Renovation of JMA-GSM

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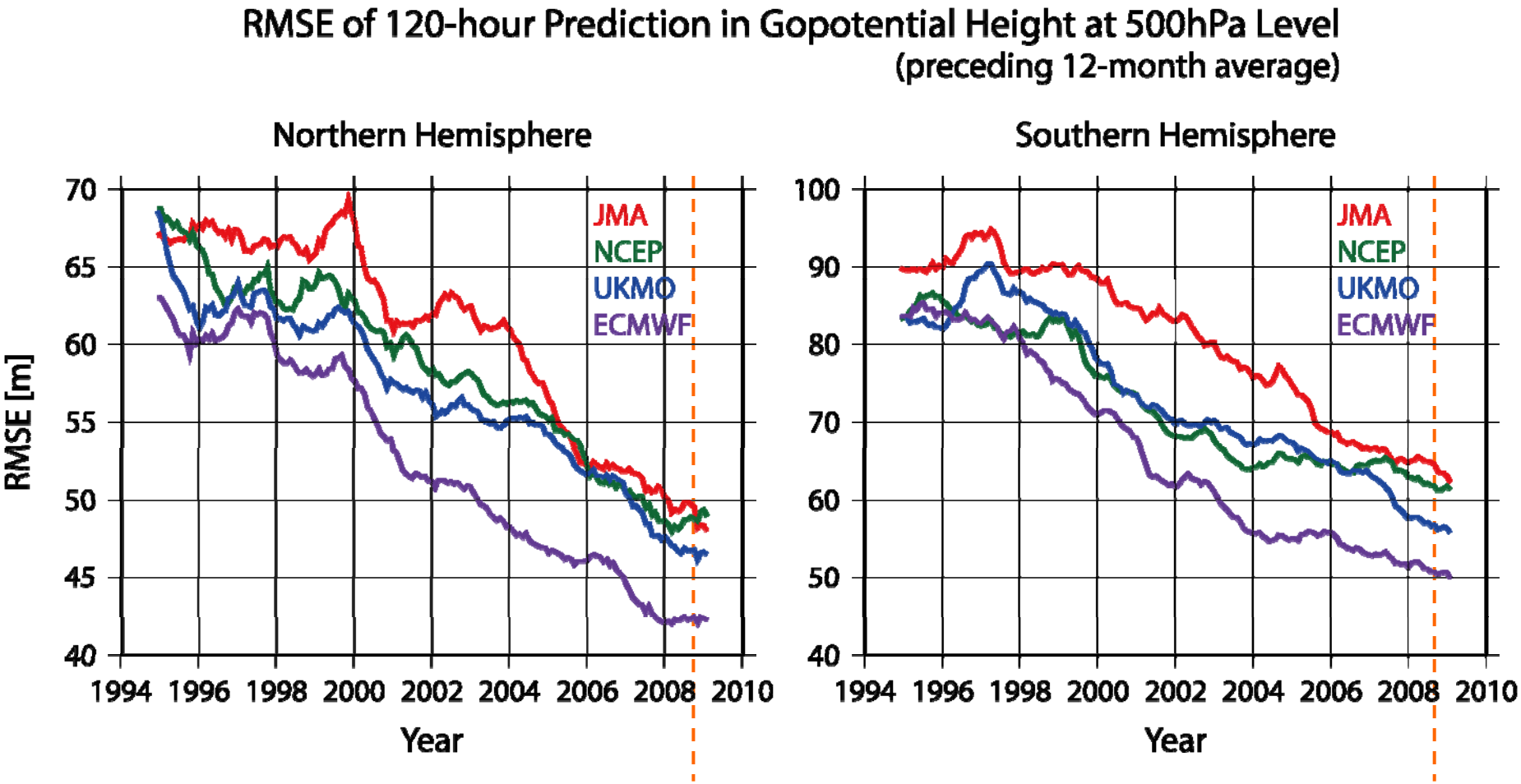
What is JMA-GSM ?

- A hydrostatic global spectrum atmospheric model
- The global model for weather forecasting at JMA
- Also used for seasonal forecasting and researches of climate change
- The spatial resolution in practical use is up to T959 (20km).
- The number of vertical levels in practical use is up to 60.
- RMSE in Z500 in deterministic weather prediction is currently almost equal to NCEP's GFS.

A Time Series of a Score Index

Currently, almost equal to NCEP



The renovated JMA-GSM has been in operation since 5 Aug., 2008.

Motivation

The JMA-GSM had been improved for many times since 1988,
when the model was set to be in operation.

However, the basic structure of the source program
had been old-fashioned in many way.

(e.g., the model could not be performed efficiently on
such the recent computer that has so many number of computational nodes.)

Additionally, a lot of efforts to improve the model accuracy
and efficiency had made the source disorganized.

Therefore, we decided to renovate the implementation of the model.

As a result of the renovation,
the execution time of the model was shortened by about 25%,
the accuracy was improved by a few percent in RMSE.

Major changes to JMA-GSM by the renovation:

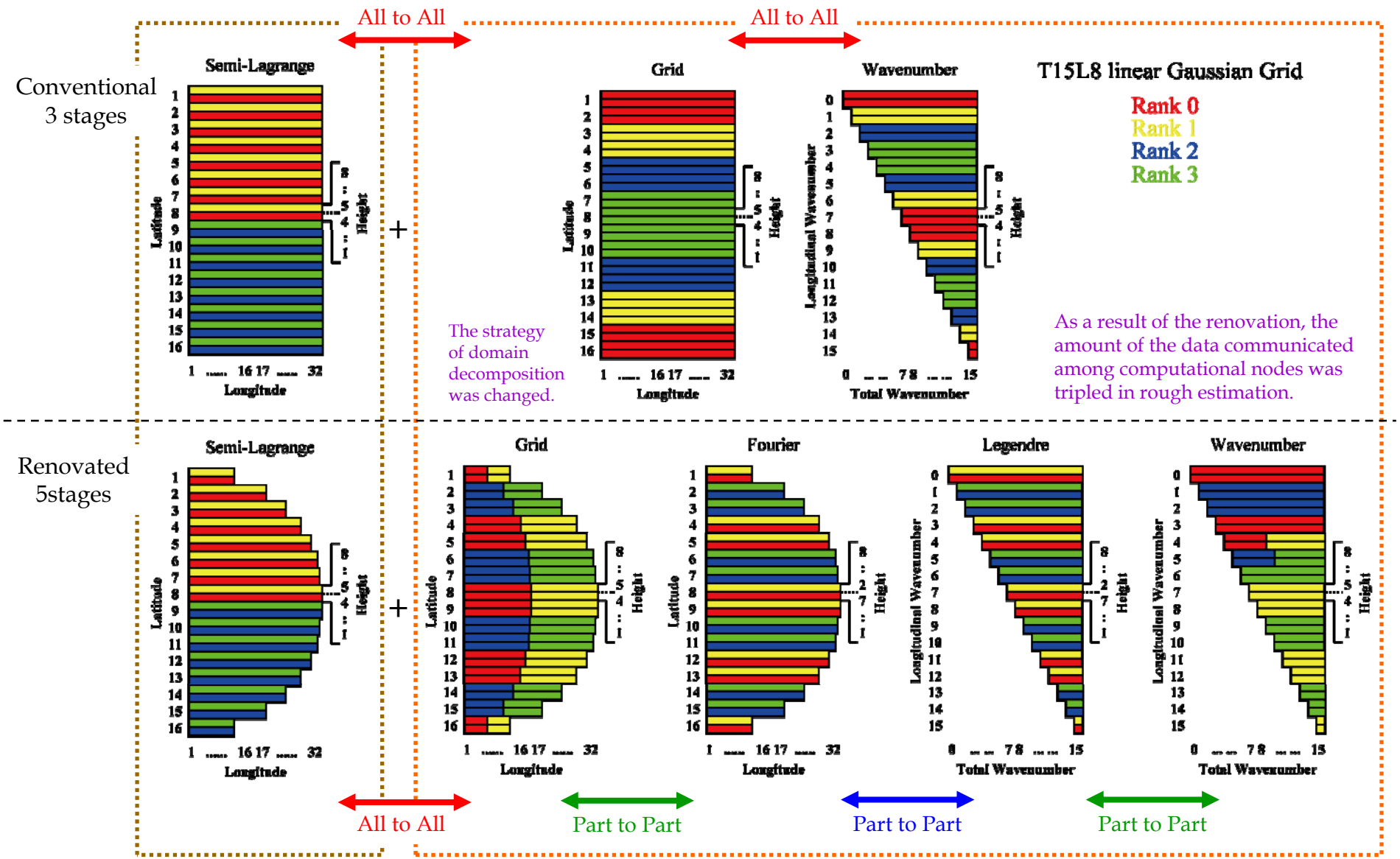
The principles of the model were not change.

- Reduced spectral transformation was introduced. → reduced Gaussian grid
- A two-dimensional decomposition method was employed for MPI parallelization.
- The procedures of inter-node communication were refined.
- OpenMP directives was adopted for shared memory parallelization.
- Some defectives as follows were corrected.

  Only in dynamical processes.
  Physical processes were not be improved.

  - The highest degree of the integrands in Legendre transformation had exceeded the limit of Gauss-Legendre quadrature.
  - The tables of Gaussian latitude, Gaussian weight, and associated Legendre functions had been evaluated in double precision arithmetic.
  - Negative amount of hydrometeors had occasionally been caused by the non-monotonic semi-Lagrangian advection process.
  - The coefficient of horizontal diffusion for divergence was the double of that for vorticity, as a relic of the implicit advection scheme.
- The source program was reorganized.

Stages in JMA-GSM



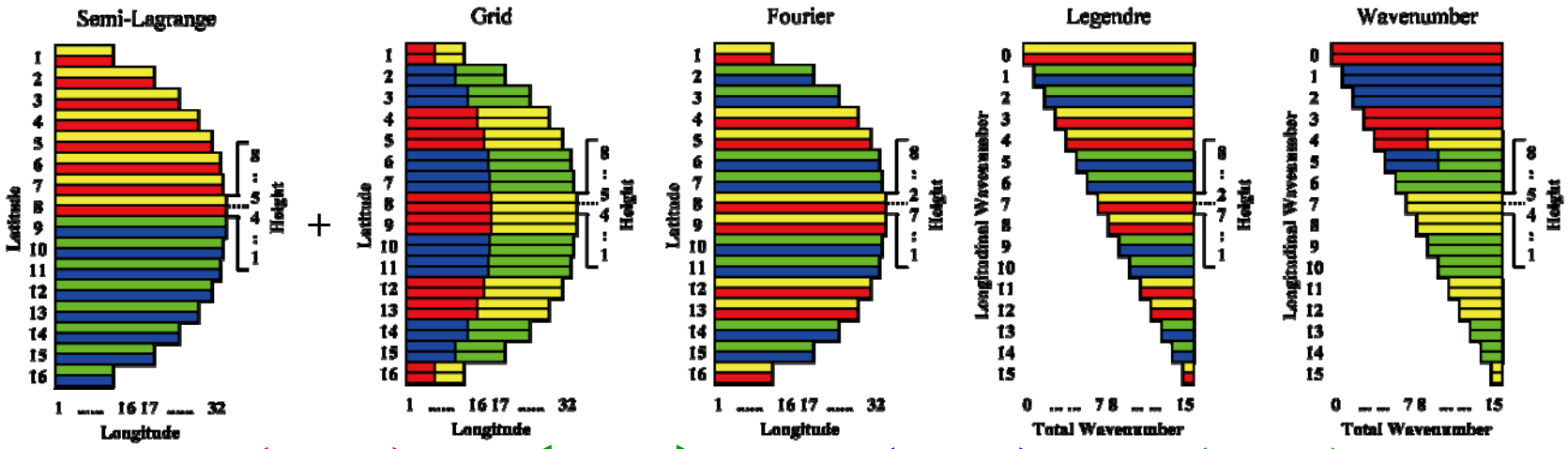
SL advection (bolt-on)
The basic structure has not been renovated yet.

Spherical Harmonic Transformation (framework of the model)
The structure has been completely renovated.

Many small "all to all" inter-node communications, not a massive "all to all"

SL advection (bolt-on)

Spherical Harmonic Transformation (framework of the model)



All to All

Part to Part

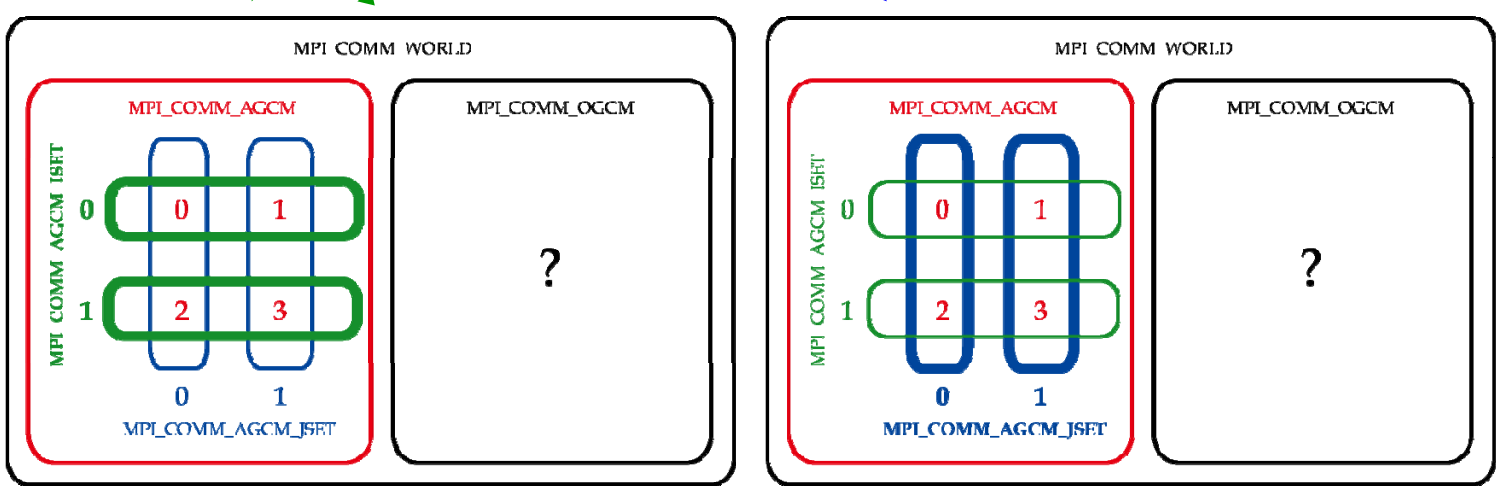
Part to Part

Part to Part

will be replaced in the near future

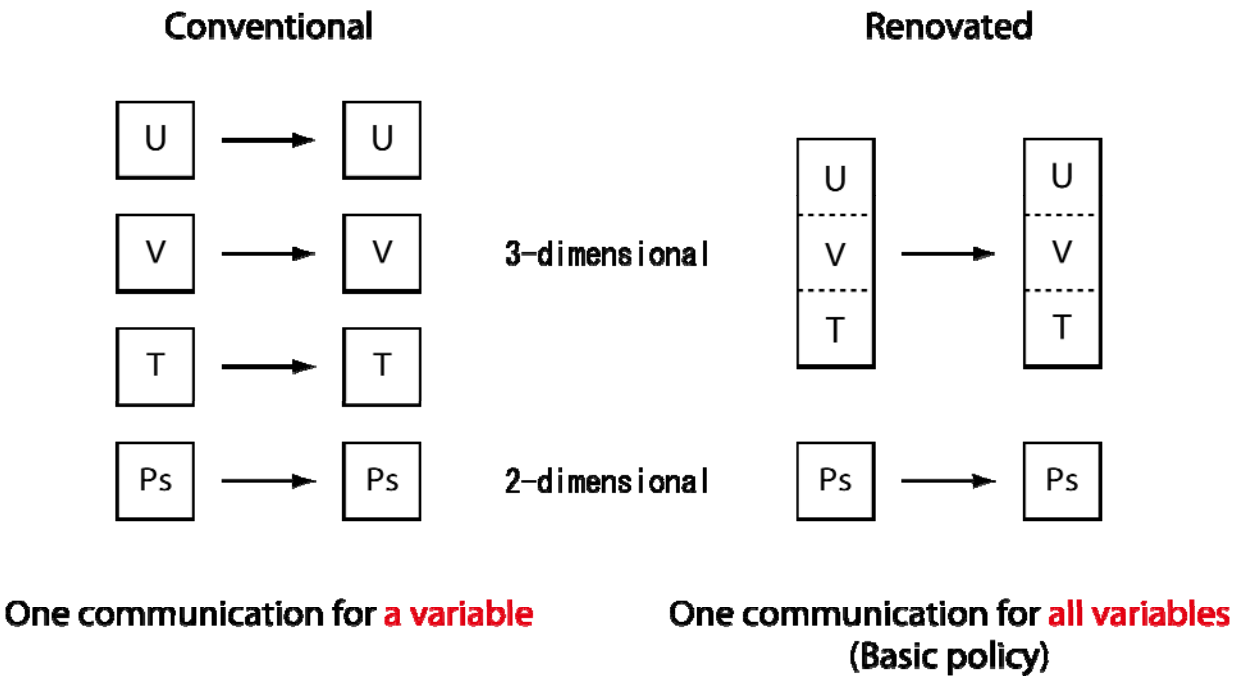
By adopting "part to part" communication, we can cut-down the number of inter-node communication.

Hierarchy of sub-communicators



In order to minimize the number of communication, …

The basic policy on inter-node communication that
"all variables should be communicated at once"
has been introduced.



Each variable was communicated independently.

A set of 3-dimensional variables and a 2-dimensional variable are currently communicated respectively.

Number of inter-node communication

The number of inter-node communication over all processes

$$120 \times 119 \times 4 = 57120 \quad \text{Conventional}$$

$$24 \times (5 \times 4 \times 2) + 5 \times (24 \times 23 \times 2) + 24 \times (5 \times 4 \times 2) = 7440 \quad \text{Renovated}$$

24 parallel "all to all" communication among 5 process

5 parallel "all to all" communication among 24 process

A set of 3-dim variables and a 2-dim variable are currently communicated independently.

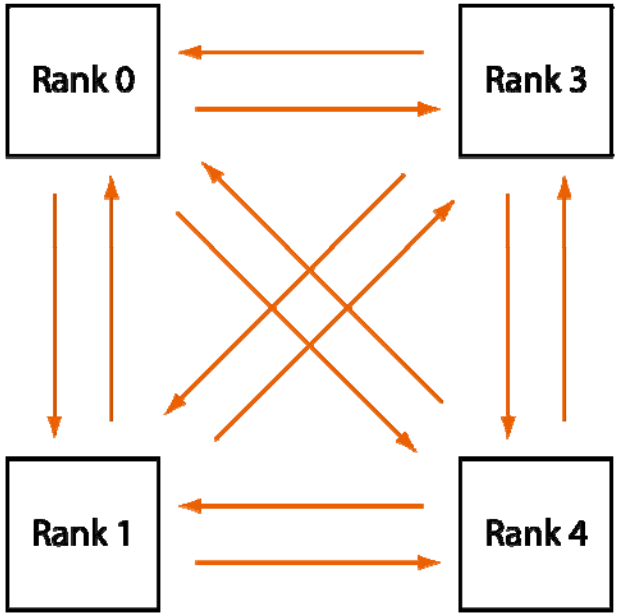
The number of inter-node communication on a process
(The number of each of SEND and RECV)

$$119 \times 4 = 476 \quad \text{Conventional}$$

$$4 \times 2 + 23 \times 2 + 4 \times 2 = 62 \quad \text{Renovated}$$

Timing of the communications perform a "all to all" communication (among 4 process)

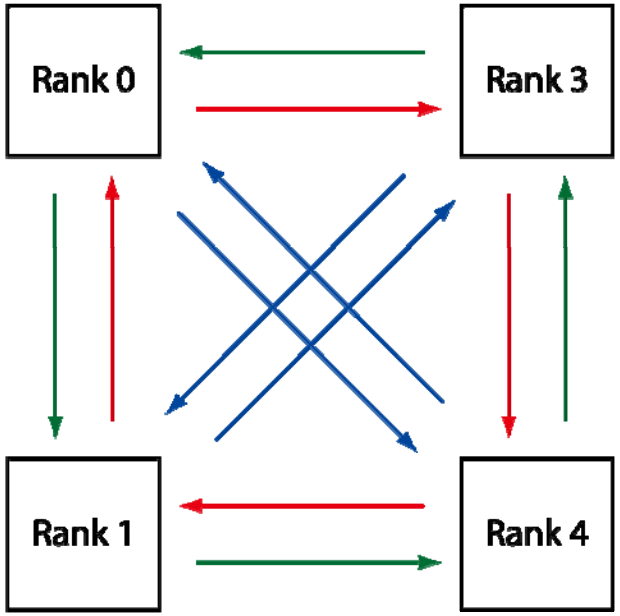
Conventional



All communications are started at once

Many collisions

Renovated



Communications are started in a sequence:

1st, 2nd, and 3rd.

No collision

Time taken for inter-node communications in a 84-hour Prediction

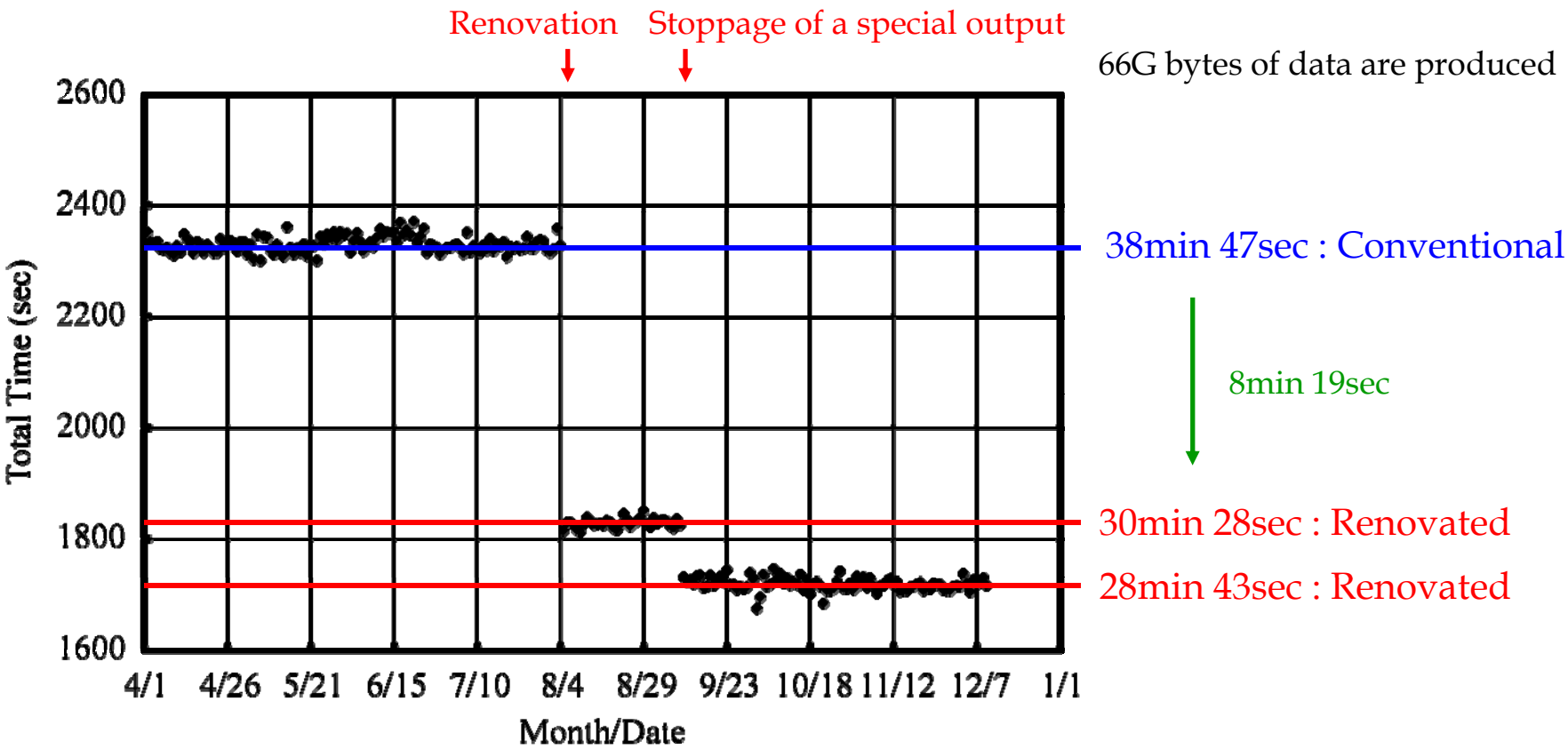
(The conditions were slightly different from those in operation)

	Name of Communication	Total Time [sec] instances=1	Total Time [sec] instances=2
Conventional (120 processes)	Semi-Lagrange = Grid	231	not measured
	Grid = Wavenumber	251	not measured
Renovated (120 processes)	Semi-Lagrange = Grid	172.59	153.11
	Grid = Fourier	66.44	93.30
	Fourier = Legendre	100.96	86.35
	Legendre = Wavenumber	22.21	27.06
		189.71	206.71
Renovated (150 processes)	Semi-Lagrange = Grid	188.11	178.47
	Grid = Fourier	59.19	81.19
	Fourier = Legendre	81.28	74.99
	Legendre = Wavenumber	18.35	24.61
		158.82	180.79

Faster than the conventional, in spite of that the amount of communicated data was about 2 times larger.

Execution Time of an operational 84-hour Prediction
(T959L60, including post processes)

Post Processes
e.g., Calculating secondary variables
Interpolation to course resolution
Data compression to 2-byte binaries



HITACHI SR11000K1, 60 nodes, 120MPIs
16 IBM Power 5+ (2.1GHz) on each node

Improvement Rate in RMSE

The improvement rate shows how much
a change to the NWP suite averagely diminish the RMSE over a 216-hour prediction.

The values is evaluated though 4D-Var data assimilation cycle experiments.

All changes to the NWP suite must be assessed
through 4D-Var data assimilation cycle experiments beforehand.

Improvement rate on the following variables are always evaluated.

	Psea	T850	Z500	W850	W250	
Aug., 2006	1.49	1.46	1.57	1.06	0.95	Conventional -> Renovated (T959)
Jan., 2007	1.95	1.78	2.10	1.39	0.92	Conventional -> Renovated (T959)
Aug., 2006	1.83	1.68	2.15	0.79	0.99	Conventional -> Renovated (T319)
Jan., 2007	0.68	0.93	0.85	0.59	0.38	Conventional -> Renovated (T319)
Aug., 2004	0.89	0.20	0.44	-0.12	1.15	T319 -> T959 (Conventional)
Jan., 2006	0.44	1.37	-0.74	-0.13	0.22	T319 -> T959 (Conventional)

Pie chart showing the relative const of various components of an 84-hour prediction (including post processes)

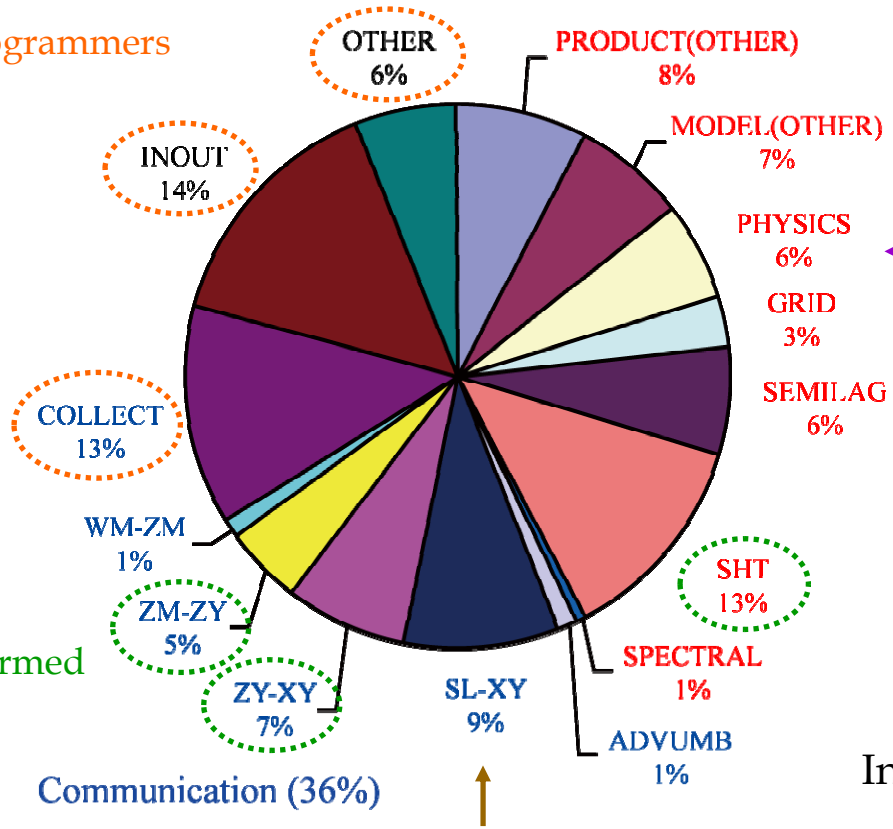
T959L60 HITACHI SR11000K1 70nodes(140MPIs)

The situation is not so different from the case of 60 nodes.

Disk access (20%)

Calculation (44%)

Impossible for programmers to speed up



too cheap

The time for calculation is less than half of the execution time.

SHT is currently performed twice a time step.

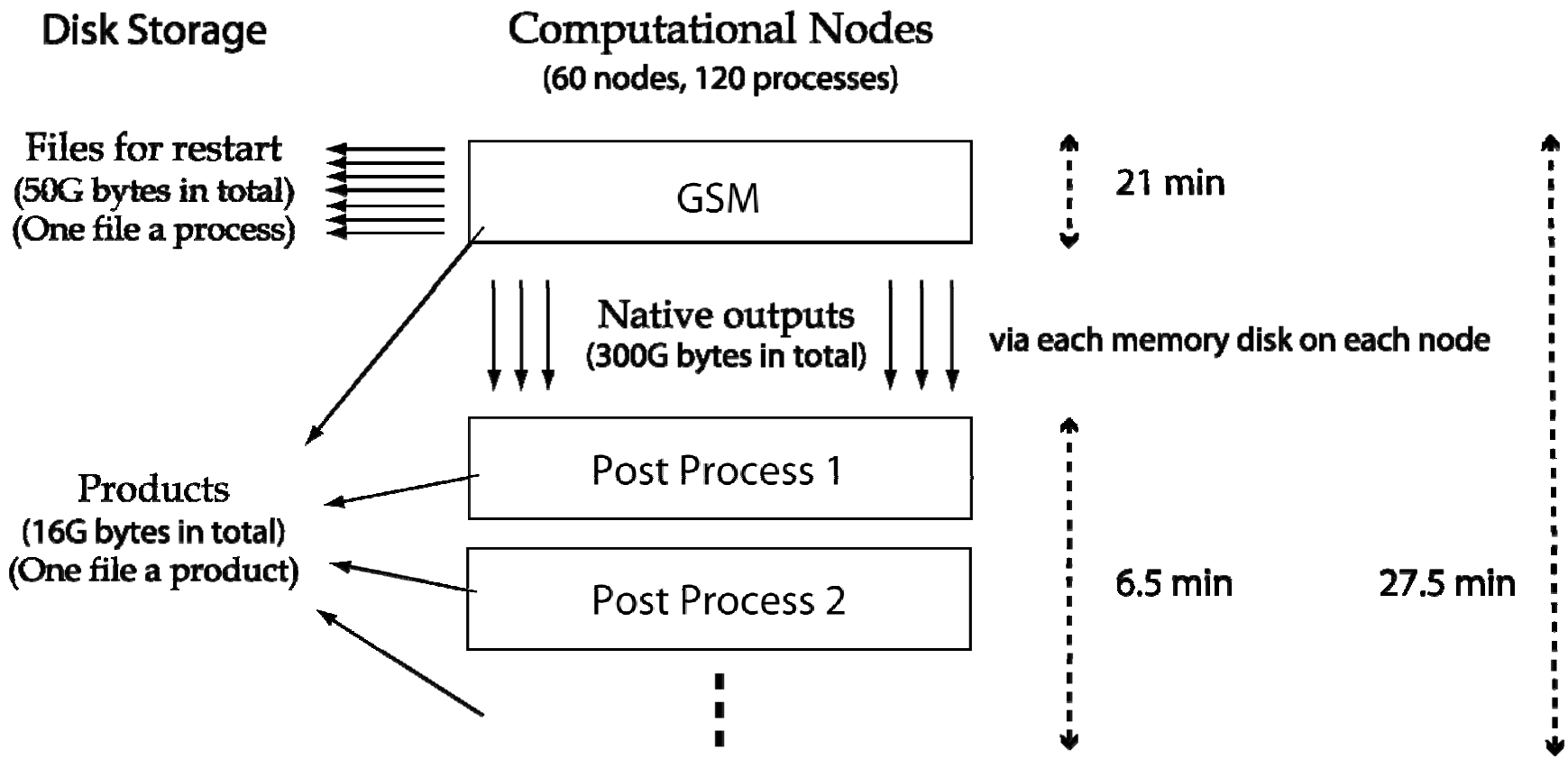
Communication (36%)

all to all

In spite of the painful effort …

Painful effort

In order to avoid put huge data into the disk storage,
almost all post processes are performed on the same nodes as the model.



Too many kinds of products
to built the post processes into GSM.

The post processes use the FORTRAN modules
of GSM that define the framework of the model.

Summary

The JMA-GSM was currently renovated.
(The source programs for the framework of the model
and the dynamical process were almost completely refreshed.)

The execution time was shortened by about 25%.

The accuracy was improved by a few percent in RMSE.

Decreasing the number of inter-node communication seemed to be
more important to shorten the execution time than decreasing the amount.

To Computer Venders

The current outstanding problem in terms of computational efficiency
is that the time to output products is huge.

The computer system is required that has a good balance between calculating,
networking, and disk accessing.

Current State of the Transition from the Conventional to the Renovated

JMA's global NWP suite

JMA's global NWP suite is currently in transition from the conventional model to the renovated.

- A deterministic prediction system (T959 reduced linear Gaussian grid, 60 layers)

4-dimensional variational data assimilation system

- outer model (T959 reduced linear Gaussian grid, 60 layers)
- inner model (T159 quadratic Gaussian grid, 60 layers)

Two ensemble prediction system

- one week prediction (T319 reduced linear Gaussian grid, 60 layers) ← 17 Mar., 2009 (Today)
- predicting possible typhoon tracks (T319 standard linear Gaussian grid, 60 layers)

The Japanese Reanalysis Project

JRA-50

- outer model (T319 reduced linear Gaussian Grid, 60 layers)
- inner model (T106 standard quadratic Gaussian grid, 60 layers)

Researches on climate change

- some one
- the others