Latent Heat Nudging in aLMo:

Experiments with Idealized Supercell Simulations

Daniel Leuenberger and Andrea Rossa

MeteoSwiss

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

MeteoSwiss

Talk Outline

- Introduction
- Supercell Storms
  - Characteristics
  - Reference simulation
- OSSE with Latent Heat Nudging
  - Sensitivity to observation insertion frequency
  - Sensitivity to environmental humidity
  - Sensitivity to horizontal grid spacing
- Findings
- Outlook

Daniel.Leuenberger@MeteoSwiss.ch
COSMO Meeting, 24.September 2003

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Introduction: Latent Heat Nudging

- Radar information is gaining importance in mesoscale data assimilation.
- LHN: Assimilation method for precipitation information.
- Trigger model precipitation where Radar detects precipitation (heating), supress it elsewhere (cooling).
- Scale model latent heating profiles by an amount derived from observed and model precipitation.

Daniel.Leuenberger@MeteoSwiss.ch

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Introduction: OSSE

- Observing System Simulation Experiment (OSSE)
  - Suited to investigate the performance of assimilation schemes
  - Gain insight in LHN
  - Reference simulation provides „ideal, artificial observations“
- Simulation of idealized supercell storm
  - Simple environment
  - Coherent, long-lived, organized system
  - Well documented in literature

Daniel.Leuenberger@MeteoSwiss.ch

Supercell Storm: Characteristics

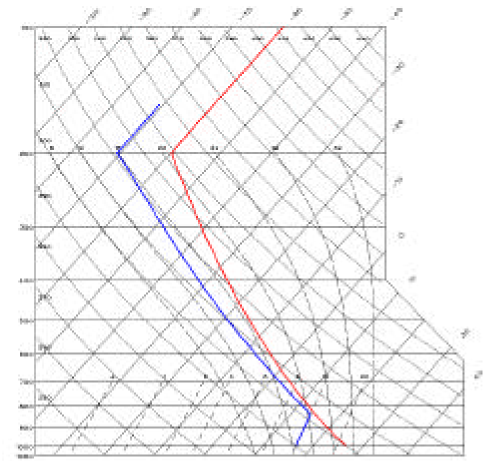
- Long-lived thunderstorm with two strong rotating updrafts
- Develops in moderate to strong windshear and is largely driven by vorticity dynamics
- Effective separation of warm moist inflow and cold downdraft enables long life (up to several hours)
- Severe, long-lived hail-storms often exhibit supercell characteristics

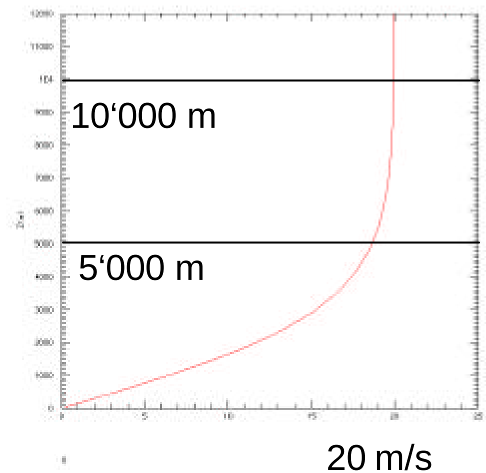
Daniel.Leuenberger@MeteoSwiss.ch
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich
MeteoSwiss

Supercell Simulations

- Idealized environment
  - Large amount of CAPE (~1200 J/kg)
  - One-directional wind shear
  - Horizontally homogeneous
- Model configuration

  $\Delta x = 1\text{km}, \Delta t = 5\text{s}$
  - Parametrizations:
    - Grid-scale one-category ice scheme
    - Default turbulence parametrization
  - New 2 TL – scheme
  - Doubled explicit horizontal diffusion (aks4 = $2.05\ 10^{-3}$)





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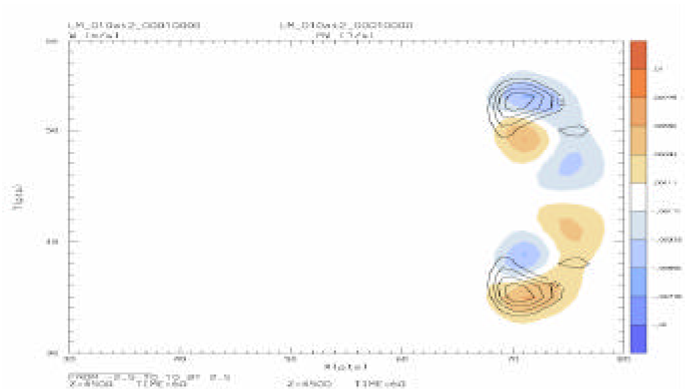
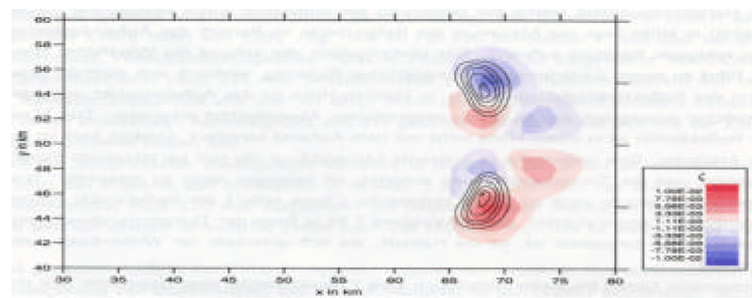
Supercell Simulations

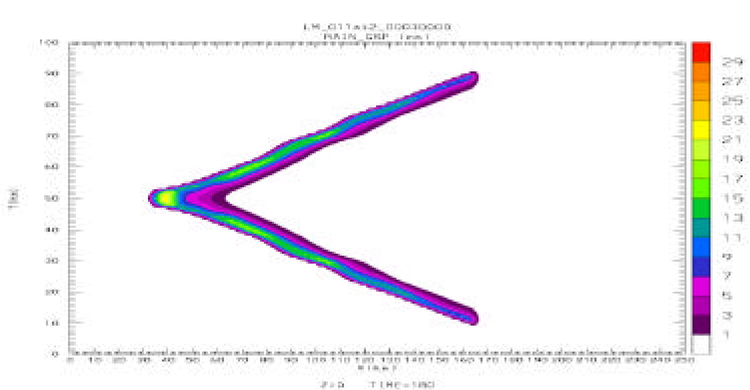
- Comparison of reference run with results from a cloud-resolving research model

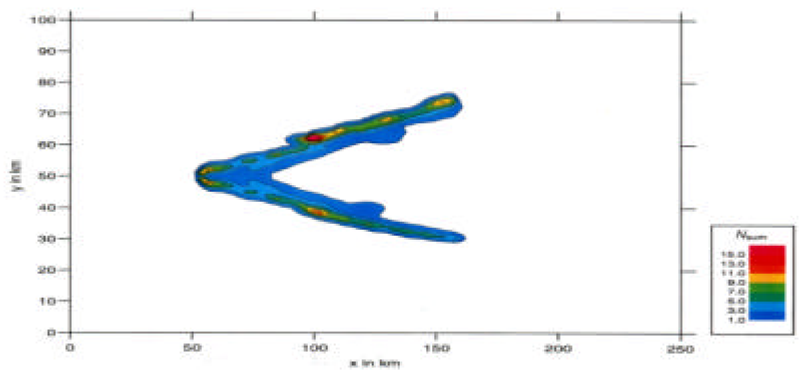
LM Reference run

KAMM2 (A. Seifert)









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Supercell Simulations

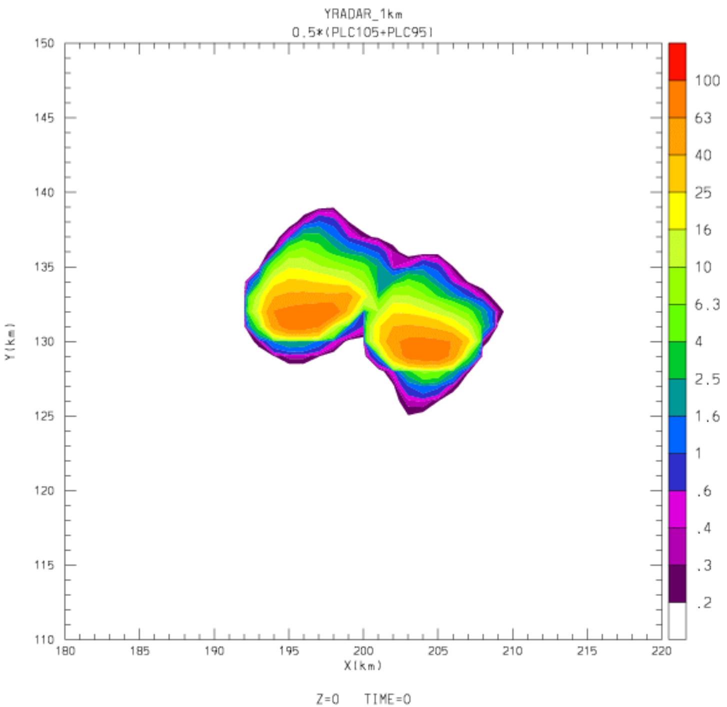
- Reference run
  - Supercell initiated with warm bubble
  - Model rain serves as „artificial radar observations“
- LHN Analysis
  - Same environment as reference run
  - No warm bubble initiation
  - LHN during 3h (artificial rain rates from reference run)
- LHN Forecast
  - LHN during first 30, 60, 90, 120, 150 min
  - Free run afterwards

Daniel.Leuenberger@MeteoSwiss.ch

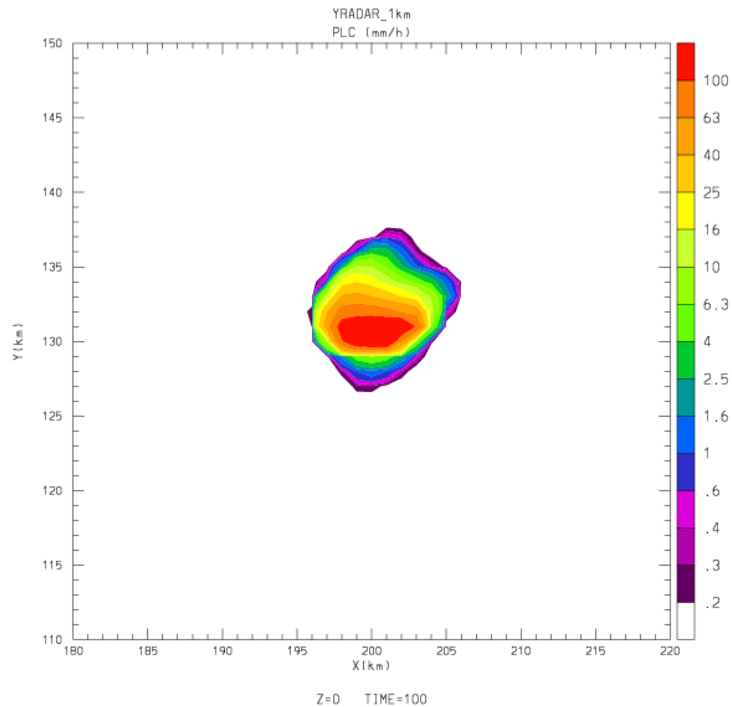
Insertion Frequency of Precipitation Input

- LHN linearly interpolates between subsequent observations
- Examine relevance of insertion frequency Δt to LHN Analysis

Δt = 10min
linear interpolation



Δt = 1min



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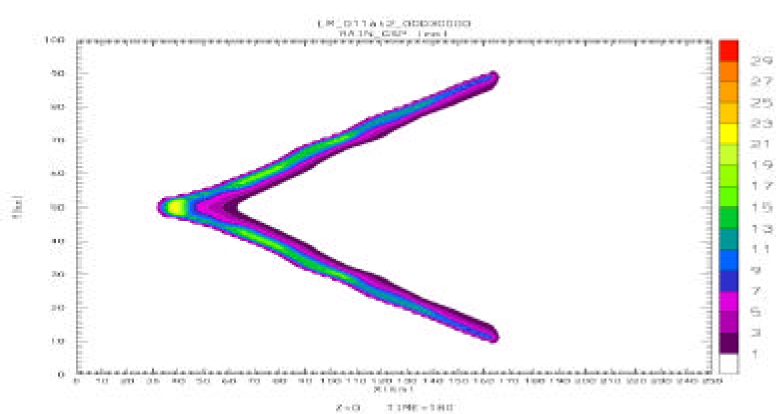
LHN Analysis (LHN during 3h)



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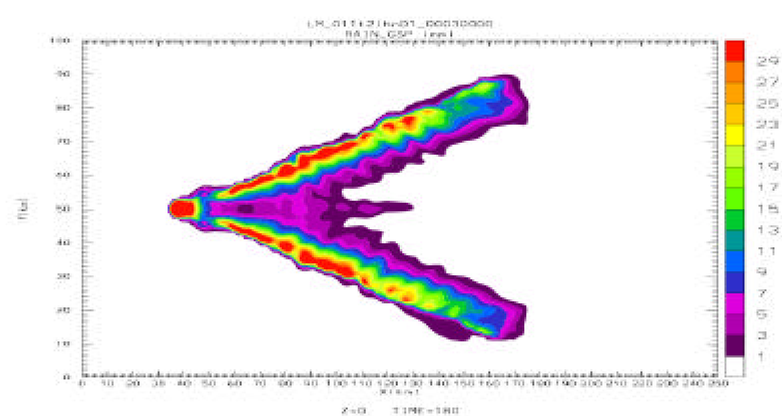
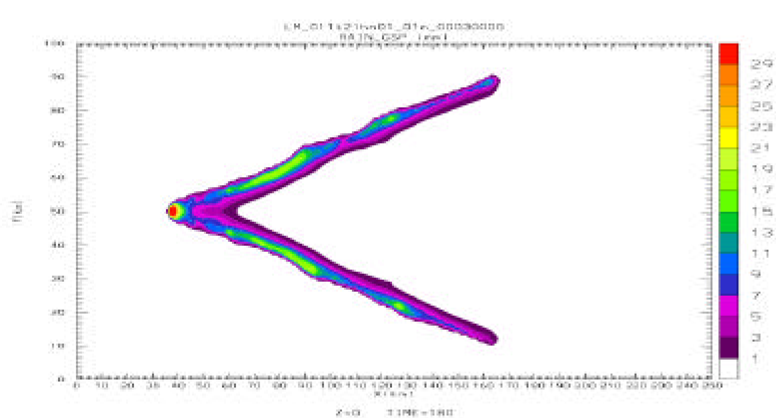
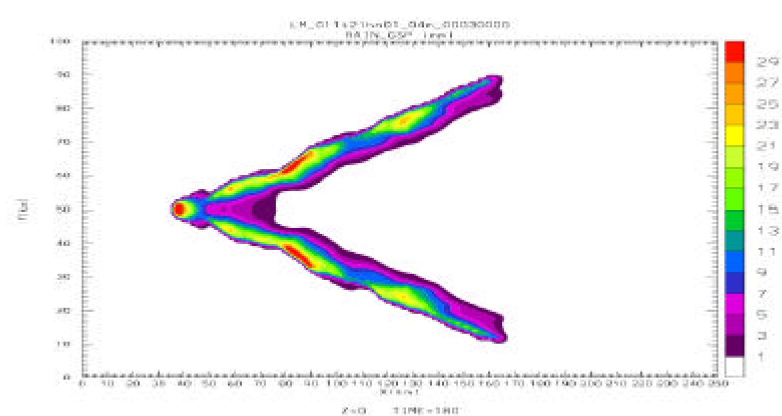


D*t* = 10min



D*t* = 1min



D*t* = 4min

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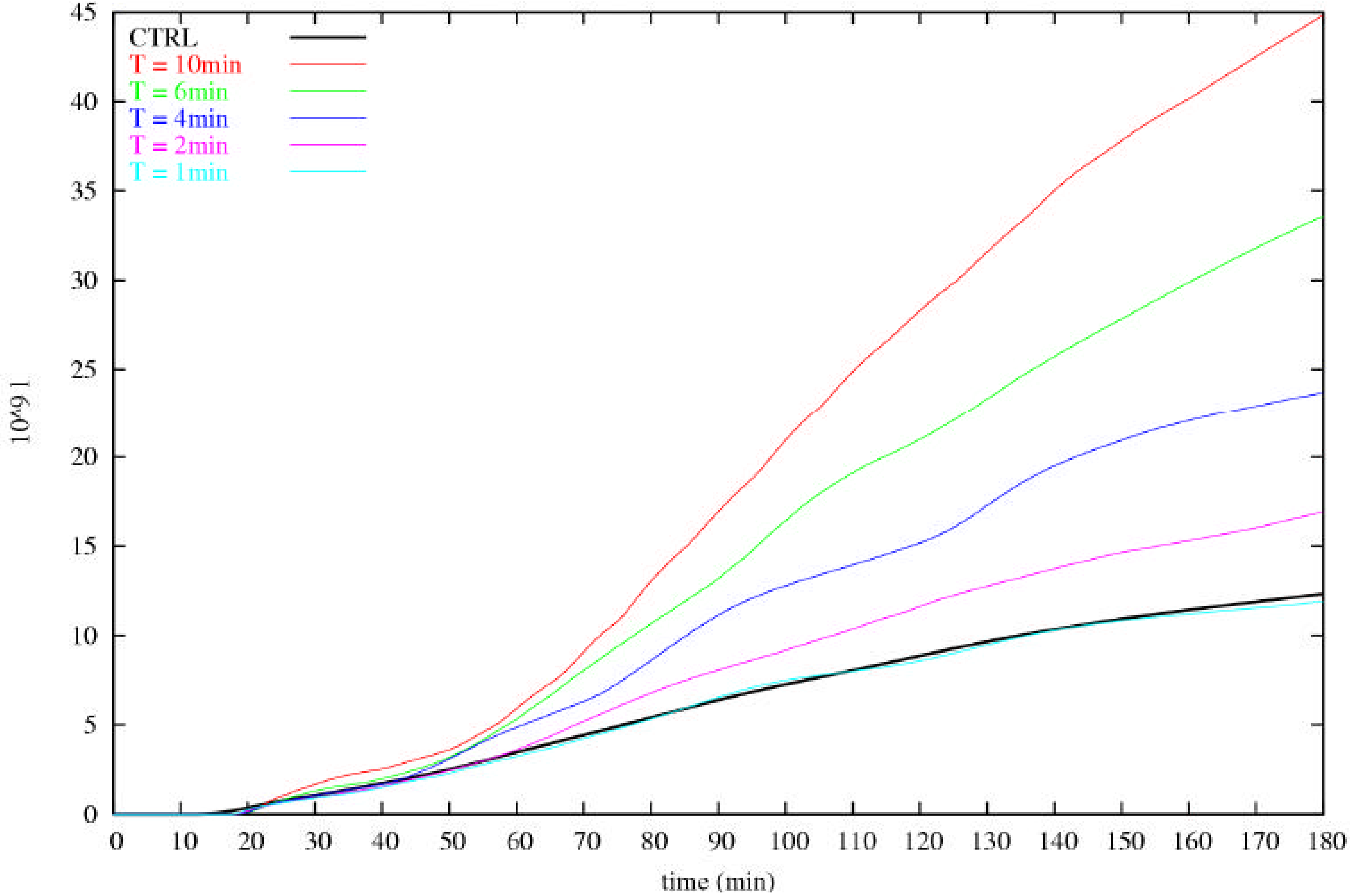
LHN Analysis: Cumulated surface rain



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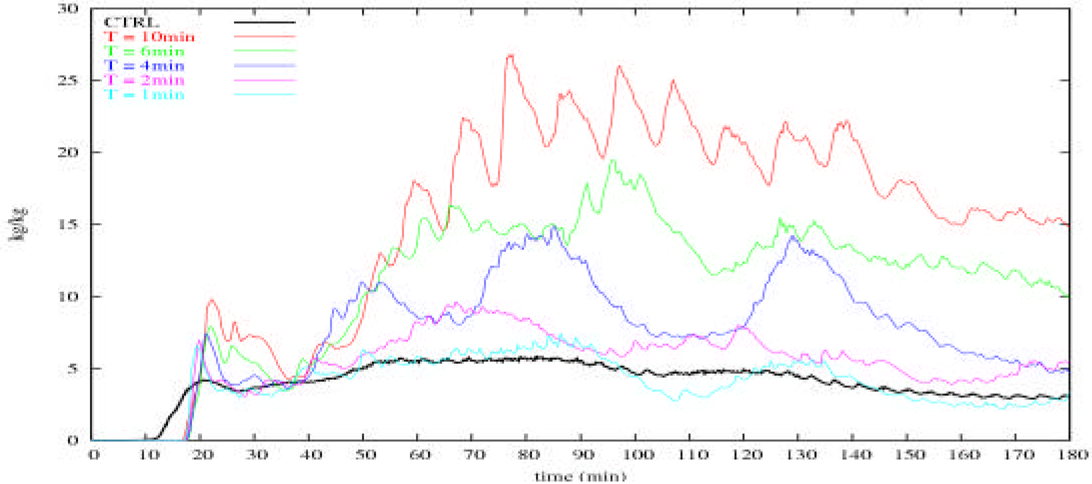
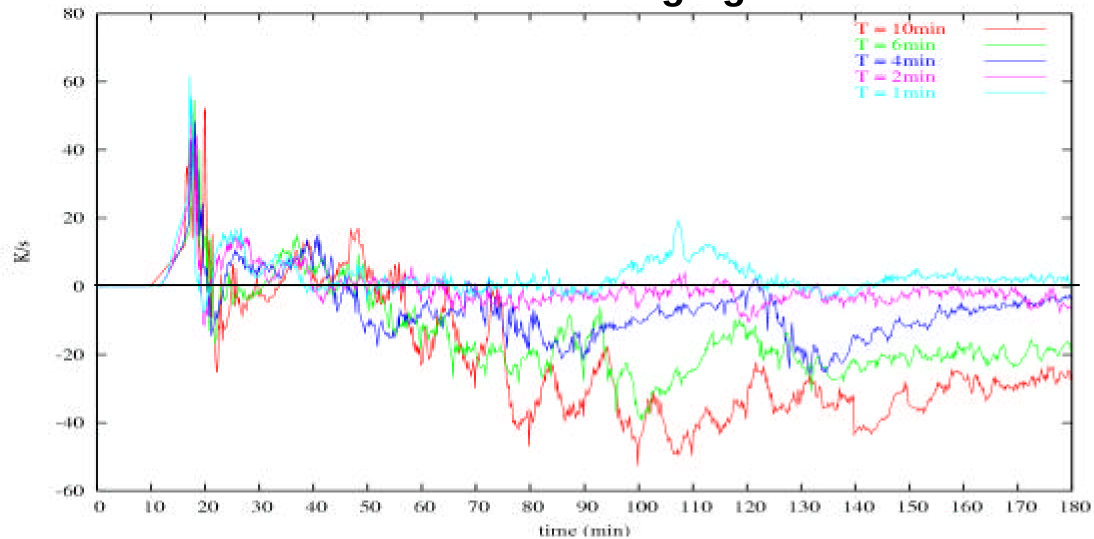
LHN Analysis

Domain sum of qr



Domain sum of LH nudging increment



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T = 10min
T = 6min
T = 4min
T = 2min
T = 1min

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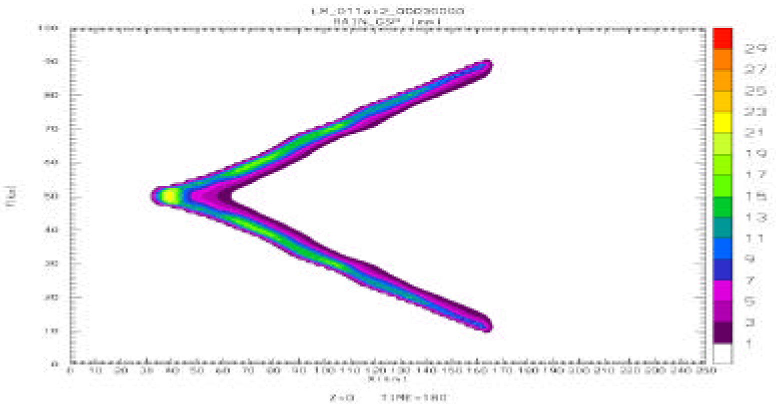
LHN Forecast (D*t* = 1min)



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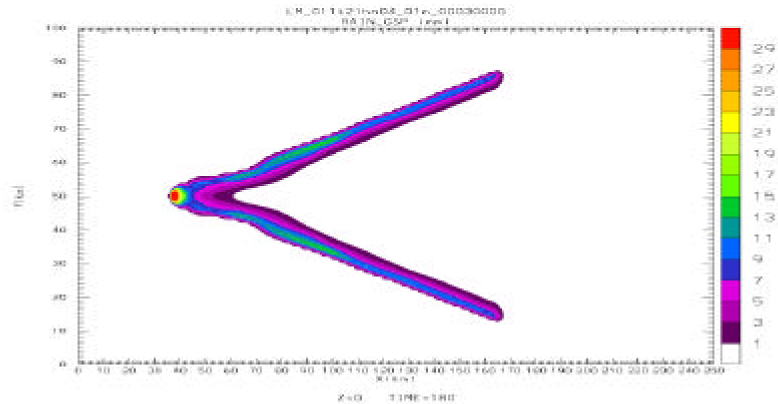
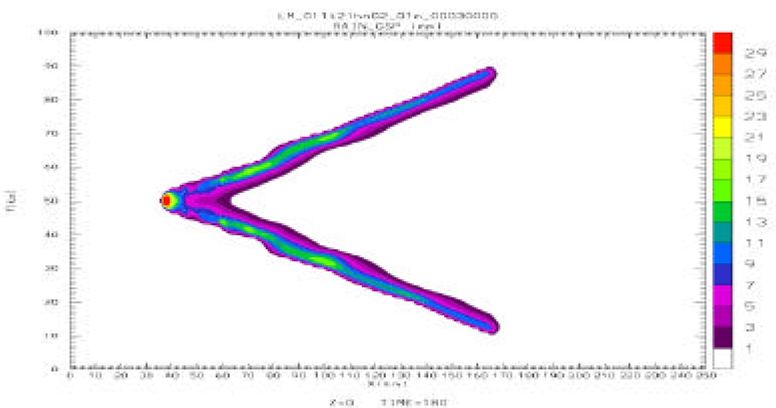
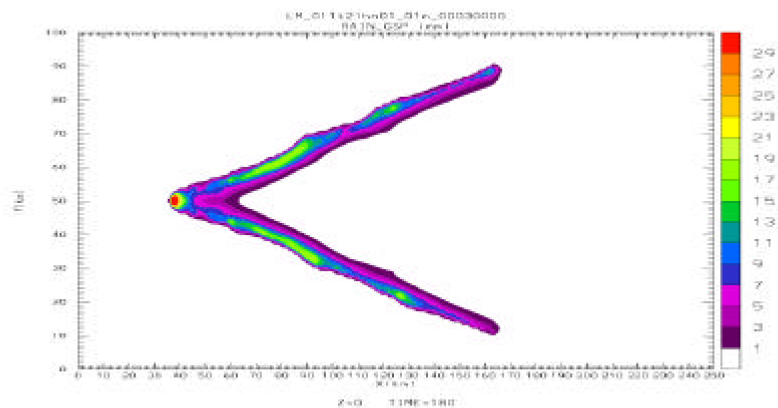


Free forecast after 30 min



Free forecast after 1h



Analysis (LHN during 3h)

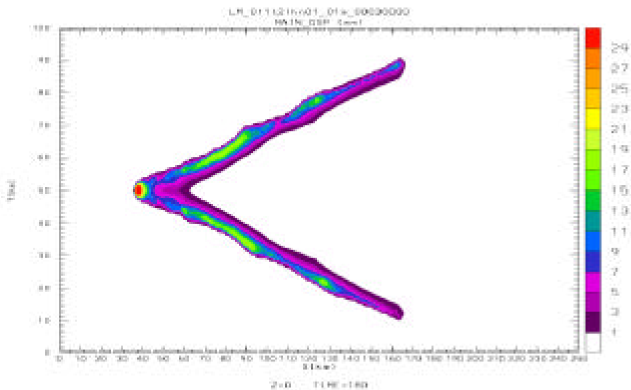
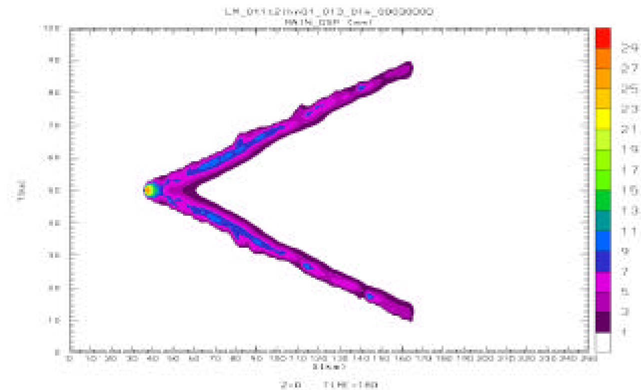
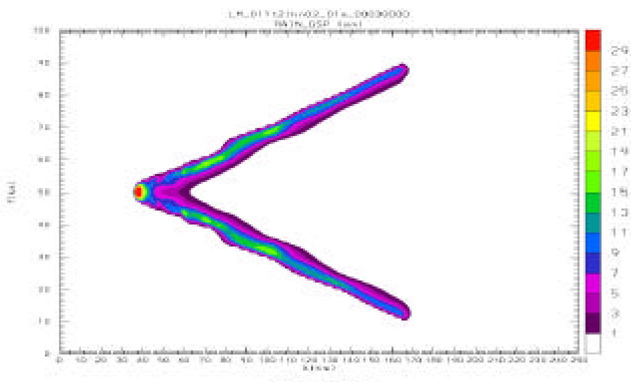
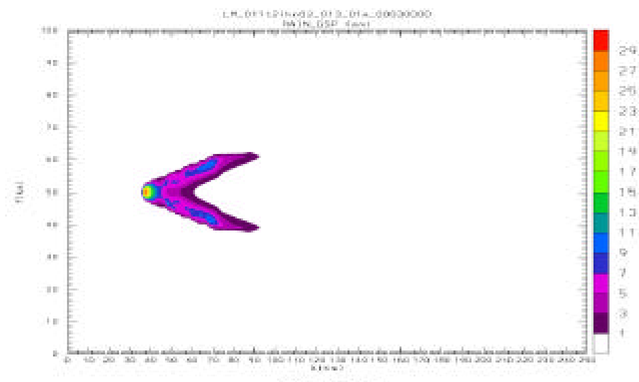
Daniel.Leuenberger@MeteoSwiss.ch

Sensitivity Experiments

- Frequent problem in assimilation of convection at small scales: Rapid loss of assimilated information in free forecast
- Try to find factors contributing to this problem: What could cause the storm to ‚die' too quickly in the free forecast?
- Sensitivity to low level humidity of environment
- Sensitivity to grid spacing

Daniel.Leuenberger@MeteoSwiss.ch

Low-level humidity

	Reference environment $q_v = 12$ g/kg	**Drier environment** $q_v = 10$ g/kg
Analysis		
Free forecast after 1h		

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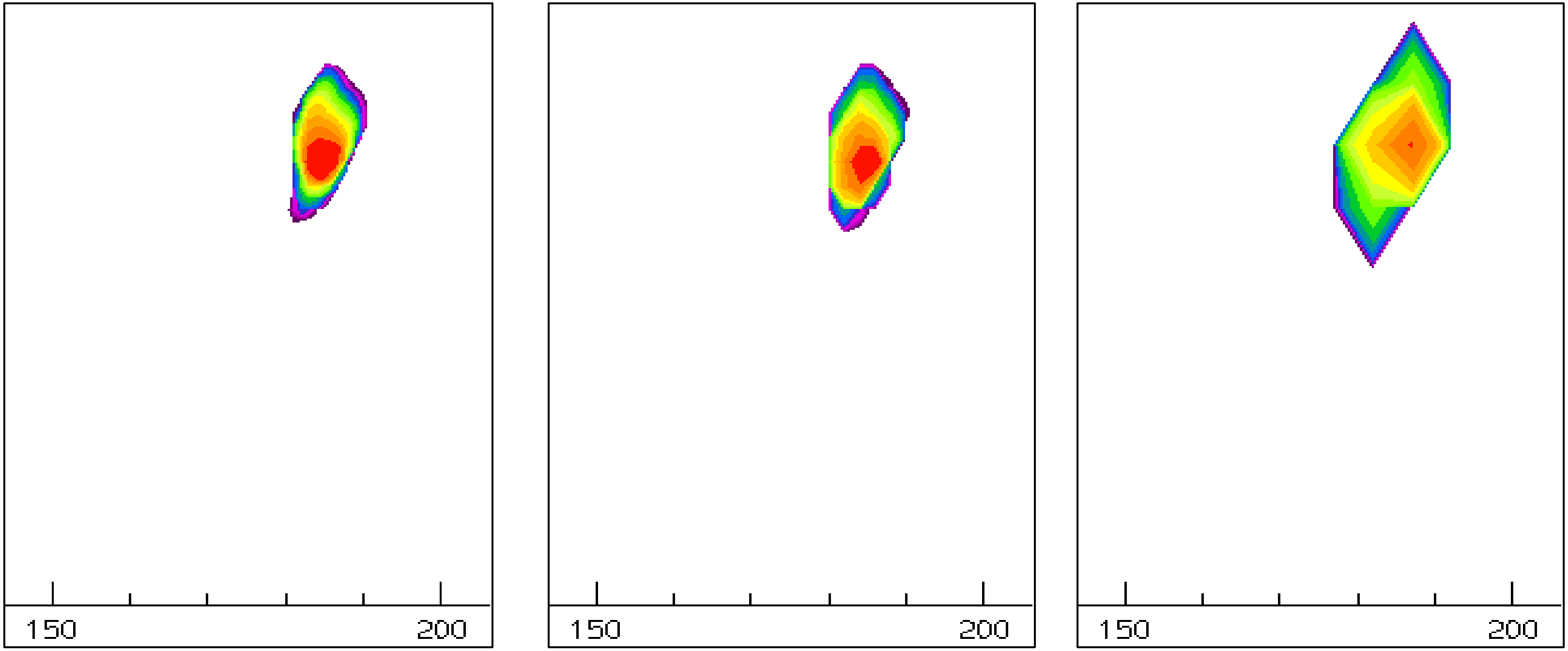
Horizontal grid spacing

- Interpolation of 1km forcing to 2km and 5km mesh
- Perform LHN runs with coarse mesh

Dx = **1km** Dx = **2km** Dx = **5km**



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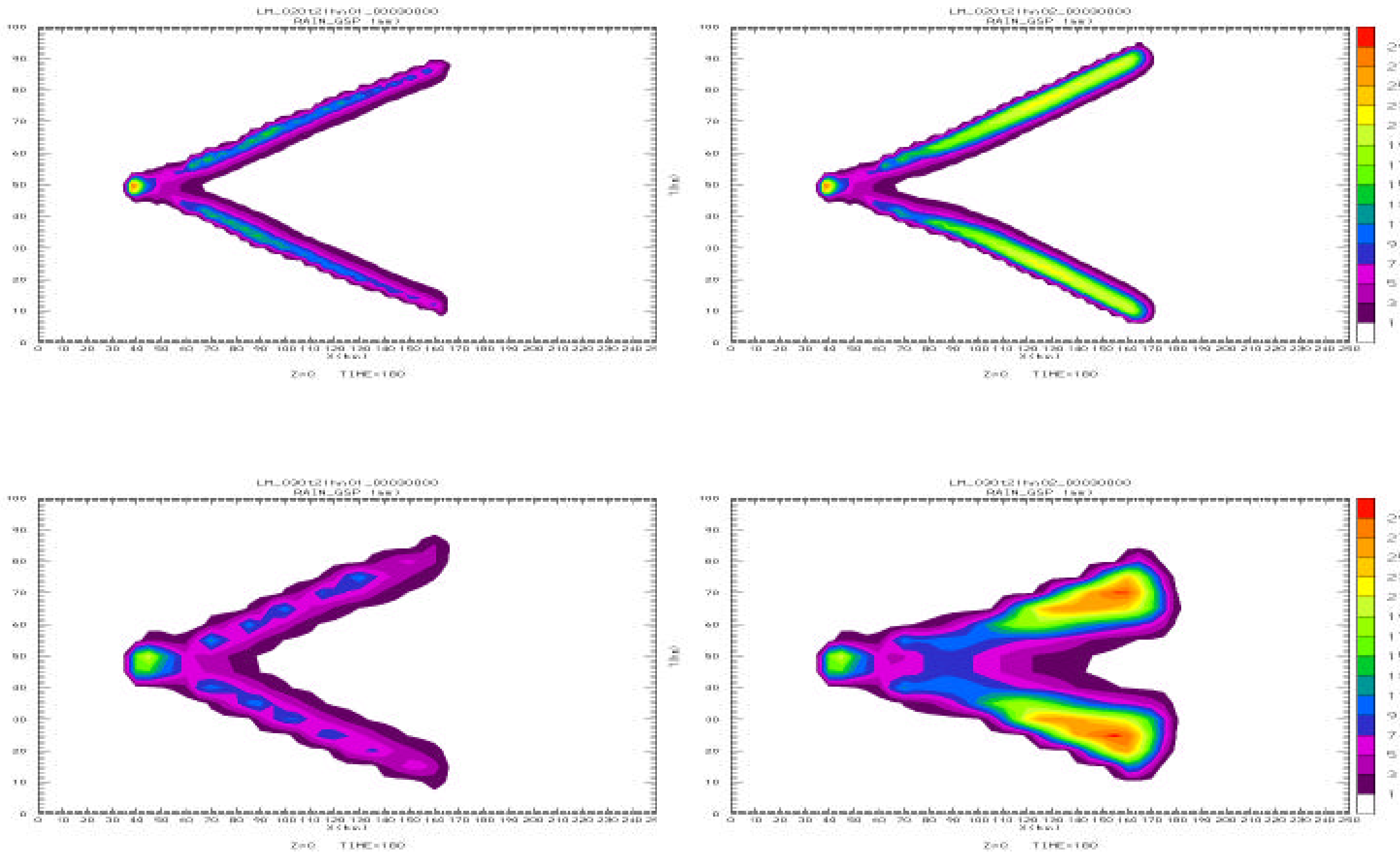
Horizontal grid spacing

Analysis (LHN during 3h) | **Free forecast after 1h**

Dx = 2km

Dx = 5km



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Findings

- Simulation of an idealized, long-lived, meso-γ convective system, showing similarities with results from literature
- LHN capable of analysing and initiating supercell storm
- High insertion frequency important in this case
- Low level humidity essential for storm development
- Even a poorly resolved forcing is able to initiate and maintain storm evolution
- Supercell storm very stable dynamics: are findings ‚portable' to other situations?

Daniel.Leuenberger@MeteoSwiss.ch

Outlook

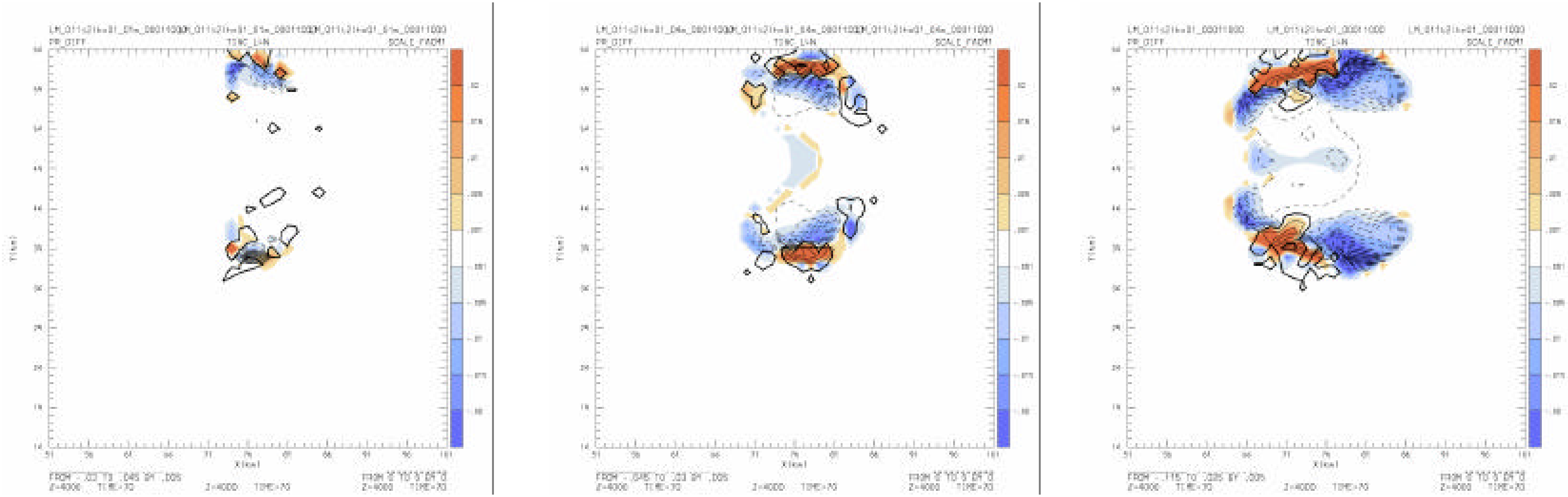
- Real-case study
  - Reduction of grid-size to 2km
  - More cases
- Idealized OSSE
  - Sensitivity of vertical forcing distribution
  - Assimilation of ideal 3D latent heating fields
  - Assimilation of horizontal winds
  - Consider case which is less driven by dynamics (initialize environment with real sounding data)

Daniel.Leuenberger@MeteoSwiss.ch

Thank you for your attention !

Daniel.Leuenberger@MeteoSwiss.ch

Different Forcing (at t = 110 min)



Dt = 1 min | Dt = 4 min | Dt = 10 min

Color: ΔT_{LHN}

Black contours: $RR_{rad} - RR_{mo}$

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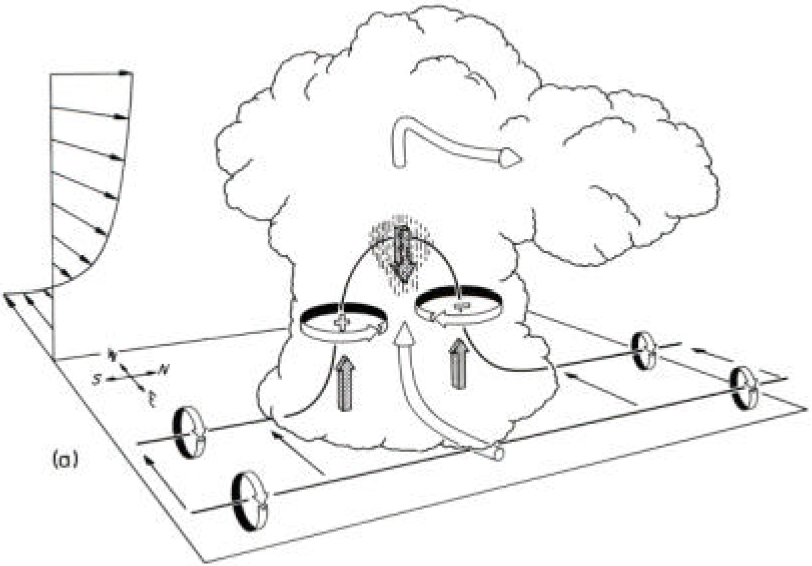
Supercell Storm: Conceptual Model

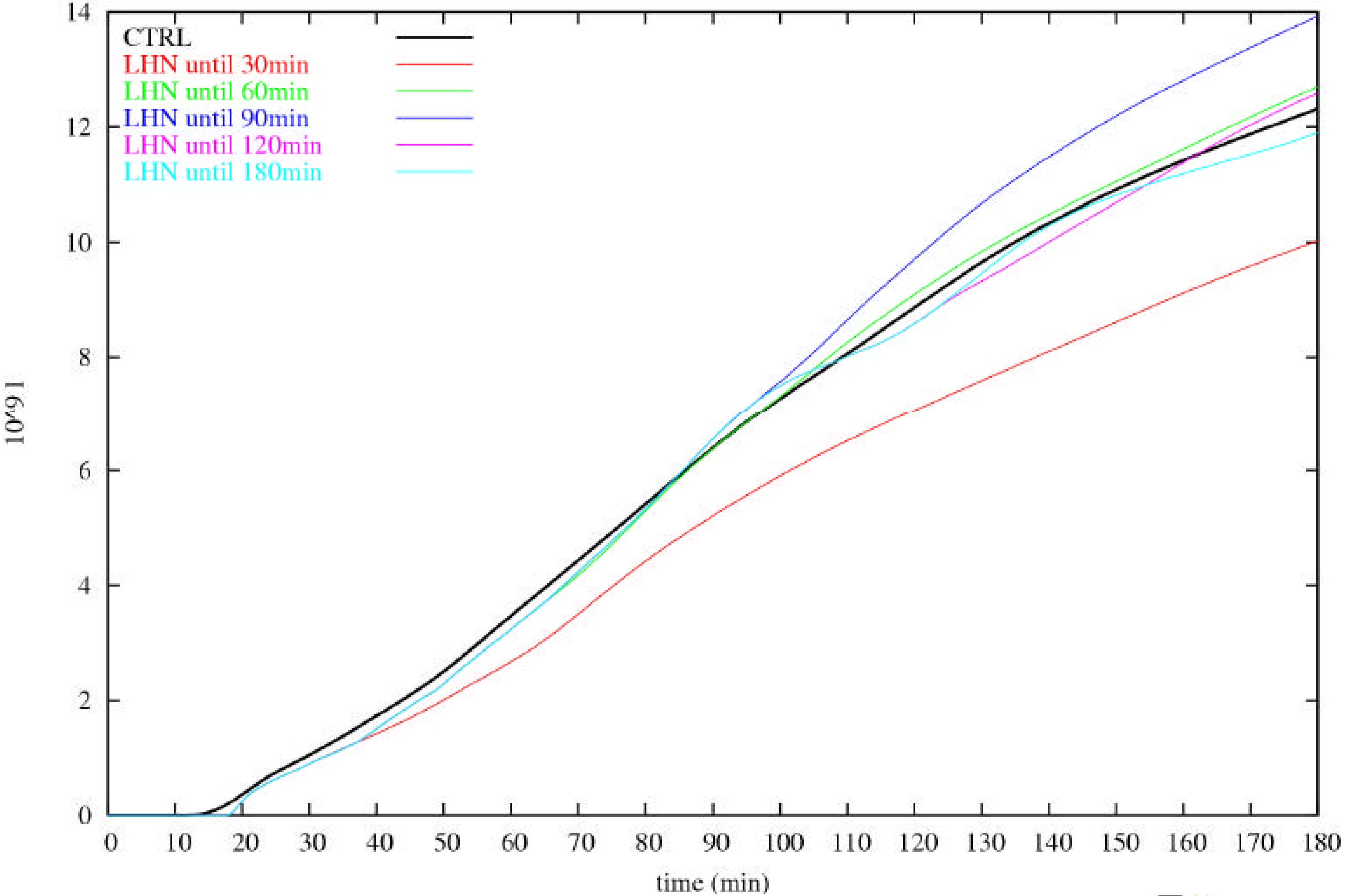


Initial stage

Splitting stage

from Klemp (1987)

LHN Forecast: Cumulated surface rain



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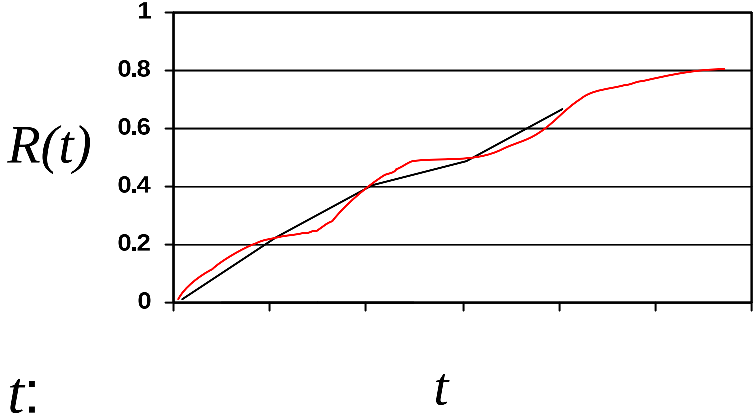
Insertion Frequency of LHN Input

- Sampling intervals of rain rates (insertion frequency of observations)

$$R(t) = \int_{t_0}^{t} RR(t\,)\,dt$$

$$RR(t) = \frac{dR(t)}{dt}$$



- Mean rain rate from t - Δt to t:

$$\overline{RR}(t,\Delta t) = \frac{\Delta R}{\Delta t} = \frac{R(t) - R(t-\Delta t)}{\Delta t} \qquad \lim_{\Delta t \to 0} \overline{RR}(t,\Delta t) = RR(t)$$

- Linear interpolation between successive rain rates in LHN
- LHN Experiments with $\Delta t = 10, 6, 4, 2, 1\ \mathrm{min}$

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LHN Temperature Increments

Temperature increment: $$\Delta T_{LHN} = (f - 1) \cdot \Delta T_{LH_{mod}}, \quad f = \frac{RR_{ana}}{RR_{mo}}$$

Analysed rain rate: $$RR_{ana} = w \cdot RR_{rad} + (1 - w) \cdot RR_{mo}$$

Observation weight: $$w = w(x, y, t) \qquad w \in [0,1]$$

		Scaling factor f	Profile to scale
Model fair	$1/a_{down} \leq \frac{RR_{ana}}{RR_{mo}} \leq a_{up}$	$\frac{RR_{ana}}{RR_{mo}}$	local profile
Model too wet	$\frac{RR_{ana}}{RR_{mo}} \leq 1/a_{down}$	$1/a_{down}$	local profile
Model too dry	$\frac{RR_{ana}}{RR_{mo}} \geq a_{up}$	$\frac{RR_{ana}}{RR_{near/ideal}}$	near / ideal. profile

Daniel.Leuenberger@MeteoSwiss.ch

Nudging Increment

- Add nudging increment to prognostic temperature equation:

$$\frac{\Delta T}{\Delta t} = Model + \frac{\Delta T_{LHN}}{\Delta t}$$

Daniel.Leuenberger@MeteoSwiss.ch

Findings

- aLMo is able to assimilate radar observations
- Good impact in analysis, sfc winds in line with observations.
- Some impact in forecast up to 03h
- aLMo loses information quickly, i.e. storm dies too early
- Why does LHN forecast so rapidly lose radar information?
  - LHN-Scheme (wrong circulation) ?
  - Model resolution ?
  - Environment (humidity) ?

Daniel.Leuenberger@MeteoSwiss.ch