The new Very Short Range Forecast Model COSMO-LMK for the Convection-Resolving scale

LM-User Seminar
05.-07.03.2007

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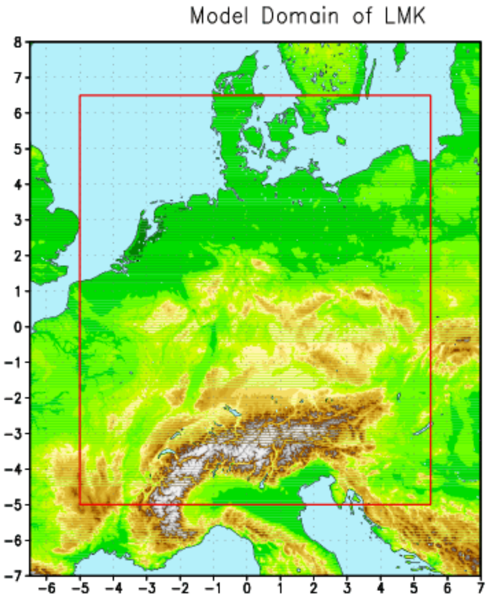
LMK - (Lokal-Modell-Kürzestfrist)
Internal Project of the Deutscher Wetterdienst (DWD)

Goals

Development of a model-based NWP system for very short range (‘*Kürzestfrist*’) forecasts (18 h) of severe weather events on the meso-γ scale, especially those related to

- deep moist convection (super- and multi-cell thunderstorms, squall-lines, MCCs, rainbands,...)
- interactions with fine-scale topography (severe downslope winds, Föhn-storms, flash floodings, fog, ...)



GME (global)
Δx = 40 km
368642 * 40 GP
Δt = 133 sec.
T = 7 days

↓

LME (Europa)
Δx = 7 km
665 * 657 * 40 GP
Δt = 40 sec.
T= 78 h

↓

LMK (regional)
Δx = 2.8 km
421 * 461 * 50 GP
Δt = 25 sec.
T = 18 h
8 forecasts / day

Development history

July 2003	Project ‘LMK’ (Aktionsprogramm 2003)
March 2006	Prototype-Version of LMK-system with LHN --> pres. Stephan, Schraff
April 2006	Radar-DXQ-Composit (RY, QY) operational
14.08.2006	Start of **pre-operational test phase** at DWD
Dez. 2006	End of ‘Aktionsprogramm 2003’

COSMO (Consortium for Small-scale Modeling)

Sept. 2005 Start of Priority Project ‚Runge-Kutta‘

Meeting Wednesday, 07.03.07, 13:30 in Room ??

--> e.g. pres. deMorsier, Petrik

Deutsche Forschungsgemeinschaft DFG

PQP Praecipitationis Quantitativae Praedictio

QUEST (Quantitative Evaluation of Regional Precipitation Forecasts Using Multi-Dimensional Remote Sensing Observations)

COPS (Convective and Orographically-induced Precipitation Study)

Physical parameterizations - LMK developments

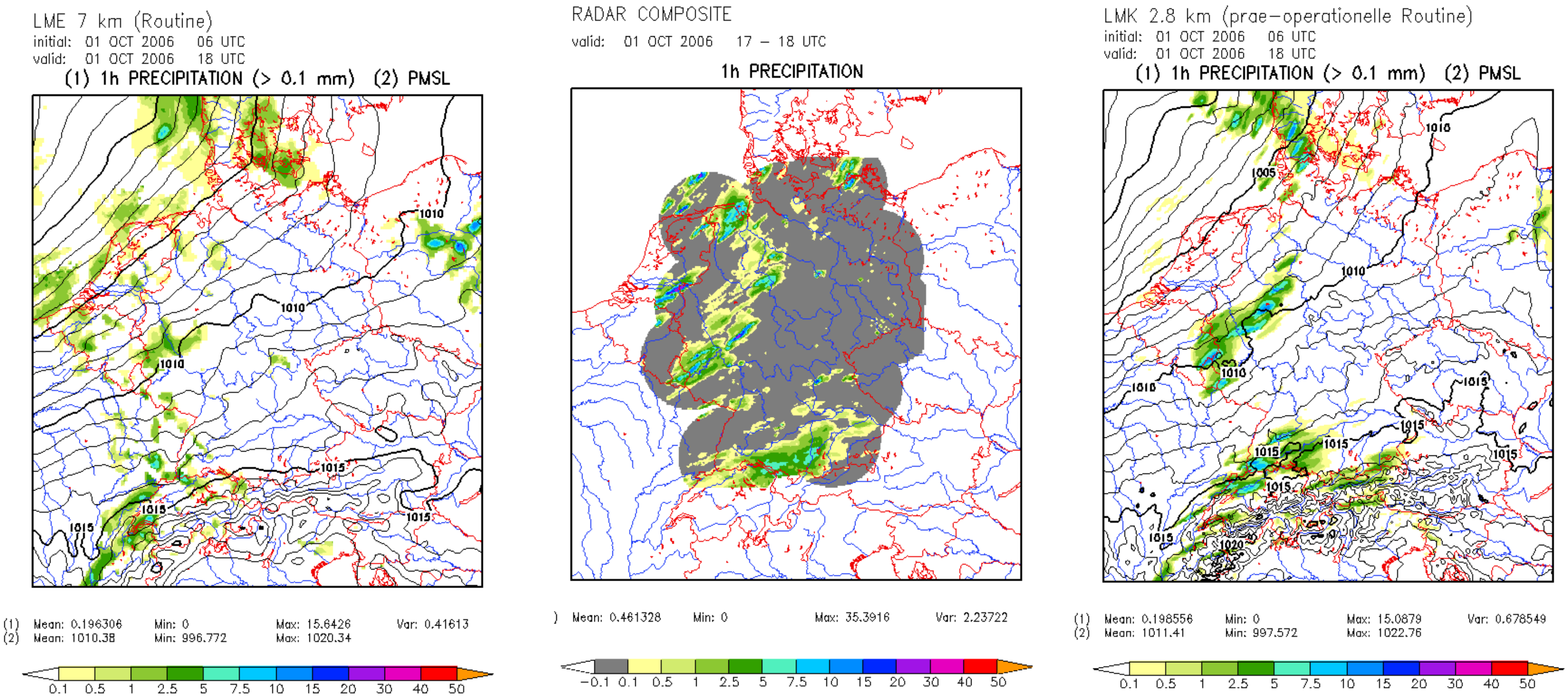
Moist convection	LME: Tiedtke (1989)
	LMK: no cumulus convection parameterization!
	→ no distinction between convective and stratiform precipitation
Shallow convection	LME: Tiedtke (1989)
	LMK: shallow conv. part from *Tiedtke (1989)* (only for H_{cloud} < 2 km)
Turbulence	1D, 1-equation model (prognostic TKE)
	3D, 1-equation-model, full coordinate transformations
	(Herzog et al., 2002; Baldauf, 2005, 2006)
	'moist turbulence' (buoyancy production of TKE altered by condensation processes)
Cloud microphysics	5-class --> 6-class-scheme (q_v, q_c, q_i, q_r, q_s, new: graupel q_g)
	Γ-distribution function for raindrops
	→ reduced evporation of rain → increased precipitation
	6-class/2-moments-scheme (for research/benchmark purposes)
	(Seifert, Beheng, 2000)
Radiation	2-flux-scheme *(Ritter, Geleyn, 1992)*
	upscaling → higher update frequency
	(consideration of topographic effects) (M. Buzzi)
Soil-Veg.-model	TERRA, 7 levels, additional freezing/melting of snow

Numerics and Dynamics - LMK developments

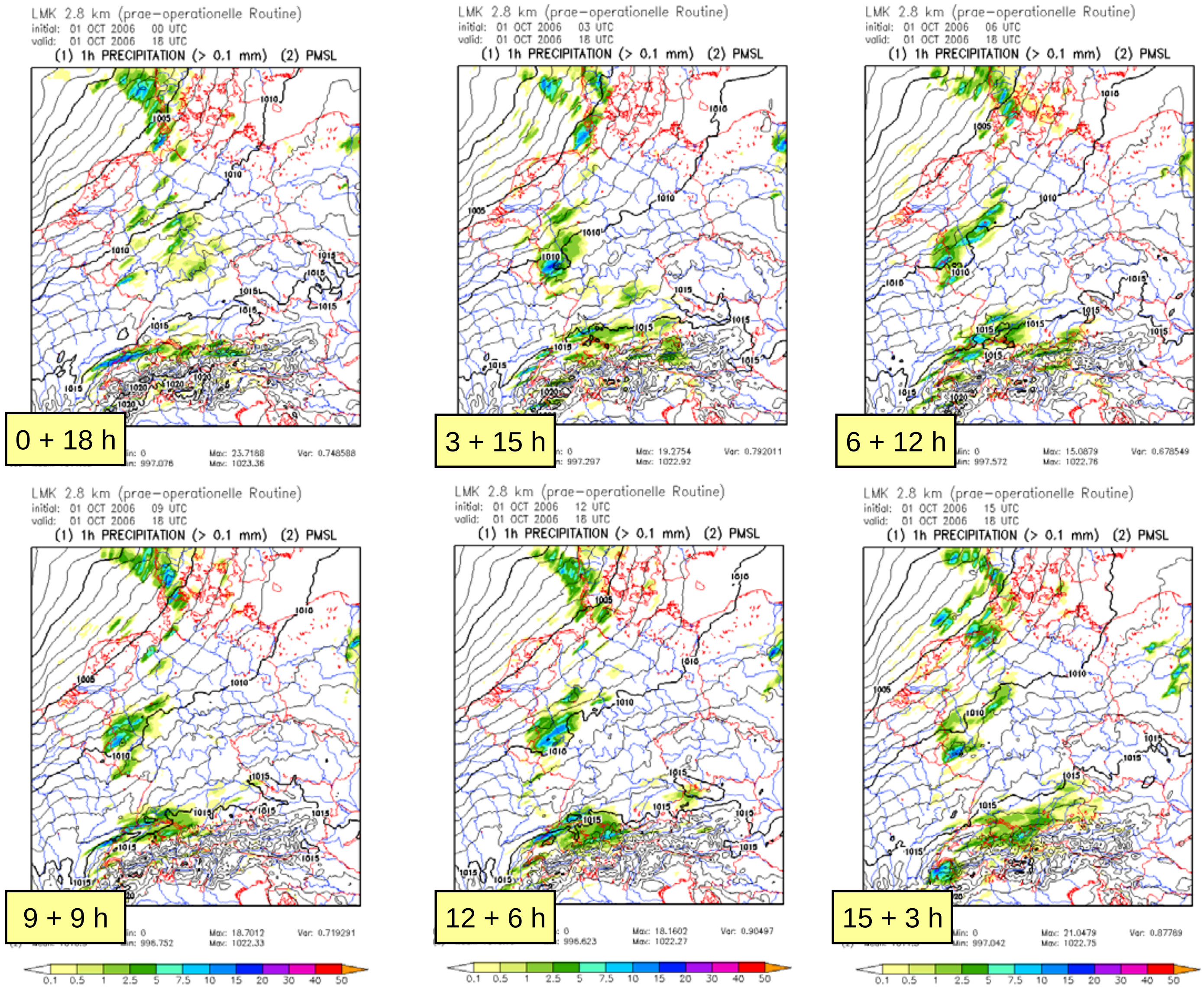
Grid structure	horizontal: Arakawa C,
	vertical: Lorenz
Prognostic Var.	u,v,w,p',T' --> pres. J. Förstner
Time integration	time-splitting between fast and slow modes
	- 3-timelevels: Leapfrog (+centered diff.) (Klemp, Wilhelmson, 1978)
	- 2-timelevels: Runge-Kutta: 2. order, 3. order, 3. order TVD
	(Wicker, Skamarock, 1998, 2002)
Fast modes	(=sound waves, buoyancy, divergence filtering)
	centered diff. 2. order, vertical implicit, (p'T'-Dyn.)
Advection	for u,v,w,p',T':
	horizontal. adv.: upwind 3., 5. order / centered diff. 4. 6. order
	vertical adv.: implicit 2. order (implicit 3. order)
	for q_v, q_c, q_i, q_r, q_s, q_g, TKE:
	Courant-number-independent (CNI)-advection:
	Bott (1989) (2., 4. order), in conservation form
	Semi-Lagrange (trilinear, tricubic)
Other slow modes	complete Coriolis terms (diploma thesis R. Petrik)
Smoothing	3D divergence damping
	horizontal diffusion 4. order
	slope dependent orographic filtering
Boundary cond.	Dynamic lower B. C. (Torrisi, Förstner, Gassmann)

Convectively enhanced frontal precipitation, 1.10.2006, 18 UTC

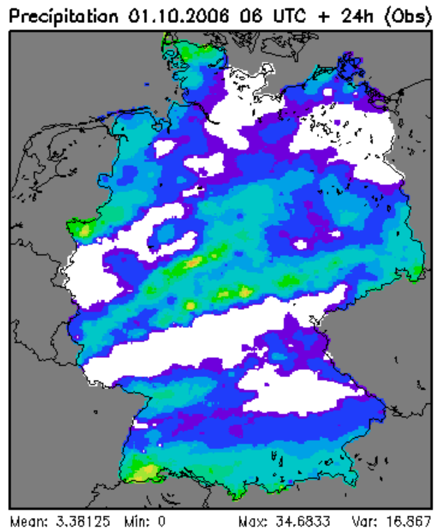
Obs.: up to 20 mm/12 h

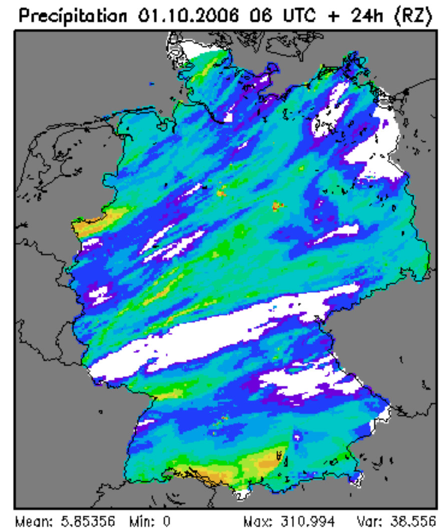


LAF-ensemble, 1h-precip.-sum**, target time: 1.10.2006, 18 UTC**

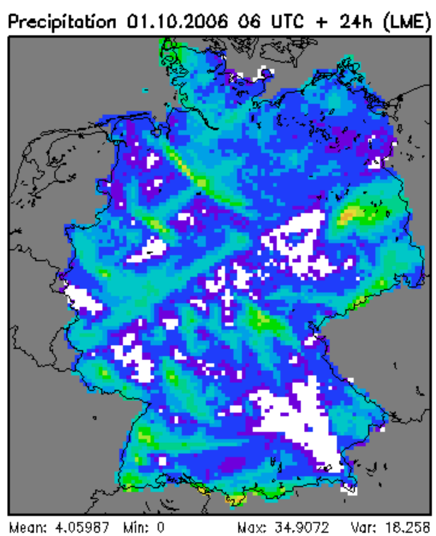


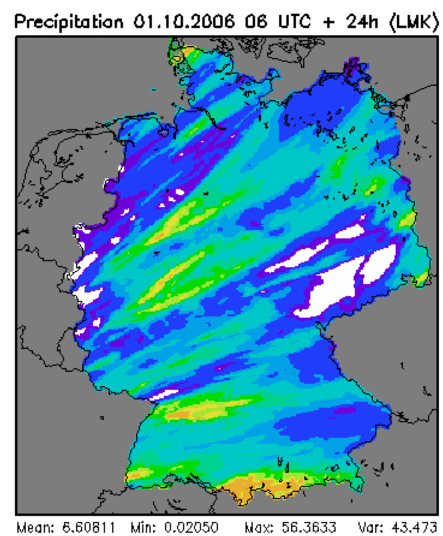
Convectively enhanced frontal precipitation, 1.10.2006, +06-30 h



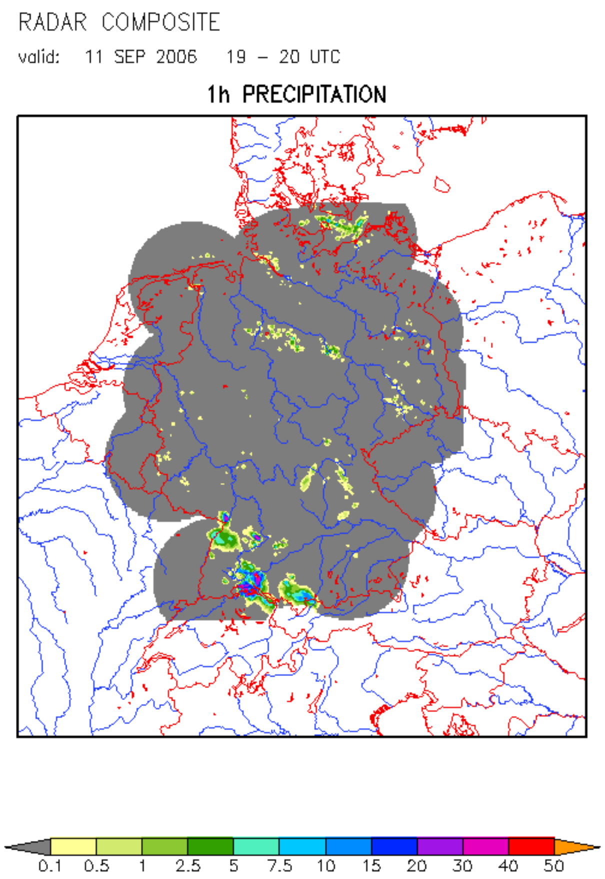


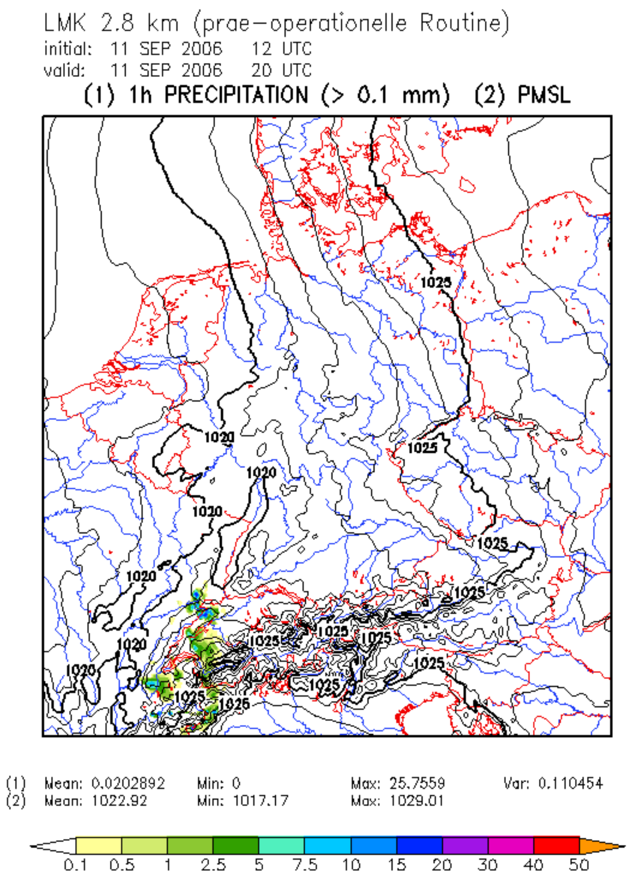
(from 0 UTC & 12 UTC-run)





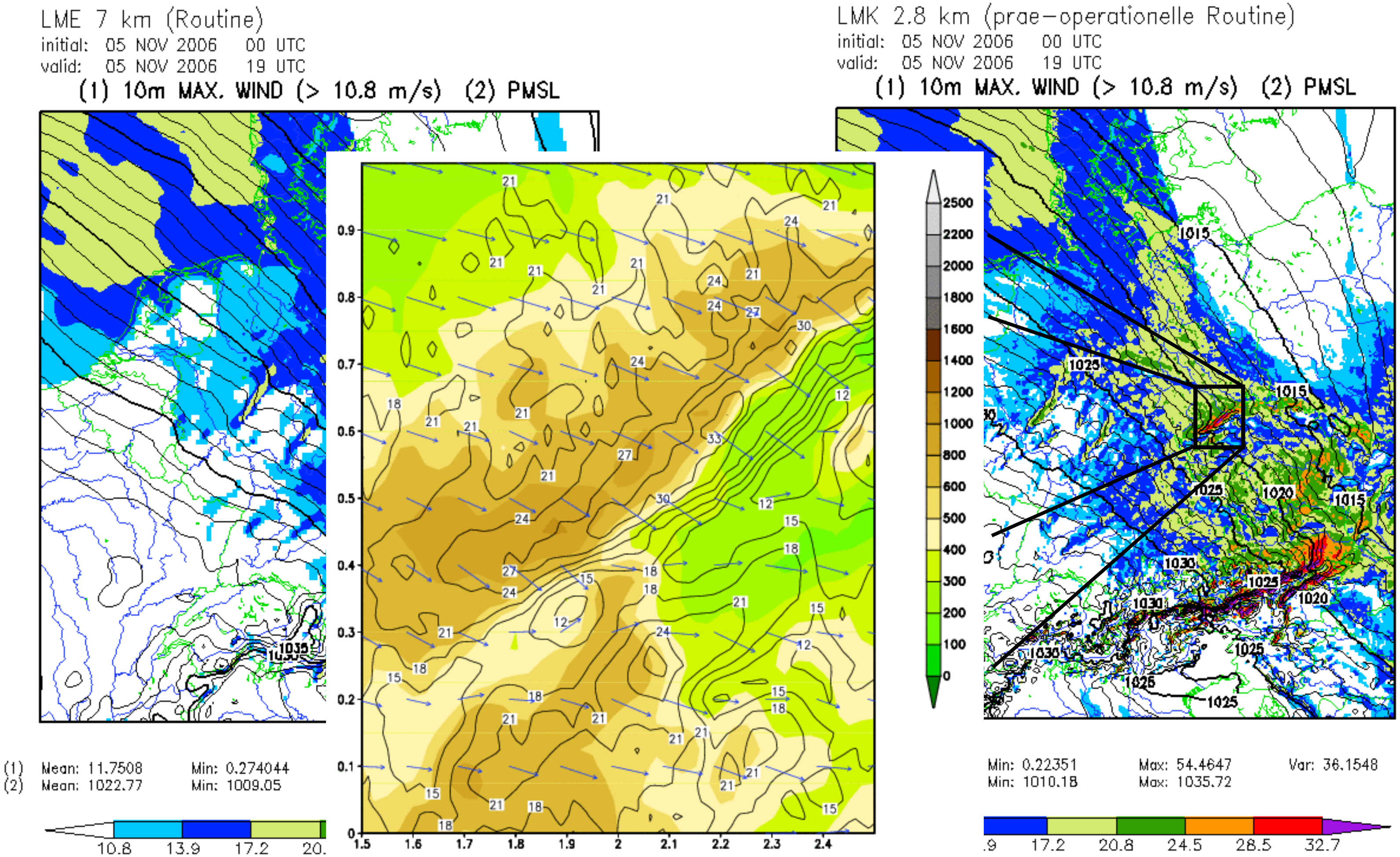
Problem: missed convection initiation in LMK (11.09.2006)



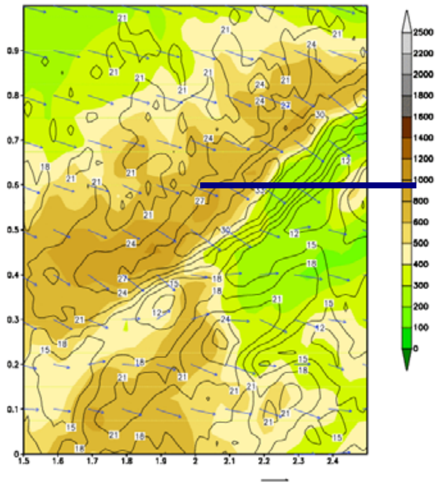


other examples: July 2006

Strong downslope winds (Erzgebirge, 05.11.2006), gusts

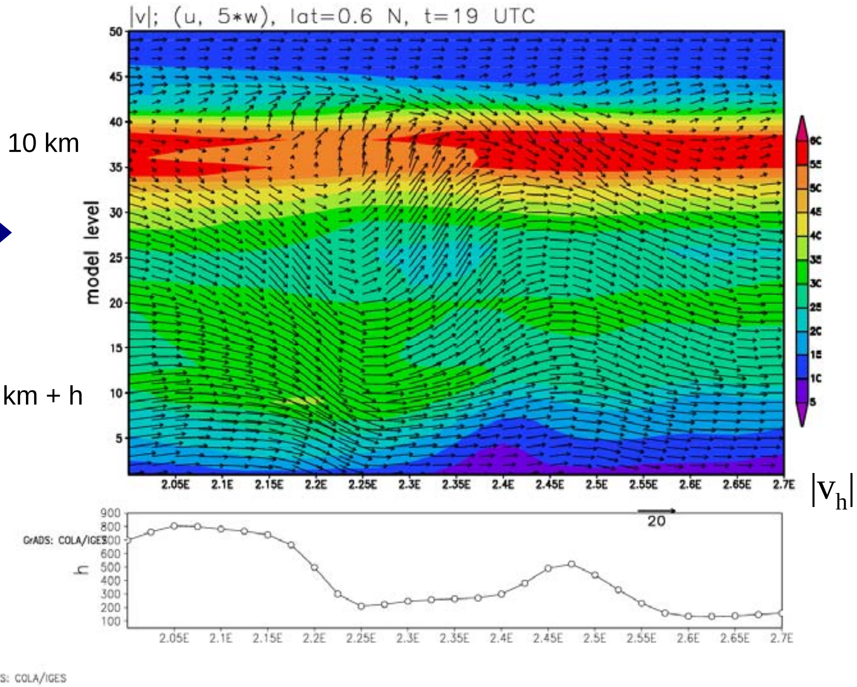


gusts ~30 m/s were observed in the mountain lee side



~ 10 km

~ 1 km + h



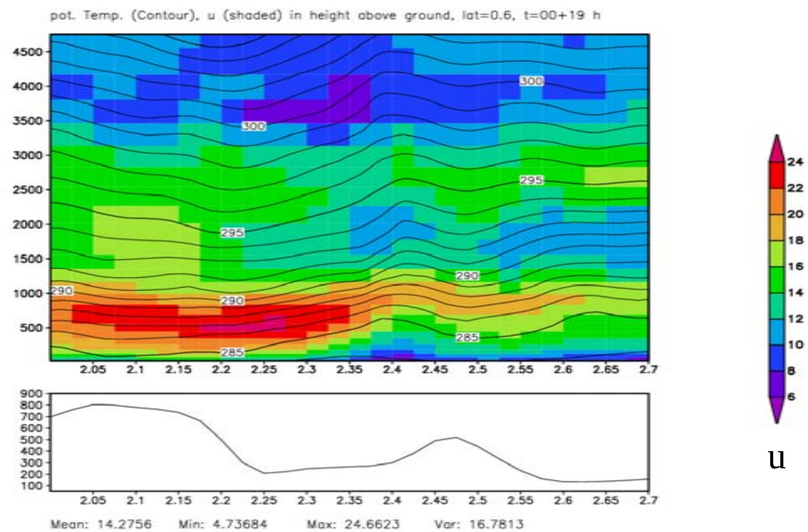
Strong downslope winds

Erzgebirge, 05.11.2006, 0 UTC-run
forecast time 19 UTC

e.g. Clarke (1971) JAM

Pot. temp. (contour)

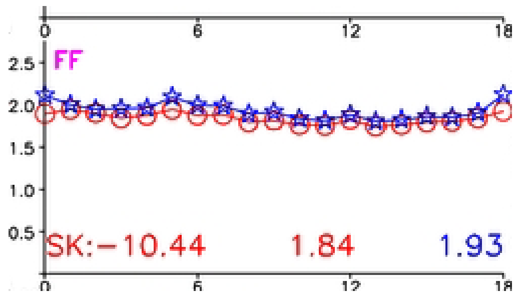
height above ground

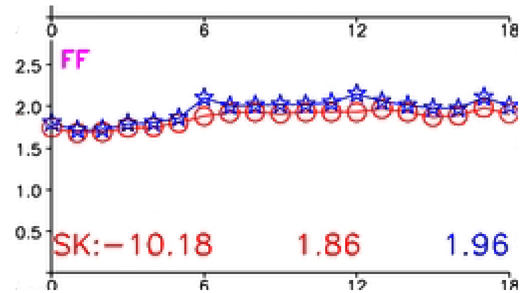


Synop-Verification

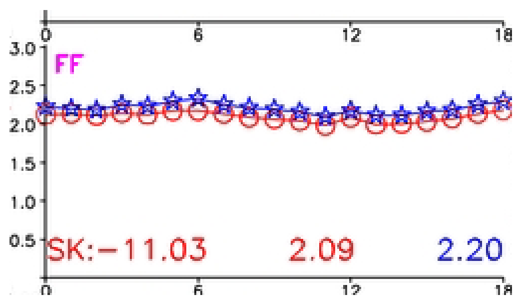
RMSE of wind speed $|v|_{10m}$

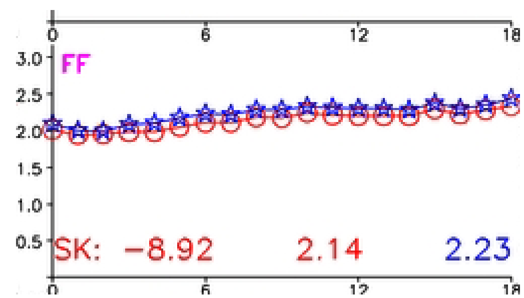
Sept. 2006





Oct. 2006





○ **LMK**
★ **LME**

0 UTC-runs

12 UTC-runs

U. Damrath

Synop-Verification of pre-operational LMK

Gusts and Precipitation

01.-31.Oct. 2006, 12 UTC-runs

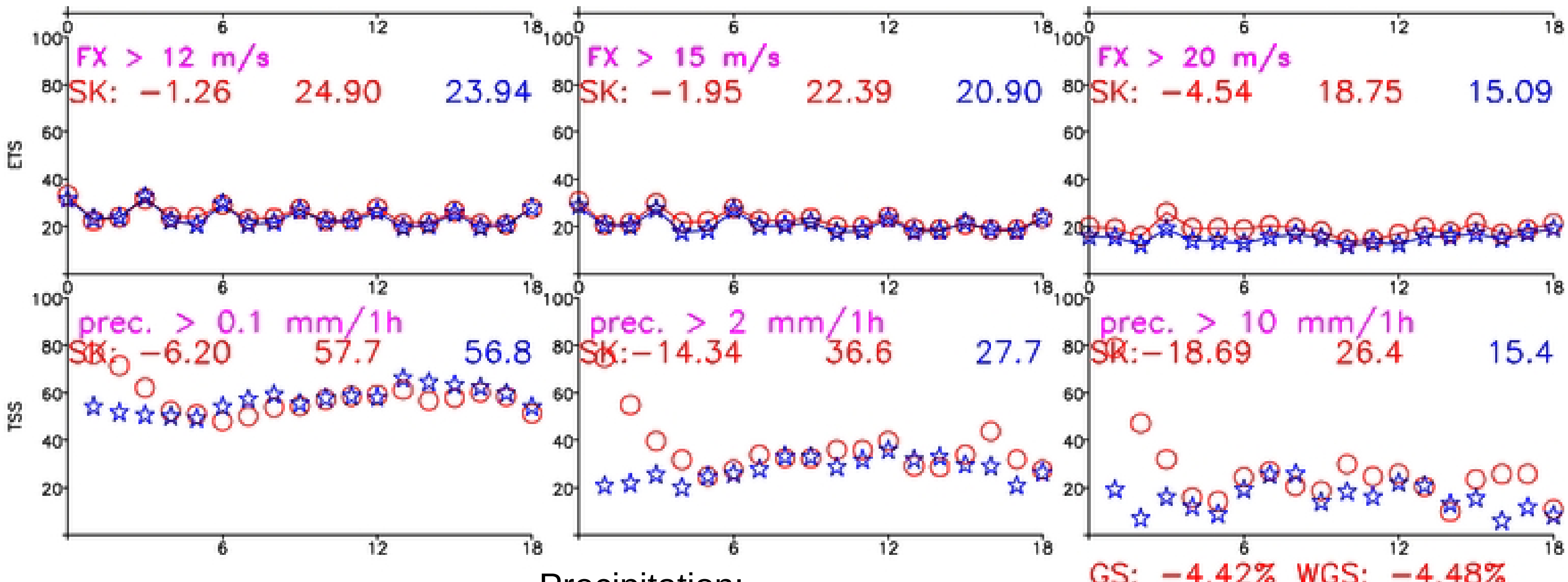
Gusts:
ETS generally higher (but sometimes also higher FBI)

ETS

Gusts

TSS

Precipitation



○ **LMK**
★ **LME**

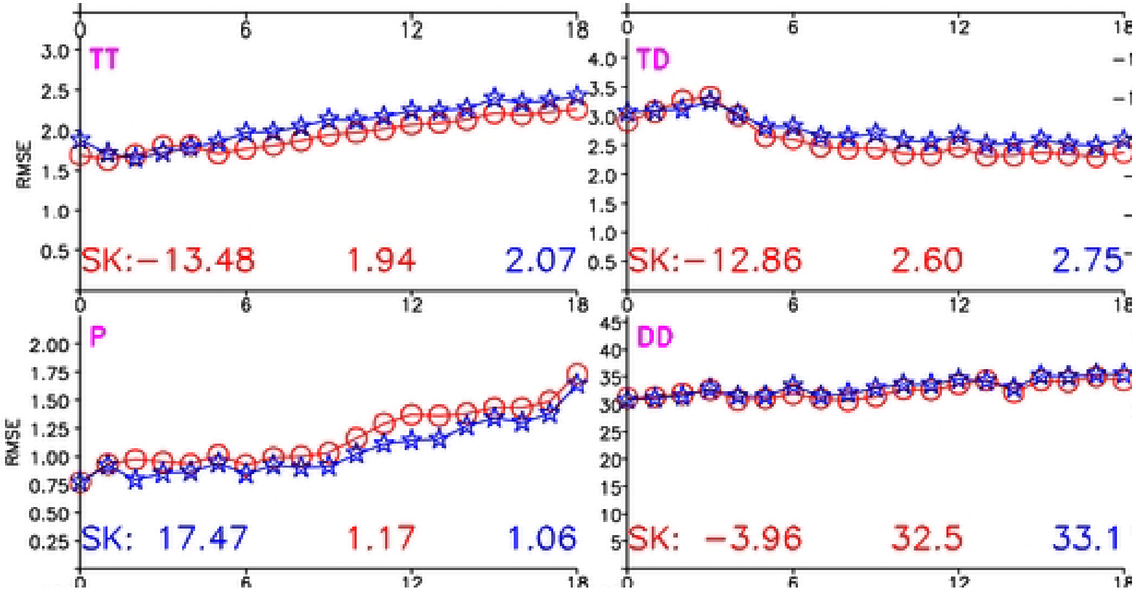
Precipitation:
July '05: TSS generally higher
Sept. '06: LMK higher TSS due to LHN,
Oct. + Nov. '06: LMK mostly higher TSS (FBI ~ equal)
Dec. '06: LMK smaller TSS (no LHN?)

Synop-Verification of pre-operational LMK
RMSE of: T2m, Td2m, pressure
01.-31.Oct. 2006, 12 UTC-runs

T2m

Td2m

pressure



○ LMK
★ LME

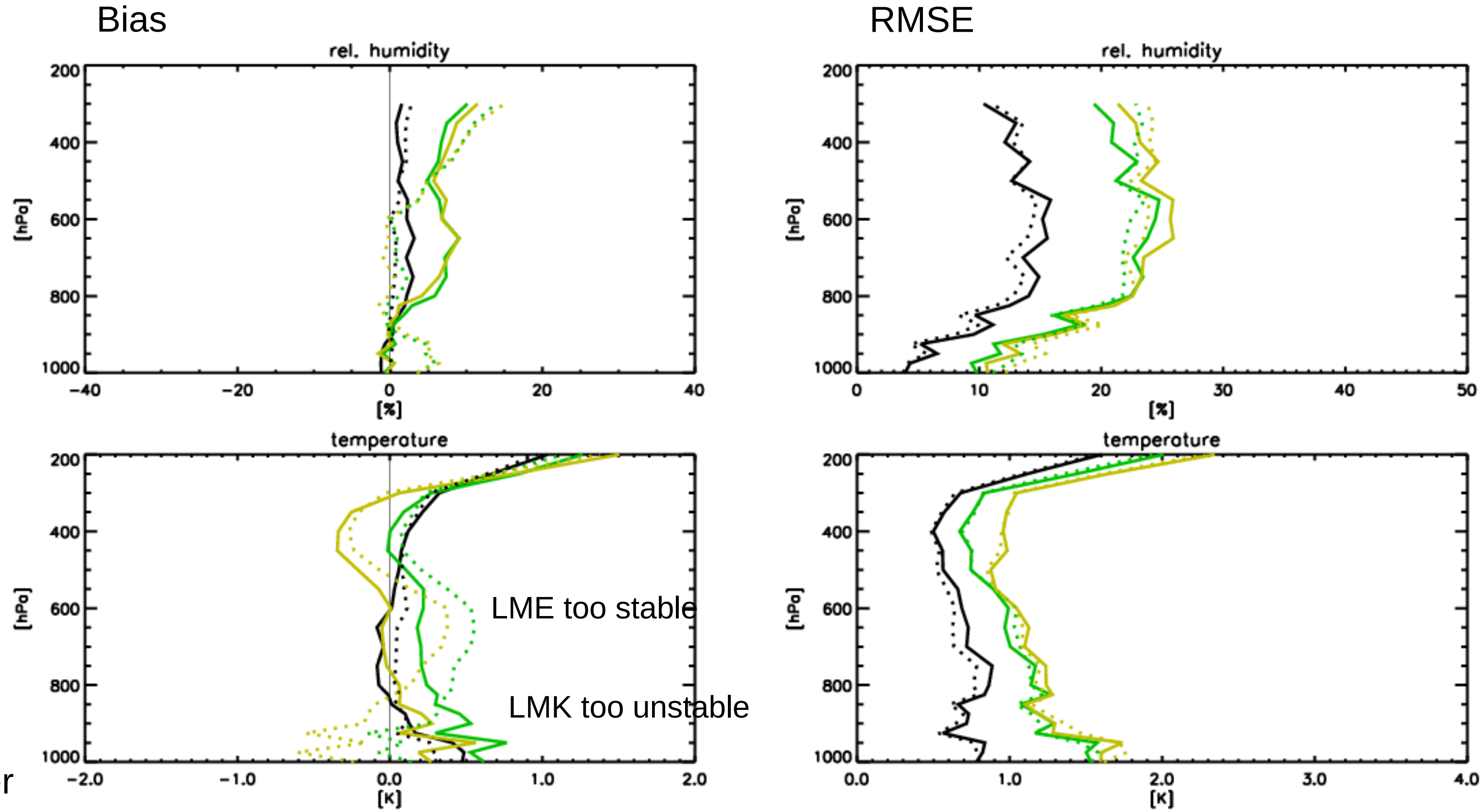
LMK compared to LME (Sept.-Dec. '06):
T_{2m}: RMSE generally smaller, Bias neutral
p: RMSE often bigger, temporal increasing of Bias bigger

LMK *with* LHN (TS 3.3b) — **LME**

LMK with LHN		LME	
yellow solid line	+ 24 h	yellow dotted line	+ 24 h
green solid line	+ 12 h	green dotted line	+ 12 h
black solid line	+ 00 h	black dotted line	+ 00 h

upper air - Verification

16.06.-15.08.2006
12 UTC-runs



U. Pflüger

Summary

- COSMO-LMK in pre-operational use since 14.08.2006
- 18 h- (21 h-) forecasts are simulated every 3 h (LAF-ensemble)
- explicit simulation of deep moist convection with its life cycle generates good predicitions of precipitation in the case of synoptic forced events
  (e.g. lines of thunderstorms)
- dynamical effects better represented due to higher resolution
  - strong downslope winds
  - lee waves (e.g. improved glider forecasts)
- radar observations of the DWD-radar network have an essential influence on the initial state
  (improved precipitation forecast for the first ~ 4..5 h)

Outlook

- **operational use** planned for ~ 16. April 2007 (unofficial date)
- Further developments:
  reduce ‚misses' in the prediction of free convection (not synoptically-driven)
  - Boundary layer parameterisation
  - Nudging of soil moisture in deeper layers to LME (uses soil moisture analyses)
- LMK-ensemble (~ 20 member, ~ 2008)

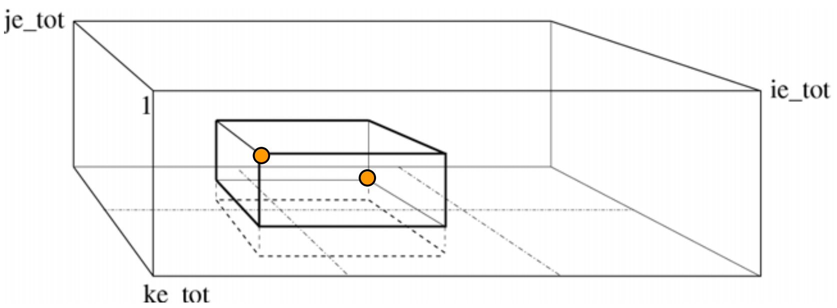
Tool for inspection of conservation properties

COSMO Priority Project ‚Runge-Kutta‘, Task 3: Conservation (Baldauf)

balance equation for scalar ϕ:

$$\frac{\partial}{\partial t}\int_V \phi \, dv + \int\int_{\partial V} \mathbf{j}_\phi \cdot d\mathbf{A} = \int_V q_\phi \, dv$$

temporal change | flux divergence | sources / sinks

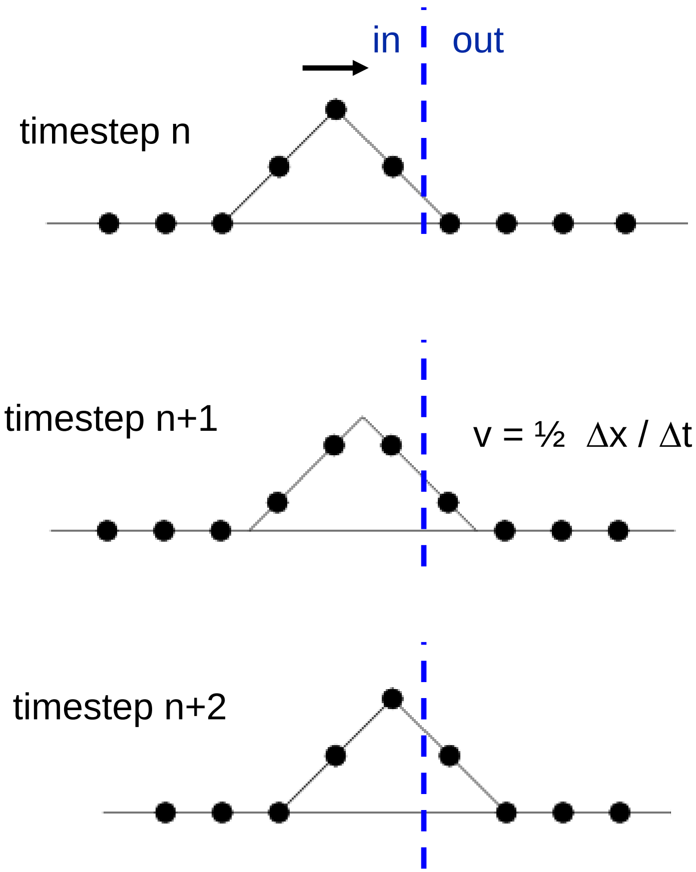


integration area = arbitrarily chosen cuboid (in the transformed grid, i.e. terrain-following)

available in LM 3.23: (new: `src_integrals.f90`)

- Subr. `init_integral_3D:` define cuboid (in the transformed grid!), prepare domain decomp.
- Function `integral_3D_total:` calc. volume integral $\Sigma_V \; \boxed{\phi_{ijk}} \; \Delta V_{ijk}$
- Subr. `surface_integral_total:` calc. surface integrals $\Sigma_{\partial V} \; \boxed{\mathbf{j}_{ijk}} \; * \; \Delta \mathbf{A}_{ijk}$

How to calculate the fluxes?



1D flux divergence

$v = 1\ \Delta x / \Delta t$ — upwind — cent. diff.

n	M^n	dM/dt	F^{n-1}_{up}	F^n_{up}	F^{n-1}_{cd}	F^n_{cd}
1	4	0	0	0	0	0
2	4	0	0	1	0	0.5
3	3	-1	1	2	0.5	1.5
4	1	-2	2	1	1.5	1.5
5	0	-1	1	0	1.5	0.5
6	0	0	0	0	0.5	0
7	0	0	0	0	0	0

$v = 1/2\ \Delta x / \Delta t$

n	M^n	dM/dt	F^{n-1}_{up}	F^n_{up}	F^{n-1}_{cd}	F^n_{cd}
1	4	0	0	0	0	0
2	4	0	0	0.25	0	0.125
3	4	0	0.25	0.5	0.125	0.25
4	3.5	-0.5	0.5	0.75	0.25	0.5
5	3	-0.5	0.75	1	0.5	0.75
6	2	-1	1	0.75	0.75	0.75
...	...	...	...	...	...	...

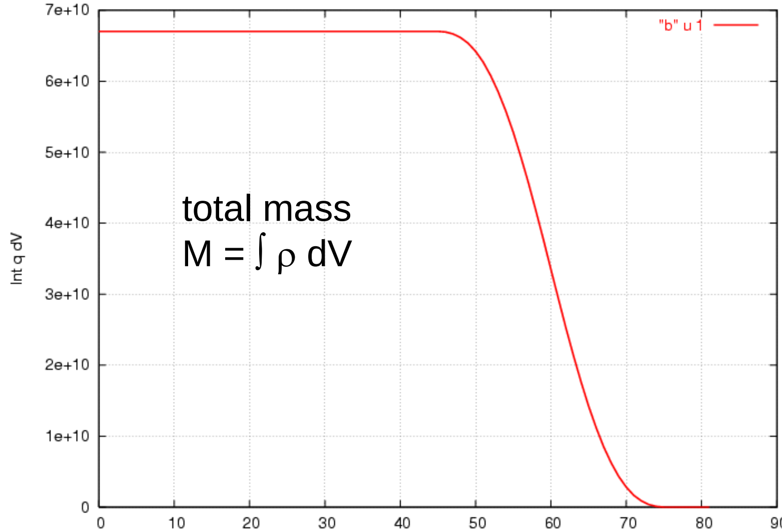
‚flux artefact‘

→ best solution: upwind calculation of fluxes at timestep n-1

Test of the integration tool

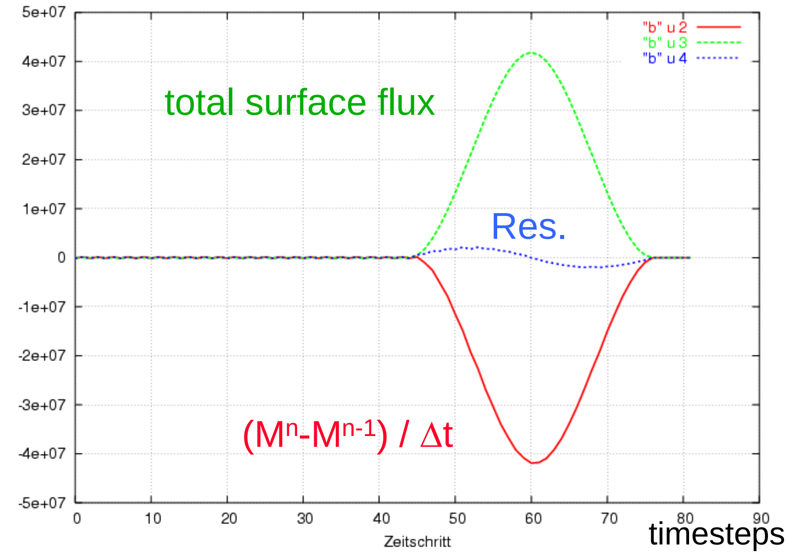
by shifting a 3D-cone through the LM-domain (‚ideal transport‘)

case v = 1 Δx / Δt, flat terrain:
correct balance in all directions (errors only by machine accuracy!)
→ domain decomposition (parallelisation) ok
→ volume-/surface-integrals properly calculated (at least without orography)



case v = 1/2 Δx / Δt:
(similar behaviour with orography)

- ‚flux artefact‘ (Res ≠ 0 by intersecting the cuboid surface)

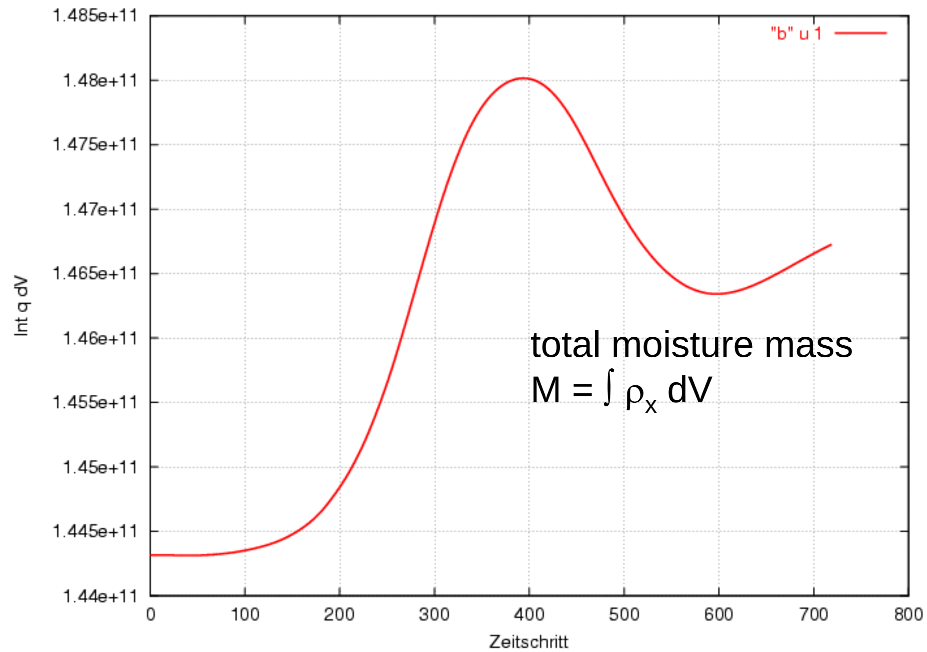


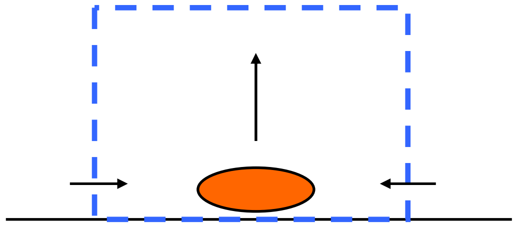
Weisman-Klemp (1982)-test case

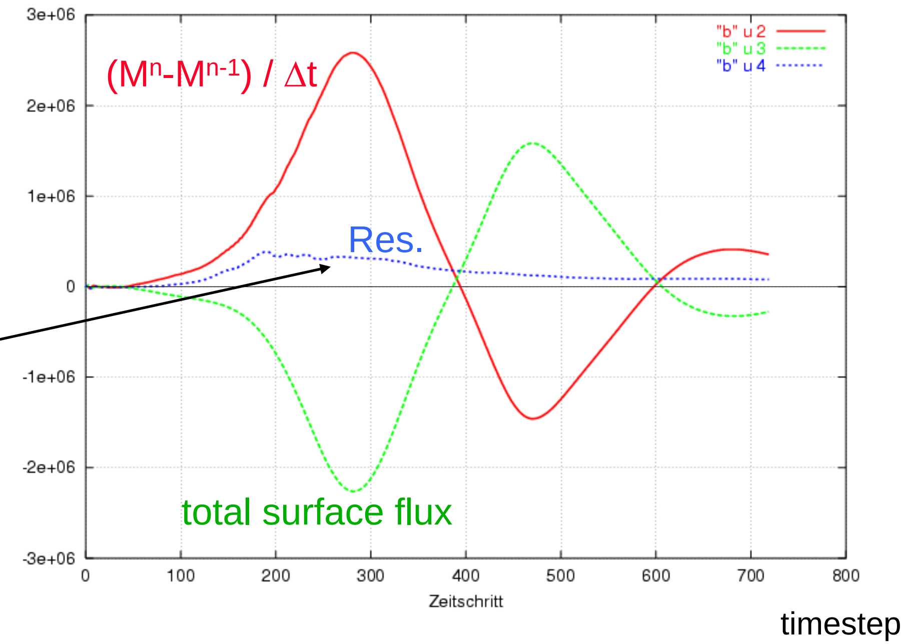
without physical parameterisation
(only advection &
Condensation/Evap.)

Semi-Lagrange-Adv. for q_x
with multiplicative filling

$\rho_x := \rho\,(q_v + q_c)$







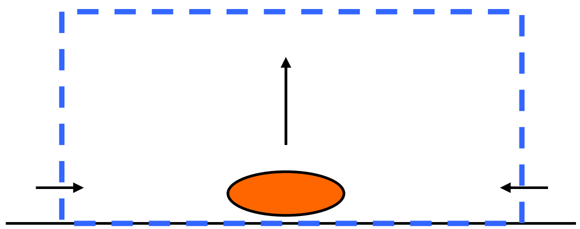
violation in moisture conservation (?)

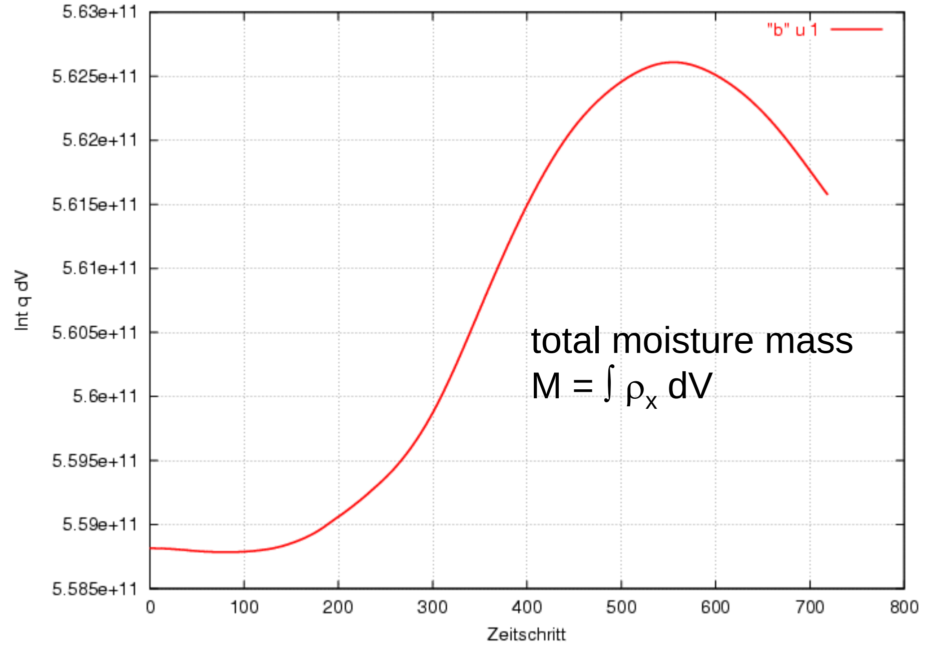
Weisman-Klemp (1982)-test case

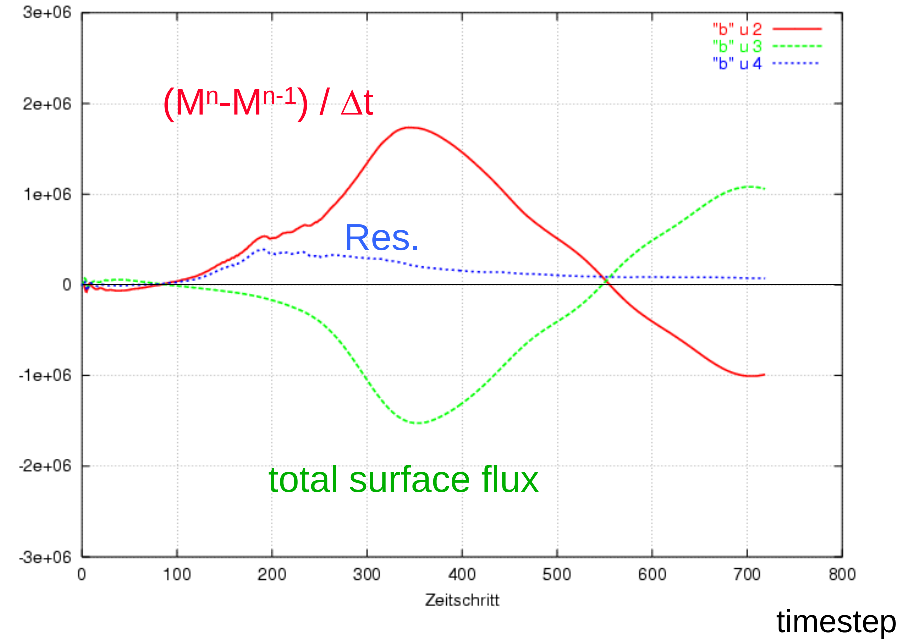
without physical parameterisation
(only advection &
Condensation/Evap.)

Semi-Lagrange-Adv. for q_x
with multiplicative filling

$\rho_x := \rho\,(q_v + q_c)$







bigger integration area

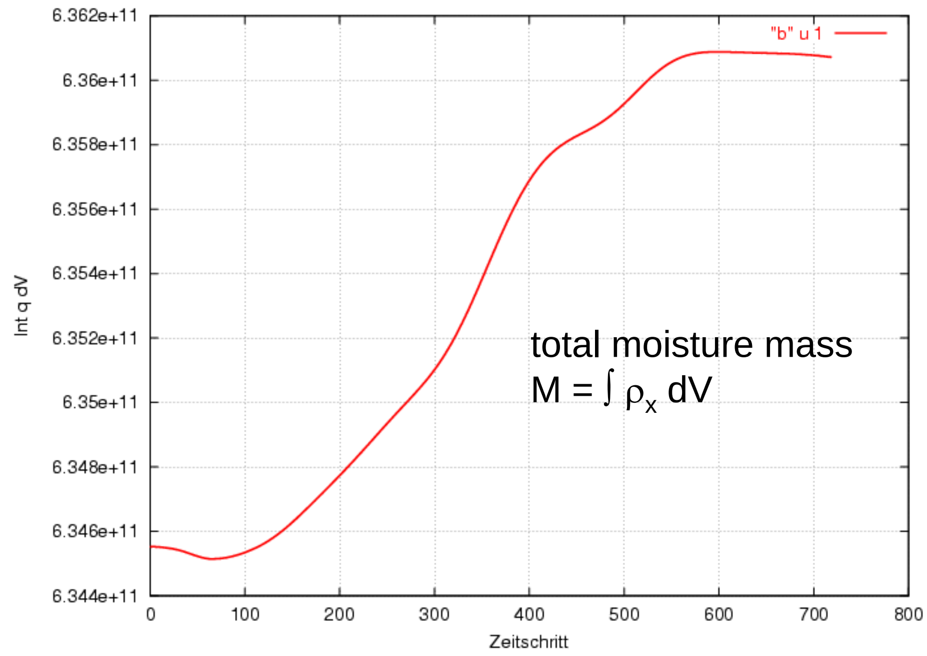
Residuum is almost the same
→ only small artifical effect by the
surface integrals

Weisman-Klemp (1982)-test case
with warmer bubble (10 K)

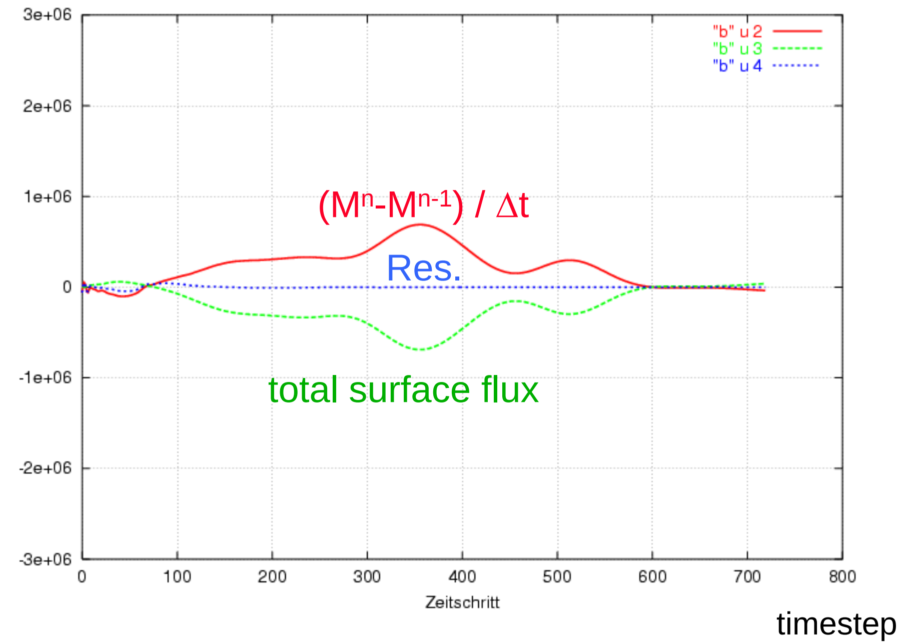
without physical parameterisation,
without Condensation/Evap.

Semi-Lagrange-Adv. for q_x
with multiplicative filling

$\rho_x := \rho\,(q_v + q_c)$



Residuum ≈ 0
→ advection seems to be ‚conservative enough'



possible reasons for conservation violation:

saturation adjustment conserves specific mass (and specific energy) but not mass (and energy) itself !

Summary ‚integration tool'

- This tool can give hints to conservation violation
- Weisman Klemp test case as a first example of application
- Results of the balance have to interpret carefully:
  especially errors in flux calculation seem to be critical
  → boundaries of the integration area should be far away from the process which will be inspected
  → compare different sizes of integration areas
- pay attention: relaxation boundaries → destroy conservation