5th European Conference on Severe Storms 12 - 16 October 2009 - Landshut - GERMANY

North Atlantic extra-tropical cyclone intensity, wind field, and CAPE: a case study

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(Dated: 15 September 2009)

I. INTRODUCTION

Extratropical cyclones cause severe weather in the mid-latitudes, in part accompanied by heavy precipitation and strong winds. Most of the precipitation is produced within the fronts, especially along the cold front (Browning and Harrold, 1970). Nevertheless convection is an important contributor to the total precipitation involved in a mid-latitude cyclone. In an occluded front, part of the precipitation is caused by convective instability, while the post-frontal precipitation is exclusively triggered by this mechanism. In this study, convective precipitation in an intense mid-latitude cyclone is analysed by CAPE (Convective Available Potential Energy) and the antagonist CIN (Convective INhibition).

II. DATA AND METHODOLOGY

The data set used is given by the re-analysis ERA-40 of the European Centre of Medium-Range Weather Forecasts (ECMWF) with 6-hour resolution. The data is interpolated to T63 spectral trunction. An intense cyclone is investigated 920 hPa pressure minimum starting at January 10, 1993, and a total life time of 5 days. This cyclone has been determined in the course of an extreme value analysis of the most intense cyclones in ERA-40 and ECHAM5 model simulations (Sienz et al., 2009).
CAPE is given by the potential energy available which can be transformed to kinetic energy to develop cumulus clouds. It is calculated as the difference of virtual temperature between an idealized rising air parcel and that of its environment, computed pseudo adiabatically from a mixed layer parcel. The mixed layer extends from the surface over the lowest 100 hPa. In the ERA-40 reanalysis CAPE is used in parametrization of convective precipitation. CIN works as the counterpart of CAPE and describes the convective energy needed by the rising parcel to overcome the usually stable boundary layer to reach the level of free convection.

III. RESULTS AND CONCLUSIONS

The life cycle in this case study is determined by the central geopotential height, and the area averaged thermodynamic variables mixed layer temperature and specific humidity, CAPE, and CIN, which are compared to the development of total and convective precipitation (Fig. 1). The mixed layer temperature and humidity are averaged in the lowest 100 hPa. The horizontal extension is given by the radius determined by a fit of a Gaussian function to the 1000 hPa geopotential height (Schneidereit et al., 2009). The radius is marked for a specific time step in Fig. 2.

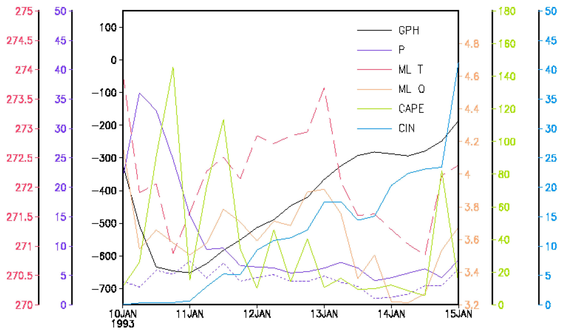

FIG. 1: Area averaged life cycle of a cyclone case study, with 1000 hPa geopotential height GPH, total precipitation (*P*, solid), convective precipitation (dashed, [mm/day],) mixed layer temperature (ML-T, [K]), and specific humidity (ML-Q, [g/kg]), CAPE, and CIN [J/kg]. The scales are given on the left and the right axes with the same colours.

During the life cycle, the central geopotential height reaches the minimum after the first day and increases to the environmental value after 6 days. The asymmetry of the life cycle characterizes intense cyclones while weak cyclones show a symmetric growth and decay (Schneidereit al., 2009). CAPE shows a rapid development during the first day and a successive slow decay superimposed by a distinct diurnal cycle determined by the near surface temperature. The initial increase of CAPE goes along with the rapid deepening of the central geopotential height. CIN starts with a negligible amount and grows with a nearly constant increase. Mixed layer temperature and humidity follow the intensity life cycle, however with symmetric growth and decay. Total precipitation which is mainly based on stratiform convection, attains its maximum during the first day. Thereafter one day total and convective precipitation remain approximately constant throughout the life cycle. During the second half of the last day high values of temperature, humidity, CAPE, and CIN are obtained.

At the CAPE maximum the distributions of total and convective precipitation are compared to CAPE (Fig. 2). At this time the cyclone is occluded and its frontal area extending from Iceland towards the North Sea. Remnants of the warm front occur near Denmark while the cold front follows the British Channel.

Intense total precipitation (left panel) is concentrated along a narrow rainbandof the occluded front. A second, minor (occluded) depression produces precipitation in the Norwegian/Barents Sea. Post-frontal rainfall west of Ireland is embedded in a north-westerly flow. Convective precipitation (middle) demonstrates the stratiform origin of frontal rainfall. Only in the centres of both cyclones convection contributes to rainfall. In the post-frontal areas of both cyclones, convective precipitation accounts for at least half of total precipitation.

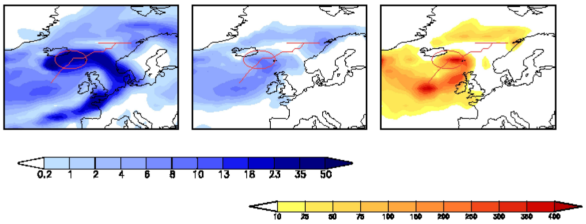

FIG. 1: Precipitation and CAPE at the maximum of CAPE (January 10, 1993, 18UTC). Left panel: total precipitation, middle convective precipitation, right CAPE. The red line is the trajectory and the marked area shows the cyclone position at the maximum, the extension indicating the width of the averages in Fig. 1.

CAPE (right panel) is closely related to convective precipitation, caused by cold Arctic air advected to the warm North Atlantic. Along the cold front CAPE vanishes and convective precipitation is absent.

The benefit of the present analysis is hampered by the fact that the parameterization of convective precipitation is based on CAPE. Therefore, the present study needs to be extended to the analysis of observed precipitation.

IV. AKNOWLEDGMENTS

Thanks to Frank Sielmann for his support in CAPE calculations, and to DKRZ, DWD, and ECMWF for the data. AS acknowledges the Sonderforschungsbereich 512 (Tiefdruckgebiete und Klimasystem des Nordatlantiks) and KRC acknowledges the support by IMPRS-ESM.

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