CDC Final report - EULAG branch

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Tests performed with EULAG stand-alone code

- ## Idealized tests – dry dynamics

✓ Inertia-gravity waves (Skamarock and Klemp, 1994)
✓ Cold density current (Straka et al., 1993)
✓ Bubble convection test (Robert, 1993)
✓ Mountain flow tests (Bonaventura, 2000)

Rosa et al. (2011)

- ## Idealized tests – moist processes

Evolution of a three-dimensional supercell over a flat terrain
✓ Klemp and Wilhelmson (1978)
✓ Weisman and Klemp (1982)

Kurowski et al. (2011)

- ## Semirealistic simulation of Alpine flows

✓ The semi-realistic frictionless and adiabatic flow over realistic steep Alpine topographies, employing horizontal grid sizes of 2.2, 1.1, and 0.55 km

Ziemiański et al. (2011)

✓ Study of summer Alpine convection on 12 July 2006 at resolution 1.1km

Tests performed with CE hybrid code

- Idealized tests – dry dynamics
  - ✓ Inertia-gravity waves (Skamarock and Klemp, 1994)
  - ✓ Cold density current (Straka et al., 1993)
  - ✓ Mountain flow tests (Bonaventura, 2000)

- Idealized tests – moist processes
  - ✓ Evolution of a moist bubble over a flat terrain

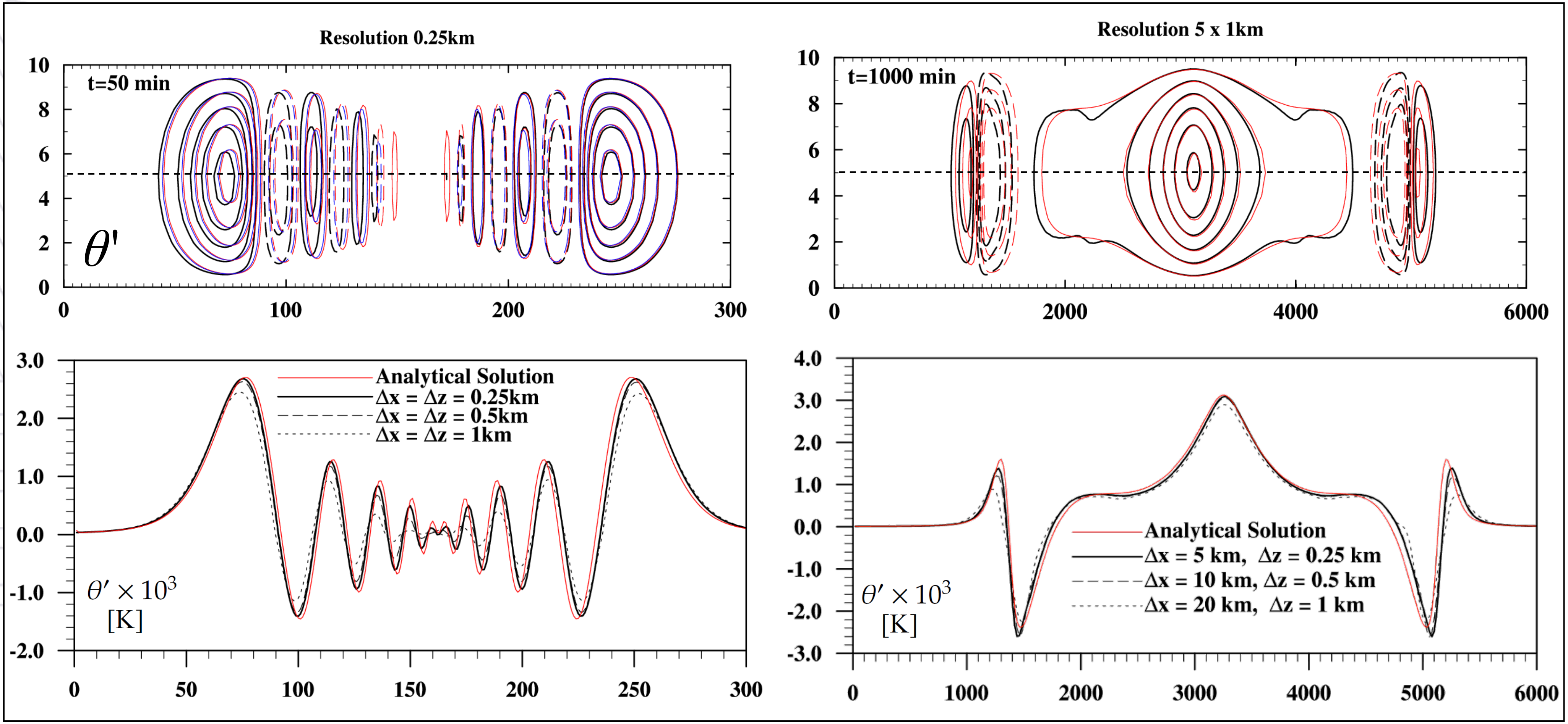
- Semi-realistic and realistic simulation of Alpine flows
  - ✓ The flow over realistic Alpine topographies employing:
    - horizontal grid size of 2.2 km, 1.1 km and 0.55 km (truncated domain)
    - viscous forces
    - surface drag
    - initial and boundary conditions and orography as for operational COSMO model for Switzerland
    - radiation
    - surface heat fluxes
    - moist processes

- A study on parallel performance of the EULAG F90/95 code Wójcik et al. (2011)

Two dimensional time dependent simulation of inertia-gravity waves

Skamarock W. C. and Klemp J. B. Efficiency and accuracy of Klemp-Wilhelmson time-splitting technique. *Mon. Wea. Rev.* **122**: 2623-2630, **1994**

C&E — Analytical — Eulag

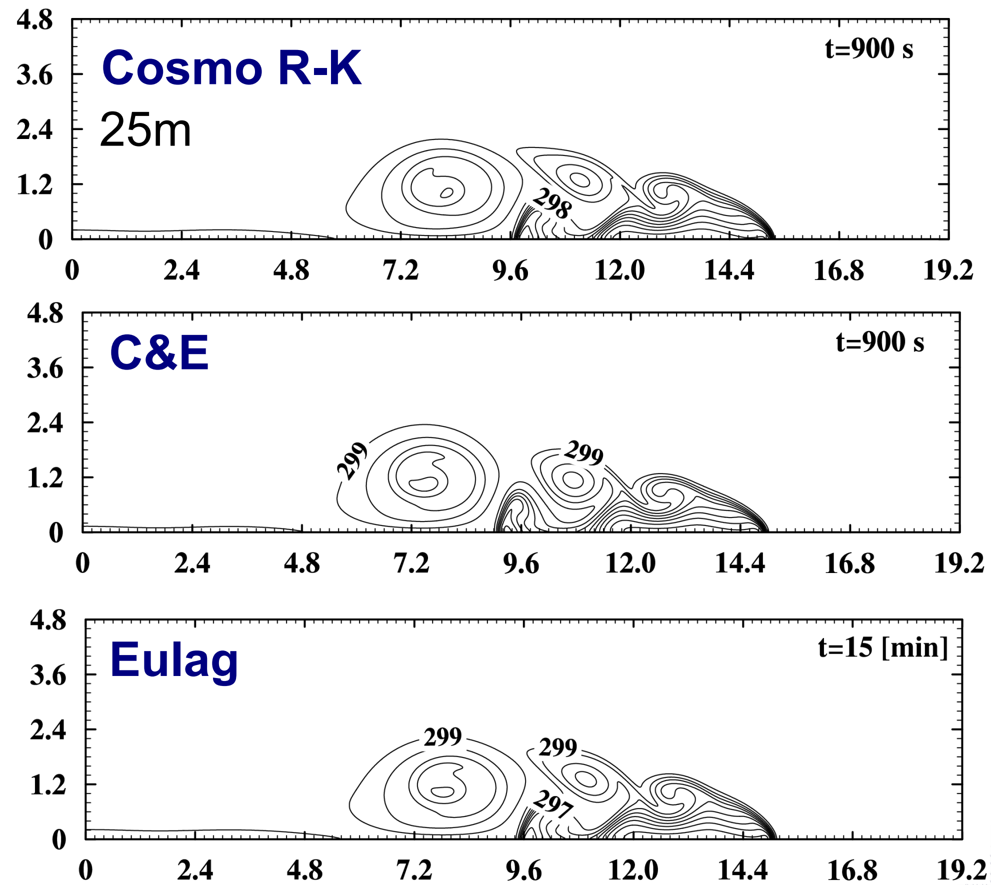


Two dimensional time dependent simulation of cold blob descending to the ground

Straka, J. M., Wilhelmson, Robert B., Wicker, Louis J., Anderson, John R., Droegemeier, Kelvin K., Numerical solutions of a non-linear density current: A benchmark solution and comparison *International Journal for Numerical Methods in Fluids*, **(17)**, 1993

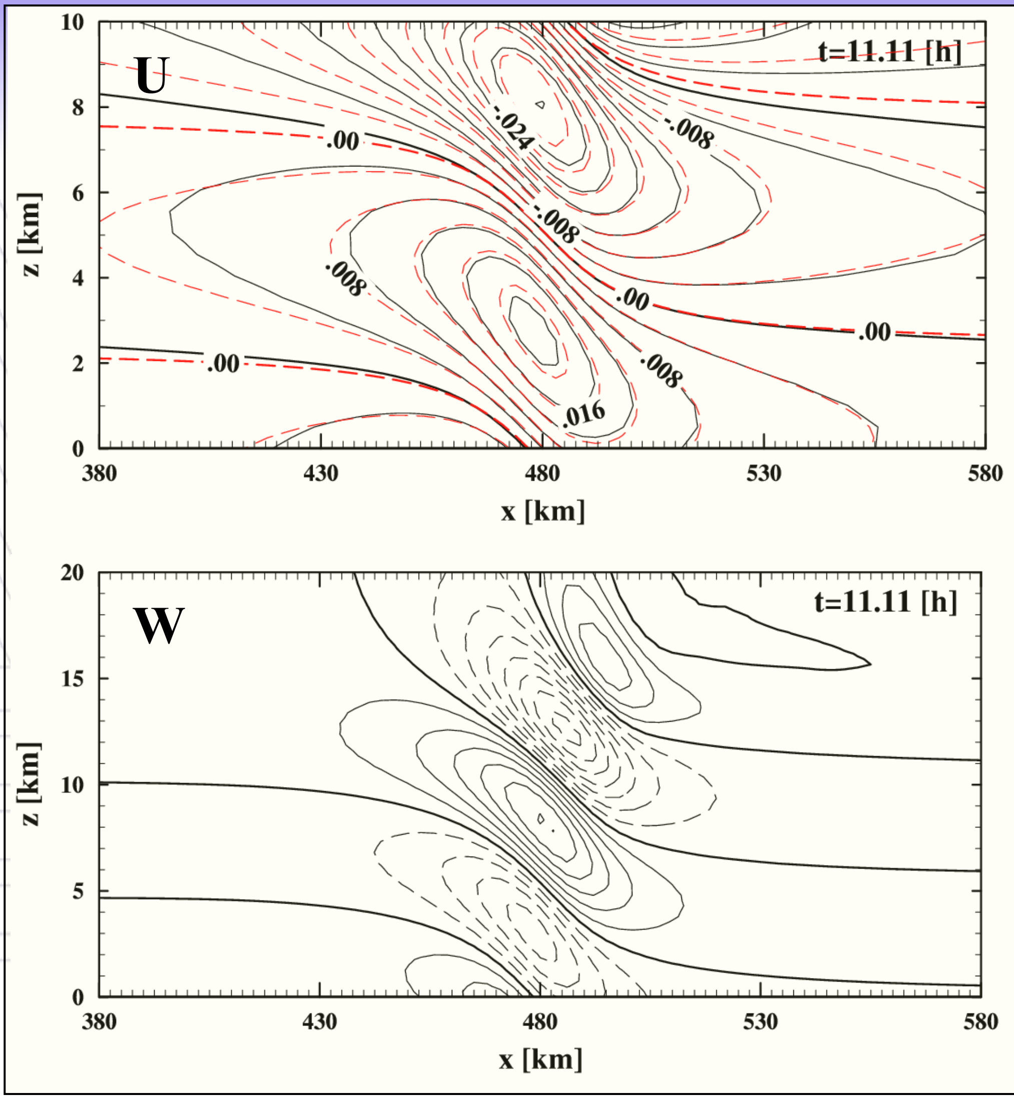
Experiment configuration:

- isentropic atmosphere, $\theta(z)$=const (300K)
- periodic lateral boundaries
- free-slip bottom b.c.
- **constant subgrid mixing, $K=75m^2/s$**
- domain size 51.2km x 6.4km
- bubble min. temperature -15K
- bubble size 8km × 4km
- no initial flow
- integration time 15 mins

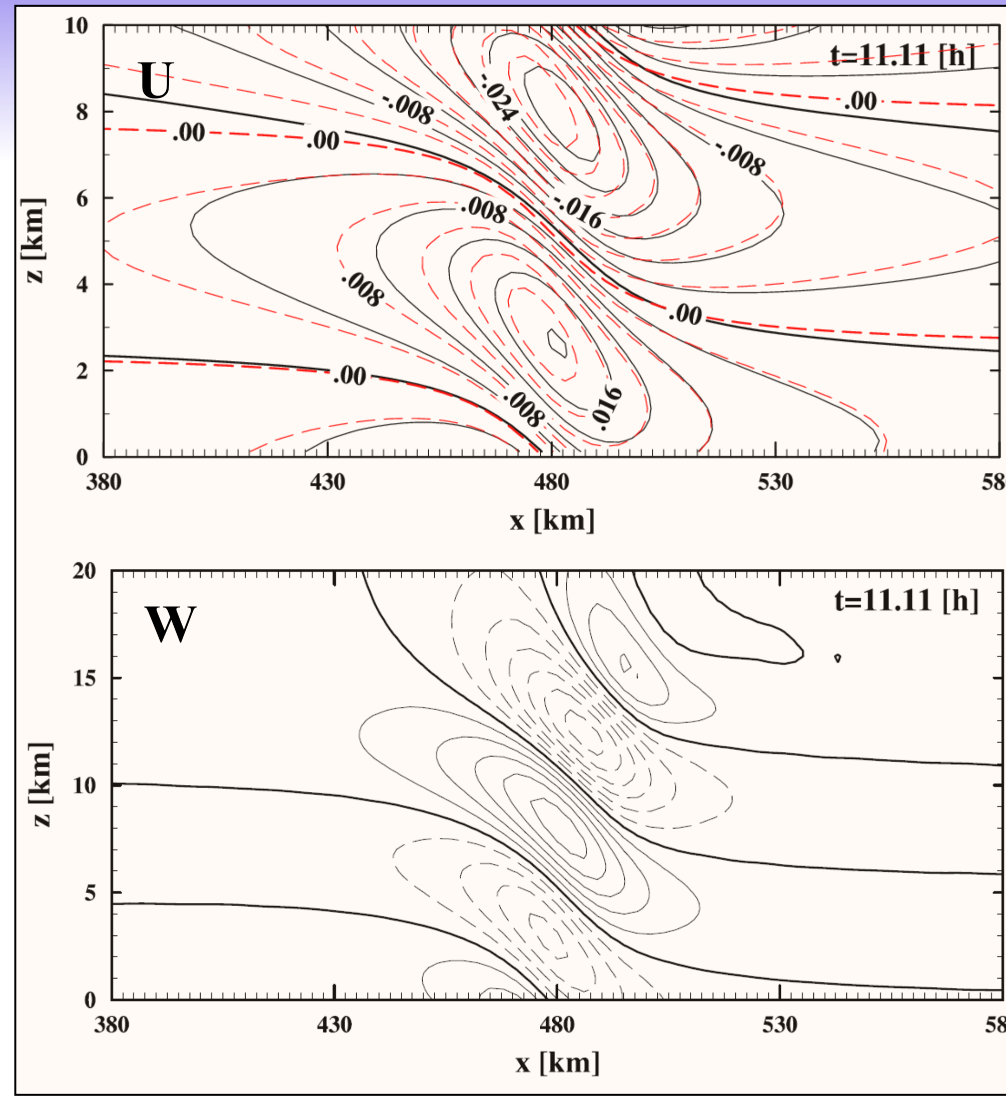


Flow over over mountain - linear hydrostatic regime

EULAG 2D



C&E 3D



Analytical solution in linear hydrostatic regime developed by Klemp and Lilly (JAS. 1978)

$$u(x,\theta) = N h_0 \gamma e^{C_p\theta/2R} \frac{\{\gamma x - (1 - C_p/2R)\}\cos\gamma\theta + \{\gamma + (1 - C_p/2R)x\}\sin\gamma\theta}{\{\gamma^2 + (1 - C_p/2R)^2\}x^2}$$

where $\gamma = \frac{\mathbf{g}}{N\bar{u}}$, $\theta = \ln(\vartheta/\vartheta_0)$, ϑ_0 is surface level potential temperature

CONCLUSIONS I

- EULAG has been successfully implemented into the COSMO model as the new conservative dynamical core.

- The new hybrid model CE has consistent setting of:
  - computational mesh
  - terrain following coordinates
  - Coriolis force
  - COSMO parameterizations (constant diffusion)

- Data communication between the dynamical core and parameterizations is carried out by a specially designed interface

- Results of the idealized tests obtained using the hybrid CE model are in good qualitative and quantitative agreement both with reference and analytical solutions.

Realistic Alpine flow

• Simulations have been performed for domains covering Alpine region

• Three computational meshes with different horizontal resolutions have been used
  - standard domain with 496 × 336 × 61 grid points and horizontal resolution of 2.2 km (similar to COSMO 2 of MeteoSwiss)
  - the same as in COSMO 2 but with resolution 1.1 km in horizontal plane
  - truncated COSMO 2 domain (south-eastern part) with 0.55 km in horizontal resolution

• Initial and boundary conditions and orography from COSMO model of MeteoSwiss. Simulation with the finest resolution has separately calculated unfiltered orography.

• TKE parameterization of sub-scale turbulence and friction (COSMO diffusion-turbulence model)

• Heat diffusion and fluxes turned on

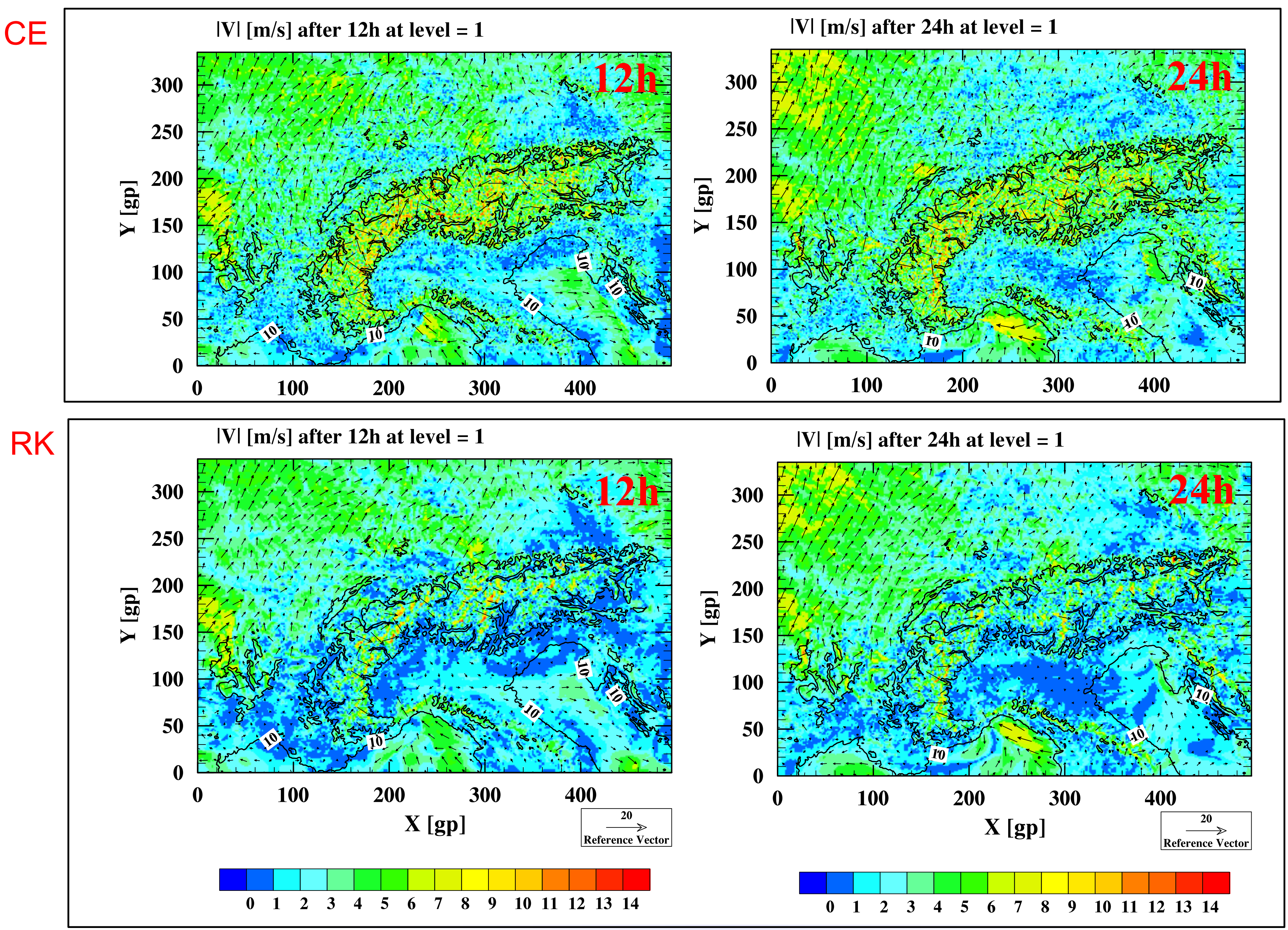
• Moist processes switched on

• Radiation switched on (*Ritter and Geleyn MWR 1992*)

• Simulation start at 00:00 UTC (midnight), 12 November 2009

• Results are compared with Runge-Kutta dynamical core

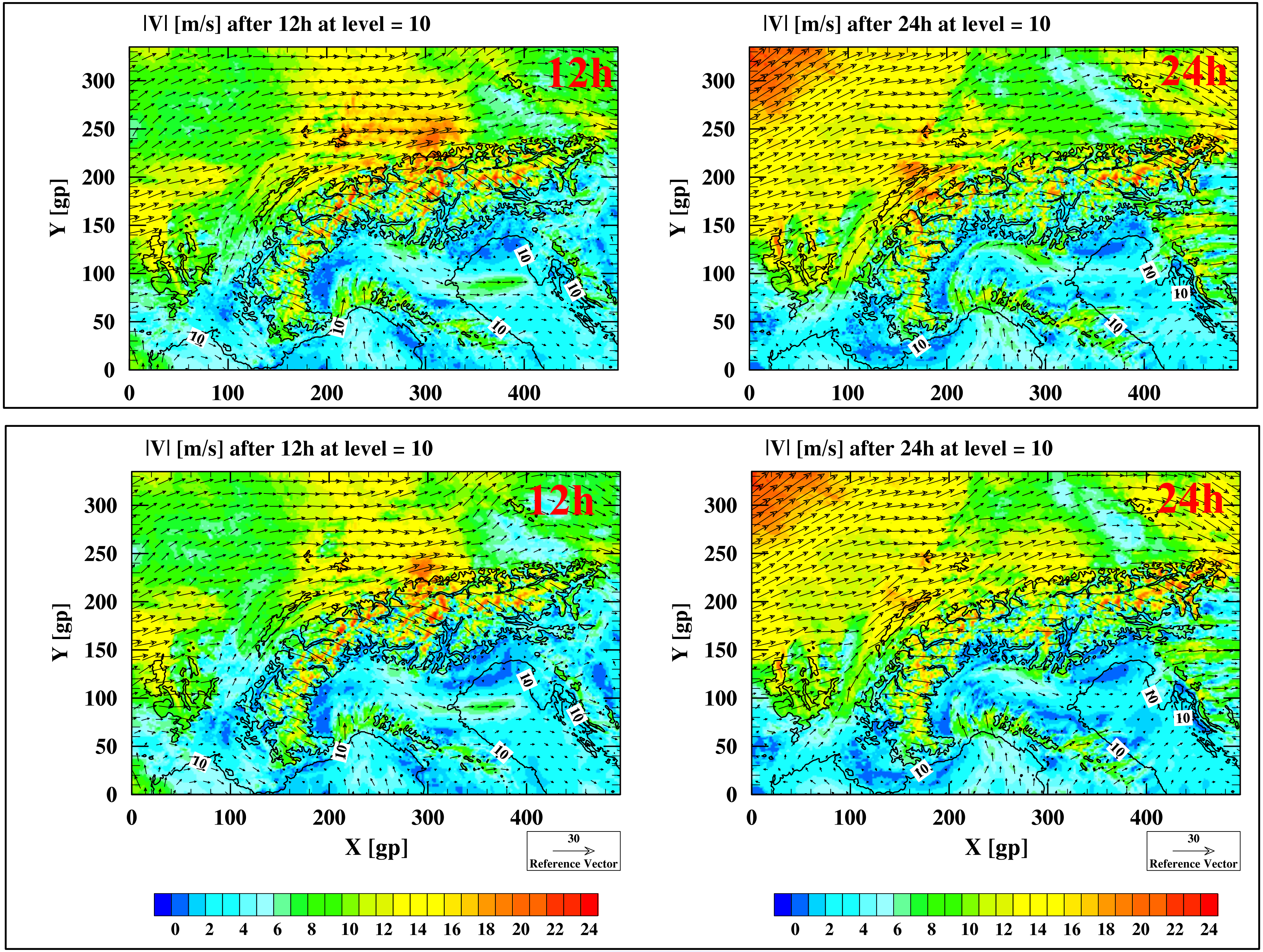
Horizontal velocity at 10m



Horizontal velocity at 500 m

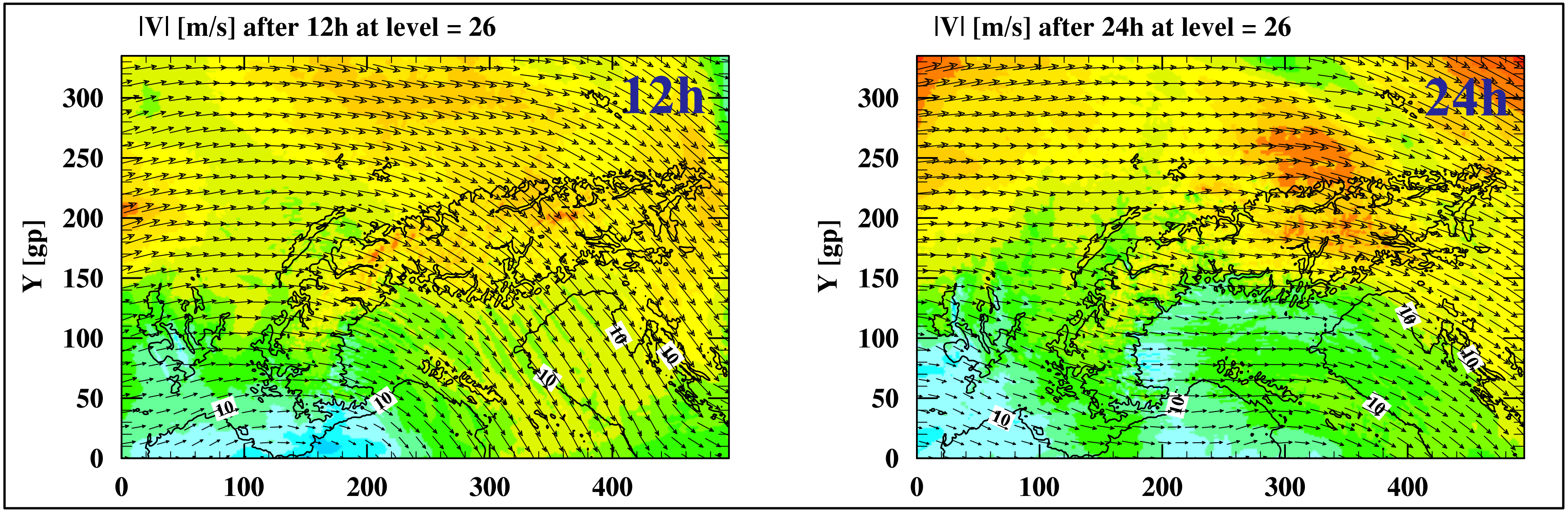
CE

RK

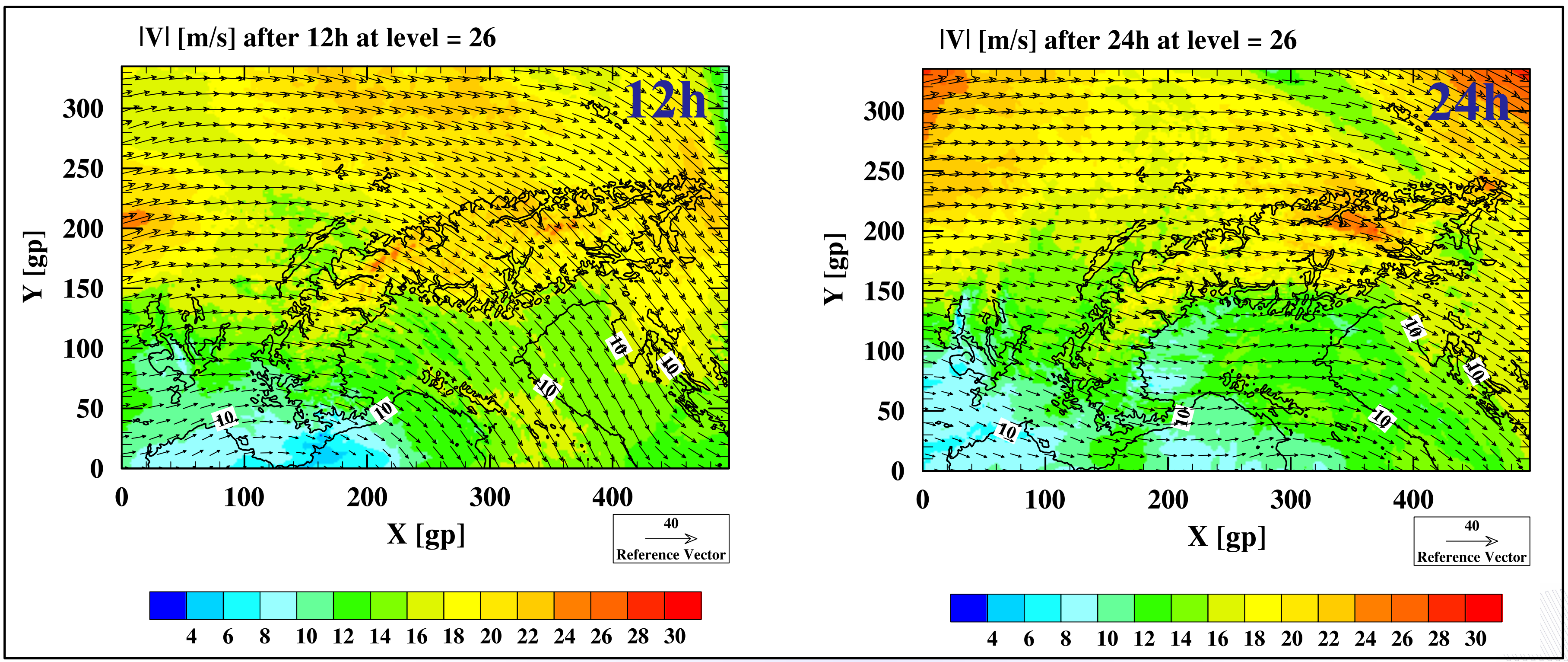


Horizontal velocity at 4.5km

CE

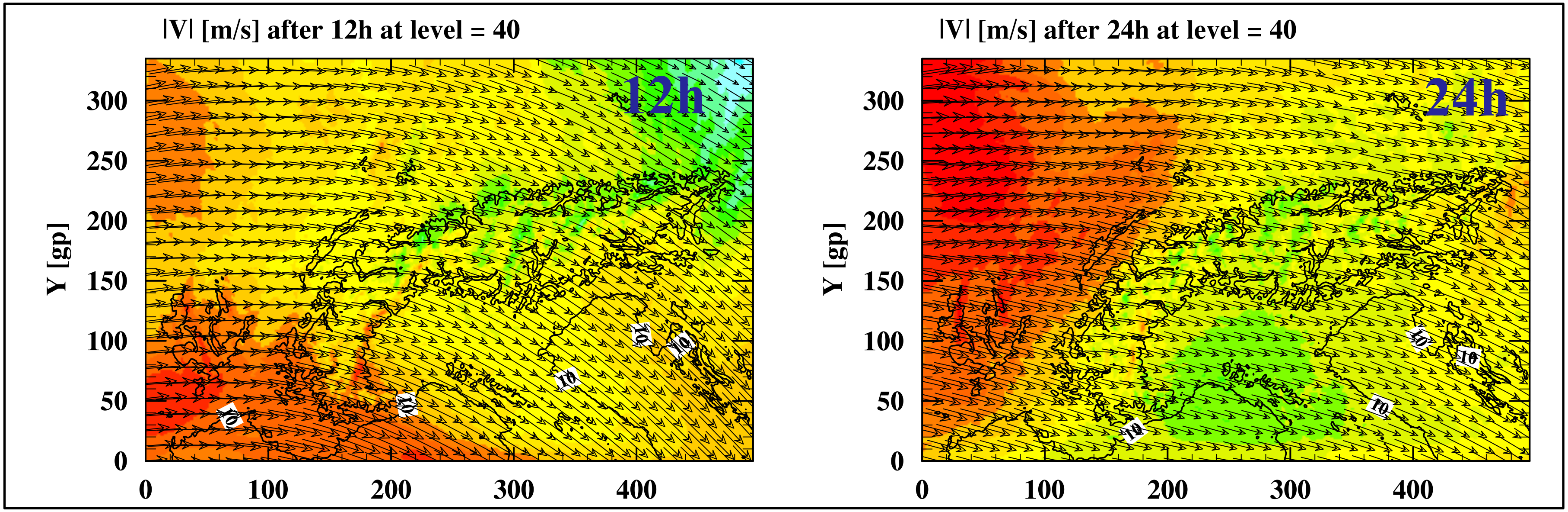


RK

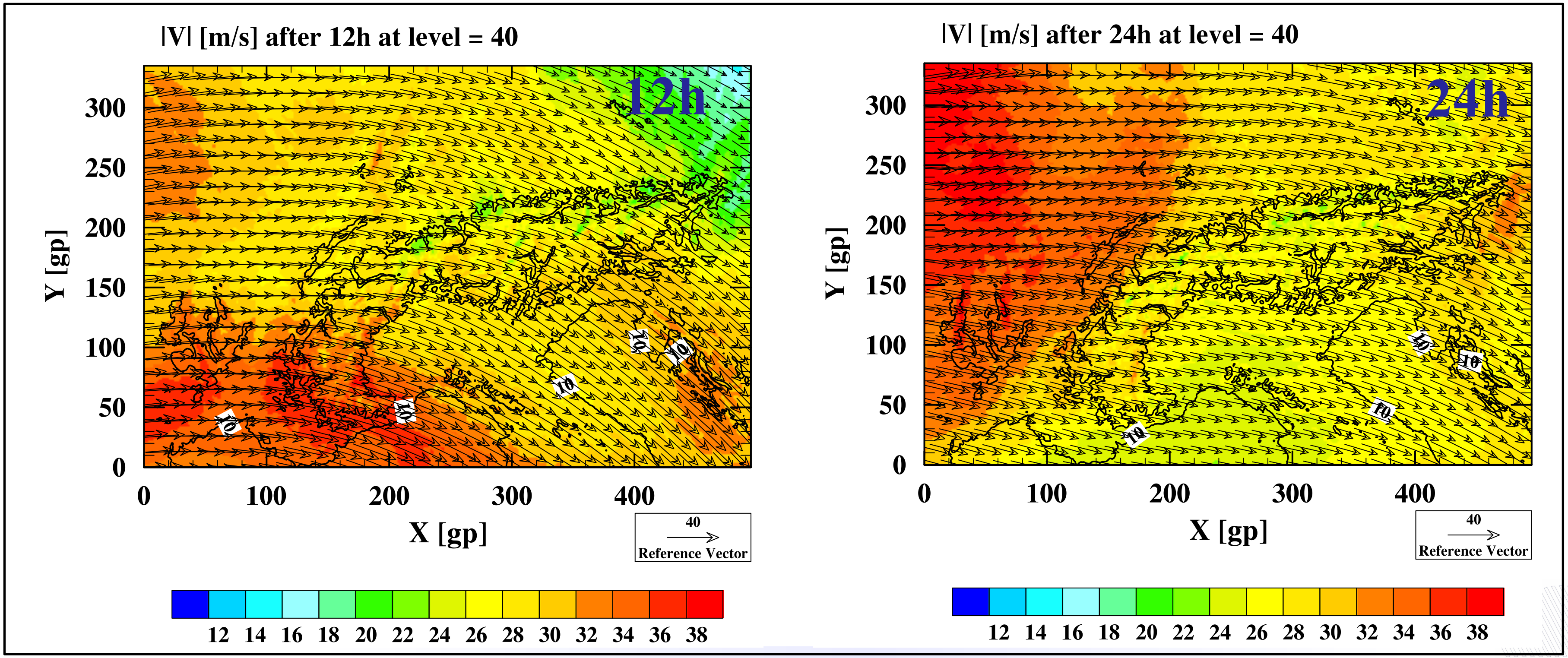


Horizontal velocity at 10km

CE

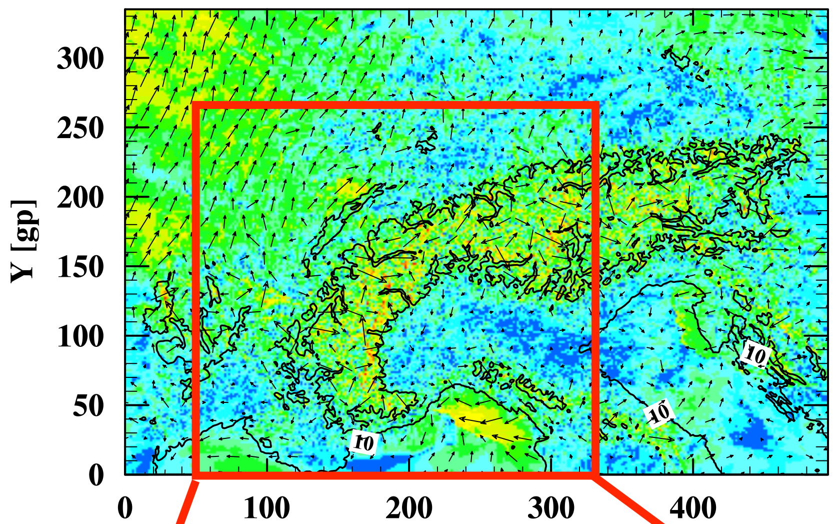


RK

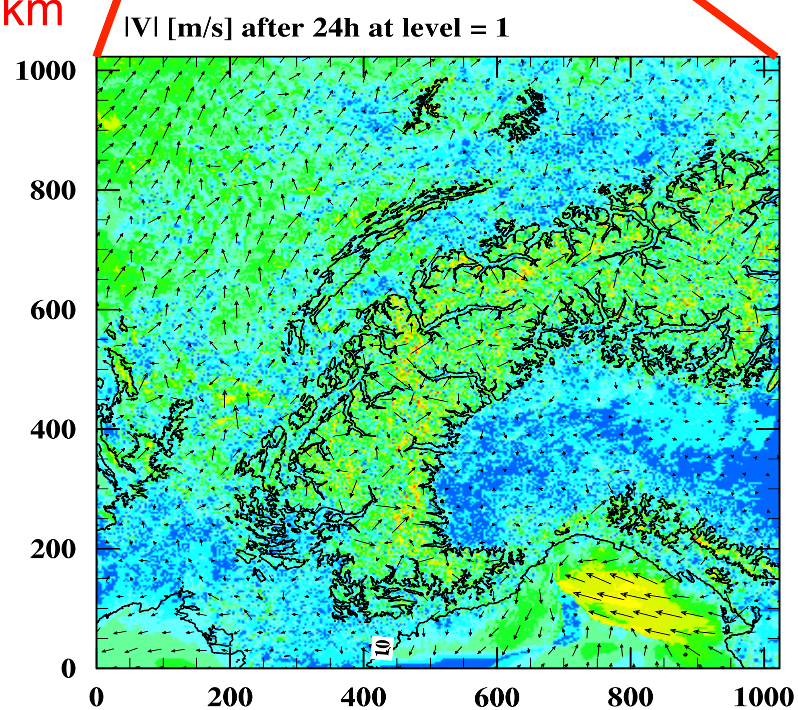


Horizontal velocity at 10m

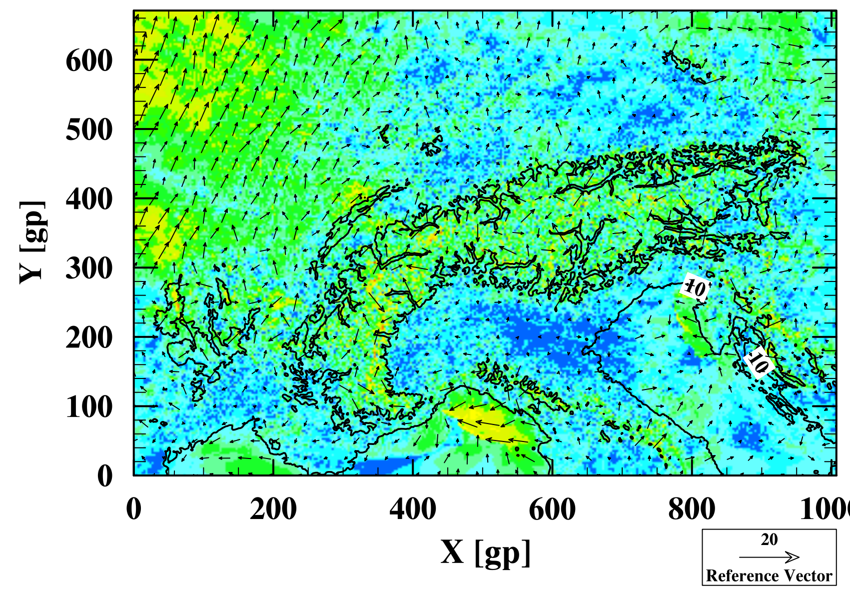
2.2 km

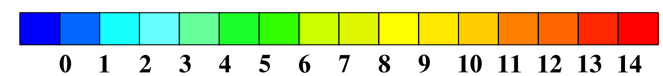


0.55 km



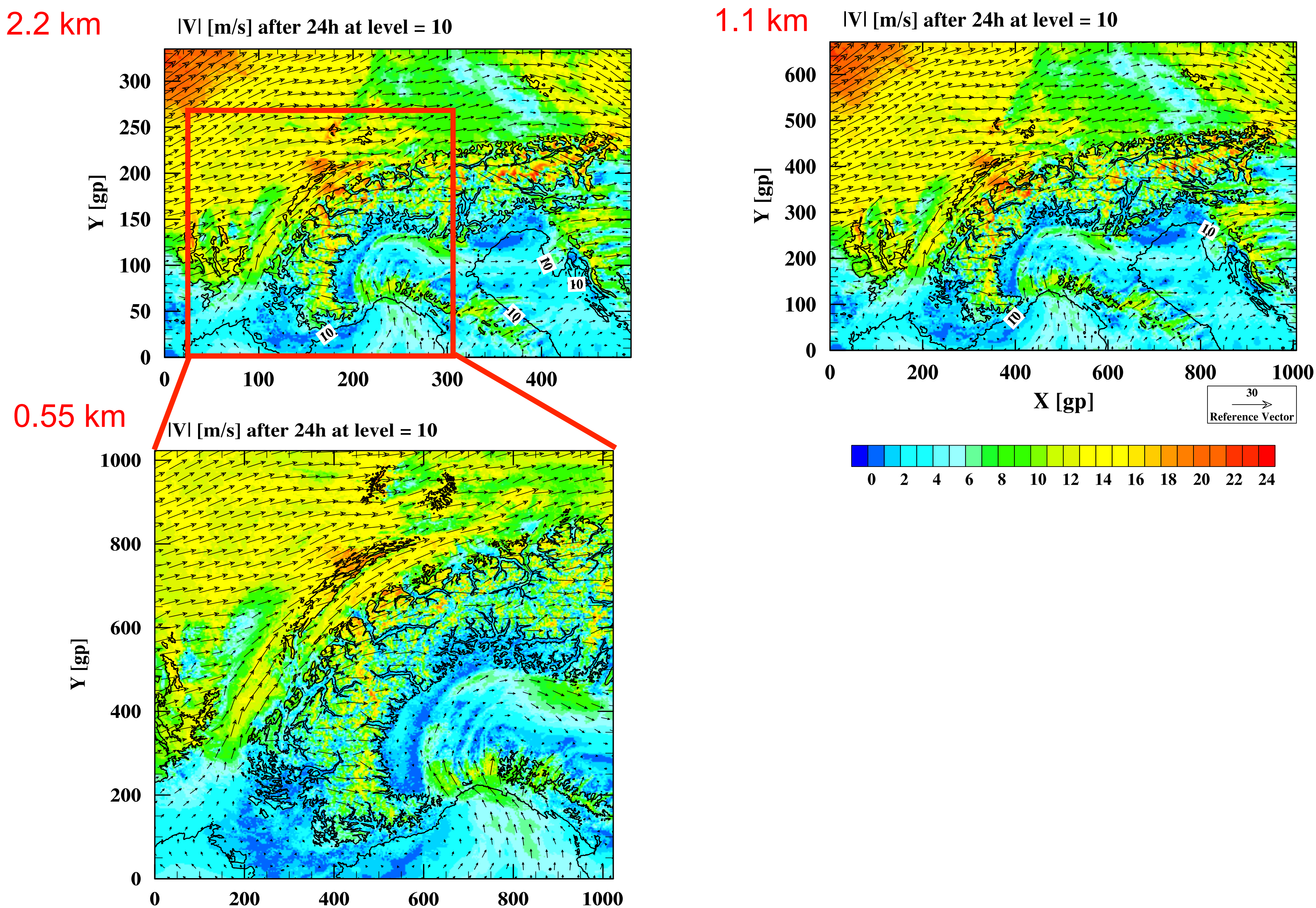
1.1 km





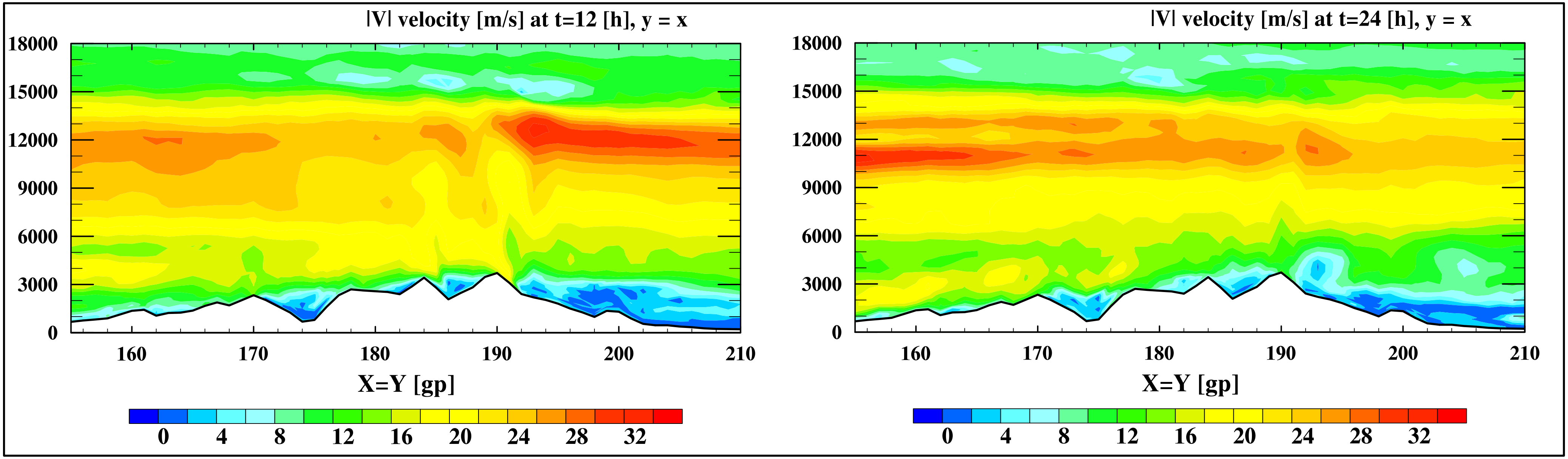
Comparison of CE solutions
for three different resolutions:
2.2 -> 1.1 -> 0.55 km

Horizontal velocity at 500m

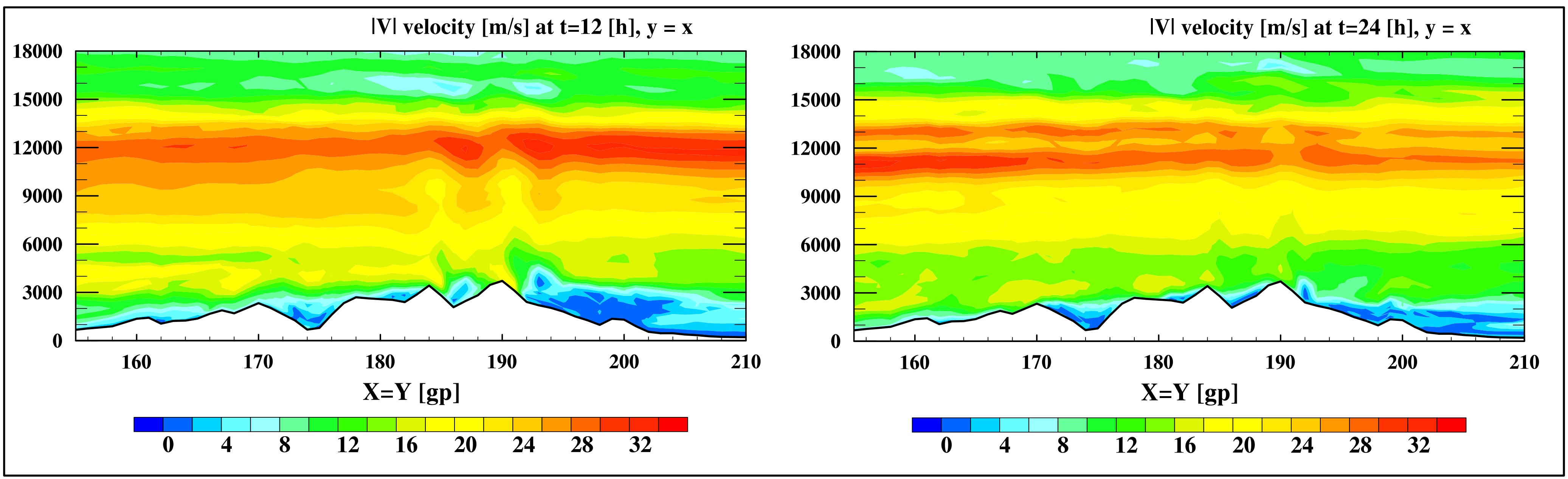


Horizontal velocity : Mont Blanc

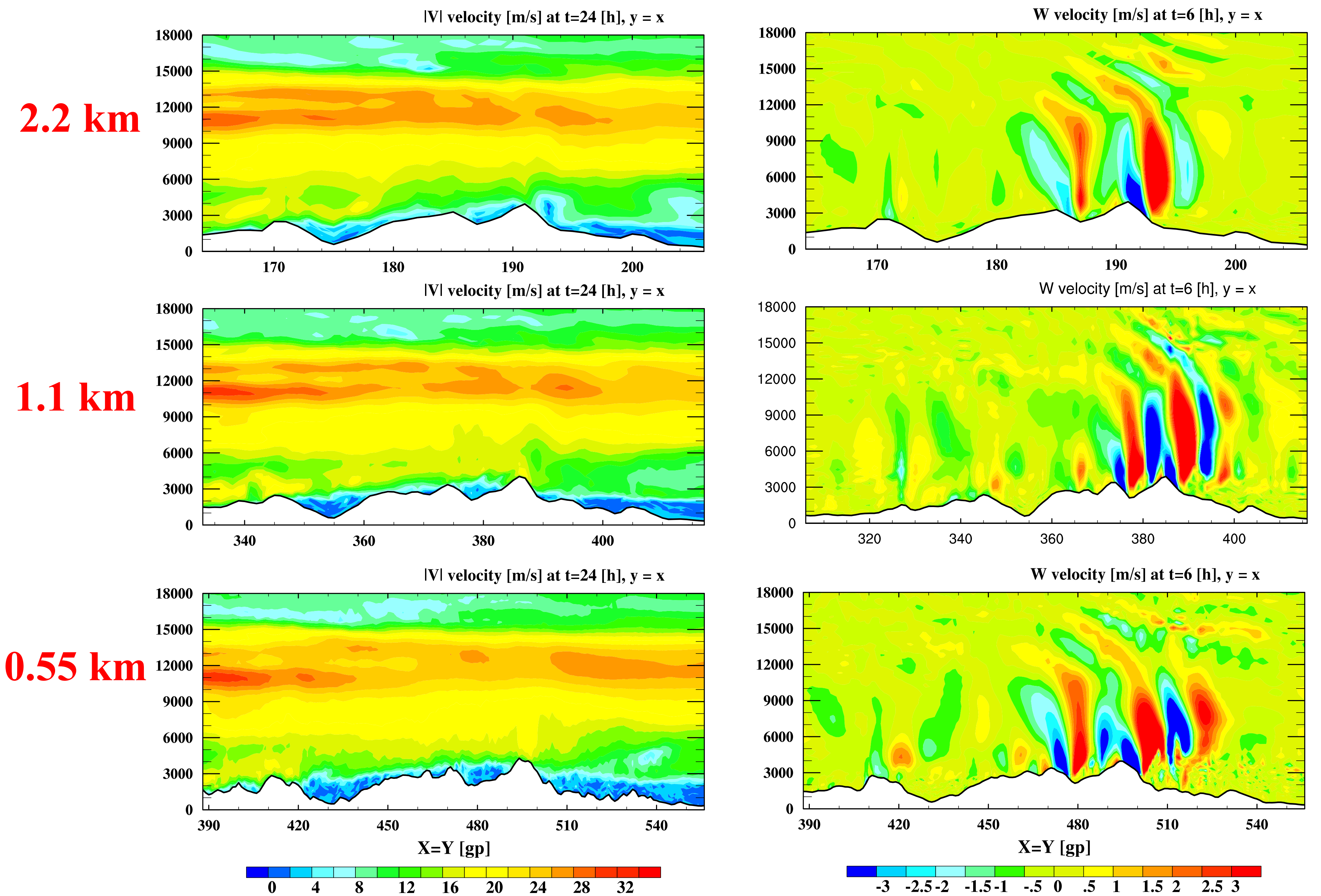
CE



R-K

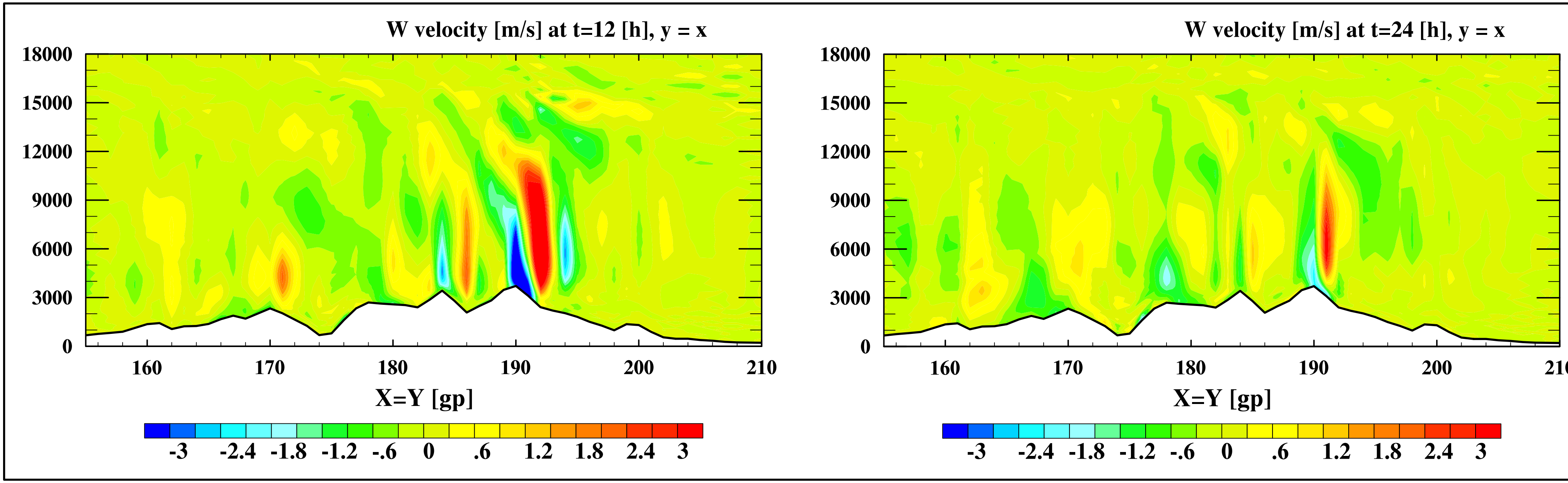


CE - horizontal and vertical velocity over Mont Blanc

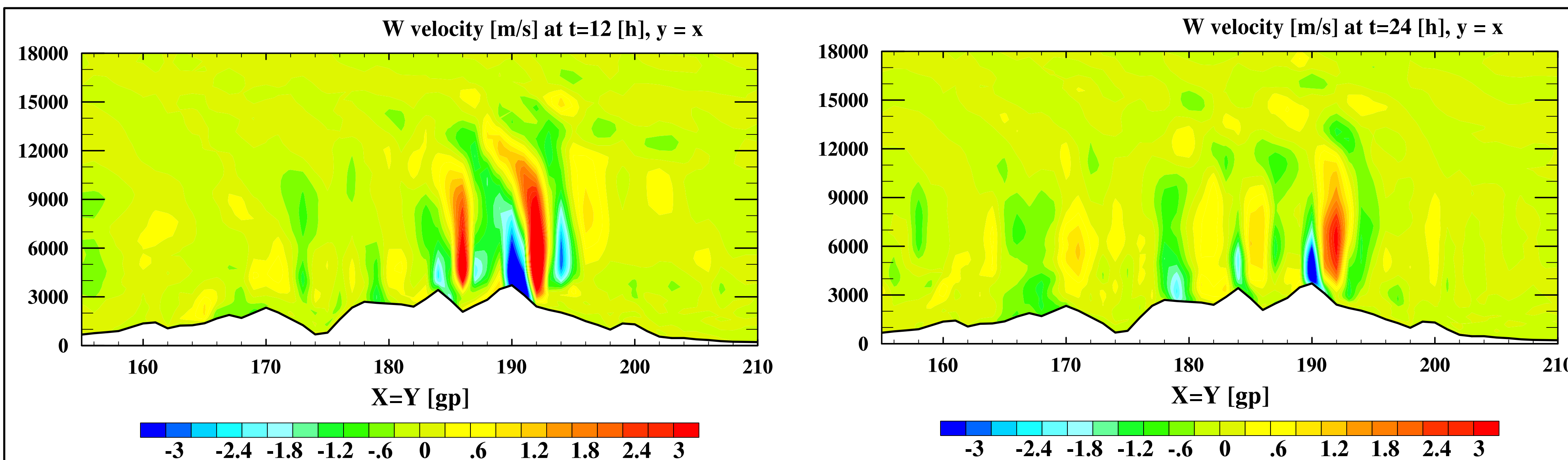


Vertical velocity

CE



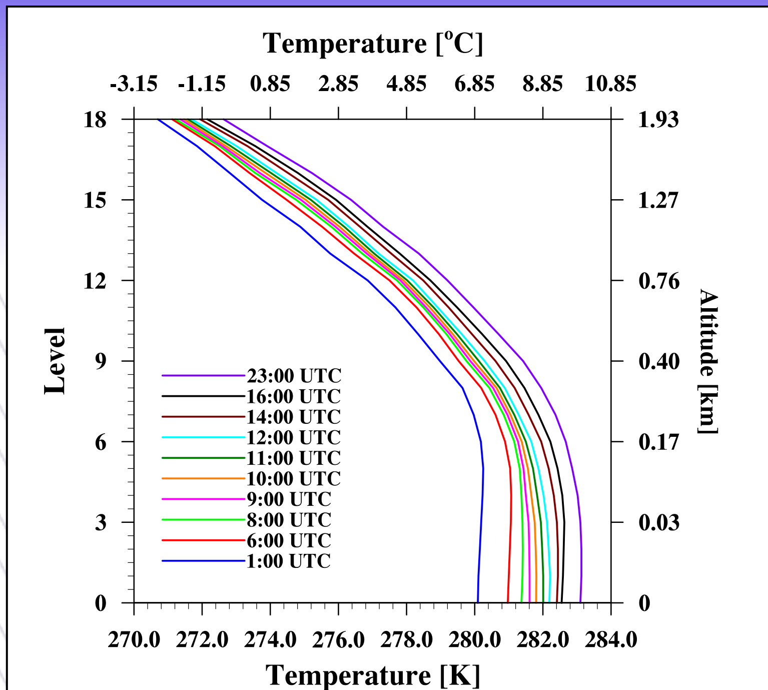
R-K

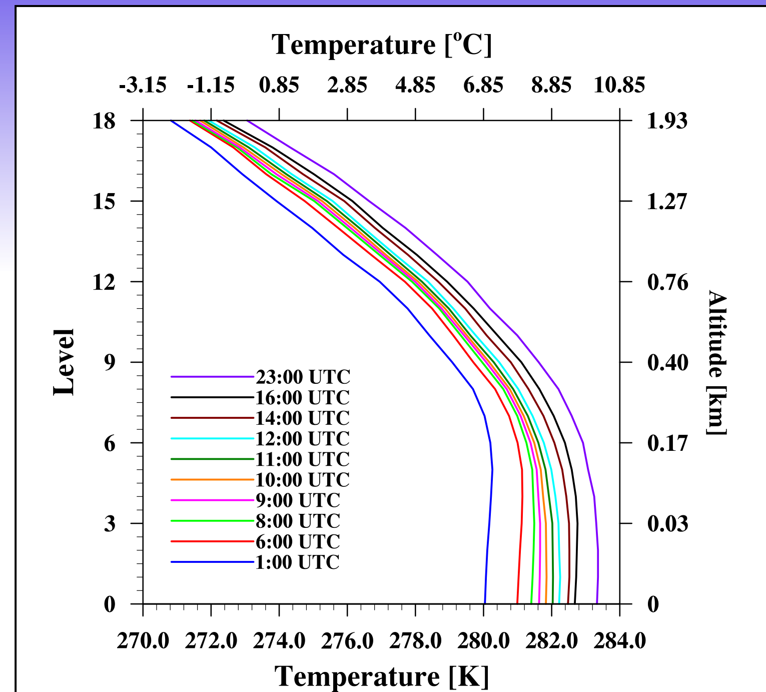


COSMO-RK 2.2 km

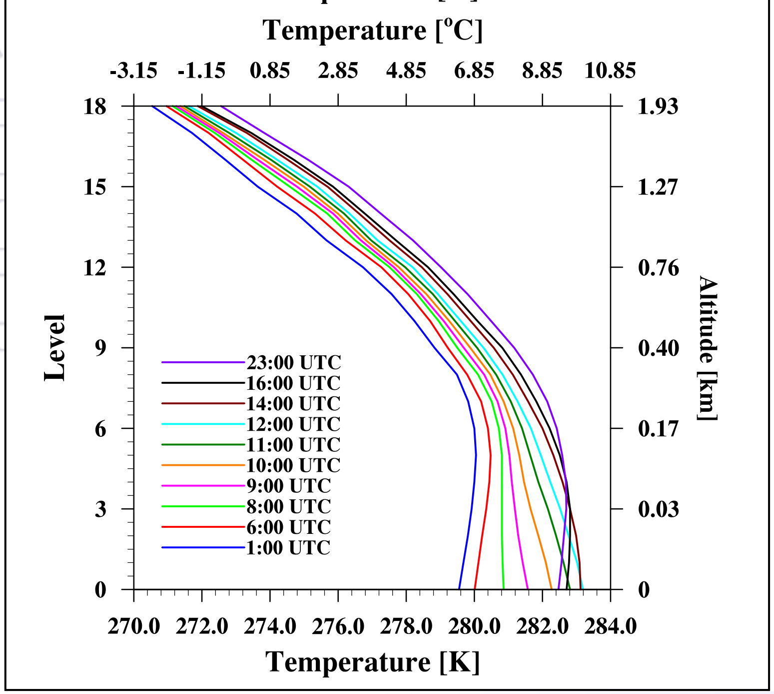
CE 2.2 km

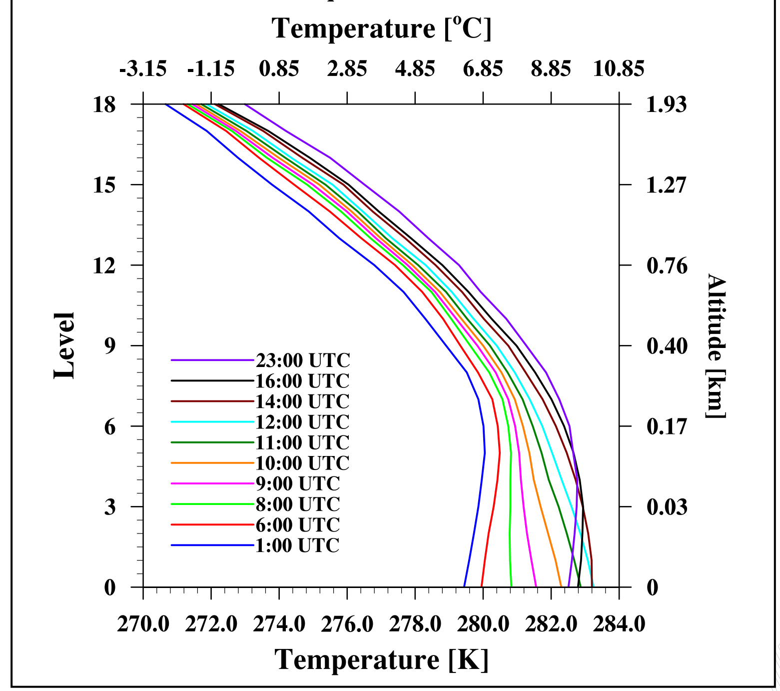
NO RADIATION



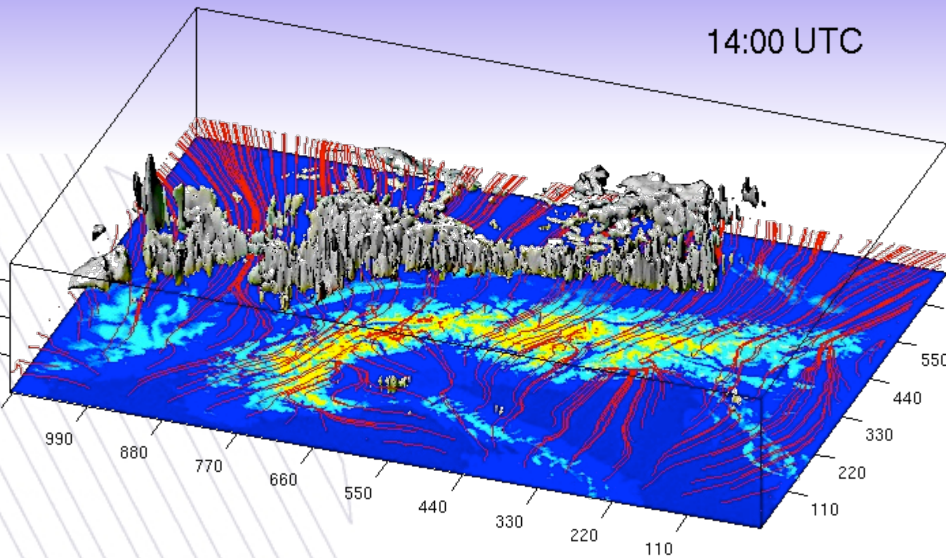


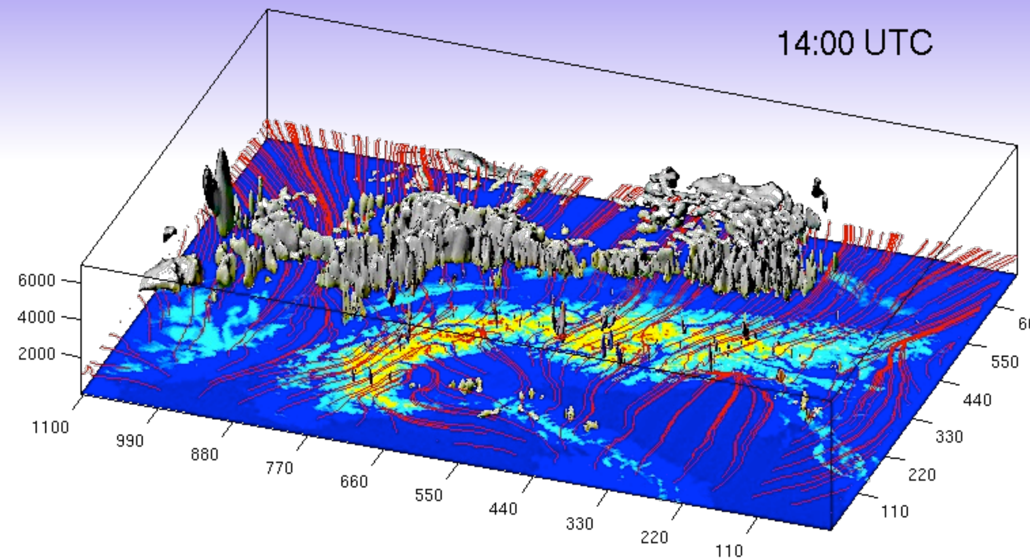
WITH RADIATION

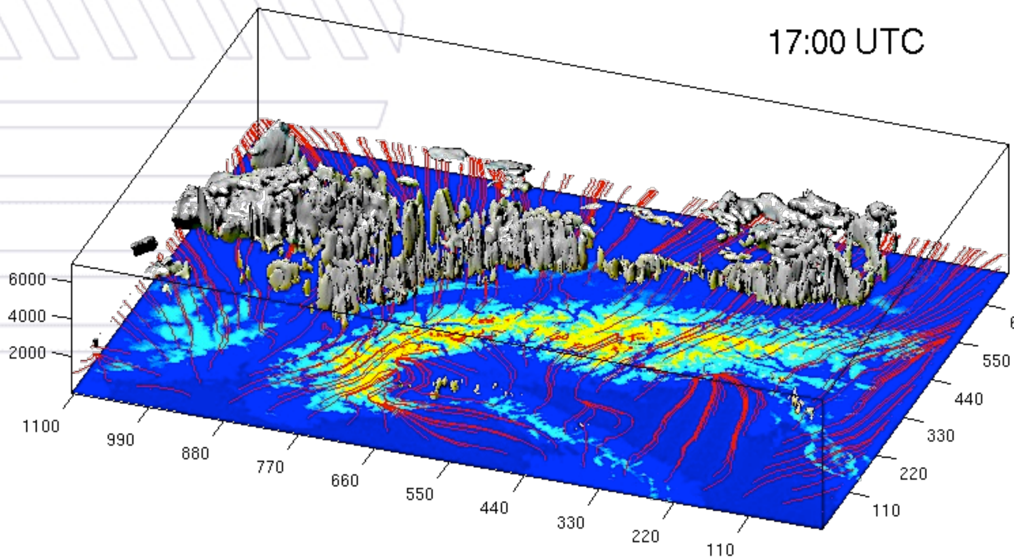


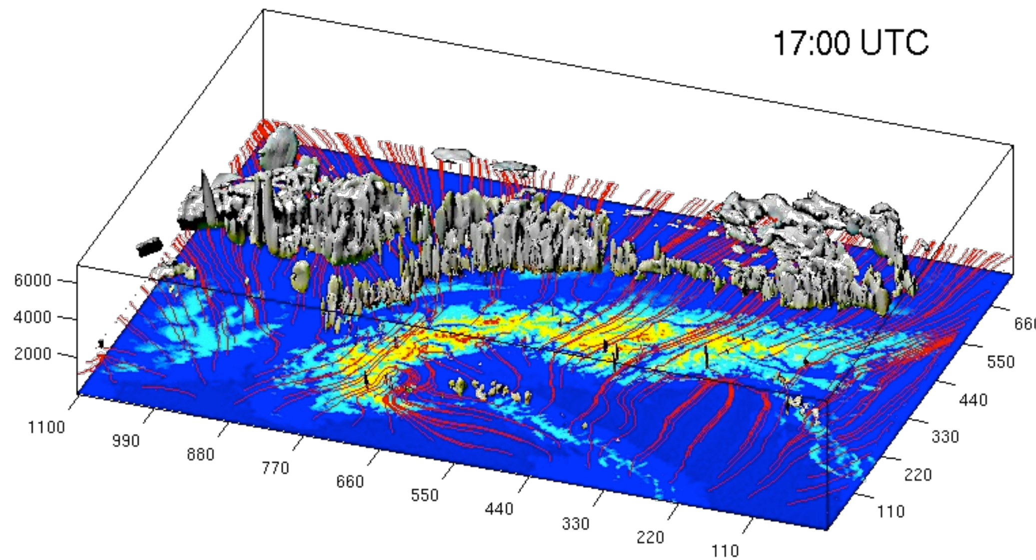


R-K 2.2 km CE 2.2 km



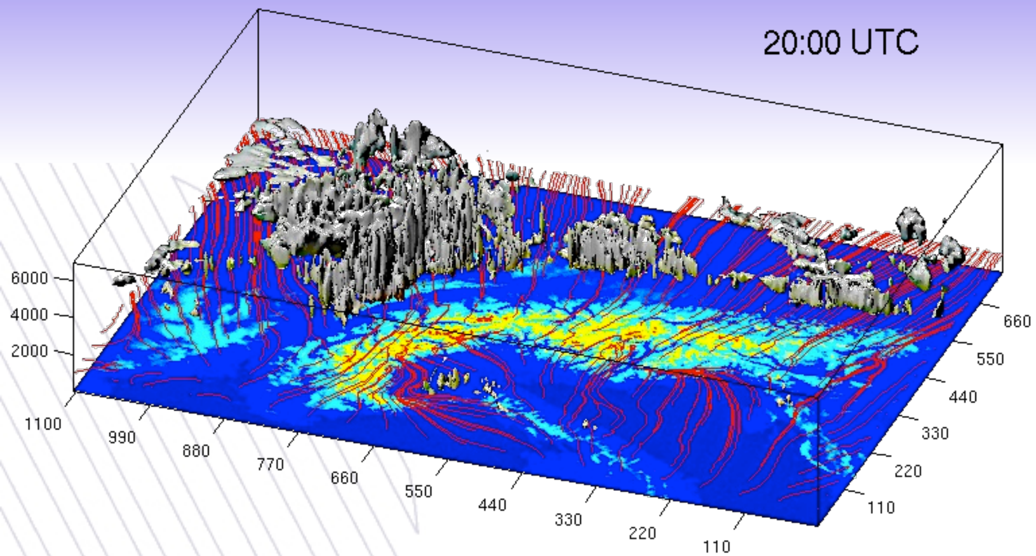


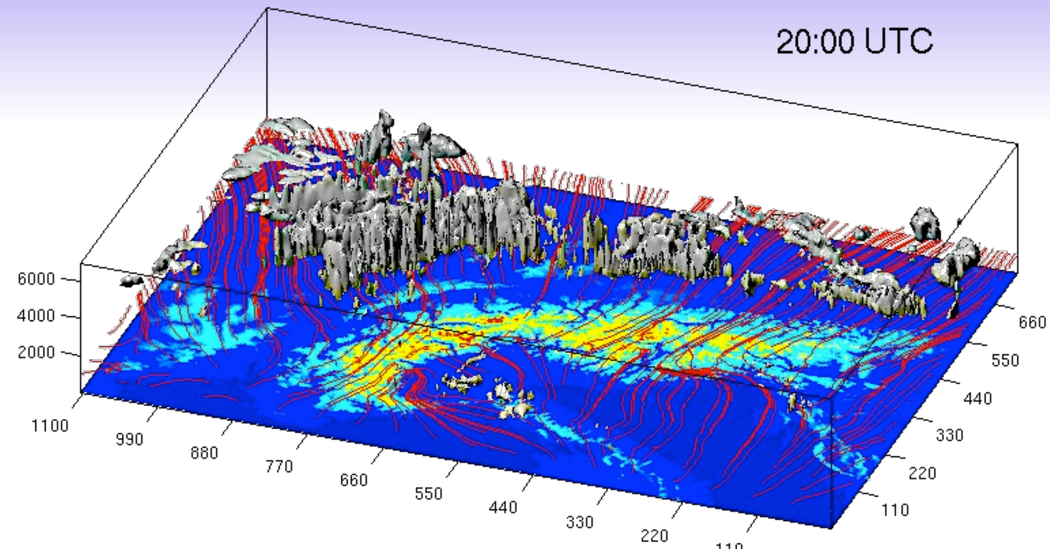


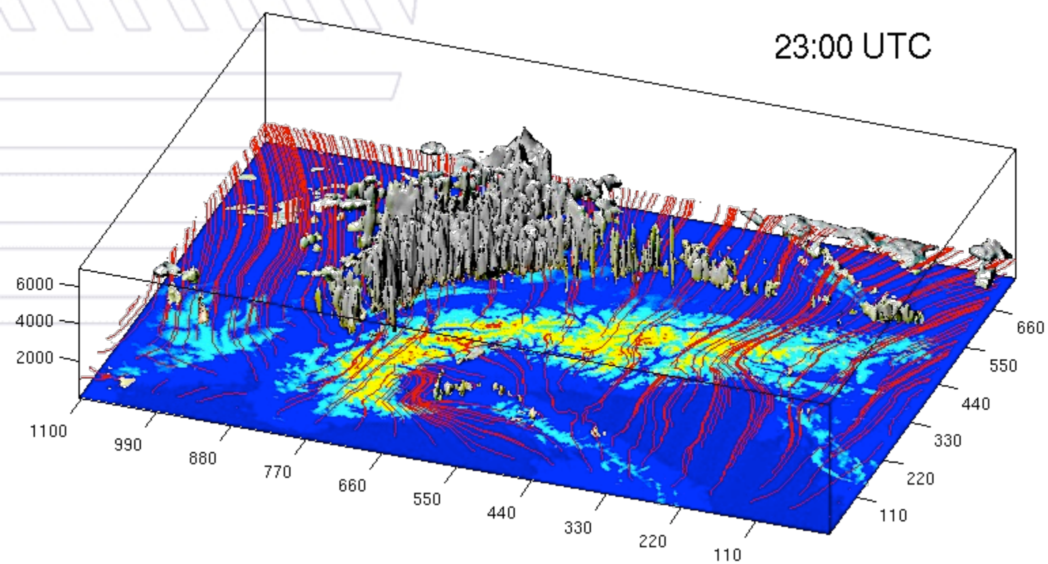


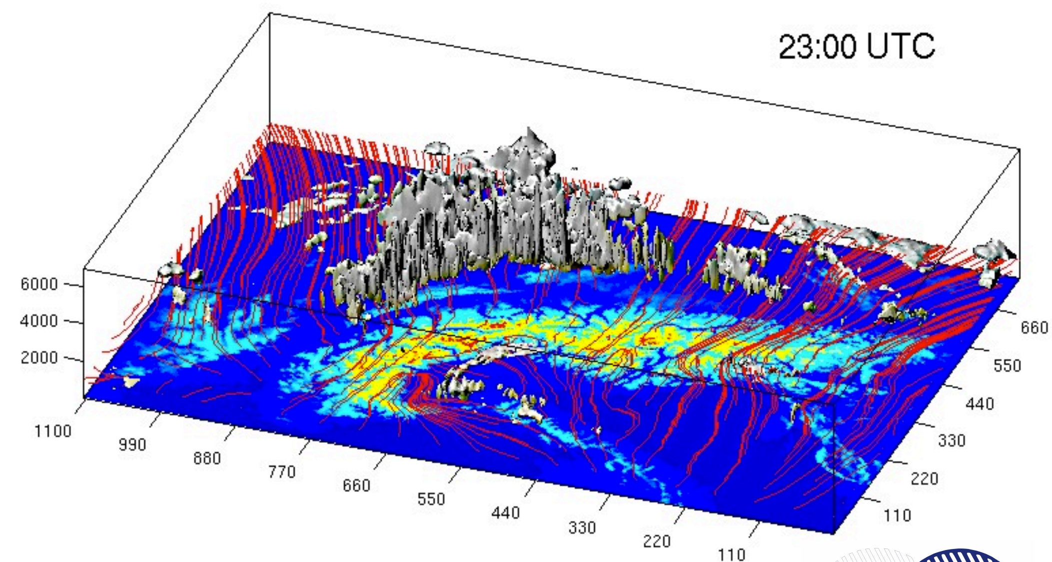
RADIATION switched on

R-K 2.2 km　　　　CE 2.2 km

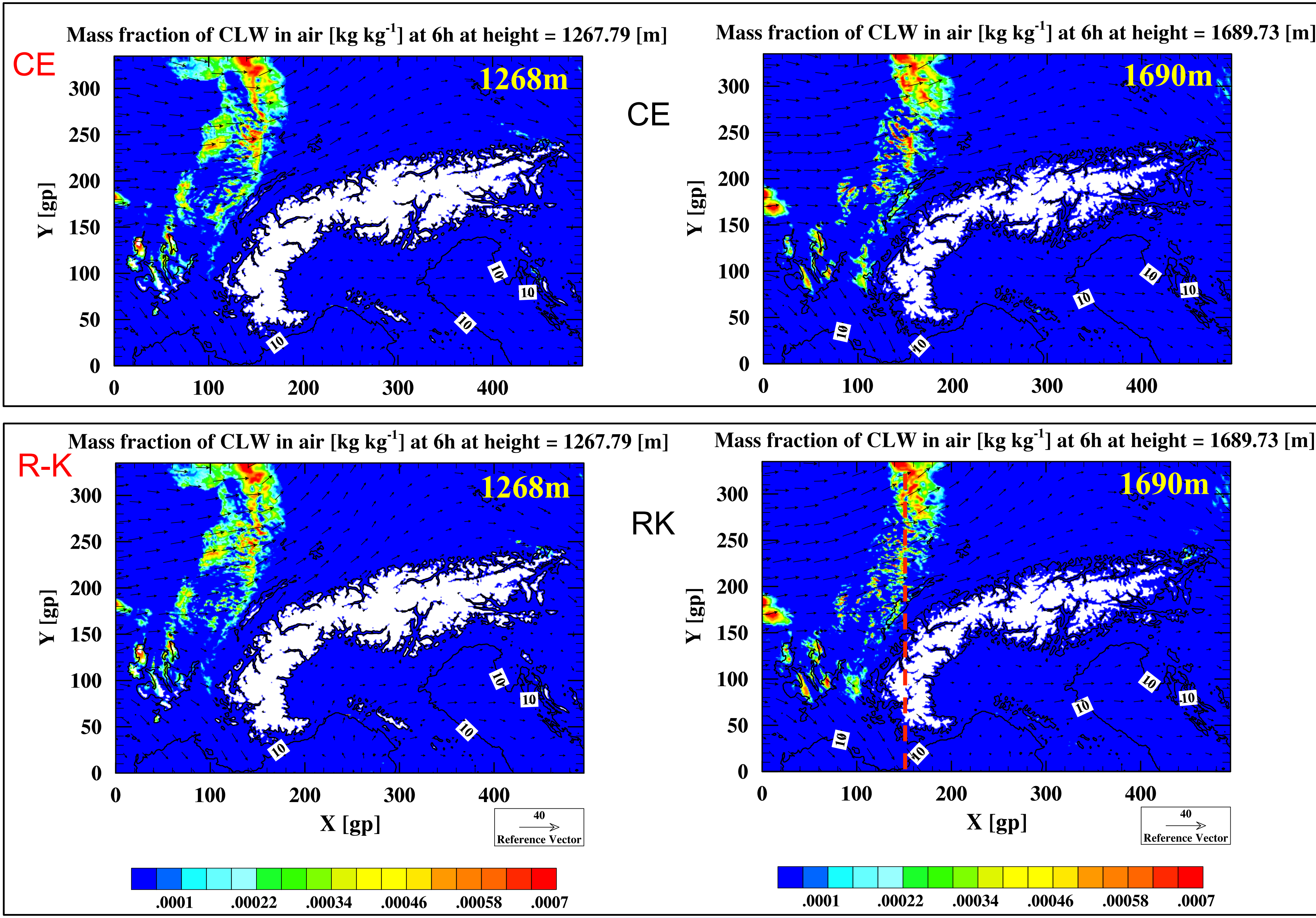




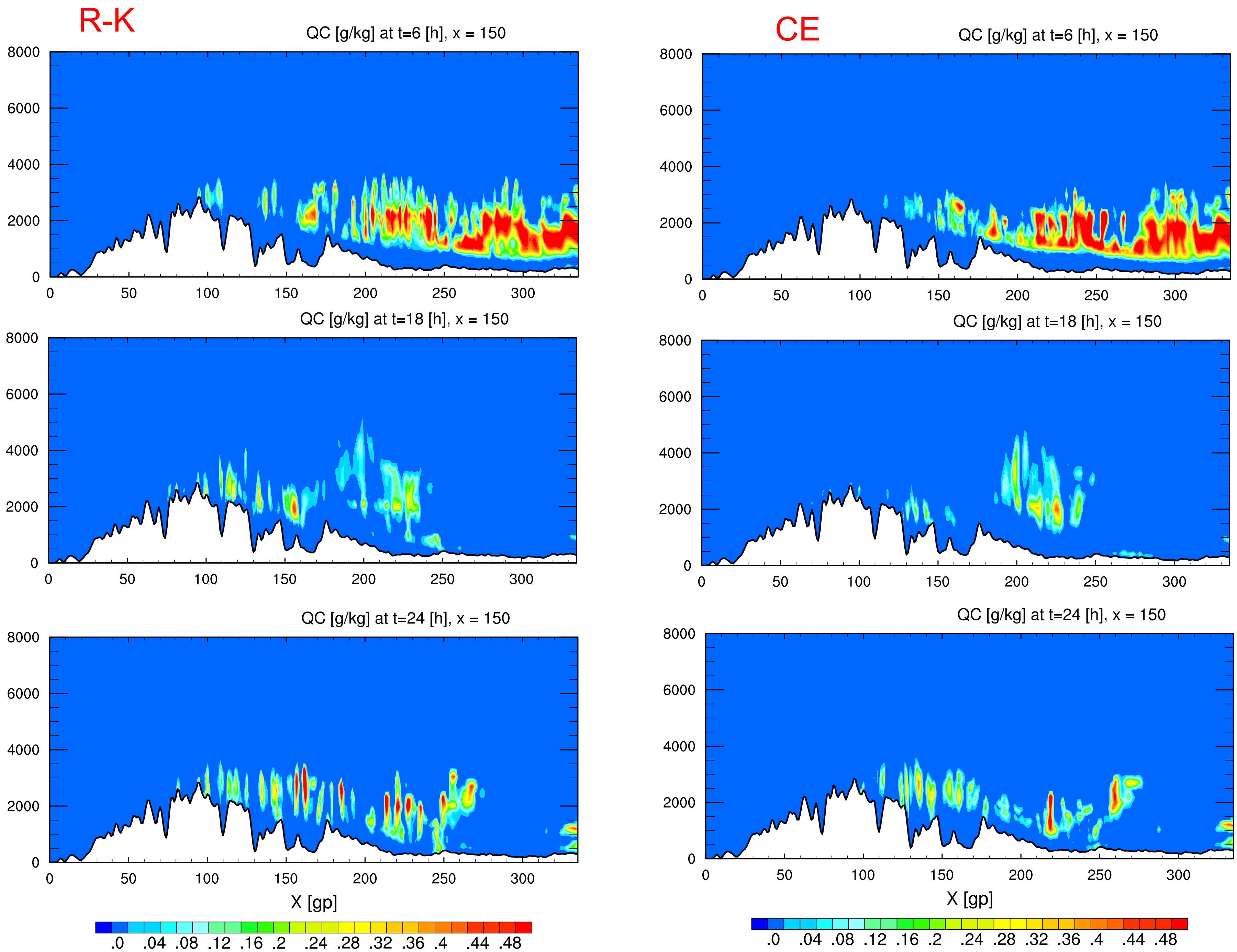




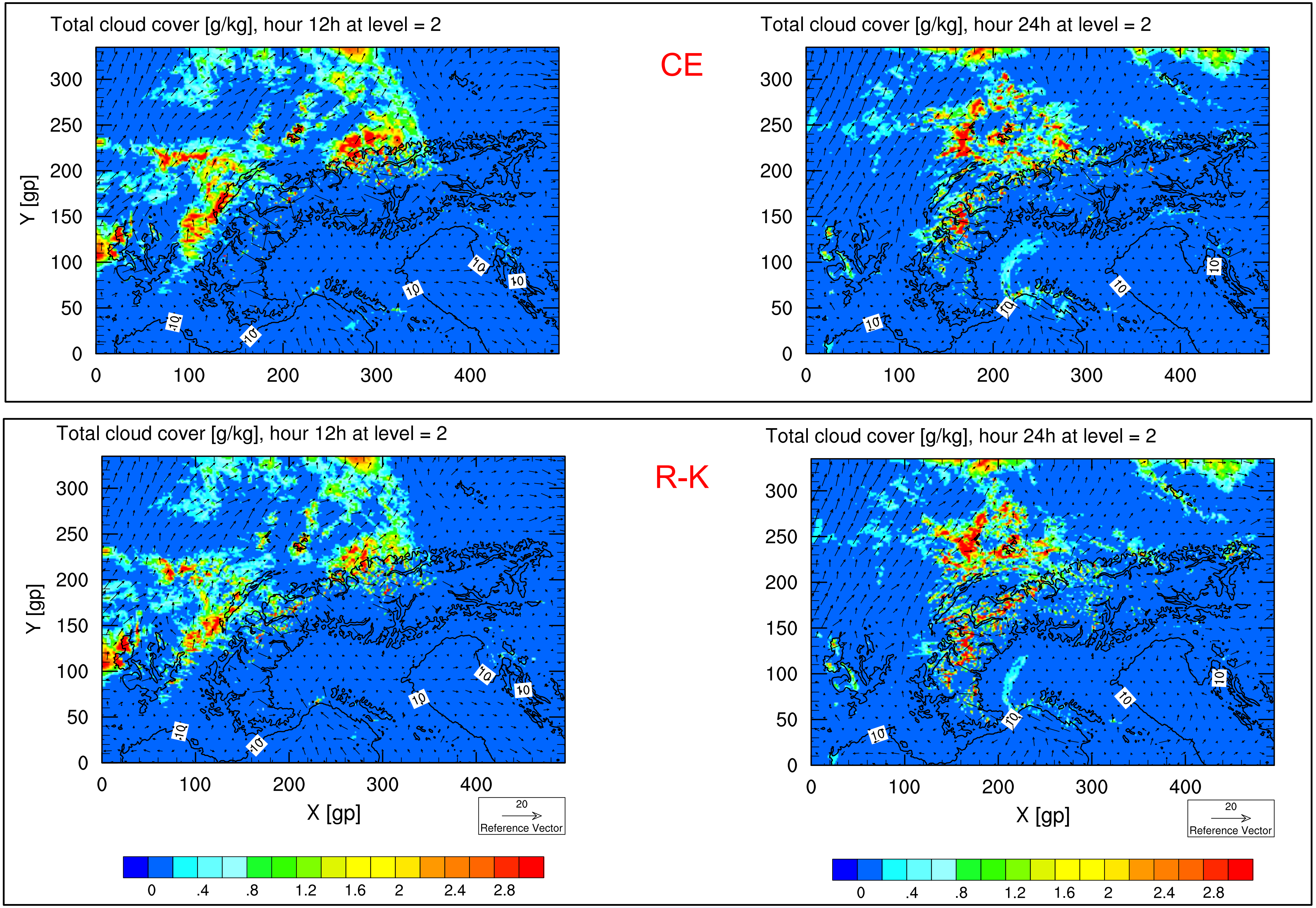
Mass fraction of cloud liquid water – simulations with radiation



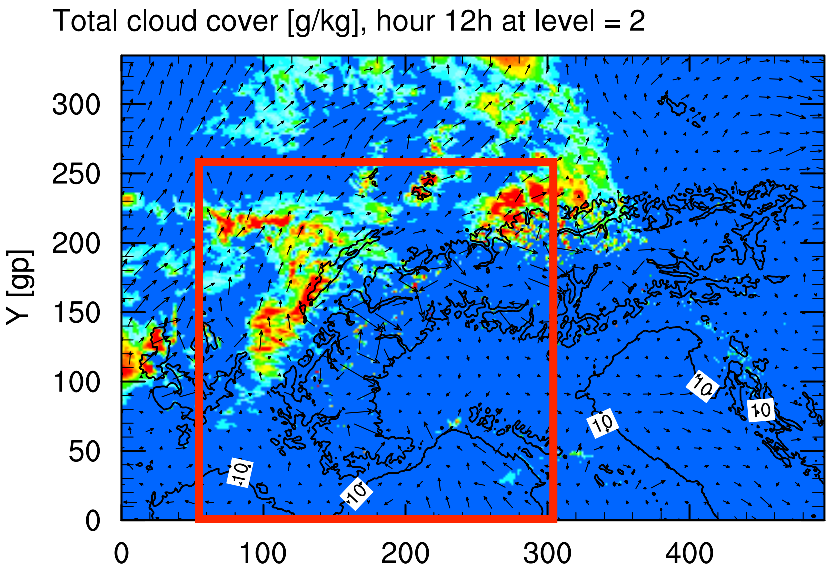
Cloud water – simulations with radiation

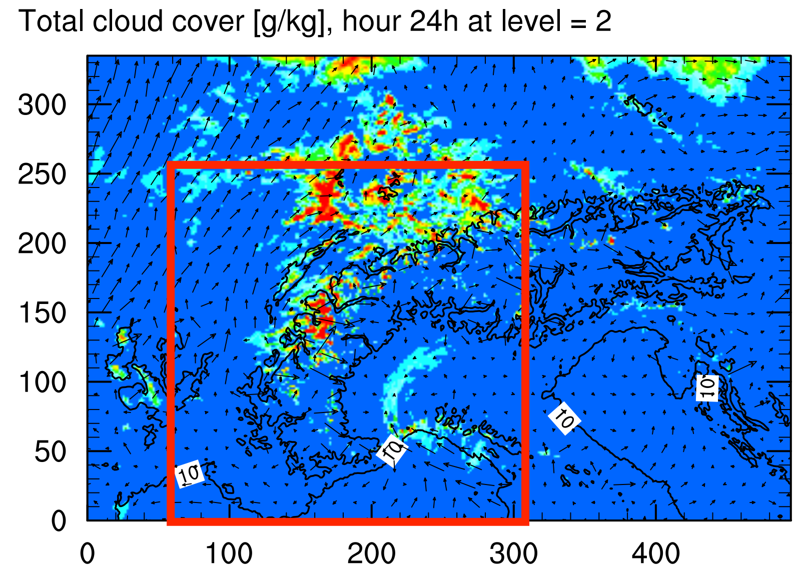


Total cloud cover – simulations with radiation

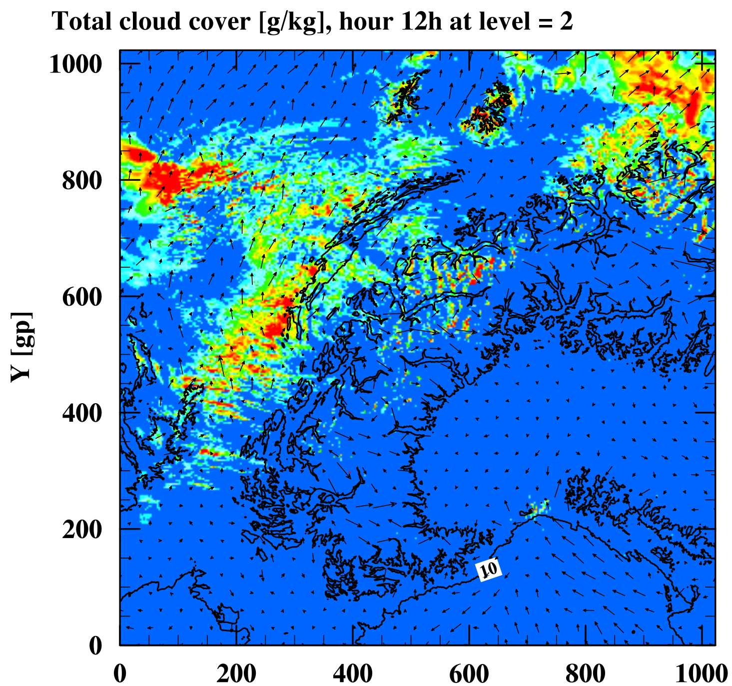


Total cloud cover – simulations CE with radiation

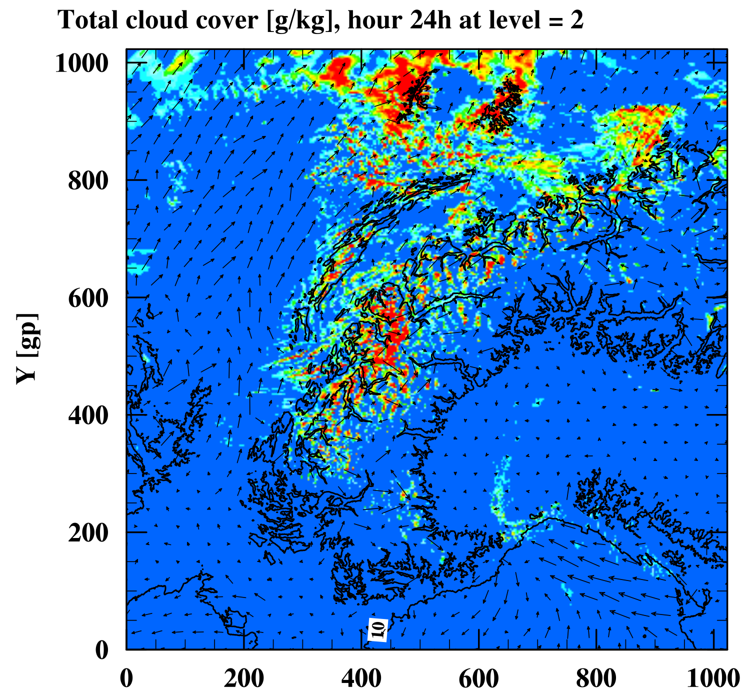




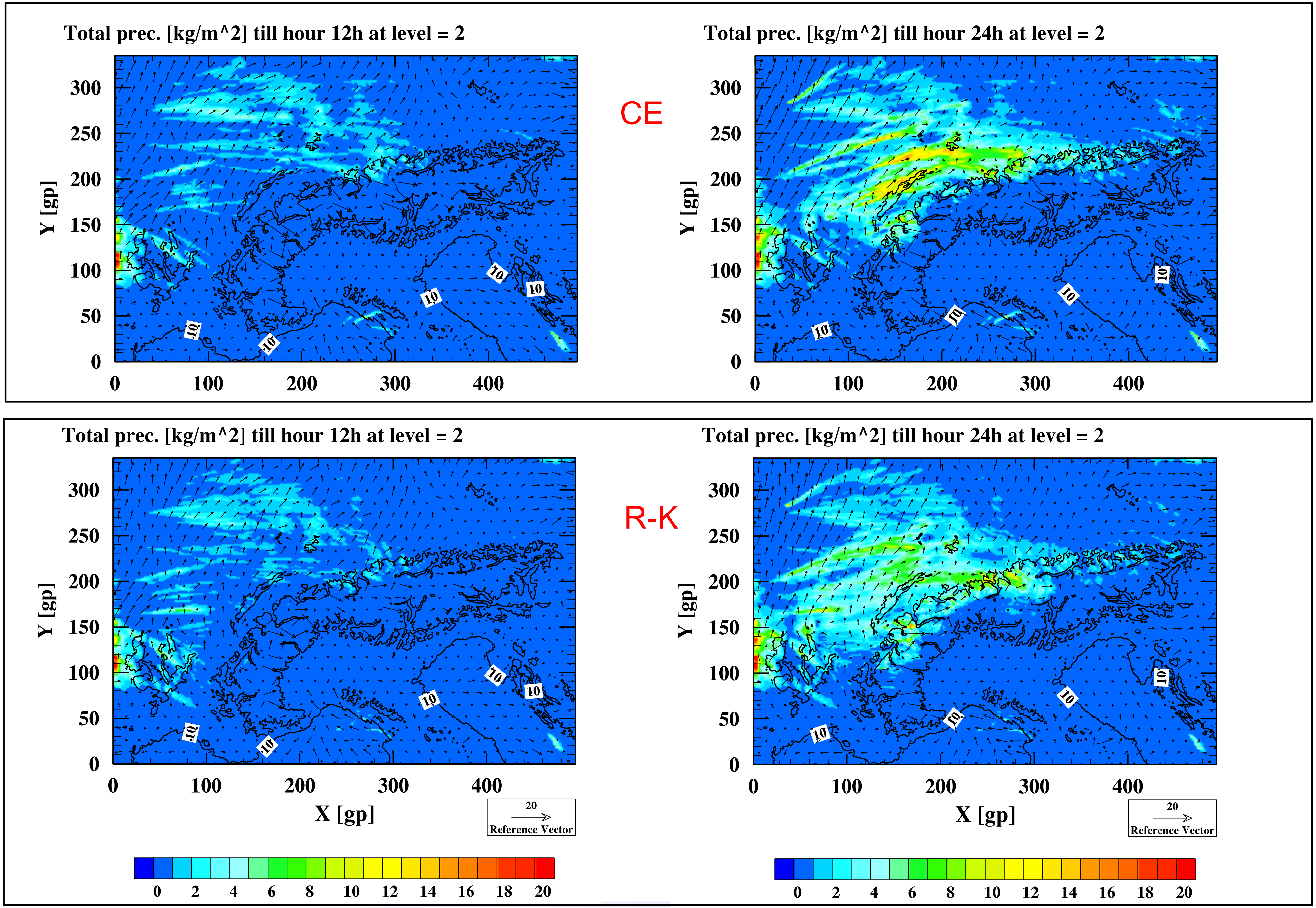
CE 2.2 km



CE 0.55 km



Total precipitation



Conclusions II

- All tasks of the CDC plan have been successfully completed.
- The main achievement of the project is the new stable version of the hybrid model (CE) in which the EULAG dynamical core is coupled with COSMO environment.
- Realistic tests for Alpine flow with COSMO parameterization of friction, turbulence, radiation, surface fluxes.
- For the performed tests no artificial smoothing was required to achieve stable solutions
- The solutions are generally similar to Runge-Kutta results and introduce more spatial variability.
- In large number of tests (idealized, semi-realistic and realistic) we have not found a single case in which an anelastic approximation would be a limitation for NWP.