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Statistical downscaling of subgridscale precipitation

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Abstract Deficiencies exist in the detailed description of precipitation in climate models and numerical weather prediction models. Therefore it is necessary to develop concepts for downscaling precipitation depending on the synoptic situation. Subgridscale precipitation which is not influenced by fronts or orography is considered (e.g. airmass showers) and a conceptual model has been developed which gives information about precipitating cells such as their intensity. Based on case studies carried out with data from OMNIS, a now-casting information system developed by the German Military Geophysical Office, and the work of Austin & Houze (1972), a modified equation for determining the statistics of precipitation intensities for single cells for cloud depth and temperature at 850 hPa is shown. Incorporating the temperature at 850 hPa leads to a wider range of expected intensities than from cloud depth alone. It is shown that the precipitation amount at ground level is also influenced by the temperature at 850 hPa.

INTRODUCTION

Some deficiencies exist in the detailed description of precipitation within climate models and numerical weather prediction models. As the gridpoint values in these models represent a temporal and spatial mean value, small-scale precipitation intensities are likely to be underestimated (Dolman & Gregory, 1992). This may lead to an overcalculation of interception loss and an incorrect discharge and evaporation estimation. Precipitation and its temporal and spatial structures are influenced by the synoptic situation, and must be considered in the development of concepts for downscaling. Some precipitation structures have large spatial and temporal extent which are described by many gridpoints in large-scale models (Müller-Popkes, 1995). On the other hand, there are precipitation structures at small scales which are not resolved, but can only be parameterized by numerical models (subgridscale precipitation). This paper presents the results of a conceptual model which gives information about precipitation structures within a grid cell of a large-scale model, relying only on the use of large-scale model output.

STATISTICAL DOWNSCALING BASED ON OMNIS DATA

OMNIS data

The information system OMNIS (Operational Meteorological Now-casting Information System) developed by the German Military Geophysical Office is currently in use and represents a method for downscaling meteorological data such as temperature, humidity and wind, at different vertical levels. This system combines information from the regional weather forecast model BLM (Boundary Layer Model) with ground observations, and predicts station related hourly forecasts of meteorological parameters by numerical-statistical and empirical-climatological methods. The grid-oriented BLM predicts three-dimensional (3D) fields of the meteorological parameters pressure, wind, temperature and specific humidity, in 17 non-equidistant layers with increasing layer depth up to the tropopause, a temporal resolution of three hours and a horizontal resolution of about 63 km (Prenosil & Becker, 1990). Thus with the predictions of these two models meteorological data is available at different scales. OMNIS represents the regionalized data of the BLM. Whereas the precipitation is not predicted by OMNIS the conceptual model estimates precipitation parameters based on OMNIS and BLM data.

Conceptual model

Using a conceptual model for downscaling precipitation includes the use of only a few input and output parameters without describing further interaction between output parameters and other meteorological data (Fig. 1). The input parameters which are used by the conceptual model are cloud depth, temperature at 850 hPa and horizontal velocity at 700 hPa. Output parameters are statistical information about precipitating cells as, e.g. intensities and precipitation amounts on the ground. A single precipitating cell is described by the maximum intensity, the temporal and spatial distribution of the intensity, the lifetime, the horizontal extent and the velocity of the cell. After nearly one third of the lifetime the precipitating cell intensity reaches maximum. The rainfall intensity is spatially symmetric around the centre of the cell with exponentially decreasing intensity with increasing distance from the centre (e.g. Valdes *et al.*, 1985). The centre of the cell shifts with velocity *v*. The precipitation amount at ground level is given by the time integral of the precipitation intensity.

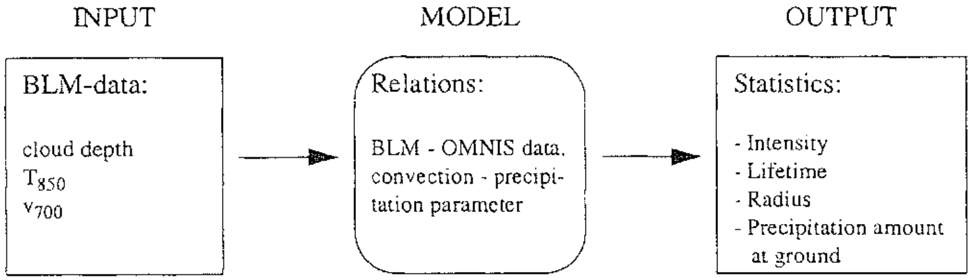

Fig. 1 Flow diagram of the conceptual model.

CASE STUDIES

To examine the input parameters of the conceptual model and their influence on the precipitation structure, three case studies were carried out. These cases are characterized by a typical weather situation where Germany is influenced by an upper level trough. The formation of airmass showers is common behind such a trough.

Estimation of precipitation intensity of a single cell

Studies by Austin & Houze (1972), Salbreiter (1986) and Gagin *et al.* (1985) show that precipitation intensities grow with increasing cloud depth and cloud height, respectively. This study is based on a linear dependence of precipitation intensity I on cloud depth cl given by Austin & Houze (1972):

$$I(cl) = a + b \cdot cl \tag{1}$$

with I in mm h^{-1}, cl in km, $a = 3.4$ and $b = 4.9$.

Further parameters exist which are suitable for qualitative description of precipitation intensities of cells. These parameters are, e.g. the temperature at cloud top, CAPE (Convective Available Potential Energy), and qw (the vertical inflow of humidity at cloud base). This last-named parameter was also used in this study. Whereas cloud depth is a more or less empirical parameter, qw is a physically based parameter. Together with the precipitation efficiency E, which can be derived by $E = I/(qw)$, the parameter qw determines the intensity I of a precipitating cell. Assuming that the linear relation between cloud depth and precipitation intensity given by Austin & Houze (1972) shows realistic conditions on average, these studies show precipitation efficiencies of about 16% which are set constant for the following applications. Such low values for the precipitation efficiencies of single shower cells are also documented by the frequently cited study of Braham (1952) who found precipitation efficiencies of about 10% for small thunderstorm cells. Investigation of storm precipitation efficiencies at different conditions, derived from numerical simulations (Ferrier *et al.*, 1996), show that efficiencies are essentially determined by the vertical orientation of the updraft (the vertical wind shear) and the humidity of the surrounding air. The humidity of the surrounding air plays a minor role as this parameter causes only 10% of the variability of the efficiency. Ferrier *et al.* (1996) refer to investigations with very different precipitation efficiencies in the range 20-120%. But, as this study is focused on storm and squall line simulations, the efficiencies given there are higher than those expected for a single precipitating cell considered in this paper. In these studies the vertical velocity is calculated indirectly by CAPE. Cloud depth and CAPE are estimated from the data of the OMNIS forecast by the classic parcel method.

Cloud depth and qw are investigated in relation to the temperature at 850 hPa given by the output of the BLM. This temperature is used instead of the temperature at ground level to eliminate the influence of the diurnal variation. Considering the parameter cloud depth in relation to the temperature at 850 hPa (Fig. 2), the tendency for higher cloud depths with increasing temperature can be seen. The mean dependence of the mean cloud depth on the temperature is entered as a linear relationship. Considering the maxima of cloud depths there is also a tendency for higher cloud depths as temperature increases, but the envelope line for the maxima is based on only a few points. The relatively small values of cloud depth at temperatures of about 0°C result also from the very small number of data in that temperature interval.

Considering the parameter qw, there is a tendency for higher values of qw with increasing temperature. But this is much more marked than the tendency regarding cloud depth as can be seen by the parameter b_{qw}, the ratio between qw and cloud depth, in Fig 3. The parameter b_{qw} is not constant for different temperatures at 850 hPa, but

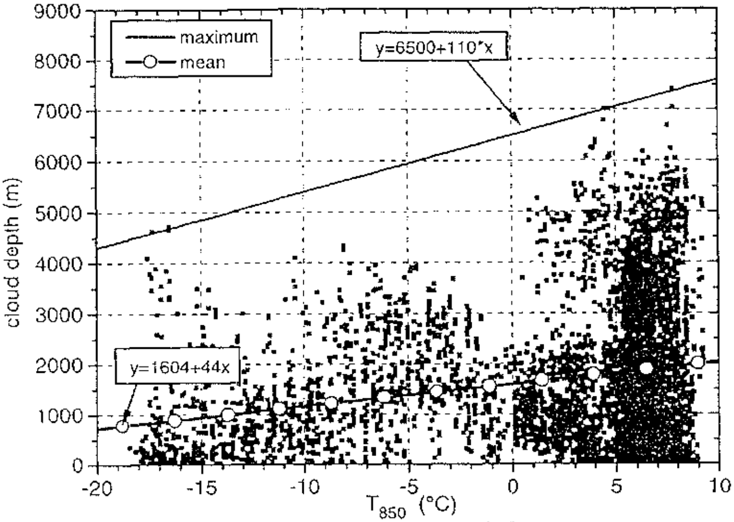

Fig. 2 Cloud depth as a function of temperature at 850 hPa.

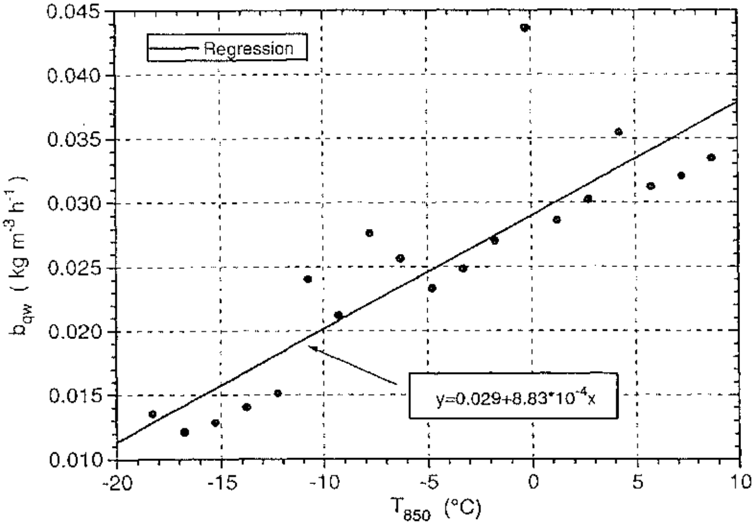

Fig. 3 Ratio between *qw* and cloud depth as a function of temperature at 850 hPa.

increases with increasing temperature. At $T_{850} = 1°C$ the value of the parameter b_{qw} is twice as high as the value at $T_{850} = -16°C$. This means that if the precipitation efficiency is constant the precipitation intensity derived by *qw* should show a marked increase with increasing temperature as opposed to the precipitation intensity derived by cloud depth. As the parameters *qw* and b_{qw} give more physically based information about the precipitation intensities, both should be incorporated in the parameterization of precipitating cells.

RESULTS

Based on this study the estimation of precipitation intensity given by Austin & Houze in equation (1) can be modified by the parameter b_{qw} depending on the temperature at 850 hPa. By introducing a correction term the intensity can be estimated from cloud depth and the temperature at 850 hPa as:

$$I(cl,T_{850}) = a + corr(T_{850})\cdot b\cdot cl \quad \text{with} \quad corr(T_{850}) = \frac{b_{qw}(T_{850})}{\bar{b}_{qw}} \qquad (2)$$

The effect of this correction term can be seen by considering the mean and maximum observed cloud depths in Fig. 4. The intensities resulting from equation (1) show a linear dependence on temperature as the intensity derived by equation (1) is proportional to the cloud depth. Considering the "corrected" intensities derived by equation (2) the dependence of the intensity on the temperature is nonlinear because the correction term in equation (2) also depends on temperature. This results in higher precipitation intensities for temperatures above 5°C and lower intensities below 5°C. Overall, this effect gives a wider range of intensities by including the temperature at 850 hPa, than estimates based on cloud depth alone.

Besides considering the precipitation intensity of showers as a moving system, it is important to know something about the precipitation amount at ground level (fixed system). Therefore the dependence of the maximum value of precipitation amount at ground level on the velocity of a moving cell and the temperature at 850 hPa (Fig. 5) is considered. On one hand a nonlinear dependence of the maximum precipitation amount on the velocity exists. Whereas the precipitation amount is nearly constant for very low velocities (up to 1 m s^{-1}), the value decreases strongly for higher velocities. At a velocity of about 5 m s^{-1} the precipitation amount is only half the value of a

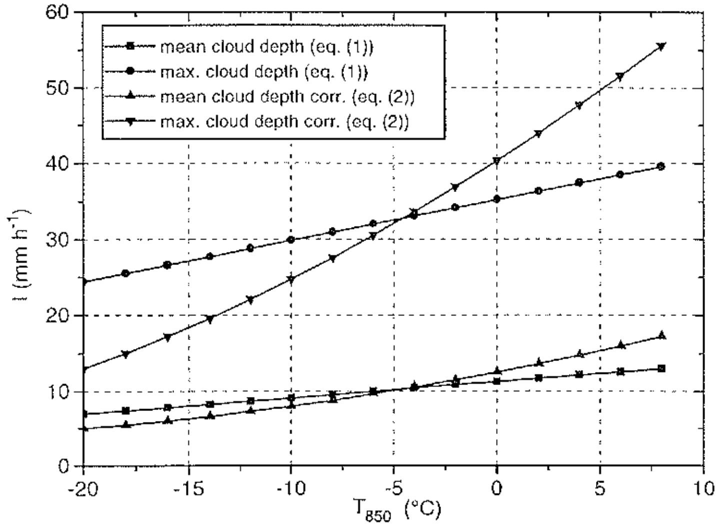

Fig. 4 Precipitation intensity as a function of temperature at 850 hPa derived by equations (1) and (2). Input data are the mean and maximum observed cloud depths (Fig. 2).

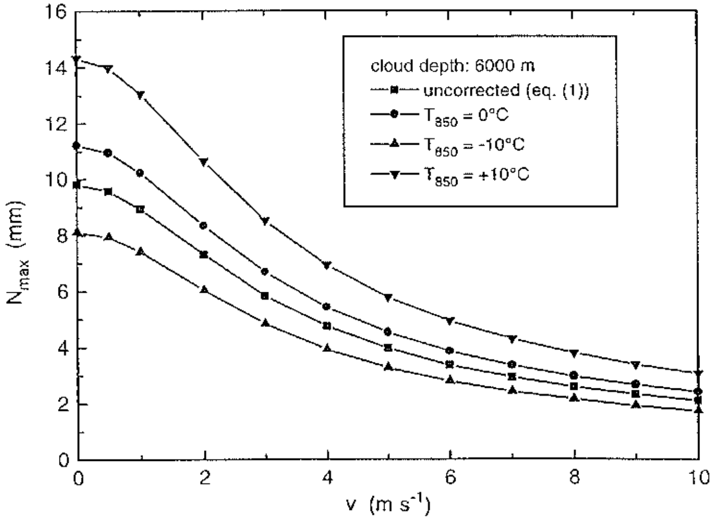

Fig. 5 Maximum precipitation amount at the ground for a single cell as a function of cell velocity v and temperature at 850 hPa (equation (2)). For comparison the precipitation amount without the influence of temperature at 850 hPa (equation (1)) is also shown.

stationary cell. On the other hand the influence of the temperature at 850 hPa given in equation (2) can be seen in Fig. 5. Considering a stationary precipitating cell, the precipitation amount at ground, without temperature correction, is nearly 10 mm. The temperature correction leads to values of about 14 mm at temperatures of 10°C and to values about 8 mm at temperatures of −10°C. Thus the maximum values of precipitation at ground level are not only influenced by the cloud depth, but also strongly influenced by the temperature at 850 hPa. The differences in precipitation amounts due to temperature correction reach values of up to 40% of the uncorrected values.

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