Use of satellite microwave observation in JMA NWP systems and expectation for future NOAA microwave sounding mission

Masahiro KAZUMORI

Japan Meteorological Agency

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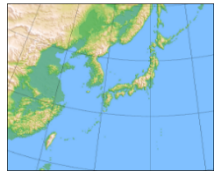
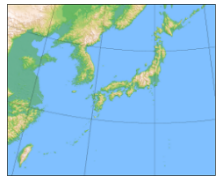
JMA's deterministic NWP model and DA system

	In Operation		
	Global Spectral Model GSM	**Meso-Scale Model MSM**	**Local Forecast Model LFM**
Objectives	Short- and Medium-range weather forecast	Disaster reduction Aviation forecast Precipitation forecast	Aviation forecast Disaster reduction
Forecast domain	Global 	Japan and its surroundings (4080 km x 3300 km) 	Japan and its surroundings (3160 km x 2600 km) 
Horizontal resolution	TL959, approx. 20 km (0.1875 deg.)	5 km	2 km
Vertical levels / Top	128 0.01 hPa	76 21.8 km	58 20.2 km
Forecast Hours (Initial time)	264 hours (00, 12 UTC) 132 hours (06, 18 UTC)	51 hours (00, 12 UTC) 39 hours (03, 06, 09, 15, 18, 21 UTC)	10 hours (00-23 UTC hourly)
Initial Condition	Global Analysis (Hybrid 4D-Var)	Meso-scale Analysis (4D-Var)	Local Analysis (3D-Var)

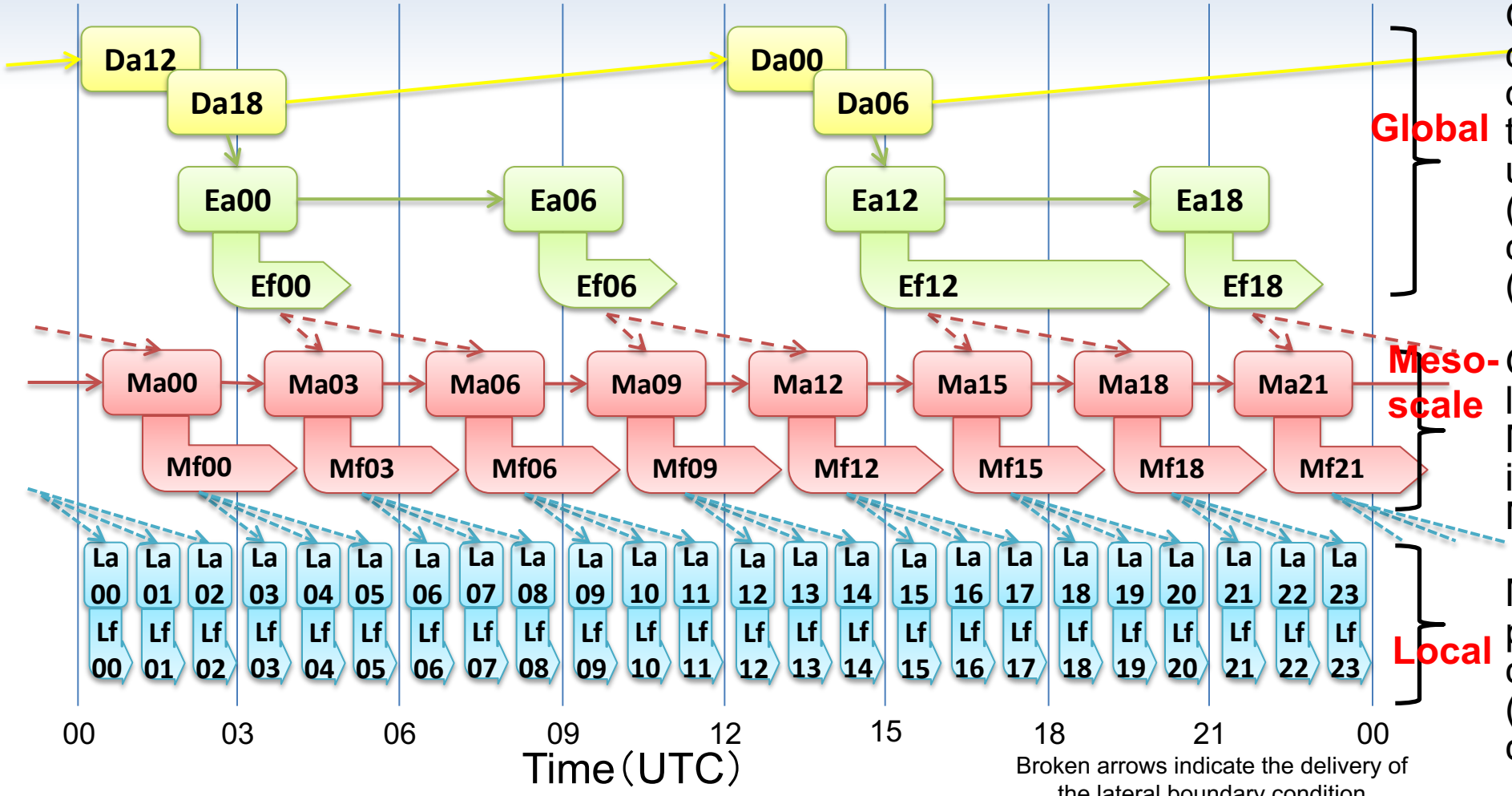
Satellite and conventional data are assimilated in data assimilation (DA) systems.

Global Analysis
6-hourly DA for delayed and early analysis
6-hr data assimilation window
Data cut-off time 2hr 50min. (earliest case)

Meso-scale Analysis
3-hourly DA
3-hr data assimilation window
Data cut-off time 50 min.

Local Analysis
Hourly DA
3-hr data assimilation window
Data cut-off time 30 min.

Dependency of JMA NWP systems and procedure of the data assimilation and NWP model forecasting



Global delayed analysis (Da) can use much observation data with its delayed cut-off time. First-guess from Da is used for early analysis (Ea). And Ea is used as initial condition for global forecast (Ef).

Global forecast (Ef) provides lateral boundary conditions for Meso-scale analysis (Ma). Ma is used as initial condition for Meso-scale forecast (Mf).

Meso-scale forecast (Mf) provides lateral boundary conditions for local analysis (La). La is used as initial condition for local forecast (Lf).

Three DA system use real time satellite data, e.g., MW observations

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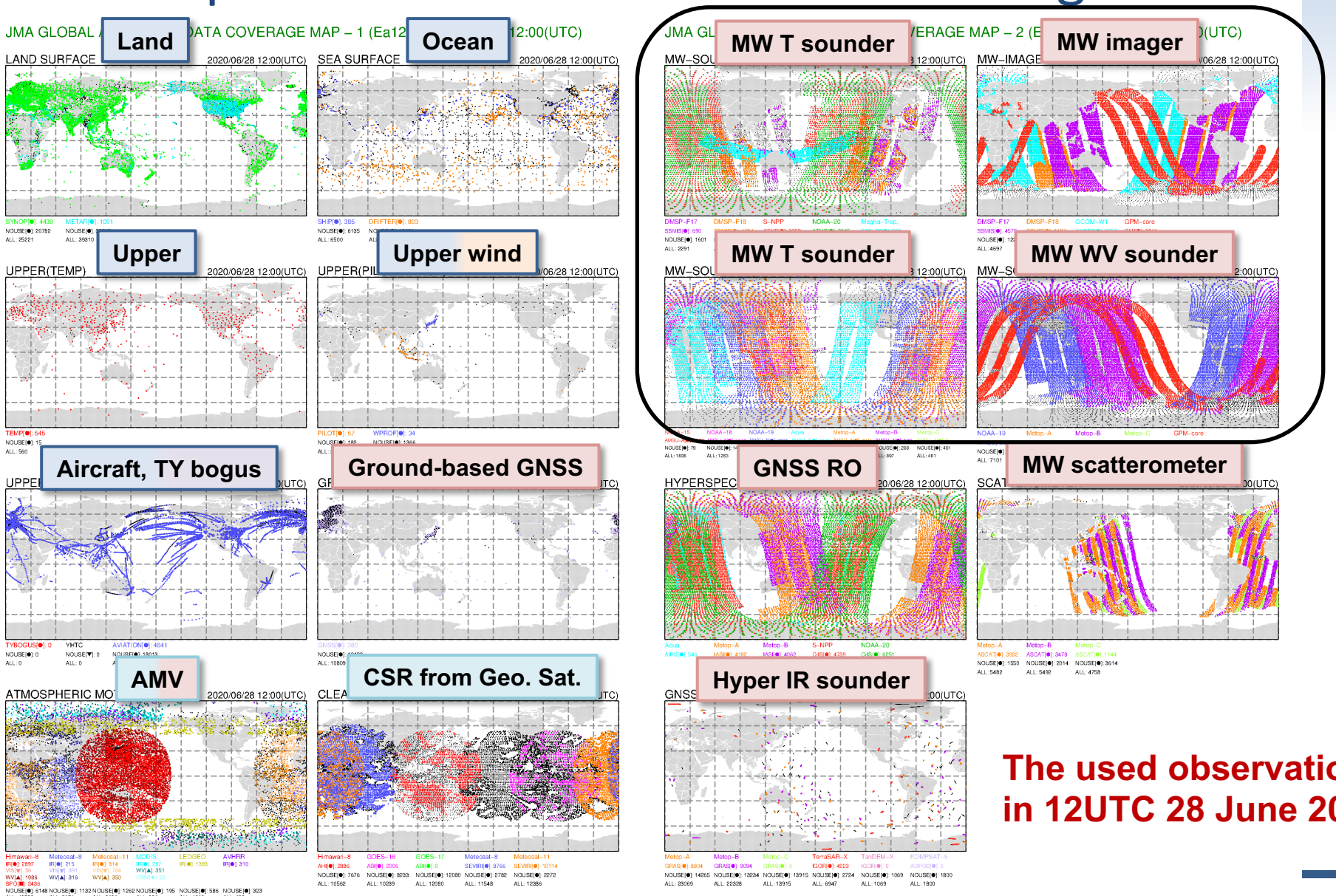
Space-based and ground-based observations are assimilated to produce initial conditions in JMA global NWP system

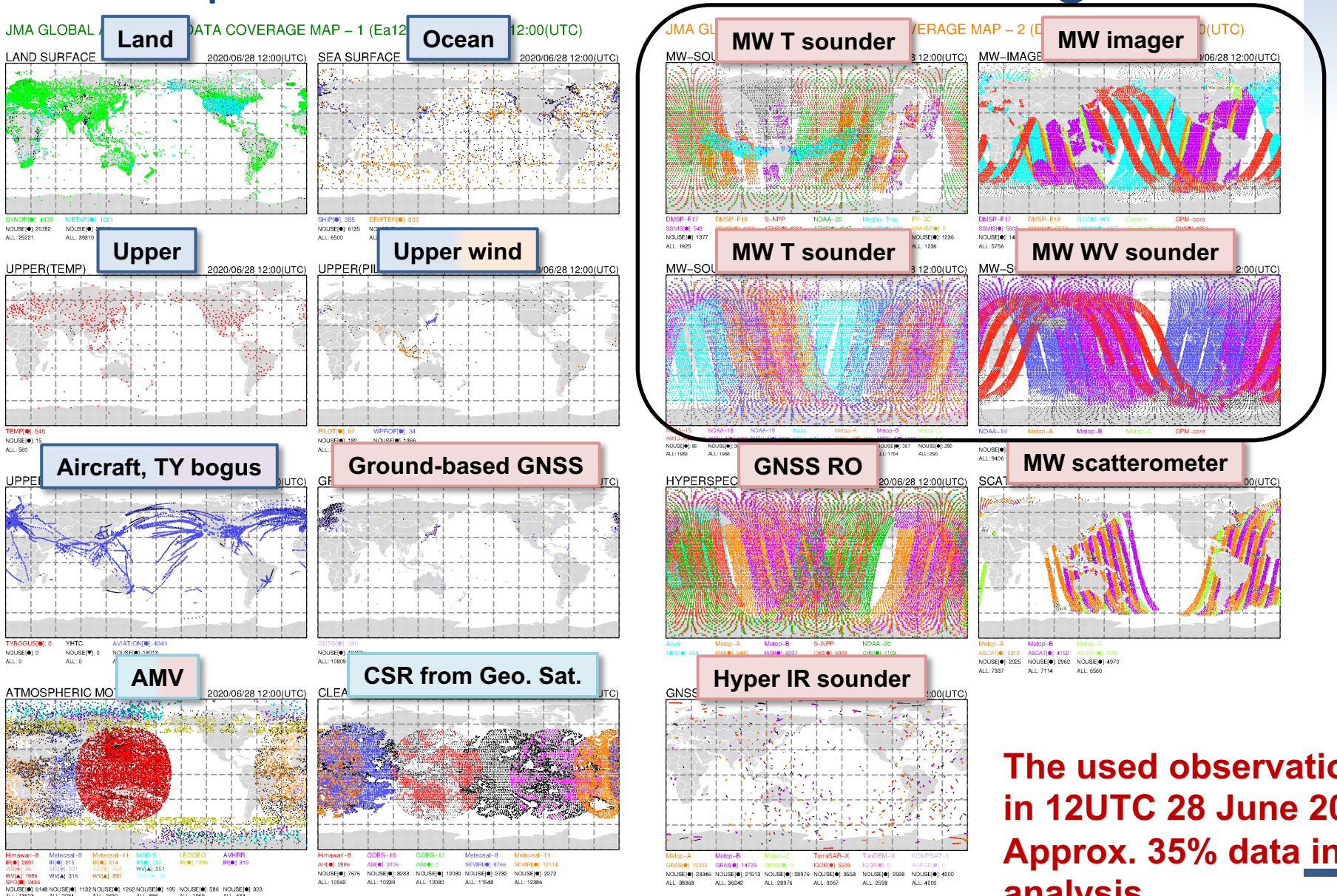


MW sounding data are key data set among operationally used observation data in JMA NWP system.

MW T sounding sensor
AMSU-A
ATMS
MW WV sounding sensor
MHS
ATMS, SSMIS, GMI, SAPHIR,MWHS-2
MW imager sensor
AMSR2, GMI, SSMIS

The used observation data coverage in 12UTC 28 June 2020 early analysis

Space-based and ground-based observations are assimilated to produce initial conditions in JMA global NWP system

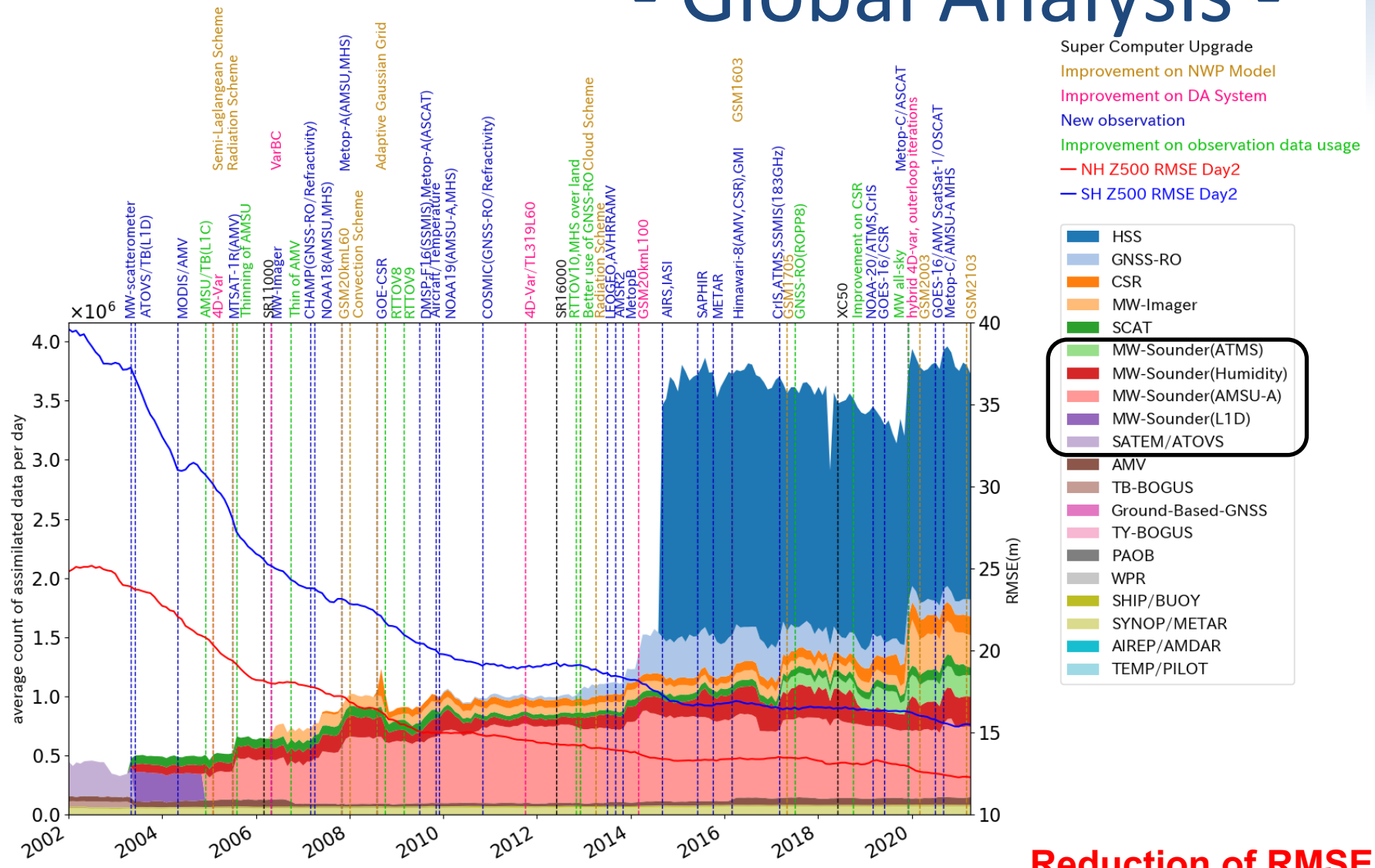


MW sounding data are key data set among operationally used observation data in JMA NWP system.

MW T sounding sensor
AMSU-A
ATMS
MW WV sounding sensor
MHS
ATMS, SSMIS, GMI, SAPHIR,MWHS-2
MW imager sensor
AMSR2, GMI, SSMIS

The used observation data coverage in 12UTC 28 June 2020 delayed analysis. Approx. 35% data increase in the delayed analysis.

Assimilated Data Amount History - Global Analysis -



Major events in MW data use

2004:
NOAA/AMSU radiance (L1D) data assimilation started.

2005:
AMSU radiance (L1C) data assimilation started.

2007:
NOAA-18/AMSU
2010: DMSP/SSMIS, Metop-A/AMSU, NOAA-19/AMSU

2013:
MHS radiance data use over land

2014:
Metop-B AMSU radiance data assimilation started.

2015:
SAPHIR radiance data assimilation started.

2016:
GMI radiance data radiance data assimilation started.

2017:
ATMS radiance data use

2019:
NOAA20/AMSU radiance data assimilation started.

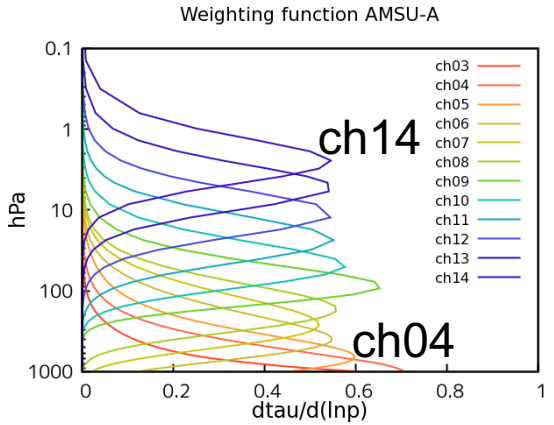
2021:
Metop-C/AMSU radiance data assimilation started.

Reduction of RMSE at 500 hPa height after the MW sounding data introduction.

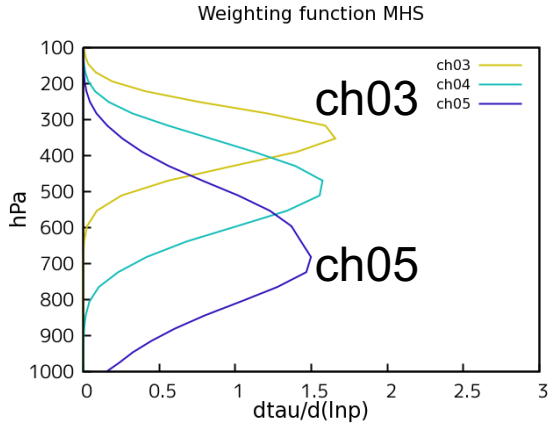
Current usage of AMSU-A,MHS observation channels

	ch	GHz	Clear-sky			Cloud	Rain
			Sea	Land	Sea Ice		
AMSU-A	01	23.800					
	02	31.400					
	03	50.300					
	04	52.800	X				
	05	53.596 ± 0.115	X				
	06	54.400	X	X(lower 1500m topo)	X		
	07	54.940	X	X(lower 2500m topo)	X	X	
	08	55.500	X	X(lower 5000m topo)	X	X	
	09	f0 = 57.290344	X	X	X	X	X
	10	f0 ± 0.217	X	X	X	X	X
	11	f0 ± 0.3222 ± 0.048	X	X	X	X	X
	12	f0 ± 0.3222 ± 0.022	X	X	X	X	X
	13	f0 ± 0.3222 ± 0.010	X	X	X	X	X
	14	f0 ± 0.3222 ± 0.0045	X	X	X	X	X
	15	89.000					
MHS	01	89.0					
	02	157.0					
	03	183.31 ±1.0	X	X		X	
	04	183.31 ±3.0	X	X		X	
	05	190.311	X	X		X	

Weighting function AMSU-A



Weighting function MHS



AMSU-A:
Cloud-screening is necessary. Cloud and precipitation affected AMSU-A radiance are not assimilated. Channel 1 to 3 are used to retrieve cloud and precipitation signal. Channel 4 to 14 are actively assimilated under clear-sky condition.

MHS:
MHS radiance data are assimilated under all-sky conditions. Channel 1 and 2 are used to estimate cloud amount for observation error assignment in the all-sky DA. Channel 3 to 5 are actively assimilated.

Usage of MW observation band in JMA NWP system

		C	X	K		Ka	V	W	F		G
I/S	Satellite/Sensor	7	10	19	23	37	50~60	90	118	150	183
S	NOAA,Metop/AMSU-A	／	／	／	■	／	○4~14	■	／	／	／
S	NOAA,Metop/MHS	／	／	／	／	／	／	■	／	■	◎3,4,5
S	Megha-Tropiques/SAPHIR	／	／	／	／	／	／	／	／	／	◎1,2,3,4,5,6
S	NOAA20,Suomi-NPP/ATMS	／	／	／	■	／	○6~9	■	／	■	◎18,19,20,21,22
IS	DMSP-F17,F18/SSMIS	／	／	◎13	◎14	◎16	■	●17	／	■8	◎9,10,11
IS	GPM-core/GMI	／	■	◎3	◎5	◎6	／	●8	／	■10	◎12,13
I	GCOM-W1/AMSR2	■	■	◎7	◎9	◎11	／	●13	／	／	／
S	FY-3C/MWHS2	／	／	／	／	／	／	■1	■	■10	◎11,12,13,14,15
S	FY-3D/MWHS2	／	／	／	／	／	／	■1	■	■10	■11,12,13,14,15
I	FY-3C/MWRI	／	■	◎3	◎5	◎7	／	■9	／	／	／
I	FY-3D/MWRI	／	■	■3	■5	■7	／	■9	／	／	／
I	Coriolis/WindSat	■	■	◎7	◎11	◎13	／	／	／	／	／

GHz

K, Ka, V, W, G band observation are actively assimilated and used for Quality Control in NWP.

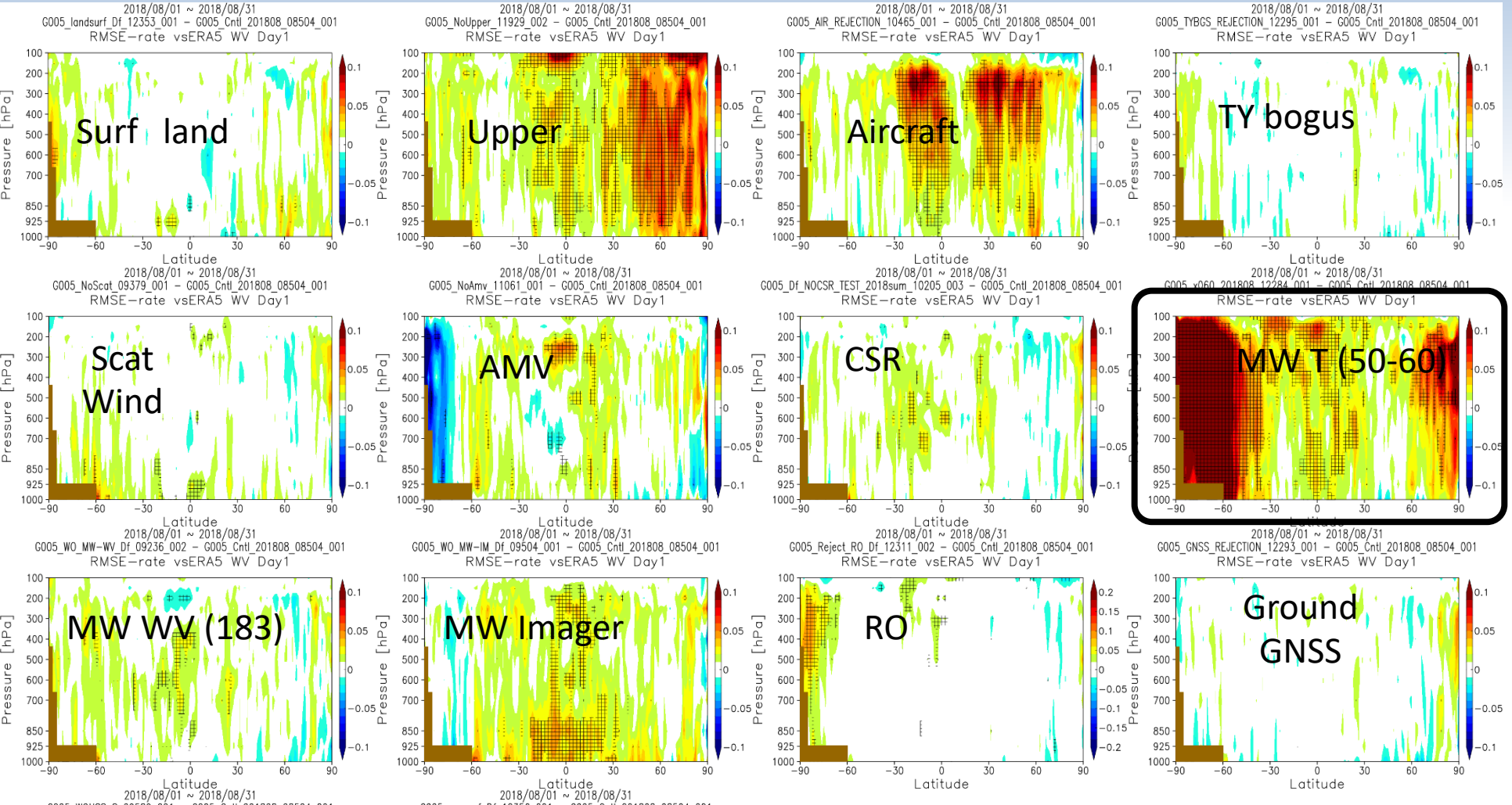
I : Imager
S : Sounder

Grouped nearest MW band for each instrument observation channels. Imager channel: V-pol. channel case

as of July 2021

／: N/A
○: Clear-Sky assimilation
◎: All-Sky assimilation
●: Used in clear-sky assimilation, now discontinued
■ : No use in NWP DA
Top right number : channel number

Normalized change of RMSE of **Wind Vector** Day 1 forecast



Control : JMA operational global NWP

Test: Data denial experiment

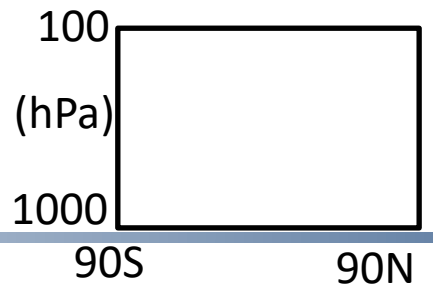
Period : Aug. 2018

Data denial experiment demonstrated **microwave temperature sounding data** has the largest impact for the forecast accuracy.

Warmer: degradation

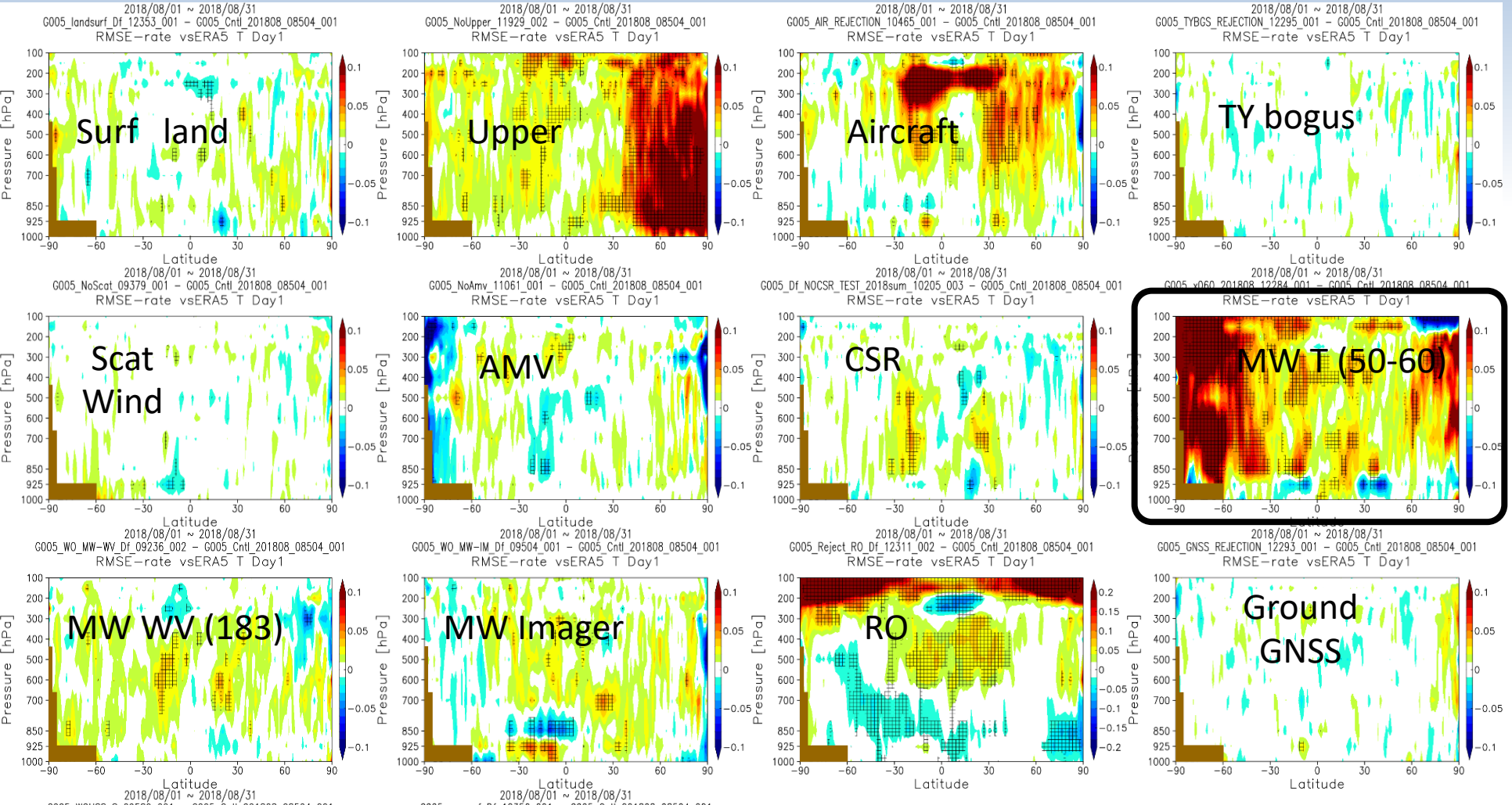
Colder: improvement

Reference: ERA5



Loss of 50-60 GHz band is huge damage on the forecast score.

Normalized change of RMSE of **Temperature** Day 1 forecast



Control : JMA operational global NWP

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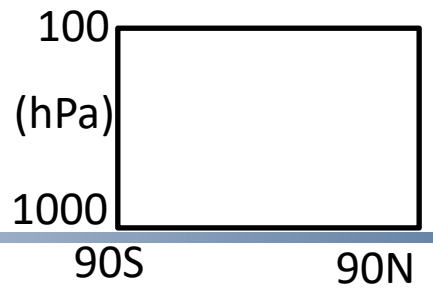
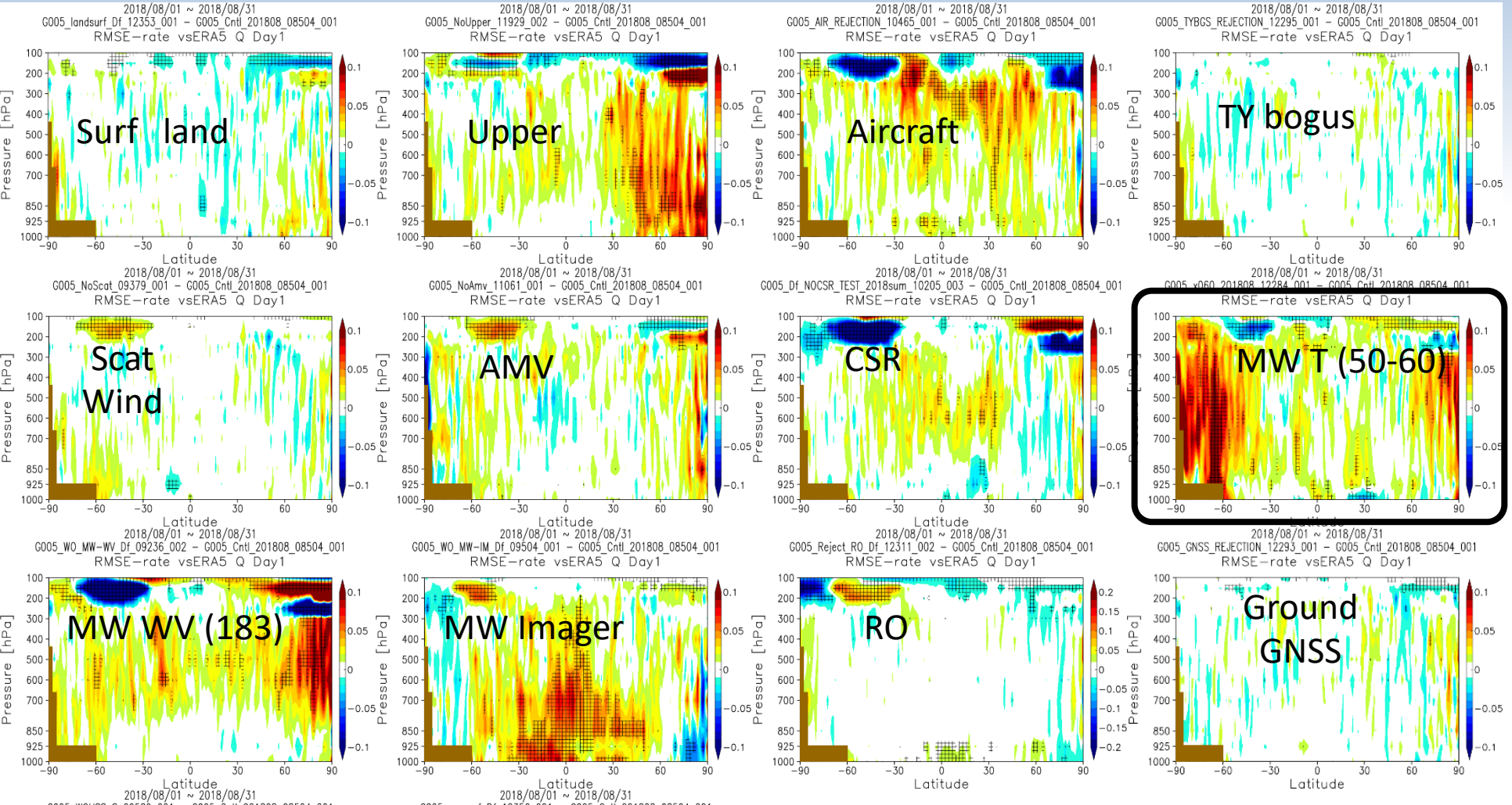


Loss of 50-60 GHz band is huge damage on the forecast score.

Normalized change of RMSE of **Water vapor** Day 1 forecast



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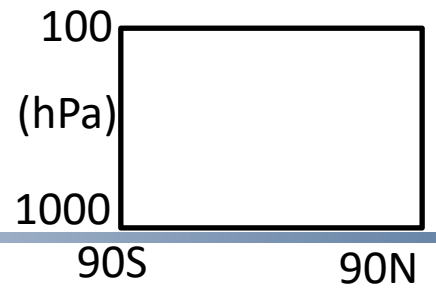
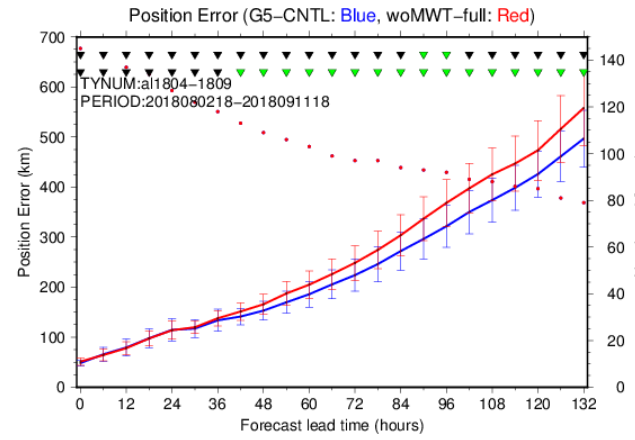
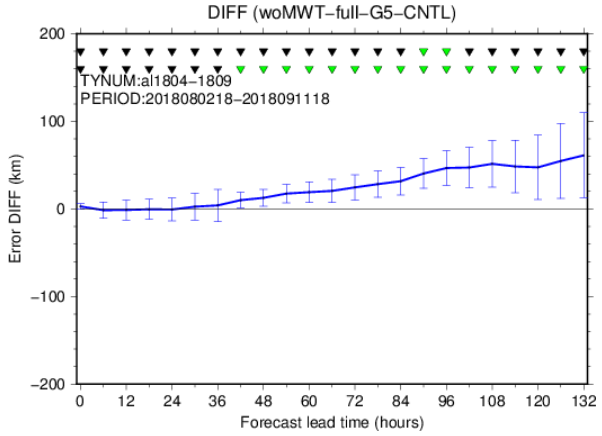


MW WV (183) and MW Imager have large contribution on the accuracy of water vapor prediction

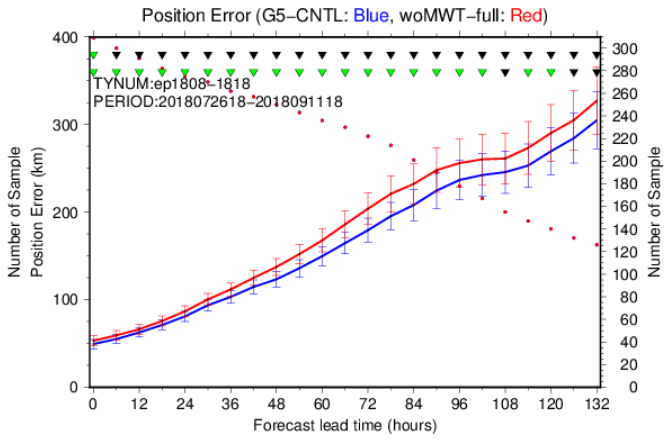
MW temperature sounder's contribution to Tropical Cyclone track prediction

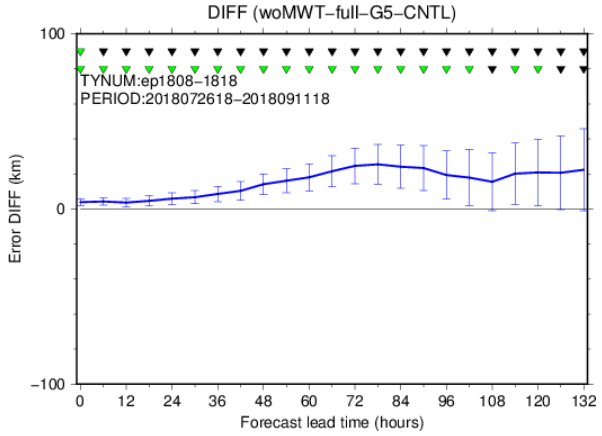
Atlantic Ocean





East Pacific Ocean





Control : JMA operational global NWP

Test: Data denial experiment

Period : Aug. 2018

Data denial experiment demonstrated that the data denial degraded the accuracy of tropical cyclone track prediction. This results indicates the use of microwave temperature sounding data improves tropical cyclone track prediction.

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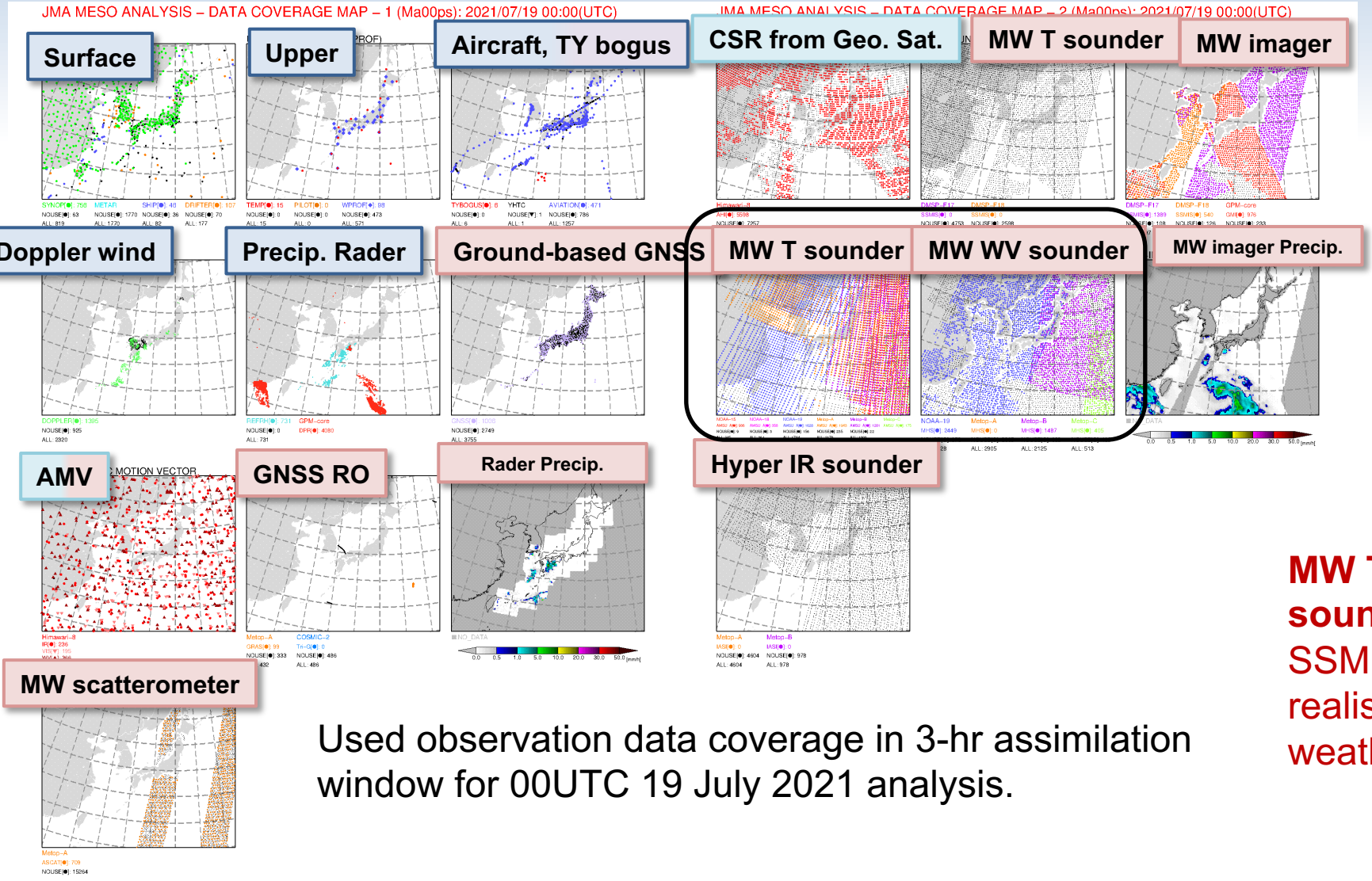
Used observation data coverage in JMA Meso-scale Analysis



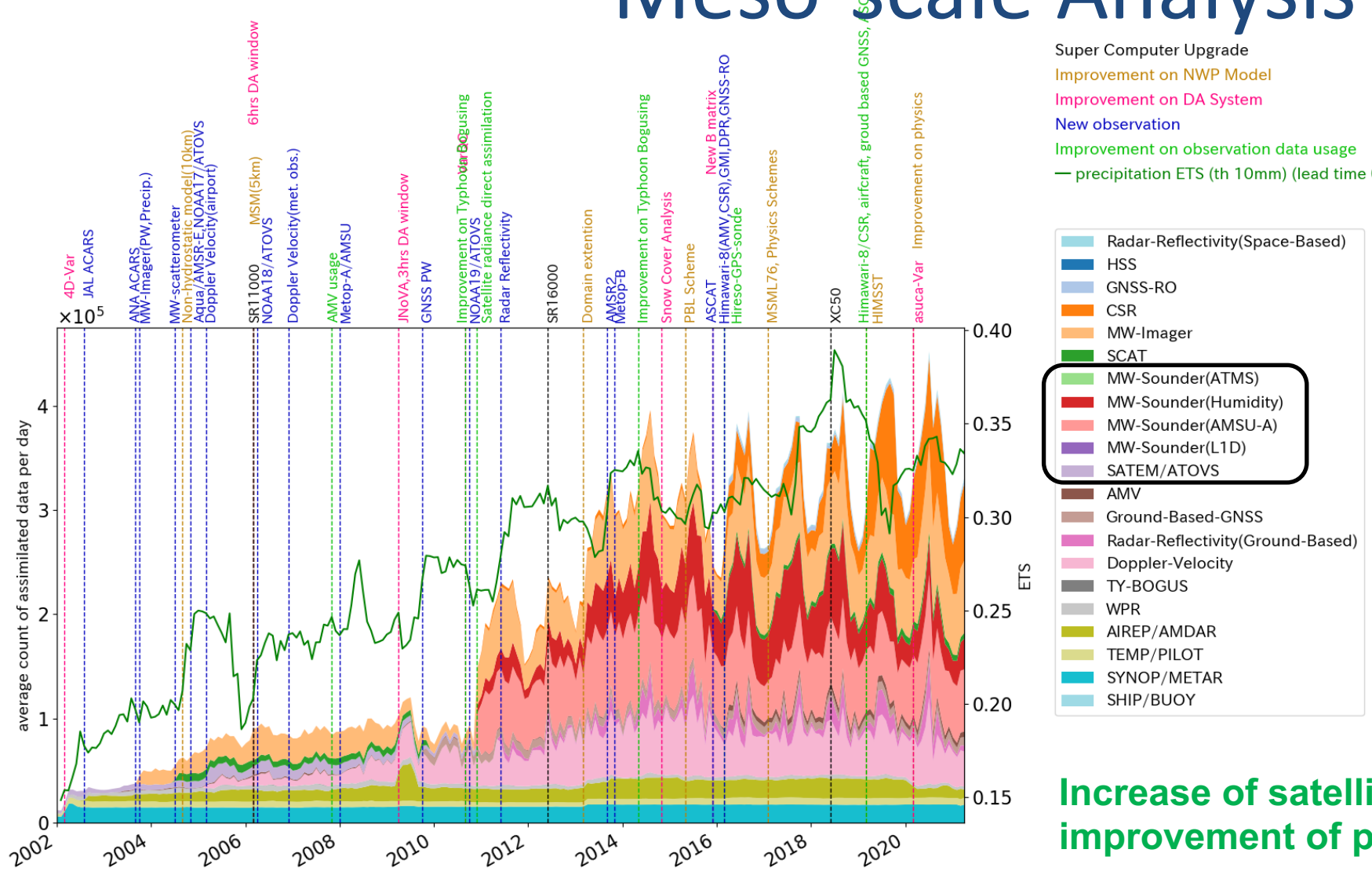
Used observation data coverage in 3-hr assimilation window for 00UTC 19 July 2021 analysis.

A variety of observations are utilized in JMA's Meso-scale NWP system.

Satellite radiance data are used in the JMA Meso-scale analysis as a form of brightness temperature.

MW Temperature and water vapor sounding (AMSU-A, MHS, ATMS, SSMIS) are a key data to produce realistic analysis field for meso-scale weather prediction.

Assimilated Data Amount History
- Meso-scale Analysis -



Major events in MW data use

2005:
NOAA-17ATOVS retrieval data use started.

2006:
NOAA-18/ATOVS retrieval data use started.

2008:
Metop-A/AMSU retrieval data use started.

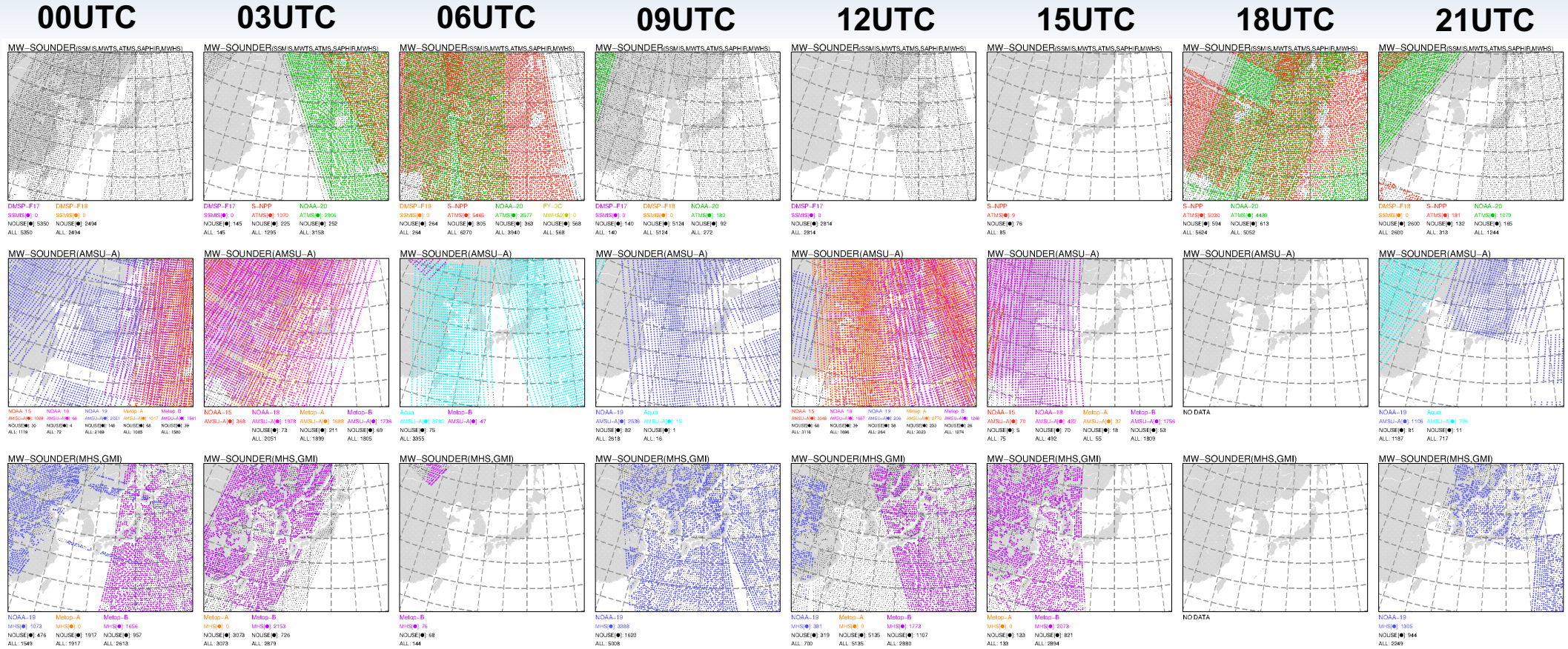
2011:
Satellite radiance direct assimilation started

2014:
Metop-B AMSU radiance data assimilation started.

2016:
GMI radiance data assimilation started.

Increase of satellite radiance data contributed improvement of precipitation forecast skill.

Data coverage of MW Temperature sounder and MW WV sounder in JMA Meso-scale Analysis



To fill the gap in the data coverage in the mid-latitude regional model domain, use of multiple satellite sensors is necessary. JMA Meso-scale analysis is 3 hourly.

Impact of MW sounder in Meso-scale analysis

MW sounder radiance **data denial experiments** with JMA Meso-scale NWP system

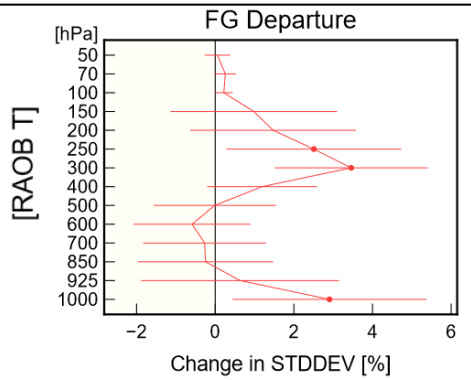
- CNTL
  - Same as JMA operational system in June 2020.
- TEST1
  - CNTL minus MW temperature sounder
    - NOAA15,18,19、Metop-A,B、Aqua/AMSU-A
- TEST2
  - CNTL minus MW water vapor sounder
    - NOAA19、Metop-A,B/MHS
    - GPM-core/GMI 183GHz
- Period：July 2020

MW temperature sounder have positive impact for upper tropospheric temperature fields.

MW water vapor sounder have positive impact for temperature, water vapor fields.

Changes of standard deviation of FG departure

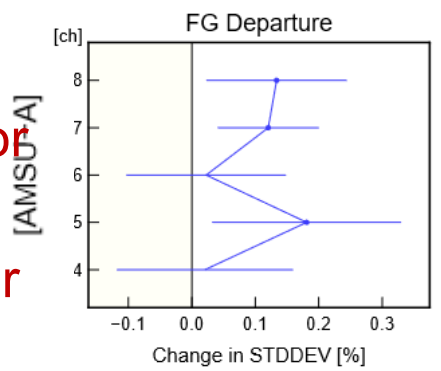
TEST1



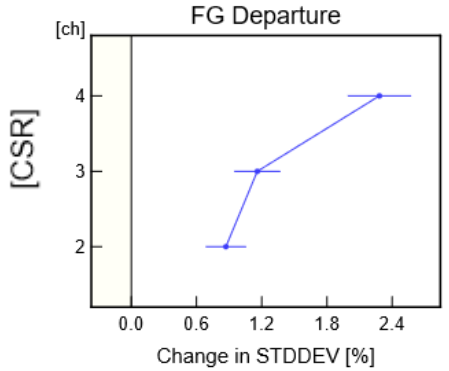
RAOB Temperature

MW positive

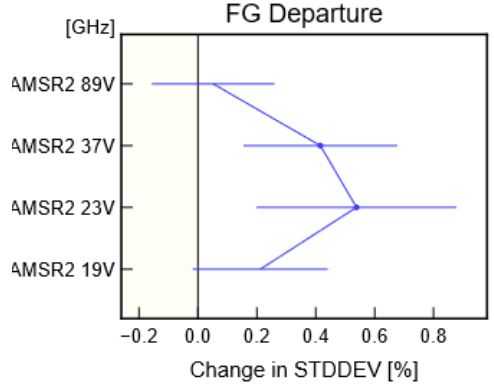
TEST2



AMSU-A



CSR



AMSR2

Importance of water vapor information from Ka band（23 GHz）

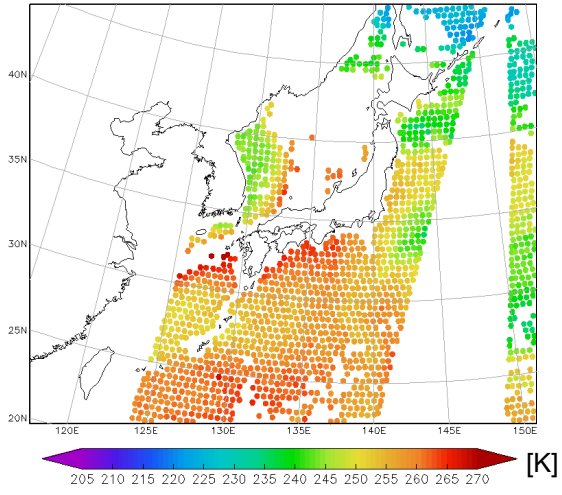
A case study: A heavy precipitation event in the Kyusyu Island in Japan

Period: 4 – 14 July 2012

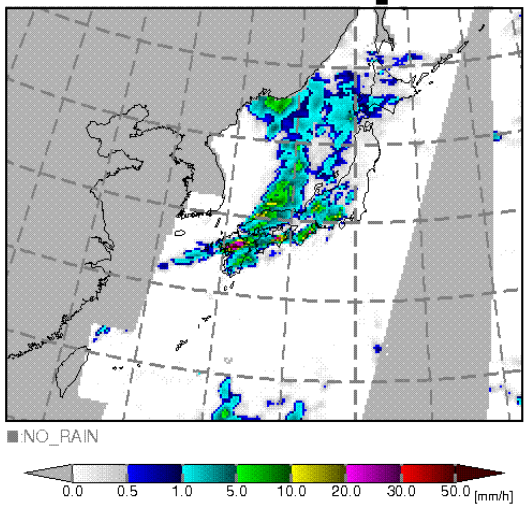
An example of assimilated AMSR2 data distribution

（18 UTC 11 July 2012）

23GHz V-pol. Tb



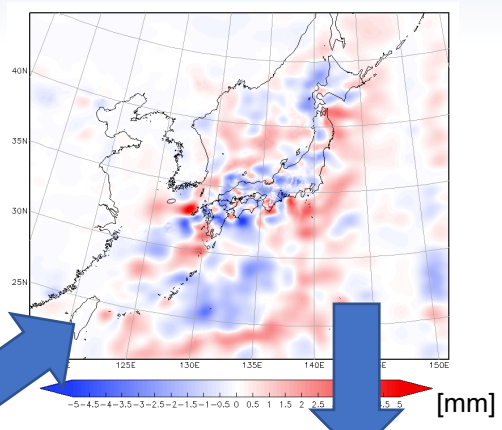
Rain Rate [mm/hr]

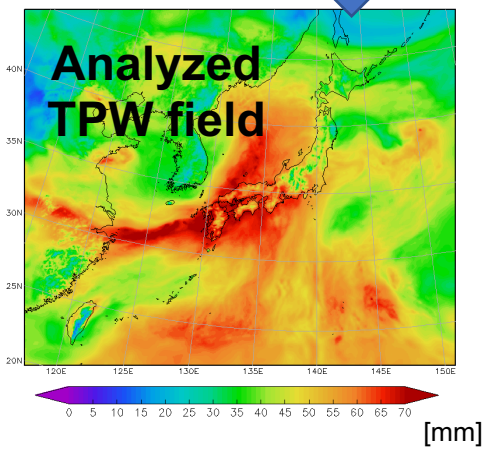


Used Tb:
19, 23, 37, 89 GHz V-pol.

Used Tb in rain retrieval:
19 - 89 GHz V and H-pol.

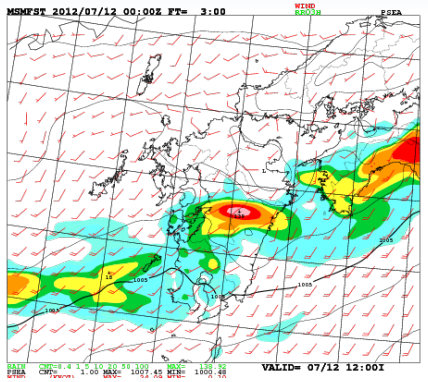
TPW increment



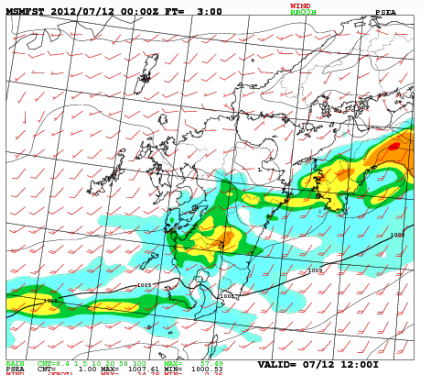


Test: with AMSR2
Control: without AMSR2

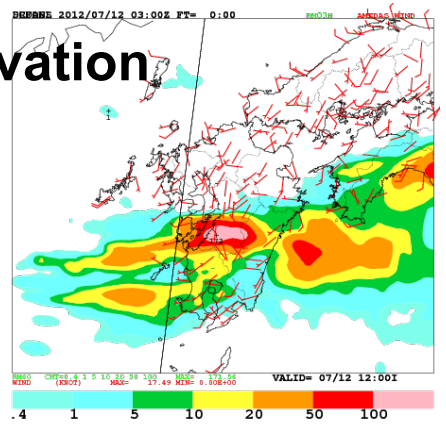
Test forecast



Control forecast



Observation



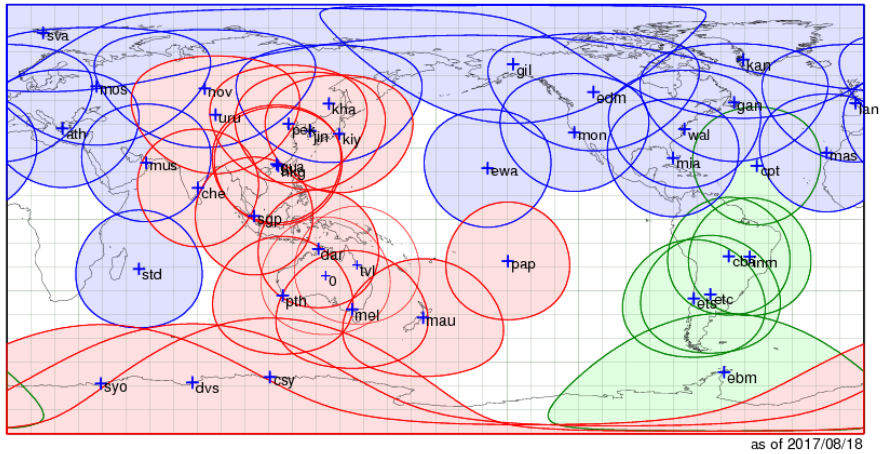
Water vapor information from Ka band (23 GHz) is crucial for realistic TPW analysis and accurate precipitation forecast.

Use of DBNet data

The DBNet (Direct Broadcast Network) is operational arrangement under the World Meteorological Organization to provide NWP centers with ATOVS data received at direct readout stations within 30 minutes of observation.

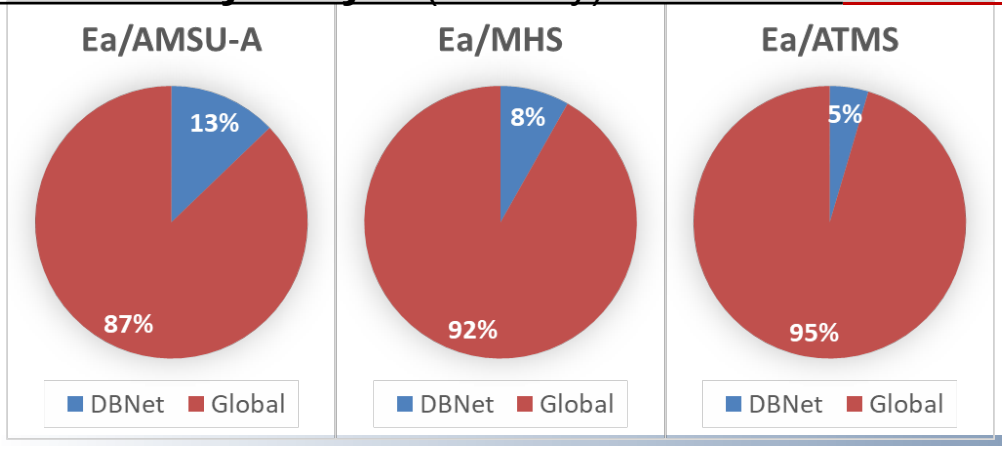
DBNet data is valuable for operational NWP system, especially for short data cut off time system.

Global map of DBNet data coverage

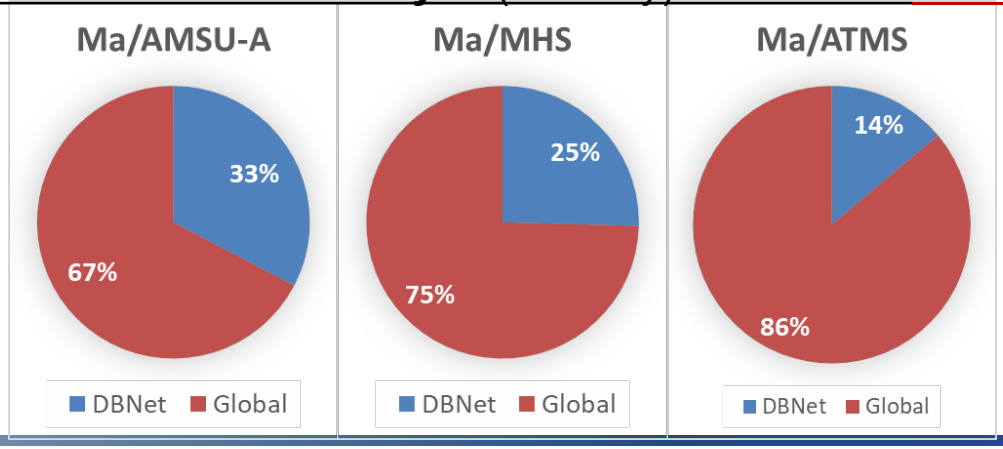


Ratio of used MW sounder data: DBNet vs Global

JMA Global early analysis(6 hourly) data cut-off 2 hr. 50min.



JMA Meso-scale analysis(3 hourly) data cut-off 50 min.



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1. JMA’s deterministic NWP systems (Global, Meso-scale, Local)
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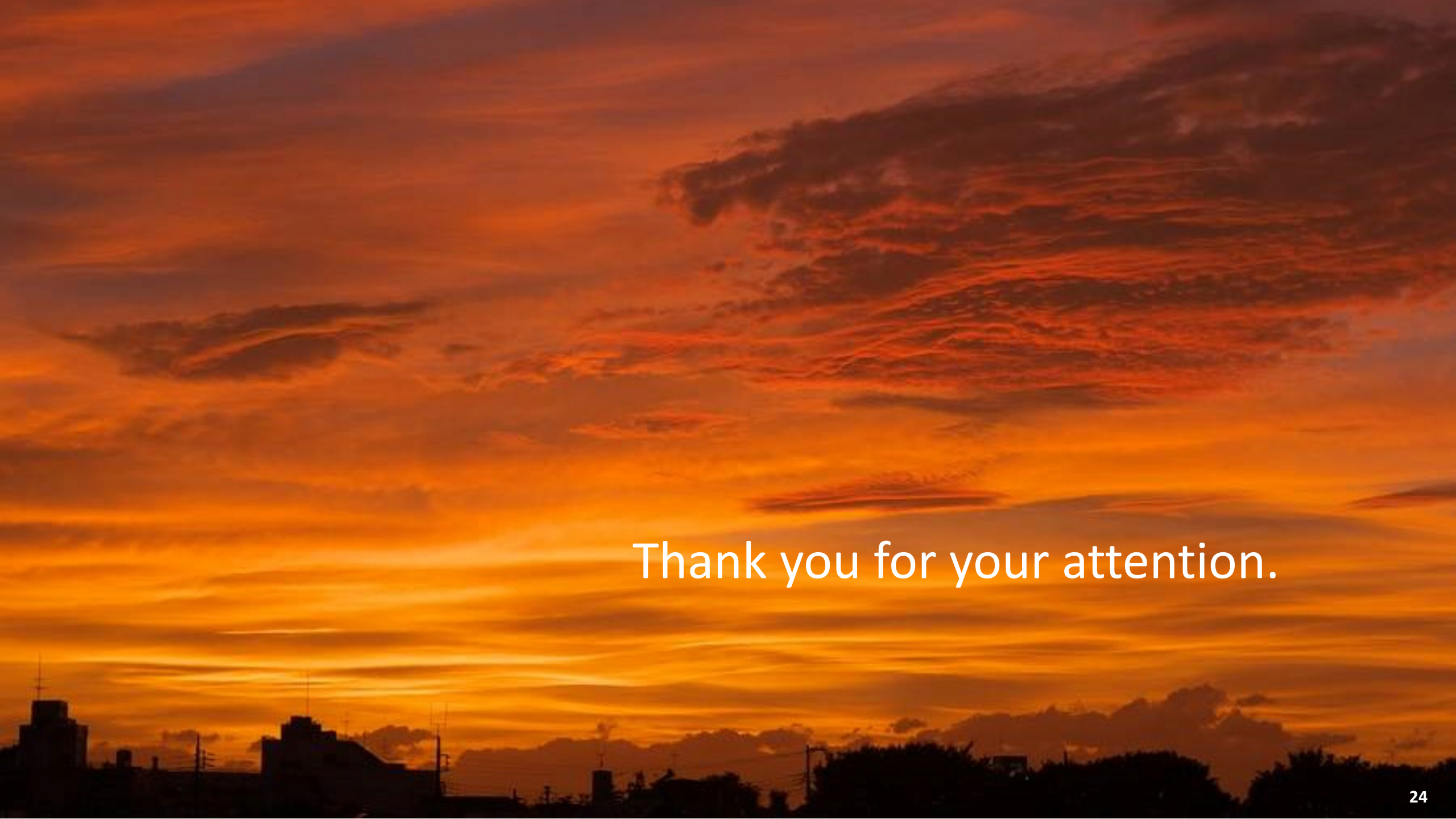
Summary and expectation

- JMA operates three major analysis systems (global, meso-scale, local analysis)
- Various meteorological observations are operationally used in the JMA systems. The observations from space-based microwave radiometers, especially temperature and humidity sounding data have big impacts on the accuracy of NWP. Temperature sounding (50-60 GHz) and water vapor sounding (183GHz) are crucial data source. Therefore, the continuity of the observation, timely and stable data delivery are highly desired.
- Current three orbit satellite configuration (i.e., morning, afternoon, early morning orbit) is a suitable to keep the satellite data coverage for 6-hour interval global data assimilation system. To capture a rapid change of water vapor field in regional NWP system (e.g., 3-hourly update in mid-latitude), multiple satellite data use with direct receiving capability is required.
- Water vapor, cloud and precipitation information from microwave Ka band are necessary for the meso-scale analysis because the model domain has large ocean area for JMA. These observations also used for cloud and precipitation estimates.
- Supplemental water vapor sounding data (183GHz) from small satellites are expected to contribute the observation on rapid change of water vapor field associated with typhoon development or heavy precipitation caused by stationary seasonal rain front in Japan.
- Future enhanced data use on microwave sounding data (data use over land and snow/ice, all-sky assimilation) would raise the impact in global and regional NWP system.


Thank you for your attention.

Other applications

- C-band: SST, Soil Moisture Content
- X-band: SSW and Rain
- K, Ka-band: WV, Cloud and Rain, Snow and ice monitoring
- 50-60 GHz: Temperature sounding, monitoring warm core structure inside typhoon
- W band 85-91GHz: Monitoring strong precipitation distribution associated with rain-band in inner core of typhoon
- G band 183GHz: Water Vapor profile