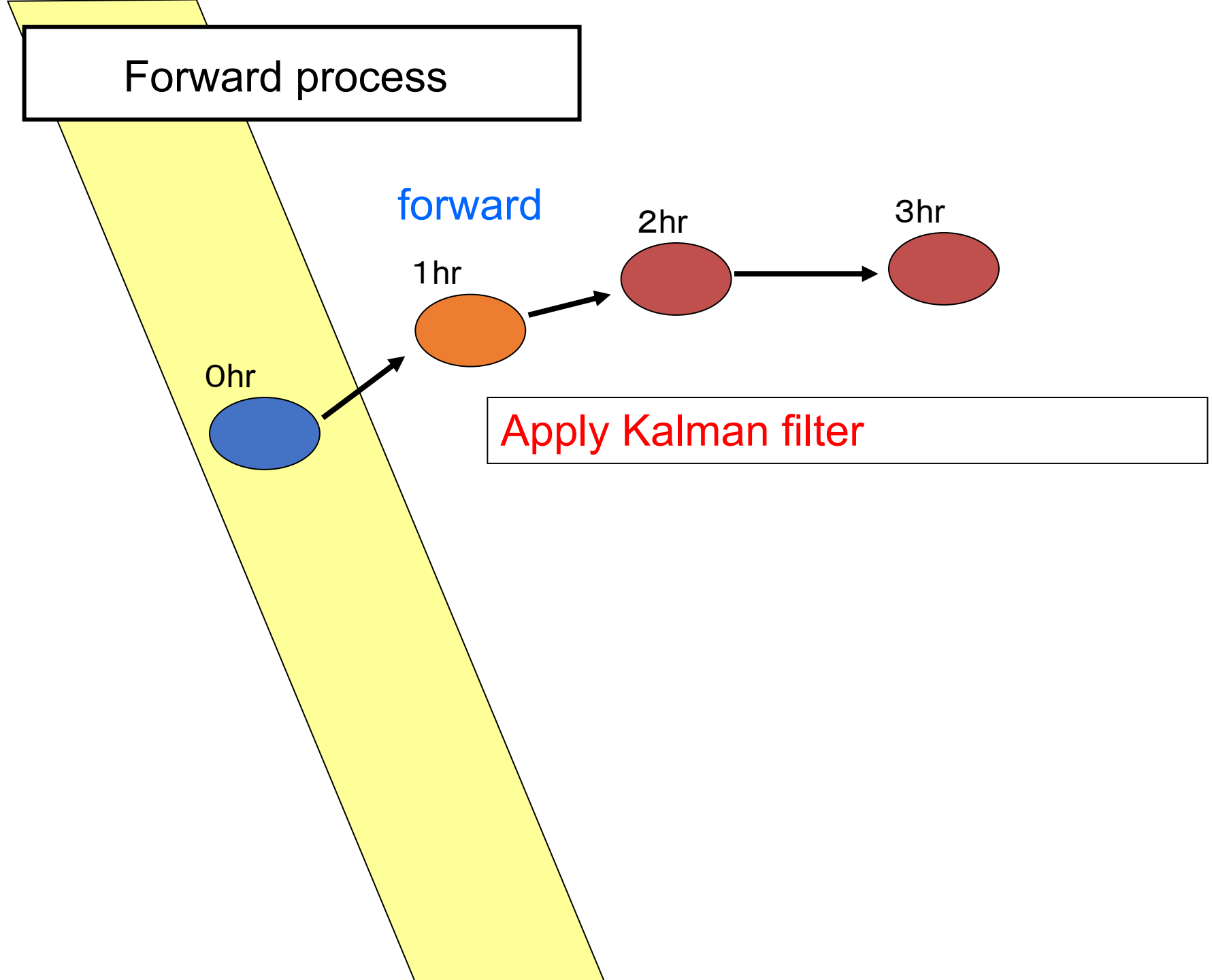
GSMaP_MVK

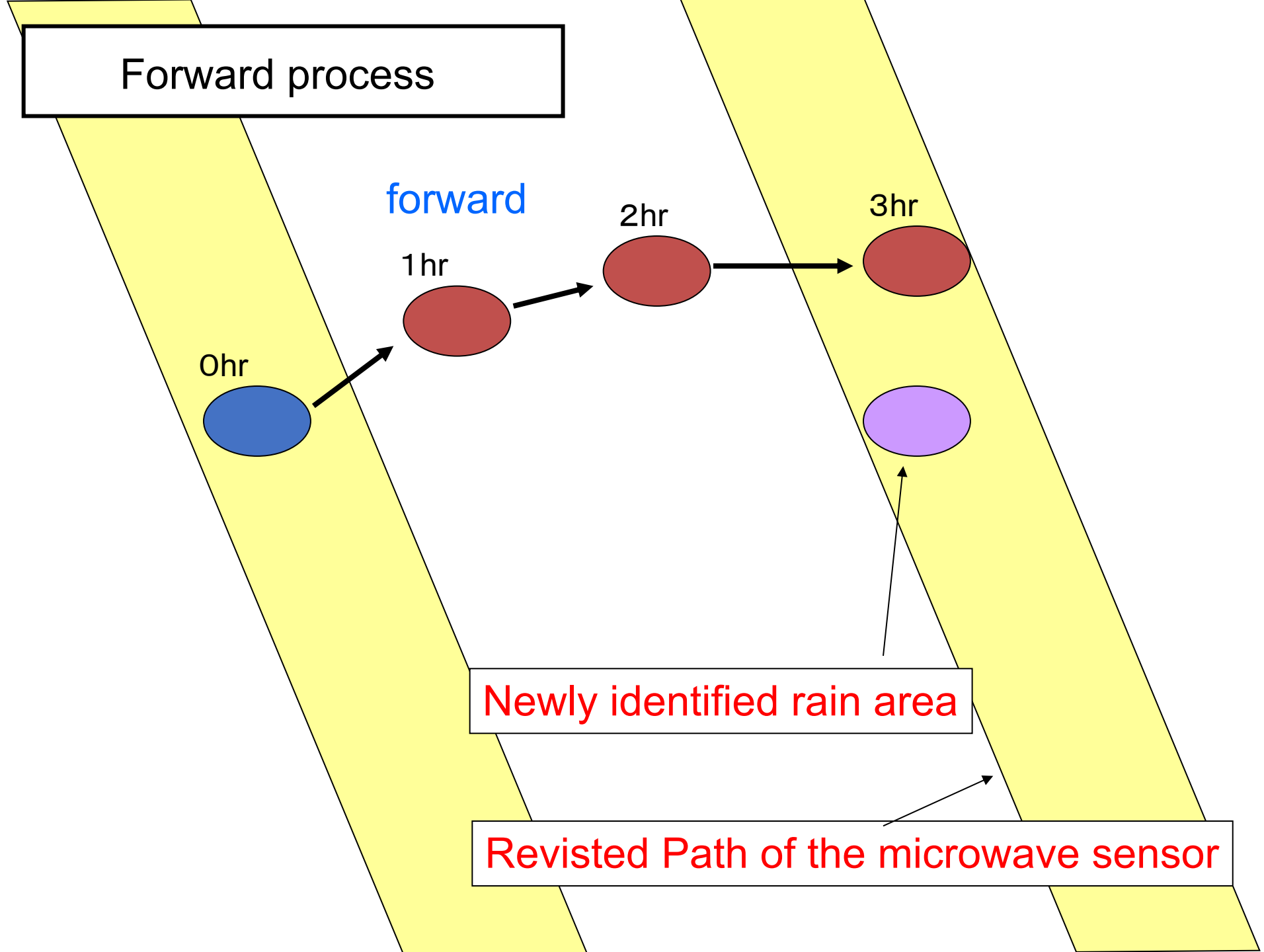
Optimization module

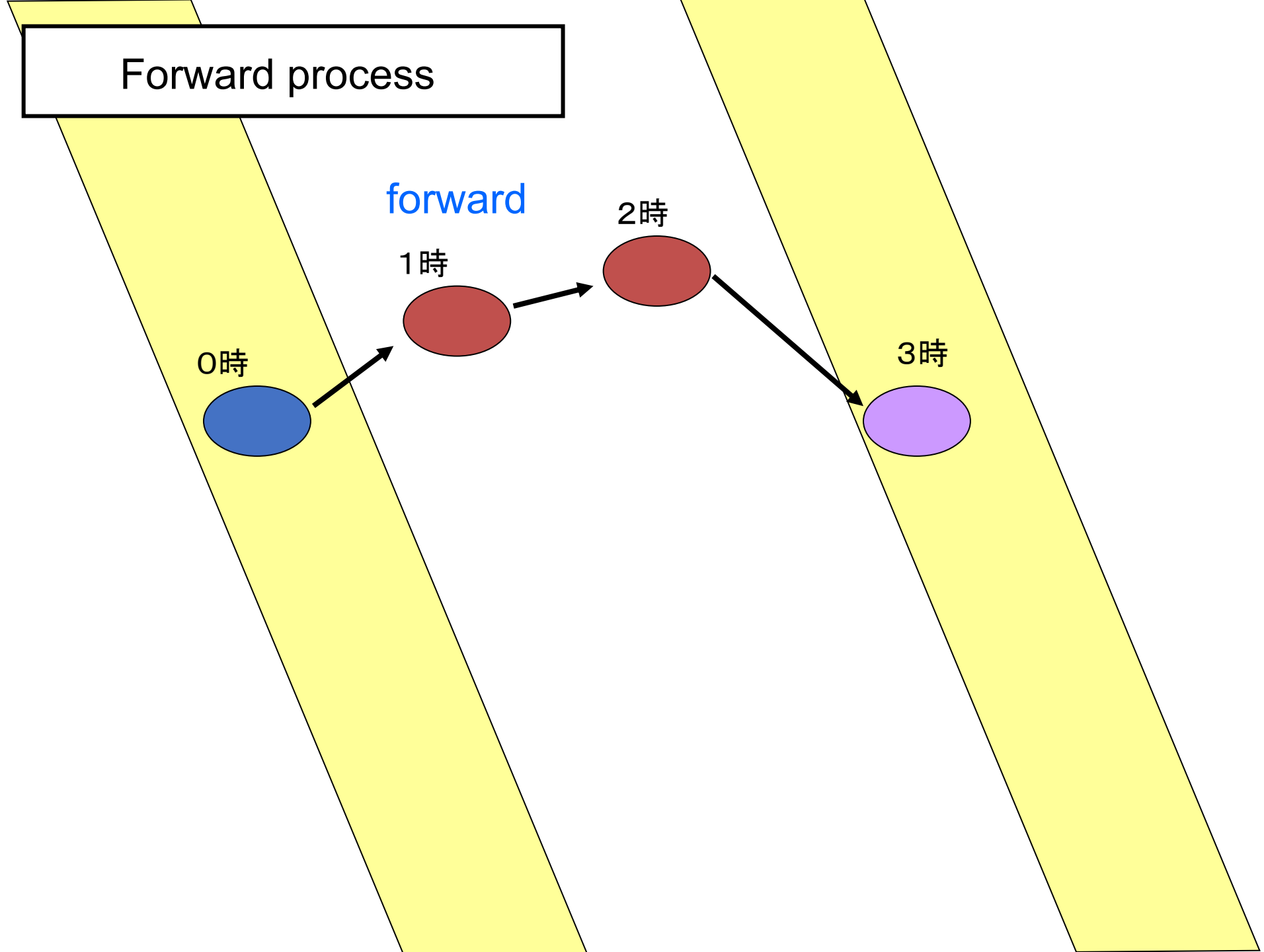
GSMaP_Gauge

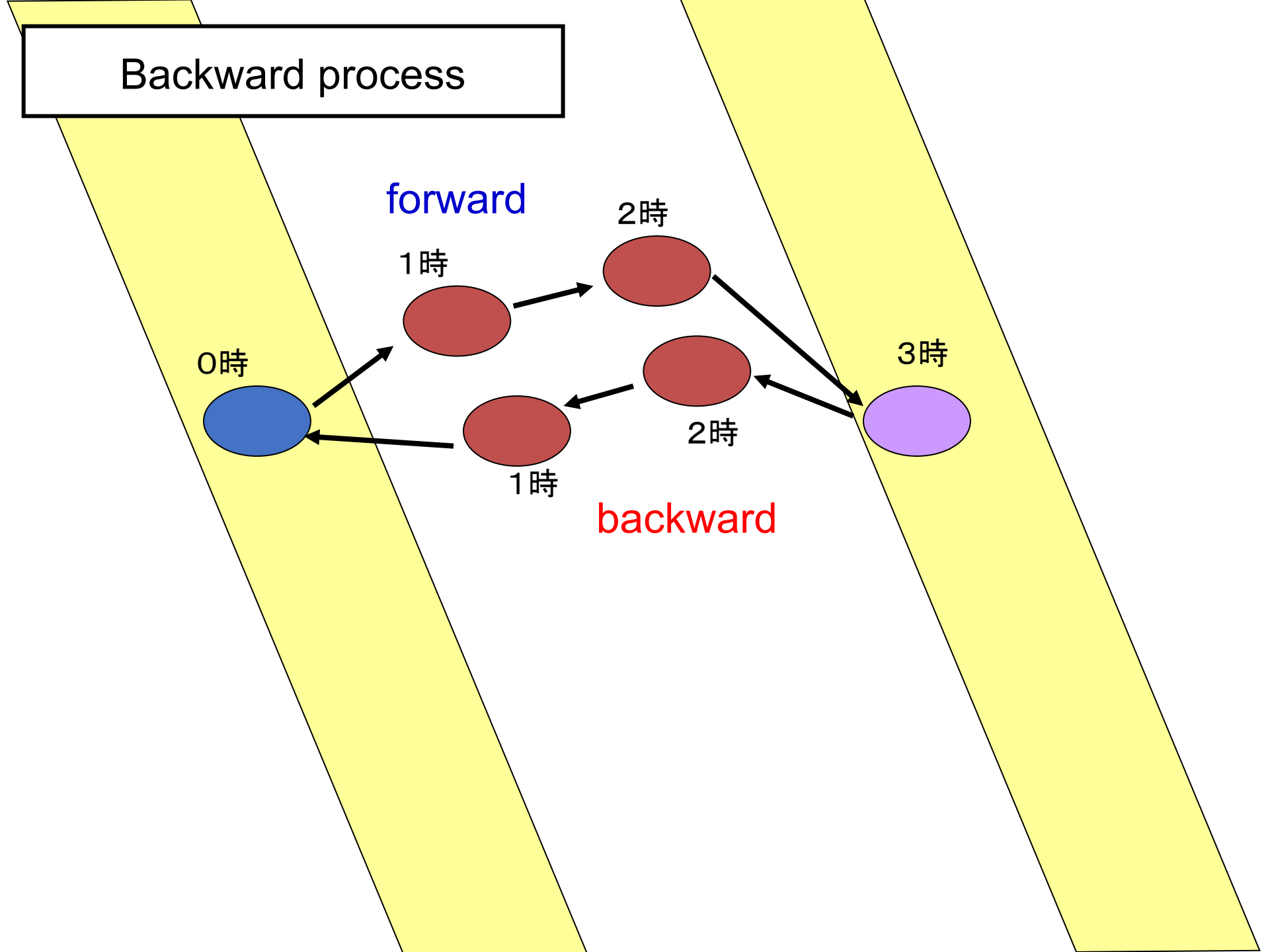

Forward process
Rain area obtained from the radiometer
Swath of the sensor

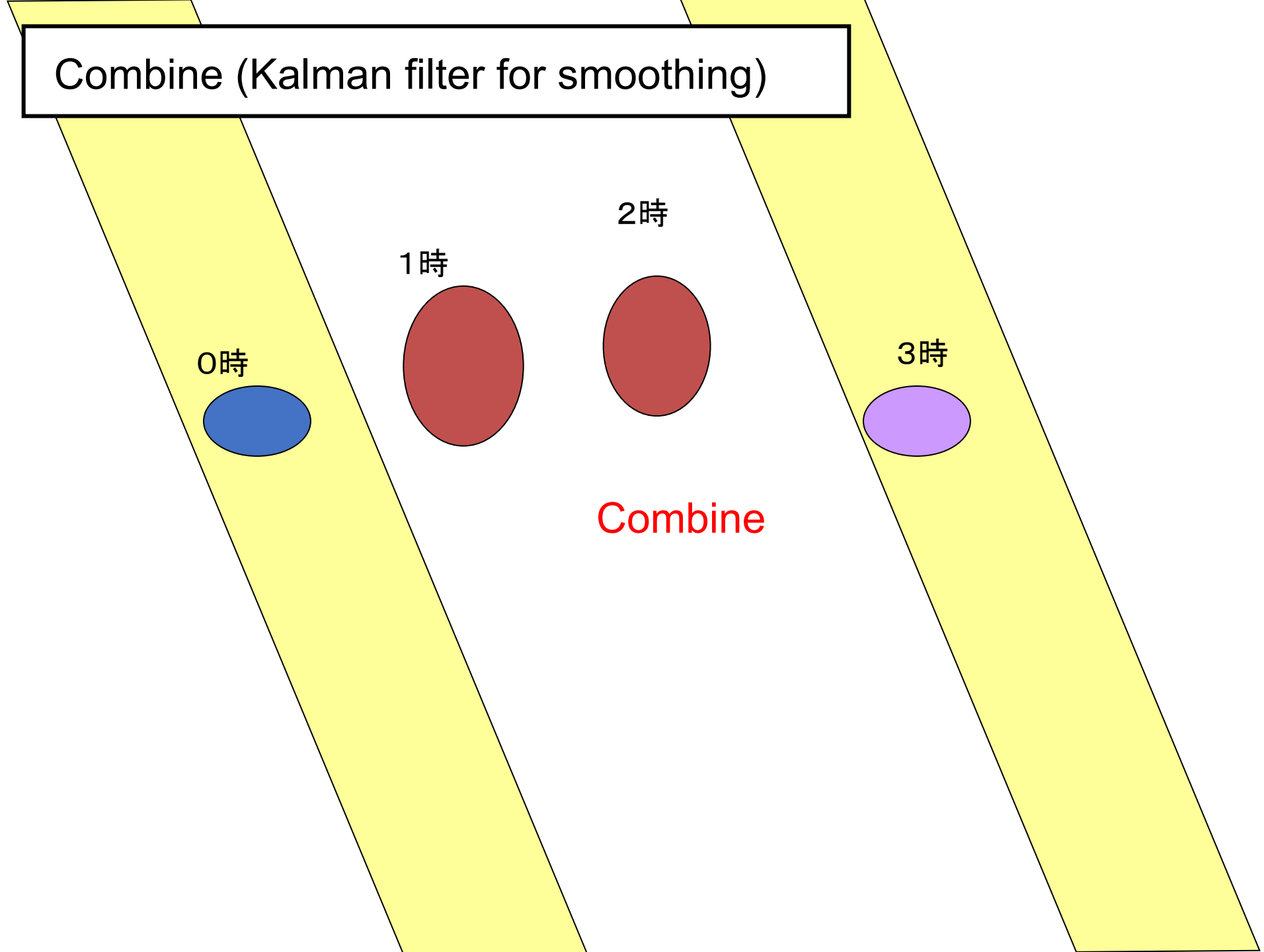

Forward process
forward
0hr
1hr
2hr
3hr
Propagating rain pixels along with
cloud motion vector every hour


Forward process
forward
0hr
1hr
2hr
3hr
Apply Kalman filter


Forward process
forward
0hr
1hr
2hr
3hr
Newly identified rain area
Revisted Path of the microwave sensor

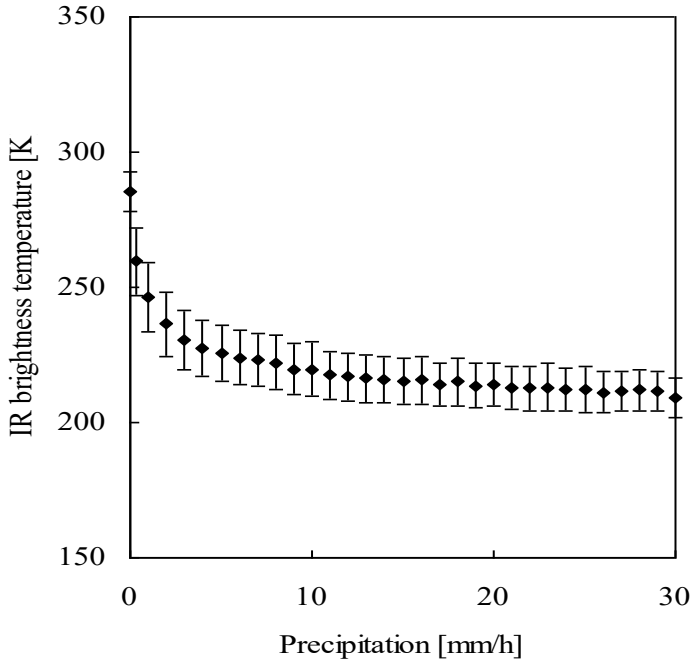

Forward process
forward
0時
1時
2時
3時


Backward process
forward
2時
1時
0時
3時
2時
1時
backward


Combine (Kalman filter for smoothing)
0時
1時
2時
3時
Combine

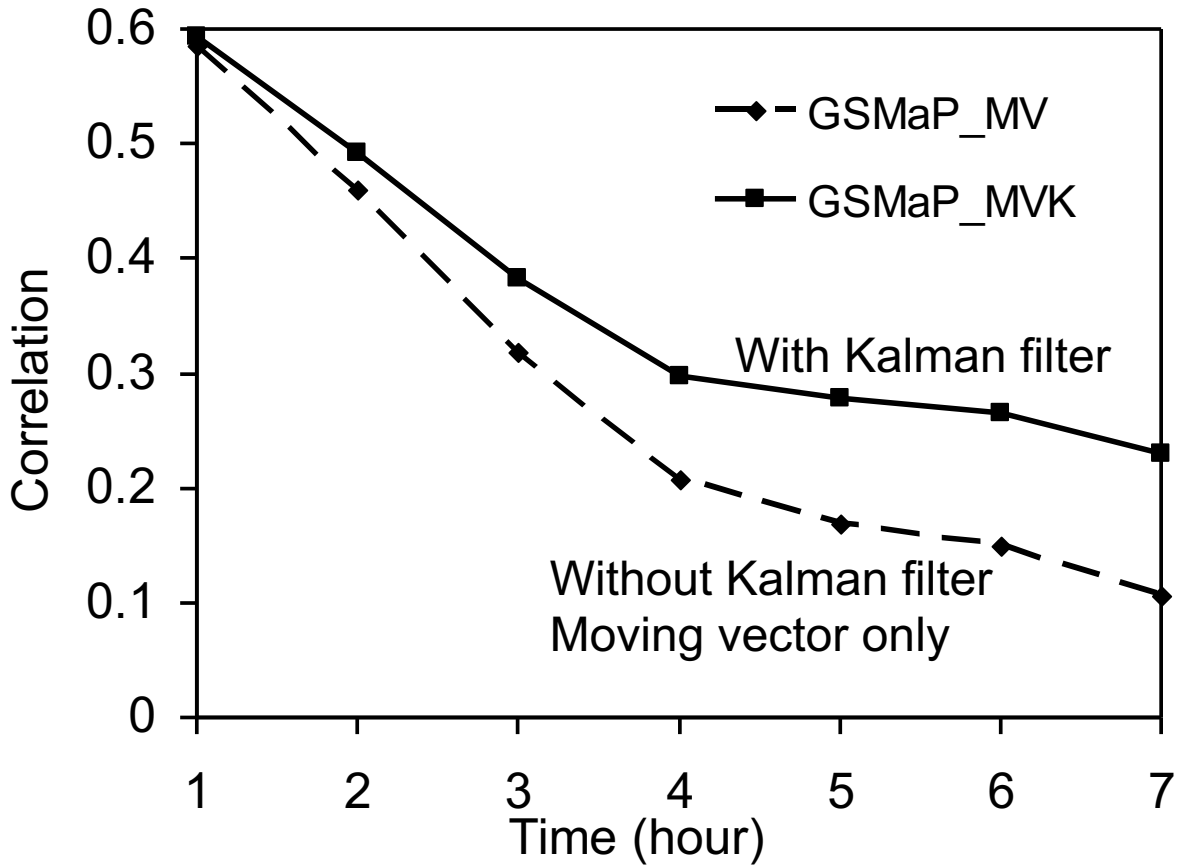
# State and observation equation used in Kalman filter

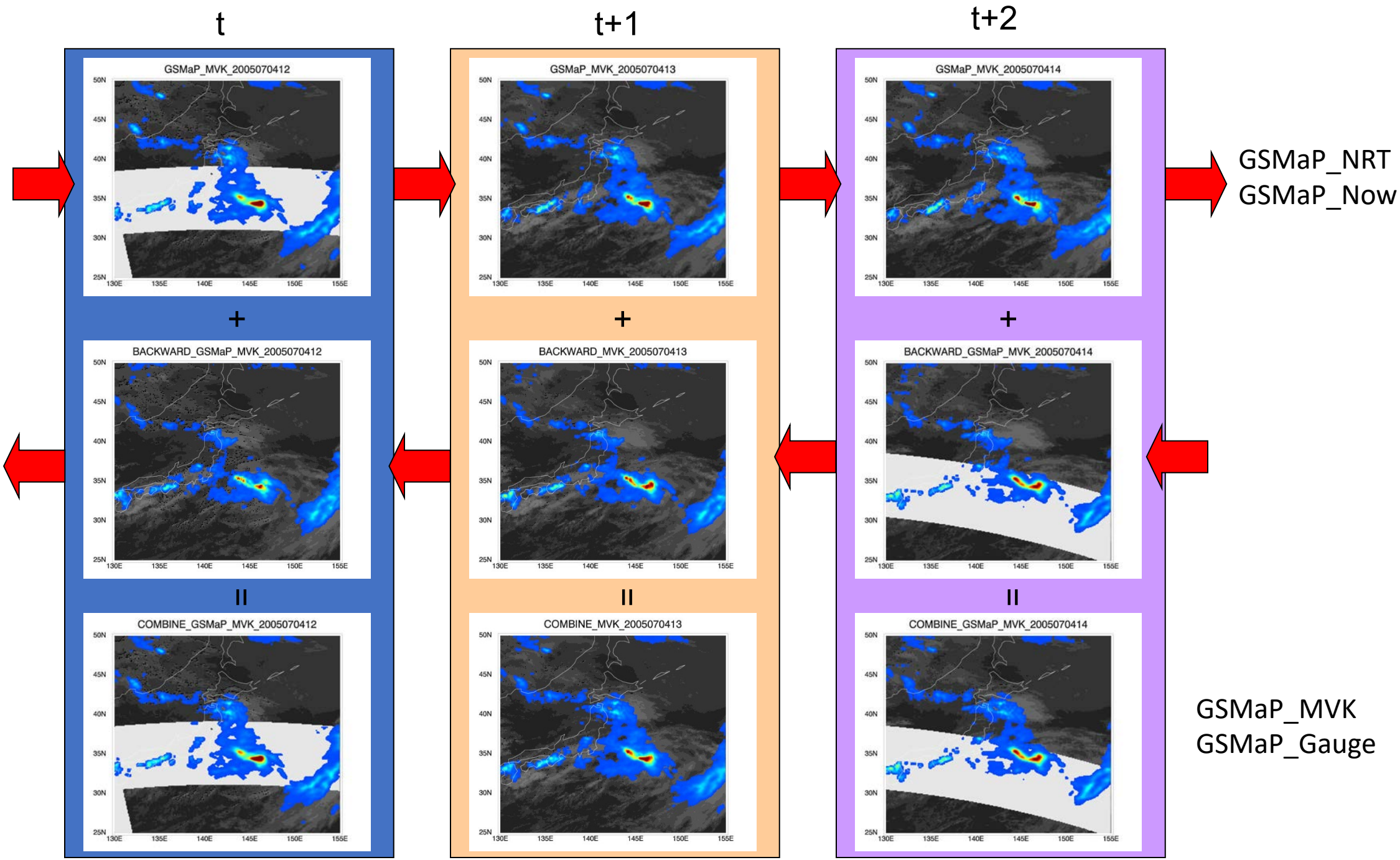
$$x_{k+1} = x_k + \sigma_w \qquad (State\ Equation)$$
$$y_k = Hx_k + \sigma_v \qquad (Observation\ Equation)$$



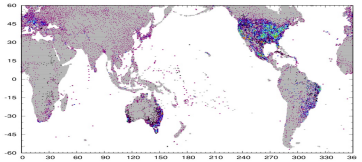

$x_k$ : Rain rate at time k
$y_k$ : Infrared Tb
$x_{k+1}$ : Rain rate at time k+1
$w$ : System noise
$v$ : Observation noise

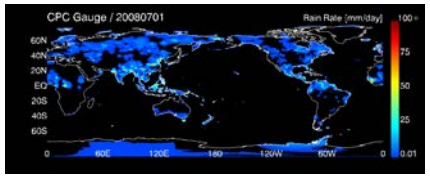
# Correlation between radar and the GSMaP product as a function of the past microwave satellite overpass




t
t+1
t+2
GSMaP_MVK_2005070412
GSMaP_MVK_2005070413
GSMaP_MVK_2005070414
+
BACKWARD_GSMaP_MVK_2005070412
BACKWARD_MVK_2005070413
BACKWARD_GSMaP_MVK_2005070414
=
COMBINE_GSMaP_MVK_2005070412
COMBINE_MVK_2005070413
COMBINE_GSMaP_MVK_2005070414
GSMaP_NRT
GSMaP_Now
GSMaP_MVK
GSMaP_Gauge

# GSMaP algorithm flow



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Daily/0.5 deg.

MWR data

GSMaP

Geo-IR image

Atmospheric Motion Vector

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Kalman Filter for smoothing

GSMaP_Gauge_NRT

GSMaP_MVK

Optimization module

GSMaP_Gauge

# System Model of the GSMaP_Gauge product

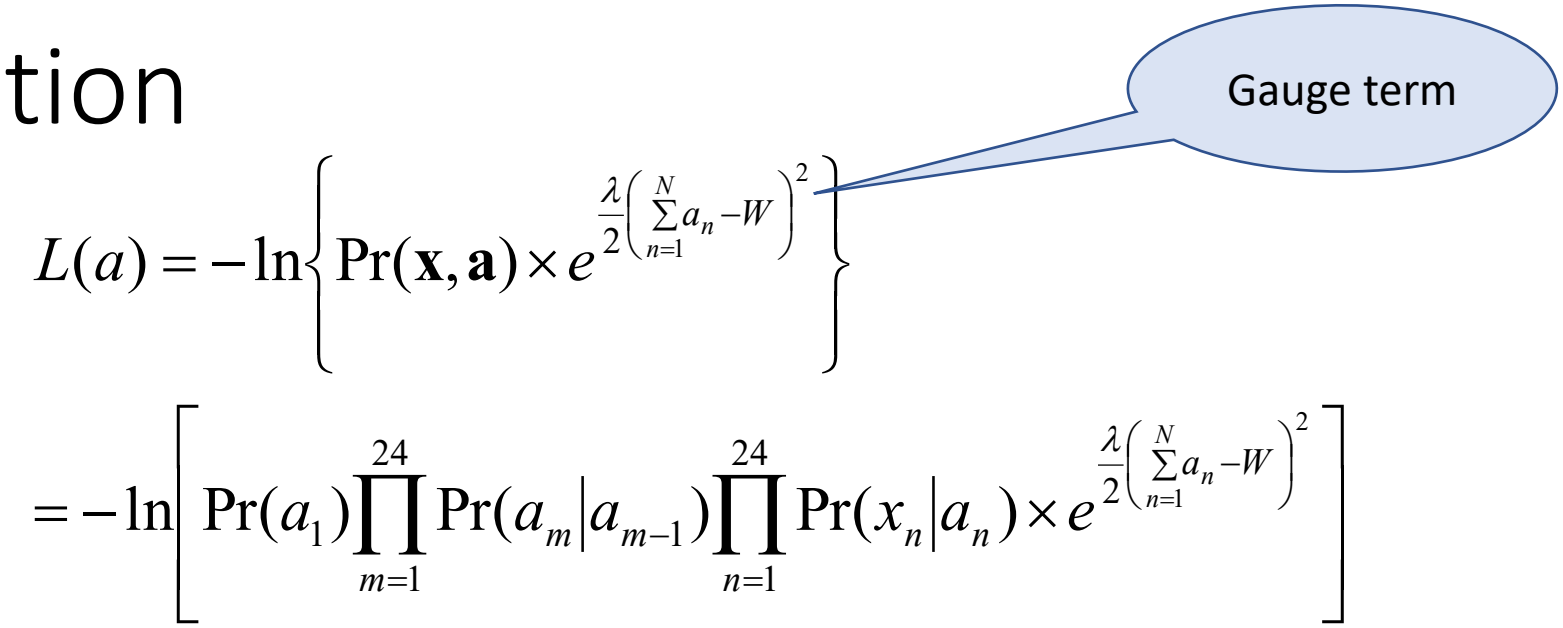
$$\begin{cases} a_{n+1} = a_n + w_n \\ x_n = \alpha a_n + v_n \\ \sum_{n=1}^{24} a_n = R \\ w_n \approx N\left(\mu_w, \sigma_w^2\right) v_n \approx N\left(\mu_v, \sigma_v^2\right) \end{cases}$$

$a_n$: GSMaP_Gauge
$x_n$: GSMaP_MVK
$n$: time
$R$: Gauge data

Based on this system model, the optimal solution for GSMaP_Gauge is derived by minimizing the cost function.

Mega, T., T. Ushio, T. Matsuda, T. Kubota, M. Kachi, and R. Oki, Gauge-Adjusted Global Satellite Mapping of Precipitation (GSMaP_Gauge), *IEEE. Trans. Geosci. Remote. Sens.*, 57, 4, DOI: 10.1109/TGRS.2018.2870199, 2019

# Cost Function




- In a word, based on the assumption that the GSMaP_Gauge – CPC Gauge data (Gauge term) has the gaussian distribution, we maximize the probability density function of the GSMaP_Gauge estimation multiplied by the Gauge term.

- The solution can be determined by calculating the dL/da = 0 equation

# GSMaP Family

## *We provide various kind of GSMaP for various utilization purposes*

*Based on multi-satellites*

| GSMaP MVK (standard) | GSMaP NRT (near-realtime) | GSMaP NOW (realtime) |
|---|---|---|
| * 3-day latency<br>* past duration available since Jan 1998 | * 4-hour latency<br>* past duration available since Mar 2000 | * On quasi-realtime (a few minutes latency) |

*Gauge-adjusted using NOAA/CPC daily precipitation (Chen et al. 2008)*

| GSMaP Gauge (standard) | GSMaP Gauge NRT (near-realtime) | GSMaP Gauge NOW (realtime) |
|---|---|---|
| * 3-day latency<br>* past duration available since Jan 1998 | * 4-hour latency<br>* past duration available since Mar 2000 | * On quasi-realtime (a few minutes latency) |

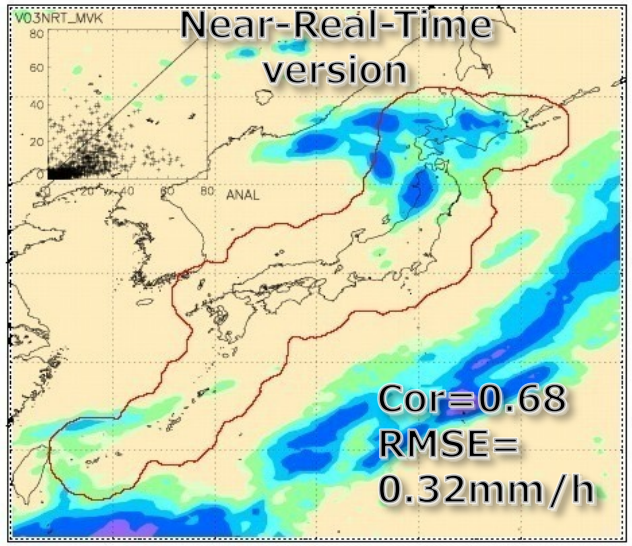

Expected Purposes

| | | |
|---|---|---|
| Long-term Analysis for climate, Agricultural monitor | Flood Analysis and/or prediction | Weather Realtime Monitoring |

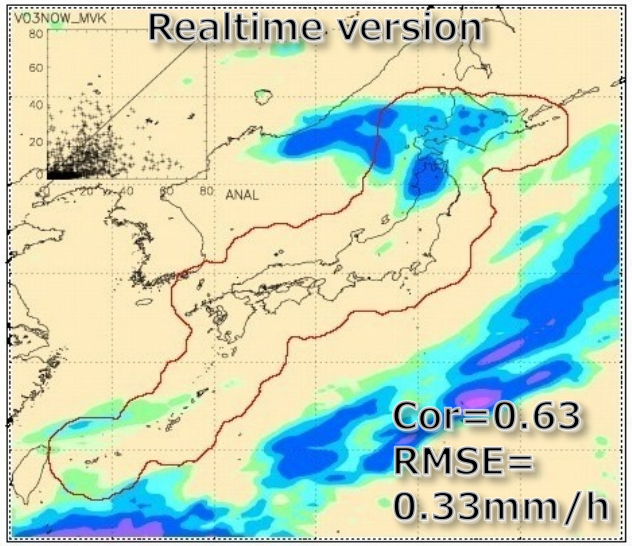
# Snapshots of Daily Validation

May. 27, 2017, in 0.25 degree grid and daily accumulation

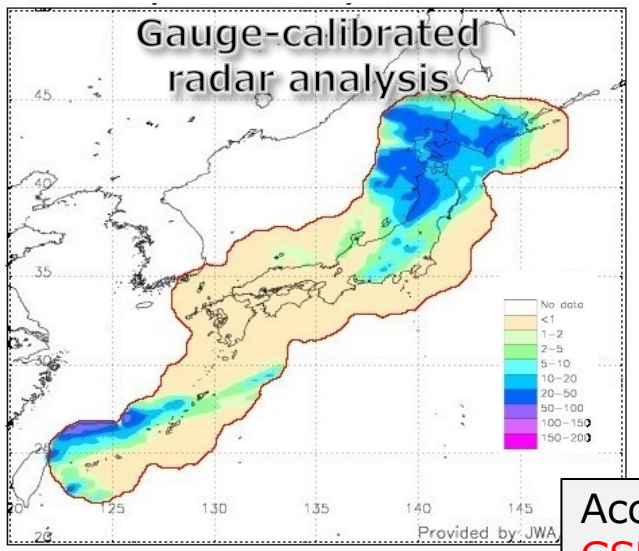
**GSMaP_NRT**



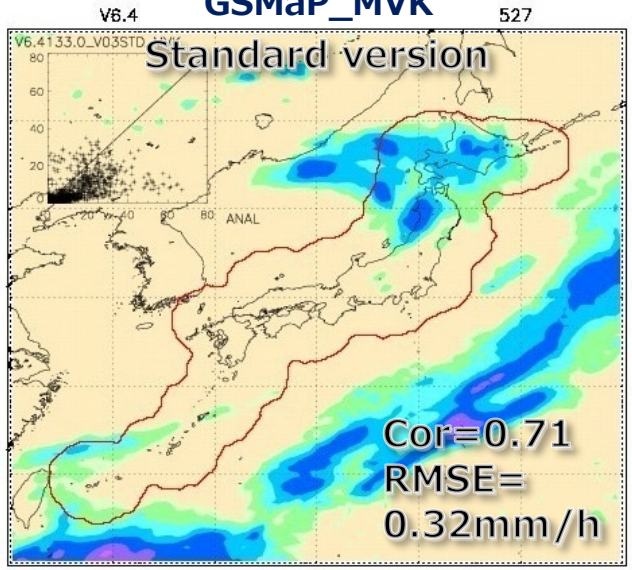

**GSMaP_NOW**



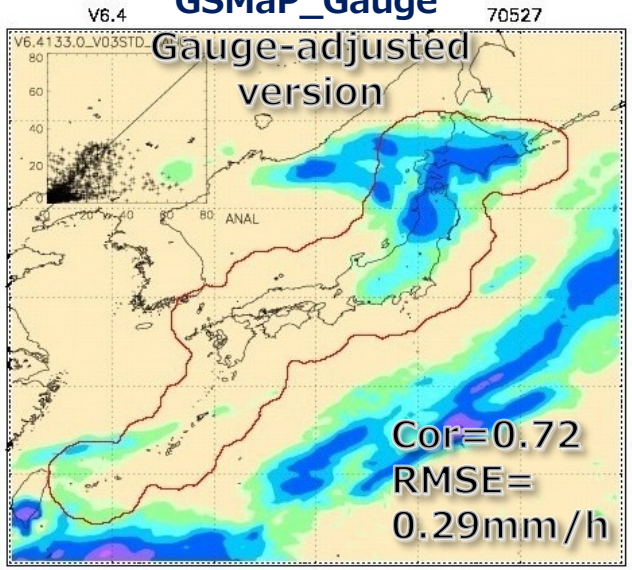

JMA's Radar-AMeDAS



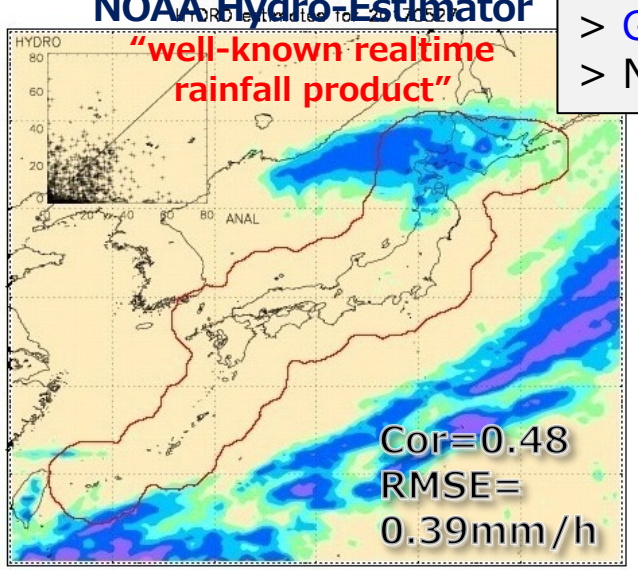

**GSMaP_MVK**




**GSMaP_Gauge**

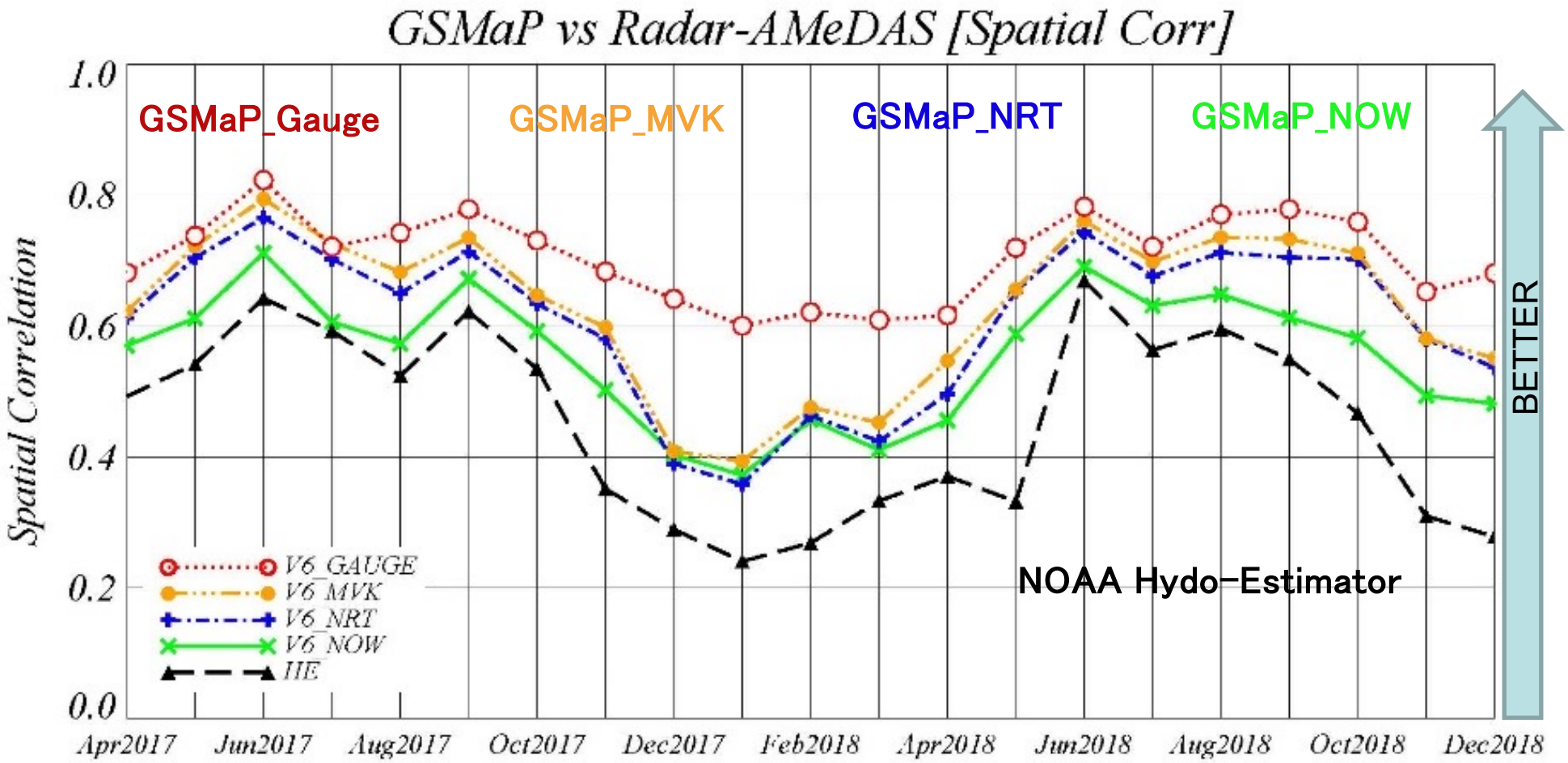



**NOAA Hydro-Estimator**




Accuracy over Japan is …
GSMaP_Gauge >GSMaP_MVK
> GSMaP_NRT > GSMaP_NOW
> NOAA H-E

# Snapshots of Daily Validation




Accuracy over Japan is …
GSMaP_Gauge >GSMaP_MVK
> GSMaP_NRT > GSMaP_NOW
> NOAA H-E

Accuracy varied seasonally around Japan, which suggested that the accuracy depends on some factors like precipitation amount and characteristics.

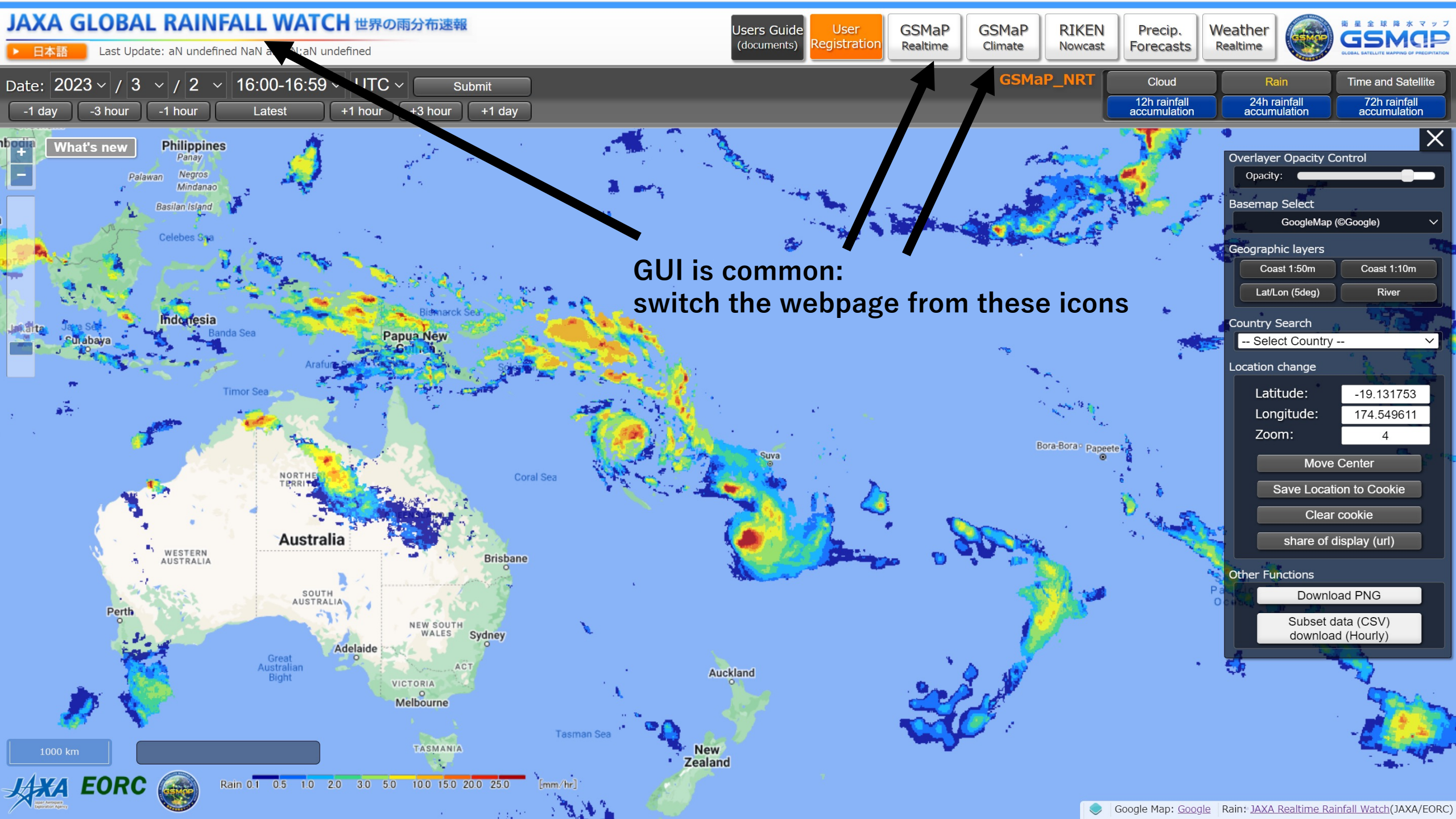
# GSMaP updates

- History of GSMaP major updates

| Date | Product version | Algorithm Version |
|---|---|---|
| Sep. 2014 | V03 | v6 |
| Jan. 2017 | V04 | v7 |
| Dec. 2021 | V05 | v8 |

  - A review paper of GPM-GSMaP V03 & V04: Kubota et al. (2020), https://doi.org/10.1007/978-3-030-24568-9_20

- GPM-GSMaP V05 (algorithm version 8) is available from:
  - G-Portal https://gportal.jaxa.jp/gpr/?lang=en
    HDF, Global-scale txt, NetCDF, GeoTiff format
  - JAXA Rainfall Watch https://sharaku.eorc.jaxa.jp/GSMaP/index.htm
    Binary, region-subset txt, NetCDF format


JAXA GLOBAL RAINFALL WATCH 世界の雨分布速報
日本語
Last Update: aN undefined NaN a :aN undefined
Users Guide (documents)
User Registration
GSMaP Realtime
GSMaP Climate
RIKEN Nowcast
Precip. Forecasts
Weather Realtime
GSMaP
Date: 2023 / 3 / 2 16:00-16:59 UTC Submit
-1 day
-3 hour
-1 hour
Latest
+1 hour
+3 hour
+1 day
GSMaP_NRT
Cloud
Rain
Time and Satellite
12h rainfall accumulation
24h rainfall accumulation
72h rainfall accumulation
What's new
GUI is common:
switch the webpage from these icons
Overlayer Opacity Control
Opacity:
Basemap Select
GoogleMap (©Google)
Geographic layers
Coast 1:50m
Coast 1:10m
Lat/Lon (5deg)
River
Country Search
-- Select Country --
Location change
Latitude: -19.131753
Longitude: 174.549611
Zoom: 4
Move Center
Save Location to Cookie
Clear cookie
share of display (url)
Other Functions
Download PNG
Subset data (CSV) download (Hourly)
Philippines
Indonesia
Papua New Guinea
Australia
Perth
Adelaide
Brisbane
Sydney
Melbourne
Auckland
New Zealand
Suva
Bora-Bora
Papeete
Coral Sea
Tasman Sea
Timor Sea
Banda Sea
Bismarck Sea
Celebes Sea
Basilan Island
Palawan
Panay
Negros
Mindanao
Surabaya
Jakarta
WESTERN AUSTRALIA
SOUTH AUSTRALIA
NEW SOUTH WALES
VICTORIA
ACT
TASMANIA
Great Australian Bight
1000 km
Rain 0.1 0.5 1.0 2.0 3.0 5.0 10.0 15.0 20.0 25.0 [mm/hr]
JAXA EORC
Google Map: Google
Rain: JAXA Realtime Rainfall Watch(JAXA/EORC)

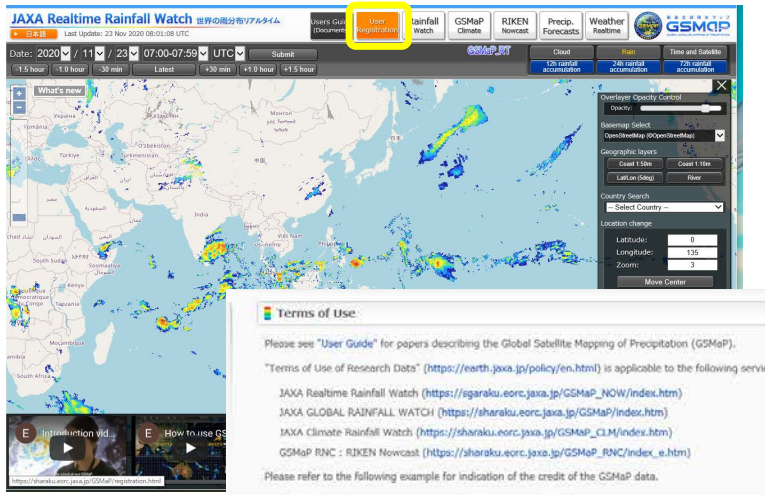
# GSMaP data distribution for analysis

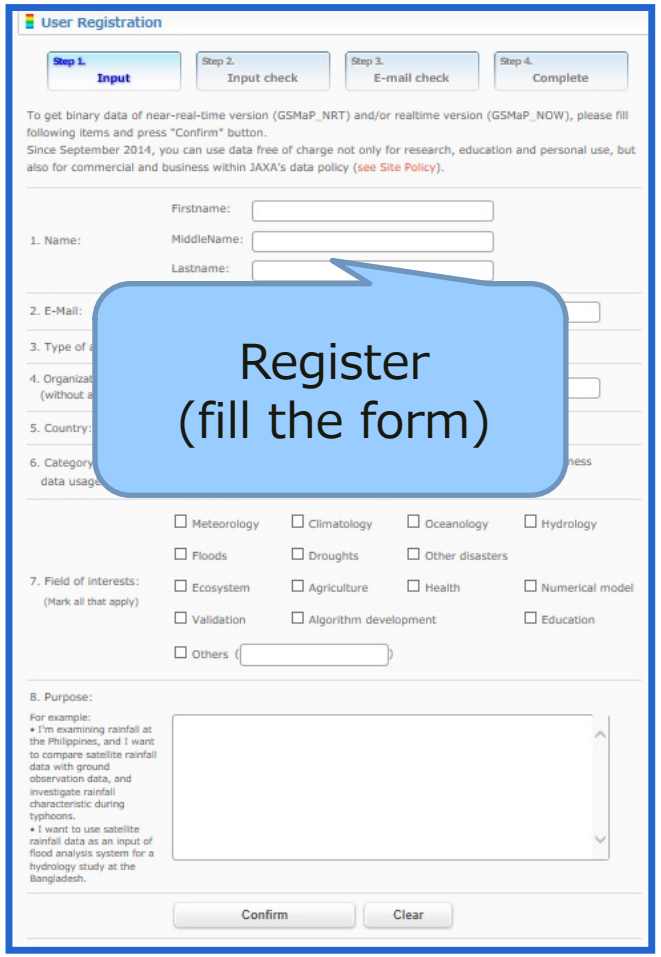
Click here

User Registration

You can download the data after user registration (free of charge).

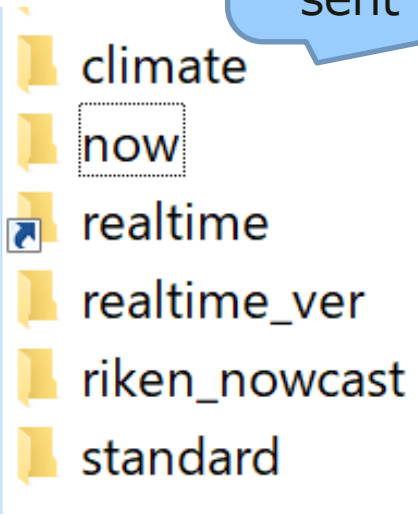
https://sharaku.eorc.jaxa.jp/GSMaP/registration.html




Register
(fill the form)

Ftp server information will be sent via email




Data specifications are explained in the documents.

https://sharaku.eorc.jaxa.jp/GSMaP/faq/GSMaP_faq18.html

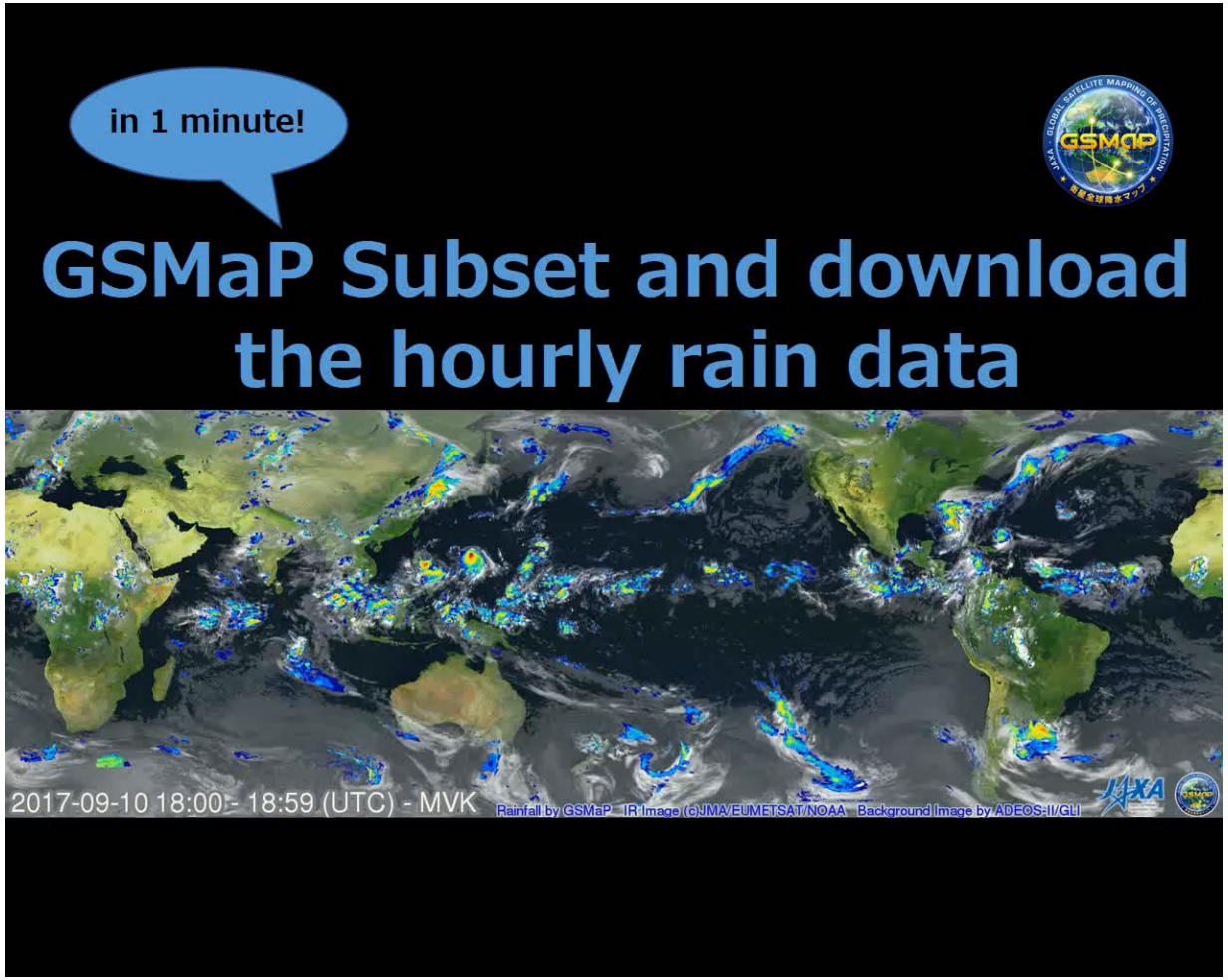
You can download 25 years precipitation data at once from FTP server.

# GSMaP websites

**How to use GSMaP website in 1 minute!**


https://youtu.be/0JanK-fZMt4

**GSMaP subset and download hourly rain data in 1 minute!**




https://youtu.be/VnxH7inZh6g

# Summary

- GSMaP is the **multi-satellite product** by combining passive microwave radiometers, IR imagers, and precipitation radars.
- GSMaP consists of some products, **realtime, near-realtime, standard and their gauge-adjusted versions**.
- Users can select the appropriate product according to their purposes, and the GSMaP products are widely used for various fields.
- We distribute the data or image via website and ftpsite and users can freely access to the data.