

APPLICATION OF INFRARED DATA FROM A GEOSYNCHRONOUS
METEOROLOGICAL SATELLITE IN SURFACE WIND MODELING

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INTRODUCTION

Analysis and prediction of atmospheric structure in mountainous areas is unusually hampered by lack of adequate data. Widely spaced weather stations cannot properly characterize the spatial derivatives of meteorological variables required by fine-mesh numerical models. Numerical models of airflow near the earth's surface are extremely sensitive to boundary conditions. Much effort has been expended in developing parameterization techniques for functional descriptions of kinetic energy (Yamada 1978) and for heat flux from the surface to provide potential energy (Sestak and Marlatt 1978) in order to specify these required boundary conditions. Specifications of these boundary conditions are particularly difficult in complex terrain where horizontal homogeneity assumptions in the parameterization methods are unsatisfactory approximations. For complex terrain, models by Anderson (1971), Fosberg and others (1976), and Danard (1977) require that the thermal boundary conditions be specified in terms of temperature at instrument shelter height. These models require temperatures rather than heat flux. We conducted an experiment which blended infrared digital data with conventional surface temperature observations in order to improve the resolution of initial and boundary conditions of the temperature field. The thermal digital data were provided by the GOES (Geostationary Operational Environmental Satellite) satellites. The temperature fields for both the surface and the blended data observations were then used to calculate the wind field with a modified potential flow model

(Fosberg and others 1976), and determine if model performance could be improved through use of the satellite data. These data could also be used to establish current performance levels of interpolation techniques and wind models in complex terrain.

WIND MODEL

The wind model simulates a two-dimensional horizontal slab solution of potential flow over complex terrain. The upper boundary condition requires that the vertical motion is zero. At the earth's surface, vertical motion is specified by the wind velocity and the shape of the terrain. Slab depth is specified by the Froude number and is typically 2 to 3 km above the terrain. Modification of the potential flow is obtained by impulse acceleration integration of the two-dimensional vorticity and divergence equations. It is in these equations that the characteristics of the temperature field is used. Initialization and boundary conditions at the surface are specified for the u and v wind components and the temperatures using a two-pass $1/R^2$ distance weighting from the surface observation stations. The first pass ensures that all calculation points are covered and the second pass provides the resolution defined by the data network.

We used the roughly 8 km square pixel data from the GOES satellite for the temperature field. The digital infrared data from GOES

(10.5 to 12.5 μ m) were converted to brightness temperatures by using the standard infrared calibration for the sensor. Because the absolute values of the satellite brightness temperatures could contain systematic errors due to atmospheric attenuation, field information blending techniques (Waters 1975) were used to combine the satellite data with the standard surface based observations. Satellite temperatures were reduced to temperature gradients by using centered differences for each pixel or approximately a 16-km mesh. The temperature gradients were then interpolated to the computational grid to be used in the numerical model. Finally, the gridded temperature field was constructed by use of Newtonian interpolation and the observed temperatures at the surface stations.

FIELD OBSERVATION PROGRAM

During summer and fall 1977, we did a field experiment to evaluate numerical models of airflow and air quality for management of smoke from agricultural and forestry prescribed burning in northwest Oregon.

The experimental area and the computational domain of the model was 240 km in the north-south direction and 160 km in the west-east direction and was bounded on the west by the Pacific Ocean and the Cascade Mountains on the east (fig. 1). Within the computational domain lay the Oregon Coast Range and the Willamette Valley. The southern portion of the computational domain is dominated by mountains. The Columbia River formed the northern boundary. A 4-km grid was used in the calculations.

The cost of obtaining measurements of the meteorological variables required for model input and verification was reduced by restricting the intensive observation periods to 6 days encompassing the most frequent, distinguishable meteorological patterns. Surface wind and temperature observations were generally obtained on an hourly basis, however some of the sites reported only on a 3-hour basis. Winds aloft were obtained by means of pilot balloons and single theodolites at 3-hour intervals while vertical temperature profiles were obtained somewhat less frequently by means of rawinsondes and an instrumented Beech D-18 aircraft. Three of the field observation days (September 9 and 13, October 12, 1977) were selected for detailed analysis and model verification studies (table 1). Surface data was collected hourly. Satellite infrared digital data were available every 30 minutes. Three days were selected for intensive analysis.

Table 1.--Prevailing meteorological conditions during three field observation days selected for model verification

Date	Meteorological conditions
9/9/77	Northerly anticyclonic flow, subsidence inversion, well-defined mesoscale flow feature including marine air penetration and up- and downslope winds.
9/13/77	Breakdown of a classical summer "heatwave." Initial east wind situation due to penetration of the California thermal trough into the Willamette Valley followed by reversal to general onshore flow conditions.
10/12/77	Prefrontal period characterized by general southerly flow, less distinct mesoscale wind systems, weaker stability aloft, and moderate transport winds.

The thermal fields defined by the surface observations of temperature, along with the blended thermal field defined by both the satellite and surface temperatures, were compared after these fields were converted to potential temperatures. The conversion to potential temperatures was done for two reasons: First, potential temperature provides the best representation of the available potential energy for wind modeling; and second, the wind model used in this study specifically required the potential temperature field as an input variable.

RESULTS

Surface layer temperature fields (fig. 2) showed considerable spatial variability. The satellite data were blended with the surface observations and converted to potential temperatures (fig. 3). Differences between the potential temperature field from surface data (fig. 4) and the potential temperature field from the blended data showed a great deal of similarity (table 2). In fact, differences between the two methods of developing the potential temperature field were not statistically significant. Use of only the surface data yielded a 2.3C root mean square error, while the blended temperature field gave a root mean square error of 2.6C. Use of surface data only was conservative and tended to underpredict the temperature. The slope of

Table 2.—Interpolated temperatures and model-determined winds compared to surface observations

	Temperature				Wind				
	Slope	Inter- cept °C	R ²	RMS error °C	Component	Slope	Inter- cept ms ⁻¹	R ²	RMS error ms ⁻¹
Surface temperatures interpolated to grid points	0.92	0.06	.75	2.3	Full model				
					u	0.69	-0.6	0.49	1.2
					v	0.73	0.6	0.47	1.6
Blended temperatures	.77	0.6	.67	2.6	Potential flow				
					u	0.74	0.4	0.16	1.5
					v	0.80	-0.3	0.20	1.9

the regression line for a least square fit of interpolated temperatures predicted by the model versus observed temperatures (fig. 5) was 0.92, with 75 percent of the variance accounted for in a linear fit. The same analysis of the blended data showed that the satellite data showed greater temperature variations, with cooler temperatures in the cold areas and warmer temperatures in the hot areas than observed. This overprediction of interpolated temperatures resulted in a slope of 0.77 predicting observed values by model values and accounted for 67 percent of the variance in a linear fit (fig. 6). Intercepts are near zero and not significant.

The predicted winds (fig. 7) showed many of the identified flow features in the region. Flow of marine air through the low level passes in the coast range were well identified by the model in the Grande Ronde gap and the Burnt Woods and Alsea gaps. Flow up the mountain slopes was represented clearly by the model on both sides of the Willamette Valley, particularly in the major drainages in the Cascades. One additional characteristic, the stagnation of flow in the Eugene-Springfield area, is well depicted. Comparison of these winds using temperature data with a potential flow calculation involving only mass balance (fig. 8) showed significant improvement.

Error statistics in the predicted wind fields are based on the surface observations. These error statistics were analyzed for the east-west component (fig. 9) and for the north-south component (fig. 10). Regression of observed versus predicted wind components showed that the model did not fully resolve the extremes, giving regression slopes of 0.69 and 0.73, respectively. Further, slightly less than half of the variances were accounted for by the models with R² of 0.49 and 0.47,

respectively (table 2). Root mean square errors for the predicted winds were 1.2 and 1.6 meters per second, respectively.

CONCLUSIONS

Attempts to improve on model performance by using high-resolution satellite thermal digital data failed to improve model error statistics. This lack of improvement may be due to inadequacies in the numerical interpolation methods rather than deficiencies in the data. In particular, the error analysis for the cases using only surface temperatures showed that the interpolation methods underpredicted the temperature gradients while use of the blended temperature field overpredicted the temperature gradients, yet error statistics of the two methods were comparable. Also, a contributing factor was that most of the data for the surface observations were located at low elevations with only a few weather stations located in the mountains. It appears that improved interpolation techniques are needed before a satisfactory blend of surface-based observations of temperature and satellite thermal digital data can be made. In general, we seem to be limited by analysis techniques rather than by data.

Attempts to predict mass consistent surface wind fields showed considerable improvement over potential flow calculations when temperature data are used to add thermally produced two-dimensional divergence. Lack of high resolution in these calculations is due to the lack of surface observations of winds required to initialize the model calculations.

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Figure 1.--Location of the study area field observation stations in northwest Oregon.

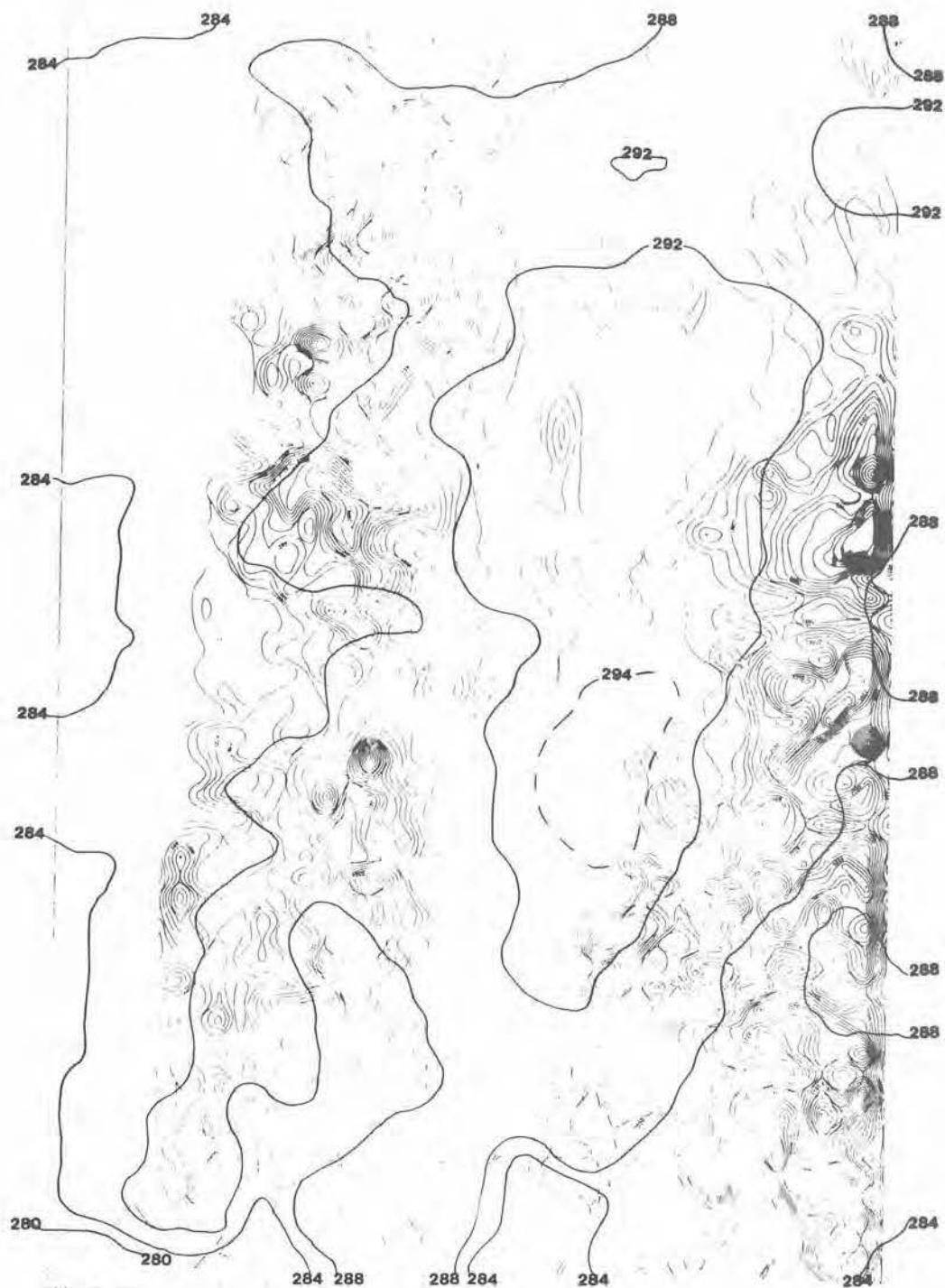


Figure 2.--Temperatures obtained from surface observations, September 9, 1977, 1000 PST.

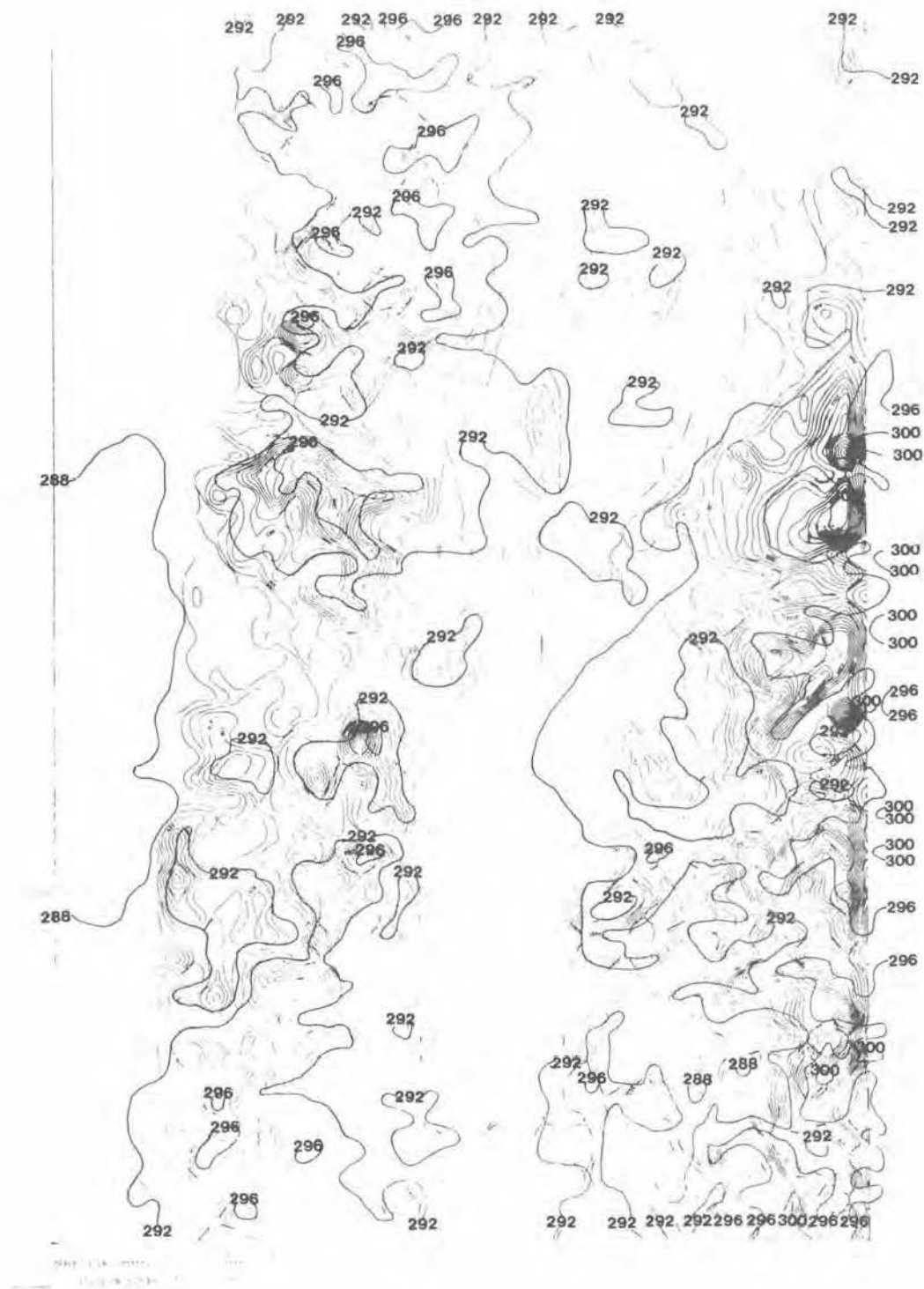


Figure 3.--Potential temperatures obtained from blended surface observation and infrared digital data, September 9, 1977, 1000 PST.

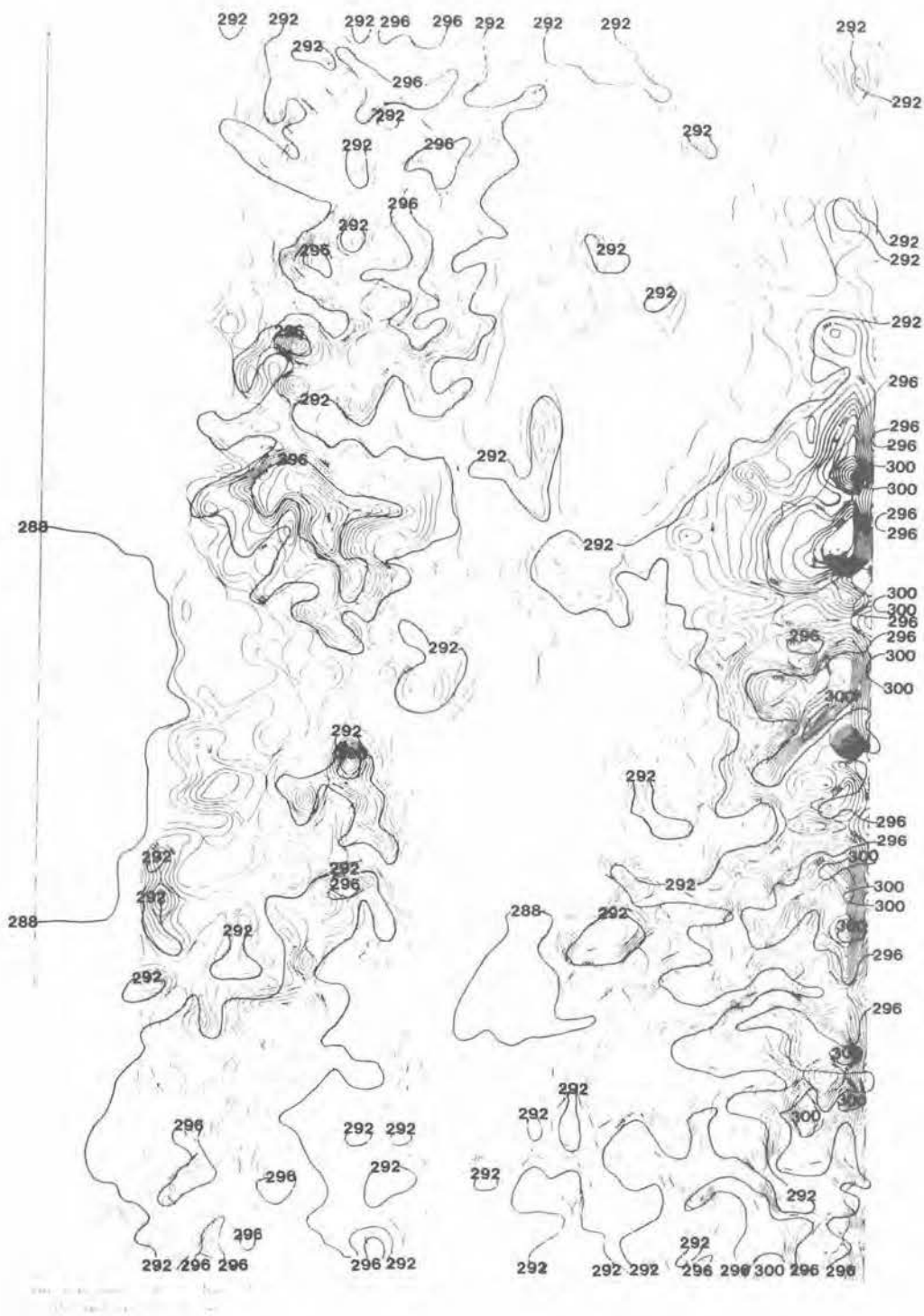


Figure 4.--Potential temperatures from surface observation, September 9, 1977, 1000 PST.

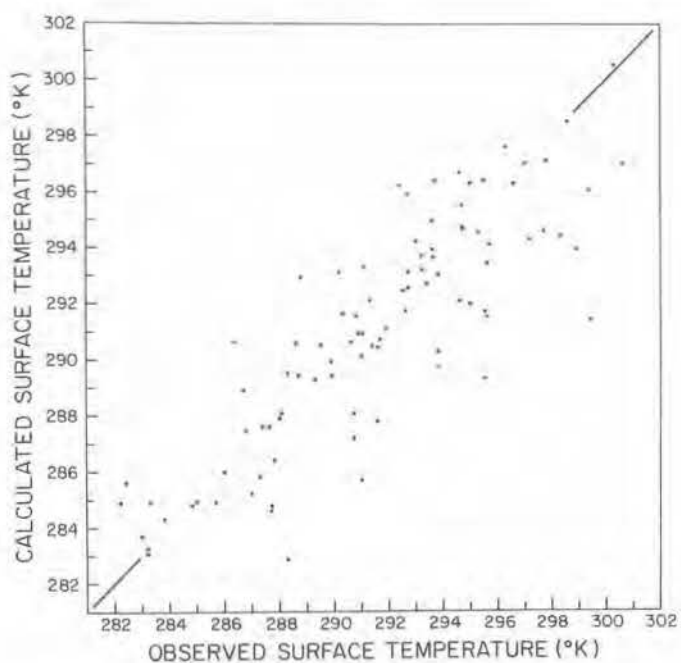


Figure 5.—Plot of observed and interpolated surface temperature for September 9, 1977, 1000 PST.

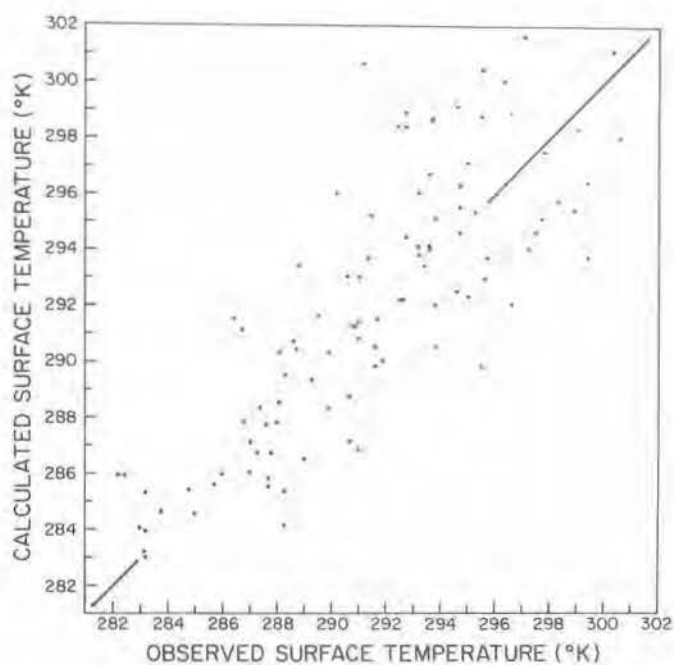


Figure 6.—Plot of observed temperatures and blended interpolated temperatures for September 9, 1977, 1000 PST.

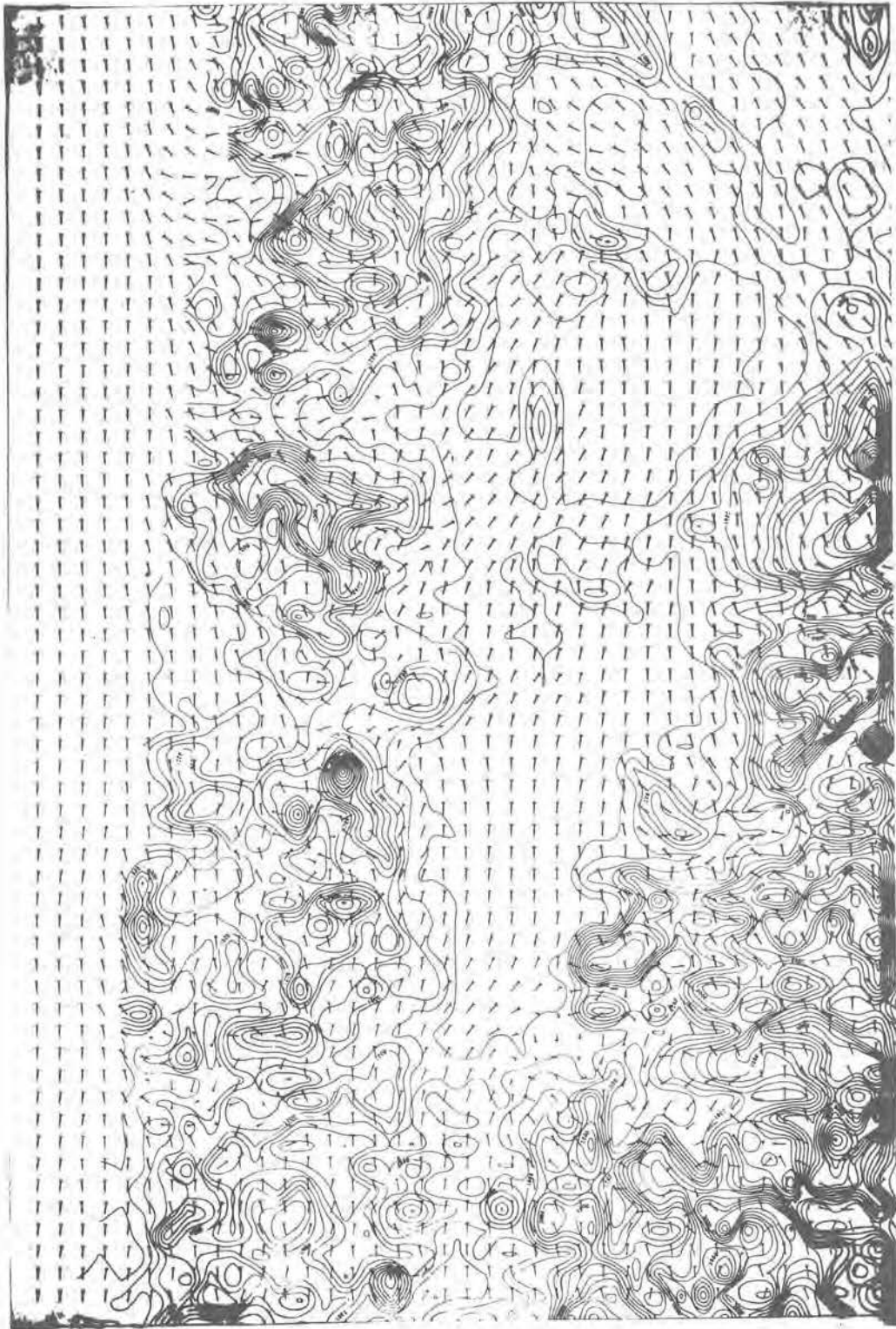


Figure 7.--Wind field predicted with blended temperature field for September 9, 1977, 1000 PST.

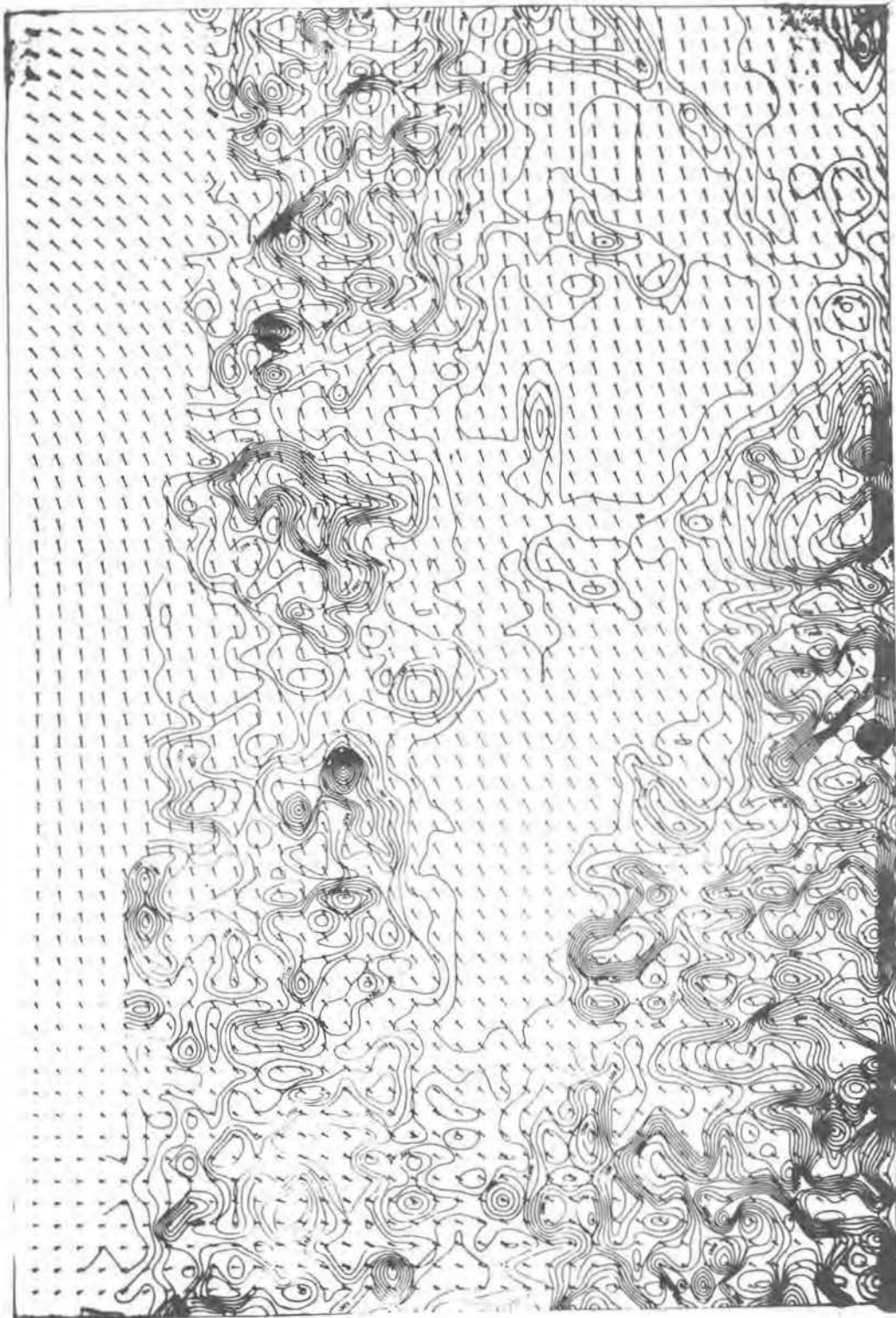


Figure 8.--Wind field predicted from potential flow solution for September 9, 1977, 1000 PST.

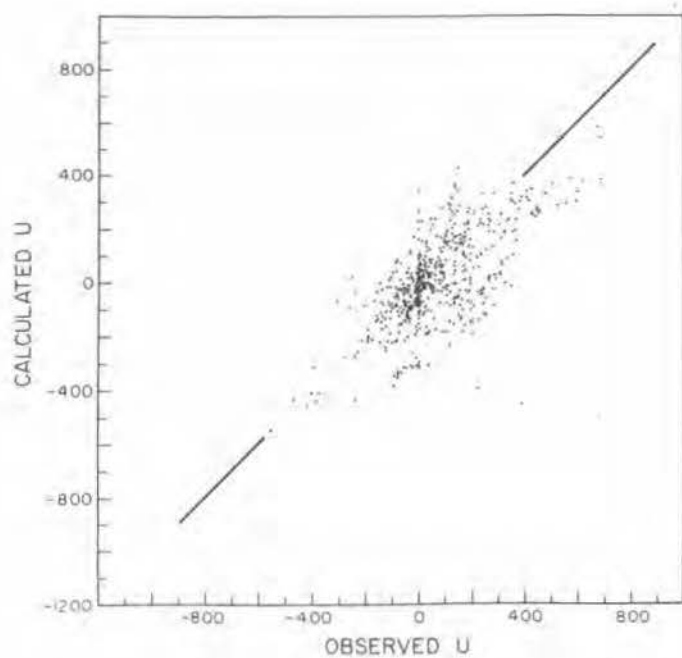


Figure 9.—Plot of observed and predicted u components of wind (ms^{-1}).

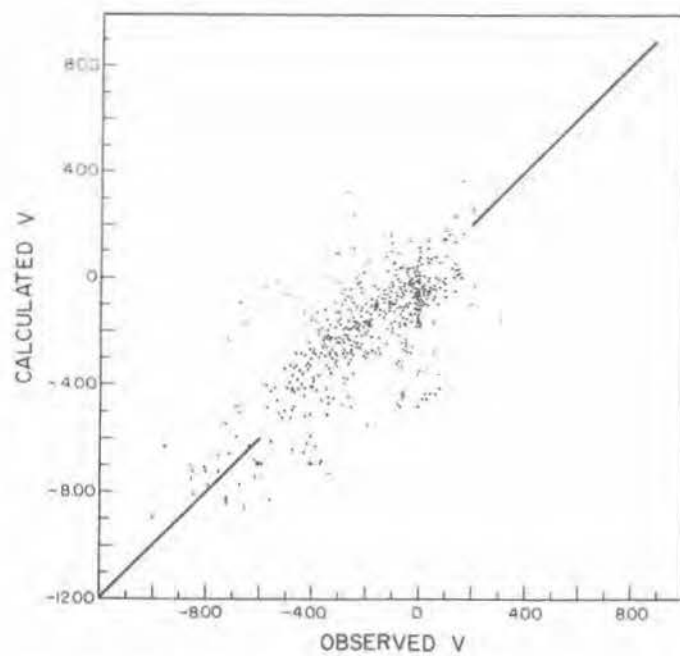


Figure 10.—Plot of observed and predicted v components of wind (ms^{-1}).