Special Report

Evaluation of the Reported January 11-12, 1997, Montague, New York, 77-Inch, 24-Hour Lake-Effect Snowfall

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
National Weather Service
Office of Meteorology
Silver Spring, Maryland 20910

March 1997

Cover photo: Snowbound House in Montague, NY, on Jan. 14, 1997. Photo courtesy of Cleve Lansing.

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Preface

On January 10-14, 1997, a massive, but localized, lake-effect snowstorm blanketed the Tug Hill area, just east of Lake Ontario in northern New York. Although heavy accumulations of snowfall are common in this area and residents are equipped to deal with them, this storm produced such a prodigious amount of snow in such a short time, that residents were briefly snowbound.

I fully support the Committee's praise of the Buffalo Weather Service Forecast Office's efforts to establish its dedicated snow spotter network and the Committee's recognition of the great benefits to be derived from the use of real-time observations from spotters in supporting National Weather Service forecasts and warning responsibilities. I also embrace the Committee's recommendations to decline acceptance of Montague's 77-inch, 24-hour snowfall as a new national record and to establish adherence to exisitng Federal standards and cooperative observer guidelines for snowfall measurements at NWS measurement sites.

I would like to express my gratitude to the Committee for its objectivity in producing this report on the January 11-12, 1997, Montague, New York, 77-inch, 24-hour snowfall. In particular, I would like to thank the state climatologists from New Jersey and New York and the assistant state climatologist from Colorado, who served on the Committee, for providing their valuable insight into the assessment of the evidence and preparation of the report.

Elbert W. Friday, Jr.
Assistant Administrator
for Weather Services

March 1997

National Weather Service
Montague, NY, January 1997, Snowfall Committee

Members:

Team Leader, **Robert J. Leffler**, Physical Scientist, Data Management Focal Point, Office of Meteorology, Science Division, National Weather Service Headquarters, NOAA.

Raymond M. Downs, Program Analyst, Office of Systems Operations, Observing Systems Branch, National Weather Service Headquarters, NOAA.

Grant W. Goodge, Data Quality Control Chief, Data Operations Division, National Climatic Data Center, NOAA.

Nolan J. Doesken, Assistant State Climatologist for Colorado, Colorado State University.

Keith L. Eggleston, State Climatologist for New York State, Cornell University.

Dr. David Robinson, Chairman, Department of Geography, New Jersey State Climatologist, Rutgers University.

Foreword

This evaluation of the reported 77-inch, 24-hour lake-effect snowfall at Montague, New York on January 11-12, 1997, was prepared by a special review committee, sponsored by the National Weather Service (NWS)Office of Meteorology. Committee members included team leader **Robert J. Leffler**, National Weather Service Headquarters; **Raymond M. Downs**, National Weather Service Headquarters; **Grant W. Goodge**, National Climatic Data Center; **Nolan J. Doesken**,, Colorado State University; **Keith L. Eggleston**, Cornell University; and **Dr. David Robinson**, Rutgers University.

In preparing the report, Committee members traveled to Montague on February 4-5, 1997, to conduct interviews with Federal, state, local officials, and private citizens; to gather facts, data, and photographs on the storm; and to visit the location where the observations were taken.

NWS management requested that the Committee independently and objectively assess all of the pertinent information regarding the snowstorm and prepare a report that documented the storm; the observations under review; the validity of the reported 77-inch, 24-hour snowfall total; and a comparison of Montague's snowfall to the previously accepted national 24-hour snowfall record from April 14-15, 1921, at Silver Lake, Colorado. The Committee assessed all of the collected information and presented its findings and recommendations in this report on March 14, 1997.

The Committee's extensive review of the January 11-12, 1997, Montague, New York, snowfall observations and related information suggests that the observer's measurements followed the Buffalo Weather Service Forecast Office's real-time operationally oriented guidelines for snow spotters, not climatological guidelines. It was recommended that the six January 11-12 Montague snowfall observations be recognized as valid, individual snowfall measurements, but that the <u>77-inch total not be recognized as an official climatological snowfall amount for that 24-hour period.</u>

In preparation for the report, the Committee identified several areas of concern, including a lack of adherence to snowfall standards and guidelines among NWS offices and volunteer observers. Additionally, there was concern regarding the lack of any mechanism in the scientific community to deal with scrutinizing potential national meteorological/climatological extreme events. In addressing these concerns, the Committee suggested that the NWS immediately take the steps necessary to establish adherence to snow measurement standards and that NOAA take the lead in creating a committee responsible for assessing new national meteorological and climatological extreme events.

I would like to thank the Committee members, who spent many hours of their own time preparing the report and delivering it in a timely fashion and the numerous other individuals whose contributions made this report possible.

Louis W. Uccellini
Director, Office of Meteorology

March 1997

Acknowledgments

The committee is grateful to many individuals who took time from their personal lives and other duties to share their measurements, observations, thoughts, and impressions of this memorable event. Their contributions largely made this report possible. They include:

Steven Bobb, snow removal, town of Montague, NY.

Gary Jock, Sheriff, Lewis Co., NY.

Ed Klein, NWS snow spotter, North Osceola, NY.

Cleve Lansing, NWS cooperative observer, Boonville, NY.

Bill Ottoshavett, NWS snow spotter, Montague, NY.

Larry Rogers, Dept. of Highways, Lewis County, NY.

Paul Scott, local resident, Montague, NY.

Wayne and Jane Swift, owners of Montague Inn, Montague, NY.

Special thanks to the volunteer NWS spotters and cooperative observers. Without their dedicated support, this snowstorm would not have been documented.

The committee also extends personal thanks to **Stephen McLaughlin** (service hydrologist) and **Thomas A. Niziol** (forecaster) from the NWS Buffalo forecast office for taking time out of their busy schedules to support this effort. Their assistance in setting up interviews, answering inquiries, and providing the committee with a wealth of documentation was critical to the success of the committee in meeting the objectives of this study.

Acronyms

ASOS	Automated Surface Observing System
ERH	Eastern Region Headquarters
EST	Eastern Standard Time
GOES	Geostationary Operational Environmental Satellite
mb	Millibar
MSL	Mean Sea Level
MT	Mountain Time
NCDC	National Climatic Data Center
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
PNS	Public Information Statement
SHEF	Standard Hydrometeorological Exchange Format
TWC	The Weather Channel
UTC	Coordinated Universal Time (the acronym "UTC" is derived from the French, (Universel Temps Coordonni))
WSFO BUF	NWS Weather Service Forecast Office, Buffalo, NY
WSH	Weather Service Headquarters
WSR-88D	Doppler Weather Surveillance Radar-1988 Design

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Executive Summary

Snowstorms can paralyze, mesmerize, or capture the attention of the public, the media, and scientists alike.

The snowstorm of January 10-14, 1997, in the Tug Hill Plateau area (Montague) of New York (just east of Lake Ontario) did all of the above. During a 24-hour period on the 11th and 12th, an NWS snow spotter, recruited to support the lake-effect snow project by the Buffalo forecast office, reported six measurements of snowfall, which when summed, totaled 77 inches. The measurement received national attention and was reported heavily by the media. In the days following the report, the media, and then the NWS Buffalo forecast office, declared the observation to be a new national 24-hour snowfall record. The national 24-hour snowfall record is considered by many to be the benchmark for the severity of snowstorms. Therefore, it was not surprising that the news of a new record immediately generated nationwide interest. Controversy quickly appeared within NOAA and among the scientific community regarding the validity of the reported 77-inch snowfall amount and whether a local NWS office held the authority to declare a local observation a new national record.

NWS Headquarters received external requests for the formation of an objective committee to review and report on this snowfall event. Given the significant controversy surrounding the amount, the NWS Office of Meteorology proceeded to quickly organize a committee, which was composed of three NOAA employees (two NWS and one from NCDC) and three external climatological community members.

The committee filed this report after site visits, interviews, fact and data gathering, and an assessment of the collected information were completed. The committee's findings and recommendations are:

Finding 1: The committee's extensive review of the January 11-12, 1997, Montague, New York, snowfall observations and related information suggests that the observer's measurements followed WSFO BUF's <u>real-time operationally oriented guidelines for snow spotters, not climatological guidelines</u>. The observer took and reported six snow measurements between 1:30 p.m. on January 11 and 1:30 p.m. on January 12, 1997 (five of which were within twelve hours), to support real-time NWS operations. All evidence suggests that the snow that fell at Montague during this storm was of a very light, fluffy nature (low density) and accumulated to a great amount.

However, an inconsistency arose when these six operationally oriented snow measurements were added by The Weather Channel to get a total for a 24-hour period. The resulting 77-inch snowfall amount was checked and then acknowledged by WSFO BUF, and thereafter reported by both sources as a new national climatological record.

NWS standards for climatological observations of snowfall require that no more than four observations, taken with a maximum frequency of once every six hours, be summed within any 24-hour period to compute the total snowfall for that period. More frequent measurements taken by clearing the snow board tend to increase totals. Recognized climatic snowfall records should be based only on observations that satisfy climatic data standards.

The summing of more frequent than 6-hour snow measurements to obtain 24-hour climatological totals is inconsistent with WSFO BUF's spotter guidelines, which explicitly instruct snow observers not to do this because "this would give an unrealistically high amount."

The six Montague observations taken on January 11-12, 1997, although measured individually in a valid scientific manner for supporting real-time NWS operations, were taken at intervals too frequent to qualify the sum of the six as an official 24-hour climatological snowfall amount.

The committee strongly reaffirms the importance of station documentation (metadata) and traceable data sets at NOAA's NCDC as a standard requirement for "official" NWS climate data stations such as the cooperative observer climate network.

There was a large body of evidence suggesting that Montague's snowstorm was indeed a very large snowstorm.

The committee applauds WSFO BUF's efforts to establish its high-density, dedicated snow spotter network, and furthermore acknowledges the great benefits to be derived from use of real-time observations from the spotters in supporting operational NWS forecast and warning responsibilities. The committee strongly supports the continuation and further development of snow spotter networks towards those means.

Recommendation 1: The committee recommends that the six January 11-12 Montague snowfall observations be recognized as <u>valid, individual snowfall measurements</u> that, when used in real-time by WSFO BUF, provided meaningful short-term snowfall intensity information for operational NWS programs. However, in consideration of the too-frequent snowfall measurement intervals summed to derive the 24-hour snowfall total, the committee further recommends that the <u>77-inch total not be recognized as an official climatological snowfall amount for that 24-hour period</u>.

Finding 2: The committee is concerned about the lack of adherence to established standards for the measurement and reporting of climatological snowfall at NWS offices and volunteer networks.

The committee identified several cases of NWS stations taking hourly snow measurements and improperly adding these measurements to obtain 6-hour and 24-hour amounts. It was also found that the availability and use of snow boards was sporadic or non-existent at numerous NWS locations. Some offices, where snow boards have not been utilized, have also been erroneously under measuring new snowfall by simply subtracting the old depth of snow on the ground from the new total snow depth to determine snowfall. Additionally, some climatological volunteer observers have not been provided with the recently revised "NWS Snow Measurement Guidelines."

The lack of consistent adherence to standards can result in inconsistent assessments of snowfall amounts and historical rankings, and degraded data quality. The committee is also concerned that publicly disseminated and published NWS snowfall products are being distributed with similar inconsistencies.

There is an urgent need to ensure that existing standards for the measurement and dissemination of climatological snowfall (not to be confused with hourly snow intensity measurements) are adhered to by all NWS sources (including forecast offices), cooperative observers, and spotters.

Recommendation 2: The NWS should vigorously and without further delay take the necessary steps to establish adherence to existing Federal Meteorological Handbook standards and cooperative observer guidelines for the taking of snowfall measurements for climatic purposes at all its manned, spotter, and cooperative observer stations. To reach this goal, the NWS should insure that training materials and equipment such as snow boards be made available and placed in use at all stations.

NWS products disseminated to external users, which include snowfall totals for 6-hours or greater (e.g., daily, monthly, and seasonal), should also conform to standards for reporting climatic snowfall totals.

Finding 3: The committee is concerned that NOAA and the climate community have no formal mechanism in place to assess national meteorological and climatological records (extreme values). WSFO BUF attempted to find such an appropriate mechanism to consider the Montague record, but found none. Without support, WSFO BUF felt pressured to make a timely decision to satisfy the widespread and understandable interest in the noteworthy Montague snowstorm.

The committee believes that the continuing explosive growth of networks (mesonets) around the nation (NWS, federal, state, county, and private) will result in further situations in which meteorological and climatological extreme values may be reported or challenged from standard and non-standard sources. With the formation of a records oversight mechanism, the quality of NOAA's climate data integrity could be significantly improved.

Recommendation 3: The NCDC should take the lead in setting up a committee that would be responsible for assessing observations submitted as national meteorological/climatological extreme values. The committee should be chaired by NCDC, and include participants from both within NOAA and the external climate community.

The mechanism created by this committee would allow for a more orderly, scientific process within NOAA and the climate community for the future determination of national extreme values and relieve the pressure put on local operational NWS forecast offices for quick determinations of complex and time-consuming designations.

Finding 4: The committee's review of the April 14-15, 1921, Silver Lake, Colorado national record-holding 24-hour storm indicates that this "record" was previously analyzed and accepted by the NWS in a peer-reviewed journal. However, the validity of the Silver Lake snowfall amount could also be questioned if the climatological guidelines in place in 1921 are rigorously applied. The different measurement techniques used in the Montague and Silver Lake storms make meaningful comparison of snowfall amounts difficult.

24-hour period) was 51 inches. Even after taking into account the compaction of the existing snow pack at Montague, the Silver Lake snowstorm clearly recorded the greatest snow depth increase.

Recommendation 4: Since the committee has recommended that the 77-inch, 24-hour total at Montague not be recognized as a climatic amount, the Silver Lake snowfall should continue to stand as the national record.

The previously proposed extreme values review committee should begin to closely scrutinize existing or potential national record-setting observations, with an emphasis on adherence to standards to protect the integrity of the data.

Introduction

Background:

The Tug Hill Plateau of New York State (locally known as "Tug Hill") has once again drawn national attention with reports of a record-setting "lake-effect" snowstorm. Historically, this area, located just east of Lake Ontario (Figure 1), has exhibited some of the heaviest and most intense snowfalls east of the Rocky Mountains. The area has long been notorious for its intense lake-effect snowstorms. Noteworthy snowfall totals from the area include unpublished amounts of 54 inches in 24 hours at Barnes Corners (elevation 1,520 feet) on January 9, 1976, and a state record-setting published seasonal total of 467 inches at the NWS cooperative station at Hooker 4N (elevation 1,680 feet) during the 1976-77 winter season. Average seasonal snowfalls in the area are around 250 inches.

The elevated rolling surface of the 15 mile-wide by 30-mile long oval-shaped Tug Hill lies about 25 miles due east of Lake Ontario. The axis of the oval is northwest-southeast. Almost 600 square miles lie at or above 1,500 feet, with maximum elevations reaching 2,000 feet (Figure 1). Tug Hill's proximity to a large unfrozen lake, with its location directly downwind from the longest fetch over the lake, the significant size of the elevated area which induces upslope flow (Lake Ontario's elevation is 236 feet), and its higher elevation and resulting lower temperatures, all combine to produce prodigious amounts of snow in the winter.

The Tug Hill Plateau was smothered on January 10-14, 1997, by one of the greatest lake-effect snow bursts ever recorded. The action began Friday morning (10th) with a frigid wind flow out of the southwest (220 to 230 degrees), setting up an intense snow band over the St. Lawrence Valley. The band shifted south to Tug Hill Saturday (11th) as winds shifted to a more westerly component and stalled from late Saturday to midday Sunday (12th). The snow continued into Tuesday (14th) before ending. Hourly amounts during the burst reached as high as 5-6 inches per hour. Unprecedented amounts of snow were reported from several NWS snow spotters. Four-day storm totals included 95 inches at Montague (elevation 1,850 feet), and 90 inches at both North Osceola (elevation 1,750 feet) and Redfield (elevation 1,700 feet). The sparsely populated but recreationally popular area was buried by the storm.

Of special interest, and the subject of this report's study, was the 77-inch, 24-hour snowfall total measured by an NWS snow spotter at Montague during the most intense period of the storm.

WSFO BUF's Internal Use of Spotter Snowfall Data (input from WSFO BUF):

The NWS uses volunteer observers, called spotters, throughout the nation to serve as its local "eyes" for real-time reports of severe weather, including snowfall and snow depth. Spotters, trained, either through NWS-provided documentation or participation in technical training courses, are a valuable, proven asset to the NWS and the communities they serve. Their observations are also considered "official" for NWS purposes ("Weather Service Operations Manual," Chapter B-61, "Certification of Observers"). Thus, Montague's observation does qualify for consideration as a new national record (extreme event). One does not have to look far to find success stories of spotter reports that have resulted in improved forecasts and warnings, and saved lives and protected property from untold dollars in damage.

WSFO BUF has a 271-station snow spotter network. Its observers were recruited to support a 3-year study of lake-effect snows.

WSFO Buffalo's area of responsibility includes 25 counties in western and central New York. Their duties include all forecasts, public and short-term; marine forecasts for Lakes Ontario and Erie (near-shore); aviation forecasts for five airports, and all warnings for 16 counties. WSFO BUF utilizes a number of tools to assist in these responsibilities, including Doppler Weather Surveillance Radar-1988 design (WSR-88D) at Buffalo, Rome, and Binghamton, satellite information, model output, and, real-time surface observations. There are seven staffed stations (three are Local Climatological Data sites) and two operational Automated Surface Observing Systems (ASOS) stations in the 25-county area. These are supplemented by 62 official cooperative observer stations and, during the winter months, the 271 snow spotters.

The NWS is in its the third and final year of the lake-effect snow study. This project was undertaken to gauge the usefulness of the new technologies (WSR-88D, satellite, and numerical weather models) in forecasting mesoscale events and the issuance of better and more precise products to the public. All of the offices subject to lake-effect snows are involved with this project, including Binghamton, State College, Pittsburgh, Cleveland, and several Central Region offices in Michigan and Wisconsin. Reports are developed for each lake-effect event and sent to the regional headquarters.

One of the most important aspects of this lake-effect project has been the development of a "snow spotter network." Since lake-effect snows are such a mesoscale phenomenon, the networks of first-order stations and cooperative observers are not dense enough to observe the narrow, heavy snow bands that frequently occur. In addition to spotters providing surface snowfall observations, radar reflectivity during snow episodes needs to be correlated with surface observations of short-term snowfall amounts to enable NWS forecasters to develop better radar algorithms that relate these two elements.

WSFO BUF recruited snow spotters via NOAA Weather Radio, local American Meteorological Society chapters, and radio stations in outlying areas. Their numbers have increased from about 220 during the 1994-95 winter to 271 during the current 1996-97 season. The snow spotters are located in WSFO BUF's 16-county warning area.

The snow-spotter network serves two purposes, the primary, real-time support of forecasts and warnings, including refinement of radar algorithms, and secondarily, WSFO BUF climate applications such as the determination of seasonal snowfall totals. Spotters call in real-time when certain criteria-driven events occur; for climate, they tabulate daily snowfall amounts and send the observations to WSFO BUF monthly.

An important point to note regarding the WSFO BUF snow spotters' mission is that the forecast office's operational requirements are different than those for climate data. Operationally, there are clear needs for hourly (or other short-term) snowfall measurements, but NWS guidelines for snowfall measurement by volunteer networks for climatic purposes require that snowfall amounts be measured at least once a day, but no more than once every six hours

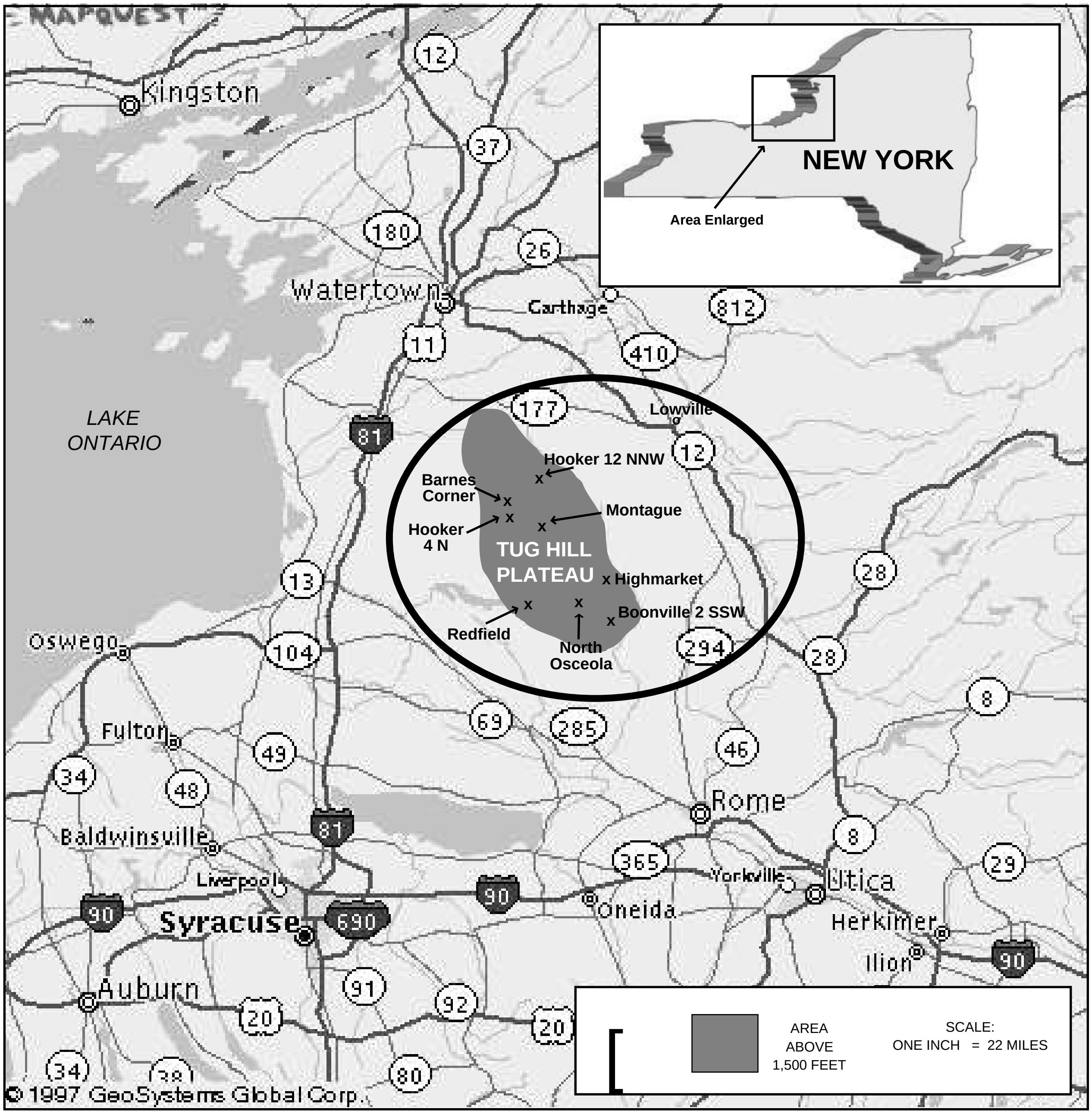

Figure 1: Location of the Tug Hill Plateau and Points of Interest in the Study Area.

(four times in 24 hours). The primary purpose of the recently revised NWS Snow Measurement Guidelines (the 4 times a day frequency was expanded from the first-order network to include volunteer observers in October 1996) was to standardize observation techniques, thereby improving the compatibility of snowfall data among first order and other (private and government) volunteer networks. WSFO BUF had provided their spotters with locally prepared snow measurement instructions (Appendix A), but no volunteer observers had been provided with updated NWS Snow Measurement Guidelines (Appendix B).

Although the lake-effect study is in its final year of the three-year project, WSFO BUF expects to maintain the snow spotter network into the foreseeable future. There is no doubt that WSFO BUF's ability to provide substantially improved snow forecasts and warnings is greatly increased by the real-time information provided by the snow spotter network.

WSFO BUF's Dissemination of Spotter Snowfall Data (input from WSFO BUF):

NWS Buffalo issues a myriad of products for winter weather. Most of them are in the watch, warning, or advisory category. Some of these products occasionally mention snow totals within them, but the vast majority of snowfall reports are disseminated through the Family of Services, NOAA Weather Wire, NOAA Weather Radio, and the Internet, under Public Information Statements (PNS). WSFO BUF has an internal software system called BUFLOG which enables the office to manually log calls received from the snow spotters during real-time events. The calls are received, written down on paper, and then, when time allows, entered into BUFLOG. BUFLOG then automatically transfers the message into Standard Hydrometeorological Exchange Format (SHEF) code and places the observation into a disseminated PNS text message. During a snow event, the PNS is not disseminated until several reports have been received, unless the event is extremely important. This supports information needs for other NWS offices and the media. WSFO BUF also tries to issue a PNS once an event is over to sum up the most significant snowfall totals.

Public Information Statements issued during an event may contain information that might not agree with the final storm totals disseminated later or with the NWS definition of snowfall for a given 24 hours. For example, if one were to add up all the reports from a single station reporting hourly, it could be more than the storm total report issued the next day. WSFO BUF attempts to quality control the data by subjectively estimating what storm totals would be if no more than four measurements a day were taken. In the case of this lake-effect snowstorm, WSFO BUF disseminated an isoline analysis map of the storm's January 10-14 snowfall totals on their Internet Home Page (Figure 2). This analysis was based on the summation of the observations that were called in during the 4-day period. The frequency of daily measurements varies from site to site, and no attempt was made to adjust the totals based on standard frequencies of measurement (no such procedures have been developed and tested). Thus, problems can arise when real-time hourly (or other more frequent than 6-hourly) snowfall observations are used for reporting storm totals or forecasting snowfall amounts. These problems in no way preclude the use of such information in useful internal operations such as forecasting snow intensity or operational forecasts and warnings.

With respect to climatological data, monthly snowfall totals are based on the daily/monthly summary cards that are mailed in by the spotters at the end of each calendar month, periodically compiled by WSFO BUF, and disseminated publicly twice a season, first at mid-season, and second, as a final total seasonal report. The daily data on the cards are reportedly derived by the observers summing up their snowfall measurements taken that day. The frequency of observations varies with both observer and event. The monthly data cards are not sent to NCDC for archive, quality control, or publication, as are "official" climate station data, but are retained at WSFO BUF for use in lake-effect storm studies and developing mesoscale climatologies.

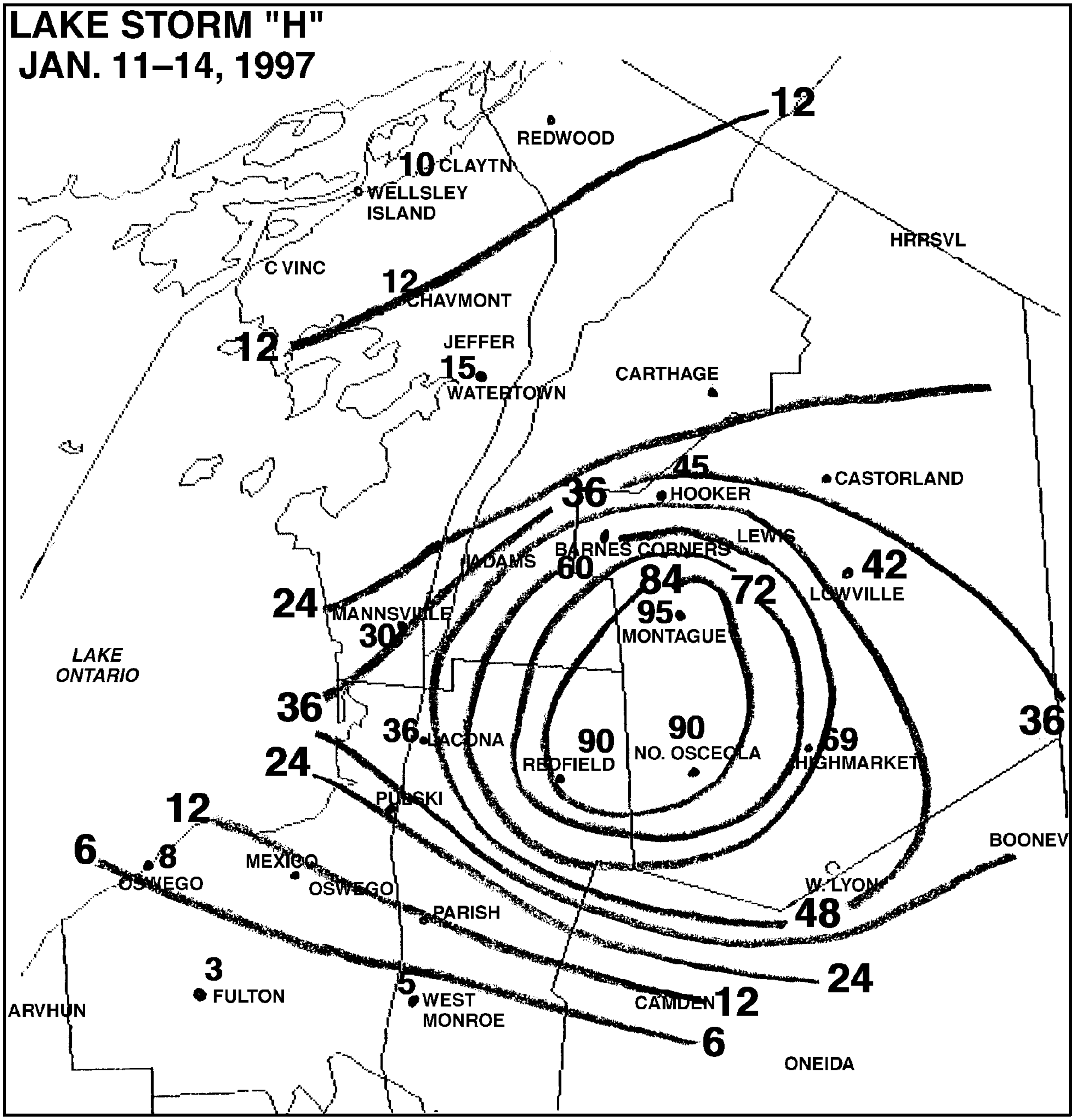

Figure 2: WSFO BUF Internet Snowfall Map for January 10-14, 1997 Tug Hill Snowstorm (date shown in upper left corner of Internet map is incorrect).

Reports of extreme snowfall amounts began to flow in from the Tug Hill spotters during January 10-11. Many of these reports were disseminated under the automated BUFLOG process through PNSs. WSFO BUF had little time to do quality control on these reports due to excessive workload responsibilities at the time. The reports were undoubtedly vital to accurate real-time forecasts for that area, as the Rome radar was not in operation for the event and there was no radar coverage of the snowfall occurring east of Lake Ontario.

Question of New National 24-Hour Snowfall Record (input from WSFO BUF):

Because of the unusual intensity of this snowstorm and reports of its national record-breaking status, it received a great amount of national media coverage. Since both NWS and private forecasters were expecting a strong lake-effect snowstorm, The Weather Channel (TWC) sent personnel into the Buffalo area to report nationally on the event as it unfolded. And report they did! By Monday morning (13th), WSFO BUF had issued PNSs highlighting the incredible 90-95 inch snowfalls reported over Tug Hill at several spotter locations.

TWC contacted WSFO BUF on Monday morning (13th) to inform them that by adding up the six reports they had received for Montague (via the PNSs issued), they came up with 77-inches of snowfall in the 24-hours from 1:30 p.m. Saturday (11th) to 1:30 p.m. Sunday (12th). Although initially skeptical of the report, WSFO BUF checked Montague's observations and confirmed the amount. Additional investigation led WSFO BUF personnel to believe that the Montague report was reasonable and within the realm of possibility. Their conclusions were based on the following circumstances:

- there were three nearby spotter reports with 90-inch storm totals (Montague's was 95 inches),
- the Montague spotter measured snowfall at intervals considered by WSFO BUF as reasonable (six in 24-hours, five of which were in 12 hours),
- the satellite data indicated that the heaviest band stalled over the Montague area for 18 hours (4 inch per hour rates were common in the bands),
- the meteorological conditions were ideal for an extreme event,
- a Utica television station reportedly verified the depth (60 inches) on Monday (13th) in the area per request by WSFO BUF,
- the 24-hour snow depth increase of 51 inches (24 inches to 75 inches, including settling of the 24 inches of snow already on the ground)was reasonable for a 77-inch lake-effect snowfall measured at frequent intervals,
- estimates of what Montague's snowfall amounts would have been if the measurements had been taken at the standard frequency of one every 6 hours (instead of six in 24 hours) still indicated about 77 inches, and
- interviews with the observer and checks with other nearby observations collaborated the snowfall total.

In the meantime, TWC had already announced to the nation that this could be a new 24-hour snowfall record. Many local and national media picked up and relayed the story.

During the time of reviewing the observation to check its validity and stature as a new national record, WSFO BUF personnel were not sure what steps needed to be taken to verify the total as a new national record. Much of the day Tuesday (14th) was spent on the case, handling many media calls, and checking with the Northeast Regional Climate Center and the New York State Climatologist, then checking with NCDC in Asheville, North Carolina. The matter was discussed, and the advice was that, ultimately, in the absence of an official review process, the decision was up to the local field office (WSFO BUF). After what they felt was careful consideration of the circumstances and evidence, WSFO BUF made the decision to accept the measurement as a new national record. A public statement was disseminated by WSFO BUF on Wednesday morning (15th), opening the door to much attention and controversy on the subject.

Controversy Over the Reported New Record:

Questions concerning the validity of the new 77-inch, 24-hour national snowfall record were well under way by Thursday (16th), the day after the public announcement was released by WSFO BUF. Correspondence (i.e., E-mail and telephone) was being received by WSFO BUF and Weather Service Headquarters (WSH) questioning how the measurement was taken and the authority of a local NWS office to declare these measurements as a new national record. This incredible snowfall total raised many questions in the minds of meteorologists, climatologists, snow scientists, and weather enthusiasts across the country. Was this an "official" observer? How had the observer been trained? What equipment was used? How often did the observer clear the snow board for the measurement during the event? Was the observer following procedures acceptable to the NWS and the scientific and business communities that utilize snowfall data? What was the water content of the snowfall? How quickly did it settle? Did the observer have and use a representative location for taking measurements? Was the observer aware of the previous national record? How would the previous record (76 inches at Silver Lake, Colorado) stand up to this same scrutiny? There were also some larger questions. Does the NWS have a procedure in place for evaluating and verifying extreme values before public dissemination and declaration of new records? Are NWS snowfall measurement standards and guidelines adequate for the collection of consistent and comparable snowfall data, and are those standards being followed nationally?

WSH also relayed concerns regarding the observation procedures used to take the measurement and the considerations that went into the declaration of its official national record status to both WSFO BUF and NCDC.

During the week that followed the announcement by WSFO BUF of the new national record, WSH took the position of supporting the concept that determination of the national record was a “local [forecast office] call.” WSH thinking was that local offices made the calls for tornadoes and other severe weather (these events are documented in the publication “Storm Data”) and this situation was similar. However, questions regarding the validity of this argument were later aired. Some argued that for severe weather events, local forecast office personnel assess physical evidence at the location of the severe weather event before an “official determination” is made. In these cases, the spotter’s observations serve merely as a starting point for the assessment, not the sole information on which the official determination is based. Discussions on the issue continued without resolution.

Calls for action became louder and louder as the controversy escalated. WSH management received direct correspondence regarding the concerns, and several private/academic sources requested that the records be made available immediately for scientific scrutiny. Requests for the formation of a committee to review and document the event were also made. After consideration of information available about the measurement and the procedures that led up to the declaration of the new national record, WSH management agreed that the concerns being voiced warranted the formation of a committee, whose purpose would be to independently and objectively review the case, and prepare a report on the subject.

Evaluation of the Montague Snowstorm

Synoptic Description of the Snowstorm (input from WSFO BUF).

Deep low pressure moved across the upper Great Lakes into central Ontario on Thursday, January 9, 1997. Western and central New York were on the mild side of this system, with some wet snow and rain falling during the evening of the 9th.

As the storm pulled away to the north, a strong southwesterly surface to 850-millibar (mb) flow of progressively colder air swept into the region (Figure 3). With both Lakes Erie and Ontario ice-free, the stage was set for the longest, most intense episode of lake-effect snow of the 1996-97 season.

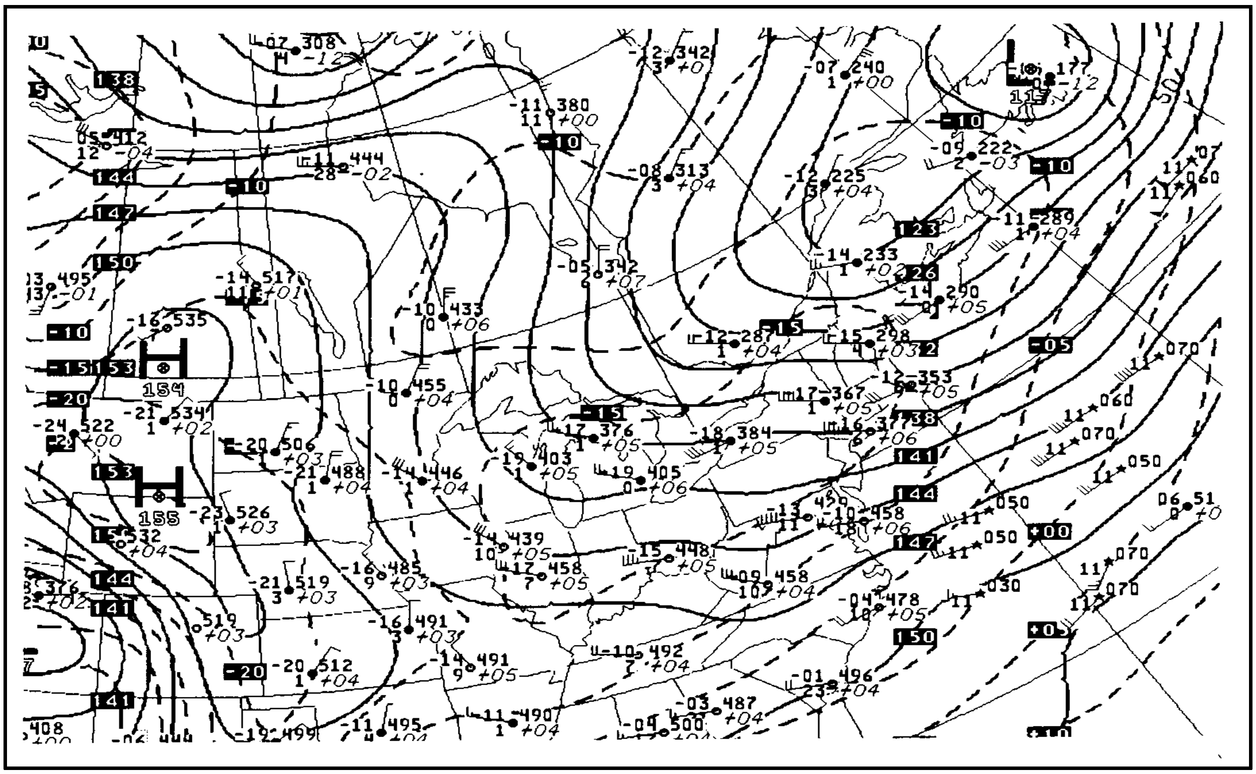

Figure 3: 850-Millibar Temperature, Wind, and Height Analysis for Tug Hill Area at 12:00 UTC on January 12, 1997.

The lake-effect snow activity began early on Friday, January 10. All the ingredients for a major event were present: deep layer of arctic air without a low-level capping inversion, deep moisture, lack of directional shear, strong upward motion (positive vorticity advection), and instability. Initially, the winds were too southerly to produce much fetch (passage over water), but as winds gradually veered from 200 to 220 degrees, single bands of snow set up off both lakes unusually far to the north. A Lake Erie band set up over the Niagara Peninsula of Ontario, Canada, while the Lake Ontario activity set up near Kingston, Ontario, and along the St. Lawrence Valley.

The mean 700-950 mb winds slowly veered to 230-240 degrees during the daylight hours on Friday. The activity drifted southward accordingly, affecting the Buffalo metro area during the afternoon with meandering intense snow bands. The activity was more organized off Lake Ontario across northern Jefferson County. Little change was noted overnight except for the consolidation into a single intense band over the northern suburbs of Buffalo. By daybreak Saturday (11th), upwards of 18 inches had fallen over northern Erie County. Eight to 16 inches were reported over most of Jefferson and northern St. Lawrence Counties off Lake Ontario.

During Saturday (11th), the Lake Erie snow bands drifted south following the passage of a weak trough and became disorganized well south of Buffalo during the afternoon. However, the Lake Ontario activity remained intense and a single band formed and slowly drifted southward as winds veered to 260 degrees by late in the day. This pushed the activity into Lewis and southern Jefferson Counties and into Tug Hill by late afternoon.

The lake-effect snows were strongest from Saturday night (11th) to midday Sunday (12th). The Lake Ontario snow bands consolidated into a single band again and drifted north up into central Erie County during the evening. This was probably the result of thermal troughing induced by the relatively warm waters of Lake Ontario. The Lake Ontario snow band remained very intense and stalled over much of Tug Hill. This band extended from the Jefferson-Oswego County line east across most of Tug Hill. The band was very narrow near the lakeshore (5-10 miles), but widened appreciably (to 10-15 miles) as it streamed up over Tug Hill before weakening as it descended into the Black River Basin on the east side of Tug Hill. Snowfall rates of 4-5 inches per hour were common within this band. Little change in movement or intensity of the band was noted until late Sunday morning when another trough passed, finally shifting winds to a 280-290 degree vector and pushing the activity southward into Oswego and northern Oneida Counties. The Lake Erie activity also weakened Sunday as it shifted south. Still, lake-effect snows continued through Monday and into Tuesday (14th), although they were not as intense and favored areas just south of those hit by the heaviest snows over the weekend. Warming aloft finally shut off the lake-effect machine by late Tuesday.

The Montague Data:

The source of data that produced the 77-inch, 24-hour snowfall value was the sum of a series of six measurements phoned in to WSFO BUF by the volunteer snow spotter at Montague (Table 1). With each measurement, the observer cleared his snowboard.

The summing of the six observations to get a 24-hour snowfall total is inconsistent with WSFO BUF's written instructions for spotters (Appendix A), which states: "Do not measure every hour and add them up...this would give an unrealistically high amount [for climatological records], every 6 or 12 hours would be fine (unless it's melting)." The called-in observations did appear consistent with the event-driven operational real-time reporting criteria also indicated in the written instructions. It should be noted that the observer did not sum the six observations himself and report the 77-inch, 24-hour amount. This was first done by TWC, then later checked and acknowledged by WSFO BUF.

The timing of these observations was different than the scheduled 7:30 a.m. daily observation at that site that was used for the observer's daily climatological log for the month.

Date Jan. 1997	Time of Observation	Observation Interval	Snowfall (Inches)
11	1:30 p.m. to 2:30 p.m.	1 hour	2
	2:30 p.m. to 5:30 p.m.	3 hours	6.5
	5:30 p.m. to 7:30 p.m.	2 hours	2.5
11-12	7:30 p.m. to 7:30 a.m.	12 hours	40
12	7:30 a.m. to 11:00 a.m.	3.5 hours	16
	11:00 a.m. to 1:30 p.m.	2.5 hours	10
Totals (11-12)	1:30 p.m. to 1:30 p.m.	6 in 24 hours	77

Table 1. Six Snowfall Measurements from the Montague, New York, Snow Spotter for the 24-Hours from 1:30 p.m. EST, January 11, 1997, to 1:30 p.m., January 12, 1997.

To evaluate the veracity of the Montague report, the committee visited and photographed the observing site and interviewed the observer. The observer was a volunteer snow spotter for WSFO BUF, participating in the lake-effect study. The observer had received a one-page letter from WSFO BUF which contained two paragraphs of simple training documentation on how to measure snowfall, and he was extremely enthusiastic about taking snow measurements and reporting to the forecast office in a timely fashion. He had moved there primarily motivated by a deep personal interest in snow. He had been a snow spotter for the NWS since the 1994-95 winter season.

The observer stated that he did not keep a written observational record (other than the monthly climate log) at his station. The only written records were the log of spotter phone reports assembled at WSFO BUF and the monthly tabulation mailed to WSFO BUF by the observer at the end of each winter month.

The interval of measurement used by the observer during this and other snowfall events was consistent with the reporting criteria provided in WSFO BUF’s written instructions to observers, with the exception that the observer was clearing the snow board near the time that each criteria threshold occurred, thus resulting in more snow board interval measurements than the "no more than once every 6 to 12 hours" specified in the written instructions.

For comparison, quantitative surface data from a number of independent sources were also assembled, including:

- reports from other snow spotters in the region who were also participants in the special "lake-effect study" coordinated by WSFO BUF,
- daily climatological observations taken by the four closest NWS cooperative observers, and
- cooperative snow surveys conducted by the Hudson River-Black River Regulating District and the Niagara-Mohawk Power Corporation.

The Montague Observing Site:

The measurement was taken in Montague, a small town of about 75 people located in the northwest third of Tug Hill. Terrain elevations slowly rise about 1,550 feet over the 26 miles from the eastern shores of Lake Ontario to Montague. The average elevation in the area is about 1,800 feet above mean sea level. The topography in the area can be best characterized as gently rolling, with woodland environments interlaced with open meadows and farms.

The Montague snowfall measurements were made in an open, flat area that is bordered south through northwest by a mature, mixed deciduous-evergreen forest. The trees are about 50 feet from the measurement site. The observer's house is located about 150 feet to the east of the measurement site. There are about one dozen 30-foot high evergreen trees on the east and northeast side of the house. Areas southeast and north are free of large trees within about 500 feet. There are scattered 8-15 foot tall deciduous saplings in the immediate vicinity of the measurement site. The site is equipped with two 6-foot-high snow stakes about 20 feet apart. A 2-foot square snow board was located between the two stakes (Figure 4).

Figure 4: The Montague Snow Spotter's Measurement Site (looking southwest). Photo courtesy of Grant Goodge.

The site was an excellent location for snow measurement, open, not affected by buildings, and with enough nearby trees to result in little drifting, even during relatively strong winds.

Surrounding Cooperative Observations and Snow Spotter Data:

Snowfall: NWS cooperative weather stations that record daily climatological observations and WSFO BUF snow spotters who send in written summaries of daily snowfall during the winter months were compared (Table 2). Due to differing times of observation at the

Date (Jan. 1997)	Lowville*	Barnes Corner	Hooker 12 NNW*	Montague	North Osceola	Redfield	High-market*	Boonville 2 SSW*
11	1.5	18.0	18.7	8.5	26.5	38.0	6.2	3.0
12	21.0	12.0	15.5	52.0	44.0	25.0	12.3	11.8
13	13.0	5.0	7.7	30.0	11.0	13.0	27.7	8.4
Totals 11-13)	35.5	35.0	41.9	90.5	81.5	76.0	46.2	23.2
Ob. Time (EST)	7:00 a.m.	6:30 a.m.	6:30 a.m.	7:30 a.m.	midnight	midnight	6:00 a.m.	7:00 a.m.

Table 2. Snowfall (inches) Reported for Stations on and in the Vicinity of Tug Hill on January 11-13, 1997 (asterisk denotes NWS cooperative station).

stations, direct comparisons of daily totals cannot be made. Likewise, the monthly log of Montague's daily data were for 24-hour periods ending at 7:30 a.m., while the 77-inch total occurred in 24-hours ending at 1:30 p.m.

Water content and density: No measurement of water content was taken by the Montague observer. These data would have been very helpful in evaluating the snowfall observation. Water content was not requested by WSFO BUF of the volunteer snow spotters participating in the lake-effect study. The nearest sites observing both snowfall and precipitation (rain and the melted water content of snow) were Hooker 12 NNW, Highmarket, and North Osceola (Table 2).

NWS cooperative observers typically report water content using the snow caught in the standard 8-inch diameter precipitation gauge. Gauges typically catch less precipitation than what actually falls, particularly if there is any significant wind, so snow densities computed by dividing the observed gauge precipitation by the observed snowfall tend to be lower than the actual density of fresh snow on the ground. The spotter at North Osceola used a different procedure. A 4-inch plastic gauge was used to take core samples of accumulated fresh snow on his snowboard at intervals frequent enough that the depth of new snow would not exceed the height of the measuring tube (12 inches).

Table 3 shows the daily maximum and minimum temperatures, precipitation (liquid equivalent), snowfall, and the ratio of snowfall to water equivalent for January 10-14 at these three stations. Ratios of 25 to 31 inches of snow for every one inch of water equivalent were measured. The North Osceola observer reported lower snow-to-water ratios, which are consistent with his procedure for taking cores of new snowfall instead of using gauge catch for determining water content. Local meteorologists familiar with lake-effect snows consider these low densities to be typical of mid-winter lake-effect snows at cold temperatures.

Snow depth and settling rates: Daily observations of the total depth of snow on the ground before, during, and after the storm were taken at three sites including the Montague station. Total depth of snow on the ground is a key element of climatological snow observations and is generally an easier quantity to measure than snowfall itself, assuming a representative measurement site is available. Table 4 shows snow depths (inches) at the time of observation for these sites. The settling rate, defined as one minus the ratio of the change in snow depth to the snowfall during a given 24-hour observing period, is also shown. This ratio gives an indication of the rate of settling of the total snow on the ground to the new snowfall. The higher the ratio, the greater the settling.

	Hooker 12 NNW					North Osceola					Highmarket				
Date (Jan).	Max Temp	Min Temp	Snow-fall	Pcpn	Ratio S/ P	Max Temp	Min Temp	Snow-fall	Pcpn	Ratio S/ P	Max Temp	Min Temp	Snow-fall	Pcpn	Ratio S/ P
10	29	0	4.7	0.33	14	28	20	3.7	0.25	15	26	-10	4.0	0.41	10
11	31	14	18.7	0.54	35	20	13	26.5	1.03	26	27	13	6.2	0.29	21
12	18	14	15.5	0.45	34	19	12	44.0	1.65	27	20	10	12.3	0.46	27
13	21	17	7.7	0.38	20	21	18	11.0	0.52	21	20	10	27.7	0.81	34
14	24	17	3.9	0.21	19	22	15	11.0	0.56	20	20	13	5.0	0.18	28
11-13	----	----	41.9	1.37	31	----	----	81.5	3.20	25	----	----	46.2	1.56	30

Table 3. Temperature (°F), Precipitation (liquid equivalent in inches), Snowfall (inches), and Snow to Water Equivalent Ratio (Snow/Pcpn in inches) for Stations on Tug Hill for January 10-14, 1997.

The snow depth at Montague was 24 inches the morning of January 10th and at 1:30 p.m. on the 11th when the heaviest 24-hour accumulation began. It had increased to 68 inches by the 7:30 a.m. observation on the 13th. A maximum storm snow depth of 75 inches was reported to WSFO BUF on the 12th; it occurred at 1:30 p.m. on the 12th.

Despite additional snowfall after the 75-inch depth was reported, the depth at observation time on the 13th had settled to 68 inches; and by the morning of the 14th, the depth had further decreased to 59 inches. Based on periodic measurements (in between scheduled 7:30 a.m. observation times) by the Montague observer, the maximum increase in snow depth was 51 inches, which occured between 1:30 p.m. on the 11th and 1:30 p.m. on the 12th.

	Hooker 12 NNW			Montague			Highmarket		
Date	Snowfall at 7:30 a.m.	Snow depth at 7:30 am	Settling rate	Snowfall at 7:30 a.m.	Snow depth at 7:30 am	Settling rate	Snowfall at 7:30 a.m.	Snow depth at 7:30 a.m.	Settling rate
10	4.7	11	----	4.5	24	----	4.0	14	----
11	18.7	25	.25	8.5	28	.53	6.2	16	.68
12	15.5	28	.81	52.0	61	.37	12.3	22	.51
13	7.7	29	.87	30.0	68	.77	27.7	27	.46
14	3.9	27	*	3.0	59	*	5.0	32	*
10-14	41.9	----	.43	90.5	----	.51	46.2	----	.50

Table 4. Daily Snowfall (inches), Depth of Snow on the Ground (inches), and Snow Settling Rate (see text on previous page), at Three Stations on Tug Hill for January 10-14, 1997 (asterisk denotes a decrease in depth even though new snowfall was measured).

On the 14th, the Boonville NWS cooperative observer traveled to Montague to see the snowfall and take independent observations. He reported a measured snow depth of 60 inches at 11:00 a.m. on the 14th, taken near the Montague Town Barn, about two miles southwest of the Montague snow spotter's measurement site. This compares very favorably with the Montague spotter's snow depth of 59 inches at 7:30 a.m. (2.5 hours earlier) the same morning.

Snow Surveys:

Monthly surveys during the winter and spring months of total snow depth and water content are taken in the Tug Hill region in an ongoing effort to anticipate spring snow melt, water supplies, and the potential for flooding. These surveys are conducted by the Hudson River-Black River Regulating District and the Niagara-Mohawk Power Corporation. Survey results were obtained from early January prior to the storm and again from early February near the time the committee was visiting the area. The data (Table 5) do not provide precise information about the event in question but do provide evidence as to total regional snow accumulation patterns.

	Highmarket		**Osceola, East**		**Boonville, 2 SSW**		**Sears Pond**	
Date	Snow Depth	Water Content	Snow Depth	Water Content	Snow Depth	Water Content	Snow Depth	Water Content
Jan. 8	23.0	3.8	16.9	2.3	9.4	1.2	Missing	Missing
Feb. 3	41.8	10.7	40.3	10.4	33.5	8.0	48.5	13.5

Table 5. Results of Snow Surveys Indicating the Depth of Snow on the Ground (inches) and the Water Equivalent of the Snowpack (inches) at Four Locations on Tug Hill on January 8 and February 3, 1997.

These data confirmed that large increases in snow depth and water content occurred throughout the region during January, with the greatest increases in the Montague (Sears Pond) and North Osceola areas. Observed snow depths at the Montague observer's home during the committee visit were about 48 inches, in agreement with the Sears Pond snow survey.

Temperatures: Temperatures varied little during the snow event. Daily high and low temperatures ranged from the upper teens to the lower twenties (Table 3). Temperatures in this range favor the formation of large and often unrimed dendritic crystals, the type associated with low-density snows. However, surface temperatures alone are insufficient to deduce fresh snowfall densities.

Wind: Only anecdotal information exists, supported by photos taken immediately after the storm, but there was consensus among all those interviewed that there was not much wind in the Montague area during the storm, particularly during the period of heaviest snowfall from Saturday (11th) into the early afternoon of Sunday (12th). NWS experts on lake-effect snow bands reported to the committee that surface wind speeds are typically quite light in the middle of lake-effect snow bands, with stronger and somewhat convergent winds on both sides of the snow band.

In addition to previously discussed data sources, the committee collected other

information for analysis as follows.
Satellite Imagery:

Geostationary Operational Environmental Satellite (GOES) visible imagery for the morning of January 13, 1997, dramatically illustrates the narrow lake-effect snow plume extending downwind from Lake Ontario and covering the Tug Hill-Montague area (Figure 5). The local nature of lake-effect snow bands is clearly illustrated in this visible image (available visible images for the 11th and 12th were not as dramatic). Tug Hill, located underneath the band at this time, was receiving snow.

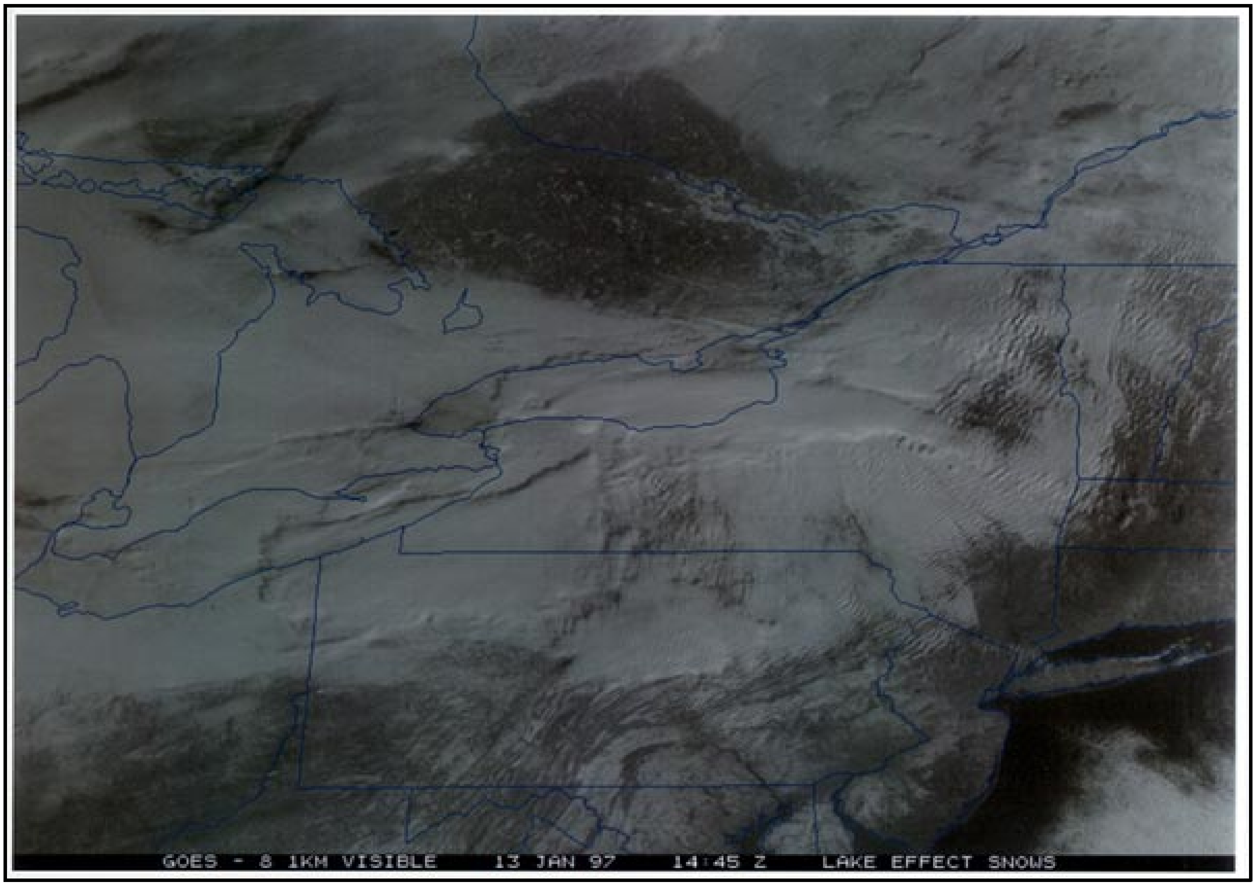

Figure 5: Visible GOES-8 Satellite Image at 9:45 EST on January 13, 1997, Showing a Lake Ontario Snow Plume Streaming Over Tug Hill (and Montague).

Radar:

The closest WSR-88D at Rome, New York (30 miles south of Tug Hill), was not in service during January 10-14, 1997. The next closest radar at Binghamton (100 miles south of Tug Hill) was functioning but was unable to detect the snow plume because, at that distance, the radar beam overshot the estimated 8,000 to 10,000 foot cloud tops in the plume. These were the only two radars close enough to Tug Hill to consider; thus, radar did not offer any substantiating evidence in this case.

Eyewitness Reports:

This section summarizes interviews with individuals in the Montague area who were able to provide first-hand accounts of the January 11-14 snowstorm. These interviews were conducted by the committee on February 4, 1997.

Snowplow Operators: Two agencies are responsible for plowing roads in Montague, the Lewis County Highway Department and the Town of Montague Highway Department. Interviews were conducted with individuals from both departments.

One town highway department employee was interviewed at the Montague Town Barn. This department plows 12 miles of roads around Montague using two large V-snowplows equipped with dual wings. In order to keep up with the extreme rate of snowfall, these plows were in constant use during the weekend of this event. The employee reported that, in his opinion, this was the worst storm in his 20-year experience of plowing snow in Montague. Other storms reportedly had periods when the rate of snowfall was as intense, but those periods did not persist as long as it did during the January 11-12, 1997, event. He stated that there was little wind associated with the storm, so drifting was not a problem. Visibilities were extremely low at times due to the intense snowfall. At times visibility was limited to the distance from the driver to the front of the plow (about 10 feet). It was stated that at the height of the storm, snow was accumulating on the road at a rate of about one foot per hour.

Lewis County snowplow operators were interviewed at the Town Barn in Lowville. The county also uses large V-snowplows, as well as large rotary snow blowers. They reported that the heavy snow band started Friday night (10th) in Harrisville, in the northern part of the county, then moved south and remained fairly stationary over an area from Montague to Osceola on Saturday and Sunday. Snowfall amounts for the storm were reported to be much lower in Barnes Corners (northwest of Montague) and Lowville (east of Montague). The snow was said to be easy to plow because it was extremely light and fluffy. There were some minor drifting problems noted on Saturday morning at the beginning of the storm, but it was not much of a problem thereafter. One plow operator, with about 25 years of experience, claimed that this was the largest single snowfall event he had ever witnessed. He estimated snowfall rates were on the order of 5 to 6 inches per hour during the height of the storm. The operators also reported that the snow on the ground settled very quickly, about 2 feet on Sunday, and that this rate of settling was common with other lake-effect storms that produced fluffy snow.

County Sheriff's Office: The county sheriff was interviewed at his office in Lowville. He reported that, in his opinion, the amount of snow that fell overnight in Montague was unprecedented for such a short period of time. The amount of new snow was deeper than the height of his deputies, who were in the area. Drifting snow was not a problem. Snowfall amounts were observed to be much less in other parts of the county. The Sheriff's Office typically receives calls during heavy snowstorms from friends and relatives of people staying in the area (residents, snowmobilers, and visitors). However, the only calls received by the Sheriff's Office during this snowfall event were inquiries from Montague residents concerning delayed arrivals of family members and friends.

Sheriff's Office deputies operate snowmobiles to get to houses to check on the safety of the occupants. Due to the light and fluffy nature of the snow, these vehicles could not be operated until snow-grooming equipment was run to compress the snow and create passable trails for the snowmobiles.

Local Residents: Interviews were conducted with several full-time Montague residents. One had experience as an official NWS cooperative observer from 1987 through 1990.

These persons reported that they had experienced many heavy lake-effect storms in Montague, but this was the greatest 1-day storm they could remember in their collective 14 years in the hamlet. It was noted that the snow in this storm was very fluffy and accumulated undisturbed by the wind. They pointed out the depth of snow following the storm on various structures in the Montague Inn area. These reports indicated that snowfall amounts of over 6 feet were certainly possible from this storm.

The NWS cooperative weather observer for Boonville, New York, was also interviewed. He has a number of years experience as an official NWS cooperative observer. In addition to operating the Boonville cooperative weather station, he also performs snow surveys during the winter at three locations for the Northeast Regional Climate Center. As previously mentioned, he visited the Montague area on January 14 and took his own snow depth measurements.

In summary, county snowplow crews and recollections of the county sheriff were consistent with reported snowfall amounts that the Montague area was hardest hit, with a dramatic decrease in snowfall within just a few miles to the north of Montague. These sources, as well as residents of the Montague area, also independently verified the timing of the maximum snowfall rates beginning on the Saturday afternoon (11th) and maximizing late on the 11th, continuing into early Sunday afternoon (12th) when the snow band drifted southward.

<u>Committee Members' Observations:</u>

Committee members visiting the area clearly observed a greater depth of snow on the ground from Montague to North Osceola, with a sharp decline northwestward from Montague to Barnes Corners. While this was noted more than 3 weeks after the snow event, it was nevertheless consistent with observations reported for the storm.

Committee members were extremely impressed with the rapid increases in snow depth as one ascended Tug Hill from the west and approached Montague from the north. Snow depths were observed to steadily increase from only several inches in spots along Interstate 81 (elevation 500 feet), 15 miles west of Tug Hill, to about 2 feet at Barnes Corners, to nearly 4 feet in the Montague-North Osceola area on February 4-5, 1997 (Figure 6). Members also observed widespread evidence of rotary-snowplow operations.

Summary of the Montague Observations.

Strengths of the Montague snowfall observations are:

- the observer was knowledgeable and competent,
- the observer was a recognized NWS snow spotter, thus making his observations official for NWS use and eligible for consideration as an "official record,"

- the measurement site was excellent and included two 6-foot snow stakes and a snow board,
- drifting was a negligible factor, and
- there were numerous sources of corroborating evidence pointing towards this being a very large snowstorm.

Figure 6: Four-Foot Snow Depth in North Osceola (Tug Hill) on February 5, 1997, Three Weeks After the Big Snowstorm. Photo courtesy of Grant Goodge.

Weaknesses of the Montague snowfall observations are:

- five of the six measurements were taken at intervals too frequent to allow summing to produce a standard 24-hour climatic snowfall total,
- the Montague observer was recruited to support real-time NWS operational and developmental programs and not as a climatic data observer. His station lacked the

documentation and traceable records normally required of climate stations (cooperative or otherwise), and

- there was no snow-to-water equivalent measurement.

National 24-Hour Snowfall Record, April 14-15, 1921, Silver Lake, Colorado

On April 15, 1921, the Silver Lake, Colorado, cooperative weather station recorded a 2-day accumulated snowfall total of 87 inches and a storm total of 95 inches in less than 48 hours. Silver Lake is a reservoir owned by the City of Boulder, perched high (elevation 10,200 feet) on the Front Range of the Rocky Mountains, approximately 17 miles directly west of the city of Boulder and about 2 miles east of the Western Continental Divide. The cooperative weather observer at Silver Lake was the reservoir caretaker who lived at the site and worked as an employee of the Boulder Water Department. Silver Lake was a published cooperative weather station for the U.S. Weather Bureau (now the National Weather Service) from 1910 until it was closed in 1996. Daily snowfall observations were taken from 1910 to 1948.

1. Documentation of the 76-Inch, 24-Hour Snowfall at Silver Lake

Little mention of this huge snowstorm appeared in climatological data publications at that time, and no mention was made of the reliability of that report. Daily snowfall amounts were not published then, and since Silver Lake was not an official temperature-measuring station, only its daily precipitation totals appeared in print. A value of 5.60 inches was published for Silver Lake on April 15, 1921, in the "Climatological Data" report, but an asterisk on the 14th indicated that the report was a 2-day accumulated value.

It wasn't until an article by J. H. L. Paulhus (U.S. Weather Bureau, Washington, D.C.) appeared in the February 1953 issue (32 years later) of the Monthly Weather Review that the Silver Lake snowfall observation became recognized as a national record. Based on a reported time when snowfall began, Paulhus prorated the 87-inch accumulated amount uniformly over 27.5 hours to come up with a 76-inch, 24-hour snowfall for the observational day (18:00 MT on April 14 to 18:00 MT on April 15, 1921). Paulhus performed an analysis that indicated that the amount of snowfall reported was indeed physically possible under the given synoptic situation.

2. Data Analysis

a) Precipitation and Snowfall Amounts

The storm was concentrated along the eastern slopes of the Rockies in north central Colorado, but precipitation fell statewide. Forty-six weather stations recorded at least one-inch of precipitation (water content) on the 15th, of which 15 stations (more than 10 percent of all the active weather stations in Colorado) received more than 3 inches in 24 hours. Most weather stations had an evening observation time in 1921, which made comparison of daily totals easy. At a few sites with long-term data, the precipitation amounts for April 15, 1921, continue, to this day, to be the maximum 1-day precipitation totals of record for the month of April. Examples include 3.97 inches at Cheesman and 4.80 inches at Idaho Springs. The Idaho Springs report is a record for any month. At elevations below about 8,000 feet, precipitation began as rain.

Precipitation changed to snow across the entire region by early on the 15th. Daily totals exceeded four inches of water content at four stations in addition to Silver Lake. A summary of precipitation and snowfall extracted from original records for selected weather stations in the vicinity of the storm center is shown in Table 6.

Station Name	Elev. (feet)	Time of Ob. (MT)	Storm Begin Time 4/15	Storm Total (inches)		April 15 (inches)		Snow depth (inches)		April 15 Ob time temp (°F)
				Pcpn	Snow-fall	Pcpn	Snow-fall	Before Storm	Max. Increase	
Lake Moraine	10,265	18:00	14:00	2.33	33	2.10	30	N/A	N/A	10
Silver Lake	10,220	18:00	14:30	6.40	95	?	?	66	90	N/A
Longs Peak	9,000	17:00	N/A	4.93	50	4.80	48	N/A	N/A	16
Fremont Exp Sta	8,850	00:00	13:00	6.28	49	3.78	28	0	49	N/A
Dillon	8,800	18:00	24:00	1.92	24	1.92	24	N/A	N/A	17
Fraser	8,560	18:00	N/A	3.18	49	3.03	48	12	38	20
Georgetown	8,550	08:00	N/A	3.77	52	2.35	30	N/A	N/A	18
Grand Lake	8,380	17:00	N/A	3.00	48	3.00	48	0	36	N/A
Estes Park	8,000	sunset	11:00	3.86	48	3.36	42	0	42	20
Idaho Springs	7,543	17:00	11:30	4.90	48	3.74	48	0	36	21
Fry's Ranch	7,500	18:00	12:00	7.65	62	7.50	60	0	60	20
Monument	7,200	07:00	17:00	4.05	37	4.05	37	N/A	N/A	22
Cheesman	6,880	17:00	11:30/ 17:00	4.73	34	3.97	32	0	32	22
Colo. Springs	6,060	18:00	N/A	4.58	15	4.27	15	0	15	25

Table 6. Comparative Weather Station Data for the April 14-15, 1921, Silver Lake, Colorado Snowstorm.

Snowfall totals ranged from around one foot of very wet snow at lower elevation weather stations just east of the mountains up to approximately four feet at several stations at elevations between 7,500 and 9,000 feet. Fry's Ranch, at 7,500 feet and well to the north of Silver Lake, reported 62 inches for the storm and 60 inches for the observational day ending at 6:00 p.m. on the 15th. Evidence of the strength of the storm was provided by the heavy snows that fell on the western (downwind) side of the Western Continental Divide at Fraser, Grand Lake, and Dillon.

These data show a trait of many of the snow observers of that era. It was common to report snowfall as simply the increase in the observed total depth of snow on the ground from one day to the next. This method for measuring snowfall provided very conservative estimates of snowfall compared to the more frequent interval snowfall measurements taken at some stations today.

b) Storm Duration

There was reasonable consistency in reported times when precipitation began ranging from as early as 11:00 a.m. on the 14th at one foothill location to as late as 6:00 p.m. at a station near Boulder (Table 6). The reported 2:30 p.m. time of beginning at Silver Lake was in the middle of the distribution of reported beginning times. Two stations, Cheesman and Idaho Springs, each independently made special note of the fact that precipitation began earlier, ended, then began again about 5:00 p.m. The Idaho Springs station, at a lower elevation but only about 20 miles south-southeast of Silver Lake, indicated that only 0.10 inches of precipitation (trace of snow) fell prior to the heavier precipitation, which began there after 5:00 p.m.

Precipitation across the area came to an end by late afternoon on the 15th at lower elevation stations, with snow continuing into the evening at the mountain stations east of the Continental Divide.

The heart of the storm across the region fell between 6:00 p.m. on the 14th and 6:00 p.m. on the 15th, which coincidently matched the 24-hour observational day at many of the stations in the area, including Silver Lake.

c) Snow Depth Observations

Total depth of snow on the ground is usually an easier observation to perform accurately and consistently than the measurement of snowfall, assuming that a representative site for measuring snow depth is available.

The Silver Lake observer recorded 6 feet of snow on the ground at the 6:00 p.m. observation on April 14, of which 5.5 feet were aged winter snowpack already compacted. The next depth of snow-on-ground observation was taken at 6:00 p.m. on the 16th, 19 hours after the snow had ended. Thirteen feet of snow were reported to be on the ground at that time, which settled to a depth of 11 feet by the 19th. This increase in snow depth is exceptionally great and nearly equals the amount of snowfall reported for the 27.5 hour period. This is strong evidence for a truly remarkable snow event. Unfortunately, it is not possible to determine if a representative site for measuring snow depth had been selected by the observer.

d) Temperatures

Temperatures throughout the storm region were above the freezing point during the afternoon of the 14th, except at elevations above 10,000 feet where they were near freezing. After the onset of precipitation over the entire area during the late afternoon and evening of the 14th, temperatures dropped to near or below freezing, and it was subfreezing across most of the area throughout the day on the 15th with slowly falling temperatures. By 6:00 p.m. on the 15th, temperatures were in the teens at high elevations, increasing to the mid to upper 20's (°F) at the lower elevations (Table 6).

e) Snow-to-Water Equivalent Ratios

Apparent snowfall densities calculated by dividing the gauge precipitation reports by the reported snowfall showed values ranging from much greater than 10-to-1 snow-to-water ratios at lower elevation stations (below 8,000 feet). Computed ratios at stations above 8,000 feet ranged between seventeen and 8-to-1. The Silver Lake's snow-to-water equivalent ratio for the accumulation period from the beginning of the storm on the 14th to the 6:00 p.m. time of observation on the 15th was 17-to-1. This is a fairly common density for freshly fallen snow and was not inconsistent with the temperatures reported throughout the storm at those higher elevation locations -- mostly 20's falling to the mid teens by the later phases of the storm late on the 15th.

f) Evidence of Convection

Thunder was reported at two cooperative stations on the evening of the 14th, providing strong evidence for embedded convection within this powerful storm system.

g) Winds

Cooperative stations in the mountains and foothills reported easterly winds during the storm. Two mountain stations noted drifting conditions, while several others made no mention of strong winds. The stations at lower elevations just east of the mountains reported prevailing northerly winds during the storm, with strong winds, blizzard conditions, and considerable drifting. No mention of strong winds was made by the Silver Lake observer for the storm. High winds had been noted by this observer on many prior snow events during the 1920-21 winter season, and the observer had recorded remarks on his observation form that specifically noted the difficulty he had experienced earlier in the winter determining an accurate depth of snow on ground due to the prevailing winds there.

It should be noted that the area from Silver Lake to Boulder is known for frequent and extremely strong down-slope (westerly) winds throughout the winter. These winds alter snow deposits considerably. The April 14-15, 1921, storm came with an east wind, so deposition patterns might be much different than the typical mid-winter snow event experienced at Silver Lake.

3. Geographic and Climatic Perspectives

Many years of climatic data for the region reveal that heavy April snowfalls are not uncommon in Colorado. April is the snowiest month of the year for areas along the Front Range at elevations roughly between 7,500 and 10,000 feet. At the Silver Lake weather station, the monthly average snowfall total for April was 49 inches during 1911-1948, and monthly totals exceeded 70 inches in April eight times during the years 1911-1948.

Geographically, the shortest distance from the lower elevation eastern plains of Colorado to the crest of the Western Continental Divide in the Rocky Mountains occurs in a small area immediately west of Boulder. As a result, the area between Boulder and the Western Continental Divide, where Silver Lake lies, has the steepest regional elevation gradient of any region of the Colorado Front Range. This causes this region of Colorado to be especially prone to heavy snow under conditions of strong easterly winds from the surface to above the height of the Western Continental Divide ridge crest. This appears to have been the weather pattern during the April 14-15, 1921, storm.

4. Summary of Evidence in Support of the Silver Lake 76-Inch, 24-Hour Snowstorm

There is considerable evidence supporting the validity of the Silver Lake observation. They are:.

- An intense snow storm did occur along the eastern slopes of the Rocky Mountains in north-central Colorado, with deep upslope conditions and abundant moisture.

- Extremely large snowfall totals (3-5 feet) were measured at several cooperative weather stations, and historical evidence such as newspaper accounts is consistent with these observations.

- Temperatures during the storm at elevations near 10,000 feet were consistent with relatively high snow-to-water equivalent ratios (15-to-1) as reported at Silver Lake.

- The beginning time for snowfall reported by the Silver Lake observer (key to the determination of a prorated 24-hour snowfall total) appears reasonable in comparison with other nearby stations.

- The recorded 7-foot increase in snow depth at Silver Lake is conservatively consistent with the reported snowfall amount.

- lt is likely, based on climatic and geographic information, that Silver Lake would receive more snowfall than the other reporting stations along the Front Range of Colorado under the meteorological conditions of the 1921 storm.

- Silver Lake was a documented and published cooperative station. Original and published records for this station still exist.

- The 76-inch, 24-hour snowfall value for Silver Lake was evaluated and approved in previous peer-reviewed scientific literature.

5. Uncertainties and Potential Challenges to the Credibility of the Silver Lake, Colorado, 76-Inch Snowfall

There are some aspects of the Silver Lake snowfall observation that limit its credibility or leave it open to challenge. They are:

- The observer did not report a 24-hour snowfall total on April 14, but accumulated snowfall for the 14th and 15th into a single reading of 87" recorded at 6 p.m. on the 15th. Therefore, any value assigned to a 24-hour period is a statistical estimate and not an observation.

- Windy conditions reported from other surrounding weather stations could have affected Silver Lake, making accurate measurements difficult.

- The Silver Lake observer had just taken over the observing responsibilities in June 1920. This was his first winter. As part of an institutional cooperative station (Boulder Water Department), where staff changed periodically, the source and extent of observer training cannot be verified.

- Many of the observer's precipitation measurements (water equivalent) were reported to the nearest tenth of an inch, suggesting either the use of scales for weighing precipitation samples or else very imprecise methods.

- Throughout the winter months of 1920-21 and 1921-22, the snow-to-water ratios at the Silver Lake station were often very low, typically in the 33 to 50-to-1 range. While low density snows of this magnitude do occur, higher densities and a wider range of ratios would be expected for the majority of snowfall events, thus introducing concerns over the quality and representativeness of either the precipitation measurements or the snowfall observations, or both.

  (Important Note: Questions concerning low density, while significant for the overall quality of the climatic record for this station, may not have applied to the April 14-15, 1921, storm. The Silver Lake observer remarked on his observation form that because of the excessively deep snows that buried the precipitation gauge, he used a different method than usual for measuring water content and filled the gauge with cores of the accumulated snowfall in order to determine precipitation. This was, in the written words of the observer, “done so very carefully.”

- The observer did not always report total snow depth on a daily basis. Snow depth was typically reported to the nearest one-half foot. There was no formal evidence that a snow stake was used for measuring total depth of snow on the ground. Based on remarks written by the observer earlier in the winter, it was difficult to take representative snow depth measurements at that site.

- The Silver Lake 1920-21 seasonal snowfall total was extremely high -- 627 inches. The 1911-1947 average for this station was 268 inches. Although other stations in the area were also considerably above average for the winter of 1920-21, their anomalies were not as great. For example, the Long's Peak Ranger Station, north of Silver Lake, at an elevation of 9,000 feet, reported 50 percent more snowfall than average for the winter of 1920-21.

6. Conclusions

Silver Lake, Colorado, received an extremely heavy snowfall on April 14-15, 1921. With certainty, several feet of snow with very large amounts of water content fell over a sizeable region along the Front Range of the Rocky Mountains in Colorado. However, the lack of a specific 24-hour measurement of snowfall during the storm, suspicions of a less-than-ideal exposure for the Silver Lake measurements, and a tendency for larger monthly and seasonal snowfall totals for the Silver Lake station in comparison with nearby stations during the 3-year period from June 1920-June 1923, when one particular observer was responsible for Silver Lake observations, all cast some doubt on the published 76-inch, 24-hour total.

The large increase in reported snow depth and the fact that snowfall then was often reported as the increase in the total depth of snow on the ground suggest that the Silver Lake snowfall measurement could have been conservative. Snow depth increases were large at other sites, and Silver Lake was likely near the center of maximum snowfall from this storm. Therefore, the 76-inch total is accepted as a reasonable estimate of 24-hour snowfall at Silver Lake, Colorado, for the observational day ending at 6:00 p.m. on April 15, 1921.

Comparison of Montague and Silver Lake Snowstorms

Thorough evaluations of each storm were conducted. There are considerable data and supporting information suggesting that both the Silver Lake, Colorado, and the Montague, New York, storms were gigantic local snowfalls. It is also apparent that neither observation was technically consistent with snowfall measurement guidelines in place either then or now. While the committee obviously could not interview the Silver Lake observer and ask the questions needed to clear up all uncertainties, there was a surprising amount of documentation that indicated what the observer experienced. The value of written remarks by observers can indeed be great. In contrast, there was little written documentation by the Montague observer, but, because a committee studied the event, answers to most questions about instrumentation, procedure, and location were answered and documented.

Due to differences in how, where, and when the two observations were taken, it is not possible to make a direct comparison. It is possible, though, to summarize the similarities and differences of these two observations of huge snowfall amounts and compare the two observations accordingly.

- Silver Lake was a published NWS (U.S. Weather Bureau in 1921) cooperative weather station with many years of nationally archived and published weather observations and a documented station history. Montague is a recognized NWS snow "spotter" with no nationally archived or published information, although there was some local forecast office retention of station data and information. As an official cooperative station and recognized snow spotter, both stations measurements are considered as official for NWS purposes, which <u>qualified them for consideration</u> as national climatic records.

- The geographic location of Silver Lake makes it vulnerable to extremely heavy spring "upslope" snowstorms on the eastern slope of the Rocky Mountains. The geographic location of Montague makes it vulnerable to extremely heavy winter "lake-effect" snowstorms downwind of Lake Ontario. Therefore, both sites are likely candidate locations for extreme snowfall events under certain meteorological conditions.

- The exposure of the Silver Lake station for measuring snowfall and snow depth cannot be fully determined, but there is evidence that it had been difficult earlier that winter to find a representative observing site due to drifting. The Montague site was protected and offered an excellent site for observing snowfall. This provides a vote of confidence for the Montague observation.

- Both Montague's and Silver Lake's snowfall totals were not standard climatic observations. The Silver Lake 76-inch, 24-hour snowfall was not a 24-hour observation. It was an estimate derived by prorating a measured 87 inches in 27.5 hours to a 24-hour period consistent with Silver Lake's scheduled 6:00 p.m. observation day. Montague's 77-inch, 24-hour total was derived by summing six too-frequent snowfall measurements. Thus, there is uncertainty in both observations. It remains a mystery as to why the observer at Silver Lake did not take a snowfall observation at 6:00 p.m. on April 14th, 3.5 hours after the snow began. He completed and recorded all other elements of his daily climatological observation except snowfall.

- The Silver Lake snow-to-water equivalent measurement was well documented and was consistent with the large snowfall amount. There was no measurement of snow-water equivalent taken for the storm at Montague, but subsequent independent snow surveys did show large monthly increases in snow-water content in the surrounding areas. This provides a vote of confidence for the Silver Lake observation but does not damage the credibility of the Montague report.

- Silver Lake reported a 2-day snow depth increase of seven feet (84 inches) from 6:00 p.m. April 14 to 6:00 p.m. on April 16. This was on top of 6 feet of primarily very dense winter snowpack that was already on the ground when the storm began (6 feet to 13 feet). This suggests that the Silver Lake observer was measuring snowfall predominantly as an increase in total snow depth, which is consistent with a conservative once-daily measuring interval.

  Montague reported a 51-inch increase in snow depth in the 77-inch, 24-hour period. This was on top of 2 feet of existing, but recently accumulated snow pack, which likely would have settled significantly as additional snow accumulated on it.

Due to uncertainties regarding both the Silver Lake and Montague observations, it is not possible to compare the two observations head-to-head. However, since the committee has recommended that the 77-inch, 24-hour total at Montague not be recognized as a climatic amount, the Silver Lake snowfall should continue to stand as the national record.

The Montague observation appears to have been just what it was -- 77-inches from 6 observations at varying short-term intervals. The Silver Lake observation appears to have been a one-time measurement of new snow in which the total increase in snow depth greatly exceeded the increase in snow depth at Montague.

Committee members discussed attemping to place both observations on an even playing field using statistical estimation procedures. However, after some debate, the committee agreed that it was inappropriate and beyond the scope of this report to add yet an additional layer of uncertainty to observations that already involved some estimation, so it was decided that the observations should be evaluated as reported. With that assumption, the committee concluded that the once in 24-hour determination of 76-inches of snowfall at Silver Lake, supported by a comparable amount of increase in depth of snow on the ground, is clearly greater than Montague's 77-inch snowfall, derived from the summation of six, shorter interval measurements.

The difficulties encountered in making the Montague and Silver Lake snowfall comparisons point out again the importance of consistent adherence to established standards for snow measurement. The comparison would be much simpler and conclusive if both snowfalls had been measured in the same manner.

NWS Standards, Guidelines, and Measurement of Snowfall

Current Standards and Guidelines:

The accurate measurement of snowfall can be very difficult. Drifting, blowing, settling, and uneven accumulation and melting make it one of the more complex weather elements to measure accurately. It can be a subjective observation under certain situations.

The NWS has standards and guidelines for measuring snowfall in place to minimize the uncertainty in taking accurate measurements. The importance of adherence to these guidelines and the taking of measurements in the prescribed consistent manner cannot be overemphasized. Long ago, it became apparent to meteorologists, climatologists, and physical scientists alike that inconsistent methods of observing and reporting snowfall result in incompatible data.

Standards and observing procedures for coding and reporting snowfall, snow depth, and liquid equivalent at manual NWS stations can be found in three documents: “Federal Meteorological Handbook Number One,” Federal Meteorological Handbook Number Two,” and “NWS Observing Handbook Number Seven.” These documents require the measurement of snow on a 6-hourly basis. Additionally, snow measurement guidelines for volunteer observers, such as snow spotter networks and the cooperative observer network, were updated in October 1996, and are documented in the “Snow Measurement Guidelines (October 1996, Appendix B).” The updated volunteer observer guidelines, in addition to containing more concise and detailed measurement guidance, include, for the first time, an option for observers to increase the frequency of measurement from once-a-day to four times per day, but not more than one measurement in a six-hour period. This expansion of the six-hourly rules for NWS manned stations to cover volunteer sites was intended to further standardize the measurement of snowfall amounts, and thus improve the quality of the snow data base and continuity of observations between differing networks. Basically, the same standards now apply to all NWS observers.

There are three basic values that are determined when reporting snowfall for climatic purposes. They are:

1. the amount of new snowfall (inches and tenths),
2. the depth of snow on the ground (nearest whole inch), and
3. the water equivalent of snowfall since the previous day’s observation (inches and hundredths).

This report addresses the first two values above since the snow spotter observations under review in this study did not include the third value (water equivalency).

To measure new snowfall consistently and accurately, standards discuss two fundamental procedures that are important and easily followed. They are (1) the use of a snow board and (2) taking the measurements at the prescribed time interval.

Snow board: The purpose of the snow board (white in color) is to allow for a more precise determination of the new snowfall that has accumulated since the last observation. Use of a snow board allows the observer to measure the amount of new snowfall, eliminating the problem of settling of the old snow as time passes. In situations where no old snow is on the ground, the snow board serves as a smooth surface that allows for more accurate measurement than a grassy surface would allow, where surface variations in density can result in uneven, differing accumulation.

Frequency (interval) of measurement: At each measurement, the snow board is swept clean of snow. This reduces the effect of settling of the snow mass to what has compacted during the last six hours. With one observation a day, the total amount of snowfall reported will generally be less than the more frequent six-hourly measurements. In general, the more frequent the measurement interval, the greater the total snowfall that will be reported for any summed period. This relationship is complex and is related to the density of the snow (fluffiness), wind speed, and temperature. The fluffier (lower density) the snow, the more inflation one will observe as the frequency of observation increases (this is due to the fact that fluffy snow compacts more and quicker than dense snow). The frequency standard is for one measurement every six hours. If the schedule of volunteers does not permit six-hourly observations, a daily observation at the scheduled observation time is acceptable.

Summing frequent snowfall measurements does not represent “snowfall” in a climatological sense because of the settling that occurs within fresh snow on the ground. It is not appropriate to report snowfall as the sum of frequent measurements of new accumulation on a cleared reference surface (a snow board). Such a summation often represents an imaginary total that exceeds any observable snow depth during the snow event and therefore misrepresents the accumulation for the many retrospective users of the data.

Frequency of measurement is not a problem when measuring liquid precipitation since liquid water does not compress and settle like snowfall does.

<u>1921 Volunteer Guidelines:</u>

The following snowfall measurement guidelines were taken from “Instructions for Cooperative Observers (1915)”and appear to be the instructions that were in place for observers during 1921, when the previous national record setting 24-hour snowfall was observed in Silver Lake, Colorado.

How to Measure Rainfall and Snowfall.

Page 20, paragraph 40. Snowfall. - During the winter season, especially in those climates where the precipitation is nearly all in the form of snow, the overflow attachment only of the rain gage should be exposed in the support as a snow gage. Remove the receiver and measuring tube to the house, as these parts can not be used for measuring snow, and even if rain should occur it is very apt to be frozen while in the measuring tube, generally bursting it and rendering it worthless or highly inaccurate.

Page 20, paragraph 41. First Method. - The snowfall collected in the overflow attachment is measured after placing the vessel in a warm room until the snow is melted. The water is then carefully poured into the measuring tube and measured just as though it were rainfall.

Page 20, paragraph 42. Second Method. - The first method is objectionable, because it often requires considerable time, and is liable to be inaccurate, owing to the loss of the snow or water by evaporation. The following plan is much better, unless clumsily conducted so as to spill and waste the water: Take the overflow into the room and pour into it, carefully, one measuring tube full to the brim with water, preferably warm water. This, in general, will mostly melt, or at least, reduce to a very fluid slush, a considerable snowfall. The measuring tube should be again carefully filled to the brim from the melted contents of the overflow and emptied; whereupon the remaining water in the overflow should be carefully measured in the measuring tube, thus giving quickly and easily the depth of the melted snow.

Page 21, paragraph 43. The amount of snow collected in the overflow of the rain gage is likely to be greatly deficient when the wind blows during the snowfall. In such cases it will be much better if the observer will discard the snowfall in the overflow, empty it out and cut out a section of the snow in an open place where the depth truly represents the precipitation. This section is to be taken by plunging the empty overflow, mouth downward, in the snow so as to cut out a cylindrical portion the size of the overflow and the depth of the snow. By the use of a thin board or other means it will not be difficult to gather up the complete section of snow inside the overflow, after which it should be reduced to slush and measured as already explained.

Precipitation Records.

Page 24, paragraph 56. Snowfall. - <u>Snowfall is preferably measured as depth of water rather than by the thickness of layer it forms on the ground</u>. When it cannot be measured accurately by melting, it is customary to take one-tenth the measured depth of the snowfall on a level open place as the water equivalent of the snowfall. The relation between the depth of snow and depth of melted snow is very different in different cases, depending on the wetness of the snow. The equivalent depth of water in some cases is as great as one-seventh of the depth of snow, and in others only one thirty-fourth. It is always best to reduce snow to a liquid condition for measurement, and the simplest way to do this is to add to it a known volume of water sufficient to reduce it to a state of slush, as explained in paragraph 42. For each entry in the column headed "Snowfall" there must be an entry in the column "Amount." For rainfall but one entry is made; for snowfall two, one of which is the depth of the snow, the other the depth of the water obtained by melting the snow.

Page 25, paragraph 57. In the winter season the overflow only of the gage should be exposed, as stated in paragraph 40, and the snow collected therein between observations (or, better, a section of snow cut out as explained in paragraph 43) should be reduced to a state of slush and measured in the manner described in paragraph 42.

Page 25, paragraph 58. In addition to this measurement by the gage <u>a measurement will be made of the actual depth in inches of the snow on the ground</u>. Select a level place of some extent, where the drifting is least pronounced, and measure the snow in at least three places. The mean of these measurements will give the snowfall, which is to be entered in the column of the report headed "Depth of snowfall in inches," and whenever it is impractical to melt the snow as described in the preceding paragraph one-tenth of this mean will give an approximate value in water for the snow which could not be melted. This value must be set down in the proper column of the report in precisely the same manner as rainfall or snow melted in the gage. After having once made a measurement of the snowfall, it is not described that the same snow be measured at each succeeding observation until it shall finally disappear, except to get the actual depth of the snow on ground for entry in the proper column. *Any fresh snow, however, should be measured and recorded after it falls.*

Page 25, paragraph 59. If no rain, snow, or hail has fallen since the last observation, make the entry 0.00 in the proper column. If the amount is too small to measure, make the entry "Trace" or "T."

The 1921 guidelines for volunteer observers stated that observations should be taken once a day with a preferred p.m. time of observation. The intent of p.m. readings was to get truer calender day maximum and minimum temperatures.

The 1921 guidelines appear somewhat contradictory and confusing in places. On page 24, paragraph 56, they state that "snowfall is preferably measured as depth of water rather than by the thickness of layer it forms on the ground." Then, on page 25, paragraph 58, they state that " a measurement will be made of the actual depth in inches of the snow on the ground." In any case, the terms "snowfall" and "snow depth" are used interchangeably. In actuality, they were then, as they are now, two separate values.

Issues Concerning NWS Adherence to Guidelines:

WSFO BUF personnel, Eastern Region Headquarters (ERH) personnel, and some committee members noted that some NWS forecast offices (including WSFO BUF) are taking hourly snowfall measurements and then incorrectly summing them to derive and report six-hourly and daily snowfall totals for climate purposes. WSFO BUF personnel even expressed concern that some of the all-time seasonal snowfall records set last year in the northeast at manual NWS stations may have been records in part because of the greater totals that resulted from the summation of hourly measurements. There are also indications that some personnel at the regional headquarters level may not fully appreciate the importance of adhering to the six-hourly snowfall measurement standards defined in Federal Meteorological Handbooks that promote accurate and consistent snowfall measurements. NWS sources have also noted that many NWS offices do not use or even have snow boards.

NWS committee members looked into reports of snowfall observing frequency inconsistencies at NWS offices and found the following. For the most part, NWS stations are properly measuring snowfall on a 6-hourly basis and are not summing hourly amounts to record the 6-hour and 24-hour totals. However, a few NWS stations were identified as improperly summing hourly values (past or present) to obtain 6-hourly and 24-hour totals. The great majority of NWS offices that are observing and reporting hourly snowfall amounts are doing so for the operationally required "snow increasing rapidly" remark that is used for watches and warnings, or heavy snow, but not for reporting climatological snowfall totals. These hourly values for the snow increasing rapidly remark are rounded to the nearest whole inch and play no part in determining the snowfall totals for climatology.

With respect to the reports of a lack of use of snow boards at NWS offices, the committee found this to be generally accurate. Surfaces on which snow is measured vary from grass to tar roof. It also appears that numerous NWS offices are calculating the amount of new snowfall by measuring the depth of snow on the ground at observation time and subtracting the previous snow depth reading from it. This incorrect procedure will yield a lower new snowfall amount when compared to stations using proper procedures. For determining the proper snowfall amount, a snow board should be used and cleared off after each observing period as stated in the guidelines.

No detailed investigation of the quality or consistency of snow measurements by NWS cooperative observers and spotters was performed as a part of this study, but all committee members have worked extensively with climatological snow data. It is widely known among climatologists and other scientists utilizing snow data that numerous inconsistencies exist now and have existed for many years. Time of observation, interval between observations, use or lack of snow boards, and highly non-uniform station exposures are the largest factors contributing to data inhomogeneities. After re-reading the 1915 observer instructions, one can understand the source of some of the confusion. It has also been noted by several committee members that the more interested and enthusiastic snow observers are, the more likely they are to use snow boards and to measure very frequently. This is a qualitative statement that was not verified in this field investigation but has been witnessed many times over.

The increasing use of snowfall reports from numerous spotters presents both problems and opportunities. Due to NWS personnel time constraints, spotters are likely to receive little training unless well-written guidelines are distributed or training videos are prepared. Without an effort to standardize observations, there is little hope for bringing consistency and comparability to snow measurements in the United States.

Findings and Recommendations

Finding 1: The committee's extensive review of the January 11-12, 1997, Montague, New York, snowfall observations and related information suggests that the observer's measurements followed WSFO BUF's real-time operationally oriented guidelines for snow spotters, not climatological guidelines. The observer took and reported six snow measurements between 1:30 p.m. on January 11 and 1:30 p.m. on January 12, 1997 (five of which were within twelve hours), to support real-time NWS operations. Spotter observations are considered official for NWS purposes, and thus qualified the report for consideration as a new national record. The observer was knowledgeable about snow measurement techniques. Additionally, the location and type of equipment used to take the observations (two snow stakes and a snow board) exceeded minimum NWS guidelines. His historical data compared well with surrounding spotters' data and cooperative observers' data; his Jan. 10-14, 1997, data compared reasonably with eyewitness and surrounding data; and he took the measurements in a well-protected yet open location. All evidence suggests that the snow that fell at Montague during this storm was of a very light, fluffy nature (low density) and accumulated to a great amount.

However, an inconsistency arose when these six operationally oriented snow measurements were added by TWC to get a total for a 24-hour period. The resulting 77-inch snowfall amount was checked and then acknowledged by WSFO BUF, and thereafter reported by both sources as a new national climatological record.

NWS standards for climatological observations of snowfall require that no more than four observations, taken with a maximum frequency of once every six hours, be summed within any 24-hour period to compute the total snowfall for that period. More frequent measurements taken by clearing the snow board increase totals. Recognized climatic snowfall records should be based only on observations that satisfy climatic data standards.

The summing of more frequent than 6-hour snow measurements to obtain 24-hour climatological totals is inconsistent with WSFO BUF's spotter guidelines, which explicitly instruct snow observers not to do this because "this would give an unrealistically high amount."

The six Montague observations taken on January 11-12, 1997, although measured individually in a valid scientific manner for supporting real-time NWS operations, were taken at intervals too frequent to qualify the sum of the six as an official 24-hour climatological snowfall amount.

The committee strongly reaffirms the importance of station documentation (metadata) and traceable data sets at NOAA's NCDC as a standard requirement for "official" NWS climate data stations such as the cooperative observer climate network. This requirement is considered necessary by most climatologists for observations to be recognized as official climate data and to insure traceable data for historical analysis.

There was a large body of evidence suggesting that Montague's snowstorm was indeed a very large snowstorm.

The committee applauds WSFO BUF's efforts to establish its high-density, dedicated snow spotter network, and furthermore acknowledges the great benefits to be derived from the use of real-time observations from the spotters in supporting operational NWS forecast and warning responsibilities. The committee strongly supports the continuation and further development of snow spotter networks towards those means.

Recommendation 1: The committee recommends that the six January 11-12, 1997 Montague snowfall observations be recognized as valid, individual snowfall measurements that, when used in real-time by WSFO BUF, provided meaningful short-term snowfall intensity information for operational NWS programs. However, in consideration of the too-frequent snowfall measurement intervals summed to derive the 24-hour snowfall total, the committee further recommends that the 77-inch total not be recognized as an official climatological snowfall amount for that 24-hour period.

Finding 2: The committee is concerned about the lack of adherence to established standards for the measurement and reporting of climatological snowfall at NWS offices and volunteer networks.

The committee identified several cases of NWS stations taking hourly snow measurements and improperly adding these measurements to obtain 6-hour and 24-hour amounts. It was also found that the availability and use of snow boards was sporadic or non-existent at numerous NWS locations. Some offices, where snow boards have not been utilized, have also been erroneously under-measuring new snowfall by simply subtracting the old depth of snow on the ground from the new total snow depth to determine snowfall. Additionally, some climatological volunteer observers have not been provided with the recently revised "NWS Snow Measurement Guidelines."

The lack of consistent adherence to standards can result in inconsistent assessments of snowfall amounts and historical rankings, and degraded data quality. The committee is also concerned that publicly disseminated and published NWS snowfall products are being distributed with similar inconsistencies.

There is an urgent need to ensure that existing standards for the measurement and dissemination of climatological snowfall (not to be confused with hourly snow intensity measurements) are adhered to by all NWS sources (including forecast offices), cooperative observers, and spotters.

Recommendation 2: The NWS should vigorously and without further delay take the necessary steps to establish adherence to existing Federal Meteorological Handbook standards and cooperative observer guidelines for the taking of snowfall measurements for climatic purposes at all its manned, spotter, and cooperative observer stations. To reach this goal, the NWS should insure that training materials and equipment such as snow boards be made available and placed in use at all stations.

NWS products disseminated to external users, which include snowfall totals for 6-hours or greater (e.g., daily, monthly, and seasonal), should also conform to standards for reporting climatic snowfall totals.

If non-standard observations from snow spotters or other networks designed to support real-time operations are used in publicly disseminated products, these products should be labeled so that users understand that these snowfall amounts indicate short-term snowfall intensities only; they are not to be interpreted as official climatic snowfall amounts and <u>cannot</u> simply be summed to derive 6-hourly or greater climatic snowfall totals.

Finding 3: The committee is concerned that NOAA and the climate community have <u>no formal mechanism</u> in place to assess national meteorological and climatological records (extreme values). WSFO BUF attempted to find such an appropriate mechanism to consider the Montague record, but found none. Without support, WSFO BUF felt pressured to make a timely decision to satisfy the widespread and understandable interest in the noteworthy Montague snowstorm.

The committee believes that the continuing explosive growth of networks (mesonets) around the nation (NWS, federal, state, county, and private) will result in further situations in which meteorological and climatological records may be reported or challenged from standard and non-standard sources. The committee also recognizes the intense pressures that can be exerted upon local NWS forecast offices to make quick determinations of the historical ranking of sometimes complex weather/climate events. The committee believes that it is in the best interest of the scientific community, the media, the public, and the NWS to avoid overloading operational forecast offices with responsibility to determine new climatic extreme values. With the formation of an extreme value oversight mechanism, the quality of NOAA's climate data integrity could be significantly improved.

Recommendation 3: The NCDC should take the lead in setting up a committee that would be responsible for assessing observations submitted as national meteorological/climatological extreme values. The committee should be chaired by NCDC, and include participants from both within NOAA and the external climate community. NOAA participants should include experts in observation standards, data management and meteorology, and station documentation (metadata) and data quality. External participants should include at least two state climatologists. The committee should have the authority to call on additional participants as appropriate (and provide funding if required) to investigate the particular record in question. The committee should have the authority to determine and enforce basic observation standards for documentation, instrument accuracy and exposure, and measurement techniques in consideration of all future observations submitted as potentially official (recognized) record-setting events.

The NWS should encourage local forecast offices to announce any new candidate national extreme values as preliminary, pending a final determination by the proposed committee.

The mechanism created by this committee would allow for a more orderly, scientific process within NOAA and the climate community for the future determination of national extreme values and relieve the pressure put on local operational NWS forecast offices for quick determinations of complex and time-consuming designations.

Finding 4: The committee's review of the April 14-15, 1921, Silver Lake, Colorado, 24-hour snowstorm indicates that this "national record" was previously analyzed and accepted by the NWS in a peer-reviewed journal. The committee was not mandated to invalidate the previously accepted record. However, the validity of the Silver Lake snowfall amount could also be questioned if the climatological guidelines in place in 1921 are rigorously applied.

The different measurement techniques used in the Montague and Silver Lake storms make meaningful comparison of snowfall amounts difficult. The Silver Lake 76-inch total consisted of one measurement from a documented, published NWS cooperative station, which was prorated from 27.5 hours to 24 hours, making it a statistical estimate, and not a true observation. The Montague 77-inch total came from six short-term measurements taken by an NWS snow spotter, later summed to derive a 24-hour total.

Analysis of snow depth data for the two storms indicates that Silver Lake's snow depth increased 84 inches in 2 days while Montague's maximum observed snow depth increase for the storm (a 24-hour period) was 51 inches. Even after taking into account the compaction of the existing snow pack at Montague, the Silver Lake snowstorm clearly recorded the greatest snow depth increase.

Recommendation 4: Since the committee has recommended that the 77-inch, 24-hour total at Montague not be recognized as a climatic amount, the Silver Lake snowfall should continue to stand as the national record.

The previously proposed extreme values review committee should begin to closely scrutinize existing or potential national record-setting observations, with an emphasis on adherence to standards to protect the integrity of the data.

In closing, it should be noted that the committee reached consensus on its findings and recommendations, but only after a great deal of rigorous debate about the issues.

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Appendix A
WSFO BUF's Snow Spotter Training Documentation

16 October 1996

FIELD(Name)
FIELD(address)
FIELD(City, State, Zip)

Spotter Number FIELD(Spotter Number)

Dear FIELD(Saluation),

Welcome to the third season of our "National Weather Service Lake-effect Spotter Network". As part of the NWS Modernization Plan, a three-year project to study Lake effect snow continues. This project involves new radars, satellite, and automatic observation stations. The most important need, however, is "ground truth", or actual surface reports to verify what is really happening..and that is where you come in!

You have been selected as one of our spotters for the 1995-96 winter season. You can help us in two ways: **Real Time** snowfall reporting...and tabulating and reporting **monthly totals**. For **Real Time** Reporting, please call us under the following conditions:
-4" or more during the past 24 hours (best call times 6-8AM and 6-8PM, but anytime OK).
-1" or more per hour (anytime)
-thunder/lightning heard/observed (anytime)
-quick start or stop of heavy snow (anytime).
Our toll-free unlisted number is **1-xxx-xxx-xxxx** (xxx-xxx-xxxx collect from Canada or just **xxx-xxxx** local around Buffalo). We would also like to be able to call **you** for verification of actual storm conditions, and of course, we will restrict our calls to reasonable hours. If you **can** receive calls overnight (10 PM-7AM), please let me know.

Measuring snow is a rough art and can be very subjective. You want a cold, flat surface. Pavement is OK if it's cold, but should not be used under milder conditions due to melting, grass is too uneven. Picnic tables and autos are fine. If drifting is a problem, take several measurements and average them. A "snow board" is best. Frequency can make a big difference. Do Not measure every hour and add them up...this would give an unrealistically high amount, every 6 or 12 hours would be fine (unless it's melting). Our Season extends from November 1 thru March 31.

I have also attached a table for you to tabulate daily snowfall (to the nearest inch). **Please clip off each month** and mail to: **National Weather Service Spotters, 587 Aero Drive, Buffalo NY 14225** at the end of each month (five stamps are attached...one for each month). We will compile the data and develop monthly maps which will be archived for future reference. You will also receive a copy of these maps along with any special maps developed for individual storms. Although daily snowfall is sufficient...feel free to add any other info to the table such as estimated water equivalent of the snowfall, high winds, temps, etc. Be sure and mark down your **Spotter Number** on the form and refer to this number when you call. **Your number is at the top of this letter**. In addition, you will find an attached sheet requesting Station Location info.

Please fill out and return with your November recording form in early December (New Spotters only). You will receive two mailings during the season: a mid-season and final season review.

Thanks again. Your time and effort is much appreciated. Feel free to call me at 1-xxx-xxx-xxxx with any questions, comments, or concerns.

Hydrometeorologist: National Weather Service Buffalo.

Appendix B
NWS Snow Measurement Guidelines

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Weather Service
Office of Meteorology

Supplements form WS TA B-0-26; 9-79

Snow Measurement Guidelines (10-23-96)

The following procedures were developed from previous National Weather Service procedures and input from a broad array of expertise from climatologists, snow specialists, weather observers, and data users. Some of the materials have been extracted from "The Snow Booklet" by Nolan J. Doesken and Arthur Judson, CSU, 1996.

It is essential for all observers to understand the importance of taking standard measurements in the prescribed consistent manner. Inconsistent observing and reporting methods result in incompatible data, which can result in profoundly incorrect differences between stations and observers.

Each season before the first snows come: Review these instructions for measuring snow. It is easy to forget what needs to be measured, especially in those parts of the country where snow falls infrequently.

At the beginning of each snowfall/freezing season, remove the funnel and inner measuring tube of the eight-inch manual rain gauge to expose the 8-inch diameter overflow can so that it can more accurately catch frozen precipitation. Put your snowboard(s) out and mark their location with a flag or some other indicator so they can be found after a new snowfall. They should be located in the vicinity of your station in an open location (not under trees, obstructions, or on the north side of structures in the shadows).

Check your gauge to make sure there are no leaks. If there are leaks, take appropriate action. Once your equipment has been readied for winter, you are prepared for taking snowfall measurements.

Observers should determine three values when reporting solid precipitation. They are:

1. measure and record the snowfall (snow, sleet, snow pellets) since the previous snowfall observation,
2. determine the depth of snow on the ground at the normal observation time, and.
3. measure and record the water equivalent of snowfall since the previous day's observation.

1. Measure and record the greatest amount of snowfall that has accumulated on your snowboard (wooden deck or ground if board is not available) since the previous snowfall observation. This measurement should be taken minimally once-a-day (but can be taken

up to four times a day, see note below) and should reflect the greatest accumulation of new snow observed **(in inches and tenths, for example, 3.9 inches)** **since the last snowfall observation.** If you are not available to watch snow accumulation at all times of the day and night, use your best estimate, based on a measurement of snowfall at the scheduled time of observation along with knowledge of what took place during the past 24 hours. If you are not present to witness the greatest snow accumulation, input may be obtained from other people who were near the station during the snow event. If your observation is not based on a measurement, record in your remarks that the "snow amount is based on estimate." Remember, you want to report the greatest accumulation since the last observation. **If snowfall occurred several times during the period, and each snowfall melted either completely or in part before the next snowfall, record the total of the greatest snowdepths of each event** and enter in your remarks "snowfall melted during the OBS period**."** For example, three separate snow squalls affect your station during your 24-hour reporting day, say 3.0, 2.2, and 1.5 inches. The snow from each event melts before the next accumulation and no snow is on the ground at your scheduled time of observation. The total snowfall for that reporting 24-hour day is the sum of the three separate snow squalls, 6.7 inches, even though the snow depth on your board at observation time was zero.

Snow often melts as it lands. **If snow continually melts as it lands, and the accumulation never reaches 0.1 inches on your measuring surface, snowfall should be recorded as a trace (T),** and you should record in your remarks that the "snow melted as it landed."

It is essential to measure snowfall (and snow depth) in locations where the effects of blowing and drifting are minimized. Finding a good location where snow accumulates uniformly simplifies all other aspects of the observation and reduces the numerous opportunities for error. In open areas where windblown snow cannot be avoided, several measurements may often be necessary to obtain an average depth, and they should not include the largest drifts. In heavily forested locations, try to find an exposed clearing in the trees. Measurements beneath trees are inaccurate since large amounts of snow can accumulate on trees and never reach the ground.

If your daily schedule permits, you may wish to make a snowfall observation every 6-hours, beginning with your regularly scheduled time of observation. This is the procedure followed by National Weather Service Forecast Offices. Follow the same rules for a once-a-day observation, but the snow accumulation reported will be the greatest for the previous six hours instead of 24 hours. If you take your observations at this frequency, **make sure that you clear your snowboard (or other measuring surface) no more than once every 6 hours.** Record the frequency of observations during the day in the comments section of your report. **Never sum more than four, 6-hourly observations to determine your 24-hour snowfall total.** If you use more than four observations, it would falsely increase snowfall totals.

Freezing rain (glaze ice) should never be reported as snowfall. This precipitation type is liquid precipitation and should be reported as such.

2. Determine the total depth of snow, sleet, or ice on the ground. **This observation is taken once a day at the scheduled time of observation with a measuring stick.** It is taken by measuring the total depth of snow on exposed ground at a permanently mounted snow stake or by taking the average of several depth readings at or near the normal point of observation with a measuring stick. When using a measuring stick, make sure the stick is pushed vertically into the snow until the bottom of the stick rests on the ground. Do not mistake an ice layer or crusted snow as "ground". **The measurement should reflect the average depth of snow, sleet, and glaze ice on the ground at your usual measurement site (not disturbed by human activities). Measurements from rooftops, paved areas, and the like should not be made.**

Note: Even though the depth of hail (usually associated with spring, summer, or fall thunderstorms) at observation time is also reported in the same manner as snow depth, make sure you record in your remarks that the "accumulation on the ground is from hail."

Report snow depth to the nearest whole inch, rounding up when one-half inch increments are reached (example: 0.4 inches is reported as a trace (T), 3.5 inches is reported as 4 inches). Frequently, in hilly or mountainous terrain, you will be faced with the situation in which no snow is observed on south-facing slopes while snow, possibly deep, remains in shaded or north-facing areas. Under these circumstances, you should use good judgement to visually average and then measure snow depths in exposed areas within several hundred yards surrounding the weather station. For example, if half the exposed ground is bare and half is covered with six inches of snow, the snow depth should be entered as the average of the two readings, or three inches. When, in your judgement, less than 50 percent of the exposed ground is covered by snow, even though the covered areas have a significant depth, the snow depth should be recorded as a trace (T). When no snow or ice is on the ground in exposed areas (snow may be present in surrounding forested or otherwise protected areas), record a "0."

When strong winds have blown the snow, take several measurements where the snow was least affected by drifting and average them. If most exposed areas are blown free of snow while others have drifts, again try to combine visual averaging with measurements to make your estimate.

<u>3. Measure the water equivalent of snowfall since the previous day's observation</u>. This measurement is taken once a day at your specified time of observation. Melt the contents of your gauge (by bringing it inside your home or adding a measured amount of warm water) and then pour the liquid into the funnel and smaller inner measuring tube and measure the amount to the nearest .01 inch (use NWS-provided measuring stick) just as you do for measuring rainfall. Do not measure the melted precipitation directly in the larger 8-inch outer cylinder. Make sure the inner measuring tube can't fall over when pouring the liquid back into it. If the melted water equivalent (including any added warm water) exceeds two inches and cannot fit into the measuring tube all at one time, empty the full measuring tube and pour the remaining liquid from the large 8-inch outer cylinder into the emptied measuring tube. Then, add and record the water equivalent of the multiple measurements. If you added warm water to the gauge to melt the snow, make sure you accurately measure the amount of warm water added before pouring it into the gauge. Then, when you take your liquid measurement, subtract the amount of warm water added from the total liquid measurement to get your final liquid water equivalent of the snowfall.

As winds increase, gauges collect less and less of the precipitation that actually falls. Generally speaking, the stronger the wind and the drier the snow, the less is captured in the gauge. If you notice that less snow is in the gauge than accumulated on the ground, you should first empty any existing snow from inside the 8-inch cylinder, then use it to take a snow sample, sometimes referred to as "take a core" or "cut a biscuit" from your snow board with the 8-inch overflow can. Melt the biscuit of snow, pour the liquid into the small measuring tube to measure the water equivalent.