Current development of JMA global NWP system

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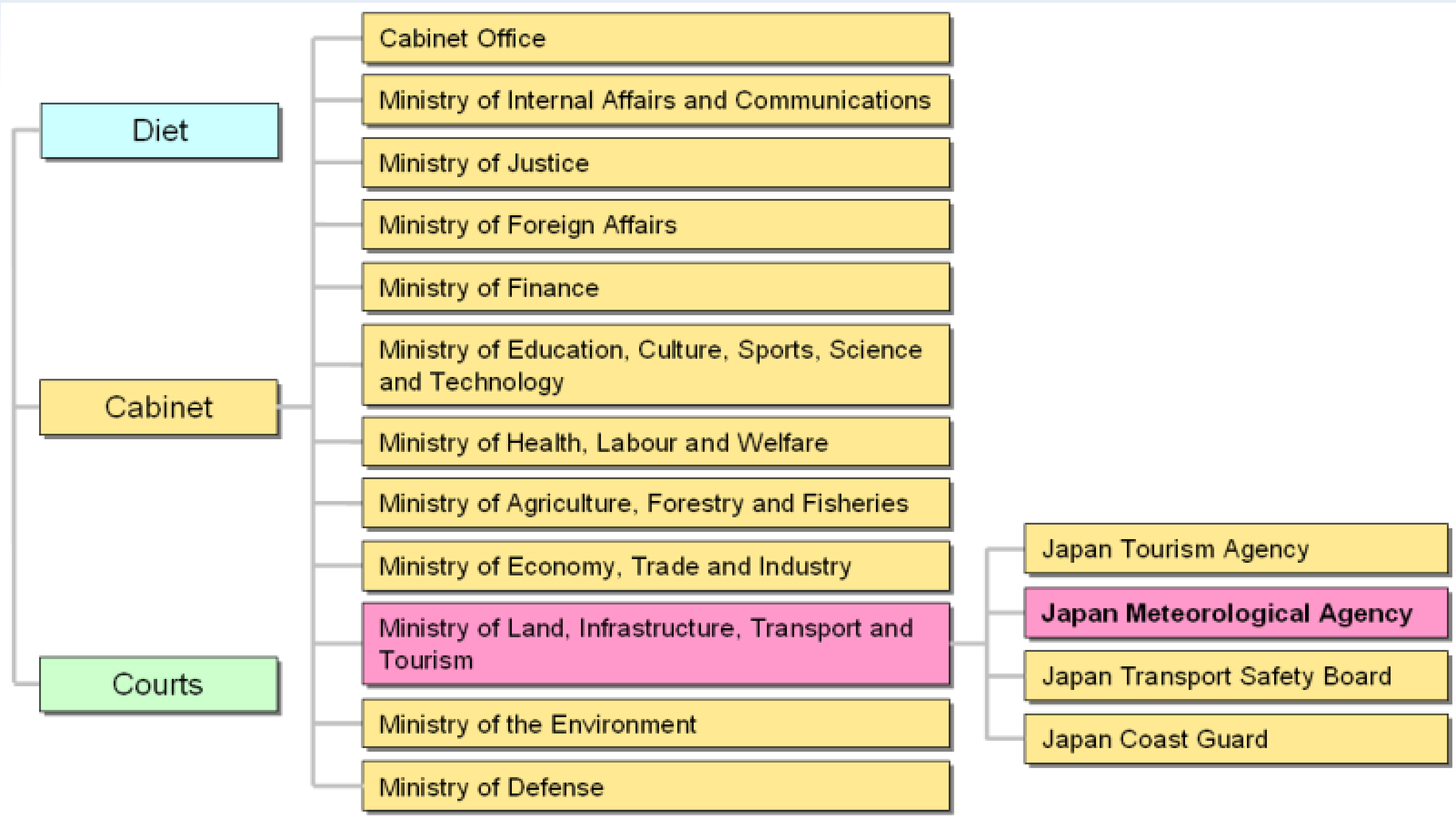
EMC (Visiting scientist from JMA)

EMC seminar 12 February 2019
@ NCWCP, College Park, US

Contents

- Overview of NPD/JMA
- JMA operational NWP
- JMA global NWP
- Future plan

Structure of Japan's Central Government



JMA is an extra-ministerial bureau of
the Ministry of Land, Infrastructure, Transport and Tourism (MLIT)

JMA's total staff ~5,100, budgetary resource ~$568 million /yr (2018)

JMA's Goals

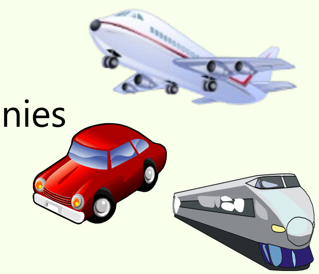
JMA implements its services with the following ultimate goals

Prevention and mitigation of natural disasters

Provide daily/monthly forecasts and warnings/Advisories for
- Preparation for disasters
- Evacuation
- Risk management

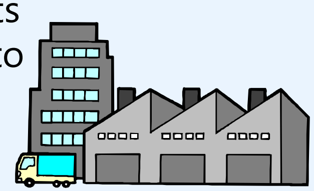
Safety of transportation

Provide meteorological information to
- Pilot and airline companies
- Road administrators
- Train companies



Development and prosperity of industry

Provide weather forecasts and climatological data to
- Energy companies
- Agriculture
- Other industries



International cooperation

- International data exchange
- Technical support
- Sharing disaster information
- Collaboration to develop technics

Organization of JMA

Director-General

Deputy Director-General

Headquarters
- Administration Department
  - Counselors (2)
- Forecast Department — Numerical Prediction Division (M. Sawada, Y. Ota, me)
- Observation Department
- Seismology and Volcanology Department
- Global Environment and Marine Department — Climate Prediction Division (Y. Sato)

Field Offices
- Regional Headquarters (6)
  - Local Meteorological Offices (50)
  - Weather Stations (2)
  - Aviation Weather Service Centers (4)
  - Aviation Weather Stations (5)

Auxiliary Organs
- Meteorological Research Institute — Typhoon Research Department (M. Nakagawa), Forecast Research Department (D. Hotta)
- Meteorological Satellite Center
- Aerological Observatory
- Kakioka Magnetic Observatory
- Meteorological College

Organization of Numerical Prediction Division (NPD)

Administration section

Numerical prediction section (43)
- Modeling, Data assimilation system, EPS

Y.Ota, me — Global modeling group (17)

M.Sawada — Mesoscale modeling group (12)

Observation group (11)

Modeling infrastructure supporting group (3)

Application section (10)
- Post processing, Product generations

Programming section (9)
- Engineering, Management of operational NWP system

Global modeling group

- Global model team (9)
  - Development of Global Spectral Model (GSM)
- Global analysis team (2) —— me
  - Development of Global Analysis system (GA)
- Global EPS team (4) —— Y. Ota
  - Development of Global EPS (GEPS)
- Other works
  - Atmospheric transport model
  - Verification

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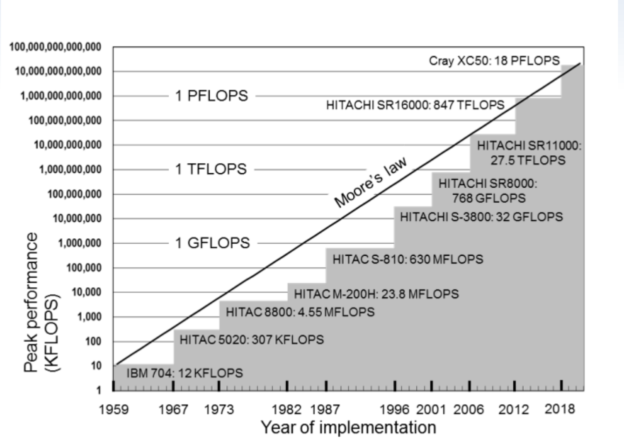
Supercomputer System

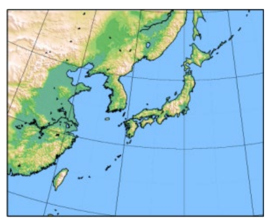
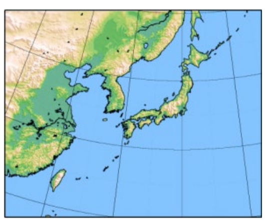
(2018.6-)

- Supercomputer … Cray XC50
  - Two independent systems.
    - Main System : Operational NWP
    - Subsystem : Backup and Development
  - Specifications



Computational Node	CPU	Intel Xeon Platinum 8160 2.1GHz x2
	# of cores	24 x2
	Peak Performance	3.2256 TFlops
	Main Memory	96 GiB
Total	Num. of Nodes	2,816 (15 cabinets) x2
	Peak Performance	9.083 PFlops x2
	Main Memory	264TiB x2
Operating system		Cray Linux Environment

Current NWP models in NPD/JMA

	In Operation				Under Trial
	Global Spectral Model **GSM**	Meso-Scale Model **MSM**	Local Forecast Model **LFM**	Global Ensemble **GEPS**	Meso-scale Ensemble **MEPS**
objectives	Short- and Medium-range forecast	Disaster risk reduction Aviation forecast	Aviation forecast Disaster risk reduction	One-week forecast Typhoon forecast	Uncertainty and probabilistic information of MSM
Forecast domain	Global 	Japan and its surroundings (4080km x 3300km) 	Japan and its surroundings (3160km x 2600km) 	Global 	Japan and its surroundings (4080km x 3300km) 
Horizontal resolution	TL959(0.1875 deg)	5km	2km	TL479(0.375 deg)	5km
Vertical levels / Top	100 0.01 hPa	76 21.8km	58 20.2km	100 0.01 hPa	76 21.8km
Forecast Hours (Initial time)	132 hours (00, 06, 18 UTC) 264 hours (12 UTC)	39 hours (00, 03, 06, 09, 12, 15, 18, 21 UTC)	9 hours (00-23 UTC hourly)	264 h (00, 12 UTC) 132 h (06, 18 UTC)* 27 members	39h 21 members (00, 06, 12, 18 UTC)
Initial Condition	Global Analysis (4D-Var)	Meso-scale Analysis (4D-Var)	Local Analysis (3D-Var)	Global Analysis with ensemble perturbations (SV, LETKF)	Meso-scale Analysis with ensemble perturbations (SV)

* when a TC of TS intensity or higher is present or expected in the RSMC Tokyo - Typhoon Center's area of responsibility (0º–60ºN, 100ºE–180º).

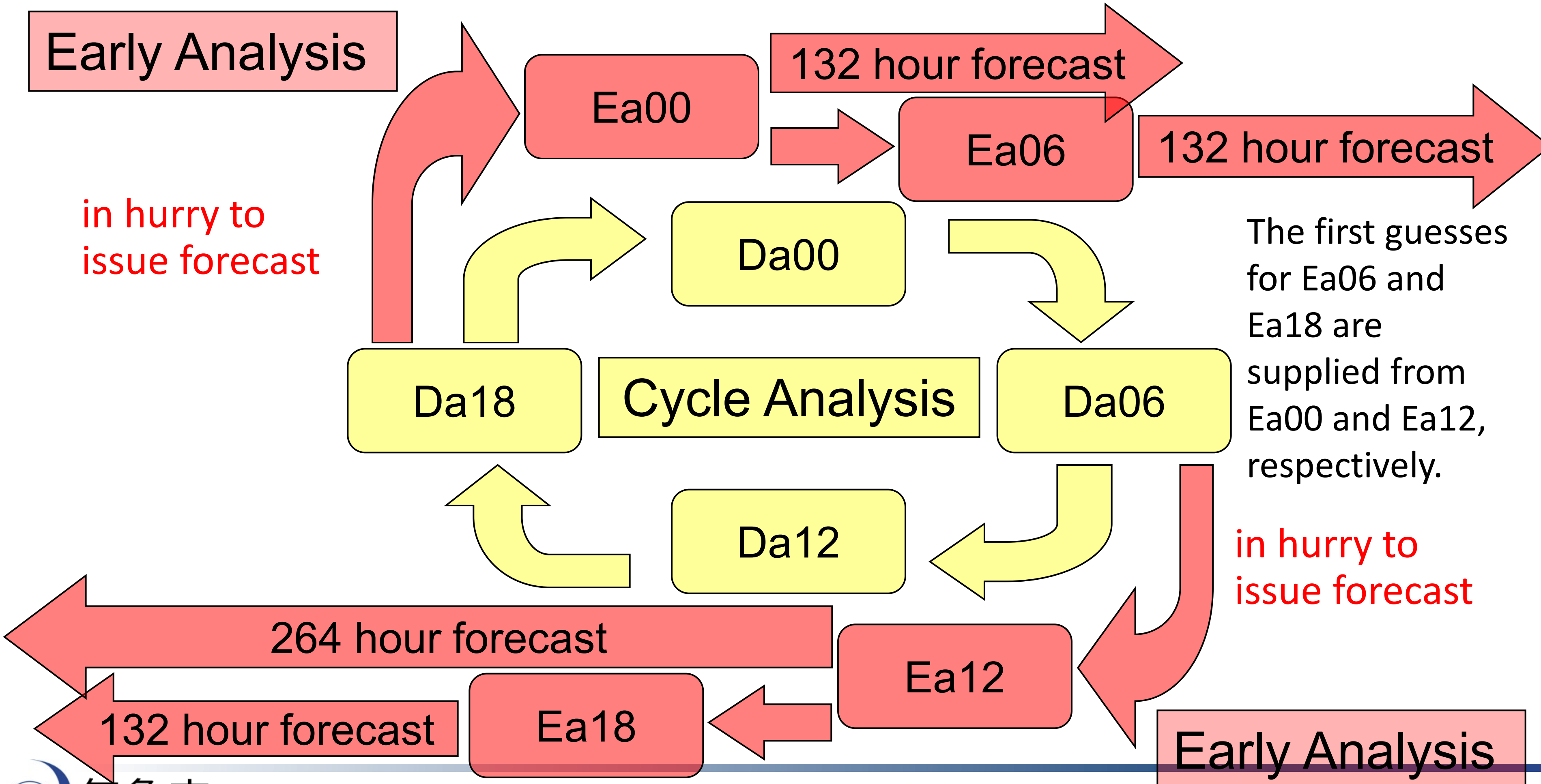
Current analysis system in NPD/JMA

	Global Analysis GA	Meso Analysis MA	Local Analysis LA
Analysis time	00, 06, 12, 18 UTC	00, 03, 06, 09, 12, 15, 18, 21 UTC	00-23 UTC hourly
Data cut-off time	Early analysis: 2h20min (00, 06, 12, 18 UTC) Cycle analysis: 11h50min (00, 12 UTC) 7h50min (06, 18 UTC)	50min (00, 03, 06, 09, 12, 15, 18, 21 UTC)	30min (Every hour)
Horizontal grid system	Reduced Gaussian grid	Lambert projection	
Horizontal resolution/ Inner model resolution	TL959(0.1875 deg)/ TL319(0.5625 deg)	5km at 60N and 30N/ 15km at 60N and 30N	5km at 60N and 30N
Number of grid points (No. of inner model grid points)	1312360 (157800)	721 x 577 (241 x 193)	441 x 501
Vertical levels	Surface + 100 levels up to 0.01 hPa	Surface +50 levels up to 21.8 km	50 levels up to 21.8 km
Assimilation window	Analysis time – 3 hours to analysis time + 3 hours	Analysis time – 3 hours to analysis time	-
Analysis scheme	4-dimensional variational method	4-dimensional variational method	3-dimensional variational method

Early Analysis and Cycle Analysis

Early Analysis: Analysis for weather forecast. The data cut off time is very short.

Cycle Analysis: Analysis for keeping quality of the global data assimilation system and for supplying the first guess to early analysis. This analysis is done after much observation data are received.



The first guesses for Ea06 and Ea18 are supplied from Ea00 and Ea12, respectively.

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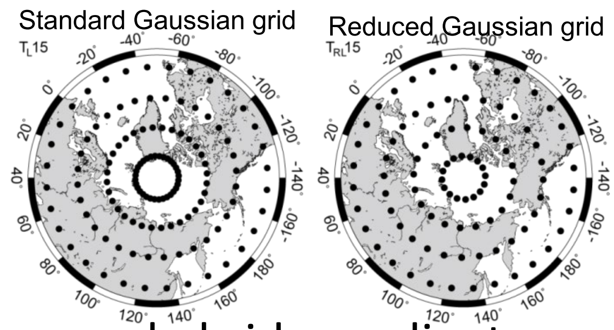
GSM

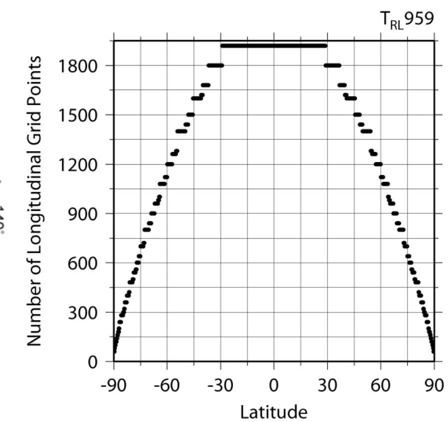
Roles of GSM

- Global NWP systems provide:
  - daily forecasts and warnings
    - for short- and medium-range forecasts
    - for one week forecast
    - for one month and seasonal forecasts (in CPD)
    - for typhoon track and intensity forecasts
    - to assist aviation and ship routing forecasts
  - lateral / upper boundary conditions
    - for the Meso-Scale Model
  - forcing data
    - for the operational ocean wave model
    - for the operational ocean data assimilation system
  - forecasted wind / temperature fields
    - for the operational chemical transport model

Numerical/Dynamical Properties (1)

- Horizontal representation
  - Spectral (spherical harmonic basis functions) with transformation to a reduced Gaussian grid for calculation of nonlinear quantities and most of the physics



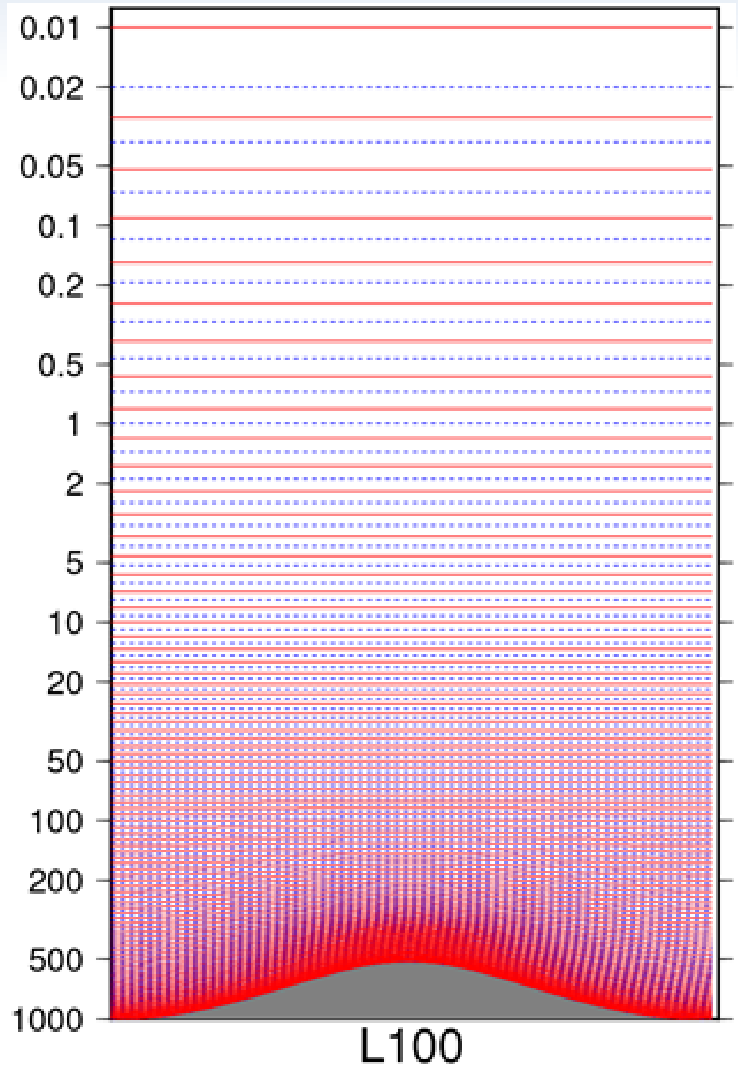


- Horizontal resolution
  - Spectral triangular TL959
- Vertical representation
  - Finite differences in sigma-pressure hybrid coordinates
- Vertical domain
  - Surface to 0.01 hPa level
- Vertical resolution
  - 100 unevenly spaced hybrid levels

Sigma-P hybrid vertical level of GSM

Full level
Half level

0.01 hPa
about 80 km



Mesosphere
（9 layers）

Stratosphere
（31 layers）

Troposphere
（60 layers）

finer in
lower atmosphere

lowest level
about 20 m

Numerical/Dynamical Properties (2)

- Time integration scheme
  - A two-time level semi-implicit semi-Lagrangian scheme is used for the time integration
  - A constant time step length 400 sec. is used for the deterministic (TL959) model
- Numerical Diffusion
  - A linear fourth-order horizontal diffusion is applied on each model level in spectral space to remove numerical noises
  - A linear second-order horizontal diffusion is applied in the divergence equation as a sponge layer around the model top region

Physical Properties

- Subgrid Gravity Wave : orographic gravity wave drag, momentum transport by non-orographic gravity waves
- Radiation : shortwave (solar) and longwave (terrestrial) radiation
- Convection : deep and shallow convection
- Cloud formation : a PDF-based cloud parameterization
- Precipitation : conversion from cloud droplets, detrainment from cumulus and conversion from cloud in convective updrafts.
- Planetary Boundary Layer : vertical transport of momentum, heat and moisture by subgrid scale flow
- Sea Ice / Snow cover
- Surface characteristics
- Surface fluxes : radiative and turbulent fluxes
- Land Surface : Simple Biosphere (SiB) model

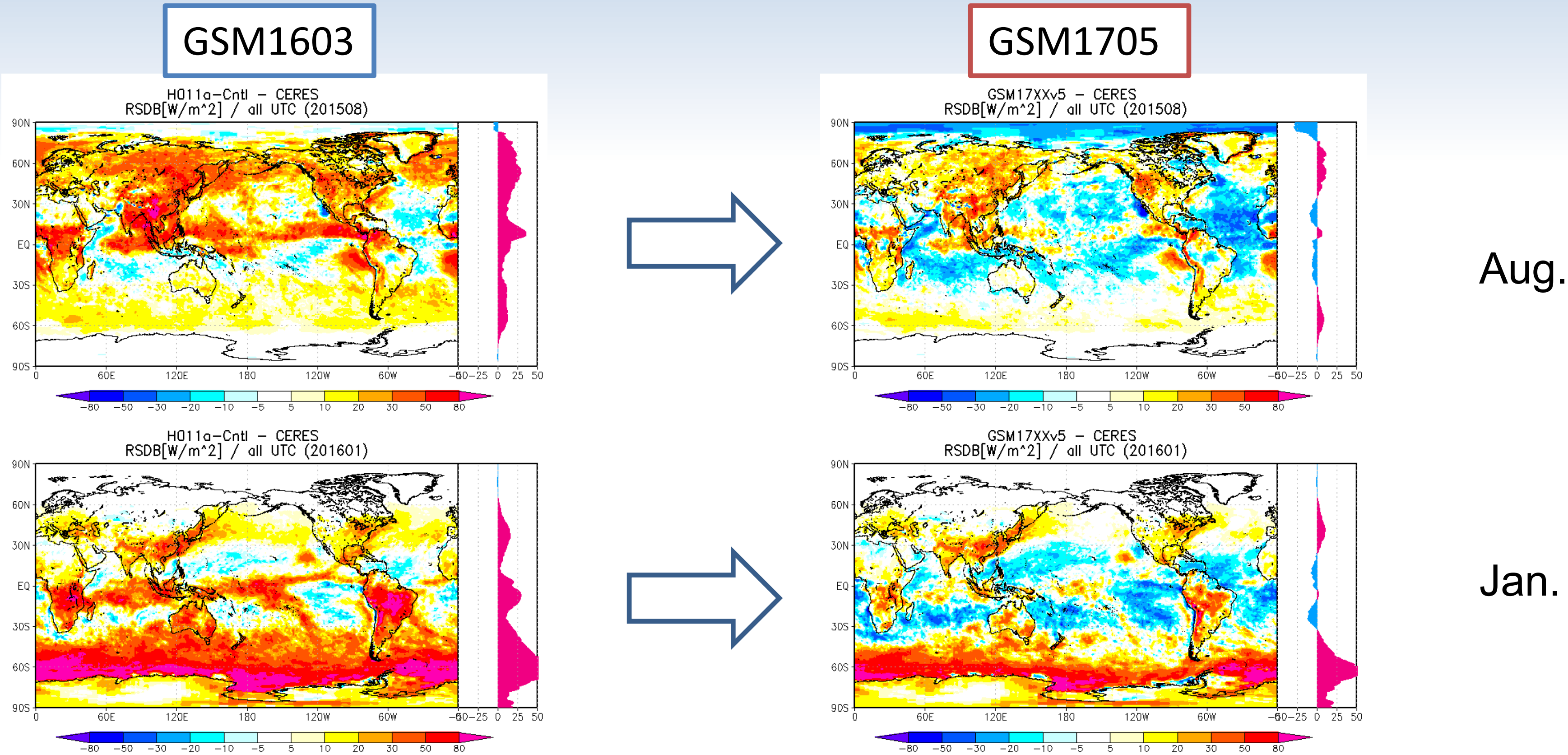
A major upgrade of the global NWP system in May 2017

→ GSM1705

- Upgrade of the physical processes
  - the deep convection parameterization
  - the cloud scheme
  - the radiation scheme
  - the land surface model
  - treatment of sea surface temperature (SST) and sea ice
- Refinement of the dynamical process

  to prevent undesirable spectral blocking in the model atmosphere
- Others
  - Introduce of the methane oxidation scheme in the middle atmosphere
  - Update of the background error statistics used in the analysis

Improvement of the Radiation Budget



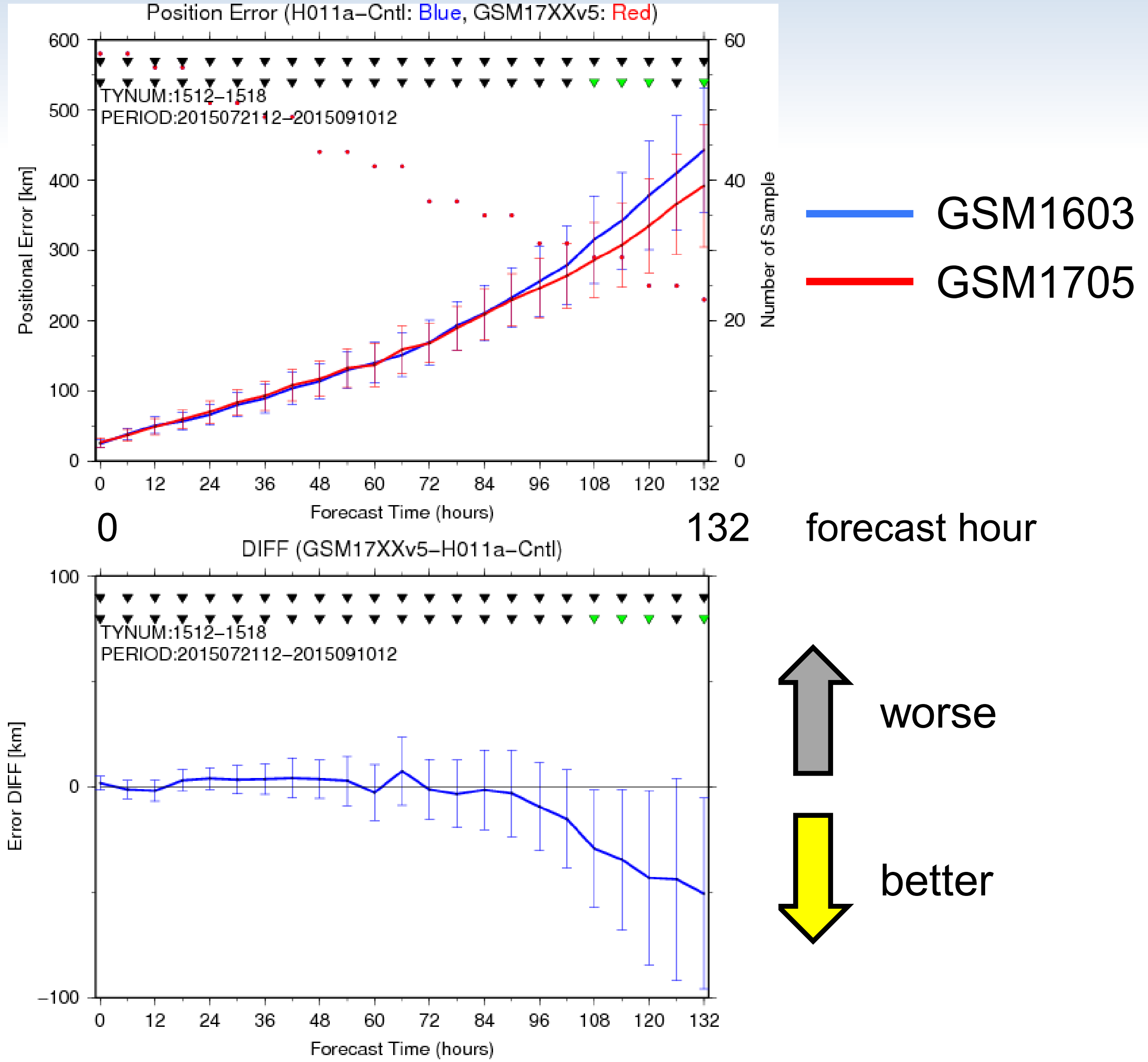
(difference of downward solar radiation at the surface from satellite-based observation)

- GSM1705 has greatly improved the excessive solar radiation of GSM1603, by revisions of the cloud diagnostic scheme and the cloud-radiation scheme.
- It is thought to be related to more adequate representation of the cumulus convection and improved performance of the surface temperature prediction.

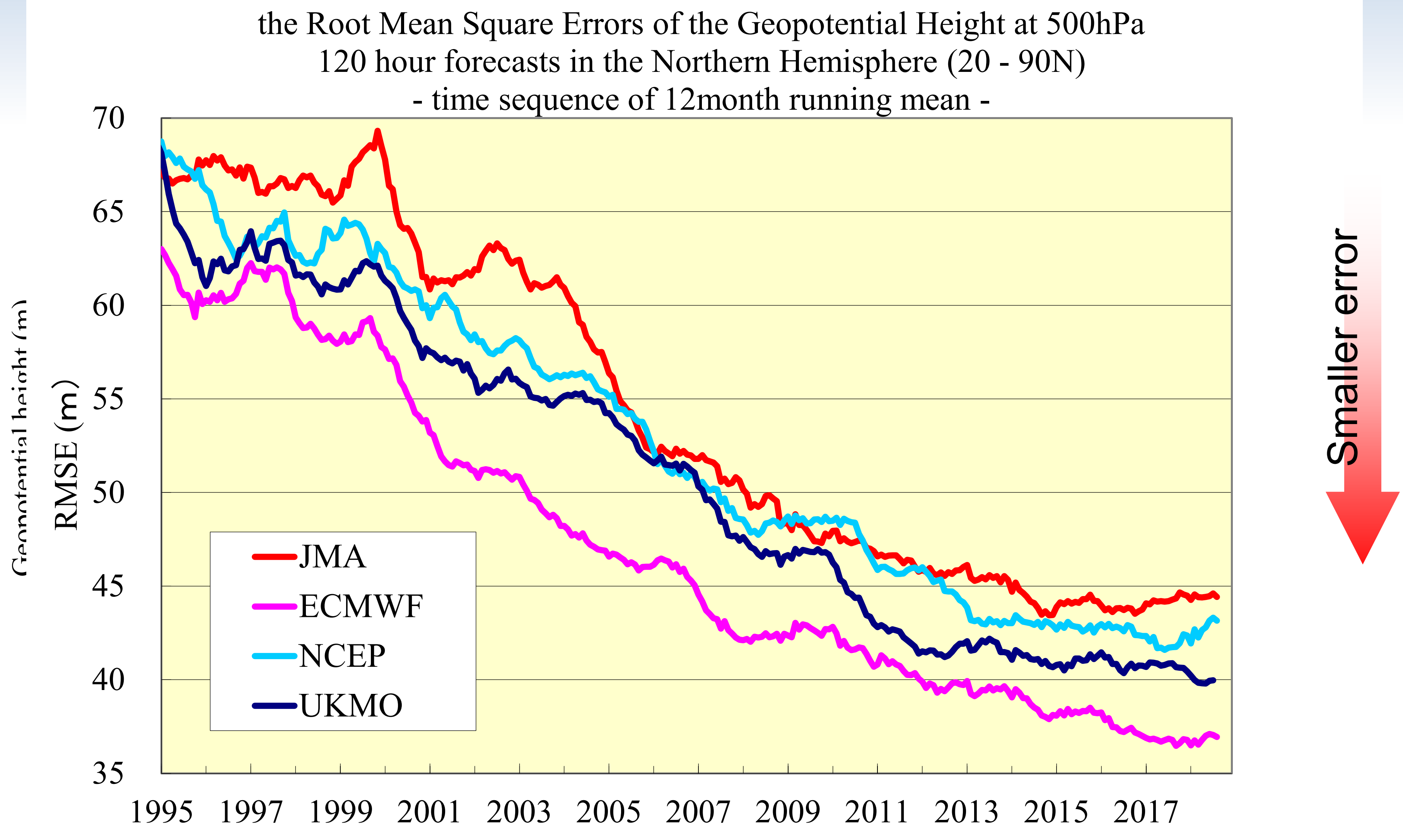
Improvement in typhoon track forecasts

Typhoon track errors
(Jul. – Sep. 2015)

error difference :
GSM1705 – GSM1603



Accuracy of Global NWP model



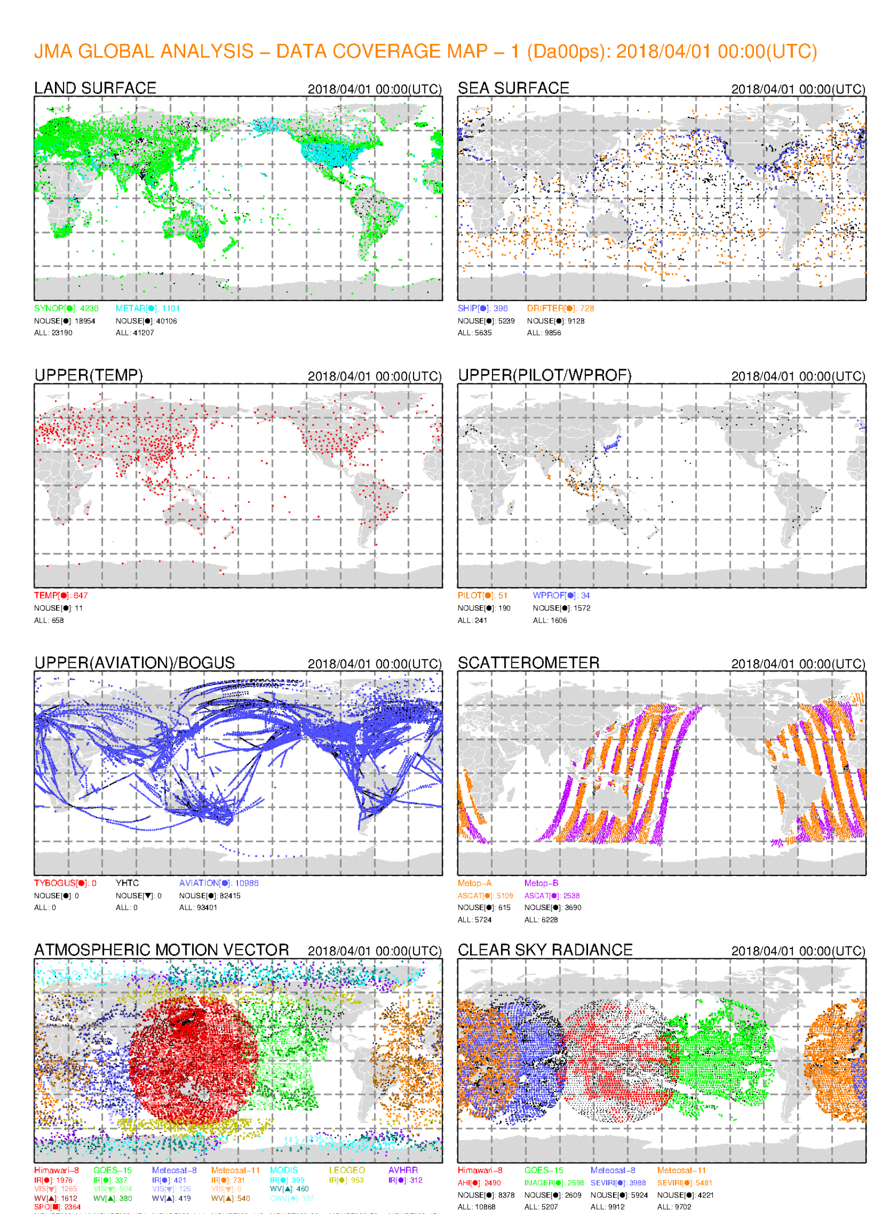

GA

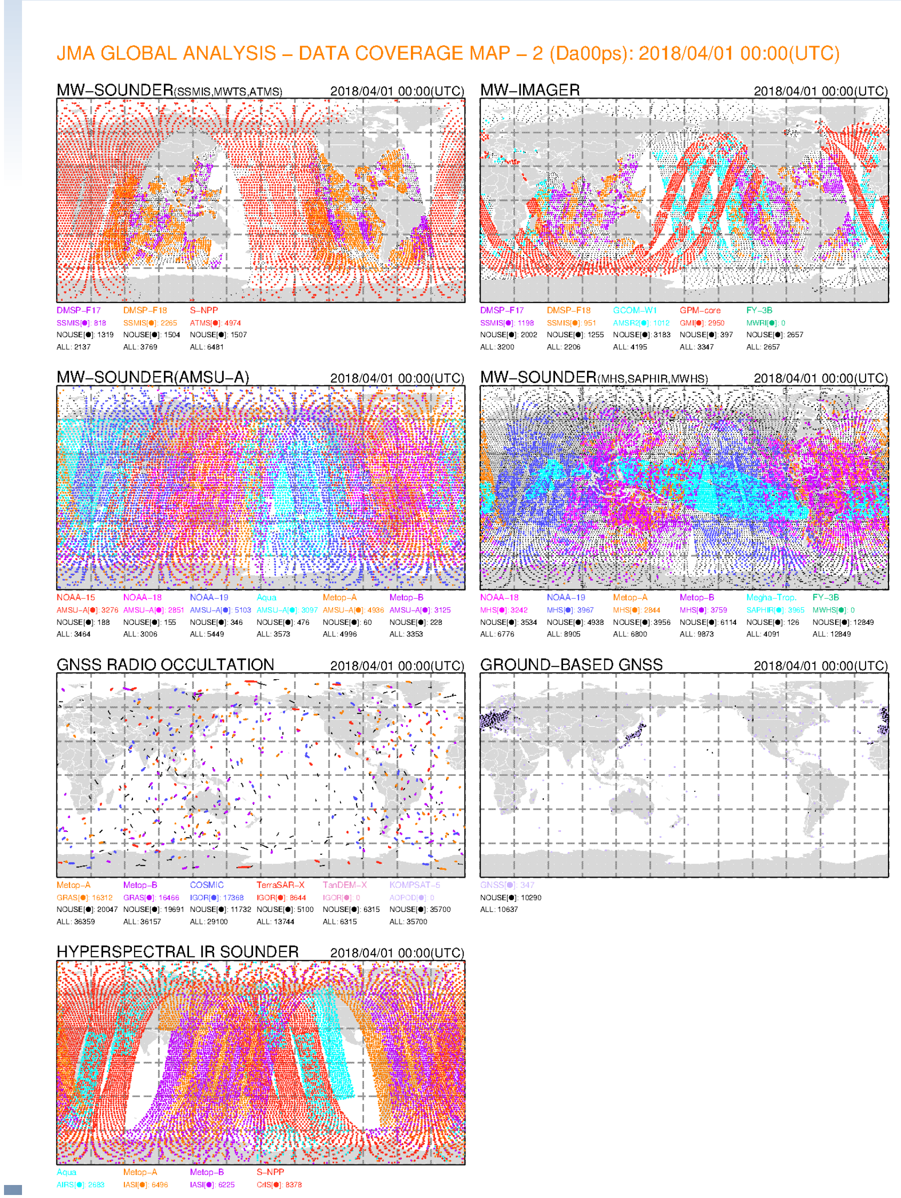
Operational Global Analysis

	GA
Cut-off time	2h20m for early run analyses at 00, 06, 12 and 18 UTC, 11h50m for cycle run analyses at 00 and 12 UTC, 7h50m for cycle run analyses at 06 and 18 UTC
Initial Guess	6-hour forecast by GSM
Grid form, Horizontal resolution	Reduced Gaussian grid, approximately 20km for outer model (TL959) Reduced Gaussian grid, approximately 55km for inner model (TL319)
Vertical resolution	100 forecast model levels up to 0.01 hPa + surface
Analysis variables	Surface pressure, temperature, winds and specific humidity
Methodology	Four-dimensional variational (4D-Var) scheme on model levels
Data Used (as of 31 December 2017)	SYNOP, METAR, SHIP, BUOY, TEMP, PILOT, Wind Profiler, AIREP, AMDAR; atmospheric motion vectors (AMVs) from Himawari-8, GOES-13, 15, Meteosat-8, 10; MODIS polar AMVs from Terra and Aqua satellites; AVHRR polar AMVs from NOAA and Metop satellites; LEO-GEO AMVs; ocean surface wind from Metop-A, B/ASCAT; radiances from NOAA-15, 18, 19/ATOVS, Metop-A, B/ATOVS, Aqua/AMSU-A, DMSP-F17, 18/SSMIS, Suomi-NPP/ATMS, GCOM-W/AMSR2, GPM-core/GMI, Megha-Tropiques/SAPHIR, Aqua/AIRS, Metop-A,B/IASI; Suomi-NPP/CrIS, clear sky radiances from the water vapor channels (WV-CSRs) of Himawari-8, GOES-13, 15, Meteosat-8, 10; GNSS RO bending angle data from Metop-A, B/GRAS, COSMIC/IGOR, GRACE-A, B/blackjack, TerraSAR-X/IGOR, zenith total delay data from ground-based GNSS
Initialization	Non-linear normal mode initialization and a vertical mode initialization for inner model*

* Based on Machenhauer (1977)

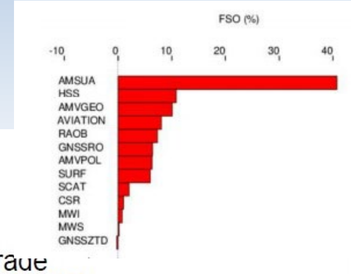
Observations assimilated in JMA Global Analysis

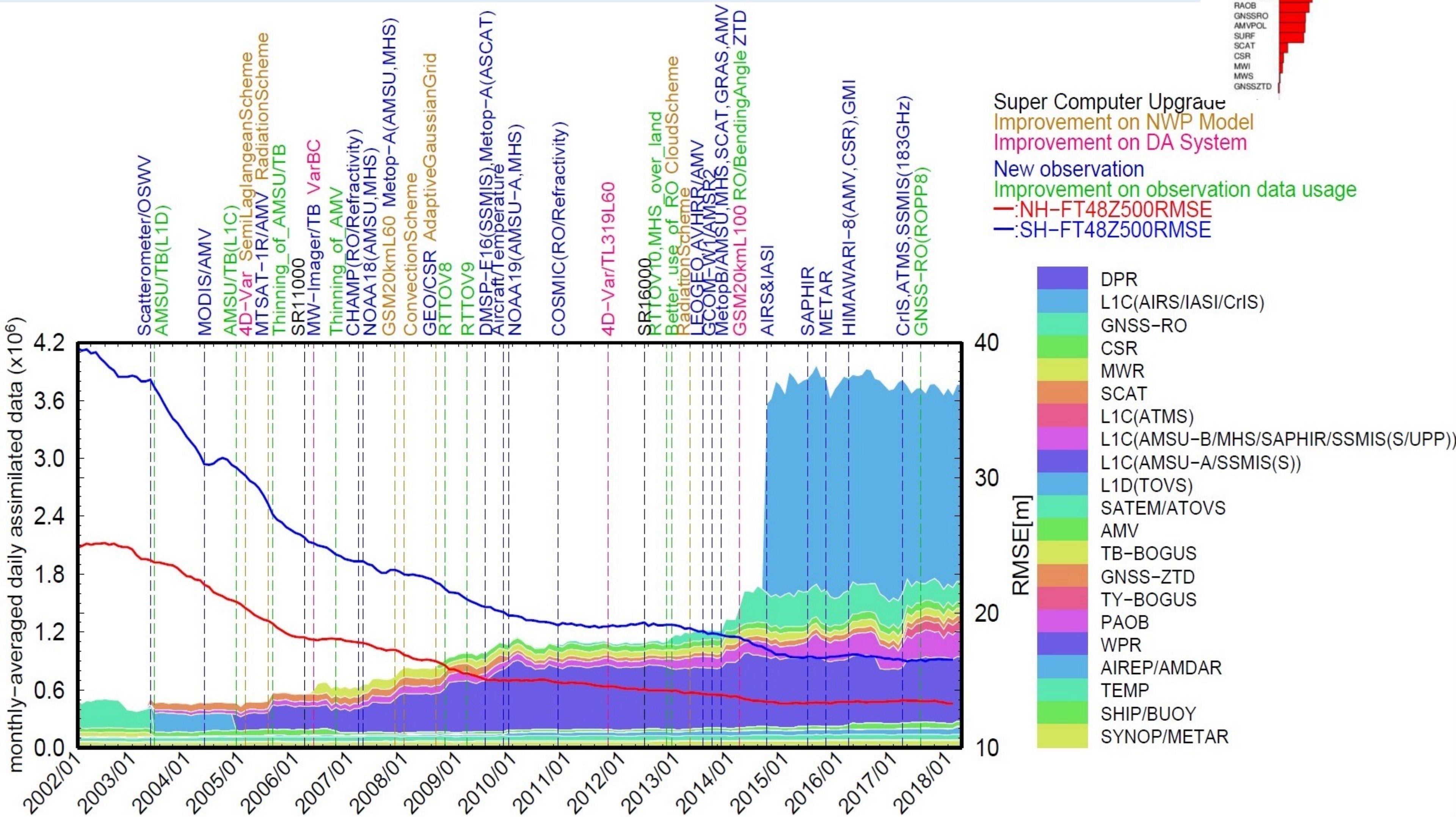




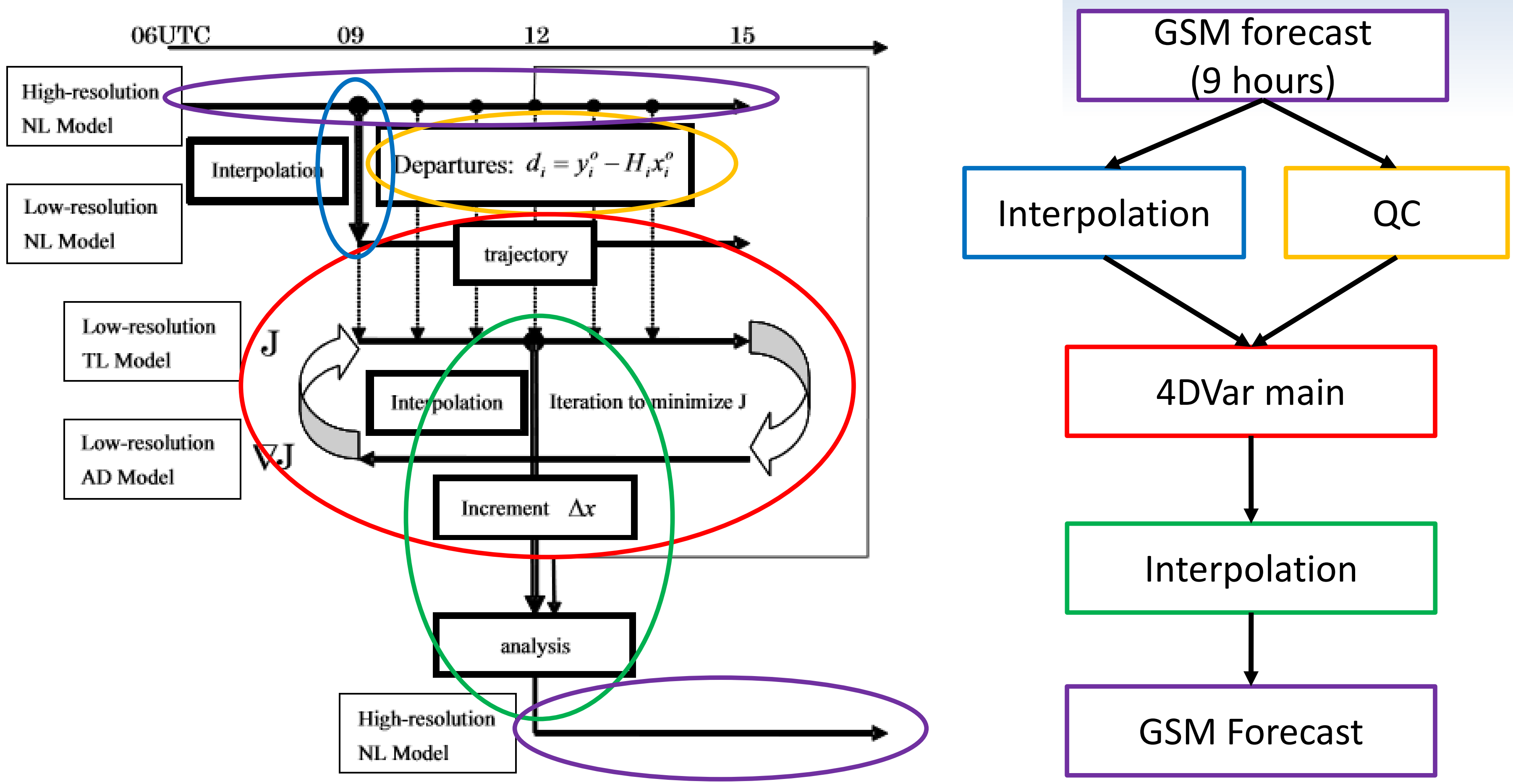
Assimilated Data Amount History

- Global Analysis -





Flow of global 4D-Var operation



JMA global 4D-var uses four models

- High-resolution NL model (outer NL model) = latest GSM
- Low-resolution NL model (inner NL model) = older and simplified GSM + NNMI
- Low-resolution TL/AD model (inner TL/AD model) = TL and AD version of inner NL model

physical processes in TL model

Dynamical properties are basically same as outer NL model

- A constant time step length 600 sec.

- Subgrid Gravity Wave : orographic gravity wave drag only
  - The Richardson number is not perturbed in some parts for long waves
- Radiation : longwave (terrestrial) radiation only
- Convection : highly simplified Arakawa-Schubert scheme
  - Vertical wind shear and the planetary mixing length are not perturbed
  - The magnitude of mass-flux perturbation is set bounds
- Clouds and Large-scale Precipitation : Smith scheme and a simple statistical approach
  - the amount of falling cloud ice and the dependence on water vapor of isobaric specific heat are not perturbed. Only certain variables are perturbed in computing the conversion from cloud water to precipitation and the evaporation of precipitation
- Planetary Boundary Layer : vertical transport of momentum, heat and moisture by subgrid scale flow
  - Those diffusion coefficients are not perturbed
- Surface fluxes : radiative and turbulent fluxes
  - Sensible and latent heat flux are perturbed only over the sea

Global 4D-Var cost function

Total cost function $J(\Delta\boldsymbol{x}_0) = J_b + J_o + J_c$ Incremental method

To control the gravity wave (based on Machenbauer 1977)

Background term $J_b = \frac{1}{2}\Delta\boldsymbol{x}_0{}^T\mathbf{B}^{-1}\Delta\boldsymbol{x}_0$

Background error covariance matrix $\mathbf{B}$

- Described in spectral space
- Estimated by NMC method (365 samples)

Observation term $J_o = \frac{1}{2}\sum_{i=0}^{n}(\mathbf{H}_i\mathbf{M}_i\Delta\boldsymbol{x}_0 - \boldsymbol{d}_i)^T\mathbf{R}^{-1}(\mathbf{H}_i\mathbf{M}_i\Delta\boldsymbol{x}_0 - \boldsymbol{d}_i)$

Pre-conditioning

Cholesky decomposition : $\mathbf{B} = \mathbf{L}\mathbf{L}^T$ ➡ $\Delta\boldsymbol{y}_0 = \mathbf{L}^{-1}\Delta\boldsymbol{x}_0$

$$J = \frac{1}{2}\Delta\boldsymbol{y}_0{}^T\Delta\boldsymbol{y}_0 + \frac{1}{2}\sum_{i=0}^{n}(\mathbf{H}_i\mathbf{M}_i\mathbf{L}\Delta\boldsymbol{y}_0 - \boldsymbol{d}_i)^T\mathbf{R}^{-1}(\mathbf{H}_i\mathbf{M}_i\mathbf{L}\Delta\boldsymbol{y}_0 - \boldsymbol{d}_i) + J_c$$

Gradient $\nabla J = \Delta\boldsymbol{y}_0 + \frac{1}{2}\sum_{i=0}^{n}\mathbf{M}_i{}^T\mathbf{H}_i{}^T\mathbf{R}^{-1}(\mathbf{H}_i\mathbf{M}_i\mathbf{L}\Delta\boldsymbol{y}_0 - \boldsymbol{d}_i) + \nabla J_c$

Control variables

- Analysis variables are
  - Winds (u, v), temperature T, surface pressure P_S, specific humidity q
- Control variables are
  - Relative vorticity ζ, unbalanced divergence η_U, unbalanced temperature and surface pressure (T_U, P_{S_U}), logarithm of specific humidity $\log q$

$$\begin{pmatrix} \Delta u \\ \Delta v \\ \Delta T \\ \Delta P_S \\ \Delta q \end{pmatrix} \rightarrow \begin{pmatrix} \Delta\zeta \\ \Delta\eta \\ \begin{pmatrix} \Delta T \\ \Delta P_S \end{pmatrix} \\ \Delta\log q \end{pmatrix} \rightarrow \begin{pmatrix} \Delta\zeta \\ \Delta\eta_U \\ \begin{pmatrix} \Delta T_U \\ \Delta P_{S_U} \end{pmatrix} \\ \Delta\log q \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ -P\tilde{L} & 1 & 0 & 0 \\ -Q\tilde{L} + RP\tilde{L} & -R & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \Delta\zeta \\ \Delta\eta \\ \begin{pmatrix} \Delta T \\ \Delta P_S \end{pmatrix} \\ \Delta\log q \end{pmatrix}$$

P, Q, R : Regression coefficients $\tilde{L}$: modified balance mass operator

Recent updates of GA

- Upgrade of the inner models (2016.3)
- Update of the background error statistics (2017.5)
- Updates of Observation data usage
  - Enhancement of QC for GNSS-RO data (2017.5)
  - Switch-over from Meteosat-10 to Meteosat-11 AMV and CSR (2018.3)
  - Use of DBNet Suomi-NPP/ATMS (2018.6)
  - Enhancement of surface sensitive CSR data use (2018.10)

GEPS

Operational global EPS

- We started operation of GEPS integrating our previous three EPSs (typhoon, one-week and one-month) in Jan 2017

	GEPS
Main targets	Typhoon forecast, One-week to One-month forecast
Frequency	4 times a day when TC exists, 2 times a day otherwise
Forecast range	5.5 day (06,18UTC), 18 days (00,12UTC) 34 days (00,12UTC on Tue. And Wed.)
Ensemble size	27 up to 11 days, 13 afterwards
Model and its resolution	GSM1705 TL479L100 (top : 0.01 hPa) up to 18 days, TL319L100 afterwards
Initial perturbations	SV (NH, TR and SH) method, LETKF and LAF method
Model ensemble	Stochastically Perturbed Physics Tendency (SPPT) Modified amplitude
Boundary Perturbations	Perturbations on SST

More details on GEPS was introduced at Y. Ota's EMC seminar in May 2016

initial perturbation generators

Specifications of SV computation

TL and AD models	Lower-resolution versions of those used in the global 4D-Var data assimilation system		
Horizontal resolution of models	Spectral triangular 63 (T63), quadratic Gaussian grid system, roughly equivalent to 1.875° ×1.875° (180 km) in latitude and longitude		
Vertical resolution (model top)	100 unevenly spaced hybrid levels (0.01 hPa)		
Norm	Moist total energy		
Targeted areas	Northern Hemisphere (30°N-90°N)	Southern Hemisphere (90°S-30°S)	Tropics (30°S-30°N)
Optional model dynamics and physics	Initialization, horizontal diffusion, surface fluxes and vertical diffusion		In addition to the left, gravity wave drag, large-scale condensation, long-wave radiation and deep cumulus convection
Optimization time	48-hours		24-hours
Number of SVs used to generate perturbations	25	25	25

Specifications of LETKF

Model name (version)	Global Spectral Model (GSM1705)
Horizontal resolution	Spectral triangular 319 (TL319), reduced Gaussian grid system, roughly equivalent to 0.5625° ×0.5625° (55 km) in latitude and longitude
Vertical resolution (model top)	100 unevenly spaced hybrid levels (0.01 hPa)
Analysis time	00, 06, 12, 18 UTC
Ensemble size	50 members
Data cut-off time	2 hours and 20 minutes
First guess	6-hour forecast of its own
Analysis variables	Wind, surface pressure, specific humidity and temperature
Observation	Same as global early analysis except for AIRS, IASI and CrIS
Assimilation window	6 hours
Perturbations to model physics	Stochastic perturbation of physics tendency
Initialization	Horizontal divergence adjustment based on the analysis of surface pressure tendendcy (Hamrud et al. 2015)
Covariance inflation	Adaptive multiplicative covariance inflation
Other characteristics	Fifty analyses are recentered so that the ensemble mean of them become consistent to the analysis of the Global Analysis (GA). Twenty six of 50 analyses are used to generate initial perturbations of GEPS.

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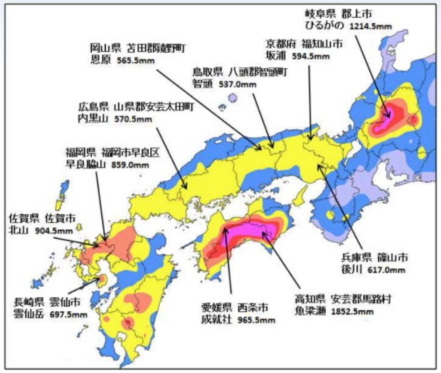
JMA NEW NWP STRATEGIC PLAN TOWARD 2030

Decided in October 2018

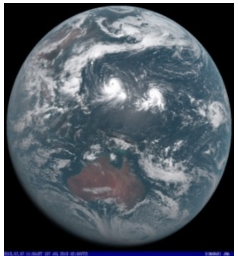
Context

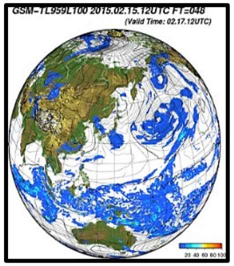
- Change of Natural Disaster
  - Severity of natural disaster with climate change
  - A rash of torrential rain disasters
  - Violent and very large typhoon



- Rapid Change of Social Condition
  - IoT and AI
  - Fragile social infrastructure with declining birthrate and aging population
  - Growth of needs for weather and climate information

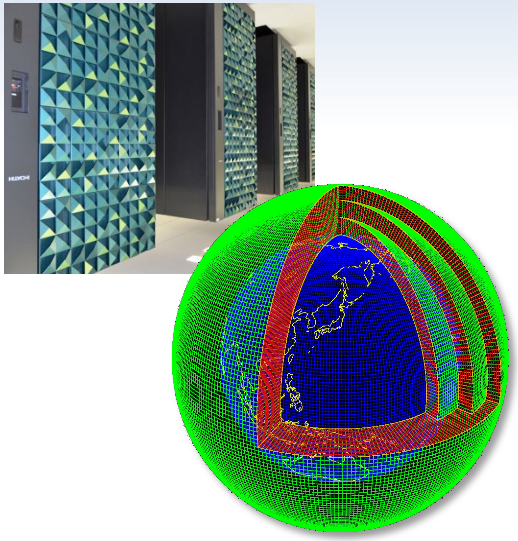
- Dramatic Advances of Science and Technology
  - Simulation technology
  - Big-data
  - International collaboration

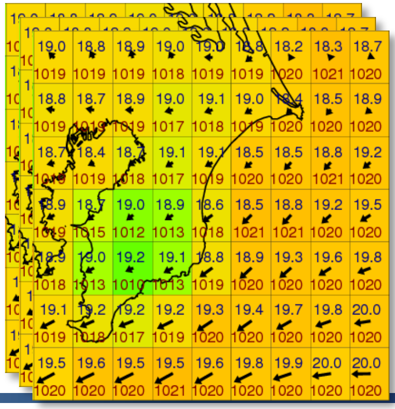




Vision

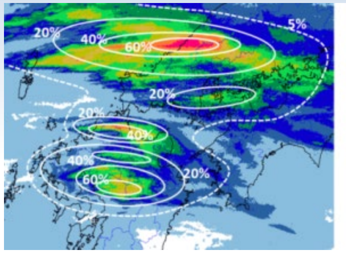
- Innovation to ensure the safety and security of the people, and to realize a vibrant society
  - NWP products are fundamentals for weather and climate forecast.
  - NWP becomes a vital social infrastructure for the safety, security and wealth life.
  - JMA promotes its improvement to achieve higher accuracy to support various social service including disaster prevention directly and effectively.
  - ***NWP will be a new national common asset!***

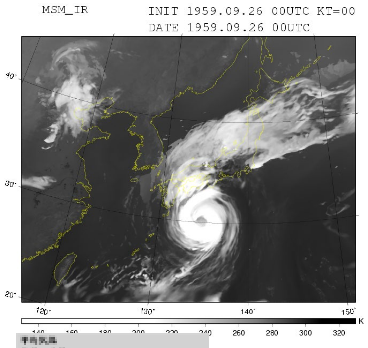


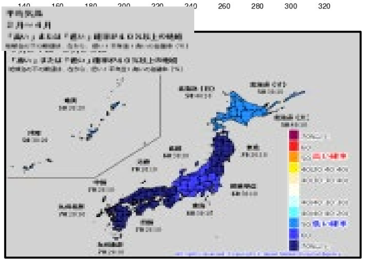


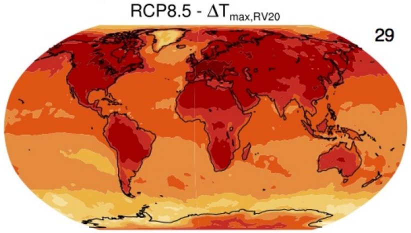
Priority objectives

- Torrential Rain Disaster Prevention
  - Improve probability forecast for genesis and stagnation of torrential precipitation
- Typhoon Disaster Prevention
  - Improvement of forecast accuracy for torrential rain caused by typhoon and synoptic scale front
- Contribution to Socio-economic activities
  - Improvement of weather and climate forecast up to 6 months.
- Adaptation to Global Warming
  - Improvement to higher resolution of global warming information based on common scenario









Promotion of technology innovation

- To achieve above priority objectives, JMA promotes following technology innovation predominantly.
  - Assimilation of Earth Big-data Observation with next generation technology
  - Simulation of Weather and Climate in Japan with world highest accuracy and resolution
  - Support of decision making by blending of Probability forecast and Artificial Intelligence technology

Intensification of Development Management and Principle of development

- Intensification of Development Management
  - Promotion of wide collaboration

    "Experts meeting about ALL-Japan NWP development"

- Principle of development
  - JMA NWP scientists share a principle of development which consists of
    - Prioritization
    - Evidence based development
    - Emphasis on logistics

Development Plan toward 2030

Objective	Development plan
Torrential Rain Disaster Prevention	• Implementation of sub-km high resolution regional model • State of the art data assimilation method with new technology including AI • Assemble of various latest knowledge
Typhoon Disaster Prevention	• Optimized hierarchical NWP system which consists of global and regional model, storm surge model, EPS and so on • Higher resolution global and regional model • Newer physical processes suitable for higher resolution • Assimilation of high density (time/space) earth observation big-data • Introduction of AI technology
Contribution to Socio-economic activities	• The major target is to improve outlooks of high impact conditions or phenomena, such as *cold summer, warm winter, heat wave and cold spell*. • Hierarchical Earth System model which reproduces various phenomena including heat and cold wave and various element • Higher resolution ocean model, Improvement of data assimilation for earth system components
Adaptation to Global Warming	• High resolution regional climate model • More accurate Earth system model which forecast global scale warming

FUTURE DEVELOPMENT PLAN OF GLOBAL NWP

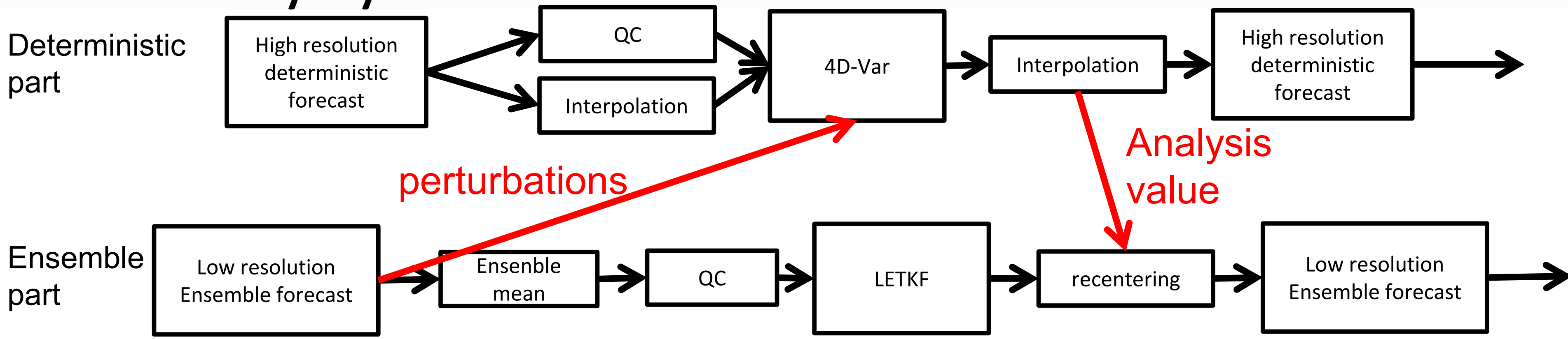
Development plan of global NWP within the next few years

- Higher resolution global model
  - GSM : 20km L100 → 13km L128
  - GA inner models : 55km L100 → ???km L128
  - GEPS : 40km L100 M27 → 25km L128 M51
- Newer physical processes suitable for higher resolution
- State of the art data assimilation
  - Introduction of hybrid DA system
- Assimilation of high density (time/space) earth observation big-data
  - Updates observation data use
  - Introduction of all-sky MW radiance assimilation

JMA global hybrid 4D-Var plan

Developing by Takashi Kadowaki

- 2-way system with 4D-Var and LETKF



- En4D-Var (extended control variable method)

$$J(\Delta x) = \frac{1}{2}\Delta x_f{}^{\mathrm{T}}\mathbf{B}_{cli}{}^{-1}\Delta x_f + \frac{1}{2}\alpha^{\mathrm{T}}\mathbf{B}_{ens}{}^{-1}\alpha + J_o + J_c$$

$$\Delta x = \beta_{cli}\Delta x_f + \sum_{n=1}^{N}\beta_{en}\left(\alpha^n \circ (x_e)_0{}^n\right)$$

$$\Delta x_k = \mathbf{M}_k\left(\beta_{cli}\Delta x_f + \sum_{n=1}^{N}\beta_{en}\left(\alpha^n \circ (x_e)_0{}^n\right)\right)$$

Lorenc (2000)
Buehner (2003)

Current settings of our hybrid DA

In development

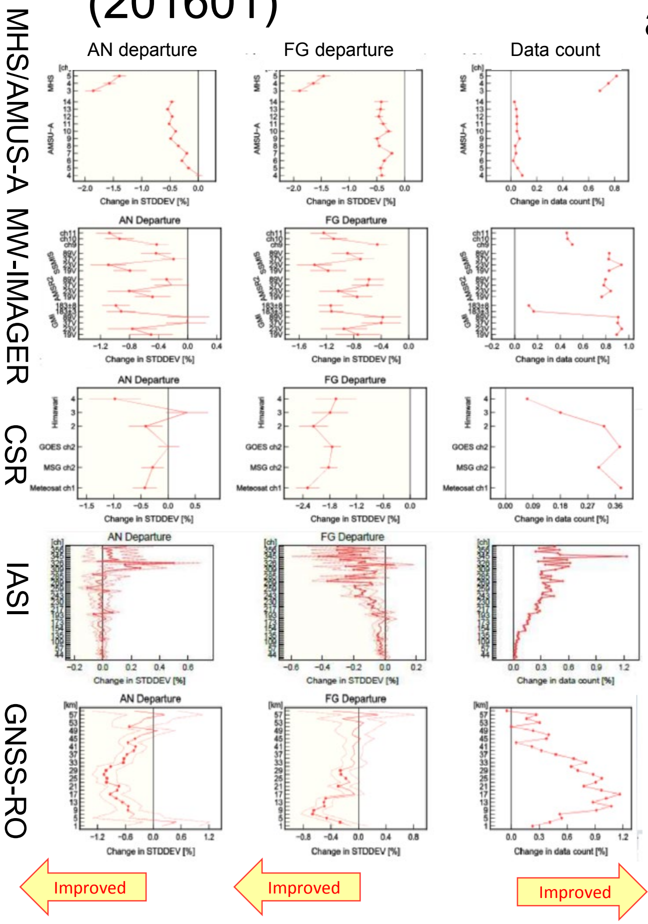
- 4D-Var
  - Resolution : outer TL959L100/inner TL319L100
  - Localization scale 800 km in horizontal, 0.8 scale height in vertical
- LETKF
  - Resolution : TL319L100
  - Ensemble size : 50
  - Localization scale 400 km in horizontal, 0.4 scale height in vertical
- Mixing weight
  - ${\beta_{cli}}^2 = 0.85, {\beta_{en}}^2 = 0.15$

Conservative settings

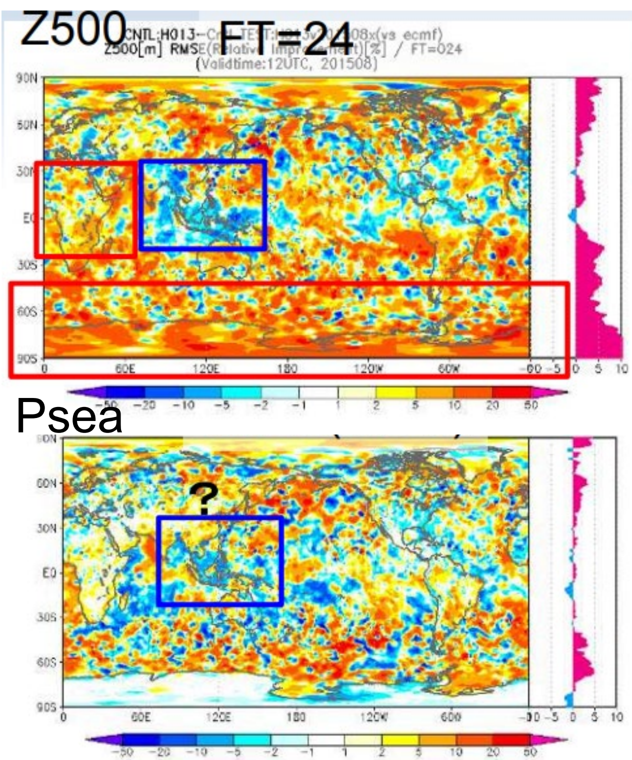
Experimental result

Cntl : 4D-Var
Test : Hybrid 4D-Var

Relative changes against observations (201601)

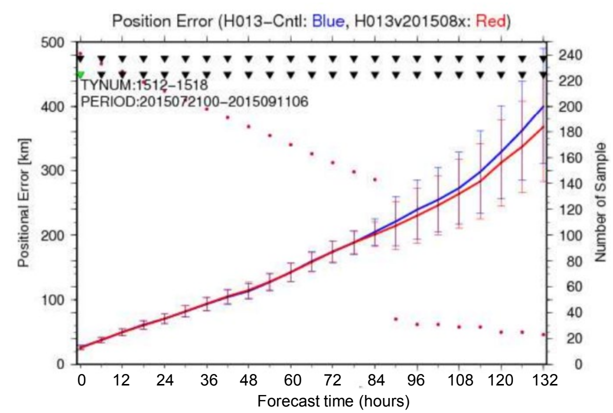


Relative improvement of RMSE against ECMWF analysis (201508)



Red : more close to EC analysis

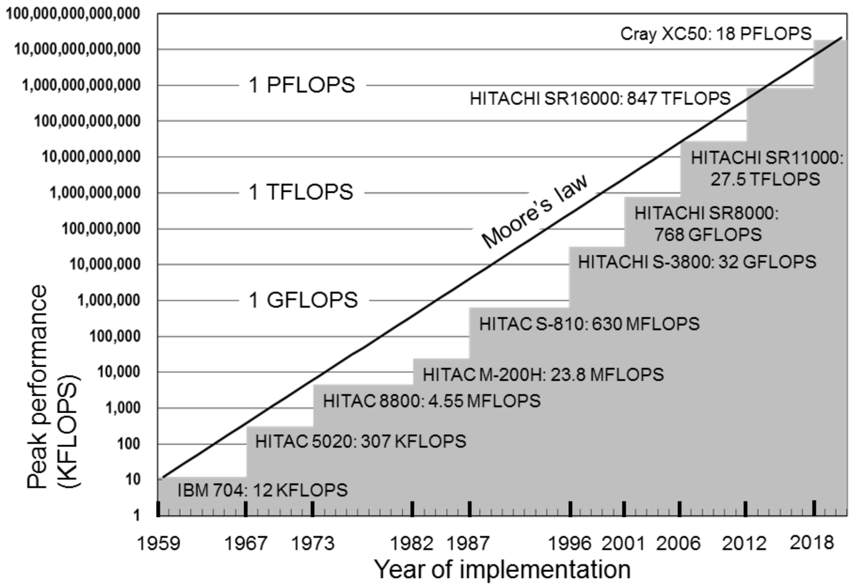
Typhoon track forecast error against JMA analysis (2015072100-2015091106)




THANK YOU!

Supercomputer replacement

- Hitachi SR series to Cray XC series
  - Brand new CPU (Big change since 2001)
    - From IBM POWER to Intel Xeon.
  - Brand new compiler (Big change since the mid 1960's)
    - From Hitachi compiler to Cray (or Intel) compiler.
  - Migration from "Hitachi Service Subroutine"
    - These are provided by Hitachi along with his compiler but not supported on Cray system.



Operationally Assimilated Satellite Data

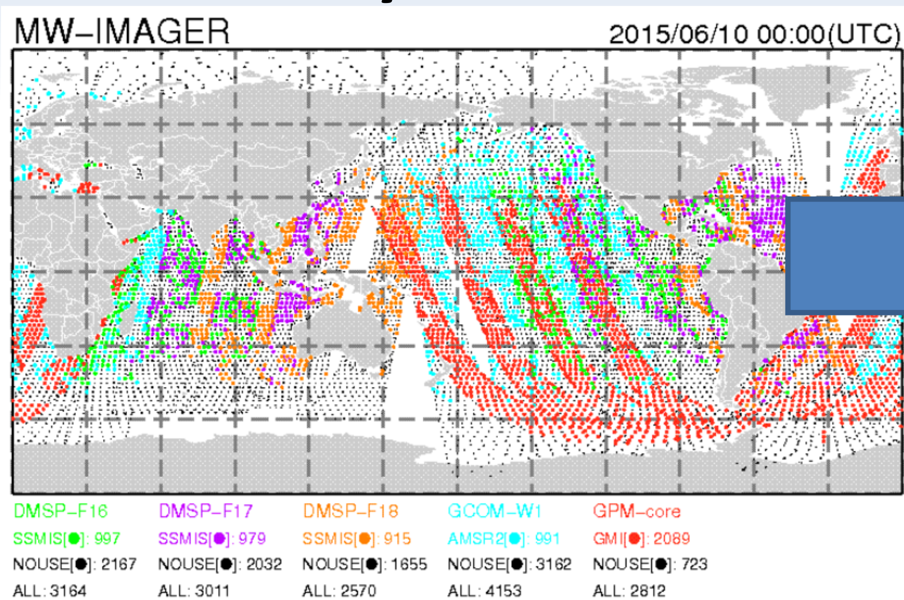
Type	Satellite/Instrument	Global Analysis	Meso Analysis	Local Analysis
1. MW Sounder	NOAA15,18,19,Metop-A,-B,Aqua/AMSU-A	Radiance	Radiance	Radiance
	NOAA18,19,Metop-A,-B/MHS	Radiance	Radiance	Radiance
	DMSP-F17,18/SSMIS	Radiance	-	-
	Suomi-NPP/ATMS	Radiance	-	-
	Megha-Tropiques/SAPHIR	Radiance	-	-
2. IR Sounder	Aqua/AIRS	Radiance	-	-
	Metop-A,B/IASI	Radiance	-	-
	Suomi-NPP/CrIS	Radiance	-	-
3. MW Imager	DMSP-F17,18/SSMIS	Radiance	Radiance, Rain Rate	Radiance
	GCOM-W/AMSR2	Radiance	Radiance, Rain Rate	Radiance
	GPM-core/GMI	Radiance	Radiance, Rain Rate	Radiance
4. VIS/IR Imager	Himawari-8	CSR, AMV	CSR, AMV	CSR, AMV
	GOES-15	CSR, AMV	-	-
	Meteosat-8,11	CSR, AMV	-	-
	NOAA15,18,19,Metop-A,-B/AVHRR	AMV	-	-
	Aqua,Terra/MODIS	AMV	-	-
	LEOGEO composite image	AMV	-	-
5. Scatterometer	Metop-A,-B/ASCAT	OSWV	OSWV	-
6. Radio Occultation	GRACE-A,-B/Blackjack	Bending Angle	Refractivity	-
	Metop-A,-B/GRAS	Bending Angle	Refractivity	-
	TerraSAR-X/IGOR	Bending Angle	Refractivity	-
	TanDEM-X/IGOR	-	Refractivity	-
	COSMIC/IGOR	Bending Angle	Refractivity	-
7. Radar	GPM/DPR	-	Relative Humidity	-
8. Soil Moisture	GCOM-W/AMSR2	-	-	Soil Moisture
	Metop-A,-B/ASCAT	-	-	Soil Moisture

CSR: Clear Sky Radiance on water vapor channels, **AMV**: Atmospheric Motion Vector, **OSWV**: Ocean Surface Wind Vectors

(as of 6 June 2018)

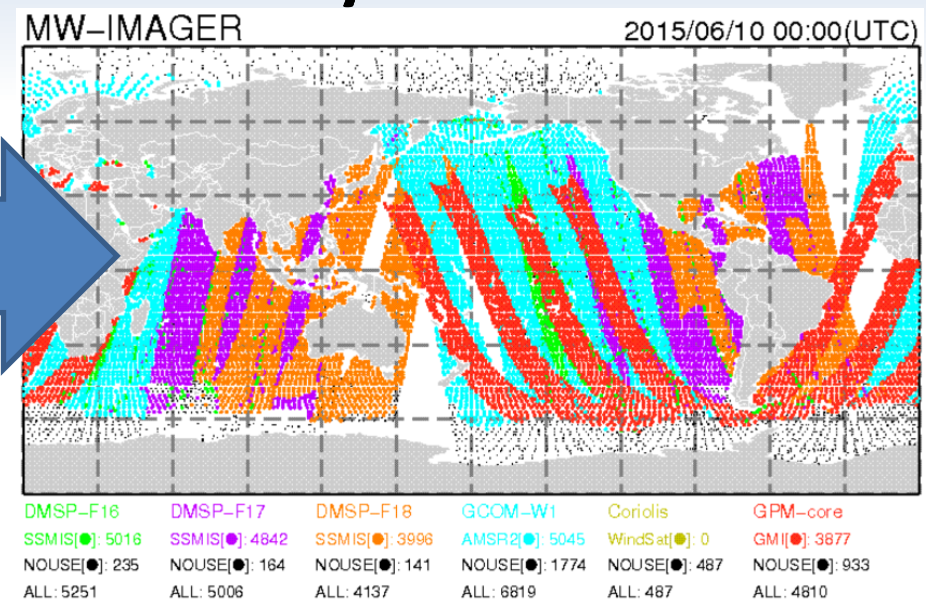
All-sky MW radiance assimilation

Clear-sky



All-sky

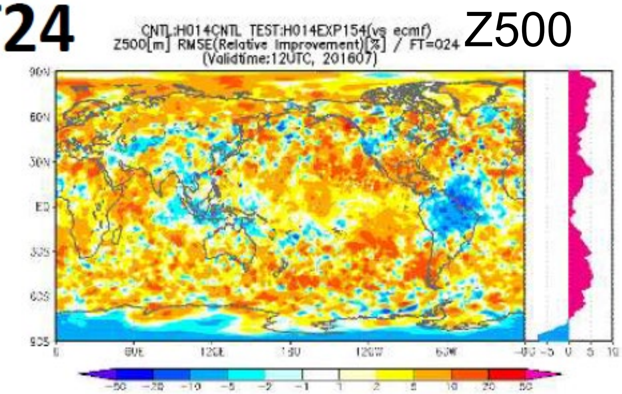
with outer loop



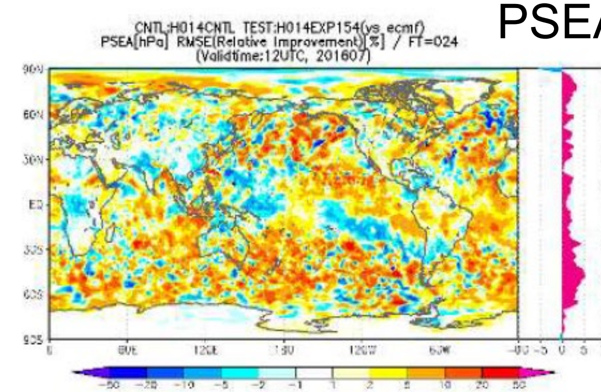
Relative improvement of RMSE against ECMWF analysis (201607)

FT24

Z500



PSEA



Introduction of outer loop on GA