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THE AIR & ITS WAYS

THE REDE LECTURE (1921) IN THE UNIVERSITY OF CAMBRIDGE, WITH OTHER CONTRIBUTIONS TO METEOROLOGY FOR SCHOOLS AND COLLEGES

BY

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PREFACE

FROM time to time I have been asked by students who are also school-masters or mistresses whether I consider the commonly received explanation on physical principles of the general circulation of the atmosphere, as it has appeared for many years in text-books of physical geography, to be a satisfactory representation of the state of our knowledge of the atmosphere in the twentieth century. Hitherto my reply could only be that I had said what seemed to me to be worth saying on the subject in various lectures, and that some day if possible I would offer the text of the lectures as the best answer which I could give to the question.

Accordingly I have put together a number of lectures and essays that dealt with the physical explanation of the atmospheric circulation and to those I have added some papers designed to set out the present position of the application of meteorology to agriculture: a subject, like that of the general circulation of the atmosphere, of perennial interest not only to meteorologists but to all who have to think about the air and its ways.

Lectures and addresses on meteorological subjects are always easy to make and sometimes interesting to hear. Curiosity about the subject is universal and spontaneous. It requires little adroitness on the part of the lecturer to stimulate the curiosity about the mutual connexion of events, which we call "explanations." Illustrations abound and they are easily expressed in maps and photographs. In the course of the daily work at the Meteorological Office they accumulated faster than the opportunities for displaying them. But it requires a good deal of courage to take the next step and publish a collection of lectures on meteorological subjects, because the illustrations, which are the lecturer's fairy godmother, are the publisher's *bête-noire* and the author's despair.

There has been, therefore, a good deal of hesitation behind the production of this volume. The text is necessarily woven round illustrations which are used over and over again; prudence demands

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that publication should be deferred until there is some reasonable balance between text and pictures. It is hoped that the accumulation in this book will satisfy that condition. It is not a text-book: it shows the subject of meteorology in its work-day clothes with loose or missing buttons here and there, and the tailoring not always perfect. But for the workman a lecture is a useful opportunity of "trying on" and I hope the reader will accept this collection of essays with the amiability that becomes that operation.

My collection is not by any means homogeneous. It rambles from climatology to physics and dynamics and back again to agriculture; the main current of such thought as there is in it is the bringing of the ascertained and coordinated facts about the weather into relation with each other and thereby with the laws and principles of physics. In this connexion three new meteorological principles are introduced to the reader as inductively justified. First, the motion of air under balanced forces as a more effective representation of actual conditions than any which we can substitute for it by observation or by theory. Secondly, the "eviction" of air by the turbulent motion between rising air and its environment as an inevitable concomitant of convexion. Thirdly, the effective stratification of successive layers of air in consequence of the "resilience" which they owe to the excess of their temperature over that which corresponds with unlimited miscibility, and the limitations of convexion which are due thereto. This principle, which carries some sort of analogy to the effect of steel rods in "reinforcing" concrete, involves some recondite ideas about potential temperature or entropy which the gentle reader must be good enough to think about as part of the natural order.

These three principles come into various theoretical and practical considerations. The introduction of the first in 1913, so far as my own experience is concerned, has created little less than a revolution in my meteorological world. Things live and move; previously they were tethered by an indefinite attachment, and paralysed by an unknown quantity which blocked every avenue: it is the dominant note of the Halley Lecture of 1918. The second is, so far as I know, entirely new and has already opened up new possibilities. The third

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simply brings into definite form ideas which have been drifting loosely in meteorological literature for many years. Its definition will I hope lead in course of time to satisfactory evidence for the process of development of high pressures the formation of which has hitherto been unexplored.

The remaining essays are less ambitious from the scientific point of view and are intended to represent certain aspects of modern meteorology as a subject of interest to the general reader. But another new principle is visible in the work on wheat-crops, namely that plants and the soil in which they grow have long memories and the resulting crop depends upon the conditions of long ago as well as those of yesterday.

In the preparation of the work and of the original lectures upon which it is based I owe much to the assistance of Miss E. E. Austin, of Newnham College, who was my personal assistant for two years at the Meteorological Office, and has been seconded by the Air Ministry to help me in my work at the Imperial College.

I have also to record my thanks to the Controller of H.M. Stationery Office for permission to reproduce Figs. 1, 2, 22, 33, 39, 58–60, 74 and 97, taken from official publications of the Meteorological Office, and to the Director of the Meteorological Office for the loan of blocks for Figs. 1, 2, 23, 66 and 74. The material for Figs. 34 (*a*) and (*b*) is also derived from official publications of the Meteorological Office.

Thanks are also due to the Royal Meteorological Society for permission to reprint Papers 1 and 3 from the *Quarterly Journal*, and for the loan of blocks for Figs. 3, 4, 5 and 65; to Captain C. J. P. Cave for the original negatives or prints of the cloud photographs reproduced in Figs. 6–12, and for the loan of blocks for Figs. 99 and 100; to Major G. M. B. Dobson for permission to reproduce Fig. 65; to the proprietors of *The Times* for permission to reprint the paper on "The Drought of 1921"; and to the Mount Everest Committee for permission to reproduce the photograph of Mount Everest in Fig. 79.

Some maps and other original illustrations are common to this publication and also to the *Dictionary of Applied Physics* edited by

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Sir Richard Glazebrook, published by Macmillan and Co., Ltd., where they appear in the article on "Thermodynamics of the Atmosphere."

The maps of mean rainfall (Figs. 16, 17 and 71), mean temperature (Figs. 18–21), mean cloudiness (Figs. 69, 70) have been taken from those compiled by Mr C. E. P. Brooks, with the assistance of the division of the Meteorological Office for the Réseau Mondial, for the *Manual of Meteorology* which is still in hand; the maps of dew-point (Figs. 51–54) are drawn from data extracted by that division.

For Fig. 13, Contessa del Vento, I owe my thanks to the cloud-atlas of Signor L. Taffara of the R. Ufficio Centrale di Meteorologia e Geodinamica.

For the reading of the proofs my thanks are due also to Captain D. Brunt of the Meteorological Office, and I carry forward a sense of personal obligation to Mr J. B. Peace, a College friend of long standing, for the trouble which he has taken in arranging the material here presented; and to the staff of the Cambridge University Press for the skill and patience by which they have succeeded in making a book out of a collection of fragments.

NAPIER SHAW

SCHOOL OF METEOROLOGY,
IMPERIAL COLLEGE OF SCIENCE AND TECHNOLOGY,
June, 1922.

POSTSCRIPT

On the evening of January 30, 1923, while my story of *The Air and its Ways* was in the press, Mr Peace's friendly guidance was suddenly terminated by his untimely death. The result of our joint work, which was intended to be a preliminary example, now becomes a grateful memory of the helpfulness which was characteristic of his life.

N. S.

February 23, 1923

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THE NORMAL DISTRIBUTION OF THE METEOROLOGICAL ELEMENTS OVER THE GLOBE

PLATES I–XXIV

The Plates which are inserted here are representative examples of the distribution of the meteorological elements over the globe, to which reference is made in many places in illustration of the lectures and essays which they precede. Together with the winds of Figs. 72 and 73 and the vertical sectional diagrams represented in Figs. 47, 55, 56, 57 and 68, they are working diagrams of the normal state of the atmosphere for the student of meteorology. In the standard meteorological scheme the month is the unit of time, and, for the work of a student, charts for each month are necessary. Those which appear here are selected as specimens from a series prepared for Part I of the *Manual of Meteorology*.

It must be remarked that the representation of the earth's surface by two circles, which is employed here, is not in accordance with any rule of geometrical projection, and the result ought therefore to be called a diagram and not a map. The method has its disadvantages but in the present examples they are less conspicuous than its advantages.

Plates I to III	represent the distribution of	rainfall.
,, IV to VII	,, ,, ,,	temperature.
,, VIII to XI	,, ,, ,,	dew-point.
,, XII and XIII	,, ,, ,,	cloud.
,, XIV to XVII	,, ,, ,,	pressure at 4000 metres.
,, XVIII } ,, XIX	,, ,, ,,	{ pressure at 8000 metres. ,, of the lower stratum.
,, XX to XXIII	,, ,, ,,	pressure at sea-level.
,, XXIV	represents the normal resultant-flow of air.	

*** The "M.O. compilation" upon which the lines of the chart on the opposite page are based is that which is referred to on p. viii of the preface to this volume as carried out in the Meteorological Office for Part I of the *Manual of Meteorology*. The same abbreviation is used in quoting the authority for other charts in the same category.

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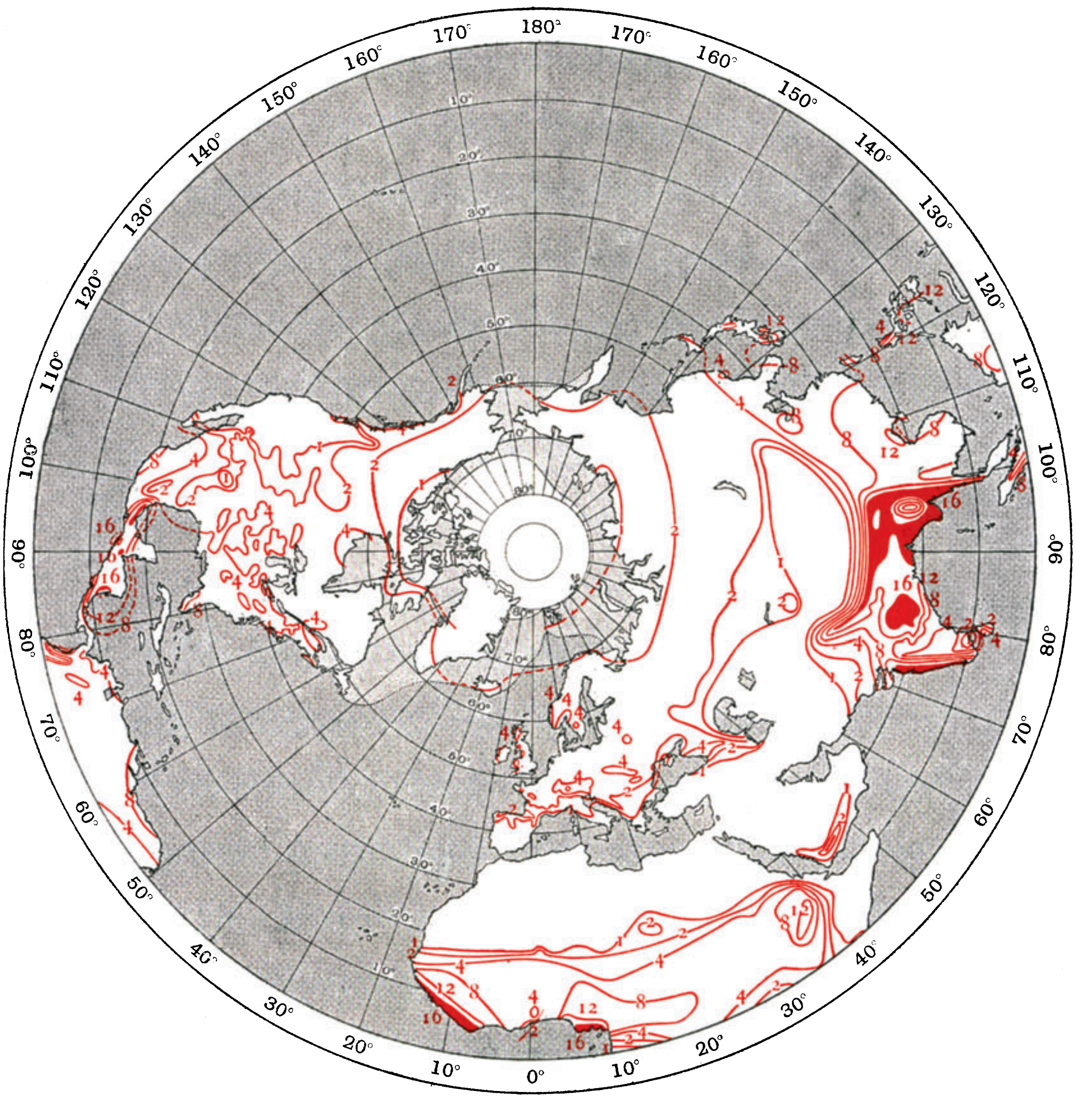
JULY

RAINFALL IN THE NORTHERN HEMISPHERE — PLATE I

Authority: M.O. compilation. — *Reference to text*, p. 143.



Isohyets—lines of equal rainfall—are drawn for:

1 inch 25 millimetres	4 inches 102 millimetres	12 inches 305 millimetres
2 inches 51 „	8 „ 203 „	16 „ 406 „

The areas over which the rainfall exceeds 16 inches are filled in

Fig. 71. Normal rainfall in July over the northern hemisphere: in inches.

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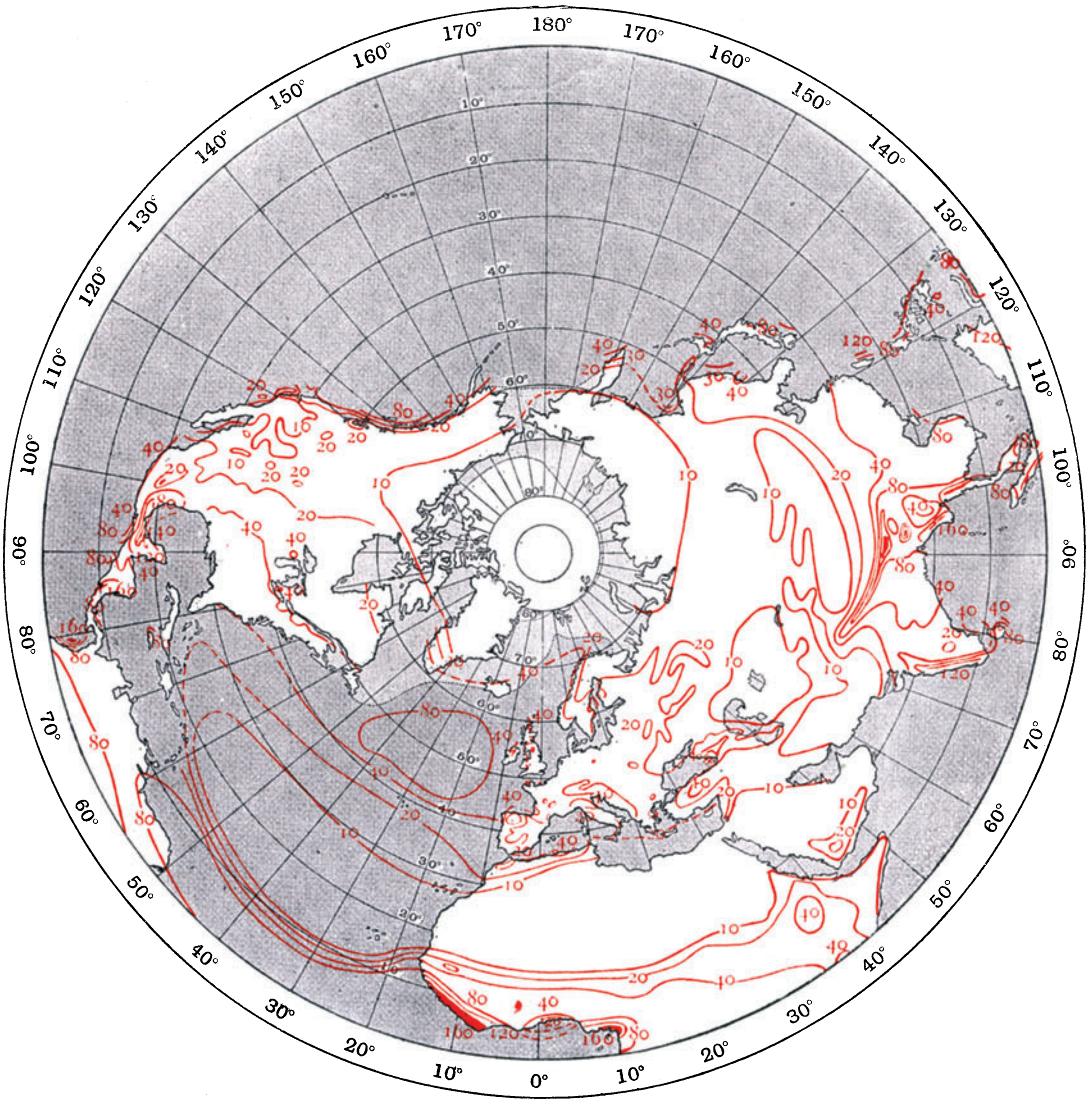
PLATE II

Reference to text, p. 37.

ANNUAL RAINFALL IN THE NORTHERN HEMISPHERE

Authority: for the land, M.O. compilation; for the sea, Prof. Supan.



Isohyets—lines of equal rainfall—are drawn for:		
10 inches 254 millimetres	40 inches 1016 millimetres	120 inches 3048 millimetres
20 ,, 508 ,,	80 ,, 2032 ,,	160 ,, 4064 ,,
The areas over which the rainfall exceeds 160 inches are filled in		

Fig. 16. Normal rainfall for the year over the northern hemisphere: in inches.

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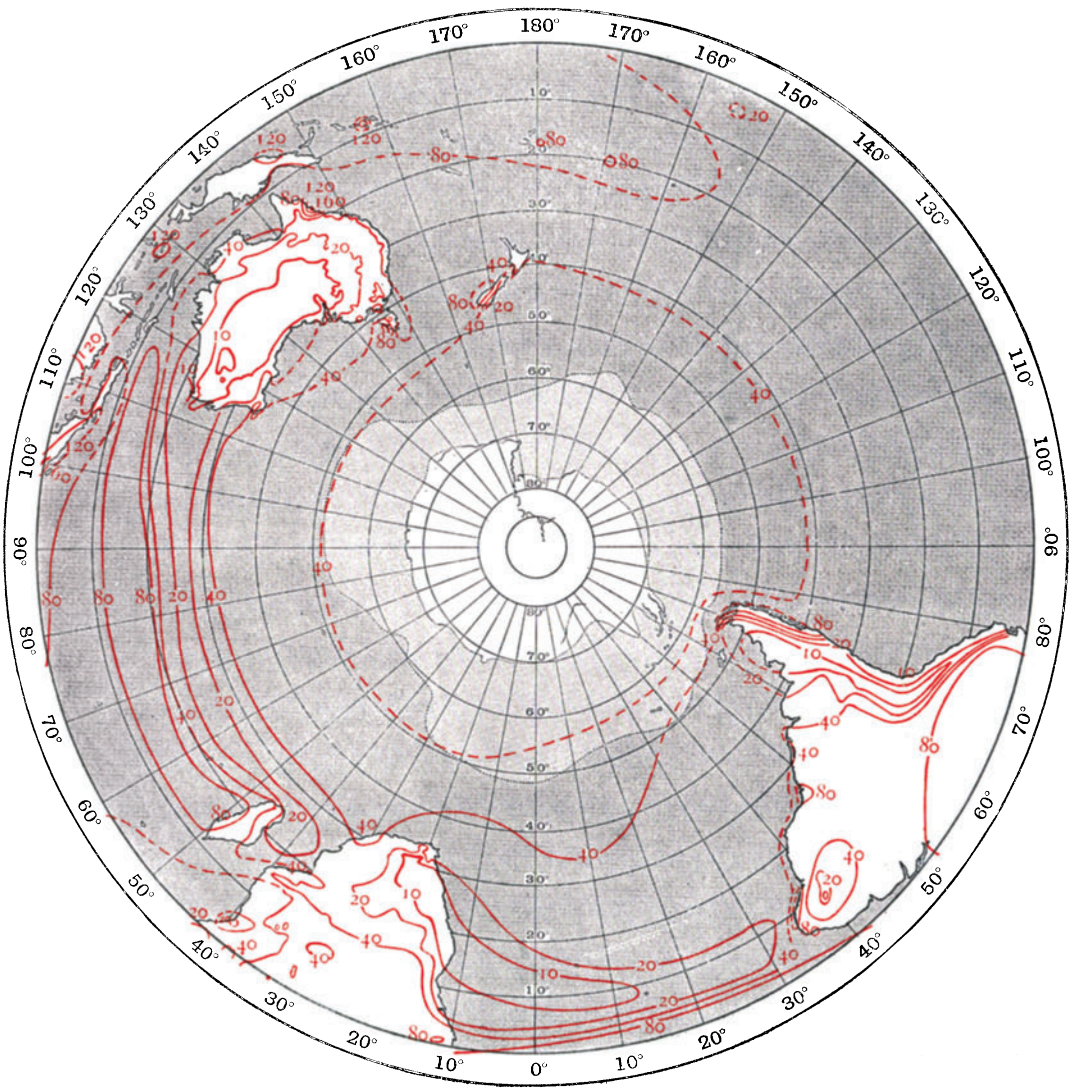
Authority: for the land, M.O. compilation; for the sea, Prof. Supan. *Reference to text*, p. 37.



Isohyets—lines of equal rainfall—are drawn for:

10 inches 254 millimetres
20 „ 508 „

40 inches 1016 millimetres
80 „ 2032 „

120 inches 3048 millimetres
160 „ 4064 „

The areas over which the rainfall exceeds 160 inches are filled in

Fig. 17. Normal rainfall for the year over the southern hemisphere: in inches.

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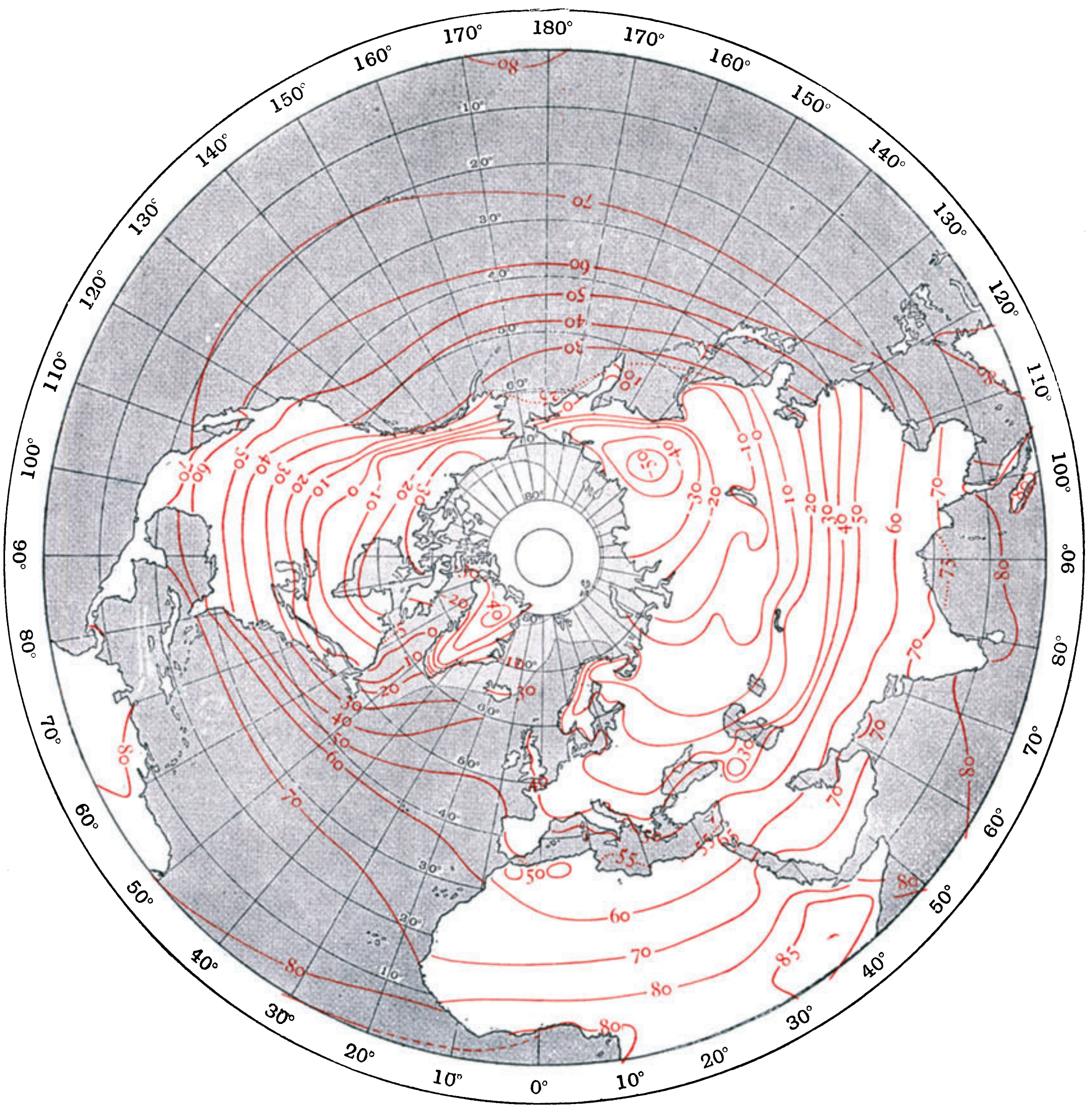
PLATE IV MEAN TEMPERATURE OF THE AIR AT SEA-LEVEL, NORTHERN HEMISPHERE

Reference to text, pp. 37, 120, 141. *Authority:* M.O. compilation.



Equivalents below 30° F			
°F	a	°F	a
− 50	227·4	− 10	249·7
− 40	233·0	0	255·2
− 30	238·6	10	260·8
− 20	244·1	20	266·3

The more lightly shaded area in the polar regions marks the probable range of ice between summer and winter.

Isotherms over land are plotted independently of those over sea. Temperatures over land have been reduced to sea-level.

Equivalents above 30° F			
°F	a	°F	a
30	271·9	60	288·6
32	273·0	70	294·1
40	277·4	80	299·7
50	283·0	90	305·2

The run of the isotherm of 80° in the equatorial region of the Pacific Ocean is not yet fully ascertained.

Fig. 18. Normal mean temperature of the air over the northern hemisphere in January: isotherms for steps of ten degrees of the Fahrenheit scale.

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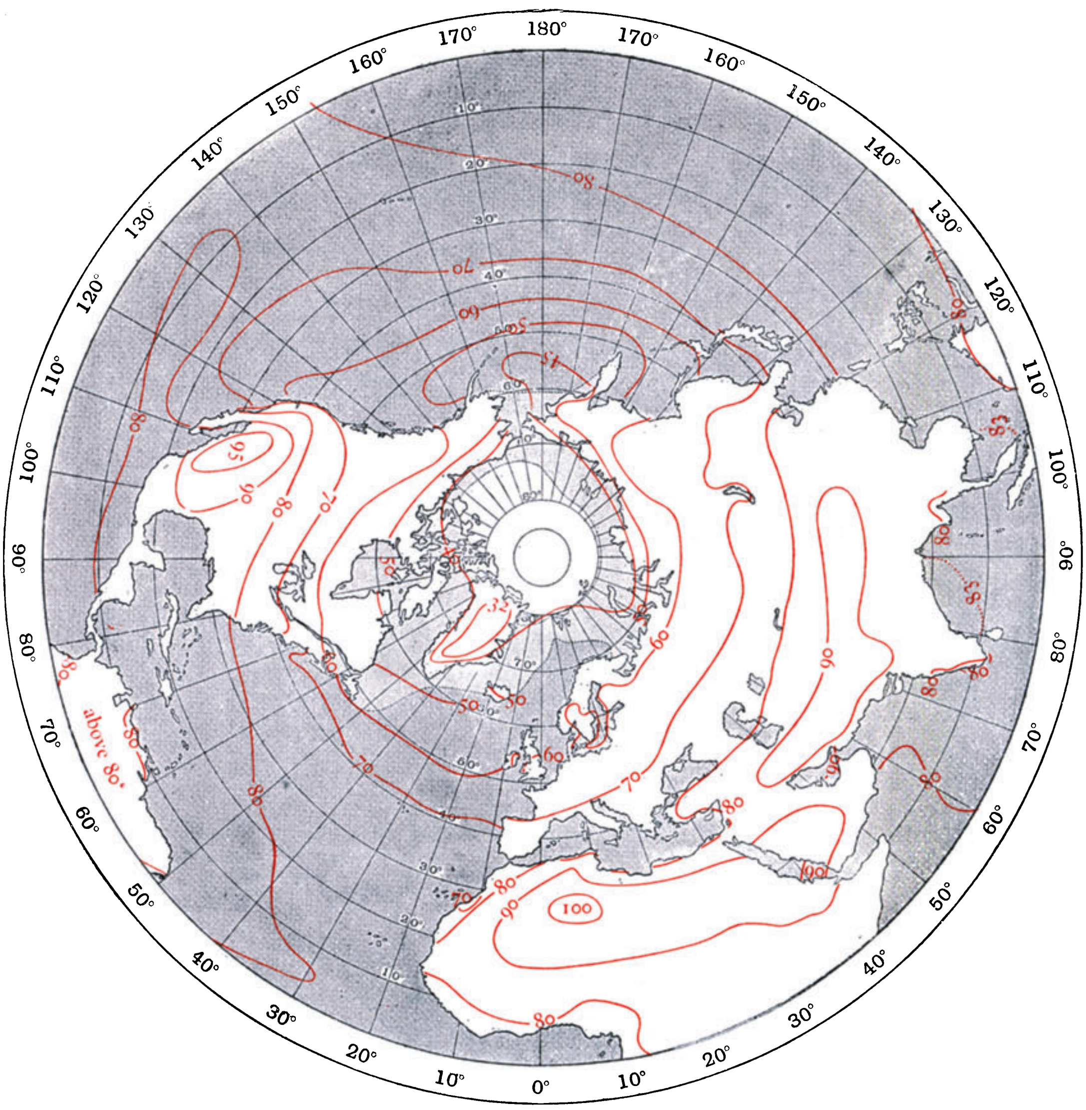
JULY

MEAN TEMPERATURE OF THE AIR AT SEA-LEVEL, NORTHERN HEMISPHERE PLATE V

Authority: M.O. compilation. *Reference to text*, pp. 37, 120, 141.



Equivalents

°F	a	°F	a
32	273·0	50	283·0
40	277·4	60	288·6

The unshaded area round the north pole marks the probable limit of field-ice in the northern summer.

Isotherms over the sea are plotted independently of those over the land. Temperatures over land have been reduced to sea-level.

Equivalents

°F	a	°F	a
70	294·1	90	305·2
80	299·7	100	310·8

Fig. 19. Normal mean temperature of the air over the northern hemisphere in July: isotherms for steps of ten degrees of the Fahrenheit scale.

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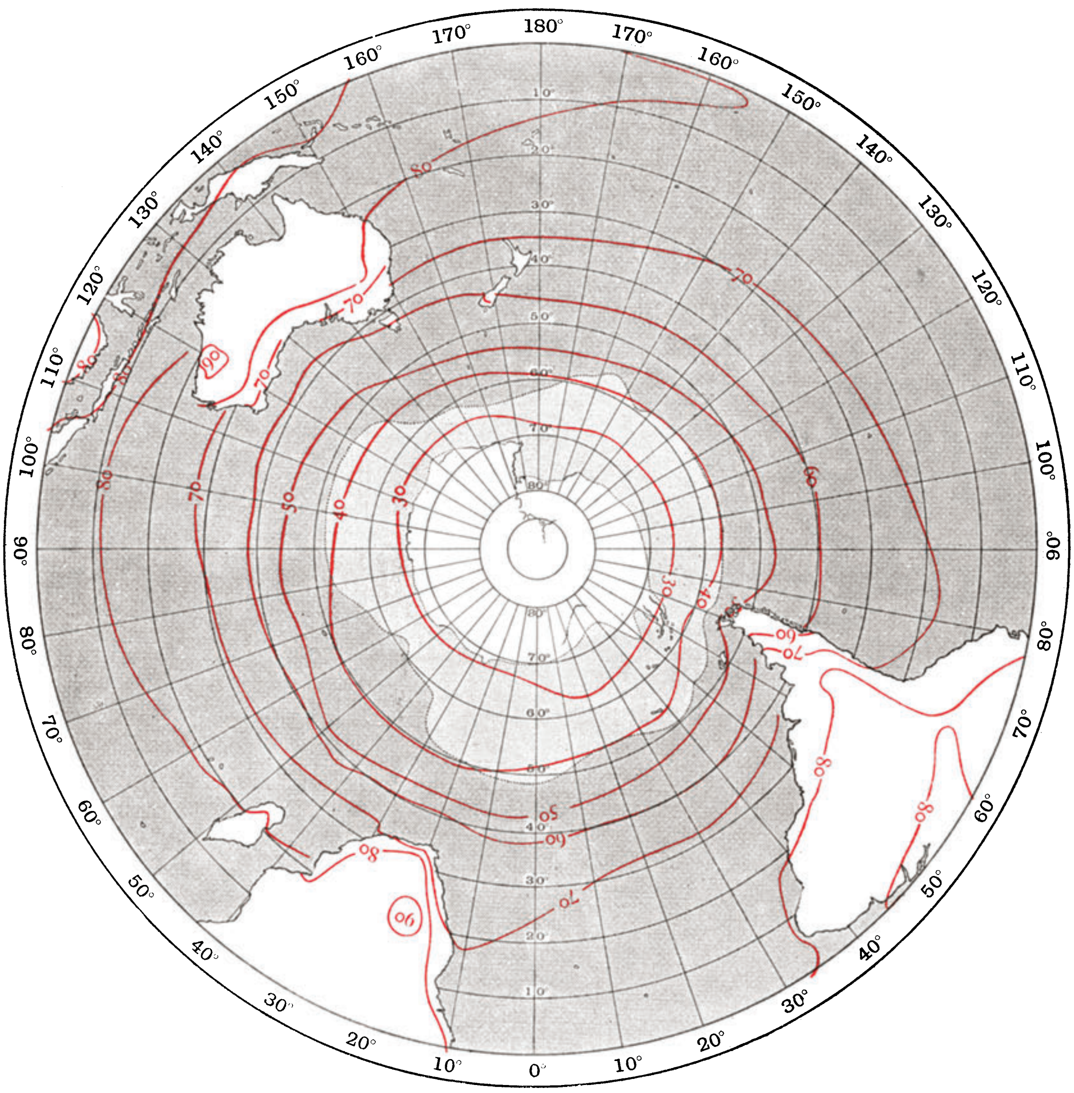
PLATE VI MEAN TEMPERATURE OF THE AIR AT SEA-LEVEL, SOUTHERN HEMISPHERE

Reference to text, pp. 37, 120, 141. *Authority:* M.O. compilation.



Equivalents

°F	a	°F	a
30	271·9	40	277·4
32	273·0	50	283·0

The unshaded area round the south pole marks the probable limit of field-ice in the southern summer.

Isotherms over the sea are plotted independently of those over the land. Temperatures over land have been reduced to sea-level.

Equivalents

°F	a	°F	a
60	288·6	80	299·7
70	294·1	90	305·2

The run of the isotherms in the equatorial region of the Pacific Ocean is not yet fully ascertained.

Fig. 20. Normal mean temperature of the air over the southern hemisphere in January: isotherms for steps of ten degrees of the Fahrenheit scale.

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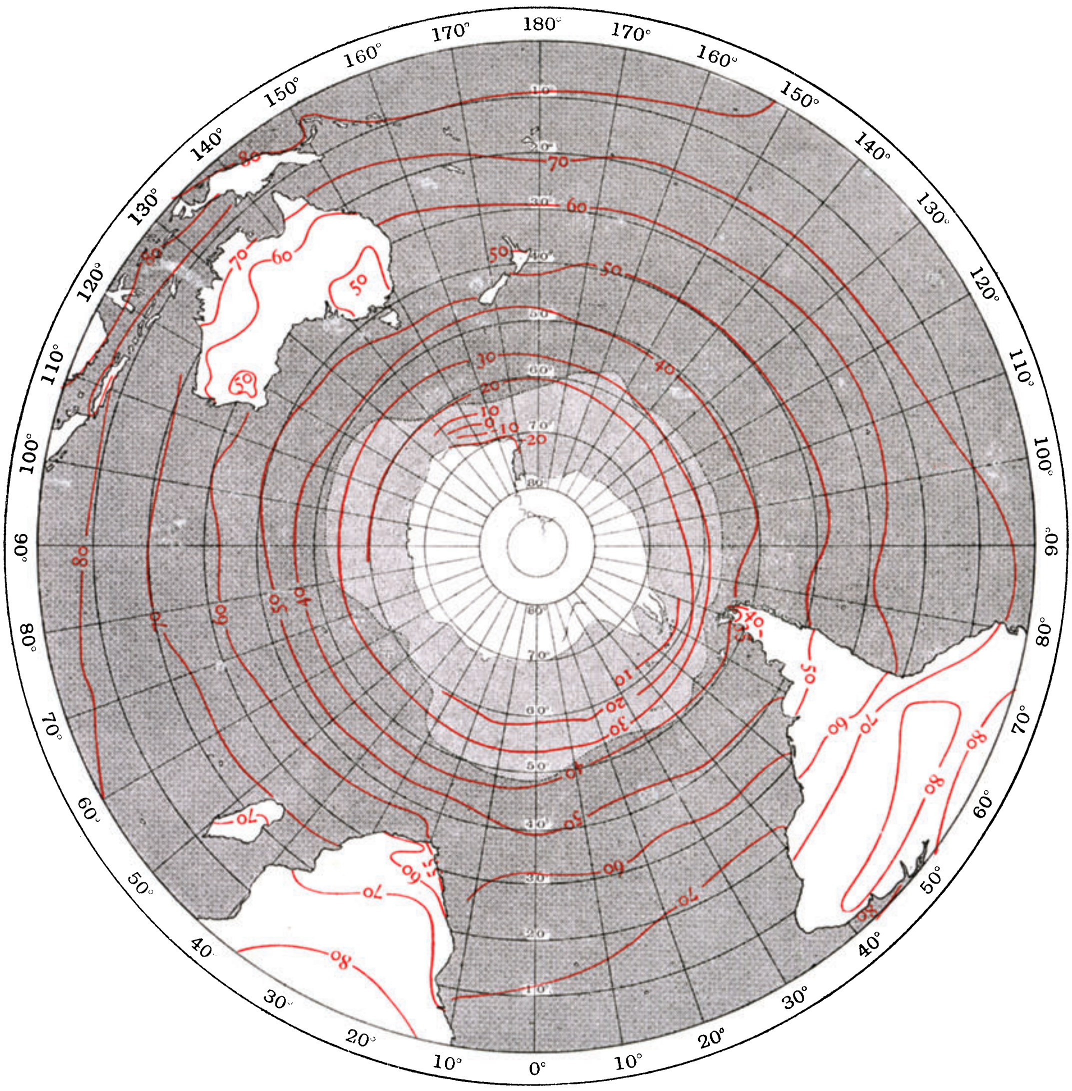
MEAN TEMPERATURE OF THE AIR AT SEA-LEVEL, SOUTHERN HEMISPHERE PLATE VII

Authority: M.O. compilation. *Reference to text*, pp. 37, 120, 141.



Equivalents

°F	a	°F	a
−20	244·1	20	266·3
−10	249·7	30	271·9
0	255·2	32	273·0
10	260·8	35	274·7

The more lightly shaded area in the polar region marks the probable range of the polar ice between summer and winter.

Isotherms over the sea are plotted independently of those over the land. Temperatures over the land are reduced to sea-level.

Equivalents

°F	a	°F	a
40	277·4	60	288·6
50	283·0	70	294·1
55	285·8	80	299·7

Fig. 21. Normal mean temperature of the air over the southern hemisphere in July: isotherms generally for steps of ten degrees of the Fahrenheit scale.

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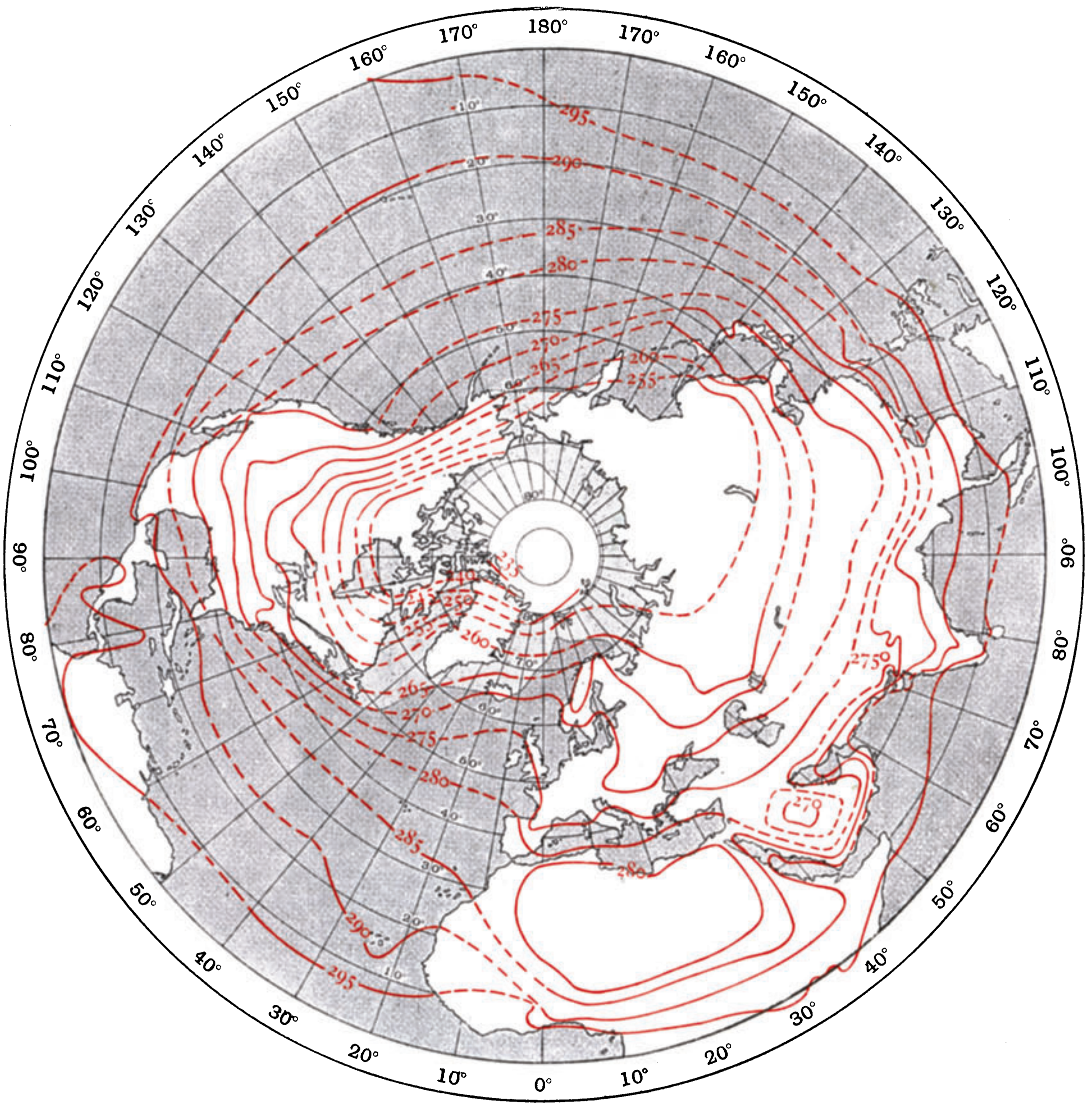
PLATE VIII MEAN DEW-POINT OF THE AIR AT SEA-LEVEL, NORTHERN HEMISPHERE

Reference to text, pp. 120, 141. *Authority:* Original compilation.



Equivalent pressure of aqueous vapour and of density at saturation

Dew-point	Vapour-pressure	Vapour-density
a	mb	g/m³
235	0·16	0·15
240	0·28	0·25
245	0·47	0·42
250	0·78	0·67
255	1·27	1·08
260	1·99	1·66
265	3·10	2·54

The mean dew-point has been obtained from the mean vapour-pressure at the several observatories and stations after reduction to sea-level by the formula:

$$e_0 = e_h\,(1 + \cdot 0004h),$$

where h is the height of the observatory in metres.

Equivalent pressure of aqueous vapour and of density at saturation

Dew-point	Vapour-pressure	Vapour-density
a	mb	g/m³
270	4·8	3·9
273	6·1	4·9
275	7·1	5·6
280	10·0	7·8
285	14·1	10·7
290	19·4	14·5
295	26·5	19·5

Fig. 51. Normal mean temperature of saturation, dew-point or cloud-temperature of the air at sea-level over the northern hemisphere in January.

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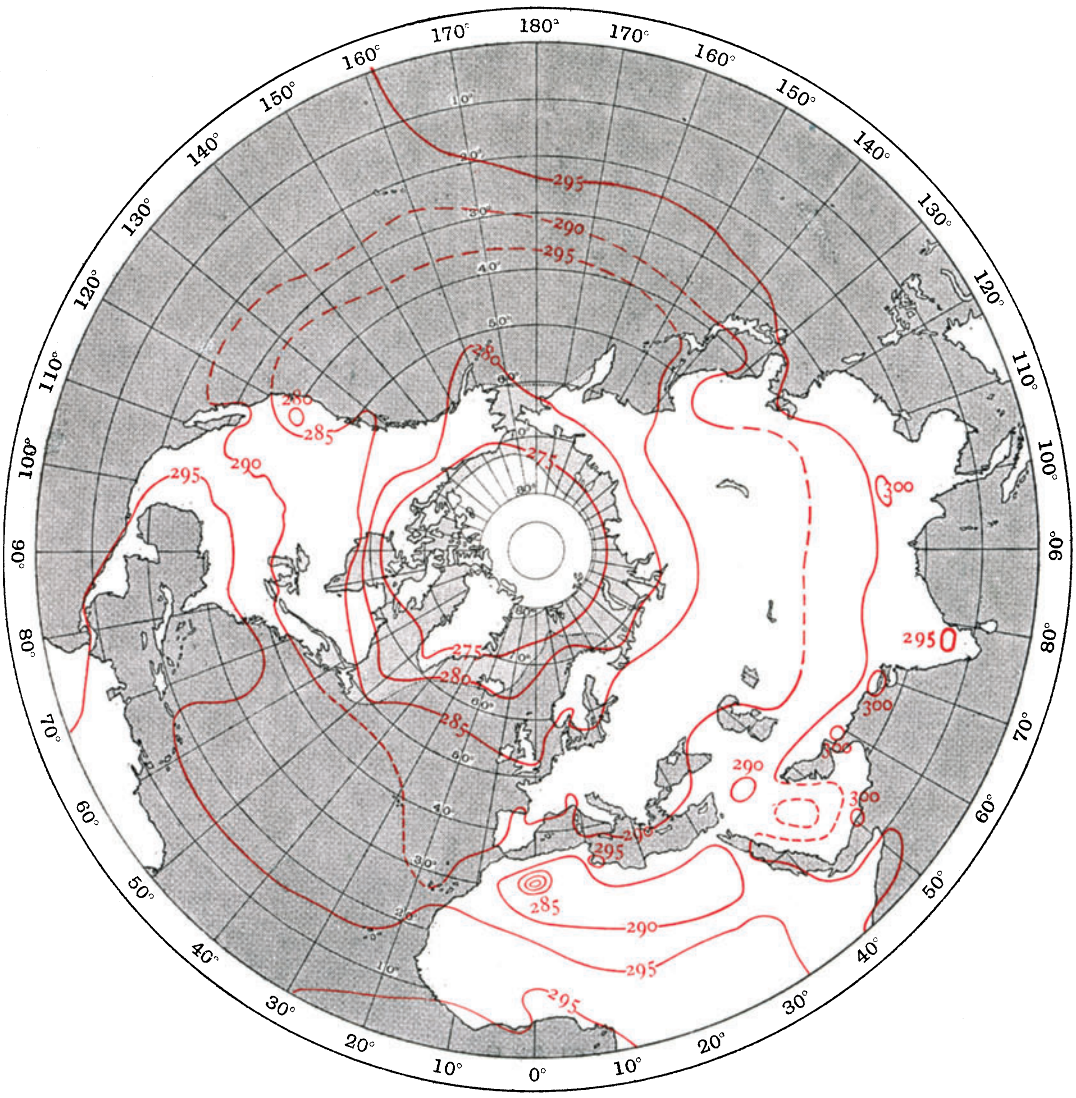
MEAN DEW-POINT OF THE AIR AT SEA-LEVEL, NORTHERN HEMISPHERE — PLATE IX

Authority: Original compilation. — *Reference to text*, pp. 120, 141.



Dew-point	Vapour-pressure	Vapour-density
a	mb	g/m³
275	7·1	5·6
280	10·0	7·8
285	14·1	10·7

Equivalent pressure of aqueous vapour and of density at saturation

The mean dew-point has been obtained from the mean vapour-pressure at the several observatories and stations after reduction to sea-level by the formula:

$$e_0 = e_h\,(1 + \cdot 0004h),$$

where h is the height of the observatory in metres.

Equivalent pressure of aqueous vapour and of density at saturation

Dew-point	Vapour-pressure	Vapour-density
a	mb	g/m³
290	19·4	14·5
295	26·5	19·5
300	35·7	25·8

Fig. 52. Normal mean temperature of saturation, dew-point or cloud-temperature of the air at sea-level over the northern hemisphere in July.

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PLATE X MEAN DEW-POINT OF THE AIR AT SEA-LEVEL, SOUTHERN HEMISPHERE

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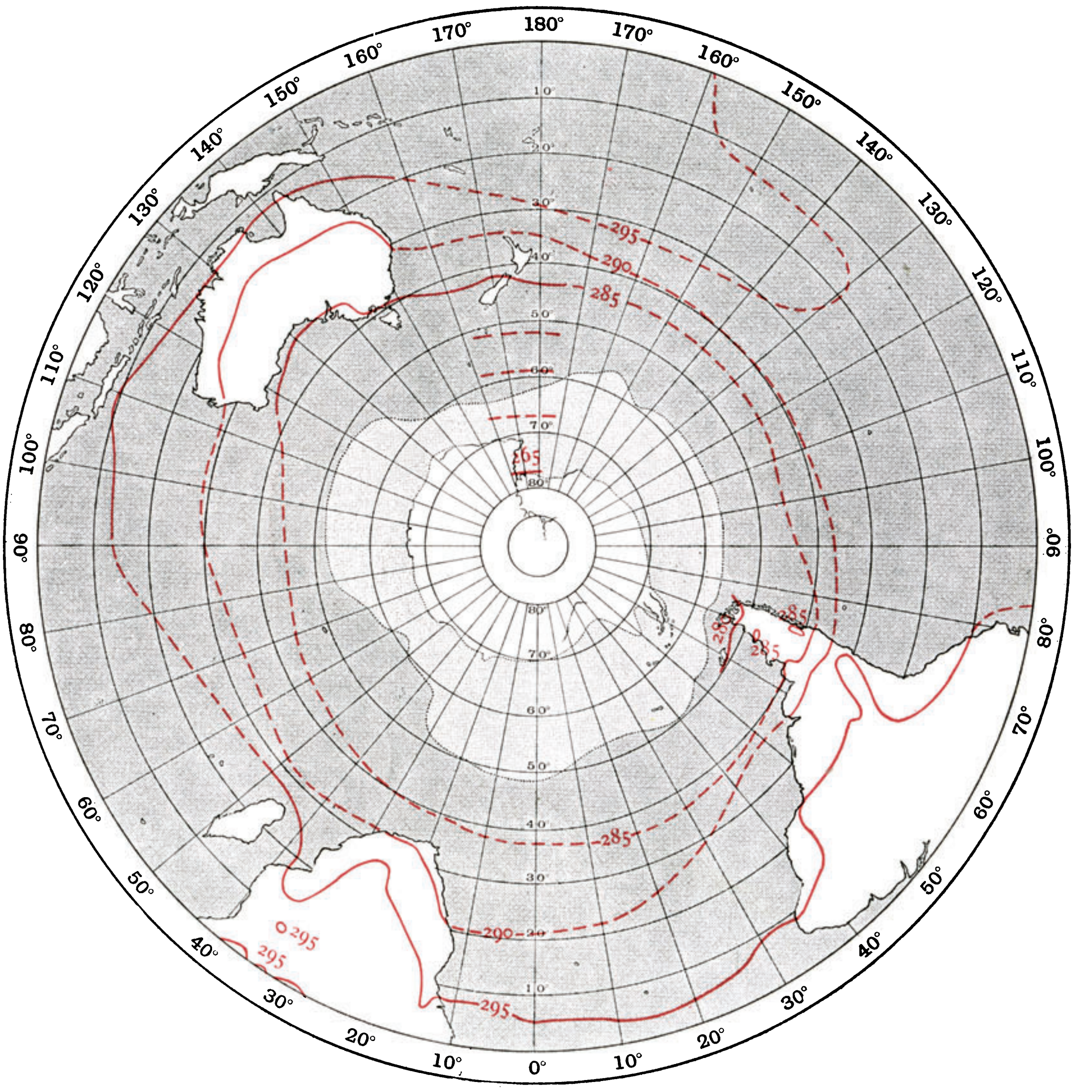

Equivalent pressure of aqueous vapour and of density at saturation		
Dew-point	Vapour pressure	Vapour-density
a	mb	g/m³
265	3·1	2 5
270	4·8	3·9
275	7·1	5·6
280	10·0	7·8

For reduction to sea-level see Plates VIII and IX.

In explanation of the run of the line in the Western Pacific see Plate VI and the map of sea-temperatures for February, *Barometer Manual*, 1919 (Plate XIII).

Equivalent pressure of aqueous vapour and of density at saturation		
Dew-point	Vapour-pressure	Vapour-density
a	mb	g/m³
285	14·1	10·7
290	19·4	14·5
295	26·5	19·5
(300)	35·7	25·8

Fig. 53. Normal mean temperature of saturation, dew-point or cloud-temperature of the air at sea-level over the southern hemisphere in January.

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