The role of convective available potential energy for tropical cyclone intensification

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The research project will focus on the investigation of the relevance of convective available potential energy (CAPE) for tropical cyclone intensification. Numerical model simulations will be conducted and analysed to reveal whether CAPE exists during the intensification phase, how it is distributed, and the particular role it may play for the evolution dynamics. According to the WISHE theory for tropical cyclogenesis (WISHE=Wind Induced Surface Heat Exchange), the existence of CAPE is not required in the intensification process. However, this theory only leads to a conclusive result, if the net latent heating in the outer region of a tropical cyclone vanishes due to the assumption of low relative humidity. Such an assumption is not necessary when CAPE can be stored in the inflow boundary layer. The 3-dimensional cloud resolving model CM1 (Bryan and Fritsch 2002) will be applied for the study. The research is based on the hypothesis that CAPE contributes to an increase in the intensification rate.

The basic assumption of the project is that CAPE in tropical cyclones could raise the intensification rate. Fig. 1 provides a sketch of a developing tropical cyclone to exemplify the idea. The red lines show isolines of entropy below the lifting condensation level (LCL) and saturation entropy above the LCL. In the case without CAPE these lines slant outwards in vertical direction and there is no region where the entropy value decreases with height. With nonzero CAPE, a negative vertical gradient appears in the lower part of the atmosphere. The arrows represent the secondary circulation. Due to air-sea interaction entropy increases towards the centre and, thereby, CAPE can be generated. Air exits the boundary layer and rises vertically in the eyewall in which the entropy is approximately individually conserved. Consequently, a large negative radial gradient of saturation entropy arises above the LCL. This gradient is related to the gradient wind via the thermal wind balance equation (e.g. Emanuel 1986). If CAPE were immediately diminished as in the WISHE theory, the radial gradient would be much weaker and possibly no intensification could take place as explained above. We suggest that tropical cyclogenesis appears as a combination of WISHE and CISK (Conditional instability of the second kind). WISHE is important for the generation of CAPE and CISK is important for the inward energy transport in the boundary layer and release of latent heat in the eyewall of the developing cyclone. Such a view is supported by Schönemann and Frisius (2012) in terms of a conceptual tropical cyclone box model. However, it is not clear that this result holds in reality and in more complex models. To decide the question, this project aims to investigate the role of CAPE in tropical cyclone intensification with axisymmetric and 3-dimensional cloud resolving models.

To gain some insight into the role of CAPE for tropical cyclone intensification, models of different complexity will be used. First, the role of the CAPE field will be investigated in idealized tropical cyclogenesis experiments. For this purpose, the three-dimensional cloud model CM1 will be adopted. The intensification rates are to be compared with different initial CAPE and different surface transfer coefficients for enthalpy and momentum. These comparisons provide information about the role of surface transfer and initial CAPE on intensification rate. The CAPE field during intensification can significantly differ from the initial CAPE field. For this reason the analysis of the CAPE field evolution is expected to give further insights into the intensification mechanism. Furthermore, it is of interest to analyse the convective inhibition energy (CIN) since CAPE can be stored by convective inhibition. Frisius and Hasselbeck (2009) found nonzero CIN in a simulation with latent cooling switched off. However, CAPE can also develop without convective inhibition. Convection has a certain time scale and, therefore, some CAPE remains when the generation rate of CAPE is large enough. This is the case in the inflow boundary layer of a tropical cyclone. As an example, if the inflow velocity is 10 m/s and the timescale for convection 2 hours, then, an inflowing control volume will lose its initial CAPE after a distance of 72 km, while in the meantime the volume can gain enough new CAPE by air-sea interaction. In the simple box-model of Schönemann and Frisius (2012) this is indeed the case and the intensification rate is proportional to the square-root of the product between the surface transfer coefficients for enthalpy and momentum. Now, we would like to test, whether this result is confirmed by the output of the complex atmospheric models.

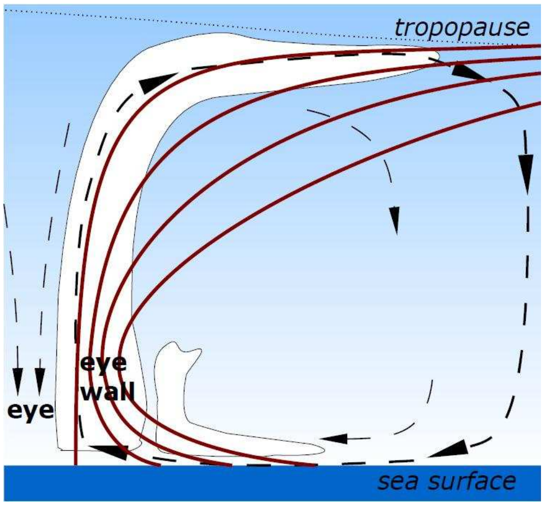

Figure 1: Schematic cross-section of an intensifying tropical cyclone. Arrows display the secondary circulation and red lines are isentropes.

References

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