Trend analysis of convective parameters relevant for hailstorms

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motivation

Severe thunderstorms and associated extreme events such as hail represent a substantial hazard potential for buildings, crops, and critical infrastructure. In the last decades, damage caused by severe hailstorms has increased significantly in Central Europe. In southwest Germany, more than 40% of all damage to buildings by natural hazards is associated with large hail (1986-2008, Kunz 2009).

Within the frame of the project **HARIS-CC („HAil RISk and Climate Change")** it is examined whether an indication is found that extreme events connected to severe thunderstorms have been increasing in the number or intensity over the past decades. Because thunder-storms are not captured uniquely and entirely by observations, the trend analyses rely on several convective indices and parameters (proxies) quantifying the thunderstorm potential of the atmosphere.

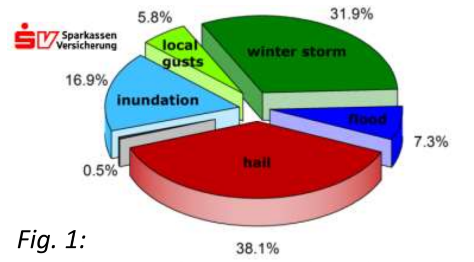

Fig. 1: Distribution of insurance loss data of damaged buildings (SV Sparkassen Versicherung, 1986-2008).

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data sets

Radiosoundings Germany (Fig. 2: A-G):

- 1957-2009 : Schleswig (A), Stuttgart (F)
  1978-2009 : Greifswald (B), Lindenberg (C), Essen (D), Meiningen (E), Munich (G)
- Summer half year (April-September), 12 UTC

Synoptic data in Germany

- Same place and time period as the soundings

Radiosoundings West/Central Europe (Fig. 2: 1-26):

- 1978-2009
- Summer half year (April-September), 12 UTC

Convective parameter related to hail (Kunz, 2007; Mohr, 2011):

- Lifted Index (LI_{100hPa}), Convective available potential energy ($CAPE_{surface}$), $CAPE_{100hPa}$, Deep Convective Index (DCI), modified K-Index (K_{mod}), Potential Instability Index (PII), KO-, Showalter- & $\Delta\theta_E$-Index

* the subscript $_{100hPa}$ indicates that the properties of the lifted air parcel are mixed over the lowest 100 hPa

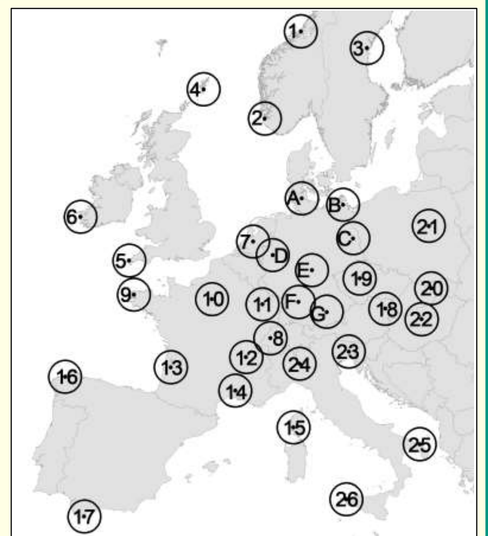

Fig. 2: Detection radius(100 km according to Haklander 2003) of radiosondings in Germany (A-G) and Europe (1-26).

trend analysis 1978-2009

"Has the convective potential of the atmosphere changed significantly over the last 30 decades in Germany?"

Methods:

- Adjustment of a distribution function (Gamma and Weibull) and quantification of the 90% / 10% percentiles per year
- Consideration of auto-correlation in time series.
- Estimation of significance after Mann Kendall (MK) test.

➡ Indices considering near-surface temperature and moisture show a trend towards higher convective potential; indices considering values at higher levels or mixed over the lowest 100 hPa show a decrease in stability.

➡ Reason: different trend directions of temperature and humidity at the various layers.

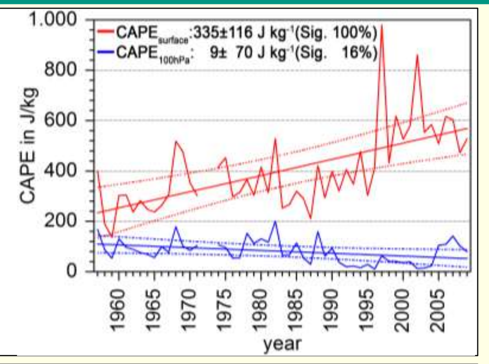

Fig. 3: Time series (1957 to 2009) of the 90% percentile of two convective parameters at station Schleswig; indicated are the linear trend (solid) with 95% confidence intervals (dashed).

a)

index	Schleswig	Greifswald	Lindenberg	Essen	Meiningen	Stuttgart	Munich
$CAPE_{Boden}$		x	x				
$CAPE_{10hPa}$	x			x	x	x	x
$CAPE_{100hPa}$	x			x	x	x	x
LI_{Boden}		x	x				
LI_{100hPa}	x		x	x	x	x	x
Showalter			x	x	x	x	x
KO-Index	x			x			x
DCI_{Boden}	x	x					
DCI_{100hPa}	x		x	x	x	x	x
K_{mod}	x	x		x		x	x
Pot.Inst.Index	x			x		x	
$\Delta Theta_E$			x				
SWISS12	x	x	x	x		x	
SWEAT	x		x	x	x	x	x

b)

meteoro-logical parameter	Schleswig	Greifswald	Lindenberg	Essen	Meiningen	Stuttgart	Munich
$TEMP_{surface}$		x					
$TEMP_{950hPa}$		x	x		x		
$TEMP_{900hPa}$		x			x		
$TEMP_{850hPa}$	x	x		x			
$TEMP_{700hPa}$	x	x	x	x	x	x	
$TEMP_{500hPa}$	x	x	x	x	x	x	
$RS_{surface}$			x				
RS_{950hPa}		x			x	x	x
RS_{900hPa}	x	x		x		x	x
RS_{850hPa}		x				x	x
RS_{700hPa}	x	x				x	x
RS_{500hPa}							
$RF_{surface}$	x	x	x	x			

labilisation / increase
stabilisation / decrease
90% significance
80% significance
no significance
CAPE calculation about surface values
CAPE calculation about low levels

Fig. 4: Linear trend (1978-2009) and significance (Mann Kendall test) of (a) different convective parameters and (b) temperature, mixing ratio (RS) and relative humidity (RF) at different pressure levels.

temporal homogeneity

"To what extent are the soundings homogenous?"

Methods:

1a) Change Point (CP) test (Wilkoxon rank sum test) according to Gaffen (2000)

1b) Estimation of sample characteristics before and after the CP

1c) Effect of deviations quantified by using a standard profile after Weisman and Klemp (1982).

2) Comparison of near-surface values from sounding and adjacent synoptic station (Fig. 5).

➡ Change Points can be detected, but not at all stations (e.g., not at Stuttgart and Munich).

➡ Trends are confirmed by synoptic station data (see Fig. 5).

➡ Trends are larger compared to the effects caused by instrumental change.

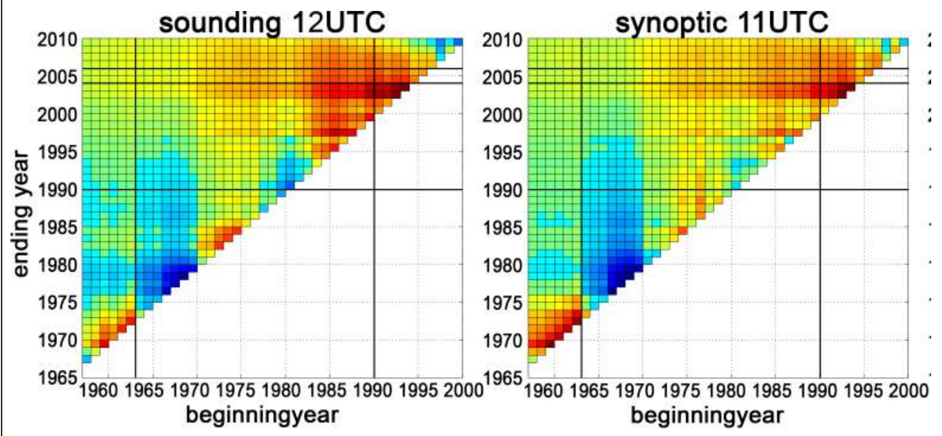

Fig. 5: Matrix with linear trend per year for varying time periods (at least 10 years) for the 90%-percentile of surface mixing ratio for the station of Schleswig from the 12 UTC sounding (left) and from synoptic data on 11 UTC (right); the x-axis represents the beginning year, the y-axis the ending year. Bold lines indicate changes in the sounding type according to IGRA and DWD metadata.

trend analysis in Europe (1978-2009)

"How has the thunderstorm potential changed in Europe?"

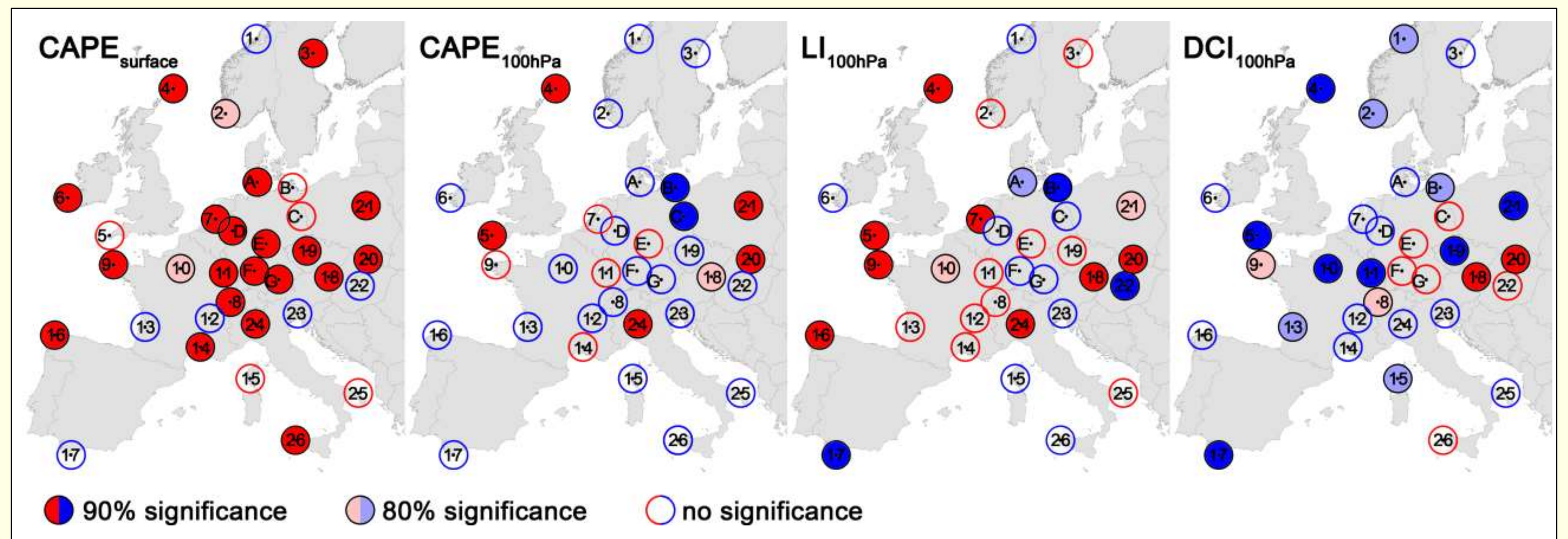

Fig. 6: Linear trend (1978-2009) and significance for different convective parameter for Germany (A-G) and Europe (1-26).

➡ A significant change towards higher convective potential is found for most indices, particularly for those calculated from near-surface values ($CAPE_{surface}$, $LI_{surface}$, PII, $\Delta\theta_E$ & KO-Index).

➡ Other indices (DCI_{100hPa} and K_{mod}) show no clear change signals.

trend matrix

"How sensitive are the trends to shifts in the time series?"

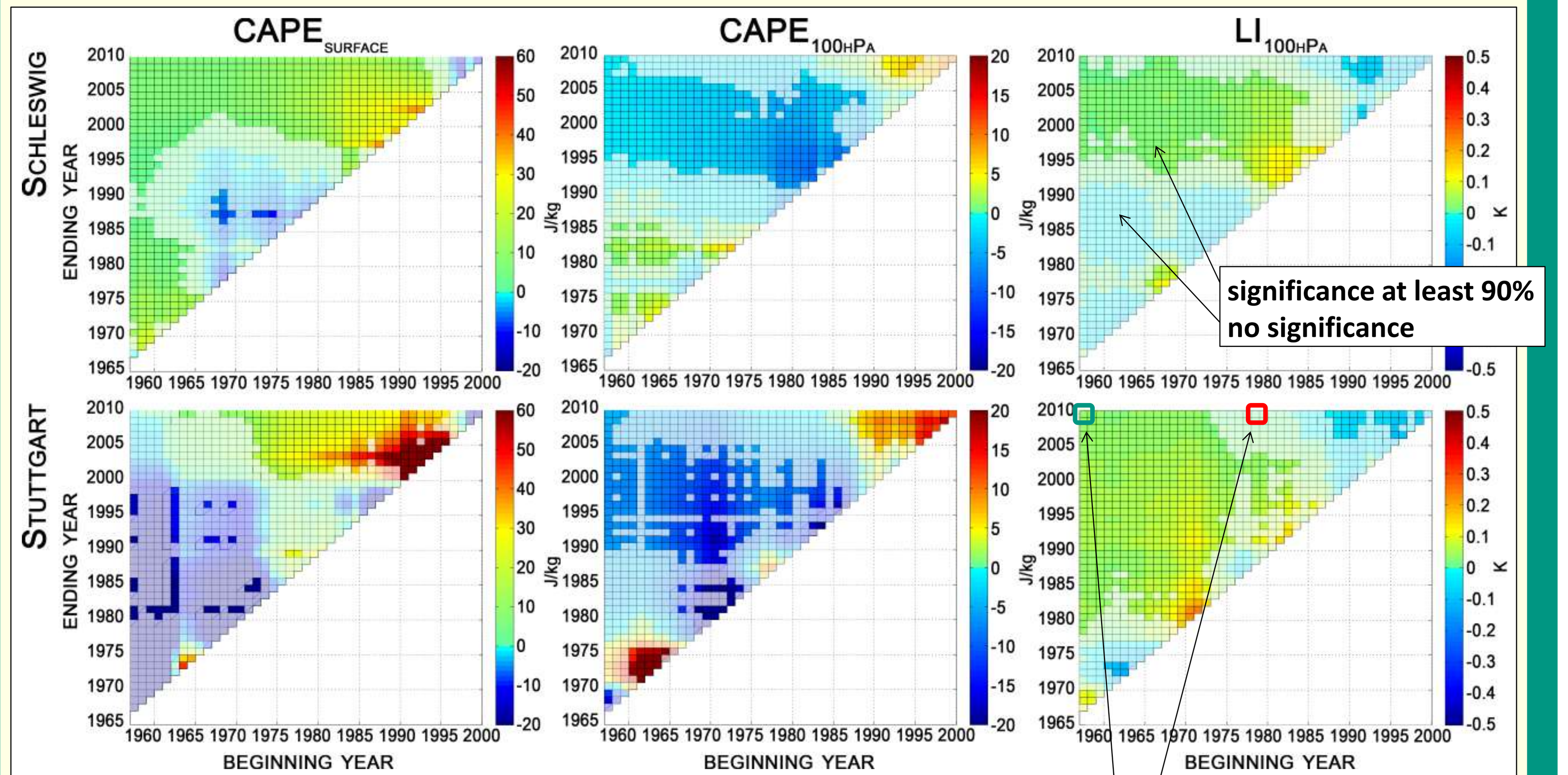

Fig. 7: Linear trends per year for varying time periods (at least 10 years) for several convective parameters calculate from the Schleswig and Stuttgart soundings. Trends with a level of significance < 90% are partly hidden by the white colour.

Example linear trend LI_{100hPa} Stuttgart :

1978-2009	**0.1 ± 0.7 (Sig. 31%)**
1957-2009	**1.6 ± 0.6 (Sig. 99%)**

➡ Indices that consider near-surface values of temperature and dewpoint (e.g., $CAPE_{surface}$) show primarily a significant increase of the thunderstorm potential at most stations in the last 20 years.

➡ Other indices (LI_{100hPa}, $CAPE_{100hPa/10hPa}$, Showalter-, modified K-, PII, Deep $Convective_{100hPa}$-, KO-Index) display an increase of the potential only in the last 10 to 20 years.

➡ Similar results were obtained for the other stations (not shown); the change in the trend direction occurred later in the north of Germany (mid-1990) compared to the south (beginning 1990s). The magnitude of the trends are higher in southern Germany compared to the northern Germany.

conclusions and outlook

- Sounding data are not homogenous. The effect on convective indices is small, but should be considered.
- Over recent decades, the convective potential changed significantly in Germany and Europe. However, the magnitude and direction of the change signal is strongly controlled by the time period considered.
- Convective parameters using near-surface values of temperature and moisture display a trend towards higher convective potential (e.g., $CAPE_{surface}$, $LI_{surface}$), while that computed from layers aloft shows no or even reverse trends (e.g., Showalter-Index, $CAPE_{100hPa}$, LI_{100hPa}, 1978-2009).
- The different trends can be attributed to different temperature and moisture changes in the various layers. Whereas both parameters increased at lowest levels, they show only marginal trends aloft.
- Further investigation will be conducted to determine which of the parameters (or which combination) is best related to severe thunderstorms associated with large hail.
- Possible changes of the convection potential in the future will be estimated from an ensemble of high-resolution regional climate models.