

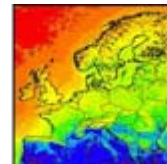
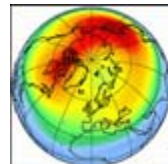
# Fuzzy verification of COSMO-LEPS Forecasts using a displacement-based Quality Measure

Christian Keil and George C.Craig

Institut für Physik der Atmosphäre  
DLR Oberpfaffenhofen, Germany



Institut für  
Physik der Atmosphäre



# Why is it called "fuzzy"?



observation

forecast

*Squint your eyes!*

*(Ebert, 2007)*

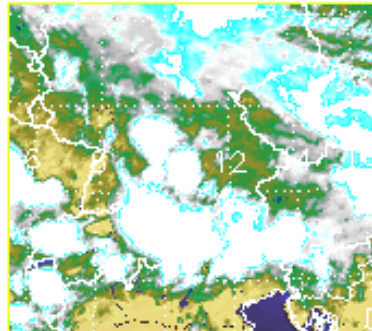
# Motivation

Exploitation of spatio-temporal information contained in remote sensing imagery

Observation

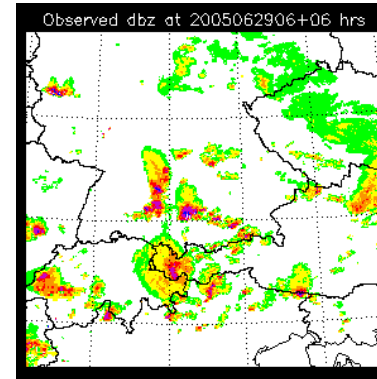
Meteosat 8

BT IR\_108 MET8 2005062900 12 UTC



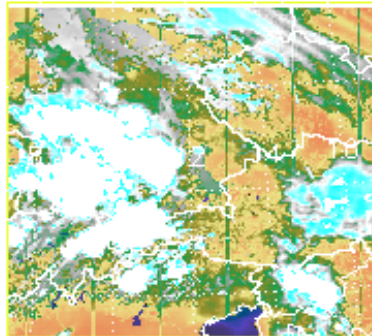
Radar

Observed dbz at 2005062906+06 hrs

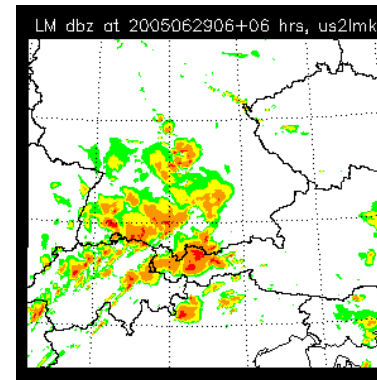


LMK Forecast  
using forward operators

BT IR\_LMK fc 2005062906 +0600h



LM dbz at 2005062906+06 hrs, us2lmk

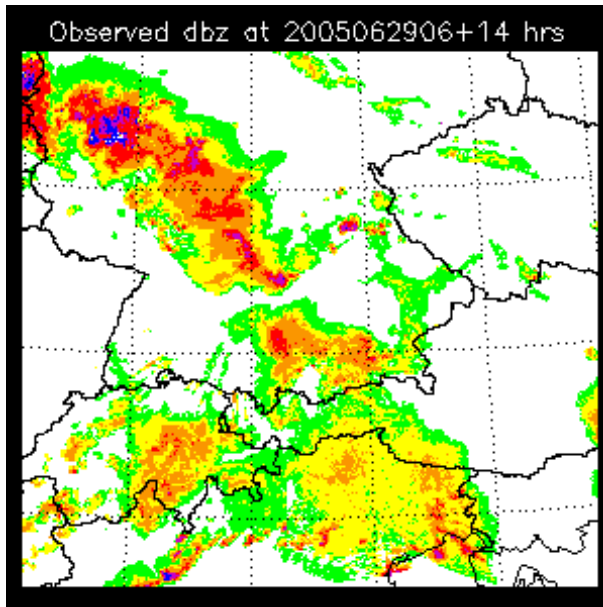


# Pyramidal Matching Algorithm (Mannstein et al., 2002)

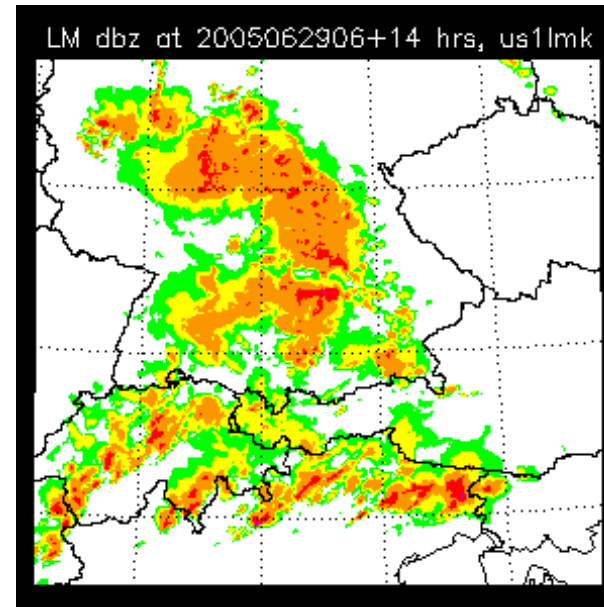
1. **Project** observed and simulated images to same grid
2. **Coarse-grain** both images by averaging of  $2^F$  pixels onto one pixel element
3. **Compute a displacement vector field** that minimizes the squared difference within the range of  $\pm 2$  pixel elements
4. **Repeat** step 2 at successively **finer scales**
5. Displacement vector for every pixel results from the **sum** over all scales

# Pyramidal Matching: Example with real data

1. **Project** observed and simulated images to same grid



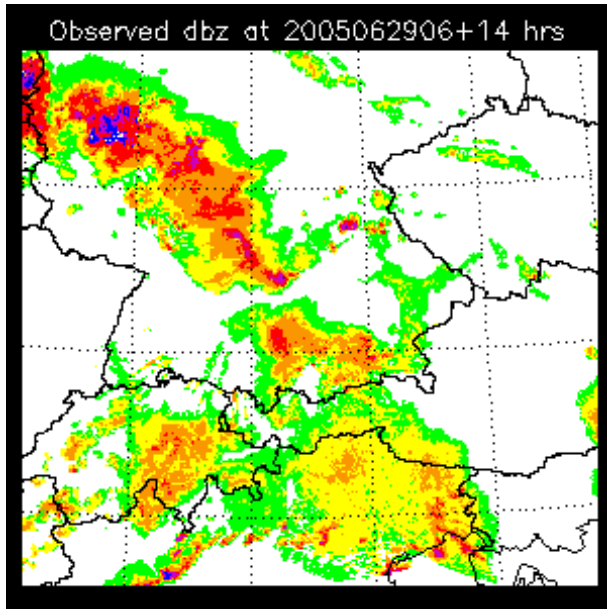
Observation



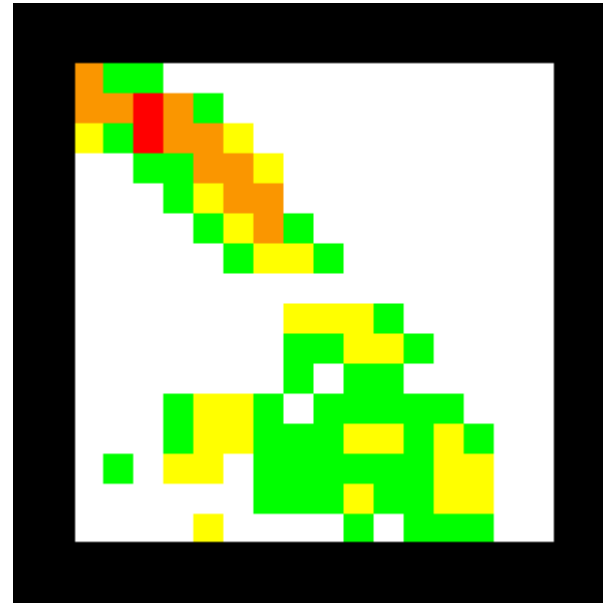
Forecast

# Pyramidal Matching: Example with real data

2. **Coarse-grain** both images by pixel averaging



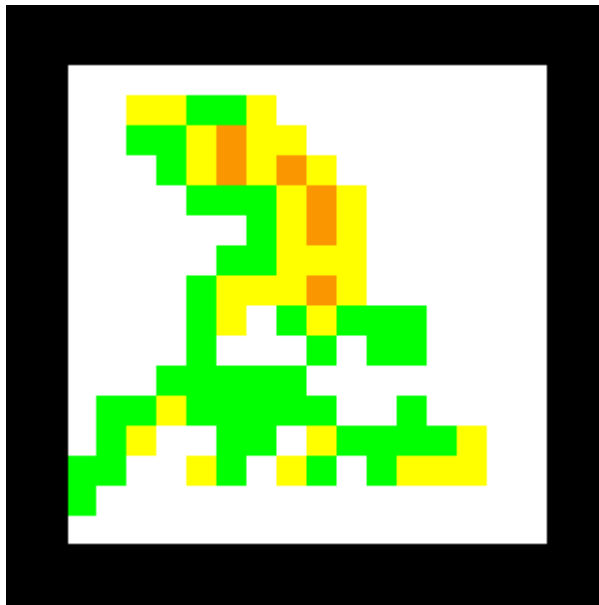
Observation



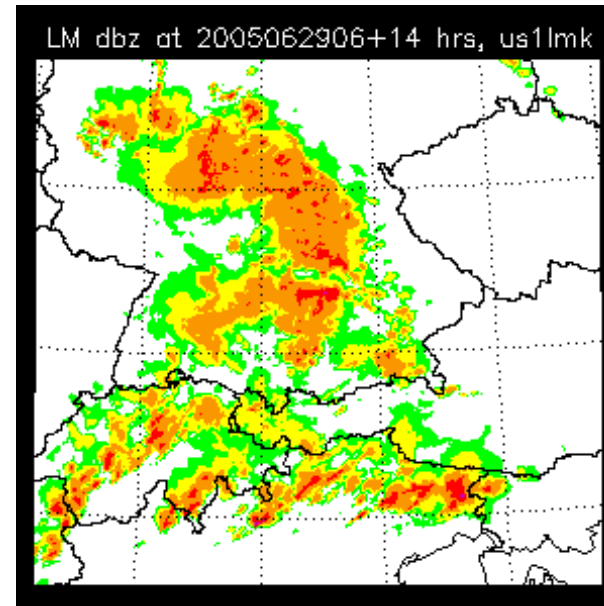
Coarse-grained observation

# Pyramidal Matching: Example with real data

2. **Coarse-grain** both images by pixel averaging



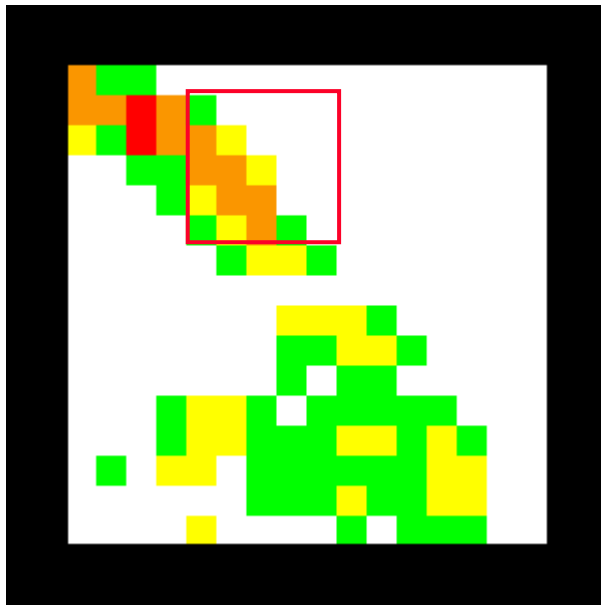
Coarse-grained forecast



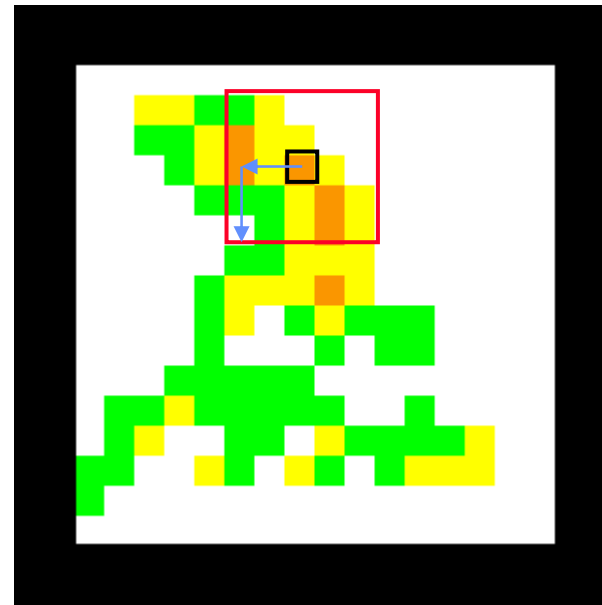
Forecast

# Pyramidal Matching: Example with real data

3. Compute **displacement vector field** that minimizes the squared difference



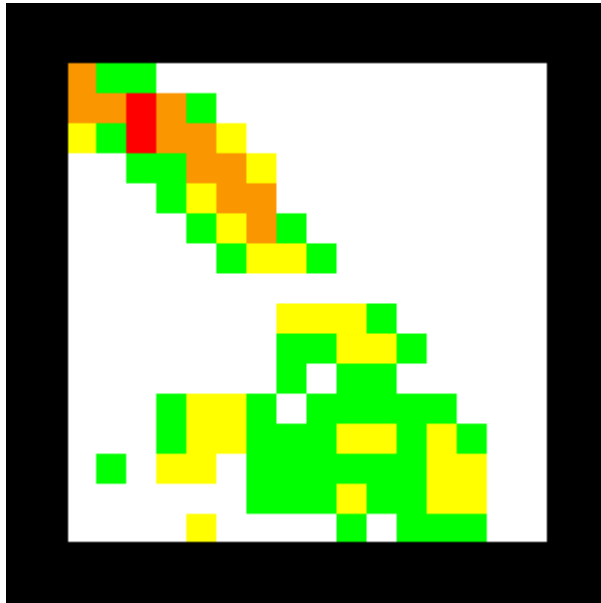
Observation



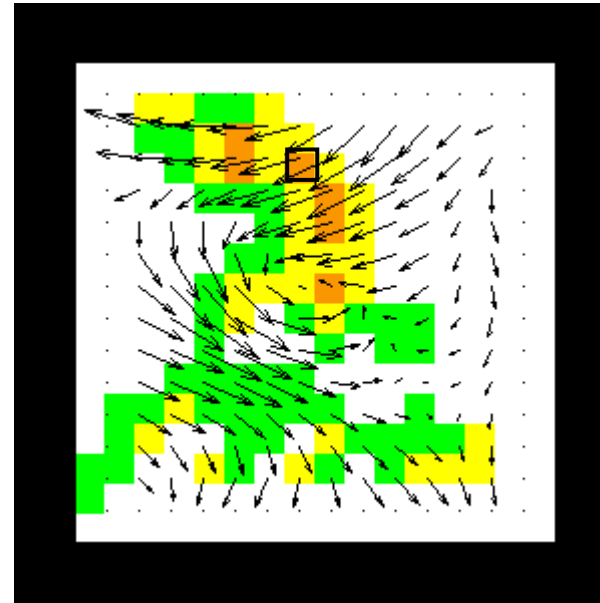
Forecast

# Pyramidal Matching: Example with real data

3. Compute **displacement vector field** that minimizes the squared difference



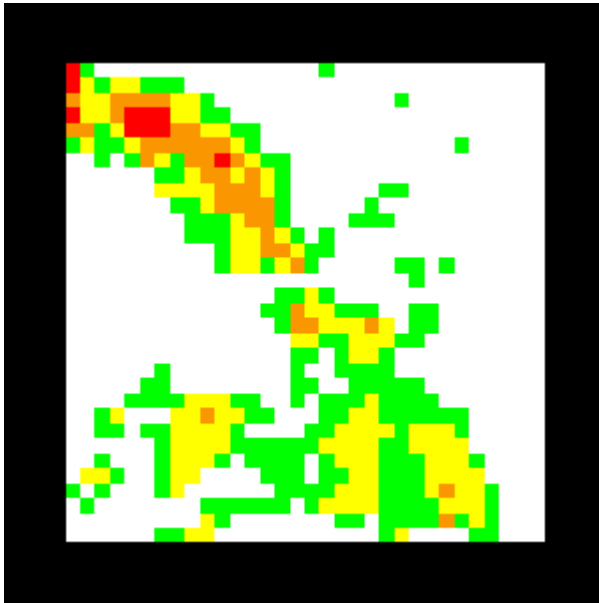
Observation



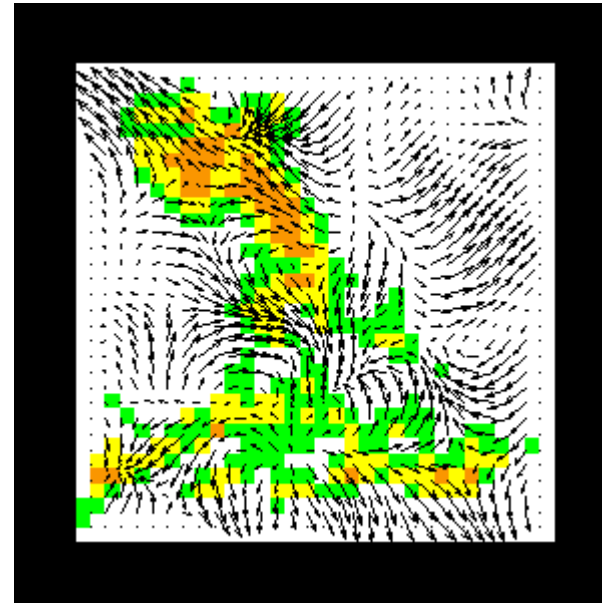
Forecast

# Pyramidal Matching: Example with real data

4. Repeat step 3 at successively finer scales



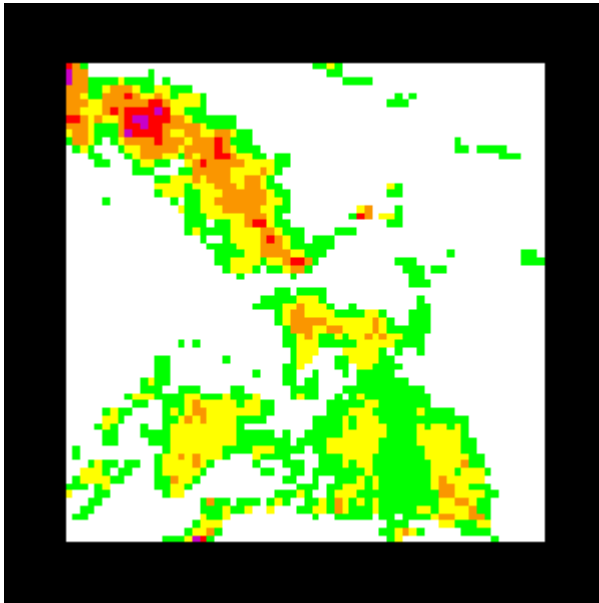
Observation



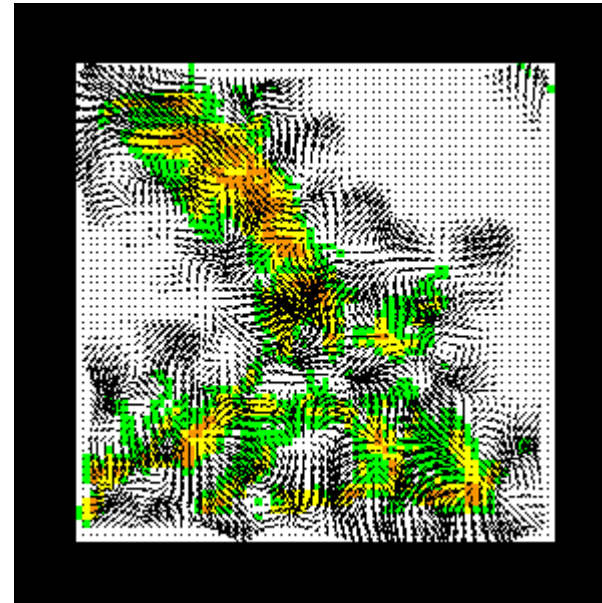
Forecast

# Pyramidal Matching: Example with real data

4. Repeat step 3 at successively finer scales



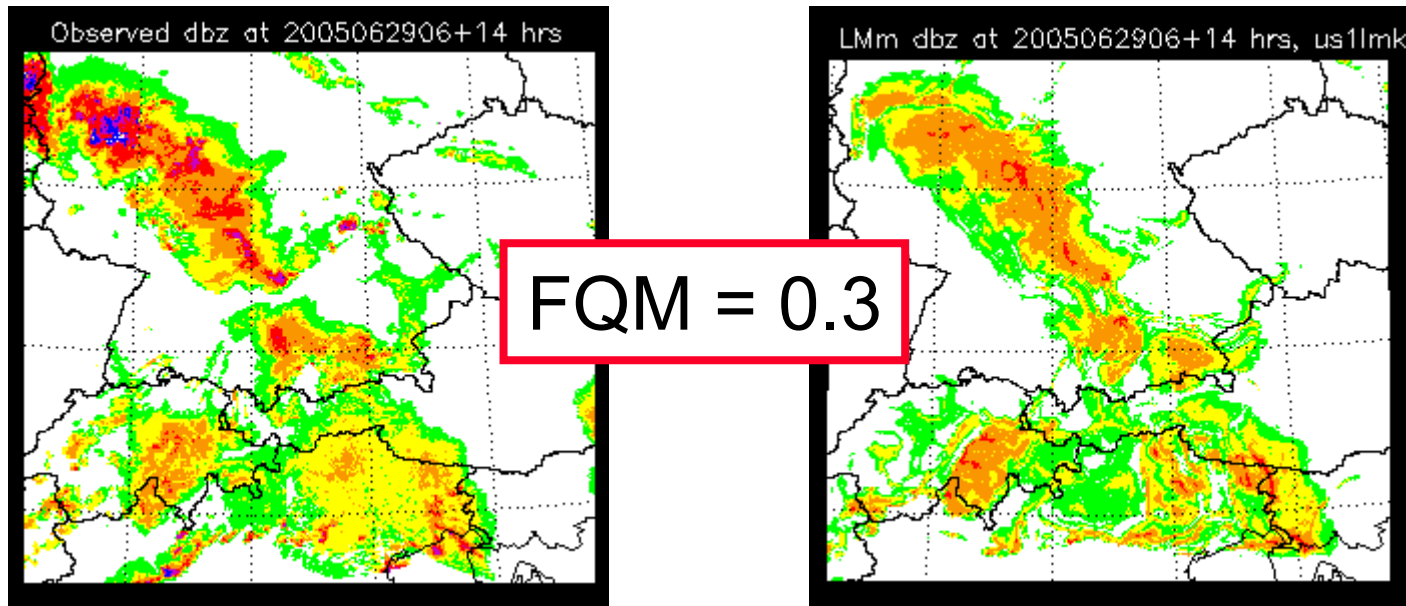
Observation



Forecast

# Pyramidal Matching: Example with real data

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



Observation

Forecast

# Forecast Quality Measure

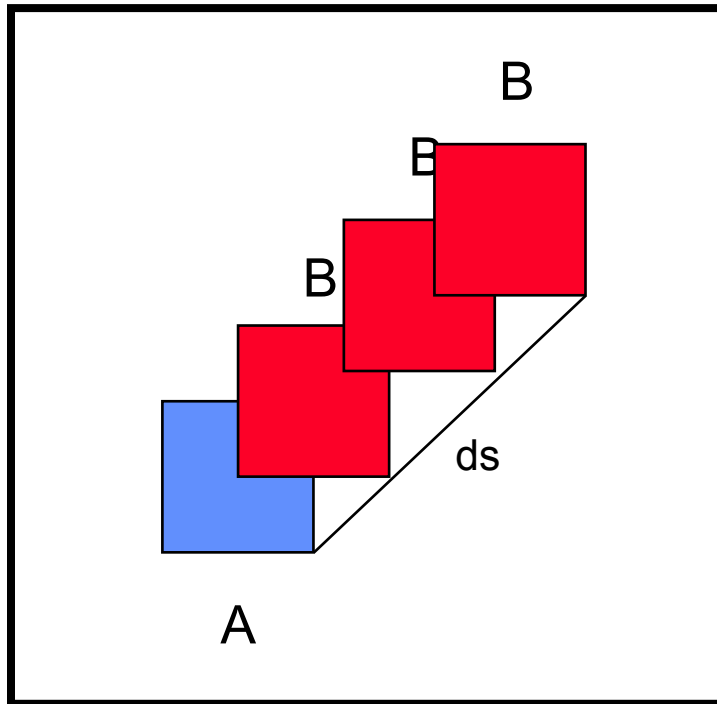
$$FQM = \frac{1}{A} \sum_A \max(c_1 \cdot DIS, c_2 \cdot LSE)$$

$$c_1 = DIS_{\max}^{-1}$$

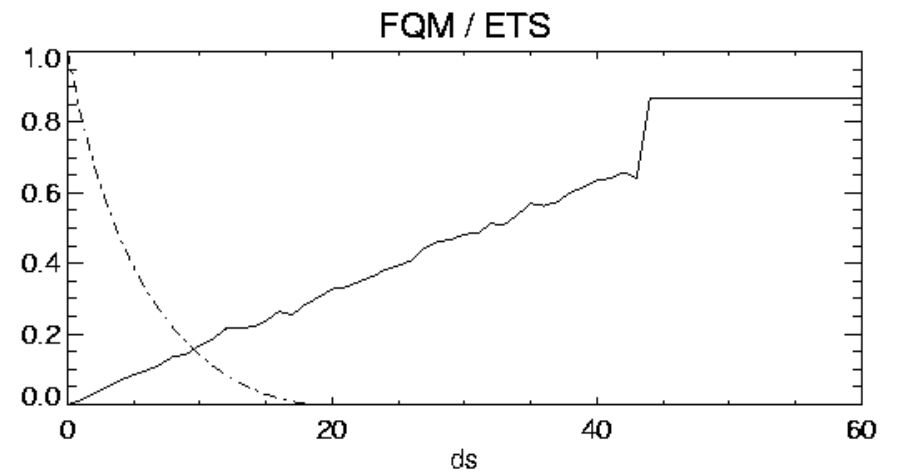
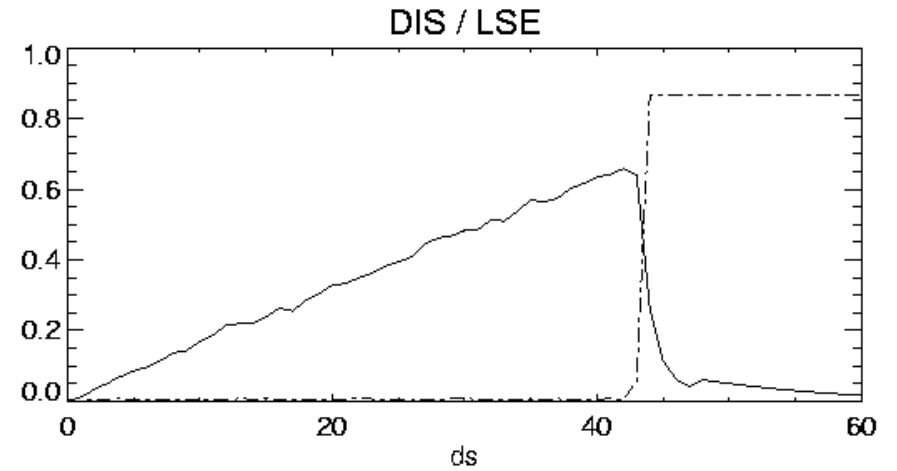
$$c_2 = (BT_{\max} - BT_{\min})^{-2}$$

If forecast and observed features can be matched, the magnitude of the displacement vector DIS characterises forecast quality, whereas when matching features cannot be found within the search distance, the local squared error LSE between both fields is used.

# Simplified case



2 identical features  
increasingly separated

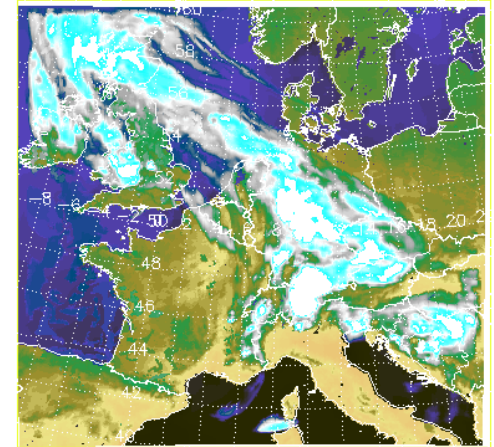


measures vs. separation distance

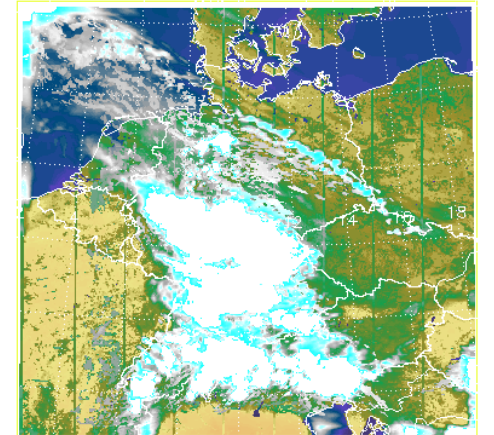
# Applied in a Regional Ensemble Forecasting System

- COSMO-LEPS: based on ECMWF EPS providing initial and boundary conditions and Lokal-Modell (LM  $\Delta x=7\text{km}$ )
- LMSynSat: forward operator (RTTOV7) to compute **synthetic satellite imagery** in LM
- High resolution **LMK** experiments ( $\Delta x=2.8\text{km}$ ) nested into representative members of COSMO-LEPS

BT IR\_108 LM fc 2005062812 +032h



BT IR\_108 LMK fc 2005062906 +014h

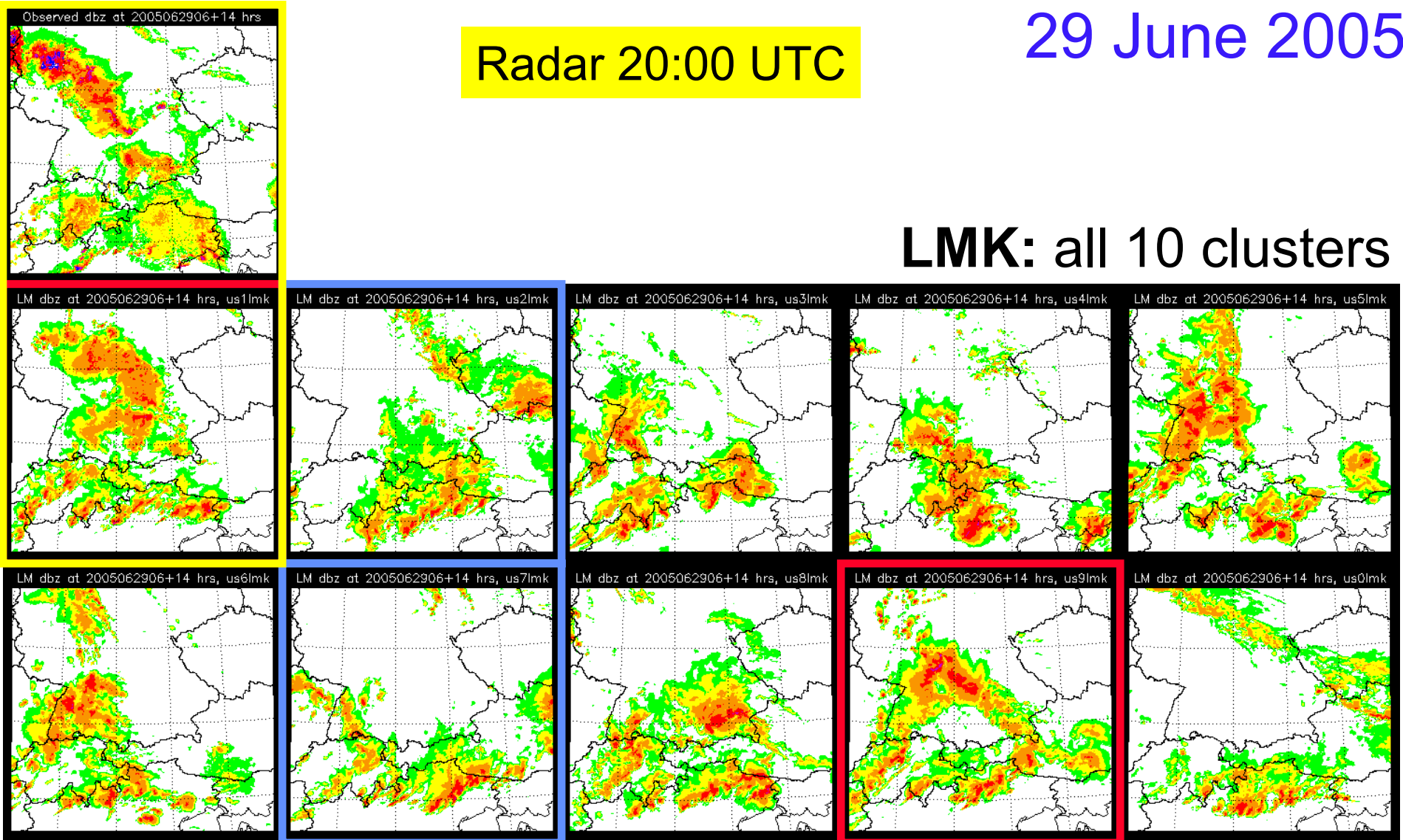


# Applied in a Regional Ensemble Forecasting System on

29 June 2005

Radar 20:00 UTC

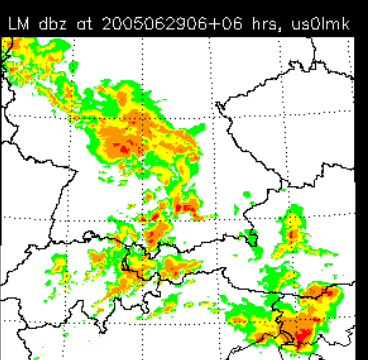
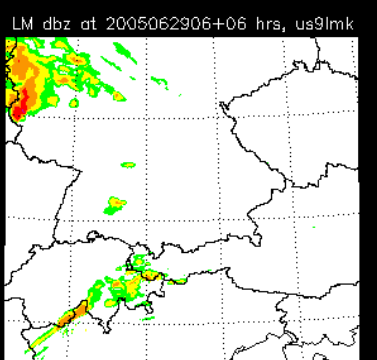
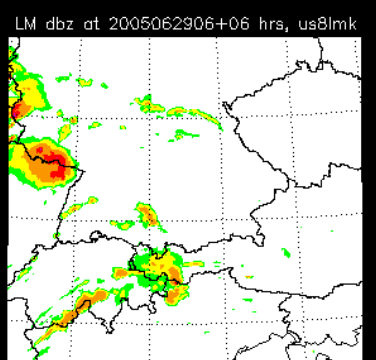
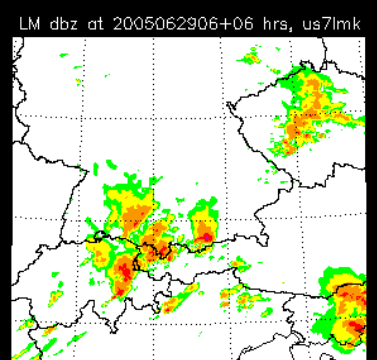
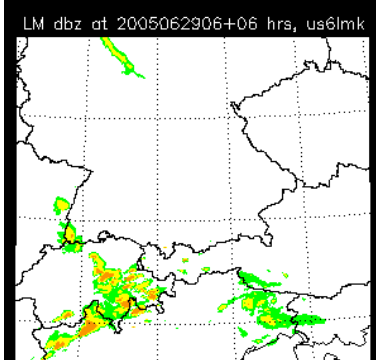
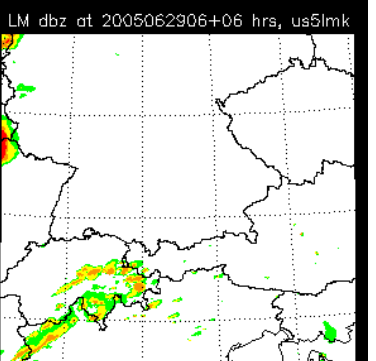
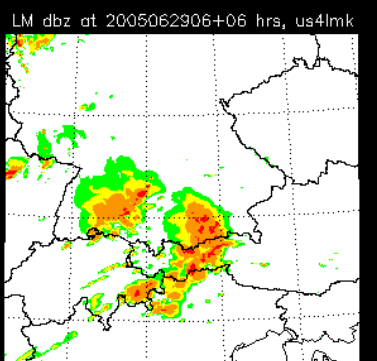
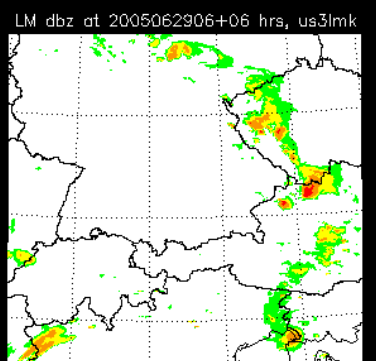
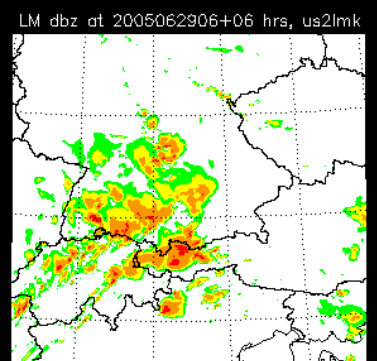
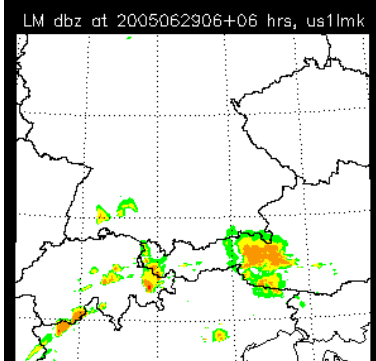
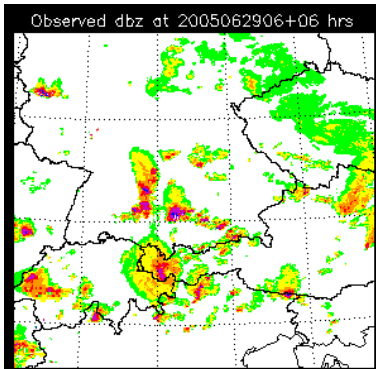
LMK: all 10 clusters



29 June 2005

Radar 12:00 UTC

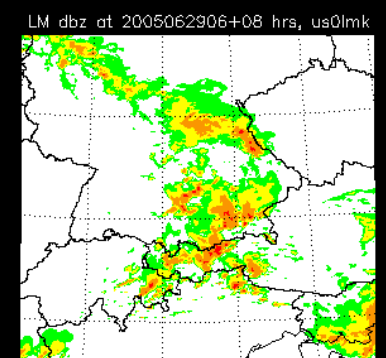
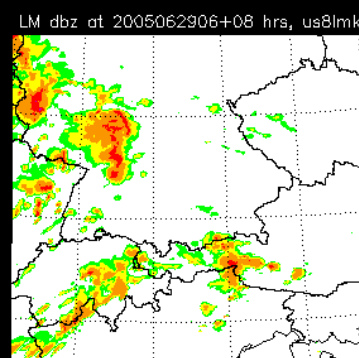
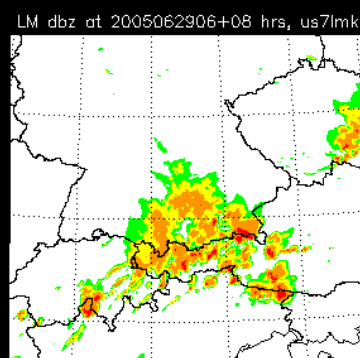
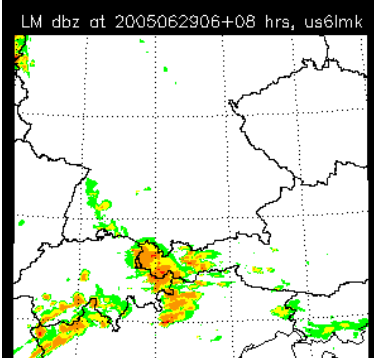
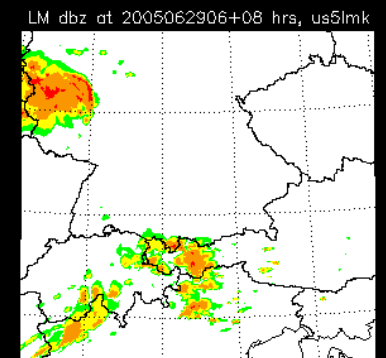
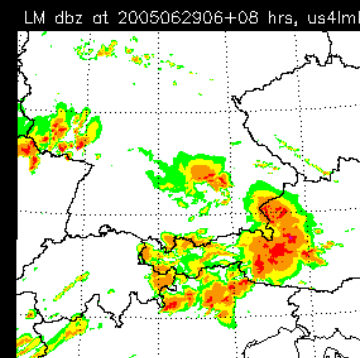
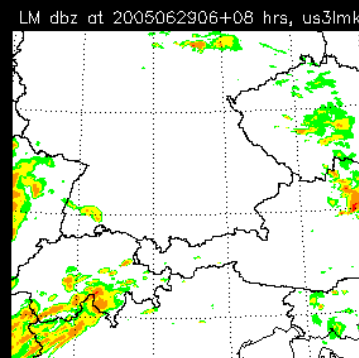
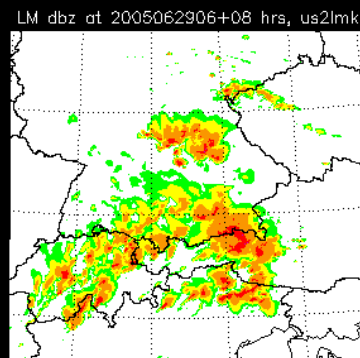
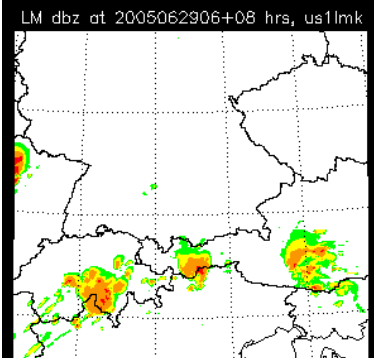
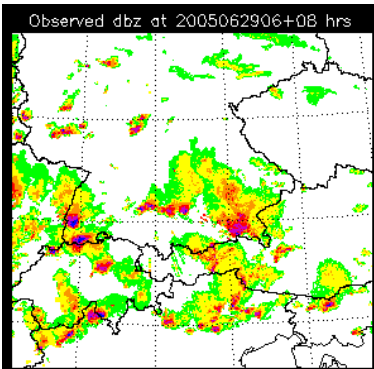
LMK: all 10 clusters



29 June 2005

Radar 14:00 UTC

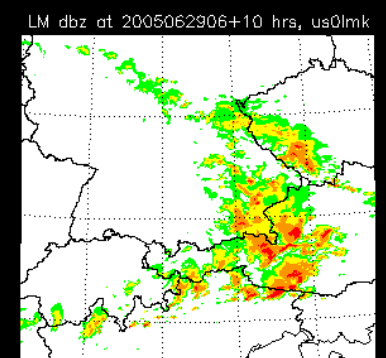
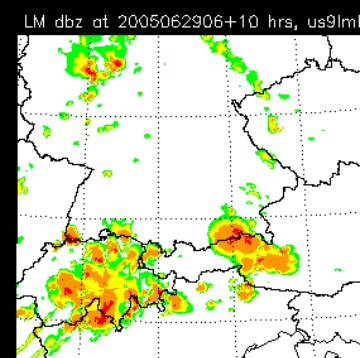
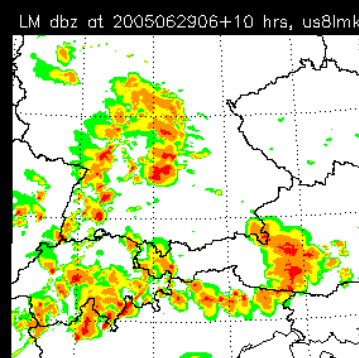
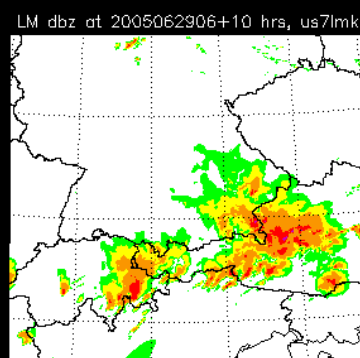
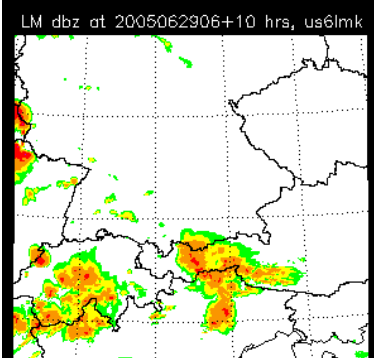
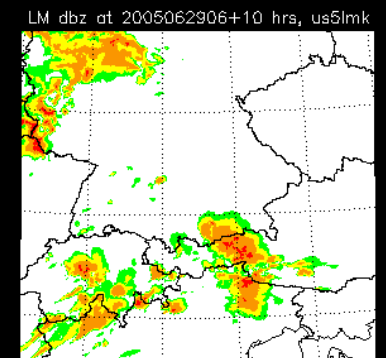
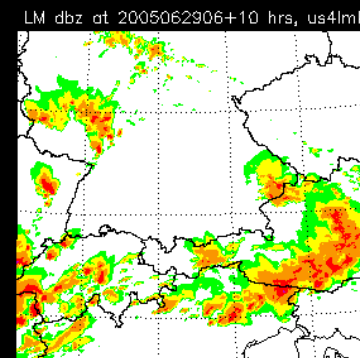
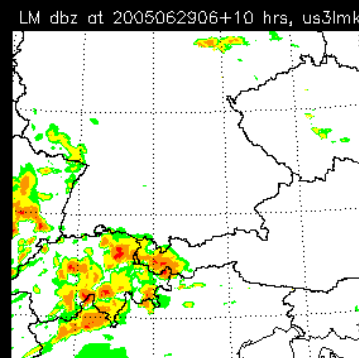
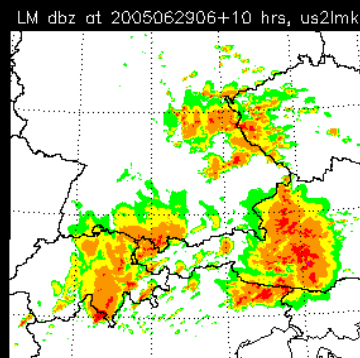
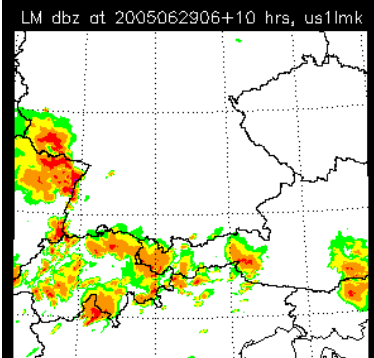
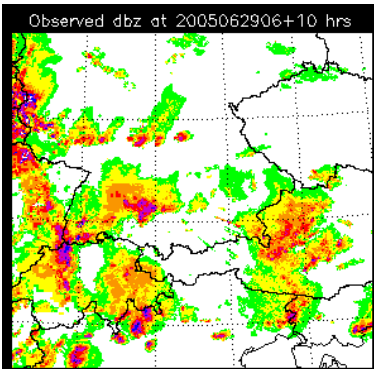
LMK: all 10 clusters



29 June 2005

Radar 16:00 UTC

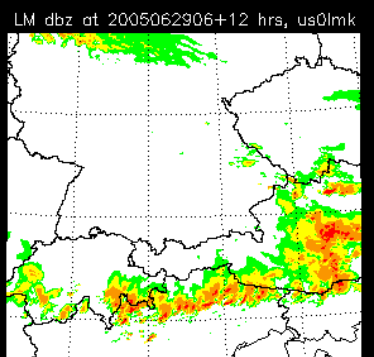
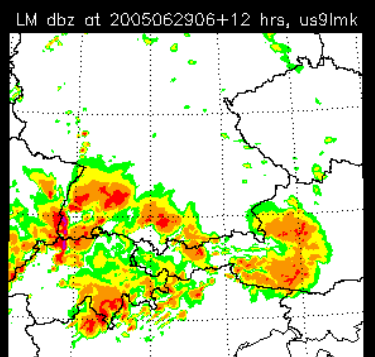
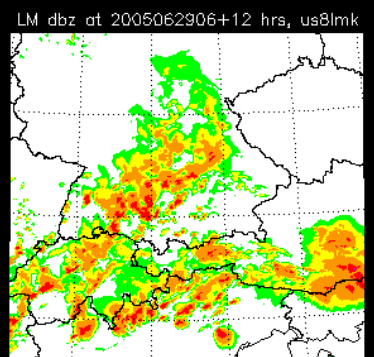
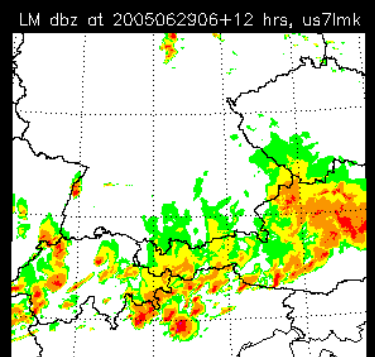
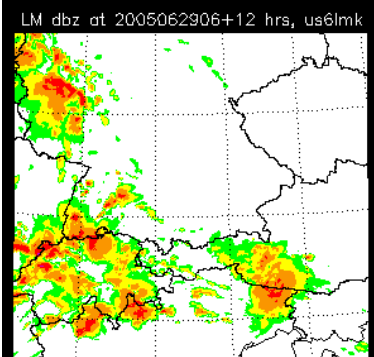
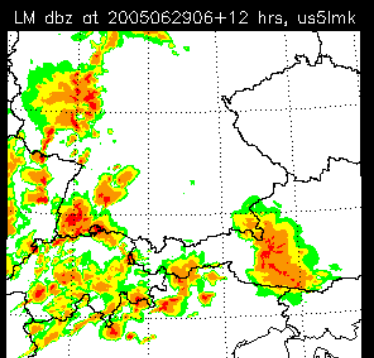
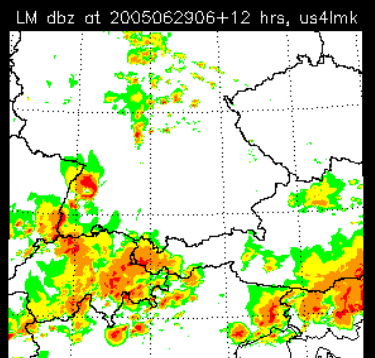
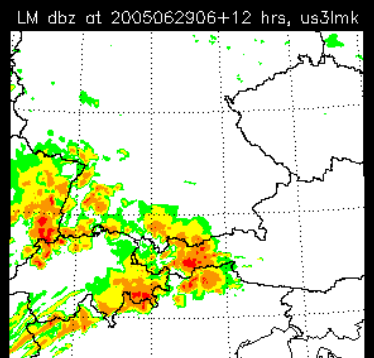
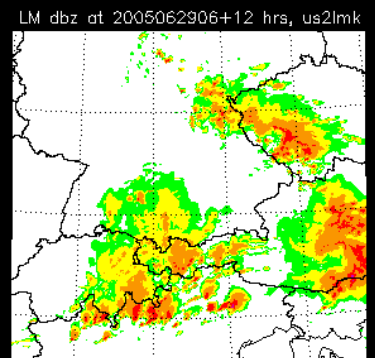
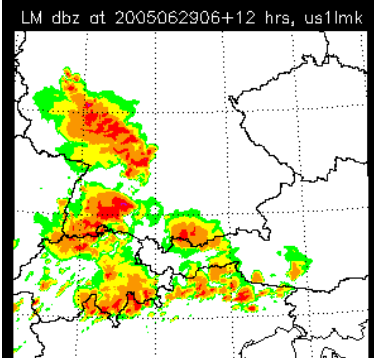
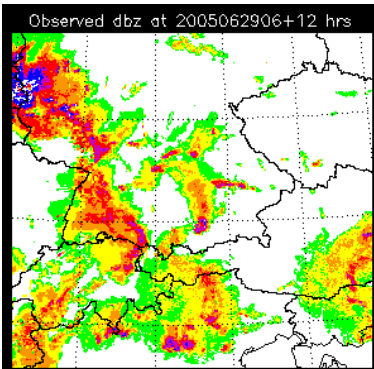
LMK: all 10 clusters



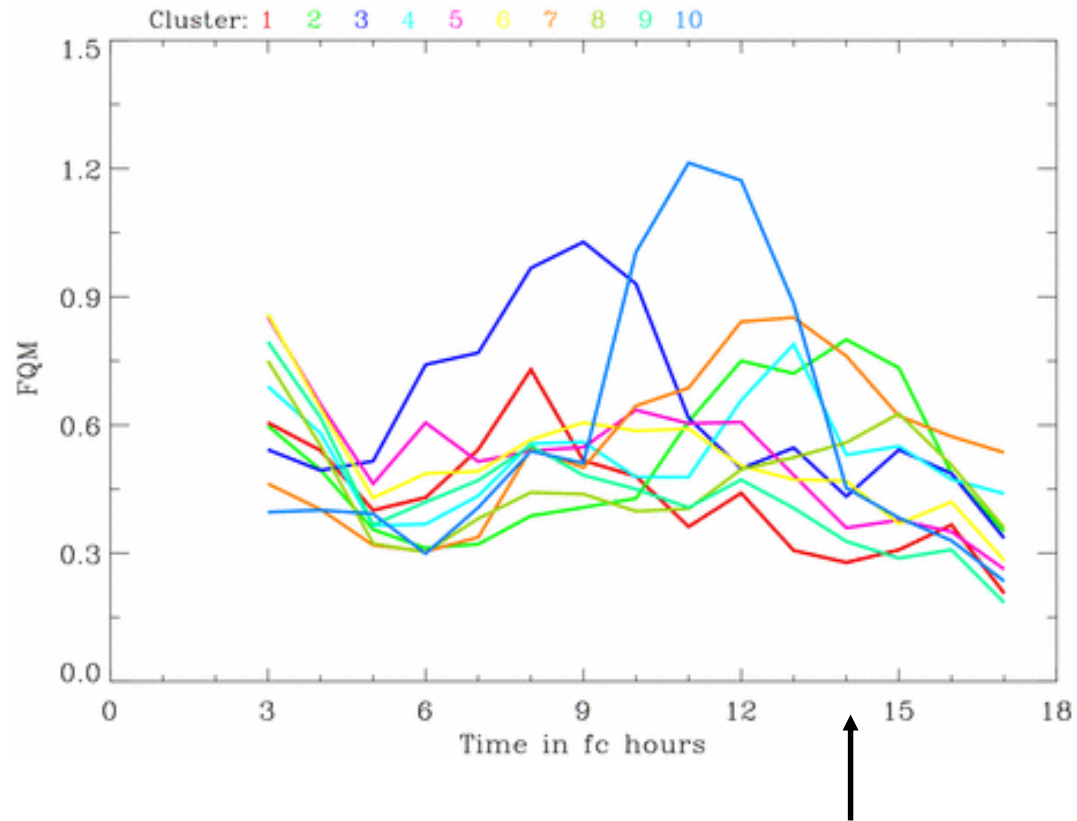
29 June 2005

Radar 18:00 UTC

LMK: all 10 clusters

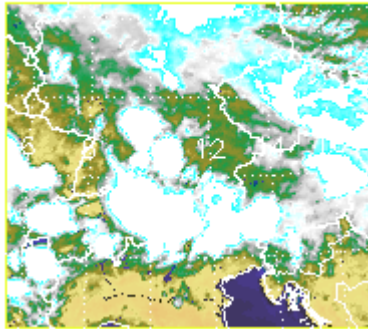


# Forecast Quality of LMK based on Radar data



29 June 2005

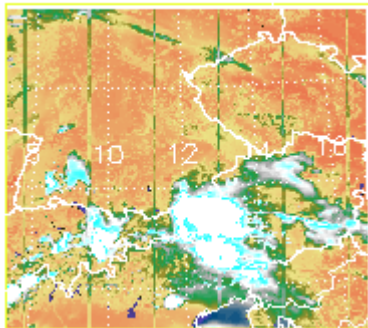
BT IR\_10.8 METS 2005062900 12 UTC



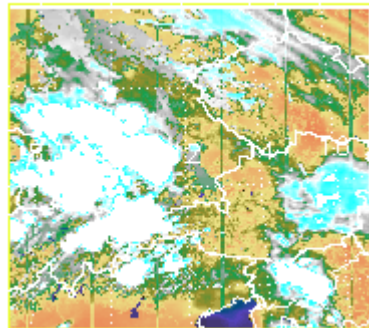
# Meteosat 8 IR10.8 12:00 UTC

## LMK: all 10 clusters

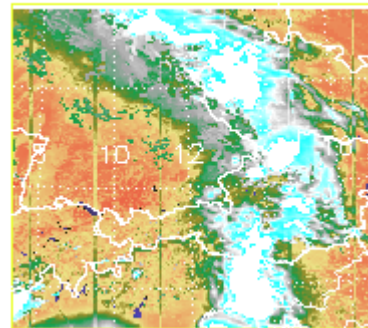
BT IR LMK fc 2005062906 +0600h



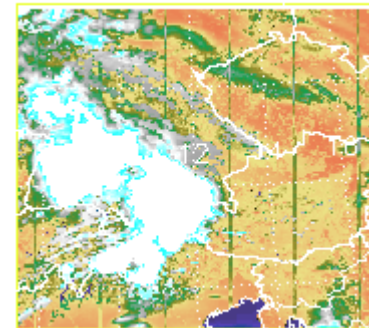
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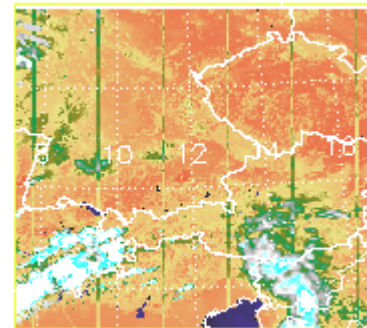
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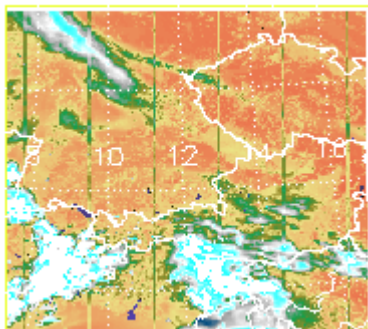
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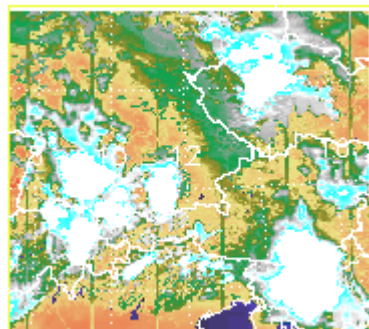
BT IR LMK fc 2005062906 +0600h



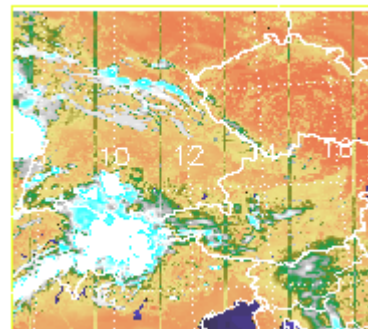
BT IR LMK fc 2005062906 +0600h



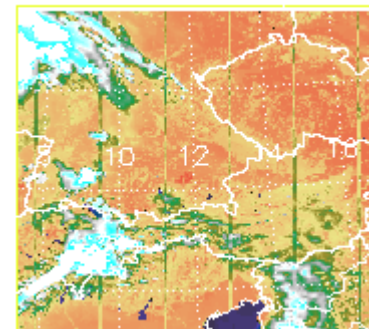
BT IR LMK fc 2005062906 +0600h



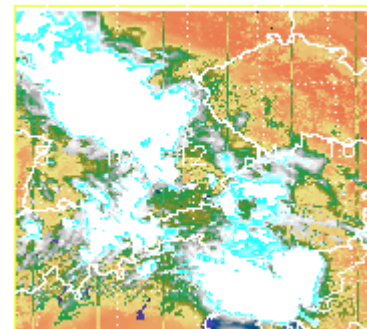
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BT IR LMK fc 2005062906 +0600h

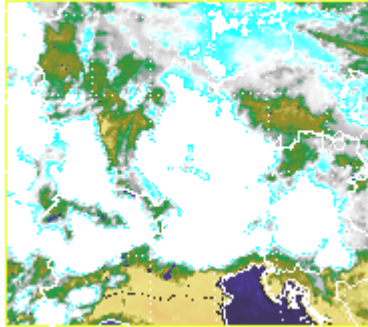


BT IR LMK fc 2005062906 +0600h



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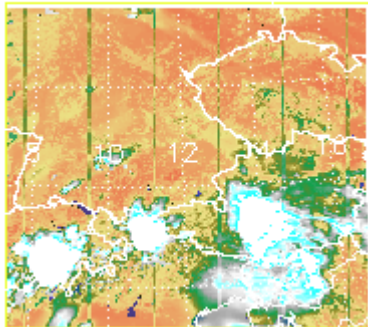
BT IR\_10.8 METS 2005062900 14 UTC



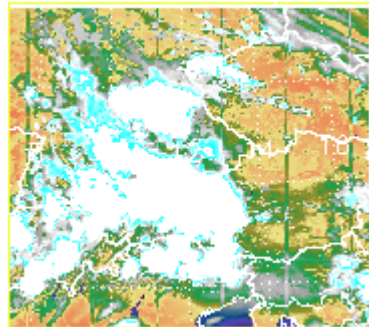
# Meteosat 8 IR10.8 14:00 UTC

## LMK: all 10 clusters

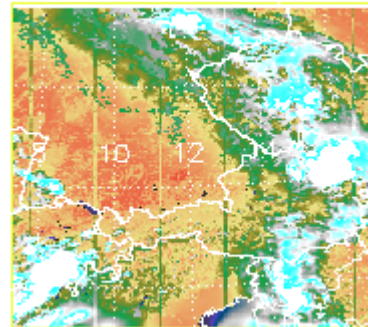
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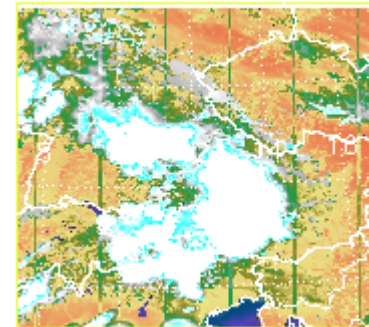
BT IR LMK fc 2005062906 +0600h



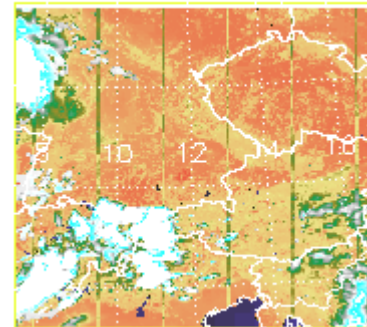
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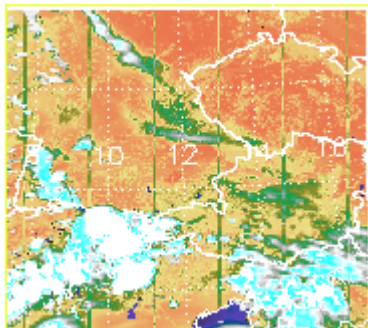
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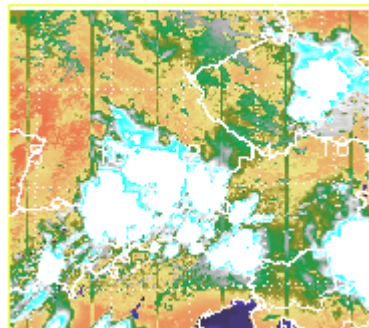
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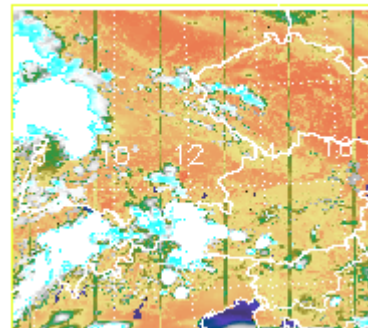
BT IR LMK fc 2005062906 +0600h



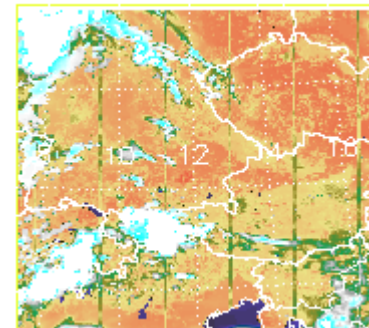
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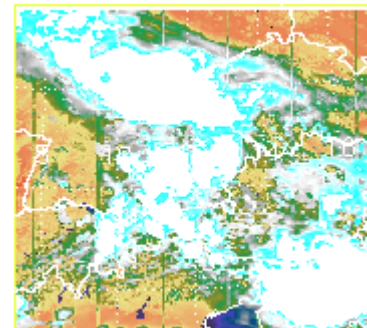
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BT IR LMK fc 2005062906 +0600h

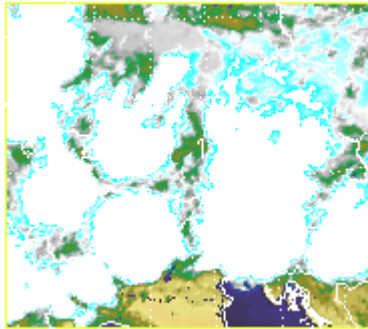


BT IR LMK fc 2005062906 +0600h



29 June 2005

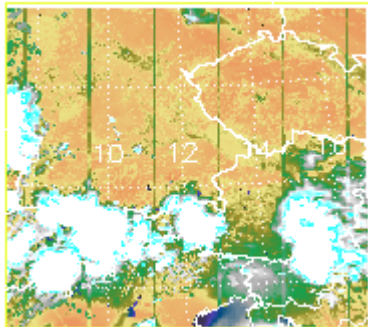
BT IR\_108 MET8 2005062906 16 UTC



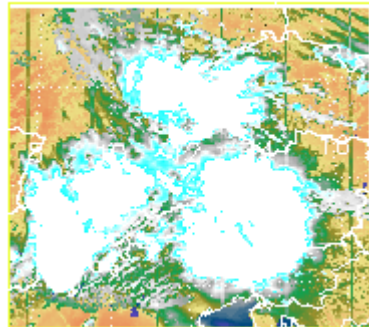
# Meteosat 8 IR10.8 16:00 UTC

## LMK: all 10 clusters

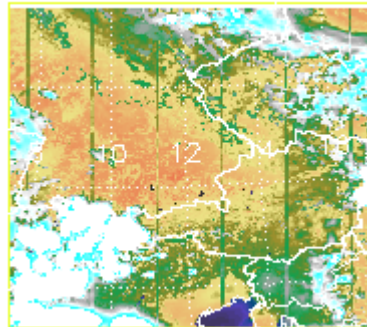
BT IR LMK fc 2005062906 +1000h



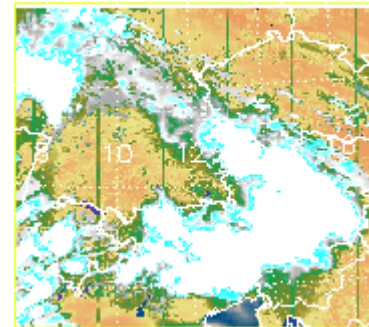
BT IR LMK fc 2005062906 +1000h



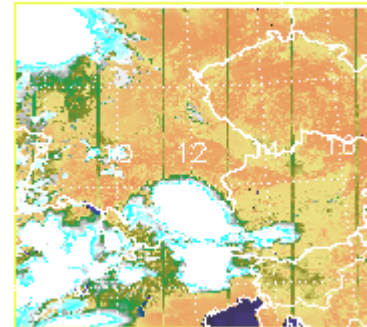
BT IR LMK fc 2005062906 +1000h



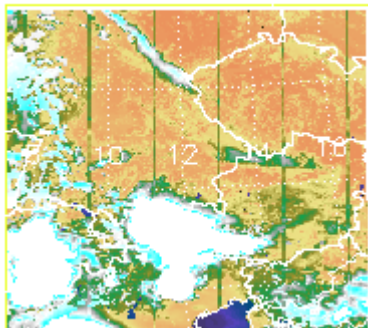
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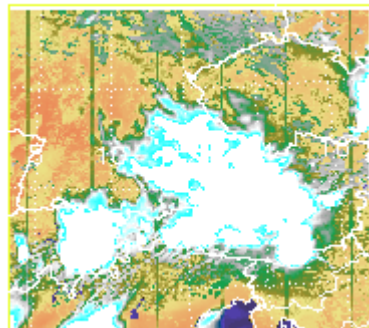
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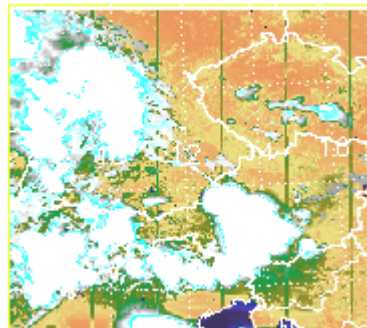
BT IR LMK fc 2005062906 +1000h



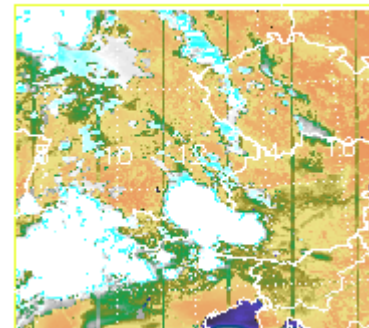
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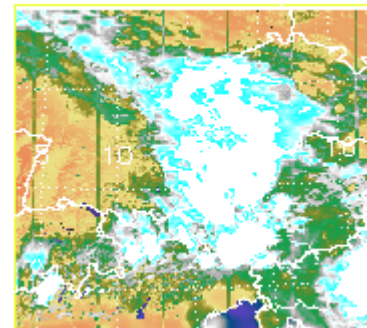
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BT IR LMK fc 2005062906 +1000h

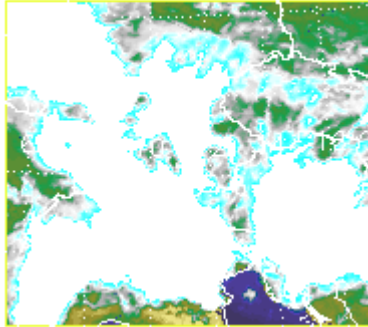


BT IR LMK fc 2005062906 +1000h



29 June 2005

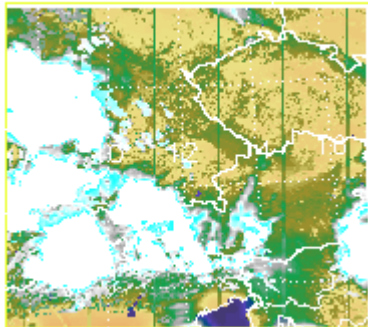
BT IR\_10.8 METS 2005062900 18 UTC



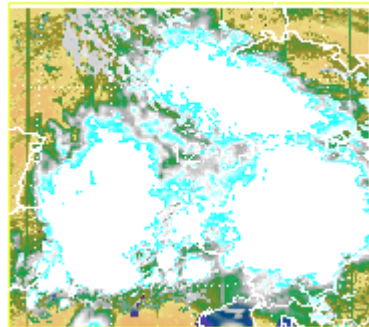
# Meteosat 8 IR10.8 18:00 UTC

## LMK: all 10 clusters

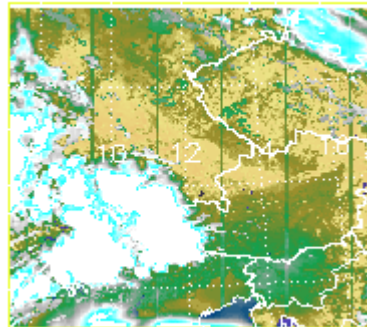
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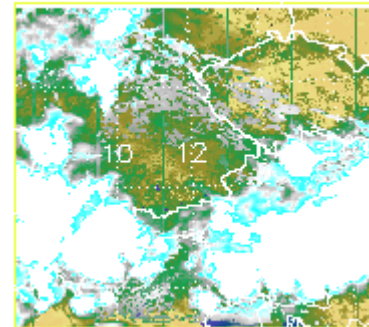
BT IR LMK fc 2005062906 +1200h



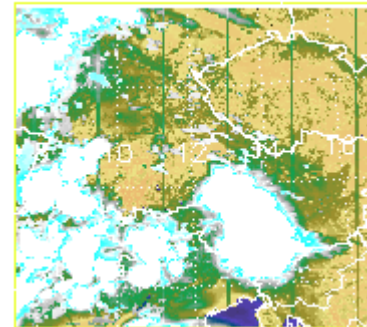
BT IR LMK fc 2005062906 +1200h



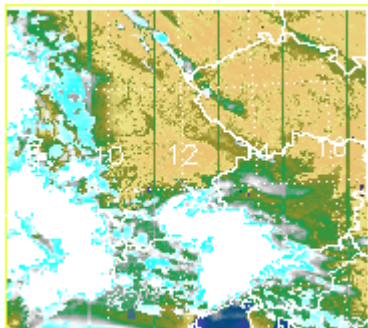
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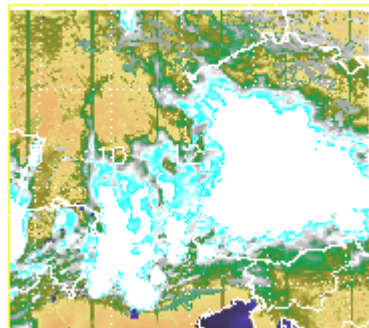
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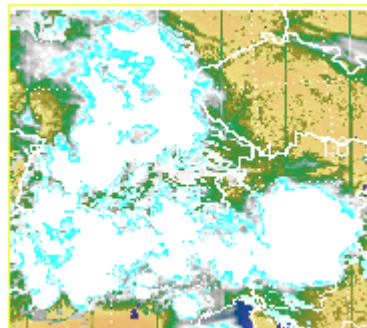
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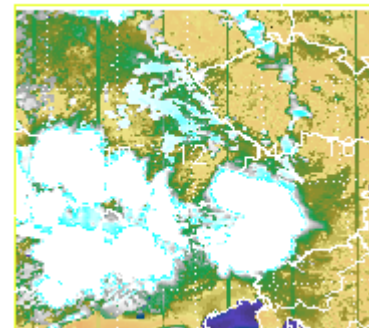
BT IR LMK fc 2005062906 +1200h



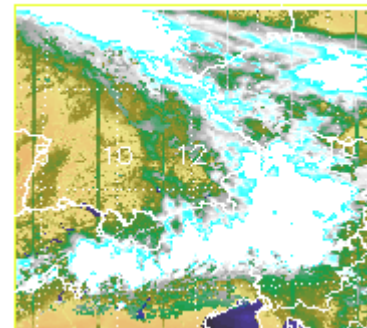
BT IR LMK fc 2005062906 +1200h



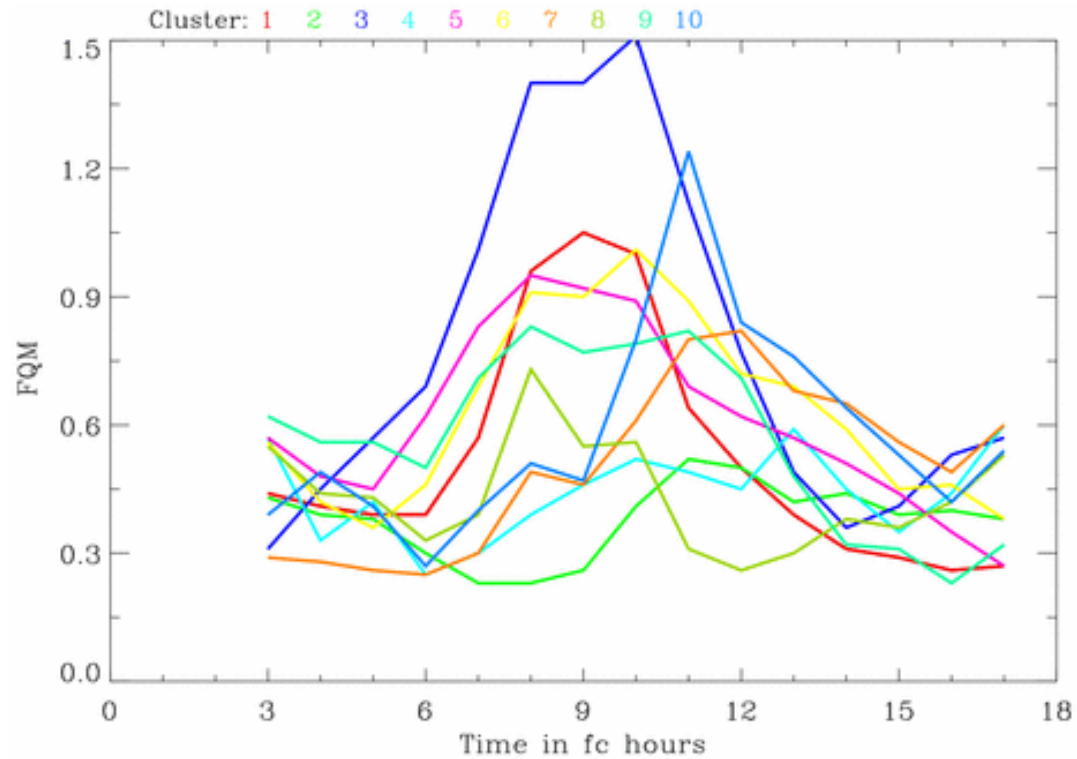
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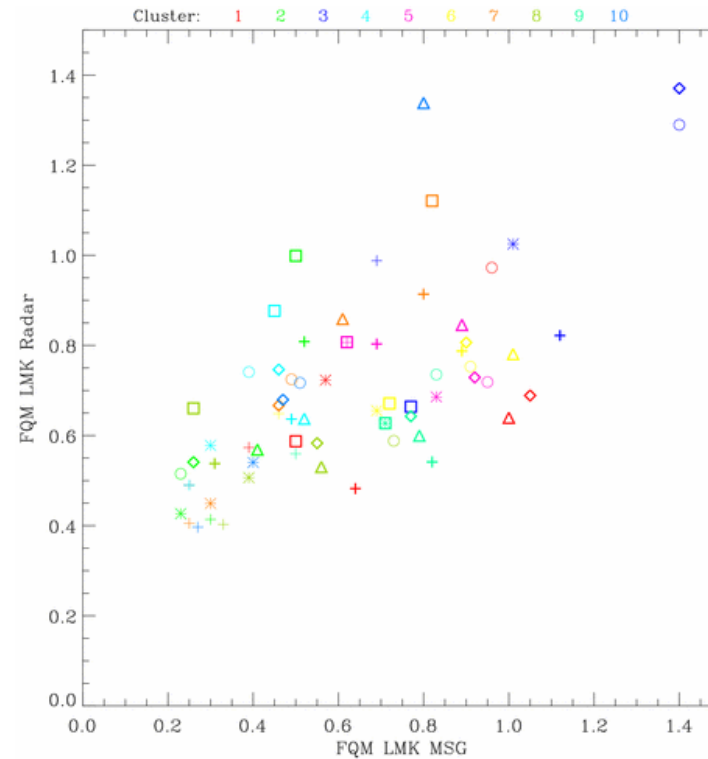
BT IR LMK fc 2005062906 +1200h



# Forecast Quality of LMK based on Satellite data

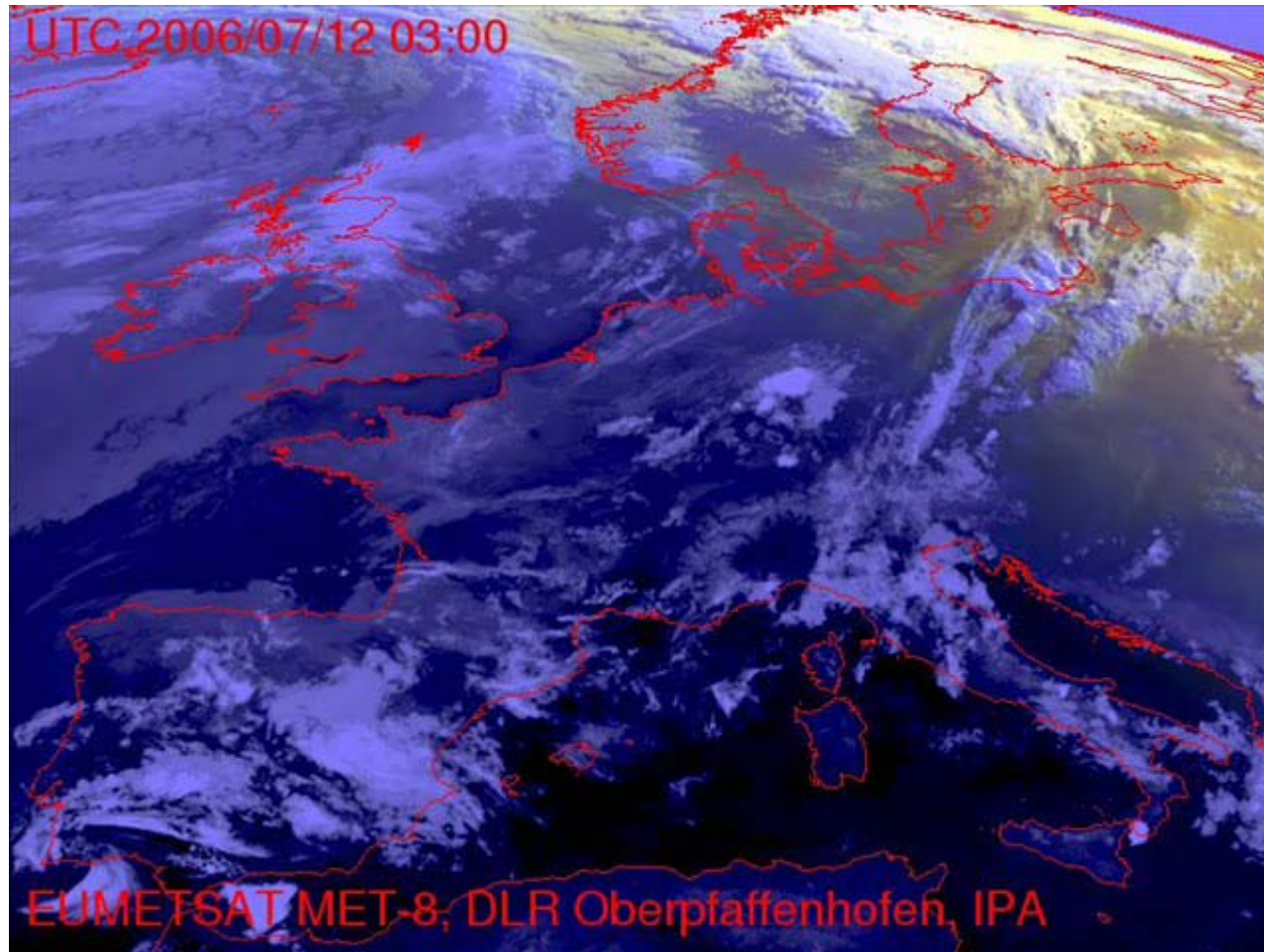


# Forecast Quality of LMK based on Satellite vs Radar data



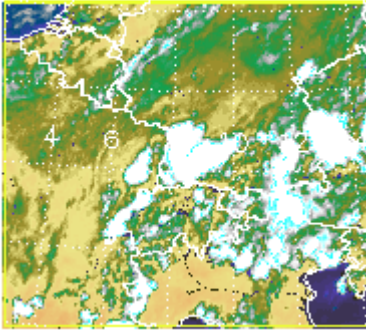
Correlation FQM(MSG vs Radar) = 0.73

# PRINCE case : 12 July 2006



# PRINCE: 12 July 2006

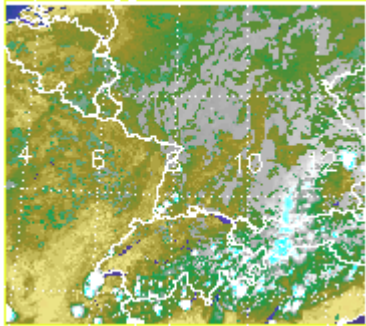
BT IR\_108 MET8 2006071200 12 UTC



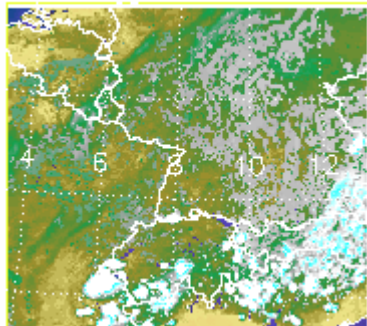
## Meteosat 8 IR10.8 12:00 UTC

# LMK

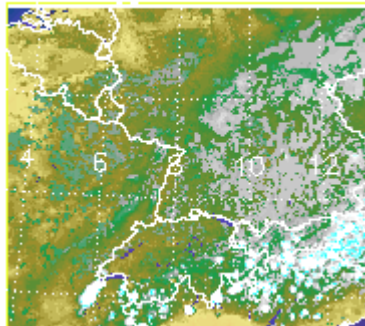
BT IR LMK fc 2006071206 +0600h



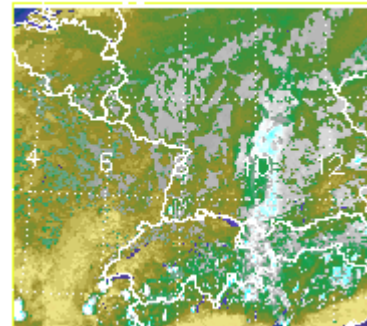
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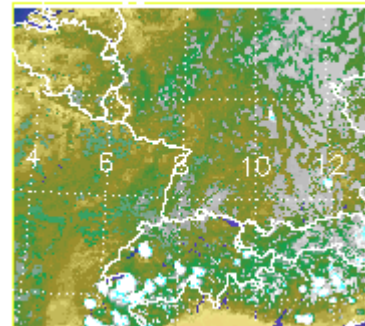
BT IR LMK fc 2006071206 +0600h



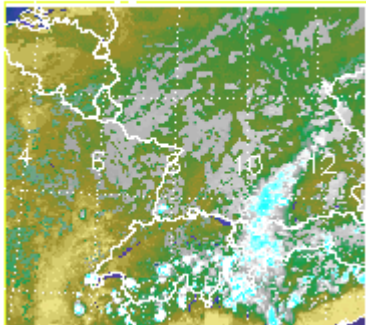
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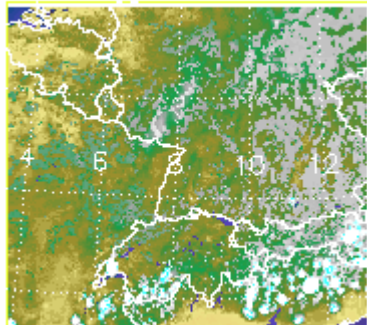
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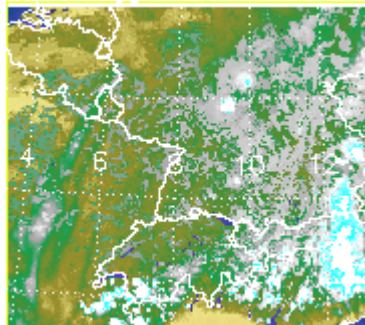
BT IR LMK fc 2006071206 +0600h



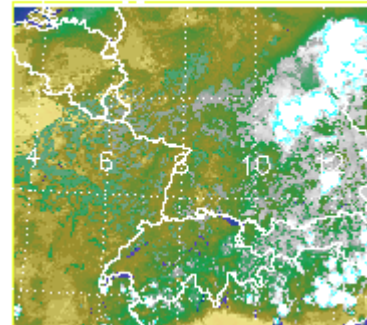
BT IR LMK fc 2006071206 +0600h



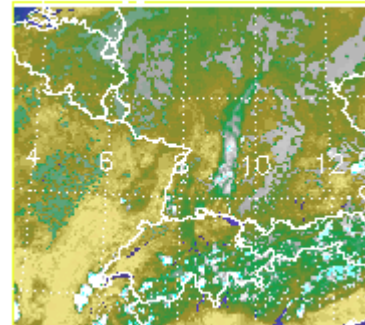
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BT IR LMK fc 2006071206 +0600h

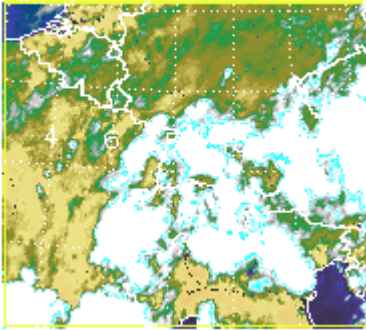


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# PRINCE: 12 July 2006

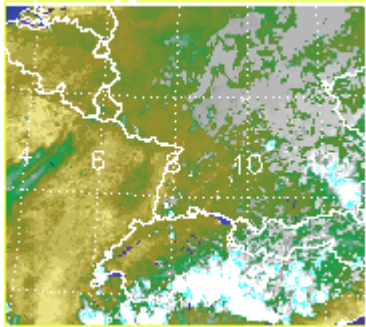
BT IR\_108 MET8 2006071200 15 UTC



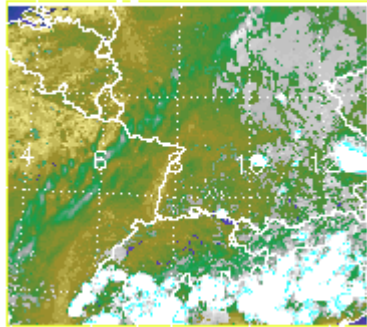
## Meteosat 8 IR10.8 15:00 UTC

# LMK

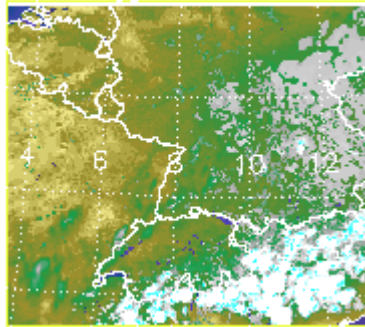
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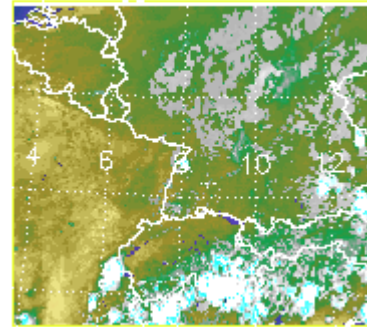
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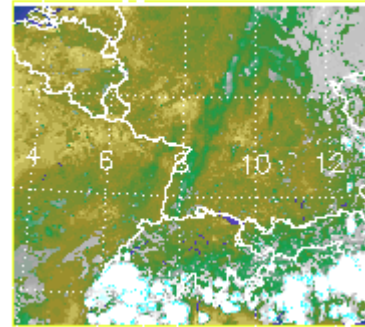
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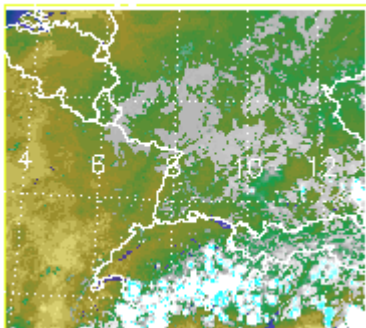
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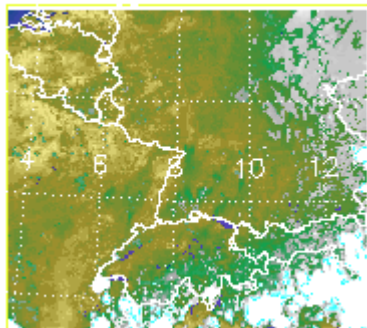
BT IR LMK fc 2006071206 +0900h



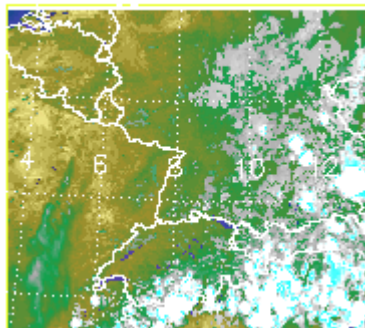
BT IR LMK fc 2006071206 +0900h



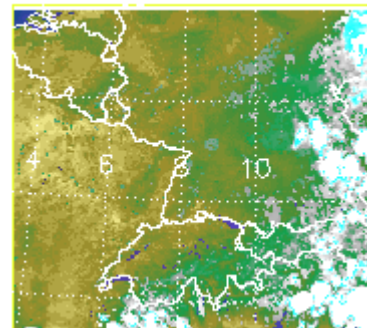
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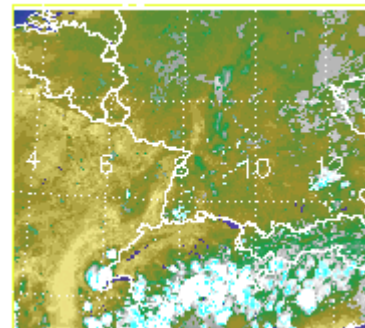
BT IR LMK fc 2006071206 +0900h



BT IR LMK fc 2006071206 +0900h

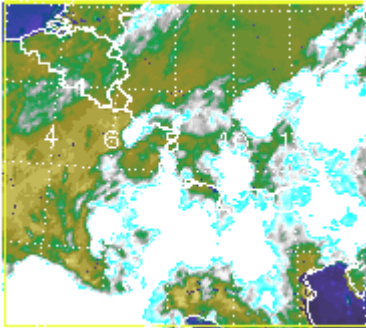


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# PRINCE: 12 July 2006

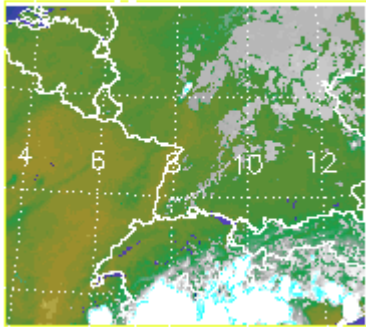
BT IR\_106 MET8 2006071200 18 UTC



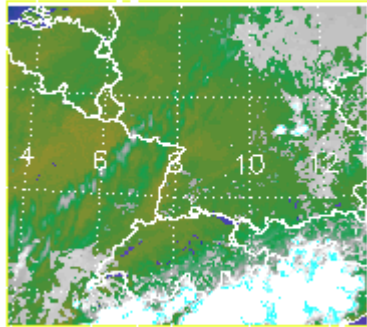
## Meteosat 8 IR10.8 18:00 UTC

# LMK

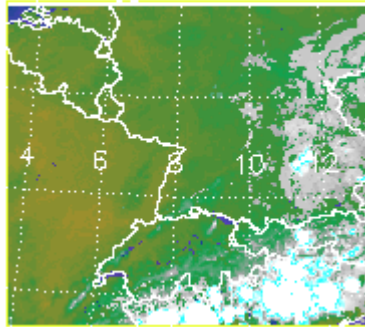
BT IR LMK fc 2006071206 +1200h



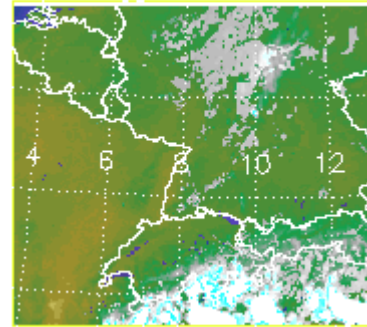
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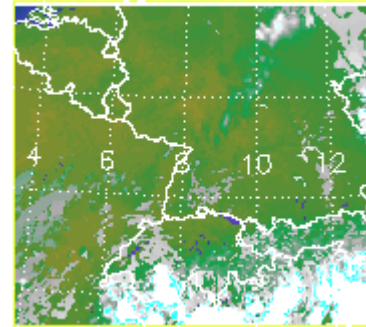
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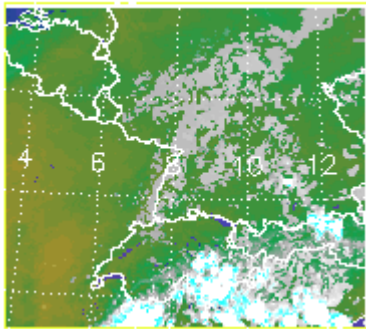
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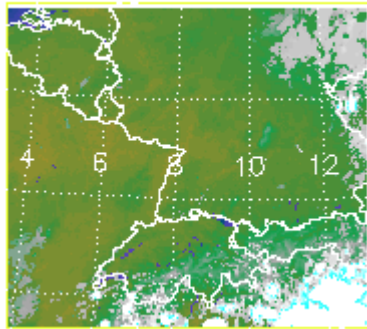
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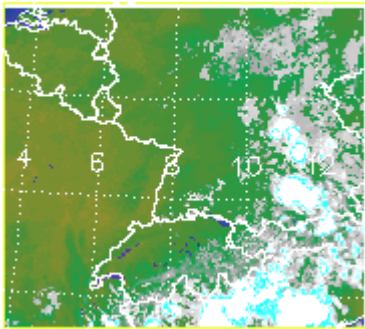
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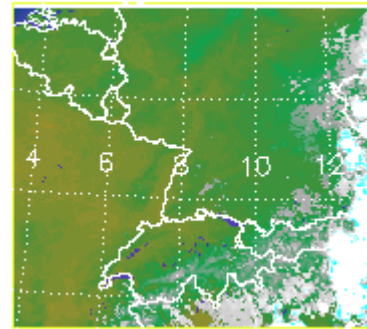
BT IR LMK fc 2006071206 +1200h



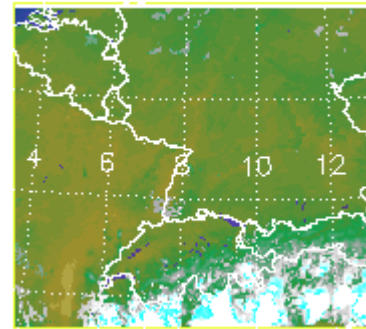
BT IR LMK fc 2006071206 +1200h



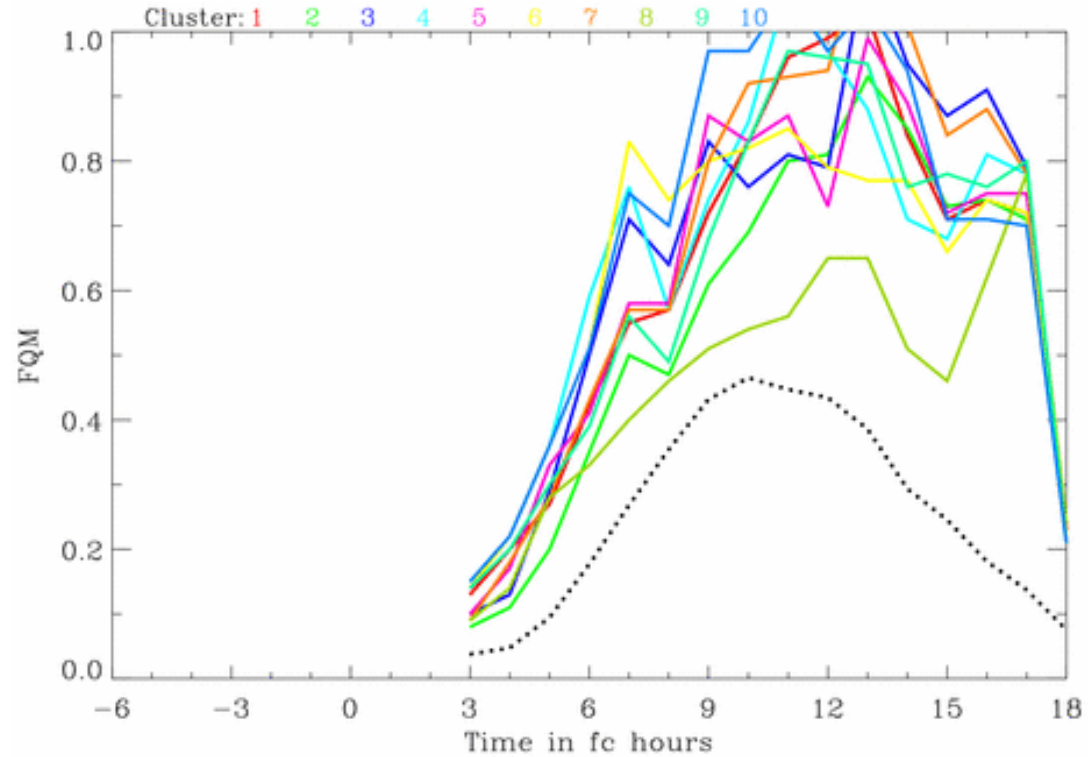
BT IR LMK fc 2006071206 +1200h



BT IR LMK fc 2006071206 +1200h



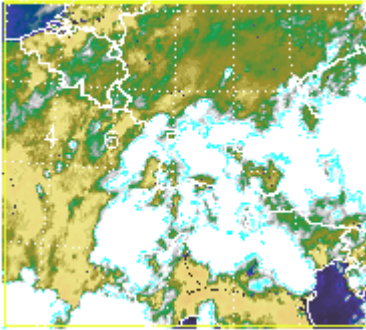
# PRINCE: 12 July 2006



Met8 cloudiness

# PRINCE: 12 July 2006

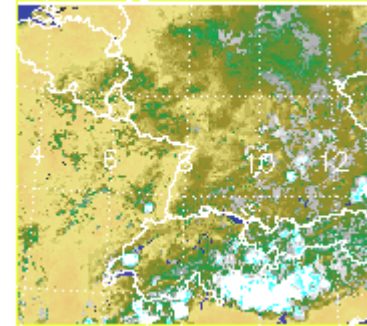
BT IR\_108 MET8 2006071200 15 UTC



## Meteosat 8 IR10.8 15:00 UTC

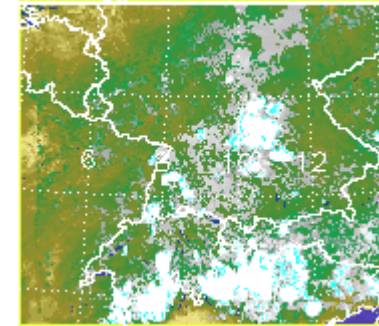
DWD

BT IR LMK fc 2006071200 +1500h

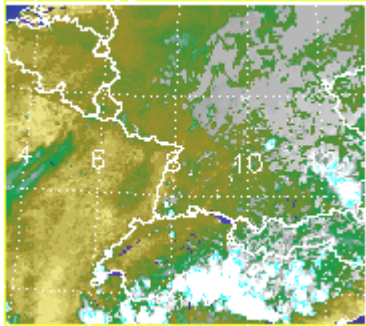


Uni Mainz

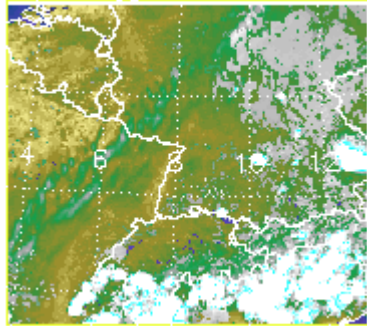
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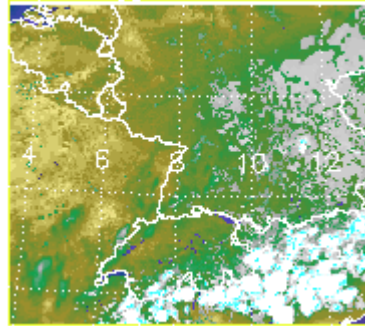
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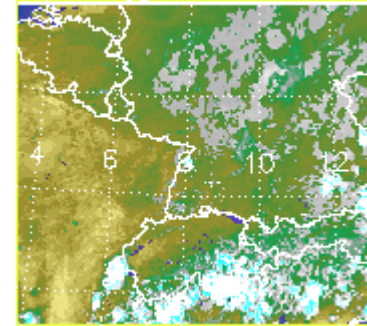
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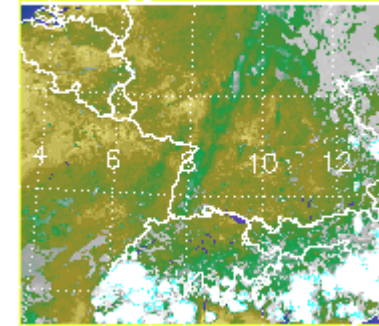
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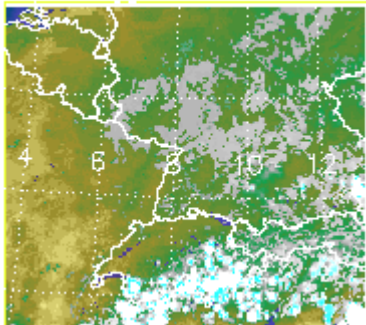
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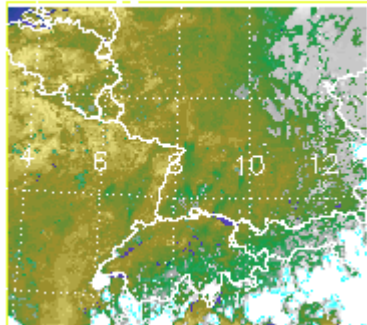
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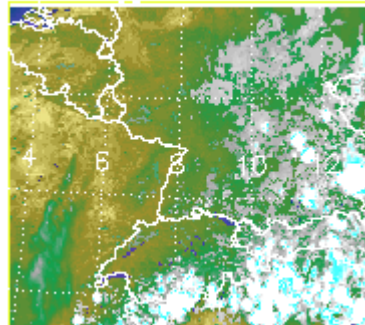
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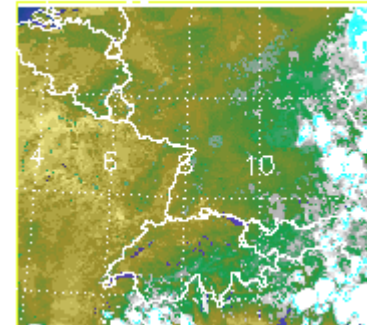
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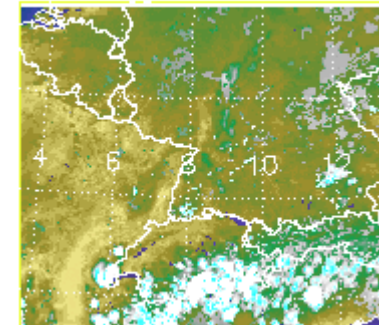
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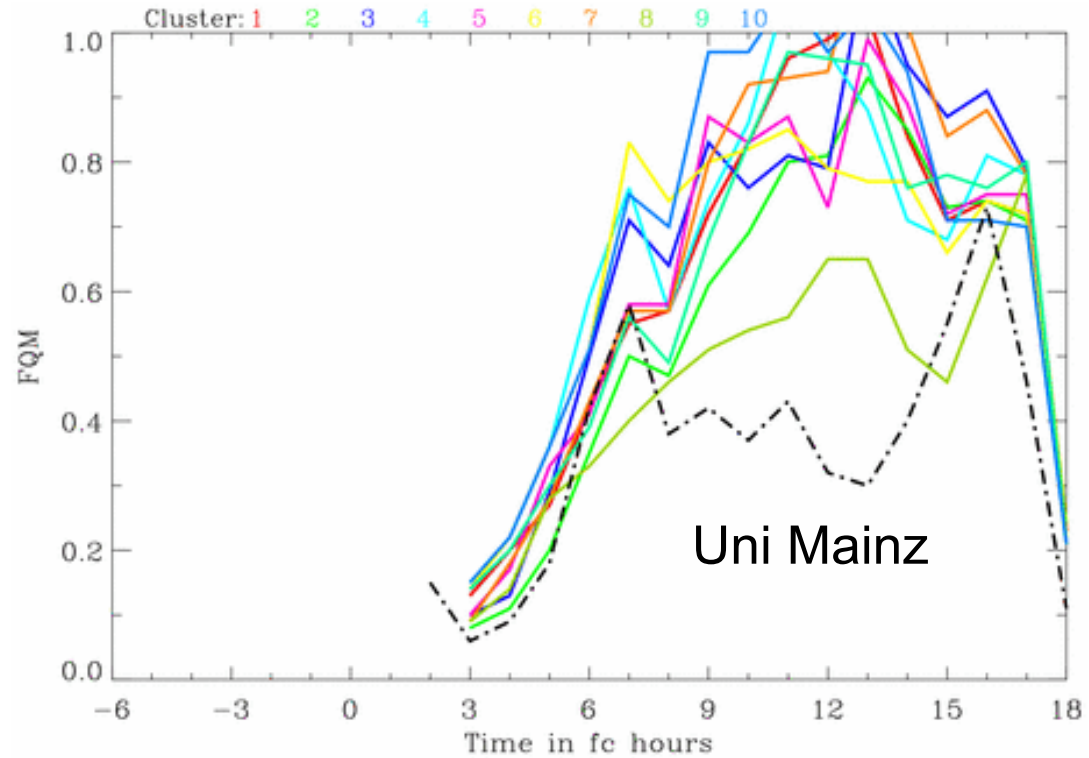
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BT IR LMK fc 2006071206 +0900h



# PRINCE: 12 July 2006



# Summary, conclusions and outlook

- The novel Forecast Quality Measure allows an objective evaluation based on image comparison.

Keil, C. and G. C. Craig, 2007: A Displacement-based Error Measure applied in a Regional Ensemble Forecasting System, *Mon. Wea. Rev.*, accepted.

- Comparison of Regional Ensemble Forecasts with Radar and Satellite data provides consistent results.
- Systematic evaluation planned during COPS/D-PHASE in 2007
- Radar rainfall assimilation experiments in selected members which are favourable for convection (in collaboration with MeteoSwiss)