25th International Conference on Radar Meteorology
June 24-28, 1991
Paris, France

Preprint

MESOSCALE ORGANIZATION OF PRECIPITATION SYSTEMS IN SWITZERLAND

H.H. Schiesser* and R.A. Houze, Jr**

*Atmospheric Physics, Swiss Federal Institute of Technology,
8093 Zürich, Switzerland
**Atmospheric Sciences, University of Washington,
Seattle, WA98195, USA

1. INTRODUCTION

The Mesoscale Precipitation Systems (MPS) associated with fronts passing over Switzerland not only bring beneficial rainfall but also the threat of severe weather, including strong winds, long-lasting rain, local heavy downpours and large hailfalls. Beside strong winds, hail and floods are responsible for much of the damage caused by natural hazards in Switzerland. Up to now, not much has been known about the organization of the MPS, which cause the severe weather in the hilly and mountainous country of Switzerland.

Case studies of midlatitude MPS show archetypical precipitation patterns marked by a leading line of convection followed by a mesoscale region of stratiform precipitation (e.g. Smull and Houze, 1985; Rutledge et al., 1988). In a study of MPS in Oklahoma, Houze et al. (1990, HSD) found that this archetypical structure exhibits two distinct forms. One is a rather symmetric, with convection evenly distributed along the leading line of convection and the stratiform region centered behind the convective line (e.g. Fujita, 1955; Pedgley, 1962). The other is a rather asymmetric structure in which intense cells develop systematically on the southern extremity of the leading convective line, while dissipating cells and stratiform cloud and rain are found toward its northern end, and the trailing stratiform region is biased in its location toward the northern end of the line (e.g. Newton and Fankhauser, 1964). HSD found a spectrum of MPS organization that spanned the gamut between these two basic types of organization. They investigated all of the spring rainstorms in Oklahoma over a 6-year period.

It is by no means obvious that the mesoscale structures observed in the flatlands of Oklahoma should be evident in the vicinity of the Alps. The purpose of this study is to determine the climatology of the mesoscale organization of major rainstorms and severe weather occurrences in Switzerland. To accomplish this task, we have undertaken a climatology of the radar echoes, precipitation and severe weather in the part of Switzerland lying north of the crest of the Alps, where radar coverage is provided by two radars of the Swiss Meteorological Service (SMA). The present paper is a pilot study, in which we have examined 16 days, which were characterized by widespread intensive rains, called Major Rain Events (MRE), and documented damage by water and/or hail.

TABLE 1 Intensity scale of radar echo

Level	Rain rate (mm/h)	Reflectivity (dBZ)	Figure hatching
1	0 - 0.3	< 17	not used
2	0.3 - 0.9	17 - 24	not used
3	1.0 - 2.9	25 - 31	
4	3.0 - 9.9	32 - 39	
5	10.0 - 29.9	40 - 46	
6	30.0 - 99.9	47 - 54	
7	≥ 100	≥ 55	

2. DATA

2.1 Radar

Since 1979 two 5cm wavelength weather radars have operated 24h a day in Switzerland. Details about the system can be found in Joss and Waldvogel (1990). The most important points are: The two radars cover a volume of 558 x 428 x 12 km^3 in and around the country for prognostic and nowcasting purposes of the SMA. Fig.1 shows the two radar sites and the combined observational area, which reaches into France in the west, from where the precipitation systems usually move into Switzerland. The radar image shows three projections (ground view, W-E and N-S cross sections). The pixel size in the ground view is 2 x 2 km^2, the vertical resolution is 1 km. Each pixel contains the maximum radar reflectivity in each vertical column or horizontal strip, which is converted to rainfall rate through the relation $Z = 300 R^{1.5}$. The range of the rain rate is divided in seven steps on a logarithmic scale, the lowest step indicating intensities < 0.3 mmh^{-1} and the highest intensities > 100 mmh^{-1} (see Table 1). The time resolution of the available images is 10 min. They are stored on 16 mm films.

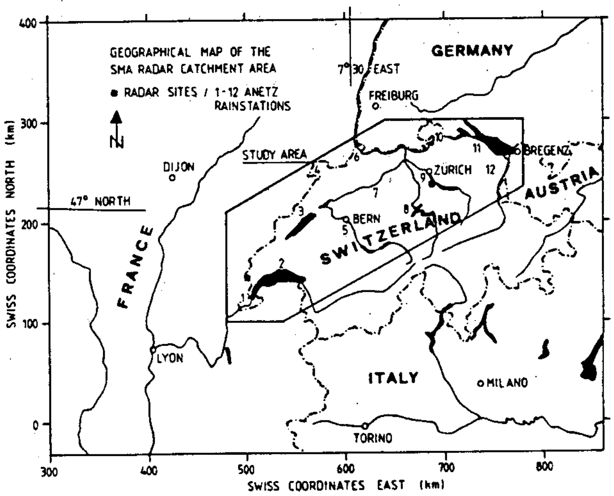

Fig.1 The combined observational area of two Swiss weather radars. The boundary of the study area is depicted.

2.2 The area and period of study

The area of interest is restricted to the part of Switzerland north of the alpine ridge. Precipitation in the region to the south is obscured by ground echos and shielded by the high mountains (Joss and Kappenberger, 1984). Fig.1 shows the boundary and the orientation of the study area within the area of radar coverage. It has a size of 36'500 km^2, of which 25'200 km^2 is within the boundary of Switzerland. The topography of the hilly and mountainous country is depicted in Fig.2, which is in stark contrast to the flat countryside of Oklahoma, where the HSD study was conducted. The different topography is expected to have modifying effects on the radar structures of the observed MPS. To start with, the study will be limited to the 5-year period 1985-89. The whole year will be considered, not just the warm season as in the study of HSD.

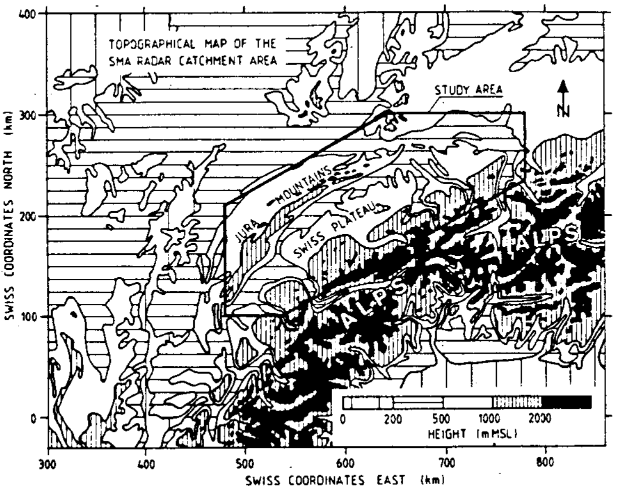

Fig.2 The topography of the observational area.

2.3 Major Rain Events (MRE)

The daily recordings (0540 - 0540, all times are given in UTC; local time = UTC+1h) of 12 stations of the automatic network of the SMA, which are equally distributed within the study area, are used to determine the days with widespread intensive rain. The locations of the stations are depicted in Fig.1. The criterion for widespread rain was chosen as follows: All 12 stations had to measure some rain, 4 of them at least 20 mm/day. If the criterion was fulfilled, the day was taken as a MRE. For the years 1985-89, a set of 64 MREs was obtained. To reduce the number of cases for the present study, a further criterion based on the amount of damage was devised and is introduced in the following section.

2.4 Damage data

To be able to determine the severity of a MRE, two sources of damage information are used: 1) Reports of damage caused by water have been collected routinely since 1972 at the Swiss Federal Institute of Forestry Research from more than 500 newspapers. From the news information the type of weather (either thunderstorm or intense rain, long-lasting rain or snowmelt with rain), the type of damage (flooding, landslide or both) and the severity of damage (small, medium, heavy) can be deduced for every community. Summaries are published yearly (e.g. Zeller and Röthlisberger, 1988). 2) Since 1950, yearly listings of hail days (having hail damage in agriculture) per community are available from the Swiss Hail Insurance Company. A hail day means that at least one report of hail damage (one crop or field) was received by the insurance company. No further information is given about the % of hail damage. For that, one has to investigate the single damage reports (Schiesser, 1990). Fig.8 shows as an example the locations of 89 communities that reported hail damage on 28 August 1988. The damage caused by water can be plotted in a similar fashion. The study area within the Swiss border contains more than 2400 communities for which the above mentioned damage information is available. Our criteria, based on damage data, are: MRE with ≥ 5 communities reporting water damage or ≥ 20 reporting hail damage. If one of these criteria are met, the MRE is considered further. Of the 64 MRE, 19 fulfilled both criteria, namely widespread rain and the specified degree of damage. An overview of the 19 cases is given in Table 2. Three cases have either no radar data or insufficient quality and are disregarded in the following, leaving 16 MRE.

TABLE 2 Overview of the Major Rain Events (MRE)

MRE No.	Date	Precipitation		Damage		Weather type		
		No.of stations ≥ 20mm/d	Max. amount (mm/d)	No.of communities Water	No.of communities Hail	S=strat. C=conv. strat.	Direction of movement	ll/ts
1	850122	5	55.8	12	0	S	NW	-
2	850408	5	40.1	11	0	S	WNW	-
3	850508	6	48.7	22	2	S	NNW	-
4	860507	4	43.4	0	59	C	SW	yes
5	860527	5	57.8	20	37	C	SW	no
6	860529	4	27.3	0	21	bad radar data		
7	860706	11	49.2	3	146	C	SW	yes
8	860723	7	32.9	0	253	C	SW	yes
9	860804	4	40.9	11	84	C	SW	yes
10	870613	4	47.0	0	94	no radar data		
11	870615	6	48.4	0	35	no radar data		
12	870817	4	63.9	14	36	C	SW	yes
13	870824	6	42.2	15	2	S	SSW	-
14	870925	9	75.2	77	2	S	WNW	-
15	880321	7	33.3	7	0	C	W	no
16	880828	4	41.1	0	89	C	SW	yes
17	881010	5	33.2	6	0	S	W	-
18	890701	4	44.4	0	141	C	W	no
19	890807	5	27.9	4	35	C	WSW	yes

3. MESOSCALE ORGANIZATION

To be able to compare the MPS within a MRE in Switzerland with the Oklahoma cases, the same MPS-definitions as were used by HSD will be adopted here. HSD considered a MPS "to be a distinct group of echo or contiguous area of radar echo that extended spatially over horizontal distances ~ 100 km or more and exhibited time continuity over several hours." To distinguish convective from stratiform rain areas, a convective echo region is defined as: "a region 20-50 km in horizontal dimension with reflectivity peaks of at least two contour levels over a horizontal distance of 10 km and contour shapes that varied spatially on a scale ≤ 10 km and temporally ≤ 1h. The definition for a stratiform echo region follows as: "any nonconvective echo on a scale of 40 km or more."

In 6 of the 16 MRE with radar data, only stratiform echos have been observed (see Table 2). On 10 days convective echo patterns were visible. The 10 convective days were subdivided into "classifiable" and "unclassifiable" patterns, according to the method of HSD. Classifiable patterns have some degree of organization into a leading-line, trailing-stratiform (ll/ts) structure. Unclassifiable cases have no such organization. Of the 10 convective days, 3 days showed a more chaotic organization of the MPS, whereas the remaining 7 days revealed at least one ll/ts structure each. Table 2 shows also that the stratiform systems occurred mostly when the direction of MPS-movement was from WNW or NW, travelling towards the Alps which block the incoming fronts and therefore induce long-lasting rain. Most of the damage through water can be observed in association with those events. The main direction of movement for convective MPS is from SW, travelling along the Alps and danger of hail is evident.

HSD suggested ten basic characteristics of ll/ts organization, 7 to define the degree of matching an ideal leading line (as arc shape, generally SW-NE orientation, rapid movement, solid appearance, strong reflectivity gradient at leading edge which is serrated and cells oriented 45-90° with respect to line) and 3 for the trailing stratiform area (as large size, large notch-like concavity at rear edge and a secondary maximum of reflectivity). Further a symmetric or asymmetric leading line in respect to the following stratiform area is also considered. The 10 characteristics were scored with 1 point for a particular feature present and -1 for absent. Half points were given if the analyst was not sure of the occurrence of a feature in either direction of scoring. Both authors of the present study made the scoring for the 7 cases first independently than checked and resolved the differences of opinion. Then information in Table 3 is recorded in the same format as in HSD. After the individual characteristics are recorded, two scores are computed. C is the sum of the numbers in columns B through K. It represents the degree that the storm is classifiable, that is the degree to which it exhibits ll/ts structure. A value of C of 5-10 was considered to be "highly classifiable" by HSD. The values of C for the Swiss storms fall well below this range, ranging from -3.5 to +3.5. These values are "weakly to moderately classifiable" according to HSD. The second score S is the sum of the data in columns M and N. It is a number between +2 and -2, which represents the extent to which the MPS exhibits a "symmetric" (positive) or asymmetric (negative) form of ll/ts structure. The Swiss storms considered presently all exhibit a distinctly "asymmetric" character, with values of S ranging from -1.5 to -2.0. Thus, the overall classification of the Swiss storms with ll/ts structure and damaging hail is weakly to moderately classifiable and asymmetric. This classification was found by HSD to be the mesoscale structure most strongly associated with severe weather in the form of tornadoes and hail (see Tables 5 and 6 of HSD). It is consistent, then, that we find this form of mesoscale structure to be associated with the severe hail producing storms of Switzerland. It is especially interesting that this structure survives even in the vicinity of highly mountainous terrain. The weakly to moderately classifiable and asymmetric form of structure is essentially the form of squall line structure described by Newton and Fankhauser (1964).

TABLE 3 Scoring of the leading-line/trailing-stratiform structure.

	A	B	C	D	E	F	G	H
1	MPS	Leading Line	Leading Line	Leading Line	Leading Line	Leading Line	Leading Line	Leading Line
2	Designator	Shape	Solid	Orientation	Speed	Strong Refl.	Edge Serrated	Cells Elongated
3		Arc-like				Gradient		45-90°to line
4	86.05.07	-1	1	1	1	-1	-1	-1
5	86.07.06	-1	1	1	1	1	-0.5	-1
6	86.07.23	-1	1	1	-0.5	1	-1	-0.5
7	86.08.04	-1	1	1	0.5	0.5	-1	-1
8	87.08.17	-0.5	1	1	-0.5	-1	-1	-1
9	88.08.28	0.5	1	1	1	1	-1	-1
10	89.08.07	-0.5	1	1	1	1	-1	-1

	I	J	K	L	M	N	O
1	Strat. Region	Strat. Region	Strat. Region	Leading-Line/	Leading Line	Strat. Region	Symmetric vs.
2	Size >	Notch	Secondary Re	Trailing-Strat	Convection	Location	Asymmetric
3	10**4km**2		Maximum	Score 'C'	Not Biased	Centered	Score 'S'
4	-1	-1	-0.5	-3.5	-1	-1	-2
5	0.5	-0.5	-0.5	1	-0.5	-1	-1.5
6	1	-0.5	0.5	1	-1	-1	-2
7	1	-0.5	0.5	1	-1	-1	-2
8	1	-0.5	1	-0.5	-1	-0.5	-1.5
9	0.5	-0.5	1	3.5	-0.5	-1	-1.5
10	1	-0.5	1	3	-1	-1	-2

4. THE "MAJOR RAIN EVENT" OF 28 AUGUST 1988

On 28 August 1988, a coldfront passed through Switzerland and produced 6 distinguishable MPS (labelled A-F) in the radar area. The synoptic situation is displayed in Fig.3 for 00h 29 August. 4 of the 6 MPS (A, B, E, F) travelled through the study area. C merged with B in France and D travelled north of the study area, through southern Germany. Fig.4 indicates the track of a qualitatively determined center of a particular system. The interval between the single systems is one to two hours. MPS A crossed the westerly border at 1600, B at 1800, both taking about 5 hours to move through the whole of Switzerland from SW to NE at an average speed of about 18 m/s. MPS E followed at about 2000, but dissipated at 2200 in the study area. F entered around 2100 and moved in a less organized fashion during the night to the east. The complex track of F is not shown here. Fig.5 depicts the situation at 2040 when the dying system A left Switzerland in the east and B was in the growing phase, organizing a ll/ts structure. E dissipated slowly, and F entered the study area in the SW. The development of ll/ts system B is shown as an example in Fig.6. For clarity, only intensity levels 4-7 are shown. The development started around 2000 and reached its culmination at 2110, when it had 5 convective cells which reached the highest intensity level, most of them producing hail and hail damage on the ground. The line dissipated around 22h20 shortly before leaving the study area in the east.

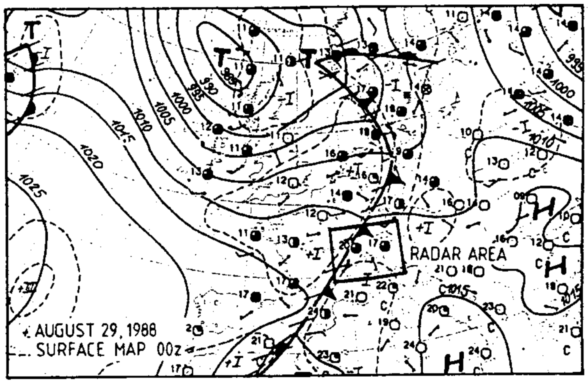

Fig.3 Synoptic situation for 00h 29 August 1988.

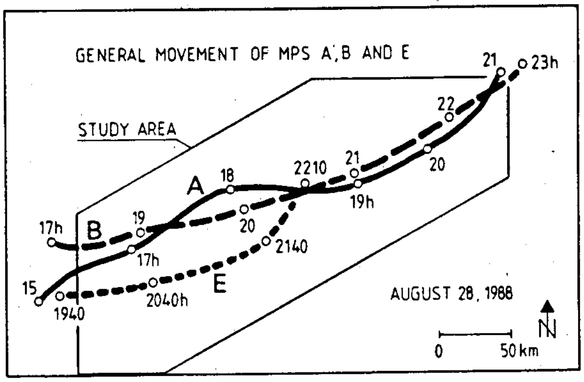

Fig.4 Tracks of 3 qualitatively determined MPS centers through the study area.

During the lifetime of MPS B, 28 convective (hail) cells were readily distinguishable. The hailswaths are depicted in Fig.7 and numbered from 1 to 28 depending on the time of occurrence. Cells 1 and 18 reached maximum life times of 110 and 90 min respectively. Half of the cells originated when the system crossed the Jura mountains, and orographic effects evidently enhanced the convection. Most of the second half developed along the Prealps, when lifting was again reinforced. The hailswaths correspond very well with the area of hail damage depicted in Fig.8. The comparison of the single cell with the ground truth made it possible to attribute the damaged areas to the particular cell of the MPS. System A was responsible for an especially large hailswath along the southern foothill of the Jura mountains (labelled A in Fig.8), MPS B for many smaller streaks in the Prealps (origine of the cells) and eastern part of the Swiss Plateau.

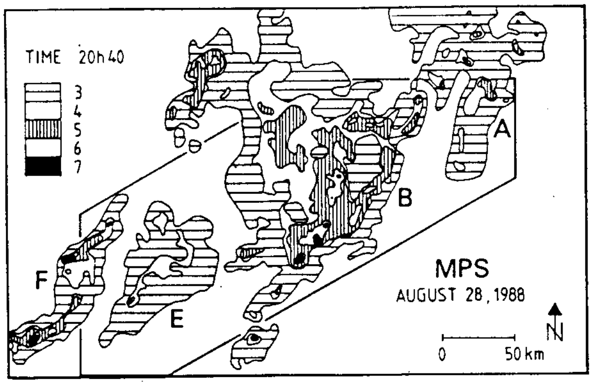

Fig.5 Radar echoes of 4 MPS at time 2040, labelled A, B, E and F.

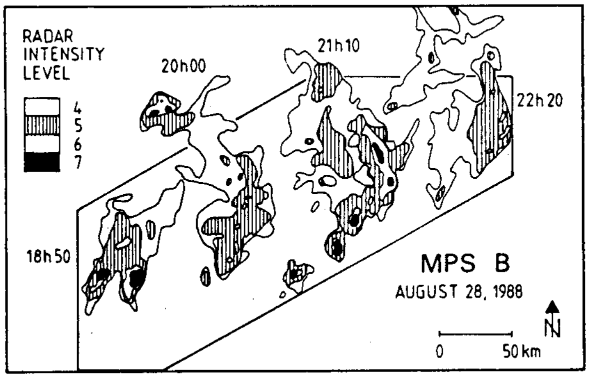

Fig.6 Radar echoes of MPS B at different stages of development. The times are indicated. The leading-line/trailing-stratiform structure is shown very well at stage 2110.

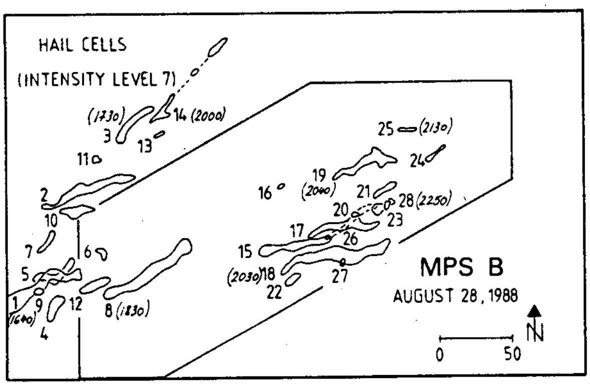

Fig.7 Tracks of hail cells of MPS B as identified by radar. The highest intensity level 7 is shown. The consecutive number of appearance is given and also in some cases the time (in brackets).

5. CONCLUSIONS

A 5-year record of radar images of two operational weather radars has been used to investigate the structure and organization of mesoscale precipitation systems (MPS) in Switzerland on days with a major rain event (MRE), in which widespread intensive rain occured in the region north of the Alpine ridge. In this preliminary study, only days also marked by extensive water and/or hail damage were considered. There were 16 such days, of which 10 exhibited deep convection. On 7 of the 10 convective days, the radar echoes exhibited mesoscale organization of a type which could be classified according to the scheme used by HSD to study Oklahoma storms. Each of the 7 convective cases exhibited weak to moderate leading-line/trailing-stratiform organization. Each also produced hail damage. This form of organization is consistent with that found for hail producing storms in Oklahoma, which occur over flat terrain, very different from the hills, valleys and mountains of northern Switzerland. Of the 3 convective days with chaotic mesoscale organization, two were major hail producers. This result is also consistent with the Oklahoma study, in which HSD found the unclassifiable or disorganized MPS structures also tended to be major hail producers. The case study of 28 August 1988 was presented to illustrate that the available radar data can reveal in great detail the structure of the observed MPS. Individual hail cells within the MPS can be tracked by using the highest intensity level of radar echo. They correspond very well with ground information on hail damage. The next step will be to broaden the study to include all of the 64 MRE of the study period to determine whether the preliminary results of this analysis will be confirmed, and if other mesoscale structures are present in non-severe MRE.

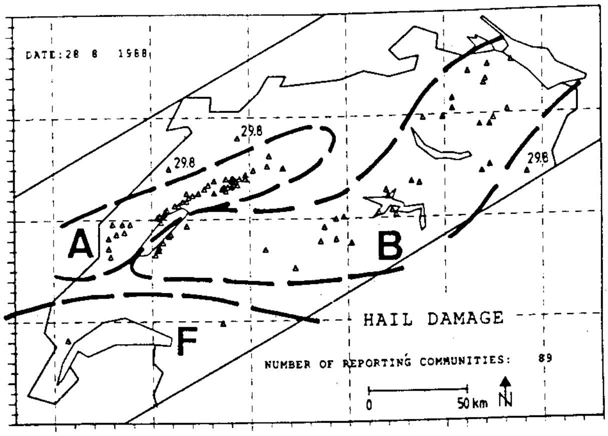

Fig.8 The locations of communities reporting hail damage to the hail insurance company. The damage area of the responsible MPS are labelled A, B and F.

REFERENCES

Fujita, T.T., 1955: Results of detailed synoptic studies of squall lines. Tellus, **7**, 405-436.

Houze, R.A., Jr., B.F.Smull and P.Dodge, 1990: Mesoscale organization of springtime rainstorms in Oklahoma. Mon.Wea.Rev., **118**, 613-654.

Joss, J. and G.Kappenberger, 1984: Quantitative measurement of precipitation with radar in an alpine country. 22nd Conf.Radar Meteorology, Zürich, AMS, 270-275.

Joss, J. and A.Waldvogel, 1990: Precipitation measurement and hydrology. In: D.Atlas (ed.): Radar in meteorology, Amer.Meteor.Soc., Boston, 577-606.

Newton, C.W. and J.C.Fankhauser, 1964: On the movements of convective storms, with emphasis on size discrimination in relation to water-budget requirements. J.Appl.Meteor., **3**, 651-668.

Pedgley, D.E., 1962: A meso-synoptic analysis of the thunderstorms on 28 August, 1958. Brit.Meteor.Off., Geophys.Mem., No. **106**, 74pp.

Rutledge, S.A., R.A.Houze, Jr., M.I.Biggerstaff and T.Matejka, 1988: The Oklahoma-Kansas mesoscale convective system of 10-11 June 1985: Precipitation structure and single-Doppler radar analysis. Mon.Wea.Rev., **116**, 1409-1430.

Schiesser, H.H., 1990: Hailfall: the relationship between radar measurement and crop damage. Atmospheric Research, **25**, 559-582.

Smull, B.F. and R.A.Houze, Jr., 1985: A midlatitude squall line with a trailing region of stratiform rain: Radar and satellite observations. Mon.Wea.Rev., **113**, 117-133.

Zeller, J. and G.Röthlisberger, 1988: Unwetterschäden in der Schweiz im Jahre 1987. Wasser, Energie, Luft, **80**, 29-42.