On the Accuracy of Interpolated LFM Forecasts and Their Use in Predicting Surface Conditions in Mountainous Terrain

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ABSTRACT

Limited-area Fine Mesh (LFM) forecasts were interpolated and compared with surface observations in the southern California mountains and on-site soundings.

Descriptive case studies show that during sea-breeze type of flow, when synoptic-scale forcing is weak, surface flow in mountain canyons can be uncoupled from free atmosphere flow and totally driven by local diurnal forcing mechanisms, while ridgeline sites conform to free atmosphere conditions. During Santa Ana flow, when synoptic-scale forcing is vigorous, surface flow in canyons and on ridges shows only kinematic adjustment of the synoptic-scale flow.

Root-mean-square difference comparisons of interpolated 12 and 24 h LFM 850, 700 and 500 mb forecasts of height, temperature, dew point and wind with on-site sounding data are presented.

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1. Introduction

It is becoming increasingly obvious that stagnating accuracy in local forecasting results, in part, from nonprediction of subsynoptic-scale phenomena (Sanders, 1973; Bosart, 1975). Locally run subsynoptic-scale models could increase forecast accuracy and fulfill forecast needs that are too localized, specific or small scale to receive active attention by the National Meteorological Center. These subsynoptic-scale models will tend to be diagnostic, or at best parameterize time variations, and require external synoptic-scale input. It is reasonable to assume that the required synoptic-scale input might be provided by the National Weather Service's Limited-area Fine Mesh model (LFM) and then be telescoped down to smaller scales by diagnostic models which include diurnally varying functions. Telescoping by iterative prognostic models would require much larger local computational facilities than can be expected to be available for operational use.

Surface weather conditions in the southern California mountains during the wildfire season, which extends from May through November, result from significant local adjustment of the synoptic-scale circulation. The need for fine-scale forecasts of a specialized nature (fair weather, mountainous terrain, high resolution) and the limited meteorological resources of the Forest Service have led to experiments in which gridded, digital LFM forecasts are used in conjunction with local specialized functional and diagnostic finite-difference models. Phillips and Shukla (1973) have shown that a two-way interactive system is superior to a one-way system. Our local models, however, are designed only for passive acceptance of LFM output since at the present time there is no mechanism for a two-way interaction.

Meteorological models developed for local geo-

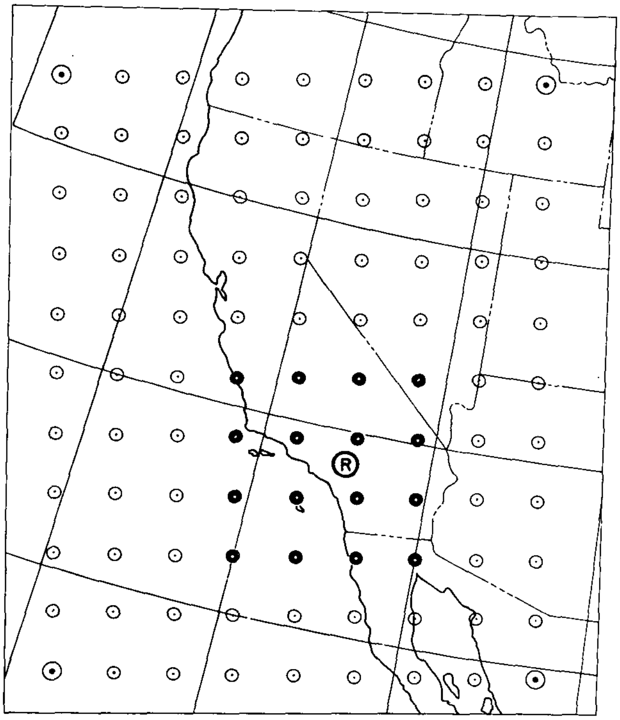

FIG. 1. The 99 points of the 11×9 subset of the Limited-area Fine Mesh (LFM) grid used in this study. The letter R indicates the location of rawinsonde unit used for verification of LFM forecasts.

FIG. 2. Station locations in Devil Canyon, San Bernardino National Forest, of meteorological research network are shown by numbers. Rawinsonde location is just below right-center margin.

graphical areas and specialized user requirements provide the modeler with greater opportunity to emphasize certain variables and deemphasize others. In addition, local models can pose more stringent requirements for resolution and accuracy. Fire weather in southern California, for example, is critically important when hot, dry weather conditions prevail, but not when moist conditions exist. Severe downslope winds in the Colorado front region appear to depend on certain upstream stability and wind profiles (Klemp and Lilly, 1975). If the LFM is going to be used to help drive local models, or if its predictions of synoptic-scale conditions are to be used as a basis for discriminately selecting from a group of local models, then the accuracy of LFM forecasts of specific variables should be assessed for a limited geographical area and for limited synoptic conditions.

TABLE 1. Site descriptions of meteorological network stations used in this study (McCutchan, 1975).

Station no.	Elevation (m)	General aspect	Slope (percent)	Description
5	930	Southwest	35	On cleared terrace on east slope of canyon
6	900	South	10	Near bottom of canyon on slight east slope
9	1625	None	0	On ridge at mountain crest

Fire danger and fire behavior in the southern California mountains are strongly affected by surface wind, temperature and relative humidity. The validity of the proposed procedure of telescoping LFM forecasts through local models, in order to predict surface conditions in the mountains, depends on how accurately the LFM predicts free atmosphere variables in the vicinity of the mountains and on how the surface conditions relate to the free atmosphere flow. This paper examines the relationship between surface conditions in the mountains and the free atmosphere, by using case studies to compare data gathered by a network of remote telemetering meteorological stations with data from on-site rawinsonde soundings; and then statistically relates LFM forecasts to the on-site soundings.

2. Data

Data used in this study consist of LFM forecasts at the 99 grid points shown in Fig. 1, surface data from a network of stations located in the Devil Canyon area of the San Bernardino mountains of southern California (Fig. 2) and soundings released from a standard GMD-1 rawinsonde unit located near the mouth of Devil Canyon on the campus of the California State College at San Bernardino. The LFM variables used were 12 and 24 h forecasts of height, temperature, dew point and u and v wind components at the 500, 700 and 850 mb pressure levels during the June–October periods of 1973, 1974 and 1975. Soundings were taken through the 400 mb level at 0000, 1200 and 1800 GMT on 39 days during the 3-year period. Network observations of wind direction, wind speed averaged over 2 min, the 2 s wind speed maximum during the 2 min average, temperature and net radiation were available at a 1 h polling interval in 1974 and at a half-hour polling interval in 1975 [see McCutchan (1975) for network details]. Table 1 lists site details of the stations used in this study.

3. Case studies

Two types of circulation (sea breeze and Santa Ana) are of predominant importance during the southern California fire season. The most prevalent is the marine air, or sea breeze, regime which is associated with smog in the Los Angeles basin and keeps the lower elevations of the coastal mountains in moister air, while the higher elevations are in drier air. Greatest fire danger usually occurs with the high winds and low relative humidities that accompany Santa Ana conditions. Santa Ana conditions are infrequent in June, July and August but are quite common in September, October and November, the latter part of the dry season.

a. Sea breeze, 13–14 August 1975

The 1200 GMT 500 mb patterns for 13 and 14 August 1975 are shown in Fig. 3. The 500 mb flow associated with the sea breeze is generally westerly or southwesterly and relatively quiescent. Fig. 4 shows soundings taken at 1200 and 1800 GMT 14 August 1975 and at 0000 GMT 15 August 1975 at our field site near the mouth of Devil Canyon. A temperature inversion that is evident at 1200 (Fig. 4a) is eroded during the day by surface heating. Depth of the marine air is indicated in the dew-point sounding. The top of the marine air is seen to lower from about 880 mb at 1200 (Fig. 4a), to about 930 mb at 1800 (Fig. 4b) and then rise again to about 870 mb at 0000 GMT (Fig. 4c). Winds are generally southerly through southwesterly.

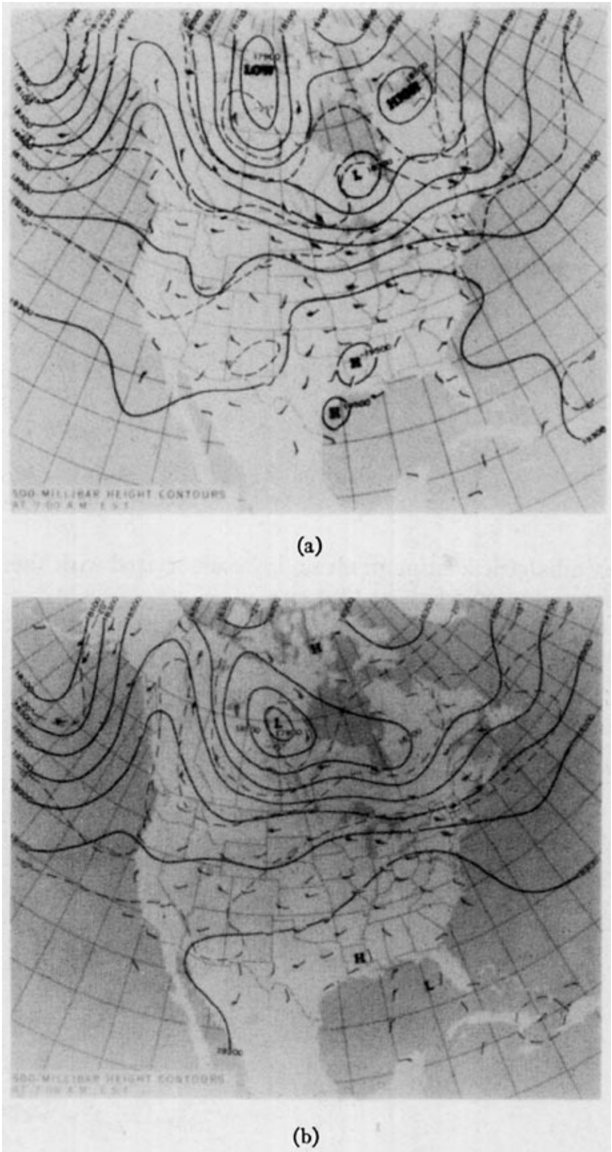

FIG. 3. The 1200 GMT 500 mb analyses for (a) 13 August 1975 and (b) 14 August 1975.

Wind and temperature data recorded half-hourly at three of our network stations are shown for the period 0000 GMT 13 August through 0000 GMT 15 August 1975 in Figs. 5 and 6. Note that the wind at station 9 (located on a ridgeline) shows little diurnal variation while the wind at station 6 (located near the canyon bottom) displays a strong diurnal trend. Direction at station 9 varies between southeast and south while direction at station 6 varies from down canyon (northerly) at night to up canyon (southerly) during midday. Speeds at station 9 are greatest during the day while speeds at station 6 are greatest at night. Station 5 is located 30 m higher than and 260 m east of station 6. Wind at station 5 is calm when station 6 is recording speeds of 4–6 m s^{-1}. Station 5 records non-zero wind only during the midday.

Winds measured by the rawinsonde are given in Table 2. Comparison with the data in Fig. 5 shows that while the wind at the ridgeline site (station 9) is comparable to free atmosphere flow, winds in the canyon are largely determined by local boundary layer effects.

Temperatures at the three locations (Fig. 6) show that station 6 records significantly higher nighttime temperatures than station 5, while both show higher daytime temperatures than station 9. The relatively high nighttime temperatures at station 6 are caused

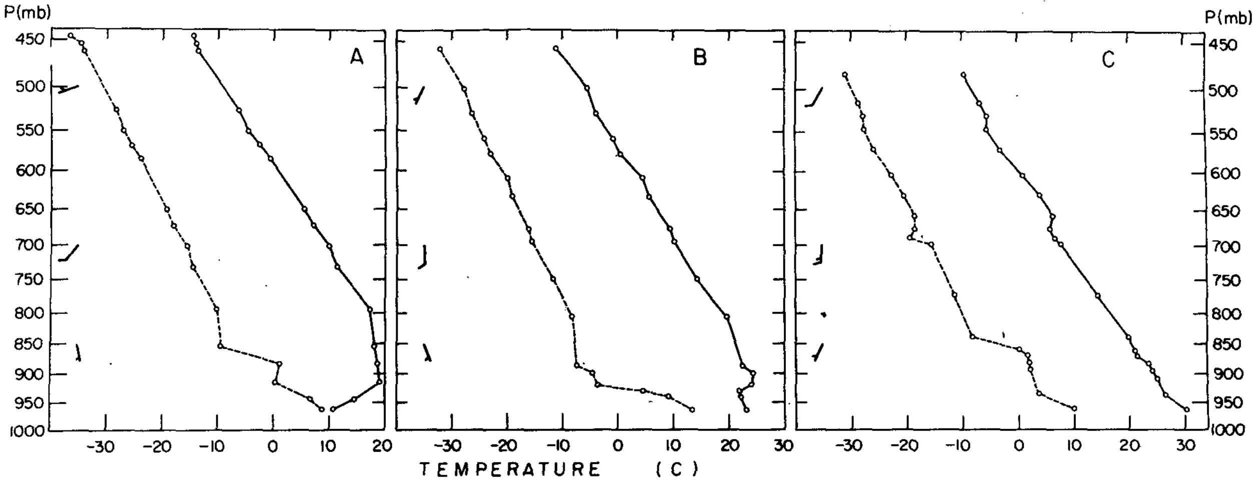

FIG. 4. Soundings for (a) 1200 GMT 14 August 1975, (b) 1800 GMT 14 August 1975 and (c) 0000 GMT 15 August 1975 releases from on-site rawinsonde.

by adiabatic heating in a thin layer associated with the down-canyon winds at that site.

This case is typical of surface conditions in the southern California mountains during sea breeze flow. It illustrates the dominance of local factors when synoptic-scale forcing is weak.

b. Santa Ana, 23–24 October 1975

The 1200 GMT 500 mb analyses for 23 and 24 October 1975 are shown in Fig. 7. A vigorous 500 mb trough has moved through the area and southern California is under moderately strong northwesterly flow at 500 mb. Fig. 8 shows soundings taken at 1200 and 1800 GMT on 23 October 1975 and at 0000 GMT 24 October 1975 at our field site near the mouth of Devil Canyon. A layer of high static stability between 730 and 630 mb is evident in the 1200 (Fig. 8a) sounding. High static above mountain ridge level is associated with strong downslope winds, and as the layer is eroded by 1800 and 0000 GMT (Figs. 8b,c) surface winds decrease in speed. Note also the development of a strong surface dew-point inversion by 0000 (Fig. 8c). Rawinsonde-measured winds (Table 2) were from the northwest through the northeast.

Wind and temperature data recorded at stations 5, 6 and 9 during the period 0000 GMT 23 October and 0000 GMT 25 October 1975 are shown in Figs. 9 and 10. Note the commencement of higher wind speeds

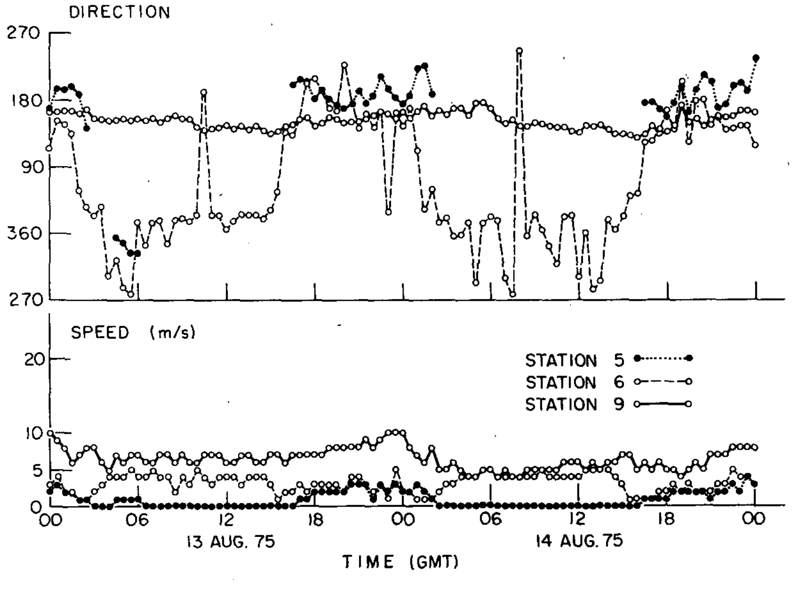

FIG. 5. Wind data recorded at stations 5, 6 and 9 from 0000 GMT 13 August to 0000 GMT 15 August 1975. Wind speeds and directions are 2 min averages, recorded half-hourly.

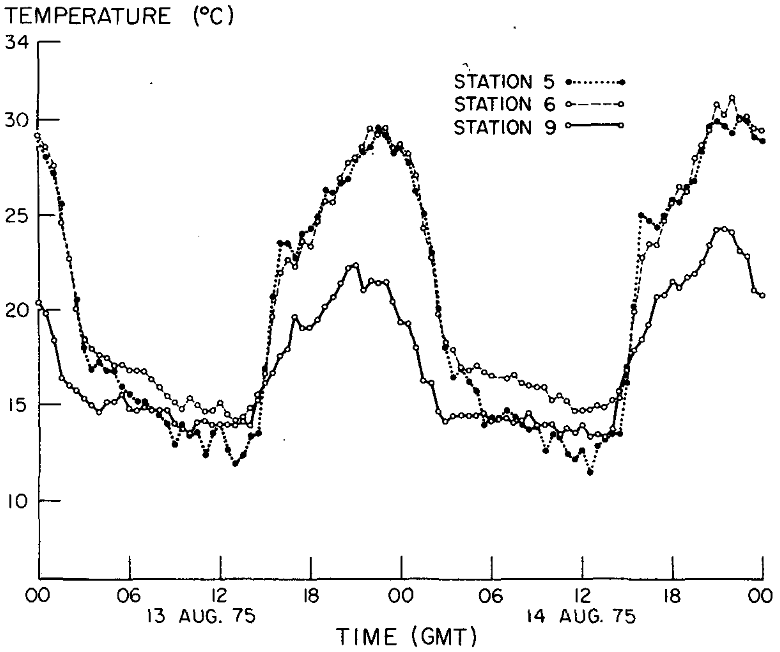

Fig. 6. As in Fig. 5 except for temperature.

at the three stations between 0800 and 1100 GMT 23 October 1975. Station 9 records the highest speeds and steadiest directions with no evident diurnal trend. Direction at station 6 vacillates between predominantly northwesterly and predominantly easterly, while directions at station 5 and 9 vary more smoothly between northwest and north.

Temperatures (Fig. 10) at stations 5 and 6 are nearly equal, while the difference between them and temperatures at station 9 is essentially adiabatic. The diurnal temperature range pattern is almost identical for stations 5, 6 and 9.

This case is typical of Santa Ana flow in the southern California mountains. Vigorous synoptic-scale circulation is the dominant forcing mechanism both at the ridgeline and in the canyon. Local adjustment appears to be essentially kinematic in the canyon. Conditions at the ridgeline station 9 are comparable to the free-atmosphere conditions. Comparison of this case with the previously discussed sea-breeze case illustrates the wide variation in the extent of synoptic-scale forcing of surface conditions that can occur in the southern California mountains.

4. Comparison of LFM predictions with on-site soundings

a. Case studies

Digital LFM forecasts for the grid points shown in Fig. 1 were interpolated to the rawinsonde site using bi-cubic splines (Sommers, 1976). Table 3 gives the interpolated LFM forecasts and the rawinsonde observations for the two case studies discussed earlier. The 12 h height and temperature forecasts for both cases are reasonably accurate. With the exception of the 500 mb wind direction verifying at 1200 GMT 14 August 1975 and the 700 mb wind speeds for the sea-

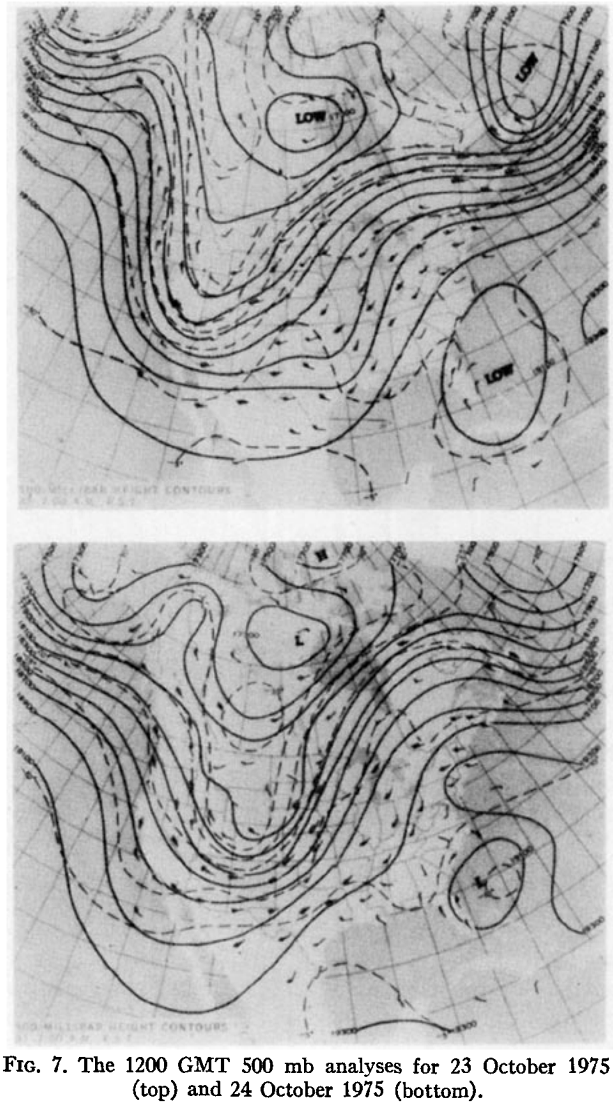

Fig. 7. The 1200 GMT 500 mb analyses for 23 October 1975 (top) and 24 October 1975 (bottom).

TABLE 2. Winds from soundings taken at California State College, San Bernardino rawinsonde location.

Time/date (GMT)	Elevation (m)	Direction (deg)	Speed (m s^{-1})	Time/date (GMT)	Elevation (m)	Direction (deg)	Speed (m s^{-1})
1200				1200			
14 Aug. 75	469	calm		23 Oct. 75	469	315	5.0
	603	014	1.6		597	305	3.3
	773	048	3.3		729	314	5.8
	952	188	1.8		861	332	9.0
	1131	212	4.1		993	348	9.8
	1347	224	1.1		1090	358	12.4
	1587	164	3.1		1187	360	17.0
	1828	150	3.4		1284	357	16.4
	1928	136	3.6		1381	357	15.7
	2027	156	4.9		1478	009	16.9
1800					1604	017	17.8
14 Aug. 75	469	250	2.0		1737	021	16.5
	650	M			1871	023	14.6
	779	M			2004	018	14.7
	908	136	0.8	1800			
	1038	133	2.1	23 Oct. 75	469	360	8.0
	1174	133	2.8		633	020	5.1
	1312	134	3.8		794	040	2.6
	1450	143	4.6		955	042	4.4
	1588	167	3.8		1094	027	8.7
	1730	212	4.3		1199	018	10.8
	1872	233	6.8		1305	024	11.1
	2014	235	8.4		1411	032	11.4
0000					1516	034	14.7
15 Aug. 75	469	260	7.0		1624	036	13.3
	634	238	4.1		1734	035	11.6
	765	254	2.4		1844	030	13.6
	896	243	1.9		1954	030	12.5
	1027	242	2.4		2064	027	11.9
	1162	246	2.4	0000			
	1304	254	1.3	24 Oct. 75	469	020	6.7
	1446	221	0.9		536	022	6.7
	1588	204	2.6		649	022	10.1
	1730	212	3.9		763	023	11.5
	1873	213	5.1		876	025	11.9
	2016	203	5.6		995	024	11.4
					1134	012	9.0
					1272	349	6.8
					1411	345	6.3
					1554	346	6.3
					1698	342	6.7
					1843	343	7.6
					1987	342	8.7
					2128	338	9.3

breeze case, the 12 and 24 h wind forecasts are also reasonably accurate. There appears to be a tendency, in our limited sample, for the 700 mb wind speed to be higher than either the 500 or 850 mb wind speeds during sea-breeze flow, and the LFM does not forecast this. Dew points in both the 12 and 24 h forecasts are predicted to be too high at 850 mb in the sea-breeze case and too low at 500 mb in the Santa Ana case.

b. *Root-mean-square difference statistics*

Approximately fifty 12 h and fifty 24 h LFM forecasts were bi-cubic spline interpolated to our rawinsonde site and compared with soundings to generate the rms difference statistics given in Table 4. Height errors are less for the 12 h forecasts than for the 24 h forecasts and increase from 850 to 500 mb. Heights tended to be under-forecast, as evidenced by positive mean errors. Temperature errors are not as consistent as evidenced by the 850 mb 24 h temperature forecast error being less than the 12 h error. This may be due in part to the strong diurnal nature of the temperature variation in the vicinity of the mountains. The decrease in temperature error with height is consistent with temperature variation magnitude during the southern California fire season.

The large differences between observed and interpolated LFM values for dew point are due in part to inability of the interpolation scheme to correctly position the sharp gradients in dew point that exist between

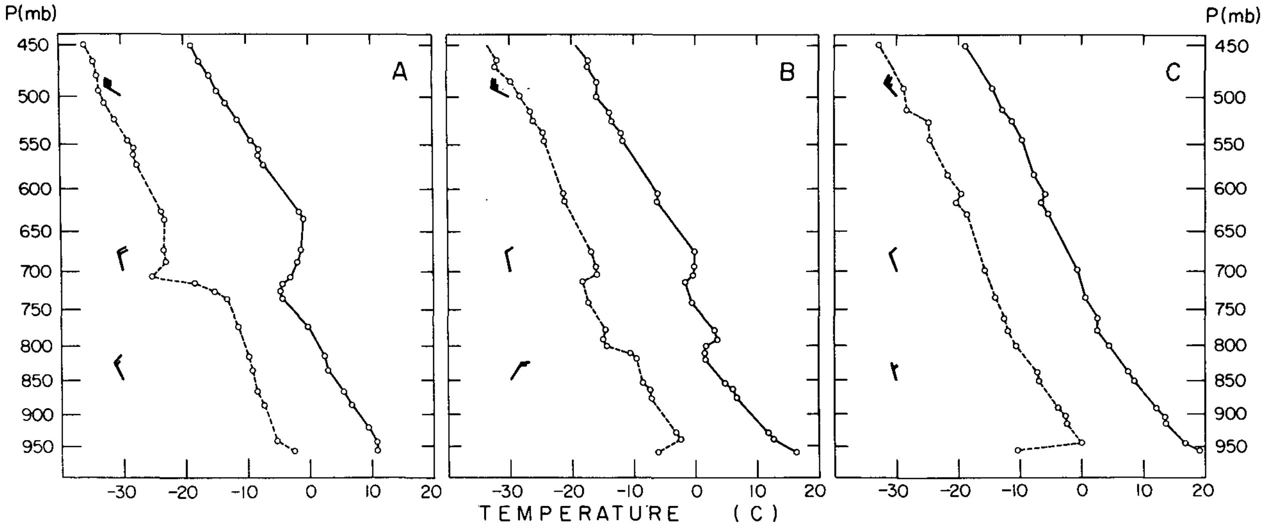

FIG. 8. Soundings for (a) 1200 23 October 1975, (b) 1800 GMT 23 October 1975 and (c) 0000 GMT 24 October 1975.

grid points and in part because slight position errors in LFM forecast dew points yield large magnitude errors in the comparison statistics. Errors at 850 mb are largest during sea-breeze conditions while errors at 500 mb are largest during Santa Ana flow.

Root-mean-square wind error values increase with height, as would be expected since wind speed generally increases with height, but do not show any significant variation between 12 and 24 h forecasts. The large rms 500 mb u component errors and negative mean errors indicate that the LFM predicts higher than observed westerly wind components at that level. The 700 mb wind errors are due, in part, to LFM under-prediction of southwesterly flow during sea-breeze conditions. LFM interpolated 850 mb wind forecasts tended to be more westerly than observed winds during sea-breeze flow.

The statistics show that while LFM height and temperature forecasts may be considered for direct interpolation, dew point and wind forecasts should be more carefully examined before any such attempt is made.

c. Box scores

A third type of comparison was made between the LFM forecasts and the on-site soundings. If the LFM forecasts were analyzed for small regions, would the

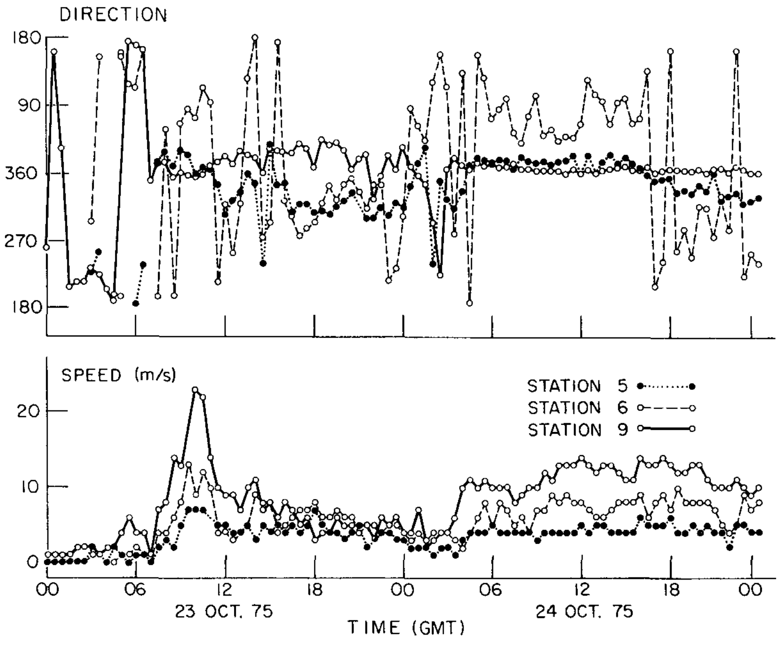

FIG. 9. As in Fig. 5 except for the period 0000 GMT 23 October through 0000 GMT 25 October 1975.

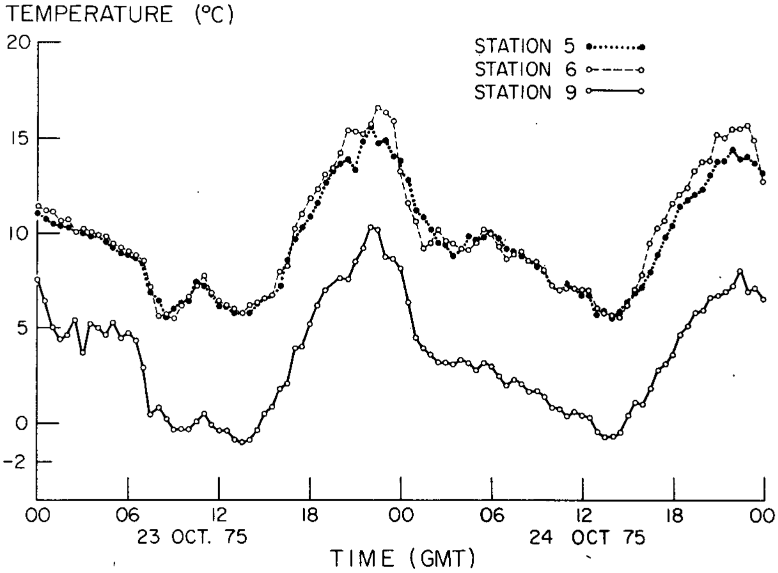

FIG. 10. As in Fig. 6 except for the period 0000 GMT 23 October through 0000 GMT 25 October 1975.

observed sounding values lie within the analyzed forecast field? In an attempt to answer this question we checked to see how often the observed values were contained within the predictive field of the four surrounding LFM grid points and the 16 surrounding LFM grid points (Fig. 1). Fig. 11 shows the results of this box test. The area included in the 4-point box extends from the ocean to the desert and covers about half of the southern California coastal mountain area. The 16-point box covers all of southern California.

Containment within the 4-point box ranged from a high of 49% of the 12 h 850 mb height forecasts to a low of 9% of the 12 h 850 mb *u* component forecasts. Containment within the 16-point box ranged from 75% of the 12 h 850 mb height forecasts to 29% of the 12 h 850 mb *u* component forecasts. The large variation of rms differences between the temperature and dew-point forecasts is not carried over into the box score test. This further indicates that large dew-point gradients are a contributing factor in the poor rms values for the dew-point forecasts. There appears to be little systematic correlation between LFM height prediction performance and the performance in wind component predictions, especially at 850 mb.

TABLE 3. Bi-cubic spline interpolated LFM forecasts and on-site soundings.

		Rawinsonde observation					12 h LFM forecast					24 h LFM forecast				
VT(Z)	Level (mb)	*H* (m)	*T* (°C)	T_d (°C)	Direction (deg)	Speed (m s⁻¹)	*H* (m)	*T* (°C)	T_d (°C)	Direction (deg)	Speed (m s⁻¹)	*H* (m)	*T* (°C)	T_d (°C)	Direction (deg)	Speed (m s⁻¹)
1200 GMT	850	152	18	−10	170	3	152	20	8	182	3	149	18	−1	197	2
8 Aug. 75	700	316	10	−16	218	9	316	10	−7	188	5	313	10	−12	201	1
	500	585	−9	−31	261	5	586	−8	−26	179	3	584	−8	−31	231	6
1800 GMT	850	155	21	−8	159	4										
8 Aug. 75	700	320	11	−15	176	11										
	500	591	−6	−28	206	3										
0000 GMT	850	154	21	−4	206	2	152	19	3	210	5	151	21	7	178	1
8 Aug. 75	700	318	8	−15	182	13	315	9	−10	190	5	315	10	−10	167	3
	500	587	−8	−30	208	9	586	−8	−27	224	5	585	−9	−30	206	9
1200 GMT	850	144	4	−9	334	16	141	9	−5	334	13	139	7	−18	322	9
23 Oct. 75	700	299	−3	−25	346	18	297	−1	−21	330	18	196	−2	−26	342	13
	500	562	−14	−33	301	28	558	−16	−41	302	22	553	−18	−43	295	20
1800 GMT	850	147	5	−9	33	13										
23 Oct. 75	700	303	0	−16	347	12										
	500	565	−16	−28	298	26										
0000 GMT	850	147	9	−7	345	6	144	8	−6	333	8	146	7	−3	360	7
24 Oct. 75	700	304	0	−16	340	8	300	−2	−26	325	14	302	−4	−25	356	15
	500	566	−14	−28	322	25	562	−16	−40	312	25	561	−18	−42	312	25

TABLE 4. Root-mean-square difference (rms d) and mean error (rawinsonde – LFM) statistics. Interpolated LFM forecasts were compared with on-site soundings for approximately 50 cases in each category. Height differences are given in dam, temperature and dew point difference in K and wind component differences in m s^{-1}.

	Pressure level and prog hour					
	850 mb		700 mb		500 mb	
Variable	12 h	24 h	12 h	24 h	12 h	24 h
Height rms d	2.20	2.81	2.75	3.14	3.14	3.35
(mean error)	(0.51)	(0.64)	(0.79)	(1.56)	(0.20)	(1.40)
Temperature rms d	2.83	2.37	2.34	2.54	1.71	1.95
(mean error)	(−0.96)	(−0.08)	(0.05)	(0.69)	(−0.42)	(0.02)
Dew point rms d	9.37	7.45	5.76	5.78	7.15	9.39
(mean error)	(−6.16)	(−4.62)	(−1.44)	(−0.67)	(−1.21)	(−2.26)
u component rms d	3.90	3.65	9.92	9.12	12.40	11.99
(mean error)	(−0.14)	(0.29)	(1.32)	(0.89)	(−3.42)	(−3.65)
v component rms d	3.58	3.44	5.61	5.77	4.68	4.39
(mean error)	(2.25)	(1.66)	(2.71)	(2.27)	(−0.82)	(0.11)

5. Conclusions

We have proposed that gridded digital LFM forecasts be used with local specialized models to provide relatively inexpensive forecasts of surface conditions in the southern California mountains during the fire season. The validity of this proposal depends on how strongly the surface conditions in mountainous terrain are linked to synoptic-scale conditions, how well the local synoptic-scale conditions are predicted by interpolated LFM forecasts, how well local specialized models that are being developed can depict the variations in small-scale surface conditions in mountainous terrain, and how well LFM forecasts can be used with these models. The last two questions are currently being investigated in studies linking the LFM with three local models that telescope down to a 100 m horizontal resolution. This paper has examined the first two questions by presenting representative case studies

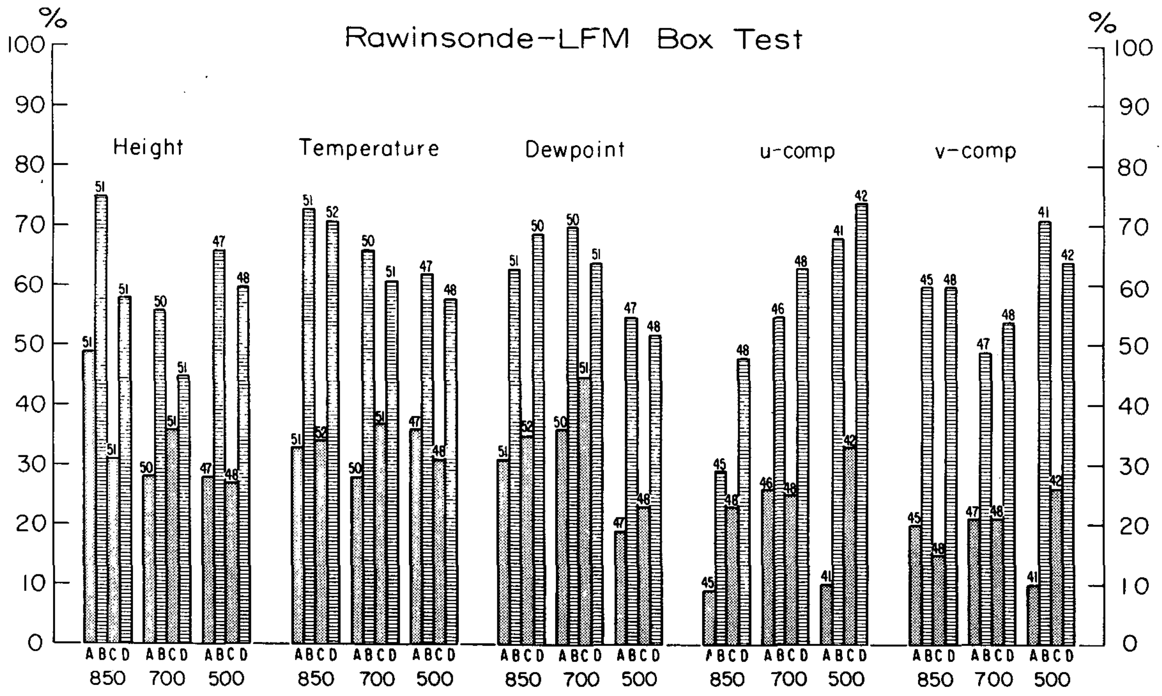

FIG. 11. Rawinsonde – LFM box test comparison. Column A represents the 12 h forecast 4-point box, column B the 12 h forecast 16-point box, column C the 24 h forecast 4-point box and column D the 24 h forecast 16-point box. Numbers at the top of each column represent the total number of cases used in the compilation.

and some limited statistical analyses. Case studies indicate that under quiescent synoptic-scale conditions, local factors largely determine flow in mountainous areas with the exception of exposed ridgeline locations. During more vigorous synoptic conditions, flow in the mountainous areas is more directly related to synoptic-scale flow. LFM forecasts are able to sufficiently differentiate between synoptic-scale conditions to allow for selection between local models that are specialized for sea-breeze or Santa Ana regimes.

Comparison of interpolated LFM forecasts and on-site soundings shows that height and temperature forecast inaccuracies are small in relation to actual spatial variation of the surface winds and temperatures in the mountains. Interpolated LFM dew-point forecasts are less accurate and, because of the sharp gradients in actual dew point, seem less applicable to solving the relative humidity forecast problem than do statistical or empirical techniques tied to a weather classification scheme. Wind forecast accuracies are the most difficult to judge. Sea-breeze conditions are the most common type of flow experienced during the time of the year covered by this study and the statistics are weighted by the larger number of cases in that category. Since local factors play an important role in determining surface winds in the mountains under light synoptic-scale wind conditions, the acceptability of LFM wind forecast accuracy cannot be determined until those forecasts are tested in combination with local specialized models. Accurate surface wind forecasts under Santa Ana conditions will be more difficult to obtain since large temporal variations in the surface winds occur that are not diurnally dependent. These temporal variations appear to be due to variations in synoptic-scale forcing and mountain wave dynamics that have a less than 12 h time scale. The LFM cannot be expected to resolve them because it does not incorporate the necessary small-scale dynamics. A fully prognostic small-scale model will be required. The LFM does, however, perform well under Santa Ana conditions if these rapid temporal variations are smoothed over a 12 h period. Combining the LFM forecasts with local diagnostic models under Santa Ana conditions will provide better spatial resolution than is currently available and greatly smoothed temporal variation.

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