A modified lightning potential index for numerical models with parameterized deep convection

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07/09/2021
EMS 2021, Online

Overview

1) Background – how does the index work
2) Some improvement with statistical post-processing
3) Comparison to LPI from ICON-D2 based on resolved convection – examples
4) Verification results

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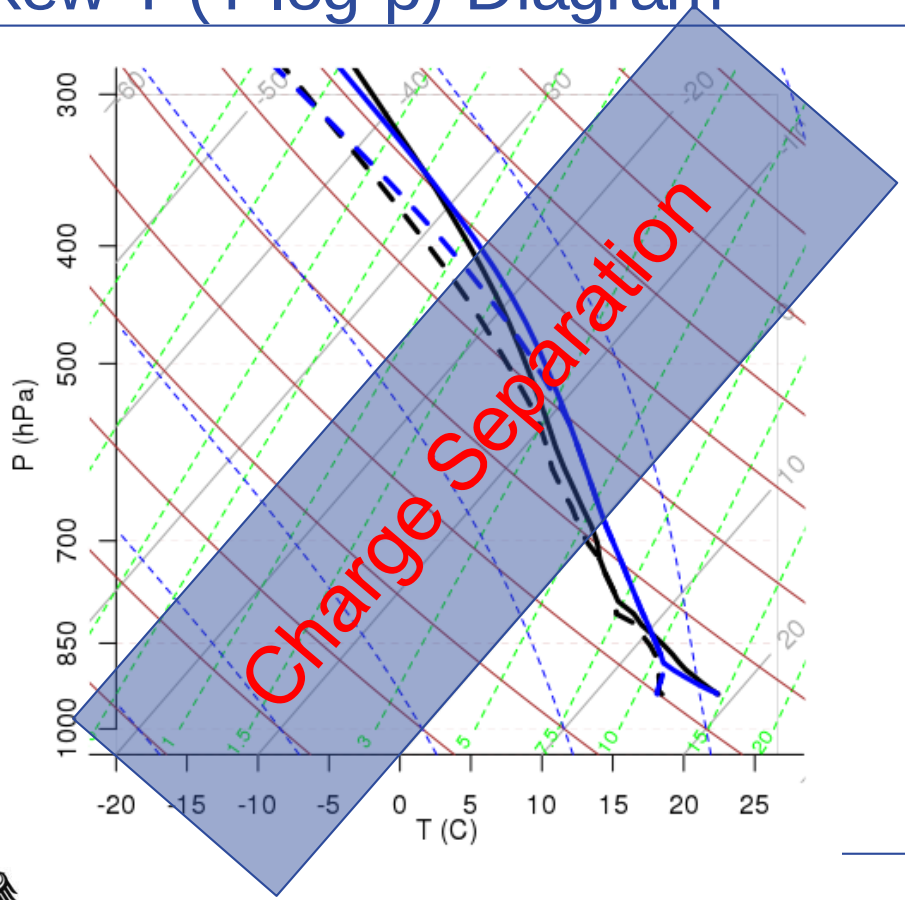
Example for convection
Skew T (T log p) Diagram



T Environment (grid-scale)

Td Environment (grid scale)

T Updraft (from convection scheme)

Td Updraft (from convection scheme)

ICON-D2: lightning potential index (LPI)

➔ Based on vertical wind, snow, ice, graupel in clouds from resolved convection and cloud microphysics

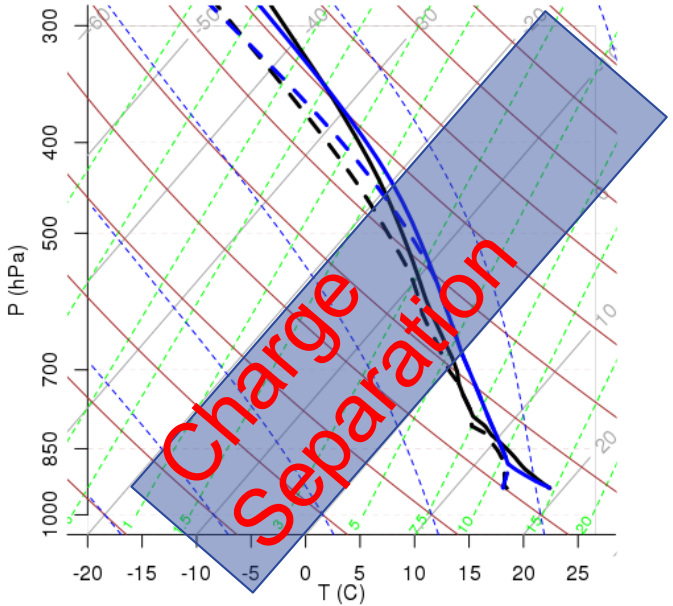
From Lynn and Yair (2010)

$$\mathrm{LPI} = 1/V \int_{Z0}^{Z-20}\int\int \varepsilon\, w^2\, dx\, dy\, dz$$

$$\varepsilon = 2(Q_i\, Q_l)^{0.5}/(Q_i + Q_l)$$

$$Q_i = q_g[((q_s\, q_g)^{0.5}/(q_s + q_g)) + ((q_i\, q_g)^{0.5}/(q_i + q_g))]$$

q : mixing ratio snow, graupel, ice, liquid



Lynn, B. und Yair, Y., 2010: Prediction of lightning flash density with the WRF model. Adv. Geosci., 23, 11-16.
Yair, Y. et al. 2010: Predicting the potential for lightning activity in Mediterranean storms based on the Weather Research and Forecasting (WRF) model dynamic and microphysical fields. J. Geo. Res., 11, 1-13

IFS: lightning flash density (LFD)

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➔ Based on CAPE, cloud base height, water, graupel and ice from Tiedtke-Bechtold convection scheme

From Lopez (2016)

$$f_T = \alpha\, Q_R \sqrt{\mathrm{CAPE}}\, \min(z_{\mathrm{base}}, 1.8)^2,$$

$$Q_R = \int_{z_0}^{z_{-25}} q_{\mathrm{graup}}\,(q_{\mathrm{cond}} + q_{\mathrm{snow}})\,\bar{\rho}\,dz$$

$\alpha = 32.4$

$\beta = 0.7\ (Land)$

$V_{graup} = 3m/s$

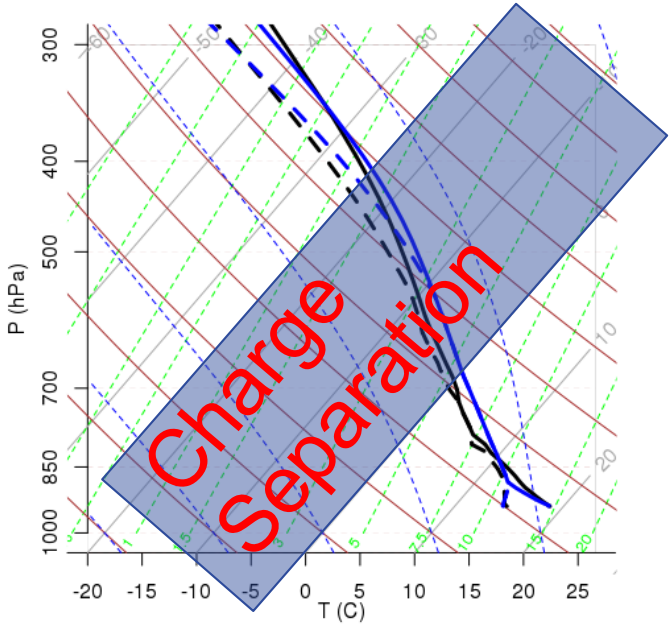
$V_{snow} = 0.5m/s$

$$q_{\mathrm{graup}} = \beta \frac{P_f}{\bar{\rho} V_{\mathrm{graup}}},$$

$$q_{\mathrm{snow}} = (1-\beta) \frac{P_f}{\bar{\rho} V_{\mathrm{snow}}},$$

P_f: precipitation flux

q : mixing ratio snow, graupel, ice+liquid



https://confluence.ecmwf.int/display/FUG/Lightning

Lopez, P., 2016: A Lightning Parameterization for the ECMWF Integrated Forecasting System. *Mon. Wea. Rev.*, **144**, 3057–3075.

Synthesis
LPI from parameterized convection

➔ Based on vertical wind, snow, ice and graupel in cloud from convection scheme – as in Lopez 2016 for LFD

From Lynn and Yair (2010)

$$\mathrm{LPI} = 1/V \int_{Z0}^{Z-20}\int\int \varepsilon\, w^2\, dx\, dy\, dz$$

$$\varepsilon = 2(Q_\mathrm{i}\, Q_\mathrm{l})^{0.5}/(Q_\mathrm{i} + Q_\mathrm{l})$$

$$Q_\mathrm{i} = q_\mathrm{g}[((q_\mathrm{s}\, q_\mathrm{g})^{0.5}/(q_\mathrm{s} + q_\mathrm{g})) + ((q_\mathrm{i}\, q_\mathrm{g})^{0.5}/(q_\mathrm{i} + q_\mathrm{g}))]$$

q : mixing ratio snow, graupel, ice, liquid

From Lopez (2016)

$\beta = 0.7\ (Land)$
$V_{graup} = 3m/s$
$V_{snow} = 0.5m/s$

$$q_\mathrm{graup} = \beta \frac{P_f}{\overline{\rho}\, V_\mathrm{graup}},$$

$$q_\mathrm{snow} = (1-\beta) \frac{P_f}{\overline{\rho}\, V_\mathrm{snow}},$$

Vertical wind speed from convection profile meaningful?

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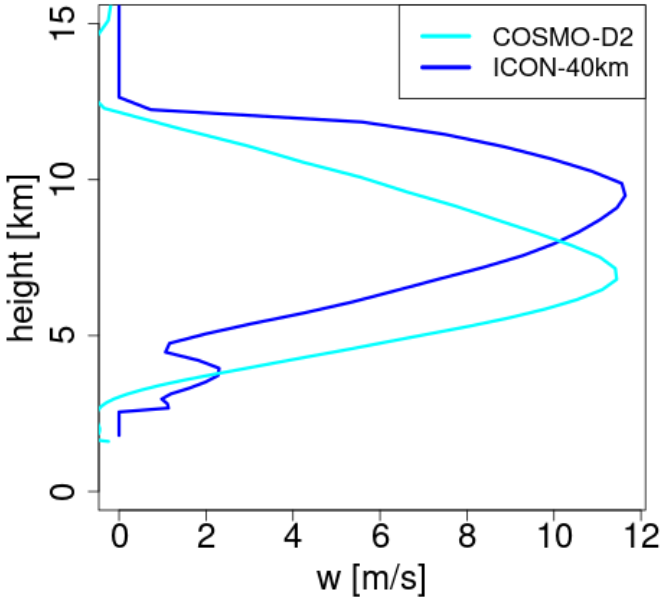
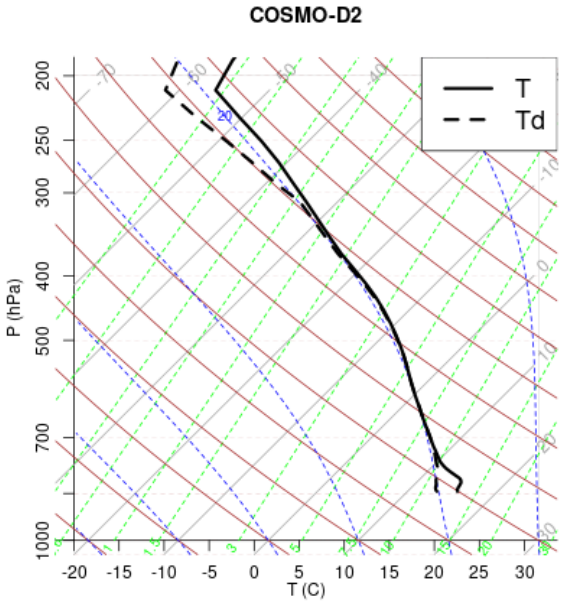
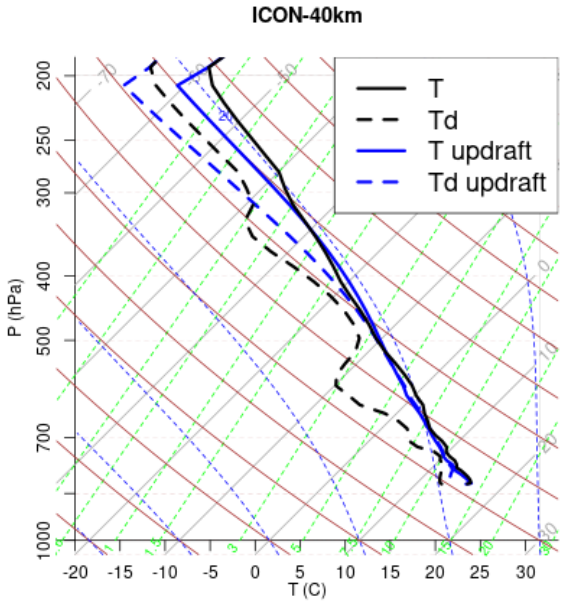
➔ Comparison of typical updraft profile in COSMO-D2/ICON-D2 (2km resolution, resolved convection) and ICON-40km (40km resolution, parameterized convection)





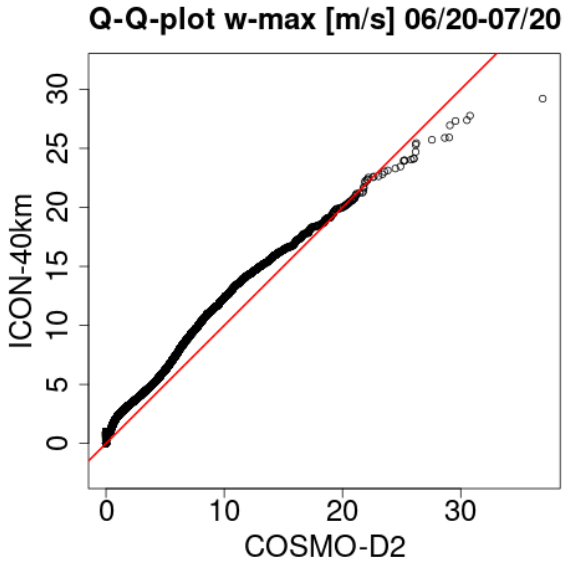


Dewpoint calculated for saturation over water

w-max
ICON-Global versus COSMO-D2

- Plot shows the sorted maximum vertical wind speeds in a 100kmx100km neighborhood for June/July 2020 for the COSMO-D2 domain
- w-max for ICON-40km from the convection scheme
- w-max for COSMO-D2 directly resolved convection
- Overall similar magnitudes
- ICON-40 has tendency to forecast maximum at higher altitudes

Statistics of vertical wind speeds in ICON-D2 and ICON-40km



Overview

1) Background – how does the index work
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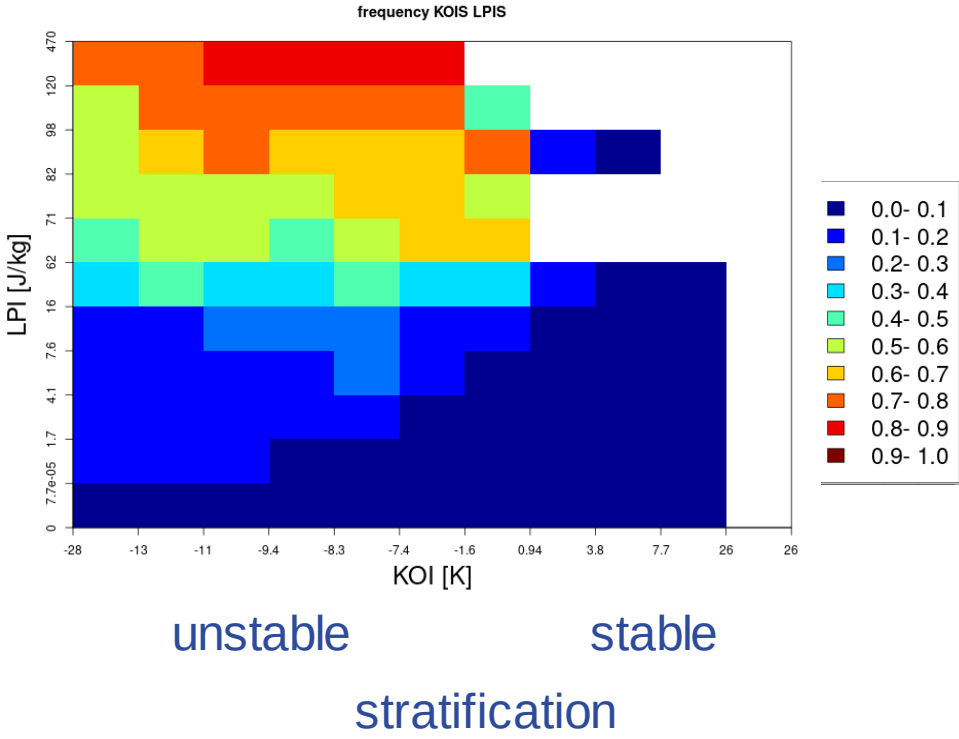
MLPI – LPI + KOI as additional indicator

- Thunderstorm frequency from Linet analysis is compared to LPI and KOI

$$KOI = 0.5[\theta_e(500hPa) + \theta_e(700hPa) - \theta_e(850hPa) - \theta_e(950hPa)]$$

- Data on 20x20km^2 grid over Germany
- Clear signal visible
- Modified LPI (MLPI) computed based on ICON-EU 3h-assimilation forecast (function fit)
- Data from 03/2019-02/2020



How does the MLPI formula work?

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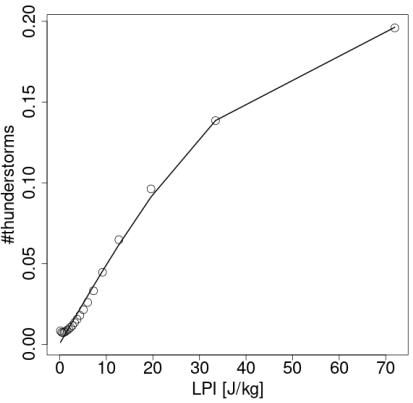
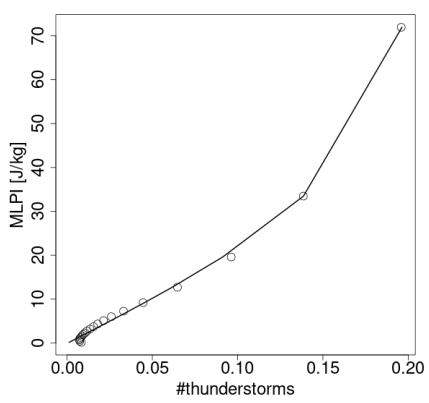
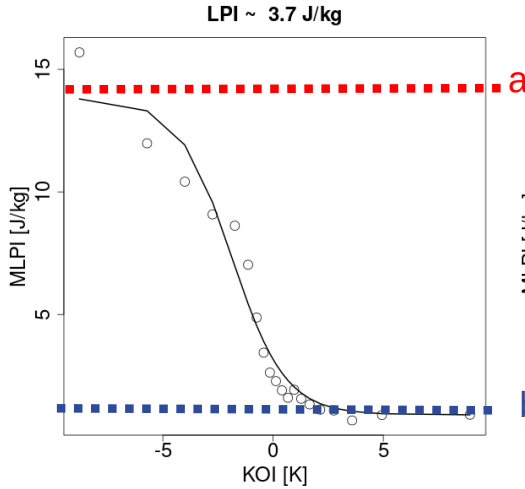
Measured thunderstorm frequency binned by modelled LPI

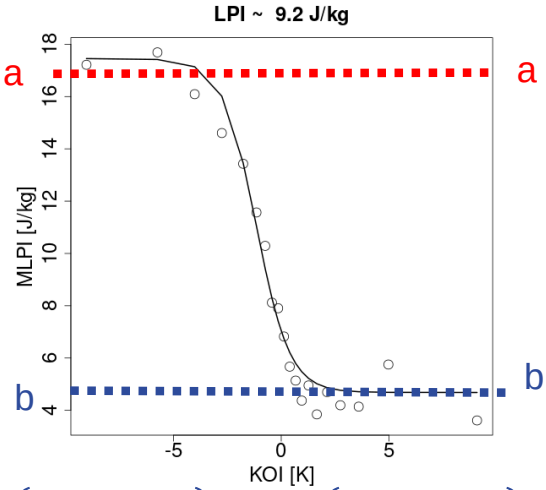
Convert thunderstorm frequency to target MLPI

For fix LPI – what is the effect of variable KOI









$$KOI = 0.5[\theta_e(500hPa) + \theta_e(700hPa) - \theta_e(850hPa) - \theta_e(950hPa)]$$

MLPI – LPI + KOI as additional indicator

- Non-linear fit for thunderstorms using KOI and LPI as predictor (on ICON-EU-Grid)
- Best formula:
  - $a = gLPI^h$; $b = \min(a, \frac{b_{max}\left(1+\tanh\left(i\left(LPI^k+j\right)\right)\right)}{2})$;
  - $MLPI = b + [\left(1+\tanh\left(-e(KOI+d)\right)\right)/2](a-b)$
  - e=0.39;d=1.27;g=4.73;h=0.63;i=1.83;j=-2.19;k=0.31;bmax=14.0
- 1 year hourly data 03/19-02/20
- Target – modified LPI (J/kg)

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Comparison of LPI (ICON-D2) and MLPI (ICON-EU) – 10/06/2021 00 UTC + 14

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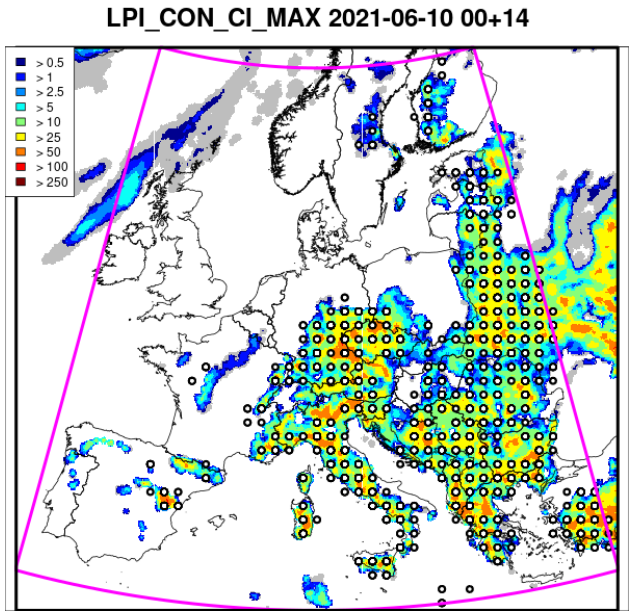
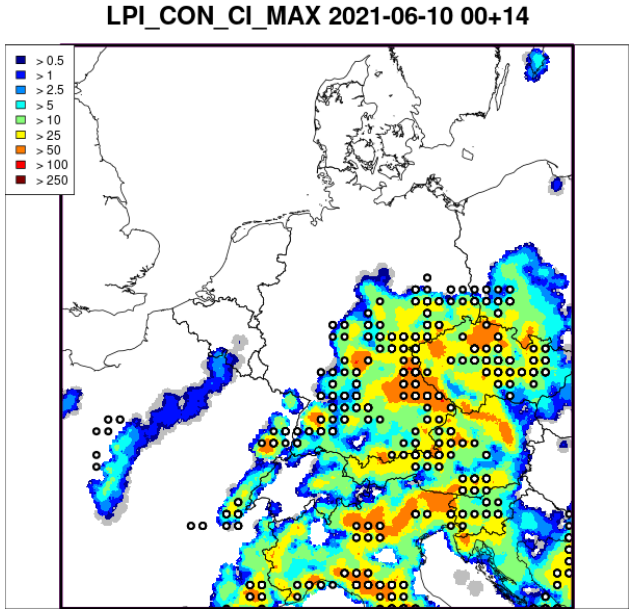
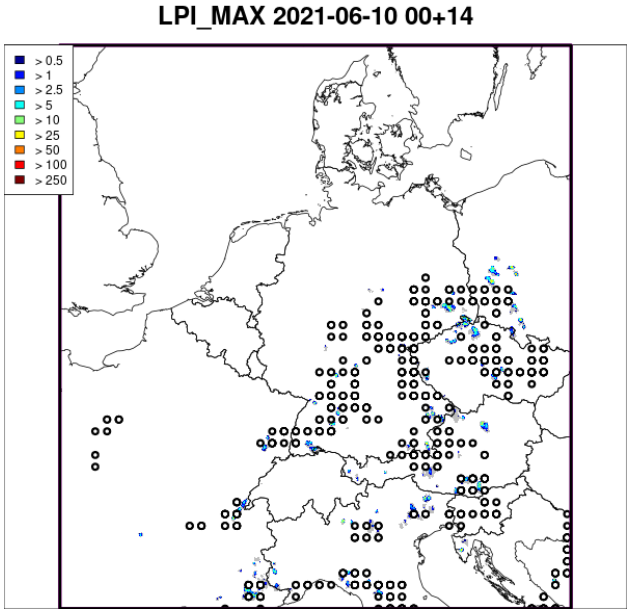
MLPI: ICON-EU-EPS Member 1
(20 km resolution)

LPI: ICON-D2-EPS Member 1
(2.2 km resolution)







- Lightning observed within the past hour

Comparison of LPI (ICON-D2) and MLPI (ICON-EU) – 10/06/2021 00 UTC + 14

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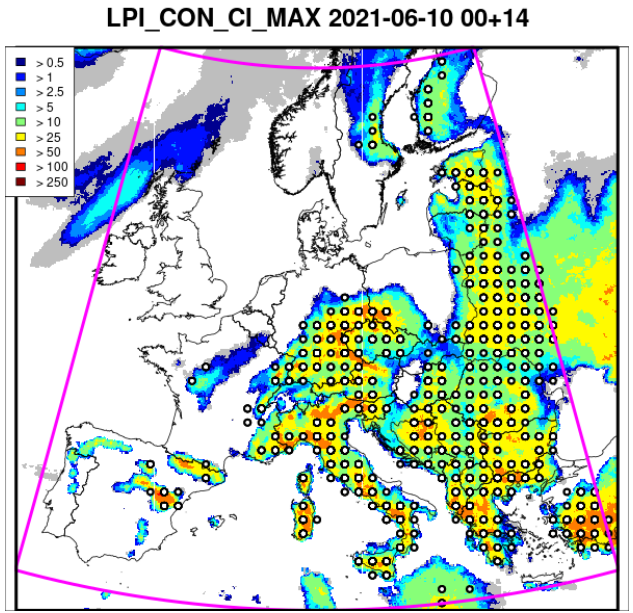
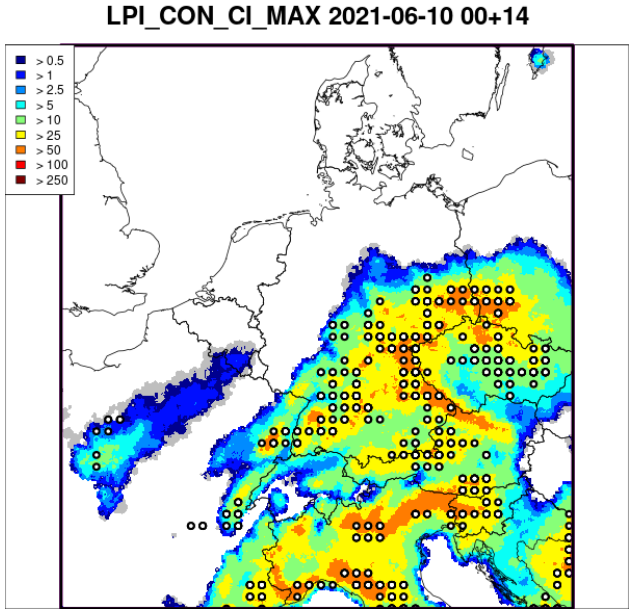
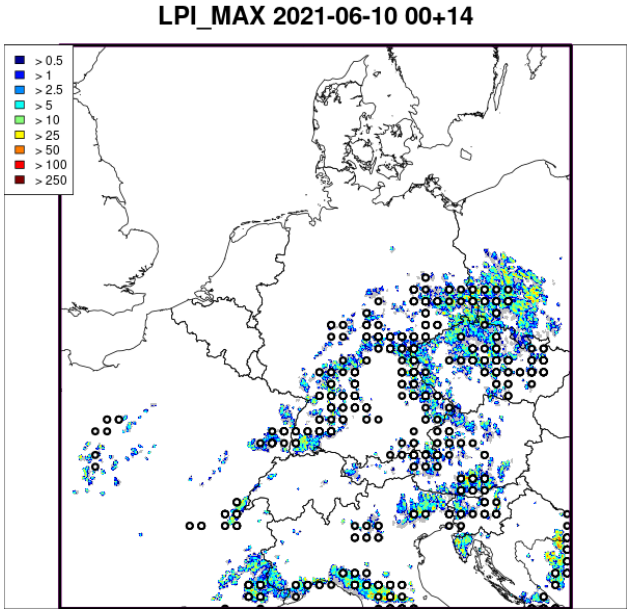
MLPI: ICON-EU-EPS Q90
(20 km resolution)

LPI: ICON-D2-EPS Q100
(2.2 km resolution)







- Lightning observed within the past hour

Comparison of LPI (ICON-D2) and MLPI (ICON-EU) – 24/07/2021 00 UTC + 18

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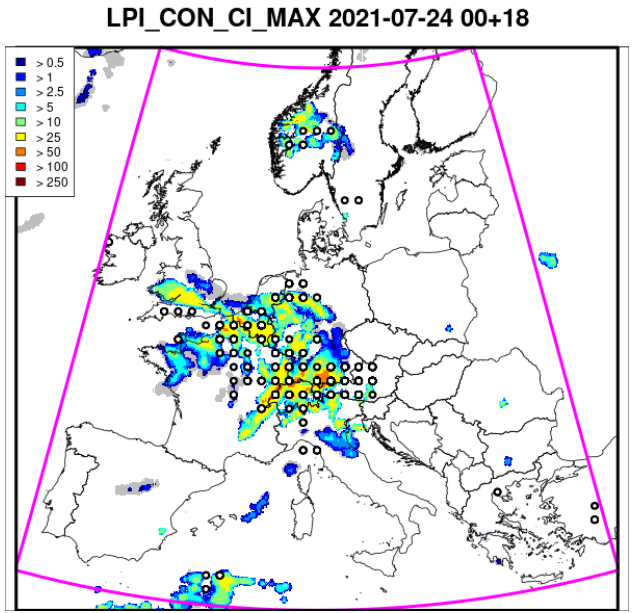
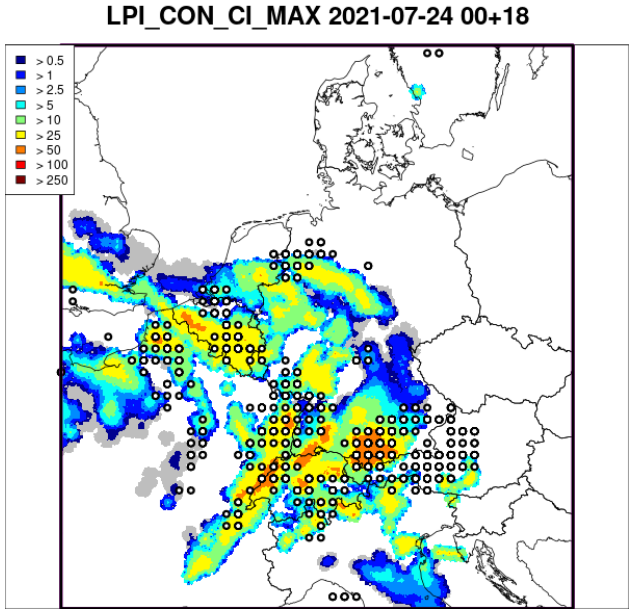
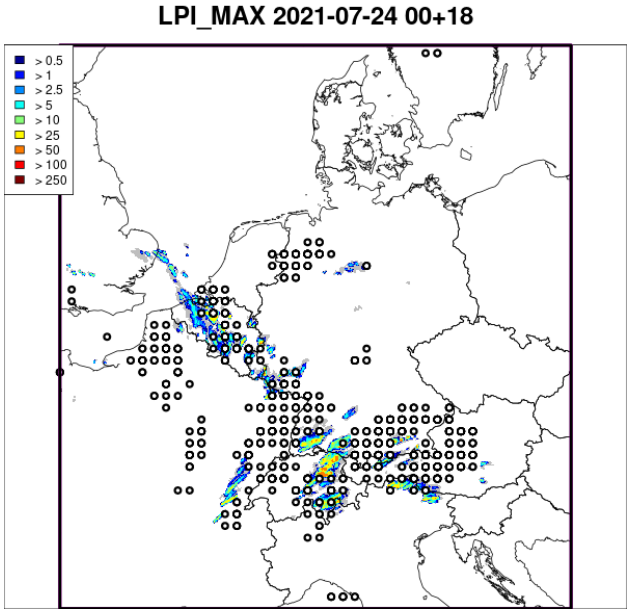
MLPI: ICON-EU-EPS Member 1
(20 km resolution)

LPI: ICON-D2-EPS Member 1
(2.2 km resolution)







- Lightning observed within the past hour

Comparison of LPI (ICON-D2) and MLPI (ICON-EU) – 24/07/2021 00 UTC + 18

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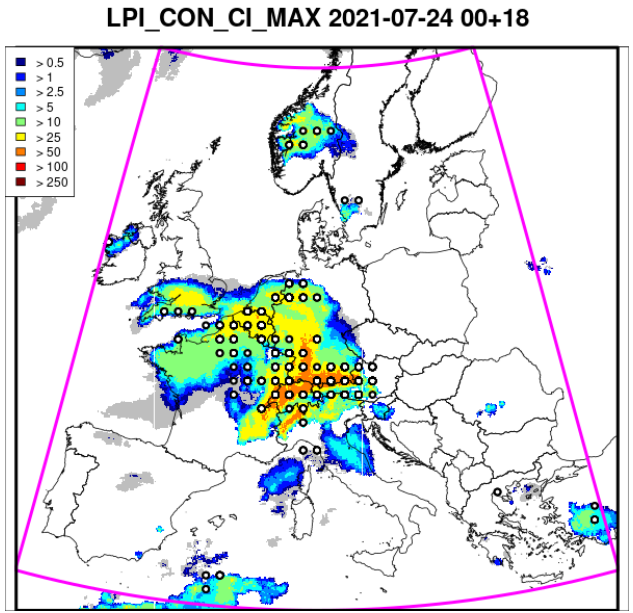
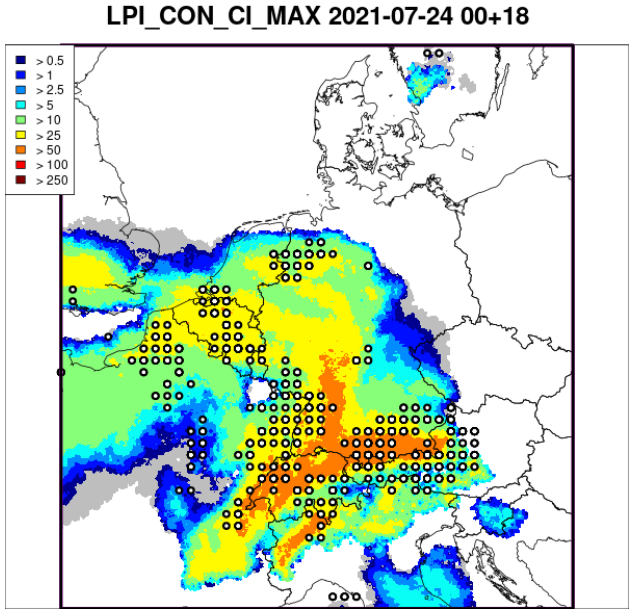
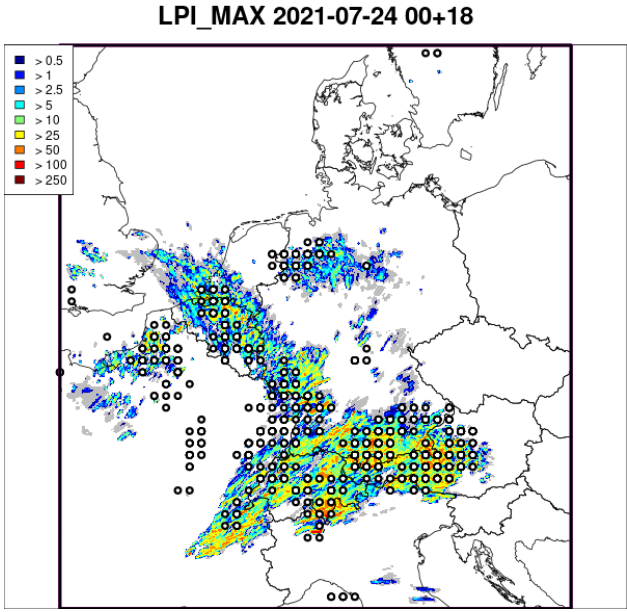
MLPI: ICON-EU-EPS Q90
(20 km resolution)

LPI: ICON-D2-EPS Q100
(2.2 km resolution)







- Lightning observed within the past hour

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Verification – ROC-curves

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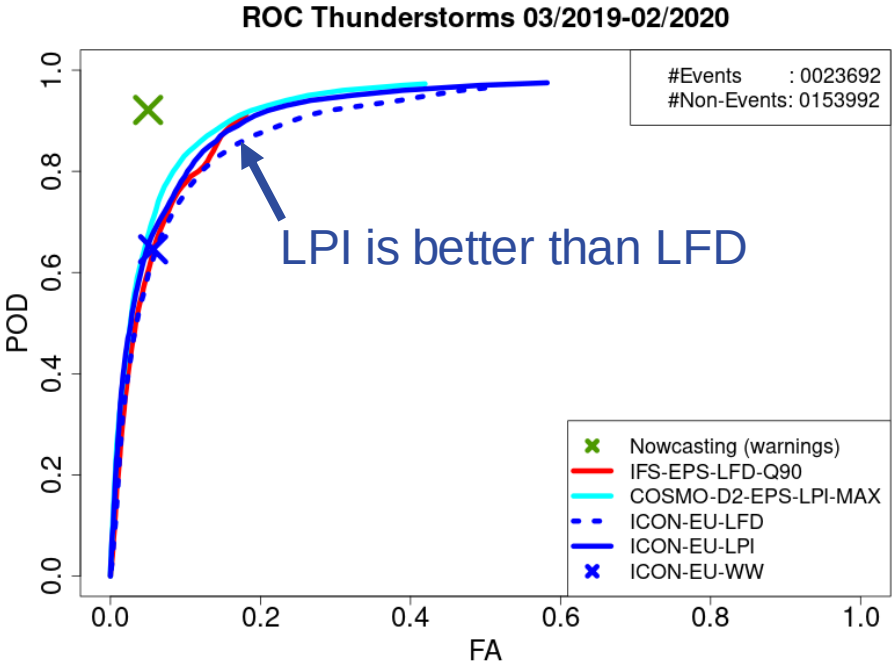
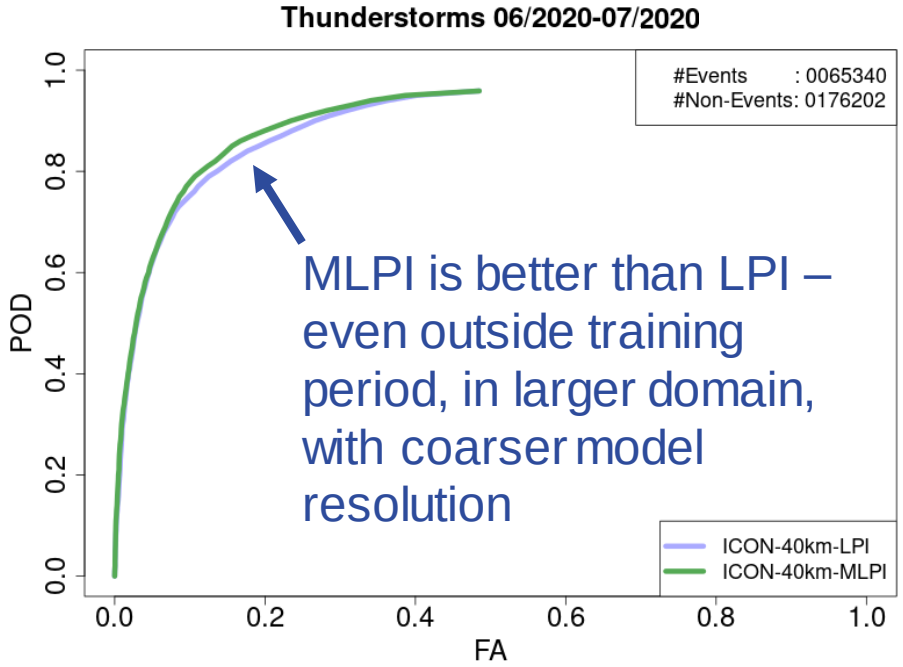
Domain : Germany

6km resolution

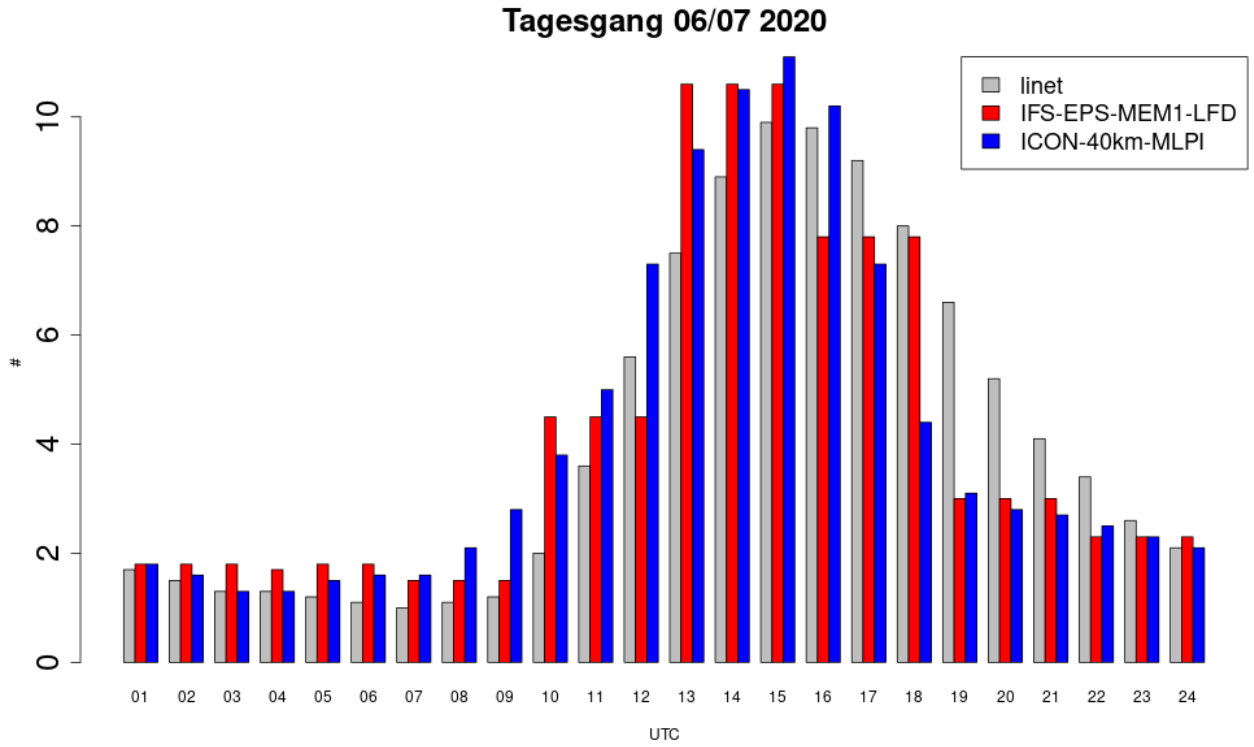


Domain : Central Europe

40km resolution



Diurnal circle



- ➔ Too little thunderstorm activity in the evening
- ➔ A bit too early onset of activity in the morning
- ➔ Well known effect of parameterized convection

Summary

- MLPI is based on LPI and KOI
- LPI is based on updraft in convection scheme
- MLPI in ICON-EU covers larger areas of lightning than LPI in ICON-D2 – since the subgrid convection is associated with more uncertainty (no individual convective cells)
- MLPI has tendency of too early onset of thunderstorms
- MLPI ensemble seems to be overly certain over mountains (convection in all ensemble member at the same place)
- Verification results show that MLPI performs better than LPI or LFD