Chapter 1

Introduction

Currently the earth-atmosphere system appears to be in a phase of rapid global climate change. This change is reflected not only in an increase of globally averaged temperatures over the last century, but also in a change in the frequency of severe weather events and intensive storm systems in the mid-latitudes of the northern hemisphere. Global and regional climate models predict that these changes will be amplified in the future with possibly severe impacts on the earth's ecosystems as well as on human society. Possibly more important than changes in temperature will be changes in storm frequency and in the spatial and temporal distribution of precipitation.

The occurrence of natural hazards has to be linked to the spatial and temporal distribution as well as the type of precipitation. To give an example, stratiform rainfall with moderate rain rates falling continously over a period of several days often results in floods over large parts of the river drainage areas. There were a number of such events in the last decade in Germany, such as the floods at the river Rhine river and tributary streams in 1993, at river Rhine and river Neckar in 1995, at river Oder in 1997 and river Donau in 2002. The "century" flood of the river Elbe in August 2002 resulted in a top damage of approx. 15 billion Euro. Further risks of steady rain events are soil erosion or slope slides in alpine mountains.

In contrast, convective precipitation is characterised by high rain intensities being observable over a time span of only a few minutes. It is frequently accompanied by heavy weather events, such as lightning, thunderstorms or hail. The risks for civilisation arise from flash floods, damages through hail, extreme horizontal and vertical wind speeds (e.g. microburst). Since the damage costs have been incredibly high, the society is interested in reliable predictions and forecasts of extreme weather events. It is thus a matter of particular interest to investigate precipitation with respect to all aspects. There have been, however, only few studies on the relationship of rain frequency and amount and synoptic situation in the mid-latitudes. This thesis may contribute to this issue.

In connexion with these considerations I wish to address the following key questions in my thesis:

1. What is the fraction of precipitation events directly associated with frontal overpasses?
2. What is the diurnal, annual and inter-annual variability of those events?

Previous classification schemes mainly emphasised the distinction between different types of cloud microphysical processes that trigger precipitation. These classifications typically assign a precipitation event either to the classes stratiform or convective based on the main cloud microphysical processes that drive the precipitation event (e.g. Steiner et al., 1995; Biggerstaff and Listemaa, 2000; Anagnostou and Kummerow, 1997). While these classifications are of great importance to understand the day to day variability of radar observations and the variability in the relation between rain rate and radar reflectivity, they clearly can not serve to answer the above questions. Since we are concerned with precipitation on scales of several 100 to 1000 km which can not be covered three-dimensionally to its full extend by a single ground based weather radar.

Rainfall characteristics are strongly linked to the synoptic weather situation in which the events occur. Sumner (1988) defined three main types of precipitation in terms of the initial processes as follows: orographic, frontal and convective. Shepherd et al. (1988) suggested the application of space-time correlation analysis to radar data in order to distinguish showery and frontal precipitation.

Tetzlaff and Hagemann (1986) analysed the precipitation type by the means of synoptical weather observations of the Hannover-Herrenhausen station (North Germany) for a period of six years (1979-1984). The rain events were subdivided into several classes according to the synoptic situation that triggered the precipitation event. The pie chart in Fig. 1.1 shows the relative frequency of occurrence of the precipitation classes warm and cold fronts, occlusions, up-slide zone at the centre of a low pressure system, warm sector, showers at throughs and at the backside of cyclones. The authors considered the first three rain classes (warm, cold front and occlusion) as parts of fronts, but not the up-slide zone. They stated, that about half of the total amount of precipitation is observed when fronts cross the observation station. The up-slide zone at the low pressure centre is directly connected spatially to the occlusion front. The connectivity of precipitation field is an essential feature of the algorithm developed within my thesis work and explained below. If one adds this class to the frontal part of precipitation about 60 % of total precipitation events fell in association with frontal systems.

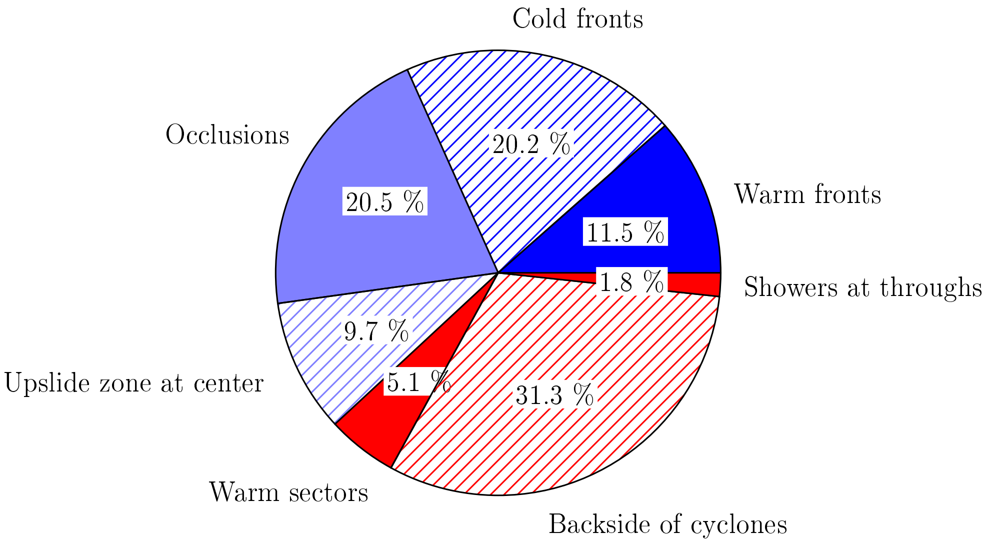

Figure 1.1: Percentage of rain classes at observation station Hannover-Herrenhausen 1979-1983 (from Tetzlaff and Hagemann, 1986). Blue parts can be associated with frontal overpasses.

The classification approach developed here is based on the work from Tetzlaff and Hagemann (1986) and is thus not strictly microphysical but distinguishes different types of precipitation based on the large scale characteristics of radar composites. Such characteristics include the horizontal extent of individual precipitating systems, their spatial homogeneity, as well as their temporal variation. It will be shown, that this classification is able to distinguish precipitation events associated with fronts and precipitation events that are triggered by isolated convective processes. Both the terms 'frontal' and 'convective' are hereafter used to describe the weather situation that triggers the precipitation event and not the microphysical processes that lead to the precipitation formation. Obviously, it is possible for the precipitation within a front to form via strong updrafts, thus being convective in a microphysical sense (embedded convection). Similarly, even the most intensive convectively driven precipitation events usually consist of parts where precipitation generation is driven by stratiform processes (stratiform tail). It is therefore important to note that the terms frontal and convective are used in a synoptic sense and not in a microphysical sense.

The classification approach introduced here is subjective in nature and depends on the human observer in a similar way as, for example, satellite cloud classifications depend on the human observer. An automatic classification based on the training by a human observer can hardly ever supersede the individual human classification. However, automated approaches allow the classification of large datasets in a fast and efficient manner. In fact, the same human observer might classify different cloud or precipitation systems differently when being presented to him a second time. An automatic classification approach will - after training - yield consistent results based on a subjective, but stable, set of decision rules.

Artificial neural networks have been employed in a number of studies for the classification of clouds using textural features as input parameters (Pankiewicz, 1997; Tian et al., 1999). These studies indicate that the use of neural network is well suitable for classifying typical patterns in remote sensed images.

A brief overview of the region of interest should be given. The Baltic Sea is a semi-enclosed sea located within the west-wind zone where cyclones usually coming from the west or southwest dominate. The water body covers about 415,000 km^2, while its catchment area is about four times as large. The average annual estimate of precipitation is about 700 mm with a maximum of 80 mm in August and a minimum of 40 mm in April (Skomorowski et al., 2003).

The Global Energy and Water Cycle Experiment (GEWEX) has been organised by the World Meteorological Organisation (WMO) to foster the understanding of the global hydrological cycle. As part of GEWEX, regional sub-experiments have been established to study the water balance over major catchment areas. The Baltic Sea Experiment (BALTEX) is the European sub-experiment of GEWEX with emphasis on the Baltic Sea. The BALTEX main observational period (BRIDGE) took place between April 1999 and March 2001. Within BALTEX-BRIDGE, the Swedish Meteorological and Hydrological Institute (SMHI) established the BALTEX Radar Data Centre (BRDC, Michelson et al., 2000). BRDC provides two-dimensional precipitation maps that covers large parts of the Baltic sea area. The size of the area is sufficient to monitor frontal overpasses in this region. Therefore BRDC data are well suitable for developing an automatic algorithm scheme for the separation of frontal precipitation by dint of the shape and texture of rain fields.

This thesis is organised as follows: The fundamentals and the observational radar data set are described in Chapter 2. The development and architecture of the method is explained in Chapter 3. I made some effort to derive the uncertainty range associated with the classification and to show that its accuracy does not depend on, for example, seasonal variations in precipitation. These results are summarised in Chapter 4. Chapter 5 shows the results of the application to three years of BALTRAD data. The method was applied to the regional climate model BALTIMOS in order to validate the model. This excurs is introduced in Chapter 6. Finally, Chapter 7 summaries the main findings of this study.