U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL WEATHER SERVICE
SYSTEMS DEVELOPMENT OFFICE
TECHNIQUES DEVELOPMENT LABORATORY

TDL Office Note 76-13

COMPARATIVE VERIFICATION OF GUIDANCE AND LOCAL AVIATION/PUBLIC WEATHER FORECASTS--NO. 1 (OCTOBER 1975 - MARCH 1976)

Gary M. Carter, Joseph R. Bocchieri,
Richard L. Crisci, and George W. Hollenbaugh

August 1976

1. INTRODUCTION

We have verified a sample of TDL's operational guidance forecasts and National Weather Service (NWS) local forecasts made at Weather Service Forecast Offices (WSFO's). Verification statistics for objective "final" guidance and subjective local forecasts of opaque sky cover, precipitation type, surface wind, ceiling height, and visibility for the cool season months of October 1975 through March 1976 are presented here. Of the 233 stations for which we issue guidance forecasts each day, the 92 shown in Table 1.1 were used for this verification.

TDL's forecasts were based on the Model Output Statistics (MOS) technique (Klein and Glahn, 1974). Input to our MOS prediction equations came from surface observations, and forecast fields from the Limited-area Fine Mesh (LFM) (Howcroft and Desmaris, 1971), Trajectory (TJ) (Reap, 1972), and/or Primitive Equation (PE) (Shuman and Hovermale, 1968) models.

WSFO forecasts were provided to us by the Technical Procedures Branch of the Office of Meterology and Oceanography in conjunction with the NWS combined aviation/public weather verification system (NWS, 1973a). These forecasts were recorded daily for verification purposes under instructions that the value recorded be "...not inconsistent with..." the official weather forecasts. Surface observations as late as two hours before the first verification time may have been used in their preparation.

We obtained observed data to verify the guidance and local weather forecasts from the National Weather Records Center in Asheville, N.C.

2. OPAQUE SKY COVER

We calculated verification scores for guidance and local forecasts of opaque sky cover for all the stations shown in Table 1.1. The guidance forecasts were based on the cool season equations described in NWS Technical Procedures Bulletin No. 124 (NWS, 1974b). These equations used forecast fields from both the PE and TJ models to produce probability forecasts of categories which correspond roughly to clear, scattered, broken, and overcast. The four-category probability estimates were converted into single "best category" forecasts so that each category was forecast nearly as often as it occured (see NWS, 1974c).

We transformed the local forecasts and the sky cover observations into categories of clear (1), scattered (2), broken (3), and overcast (4) in the manner shown in Table 2.1.

The transformed subjective forecasts and objective best category estimates were used to prepare four-category, forecast-observed contingency tables. Percent correct, skill score, and bias by category (i.e., the number of forecasts in a particular category divided by the number of observations in that category) were computed from these tables.

Table 1.1 Ninety-two stations used for comparative verification of guidance and local aviation/public weather forecasts.

PWM	Portland, Maine	TCC	Tucumcari, New Mexico
BTV	Burlington, Vermont	SSM	Sault Ste Marie, Michigan
CON	Concord, New Hampshire	DTW	Detroit, Michigan
BOS	Boston, Massachusetts	SBN	South Bend, Indiana
PVD	Providence, Rhode Island	IND	Indianapolis, Indiana
BUF	Buffalo, New York	LEX	Lexington, Kentucky
SYR	Syracuse, New York	SDF	Louisville, Kentucky
ALB	Albany, New York	MSN	Madison, Wisconsin
JFK	New York (Kennedy), New York	MKE	Milwaukee, Wisconsin
EWR	Newark, New Jersey	ORD	Chicago (Ohare), Illinois
ERI	Erie, Pennsylvania	SPI	Springfield, Illinois
PIT	Pittsburgh, Pennsylvania	STL	St. Louis, Missouri
PHL	Philadelphia, Pennsylvania	MCI	Kansas City, Missouri
CLE	Cleveland, Ohio	TOP	Topeka, Kansas
CMH	Columbus, Ohio	DDC	Dodge City, Kansas
BKW	Beckley, West Virginia	DEN	Denver, Colorado
CRW	Charleston, West Virginia	GJT	Grand Junction, Colorado
DCA	Washington, D.C.	SHR	Sheridan, Wyoming
ORF	Norfolk, Virginia	CYS	Cheyenne, Wyoming
RDU	Raleigh-Durham, North Carolina	BIS	Bismarck, North Dakota
CLT	Charlotte, North Carolina	FAR	Fargo, North Dakota
CAE	Columbia, South Carolina	RAP	Rapid City, South Dakota
ATL	Atlanta, Georgia	FSD	Sioux Falls, South Dakota
SAV	Savannah, Georgia	BFF	Scottsbluff, Nebraska
MIA	Miami, Florida	OMA	Omaha, Nebraska
JAX	Jacksonville, Florida	MSP	Minneapolis, Minnesota
BHM	Birmingham, Alabama	DSM	Des Moines, Iowa
MOB	Mobile, Alabama	BRL	Burlington, Iowa
TYS	Knoxville, Tennessee	INL	International Falls, Minnesota
MEM	Memphis, Tennessee	FLG	Flagstaff, Arizona
MEI	Meridian, Mississippi	PHX	Phoenix, Arizona
JAN	Jackson, Mississippi	CDC	Cedar City, Utah
MSY	New Orleans, Louisiana	SLC	Salt Lake City, Utah
SHV	Shreveport, Louisiana	LAS	Las Vegas, Nevada
IAH	Houston, Texas	RNO	Reno, Nevada
SAT	San Antonio, Texas	SAN	San Diego, California
DFW	Forth Worth, Texas	LAX	Los Angeles, California
ABI	Abilene, Texas	FAT	Fresno, California
LBB	Lubbock, Texas	SFO	San Francisco, California
ELP	El Paso, Texas	PDX	Portland, Oregon
LIT	Little Rock, Arkansas	PDT	Pendleton, Oregon
FSM	Fort Smith, Arkansas	SEA	Seattle (Tacoma), Washington
TUL	Tulsa, Oklahoma	GEG	Spokane, Washington
OKC	Oklahoma City, Oklahoma	BOI	Boise, Idaho
ABQ	Albuquerque, New Mexico	PIH	Pocatello, Idaho
GTF	Great Falls, Montana	MSO	Missoula, Montana

Table 2.1 Categories used to verify opaque sky cover forecasts.

Category Number	Tenths of Opaque Sky Cover
1	0-1
2	2-5
3	6-9
4	10 (Includes Obscured)

Tables 2.2-2.6 show the comparative verification scores for October 1975 through March 1976 for three different projections. The guidance forecasts were made from 0000 GMT data and projections were 18, 30, and 42 hours; however, the 18-hour forecasts used 0500 GMT surface observations in addition to forecast fields from the numerical models.

Table 2.2 is a summary of the results for all the stations combined. The percents correct and skill scores indicate that the local and guidance forecasts were about equal overall for the 18-hour projection. However, the guidance forecasts were superior to the local estimates at 30 and 42 hours. The bias by category scores show that the local forecasts strongly overestimated scattered conditions, and to a lesser extent broken clouds. The guidance forecasts were much better in this respect.

Tables 2.3-2.6 give the verification scores for the NWS Eastern, Southern, Central, and Western Regions, respectively. These results exhibit the same characteristics as those for all 92 stations combined; except for the Western Region (see Table 2.6) where the 18-hour local forecasts are more accurate and skillful than the guidance estimates.

In general, these findings are quite similar to those from our previous comparison study of guidance and local cloud forecasts for December 1974 through March 1975 (Carter, 1975).

3. PRECIPITATION TYPE

TDL's system for predicting the conditional probability of frozen precipitation (PoF) has been operational within the NWS since November 1972. The evolution of the PoF system is described in detail by Glahn and Bocchieri (1975) and Bocchieri and Glahn (1976).

Bocchieri and Glahn (1976) give the verification procedures used to compare the MOS PoF guidance forecasts with the local predictions. The paper includes comparative verification results for February through April 1974 and November 1974 through February 1975; the MOS forecasts

Table 2.2 Verification scores for subjective local and objective guidance forecasts of four categories of cloud amount (clear, scattered, broken, and overcast) for 92 stations across the United States during October 1975 through March 1976.

PROJECTION (HOURS)	TYPE OF FORECAST	BIAS - NO. FCST/NO. OBS				PERCENT CORRECT	SKILL SCORE	NO. OF CASES
		CAT 1 (No. Obs.)	CAT 2 (No. Obs.)	CAT 3 (No. Obs)	CAT 4 (No. Obs.)			
18	GUIDANCE	1.11	0.85	0.93	1.02	50	0.32	15192
	LOCAL	0.73 (4920)	1.47 (3099)	1.31 (2705)	0.78 (4468)	50	0.33	
30	GUIDANCE	1.08	0.75	0.82	1.06	57	0.35	15052
	LOCAL	0.68 (6707)	2.09 (1993)	1.90 (1564)	0.70 (4788)	47	0.28	
42	GUIDANCE	1.09	0.89	0.86	1.06	46	0.26	15188
	LOCAL	0.58 (4907)	1.86 (3061)	1.39 (2731)	0.63 (4489)	39	0.20	

Table 2.3 Verification scores for subjective local and objective guidance forecasts of four categories of cloud amount (clear, scattered, broken, and overcast) for 22 stations in the Eastern Region of the NWS during October 1975 through March 1976.

PROJECTION (HOURS)	TYPE OF FORECAST	BIAS - NO. FCST/NO. OBS				PERCENT CORRECT	SKILL SCORE	NO. OF CASES
		CAT 1 (No. Obs.)	CAT 2 (No. Obs.)	CAT 3 (No. Obs)	CAT 4 (No. Obs.)			
18	GUIDANCE	0.98	1.02	0.96	1.03	49	0.30	3580
	LOCAL	0.62	1.49	1.40	0.77	49	0.32	
		(839)	(710)	(704)	(1327)			
30	GUIDANCE	1.08	0.77	0.78	1.06	58	0.36	3586
	LOCAL	0.68	2.05	1.92	0.72	47	0.28	
		(1255)	(444)	(387)	(1500)			
42	GUIDANCE	0.97	1.07	0.92	1.02	45	0.24	3583
	LOCAL	0.43	1.79	1.56	0.65	39	0.19	
		(841)	(706)	(699)	(1337)			

Table 2.4 Verification scores for subjective local and objective guidance forecasts of four categories of cloud amount (clear, scattered, broken, and overcast) for 24 stations in the Southern Region of the NWS during October 1975 through March 1976.

PROJECTION (HOURS)	TYPE OF FORECAST	BIAS - NO. FCST/NO. OBS				PERCENT CORRECT	SKILL SCORE	NO. OF CASES
		CAT 1 (No. Obs.)	CAT 2 (No. Obs.)	CAT 3 (No. Obs)	CAT 4 (No. Obs.)			
18	GUIDANCE	1.11	0.94	1.01	0.86	53	0.34	3934
	LOCAL	0.84 (1580)	1.57 (788)	1.28 (668)	0.57 (898)	52	0.34	
30	GUIDANCE	1.04	0.82	0.91	1.04	60	0.34	3950
	LOCAL	0.78 (2216)	2.29 (477)	1.69 (371)	0.57 (886)	52	0.29	
42	GUIDANCE	1.10	0.88	1.02	0.91	48	0.28	3947
	LOCAL	0.73 (1554)	2.10 (793)	1.19 (697)	0.35 (903)	41	0.20	

Table 2.5 Verification scores for subjective local and objective guidance forecasts of four categories of cloud amount (clear, scattered, broken, and overcast) for 28 stations in the Central Region of the NWS during October 1975 through March 1976.

PROJECTION (HOURS)	TYPE OF FORECAST	BIAS - NO. FCST/NO. OBS				PERCENT CORRECT	SKILL SCORE	NO. OF CASES
		CAT 1 (No. Obs.)	CAT 2 (No. Obs.)	CAT 3 (No. Obs)	CAT 4 (No. Obs.)			
18	GUIDANCE	1.17	0.74	0.87	1.08	49	0.30	4700
	LOCAL	0.56 (1454)	1.59 (990)	1.32 (806)	0.86 (1450)	46	0.28	
30	GUIDANCE	1.15	0.66	0.79	1.00	56	0.33	4537
	LOCAL	0.53 (1900)	2.42 (598)	2.15 (441)	0.71 (1598)	42	0.23	
42	GUIDANCE	1.17	0.77	0.72	1.13	43	0.22	4692
	LOCAL	0.36 (1464)	1.97 (970)	1.47 (808)	0.73 (1450)	35	0.15	

Table 2.6 Verification scores for subjective local and objective guidance forecasts of four categories of cloud amount (clear, scattered, broken, and overcast) for 18 stations in the Western Region of the NWS during October 1975 through March 1976.

PROJECTION (HOURS)	TYPE OF FORECAST	BIAS - NO. FCST/NO. OBS				PERCENT CORRECT	SKILL SCORE	NO. OF CASES
		CAT 1 (No. Obs.)	CAT 2 (No. Obs.)	CAT 3 (No. Obs)	CAT 4 (No. Obs.)			
18	GUIDANCE	1.16	0.70	0.88	1.10	50	0.31	2978
	LOCAL	0.91 (1047)	1.11 (611)	1.21 (527)	0.90 (793)	54	0.38	
30	GUIDANCE	1.04	0.75	0.79	1.18	54	0.32	2979
	LOCAL	0.74 (1336)	1.53 (474)	1.78 (365)	0.77 (804)	49	0.31	
42	GUIDANCE	1.07	0.88	0.80	1.13	47	0.27	2966
	LOCAL	0.79 (1048)	1.45 (592)	1.33 (527)	0.72 (799)	44	0.26	

were shown to be generally more accurate for both samples. One of our concerns in the verification was that, because of the conditional nature of the forecasts, there were many cases when the forecasters may not have put much effort into making the forecast. That is, if a forecaster decided that the probability of precipitation (PoP) was small, he may have been reluctant to put much effort into making a forecast of precipitation type. To get insight into this, we did another comparative verification in a different manner. In our paper, we divided the verification into two parts, A and B. For verification A, we included all cases, both the obvious and the difficult. In verification B, we included only those cases when the guidance and local forecasts of precipitation type differed; therefore, some of the more difficult forecast situations were isolated. In all verifications, we could include only cases where precipitation actually occurred. However, we did not account for the fact that the forecaster's assessment of the PoP may have been small or zero in some of the cases.

In order to isolate those cases when the forecaster would have been more confident that precipitation was to occur, we repeated verification B but used only the cases when the local PoP forecast was greater than or equal to certain critical values--0, 30, 40, and 50%. The PoP values were valid for the 12-hour periods centered on the 18-, 30-, and 42-hour projections, which were used in the comparative verification. The sample consisted of data from the period November through April 1975. The results showed that as the PoP value increased, the percent correct for the local forecasts generally increased for all forecast projections. However, the percent correct for the guidance was still higher than that for the local forecasts for all projections and PoP values. Based on these results, we concluded that the forecasters became more diligent and thus more accurate in their precipitation type forecasts as their estimate of the PoP increased.

Tables 3.1 and 3.2 show the verification results for October 1975 through March 1976 for verifications A and B respectively. The sample includes only cases when the local PoP was 30% or greater. We included all stations listed in Table 1.1 except for Newark, N.J.; New York, N.Y.; Burlington, Iowa; and Chicago, Ill. Local PoP data were not available for those stations. For verification A (Table 3.1),we computed verification scores for each NWS region and for all 88 stations combined. In verification B (Table 3.2), verification scores are not provided for each NWS Region because of the small number of cases involved. Also, in verification B, only the percent correct was computed because the other scores would not have been very meaningful for this specialized sample.

The results for verification A can be summarized as follows:

a. For all stations combined the guidance was better than the local forecasts for the percent correct and skill score for all projections. Guidance had a tendency to overforecast the snow event (bias > 1.00); the locals showed a tendency to underforecast snow (bias < 1.00).

Table 3.1 Comparative verification of "final" PoF guidance and local forecasts by NWS Region for October 1975 through March 1976 (verification A). Only cases when local PoP was ≥ 30% were included.

Projection (Hrs)	Region	System	Bias Snow	Bias Rain	Percent Correct	Skill Score	Number of Cases
18	Eastern	Guidance Local	1.06 .86	.95 1.12	90 87	.81 .74	513
	Southern	Guidance Local	.83 .50	1.01 1.02	97 98	.53 .66	173
	Central	Guidance Local	1.12 .91	.82 1.13	90 87	.79 .74	396
	Western	Guidance Local	1.01 .89	.99 1.07	94 91	.88 .79	192
	All Stations	Guidance Local	1.08 .88	.94 1.09	92 89	.84 .78	1274
30	Eastern	Guidance Local	1.09 1.01	.93 1.00	90 87	.79 .73	452
	Southern	Guidance Local	.57 .71	1.02 1.01	96 96	.34 .48	164
	Central	Guidance Local	1.10 .99	.83 1.01	86 82	.70 .62	458
	Western	Guidance Local	1.07 .88	.97 1.06	90 86	.78 .67	183
	All Stations	Guidance Local	1.09 .98	.98 1.05	89 86	.78 .72	1257
42	Eastern	Guidance Local	1.02 .90	.98 1.08	87 80	.74 .60	464
	Southern	Guidance Local	1.00 .67	1.00 1.01	100 98	1.00 .39	134
	Central	Guidance Local	1.09 .95	.85 1.09	86 83	.69 .64	334
	Western	Guidance Local	1.07 .91	.96 1.05	91 90	.81 .77	198
	All Stations	Guidance Local	1.06 .92	.95 1.06	89 85	.78 .69	1130

Table 3.2 Comparative verification of "final" PoF guidance and local forecasts for October 1975 through March 1976 (verification B). Only cases when local PoP was ≥ 30% were included.

Projection (Hrs)	Forecast	Percent Correct	Number of Cases
18	Guidance Local	61 39	152
30	Guidance Local	66 34	122
42	Guidance Local	67 33	134

b. In the regional breakdown, the guidance was generally better than the local forecasts for the percent correct and skill score for all projections. Exceptions to this appear for the Southern Region for the 18- and 30-hour projections where the local predictions were slightly better. Again the guidance showed a tendency to overforecast snow, while the local predictions tended to underforecast snow. The local forecasts were less biased than the guidance for the Central Region for all projections and for the Eastern and Southern Regions for the 30-hour projection.

c. Percent correct and skill scores were rather high because the sample contained many cases when the form of precipitation would be rather obvious.

For verification B (when the local and guidance forecasts differed), the guidance was correct 60% to 70% of the time for all stations combined and for all projections.

The above results are quite similar to those found for the period November 1974 through February 1975 by Bocchieri and Glahn (1976).

4. SURFACE WIND

Guidance and local surface wind forecasts also have been comparatively verified for the cool season of 1975-76. The guidance forecasts were generated using the cool season linear regression equations described in NWS Technical Procedures Bulletin No. 98 (NWS, 1973b). Most of the predictors in these equations were forecast fields from the PE model. The definition of this objective wind forecast is the same as that of the observed wind: namely, the one-minute average direction and speed for a specific time.

Since the local forecasts were recorded as calm if the wind speed was expected to be less than 8 knots, we verified these forecasts in two ways. First, for all those cases where both the local and guidance wind speed forecasts were at least 8 knots, the mean absolute error (MAE) of speed was computed. Cases where the observed wind was calm were then eliminated from this sample and the MAE of direction was computed. Secondly, for all cases where both local and guidance forecasts were available, skill score, percent correct, and bias by category (i.e., the number of forecasts in a particular category divided by the number of observations in that category) were computed from contingency tables of wind speed. The seven categories were; less than 8, 8-12, 13-17, 18-22, 23-27, 28-32, and greater than 32 knots. Tables 4.1-4.11 show comparative verification scores for three projections. These are 18, 30, and 42 hours for the guidance forecasts which were made entirely from 0000 GMT cycle data. It should also be noted that all the objective speed forecasts were "inflated" by the method described in NWS Technical Procedures Bulletin No. 137 (NWS, 1975). Specifically, each forecast of speed was adjusted by an equation involving the multiple correlation coefficient and the mean value of wind speed for

Table 4.1 Verification scores for subjective local and objective guidance surface wind forecasts for 92 stations across the United States during October 1975 through March 1976.

FCST. PROJ. (HRS.)	TYPE OF FCST.	DIRECTION		SPEED													
								CONTINGENCY TABLE									
										BIAS-NO. FCST./NO. OBS.							
		MEAN ABS. ERROR (DEG.)	NO. OF CASES	MEAN ABS. ERROR (DEG.)	MEAN FCST (KTS.)	MEAN OBS. (KTS.)	NO. OF CASES	SKILL SCORE	PERCENT FCST. CORRECT	CAT1 (NO. OBS.)	CAT2 (NO. OBS.)	CAT3 (NO. OBS.)	CAT4 (NO. OBS.)	CAT5 (NO. OBS.)	CAT6 (NO. OBS.)	CAT7 (NO. OBS.)	NO. OF CASES
18	GUIDANCE	30	9084	3.6	13.4	12.5	9158	0.28	49	0.93	1.06	0.98	1.10	0.92	1.05	0.70	15206
	LOCAL	33		3.8	13.9			0.26	47	0.72	1.15	1.17	1.15	0.85	1.03	0.70	
										(5377)	(5106)	(3262)	(1116)	(258)	(64)	(23)	
30	GUIDANCE	34	5581	4.0	12.1	10.9	5704	0.29	58	0.98	1.08	1.00	0.77	0.80	0.28	0.30	15251
	LOCAL	40		4.2	12.5			0.26	54	0.85	1.30	1.08	0.77	0.52	0.78	0.90	
										(8402)	(4355)	(1817)	(561)	(88)	(18)	(10)	
42	GUIDANCE	41	8788	4.2	13.1	12.0	8906	0.22	45	0.91	1.11	1.03	0.92	0.82	0.61	0.20	15171
	LOCAL	47		4.2	12.9			0.18	42	0.75	1.33	1.08	0.65	0.37	0.19	0.35	
										(5385)	(5069)	(3262)	(1106)	(260)	(69)	(20)	

Table 4.2 Contingency tables for subjective local and objective guidance surface wind forecasts for 92 stations across the United States during October 1975 through March 1976.

18-Hr Forecasts

GUIDANCE FCST

OBS	1	2	3	4	5	6	7	T
1	3335	1651	352	37	2	0	0	5377
2	1397	2434	1040	205	25	3	2	5106
3	259	1125	1295	502	73	8	0	3262
4	29	196	446	346	81	16	2	1116
5	4	17	62	112	36	24	3	258
6	2	4	11	15	19	9	4	64
7	0	1	2	6	2	7	5	23
T	5026	5428	3208	1223	238	67	16	15206

LOCAL FCST

OBS	1	2	3	4	5	6	7	T
1	2753	2059	495	64	6	0	0	5377
2	931	2553	1343	236	32	8	3	5106
3	174	1072	1429	507	65	13	2	3262
4	34	184	478	339	58	20	3	1116
5	4	20	73	107	40	12	2	258
6	1	1	12	25	16	9	0	64
7	0	2	0	8	3	4	6	23
T	3897	5891	3830	1286	220	66	16	15206

30-Hr Forecasts

GUIDANCE FCST

OBS	1	2	3	4	5	6	7	T
1	6213	1823	330	34	1	1	0	8402
2	1734	1868	625	113	14	1	0	4355
3	252	799	587	159	20	0	0	1817
4	38	173	225	102	20	2	1	561
5	4	18	36	20	10	0	0	88
6	2	5	4	4	2	0	1	18
7	0	2	1	2	3	1	1	10
T	8243	4688	1808	434	70	5	3	15251

LOCAL FCST

OBS	1	2	3	4	5	6	7	T
1	5400	2487	457	48	6	0	4	8402
2	1460	2133	638	114	5	3	2	4355
3	214	823	599	161	16	3	1	1817
4	48	185	225	85	11	5	2	561
5	6	25	30	20	5	2	0	88
6	2	8	3	4	0	1	0	18
7	1	1	3	2	3	0	0	10
T	7131	5662	1955	434	46	14	9	15251

42-Hr Forecasts

GUIDANCE FCST

OBS	1	2	3	4	5	6	7	T
1	2974	1772	549	79	11	0	0	5385
2	1414	2308	1105	211	27	4	0	5069
3	417	1227	1169	374	65	9	1	3262
4	80	269	425	259	60	12	1	1106
5	13	36	95	71	32	12	1	260
6	3	11	20	20	12	2	1	69
7	1	2	5	3	6	3	0	20
T	4902	5625	3368	1017	213	42	4	15171

LOCAL FCST

OBS	1	2	3	4	5	6	7	T
1	2442	2235	606	96	6	0	0	5385
2	1129	2610	1150	157	16	4	3	5069
3	379	1446	1173	234	26	3	1	3262
4	81	384	452	161	24	1	3	1106
5	12	72	105	52	17	2	0	260
6	3	9	34	15	6	2	0	69
7	1	7	4	5	2	1	0	20
T	4047	6763	3524	720	97	13	7	15171

Table 4.3 Verification scores for subjective local and objective guidance surface wind forecasts for 22 stations in the Eastern Region of the NWS during October 1975 through March 1976.

FCST. PROJ. (HRS)	TYPE OF FCST.	DIRECTION		SPEED													
								CONTINGENCY TABLE									
										BIAS-NO. FCST./NO. OBS.							
		MEAN ABS. ERROR (DEG.)	NO. OF CASES	MEAN ABS. ERROR (DEG.)	MEAN FCST (KTS.)	MEAN OBS. (KTS.)	NO. OF CASES	SKILL SCORE	PERCENT FCST. CORRECT	CAT1 (NO. OBS.)	CAT2 (NO. OBS.)	CAT3 (NO. OBS.)	CAT4 (NO. OBS.)	CAT5 (NO. OBS.)	CAT6 (NO. OBS.)	CAT7 (NO. OBS.)	NO. OF CASES
18	GUIDANCE	28	2471	3.4	13.4	12.2	2477	0.25	47	0.82	1.05	1.02	1.33	1.19	1.36	3.00	3577
	LOCAL	30		3.5	13.6			0.21	44	0.62 (1033)	1.11 (1359)	1.19 (882)	1.30 (244)	1.06 (47)	0.73 (11)	1.00 (1)	
30	GUIDANCE	33	1474	3.9	12.4	10.9	1496	0.28	55	0.93	1.12	1.06	0.84	1.11	0.0	0.0	3585
	LOCAL	37		4.2	12.9			0.23	50	0.77 (1900)	1.35 (1032)	1.15 (483)	0.97 (147)	0.83 (18)	1.25 (4)	6.00 (1)	
42	GUIDANCE	39	2339	4.0	13.2	11.9	2356	0.18	42	0.90	1.07	0.97	1.13	1.09	1.27	1.50	3568
	LOCAL	43		4.0	12.9			0.15	41	0.59 (1043)	1.34 (1340)	1.04 (881)	0.88 (245)	0.46 (46)	0.27 (11)	0.50 (2)	

Table 4.4 Verification scores for subjective local and objective guidance surface wind forecasts for 24 stations in the Southern Region of the NWS during October 1975 through March 1976.

FCST. PROJ. (HRS.)	TYPE OF FCST.	DIRECTION		SPEED													
								CONTINGENCY TABLE									
										BIAS-NO. FCST./NO. OBS.							
		MEAN ABS. ERROR (DEG.)	NO. OF CASES	MEAN ABS. ERROR (DEG.)	MEAN FCST (KTS.)	MEAN OBS. (KTS.)	NO. OF CASES	SKILL SCORE	PERCENT FCST. CORRECT	CAT1 (NO. OBS.)	CAT2 (NO. OBS.)	CAT3 (NO. OBS.)	CAT4 (NO. OBS.)	CAT5 (NO. OBS.)	CAT6 (NO. OBS.)	CAT7 (NO. OBS.)	NO. OF CASES
18	GUIDANCE	28	2347	3.3	12.8	12.2	2358	0.28	50	1.06	1.01	0.86	1.16	1.05	0.50	0.50	3987
	LOCAL	31		3.4	13.4			0.26	49	0.73 (1309)	1.17 (1508)	1.06 (880)	1.24 (232)	0.79 (42)	0.92 (12)	0.25 (4)	
30	GUIDANCE	33	1143	3.6	11.7	10.7	1165	0.34	65	1.07	0.89	0.97	0.67	0.73	1.00	0.0	4004
	LOCAL	37		3.6	11.7			0.28	60	0.92 (2395)	1.25 (1128)	0.92 (376)	0.54 (92)	0.09 (11)	1.00 (1)	0.0 (1)	
42	GUIDANCE	38	2267	3.7	12.4	11.8	2281	0.21	46	1.00	1.10	0.89	0.87	0.62	0.38	0.0	3985
	LOCAL	45		3.7	12.4			0.16	43	0.84 (1313)	1.27 (1495)	0.96 (892)	0.52 (227)	0.24 (42)	0.08 (13)	0.33 (3)	

Table 4.5 Verification scores for subjective local and objective guidance surface wind forecasts for 28 stations in the Central Region of the NWS during October 1975 through March 1976.

FCST. PROJ. (HRS.)	TYPE OF FCST.	DIRECTION		SPEED													
								CONTINGENCY TABLE									
										BIAS-NO. FCST./NO. OBS.							
		MEAN ABS. ERROR (DEG.)	NO. OF CASES	MEAN ABS. ERROR (DEG.)	MEAN FCST (KTS.)	MEAN OBS. (KTS.)	NO. OF CASES	SKILL SCORE	PERCENT FCST. CORRECT	CAT1 (NO. OBS.)	CAT2 (NO. OBS.)	CAT3 (NO. OBS.)	CAT4 (NO. OBS.)	CAT5 (NO. OBS.)	CAT6 (NO. OBS.)	CAT7 (NO. OBS.)	NO. OF CASES
18	GUIDANCE	29	3247	3.7	13.8	12.9	3280	0.25	45	0.87	1.10	1.01	1.03	0.89	1.00	0.73	4665
	LOCAL	35		4.0	14.4			0.19	41	0.59	1.14	1.21	1.15	0.99	1.06	0.36	
										(1283)	(1580)	(1183)	(466)	(111)	(31)	(11)	
30	GUIDANCE	34	2155	4.1	12.2	11.3	2205	0.25	51	0.96	1.15	0.92	0.73	0.77	0.30	0.29	4690
	LOCAL	41		4.3	12.5			0.21	47	0.76	1.35	1.10	0.73	0.47	0.30	0.29	
										(2167)	(1519)	(712)	(235)	(40)	(10)	(7)	
42	GUIDANCE	42	3198	4.3	13.5	12.5	3245	0.17	40	0.85	1.10	1.12	0.86	0.85	0.37	0.0	4660
	LOCAL	49		4.5	13.2			0.12	37	0.58	1.37	1.19	0.64	0.37	0.11	0.0	
										(1279)	(1593)	(1173)	(459)	(113)	(35)	(8)	

Table 4.6 Verification scores for subjective local and objective guidance surface wind forecasts for 18 stations in the Western Region of the NWS during October 1975 through March 1976.

FCST. PROJ. (HRS)	TYPE OF FCST.	DIRECTION		SPEED														
								CONTINGENCY TABLE										
										BIAS-NO. FCST./NO. OBS.								
		MEAN ABS. ERROR (DEG.)	NO. OF CASES	MEAN ABS. ERROR (DEG.)	MEAN FCST (KTS.)	MEAN OBS. (KTS.)	NO. OF CASES	SKILL SCORE	PERCENT FCST. CORRECT	CAT1 (NO. OBS.)	CAT2 (NO. OBS.)	CAT3 (NO. OBS.)	CAT4 (NO. OBS.)	CAT5 (NO. OBS.)	CAT6 (NO. OBS.)	CAT7 (NO. OBS.)	NO. OF CASES	
18	GUIDANCE	37	1019	4.6	13.7	12.5	1043	0.30	58	0.95	1.13	1.12	0.87	0.67	1.50	0.43	2977	
	LOCAL	36		4.5	14.0			0.31	58	0.88 (1752)	1.25 (659)	1.32 (317)	0.82 (174)	0.47 (58)	1.40 (10)	1.43 (7)		
30	GUIDANCE	41	809	4.5	12.2	10.4	838	0.27	61	0.94	1.16	1.10	0.89	0.58	0.33	1.00	2972	
	LOCAL	45		4.5	12.6			0.27	61	0.93 (1940)	1.19 (676)	1.11 (246)	0.80 (87)	0.58 (19)	1.67 (3)	1.00 (1)		
42	GUIDANCE	49	984	5.4	13.6	11.7	1024	0.25	54	0.89	1.22	1.30	0.83	0.69	1.00	0.14	2958	
	LOCAL	51		5.4	13.1			0.20	52	0.90 (1750)	1.38 (641)	1.15 (316)	0.54 (175)	0.41 (59)	0.50 (10)	0.71 (7)		

Table 4.7 Distribution of mean absolute errors associated with subjective local and objective guidance forecasts of surface wind direction for 92 stations in the United States during October 1975 through March 1976.

FCST. PROJ. (HRS.)	TYPE OF FCST.	FREQUENCY OF MEAN ABSOLUTE ERRORS BY CATEGORY					
		0-30°	40-60°	70-90°	100-120°	130-150°	160-180°
18	Guidance	6660	1437	455	232	177	123
	Local	6201	1686	587	271	194	145
30	Guidance	3794	929	385	215	148	110
	Local	3373	1127	487	269	190	135
42	Guidance	5208	1797	739	454	324	266
	Local	4679	1902	908	556	419	324

Table 4.8 Distribution of mean absolute errors associated with subjective local and objective guidance forecasts of surface wind direction for 22 stations in the Eastern Region of the NWS during October 1975 through March 1976.

FCST. PROJ. (HRS.)	TYPE OF FCST.	FREQUENCY OF MEAN ABSOLUTE ERRORS BY CATEGORY					
		0-30°	40-60°	70-90°	100-120°	130-150°	160-180°
18	Guidance	1817	418	127	47	39	23
	Local	1724	477	151	58	43	18
30	Guidance	1008	258	101	61	30	16
	Local	914	303	125	66	39	27
42	Guidance	1438	466	199	112	67	57
	Local	1291	540	243	114	85	66

Table 4.9 Distribution of mean absolute errors associated with subjective local and objective guidance forecasts of surface wind direction for 24 stations in the Southern Region of the NWS during October 1975 through March 1976.

FCST. PROJ. (HRS.)	TYPE OF FCST.	FREQUENCY OF MEAN ABSOLUTE ERRORS BY CATEGORY					
		0-30°	40-60°	70-90°	100-120°	130-150°	160-180°
18	Guidance	1759	380	104	48	34	22
	Local	1632	439	147	59	44	26
30	Guidance	797	188	63	36	34	25
	Local	745	208	82	45	29	34
42	Guidance	1367	503	186	99	65	47
	Local	1249	488	227	136	83	84

Table 4.10 Distribution of mean absolute errors associated with subjective local and objective guidance forecasts of surface wind direction for 28 stations in the Central Region of the NWS during October 1975 through March 1976.

FCST. PROJ. (HRS.)	TYPE OF FCST.	FREQUENCY OF MEAN ABSOLUTE ERRORS BY CATEGORY					
		0-30°	40-60°	70-90°	100-120°	130-150°	160-180°
18	Guidance	2424	469	155	87	58	54
	Local	2169	599	225	110	71	73
30	Guidance	1484	357	143	75	57	39
	Local	1265	448	205	111	83	43
42	Guidance	1864	657	273	171	119	114
	Local	1604	709	363	233	163	126

Table 4.11 Distribution of mean absolute errors associated with subjective local and objective guidance forecasts of surface wind direction for 18 stations in the Western Region of the NWS during October 1975 through March 1976.

FCST. PROJ. (HRS.)	TYPE OF FCST.	FREQUENCY OF MEAN ABSOLUTE ERRORS BY CATEGORY					
		0-30°	40-60°	70-90°	100-120°	130-150°	160-180°
18	Guidance	660	170	69	50	46	24
	Local	676	171	64	44	36	28
30	Guidance	505	126	78	43	27	30
	Local	449	168	75	47	39	31
42	Guidance	539	171	81	72	73	48
	Local	535	165	75	73	88	48

that particular station and forecast valid time.

Statistics for all 92 stations (see Table 1.1) combined are shown in Tables 4.1 and 4.2. The MAE scores for direction in Table 4.1 reveal an advantage for guidance that increases from 3^{o} at 18 hours to 6^{o} at 30 and 42 hours. The mean error, skill score, and percent correct of speed forecasts are generally better for guidance at all three projections, but these scores do not exhibit the relative improvement of guidance with longer projections that is shown for the direction forecasts. The individual biases by category shown in Table 4.1 and the contingency tables in Table 4.2, show that both guidance and locals tend to underforecast winds greater than 32 knots (category 7).

Tables 4.3-4.6 give verification results for the NWS Eastern, Southern, Central, and Western Regions, respectively. The regional values have the same general characteristics as those for the overall average except for the Western Region (see Table 4.6) where the comparative scores are very close for all three projections.

These results are similar to those associated with our previous verification study of guidance and local wind forecasts during the cool season of 1974-75 (Carter and Hollenbaugh, 1975). However, the bias characteristics for the guidance forecasts have been improved considerably by use of the inflation technique. There has also been a slight decrease in overall skill for the guidance forecasts of wind speed as a result of the inflation adjustment.

Table 4.7 shows the distribution of wind direction MAE's by categories--0-30^{o}, 40-60^{o}, 70-90^{o}, 100-120^{o}, 130-150^{o}, and 160-180^{o}--for all 92 stations combined. Here, the guidance had fewer errors of 40 degrees or more for all three projections.

The distribution of direction MAE's for each region are given in Tables 4.8-4.11. These results are like those in Table 4.7; however, once again the Western Region 18-hour local forecasts had slightly fewer errors of 40 degrees or more (see Table 4.11).

5. CEILING AND VISIBILITY

We computed verification scores for these two elements from guidance and local forecasts at both the 0000 GMT and 1200 GMT cycles for all 92 terminals shown in Table 1.1. Our guidance forecasts were generated from the cool season equations described in NWS Technical Procedures Bulletin No. 120 (NWS, 1974a). The equations are made up of predictors from surface observations, the PE model, and the TJ model.

We also computed verification scores for persistence forecasts of ceiling and visibility for the same group of terminals. Persistence forecasts were determined from the last surface airways observation available to the WSFO forecaster before the aviation terminal forecast (FT) filing deadline. The ceiling and visibility values which existed in that observation were used for each verification time that followed.

Our guidance forecasts are expressed as the probability of each of five categories for both ceiling and visibility; the category definitions are shown in Table 5.1. The probability forecasts are transformed into a categorical forecast and presented as the "best category" in the forecast message. The transformation is made such that the verification score for the NWS scoring matrix (NWS, 1973a) is maximized. For comparative verification, we used this categorical forecast since the local and persistence forecasts are for specific values of ceiling and visibility, which can be assigned to a category for direct comparison.

Table 5.1 Ceiling and visibility categories used for MOS five-category aviation guidance forecasts.

Category	Ceiling (ft)	Visibility (mi)
1	≤ 100	≤ 3/8
2	200-400	1/2-7/8
3	500-900	1-2 1/2
4	1000-1900	3-4
5	≥ 2000	≥ 5

Our MOS system generates ceiling and visibility guidance forecasts for projections of 12, 18, 24, and 30 hours from the numerical model runs at both 0000 GMT and 1200 GMT; we have computed verification statistics for the first three projections. FT's are expressed in a form which covers all hours of the 24-hour period for which they are valid; officially, they are verified at 12, 15, and 21 hours after 0000 GMT or 1200 GMT. Therefore, direct comparison between the guidance and local forecasts was possible only at the 12-hour projection.

For all the forecasts involved in this comparative verification, we constructed contingency tables which were then used to compute several different verification scores: bias by category, percent correct, and the NWS matrix score. We have summarized the scores in Tables 5.2 through 5.5; each table covers one element for one cycle time, for all forecast systems, arranged by projection.

For 12-hour projections, the tables show persistence and local forecasts were superior to our guidance forecasts for both elements at both cycles, all scores considered. We have encountered results like these in previous comparative verifications of ceiling and visibility for this projection (e.g. Crisci, 1976); they occur because of the advantage persistence and the local forecasters have over the MOS system for the first projection. The last observation which the local forecaster sees before the FT filing deadline is two or three hours (depending on the cycle and region) before the first verification; the same observation is used for the persistence

Table 5.2 Comparative verification of persistence, MOS guidance, and local ceiling forecasts, 0000 GMT cycle, for the period October 1975–March 1976, for 92 stations. PC is percent correct, MS is NWS matrix score.

Projection (Hr)	Type	Bias by Category					PC	MS
		1	2	3	4	5		
12	Guidance	.46	.66	.80	1.01	1.04	81.1	64.5
	Persistence	.83	.81	.97	.95	1.02	85.8	67.0
	Local	.65	.80	.94	1.17	1.01	84.3	66.5
15	Local	.51	.55	.70	1.14	1.04	80.9	64.8
	Persistence	1.24	.86	.81	.87	1.03	80.7	64.6
18	Guidance	.00	.24	.59	1.13	1.04	82.7	65.2
	Persistence	3.49	1.33	1.03	.91	.99	79.4	63.8
21	Local	.52	.32	.57	.99	1.03	86.0	66.1
	Persistence	5.33	1.78	1.26	1.06	.95	80.0	63.6
24	Guidance	.00	.11	.49	.84	1.05	86.9	65.9
	Persistence	4.12	1.69	1.30	1.26	.94	79.0	62.9

Table 5.3 Comparative verification of persistence, MOS guidance, and local visibility forecasts, 0000 GMT cycle, for the period October 1975-March 1976, for 92 stations. PC is percent correct, MS is NWS matrix score.

Projection (Hr)	Type	Bias by Category					PC	MS
		1	2	3	4	5		
12	Guidance	.38	.63	.70	.74	1.06	84.3	64.7
	Persistence	.73	.89	.73	.83	1.04	87.5	66.7
	Local	.58	1.17	.64	1.56	1.00	85.1	66.3
15	Local	.45	.57	.40	1.19	1.05	82.9	64.7
	Persistence	1.04	.75	.59	.77	1.05	83.0	64.5
18	Guidance	.09	.17	.47	.87	1.05	87.6	65.7
	Persistence	2.68	1.00	.77	1.11	1.00	84.1	64.5
21	Local	.26	.29	.39	1.29	1.03	88.8	66.4
	Persistence	3.35	1.27	.91	1.28	.98	84.4	64.3
24	Guidance	.00	.00	.19	.89	1.05	90.4	66.7
	Persistence	3.45	1.42	1.16	1.25	.97	84.3	64.3

Table 5.4 Comparative verification of persistence, MOS guidance, and local ceiling forecasts, 1200 GMT cycle, for the period October 1975–March 1976, for 92 stations. PC is percent correct, MS is NWS matrix score.

Projection (Hr)	Type	Bias by Category 1	2	3	4	5	PC	MS
12	Guidance	.29	.73	.70	1.07	1.02	87.1	66.5
	Persistence	.90	.91	1.00	1.12	.99	90.0	68.0
	Local	.40	.75	.85	1.17	1.00	89.8	67.9
15	Local	.33	.70	.78	1.30	1.00	86.7	66.7
	Persistence	.56	.78	.90	1.12	1.00	86.2	66.4
18	Guidance	.03	.38	.67	.95	1.05	83.8	65.0
	Persistence	.37	.69	.80	.97	1.03	83.3	65.0
21	Local	.30	.58	.95	1.38	1.00	80.5	64.3
	Persistence	.25	.53	.80	.93	1.05	80.6	63.6
24	Guidance	.13	.18	.82	1.07	1.06	79.6	63.1
	Persistence	.20	.44	.75	.87	1.07	78.4	62.2

Table 5.5 Comparative verification of persistence, MOS guidance, and local visibility forecasts, 1200 GMT cycle, for the period October 1975-March 1976, for 92 stations. PC is percent correct, MS is NWS matrix score.

Projection (Hr)	Type	Bias by Category					PC	MS
		1	2	3	4	5		
12	Guidance	.17	.28	.72	1.35	1.01	90.2	67.1
	Persistence	.89	1.21	1.21	.89	1.00	92.2	68.1
	Local	.59	.77	.82	1.48	.99	91.7	68.1
15	Local	.49	1.02	.96	1.69	.98	89.4	67.3
	Persistence	.74	1.39	1.33	.88	.99	90.1	67.0
18	Guidance	.11	.19	.32	1.14	1.04	89.1	66.3
	Persistence	.43	1.05	1.09	.84	1.01	87.8	65.9
21	Local	.36	.81	1.13	1.94	.96	83.2	64.9
	Persistence	.29	.79	1.04	.72	1.03	85.5	64.7
24	Guidance	.11	.06	.38	1.08	1.07	83.5	63.9
	Persistence	.19	.72	.72	.63	1.07	82.1	63.0

forecasts. The MOS equations use, in addition to the numerical model forecasts, predictors from surface observations taken seven hours prior to the valid time of the first projection. This is necessary because of time constraints imposed by operational deadlines. Therefore, persistence and local forecasts use data which are four to five hours more recent than the MOS system--this handicap is too much for our guidance forecasts to overcome in the first projection. Indeed, even the local forecasts lost to persistence across the board for what is considered to be a short-range forecast.

Eighteen-hour and 24-hour MOS guidance forecasts were better overall than persistence, in terms of PC and MS. This was particularly true in the 0000 GMT cycle when persistence can be saddled with an early morning ceiling or visibility condition that has a much lower frequency of occurrence in the afternoon and evening hours and is therefore less likely to verify.

Our MOS guidance forecasts displayed the same bias characteristic we have seen before--very few forecasts of the lower two or three categories, especially at the 18- and 24-hour projections. We have addressed this feature in the recent past (Crisci, 1976) and we expect to reduce the problem in the near future with the use of threshold probabilities. Notice that 18- and 24-hour persistence forecasts in the 0000 GMT cycle are also quite biased for the lower two or three categories, but in the opposite sense--far too many forecasts. This occurs, of course, for the reasons discussed in the previous paragraph. In the 1200 GMT cycle, persistence forecasts have generally better bias scores than our guidance forecasts, for all projections.

6. CONCLUSIONS

This verification shows that, overall, TDL's aviation/public weather guidance forecasts compare very favorably with local forecasts produced at WSFO's. In particular, automated guidance is substantially better than the local predictions for opaque sky cover and surface wind for the 30- and 42-hour projections, and for precipitation type for all projections. While both the objective and subjective estimates of ceiling and visibility are poorer than persistence forecasts for the initial (12-hour) projection, they are generally more accurate for longer periods. However, the bias characteristics of the objective estimates are unsatisfactory and will require improvement to meet the needs of users of these two products.

ACKNOWLEDGMENTS

We wish to thank the Technical Procedures Branch of the Office of Meteorology and Oceanography for providing us with the local forecasts, and especially Gerry Cobb of that Branch who processed the data. We are also grateful to Harry Akens, Fred Marshall, and Dean Costantinou of the Techniques Development Laboratory for assistance in archiving the guidance forecasts and error-checking the observations used for verification. Additional thanks are extended to Mary Battle for typing the text and the many tables shown in this report.

REFERENCES

Bocchieri, J. R., and H. R. Glahn, 1976: Verification and further development of an operational model for forecasting the probability of frozen precipitation. Mon. Wea. Rev., 104, 691-701.

Carter, G. M., 1975: Comparative verification of local and guidance cloud amount forecasts--No. 1. TDL Office Note, No. 75-7, Techniques Development Laboratory, Silver Spring, Md., pp. 8.

______, and G. W. Hollenbaugh, 1975: Comparative verification of local and guidance surface wind forecasts--No. 3. TDL Office Note, No. 75-9, Techniques Development Laboratory, Silver Spring, Md., pp. 13.

Crisci, R. L., 1976: Improving the bias in MOS ceiling and visibility forecasts. TDL Office Note, No. 76-4, Techniques Development Laboratory, Silver Spring, Md., pp. 8.

______, G. W. Hollenbaugh, and D. J. Vercelli, 1976: Comparative verification of guidance, local, and persistence forecasts of ceiling and visibility--No. 1. TDL Office Note, No. 76-11, Techniques Development Laboratory, Silver Spring, Md., pp. 8.

Glahn, H. R., and J. R. Bocchieri, 1975: Objective estimation of the conditional probability of frozen precipitation. Mon. Wea. Rev., 103, 3-15.

Howcroft, J., and A. Desmaris, 1971: The Limited Area Fine Mesh (LFM) model. NWS Tech. Proc. Bull., No. 67, pp. 11.

Klein, W. H., and H. R. Glahn, 1974: Forecasting local weather by means of model output statistics. Bull. Am. Meteor. Soc., 55, 1217-1227.

National Weather Service, 1973a: Combined aviation/public weather forecast verification. National Weather Service Operations Manual, Chapter C-73, pp. 15.

______, 1973b: Surface wind forecasts based on model output statistics (MOS)--No. 3. NWS Tech. Proc. Bull., No. 98, pp. 6.

______, 1974a: The use of model output statistics for predicting ceiling and visibility. NWS Tech. Proc. Bull., No. 120, pp. 10.

______, 1974b: Cloud amount forecasts based on model output statistics (MOS). NWS Tech. Proc. Bull., No. 124, pp. 9.

______, 1974c: Cloud amount forecasts based on model output statistics (MOS)--No. 2. NWS Tech. Proc. Bull., No. 125, pp. 6.

______, 1975: Warm season surface wind forecasts based on MOS--No. 4. NWS Tech. Proc. Bull., No. 137, pp. 6.