Very-high resolution NWP over Alps

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- quasi-stationary Alpine flows
- Alpine convection – preliminary results

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Introduction

Dynamical cores of contemporary regional numerical weather prediction (NWP) models typically originate from global circulation models, employing:

- horozontal grid intervals of $O(100)$ km
- hydrostatic primitive equations

However, the contemporary regional NWP aims at horizontal domains of a synoptic scale, $O(1000\text{x}1000)$ km^2, with:

- mesoscale horizontal grid interval of $O(1)$ km
- non-hydrostatic equations
- and explicit convection representation

This requires substantial advancements in the dynamical cores for contemporary regional NWP modeling

Problem discussed also within COSMO: Consortium for Small Scale Modeling, even that its regional model is based on non-hydrostatic Runge-Kutta dynamical core (IMGW a member)

Discussion from the COSMO Science Plan:

Problems encountered:

• explicit simulation of deep convection requires close coupling between the dynamics and the parameterizations; i.e., dynamical core has to describe faithfully adiabatic equations as well as the diabatic terms, in particular, due to the latent heat release

• the transition to finer resolutions requires dealing with steeper slopes, which becomes more and more difficult for a terrain-following coordinate formulation

Solution proposed:

• "conservation of the dynamical variables: mass, momentum or energy is one of the fundamental guiding principles in the development of dynamical cores in all branches of fluid dynamics"

• conservation properties should be also implemented in a future version of the COSMO model; its current version has no explicit (round-off error) conservation of mass, momentum or energy

Introduction

Consequently, in parallel to fully compressible dynamic cores, the "sound-proof" cores attract attention:

- while linked with the finite volume (FV) discretization methods they can be integrated in fully conservative form
- due to the absence of sound waves, they allow for accurate integrations with long time steps, important for very high resolution simulations on large and deep domains
- problems discussed in the COSMO Science Plan were successfully solved in the frame of the anelastic EULAG model

EULAG – computational research model for multiscale flows (~ 20 years of history), nonhydrostatic, anelastic, finite volume non-oscillatory transport algorithms, proven record of applications from laboratory to stellar scales (cf. Prusa et al., 2008, Computers and Fluids)

Task 1 of CDC Project Plan: Testing EULAG as a prospective dynamical core of a future operational weather prediction COSMO model for very high horizontal resolutions.

Task 1.1: Idealised tests of the EULAG dynamical core

Simulate 2D and 3D idealized flows over mountains and 2D and 3D potential flows to compare with COSMO results, laboratory flows and analytic solutions. (...)

Task 1.2: Tests of the EULAG dynamical core for realistic flows over the Alpine topography

Simulate realistic flows over the Alpine topography (in particular orography containing deep valleys), with resolution ranging from 2.2 km, 1.1 km to 0.25 km, case studies for different weather regimes ranging from simple (without much weather), to summer (convective) and winter (frontal) situations. (...)

Task 1.3: Tests of the EULAG dynamical core for realistic flows over the Alpine topography with simplified physics parameterization

… as above, but with simplified moist microphysics and friction

Introduction

Recent discussion during the Brac-HR workshop (BRain-storming on Advanced Concepts for High Resolution modelling), the island of Brač in Croatia, 17-20/5/2010:

- the joint ALADIN-HIRLAM event hosted by RC LACE
- 24 participants, including guests from COSMO, ECMWF, MetOffice
- the basic results reported to the COSMO General Meeting, Moscow, September 2010, by Detlev Majewski

Selected issues:

- distinction between ‘convection permitting’ and ‘convection resolving’ resolutions
- problems of NWP simulations with very high resolutions (~ 2-1 km):
  - deep convection too active (convection ‘sparks’, too high frequency of extreme events),
  - incorrect diurnal cycle of convection (too early and too intensive initiation)
- significant divergence of opinions on the influence of the dynamical core on the problems and need for its substantial revision (replacement)
  - conservative properties needed? (AROME is semi-Lagrangian)
- needs for tests like Weisman and Klemp, 1982
- anelastic core to be considered ? (Meteo France)

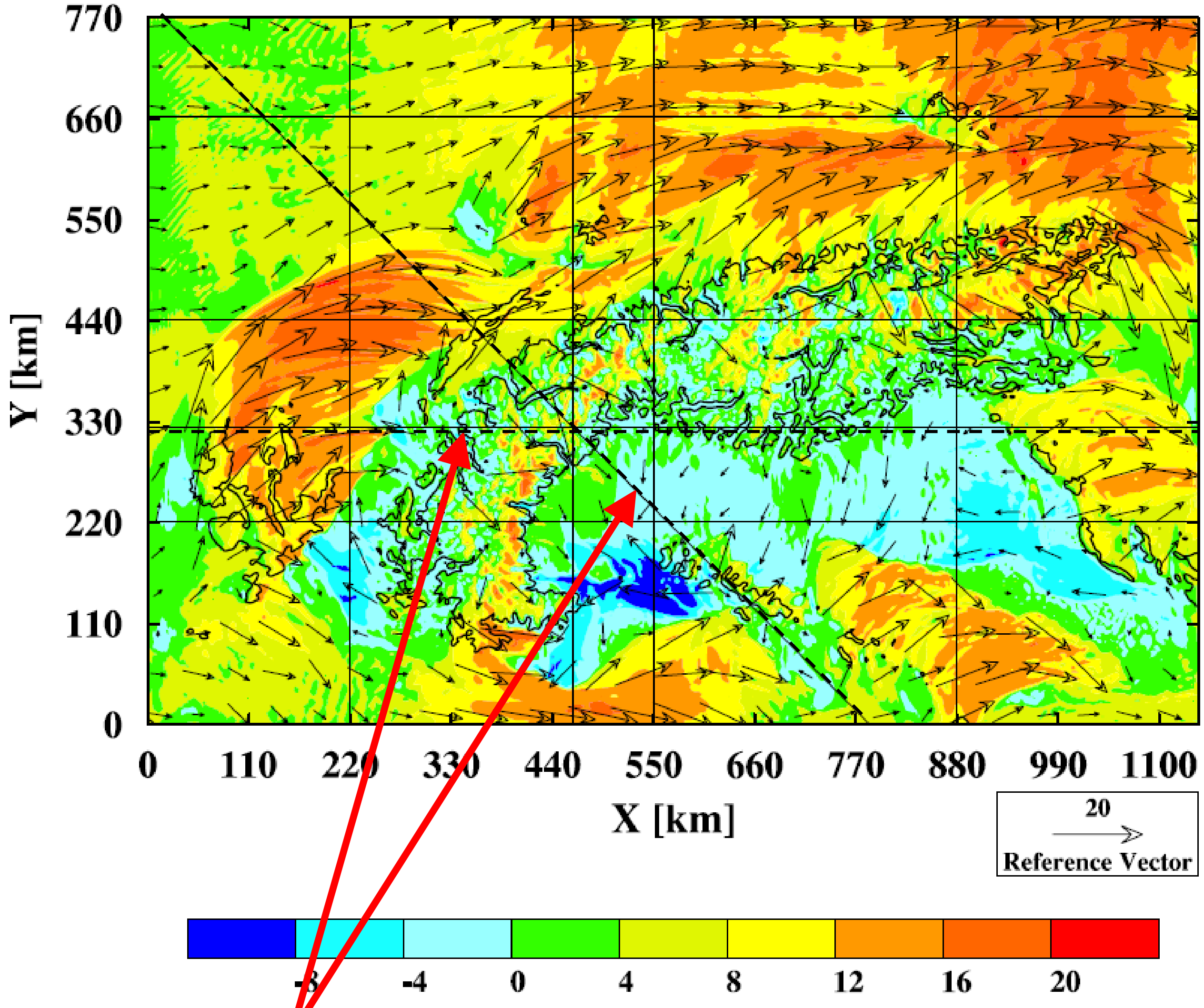
Quasi-stationary Alpine flows

Quasi-stationary Alpine flows with very high resolutions:

Setup of the experiment:

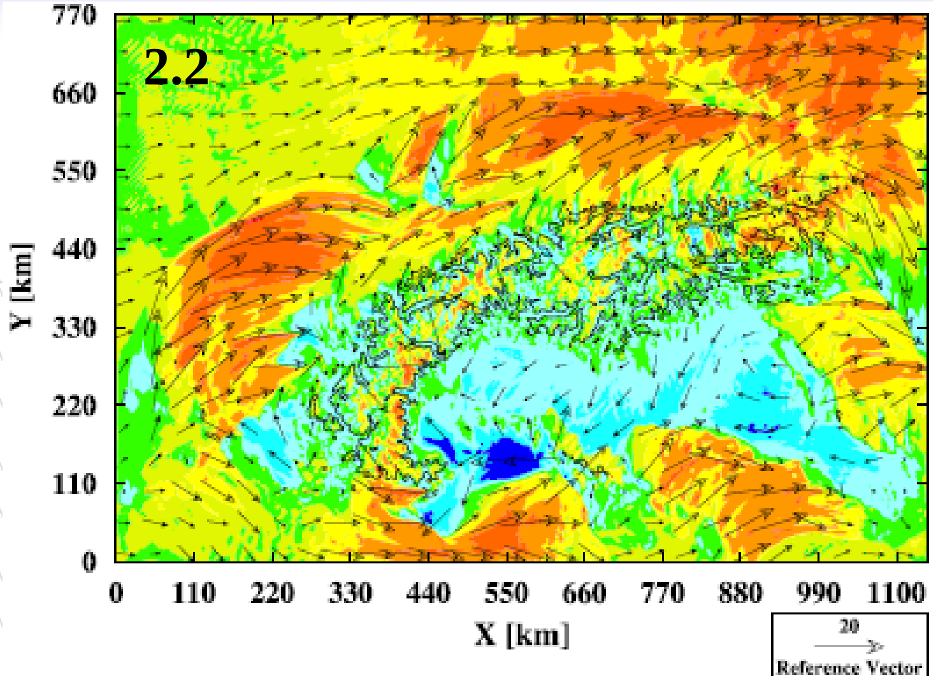
- 24 hour forecast
- initial conditions: horizontally averaged wind and temperature from MeteSwiss COSMO2 operational analysis from 12. 11. 2009, 00z
- boundary conditions: constant in time and defined as above
- horizontal resolution (grid step): 2.2, 1.1, 0.55 km
- for 2.2 km resolution: grid points, main model levels, horizontal domain as for COSMO2
- for higher resolutions: grid points generated by halfing horizontal grid spacings, domain size as for 2.2 km experiment
- orography: MeteoSwiss 2.2 km dataset or derived from 90m SRTM satellite data for 1.1 and 0.55 km resolutions
- no parameterizations of subscale processes

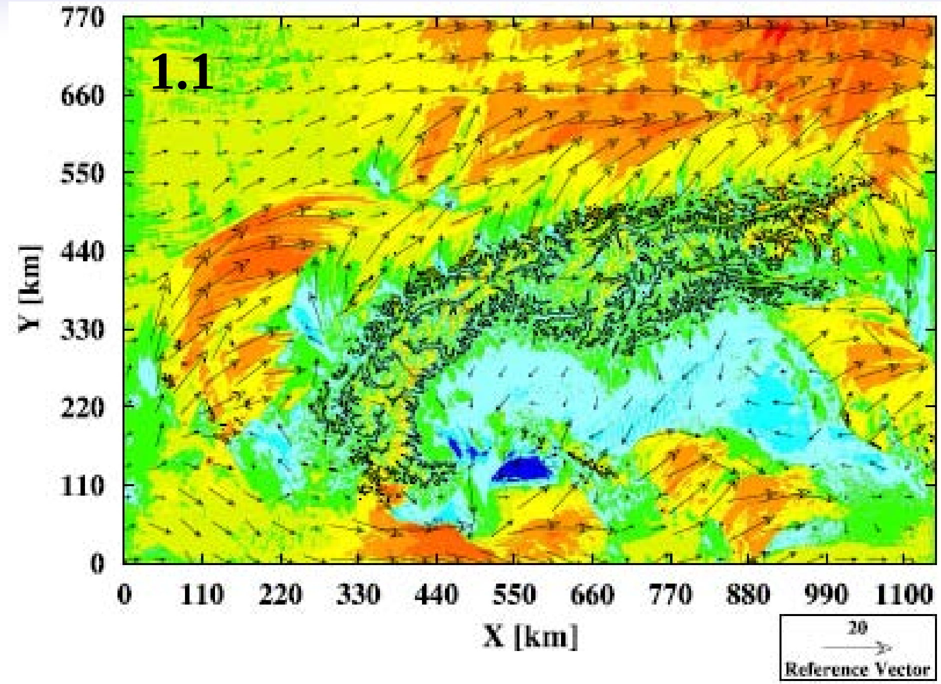
Quasi-stationary Alpine flows

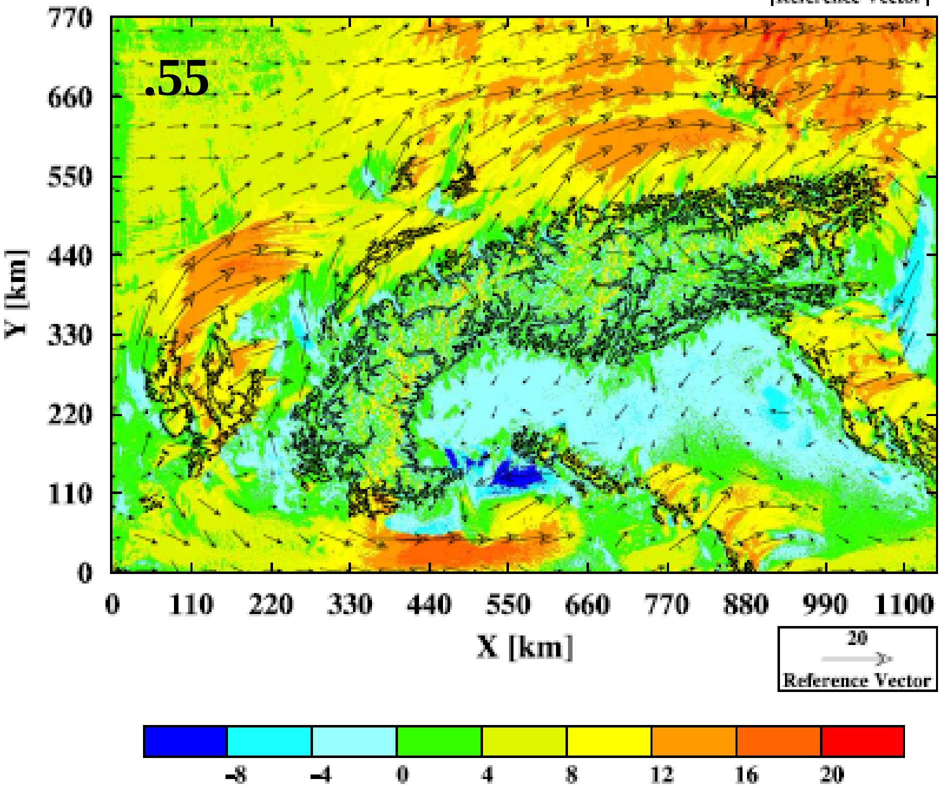


COSMO2 domain and localization of crosssections, Alpine orography at z = 1000 m shown

Quasi-stationary Alpine flows

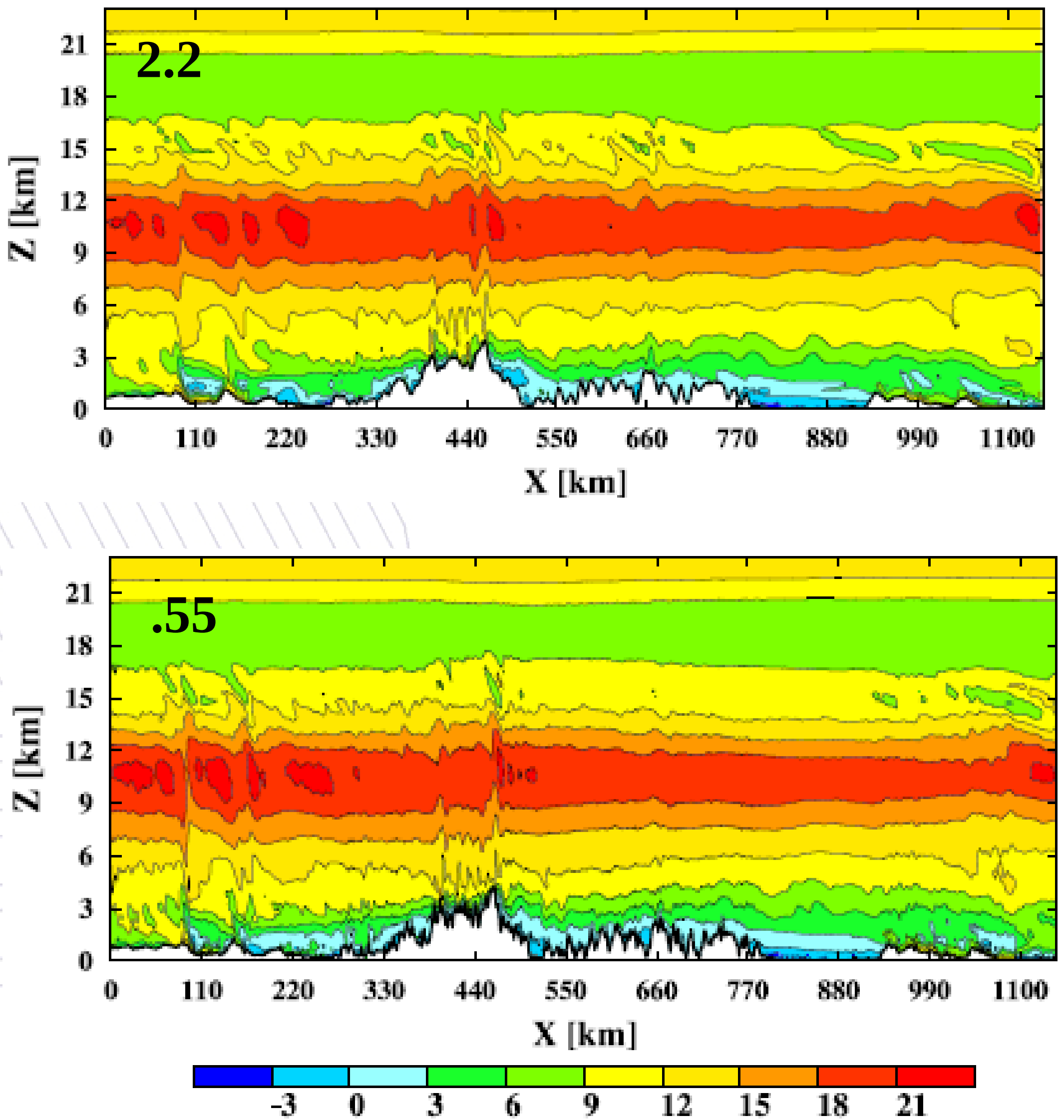




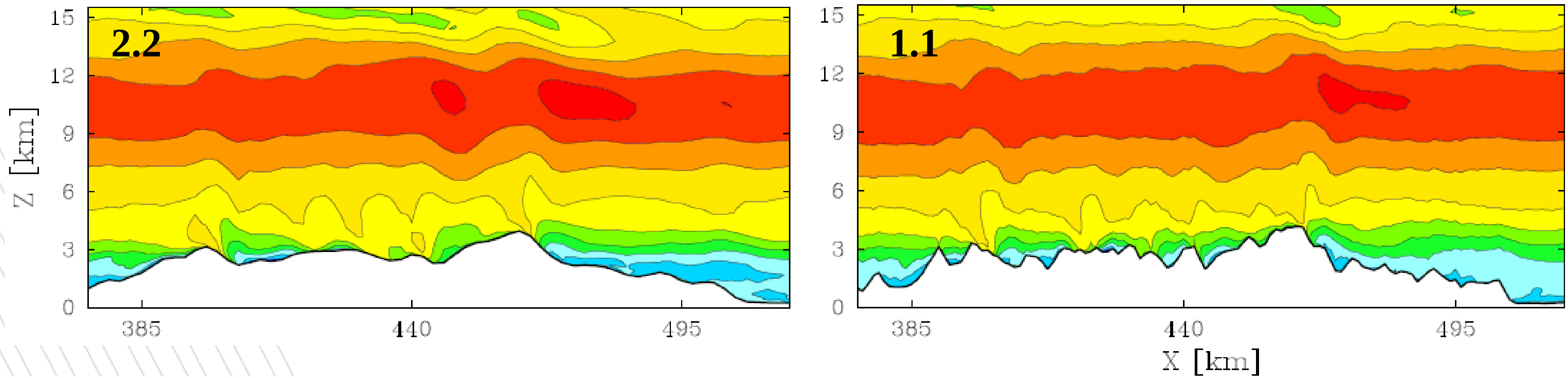


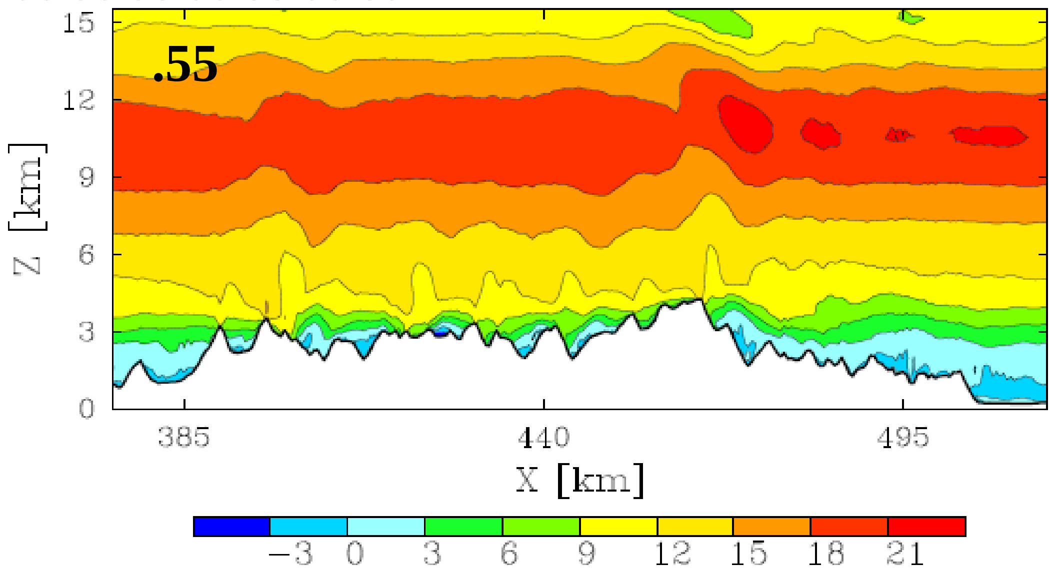
U-component of velocity after 24 hours, 10 m above surface, resolution 2.2, 1.1 and 0.55 km

Quasi-stationary Alpine flows



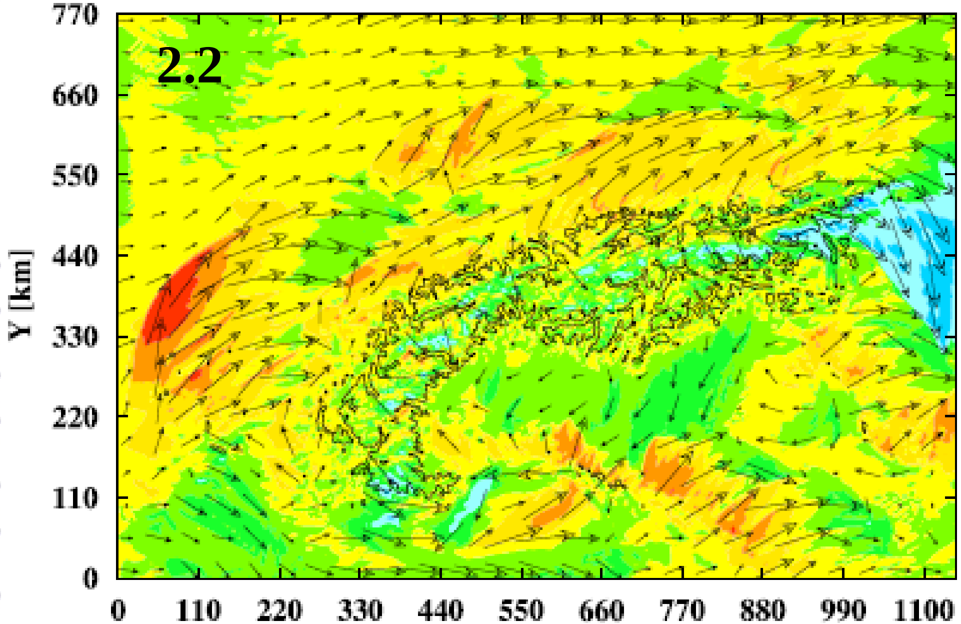
U-component of velocity after 24 hours, vertical-’zonal’ cross-section, Mt. Blanc, resolution 2.2, 1.1 and 0.55 km

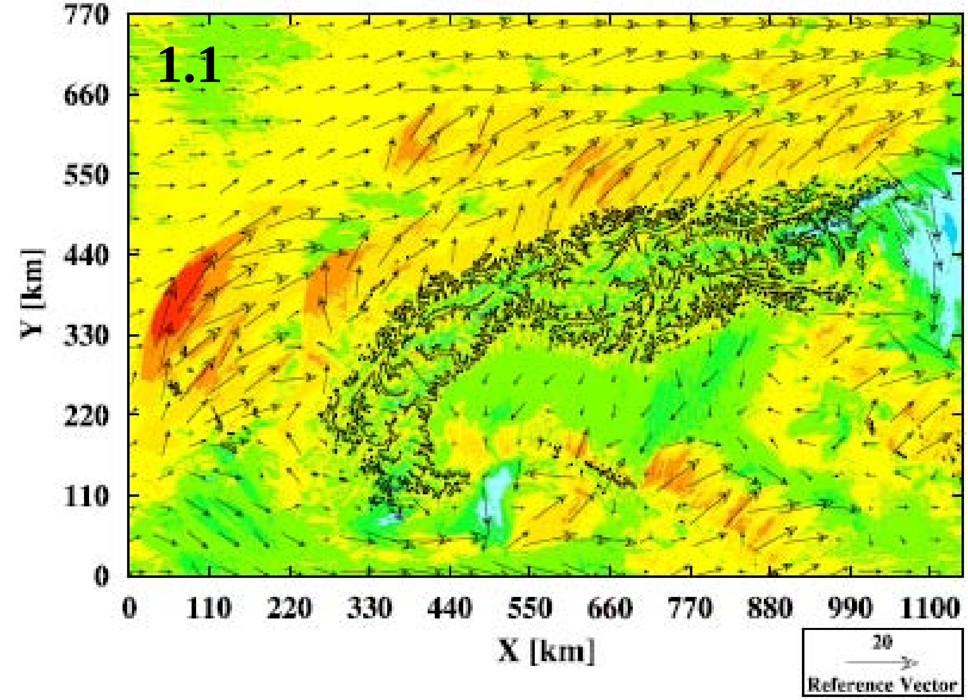


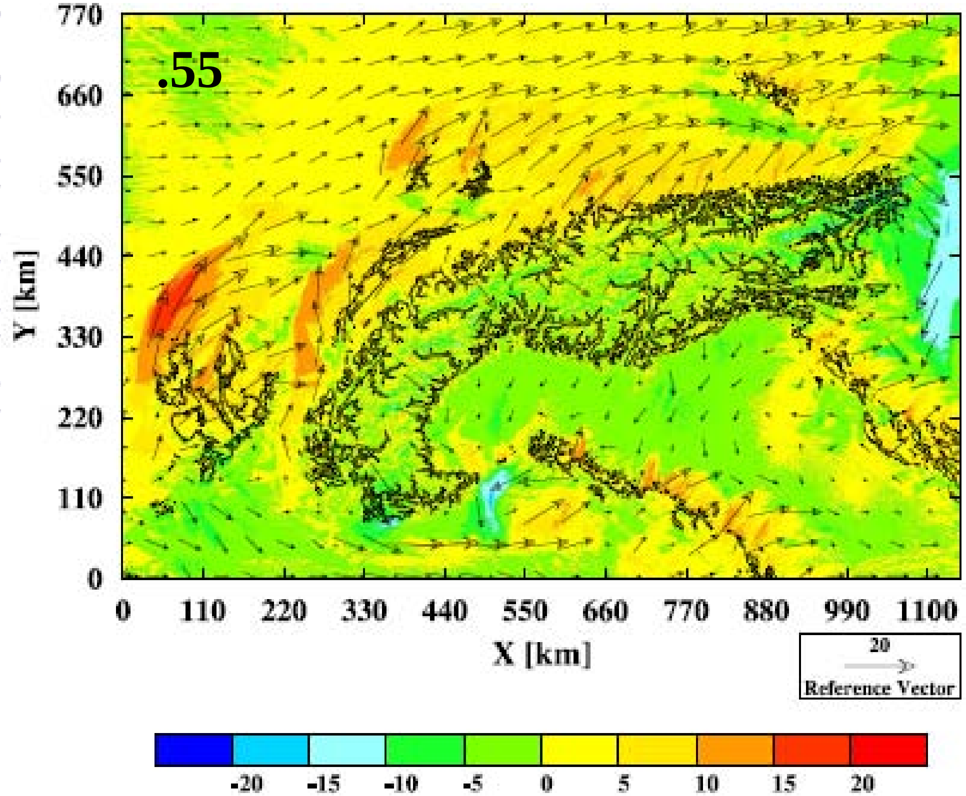


U-component of velocity after 24 hours, vertical-'zonal' cross-section, Mt. Blanc, resolution 2.2, 1.1 and 0.55 km

Quasi-stationary Alpine flows

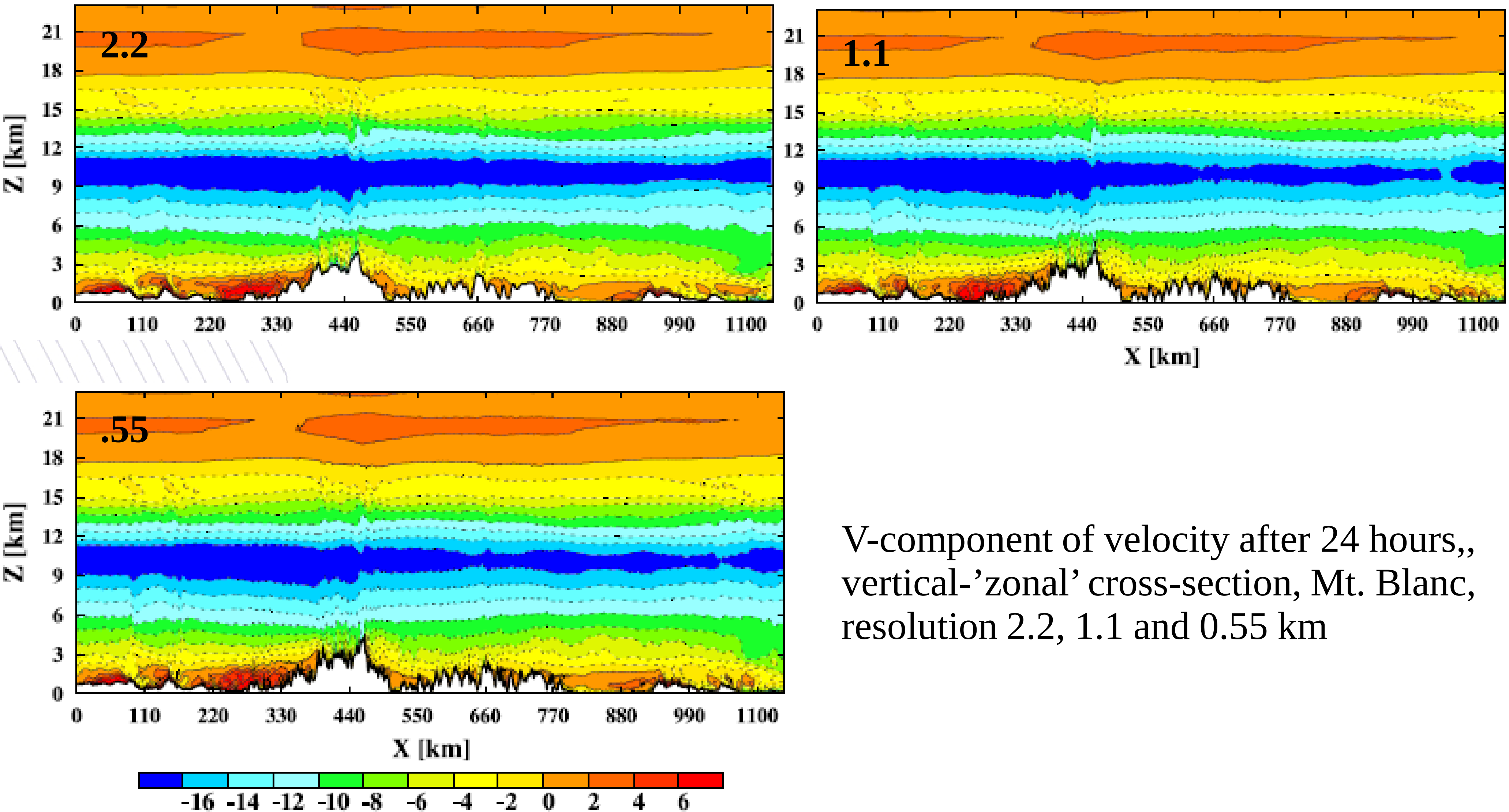






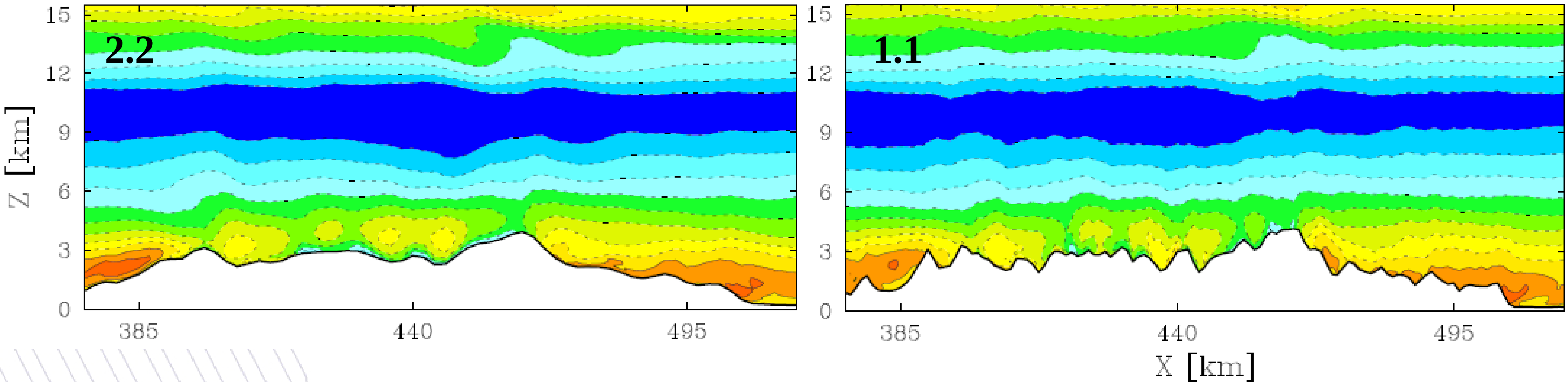
V-component of velocity after 24 hours,
10 m AGL, resolution 2.2, 1.1 and 0.55 km

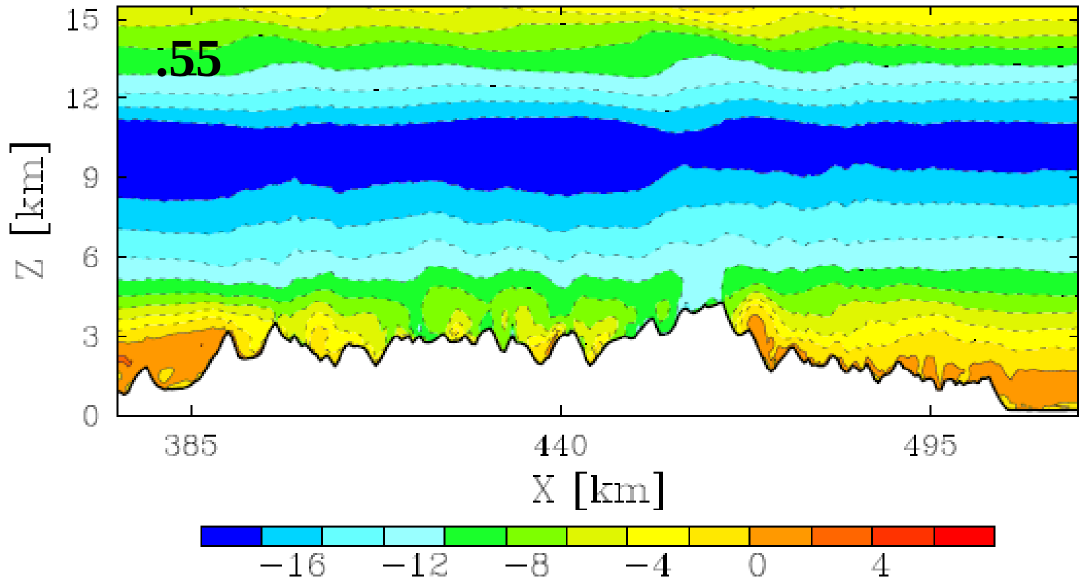
Quasi-stationary Alpine flows



V-component of velocity after 24 hours,, vertical-’zonal’ cross-section, Mt. Blanc, resolution 2.2, 1.1 and 0.55 km

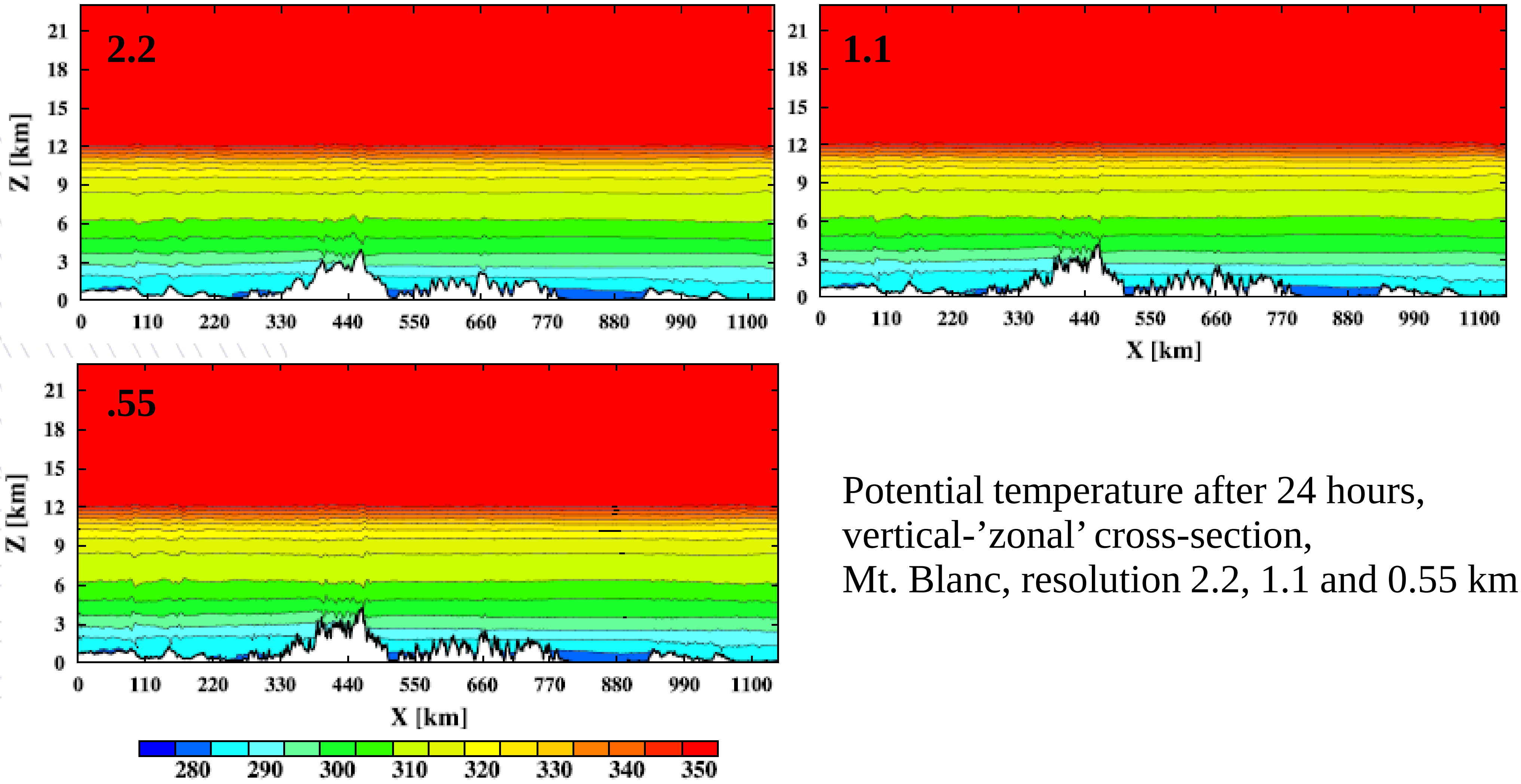
Quasi-stationary Alpine flows





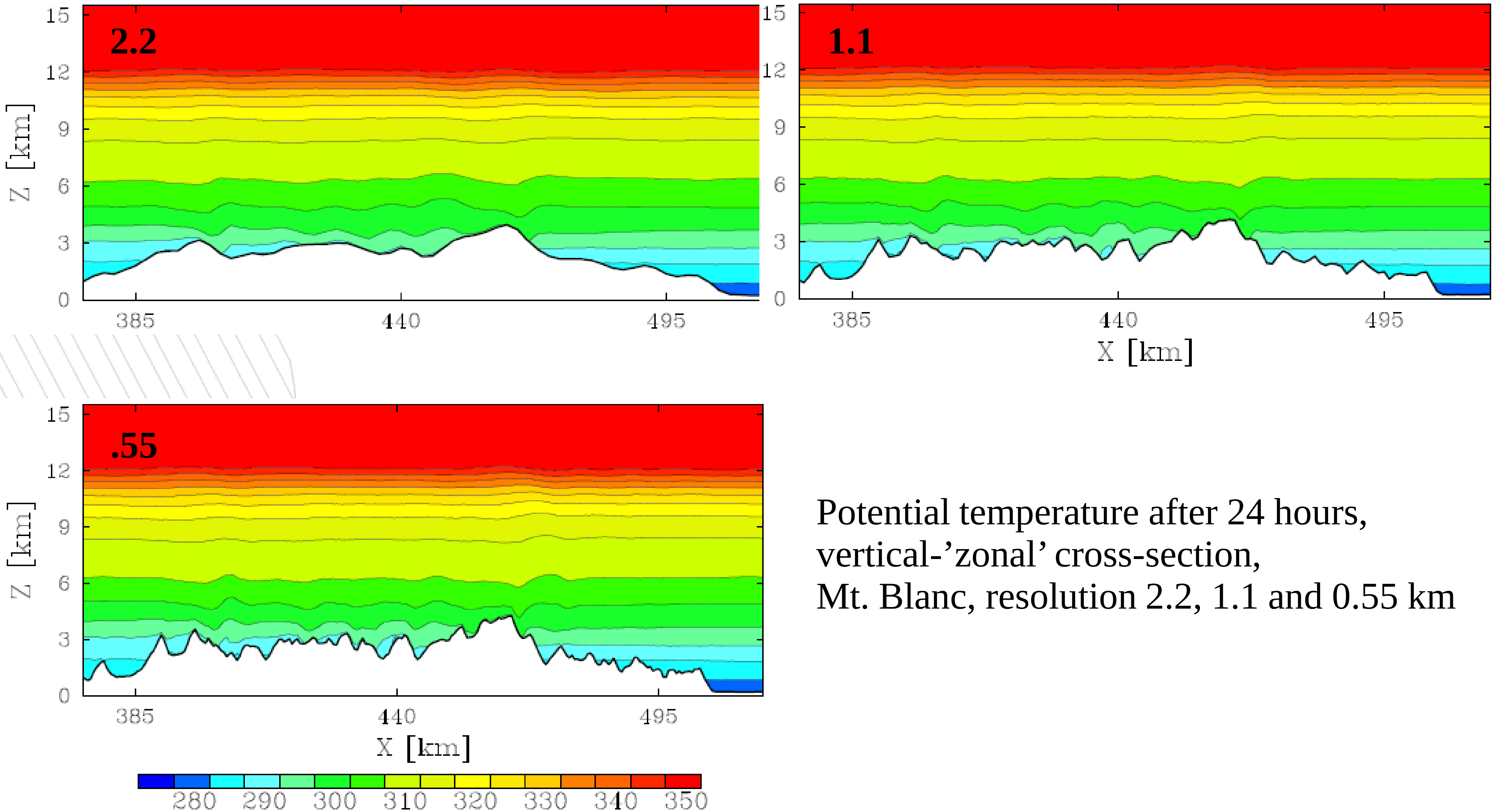
V-component of velocity after 24 hours,, vertical-’zonal’ cross-section, Mt. Blanc, resolution 2.2, 1.1 and 0.55 km

Quasi-stationary Alpine flows



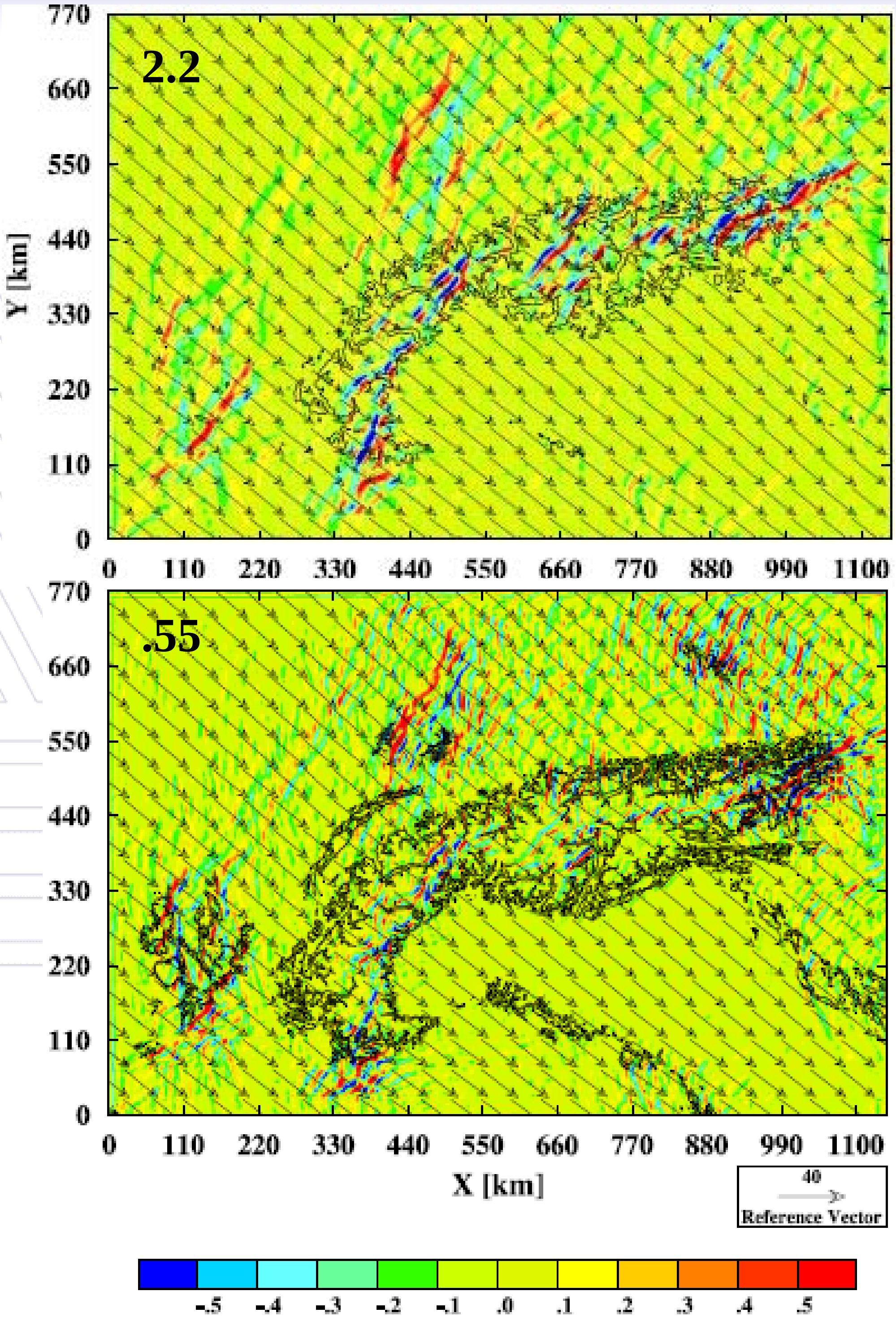
Potential temperature after 24 hours,
vertical-’zonal’ cross-section,
Mt. Blanc, resolution 2.2, 1.1 and 0.55 km

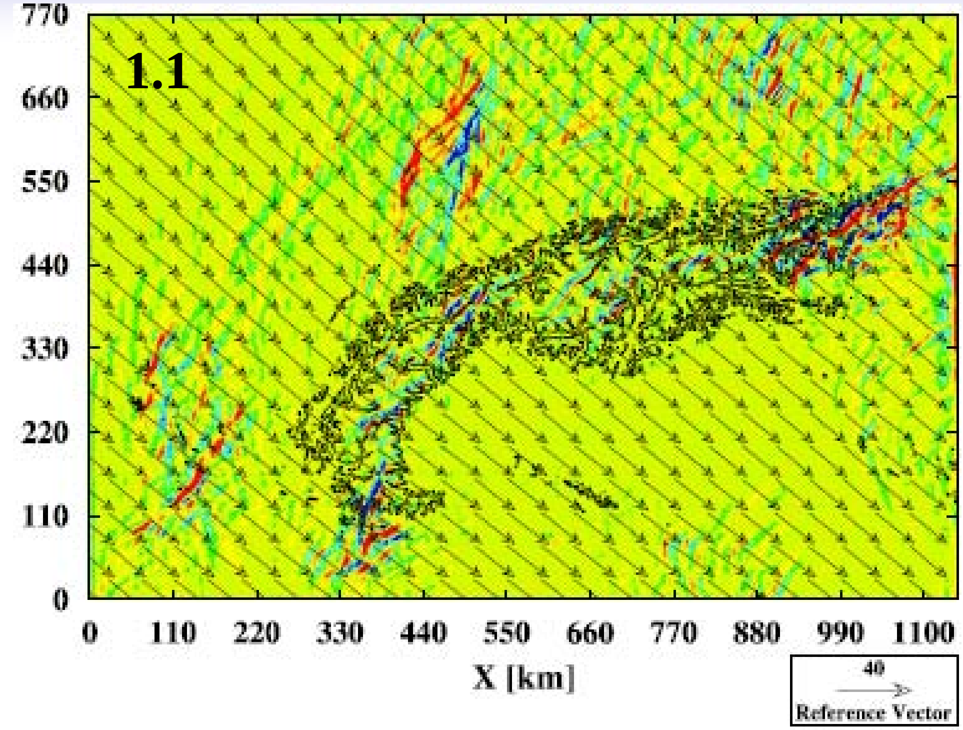
Quasi-stationary Alpine flows



Potential temperature after 24 hours, vertical-’zonal’ cross-section, Mt. Blanc, resolution 2.2, 1.1 and 0.55 km

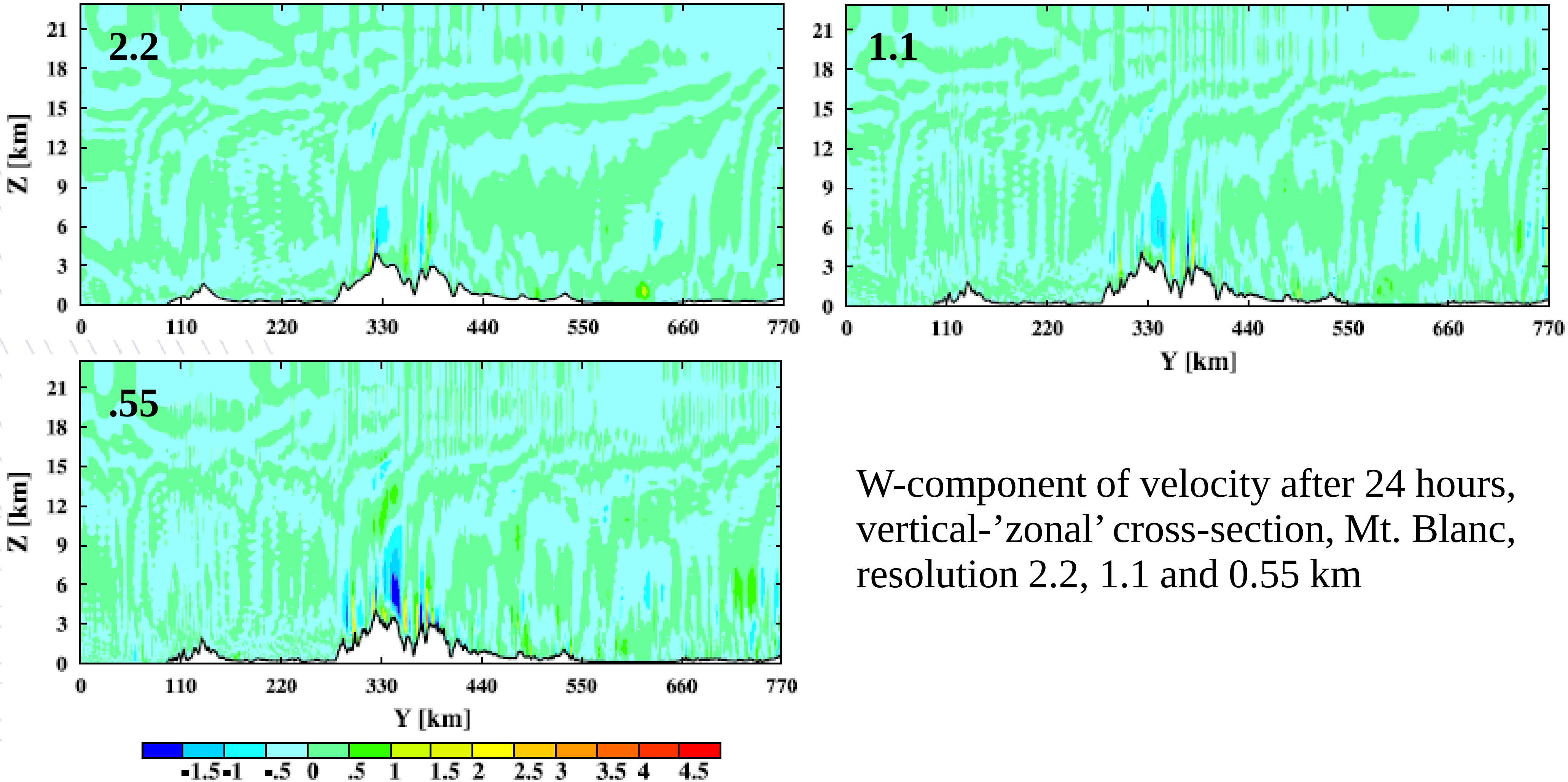
Quasi-stationary Alpine flows





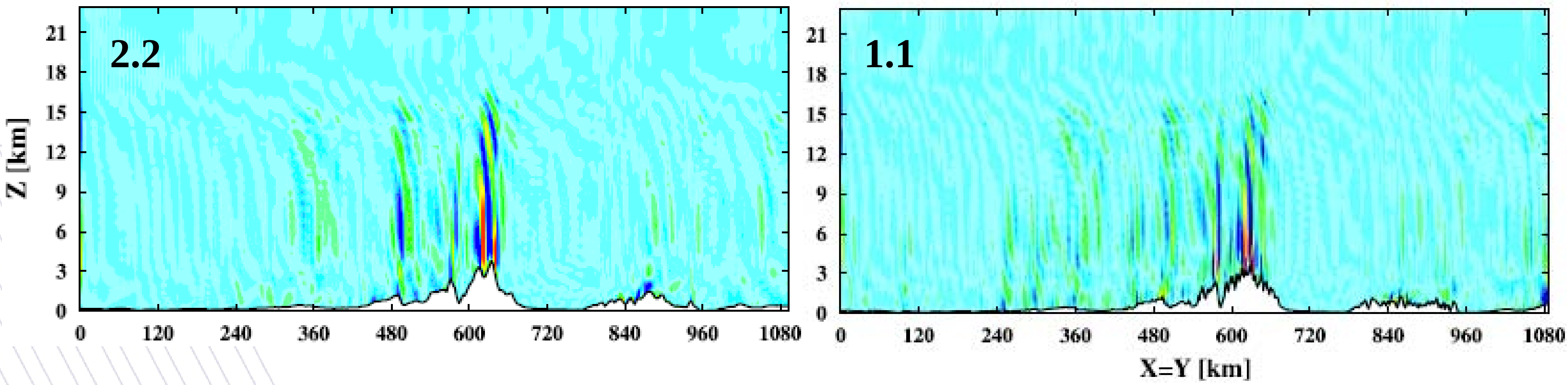
W-component of velocity after 24 hours, on 40 model level, resolution 2.2, 1.1 and 0.55 km

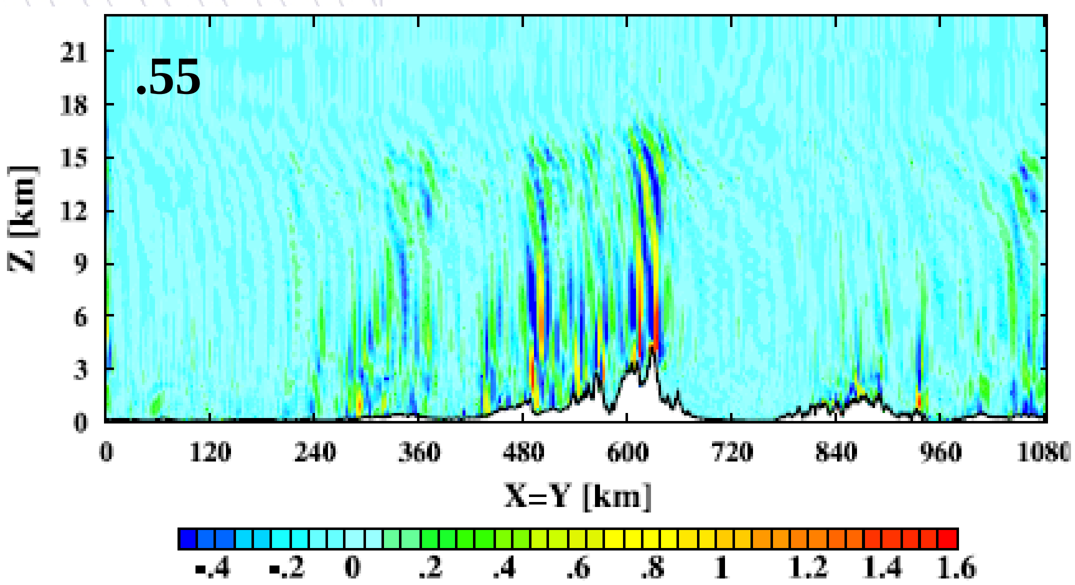
Quasi-stationary Alpine flows



W-component of velocity after 24 hours, vertical-’zonal’ cross-section, Mt. Blanc, resolution 2.2, 1.1 and 0.55 km

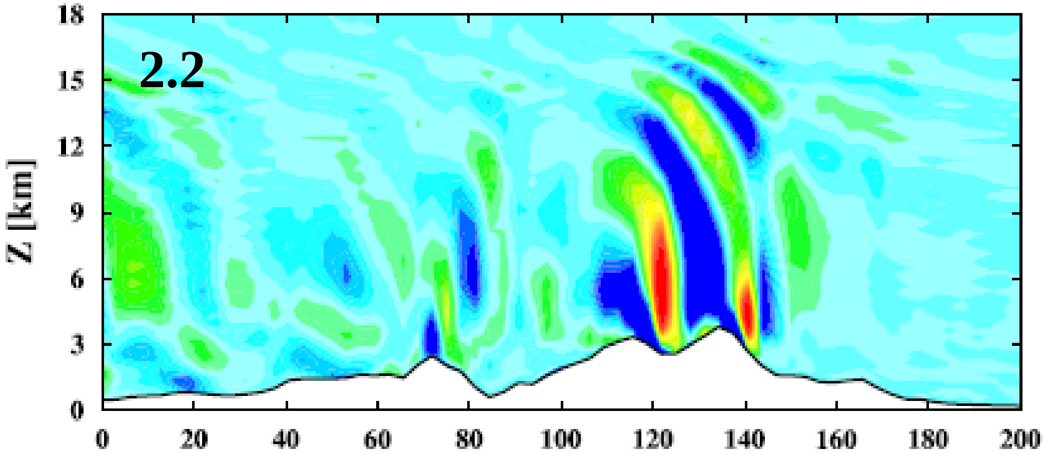
Quasi-stationary Alpine flows

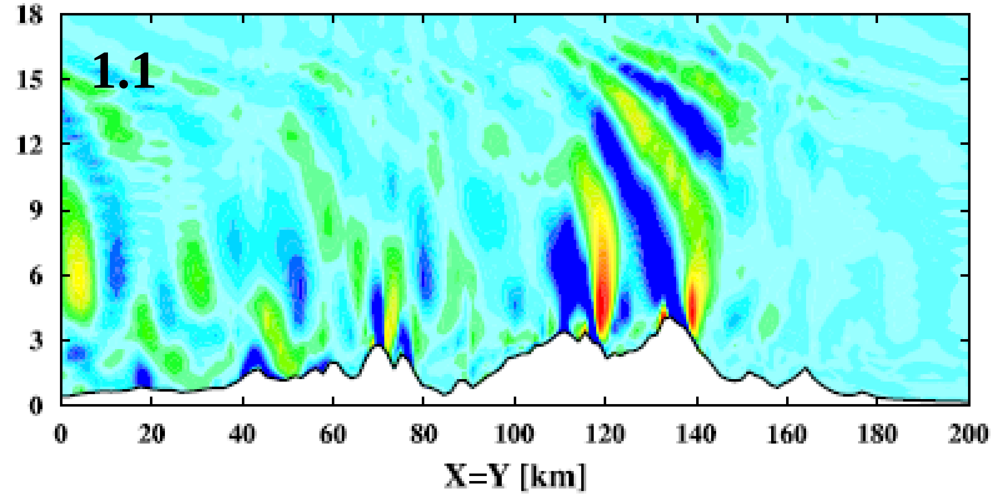


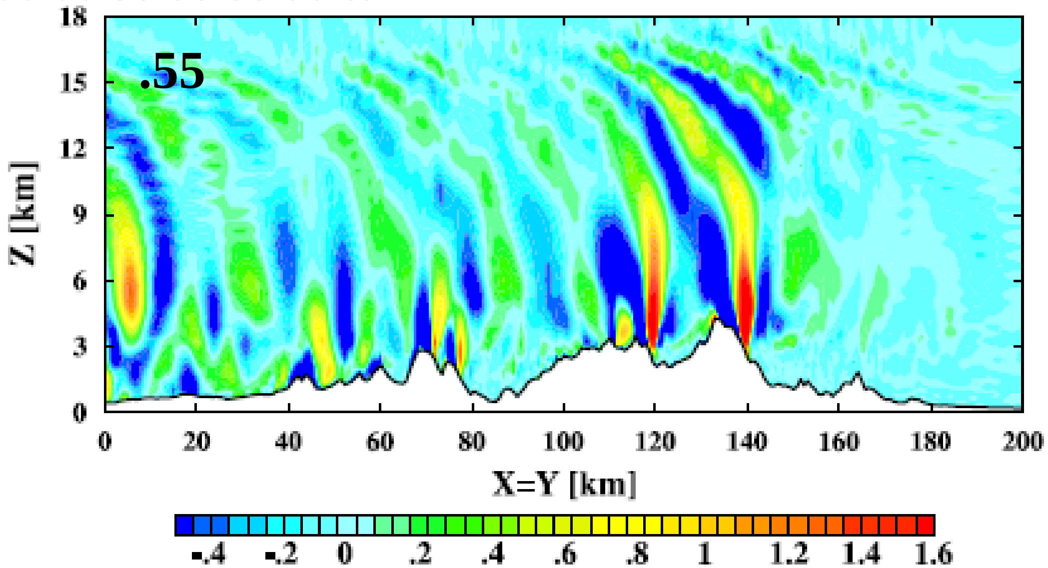


W-component of velocity after 24 hours, along-flow cross-section, Mt. Blanc, resolution 2.2, 1.1 and 0.55 km

Quasi-stationary Alpine flows







W-component of velocity after 24 hours, along-flow cross-section, Mt. Blanc, resolution 2.2, 1.1 and 0.55 km

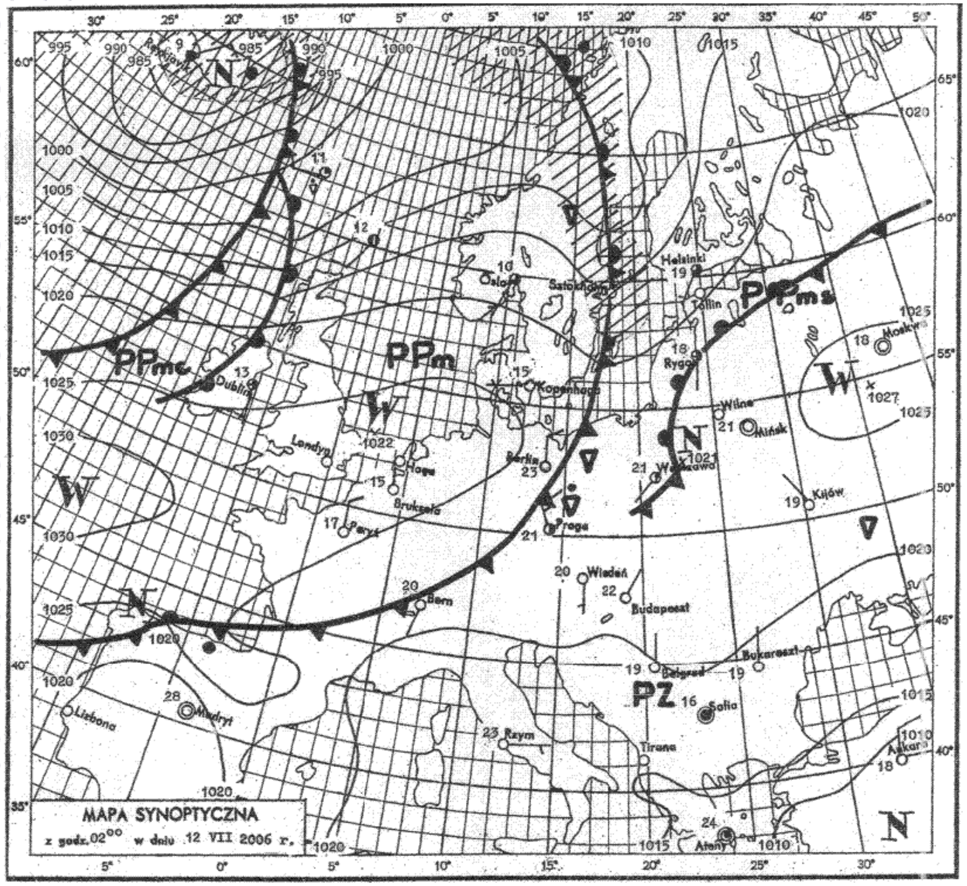
Alpine convection – preliminary results

A case study for the Alpine summer convection:

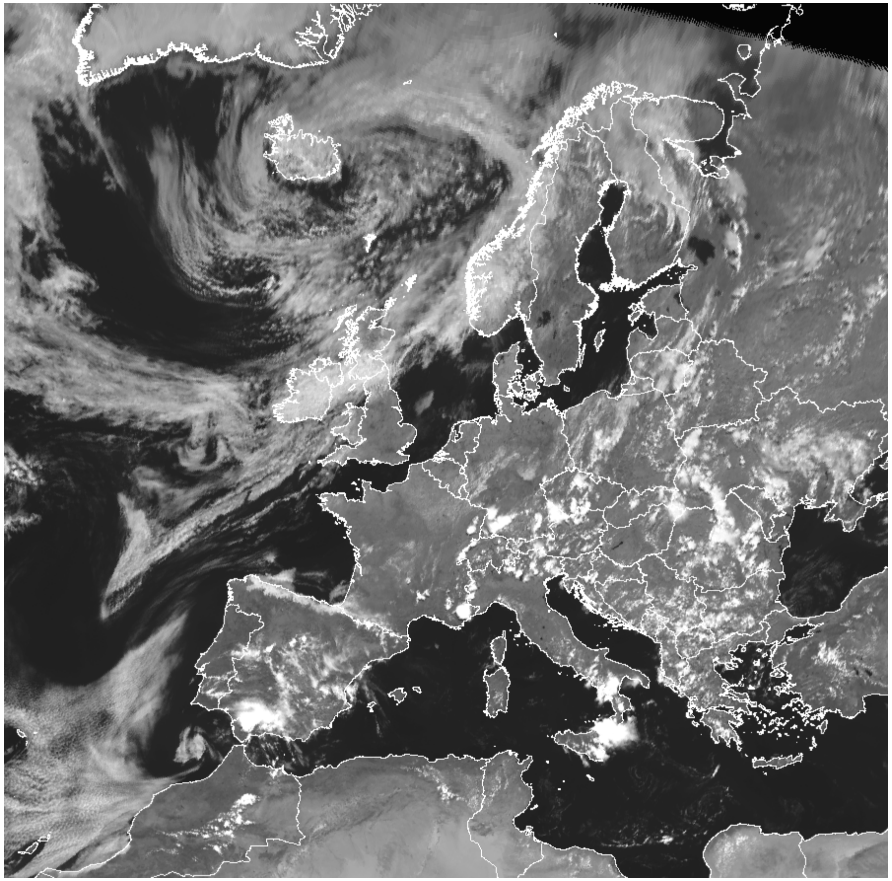
- use EULAG dynamical core with horizontal resolutions of 2.2, 1.1 and 0.55 km
- simple representations of boundary layer processes:
  a) TKE turbulent kinetic energy
  b) ILES (no subgrid-scale model) + prescribed form of surface heat fluxes in boundary layer
- simple representation of moist processes (warm rain Kessler scheme)
- initial and boundary conditions from operation run of COSMO2 model for Switzerland, with resolution of 2.2 km; for higher resolutions the boundary condition are interpolated from the COSMO2 model
- orography: MeteoSwiss 2.2 km dataset, or derived from 90m SRTM data for 1.1 and 0.55 km resolutions
- compare the results with observations, especially satellite data
- compare the results with operation run of COSMO2 (compressible Runge-Kutta core)
- EULAG simulations start at 06 UTC

Alpine convection

Synoptic situation in the area: slow-moving cold front in a shallow surface trough of low pressure

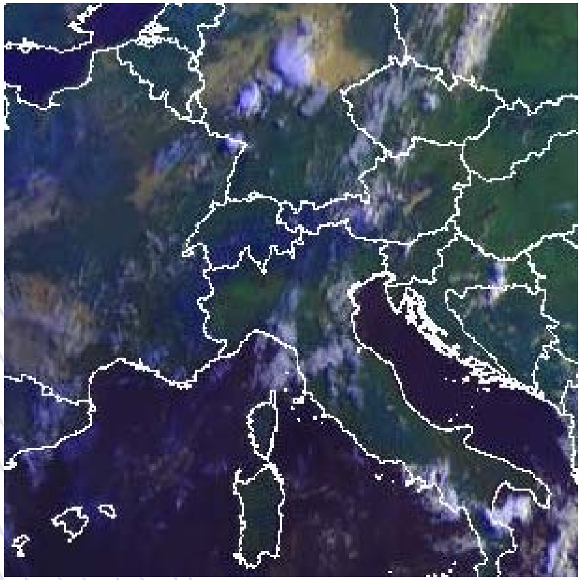


Synoptic map – 00 UTC, 12 July 2006



MSG (Meteosat Second Genertion) 12 UTC

Alpine convection

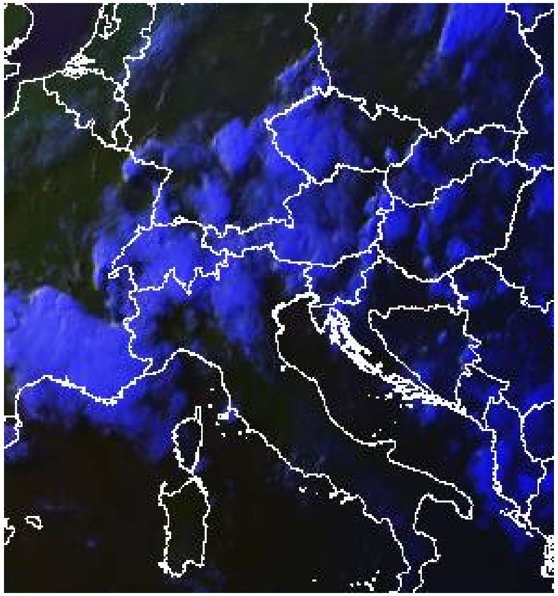


MSG 6:00 UTC

MSG 9:00 UTC

MSG 12:00 UTC

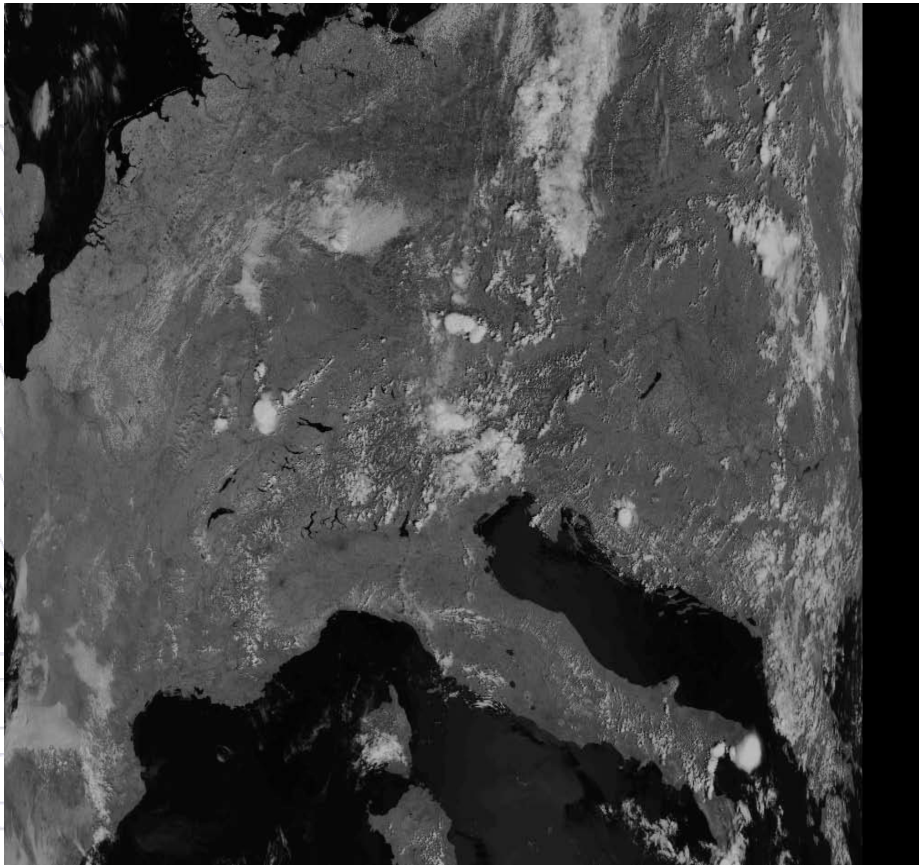
MSG 15:00 UTC



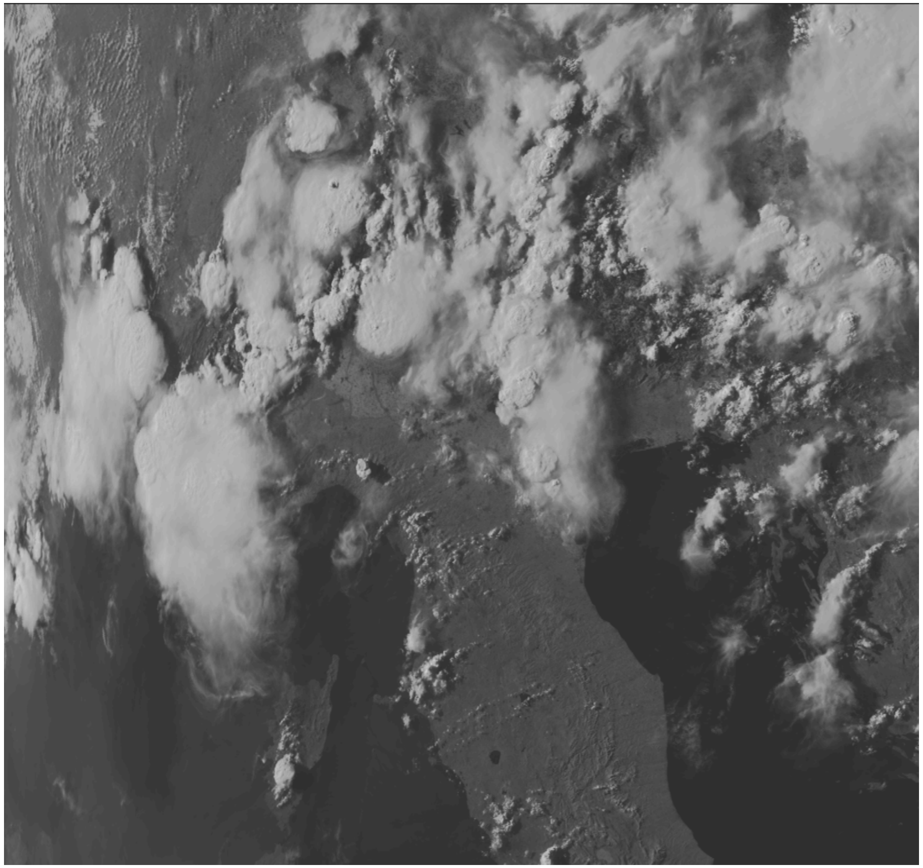
MSG 18:00 UTC

MSG images: superposition of visible and infrared channels in false colours

High resolution NOAA satellite images from 12 July 2006

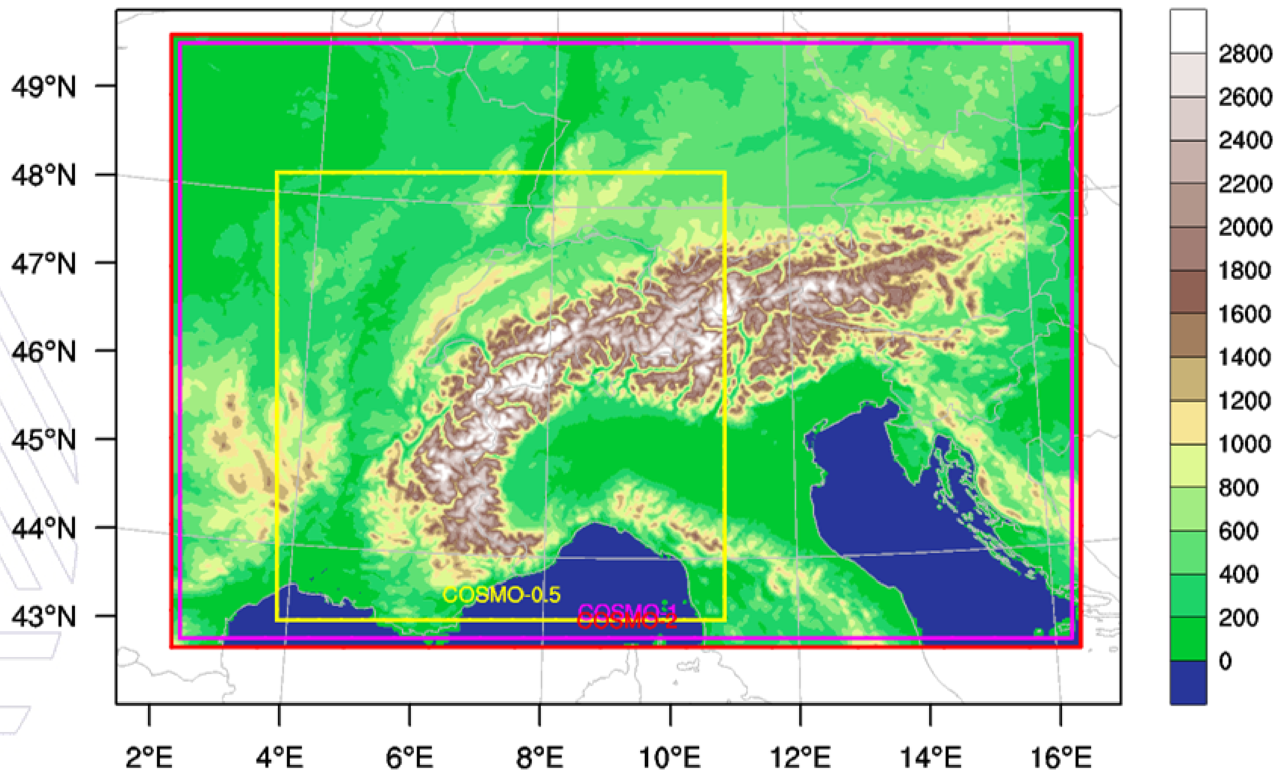


NOAA 9:00 UTC



NOAA 15:00 UTC

Simulation domains and characteristics

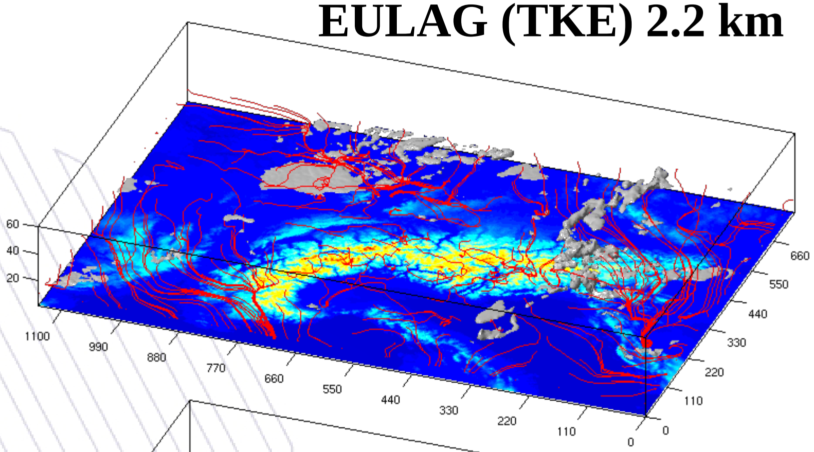


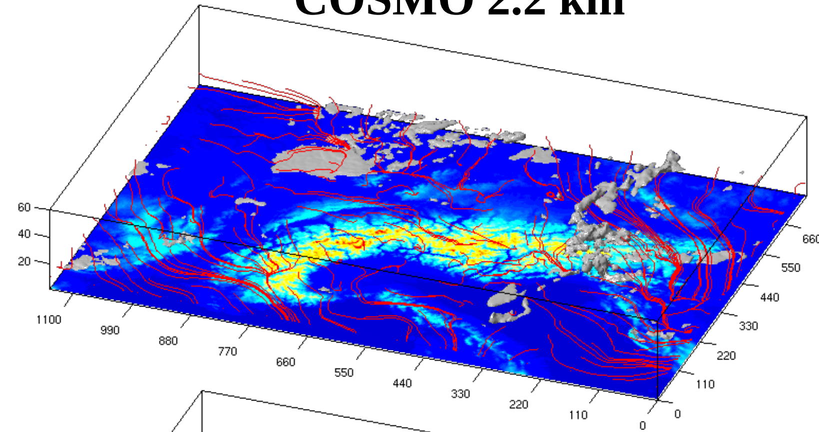
Horizontal resolution	Domain size in grid points	# processsors and machine	Forecast	Wall clock time
2.2km	520 x 350 x 61	500 - CRAY XT4	12 hours	1h 10 min
1.1km	1020 x 680 x 61	400 - CRAY XT4	7 hours	~6 h
0.55km	1020 x 1020 x 61	400 - CRAY XT5m	12 hours	~18 hours

Comparison of cloud condensate and near-surface streamlines

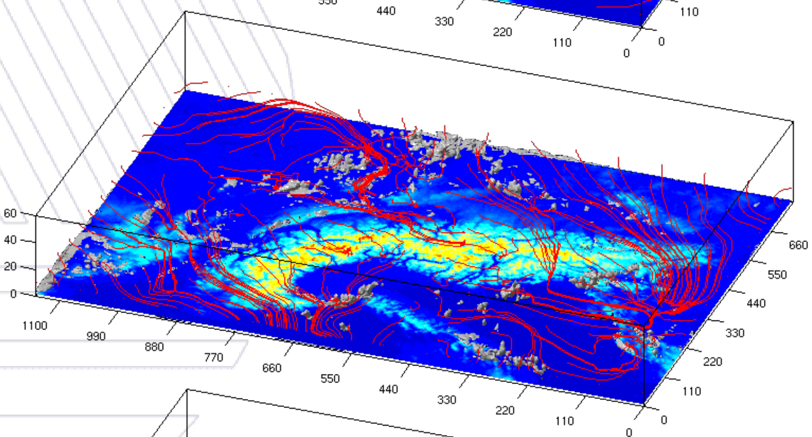
EULAG (TKE) 2.2 km | **COSMO 2.2 km**

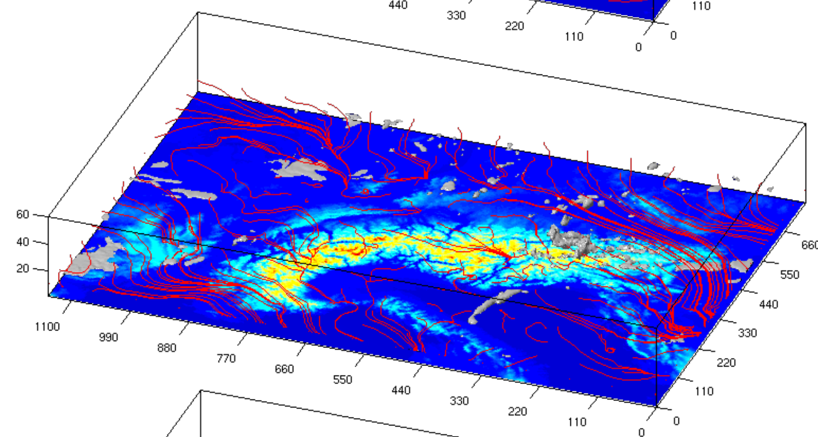
6:00 UTC



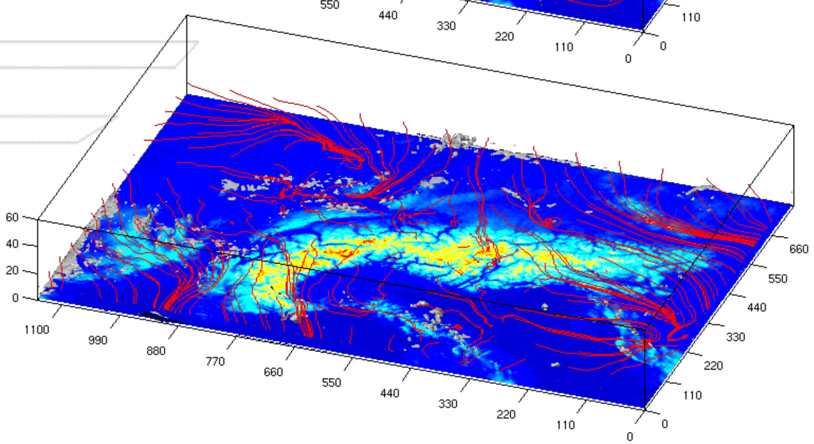


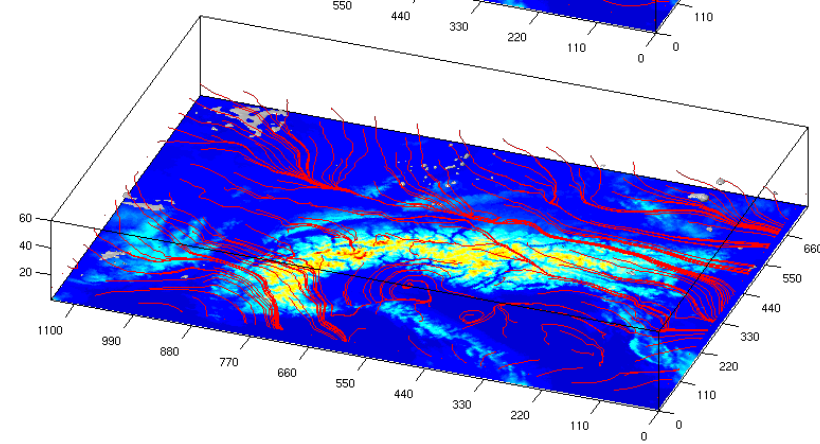
9:00 UTC





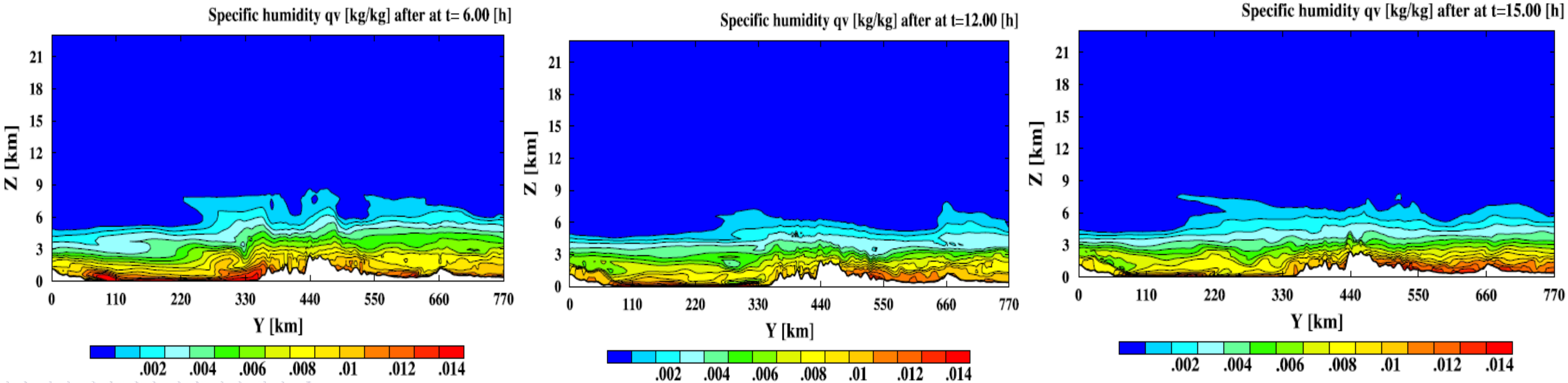
15:00 UTC



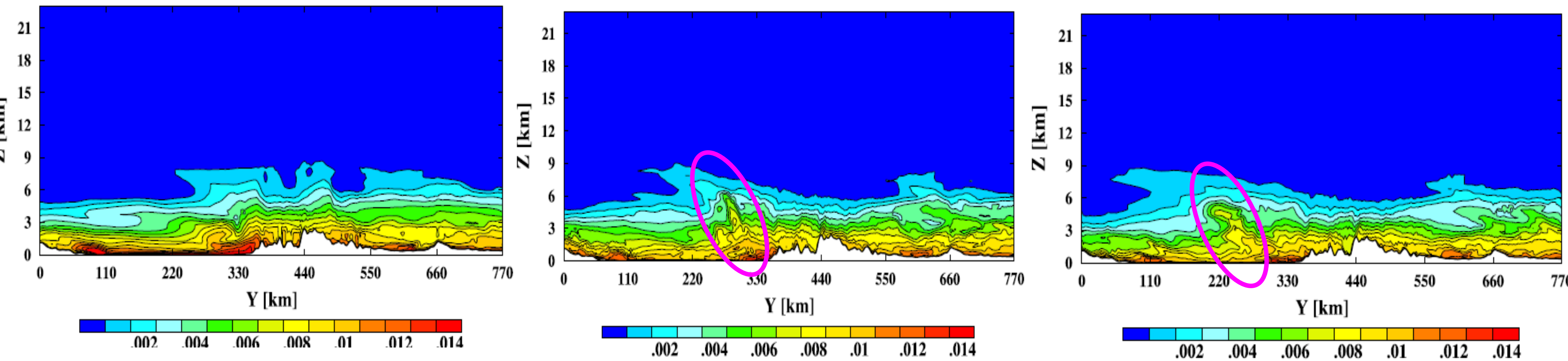


Evolution of specific humidity – vertical cross-sections.

COSMO 2.2 km

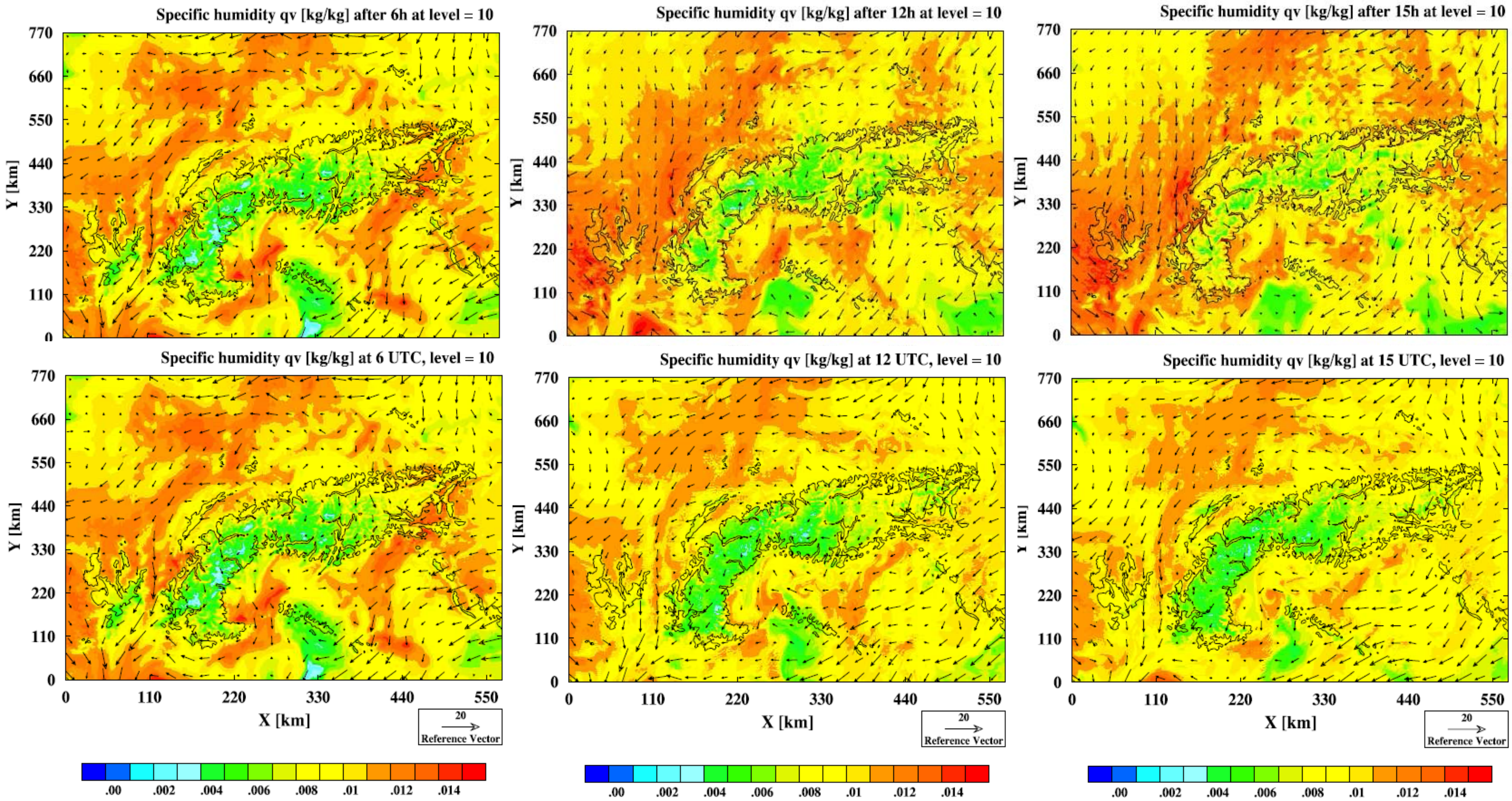


EULAG (TKE) 2.2 km



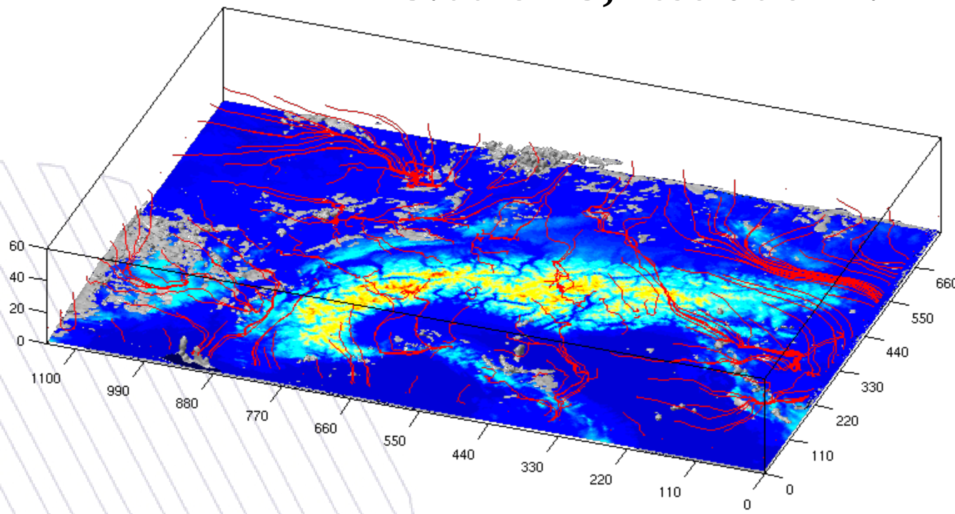
Evolution of velocity and specific humidity at <Z>~625m

COSMO 2.2 km

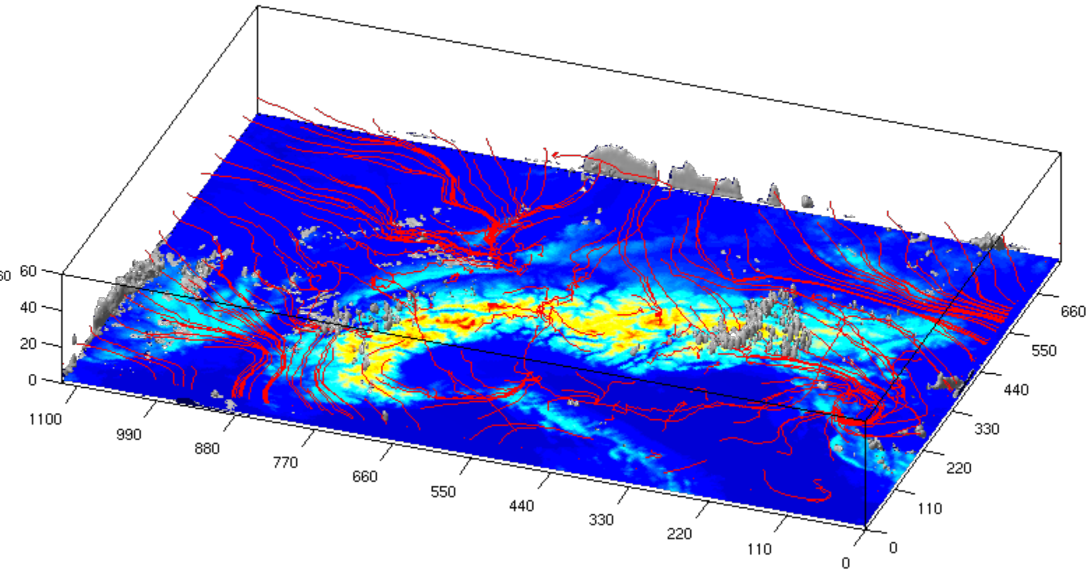


EULAG (TKE) 2.2 km

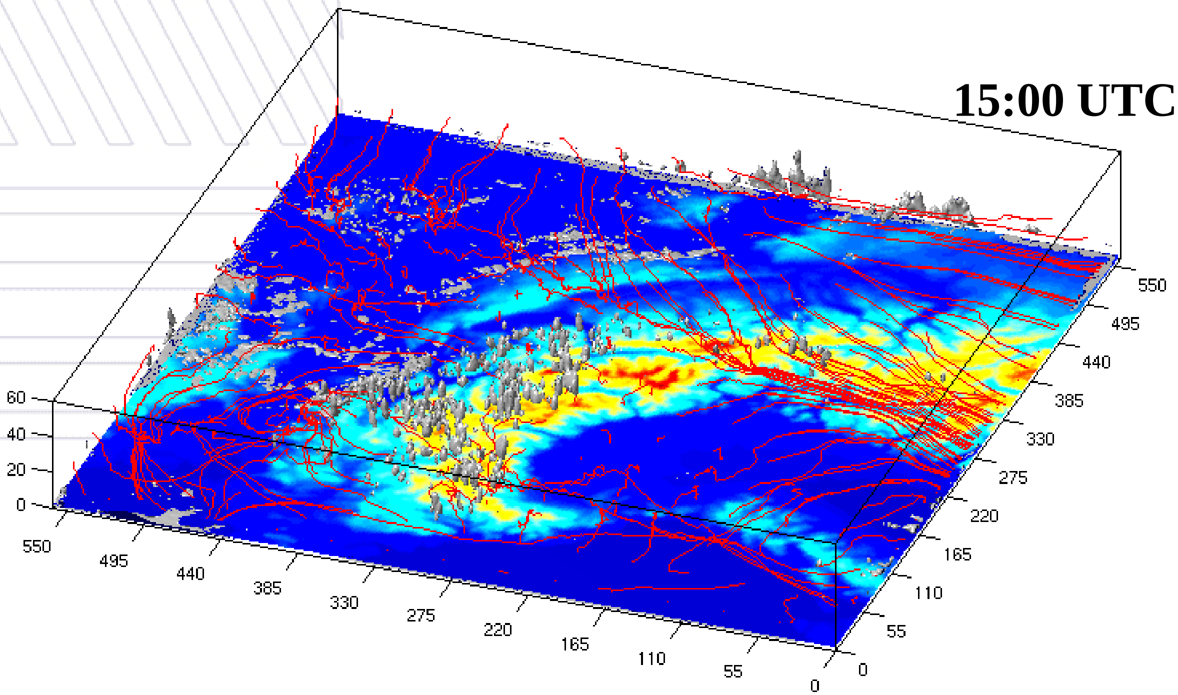
15:00 UTC, resolution 2.2km



13:00 UTC, resolution 1.1km



15:00 UTC, resolution 0.55km

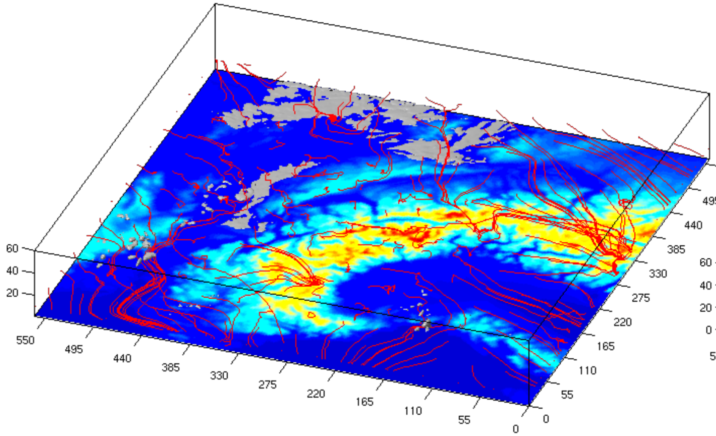


Cloud condensate and near-surface streamlines for EULAG simulations of varying resolution

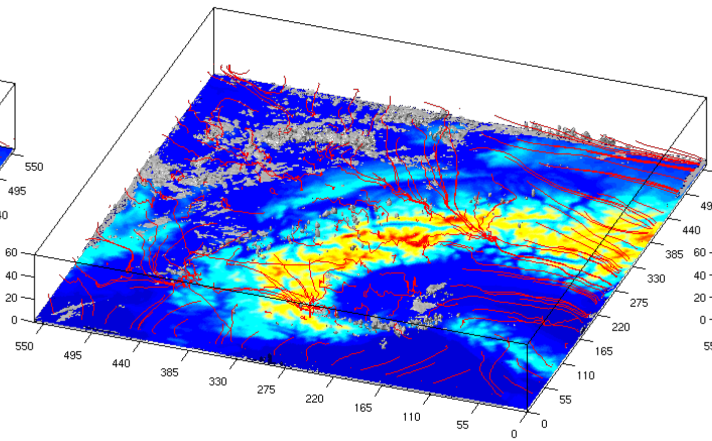
Alpine convection

EULAG simulation for 0.55 km resolution (ILES)

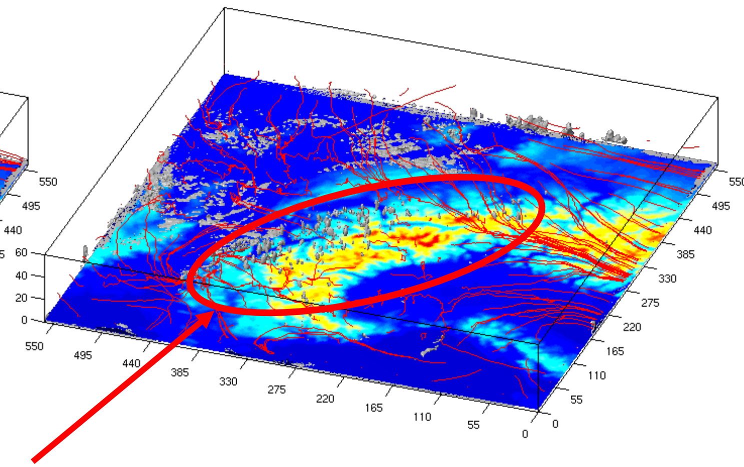
6:00 UTC



9:00 UTC

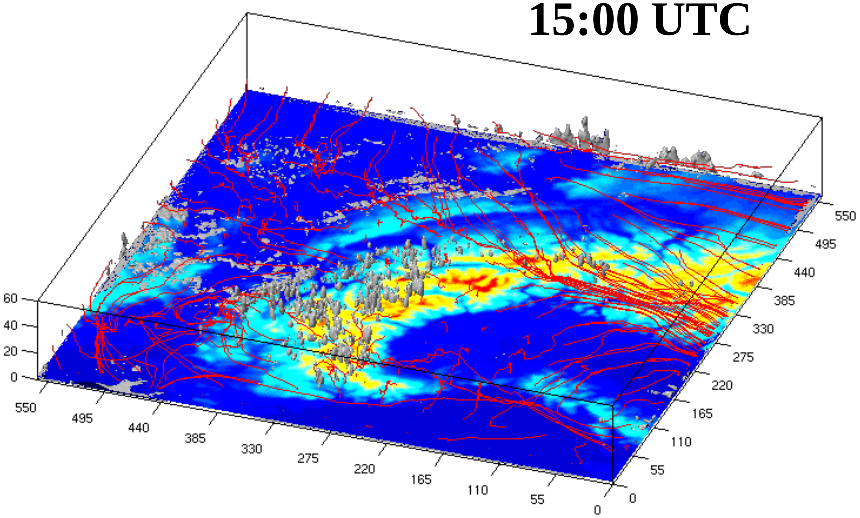


12:00 UTC

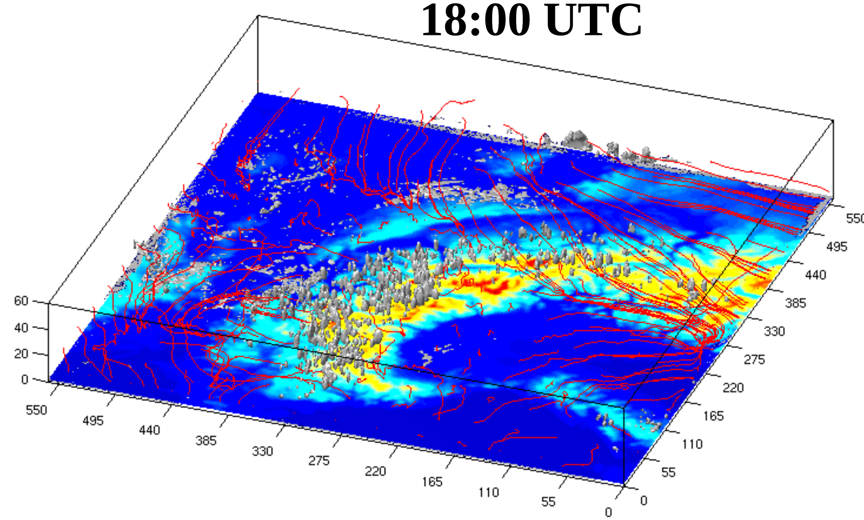


Process of cloud formation starts shortly before 12 UTC

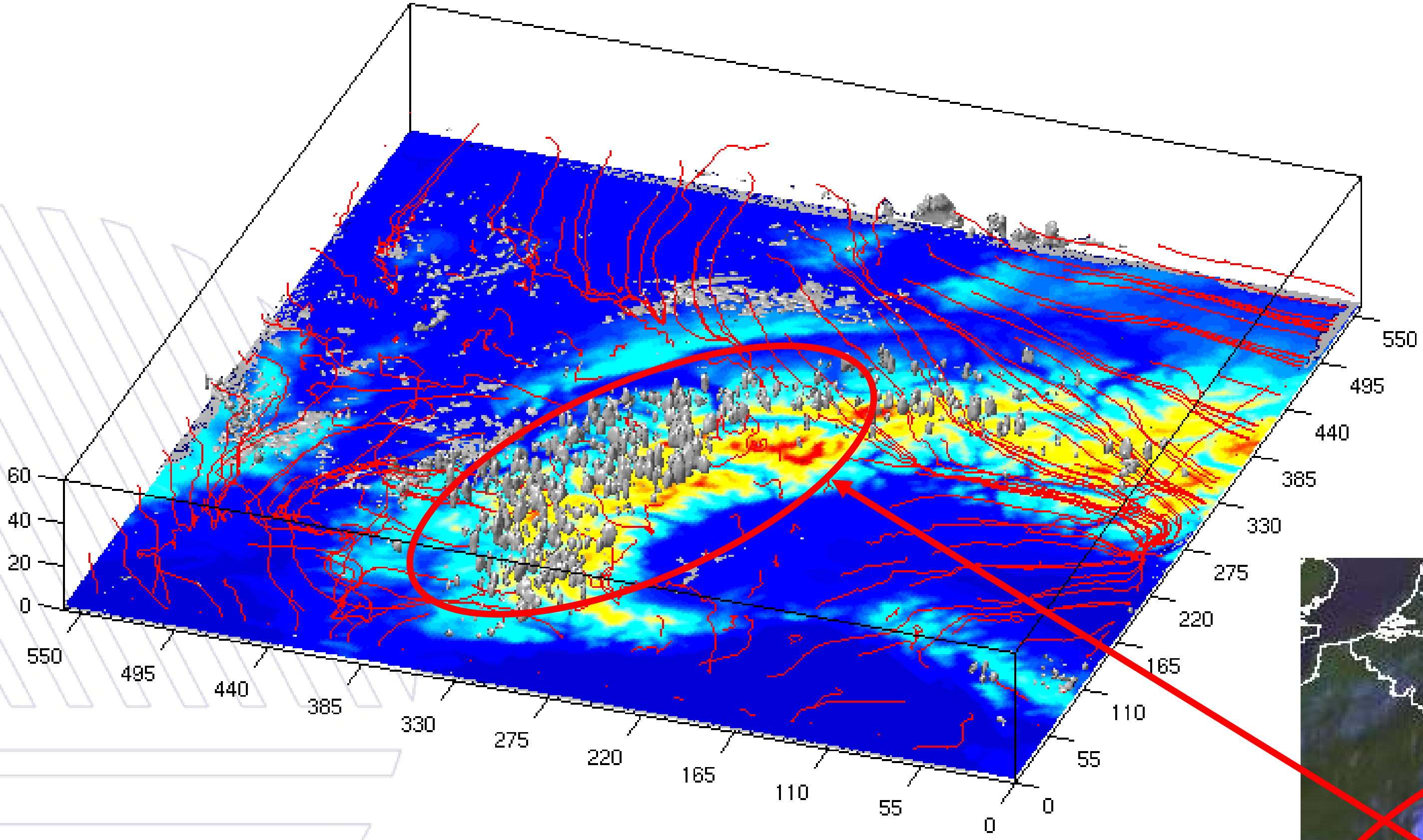
15:00 UTC

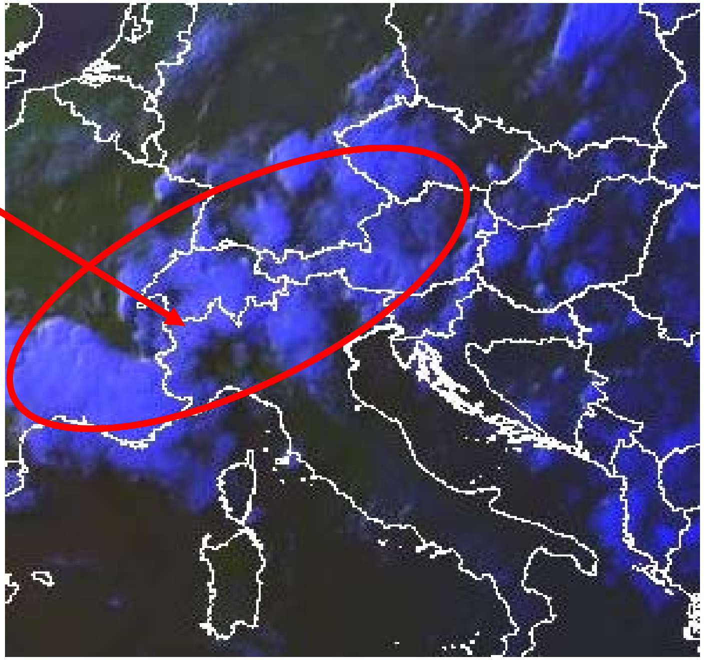


18:00 UTC



Alpine convection





EULAG simulation for 0.55km resolution
and satellite MSG image at 18:00 UTC

4. Summary

The results, so far:

• consistent and realistic results for quasi-stationary Alpine flows simulated with very-high resolutions

• lack of numerical problems (instabilities) related to strong orography or simplified physics

• the model starts to resolve the convection over SW Alps at resolutions of 1.1 to 0.55 km

• even at resolution of 0.55km the model is still far from representation of organization of deep convection

Near future:

• implementation of EULAG to COSMO environment (updated COSMO CDC project plan) for extensive tests with COSMO physics

• continuation of tests for Alpine flows

Thank you …

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