LPI (Lightning Potential Index) derived from COSMO-DE fields

Ulrich Blahak (DWD)

Concept of the LPI

- Yair et al. (JGR, 2010), Lynn and Yair (Adv. Geosci., 2010)
- Charge separation in thunderstorms is correllated with the simultaneous presence of updrafts, supercoolded liquid water, graupel and other frozen hydrometeor types („cloud ice“, „snow“)
- This concept was modeled by the authors within the LPI-Index. In some details **the original literature is unclear. My interpretation is:**

$$\mathrm{LPI} = f_1 \, f_2 \, \frac{1}{H_{-20°\mathrm{C}} - H_{0°\mathrm{C}}} \int_{H_{0°\mathrm{C}}}^{H_{-20°\mathrm{C}}} \epsilon \, w^2 \, g_{(w)} \, dz$$

$$\epsilon = \frac{2\sqrt{q_L \, q_F}}{q_L + q_F}$$

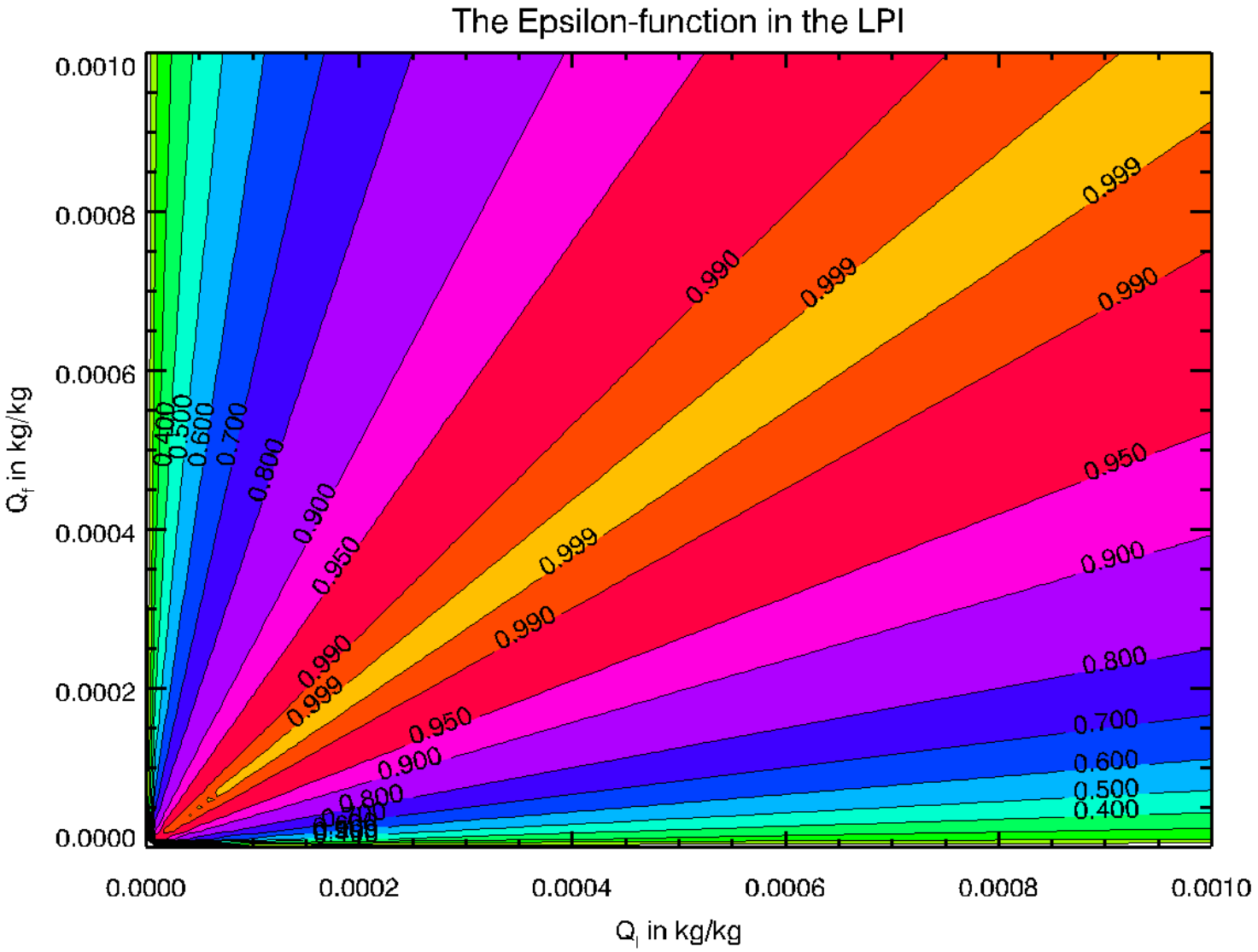
$$q_L = q_c + q_r$$

$$q_F = \frac{q_g}{2}\left[\frac{2\sqrt{q_i \, q_g}}{q_i + q_g} + \frac{2\sqrt{q_s \, q_g}}{q_s + q_g}\right]$$

f_1, f_2 and g(w) see next-next slide!

Concept of the LPI: ε

➔ **Function ε:**



Concept of the LPI: f_1, f_2 and g(w)

➔ Filter functions f_1, f_2 and g:

$$\mathrm{LPI} = f_1 \, f_2 \, \frac{1}{H_{-20°\mathrm{C}} - H_{0°\mathrm{C}}} \int_{H_{0°\mathrm{C}}}^{H_{-20°\mathrm{C}}} \epsilon \, w^2 \, g_{(w)} \, dz$$

$$f_1 = \begin{cases} 1 & a \geq 0.5 \\ 0 & \text{sonst} \end{cases}$$

$$a = \frac{\iint \begin{cases} 1 & \max[w(z)] \geq w_{max,0} \\ 0 & \text{else} \end{cases} dx\,dy}{\iint dx\,dy}$$

$$f_2 = \begin{cases} 1 & B_{ML} \geq B_0 \\ 0 & \text{sonst} \end{cases}$$

$$B_{ML} = \frac{\iint \int_{p_s - 550\mathrm{hPa}}^{p_s - 50\mathrm{hPa}} R_d \, (T_{v,parcel} - T_{v,u}) \, d \ln p \, dx\,dy}{\iint dx\,dy}$$

$$g = \begin{cases} 1 & w \geq 0.5\,\mathrm{m\,s^{-1}} \\ 0 & \text{else} \end{cases}$$

Neighbourhood criterion 1, updraft based: majority of surroundings must have an updraft > $w_{max,0}$.
„Surroundings“: ~10 x 10 km²

Neighbourhood criterion 2, stability based: average of the vert. integrated buoyancy-term must be > B_0 .
Parcel: similar to mixed-layer CAPE (100 hPa layer)
„Surroundings“: ~20 x 20 km²

updraft filter within column

Concept of the LPI

➔ Investigated variants:

$$\mathrm{LPI}_1 = \frac{1}{H_{-20^\circ\mathrm{C}} - H_{0^\circ\mathrm{C}}} \int_{H_{0^\circ\mathrm{C}}}^{H_{-20^\circ\mathrm{C}}} \epsilon\, w^2\, dz$$

$$\mathrm{LPI}_2 = \frac{1}{H_{-20^\circ\mathrm{C}} - H_{0^\circ\mathrm{C}}} \int_{H_{0^\circ\mathrm{C}}}^{H_{-20^\circ\mathrm{C}}} \epsilon\, w^2\, g_{(w)}\, dz$$

$$\mathrm{LPI}_3 = f_1 f_2 \frac{1}{H_{-20^\circ\mathrm{C}} - H_{0^\circ\mathrm{C}}} \int_{H_{0^\circ\mathrm{C}}}^{H_{-20^\circ\mathrm{C}}} \epsilon\, w^2\, dz$$

$$\mathrm{LPI}_4 = f_1 f_2 \frac{1}{H_{-20^\circ\mathrm{C}} - H_{0^\circ\mathrm{C}}} \int_{H_{0^\circ\mathrm{C}}}^{H_{-20^\circ\mathrm{C}}} \epsilon\, w^2\, g_{(w)}\, dz$$

A first test using COSMO-DE

- Time period: 28.7. – 16.8. 2014
- Hourly computation of the LPI based on COSMO-DE operational forecast data from DWD data base with the help of an IDL test program.
- 00 UTC run up to +11 h and 12 UTC run up to + 11 h combined to a continuous hourly data set.
- Comparison to LINET data (total lightning) in COSMO-DE resolution (data provided by K. Wapler, DWD). Because „it had to go fast“, the data were only available on a smaller domain (KONRAD domain).
  Computation of the **time averaged flash rate +-15 min around the date** in the unit 1 / (km^2 min). **NOTE: depends on the grid spacing!**
- **Only f_1** could be tested, because B_{MF} is not in data base. For **f_2** it is assumed that it has no effect during this period. **The parameter $w_{max,0}$ has been varied** to determine the „best“ value **(which is resolution dependent!):**

  $w_{max,0}$ = 1.1 m/s

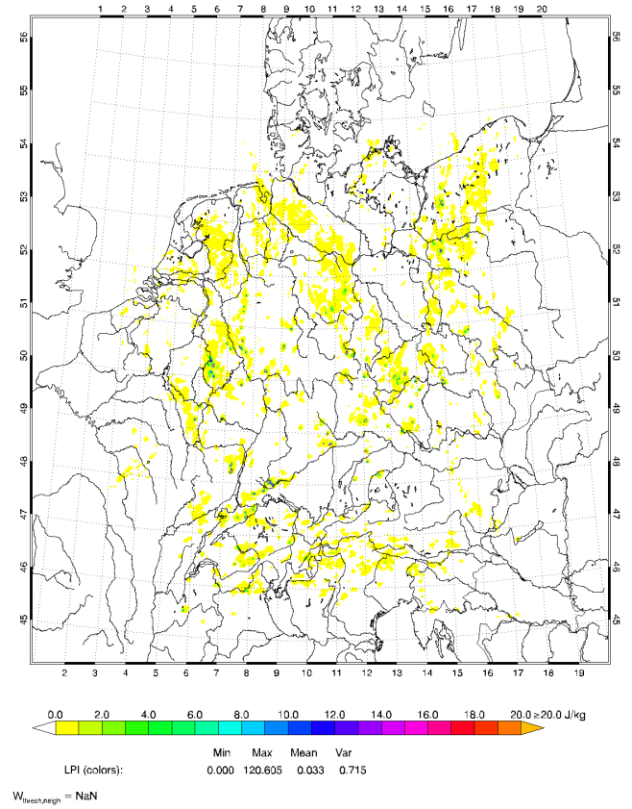
A first test using COSMO-DE

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

CDE-Routi: LPI_1

LPI COSMO-DE no neighbourhood crit.

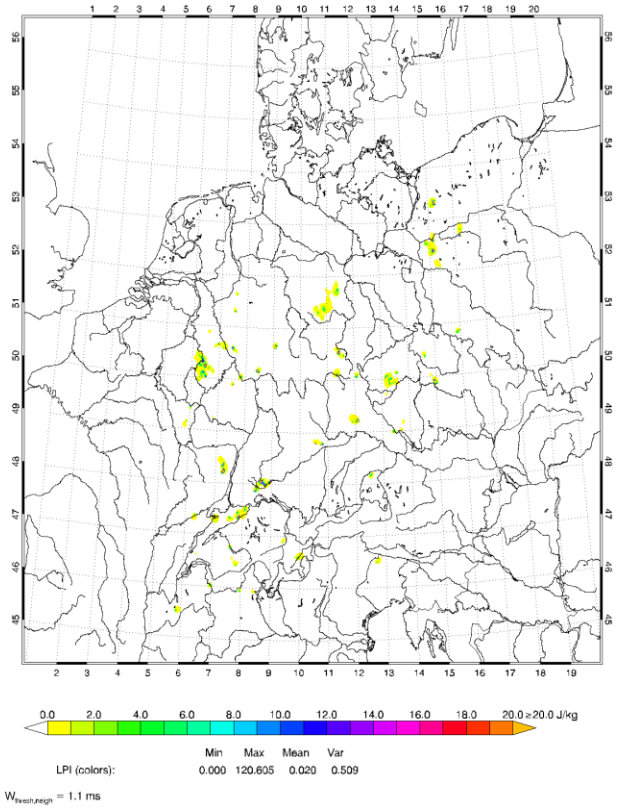
LPI 20140804120000 UTC +00020000



LPI_3 (without f_2)

LPI COSMO-DE neighbourhood crit.

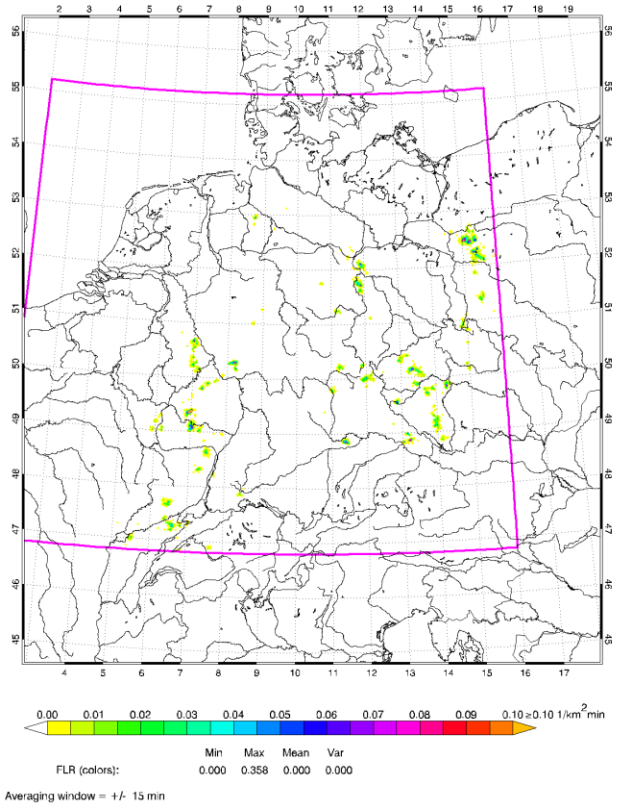
LPI 20140804120000 UTC +00020000



Obs LINET t +- 15 min

FLR +- 15 min LINET

FLR [1/km^{2}min] 20140804140000 UTC +/- 15 min

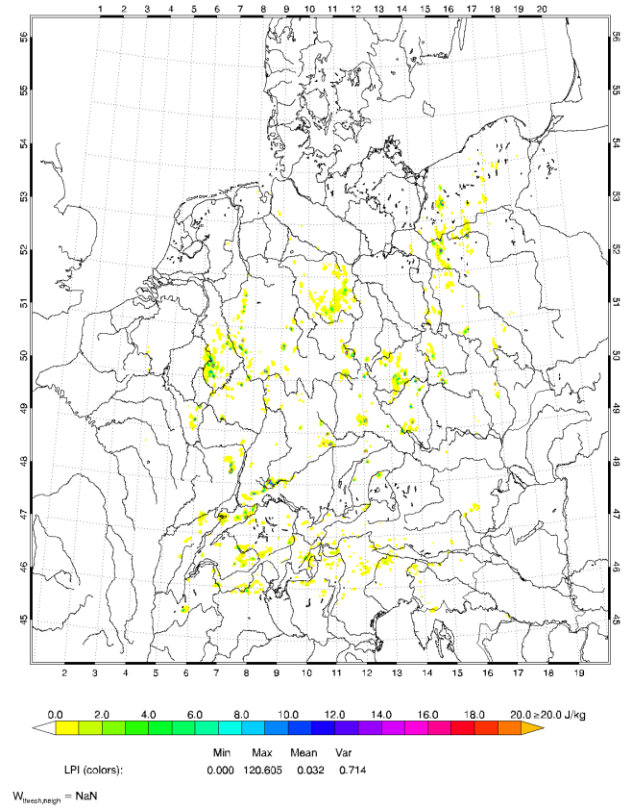


A first test using COSMO-DE

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

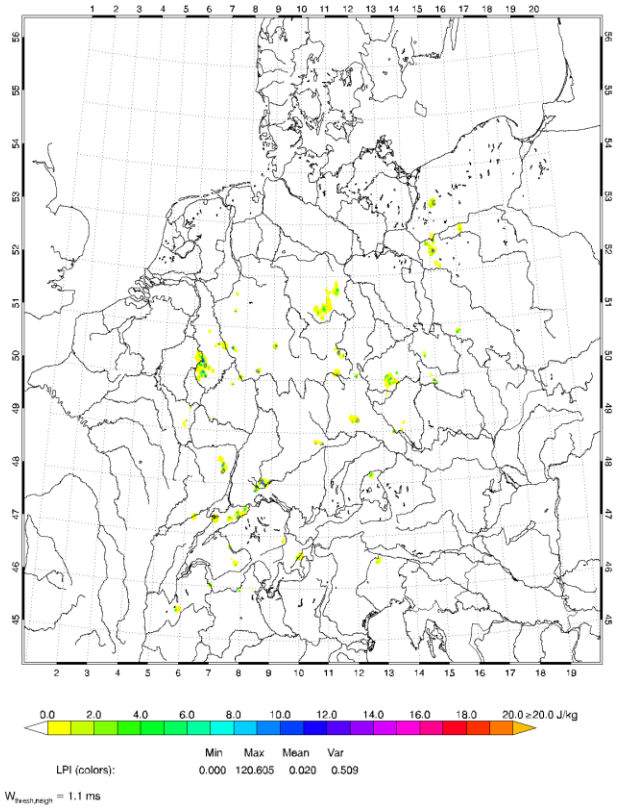
CDE-Routi: LPI_2

LPI COSMO-DE no neighbourhood crit.



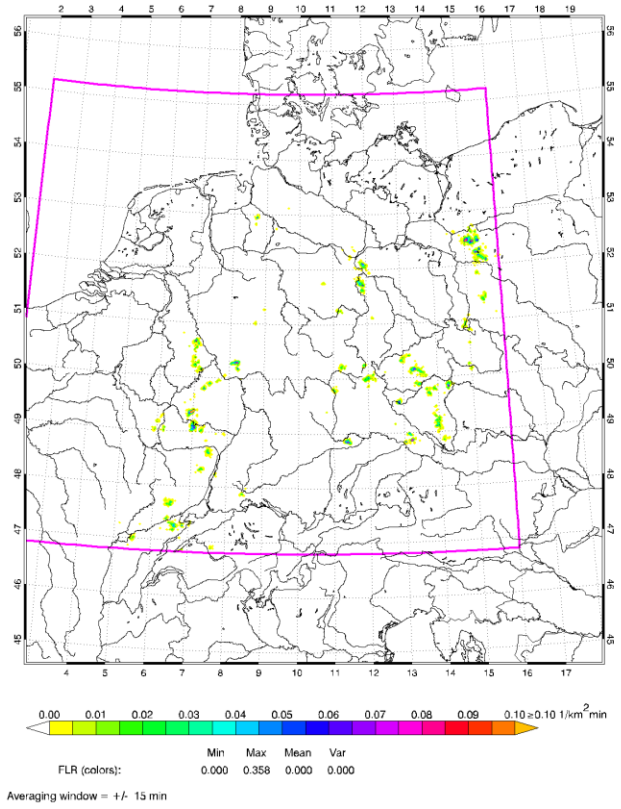
LPI_4 (without f_2)

LPI COSMO-DE neighbourhood crit.



Obs LINET t +- 15 min

FLR +- 15 min LINET

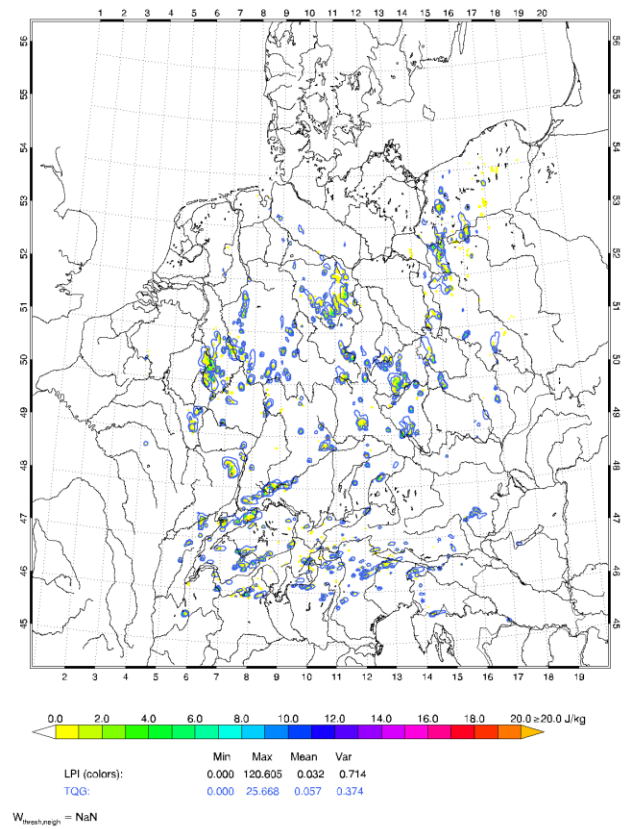


A first test using COSMO-DE

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

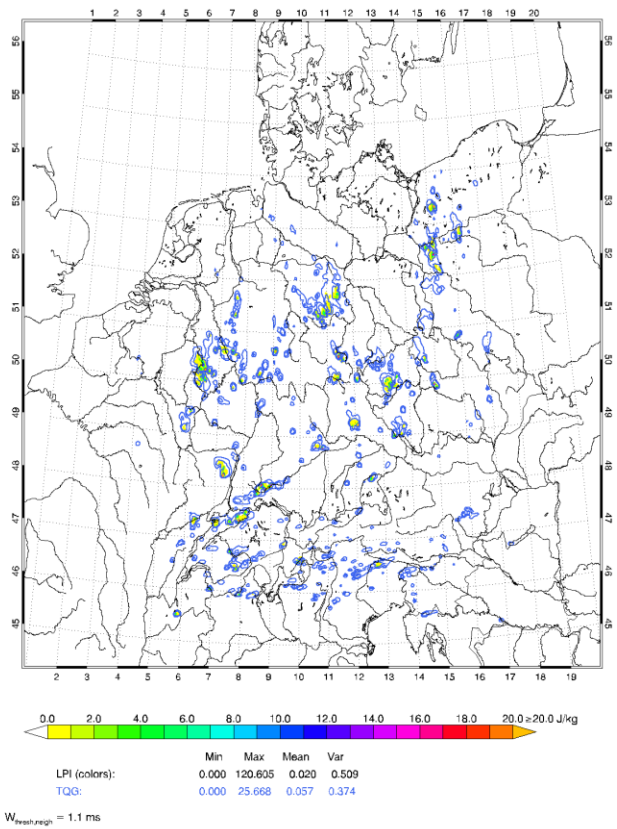
CDE-Routi: LPI_2 + TQG

LPI COSMO-DE no neighbourhood crit.



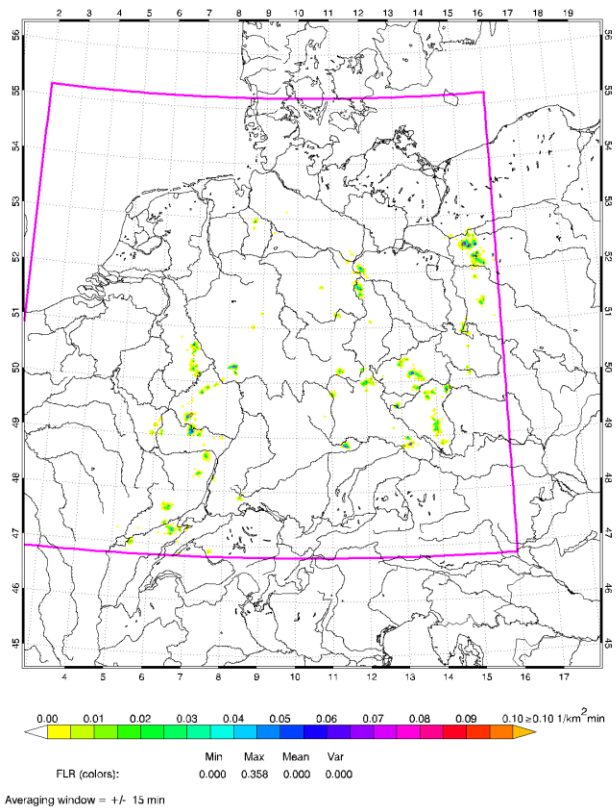
LPI_4 (without f_2) + TQG

LPI COSMO-DE neighbourhood crit.



Obs LINET t +- 15 min

FLR +- 15 min LINET

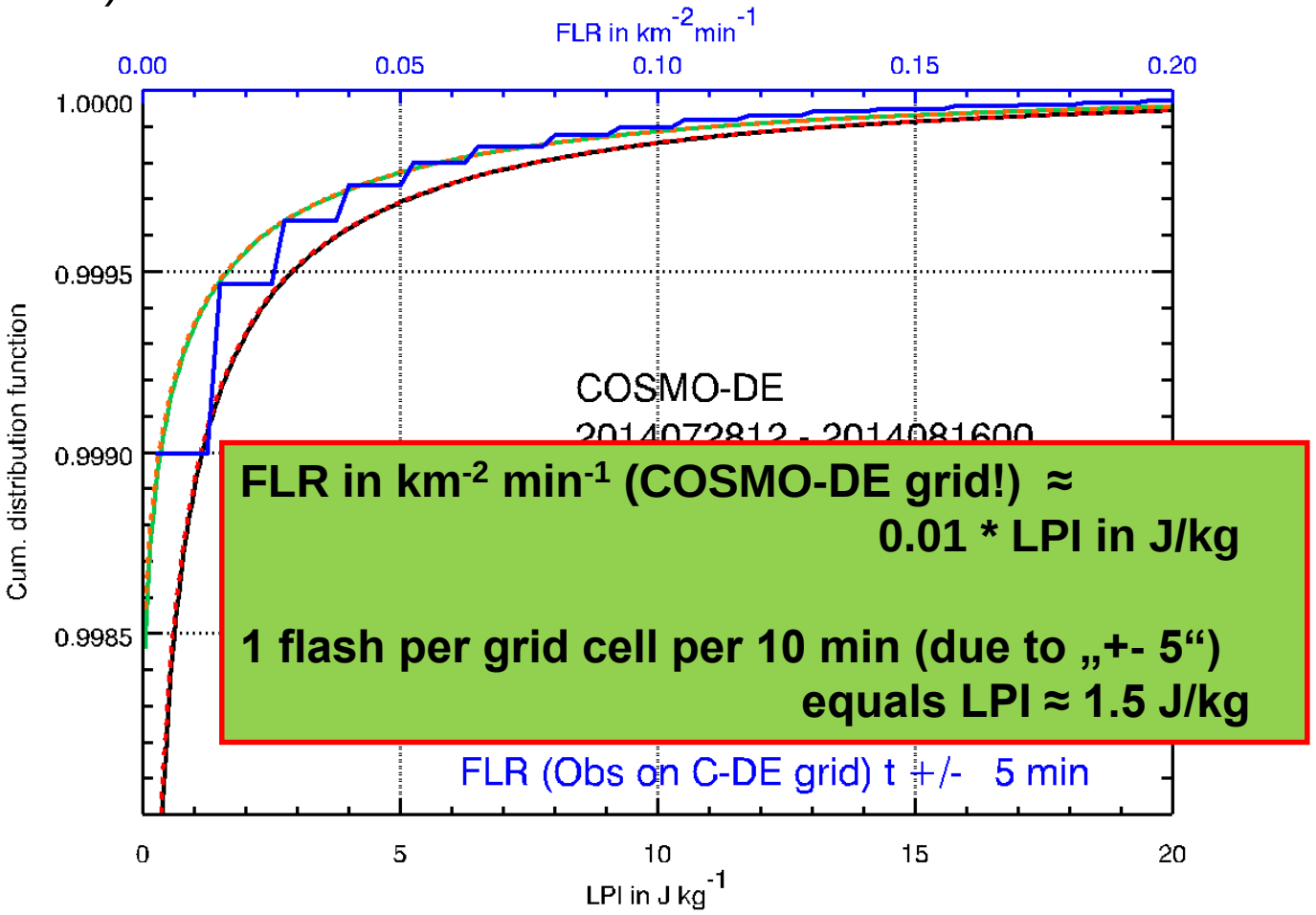


(TQG: Isolines 0.1 and 1.0 kg/m²)

A first test using COSMO-DE

➔ Cumulated space-time distribution function of the 3-weeks period (only KONRAD-domain):

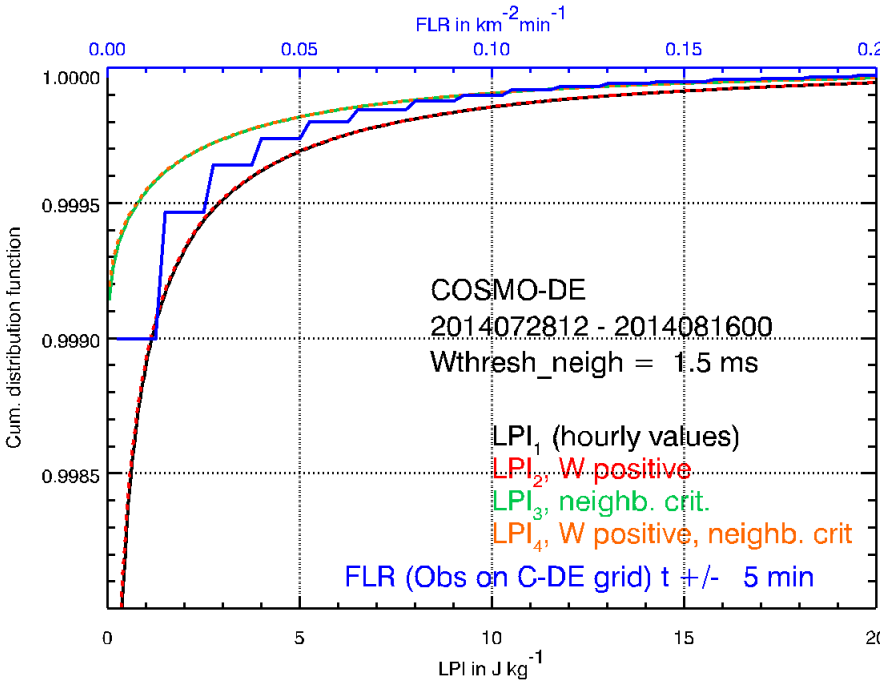
Relative scale of FLR to LPI „by eye“ in such a way, that it leads approximately to a constant factor.



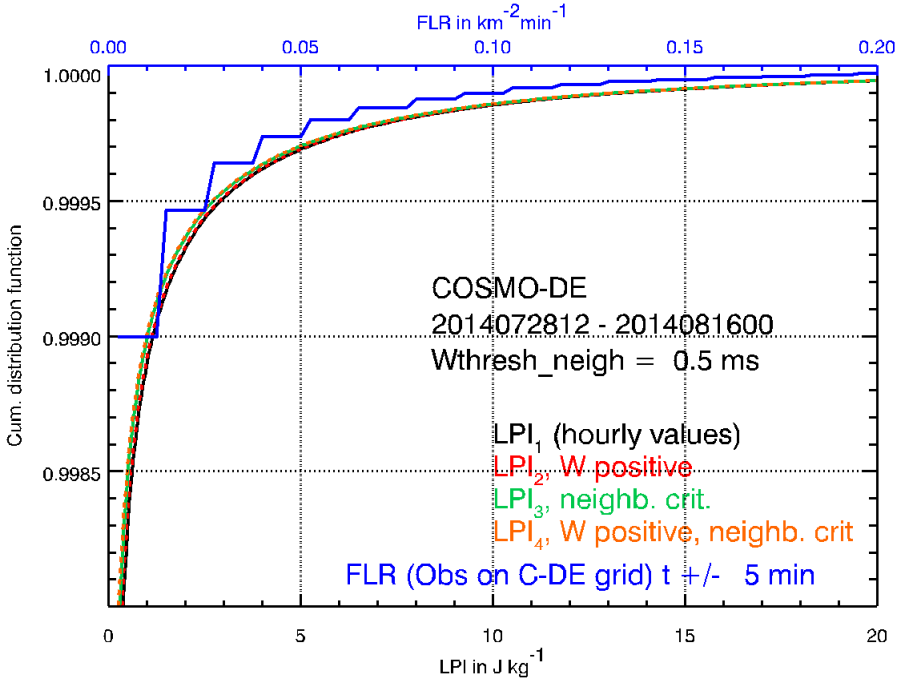
A first test using COSMO-DE

➔ Variation des $w_{max,0}$:

1.5 m/s



0.5 m/s

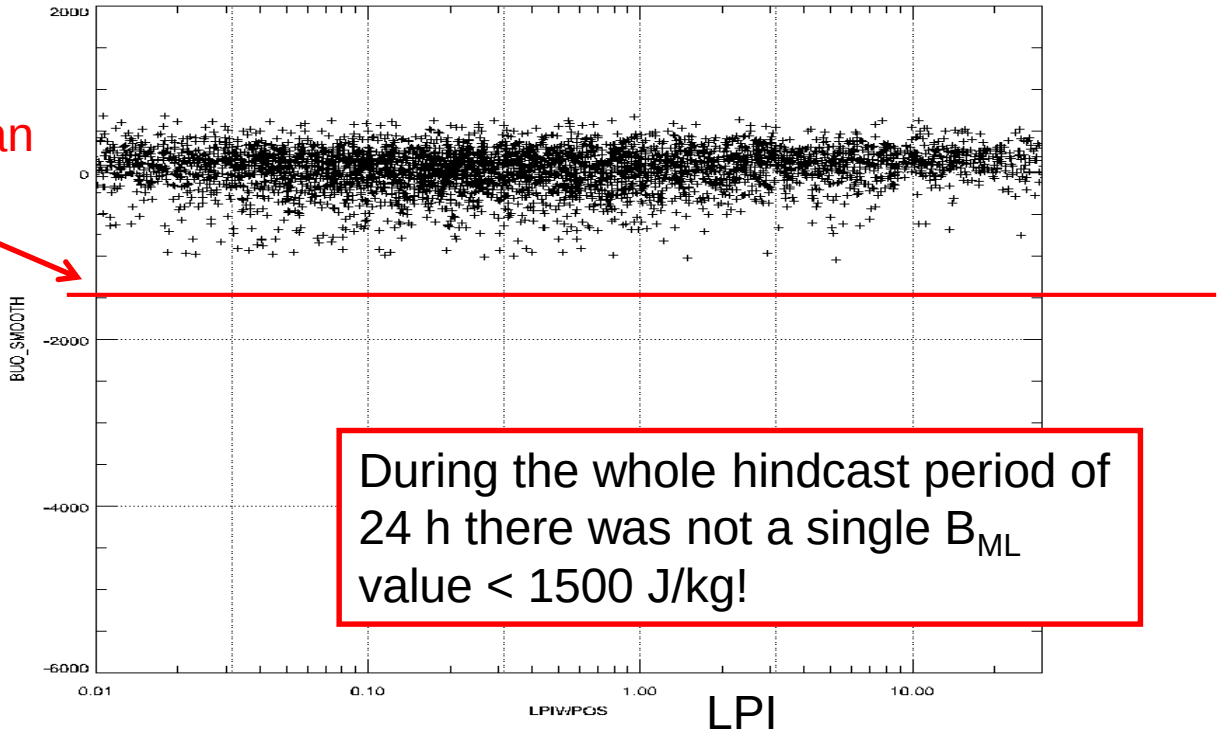


A first test using COSMO-DE

- What about the $B_{ML} > B_0$ criterion?
- It should not be relevant in this time period, because it was a convective period. **Example from a COSMO-DE Hindcast:**

2014080312 UTC + 02 h

B_0 = -1500 J/Kg (determined from an October case, see later)



B_{ML}

During the whole hindcast period of 24 h there was not a single B_{ML} value < 1500 J/kg!

A second test using COSMO-DE

- Time period: 6.10. – 23.10. 2014
- Hourly computation of the LPI based on COSMO-DE operational forecast data from DWD data base with the help of an IDL test program.
- 00 UTC run up to +11 h and 12 UTC run up to + 11 h combined to a continuous hourly data set.
- Comparison to LINET data (total lightning) in COSMO-DE resolution (data provided by K. Wapler, DWD). This time, we have data everywhere in the COSMO-DE domain.
  Computation of the **time averaged flash rate +-15 min around the date** in the unit 1 / (km^2 min). **NOTE: depends on the grid spacing!**
- **At first, still only f_1 filter possible.**
- **Concerning f_2 the 22.10.2014 was simulated as HINDCAST (newer model version, driven by analyses),** and **parameters $w_{max,0}$ and B_0 have been varied** to find their „best“ values **(model-, resolution dependent!)**:

  $w_{max,0}$ = 1.1 m/s **B_0 = -1500 J/kg**

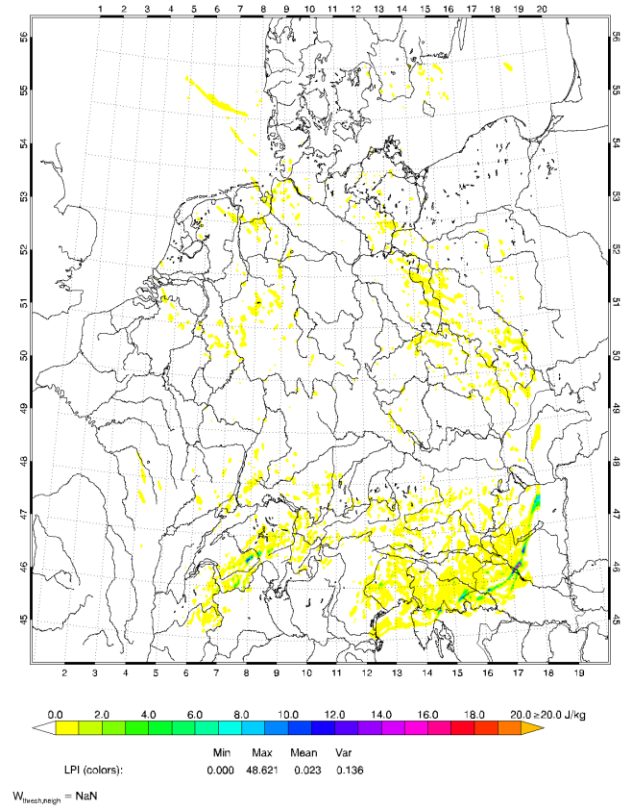
A second test using COSMO-DE

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

CDE-Routi: LPI_2 LPI_4 (without f_2) Obs LINET t +- 15 min

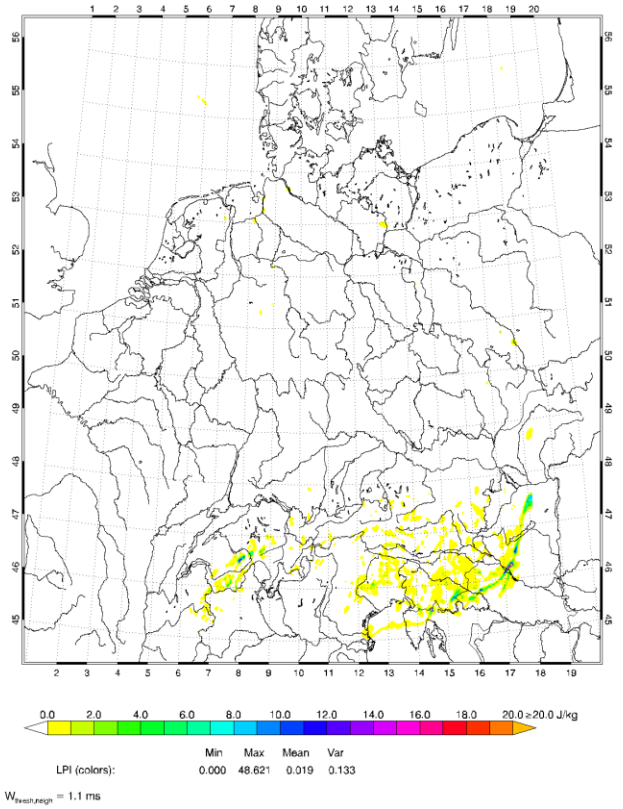
LPI COSMO-DE no neighbourhood crit.

LPI 20141022000000 UTC +00010000



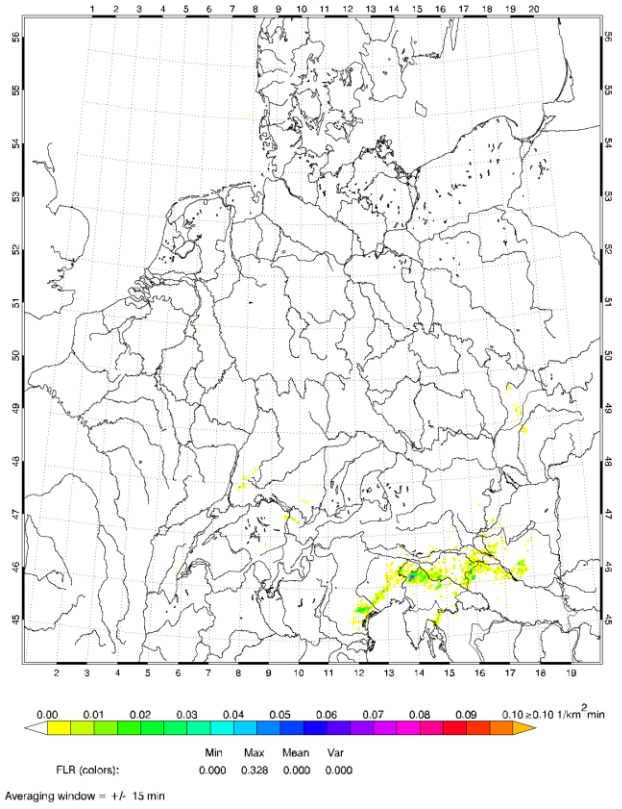
LPI COSMO-DE neighbourhood crit.

LPI 20141022000000 UTC +00010000



FLR +- 15 min LINET

FLR [1/km^{2}min] 20141022010000 UTC +/- 15 min



Graupel formation in orogr. wave clouds gives LPI > 0!
Therefore additional filter necessary: $B_{MF} > B_0$

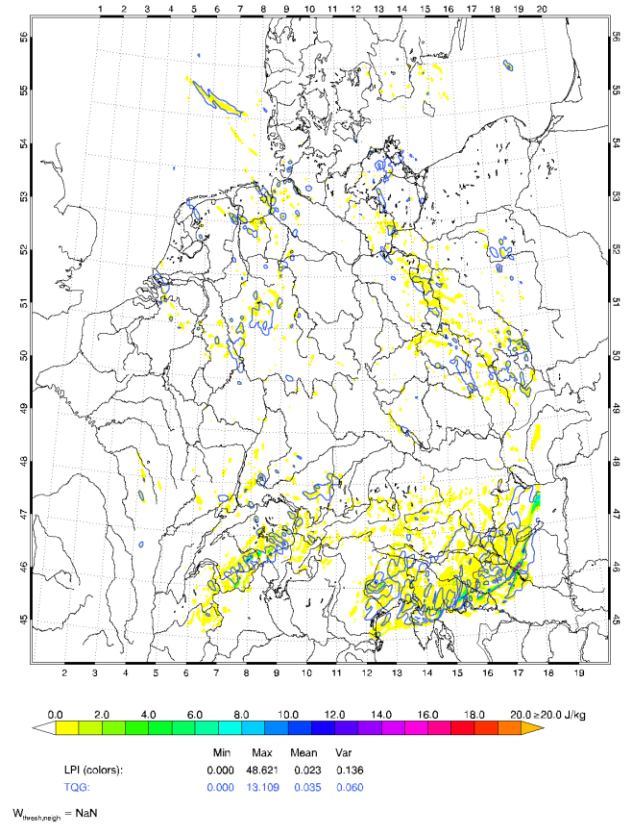
A second test using COSMO-DE

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

CDE-Routi: LPI_2 LPI_4 (without f_2) Obs LINET t +- 15 min

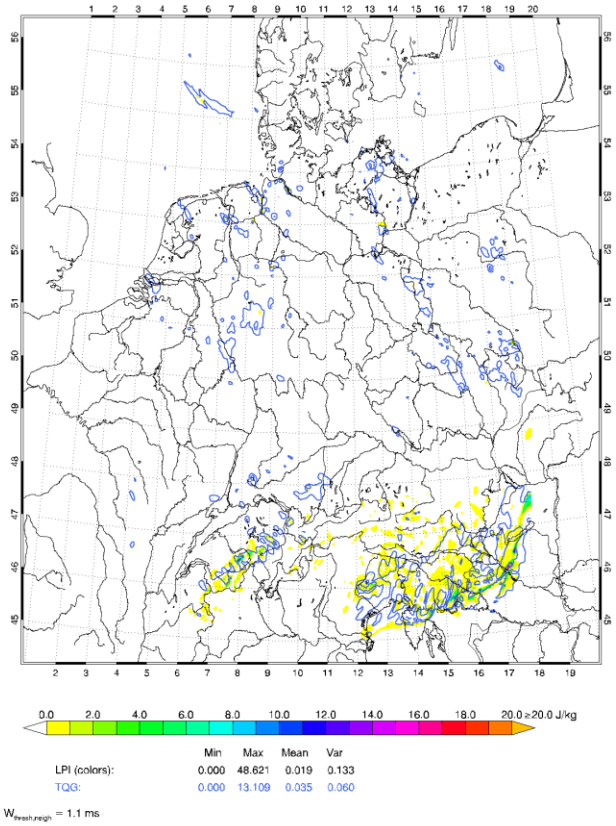
LPI COSMO-DE no neighbourhood crit.

LPI, TQG, 20141022000000 UTC +00010000



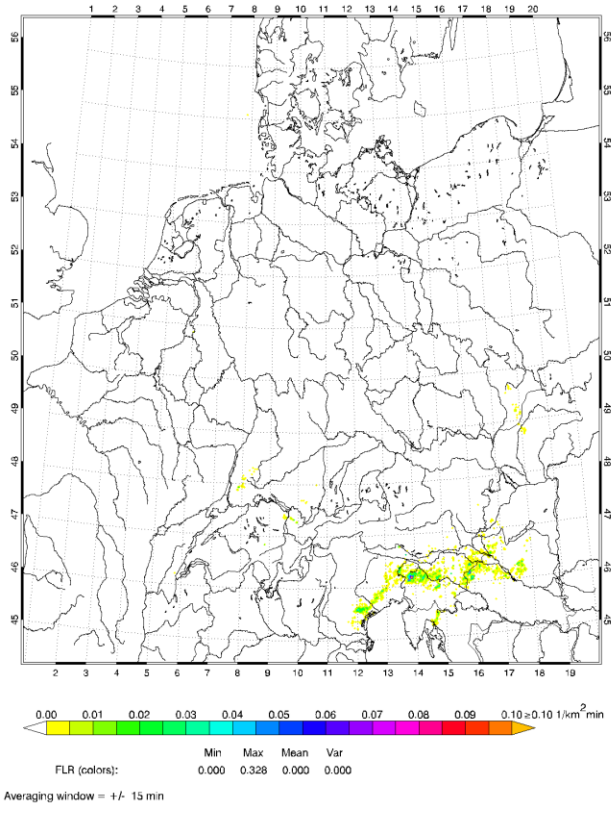
LPI COSMO-DE neighbourhood crit.

LPI, TQG, 20141022000000 UTC +00010000



FLR +- 15 min LINET

FLR [1/km^{2}min] 20141022010000 UTC +/- 15 min



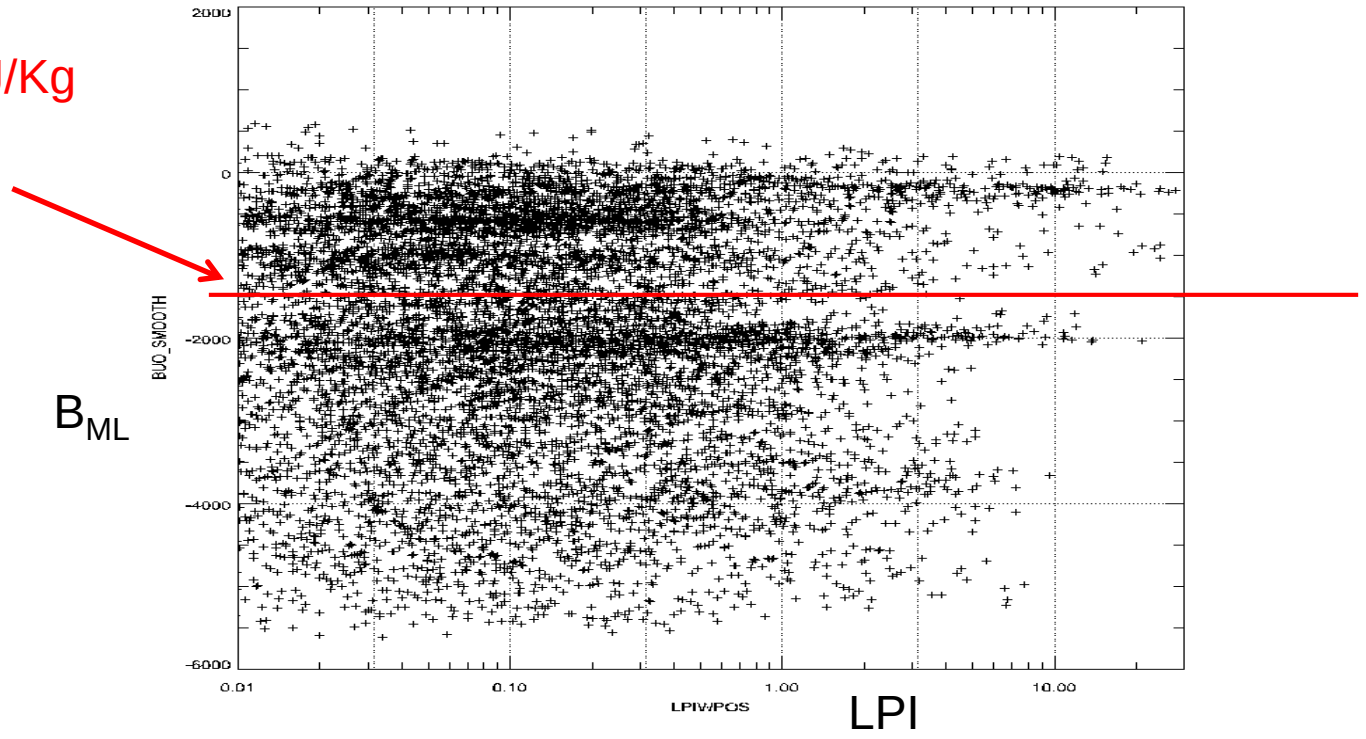
Graupel formation in orogr. wave clouds gives LPI > 0!
Therefore additional filter necessary: $B_{MF} > B_0$

A second test using COSMO-DE

- $B_{ML} > B_0$ criterion:
- From COSMO-DE hindcast, not routine data base!

2014102200 UTC + 01 h

B_0 = -1500 J/Kg



B_{ML}

LPI

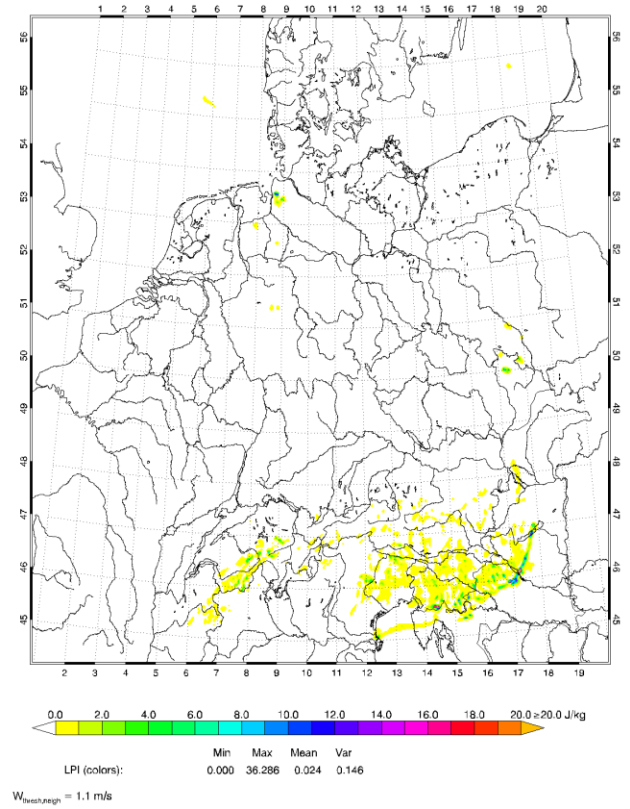
A second test using COSMO-DE

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Hindcast: LPI_2 LPI_4 (with f_2) Obs LINET t +- 15 min

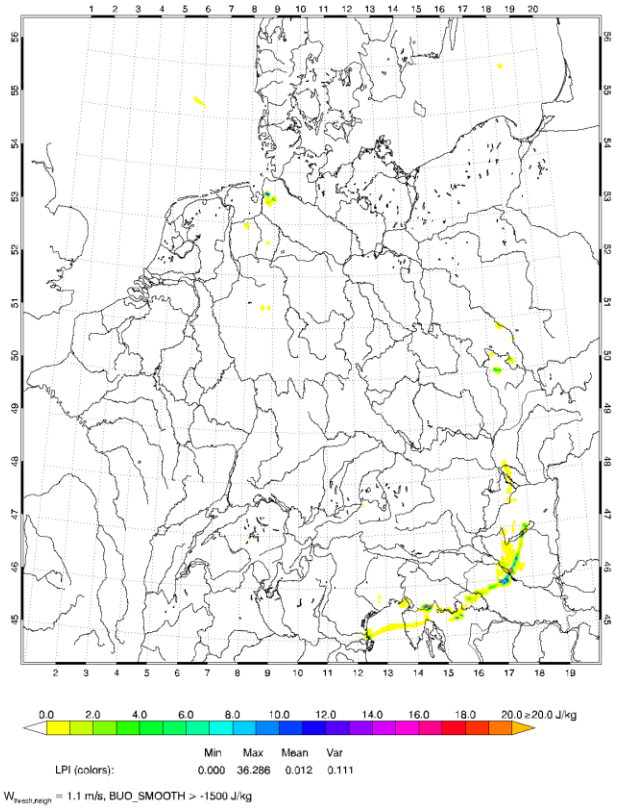
LPI COSMO-DE no buoyancy filter

LPI 20141022000000 UTC +00010000



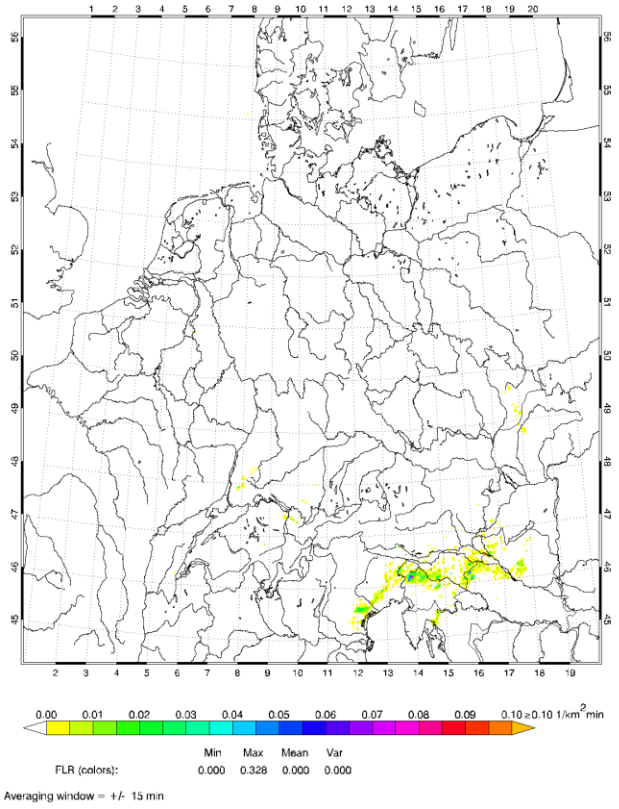
LPI COSMO-DE buoyancy filter

LPI (BUO_SMOOTH-filtered) 20141022000000 UTC +00010000



FLR +- 15 min LINET

FLR [1/km^{2}min] 20141022010000 UTC +/- 15 min



Graupel formation in orogr. wave clouds gives LPI > 0!
Filter $B_{MF} > B_0$ works well!

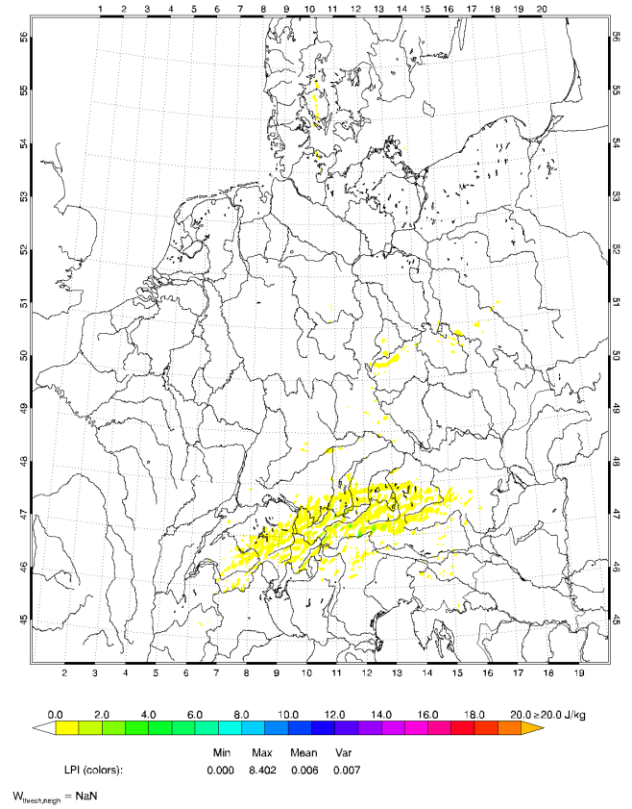
A second test using COSMO-DE

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

CDE-Routi: LPI_2 LPI_4 (without f_2) Obs LINET t +- 15 min

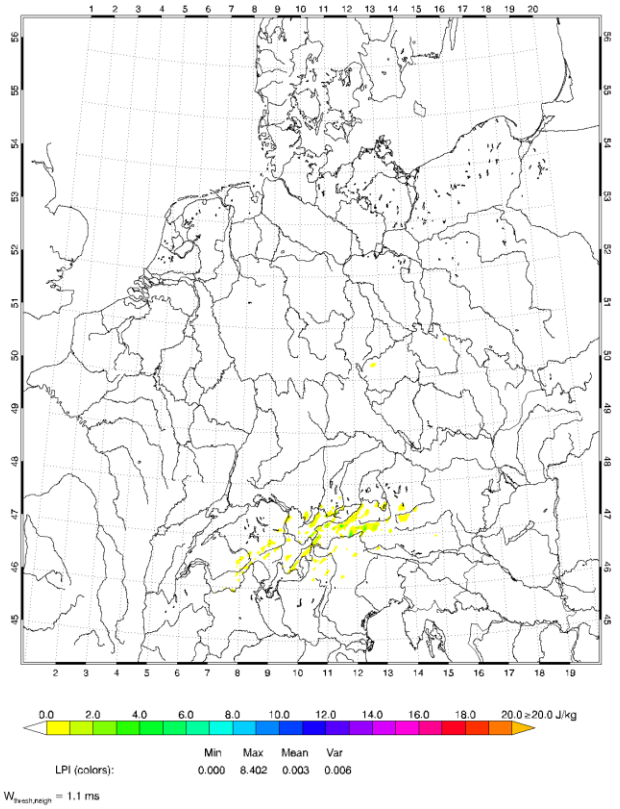
LPI COSMO-DE no neighbourhood crit.

LPI 20141022120000 UTC +00110000



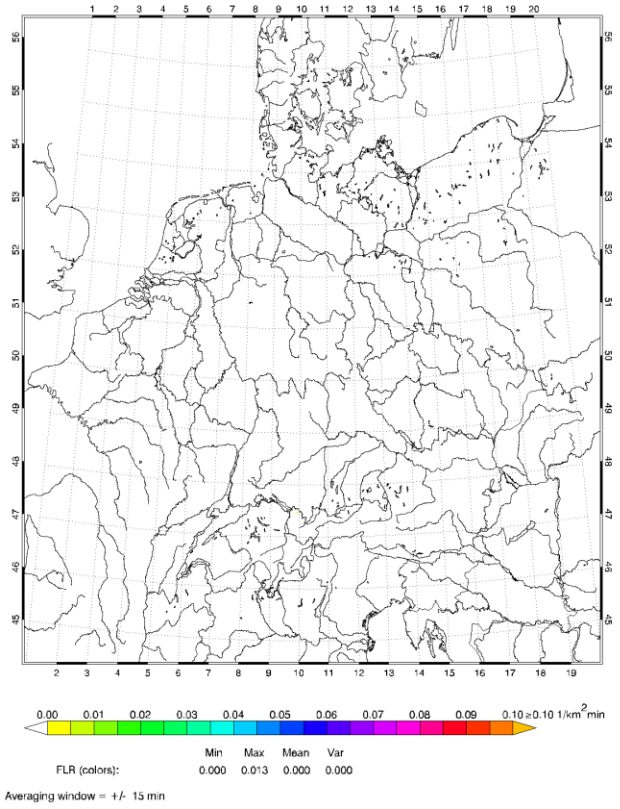
LPI COSMO-DE neighbourhood crit.

LPI 20141022120000 UTC +00110000



FLR +- 15 min LINET

FLR [1/km^{2}min] 20141022230000 UTC +/- 15 min



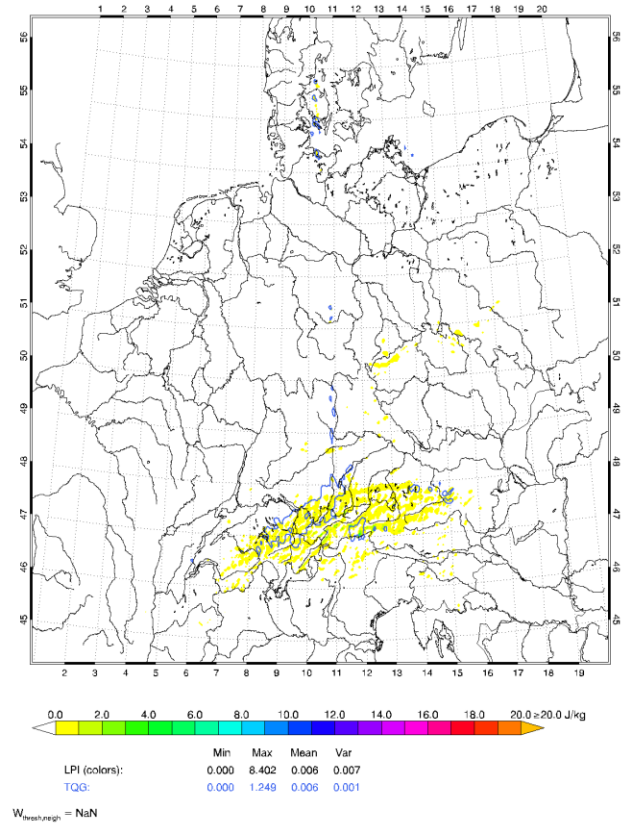
Graupel formation in orogr. wave clouds gives LPI > 0!
Therefore additional filter necessary: $B_{MF} > B_0$

A second test using COSMO-DE

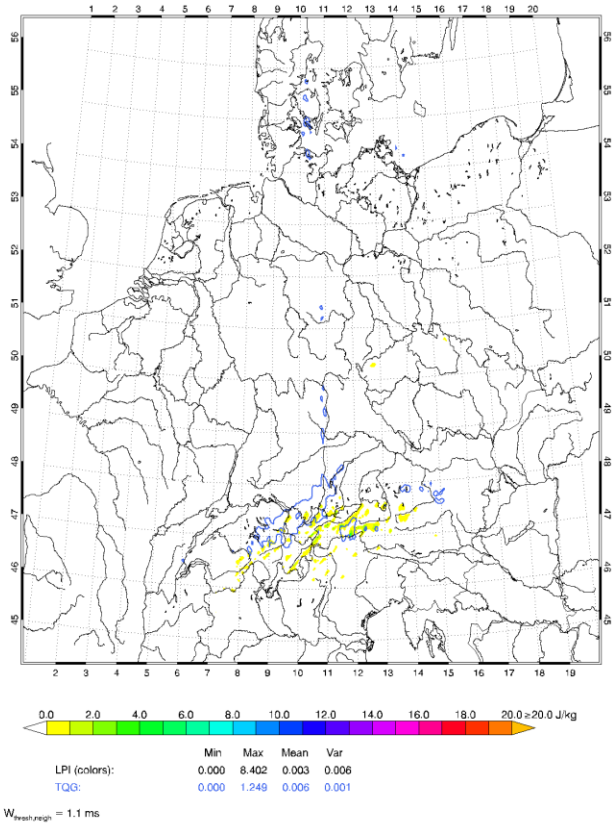
Deutscher Wetterdienst
Wetter und Klima aus einer Hand

CDE-Routi: LPI_2 LPI_4 (without f_2) Obs LINET t +- 15 min

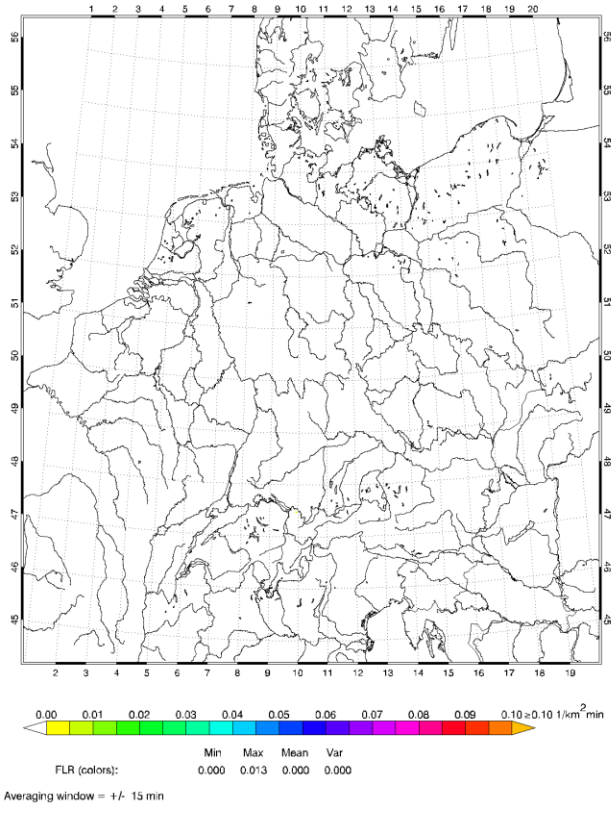
LPI COSMO-DE no neighbourhood crit.



LPI COSMO-DE neighbourhood crit.



FLR +- 15 min LINET



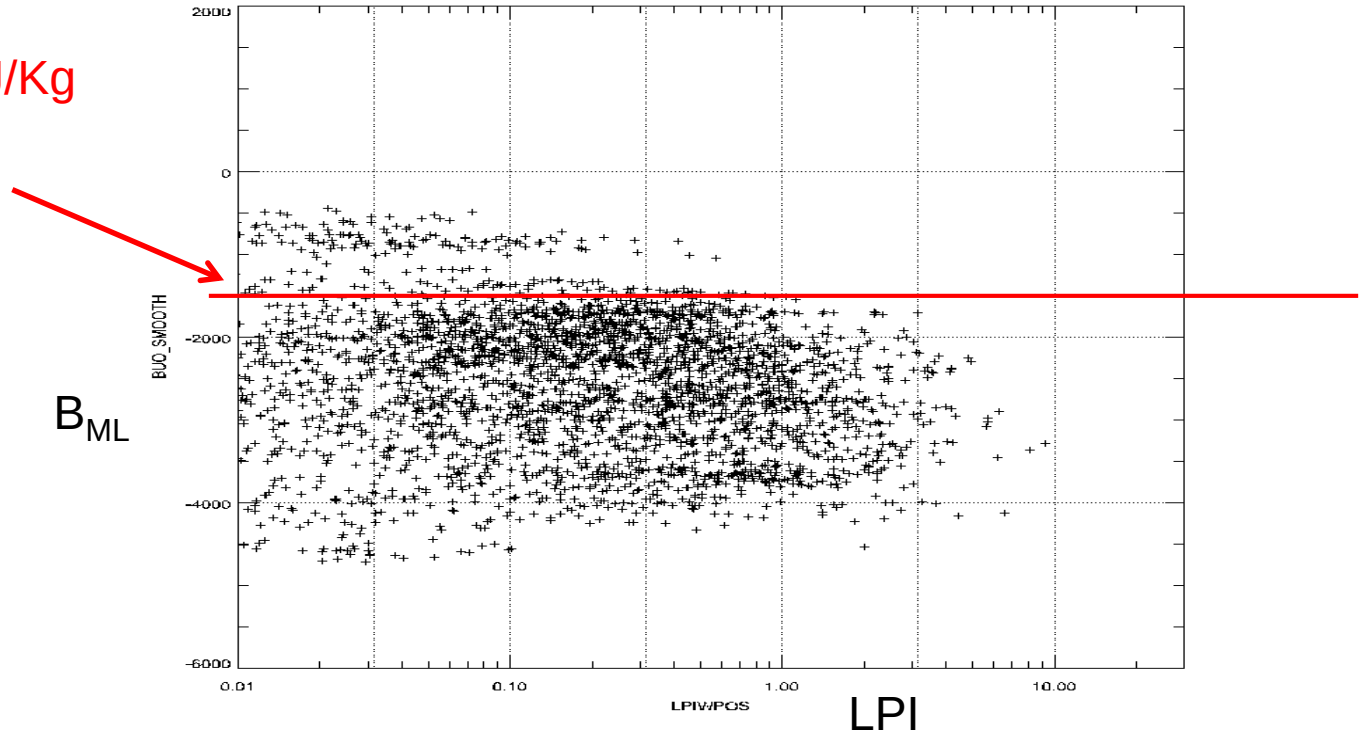
Graupel formation in orogr. wave clouds gives LPI > 0!
Therefore additional filter necessary: $B_{MF} > B_0$

A second test using COSMO-DE

- $B_{ML} > B_0$ criterion:
- From COSMO-DE hindcast, not routine data base!

2014102200 UTC + 23 h

B_0 = -1500 J/Kg



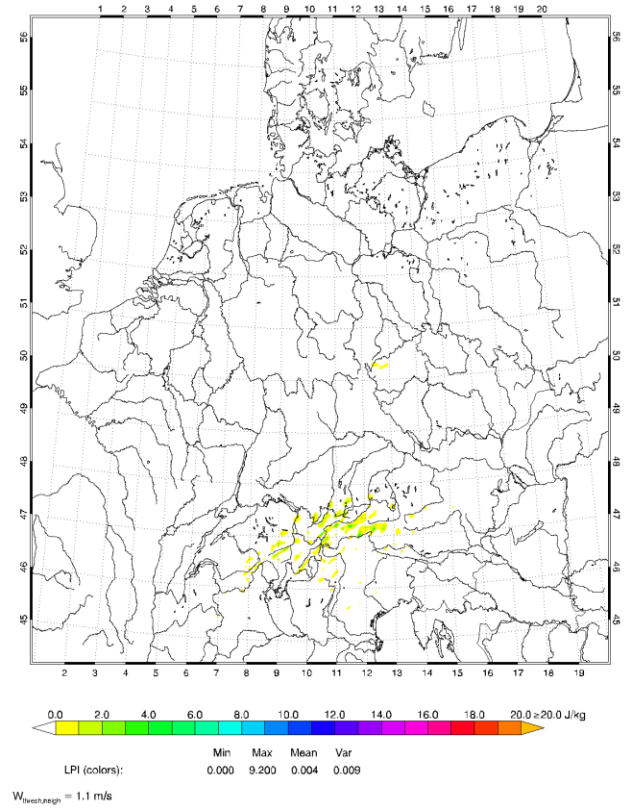
B_{ML}

A second test using COSMO-DE

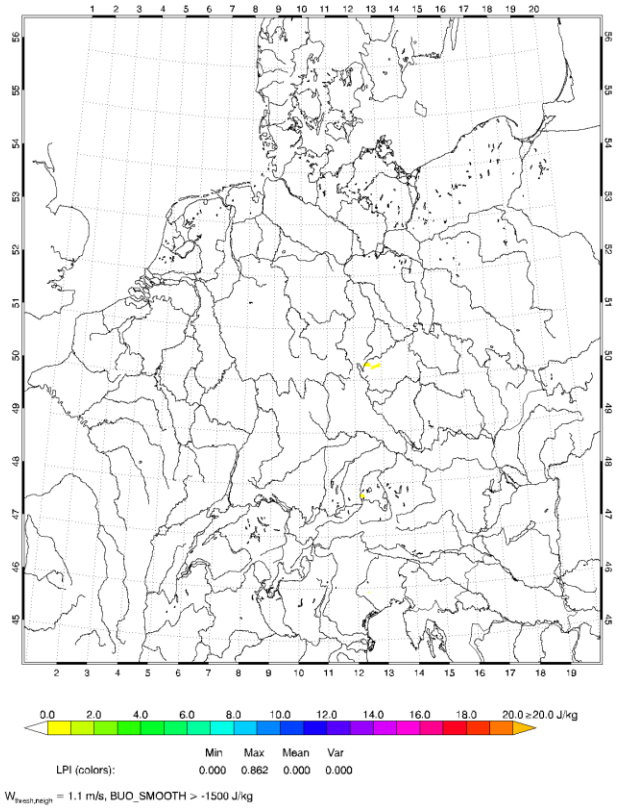
Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Hindcast: LPI_2 LPI_4 (mit f_2) Obs LINET t +- 15 min

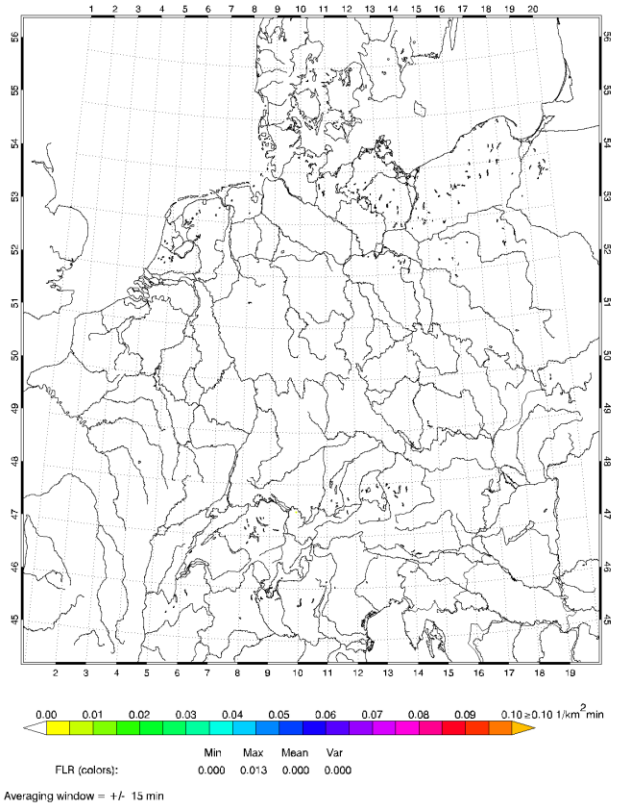
LPI COSMO-DE no buoyancy filter
LPI 20141022000000 UTC +00230000



LPI COSMO-DE buoyancy filter
LPI (BUO_SMOOTH-filtered) 20141022000000 UTC +00230000



FLR +- 15 min LINET
FLR [1/km^{2}min] 20141022230000 UTC +/- 15 min



Graupel formation in orogr. wave clouds gives LPI > 0!
Filter $B_{MF} > B_0$ works well!

Summary

The comparison with lightning data (flash rates) „by eye“ shows:

- Statistics of the space-time distribution of the LPI values > 0 corresponds well with that of the observed flash rates.
- LPI intimately tied to the explicit simulation of convective cells in the model and its ice microphysics (updraft strength, supercooled liquid, graupel, cloud ice, snow). **Ensemble prediction like COSMO-DE-EPS!**
- LPI leads to different flash signals compared to, e.g., TQG or TOT_PREC alone. Not every convective Cell, which has a high TQG, leads to an LPI signal.
- Spatial filtering by the W_{max} – majority criterion (f_1) and the smoothed buoyancy-criterion (f_2) in a horizontal neighbourhood seems to successfully eliminate spurious and false week signals.
- Time aggregation between output timesteps? Seems not necessary for a 15-minute output interval like in COSMO-DE. And would be expensive, because spatial filtering requires a gather_field(…) for a global 2D field, and one wants to avoid this for every time step.

Possible applications at DWD

- Diagnose the LPI directly in the COSMO-Model at output time steps, or in fieldextra.
- Application in COSMO-DE-EPS:
  - Either directly (probability of exceeding some threshold etc.),
  - or as an additional predictor in a currently developed statistical method (FE 15), which derives flash rates directly from a variety of different ensemble fields.
- Application as forward operator in data assimilation
- Status:
  - Subroutines in Fortran90
  - grib numbers in next DWD grib_api version (until then no LPI in grib2!)
  - Implem. in COSMO src_output.f90 + performance tuning (gather_field())
  - Timings: 24 h COSMO_DE, LPI-output every 15 minutes, (20x10 PEs):
    - without LPI: total: 1755 s comp_O: 23 s
    - with LPI: total: 1770 s (+ ~1 %) comp_O: 30 s (+ ~30 %)
    - crayftn: Gfast -Ktrap=divz,inv,ovf -O2 -hflex_mp=conservative -K trap=fp