Climatology

A MESOCLIMATOLOGY OF THE MEDIAN RAIN-SNOW LINE IN NEW JERSEY

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ABSTRACT

A method for the determination of the Median Rain-Snow Line in New Jersey, for snowfalls of 4.0 inches or greater in a 24-hour period, was developed using 32 years of data. The Median Rain-Snow Line was defined in 43% of the 172 Events, while 28% were considered to be statewide Snow Events with the Median Rain-Snow Line lying south of the State. The remaining 29% were either coincident with a separate occurrence of rain during the period of observation, or were poorly defined by the criteria. The Rain-Snow Lines were generally oriented from northeast to southwest, and were widely distributed across the State. Median Rain-Snow Lines were found to be independent of Cyclone Type with one notable exception.

1. INTRODUCTION

Considerable research has been done on the problem of rain-snow forecasting. Synoptic conditions favorable for frozen or freezing precipitation were analyzed by Laird and Dickey (3), Penn (4), George (5), and Spiegler and Fisher (6). Basic forecasting guides for precipitation type based on numerical guidance and statistical analogs were presented by Wagner (7), Pandolfo (8), Younkin (9), and Wasserman (10). Statistical guides based on synoptic conditions were developed to aid in the forecasting of precipitation type for the New York City-New Jersey area by Dunlap (11), Hovey and Shulman (12), Addess and Shulman (13), Greenway and Shulman (14), Grillo and Spar (15), Shulman and McCarthy (16), and Broccoli (17). Little research however, has been done on the climatology of the rain-snow line. The rain-snow line may be defined several different ways. It can be a boundary separating areas in which snow or rain predominated during a precipitation event and may be visible after the fact in satellite photographs. The rain-snow line may also be defined at any time during an event, through synoptic reports, as the instantaneous boundary between frozen and unfrozen precipitation. The Median Rain-Snow Line in this study is defined as the dividing line, or boundary separating areas where, during a precipitation event, greater than 50% of the precipitation fell as snow or where less than 50% fell as snow. To identify the boundary, climatological data including maximum and minimum temperatures, total snowfall, and total precipitation data were used.

2. METHODOLOGY

An Event was defined as the occurrence of at least 4.0 inches of snow in a 24-hour period at at least one of 27 New Jersey stations. Events were further divided into spring and winter cases based on temperature and precipitation relationships.

The variables used to define the Median Rain-Snow were maximum and minimum temperatures, total Event snowfall, and total Event melted precipitation. The data were obtained from New Jersey Climatological Data (1950-1981) for 27 first-order and cooperative observing stations (Table 1, Figure 1) for each Event. Using these criteria, data were collected for 172 individual Events for the years 1950-1981. Two stations, Audubon and Branchville, started data collection in 1950 and 1954 respectively. Station names and latitude and longitude are values as of December 1983 while elevations are as of December 1981.

The duration of individual Events varied between 24 and 72 hours. When the duration exceeded 24 hours, the total snowfall, total melted precipitation, and the maximum temperature (MAXT) and minimum temperature (MINT) were considered for the same period. In selecting the MAXT and MINT for each event, station observation time and prevailing synoptic conditions were considered.

Using total Event snowfall and total event melted precipitation, a "snow to rain" RATIO was computed for each station for each case by dividing the total Event snowfall by the total Event melted precipitation. For each station the RATIO was plotted against its corresponding MAXT and MINT. Through examination, it was found that a linear relationship existed between the RATIO and the temperature. Those cases in which the relationship was better defined between the MAXT and the RATIO were labeled winter cases (102) while those where the MINT gave better definition were labeled

Station Name	Station Number	LAT/LON	ELEV (ft)	COUNTY
Belvidere Bridge	1	40° 50'/75° 05'	275	Warren
Canoe Brook	2	40° 45'/74° 21'	180	Essex
Charlotteburg Reservoir	3	41° 02'/74° 26'	760	Passaic
Flemington	4	40° 30'/74° 52'	140	Hunterdon
Lambertville	5	40° 22'/74° 57'	60	Hunterdon
Little Falls	6	40° 53'/74° 14'	150	Passaic
Long Valley	7	40° 47'/74° 47'	550	Morris
Morris Plains 1 W	8	40° 50'/74° 30'	400	Morris
Newark WSO AP	9	40° 42'/74° 10'	30	Essex
Newton St Paul's Abbey	10	41° 02'/74° 48'	600	Sussex
Plainfield	11	40° 36'/74° 24'	90	Union
Somerville 3 NW	12	40° 36'/74° 38'	160	Somerset
Atlantic City WSO AP	13	39° 27'/74° 34'	138	Atlantic
Audubon	14	39° 53'/75° 05'	40	Camden
Freehold	15	40° 16'/74° 15'	194	Monmouth
Hightstown 2 W	16	40° 16'/74° 34'	100	Mercer
Indian Mills 2 W	17	39° 48'/74° 47'	100	Burlington
Millville FAA AP	18	39° 22'/75° 04'	68	Cumberland
Moorestown	19	39° 58'/74° 58'	45	Burlington
New Brunswick 3 SE	20	40° 28'/74° 26'	86	Middlesex
Pemberton 3 S	21	39° 56'/74° 42'	50	Burlington
Toms River	22	39° 57'/74° 13'	10	Ocean
Cape May 2 NW	23	38° 57'/74° 56'	7	Cape May
Long Branch Oakhurst	24	40° 16'/74° 00'	30	Monmouth
Rahway	25	40° 36'/74° 16'	20	Union
Mays Landing 1 W	26	39° 27'/74° 45'	20	Atlantic
Branchville	27	41° 09'/74° 45'	580	Sussex

Table 1. New Jersey first-order and cooperative stations by station number, latitude and longitude, elevation, and county. Station numbers refer to Figure 1.

spring cases (20). Winter cases in the winter (Dec. through Feb.) totalled 86, or 84% of all winter Events; and spring cases in the spring totalled 15, or 75% of all spring Events. This distinction was necessary because boundary layer temperatures are higher in the fall and spring than in the winter. Evaporative cooling and minimum temperatures are important factors for the occurrence of snow, but are less critical in the winter than in the spring. It was possible for a winter case to occur outside of the meteorological winter (Dec through Feb) and a spring case to occur during the winter since the distinction was based only on the relationship between the MAXT or MINT and the RATIO.

Cases in which the plots of MAXT vs. RATIO and MINT vs. RATIO showed little or no linearity (50) were further investigated. It was found from Newark Local Climatological Data (1950-1981) that during the given 24 to 72 hours during which an Event was observed, it was possible, in 35 cases, for a separate period of rain to occur. This obscured the temperature and ratio relationship and these Events were eliminated from consideration. Another 15 Events were found to have no discernible relationship between temperature and RATIO and were also omitted.

To define the Rain-Snow Line in terms of temperature and RATIOS, reference was made to the study by Grillo and Spar (15). They found median temperature values for the occurrence of snow in northern New Jersey to average 37.5°F. A median value of 37°F was adopted for this study for the entire State since Grillo and Spar (15) found the critical values for rain vs. snow to decrease somewhat from north to south. An examination of the data found median RATIOS of 8:1 and 5:1 appropriate for winter and spring cases, respectively. These values were selected based on a study of east coast snowstorms by Spiegler and Fisher (6) which determined that these storms produce snow to rain RATIOS of close to 10:1 in the area to the left of the trajectory of the 850-mb cyclone. RATIOS were found to be considerably lower when the 850-mb cyclone moved over or to the west of the region. For the Events under study here, it was possible for the 850-mb cyclone to track to the west of, over, or to the east of New Jersey. This meant that snow to rain RATIOS were likely to be 10:1 or lower. With these considerations, and since Events were not stratified according to the 850-mb cyclone trajectory, representative statewide RATIOS were assigned. In winter cases, an 8:1 RATIO was chosen since synoptically, cold and dry air is already in place and tends to produce low density snowfall. For spring cases, a 5:1 RATIO was chosen with warmer boundary layer temperatures resulting in higher density snowfall.

Each station's MAXT and RATIO was plotted for each winter case and then the 37°F isotherm and the 8:1 RATIO isopleth were analyzed. The Median Rain-Snow Line was located by interpolating between the two isopleths. This procedure worked well in most winter cases with 40, or 39%, having an identifiable Line. Only 16, or 16%, of the

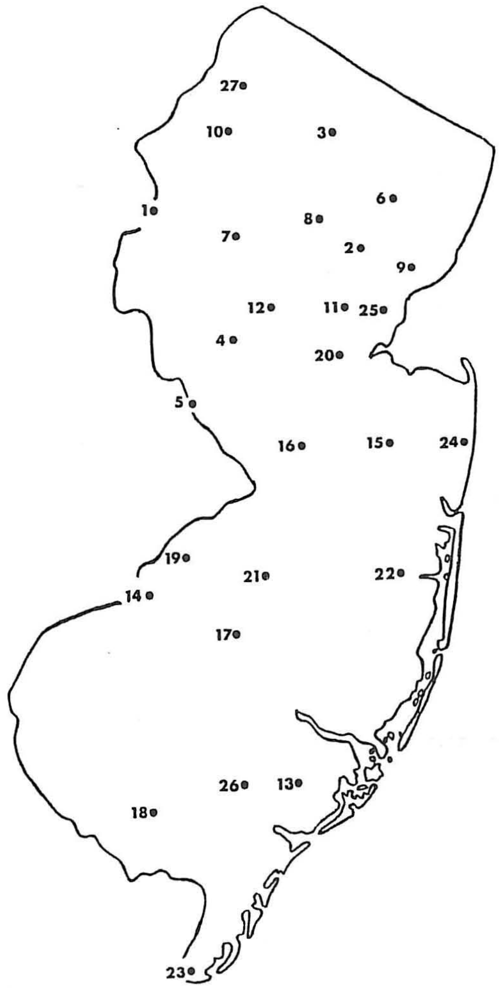

Figure 1. New Jersey first-order and cooperative observing stations, with Station Numbers (see Table 1).

winter cases were not well fit. Those cases in which the 37°F MAXT isotherm was in southern New Jersey, or south of the State, were considered to be all snow cases statewide and accounted for 46, or 45%, of all winter cases.

A similar procedure was used for spring cases except that a MINT of 32°F and a RATIO of 5:1 were isoplethed. The 32°F MINT isotherm was chosen because it is a critical temperature for the occurrence of frozen precipitation and, as mentioned earlier, minimum temperatures are more important in spring than in winter. The 5:1 RATIO accounted for the wetter, denser snowfall prevalent at the near-freezing temperatures common in the spring. This decision was supported by examination of the data, with all but 3, or 15%, of the spring cases well fit by this procedure. All cases unaccounted for by the above procedure were subjectively analyzed by comparing station RATIOs and total case snowfall amounts to determine the appropriate line.

Finally, using the Daily Weather Map Series, Northern Hemisphere Surface Charts, and the Monthly Weather Review, Events were separated by cyclone type according to Hovey and Shulman (12) (Figure 2). Note that Type 2 cyclones originate further north than Type 3 cyclones. Similarly, Type 5 cyclones originate further north than do Type 4 cyclones. Any cyclone which did not readily fit one of the six categories was labeled as a Type 7 cyclone. This was done to determine Rain-Snow Line dependence on Cyclone Type and track. Considering the size of the data sample, it was felt that individual station missing data did not greatly affect the study. For example, the lowest number of stations reporting for any Event was 17 of 27, or 63%, of the total. In most cases at least 20 of 27, or at least 74%, stations reported.

3. RESULTS

This study determined the Median Rain-Snow Line in 122 of 172 Events, or 71%, of the sample. Events lasting from 24 to 72 hours were further divided into spring and winter cases. Table 2 summarizes all Events by month and indicates the percentage of cases, by Cyclone Type, for which a rain-snow delineation was possible. The Median Rain-snow Line was most frequently identified for Cyclone Types 3, 5, and 6 (82%, 80%, and 84%, respectively; see Table 2). Table 3 lists the number of Events by year and shows that the highest frequency of Events observed was 11 in 1967, and that the lowest was 2 in 1973. Note that the values for 1972 do not include March and April. The average number of Events per year is 5.4. Table 4 shows the frequency of Cyclone Type by month and is in close agreement with Hovey and Shulman (12). While they found Cyclone Type 3 to account for 26.9% and Type 7 for 19.2% of the Events, this study found 28.5% and 23.8%. The largest difference occurred for Type 5 Cyclones with Hovey and Shulman reporting a frequency of 11.5% while this study found the occurrence to be 5.8%.

Overall, the position and orientation of the Median Rain-Snow Line was found to vary greatly across the State with little if any dependence on Cyclone Type except for Type 5. Minimal variability in both position and orientation of the Median Rain-snow Line was found with Cyclone Type 5. The Median Rain-Snow Lines for Cyclone Type 5 pass through Monmouth and Ocean Counties southwestward through Burlington County (Figure 3).

In summary, the method located a Median Rain-Snow Line for nearly 3 out of every 4 Events. The Median Rain-Snow Line was generally oriented from the urban northeast, through the midsection of the State, to the southwest. There was some variation of the Line from a north-south orientation parallel to the coast or to a more east-west orientation. Those Events which were obscured by separate occurrences of rainfall (35) and those with no relationship between temperatures and ratios (15) were omitted since analysis was not possible. It was found that the Median Rain-Snow Line was generally independent of Cyclone Type after Hovey and Shulman (12), except for Cyclone Type 5. Cyclone Type 5 is associated with a fast moving, progressive upper air trough which inhibits strong

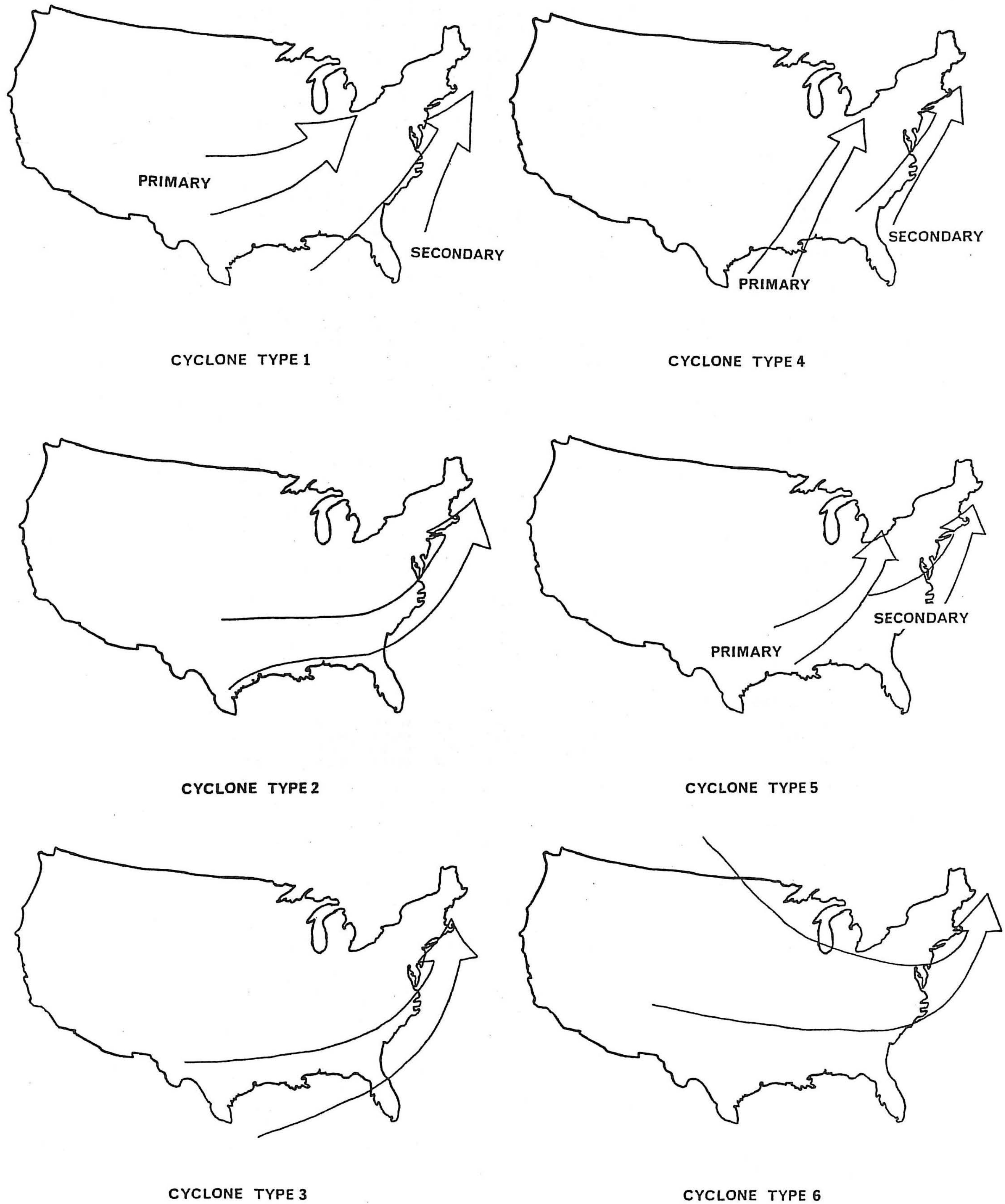

Figure 2. Cyclone Type after Hovey and Shulman (12).

Cyclone Type 1	# of Cases	SEASON TYPE WINTER/SRING	SNOWFALL (in) MAX/MIN	AVG	RATIO MAX/MIN	AVG	# EVENTS R-S/SNOW	% EVENTS R-S/SNOW
November	1	1/0	5.0/0	2.3	16.7/0.9	5.6	1/0	
December	5	4/1	18.5/0	5.0	17.4/0	6.5	2/0	
January	3	1/1	20.0/0	6.7	45.7/0	7.0	1/1	
February	4	3/1	24:0/0	6.0	50.0/0	8.6	0/2	
March	8	2/6	12:0/0	3.9	40.0/0	6.6	7/0	
SubTotals	21	13/8		4.8		6.9	11/3	67
Cyclone Type 2								
November	2	0/2	7.5/0	2.2	15.5/0	5.9	2/0	
December	3	3/0	17:0/0	5.3	17.2/0	7.0	1/1	
January	4	4/0	13.8/0	5.3	18.8/0	8.5	3/0	
February	10	9/1	17.0/0	3.7	75.0/0	9.5	6/2	
March	7	7/0	21.0/0	4.8	37.0/0	7.1	3/1	
SubTotals	26	23/3		4.3		7.6	15/4	73
Cyclone Type 3								
November	4	0/4	15.5/0	2.4	9.7/0	2.4	3/0	
December	6	5/1	21.0/0	5.5	73.9/0	6.1	3/1	
January	19	19/0	17:8/0	3.5	50.0/0	9.1	6/11	
February	17	12/5	24:0/0	4.7	62.5/0	9.0	8/6	
March	2	2/0	7.4/1.2	4:3	32.0/6.8	15.2	0/2	
April	1	0/1	5.0/0	2.4	2.4/0	1.1	0/0	
SubTotals	49	38/11		3.8		7.2	20/20	82
Cyclone Type 4								
November	1	1/0	8.2/2.5	4.7	21.6/7.9	13.7	0/1	
December	1	1/0	6.6/0	2.5	22.7/0	10.8	1/0	
January	2	2/0	5.0/0	2.6	28:1/0	8:3	0/1	
March	2	0/2	12.0/0	2.7	8.3/0	2:0	0/0	
SubTotals	6	4/2		2.6		8.7	1/2	50
Cyclone Type 5								
October	1	0/1	5.0/0	0.8	4.7/0	0.75	0/0	
December	1	1/0	6.5/0	3.8	17.1/0	9.5	1/0	
February	3	3/0	8.3/0	3:8	33.3/0	10.7	2/1	
March	4	3/1	20.0/0	6.2	50.3/0	9.5	1/2	
April	1	0/1	13.5/0	4:0	11.8/0	3.6	1/0	
SubTotals	10	7/3		3.7		6.8	5/3	80
Cyclone Type 6								
December	6	6/0	10.6/0	3.2	46.7/0	9.0	3/1	
January	3	3/0	20.0/0	5.9	66.7/0	16.7	0/2	
February	6	6/0	12.0/0	3:5	100:0/0	13:3	4/2	
March	4	2/2	23.0/0	7.2	40.8/0	10.7	2/2	
SubTotals	19	17/2		5.0		12.4	9/7	84
Cyclone Type 7								
December	11	11/0	7.5/0	2.2	100.0/0	5.4	3/1	
January	11	11/0	10.5/0	2.9	60.0/0	9.5	3/6	
February	10	9/1	22.0/0	3:2	59.5/0	6.4	5/1	
March	8	3/5	9.0/0	1.8	18.0/0	3.5	2/1	
April	1	0/1	7:5/0	2.8	3.9/0	1:5	0/0	
SubTotals	41	34/7		2.6		5.3	13/9	54
TOTALS	172	136/36		3.8		7.8	74/48	

Table 2. Summary of all Events by month and Cyclone Type (Hovey and Shulman (12), indicating the number of cases; the Event type; maximum, minimum, and average snowfall and snow to rain Ratio for each month and Cyclone Type; and the number and percentage of Events for which a rain-snow line could be defined.

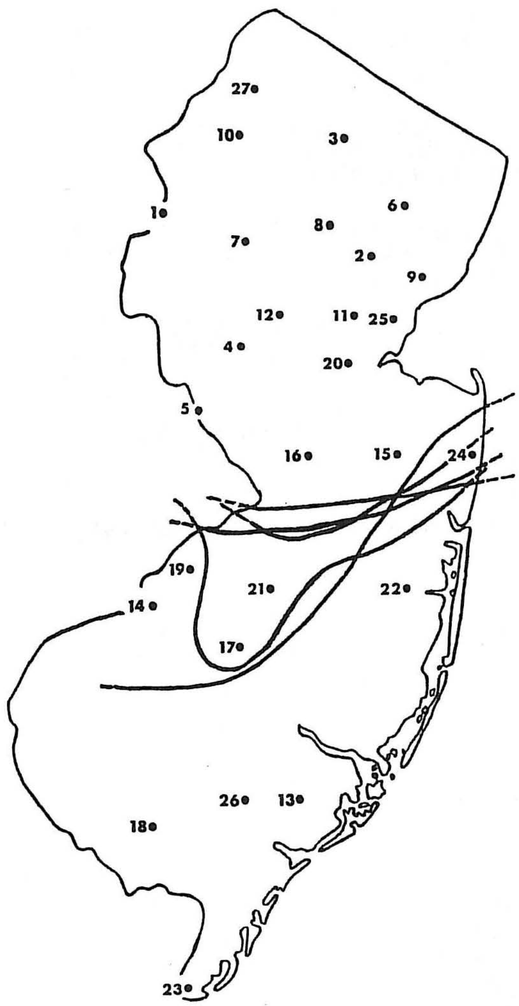

Figure 3. Median Rain-Snow Lines drawn for Cyclone Type 5.

upper level warming. At the surface, the primary and/or secondary storm system moves quickly northeastward, south of New Jersey. This limits maritime influences since surface air trajectories over New Jersey have a northerly component of cold air. Therefore, once an initial Rain-Snow Line is established, its location does not vary greatly with time since local synoptic conditons remain relatively static. The small variability in the Rain-Snow Line between separate Events is due to the similarity of the cyclone tracks.

ACKNOWLEDGMENTS

This is a paper of the Journal Series, New Jersey Agricultural Experiment Station, Cook College, Rutgers University, New Brunswick, N.J. This work was performed as part of NJAES Project No. D-13001-7-85, supported in part by the New Jersey Agricultural Experiment Station and Hatch Act funds. Thanks are extended to Keith Arnesen for his comments and suggestions concerning this paper.

NOTES AND REFERENCES

1. Paul J. Croft is a graduate student at Cook College, Rutgers University, where he received his B.S. in Meteorology.

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3. Laird, H. B. and W. W. Dickey, 1953: Forecasting Rain-or-Snow at Denver, Colorado, September-November. Bulletin, New Jersey Meteorological Society, 34, pp. 287-292.

4. Penn, S., 1957: The Prediction of Snow vs. Rain. U.S. Weather Bureau Forecasting Guide No. 2. NOAA Library, 29 pp.

5. George, J. J., 1960: Weather Forecasting for Aeronautics. Academic Press, New York, N.Y., 673 pp.

6. Spiegler, D. B. and G. E. Fisher, 1971: A Snowfall Prediction Method for the Atlantic Seaboard. Monthly Weather Review, 99, pp. 311-325.

7. Wagner, J. A., 1957: Mean Temperature from 1000 mb to 500 mb as a Predictor of Precipitation Type. Bulletin, American Meteorologial Society, 38, pp. 584-590.

8. Pandolfo, J. P., 1957: an Objective Method for Forecasting Precipitation Type During the Winter Months at New York City. Bulletin, American Meteorological Society, 38, pp. 571-574.

9. Younkin, R. J., 1967: A Snow Index. Technical Memo WBTM NMC-40. Washington, D.C., U.S. Weather Bureau.

10. Wasserman, Stanley E., 1972: Forecasting Type of Precipitation. NOAA Technical Memo NWS ER-45, National Weather Service, Eastern Region.

11. Dunlap, D., 1963: Maximum 24-Hour Snowfall in New Jersey. M.S. Thesis, Cook College, Rutgers University, New Brunswick, N.J., 29 pp.

12. Hovey, W. B. and M. D. Shulman, 1956: A Synoptic Climatolofy of Heavy Snow-storms for New Jersey. Bulletin, New Jersey Academy of Science, 10, pp. 1-6.

13. Addess, S. R. and M. D. Shulman, 1966: A Synoptic Analysis of Freezing Precipitation for New Jersey. Bulletin, New Jersey Academy of Science, 11, pp. 2-6.

14. Greenway, A. R. and M. D. Shulman, 1969: Forecasting Snow and Rain for the New York City Area Using the Method of Ordered Statistics. Water Resources Bulletin, 5, pp. 56-62.

15. Grillo, J. N. and J. Spar, 1971: Rain-Snow Mesoclimatology of the New York Metropolitan Area. Journal of Applied Meteorology, 10, pp. 56-61.

16. Shulman, M. D. and E. F. McCarthy, 1976: A Rain-Snow Climatology of New Jersey. Bulletin, New Jersey Academy of Science, 21, pp. 6-9.

17. Broccoli, A. J., 1977: A Climatology of Conditional Probabilities of Winter Precipitation Types in New Jersey. Report to the George H. Cook Scholar Honors Program, Cook College, Rutgers University, New Brunswick, N.J., 14 pp.

18. Climatological Data for New Jersey 1950-1981, NOAA Publication, National Climatic Data Center, Asheville, N.C.

19. Local Climatological Data for Newark 1950-1981. NOAA Publication, National Climatic Data Center, Asheville, N.C.

20. Daily Weather Map Weekly Series 1950-1981, NOAA Publication, National Weather Service, Washington, D.C.

21. Northern Hemisphere Surface and 500-mb Level Synoptic Charts 1951, 1954, and 1955, NOAA Publication.

22. Monthly Weather Review, 1957, 1958, and 1960: Cyclone Tracks (Monthly).

YEAR	TOTAL # OF CASES	YEAR	TOTAL # OF CASES
1950	4	1966	8
1951	3	1967	11
1952	4	1968	3
1953	2	1969	8
1954	3	1970	6
1955	5	1971	6
1956	6	1972	4
1957	5	1973	2
1958	6	1974	4
1959	3	1975	5
1960	4	1976	5
1961	7	1977	7
1962	6	1978	10
1963	6	1979	7
1964	6	1980	5
1965	5	1981	6

Table 3. Number of Events by calendar year for 32-year period 1950-1981.

Cyclone Type	# Events	% of all Cases	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
1	21	12.2	0	1	5	3	4	8	0	0
2	26	15.1	0	2	3	4	10	7	0	0
3	49	28.5	0	4	6	19	17	2	1	0
4	6	3.5	0	1	1	2	0	2	0	0
5	10	5.8	1	0	1	0	3	4	1	0
6	19	11.0	0	0	6	3	6	4	0	0
7	41	23.8	0	0	11	11	10	8	1	0
Totals	172	100.0	1	8	33	42	50	35	3	0

Table 4. Frequency of Cyclone Type by month indicating number and percentage of Events.