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A STEP BY STEP GUIDE TO BUILDING AN ALL INCLUSIVE SNOW SPOTTER NETWORK

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1. INTRODUCTION

With the introduction of the WSR-88D radar system, the ability to resolve a wide range of reflectivities in a typical snow event increased dramatically. This was especially significant in the area of short term forecasting. Unfortunately some problems arose when forecasters attempted to use this new information operationally.

The WSR-88D was not delivered with a ready-made snowfall algorithm (Klazura and Imy 1993) and estimation of snowfall rate was usually based on what could be deduced from occasional volunteer spotter reports. Many times, the lack of full-time manned observing sites made it difficult to relate radar reflectivities to snowfall rates on a real-time basis. With this limited amount of ground truth observations, forecasters could only guess at the snowfall associated with particular reflectivities. To effectively use this new technology, the relationship between reflectivity and snowfall rate was explored to produce a practical formula.

Past studies relating reflectivity to snowfall rate (generally termed Z-S) have been limited in scope due to the resolution of the radars and the small number of observers in the associated networks (Carlson and Marshall 1972; Wilson 1975; Boucher and Wieler 1985; Smart and McGinley 1989; Fujiyoshi et al. 1990). Empirical formulas obtained from these studies produced hit and miss results when applied operationally.

Although work on a general snowfall algorithm for the WSR-88D is underway (Super and Holroyd III 1996, 1997), this activity is confined to only a few sites across the country and may not be fully representative of local environments at NWS offices in all locations. Significant snow events are produced by a wide variety of processes (i.e. overrunning, lake effect, terrain-induced, cyclones, etc.) unique to a specific location. In addition, these processes take place across a wide range of temperature and moisture profiles resulting in different snowflake types which have a direct bearing on return power (Ohtake and Henmi 1970). All of these factors contribute to variable snowfall rates for a given radar reflectivity in various events, thus the need for local studies is apparent.

To form an accurate correlation between snowfall rate and reflectivity, a number of variables have to be consistently recorded during snow events. Naturally, the more observations that are available, the greater the operational confidence in the resulting Z-S correlations. The critical first step in this effort, is thus to recruit and coordinate the largest number of reliable observers as practical. This paper will document the methods used and highlight some of the problems encountered when such a network was constructed by NWSFO Albany, NY beginning in 1994.

2. NETWORK DESIGN AND METHODS

The main objective of creating the network was to support a project to build an equation relating .54 nm, 0.5 degree elevation, base reflectivity data (REF) from the WSR-88D radar to hourly snowfall rates by using multiple linear regression techniques. To do this, accurate snowfall measurements were needed over the widest range of reflectivities possible, and it was decided that the work of recording ground measurements could be done by volunteers. Before recruiting these volunteers, the area of study had to be defined based on the limitations imposed by the radar system, by the local terrain, and other factors. In addition, the types of data required had to be identified and possible sources of measurement inaccuracies explored.

2.1 Identifying the Geographical Area of Study

The primary factor in defining the geographical area involved in this study was the change in radar beam height with distance from the radar site. In a standard atmosphere, a 0.5^{o} elevation slice above ground level (AGL) ranges from tower height at the point of transmission to approximately 17,000 ft at 120 nm (Fig. 1).

Beam height was critical in this study, as several sources of error become more significant as the distance from the radar increases. Reflectivity data may be compromised at longer ranges due to overshooting of precipitation occurring below the radar beam and partial beam filling by precipitation. Other sources of errors occurring at greater distances from the radar, include the below-beam advection of the detected precipitation and possible evaporation of snow particles.

To minimize these factors, the area of the Z-S study and thus network recruitment was initially restricted to within 50 nm of the radar site. This area was later reduced to 27 nm (50 km) which was found to be the optimal range by Boucher and Wieler (1985). Depending on vertical temperature and humidity profiles, the radar beam axis passes between 5000 ft and 6000 ft at the outer limits of the study area. Beam diameter at this point is approximately 5064 ft.

After defining the general area in terms of distance from the radar site, the next consideration was terrain. As with many WSR-88D sites across the country, beam blockage due to man-made objects or local terrain was another source of degradation to reflectivity estimates, and this had to be considered in determining suitable areas for observations.

The most helpful tool for highlighting areas of beam blockage, besides occultation or hybrid scan maps, was the RDRHGT (RDRHGT.FOR) program, a PC software package developed by Tim Barker (1994). This program displays the WSR-88D beam in plane view and vertical cross section using topographical files created for the specific WSR-88D site of interest. The program uses the standard atmosphere by default to determine beam height, but it is also capable of ingesting sounding data and calculating changes in blockage due to beam refraction.

Another problem caused by terrain was complications resulting from downslope flow. Areas which frequently experienced subsidence and inhibited precipitation amounts due to downslope flow in storms were eliminated from the Z-S study.

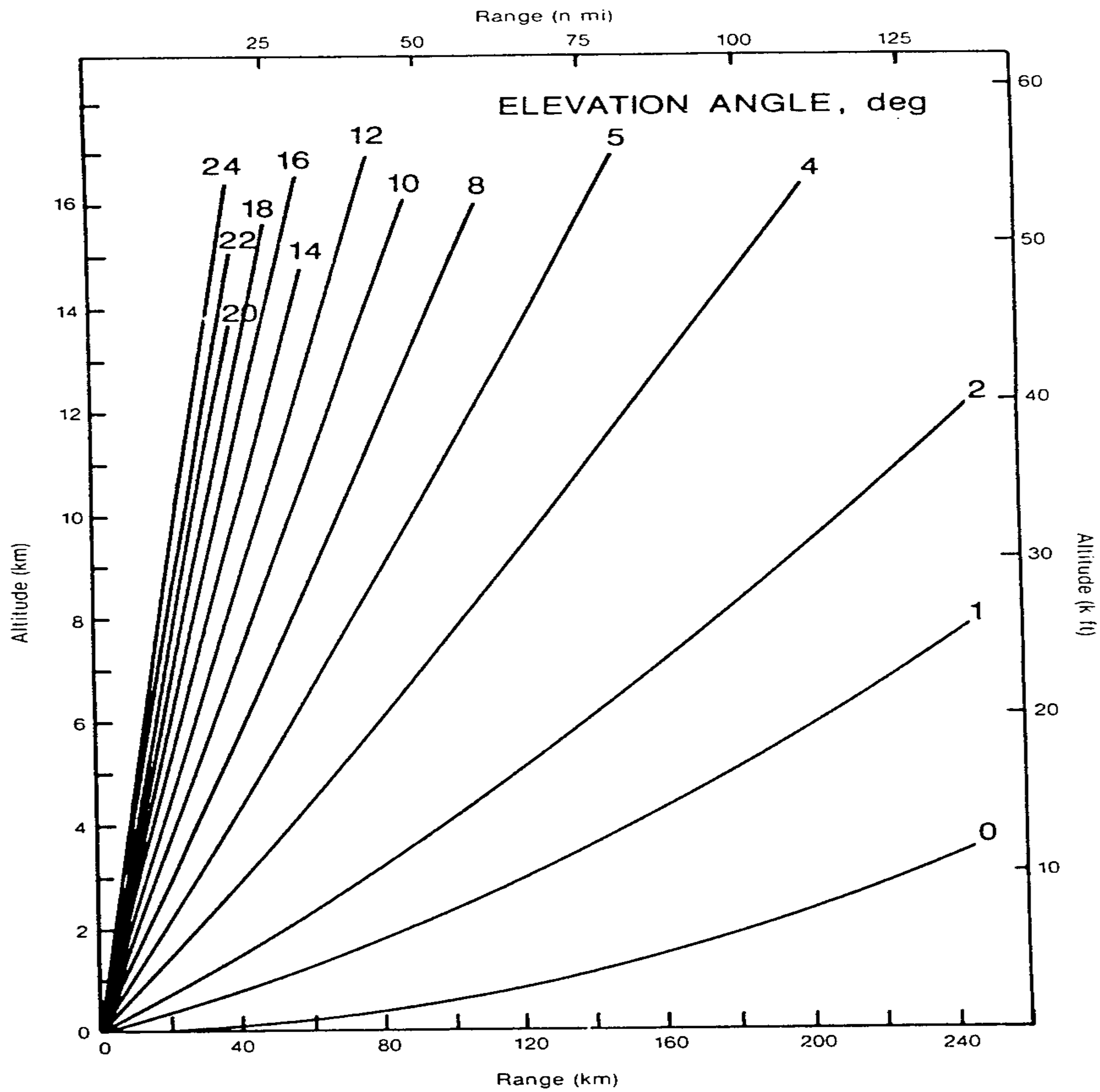

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Figure 1. Range-Radar Beam Altitude Nomogram for the Standard Atmosphere (Federal Meteorological Handbook, No. 11, Part B, 1990).

Since ground clutter returns within a mile or two of the radar site are often a problem with the KENX radar, no observers were recruited in this area.

2.2 Data Elements and Measurements

Information on a number of variables was required for this study, the most important of these being accurate measurement of snowfall and water equivalent. Because the main goal of the Z-S study was to determine a snowfall rate per hour in relation to an average reflectivity, observations were required on an hourly basis. To simplify later analyses, it was decided that snowfall measurements would be recorded at the top of each hour.

Observers were not uniformly equipped in terms of personal weather instruments. Some individuals possessed sophisticated sensors for measuring wind, temperature, etc.; others owned little more than a mercury thermometer. It was determined as a cost saving measure that all participants would only be supplied with the identical equipment necessary for recording the critical elements of hourly snowfall and water equivalent.

The observation form created by NWSFO Albany, NY appears as Fig. 2. All of the necessary elements were contained on one sheet with handy reference numbers in each column. These numbers provide reference to instructions in a step by step guide for completing each element of the observation form. An abbreviated version of the step by step guide is contained in the following paragraphs.

Spotter:			Location:			Lat:	Long:	El:
1	2	3	4	5	6	7	8	9
Date	Time	Snow Type / Intensity	Snowfall (hourly)	Snow Depth	Water Equvlnt (total)	Barometric Pressure*	Temperature / Dewpoint	*Wind Dir / Spd

Figure 2. NWSFO Albany, NY Snow Study Observation Form

Information at the top of the form identified the observer and location. Observers were also asked to provide the approximate time of precipitation onset if known.

Elements 1 and 2

Date and Time - This information was necessary because of events lasting more than 24 hrs and observers starting or ending measurements at different times during an event. Observers were requested to use local standard time (LST).

Element 3

Snow Type and Intensity - These observations were recorded using a simple guide for snow particle identification, that included brief descriptions of snow particle size, form and shape (Appendix A). This information was used to identify the largest snowflakes which may account for almost all of the returned signal (Ohtake and Henmi, 1970; and Smart and Albers, 1991). In addition this information provided an estimate of the terminal velocity of the snowflakes which is based on snowflake type. Type identification also indicated if melting and refreezing of snowflake were occurring over the observation site.

To rule out contamination of reflectivity values due to melting of precipitation, only events certain to remain all snow were to be used in the Z-S study. However, anomalies associated with larger storms can produce brief periods of upper level warming which are transient in nature. Only snow type observations can show evidence of these features. Therefore, observations of rain, drizzle, freezing rain, freezing drizzle, snow grains, snow pellets, etc., were considered vital and given a high priority.

Intensity of snowfall was determined using the NWS criteria shown in Table 1 and it was estimated if fog was present.

Table 1. NWS Criteria for Snowfall Intensity.

METAR INTENSITY AND PRECIPITATION CODE	PRECIPITATION	NWS DEFINITION
-SN	LIGHT SNOW	VISIBILITY 3/4 MILE OR GREATER
SN	MODERATE SNOW	VISIBILITY 1/2 MILE
+SN	HEAVY SNOW	VISIBILITY 1/4 MILE OR LESS

Element 4
Snowfall (hourly) - Hourly snowfall measurements were taken to the nearest tenth of an inch using a 6-inch snow stick and snow board provided to each observer.

Element 5
Total Snow Depth - Recorded hourly and measured in an area free of drifts, this information was requested mainly as a crude check on reported hourly amounts.

Element 6
Water Equivalent - Initially, the water equivalent was measured by placing the outside cylinder of a 4-inch diameter All Weather (Clear-Vu) rain gauge next to the snow board. At observation time, this was then replaced by a second gauge and the contents of the first were melted and measured.

This technique was later modified to compensate for the loss of precipitation catch due to wind currents around the cylinder. Observers were instructed to take a "core sample" by placing the outer Clear-Vu cylinder upside-down near the center of the snow board and then measure snow depth between the corners and the gauge, taking an average of several readings. Excess snow was then brushed away from the gauge and the board and the gauge were inverted. Any snow left clinging to the board (within the gauge circumference) was then carefully scraped into the gauge and snow was then melted to obtain a water equivalent. After all the precipitation was melted, the liquid was transferred to the graduated inner tube of the Clear-Vu gauge for measuring. Observers were instructed not to empty this inner tube between measurements, but to let the liquid accumulate. The difference between the present and prior readings was then calculated for the hourly amount (Super and Holroyd III 1996).

Element 7
Barometric Pressure - Taken at the time of observation, this element was optional and was only reported if the observers possessed the proper equipment.

Element 8
Temperature/Dewpoint in degrees Fahrenheit - Temperature was recorded at the time of observation and dewpoint was included if available. Along with hourly snowfall and water equivalent, surface temperature was a critical element to be tested for significance in the relationship between reflectivity and snowfall rate. It was also requested to monitor possible contamination of data due to melting.

Element 9
Wind Speed and Direction - Only a few observers possessed wind equipment, but all observers were requested to estimate a direction and speed (using the Beaufort Wind Scale)(List 1951) and note any blowing or drifting of snow which could interfere with accurate snow measurement. Observed surface winds were used to determine when snowfall measurements were likely inaccurate.

3. ORGANIZING THE OBSERVER NETWORK

The significance of accurate measurements of snowfall and water equivalent for relating radar reflectivity with snowfall rate cannot be overemphasized. The accuracy of snowfall and water equivalent measurements are directly related to the performance of the observers taking the measurements. The demands of this tedious job, which sometimes spanned the better part of a day or more, called for highly motivated individuals who understood the methods and final goals of this project.

3.1 Recruiting Observers

To create a network of volunteer observers, our first step was to create a list of potential snowfall observers, looking to utilize those individuals with prior training and interest in weather. Thus, our list consisted of NWS Cooperative Observers including the Capital District Weather Network[1], Advanced SKYWARN Spotters, and members of the Eastern New York Weather Observers[2]. These volunteer observers represented the most experienced group of individuals involved in taking routine weather observations within NWSFO Albany's County Warning Area (CWA).

Once potential volunteer observers were identified, a mailing list was created and form letters were sent to 144 individuals. A copy of the form letter which was sent to the potential volunteers appears as Appendix B. The form letter garnered a positive response from 75 potential volunteer spotters representing 52% of those canvassed. This is not to say that most attempts at setting up a volunteer network will achieve such a response, but rather, that by targeting those already known to have an interest in weather, one can significantly increase the likelihood of a positive response.

Upon receipt of confirmation from those potential volunteer observers interested in participating in the NWSFO Albany Snow Study, a database was created using commercial software and eventually grew to include the fields listed in Table 2. All pertinent information about the observer was documented including name and location, home and work phone numbers, latitude/longitude /elevation, direction/distance from the radar, and the height of the radar beam at that location for an elevation angle of 0.5 degree. It should also be noted that a detailed listing of weather instruments which the observers already had at their disposal (including manufacturer and model) was created. This made it easier to ascertain how many volunteer spotters would be providing complete weather observations each hour.

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[1] A group of cooperative observers who are also amateur radio operators.

[2] An organization of weather observers established in 1978 by Bob Kovachick, chief meteorologist at WNYT-TV 13 in Albany, NY; and Doc Taylor, air pollution meteorologist and chief of the impact assessment and meteorology section at the New York State Dept. of Environmental Conservation in Albany, NY (initially the organization was affiliated with the now defunct Interior of Eastern New York Chapter of the American Meteorological Society).

Table 2. NWSFO Albany's Snow Study Observer Database Fields.

FIELD NAME	FIELD NAME
SPOTTER NUMBER	COUNTY NAME
GPS READING NUMBER	LATITUDE (TENTHS OF A SECOND)
FIRST NAME	LATITUDE (TENTHS OF A SECOND)
LAST NAME	ELEVATION (FT MSL)
ADDRESS	TYPE OF RAIN GAUGE(S)
CITY	NUMBER OF CLEAR-VU GAUGES PROVIDED BY NWS
STATE	WEATHER INSTRUMENTS AT SPOTTER LOCATION
ZIP CODE	DATE VISITED BY NWS
HOME PHONE	DIRECTION FROM RADAR (AZIMUTH)
WORK PHONE	RANGE FROM RADAR (NM)
COUNTY FIPS NUMBER	HEIGHT OF 0.5 DEGREE ELEVATION ABOVE SPOTTER LOCATION (FT MSL)
COUNTY ZONE NUMBER	

3.2 Essential Equipment and Procurement

Our goal was to provide all observers with a minimum set of observing equipment. In order to make snowfall and snow depth measurements, all of the volunteer observers in the network were provided plywood snow boards with dimensions of one-foot by one-foot (typical dimensions are two-feet by two-feet) and ½ inch thick.

Other than the dimensions of the plywood snow boards, every effort was made to ensure that they conformed to NWS specifications. All of the snow boards were painted white on all sides using an exterior flat latex house paint to minimize radiation and melting effects. We cut and painted the boards ourselves and estimated the final cost to be between 60 and 70 cents each. Using the smaller than standard boards saved several dollars on each piece.

All of the volunteer observers in the network were also provided with 5 inch snow sticks which were initially manufactured by making a transparency from an official NWS snow stick and affixing the transparency to a piece of plastic siding. These manufactured snow sticks proved to be accurate, but not durable as the transparencies became brittle over time. Starting with the second year of the study , 6-inch flexible stainless steel rulers were purchased from a local lumber company at a cost of several dollars apiece. These rulers were ideal as they were graduated in 10ths, 100ths, 32nds and 64ths of an inch.

There are many types of rain gauges which vary in cost and accuracy which could be used for the purpose of determining the water content of snowfall. Some comparative information on various gauge types is given in Table 3. Most of our volunteer observers utilized All Weather Clear-Vu gauges which we provided at a cost of 21 dollars each. Some observers were already equipped with All Weather Clear-Vu gauges or NWS Standard 8 inch gauges.

Table 3. Comparative Information on Various Rain Gauges Used for the Measurement of the Water Content of Snowfall.

GAUGE TYPE	COST ($)	ACCURACY	SOURCES OF ERRORS
TRU-CHEK WEDGE GAUGE	8.95	VERY POOR FOR MEASURING THE WATER EQUIVALENT OF SNOWFALL.	SMALL SIZE OF GAUGE OPENING AND VARIABLE GRADUATIONS. UNDER CATCH OF SNOWFALL DUE TO WINDS.
ALL WEATHER CLEAR-VU GAUGE	20.74	ADEQUATE (NOT IDEAL) AND INEXPENSIVE MEANS FOR OBTAINING REASONABLY ACCURATE SNOW SAMPLES.	MEDIUM SIZE OF GAUGE OPENING AND UNDER CATCH OF SNOW DUE TO WINDS.
NWS STANDARD 8 INCH GAUGE	213.	BEST GAUGES AVAILABLE FOR DETERMINING WATER CONTENT OF SNOW DUE TO LARGE GAUGE OPENING AND EASE WITH WHICH IT CAN BE SHIELDED.	UNDER CATCH OF SNOW DUE TO WINDS.
RECORD-ING GAUGE	2490.	GOOD, BUT HIGH COST OF EQUIPMENT AND MAINTENANCE MAKES THIS GAUGE IMPRACTICAL FOR LARGE DEPLOYMENTS.	UNDER CATCH OF SNOW DUE TO HIGH WINDS.
HEATED TIPPING BUCKET GAUGE	1252.	EXTREMELY POOR FOR SAMPLING SNOWFALL.	LOSS OF LIQUID DUE TO EVAPORATION AND DEFLECTION OF SNOWFLAKES DUE TO THE “CHIMNEY EFFECT”. UNDER CATCH OF SNOWFALL DUE TO WINDS.

There are several sources of error associated with measuring the liquid equivalent of snowfall. Some of the more significant problems include: a) The "chimney effect" - snowflakes are deflected away from the collector due to warm air rising from the gauge when the heaters are operating (ASOS Trainer"s Tool Box, 1995). b) Under catch of snowfall - most affected by the height of the rain gauge above the surface. Goodison (1978) proved that an unshielded Universal (Belfort) weighing gauge routinely under catches ground-level snowfall by a significant amount (50 percent under catch with wind speeds as low as 6 m.p.h. (5 kts)). Even those gauges which are equipped with wind shields can experience significant errors under strong winds (Warnick, 1956). The wind velocity typically varies from near zero at the surface to the mean velocity of the unobstructed wind field as the height of the gauge above the surface is increased. Even though wind shields can improve gauge catch of snowfall, they cannot overcome problems associated with windy sites or those with poor exposure. Goodison (1978) also examined Universal (Belfort) weighing gauges equipped with Alter wind shields and still found the under catch to be significant (30 percent under catch with wind speeds as low as 6 m.p.h. (5 kts)).

3.3 Site Inspection

In order to ensure that accurate measurements were taken, NWSFO Albany staff visited each volunteer snowfall observer. These visits not only provided an opportunity to answer any questions that the spotter may have had regarding the observation form and accompanying instructions, but also allowed for the proper sighting of the snow board to minimize wind effects. A time efficient route was established for visitation using two computer software programs from Delorme Mapping (MAPEXPERT V2.0 for Windows and Map'n'Go)[3]. Even with the aide of these software programs a considerable amount of travel time was needed to set up the network. During an 8-hour day it was possible to set up 6 to 8 spotters with a half hour allocated for each spotter.

A Global Positioning System (GPS) was used to determine the latitude and longitude of each snow board location. The GPS readings were accurate to within +/- 49 ft (15 m) for each location. The accuracy of the GPS readings permitted the creation of a ground-truth background map for the WSR-88D which then could be used in real-time operations or in post analysis.

The GPS readings were also used to obtain accurate (+/- 5ft) elevations for each location using a Geographic Information System (GIS) at the New York State Emergency Management Office. The spotter elevations were calculated from the USGS 1:250,000 Digital Elevation Model. Maps were created of spotter locations using both MAPEXPERT and GIS. The determination of precise elevations for each spotter was critical for this study in order to estimate the height of the 0.5^{o} elevation slice above each volunteer observer's location.

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[3]No endorsement of these commercial products is expressed or implied.

One of the most difficult tasks was selecting suitable locations for the placement of the snow boards. Brown and Peck (1962) found that small clearings amongst a large coniferous forest provided the best snowfall measurement sites. They also found that clearings in a thick deciduous forest can also provide good snowfall measurement sites. These rules were applied when choosing a suitable location for the snow board. The prevailing wind direction(s) at each volunteer observer's location was also considered. Windy sites must always be avoided for snowfall measurements due the effects of blowing and drifting of additional snow onto and off of the snow boards.

3.4 Network Activation and Data Collection.

The most tedious and time-consuming task in managing the volunteer observer network involved the activation of the network prior to snowfall events. Attempts were made using NOAA Weather Radio, Packet Radio, the NWSFO Albany, NY Homepage on the Internet as well as fan-out telephone calling lists to activate the volunteer observer network with only limited success. Since the activations were usually made only 12 to 24 hours prior to the onset of snowfall, these means of activation could not guarantee full activation of the observer network. The only method of activation which proved successful was to contact each spotter directly by telephone.

Observers were recruited on the basis of availability. Many of the volunteers selected were retired or spent most of their time at home, aiding in activation of the network on short notice and insuring good coverage of events during several consecutive hours. Unfortunately, observers were not always near the phone when activation calls were made. In addition, this sizable number of calls were usually handled by only one or two people, which occasionally extended the process of network activation to 8 hours or more.

The process of consistently recording and moving information from the field to the forecast office was expedited by accomplishing as much of this task as possible for observers ahead of time. Observation forms for recording various elements were designed to insure consistency. Detailed instructions highlighting measurement techniques and recording of each variable made the observing process clear and as uncomplicated as possible. Pre-addressed postage paid envelopes made it easy for observers to mail observation forms in after the event, making data available for investigation in just a few working days. Observers were also given toll-free telephone numbers to contact NWSFO Albany, NY whenever they observed 4 inches or more of snowfall in 24 hours or less. Thus, the network also aided in real-time ground truth verification during snow events.

4. NETWORK EFFECTIVENESS

In general, the use of volunteer observers in this study proved to be a practical method of gathering numerous data sets from sites scattered over a broad geographical area. Observers demonstrated a high degree of skill and dedication in performing a time consuming, sometimes chilly and tedious task. Pre-planning was the key to the success of this project, but several other factors aided in establishing a useful snowfall observing network. A major factor was that observers were recruited from a large pool of people already taking observations on a daily or part time basis in NWSFO Albany's CWA. A portion of this group had over 50 years of observing experience and technical or scientific backgrounds. This minimized time spent on training and ensured high quality data needed for the Z-S study.

By designing and building some of the required equipment, costs for organizing this network were kept to a minimum. Uniformity of the equipment used in measuring the critical elements of hourly snowfall and snow water equivalent helped ensure data consistency.

Most importantly, face to face meetings with each of the volunteers personalized the relationship between the NWS and the observers. Although time was at a premium when inspecting sites and delivering equipment, taking the time to get to know each individual was vital in making that person understand his or her role in the Z-S study. An extra 15 minutes spent over a cup of coffee was usually all that was required to become acquainted and cement a first-name working relationship.

4.1 Network Weaknesses and Improvements

Any improvements to a volunteer observer network must center around the quality of the equipment being used, the performance of the observers taking the measurements, simplification of instructions and observer forms being used, as well as quick and easy activation of the network. It is also extremely important to take care of any needs which the volunteer observers may have, otherwise the observer's interest and thus the data network may be short-lived.

Most potential problems were anticipated and accounted for, but on occasion, data were lost or contaminated. At times, a snowfall event would occur late at night. Volunteers were never requested to stay up past their normal hours to record data, although a few did. This restricted the data for the Z-S study to mainly early morning through late evening hours. Other routines of daily life also interfered with data collection such as work, sickness, vacations, etc.

Some problems encountered were environmental in nature and an inherent part of the phenomena being investigated. High winds, (> 15 mph) created problems which were insurmountable and basically brought data collection to an end during some events. During extremely high wind, blowing and drifting snow made accurate measurements impossible, especially for observers located in exposed areas. Fortunately, a number of observers were situated in sheltered locations that rarely experienced strong winds, ensuring at least some data availability for most events.

The method of measuring water equivalent was refined in light of data observed for initial events. At first, the outer cylinder of a 4-inch diameter Clear-Vu rain gauge was employed in this process. Water equivalent was determined from what fell into the gauge placed in the immediate vicinity of the snow board. Satisfactory results could be expected in calm conditions, but in most situations this was not the case. It was determined that a more representative figure could be obtained by taking the water equivalent directly from the snow board in the form of a core sample. This produced a much more accurate measure of water equivalent for a given depth of snow. It is our opinion that this is the most accurate and cost-effective method to obtain the water equivalent from snow.

5. RECOMMENDATIONS FOR FUTURE EFFORTS

As previously mentioned, one area of improvement in this network would be in the quality of the equipment provided. Unfortunately, this is highly dependent on the availability of scarce funds. A cost versus benefit analysis should be performed before selecting or purchasing any equipment for an observer network. Equipment changes we recommend if additional funds become available in the future are: 1) replacement snowboards with 2-foot by 2-foot and ½ inch thick dimensions; 2) replacement of Clear-Vu gauges with the standard 8-inch NWS gauges; 3) replace Alter shields with Nipher shields and 4) replacement of current snowsticks with official NWS snowsticks.

Most of these changes would improve core samples and minimize adverse environmental affects. Use of 8-inch rain gauges equipped with Nipher shields (as opposed to Alter shields) would provide more reliable data in low wind environments. Goodison (1978) found that the Nipher shields were far superior to the Alter shields for wind speeds less than 9 m.p.h. (8 kts). Each observer should be provided with an official NWS Snowstick (if available) which is much larger and much easier to read than the snowsticks used in this study.

While the observation form used in this study was short and concise, the set of accompanying instructions were rather lengthy although not too difficult to follow (except for the identification of snow particles). In the future a more concise set of instructions will be provided to observers.

It is important to have as many volunteer observers as possible who have a thorough understanding of the data which is being measured and how that data is being used. This will not only improve the quality of observations but diminish the amount of time spent on instruction. In the future it may be prudent to further refine the target groups which are selected as potential volunteer observers based on the type(s) of studies being performed.

Finally, it is very important to meet the needs of each individual spotter in a timely and courteous manner. A positive response will help the observer feel that their role in the study is important and valued by the NWS. This will ensure that the network has a long-life and at the same time improve the quality of data which is received.

6. SUMMARY

The volunteer snowfall spotter network organized in Eastern New York and Western New England during the Fall of 1994 proved to be a valuable source of high quality data and is still active as of December 1998. Initially envisioned as a network of 30 to 40 observers, the volunteer response was overwhelming with over 100 observers participating as of the Fall 1996. Although several problems were inherent in obtaining accurate hourly measurements of snowfall and water equivalent, the on-going nature of this study allowed methods and techniques to be refined and fine-tuned as problems were identified.

Due to the broad geographical area involved in the Z-S study, the amount of equipment that needed to be produced or procured, and the large number of observers, 4 to 5 months of work was required to set up the network. Although the initial time and preparation in setting up such an extensive network was substantial, the final results certainly justified the many hours spent. Once such a network is established, local studies need not be limited to snowfall. Volunteer observing networks can also be extremely valuable in investigating rainfall/reflectivity relationships, especially in situations when rain gauge and radar precipitation estimates do not agree. The working relationship established in the development of such a network can often lead to volunteer involvement in other Weather Service programs such as SKYWARN.

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Appendix A. A Brief Guide for Snow Particle Identification for Support of NEXRAD Radar Studies of Falling Snow

Assembled by Edmond W. Holroyd, III (Bureau of Reclamation, Denver, CO), copying images from Field Guide to Snow Crystals by Edward R. LaChapelle, 1969, Univ. of Washington Press, and Snow Crystals by W.A. Bentley and W.J. Humphreys, 1931 (1962 Dover reprint).

INTRODUCTION

Our study seeks to measure the relationship between the intensity of radar echoes measured by the NEXRAD radar systems and the amount of snowfall on the ground below, both depth of snow and liquid equivalent. The various types of snow should each have different relationships. While it is not necessary to describe the snow particles in great detail (there are many possible classes), we need some basic characteristics.

Size. The radar reflectivity is proportional to the sixth power of the equivalent melted diameter of the snow particle. Therefore, it is mostly the largest particles that contribute to the radar echo intensity. We therefore want a size estimate of the typical large particles. Some extreme particles can be larger than what is recorded; most will be smaller. We are not asking you to melt any individual particles before measurement because that is too difficult.

Form. There are several basic forms of snow that fall from the sky. We are interested in single crystals, aggregates (the fluffy assemblages of many crystals), graupel (the white pellets of snow that can bounce on the ground), and broken and irregular particles that are hard to describe.

Our study involves only dry snow. However, it is important to note other types of icy particles so that we can exclude them. We want to know about sleet (frozen rain and drizzle droplets), slush (partly melted snow), and hail (not expected in winter) because any melting of the snow as it falls intensifies the radar echo.

Shape. The shape of a snow crystal, grown from water vapor directly, is determined primarily by the air temperature in the growth region of the cloud and secondarily by the amount of moisture available there. A key is illustrated later, for those spotters interested in the temperature and moisture history of each snow crystal type.

Riming. The word "riming" refers to a fluffy white deposit of frozen cloud droplets on some cold surface. The tiny droplets freeze so quickly onto snow crystals, trees, wires, etc., that they do not have time to spread out to a flat layer of ice. Rime presence tells us that there is an abundance of cloud droplets that are "supercooled", colder than 0 ^{o}C but still liquid. Such cloud droplets are common in nature. The supercooled droplets collect on the snow crystals when they are hit by the falling snow. For your information, supercooled water can be chilled to -40 ^{o}C if it is pure, but dust in the atmosphere usually makes it freeze by about -20 ^{o}C.

The combination of these four basic observations of **size**, **form**, **shape**, and **riming** tell us much about the snow that is falling at your location. We may have to develop different Z-S relationships to cover the many categories of snow.

SIZES

We are asking you to provide measurements in tenths of an inch rather than fractions, like 7/16", which are easy to misread. We will provide rulers graduated in 0.1 inch increments.

You do not have to find the absolutely largest snowflake that is falling. You can catch some "representative" sample, but <u>only</u> of the largest 10 percent or so of all snowflakes falling, since they provide almost all of the radar signal. If most larger snowflakes are about 0.3" across and there is a rare one at 0.5", record the range 0.3" to 0.5".

FORMS

You will find that most of the snow that falls from the sky is **broken** and **irregular** in basic shape. Those words are sufficient if that is really the case. However, there are other forms of interest if they occur: **single crystals, aggregates,** and **graupel**. We have already said to tell us about **sleet** and **slush** and we do not expect you to see hail.

Broken and **irregular** snow falls as single particles that do not have a reoccurring shape.

Single crystals are snow crystals that have grown directly from water vapor. They are mostly not interlocking but fall separately from each other.

Aggregates are assemblages of crystals into large fluffy snowflakes. There may be several to even hundreds of single crystals in each aggregate. The presence of aggregates is usually associated with intense snowfalls.

We will want to know the shapes of the crystals within the aggregates, so try to see what is inside. The shape section will tell what to expect.

Graupel (from the German word for grapes) are mostly clusters of frozen cloud droplets called rime. We can also call graupel by the term snow pellets. The seed or starting point for graupel is usually a snow crystal, but sometimes it is a large frozen water droplet. There is a series of degrees of riming that ranges from the single crystals with light, moderate, or heavy rime, to graupel-like snow, to graupel, to hail. The presence of graupel is usually associated with convective showers and thundershowers. It indicates an abundance of supercooled water in the cloud.

SHAPES

The shapes of snow crystals grown directly from the water vapor (not from freezing of cloud droplets) is determined by the cloud temperatures and moisture contents. The chart (A-10) sketches the relationships with some of the crystal shapes illustrated. The temperature scale along the bottom is in degrees Celsius; melting is at the left and very cold is at the right.

Notice that the crystals with hexagonal (six-sided) branching are grown at about -15 ^{o}C. Increasing moisture supply makes them branch in more detail. These are the most rapidly-growing crystals. Another type of crystal that grows rapidly is the "needle" at about -5 ^{o}C.

A few of the basic shapes are illustrated on pages 22 and 23. There are many intermediate and combination shapes. For example, a hexagonal plate, initiating at -18 ^{o}C, can fall to warmer regions of a cloud at -15 ^{o}C and get dendritic branches on the tips. It can then fall to -12 ^{o}C and get small hexagonal plates on the tips of those branches. A hexagonal column can fall into those same temperature zones and get hexagonal plate or dendritic caps on its ends. We are not interested in recording such fine details about the growth conditions, but rather just noting the shape on the attached form (p. 24).

Columnar crystals. Columnar crystals are those which are longest in the direction perpendicular to the hexagonal symmetry. There is a continuous series from **needle** (the longest) to **column** (intermediate length-to-width ratio) to **thick plate** (ranging from equal dimensions in all directions to being thinner than wide). There is also a special form of column having the shape of a **bullet** that grows at or colder than -20 ^{o}C. Needles indicate relatively warm growth conditions for the snow. They easily gather into aggregates or become rimed. Columns are from somewhat colder air or, in rare cases, from very cold temperatures.

Planar crystals. The series of crystals that grow between -10 and -20 ^{o}C are mostly flat and show hexagonal symmetry in the longest directions. It should be easy to memorize the growth conditions for this series. There are many intermediate types of planar shapes but four names will suffice for these descriptions: **plate** (simple flat hexagons or rarely triangles, often with designs and edge notches), **broadbranch** (which has six wide straight branches), **stellar** (which has six narrow branches without any significant further branching along them), and **dendrite** (which has branches on branches to the extreme of being feathery). These are the crystals that you will see most often. They grow faster than any others but still take about an hour to grow to about a quarter inch across. They interlock easily into aggregates. If there is a greater abundance of cloud droplets than the crystals can consume by vapor transfer, then the crystals will collect cloud droplets by riming.

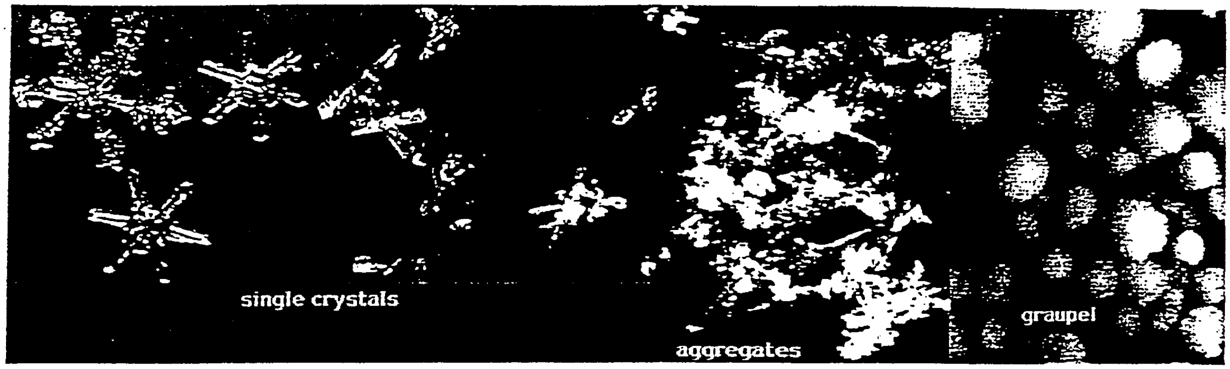
Spatial crystals. Spatial crystals form on cloud droplets that froze at temperatures about -20 ^{o}C and colder. Each frozen droplet becomes a mixture of crystals within, each part having different crystal axis directions. Subsequent growth shapes will be determined by air temperatures. So we can have spatial bullets, spatial plates, and spatial dendrites. They indicate that the snow is coming from very cold parts of the cloud system. Usually they will be small. They may look broken or like small aggregates or just irregular.

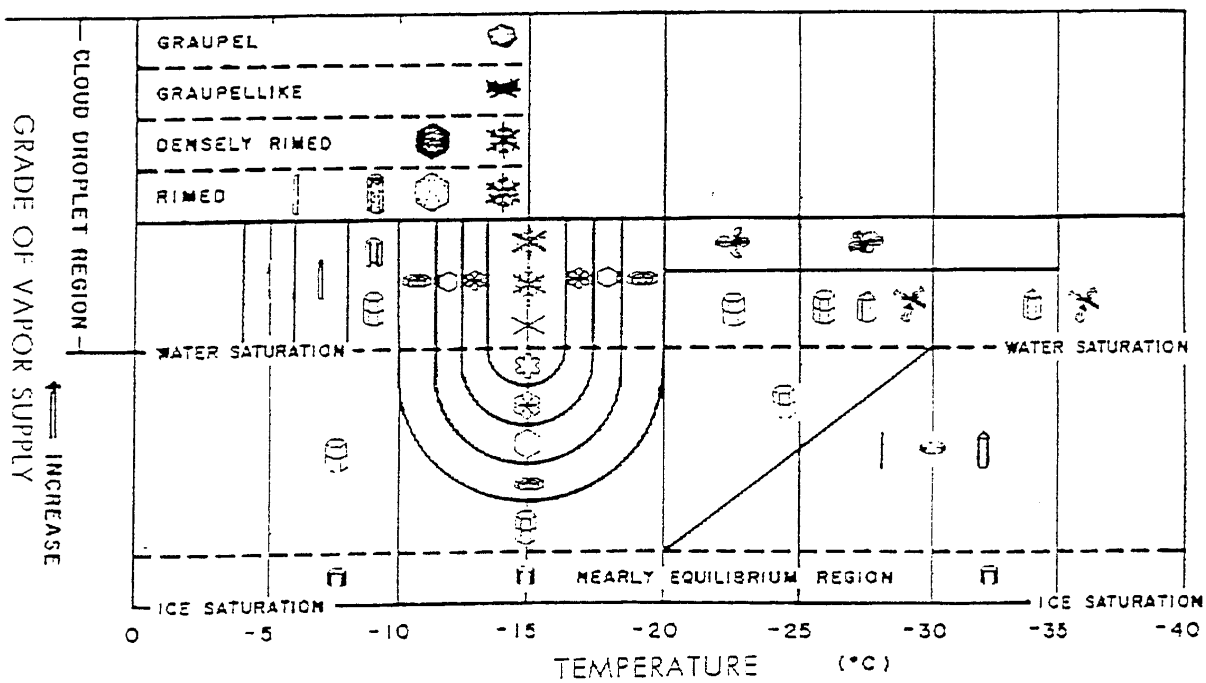
RIMING

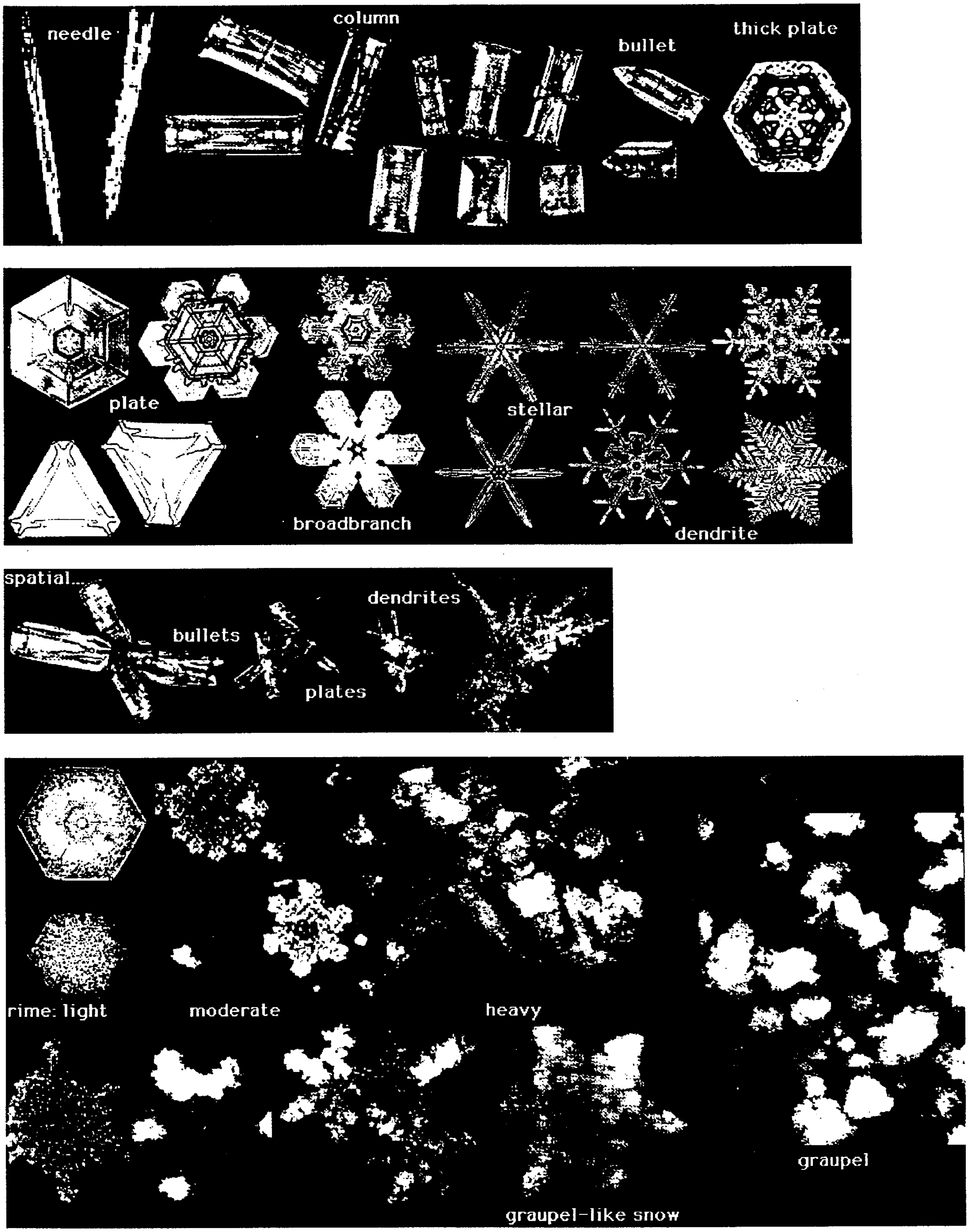
The freezing of cloud droplets onto snow crystals makes rime, a white fluffy deposit that can obscure the crystal within. The illustrations should give an indication of the continuous series from **light** to **moderate** to **heavy rime**. With light rime you could see individual frozen cloud droplets if you had a magnifier. With moderate rime the droplets are piled on top of each other and begin to obscure the crystal within. With heavy rime, shown with the coated needles above and the hexagonal star below, the crystals are so obscured that only their basic shape remains visible. Heavily rimed crystals are sometimes called graupel-like snow. Further riming may change snowflakes completely to graupel.

SUMMARY

In your snow particle observations tell us:
1. The typical **sizes** of the largest 10 percent or so of the particles, expressed as a single size or as a range of sizes as seems most appropriate.
2. The basic **form**: single crystals, aggregates, graupel, broken and irregular. If there is sleet or slush, please mention it so that we will understand that melting is present above your site.
3. The basic **shapes**: needle, column, plate, stellar, dendrite, spatial types, and a few others.
4. The amount of **riming**: none, light, moderate, heavy.


single crystals
aggregates
graupel


GRAUPEL
GRAUPELLIKE
DENSELY RIMED
RIMED
CLOUD DROPLET REGION
GRADE OF VAPOR SUPPLY
INCREASE
WATER SATURATION
WATER SATURATION
NEARLY EQUILIBRIUM REGION
ICE SATURATION
ICE SATURATION
0
-5
-10
-15
-20
-25
-30
-35
-40
TEMPERATURE (°C)


needle
column
bullet
thick plate
plate
stellar
broadbranch
dendrite
spatial...
bullets
dendrites
plates
rime: light
moderate
heavy
graupel
graupel-like snow

HOURLY SNOW PARTICLE IDENTIFICATION FORM

NOTE: USED **ONLY** WHEN FROZEN OR MELTING PRECIPITATION IS OCCURRING DURING THE HOURLY OBSERVATION

LOCATION DAY-MONTH-YEAR DAY OF WEEK

OBSERVER LOCAL TIME (HR-MIN) A.M. P.M.

FOR ONLY THE **LARGEST** 10 PERCENT OR SO OF ALL SNOW PARTICLES FALLING, CHECK ONE OR MORE WITHIN EACH CATEGORY AS APPROPRIATE:

FORM:
SINGLE IDENTIFIABLE CRYSTALS
BROKEN AND IRREGULAR CRYSTALS
AGGREGATES
GRAUPEL (SNOW PELLETS)
SLEET
SLUSH

SHAPES:
NEEDLES
COLUMNS
PLATES
BROADBRANCH
STELLARS
DENDRITES
BULLETS
BROKEN AND IRREGULAR CRYSTALS - NOT SURE
AGGREGATES - NOT SURE OF SHAPES

MOST SHAPES ARE THE MORE COMMON TWO-DIMENSIONAL PLANAR
THE LESS COMMON SHAPES ARE THREE-DIMENSIONAL SPATIAL

RIMING:
NONE
LIGHT
MODERATE
HEAVY (GRAUPEL ALWAYS HEAVY)

SIZES: TYPICAL SIZE OF LARGEST 10% OF SNOWFLAKES

OR WITHIN SIZE RANGE TO (TENTHS OF INCH)

OR LARGEST CRYSTALS ARE LESS THAN 0.1" ACROSS

Appendix B. Copy of the Original Form Letter Sent to Potential Volunteer Observers.

Albany County Airport
Albany, NY 12211
November 18, 1994

Dear SKYWARN Spotter, Cooperative Observer or Eastern New York Weather Observer:

You are being sent this letter in the hopes that you will be able to help us with an important study we are conducting at the National Weather Service in Albany, NY. We are looking for 25 to 50 Spotters to provide us with hourly weather observations during selected snow storms this winter. This information will then be used to correlate Doppler radar data to water equivalent of the snow and snowfall. You have been selected to receive this letter since you already have some of the equipment needed for the observations.

The information we will need on an hourly basis will be snow crystal or precipitation type and intensity, snowfall, snow depth, water equivalent of the snow, dew point (optional), wind speed (optional), wind direction (optional), and barometric pressure (optional). The enclosed form shows you the necessary information we need (Figure 2). We realize that this involves a good amount of time and effort, but if you are willing to participate in this study we will set you up with an additional rain gauge(s), a snow board and snow stick. We will be contacting you after November 25th to see if you are interested.

Sincerely yours,

John Quinlan
Eric Sinsabaugh