Development and Applications of the GSMaP:
Overview & Lessons learned in a real-world case for Hydrological Status and Outlook System

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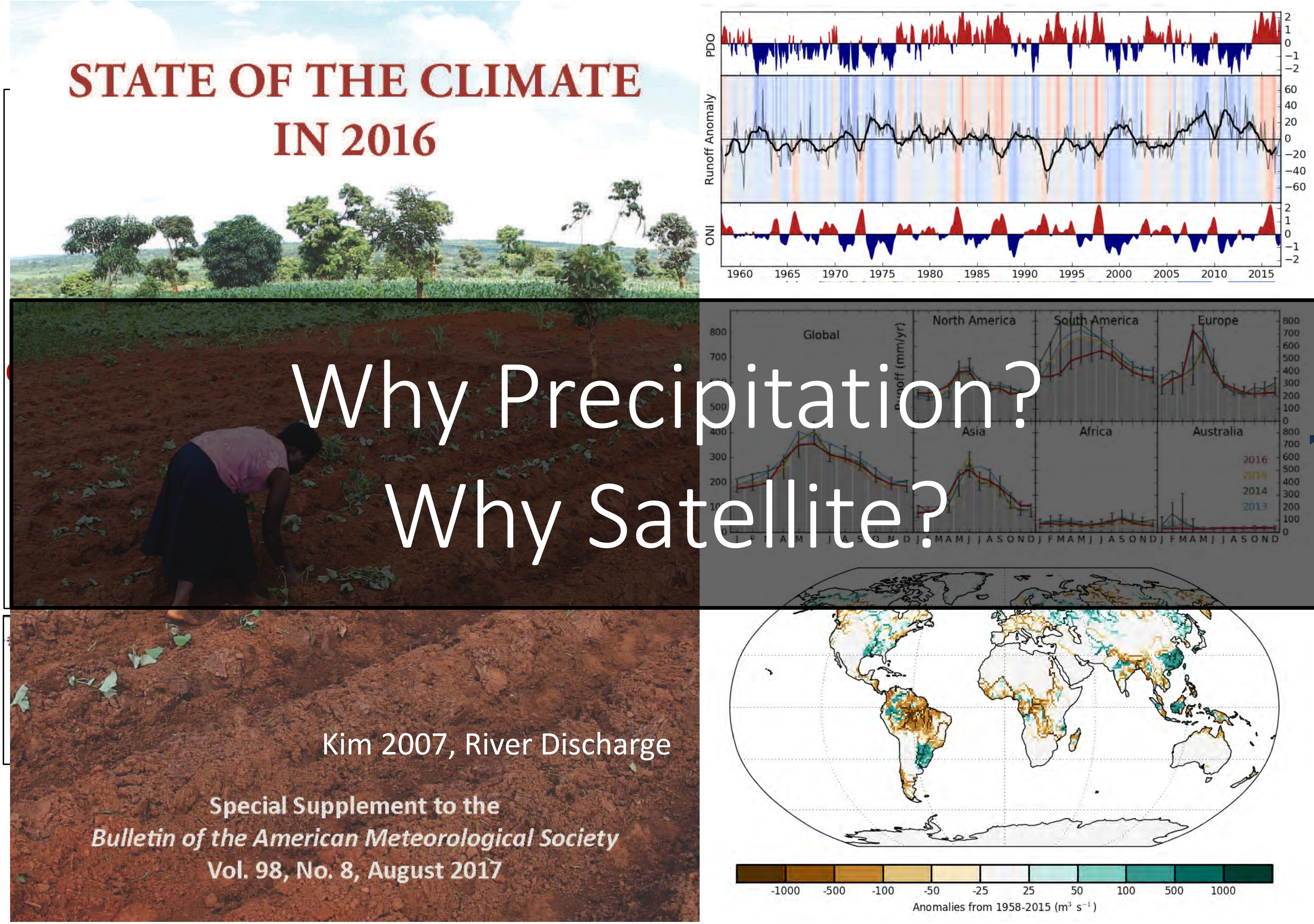
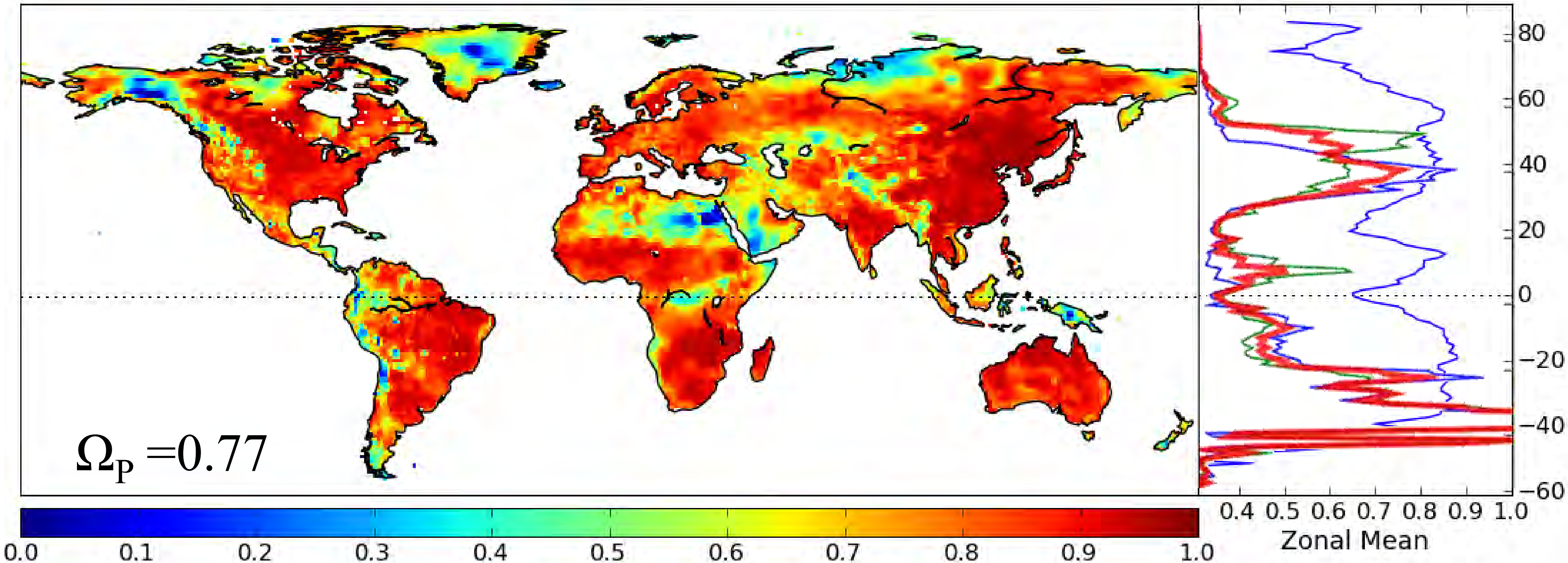
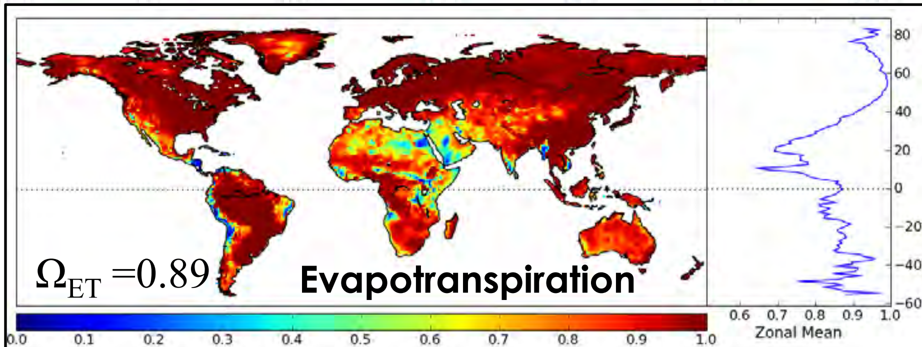
Image courtesy of http://www.satnavi.jaxa.jp/gpmdpr_special/

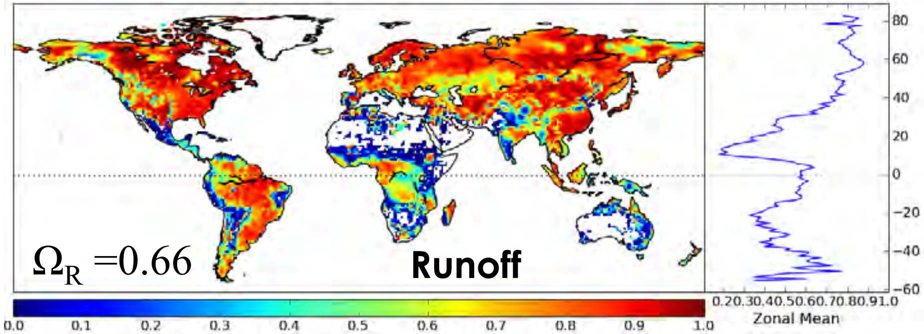


STATE OF THE CLIMATE IN 2016
Special Supplement to the
Bulletin of the American Meteorological Society
Vol. 98, No. 8, August 2017
Why Precipitation?
Why Satellite?
Kim 2007, River Discharge
PDO
Runoff Anomaly
ONI
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
Global
North America
South America
Europe
Asia
Africa
Australia
Runoff (mm/yr)
2016
2015
2014
2013
-1000
-500
-100
-50
-25
25
50
100
500
1000
Anomalies from 1958-2015 (m³ s⁻¹)

Uncertainty in Observational Precipitation



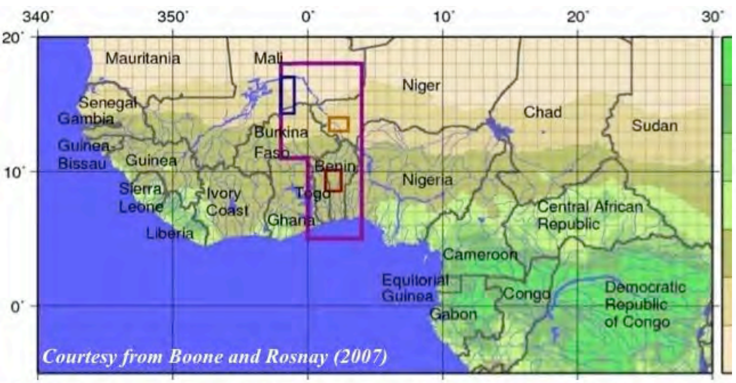




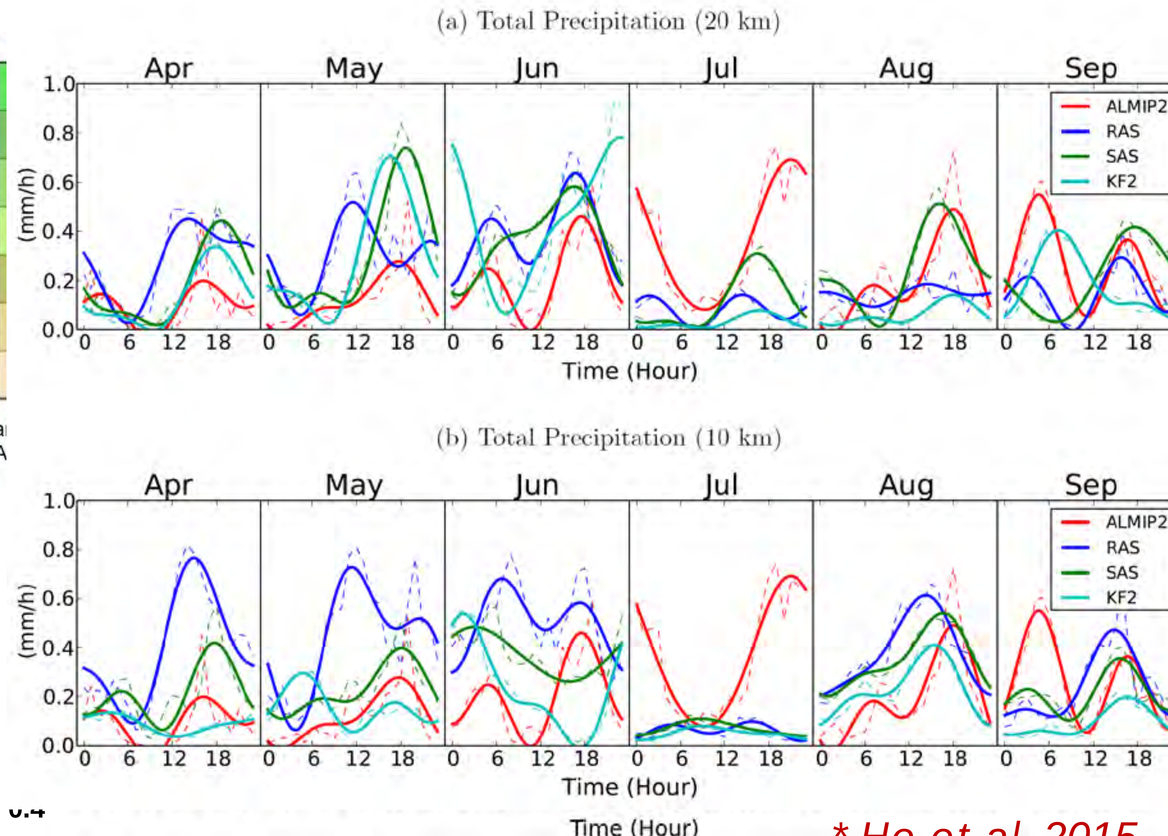
+ Uncertainty in precipitation has heterogeneous global distribution
+ Non-linear impacts in land surface simulations

* *Kim 2010*

Diurnal Cycle over African Monsoon Region

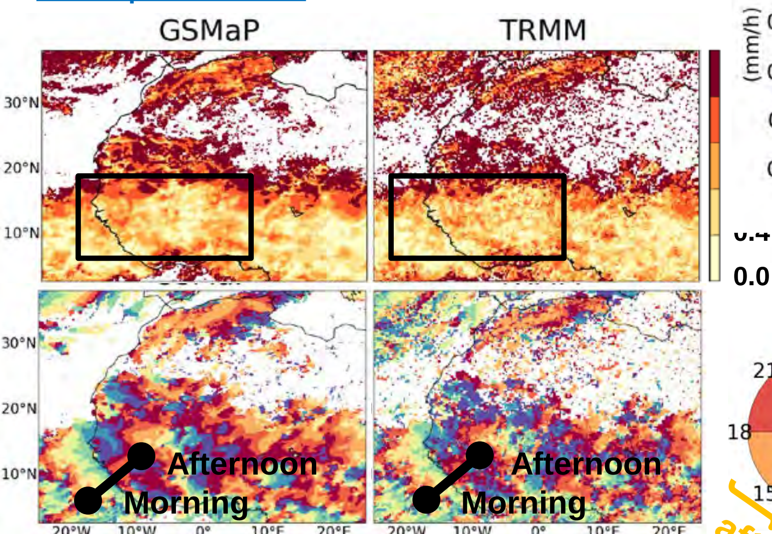


Location of three meso-scale sites: Oueme-Benin (red), South-West Niger (orange) and Gourma-Mali (blue). Contours correspond to the annually-averaged Leaf Area Index (LAI m^2m^{-2})



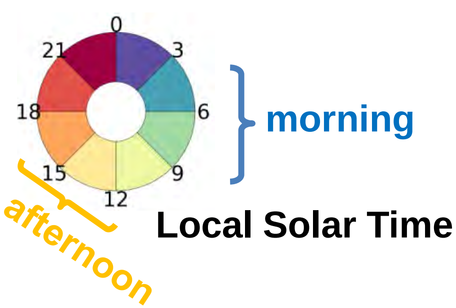
** He et al. 2015*

Amplitude



Phase

land (afternoon)
ocean (morning)



- Diurnal cycle of precipitation highly depends on mode convection schemes
- Satellite products capture diurnal cycle successfully

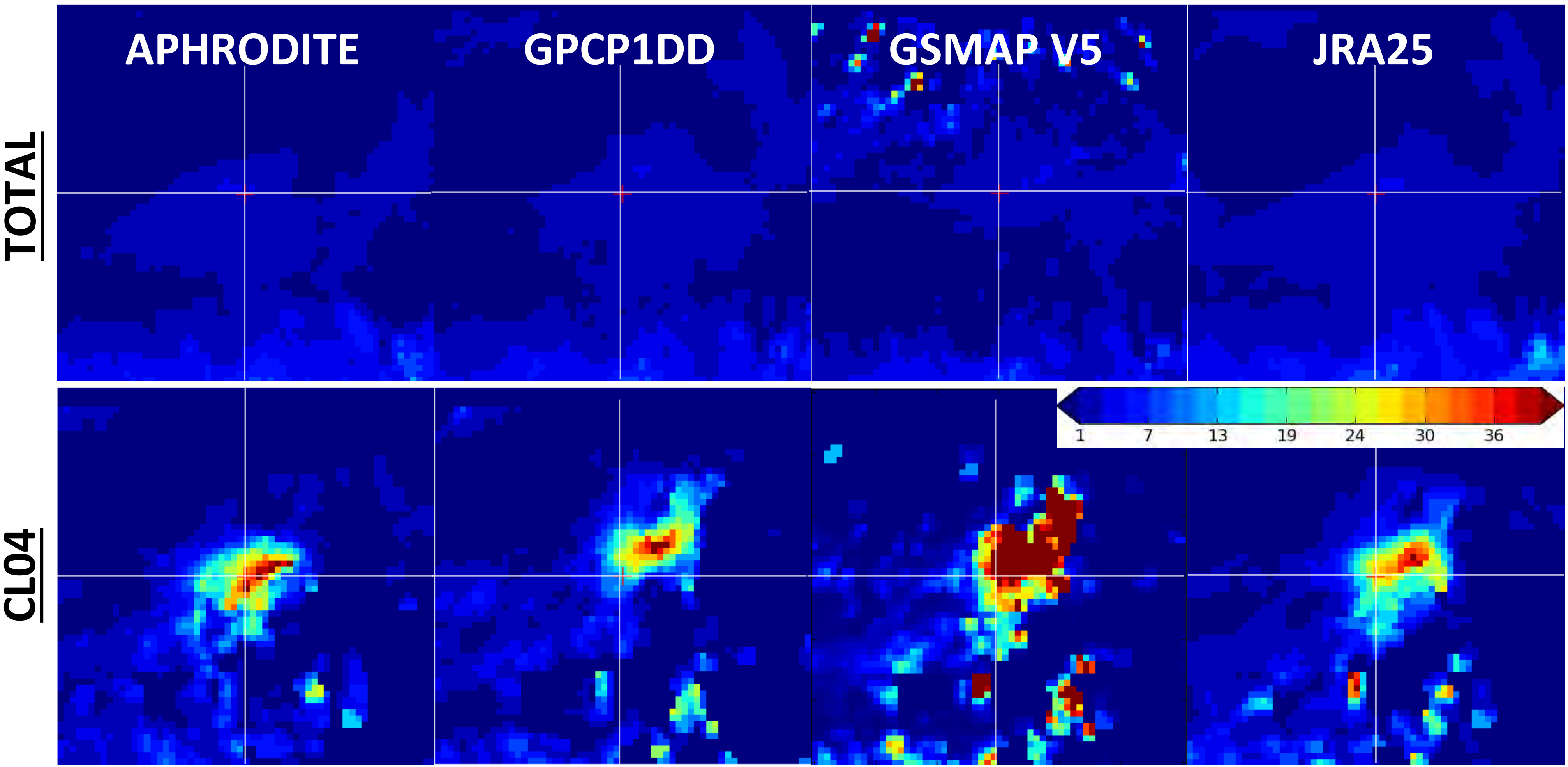
Domain: 30°N – 38°N; 60°E – 149°E

Precipitation Composite for @ 2001 – 2004 (DJF)

Intercomparison for Extratropical Cyclone

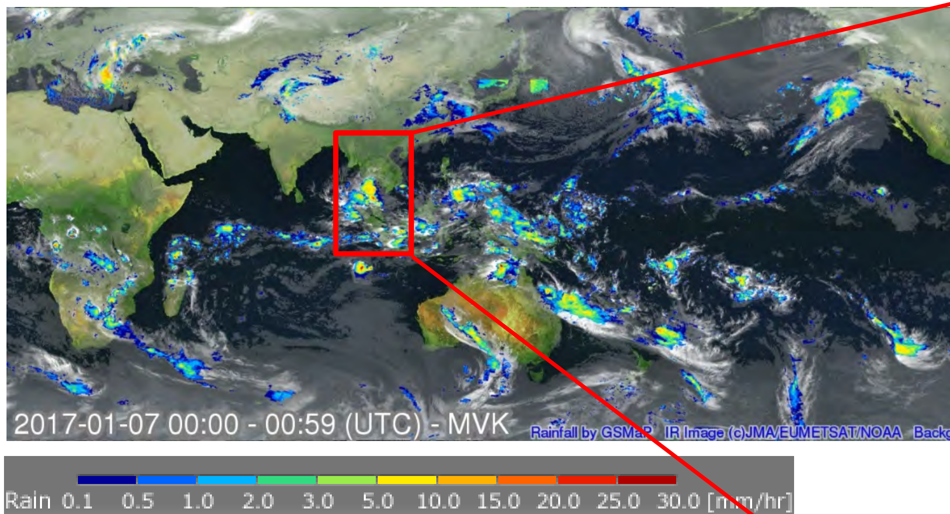
Class	Central Pressure Gradient
CL01	0.3 – 5.0 [hPa/1000km]
CL02	5.0 – 10.0
CL03	10.0 – 15.0
CL04	15.0 –

Product	Type	S. Res.	T. Res.	Period
[1]APHRODITE	Gauge	0.25°	Daily	1951 – 2007
[2]GPCP 1DD	Hybrid	1.0 °	Daily	1996 – 2009
[3]GSMaP V5.222.1	Satellite	0.1°	Hourly	2000 – 2010
[4]JRA25	Reanalysis	T106°	Monthly	1979 –



Global Satellite Mapping of Precipitation (GSMaP)

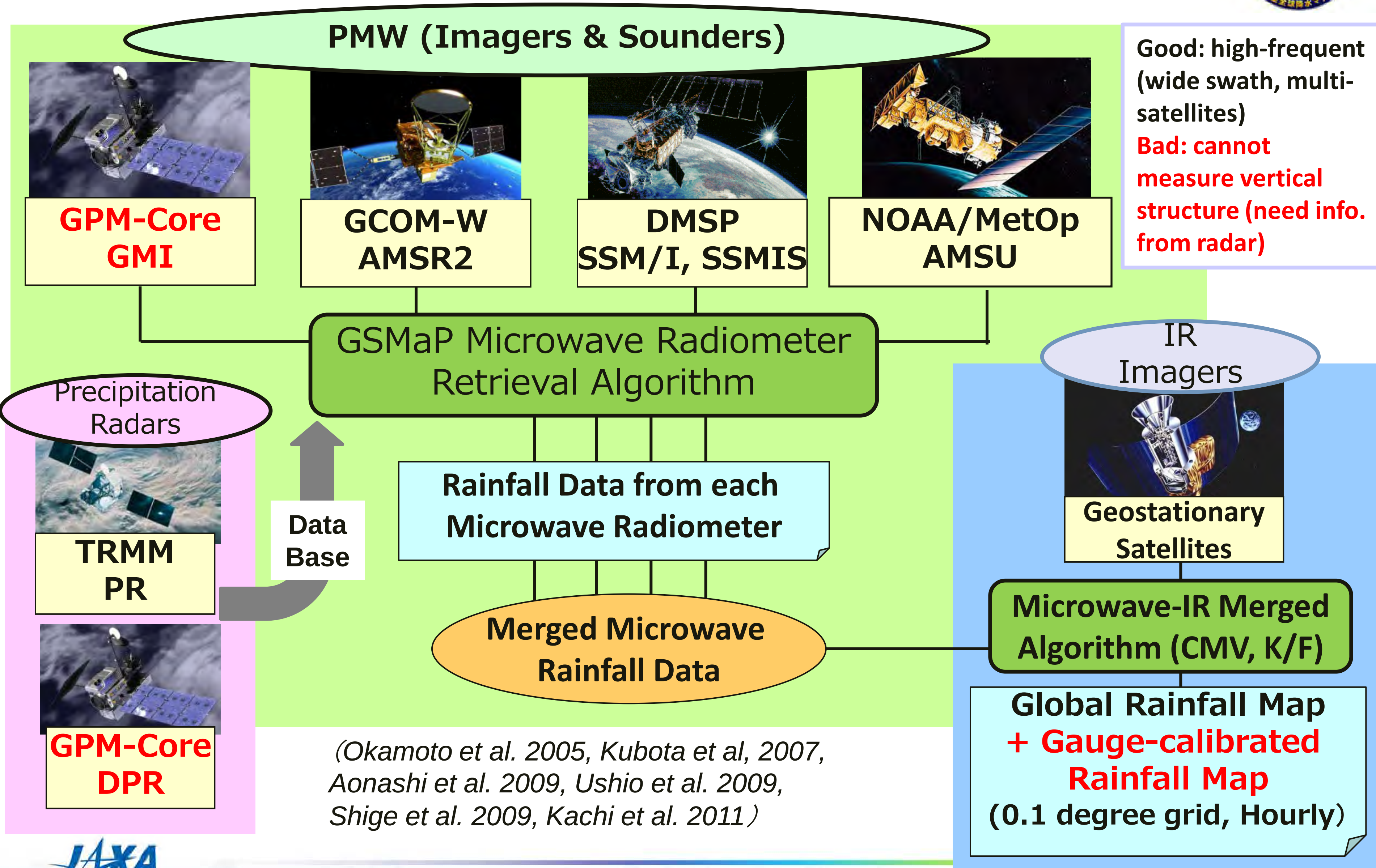
GSMaP_NRT hourly rain with Himawari-8 cloud (1-12 Jan 2017)



http://sharaku.eorc.jaxa.jp/GSMaP/

- GSMaP is a blended Microwave-IR product and has been developed in Japan toward the GPM mission (as JAXA GPM standard product).
  - U.S. counterpart is “IMERG”
  - GSMaP (v6) data since Mar. 2000 period was reprocessing as reanalysis version (GSMaP_RNL), and was open to the public on Apr. 2016.
  - New version, GSMaP (v7) was released on 17 Jan. 2017.

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)

http://sharaku.eorc.jaxa.jp/GSMaP/

GSMaP Product list

Product name	Variables	Resolution	Latency	Update interval
Standard product	Hourly Precip Rate (**GSMaP_MVK**)	Horizontal: 0.1×0.1 deg.lat/lon Temporal: 1 hour	3 days	1 hour
	Gauge-adjusted Hourly Precip Rate (**GSMaP_Gauge**)			
Near-real-time product	Hourly Precip Rate (**GSMaP_NRT**)		4 hours	
	Gauge-adjusted Hourly Precip Rate (GSMaP_Gauge_NRT)			
Real-time product	Hourly Precip Rate (**GSMaP_NOW**)		0 hours	0.5 hour

In addition, there are reanalysis products (GSMaP_RNL, GSMaP_RNL_Gauge), calculated with Japanese 55-year reanalysis (JRA55), and GSMaP Riken NowCast (GSMaP_RNC, Otsuka et al. 2016) by AICS/RIKEN (in preparation).

GSMaP realtime version: GSMaP_NOW (Since Nov. 2015)

- Differences from the GSMaP_NRT
  - Using data that is available within 0.5-hour (GMI, AMSR2 direct receiving data, AMSU direct receiving data and Himawari-IR) to produce GSMaP at 0.5-hr before (observation).
  - Applying 0.5-hour forward extrapolation (future direction) by cloud motion vector to produce GSMaP at current hour (just now).

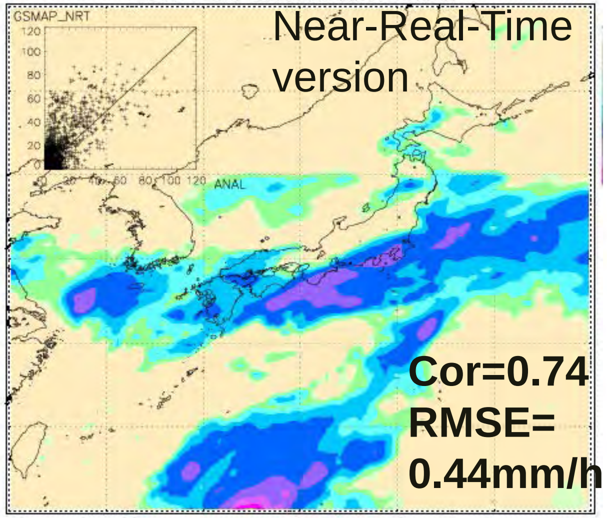
http://sharaku.eorc.jaxa.jp/GSMaP_NOW/

Description
Variable: Rainfall rate (mm/hr)
Grid resolution: 0.1 degree lat/lon
Temporal resolution: 1 hour
Update interval: 30 min
Data latency: 0-hour after observation
Domain: JMA "Himawari" area

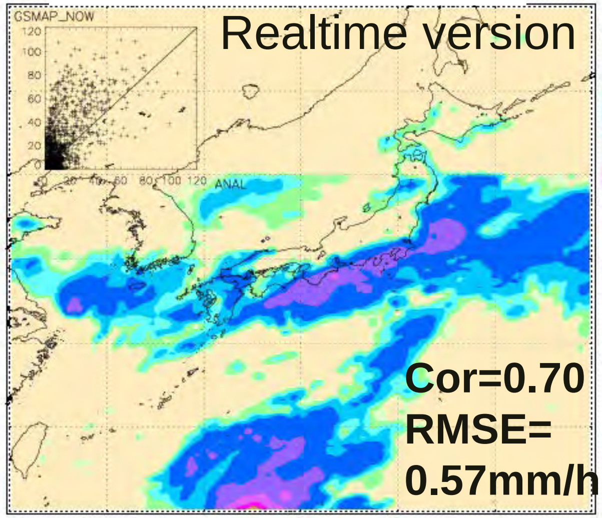
Future extension to the global domain using the EUMETSAT/NOAA GEO data

Snapshots of Daily Validation

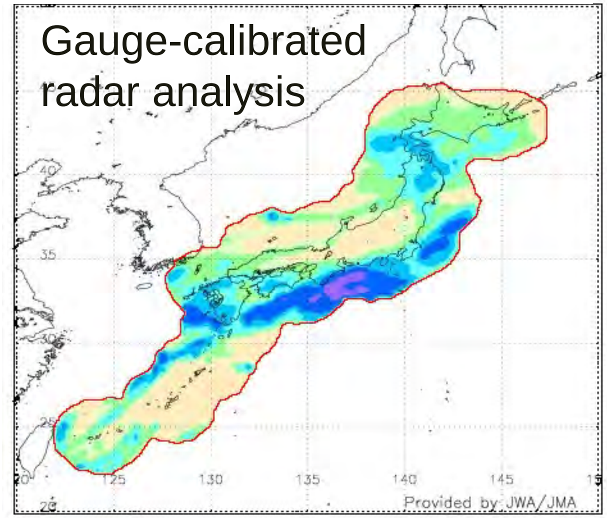
GSMaP_NRT



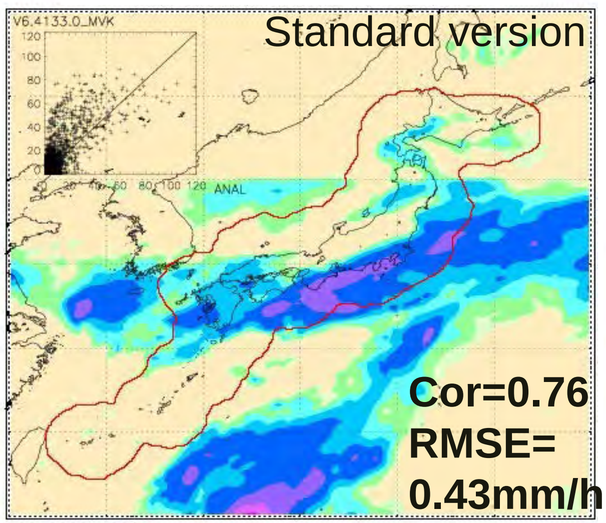
GSMaP_NOW



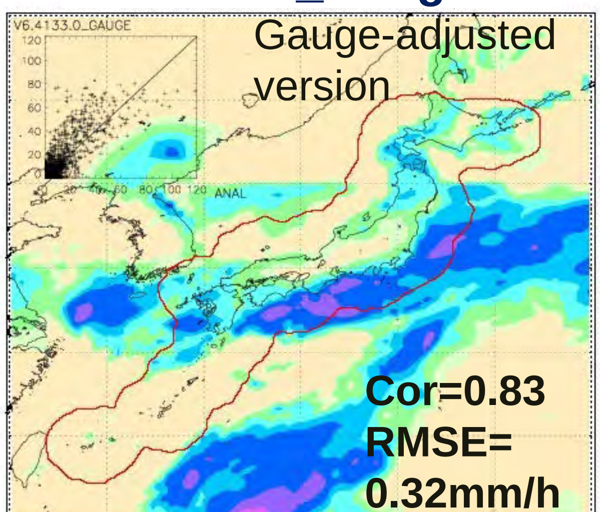
JMA's Radar-AMeDAS

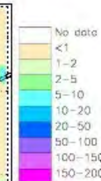


GSMaP_MVK



GSMaP_Gauge

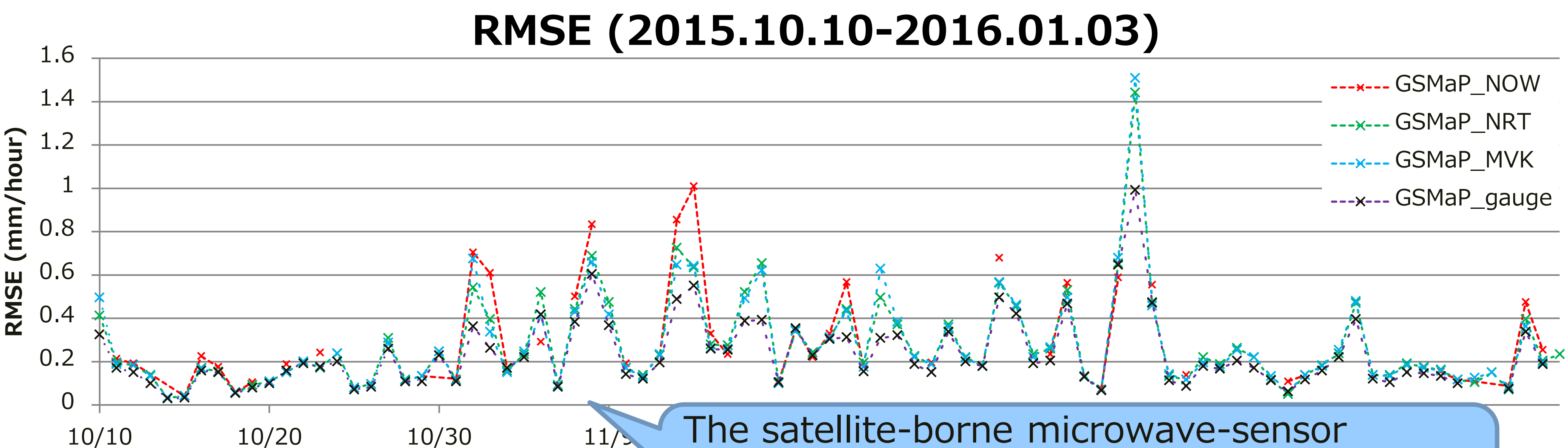




Nov. 23, 2015
in 0.25 degree grid
and daily accumulation

Validation using JMA's Radar-AMeDAS

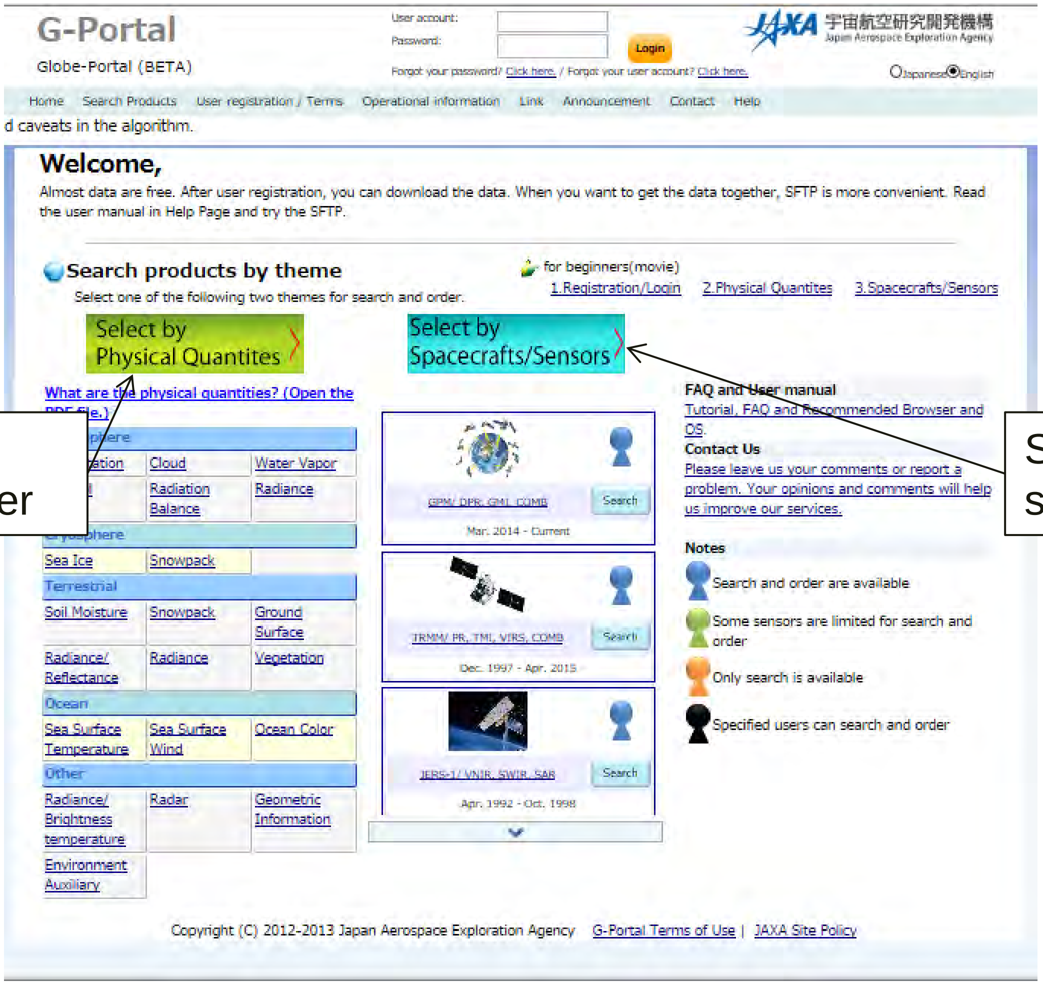
- Following GSMaP products were compared with JMA's Radar-AMeDAS (gauge-calibrated radar analysis rainfall) around Japan in 0.25 degree grid and daily accumulation for the period from Oct. 10, 2015 to Jan. 3, 2016.
  - **GSMaP_NOW: GSMaP Realtime version (latency: 0 hour)**
  - **GSMaP_NRT: GSMaP Near-Real-Time** version (latency: 4 hour)
  - **GSMaP_MVK: GSMaP Standard** version (latency: 3 days)
  - **GSMaP_Gauge: Gauge-adjusted** version (latency: 3 days)



The satellite-borne microwave-sensor coverage is decreased with latencies earlier.
→ This leads less accurate estimates.

Globe Portal (G-Portal)

https://www.gportal.jaxa.jp/



Select by category / geophysical parameter

Select by satellite / sensor name

Format

- HDF
- txt(only GSMaP)

How Does It Work In the Real World?

Torrential precipitation over Kanto-area, Japan between Sep. 9 – 10, 2015 caused flood disaster in Tone-river basin.

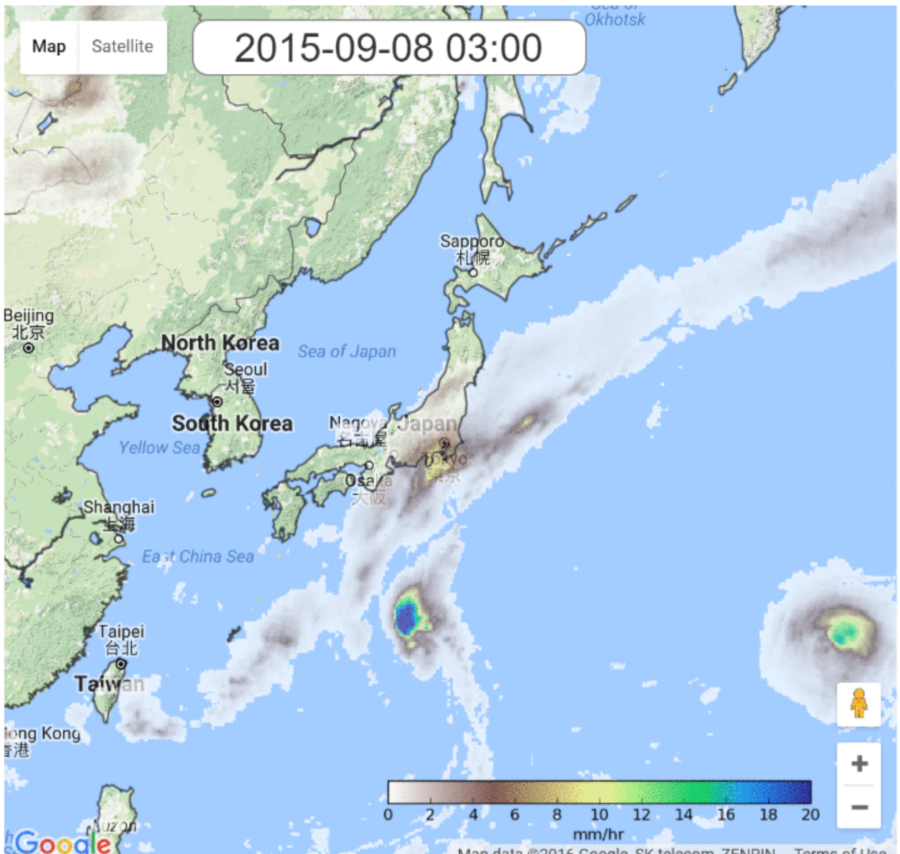
Photo Courtesy of Yuta Ishitsuka

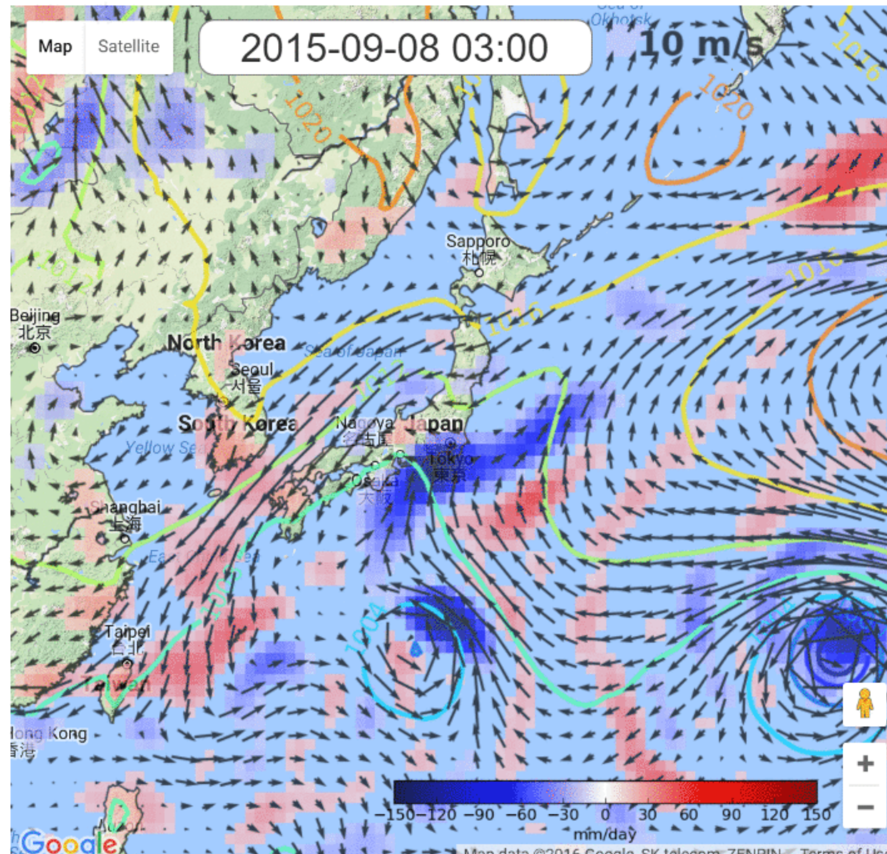
hydro.iis.u-tokyo.ac.jp/~hjkim/FLOOD.H27KT/app/

H27.09 KANTO/TOHOKU HEAVY RAIN (a.k.a. KINUGAWA KOUZUI)

GSMaP Precipitation (shade:left), JRA55 Column Integrated Water Vapor Divergence (shade:right), JRA55 Wind@900mb (vector:right), JRA Mean Sea Level Pressure (contour:right)

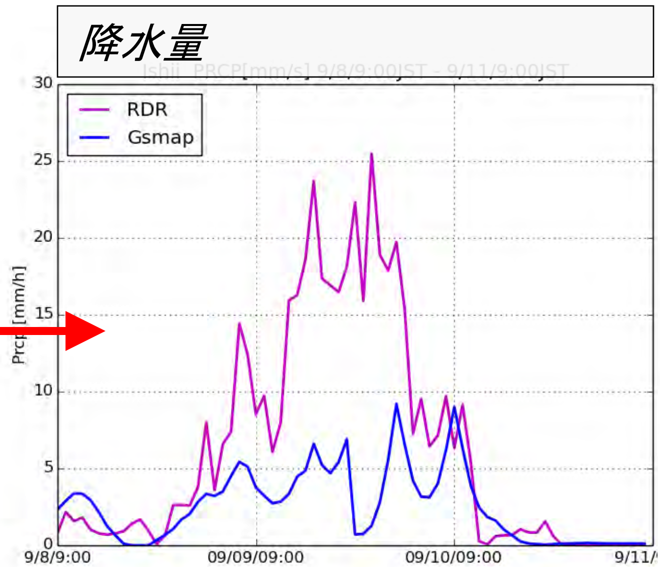
Rate: 1000ms Opacity: 70%

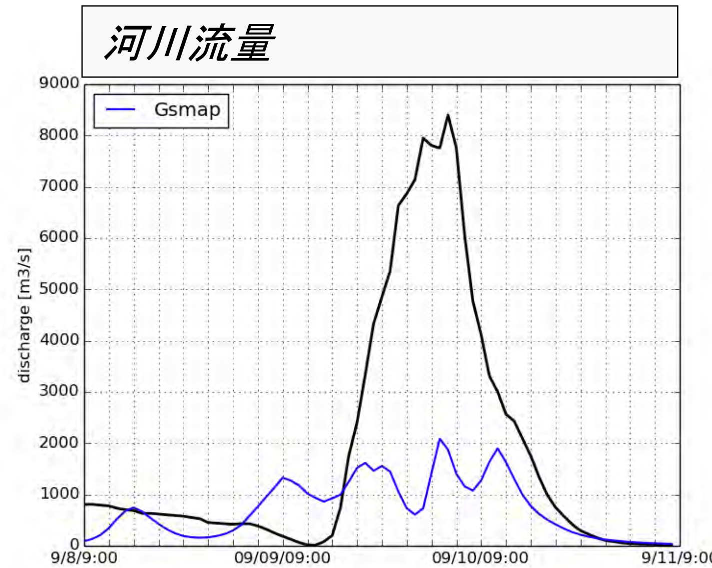


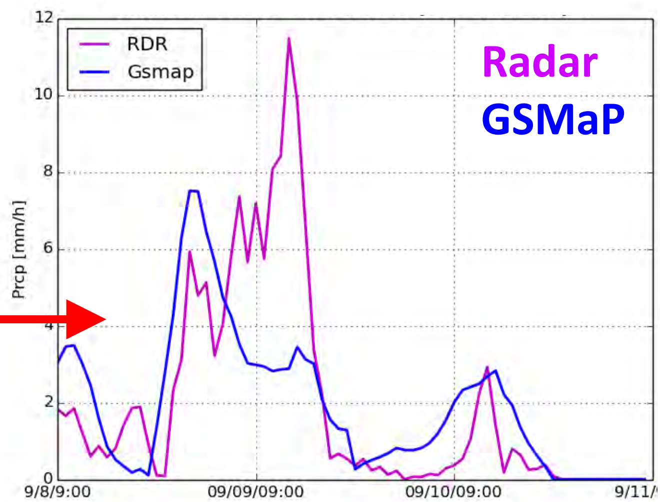


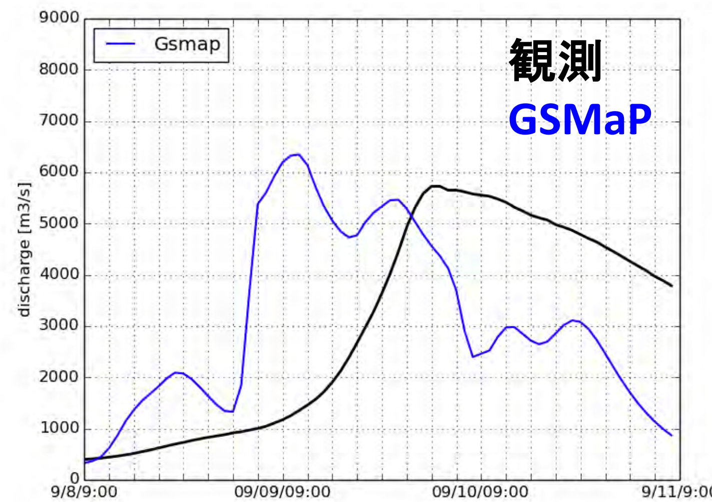
http://hydro.iis.u-tokyo.ac.jp/~hjkim/FLOOD.H27KT/app/

Comparison between Satellite and Ground Radar









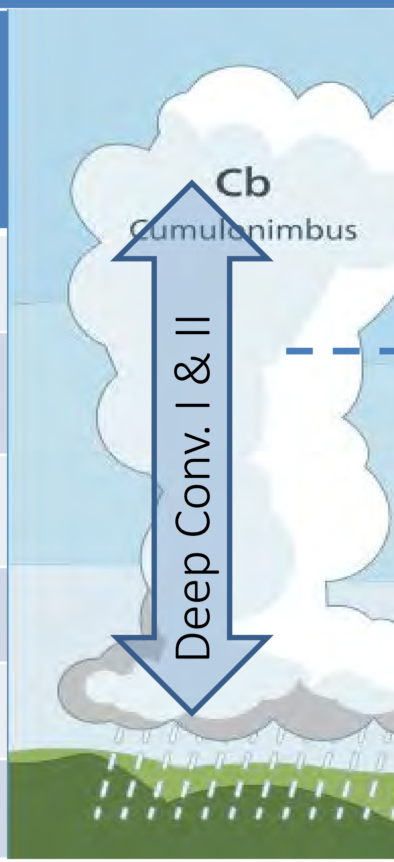
Images Courtesy of http://www.ktr.mlit.go.jp/shimodate/shimodate_know010.html

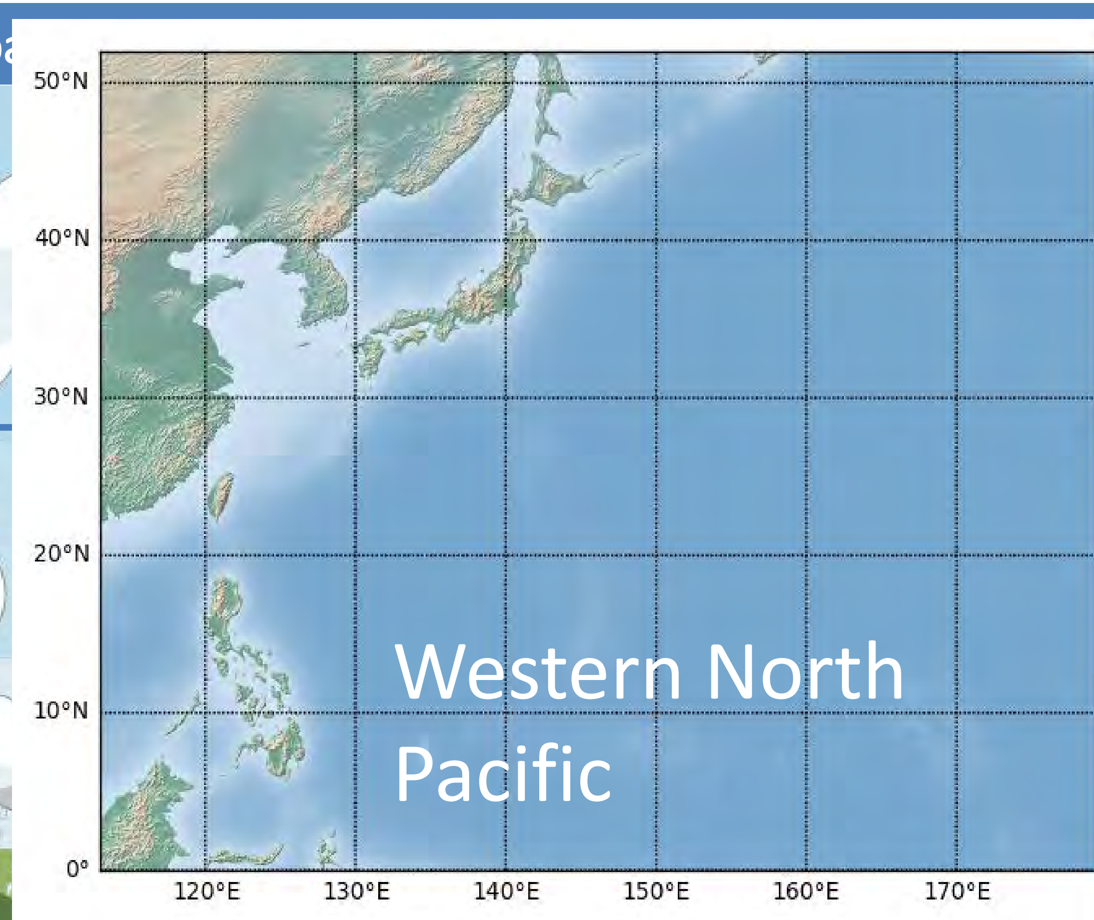
Cloud Mask Based on Geostationary Satellite

Original Data: Satellite Cloud Grid Information by JMA
(Vis. and IR of Himarwari-6)
@ 0.2 deg x 0.25 deg of WN Pacific / hourly
Fractions of each cloud types in a grid-cell

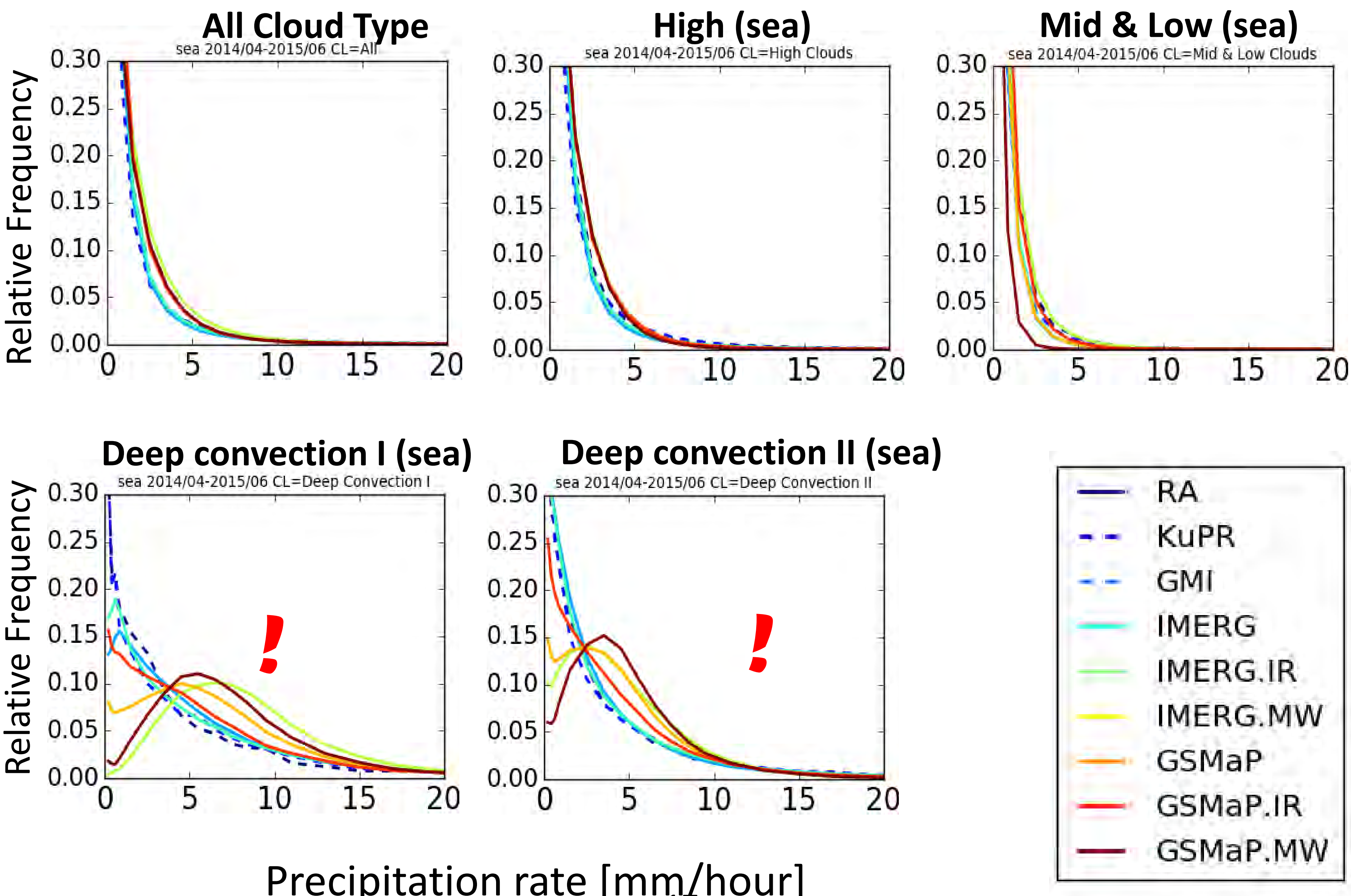
Rule-ba

Types (New classification)
Deep Conv. I
Deep Conv. II
High
Mid & Low
Mixed
Clear Sky



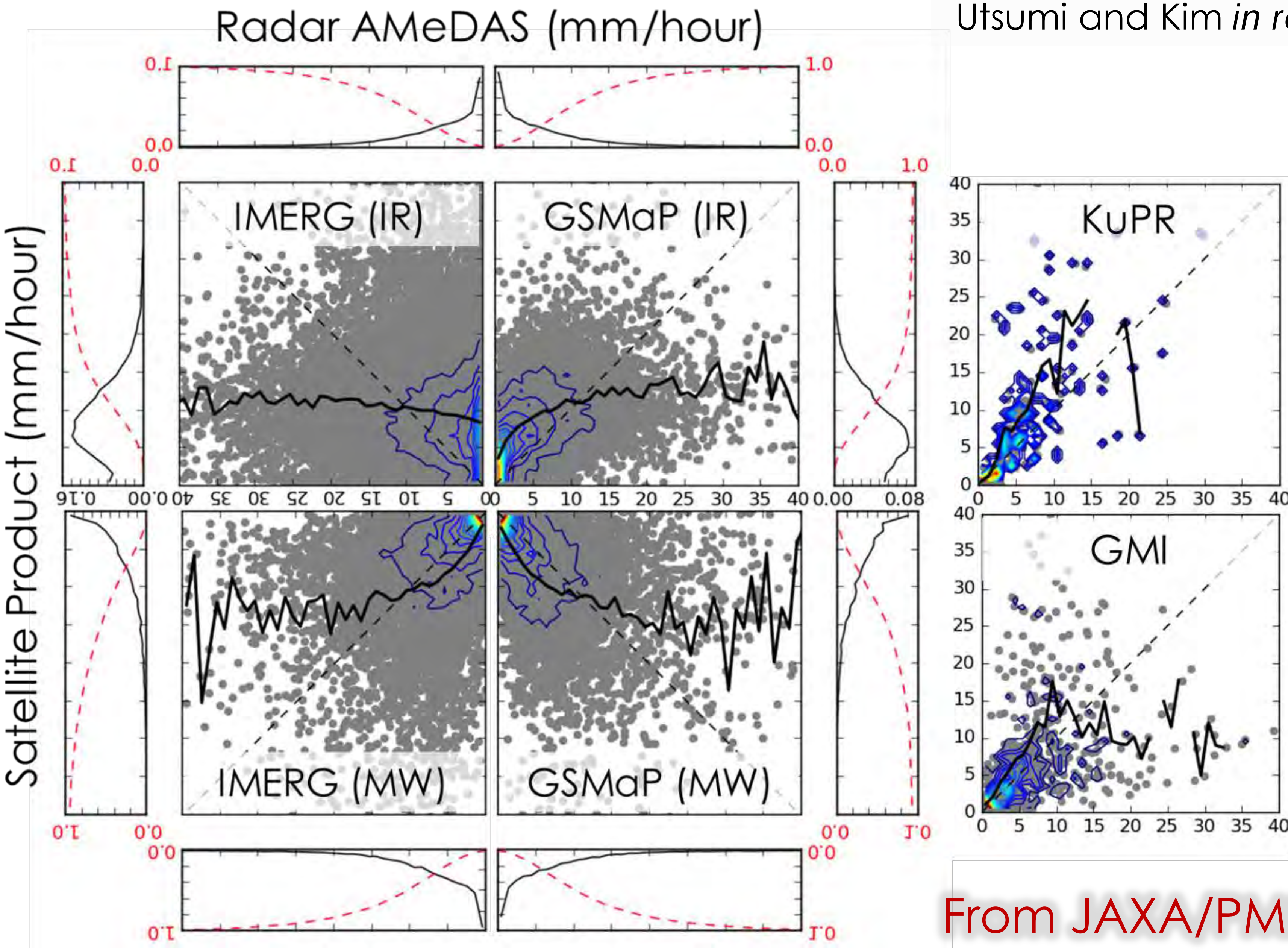


Relative Frequency



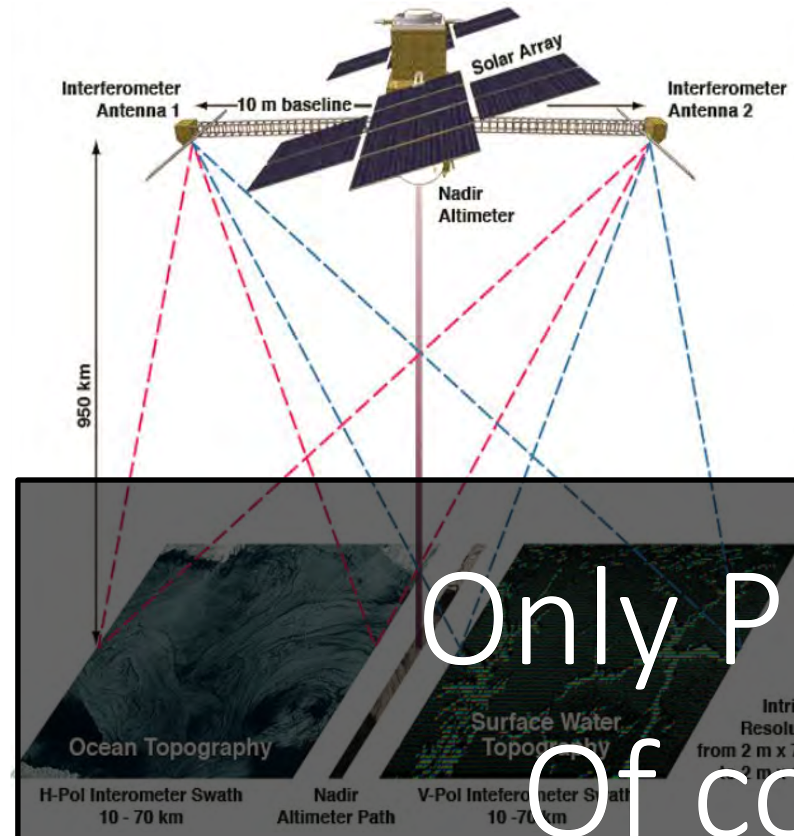
Retrieval Sensitivity by Cloud Types /* Cumulonimbus */

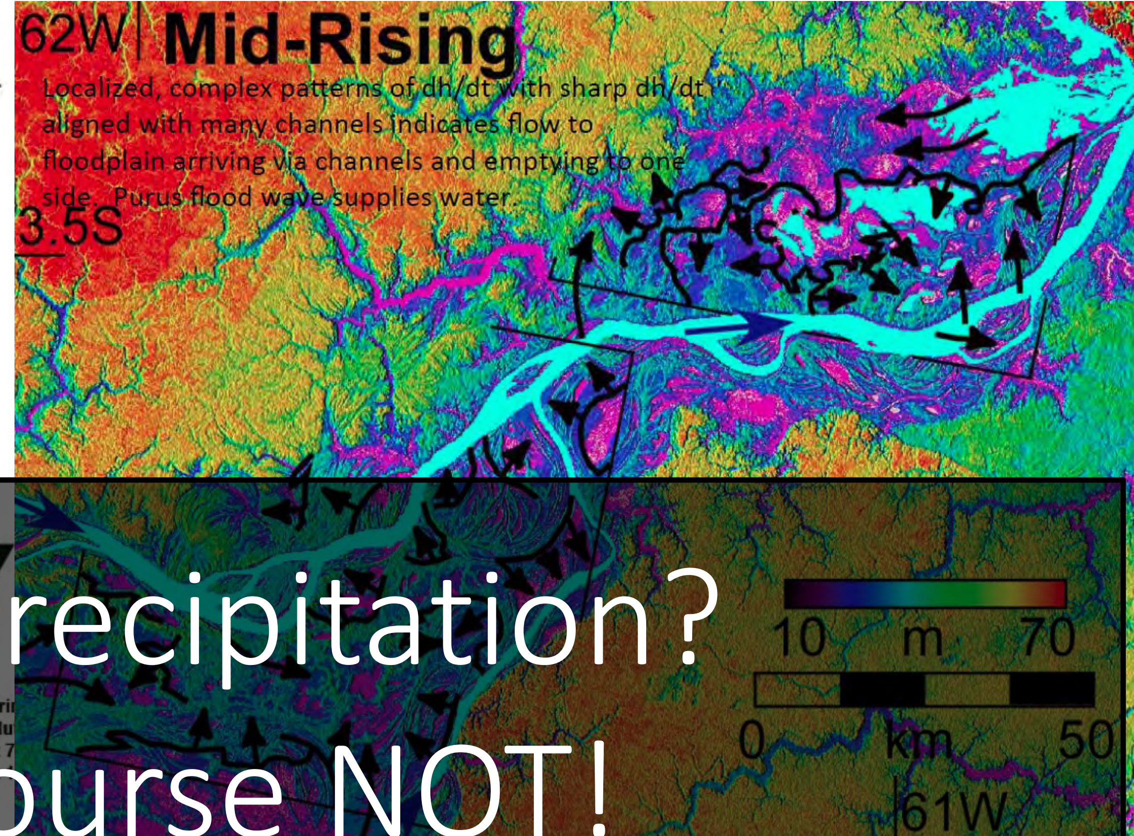
Utsumi and Kim *in revision*

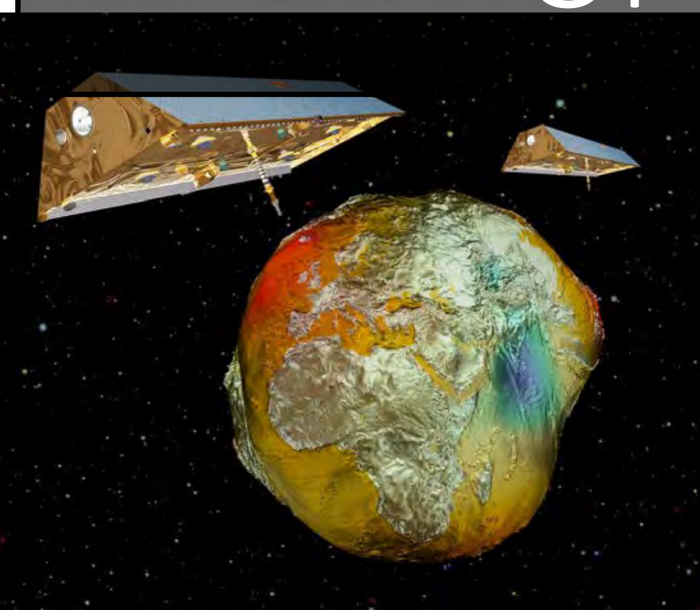


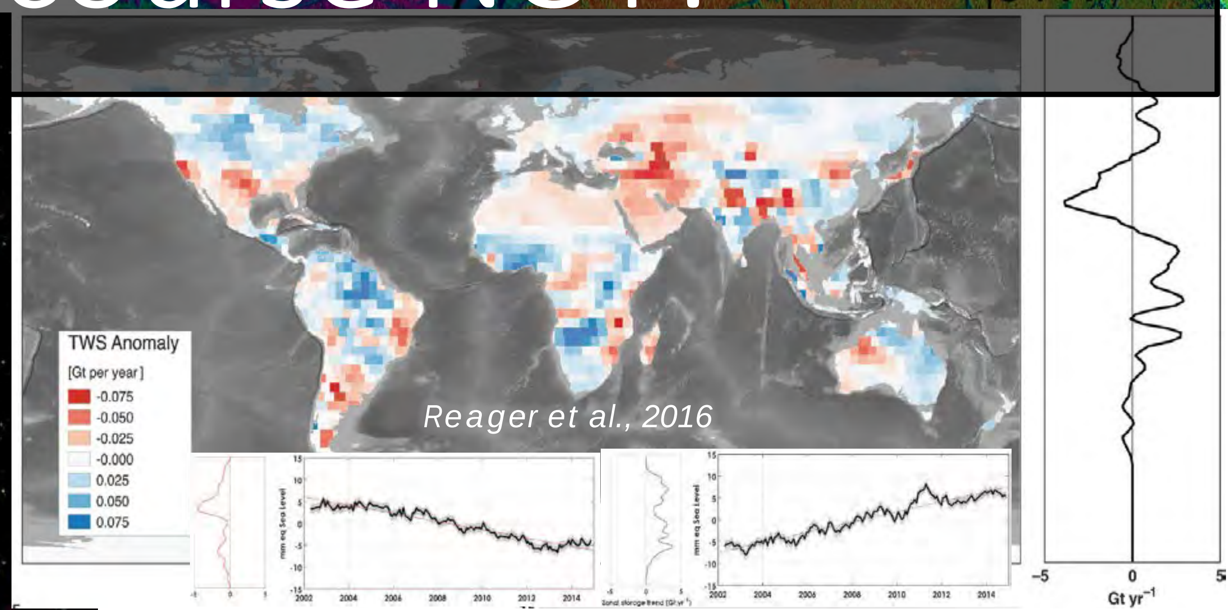
From JAXA/PMM 8th

Only Precipitation?
Of course NOT!









Reager et al., 2016

Summary

+ **Precipitation products include various systematic biases which affects land surface simulation in asymmetric way.**
+ **GPM-GSMaP V05 (algorithm version 7) data was released on Jan. 2017.**
+ **GSMaP realtime product (GSMaP_NOW)**

  - The data in the domain of GEO-Himawari (JMA meteorological satellite) was open to the public on Nov. 2015.

  - Extension to the global domain using the EUMETSAT and the NOAA GEO data will be planed.
+ **Significant underestimation found in atmospheric river type precipitation**
+ **Cloud type dependencies of the bias structures are found.**
  - KuPR ≃ GMI @ Deep conv (sea)
  - KuPR > GMI @ High clouds, Mid&Low clouds (sea)

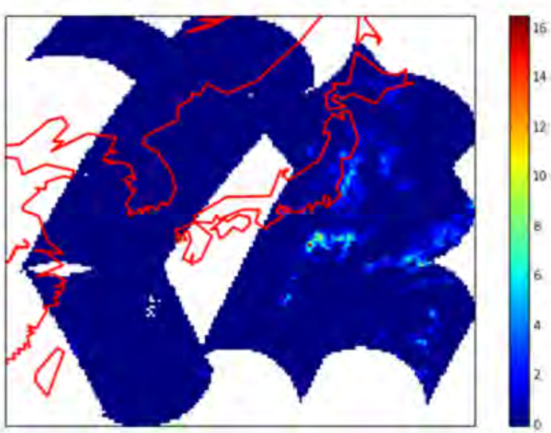
  - IR-based products show weak precipitation of Deep convection is overestimated.

GPyM: a Python Module to Interface TRMM/GPM Data

```
In [2]: from GPyM import GPM

In [3]: prdLv   = 'L2'
        prdVer  = '03'
        #prdName = 'GPM.KuPR'
        #varName = 'NS/SLV/precipRateESurface'
        prdName = 'GPM.GMI'
        varName = 'S1/surfacePrecipitation'

In [4]: gpm = GPM( prdName, prdLv, prdVer )

In [5]: sdtime = datetime(2014,4,30,12)
        edtime = datetime(2014,5,2,12)
        domain = [[20,118],[48,150]]
        res    = 0.2

In [7]: jp = gpm( varName, sdtime, edtime, domain, res)
        * [_] ground track dimension (cached): /tank/hjkim/GPM/GPM.GMI/L2/03/2014/04/GPMCOR_GMI_1404301136_1308_000962_L2S_GL2_03C.h5
        * [_] ground track dimension (cached): /tank/hjkim/GPM/GPM.GMI/L2/03/2014/04/GPMCOR_GMI_1404301308_1441_000963_L2S_GL2_03C.h5
        * [V] ground track dimension (cached): /tank/hjkim/GPM/GPM.GMI/L2/03/2014/04/GPMCOR_GMI_1404301441_1613_000964_L2S_GL2_03C.h5
        * [V] ground track dimension (cached): /tank/hjkim/GPM/GPM.GMI/L2/03/2014/04/GPMCOR_GMI_1404301613_1746_000965_L2S_GL2_03C.h5
        * [_] ground track dimension (cached): /tank/hjkim/GPM/GPM.GMI/L2/03/2014/04/GPMCOR_GMI_1404301746_1918_000966_L2S_GL2_03C.h5
        * [_] ground track dimension (cached): /tank/hjkim/GPM/GPM.GMI/L2/03/2014/04/GPMCOR_GMI_1404301918_2051_000967_L2S_GL2_03C.h5
```

```
        [READ_HDF5] /tank/hjkim/GPM/GPM.GMI/L2/03/2014/05/GPMCOR_GMI_1405012305_0037_000985_L2S_GL2_03C.h5 (2962, 221) -> (112,
 221)
        [GRANULE2MAP] Domain:[[20, 118], [48, 150]] (112, 221) -> (140, 160)
        [READ_HDF5] /tank/hjkim/GPM/GPM.GMI/L2/03/2014/05/GPMCOR_GMI_1405020037_0210_000986_L2S_GL2_03C.h5 (2962, 221) -> (96, 2
21)
        [GRANULE2MAP] Domain:[[20, 118], [48, 150]] (96, 221) -> (140, 160)
```

```
        M.imshow( ma.masked_less_equal( jp.griddata, 0).sum(0),
                  interpolation='nearest' )
        colorbar()

Out[10]: <matplotlib.colorbar.Colorbar instance at 0x4601ab8>
```



I/O Interface

```
In [2]: gpm = GPM( 'GPM.KuPR', 'L2', '03' )

In [3]: gpmJP = gpm( 'NS/SLV/precipRateESurface',
   ...: datetime(2014, 4, 1, 12), datetime(2014, 4, 3),
   ...: [[30.0, 125.0], [45.0, 145.0]],
   ...: 0.1 )
```

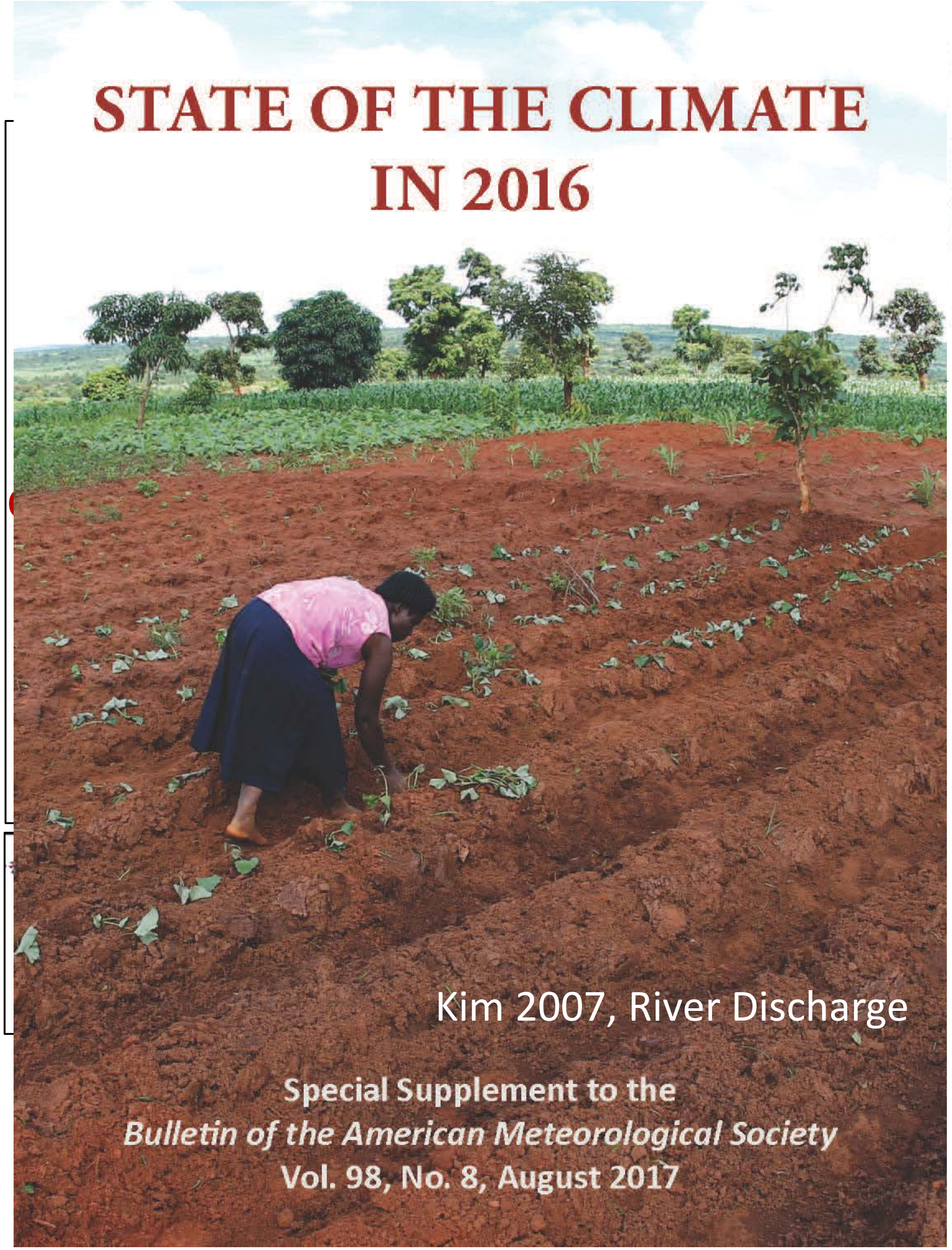
Features

+ Archive data from G-Portal (SFTP protocol)
+ Search granules by timespan and spatial domain
+ Convert and upscale granules to maps
+ Cached IO (e.g., orbits)

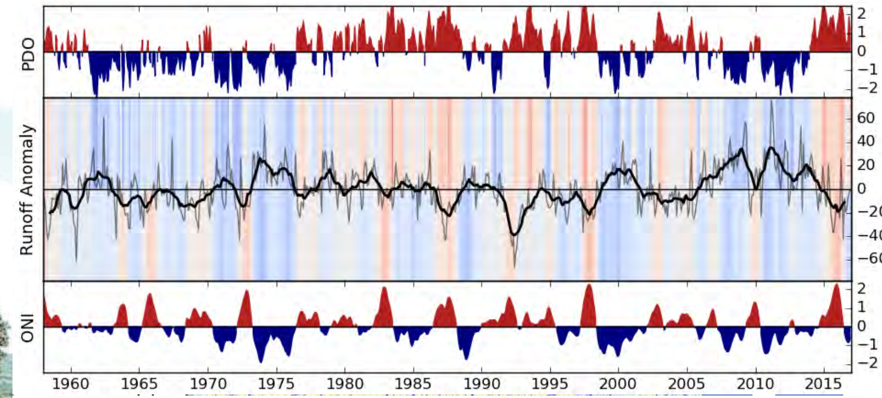
https://github.com/kimlab/GPyM

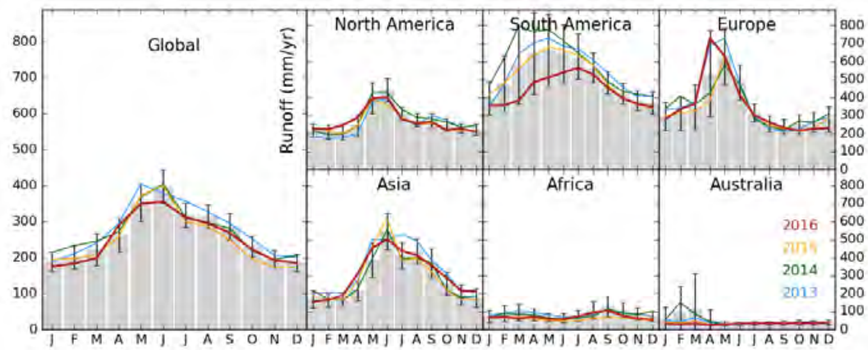
Thank you

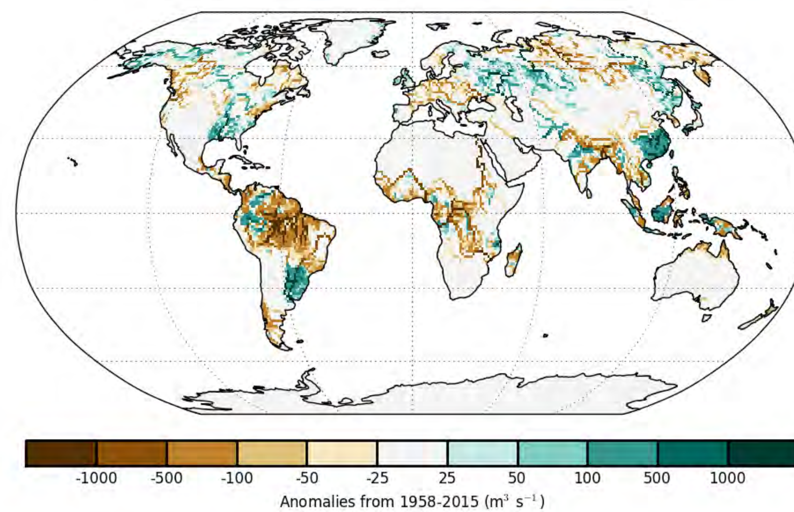
Image courtesy of http://www.satnavi.jaxa.jp/gpmdpr_special/



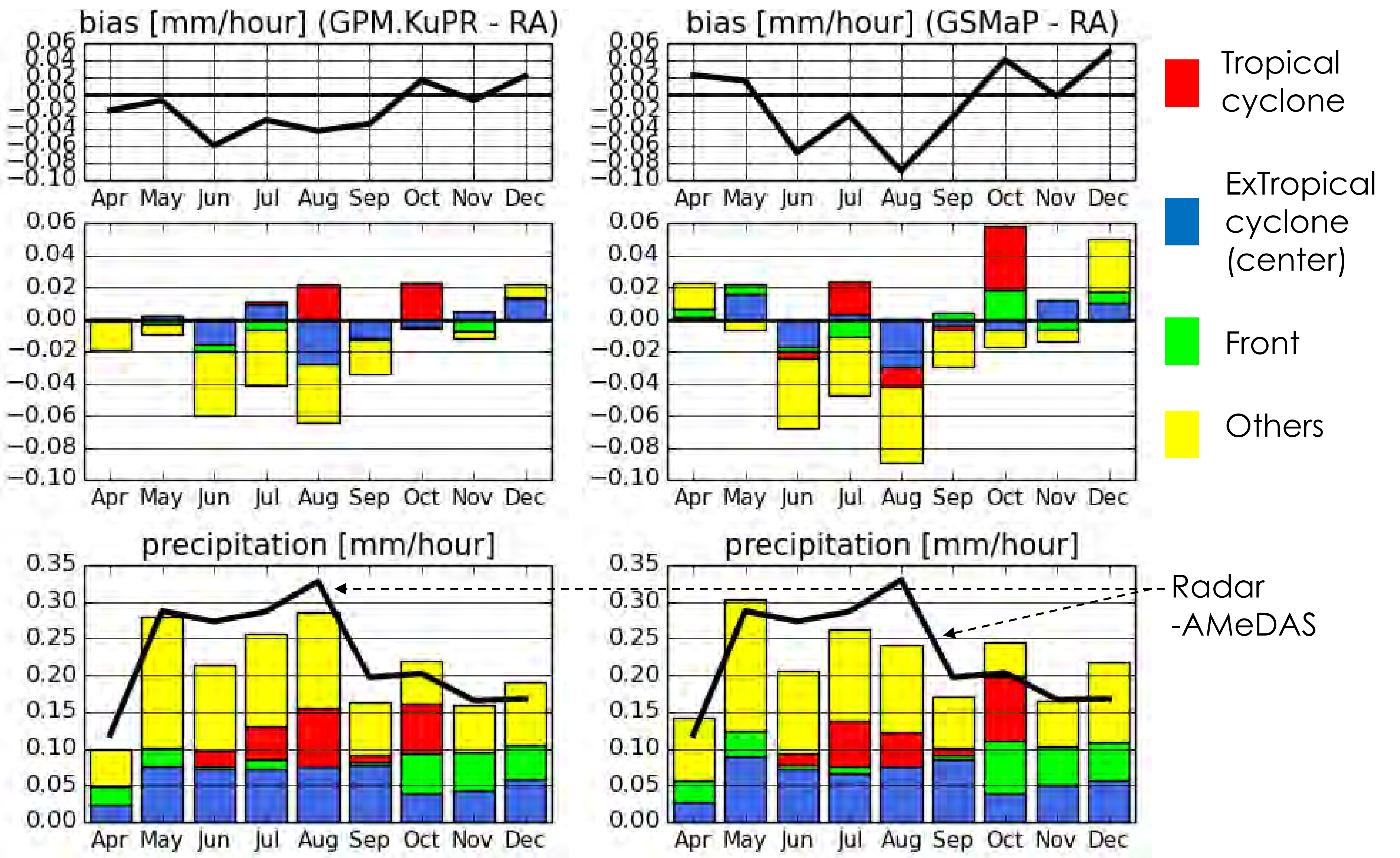
Kim 2007, River Discharge







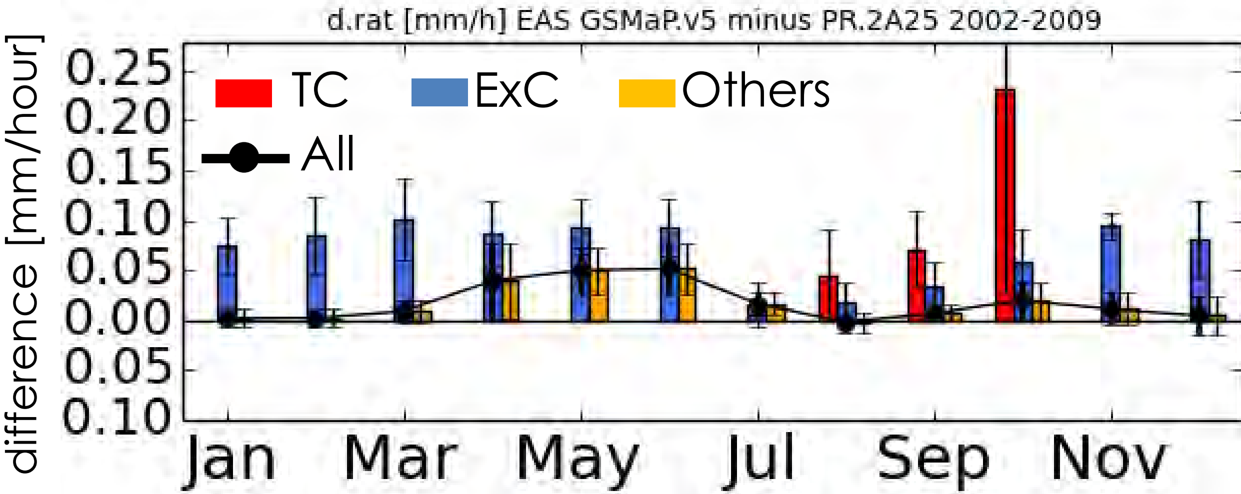
Error Estimation by Weather Systems: Sensitivity

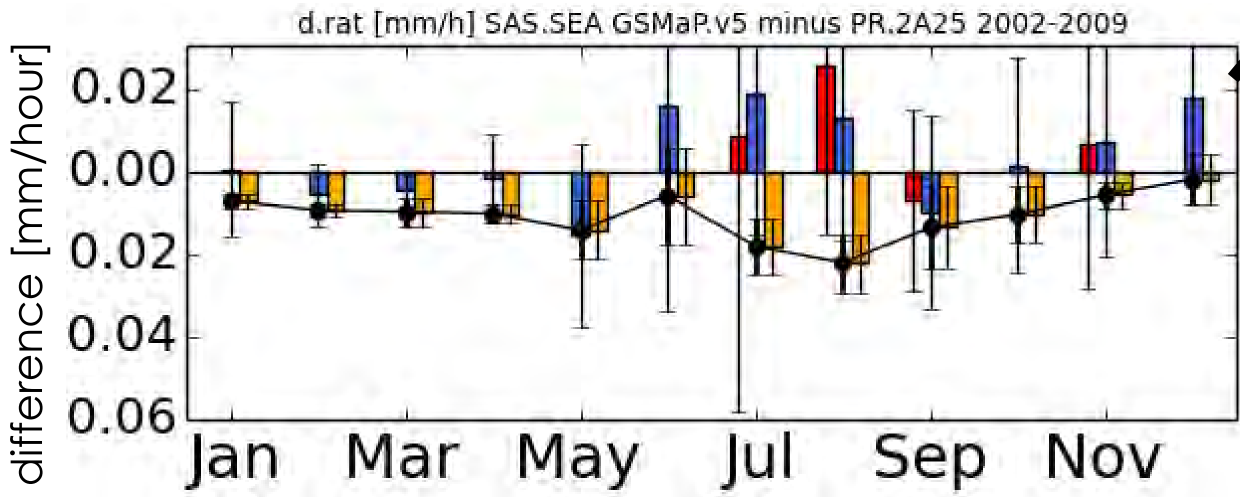


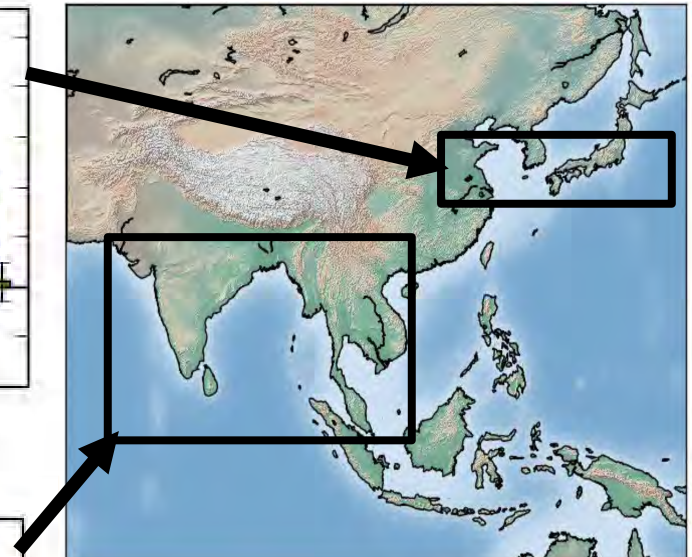
+ Different algorithms show biases of different amounts and directions.

Error Estimation by Weather Systems: Sensitivity

(GSMaPv5 – TRMM/PR 2A25v7; 2002-2009)







Different biases for …
- ✓ Different weather systems
- ✓ Different seasons
- ✓ Different regions

** Utsumi et al., in preparation; Azariah et al., in preparation*

Concluding Remarks

+ Uncertainty in forcing data is one of important uncertainty sources of hydrologic simulations.

+ Multiple precipitation products including satellite measurement show systematic bias by different causal weather systems.

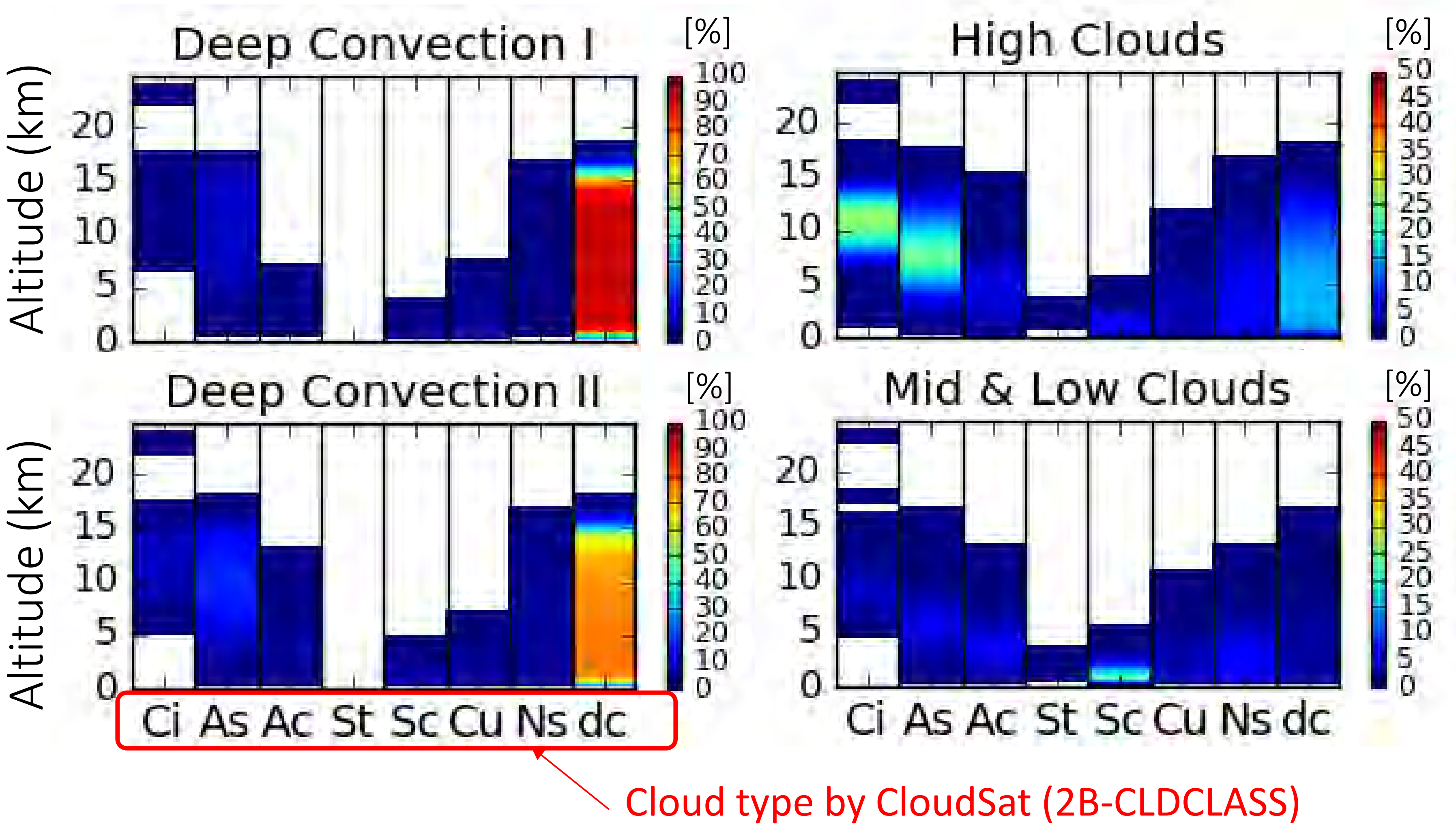
+ Weather system mask is not only useful to classify measurement error and update algorithms but also to trace reasons of water excess (flood) or deficit (drought) in different spatiotemporal scale.

+ Satellite retrieval algorithms show different sensitivities to various cloud types.

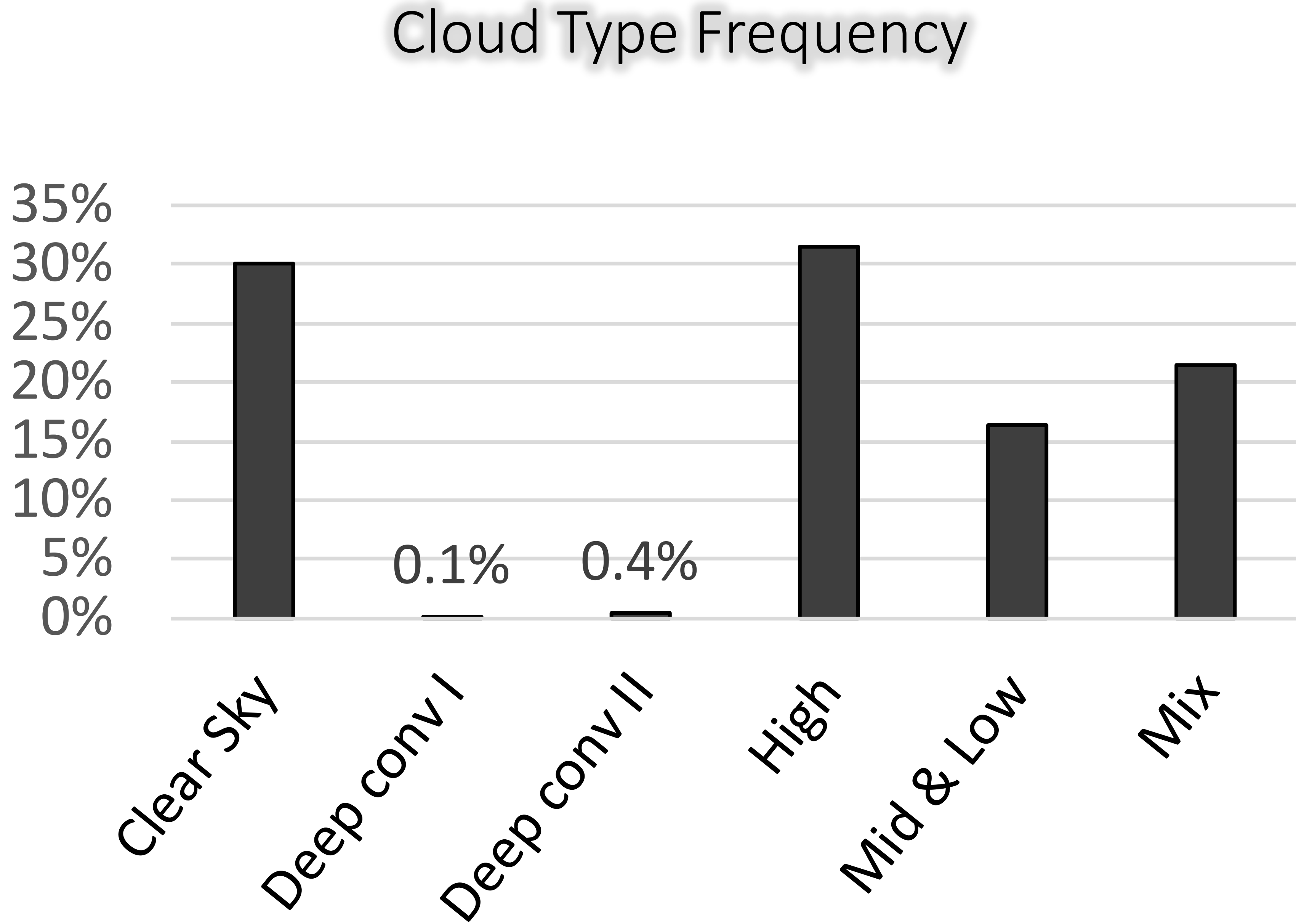
+ Algorithms using IR tend to underestimate week precipitation, but its impact is not considerable in IMERG product.

+ Overall, current satellite precipitation retrievals mostly underestimate precipitation comparing to Radar-AMeDAS.

Validation of Cloud Mask (vs CloudSat)



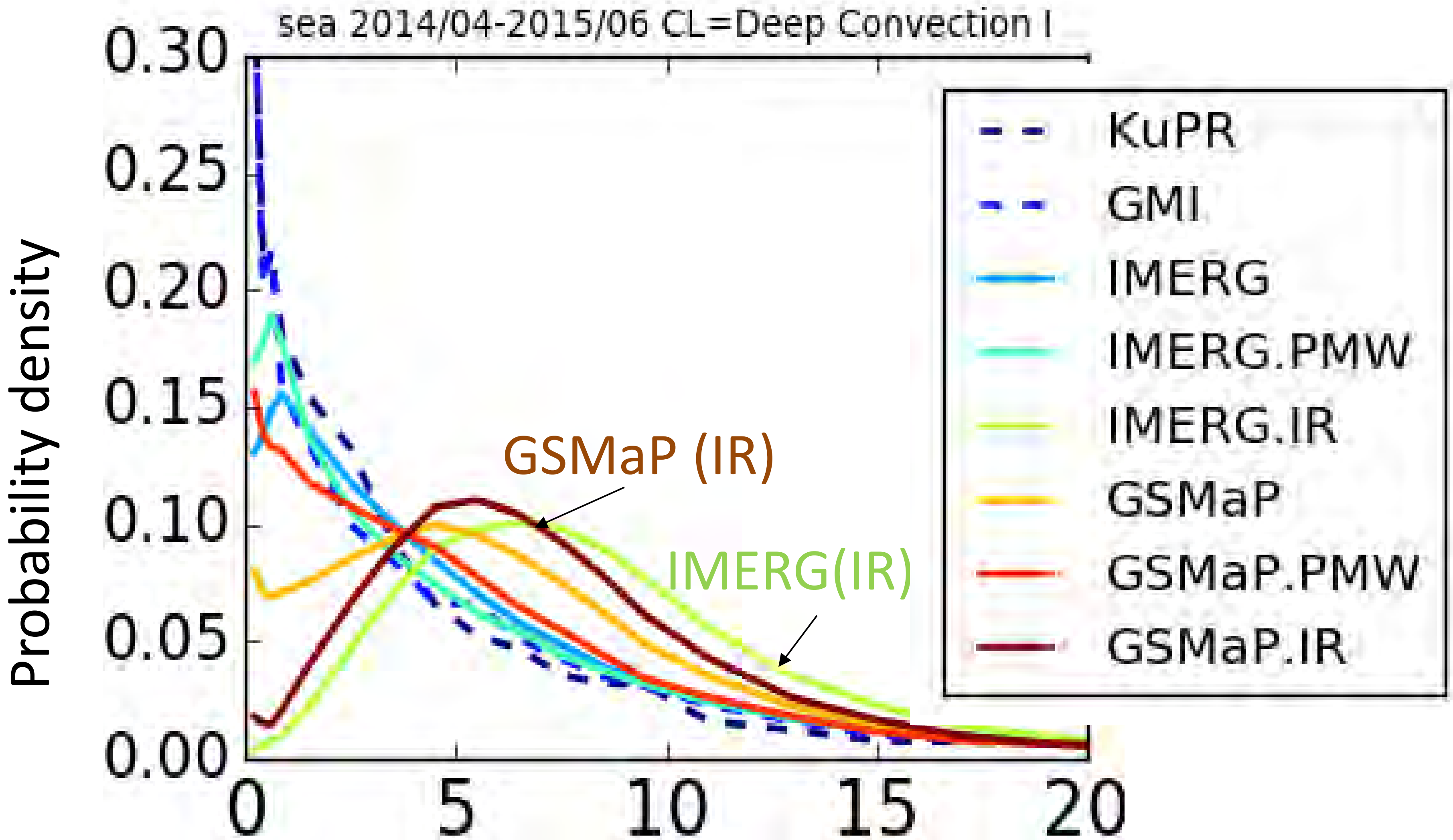
+ Rule based reclassification works properly.
+ Bayesian based classification is under development.



Cloud Type Frequency
35%
30%
25%
20%
15%
10%
5%
0%
0.1%
0.4%
Clear Sky
Deep conv I
Deep conv II
High
Mid & Low
Mix

Relative Frequency

Deep convection I (sea)

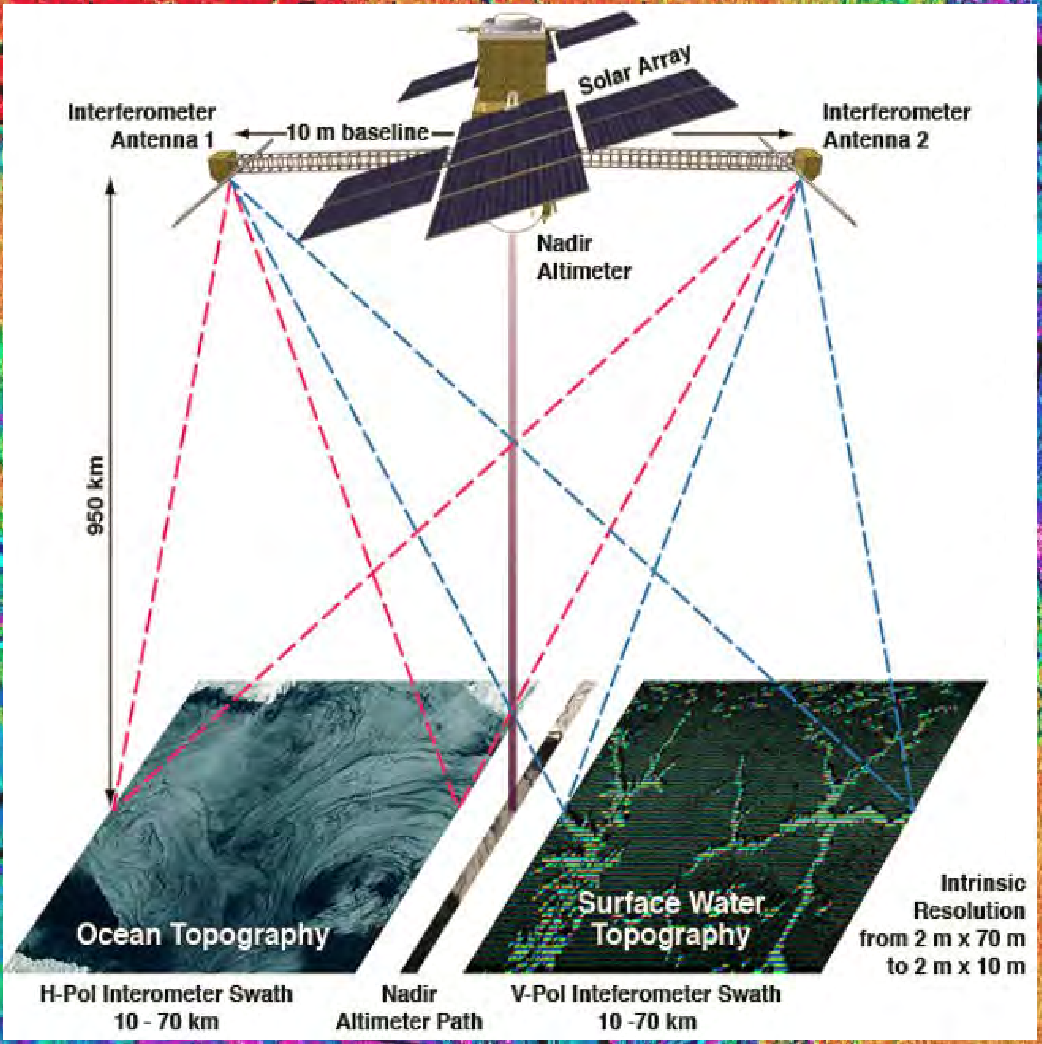


- IR-based products have very different feature for Deep Conv.

62W | Mid-Rising

Localized, complex patterns of dh/dt with sharp dh/dt aligned with many channels indicates flow to floodplain arriving via channels and emptying to one

Surface Water and Ocean Topography



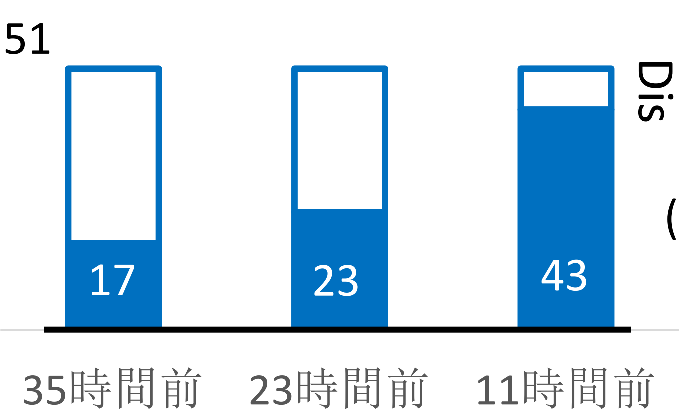
- + Ka-band SAR interferometric system with 2 swaths, 10-60km on each side of the nadir track
- + Produces heights and co-registered all-weather imagery
- + 200MHz bandwidth (0.75cm range resolution) for higher resolution imaging
- + Uses near-nadir returns for SAR altimetry to fill in nadir swath

2014. 04. 08. 11PM, IIS

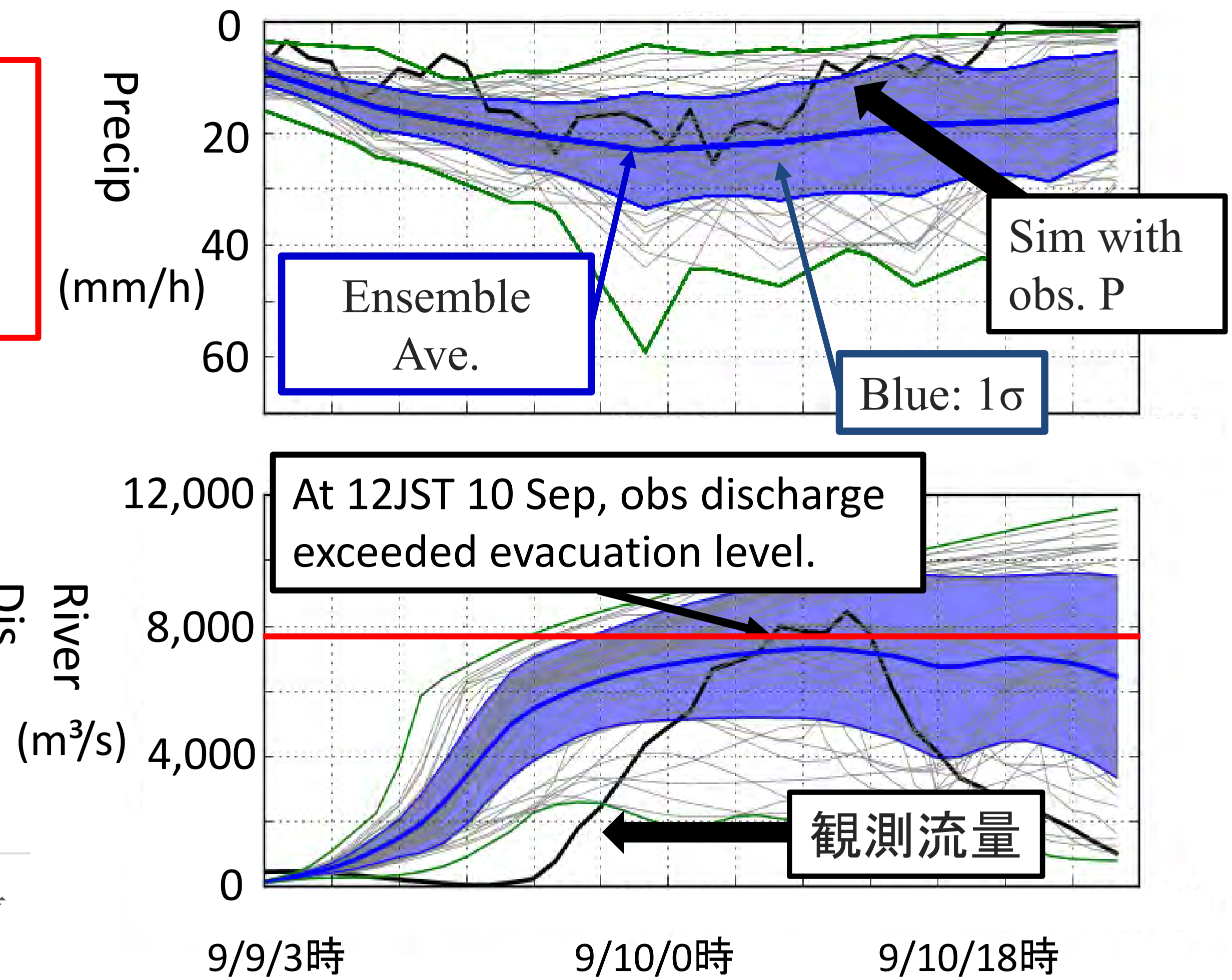
Hindcasted for 2015 Sep Kinu-river flood with **ensemble** precipitation forecast data (up to 32 hours ahead).

Atmos data：
ECMWF ensemble
No. of ensemble：51

When it was surpassed the "evacuation level", our system showed 23/51 were indeed in danger condition.

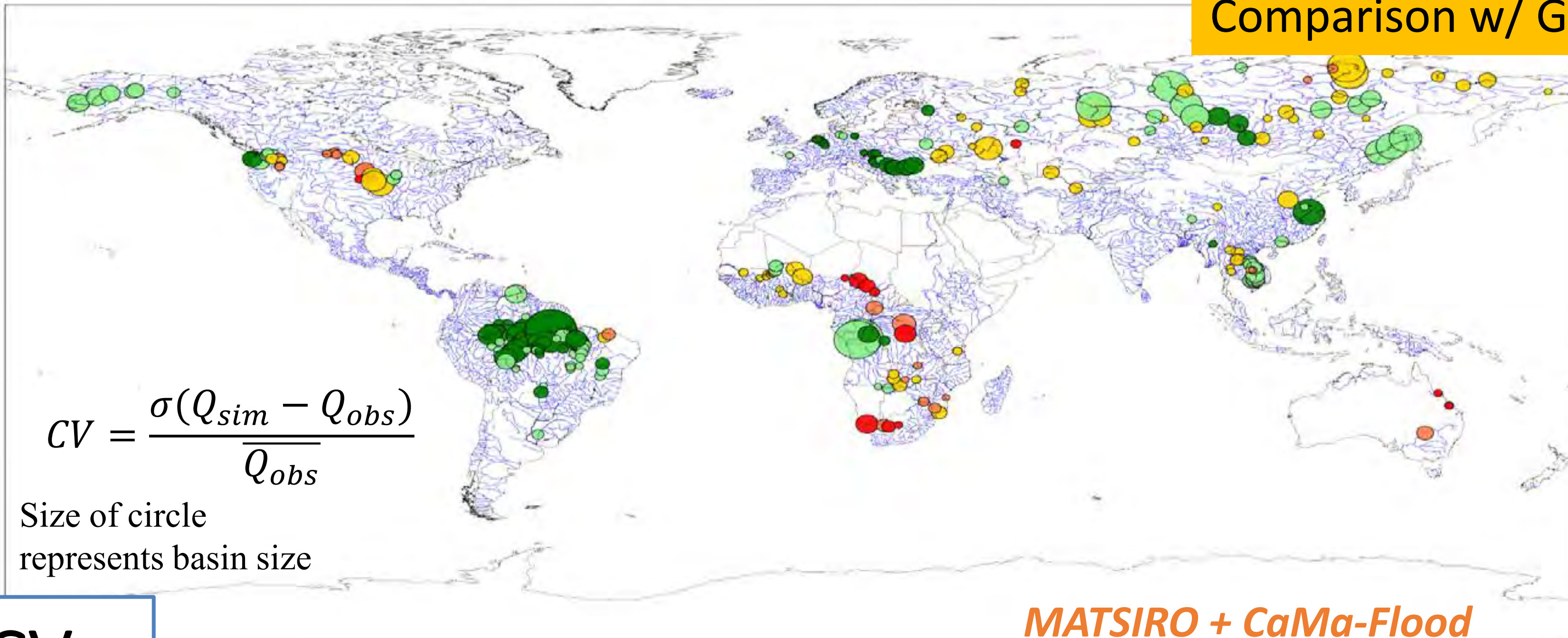


39-hour forecast at 3JST Sep 9



Comparison w/ GloFAS

CV



$$CV = \frac{\sigma(Q_{sim} - Q_{obs})}{\overline{Q_{obs}}}$$

Size of circle represents basin size

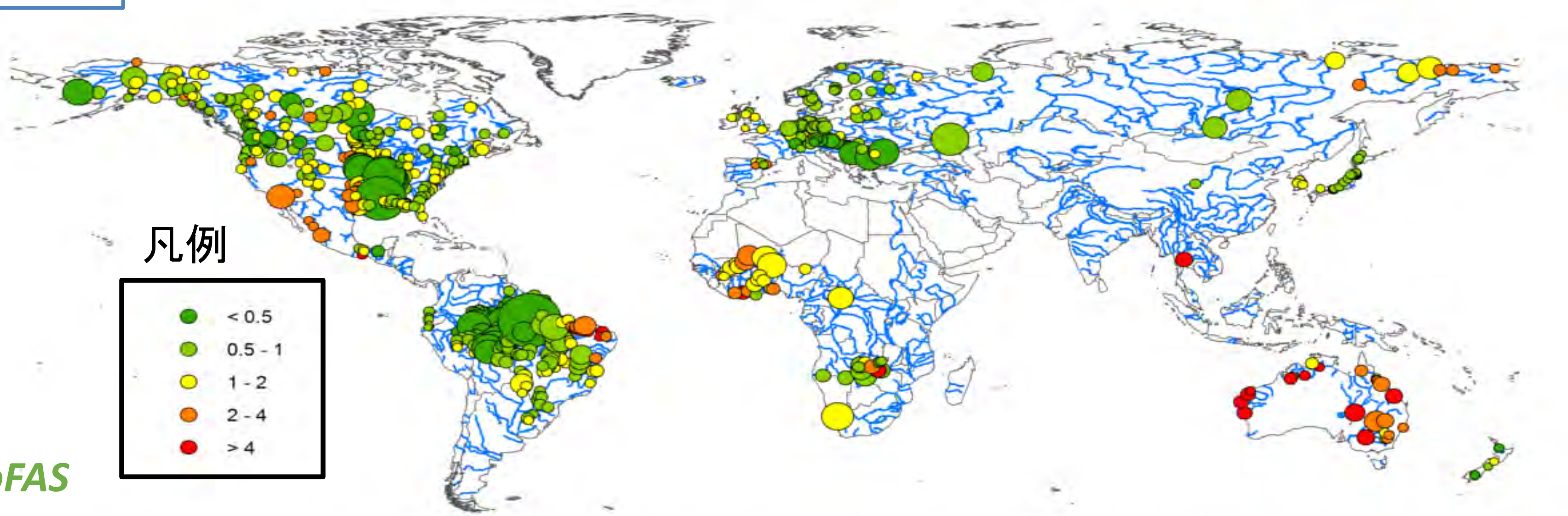
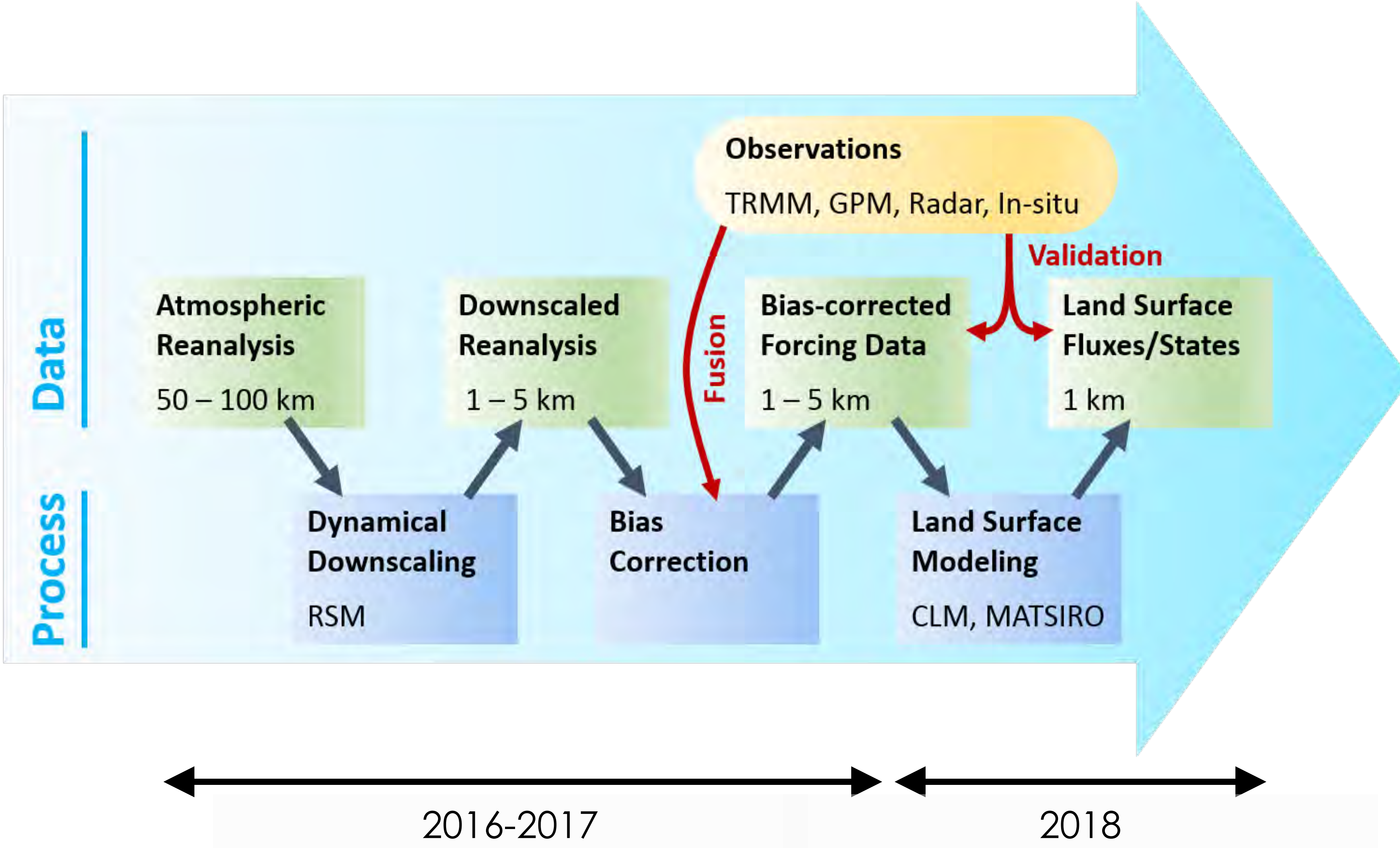


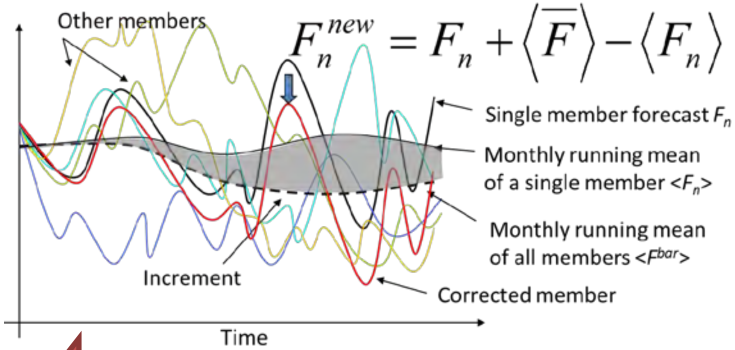
Fig. 2. Coefficient of variation of the estimation residuals for the 620 stations considered. Circle size is proportional to the upstream area of the river station.

Alfieri et al. (2013)

Work Flow & Plan

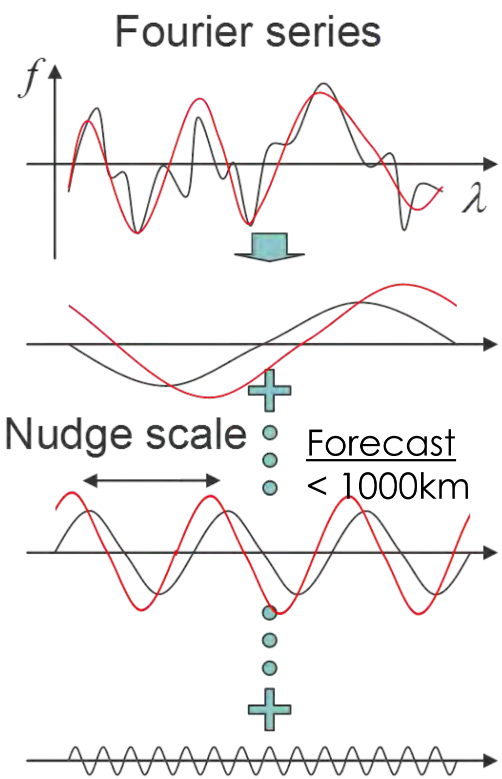


Spectral Nudging for Global Dynamical Downscaling

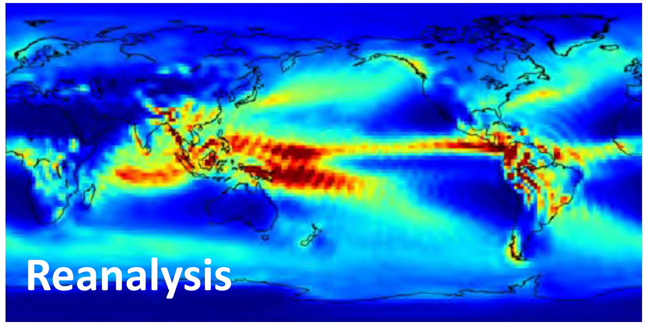


Incremental Correction of Single Member

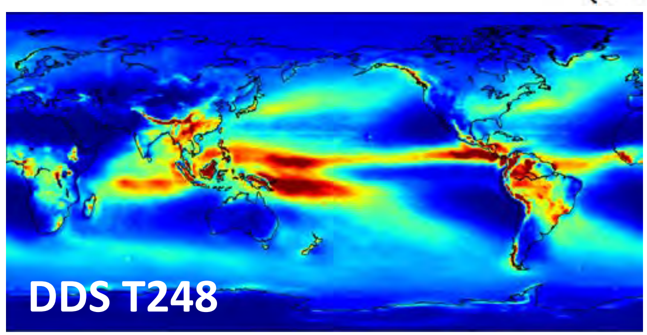
Yoshimura and Kanamitsu 2013



Yoshimura and Kanamitsu 2008



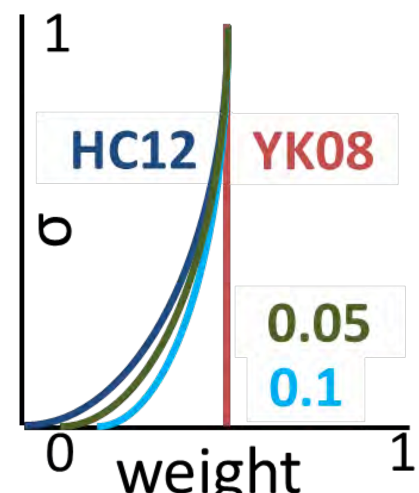
Nudging
U, V, T, P



$$f_{(\lambda,\phi)} = \sum_{m=-M}^{m=M} A_{(m,\phi)} e^{im\lambda}, \quad \text{with}$$

$$A_{(m,\phi)} = \begin{cases} A_{f(m,\phi)} & \left(|m| > \dfrac{2\pi R_E \cos\phi}{L} \right) \\ \dfrac{1}{\alpha + 1}\left[A_{f(m,\phi)} + \alpha A_{a(m,\phi)}\right] & \left(|m| \le \dfrac{2\pi R_E \cos\phi}{L} \right) \end{cases}$$

Vertically Weighted Damping Coef.

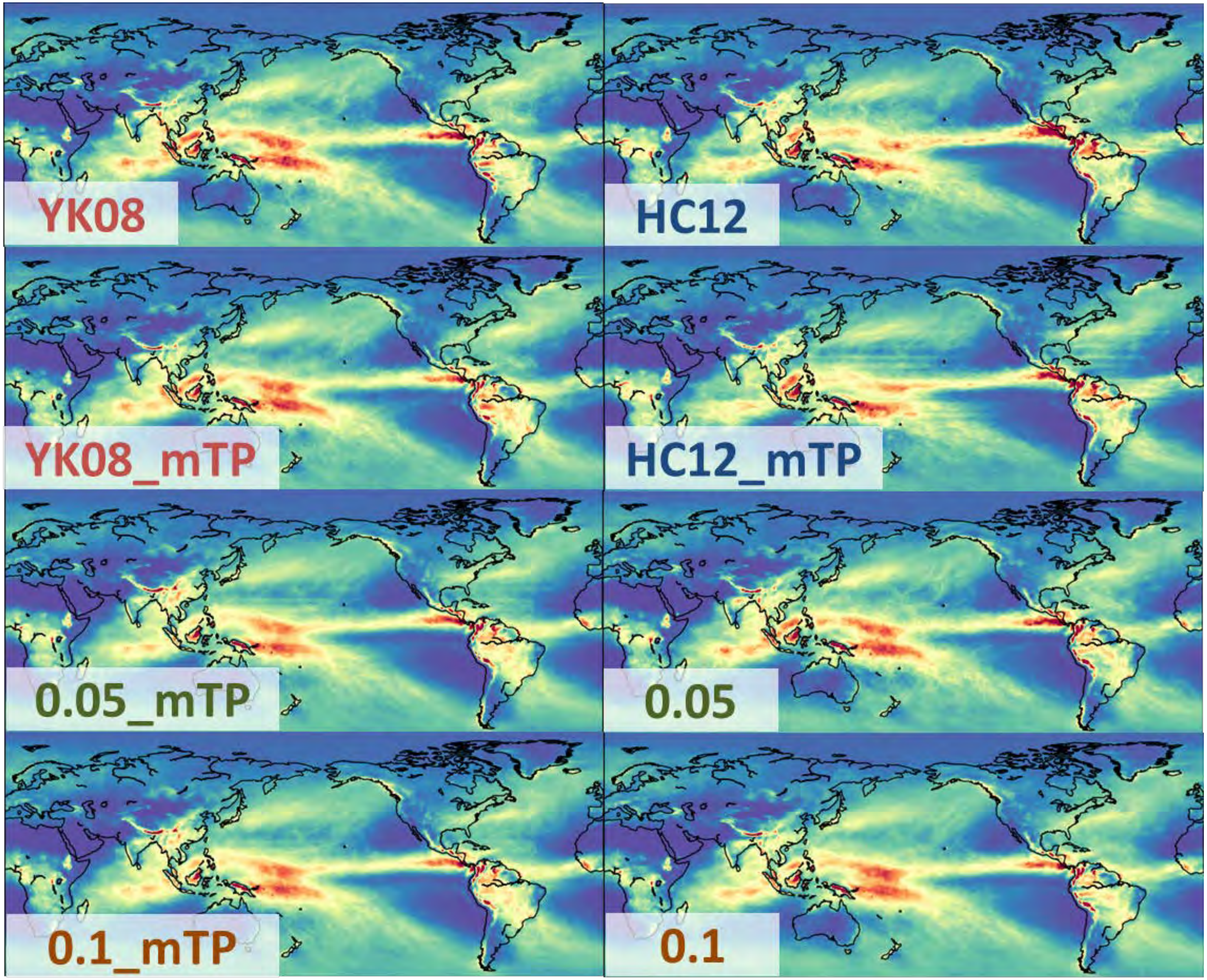


Hong and Chang 2012

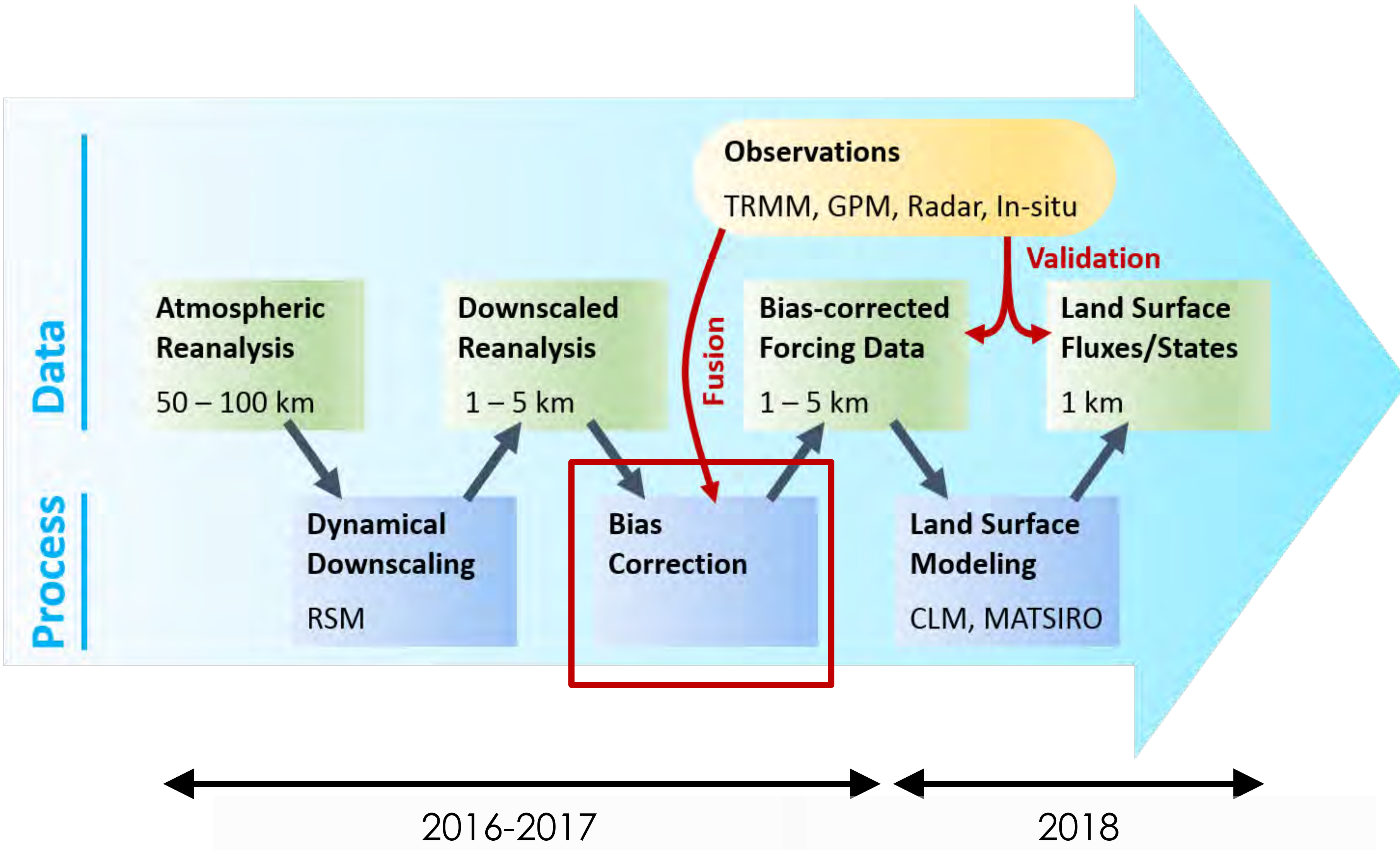
Successfully generate high frequency signals preserving low frequency background.

Effectively relieves ripple-like pattern (an artifact of 20CR due to high-res. topography mismatch)

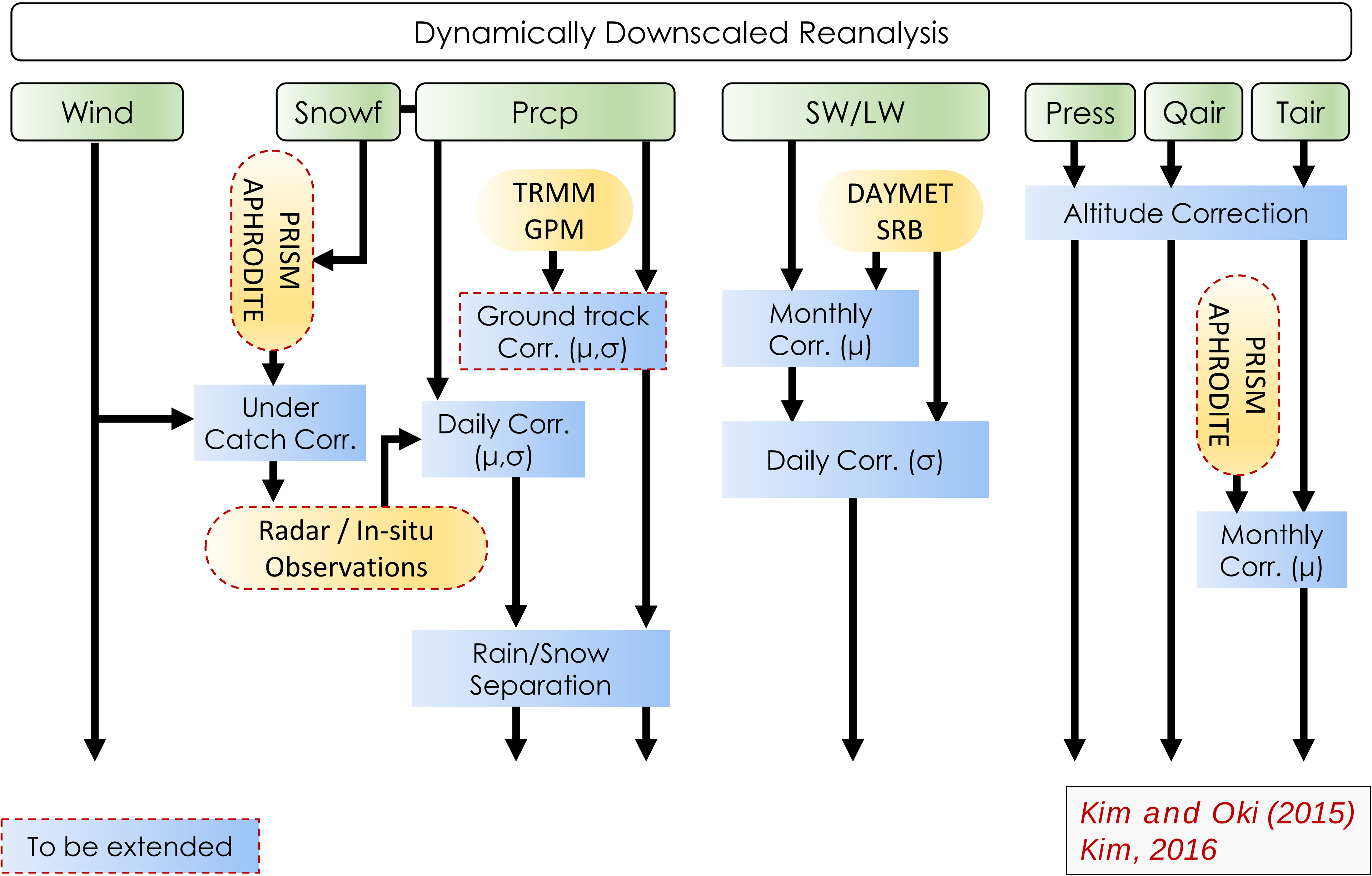
Sensitivity Tests for Damping Weight Profiles



Work Flow & Plan



Bias-correction



Kim and Oki (2015)
Kim, 2016