AIRCRAFT PENETRATIONS OF SWISS HAILSTORMS -- AN UPDATE

Dennis J. Musil and Paul L. Smith
Institute of Atmospheric Sciences
South Dakota School of Mines and Technology
Rapid City, South Dakota 57701-3995

Abstract. An armored T-28 aircraft was used to make observations of the interiors of Swiss hailstorms during the summers of 1982 and 1983. The main objective was to determine the presence of any accumulations of supercooled raindrops in the so-called "Big Drop Zone." The principal finding was that extremely few supercooled raindrops were found in the Swiss storms. On the other hand, concentrations of ice particles, principally in the form of graupel, were of the order of 10^3-10^5 m^{-3}. Since there were so few supercooled raindrops, attempts to glaciate them by seeding in order to reduce the potential for hail do not appear to be appropriate. The observations strongly suggest that an ice process is the predominant precipitation mechanism.

1. INTRODUCTION

Operational hail suppression programs in the Soviet Union have persistently claimed substantial damage reduction for many years (Burtsev, 1985). The seeding method involves rapid introduction of quantities of glaciogenic material into certain regions of the clouds by means of artillery shells or rockets. Those regions are thought to contain large quantities of supercooled raindrops. The Soviet programs are nonrandomized and have relied upon historical or target-control techniques for evaluation, with the result that the claimed reductions are difficult to substantiate satisfactorily.

Accordingly, a closely analogous, but randomized, test of the Soviet approach was carried out in Switzerland as Grossversuch IV (Federer et al., 1979). In that experiment, radar methods similar to those devised by the Soviets were used to identify the so-called "Big Drop Zone" (BDZ) in the clouds, and rockets of Soviet manufacture were used to seed those zones. Effects of the seeding upon hailfall were then evaluated using radar and hailpad networks (e.g., Federer et al., 1982b).

The principal indication that the hypothesized concentrations of supercooled raindrops might occur in Swiss storms came from the frequent occurrence of frozen-drop embryos in the hailstones (Federer et al., 1982a). In order to obtain more direct evidence about the microphysical characteristics of the BDZ's, a series of observations of the interior characteristics of Swiss hailstorms was made with the T-28 armored research aircraft (Johnson and Smith, 1980) during the summers of 1982 and 1983. The main objective was to determine the presence of any accumulations of supercooled raindrops in the BDZ. Other objectives included gathering information to increase our understanding of the basic cloud physics in the mechanism of hail formation in the Swiss storms.

2. THE BIG DROP ZONE

2.1 Radar criteria

The BDZ was identified by 3-cm radar measurements in a range height indicator (RHI) mode. First, the maximum equivalent reflectivity factor above the 0°C level (Z_m) was determined. When 45 dBz $< Z_m <$ 55 dBz, the radar-identified BDZ was that region above the -5°C level where the radar reflectivities were $>$ (Z_m - 10 dB). If $Z_m >$ 55 dBz, the BDZ was that region where the radar reflectivities were $>$ 45 dBz above the -5°C level. In addition, the BDZ could be extended into any overhang region identified in the radar data, even if the reflectivities there were less than the above-described limits. Thus, the BDZ can be a region of high reflectivity aloft and/or a weak echo region in the storm.

The above method was used routinely during Grossversuch IV for conducting the seeding operations with rockets which were aimed at the BDZ's. The same technique was used to identify the target region toward which the T-28 was vectored to investigate the characteristics of the BDZ. The formal Grossversuch IV randomized seeding experiment had ended by the time the T-28 investigations began, and because of the possible flight hazards associated with the rockets none of the storms investigated by the T-28 were seeded.

2.2 Sample

An example of a T-28 penetration of a high-reflectivity BDZ on 13 July 1983 is shown in Fig. 1. The penetration (No. 3 on this flight) was along almost the same direction as the RHI section shown in the inset. The area of the BDZ at the T-28 altitude was estimated as approximately 10 km^2 in this case. The time period during which the T-28 encountered the BDZ at the -9°C level, about 25 seconds, was characterized by updrafts and cloud liquid water, which at times exceeded 15 m s^{-1} and 1 g m^{-3}, respectively. The

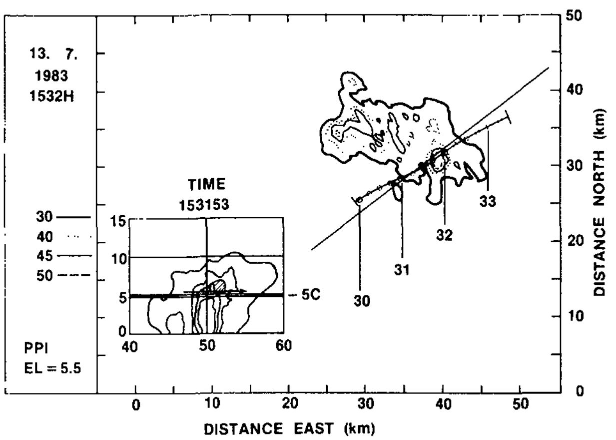

Fig. 1: Radar views of a BDZ penetration on 13 July 1983. Slant PPI view (10-cm) has aircraft flight track superimposed, with squares representing minutes after 1500 SDT. RHI section (3-cm; contours 10, 20, 40, and 45 dBz) along the direction indicated shows position where T-28 crossed the RHI plane, which is almost along the flight track.

storm maximum reflectivity factor during the time of the T-28 flight exceeded 50 dBz.

2.3 Penetrations of BDZ's

Nine research flights were made during the two field seasons, including a total of 54 storm penetrations. With the exception of one fast moving storm (Smith et al., 1983), all of the storms were relatively small air-mass-type storms. The best flights during which radar-identified BDZ's were penetrated occurred on three days as indicated in Table 1. Those days were characterized by cloud base temperatures in the range from +4 to +11°C; low-level mixing ratios from 7-11 g kg^{-1}; weak to moderate instability; and weak vertical wind shear (Smith et al., 1984).

To actually pass through the BDZ, which is a transitory target that varies in size and location, proved to be something of a challenge. The BDZ was still identifiable at the time the aircraft passed through the storm on about two-thirds of the penetrations; in about two-thirds of those cases, the aircraft actually went through the BDZ as intended. [The flight tracks were determined by a separate high precision tracking radar.]

TABLE 1

Summary of Basic T-28 Data from Storm Penetrations of Radar-Identified Big Drop Zones

Date	Pen	Type*	Time in BDZ (sec)	Accuracy** (km)	Temp (°C)	Max in BDZ Updraft ($m\ s^{-1}$)	Max in BDZ LWC ($g\ m^{-3}$)
16 Aug 82	1	O	40	0.5	-10.9	25	3.1
	2	O	55	0.5	-11.0	29	4.4
	5	H	40	0.5	-13.3	16	1.4
	6	H	25	3.0	-12.3	11	1.6
23 Jun 83	5	H	2	3.0	- 7.7	23	1.2
	6A	H	35	0	- 7.7	12	0.4
	6B	H	10	0.5	- 7.7	12	0.9
	7	O	10	3.0	- 7.7	4	0.2
	9A	O	20	2.0	- 7.6	9	1.3
	9B	O	2	0.5	- 7.6	17	1.6
	10	O	20	1.0	- 7.8	8	0.8
	11	H	20	0.5	- 7.6	10	0.1
13 Jul 83	2	H	15	1.0	- 8.9	10	0.7
	3	H	25	0	- 9.0	21	1.2

*O - Overhang; H - High Reflectivity.

**Distance to BDZ center.

This resulted in 14 penetrations on the three days which passed through some portion of the BDZ's. The observations from these penetrations of the BDZ form the basis of the rest of this paper.

3. SUMMARY OF BDZ CHARACTERISTICS

The sizes and concentrations of precipitation particles in the storms were measured with a Particle Measuring Systems "2D-C" optical array probe (Knollenberg, 1981), a particle camera (Cannon and Woltz, 1977) and a foil impactor. The camera provides clear indications of particle phases, and inferences about phase can also be drawn from the 2D-C image data.

The principal finding of this research is that there was no evidence of accumulations of supercooled raindrops in the region constituting the BDZ. In fact, extremely few raindrops were found anywhere during the penetrations. Even when they did occur, they were accompanied by substantial concentrations of ice particles. Estimated concentrations of liquid drops of precipitation sizes were no more than about 0.1 m^{-3}, while the accompanying ice particles had concentrations ranging between approximately 10^3-10^5 m^{-3}. The latter concentrations of ice particles were typical of all the BDZ's penetrated, and concentrations were typically higher in the BDZ than outside. Graupel was by far the most common ice crystal habit observed. Most of the BDZ's included particles up to centimeter sizes, which is consistent with the high reflectivities therein.

The BDZ's were usually updraft regions; in fact, the updraft maximum for the penetration was often located in the BDZ. The largest updraft speed observed was about 30 m s^{-1}. The penetrations of the BDZ were also characterized by substantial amounts of cloud liquid water, typically ranging between 1-2 g m^{-3}. The droplet spectra were maritime in character, in that they often showed the presence of large cloud droplets (>45 µm in diameter) in a generally broad distribution.

4. IMPLICATIONS FOR HAIL SUPPRESSION

Recognizing the limitations that the T-28 observations are from essentially a single level and that the full spectrum of Swiss hailstorm types may not have been sampled, it appears that BDZ is something of a misnomer because very few supercooled raindrops were found there. Furthermore, the high concentrations of ice particles found in the BDZ's suggest that any supercooled drops which do occur would have very short lifetimes. Therefore, the BDZ region in the storms does not appear to be one in which hail growth takes place by the accretion of supercooled raindrops on hail embryos, as theorized by some Soviet scientists. Consequently, the use of seeding rockets to attempt to glaciate drops in the BDZ and thereby reduce the potential for hail growth, either by a beneficial competition mechanism or by simply removing the drops as potential hailstone growth material, does not appear to be appropriate for these storms. The use of an inapplicable seeding concept could account for the absence of any significant effect of the seeding upon the hailfalls, in the confirmatory statistical evaluations of Grossversuch IV (e.g., Federer et al., 1982b).

There may be some question about the timing of the T-28 observations, because it obviously requires some time to fly the aircraft through the BDZ after it has been identified by radar. On the other hand, it would also take some time to launch the rockets, dispense the seeding material in the BDZ, and nucleate any liquid particles therein. Moreover, on at least two occasions, the radar BDZ signatures persisted for three successive T-28 penetrations spanning 20 minutes or more, and yet no evidence was found of appreciable quantities of supercooled raindrops. Thus, the likelihood that such drops contribute significantly to the hail growth process seems to be very small.

The large amounts of ice observed in these penetrations strongly suggest that an ice process is the predominant precipitation mechanism. The most probable hail growth mechanism in these storms appears to involve the growth of ice particles through the accretion of cloud liquid water; this is also the hail growth mechanism identified in hailstorms of the High Plains of North America (Knight and Squires, 1982). Such a mechanism is certainly adequate to grow hailstones to the sizes observed with the T-28 in the Swiss storms. Some other seeding approach will evidently be needed to mitigate the production of hail by those storms.

Acknowledgments. This research was carried out with partial support from the U.S. National Science Foundation under Grant Nos. ATM 82-04652 and ATM 84-14496. Additional support was provided by the Swiss National Science Foundation and important assistance was furnished by the U.S. Navy, Swiss Air Force, and NCAR Convective Storms Division. We acknowledge the contributions of our Swiss colleagues, especially Albert Waldvogel, Laszlo Klein, and the late Dr. Bruno Federer, to this research.

REFERENCES

Burtsev, I. I., 1985: Crop protection against hail damage in the U.S.S.R. Preprints 4th WMO Sci. Conf. Wea. Mod., Honolulu, Hawaii, Amer. Meteor. Soc., Vol. 2, 613-617.

Cannon, T. W., and R. Woltz, 1977: Camera for in situ photography of atmospheric cloud particles from an armored T-28 hail research aircraft. SPIE Semin. Proc., 125, 114-120.

Federer, B., B. Thalmann, and J. Jouzel, 1982a: Stable isotopes in hailstones: Part II. Embryo and hailstone growth in different storms. J. Atmos. Sci., 39, 1336-1355.

Federer, B., A. Waldvogel, W. Schmidt, F. Hampel, M. Schweingruber, W. Stahel, J-F. Mezeix, N. Doras and D. Vento, 1982b: First results of Grossversuch IV. Preprints 2nd Intn'l. Conf. Hailstorms and Hail Prevention, Sofia, Bulgaria, 367-374.

______, A. Waldvogel, W. Schmid, F. Hampel, E. Rosini, D. Vento, P. Admirat and J-F. Mezeix, 1979: Plan for the Swiss randomized hail suppression experiment. Pageoph, 117, 548-571.

Johnson, G. N., and P. L. Smith, 1980: Meteorological instrumentation system on the T-28 thunderstorm research aircraft. Bull. Amer. Meteor. Soc., 61, 972-979.

Knight, C. A., and P. Squires, eds., 1982: Hailstorms of the Central High Plains. Vol. I: The National Hail Research Experiment. Colorado Assoc. Univ. Press, Boulder, CO. 282 pp.

Knollenberg, R. G., 1981: Techniques for probing cloud microstructure. Clouds, Their Formation, Optical Properties and Effects. (P. V. Hobbs and A. Deepak, eds.). Academic Press, NY. 497 pp.

Smith, P. L., D. J. Musil and A. Waldvogel, 1983: Clues regarding hail development processes from observations inside Swiss hailstorms. Preprints 13th Conf. Severe Local Storms, Tulsa, OK, Amer. Meteor. Soc., 9-12.

______, ______, and ______, 1984: Aircraft observations inside Swiss hailstorms. Preprints 9th Intn'l. Cloud Physics Conf., Tallinn, USSR, 561-564.