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U.S. DEPARTMENT OF COMMERCE
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Experimental Air Quality Forecasts in the Sacramento Valley

NORMAN S. BENES

Western Region

SALT LAKE CITY,
UTAH

August 1970

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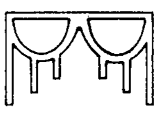

A western Indian symbol for rain. It also symbolizes man's dependence on weather and environment in the West.

U. S. DEPARTMENT OF COMMERCE
ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION
WEATHER BUREAU

Weather Bureau Technical Memorandum WR-53

EXPERIMENTAL AIR QUALITY FORECASTS IN THE SACRAMENTO VALLEY

Norman S. Benes
Principal Assistant
WBO, Sacramento, California

WESTERN REGION
TECHNICAL MEMORANDUM NO. 53

SALT LAKE CITY, UTAH
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INTRODUCTION

About 400,000 acres of rice are harvested annually in the Sacramento Valley (see Figure 1). The disposal of straw and rubble residue after harvest presents a problem of large proportions to the rice grower. Historically, burning of this straw has been the most efficient means of disposal. With steady urban encroachment into the agriculturally productive areas of California, a tolerance limit is fast approaching regarding acceptable air quality standards. Dr. Douglas H. K. Lee (1963) listed 13 atmospheric factors affecting man; among them were smoke and dust.

Rice-straw burning generally produces a highly visible smoke. With sufficient acreage afire under certain atmospheric conditions, this smoke may interfere with many human urban and suburban pursuits. Principally affected is horizontal visibility, an aesthetical variable especially important in this location. The California State Forester, Francis Raymond, commented (1967), "Sacramento city is currently being 'scourged' daily with smoke from burning rice stubble. Outcries demanding control of this air pollution are in each daily paper." This remark was triggered by the rapid deterioration in visibility from one day to the next as shown in Figures 2a and 2b. Figures 3a and 3b show that a decrease in mixing height on the 31st was associated with the decrease in visibility. In the middle of 1968, representatives of the agricultural community in the Sacramento Valley contacted the Sacramento Weather Bureau Office regarding the possibility of providing a weather forecast that would enable them to dispose of their agricultural wastes by burning and still maintain a socially acceptable level of air quality.

During the "twilight" period before the Air Resources Board set air quality standards for California, concern was felt by the rice growers regarding the impact that their farming practices might have on a well-publicized, and at times somewhat emotional, issue. At the time of their request for aid from our Sacramento Weather Bureau Office, it was pointed out that Weather Bureau forecast information would be advisory only. The State Air Resources Board (ARB), under provisions of the Mulford-Carrell Act (1967), was empowered to establish air basins throughout the state (see Figure 4). One of these basins is, essentially, the Sacramento Valley. However, in that same act, individual counties within the air basins retained the right to establish their own air pollution control district (APCD). In addition to the San Francisco APCD and the Los Angeles APCD, almost one-half of the state's counties have formed their own APCDs.

Sacramento County was reported by NACORF (1967) to have a 1965 expenditure of 5.6¢ per capita for air pollution control, compared to 60.8¢ per capita for Los Angeles County and 31.8¢ per capita for the San

Francisco Bay Area. This means that more than three and one-half million dollars for Los Angeles County, a little over one million dollars for the San Francisco Bay Area, but only twenty-eight thousand dollars for Sacramento County were spent in 1965 for air pollution control. The NACORF report does not list any areas in the United States spending less than five thousand dollars annually.

Air pollution potential (APP) forecasts are available via national teletype. The nearest locality to Sacramento for which a forecast is made is Oakland in the San Francisco Bay Area. However, the San Francisco APCD (1968) does not rely on APP forecasts for their regulatory activities concerning agricultural waste disposal by burning, as they are not detailed enough. Consequently, they have established procedures based on a local temperature-inversion climatology. A minimum requirement of 2500-feet vertical mixing (to the base of the inversion) is considered adequate, provided that there is a 7.5 degree centigrade temperature decrease in that layer from the ground to 2500 feet. In the fall of 1968 and 1969, the National Meteorological Center (NMC) mixing-height forecasts for Oakland showed a bias toward higher values with time. Forecasts for "tomorrow afternoon" were higher about 80 percent of the time than forecasts for "this afternoon". Data compiled for the Sacramento Valley by the Sacramento Weather Bureau Office, using Oakland radiosonde data and valley maximum temperatures, indicated that in the autumn of 1968, mixing heights were the same or higher the next afternoon 45 percent of the time and lower 55 percent of the time. In autumn 1969, mixing heights for the next afternoon were the same or higher 56 percent of the time and lower 44 percent of the time.

In response to pollution problems in the Willamette Valley of Oregon, Bates and Chilcote (1969) derived a regression equation that provides the approximate number of acres of agricultural waste that can be burned before visibility at a control point (Eugene) is reduced to a prescribed value, six miles. Variables used were 850-millibar wind speed and direction at Salem and 7:00 a.m. visibility at Eugene. Smoke management advisories were recently inaugurated in Oregon as aids in critical silviculture operations.

PROCEDURES

The Sacramento Weather Bureau Office approach was to generate a rather easily understood forecast that would enable the decision maker (the agriculturist) to choose from his options, whether to burn and how much to burn, in a manner that will produce the least particulate matter concentration in lower levels of the atmosphere. The forecast ability of the atmosphere to diffuse pollutants was called the "Ventilation Index". Panofsky (1969) states that the concentration of pollutants is inversely proportional to V x D, the "Ventilation Factor", where V is the average wind speed in the mixed layer D. The Sacramento Valley is similar to a large box canyon, easily trapping pollutants. However, with sufficient vertical lifting and sufficient horizontal wind movement, pollutants can be dispersed.

A measure of atmospheric stability is obtained from the early morning Oakland radiosonde. Lower-level mean winds are transmitted on the preliminary raob report and provide the mean speed from the surface to five thousand feet, and from five thousand feet to ten thousand feet. Sacramento WBO used the former. Wind speeds in the valley south of Sacramento were obtained from a television broadcasting tower at Walnut Grove via a telephone call to the duty engineer at about 5:00 a.m. Wind speed there is measured near the 600-foot level and near the top, 1500 feet.

Knowledge of low-level, lower Sacramento Valley wind speeds provides the forecaster with more confidence as to existing conditions when extrapolating the Oakland surface to 5000-foot winds into the entire Sacramento Valley during the preparation of air pollution forecasts. Pibal observations taken at 1800 GMT at the Sacramento Executive Airport were used as input for possible forecast revision in the noon release via direct radio broadcasts. This noon forecast includes an "outlook" for ventilation conditions expected the next afternoon. The U. S. Air Force has a weather detachment at Chico, California, which takes some radiosonde observations in support of the Air Force's high-altitude, balloon-borne soundings released there. Prior to Sacramento WBO's first ventilation forecast season (autumn 1968), all Chico flights that were launched in the early morning during October 1967 were obtained and compared with Oakland 1200 GMT flights for the same day. The comparison indicated that the observations were similar enough to use the Oakland sounding in an experimental forecast program (see Figure 5).

Since visibility was used as the measure of air quality, the aid of several cooperators was obtained in reporting the 4 p.m. visibility at Biggs, Willows, Woodland, Arbuckle, and Davis (see Figure 1). In addition, hourly visibility reports were available from the following aviation weather-reporting stations in the Sacramento Valley: Redding (RDD), Chico (CIC), Red Bluff (RBL), Beale Air Force Base (BAB), Marysville (MYV), Sacramento Metropolitan Field (SMF), Sacramento Executive Airport (SAC), McClellan Air Force Base (MCC), Mather Air Force Base (MHR), and Travis Air Force Base (SUU). Cooperators were supplied with charts indicating prominent landmarks at known distances, and arrangements were made to have their observations telephoned to Sacramento WBO each afternoon. This would, ordinarily, be the time of day that maximum ventilation through mixing should occur. These observations would also indicate the accuracy of forecasts distributed via radio broadcast at 6:30 a.m. that morning. Holzworth (1961) concluded that visibility data can be an important source of information in the evaluation of air pollution problems.

Two work sheets were used by the Sacramento WBO forecaster: one was the forecast form (Figure 6), the other was a portion of a large pseudoadiabatic diagram (Figure 5). On the pseudoadiabatic chart, 850- and 700-mb mandatory level data, mean-layer winds and significant level data to 700 mbs were plotted. After forecasts of representative maximum temperatures for the southern and northern halves of the valley had been made, the mixing height was determined by following the dry adiabat from its point at the surface corresponding to the forecast maximum temperature up to its intersection with the observed free-air temperature curve. An objective maximum-temperature forecasting aid based on the 850-mb temperature at 1200 GMT and the Travis AFB surface wind speed and direction at 1500 GMT was used, but modified to fit operational time requirements (see Figure 7).

The formula used for the Ventilation Index (VI) is:

$$VI \text{ equals } MH \text{ times } \overline{WS}$$

where MH is the mixing height (hundreds of feet) based on the forecast maximum temperature and $\overline{WS}$ is the forecast average wind speed in knots through the mixed layer. In the first season, late September - early December of 1968, the numerical ventilation categories were labeled as shown in Table 1:

TABLE I - VENTILATION CATEGORIES

Ventilation Index (VI)	Category
>600	Excellent
401 - 600	Good
181 - 400	Fair
<180	Poor

Miller (1968) reported that the average mixing depth for the Sacramento Valley in October was a relatively low value of 3000 feet. This was the next to the lowest value of the four seasons sampled; therefore, it was considered more appropriate to label the best ventilating conditions something other than "Excellent", particularly when used in one of the poorer seasons. In 1969, the label for the best ventilation category was changed from "Excellent" to "Very Good".

During the 1968 and 1969 seasons, forecasts were made daily except Sunday in fall and early winter, but verification data were not available on all days. Distribution of forecasts according to category is given in Table II:

TABLE II - VENTILATION FORECASTS

Category	1968	1969
Excellent (Very Good)	0	7
Good	8	10
Fair	25	15
Poor	13	28
Total	48	60

These forecasts were based on forecast mean wind speed through the mixing height stratum and forecast mixing height. The latter is a function of the observed temperature lapse rate and the forecast surface maximum temperature. In the two seasons, maximum-temperature forecasts were just a little more than two degrees in error on the average. However, the average mixing height forecast was in error by almost 1000 feet.

In the list of criteria proposed by the California Air Resources Board, the following conditions are considered to exceed (be worse than) the air quality standard: Relative humidity less than 70 percent, and two successive observations one hour apart indicating visibility 7.5 miles or less occurring on seven or more days in a 90-day period or on three or more consecutive days. Data from Sacramento Executive Airport show that this standard was not met in the 1969 season. From the 22nd of September through the 6th of December, 32 of the 75 days were below proposed standards. Every day that showed two successive observations one hour apart with visibility 7 miles or less and relative humidity less than 70 percent was counted; from the 21st of November through the 6th of December, this was a daily occurrence. During most of this latter period, the Sacramento Valley was included in the area forecast by the Washington National Meteorological Center to have high air pollution potential. A comparison of two categories of visibility (six miles less, and less than three miles) for November 1969 proved interesting when arrayed against a ten-year November record, 1951-1960, for the Sacramento Executive Airport, as shown in Table 3.

TABLE III - OBSERVED VISIBILITY CATEGORIES

	November 1951-1960 Average	November 1969
Less than 3 miles	101	84
6 miles and less	302	343

Thus, November 1969 conditions were not grossly different from normal conditions. Data from hourly observations were used in the comparison.

Verification by category of forecast, i.e., "Poor", "Fair", "Good", or "Excellent" (Very Good) for the 1968 and 1969 fall seasons is given in Table 4. The 0000GMT Oakland radiosonde data was used in the verification, assuming that it represented afternoon low atmospheric structure in the Sacramento Valley. The Oakland observed lapse rate and Sacramento observed maximum temperature were used to determine the mixing depth. Oakland winds aloft were then used to compute the mean-layer wind speed through the mixing depth. This speed was then assumed to be representative of the Sacramento Valley.

It may be seen that verification was good, with 59/96 or 62% of the forecasts in the correct category for combined data and 80/96 or 83% within one category of being correct.

Informal verification was obtained also through aircraft flights during the 1968 season. Several flights were made by University of California Agricultural Extension Service personnel to assess the degree of cooperation on the part of the user (rice grower) and as a check on Weather Bureau forecasts, the 6:35 a.m. forecast broadcast through commercial radio being closely monitored. Through personal communication, the Sacramento WBO learned that its forecasts were judged to be highly satisfactory.

CONCLUSIONS

In response to a request from private citizens, the Sacramento Weather Bureau Office initiated an advisory air quality forecast program based on a "ventilating index" concept. Forecast terminology was kept simple, as was the method of forecast preparation. Decisions regarding management of agricultural waste disposal were incumbent upon the forecast user. Wind observations from a TV tower in the valley were used and a temporary meso-scale network of visibility observing stations was set up. This satisfied, in part, recommendation of the Meteorology Panel, United States Technical Conference on Air Pollution (1950), and Recommendation A1 of an American Chemical Society Subcommittee on Environmental Improvement (1969) regarding low-level winds, more dense observation sites, and general measurement of the atmosphere's turbidity. Information to date indicates that the Sacramento WBO program was successful.

The simple methods used in arriving at an estimation of atmospheric ventilating qualities presented here may not suffice for the more complex future requirements. When legal constraints are added to strict California Air Resource Board ambient air quality standards, more pertinent data may be required than that used in this experiment.

Smaller scale wind observing networks and low-level temperature soundings in the Sacramento Valley will undoubtedly be required.

TABLE IV

VENTILATION INDEX FORECAST VERIFICATION BY CATEGORY

P-Poor; F-Fair; G-Good; E-Excellent. E(1968) equals VG(1969)

1968 OBSERVED

FORECAST	P	F	G	E	Total
P	8	2	0	2	12
F	4	14	3	4	25
G	2	3	1	0	6
E	0	0	1	1	2
Total	14	19	5	7	45

1969 OBSERVED

FORECAST	P	F	G	VG	Total
P	19	4	0	0	23
F	2	8	2	2	14
G	1	3	2	1	7
VG	0	1	1	6	8
Total	22	16	5	9	52

1968-1969 COMBINED

FORECAST	P	F	G	E,VG	Total
P	27	6	0	2	35
F	6	22	5	6	39
G	3	6	3	1	13
E,VG	0	1	2	7	10
Total	36	35	10	16	97

1968-1969 COMBINED
OBSERVED PERCENT

FORECAST	P	F	G	E,VG
P	77	17	0	6
F	15	56	14	15
G	23	46	23	8
E,VG	0	11	11	78

ACKNOWLEDGMENT: Mr. James R. Miller, Meteorologist in Charge; and Mr. David I. Wise, Agricultural Forecaster, deserve most of the credit for initiating and designing the working features of this program.

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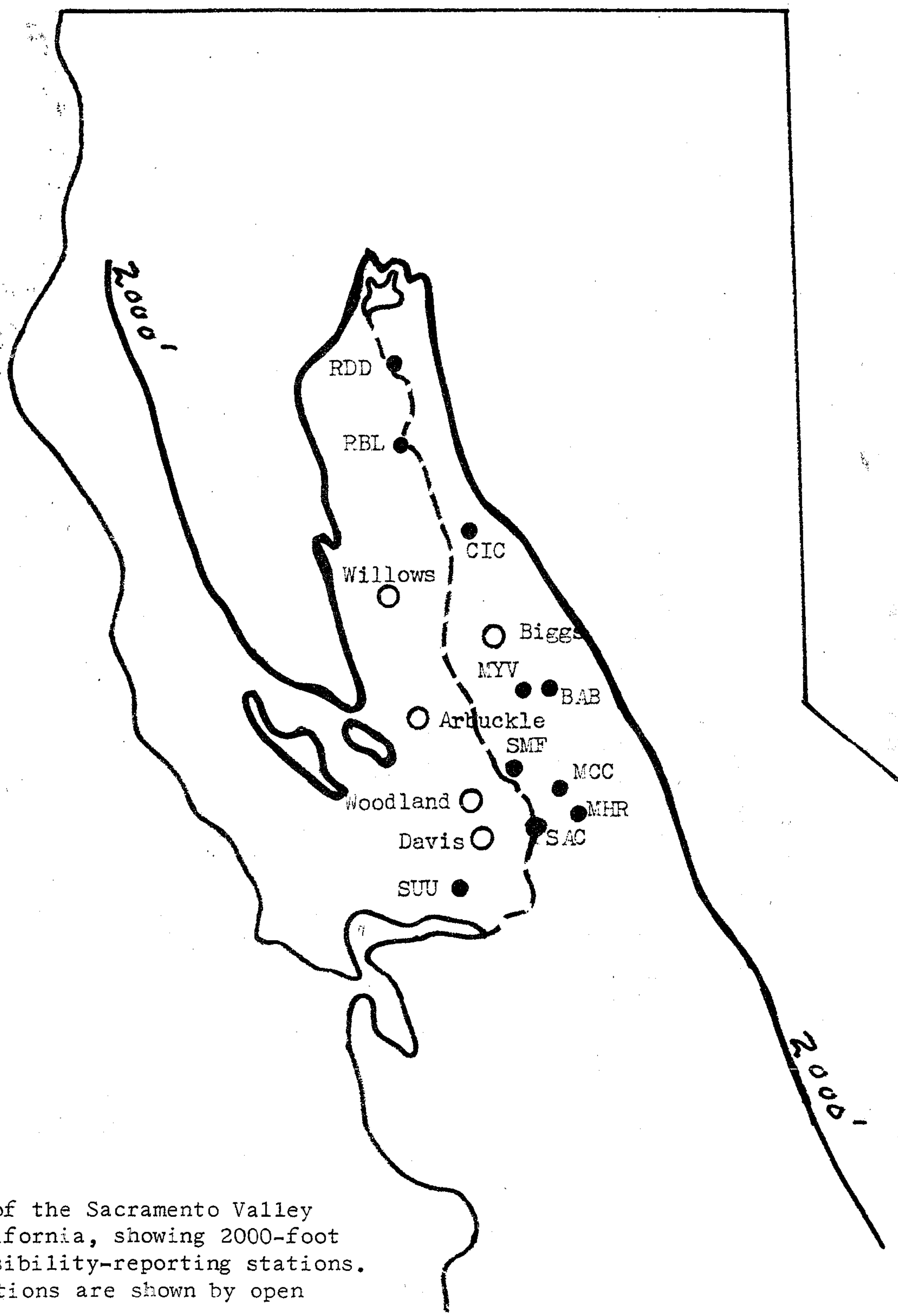

Figure 1. Map of the Sacramento Valley of northern California, showing 2000-foot contours and visibility-reporting stations. Cooperative stations are shown by open circles.

WBAN FORM 10A
(REV. 1-1-64)

U.S. DEPARTMENT OF COMMERCE - WEATHER BUREAU

SURFACE WEATHER OBSERVATIONS

STATION: Sacramento, Calif. (Airport)

DATE: OCT 30 1967

Type (1)	Time (LST) (2)	Sky and ceiling (Hundreds of Feet) (3)	Visibility (Statute Miles) Surface (4)	Tower (4a)	Weather and obstructions to vision (5)	Sea level press. (Mbs.) (6)	Temp. (°F) (7)	Dew pt. (°F) (8)	Wind Direction (9)	Speed (Kts) (10)	Character (11)	Altimeter setting (Ins.) (12)	Remarks and supplemental coded data (13)	(14a)	(14b)	Observer's initials (15)
R	0055	O	15+			207	50	32	35	03		013 014	317			BB
R	0157	O	15+			212	51	33	35	04		014				JT
R	0258	O	15+			214	49	35	00	00		015				JT
R	0358	O	15+			218	48	35	00	00		016				JT
72483		00000	74020		21809	00900			02210			47847	CITY765152 640000Φ			RL
R	0458	O	15+			216	45	33	00	00		017				RL
R	0558	O	15+			222	44	33	00	00		018				RL
R	0658	O	25			229	45	35	00	00		020	312			RL
R	0758	O	20			236	54	37	00	00		022	KOCTY			RL
R	0858	O	15			239	62	40	00	00		023	VSBY NS KOCTY			RL
R	0958	O	15			239	66	40	16	02		023	KOCTY			RL
72483		01602	74020		23919	00900			04110				46744Φ			RL
R	1058	O	10			239	71	46	18	04		023				RL
R	1158	-X	6		K	233	72	47	24	06		021	KI			RL
R	1259	O	10			223	74	48	19	06		018	817 1001			JC
R	1355	O	10			216	77	47	24	06		016				JC
R	1456	-Φ	15			216	78	46	18	03		016				JC
R	1555	-Φ	15			212	78	45	15	04		015	KLYR W-N			JC
72483		11504	74020		21226	00901			07710			47944	CITY 804979Φ			JC
R	1657	20Φ/Φ	10			212	74	46	15	03		015	K20Φ			JC
R	1756	O	15			216	68	46	18	04		016	KLYR W-N			JC
R	1857	O	15			219	65	43	00	00		017	307			JC
R	1956	O	15			219	61	44	00	00		017				JC
R	2055	O	15			222	59	44	10	05		018				SD
R	2155	O	15			226	57	43	12	05		019	307 79			SD
R	2258	O	15			229	56	42	00	00		020				SD
R	2355	O	15			229	56	41	00	00		020				SD

555 26

Figure 2a

ine following related aviation observation.

WBAN FORM 10A
(REV. 1-1-64)

U.S. DEPARTMENT OF COMMERCE - WEATHER BUREAU

SURFACE WEATHER OBSERVATIONS

STATION Sacramento, Calif. (Airport)

DATE OCT 31 1967

Type (1)	Time (LST) (2)	Sky and ceiling (Hundreds of Feet) (3)	Visibility (Statute Miles) Surface (4)	Visibility Tower (4a)	Weather and obstructions to vision (5)	Sea level press. (Mbs.) (6)	Temp. (°F) (7)	Dew pt. (°F) (8)	Wind Direction (00-36) (9)	Wind Speed (Kts) (10)	Wind Character (11)	Altimeter setting (Ins.) (12)	Remarks and supplemental coded data (13)	(14a)	(14b)	Observer's initials (15)
R	0055	O	15			229	54	40	11	03		020	103			BB
R	0155	O	15			236	52	40	33	03		021	WND DIR VRBL			BB
R	0255	O	15			229	50	41	30	02		020				BB
R	0358	O	10			229	49	40	00	00		020	7			RL
72483		00000	66020		22909		99/10	04400				41794	4 CITY 805253 ①			RL
R	0458	O	10			233	49	40	00	00		021				RL
R	0558	O	10			236	49	40	00	00		022				RL
R	0618	O	8			237	48	42	00	00		022	208			RL
R	0758	O	4		K	241	54	44	36	03		023				RL
R	0858	O	4		K	241	62	45	36	04		023				RL
R	0958	O	5		K	241	66	47	30	03		023				RL
72483		03003	58040		24119	00900			08	103		46747 ①				RL
R	1058	O	4		K	236	70	47	32	04		022				RL
R	1158	O	5		K	226	76	48	32	07		019				RL
R	1258	O	6		K	212	79	47	34	06		015	829			JC
R	1357	O	5		K	202	80	45	33	05		012				JC
S	1430	−X	2	2	K				36	07		011	VSBY SSW3 K6			JC
R	14[illegible]	−X	1½	1½	K	195	80	45	35	04		010	R02VV1½+ K6			JC
R	15[illegible]	−X	1½	1½	K	191	79	46	02	04		008	R02VV1½+ K6			JC
72483		00204	24040		19126	00900			08622			48147	CITY 794878 ①			JC
R	16[illegible]	−X	1	1	K	185	72	48	00	00		007	R02VV1⅜ K8			JC
R	17[illegible]	−X	1½	1½	K	183	68	47	00	00		006	R02VV1½+ K8			JC
R	18[illegible]	−X	1½	1½	K	182	64	46	26	03		006	R02VV1½+ K7 608			JC
R	19[illegible]	−X	1½	1½	K	182	59	45	00	00		006	R02VV1½+ K7			JC
S	2031	−X	3	3	K	–	–	–	00	00		006	K7			RK
R	2057	−X	3	3	K	185	59	47	00	00		007	K7			WT
RS	2157	−X	2	2	K	185	58	46	10	04		007	K7 / 103 81			RK
R	2256	−X	2	2	K	181	57	43	10	04		005	K46 VSBY E2½			RK
S	2329	−X	3	3	K	–	–	–	11	04		005	K7 VSBY NW2½			RK
R	2355	−X	4	4	K	180	55	42	11	03		005	K6			RK

Figure 2b

...related aviation observation.

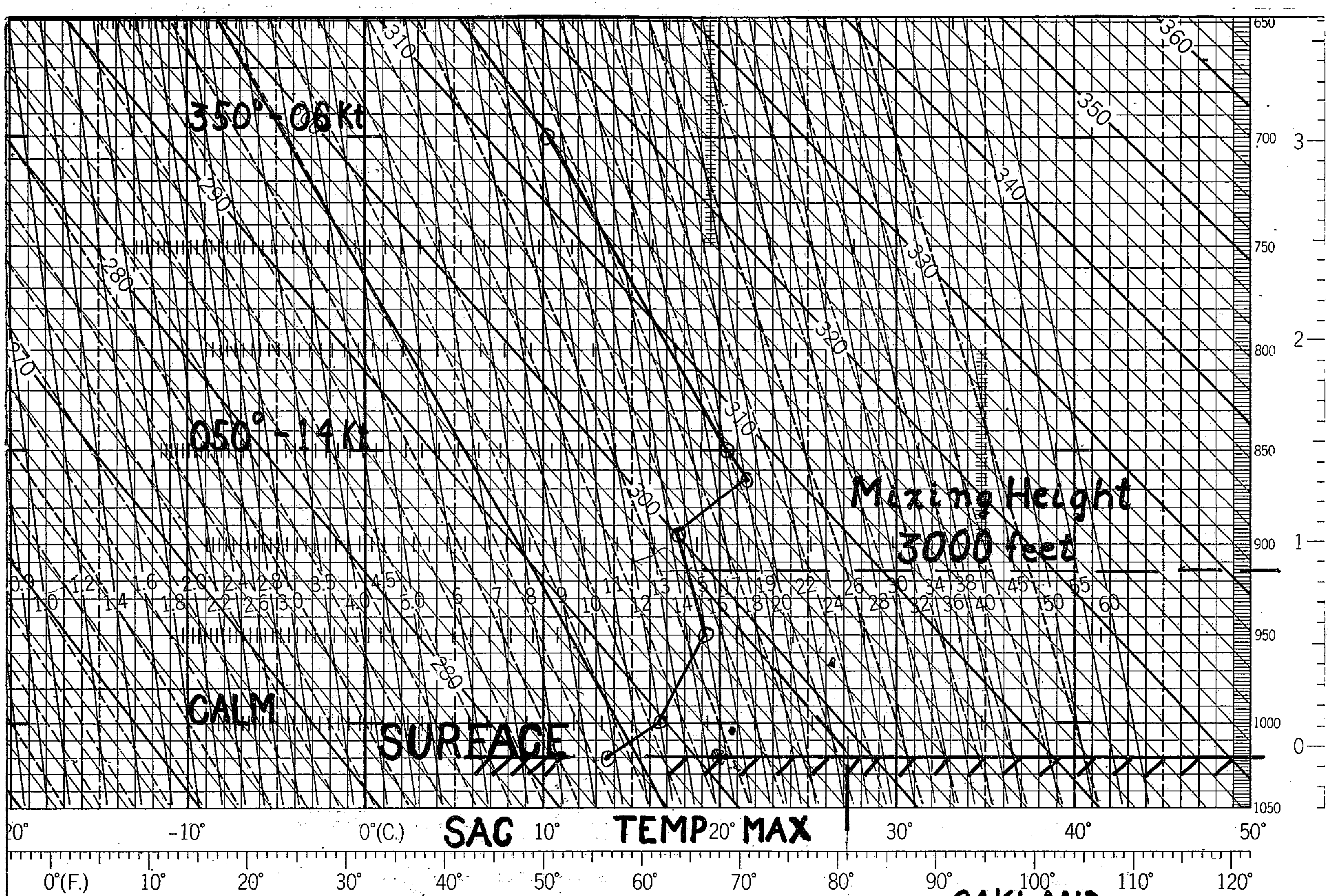

Figure 3a

Station OAKLAND

Date (G.C.T.) OCT. 31, 1967

Hour (G.C.T.) 1200 Drawn by NB

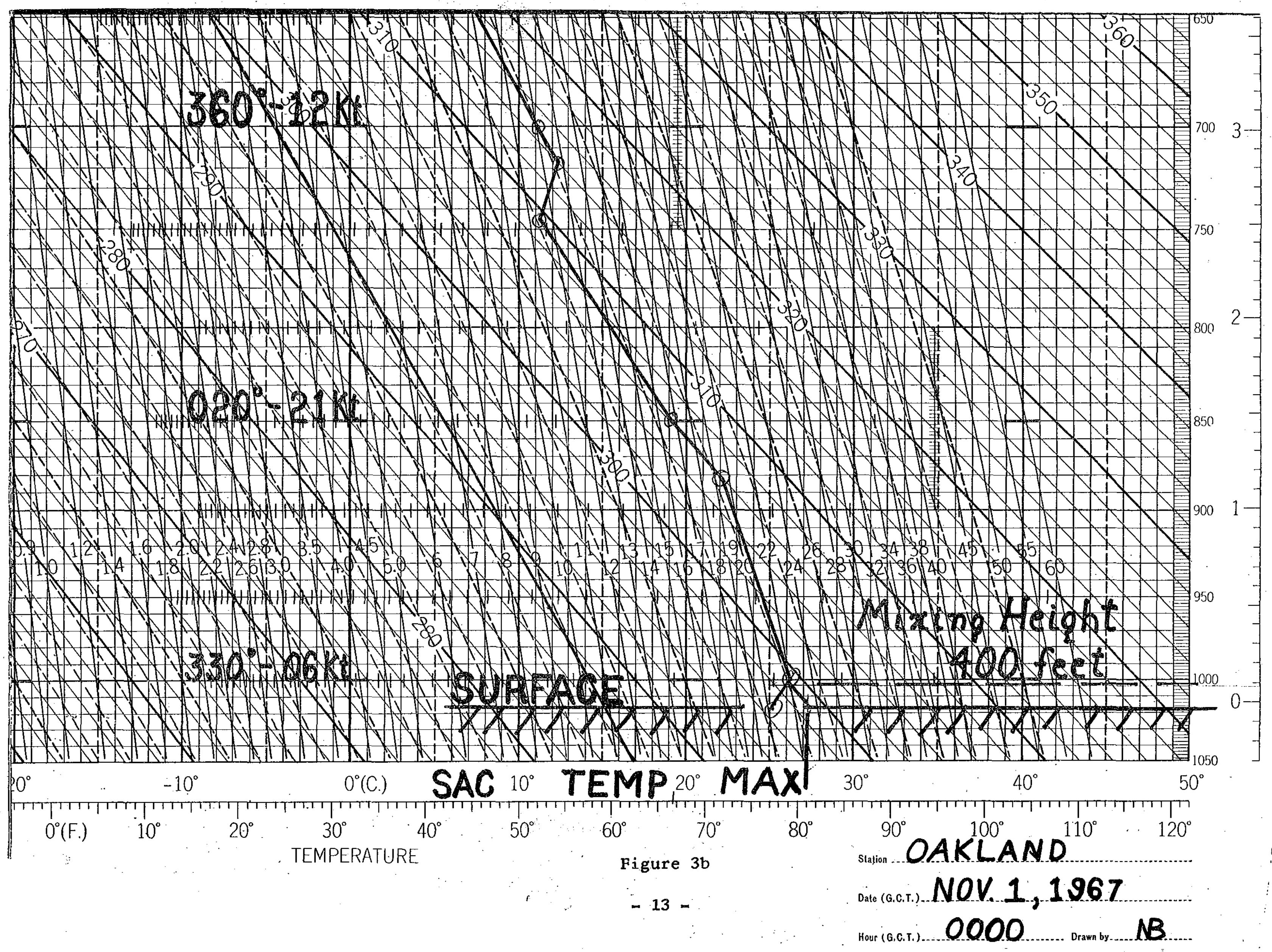
360°-12Kt
020°-21Kt
330°-06Kt
SURFACE
Mixing Height
400 feet
SAC TEMP MAX
TEMPERATURE
Station OAKLAND
Date (G.C.T.) NOV. 1, 1967
Hour (G.C.T.) 0000
Drawn by NB

Figure 3b

STATE OF CALIFORNIA
AIR BASINS

CALIFORNIA AIR RESOURCES BOARD
Adopted November 1968

Figure 4

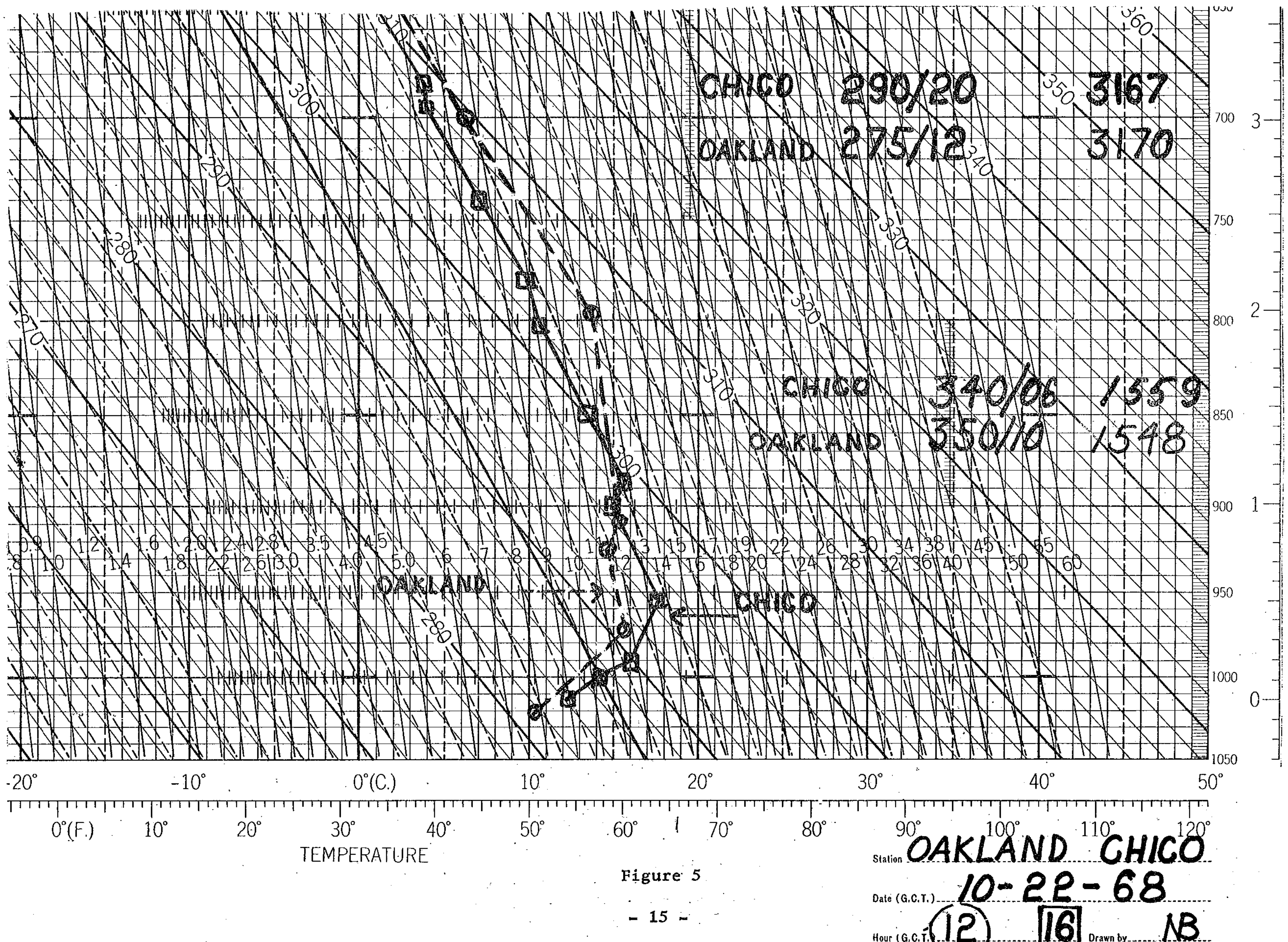
CHICO 290/20 3167
OAKLAND 275/12 3170
CHICO 340/06 1559
OAKLAND 350/10 1548
OAKLAND
CHICO
TEMPERATURE
Station OAKLAND CHICO
Date (G.C.T.) 10-22-68
Hour (G.C.T.) 12 16 Drawn by NB

Figure 5

VENTILATION FORECAST

WBO, Sacramento, California   Date: ________________

The atmospheric ventilation forecast for agricultural operations in the Sacramento Valley indicates that this afternoon conditions will be:

(6:30 AM)

(Noon)

The outlook for tomorrow afternoon indicates the atmospheric ventilation conditions will be (the same) (better) (worse).

OAKLAND 12Z RAOB DATA

Lower Inversion	Upper Inv/Isothermal	
Base ________ Ft. MSL	Base ________ Ft. MSL	OAK 850 Mb. Temp.________
Top ________ Ft. MSL	Top ________ Ft. MSL	SAC 850 Mb. Temp.________(Est.)

	Fcst Sfc Wnd Speed & Dir	Max Temp Fcst	Max Temp Obs	Mixg Hgt Based on Fcst T	Mixg Hgt Based on Obsr T	Mean Wnd in Mixg Layer	Ventilation Index*	Rating
N. Sutter B								
S. Sutter B								

*Ventilation Index = Mixing Height in 100' x Mean Wind in Knots

Ventilation Index: Under 180 - Poor; 181-400 - Fair; 401-600 - Good; Over 600 - Very Good

OAKLAND AIR POLLUTION POTENTIAL DATA (Sent 1720Z)

This AM MH - Wnd	This PM MH - Wnd	Tomorrow PM MH - Wnd	Verification Prev. Col.

(Decameter x 30 = Ft.; Mps x 2.2 = Mph)

WIND DATA

	TV 590'	1440'	SAC	SMF	MYV	RBL	BIGGS	WILLOWS	WILLIAMS	WOODLAND	ARBUCKLE
6 AM							X	X	X	X	X
11 AM							X	X	X	X	X
4 PM											

VISIBILITY REPORTS

	SAC	SMF	MYV	RBL	BIGGS	WILLOWS	WILLIAMS	WOODLAND	ARBUCKLE
Sunrise					X	X	X	X	X
10 AM					X	X	X	X	X
Noon					X	X	X	X	X
4 PM									
Sunset					X	X	X	X	X

Figure 6

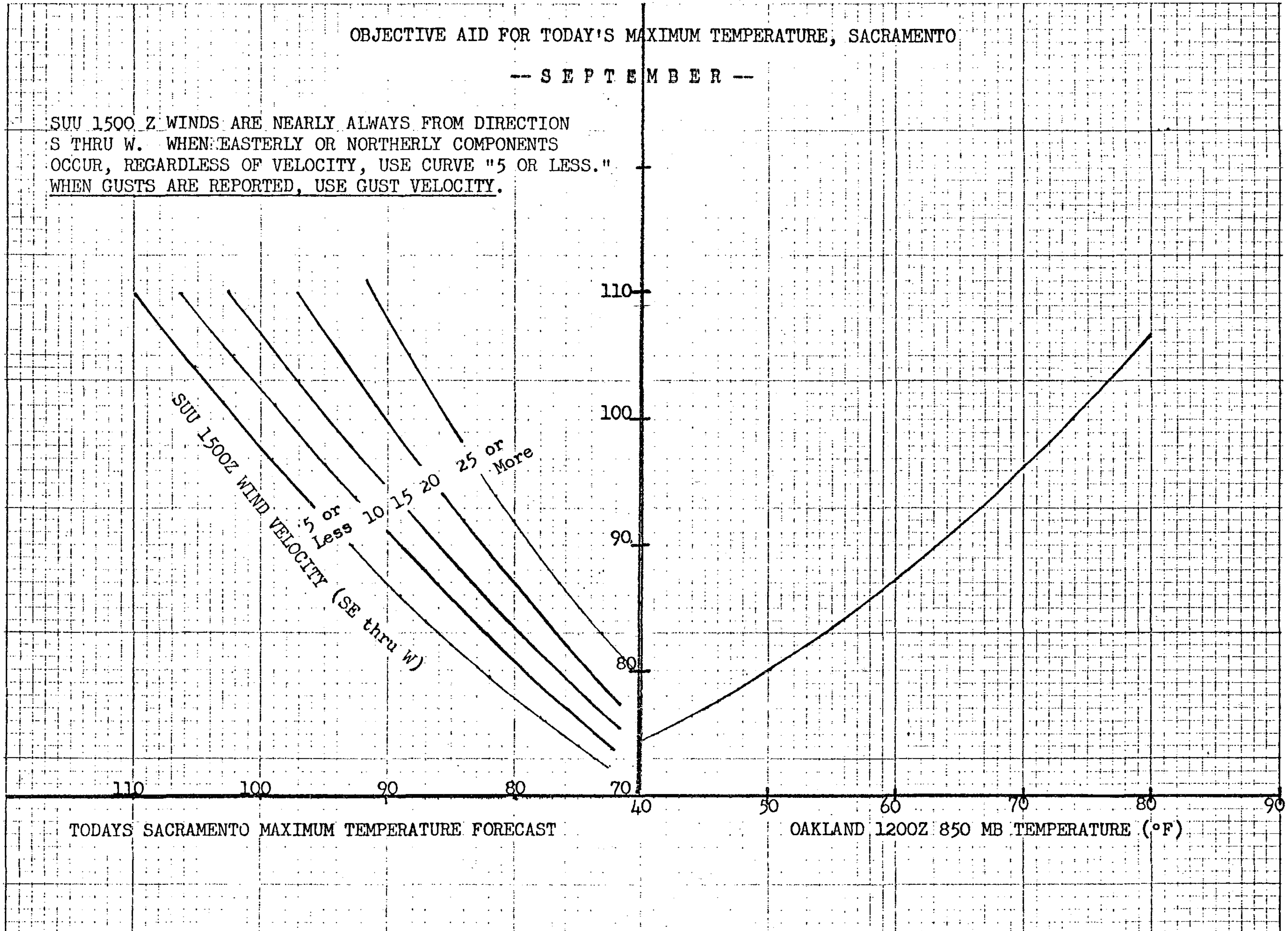
OBJECTIVE AID FOR TODAY'S MAXIMUM TEMPERATURE, SACRAMENTO
-- S E P T E M B E R --
SUU 1500 Z WINDS ARE NEARLY ALWAYS FROM DIRECTION S THRU W. WHEN EASTERLY OR NORTHERLY COMPONENTS OCCUR, REGARDLESS OF VELOCITY, USE CURVE "5 OR LESS." WHEN GUSTS ARE REPORTED, USE GUST VELOCITY.
SUU 1500Z WIND VELOCITY (SE thru W)
5 or Less
10
15
20
25 or More
110
100
90
80
70
110
100
90
80
70
40
50
60
70
80
90
TODAYS SACRAMENTO MAXIMUM TEMPERATURE FORECAST
OAKLAND 1200Z 850 MB TEMPERATURE (°F)

Figure 7

Western Region Technical Memoranda (Continued):

No. 28** Weather Extremes. R. J. Schmidli. April 1968. (PB-178 928)

No. 29 Small-Scale Analysis and Prediction. Philip Williams, Jr. May 1968. (PB-178 425)

No. 30 Numerical Weather Prediction and Synoptic Meteorology. Capt. Thomas D. Murphy, U.S.A.F. May 1968 (AD-673 365)

No. 31* Precipitation Detection Probabilities by Salt Lake ARTC Radars. Robert K. Belesky. July 1968. (PB-179 084)

No. 32 Probability Forecasting in the Portland Fire-Weather District. Harold S. Ayer. July 1968. (PB-179 289)

No. 33 Objective Forecasting. Philip Williams, Jr. August 1968. (AD-680 425)

No. 34 The WSR-57 Radar Program at Missoula, Montana. R. Granger. October 1968. (PB-180 292)

No. 35** Joint ESSA/FAA ARTC Radar Weather Surveillance Program. Herbert P. Benner and DeVon B. Smith. December 1968. (AD-681 857)

No. 36* Temperature Trends in Sacramento--Another Heat Island. Anthony D. Lentini. February 1969. (PB-183 055)

No. 37 Disposal of Logging Residues Without Damage to Air Quality. Owen P. Cramer. March 1969. (PB-183 057)

No. 38 Climate of Phoenix, Arizona. R. J. Schmidli, P. C. Kangieser, and R. S. Ingram. April 1969. (PB-184 295)

No. 39 Upper-Air Lows Over Northwestern United States. A. L. Jacobson. April 1969. (PB-184 296)

No. 40 The Man-Machine Mix in Applied Weather Forecasting in the 1970s. L. W. Snellman. August 1969. (PB-185 068)

No. 41 High Resolution Radiosonde Observations. W. W. Johnson. August 1969. (PB-185 673)

No. 42 Analysis of the Southern California Santa Ana of January 15-17, 1966. Barry B. Aronovitch. August 1969. (PB-185 670)

No. 43 Forecasting Maximum Temperatures at Helena, Montana. David E. Olsen. October 1969. (PB-187 762)

No. 44 Estimated Return Periods for Short-Duration Precipitation in Arizona. Paul C. Kangieser. October 1969. (PB-187 763)

No. 45/1 Precipitation Probabilities in the Western Region Associated with Winter 500-mb Map Types. Richard P. Augulis. Dec. 1969. (PB-188 248)

No. 45/2 Precipitation Probabilities in the Western Region Associated with Spring 500-mb Map Types. Richard P. Augulis. Jan. 1970. (PB-184 434)

No. 45/3 Precipitation Probabilities in the Western Region Associated with Summer 500-mb Map Types. Richard P. Augulis. Jan. 1970. (PB-189 414)

No. 45/4 Precipitation Probabilities in the Western Region Associated with Fall 500-mb Map Types. Richard P. Augulis. Jan. 1970. (PB-189 435)

No. 46 Applications of the Net Radiometer to Short-Range Fog and Stratus Forecasting at Eugene, Oregon. L. Yee and E. Bates. Dec. 1969. (PB-190 476)

No. 47 Statistical Analysis as a Flood Routing Tool. Robert J. C. Burnash. December 1969. (PB-188 744)

No. 48 Tsunami. Richard P. Augulis. February 1970. (PB-190 157)

No. 49 Predicting Precipitation Type. Robert J. C. Burnash and Floyd E. Hug. March 1970. (PB-190 962)

No. 50 Statistical Report of Aeroallergens (Pollens and Molds) Fort Huachuca, Arizona 1969. Wayne S. Johnson. April 1970. (PB-191 743)

No. 51 Western Region Sea State and Surf Forecaster's Manual. Gordon C. Shields and Gerald B. Burdwell. July 1970. (PB-193 102)

No. 52 Sacramento Weather Radar Climatology. R. G. Pappas and C. M. Veliquette. July 1970.

* Out of Print
** Revised