Development of a nonhydrostatic model at JMA

Junichi Ishida
Numerical Prediction Division
Japan Meteorological Agency
j-ishida@met.kishou.go.jp

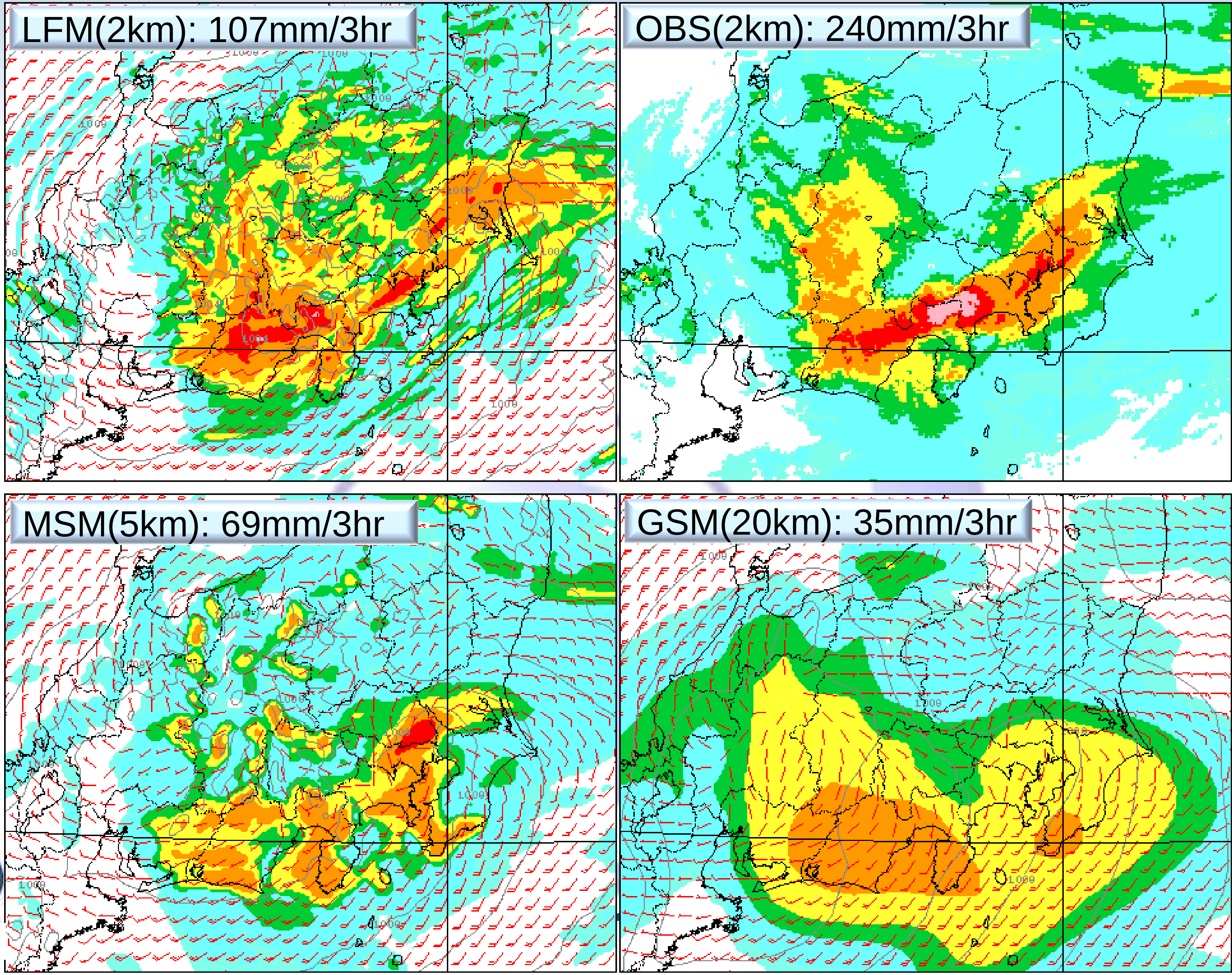
JMA's super computer system will be upgraded in 2012.

	Mar. 2006- Feb. 2012	Mar. 2012 –
	HITACHI SR11000 	Successor of HITACHI's current super computer SR16000
Total Peak Performance	27.584TFlops	829.4TFlops
Total number of nodes	210 nodes （16Core/1node）	864 nodes （32Core/1node）
Memory	64GB/node	128GB/node
Memory Bandwidth	67.2-134.4GB/s/node	612GB/s/node
Network Bandwidth	8GB/s (one-way)	96GB/s (one-way)
System configuration	80nodes x 2 + 50nodes x 1	432nodes x 2

Current and Plan NWP models

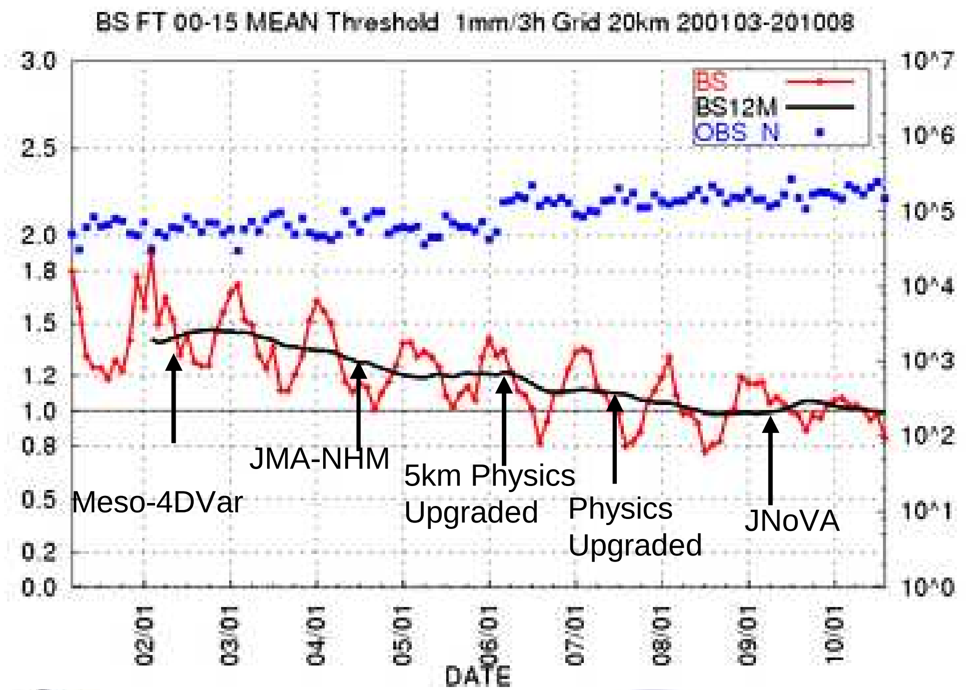
		Current	Plan on next super computer system
MSM Meso Scale Model	Status	Operation	Operation
	Grid spacing	5km	5km
	Forecast length	15/33hour, 8times/day	36hour (TBD), 8times/day
	No. of grid points	721x577x50	817x661x75 (TBD)
	Forecast model	JMA nonhydrostatic model (JMANHM)	JMA nonhydrostatic model
	Data assimilation	4D-Var based on JMANHM	4D-Var based on JMANHM
LFM Local Forecast Model	Status	Experimental run → trial run	Operation
	Grid spacing	2km	2km
	Forecast length	9hour, 8times/day	9hour, 24times/day
	No. of grid points	800x550x60	1581x1301x60 (TBD)
	Forecast model	JMA nonhydrostatic model (JMANHM)	JMA nonhydrostatic model
	Data assimilation	Rapid update cycle using 3D-Var	Rapid update cycle using 3D-Var
MEPS Meso Ensemble Prediction System	Status	Under development	Experimental run
	Grid spacing	-	10km or 5km (TBD)
	Forecast length	-	39hour (TBD), 4times/day
	Forecast domain	-	Same domain as MSM
	No. of member	-	41 or 5 (TBD)

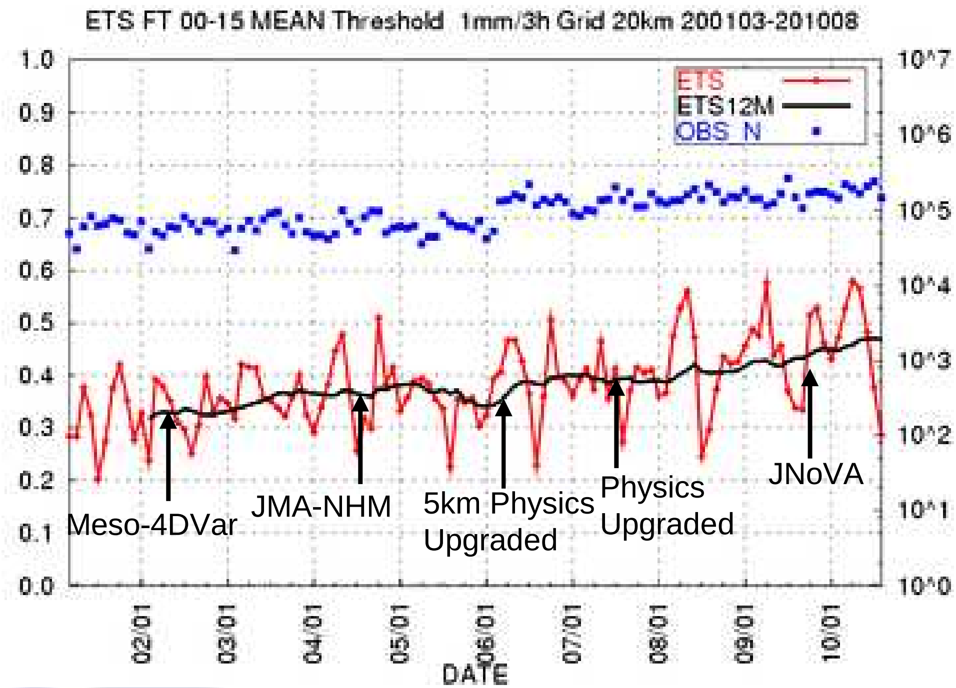
Quantitative precipitation forecast, Typhoon Malou



Score of Precipitation Forecasts of MSM

2001/03; Operation of MSM was started
2002/03; Meso-4DVar based on hydrostatic model was started to operate.
2004/09; Forecast model was changed to JMA nonhydrostatic model
2006/03; Horizontal resolution was enhanced into 5km and some physics was changed.
2007/05; Forecast length was extended to 33hour and some physics processes was upgraded.
2009/04; 4D-Var system was changed to use JNoVA based on JMANHM





Overview of JMANHM

- Fully compressible equations with map factors
- Hybrid terrain-following vertical coordinate
- The terms responsible for sound and gravity waves
  - Split explicit scheme
- Advection terms
  - Horizontal : 4th order , Vertical : 2nd order with flux correction scheme
- Cloud microphysics
  - Bulk method : qc,qr,qci,qs,qg,Nci
- Cumulus parameterization
  - Kain-Fritsch scheme (not used in LFM)
- Surface processes
  - computation of bulk coefficients : Beljaars and Holtslag
- Boundary layer process
  - Improved Mellor-Yamada Level3 scheme
- Radiation
  - Short and long radiation are calculated every 15 minutes

Development of a New Dynamical Core

Motivation

- JMANHM is used not only for operation but for research such as regional climate change study.
- The aims of our new dynamical core are
  - Higher accuracy, computational stability and efficiency
  - Conservation of mass and some other quantities
- We are developing a new dynamical core, named “ASUCA”.

Current Status

- The development of main components of dynamical core has been almost done.
- We have just started to test the combination between dynamical core and physics processes.
  - Simple cloud micro physics and turbulence scheme are installed.

Comparison of dynamical core between ASUCA and JMANHM

	ASUCA	JMANHM
Governing equations	Flux form Fully compressible equations	Quasi flux form Fully compressible equations
Prognostic variables	ρu, ρv, ρw, ρθ, ρ	ρu, ρv, ρw, θ, p
Spatial discretization	Finite volume method	Finite difference Method
Time integration	Runge-Kutta 3rd (long and short)	Laepflog with time filter (long) Forward backward (short)
Treatment of sound	Split explicit	Split explicit
Advection	Flux limiter function by Koren	4th (hor.) and 2nd(ver.) order with advection correction
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.)

Governing equations

$$\frac{\partial}{\partial t}\left(\frac{1}{J}\rho u^i\right)+\frac{\partial}{\partial \hat{x}^n}\left(\frac{1}{J}\rho u^i \hat{u}^n\right)+\frac{\partial}{\partial \hat{x}^n}\left(\frac{1}{J}\frac{\partial \hat{x}^n}{\partial x^i}p'\right)+\frac{1}{J}\rho' g\delta_3^i=\frac{1}{J}F_{u^i}$$

$$\frac{\partial}{\partial t}\left(\frac{1}{J}(\rho\theta_m)'\right)+\frac{\partial}{\partial \hat{x}^n}\left(\frac{1}{J}\rho\theta_m \hat{u}^n\right)=\frac{1}{J}F_{\theta_m}$$

(x1, x2, x3) : physical space.
(ˆx1, ˆx2, ˆx3) : computational space.

J is a Jacobian of the coordinate transformation

$$\frac{\partial}{\partial t}\left(\frac{1}{J}\rho q_\alpha\right)+\frac{\partial}{\partial \hat{x}^n}\left(\frac{1}{J}\rho q_\alpha(\hat{u}^n+\hat{u}^n_{t\alpha})\right)=\frac{1}{J}F_{q_\alpha}$$

$$\frac{\partial}{\partial t}\left(\frac{1}{J}\rho'\right)+\frac{\partial}{\partial \hat{x}^n}\left(\frac{1}{J}\rho \hat{u}^n\right)=\frac{1}{J}F_\rho$$

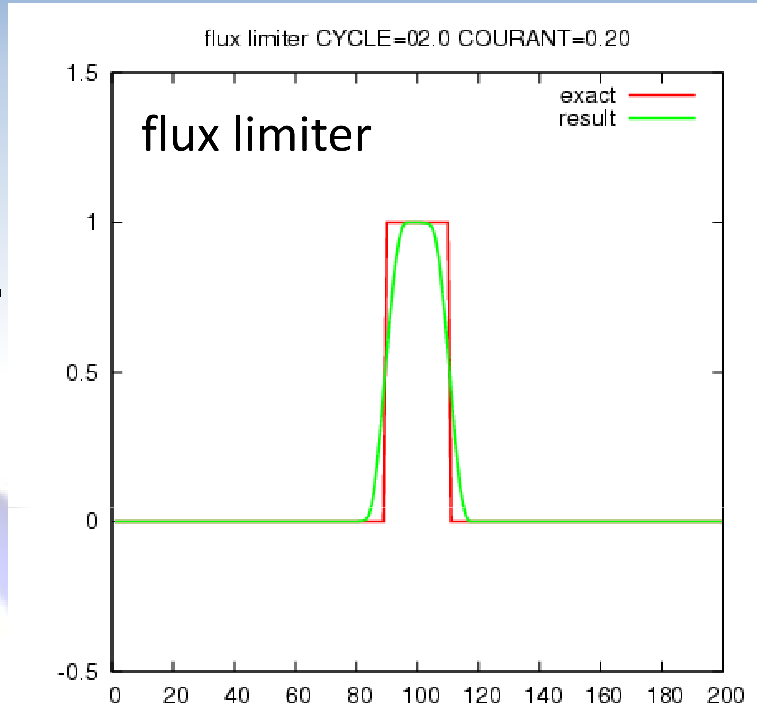
u, v, w : velocity components in the physical space
ˆu, ˆv, ˆ w : those in the computational space
ρ : total mass density
q_α : ratio of the density of a water substance α to the total mass density

$$p=p_0\left(\frac{R_d\rho\theta_m}{p_0}\right)^{\frac{C_p}{C_v}}, \quad p'=\frac{C_p}{C_v}R_d\pi(\rho\theta_m)', \quad \pi=\left(\frac{p}{p_0}\right)^{\frac{R_d}{C_p}}$$

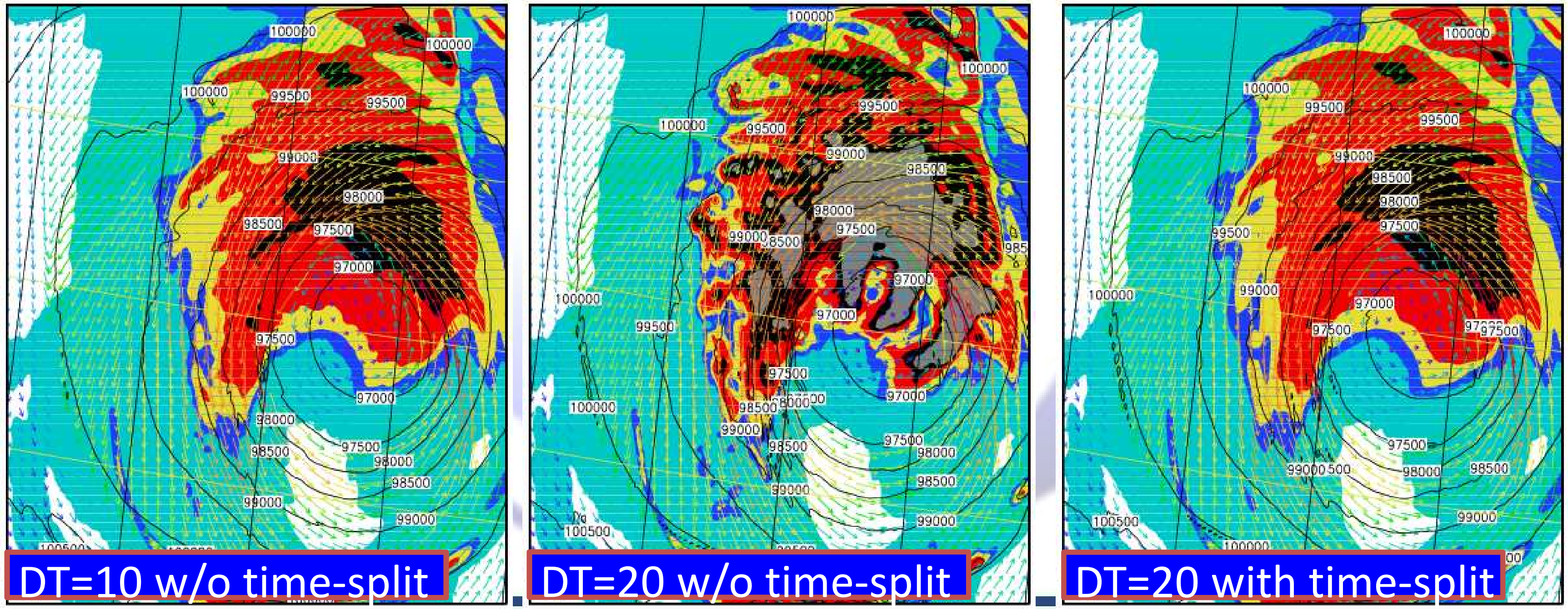
- The RHS terms involve not only physics process but Coriolis terms, curvature terms and the term arising from change of density by precipitation.

Advection

- The flux limiter function proposed by Koren (1993) is employed for advection.
  - 3^{rd} order accurate in smooth field
  - Preserve monotonicity
- The vertical advection terms of precipitation which has fast terminal velocity is time integrated using time split manner.



Result of 1D advection test



Typhoon Case experiment; DX=2km, MSLP and 3hourly precipitation

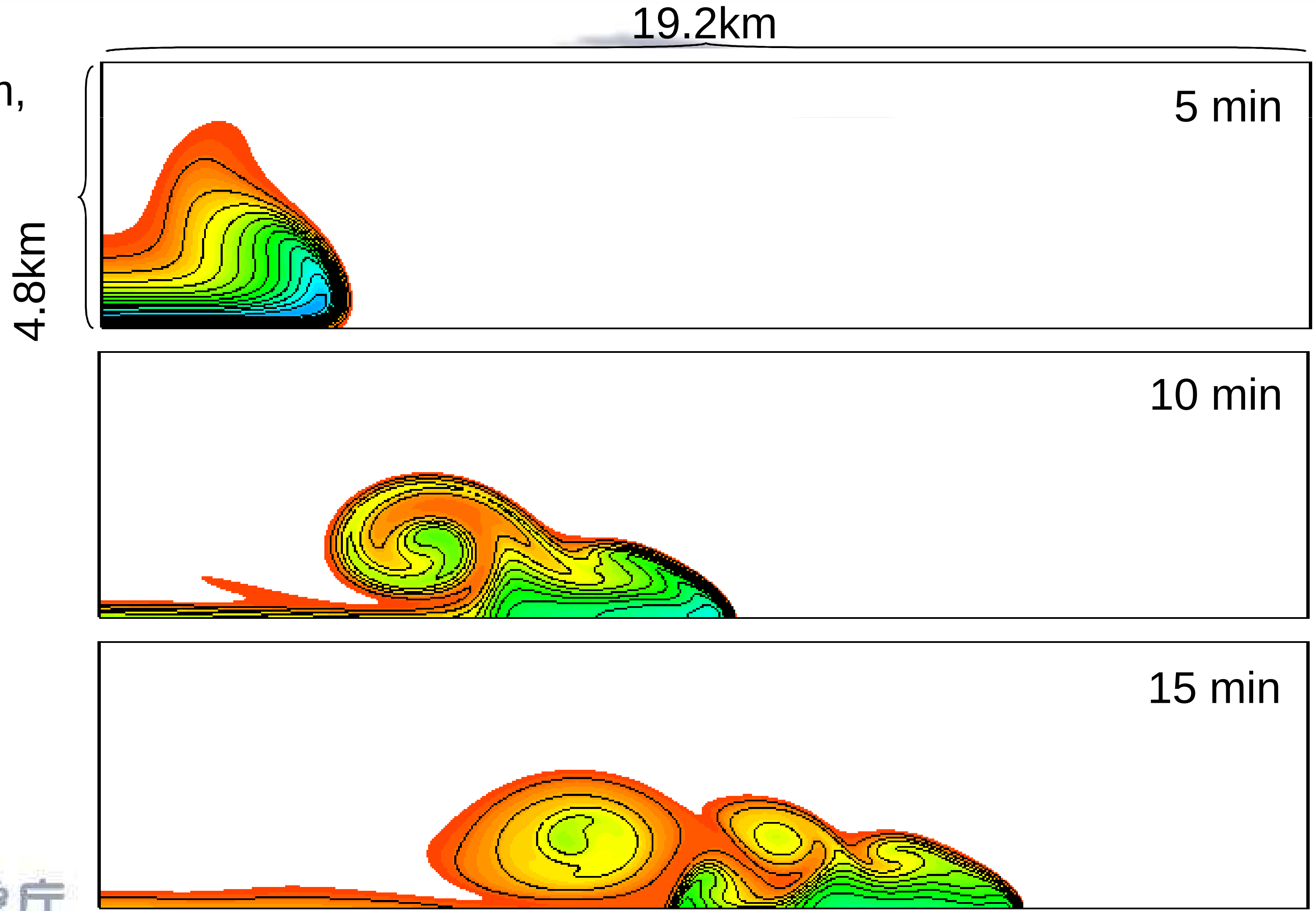
Density current experiment

Based on Straka et al. (1993)

Initial state background : neutral layer (potential temperature = 300K)

perturbation : max perturbation = -15K at centre, z=3000m

dx = 50m,
dt = 1s



Typhoon case experiment by ASUCA

Initial time
2010/09/08/00UTC
Grid spacing : 2km
Time step: 20s.
No. of grid points:
400x300x48
Forecast length :
6 hour
3hourly precipitation,
MSLP and wind