Mesoscale Ensemble Forecasting at DLR - First Results and Future Plans

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George Craig, Arnold Tafferner, Hermann Mannstein

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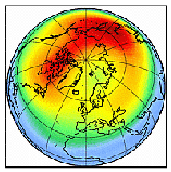
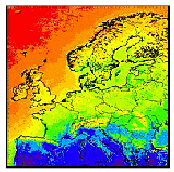
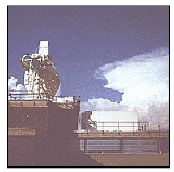
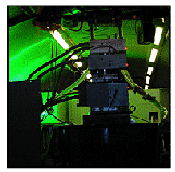


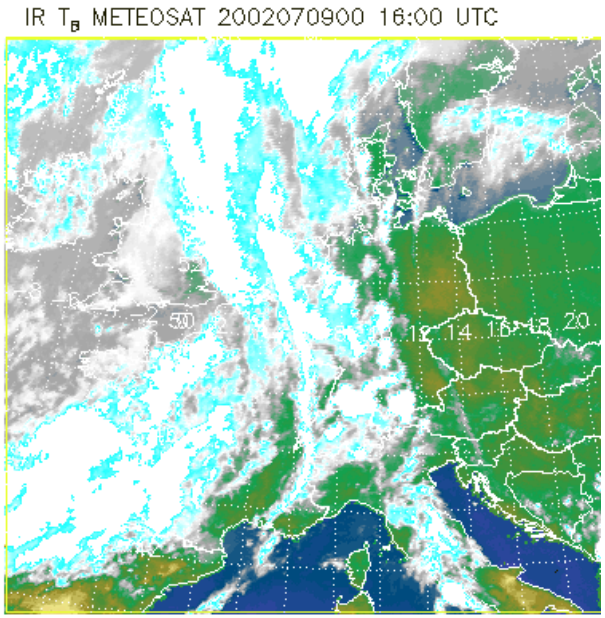
Outline

0. Motivation
1. **COSMO-LEPS**

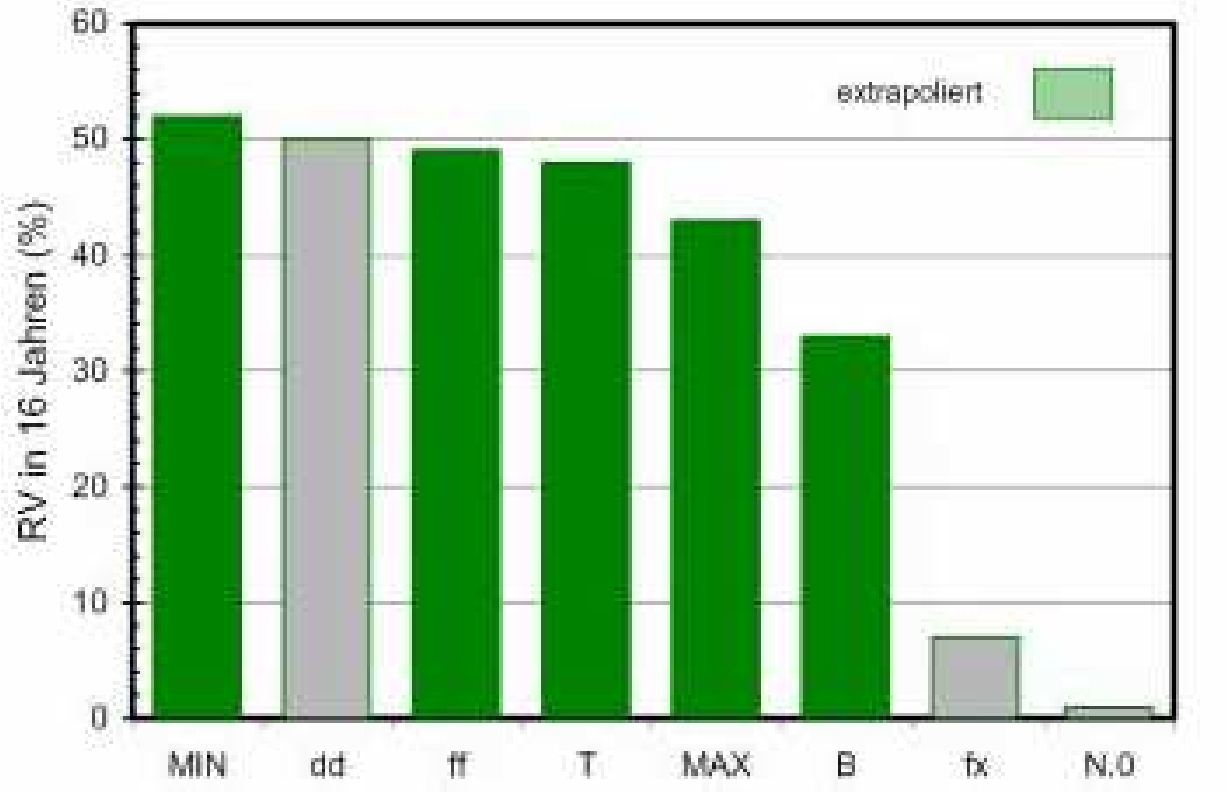
   regional EPS based on ECMWF EPS and Lokal-Modell
   quasi-operational in Italy since November 2002
2. **LMSynSat**

   production of synthetic satellite images in LM
3. **Pyramidal Image Matching**

   objective validation
4. Summary and outlook



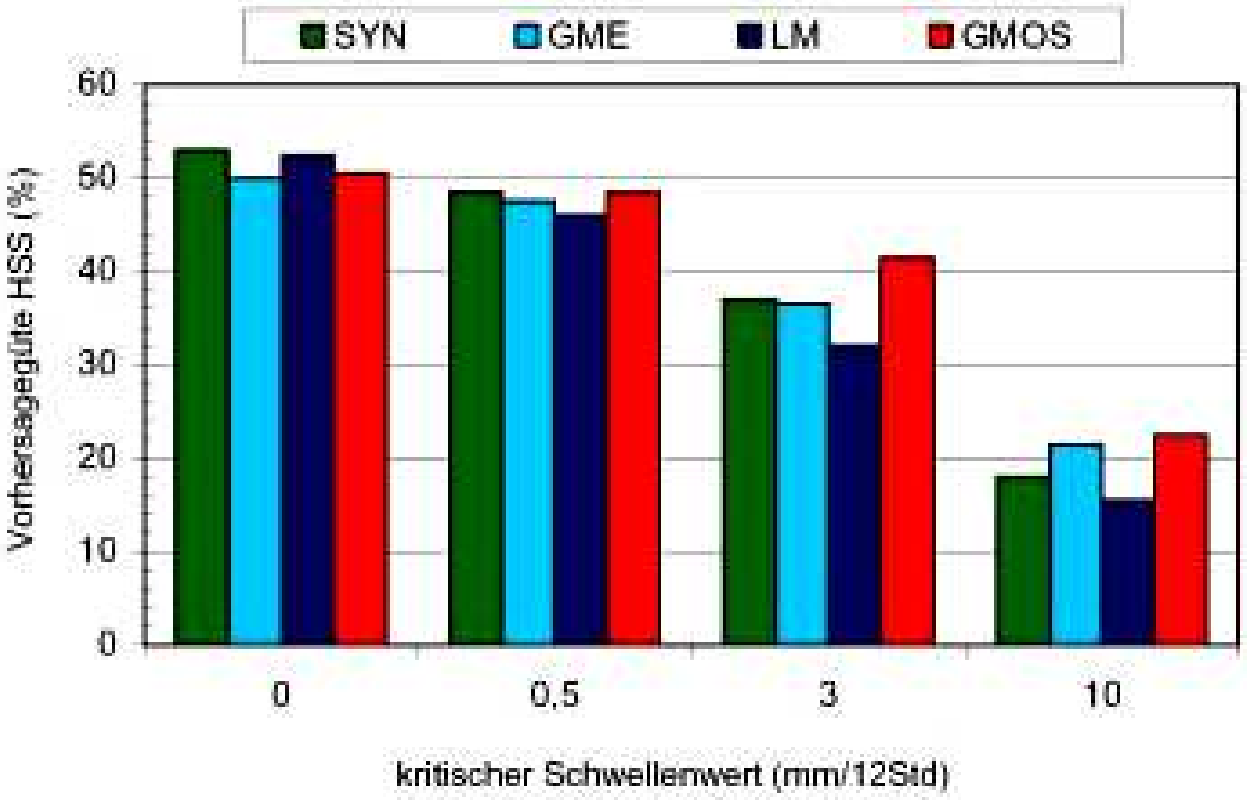
Motivation



Increase in 24h forecast quality of DWD

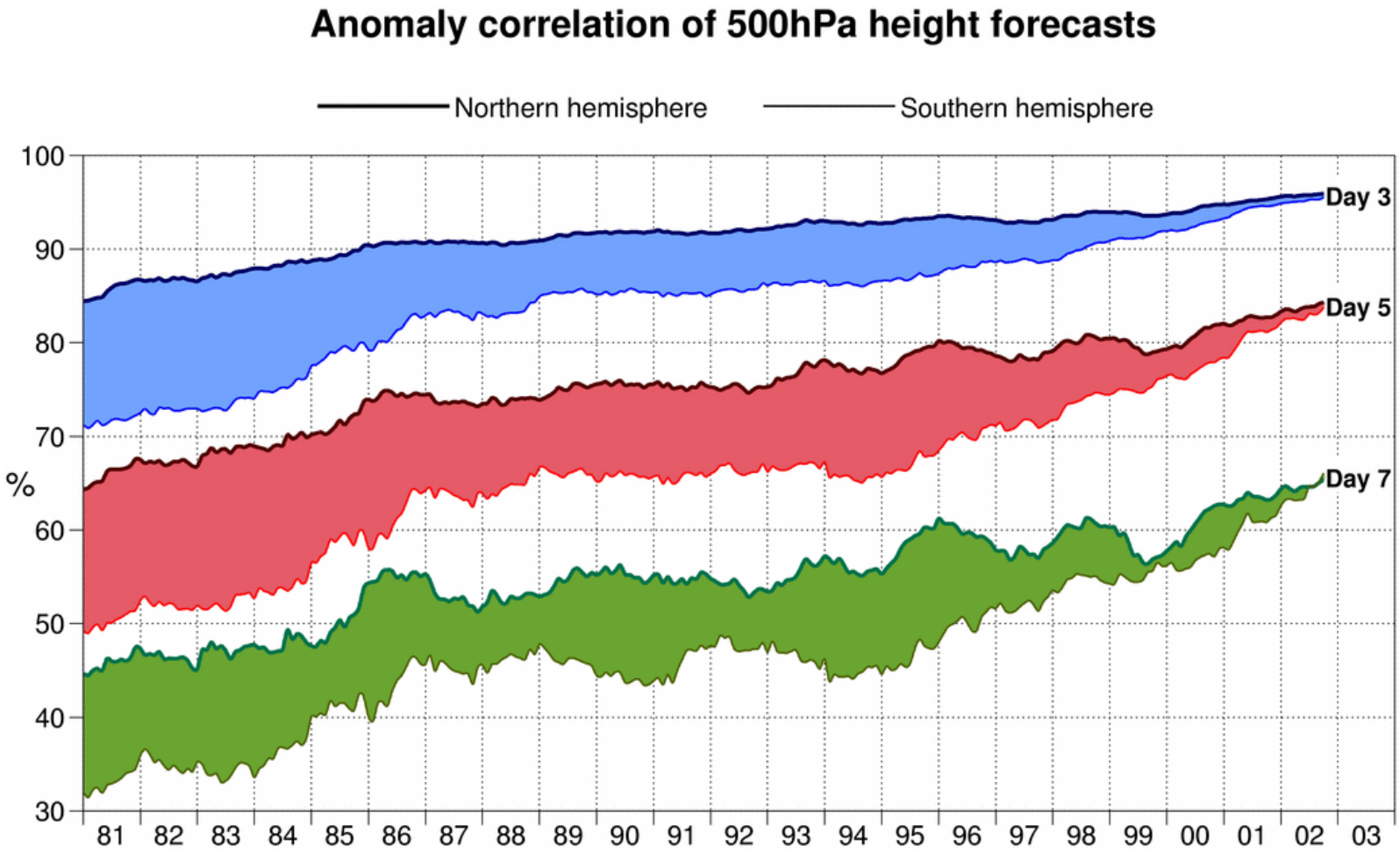
in the last 16 years (DWD, 2002)

Motivation



Quality of short-range precipitation forecast (DWD, 2002)

Motivation



Improvement in forecast quality for ECMWF Model

(Hollingsworth et al, 2002)

Motivation

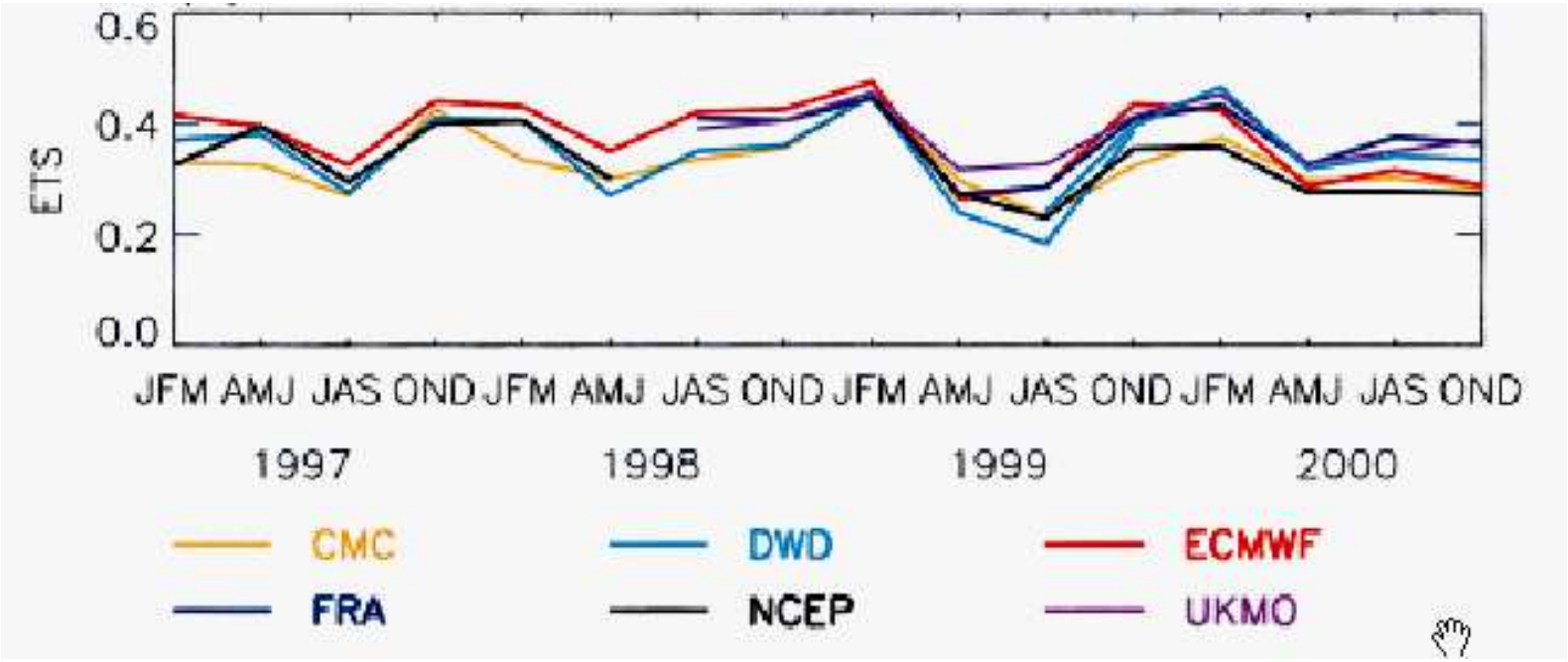


Figure 5. Time evolution of the bias score (top), and the equitable threat score (bottom) over Germany between January 1997 and June 2000 for a rain threshold of 2 mm d^{1}. The forecast valid time is 42 hours (ECMWF) and 30 hours (other models).

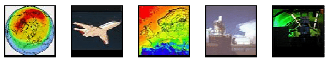
(Ebert et al.,BAMS 2002)

Motivation

Goal: Improved precipitation forecasts

Problem: space-time variability,
frequent phase errors in model forecast

DFG SPP1167 'Quantitative Precipitation Forecasting'
includes 22 projects directed towards
improving the **operational** precipitation forecast of the DWD



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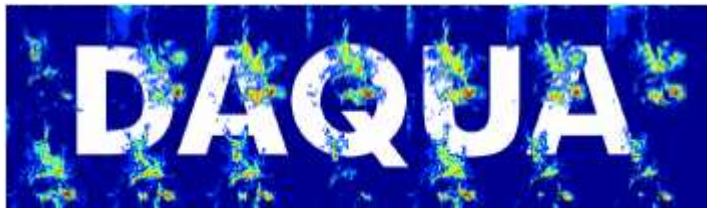
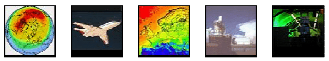


Combined **D**ata **A**ssimilation with Radar and Satellite Retrievals and Ensemble Modelling for the Improvement of Short Range **Qua**ntitative Precipitation Forecasts

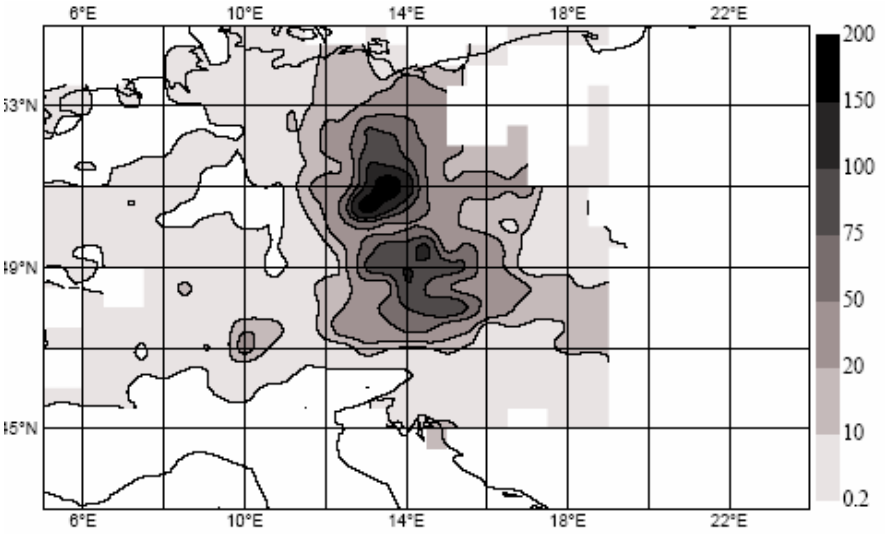
Development of a regional Ensemble System, that represents different sources of forecast uncertainty

1. Initial conditions
2. Boundary conditions
3. Physical Parameterisations

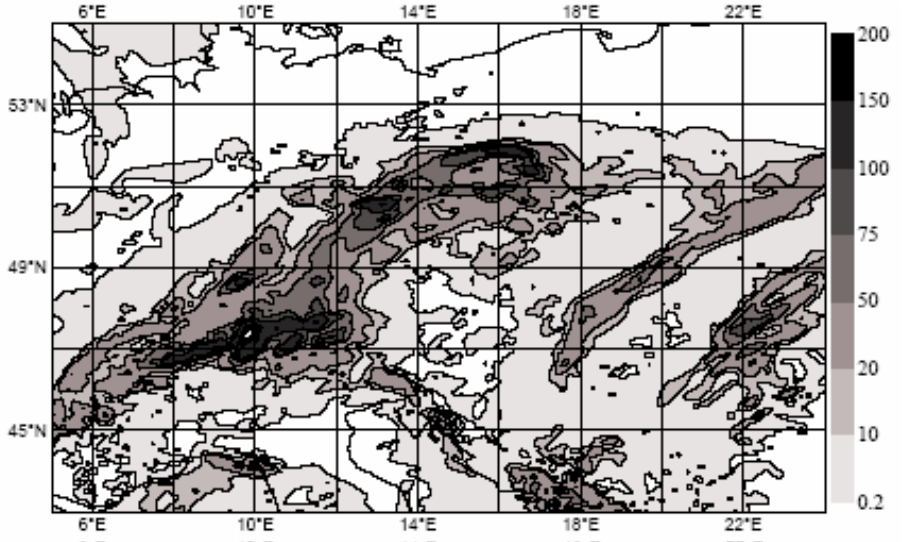


Regional Ensemble System: COSMO-LEPS

COSMO-LEPS performance during the period leading to the Elbe flooding



Observation on 12. Aug 2002



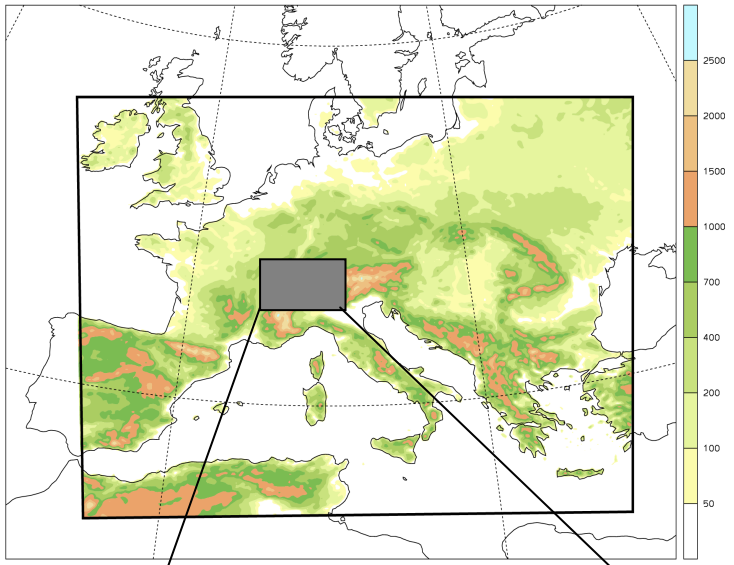
4-day fc of COSMO-LEPS

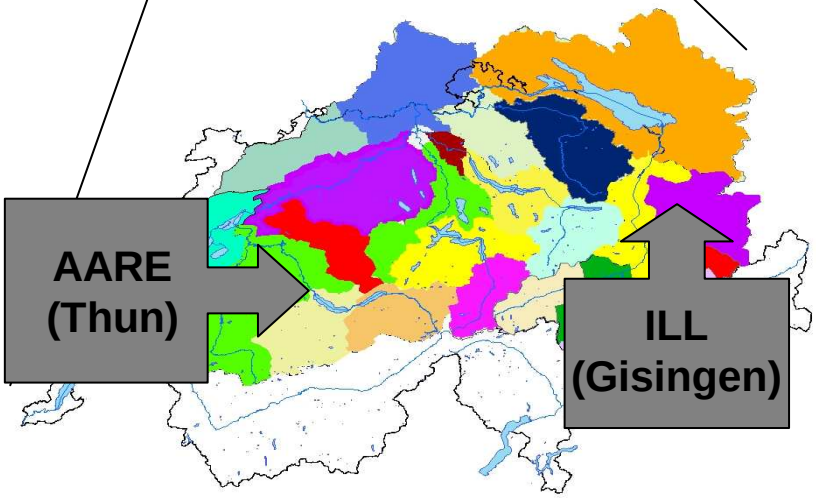
weight based on cluster population:

81 / 7 / 3 / 4 / 5 %

(Marsigli et al.,2003)

Using COSMO-LEPS for hydrological forecasting





COSMO-LEPS Setup:

- quasi-operational since November 2002
- initial and boundary cond. from ECMWF EPS
- Integration period: 120 h
- Model: Lokal Modell (LM)
- Grid-spacing: 10 km, 32 levels

Hydrological Model Setup:

- Rhine upstream of Rheinfelden (34550 km^2)
- Model: PREVAH (Gurtz et al. 1999)
- Driven by LM / COSMO-LEPS
- A few test cases with 51 EPS members

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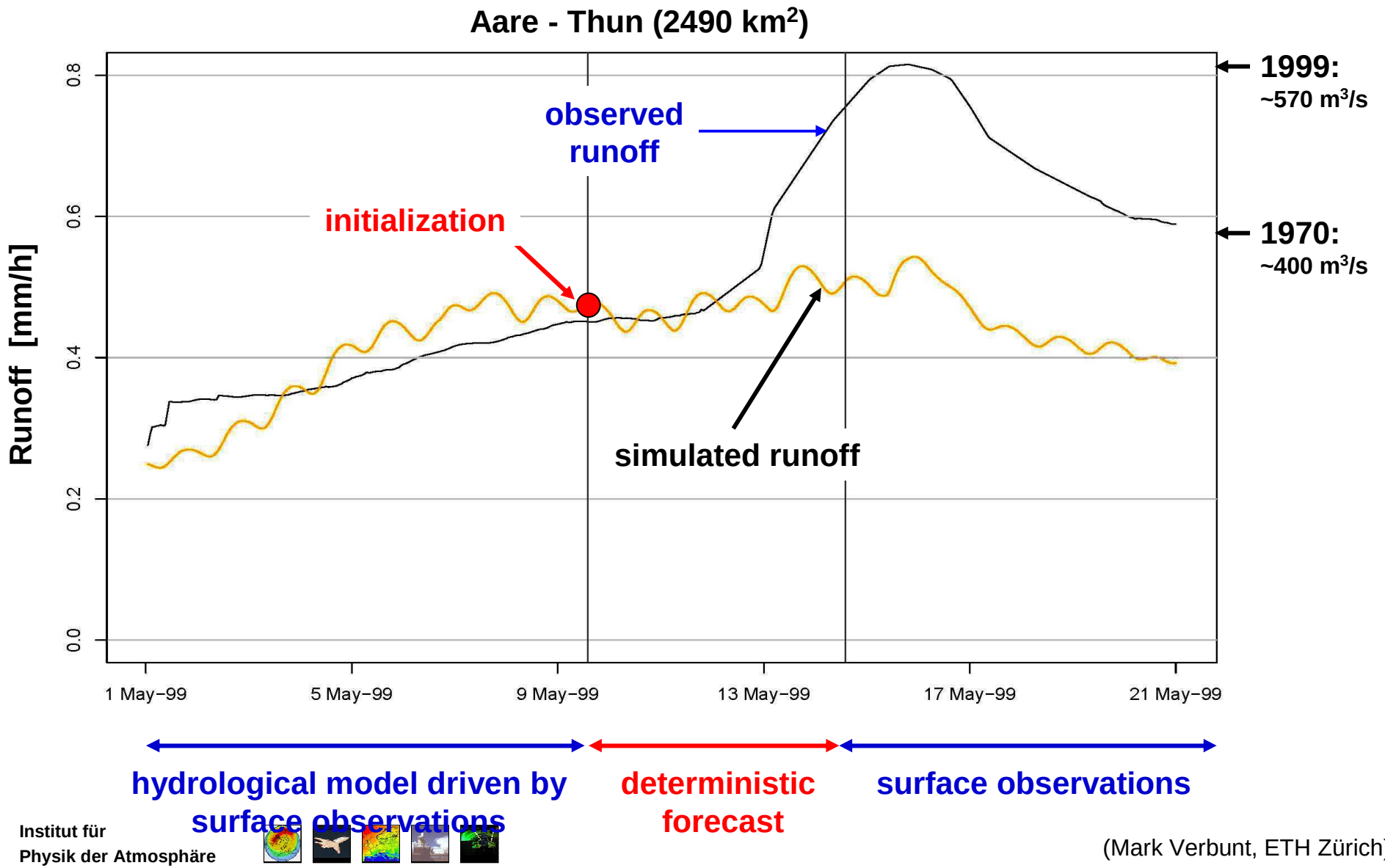
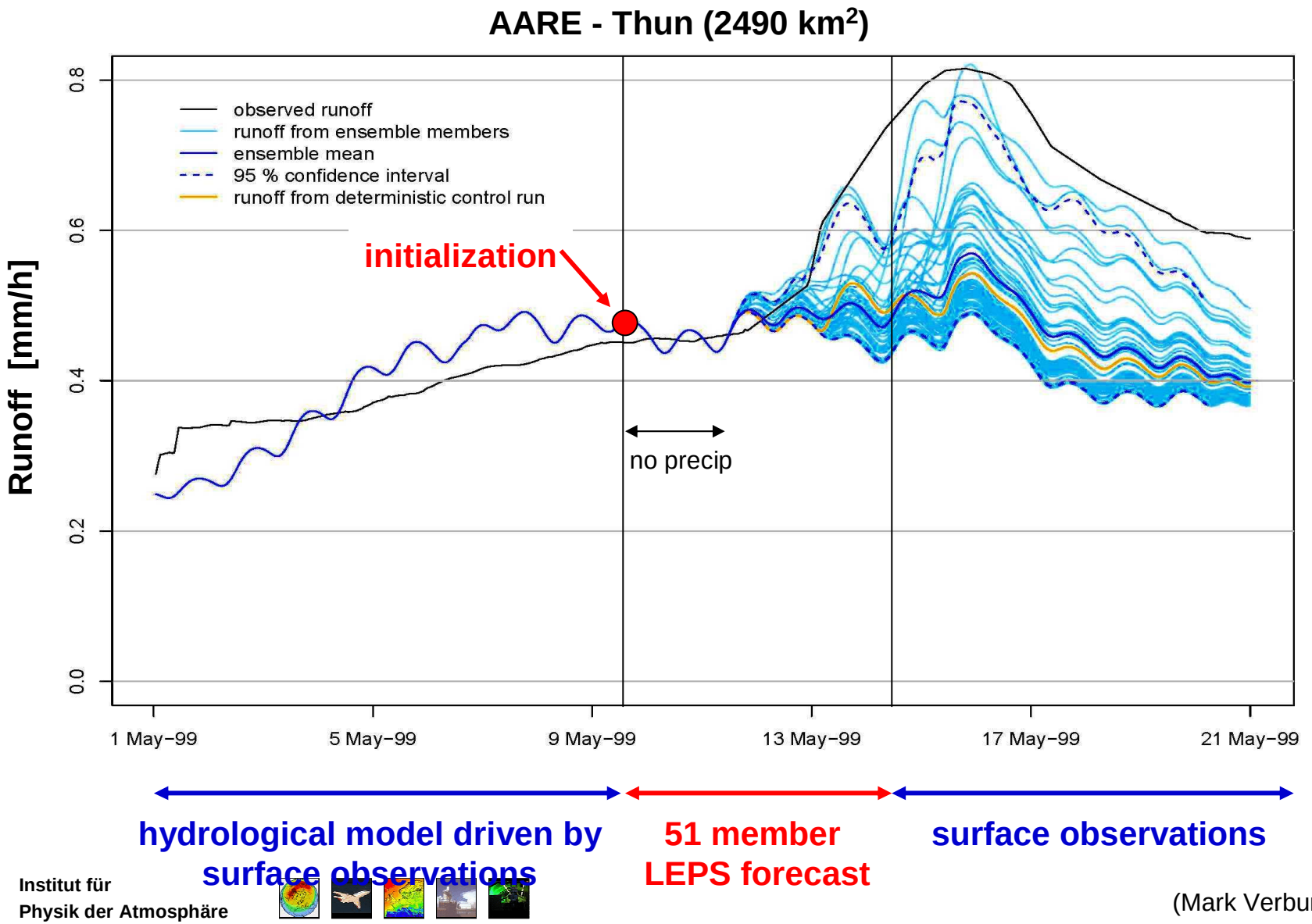
(Mark Verbunt, ETH Zürich, André Walser, Chiara Marsigli)

Deterministic Runoff Forecast



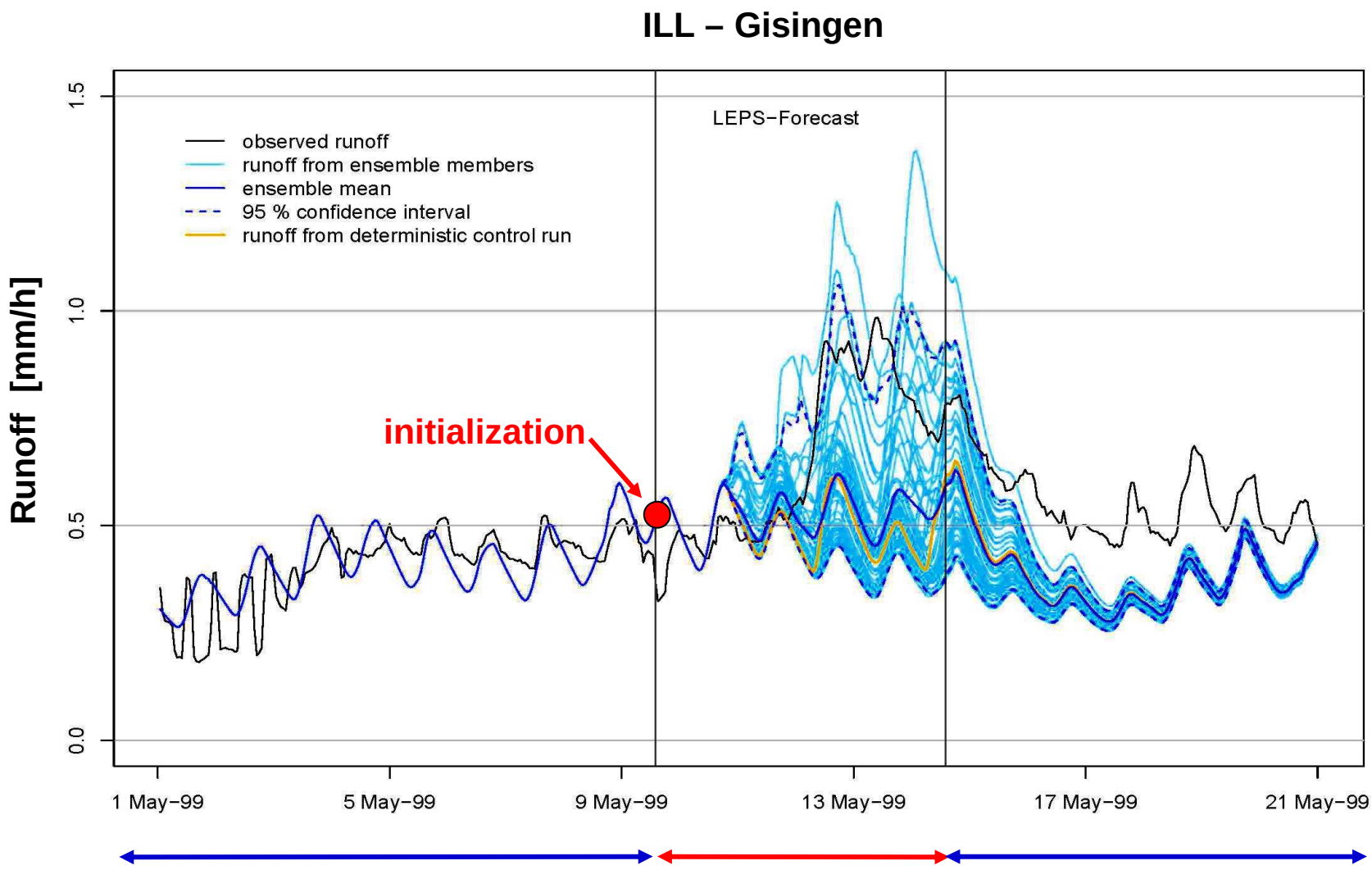
(Mark Verbunt, ETH Zürich)

Deterministic versus Probabilistic Forecast



(Mark Verbunt, ETH Zürich)

Deterministic versus Probabilistic Forecast

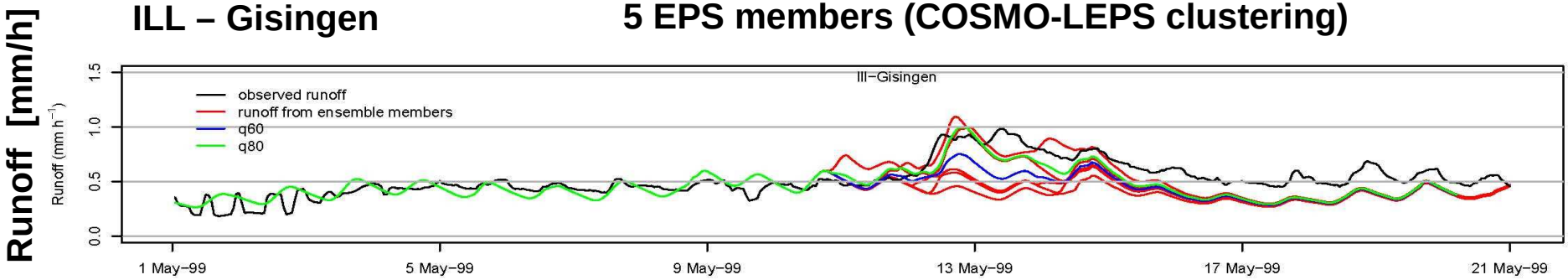


(Mark Verbunt, ETH Zürich)

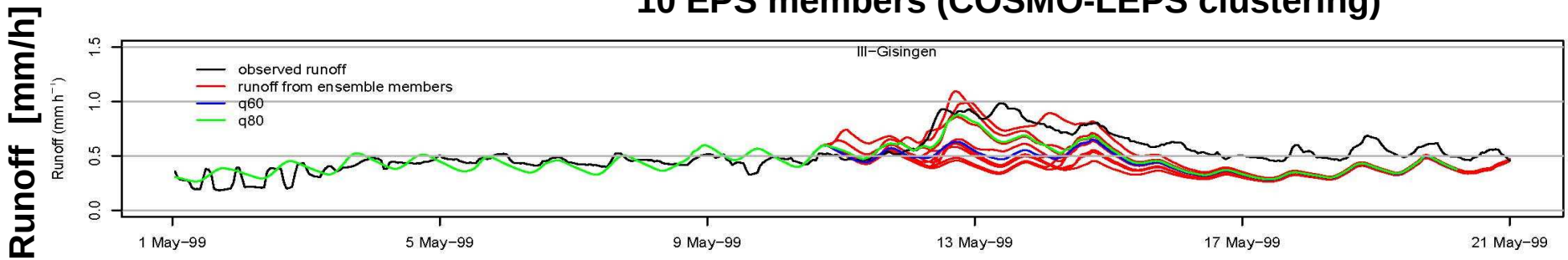
Representative members

ILL – Gisingen

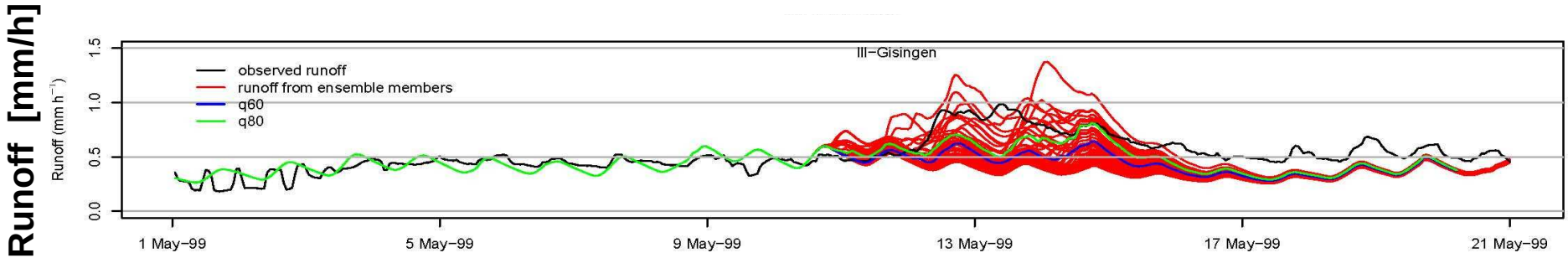
5 EPS members (COSMO-LEPS clustering)

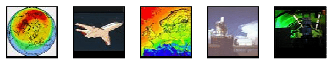


10 EPS members (COSMO-LEPS clustering)



51 EPS members



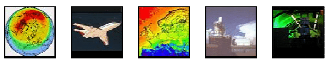


(Mark Verbunt, ETH Zürich)

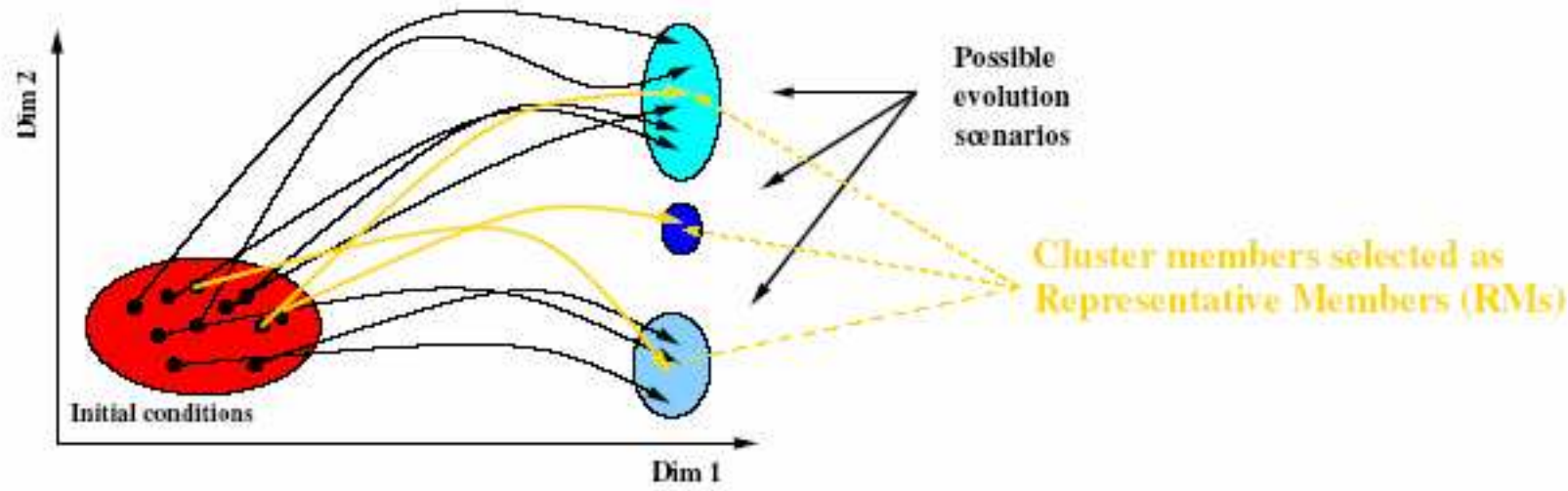
The Ensemble System

COSMO-LEPS regional ensemble

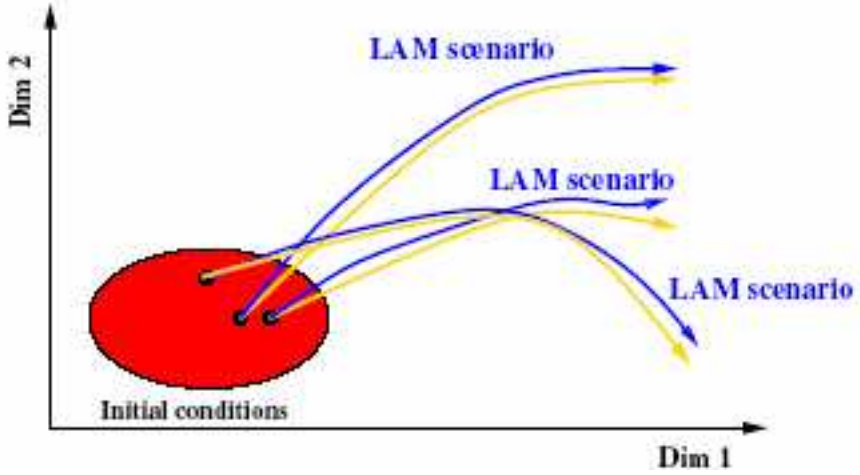
1. identify ten clusters from ECMWF 51 member ensemble



Ensemble size reduction technique



LAM integrations driven
by RMs



(Montani et al, 2003)

COSMO-LEPS case-study: 9 July 2002

Clustering of 1 EPSs fc range +48..60h (2002070912-00) using 4 discriminating variables at 3 pressure levels (u,v,Φ,q at 500/700/850 hPa):

Clustering method -----> COMPLETE LINKAGE
Selection mode --------> MINIMIZE INT/EXT RATIO
Ensemble ---------------> 1
Initial Date ----------> 2002 7 7 12 UTC
Forecast range (hours) -> 48 - 60
Area Limits (N/S/W/E) --> 60.0 30.0 -10.0 30.0
Number of clusters ----> 10
Explained Variance(%) -> 42.8

Cluster ---------->	1	2	3	4	5	6	7	8	9	10
Size ---------->	6	8	10	6	6	4	4	5	1	1
Internal variance(%) -->	5.8	9.8	12.3	6.9	6.8	4.6	4.6	6.5	.0	.0
Radius ---------->	12.3	13.8	13.8	13.3	13.3	13.4	13.4	14.2	.0	.0

CL 1: (5) 0 5 17 24 40 41
CL 2: (1) 1 4 9 11 18 32 33 49
CL 3: (31) 2 3 10 12 26 28 31 34 46 50
CL 4: (39) 6 16 22 29 39 42
CL 5: (43) 7 13 36 38 43 48

CL 6: (45) 8 25 27 45
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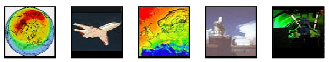
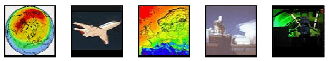
CL 8: (15) 15 20 21 30 47
CL 9: (19) 19
CL 10: (23) 23



The Ensemble System

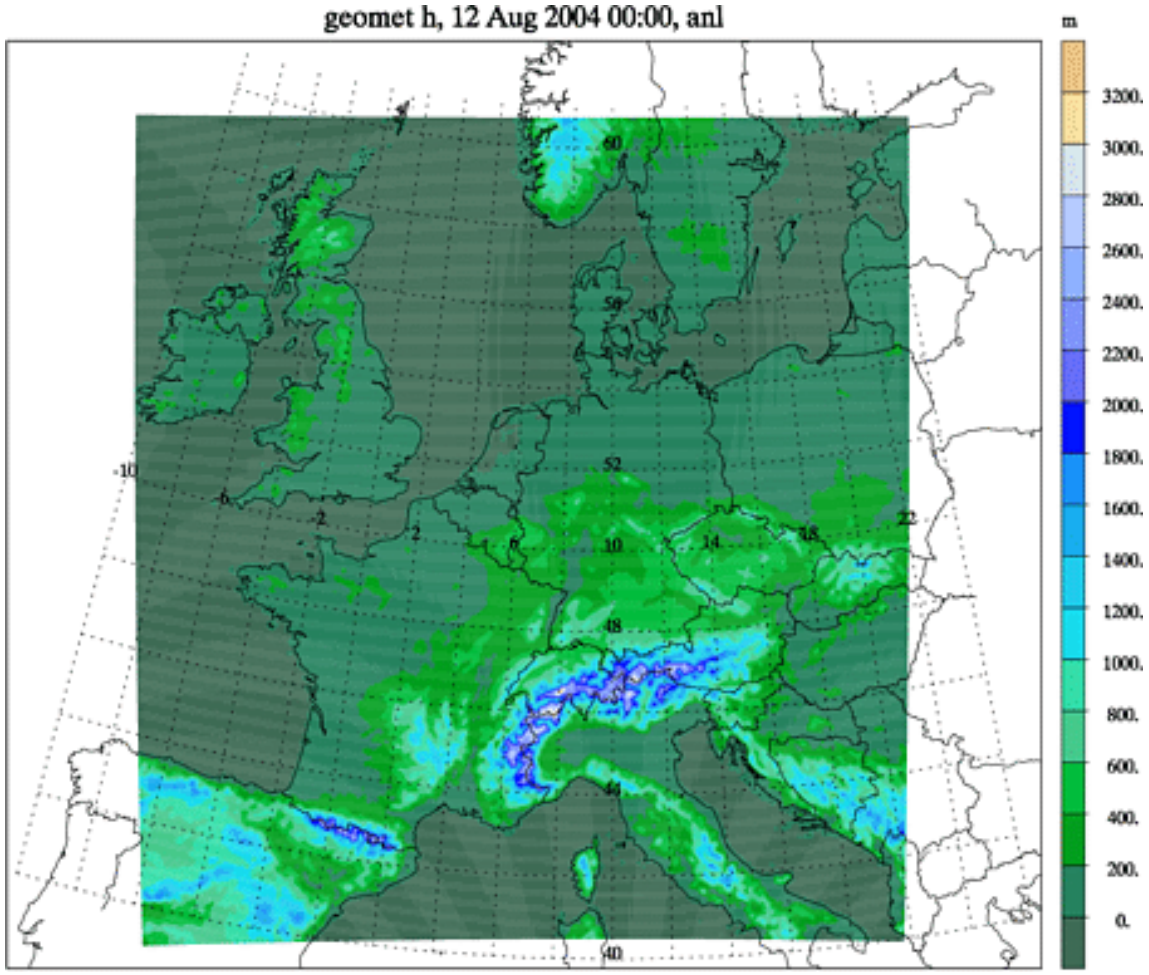
COSMO-LEPS regional ensemble

1. identify ten clusters from ECMWF 51 member ensemble
2. use a representative member from each cluster to drive a regional model (DWD **Lokal Modell**)



Lokal-Modell

- operational @ DWD
- non-hydrostatic
- 325x325x35 GP
- Grid length 7km
- Parameterized moist convection (Tiedtke)
- resolved cloud with cloud ice (since 09/03)
- prognostic precip. (since 04/04)

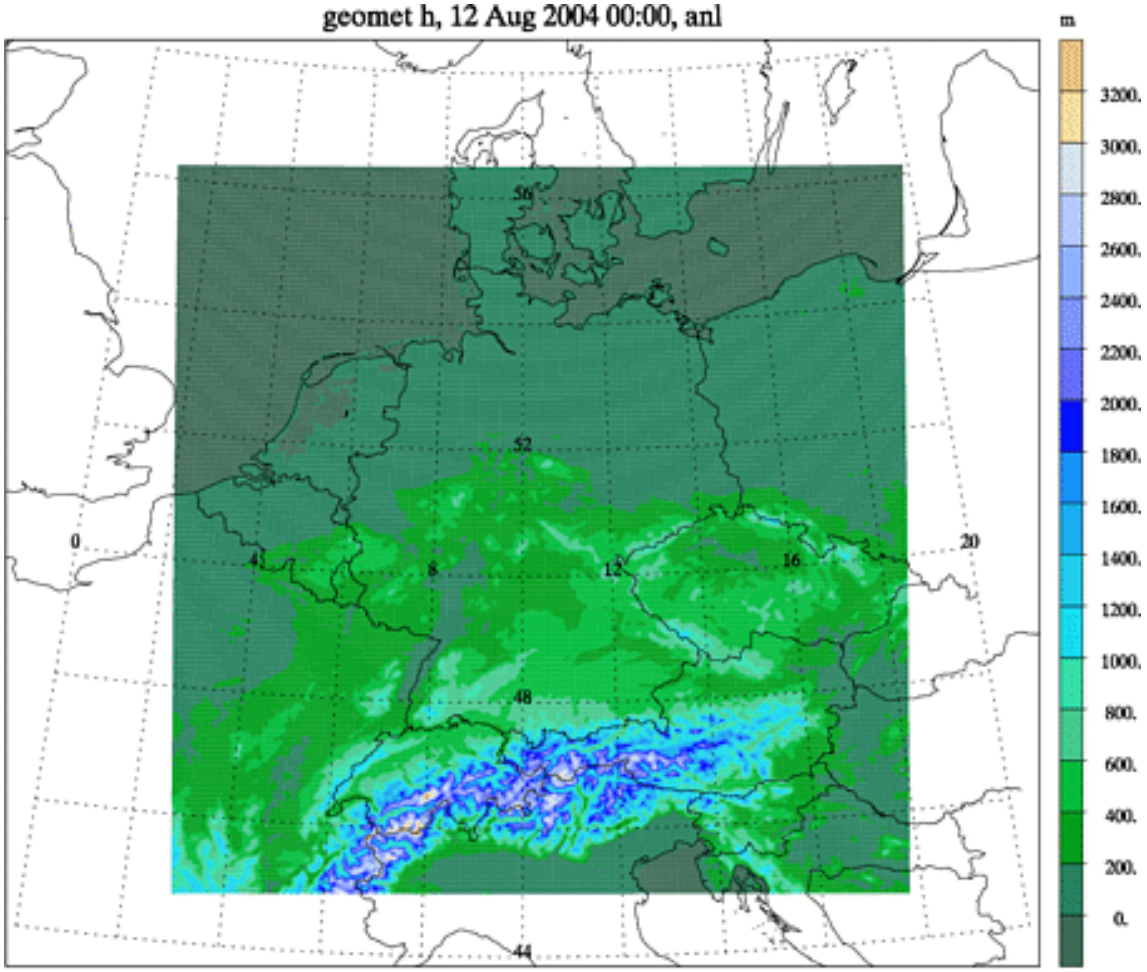


- prognostic variables: u, v, w, T, p', qv, qc, qi, qs, qr

Lokal-Modell-Kürzesfrist

LMK @ DWD:

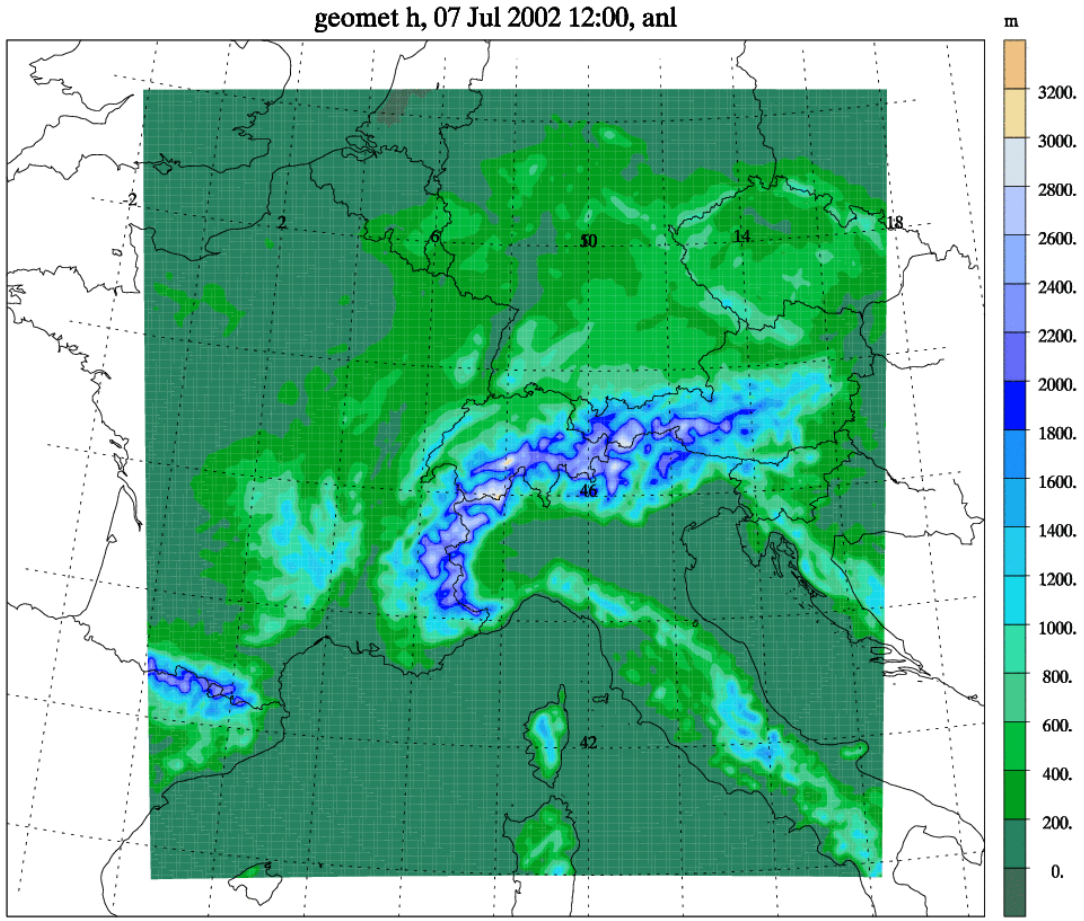
- Trials summer 2005
- 421 x 461 x 50 GP
- Grid length 2.8 km
- progn. cloud with qi
- progn. TKE scheme
- no convective param.
- fc +18h, every 3h



- prognostic variables: u, v, w, T, p', qv, qc, qi, qs, qr

COSMO-LEPS case-study: 9 July 2002

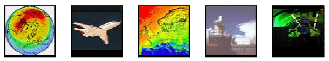
- 201x201x35 GP
- Grid length 7km
- Start: 2002070712
- fc range: 0...+72h
- 10 RM (1 per cluster)



The Ensemble System

COSMO-LEPS regional ensemble

1. identify ten clusters from ECMWF 51 member ensemble
2. use a representative member from each cluster to drive a regional model (DWD Lokal Modell)
3. to construct probabilistic forecasts, need to weight clusters
   - use cluster populations, or
   - use most recent data (e.g. satellite imagery)



Generation of synthetic satellite images in LM - LMSynSat

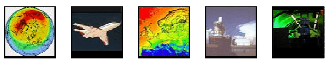
- RTTOV-7 radiative transfer model (Saunders et al, 1999)
- **Input**: 3D fields: T,qv,qc,qi,(qs),clc,ozone

  surface fields: T_g, T_2m, qv_2m, fr_land
- **Output**: cloudy/clear-sky brightness temperatures for

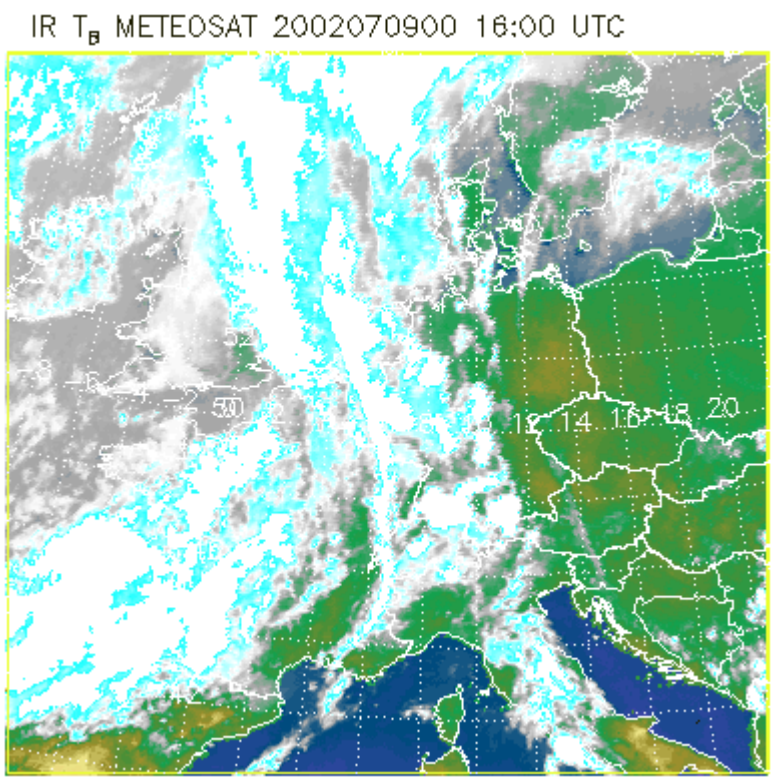
  Meteosat7 (IR and WV channels) and

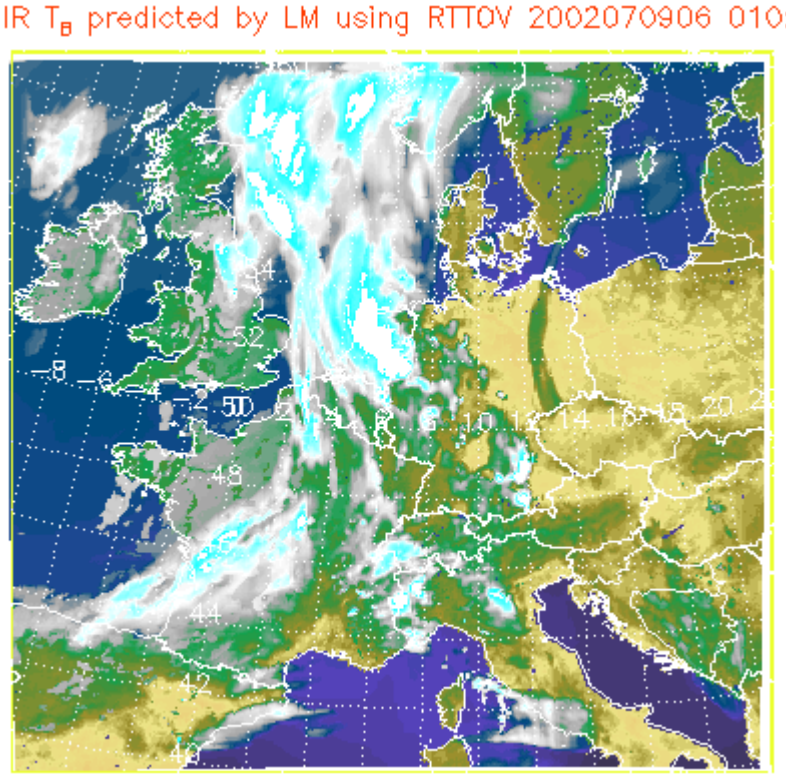
  MSG (8 channels)

(Keil et al, submitted to ATMOS RES 2005)



LM experiments for 9 July 2002

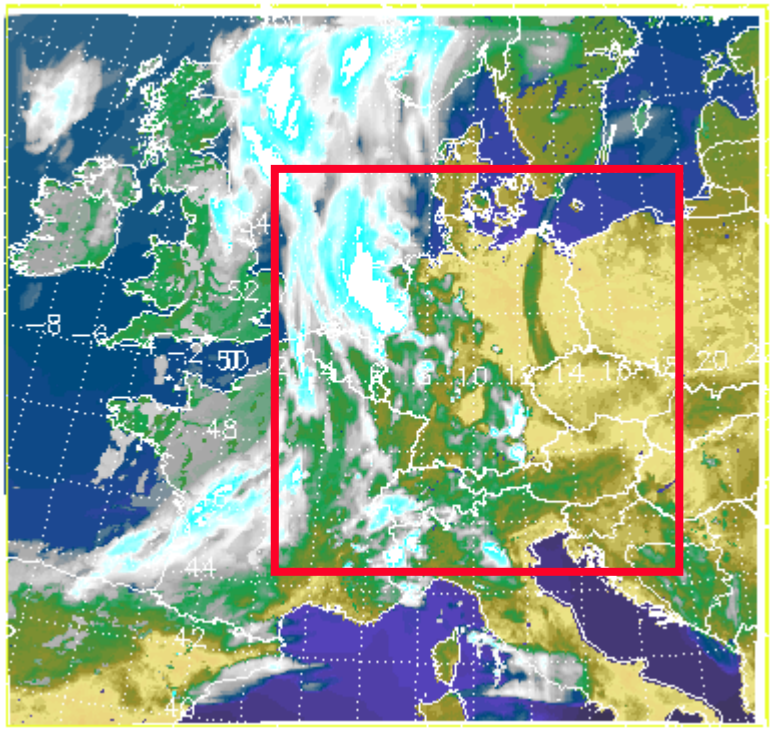




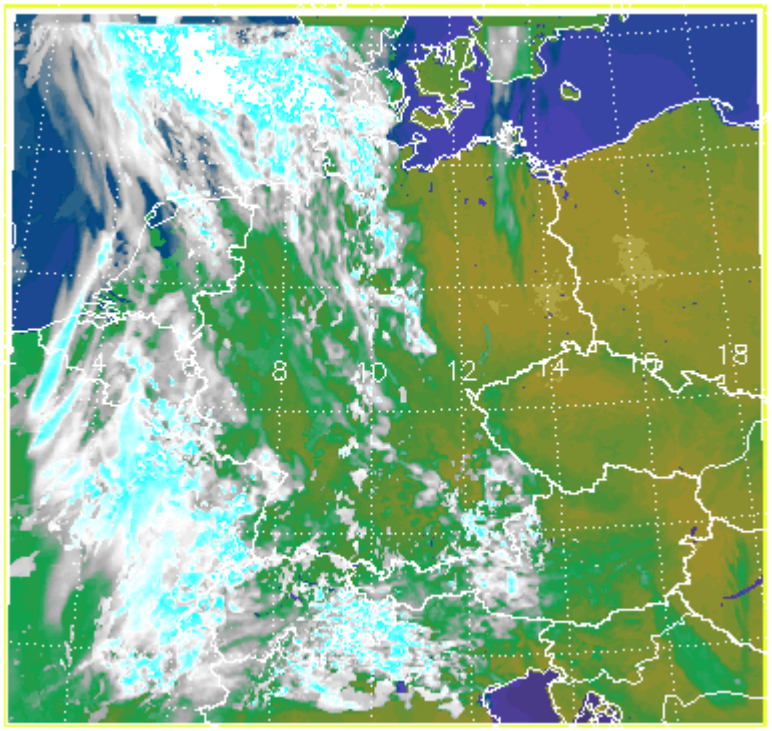
LM 3.8

LM-K experiments for 9 July 2002

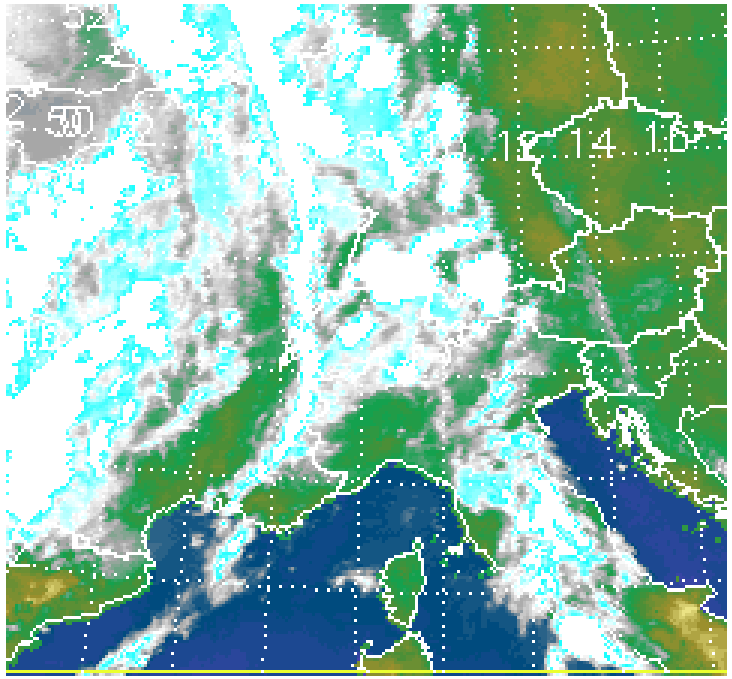
IR T_B predicted by LM using RTTOV 2002070906 010:



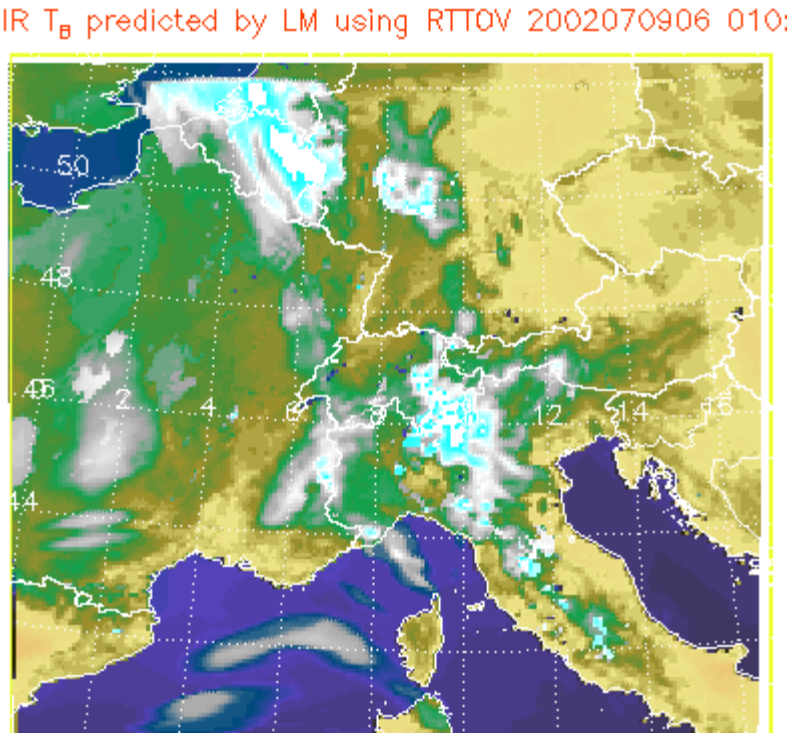
IR T_B predicted by LM using RTTOV 2002070906 015:



IR Imagery from Lokal-Modell: 9 July 2002



Meteosat 7 IR 16:00 UTC



LM Exp: ve0_3

ECMWF det

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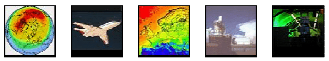

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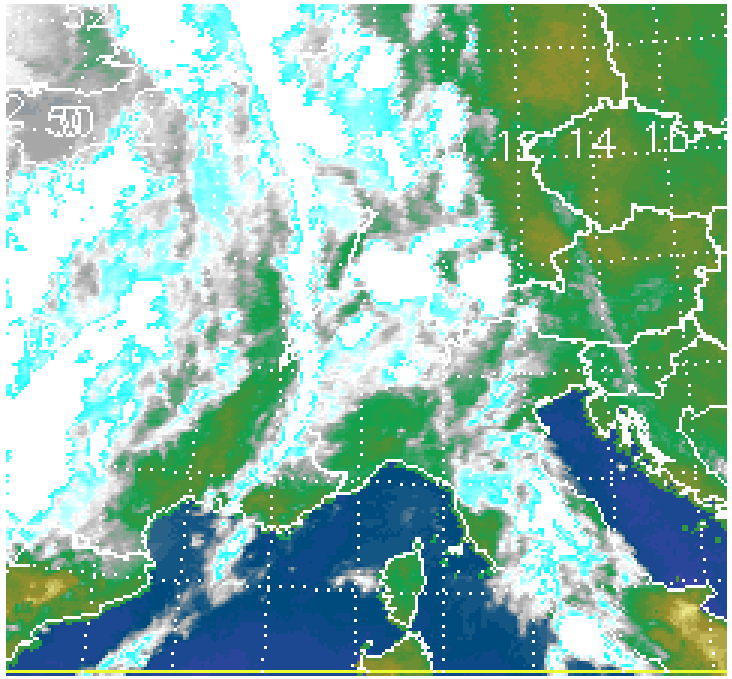

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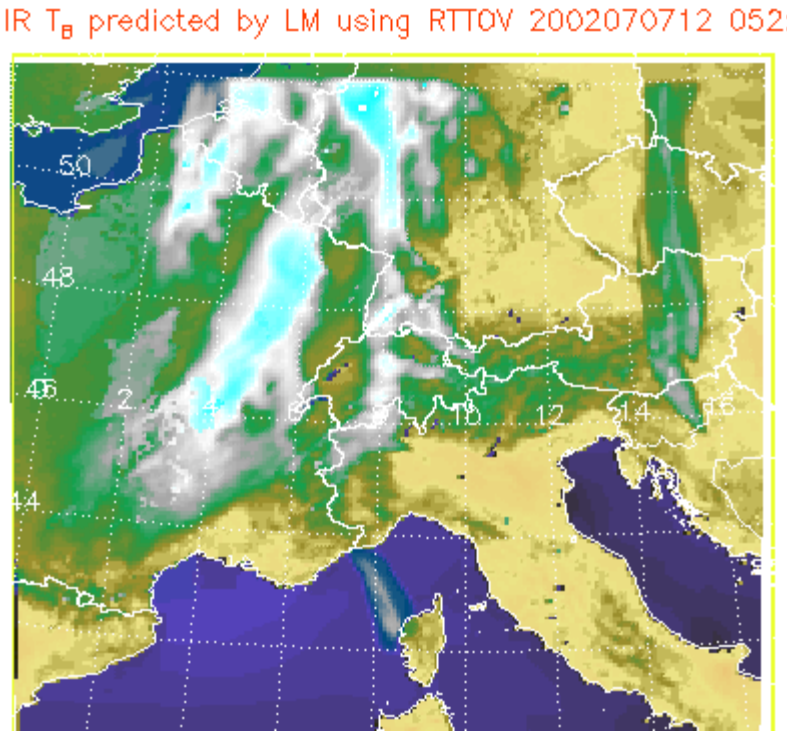
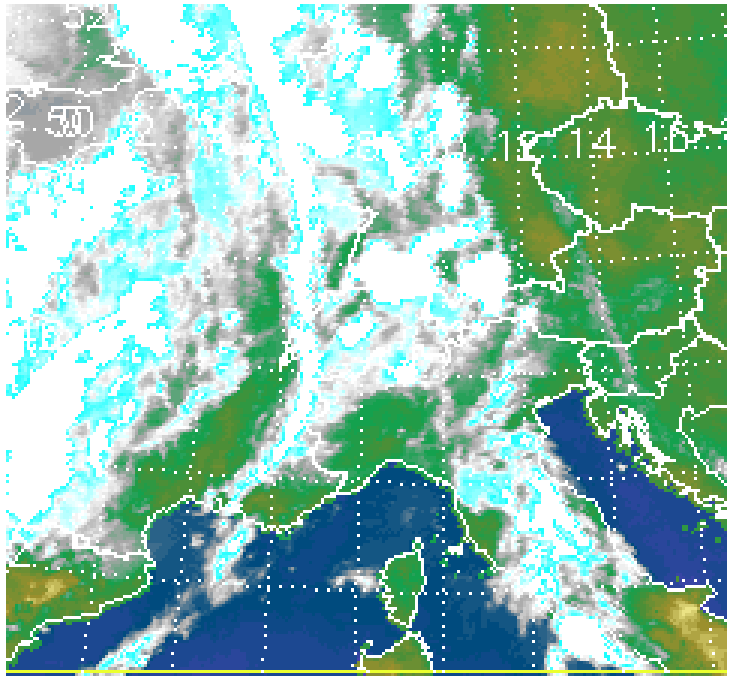


LM Exp: va1

Cluster 1, RM 5

COSMO-LEPS: 9 July 2002



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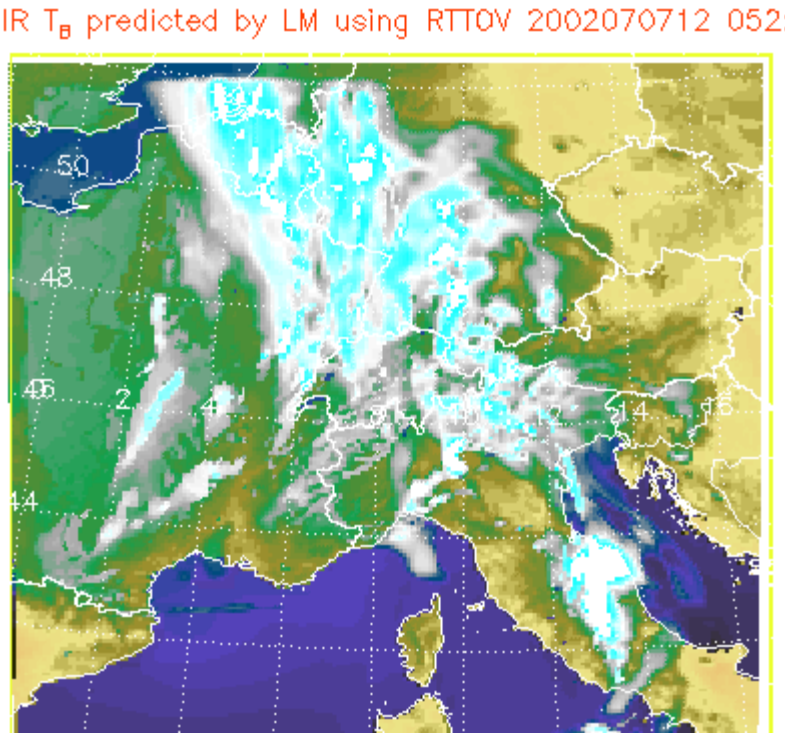
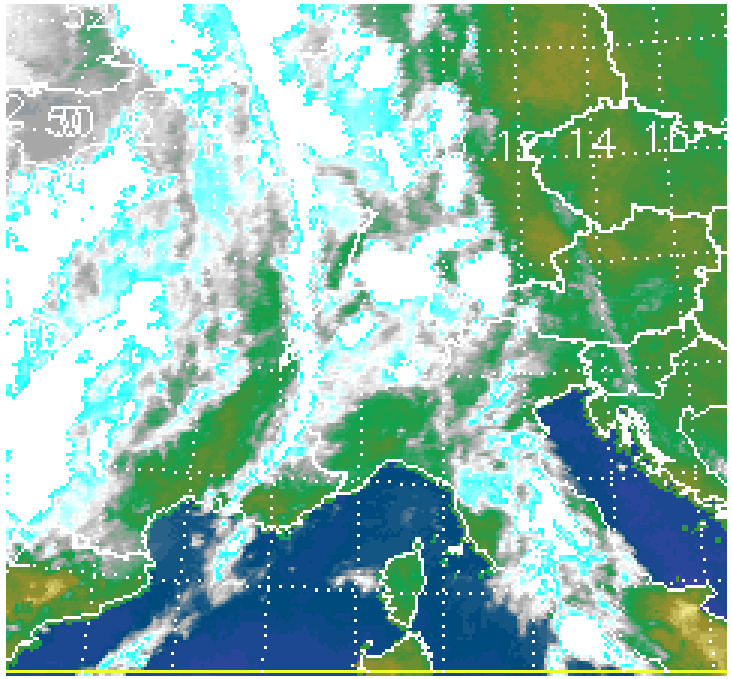


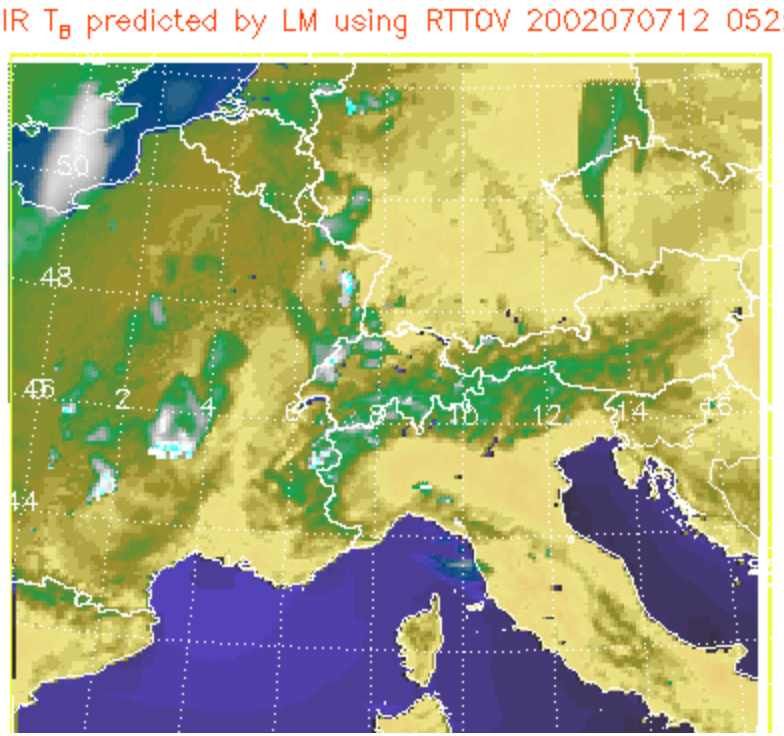
LM Exp: ve1

Cluster 2, RM 1

COSMO-LEPS: 9 July 2002



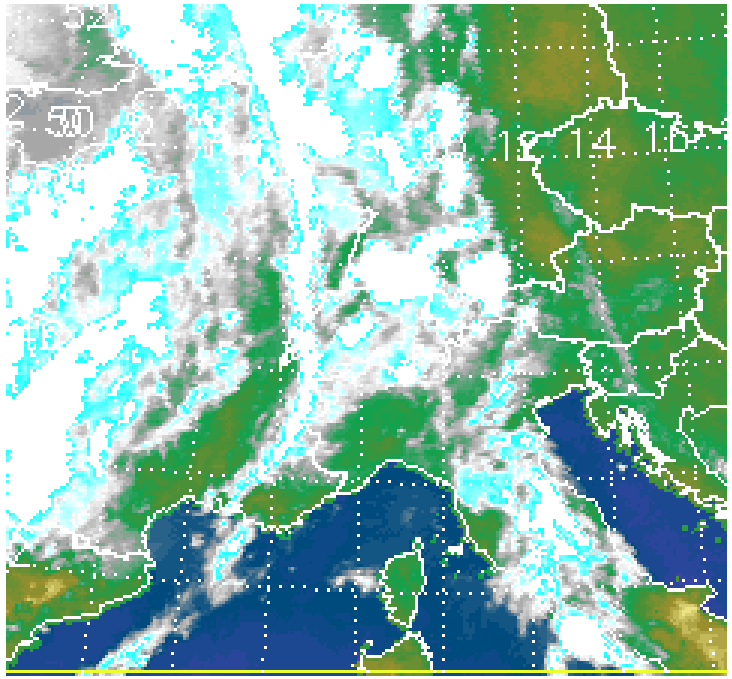
Meteosat 7 IR 16:00 UTC



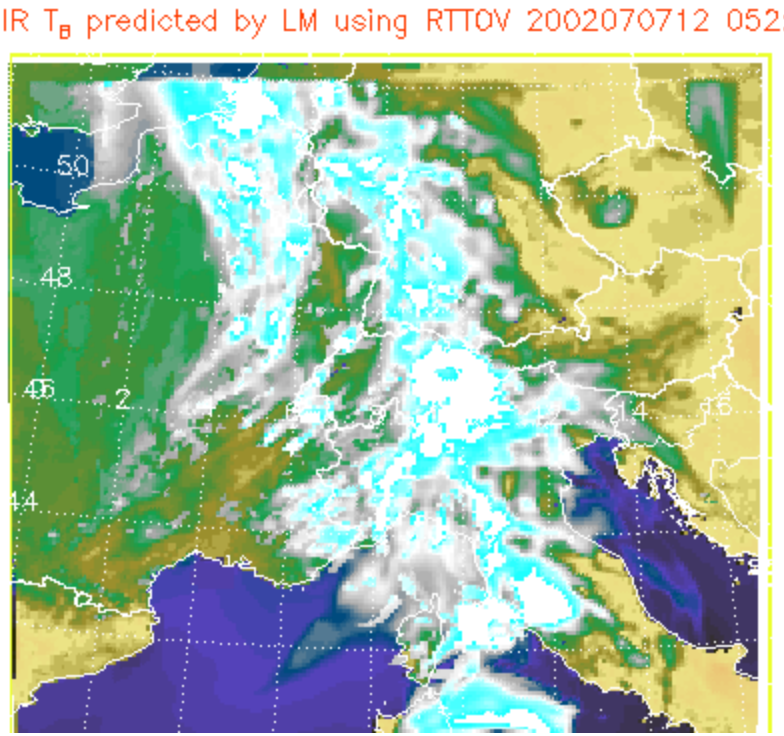
LM Exp: vc1

Cluster 3, RM 31

COSMO-LEPS: 9 July 2002



Meteosat 7 IR 16:00 UTC



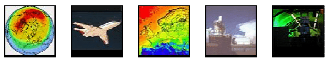
LM Exp: vd1

Cluster 4, RM 39

Validation using visual inspection

Table 1. In order of mean rank by people												Cluster
	1	2	3	4	5	6	7	8	9	10	11	Pop.
2	3	4	1									8
10	3	3	2									1
4	2	1	5									6
7				6	2							4
9				1	2		2	2		1		1
1				1	2	1	1	1	1	1		6
5						3	3	1	1			6
4V						2	2	2	2			
6					2	1		2	2	1		4
8						1			2	5		5
3											8	10
Table 1 shows that 9, 1 and 6 were the most difficult for people to classify												
(biggest spread about the diagonal)												

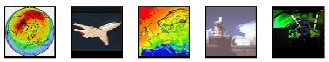
8 scientists educated in meteorology ordered 11 ensemble members as regards to forecast skill by visually comparing forecasted and observed satellite images.



The Ensemble System

COSMO-LEPS regional ensemble

1. identify ten clusters from ECMWF 51 member ensemble
2. use a representative member from each cluster to drive a regional model (DWD Lokal Model)
3. to construct probabilistic forecasts, need to weight clusters
   - use cluster populations, or
   - use most recent data (e.g. satellite imagery)
4. use objective pattern recognition algorithm



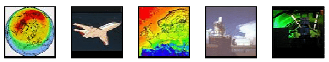
Pyramidal Image Matching

1. Project observed and simulated images to same grid

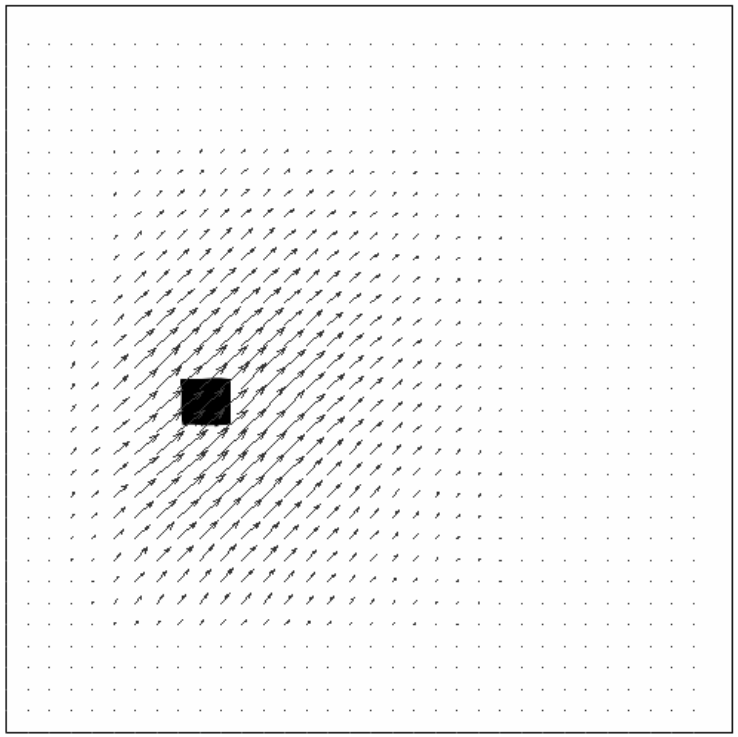
2. Coarse-grain both images by pixel averaging, then compute displacement vector field that maximizes correlation in brightness temperature

3. Repeat step 2 at successively finer scales

4. Displacement vector for every pixel results from the sum over all scales

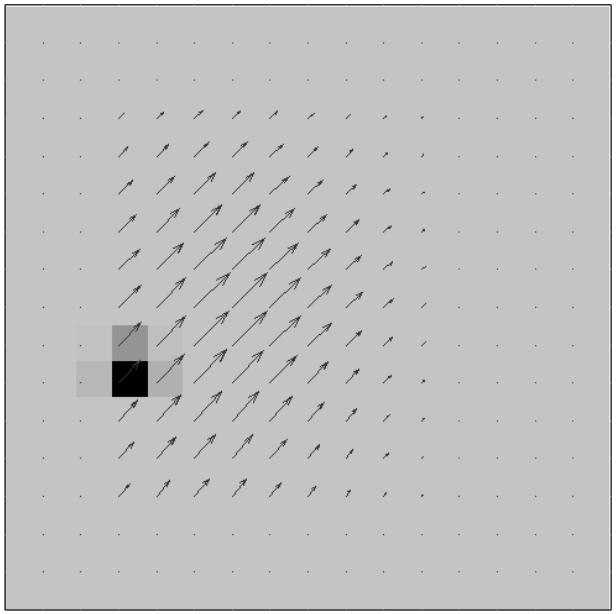


Idealized Case: Pure displacement

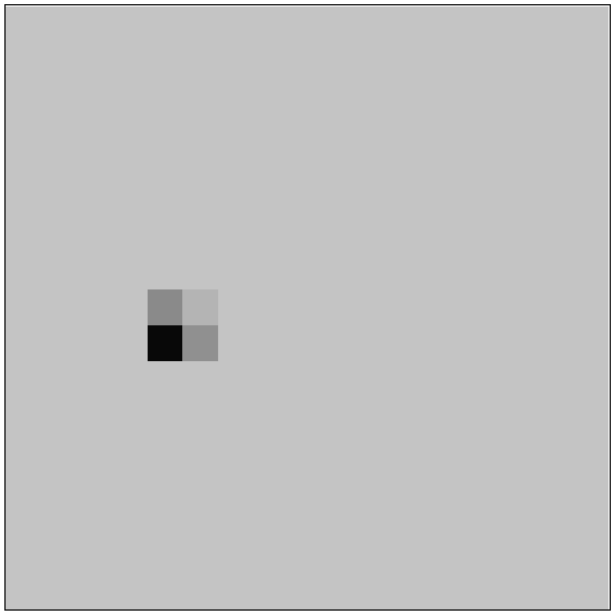


Matched image

Idealized Case: Pure displacement

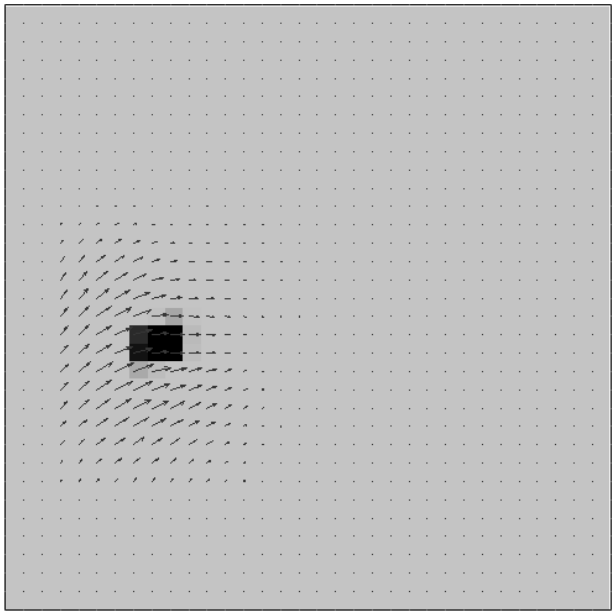


LM; factor=5 sx= 017 sy=017



M7; factor=5 sx= 017 sy=017

Idealized Case: Pure displacement



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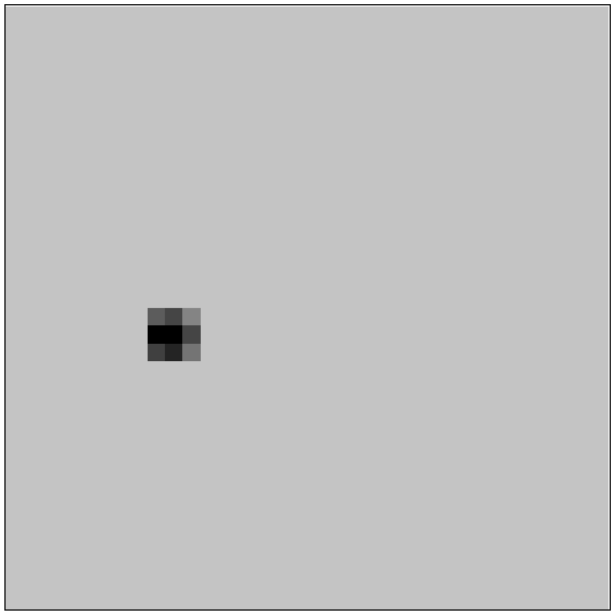

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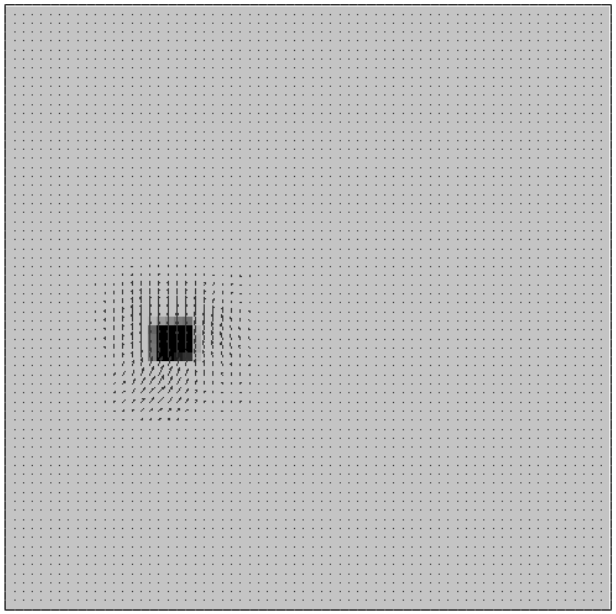
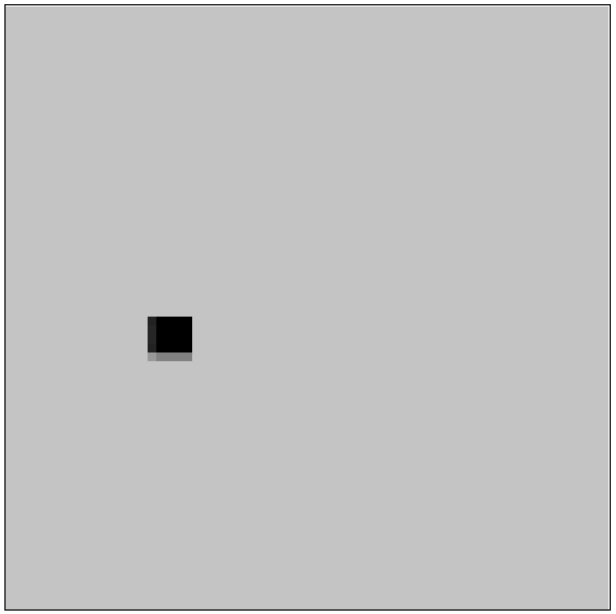
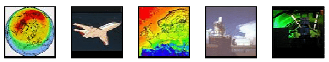
Idealized Case: Pure displacement



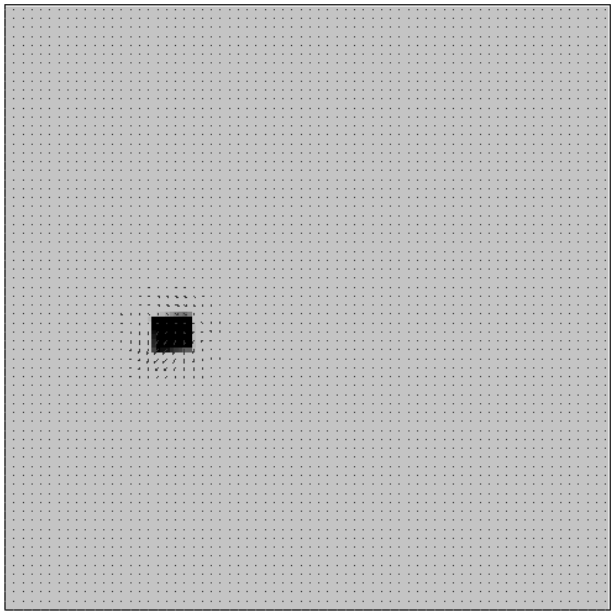
LM; factor=3 sx= 068 sy=068



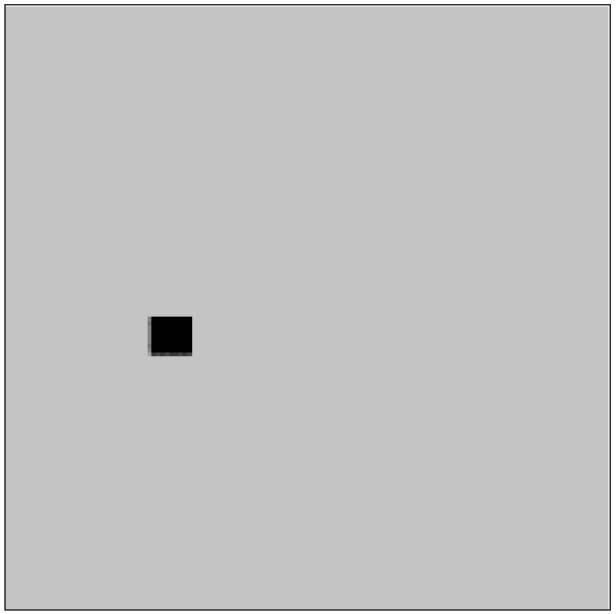
M7; factor=3 sx= 068 sy=068



Idealized Case: Pure displacement

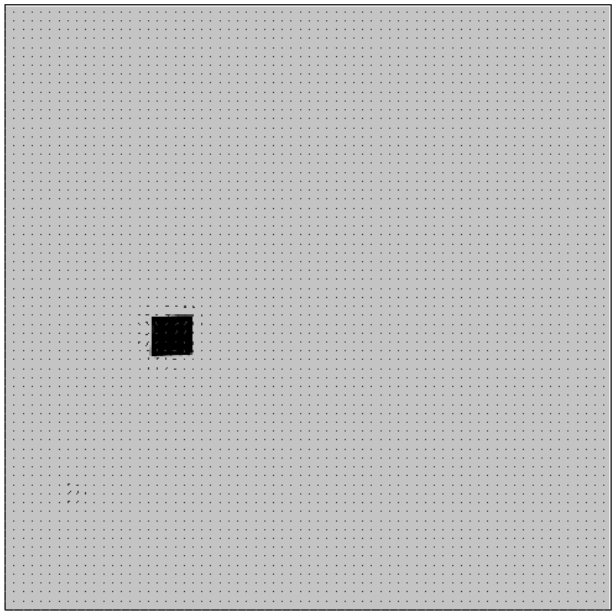


LM; factor=2 sx= 136 sy=136



M7; factor=2 sx= 136 sy=136

Idealized Case: Pure displacement



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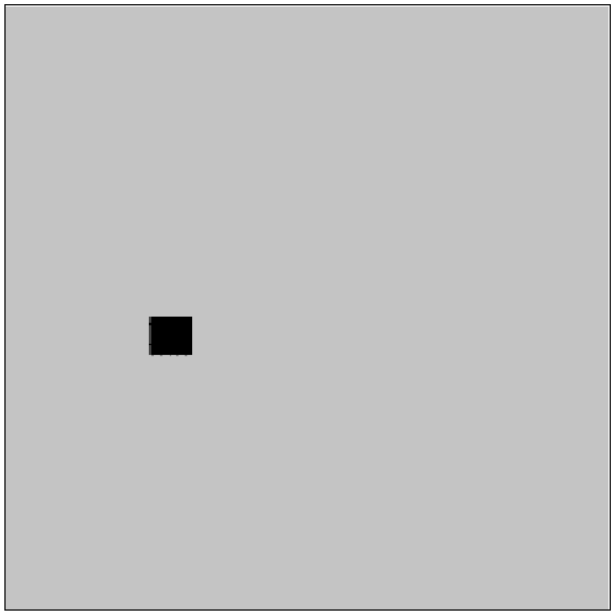
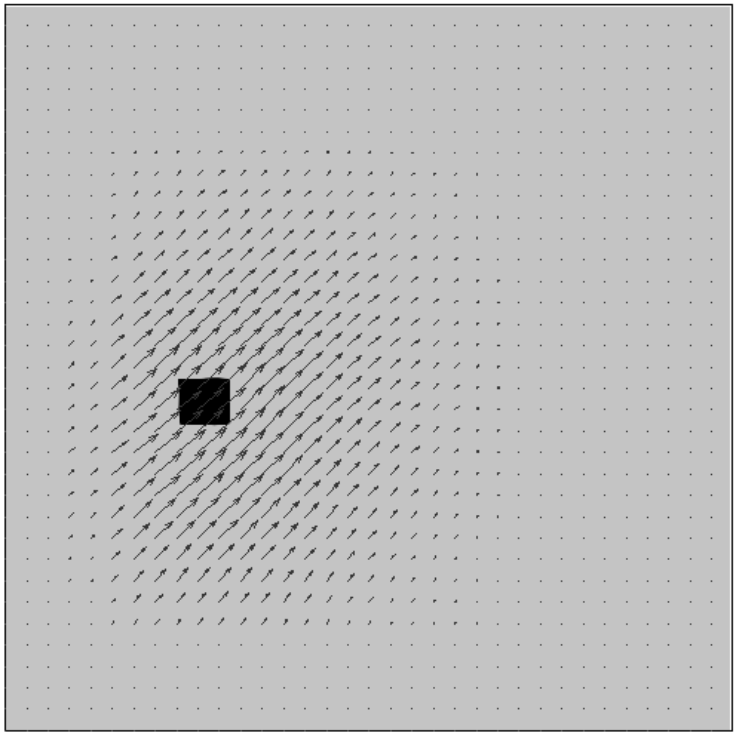


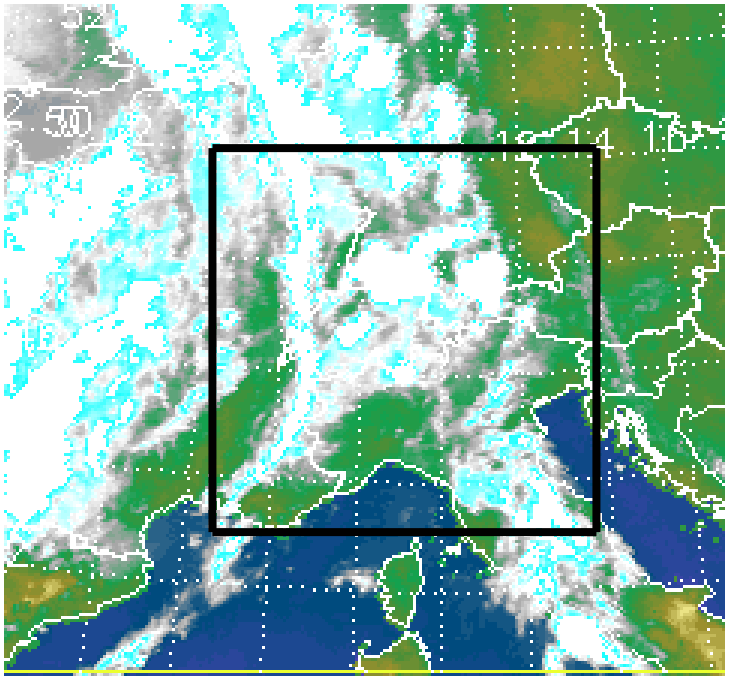
M7; factor=1 sx= 272 sy=272

Idealized Case: Pure displacement

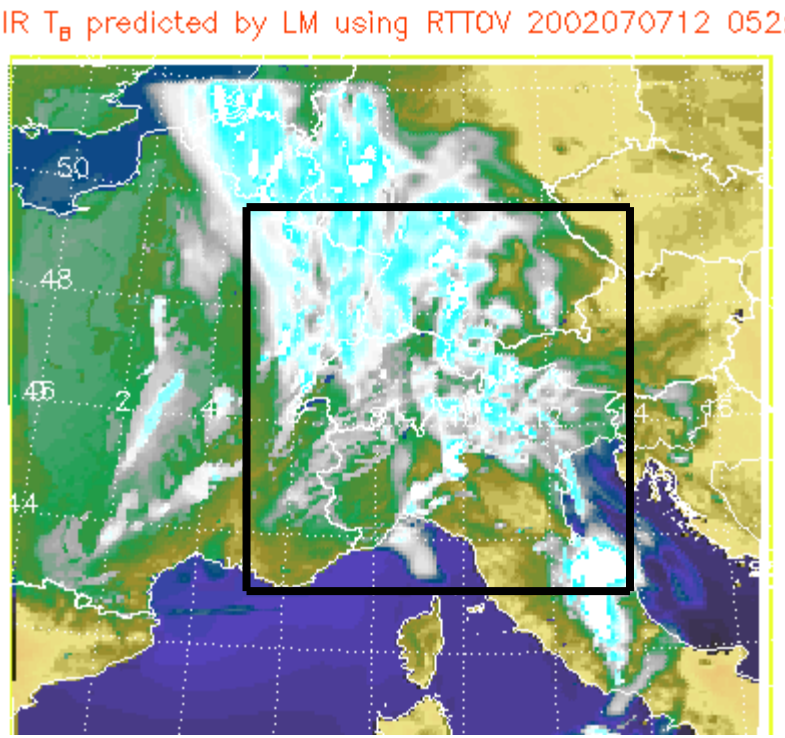


f1; factor=1 sx= 272 sy=272

Image Matching: VERTIKATOR case (9.7.2002)

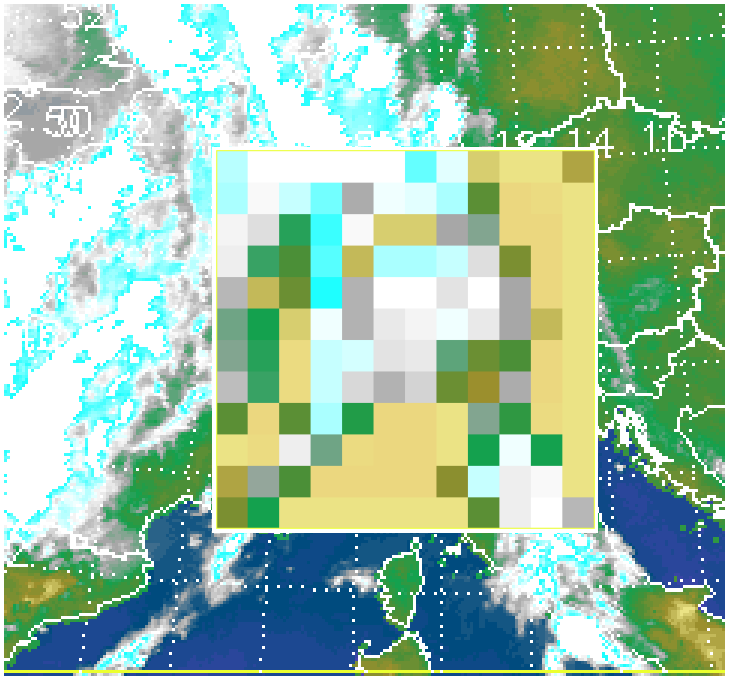


Meteosat 7 IR

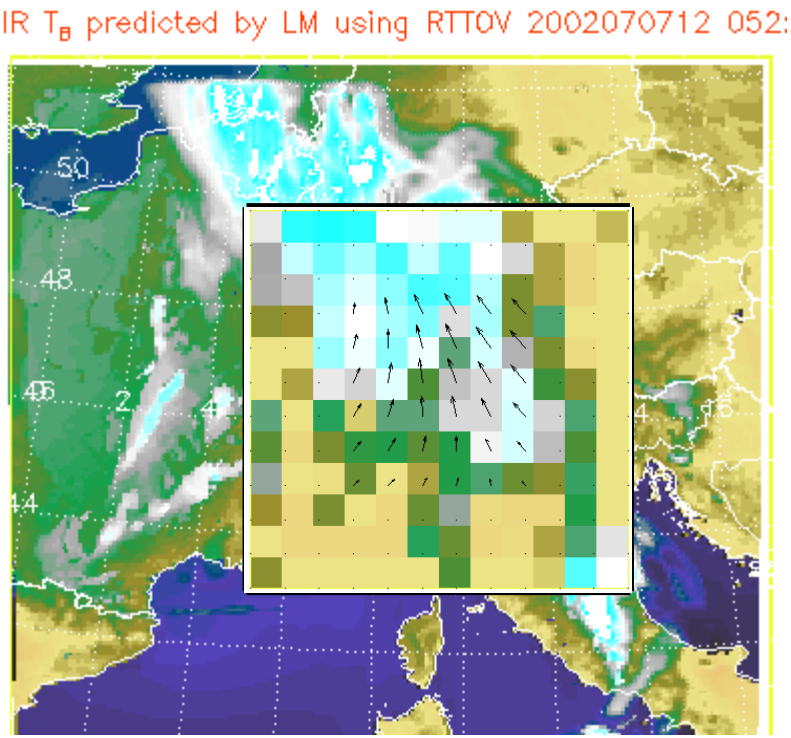


LM Exp: ve1

Image Matching:

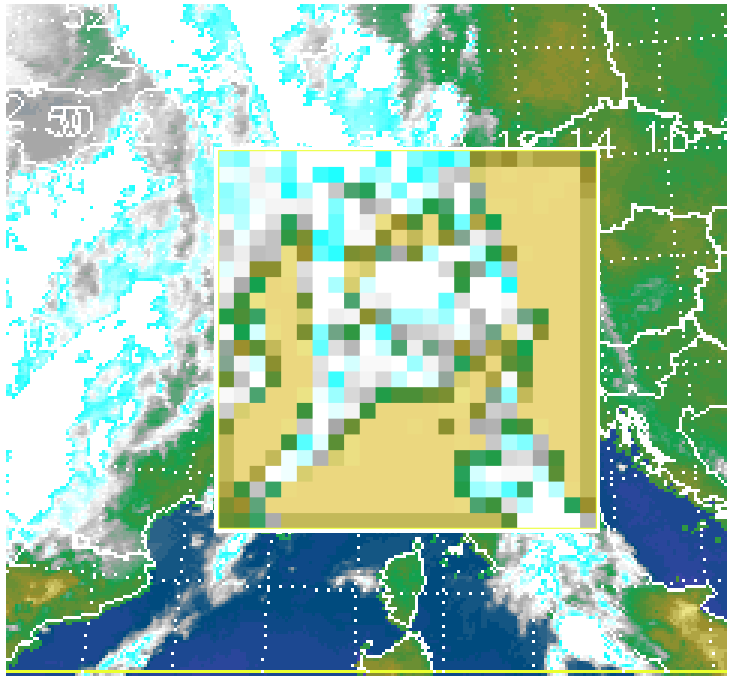


Meteosat 7 IR

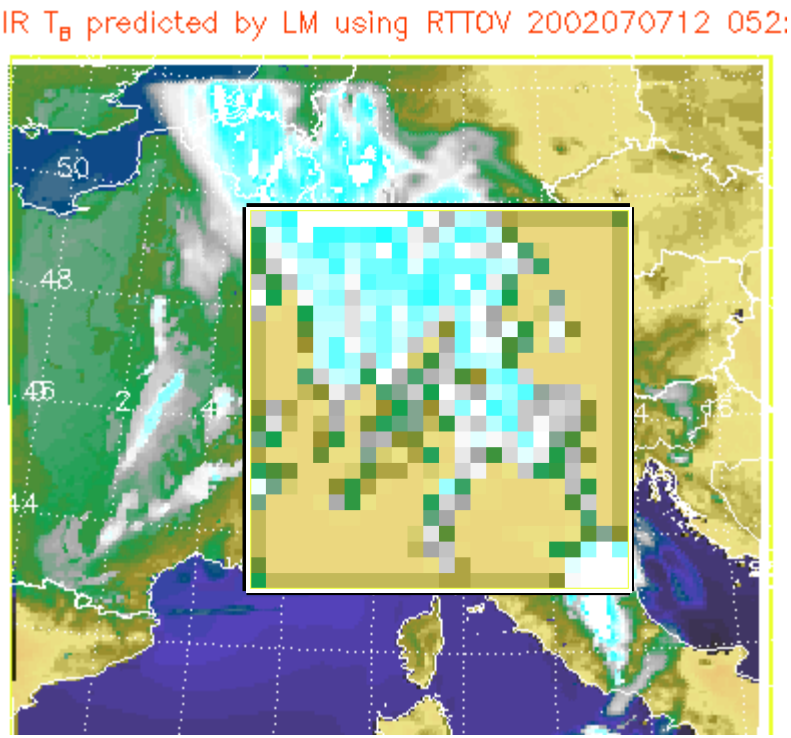


LM Exp: ve1

Image Matching:

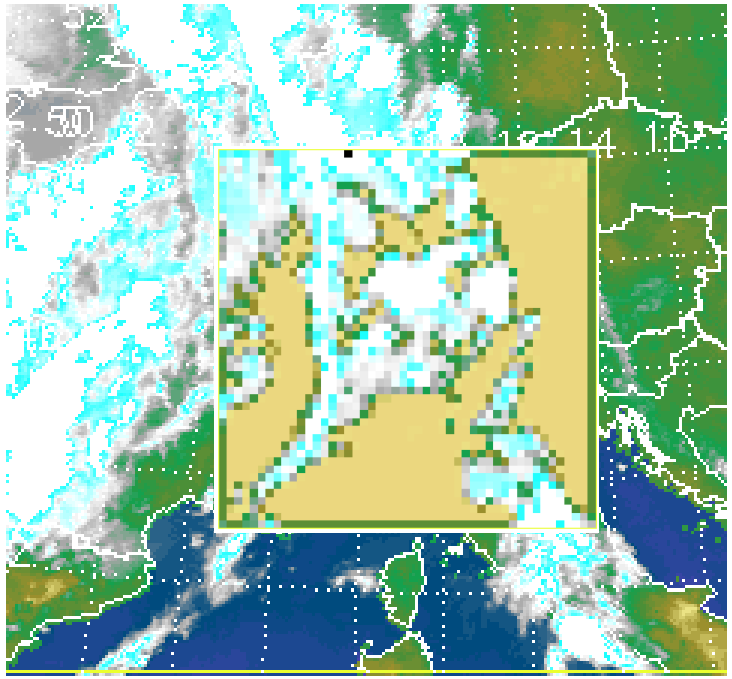


Meteosat 7 IR

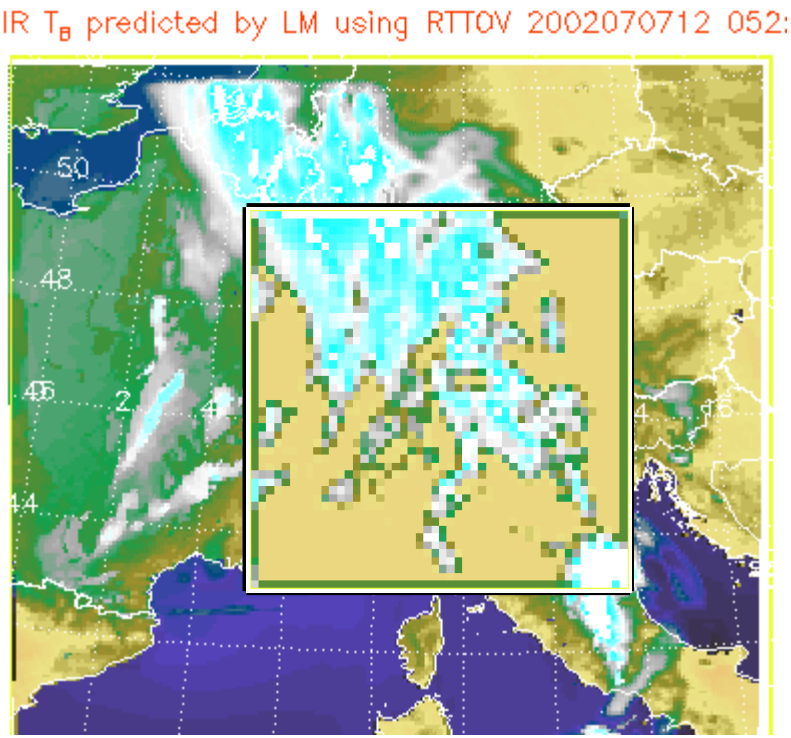


LM Exp: ve1

Image Matching:



Meteosat 7 IR



LM Exp: ve1

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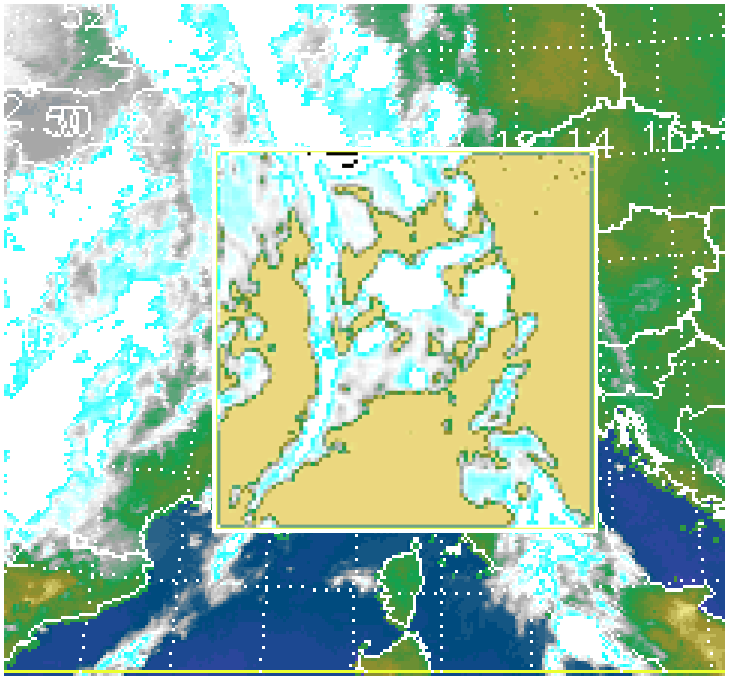
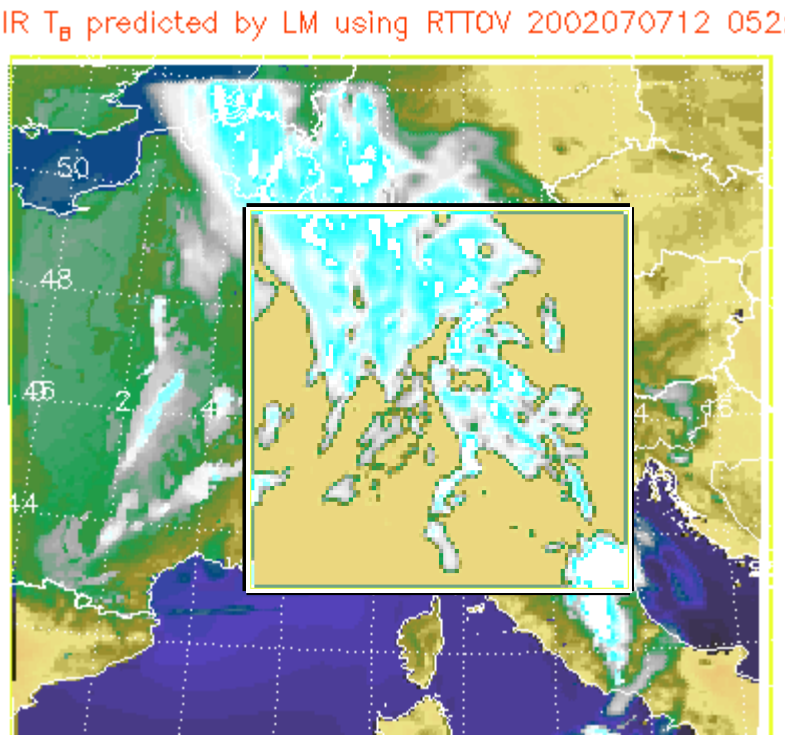


Meteosat 7 IR



LM Exp: ve1

Image Matching Test:

Validation of forecasts by human eye against image matcher

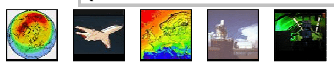
8 scientists educated in meteorology ordered 11 ensemble members as regards to forecast skill by visually comparing forecasted and observed satellite images.

Table 1. In order of mean rank by people												Cluster
	1	2	3	4	5	6	7	8	9	10	11	Pop.
2	3	4	1									8
10	3	3	2									1
4	2	1	5									6
7				6	2							4
9				1	2		2	2		1		1
1				1	2	1	1	1	1	1		6
5						3	3	1	1			6
4V						2	2	2	2			
6					2	1		2	2	1		4
8						1			2	5		5
3											8	10

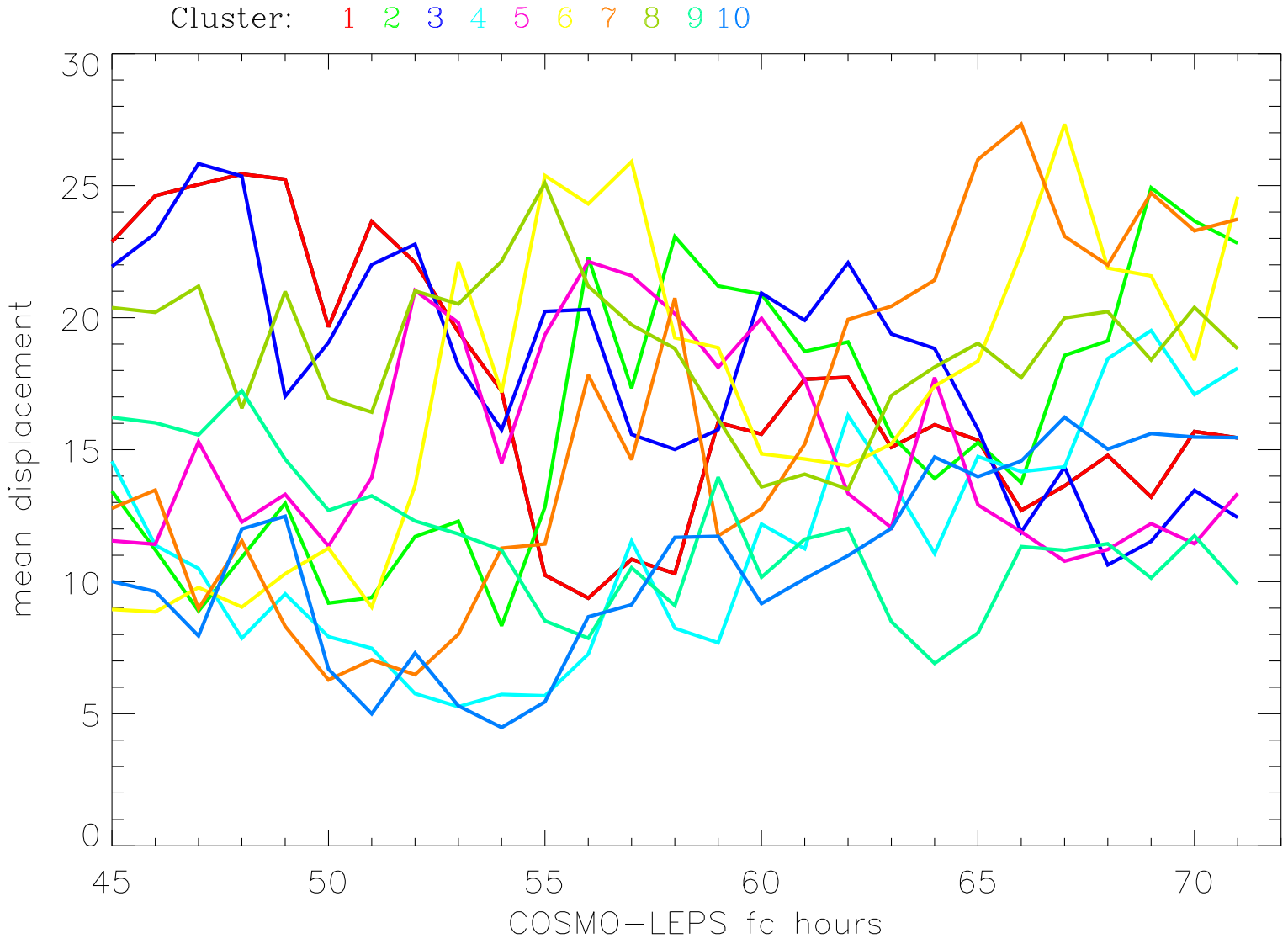
Table 1 shows that 9, 1 and 6 were the most difficult for people to classify (biggest spread about the diagonal)

Table 2. In order of rank from image matcher												Cluster
	1	2	3	4	5	6	7	8	9	10	11	Pop.
4	2	1	5									8
7				6	2							1
10	3	3	2									6
2	3	4	1									4
4V						2	2	2	2			1
9				1	2		2	2		1		6
6					2	1		2	2	1		6
5						3	3	1	1			
8						1			2	5		4
1				1	2	1	1	1	1	1		5
3											8	10

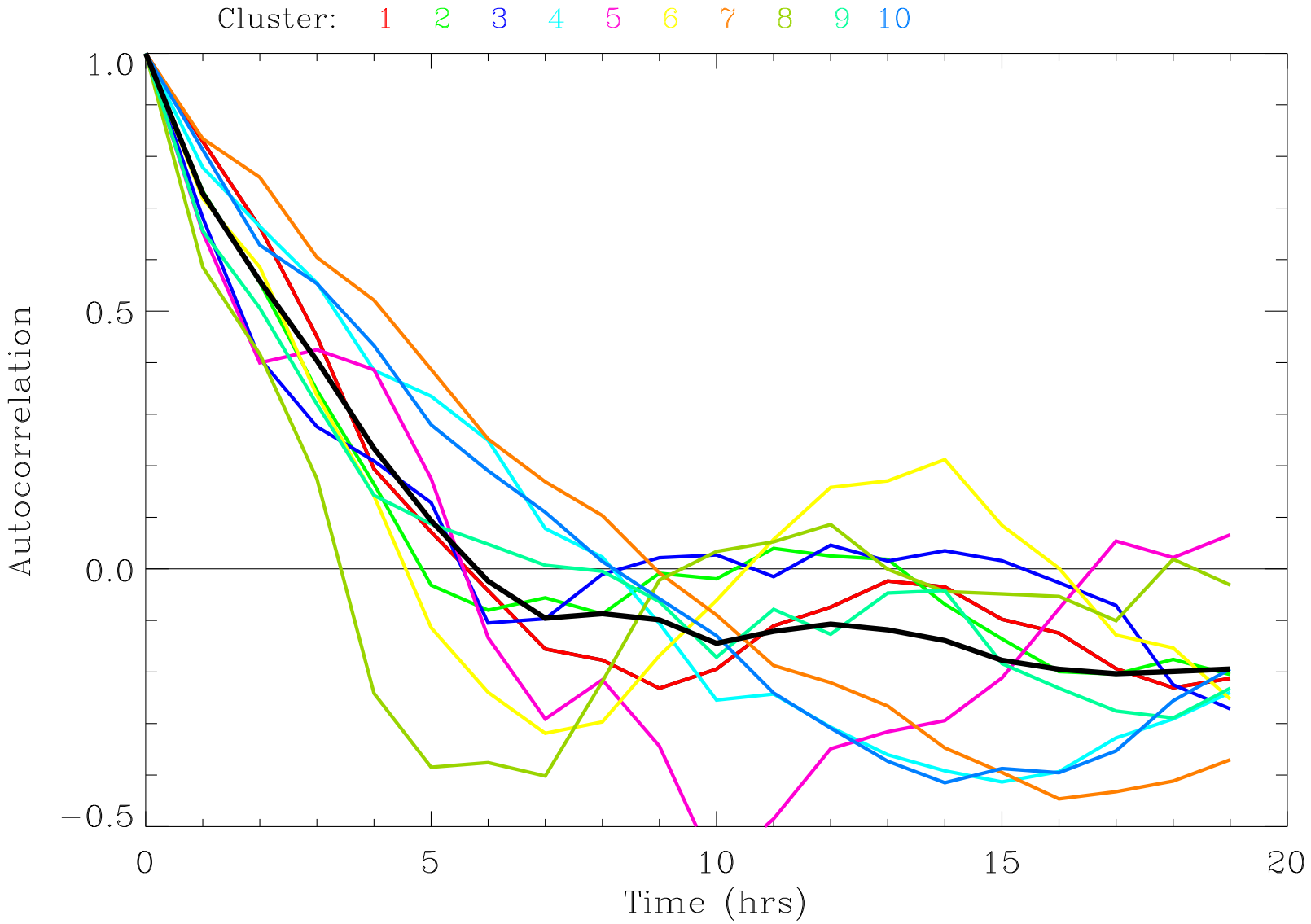
Table 2 suggests that the image matching algorithm ranked 7 and 4V too high, and 1 too low (distribution for that forecast is above or below the diagonal)



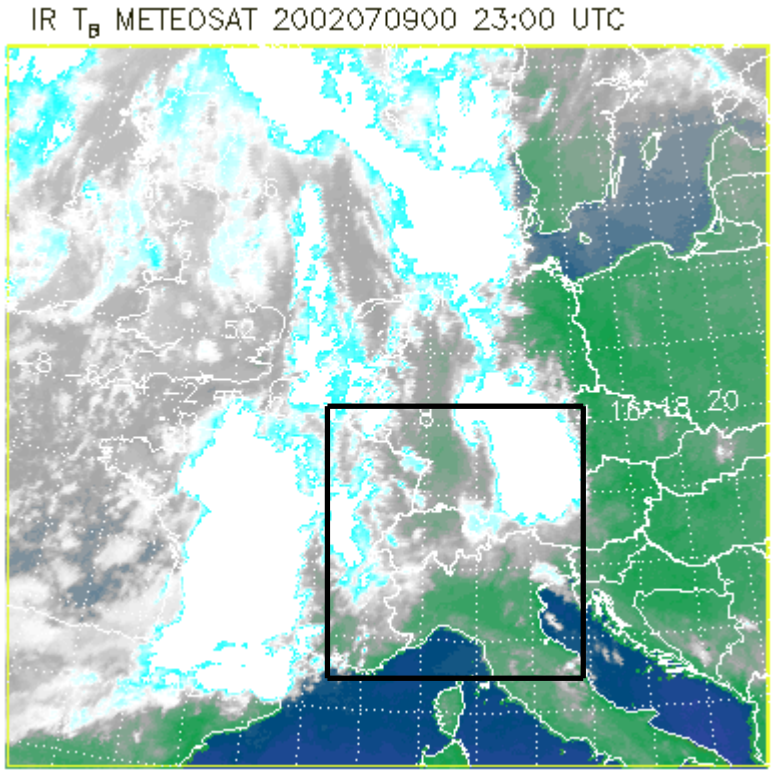
Error (mean displacement) vs. time



Autocorrelation of error



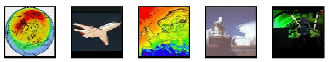
IR sequence for 9 July 2002



Meteosat 7 IR

Summary

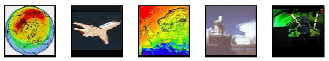
1. Prototype for a Regional Ensemble System (COSMO-LEPS, LMSynSat, Image Matching) demonstrated on a VERTIKATOR case study
2. Objective image matching score gives independent information from COSMO-LEPS cluster population
3. Persistence of forecast quality is about 6 h (Convective life cycle? Advection across domain?)



Outlook

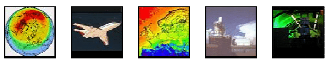
1. Introduction of small-scale variability (first noise in initial conditions, then stochastic convection scheme)
2. Validation of precipitation (new DWD Radar product: 5 min rain rates)
3. Development of further quality measures
4. Investigation of additional cases (MAP,CSIP,COPS)

5. DLR Adaptive Regional Ensemble System (resampling, nudging, physical initialisation)



Ongoing Project Work

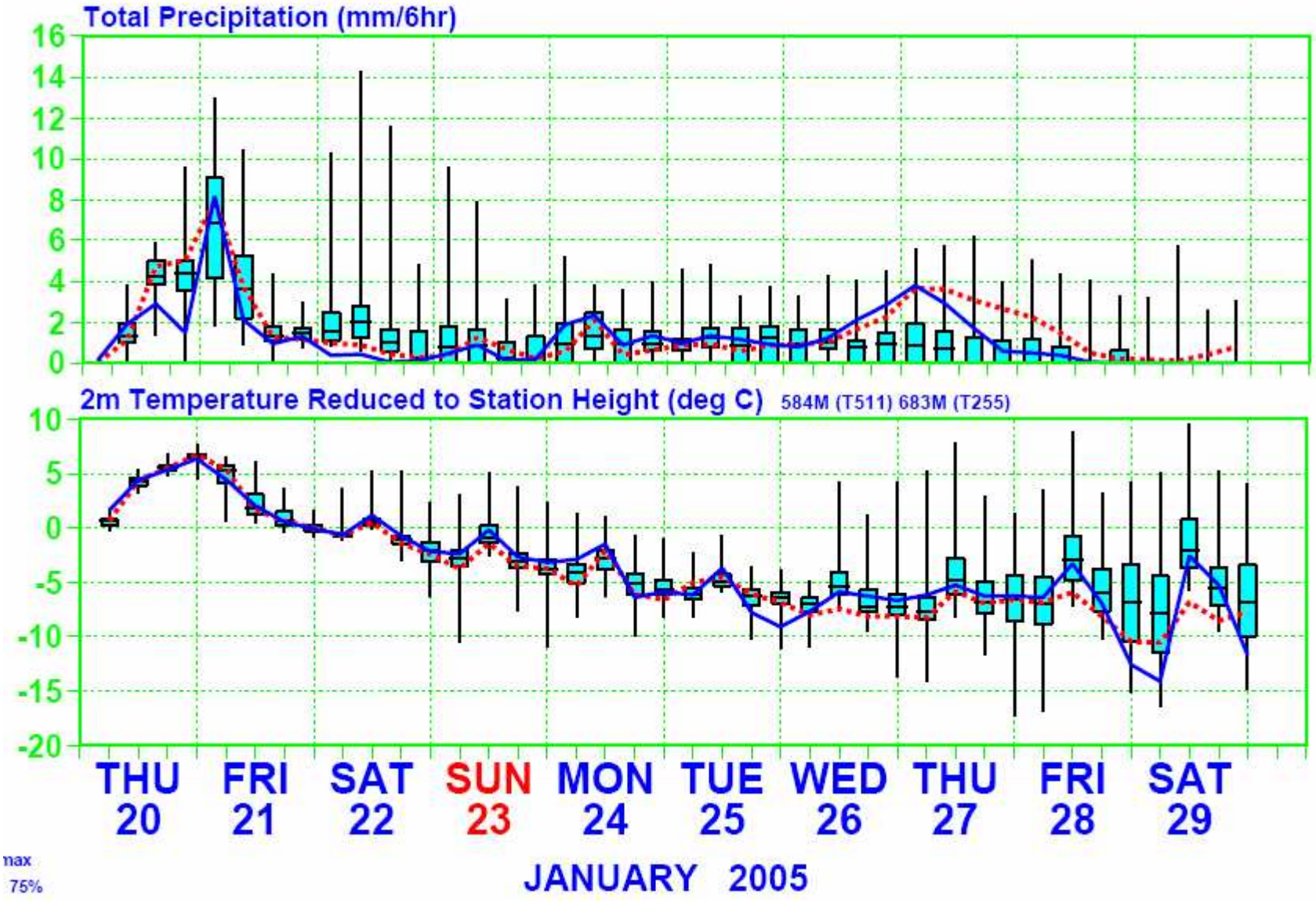
- **DAQUA**: Ensemble Experiments provide basis for Assimilation-Experiments (LHN, MeteoSwiss); DWD plans for GME-Ensemble
- **D-Phase**: MAP-FDP; establish a forecast chain for high-impact weather events
- **COST731**: Propagation of Uncertainty in advanced Hydro-Meteorological Forecast Systems
- **Special thanks to DWD & ECMWF, no HPC @ DLR**



EPS Meteogram

Muenchen 48.1° N 11.5° E 508M

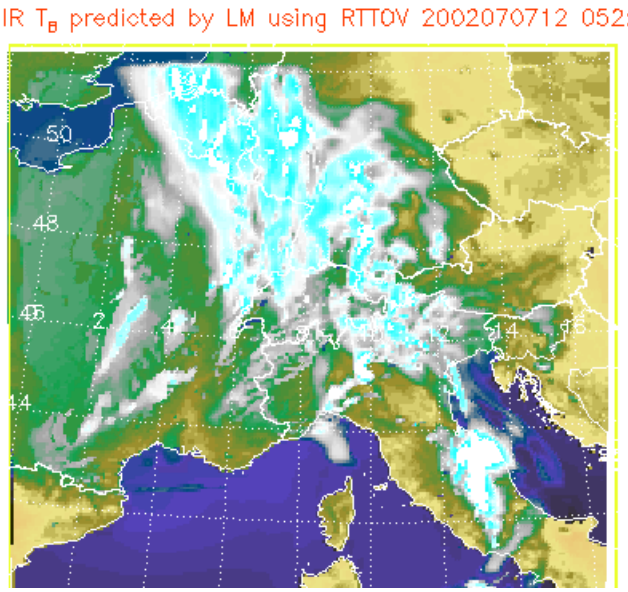
Deterministic Forecasts and EPS Distribution 20 January 2005 00 UTC

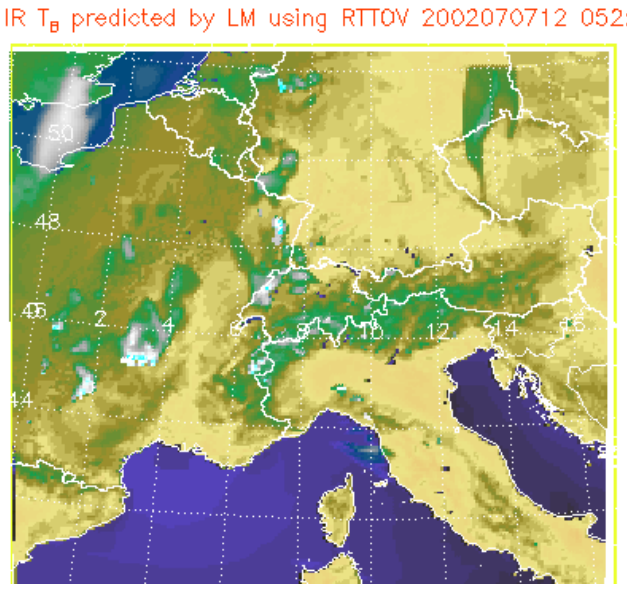


nax
75%

DLR Institut für Physik der Atmosphäre

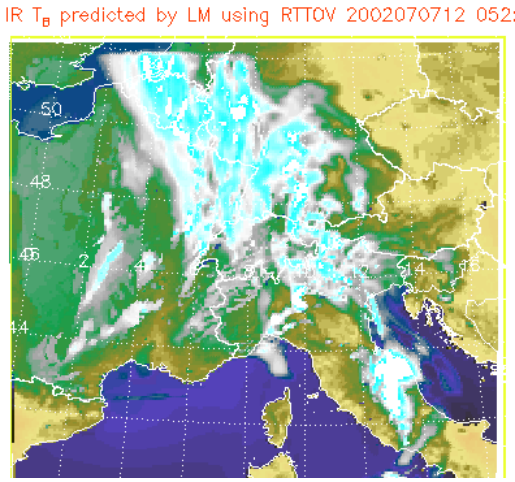
COSMO-LEPS: 9 July 2002

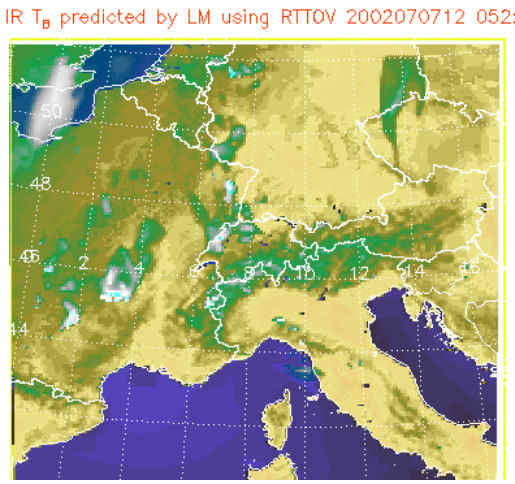


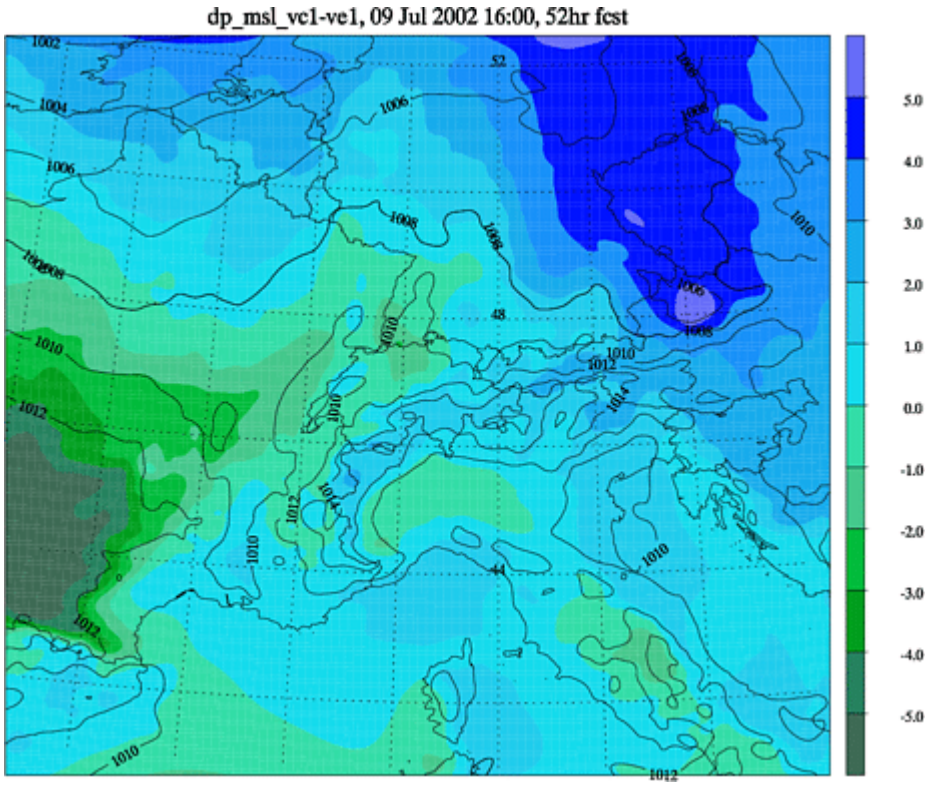


Why are the clusters so different?
Comparison of pressure, wind and moisture fields between Cl2 and Cl3

COSMO-LEPS: 9 July 2002

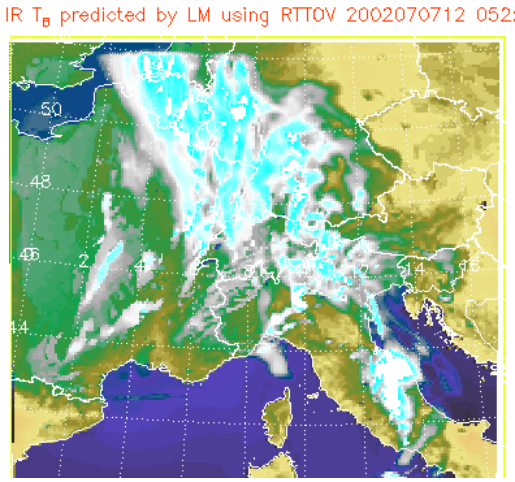


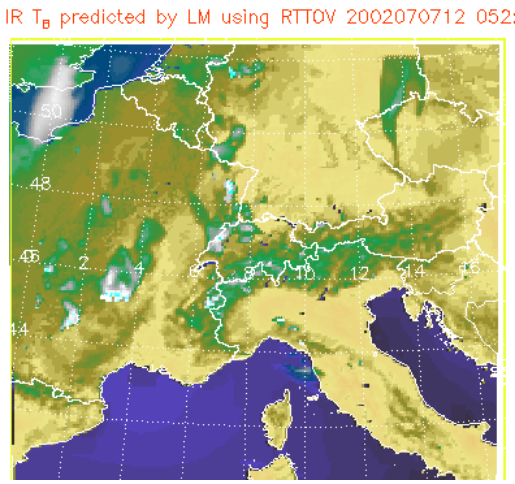


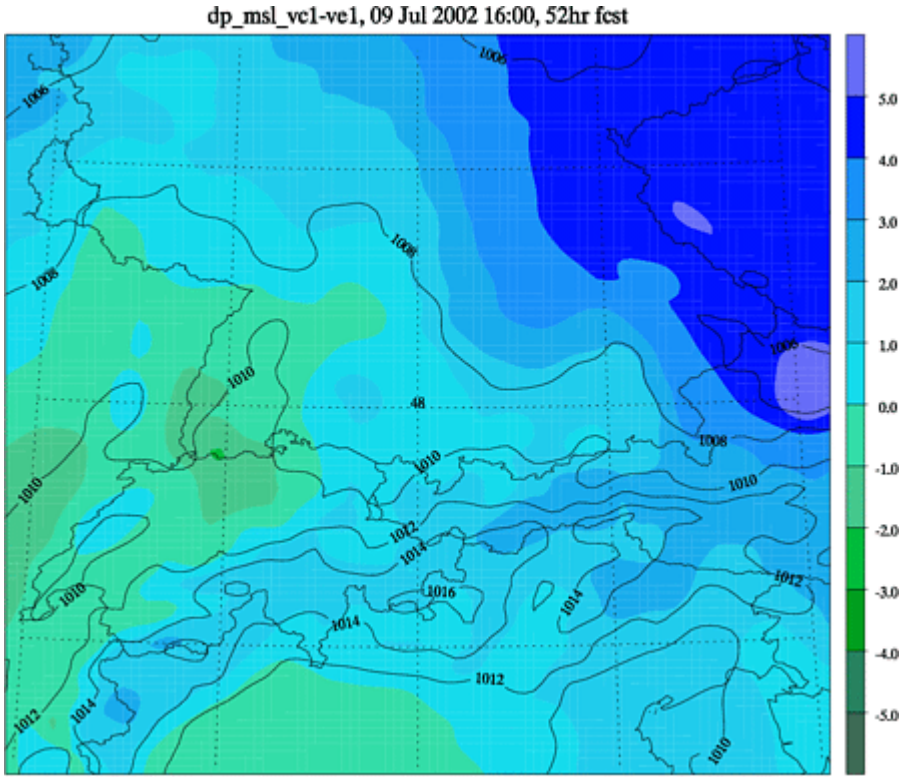


LM: difference in PS_msl

COSMO-LEPS: 9 July 2002

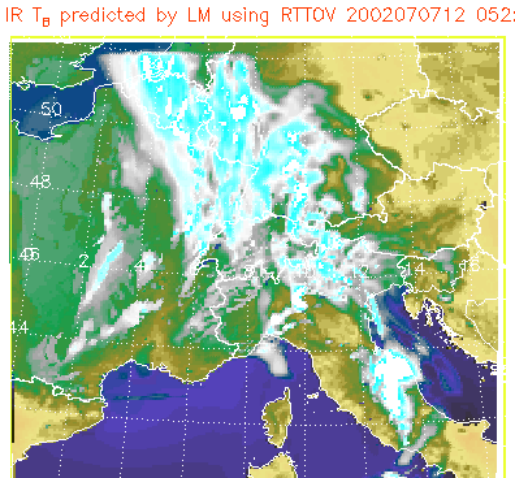


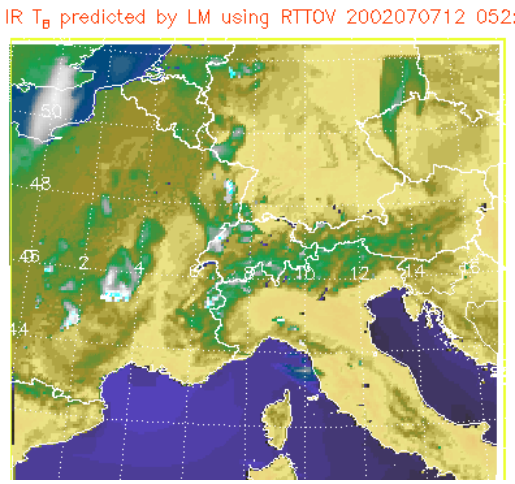


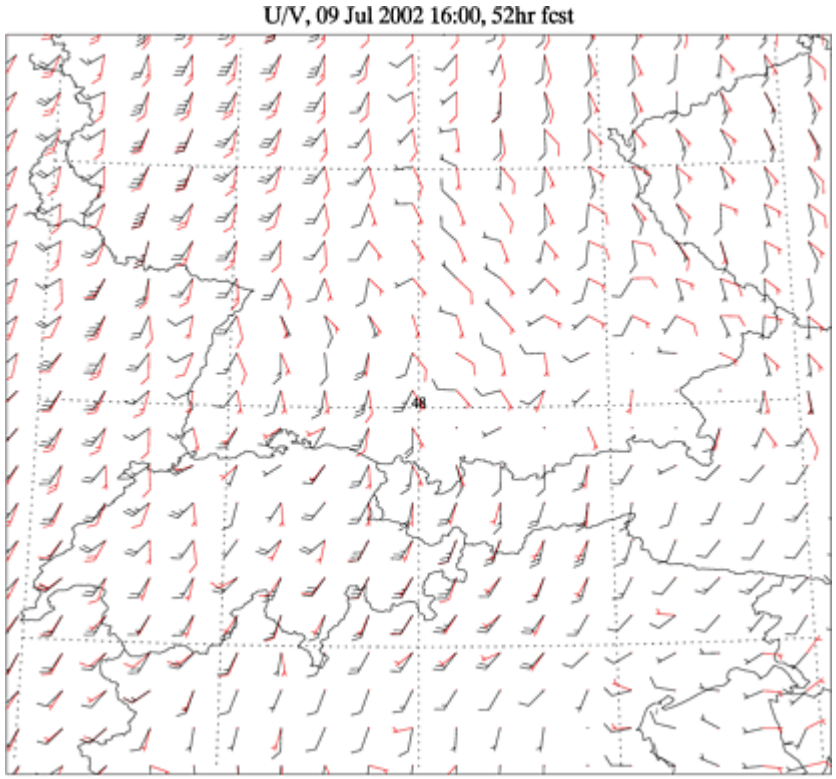


LM: difference in PS_msl

COSMO-LEPS: 9 July 2002



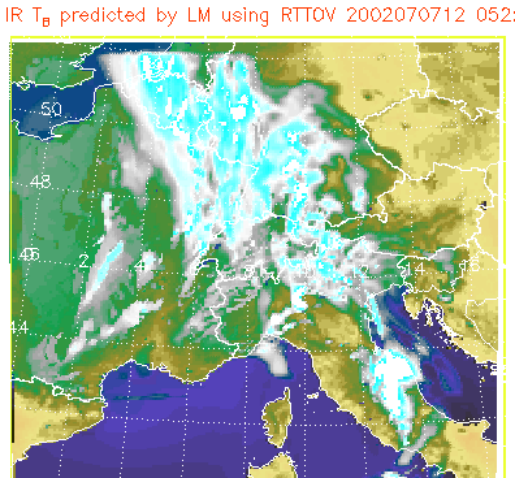


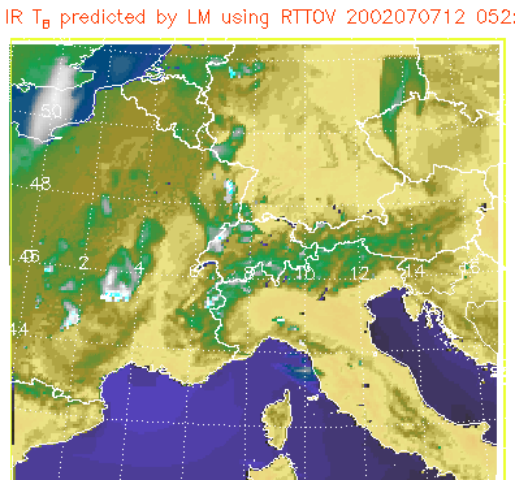


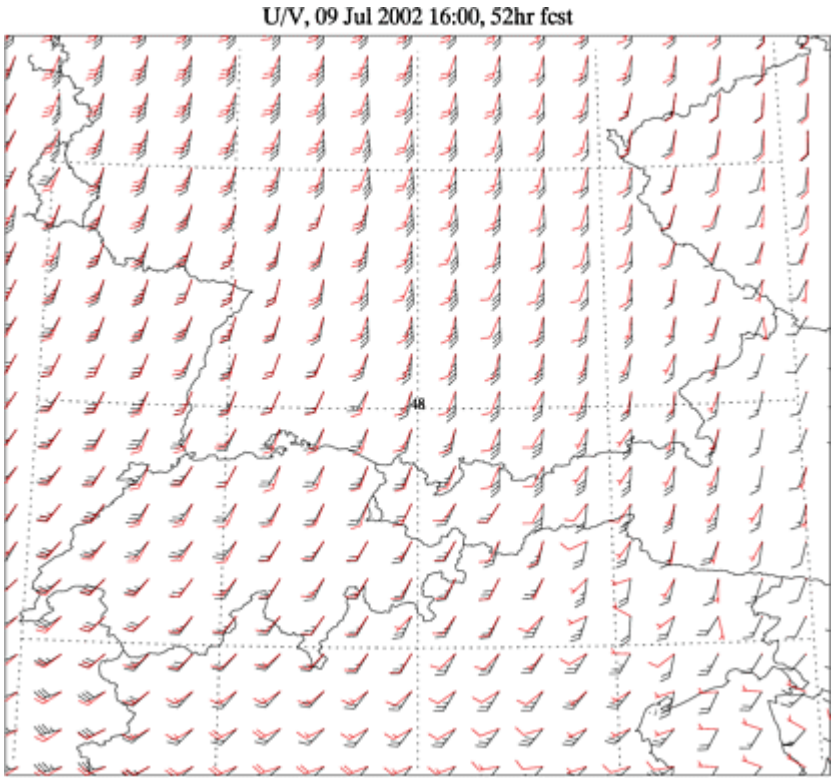
LM: horizontal wind @ 850 hPa (ml26)

LM exp. ve1 (black) and vc1 (red)

COSMO-LEPS: 9 July 2002



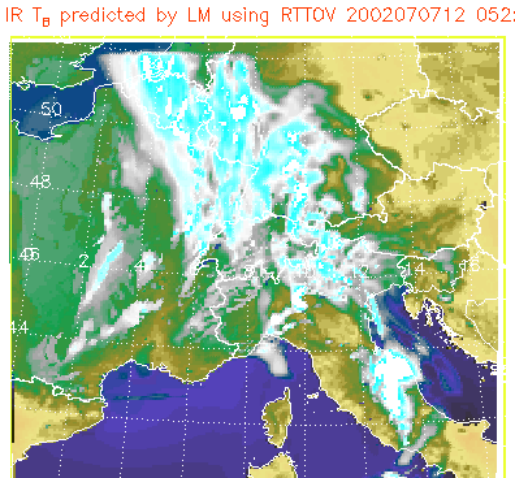


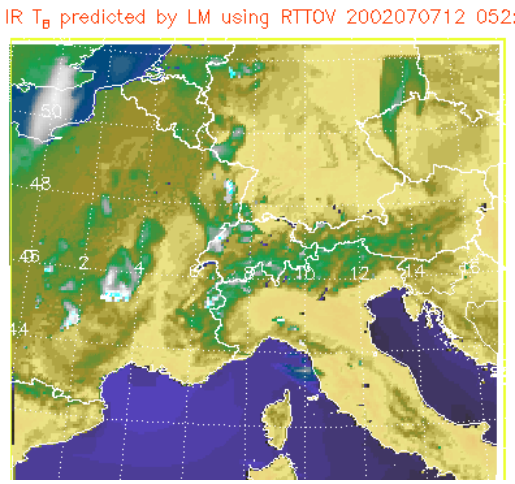


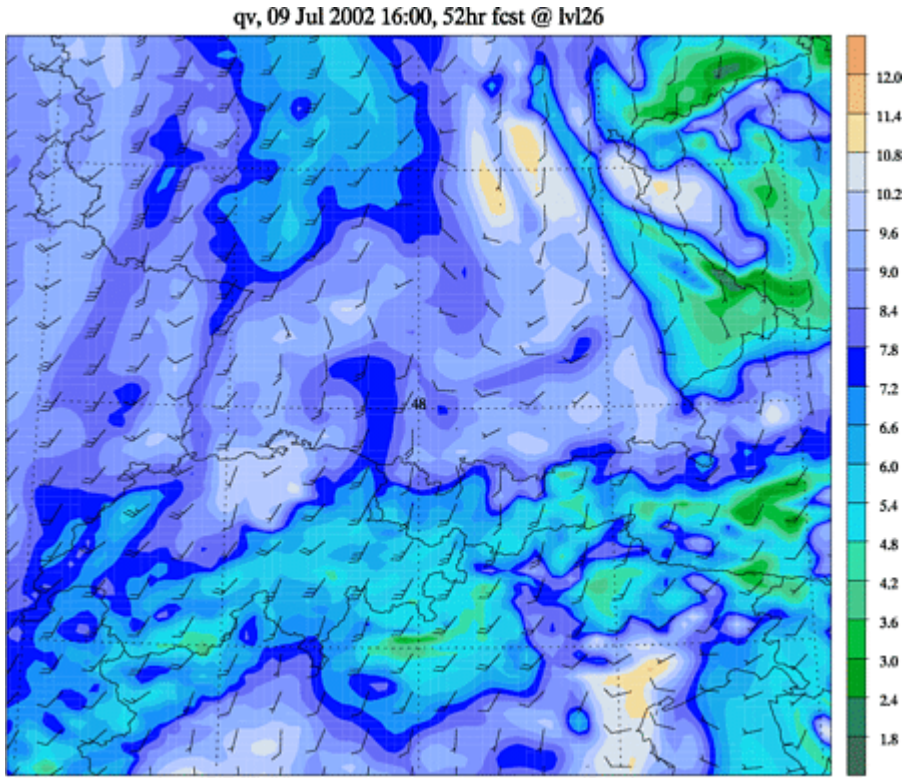
LM: horizontal wind @ 500 hPa (ml16)

LM exp. ve1 (black) and vc1 (red)

COSMO-LEPS: 9 July 2002

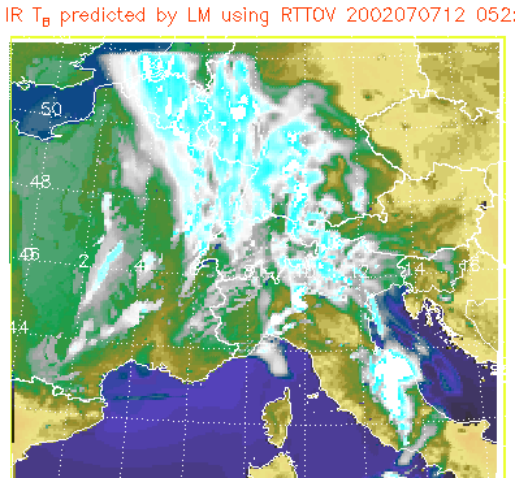


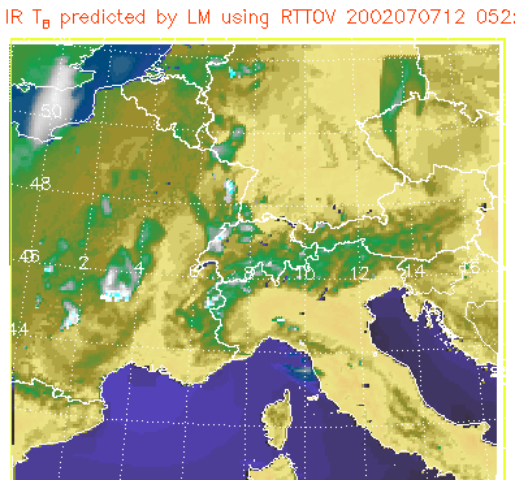


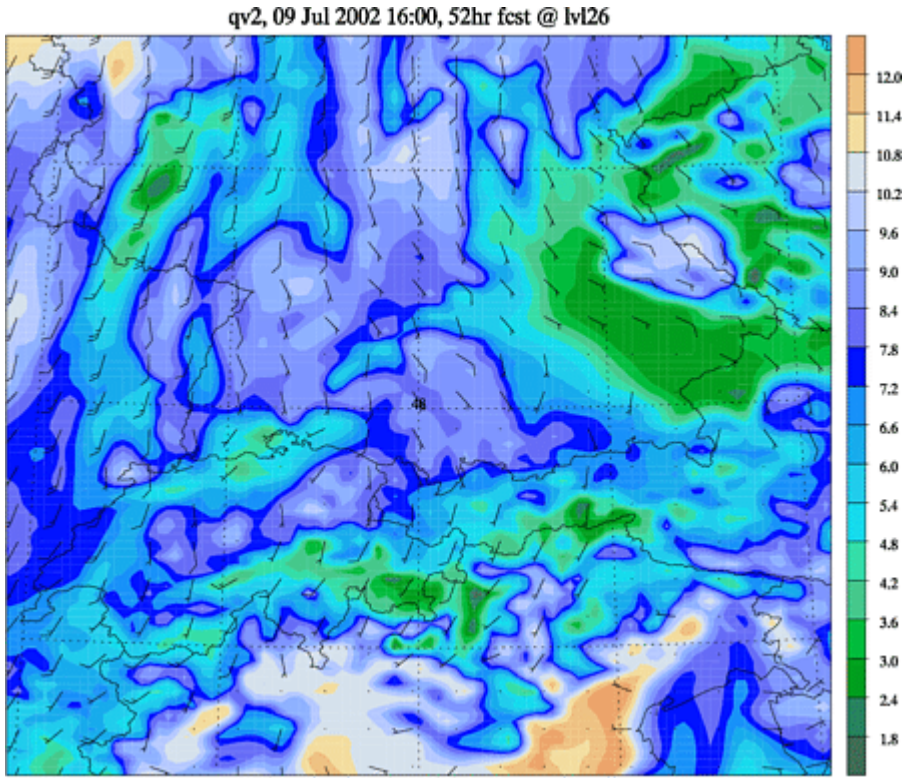


LM(ve1): spec. humidity @ 850 hPa (ml26)

COSMO-LEPS: 9 July 2002

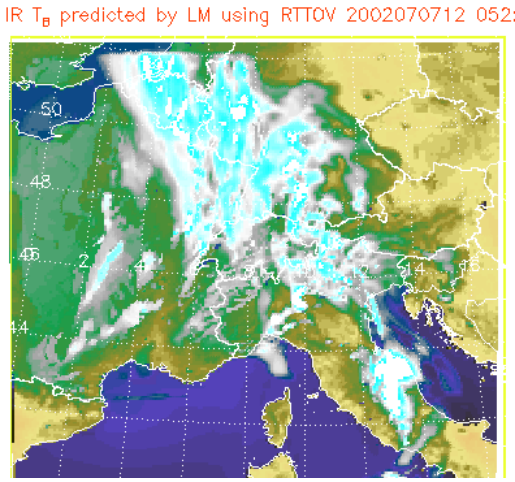


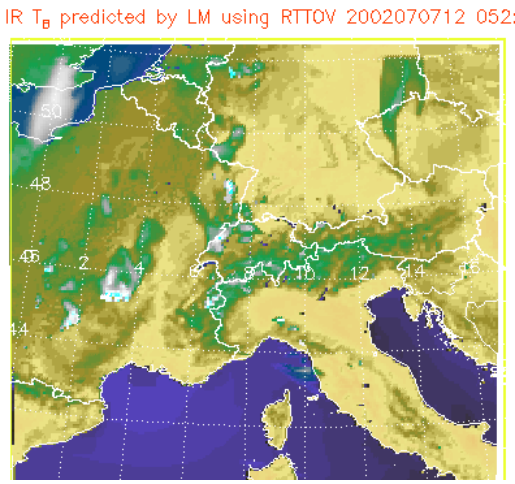


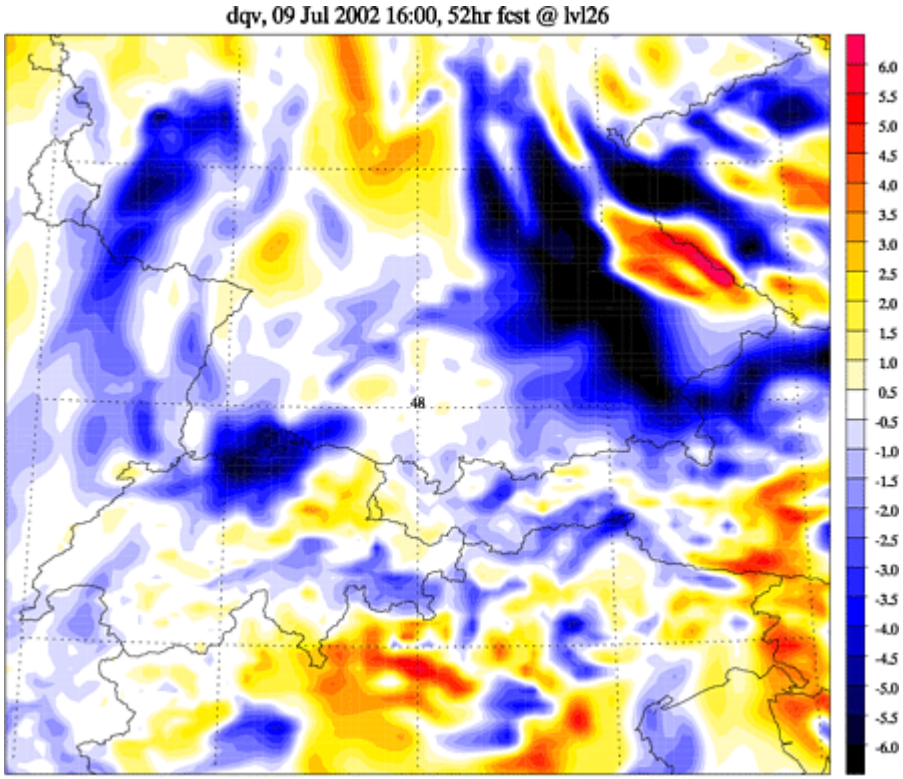


LM(vc1): spec. humidity @ 850 hPa (ml26)

COSMO-LEPS: 9 July 2002







LM: spec. humidity @ 850 hPa (ml26)

difference between exp. vc1-ve1