NOAA Technical Memorandum ERL NSSL-74

MESONETWORK ARRAY: ITS EFFECT ON THUNDERSTORM FLOW RESOLUTION

Stanley L. Barnes

National Severe Storms Laboratory
Norman, Oklahoma
October 1974

UNITED STATES DEPARTMENT OF COMMERCE
Frederick B. Dent, Secretary

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
Robert M. White, Administrator

Environmental Research Laboratories
Wilmot N. Hess, Director

CONTENTS

LIST OF FIGURES

LIST OF TABLES

MESONETWORK ARRAY: ITS EFFECT ON THUNDERSTORM FLOW RESOLUTION

Stanley L. Barnes

National Severe Storms Laboratory
Norman, Oklahoma

The fidelity of thunderstorm surface wind analyses is examined objectively in relation to the pattern and density of observation points. Analyses using all data recorded in a 44-station mesonetwork are compared with analyses based on data from 75, 50 and 25% of the stations. Stations are eliminated both randomly and selectively to achieve in one test approximate even spacing and in another test dense observation lines across storm motion.

With time-series data (observations at 5-min intervals for ± 30 min), it requires only 22 stations to delineate adequately surface flows associated with one multicell and one supercell thunderstorm. However, pattern fidelity deteriorates quickly when observations are analyzed only synoptically. In fact, all station density reductions produce unacceptable synoptic analyses.

Quasi-steady thunderstorm flows can be well depicted by 5 min interval time-series observations at stations 15 km apart on the vertices of equilateral triangles.

1. INTRODUCTION

The National Severe Storms Laboratory (NSSL) has experimented with several arrays of surface mesonetworks in its yearly acquisition of data concerning severe thunderstorms. Beginning in 1961, a Beta network (Fujita, 1963) of automatically recording stations 20-30 km apart was established in southwestern Oklahoma to study squall line thunderstorms (Staff, 1961; Lee, 1962; Fujita, 1962). The network was operated essentially unchanged every spring until, in 1968, it was partly relocated to form a cross of closely spaced (10 km) stations near the Beta array center (Barnes et al., 1971). The purpose of the cross was to detect significant thunderstorm features, if any, missed by the Beta network. However, the cross data have not been analyzed; the dense 1969 and 1970 networks produced more complete data sets (Barnes et al., 1971) on which subsequent studies have been based.

Since 1969, the network station density has been designed to sense structures associated with individual large thunderstorms, and particularly gust fronts. Although no rigorous study had been accomplished prior to 1969 to determine the scale of flow features associated with thunderstorms, these networks resolved successfully the principal features of thunderstorm-related surface wind fields (Operations Staff, 1971; Lemon, 1974; Barnes, 1974). The development of an objective technique for analyzing these data (Barnes, 1973) provided a means to evaluate quantitatively network sensing capabilities. Our meteorological studies showed redundancy in the network sampled storm features. The test suggested itself: exclude a progressively larger number of stations from the analyses and determine for which station arrays the representation of known storm features significantly degenerates.

Wind field was chosen as the test parameter. Winds observed at 1-min intervals were averaged over 5-min periods. Rainfall amounts also were analyzed in the initial tests, but significant pattern degeneration accompanied any reduction in station density.[1]

Our test data were obtained from the 29-30 April 1970 Oklahoma storms, a principal subject of NSSL's meteorological research during the past 4 years (Barnes, 1974). The 1970 mesonetwork comprised 44 stations arrayed approximately 11 km apart (Fig. 1). Objectively interpolated values at points on a 20 by 24 grid (3.175 km mesh) were analyzed with a technique incorporating weighted time-series observations. Details of the analysis technique are published in Barnes (1973).

2. TEST PROCEDURE

Five test networks were produced by excluding selected stations. Three of these networks were based on random draws and two were more orderly arrays. Dot patterns (Fig. 2-7) illustrate station arrays for the standard and test networks.

For the three random draws, station identifiers were written on paper slips, which were then folded and mixed in a container. The 33 and 22 station networks (Fig. 3 and 4) were determined by eliminating stations marked on the first 11 and first 22 slips drawn. The 75%-reduced 11 station network (Fig. 5) was drawn from the 44 stations after returning all slips to the container, mixing, and drawing 11 retained stations.

Another network (Fig. 6) was designed by selecting 22 evenly spaced stations (50%) from the standard network. The fifth network designed to measure storms with greater resolution across their direction of travel included 23 stations selected along lines oriented approximately southeast-northwest (Fig. 7).

---

[1]Rainfall distributions from convective storms are known to exhibit larger spatial variability than the 1970 network could detect. Radar reflectivity data more adequately represents the rainfall distribution. Brandes (1974) demonstrated a technique to incorporate these data into an objective rainfall analysis.

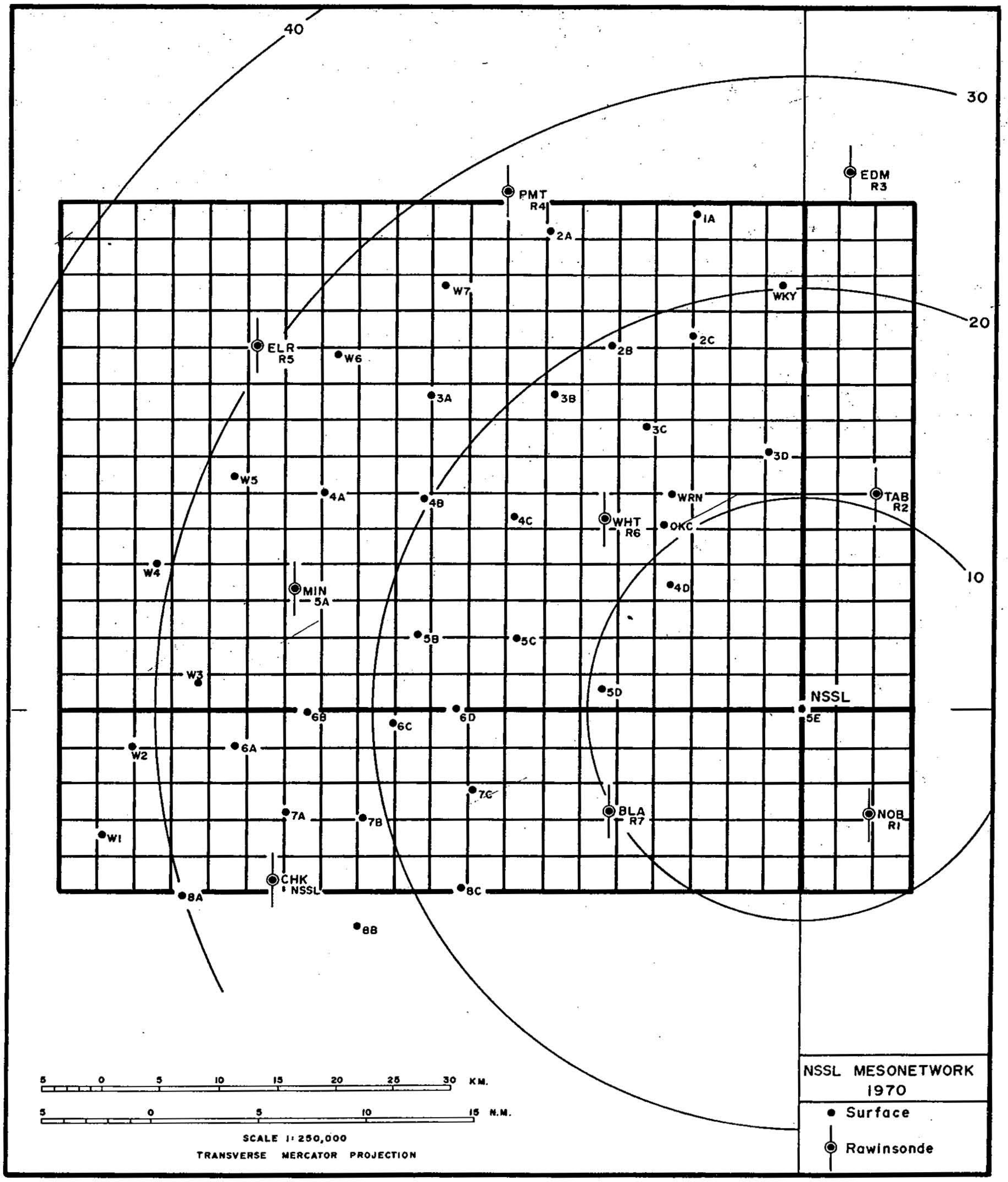


Figure 1. NSSL's 1970 mesonetwork composed of 44 stations at 11 km spacing (average) and 3.175 km mesh used for objective interpolation of field parameters.

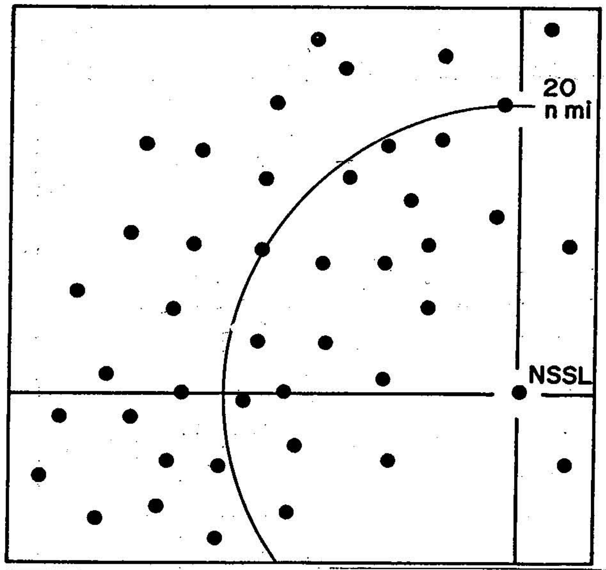


Figure 2. NSSL's 44-station mesonetwork standard configuration for all test comparisons.

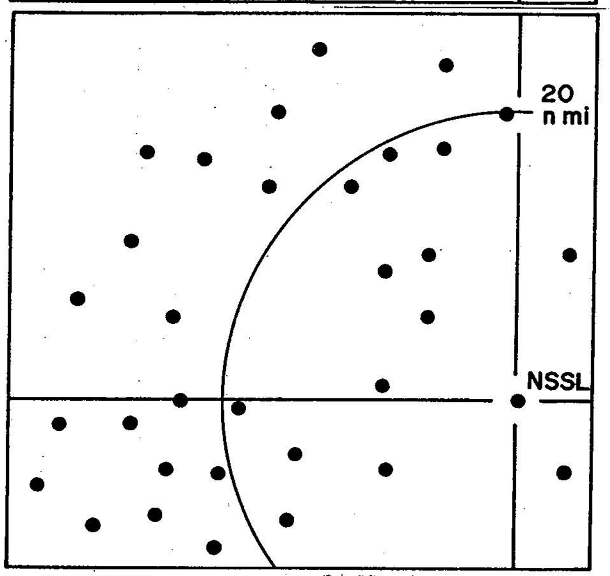


Figure 3. Network configured by eliminating randomly 25% of standard network: Tests 1 and 6; 33 stations.

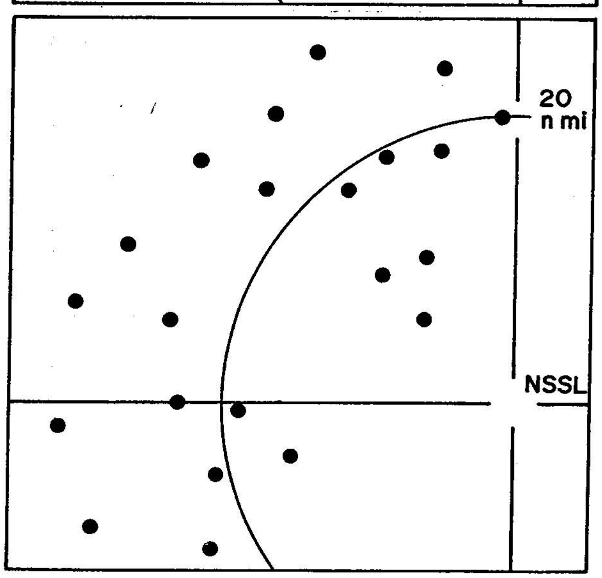


Figure 4. Network configured by eliminating randomly 50% of standard network: Tests 2 and 7; 22 stations.

Figure 5. Network configured by eliminating randomly 75% of standard network: Tests 3 and X; 11 stations.

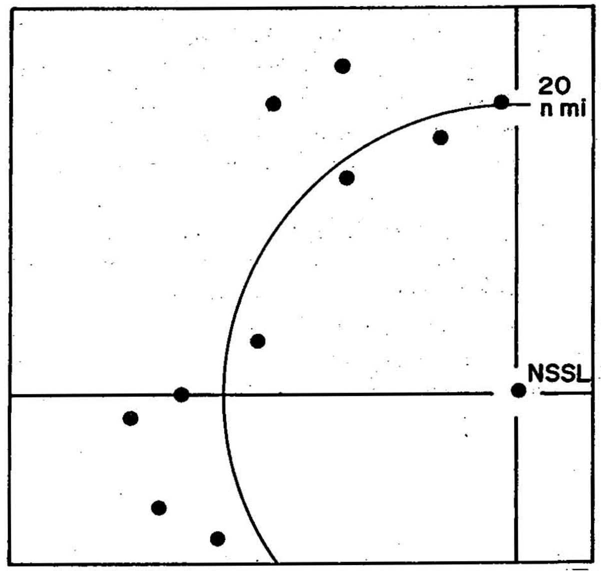


Figure 6. Network configured by selecting 22 evenly spaced stations from standard network: Tests 4 and 8.

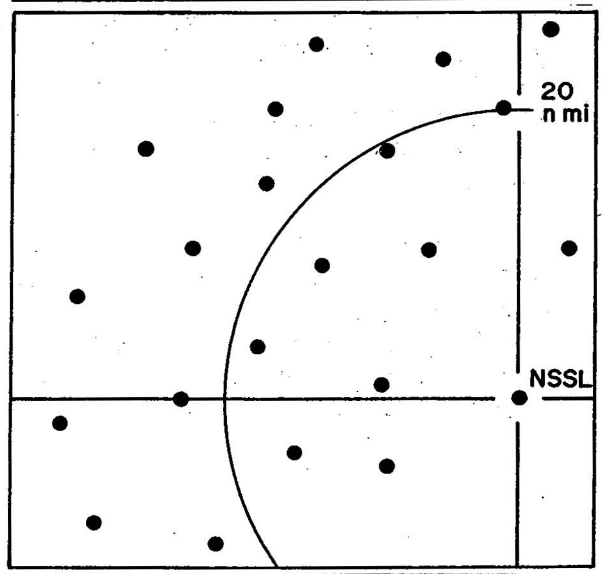
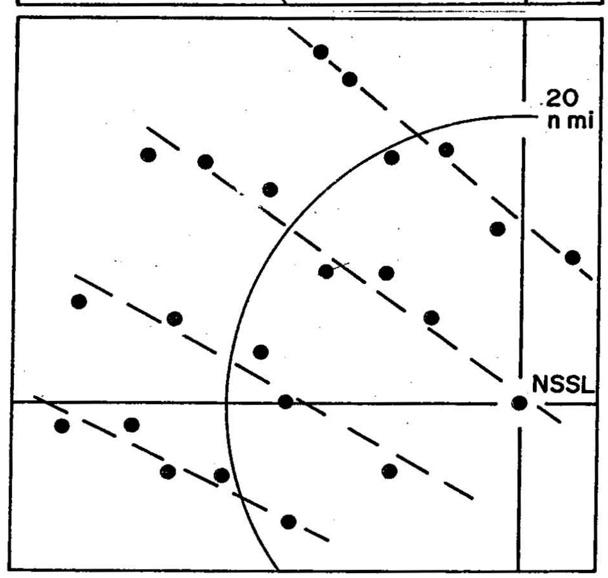


Figure 7. Network configured by selecting 23 station aligned across direction of storm travel: Tests 5 and 9.



Ten tests were performed on each of two independent data sets, 2240 CST 29 April 1970 (Fig. 8 and 9) and 0030 CST 30 April 1970 (Fig. 10 and 11). These sets were chosen because they represent wind patterns of different complexity beneath large thunderstorms. Meteorological conditions surrounding these two storms are described in Barnes (1974).

Observations from each test network were analyzed both synoptically and by a method that uses time-series observations. Each synoptic analysis was based only on observations for a specified time. Time-series observations were positioned relative to moving storms, and each influenced the analysis in proportion to its proximity with maptime (Barnes, 1973). Weight parameters are constant in all analyses.

3. TEST RESULTS

In Fig. 8-11, the time-series analyses (tests 1-5) are displayed on the left; the synoptic analyses (tests 6, 7, X, 8 and 9) are on the right. The standard results are based on the time-series data from all 44 stations (top frame; Fig. 8 and 10). Time-series test analyses are essentially similar to the standard result in tests that used at least 22 stations (tests 1 and 2, Fig. 8 and 10; tests 4 and 5, Fig. 9 and 11; see table 1 for summary of coded tests).

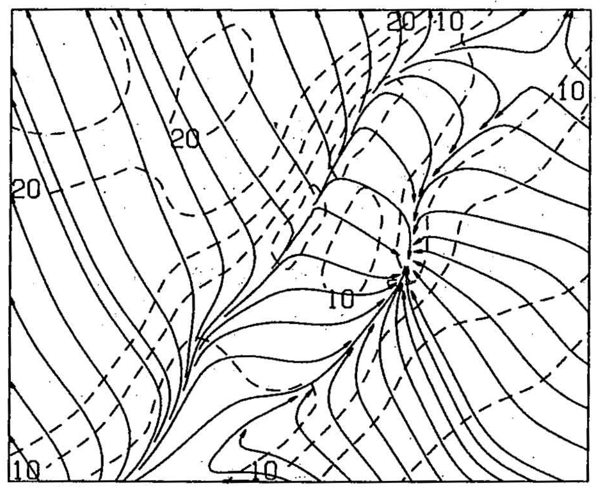
However, when only one observation at each station is analyzed, patterns quickly deterioriate and often contain superfluous details (aliasing?) not in the standard result (tests 6 and 7, Fig. 8 and 10; tests 8 and 9, Fig. 9 and 11). Test 3 (Fig. 9 and 11) with only 11 stations shows details similar to the standard, but they are conspicuously distorted. In the 11 station synoptic test, (test X; Fig. 9 and 11), pattern distortion is extreme and in the 0030 result, details are nonexistant—the circulation center is lost. The value of time-series data becomes clear.

Test analyses were compared quantitatively to standard analyses by forming the gridpoint by gridpoint differences and computing means and standard deviations for each map (480 points per map). Compared parameters included wind direction, wind speed, and the gradient-sensitive quantities divergence and vorticity. These numerical results (Fig. 12 and 13) confirm our subjective evaluations of pattern fidelity.

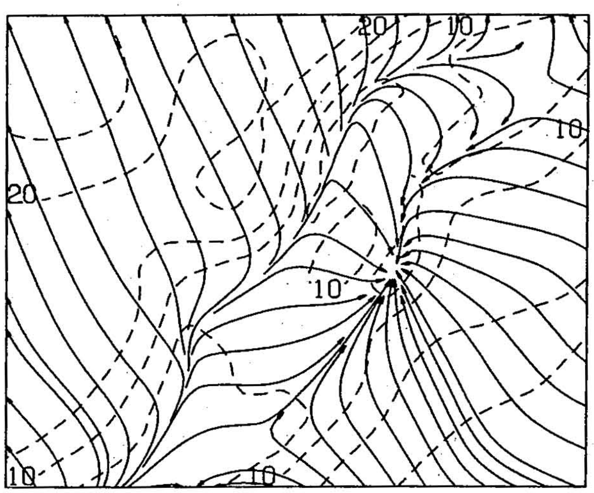
Test 1 (33 stations) comes closest to reproducing the standard analysis. Deviations in direction are 14° for the 2240 result and only 6° at 0030 (Fig. 12 and table 1). Considering the wind instrument's basic 22.5° measurement resolution, these deviations are definitely acceptable. Speed differences are on the order of 1 kt—also comparable to the accuracy of the observations (Operations Staff, 1971). Test 1 divergence and vorticity deviate from the standard result by about 10^{-4} sec^{-1}, the general level of background noise for these parameters on this observation scale (Barnes, 1974, pages 127-133). Significant storm induced centers of divergence and vorticity range in magnitude from 5×10^{-4} sec^{-1} to 5×10^{-3} sec^{-1}. The synoptic test for this network (test 6) has significantly larger deviation from

Table 1. WIND ANALYSES MEANS AND STANDARD DEVIATIONS. A gridpoint by gridpoint comparison to standard analyses for 2240 CST 29 April 1970 and 0030 CST 30 April 1970. Mean deviation is upper number in each row; standard deviation is lower number.

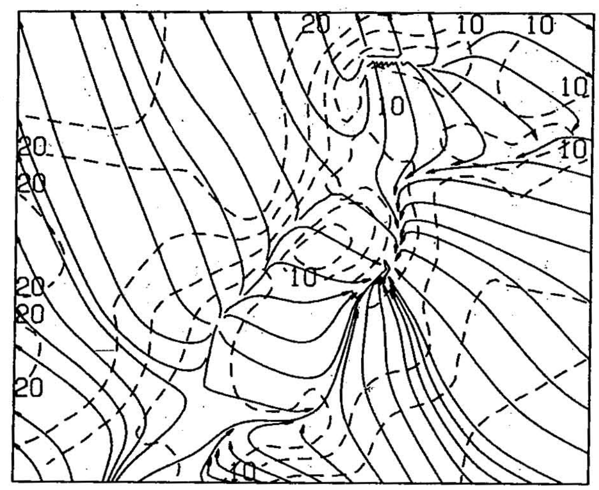
TEST	NO. STATIONS and SELECTION	DIRECTION (degrees) 2240	DIRECTION (degrees) 0030	SPEED (knots) 2240	SPEED (knots) 0030	DIVERGENCE (10^{-5} sec^{-1}) 2240	DIVERGENCE (10^{-5} sec^{-1}) 0030	VORTICITY (10^{-5} sec^{-1}) 2240	VORTICITY (10^{-5} sec^{-1}) 0030
	TIME-SERIES								
1	33	-0.22	0.56	0.20	0.33	-0.51	0.18	-0.14	0.83
	Random	14.50	5.98	1.16	0.95	16.28	10.86	11.46	9.67
2	22	1.50	-0.60	0.01	1.43	6.64	4.34	-3.00	7.43
	Random	25.52	16.26	4.43	3.30	30.01	32.75	19.50	26.27
3	11	-5.08	14.52	0.17	0.61	4.07	-0.13	-8.16	-2.44
	Random	48.89	35.44	4.17	5.42	75.90	55.47	34.46	38.60
4	22	3.48	0.13	-0.35	-0.19	2.35	1.26	-1.89	-1.37
	Uniform	30.69	8.21	2.41	1.78	28.29	15.94	21.89	17.59
5	23	-0.46	-1.66	-0.38	-0.32	1.90	0.03	-4.29	-1.04
	In lines	25.41	7.85	2.13	1.63	22.43	12.43	16.85	13.89
	SYNOPTIC								
6	33	-4.23	-1.08	-0.20	0.88	-1.44	3.09	3.46	2.07
	Random	39.46	26.26	3.32	3.60	38.75	38.46	34.51	35.45
7	22	-13.09	-2.99	0.90	2.67	-4.98	0.71	-4.17	0.50
	Random	59.39	35.11	4.53	5.19	44.17	44.87	51.11	40.39
8	22	4.09	1.36	-1.10	1.02	0.99	3.28	-0.47	0.80
	Uniform	55.82	30.30	4.12	4.47	51.80	41.56	42.72	40.45
9	23	-1.42	-2.31	-0.88	-0.00	2.56	2.80	1.12	-0.29
	In lines	36.67	29.27	3.31	3.82	38.56	36.87	31.51	33.07



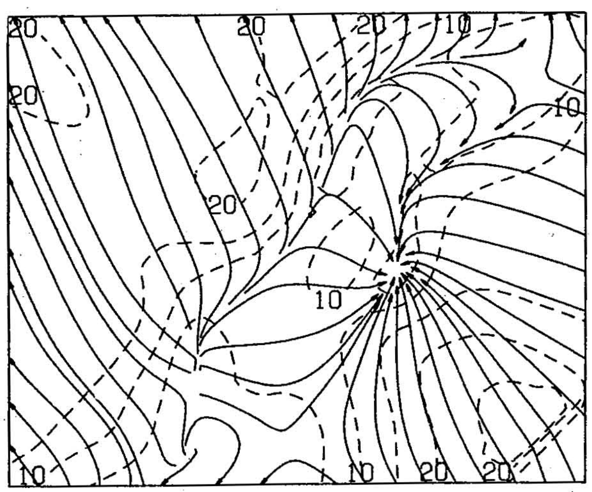
NETWORK DENSITY TEST . STANDARD RESULT 44 STATIONS



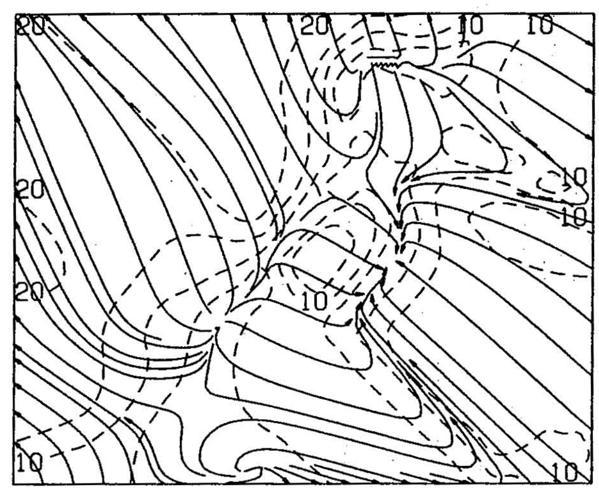
NETWORK DENSITY TEST 1 33 STATIONS RANDOM PICK



NETWORK DENSITY TEST 6 33 STATIONS RANDOM PICK



NETWORK DENSITY TEST 2 22 STATIONS RANDOM PICK



NETWORK DENSITY TEST 7 22 STATIONS RANDOM PICK

Figure 8. Wind field standard and test results 1, 2, 6 and 7 for 2240 CST 29 April 1970. Synoptic tests (right) use only 2240 observations; time-space tests (left) use 5 min observations from 2210 to 2310. Isotachs are labeled in knots; streamlines and isotachs drawn by a computer-driven plotter.

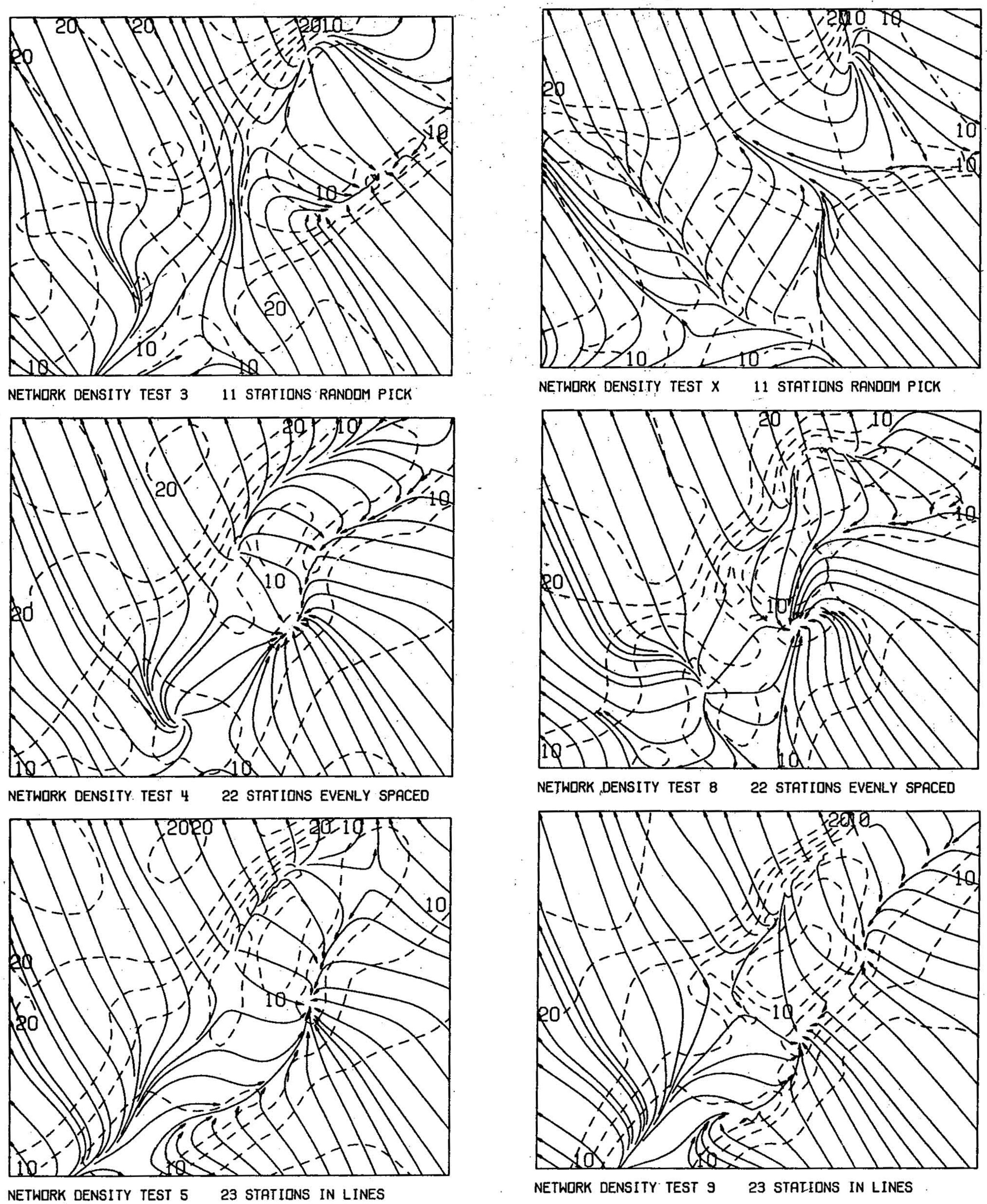


Figure 9. Wind field test results 3, 4, 5, X, 8 and 9 for 2240 CST 29 April 1970. Time-series results on left; synoptic analyses on right.

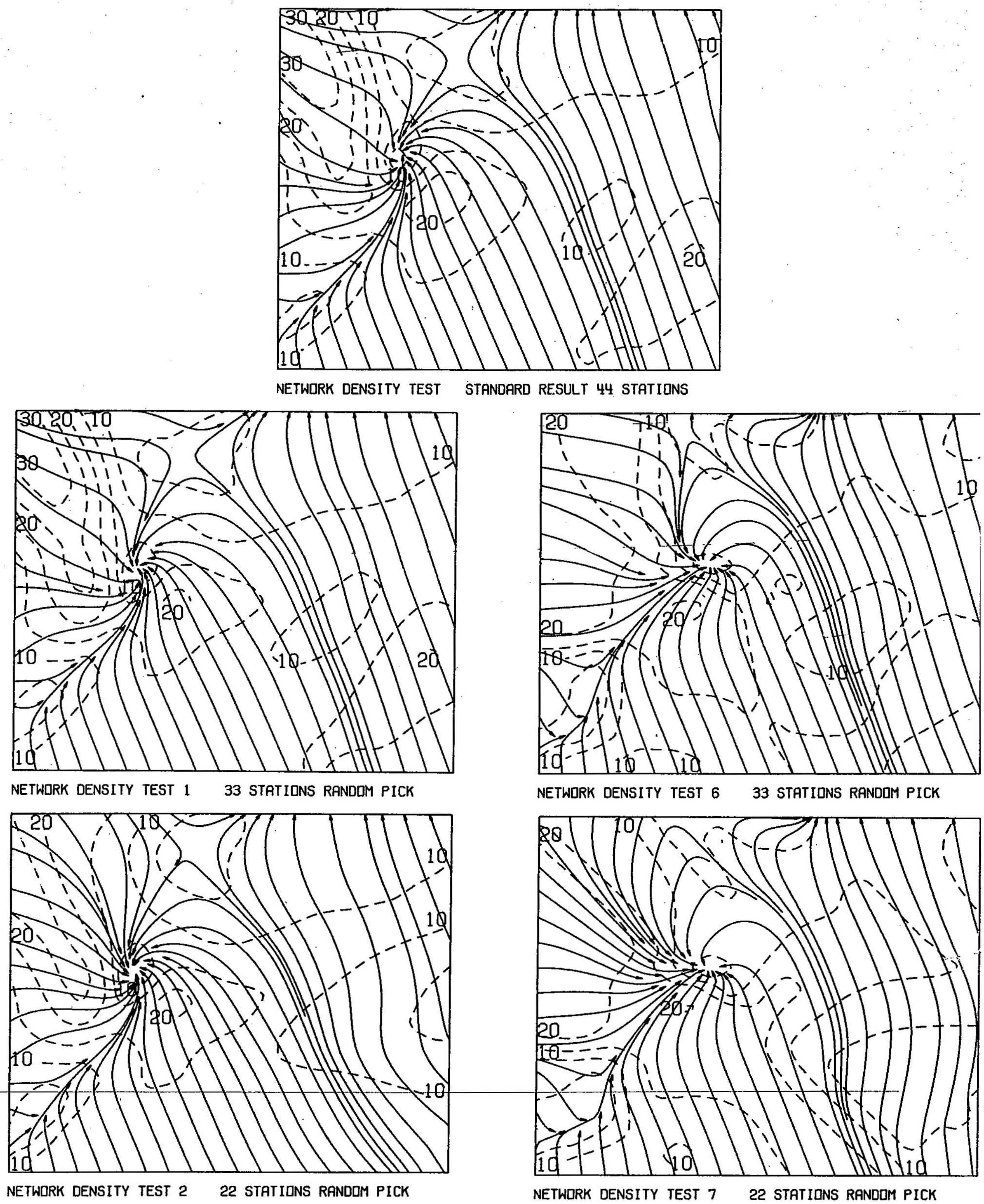


Figure 10. Wind Field standard and test results 1, 2, 6 and 7 for 0030 CST 30 April 1970. Time-series results on left; synoptic analyses on right.

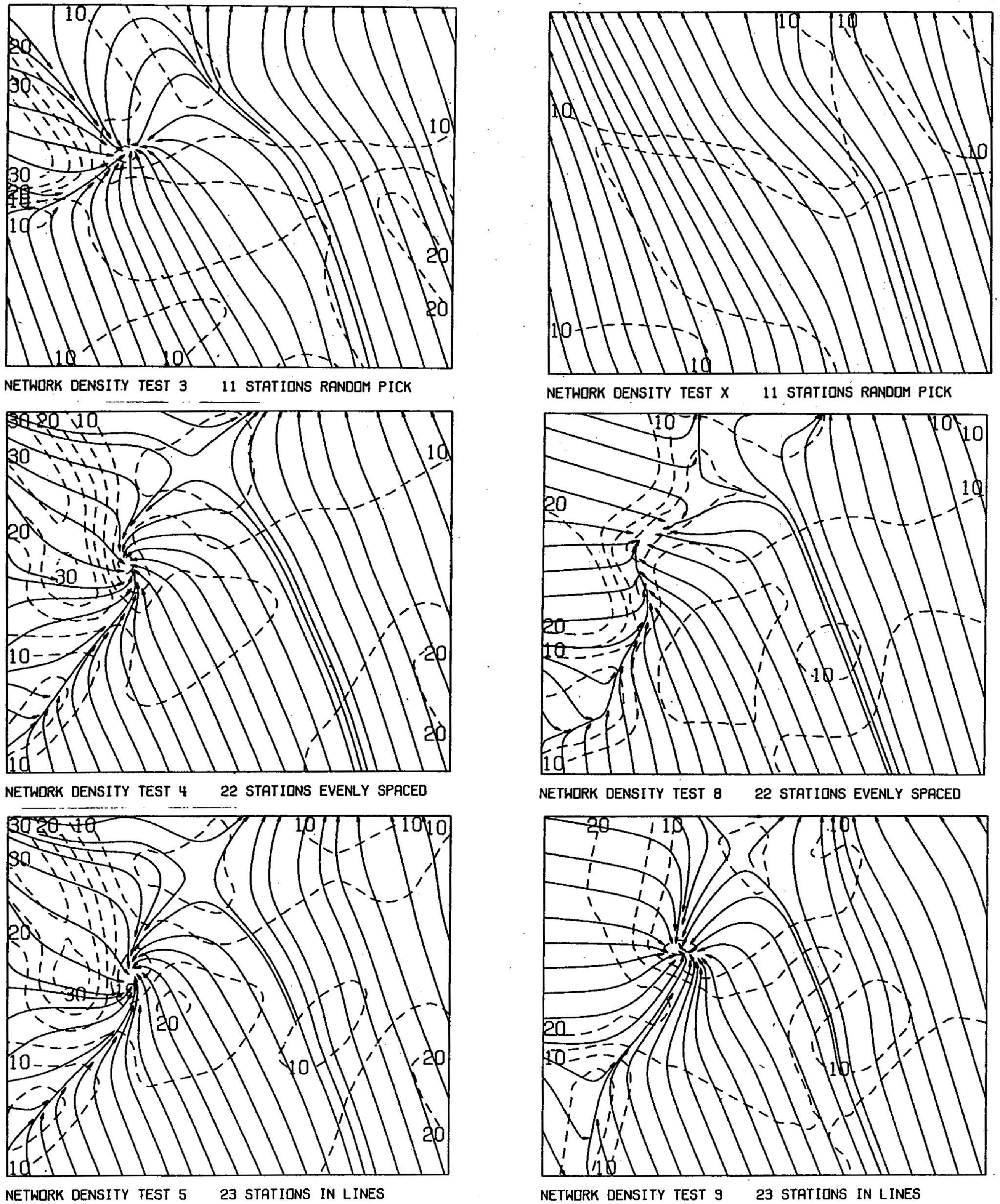


Figure 11. Wind field test results 3, 4, 5, X, 8 and 9 for 0030 CST 30 April 1970. Time-series results on left; synoptic analyses on right.

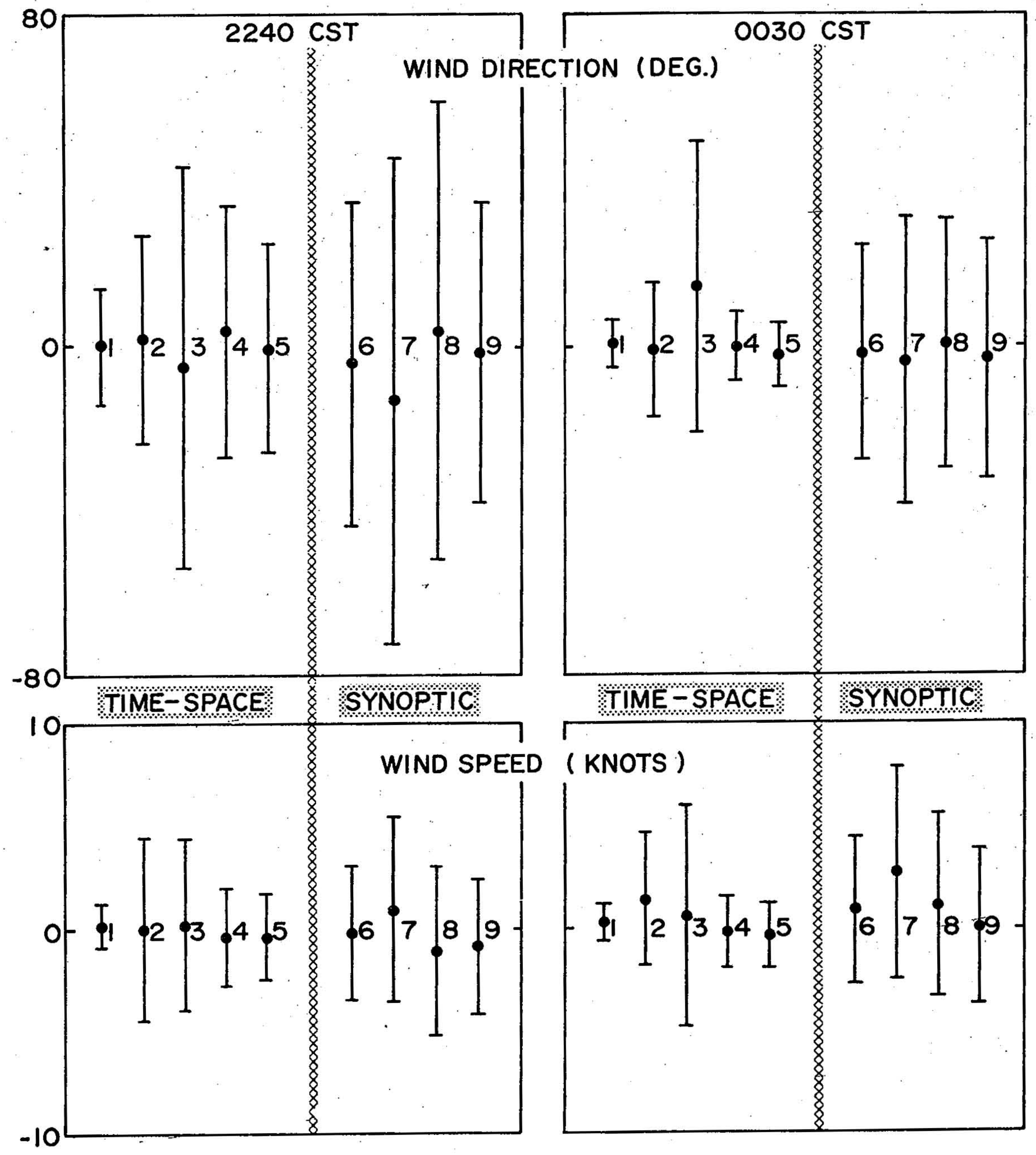


Figure 12. Means (dots) and standard deviations (bars) of test wind analyses compared to standard analyses for 2240 CST 29 April 1970 (left) and 0030 CST 30 April 1970 (right). Table 1 identifies numbered tests.

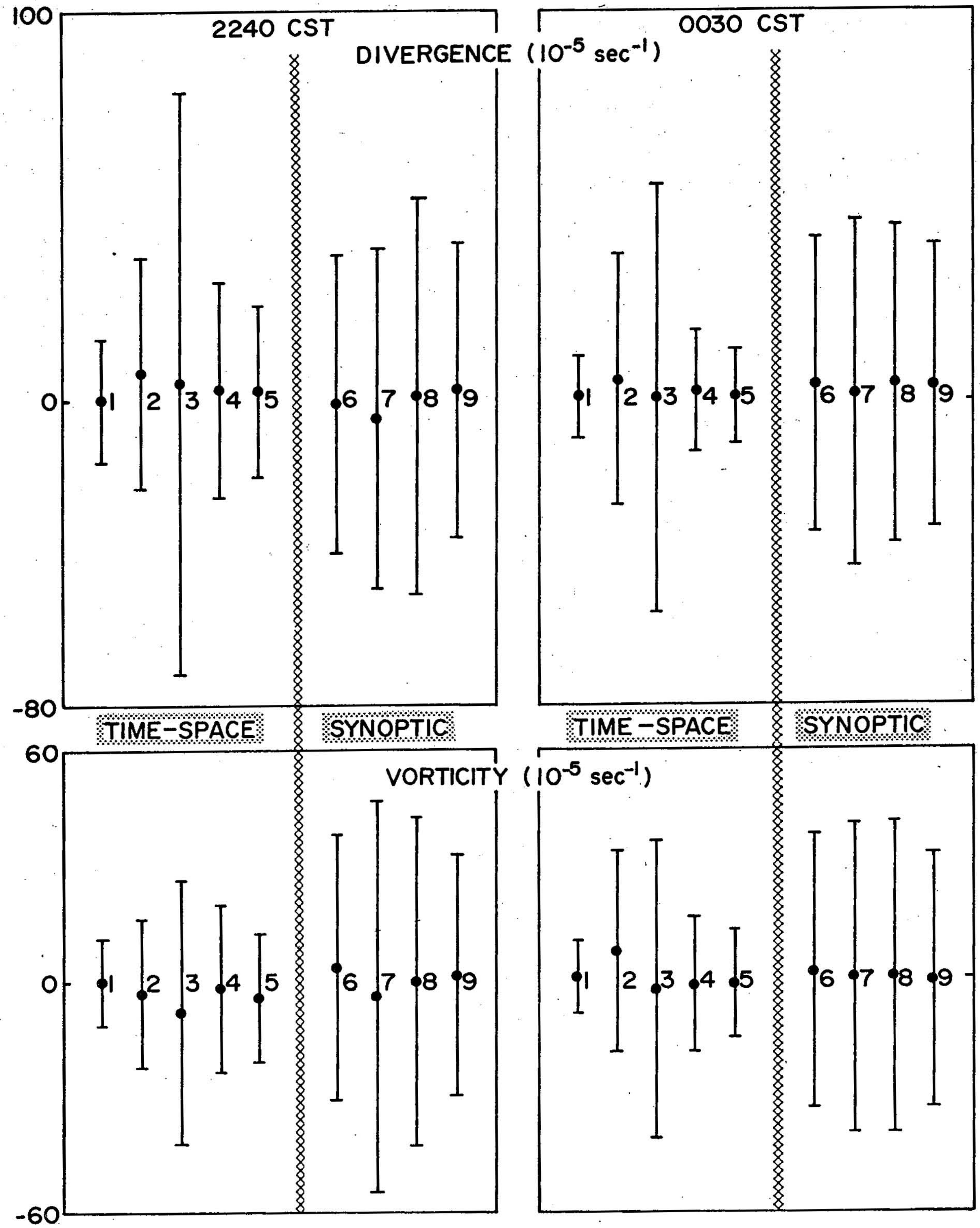


Figure 13. Means (dots) and standard deviations (bars) of test divergence and vorticity compared to standard analyses for 2240 CST 29 April 1970 (left) and 0030 CST 30 April 1970 (right). Table 1 identifies numbered tests.

the standard. Directions deviate 39° and 26° while speeds are 3-4 kt different (table 1).

The "half-as-dense" networks with time-series observations (tests 2, 4 and 5) produce relatively good results at 0030, but suffer apparent degradation at 2240. The 2240 standard pattern appears to have more small-scale features and larger areas of light (less than 5 kt) winds than does the 0030 standard map. This interpretation is consistent with what is known about the structure of these storms: the 2240 storm echo is multicellular while the 0030 storm is a supercell (see pages 111-140, Barnes, 1974). Had vector difference been the comparison parameter, the 2240 tests might have produced more favorable statistics. The best results for the "half dense" networks are obtained with uniform and lined station spacings (tests 4 and 5) at 0030 and are nearly equivalent to the 33-station network (test 1). In nearly every instance, the 22 station, randomly selected network produced poorer results than either test 4 (uniform) or 5 (in lines). This may be partly a consequence of the random selection process; there is a gaping hole in the middle of the network where many of the fine scale features lie (Fig. 4).

Again, the synoptically analyzed results (tests 7, 8 and 9) are not acceptable reproductions. Deviations in divergence and vorticity approach the magnitudes of meteorologically significant storm-related values (5×10^{-4} sec^{-1}). Except for a seemingly fortuitous representation of the 2240 speed field (test 3, Fig. 12 and table 1), the 11-station network does not produce results of adequate fidelity.

The conclusion is that a 33-station network (incidentally containing a data void region) produces flow patterns essentially equivalent to the 44-station network when time-series observations are used for the analysis, even for rather fine scale features associated with the transient stages of multicelled thunderstorms. For more significant (larger scale, quasi-steady) features of surface flow near large thunderstorms (updraft sinks, wind shift line, col) a 22-station network adequately represents the flow field. Considering pattern only, stations densely arrayed in lines across the direction of storm motion are preferrable (compare tests 4 and 5 in Fig. 9 and 11 with the standard analyses). However, because storms in Oklahoma move from a wide range of directions—typically, anywhere from south to north-northwest—it isn't practical to establish a lined network array that can accomodate this range of movements. For example, many important features could pass undetected should a storm move from the northwest between the rows of a network such as that in Fig. 7. For this reason, we recommend the evenly spaced network (Fig. 6) which depends less upon storm direction for sensing details in the flow field.

4. CONCLUSIONS

By excluding data from an objective analysis of wind fields at the earth's surface, we determined that NSSL's 1970 44-station network oversampled in regard to quasi-steady features associated with updraft-downdraft couplets in large thunderstorms provided that time-series observations were used (± 30 min at 5 min intervals). Fidelity of analyses based only on synoptic (singular) observations from each station degenerated rapidly with decreasing station density.

On several occasions in 1970, the closely spaced network (about 11 km) did record singularly interesting events associated with passing tornadoes, but in every case these events were sensed at only one station. Thus, that network density was much too sparse for adequate sensing of tornado scale distributions, while it was more dense than needed to define flow associated with the larger tornado cyclones, gust fronts, and updraft-downdraft couplets. Network arrays containing as few as 22 stations (over the same area as the 44 stations) are judged adequate to resolve these storm features. In 1970, the network area encompassed 4400 km^2. If equally spaced, each of the 22 stations would sample 200 km^2. In consideration of this, the most recent NSSL surface mesonetwork (spring 1974) was designed on a 15 km grid of equilateral triangles; each station samples 195 km^2. Meteorological analyses of data acquired with this network are pending.

Appropriate network spacing will vary with the phenomenon to be observed. In 1970, our knowledge of the predominant scale of thunderstorm-related flow was less complete than it is now, and oversensing was then a decided advantage.

Finally, we emphasize the dangers inherent in under-sampling. Typical size of severe thunderstorms was known from radar studies long before the 1970 network was designed. Had the design called for only 11 stations in the same network area (perhaps to cover a larger total area and obtain more samples of thunderstorm phenomena), the resolved flow fields could have been misinterpreted.

5. ACKNOWLEDGMENTS

Thanks are extended to my colleagues at NSSL for technical and editorial comments and assistance.

6. REFERENCES

Barnes, S. L., 1973: Mesoscale objective map analysis using weighted time-series observations. NOAA Technical Memorandum ERL NSSL-62, 60 pp. [NTIS No. COM-73-10781, National Technical Information Service, Springfield, Va.]

Barnes, S. L. Editor, 1974: Papers on Oklahoma thunderstorms, April 29-30, 1970. NOAA Technical Memorandum ERL NSSL-69, 233 pp.

Barnes, S. L., J. H. Henderson, and R. J. Ketchum, 1971: Rawinsonde observation and processing techniques at the National Severe Storms Laboratory. NOAA Technical Memorandum ERL NSSL-53, 246 pp. [NTIS No. COM-71-00707, National Technical Information Services, Springfield, Va.]

Brandes, E. A., 1974: Radar rainfall pattern optimizing technique. NOAA Technical Memorandum ERL NSSL-67, 16 pp.

Fujita, T., 1962: Index to the NSSP surface network. Report No. 6, National Severe Storms Project, 32 pp. [NTIS No. PB-168212, National Technical Information Service, Springfield, Va.]

Fujita, T., 1963: Analytical mesometeorology: a review, Meteor. Monographs, 5, No. 27, 77-125.

Lee, J. T., 1962: A summary of field operations and data collection by the National Severe Storms Project in Spring 1961, Report No. 5, National Severe Storms Project, 47 pp. [NTIS No. PB-165095, National Technical Information Service, Springfield, Va.]

Lemon, L. R., 1974: Interaction of two convective scales within a severe thunderstorm: a case study, and Thunderstorm wake vortex structure and aerodynamic origin. NOAA Technical Memorandum ERL NSSL-71, 42 pp.

Operations Staff, 1971: The NSSL surface network and observations of hazardous wind gusts. NOAA Technical Memorandum ERL NSSL-55, 20 pp. [NTIS No. COM-71-00910, National Technical Information Service, Springfield, Va.]

Staff, 1961: National Severe Storms Project objectives and basic design. Report No. 1, National Severe Storms Project, 16 pp. [NTIS No. PB-168207 National Technical Information Service, Springfield, Va.]

NATIONAL SEVERE STORMS LABORATORY

The NSSL Technical Memoranda, beginning with No. 28, continue the sequence established by the U. S. Weather Bureau National Severe Storms Project, Kansas City, Missouri. Numbers 1-22 were designated NSSP Reports. Numbers 23-27 were NSSL Reports, and 24-27 appeared as subseries of Weather Bureau Technical Notes. These reports are available from the National Technical Information Service, Operations Division, Springfield, Virginia 22151, for $3.00, and a microfiche version for $0.95. NTIS numbers are given below in parentheses.

No. 1 National Severe Storms Project Objectives and Basic Design. Staff, NSSP. March 1961. (PB-168207)

No. 2 The Development of Aircraft Investigations of Squall Lines from 1956-1960. B. B. Goddard. (PB-168208)

No. 3 Instability Lines and Their Environments as Shown by Aircraft Soundings and Quasi-Horizontal Traverses. D. T. Williams. February 1962. (PB-168209)

No. 4 On the Mechanics of the Tornado. J. R. Fulks. February 1962. (PB-168210)

No. 5 A Summary of Field Operations and Data Collection by the National Severe Storms Project in Spring 1961. J. T. Lee. March 1962. (PB-165095)

No. 6 Index to the NSSP Surface Network. T. Fujita. April 1962. (PB-168212)

No. 7 The Vertical Structure of Three Dry Lines as Revealed by Aircraft Traverses. E. L. McGuire. April 1962. (PB-168213)

No. 8 Radar Observations of a Tornado Thunderstorm in Vertical Section. Ralph J. Donaldson, Jr. April 1962. (PB-174859)

No. 9 Dynamics of Severe Convective Storms. Chester W. Newton. July 1962. (PB-163319)

No. 10 Some Measured Characteristics of Severe Storms Turbulence. Roy Steiner and Richard H. Rhyne. July 1962. (N62-16401)

No. 11 A Study of the Kinematic Properties of Certain Small-Scale Systems. D. T. Williams. October 1962. (PB-168216)

No. 12 Analysis of the Severe Weather Factor in Automatic Control of Air Route Traffic. W. Boynton Beckwith. December 1962. (PB-168217)

No. 13 500-Kc./Sec. Sferics Studies in Severe Storms. Douglas A. Kohl and John E. Miller. April 1963. (PB-168218)

No. 14 Field Operations of the National Severe Storms Project in Spring 1962. L. D. Sanders. May 1963. (PB-168219)

No. 15 Penetrations of Thunderstorms by an Aircraft Flying at Supersonic Speeds. G. P Roys. Radar Photographs and Gust Loads in Three Storms of 1961 Rough Rider. Paul W. J. Schumacher. May 1963. (PB-168220)

No. 16 Analysis of Selected Aircraft Data from NSSP Operations, 1962. T. Fujita. May 1963. (PB-168221)

No. 17 Analysis of Methods for Small-Scale Surface Network Data. D. T. Williams. August 1963. (PB-168222)

No. 18 The Thunderstorm Wake of May 4, 1961. D. T. Williams. August 1963. (PB-168223)

No. 19 Measurements by Aircraft of Condensed Water in Great Plains Thunderstorms. George P. Roys and Edwin Kessler. July 1966. (PB-173048)

No. 20 Field Operations of the National Severe Storms Project in Spring 1963. J. T. Lee, L. D. Sanders and D. T. Williams. January 1964. (PB-168224)

No. 21 On the Motion and Predictability of Convective Systems as Related to the Upper Winds in a Case of Small Turning of Wind with Height. James C. Fankhauser. January 1964. (PB168225)

No. 22 Movement and Development Patterns of Convective Storms and Forecasting the Probability of Storm Passage at a Given Location. Chester W. Newton and James C. Fankhauser. January 1964. (PB-168226)

No. 23 Purposes and Programs of the National Severe Storms Laboratory, Norman, Oklahoma. Edwin Kessler. December 1964. (PB-166675)

No. 24 Papers on Weather Radar, Atmospheric Turbulence, Sferics, and Data Processing. August 1965. (AD-621586)

No. 25 A Comparison of Kinematically Computed Precipitation with Observed Convective Rainfall. James C. Fankhauser. September 1965. (PB-168445).

No. 26 Probing Air Motion by Doppler Analysis of Radar Clear Air Returns. Roger M. Lhermitte. May 1966. (PB-170636)

No. 27 Statistical Properties of Radar Echo Patterns and the Radar Echo Process. Larry Armijo. May 1966. The Role of the Kutta-Joukowski Force in Cloud Systems with Circulation. J. L. Goldman. May 1966. (PB-170756)

No. 28 Movement and Predictablity of Radar Echoes. James Warren Wilson. November 1966. (PB-173972)

No. 29 Notes on Thunderstorm Motions, Heights, and Circulations. T. W. Harrold, W. T. Roach, and Kenneth E. Wilk. November 1966. (AD-644899)

No. 30 Turbulence in Clear Air Near Thunderstorms. Anne Burns, Terence W. Harrold, Jack Burnham, and Clifford S. Spavins. December 1966. (PB-173992)

No. 31 Study of a Left-Moving Thunderstorm of 23 April 1964. George R. Hammond. April 1967. (PB-174681)

No. 32 Thunderstorm Circulations and Turbulence from Aircraft and Radar Data. James C. Fankhauser and J. T. Lee. April 1967. (PB-174860)

No. 33 On the Continuity of Water Substance. Edwin Kessler. April 1967. (PB-175840)

No. 34 Note on the Probing Balloon Motion by Doppler Radar. Roger M. Lhermitte. July 1967. (PB-175930)

No. 35 A Theory for the Determination of Wind and Precipitation Velocities with Doppler Radars. Larry Armijo. August 1967. (PB-176376)

No. 36 A Preliminary Evaluation of the F-100 Rough Rider Turbulence Measurement System. U. O. Lappe. October 1967. (PB-177037)

No. 37 Preliminary Quantitative Analysis of Airborne Weather Radar. Lester P. Merritt. December 1967. (PB-177188)

No. 38 On the Source of Thunderstorm Rotation. Stanley L. Barnes. March 1968. (PB-178990)

No. 39 Thunderstorm - Environment Interactions Revealed by Chaff Trajectories in the Mid-Troposphere. James C. Fankhauser. June 1968. (PB-179659)

No. 40 Objective Detection and Correction of Errors in Radiosonde Data. Rex L. Inman. June 1968. (PB-180284)

No. 41 Structure and Movement of the Severe Thunderstorms of 3 April 1964 as Revealed from Radar and Surface Mesonetwork Data Analysis. Jess Charba and Yoshikazu Sasaki. October 1968. (PB-183310)

No. 42 A Rainfall Rate Sensor. Brian E. Morgan. November 1968. (PB-183979)

No. 43 Detection and Presentation of Severe Thunderstorms by Airborne and Ground-Based Radars: A Comparative Study. Kenneth E. Wilk, John K. Carter, and J. T. Dooley. February 1969. (PB-183572)

No. 44 A Study of a Severe Local Storm of 16 April 1967. George Thomas Haglund. May 1969. (PB-184-970)

No. 45 On the Relationship Between Horizontal Moisture Convergence and Convective Cloud Formation. Horace R. Hudson. March 1970. (PB-191720)

No. 46 Severe Thunderstorm Radar Echo Motion and Related Weather Events Hazardous to Aviation Operations. Peter A. Barclay and Kenneth E. Wilk. June 1970. (PB-192498)

No. 47 Evaluation of Roughness Lengths at the NSSL-WKY Meteorological Tower. Leslie D. Sanders and Allen H. Weber. August 1970. (PB-194587)

No. 48 Behavior of Winds in the Lowest 1500 ft in Central Oklahoma: June 1966 - May 1967. Kenneth C. Crawford and Horace R. Hudson. August 1970.

No. 49 Tornado Incidence Maps. Arnold Court. August 1970. (COM-71-00019)

No. 50 The Meteorologically Instrumented WKY-TV Tower Facility. John K. Carter. September 1970. (COM-71-00108)

No. 51 Papers on Operational Objective Analysis Schemes at the National Severe Storms Forecast Center. Rex L. Inman. November 1970. (COM-71-00136)

No. 52 The Exploration of Certain Features of Tornado Dynamics Using a Laboratory Model. Neil B. Ward. November 1970. (COM-71-00139)

No. 53 Rawinsonde Observation and Processing Techniques at the National Severe Storms Laboratory. Stanley L. Barnes, James H. Henderson and Robert J. Ketchum. April 1971. (COM-71-00707)

No. 54 Model of Precipitation and Vertical Air Currents. Edwin Kessler and William C. Bumgarner. June 1971. (COM-71-00911)

No. 55 The NSSL Surface Network and Observations of Hazardous Wind Gusts. Operations Staff. June 1971. (COM-71-00910)

No. 56 Pilot Chaff Project at the National Severe Storms Laboratory. Edward A. Jessup. November 1971. (COM-72-10106)

No. 57 Numerical Simulation of Convective Vortices. Robert P. Davies-Jones and Glenn T. Vickers. November 1971. (COM-72-10269)

No. 58 The Thermal Structure of the Lowest Half Kilometer in Central Oklahoma: December 9, 1966 - May 31, 1967. R. Craig Goff and Horace R. Hudson. July 1972. (COM-72-11281)

No. 59 Cloud-to-Ground Lightning Versus Radar Reflectivity in Oklahoma Thunderstorms. Gilbert D. Kinzer. September 1972. (COM-73-10050)

No. 60 Simulated Real Time Displays of Velocity Fields by Doppler Radar. L. D. Hennington and G. B. Walker. November 1972. (COM-73-10515)

No. 61 Gravity Current Model Applied to Analysis of Squall-Line Gust Front. Jess Charba. November 1972. (COM-73-10410)

No. 62 Mesoscale Objective Map Analysis Using Weighted Time-Series Observations. Stanley L. Barnes. March 1973. (COM-73-10781)

No. 63 Observations of Severe Storms on 26 and 28 April 1971. Charles L. Vlcek. April 1973. (COM-73-11200)

No. 64 Meteorological Radar Signal Intensity Estimation. Dale Sirmans and R. J. Doviak. September 1973. (COM-73-11923/2AS)

No. 65 Radiosonde Altitude Measurement Using Double Radiotheodolite Techniques. Stephan P. Nelson. September 1973. (COM-73-11934/9AS)

No. 66 The Motion and Morphology of the Dryline. Joseph T. Schaefer. September 1973. (COM-74-10043)

No. 67 Radar Rainfall Pattern Optimizing Technique. Edward A. Brandes. March 1974.

No. 68 The NSSL/WKY-TV Tower Data Collection Program: April - July 1972. R. Craig Goff and W. David Zittel. May 1974.

No. 69 Papers on Oklahoma Thunderstorms, April 29-30, 1970. Stanley L. Barnes, et al. May 1974.

No. 70 Life Cycle of Florida Key's Waterspouts. Joseph H. Golden. June 1974.

No. 71 Interaction of Two Convective Scales Within a Severe Thunderstorm: A Case Study and Thunderstorm Wake Vortex Structure and Thunderstorm Wake Vortex Structure and Aerodynamic Origin. Leslie R. Lemon. June 1974.

No. 72 Updraft Properties Deduced from Rawinsoundings. Robert P. Davies-Jones and James H. Henderson. October 1974.

No. 73 Severe Rainstorm at Enid, Oklahoma - October 10, 1973. L.P. Merritt, K.E. Wilk, and M.L. Weible. November 1974.

☆GPO 1974 — 677-236/1226 REGION NO. 8