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MESOSCALE ORGANIZATION OF PRECIPITATION SYSTEMS CAUSING SEVERE DAMAGE BY INTENSE OR LONG-LASTING RAIN IN SWITZERLAND

Mesoskalige Organisation von Niederschlagssystemen in der Schweiz, welche grosse Schäden durch intensiven oder langandauernden Regen verursachen

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ABSTRACT

The mesoscale organization of major rainstorms and severe weather occurrences in Switzerland north of the Alps is studied using data of two weather radars of the Swiss Meteorological Service. A 5-year record (1985-89) is used to investigate the radar echo structures of Mesoscale Precipitation Systems (MPS) on days declared as Severe Rain Events (SRE). The criterion for a SRE was chosen as follows: At least 10 communities had to report water damage. From each SRE the MPS with most damage potential was taken into the analysis. 8 of the 31 investigated MPS showed only stratiform echos, whereas 23 exhibited convective echos. They can be subdivided into 9 with some organization into a leading line / trailing stratiform (ll/ts) structure, 11 MPS with line formation and 3 systems with a chaotic or noline pattern. The "ll/ts" type was classified after the scheme of HOUZE et al. (1990), who analysed rainstorms in Oklahoma. The Swiss "ll/ts"-storms exhibited storm structures which were also found in Oklahoma for storms producing mainly flood events, but the structures were not so strongly visible. Two case studies illustrate the line formation type and the "ll/ts" type of mesoscale organization, respectively.

ZUSAMMENFASSUNG

Die mesoskalige Organisation von Sturmereignissen in der Schweiz nördlich der Alpen, wo Radardaten von den zwei Wetterradars der Schweizerischen Meteorologischen Anstalt verfügbar sind, wird untersucht. An Tagen, welche als "Severe Rain Events" (SRE) oder als "Stark Regen Ereignisse" bezeichnet werden, wurden die Radarstrukturen der mesoskaligen Niederschlagssysteme (MPS) analysiert und mit den Wasserschadengebieten verglichen, dies für die Jahre 1985-89. Das Kriterium für ein SRE wurde dabei folgendermassen definiert: Mindestens 10 Gemeinden mussten Wasserschäden aufweisen. Von jedem SRE wurde dasjenige MPS mit dem grössten Schadenausmass in die Analyse aufgenommen. 8 von den 31 untersuchten MPS zeigten stratiforme Radarechos, während 23 konvektive Strukturen aufwiesen. Die Letzteren können in 9 MPS mit einer gewissen Organisation zu einer "leading line /trailing stratiform" (ll/ts) Struktur, in 11 Systeme mit einer Linienformation und in 3 Systeme mit einem chaotischen oder nichtlinearen Muster eingeteilt werden. Der "ll/ts" Typ wurde nach dem Schema von HOUZE et al. (1990) klassifiziert, welche Regenstürme in Oklahoma analysierten. Die Schweizer Stürme zeigten Sturmstrukturen, welche auch in Ueberschwemmungen produzierenden Oklahoma-Stürmen gefunden wurden. Zwei Fallstudien zeigen eine Linienformation respektive den Typ der "ll/ts"-Organisation.

1. INTRODUCTION

The Mesoscale Precipitation Systems (MPS) not only bring beneficial rainfall but also the threat of severe weather. Beside strong winds, hail and floods are responsible for much of the damage caused by natural hazards in Switzerland. Up to now, only little is 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 either stratiform or convective/stratiform precipitation patterns. The latter systems with convection are called Mesoscale Convective Systems (MCS). The most organized and often very intense systems are marked by a leading line of convection (squall line) 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 type of 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. The other is a rather asymmetric structure in which intense cells develop systematically on the southern part 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. HSD found a spectrum of MPS organization that spanned the gamut between these two basic types of organization. Other MCS-patterns described e.g. by BLANCHARD (1990) are lines of convective cells, occluding structures or chaotically (noline) arranged convective cells.

It is by no means obvious that the mesoscale structures observed in the flatlands of Oklahoma should exist also in the vicinity of the Alps. The purpose of this study is to determine the climatology of the mesoscale organization of severe rainstorms in Switzerland. To accomplish this task, we have undertaken a climatology of the radar echoes of severe weather events in the part of Switzerland lying north of the crest of the Alps. In a first attempt SCHIESSER and HOUZE (1991) investigated 19 socalled Major Rain Events, namely days with widespread and intense rain over the entire area, which produced damage by water and/or hail. The present paper is a further study, in which we have examined 36 days, which were characterized by intensive or long-lasting rain, not necessarely in the whole area, called Severe Rain Events (SRE), and documented extended damage by water.

2. DATA

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. Fig.1 shows the two radar sites and the combined observational area, which penetrates 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

Table 1 Intensity scale of radar echo
Tabelle 1 Intensitätsskala der Radarechos

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	

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 can be seen from Table 1. The time resolution of the available images is 10 min. They are stored on 16 mm films.

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. 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.

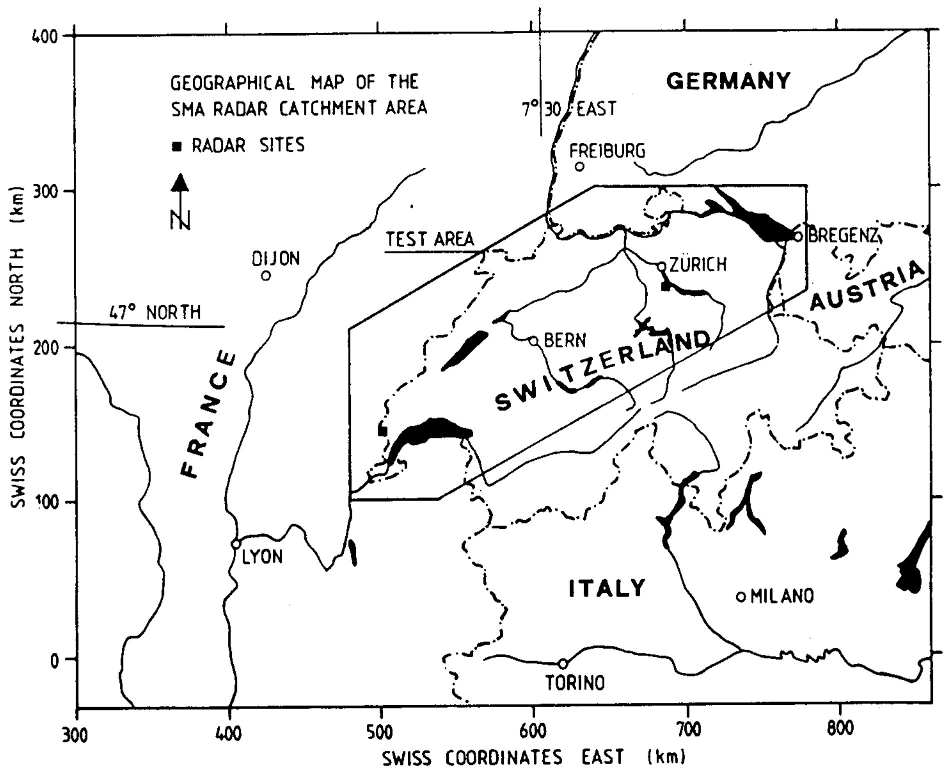

Fig.1 The combined observational area of two Swiss weather radars. The boundary of the study area is depicted. SMA = Swiss Meteorological Service.
***Abb.1** Das kombinierte Ueberwachungsgebiet der beiden Schweizer Wetterradars. Die Grenze des Testgebietes ist eingezeichnet. SMA = Schweizerische Meteorologische Anstalt.*

To determine the severity of a SRE, two sources of damage information are available: 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, land-slide or both) and the severity of damage (light, medium, severe) can be deduced for every community. Summaries are published yearly (e.g. ZELLER and ROETHLISBERGER, 1988). 2) Since 1950, yearly listings of hail days (having hail damage in agriculture) per community are available from the Swiss Hail Insurance Company. Fig.2 shows as an example the locations of 39 communities that reported water damage on 1 July 1987. The damage caused by hail 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.

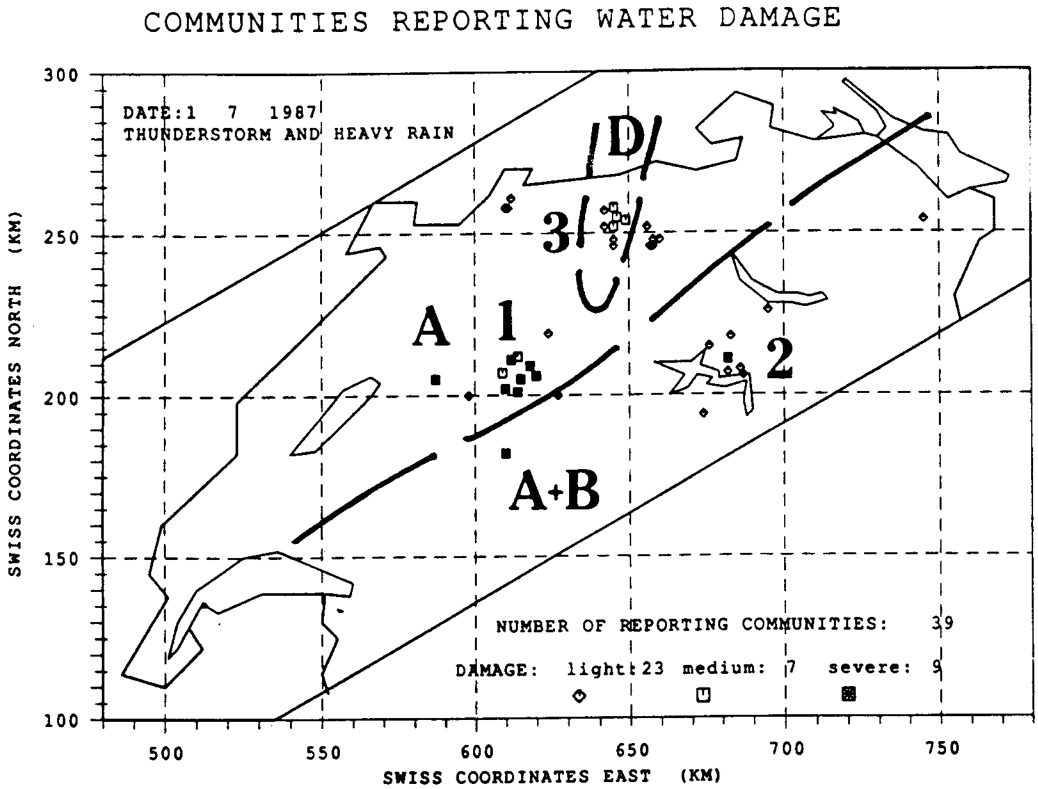

Fig.2 The areas with damage caused by water on 1 July 1987. Each symbol represents a community. Capital letters are the responsible mesoscale precipitation systems (MPS), numbers represent special damage areas discussed in section 4. The dashed line is the boundary between damage region of MPS A and the one of B or D.

Abb.2 Die Schadengebiete, welche durch Wasser am 1.Juli 1987 betroffen wurden. Jedes Symbol zeigt eine betroffene Gemeinde. Grossbuchstaben bezeichnen die für den Schaden verantwortlichen Niederschlagssysteme, die Nummern sind spezielle Schadengebiete, welche im Abschnitt 4 besprochen werden. Die gestrichelte Linie ist die Grenze zwischen Schadengebiet von MPS A und demjenigen von B oder D.

This study is limited to the 5-year period 1985-89. During these years there are 150 days which show at least one community with damage caused by water. Our criterion to select and reduce the cases, based on damage data, is: SRE = a day with ≥ 10 communities reporting water damage. For the five years a set of 36 SRE was obtained. An overview of the cases is given in Table 2. Five cases have either no or bad radar data and are disregarded in the following, leaving 31 SRE. Table 2 shows the date, number of communities with water (stratified in light, medium, severe) and hail damage during the whole SRE, the weather situation given as frontal or air mass day and as stratiform or convective type of precipitation. Further some data about the MPS, which produced most of the damage on that particular SRE: The total number of MPS on that day and the number of the one which is used in the present investigation, the number of communities with water/hail damage caused by this particular (convective) MPS, the origine of the MPS (moved into or originated in the study area), the direction and speed (for moving convective systems) of the movement and the occurrence (starttime and duration of the

Table 2 Overview of the "Severe Rain Events" (SRE)

Tabelle 2 Ueberblick über die "Stark Regen Ereignisse" (SRE)

SRE	Damage			Weather[2]		MPS[3]						MO[5]
Date YYMMDD	No of communities Water[1]		Hail	F/A	S/C	No	W/H	M/O	Direction/ Speed(m/s) of movement	Start UTC	Duration h	ll/ts Line Noline
850122	12	(12/ 0/ 0)	0	F	S	1/1		M	NW	0800	25	-
850408	11	(10/ 1/ 0)	0	F	S	2/1		M	WNW	2000[4]	20	-
850508	22	(22/ 0/ 0)	2	A	S	2/2		M	W	1200	24	-
850704	27	(21/ 4/ 2)	33	F	C	1/1	27/ 33	M	SW/12	1300	9	ll/ts
850706	22	(18/ 1/ 3)	0	F	C	1/1	22/ 0	M	NW/ 8	0600	13	line
860410	15	(15/ 0/ 0)	0	F	S	1/1		M	NE	1200[4]	24	-
860523	28	(26/ 0/ 2)	0	A	C	1/1	28/ 0	M	SW/17	1400	7	ll/ts
860527	20	(18/ 2/ 0)	37	F	C	4/3	15/ 23	M	SW/ 7	1430	6	line
860602	16	(16/ 0/ 0)	0	F	S	2/2		M	NW	1100	16	-
860616	52	(40/ 6/ 6)	95	A	C	2/2	50/ 54	O/A	SE/ 3	1230	7	line
860617	19	(16/ 1/ 2)	72	A	C	bad radar data						
860619	15	(11/ 2/ 2)	22	F	C	bad radar data						
860620	45	(35/ 8/ 2)	49	A	C	1/1	45/ 49	O/A	SW/ 8	1300	8	ll/ts
860623	18	(15/ 1/ 2)	146	F	C	bad radar data						
860718	10	(10/ 0/ 0)	0	F	C	3/1	7/ 0	O/A	W/ 7	1800	22	noline
860804	11	(11/ 0/ 0)	84	F	C	6/2	5/ 33	M	SW/10	0700	12	line
860818	12	(12/ 0/ 0)	197	F	C	2/1	11/ 46	M	SW/14	0900	9	ll/ts
870614	22	(22/ 0/ 0)	73	F	C	no radar data						
870618	16	(16/ 0/ 0)	26	F	C	no radar data						
870624	13	(13/ 0/ 0)	0	A	S	4/2		M	WNW	1400	7	-
870701	39	(23/ 7/ 9)	134	F	C	4/1	19/115	M	NW/ 8	0900	8	line
870703	35	(28/ 6/ 1)	0	F	C	2/2	24/ 0	O/A	st	1300	7	line
870707	27	(19/ 4/ 4)	29	A	C	3/3	21/ 24	M	SW/ 4	1530	8	line
870708	12	(12/ 0/ 0)	0	A	C	4/2	9/ 0	M	W/ 6	1400	6	ll/ts
870718	20	(18/ 2/ 0)	4	F	S	3/1		O/A	st	2000[4]	24	-
870817	14	(14/ 0/ 0)	36	F	C	1/1	14/ 36	M	SW/10	1700	11	ll/ts
870824	15	(3/ 0/12)	2	F	C	3/3	15/ 0	M	st	1700	16	noline
870925	77	(68/ 2/ 7)	2	F	S	1/1		M	WNW	1100	28	-
880515	35	(33/ 1/ 1)	125	F	C	4/2	17/ 52	O/A	st	1030	8	line
880526	31	(29/ 2/ 0)	158	F	C	8/7	29/141	M	N/12	1600	8	line
880611	19	(10/ 6/ 3)	203	F	C	2/1	19/171	M	SW/11	1100	9	ll/ts
880614	14	(3/ 3/ 8)	0	A	C	3/2	13/ 0	O/A	st	1100	9	line
880616	37	(22/ 5/10)	132	A	C	5/3	27/ 91	O/A	st	0900	10	noline
880909	20	(15/ 5/ 0)	0	F	C	2/1	20/ 0	O/J	st	1330	8	ll/ts
890710	35	(33/ 2/ 0)	45	A	C	1/1	35/ 45	M	SW/ 9	0830	11	ll/ts
890724	11	(11/ 0/ 0)	201	F	C	5/4	6/ 38	O/A	SW/12	1430	6	line

1) in brackets: number of communities with (light/medium/severe) damage
2) F/A = Frontal or Air Mass days
S/C = Stratiform or Convective/stratiform precipitation
3) No = Number of MPS during SRE / No of MPS with most damage, which is used for the present investigation
W/H = Number of communities with damage by Water and/or Hail
M/O = Moves into the observational area/Originated in the area: A = Alps; J = Jura
st = stationary
Start = Time when the contour of intensity level 1 mm/h moves into the area or starts to develop within the area (local time = UTC+1h)
4) Time of the day before
5) MO = Mesoscale Organization
ll/ts = leading line/ trailing stratiform structure

MPS in the area). The last column shows the mesoscale organization for the convective MPS, which is stratified into "leading line/trailing stratiform" (ll/ts), "line" and "noline" types of organization (see section 3).

3. MESOSCALE ORGANIZATION

To compare the MPS within a SRE 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." In our case the contour of the radar intensity level ≥ 1mm/h is observed. 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." The decision scheme, which is depicted in Fig.3, is used to classifiy the 31 MPS, producing most of the damage on that day.

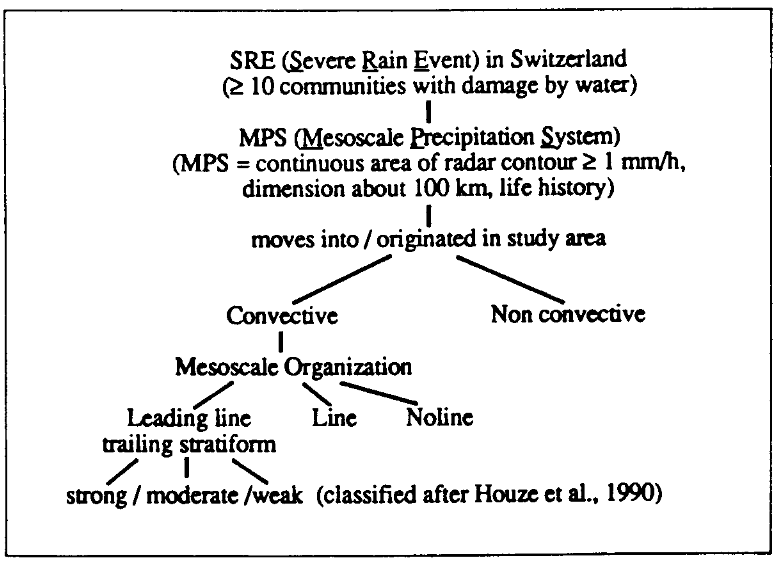

Fig.3 Decision tree to classify the type of mesoscale organization of a particular mesoscale precipitation system.

Abb.3 Entscheidungsschema für die Typisierung der mesokaligen Organisation von Niederschlagssystemen.

On 8 of the 31 SRE with useable radar data only stratiform echos have been observed (see Table 2). The total number of MPS in this category is 16, on the average 2 per day. A number of 7 stratiform systems moved into the study area, mainly from W - NW and were responsible for long-lasting rainfall in Switzerland. On the average 21 hours passed from the time of entry of a radar echo (1 mm/h) until the system died or the last echo left the area of interest.

On 23 days convective echo patterns were visible with a total number of 68 MPS, on the average 3 MPS per day. The 23 MPS (or MCS) can be subdivided into 9 MCS, showing some degree of organization into a "ll/ts" structure, 11 MCS, which show a "line" organization and 3 MCS, which reveal a more chaotic type of organization, called "noline". 14 MCS (ll/ts / line / noline = 7/6/1) moved into the area mostly from W - SW, 9 MCS (2/5/2) originated in Switzerland, 8 in the alpine area and one in the Jura mountains. The average duration of a system was 8.7/8.4/16.0 hours, the "noline" system showing almost a double duration (but only 3 cases). The earliest daytime of occurrence of a system (850706), which moved into the area, was 0600. The latest occurrence of a system (860718), which originated in the area, was at 1800. The average speed of a moving system was 10.9/8.0/7.0 (1 case) m/s. 6 systems (1/3/2) could have been described as stationary, 5 of them originated in the study area whereas one (870824) moved to the southern border of the study area and stayed stationary above the alpine ridge. That case (a "noline" organization) is well known, because of the severe damage in the Reuss valley and therefore is included in the present set of SRE (see EIDG. VERKEHRS- und ENERGIEWIRTSCHAFTSDEP., 1991).

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, or, in the case of speed and direction, a scale was defined to give half or full points. After the individual characteristics are recorded in the same format as in HSD, two scores are computed (see Table 3). 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 9 Swiss storms fall well below this range, ranging from -2.0 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" or asymmetric form of ll/ts structure. From the 9 Swiss storms considered presently, 6 exhibit a distinctly "symmetric" character, with values of S ranging from +1.0 to +2.0, one of intermediate character (S = 0) and 2 of them a "asymmetric" one (S = -1.5 to -2.0). Thus the overall classification of the Swiss storms with "ll/ts" structure and damage by water is weakly to moderate classifiable and more symmetric. HSD found for Oklahoma that flood producing storms tended to be strongly classifiable but also symmetric as the Swiss storms (see Table 6 of HSD). Evidently, the topography of Switzerland disturbs the storms in organizing the structures as good as in the flatlands of Oklahoma. For 7 hail producing Swiss storms (in 6 cases no water damage at all) SCHIESSER and HOUZE (1991) found weakly to moderately classifiable and asymmetric storm structures, which is consistent with the findings of HSD for hail and tornadoes producing storms in Oklahoma. It is especially interesting that this structure survives even in the vicinity of highly mountainous terrain. The average speed of the 7 hail producing systems was 15.3

m/s, faster than the flood producing systems (10.9 m/s) from this study, another difference in the behavior of the two storm categories.

Table 3 Scoring of the leading line / trailing stratiform structure

Tabelle 3 Bewertung der "leading line / trailing stratiform" Struktur

	A	B	C	D	E	F	G	H	
1	MPS	Leading Line	Leading Line	Leading Line	Leading Line	Leading Line	Leading Line	Leading Line	Stra[illegible]egion
2	Designator	Shape	Solid	Orientation	Speed	Strong Refl.	Edge Serrated	Cells Elongate	[illegible]e >
3		Arc-like				Gradient		45-90°to line	10**4km**2
4	85.07.04	1	1	0.5	0.5	- 1	- 1	- 1	1
5	86.05.23	1	1	- 1	1	1	-0.5	- 1	- 1
6	86.06.20	1	1	0.5	- 1	1	- 1	- 1	- 1
7	86.08.18	- 1	0.5	1	1	-0.5	0.5	1	1
8	87.07.08	- 1	- 1	1	- 1	1	0.5	0.5	- 1
9	87.08.17	-0.5	1	1	-0.5	- 1	- 1	- 1	1
10	88.06.11	0.5	0.5	0.5	0.5	0.5	- 1	- 1	1
11	88.09.09	1	1	1	- 1	1	-0.5	-0.5	- 1
12	89.07.10	- 1	0.5	1	-0.5	1	- 1	- 1	- 1

	J	K	L	M	N	O
1	Strat. Region	Strat. Region	Leading-Line/	Leading Line	Strat. Region	Symmetric vs.
2	Notch	Secondary Re	Trailing-Stra	Convection	Location	Asymmetric
3		Maximum	Score 'C'	Not Biased	Centered	Score 'S'
4	-0.5	1	1.5	- 1	- 1	- 2
5	- 1	1	0.5	1	1	2
6	- 1	1	-0.5	1	- 1	0
7	- 1	1	3.5	1	1	2
8	- 1	1	- 1	0.5	1	1.5
9	-0.5	1	-0.5	- 1	-0.5	-1.5
10	-0.5	1	2	0.5	0.5	1
11	1	1	3	1	1	2
12	- 1	1	- 2	1	1	2

For illustration an example of a moving large convective "line" interacting with a stationary "line" of convection will be given in section 4 and an example of a "leading line/trailing stratiform" type of organization is given in section 5.

4. THE "SEVERE RAIN EVENT" OF 1 JULY 1987

On 1 July 1987 a coldfront passed through Switzerland and produced 4 distinguishable MPS (labelled A-D) in the test area. Fig.4 shows a time sequence of MPS A+B, which were responsible for most of the damage on that particular SRE. Both systems started around 0900 UTC (local time = UTC + 1h). System A entered from NW into Switzerland as a long squall line having a length of more than 300 km (visible on the radar). B originated as a line of cells at the northern slope of the alpine ridge. C moved also from NW into the test area in the evening but stayed stationary and decayed without being harmful, D will be discussed later. At 1100 system A crossed the Jura and the most northern cell of MPS B developed into an intense hailstorm (Fig.4a). An hour later (Fig.4b) the squall line A, showing intense cells with rain intensities ≥ 100 mm/h, merged in the northeast with the stationary system B and at 1300 (Fig.4c) MPS A totally occluded with B, moving then southeast over the alpine ridge, getting weaker (Fig.4d), leaving behind a huge area of stratiform rain in the north of the Alps.

The slowly moving line of system A (speed = 8 m/s) and the stationary line of system B were responsible for considerable damage by intense rain and hail in the northern part of Switzerland. Fig.2 depicts the communities with light, medium or severe damage by

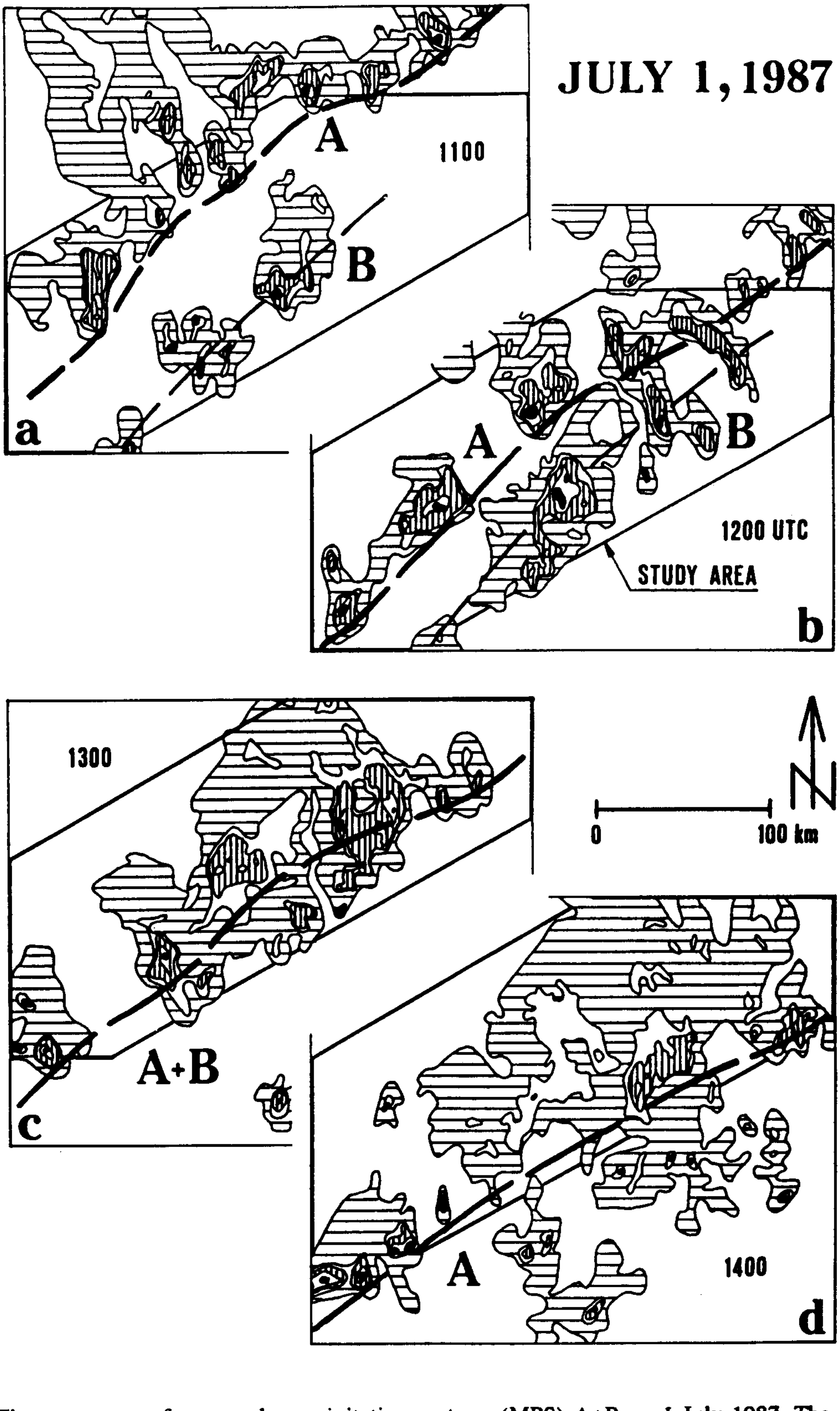

Fig.4 Time sequence of mesoscale precipitation systems (MPS) A+B on I July 1987. The different intensity levels are drawn according Table 1. The thick dashed line represents the front of the squall line, the thin dashed line the row of the stationary cells.

Abb.4 Zeitliche Abfolge der mesoskaligen Niederschlagssysteme A+B am 1.July 1987. Die verschiedenen Intensitätsstufen sind nach Tabelle 1 gezeichnet. Die dicke gestrichelte Linie stellt die Frontlinie der "Squall line" dar, die dünne gestrichelte Linie die Reihe der stationären Gewitterzellen.

water. The damage area labelled (1) is the region of "Emmental" where a total amount of damage by water was estimated as over 60 million Swiss francs (ZELLER and ROETHLISBERGER, 1988). An other badly damaged area was at the northern slope of "Mt.Rigi" in Central Switzerland (area 2 in Fig.2) with a damage total of about 20 million. The damage in the "Fricktal" (labelled 3 in Fig.2) was produced by MPS D during the following night. A single isolated and stationary cell was responsible for it.

5. THE "SEVERE RAIN EVENT" OF 9 SEPTEMBER 1988

On 9 September 1988 a stationary prefrontal MPS developed in the southwest of the study area, the location of origin half way between Lake Geneva and Lake of Neuchâtel at the edge of the Jura chain. The first echo was observed at 1340. A line (contour ≥ 10 mm/h) started to grow at 1400, extending to the north as well as to the south from the point of origin (see Fig.5a) and reached the maximum extent as a broken line at 1740 with a length of 115 km. The maximum length of 100 km of the solid (not broken) line was reached at 1640 (Fig.5b). At about 1500 the "trailing stratiform" area started to grow to the east from the now "leading line" (Fig.5c) until the maximum area (size 10'000 km^2) was reached at about 1810. This situation is shown in Fig.5d, the leading line already in the decaying stage, having now only a length of 55 km. At 1920 the convective line died and the last stratiform echo was detected at 2120. The whole system never moved away from its origin, it just spread out and shrank again. Fig.5e depicts the two damage areas, namely Lausanne and surroundings (1) and around Neuchâtel (2) in the north of the leading line area. The dashed line in Fig.5e represents the boundary of the area covered by the leading line (≥ 10 mm/h). Fig.5f shows the rainfall amount in mm/10min from the ANETZ-station Neuchâtel, measured during that event. In Fig.5a, 5c and 5e the location of the station is indicated by a black star . The curve is typical for the life cycle of a convective system turning into stratiform rain. In the first phase high rainfall amounts as peaks from single convective cells are registered, at the end of the curve lower amounts from the stratiform and decaying phase.

6. 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 severe rain event (SRE), in which intensive or long lasting rain occured in the region north of the alpine ridge. In this study, only days marked by extensive water damage were considered. There were 31 such days, of which 23 exhibited deep convection. On 11 of the 23 convective MPS, the radar echos exhibited mesoscale organization of "line" formation, 3 cases of a more chaotic or "noline" pattern. Another 9 cases showed a type of organization which could be classified according to the scheme used by HSD to study Oklahoma storms. Each of the 9 convective cases exhibited weak to moderate "leading line/trailing stratiform" organization and tended to be symmetrically arranged. The symmetric type of organization is consistent with that found for flood producing storms in Oklahoma, which occur over flat terrain, very different

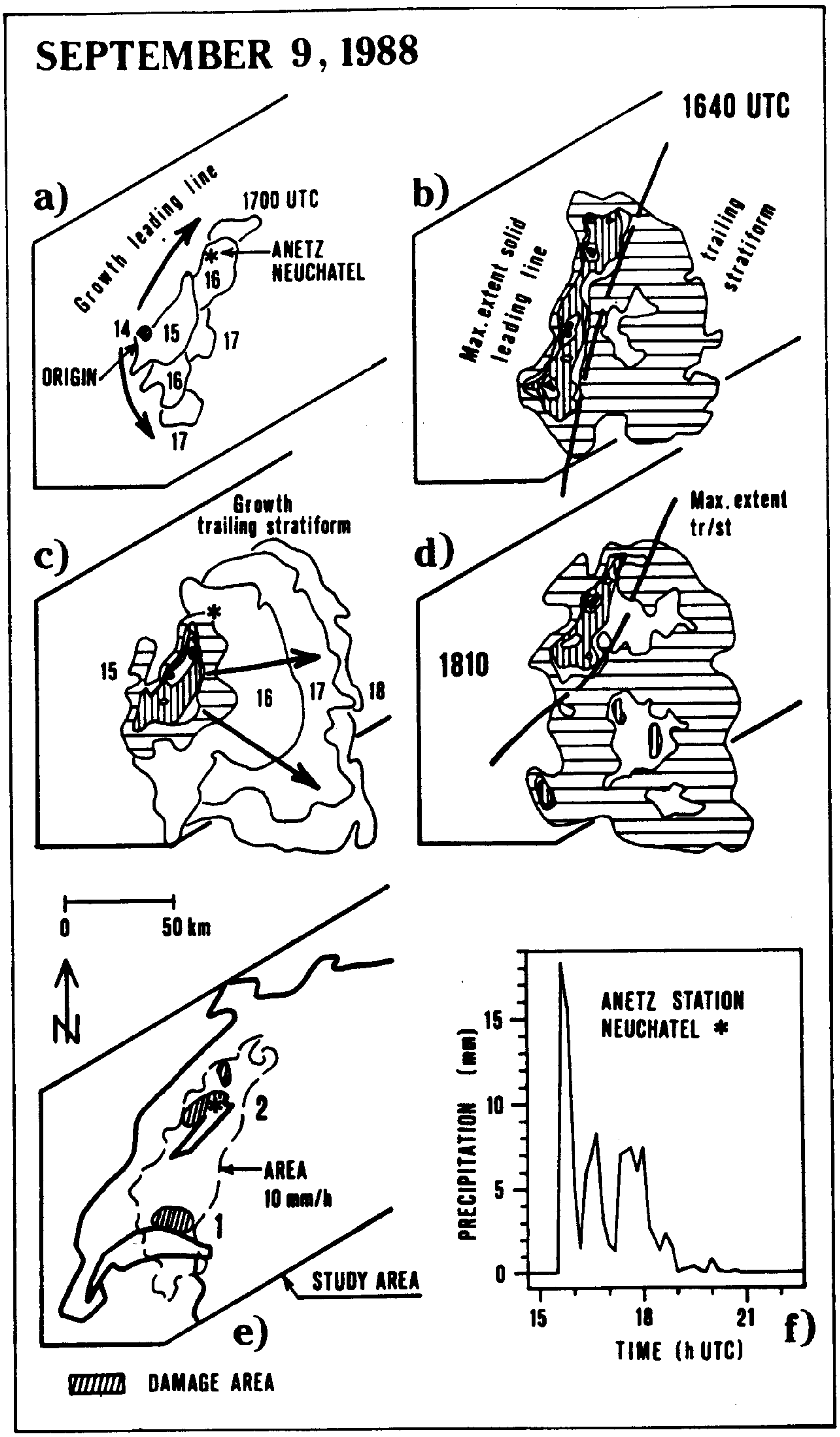

Fig.5 Growth of the leading line (ll) and trailing stratiform (ts) part of the mesoscale convective system (MCS) on 9 September 1988. a) Growth of "ll" (contour 10 mm/h) in hourly steps. b) Maximum extent of the "ll" at 1640 UTC. c) Growth of the "ts"-part in hourly steps (contour 1 mm/h). d) Maximum extent of the stratiform area at 1810 (for the contour levels in Fig. b and d see Table 1). e) The damage areas (1 = Lausanne, 2 = Neuchâtel) and the boundary of "ll"- area with rain intensity of ≥ 10 mm/h. f) The rainfall amount per 10 min at ANETZ (automatic network of SMA) station Neuchâtel. The location of the station is indicated in Fig. a, c and e.

Abb.5 Wachstum der "leading line" (ll) und des "trailing stratiform" (ts) Teils von dem mesoskaligen konvektiven System (MCS) am 9. September 1988. a) Wachstum der "ll" (Kontur 10 mm/h) in stündlichen Schritten. b) Maximale Ausdehnung der "ll" um 1640 UTC als eine kompakte Linie. c) Wachstum des "ts"-Teils in stündlichen Schritten (Kontur 1 mm/h). d) Maximale Ausdehnung des stratiformen Teils um 1810 (für die Intensitätsniveaus in den Fig. b und d siehe Tabelle 1). e) Die Schadengebiete (1 = Lausanne, 2 = Neuchâtel) und die Grenze des "ll"- Gebietes mit Regenintensitäten von ≥ 10 mm/h. f) Die zehnminütige Regenmenge an der ANETZ- (automatisches Messnetz der SMA) Station Neuchâtel. Die Lage der Station ist in den Fig. a, c und e eingezeichnet.

from the hills, valleys and mountains of northern Switzerland. But the storm structures there are more pronounced and were strongly classifiable.

The case studies of 1 July 1987 ("line"-formation) and 9 September 1988 ("ll/ts"-formation) were presented to illustrate that the available radar data can reveal in great detail the structure of the observed MPS. Individual intense convective rain cells within the MPS can be tracked by using the two highest intensity levels of radar echo. They correpond very well with ground information on damage by water. Further the whole life history of a system can be studied.

The next step will be to broaden the study to include more cases with water damage as well as hail cases of the study period to determine whether the preliminary results of this analysis will be confirmed, and if other mesoscale structures are present in less-severe rain and hail events.

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