Development of nonhydrostatic models at the JMA

Junichi Ishida

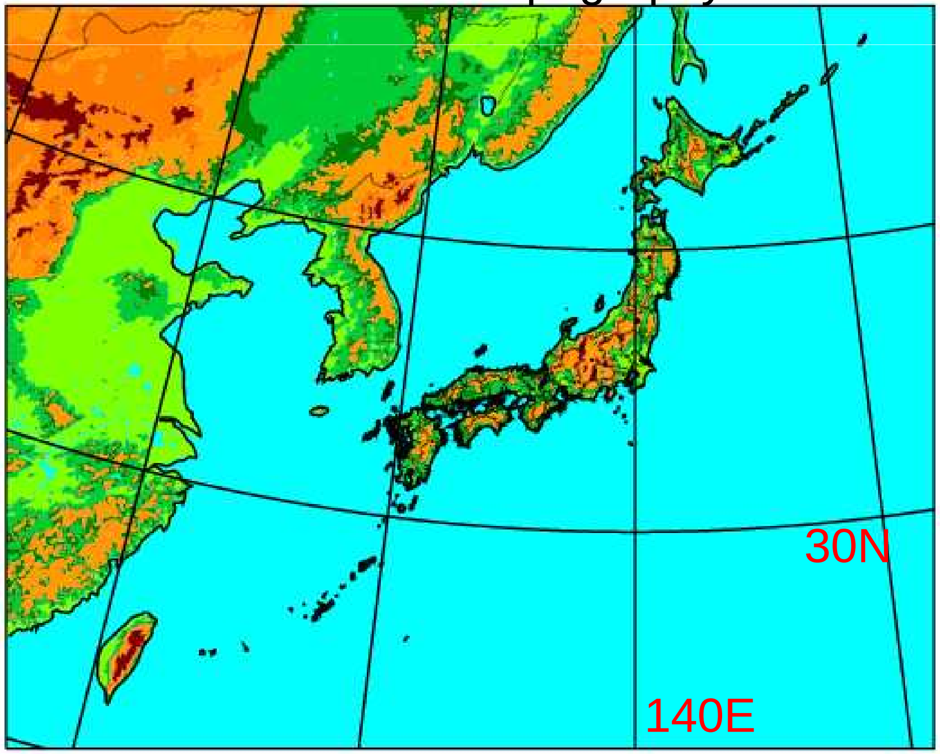
Numerical Prediction Division /
Japan Meteorological Agency

j-ishida@met.kishou.go.jp

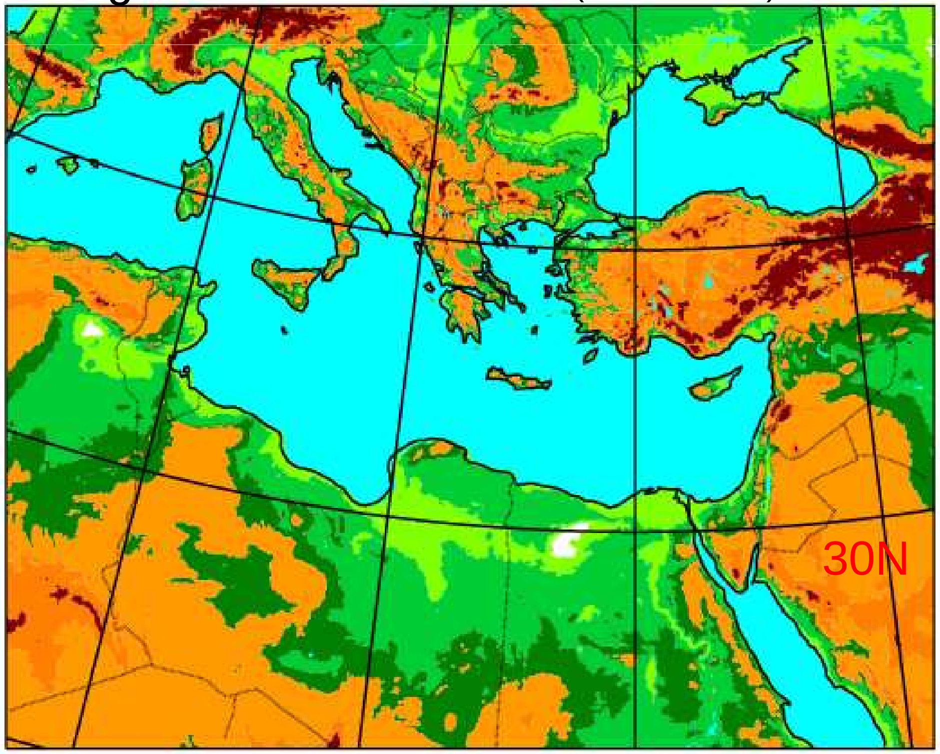
Meso Scale Model (MSM) at JMA (operating since Mar. 2001)

Objectives	: Disaster prevention / Aviation forecast
Resolution	: 5km
Forecast length	: 33hr (03,09,15,21 UTC) 15hr (00,06,12,18 UTC)
No. of grid points	: 721 x 577
Levels	: 50 levels up to 21,800m
Forecast model	: JMA nonhydrostatic model (JMANHM) since Sep. 2004
Data assimilation	: 4D-Var based on JMANHM since Apr. 2009

Forecast Domain and Topography of MSM



A region of the same size (for reference)



Development of Local Forecast Model (LFM) at JMA

Objectives : Disaster prevention / Aviation forecast
Resolution : 2km
Forecast Domain : 3 domains to cover the whole area of the JMA radar network
Operation : Planning to start operation in Mar. 2012

Development schedule of LFM

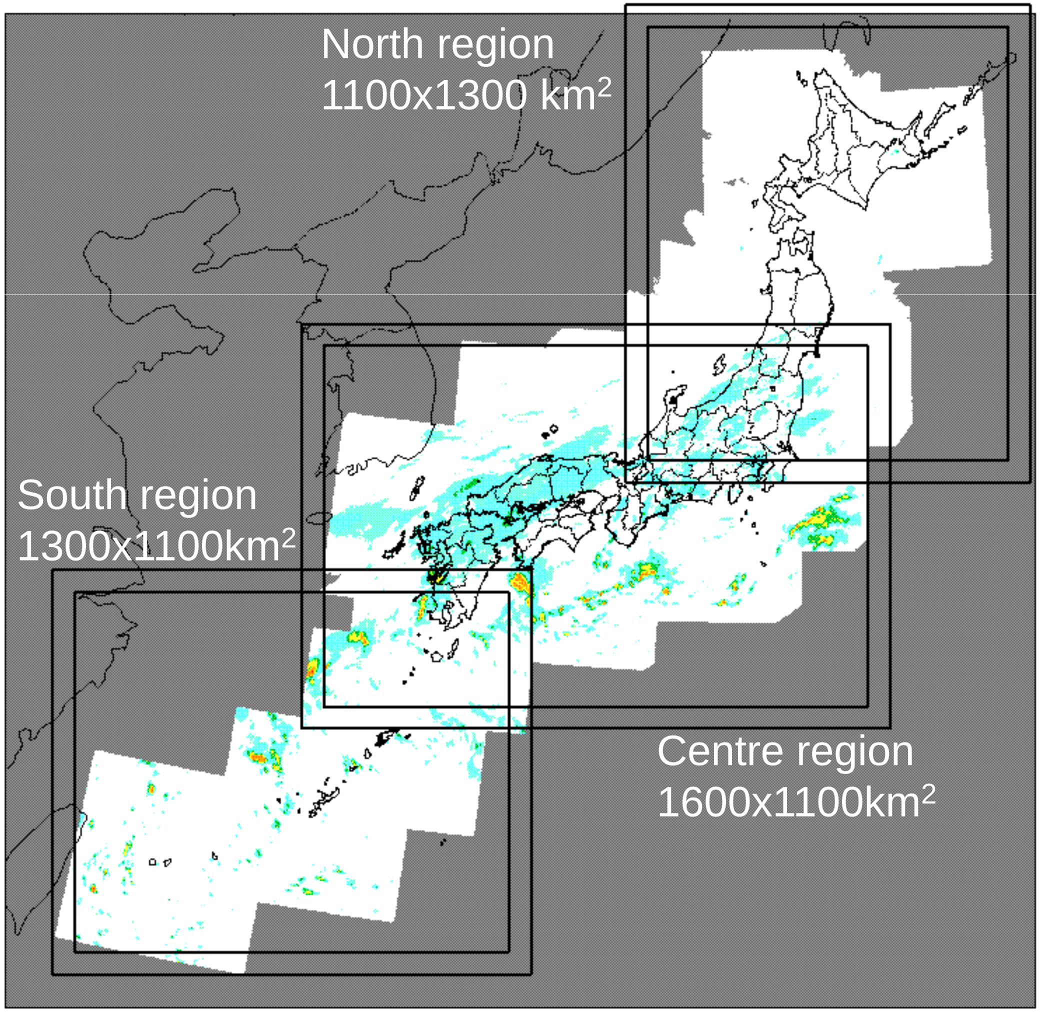
Phase 1: Jun. 2006 – Mar. 2009
Domain ... Around Tokyo (300x300km^2)
To check the basic characteristic of LFM

Phase 2: Aug. 2009 – Feb. 2011
Domain ... Centre region
To improve the issues revealed at the Phase 1

Phase 3: Mar. 2011 – Feb. 2012
Domain ... Centre region
To verify the total performance of LFM

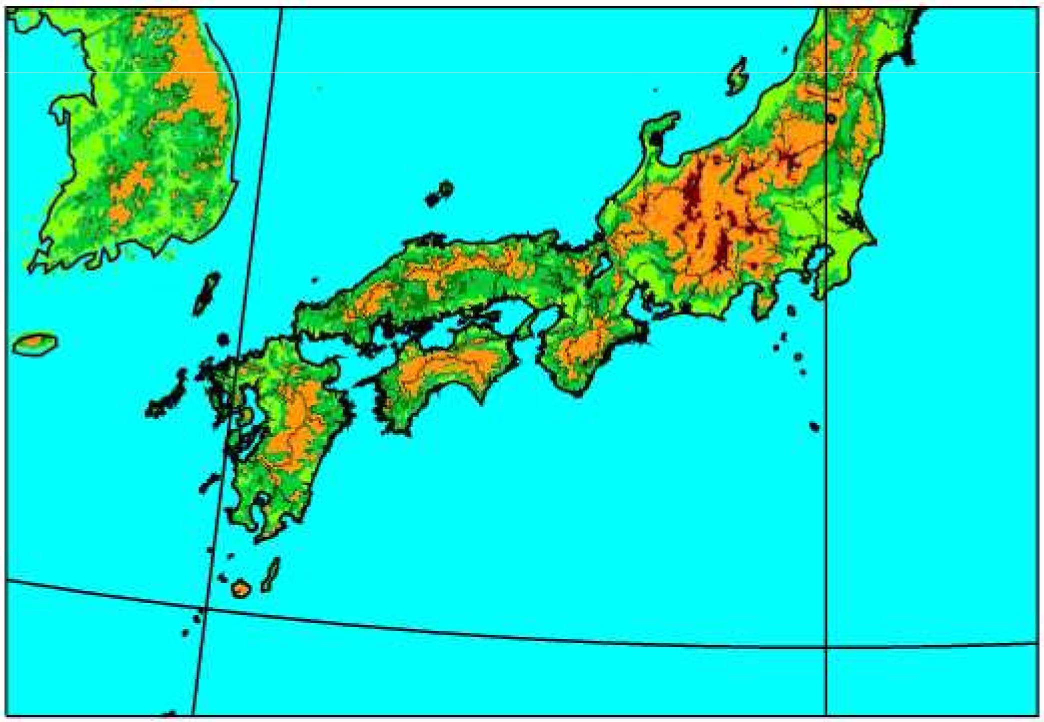
Operation : Mar. 2012 –
Domain ... 1 domain (Mar. 2012-)
3 domains (Mar. 2013-)

•A new super computer was installed in Apr. 2009 and the LFM system has been transplanted.



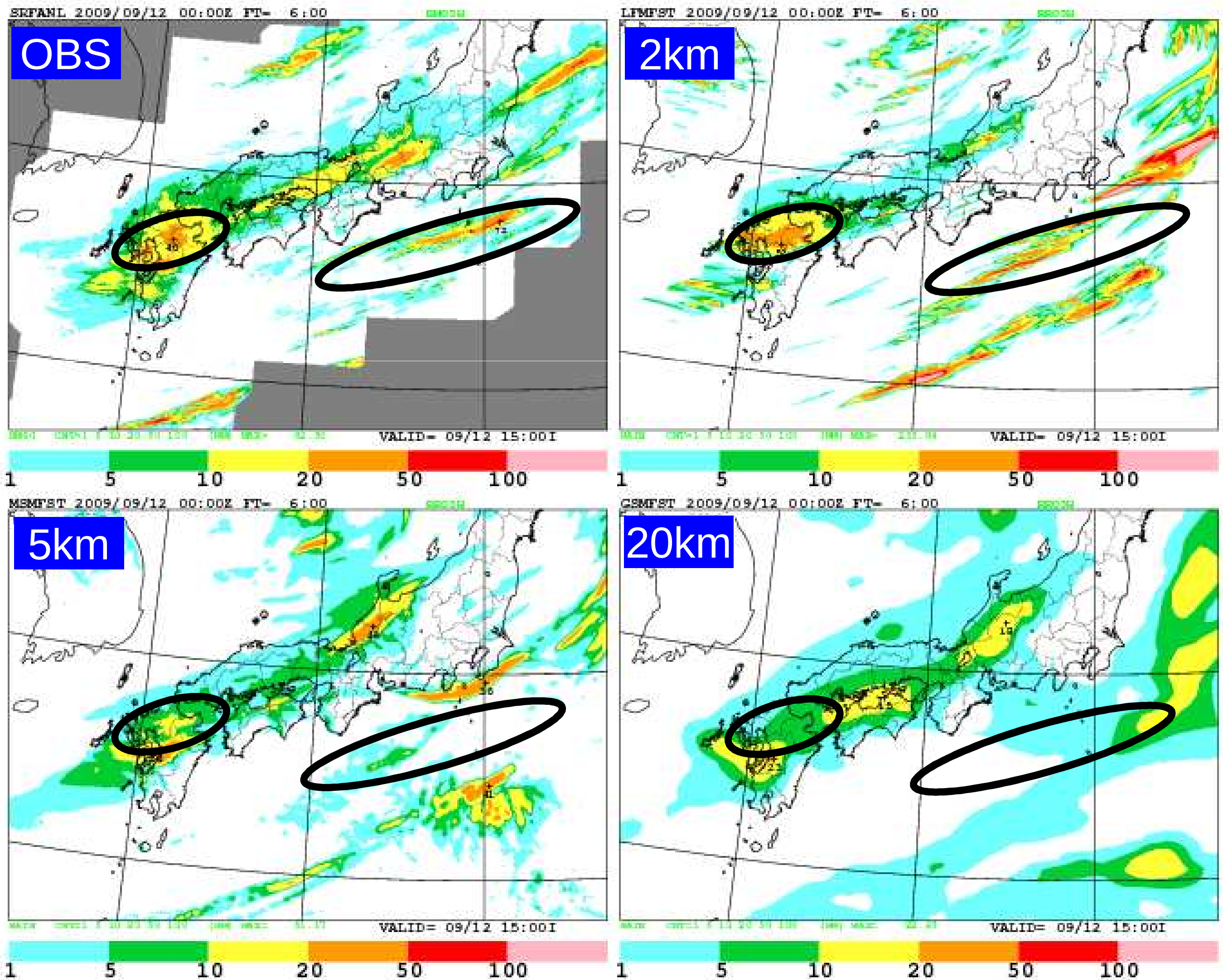
Current status of LFM (experimental operating since Aug. 2009)

Resolution	: 2km
Forecast length	: 12hr
No. of grid points	: 800 x 550
Levels	: 60 levels up to 20,500m
Forecast model	: JMA nonhydrostatic model (JMANHM)
Data assimilation	: 3D-Var



Quantitative Precipitation Forecast 06 UTC on 12th Sep. 2009

Initial time is 00 UTC on 12th 2009



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 : fourth order , Vertical : second order
- 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

- The JMANHM has been used since 1990's.
  - Well tested and checked but ...
- We need
  - Higher accuracy
    - Accurate mass conservation
  - Higher computational stability
    - Monotonicity in advection
  - Higher efficiency
    - Less data communication
    - Suitable to the current computer architecture
  - Reconstruction of the model program
- We are developing a new dynamical core, named "asuca".

Comparison of dynamical core between JMANHM and asuca

	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 diffence method
Time integration	Runge-Kutta 3rd (long and short)	Leapflog 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
Coordinate	Generalized coordinate	Conformal mapping (hor.) Hybrid – Z (ver.)
Grid	Arakawa-C (hor.) Lorentz (ver.)	Arakawa-C (hor.) Lorentz (ver.)
Correction scheme to conserve mass	unnecessary	necessary but omitted

Basic equations

$$\frac{\partial(\rho u^i)}{\partial t} + \nabla_j \cdot (\rho u^i u^j) + (\nabla p)^i + \rho g \delta_3^i = F_{u^i}$$

$$\frac{\partial \rho\theta}{\partial t} + \nabla_i \cdot (\rho\theta u^i) = F_\theta$$

$$\frac{\partial \rho}{\partial t} + \nabla_i \cdot (\rho u^i) = 0$$

$$p = p_0 \left(\frac{R\rho\theta}{p_0}\right)^{\frac{C_p}{C_v}}$$

asuca's equations

ρ is a prognostic variable.

$$\frac{\partial(\rho u^i)}{\partial t} + \nabla_j \cdot (\rho u^i u^j) + (\nabla p)^i + \rho g \delta_3^i = F_{u^i}$$

$$\frac{\partial \theta}{\partial t} + \frac{1}{\rho}\left\{\nabla_i(\rho u^i \theta) - \theta \nabla_i(\rho u^i)\right\} = F_\theta$$

$$\frac{\partial p}{\partial t} = C_s^2 \left(-\nabla_i \cdot (\rho u^i) + \frac{\rho}{\theta}\frac{\partial \theta}{\partial t}\right)$$

$$\rho = \frac{p_0}{R\theta}\left(\frac{p}{p_0}\right)^{\frac{C_v}{C_p}}$$

JMANHM's equations

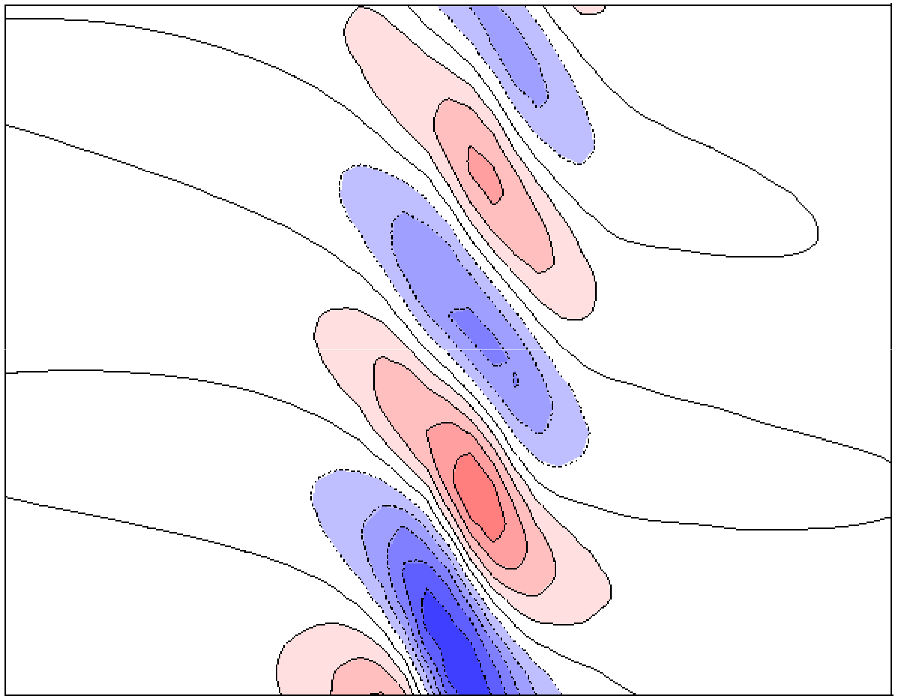
ρ is not a prognostic variable.

Asuca employs density as a prognostic variable to assure mass conservation.

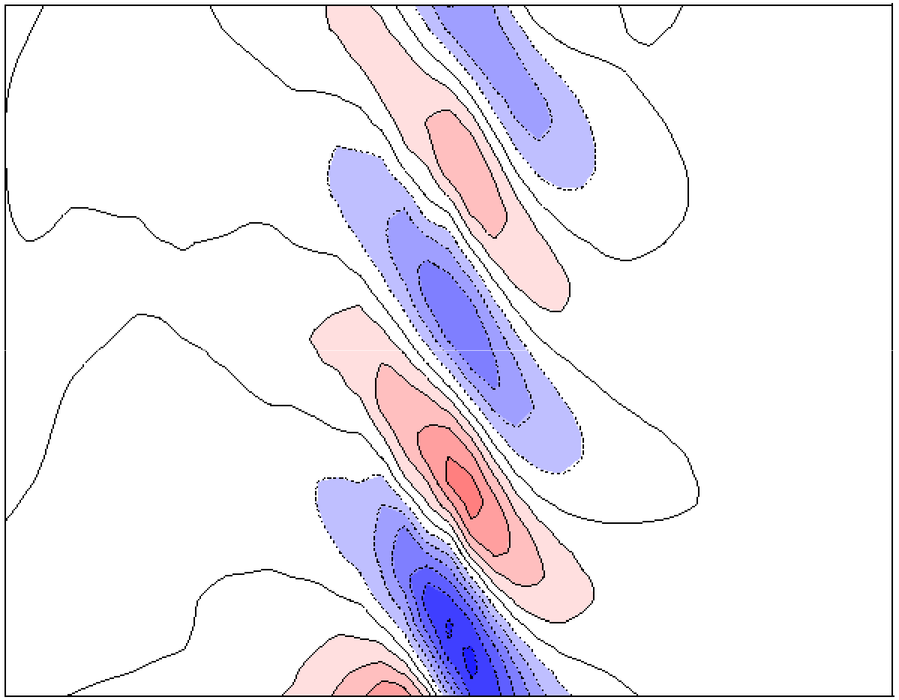
Mountain wave experiment (2D)

Brunt Baisala frequency = 0.02, U = 10m/s, dx = 1000m, dz = 250m

Number of grid points : 63 (hor.) x 48 (ver.)



asuca, dt = 60s.
dynamical core
+ turbulence scheme



JMANHM, dt = 20s.
dynamical core
+ turbulence scheme

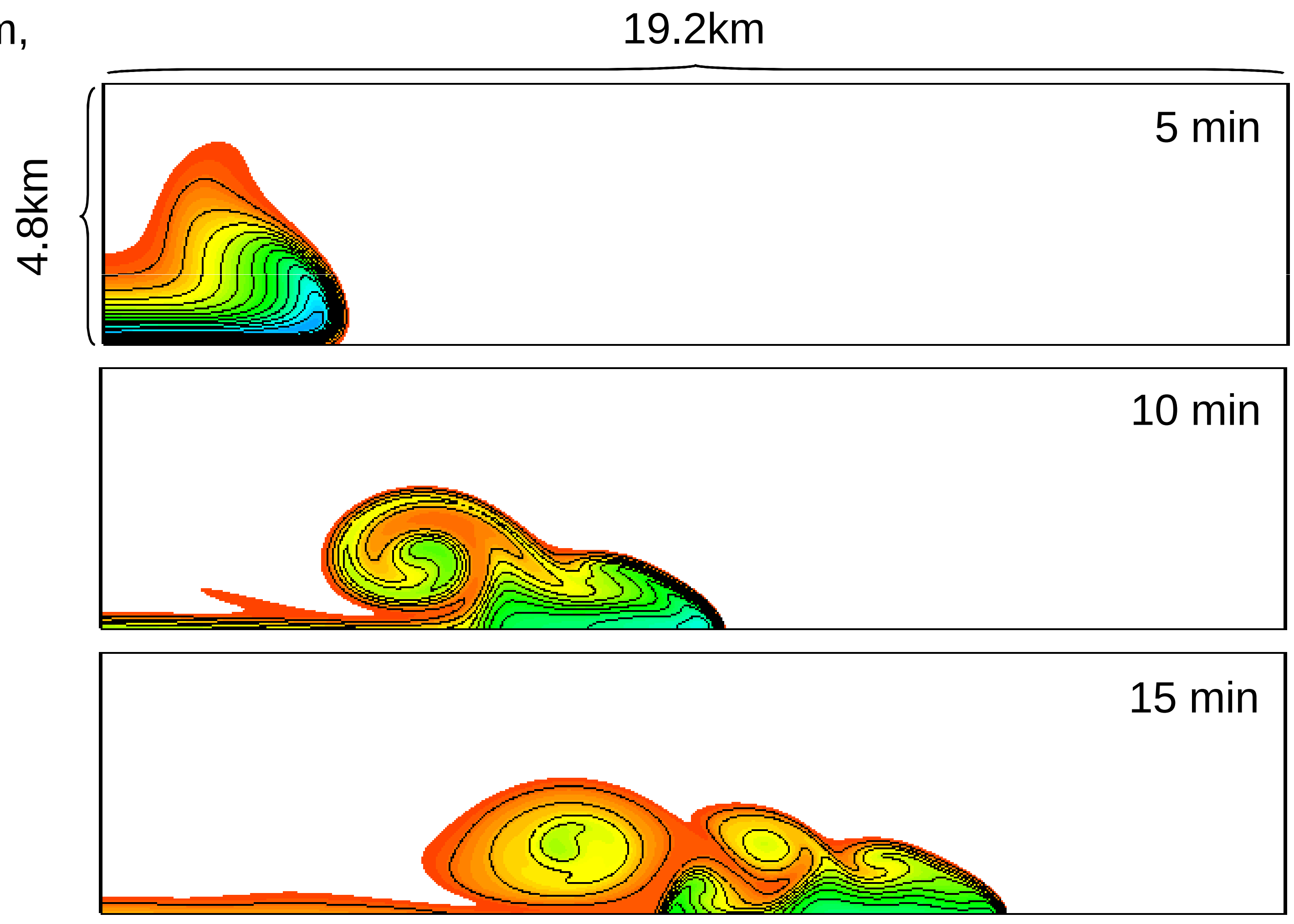
Density current experiment

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



Comparison of advection scheme