PRESSURE AS A FACTOR IN THE PREDICTION OF FOG FORMATION

a thesis by

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I

INTRODUCTION

1. History of Fog

In the days of railroad and ship travel, fog did not present as great a problem to operations as it does today. As a consequence, the physical basis of condensation was limited to theoretical considerations and a few controlled laboratory experiments.

With the advent of the age of air travel, a more thorough investigation of the problem of fog formation has become necessary; but as yet the problem has not been solved completely. A simple method of predicting the time of fog formation and the length of its duration would be a vital step in increasing the operating efficiency of air transportation.

It was first thought that condensation occurred in the atmosphere when the temperature reached the dew point. No consideration was given to impurities in the air. It was left to laboratory experiment to show that pure air was condusive to supersaturation with fog formation virtually impossible. As a result, assumptions were made as to the nature of some type of condensation nuclei upon which moisture could condense. One of the first steps in this direction postulated that condensation took place upon ions which are at all times present in the atmosphere. For this case, the laboratory again showed that conditions of supersaturation occurred before condensation took place upon the ions. Next, dust particles were considered, but it was also found that condensation took place in the atmosphere before it occurred on the dust particles. The present ideas including the nuclear hypothesis postulate the universal presence of hygroscopic particles, such as salt or sulphur oxides, in the atmosphere. It has been found that fogs can form upon such nuclei before the temperature reaches the dew point. This is in accordance with observed conditions of fog formation in the atmosphere.

2. Fog Dissipation.

The problem of fog dissipation has been investigated by Dr. Irving P. Krick of the California Institute of Technology. The method developed by him determines the time of breaking of a fog or stratus system, but does not apply to the problem of fog formation. The dissipation of a fog or stratus requires heating of the system until all the water droplets held in suspension are evaporated.

This heating may be done by the advection of the fog or stratus into a region of higher temperature, or by surface heating and turbulence produced by insolation. The convective activity produced by insolation causes an upward transport of heat in the lower layers of the atmosphere. If insolation continues long enough, the convection and turbulence will transport ehough heat aloft to evaporate the fog or stratus. The convective activity is produced in the following manner. The portion of the solar radiation which is not reflected by the fog or cloud top passes through to the ground and is effective in raising the temperature of the surface. Superadiabatic lapse rates are produced near the ground, and an overturning of the lower layers of the atmosphere results. The overturning reduces the specific humidity near the surface and increases the temperature. This dissipates the lower layers of the cloud or stratus and the process may continue until the entire system has evaporated. The problem then reduces to a determination of the surface temperature which will produce an upward transport of heat sufficient to evaporate the fog or stratus. The adiabatic chart is useful in determining the critical temperature of dissipation. An upper air sounding is made and the temperature and specific humidity curves are plotted on the adiabatic chart. As the fog or cloud dissipates from the lower layer upward, a constant value of specific humidity is assumed to exist at the base during the process. The constant specific humidity line which is located at the base of the system is followed upward until it intersects the original temperature curve. This point is the point is dissipation. The point is then traced downward along a dry adiabat to the level of station pressure. The temperature of dissipation of the cloud system corresponds to the temperature of the final position upon the adiabatic chart, and is the temperature which must be reached at the station in order to dissipate the fog or stratus. The final step is to determine the time of day the critical temperature will be reached at the ground level. This can be done with a knowledge of the diurnal variation of temperature under the conditions present.

3. Conditions Favorable For Fog Formation.

The fundamental conditions for fog formation are that for a particular value of pressure and specific humidity, the temperature must approach the temperature of saturation. A consideration of fog formation as a function of pressure, specific humidity, and temperature, is fundamental. If saturation pressure is plotted against saturation temperature a very definite zone of fog is found to exist for any particular value of specific humidity. If two of the variables are known, the third may be determined from the functional relation. The fog zone appears as a singular solution of the equations involved. The position of any point in a field of temperature and pressure, or one of pressure and volume, will determine whether or not a fog will form.

Pressure changes on the Earth are determined by the movement of pressure centers. The volume changes are a function of pressure, temperature, and the amount of water vapor in the atmosphere. Temperature changes are due to insolation, radiation escaping to space, advection and turbulence, and adiabatic expansion or compression. Large variations of specific humidity change the volume occupied by a unit mass of air only slightly; but this variation of specific humidity changes the position and form of the fog zone in the pressure volume field. The variation of the fog zone will be discussed more fully.

Theoretically, no fog will develop in a dead calm as there can be no cooling to any altitude. The conduction of heat is very small in air, and under these conditions a heavy dew is all that will develop when the temperature reaches the dew point at the surface.

4. Present Methods of Predicting Fog Formation.

The adiabatic chart may be used in the problem of fog formation. The temperature and specific humidity curves are plotted from an upper air sounding. If the diurnal variation of temperature is great enough to decrease the temperature until it intersects the specific humidity curve at any point, condensation will occur. If the intersection occurs at a high level stratus will develop. If no intersection is possible for a particular diurnal range of temperature, no condensation will occur.

It is impossible to determine from the adiabatic chart whether precipitation will develop from a cloud or fog. It also does not take into account the effect of a critical pressure of saturation, as it includes only temperature and specific humidity.

II

HYPOTHESIS

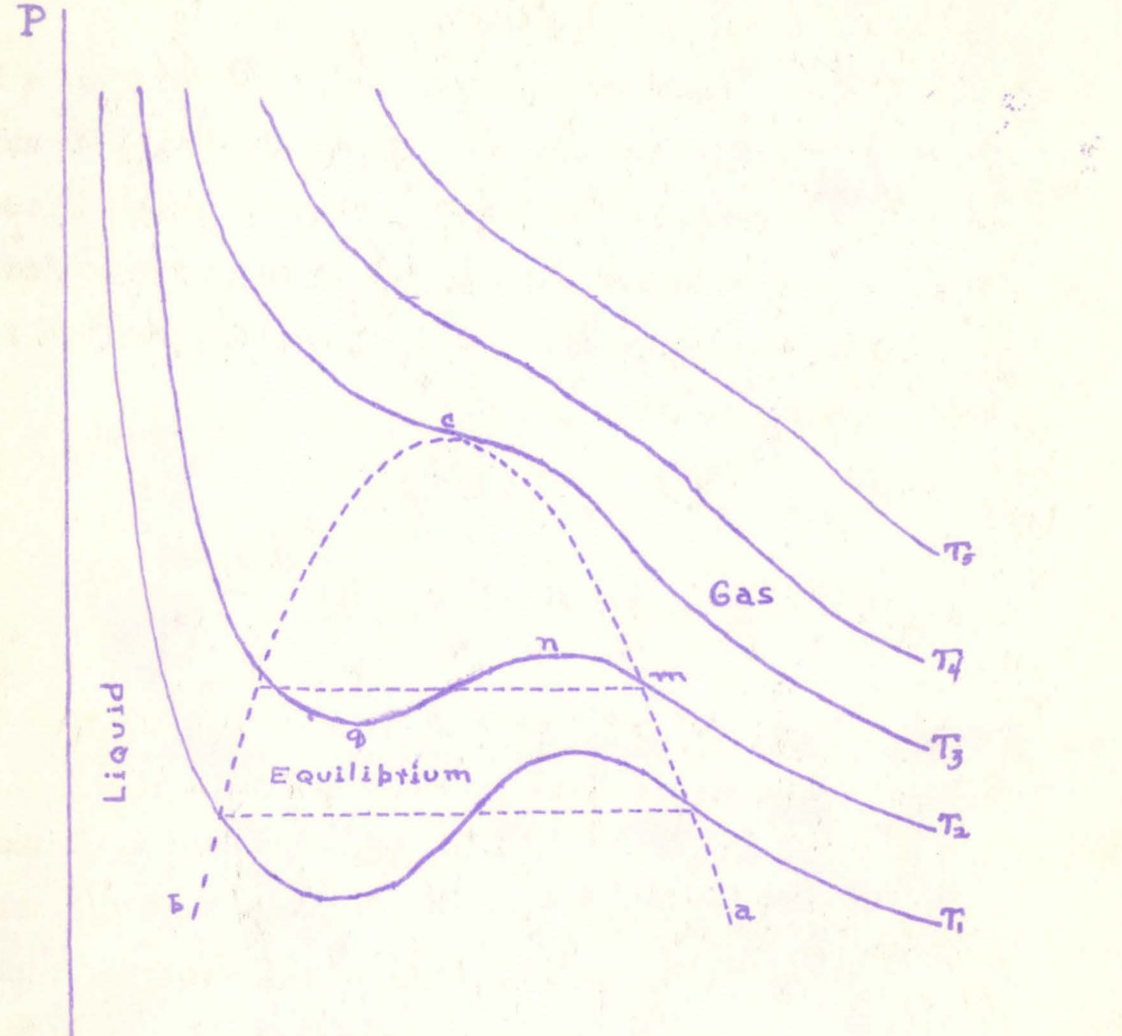
From a descriptive point of view, the conception that a fog is a cloud on the ground which limits visibility to one mile or less is quite adaquate but of little value to the forecaster. A less qualitative concept would be to describe fog as an equilibrium condition between water vapor and liquid water. The restriction of visibility may yet be retained. From this point of view, a fog, together with the air in which it has formed, may be considered as a vapor which does not obey the equation of state of a perfect gas. It is necessary to apply corrections to the equation of state; and this was first done by Van der Waal[1] and later by Clausius and D. Berthelot. The Van der Waal equation can be derived from kinetic theory and is not strictly empirical in its conception. For this reason it will be used in this investigation. Planck[2] has shown that an equation such as that of Van der Waal applies near the saturation for mixtures of gases, and is therefore valid in a consideration of the atmosphere. The cubic form of Van der Waals' equation indicates the form of an equilibrium or fog zone in a field of pressure, volume, and temperature. An evaluation of the constants involved fixes the position of the equilibrium zone.

The purpose of this investigation is to show from a consideration of the Van der Waal equation that fog can form only between narrow limits of pressure and saturation temperature for any particular distribution of specific humidity.

The zone of fog in a pressure volume field, also in a pressure dew point field, has been determined for the atmospheric conditions appearing over the United States and Canada.

The solution of the above problem together with a knowledge of the specific humidity distribution in the upper atmosphere will enable the forecaster to determine, from an examination of the pressure and dew point at a particular station, whether or not there is a possibility of fog forming. The method described will apply to relatively stable situations and will eliminate fog forecasts under unfavorable pressure dew point combinations.

Figure 1.



III

THEORY

1. The Van der Waal Equation.

Van der Waals' equation is not accurate over a large range of temperature; but it has the advantage of applying to both the gaseous and liquid phases of mixtures such as air. As the equation applies in the neighborhood of the fog zone, the result will be sufficiently accurate for this consideration.

Van der Waals' equation[3]

$$\left(P + \frac{a}{V^2}\right)(V - b) = RT$$

Expanding in powers of V

$$V^3 - \left(b + \frac{RT}{P}\right)V^2 + \frac{a}{P}V - \frac{ab}{P} = 0$$

where "a" and "b" are constants. The term a/v^2 is added to the pressure to compensate for the diminution in the pressure of a real gas due to the attractions of the molecules for one another, and the constant "b" is subtracted from the volume to take account of the space actually filled by the molecules. P is the pressure term. V is the volume occupied by the gas. T is the temperature of the gas in absolute units. R is the universal gas constant. It is seen that the equation is a cubic in V. The critical point is that point where pressure and temperature are such as to make the three roots equal. Above the critical point the equation has only one real root; below, it has three.

Expanding the binomial relation between Volume and the Specific Volume of the critical point we have

$$(V - V_c)^3 = V^3 - 3V_cV^2 + 3V_c^2V - 3V_c^2 = 0$$

which, when compared with the expanded form of the Van der Waal equation enables an evaluation of the constants.

$$a = 3V_c^2P_c \qquad b = \frac{V_c}{3} \qquad R = \frac{8P_cV_c}{T_c}$$

This fixes the constants in terms of quantities which may be determined experimentally.

Figure 1. represents Van der Waals' equation graphically with the fog or equilibrium zone defined for a particular value of specific humidity. The isotherms have been sketched in near the region of the critical point "c". For pure water vapor, "c" occurs at a temperature of 33.8 degrees Centigrade, and a pressure of 14.0 atmospheres.[4] For a mixture of air and water vapor the critical point is different. The liquid line is represented by "bc" and the saturated vapor line by "ac". Only inside the curve "abc" may the liquid and vapor

exist together in equilibrium. This region is the fog zone in the field of pressure and volume.

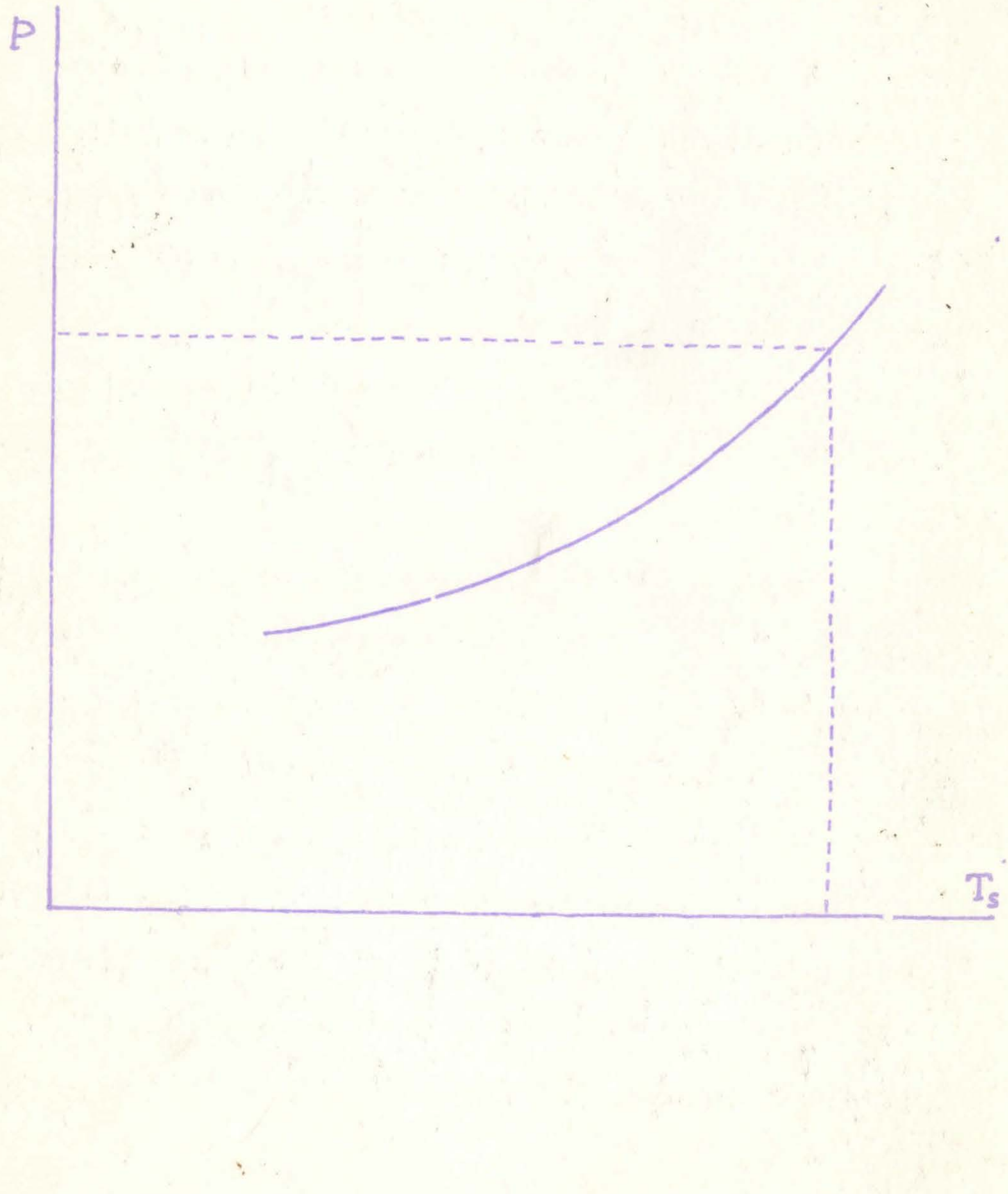
The portion of the isotherm extending from "m" to "n" represents supersaturation; that from "n" to "q", a region of instability. These regions will not be considered in detail; but the theoretical possibility of these states should be borne in mind. It appears that the presence of condensation nuclei destroys these zones and makes fog formation possible.

Van der Waals' equation may be reduced to an expression which is independent of the characteristics of the particular substance under consideration. The problem will not be attacked from this point of view. A determination of the saturation zone for the free atmosphere will be made.

2. The Pressure Saturation Temperature Curve.

It will be noted in figure 1. that the point where an isotherm crosses the saturation vapor line corresponds to a particular pressure and volume. The temperature of this saturation point is analogous to the dew point. It is evident that a particular dew point, or saturation temperature, corresponds to a particular saturation pressure; and that saturation will not take place for this temperature at pressures other than the saturation pressure.

Figure 2.



In figure 2. pressure is plotted against saturation temperature. The figure is constructed from the Van der Waal diagram, and shows the saturation or fog zone to be a very narrow line when plotted in these coordinates. Figure 2. shows an increase in saturation temperature with an increase in pressure. This condition holds for any adiabatic process.

Figure 2. shows also that the temperature of the atmosphere can become a saturation temperature only for a particular value of pressure. Variations in the position of the saturation curve have been included implicitly in figures 1. and 2.. It is necessary to investigate the relation between volume and specific humidity in order to determine the shape and position of the curves.

It is readily seen why temperature and dew point may approach each other at times without restricting the visibility; and at other times causing fog or drizzle. In the first case, any point to the right of the saturation line in figure 1. will not have a visibility restriction as no condensation can occur. If the pressure does not correspond to the pressure of saturation, the temperature may approach the saturation temperature isotherm outside the fog zone and no fog will form.

This corresponds to a point located to the right of the curve in figure 2.

The second case occurs within the fog zone in figure 1., or on the curve in figure 2. A point so located will be found to produce fog under normal atmospheric conditions.

Case number three corresponds to a position located well within the saturation dome, or even in the liquid region of figure 1. In figure 2. such a point would be located to the left of the curve and a drizzle would result.

No complete conclusion can be drawn immediately from this analysis as other atmospheric factors enter which tend to change the idealized saturation dome and the curve which has been derived from it. The following generalization can be made.

1. A fog zone exists in a pressure, volume, and temperature field.
2. Points on either side of the fog zone permit the temperature and dew point to become coincident without the formation of fog.

Having reduced the fog zone to a linear function in a field of pressure and saturation temperature, it is next necessary to determine whether or not the zone is conservative in the atmosphere.

3. Dependence on Specific Humidity.

The volume occupied by a mixture of water vapor and air, in addition to being a function of pressure and temperature, depends on the specific humidity. This is shown clearly by the following equation which is taken from Brunt.[5]

$$V = \frac{RT}{P}(1 - K\omega)$$

The variation of volume with specific humidity is reflected in figure 1. by a shift in position of the equilibrium dome. An increase in specific humidity shifts the saturation dome to the right; where-as a decrease shifts it to the left. This in turn displaces the saturation curve in figure 2. In this case, an increase in specific humidity decreases the pressure of saturation for a fixed temperature. This lowers the curve. A decrease in specific humidity raises the curve in figure 2.

4. The Variation of Specific Humidity in the Atmosphere.

If there were no variation of specific humidity with altitude or geographical position in the Earth's atmosphere, the problem of fog formation would simplify.

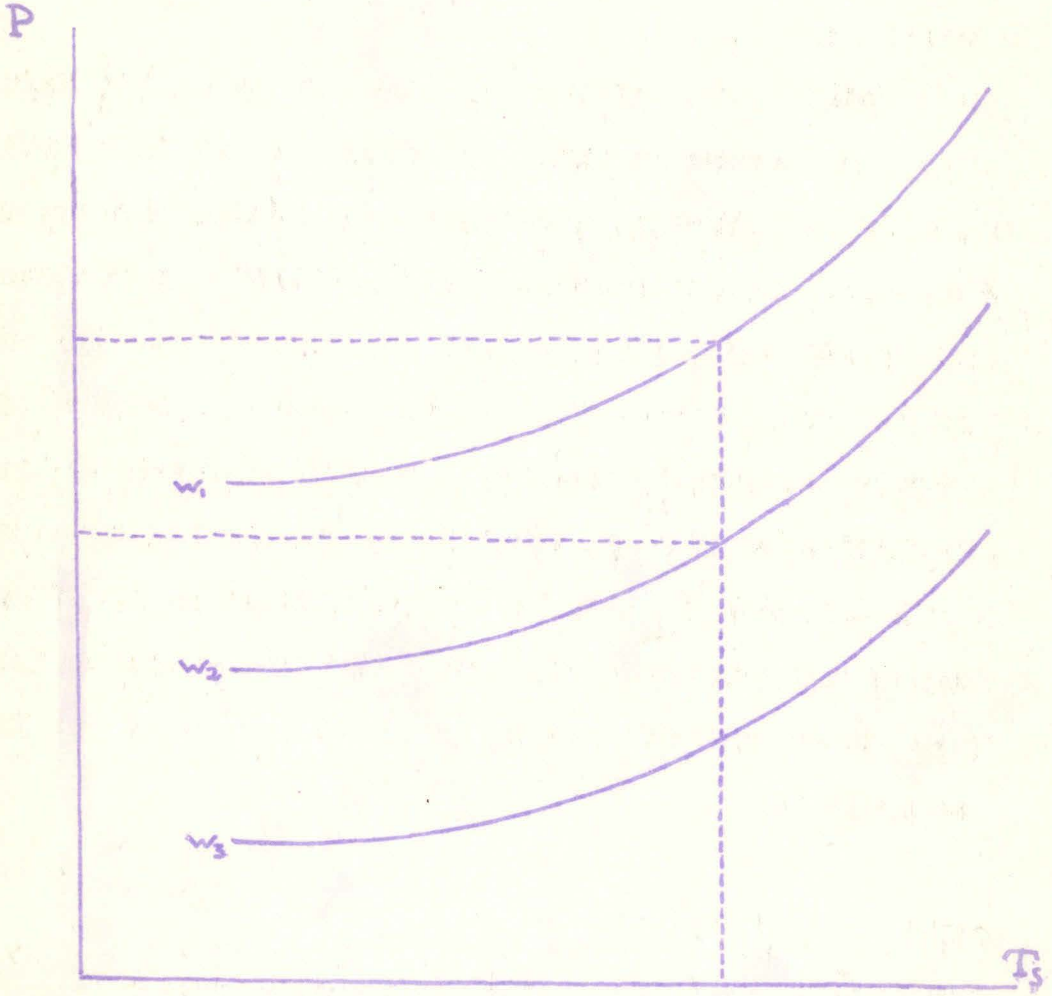
It would be necessary only to know the value of the specific humidity to determine the location of the fog zone in the pressure volume field. The formation of fog would then be determined by whether or not any point in the field lay within the equilibrium zone.

In the atmosphere it is found that a variation of specific humidity with altitude as well as position on the Earth's surface occurs. This complicates the problem by producing a different location of the equilibrium zone for each value of specific humidity. Each specific humidity introduces a new set of constants in Van der Waals' equation.

The distribution of specific humidity in the atmosphere is a problem which has not been solved completely. The complete solution of the fog problem may have to wait until such an investigation can be carried out fully unless a method can be found which will eliminate the exact distribution function.

A distribution of specific humidity within an air mass may be determined empirically from upper air soundings. If such soundings are made during fog conditions, the distribution of specific humidity most favorable for fog formation may be determined. The optimum conditions are likely to be reproduced in air masses which have

Figure 3.



recurring trajectories. The periodic outbreak of the polar Canadian air mass is a good example. If the optimum conditions of fog formation can once be recognized, it is possible to recognize them again under similar circumstances and make a prediction which is accurate.

5. Modification of the Fog Zone within an Air Mass.

Any system in which the specific humidity varies may be described by a pressure saturation temperature diagram. It was seen in section 3 that a variation of specific humidity shifted the position of the saturation curve within the field. In such a system of varying specific humidity, a family of curves exists as indicated in figure 3. For a particular pressure, each curve of the family is intersected by a different saturation temperature. The points of intersection of the curves are determined by the solution of the following equations.

$$P = f(x, y, z) = \text{Const}$$

$$w = f(x, y, z)$$

The solution of the above simultaneous equations form a curve which is continuous. For pressure variation within an air mass, it is necessary to indicate the intersection points formed by the following curves.

The curves intersect and their solubion is a continuous curve in the pressure saturation temperature field.

$$p = f(x, y, z)$$

$$w = f(x, y, z)$$

The curve resulting from the intersection of the above curves is the true fog zone. If the functional relationship between the variables could be determined for a particular air mass, the problem of condensation within the air mass would be completely solved. Condensation can occur only at the points of intersection of the two curves. The temperature of condensation can be read directly from the abscissa of figure 3.. Having located the most probable points of condensation within the air mass, the problem then is to determine whether or not the temperature will reach the saturation temperature at these points. This can be done from a knowledge of the diurnal variation of temperature within the air mass.

The vertical distribution of specific humidity within the air mass is very important. Due to the motions of the air within the mass, stratification occurs which leads to irregularity in the condensation pattern. It is expected that the position of the saturation curve will be different for different air masses. It is also possible to have different saturation curves in the same air mass. If one part of the air mass has had a different trajectory than the rest of the mass this is true. If the trajectory of the entire air mass has been over a uniform surface, the distribution of specific humidity within the mass will be a continuous function. The saturation or fog zone will be a continuous function also and may be determined from upper air soundings and surface data.

The dependence of ground fog upon pressure and the form of the saturation curve found from a consideration of Van der Waals', shows that pressure in the zones of fog must lie within very narrow limits. Optimum pressure conditions may be reached in air masses as they move about. These critical values of pressure will be determined by the specific humidity distribution within the air mass.

IV

METHOD

As an experimental check on the foregoing considerations, the daily synoptic weather charts were consulted in an affort to determine the limiting values of pressure and dew point for fog formation. Stations at which fog occurred were examined. All stations at which temperature and dew point were coincident were tabulated along with the weather conditions prevailing at the time of observation.

Fogs existing in relatively high pressure areas were investigated as they include the most uniform and the widest variation of specific humidity and temperature.

As nearly all stations are at different altitudes, it was necessary to convert the reduced pressures to the actual pressure at each station. Reduced pressures were plotted against saturation temperature in an effort to obtain a result which is usable. Table I. includes station pressure, reduced pressure, and saturation temperature occurring at stations within the polar Canadian air mass.

The station pressure was found by the use of the adiabatic chart although conversion tables are easier to use.

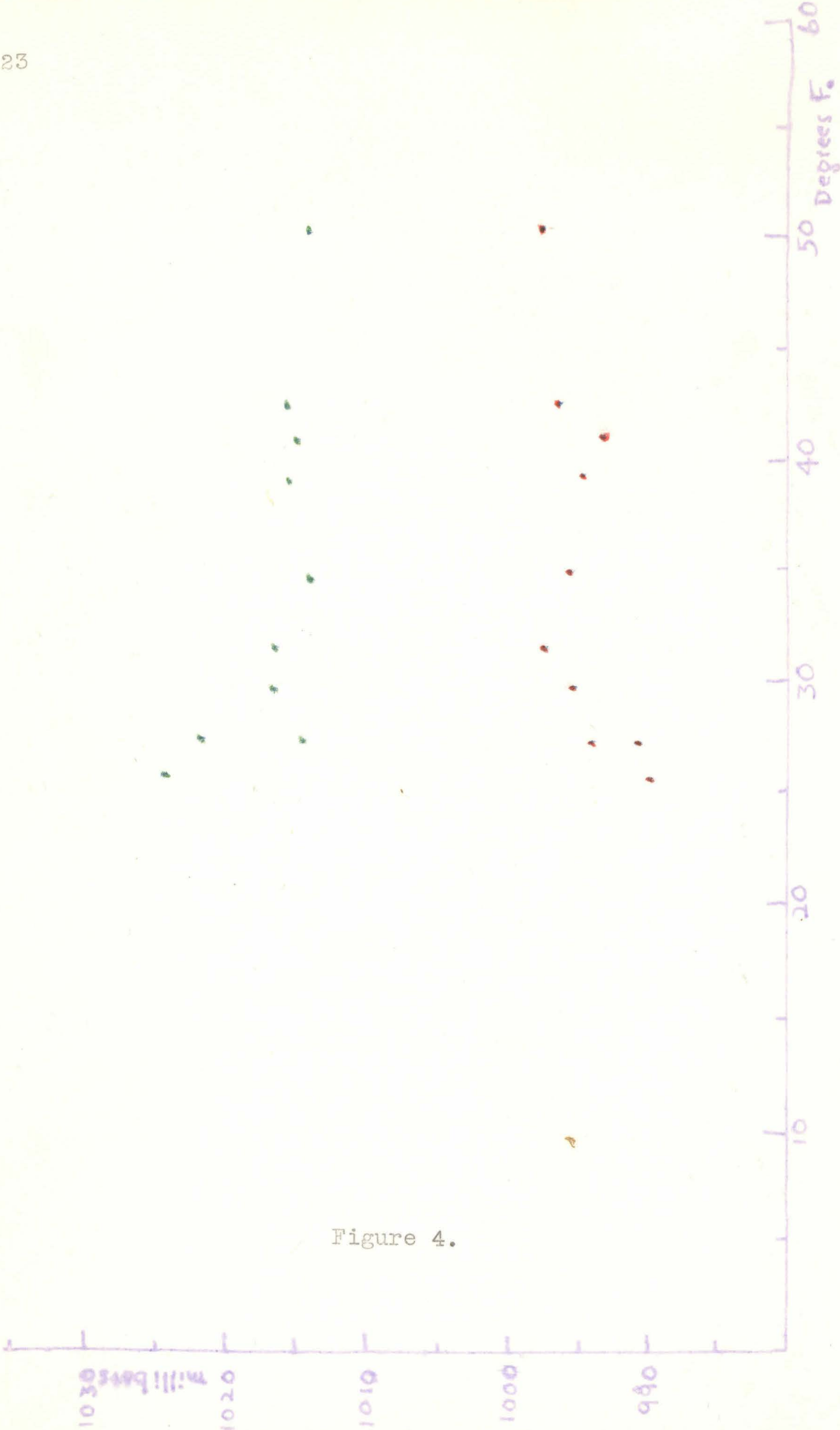


Figure 4.

TABLE 1.

Station	Elevation	Reduced Press.	Station Press.	Sat. Temp.
363	565 meters	1015.2 mb.	945 mb	27° F
662	1080	1024.7	904	26°
465	935	1023.7	913	27
266	575	1016.9	946	41
327	163	1016.6	996	50
423	172	1017.6	997	43
438	232	1019.3	974	32
428	268	1016.6	966	39
524	265	1016.3	966	29
527	360	1014.6	964	34

Table 1. includes the actual pressure existing at the stations during fog conditions.

Figure 4. is plotted from the data in table 1. and shows the fog zone in terms of pressure and saturation temperature. The zone of red shading is the fog zone in terms of station pressure. The region of green shading is the fog zone in terms of reduced pressure. Both regions are continuous and identical except for a shift along the pressure axis. The curves tend to converge in the positive region of temperature. This is due to the fact that the stations in this region were at low elevations. It is significant that a plot of the reduced pressure does not destroy the fog zone but merely shifts it in the pressure field. This indicates that reduced pressures may be used in a determination of the fog zone in the pressure saturation temperature field.

Reduced pressures were used in this investigation in an effort to obtain a result which would make use of the pressures found on the weather chart. This facilitates forecasting as it circumvents the calculation of station pressure from reduced pressure and saves time in making the forecast. This procedure no doubt leads to discrepancies, but the results are quite consistent and warrant the neglect of rigor for more practical methods.

The following abbreviations have been incorporated in the tables, and wherever possible the international weather symbols have been used.

ppp	Barometric pressure in millibars.
TT	Temperature in degrees F.
V	Visibility.
H	Ceiling
aa	Barometric tendency during the past 3 hours.
pp	Amount of barometric change in the past 3 hours.
ww	Present weather.
w	Specific humidity.

V

DATA AND RESULTS

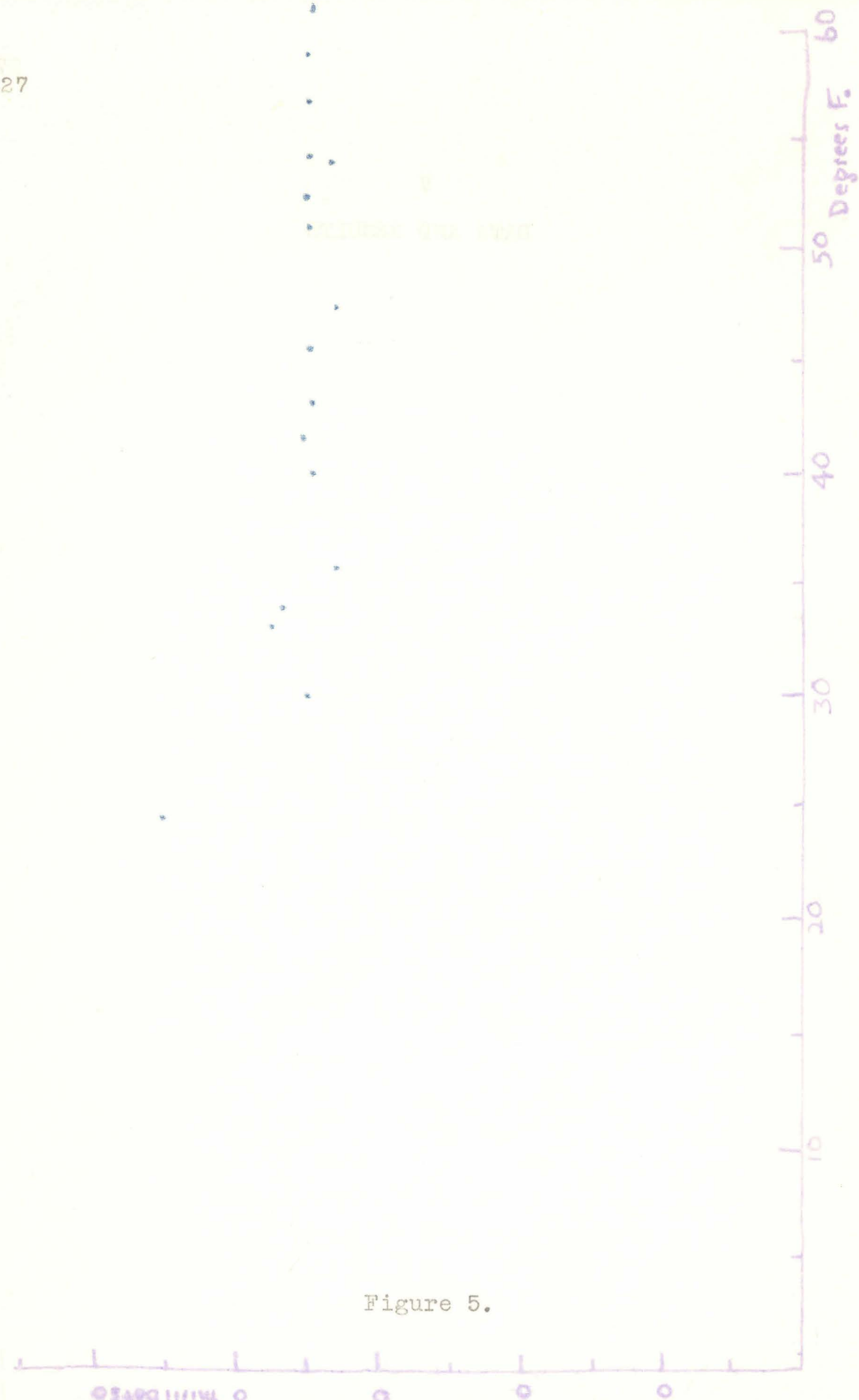


Figure 5.

TABLE 2.

3/24/41

station	PPP	TT	TT'	aapp	V	H	vel	ww
860 Rivers	326	9	9	\-2	U	U	3	⦶
852 winnipeg	332	2	2	/+2	U	U	2	○
842 Sioux Lookout	308	-2	-2	✓+10	U	U	2	○
841 Wagaming	286	5	5	✓+2	U	1500	2	* *
757 Devil's Lake	335	2	2	L-4	0	0	2	≡
669 Lemmon	274	22	22	✓+6	1	800	4	⊕
662 Rapid City	247	26	26	✓+6	0	—	2	≡
563 Sidney	186	34	33	/+6	0	0	4	≡
267 Lubbock	180	43	42	✓+4	1	4000	2	=
266 Abilene	169	41	41	✓+0	0	0	2	≡
249 Sulphur Springs	173	50	50	✓+12	0	U	2	≡
247 Palestine	169	53	51	Γ+12	2	U	2	=
231 New Orleans	163	60	60	✓+8	0	U	2	≡
223 Mobile	163	59	59	✓+4	0	0	2	≡
220 Apalachicola	156	55	55	✓+10	0	U	2	≡
214 Tallahasse	152	56	56	✓+12	0	400	2	≡
210 Ft. Meyers	148	63	63	/+16	0	0	2	≡
327 Nashville	166	50	50	/+10	0	400	2	≡
423 Louisville	176	43	43	✓+8	0	2500	2	≡
438 Indianapolis	193	32	32	/+16	2	8000	3	=
428 Columbus	166	39	39	✓+10	0	0	3	≡
524 Cleveland	163	29	29	/+0	0	U	2	≡
527 Knapp Creek	146	34	34	/+0	1	1500	0	=
317 Greensboro	159	46	46	L-2	1	4000	2	• •

Table 2. includes data taken from the polar Canadian air mass in spring. The fog region is rather extensive and figure 5. shows a definite fog zone.

Figure 6.

TABLE 3.

3/25/41

	Station	PPP	TT	TT'	app	V	H	ww	ww
863	Regina	258	27	27	\-4	0	0	2	≡
892	Vancouver	208	39	39	L-8	2	0	2	≡
793	Seattle	203	39	39	\-14	0	0	2	≡
698	Portland O	186	40	40	L-10	0	0	2	≡
860	Rivers	236	27	26	\-2	5	200	2	=
850	Kenora	210	15	15	\-12	2	U	3	**
842	Sioux Lookout	217	10	10	\-10	10	U	2	⊕
870	Swift Current	251	30	30	/+0	U	4	3	⊕
867	The Pas	254	10	10	/+0	10	U	2	○
878	Penhold	208	30	30	\-8	0	—	2	≡
567	Valentine	271	25	25	L-6	1	800	2	**
563	Sidney Neb	240	22	22	\-6	10	2500	2	**
465	Goodland	237	27	27	\+6	1	200	2	=
469	Denver	2241	22	22	L-6	2	200	2	=
267	Lubbock	125	47	47	L-6	0	0	3	≡
253	San Antonio	132	58	58	V+6	2	1500	2	, ,
251	Corpus Christi	125	60	60	⌐+4	10	1500	3	••
509	Boston	095	36	36	L-4	1	200	2	••
506	Nantucket	074	42	42	\-16	2	800	2	••
608	Eastport	132	33	33	^+2	1	400	3	**
363	Amarillo	152	27	27	\-14	0	0	4	≡
457	Dodge City	210	18	18	L-10	1	0	3	**
220	Charleston	146	47	47	V+10	0	0	2	≡

Table 3. includes data taken from various regions of North America. The conditions under which fog formed varied greatly, but figure 6. shows a rather definite zone of fog formation.

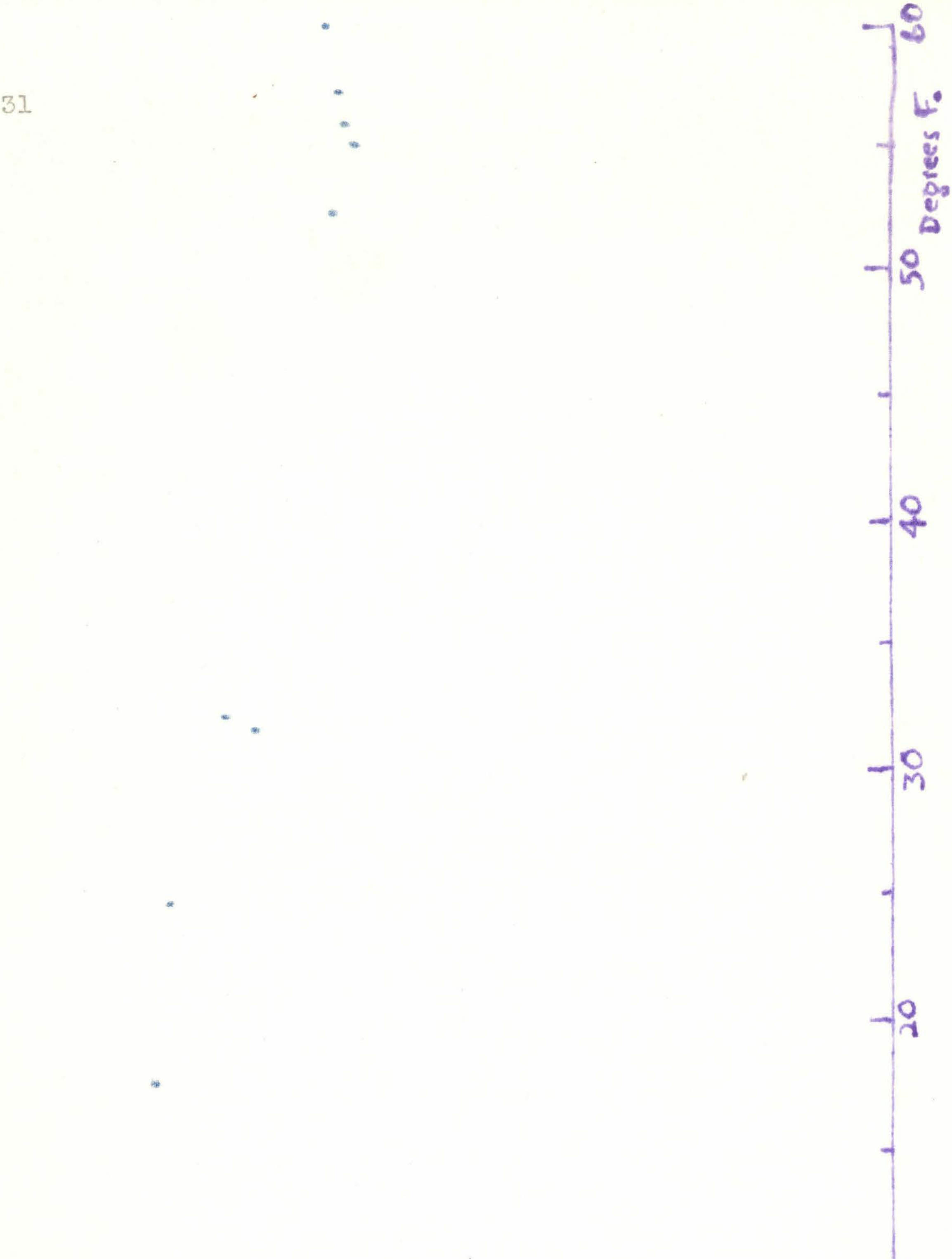


Figure 7.

TABLE 4.

3/23/41

Station	PPP	TT	TT'	aapp	V	H	vel	ww
340 Littlerock	156	52	52	/+2	1	—	2	••
334 Memphis	156	54	54	/+0	5	800	2	,,
465 Goodland	193	33	33	L-6	1	200	3	≡•
662 Rapid City	251	24	24	L-2	0	0	3	≡
863 Regina	320	7	7	✓+2	0	0	2	≡
253 San Antonio	152	50	50	✓+6	10	·v	3	Φ
206 Jacksonville	180	59	59	✓+6	5	—	2	=
223 Mobile	166	57	57	✓+10	0	0	2	≡
568 Chadron	156	43	43	✓+6	v	v	2	○
757 Devils Lake	295	7	7	✓+4	v	v	2	○
878 Penhold	247	32	32	/+8	1	1500	2	**
842 Sioux Lookout	284	15	15	✓+10	v	v	4	**
877 Calgary	233	32	32	/+18	1	0	3	≡*
852 Winnipeg	320	7	7	✓+2	0	0	2	≡
242 Galveston	149	56	55	✓+6	0	v	2	=
231 New Orleans	154	54	53	✓+8	0	v	2	|≡
771 Livingston	183	26	26	✓+4	2	—	5	|≡
571 Craig	105	32	32	\-10	0	0	2	⁂

Table 4. also is taken from the polar Canadian air mass. Fog extended into the gulf states and the air mass in this region could be called returning polar Canadian. Again, figure 7. shows a definite fog zone.

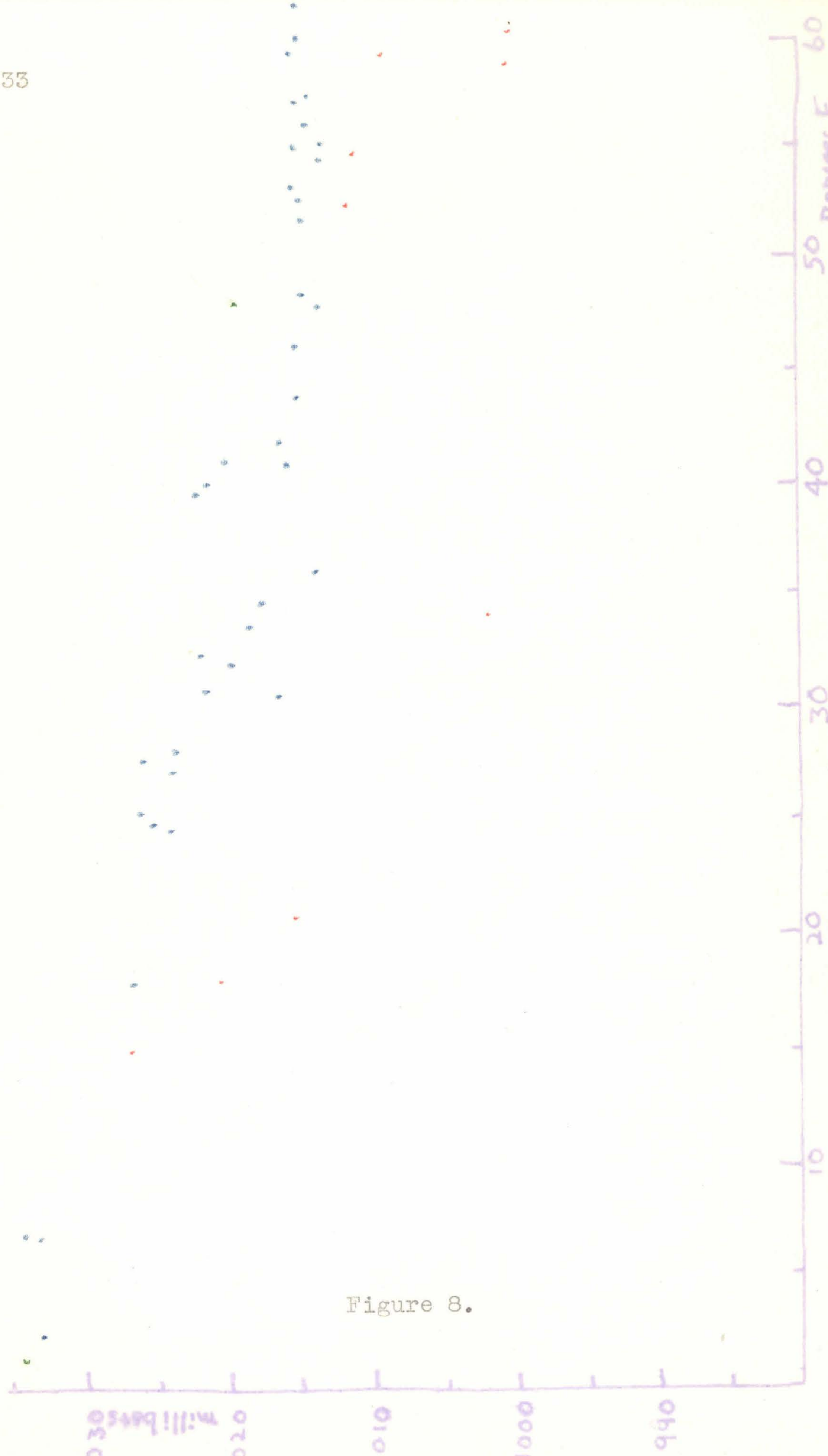


Figure 8.

1. The Graphical Form of the Fog Zone in the Polar Canadian Air Mass.

Figure 8. is a composite of the data included in tables 2, 3, and 4. This figure was constructed from data found on different days and at different places within the polar Canadian air mass. A further check of the values of pressure and dew point favorable to fog formation was made for a great many cases. It was found that the fog zone shaded in green in figure 8. was valid in nearly every case. If the point in question lies to either side of the fog zone, no fog will form at the station. If the pressure and dew point lie above the fog zone, there will be no fog although the temperature and dew point approach each other. The points plotted in green in figure 8. show this condition. Clear skies should be forecast for such a condition. If the pressure and temperature point lies below the fog zone in figure 8., fog will not form; but precipitation may be expected. This is shown by the points plotted in red in figure 8. If the point lies within the zone of fog in figure 8., a prediction of fog will very likely verify.

2. Application to the Synoptic Situation.

On March 3, 1941 and April 9, 1941, a forecast of fog was made for the great plains area of the United States. This forecast was based upon the expected pressures and dew points being located within the fog zone of figure 8. The day the forecast was made no fog existed in the Polar Canadian air mass. The following day, the fog area was general and wide spread. The pressures and dew points of the stations having visibility restrictions were within the critical values indicated in figure 8.

Another case of successful forecasting by the use of figure 8. is that of Seattle, Washington on March 23, 1941. A high pressure cell was moving toward Seattle from the West. A forecast of clear was made with the expectation that the pressure would be greater than 1028 millibars at map time. The pressure reached 1029.1 millibars and no fog appeared at Seattle. As the high passed over Seattle, fog was forecast when the pressure became less than 1028 millibars. On March 25, the pressure at Seattle was 1027.8 millibars and the dew point 37 degrees F. Fog verified. No fog was predicted for March 26, and the pressure dropped to 1012.5 millibars with a dew point of 47 degrees.

It is significant that figure 8., which was developed from fog conditions in the polar Canadian air mass, should apply to conditions of fog formation at Seattle.

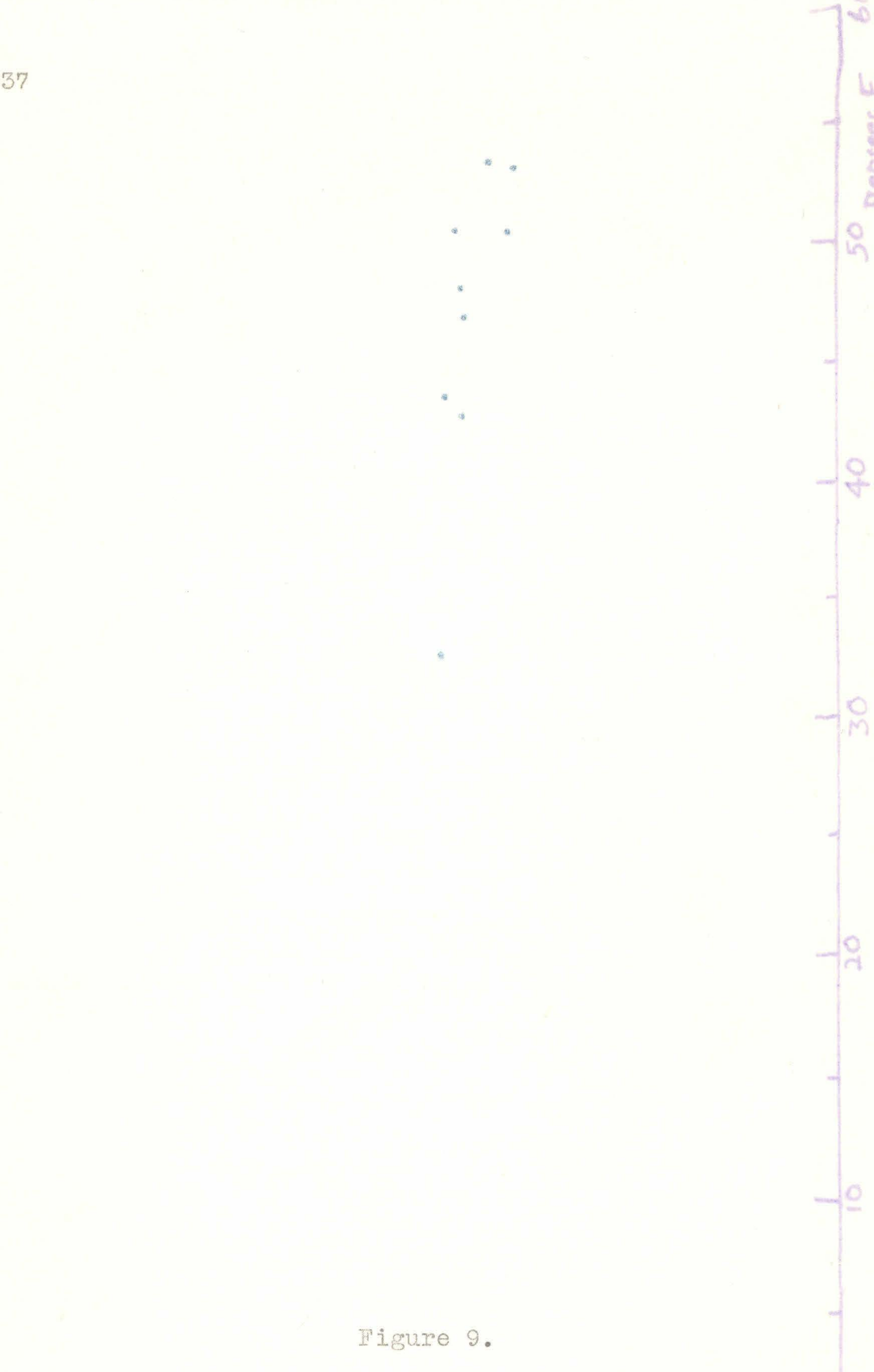


Figure 9.

Table 5.

4/18/41

station		PPP	TT	TT'	aaPP	V	H	vel	WW
745	Duluth	095	43	43	✓+6	0	0	0	≡
751	Alexandria	074	47	47	✓+0	0	—	0	≡
653	Springfield	064	46	46	\-4	0	0	2	|≡
654	Huron	078	42	41	⌉-2	0	0	4	≡
567	Valentine	085	32	32	⌐+2	—	2500	4	••
557	Sioux City	034	52	49	L-24	5	800	4	=
546	Des moines	054	53	53	⌐+2	0	0	3	≡
451	Dodge City	003	49	49	✓+10	0	0	3	|≡

4/22/41

645	Green Bay	132	40	39	✓+4	1	—	3	≡
640	Milwaukee	149	41	41	✓+4	0	0	3	≡
534	Chicago	159	46	43	✓+16	2	500	5	=
546	Desmoines	095	48	48	L-4	0	0	4	|≡

Table 5. includes data taken from fog conditions existing within a cyclone.

3. Prefrontal Fog.

Prefrontal fog which is found at low values of pressure in cyclones is instructive. In most cases it is necessary for the temperature to reach the dew point at the ground in order that a fog may form. The fog zone as outlined in figure 8. is still continuous, and is located within a restricted pressure and temperature range. Unstable conditions existing within the cyclone may cause the specific humidity to vary greatly. This will cause the zone in figure 8. to become quite thick and poorly defined.

In the cyclone, temperature drops due to nocturnal cooling are restricted by extensive cloud decks and the diurnal variation of temperature is small. Fogs have been known to form beneath such cloud decks and are accompanied by substantial drops in pressure. Any pressure drop is accompanied by an adiabatic expansion and cooling. This temperature change is small, being of the order of one degree C. for every 10 millibars change of pressure. The combined effect of radiative cooling may be sufficient to bring the temperature to the saturation point at the ground. Prefrontal rain is another factor which tends to produce fog. The effect of the rain is to produce greater values of specific humidity near the ground.

VI

CONCLUSION

The investigation of the problem of fog formation was made from the fundamental idea of a corrected equation of state. Van der Waals' equation was assumed to apply to a mixture of water vapor and atmospheric gases. As the pressure and saturation temperature were conservative within the equilibrium dome of the Van der Waal diagram, it was thought that this dome could be reduced to a line by changing the coordinates from pressure and volume to pressure and saturation temperature.

It was found that a definite zone within a pressure saturation temperature field was necessary to produce fog, and the location of this narrow zone was attempted for atmospheric conditions.

The definite zone of pressure and dew point exists and was found to be condusive to fog formation in high pressure cells. The limiting values of pressure and saturation have been determined in figure 8.

It was also found that prefrontal fog could be formed from a drop in pressure and the accompanying adiabatic expansion and cooling throughout the atmosphere.

The fog zone found in figure 8. applies to prefrontal fog, but the instability conditions within the cyclone causes a wide variation of specific humidity. This variation of specific humidity causes the fog zone to become poorly defined.

As a general conclusion, it may be stated that for the production of a radiative fog, pressure and dew point must be within certain critical limits. These limits are determined in figure 8. The specific humidity distribution must be continuous. The surface wind must be below 10 miles per hour to prevent turbulence and the destruction of the temperature inversion and a lowering of the specific humidity near the ground.

Further Problems Which May Be Developed.

Theoretically, the fog zone in a pressure saturation temperature field should be a line. The finite width of the zone in figure 8. may be due to the hygroscopic properties of the nuclei necessary for fog formation. A measure of the width of the fog zone may be used as a measure of the hygroscopic properties of these nuclei.

VII

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VIII

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