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Mesoscale Wind Prediction
With the Inertial Equation of Motion

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LAS VEGAS,
NEVADA
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John S. Cornett and Darryl Randerson

ABSTRACT

A mesoscale wind-prediction model based solely on the inertial equation of motion is verified on an hourly basis against persistence for 33, independent, 6-hr periods. The model is also compared with another mesoscale wind-prediction model derived from a horizontal vorticity theorem. The inertial model is demonstrated to be a better model for prediction times ranging from 3 through 6 hr. In the free atmosphere, both models have difficulty outperforming a persistence wind forecast for time periods of 1 to 2 hr and do no better than persistence in the boundary layer. However, the vertical wind-shear forecasts by the inertial model are better than persistence for both the early (1 to 2 hr) prediction times and at lower levels in the atmosphere.

Key Words: Inertial motion, mesoscale model, mesoscale wind prediction, numerical model, verification, wind persistence

1. INTRODUCTION

In previous papers, we have described the philosophical aspects of our mesoscale wind-prediction project (Randerson and Cornett, 1973) and have developed a numerical model based on a horizontal vorticity theorem (Cornett and Randerson, 1974). The model based on the horizontal vorticity theorem demonstrated some predictive skill in the free atmosphere when compared against persistence as the control forecast or standard. Our next concern was to determine statistically whether a simple model based solely on the inertial equations of motion is also more skillful than persistence. This paper describes the results of that investigation.

2. THE NUMERICAL MODELS

2.1 Equations

The component form of the equation of horizontal, nonviscous motion is

$$\frac{\partial u}{\partial t} = - (u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + w \frac{\partial u}{\partial z}) + f(v-v_g) - 2\Omega\, w \cos \phi \qquad (1)$$

$$\frac{\partial v}{\partial t} = - (u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} + w \frac{\partial v}{\partial z}) - f(u-u_g) \qquad (2)$$

where the geostrophic approximation has been substituted for the pressure terms. In the present investigation, we are concerned only with the inertial contribution to the motion so that just the three terms within the first parenthesis on the right-hand side of (1) and (2) were solved numerically. The ageostrophic and Coriolis terms were specified as zero for this experiment.

Equations (1) and (2) were solved for 6-hr time periods over a 200 x 200 n mi grid having a horizontal grid spacing of 20 n mi and a vertical spacing of 1000 ft. The vertical extent of the model ranges from 4000 to 14,000 ft above mean sea level (MSL). The grid network is centered over the Energy Research and Development Administration's (ERDA) Nevada Test Site (NTS), located in the southern part of Nevada (fig. 1). As revealed by figure 1, the average terrain elevation is about 4500 ft MSL and ranges from 3000 ft MSL in the southern end of the grid to 7000 ft MSL in the northern portion.

The inertial terms in (1) and (2) were solved numerically by use of a quasi-Lagrangian scheme proposed by Wiin-Nielsen (1959) and Krishnamurti (1962) and tested by LeBlanc (1972). A 15-min time step was used to obtain predictions out to 6 hr beyond the initial time.

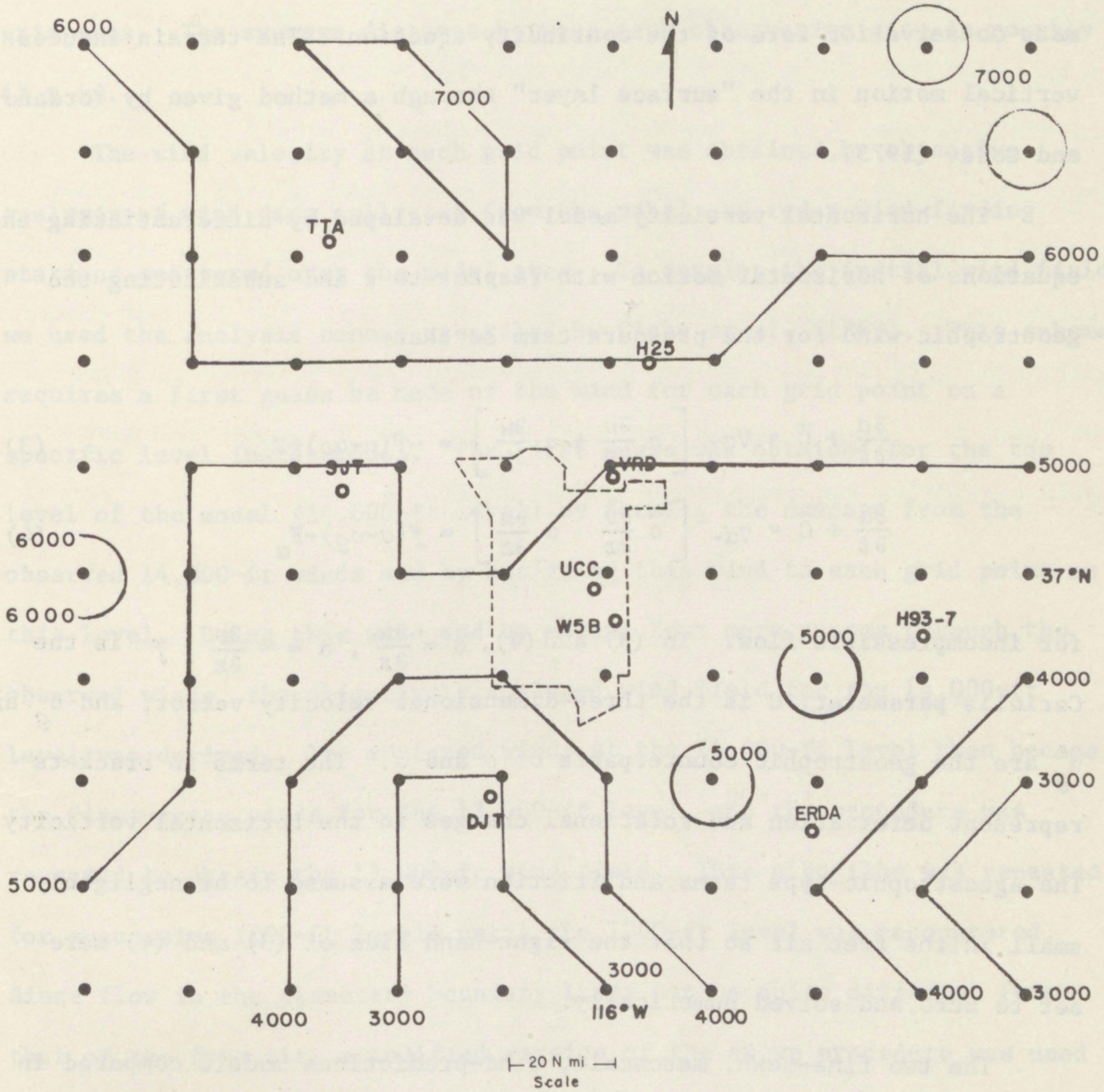

Figure 1. Model grid network and smoothed terrain elevation (feet above mean sea level). The perimeter of the Nevada Test Site is represented by the dashed line in the center of the grid network.

The vertical velocities for the flow field were calculated from the u- and v-wind components by assuming incompressible flow and by solving the mass-conservation form of the continuity equation. The terrain induces vertical motion in the "surface layer" through a method given by Yordanov and Godev (1973).

The horizontal vorticity model was developed by differentiating the equations of horizontal motion with respect to z and substituting the geostrophic wind for the pressure term so that

$$\frac{\partial \sigma}{\partial t} + \vec{C} \circ \nabla\sigma - \left[\sigma \frac{\partial v}{\partial y} + \alpha \frac{\partial u}{\partial y} \right] = -f(\alpha - \alpha_g) + F_\sigma \tag{3}$$

$$\frac{\partial \alpha}{\partial t} + \vec{C} \circ \nabla\alpha - \left[\sigma \frac{\partial v}{\partial x} \quad \alpha \frac{\partial u}{\partial x} \right] = f(\sigma - \sigma_g) - F_\alpha \tag{4}$$

for incompressible flow. In (3) and (4), $\sigma = \frac{\partial u}{\partial z}$, $\alpha = -\frac{\partial v}{\partial z}$, f is the Coriolis parameter, C is the three-dimensional velocity vector, and σ_g and α_g are the geostrophic counterparts of σ and α. The terms in brackets represent deformation and rotational changes in the horizontal vorticity. The ageostrophic-type terms and friction were assumed to be negligibly small in the free air so that the right-hand side of (3) and (4) were set to zero and solved numerically.

The two fine-mesh, mesoscale, wind-predictions models compared in this memorandum simulate *only* the mesoscale wind field from 4000 to 14,000 ft MSL. Neither model simulates surface layer (ground level to 1000 ft above ground) wind regimes; however, both models are truly mesoscale in nature because a special set of mesoscale upper air wind observations is used to initialize the models.

2.2 Initialization and Verification Data

Typically, there are eight stations available for wind analysis in the grid area. The average distance between each observation site is roughly 45 n mi.

The wind velocity at each grid point was obtained by objective analysis of wind data collected from the pibal and radar wind-finding stations scattered over the model area. To develop the initial wind field, we used the analysis scheme described by Glahn *et al.* (1969). This scheme requires a first guess be made of the wind for each grid point on a specific level in the model. The first guess was obtained for the top level of the model (14,000-ft level) by forming the average from the observed 14,000-ft winds and by assigning this wind to each grid point on this level. Using this wind and by making four more passes through the observed winds, the objectively analyzed wind field for the 14,000-ft level was derived. The analyzed winds at the 14,000-ft level then became the first-guess winds for the 13,000-ft level, and the procedure was repeated to obtain the 13,000-ft wind field. This algorithm was repeated for successive 1000-ft levels until the 7000-ft level was encountered. Since flow in the planetary boundary layer can be quite different from that of the free air, a modified version of the above procedure was used for the boundary layer; namely, the 4000- through 7000-ft levels. The first-guess winds for each of these levels were derived from the observed winds by calculating the average wind at each level and using this average wind as the first-guess wind for that level.

The verification data set consists of 33 independent cases randomly scattered by month throughout the period from June 1966 to July 1973. Each case consists of 7 consecutive hr of objectively analyzed wind data in the grid area where the first hour was used to initialize the models and the following 6 hr to verify the predictions at hourly intervals. Nearly all cases are in the time period between local midnight and noon because this is the time period in which observations are taken to support operations at the NTS. A summary of the mean initial flow for the entire prediction grid for each of the 33 independent cases is shown in figure 2 and table 1. These diagrams show that each direction octant and most speed categories are represented in the data.

2.3 Boundary Conditions

The following commonly used boundary conditions were assumed:

a. Windward boundary: u and v constant;

b. Lee boundary: u and v are permitted to flow out;

c. Top boundary: u and v are permitted to flow upward and out, but there is no flux of u and v downward into the model.

d. Bottom boundary: u and v are permitted to flow downward and out, but there is no flux upward and into the model.

e. Ground boundary: u and v are permitted to flow parallel to the terrain. Tests of various ground-boundary conditions showed this one to be superior.

Table 1. Mean Wind-speed Distribution for the 33 Cases Used in the Verification of the Mesoscale Wind-Prediction Model

	Speed categories (kt)						
	0-5	6-10	11-15	16-20	21-25	26-30	31-35
Vector speed	10	8	10	3	1	0	1
Scalar speed	3	11	13	3	2	0	1

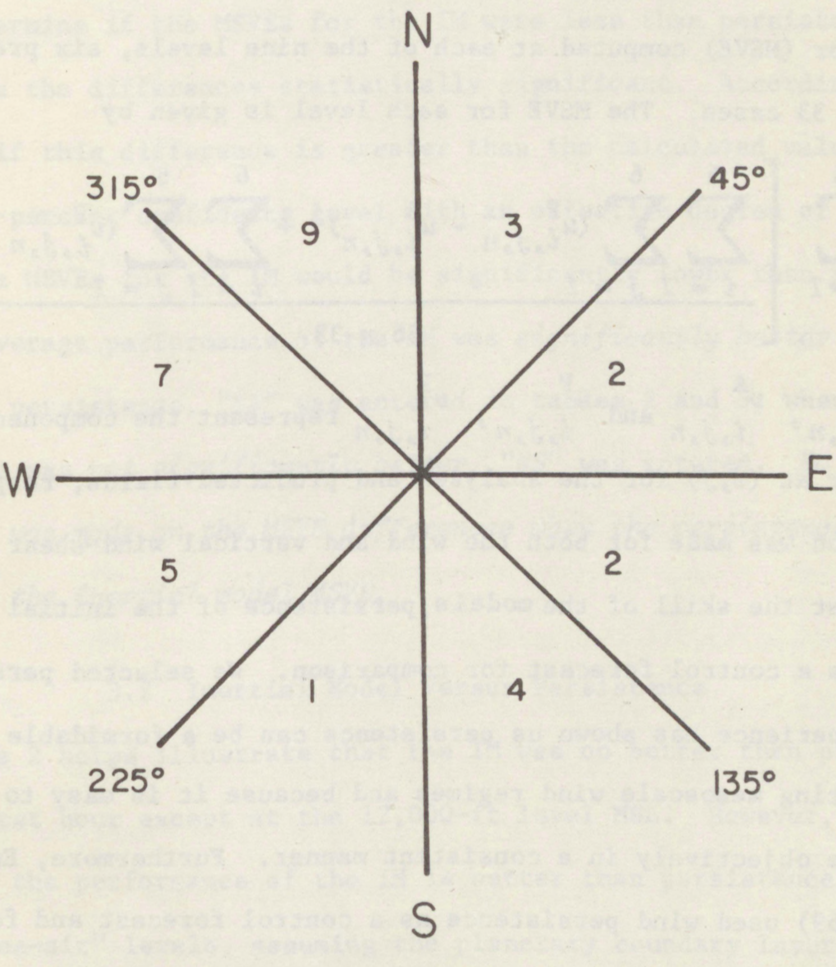

Figure 2. Mean wind-vector direction distribution for the 33 cases used in the verification of the mesoscale wind-prediction model.

3. VERIFICATION

3.1 Introduction

Verification was made over a 120 x 120 n mi area centered within the model's grid network for nine levels ranging from 5000 to 13,000 ft MSL and for hourly intervals from 1 to 6 hr. There are 36 grid points located on each of the levels, yielding a total of 324 grid points in the volume used for verification. Verification was based on the mean-square vector error (MSVE) computed at each of the nine levels, six predictions times, and 33 cases. The MSVE for each level is given by

$$\text{MSVE} = \sum_{n=1}^{33} \left[\frac{\sum_{i=1}^{6}\sum_{j=1}^{6} (u^{P}_{i,j,n} - u^{A}_{i,j,n})^2 + \sum_{i=1}^{6}\sum_{j=1}^{6} (v^{P}_{i,j,n} - v^{A}_{i,j,n})^2}{36 \times 33} \right]$$

where $u^{A}_{i,j,n}$, $v^{A}_{i,j,n}$ and $u^{P}_{i,j,n}$, $v^{P}_{i,j,n}$ represent the components of the wind vector at (i,j) for the analyzed and predicted fields, respectively. Verification was made for both the wind and vertical wind-shear fields.

To test the skill of the models, persistence of the initial flow field was used as a control forecast for comparison. We selected persistence because experience has shown us persistence can be a formidable opponent in forecasting mesoscale wind regimes and because it is easy to specify persistence objectively in a consistent manner. Furthermore, Entrekin *et al.* (1969) used wind persistence as a control forecast and found it to be a difficult forecast to beat for short-range forecasts.

To judge objectively whether the average performance of the simple inertial model (IM) was better than persistence, we decided to use a one-sided Student's T-test for the 95-percent confidence level ($\alpha = 0.05$). In the application of this test to each time and level, we assumed the variability of the squared vector errors for the IM and persistence were unknown and not equal. The procedure for doing this is given by Natrella (1963).

Results of the verification are tabulated in table 2 for the wind vector and in table 3 for the vertical shear vector. Our main concern was to determine if the MSVEs for the IM were less than persistence and, if so, were the differences statistically significant. According to Natrella, if this difference is greater than the calculated value u, given a 95-percent confidence level with an effective degree of freedom f, then the MSVEs for the IM would be significantly lower than persistence. When the average performance of the IM was *significantly better* (lower MSVE) than persistence, "*SB*" was entered in tables 2 and 3; when the performance was *not significantly better*, "*NS*" was entered. *No significance test was made on the MSVE differences when the persistence MSVE was lower than the inertial model MSVE.*

3.2 Inertial Model Versus Persistence

Table 2 helps illustrate that the IM was no better than persistence for the first hour except at the 12,000-ft level MSL. However, beginning at hour 2, the performance of the IM is better than persistence at all of the "free-air" levels, assuming the planetary boundary layer (PBL) is 4000 ft in depth. In the PBL, the IM's performance is no better than persistence. In comparison with persistence, table 2 also shows the IM performance improves with height above terrain and with length of the forecast period.

Table 2. Inertial Model Wind Forecast Verification Statistics (33 Cases)

Hour	Level	MSVE (kt^2)		Standard deviation SVE			Significance	Effective degrees of freedom
	x 10^3 ft	P	IM	P	IM	U	S	f
1	13	22.1	23.0	51.9	50.1	3.4	-	-
	12	22.1	17.6	39.7	30.0	2.4	SB	2211
	11	18.5	16.0	47.7	36.0	2.9	NS	2208
	10	17.6	17.6	57.5	45.0	3.5	NS	2246
	9	18.5	19.4	57.1	44.9	3.5	-	-
	8	15.2	16.8	33.0	32.9	2.2	-	-
	7	13.0	16.0	25.3	31.8	1.9	-	-
	6	10.2	13.0	23.1	30.3	1.8	-	-
	5	5.3	6.8	14.1	18.7	1.1	-	-
2	13	30.2	26.0	43.7	37.7	2.8	SB	2326
	12	32.5	25.0	51.3	37.3	3.0	SB	2170
	11	36.0	24.0	80.4	37.7	4.2	SB	1685
	10	34.8	29.2	78.9	46.4	4.4	SB	1923
	9	33.6	27.0	74.4	38.6	4.0	SB	1783
	8	31.4	28.1	51.6	43.4	3.2	NS	2309
	7	23.0	27.0	38.5	43.6	2.8	-	-
	6	17.6	20.2	35.9	36.9	2.5	-	-
	5	9.0	10.9	31.5	28.1	2.0	-	-
3	13	49.0	34.8	81.4	76.5	5.3	SB	2367
	12	51.8	37.2	84.1	70.2	5.2	SB	2302
	11	50.4	38.4	99.2	63.6	5.6	SB	2023
	10	50.4	39.7	113.7	60.1	6.1	SB	1804
	9	47.6	42.2	85.2	67.1	5.2	NS	2253
	8	37.2	39.7	54.6	60.9	3.9	-	-
	7	30.2	37.2	45.6	60.3	3.6	-	-
	6	25.0	26.0	48.3	49.8	3.3	-	-
	5	13.0	14.4	35.0	36.2	2.4	-	-
4	13	79.2	46.2	121.1	68.0	6.6	SB	1868
	12	75.7	46.2	116.8	64.9	6.4	SB	1857
	11	68.9	49.0	112.1	68.1	6.3	SB	1959
	10	62.4	53.3	92.5	84.3	6.0	SB	2356
	9	59.3	54.8	86.7	79.4	5.6	NS	2358
	8	51.8	53.3	72.0	78.7	5.1	-	-
	7	38.4	44.9	52.5	68.0	4.1	-	-
	6	28.1	30.2	49.0	55.2	3.5	-	-
	5	15.2	16.8	44.1	40.5	2.9	-	-

Table 2. Inertial Model Wind Forecast Verification Statistics (33 Cases)
--continued

Hour	Level	MSVE (kt^2)		Standard deviation SVE			Significance	Effective degrees of freedom
	x 10^3 ft	P	IM	P	IM	U	S	*f*
5	13	92.2	53.3	153.2	73.3	8.1	SB	1704
	12	90.2	50.4	166.8	67.0	8.6	SB	1561
	11	90.2	56.2	177.1	84.0	9.4	SB	1696
	10	81.0	62.4	139.0	88.0	7.9	SB	2008
	9	75.7	64.0	118.8	84.0	6.9	SB	2138
	8	65.6	64.0	93.1	87.0	6.1	NS	2365
	7	51.8	56.2	69.3	82.1	5.1	-	-
	6	37.2	37.2	61.1	64.0	4.2	NS	2371
	5	19.4	19.4	55.7	45.3	3.4	NS	2280
6	13	108.2	68.9	163.9	91.4	9.0	SB	1861
	12	102.0	64.0	165.4	87.2	8.9	SB	1801
	11	104.0	68.9	179.0	95.8	9.7	SB	1817
	10	102.0	79.2	176.7	113.8	10.0	SB	2029
	9	92.2	75.7	158.9	101.9	9.0	SB	2023
	8	75.7	68.9	108.6	87.4	6.7	SB	2271
	7	65.6	64.0	87.3	83.4	5.8	NS	2371
	6	50.4	47.6	85.8	82.7	5.7	NS	2373
	5	27.0	26.0	85.7	67.0	5.2	NS	2245

Table 3 indicates that the IM yields better predictions of vertical wind shear than of horizontal wind because its performance is significantly better than persistence even for the 1-hr forecast period. Also notice the predictions of vertical wind shear are better than persistence for levels closer to the ground. The reason for this improvement may be the result of a bias in the wind predictions at all levels (*i.e.*, too fast or too slow at all levels). Consequently, the process of differencing adjacent levels to obtain the predicted shears may tend to cancel out errors which are approximately equal in magnitude and in sign.

Table 3. Inertial Model Vertical Wind-Shear Forecast Verification Statistics (33 Cases)

Hour	Level	MSVE (kt^2/1000 ft)		Standard deviation SVE			Significance	Effective degrees of freedom
	x 10^3 ft	P	IM	P	IM	U	S	*f*
1	13	13.7	8.4	23.2	14.0	1.3	SB	1948
	12	14.4	10.9	27.3	26.1	1.8	SB	2371
	11	14.4	10.2	25.5	18.7	1.5	SB	2131
	10	12.2	8.4	21.0	12.4	1.2	SB	1928
	9	9.0	7.8	12.9	11.7	0.8	SB	2356
	8	11.6	9.0	21.8	15.7	1.3	SB	2163
	7	10.2	8.4	18.1	17.2	1.2	SB	2369
	6	9.6	9.6	15.4	17.8	1.1	-	-
	5	10.9	13.0	19.1	24.5	1.5	-	-
2	13	17.6	10.2	29.2	15.3	1.6	SB	1790
	12	20.2	12.2	48.1	30.1	2.7	SB	1994
	11	16.0	10.2	27.4	19.6	1.6	SB	2150
	10	20.2	14.4	36.6	31.7	2.3	SB	2328
	9	13.0	10.9	20.7	19.8	1.4	SB	2372
	8	13.0	9.0	26.3	16.4	1.5	SB	1989
	7	13.7	10.2	22.0	15.7	1.3	SB	2151
	6	16.8	14.4	31.2	24.0	1.9	NS	2230
	5	28.1	19.4	50.0	32.1	2.8	SB	2023
3	13	18.5	10.9	29.2	16.1	1.6	SB	1852
	12	18.5	12.2	30.3	21.6	1.8	SB	2147
	11	20.2	13.0	31.0	23.7	1.9	SB	2223
	10	19.4	12.2	32.1	24.6	1.9	SB	2227
	9	15.2	12.2	21.7	21.9	1.5	SB	2376
	8	16.8	9.6	30.1	13.0	1.6	SB	1619
	7	16.0	13.7	23.5	21.6	1.5	SB	2359
	6	20.2	19.4	33.7	29.6	2.1	NS	2336
	5	34.8	24.0	58.3	40.1	3.4	SB	2108
4	13	22.1	13.7	41.6	40.1	2.8	SB	2373
	12	19.4	13.0	32.0	18.4	1.8	SB	1896
	11	24.0	14.4	35.6	25.4	2.1	SB	2149
	10	21.2	10.9	31.4	22.3	1.8	SB	2140
	9	16.8	10.9	24.2	15.7	1.4	SB	2038
	8	16.8	12.2	25.3	17.3	1.5	SB	2103
	7	21.2	16.8	33.4	29.2	2.1	SB	2335
	6	22.1	20.2	36.5	34.7	2.4	NS	2370
	5	32.5	29.2	49.4	48.6	3.3	SB	2375

Table 3. Inertial Model Vertical Wind-Shear Forecast Verification Statistics (33 Cases)--continued

Hour	Level	MSVE (kt^2/1000 ft)		Standard deviation SVE			Significance	Effective degrees of freedom
	x 10^3 ft	P	IM	P	IM	U	S	*f*
5	13	18.5	11.6	24.7	14.9	1.4	SB	1948
	12	20.2	13.7	32.0	21.1	1.8	SB	2058
	11	23.0	13.7	34.5	21.7	1.9	SB	2002
	10	23.0	12.2	32.1	18.3	1.8	SB	1885
	9	17.6	9.6	26.4	12.6	1.4	SB	1699
	8	19.4	11.6	30.4	17.8	1.7	SB	1917
	7	20.2	16.0	27.9	22.8	1.7	SB	2285
	6	28.1	26.0	48.4	48.3	3.3	NS	2376
	5	42.2	39.7	66.5	65.9	4.5	NS	2376
6	13	24.0	15.2	35.4	27.4	2.1	SB	2237
	12	27.0	15.2	41.5	26.1	2.3	SB	1998
	11	24.0	13.7	33.3	20.2	1.9	SB	1959
	10	25.0	16.0	36.5	30.2	2.3	SB	2296
	9	20.2	11.6	32.1	20.2	1.8	SB	2002
	8	22.1	12.2	35.9	22.1	2.0	SB	1978
	7	25.0	16.8	39.8	26.9	2.3	SB	2086
	6	31.4	28.1	54.7	45.8	3.4	SB	2306
	5	44.9	41.0	68.3	59.8	4.3	NS	2336

Table 4 is a tabulation of the percent frequency of cases the IM had *significantly* better performance than persistence, while table 5 gives the percent frequency of the cases in which the IM was *not* significantly better than persistence. Thus, for example, for a 5-hr wind prediction at the 12,000-ft level, table 4 shows that in 58 percent of the cases the IM had significantly better performance than persistence; while table 5 shows that in 39 percent of the cases, there was no reason to believe that the IM was better than persistence. These tables seem to emphasize the difficulty in significantly improving on wind persistence

Table 4. Percentage of the 33 Cases in Which the IM Exhibited Significantly Less Root-Mean-Square Vector Error (RMSVE) Than Persistence in Predicting the Wind Vector

	Level ($\times 10^3$ ft)									
TIME (hr)	5	6	7	8	9	10	11	12	13	Mean
1	3	0	3	15	3	6	24	24	21	11
2	0	0	3	18	27	30	24	36	27	18
3	3	3	12	18	24	24	30	42	45	22
4	6	3	18	30	27	33	42	61	52	30
5	9	27	27	24	27	36	52	58	39	33
6	6	21	30	27	27	30	49	45	45	31
Mean	5	9	16	22	22	26	37	44	38	

Table 5. Percentage of the 33 Cases in Which the IM Wind Vector Predictions Were Not Significantly Better Than Those of Persistence

	Level ($\times 10^3$ ft)									
TIME (hr)	5	6	7	8	9	10	11	12	13	Mean
1	91	91	76	64	76	76	67	61	70	75
2	82	85	70	61	49	55	64	61	64	66
3	73	73	58	55	55	58	55	55	49	59
4	73	85	64	49	49	49	46	36	39	55
5	73	58	49	45	58	45	36	39	52	51
6	76	58	49	45	55	52	36	49	45	52
Mean	78	75	61	53	57	56	51	50	53	

Table 6. Percentage of the 33 Cases in Which the IM RMSVEs Were Numerically Better Than Those of Persistence (Ties Were Counted as no Better)

		Level (x 10^3ft)									
		5	6	7	8	9	10	11	12	13	
T	1	36	49	39	42	39	45	52	67	61	48
I	2	24	36	30	52	49	45	61	70	67	48
M	3	27	42	33	49	52	61	70	79	82	55
E	4	45	64	36	58	58	70	70	85	82	63
	5	49	70	42	61	49	70	70	79	70	62
(hr)	6	55	61	55	49	42	61	67	82	70	60
		39	54	39	52	48	59	65	77	72	- Mean

as a forecast over short time periods, and, of course, it is impossible to outperform persistence if the airflow is "steady-state" (*i.e.*, $\partial\vec{V}/\partial t = 0$).

Table 6 contains the percentage of the cases in which the IM root-mean-square vector errors (RMSVE) were less than persistence. In developing this table, ties were counted as no better. Table 6 helps demonstrate that the IM was frequently capable of yielding less RMSVE than persistence, especially in the free air. We conclude from this table that the IM tends to predict the correct trends in the evolution of mesoscale wind fields.

3.3 Horizontal Vorticity Model Versus the Inertial Model

In figures 3, 4, and 5, the RMSVEs for the 33 cases are plotted versus forecast period for the 7000-, 10,000-, and 13,000-ft levels MSL, respectively, for persistence, IM, and the horizontal vorticity (HV) model.

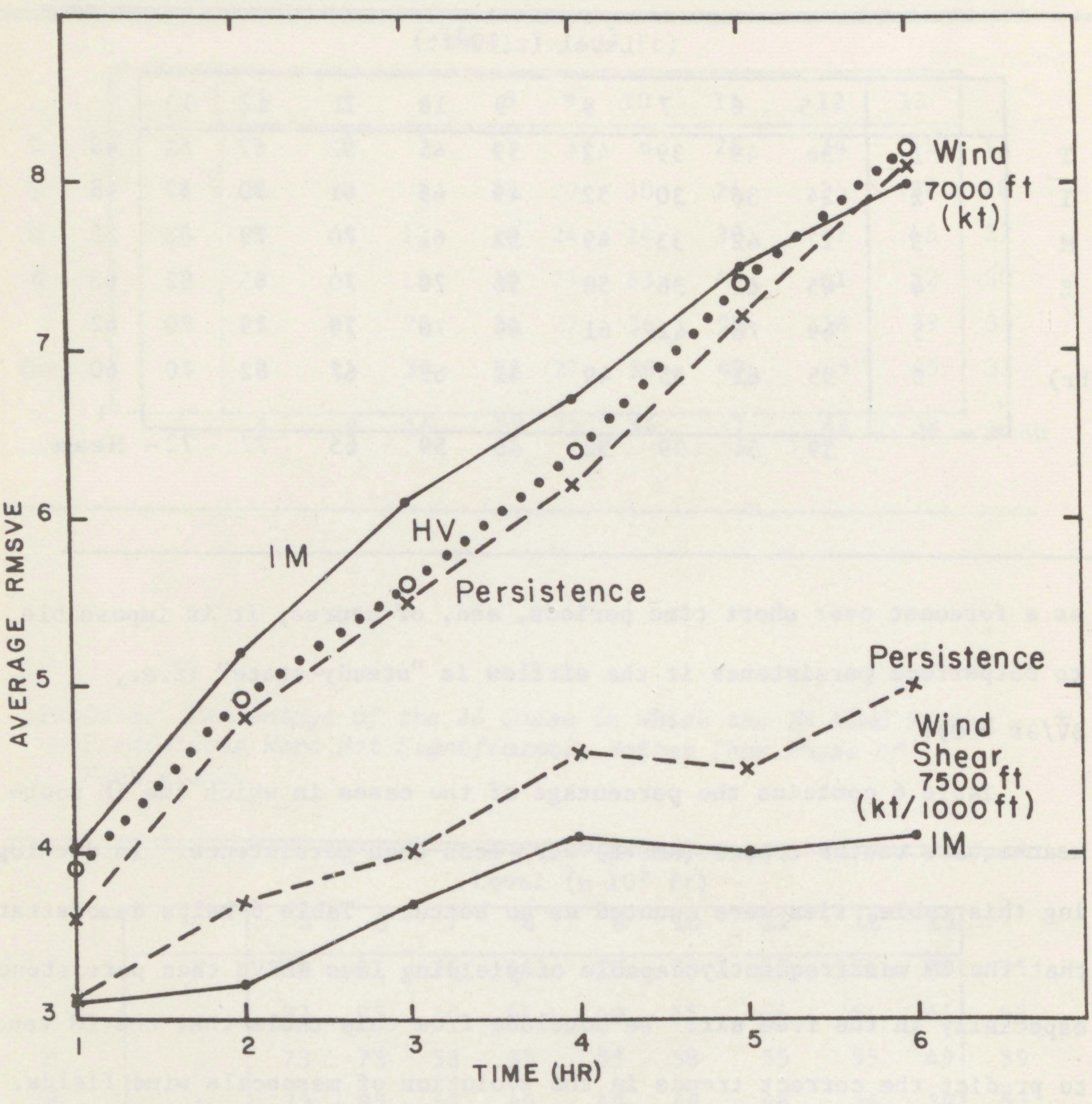

Figure 3. Average root-mean-square vector error (RMSVE) for the 7000-ft level and the average vertical wind-shear vector error for the 7500-ft level versus time for 33 cases.

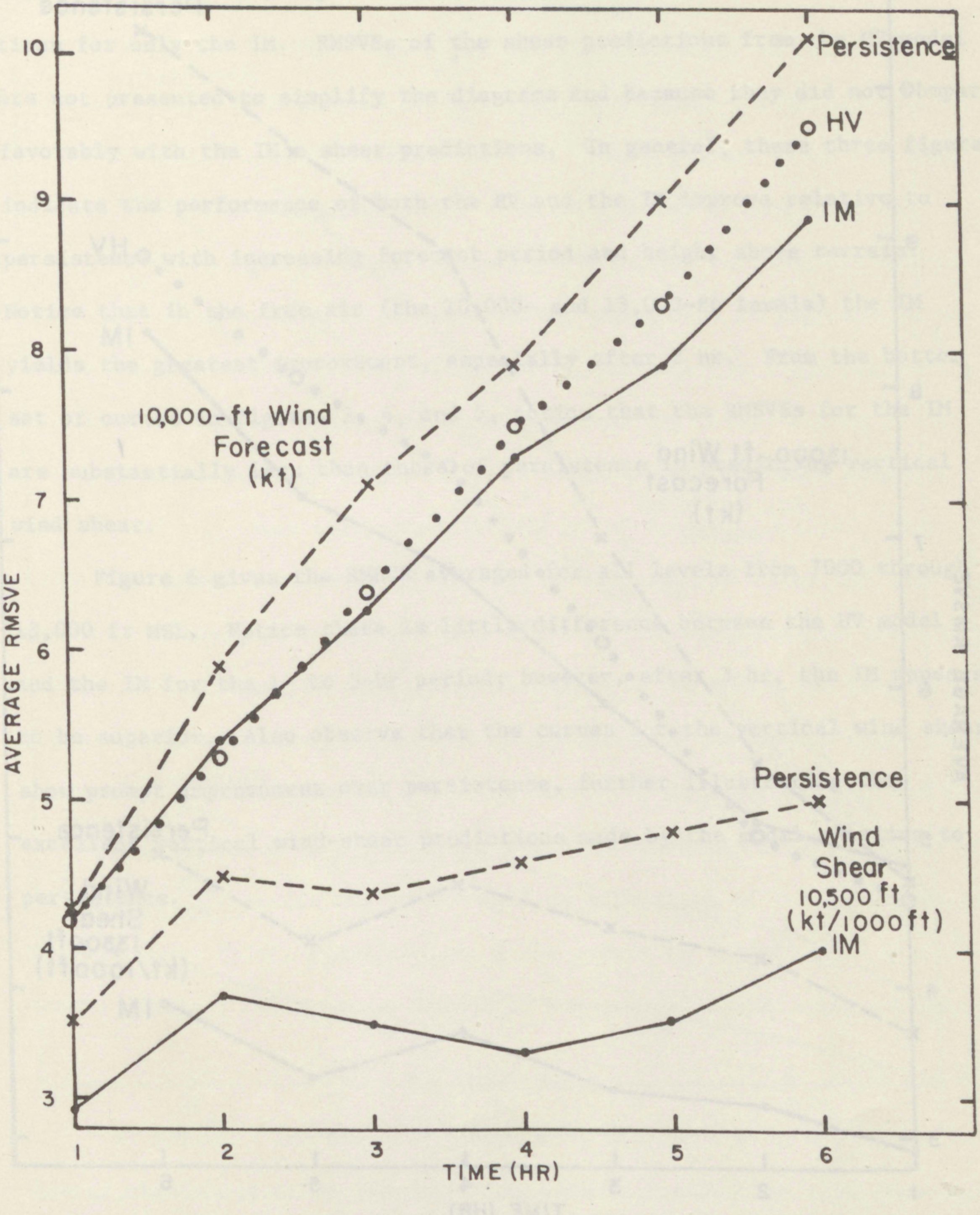

Figure 4. Average RMSVE for the 10,000-ft level and the average vertical wind-shear vector error for the 10,500-ft level versus time for 33 cases.

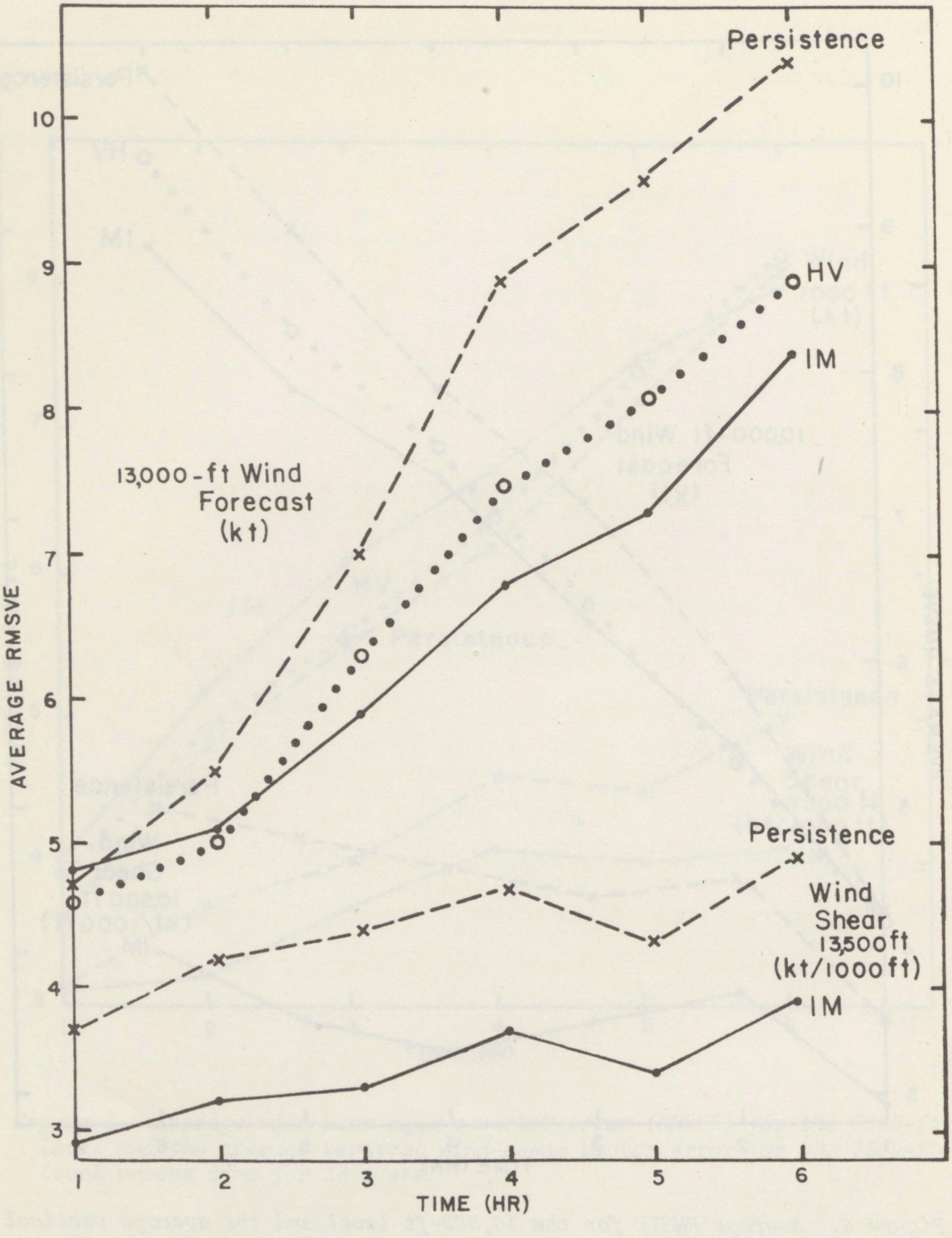

Figure 5. Average RMSVE for the 13,000-ft level and the average vertical wind-shear vector error for the 13,500-ft level versus time for 33 cases.

Also displayed in the figures are the RMSVEs of the vertical shear predictions for only the IM. RMSVEs of the shear predictions from the HV model are not presented to simplify the diagrams and because they did not compare favorably with the IM's shear predictions. In general, these three figures indicate the performance of both the HV and the IM improve relative to persistence with increasing forecast period and height above terrain. Notice that in the free air (the 10,000- and 13,000-ft levels) the IM yields the greatest improvement, especially after 2 hr. From the bottom set of curves in figures 3, 4, and 5, notice that the RMSVEs for the IM are substantially less than those of persistence in predicting vertical wind shear.

Figure 6 gives the RMSVE averaged for all levels from 7000 through 13,000 ft MSL. Notice there is little difference between the HV model and the IM for the 1- to 3-hr period; however, after 3 hr, the IM appears to be superior. Also observe that the curves for the vertical wind shear show prompt improvement over persistence, further illustrating the excellent vertical wind-shear predictions made by the model relative to persistence.

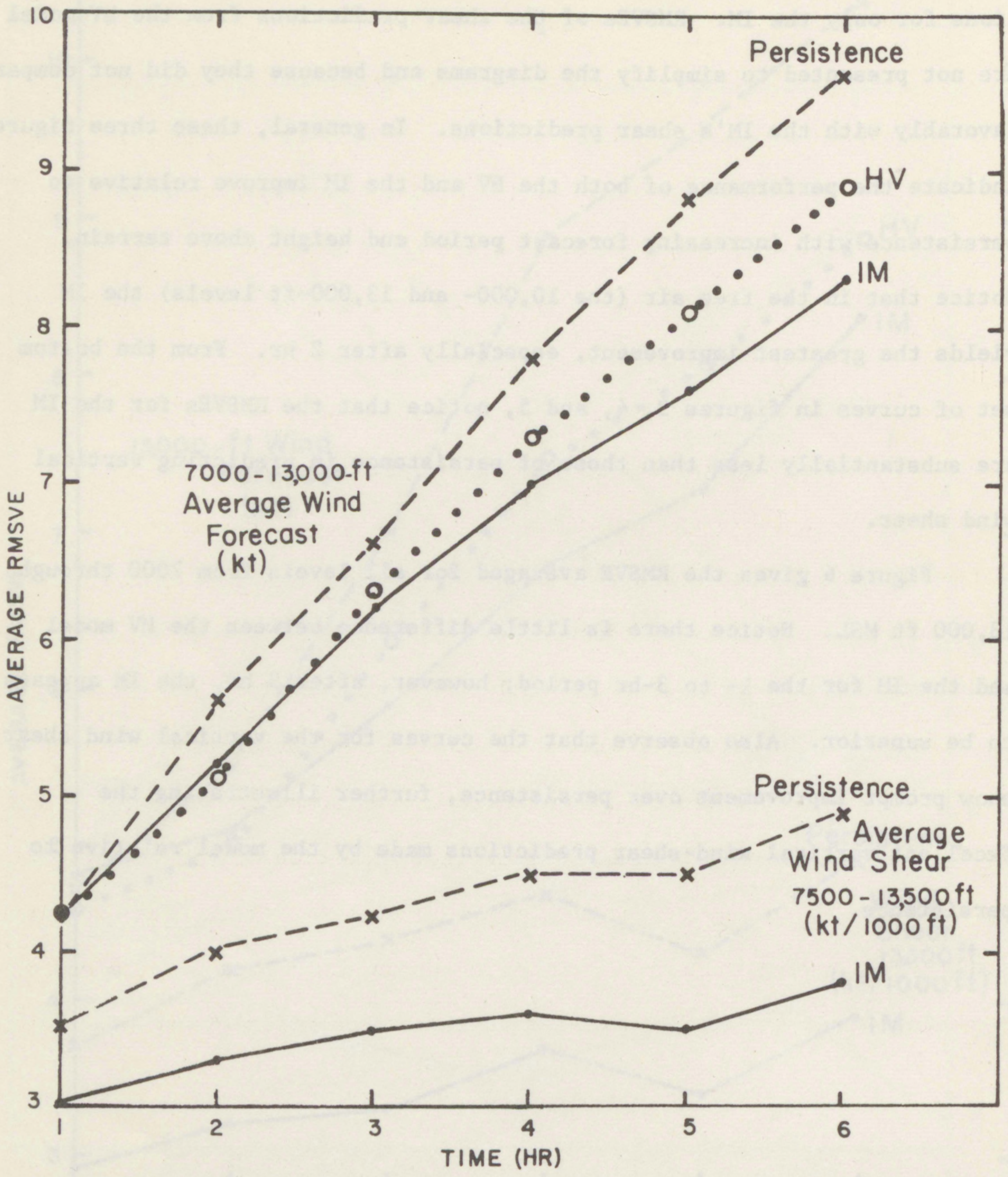

Figure 6. The RMSVE averaged over the 7000 through 13,000-ft levels and the vertical wind-shear vector error averaged from the 7500- through 13,500-ft levels.

4. LOGISTICS

A slightly modified version of the inertial model is currently being used experimentally to predict the temporal and spatial evolution of the mesoscale wind field over the NTS. The predicted winds are input to a radiological prediction model (RPM), developed by Randerson and Cornett (1973), that predicts the trajectory of any radiological debris that might accidentally be released to the atmosphere during underground nuclear tests. Table 7 is a tabulation of the wall-clock time necessary to take the required wind observations, to run the model, and to output the wind predictions in plotted form. In table 7, notice the complete operational run takes approximately 1.25 hr of wall-clock time. This table also shows that about 25 percent of the required operation time is used in obtaining plots of the wind field and the radiological field (RPM) and in transmitting the plots via telecopier to the NTS. The Central Processor Unit (CPU) time required to run the wind-prediction model (WIP) is of the order of 2 min on a Control Data 6400 computer system, the RPM using about 5 min of CPU time. A potential reduction of total elapse time by at least 50 percent can be achieved by automation of the data acquisition procedure, by direct transmission of the output to a high-speed electrostatic plotter, and by improvements in our general operational procedure.

5. CONCLUSIONS

In general, the free-air predictions made by the IM are significantly better than those of persistence at later times. We have also demonstrated persistence is a difficult forecast for the HV model and the IM to beat for time periods on the order of 1 to 2 hr; especially in the atmospheric

Table 7. Operational Schedule

Operation	Required time	Elapsed time
1. Take PIBALS	10	10
2. Transmit and hand record angles	10	20
3. Punching and checking of data	10	30
4. Run time (wall clock) --CDC 6400 Computer	7	37
5. Plot time-- WIP/11, RPM/4	15	52
6. Assembly of plots for transmission	8	60
7. Transmission to CP via telecopier	15-20	75-80

boundary layer. In the boundary layer (5000 through 7000 ft MSL), the wind and wind-shear forecasts generated by the HV model and the IM are no better than a persistence forecast; in fact, the predictions made by both models are probably worse than persistence for time periods of 3 hr or less below the 8000-ft level. Furthermore, the vertical wind-shear predictions made by the IM are significantly better than persistence for all levels and all times except in the lowest 2000 ft above ground. Even though vertical wind shear and wind vector have different dimensions, the predictions by the IM of vertical wind shear appear to be of better quality than those of wind vector, relative to persistence.

Having confirmed the mesoscale performance of the IM, we now look ahead to improve our wind forecasts. Intuitively, we believe further work with a more complete equation of motion should improve the wind forecasts, but will more physics significantly improve the mesoscale wind forecasts? Can simulations of the boundary-layer winds be improved significantly through use of contemporary closure approximations? These are the type questions we hope to answer as our research effort continues.

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