Future Development of Mesoscale Modelling and Data Assimilation in JMA

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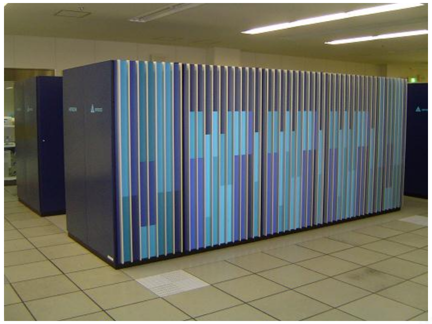
Training Workshop on the Latest Developments on the Use and Interpretation of NWP Models

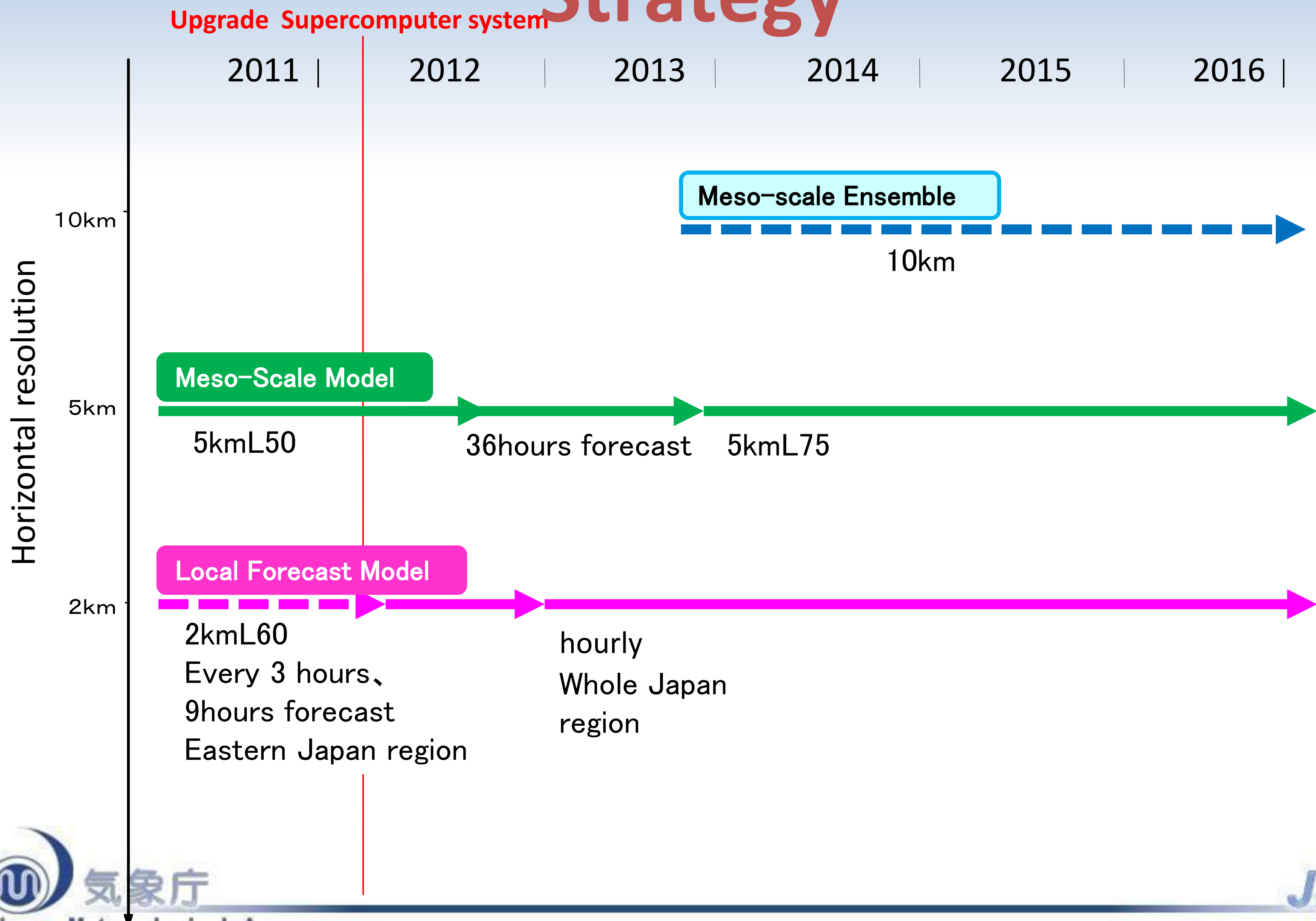
HKO, 3-7 Dec 2012

New Super Computing Systems

	New	Old
Machine	Hitachi SR16000/M1	Hitachi SR11000/K1 Hitachi SR11000/J1
CPU	Power 7 (3.83GHz, 8core)	Power 5 (1.9GHz), Power 5+ (2.1GHz)
CPU/NODE	4 processors (total 32cores)	16 processors
NODE	864 (432x2)	210 (80x2+50)
Peak Performance	847 (423.5x2) T Flops	27.5 (10.75x2+6) T Flops
Main Memory	108 T Byte	13.1 T Byte
operation was started on	5 June 2012 -	1 March 2006 -



Strategy



Upgrade Supercomputer system
2011
2012
2013
2014
2015
2016
Horizontal resolution
10km
5km
2km
Meso-scale Ensemble
10km
Meso-Scale Model
5kmL50
36hours forecast
5kmL75
Local Forecast Model
2kmL60
Every 3 hours、
9hours forecast
Eastern Japan region
hourly
Whole Japan
region

Development

- **Recent changes**
  - ***Aug 2012: 2km-LFM/LA operation was started***
  - Nov.15 2012: RTM upgrades (RTTOVv9.3→v10) in MA

- **Under development**
  - ***Mar? 2013:*** 5km-MSM configuration upgrade
    - Expand the model domain
    - Extend the forecast range (36 or 39 hours <-15hours/33hours)
  - ***May? 2013:*** 2km-LFM configuration upgrade
    - Increase the operation frequency from three-hourly to hourly
    - Expand the model domain (whole Japan region <- Eastern Japan)
  - Increase the model levels (from 50 to 75)
  - Raise the model top (TBD). Enhancement of land surface scheme ← my work
  - new dynamical core for the non-hydrostatic model "ASUCA"
  - ***2013:*** Start test operation of the EPS system

I'm going to talk about this

“ASUCA” new nonhydrostatic model of JMA

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Development of a new dynamical core
Motivation

- The dynamical core of our current nonhydrostatic model (JMA-NHM) has several issues to be improved:
  1. **Many additional cares for computational stability are accumulated, but it is still need to be improved**
  2. **Not secure exact conservation of mass**
  3. **Not enough efficiency on scalar architecture**
  4. Artificial parameters are used as keys for computational stability
  5. … model codes are now complicated with additional codes.

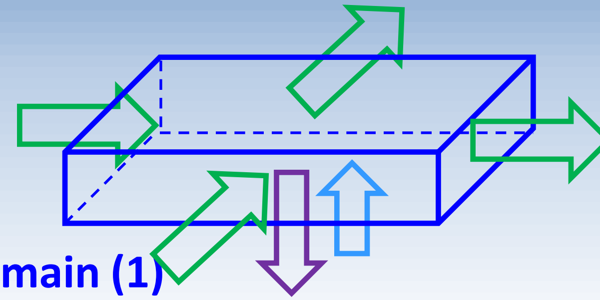
Development of a new dynamical core Motivation

- A nonhydrostatic dynamical core named “ASUCA” is under development aiming at
  1. **Improved computational stability**
  2. **exact conservation of mass**
  3. **Higher efficiency on massive parallel scalar multi-core architecture**
  4. Exclusion of artificial parameters
  5. Keep the codes as modular as possible to facilitate the developments and long term maintenance

Comparison of the specification of the dynamical core between ASUCA and JMA-NHM

	ASUCA	JMA-NHM
Governing equations	Flux form Fully compressible equations	Quasi flux form Fully compressible equations
Prognostic variables	ρu, ρv, ρw, $\rho\theta_m$, ρ	ρu, ρv, ρw, θ, p
Spatial discretization	Finite volume method	Finite difference Method
Time integration	Runge-Kutta 3^{rd} (long and short)	Leapflog with time filter (long) Forward backward (short)
Treatment of sound	Conservative Split explicit	Split explicit
Advection	Flux limiter function by Koren (1993)	4^{th} (hor.) and 2^{nd}(ver.) order with advection correction
Numerical diffusion	None	4^{th} order linear and nonlinear diffusion
Treatment of rain-drop	Time-split	Box-Lagrangian
Coordinate	Generalized coordinate or Conformal mapping + Hybrid-Z	Conformal mapping (hor.) Hybrid – Z (ver.)
Grid	Arakawa-C (hor.) Lorentz (ver.)	Arakawa-C (hor.) Lorentz (ver.)

Mass conservation



- Variation of the total mass in the computational domain (1)

  should be Sum of inflow and outflow of the mass at boundaries
- Sum of inflow and outflow of the mass at boundaries

  = flux of mass at lateral boundaries (2)

  \- loss of mass by precipitation (3)

  \+ water vapour flux at the surface (4)

(1) is computed directly from the density

<How much (1) is consistent to sum of (2), (3) and (4) >

・・・

total mass diff, total flux =

-227802864231.908875

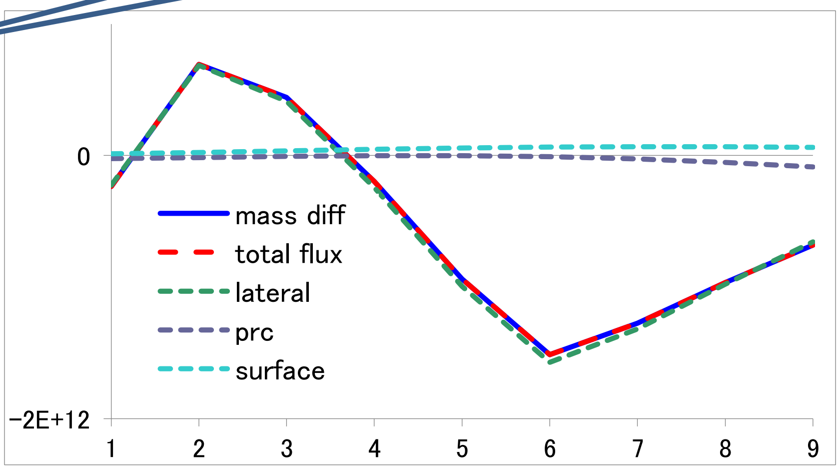
-227802864231.934052

total error = 0.251770019531250000E-001

(total lateral flux) = -224912457213.078125

(total prc flux) = -16499942061.0891171

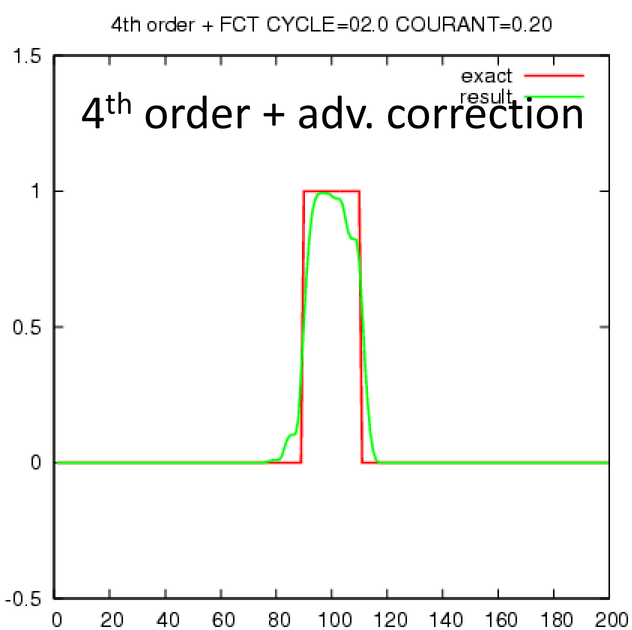
(total surface flux) = 13609535042.2331963

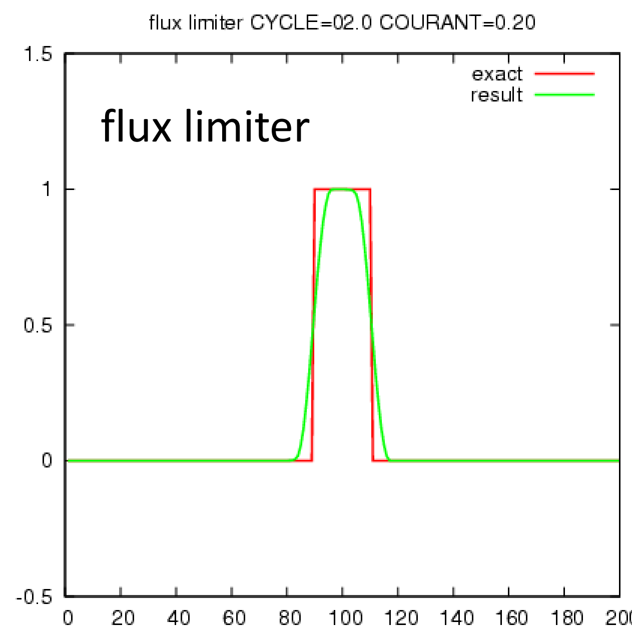


- JMA-NHM has an option to care the mass conservation, which requires MPI comm. of all to one.
- Keeping mass conservation also contributes to not let down computational efficiency.

Advection

- **ASUCA**: The flux limiter function proposed by Koren (1993) is employed for advection.
  - 3rd order (in smooth field)
  - Monotonicity
  - Efficiency: (no need for MPI comm.)





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no overshoot and no undershoot appeared.

Software design of ASUCA

- To achieve **higher efficiency on massive parallel scalar multi-core architecture**
  - **kij - ordering** real(8) :: u(nz, nx, ny)
    - Three-dimensional arrays in space are stored sequentially in the order of z (k), x (i) and y (j).
      - Aiming at low memory usage to improve **cache efficiency**
      - Advantageous to parallelize at outermost loop.
  - **reduce the number of MPI communication**
    - Subroutine for data stock before MPI comm. & subroutine for MPI comm. of stocked data are separately prepared.
    - Procedure of diagnosing variables are collected up before the procedure of dynamics and physics, intending not to increase unnecessary doubled diagnosis and its sequential MPI comm.

	ASUCA	JMA-NHM
Number of calling MPI comm.	**72600**	**138652**

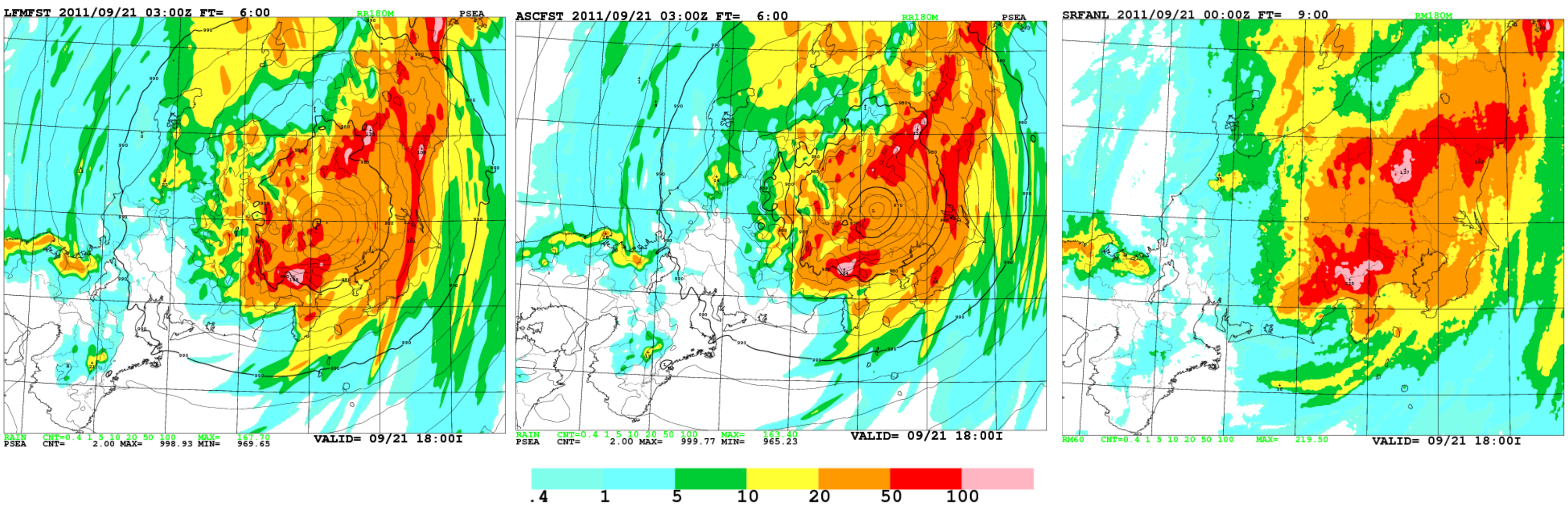
Asuumption of 1hour forecast of LFM(dx=dy=2km)
JMA-NHM:dt=8, asuca:dt=16

Current Status of ASUCA

- Main part of the developments of dynamical core has almost completed.
- Physical processes equivalent to those of JMA-NHM have been implemented using the “Physics Library”.
- Daily experiments have been carried out with dx=2km and dt =16 sec since April 2011 to clarify and fix the problems for practical use.
  - No computationally unstable case with these configurations.
- Further evaluations are continued by a certain period of experiments to compare the statistical aspects with those of JMA-NHM.

A result of the T1115 typhoon case

JMA-NHM　　　　ASUCA　　　　Observation

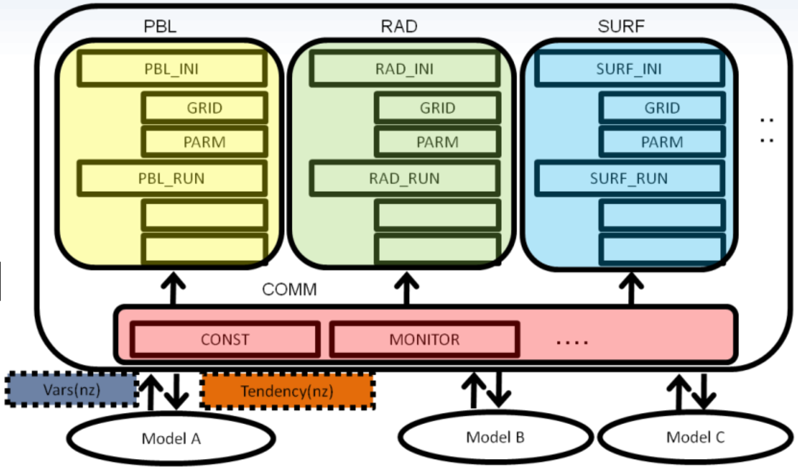


Simulation results initialized 03 UTC 21 September 2011.
Mean sea level pressure and 3-hour accumulated precipitation.

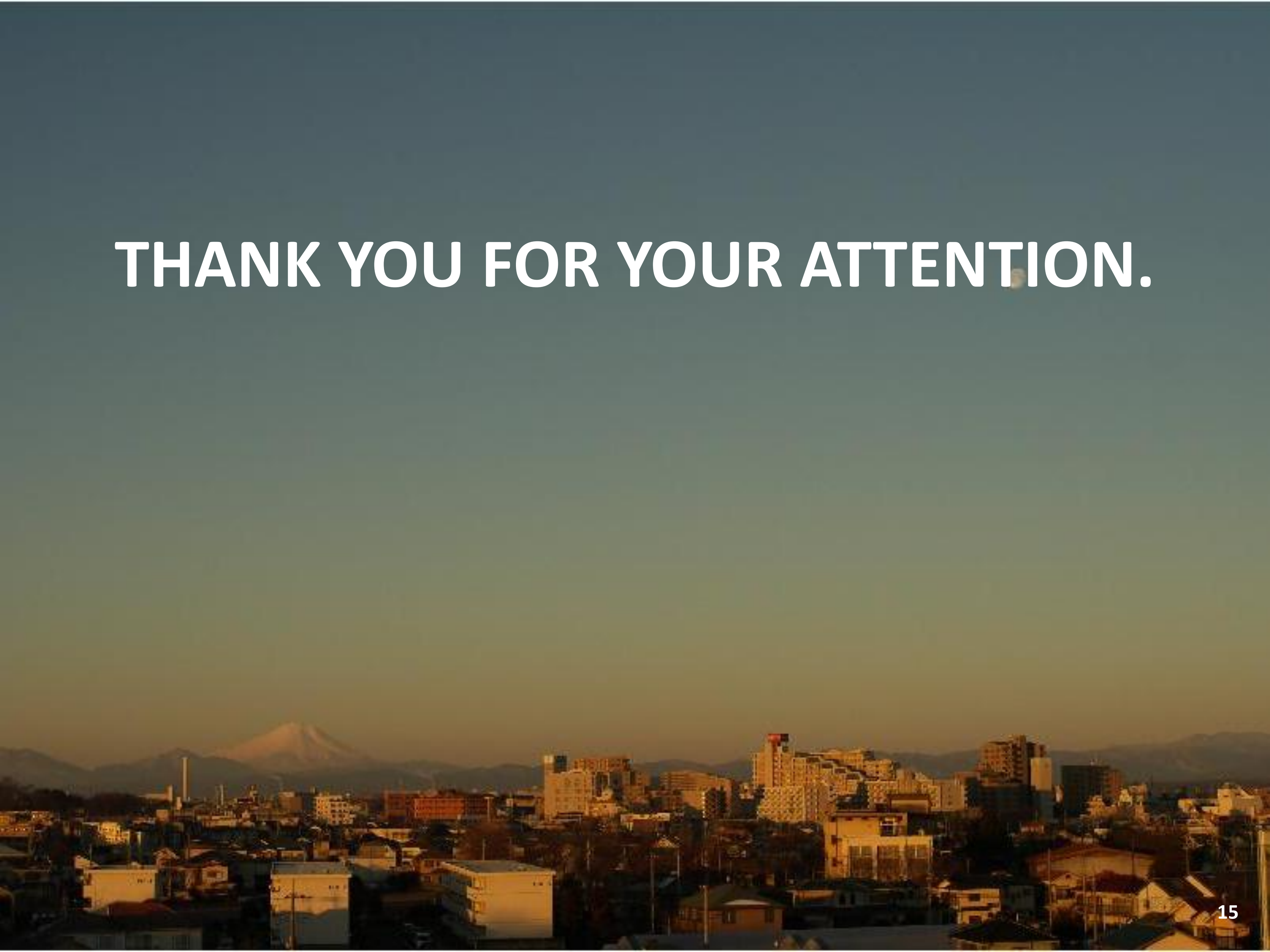
- ASUCA and JMA-NHM resemble each other and both of them give good forecasts for this case

Physics Library

- **Purpose: What is the physics library?**
  - The Physics Library is intending to serve as a repository for various subroutines related to physical processes with unified coding and interface rules, and allows them to be shared among various forecast models.



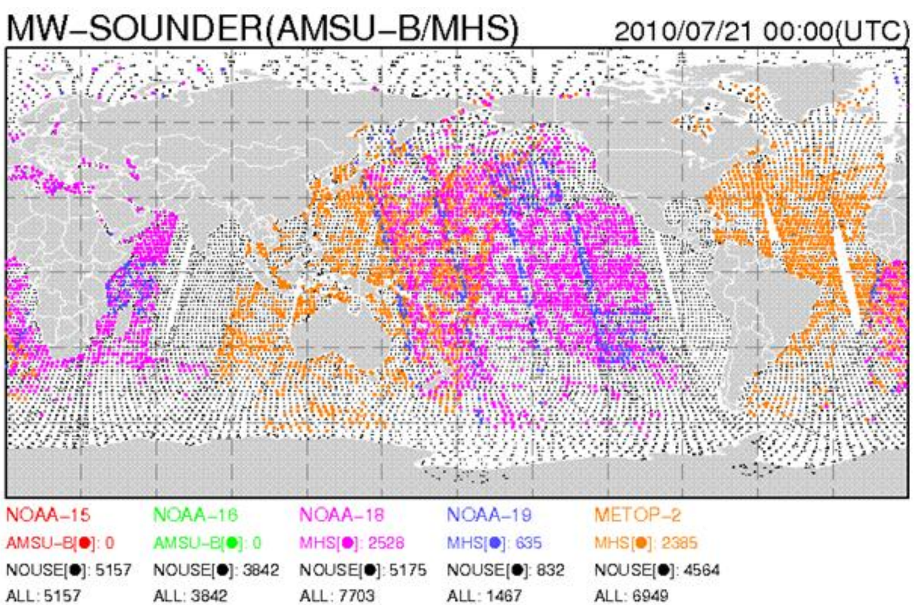
- **Designs and Coding Policies**
  - Implemented as vertical one-dimensional models aiming at low memory usage to improve cache efficiency
  - (absolutely crucial for scalar computers)
  - This simple one dimensional implementation is expected to make the development of physical processes more efficient.
  - Established detailed rules on names of subroutines etc.


THANK YOU FOR YOUR ATTENTION.

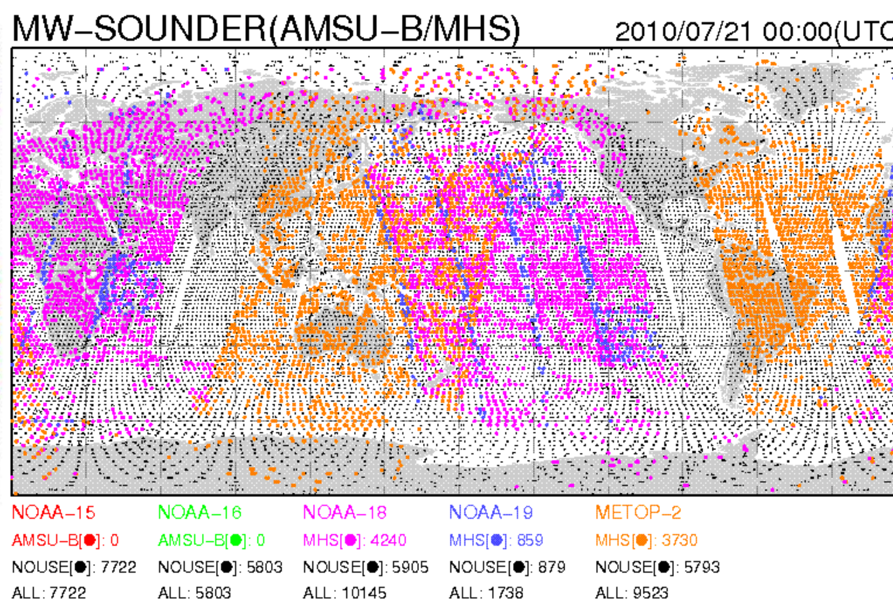
RTM upgrade

- JMA is not using MHS data over land area and is testing to use the data with replacing the RTM RTTOV v9.3 by v10 (with the emissivity ATLAS).

CNTL

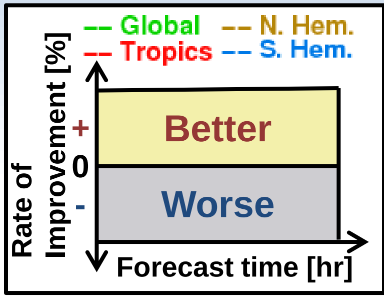


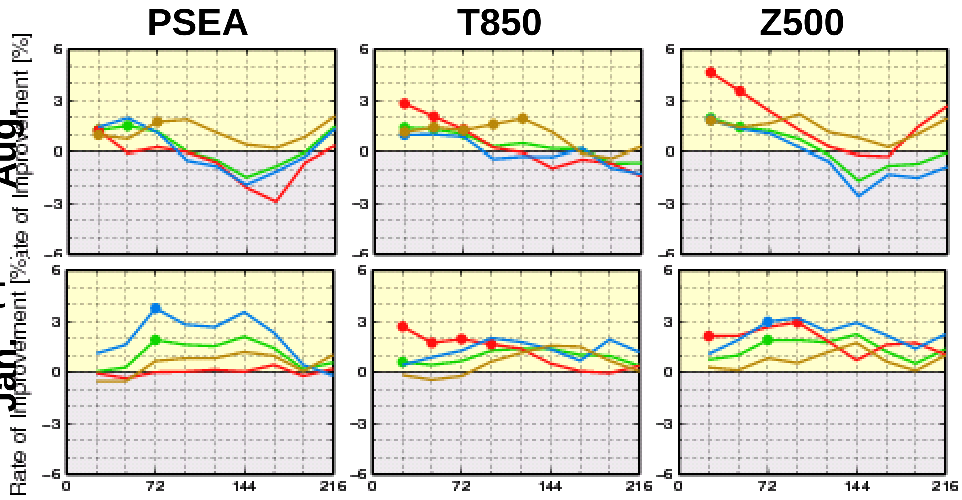
TEST

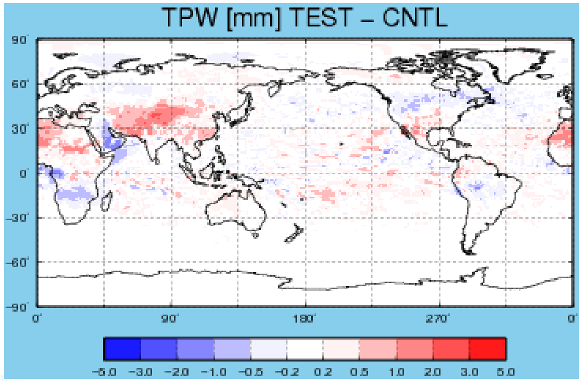


Test results

- Performance test for operational use
  - Test periods: Jan. 2012 and Aug. 2011
    - The test used MHS over the land area with RTTOV v10
  - Results:
    - the data humidifies the analysis field over land and showed the positive impact



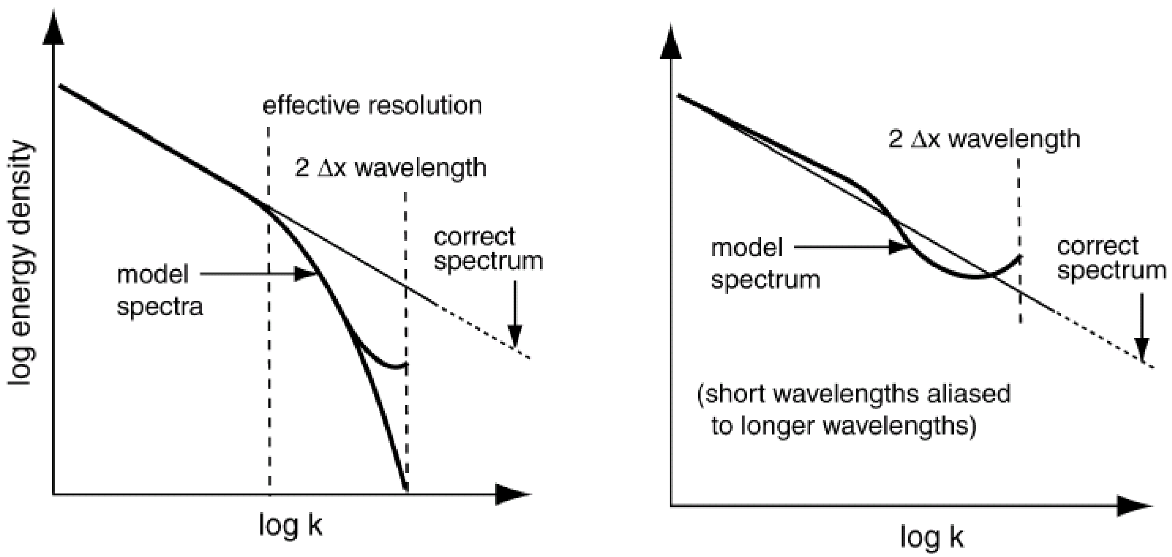




Parallel operation of this system was underway.

Check of Kinetic Energy Spectrum

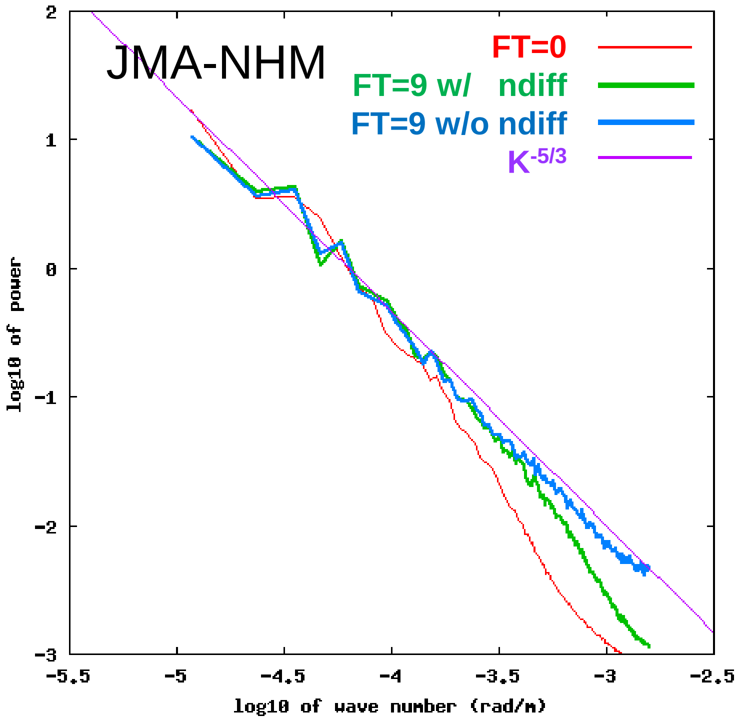
- Follows $k^{-5/3}$ in the mesoscale.
- Effective resolution could be evaluated where a model's spectrum begins to decay relative to $k^{-5/3}$.（Higher wavenumber modes are desired to be eliminated.）
- If the highest wavenumber modes are poorly handled, the tail of the spectrum exceeds $k^{-5/3}$ line.

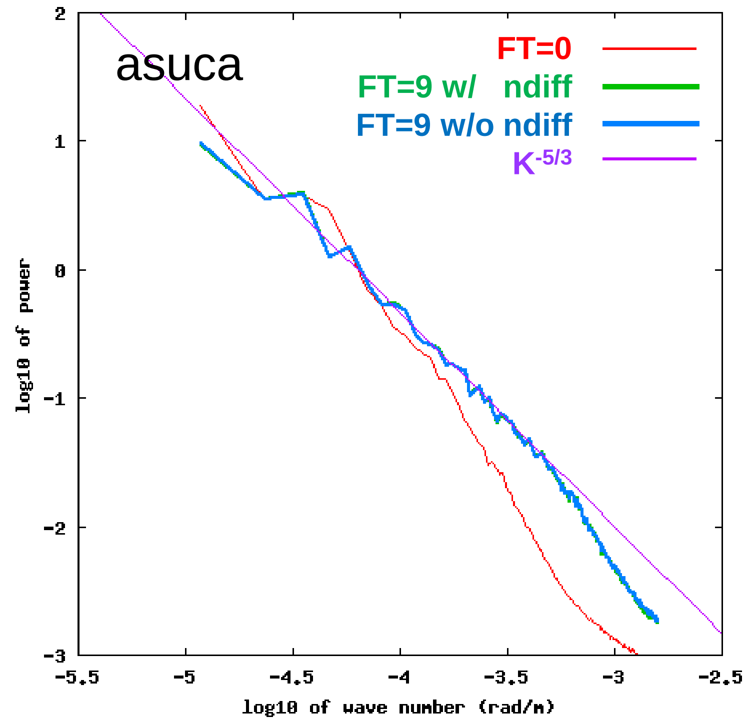


Skamarock, 2004

Comparison of spectra computed from the results of the models, w/ and w/o numerical diffusion

- Higher wave number modes suppressed even w/o explicit numerical diffusion.





- In order to damp higher wavenumber mode, explicit diffusion is necessary.

- This result suggests that we need no explicit numerical diffusion with artificial parameter because of the implicit diffusivity imposed in the flux-limiter function.

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