JST/CREST

R&D of Hydrological Modeling And Water Resources System

Production of High Precision and High Resolution Global Precipitation Map by Using Satellite-borne Microwave Radiometers

GSMaP (Global Satellite Mapping of Precipitation)

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  - Global Precipitation Map
  - Observation of Global Precipitation from Satellite
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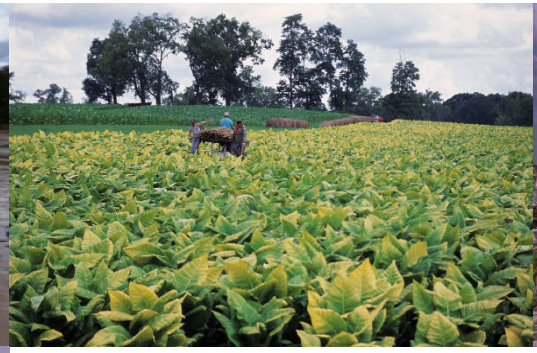
    - Ground Radar Observation
    - Precipitation Physical Model
    - Rain Rate Retrieval Algorithm
    - Evaluation of the GSMaP Products
- Summary and Future Plans

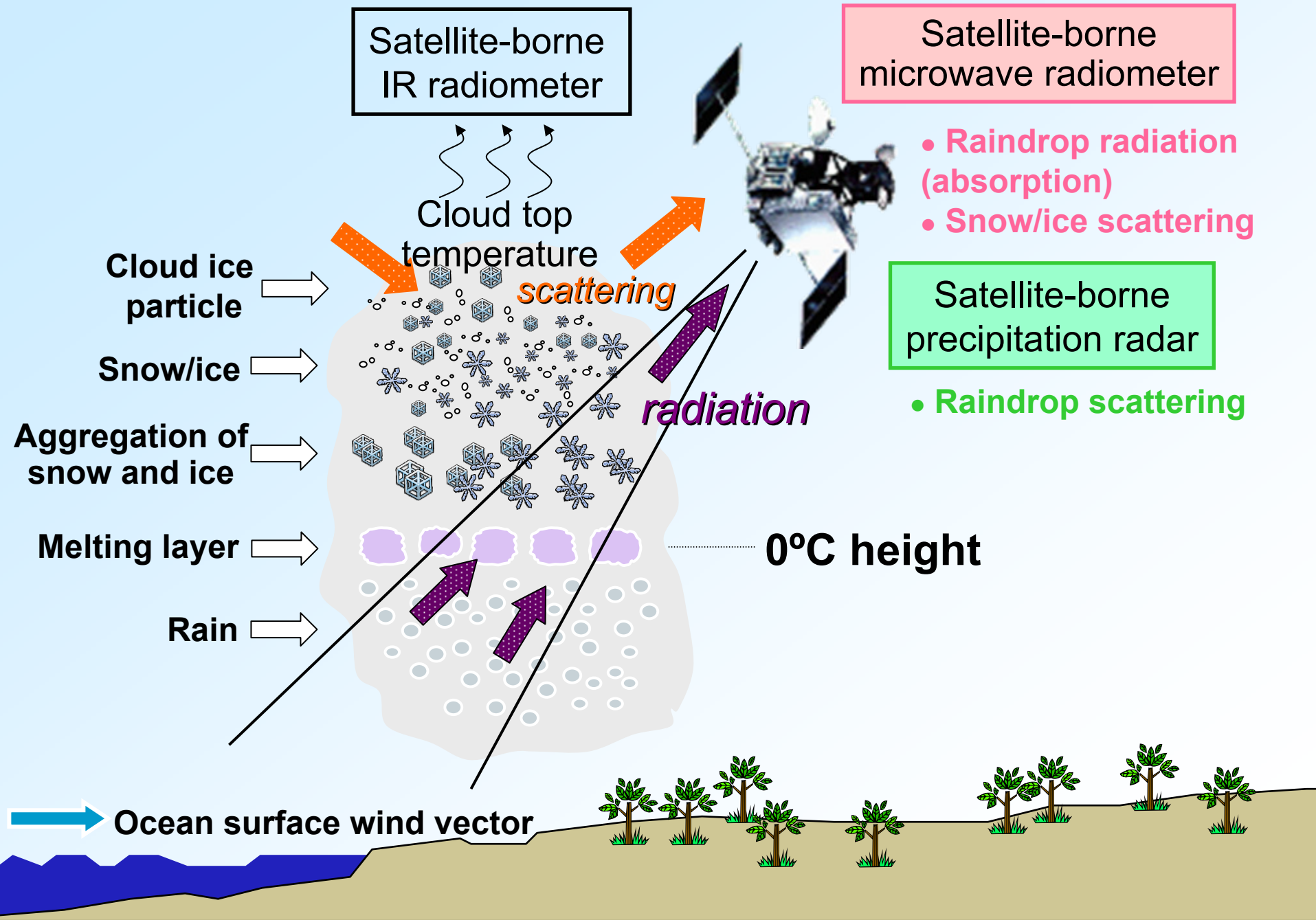
Production of High-Precision and High-Resolution Global Precipitation Map


- Global water circulation model building
- Research on global warming and climate changes
  - Monitor the variation in rain rates and raining area caused by climate changes
- Accuracy improvement of weather forecast
  - Utilization of the quasi-real time numerical forecast model
- Management of water resources
  - Flood forecasting, River management, Dam pondage management, Agricultural water securement
- Prediction of agricultural productivity

Rain Observation Using a Satellite?

Observation of Precipitation from the Satellite



Observations of Rain by Satellite-borne Rain Sensors

(Heavy Rainfalls over Ocean Observed by TRMM, South of Kyusyu)

(a) Precipitation Radar:

Backscattering by rain drops, very accurate but narrow swath

(b) IR radiometer:

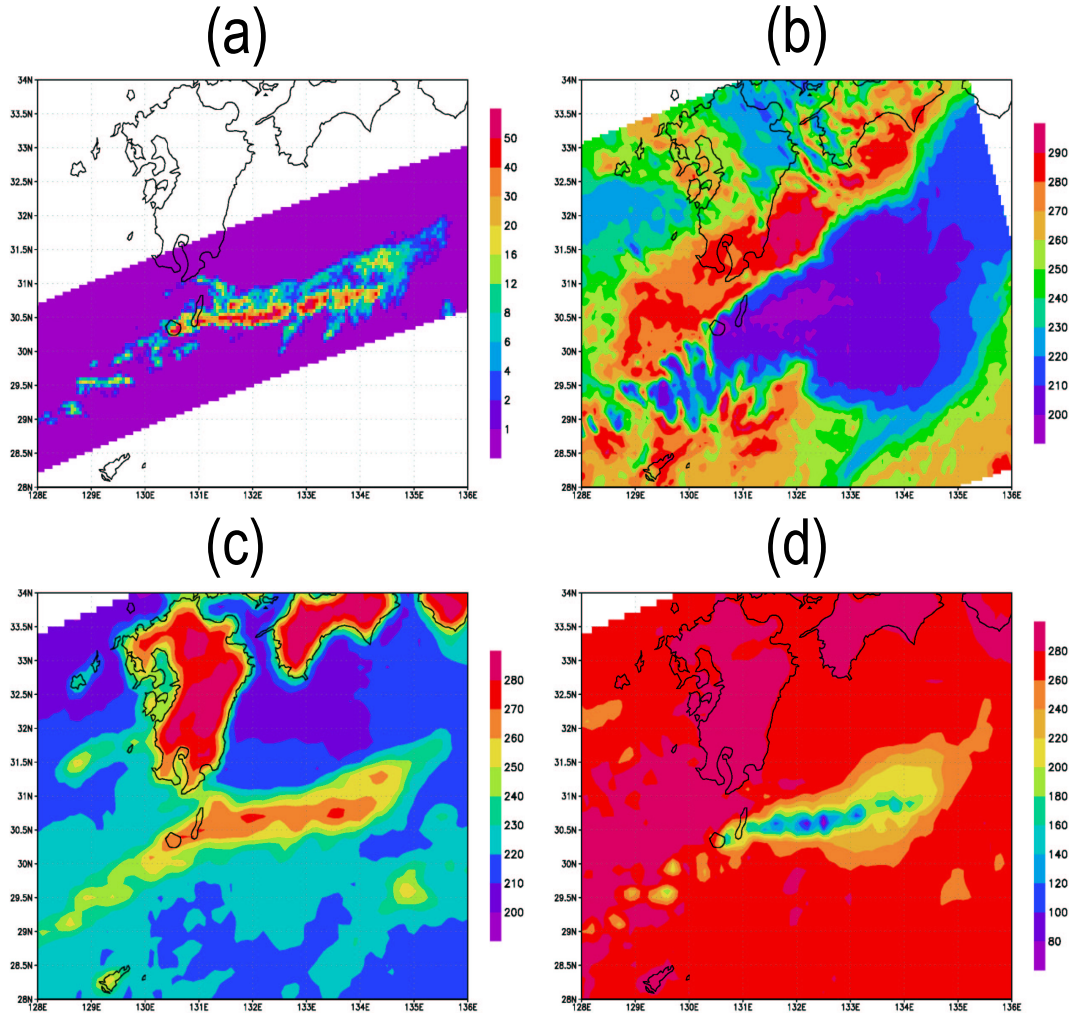
Cloud top temperature (small correlation with rain)

(c) Microwave Radiometer (19GHz):

(d) Microwave Radiometer (85GHz):

Over ocean --- accumulation of radiation of rain drop and scattering of snow/ice particles

Over land --- accumulation of scattering of snow/ice particles



Satellites with Microwave Radiometers

With the high observation frequency, microwave radiometers will be the main sensor to produce global precipitation maps.

TRMM
TMI
Precipitation Radar

Aqua
AMSR-E

ADEOS-II
AMSR

DMSP
SSM/I

Satellites with microwave radiometers used in the GSMaP

Main Satellite
Dual frequency precipitation radar (DPR)
Microwave Radiometer

Sub-satellites (8)
Microwave radiometers

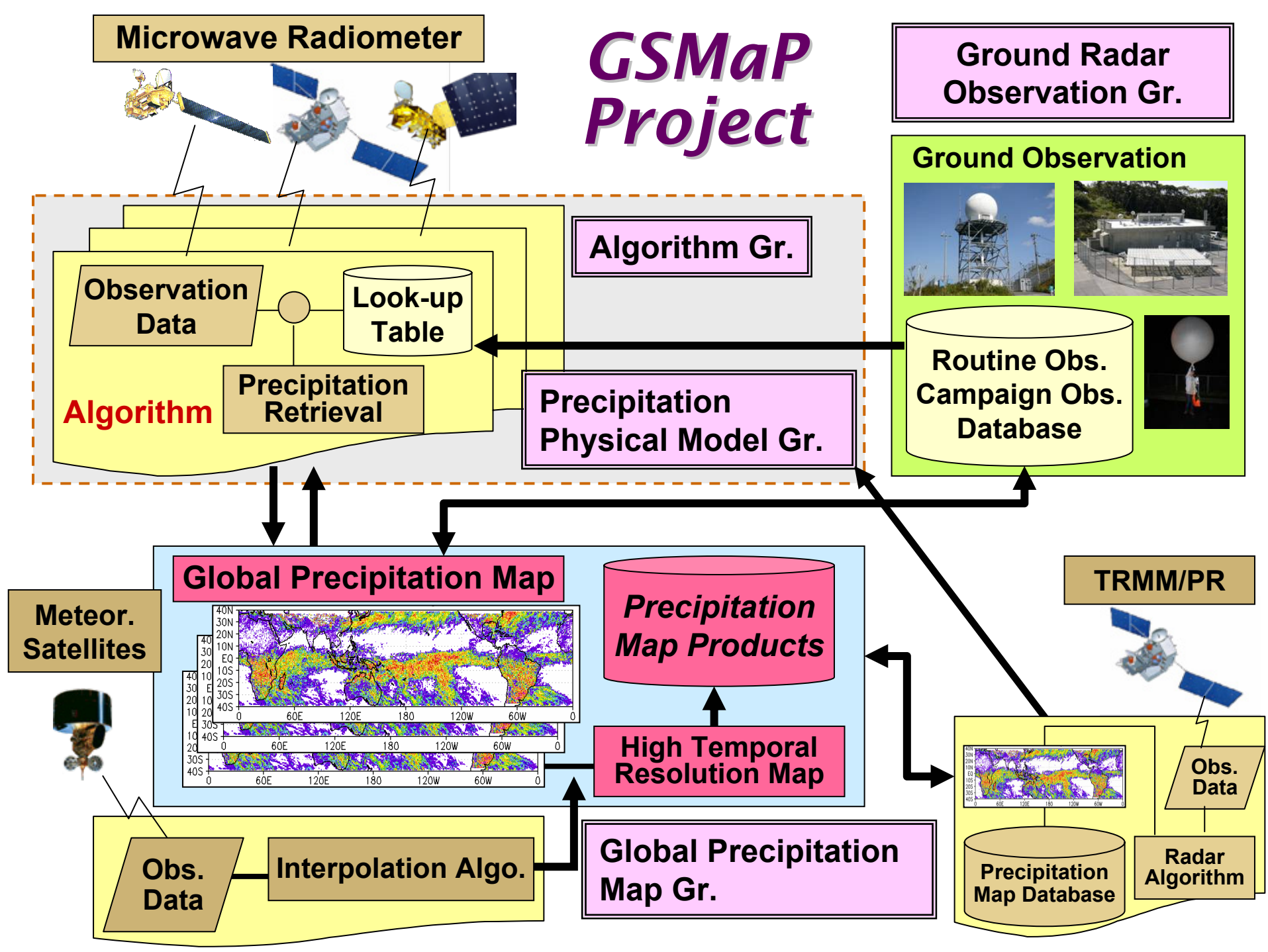
Concept of the GPM : Global Precipitation Measurement Mission (2010-)

Goals of the Research

- Production of high precision and high resolution global precipitation map by using satellite-borne microwave radiometers.
  - e.g. spatial resolution:0.1º × 0.1º, temporal resolution:1 day
  - Microwave radiometers (TMI, AMSR-E, SSM/I × 3)
  - Precipitation radar, GEO's visible and IR radiometers

Goals of the Research

- Development of reliable microwave radiometer algorithm
  - Based on the common physical precipitation model that precipitation radar also uses.
- Precipitation map production technique for the coming GPM (Global Precipitation Measurement) satellite around 2010.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Routine Obs. Campaign Obs. Database
Global Precipitation Map
Precipitation Map Products
Meteor. Satellites
TRMM/PR
High Temporal Resolution Map
Obs. Data
Interpolation Algo.
Global Precipitation Map Gr.
Obs. Data
Radar Algorithm
Precipitation Map Database

Composition of GSMaP Products

TRMM
TMI

Aqua
AMSR-E

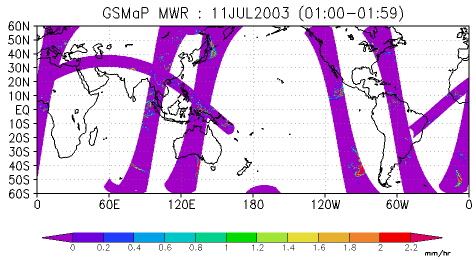
ADEOS-II
AMSR

DMSP
SSM/I

GSMaP
Microwave Radiometer Algorithms

Rain rates retrieved by each satellite microwave radiometer

Geostationary Satellite



1-hour data by TRMM/TMI, Aqua/AMSR-E, ADEOS-II/AMSR, DMSP/SSMI (F13, 14, 15)

Combination

Motion Vector
Kalman filtering

GSMaP_MWR

Combined Product
0.25° grid

- 6 hours
- 1 day
- 1 month

GSMaP_MV
GSMaP_MVK

Combined IR/MWR Products
0.1° grid·hourly

Status of satellite-borne microwave radiometer data processed by GSMaP algorithm

Table1: Status of each satellite data

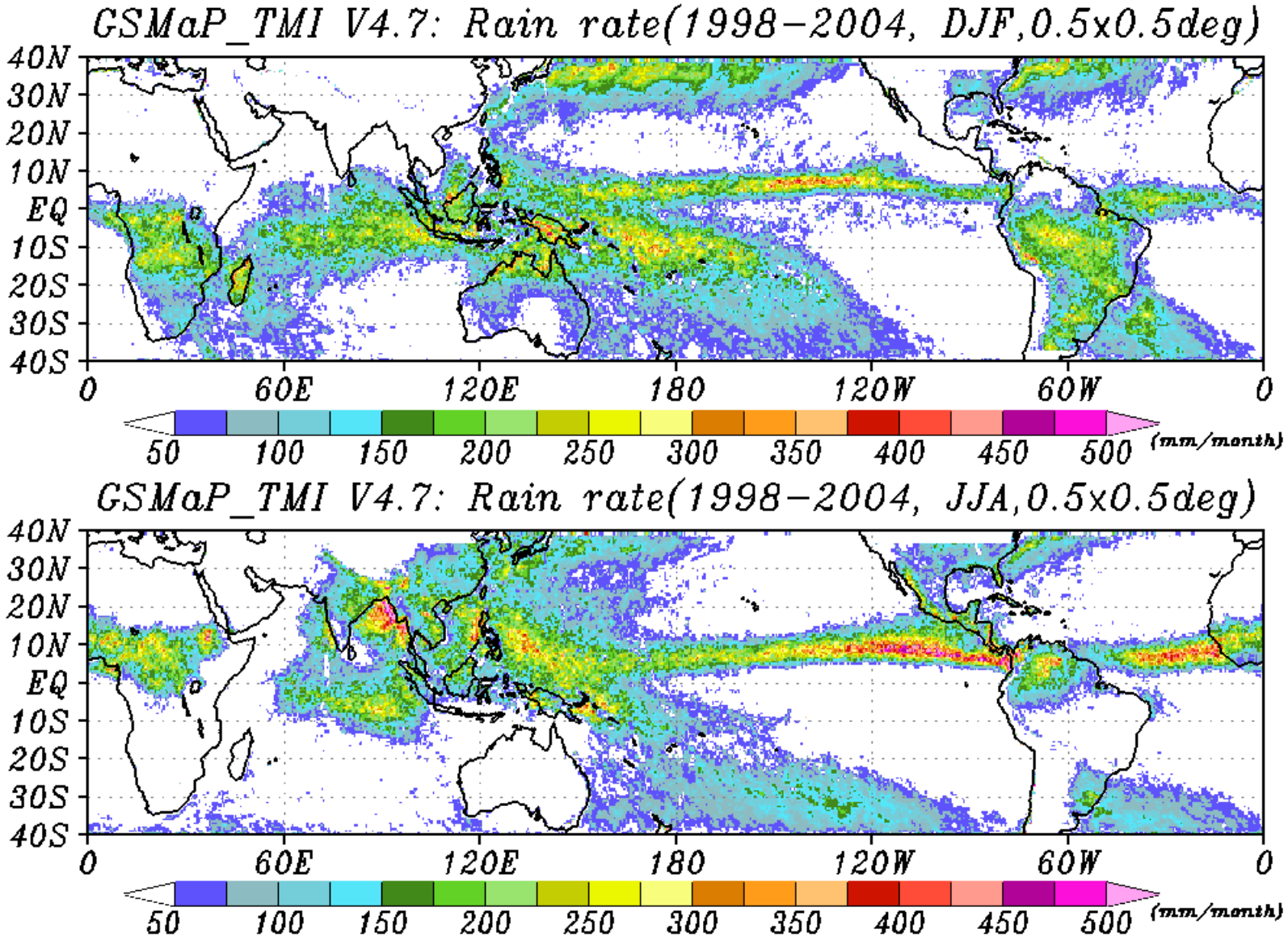
Satellite (Sensor)	Processed period	Features
TRMM（TMI）	Jan 1998-Dec 2005	Ver.4.7.2
Aqua（AMSR-E）	Jan 2003-Dec 2005	Ver.4.7.2
ADEOS-II（AMSR）	Apr 2003-Oct 2003	the same as above
DMSP F13, F14, F15（SSM/I）	Jan 2003-Dec 2005	the same as above

Table2: Status of each products

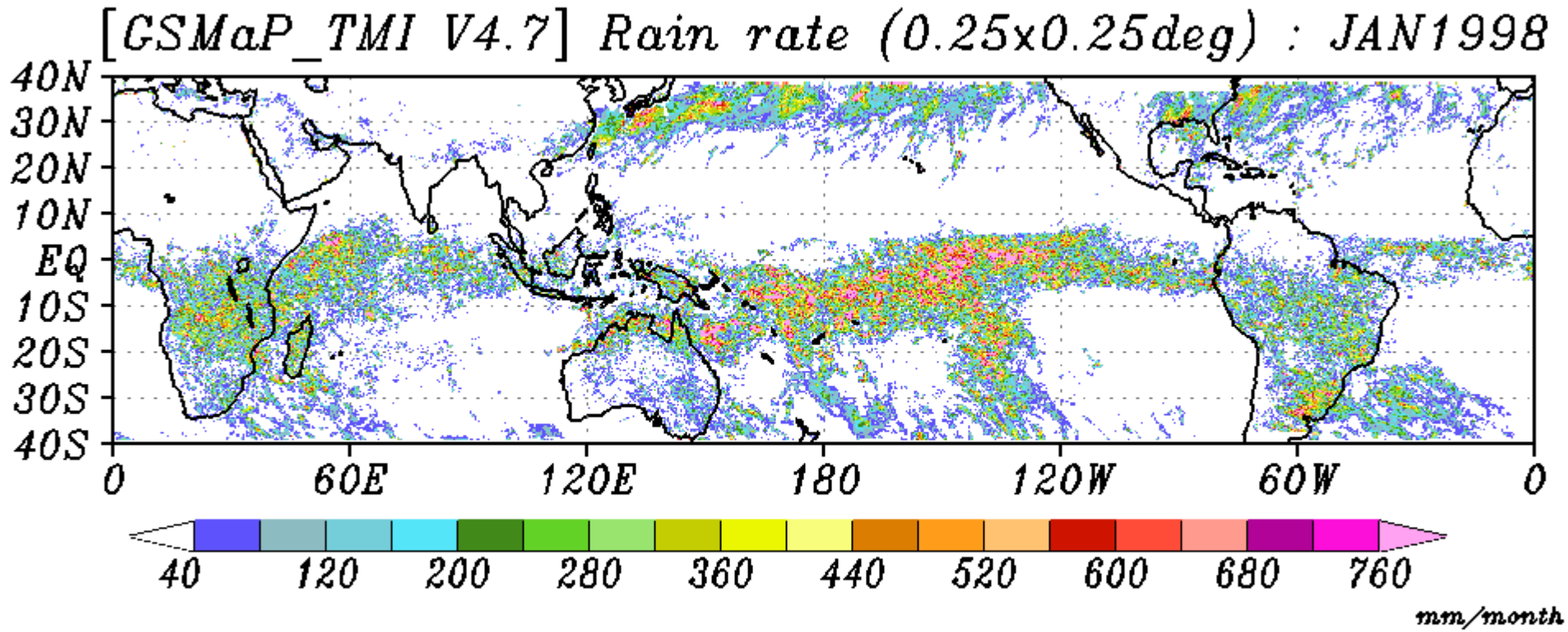
Spatial resolution	Time resolution	Archives	Data source
0.1 degrees	hourly	July 2005	Combined microwave radiometers (TMI, AMSR-E, AMSR, SSM/I × 3) (Latitude ±60º)
0.25 degrees	Various*	Jan 2003-Dec 2005	Combined TMI and AMSR-E (AMSR added from April 2003-October 2003) (Latitude ±60º)
0.25 degrees	Various*	Jan 1998-Dec 2005	TMI (Latitude ±40º)

Various (6-hourly, 1 day, 1 month)*

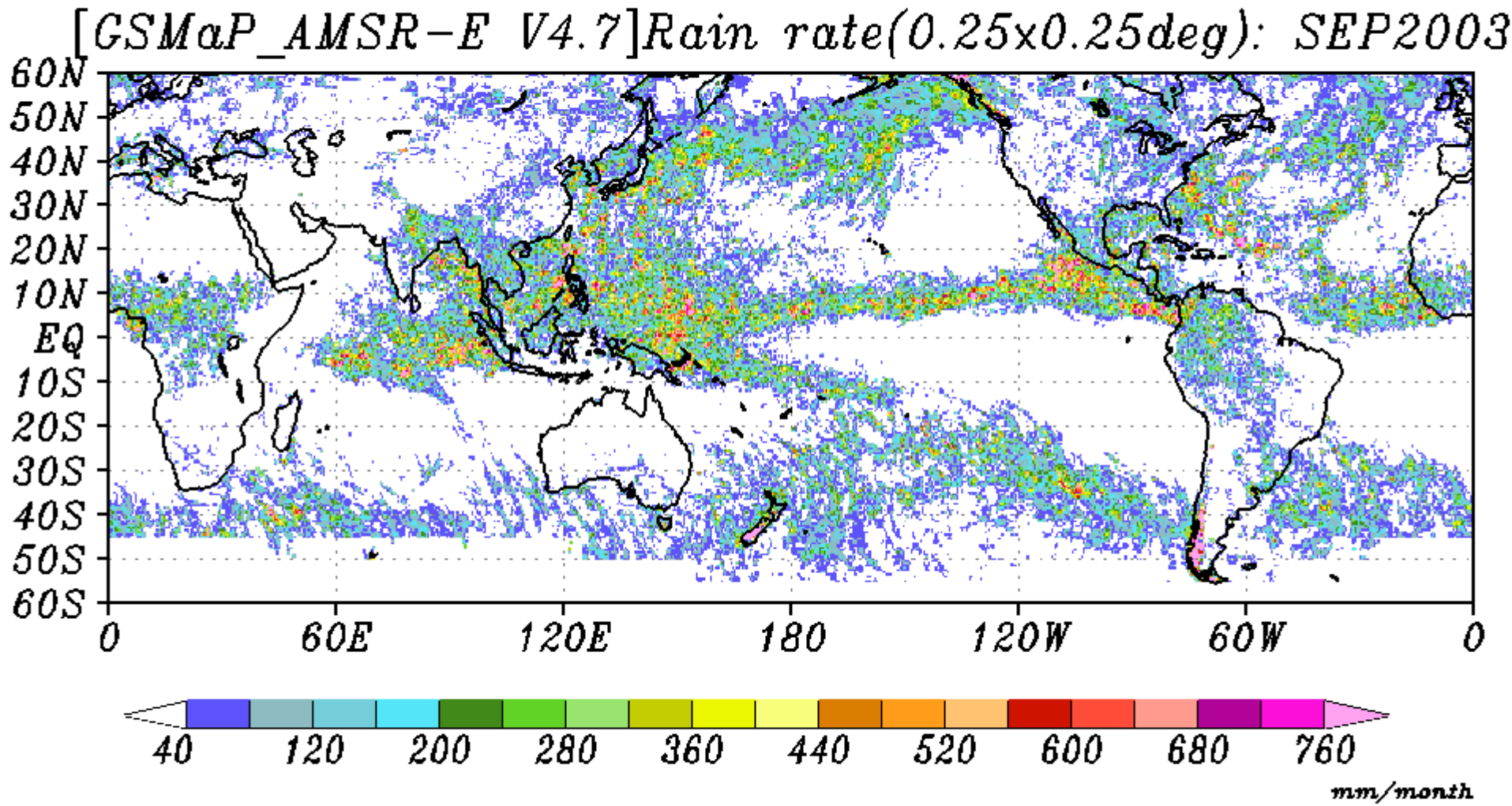
Global precipitation map observed by TMI (climatological rain rate: 1998-2004)



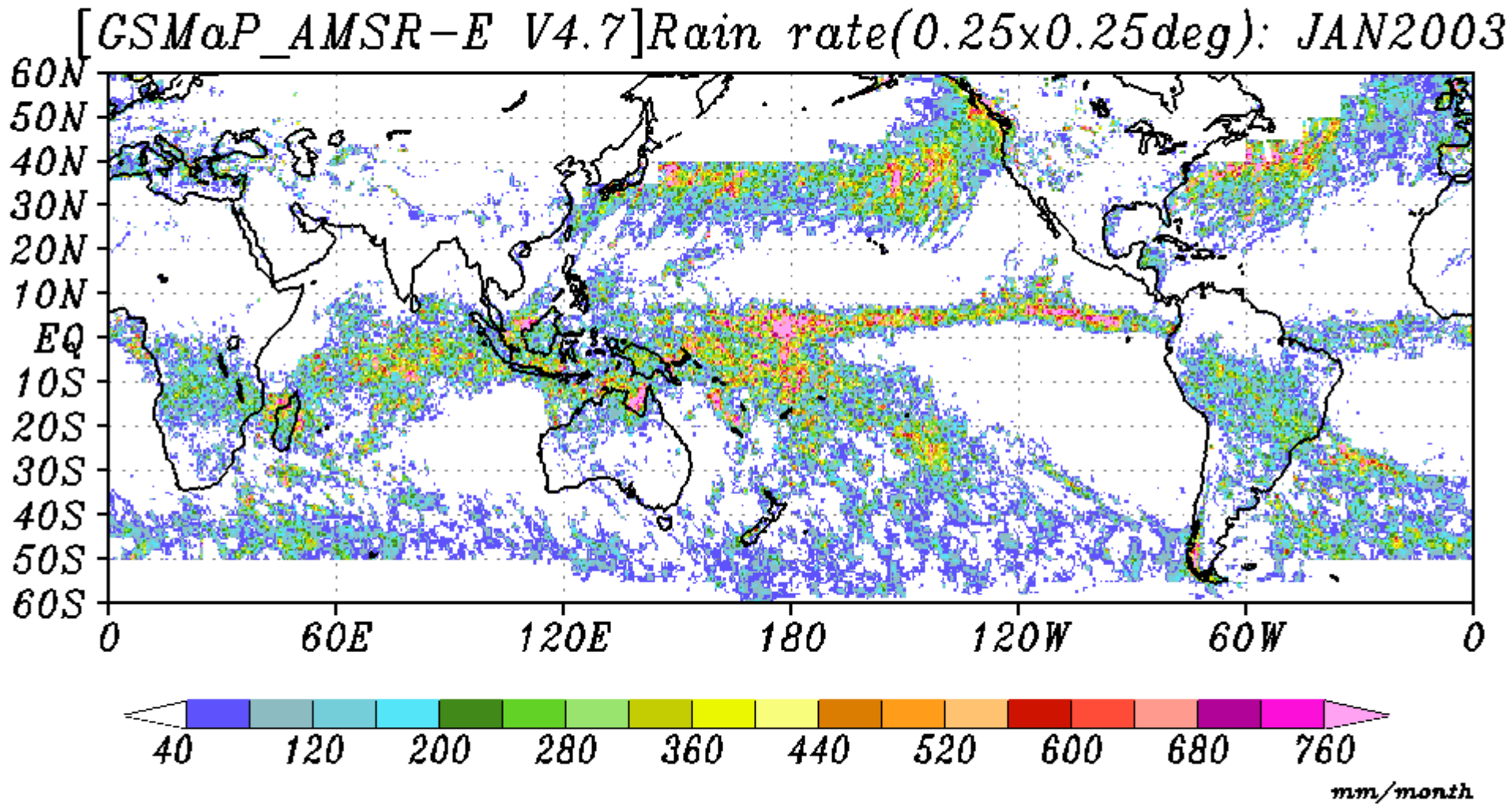
Global precipitation map observed by TMI
(monthly rain rate average: Jan 1998–Dec 2004)



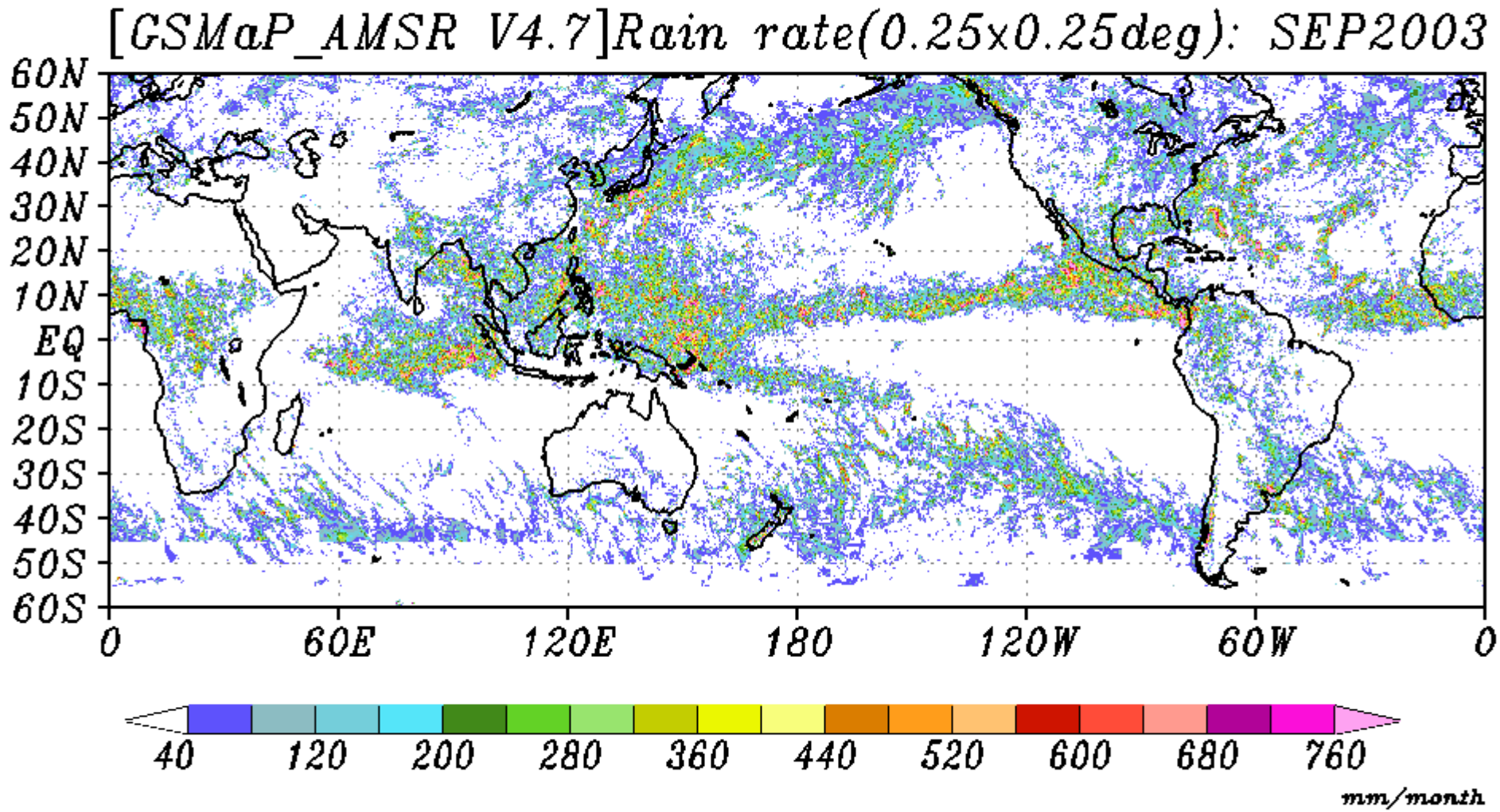
Global precipitation map observed by AMSR-E (monthly rain rate average: September 2003)



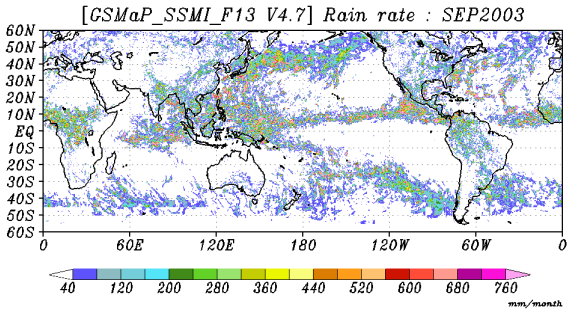
Global precipitation map observed by AMSR-E (monthly rain rate average: Jan 2003–Dec 2003)



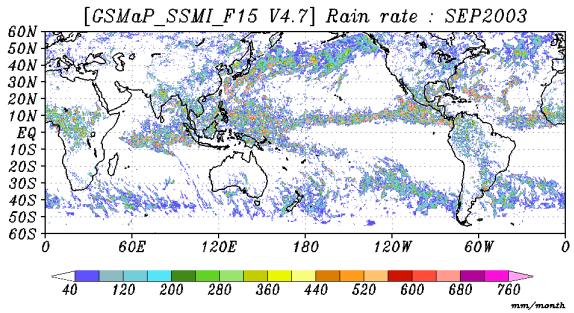
Global precipitation map observed by AMSR (monthly rain rate average: September 2003)



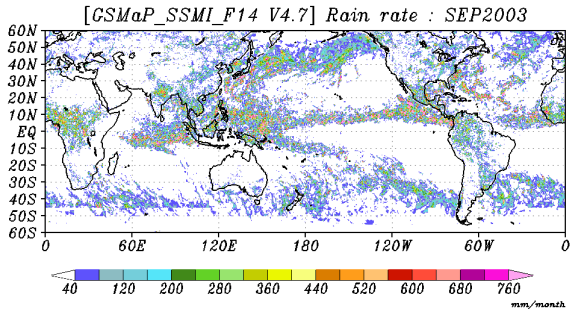
Global precipitation map observed by DMSP (F13, F14, F15)/SSM/I (monthly rain rate average: September 2003)



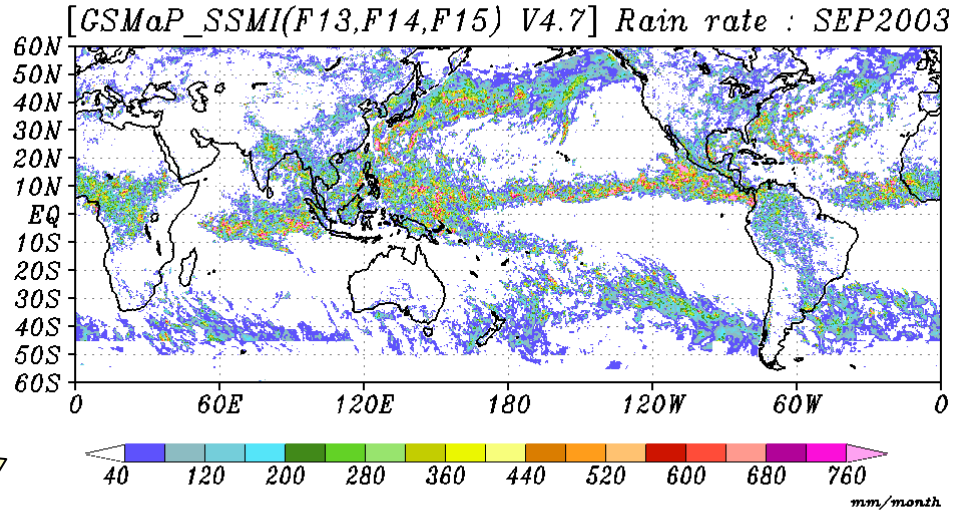
F13



F15

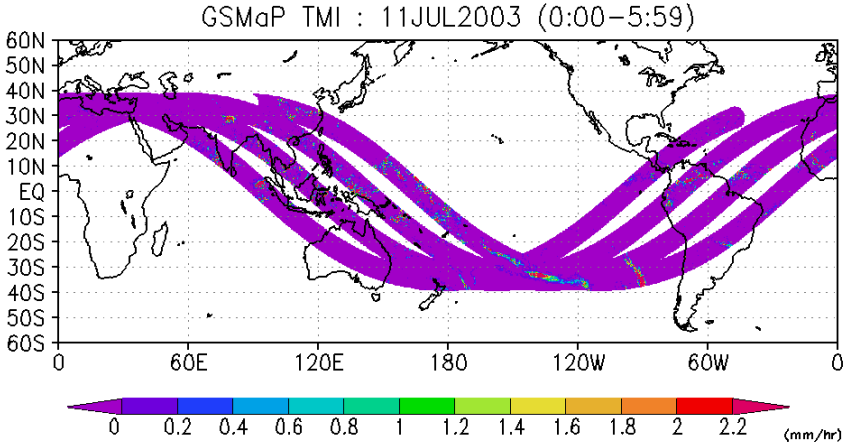


F14

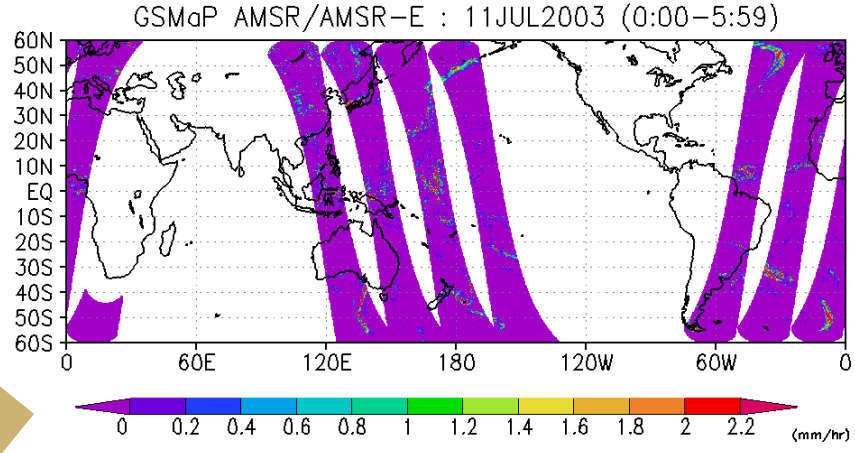


Example of combined global precipitation map of microwave radiometer data retrieved by TMI, AMSR-E, AMSR and SSM/I (DMSP F13, F14, F15) --- 6 hours

TMI

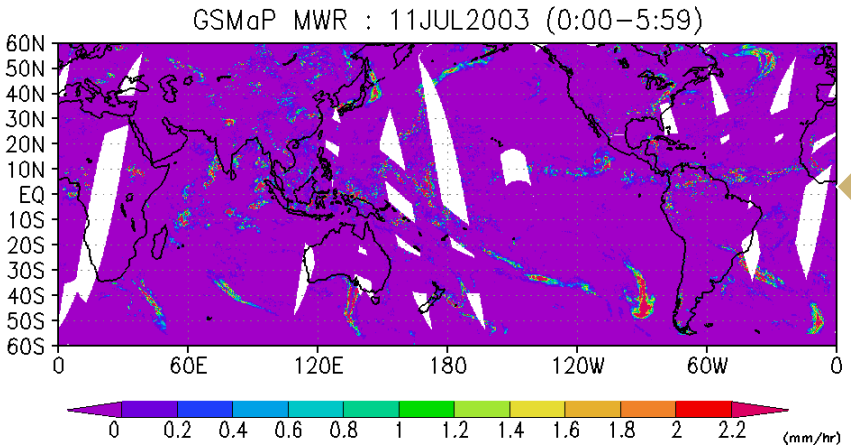


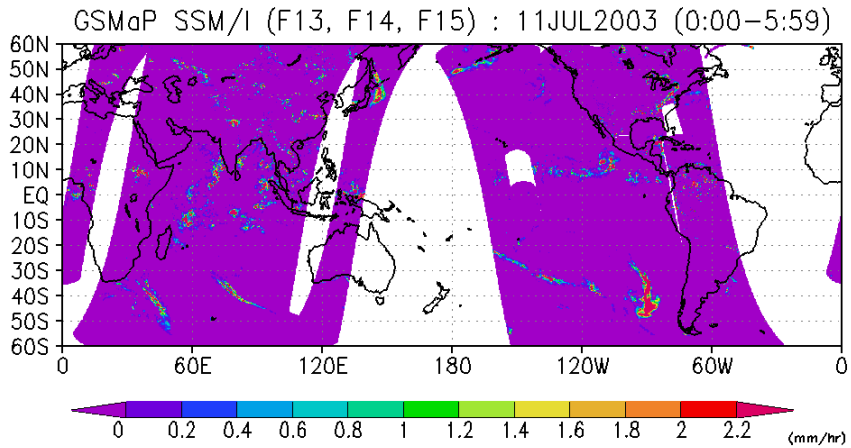
AMSR & AMSR-E



Combined Data (6 hours)

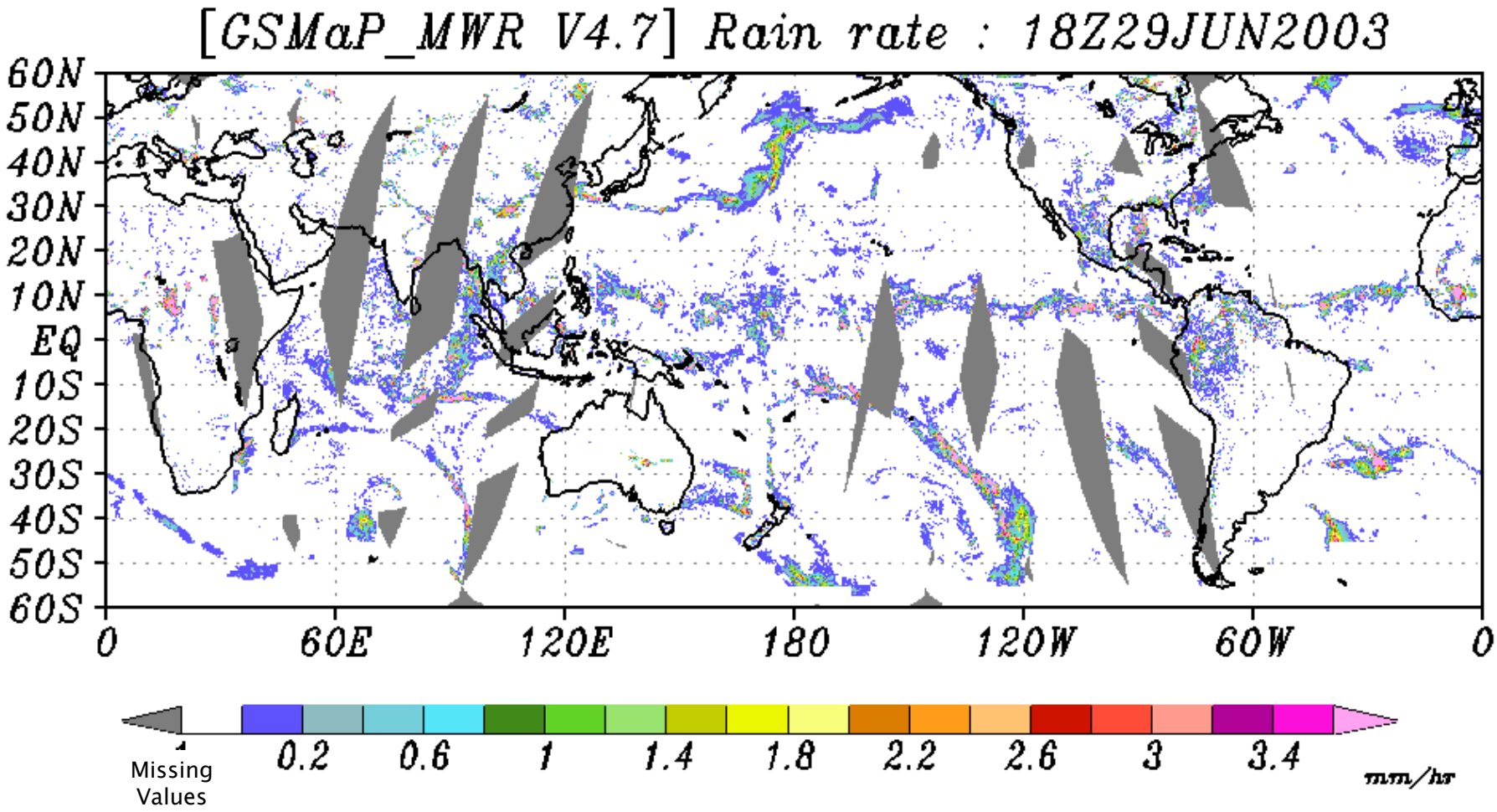
SSM/I（F13, F14, F15）





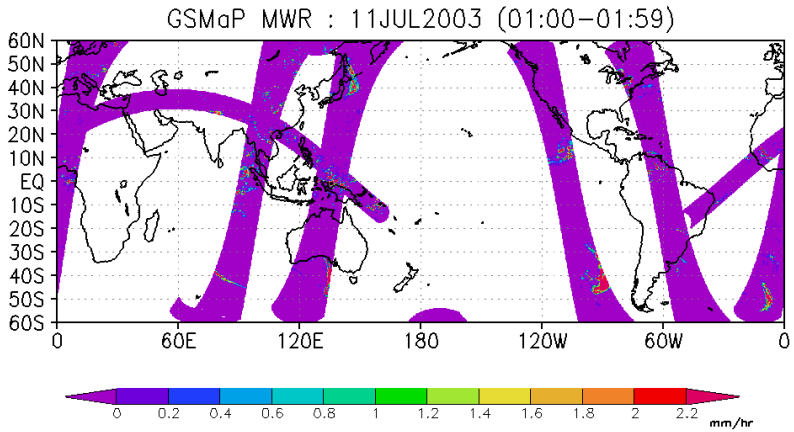
Integrated 6-hour Microwave radiometer Precipitation Map

(TMI+AMSR+AMSR-E+F13,F14,F15 SSM/I; Jul., 2003)



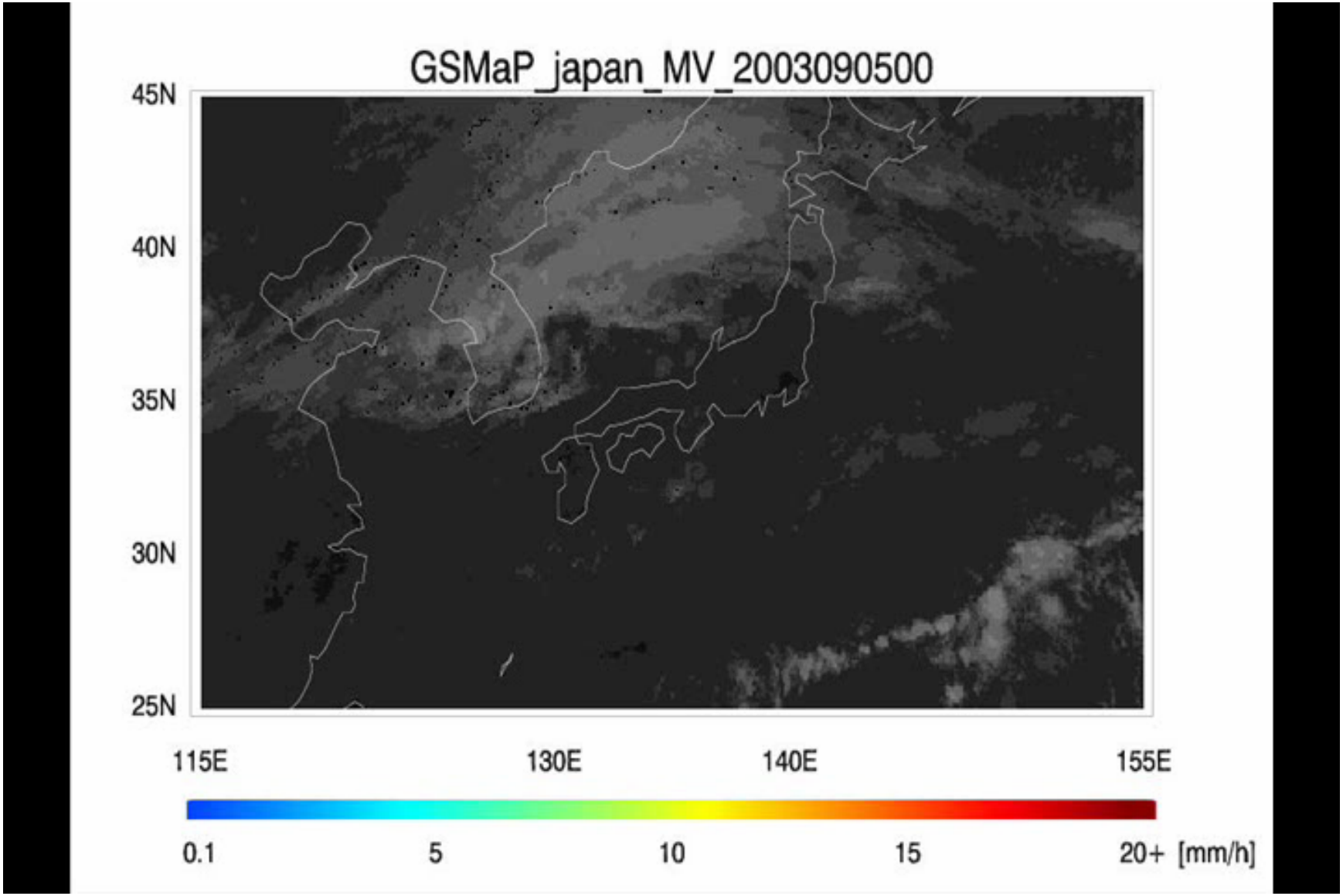
Need and Means of 1-hour Global Precipitation Map

- There are practical needs for much higher temporal and spatial resolution precipitation map.
- Integrated 1-hour resolution microwave radiometer precipitation map still has scattered gap areas.
- Data from other satellites are required to fill these gaps.



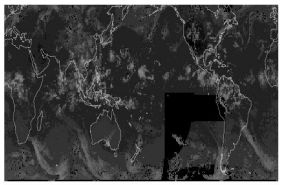
Integrated 1-hour resolution precipitation map by TRMM/TMI, Aqua/AMSR-E, ADEOS-II/AMSR, DMSP/SSMI (F13, 14, 15) data.

Example of GSMaP MV (0.1º, 1 hour, September 2003 around Japan)



Outline of GSMaP MV algorithm

Infrared (IR) Data



Present GEO IR data

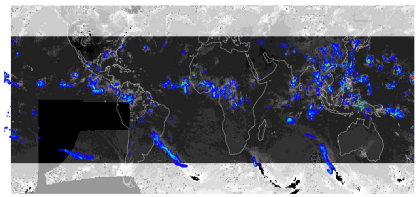
GEO data of 1 hour before

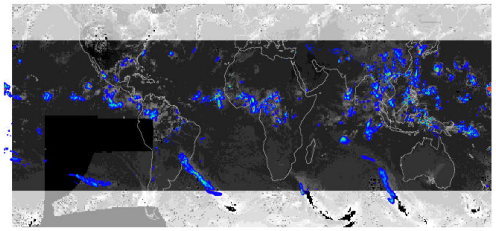
Cloud Motion Vector for 1 hour

We are developing estimates by Kalman filtering using IR data ("GSMaP MVK")

GSMaP MV

GSMaP MV of 1 hour before

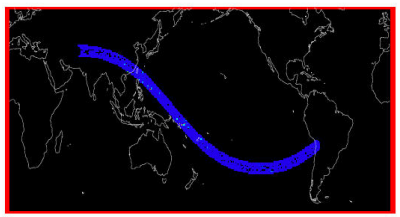




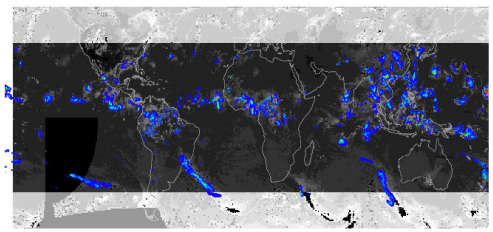
Intermediate map considering only cloud motion vector

Rain from Microwave Radiometer (MWR)

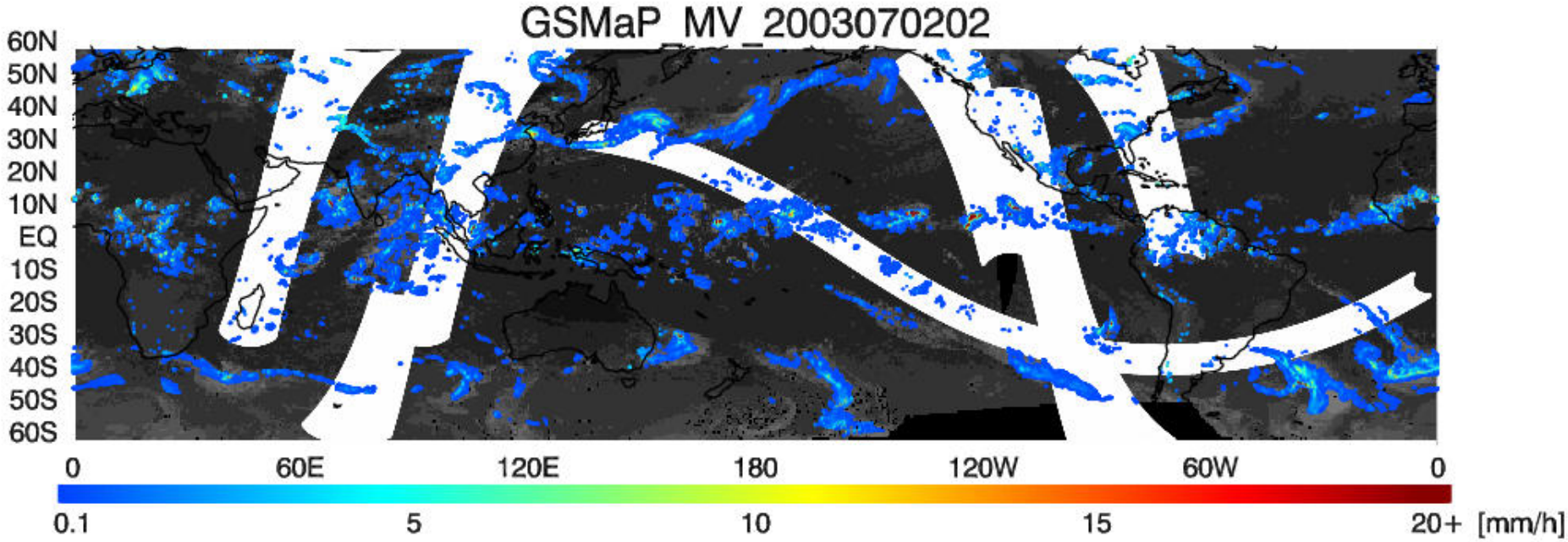
GSMaP MWR for past 1 hour



Present GSMaP MV



Global precipitation map of GSMaP MV (0.1degs., 1 hour : July 2003)



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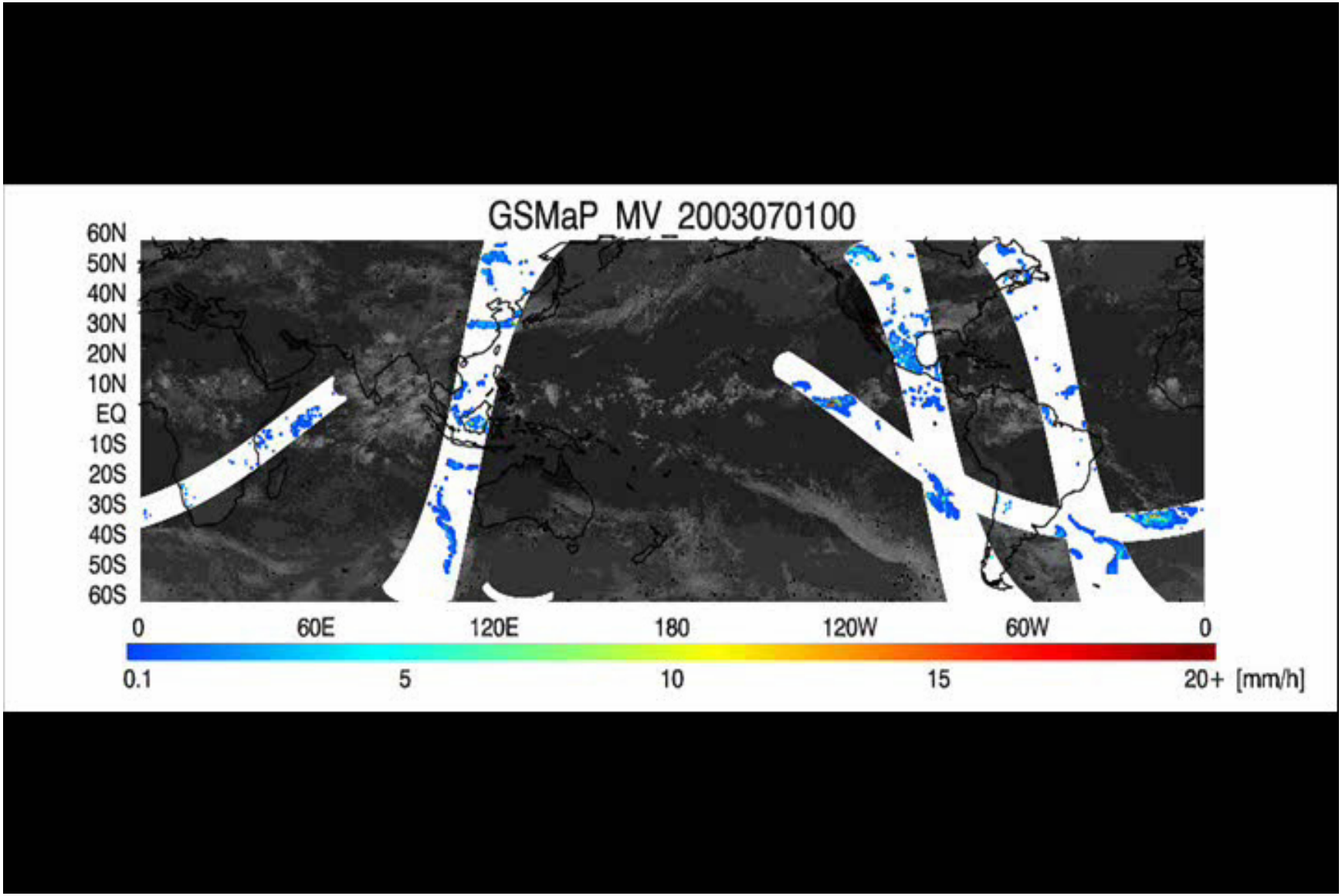
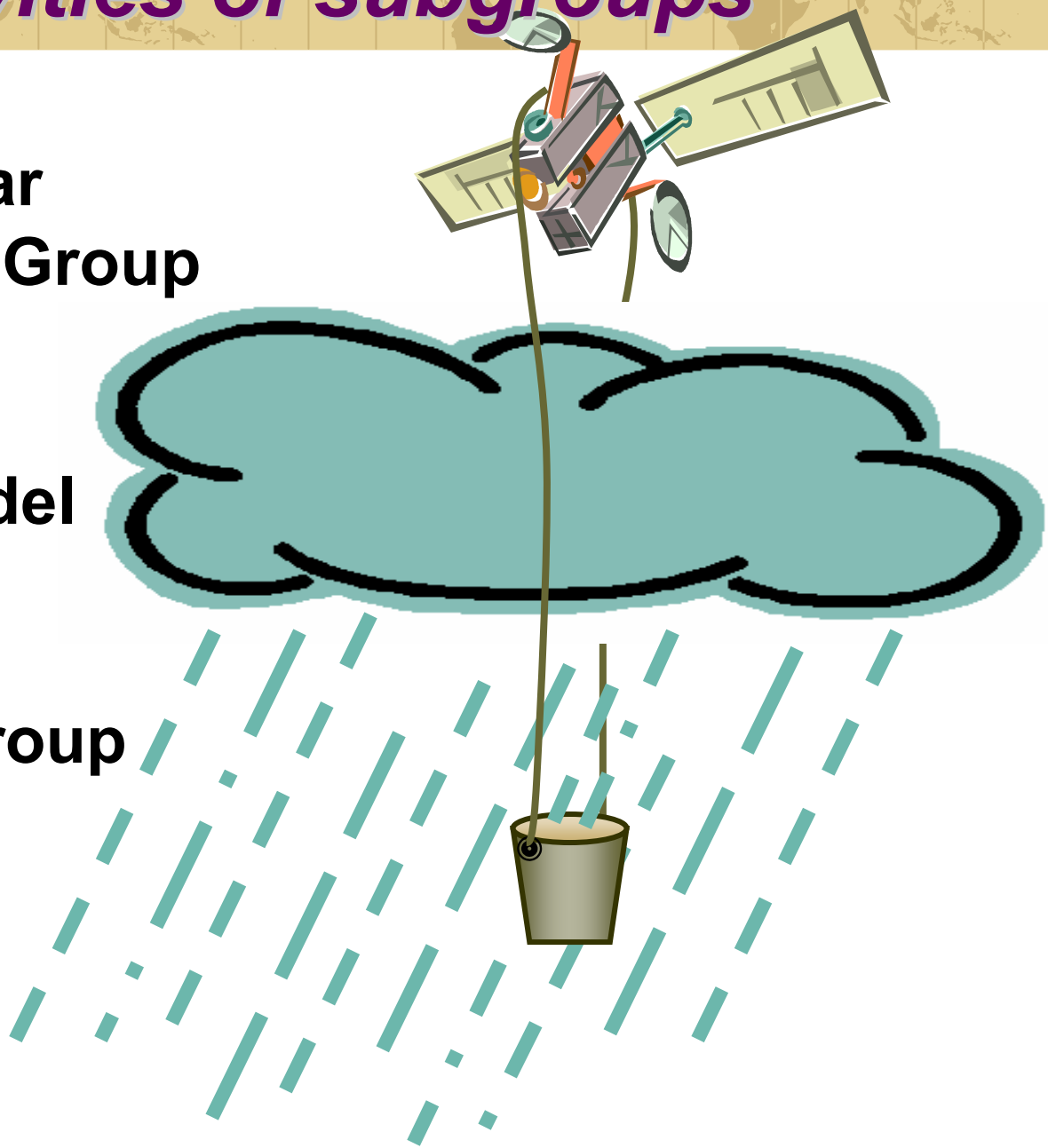


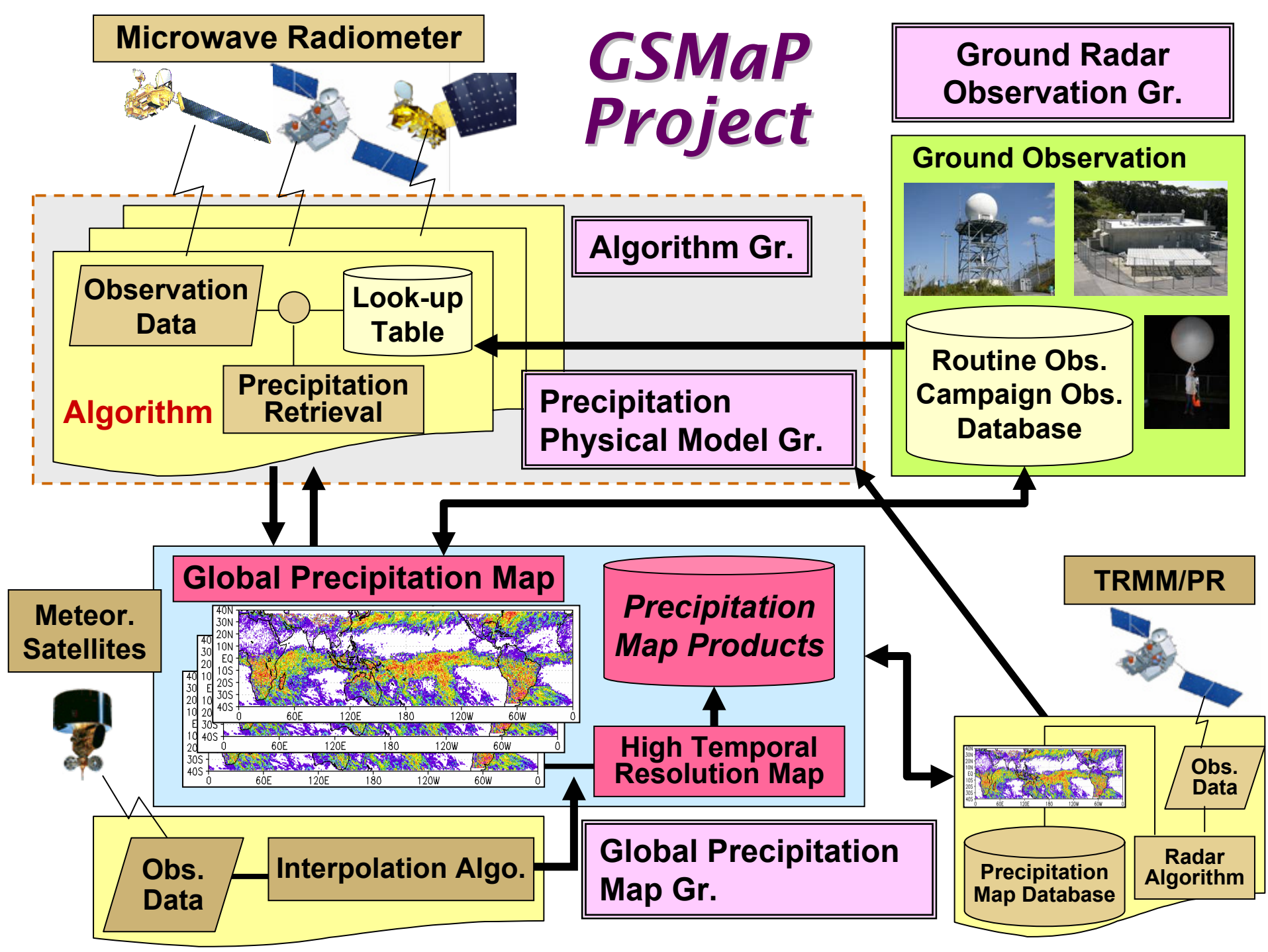
Activities of subgroups

Ground Radar Observation Group

Precipitation Physical Model Group

Algorithm Group

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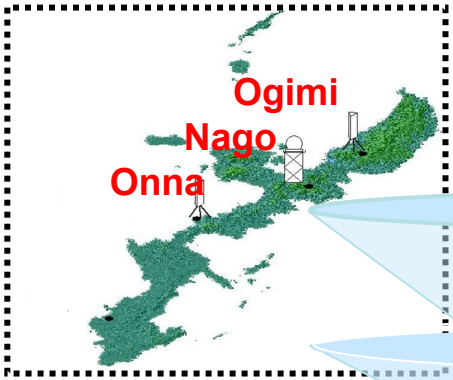
Okinawa Baiu Campaign Precipitation Observation
22 May 2004-9 June 2004



Observation by COBRA
(NICT C-band Doppler Polarimetric Radar)
- Detailed polarimetric observation
- Volume Scan
- RHI Obs. (NICT Ogimi, Nict Onna)
- Synchronous Observation with TRMM

Volume Scan

RHI Scan

RHI Scan

NICT Onna

NICT Ogimi

NICT Nago

COBRA

400MHz WPR MP-Ka 1.3GHz WPR

- Disdrometer
- Optical rain gauge
- Micro Rain Radar
- 2D-Video Distrometer

- Supersonic wind meter
- Disdrometer
- Optical Rain Gause
- Ceilometer
- GPS sonde
- Micro Rain Radar
- 2D-Video Distrometer
- μ -Wave radiometer

Major Rain Observation Equipment

10-minute cycle
Volume scanning with 15 elevation angles
＋RHI scanning with 2 or 4 azimuth angles
(Ogimi/Onna)

Temporal resolution: 164s (horizontal and vertical wind)
Height resolution: 100m (1.3μs)

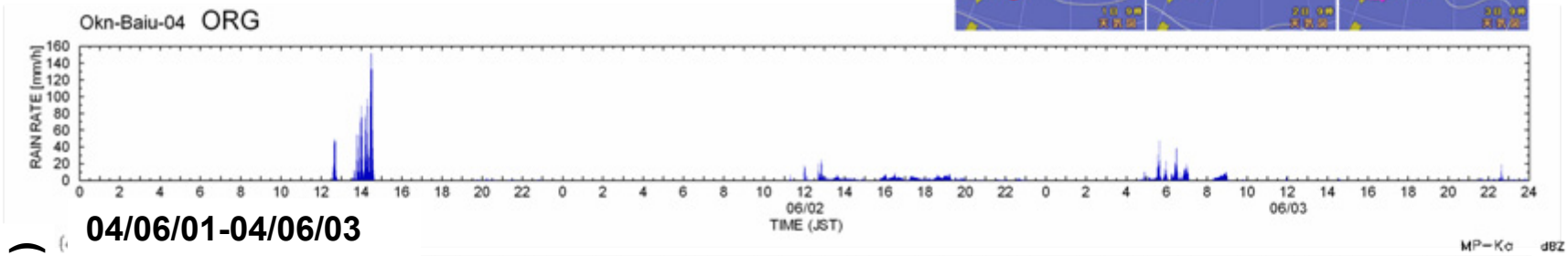
Temporal resolution: 1/3s→60sec average
Height resolution: 50m, continuous observation zenith direction

Precipitation Data Set at the Okinawa Baiu Campaign Observation

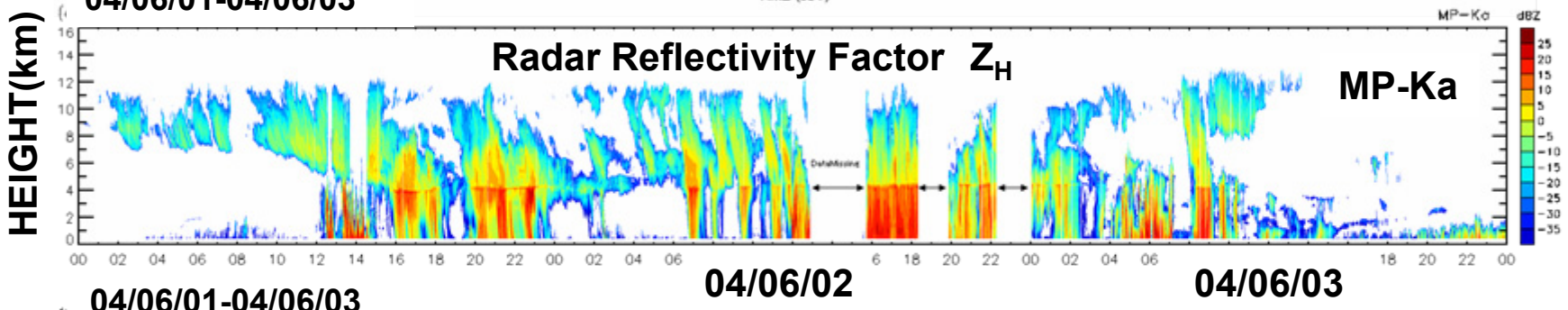
Okn-Baiu-04 web page = http://www3.nict.go.jp/dk/c218/okn-baiu04/

No.	Data/Sensor	Time
1	GPS sonde	UTC
*2	COBRA radar (C-band Doppler Polarimetric Radar)	UTC
3	400MHz WPR (wind profiler)	JST
4	MP-Ka Radar (Ka-band Doppler Radar)	JST
5	MRR (Micro Rain Radar)	JST
6	Microwave Radiometer	JST
7	Ceilometer	JST
8	Meteorological Instruments	JST
9	Optical Rain Gauge	JST
*10	2D Video Disdrometer	JST
11	TRMM/PR(2A25), TMI(2A12), VIRS(1B01)	UTC/JST
*12	AMSR-E	UTC
*13	QSCAT Ocean Wind	UTC
14	AMeDAS	JST
*15	RSM SFC(03-48), 850/700/500hPa(00-51) (numerical weather model)	JST

04/06/01-03 (Baiu Rain Front; 93.5mm)

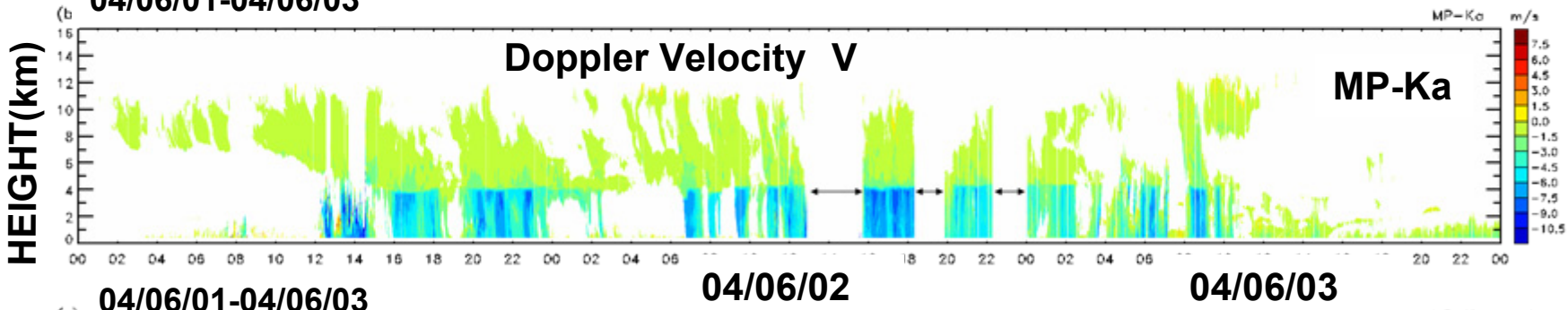


04/06/01-04/06/03



04/06/02 04/06/03

04/06/01-04/06/03



04/06/02 04/06/03

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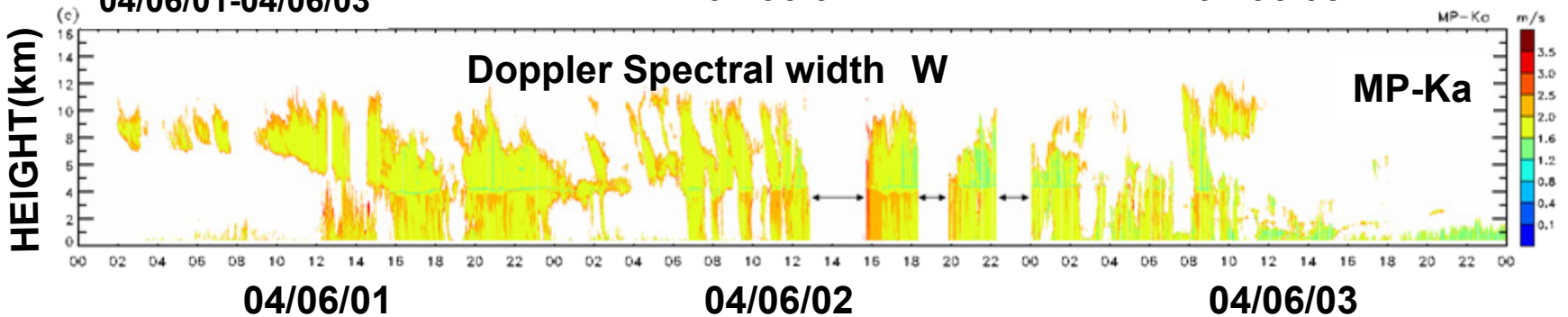
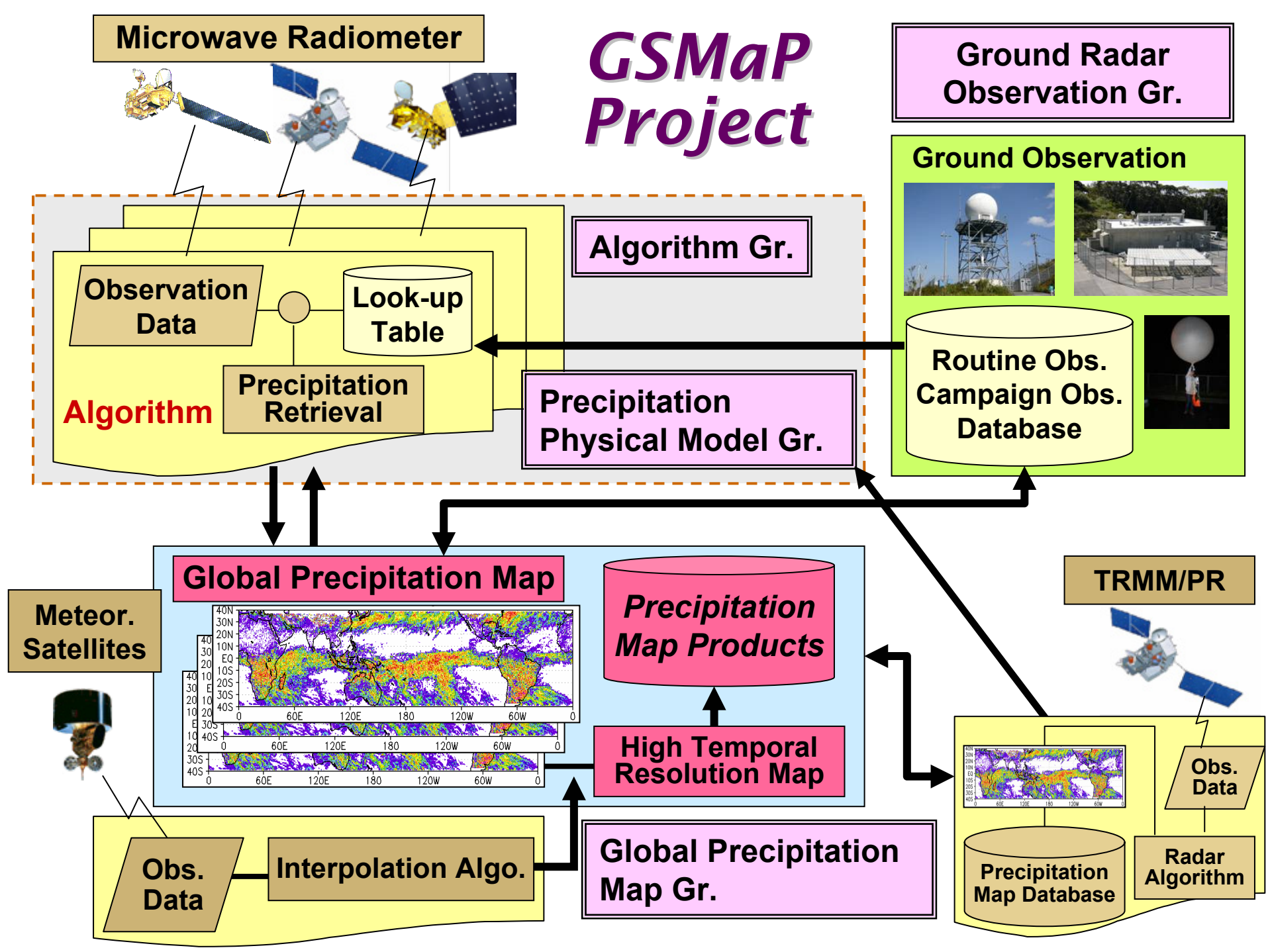


04/06/01 04/06/02 04/06/03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Roles of Algorithm Development Group

To develop and improve rain rate retrieval algorithms.

- Improvement of Aonashi's algorithm (scattering algorithm)
- Rain/No-rain determination over land

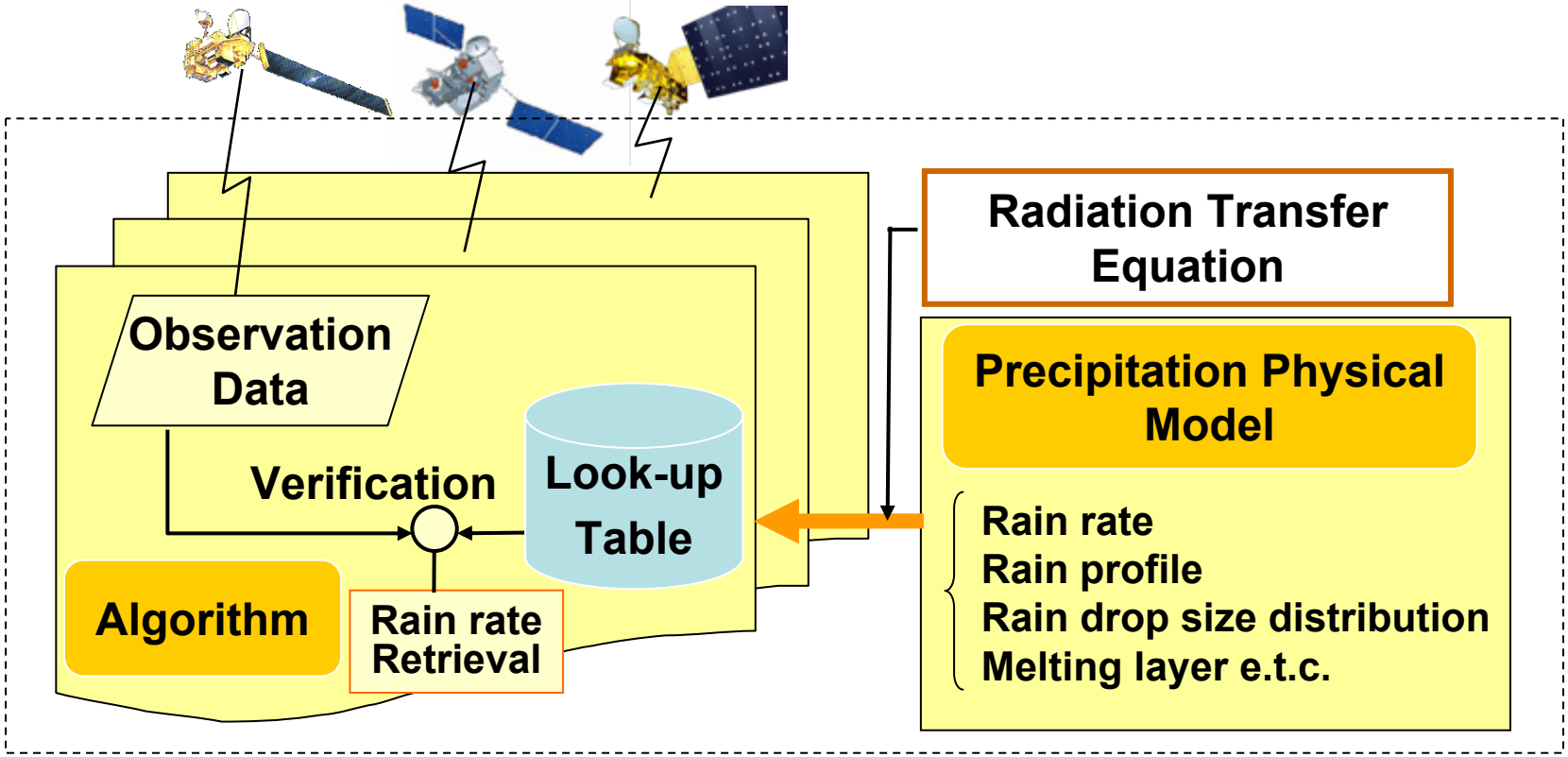
- Evaluation method by radiative transfer model
- Evaluation by numerical cloud resolving model

Roles of Precipitation Physical Model Group

To make physical models of precipitation (rain profile, melting layer, raindrop size distribution.)
To build those models onto retrieval algorithms.

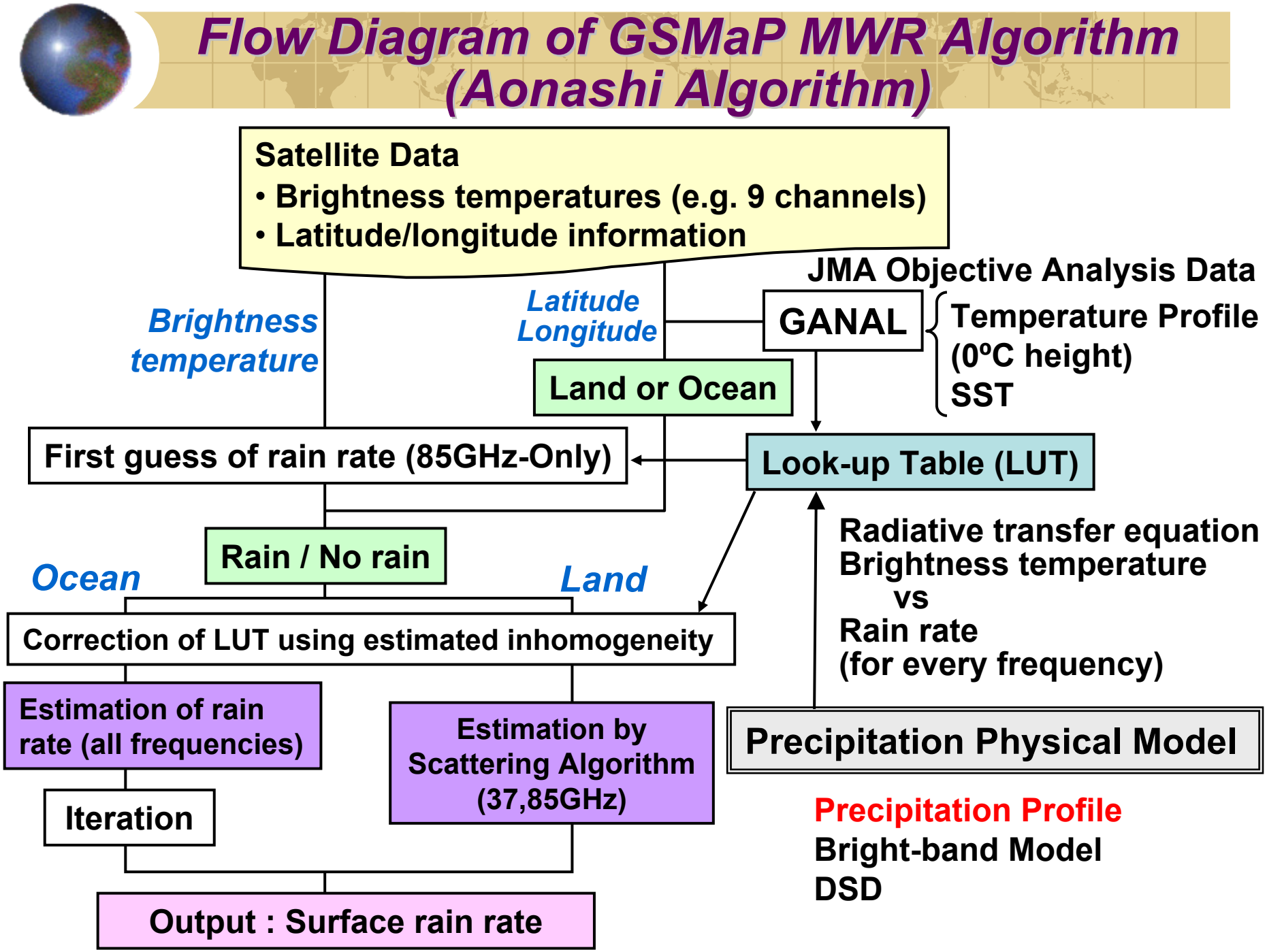
- Precipitation profile model
- Melting layer model
- Rain drop size distribution model
- Snow particle model

Basis of Rain Rate Retrieval by Microwave Radiometers



- Satellites observe the brightness temperature, integration of radiation and scattering power.
- The relation between rain rate and brightness temperature is tabulated by assuming precipitation physical model and calculating the radiative transfer equation. The rain rates giving the nearest brightness temperature values to the observed ones are considered to be the most appropriate estimation.

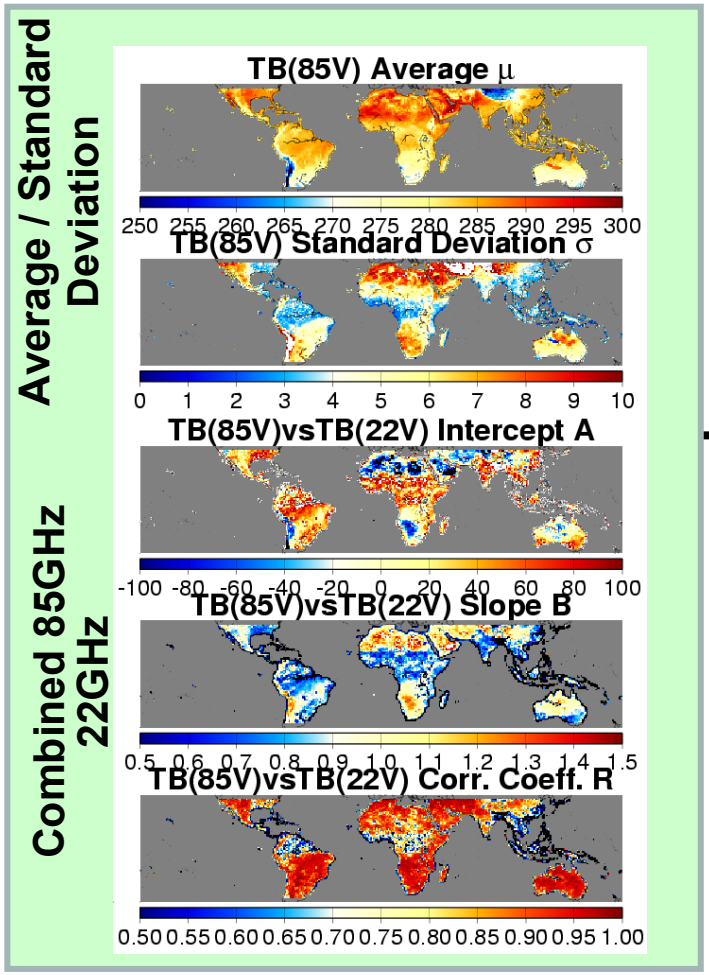
Flow Diagram of GSMaP MWR Algorithm (Aonashi Algorithm)



Improvement of Land Algorithm

Development of Rain/No Rain Determination Algorithm Using Database

Database of Brightness Temperature with No Rain



Observation Data
TB(85V)

Rain → **Retrieval** → **Rain/No-rain Determination R>=0**

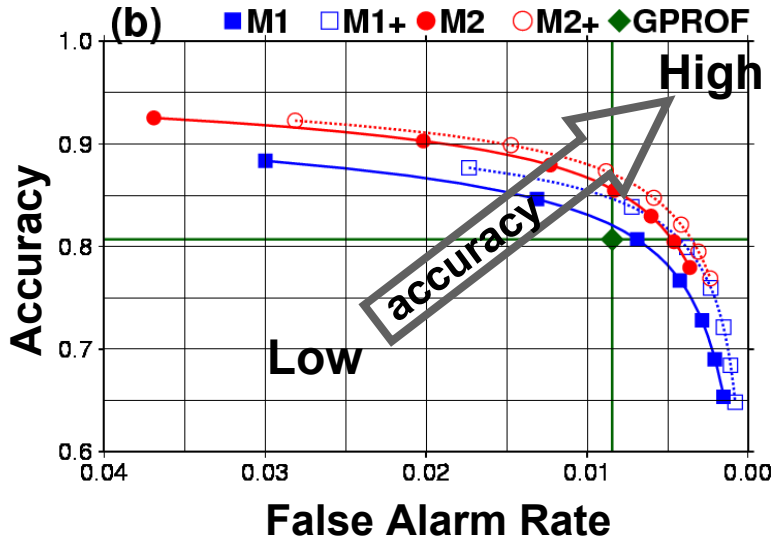
Rain/No-rain Determination
Rain, if $TB_e(85V) - TB(85V) > 0$

No-Rain
$TB_e(85V) = a + b \times TB(22V) - k_0 \times \sigma_e$

No-rain → **Rain rate R=0**

Results

Rain/No-rain determination accuracy becomes better than that of GPROF

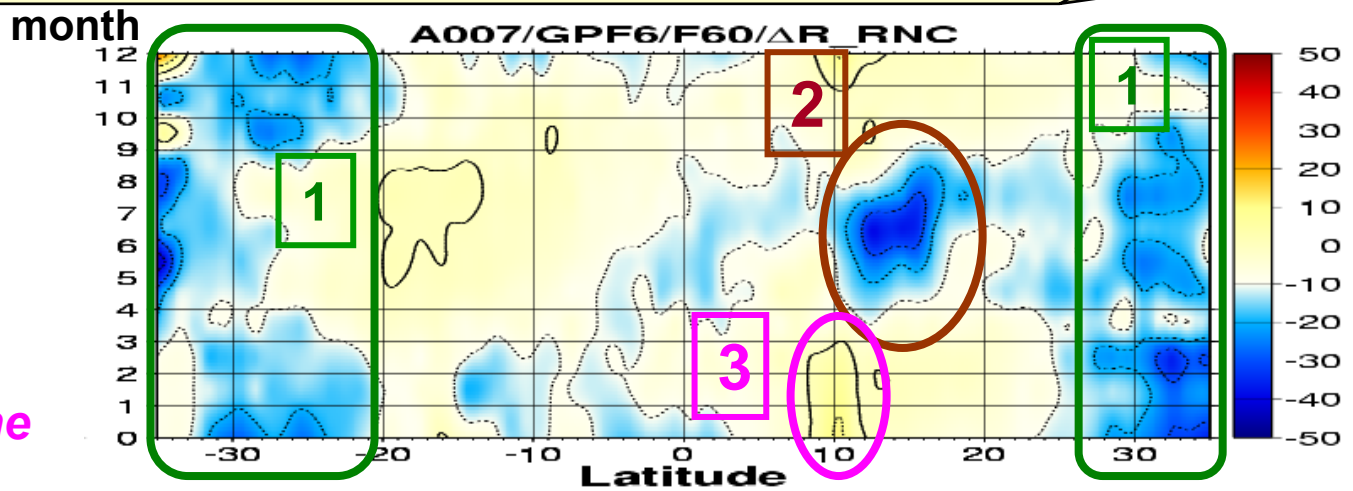


Evaluation by Rain/No-rain Determination Error

- Rain rate estimation error = rain/no-rain determination error + retrieval error
- Rain/no-rain determination error = (rain rate retrieved by mistaking no-rain for rain) -(missed rain rate by mistaking rain for no-rain)

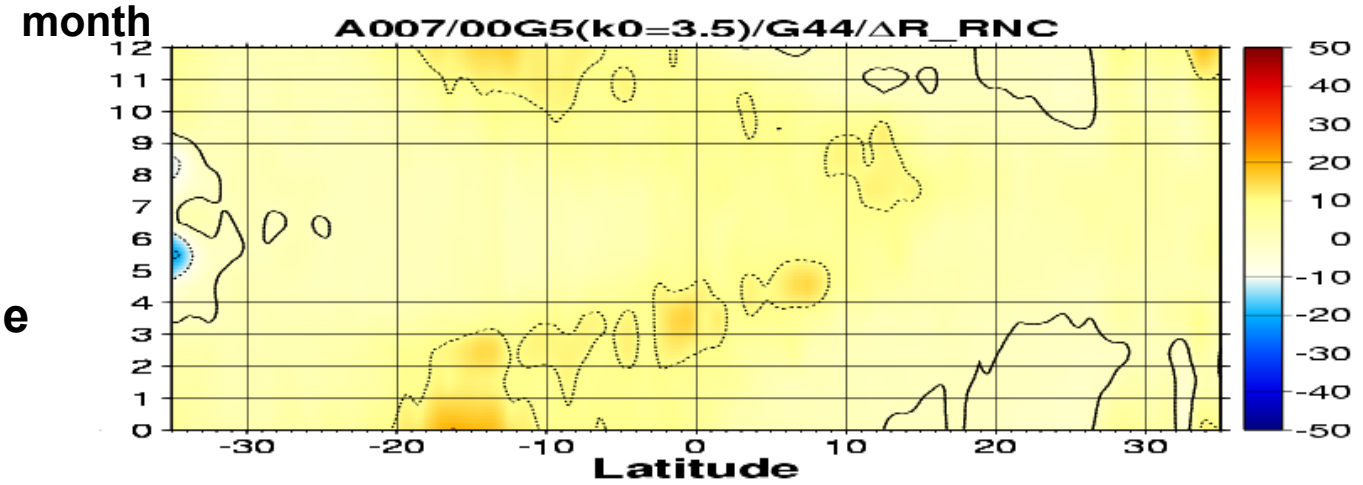
GPROF

1. Underestimated in the mid-latitude
2. Underestimated in the semi-acid area in summer
3. Overestimated in the semi-acid area in winter



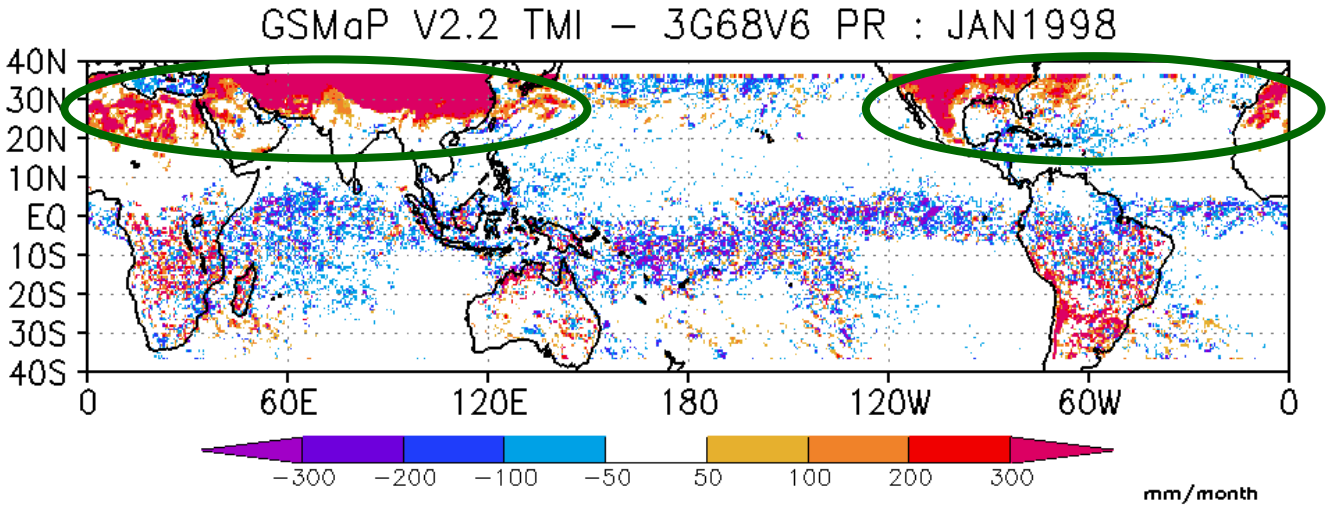
GSMaP

Absolute values of the errors are smaller.

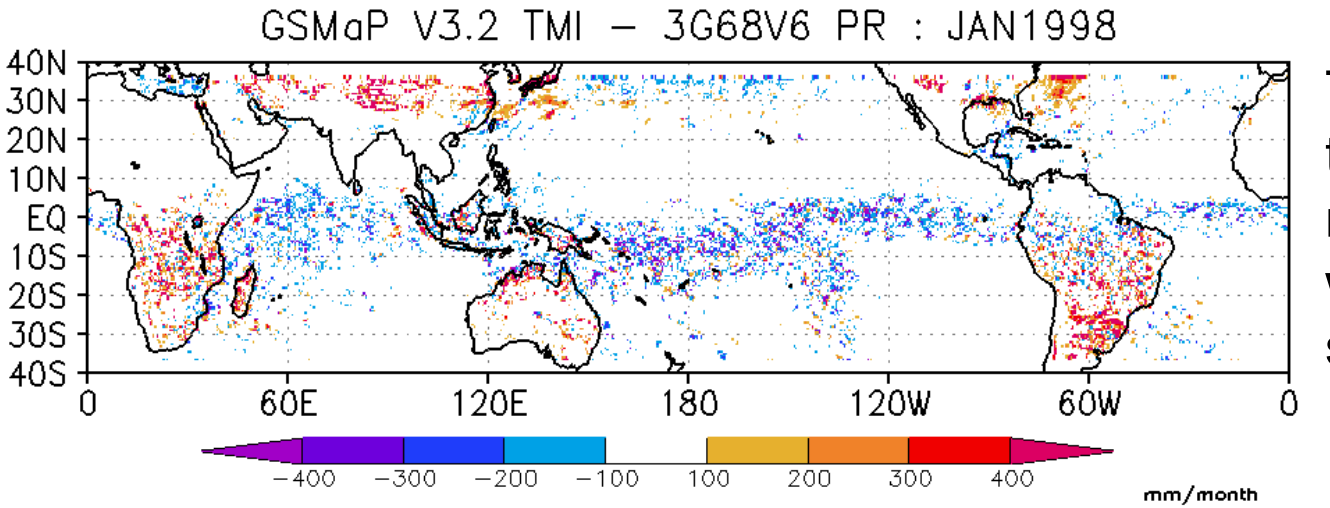


Improvement of GSMaP-TMI

(Rain/No-rain determination algorithm over land)



January 1998



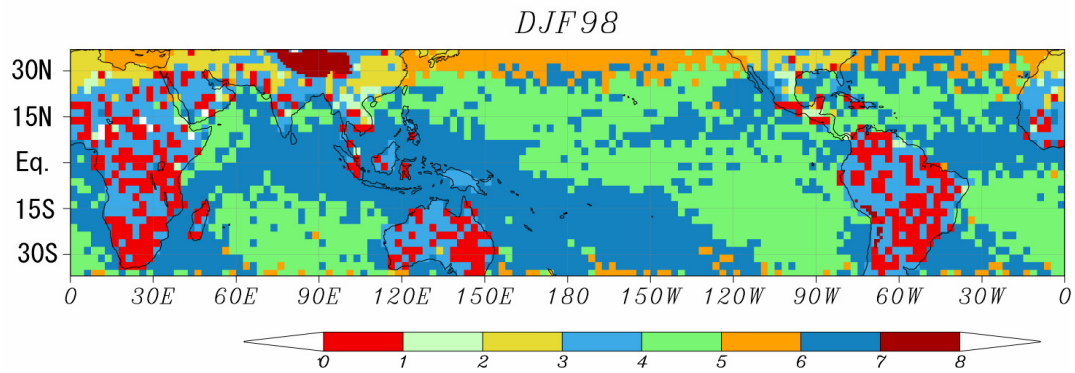
The areas circled in the map above are now proved to be with not rain but snow covering.

Development of Precipitation Profile Model

Classification of Precipitation Type

Precipitation type database

2.5º grid
Every 3 months
8 types (ocean × 3, land × 5)

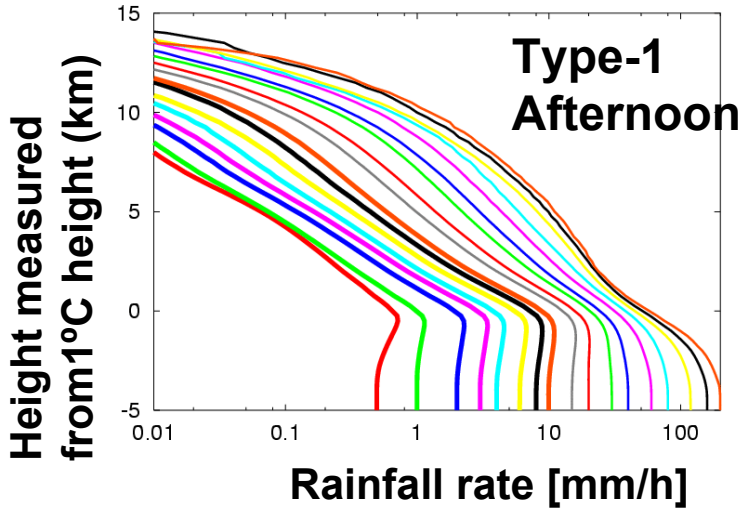


(Land) 1: afternoon shower, 2: shallow rain, 3: Midlat front. systems, 4: organized rain systems
(Ocean) 5: shallow rain, 6: Midlat front. Systems, 7: organized rain systems, 8: Tibet

Production of Precipitation Profile

Precipitation profile database

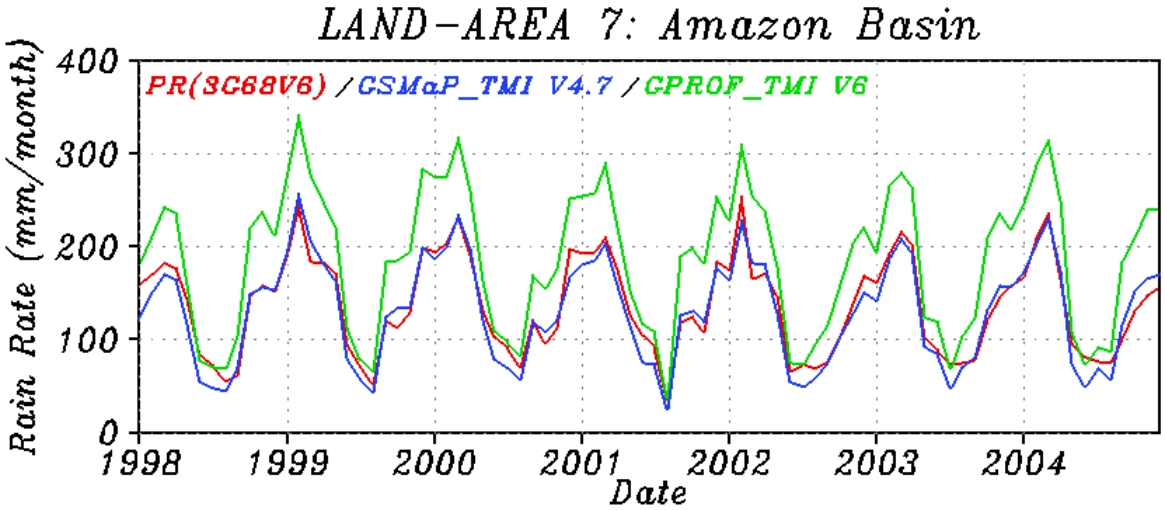
Classified by precipitation type
Classified by rainfall rate



Rainfall rate profiles classified by rainfall rate (Type-1)
0.5, 1, 2, 3, 4, 6, 8, 10, 15, 20, 30, 40, 60, 80, 120, 160, 200 mm/h

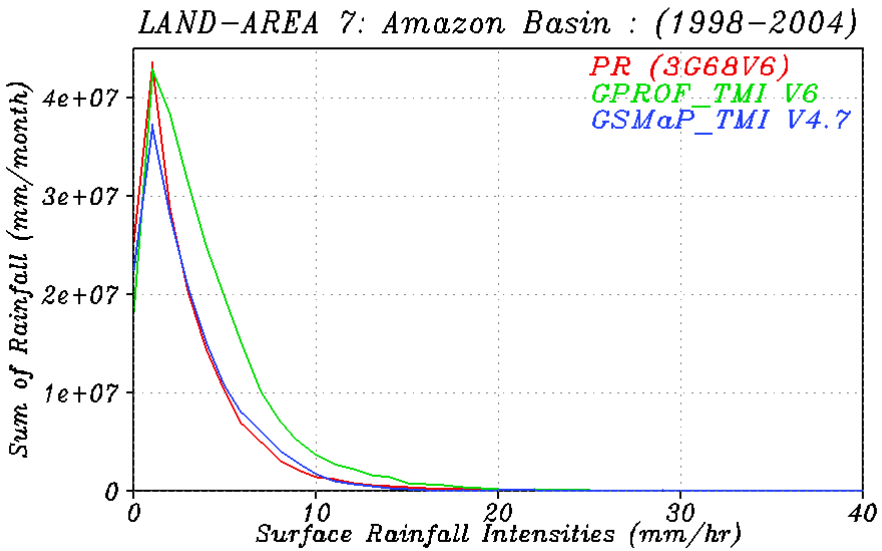
Comparison over Amazon Area

Monthly time series

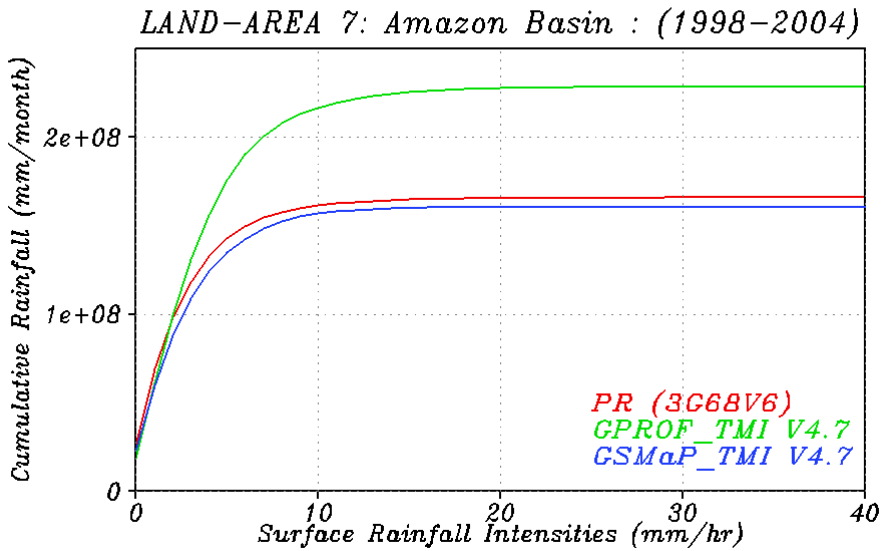


GSMaP V4.7 follows PR better than GPROF over amazon area (80W-45W, 10S-EQ).

Histogram analysis (sum of rain rate)

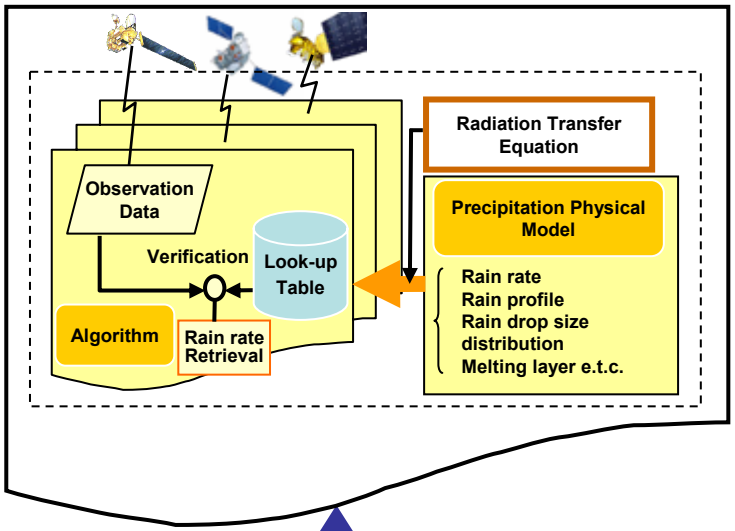


Cumulative distribution

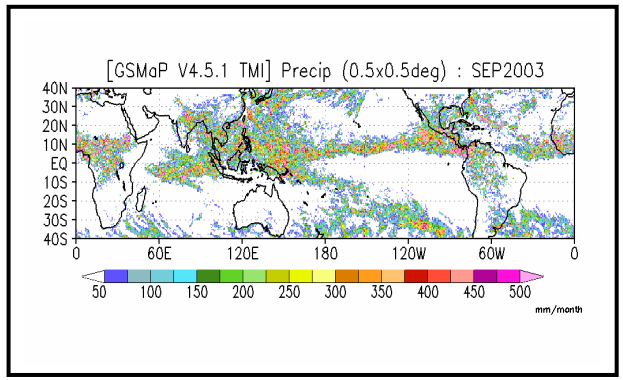


Evaluation of Global Precipitation Map and Algorithm Development and Improvement

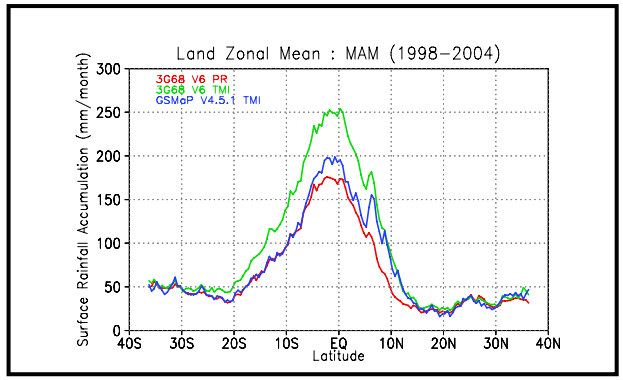
Algorithm Development



Production of Global Precipitation Map



Evaluation of Global Precipitation Map



Feed back to the algorithm improvement

Evaluation of algorithms

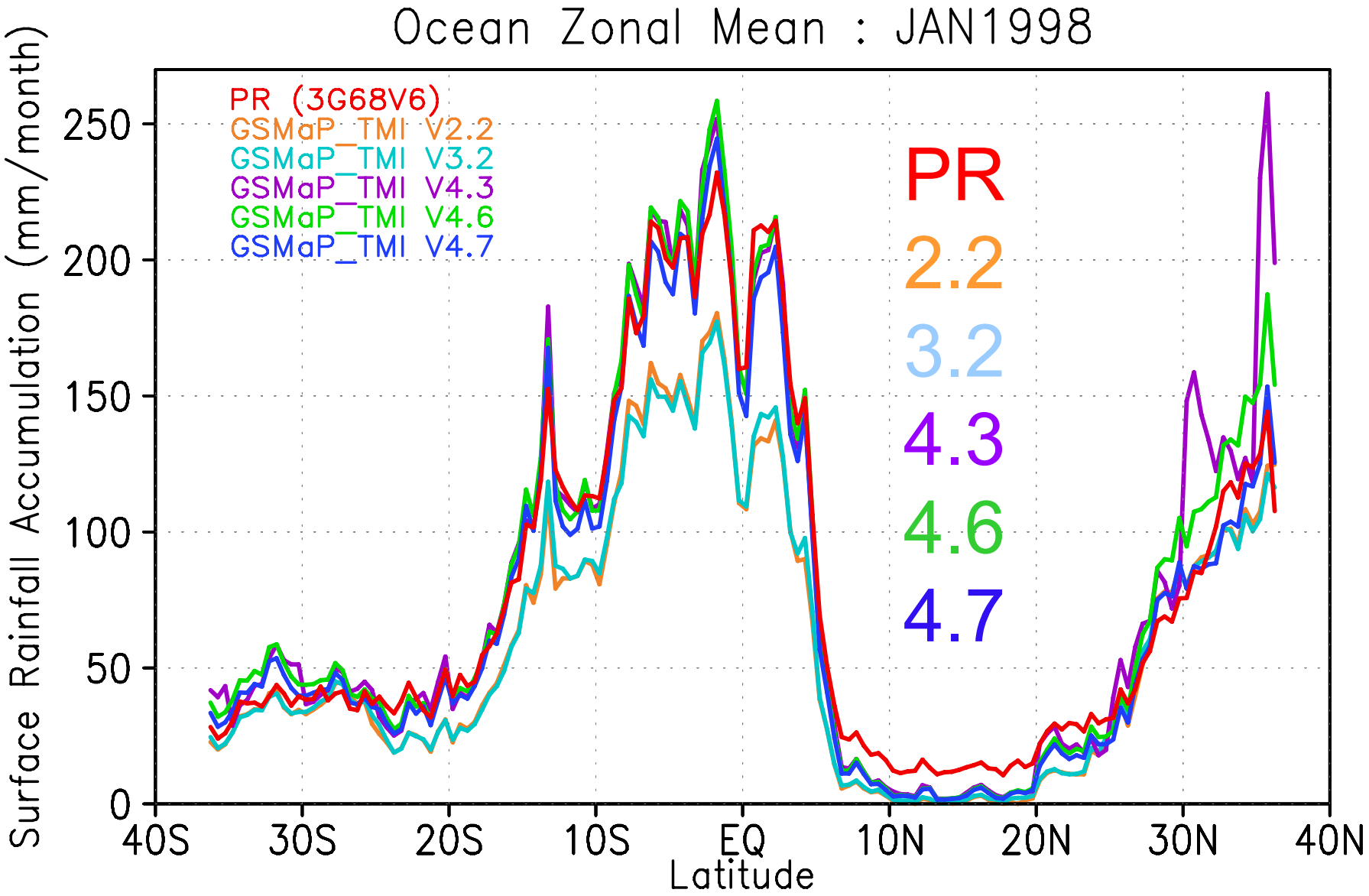
Comparative evaluation with:

- Rain rate retrieved by **TRMM/PR**, which is considered to provide the most accurate estimation
- **GPROF**, which NASA/GSFC developed for TRMM/TMI
- **Liu's algorithm**, standard algorithms of JAXA for Aqua/AMSR-E

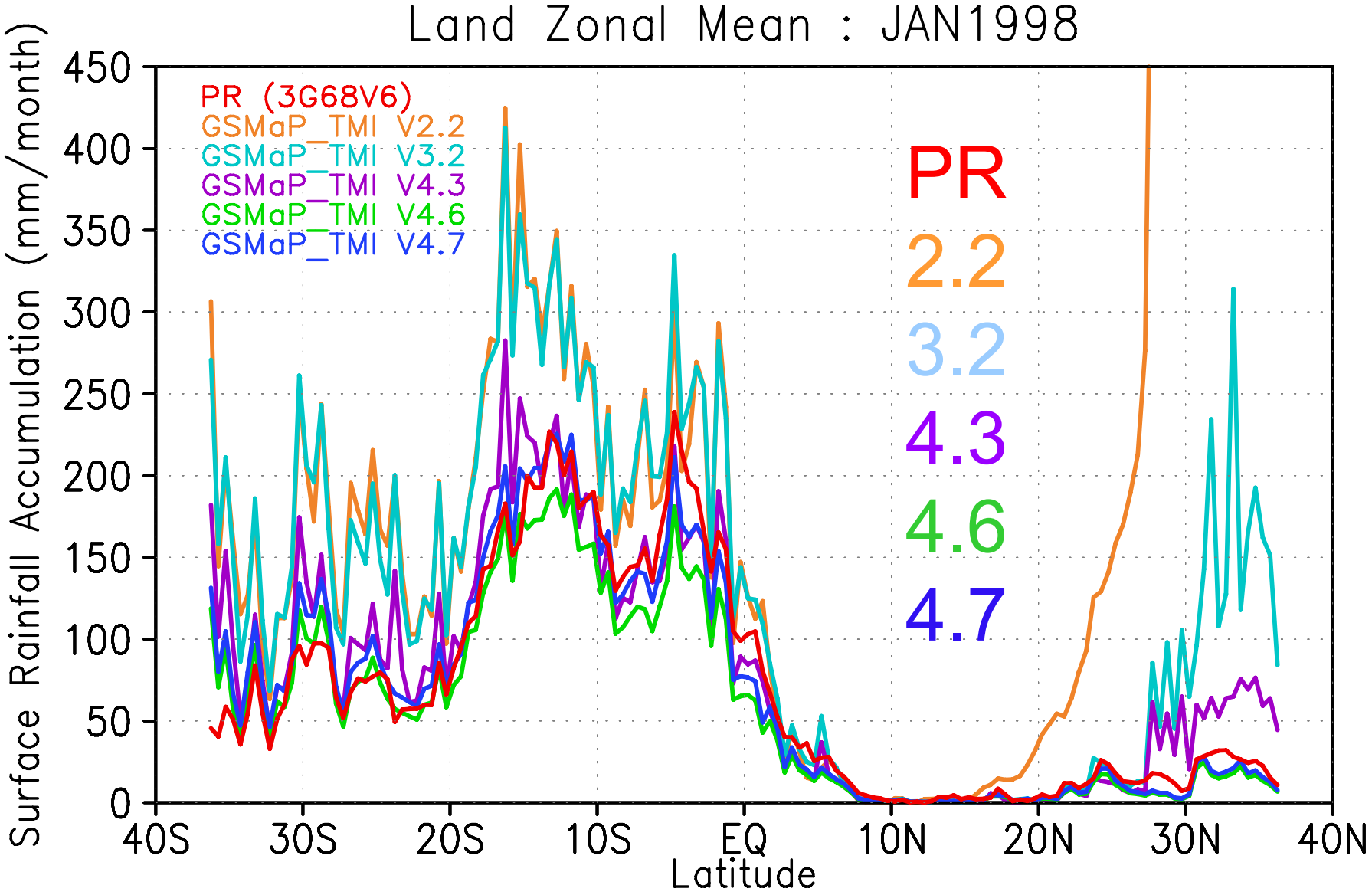
Main Progress of GSMaP-TMI Rain Retrieval Algorithm

Version	Rain/No-rain Determination over land	Rain Profile	Notes
V2.2	—	Liu and Fu	Aonashi's original algorithm
V3.2	Seto V1	Liu and Fu	Rain/No-rain determination over land by Seto. Database V1 based on no raining 85GHz brightness temperature.
V4.3	Seto V1	Hirose V1	Rain profiles classified by 8 different rain types (Land: 5 types, Ocean:3 types), and rain rates. Rain Profile V1.
V4.5	Seto V2	Hirose V2	Improved rain profiles. Rain Profile V2. Improve rain/no-rain determination over land.
V4.6	Seto V2	Hirose V2	Improvement of scattering algorithm using PCT85 and PCT37.
V4.7	Seto V2	Hirose V2	RTM calculation using the melting layer model (Nishituji model).
V4.7.2	Seto V2	Hirose V2	LUT computed separately between convective and stratiform rains.

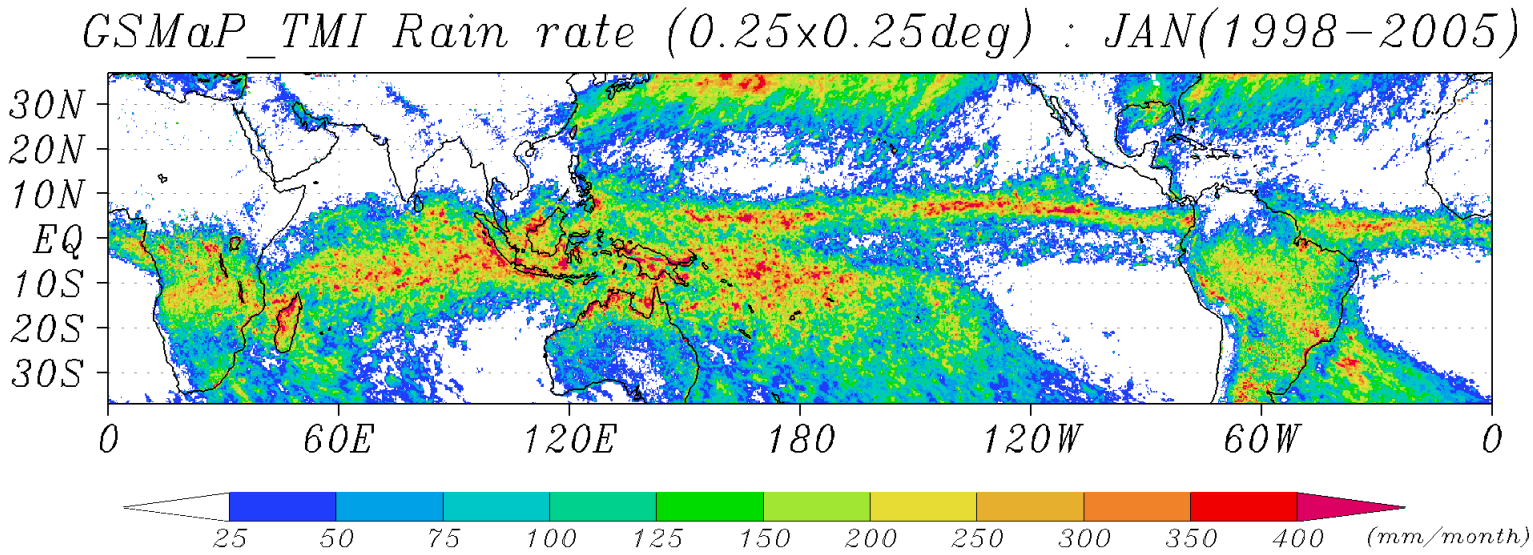
Comparison of Zonal Rain Rate Average (Ocean, January 1998)

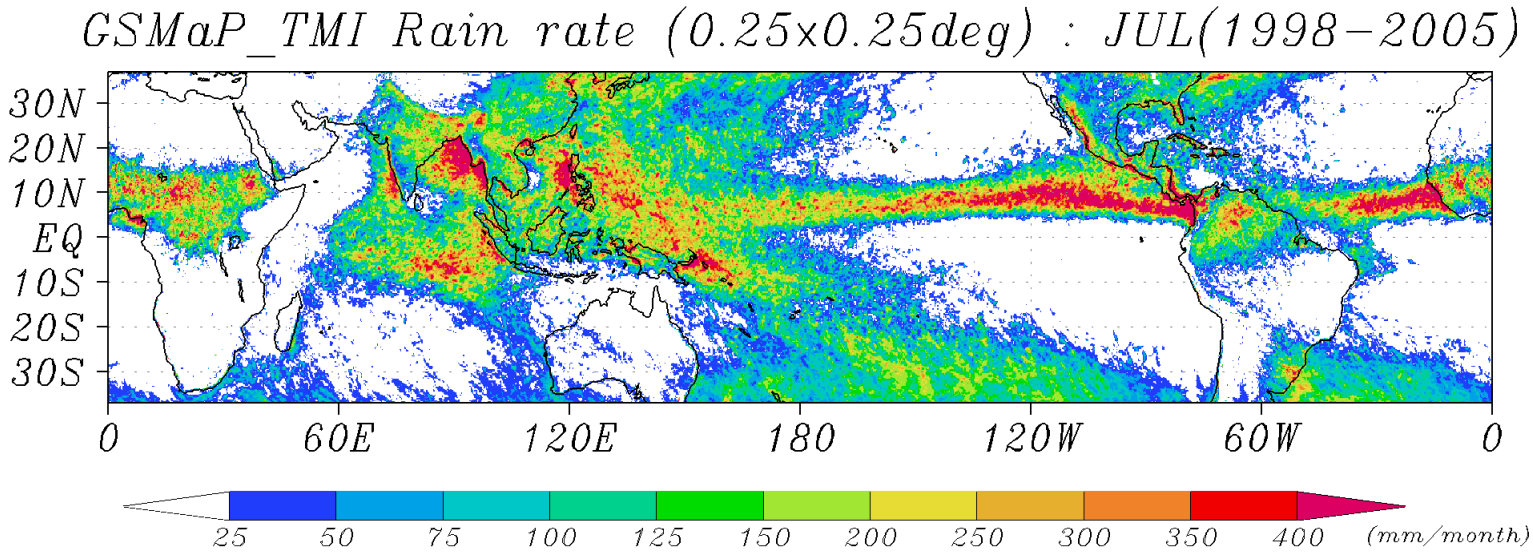


Comparison of Zonal Rain Rate Average (Land, January 1998)

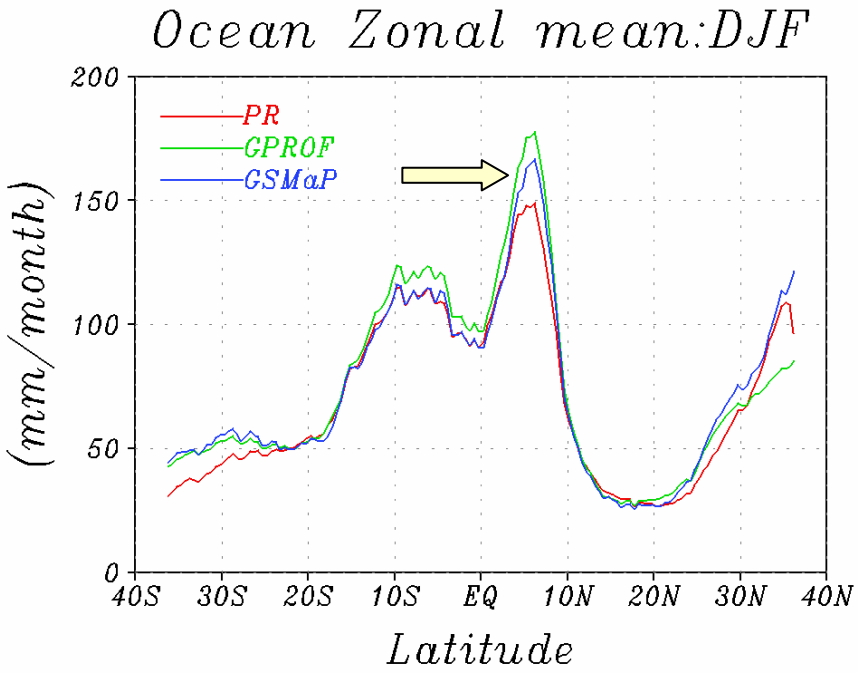


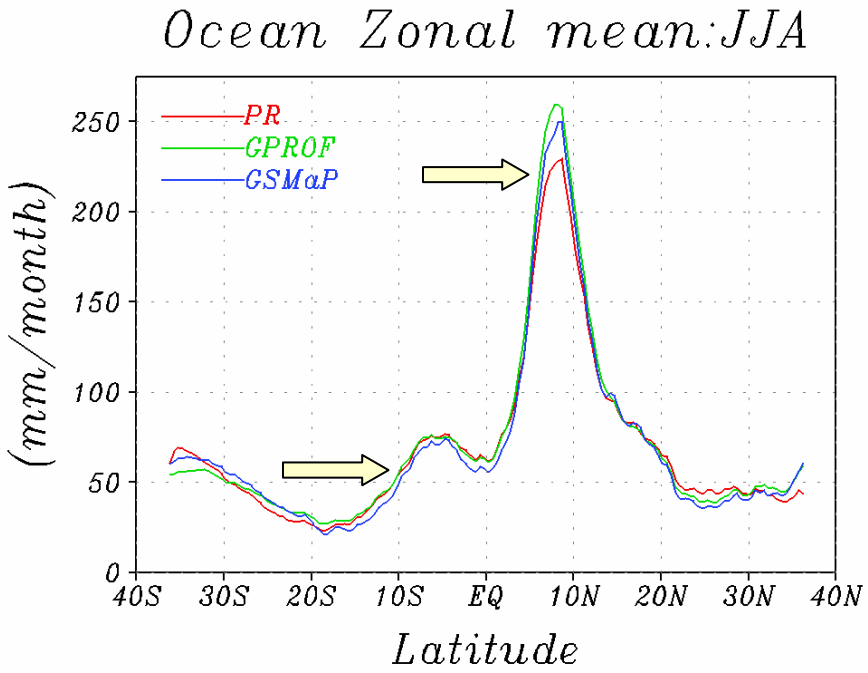
GSMaP_TMI V4.7.2:
Eight-year Rain Rate Average, winter and summer





GSMaP_TMI V4.7.2:
Comparison of Zonal Rain Rate Average (Ocean)





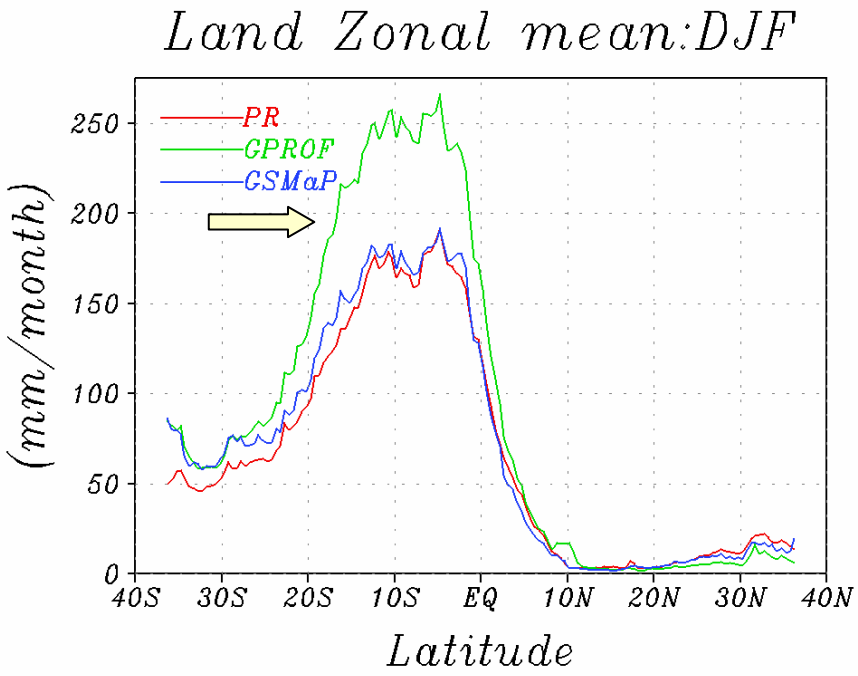
PR V6

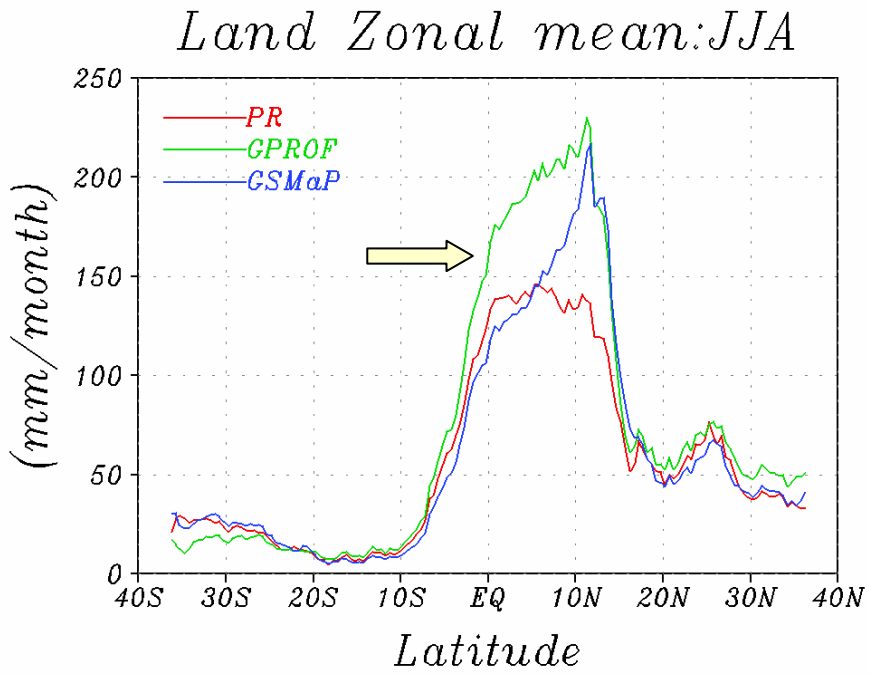
GPROF_TMI V6

GSMaP_TMI V4.7.2

- GPROF overestimates rain rates in the low latitude ocean area, especially in the inter-tropical convergence zone, while GSMaP estimation follows the PR well.
- GSMaP underestimates rain rates in the subtroical ocean.

GSMaP_V4.7.2 TMI:
Comparison of Zonal Rain Rate Average (Land)





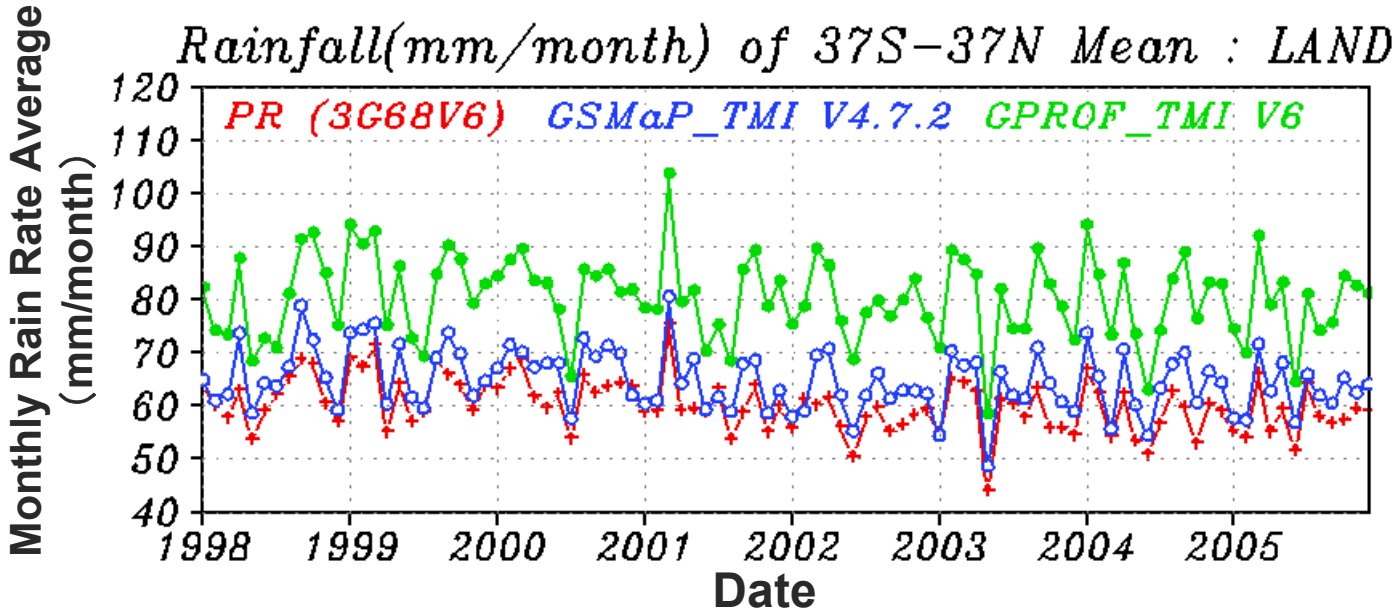
PR V6

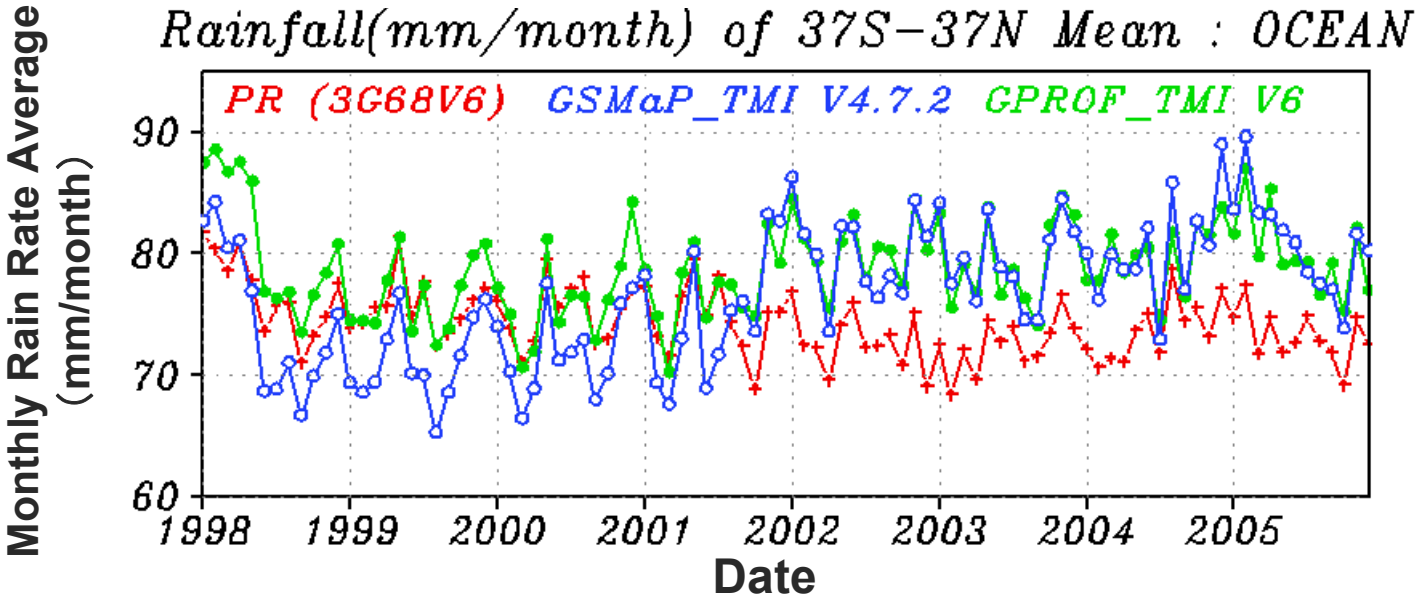
GPROF_TMI V6

GSMaP_TMI V4.7.2

- GPROF overestimates rain rates over land in the tropical raining area.
- GSMaP follows the PR well, except for the Africa area (5N-15N) in the boreal summer.

Time Series Comparison of Monthly Global Rain Rate Average (Land and Ocean)



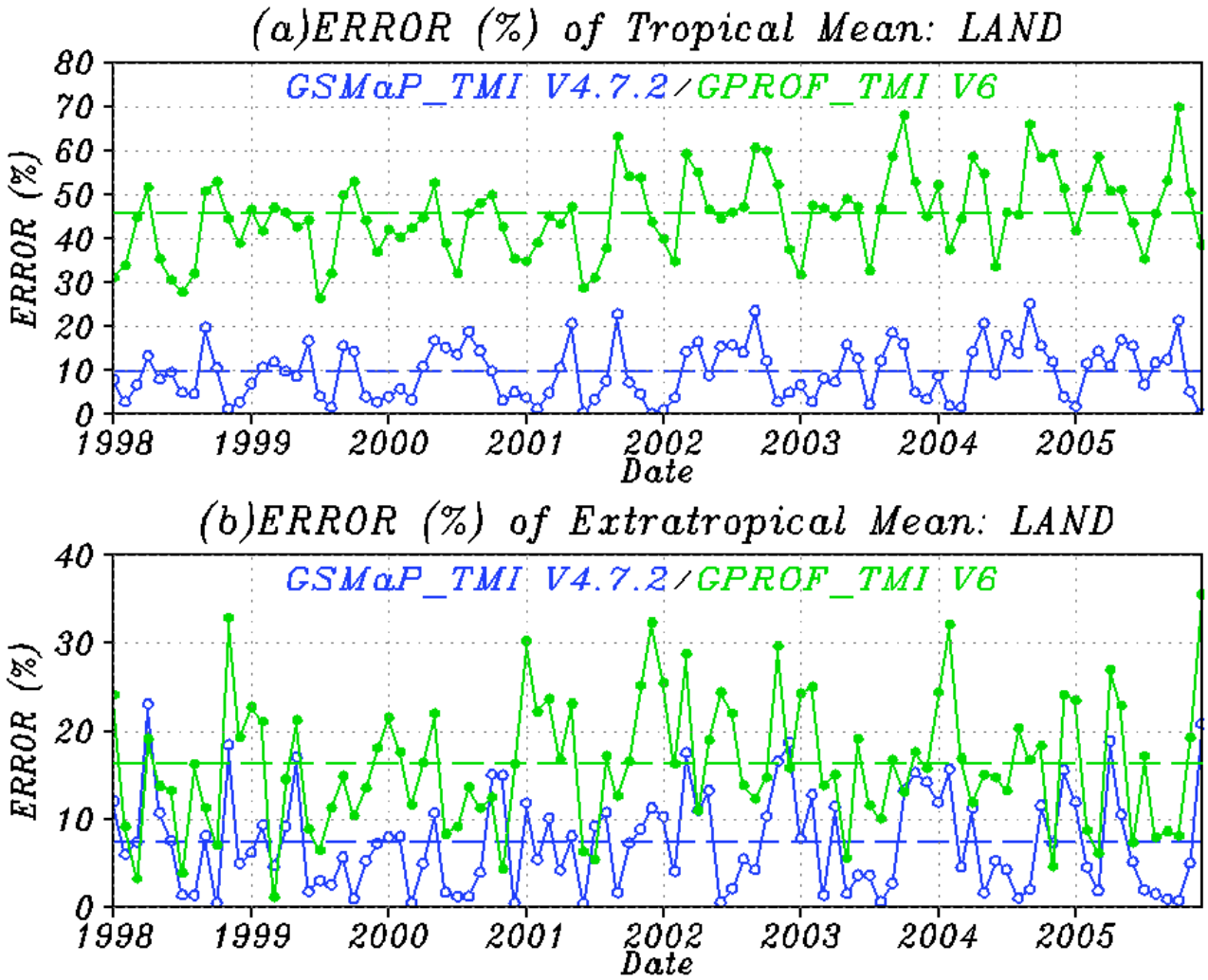


Relative Error to Tropical Rain Rate retrieved by PR (LAND)

Error over Tropics: (LAND)
GSMaP:9.6%
GPROF:46.7%

Error=100 × |TMI – PR|/PR %
(Tropics : 15S-15N
Extratropics : 15N-37N, 15S-37S)

Error over Extratropics: (LAND)
GSMaP:7.4%
GPROF:16.3%

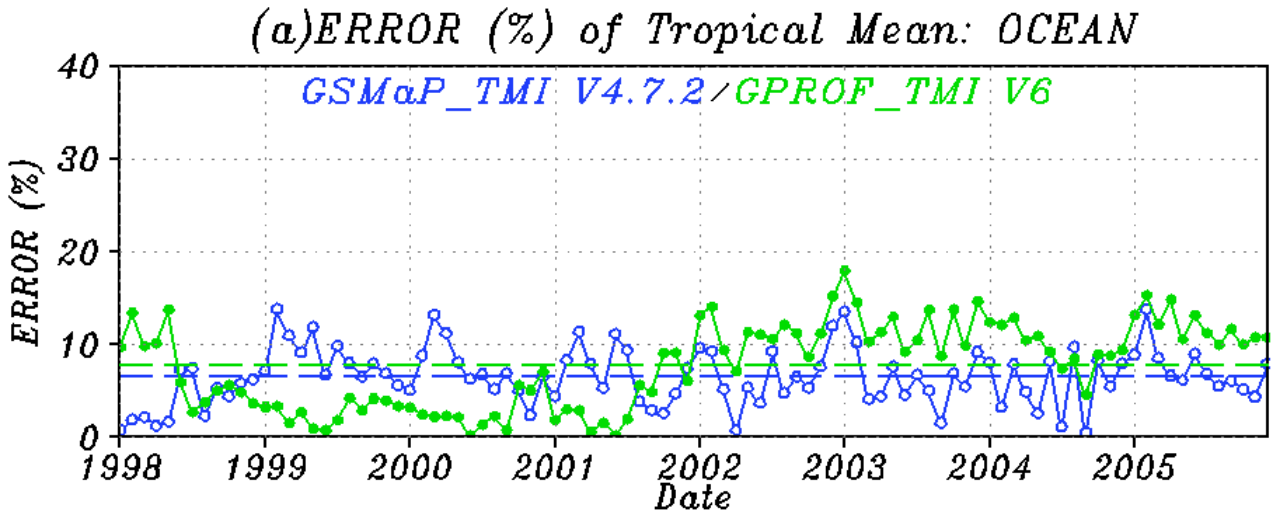


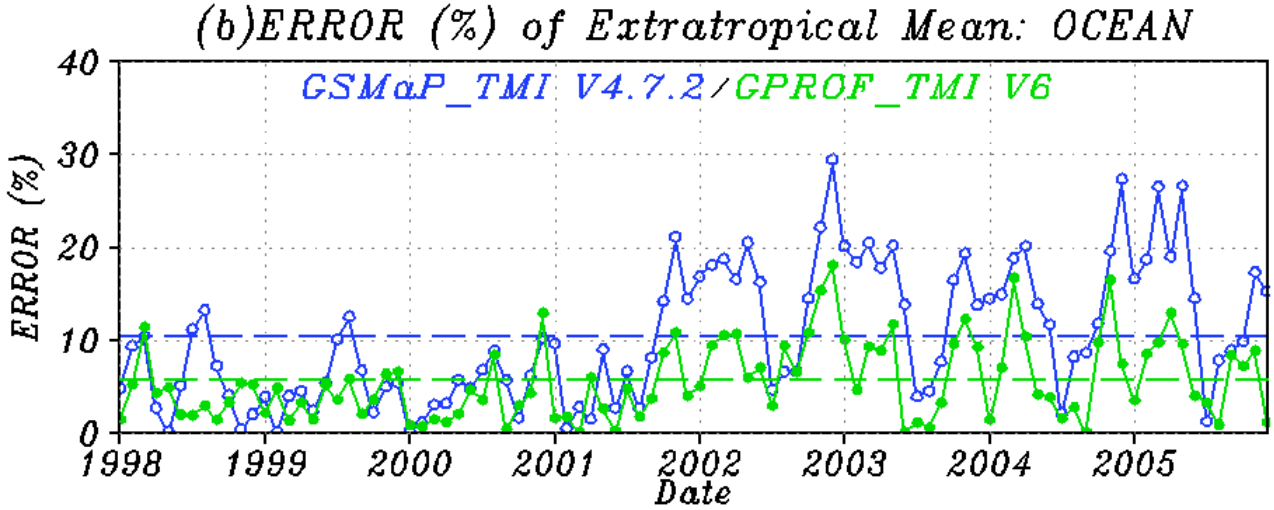
Relative Error to Global Rain Rate retrieved by PR (OCEAN)

Error over Tropics: (OCEAN)
GSMaP:6.6%
GPROF:7.8%

Error=100 × |TMI – PR|/PR %
(Tropics : 15S-15N
Extratropics : 15N-37N, 15S-37S)

Error over Extratropics: (OCEAN)
GSMaP:10.5%
GPROF:5.7%





Summary and Future Plan

Making good progress…

- Development of TRMM/TMI algorithm
- Production of global precipitation map using TRMM/TMI algorithm
  (Data processing from Jan 1998 to Dec 2004 has been completed.)
  - DSD model are to be built onto the algorithm for reprocessing.
- Development of Aqua/AMSR-E (ADEOS-II/AMSR) algorithm
- Production of global precipitation map using Aqua/AMSR-E (ADEOS-II/AMSR) algorithm
  (Data processing from Jan 2003 to Dec 2004 has been completed.)
  - Rain/No-rain determination of the high latitude area without TRMM PR data is under development
  - As there is no other reference precipitation data, simple classification model is applied.

Summary and Future Plan

There <u>are</u> some challenges to confront…

- Development of DMSM/SSMI Algorithm
  - Development of the algorithm that uses both 19.35GHz brightness temperature and polarization corrected temperature should be achieved.

Summary and Future Plan

We have developed…

- A method of integrating rain rate data retrieved by some different satellite-borne microwave radiometers.
- A method of producing high temporal resolution precipitation map by applying IR cloud moving vector to precipitation map data retrieved by several microwave radiometers.

Summary and Future Plan

We will plan to…

- Join the international PEHRPP (Pilot Evaluation of High Resolution Precipitation Product) group and evaluate various precipitation maps around Japan using Radar-AMeDAS data.
- Develop a rain retrieval algorithm by combining TRMM/PR and microwave radiometer algorithms.

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