ANALYSIS OF THUNDERSTORMS WITH THE DYNAMIC STATE INDEX (DSI) IN A LIMITED AREA HIGH RESOLUTION MODEL

T. Schartner[1], P. Névir[1], G. C. Leckebusch[1], U. Ulbrich[1]

[1]*Freie Universität Berlin, Carl-Heinrich-Becker Weg 6-10, 12165 Berlin, Germany,*
thomas.schartner@met.fu-berlin.de
(Dated: 15 September 2009)

I. INTRODUCTION

Convective extreme weather events like heavy precipitation, large hail and lightning strikes are related with non-stationary, diabatic and moist processes. Parameters generally used for the analyses of the potential of thunderstorms like CAPE or the KO-Index consider only the thermodynamical aspects. However, the state of the atmosphere described by these parameters is used for the parameterization of convective activity in global and high resolution models like COSMO-DE. On the basis of the energy-vorticity theory a novel parameter is proposed to diagnose non-stationary, diabatic, moist and friction processes. This parameter, called Dynamic State Index (DSI), shows the deviation from an adiabatic, dry, inviscid and stationary state of the atmosphere. Therefore, the DSI shows important atmospheric phenomena associated with diabatic, wet, frictional and non-stationary processes.

In this study, we investigate the DSI and other thunderstorm parameters computed from output of a limited area model. We utilize the DSI as an activation parameter, and CAPE as an availability parameter. It is shown that the combination of these two parameters gives a more reliable indication for convective activity than a single parameter.

II. THEORY

The Dynamic State Index was innovated on basis of the energy-vorticity theory. In the physical sense, the index links the conservation of energy together with the conservation of Ertel's potential enstropy. An index value of zero (DSI=0) means the atmosphere is in an energy vorticity state, which is given by a stationary, inviscid, dry and adiabatic solution of the primitive equation (Weber and Névir, 2008). The index is defined in the following way.

$$DSI = \frac{1}{\rho}\frac{\partial(\Pi,\theta,B)}{\partial(x,y,z)}$$

Π – Ertel's Potential Vorticity
θ – Potential Temperature
B – Bernoulli Streamfunction
ρ – Density

Thus, the index (DSI ≠ 0) incorporates the effects of all non-stationary, diabatic, moist processes an friction in the atmosphere, calculated from temperature, geopotential height and wind velocity data. Weber and Névir (2008) have applied the DSI concept to describe synoptic scale processes. They have shown that the DSI can identify the location and the strength of extra-tropical storm tracks. Claußnitzer et al. (2008) have applied the DSI to high resolution numerical models of the atmosphere, like COSMO-EU and COSMO-DE. They found a high correlation between local values of DSI and precipitation in the data. Moreover, calculating the DSI with the non-hydrostatic COSMO-DE convective cells can be detected.

III. METHODS

For our comparison we choose the time period from 1st May until 31th May 2007. The meteorological data sets stem from the limited area high resolution model COSMO-DE of the German Weather Service (DWD). This model has 50 layers in vertical direction and a spatial resolution of 2.8 km. The temporal resolution of the archived data is one hour. The model area of COSMO-DE comprised Germany, Austria and Switzerland. For detection of thunderstorms the nowcast GmbH provided the lightning data from the lightning detection network (LINET). The examined parameters are CAPE and the combination of DSI&CAPE.

Our approach is the combination of an activation parameter (DSI) and the availability parameter (CAPE), the Thundery Index (TI).

$$\mathsf{TI} = |DSI|^{\alpha} * CAPE^{\beta}$$

In this equation α and β are adjustable exponents. For our comparison we choose α = 0.6 and β = 0.5.

As verification parameters, the Thundery Case Probability – TCP (Haklander and van Delden, 2003) and scores based on contingency tables such as Heidke Skill Score and True Skill Score are used.

IV. RESULTS AND CONCLUSIONS

This chapter points out that the combination of an activation parameter (DSI) and the availability parameter (CAPE) is useful for the diagnosing of thunderstorms. Answering the question whether a lightning strike occurs or not, we take the Thundery Case Probability (TCP). The TCP for the all individual CAPE values shows a rather small dependence on CAPE for values higher than about 400 J/kg, with a maximum TCP of 50% (Fig. 1).

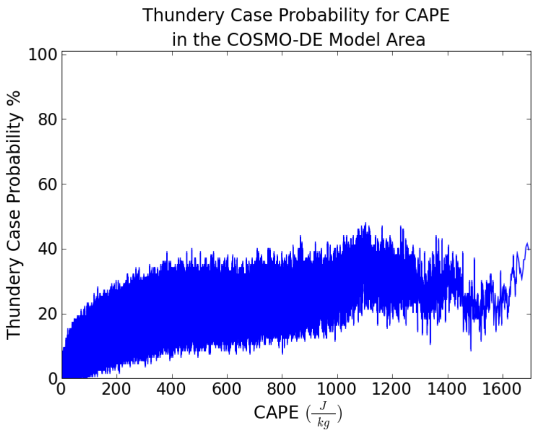

Fig1: Thundery Case Probability for CAPE

Concerning CAPE alone, a thunderstorm may occur or not. By contrast, the TCP has a stronger dependence from the Thundery Index, with a maximum value of 100% (Fig.2).

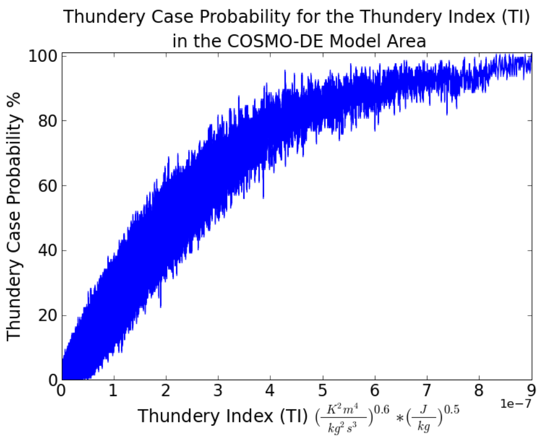

Fig2: Thundery Case Probability for the Thundery Index (TI)

Thus, the TI gives a good estimation and a definite value of the occurrence of a thunderstorm event in the COSMO-DE analysis, which is a clear improvement against the estimation from CAPE. Furthermore, the curve shows that the magnitude of the Thundery Index is related to atmospheric conditions generating thunderstorms.
If we choose the Thundery Index as a dichotomous thunderstorm predictor, indicating the occurrence of thunderstorms when a certain upper threshold value is exceeded, we calculate the Heidke Skill Score and the True Skill Score (TSS) for all values of the Thundery Index (Fig.3).

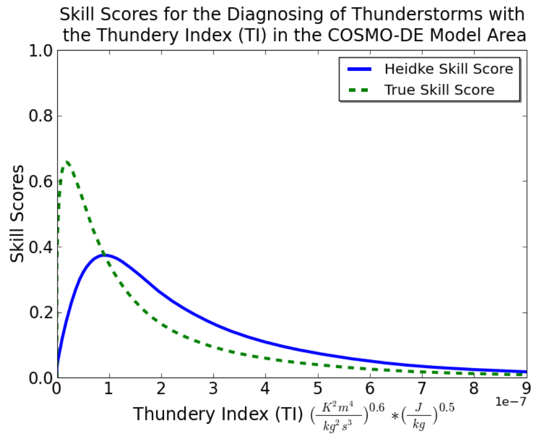

Fig3: Heidke Skill Score and True Skill Score for the Thundery Index (TI)

The difference between Heidke and TSS is due to the characteristics of this score. While the TSS is linked with a high probability of detection (POD), the Heidke Skill Score penalises every mistake (missing and false). So, the Heidke Skill Score is related with the false alarm rate (FAR). The Heidke skill score and the TSS for the Thundery Index have maximal values of 0.37 and 0.66 respectively (Fig 3). Considering the random errors in space (2.8 km) and time (hourly data sets) for high resolution models like COSMO-DE, the Thundery Index is in contrast to CAPE a novel approach for the diagnosing of thunderstorm. The advantage of the Thundery Index is the combination of all relevant dynamical processes and thermodynamical processes.

In conclusion this study reveals the potential of the DSI to forecast convective and lightning events in spatial temporal range of the mesoscale. Down to the present day, the understanding of this scale is a challenge. Therefore, further work will focus on the agreement of TI with local convective cells resolved in the non-hydrostatic COSMO-DE.

V. ACKNOWLEDGMENTS

This work is funded by the Federal Ministry of Education and Research (BMBF) and is part of the klimazwei project. The cooperation with other groups was essential for the success of this work. H.-D. Betz (nowcast GmbH) provided the lightning data from the LINET System and J. Sander (DLR) the CAPE algorithm.

VI. REFERENCES

Claußnitzer, A., Névir, P., Langer, I., Reimer, E., Cubasch, U., 2008: Scale-dependent analyses of precipitation forecasts and cloud properties using the Dynamic State Index, *Meteorol. Zeitschrift*, 17, 813-825.

Haklander, A. J.., Van Delden, A., 2003: Thunderstorm Predictors and their Forecast Skill for the Netherlands, *Atmos. Res.*, 67-68, 273-299

Weber, T., Névir, P., 2008: Storm Tracks and Cyclone Development using the Theoretical Concept of the Dynamic State Index (DSI), *Tellus*, 60(A), 1-10