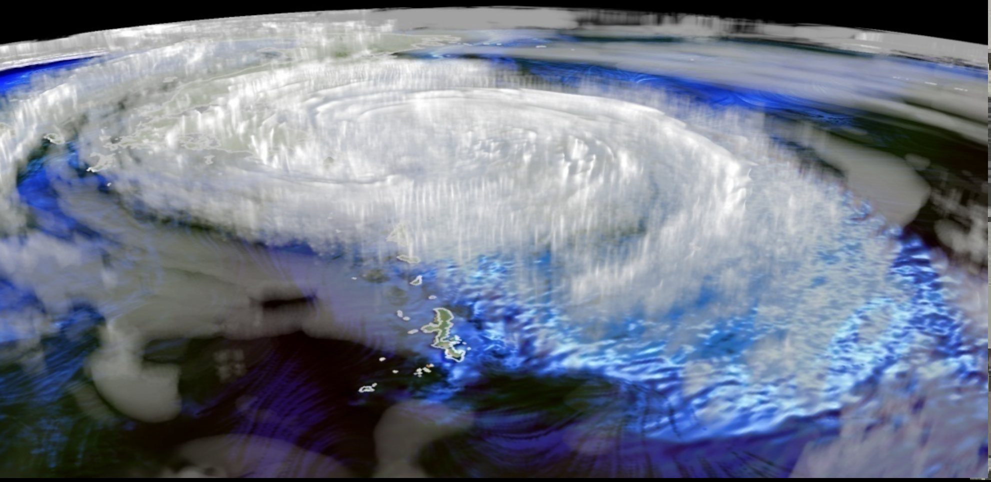
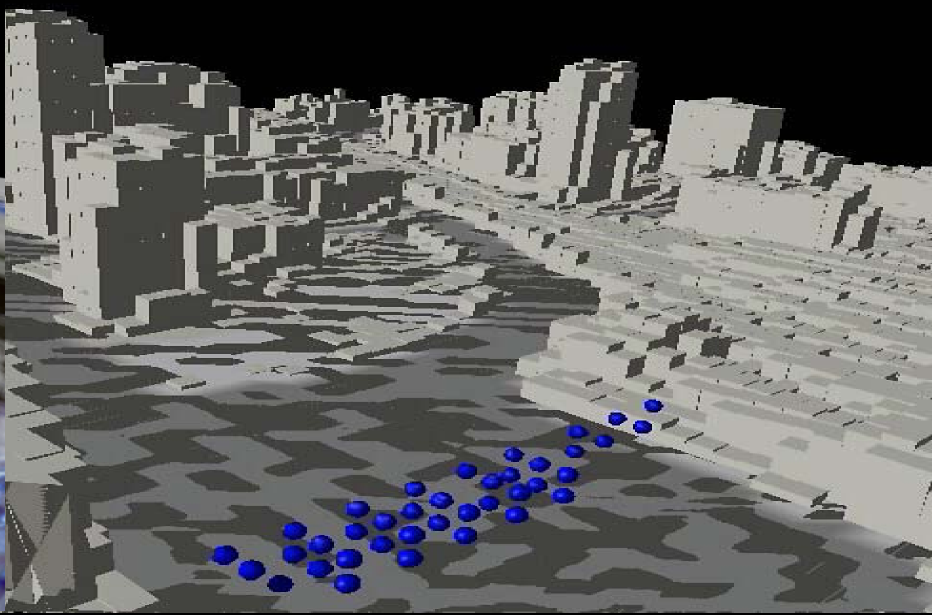
Seamless Simulations with Multi-Scale Simulator for the Geoenvironment (MSSG)





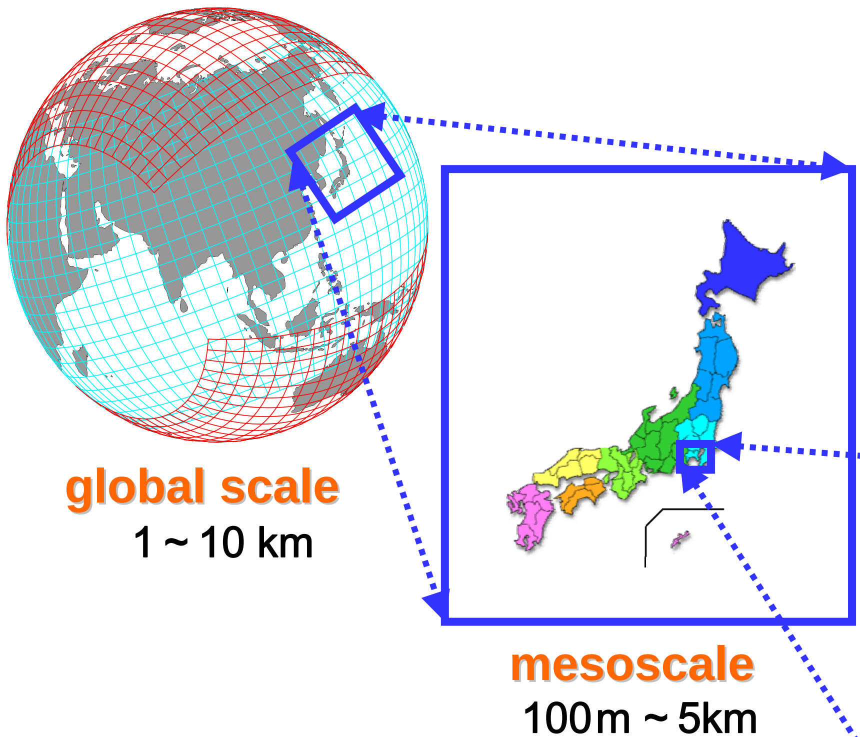
Ryo Onishi, Takeshi Sugimura, Yuya Baba and **Keiko Takahashi**

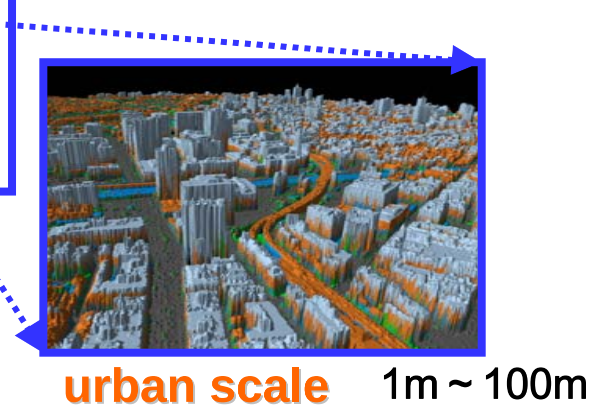
Earth Simulator Center (ESC), Japan Agency of Marine-Earth Science and Technology (JAMSTEC)

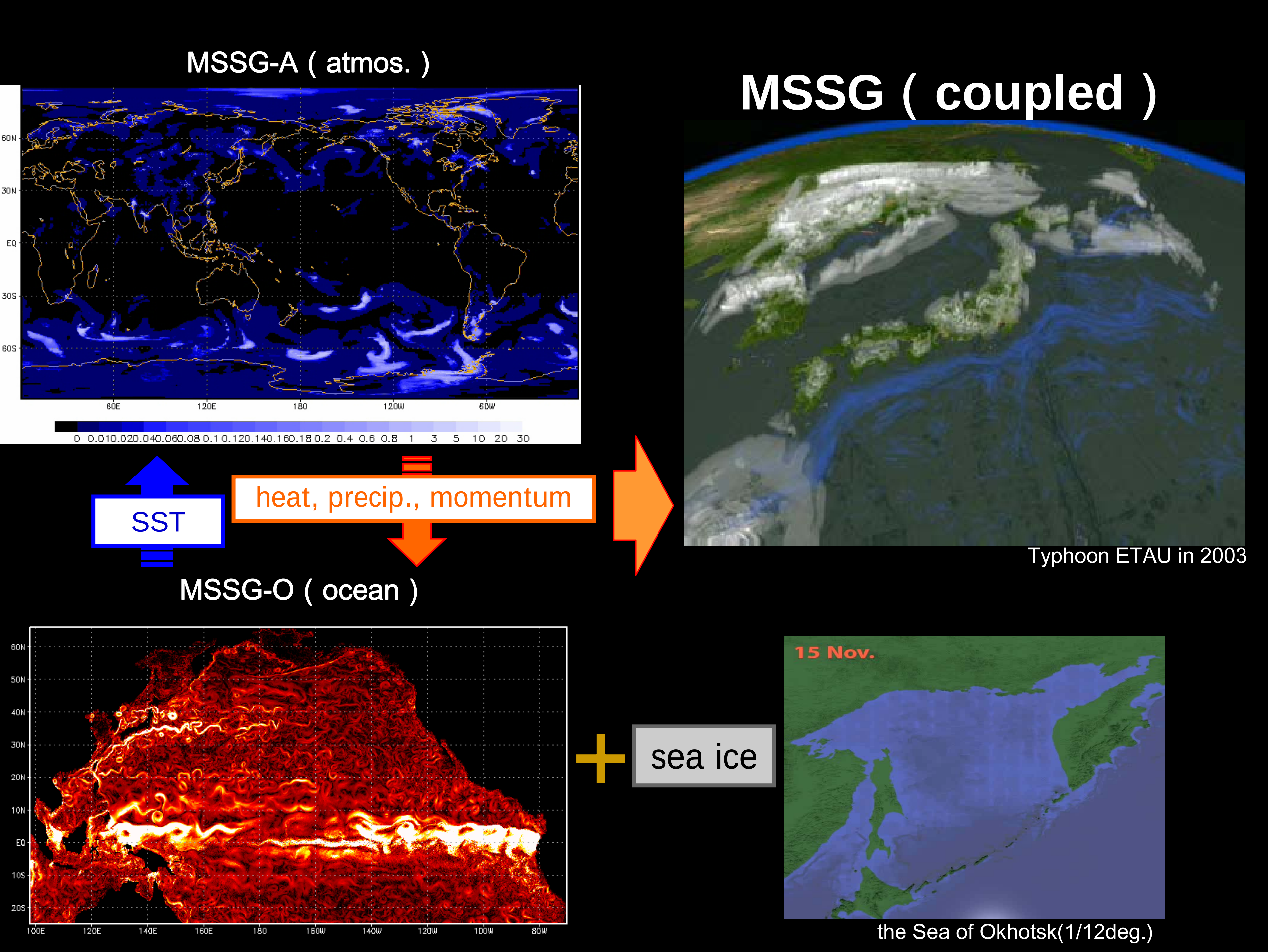
<13th WS on Use of HPC in Meteorology @ ECMWF, 3 Nov. 2008>

Multi-Scale Simulator for the Geoenvironment (MSSG)

- Applicable to global, regional and local scales seamlessly
- Ying-Yang grid for globe
- Consists of 3 modes; atmos. / ocean / coupled
- Highly optimized for the Earth Simulator (ES)





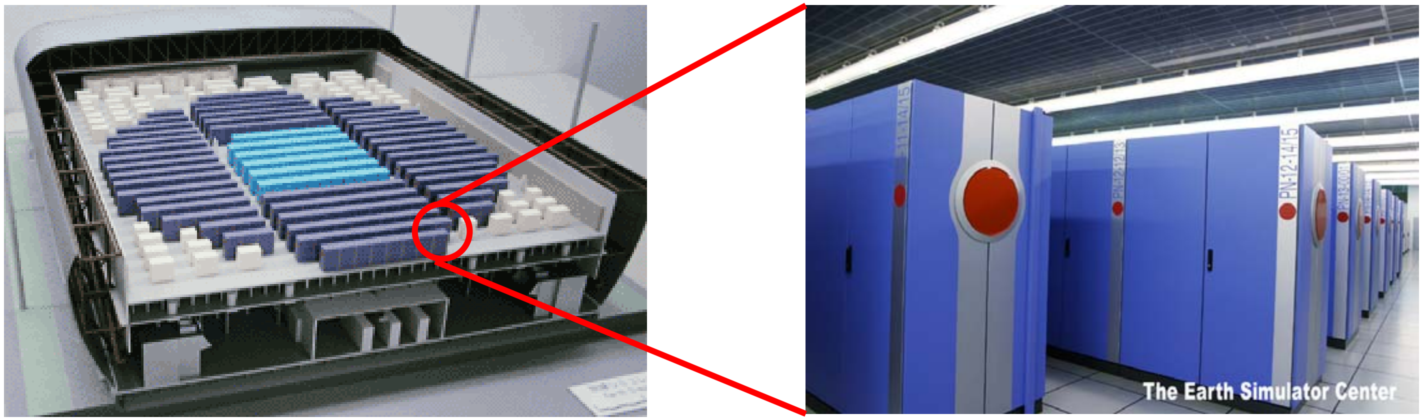


MSSG-A (atmos.)
60N
30N
EQ
30S
60S
60E
120E
180
120W
60W
0 0.01 0.02 0.04 0.06 0.08 0.1 0.12 0.14 0.16 0.18 0.2 0.4 0.6 0.8 1 3 5 10 20 30
MSSG (coupled)
Typhoon ETAU in 2003
SST
heat, precip., momentum
MSSG-O (ocean)
60N
50N
40N
30N
20N
10N
EQ
10S
20S
100E
120E
140E
160E
180
160W
140W
120W
100W
80W
sea ice
15 Nov.
the Sea of Okhotsk(1/12deg.)

Outline of MSSG

		MSSG-A	MSSG-O
		Non-hydrostatic AGCM	Non-hydrostatic /hydrostatic OGCM
governing eqs.		Fully compressive N-S eqs.	incompressive N-S eqs.
grid system		Yin-Yang grid (overlapped 2 lat-lon)	Yin-Yang grid (overlapped 2 lat-lon)
discritization	space	Arakawa-C grid (horizontal), Z* (vertical)	Arakawa-C grid (horizontal), Z* (vertical)
	time	$3^{rd}/4^{th}$ Runge-Kutta	$3^{rd}/4^{th}$ Runge-Kutta
adv. schemes		5^{th} flux form, WAF, CIP-CSLR	5^{th} flux form
non-adv. schemes		4^{th} flux form	4^{th} flux form
sound wave		HEVI, HIVI	Implicit methods (2D, 3D)
microphysics		Bulk method (Qc,Qr,Qi,Qs,Qg)/ hybrid-Bin method	-
turbulence model		static Smagorinsky scheme	static Smagorinsky model
other models		cloud radiation model, backet land model, UCSS urban canopy model	sea-ice model
parallelization		horizontal 2D decomposition by MPI/ vertical decomposition by micro-task	horizontal 2D decomposition by MPI/ vertical decomposition by micro-task

the Earth Simulator (ES)



current ES (since 2002)

- Vector-type super computer
- 640 nodes (5120 CPUs)
- Theoretical Peak Performance = <u>40 TFLOPS</u>.
- Main Memory= 10 TB.

March,2009

replaced →

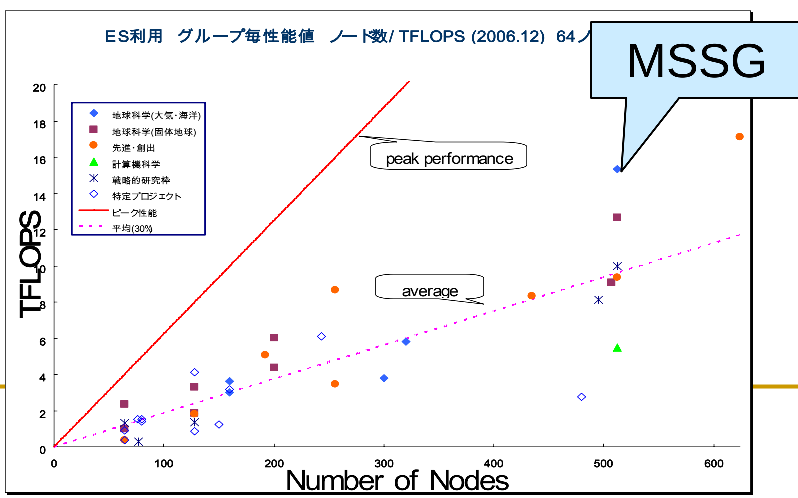
upgraded ES

- Vector-type super computer
- 160 nodes (1080 CPUs)
- Theoretical Peak Performance = <u>131 TFLOPS</u>.
- Main Memory=20 TB.

Performance of the MSSG on the Earth Simulator

CASE	TPN	TAP	grid pts	Mflops/AP	Vector Length	V.OP ratio	Tflops	Peak ratio	Parallel efficiency	Speed up
C	512	4096	3,866,296,320	4166.7	229	99.3%	17.07	52.1%	90.0%	461.0
	384	3072		4273.8	229	99.3%	13.13	53.4%	92.3%	354.6
	256	2048		4401.9	229	99.3%	9.02	55.0%	94.8%	242.6
A	512	4096	2,882,764,800	4575.2	228	99.5%	18.74	57.2%	93.6%	479.1
	384	3072		4606.1	228	99.5%	14.15	57.6%	95.1%	365.2
	256	2048		4692.4	228	99.5%	9.61	58.7%	96.7%	247.5
RA	512	4096	2,882,764,800	4340.8	229	99.4%	17.78	54.3%	90.7%	464.4
	384	3072		4401.0	229	99.4%	13.52	55.0%	92.9%	356.6
	256	2048		4560.5	229	99.4%	9.34	57.0%	95.1%	243.5
O	498	3984	4,954,521,600	3629.3	240	99.3%	14.46	45.4%	80.6%	401.3
	398	3184		3568.5	240	99.3%	11.36	44.6%	83.8%	333.7
	303	2424		3986.8	240	99.3%	9.66	49.8%	87.2%	264.2
	207	1656		4234.3	240	99.3%	7.01	52.9%	90.9%	188.2

C: Coupled; A: Atmos.; RA: regional Atmos.; O: Ocean



Simple linearity will be kept until 2 PFLOPS

MSSG is selected as a core application for the next Japanese flagship supercomputer with 10PFLOPS


Image © 2008 TerraMetrics
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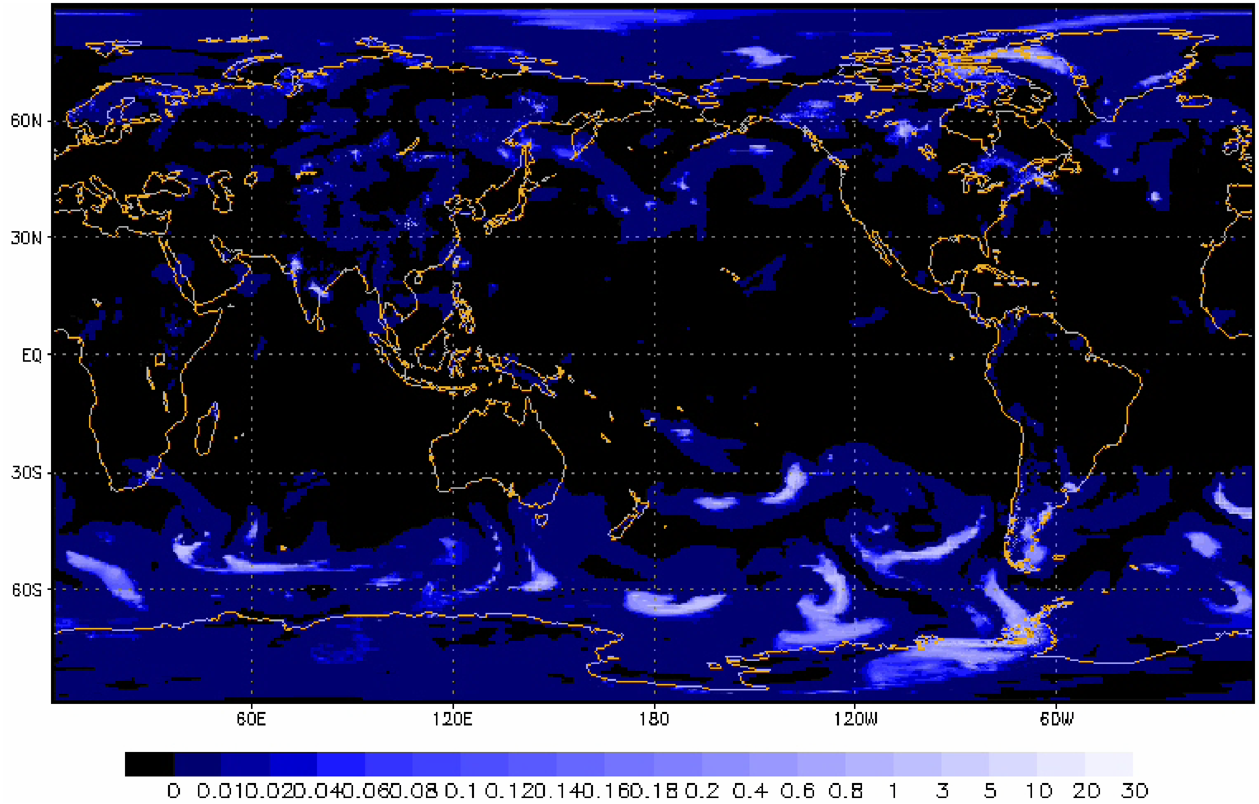
Image NASA

1.9km global atmosphere simulation

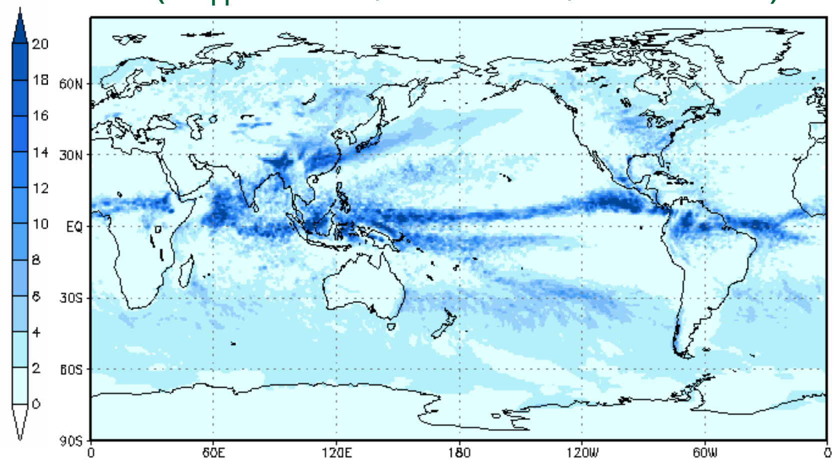
Δ_H=1.9 km, 32 levels



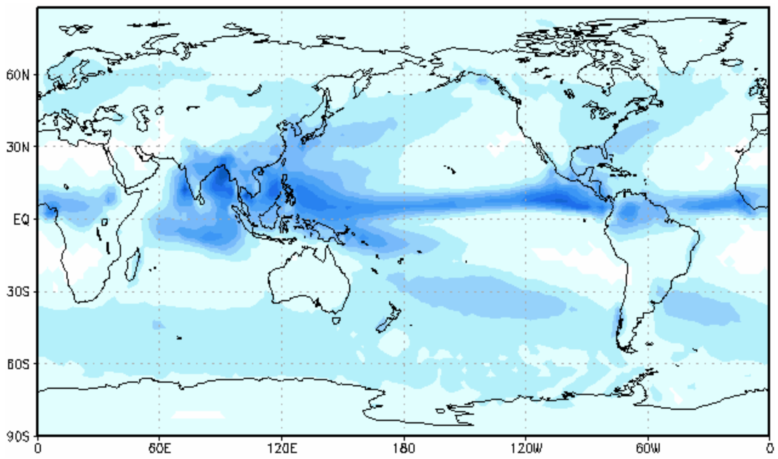
Seasonal atmosphere simulation

seasonal simulation with Δ_H=40 km

MSSG-A
(Δ_H=40 km, 32 levels, 1996JJA)

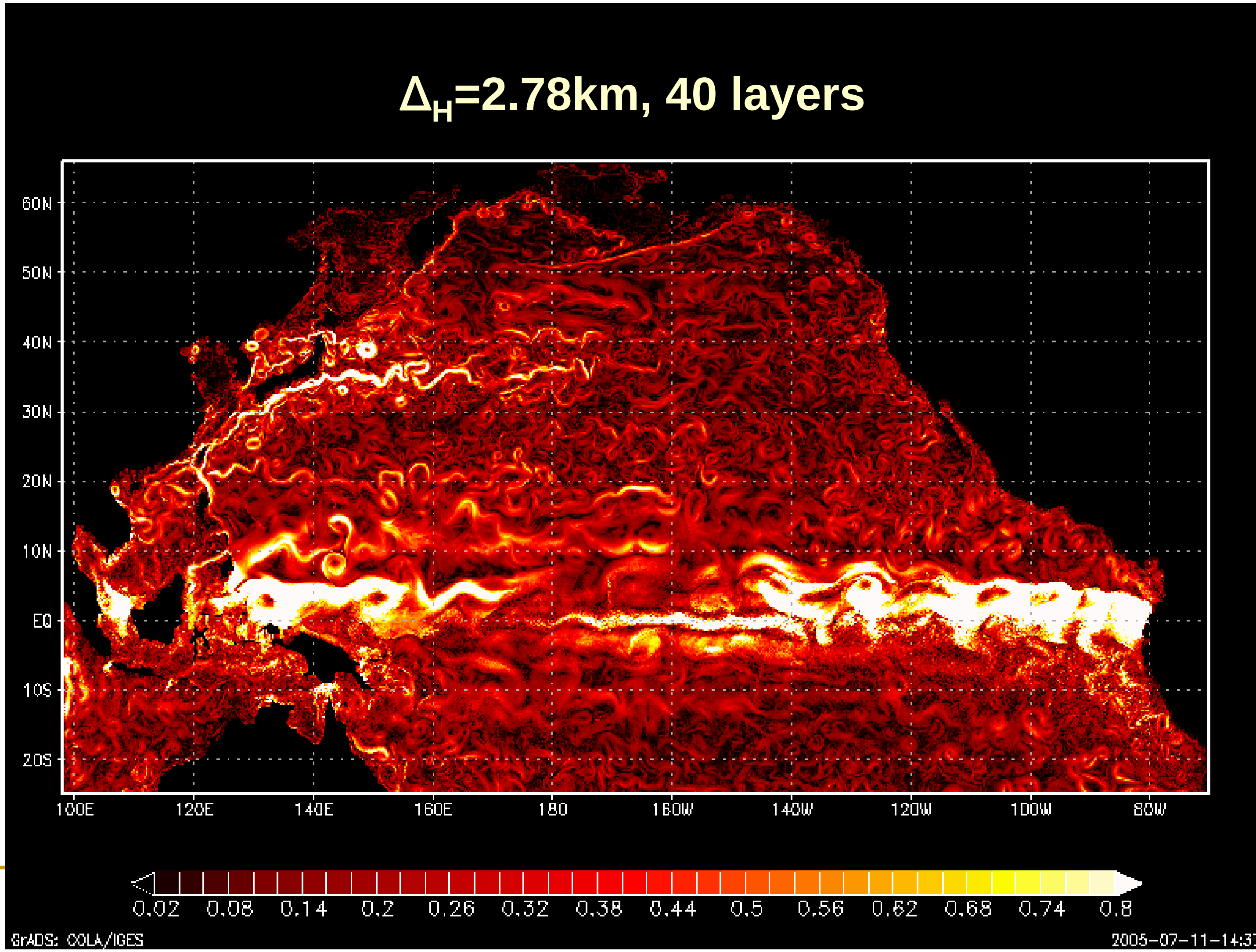


Observation
(CMAP, 1979-2001JJA)



precipitation at JJA (summer in NH)

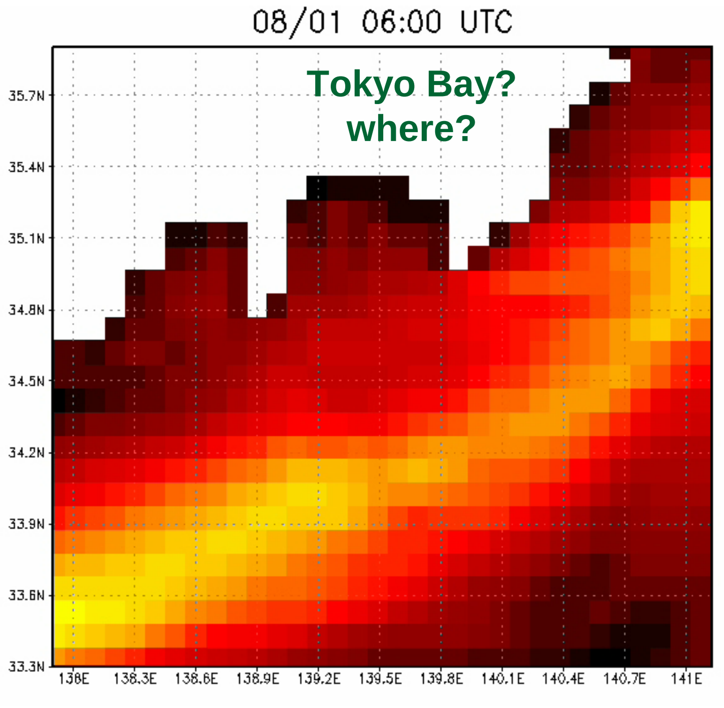
Northern Pacific Ocean with MSSG-O



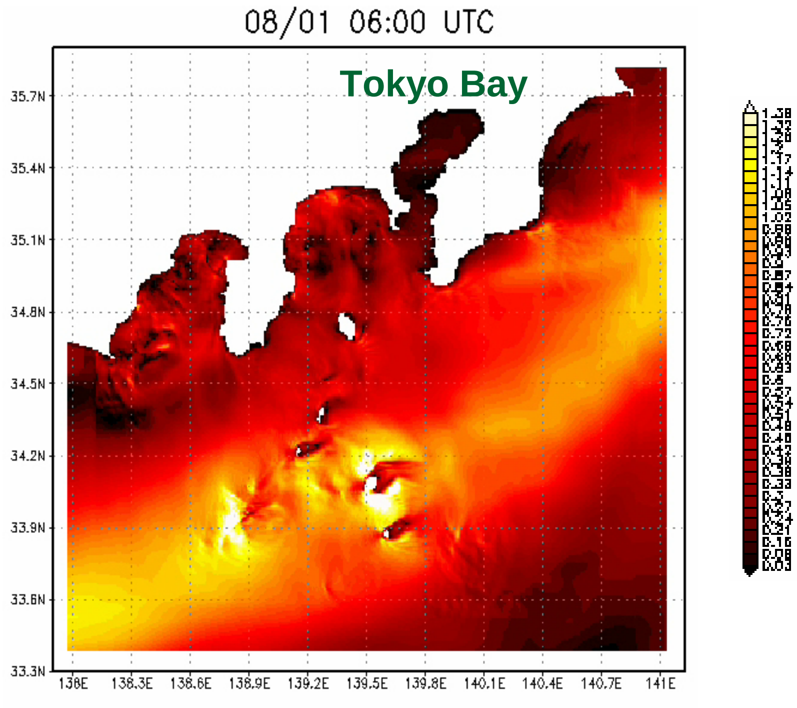
Coastal current with MSSG-O

The Northern Pacific Ocean nesting to Japan region

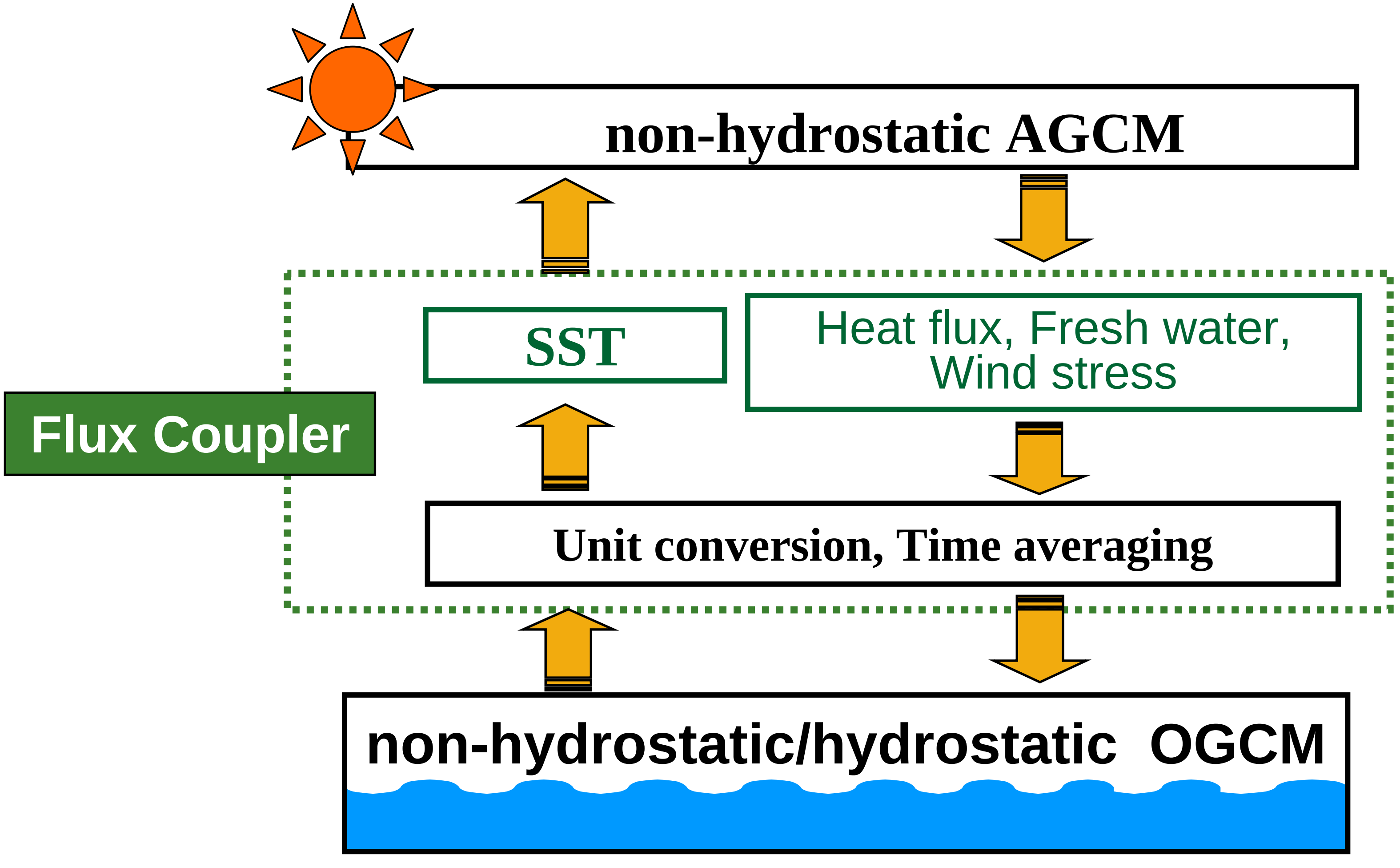
Δ_H=11km, 40 vertical layers

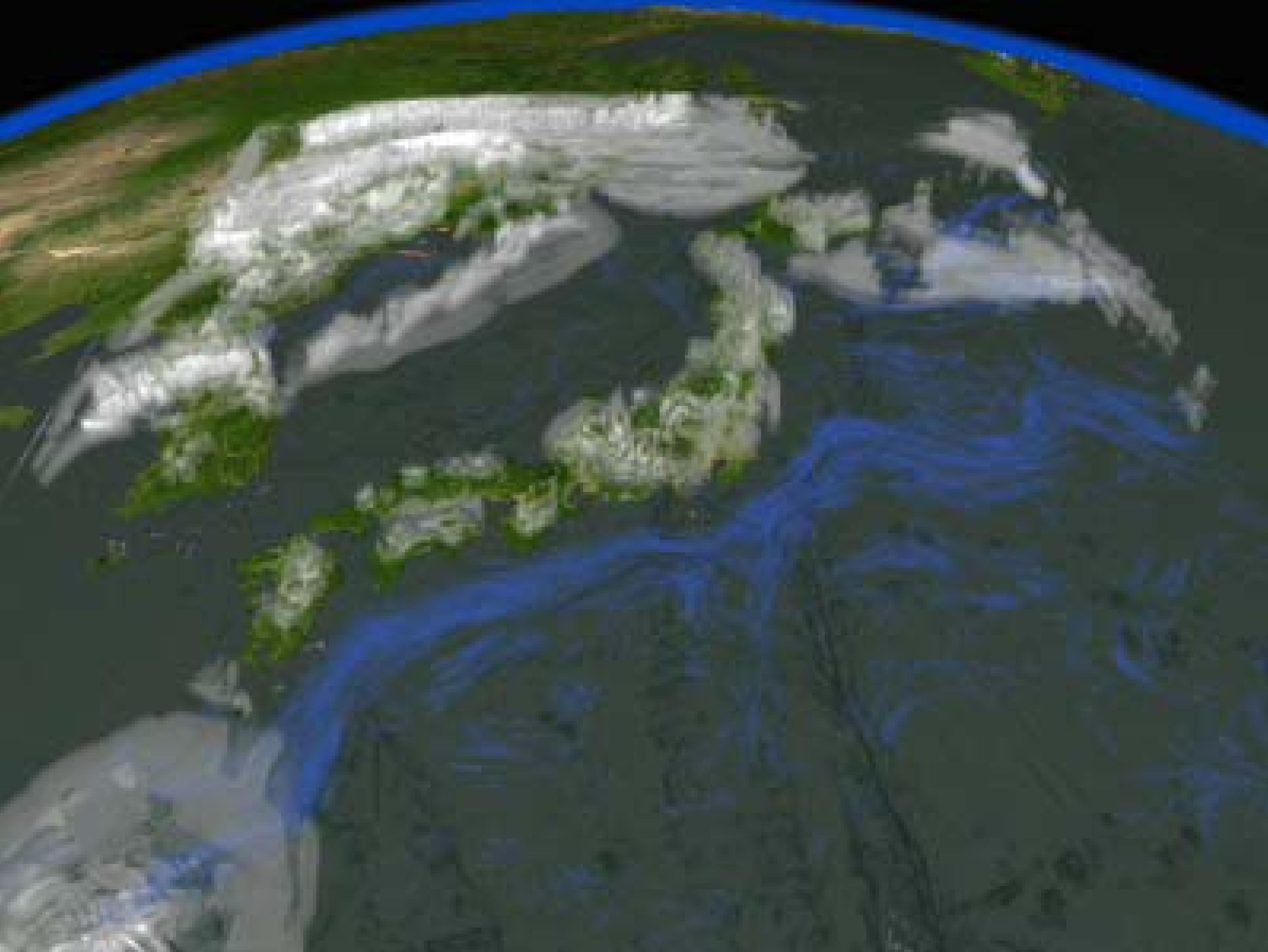


Δ_H=850m, 40 vertical layers

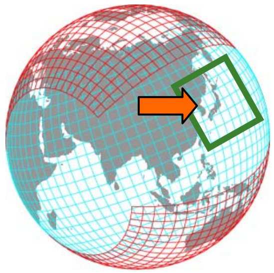


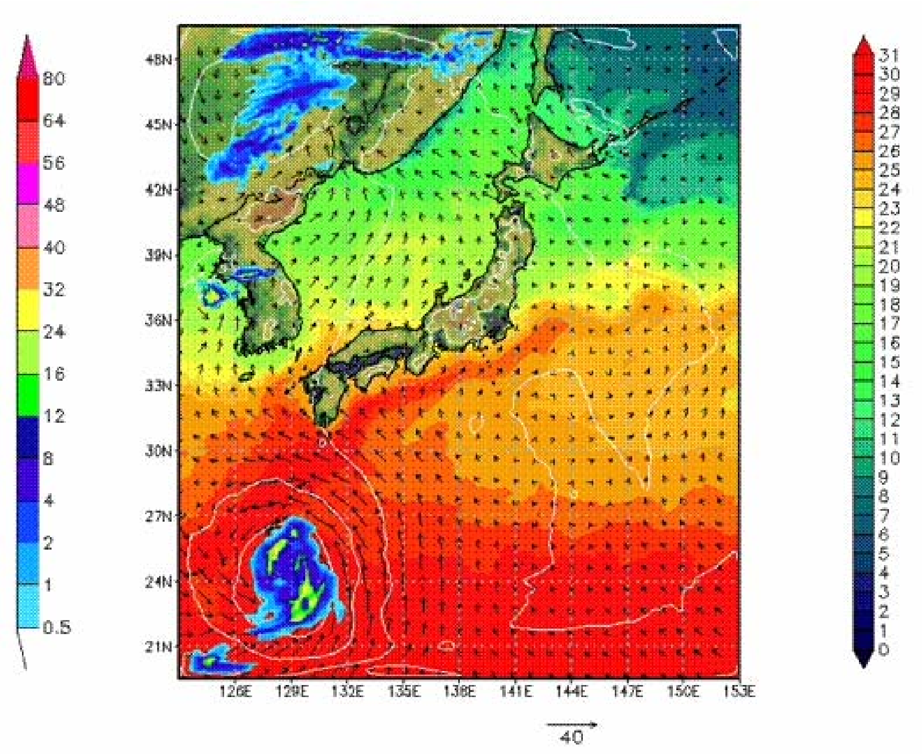
Atmosphere-Ocean coupling system

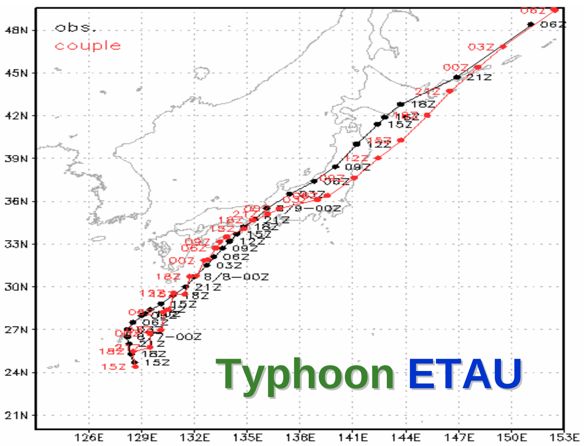




Coupled simulation for Typhoon 10 of 2003

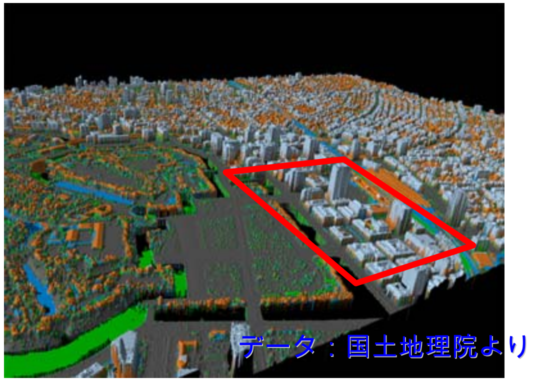


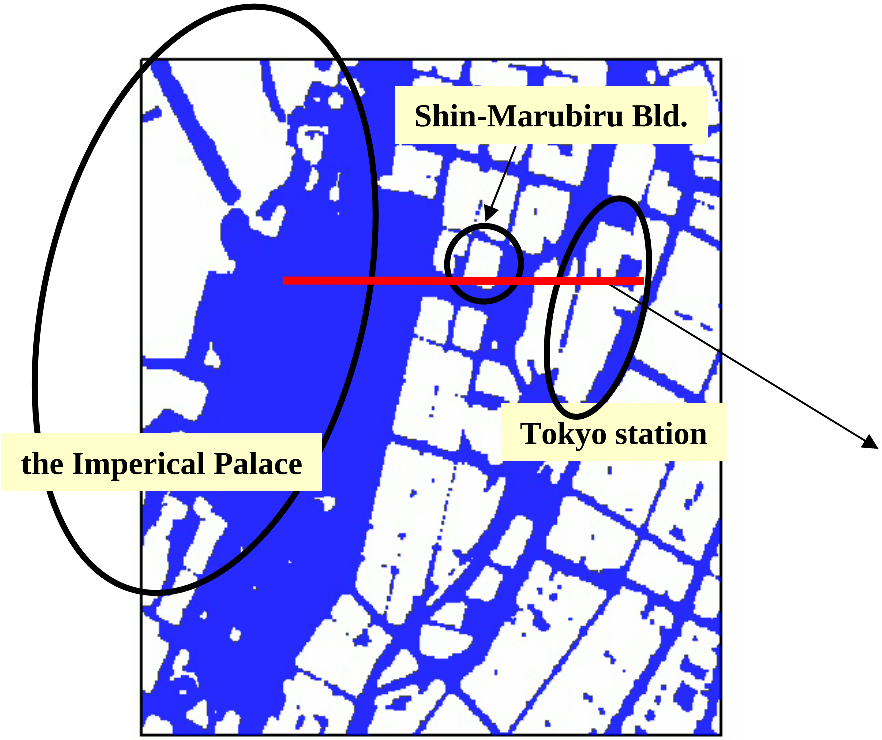




Δ_H=2.7 km, 72 layers

Urban simulation with Δ=5m (Tokyo station area)

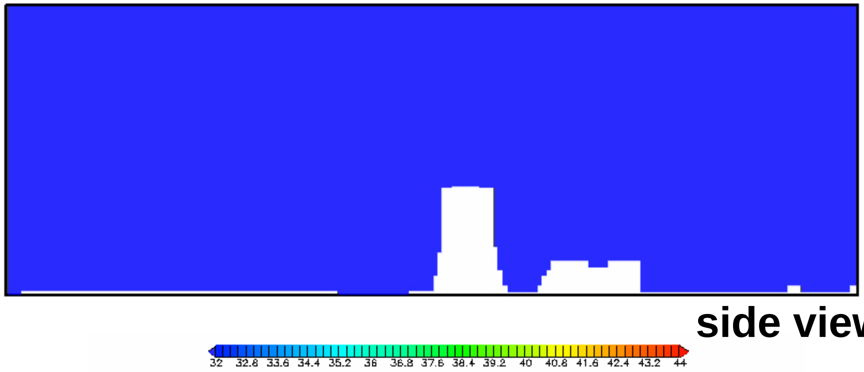




Top view

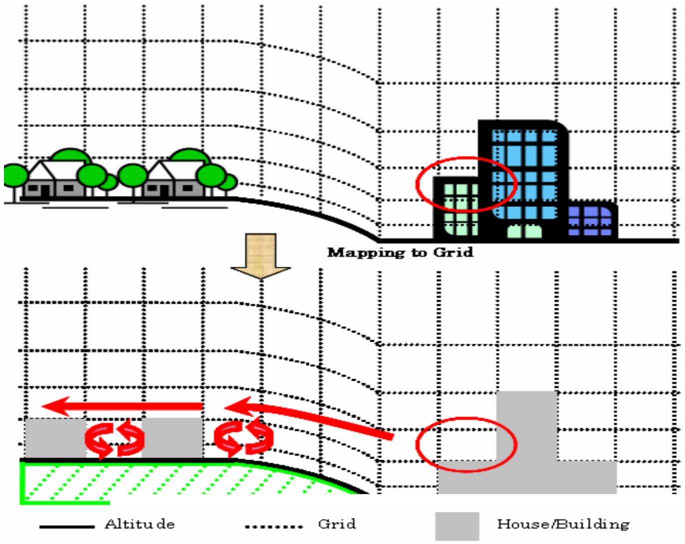
Investigation of redevelopment project

Shin-Marubiru Bld.



side view

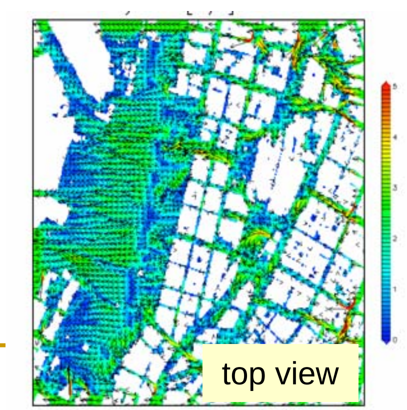
Hybrid vertical coordinate system (σ- & z-system)

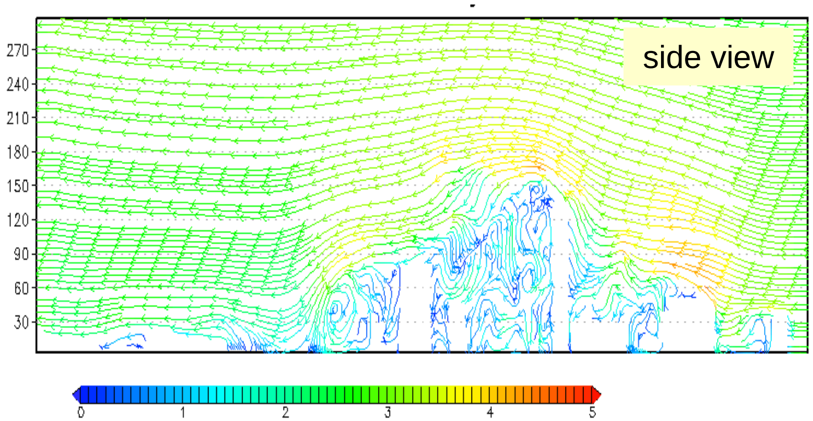


vertical σ-coordinate system

vertical σ- & z -coordinate system

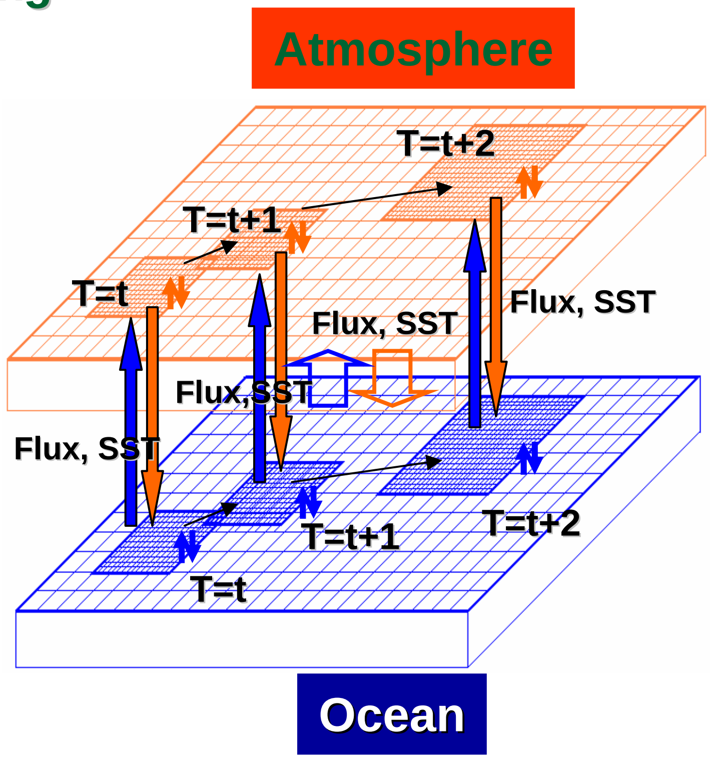
Snapshot of wind distribution in a summer afternoon

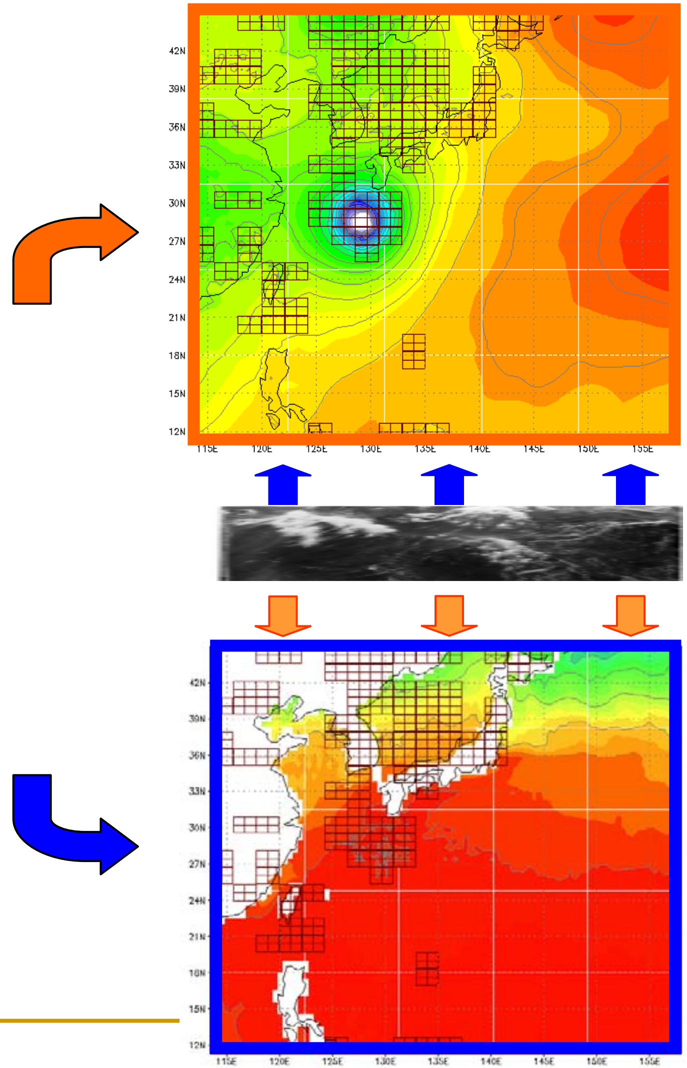




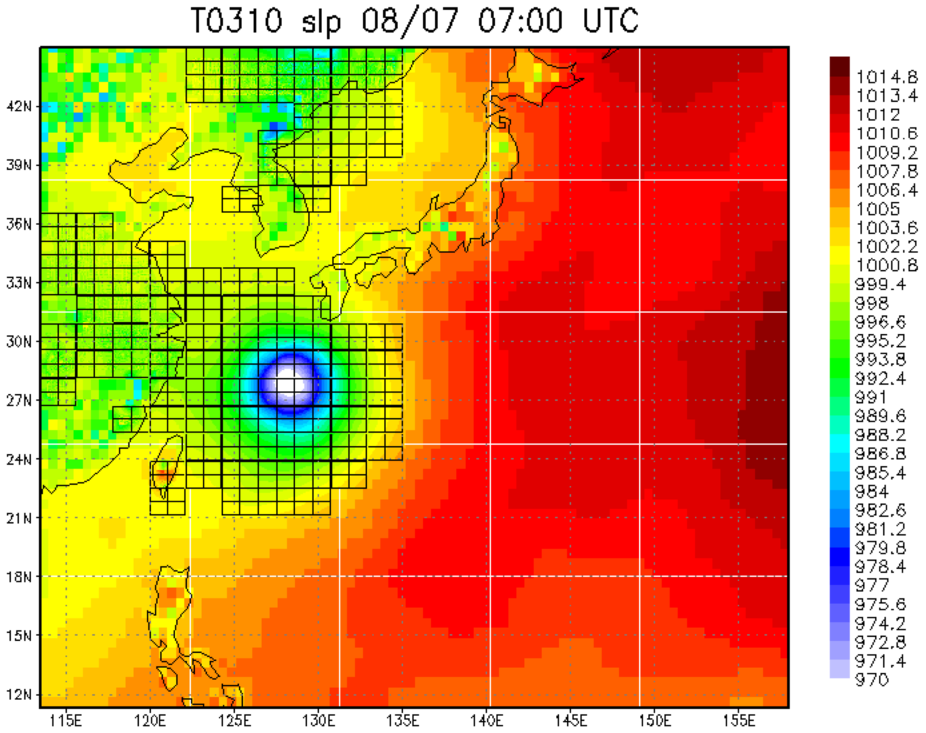
Adaptive Mesh Refinement for Coupled simulation

Adaptive Mesh Refinement (AMR)
+ 2-way nesting
+ Coupling





Coupled Typhoon simulation by AMR



	Atmos.	Ocean
Level 0 (static)	Δ_H=11km (global)	Δ_H=11km (global)
Level 1 (static)	Δ_H=5.5km	Δ_H=5.5km
Level 2 (dynamic)	Δ_H=2.8km	Δ_H=2.8km

MSSG is selected as a core application for the next Japanese flagship supercomputer with 10PFLOPS

Concluding Remarks (intermediate)

- MSSG (Multi-Scale Simulator for the Geoenvironment) for seamless simulations
  - Applicable to global, regional and local scales seamlessly
  - Consists of 3 modes; atmos. (MSSG-A) / ocean (MSSG-O) / coupled (MSSG)
  - High performance of more than 50% of the peak performance with 4096 vector processors.
  - AMR system for efficient simulations
- MSSG is being tuned for the next Japanese flagship supercomputer with 10PFLOPS.

Research on cloud microphysics using MSSG

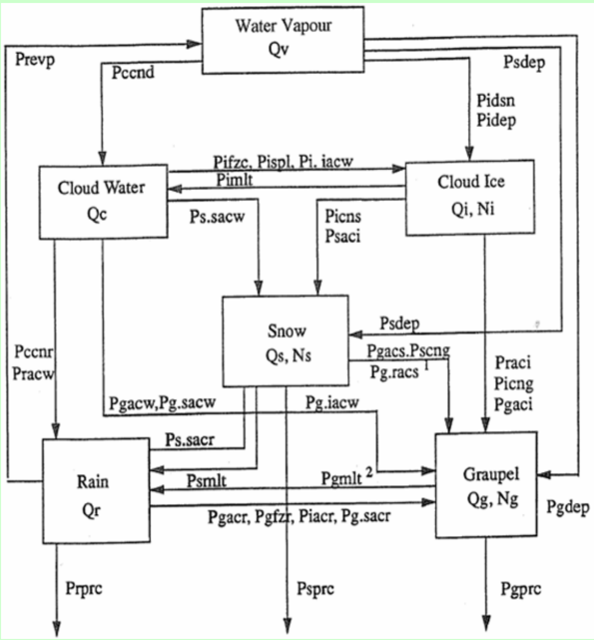
MSSG has Hybrid-Bin method

as well as a conventional Bulk method.

MSSG-Bin method (Hybrid-Bin method)

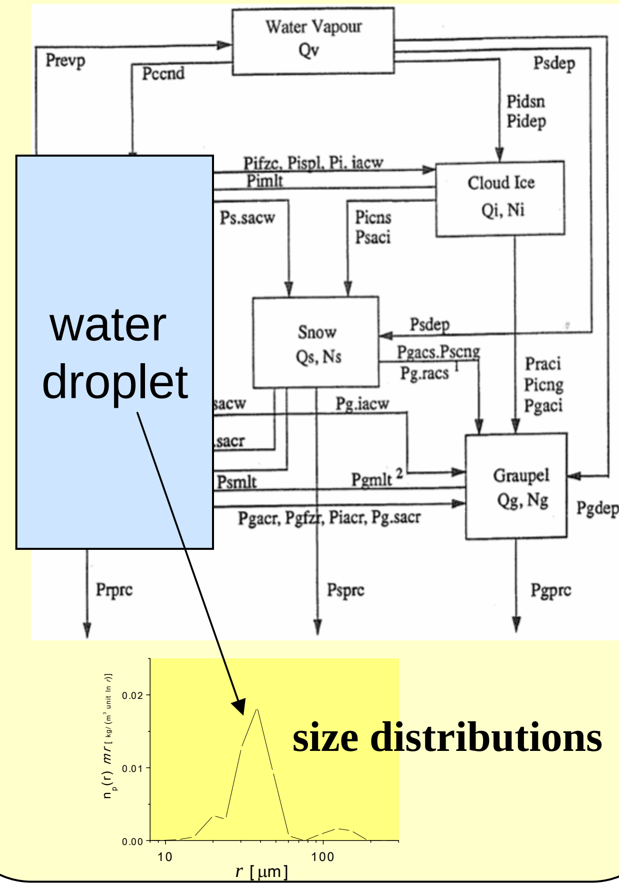
spectral Bin method for liquid water, and conventional Bulk method for solid water

Bulk method

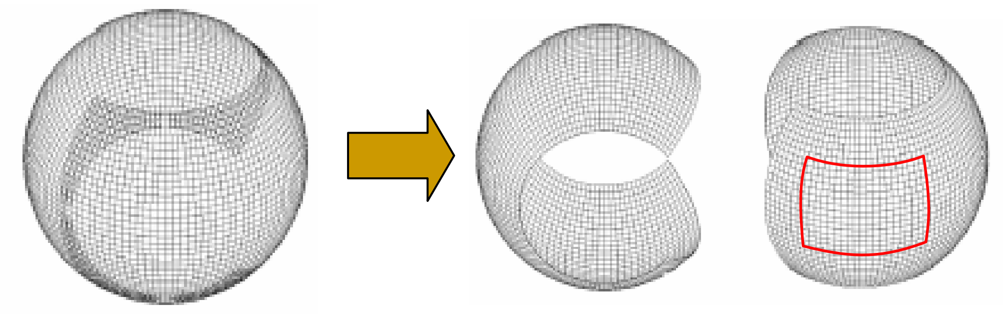


Reisner et al. (1998)

MSSG-Bin method



Use of MSSG as a Mesoscale model



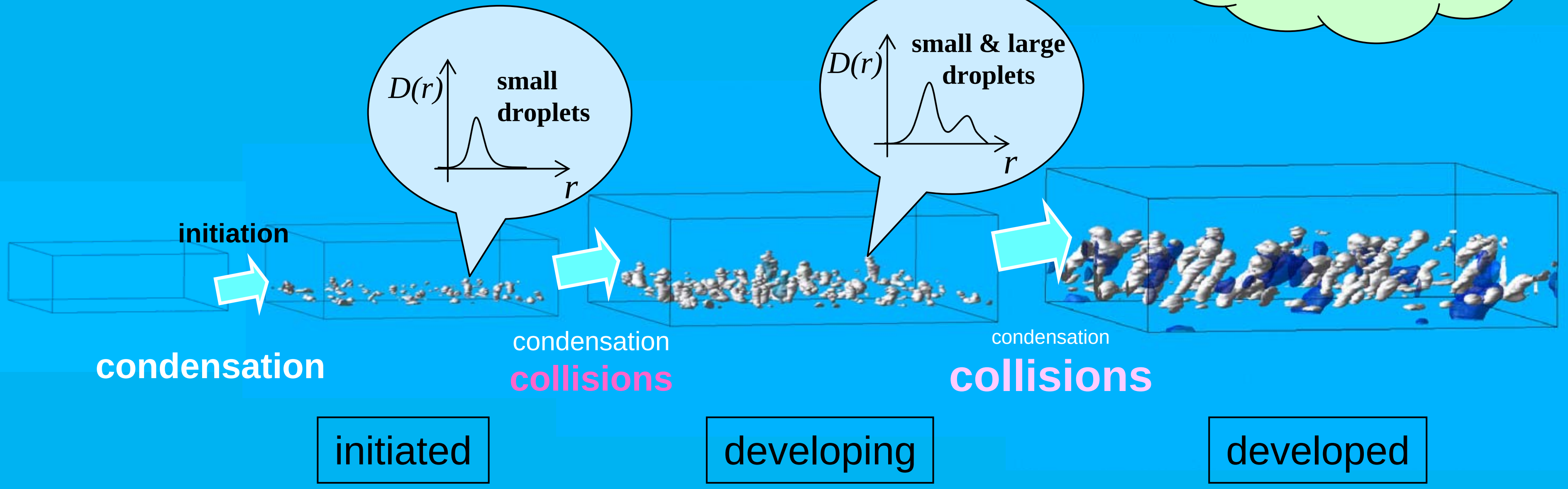
Yin-Yang system **lat-lon system**

- MSSG has been validated in idealized tests
  - **StMIP**-Steep Mountain Model Intercomparison Project (Satomura et al., 2003)
  - **orographic precipitation** with mixed-phase microphysics (Thompson et al., 2004)
  - **RICO**-Rain In Cumulus over the Ocean (GCSS)

Droplet growth in clouds

cloud stage	dominant process
initiation	condensation (nucleation)
initiated ⇒ developing	condensation **turbulent** collisions of <u>mono-dispersed</u> (small) droplets
developing ⇒ developed	gravitational & **turbulent** collisions of <u>bi-dispersed</u> (small & large) droplets

How significant is the turbulent collisions??



Droplet collision growth in Bin method

Stochastic Collection Equation (SCE)

$r'' + r' \rightarrow r$ ↑

$$\left(\frac{\partial n_p(r)}{\partial t}\right)_{col} = \frac{1}{2}\int_0^r K_c(r'',r')n_p(r'')n_p(r')dr'$$

$$-\int_0^\infty K_c(r,r')n_p(r)n_p(r')dr'$$

r ↓ $+ r' \rightarrow r''$

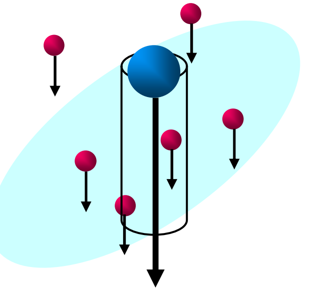
'number density function' change due to collision

$$N_c(r_1,r_2) = K_c(r_1,r_2)n_p(r_1)n_p(r_2)$$

collision frequency — collision kernel

Collision kernel models

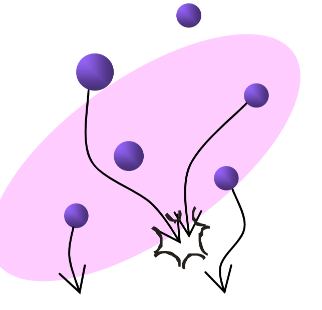
<u>Hydrodynamic (Gravitational) Collision Kernel Model</u>
(No turbulent collisions)



$$K_c(r_1, r_2) = \pi R^2 \left| V_\infty(r_1) - V_\infty(r_1) \right|$$

(R : collision radius (= r_1 + r_2), V_∞ :settling velocity)

our <u>Turbulent Collision Kernel Model</u>
(with turbulent collisions)

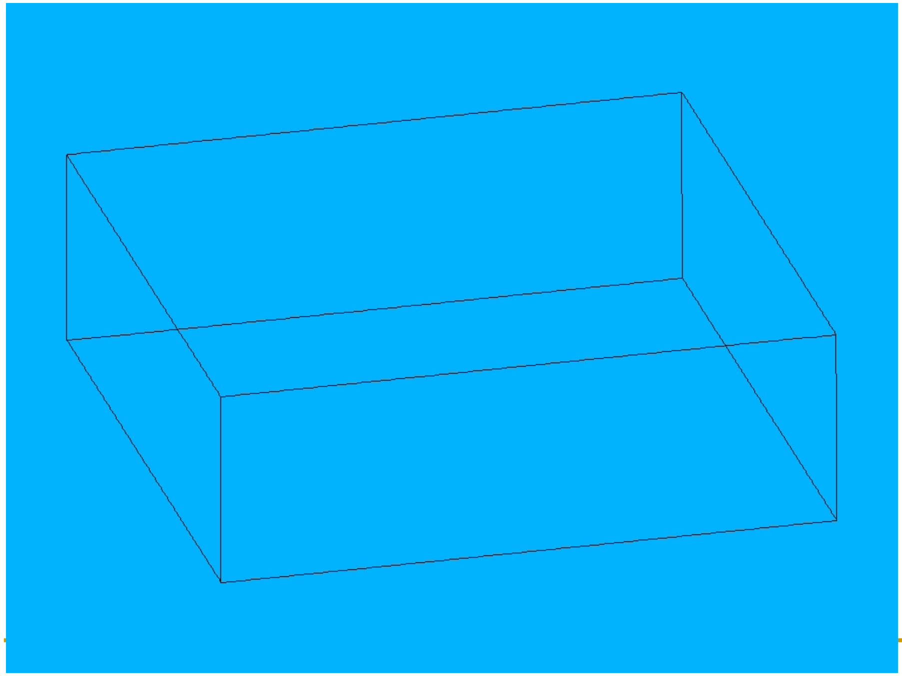


$$\left\langle K_c(r_1, r_2, \underline{l_\eta, u', \mathrm{Re}_\lambda}) \right\rangle = 2\pi R^2 \left\langle |w_r| \right\rangle g(R)$$

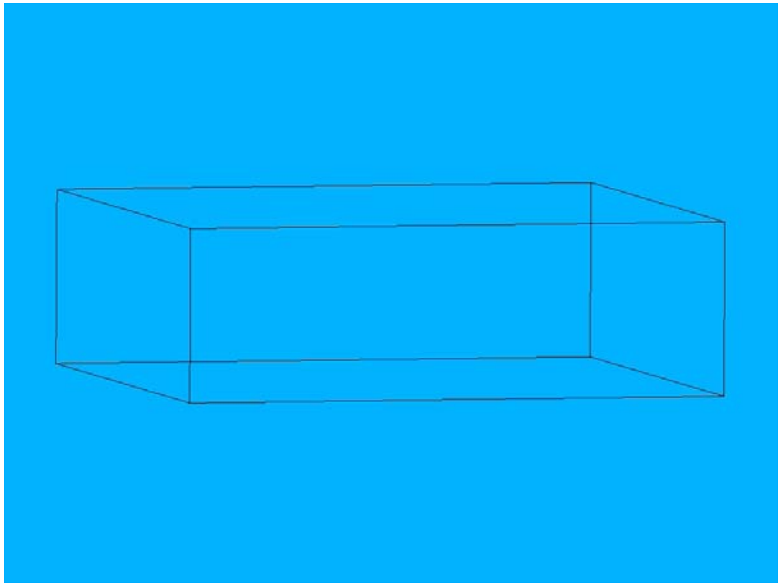
- $|w_r|$: radial relative velocity at contact (Wang et al. 2000)
- $g(R)$: radial distribution function at contact (original model)

RICO model intercomparison

- Initial data from "Rain In Cumulus over the Ocean" field campaign by GCSS
- Practical for investigating cloud microphysical processes

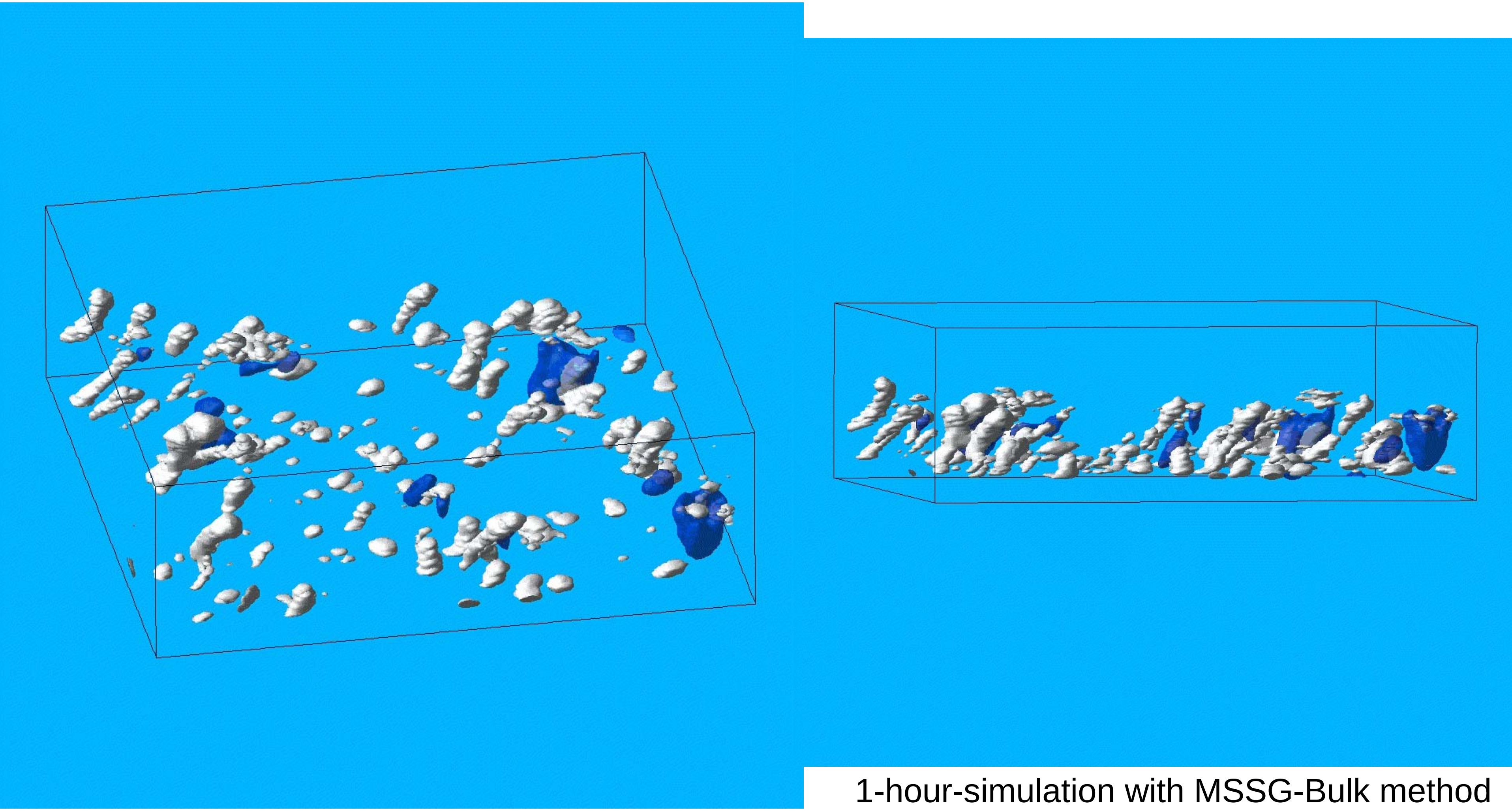


24-hour-simulation with MSSG-Bulk method



12.8×12.8×4km domain, Δ_H=100m, Δ_z=40m, Periodic B.C., 24 hours integration

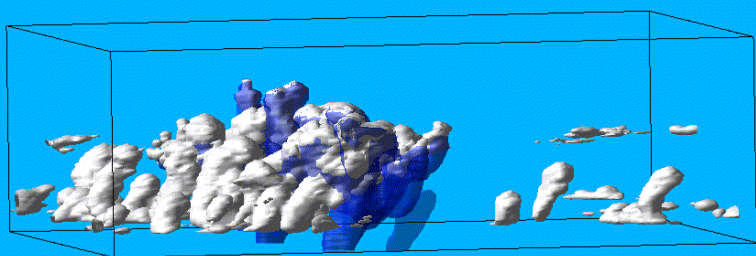
extra 1-hour simulation for visualization (MSSG-Bulk)



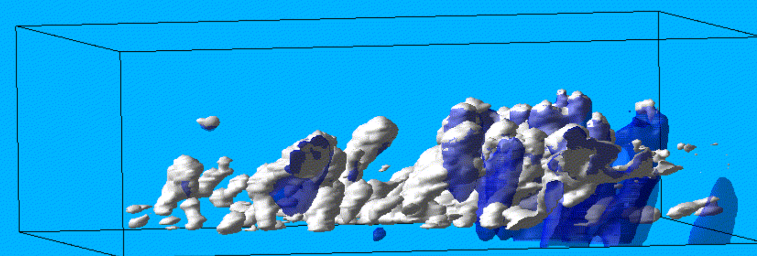
1-hour-simulation with MSSG-Bulk method

MSSG-Bin results (Hydrodynamic Kc v.s. Turbulent Kc)

Snapshots at 24h (blue: *r* > 100μm)



MSSG-Bin with Hydrodynamic (Gravitational) collision kernel (no turbulent collisions)



MSSG-Bin with Turbulent collision kernel

RICO intercomparison participants

model	microphysics	timestep [s]	duration for 24h integration [h]
MESO-NH	1st moment, Kessler	1	440
SAM	1st moment	2	320
JAMSTEC	1st moment	1	68
Utah	1st moment	?	?
EULAG	1st moment	?	?
2DSAM	1st moment	?	?
DALES	2nd moment, Nc fixed	1	190
UCLA	2nd moment, Nc fixed	~ 1.5	80
WVU	2nd moment, Nc fixed	~ 1.65	72
COAMPS	2nd moment	?	?
UKMO	2nd moment, Nc fixed	~ 0.7	500
RAMS	2nd moment+CCN	2	weeks
2DHARMA	bin model (33)	3.5	10,000
RAMS@NOAA	bin model (33)	2	5,400
SAMEX	bin model	?	?
MSSG-Bulk	1st moment (2nd for ice), Nc fixed	~ 2.2	250
MSSG-Bin	bin model (33)	~ 2.2	1,750

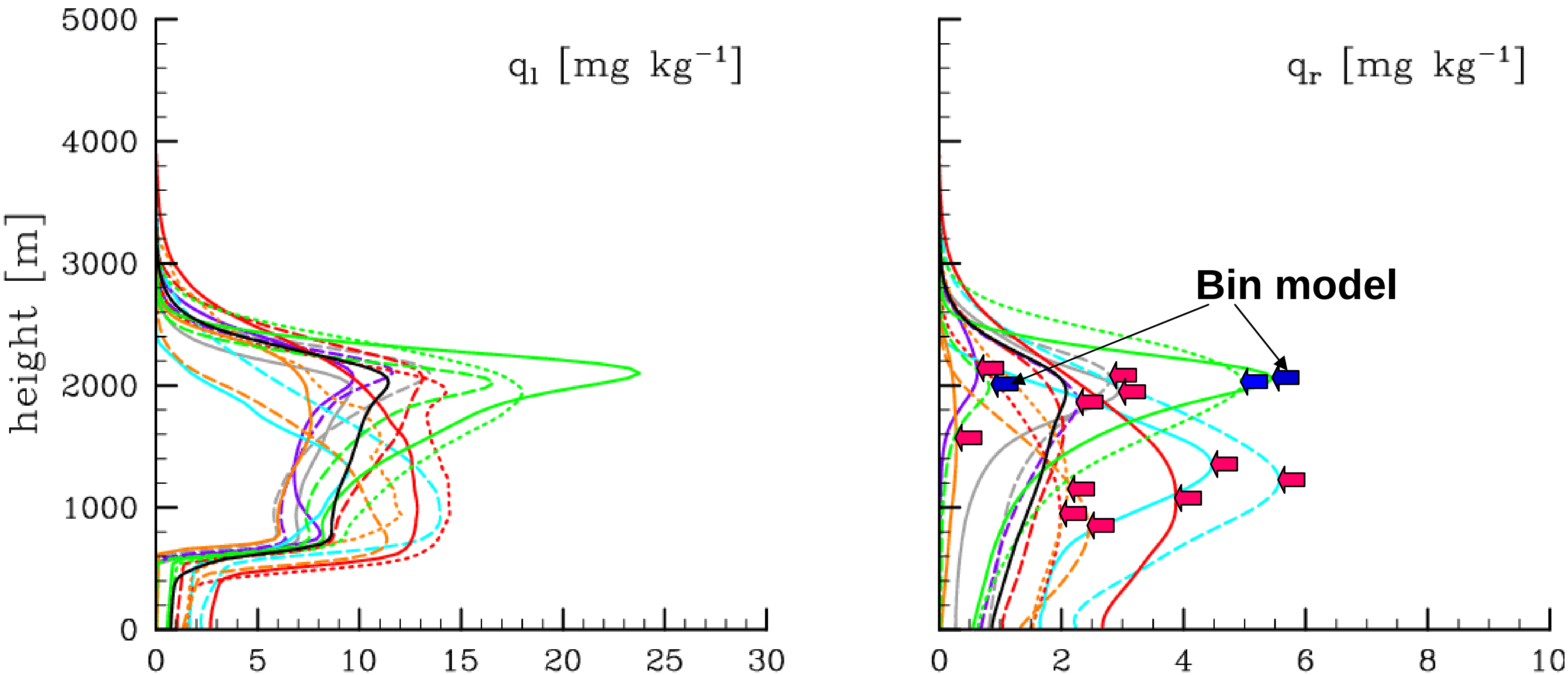
*yellow: Bulk models

* blue: Bin models

3 bin models &
12 bulk models

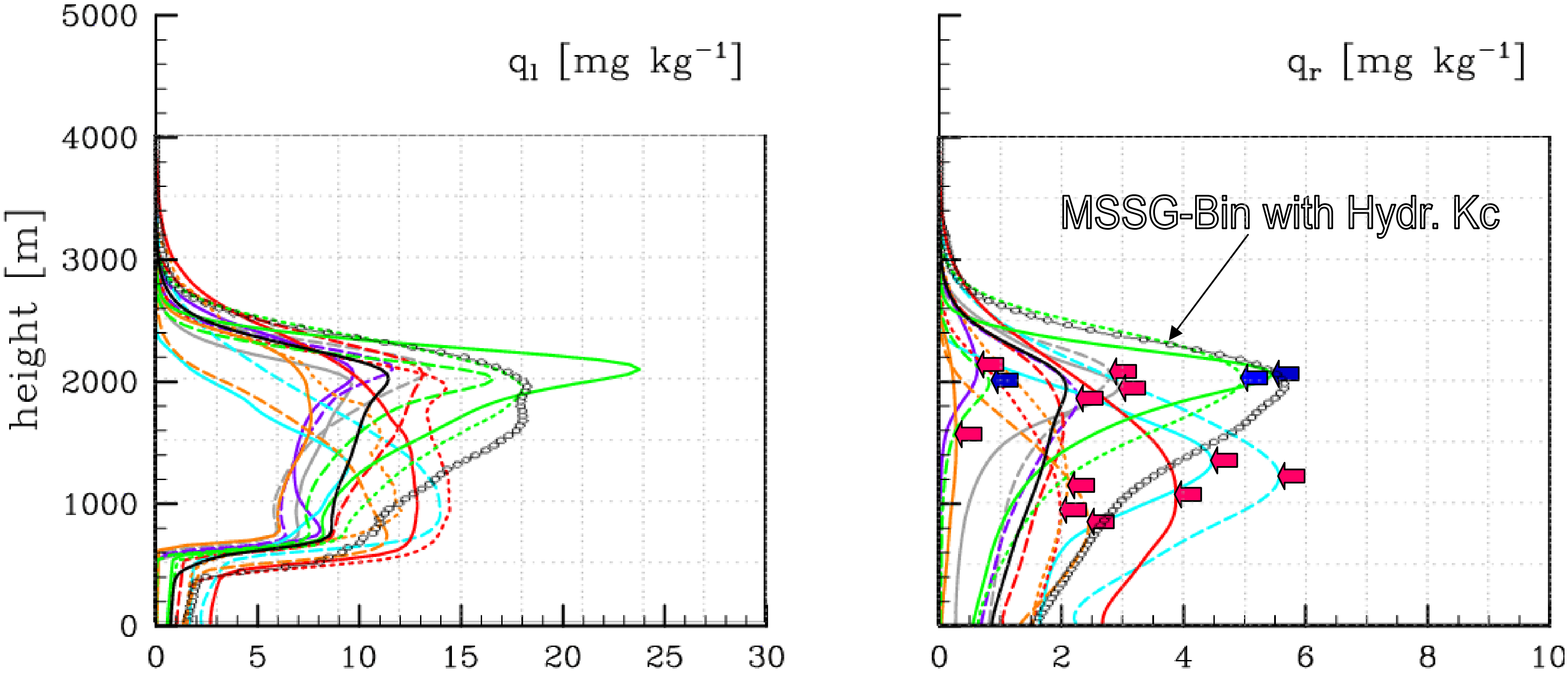
Ref: Margreet van Zanten, GCSS-GPCI/BLCI-RICO Workshop, NY, 2006

Mixing Ratios of Liquid Water (q_l) and Rain Water (q_r)



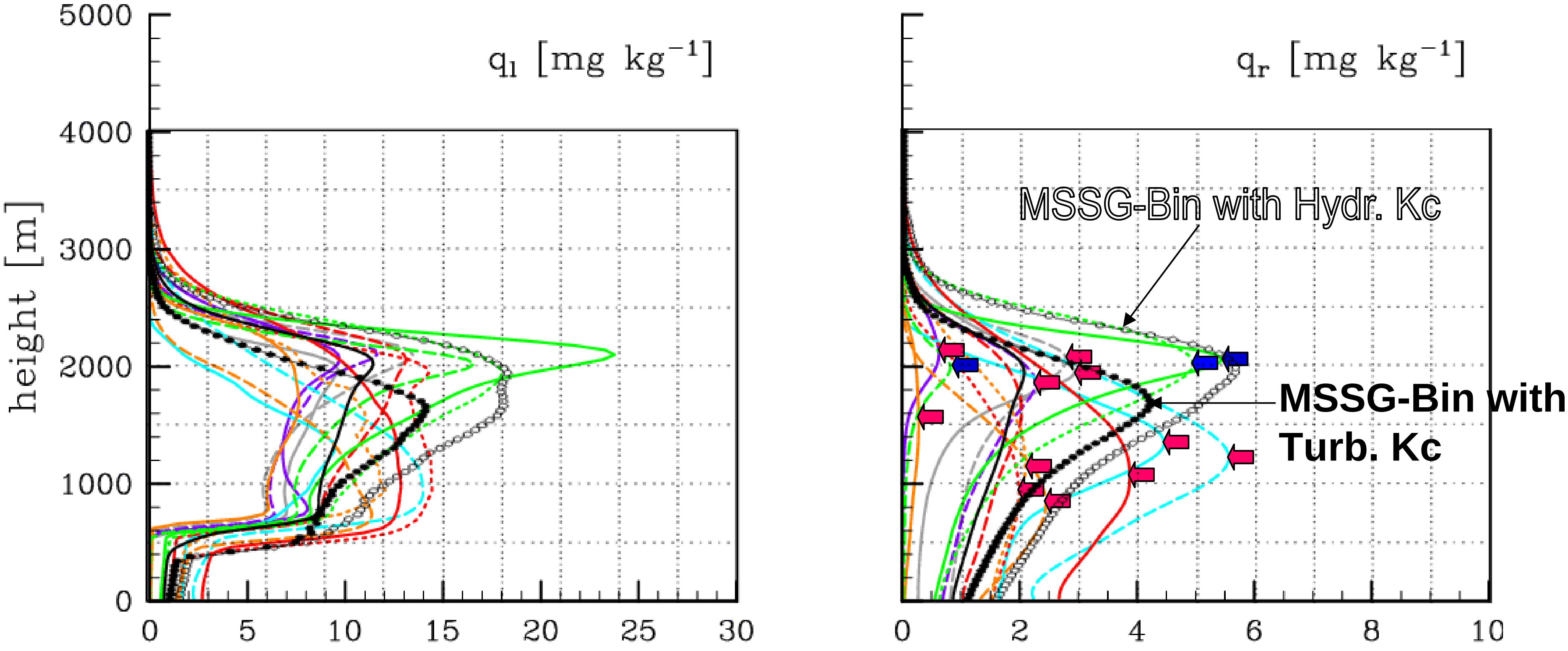
graphs from GCSS-BLCwg, RICO<http://www.knmi.nl/samenw/rico/>

Mixing Ratios of Liquid Water (q_l) and Rain Water (q_r)



+ MSSG-Bin with Hydr. Kc

Mixing Ratios of Liquid Water (q_l) and Rain Water (q_r)



Large impact of turbulent collisions is shown.

Discussion

- Two Bin-models & “MSSG-Bin model with Hydr. Kc (conventional gravitational collision kernel)” have max q_r at high altitude (z=2km).
- “MSSG-Bin with Turb. Kc” and many of Bulk-models have max q_r at lower altitude.

- In conventional Bin-models, where turbulent collisions are not considered, it takes time for droplets to grow and fall, and therefore they are raised higher.
- Some Bulk-models empirically consider some turbulent collision enhancement to some extent, and therefore show similar results to those by “MSSG-Bin model with Turb. Kc”.

Concluding Remarks

- MSSG (Multi-Scale Simulator for the Geoenvironment) for seamless simulations
  - Applicable to global, regional and local scales seamlessly
  - Consists of 3 modes; atmos. (MSSG-A) / ocean (MSSG-O) / coupled (MSSG)
  - High performance of more than 50% of the peak performance with 4096 vector processors.
  - AMR system for efficient simulations
- MSSG is being tuned for the next Japanese flagship supercomputer with 10PFLOPS.
- MSSG-Bin model with turbulent collision model reveals the importance of turbulent droplet collisions in cloud development.

Thank you.