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FIRST RESULTS OF CLIMATE CHANGE IMPACTS ON SEVERE CONVECTIVE STORMS IN EUROPE

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1. INTRODUCTION

Extreme weather events from severe convective storms (straight-line winds and tornadoes, hail, heavy precipitation and lightning strikes) pose a threat to life and safety of European citizens and lead to significant property damage each year. For Germany, the Munich Reinsurance Group estimates a total damage of 1 to 2 billion EUR per year. For Europe as a whole, thunderstorms are likely to cause 5 to 8 billion EUR annual total damage. A field of particular concern, and also at the cutting edge of science, is the estimation of regionalised severe convective storm risk in a changing climate with time horizon 2030.

To consider the impact of climate change on severe thunderstorms, it is necessary to assess atmospheric conditions and derived convection-indices. Therefore, an algorithm was developed for calculating reversible CAPE and vertical wind shear on the basis of 3-dimensional meteorological fields. This is in line with recent investigations by Brooks et al. (2003) and Trapp et al. (2007) for the United States but extends them to Convective Inhibition (CIN, see also Colby, 1984).

This study is focussed on Central Europe. The analysis of environmental conditions associated with different kinds of weather events by using soundings is limited by spatial and temporal distribution. The development of reanalysis datasets and future scenarios with homogenous temporal and grid spacing enables the investigation of long-term studies by computing synthetic soundings.

The current atmospheric state (1958-2001) is evaluated by analysing ERA-40 reanalysis data at full vertical model level resolution. Future trends are to be derived from simulations of the regional climate model CLM. Verification of the method is attained by comparing the results with sounding-derived parameters and severe storm reports from the European Severe Weather Database (ESWD).

Our study will eventually provide an assessment of the thunderstorm probability for the current atmospheric situation and how this state is going to change due to a climate change scenario. First, some case studies are investigated to determine if severe convection may be diagnosed in reanalysis data with horizontal resolution of more than 100 km. After that, there is a closer look at convection over the last few decades and if changes in quantity or intensity of thunderstorms can already be detected. The main objective is to estimate, if and how climate change might impact convection over Europe in the future.

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2. BACKGROUND AND DATA

The research project RegioExAKT (Regional Risk of Convective Extreme Weather Events: User-oriented Concepts for Trend Assessment and Adaptation) is funded by the German research ministry. Its main objective is to determine the trends in occurrence of, and threat by, severe convective storms in Germany until 2030 and to develop adaptation concepts for targeted main users on the spatial and temporal scales relevant for their business operations.

There is a strong demand for regionalised risk assessments and adaptation strategies by weather-sensitive economic sectors like the insurance industry, international airports, and water management. The same holds for national weather services like the DWD in Germany in its efforts for optimisation of forecasts and warnings of such convective extreme events. The adaptation of existing building codes with respect to wind loads and precipitation maxima to climatic trends in extreme weather events is also economically relevant. From these target groups, Munich international airport and the Munich Reinsurance Group were chosen as exemplary users.

Our study is based on the following data:

- The current atmospheric state (1958-2001) is evaluated by analysing ERA-40 reanalysis data at full vertical model level resolution. (1.125° horizontal resolution, 6h time resolution, atmospheric fields: wind, temperature, specific humidity, pressure).
- Verification of the ERA-40 parameters is attained by comparing them with those from radiosondes (http://weather.uwyo.edu/upperair/sounding.html) and severe storm reports from the European Severe Weather Database (www.essl.org/ESWD/, Dotzek et al. 2008).
- Future trends will be derived from simulations of the regional climate model CLM (www.clm-community.eu, Scenarios A2, A1B, B1).

The present study focuses on the first two steps: Investigation of the environmental conditions derived from the ERA-40 reanalysis dataset and verifying the method/results with those from available soundings.

3. METHOD AND VERIFICATION

At the University of Hamburg, trend-studies of CAPE on the base of ERA-40 reanalysis on pressure levels have already been made in a different context (Riemann, 2007). Their existing routine for an ascent of a parcel was the starting point for the present ERA-40 evaluation.

The program was adapted for model-level data. The advantage of ERA-40 reanalysis on model levels is the high vertical resolution in the lower troposphere. However, because of pressure-differences of more than 50 hPa between upper model levels, an interpolation routine was applied to optimize the integration. The new model levels had a maximal vertical spacing of 5 hPa.

We took the features of a parcel representing the atmospheric conditions of the lowest 100 hPa for calculating Mixed-layer-CAPE (MLCAPE). Additionally, vertical wind shear between surface and 6 km was computed, as Brooks et al. (2003) and Trapp at al. (2007) had advocated the product of CAPE and deep-layer vertical wind shear as suitable to estimate thunderstorm probability. Furthermore, CIN is a critical parameter for the initiation of deep convection.

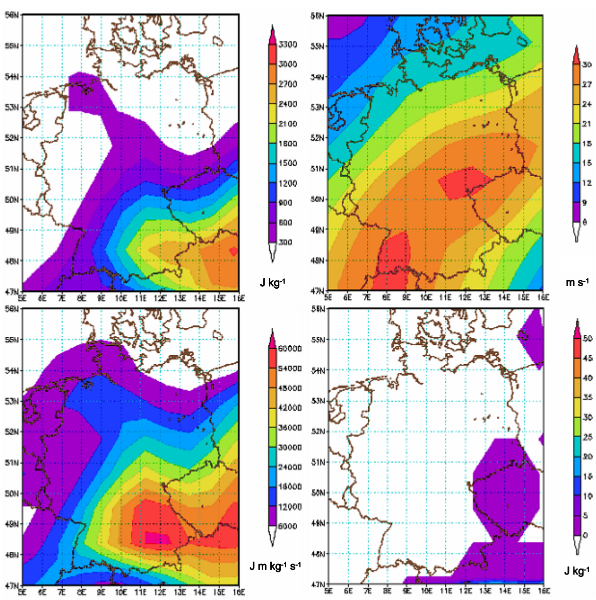

Figure 1: Convection parameters for the severe hailstorm in Munich on 12 July 1984, 18 UTC. Top left: CAPE; Top right: SHEAR (0-6 km); Bottom left: CAPE x SHEAR; Bottom right: CIN.

A first investigation if reanalysis data with a horizontal resolution of more than 100 km show the potential of significant convection was made for the hailstorm in Munich on 12 July 1984. Fig. 1 shows the results of CAPE, vertical deep-layer wind SHEAR, CAPE x SHEAR and CIN for this severe convective event. High CAPE-values advance from Austria/Czech Republic to the south-east of Germany. Accordingly SHEAR shows a ridge of high values from south-west to eastern Germany. The product of CAPE and SHEAR has peak values in the Munich region. Our analysis also revealed that CIN was approaching zero, thus enabling convective initiation (Colby, 1984). So this and other studies like for the F4 tornado in Pforzheim on 10 July 1968 confirm that convective events can be diagnosed with ERA-40 reanalysis, despite their low spatial resolution.

Brooks et al. (2003) showed that a combination of CAPE and vertical wind shear has a broad distribution for non-severe thunderstorms in CAPE and shear values, and that this distribution becomes narrower for more severe thunderstorms. Tornadoes are primarily connected to high shear values (Fig. 2, top).

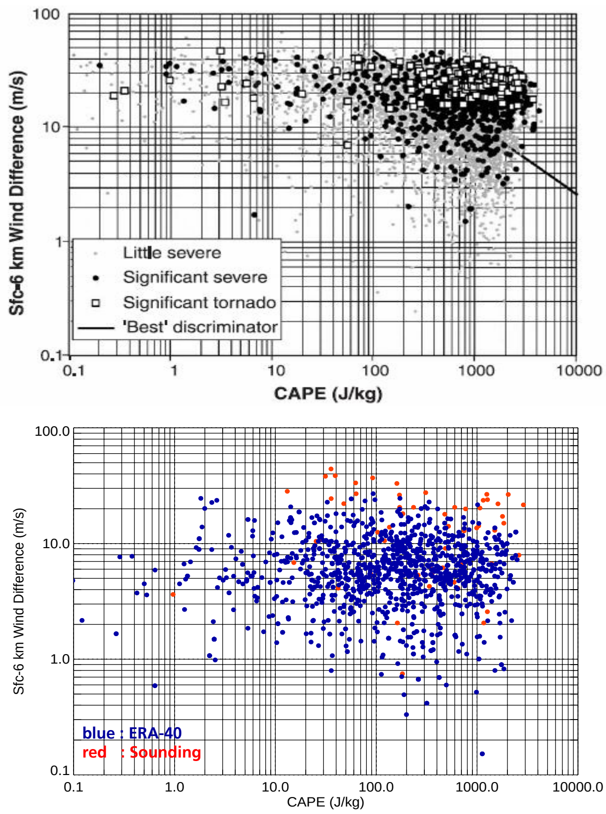

Figure 2: Scatterplots of CAPE and SHEAR 0-6 km, top: Brooks et al. (2003) results for days with severe convection in the US; bottom: our results for days with severe convective events in Europe on the basis of ERA-40 (blue) and soundings (red).

The same study was made by using ESWD-reports (damaging winds, large hail, tornadoes, floods, heavy precipitation, etc.) and plotting the CAPE vs. 0-6 km SHEAR (fig.2, bottom) as well as LCL vs. 0-1 km SHEAR (fig.3, bottom). The blue dots are computed convection-index values of the ERA-40 grid point. The red points are the computed values from the associated sounding of this grid point.

Johns, Davies and Leftwich (1993) derived a hyperbolic relation of CAPE and low-level vertical wind shear (0-1 km) in the environment of a tornado (Fig. 3). This is also notable in our ERA-40 analysis for Europe.

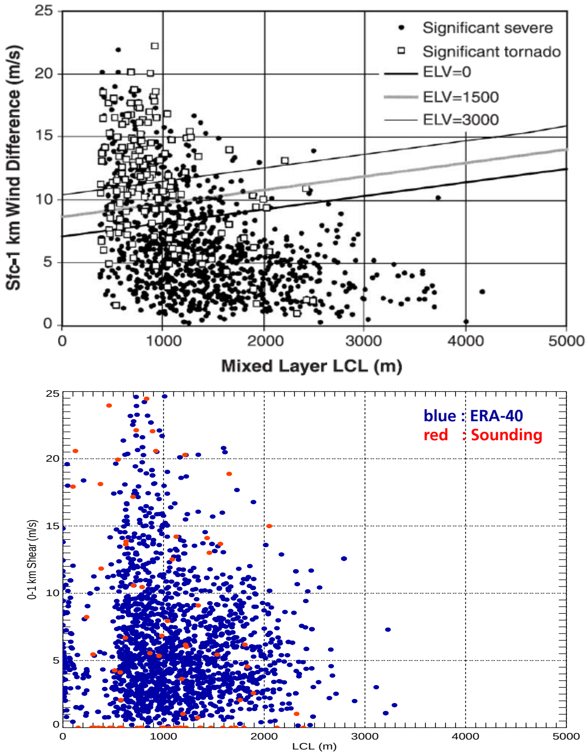

Figure 3: Scatterplots of LCL and SHEAR 0-1 km, top: Brooks et al. (2003) results for days with severe convection in the US; bottom: results for days with severe convective events in Europe on the basis of ERA-40 (blue) and soundings (red).

To generate the scatterplots of Fig. 2 and Fig. 3 we consulted the ESWD-database with all verified events between 1958 and 2002 and determined the point of time and geographical position. Afterwards the CAPE-algorithm calculated a synthetic sounding at associated grid point in ERA-40 (red dots in Fig. 2 and Fig. 3).

Next step was the acquisition of observed soundings from the homepage of the University of Wyoming (http://weather.uwyo.edu/upperair/sounding-.html). This database contains soundings from 1973 onward. Events between 1958 and 1972 could not be cross-checked this way and were only computed on the basis of ERA-40 reanalysis.

Not every grid point has a sounding associated with it. In addition, some soundings do not provide measurements homogenously in time. All available soundings that could be used for deriving convection indices are shown by red dots in Fig. 2 and Fig. 3.

Aside from the parameter analysis, we have also investigated trends in CAPE for recent decades in Europe. For this purpose CAPE computed from ERA-40 was separated in different classes: zero CAPE, <500 J/kg, 500-1000 J/kg, and so on.

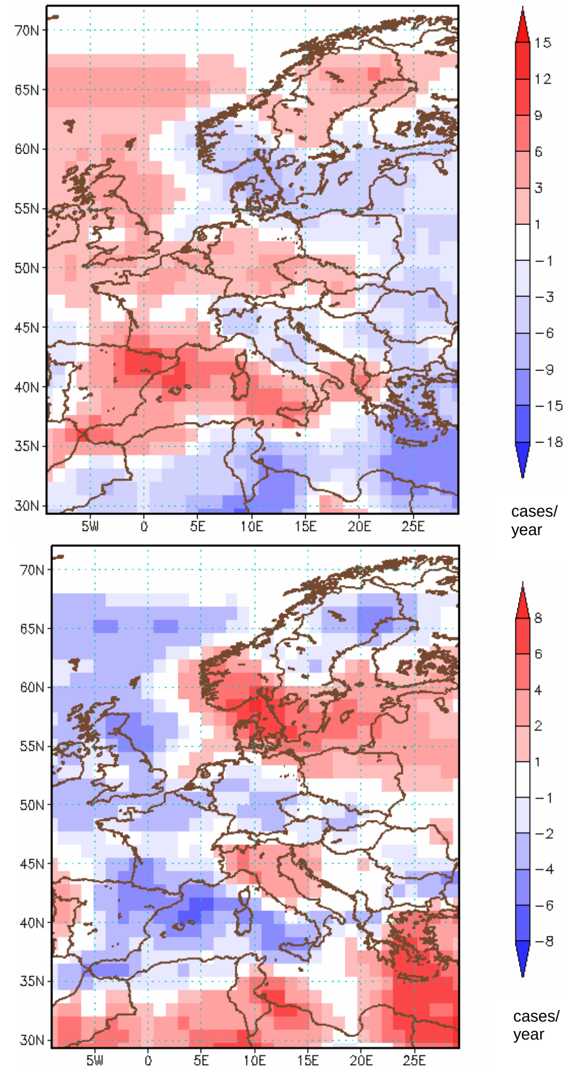

Figure 4: Annual trends of zero-CAPE (top) and CAPE < 500 J/kg (bottom) situations between 1979 and 2001, based on ERA-40 data.

Fig. 4 shows an increase in zero-CAPE cases in ERA-40 data over Western Europe. There is an increase in convective events with CAPE-values between 0 and 500 J/kg over Northern Italy, Southern Norway and Greece. However, these different trends need further corroboration.

Presently there is neither a separation of summer or winter trends, nor of the daily cycles. There have to be further investigations on the initiation of convection occurring between April and September and how this initiation is caused. We are interested in the initiation effects caused by a changing climate. So there is also the challenge to distinguish between air mass thunderstorms and storms that are forced by large-scale weather situations.

4. CONCLUSION

Our study presented first results for trends in severe convective storms over Europe. We conclude:

- Convection parameters can be evaluated from reanalysis data with horizontal resolution of more than 100 km;
- It is important to make a synopsis of all relevant parameters to obtain robust results. The change of a single convection-index alone does not necessarily imply a change in severe thunderstorm probability;
- There are weak trends in different CAPE-classes over Europe in recent decades. Given the inherent uncertainties of reanalysis data, the significance of these trends needs further confirmation.

We will perform similar studies for IPCC-scenarios with CLM-model results and investigate potential changes in number or intensity of thunderstorms until 2030.

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