in a standard shelter at the station, the thermometer in the open, and the thermometer in a shelter at the bottom of a neighboring arroyo (dry river bed) 14 feet below the station. The humidity that prevails during the continuance of a "norther" is shown by the chart of March 16, and the curve of observed humidity is shown by the hygrogram of March 16–20, 1914. Mr. Garthwaite tells me that he has observed the varying currents of wind in the early morning, when smudge fires were first started, to follow the contours in a most accurate way. He is constructing a delicate wind register so as to show the relative direction and force of the wind in the arroyo and at his station. If it were feasible, it might seem advisable to furnish the cooperative observer two anemometers and a register on which would be recorded both the station and the arroyo winds. Another thermograph for use in the arroyo would also give interesting and instructive results.

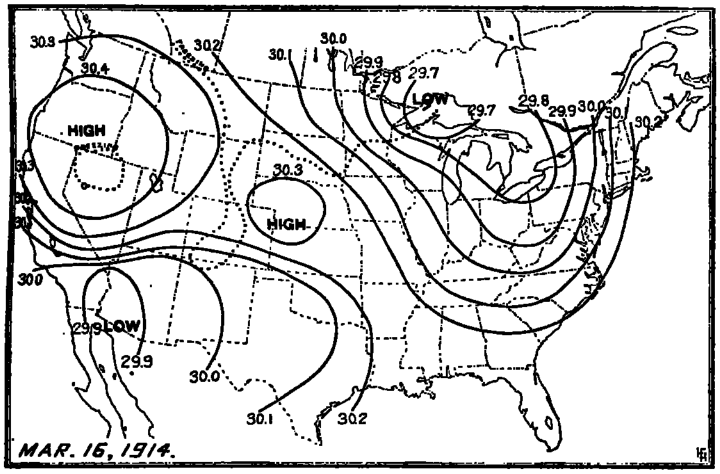

FIG. 4.—

LOS ANGELES, CAL., MONDAY, MAR. 16, 1914.

FORECAST TILL 5 P. M. TUESDAY.

For Los Angeles and vicinity: Fair to-night and Tuesday. Moderate northerly to north easterly winds.
For California, south of the Tehachipi: Fair to-night and Tuesday.

WEATHER CONDITIONS.

The barometric pressure continues high from Oregon and Washington southeasterly to Florida, and fair weather and moderate temperatures prevail throughout the greater portion of the United States. A moderate southwesterly gale is in progress at Buffalo.
We are entering on the fourth consecutive week without storms on the Pacific slope. The barometer remains high in the Northwest and moderately low in the valley of the Colorado. This considerable difference in pressure conditions will bring about marked "norther" weather during the ensuing 36 hours. Warning of moderate to strong northerly and northeasterly winds was sent by wireless to Avalon this morning at 6:50. The weather will continue fair and dry in Los Angeles and vicinity to-night and Tuesday, with moderate northerly and northeasterly winds.

Special California reports.

Orchard readings.

Stations.	Weather.	Temperature.		Precipitation.	
		Highest yesterday.	Lowest last night.	Daily.	Seasonal to date.
Pasadena	Clear	83	50	0.00	31.77
Pomona	Clear	77	43	.00	25.56
Redlands	Clear	82	50	.00	15.59
Riverside	Clear	79	48	.00	12.51
San Bernardino	Clear	83	45	.00	17.20
Santa Barbara	Clear	68	46	.00	29.58

FORD A. CARPENTER, *Local Forecaster.*

[NOTE BY F. A. C.]

Fishing fleet obeyed warnings and were safely anchored hours before the "norther" began to blow.

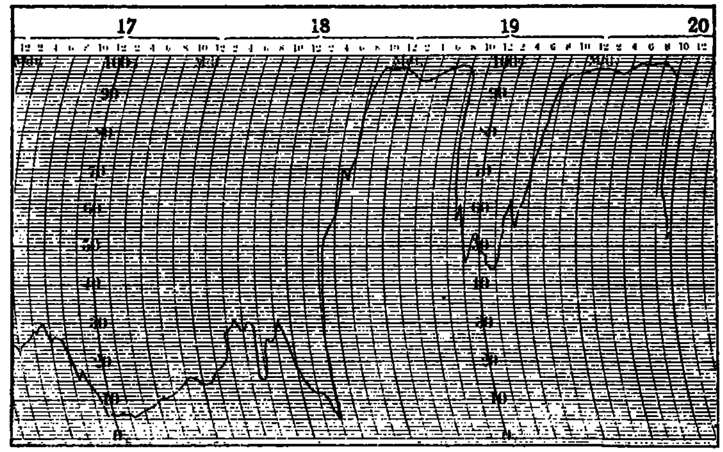

FIG. 5.—Hygrogram at Claremont, Pomona, Cal., March 16–20, 1914. "Norther" humidity conditions are shown by the above record for the 17th and 18th, while the normal curve is shown on the 19th and 20th. The hygrograph was in excellent condition and tested at the beginning of the month; the records may be relied on to within 4 or 6 per cent. At 4 p. m. of the 18th the relative humidity was 5 per cent, but within four hours the humidity rose to 97 per cent as the effect of the cessation of "norther" conditions.

V.

FROST WARNINGS AND ORCHARD HEATING IN OHIO.

By J. WARREN SMITH, Professor of Meteorology.

[Dated Weather Bureau, Columbus, Ohio, Nov. 4, 1914.]

(*a*) Introduction; (*b*) Orchard heating in 1913; (*c*) Fruit-frost stations in 1914; (*d*) Frost warnings issued, 1914; (*e*) The results of orchard heating in 1914; (*f*) Different methods of heating orchards; (*g*) Oil heaters; (*h*) Coal heaters; (*i*) Wood fires; (*k*) Temperatures dangerous to fruit buds; (*l*) When to expect frost; (*m*) Dates of blossoming of fruits; (*n*) Predictions of frost and minimum temperature; (*o*) Frost conditions vary; (*p*) Differences in minimum temperatures; (*q*) Daily range in temperature; (*r*) Predicting minimum temperatures from dew point; (*s*) Diurnal temperature changes; (*t*) Typical thermograph curves, May 11–18, 1914; (*u*) Predicting minimum temperatures from median; (*v*) Rules for predicting minimum from median temperature; (*w*) Suggestions to fruit growers in predicting minimum temperatures from the median; (*x*) Instruments to be used; (*y*) Prospective extension of this service.

(*a*) *Introduction.*—For a number of years the writer has been urging the practicability in Ohio of protecting orchard and garden crops from frost damage by smudging and heating. Within the past few years quite a number of the most progressive fruit growers of the State have taken up the matter of frost protection in a serious manner.

Warnings of general frosts have been widely distributed by telegraph and telephone, but it has seemed desirable to give more specific information as to the probable severity of the frost and the probable minimum temperature in the orchards or sections of the State where orchard heating has been taken up.

Therefore, in 1912, we began the organization of a special fruit-frost service in Ohio and in the spring of 1913 had special stations in complete operation at Delaware and Toboso, and in partial operation at a few other points.

It was estimated that the special warning service and the work of orchard heating about Delaware, Ohio, saved the fruit growers in that vicinity some $35,000 or $40,000 during the severe freeze in May, 1913.

(*b*) *Orchard heating in 1913.*—In Table 1 the result of some of the orchard heating as done in 1913 and in a few previous years is given. The notes following the table give additional information as to heaters used, fuel, mistakes in having insufficient fuel, discouragements, etc.

TABLE 1.—*A summary of experiences in orchard heating in Ohio.*

Place and county.	ear.	A	Kind of fruit.[1]	Fuel used.	Number of fires per acre.	Temperature outside orchard.	Temperature within orchard.	Enough fires?
						°F.	°F.	
Ashville, Pickaway	1910	27	Ap.; ph.; pr.; pm.; ch.	Stove wood	50	30	38	Yes.
Bellefontaine, Logan	1913	5	Ap.; ph.; pr.; ch.	Logs, brush	4	28	34	No.
Bellevue, Huron [2]	1913	80	Ch	3 gals. oil	35	22	30–32	Yes.
Cadiz, Harrison	1913	30	Ap.; ph.; pr	Coal slack	5	20	......	No.
Celina, Mercer	1913	6	Ap	Wood trash	3	23	......	No.
Cheshire, Gallia	1913	....	Tm	2 gals. oil	25	26	38	......
Chillicothe (1), Ross	......	225	Ap.; ph.; sm	3 gals. oil	50	30	36	Yes.
Chillicothe (2), Ross	......	20	Ap.; ph	Brush sawdust.	......	....	......	No.
Clyde, Sandusky	1913	10	A	1½ gals. oil	75	22	27	No.
Delaware (1), Delaware.	1913	45	Ap	3 gals. oil	30	23	30	No.
Delaware (2), Delaware.	1913	40	Ap	.....do	35	23	30–32	Yes.
Dellroy, Carroll	1913	6	Ap	Coal, wood	......	24	33	......
Frankfort, Ross	1913	20	Ap	Wood	......	28	......	......
Freeport, Harrison	1910–1911	33	Ap	Coal, 6 qts. oil.	60–80	26	34	Yes.
Glouster, Athens	......	....	......	Coal, oil	......	....	......	......
Marion, Marion	1913	7	Pr.; pm.; ch	7 qts. oil	135	26	30–32	Yes.
Shelby, Richland	1913	14	Ap	See rmks	4–8	....	......	No.
Toboso, Licking	1912	....	Ch.; str	Oil pots	30–50	29	36	Yes.
Wakefield, Pike	1913	95	Ph	8 gals. oil	75	26	32	Yes.
Waterville, Lucas	1913	125	A	3 gals. oil	40	28	33	Yes.
Wooster, Wayne	1913	10	Ap.; ph	.....do	120	21	27–30	Yes.

[1] Contractions.—A., all kinds; ap., apples; ch., cherries; ph., peach; pr., pear; pm., plum; sm., small fruit; str., strawberries; tm., tomatoes.
[2] Mail address, but the orchard is in Sandusky County.

Remarks from stations in Table No. 1.

Ashville.—"In 1910 I saved 75 per cent of my crop by means of the fire. When the temperature fell to 34° I would begin and light every other fire, and then if the temperature kept on falling lower I would light every pile of wood."

Bellefontaine.—"I saved 400 bushels of fruit, but should have saved 1,600 more; had four cold nights and ran short of fuel. Have ordered 3-gallon Hamilton heaters for use another year."

Bellevue.—"Gathered 99 tons of cherries; would probably have had from $5,000 to $7,000 worth more if we had had a larger number of heaters. It took six men 2 hours to light 2,200 stoves."

Cadiz.—"I saved about one-fourth of the crop. The coal was in 5-bushel piles."

Celina.—"I am a firm believer in the heating business as I have used it for over 20 years and have gotten good results from it. This year I did not have fires enough to the acre and no fruit worth speaking of was saved."

Cheshire.—"On the night of October 21, 1913, we tried the oil heaters in the tomato field and raised the temperature from 26 to 38 degrees with 25 heaters burning, Later in the night we began to have some trouble and the temperature fell to such an extent that we were unable to raise it in time to keep the tomatoes from freezing. I think the oil heaters are all right when cheap oil can be secured; for southern Ohio I think the coal heaters would be better. One of my neighbors used two coal smudges for his garden and they were a success. On the night of October 13 with 25 smudge fires burning on 1 acre we raised the temperature 5°."

Chillicothe, No. 2.—"I have succeeded in years past with fires in orchards on calm frosty nights, but failed in April of this year because of the very high wind that accompanied the cold weather. I hope to use heaters hereafter."

Clyde.—"There were not enough heaters to the acre of the size used. There has scarcely been a proper test of oil orchard heating around here; as we have either run out of oil or have not for some reason used heaters every night when we should have. This year I ran the heaters from about 10 p. m. till morning during the very cold spell about three weeks before May 10; and May 10, when we should have by all means had oil and run the heaters, we had none here. My heaters are too small to burn all night."

Delaware, No. 1.—"Thirty fires to the acre was not enough this year; there should be at least 50. On the upland the temperature was about 30° where the heaters were used. On the black land it was considerably lower than that. I was a little late in lighting my heaters. I should have begun at least one hour earlier. If I had twice as many heaters I would have saved fully $10,000 worth of apples. Some of the trees in this orchard showed a good crop on the side of the tree where the heater stood and practically no fruit on the opposite side."

Delaware, No. 2.—"I saved fully 8,000 bushels of apples by the use of the orchard heaters."

Dellroy.—"I did not use heaters, but built fires of old rails and coal and find that where I had about three small fires for each tree I saved most of the fruit, but where I had but one fire in the square of four trees I lost all of it even though the fires were large. I fired four nights and the consequence was the last night, which was the worst of all, I fell short of fuel just when I needed it most. I did not heat all of the orchard, but saved 200 bushels, and would not have had any except for the heating. I expect to put 1,000 bushels of coal in the orchard this winter and 100 loads of wood and have plenty of fuel and do the thing right next time."

Frankfort.—"We used small wood fires in every other row in the orchard. We saved possibly 2,000 bushels of fruit. In this same orchard heaters were used in the fall at picking time. The temperature was falling rapidly and reached about 22° outside the orchard, but by burning the fires between the rows the temperature was kept up to about 28°."

Freeport.—"Three years ago I used the fire pots with great success, and they saved the crop. This year my men were rather unprepared, there was a great gale, they could not get help, got a bad start, had the blues, did not put out their thermometers, selected only the most desirable places and trees, but undoubtedly saved enough apples to make about half a crop. In 1910 we saved 2,000 barrels and in 1913, 1,000 barrels. In 1911 I saved about 2,000 barrels on 8 acres."

Glouster.—"I used crude oil, shavings, and coal last year, which made a good fire, and I probably saved the apples. This year I had coal distributed over the orchard, but could not get the help to properly fire it, so I have given up the idea of coal. I expect to get oil heaters next year to use crude oil in as I have the oil and think it most practicable."

Marion.—"I did not fire early enough this year to save the crop. I waited until the temperature was down to 26°, which is too low. It should be fired when the temperature is not lower than 30°."

Shelby.—"We can control an ordinary frost with saltpeter, sawdust, corncobs, and coal oil by making a smoke, but in this instance water froze in the early part of May from one-fourth to one-half inch. We take corncobs and dip them in a solution of wood alcohol and saltpeter. We use about two or three of these cobs, ignite and set in sawdust, more or less damp, impregnated with coal oil and saltpeter. One pint of coal oil, one ounce of saltpeter put into a kettle of sawdust will burn and permeate a wonderful amount of smoke for 12 to 24 hours. We used four to eight kettles per acre. We aim to have lanterns made with large hoods to spread the heat and put in the center of each apple tree during freezing weather."

Toboso.—"At this place they have positively demonstrated the practical value of orchard heaters in small fruit. In 1911 they lost 70 per cent of the cherries and all of the strawberries that were outside of the firing area and saved all within. They lighted 30 to 50 pots to the acre and raised the temperature 7° when outside the area it fell to 29°. In 1912 they saved 10 acres of strawberries yielding 5,000 quarts per acre."

Waterville.—"I do not think I saved any fruit by the use of the heaters."

Wakefield.—"We saved about two-thirds of a crop, or about 8,000 bushels of peaches. Did not heat one night when we should have done so."

Wooster.—"We saved about one-half bushel per oil pot. It was necessary to fire five nights and we had unusually severe conditions this year. We light the pots on low ground when the temperature falls to 30° and gives reason to believe that it will go lower, and try to keep it above 28°."

(*c*) *Fruit-frost stations in 1914.*—After the experience in 1913 there seemed no question as to the value of orchard heating in this State. Believing also that special reports from different sections of the State were an aid in predicting minimum temperatures the following-named stations were set in operation in the spring of 1914.

TABLE 2.—*Special fruit-frost stations, 1914.*

Station.	County.	Observer.
Clyde	Sandusky	Mrs. Ella P. Heffner.
Delaware	Delaware	DeWitt H. Lees.
Germantown	Montgomery	Henry M. Wachter.
Green Hill	Columbiana	Joseph E. Bentley.
Haydenville	Hocking	H. W. Stiers.
Jackson	Jackson	David F. Jones.
Marietta	Washington	Charles K. Wells.
Mount Healthy	Hamilton	Victor Herron.
Toboso	Licking	H. A. Albyn.
Wooster	Wayne	Paul Thayer.
Worthington	Franklin	Frame C. Brown.

Maximum and minimum thermometers, a raingage, and a sling psychrometer were furnished these points, and at Delaware, Toboso, Wooster, and Worthington self-recording thermometers were put into operation.

Daily observations of the highest and lowest temperature, dew point, state of weather, wind direction and approximate velocity, and rainfall were regularly made at 6 p. m. during March, April, and May. Daily mail reports were sent from all of these points and daily telegraphic reports from most of them immediately after the observation was taken.

The location of these special fruit-frost stations is shown on chart 1 (fig. 12) as well as the location of some of the orchards where frost protection is being carried on in some form.

Figure 1 [omitted] shows the thermometer shelter and instruments at the special station at Delaware, Ohio. These instruments are located in the open back yard of the residence of the observer on West Winter Street. It is a rather open residence district and the exposure of the instruments is very similar to an exposure in an orchard.

The shelter faces north. The maximum and minimum thermometers and thermograph are shown within the shelter and the sling psychrometer hangs on the outside of the shelter beside the door. At the right side within the shelter there is a tipping-bucket raingage, made by the observer. The receiver is seen projecting above the top of the shelter. The official raingage sets on the ground just outside the picture in an open yard, with the top about 3 feet above the surface of the ground.

the observer at Delaware passed the special forecast on to 10 different men, all of whom were prepared for heating. At Gallipolis arrangements were completed to have 18 different fruit men telephoned immediately upon receipt of the special forecast.

These special warnings were issued widely on the nights of April 19, 20, and 30, and on May 1, 2, 14, 15, and 16. In Table 3 there is given the temperatures predicted and the temperatures recorded the next morning as reported by orchardists in the vicinity. It will be seen that the predictions were too low for the first two nights, but improved steadily with study as the season advanced.

(*e*) *The results of orchard heating in 1914.*—In Table 4 there has been condensed something of the results of orchard heating in the spring of 1914. This will show that general heating was done on April 30 and May 1 and 15, and to a slight extent on May 2.

It is not possible to determine just what saving resulted from orchard heating this year. In a good many cases it is evident that the temperature would not have gone low enough to cause serious damage if no fires had been lighted. On the other hand, Mr. Koeppel of Delaware reported a severe loss to pears and apples on the night of May 15 because he did not have heaters enough to cover the orchard. In other cases strawberries were damaged and there is good evidence that fruit was damaged and dropped worse because of the cold weather than would have been the case if protected by heating.

Messrs. Pickett and Heffner of Clyde state that it is quite a question whether the waste and expense in years when heating is not necessary added to the expense when it is necessary does not make the cost too great to make heating profitable.

TABLE 3.—*Temperatures predicted and recorded, 1914.*

Stations.	Apr. 19.		Apr. 20.		Apr. 30.		May 1.		May 2.		May 14.		May 15.		May 16.	
	Predicted.	Recorded.	Predicted.	Recorded.	Predicted.	Recorded.	Predicted.	Recorded.	Predicted.	Recorded.	Predicted.	Recorded.	Predicted.	Recorded.	Predicted.	Recorded.
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.		°F.	°F.	°F.	°F.	°F.	°F.	°F.
Clyde	25-28	34	25-28	34	27-28	33	30-32	35	Not so low	40	38-40	42	32-34	38	40	45
Columbus	30	36	30-32	35	29-30	32	29-30	30	do	46	....	....	35-38	31	....	34
Delaware	28-30	34	26-28	30	29-30	27-30	29-30	27-30	do	32	35	36	32	29-32	36	36
Green Hill	28-30	34	26-28	34	28-29	28	28-29	29	do	30	35-36	33	28-30	29	31-32	33
Haydenville	30	39	30	36	30-32	29	28-30	29	do	33	....	33	32	30	34-36	34
Jackson	30-32	41	28-30	36	30-32	33	30	36	do	39	38-40	38	33-35	35	36	38
Marietta	30-35	40	30-32	37	31-32	35	30	38	do	41	38-40	40	35	36	37	36
New Lexington	30	40	30	36	30-32	30	30	28-30	do	....	38-40	38	33-35	....	....	38
Toboso	28-30	36	26-28	35	27-28	28	27-28	29	do	35	35-36	35	30-31	29	35	....
Wooster	28-30	34	26-28	32	27-28	29	27-28	33	do	36	35-36	39	29-30	33	35-36	39
Worthington	28-30	35	28	....	28-29	30	28-29	29	do	38	32	....	31	30	35	....

Individual orchardists who carry on orchard heating provide themselves with reliable thermometers and make daily card reports to the Columbus office to determine the difference between their orchard temperatures and those at the nearest special station.

(*d*) *Frost warnings issued.*—During the spring of 1914 frost warnings for Ohio were issued as usual in connection with the general forecasts, at about 9 a. m. In addition to this the Columbus office arranged to telephone certain fruit centers at about 9 o'clock in the evening, giving our estimate of the probable minimum temperature during the coming night. This was done only when frost conditions threatened and to aid the orchardists to determine whether to carry out plans for heating and what temperature they must fight against.

This special telephone service is furnished to the places shown in Table 3, as also to Marion and Gallipolis. The men telephoned to then further distributed the information to surrounding fruit and truck men. For example,

Mr. Koeppel states that on some of the nights this year he had visitors from places distant 12 to 15 miles away who came to see the results of heating and who went home in the early morning satisfied of the practicability of the plan.

(*f*) *Different methods of heating orchards.*—Fires may be made of oil, coal, wood, or any other material that will burn readily. The majority of fruit men in Ohio use oil.

(*g*) *Oil heaters.*—There are some 10 or 15 different types of oil heaters on the market, varying from 1 to 6 gallons in capacity and costing from 15 cents to $1 or more. Figure 5 shows some of the kinds of oil heaters used.

The round heaters of the lard-pail type with the top about 7 inches across will burn at the rate of about 1 quart an hour. With 50 pots of the 1-gallon capacity burning per acre, 12½ gallons of oil will be consumed per hour.

TABLE 4.—*Results of orchard heating in Ohio on April 30–May 16, 1914.*

Location of orchard.	On high or low ground.	Condition of fruit buds. Apple.	Peach.	Cherry.	Pear.	Plum.	Kind of fuel.	Acres heated.	Number of fires to the acre.	Were there fires enough.	Hour when firing began.	Temperature when firing began.	Lowest temperature outside heated area.	Temperature where firing was effective.	Was fruit saved.	Name of orchardist.
NIGHT OF APRIL 30-MAY 1.																
												°F.	°F	°F.		
Barnesville	Both	Opening	Full bloom	Full bloom	Full bloom	Full bloom	Coal	1/2	36	Yes.	10 p. m.	34	29	38	Yes.	C. J. Eichhorn.
Bellefontaine	High	Showing pink	do	do	Nearly out		Wood and coal.		40	Yes.	Midnight	36	33	35	Yes.	J. L. Shawver.
Delaware	do	In bud	In bud	In bloom	In bloom	In bloom	Coal		100		do	37	33.5	38		J. B. Taggart.
Do	do	Nearly open		do	do	do	Crude oil	8		Yes.	9 p. m.	30	29			J. H. Miller.
Do	Both	Not open	Full bloom	do	do		do	23		Yes.	8 p. m.	32	28	40	Yes.	G. H. Koeppel.
Do	High	Opening		Not quite full bloom.	do		do				10:30 p. m.	34	30	35	Yes.	H. T. Main.
Do	do	Not open		do			do	1	30		9 p. m.			32		M. H. Main.
Do	Low	Showing pink		do		Full bloom	do	3		Yes.	9:30 p. m.	29	27		Yes.	R. L. Hudson.
New Lexington	do	Full bloom					Wood	3/4	22	Yes.	1:30 a. m.	33	30	34	Yes.	C. E. Pace.
Do	High	Opening	Full bloom	Full bloom	Full bloom	Full bloom	Coal	6	25	Yes.	1 a. m.	34	30	35	Yes.	J. W. Riley & Son.
Toboso	Both	Half open	Petals falling.	do		do	Crude oil	60	40	Yes.	3 a. m.	31	28	33	Yes.	H. A. Albyn.
Worthington	do	Showing pink	Full bloom	do	Full bloom	Blooming	do	50	40	Yes.	11:45 p. m.	32	30	36	Yes.	F. C. Brown.
Wooster	High		In bloom	do		In bloom	do	2	50	Yes.	3 a. m.	32	29.5	35		Paul Thayer.
NIGHT OF MAY 1-2.																
Delaware	Both	Not open	Full bloom	Full bloom	Full bloom		Crude oil	23	80	Yes.	8 p. m.	34	27	40	Yes.	G. H. Koeppel.
Do	High	Opening		Not quite full bloom.	do		do				10:30 p. m.	35	29.5	35	Yes.	H. T. Main.
Do	Neither	One-half out		do	Almost full bloom.		do		20		11 p. m.	35	30			W. E. Main.
Do							do	3			10:30 p. m.	32	27			R. L. Hudson.
Kent		About to open	In bloom	Nearly in bloom.	In bud		Coal and wood.	3	1⅜	Yes.	Midnight	32	26	33	Yes.	M. H. Heighton.
New Lexington	Low	Full bloom					Wood	3/4	22	Yes.	1:30 a. m.	33	30	34		C. E. Pace.
Do	High	Bursting	In bloom	In bloom	In bloom		Coal and wood.	6	25	Yes.	2 a. m.	34	28	34	Yes.	J. W. Riley & Son.
Toboso	Both	Half open	Falling	do	do	Full bloom	Crude oil	75	50	Yes.	3 a. m.	31	29	33	Yes.	H. A. Albyn.
NIGHT OF MAY 2-3.																
Delaware							Fuel oil						32			W. E. Main.
Do	Both	Not open	Full bloom	Full bloom	Full bloom		Oil	23	40	Yes.	11 p. m.	34	32	36	Yes.	G. H. Koeppel.
NIGHT OF MAY 15-16.																
Ashland	Rolling	Bloom off	Shedding shucks.	Shucks nearly off.	Forming fruit.		Wood	12	40	Yes.	1:30 a. m.	36	32	40	Yes.	L. H. Ward.
Barnesville	Both	Some done	do	do	Shucks off		Coal and wood.	1	32		12:15 a. m.	33	32	35		C. J. Eichhorn.
Camp Chase	Rolling	Bloom off	Shedding bloom.	Fruit set	Fruit set		do	1	12	Yes.	2 a. m.	34	31-32	34	Yes.	E. A. Brenneman.
Chillicothe	Low	Fruit size of peas.	Fruit size of peas.	Fruit size of peas.	Fruit size of peas.		Saw dust, cobs, and oil.	4	18-30		1:30 a. m.	38	32	36-40	Yes.	M. I. Shively.
Delaware	Rolling						Crude oil	38	40-60	Yes.	11:30 p. m.	35	29	38	Yes.	G. H. Koeppel
Do	Hillside	Petals dropping.		Nearly off	All off		Oil			Yes.	1 a. m.	34	32	35	Yes.	H. T. Main.
Dublin	High	Most petals off					Wood	20	10	Yes.	do	31			Yes.	J. J. Dunn.
Freeport	do	Bloom well off					Oil and coal.	30	100	Yes.	Midnight	34	28-31	36		O. P. Kinsey.
Lisbon	do	In bloom		Fruit formed	In bloom		Black oil	3	45		2 a. m.	32	30	33	Yes.	C. W. Armstrong.
Toboso	Both	All off	Fruit size of peas.	Fruit size of peas.			Oil	50	60	Yes.	Midnight	33	29	32	Yes.	H. A. Albyn.
Worthington	Rolling	Fruit set	Fruit set	Fruit set	Fruit set		Fuel oil	20	40	Yes.	2:30 a. m.	30	30	35		F. C. Brown.

The fuel oil used should be of medium weight, as the light gravity oil burns too rapidly and is too expensive, and too heavy oil does not burn clean and a large amount of soot is deposited on the trees.

Oil heaters should be set at the rate of from 80 to 120 per acre. It is better to have too many heaters than too few. The fires should be thicker around the outside edge of the orchard and in low places. The temperature should be watched closely and when it has fallen nearly to the danger point every third or fourth heater should be lighted and then the others as needed. With heaters, where the burning surface can be controlled, the intensity of the fires can be varied as the temperature changes.

With an equipment of oil heaters having a capacity to go through the night without refilling, the general practice is to have 1 man for each 5 acres to take care of the fires.

The matter of lighting is interesting. Mr. Koeppel reports that on May 1 it took 4 men 3 hours to light the fires on 23 acres set at the rate of 80 to the acre. On the

14th, when they had 38 acres set at the rate of 40 to the acre on upland and 60 to the acre on lowland it took 5 men 3 hours to light the fires. On the 15th with the heaters the same as on the 14th it took 5 men 2 hours and 40 minutes.

Mr. Hudson at Delaware states that it took 3 men 1 hour to light 3 acres. At Lisbon they use black oil and 3 men lighted 140 fires in less than half an hour. Dr. Miller of Delaware used a wick fastened to wires for a torch and saturated it with oil. One man could light 100 fires in half an hour with this.

At Toboso on April 30 they had heaters set at the rate of 120 to the acre in the lowest part of their orchard. It took 4 men 1 hour to light one-third of these heaters on 60 acres. They use a torch that drops gasoline. At this place on May 1 they heated 75 acres with 50 pots to the acre and it took 5 men 1½ hours to light up.

The number of hours that the heaters will be burned will vary with each season, but if one stores 400 gallons of oil for each acre it will allow for burning one hundred 1-gallon pots per acre for 12 hours—sufficient for most seasons.

The initial investment for a 10-acre orchard, including tank, heaters, fuel for one season, etc., will be not far from $500, or $50 per acre. After the first year the cost will average $3 to $5 per acre for each night that heating is done. It is quite evident, however, that in a season like that of 1913 the saving resulting from the protection would cover the expense for a good many years.

(*h*) *Coal heaters.*—Coal heaters cost more than the oil burners, but it takes only about half as many per acre. The best coal burners hold 25 to 30 pounds of coal and will burn from 4 to 6 hours. It is considered that 1 ton of coal will equal 100 gallons of oil in heating value. At Barnesville, in 1914, with 36 coal fires to the acre, they kept the temperature 9° higher in the orchard than outside.

Oil-soaked waste and kindlings should be placed in the bottom of the coal heaters and then with a torch they may be lighted even faster than the oil heaters. The work of refilling will take about twice as much time as the oil heaters.

Mr. J. M. Stockham, of Portsmouth, has had success in making coal heaters from discarded cans used in making artificial ice. He cuts a 300-pound size can into three sections with a cold chisel. The lower section has holes punched through the sides for ventilation and is set on the ground. A cut is made near each of the corners, in the other sections, high enough to allow the sides to be turned under far enough to make a bottom that will hold wood and coal and yet allow for draft.

Each of these heaters will hold about 1 bushel of coal, so that for heating one night not more than one-third or one-fourth of a bushel should be put in. Mr. Stockham uses part coal and part wood. These discarded cans can be bought very cheaply, it is not a hard task to fix them as suggested, and they must be very durable.

Quite a number of men merely pile the coal on the ground between the rows of trees. In order to make the coal start to burning, Mr. H. W. Stiers, of Haydenville, has made a unique "kindler." He gets waste sticks about 1 inch square from a near-by planing mill and has them cut into 4-inch lengths. He then inserts these short pieces into a preparation of 1 part tallow to 10 parts rosin, and after sticking six of these pieces together he rolls them in fine shavings before they are quite dry. By pouring a small amount of oil on the kindlers they burn freely and ignite the pile of coal. The total cost of these kindlers to him is about one-third of a cent each.

By this plan the cost of heaters is saved, and where coal can be obtained as cheaply as it is in parts of Ohio it is recommended that the coal be given a thorough trial. It must be remembered, however, that there must be a good many piles of coal to the acre. Mr. Linard Rowland, of Cadiz, demonstrated in 1913 that five piles to the acre was insufficient.

(*i*) *Wood fires.*—Fires have been made of old rails, brush, and cordwood. In using cordwood the sticks are piled dovetailed together and are bushed together as the ends burn off. About six sticks of wood will last 4 or 5 hours. Wood needs more attention than either coal or oil and must be started earlier, as it takes some time to get the wood to burning enough to affect the temperature.

Mr. L. H. Ward, of Ashville, reports that it took 3 men 2 hours to light the wood fires on 12 acres at the rate of 40 fires to the acre. He used a few cobs soaked in coal oil at each fire. Mr. Pace, of New Lexington, states that it takes about 2 minutes to light each fire. His fuel was dry and burned readily. Some others found difficulty in getting the wood started.

The tables will show differences in temperature between the heated area and that outside with the different kinds of fuel, different number of fires to the acre, and under different temperature conditions. They show without question that a few fires to the acre will not prevent frost damage, but that with a large number of small fires the temperature can be kept above the danger point.

The reports of these fruit men show also that one must be thoroughly prepared in every respect. There must be plenty of fuel, men enough to keep the fires burning, and constant vigilance until the frost season is over. Care must be taken not to waste the fuel by lighting too early or on nights when the temperature does not fall to a dangerous point.

Thermometers should be distributed throughout the orchard and watched carefully, and when the temperature approaches the danger point the lighting should be begun in the coldest part of the orchard. Figure 6 shows some of the heaters in operation.

(*k*) *Temperatures dangerous to fruit buds.*—The hardiness of fruit buds varies with the season of the year, weather of the preceding days or weeks, the kind and variety of fruits, the condition of the tree during the preceding autumn, the position of the buds on the limb, etc. In general it is believed that the temperatures given below are safe temperatures if the cold is not of too long duration, but that damage would result if the temperature is below these values for any length of time.

PEACHES.

When the peach buds are showing pink, the dangerous temperature is about 20°F. When almost open, 25°; when newly opened, 26°; when petals are beginning to fall, 28°; when petals are all off, 30°; when the shucks or calyx tubes are beginning to fall—that is, just after the fruit is formed, 32°.

APPLES.

When the petals are beginning to show, 22°; when in full blossom, 29°; when the petals are dropping and the young fruit is increasing in size, 32°.

PEARS.

When just opening, 28°; in blossom, 29°; setting fruit, 30°.

CHERRIES AND PLUMS.

When just opening, 29° to 30°; when in blossom and setting fruit, about 31°. At Haydenville, in 1914, cherries were not injured, although the temperature fell to 28° while they were in full bloom. At Clyde, in 1913, the temperature reached below 25° while cherries were in bloom, and yet a fair crop was harvested, so that further investigations may develop the fact that cherries will stand a lower temperature than given above.

Fully dormant apple, pear, cherry, and plum buds will stand the usual winter temperatures that may be experienced in this State. Just how much cold a fully dormant peach bud will stand, it is difficult to determine. Some investigations made by the writer as to winter damage to peach buds in Fulton County, Ohio, covering a period of 30 years showed that few, if any, peaches were harvested whenever the temperature during the preceding winter fell to −17°F. Much depends upon the weather of the previous autumn and winter and the condition of the trees when they go into the winter.

The question of protecting peach buds from low winter temperatures by heating is receiving consideration in this State, and peach growers generally should try some experiments in this direction. There has been some difficulty in getting fuel oil to burn at low temperatures, but a lighter and better grade, as well as coal and wood, should be tried.

(*l*) *When to expect frost.*—Chart No. 2 (fig. 13) shows the average date of the last killing frost in the spring in Ohio and chart 3 (fig. 14) the average date of the first killing frost in the autumn. These date lines as they are drawn are only approximate because the dates depend so much upon the local topography. Locations in valleys always have later spring and earlier fall frosts than at near-by higher elevations.

The latest frost ever recorded in the spring is about four weeks later than the average date, at most stations. At stations in northern Ohio the earliest killing frost ever recorded has been about four weeks earlier than the average killing fall frost, and in the central and southern parts of the State the earliest killing frost has been about three weeks earlier than the average.

(*m*) *Dates of blossoming of fruits.*—Chart 4 (fig. 15) shows the average date of the blossoming of apples and chart 5 (fig. 16) the average date of the blossoming of peaches in Ohio.

In general, pears blossom a day or two earlier than apples, strawberries slightly earlier than apples, and cherries and plums slightly later than peaches.

By comparing charts 2, 4, and 5 it will be seen that the average date of the blossoming of fruit is earlier than the average date of the last killing frost in the spring. The frost season may be over before apples bloom in some seasons, but the other fruits are apt to be caught.

(*n*) *Predictions of frost and probable minimum temperature.*—The daily weather maps issued by the United States Weather Bureau show approaching areas of cool weather which may cause frosts, and when these conditions are anticipated the bureau issues general frost warnings.

Charts 6 to 8 (figs. 17 to 19) are typical frost maps and show the movement of the area of high pressure that caused the low temperature and frosts in Ohio the first of May, 1914.

On the map of April 30 there was much cloudy weather, and the indications were that it would continue cloudy with brisk northerly winds over Ohio that night with temperatures between 35° and 40°. The prediction was made, however, that if it should clear off frosts would occur.

The map of May 1 shows that while it did remain cloudy over much of the area it cleared in central and southeastern Ohio, and frosts resulted. It was very plain from that map that the high pressure area would be central over Ohio the next night, and thus the night would be clear with little wind and that general frosts would result.

The frost warnings are telegraphed and telephoned widely over the State, and every orchardist who plans to protect his crops by heating should take steps to obtain the warnings. The weather maps will be found to be of great help also.

(*o*) *Frost conditions vary.*—When the weather map indicates frost, and warnings are issued by the Weather Bureau, it is plain that the frost will be more severe in some sections of the State than others and that the temperature will be lower in the valleys and lowest parts of the farm during nights with clear and comparatively still air, when late spring and early fall frosts are most apt to occur. When the wind is blowing and the whole layer of air is below the freezing point then the hilltops suffer quite as much as the valleys.

The extremely low temperatures recorded in Ohio have been at the valley stations, because the lowest temperatures have come with clear, nearly still air. On the morning of February 10, 1899, the temperature was 21° below zero at Somerset, Perry County, while at Milligan, only a few miles away, it reached −39°F. Both stations have reliable thermometers well exposed, but while Somerset is near the top of a hill at an elevation of 1,080 feet above sea level, Milligan is in a narrow cup-like valley about 200 feet lower.

On May 1, 1914, the temperature at Somerset was 34° and at Milligan 29°. On May 2 it was 36° at Somerset and 28° at Milligan. On the 3d it was 41° at Somerset and 32° at Milligan. It is plain that frost would have damaged fruit and garden crops on all three nights at the valley station and probably on only one at Somerset.

(*p*) *Differences in minimum temperatures.*—In our forecasting of probable minimum temperatures in 1914 we found it of distinct advantage to know something of the average difference between the minimum temperatures at Columbus and the lowest in other sections of Ohio, under similar weather conditions.

Tables were prepared, therefore, showing the average differences between Columbus and points for which we wished to issue minimum temperature forecasts for April and May. These average differences were found when the weather conditions were favorable for free radiation, when the approach of a low pressure area caused rising temperature, when colder weather was approaching from the northwest, and finally when no marked change in temperature seemed probable.

It has seemed best to publish one of these tables, giving the average and extreme difference in minimum temperature in April and May, for the main fruit district or topographic stations. Some of the stations have been in operation but a short time, hence a 10-year average could not be obtained. Somerset was used as being characteristic of many of the hill orchards in eastern and southern Ohio. Table 5 gives the data referred to.

TABLE 5.—*Minimum temperatures lower than Columbus, at certain stations in Ohio, in April and May, 1914.*

Station.	County.	April. Average deficit for April for 10 years.	April. Average under radiation conditions, 1914.	April. Greatest deficit in 1914.	May. Average deficit for May for 10 years.	May. Average under radiation conditions (6 years).	May. Greatest deficit for any day (6 years).
		°F.	°F.	°F.	°F.	°F.	°F.
Delaware	Delaware	3.3	4.4	8	4.0	7.7	13
Green Hill	Columbiana	6.5	9.9	16	7.7	12.6	20
Haydenville	Hocking	......	6.8	11	......	[1] 10.7	[1] 16
Jackson	Jackson	......	3.9	11	......	[1] 5.0	[1] 12
New Lexington	Perry	......	......	......	......	[1] 0.4	[1] 9
Toboso	Licking	......	5.4	12	......	[1] 10.1	[1] 14
Somerset	Perry	......	......	......	1.5	3.2	13
Wooster	Wayne	4.1	5.7	11	5.0	9.1	16

[1] For 1914 only.

(*q*) *Daily range in temperature.*—In anticipating probable minimum temperatures when frost threatens, it is important to know the average fall in temperature from the warmest part of the day to the coldest of the following night.

Hence in Table 6 there has been given the average and extreme ranges in temperature from the maximum of one day to the minimum of the following morning in May for nine years, under conditions favorable for radiation, and for characteristic topographic stations in the State of Ohio.

TABLE 6.—*Average and extreme range in temperature in Ohio during May, 1909 to 1914, when an area of high pressure is centered over Ohio and adjacent States, giving radiation conditions.*

Station.	County.	Height above sea.	Location and topographical surroundings.	Range between P. M. maximum, and next A. M. minimum under conditions of free radiation. First half of May.	Second half.	For whole month. Average.	For whole month. Greatest.	For whole month. Least.
		Feet.		°F.	°F.	°F.	°F.	°F.
Bellefontaine	Logan	1,276	On hillside	24	26	25	39	13
Cadiz	Harrison	1,245	Near top of hill	26	25	26	37	11
Cambridge	Guernsey	803	In narrow valley	32	32	32	44	13
Camp Dennison	Hamilton	570	In broad valley	28	30	29	41	14
Columbus	Franklin	918	...do	19	20	19	29	7
Delaware	Delaware	896	In valley	27	30	28	38	10
Garrettsville	Portage	1,005	...do	30	29	30	49	9
Green Hill	Columbiana	1,135	...do	28	30	29	42	10
Haydenville	Hocking	700	...do	31	33	32	43	18
Hiram	Portage	1,260	On hill	22	22	22	37	13
Marietta	Washington	627	In broad valley	30	30	30	42	19
Milligan	Perry	875	In narrow valley	31	34	33	44	19
Ottawa	Putnam	720	Level prairie	25	26	25	40	7
Somerset	Perry	1,080	Top of hill	24	25	25	35	10
Summerfield	Noble	1,187	In valley	30	32	31	43	11
Toboso [1]	Licking	789	In narrow valley	32	34	33	44	21
Vickery	Sandusky	588	Slightly rolling	24	27	25	40	10
Waverly	Pike	590	Broad valley	30	32	31	40	18
Waynesville	Warren	700	Elevated plain	22	22	22	40	9
Wooster	Wayne	1,030	On hillside	27	29	28	45	12

[1] 2 years only.

As is to be expected, the range in temperature is greater at stations in the valleys than at those on the hills, the greater part of the difference being because of lower night temperatures rather than because of much difference in the daytime temperatures.

One marked example in this table is the difference between Hiram and Garrettsville, both in Portage County and not far apart but one in a valley and the other on a hill top.

Fruit men should keep a careful record of both maximum and minimum temperatures with reliable thermometers so as to determine what the average daily temperature fall amounts to, especially under frost conditions, because they can make a rough estimate of the probable lowest temperature that will be experienced.

(*r*) *Predicting minimum temperature from the dewpoint temperature of the evening before.*—It has long been believed that during conditions favorable for frost the dew point in the late afternoon would be approximately the same as the minimum temperature during the following night.

O'Gara in Oregon (Farmers' Bulletin 401) found that at no time in April and May, 1909, did the minimum temperature fall much below the dewpoint that was observed at about 8 or 9 o'clock in the evening. On the other hand, Cox (Bulletin T, p. 84) states that in the moorlands of Wisconsin "the dewpoint in the evening is no indication of the ensuing minimum temperature."

In order to give this matter a good test in Ohio dewpoint observations have been made at the special fruit stations and the results are given in Table 7. Not many stations were in operation in May, 1913, or March, 1914, but during April and May, 1914, records were obtained at 10 different points.

In the first five columns of the table the data are for the entire month, but in the last five columns the dewpoint and minimum temperature data are only for those nights which were favorable for free radiation, or, in other words, favorable for frost if the temperature should fall low enough.

The table shows that the minimum temperatures average higher than the dewpoints at Clyde and Columbus in April and May and at Mount Healthy in May, even on clear still nights.

At Jackson, Toboso, and Worthington, on the other hand, during May, 1914, the minimum temperature was never higher than the dewpoint on nights favorable for radiation. At some of the stations the minimum was never very much lower than the dewpoint, but in general the difference may be great enough to make this method of predicting the probable minimum temperature most unreliable.

For example, at Delaware in the month of May if we must feel that the minimum temperature may be either 7° higher or 10° lower than the dewpoint of the evening before, forecasts from the dewpoint can be of little value. At Toboso the minimum was 26° below the dewpoint on one night in May, 1914.

A study of the daily observations shows that when it is cloudy or partly cloudy in the evening and clears off during the night the morning minimum temperature will always be considerably lower than the evening dewpoint. On the other hand, if it clouds up during the night the minimum will generally not go so low as the dewpoint.

From a few dewpoint observations made later than 6 p. m. at Worthington it seems probable that later dewpoint observations may show a closer relation to the coming minimum temperature. Steps will be taken during the coming spring to have such records made.

Some of the records indicate that some of the wide variations between the dewpoint and minimum temperature may be because the wet-bulb temperature had not been accurately obtained, through failure to whirl the sling psychrometer long enough. But the fruit observers are all specially selected observers, and they were given definite instructions as to the use of this instrument, and if they were unable to obtain accurate results it shows that when the average orchardist or truck grower attempts to use the sling psychrometer for determining the probable minimum temperature the results will be still more unsatisfactory.

Further studies seem to show that when the relative humidity is high on a clear, still evening the minimum temperature during the coming night will be lower than the evening dewpoint, and that when this relative humidity is low the minimum will not be so low as the dewpoint. Also that during nights when the minimum has run much below the evening dewpoint there has been a marked lowering of the dewpoint, although there are exceptions to this.—[Note by the author, Nov. 20, 1914.]

TABLE 7.—*Average and extreme differences between dewpoints observed at 6 p. m. and the lowest temperatures during the following night (for severe months and for those nights only when the conditions were favorable for radiation).*

Stations in Ohio.	For the whole month.					For nights when conditions were favorable for radiation.				
	Average.		Variation of minimum from the dewpoint.			Average.		Variation of minimum from the dewpoint.		
	Dewpoint at 6 p. m.	Minimum temperature during the night.	Average.	Greatest above dewpoint.	Greatest below dewpoint.	Dewpoint at 6 p. m.	Minimum temperature during the night.	Average.	Greatest above dewpoint.	Greatest below dewpoint.
	FOR MAY, 1913.									
Columbus [1]	49.2	53.1	+ 3.9	22	− 8	40.4	48.4	+ 8.0	13	0
Columbus [1,2]	49.2	50.0	+ 0.8	19	− 8	40.4	43.1	+ 2.7	4	− 4
Delaware	50.2	47.0	− 3.2	6	−10	41.8	39.4	− 2.4	0	− 5
Marietta	51.4	49.9	− 1.5	11	−12	41.5	42.2	+ 0.7	11	− 4
	FOR MARCH, 1914.									
Clyde	27.3	28.6	+ 1.3	17	−14	23.4	24.9	+ 1.5	17	−14
Delaware	29.0	26.8	− 2.2	7	−12	24.1	20.2	− 3.9	0	−11
Marietta [3]	32.8	31.9	− 0.9	12	−11	23.8	25.3	+ 1.5	4	− 3
Wooster	28.4	27.1	− 1.1	13	−11	24.8	22.4	− 2.4	8	−11
	FOR APRIL, 1914.									
Clyde	38.2	38.6	+ 0.4	15	−10	35.4	37.7	+ 2.3	11	− 8
Columbus [1]	42.5	43.0	+ 0.5	15	−12	36.4	38.1	+ 1.7	7	− 5
Columbus [1,2]	42.5	41.6	− 0.9	13	−14	36.4	36.1	− 0.3	7	− 7
Delaware	42.3	39.8	− 2.5	9	−14	39.3	36.8	− 2.5	7	− 9
Green Hill	39.6	35.3	− 4.3	7	−24	32.9	27.7	− 5.2	0	−17
Jackson	47.7	41.5	− 6.2	15	−22	45.2	34.3	−10.9	0	−22
Marietta	45.6	41.6	− 4.0	7	−14	42.0	37.3	− 4.7	3	−10
Mount Healthy [3]	45.0	43.3	− 1.7	11	−25	39.8	38.2	− 1.6	5	− 7
Toboso	44.4	38.6	− 5.8	14	−33	43.1	34.4	− 8.7	6	−22
Wooster	40.2	38.0	− 2.2	12	−19	36.8	36.0	− 0.8	8	−12
Worthington [3]	45.8	42.3	− 3.5	9	−16	44.0	37.2	− 6.8	0	−13
	FOR MAY, 1914.									
Clyde	49.1	51.9	+ 2.8	24	−11	43.3	47.2	+ 3.9	10	− 7
Columbus [1]	49.9	54.7	+ 4.8	15	− 4	43.2	50.8	+ 7.6	15	− 2
Columbus [1,2]	49.9	50.1	+ 0.2	14	−19	43.2	43.3	+ 0.1	6	− 5
Delaware	50.8	47.7	− 3.1	7	−18	45.7	42.1	− 3.6	7	−10
Green Hill	50.0	44.5	− 5.5	5	−20	43.4	34.4	− 9.0	1	−16
Jackson	58.3	51.1	− 7.2	2	−19	54.8	44.9	− 9.9	0	−19
Mount Healthy	53.2	54.7	+ 1.5	13	−14	48.4	48.9	+ 0.5	6	− 4
Toboso	61.7	47.4	−14.3	0	−26	59.6	39.2	−20.4	0	−26
Wooster	50.2	48.6	− 1.6	16	−16	44.8	42.7	− 2.1	6	−15
Worthington [3]	43.4	38.1	− 5.3	5	−12	42.6	36.4	− 6.2	0	− 9

[1] Dewpoint 7 p. m.
[2] Dewpoint at the Weather Bureau station minus the minimum temperature at the Ohio State University.
[3] For part of month only.

(*8*) *Diurnal temperature changes.*—It is well known that the highest temperature is generally during the day and the lowest temperature at night, and that on some days the range in temperature between the day and night is greater than on others. It may not be so well known, however, that the lowest temperature at night is usually just before sunrise and that typical weather conditions produce certain characteristic temperature variations.

To illustrate this point we have shown in figures 9 and 10 the records made by a self-recording thermometer at Delaware, Ohio, for the weeks of May 5 to 12, 1913, and May 11 to 18, 1914, respectively.

Temperature changes at any locality depend very largely upon the direction and force of the wind. If strong winds prevail from the northwest, there will be a fall in temperature, and if high winds prevail from the south the temperature will rise. In clear comparatively still weather the temperature will rise in the daytime under the strong sunshine and will fall to a low point at night because of free radiation of heat from the ground.

As a good deal of damage was done in Ohio by the cold weather of May 9 and 10, 1913, an analysis of the temperature changes for that week as shown in figure 9 will prove of interest.

On May 5, 1913, warm southerly winds prevailed in Ohio and the temperature was unseasonably high, as shown by the thermograph record in figure 9. The wind changed to westerly in the evening and there was an irregular drop in temperature.

On the 6th it was cloudy with strong northwesterly winds and there was only a moderate rise in temperature. It was cloudy at night and there was a very irregular drop in temperature.

The northwesterly wind continued on the 7th and although it was clear there was only a moderate rise in temperature. The wind decreased at night and as it was clear there was quite a rapid drop in temperature to 34° at about 5 o'clock a. m.

An area of high barometric pressure was central over this district on the morning of the 8th and there was a rapid and strong rise in temperature to 73° at about 3:30 p. m. It was clear in the afternoon and evening and the temperature began to drop rapidly, but it clouded up in the night and the wind increased, so that the temperature began to rise soon after 2 a. m.

The temperature increased very irregularly on the 9th because of cloudy weather and northwesterly winds. In the evening of the 9th the wind increased from the north and from about 4 p. m. to 6 a. m. of the 10th the thermograph curve shows the characteristic fall in temperature due to importation of cold air from the north in conjunction with the diurnal drop in temperature. The thermograph record made nearly a straight line in comparison with the concave curve of the records on clear afternoons with little wind.

The only way to predict the probable minimum temperature on nights like May 9, 1913, is by a study of the weather map. High wind continued all night and orchardists who tried to keep the temperature up by building fires found that the warmed air was carried away rapidly and that the temperature fell nearly as steadily where the fires were burning as outside.

The wind continued on the 10th, but as the sky was clear there was a moderate rise in temperature. However, the wind decreased the night of May 10, the radiation was rapid, and the temperature went considerably below freezing. Fruit men who failed to keep the temperature above the danger point during the night of the 9th/10th thought it useless to try to protect, or perhaps ran out of fuel, so that much damage was done throughout Ohio. The few who did make the fight with plenty of fuel obtained splendid crops.

There was little wind on the 11th and with a large high-pressure area central over Ohio the thermograph curve for the 11th shows the typical rise and fall under anticyclonic conditions such as was recorded at Delaware.

(*t*) *Typical thermograph curve May 11 to 18, 1914.*—The characteristic temperature curve under conditions of high pressure and clear skies is shown during the last four days of figure 10. The rise in temperature is rapid in the morning and the curve has a convex shape. The highest temperature is about 3 p. m., and then there is at first a very rapid fall in temperature until about 7 p. m., then it falls more slowly until the lowest point at about 5 a. m. The afternoon and evening curve is concave in shape. These are the conditions under which frost is apt to occur.

On May 13, 1914, as shown on figure 10, there was very little change in temperature, due to rainy weather and a strong northerly wind. The wind shifted to northwest at about 10 a. m. on the 12th, causing a rapid drop in temperature from that hour, so that the highest temperature for the day was before 10 a. m. instead of in the afternoon.

In figure 11 the range in temperature is shown in a commercial orchard at Council Bluffs, Iowa, May 1, 1911, as shown in Iowa Experiment Station Bulletin No. 129. The solid line shows the temperature drop in an unheated part of the orchard while, beginning at 2:30 a. m., the dotted line gives the temperature in a part of the orchard protected by orchard heaters. These curves were drawn from hourly temperature observations. The heaters were lighted when the temperature had fallen to 29° and it immediately began to rise.

(*u*) *Predicting minimum temperatures by means of the afternoon or evening median temperatures.*—A study of any thermograph record will show that during periods of clear and calm weather, when an area of high pressure is centered over the district and the conditions are favorable for strong insolation in the daytime and for free radiation at night, there is a marked similarity in the daily curves. This is particularly well marked for May 14, 15, 16, and 17, in the last part of figure 10.

This being true, the question has been raised whether the halfway point in the temperature fall from the maximum of one day to the minimum of the next morning might not occur at about the same hour each evening on days when high-pressure conditions prevail.

A study was therefore made of the records of the self-recording thermometers at Delaware, Toboso, and Columbus, with very satisfactory results. It seems probable that the minimum can thus be predicted very accurately by taking the difference between the temperature at the time of the average median and the maximum for the day and subtracting that difference from the temperature at the average time of the median.

Table 8 shows the average time of the median temperature from April to November, inclusive, together with the earliest and latest median hours for the same months. At Delaware, for example, for the month of May, which is the critical frost month in that vicinity, the average median hour in 1913 was 7:36 p. m., and in 1914, 7:35 p. m. And more interesting still is the fact that the difference between the earliest median hours and latest median hours for May, 1913, was the same as for May, 1914, and was only 35 minutes. These figures are, of course, under conditions favorable for radiation or frost conditions.

At Toboso the variation is somewhat greater, but at Toboso the thermograph record is not quite so accurate as to the exact time correction. At Columbus the average for May, 1912, was 8:52 p. m., for May, 1913, 9:12 p. m., and for May, 1914, 9:15 p. m. The later median hour at Columbus is due to the less rapid drop in the temperature in the afternoon because of the city influence.

METHOD OF DETERMINING THE MEDIAN.

In Table 9 the method of determining the time of the median is shown for Delaware for May, 1913 and 1914. This table also shows the difference between the minimum temperature that would have been predicted by this method and that which actually occurred during those two months. On two days the minimum predicted from the median would have been 4° higher than the actual and on one day 5° too low, but the greater part of the time it would not have differed over 1°.

TABLE 8.—*Average times of median temperature, between the highest of one day and lowest of next morning, under conditions favorable for radiation.*

Data.	April, p. m.	May, p. m.	June, p. m.	July, p. m.	August, p. m.	September, p. m.	October, p. m.	November, p. m.
				At Delaware, Ohio.				
Average, 1912	......	......	......	......	......	......	5:30	6:24
Average, 1913	7:12	7:36	7:08	7:24	6:51	6:24	5:55	5:53
Average, 1914	7:11	7:35	7:34	......	......	......	......	......
Earliest, 1912	......	......	......	......	......	......	5:00	5:30
Latest, 1912	......	......	......	......	......	......	6:00	7:30
Earliest, 1913	6:30	7:15	6:00	7:00	6:00	5:30	5:00	5:30
Latest, 1913	8:15	7:50	8:00	8:15	8:00	7:30	7:00	7:15
Earliest, 1914	6:00	7:15	7:00	......	......	......	......	......
Latest, 1914	8:15	7:50	8:15	......	......	......	......	......
				At Toboso, Ohio.				
Average, 1913	7:22	7:42	7:22	7:53	7:10	6:51	5:57	6:20
Average, 1914	7:43	8:06	7:37	......	......	......	......	......
Earliest, 1913	6:30	7:00	6:00	6:30	6:00	6:00	5:30	5:30
Latest, 1913	8:00	9:00	8:30	9:00	8:30	8:00	7:00	7:15
Earliest, 1914	5:30	7:30	6:30	......	......	......	......	......
Latest, 1914	9:30	9:00	8:30	......	......	......	......	......
				At Columbus, Ohio.				
Average, 1912	9:15	8:52	......	......	......	8:36	8:23	7:35
Average, 1913	9:28	9:12	9:04	......	......	8:49	9:06	8:50
Average, 1914	9:30	9:15	8:38	......	......	......	......	......
Earliest, 1912	7:00	7:00	......	......	......	6:00	6:15	6:00
Latest, 1912	10:30	11:00	......	......	......	11:00	10:15	8:15
Earliest, 1913	7:45	8:00	7:00	......	......	6:15	8:00	6:30
Latest, 1913	11:00	10:00	11:15	......	......	10:00	12:00	10:00
Earliest, 1914	7:45	7:30	6:15	......	......	......	......	......
Latest, 1914	11:00	10:00	11:00	......	......	......	......	......
	Median between maximum at Weather Bureau office, Columbus, Ohio, and minimum at the Ohio State University.							
Average, 1912	......	10:15	......	......	......	9:32	10:51	8:20
Average, 1913	9:50	10:36	10:13	......	......	10:43	10:10	11:04
Average, 1914	10:34	10:48	10:18	......	......	......	......	......

TABLE 9.—*Method of determining time of median under conditions favorable for radiation, and difference between temperature estimated from median and from the dewpoint of the night before, and the actual minimum recorded at Delaware, Ohio.*

Date.	Maximum temperature.	Time maximum occurred.	Minimum temperature next morning.	Time that minimum occurred.	Median temperature.	Time of median temperature.	Minimum temperature estimated from the median.	Variation of estimated minimum from actual.	Minimum temperature estimated from dew-point.	Variation of estimated minimum from dew-point from actual temperature.
May, 1913.	°F.	P. M.	°F.	A. M.	°F.	P. M.	°F.	°F.	°F.	°F.
1	81	4:00	43	6:00	62.0	7:50	47	+4	48	+5
2	88	3:00	51	6:00	69.5	7:30	51	0	54	+3
3	87	2:30	51	5:30	69.5	7:40	52	+1	54	+3
7	67	2:15	34	5:00	50.5	7:40	35	+1	34	0
10	54	2:00	27	4:30	40.5	7:30	27	0	26	−1
11	63	3:00	29	4:30	46.0	7:40	30	+1	28	−1
18	76	1:00	39	3:00	57.5	7:45	41	+2	44	+5
19	71	3:30	48	1:00	59.5	7:45	49	+1	41	−7
24	70	3:00	44	1:00	57.0	7:15	40	−4	46	+2
31	80	3:15	54	3:00	67.0	7:30	54	0	57	+3
May, 1914.										
1	57	1:00	29	5:00	43.0	8:00	33	+4	36	+7
2	66	3:00	38	5:00	52.0	7:30	38	0	48	+10
6	71	12:15	43	1:30	57.0	7:30	43	0	50	+7
14	65	3:15	36	5:00	50.5	7:50	37	+1	41	+5
15	64	1:30	33	4:30	48.5	7:45	34	+1	39	+6
16	68	3:00	36	4:30	52.0	7:30	36	0	42	+6
17	74	3:00	39	4:45	56.5	7:30	39	0	42	+3
18	80	1:45	45	5:00	62.5	7:15	40	−5	44	−1
19	84	2:45	46	5:00	65.0	7:30	46	0	52	+6
20	86	3:30	50	4:30	68.0	7:30	50	0	52	+2
21	87	2:00	50	5:00	68.5	7:30	50	0	57	+7
23	77	2:00	47	4:30	62.0	7:30	47	0	47	0
30	80	2:15	43	5:00	61.5	7:50	46	+3	44	+1

At Delaware the average time of median for May is 7:36 p. m.

This is a remarkable showing, and because May is the critical frost month it makes this method of great importance. In the latter part of Table 9 the minimum temperature as predicted from the 6 p. m. dewpoint is given for the same days, together with the difference between the predicted and the actual temperatures. This shows that while at times the dewpoint and minimum agree fairly closely, at other times the variation may be 10° above or 7° below the actual temperature.

In April and June the differences are not much greater than in May. In December, January, February, and March there are few well-defined periods with conditions favorable for free radiation with light wind.

(*v*) *Rules to be followed.*—When it is partly cloudy in the evening the actual time of the median will be later than the average. When a moderate wind is blowing this is also true, especially if the wind is from the northwest and there is an importation of cold air from that point.

In all cases when there has been a warm southerly wind blowing with a comparatively high temperature and the wind shifts to northwest with decidedly colder it is useless to try to predict the minimum from the median. The temperature curve then takes the form of that on the night of May 9, 1913, as shown in figure 9.

(*w*) *Suggestions for predicting minimum temperatures by means of the median for fruit growers and gardeners.*—The afternoon median temperature is the half-way temperature between the maximum of the day and the minimum of the next morning. In cloudy and stormy weather, or when strong southerly winds prevail, or when the wind is high from the northwest the time of the median varies so much that no attempt should be made to make predictions from it.

This is especially true when, after a period of warm weather, the wind shifts to northwest and the temperature begins to fall rapidly. This indicates the approach of a cool wave or cold wave, and the only possible way to forecast the probable temperature is from the daily weather maps. The orchardist or gardener who has crops in a critical condition in the spring or fall when these conditions prevail should lose no time in getting into communication with the Weather Bureau officials at such times.

But after the windy front of the cool wave has passed by, however, and the air is clear and still and the days are warm and the nights cool, then the probable minimum temperature and probability of frost damage can apparently be closely estimated for one's own orchard or garden by means of the median temperature.

To accomplish this, the difference between the temperature at the time of the half-way point, or median, in the evening and the highest temperature for the day must be subtracted from the median temperature. For example, if the highest temperature during the day is 68° and at the time of the median in the early evening it has fallen to 50°, the difference, or 18° subtracted from 50° leaves 32° as the probable minimum temperature during the night.

The average time of this median temperature, even under conditions of clear skies and still air, will vary slightly at different seasons of the year and in different localities.

In central Ohio, outside of the cities, the average time of the evening median will be at about 7:15 p. m. in April, 7:30 p. m. in May and June, 6:30 p. m. in September, and close to 6 p. m. in October and November. In July it is about 7:30 p. m., and in August 7:00 p. m. So far as we are able to determine it is not far from 6:30 p. m. in December and 7:00 p. m. in January, February, and March, although our observations and studies are not very complete in the winter months.

If a strong wind is blowing in the afternoon, or if it remains cloudy or partly cloudy until evening and then clears off, the time of the median will be from 30 to 45 minutes later than the averages above given.

If it should cloud up during the night after a clear afternoon and evening, the minimum will not be so low as is indicated by the median.

Records that are at hand indicate that the average time of median will be slightly later in the valleys than at higher elevations.

At Columbus, which represents a city station, the average time of median is later than at Delaware, and the variation between the earliest and latest hours is greater, but the error made by predicting the minimum from the average median is only slightly greater than at Delaware.

(*x*) *Instruments to be used.*—Orchardists and gardeners should provide themselves with reliable self-registering maximum and minimum thermometers. They may be the separate thermometers, as shown in figure 2, the best of which cost about $8 per pair. These are the standards used by the United States Weather Bureau. Or the two thermometers may be combined in one tube, as shown in figure 3. These cost about $5. They are somewhat easier to handle but are generally sluggish and not very accurate.

These thermometers should be exposed in a thin latticework shelter so that there will be a free circulation of air around them. Cheaper thermometers may be obtained, compared, and checked with the standards at critical temperatures, and then exposed in different parts of the

FIG. 1.—Instruments shelter and instruments at the special fruit-frost station at Delaware, Ohio. [Figure omitted.]

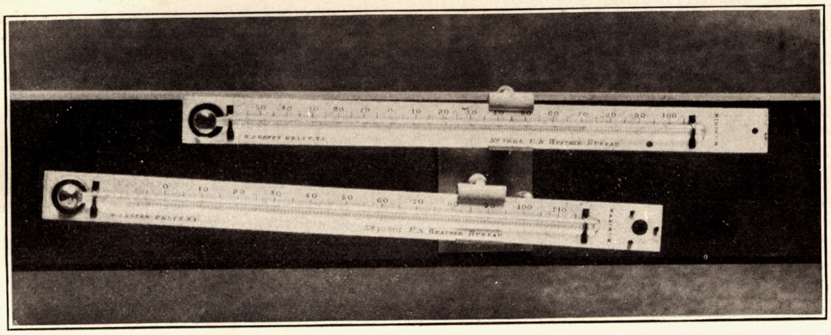

FIG. 2.—Maximum and minimum thermometers on the Townsend support as used at Weather Bureau stations.

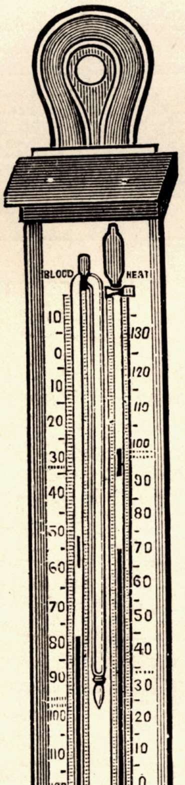

FIG. 3.—Self-registering maximum and minimum thermometer: devised by James Six; Phil. Trans., London, 1782.

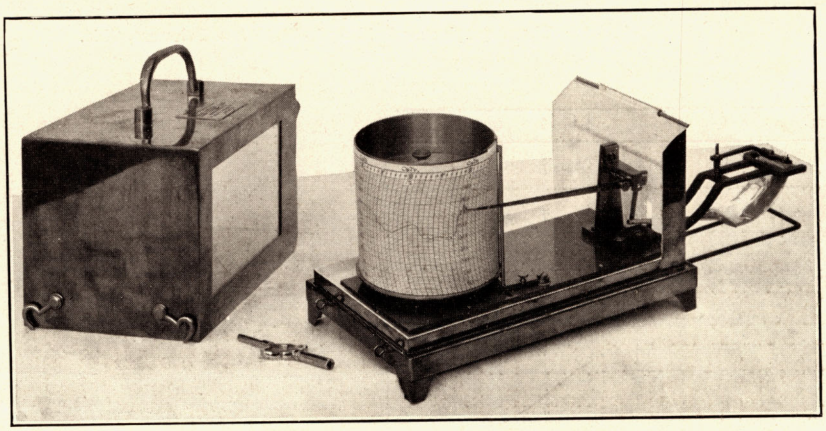

FIG. 5.—Thermograph, or self-registering thermometer, as used at many stations of the Weather Bureau.

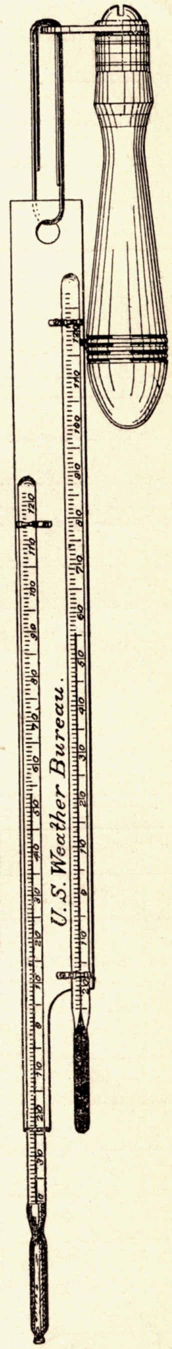

FIG. 4.—Sling psychrometer, Weather Bureau pattern.

FIG. 6.—A view in the orchard of G. H. Koeppel, Delaware, Ohio, at midnight, May 1, 1914. [Figure omitted.]

FIG. 7.—The Hamilton heaters in operation in the experiment station orchard at Wooster, Ohio. [Figure omitted.]

FIG. 8.—Troutman heaters in the orchards at Wooster, Ohio. [Figure omitted.]

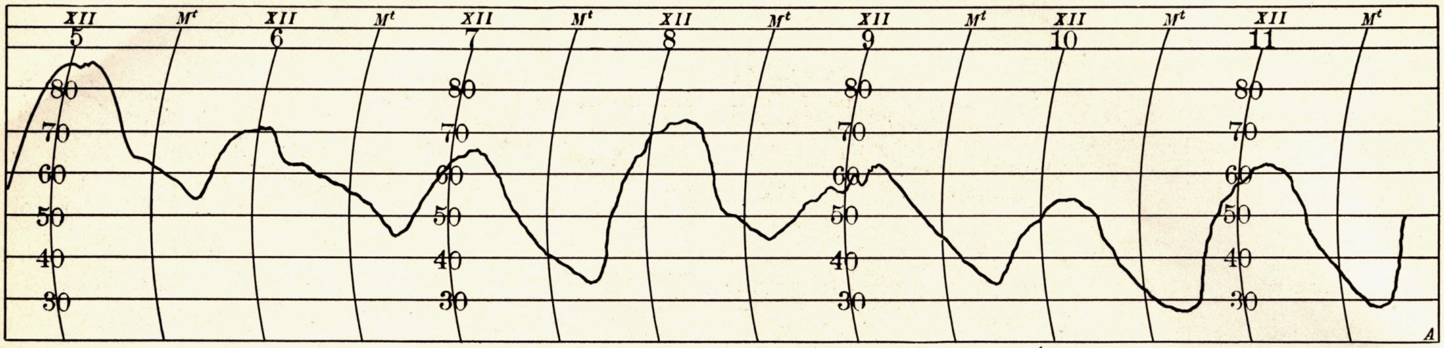

FIG. 9.—Thermograph record of May 5–12, 1913, at Delaware, Ohio.

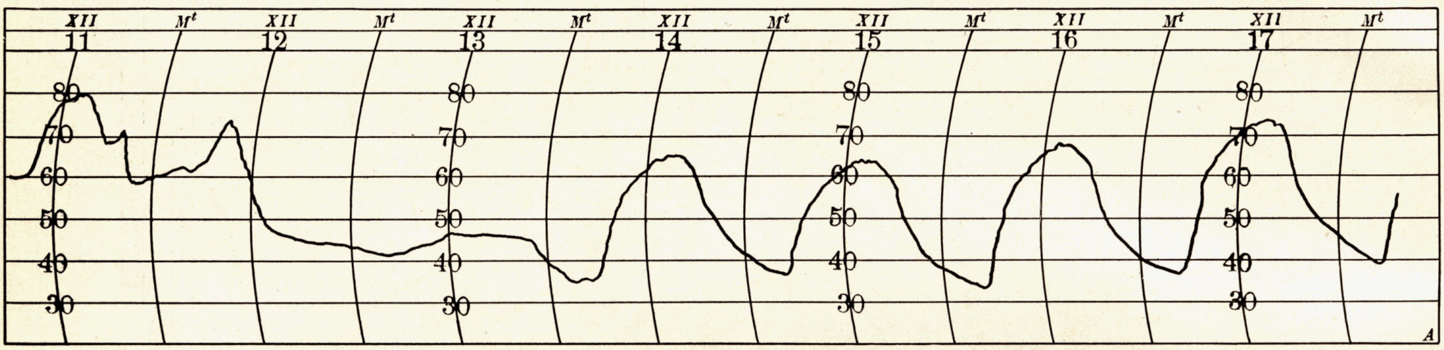

FIG. 10.—Thermograph record of May 11–18, 1914, at Delaware, Ohio.

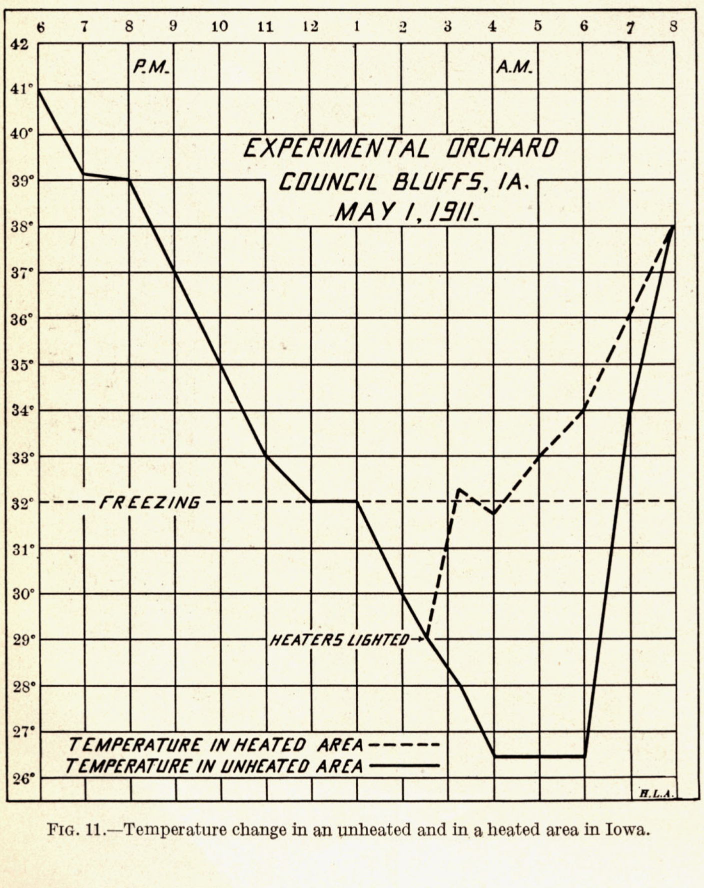

FIG. 11.—Temperature change in an unheated and in a heated area in Iowa.

FIG. 12.—Location of special fruit-frost stations in Ohio.

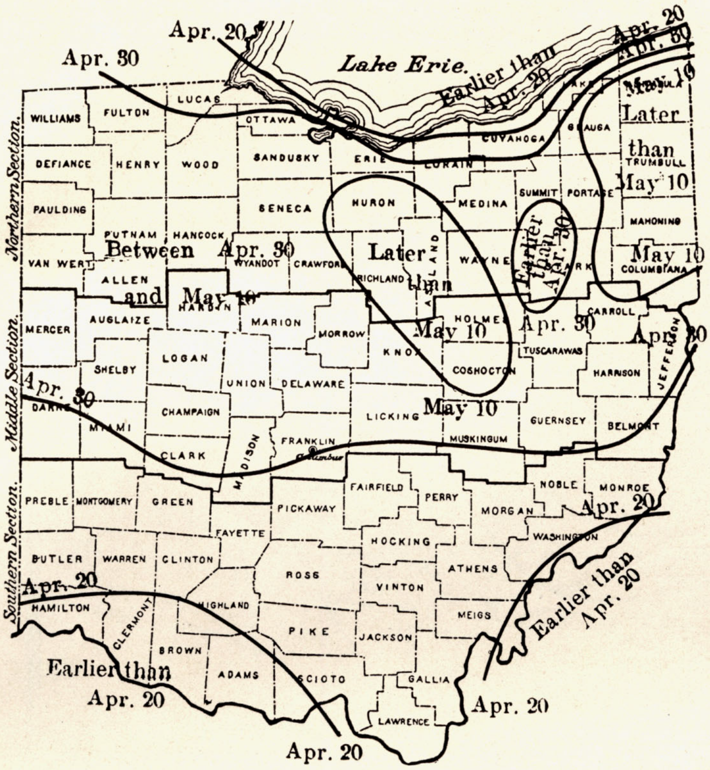

Fig. 13.—Average dates of last killing frosts in spring in Ohio.

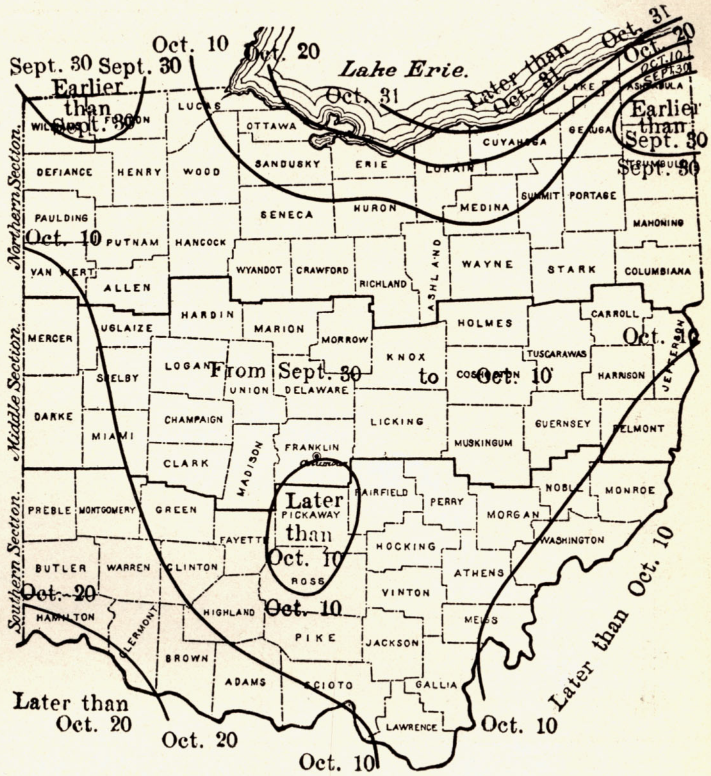

Fig. 14.—Average dates of first killing frost in autumn in Ohio.

Fig. 15.—Average date of first bloom of apples in Ohio.

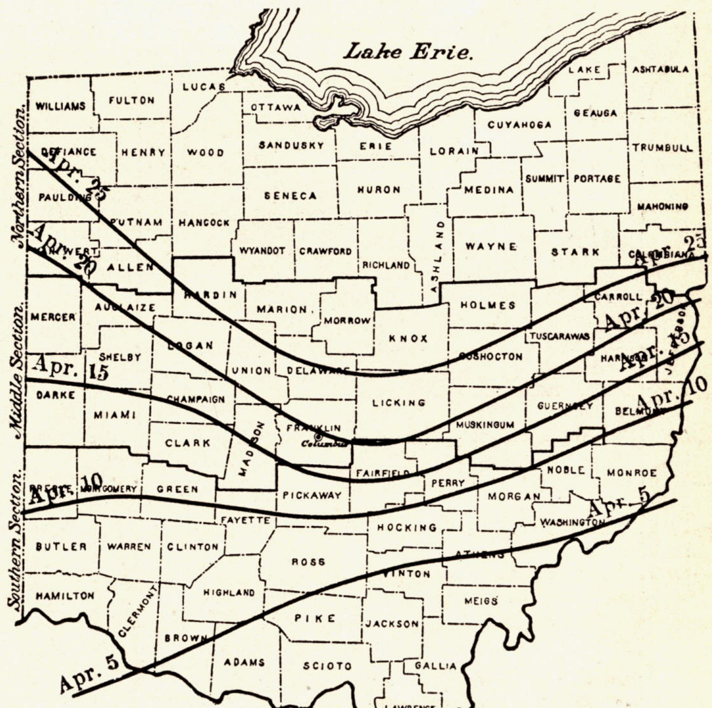

Fig. 16.—Average date of first bloom of peaches in Ohio.

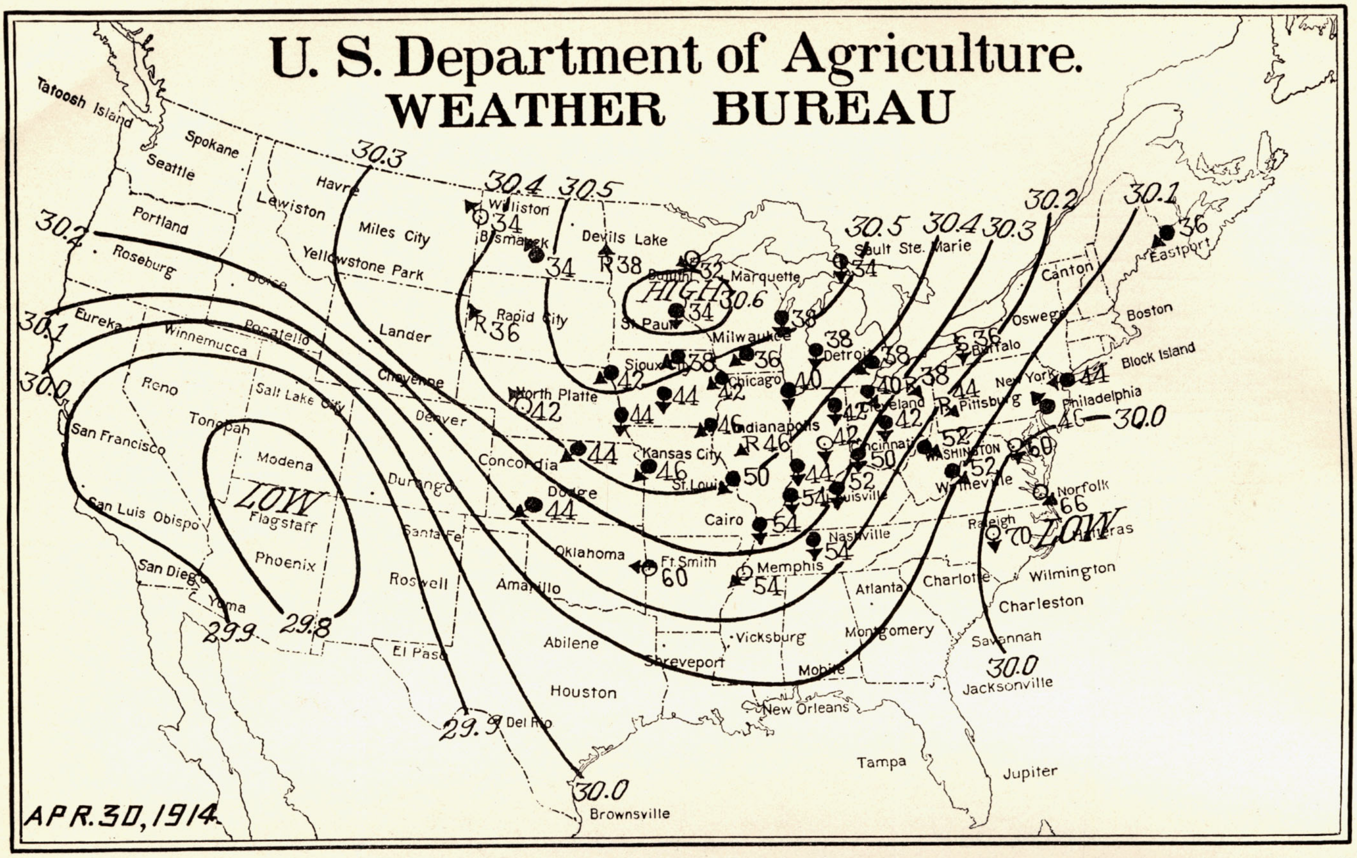

FIG. 17.—Daily Weather Map, 8 a. m., April 30, 1914. Showing an area of high pressure with a cool wave in the northwest that may be expected to overspread Ohio in the next 48 hours with general frosts. The lines are drawn for equal barometer pressure. The arrows fly with the wind, and show wind direction. The symbols indicate state of weather: ◯, clear; ◑, partly cloudy; ●, cloudy; R, rain; S, snow. The figures at the station shows current temperature.

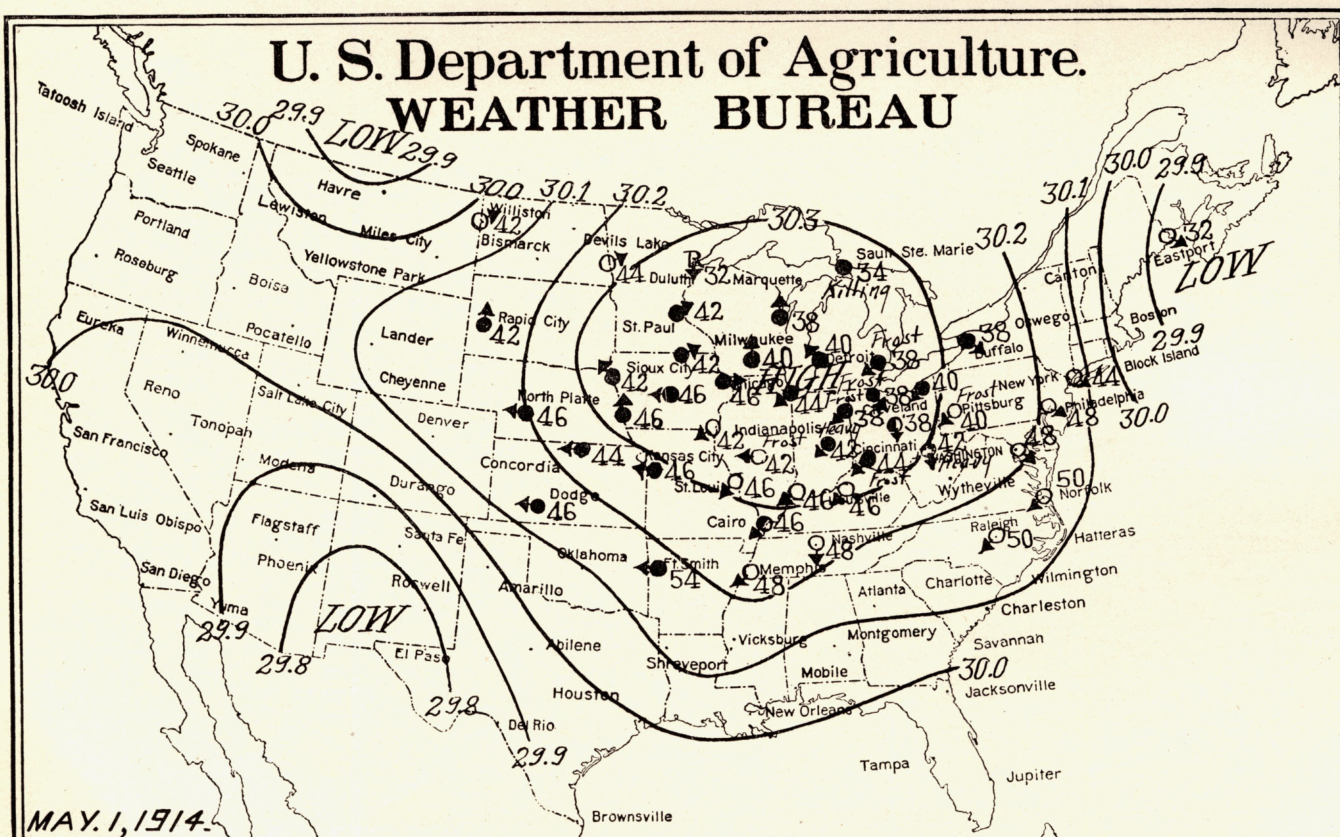

FIG. 18.—Daily Weather Map, 8 a. m., May 1, 1914. The high pressure area and cool wave is spreading southeastward and is causing frosts in Ohio. The lines are drawn for equal barometric pressure. The arrows show wind direction and fly with the wind. ◯, clear weather; ◑, partly cloudy; ●, cloudy; R, rain; S, snow. The figures at the station indicate current temperature. Light, heavy, or killing frosts are indicated by frost, heavy, and killing.

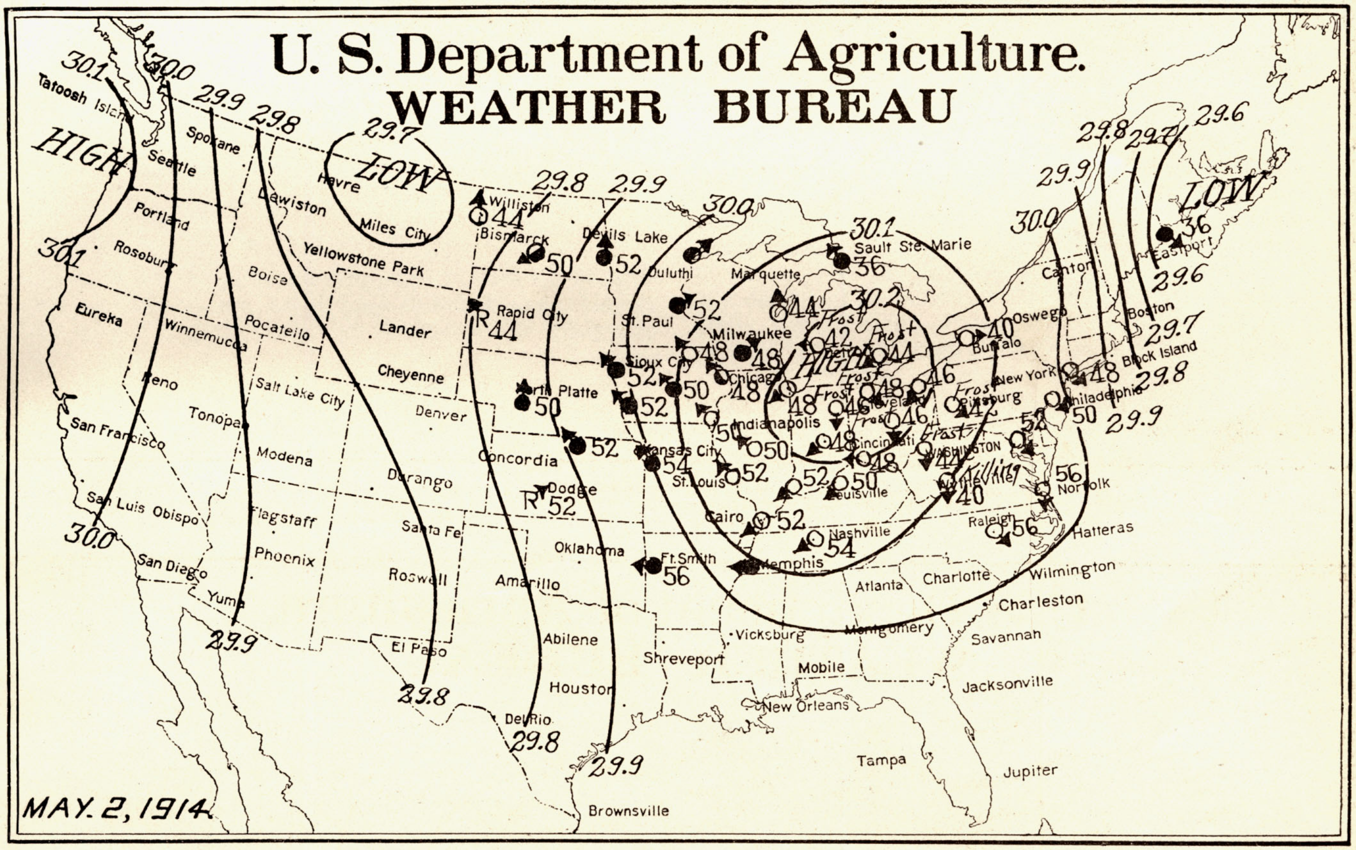

FIG. 19.—Daily Weather Map, 8 a. m., May 2, 1914. The high pressure area now overspreads Ohio and frosts are widespread. From now on the temperature will rise gradually as the high moves eastward. The lines are drawn for equal barometric pressure. Arrows show wind directions; symbols, state of weather; figures, current temperature; frost has occurred where the appropriate word is used.

orchard by hanging them against the tree or suspending from the branches. Thermometers should be exposed where the sun will not strike them and where they will have a free circulation of air, but always with a light protection over them to prevent too free radiation of heat from the instrument itself to the sky or other object. A thermometer hung out in the open will, in the sunshine, give a temperature much higher than that of the atmosphere, and at night it will be several degrees colder than the temperature of the air that surrounds it.

(*y*) *Prospective extension of the fruit-frost service and warning service.*—A few additional fruit-frost stations will be established in Ohio and steps will be taken to give the regular and special "frost warning" service to any fruit section or market-gardening section in the State where action is being taken to protect from frost damage.

551.553, 001

VI.

AIR DRAINAGE EXPLAINED.

By CHARLES FREDERICK MARVIN, Chief of Bureau.

[Dated Weather Bureau, Washington, D. C., Nov. 20, 1914.]

1. Orchardists and others engaged or interested in agricultural pursuits, as well as physicists and meteorologists often employ the expression "air drainage" to designate certain features of atmospheric circulation attending the occurrence of frost during clear, still, cool nights in regions characterized by hill and valley conditions of topography. The popular conception of the actual phenomenon in question is often technically incorrect, and it seems worth while, therefore, to explain this particular species of atmospheric circulation in some detail in order that forecasters interested in the issue of frost warnings and orchardists and others who are prepared to prevent frost injuries by artificial protective measures may have a proper understanding of this interesting circulation. The faulty conception of air drainage is often conveyed by some such condensed statement as the following: The air on the higher slopes, cooled by contact with the surface soil or vegetal cover which is itself cooled by the active radiation under clear skies, *flows or drains downhill substantially as water would flow on the same slope.* This analogy of the flow of water is not materially inexact under particular conditions, but it is especially inappropriate and misleading as applied to the circulation of the air during the nighttime in such hill and valley regions as are now under consideration and that are frequently devoted to orchard and garden purposes. Air drainage on a hillside is *not* like the flow of water on the same slope because (1) air is a compressible gas and its flow is influenced by important thermodynamic actions as well as by gravity while the flow of water which is an incompressible liquid is determined practically by gravity alone; (2) water in place may flow completely away leaving the space it occupied vacant as regards water. Air, however, on a hillside, for example, can only change places with some other air, and then only under specific and prescribed conditions.[1]

2. In what follows an effort is made to clearly describe the interesting type of circulation commonly designated air drainage and to indicate the physical laws in operation.

The author realizes that the explanation of air drainage now offered is at variance with the water-like-flow theory commonly entertained and found superficially discussed in even the best textbooks. This theory, nevertheless, is fallacious as applied to the conditions now under consideration, and will not stand critical analysis. It completely fails to explain the development of the vertical inversion of temperature. It asserts that a stream of cold surface air flows down the slope, filling up the valley with frigid air. How can there be a *thermal belt* on the hillsides if such a water-like flow of cold air exists? How can the alleged water-like flow of cold surface air on the hillside keep one part of the hillside warm and yet fill the whole valley below this level with much colder air? The *reductio ad absurdum* of this theory is brought out by the question: How can a stream of cold surface air flowing in a water-like fashion down a hillside produce a region like the so-called thermal belt that is warmer than any other locality, and how can the same stream flowing onward fill the whole valley below the thermal belt with frigid air?

3. While great diversities prevail in the topographic character of different regions causing corresponding modifications in the local circulation, yet the same general principles operate in all cases and a connected statement of the essential features under simple representative conditions will suffice. Consider, for example, an ordinary extensive valley, such as is to be found almost anywhere in a hilly, rolling country. The sides of the valley, as a rule, will be relatively steep, especially as compared with the bottom or floor, which for the present purposes may be regarded as comparatively level, although in fact it also slopes gently downward, as evidenced by the onward flow of a stream or river of water that may be found therein.

4. Observations tell us that during clear, still nights valleys of this character fill up to a considerable depth with a great riverlike mass of cold air. The temperature is lowest at the bottom, increasingly warmer at intermediate layers and warmest at the surface of the aerial river. Above the river the temperature of the air decreases more or less rapidly with increase of elevation. The term "air drainage" from the present point of view, is the name assigned to the local circulation that is able to create and to build up during a nighttime a deep river, or lakelike mass of cold air similar to that just described.

5. We may for a moment consider another species of air drainage, namely, the sluggish flow of the whole river of cold air down the nearly level floor of the valley on its way to the sea. This sluggish flow does take place and is fairly like that of water. Also in the afternoons and early evenings, while the surface air is still warm and the surface temperature gradient is not as yet strongly nonadiabatic, the flow of cooling surface air even on the steeper slopes may somewhat resemble the flow of water on the same slopes. Nevertheless, both the sluggish flow of the river of cold air and the waterlike flow of portions of surface air in the afternoons constitute for the orchardist relatively unimportant species or aspects of air drainage and need no further mention here.

6. In order to fully understand the circumstances leading to the formation of the river of cold air, it is necessary to begin with a brief account of the condition of the air in and over the valley during the preceding day and incidentally to explain the significance of the adiabatic relation of atmospheric temperatures.

7. In the course of a bright, sunshiny day with little or no wind, the free air occupying the lower strata of the atmosphere for a depth of one or two thousand feet or more, is practically in adiabatic equilibrium, which means

---

[1] Prof. W. R. Blair, in his Five Year Summary of Free Air Data, Bulletin Mount Weather Observatory, 1913, 6: 118–124, devotes some space to the discussion of mountain and valley temperatures in the vicinity of Mount Weather, and very correctly indicates the kind of circulation that can occur in such regions. In the present paper I am applying the term "air drainage," even though it be a misnomer, to the whole characteristic circulation of air on clear nights in hill and valley regions, whereas Prof. Blair, without specifically declaring himself on the point in question, has limited his use of the term to a real waterlike flow of air that may sometimes take place on relatively gentle slopes.