REASONS FOR THE CLIMATOLOGICAL PRECIPITATION GRADIENT BETWEEN THE ALPINE FORELAND AND THE NORTHERN ALPS

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Abstract: This study examines the factors leading to the climatological precipitation gradient between the northern Alpine rim and the Alpine foreland, based on routine observations and reanalysis-driven simulations with the MM5 model for the time period of 1991 – 2000. To investigate the relative contribution of different precipitation types, precipitation events are classified into 4 groups. These are: Cold fronts, warm fronts, convection and a group carrying the remaining events. Convective precipitation in connection with fronts is attributed to the respective frontal class. Unclassified events predominantly consist of postfrontal upslope precipitation and quasi-stationary fronts. In addition, the wind direction at Alpine crest level (700 hPa) is used to categorize the events, and a distinction between summer and winter is made. Two mechanisms are found to be mainly responsible for the precipitation gradient towards the Alps. On the one hand, convective precipitation in connection with southwesterly flows is more abundant in the Alps than in the adjacent forelands because convection is primarily triggered over the Alps. This mechanism is predominantly active in summer. On the other hand, frontal precipitation in connection with northwesterly and northerly winds is intensified at the northern Alpine rim due to orographic lifting. Also, postfrontal precipitation occurring with northerly flow is more intense in the Alps than in the foreland. In contrast, fronts from exactly 270° produce more precipitation in the forelands than in the Alps. In this case, the wind blows parallel to the mountain range and lee effects related to upstream topography reduce the precipitation intensity in the Alps.

Keywords: *Spatial precipitation gradients, orographic precipitation enhancement, precipitation climatology*

1. INTRODUCTION

As known from precipitation climatologies (e.g. Fliri, 1975; Frei and Schär, 1998; Schwarb et al., 2001) the Alps receive substantially more precipitation than the surrounding lowlands. The largest annual precipitation amounts are found along the northern (Allgäu, Salzkammergut) and the southern Alpine rim (Lago Maggiore-Ticino, Julian Alps), respectively. In addition, precipitation differences between different geographical regions within the Alps can vary strongly during a year (e.g. Kubat, 1972). Climatological studies point out a tendency of precipitation to increase with orographic height (Blumer, 1994). Moreover, it is well known that the Alpine precipitation enhancement extends somewhat into the adjacent forelands (Schwarb et al., 2001). However, very little research has yet been done to quantify the relative importance of specific precipitation enhancement processes for observed climatological gradients. With this study, we make a first step towards closing the gap between existing climatological studies and process studies by investigating the climatological relevance of various enhancement processes for the north Alpine region. The analysis is conducted for three selected regions in the northern Alps, which are compared with nearby regions in the northern foreland.

2. DATA AND METHODOLOGY

The database for this investigation comprises a simulation with the Penn State-National Center for Atmospheric Research MM5 model and data from operational weather stations. The MM5 simulation is conducted in climate mode for the time period of 1991 - 2000 and is driven with ERA-40 reanalysis data. The model output is used every three hours to determine the synoptic situation during the precipitation events. Specifically, we consider the equivalent potential temperature (θ_e) at 850 hPa, wind speed and direction at 700 hPa, CAPE and simulated convective and explicit precipitation.

Observational data are available from more than 1000 stations in Bavaria and western Austria for the same period. Most of the stations provide only 24-h precipitation values, others are climate stations (three readings per day) and the rest are synoptic stations (hourly data for automatic stations, otherwise six-hourly data). Hence, the data of the climate and precipitation stations need to be disaggregated into 6h-intervals. This is made by a Gaussian weighting between a certain precipitation or climate station and the surrounding SYNOP stations.

The next step is to determine the precipitation types for each 6-h interval with nonzero precipitation. Based on θ_e at 850 hPa and the 700-hPa wind turning and speed, the events are classified into cold and warm fronts. To diagnose convective precipitation, CAPE and the simulated convective precipitation are regarded. If a certain 6h period satisfies none of the criteria, it is regarded as unclassified. To analyze the relationship between spatial precipitation gradients and the wind direction at 700 hPa, the data are also subdivided into 36 wind sectors. To reduce small scale effects, selected stations are combined into geographical groups with ten stations each. Only stations with a similar precipitation climatology are put together.

3. RESULTS

3..1 Precipitation differences between regions A2 and F2

Precipitation differences between regions A2 and F2 (centered around Garmisch and Munich, respectively), depending on precipitation type and wind direction, are displayed in Fig. 1a (summer) and Fig. 1b (winter). The net differences for summer and winter show almost exclusively positive values, which means that region A2 receives on average higher precipitation amounts than region F2. In summer the largest differences are found for southwesterly flows, reaching about 20 - 30 mm/yr per 10° wind interval. This difference is predominantly due to convective precipitation, either prefrontal (denoted as "convective") or in connection with cold fronts. Convective cells preferentially develop in the Alps and then move into the Alpine foreland with the southwesterly wind, whereby they weaken. For westerly and northwesterly flow, the majority of the precipitation difference arises from cold fronts, indicating that precipitation enhancement by orographic lifting also plays a role. Warm fronts and unclassified events are unimportant in summer.

A completely different picture arises in winter. Now, convective precipitation is negligible and the majority of the precipitation surplus in region A2 is found for northwesterly flow. The difference is dominated by cold-frontal precipitation, but warm fronts and unclassified events (postfrontal precipitation or quasi-stationary frontal zones) also make a notable contribution. This implies that precipitation enhancement by orographic lifting is the dominant process in winter. The largest absolute difference occurs at 320°, but in terms of relative numbers, the largest difference is found at 0° and 10 ° where region A2 receives more than twice as much precipitation as region F2. However, purely northerly flow is climatologically less frequent than northwesterly flow. The second remarkable feature is the narrow but pronounced peak of negative precipitation differences at exactly 270°. Obviously, the Alpine foreland receives significantly more precipitation than the Alps for exactly westerly flow, particularly in connection with cold fronts, whereas all other wind directions favour either more precipitation in the Alps or a negligible difference. One possible explanation for this feature is that the Alpine region under consideration (A2) suffers from a lee effect of more western parts of the northern Alps. On the other hand, precipitation enhancement due to orographic lifting becomes active only when the crest-level flow has a component towards the Alps. Another contribution might arise from cold fronts that move very slowly towards the Alps and reach the Alpine region only in a subsequent 6-h interval when the crest level flow has already attained a northerly component.

3..2 Other regions

Two further pairs of regions are examined in order to reveal possible east-west gradients of the precipitation increase towards the Alps. In summer, A1 (Fig. 1c) and A3 (Fig. 1e) receive more precipitation than the corresponding foreland regions (F1, F3) for virtually all wind directions. Compared to regions A2/F2, the relative importance of summertime convection at southwesterly flow is somewhat smaller, and a larger fraction of precipitation increase towards the Alps occurs at westerly and northwesterly flow. Moreover, the absolute magnitudes are higher because of higher differences in annual mean precipitation (not shown). The differences between regions A3 and F3 (Fig. 1e) are larger than between A1 and F1 (Fig. 1a) for wind directions between 320° and 30°. As a consequence, the summertime A3 - F3 difference exhibits not only a peak at southwesterly flow but also at northwesterly flow. The most noteworthy feature of the wintertime precipitation differences

(Fig. 1d,f) is the absence of a negative difference at 270° between A1 - F1. Since the topography in this region favours orographic precipitation enhancement even for westerly flow, precipitation increases towards the Alps for all wind directions. However, the negative peak is present between the regions A3 and F3, because the Alpine rim is west-east orientated there so that upstream topography reduces the precipitation efficiency for exactly westerly flow.

4. CONCLUSION

This study investigates the processes responsible for the climatological precipitation gradient between the Alpine foreland and the northern Alpine rim. The results reveal two primary mechanisms contributing to the climatological precipitation increase towards the Alps. The first one is related to summertime convection under southwesterly flow conditions. Showers and thunderstorms form primarily over the Alps and then move into the Alpine foreland, whereby they gradually decay. Another important contribution arises from orographic lifting in the presence of northerly or northwesterly winds. In particular, cold fronts produce much more precipitation in the Alps than in the foreland due to orographic precipitation enhancement. A negative precipitation gradient (more precipitation in the foreland than in the Alps) is found for a crest-level wind direction of exactly 270°. This feature can be partly explained by fronts that move parallel to the northern Alps and are associated with a reduced precipitation efficiency in the east-west orientated part of the Alps due to adverse effects of upstream topography.

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5. FIGURES

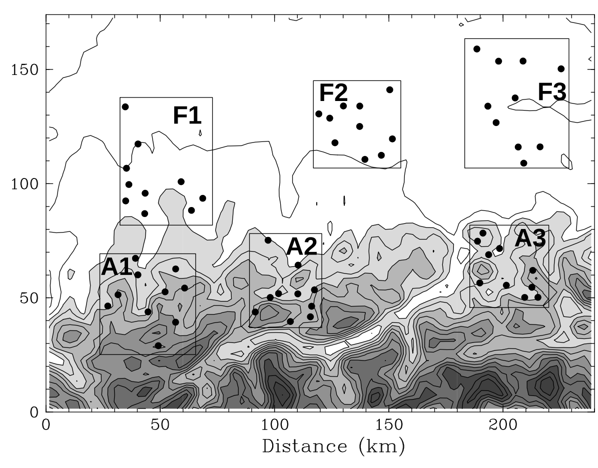

Figure 1: Location of the regions selected for investigation. Each region consists of 10 stations as indicated by the dots.

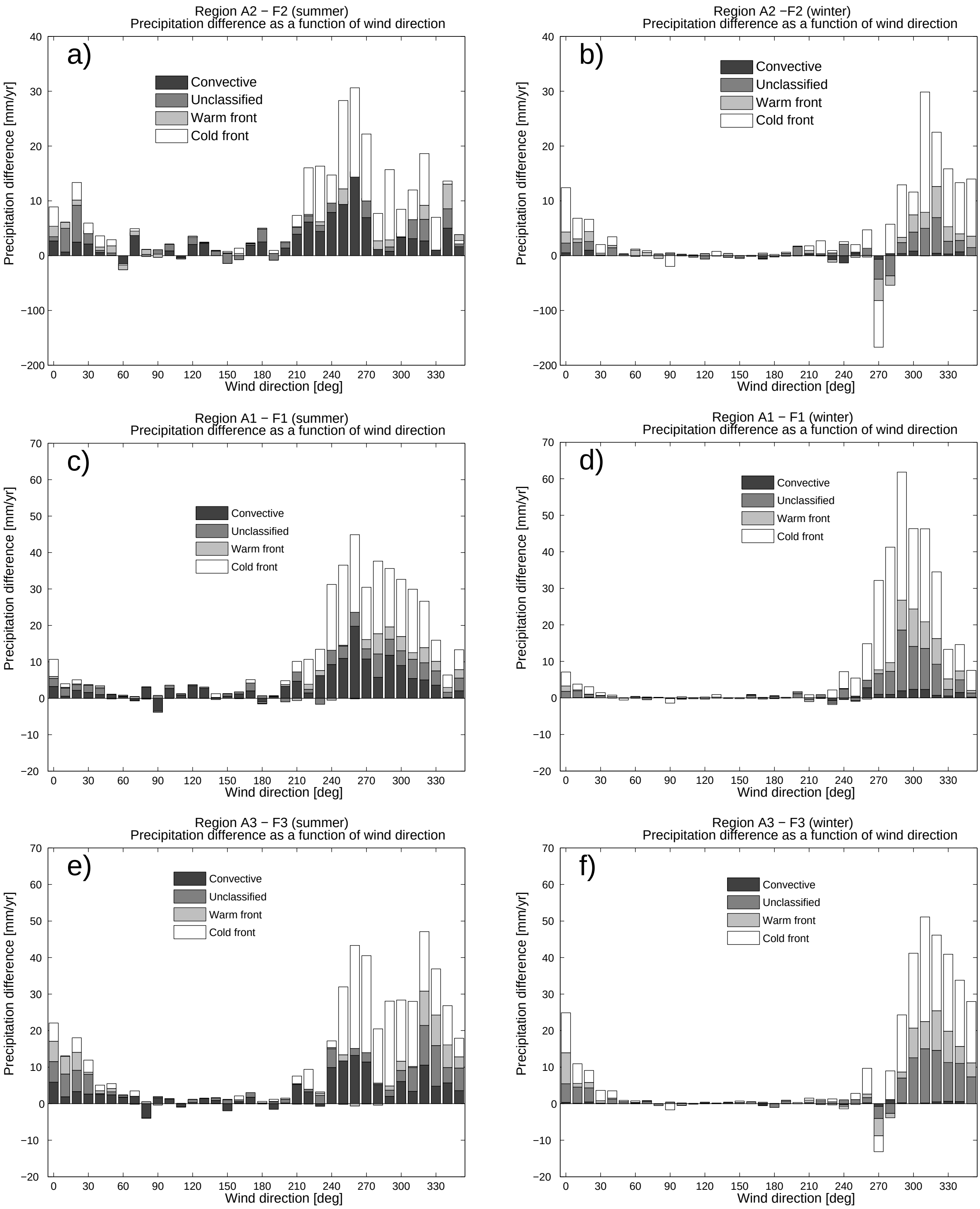

Figure 2: Accumulated precipitation differences (mm/yr) between three regions in the Alpine foreland (F1,F2,F3) and three in the Alps (A1,A2,A3) Net differences are displayed in panels (a,c,e) and (b,d,f) for summer and winter, respectively.