Convection-permitting simulations using explicit numerical diffusion

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Introduction

- Runge-Kutta cores using upstream-biased advection in principle demand no explicit numerical small-scale filters
- Still it is convenient to apply explicit numerical filters (e.g., aliasing, phase errors)
- Effective resolution depends on filtering of short wavelengths → Importance for CRM
- Idealized studies of squall lines show strong influence of numerical and sub-grid turbulent filtering at kilometer-scales (Takemi and Rotunno 2003)

Objectives

- Investigate kilometer-scale real-case simulations using explicit diffusion
- How's diffusion of specific prognostic variables related to convective precipitation?
- Are bulk heat and moisture budgets sensitive to explicit diffusion?

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Outline

IAC ETH
INSTITUTE FOR ATMOSPHERIC AND CLIMATE SCIENCE ETH ZURICH
C2SM Center for Climate Systems Modeling

COSMO setup

Version: 4.3
Dynamics:

- split-explicit RK-3 scheme (Wicker and Skamarock, 2002)
- 5th-order advection, pos. definite qx advection
- Monotonic 4th-order diffusion operator (orogr. flux limiter)

Physics:

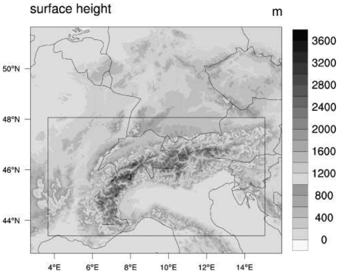
- prognostic TKE-based 1D turbulence scheme
- no cumulus scheme
- graupel scheme
- TERRA_ML

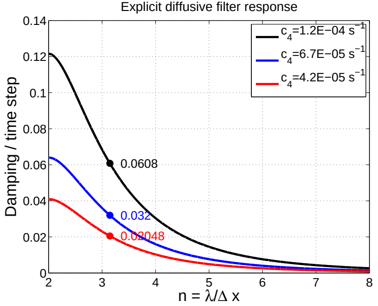
Large Alpine domain:

- $501 \times 451 \times 45$
- $\Delta\varphi = \Delta\lambda = 0.02°$, $\Delta t = 30$ s

IC/BC:

- ECMWF





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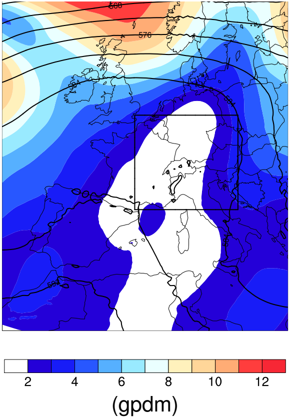
500 hPa geopotential height
11.-20. July 2006



COSMO budget diagnosis

What? Extracts 3D fields of model tendencies

$$\frac{\partial\theta}{\partial t} = -ADV + \frac{L_v}{c_{pd}}S^l + \frac{L_s}{c_{pd}}S^f + M_T + Q_r + M_{HD}$$

$$\frac{\partial q_x}{\partial t} = -ADV - (S^l + S^f) - \frac{1}{\rho\sqrt{G}}\frac{\partial}{\partial\zeta}(\rho v_x^T q^x) + M_{qx} + M_{HDqx}$$

Aims?

- Better understanding of model behaviour
- Evaluation of Alpine budgets

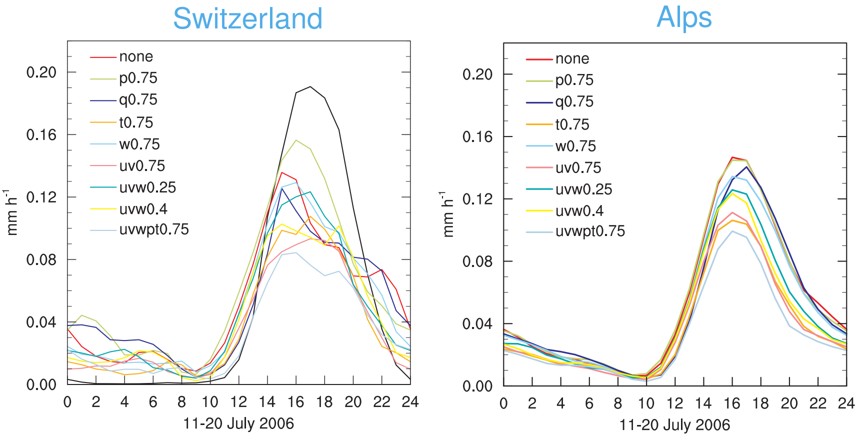
Numerical sensitivity study

Run name
none
uvwpt0.75
uv0.75
p0.75
t0.75
q0.75
uvw0.4
uvw0.25
w0.75

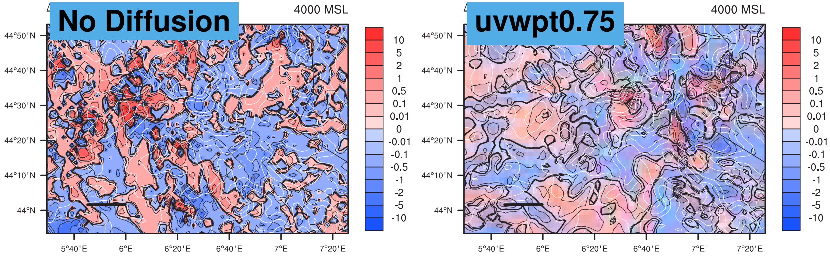
Motivation:
How's diffusion of specific prognostic variables related to convective precipitation?

Numerical sensitivity study

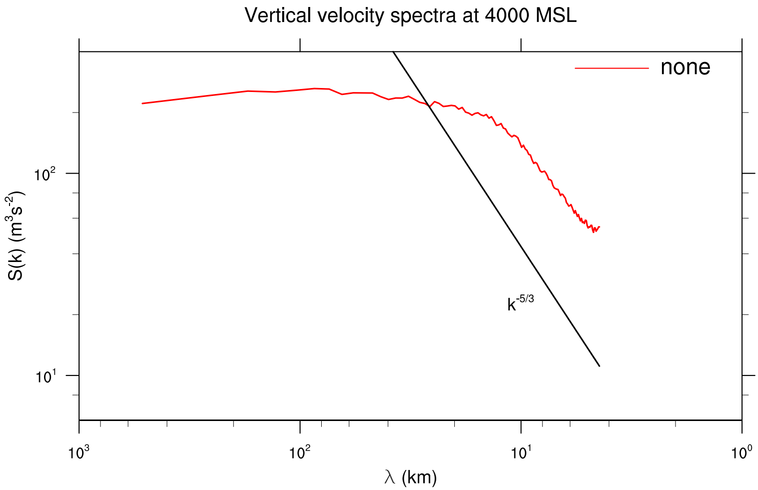
Mean diurnal cycle of precipitation



Vertical velocity at 4 km MSL



Vertical velocity spectra at 18 LT



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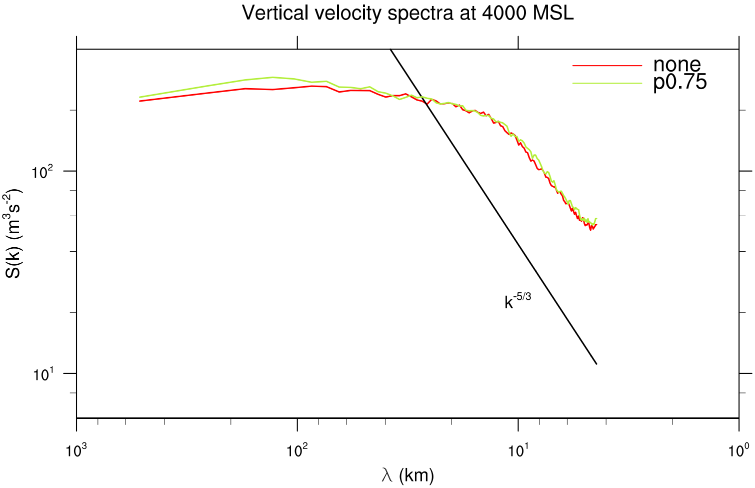

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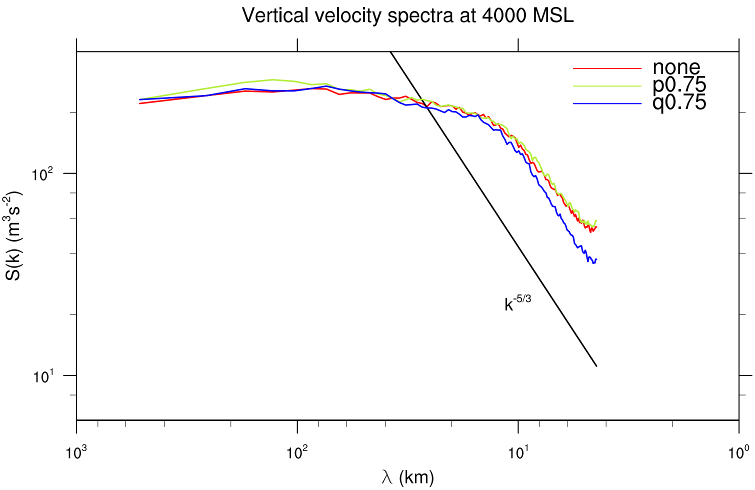

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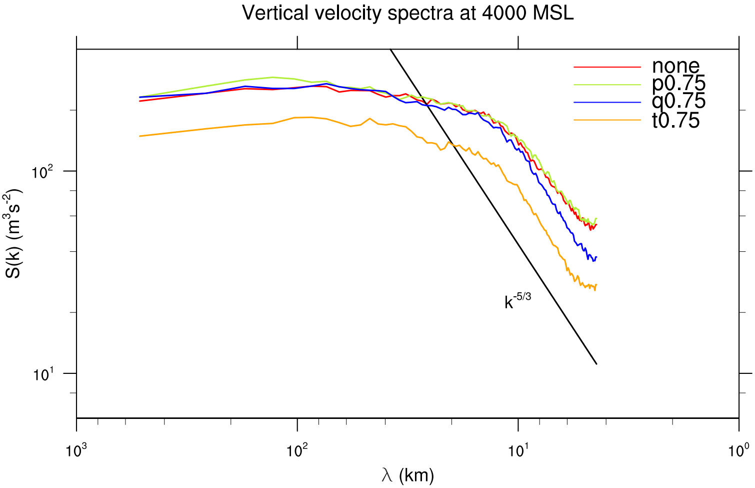

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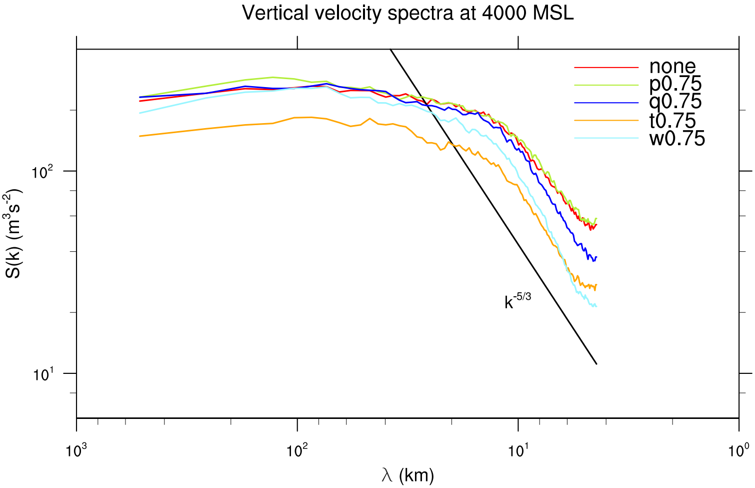

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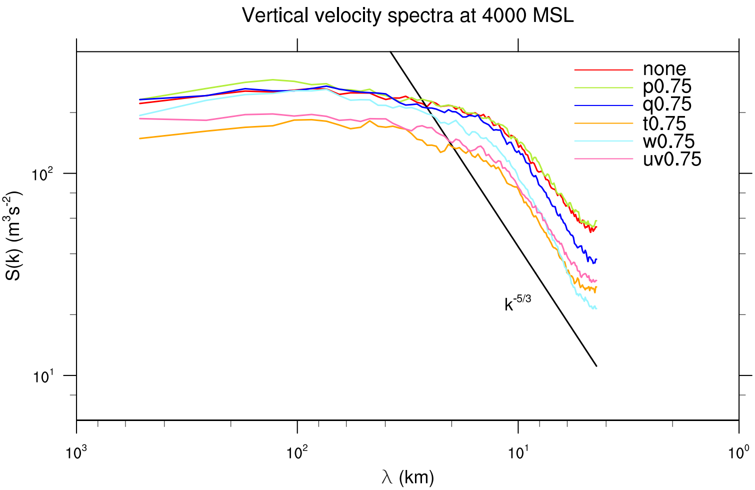

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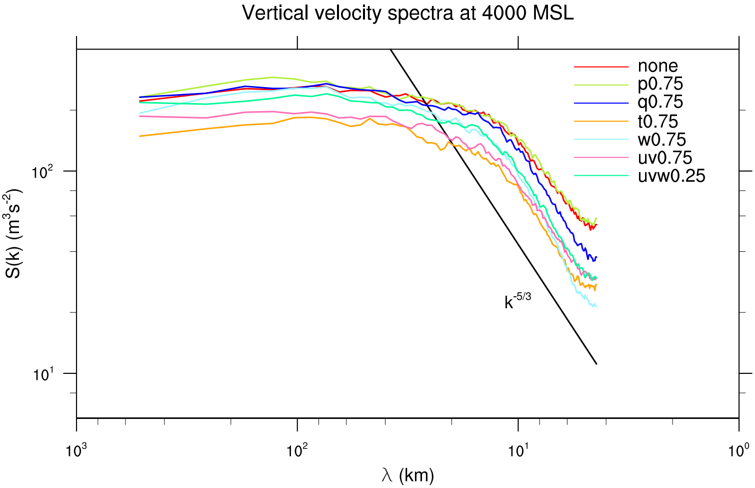

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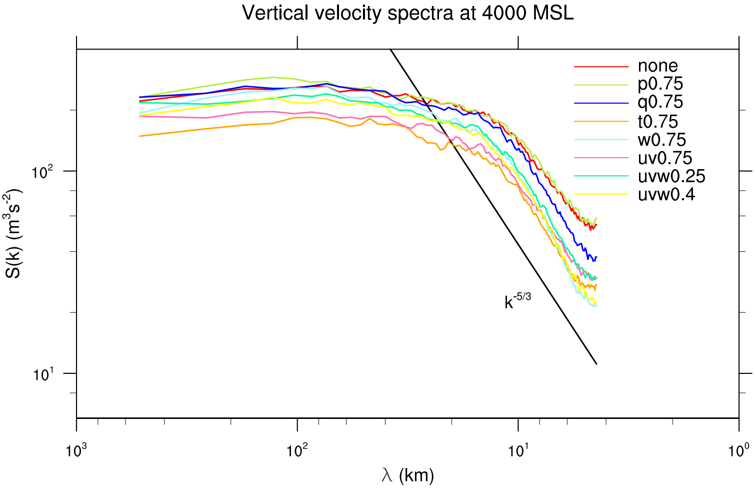

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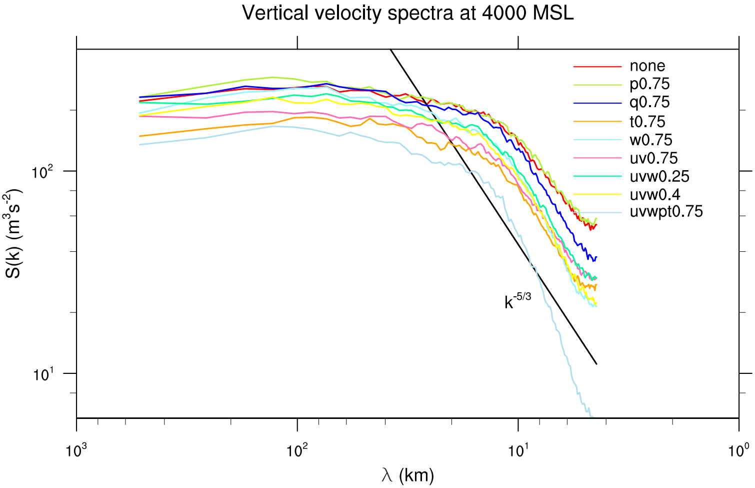
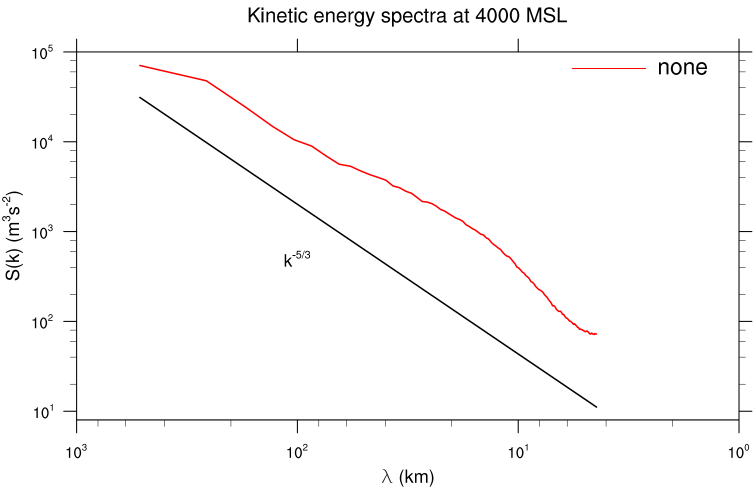


Kinetic energy spectra at 18 LT



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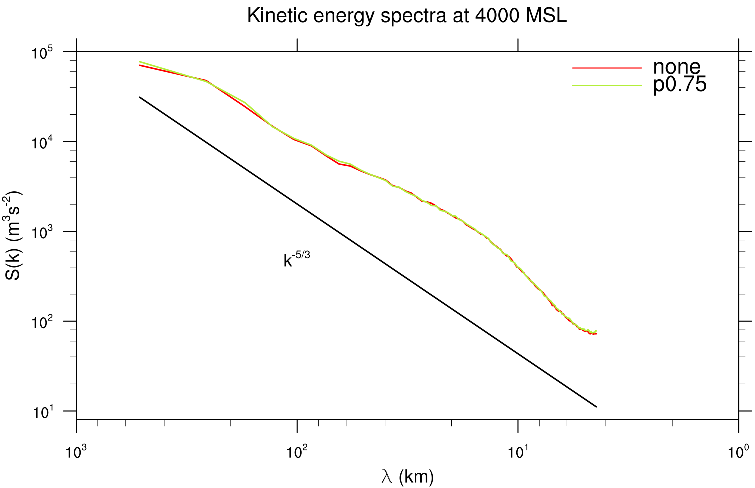

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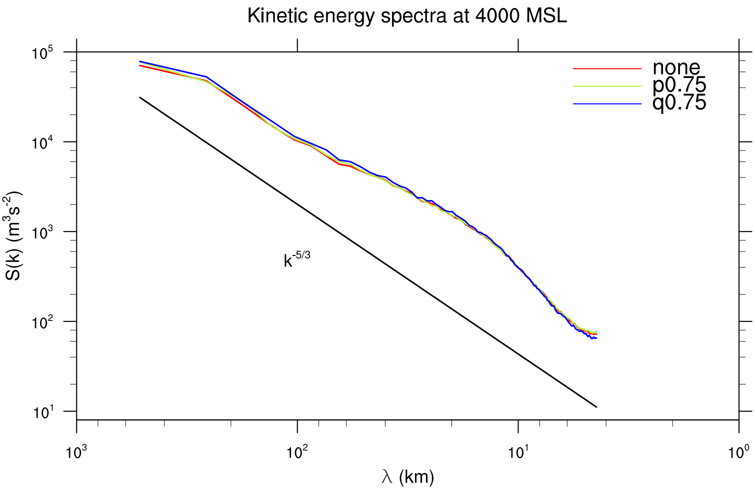

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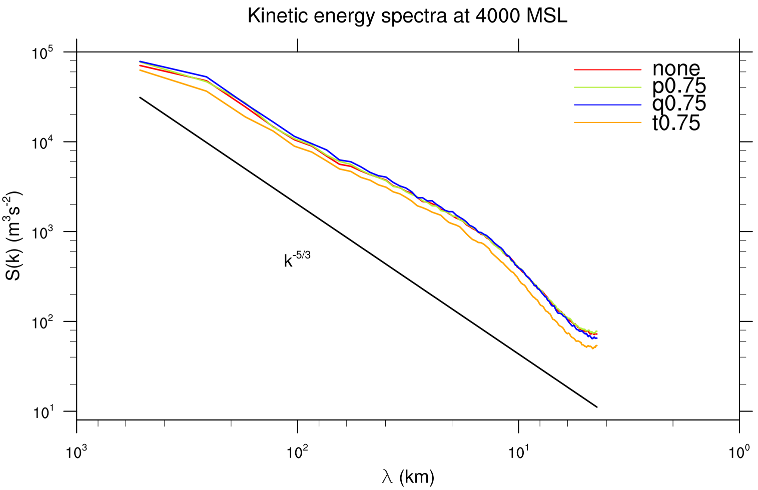

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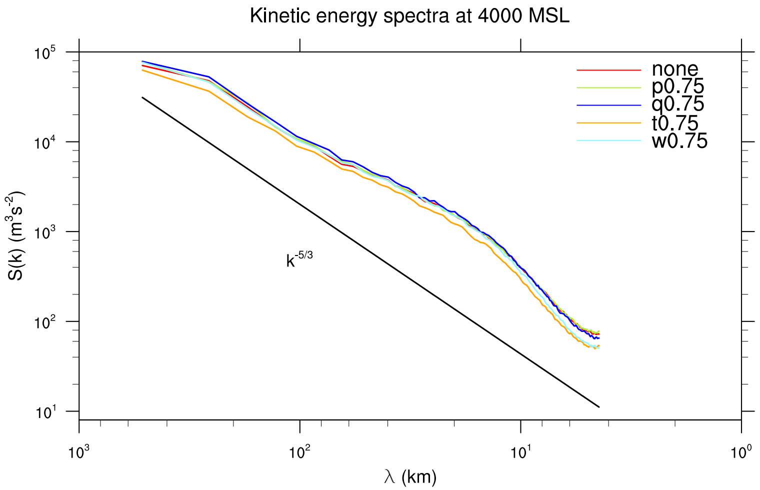

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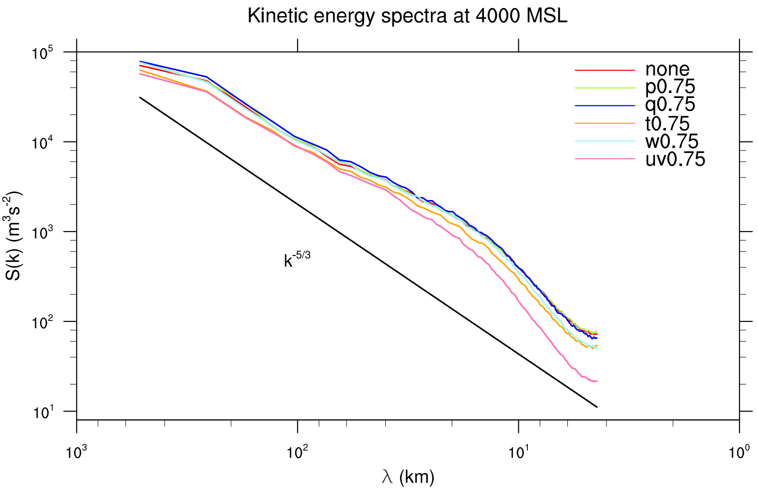

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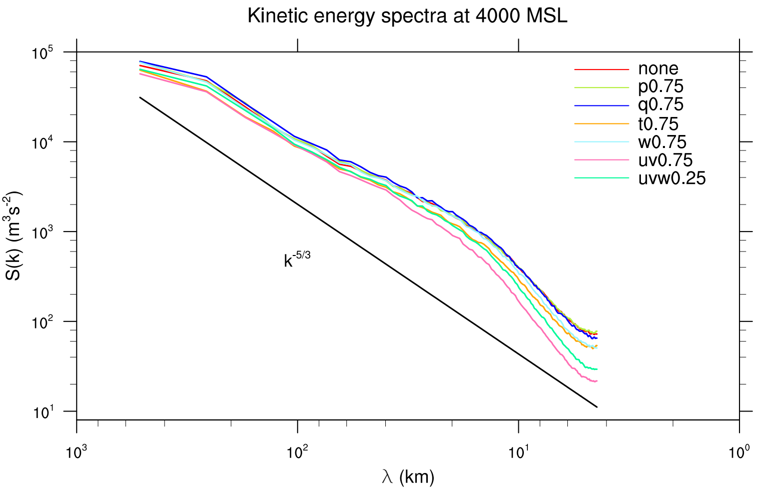

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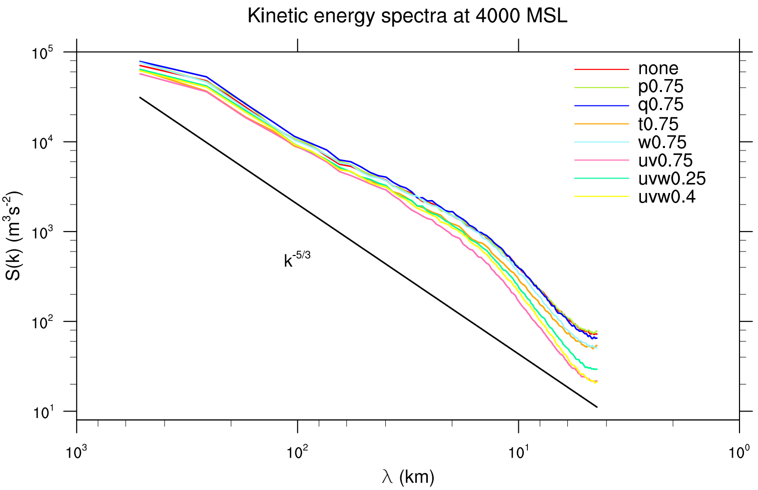

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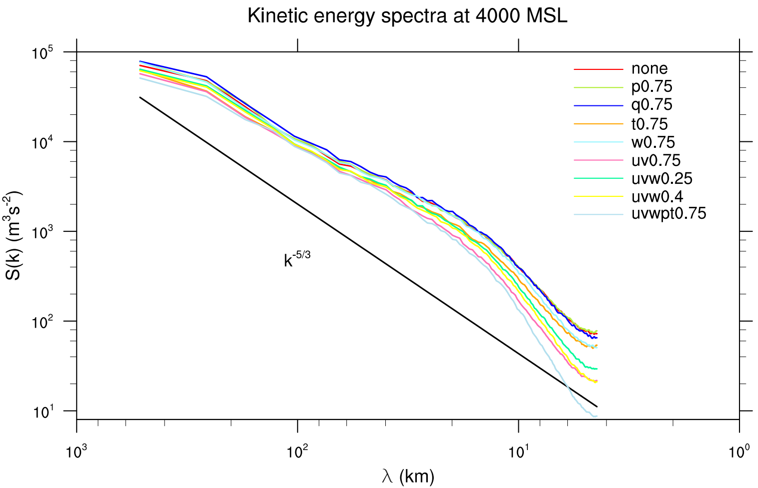
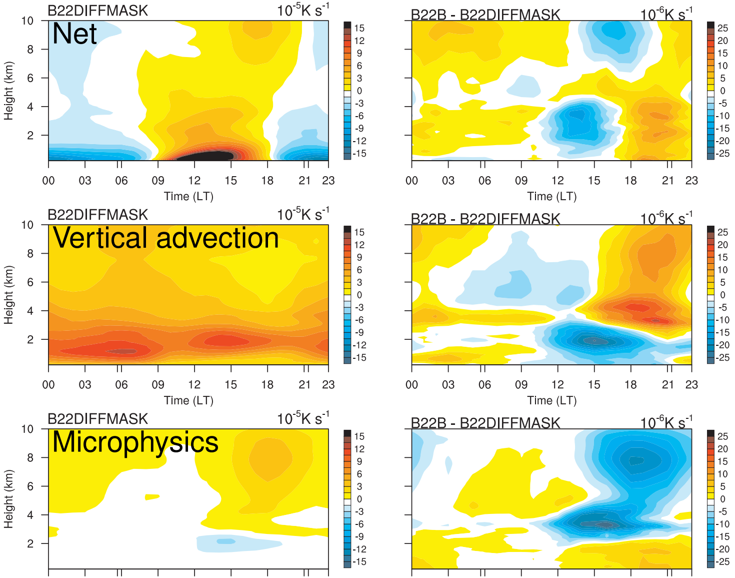


Diurnal cycle of the heat budget

absolute tendencies “no diffusion” | modification by diffusion



Linear stability theory

Following Fuhrer and Schär (2005), Kirshbaum and Durran (2004), Emanuel (1994), Drazin (2004)

$$
\begin{aligned}
\frac{\partial u}{\partial t} + \overline{U}\frac{\partial u}{\partial x} &= -\frac{1}{\overline{\rho}}\frac{\partial p}{\partial x} + K_m\frac{\partial^2 u}{\partial z^2} - \nu_h \nabla_h^2\nabla_h^2 u \\
\frac{\partial v}{\partial t} + \overline{U}\frac{\partial v}{\partial x} &= -\frac{1}{\overline{\rho}}\frac{\partial p}{\partial y} + K_m\frac{\partial^2 v}{\partial z^2} - \nu_h \nabla_h^2\nabla_h^2 v \\
\frac{\partial w}{\partial t} + \overline{U}\frac{\partial w}{\partial x} &= -\frac{1}{\overline{\rho}}\frac{\partial p}{\partial z} + K_m\frac{\partial^2 w}{\partial z^2} - \nu_v \nabla_h^2\nabla_h^2 w \\
\frac{\partial B}{\partial t} + \overline{U}\frac{\partial B}{\partial x} &= -N^2 w + K_h\frac{\partial^2 B}{\partial z^2} - \nu_b \nabla_h^2\nabla_h^2 B \\
\nabla\cdot\mathbf{v} &= 0
\end{aligned}
$$

$$
\begin{aligned}
w &= \hat{w}\exp(ikx + ily + imz - i\omega t) \\
k_h &= \sqrt{(k^2 + l^2)} \\
\nu_h = \nu_w = \nu_h \quad K_h = K_m \rightarrow \quad \omega &= k\overline{U} - i\left(\nu(k^4 + l^4) + Km^2\right) + \sqrt{k_h^2 N_m^2/(k_h^2 + m^2)} \\
\tau &= \frac{i}{\omega - k\overline{U}}
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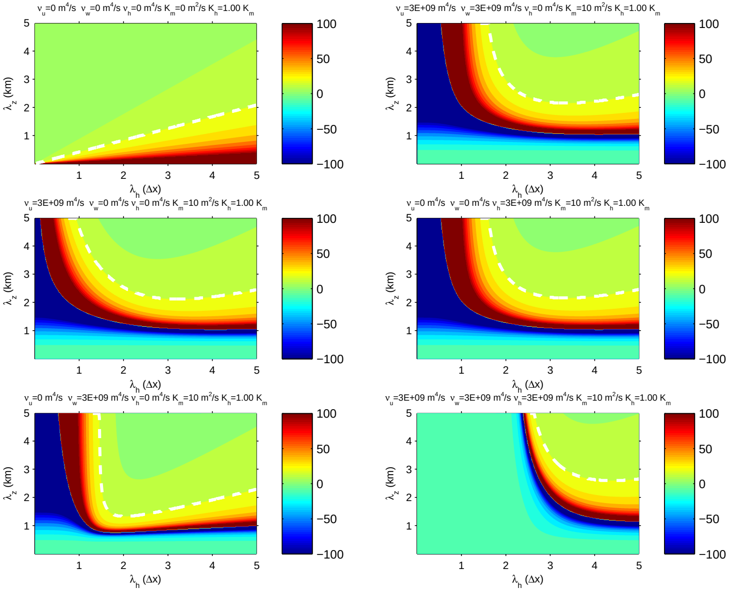
Characteristic growth time



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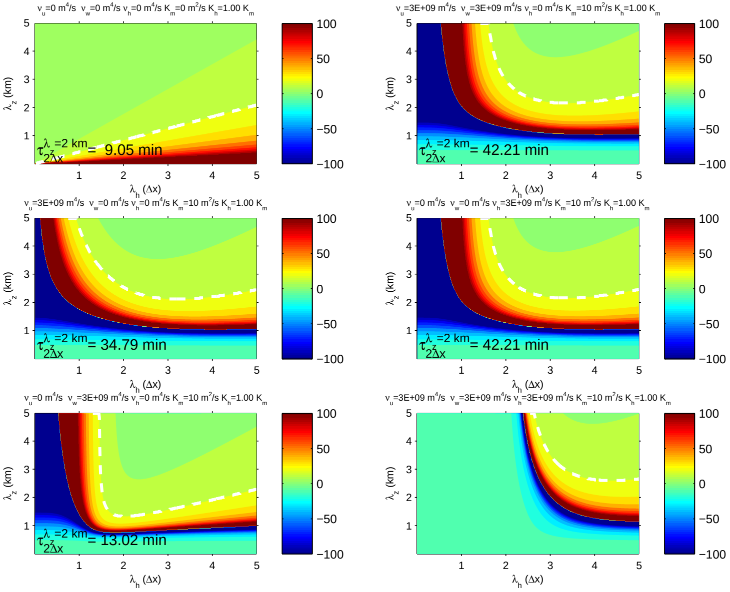

Conclusions

- "Dilemma": Strong explicit diffusion → smooth ("error free") fields, but artificial reduction of convective growth
- Feedback to well-resolved scales, influencing also the bulk Alpine budgets
- Large sensitivity to explicit diffusion:
  - Diffusion of q_v,p',w little influence
  - Diffusion of u,v,t' large influence
- LST indicates that the initial convective growth is damped, especially for diffusion of u,v, and t'.
- Suggestion: Weak diffusion of u,v,w, since kinetic energy removed sufficiently, thereby permitting amplification of grid-scale perturbations

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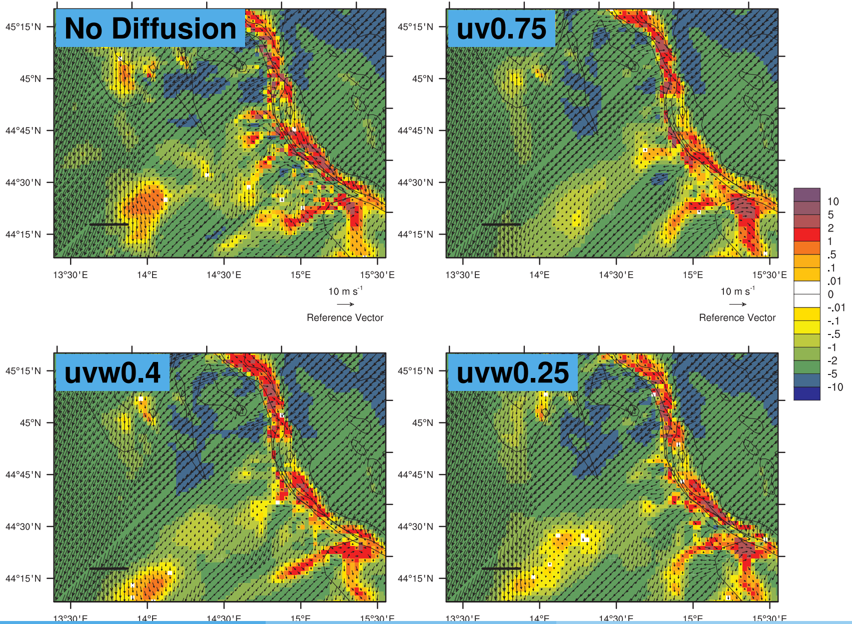
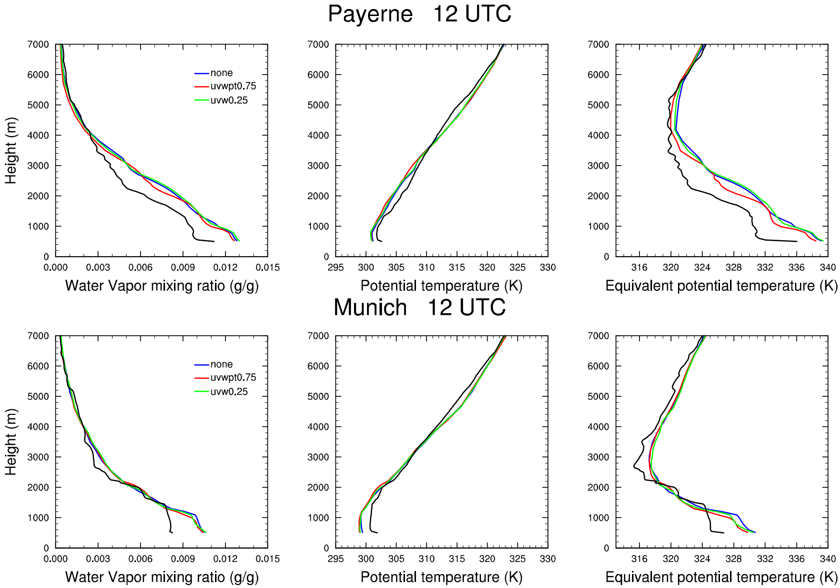
Thanks for your attention

U-wind component at $\sigma = 0.72 \sim 2.6$ km



Soundings



Payerne 12 UTC
Height (m)
Water Vapor mixing ratio (g/g)
Potential temperature (K)
Equivalent potential temperature (K)
none
uvwpt0.75
uvw0.25
Munich 12 UTC
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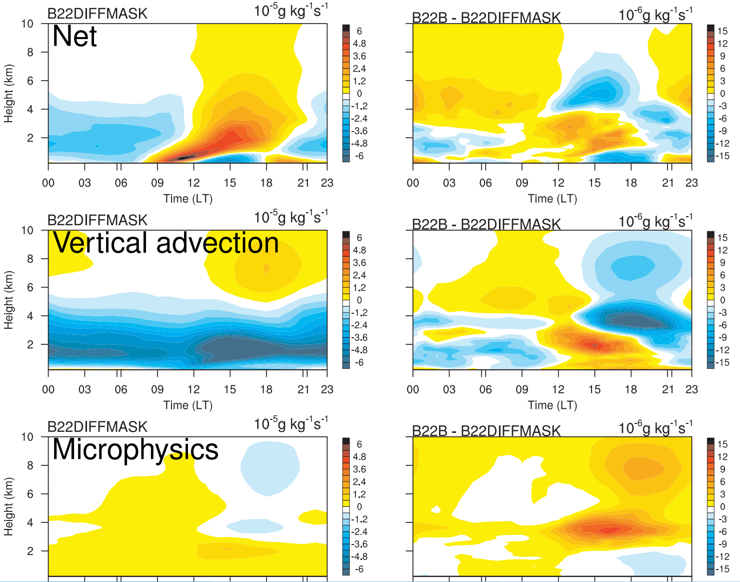

Reduction of preciptiation

RUN	TOT_{CH}	$PEAK_{CH}$	TOT_{ALPS}	$PEAK_{ALPS}$
none	-00.58	-28.83		
uvwpt0.75	-37.94	-55.76	-37.26	-32.27
uv0.75	-30.23	-51.08	-27.32	-24.13
p0.75	-13.88	-17.97	+00.91	-01.25
t0.75	-27.52	-43.59	-29.06	-27.56
q0.75	-04.04	-34.17	-06.14	-04.17
uvw0.4	-17.93	-46.14	-20.22	-15.86
uvw0.25	-12.23	-35.32	-16.06	-14.21
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	(%)			

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