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COMPARATIVE VERIFICATION BETWEEN GEM AND THE OFFICIAL AVIATION TERMINAL FORECAST (FT)

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ABSTRACT

This paper reports on a comparative verification between the predominant conditions of the National Weather Service's Aviation Terminal Forecasts (FT's) and the statistically-produced forecasts of the Generalized Exponential Markov (GEM) model. Five weather elements were compared: ceiling, visibility, fog, thunderstorms, and wind. From an independent sample covering a 6-month period and for a set of stations located in four areas of the country, skill scores were determined. The outcome of this work indicates that GEM provides useful objective guidance over the 1 to 6 hour period tested, and has better skill inside 2 hours than the FT, while the FT's skill is higher at 3 hours and beyond. GEM also succeeds in bettering persistence throughout this 6-hour period.

1. INTRODUCTION

In this study, forecasts from the Generalized Exponential Markov (GEM) model, a single-station short-range statistical weather forecasting technique capable of producing hour-by-hour forecasts of weather elements important for aviation operations, are compared with the predominant conditions of National Weather Service (NWS) Official Aviation Terminal Forecasts (FT's) for the first 6 hours after FT issuance. A comparison is also made with persistence, widely-recognized as a tough competitor within the first 6 hours.

GEM as a forecasting procedure has been fully described elsewhere (see, e.g., Miller, 1981 and Miller et al., 1983) and will not be described here. Readers of this paper, however, may find of particular interest the results of two other comparative verifications involving GEM: one with Model Output Statistics (Perrone and Miller, 1983) and the other with persistence (Miller, 1981). Because of the much larger sample size used in the previous GEM/persistence study than here, the results presented in comparing GEM with persistence there are more statistically reliable; consequently, less emphasis will be placed here on comparing GEM with persistence than with the FT's.

Under AFOS-era[2] verification procedures, automated objective verification of aviation forecasts has replaced verification produced from mark-sense data cards, manually encoded by forecasters in NWS Forecast Offices. The FT encoding procedures used in this study lie somewhere between those of the automated AFOS-era verification procedures and manually-encoded mark sense cards, from the standpoint of automation of data collection. More importantly, however, this study marks the first time (to the best of the authors' knowledge) that extensive verification statistics have been produced for each of the first 6 hours of the FT.

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[2]Automation of Field Operations and Services.

This study was motivated by the following concerns:

a) Four NWS Forecast Offices had participated in a field test of GEM to evaluate the "user-friendliness" of the GEM forecasting software on AFOS for such items as the presentation and format of GEM forecast data, ease of software use, and field reaction to the size of programs comprising the GEM software package. Forecast office personnel also subjectively evaluated the utility of the GEM forecasts as short-range guidance. The results of the field study may be found in Vercelli et al. (1983). The concern is that the field test, while useful, was incomplete in that a straightforward objective verification of GEM, the FT, and persistence was not performed.

b) The Federal Aviation Administration (FAA) is interested in improved short-range forecasting, and has underwritten NWS development of the GEM forecast technique in the very short range (for making forecasts under 1 hour) (see, e.g., Miller, 1984). The FAA is also aware of the version of GEM reported on in this study (capable of making forecasts in hourly intervals). One potential use for the hour-by-hour version of GEM might be in support of FAA flow control operations, where changes in the weather out to 4 hours may have significant impact on the flow of aircraft into and through the FAA's enroute air traffic control system. The concern of the FAA is how well does hour-by-hour GEM compare with the official forecast.

Section 2 describes the data used in this study: the FT's, the characteristics of the GEM forecast procedure, and the extraction and processing of weather observation data used for persistence and forecast verification. Also described is the quality control of the transformation of FT forecast information from predominant conditions expressed as text into categories for the weather elements examined here. Section 3 describes in detail the weather elements and forecast projections that were verified, the verification scores that were used, and the results along with some pertinent observations. Section 4 offers conclusions and recommendations.

2. DATA

This section describes the data used in this study and the techniques used to process the data. Addressed are official FT collection and processing, extraction of persistence and verification information from observational data, and a brief description of the production of the GEM forecasts.

The FT forecasts used in this study consist of a total of approximately 3000 FT's. They were made three times daily from April through September by four NWS Forecast Offices for airports within their area of responsibility. These are the same forecast offices, one from each NWS Region, which participated in the field study of GEM in 1983: Cleveland (Eastern Region), Des Moines (Central Region), Birmingham (Southern Region), and Portland, Oregon (Western Region). A list of the airports, tabulated by Forecast Office, appears in Table 1.

The predominant conditions in each FT, valid for each of the first 6 hours covered by the FT, were used in this study, for the weather elements listed in Table 2. Remarks were not considered in expressing the forecast in the FT because of the difficulty associated with deciphering "chance," "slight

chance," "occasional," etc. into a categorical selection. This difficulty is avoided when predominent conditions constitute the forecast in the FT. Weather element information is used throughout this study in categorical form. The limits on each of the weather element categories are also presented in Table 2. Verification statistics were also compiled on lowest cloud height and amount, second cloud height and amount, total cloud cover, and precipitation occurrence. Only the variables considered vital to the issue of an FT amendment are presented here. Using the weather observation available 1 hour before FT issuance (0900 GMT, 1400 GMT, 2100 GMT (2200 GMT in the Western Region)) as input, GEM made categorical forecasts for each of the 6 hours for each element in Table 2, corresponding to those of the matching FT. The weather observation (needed as input to GEM) was also used, in categorized form as a persistence forecast.

FT's were collected in hard copy form from AFOS at the AFOS Experimental Facility at NWS Headquarters in Silver Spring, Maryland. Categorical data of the sort illustrated in Table 2 were extracted by use of an interactive computer program written for the purpose. The program prompted the operator to enter certain data contained in the predominant forecasts expressed in the FT; the program then generated the forecast categories for the weather elements of interest. Since extraction of the FT categories was not accomplished through fully automated means, we performed a quality control analysis to determine the accuracy of the categorical extraction. A 15% sample of the approximately 3000 decoded FT's was found to contain no errors of any kind. We concluded that the original decoding operation was sufficiently accurate. By not totally duplicating the decoding process in the quality control analysis, many hours of effort were saved.

Hourly weather observations archived at NWS Techniques Development Laboratory (TDL) were used in three ways: as the initial observations needed by GEM to produce its short-range forecasts, as verifying conditions for the FT/GEM comparison, and as the basis for persistence.

As indicated above, all weather forecast and observational data were converted to categorical form for the weather elements considered in this study. Consequently, the hourly weather observations in the TDL archive needed to be converted to the categories given in Table 2 for verification, as persistence, and as input to GEM. Unlike the FT, however, totally automated procedures were used to categorize the weather observation data.

Table 1. Airports, listed according to forecast office, whose data were used in this study.

Forecast Office	Airport	Forecast Office	Airport
Cleveland	CLE Cleveland	Birmingham	BHM Birmingham
	ZZV Zanesville		ANB Anniston
	CAK Akron		MGM Montgomery
			MOB Mobile
Des Moines	DSM Des Moines	Portland, Ore.	PDX Portland, Ore.
	ALO Waterloo		AST Astoria
			OTH North Bend
			MFR Medford

Table 2. Weather elements and categories that were verified in this study.

Element	Index	Category
Ceiling	1	0-100 ft
	2	200-400 ft
	3	500-900 ft
	4	1000-2900 ft
	5	3000-7500 ft
	6	> 7500 ft
Visibility	1	< 1/2 mi
	2	1/2-7/8 mi
	3	1-2 1/2 mi
	4	3-4 mi
	5	5-6 mi
	6	> 6 mi
Fog	1	Fog
	2	No Fog
Thunderstorm	1	Thunderstorm
	2	No thunderstorm
Wind	1	Any direction <10 Kt
	2	020-050° 10-19 Kt
	3	060-100° 10-19 Kt
	4	110-140° 10-19 Kt
	5	150-190° 10-19 Kt
	6	200-230° 10-19 Kt
	7	240-280° 10-19 Kt
	8	290-320° 10-19 Kt
	9	330-010°* 10-19 Kt
	10	020-100 ≥ 20 Kt
	11	110-190° ≥ 20 Kt
	12	200-280° ≥ 20 Kt
	13	290-010°* ≥ 20 Kt

*Through 360°.

3. RESULTS AND ANALYSIS

A. Results

Contingency tables and the skill scores derived from them (percentage correct, Heidke[3], and threat[4]) are presented in this subsection. Tables 3.1-3.42 display the contingency tables and verification statistics separately for each of the five elements of ceiling, visibility, fog, thunderstorm, and wind. Shown for each element are the results of all three methods being compared--Official FT, persistence, and GEM--for each of the six time projections--1, 2, 3, 4, 5, and 6 hours. In the subsection entitled Analysis we organize the results into a coherent picture leading us to the conclusions and recommendations found in the final section of this study.

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[3]The Heidke skill score measures skill relative to chance (Panofsky and Brier, 1965).

[4]Threat score = H/(F+O-H) is a measure of skill regarding threatening events where H is the number of correct forecasts of a category, and F and O are the number of forecasts and observations of that category, respectively. For ceiling and visibility, the threat score is calculated on the lowest two categories combined.

Table 3.1. Contingency tables and attendant verification scores (percentage correct, Heidke skill score, and threat score for the FT, persistence, and GEM--ceiling 1-h projection.

	Forecast Category	Verifying Observation Category 1	2	3	4	5	6	Total
	1	5	0	0	0	0	0	5
	2	6	22	7	5	0	6	46
FT	3	1	9	42	15	3	3	73
Forecast	4	0	5	35	190	42	56	330
	5	0	0	4	45	185	175	409
	6	4	7	4	26	108	2059	2208
	Total	16	43	92	281	338	2301	3071
	Hits:			81.50%				
	Heidke skill score:			.5757				
	Threat score:			.4286				
	1	8	3	0	0	0	1	12
	2	2	26	10	8	0	5	51
Persistence	3	1	5	53	33	3	9	104
Forecast	4	0	3	13	182	39	36	273
	5	0	1	6	25	212	127	371
	6	5	5	10	33	84	2123	2260
	Total	16	43	92	281	338	2301	3071
	Hits:			84.79%				
	Heidke skill score:			.6430				
	Threat score:			.4699				
	1	8	3	0	0	0	1	12
	2	2	29	11	10	1	5	58
GEM	3	1	3	54	44	3	9	114
Forecast	4	0	2	11	171	43	41	268
	5	0	1	6	24	208	134	373
	6	5	5	10	32	83	2111	2246
	Total	16	43	92	281	338	2301	3071
	Hits:			84.04%				
	Heidke skill score:			.6282				
	Threat score:			.4828				

Table 3.2. Same as Table 3.1--ceiling 2-h projection.

	Forecast Category	Verifying Observation Category 1	2	3	4	5	6	Total
	1	3	2	0	0	0	0	5
	2	5	13	7	4	1	8	38
FT	3	2	9	35	13	7	11	77
Forecast	4	1	3	33	154	43	72	306
	5	0	0	6	40	163	184	393
	6	2	8	13	46	115	1966	2150
	Total	13	35	94	257	329	2241	2969
	Hits:			78.61%				
	Heidke skill score:			.5013				
	Threat score:			.3382				
	1	4	4	0	0	0	4	12
	2	3	15	12	6	3	7	46
Persistence	3	1	4	37	33	9	18	102
Forecast	4	1	1	26	131	48	51	258
	5	0	2	3	33	150	169	357
	6	4	9	16	54	119	1992	2194
	Total	13	35	94	257	329	2241	2969
	Hits:			78.44%				
	Heidke skill score:			.4869				
	Threat score:			.3250				
	1	4	4	0	0	0	4	12
	2	3	16	12	7	5	7	50
GEM	3	2	5	45	46	14	18	130
Forecast	4	0	0	20	127	53	59	259
	5	0	1	1	28	124	119	273
	6	4	9	16	49	133	2034	2245
	Total	13	35	94	257	329	2241	2969
	Hits:			79.15%				
	Heidke skill score:			.4914				
	Threat score:			.3253				

Table 3.3. Same as Table 3.1--ceiling 3-h projection.

	Forecast Category	Verifying Observation Category 1	2	3	4	5	6	Total
	1	3	0	1	0	0	3	7
	2	5	7	7	2	4	8	33
FT	3	2	12	23	20	9	14	80
Forecast	4	1	6	35	129	39	88	298
	5	0	3	2	64	148	207	424
	6	5	9	11	61	155	1931	2172
	Total	16	37	79	276	355	2251	3014*
	Hits:			74.35%				
	Heidke skill score:			.4109				
	Threat score:			.1923				
	1	4	0	2	0	0	7	13
	2	4	9	12	14	3	7	49
Persistence	3	2	7	18	46	15	23	111
Forecast	4	0	4	24	114	52	72	266
	5	0	4	8	36	126	186	360
	6	6	13	15	66	159	1956	2215
	Total	16	37	79	276	355	2251	3014*
	Hits:			73.89%				
	Heidke skill score:			.3896				
	Threat score:			.1735				
	1	4	0	2	0	0	7	13
	2	4	9	13	13	4	8	51
GEM	3	2	11	21	53	16	23	126
Forecast	4	0	1	24	120	63	79	287
	5	0	3	3	36	89	119	250
	6	6	13	16	54	183	2014	2286
	Total	16	37	79	276	355	2250	3013*
	Hits:			74.91%				
	Heidke skill score:			.3933				
	Threat score:			.1700				

*Sample sizes may differ slightly because a forecast for that method had to be rejected. Microcomputer processing required evaluating each method separately, so the extra effort necessary to precisely match the samples was not expended. Samples differ by no more than one observation.

Table 3.4. Same as Table 3.1--ceiling 4-h projection.

	Forecast Category	Verifying Observation Category 1	2	3	4	5	6	Total
	1	3	2	0	0	0	0	5
	2	6	7	4	3	2	9	31
FT	3	1	16	16	19	6	16	74
Forecast	4	0	11	35	127	55	81	309
	5	0	3	11	65	153	184	416
	6	6	11	15	56	204	1917	2209
	Total	16	50	81	270	420	2207	3044
	Hits:			73.03%				
	Heidke skill score:			.3941				
	Threat score:			.2143				
	1	3	0	2	0	0	6	11
	2	5	12	6	11	5	10	49
Persistence	3	1	9	18	47	13	23	111
Forecast	4	0	7	25	105	60	71	268
	5	0	4	10	35	128	191	368
	6	7	18	20	72	214	1906	2237
	Total	16	50	81	270	420	2207	3044
	Hits:			71.35%				
	Heidke skill score:			.3511				
	Threat score:			.1887				
	1	2	0	1	0	0	6	9
	2	6	11	8	9	4	10	48
GEM	3	1	14	23	49	12	26	125
Forecast	4	0	6	24	104	81	68	283
	5	0	1	9	34	75	125	244
	6	7	18	16	74	248	1972	2335
	Total	16	50	81	270	420	2207	3044
	Hits:			71.85%				
	Heidke skill score:			.3347				
	Threat score:			.1827				

Table 3.5. Same as Table 3.1--ceiling 5-h projection.

	Forecast Category	Verifying Observation Category 1	2	3	4	5	6	Total
	1	0	2	0	0	0	1	3
	2	5	3	3	4	1	4	20
FT	3	3	10	13	18	8	17	69
Forecast	4	1	7	35	112	52	83	290
	5	0	4	13	76	147	181	421
	6	4	8	22	65	207	1929	2235
	Total	13	34	86	275	415	2215	3038
	Hits:			72.55%				
	Heidke skill score:			.3694				
	Threat score:			.1667				
	1	1	0	1	2	0	9	13
	2	3	7	7	15	5	9	46
Persistence	3	2	5	14	45	16	26	108
Forecast	4	1	4	19	94	66	78	262
	5	1	3	13	34	103	217	371
	6	5	15	32	85	225	1877	2239
	Total	13	34	86	275	415	2216	3039
	Hits:			68.97%				
	Heidke skill score:			.2901				
	Threat score:			.1158				
	1	0	0	1	2	0	8	11
	2	4	5	7	10	2	9	37
GEM	3	3	10	17	44	17	27	118
Forecast	4	0	4	23	109	71	78	285
	5	1	0	11	26	56	110	204
	6	5	15	27	84	269	1984	2384
	Total	13	34	86	275	415	2216	3039
	Hits:			71.44%				
	Heidke skill score:			.3018				
	Threat score:			.1047				

Table 3.6. Same as Table 3.1--ceiling 6-h projection.

	Forecast Category	Verifying Observation Category 1	2	3	4	5	6	Total
	1	0	1	0	0	0	0	1
	2	5	4	3	0	0	4	16
FT	3	2	5	14	17	10	11	59
Forecast	4	1	5	32	105	53	92	288
	5	0	0	13	81	140	190	424
	6	2	4	15	63	213	1949	2246
	Total	10	19	77	266	416	2246	3034
	Hits:			72.91%				
	Heidke skill score:			.3610				
	Threat score:			.2778				
	1	1	0	0	1	0	10	12
	2	2	8	8	13	6	11	48
Persistence	3	2	3	16	38	22	29	110
Forecast	4	1	2	19	89	67	91	360
	5	1	1	8	38	85	233	366
	6	3	5	26	87	236	1872	2229
	Total	10	19	77	266	416	2246	3034
	Hits:			68.26%				
	Heidke skill score:			.2632				
	Threat score:			.1410				
	1	0	0	0	0	0	8	8
	2	3	4	6	9	3	9	34
GEM	3	3	7	16	38	16	27	107
Forecast	4	1	3	23	99	71	86	283
	5	0	0	5	30	36	105	176
	6	3	5	27	90	290	2011	2426
	Total	10	19	77	266	416	2246	3034
	Hits:			71.39%				
	Heidke skill score:			.2682				
	Threat score:			.1094				

Table 3.7. Same as Table 3.1--visibility 1-h projection.

	Forecast Category	Verifying Observation Category 1	2	3	4	5	6	Total
	1	5	1	0	0	0	0	6
	2	4	5	9	0	1	3	22
FT	3	4	10	52	16	5	2	89
Forecast	4	2	1	28	116	49	58	254
	5	1	1	16	59	152	208	437
	6	0	0	10	23	117	2113	2263
	Total	16	18	115	214	324	2384	3071
	Hits:			79.55%				
	Heidke skill score:			.4965				
	Threat score:			.3191				
	1	8	3	5	0	1	1	18
	2	0	5	6	3	1	5	20
Persistence	3	5	8	74	22	6	8	123
Forecast	4	1	1	14	130	51	12	209
	5	1	0	4	34	187	73	299
	6	1	1	12	25	78	2285	2402
		16	18	115	214	324	2384	3071
	Hits:			87.56%				
	Heidke skill score:			.6694				
	Threat score:			.2857				
	1	8	3	5	0	1	1	18
	2	0	5	5	2	1	5	18
GEM	3	5	8	75	23	5	8	124
Forecast	4	1	1	14	130	51	12	209
	5	1	0	4	34	185	72	296
	6	1	1	12	25	81	2286	2468
	Total	16	18	115	214	324	2384	3071
	Hits:			87.56%				
	Heidke skill score:			.6686				
	Threat score:			.2963				

Table 3.8. Same as Table 3.1--visibility 2-h projection.

	Forecast Category	Verifying Observation Category 1	2	3	4	5	6	Total
	1	2	2	0	0	2	0	6
	2	2	2	9	0	2	3	18
FT	3	7	8	48	16	4	10	93
Forecast	4	1	3	45	91	53	47	240
	5	3	0	17	67	132	198	417
	6	0	4	9	36	129	2019	2197
	Total	15	19	128	210	322	2277	2971
	Percent Correct:	77.21%						
	Heidke skill score:	.4455						
	Threat score:	.1600						
	1	3	2	4	0	5	4	18
	2	0	3	5	3	1	8	20
Persistence	3	5	4	60	22	11	16	118
Forecast	4	3	2	30	79	59	24	197
	5	1	1	13	41	131	99	286
	6	3	7	16	65	115	2126	2332
	Total	15	19	128	210	322	2277	2971
	Percent Correct:	80.85%						
	Heidke skill score:	.4980						
	Threat score:	.1250						
	1	3	3	5	1	5	4	21
	2	0	0	3	1	0	3	7
GEM	3	5	6	52	18	7	16	104
Forecast	4	3	2	35	70	31	18	159
	5	1	1	17	51	135	63	268
	6	3	7	16	69	144	2173	2412
	Total	15	19	128	210	322	2277	2971
	Percent Correct:	81.89%						
	Heidke skill score:	.5007						
	Threat score:	.1071						

Table 3.9. Same as Table 3.1--visibility 3-h projection.

	Forecast Category	Verifying Observation Category 1	2	3	4	5	6	Total
	1	3	0	1	0	2	0	6
	2	3	2	6	2	1	6	20
FT	3	7	8	47	9	8	12	91
Forecast	4	4	4	58	77	47	55	245
	5	0	2	34	67	121	179	403
	6	1	3	17	56	150	2023	2250
	Total	18	19	163	211	329	2275	3015
	Hits:			75.39%				
	Heidke skill score:			.4069				
	Threat score:			.1455				
	1	3	0	5	1	3	6	18
	2	0	1	3	4	2	12	22
FT	3	6	9	54	22	19	20	130
Forecast	4	3	1	36	65	61	43	209
	5	1	4	21	40	105	125	296
	6	5	4	44	79	139	2069	2340
	Total	18	19	163	211	329	2275	3015
	Hits:			76.19%				
	Heidke skill score:			.3992				
	Threat score:			.0548				
	1	3	1	6	1	3	6	20
	2	0	0	0	2	0	3	5
GEM	3	6	9	38	12	13	19	97
Forecast	4	2	1	50	44	23	23	143
	5	2	3	19	67	81	59	231
	6	5	5	50	85	209	2164	2518
	Total	18	19	163	211	329	2274	3014
	Hits:			77.31%				
	Heidke skill score:			.3629				
	Threat score:			.0690				

Table 3.10. Same as Table 3.1--visibility 4-h projection.

	Forecast Category	Verifying Observation Category 1	2	3	4	5	6	Total
	1	2	0	0	0	2	1	5
	2	3	1	2	0	1	8	15
FT	3	4	9	31	10	6	16	76
Forecasts	4	2	7	57	64	47	67	244
	5	0	2	34	61	110	178	385
	6	2	3	23	43	171	2078	2320
	Total	13	22	147	178	337	2348	3045
	Percent correct:	75.07%						
	Heidke skill score:	.3651						
	Threat score:	.1224						
	1	2	1	2	2	2	7	16
	2	0	1	0	4	0	16	21
Persistence	3	5	7	45	28	18	26	129
Forecast	4	1	1	36	49	56	68	211
	5	0	4	20	38	92	141	295
	6	5	8	44	57	169	2090	2373
	Total	13	22	147	178	337	2348	3045
	Percent correct:	74.84%						
	Heidke skill score:	.3418						
	Threat score:	.0588						
	1	2	1	2	3	2	6	16
	2	0	1	0	0	0	4	5
GEM	3	4	8	22	17	4	25	80
Forecast	4	2	1	38	24	23	29	117
	5	0	3	34	62	52	60	211
	6	5	8	51	72	256	2224	2616
	Total	13	22	147	178	337	2348	3045
	Percent correct:	76.35%						
	Heidke skill score:	.2754						
	Threat score:	.0769						

Table 3.11. Same as Table 3.1--visibility 5-h projection.

	Forecast Category	Verifying Observation Category 1	2	3	4	5	6	Total
	1	0	0	0	1	0	2	3
	2	3	3	0	0	0	4	10
FT	3	1	2	16	9	2	13	43
Forecast	4	2	3	43	67	42	53	210
	5	0	2	25	59	114	202	402
	6	2	7	11	50	153	2147	2370
	Total	8	17	95	186	311	2421	3038
	Percent correct:	77.25%						
	Heidke skill score:	.3683						
	Threat score:	.1875						
	1	0	0	2	2	2	11	17
	2	0	0	1	3	1	16	21
Persistence	3	1	4	37	29	21	39	131
Forecast	4	1	0	18	60	49	76	204
	5	0	2	18	36	81	159	296
	6	6	11	19	56	157	2121	2370
	Total	8	17	95	186	311	2422	3039
	Percent correct:	74.65%						
	Heidke skill score:	.3292						
	Threat score:	.0000						
	1	0	0	2	3	1	11	17
	2	1	0	0	0	0	2	3
GEM	3	1	3	12	14	8	25	63
Forecast	4	0	2	30	26	17	33	108
	5	0	2	27	55	40	53	177
	6	6	10	24	88	245	2298	2671
	Total	8	17	95	186	311	2422	3039
	Percent Correct:	78.18%						
	Heidke skill score:	.2496						
	Threat score:	.0227						

Table 3.12. Same as Table 3.1--visibility 6-h projection.

	Forecast Category	Verifying Observation Category 1	2	3	4	5	6	Total
FT Forecast	1	0	0	0	0	0	1	1
	2	2	1	2	0	0	5	10
	3	1	3	10	5	1	9	29
	4	1	2	26	52	33	55	169
	5	1	0	18	57	111	206	393
	6	1	5	20	52	161	2193	2432
	Total	6	11	76	166	306	2469	3034
	Hits:			78.02%				
	Heidke skill score:			.3365				
	Threat score:			.1200				
Persistence Forecast	1	0	0	0	3	2	10	15
	2	0	0	1	2	3	16	22
	3	1	4	30	26	28	40	129
	4	0	0	10	52	52	84	198
	5	0	0	12	30	83	171	296
	6	5	7	23	53	138	2148	2374
	Total	6	11	76	166	306	2469	3034
	Hits:			76.24%				
	Heidke skill score:			.3186				
	Threat score:			.0000				
GEM Forecast	1	0	0	0	2	1	7	10
	2	0	0	1	1	1	4	7
	3	1	3	5	9	9	20	47
	4	0	1	18	16	19	33	87
	5	0	0	19	39	34	54	146
	6	5	7	33	99	242	2351	2737
	Total	6	11	76	166	306	2469	3034
	Hits:			79.30%				
	Heidke skill score:			.2010				
	Threat score:			.0000				

Table 3.13. Same as 3.1--fog 1-h projection.

	Forecast Category	Verifying Observation Category 1	2	Total
FT Forecast	1	270	194	464
	2	77	2537	2604
	Total	347	2721	3068
	Percent correct:	91.17%		
	Heidke skill score:	.6162		
	Threat score:	.4991		
Persistence Forecast	1	264	95	359
	2	83	2626	2709
	Total	347	2721	3068
	Percent correct:	94.20%		
	Heidke skill score:	.7151		
	Threat score:	.5973		
GEM Forecast	1	264	95	359
	2	83	2626	2709
	Total	347	2721	3068
	Percent correct:	94.20%		
	Heidke skill score:	.7151		
	Threat score:	.5973		

Table 3.14. Same as 3.1--fog 2-h projection.

	Forecast Category	Verifying Observation Category 1	2	Total
FT Forecast	1	268	175	443
	2	111	2414	2525
	Total	379	2589	2968
	Percent correct:	90.36%		
	Heidke skill score:	.5965		
	Threat score:	.4838		
Persistence Forecast	1	213	132	345
	2	165	2457	2622
	Total	378	2589	2967
	Percent correct:	89.99%		
	Heidke skill score:	.5324		
	Threat score:	.4176		
GEM Forecast	1	214	132	346
	2	165	2457	2622
	Total	379	2589	2968
	Percent correct:	89.99%		
	Heidke skill score:	.5335		
	Threat score:	.4188		

Table 3.15. Same as 3.1--fog 3-h projection.

	Forecast Category	Verifying Observation Category 1	2	Total
FT Forecast	1	272	173	445
	2	135	2432	2567
	Total	407	2605	3012
	Percent correct:	89.77%		
	Heidke skill score:	.5791		
	Threat score:	.4690		
Persistence Forecast	1	196	168	364
	2	210	2437	2647
	Total	406	2605	3011
	Percent correct:	87.45%		
	Heidke skill score:	.4374		
	Threat score:	.3415		
GEM Forecast	1	193	131	324
	2	214	2473	2687
	Total	407	2604	3011
	Percent correct:	88.54%		
	Heidke skill score:	.4638		
	Threat score:	.3587		

Table 3.16. Same as 3.1--fog-4 h projection.

	Forecast Category	Verifying Observation Category 1	2	Total
FT Forecast	1	207	194	401
	2	119	2524	2643
	Total	326	2718	3044
	Percent correct:	89.72%		
	Heidke skill score:	.5118		
	Threat score:	.3981		
Persistence Forecast	1	151	211	362
	2	174	2507	2681
	Total	325	2718	3043
	Percent correct:	87.35%		
	Heidke skill score:	.3685		
	Threat score:	.2817		
GEM Forecast	1	119	124	243
	2	207	2594	2801
	Total	326	2718	3044
	Percent correct:	89.13%		
	Heidke skill score:	.3597		
	Threat score:	.2644		

Table 3.17. Same as 3.1--fog 5-h projection.

	Forecast Category	Verifying Observation Category 1	2	Total
FT Forecast	1	115	184	299
	2	129	2610	2739
	Total	244	2794	3038
	Percent correct:	89.70%		
	Heidke skill score:	.3676		
	Threat score:	.2687		
Persistence Forecast	1	108	252	360
	2	136	2542	2678
	Total	244	2794	3038
	Percent correct:	87.23%		
	Heidke skill score:	.2896		
	Threat score:	.2177		
GEM Forecast	1	73	111	184
	2	171	2684	2855
	Total	244	2795	3039
	Percent correct:	90.72%		
	Heidke skill score:	.2923		
	Threat score:	.2056		

Table 3.18. Same as 3.1--fog 6-h projection.

	Forecast Category	Verifying Observation Category 1	2	Total
FT	1	76	155	231
Forecast	2	113	2690	2803
	Total	189	2845	3034
	Percent correct:	91.17%		
	Heidke skill score:	.3150		
	Threat score:	.2209		
Persistence	1	69	287	356
Forecast	2	120	2557	2677
	Total	189	2844	3033
	Percent correct:	86.58%		
	Heidke skill score:	.1870		
	Threat score:	.1450		
GEM	1	48	105	153
Forecast	2	141	2740	2881
	Total	189	2845	3034
	Percent correct:	91.89%		
	Heidke skill score:	.2382		
	Threat score:	.1633		

Table 3.19. Same as 3.1--thunderstorm 1-h projection.

	Forecast Category	Verifying Observation Category 1	2	Total
FT	1	3	5	8
Forecast	2	37	3023	3060
	Total	40	3028	3068
	Percent correct:	98.63%		
	Heidke skill score:	.1212		
	Threat score:	.0667		
Persistence	1	20	29	49
Forecast	2	20	2999	3019
	Total	40	3028	3068
	Percent correct:	98.40%		
	Heidke skill score:	.4414		
	Threat score:	.2899		
GEM	1	20	29	49
Forecast	2	20	2999	3019
	Total	40	3028	3068
	Percent correct:	98.40%		
	Heidke skill score:	.4414		
	Threat score:	.2899		

Table 3.20. Same as 3.1--thunderstorm 2-h projection.

	Forecast Category	Verifying Observation Category 1	2	Total
FT Forecast	1	5	4	9
	2	37	2922	2959
	Total	42	2926	2968
	Percent correct:	98.62%		
	Heidke skill score:	.1921		
	Threat score:	.1087		
Persistence Forecast	1	10	37	47
	2	32	2888	2920
	Total	42	2925	2967
	Percent correct:	97.67%		
	Heidke skill score:	.2130		
	Threat score:	.1266		
GEM Forecast	1	10	37	47
	2	32	2889	2921
	Total	42	2926	2968
	Percent correct:	97.68%		
	Heidke skill score:	.2130		
	Threat score:	.1266		

Table 3.21. Same as 3.1--thunderstorm 3-h projection.

	Forecast Category	Verifying Observation Category 1	2	Total
FT	1	2	8	10
Forecast	2	36	2966	3002
	Total	38	2974	3012
	Percent correct:	98.54%		
	Heidke skill score:	.0785		
	Threat score:	.0435		
Persistence	1	6	43	49
Forecast	2	32	2930	2962
	Total	38	2973	3011
	Percent correct:	97.51%		
	Heidke skill score:	.1255		
	Threat score:	.0741		
GEM	1	6	44	50
Forecast	1	32	2929	2961
	Total	38	2973	3011
	Percent correct:	97.48%		
	Heidke skill score:	.1238		
	Threat score:	.0732		

Table 3.22. Same as 3.1--thunderstorm 4-h projection.

	Forecast Category	Verifying Observation Category 1	2	Total
FT Forecast	1	3	4	7
	2	41	2996	3037
	Total	44	3000	3044
	Percent correct:	98.52%		
	Heidke skill score:	.1141		
	Threat score:	.0625		
Persistence Forecast	1	5	42	47
	2	39	2957	2996
	Total	44	2999	3043
	Percent correct:	97.34%		
	Heidke skill score:	.0964		
	Threat score:	.0581		
GEM Forecast	1	5	39	44
	2	39	2961	3000
	Total	44	3000	3044
	Percent correct:	97.44%		
	Heidke skill score:	.1006		
	Threat score:	.0602		

Table 3.23. Same as 3.1--thunderstorm 5-h projection.

	Forecast Category	Verifying Observation Category 1	2	Total
FT	1	1	2	3
Forecast	2	29	3006	3035
	Total	30	3008	3038
	Percent correct:	98.98%		
	Heidke skill score:	.0589		
	Threat score:	.0313		
Persistence	1	1	45	46
Forecast	2	29	2963	2992
	Total	30	3008	3038
	Percent correct:	97.56%		
	Heidke skill score:	.0145		
	Threat score:	.0133		
GEM	1	0	15	15
Forecast	2	30	2994	3024
	Total	30	3009	3039
	Percent correct:	98.52%		
	Heidke skill score:	-.0064		
	Threat score:	0.0000		

Table 3.24. Same as 3.1--thunderstorm 6-h projection.

	Forecast Category	Verifying Observation Category 1	2	Total
FT Forecast	1	0	2	2
	2	36	2996	3032
	Total	36	2998	3034
	Percent correct:	98.75%		
	Heidke skill score:	-.0024		
	Threat score:	.0000		
Persistence Forecast	1	1	48	49
	2	35	2948	2983
	Total	36	2996	3032
	Percent correct:	97.26%		
	Heidke skill score:	.0097		
	Threat score:	.0119		
GEM Forecast	1	0	2	2
	2	36	2996	3032
	Total	36	2998	3034
	Percent correct:	98.75%		
	Heidke skill score:	-.0024		
	Threat score:	.0000		

Table 3.25. Contingency tables and attendant verification scores (percentage correct, Heidke skill score, and threat score for the FT, persistence and GEM--wind 1-h projection for the FT.

	Forecast Category	Verifying Observation Category 1	2	3	4	5	6	7	8	9	10	11	12	13	Total
	1	1909	15	6	7	27	18	35	17	15	0	0	0	0	2049
	2	28	18	1	0	0	0	0	0	6	2	0	0	0	55
	3	21	4	14	5	1	0	0	0	0	0	0	0	0	45
	4	44	0	0	14	8	0	0	0	0	0	2	0	0	68
	5	96	0	1	11	58	16	0	1	0	0	1	0	0	184
FT	6	81	0	0	0	22	62	17	1	2	0	0	1	0	186
Forecast	7	45	0	0	0	0	13	45	8	0	0	0	0	1	112
	8	73	0	0	0	0	1	10	67	18	0	0	0	2	171
	9	89	4	0	0	1	1	0	18	53	0	0	0	6	172
	10	0	1	1	0	0	0	0	0	0	0	0	0	0	2
	11	0	0	0	0	3	0	0	0	0	0	1	0	0	4
	12	0	0	0	0	0	0	2	0	0	0	0	7	0	9
	13	0	0	0	0	0	0	0	1	1	0	0	0	9	11
	Total	2386	42	23	37	120	111	109	113	95	2	4	8	18	3068

Percent correct: 73.57%
Heidke skill score: .4380

Table 3.26. Same as Table 3.25--wind 1-h projection for persistence.

Forecast Category	Verifying Observation Category 1	2	3	4	5	6	7	8	9	10	11	12	13	Total
1	2221	12	7	12	30	25	39	31	28	0	0	0	0	2405
2	15	19	1	0	0	0	0	0	4	1	0	0	0	40
3	10	3	13	3	1	0	0	0	0	1	0	0	0	31
4	11	0	0	15	9	1	0	0	0	0	2	0	0	38
5	27	0	1	5	56	16	0	0	0	0	1	0	0	106
Persist- 6	22	0	0	0	22	55	13	0	0	0	0	2	0	114
ence 7	34	0	0	0	0	12	49	13	2	0	0	0	0	110
Forecast 8	20	0	0	1	0	0	7	54	16	0	0	0	4	102
9	26	7	0	0	0	0	1	13	43	0	0	0	4	94
10	0	1	1	0	0	0	0	0	0	0	0	0	0	2
11	0	0	0	1	1	0	0	0	0	0	1	0	0	3
12	0	0	0	0	1	2	0	0	0	0	0	6	0	9
13	0	0	0	0	0	0	0	2	2	0	0	0	10	14
Total	2386	42	23	37	120	111	109	113	95	2	4	8	18	3068

Percent correct: 82.86%
Heidke skill score: .5533

Table 3.27. Same as Table 3.25--wind 1-h projection for GEM.

	Forecast Category	Verifying Observation Category 1	2	3	4	5	6	7	8	9	10	11	12	13	Total
	1	2221	12	7	12	30	25	39	31	28	0	0	0	0	2405
	2	15	19	1	0	0	0	0	0	4	1	0	0	0	40
	3	10	3	13	3	1	0	0	0	0	1	0	0	0	31
	4	11	0	0	15	9	1	0	0	0	0	2	0	0	38
	5	27	0	1	5	56	16	0	0	0	0	1	0	0	106
GEM	6	22	0	0	0	22	55	13	0	0	0	0	2	0	114
Forecast	7	34	0	0	0	0	12	49	13	2	0	0	0	0	110
	8	20	0	0	1	0	0	7	54	16	0	0	0	4	102
	9	26	7	0	0	0	0	1	13	43	0	0	0	4	94
	10	0	1	1	0	0	0	0	0	0	0	0	0	0	2
	11	0	0	0	1	1	0	0	0	0	0	1	0	0	3
	12	0	0	0	0	1	2	0	0	0	0	0	6	0	9
	13	0	0	0	0	0	0	0	2	2	0	0	0	10	14
	Total	2386	42	23	37	120	111	109	113	95	2	4	8	18	3068

Percent correct: 82.86%
Heidke skill score: .5533

Table 3.28. Same as Table 3.25--wind 2-h projection for the FT.

	Forecast Category	Verifying Observation Category 1	2	3	4	5	6	7	8	9	10	11	12	13	Total
	1	1844	17	14	11	21	26	27	14	17	0	0	0	0	1991
	2	27	14	2	0	0	0	0	0	8	0	0	0	1	52
	3	22	4	11	5	0	0	0	0	0	1	0	0	0	43
	4	37	0	2	11	8	0	0	0	1	0	1	0	0	60
	5	90	0	0	6	61	16	1	0	1	0	0	1	0	176
FT	6	78	0	0	0	22	61	16	1	2	0	0	0	0	180
Forecast	7	49	0	0	0	0	13	36	11	0	0	0	3	0	112
	8	86	1	0	0	0	0	14	49	17	0	0	0	1	168
	9	88	6	0	0	0	0	2	18	45	0	0	0	4	163
	10	0	0	1	0	0	0	0	0	0	1	0	0	0	2
	11	0	0	0	0	2	0	0	0	0	0	2	0	0	4
	12	0	0	0	0	0	0	2	0	0	0	0	6	0	8
	13	0	0	0	0	0	0	0	0	1	0	0	1	7	9
	Total	2321	42	30	33	114	116	98	93	92	2	3	11	13	2968

Percent correct: 72.37%
Heidke skill score: .4064

Table 3.29. Same as Table 3.25--wind 2-h projection for persistence.

Forecast Category	Verifying Observation Category 1	2	3	4	5	6	7	8	9	10	11	12	13	Total
1	2105	22	15	16	31	43	44	30	34	0	0	0	0	2340
2	18	10	2	0	0	0	0	0	3	0	0	0	1	34
3	7	4	10	4	0	0	0	0	1	1	0	0	0	27
4	12	0	2	11	8	1	0	0	0	0	1	0	0	35
5	32	0	0	1	50	16	0	0	1	0	0	1	0	101
Persist- 6	34	0	0	0	22	44	11	0	0	0	0	2	0	113
ence 7	40	0	0	0	2	9	38	10	3	0	0	3	0	105
Forecast 8	35	1	0	0	0	0	4	43	16	0	0	0	2	101
9	36	5	0	0	0	1	0	8	34	0	0	0	2	86
10	0	0	1	0	0	0	0	0	0	1	0	0	0	2
11	0	0	0	1	1	0	0	0	0	0	1	0	0	3
12	1	0	0	0	0	2	1	0	0	0	1	4	0	9
13	0	0	0	0	0	0	0	2	0	0	0	1	8	11
Total	2320	42	30	33	114	116	98	93	92	2	3	11	13	2967

Percent correct: 79.51%
Heidke skill score: .4564

Table 3.30. Same as Table 3.25--wind 2-h projection for GEM.

	Forecast Category	Verifying Observation Category 1	2	3	4	5	6	7	8	9	10	11	12	13	Total
	1	2106	22	15	16	31	43	44	30	34	0	0	0	0	2341
	2	18	10	2	0	0	0	0	0	3	0	0	0	1	34
	3	7	4	10	4	0	0	0	0	1	1	0	0	0	27
	4	12	0	2	11	8	1	0	0	0	0	1	0	0	35
	5	32	0	0	1	50	16	0	0	1	0	0	1	0	101
GEM	6	34	0	0	0	22	44	11	0	0	0	0	2	0	113
Forecast	7	40	0	0	0	2	9	38	10	3	0	0	3	0	105
	8	35	1	0	0	0	0	4	43	16	0	0	0	2	101
	9	36	5	0	0	0	1	0	8	34	0	0	0	2	86
	10	0	0	1	0	0	0	0	0	0	1	0	0	0	2
	11	0	0	0	1	1	0	0	0	0	0	1	0	0	3
	12	1	0	0	0	0	2	1	0	0	0	1	4	0	9
	13	0	0	0	0	0	0	0	2	0	0	0	1	8	11
	Total	2321	42	30	33	114	116	98	93	92	2	3	11	13	2968

Percent correct: 79.51%
Heidke skill score: .4564

Table 3.31. Same as Table 3.25--wind 3-h projection for the FT.

	Forecast Category	Verifying Observation Category 1	2	3	4	5	6	7	8	9	10	11	12	13	Total
	1	1858	13	7	6	19	23	22	17	15	0	0	1	0	1981
	2	36	15	2	0	0	0	0	0	9	0	0	0	0	62
	3	29	3	9	3	1	0	0	0	0	2	0	0	0	47
	4	37	0	4	10	11	1	0	0	0	0	1	0	0	64
	5	96	0	1	9	59	21	1	1	0	0	3	0	0	191
FT	6	92	0	0	0	27	52	18	0	1	0	0	2	0	192
Forecast	7	63	0	0	0	1	10	21	10	0	0	0	2	1	108
	8	104	0	0	0	1	0	15	40	16	0	0	0	1	177
	9	99	5	0	0	0	0	1	16	46	0	0	0	0	167
	10	0	1	1	0	0	0	0	0	0	0	0	0	0	2
	11	0	0	0	0	2	0	0	0	0	0	2	0	0	4
	12	0	0	0	0	0	0	2	1	0	0	0	4	0	7
	13	0	0	0	0	0	0	0	2	1	0	0	1	6	10
	Total	2414	37	24	28	121	107	80	87	88	2	6	10	8	3012

Percent correct: 70.45%
Heidke skill score: .3621

Table 3.32. Same as Table 3.25--wind 3-h projection for persistence.

Forecast Category		Verifying Observation Category													Total
		1	2	3	4	5	6	7	8	9	10	11	12	13	
Persistence Forecast	1	2128	18	10	11	53	52	32	33	31	1	0	1	0	2370
	2	22	10	3	0	0	0	0	0	3	0	0	0	0	38
	3	14	4	8	1	0	0	0	0	1	1	1	0	0	30
	4	15	0	1	10	9	1	0	0	0	0	0	0	0	36
	5	41	1	1	5	42	12	1	0	0	0	2	0	0	105
	6	44	0	0	0	16	38	9	0	0	0	0	3	0	110
	7	60	0	0	0	1	4	28	7	4	0	0	3	1	108
	8	43	0	0	0	0	0	8	36	15	0	0	0	0	102
	9	45	3	0	0	0	0	0	8	31	0	0	0	1	88
	10	0	1	1	0	0	0	0	0	0	0	0	0	0	2
	11	0	0	0	1	0	0	0	0	0	0	2	0	0	3
	12	1	0	0	0	0	0	2	0	0	0	1	2	0	6
	13	0	0	0	0	0	0	0	3	3	0	0	1	6	13
	Total	2413	37	24	28	121	107	80	87	88	2	6	10	8	3011

Percent correct: 77.75%
Heidke skill score: .3876

Table 3.33. Same as Table 3.25--wind 3-h projection for GEM.

	Forecast Category	Verifying Observation Category 1	2	3	4	5	6	7	8	9	10	11	12	13	Total
	1	2127	18	10	11	53	52	32	33	31	1	0	1	0	2369
	2	22	10	3	0	0	0	0	0	3	0	0	0	0	38
	3	14	4	8	1	0	0	0	0	1	1	1	0	0	30
	4	15	0	1	10	9	1	0	0	0	0	0	0	0	36
	5	41	1	1	6	42	12	1	0	0	0	4	0	0	108
GEM	6	44	0	0	0	16	38	9	0	0	0	0	3	0	110
Forecast	7	60	0	0	0	1	4	28	7	4	0	0	3	1	108
	8	44	0	0	0	0	0	8	36	15	0	0	0	0	103
	9	45	3	0	0	0	0	0	8	31	0	0	0	1	88
	10	0	1	1	0	0	0	0	0	0	0	0	0	0	2
	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	12	1	0	0	0	0	0	2	0	0	0	1	2	0	6
	13	0	0	0	0	0	0	0	3	3	0	0	1	6	13
	Total	2413	37	24	28	121	107	80	87	88	2	6	10	8	3011

Percent correct: 77.65%
Heidke skill score: .3852

Table 3.34. Same as Table 3.25--wind 4-h projection for the FT.

	Forecast Category	Verifying Observation Category 1	2	3	4	5	6	7	8	9	10	11	12	13	Total
	1	1839	11	13	11	16	16	26	19	25	0	0	0	0	1976
	2	32	8	1	0	0	0	0	0	11	0	0	0	0	52
	3	22	5	14	5	1	0	0	0	0	0	0	0	0	47
	4	53	0	5	12	6	2	0	0	0	0	1	0	0	79
	5	97	0	1	9	67	15	6	0	0	0	2	0	0	197
FT	6	125	0	0	1	18	39	23	0	0	0	0	1	0	207
Forecast	7	67	0	0	0	1	7	22	9	2	0	0	2	0	110
	8	100	0	1	0	1	0	13	39	23	0	0	0	0	177
	9	98	8	1	0	0	1	1	20	42	0	0	0	5	176
	10	1	0	1	0	0	0	0	0	0	2	0	0	0	4
	11	0	0	0	0	0	1	0	0	0	0	0	0	0	1
	12	0	0	0	0	0	0	1	0	0	0	1	6	0	8
	13	0	0	0	0	0	0	0	1	4	0	0	0	5	10
	Total	2434	32	37	38	110	81	92	88	107	2	4	9	10	3044

Percent correct: 68.82%
Heidke skill score: .3385

Table 3.35. Same as Table 3.25--wind 4-h projection for persistence.

Forecast Category	Verifying Observation Category 1	2	3	4	5	6	7	8	9	10	11	12	13	Total
1	2071	19	21	17	59	47	51	44	56	0	1	0	0	2386
2	24	5	3	0	0	0	0	0	5	0	0	0	1	38
3	12	3	9	4	0	0	0	0	1	1	0	0	0	30
4	18	0	2	11	6	0	0	0	0	0	0	0	0	37
5	54	1	1	4	37	6	2	1	0	0	2	0	0	108
Persist- 6	69	1	0	1	8	22	11	0	0	0	0	2	0	114
ence 7	73	0	1	0	0	4	21	7	4	0	0	1	0	111
Forecast 8	50	0	0	0	0	0	7	28	15	0	0	0	2	102
9	59	3	0	0	0	1	0	6	21	0	0	0	2	92
10	1	0	0	0	0	0	0	0	0	1	0	0	0	2
11	0	0	0	1	0	0	0	0	0	0	1	1	0	3
12	2	0	0	0	0	1	0	0	0	0	0	5	0	8
13	0	0	0	0	0	0	0	2	5	0	0	0	5	12
Total	2433	32	37	38	110	81	92	88	107	2	4	9	10	3043

Percent correct: 73.51%
Heidke skill score: .2788

Table 3.36. Same as Table 3.25--wind 4-h projection for GEM.

	Forecast Category	Verifying Observation Category 1	2	3	4	5	6	7	8	9	10	11	12	13	Total
	1	2070	19	22	18	59	47	50	44	56	0	1	0	0	2386
	2	24	5	3	0	0	0	0	0	5	0	0	0	1	38
	3	12	3	9	4	0	0	0	0	1	1	0	0	0	30
	4	15	0	2	10	5	0	0	0	0	0	0	0	0	32
	5	56	1	1	5	37	6	2	1	0	0	3	1	0	113
GEM	6	71	1	0	1	8	22	11	0	0	0	0	2	0	116
Forecast	7	67	0	0	0	0	4	21	7	4	0	0	1	0	104
	8	57	0	0	0	1	0	8	30	20	0	0	0	6	122
	9	59	3	0	0	0	1	0	6	21	0	0	0	2	92
	10	1	0	0	0	0	0	0	0	0	1	0	0	0	2
	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	12	2	0	0	0	0	1	0	0	0	0	0	5	0	8
	13	0	0	0	0	0	0	0	0	0	0	0	0	1	1
	Total	2434	32	37	38	110	81	92	88	107	2	4	9	10	3044

Percent correct: 73.32%
Heidke skill score: .2736

Table 3.37. Same as Table 3.25--wind 5-h projection for the FT.

	Forecast Category	Verifying Observation Category 1	2	3	4	5	6	7	8	9	10	11	12	13	Total
	1	1772	13	13	14	32	16	33	13	24	0	0	0	0	1930
	2	29	10	3	0	0	0	0	0	11	0	0	0	0	53
	3	31	4	11	2	2	0	0	0	1	0	0	0	0	51
	4	57	0	4	14	13	0	0	0	0	0	0	0	0	88
	5	99	0	1	7	60	21	4	0	0	0	2	0	0	194
FT	6	109	0	1	0	24	46	15	2	0	0	0	3	0	200
Forecast	7	75	0	0	0	0	9	17	12	1	0	0	2	0	116
	8	108	0	0	0	0	2	17	54	17	0	0	0	1	199
	9	93	11	1	0	0	1	2	17	54	0	0	0	3	182
	10	0	0	1	0	0	0	0	0	0	3	0	0	0	4
	11	0	0	0	0	0	0	0	0	0	0	1	0	0	1
	12	0	0	0	0	0	1	3	0	0	0	0	6	0	10
	13	0	0	0	0	0	0	0	2	3	0	0	0	5	10
	Total	2373	38	35	37	131	96	91	100	111	3	3	11	9	3038

Percent correct: 68.58%
Heidke skill score: .3419

Table 3.38. Same as Table 3.25--wind 5-h projection for persistence.

	Forecast Category	Verifying Observation Category 1	2	3	4	5	6	7	8	9	10	11	12	13	Total
	1	2009	24	20	19	75	60	55	60	63	0	0	0	2	2383
	2	23	6	1	2	0	0	0	0	6	0	0	0	1	39
	3	12	3	8	2	2	0	0	0	2	2	0	0	0	31
	4	16	0	3	10	6	0	0	0	0	0	1	1	0	37
	5	56	0	2	3	30	8	1	2	0	0	2	0	0	104
Persist-	6	65	0	0	0	14	22	10	0	0	0	0	2	0	113
ence	7	76	0	0	0	0	4	18	7	3	0	0	3	0	111
Forecast	8	60	0	0	0	1	1	5	25	9	0	0	0	1	102
	9	58	5	0	0	1	0	1	4	23	0	0	0	0	92
	10	0	0	1	0	0	0	0	0	0	1	0	0	0	2
	11	0	0	0	1	1	0	0	0	0	0	0	1	0	3
	12	2	0	0	0	0	1	1	0	0	0	0	4	0	8
	13	1	0	0	0	0	0	0	2	5	0	0	0	5	13
	Total	2374	38	35	37	130	96	91	100	111	3	3	11	9	3038

Percent correct: 71.00%
Heidke skill score: .2382

Table 3.39. Same as Table 3.25--wind 5-h projection for GEM.

Forecast Category	Verifying Observation Category 1	2	3	4	5	6	7	8	9	10	11	12	13	Total
1	2069	24	22	20	79	63	50	54	63	0	0	0	2	2446
2	23	6	2	2	0	0	0	0	6	1	0	0	1	41
3	5	3	7	2	2	0	0	0	2	2	0	0	0	23
4	2	0	2	5	2	0	0	0	0	0	0	1	0	12
5	53	0	2	6	31	8	2	3	0	0	3	1	0	109
GEM 6	40	0	0	0	12	20	9	0	0	0	0	3	0	84
Forecast 7	43	0	0	0	3	3	19	8	3	0	0	5	0	84
8	82	0	0	2	1	2	10	31	14	0	0	0	5	147
9	57	5	0	0	1	0	1	4	23	0	0	0	0	91
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	1	0	1
13	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Total	2374	38	35	37	131	96	91	100	111	3	3	11	9	3039

Percent correct: 72.82%
Heidke skill score: .2554

Table 3.40. Same as Table 3.25--wind 6-h projection for the FT.

	Forecast Category	Verifying Observation Category 1	2	3	4	5	6	7	8	9	10	11	12	13	Total
	1	1729	13	11	7	26	25	38	28	32	0	0	0	0	1909
	2	38	14	1	0	0	0	0	0	9	2	0	0	0	64
	3	32	1	14	5	3	0	0	0	0	0	0	0	0	55
	4	58	2	2	11	15	2	0	0	0	0	0	0	0	90
	5	94	0	0	8	61	21	5	1	0	0	2	0	0	192
FT	6	92	0	1	2	19	56	19	3	4	0	1	2	0	199
Forecast	7	68	0	0	0	2	9	20	15	3	0	0	2	0	119
	8	121	0	0	1	0	3	18	40	16	0	0	0	2	201
	9	101	5	2	0	0	0	1	15	51	0	0	0	7	182
	10	0	0	0	0	0	1	0	0	0	3	0	0	0	4
	11	0	0	0	0	0	0	0	0	0	0	1	0	0	1
	12	0	0	0	0	1	0	3	0	0	0	1	6	0	11
	13	0	0	0	0	0	0	0	0	3	0	0	0	4	7
	Total	2333	35	31	34	127	117	104	102	118	5	5	10	13	3034

Percent correct: 66.25%
Heidke skill score: .3307

Table 3.41. Same as Table 3.25--wind 6-h projection for persistence.

	Forecast Category	Verifying Observation Category 1	2	3	4	5	6	7	8	9	10	11	12	13	Total
	1	1945	22	20	21	74	74	72	62	77	1	0	0	7	2375
	2	20	9	2	1	1	0	0	0	5	1	0	0	0	39
	3	14	1	7	3	2	0	0	0	1	2	1	0	0	31
	4	18	0	2	8	6	0	0	0	0	0	0	1	0	35
	5	54	1	0	1	30	13	3	0	0	0	4	1	0	107
Persist-	6	60	0	0	0	14	24	11	0	3	0	0	2	0	114
ence	7	79	1	0	0	0	4	14	11	2	0	0	1	0	112
Forecast	8	68	0	0	0	0	0	4	23	7	0	0	0	0	102
	9	66	1	0	0	0	0	0	5	20	0	0	0	0	92
	10	0	0	0	0	0	1	0	0	0	1	0	0	0	2
	11	2	0	0	0	0	0	0	0	0	0	0	1	0	3
	12	2	0	0	0	0	1	0	0	0	0	0	4	0	7
	13	3	0	0	0	0	0	0	1	3	0	0	0	6	13
	Total	2331	35	31	34	127	117	104	102	118	5	5	10	13	3032

Percent correct: 68.96%
Heidke skill score: .2060

Table 3.42. Same as Table 3.25--wind 6-h projection for GEM.

	Forecast Category	Verifying Observation Category 1	2	3	4	5	6	7	8	9	10	11	12	13	Total
	1	2033	24	19	20	76	74	62	58	79	1	0	0	6	2452
	2	13	8	2	1	1	1	0	0	5	2	0	0	0	33
	3	6	1	5	3	2	0	0	0	1	2	1	0	0	21
	4	2	0	2	1	0	0	0	0	0	0	0	0	0	5
	5	65	1	1	6	33	16	3	0	0	0	4	3	0	132
GEM	6	26	0	0	1	9	20	15	1	2	0	0	2	0	76
Forecast	7	36	0	0	0	4	6	13	10	2	0	0	4	0	75
	8	106	0	2	2	2	0	11	29	12	0	0	0	7	171
	9	46	1	0	0	0	0	0	4	17	0	0	0	0	68
	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	12	0	0	0	0	0	0	0	0	0	0	0	1	0	1
	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total	2333	35	31	34	127	117	104	102	118	5	5	10	13	3034

Percent correct: 71.19%
Heidke skill score: .2255

B. Analysis

Based upon the foregoing statistics we have compiled three summary tables. The first of these tables, Table 4, compares GEM and the FT using the individual skill measures of percentage hits, Heidke skill score, and threat. A "G" in the table indicates that GEM's score is best while an "F" signifies the FT is best. This is done for all six projection hours with a tally of the number of G's and F's appearing in each column plus a grand total.

Table 5 gives a similar set of summary statistics comparing persistence with the FT. Finally, Table 6 gives the same summarizing information comparing GEM against persistence. The entries in Tables 4-6 are based on the statistics presented in Tables 3.1-3.42.

One objective of this study was to determine the crossover projection time where the two methods, GEM and the FT, are about equal, implying at shorter projections GEM is better while at longer projections the FT is better. Table 4 indicates that a reasonable crossover is at hour 2, the place where the total number of scores favoring GEM and the FT are equal, namely 7 and 7.

Table 5 shows that the FT dominates persistence in skill measures after 1 hour. At 1 hour, however, persistence decidedly dominates the FT in the number of scores and in their magnitudes.

GEM versus persistence, as summarized in Table 6, shows the two approaches tying at 1 hour with GEM strongly dominating persistence at 2 hours. From 3 hours to 6 hours, GEM is as good as or better than persistence.

An additional experiment was done to analyze why the FT performs less well against GEM and persistence at 1 hour. A subset of the data for a 1-h projection was reprocessed to create additional verification tables and scores. The subset includes only those forecasts for which the FT deviated from persistence. The results are presented in Tables 7-11.

Consider ceiling, which seems representative. The FT deviated from persistence 815 times. Of the 815 FT deviations, the percent correct score is 54.60% as compared with a persistence percent correct under these same conditions of 66.99%. Another thing to observe is that for fog and thunderstorms, the resulting skill is negative, meaning these deviation-from-persistence forecasts at 1 hour are not as good as a chance forecast.

The following observations have been made as a result of this and other GEM verification studies:

1. The equivalence in performance between GEM and the FT at 2 hours suggested by the results presented here, is interestingly similar to the equivalence in performance between GEM and MOS at a 3-h projection (see Perrone and Miller, 1983).

   Two points are suggested by the similarity:

   a. Perhaps the time and space scale of the synoptic information used by NWS forecasters, as well the time/space scale of the LFM and

Table 4. Individual comparisons of verification scores between two procedures. A "G" denotes GEM has a better score, an "F" denotes the FT is better, a "P" denotes persistence is better, and a "T" denotes a tie. GEM versus FT.

Element	Score	Projection (h) 1	2	3	4	5	6	Total
Ceiling								
	Percent Hits	G	G	G	F	F	F	
	Heidke	G	F	F	F	F	F	
	Threat	G	F	F	F	F	F	
Visibility								
	Percent Hits	G	G	G	G	G	G	
	Heidke	G	G	F	F	F	F	
	Threat	F	F	F	F	F	F	
Fog								
	Percent Hits	G	F	F	F	G	G	
	Heidke	G	F	F	F	F	F	
	Threat	G	F	F	F	F	F	
Thunderstorm								
	Percent Hits	F	F	F	F	G	T	
	Heidke	G	G	G	F	F	T	
	Threat	G	G	G	F	F	T	
Wind								
	Percent Hits	G	G	G	G	G	G	
	Heidke	G	G	G	F	F	F	
Total	G's	12	7	6	2	4	3	34
	F's	2	7	8	12	10	8	47

G denotes GEM's score is better than FT's score.
F denotes FT's score is better than GEM's score.
T denotes tie.

Table 5. Same as Table 4. Persistence versus FT.

Element	Score	Projection (h) 1	2	3	4	5	6	Total
Ceiling								
	Percent Hits	P	F	F	F	F	F	
	Heidke	P	F	F	F	F	F	
	Threat	P	F	F	F	F	F	
Visibility								
	Percent Hits	P	P	P	F	F	F	
	Heidke	P	P	F	F	F	F	
	Threat	F	F	F	F	F	F	
Fog								
	Percent Hits	P	F	F	F	F	F	
	Heidke	P	F	F	F	F	F	
	Threat	P	F	F	F	F	F	
Thunderstorm								
	Percent Hits	F	F	F	F	F	F	
	Heidke	P	P	P	F	F	P	
	Threat	P	P	P	F	F	P	
Wind								
	Percent Hits	P	P	P	P	P	P	
	Heidke	P	P	P	F	F	F	
Total	P's	12	6	5	1	1	3	28
	F's	2	8	9	13	13	11	56

F denotes FT's score is better than GEM's score.
P denotes persistence score is better than FT's score.

Table 6. Same as Table 4. GEM versus Persistence.

Element	Score	Projection (h) 1	2	3	4	5	6	Total
Ceiling								
	Percent Hits	P	G	G	G	G	G	
	Heidke	P	G	G	P	G	G	
	Threat	G	G	P	P	P	P	
Visibility								
	Percent Hits	T	G	G	G	G	G	
	Heidke	P	G	P	P	P	P	
	Threat	G	P	G	G	G	T	
Fog								
	Percent Hits	T	G	G	G	G	G	
	Heidke	T	G	G	P	G	G	
	Threat	T	G	G	P	P	G	
Thunderstorm								
	Percent Hits	G	G	P	G	G	G	
	Heidke	T	G	P	P	G	P	
	Threat	T	T	P	P	P	P	
Wind								
	Percent Hits	T	G	P	P	G	G	
	Heidke	T	G	P	P	G	G	
Total	G's	3	12	7	7	9	9	47
	P's	3	1	7	7	5	4	29

G denotes GEM's score is better than FT's score.
F denotes FT's score is better than GEM's score.
T denotes tie.

Table 7. FT forecast verification results when the FT deviated from persistence in a 1-h ceiling forecast.

	Forecast Category	Verifying Observation Category 1	2	3	4	5	6	Total
	1	1	0	0	0	0	0	1
	2	4	4	2	1	0	4	15
Special	3	0	5	15	9	2	1	32
FT	4	0	2	28	107	30	47	214
Forecast	5	0	0	2	37	92	126	257
	6	0	3	2	8	57	226	296
	Total	5	14	49	162	181	404	815

Percent correct: 54.60%
Heidke skill score: .3468
Threat score: .3462

Table 8. FT forecast verification results when the FT deviated from persistence in a 1-h visibility forecast.

	Forecast Category	Verifying Observation Category 1	2	3	4	5	6	Total
	1	0	0	0	0	0	0	0
	2	4	2	9	0	1	3	19
Special	3	3	5	27	12	5	1	53
FT	4	2	1	24	70	40	58	195
Forecast	5	1	1	16	48	74	186	326
	6	0	0	3	13	68	48	132
	Total	10	9	79	143	188	296	725

Percent correct: 30.48%
Heidke skill score: .0703
Threat score: .1875

Table 9. FT forecast verification results when the FT deviated from persistence in a 1-h fog forecast.

	Forecast Category	Verifying Observation Category 1	2	Total
Special FT Forecast	1	40	162	202
	2	34	63	97
	Total	74	225	299
Bias		2.73	.43	

Percent correct: 34.45%
Heidke skill score: -.1136
Threat score: .1695

Table 10. FT forecast verification results when the FT deviated from persistence in a 1-h thunderstorm forecast.

	Forecast Category	Verifying Observation Category 1	2	Total
Special FT Forecast	1	1	4	5
	2	18	28	46
	Total	19	32	51
Bias		.26	1.44	

Percent correct: 56.86%
Heidke skill score: -.0851
Threat score: .0435

Table 11. FT forecast verification results when the FT deviated from persistence in a 1-h wind forecast.

	Forecast Category	Verifying Observation Category 1	2	3	4	5	6	7	8	9	10	11	12	13	Total
	1	58	6	2	3	13	10	11	3	5	0	0	0	0	111
	2	22	6	1	0	0	0	0	0	4	1	0	0	0	34
	3	17	4	2	3	1	0	0	0	0	0	0	0	0	27
	4	41	0	0	5	4	0	0	0	0	0	0	0	0	50
	5	79	0	0	6	16	8	0	1	0	0	0	0	0	110
Special	6	67	0	0	0	11	20	7	1	2	0	0	1	0	109
FT	7	41	0	0	0	0	9	11	4	0	0	0	0	1	66
Forecast	8	64	0	0	0	0	1	6	22	10	0	0	0	1	104
	9	78	1	0	0	1	1	0	10	22	0	0	0	3	116
	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	11	0	0	0	0	3	0	0	0	0	0	0	0	0	3
	12	0	0	0	0	0	0	2	0	0	0	0	2	0	4
	13	0	0	0	0	0	0	0	0	1	0	0	0	1	2
	Total	467	17	5	17	49	4	37	41	44	1	0	3	6	736

Percent correct: 22.42%
Heidke skill score: .0976

observation data used as input to MOS, are too coarse to satisfactorily support prediction inside 3 hours. Local observations, massaged statistically through a method based upon interrelationships in a large number of observations, such as through GEM, may provide the best approach to forecasting inside 3 hours, until smaller scale observing networks become widespread.

b. The GEM-MOS study also demonstrated the improvement over either GEM or MOS when the two were blended. The results are very promising, especially out beyond 3 hours, suggesting that such a combination would produce powerful guidance for the FT well beyond 6 hours.

2. In an additional experiment, we computed the results of GEM versus the FT for a single forecast office, CLE, to determine if the relative performance of the two forecast techniques was any different on this one station's data than on all the data. The results were similar, precluding the need to stratify the data geographically for verification.

3. GEM seems to be a good "point of departure" for an official FT--either in its present form or as part of a computer-worded FT procedure. The FT verification results presented here suggest that forecasters often appear to suffer from "buck fever." In the sport of hunting, this term refers in part to the tendency, under anticipating pressure when sighting game, to fire the weapon too

soon. Forecasters, anticipating a significant synoptic change, often forecast the change event too early. Perhaps their synoptic training focuses so much on anticipating, capturing, and not missing important changes, that their sense of timing suffers. GEM, as this study shows, is clearly more conservative; it can offer a valuable counterweight to forecasters' "buck fever."

4. The results obtained in this study should interest the FAA for two reasons: 1) they show that improvements can be realized inside the vital 2-h projection period using hour-by-hour GEM and 2) they give encouragement to the support they are providing to developing a minute-by-minute GEM where the only competition is persistence.

4. CONCLUSIONS, RECOMMENDATIONS, AND PLANS

A. Conclusions

In the Results and Analysis section, we substantiate the following conclusions:

- GEM provides forecast information inside 2 hours which is superior to the predominant conditions of the official FT. Beyond that time the FT is superior.

- GEM's skill relative to persistence has been demonstrated as being as good as or better over the entire 1-6 h period.

B. Recommendations and Plans

Based upon the above conclusions and on the analysis of the results, we make the following recommendations for further work:

1. We recommend that GEM forecasts be used as objective guidance to field forecasters to cover the 1-6 h period. The later hours of the period should be deemed as a "point of departure" for making an official FT. Feedback from this effort should be beneficial to enhancing the method.

2. We plan to continue work on improving GEM. In particular:

   a. Study ways to include nonlinear predictive information such as Discrete Likelihood Functions (DLF), (see Miller, 1979).

   b. Produce a more efficient operational version of GEM for AFOS and for the microcomputer such as with eigenvalues (see Whiton, 1977).

   c. Develop a better way to convert GEM's probability forecasts into categorical forecasts to replace or improve upon the Beta thresholding method that is used presently. The framework for this effort is likely to be in classical statistical decision theory or in operations research.

3. We plan to continue field testing GEM at the FAA's flow control center to evaluate the operational importance of this objective guidance under meteorologically important situations and important aviation decisions.

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