The anelastic dynamical core of COSMO - first six months of "COSMO-EULAG operationalization (CELO)" priority project

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CELO priority project tasks – an overview

Task 1: Integration of EULAG DC with COSMO framework
(coupling to parametrizations and surface model,
global model data management)

Task 2: Consolidation and optimization of the EULAG DC formulation
(flexible vertical coordinate, full pressure retrival,
boundary conditions optimization, pressure solver effeciency)

Task 3: Integration of EULAG DC with COSMO framework
(code optimization and restructuring, restart, consolidation
of MPI parallelism, stencil library)

Task 4: Optimization and testing of COSMO with EULAG DC
(after completion of Task 1-3)

Task 1 activities

Highlights:

- **Review of the moist physics coupling, testing convective scenarios over the Alps (COSMO framework with EULAG dynamical core for 2.2 km, 1.1 km and 0.55 km, compared to RK dynamical core with 2.2 km)**

- **Consolidation of global model data management (not shown)**

Setup of realistic simulations

Domain :

- (ie_tot x je_tot) = (520 x 350) / (1014 x 678) / (806 x 806)
- (2.2km) / (1.1km) / (0.55km)
- Gal-Chen coord. system : vcflat = 23588.50, standard level distribution
- rlwidth = 50km / 25km / 20km lateral absorber
- rd_height = 15km upper sponge

Dynamics :

- lcond =TRUE condensation is switch on
- lhoridiff=F *(T for the RK core) numerical diffusion necessary for RK*
- lsl_adv_qx=T (semi-lagranian advection of the moisture quantities)

Microphysics :

lgsp=T, itype_gscp=4 (ice, rain, snow, graupel) grid scale precipitation

Radiation :

- lrad=T Radiation switched on
- hincrad=0.25 for 2.2km, *0.1 for higher resolutions (every 15 min for 2.2km, every 6 min for both 1.1km and 0.55km)*

Others :

- Soil model : lsoil=T, lforest=T
- Turbulence : ltur=T, itype_turb=3, imode_turb=1
- Surface layer fluxes : itype_tran=2, imode_tran=1
- Convection parametrisation : lconv=F switched off
- Sgs orography : lsso=F, ltkesso=F, lradtopo=F

Note no convection parameterization !

Setup of realistic simulations

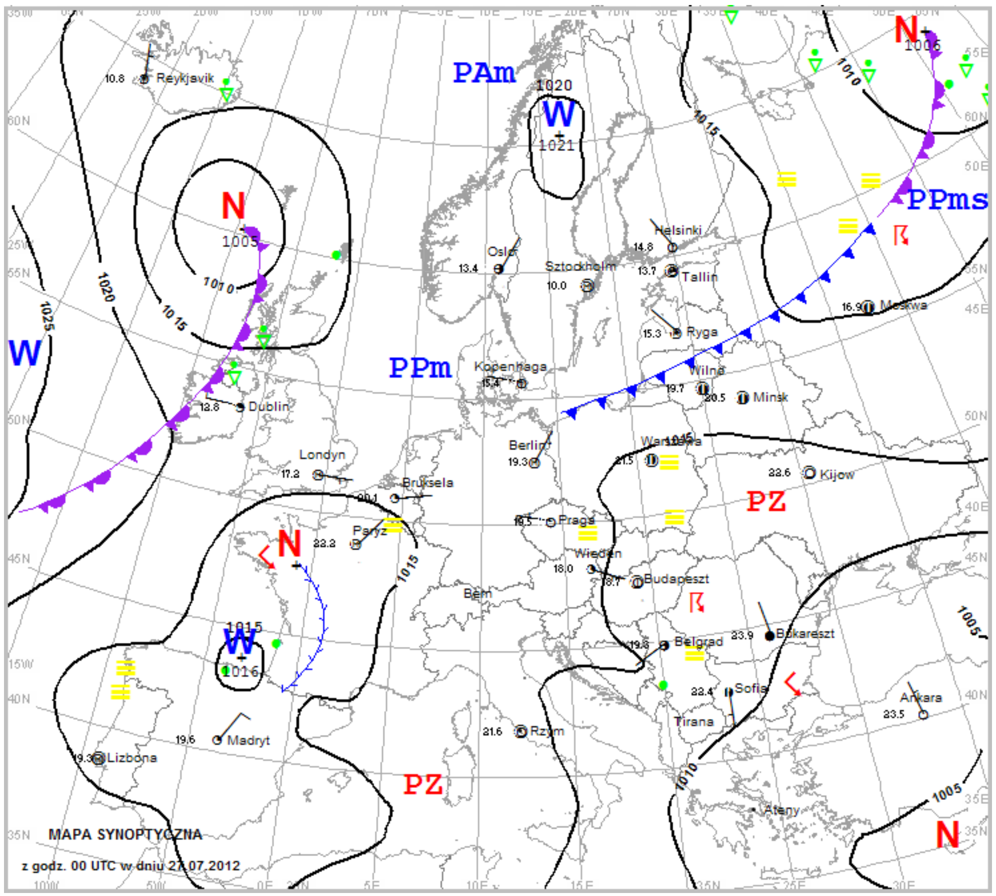
Initial and boundary data:

Data for COSMO-2RK and CE-2 are interpolated directly from COSMO-7 of MeteoSwiss.
Data for CE-1 and CE-05 are interpolated directly from COSMO-2 of MeteoSwiss.
For presented results standard orography filtering was applied:
lfilter_oro=T
ilow_pass_oro=4
numfilt_oro=1
ilow_pass_xso=5
numfilt_xso=1
rxso_mask=750.0

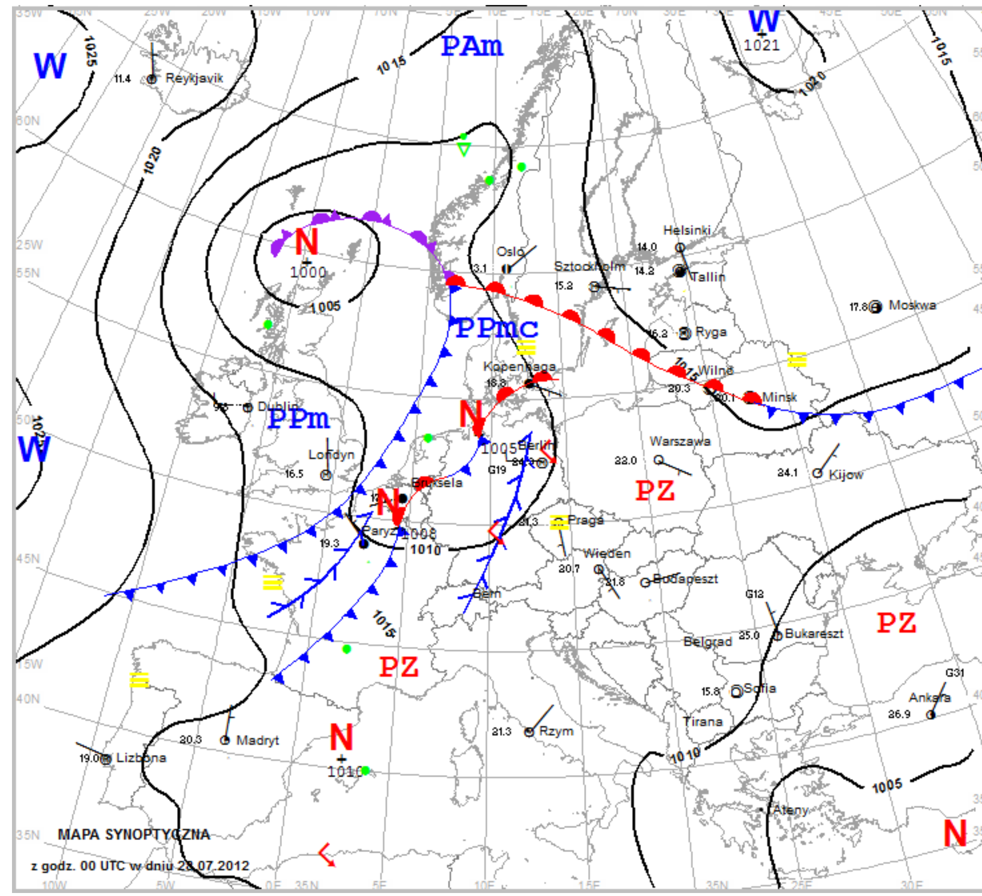
Maximum slopes :
- 2.2km -> 20°
- 1.1km -> 31°
- 0.55km -> 55°

Synoptic convective scenario – case study of internal air mass convection

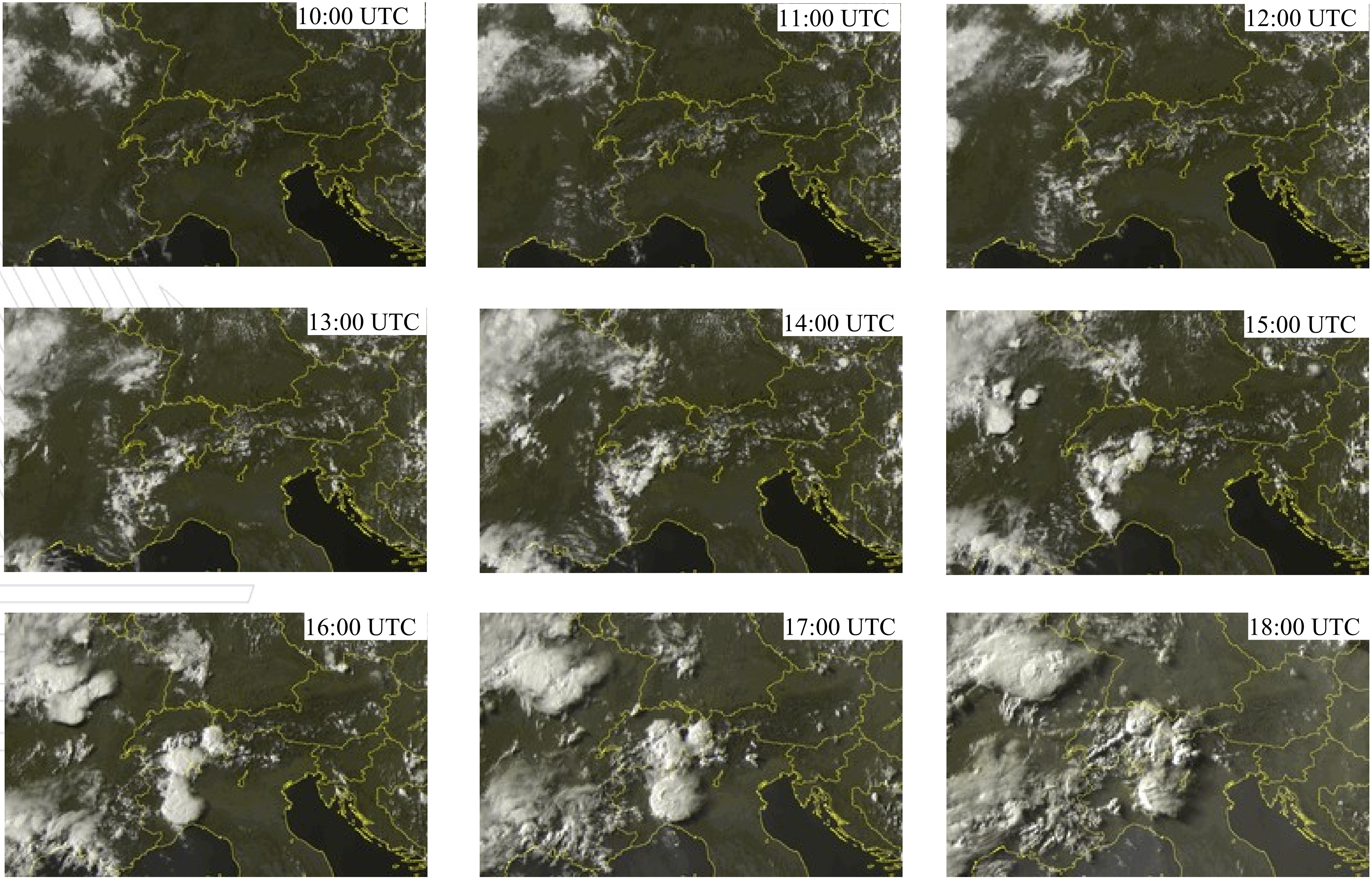
Synoptic map for 27.07.2012



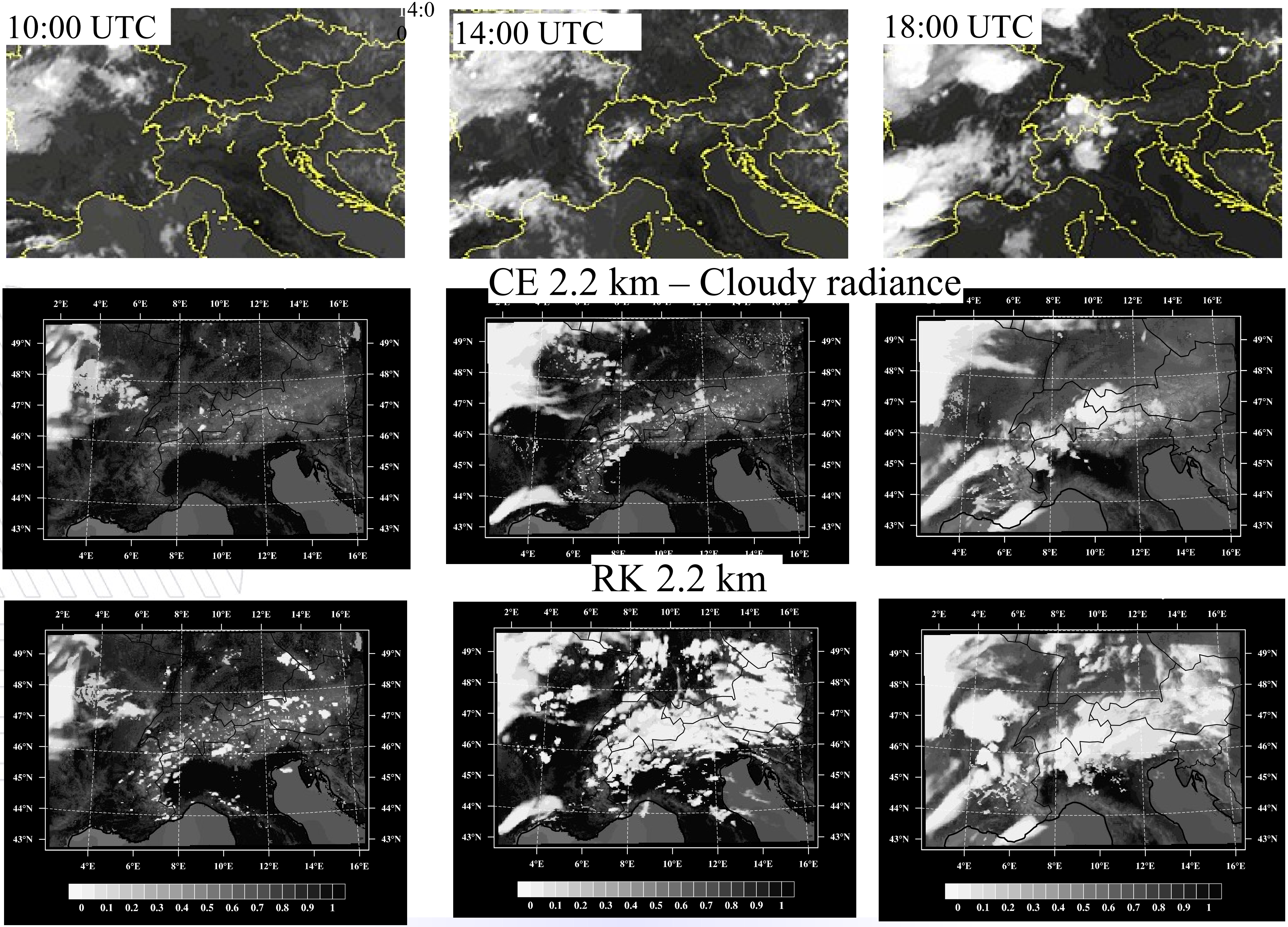
28.07.2012



MSG - High Resolution Visible (HRV) channel

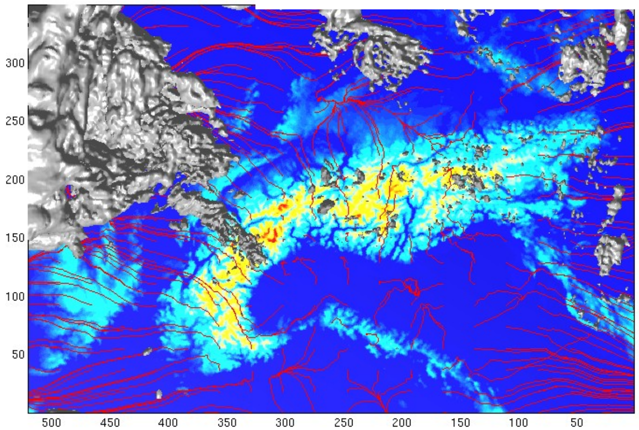


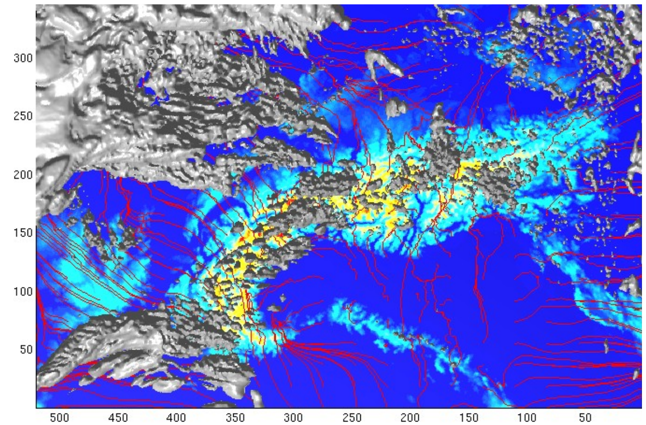
MSG infrared band

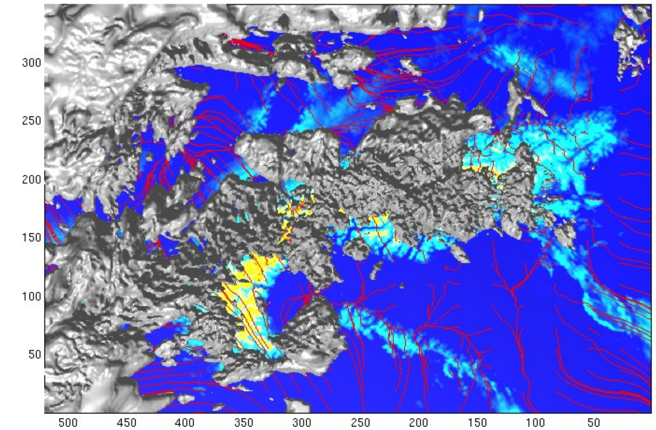


Cloud area fraction, isosurface at 0.8

CE 2.2 km

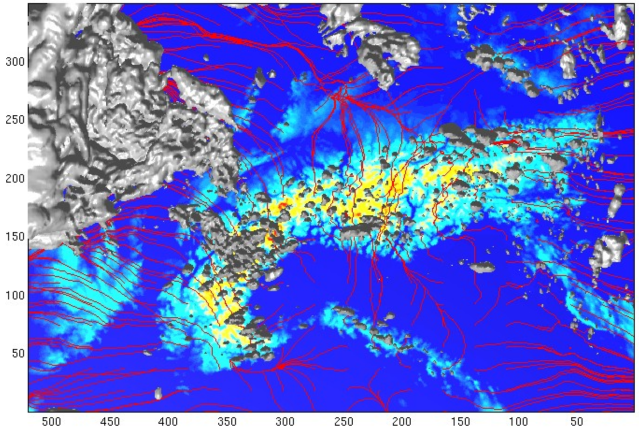


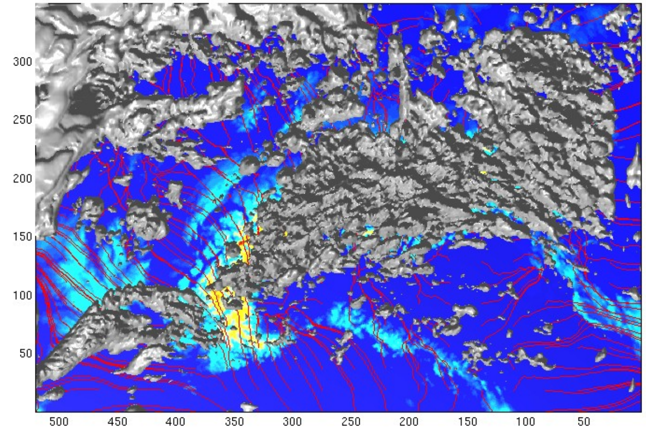


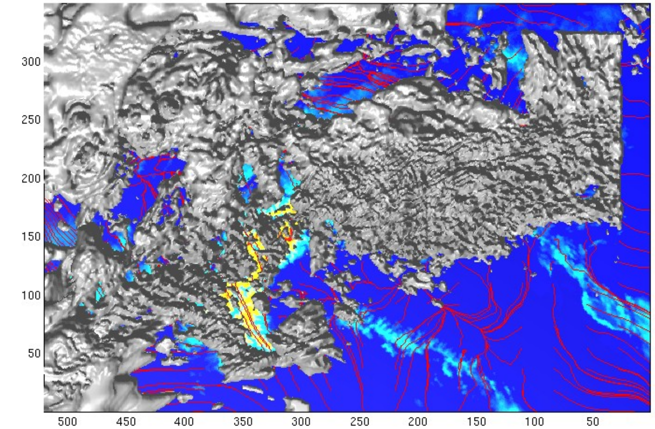


10:00 UTC 15:00 UTC 20:00 UTC

RK 2.2 km

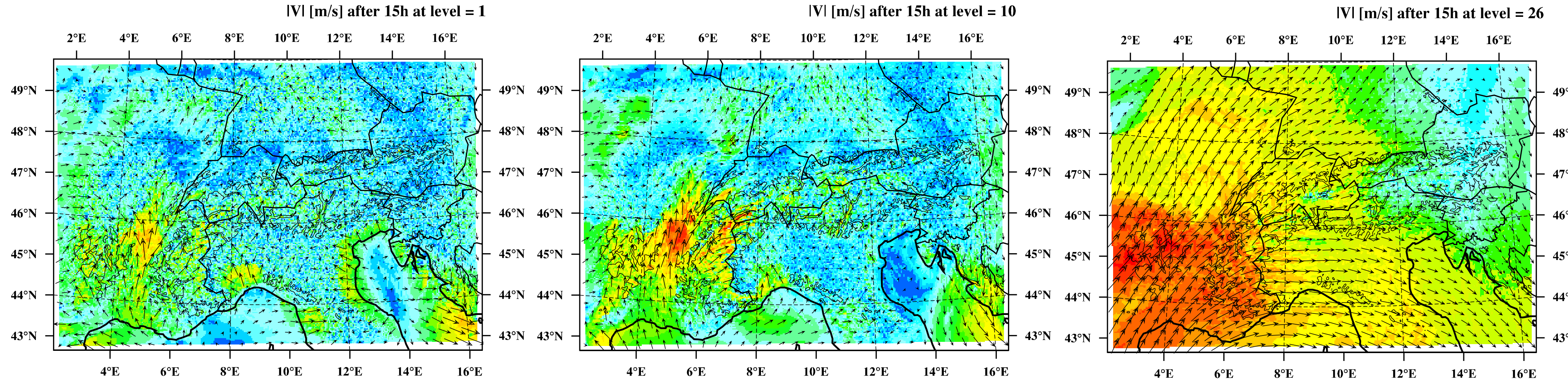




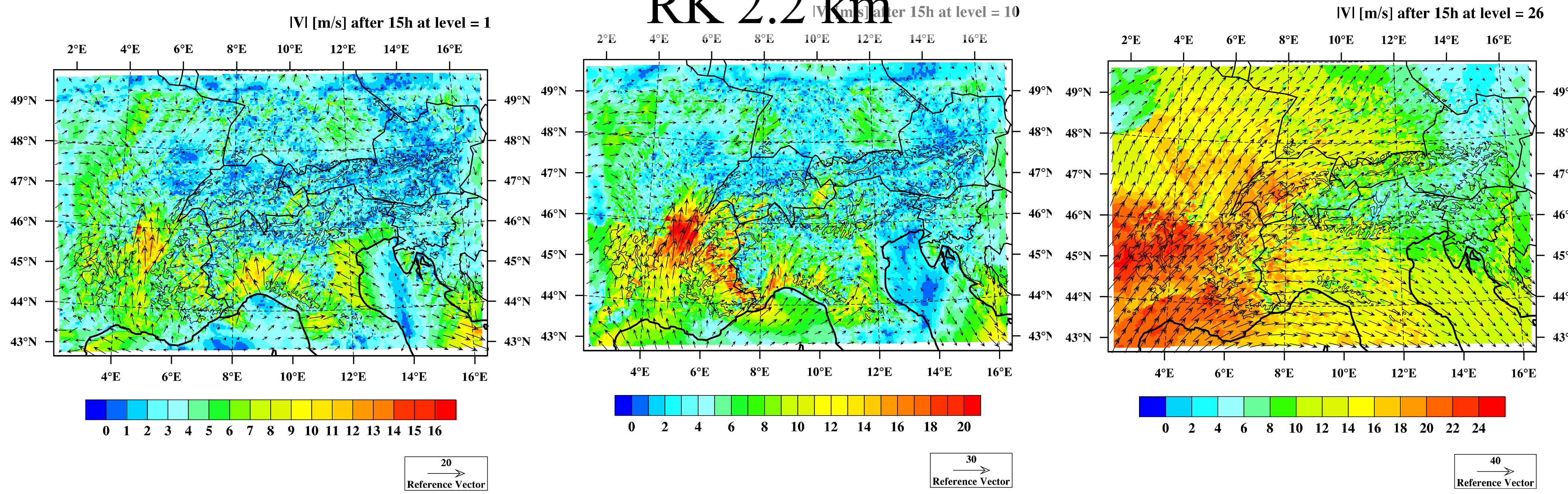


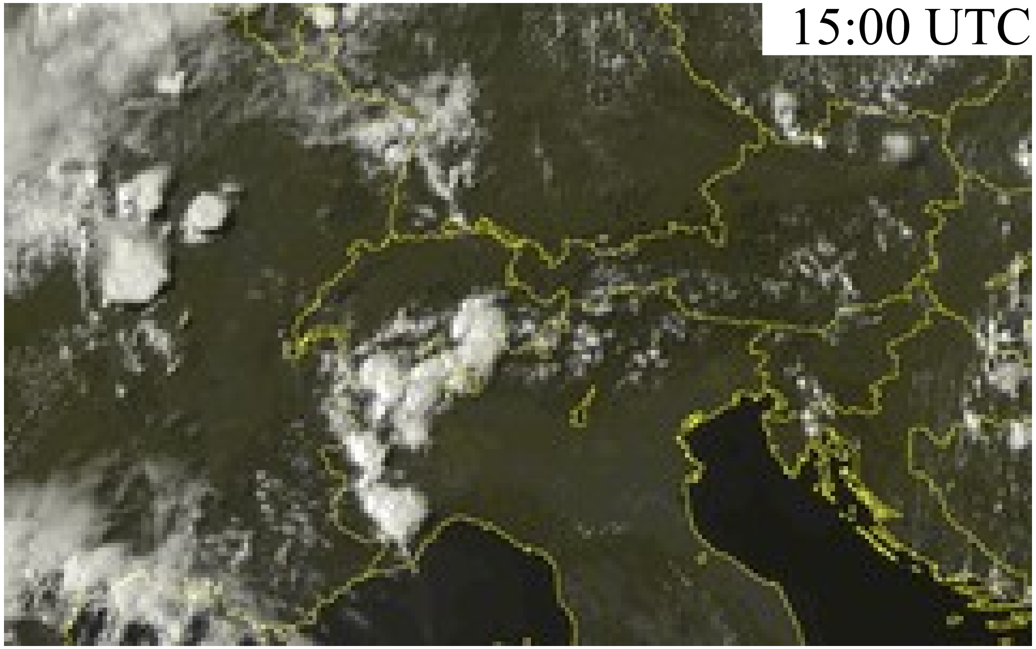
Velocity module at model level 1, 10, 26 – 15 UTC

CE 2.2 km

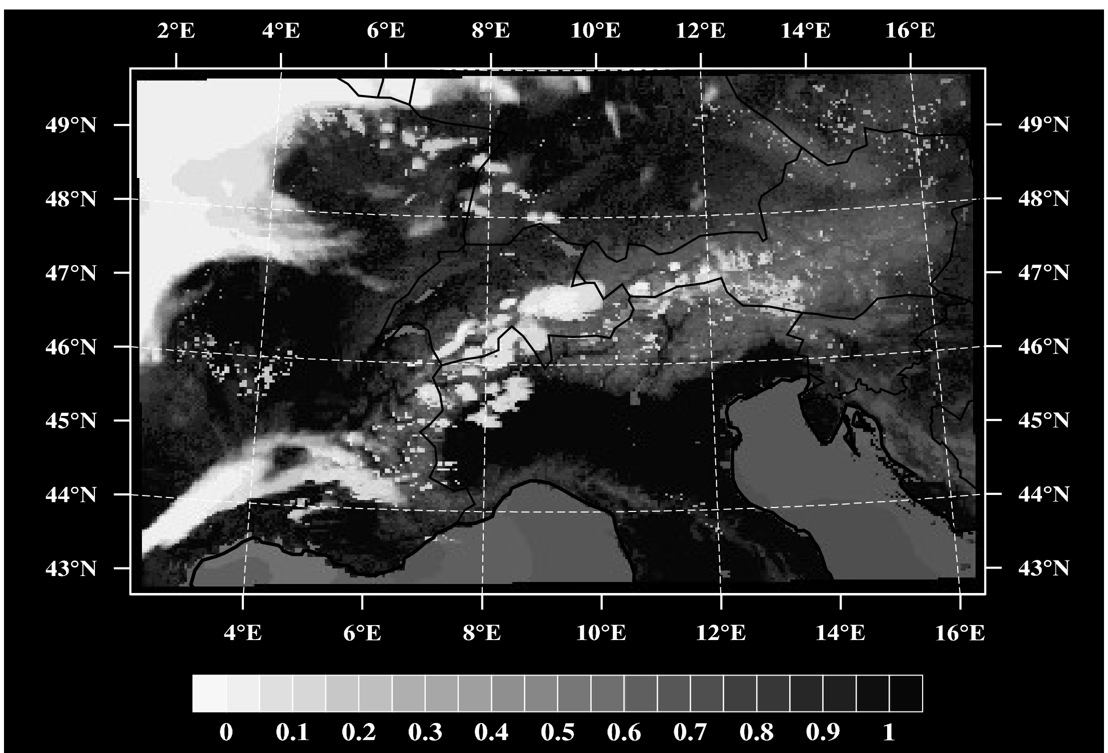


RK 2.2 km

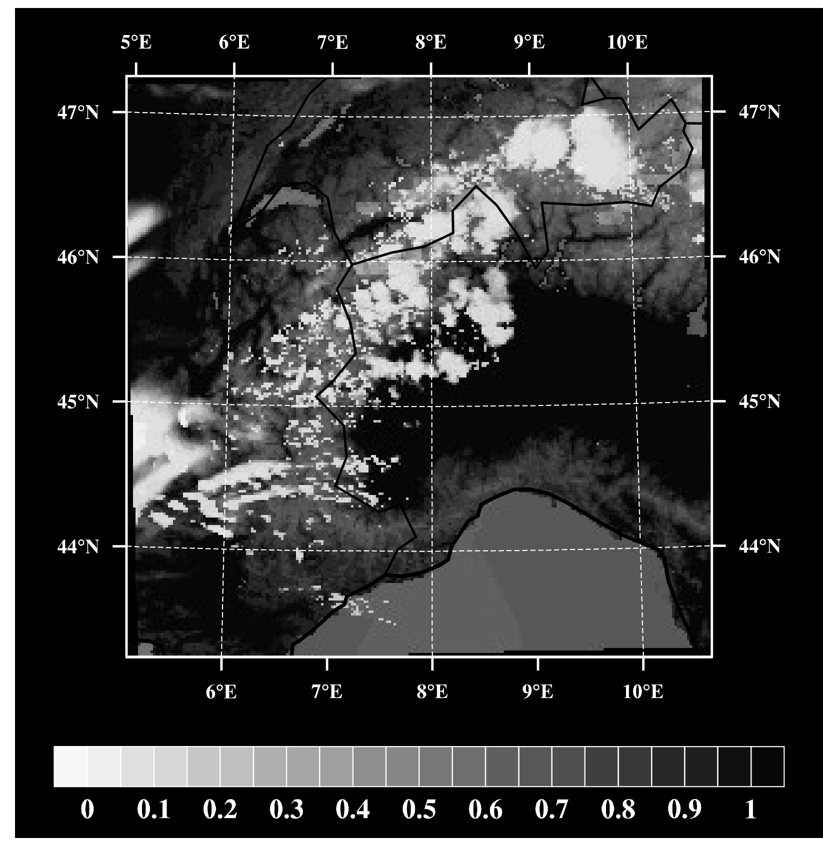




CE 2.2 km – Cloudy radiance

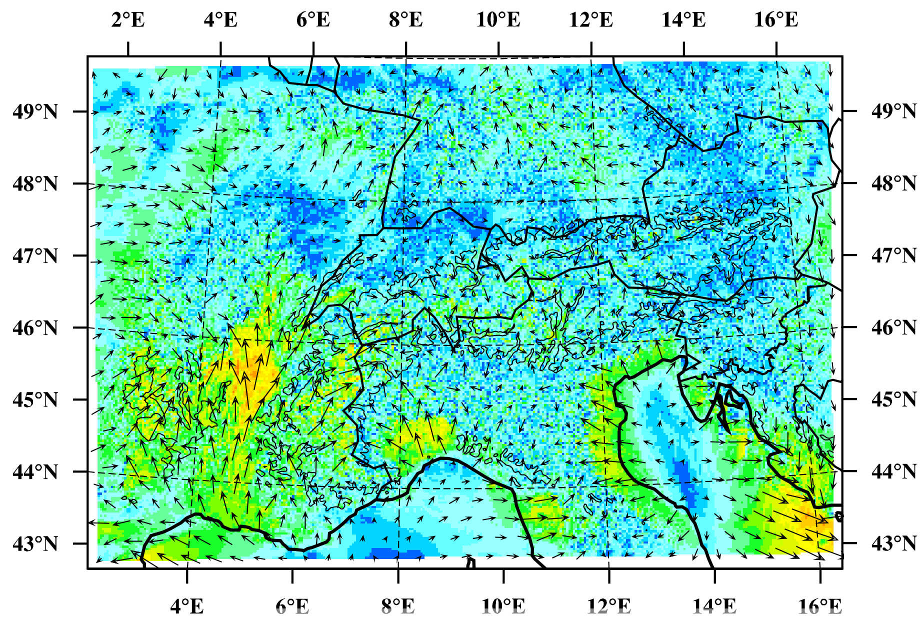


CE 0.55 km

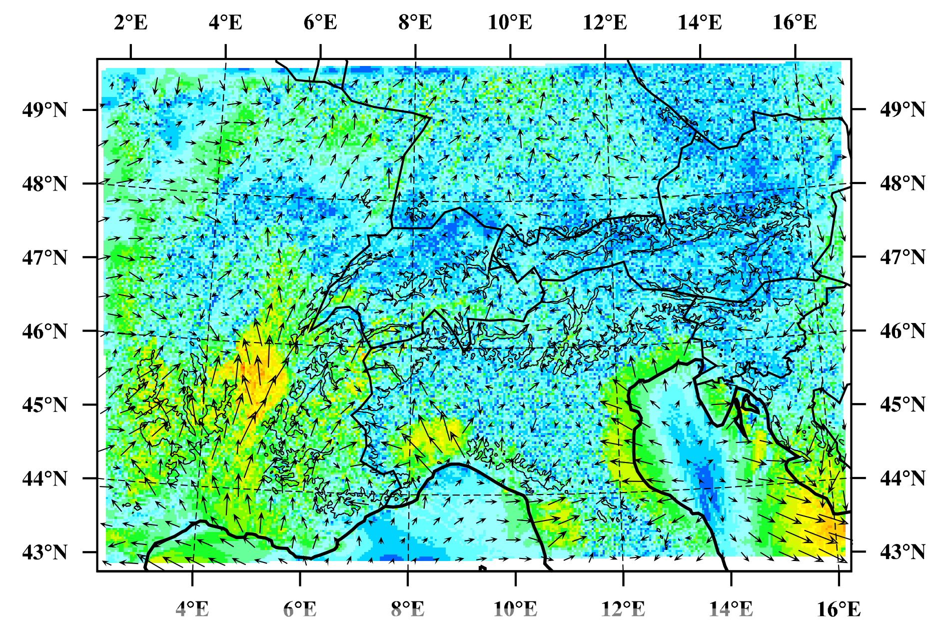


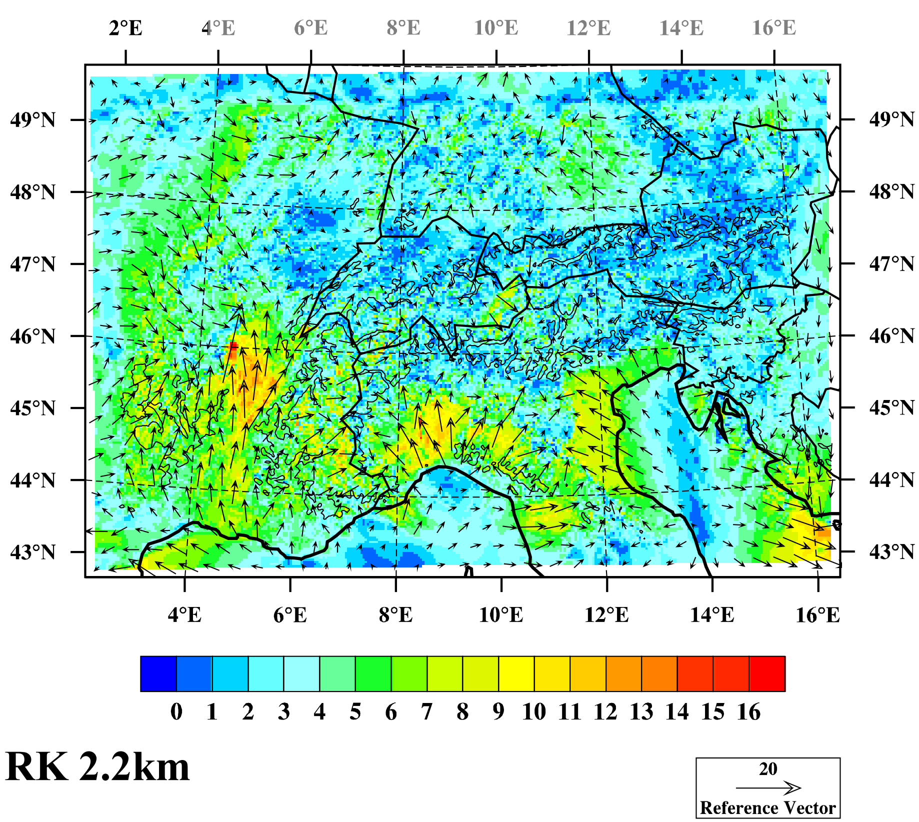
Velocity module at model level 1 (15 UTC)

CE 2.2km

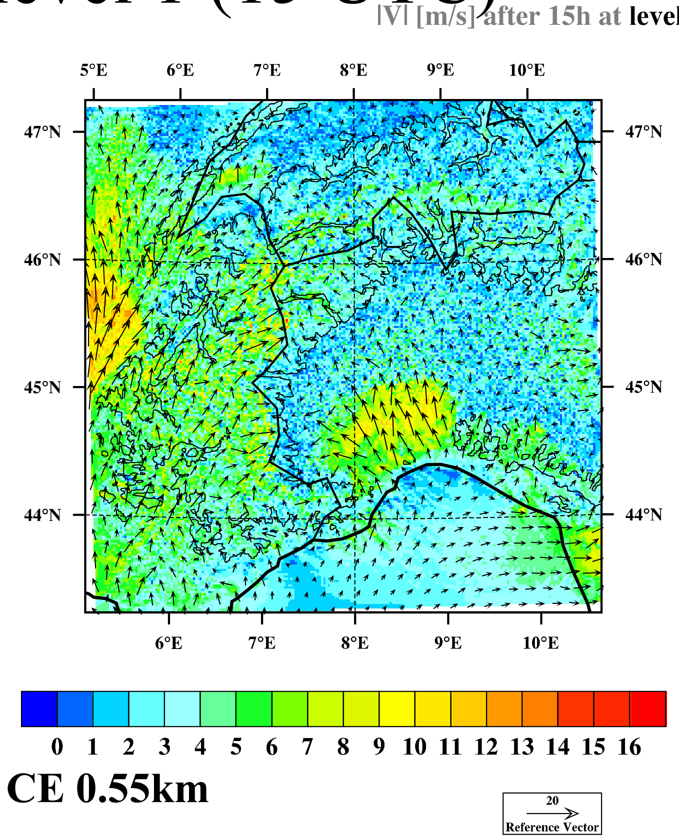


CE 1.1km

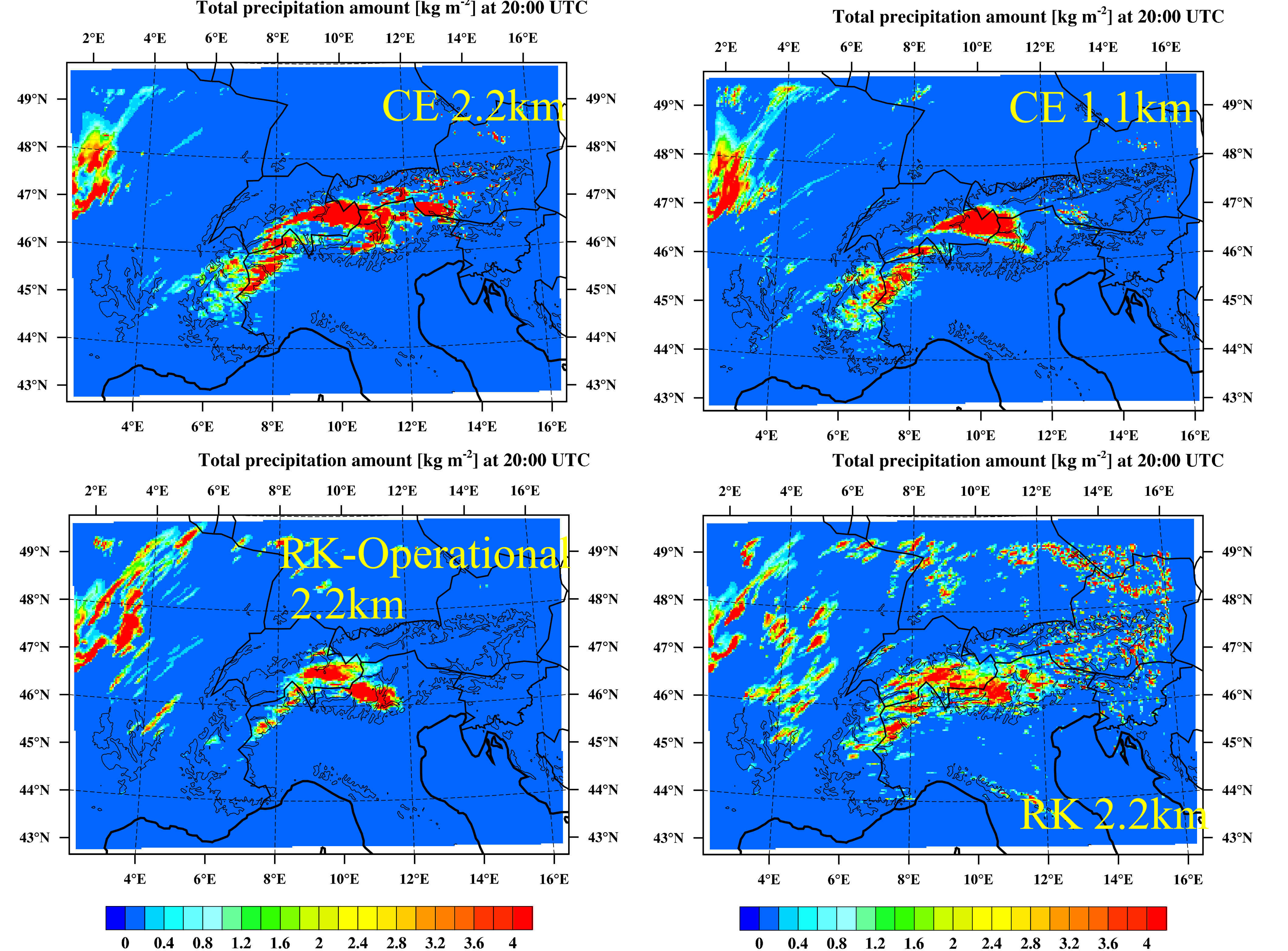




RK 2.2km



CE 0.55km


Total precipitation amount [kg m-2] at 20:00 UTC
CE 2.2km
Total precipitation amount [kg m-2] at 20:00 UTC
CE 1.1km
Total precipitation amount [kg m-2] at 20:00 UTC
RK-Operational
2.2km
Total precipitation amount [kg m-2] at 20:00 UTC
RK 2.2km
2°E 4°E 6°E 8°E 10°E 12°E 14°E 16°E
43°N 44°N 45°N 46°N 47°N 48°N 49°N
0 0.4 0.8 1.2 1.6 2 2.4 2.8 3.2 3.6 4

Task 2 activities

Highlights:

- **Implementation of the generalized metric terms for arbitrary vertical coordinate and removal of Gal-Chen coordinate transform dependence**

- **Role of anelastic pressure perturbation in moist processes – idealized study**

Computation of the inverse metric coefficients

Equations are derived based on the assumption that 16 differential identities:

$$\delta^r_s \equiv \frac{\partial \overline{x}^r}{\partial x^q}\frac{\partial x^q}{\partial \overline{x}^s}$$

x,y,z – physical coordinates, here in lat-lon-z for EULAG DC

are satisfied. For the transformation at hand:

$$(\overline{t},\overline{x},\overline{y},\overline{z}) \equiv (t, E(t,x,y), D(t,x,y), C(x,y,z,t))$$

computational space (ordered like Cartesian grid)

we are left with 9 non-trivial equations:

$$\begin{bmatrix} \frac{\partial x}{\partial E} & \frac{\partial y}{\partial E} & 0 \\ \frac{\partial x}{\partial D} & \frac{\partial y}{\partial D} & 0 \\ \frac{\partial x}{\partial \overline{t}} & \frac{\partial y}{\partial \overline{t}} & 1 \end{bmatrix} \begin{bmatrix} \frac{\partial E}{\partial x} \\ \frac{\partial E}{\partial y} \\ \frac{\partial E}{\partial t} \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} \frac{\partial x}{\partial E} & \frac{\partial y}{\partial E} & 0 \\ \frac{\partial x}{\partial D} & \frac{\partial y}{\partial D} & 0 \\ \frac{\partial x}{\partial \overline{t}} & \frac{\partial y}{\partial \overline{t}} & 1 \end{bmatrix} \begin{bmatrix} \frac{\partial D}{\partial x} \\ \frac{\partial D}{\partial y} \\ \frac{\partial D}{\partial t} \end{bmatrix} = \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}$$

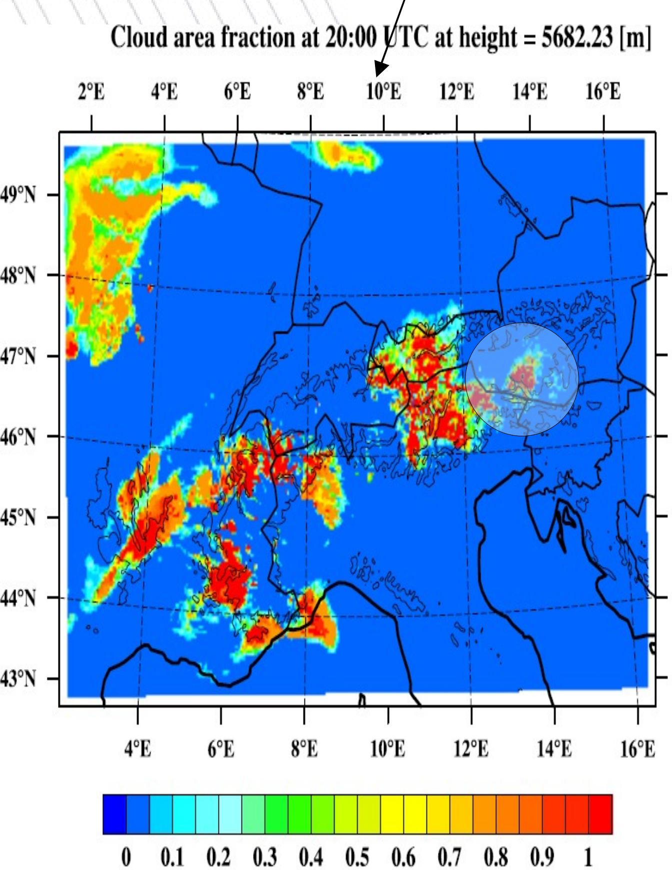
that are solved analytically for the metric terms.

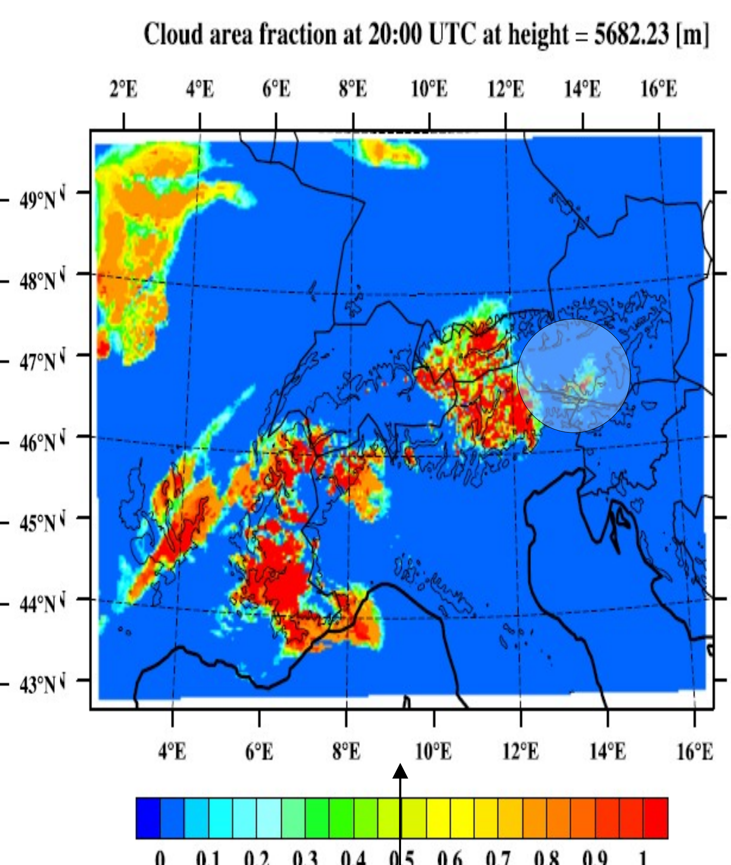
$$\begin{bmatrix} \frac{\partial x}{\partial E} & \frac{\partial y}{\partial E} & 0 \\ \frac{\partial x}{\partial D} & \frac{\partial y}{\partial D} & 0 \\ \frac{\partial x}{\partial \overline{t}} & \frac{\partial y}{\partial \overline{t}} & 1 \end{bmatrix} \begin{bmatrix} \frac{\partial C}{\partial x} \\ \frac{\partial C}{\partial y} \\ \frac{\partial C}{\partial t} \end{bmatrix} = \begin{bmatrix} -\frac{\partial z}{\partial E} / \frac{\partial z}{\partial C} \\ -\frac{\partial z}{\partial D} / \frac{\partial z}{\partial C} \\ -\frac{\partial z}{\partial \overline{t}} / \frac{\partial z}{\partial C} \end{bmatrix}$$

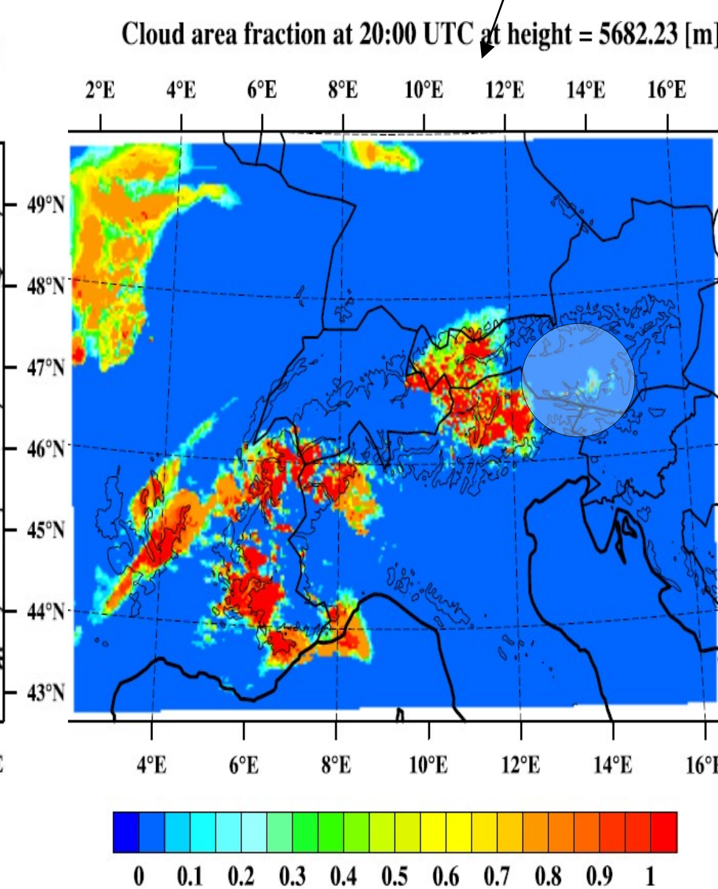
Metric term formulations – impact on cloud area fraction

Standard formulation of EULAG DC with hard-coded Gal-Chen coordinate transform.

New metric terms definition independent of Gal-Chen coordinate transform,







Default COSMO metric term formulation

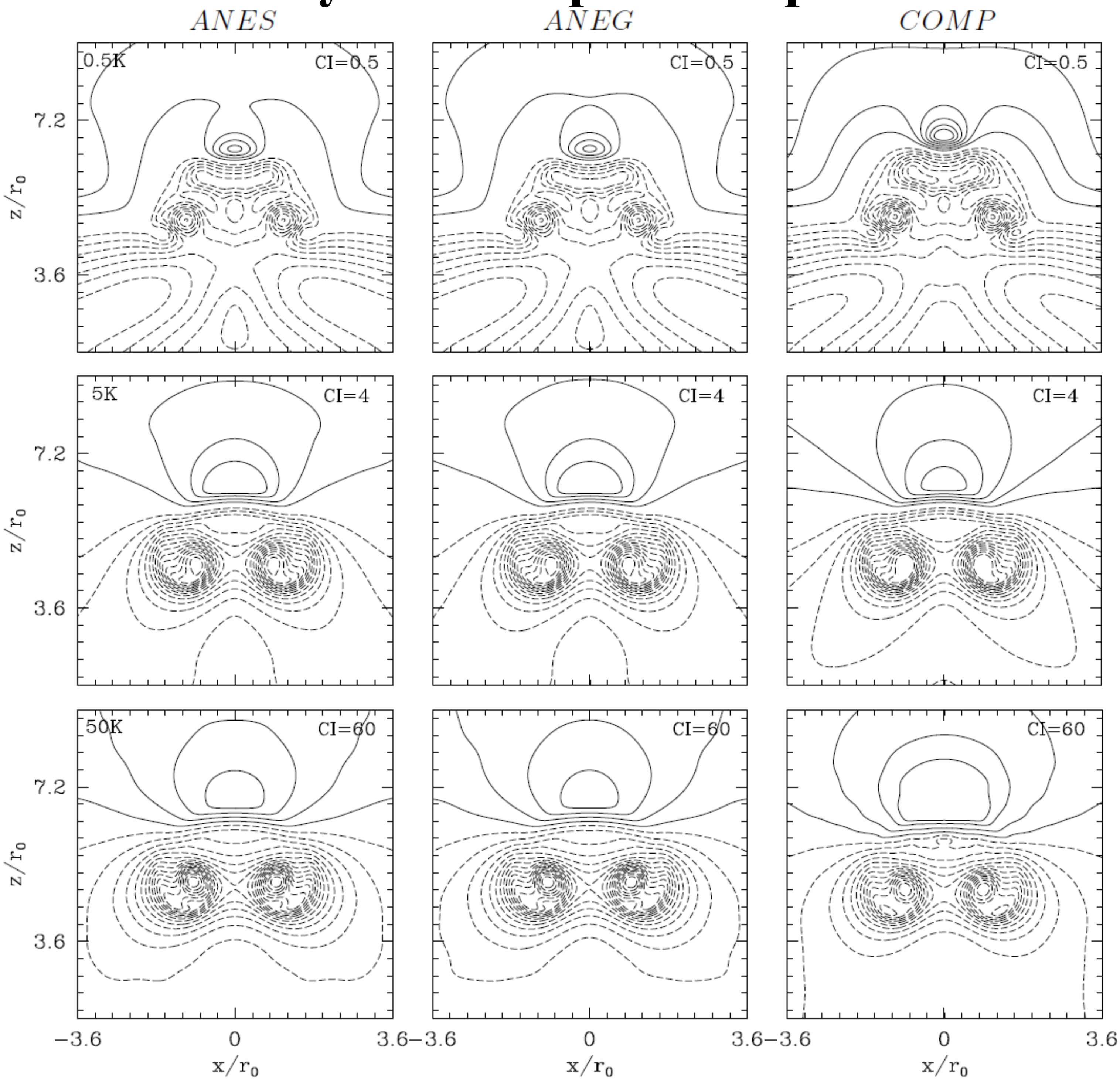
Anelastic vs Compressible pressure – study by dr Marcin Kurowski et al. at NCAR

We examine 2D moist saturated thermal developing in a stratified atmosphere

- 10m horizontal/vertical resolution, 4x4km domain size
- potential temperature perturbation 0.5, 5 and 50K
- small explicit diffusion to delay onset of cloud-edge instabilities
- 20% relative humidity of the environment
- non-dimensional time scale (Sanchez et al. 1989) t/Tb, where

$$T_b = r_0(2gr_0\theta'/\bar{\theta})^{-1/2}$$

Non-hydrostatic pressure perturbations after 5t/Tb



ANES – standard anelastic

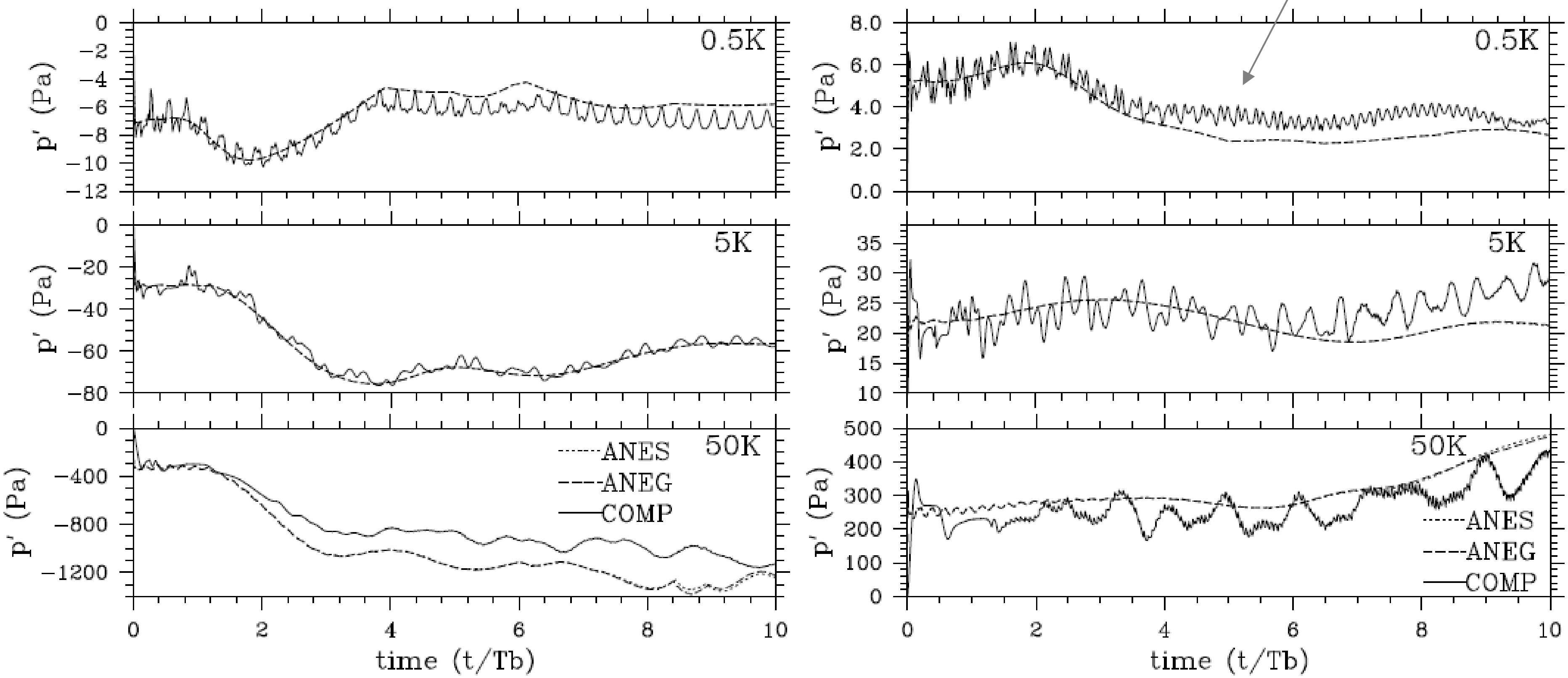
ANEG – generalized anelastic (with p' included in moist thermo-dynamics)

COMP – fully compressible

Anelastic vs Compressible pressure perturbation – study by dr Marcin Kurowski et al.

Time evolution of non-hydrostatic pressure perturbations (min/max)

Sound waves effect



min(p')

max(p')

Anelastic vs Compressible pressure perturbation – study by dr Marcin Kurowski et al.

Main findings:

- scale analysis suggests non-hydrostatic pressure perturbations are of minor importance to the saturation condition within the range of temperature and pressure changes that occur in the troposphere;
- anelastic non-hydrostatic pressure from the elliptic solver has a physical meaning and compares well with its compressible counterpart;
- thus it suggests that it may be used to construct a full pressure (p_bar+p') which can then be employed in moist thermodynamics
- however, the importance of p' for moist thermodynamics seems to be insignificant, at least in the range of parameters examined; more tests needed (deep convection, baroclinic wave, etc.);

Highlights of Task 3 activities

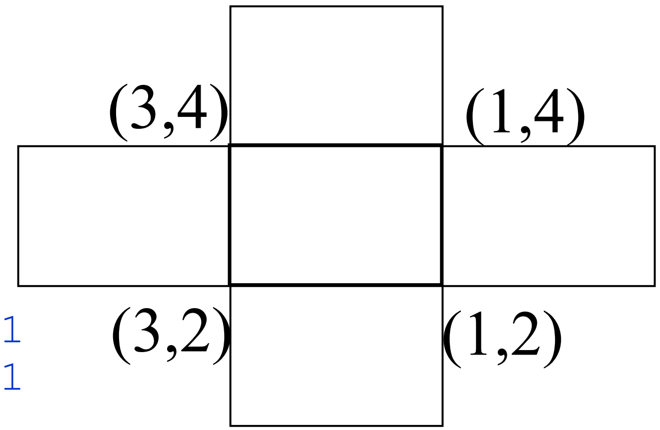
- **Introduction of fully flexible computational domain decomposition – restriction that the number of cores must divide number of grid points is now waived**

- **Code optimizations and simplifications, e.g. optimized and simplified halo update subroutines, vector global communication in iterative pressure solver (GCR)**

- **Rewrite of dynamical core components to expose stencil computations, preparation of the EULAG DC code for external cooperation with Technical University of Czestochowa and Poznan Supercomputing Centre on porting to modern architectures**

Flexible computational domain decomposition

Introduction of flexible parallelization subdomains - loop ranges and boundary conditions are modified to allow for flexible subdomain size




```
np = n/nprocx
mp = m/nprocy
```

```
np = isubpos(my_cart_id,3)-isubpos(my_cart_id,1)+1
mp = isubpos(my_cart_id,4)-isubpos(my_cart_id,2)+1
```

```
isubpos,      & ! positions of the subdomains in the total domain. Given
                ! are the i- and the j-indices of the lower left and the
                ! upper right grid point in the order
                !                  i_ll, j_ll, i_ur, j_ur.
```

MPI procedures has been thoroughly verified and tested in a number of simulations.

Outlook of CELO activities for the next 6 months

Further parameterization coupling review and implementation of MPDATA for moist species

Extension of a study on the role of anelastic pressure perturbation for moist physics at large scale flows (external work at NCAR)

Effeciency and coding optimizations to EULAG DC and preparation of the report on the performance of EULAG DC for COSMO GM

Cooperation with external partners on „EULAG on modern architectures" project and steps towards assessment of the applicability of the stencil library

Conclusions

- **EULAG DC was tested within COSMO framework for a summer convective scenario with 2.2 km, 1.1 km and 0.55 km with promising results**

- **Dynamics – moist physics coupling was reviewed and successfully tested**

- **New formulation of metric coefficients allows for arbitrary vertical coordinate**

- **Boundary conditions, global model data management and parallelization were consolidated between RK and EULAG DC**