N71-38189

NASA CONTRACTOR REPORT

NASA CR-61362

DEVELOPMENT OF FOUR-DIMENSIONAL ATMOSPHERIC MODELS (WORLDWIDE)

By David B. Spiegler and James R. Greaves

Allied Research Associates, Inc.
Virginia Road
Concord, Massachusetts

August 1971

Final Report

Prepared for

NASA-GEORGE C. MARSHALL SPACE FLIGHT CENTER
Marshall Space Flight Center, Alabama 35812

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
NASA CR-61362		

4. TITLE AND SUBTITLE	5. REPORT DATE
DEVELOPMENT OF FOUR-DIMENSIONAL ATMOSPHERIC MODELS (WORLDWIDE)	August 1971
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR (S)	8. PERFORMING ORGANIZATION REPORT #
David B. Speigler and James R. Greaves	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. WORK UNIT NO.
Allied Research Associates, Inc. Virginia Road Concord, Massachusetts	11. CONTRACT OR GRANT NO. NAS8-25618
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT & PERIOD COVERED
NASA Washington, D. C.	CONTRACTOR REPORT
	14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

Prepared under the technical monitorship of the Aerospace Environment Division, Aero-Astrodynamics Laboratory, NASA-Marshall Space Flight Center

16. ABSTRACT

Mean monthly values and daily variances of moisture, temperature, density, and pressure were generated at 1 km intervals from the surface to 25 km using global atmospheric data extracted from various sources. The resultant profiles were stratified into "homogeneous moisture regions" covering both hemispheres. Analytic functions were developed to fit the mean and daily variance profiles within each region. Given the latitude, longitude and month, the mean and daily variance profiles of all four atmospheric parameters can be generated. These profiles can then serve as input to attenuation models that predict the degree of atmospheric attenuation likely to be encountered by satellite or air-borne electromagnetic sensors engaged in earth resources observations.

Detailed moisture profiles for two radiosonde locations along the mid-Atlantic Coast and the Gulf Coast were analyzed and 12- and 24-hour conditional tables of moisture amount were generated at kilometer levels. The feasibility of developing frequency distributions of moisture content profiles was investigated using the data from the two radiosonde stations. Results indicated that the moisture profiles may be classified into meaningful categories of moisture content if the presence (or absence) of an upper level moist layer is considered in the classification scheme.

17. KEY WORDS	18. DISTRIBUTION STATEMENT
atmospheric attenuation, earth observations from space, four-dimensional worldwide atmospheric model, homogeneous moisture areas, vertical mean profiles	Unclassified-Unlimited E. D. Geissler E. D. GEISSLER Director, Aero-Astrodynamics Lab, MSFC

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE
Unclassified	Unclassified	100	$3.00

MSFC - Form 3292 (May 1969)

FOREWORD

The objective of the four-dimensional atmospheric modeling task is to provide world-wide profiles of pressure, temperature, density, and moisture from the surface to 25 km altitude. The model gives mean monthly values and daily variations of the four parameters by homogeneous moisture region. This model can then serve as input for attenuation models that predict the degree of atmospheric attenuation likely to be encountered by satellite or air-borne electromagnetic sensors engaged in earth resources observations.

The four-dimensional atmospheric model is being improved by the addition of atmospheric data and by changing the basic computer subroutine so that the acquisition of an atmospheric profile at any requested latitude, longitude, and month can be obtained. The model is to ultimately present pressure, temperature, density, moisture, and cloud cover as one attenuation model for earth resources problems. It can also be used as mean model atmospheres in trajectory and vehicle heating analyses.

Associated work has been and is still being done in this field. For example, Allied Research Associates, Inc., under Contracts NAS8-21040 and NAS8-25812, has developed a world-wide cloud cover model (NASA CR 61226 and NASA CR 61345), and Environmental Research Technology, under Contract NAS8-26275, has developed an interaction model involving microwave energy and atmospheric variables (NASA CR 61348).

ACKNOWLEDGEMENTS

The research described in this report was performed by the Geophysics and Aerospace Division of Allied Research Associates, Inc. (ARA) under sponsorship of the George C. Marshall Space Flight Center, Aerospace Environment Division (AED) of the National Aeronautics and Space Administration, Contract No. NAS 8-25618. Our thanks to S. Clark Brown and Dale L. Johnson of NASA (AED) for their participation in technical discussions of value to the study.

The northern and southern hemisphere monthly data on the 5^{o} latitude-longitude grid and the northern hemisphere high-altitude daily data on the NMC grid were made available for use in this study by Dr. Harold Crutcher of the National Climatic Center and Roy Jenne of NCAR. Our thanks to Frank Lewis of the Techniques Development Laboratory, NOAA, for providing daily northern hemisphere data at constant pressure surfaces, and to Professor Victor Starr of Massachusetts Institute of Technology (MIT) for permitting us to copy the "water balance" tape which contains mean precipitable water data by season and year for a 5-year sample. Data on this tape were generated under a grant from the National Science Foundation to MIT.

We also appreciate the contributions to this study by the following ARA scientists: Paul E. Sherr, Robert F. Smiley, David T. Chang and C. James Bowley. Mary Grace Fowler and James H.Willand provided programming support for this project. Details of the computer programs and how to use them are contained in an accompanying Users Manual for the 4-D models (Willand et al, 1971). *

*Appendix B

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF TABLES

1. INTRODUCTION

Observations of earth resources from satellites and aircraft, equipped with sophisticated electromagnetic sensors, will be of considerable interest to many users groups in the near future. NASA and others have recognized that it is important to consider the effects of atmospheric attenuation on the earth resources data being received. Users of these data will need to know the degree to which the data have been degraded by the atmosphere. This information may be supplied by atmospheric attenuation models.

Experience has shown that moisture in the form of water vapor or liquid water is the principle contributor to the attenuation of electromagnetic energy passing through the atmosphere. Temperature and density of the air also have an influence on the accuracy of the remote sensing instruments, but to a much lesser extent than moisture.

The major objectives of this study were:

1, To develop statistics (monthly means and variances applicable to daily values) of vertical profiles of moisture, temperature, density and pressure at 1 km intervals from the surface to 25 km on a global grid network for all months of the year.

2. To derive atmospheric profile models based on these statistics that may be used as the input to atmospheric attenuation models planned to be developed at a future time. These models will provide information on the expected electromagnetic sensor degradation effects for a particular location and time of the year.

In addition, detailed radiosonde data from Burrwood and Boothville, Louisiana and Norfolk and Wallops Island, Virginia were available for processing and analysis of moisture content. The specific goals of the moisture analysis at these stations were to (1) generate 12 and 24 hour conditional tables of moisture content at each height level up to 10 km and (2) to investigate the feasibility of developing frequency distributions of moisture content profiles.

The approach to satisfying the major objectives of this study is to define homogeneous regions (based on moisture data) and to fit analytic functions to the mean profile and variance statistics for each region and month.

Details of the data processing, approach and results follow.

2. DATA AND DATA PROCESSING

2.1 Data

The data available to develop the required global statistics consists of magnetic tapes obtained from several sources.

- Northern hemisphere monthly means and variances of temperature (T), dewpoint (T_d) and constant pressure surface height (Z) at 5^o latitude-longitude grid points for standard constant pressure surfaces to 100 mb for all months of the year. (Dewpoints provided only to 500 mb.) Also included are means for the sea-level pressure T and T_d. These data were obtained from Dr. Harold Crutcher of the National Climatic Center (NCC) and are on one standard reel of magnetic tape.

- Daily values of T and Z at constant pressure surfaces from 100 to 10 mb for a seven-year period for the northern hemisphere on the National Meteorological Center (NMC) 1977 point octagonal grid which extends to approximately 10^oN (Figure 1). (7 reels of tape provided by Mr. Roy Jenne of NCAR.)

- Daily values of T, dewpoint depression (DPD) and D-values (departure from reference height) from standard constant pressure surface height fields from 1000- to 300-mb for the northern hemisphere NMC grid, for an eight-year period (except DPD values are not given for 1000 mb and 300 mb). (24 reels of tape provided by Mr. Frank Lewis of NOAA.)

- Southern hemisphere monthly means of T, T_d and Z for constant pressure surfaces up to 100 mb for all months of the year on a 5^o latitude-longitude grid. In addition, mean sea level P, T, and T_d are given for all months. (1 reel of tape provided by Dr. Crutcher of NCC.)

The four data sources represent approximately 67 million pieces of data. Despite the enormous amount of data available, certain data was missing. Tables 1 and 2 present schematically the data that were not available to us for processing for the northern and southern hemispheres, respectively. In general, although the dewpoint data were not available above 500 mb, the contribution of the moisture above 500 mb to the total moisture in a column above the surface is known to be relatively small (less than 10% (Peixoto, 1970)). (A method for accurately estimating moisture above 500 mb using an analytic function with the data below 500 mb is discussed in Section 3.0.)

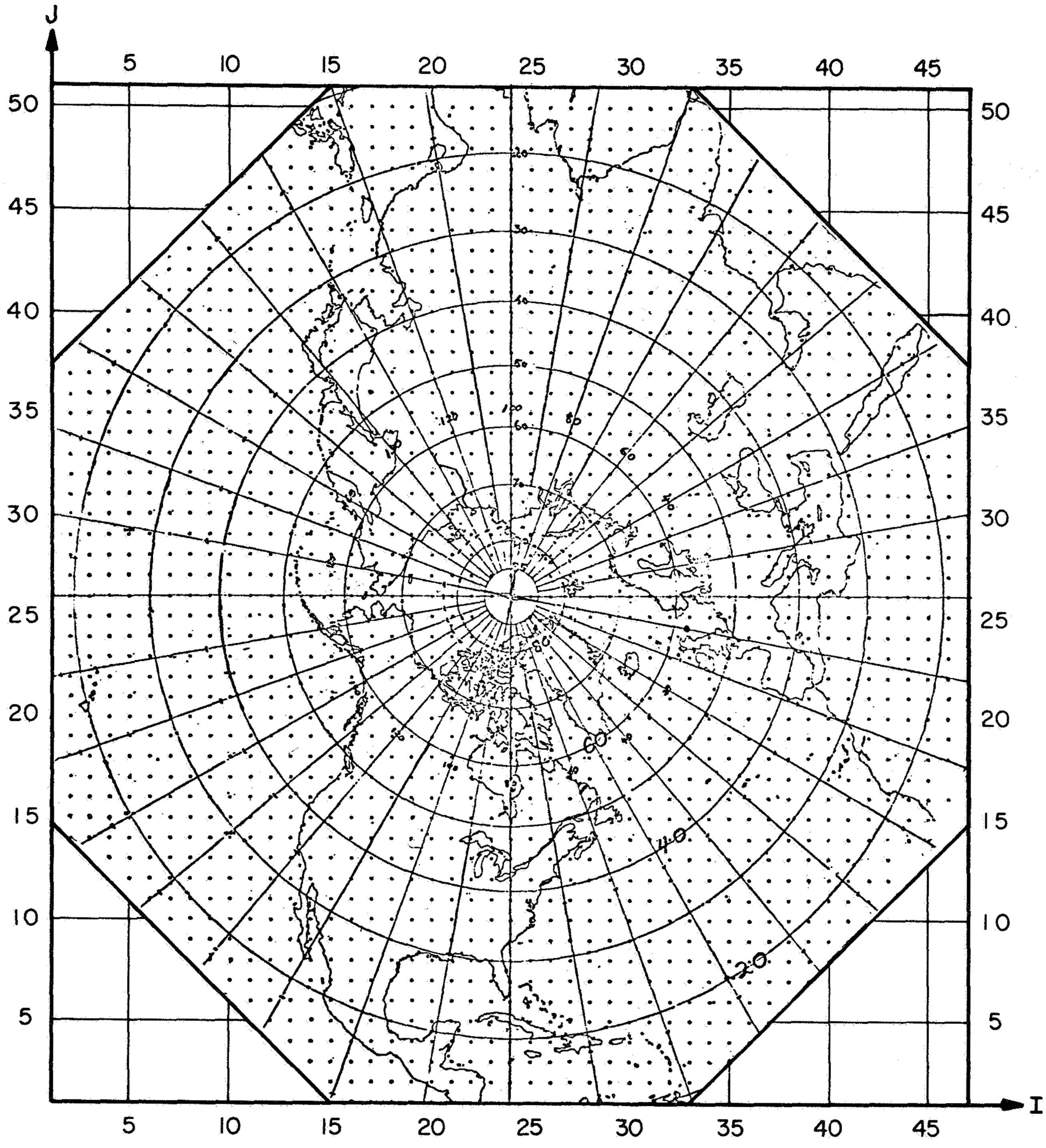


Figure 1 Northern Hemisphere NMC 1977-Point Octagonal Grid

7489

TABLE 1

NORTHERN HEMISPHERE MISSING DATA

	Temperature and Height		Moisture	
	Means	Variances	Means	Variances
Surface	—	Equator to ~ 15°N	—	All latitudes
850, 700, 500 mb	—	—	—	—
300 mb	—	—	All latitudes	
200 mb	—	All latitudes	↓	↓
100 mb	—	—	↓	↓
50 mb	Equator to ~ 15°N		↓	↓
30 mb	↓	↓	↓	↓

TABLE 2

SOUTHERN HEMISPHERE MISSING DATA

	Temperature and Height		Moisture	
	Means	Variances	Means	Variances
Surface	—	All latitudes	All latitudes	
850, 700, 500 mb	—	↓	—	↓
300 mb	—	↓	All latitudes	↓
200 mb	—	↓	↓	↓
100 mb	—	↓	↓	↓
50 mb	All latitudes	↓	↓	↓
30 mb	↓	↓	↓	↓

The varied sources of data (all in different formats) were processed with the aim of filling in the data gaps and producing, at 1 km intervals from the surface to 25 km, global statistics of the means and variances (of daily values) of temperature (T), absolute humidity (ρ_w), pressure (P) and density (ρ).

Major data problems seen by examining Tables 1 and 2 that needed to be overcome to meet the required objectives were:

1. The northern hemisphere 5^o latitude-longitude tape contained variances computed from monthly means only, while variances applicable to daily values are required.

2. The data provided for the southern hemisphere extended only to the 100-mb level (~16 km) while profiles are required to 25 km.

3. Variances were unavailable on tape for the southern hemisphere.

A partial solution to the first problem was to use the northern hemisphere daily tropospheric data on the NMC grid to generate variances applicable to daily values. However, surface dewpoint, dewpoint above 500 mb and data at 200 mb were not available on these tapes.

Several other minor problems are also evident (e.g., no data above 100 mb from ~ 15^oN to the equator).

Complete solutions to all the data problems were formulated and are given in the next section describing the computational and processing procedures in some detail.

2.2 Data Processing

The basic computations required include:

1. Linear interpolation of temperature and dewpoint (dewpoint depression converted to dewpoint) from the constant pressure surfaces to 1 km intervals.

2. Conversion of dewpoint to absolute humidity (ρ_w) from the following standard relationships:

$$\overline{\rho}_w = 216.7 \frac{\overline{e}}{\overline{T}} \quad (g/m^3) \tag{1}$$

where

$\overline{\rho}_w$ is the mean monthly absolute humidity

$\overline{T}$ is the mean monthly temperature in ^{o}Absolute

and $\overline{e}$ is the mean monthly vapor pressure given by the empirical formula of Tetens (1930):

$$\bar{e}_{(mb)} = 6.11 \times 10^{\left(\frac{a\,\bar{T}_d}{\bar{T}_d + b}\right)} \qquad (2)$$

$a = 7.5$

$b = 237.3$

and

$\bar{T}_d$ is the mean monthly dewpoint in ^{o}Centigrade.

3. To insure hydrostatic consistency, the computation of pressure, P, is given by the hypsometric equation

$$\bar{h} = \frac{R\bar{T}}{g} \log \frac{\bar{P}_o}{\bar{P}_1} \qquad (3)$$

where

$\bar{h}$ is the mean monthly thickness of a layer of the atmosphere between two levels P_o and P_1

R is the gas constant

g is the gravity force

$\frac{R}{g} = 67.442$

and

$\bar{T}$ is the monthly mean of the mean temperature of the layer between P_o and P_1

$\bar{P}_o$ is the mean monthly pressure at the lower level (mandatory constant pressure surface) bounding the layer

$\bar{P}_1$ is to be computed and is the mean monthly pressure at the upper level bounding the layer.

Solving for $\bar{P}_1$

$$\log \bar{P}_{1\,(mb)} = \log \bar{P}_o - \frac{h}{67.442\,(\bar{T})} . \qquad (4)$$

4. Computation of density (ρ) follows from equation of state (5)

$$\bar{\rho} = 348.3 \frac{\bar{P}}{\bar{T}} \quad (g/m^3) \qquad (5)$$

where

$\bar{\rho}$ is the mean monthly density

$\bar{P}$ is the mean monthly pressure

and

$\bar{T}$ is the mean monthly temperature.

The objective of the processing was to combine all the data sources and perform the interpolations and computations described above to arrive at a set of hydrostatically consistent global statistics for monthly means and daily variances of the profiles of the four parameters from the surface to 25 km. The processing proceeded according to the flow diagram shown in Figure 2.

Procedures and assumptions necessary to overcome the data gaps shown in Tables 1 and 2 are self-contained within the flow diagram.

The vertical extrapolation regression equations referred to in Figure 2 (for generating data above 16 km where data was missing) were originally derived for the northern hemisphere to generate data at the 50 mb and 30 mb levels (Lea, 1961). We used them for the northern hemisphere in the region from the equator to 10°N and for the entire southern hemisphere. Although the equations were developed from a data sample from the northern hemisphere, the assumption was made that the climatology of temperature and height for stratospheric constant pressure surfaces is similar for both hemispheres at similar latitudes and seasons. A study by Finger and Woolf (1967) supports this assumption.

The equations are of the form:

$$Z_{50} = a_o + a_1 (Z_{100}) + a_2 (T_{100}) \quad (6)$$

$$T_{50} = a_o + a_1 (Z_{100}) + a_2 (T_{100}) \quad (7)$$

$$Z_{30} = a_o + a_1 (Z_{50}) + a_2 (T_{50}) \quad (8)$$

$$T_{30} = a_o + a_1 (Z_{50}) + a_2 (T_{50}) \quad (9)$$

where

Z and T are height (meters) and temperature (°C) and the subscripts refer to the standard constant pressure surface

a_o, a_1 and a_2 are coefficients that are a function of latitude and month of the year.

The final output from the processing consists of three sets of data that comprise the global statistics of moisture, temperature, pressure and density at 1 km intervals from the surface to 25 km.

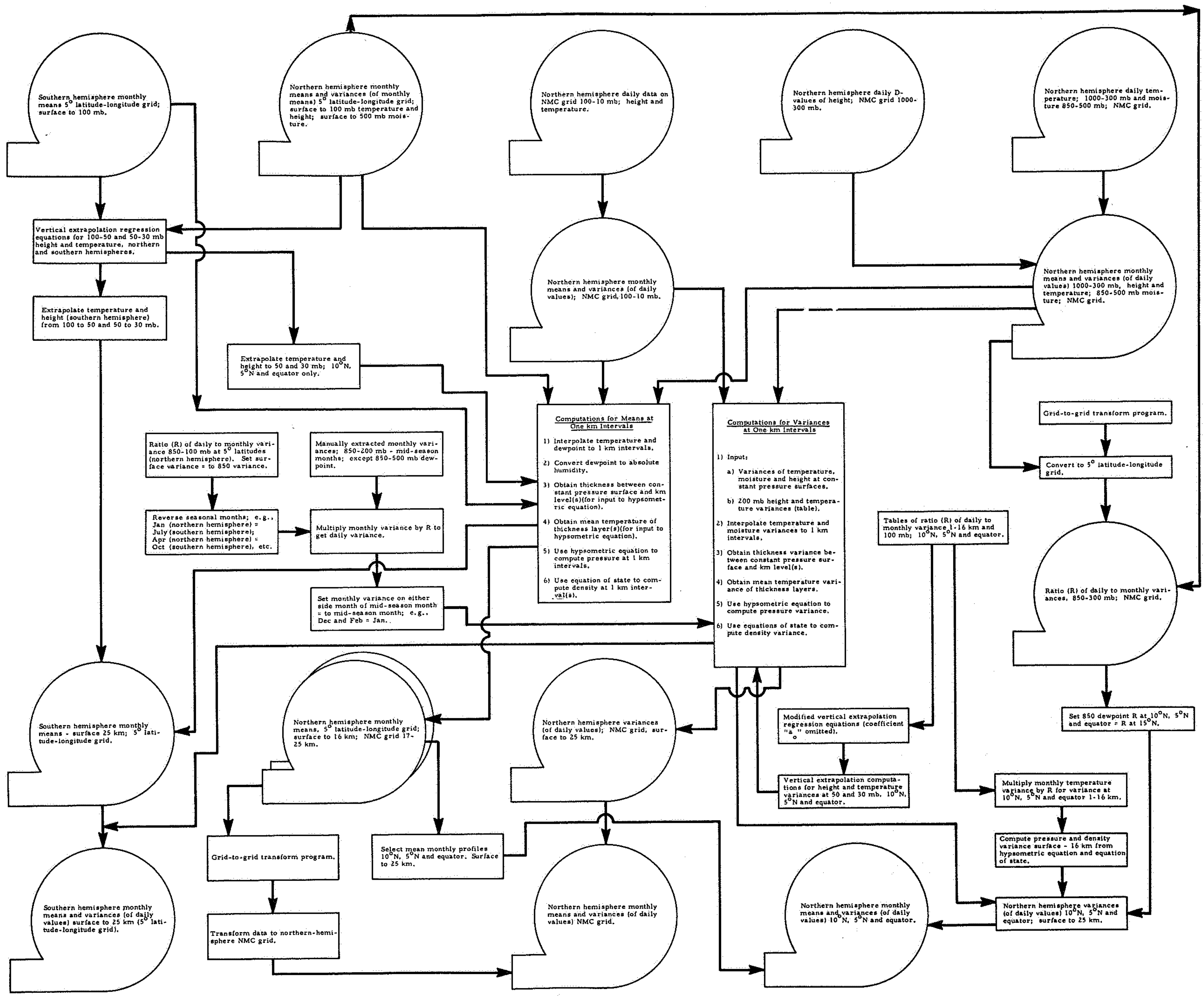


Figure 2 Four-Dimensional Model Development; Data Processing and Computations

1. Northern hemisphere monthly means and variances (of daily values) on the NMC grid (Figure 1) which extend to approximately 10°N near the outermost grid points.

2. Northern hemisphere monthly means and daily variances at 5° latitude-longitude intersections from 15°N to the equator.

3. Southern hemisphere monthly means and daily variances at 5° latitude-longitude intersections.

The amount of data represented by the three sets of tapes though reduced from the original ~ 67 million values was still formidable:

> 26 levels (surface to 25 km) x 4 parameters x 2 values/per level (mean and variance) x 12 months x 2265 grid points northern hemisphere (1977 point NMC grid + 288 point 5° latitude-longitude grid) = 5, 653, 440 pieces of data. On the 1368 point southern hemisphere grid, 3, 414, 528 pieces of data for total global data base of 9, 067, 968 values.

3. THE FOUR-DIMENSIONAL ATMOSPHERIC MODELS

The purpose of modeling atmospheric profiles is to reduce the enormous amount of data to a manageable size for such practical applications as input to future atmospheric attenuation models. As part of this task we used the concept of "homogeneous regions" over the globe (Sherr et al, 1968) and fitted analytic functions to the statistical profiles within the homogeneous regions; i.e., we derived the atmospheric models based on the tabulated statistical values of moisture, temperature, pressure and density at each of the 25 km levels and at the surface.

3.1 The "Homogeneous" Moisture Regions

Moisture in the atmosphere has the most pronounced effect on electromagnetic sensor data, while the influence of temperature and density is considerably less than that of moisture. Dewpoint was the measure of moisture given in the original data, but dewpoint was converted to absolute humidity in g m^{-3} to facilitate its eventual use in atmospheric attenuation models. The atmosphere's ability to hold moisture is a function of temperature. Because of the relationships between absolute humidity and temperature and between temperature, density and pressure, the "homogeneous" regions defined on the basis of a detailed analysis of moisture are also relatively homogeneous with respect to the other parameters.

Four sources of information were used as an aid in defining the homogeneous regions.

1. Mean precipitable water grids for the year and each season (5-year data sample) as given on the "water balance" data tape obtained through the courtesy of Professor V. Starr of the Massachusetts Institute of Technology (MIT) (who developed the information under an NSF grant).
2. Homogeneous moisture regions specified by ARA in a previous study on cloud statistics (Sherr et al, 1968).
3. The mean moisture profile statistics at selected points over the globe.
4. The U. S. Navy Climatic Atlas (Crutcher and Davis, 1969).

The criteria used in the analysis of the moisture data for defining the regions were:

- The annual average moisture
- The degree of seasonal change
- The degree of variability across the region
- The geographic location

A description of the above characteristics for each of the 36 regions is given in Table 3 and the regions are shown in Figure 3.

Regions were defined with the objective of minimizing the variability across the region. For some portions of the globe and seasons of the year, it was not possible to completely satisfy this objective due to the existence of rather large moisture gradients. The annual variation in precipitable water and areas of strong moisture gradients are illustrated by Figures 4 and 5 which show mean precipitable water values for the three-month periods, December, January and February; June, July and August, respectively. Because the absolute moisture is temperature dependent, large moisture gradients exist near the mean position of the polar front. These gradients shift from the subtropical-tropical border in late fall, winter and early spring, to near the high mid-latitudes in summer. Thus, some of the homogeneous regions (with respect to annual average moisture) are transition regions with relatively large moisture variability during some seasons of the year; e.g., Region 7 (high mid-latitude, continent) exhibits relatively large variability across the region in the summer and Region 19 (subtropical-tropical border) has large variability during the spring and fall.

In addition to relatively low average annual moisture in mountain and desert regions (compared to regions at the same latitudes and adjacent longitudes), there are also significant moisture differences within the same latitude belts from continent to ocean and from western portions of oceans to eastern portions of oceans; i.e., the eastern continental regions generally have lower moisture amounts than adjacent ocean regions and the eastern ocean regions have lower amounts than western portions of oceans. The physical explanations for these moisture differences across longitudes along similar latitudes is simple and straightforward:

The underlying surface makes continental air inherently drier (mostly in the lower 2 km) than air over ocean areas at the same latitudes.

The semipermanent subtropical ocean anticyclone circulation causes general rising air in the western portion of the anticyclone enhancing convective instability with relatively deep moist layers (particularly in summer and early fall) while subsiding air in the eastern portion of the anticyclone inhibits convection. The result is lower mean moisture profile values in the eastern oceans than at the same latitudes in the western ocean areas.

The next two sections discuss the profile statistics and the methodology for fitting these statistics with analytic functions.

TABLE 3

HOMOGENEOUS MOISTURE REGIONS

Region Number	Annual Average Moisture	Seasonal Change	Variability Across Region	Location	Remarks
1	Extremely low	Small	Small	Arctic	
2	Very low	Small to moderate	Small, except moderate in summer	Subarctic and Arctic - continent	
3	Low	Small	Small, except moderate in summer	Subarctic ocean	Very low moisture late fall to early spring
4	Low	Moderate to large	Small, except large in summer	Polar - continent	Moderate moisture summer
5	Low	Moderate to large	Small, except moderate in summer	Subpolar	Very low moisture winter
6	Low	Small	Small, except large in summer	Polar ocean	
7	Low to moderate	Moderate	Small fall, winter and early spring, large in summer	High mid-latitude - continent	Summer maximum higher, and winter minimum lower than Regions 8, 9 and 10
8	Low to moderate	Small to moderate	Small to moderate	High mid-latitude - ocean	
9	Low to moderate	Small to moderate	Small, except moderate summer	High mid-latitude - ocean	Winter maximum lower than Region 8
10	Low to moderate	Small	Small	High mid-latitude - ocean	Moisture higher than Regions 8 & 9
11	Moderate	Small to moderate	Moderate, except large in summer	Mid-latitude - ocean	
12	Moderate	Small to moderate	Small to moderate	Eastern low mid-latitude oceans	Higher winter moisture than Region 11
13	Moderate	Large	Moderate, except small in winter and large early fall	Mid-latitude continent	
14	Moderate	Large	Moderate, except large in fall	Lower mid-latitude continent	Somewhat higher average than Regions 11-13.
15	Moderate	Moderate to large	Moderate, except large in fall	Lower mid-latitude oceans	Very high summer and early fall moisture; winter moisture higher than Region 14 (lowest 2 km)
16	Moderate	Small to moderate	Moderate	Subtropical eastern portion of oceans	
17	Moderate to high	Moderate	Moderate to large	Subtropics including western 2/3 of oceans	
18	Moderate to high	Small	Small, except small to moderate in summer and fall	Eastern subtropical and tropical oceans	Winter moisture higher than Region 17
19	High	Small to moderate	Moderate, except large in spring and fall	Subtropical-tropical border	
20	High	Small	Small, except moderate in summer and fall	Tropical eastern portion of oceans	
21	Very high	Small to moderate	Moderate, except large in spring	Tropical	
22	Very high	Small	Moderate	Tropical oceans except near Eq. in E. oceans	
23	Moderate	Moderate	Moderate, except small in spring	Tropical interior continent region	
24	Extremely high	Very small	Small	Equatorial oceans for parts of globe	
25	Moderate to high	Small to moderate	Small, except moderate in winter and spring	Equatorial continent	Lower winter moisture than Region 24
26	Low	Small to moderate	Small to moderate	Major mountain ranges average elev. ~2-3 km	
27	Very low	Small	Small to moderate	Major mountain ranges average elev. ~4-7 km	
28	Low	Small	Small	Border of mountains mid and high latitudes	
29	Low to moderate	Moderate to large	Moderate, except large in summer	Border of mountains subtropics and tropics	
30	Low	Small	Small, except moderate in summer	Deserts	
31	Low	Small to moderate	Small	Border of desert	
32	Low to moderate	Moderate	Small to moderate	Border of desert	
33	Low to moderate	Moderate	Moderate, except large in fall	Border of desert (tropical and equatorial)	Average moisture similar to Region 23
34	Moderate	Very large	Very large, except small in summer	Mid-latitude - E. coast Asia	
35	Moderate to high	Small to moderate	Moderate to large, except small in fall	Tropics - near continents	Similar to Region 19, except lower moisture in spring
36	Moderate to high	Large	Moderate, except small in summer	India and Indian Ocean	Extremely high late spring and summer moisture

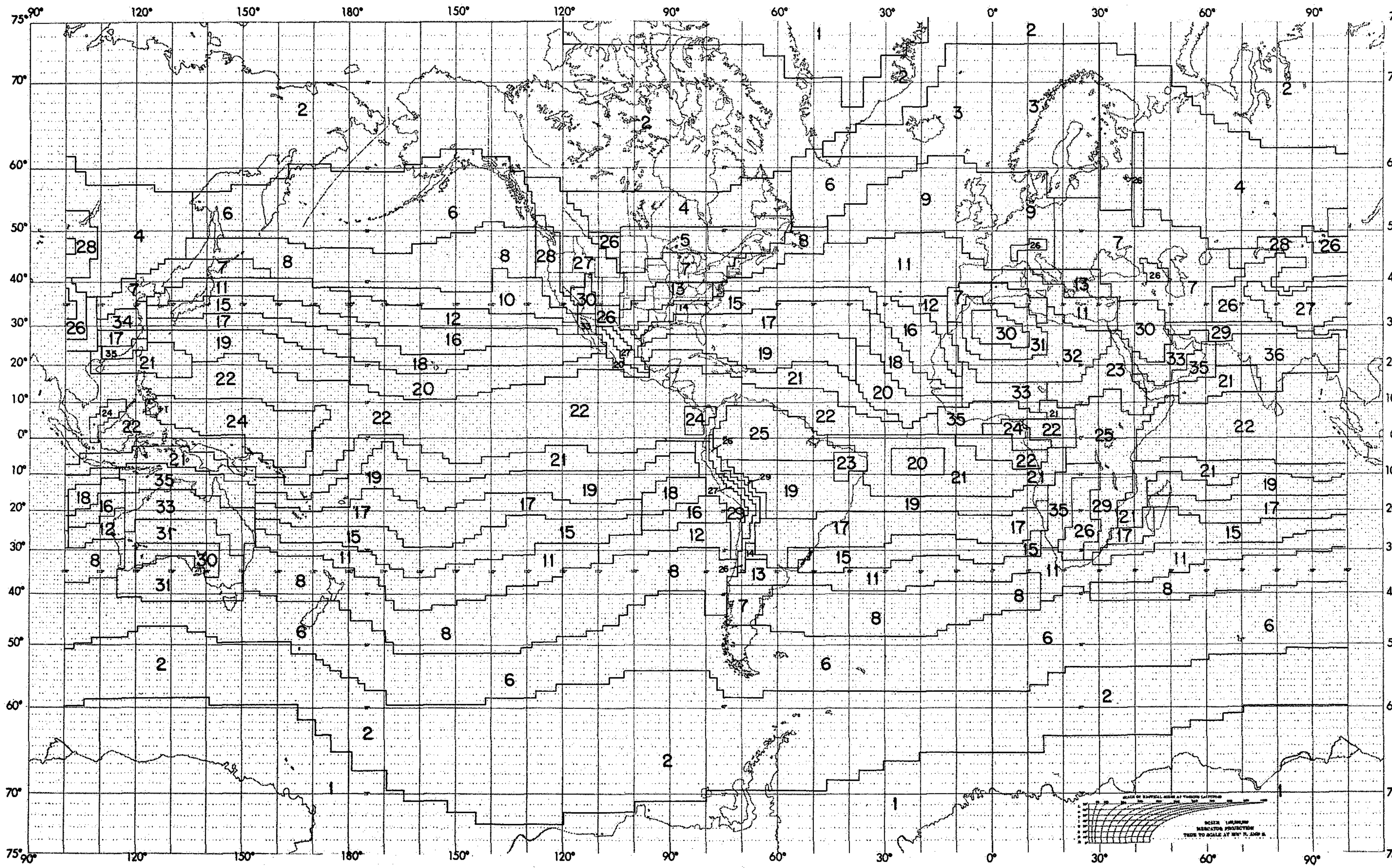


Figure 3   Homogeneous Moisture Regions

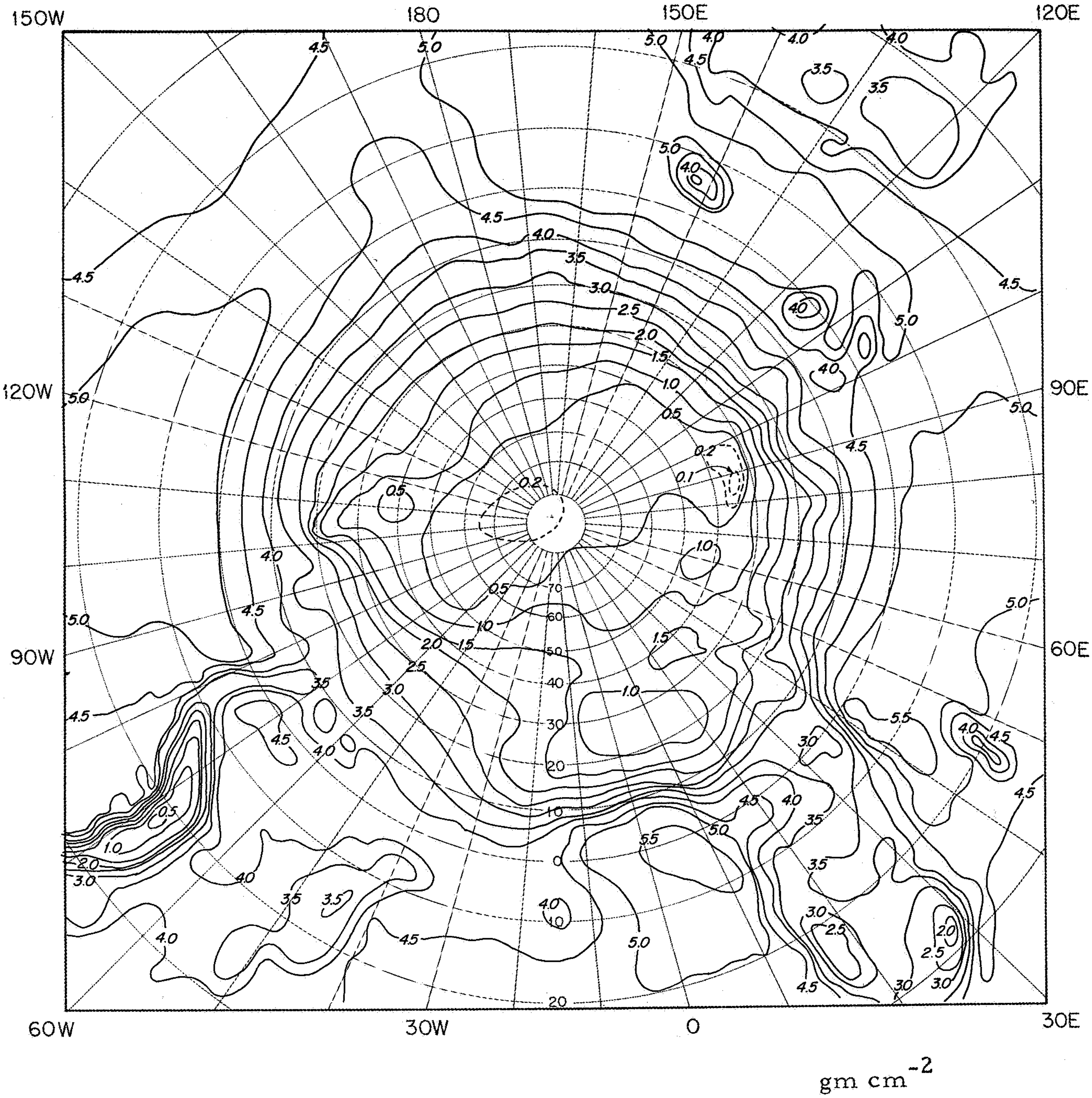


Figure 4 Five Year Mean Precipitable Water for December through February

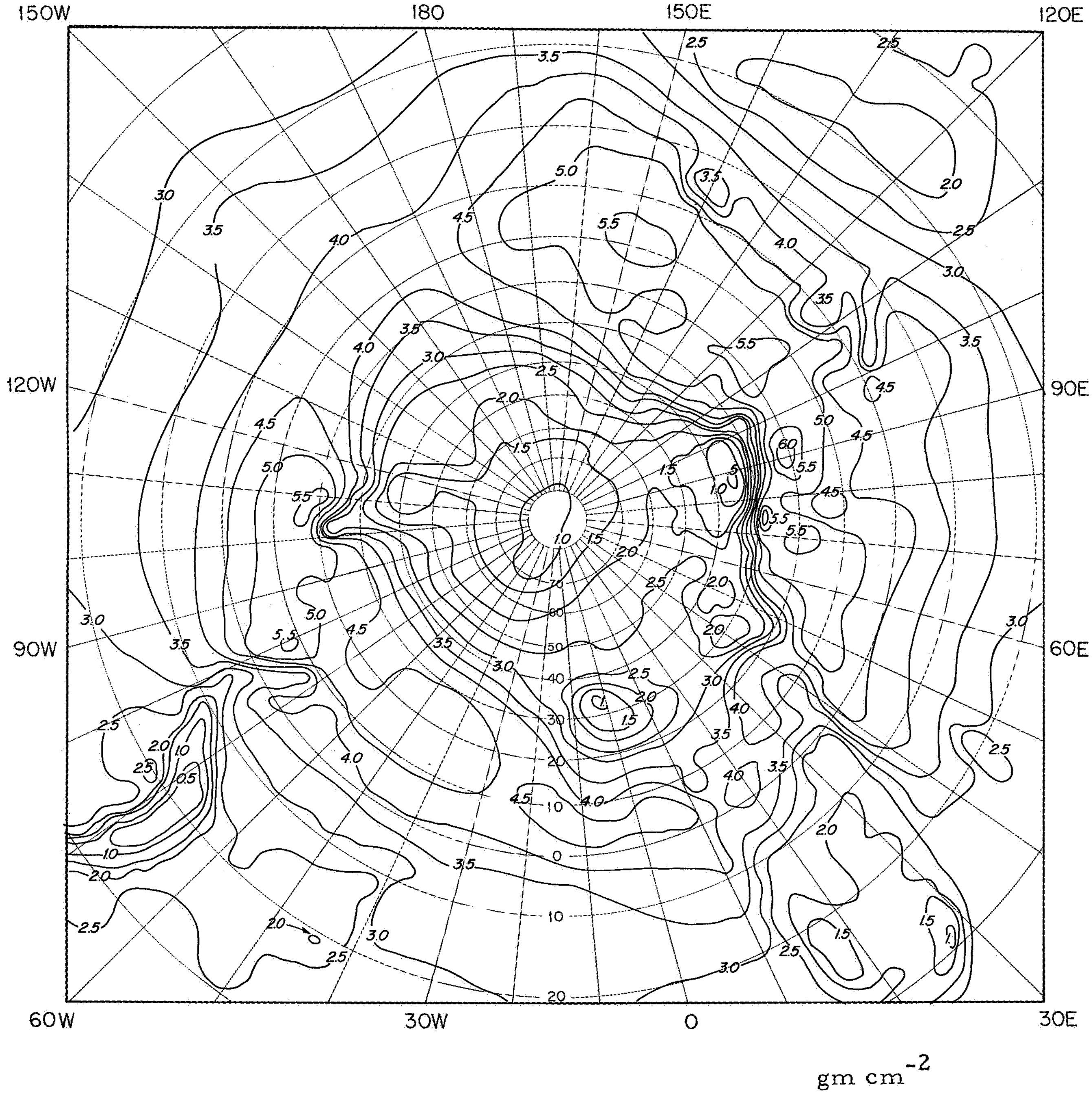


Figure 5 Five-Year Mean Precipitable Water for June through August

3.2 The Profile Statistics

For each of the 36 regions, mean monthly profiles and variances of moisture, temperature, pressure and density were computed at 1-km intervals from the surface to 25 km for each month of the year. Because the seasons are reversed between hemispheres, it was necessary to take the seasonal reversal into account in computing the means and variances for those regions that appear in both hemispheres. Thus, for example, the regional means for "January" were computed from January northern hemisphere data and July southern hemisphere data. In application, if one wanted to determine the mean January profiles and variances of a northern hemisphere location, he would use the January statistics. If means and variances for a southern hemisphere location for Winter Time conditions are required, the June, July, or Aug, etc. statistics are used. Table 4 illustrates this point. In practice, the computer program provides the necessary manipulations to arrive at the correct data set.

The mean monthly profile and variance statistics for all data points, as well as the mean regional profile and variance statistics are available on magnetic tape for all months.

TABLE 4

KEY TO SELECTION OF PROFILE STATISTICS FOR HOMOGENEOUS REGIONS

	Month											
Profiles Desired in Northern Hemisphere	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Month Selected	1	2	3	4	5	6	7	8	9	10	11	12
Profiles Desired in Southern Hemisphere	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Month Selected	7	8	9	10	11	12	1	2	3	4	5	6

Representative examples of mean moisture profiles are shown by ●'s in Figures 6 through 13 for homogeneous regions from the Arctic to the equator and for mountain and desert areas (solid line is complete profile from curve fit and extrapolation procedures, see Section 3.3 for details). Examination of these moisture profiles indicate:

- The majority of mean profiles exhibit an exponential decrease with height (nearly straight lines on semi logarithmic paper).

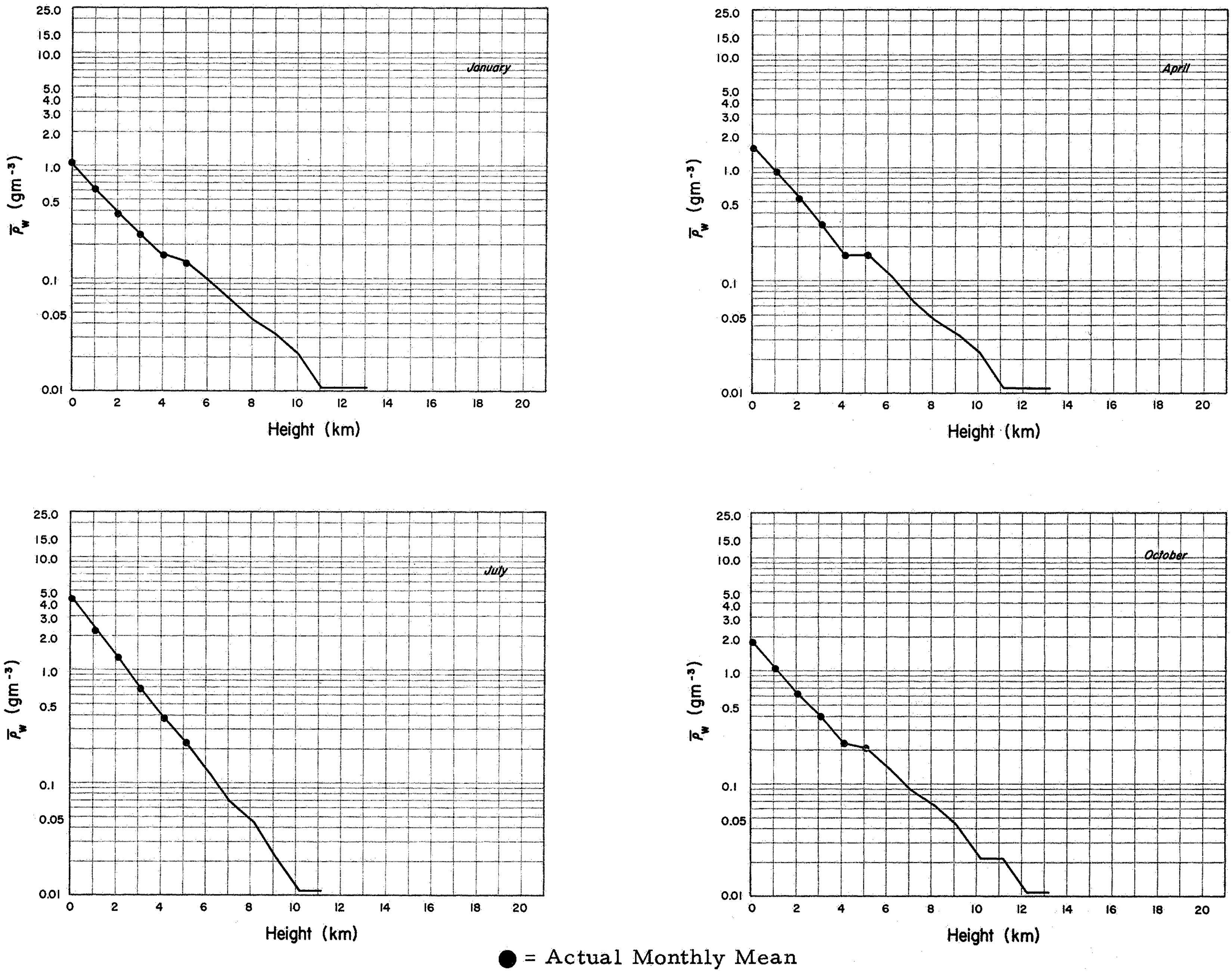
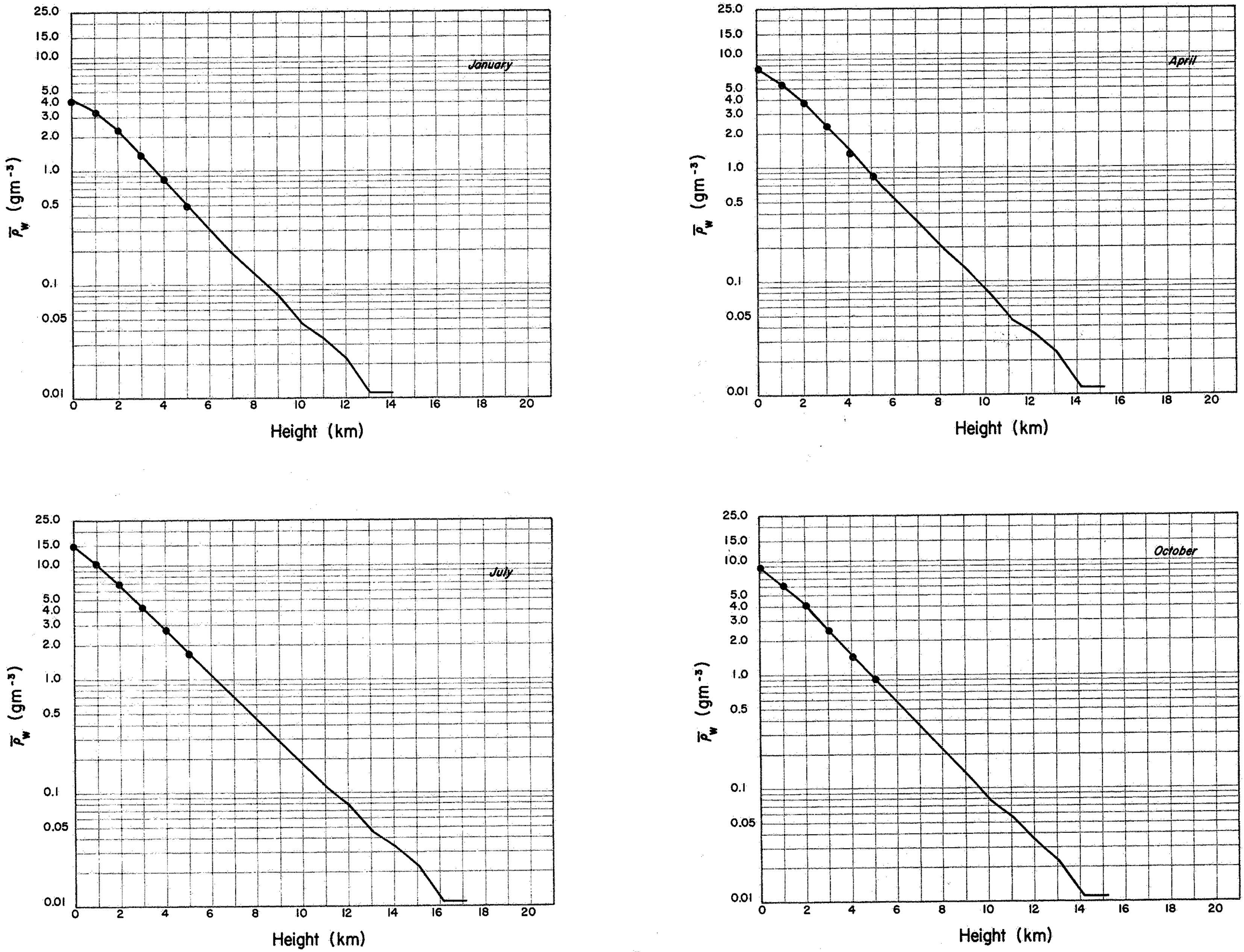
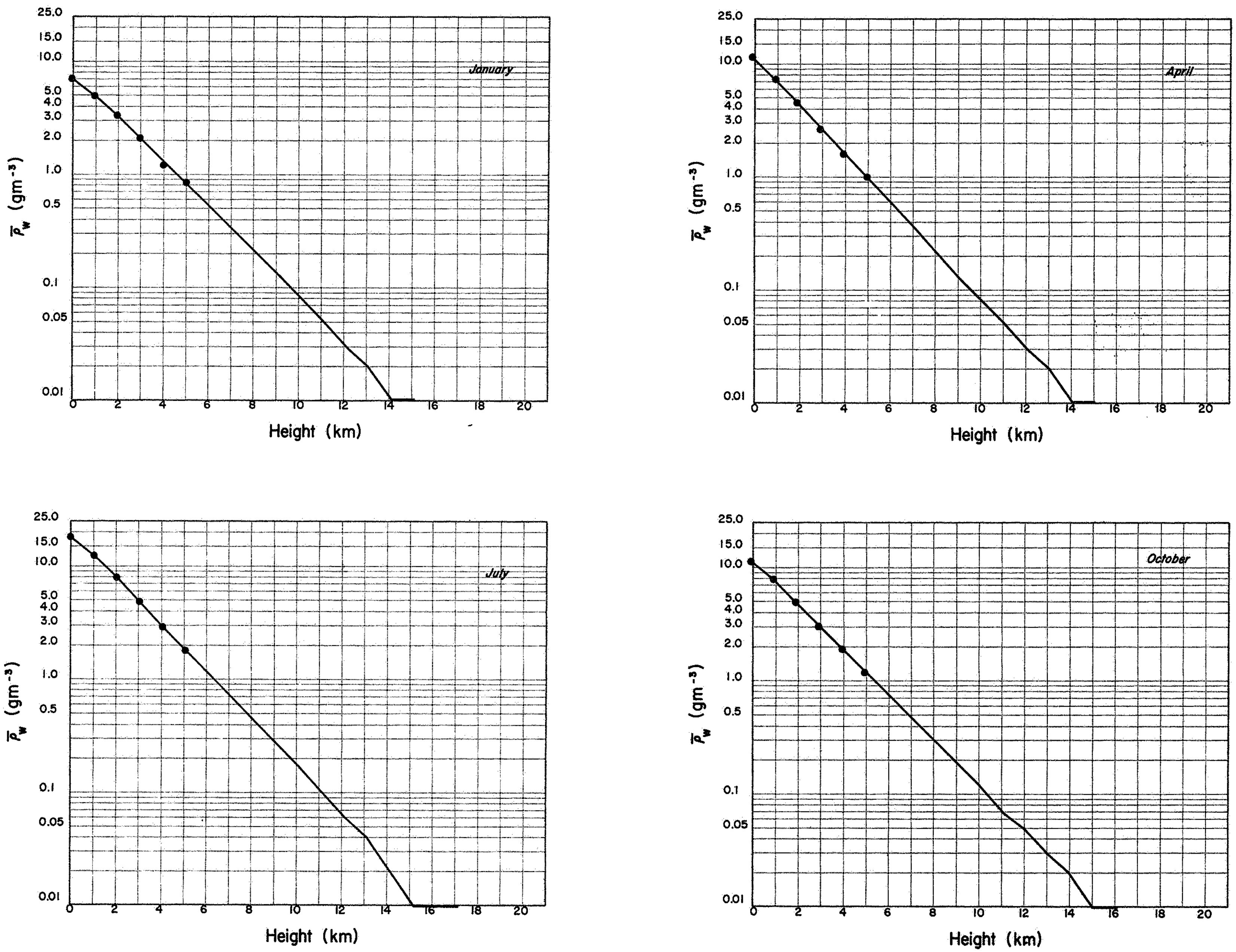


Figure 6 Comparison between Actual and Derived Mean Absolute Humidity vs Height for Midseason Months - Region 1



● = Actual Monthly Mean

Figure 7 Comparison between Actual and Derived Mean Absolute Humidity vs Height for Midseason Months - Region 7



● = Actual Monthly Mean

Figure 8 Comparison between Actual and Derived Mean Absolute Humidity vs Height for Midseason Months - Region 14

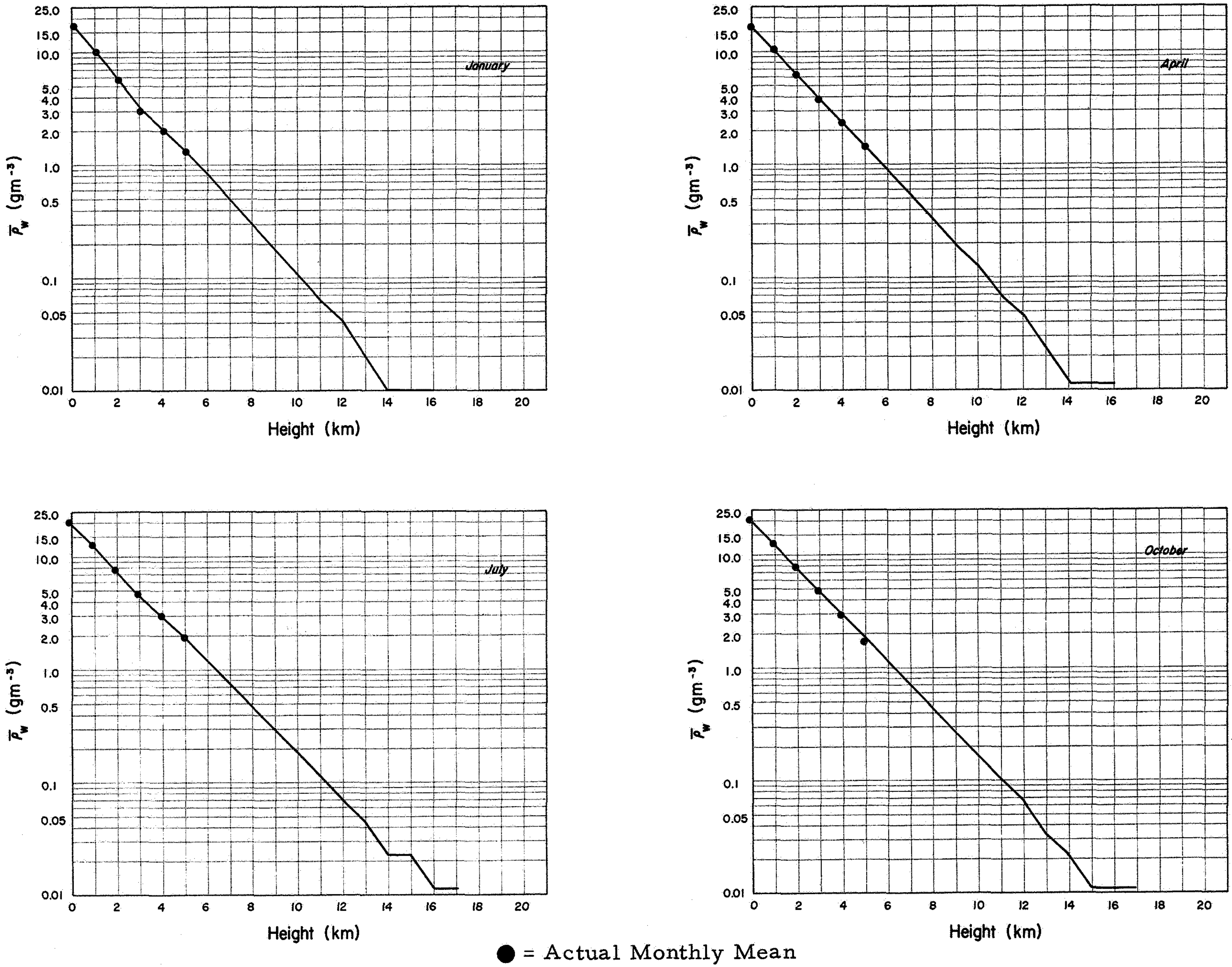


Figure 9 Comparison between Actual and Derived Mean Absolute Humidity vs Height for Midseason Months - Region 18

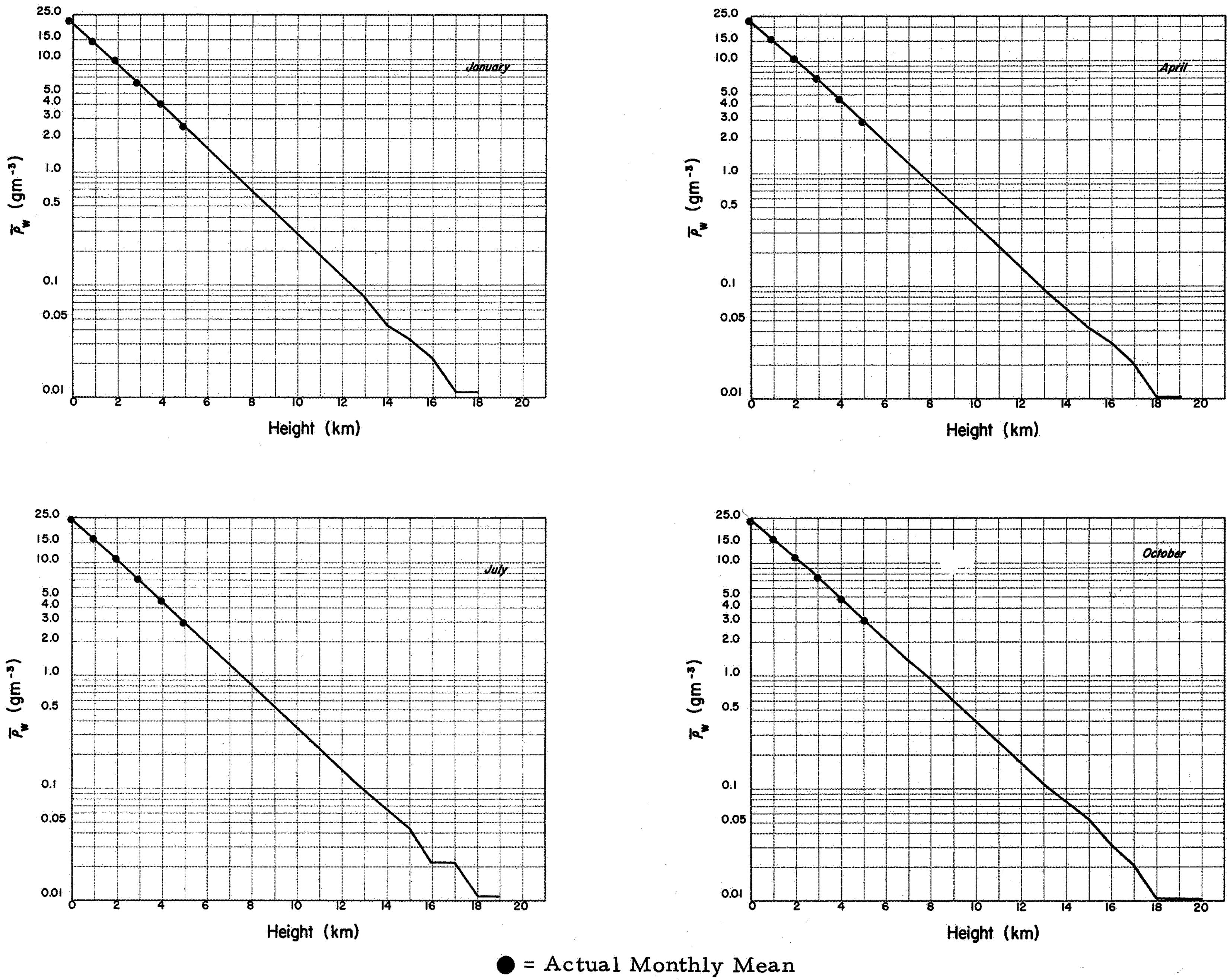
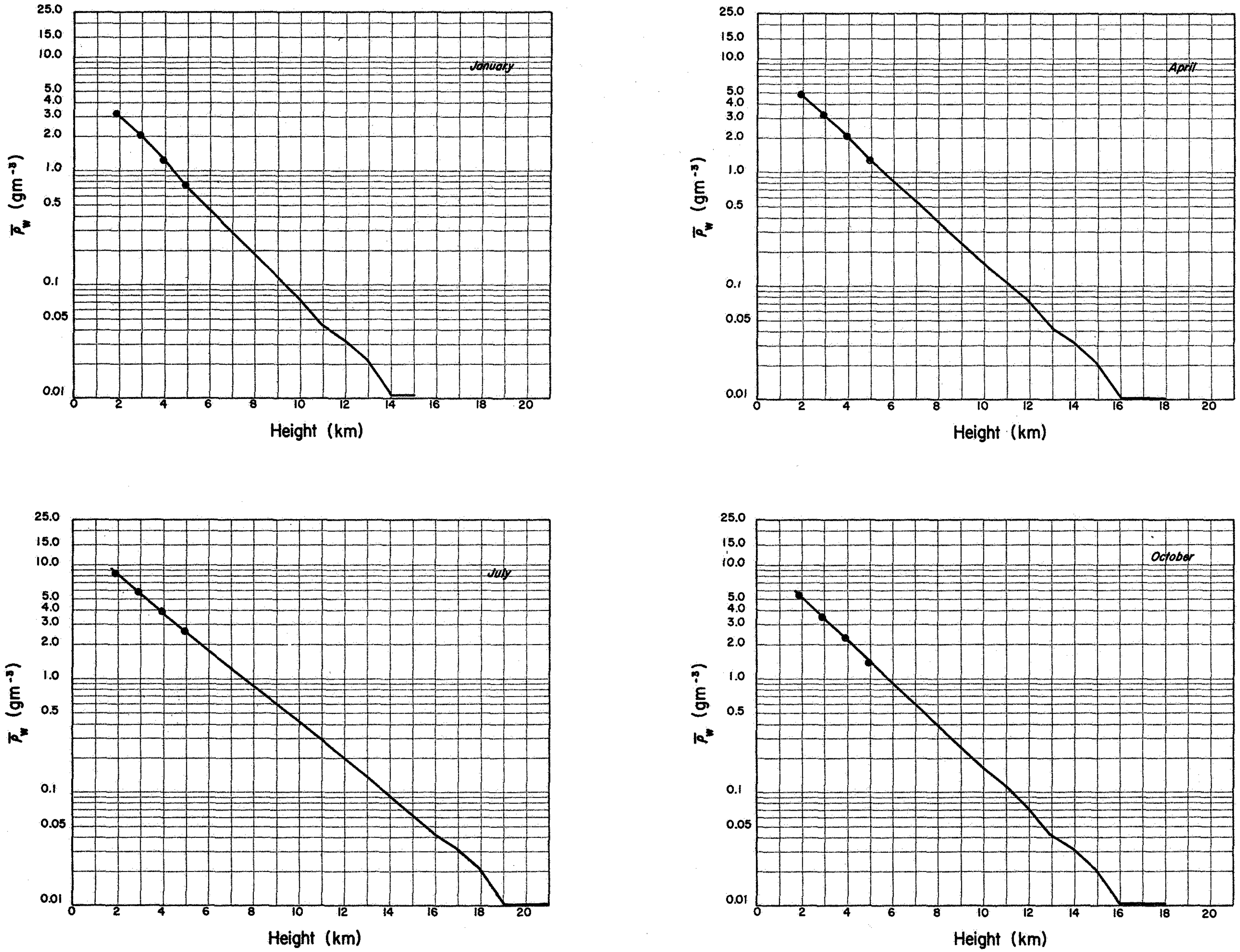


Figure 10 Comparison between Actual and Derived Mean Absolute Humidity vs Height for Midseason Months - Region 24



● = Actual Monthly Mean

Figure 11 Comparison between Actual and Derived Mean Absolute Humidity vs Height for Midseason Months - Region 26

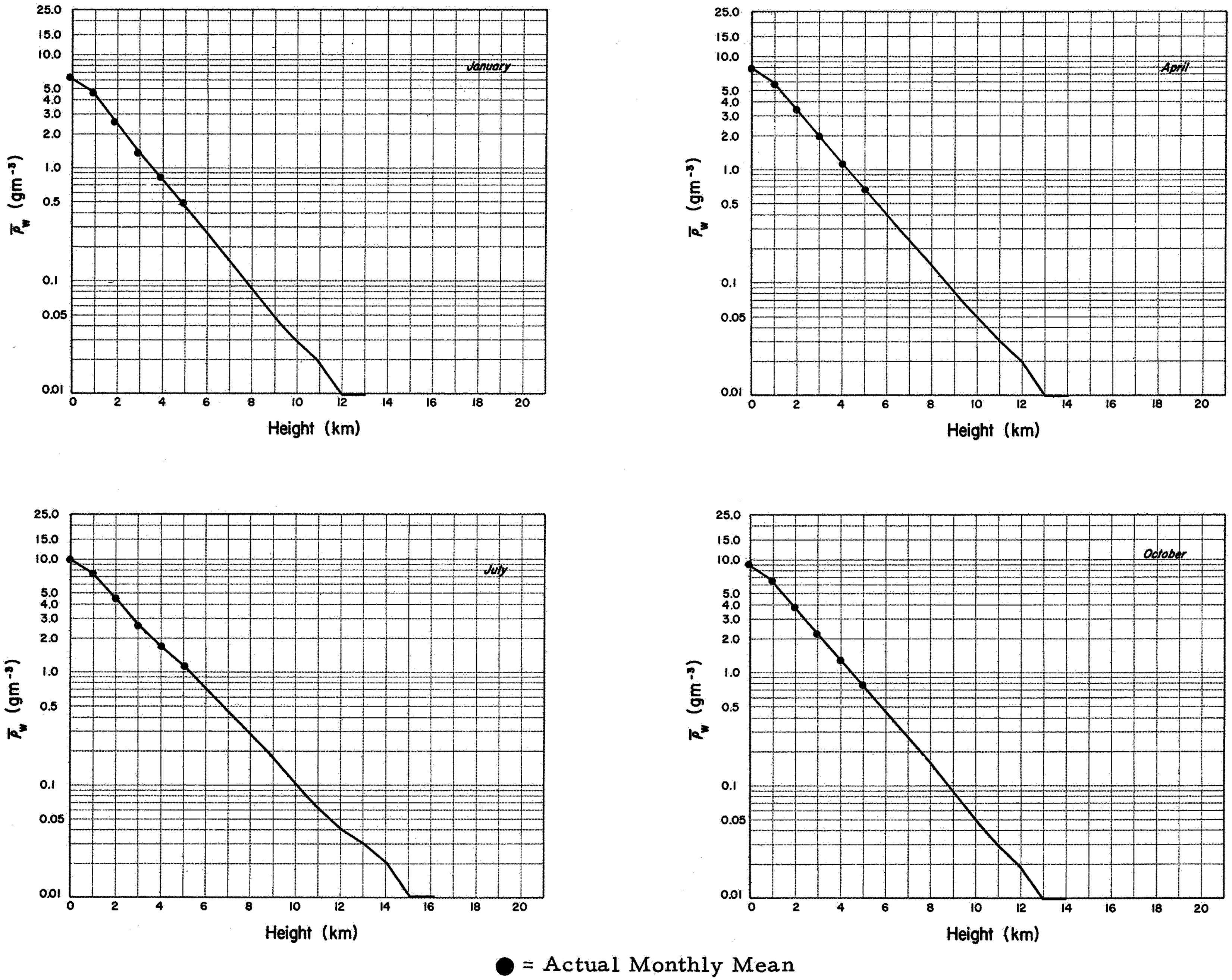


Figure 12 Comparison between Actual and Derived Mean Absolute Humidity vs Height for Midseason Months - Region 30

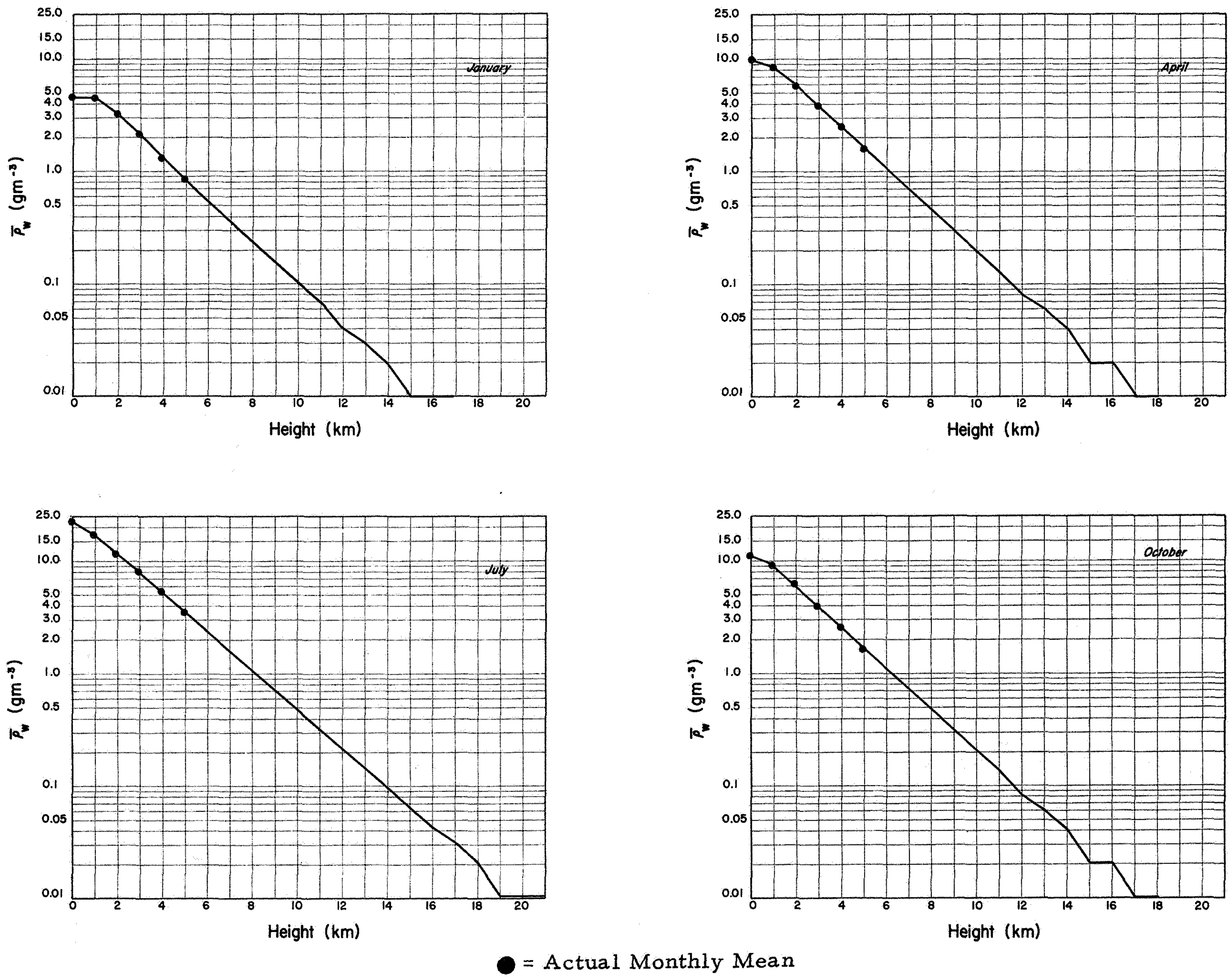


Figure 13 Comparison between Actual and Derived Mean Absolute Humidity vs Height for Midseason Months - Region 34

- Highest annual average moisture is found in equatorial regions (Region 24, Figure 10) with mean surface moisture consistently over 20 g m^{-3} and lowest annual average moisture in the Arctic (Region 1, Figure 6) with surface values consistently less than 4 g m^{-3}. (Smallest seasonal variation is also evident in these regions.)
- Moderate to large seasonal variation occurs in mid-latitude regions (Regions 7, 14 and 34; Figures 7, 8 and 13, respectively).
- Total mean moisture in the column from the surface to 5 km is higher for July in the mid-latitude (Region 34, Figure 13) than it is for the equatorial region (Region 24, Figure 10).
- Average moisture is higher for the desert (Region 30, Figure 12) for most of the year, except summer, than it is for the high mid-latitude continent (Region 7, Figure 7).
- Eastern subtropical and tropical ocean areas (Region 18, Figure 9) show only minor seasonal changes with lowest moisture in winter and spring.
- Moisture from 2 km to 5 km is noticeably higher for mountain regions (Region 26, Figure 11) than it is for the desert areas (Region 30, Figure 12).

The gradient of moisture across a region for a particular month is related, in part, to the mean variance value for the region. It is possible, however, to have a relatively high daily variance in a region where the moisture gradient is small; e.g., in the tropical (high moisture) regions. Conversely, it is also possible to have relatively small mean daily variance values in a region where there is a strong moisture gradient for a particular month (due to little movement of the moisture gradient from day to day). For example, mid latitude Regions 6 and 7 in July have fairly strong moisture gradients, but mean variance values are not high.

Although moisture data were not available above 5 km and are therefore not part of the statistics at each data point, fitting points on the moisture profiles for each month and each region with the exponential functions (described in the next section) result in complete moisture profiles. Examples of the complete profile curves from fitting exponential functions to the data are shown in Figures 6 through 13. Differences between "actual" and "curve fitted" profiles in the lower 5 km are nearly negligible.

Moisture profiles for all the homogeneous regions are given in Appendix A. The highest mean moisture profile values in the world are over India and the north Indian Ocean (Region 36) during the monsoon season (late spring through summer).

Mean temperature profiles for each region (shown for selected regions and months in Appendix A behave as expected with the usual Arctic to equatorial increase and with an annual cycle for most of the globe. The exceptions are highest temperatures observed over the desert regions of the world in the summer months and lower temperatures in Regions 4 and 5 (polar continent and subpolar) than in Region 3 (subarctic oceans).

Mean monthly pressure is not very meaningful across some of the high latitude regions, because of the strong mean pressure gradient across these regions, particularly in the winter months. Mean pressure values for the surface in some non-ocean regions may consist of values computed from locations that are at different elevations above sea level. Thus the mean surface pressure values as given in the statistics for these regions are not really representative of the value at any specific location. This is particularly true in mountainous regions (26 and 27) where elevations vary widely over short distances. For Region 27, any data below 3 km should be disregarded.

The analytic functions, however, provide for computations of surface pressure from the hydrostatic equation using temperature data at the surface and 1 km above the surface. Thus, the computed surface pressures for these regions are hydrostatically consistent with the temperature data. Mean monthly density is nearly the inverse of the temperature distributions because of the relationship given by the equation of state; i.e., maximum densities in the cold season and colder regions, lowest densities in the high temperature regions and the summer season. Selected density curves are shown in Appendix A.

3.3 Analytical Representation of Atmospheric Profiles

The statistics comprising mean monthly values and variances of the atmospheric variables developed for each region and month at 1-km intervals from the surface to 25 km were fitted by analytical functions in a manner designed to minimize the number of numerical coefficients.

All variables and their standard deviations, except means for pressure and density, were represented as simple power series, multiplied by a single exponential term (for the more rapidly decaying variables), according to Eq. (10)*.

---

*For the special case of the water vapor variable, for altitudes above 5 km (for which no data were available), instead of using Eq.(10), extrapolated estimates of water vapor were made from the equation $Y = Y_5 \exp(-G(z-5))$, where Y_5 is the computed value of Y at 5 km.

$$Y = \exp(-Gz)\left[\sum_{n=1}^{N} a_n z^{n-1}\right]^M \qquad (10)$$

where

Y is the atmospheric variable

N is the number of terms in the power series for each variable

G is a constant to be determined for each region and month

a_n are coefficients to be computed for each region and month

z is altitude above sea level in km

and M is +1 or -1 (see Table 5)

Some values and bounds of values for G, M and N for each variable are listed in Table 5. Note that temperature has been represented as the reciprocal of a power series (M = -1) rather than as a direct series (M = 1) because this has the advantage of permitting use of the same coefficients to compute temperature, pressure and density.

Specifically, the pressure follows from the hydrostatic equation ($dp/dz = -\rho g$):

$$p = p_o \exp\left[-\int_o^z (g/RT)\, dz\right]$$

Substituting for T from Eq. (10), we have

$$p = p_o \exp\left[-(g/R) \sum_{n=1}^{N} a_n z^n/n\right] \qquad (11)$$

The density follows from the ideal gas law ($p = \rho RT$)

$$\rho = p/(RT)$$

Substituting for T and p from Eqs. (10) and (11), we have

$$\rho = (p_o/R) \left(\sum_{n=1}^{N} a_n z^{n-1}\right) \exp\left[-(g/R) \sum_{n=1}^{N} a_n z^n/n\right] \qquad (12)$$

where

p is pressure

p_o is pressure at sea level

g is the acceleration of gravity

R is the gas constant

t is temperature

ρ is density

and where the values of the a_n's are those determined for the temperature series according to Eq. (10).

TABLE 5

VALUES FOR CONSTANTS IN EQUATION (10)

Variable	G	M	N
Temperature	0	-1	9
Absolute humidity	>0		6
Standard deviation of pressure	0	1	9
Standard deviation of temperature	0	1	9
Standard deviation of density	0	1	9
Standard deviation of absolute humidity	>0	1	1

To evaluate the coefficients for Eq. (10), first the constant G (if not taken as zero) was determined. For water vapor and its variance, the data, in general, varied exponentially with altitude. Thus, a good estimate of G could be established without much ambiguity.

The a_n coefficients for temperature, temperature variance, pressure variance and density variance were obtained by the least squares method for an 8th degree polynomial (resulting in 9 coefficients).

The a_n coefficients for the water vapor variable were determined exactly by fitting the lowest possible degree polynomial to the not more than 6 data points used as a basis for each set of calculations.

For all of the variables, for at least some conditions, it was found by application of techniques described by Lanczos (1956) that lower degree polynomials than are indicated by the N-values in Table 5 could be systematically fitted to the data without serious loss of accuracy. This systematic procedure was incorporated in the computer program used to determine the a_n coefficients in our study. It was used primarily as an internal check on the reliability of the a_n coefficients determined by the least squares method, but it also permitted us to eliminate coefficients of higher degree in the power series for the water vapor variables.

This curve fitting procedure produced profiles of the various parameters and their variances that, in general, were very near the input values from the profile statistics; i.e., note that ●'s on Figures 6 through 13 fall either on or very close to solid curves. Also, compare actual vs curve fit profiles of temperature shown in Appendix A. For density, actual and curve fit profiles were nearly identical when plotted on semilog paper.

For operational purposes, the coefficients for generating mean profiles and variances for all variables, months and regions are available on both punched cards and magnetic tape. This library of coefficients is to be used with the computer program that selects the appropriate coefficients given the latitude, longitude, and month.

4. DETAILED MOISTURE ANALYSES

Using individual radiosonde observations, more detailed analyses were performed for two sites. Temporal conditional tables at 12 and 24 hour intervals were computed for the moisture content (expressed in absolute humidity) at kilometer levels. In addition, the feasibility of developing frequency distributions of categorized moisture content profiles was investigated. By suitably combining the temporal conditionals for moisture with the frequency distributions, it should be possible to develop unconditional and temporal conditional descriptions of the water vapor field as has recently been done with cloud-amount statistics (Sherr et al, 1968). The next logical step would be the incorporation of simulation routines to predict the attenuation characteristics likely to be encountered as a function of location and time of year and/or time of day.

4.1 Conditional Probability Relationships

Two magnetic tapes containing daily (0000 and 1200 GMT) radiosonde data for homogeneous moisture regions 11 and 17 were acquired from NASA/MSFC. The individual stations and their corresponding periods of record are shown in Table 6. The data were in the Card Deck 645 format at standard pressure levels up to 1 mb. At each pressure level, the height, temperature, relative humidity, wind direction and wind speed are recorded. For the surface observations, the atmospheric pressure is recorded in those columns otherwise reserved for height values.

TABLE 6

STATIONS USED FOR DETAILED MOISTURE ANALYSES

Region	Station Name	Station Number	Period of Record
11	Norfolk, Va.	13737	1/1/61 - 8/2/65
11	Wallops Island, Va.	93739	8/3/65 - 6/3/70
17	Burrwood, La.	12863	1/1/61 - 2/12/65
17	Boothville, La.	12884	2/13/65 - 8/10/69

A computer program was written to do the following:

1) Use the relative humidity and temperature data to calculate absolute humidities at the indicated pressure levels.

2) Linearly interpolate these values to generate absolute humidities at kilometer levels (11 levels, surface through 10 km).

3) Output these data onto magnetic tape for subsequent processing.

In the linear interpolations of Step 2 above, "motor-boating" values were assigned an absolute humidity of zero. In setting up the desired 12 and 24 hour conditional tables, a separate "zero" water vapor content category was established which is to be interpreted as motor-boating data rather than a complete absence of water vapor. The output tape of Step 3 has been preserved and can be used for developing conditional relationships other than those described here.

Because of the rapid decrease of water vapor with height, no single set of water vapor categories can work at all levels. Our objective in this case was to generate tables which would be compatible with the general results described in the previous sections. Eight water vapor categories were defined relative to the regional mean (as given in the overall results) for the appropriate height, location and month. These water vapor categories and their corresponding definitions are listed below.

Category No.	Definition
1	Motor Boating
2	More than two standard deviations below the regional mean
3	Between one and two standard deviations below the regional mean
4	Between one-half and one standard deviation below the regional mean
5	Within one-half a standard deviation of the regional mean
6	Between one-half and one standard deviation above the regional mean
7	Between one and two standard deviations above the regional mean
8	More than two standard deviations above the regional mean

The monthly means and variances (applicable to daily values) for Regions 11 and 17 were extracted for six kilometer levels (surface through 5 km). These were then used to assign water vapor categories to the daily Virginia and Louisiana data. (In setting up the final tables, we did not distinguish between Norfolk and Wallops Island or between Burrwood and Boothsville because in each case the stations are sufficiently close to each other to be equally representative of their respective local areas.)

Temporal conditional tables were generated at all six height levels and for both 12 and 24 hour time intervals. In addition, 24 hour conditionals for both noon and midnight (GMT) were developed. Figures 14 through 16 show sample output tables for Region 17, Month 1 (January). Two eight by eight conditional tables (for two height levels) are printed on each computer page. The regional means and corresponding standard deviations for the appropriate month for all six height levels are listed just under the identification line at the top of each page. Level 0 indicates the surface observations, while Levels 1, 2, etc., refer to heights of 1, 2, etc. kilometers. The first line (F) of each row indicates the actual number of times a particular category was entered. The second line (P) indicates the final probabilities

STATION NUMBERS 12863 AND 12884 REGION NUMBER 17 MONTH 1 12 HR CONDITIONAL PROBABILITY

REGION DATA

MEANS
12.40 7.61 4.31 2.42 1.49 0.91

STANDARD DEVIATIONS
3.59 2.39 1.62 1.06 0.70 0.47

LEVEL 0	1	2	3	4	5	6	7	8	T
1F	0	0	1	0	1	0	0	0	2
P	0.0	0.0	0.50	0.0	0.50	0.0	0.0	0.0	1.00
2F	0	46	25	1	0	0	0	0	72
P	0.0	0.64	0.35	0.01	0.0	0.0	0.0	0.0	1.00
3F	0	21	110	33	15	0	0	0	179
P	0.0	0.12	0.61	0.18	0.08	0.0	0.0	0.0	1.00
4F	0	3	22	21	41	0	0	0	87
P	0.0	0.03	0.25	0.24	0.47	0.0	0.0	0.0	1.00
5F	0	4	15	25	65	25	11	0	145
P	0.0	0.03	0.10	0.17	0.45	0.17	0.08	0.0	1.00
6F	0	0	3	4	18	10	4	0	39
P	0.0	0.0	0.08	0.10	0.46	0.26	0.10	0.0	1.00
7F	0	0	4	2	4	5	3	0	18
P	0.0	0.0	0.22	0.11	0.22	0.28	0.17	0.0	1.00
8F	0	0	0	0	0	0	0	0	0
P	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T P	0.00	0.13	0.33	0.16	0.27	0.07	0.03	0.0	542.

LEVEL 1	1	2	3	4	5	6	7	8	T
1F	0	5	1	1	0	1	1	0	9
P	0.0	0.56	0.11	0.11	0.0	0.11	0.11	0.0	1.00
2F	4	73	26	11	10	1	1	0	126
P	0.03	0.58	0.21	0.09	0.08	0.01	0.01	0.0	1.00
3F	2	28	27	8	22	3	2	2	94
P	0.02	0.30	0.29	0.09	0.23	0.03	0.02	0.02	1.00
4F	0	6	10	3	17	5	3	0	44
P	0.0	0.14	0.23	0.07	0.39	0.11	0.07	0.0	1.00
5F	0	8	21	15	42	23	14	0	123
P	0.0	0.07	0.17	0.12	0.34	0.19	0.11	0.0	1.00
6F	1	4	2	3	18	11	18	2	59
P	0.02	0.07	0.03	0.05	0.31	0.19	0.31	0.03	1.00
7F	0	4	7	1	15	13	38	1	79
P	0.0	0.05	0.09	0.01	0.19	0.16	0.48	0.01	1.00
8F	0	0	1	1	0	2	2	2	8
P	0.0	0.0	0.13	0.13	0.0	0.25	0.25	0.25	1.00
T P	0.02	0.23	0.17	0.08	0.23	0.11	0.15	0.01	542.

Figure 14 Example of Twelve Hour Moisture Conditionals for January - Region 17

STATION NUMBERS 12863 AND 12884   REGION NUMBER 17   MONTH 1   24 HR CONDITIONAL PROBABILITY 0

REGION DATA

MEANS 12.40 7.61 4.31 2.42 1.49 0.91

STANDARD DEVIATIONS 3.59 2.39 1.62 1.06 0.70 0.47

LEVEL 0	1	2	3	4	5	6	7	8	T
1F	0	0	0	1	0	0	1	0	2
P	0.0	0.0	0.0	0.50	0.0	0.0	0.50	0.0	1.00
2F	0	13	16	4	2	0	0	0	35
P	0.0	0.37	0.46	0.11	0.06	0.0	0.0	0.0	1.00
3F	0	11	32	16	18	2	0	0	79
P	0.0	0.14	0.41	0.20	0.23	0.03	0.0	0.0	1.00
4F	0	7	9	6	15	3	1	0	41
P	0.0	0.17	0.22	0.15	0.37	0.07	0.02	0.0	1.00
5F	0	3	16	9	32	7	7	0	74
P	0.0	0.04	0.22	0.12	0.43	0.09	0.09	0.0	1.00
6F	0	1	2	3	3	8	3	0	20
P	0.0	0.05	0.10	0.15	0.15	0.40	0.15	0.0	1.00
7F	0	1	5	1	4	1	3	0	15
P	0.0	0.07	0.33	0.07	0.27	0.07	0.20	0.0	1.00
8F	0	0	0	0	0	0	0	0	0
P	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T P	0.01	0.13	0.30	0.15	0.28	0.08	0.06	0.0	266.

LEVEL 1	1	2	3	4	5	6	7	8	T
1F	1	1	1	0	0	1	1	0	5
P	0.20	0.20	0.20	0.0	0.0	0.20	0.20	0.0	1.00
2F	1	19	12	8	16	1	3	1	61
P	0.02	0.31	0.20	0.13	0.26	0.02	0.05	0.02	1.00
3F	1	13	13	6	8	4	0	1	46
P	0.02	0.28	0.28	0.13	0.17	0.09	0.0	0.02	1.00
4F	0	2	3	4	8	1	5	1	24
P	0.0	0.08	0.13	0.17	0.33	0.04	0.21	0.04	1.00
5F	0	14	5	2	15	8	11	0	55
P	0.0	0.25	0.09	0.04	0.27	0.15	0.20	0.0	1.00
6F	0	4	3	3	5	7	4	1	27
P	0.0	0.15	0.11	0.11	0.19	0.26	0.15	0.04	1.00
7F	0	7	8	1	5	4	16	1	42
P	0.0	0.17	0.19	0.02	0.12	0.10	0.38	0.02	1.00
8F	1	2	0	0	0	2	1	0	6
P	0.17	0.33	0.0	0.0	0.0	0.33	0.17	0.0	1.00
T P	0.02	0.23	0.17	0.09	0.21	0.10	0.16	0.02	266.

Figure 15 Example of Twenty-Four Hour Moisture Conditionals for 0000 GMT, January - Region 17

STATION NUMBERS 12863 AND 12884 REGION NUMBER 17 MONTH 1 24 HR CONDITIONAL PROBABILITY 12

REGION DATA

MEANS 12.40 7.61 4.31 2.42 1.49 0.91

STANDARD DEVIATIONS 3.59 2.39 1.62 1.06 0.70 0.47

LEVEL 0	1	2	3	4	5	6	7	8	T
1F	0	0	0	0	0	0	0	0	0
P	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2F	0	16	14	5	1	0	0	0	36
P	0.0	0.44	0.39	0.14	0.03	0.0	0.0	0.0	1.00
3F	0	10	55	16	15	2	0	0	98
P	0.0	0.10	0.56	0.16	0.15	0.02	0.0	0.0	1.00
4F	0	1	10	12	19	3	0	0	45
P	0.0	0.02	0.22	0.27	0.42	0.07	0.0	0.0	1.00
5F	0	8	12	8	26	11	2	0	67
P	0.0	0.12	0.18	0.12	0.39	0.16	0.03	0.0	1.00
6F	0	1	4	3	7	2	0	0	17
P	0.0	0.06	0.24	0.18	0.41	0.12	0.0	0.0	1.00
7F	0	0	2	1	0	0	0	0	3
P	0.0	0.0	0.67	0.33	0.0	0.0	0.0	0.0	1.00
8F	0	0	0	0	0	0	0	0	0
P	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T P	0.0	0.14	0.37	0.17	0.25	0.06	0.01	0.0	266.

LEVEL 1	1	2	3	4	5	6	7	8	T
1F	0	2	0	0	1	0	0	0	3
P	0.0	0.67	0.0	0.0	0.33	0.0	0.0	0.0	1.00
2F	1	25	14	6	14	2	2	0	64
P	0.02	0.39	0.22	0.09	0.22	0.03	0.03	0.0	1.00
3F	2	13	8	2	15	6	1	0	47
P	0.04	0.28	0.17	0.04	0.32	0.13	0.02	0.0	1.00
4F	0	6	6	2	5	0	0	0	19
P	0.0	0.32	0.32	0.11	0.26	0.0	0.0	0.0	1.00
5F	0	10	9	5	18	9	14	0	65
P	0.0	0.15	0.14	0.08	0.28	0.14	0.22	0.0	1.00
6F	0	4	3	0	8	6	8	1	30
P	0.0	0.13	0.10	0.0	0.27	0.20	0.27	0.03	1.00
7F	0	3	8	2	6	6	11	0	36
P	0.0	0.08	0.22	0.06	0.17	0.17	0.31	0.0	1.00
8F	0	0	0	2	0	0	0	0	2
P	0.0	0.0	0.0	1.00	0.0	0.0	0.0	0.0	1.00
T P	0.01	0.24	0.18	0.07	0.24	0.11	0.14	0.01	266.

Figure 16 Example of Twenty-Four Hour Moisture Conditionals for 1200 GMT, January - Region 17

as determined by dividing through by the marginal sums of the (F) lines. The (T) column contains the marginal sums. The last data row (labeled TP) presents the unconditional distribution of water vapor amounts as divided among the eight categories. The computer printouts for both regions for the remaining levels and months will be provided to NASA/MSFC separately.

Clearly, any number of other water vapor categorizations, or presentation formats, could be imagined. The format presented here would be most useful for research applications in which day to day water vapor variations or departures from the mean are of interest. If the individual station data are sufficiently different from the regional areas, undesirable biases may develop. This situation could be rectified by using the means of individual data sets to define water vapor categories, but then every station and time period would have different category limits. Of course, this might be perfectly acceptable for localized research studies.

On the basis of the experience gained in developing the detailed tabulations (examples shown in Figures 14, 15 and 16), we recommend for practical operational applications of conditional data (such as in mission simulation work) that the following guidelines be used:

1) Reduce the number of water vapor categories to a maximum of five.

2) For strictly operational applications, the moisture categories should be based on actual water vapor amounts keyed to sensor response characteristics rather than to season or region. For research studies, categories centered around the regional means can be used.

3) Stratify the tabulated data by three-month seasons rather than by month.

4) Drop both the noon and midnight 24 hour conditionals and use only the 12 hour conditionals together with a Markov scaling routine.

In establishing the category limits suggested in Item 2 above, remote sensing systems specialists should be consulted to ensure that the water vapor amounts fall into physically significant groupings. In Figure 14, for example, it is seen that the mean water vapor amount at 5 km is 0.91 g/m^3. Given the much larger water vapor amounts at other levels, even a factor of 2 change in this value may have no real significance. It may be that different category limits will be required for different sensor types, although a five-category subdivision of water vapor amounts should suffice for most seasors.

4.2 Moisture Content Profiles

The mean moisture content profiles as derived for the regions described in Section 3.2 reveal an orderly decrease of moisture content with height. Figure 17 is a typical case showing the mean absolute humidity profile for Region 17 in January. Also shown are the one standard deviation curves about the mean. In order to compare mean curves such as these with the actual day to day water vapor profiles, a full year (1961) of twice-daily profiles were examined for the Burrwood, Louisiana station. A variety of listing formats were studied including a tabulation of the actual absolute humidity values, profiles as normalized by the total water content in the column, and cumulative normalized profiles.

With few exceptions, the actual day to day profiles exhibit only small departures from the basic class of curve seen in Figure 17. These departures from the mean and from each other generally fall into three main categories.

1) The total moisture in the column

2) The level at which moisture becomes insignificant

3) The presence (or absence) of a cloud or moist layer at some level above the surface.

Total Moisture

An estimate of the total moisture in a column was determined by adding together the absolute humidities at all levels including the surface. Although this procedure is not strictly correct, the regular spacing of the kilometer level insures that the final absolute humidity total is at least directly proportional to the column moisture total. For the 730 profiles of the Burrwood 1961 data, the column totals ranged from 5.24 g/m^3 to 71.54 g/m^3 with a mean of about 36.40 g/m^3. The frequency distribution of column totals is shown in Figure 18. Clearly the column totals represent one possible means of stratifying the data.

Last Significant Moisture Level

Curves A and B in Figure 19 represent typical moisture profiles. Both are similar in shape to the mean curve displayed in Figure 17. They are fundamentally different, however, in that in curve A measurable moisture occurs as high as 10 km, while in B the last non-motor-boating value was measured at 2 km. Thus another way of categorizing moisture profiles would be by specifying the level at which the absolute humidity falls permanently below some threshold. If only the shape of the profile is of interest, the profiles could be normalized by the total moisture in the column, arranged in a cumulative format and finally categorized by the level at which some percentage of the column total is achieved.

7800

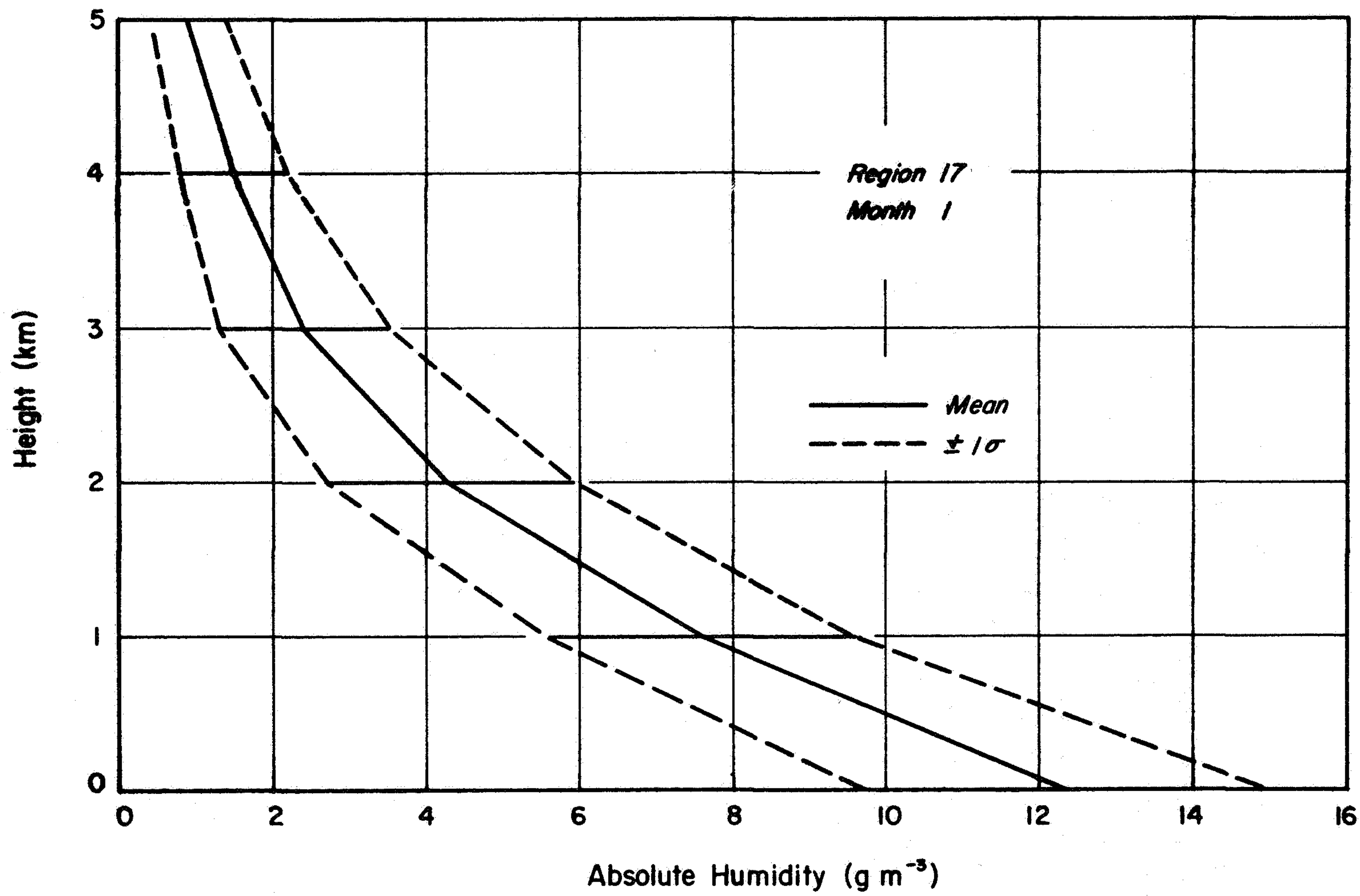


Figure 17 Mean Water Vapor Profile for January - Region 17

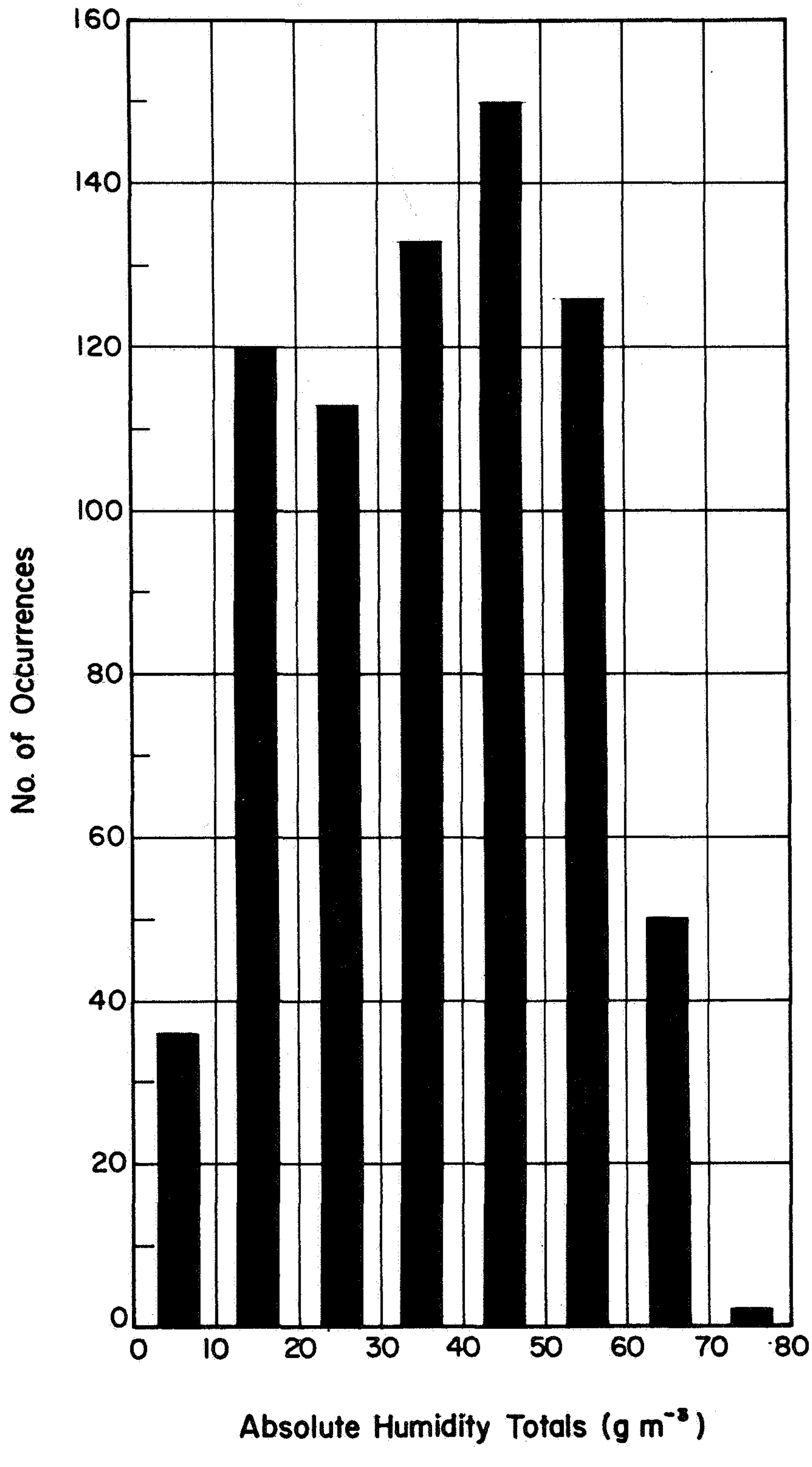


Figure 18 Frequency Distribution of Absolute Humidity Column Totals for 1961 Burrwood Data

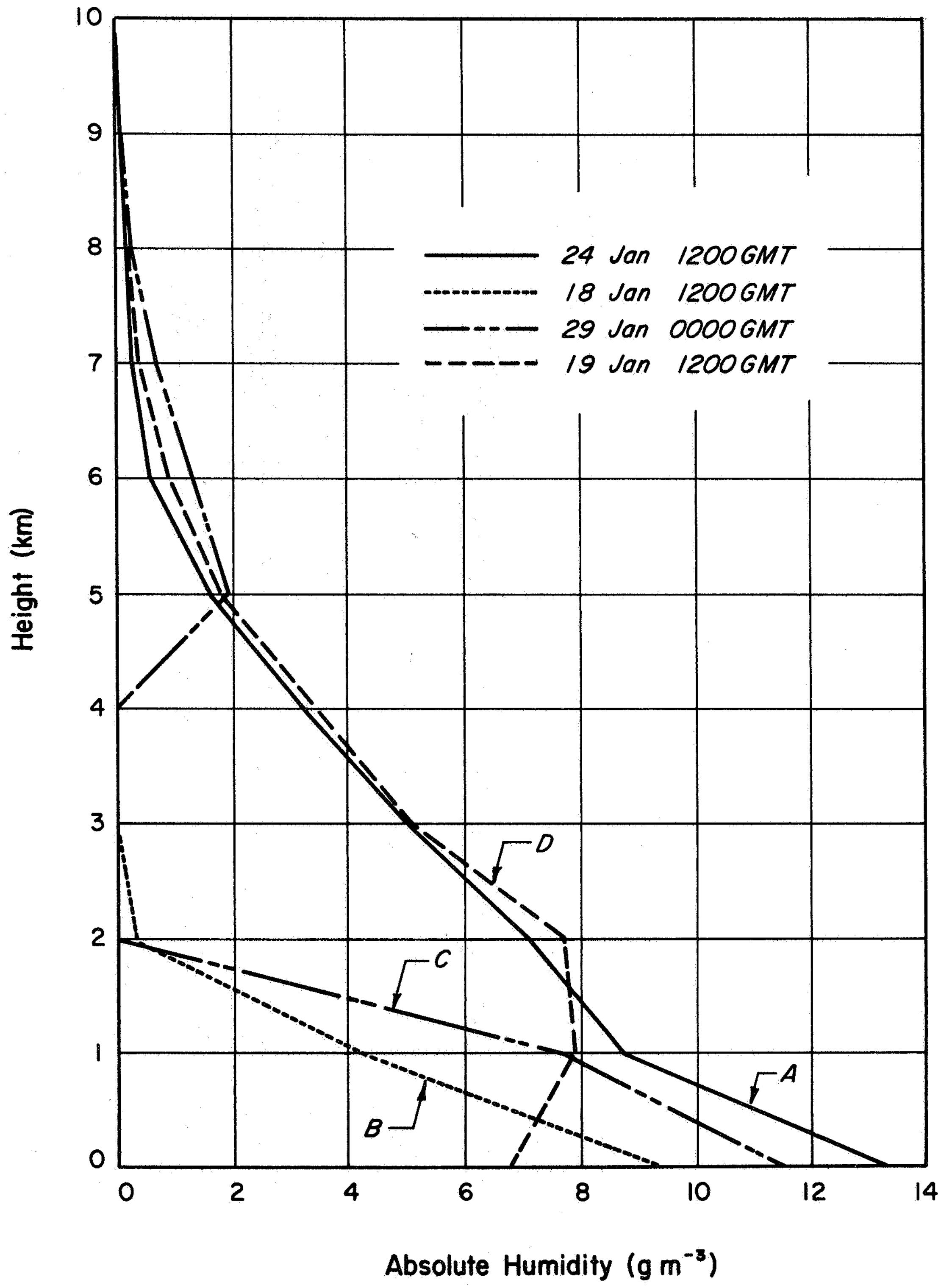


Figure 19 Profile Characteristics for 1961 Burrwood Data

7801

Moisture Layers

Curve C in Figure 19 is typical of those cases where a cloud or other moisture layer is present at some level above the surface. The lower portion of the curve begins as usual, approaching or reaching the zero moisture level, but then increases again when a moist layer is entered. Subsequently it again approaches zero moisture at higher levels. The presence or absence of such an upper level moist layer is thus another categorization parameter.

In about 1% of the cases examined a moisture inversion was noted at the surface. Curve D in Figure 19 presents one such case. It is readily noted by an increase or a very small decrease in the moisture content between the surface and 1 km, rather than the more usual 40% decrease. Again, the presence or absence of such an inversion can be used to establish profile categories, although in this case, the rarity of the phenomenon limits its applicability to a general classification scheme.

On the basis of our study we would recommend a categorization scheme based upon the total moisture content in a column and the presence or absence of an upper level moist layer. Once this or some other categorization scheme is adopted, the development of frequency distributions would be straightforward. As mentioned before, the actual categorization can be tailored to specific research or operational needs. The potential categorization parameters listed above all lend themselves to computer processing and decision making.

5. CONCLUSIONS AND RECOMMENDATIONS

Because the moisture the atmosphere can hold is temperature dependent, and because the temperature over most regions of the globe undergoes an annual cycle and a pole to equator increase, analysis of annual average moisture and its variability lends itself rather well to a homogeneous region classification system. Analytic descriptions of the monthly mean and daily variance profiles of atmospheric parameters for each of the 36 homogeneous regions defined in this study closely approximate the actual profiles computed for each region.

The computer programs written to use the techniques developed here (Willand et al, 1971)* permit simple access to the parameter profiles and their variances from the surface to 25 km, given the month, latitude and longitude (or region number).

These model atmospheric profiles and their variances, when used as input to atmospheric attenuation models, provide useful guidance as to the range and degree of degradation to expect in earth resources data obtained from remote electromagnetic sensors. They may also be used as an aid in the selection of sensors or spectral bands.

On the basis of the results of this study and the continued requirement for knowing the degree of atmospheric attenuation to expect on a particular day and at a specific location, we recommend the following:

1) That the 4-D models be (a) extended upward to 55 km where data permit and (b) refined where appropriate.

2) That techniques and procedures be developed to allow use of the models in computer mission simulations.

3) That the feasibility of combining the 4-D models and the cloud statistics model, to completely describe the expected attenuation, be investigated.

*Appendix B of this report.

6. REFERENCES

Crutcher, H. L. and O. M. Davis, 1969: U. S. Navy Marine Climatic Atlas of the World, Vol. VIII, The World, NAVAIR 50-1C-54, Commander, Naval Weather Service Command.

Finger, F. G. and H. M. Woolf, 1967: Southern Hemisphere Stratospheric Circulation as Indicated by Shipboard Meteorological Rocket Observations, NASA Tech. Memo TMX-1346, Washington, D. C.

Lanczos, C., 1956: Applied Analysis, Prentice Hall, Inc., Englewoods Cliffs, N. J., pp. 457-463.

Lea, D. A., 1961: Regression Equations for Vertical Extrapolation of Constant Pressure Surface Heights and Temperatures Between 200 mb, and 30 mb, (MS 8 pp), U. S. Navy Weather Research Facility, Norfolk, Va.

Peixoto, Jose P., 1970: "Water Balance of the Atmosphere from Five Years of Hemispheric Data," Nordic Hydrology, Vol. 2, 120-138, Copenhagen, Denmark.

Sherr, P. E., A. H. Glaser, J. C. Barnes and J. H. Willand, 1968: Worldwide Cloud Cover Distributions for Use in Computer Simulations, Final Report, Contract No. NAS 8-21040, Allied Research Associates, Inc., Concord, Mass. NASA CR 61226.

Tetens, O., 1930: Zeitschrift für Geophysik, Vol. VI.

APPENDIX A

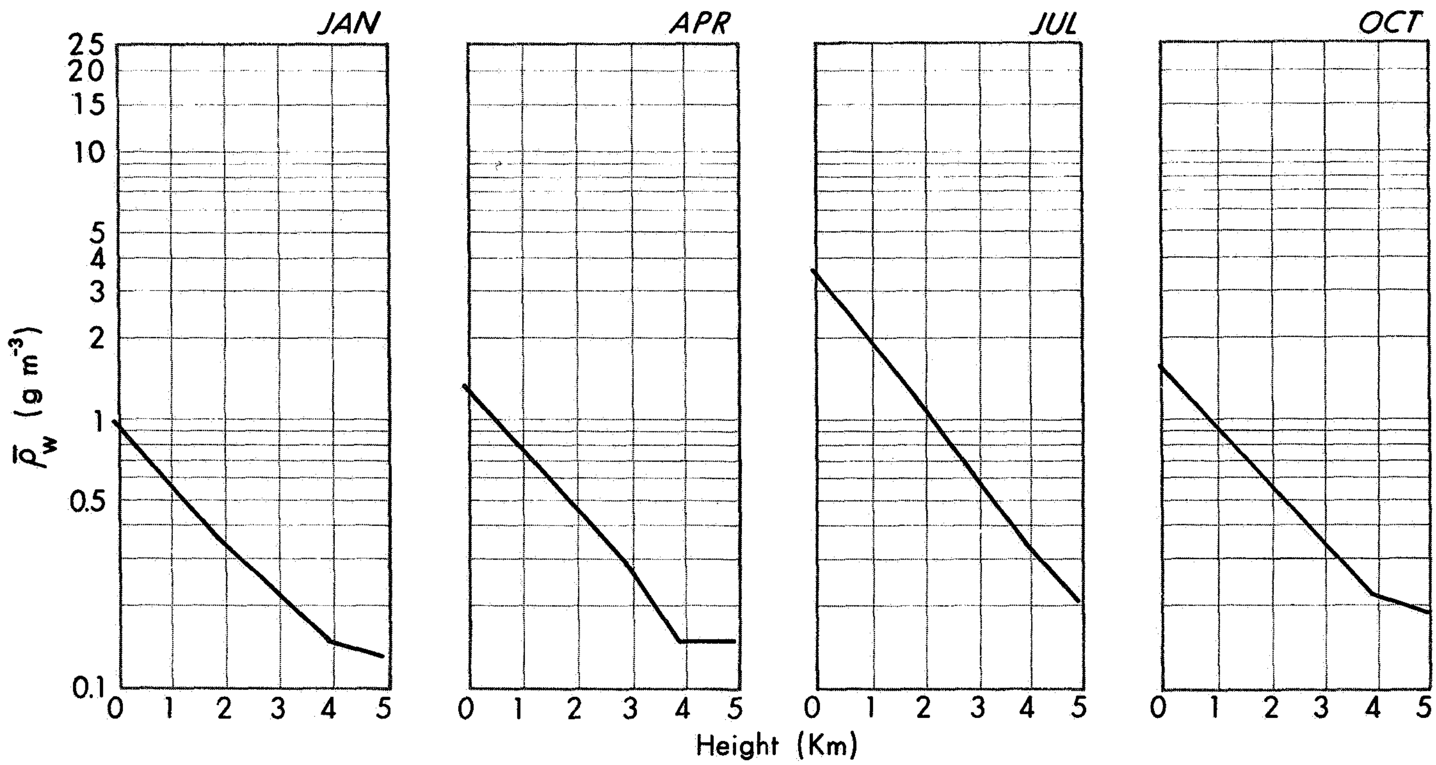


Figure A-1 Mean Absolute Humidity vs Height for Midseason Months - Region 1

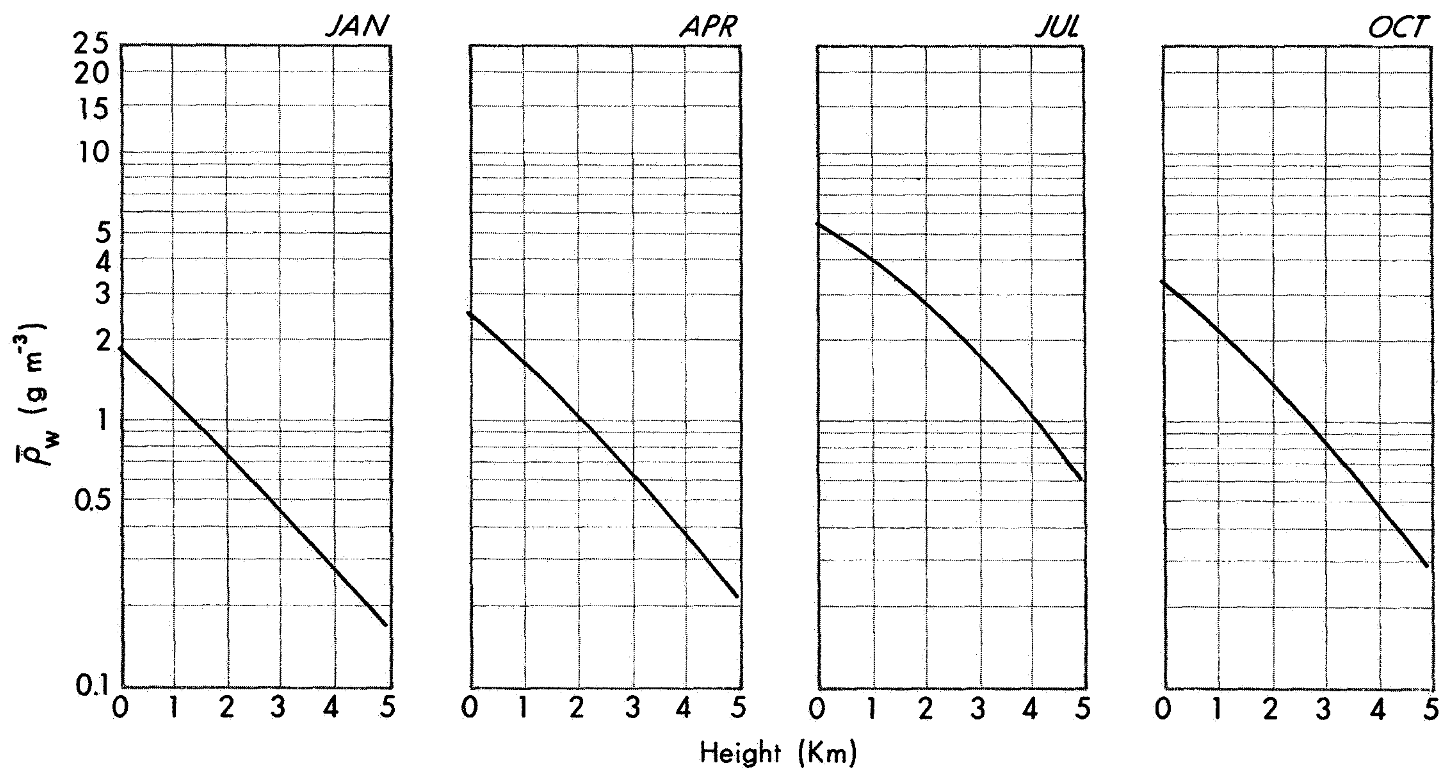


Figure A-2 Mean Absolute Humidity vs Height for Midseason Months - Region 2

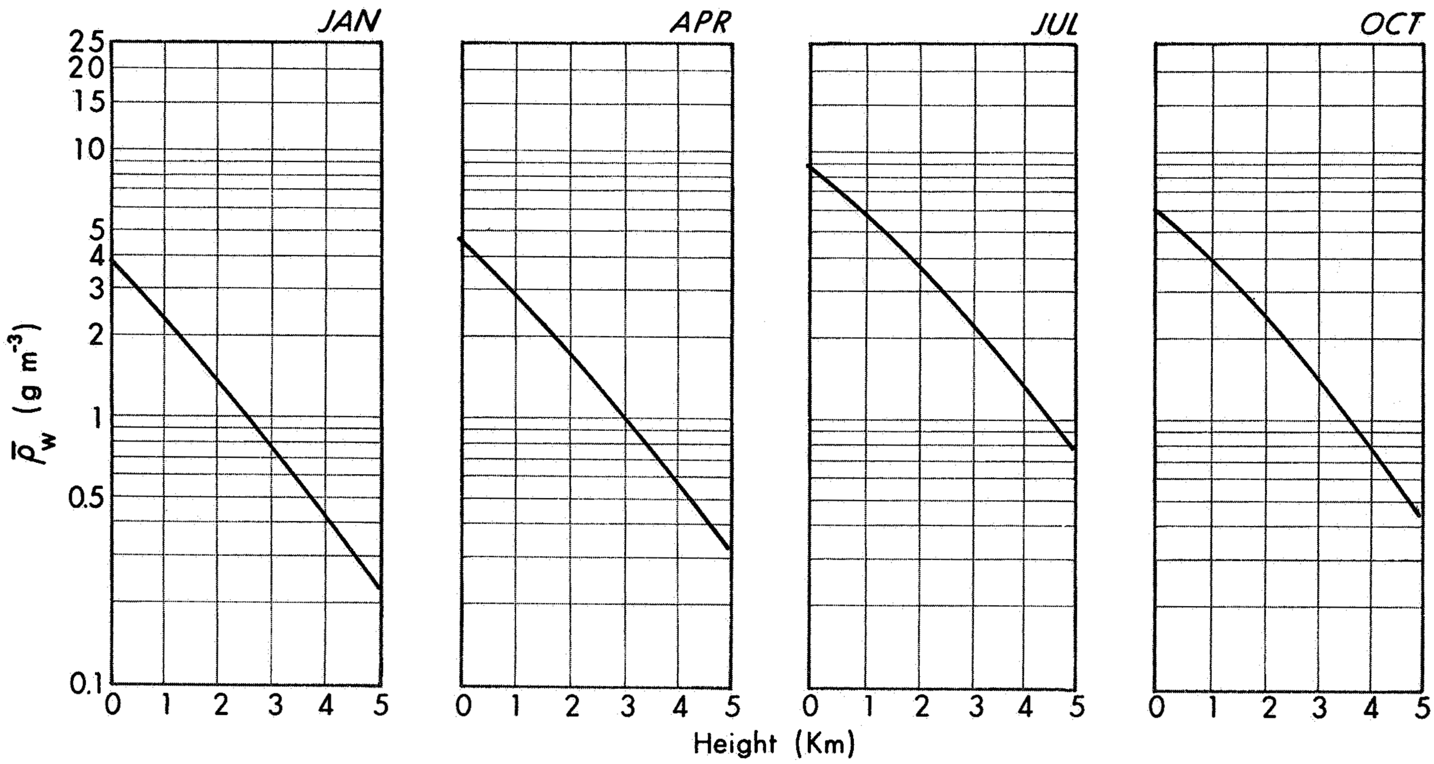


Figure A-3 Mean Absolute Humidity vs Height for Midseason Months - Region 3

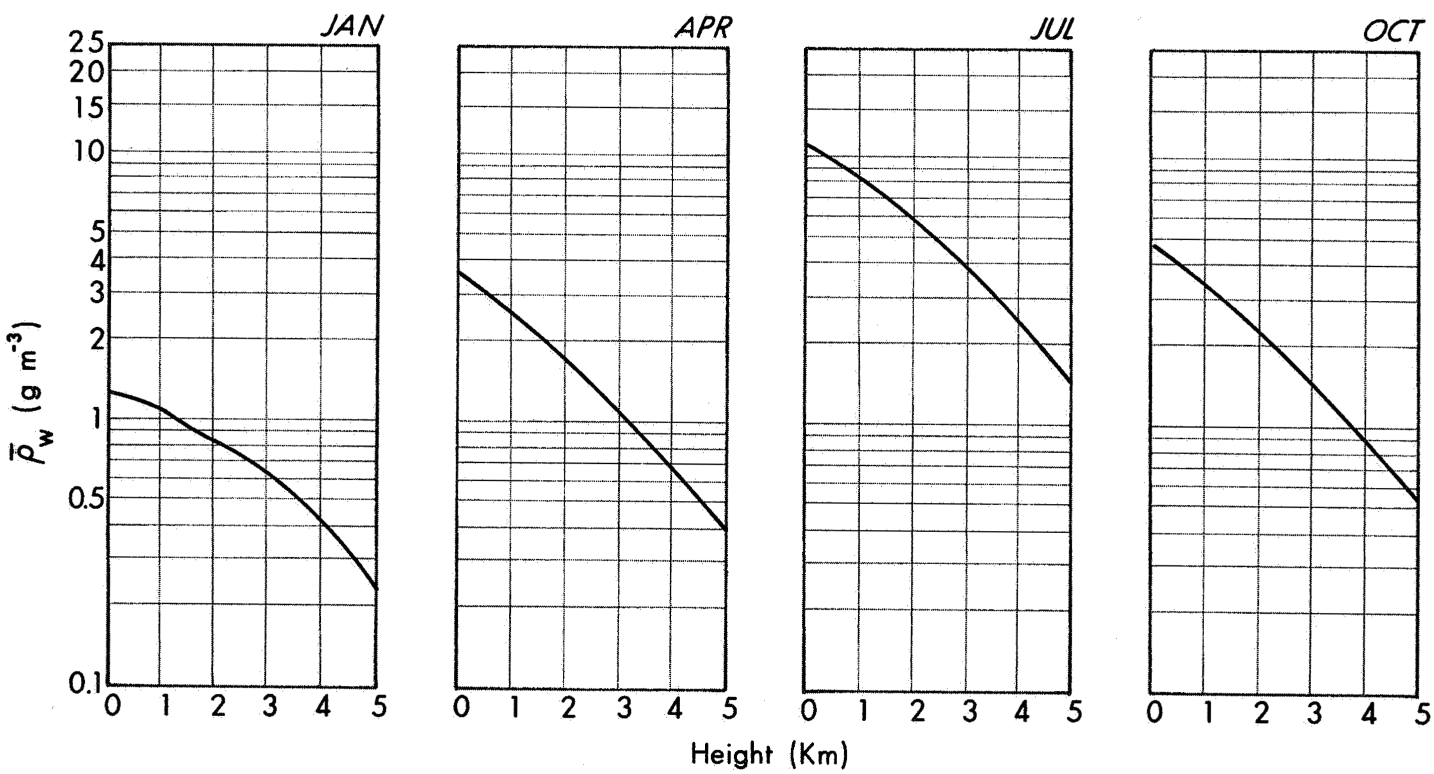


Figure A-4 Mean Absolute Humidity vs Height for Midseason Months - Region 4

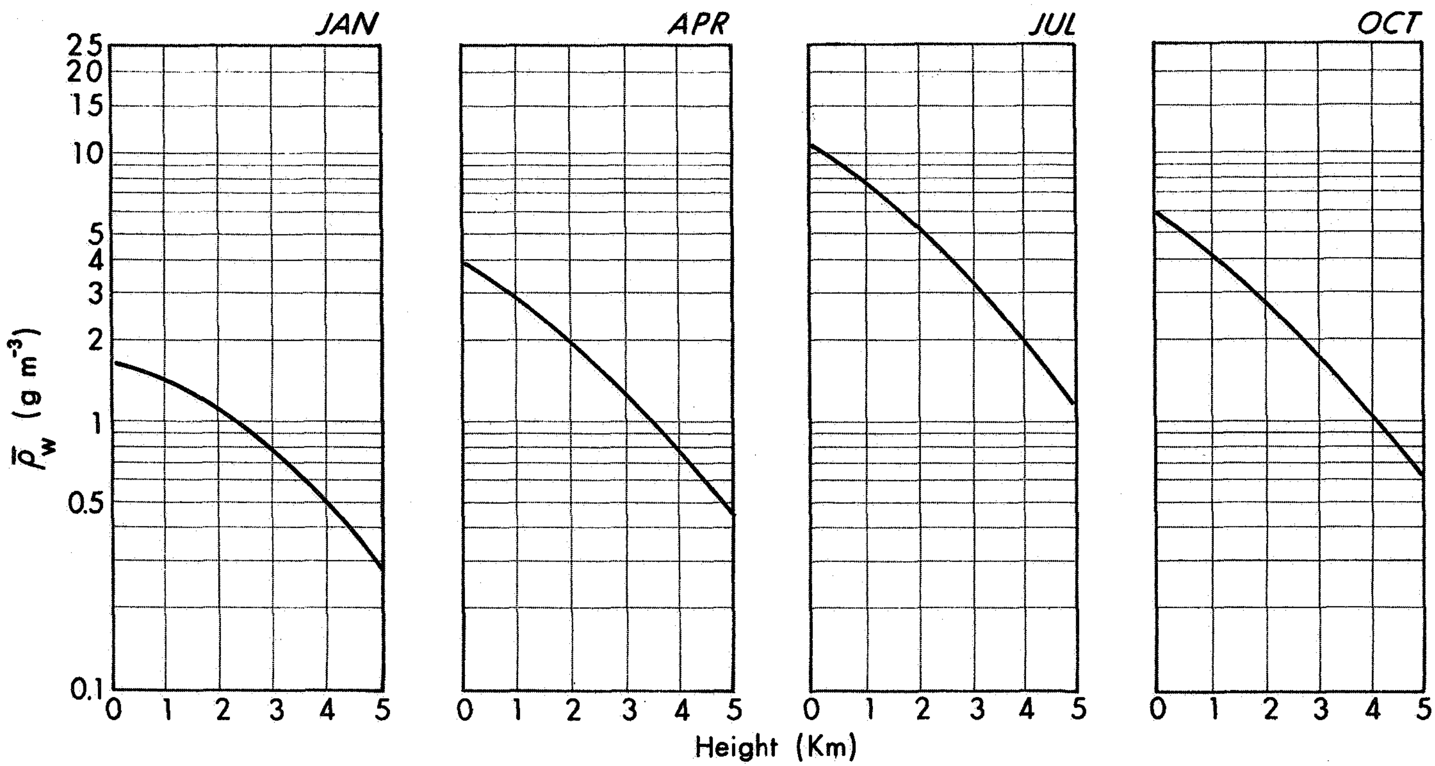


Figure A-5 Mean Absolute Humidity vs Height for Midseason Months - Region 5

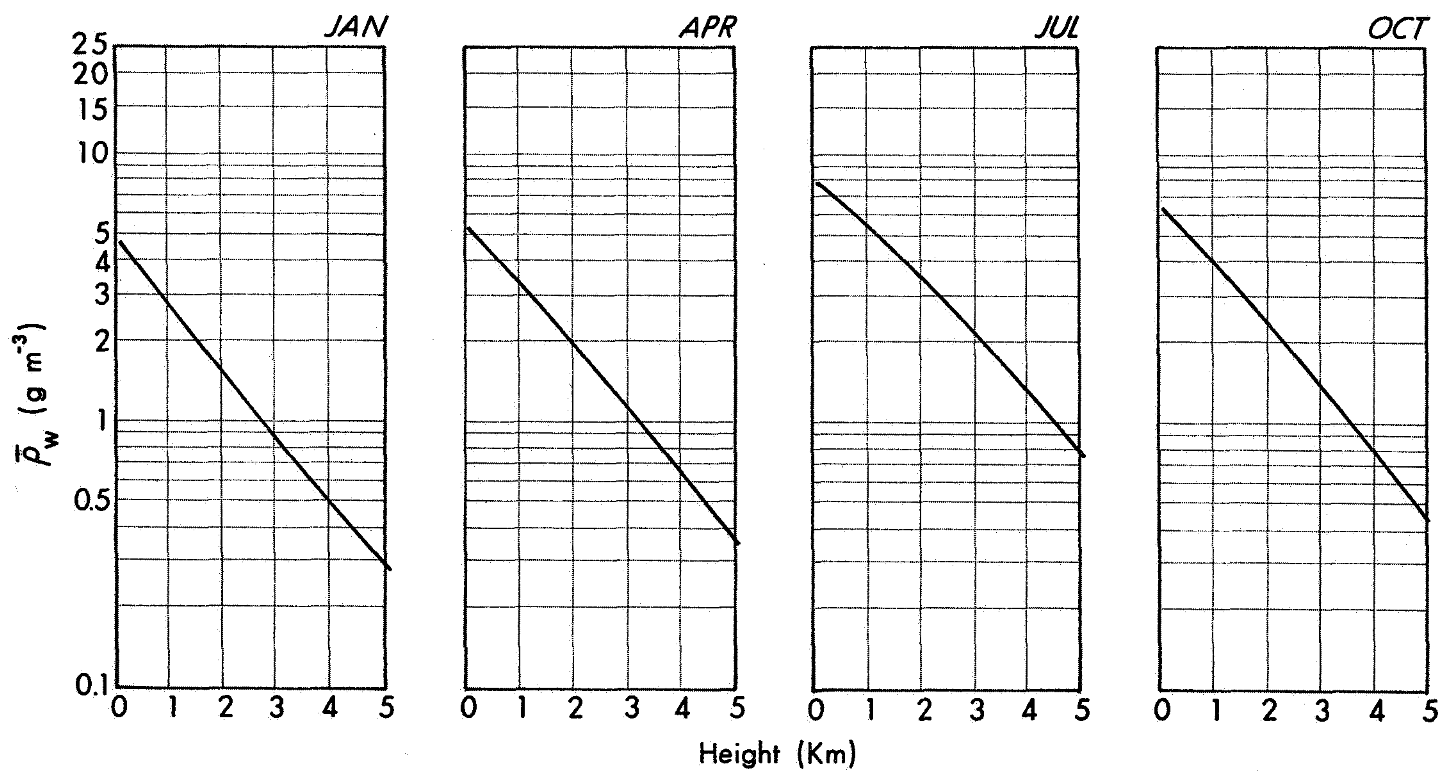


Figure A-6 Mean Absolute Humidity vs Height for Midseason Months - Region 6

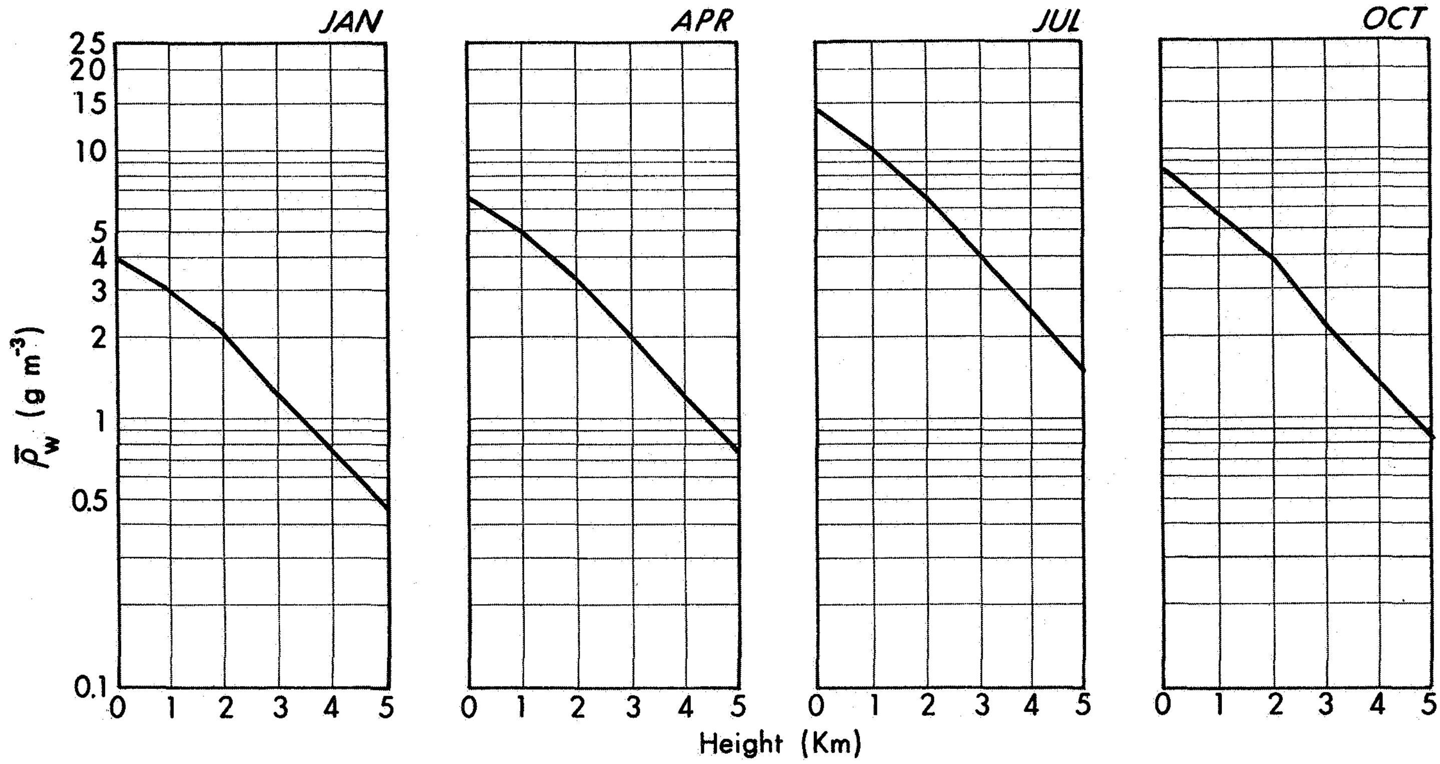


Figure A-7 Mean Absolute Humidity vs Height for Midseason Months - Region 7

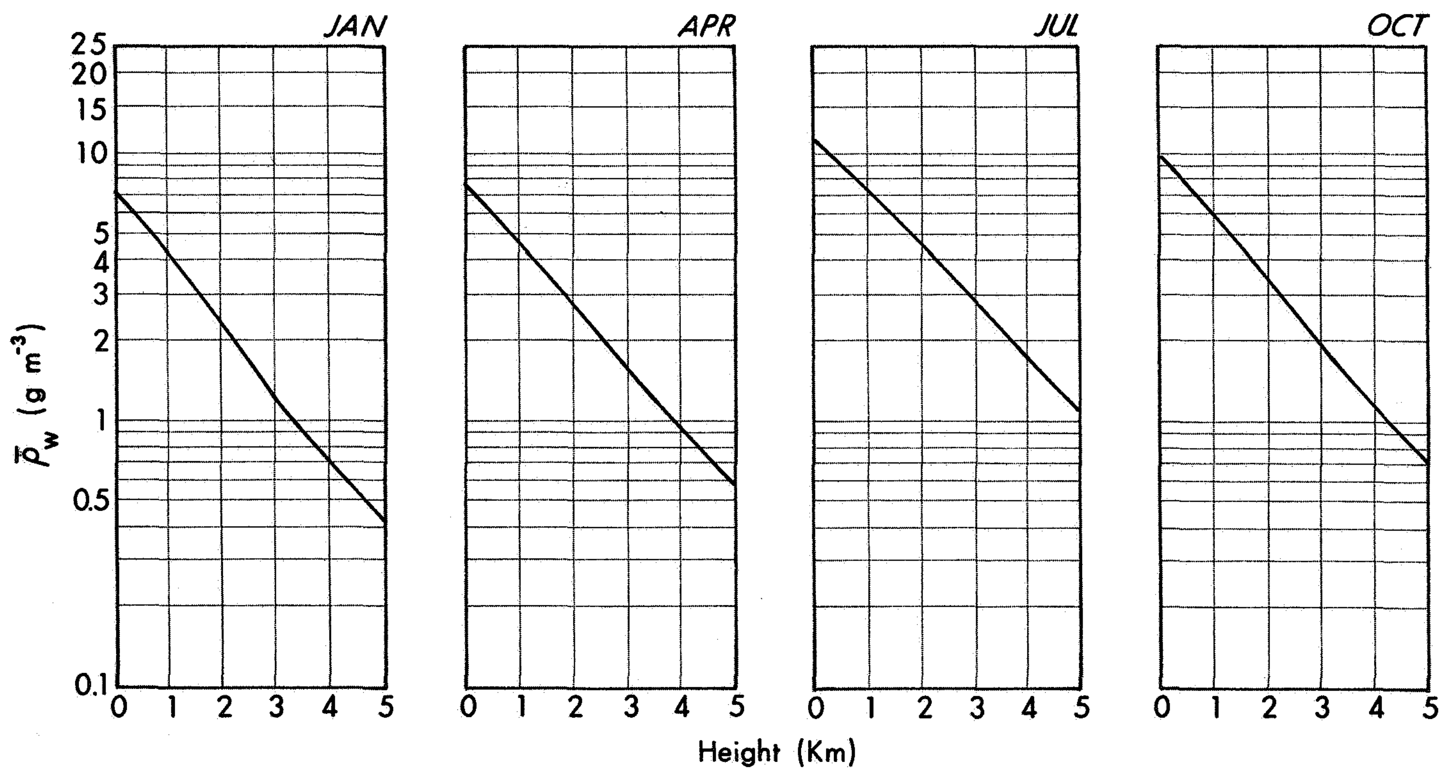


Figure A-8 Mean Absolute Humidity vs Height for Midseason Months - Region 8

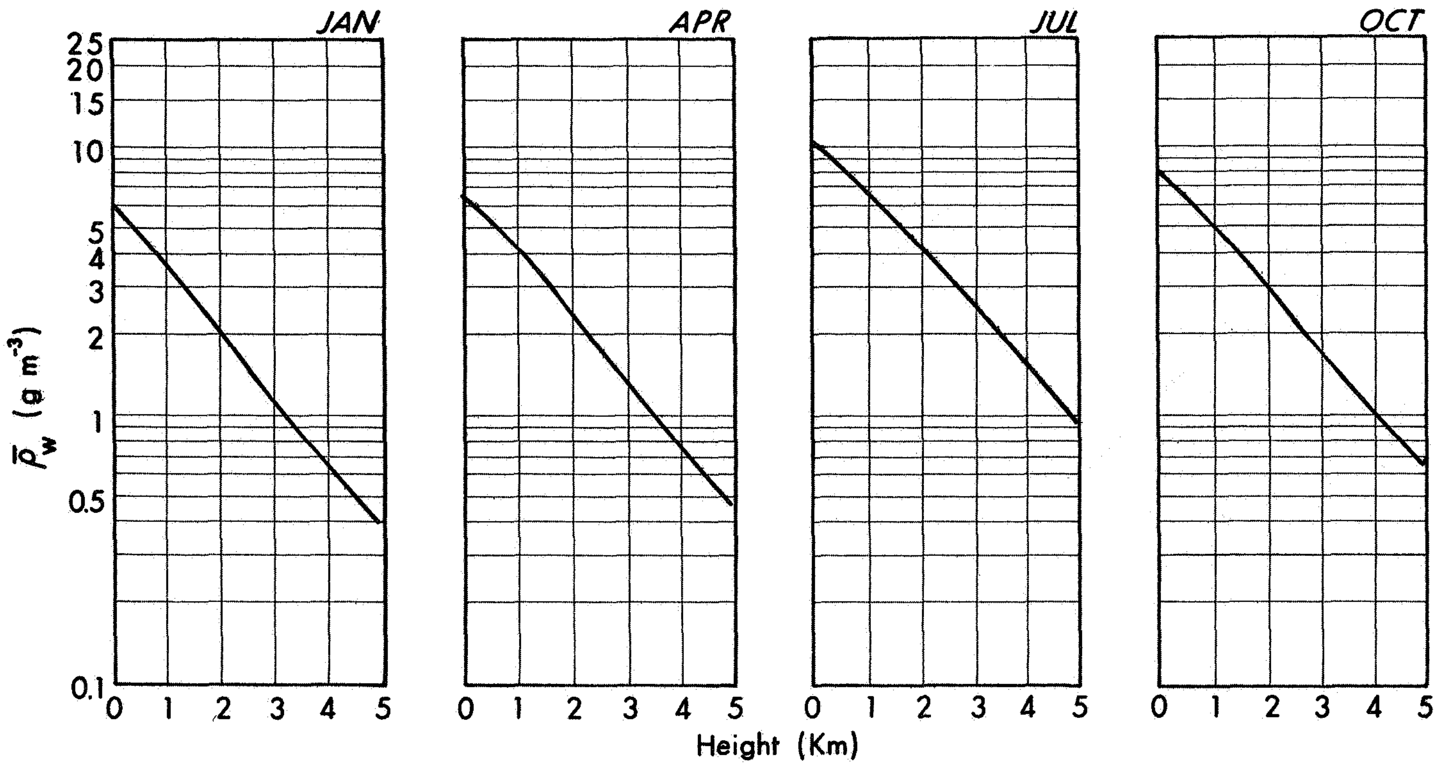


Figure A-9 Mean Absolute Humidity vs Height for Midseason Months - Region 9

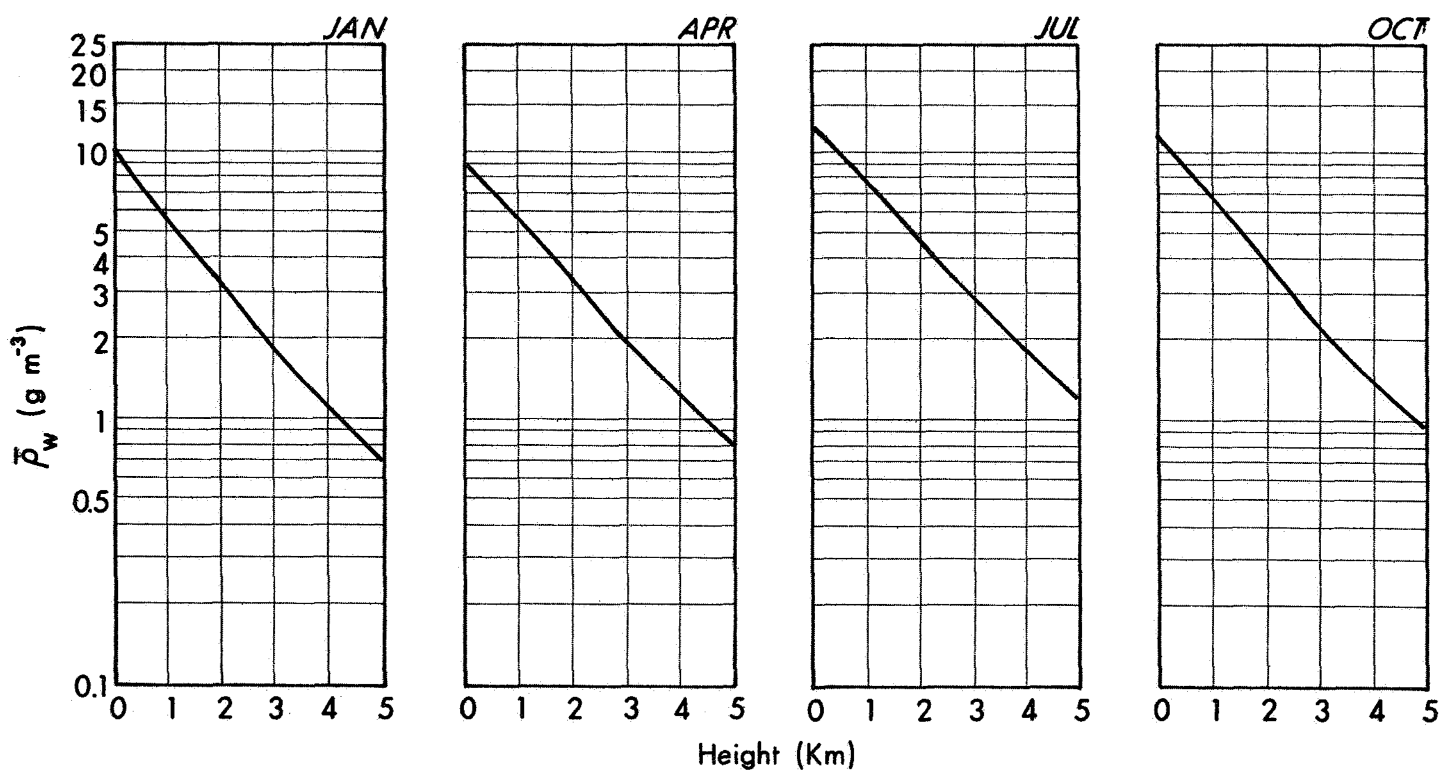


Figure A-10 Mean Absolute Humidity vs Height for Midseason Months - Region 10

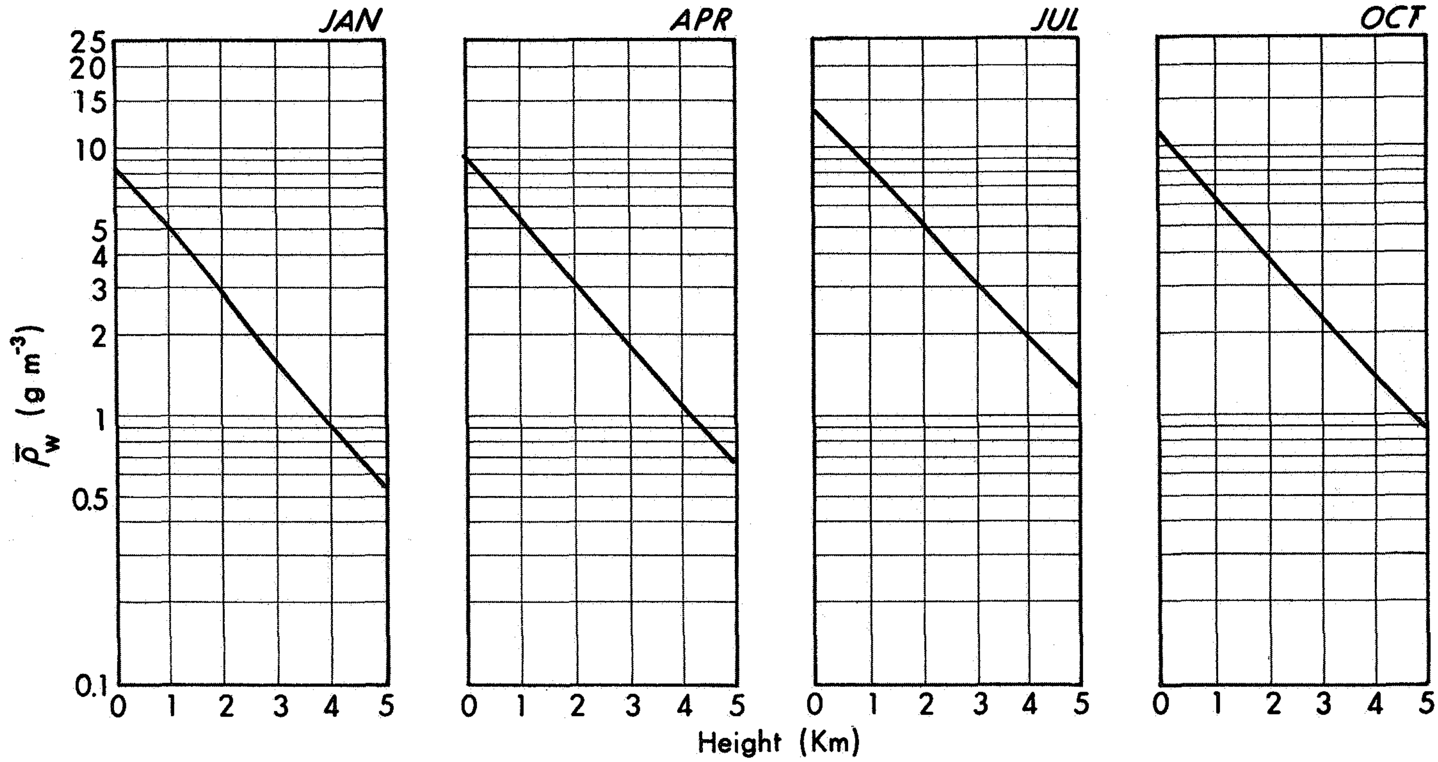


Figure A-11 Mean Absolute Humidity vs Height for Midseason Months - Region 11

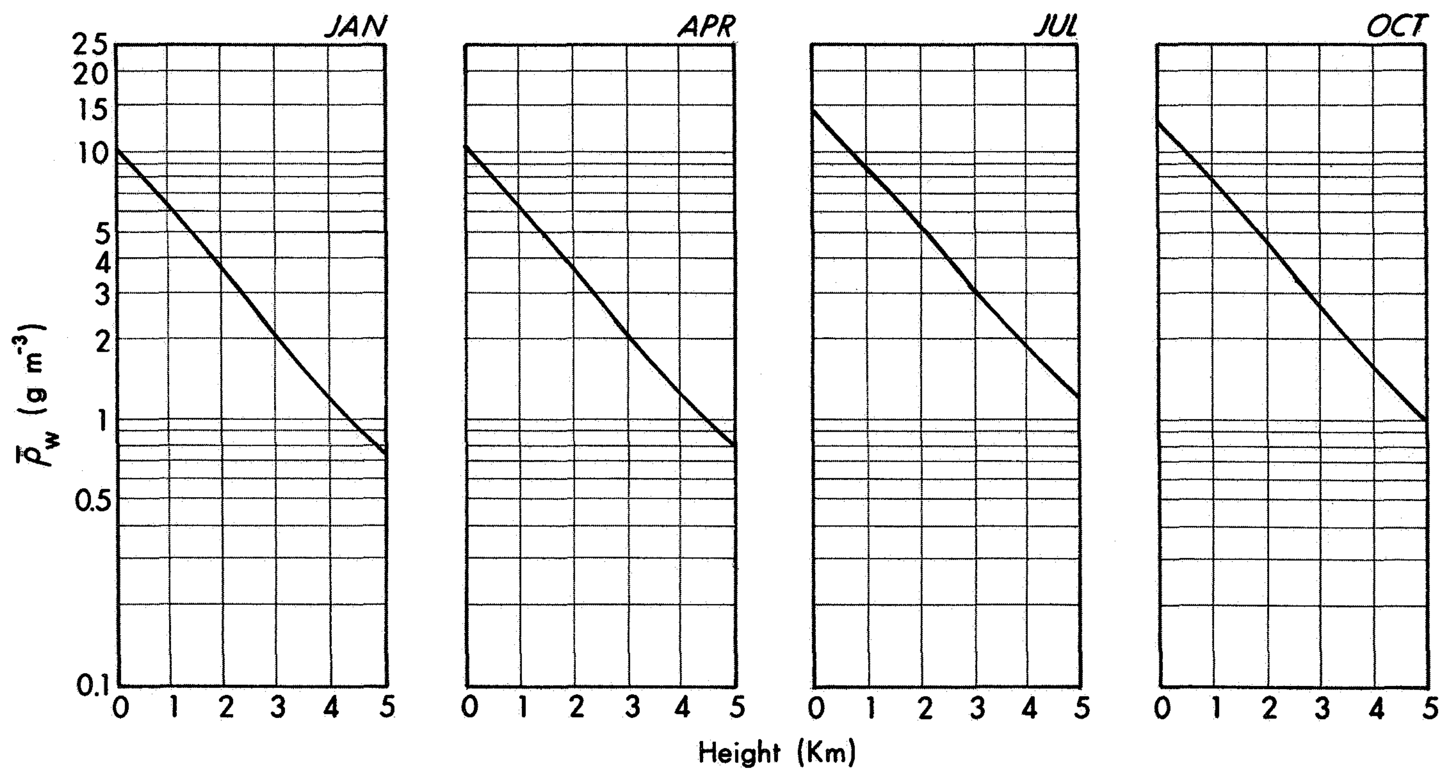


Figure A-12 Mean Absolute Humidity vs Height for Midseason Months - Region 12

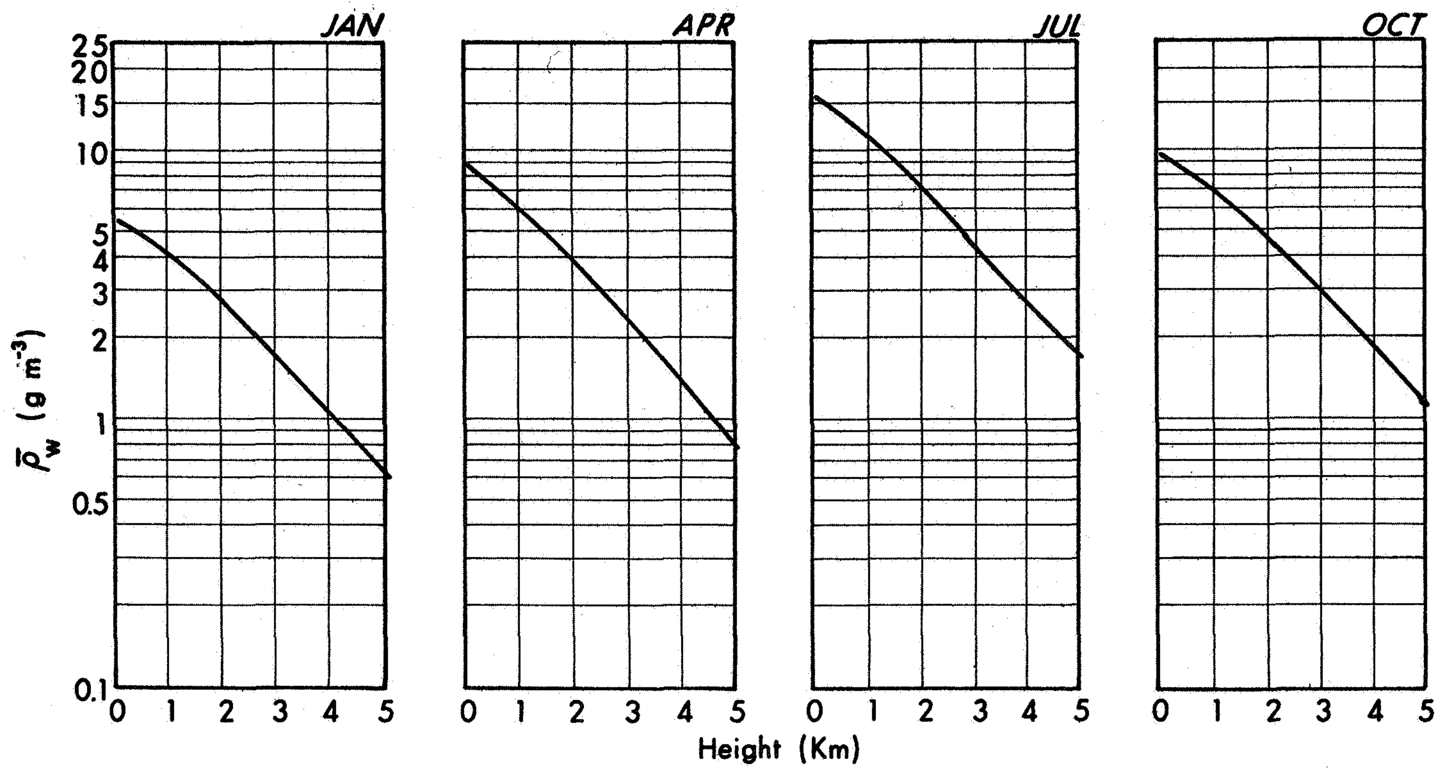


Figure A-13 Mean Absolute Humidity vs Height for Midseason Months - Region 13

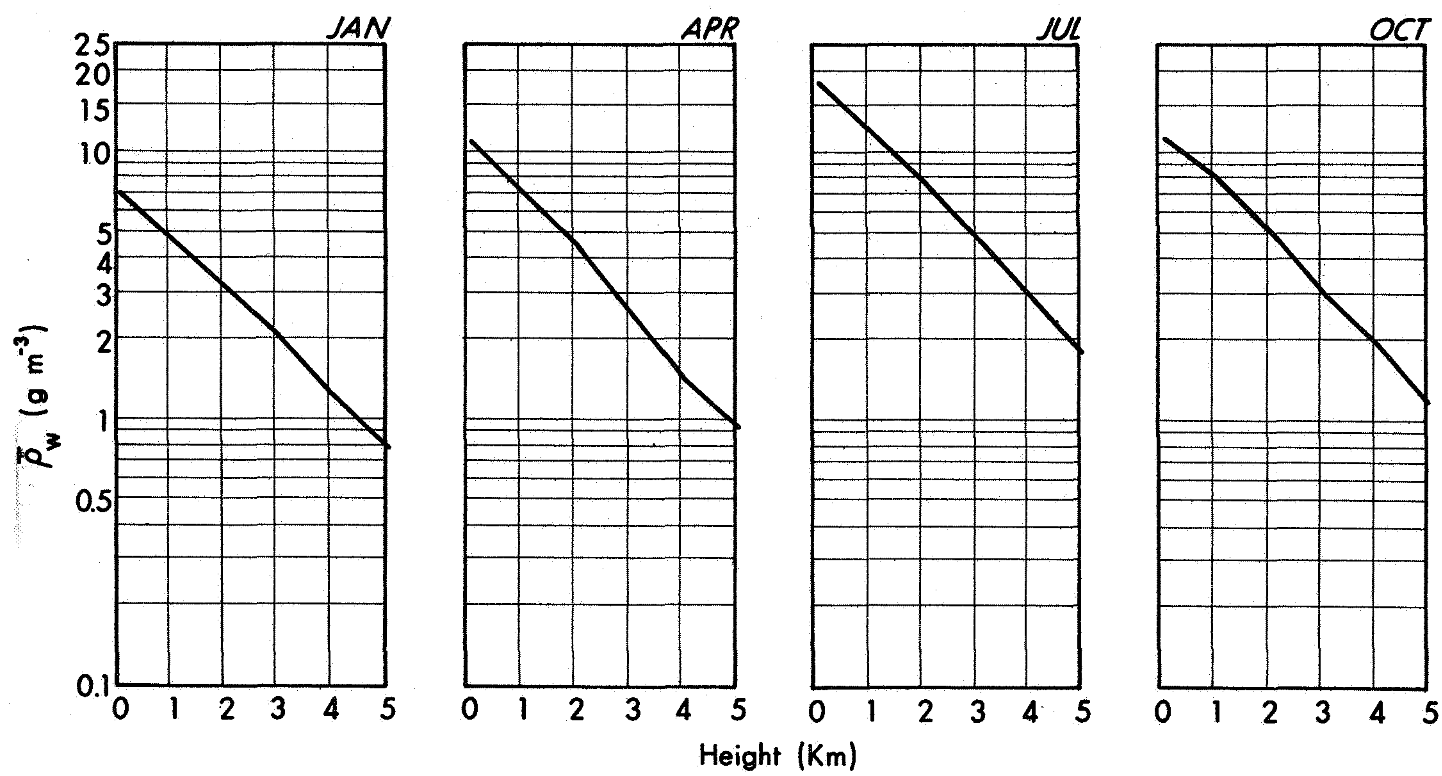


Figure A-14 Mean Absolute Humidity vs Height for Midseason Months - Region 14

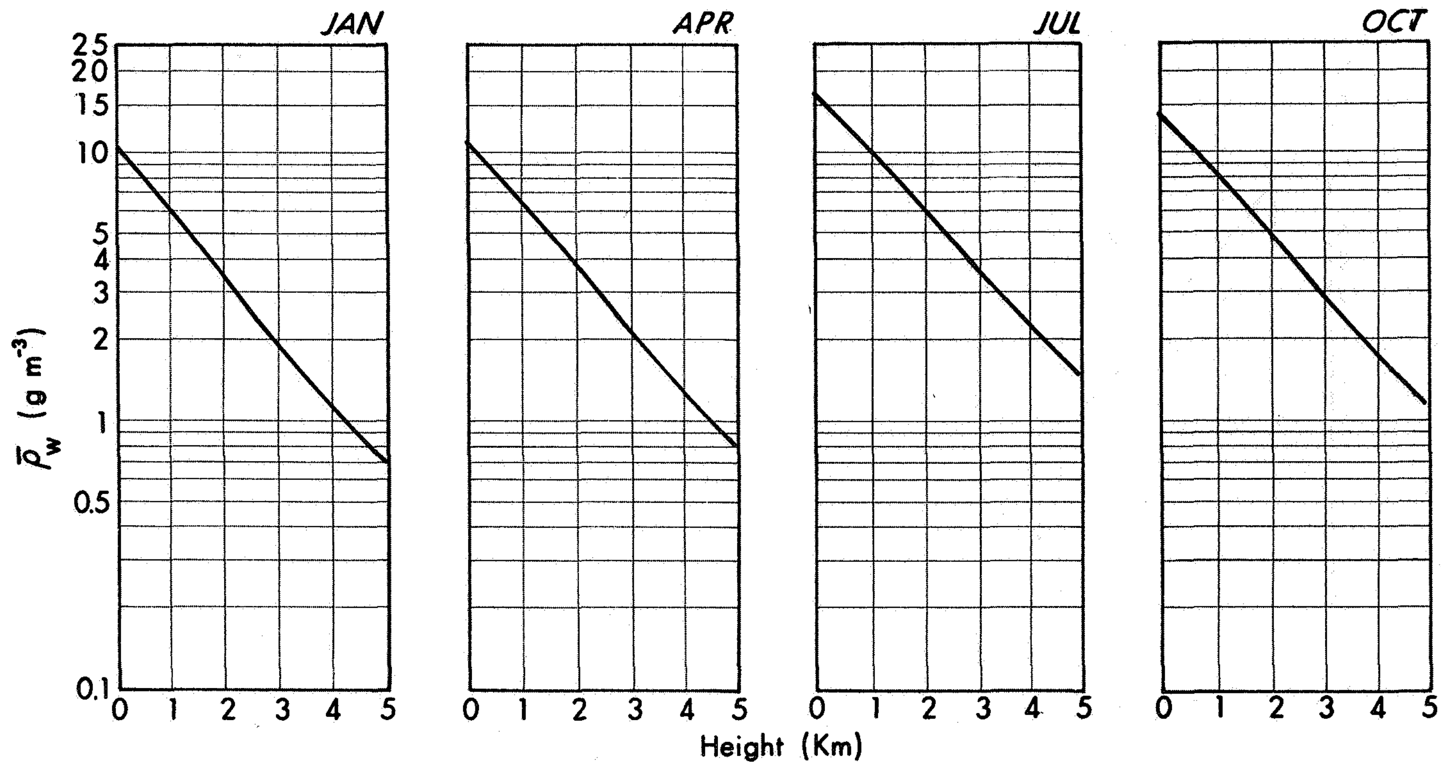


Figure A-15 Mean Absolute Humidity vs Height for Midseason Months - Region 15

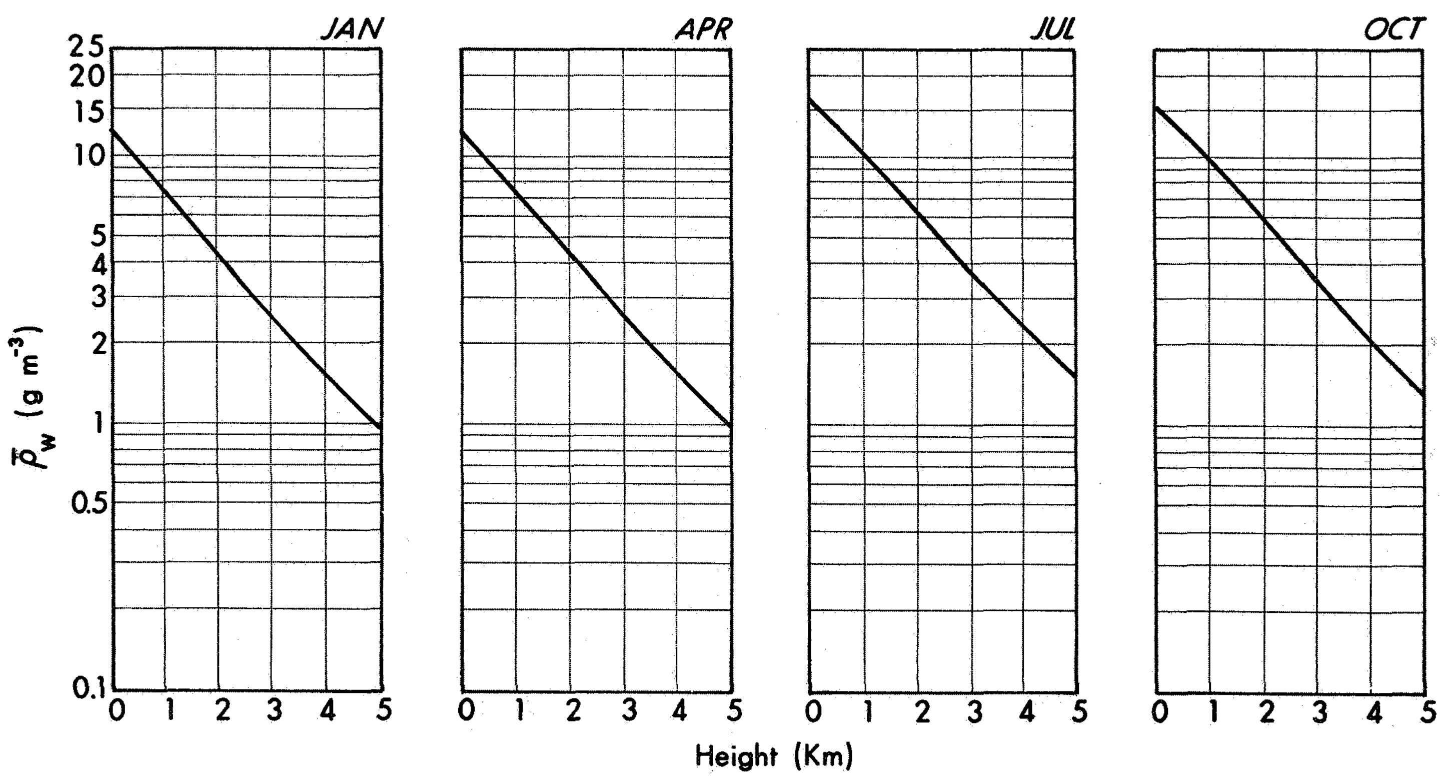


Figure A-16 Mean Absolute Humidity vs Height for Midseason Months - Region 16

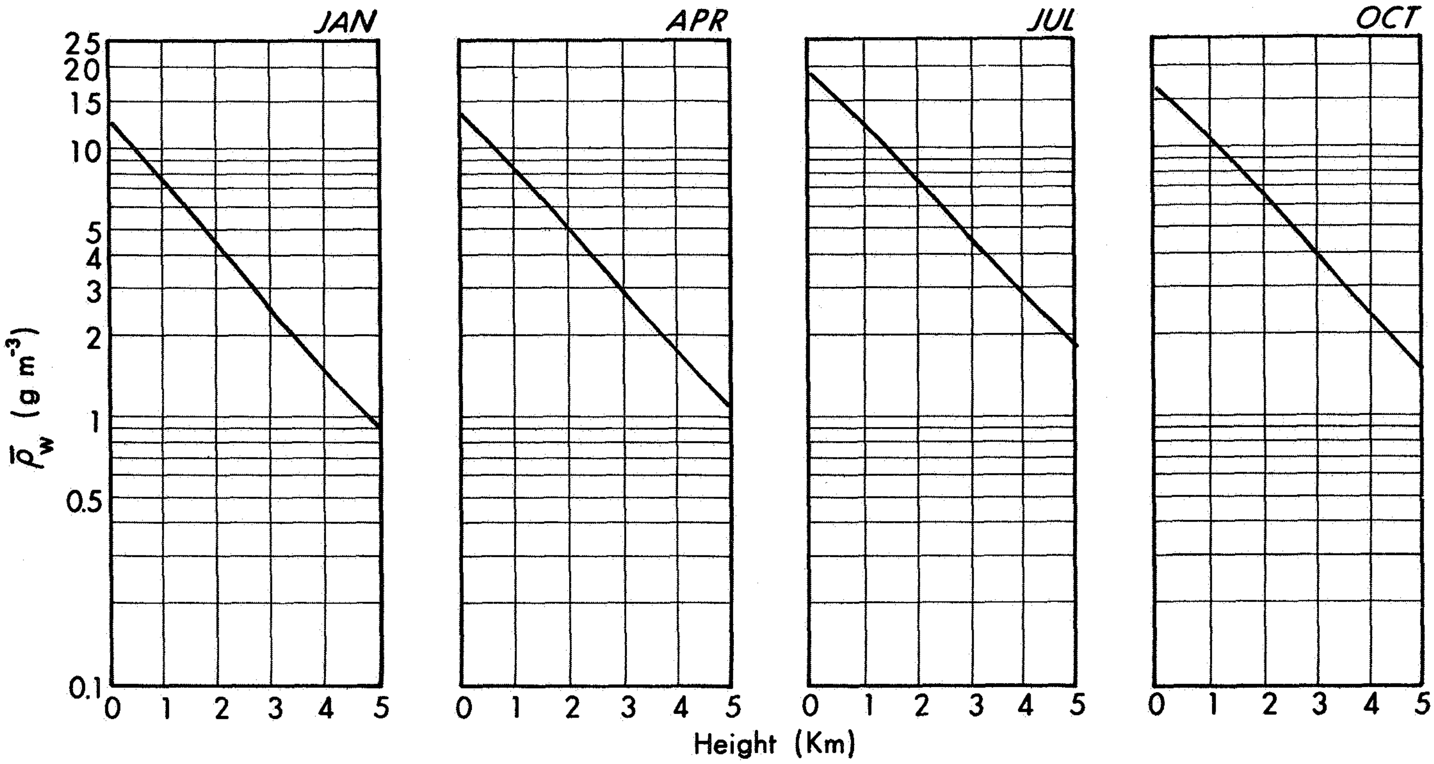


Figure A-17 Mean Absolute Humidity vs Height for Midseason Months - Region 17

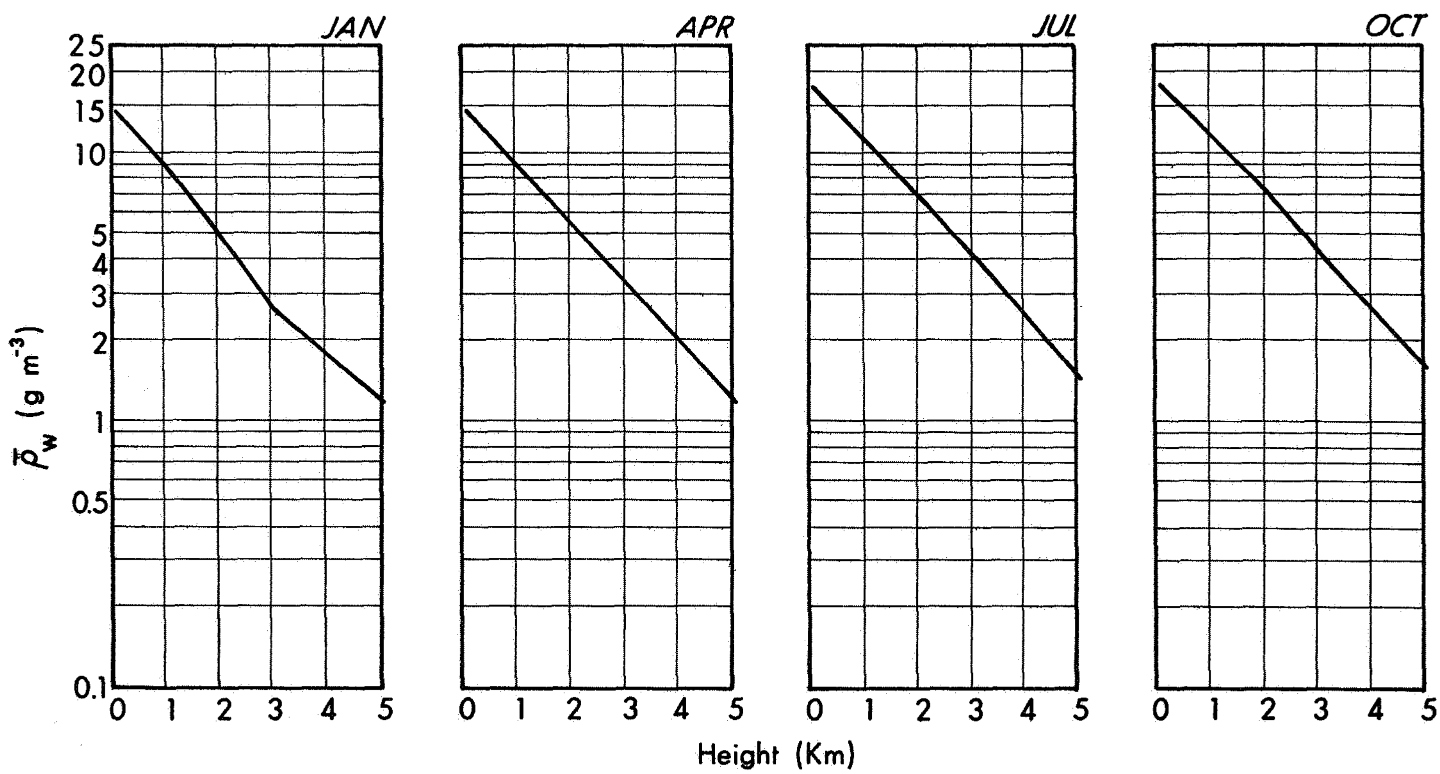


Figure A-18 Mean Absolute Humidity vs Height for Midseason Months - Region 18

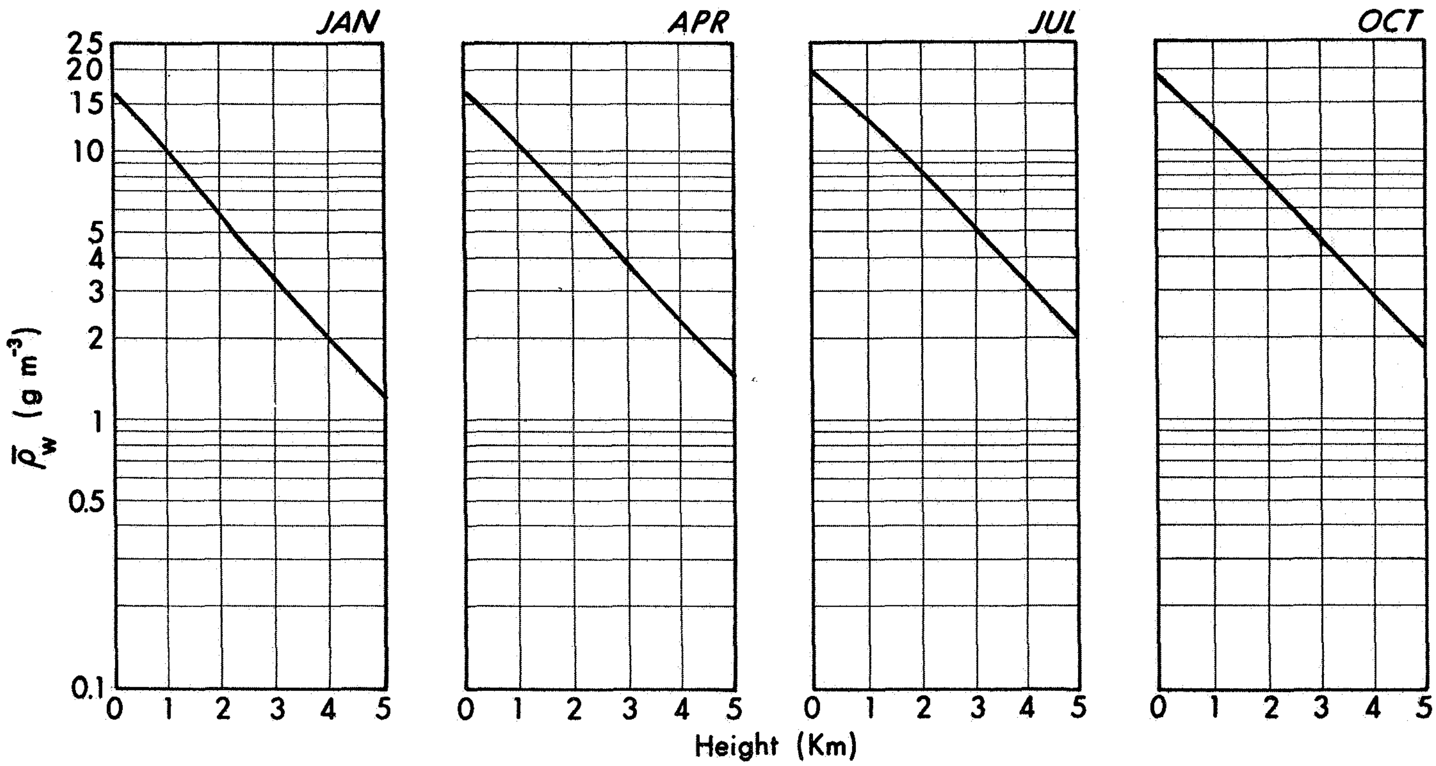


Figure A-19 Mean Absolute Humidity vs Height for Midseason Months - Region 19

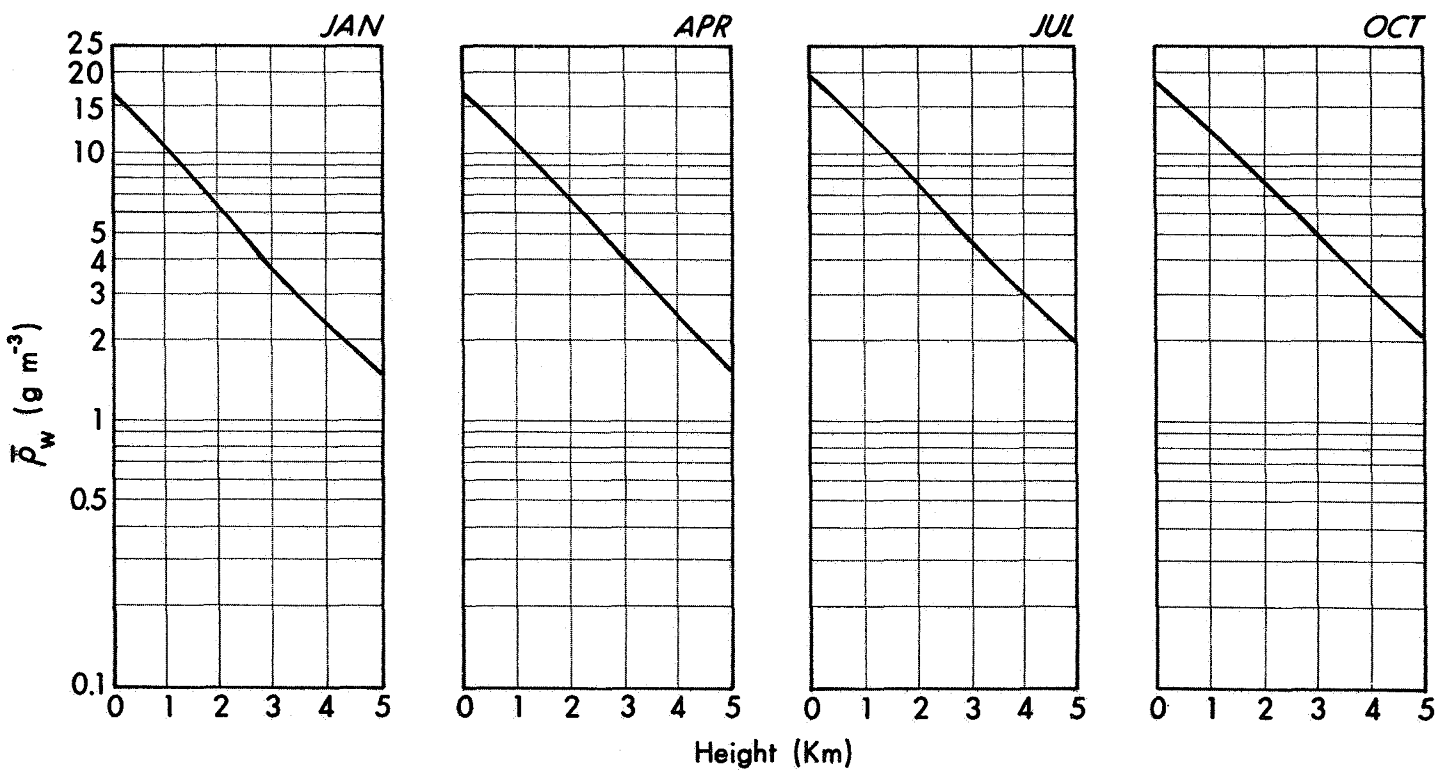


Figure A-20 Mean Absolute Humidity vs Height for Midseason Months - Region 20

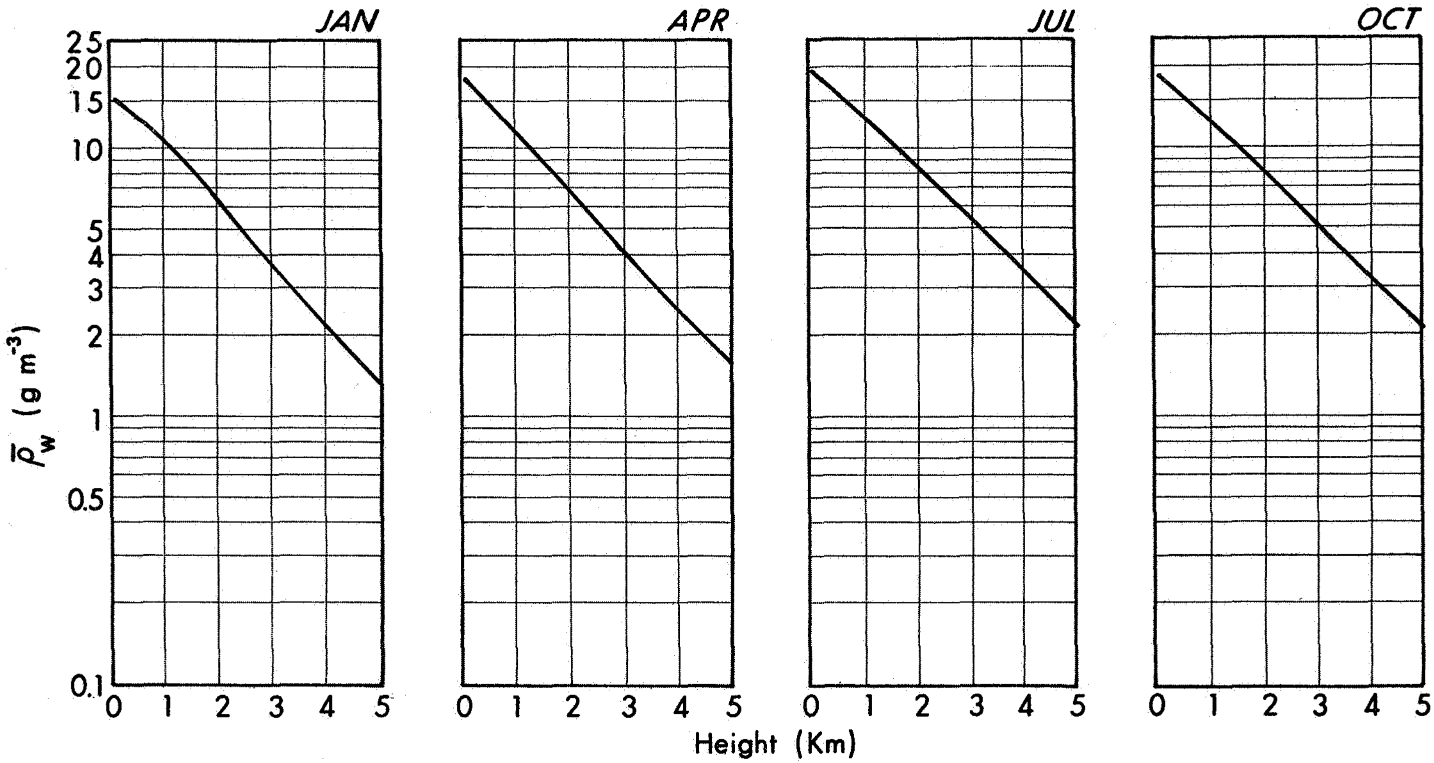


Figure A-21 Mean Absolute Humidity vs Height for Midseason Months - Region 21

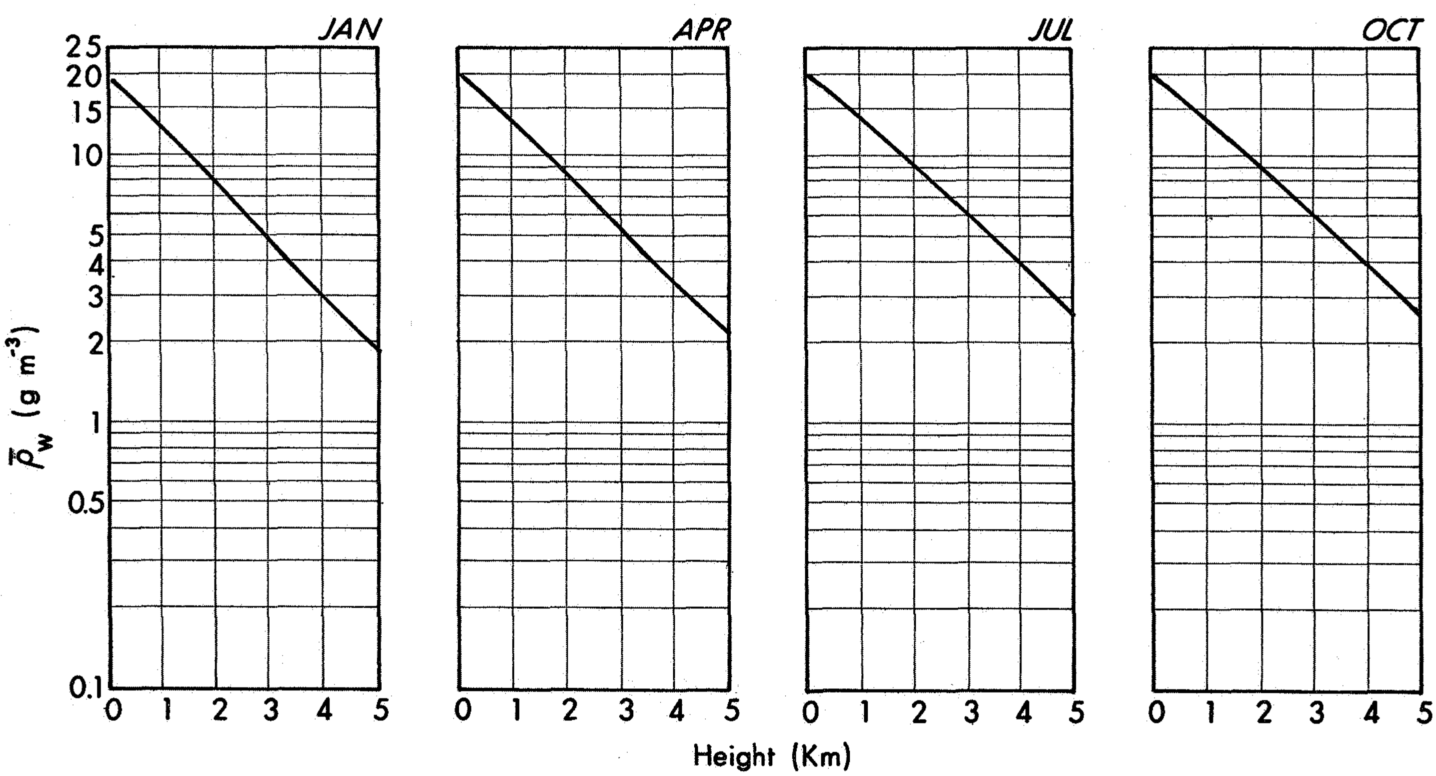


Figure A-22 Mean Absolute Humidity vs Height for Midseason Months - Region 22

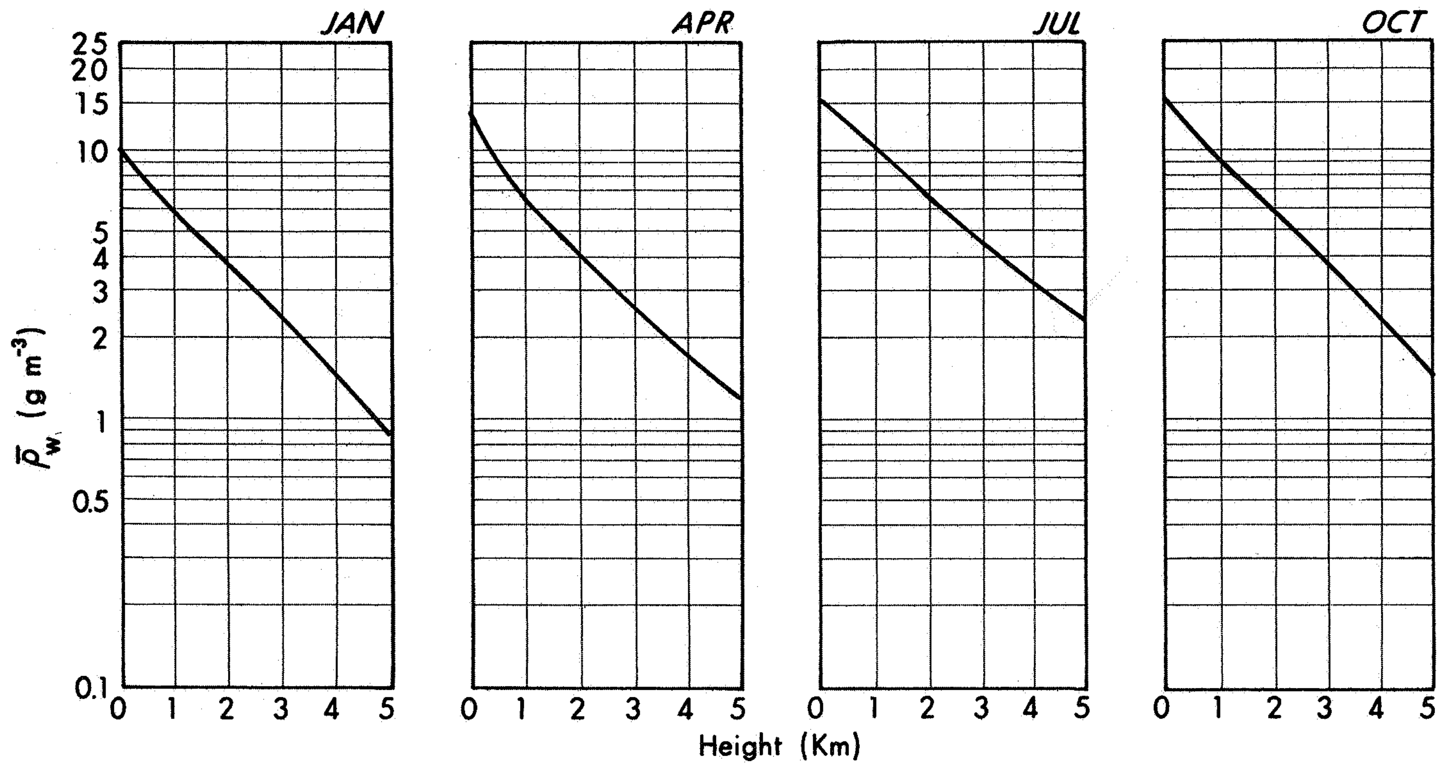


Figure A-23 Mean Absolute Humidity vs Height for Midseason Months - Region 23

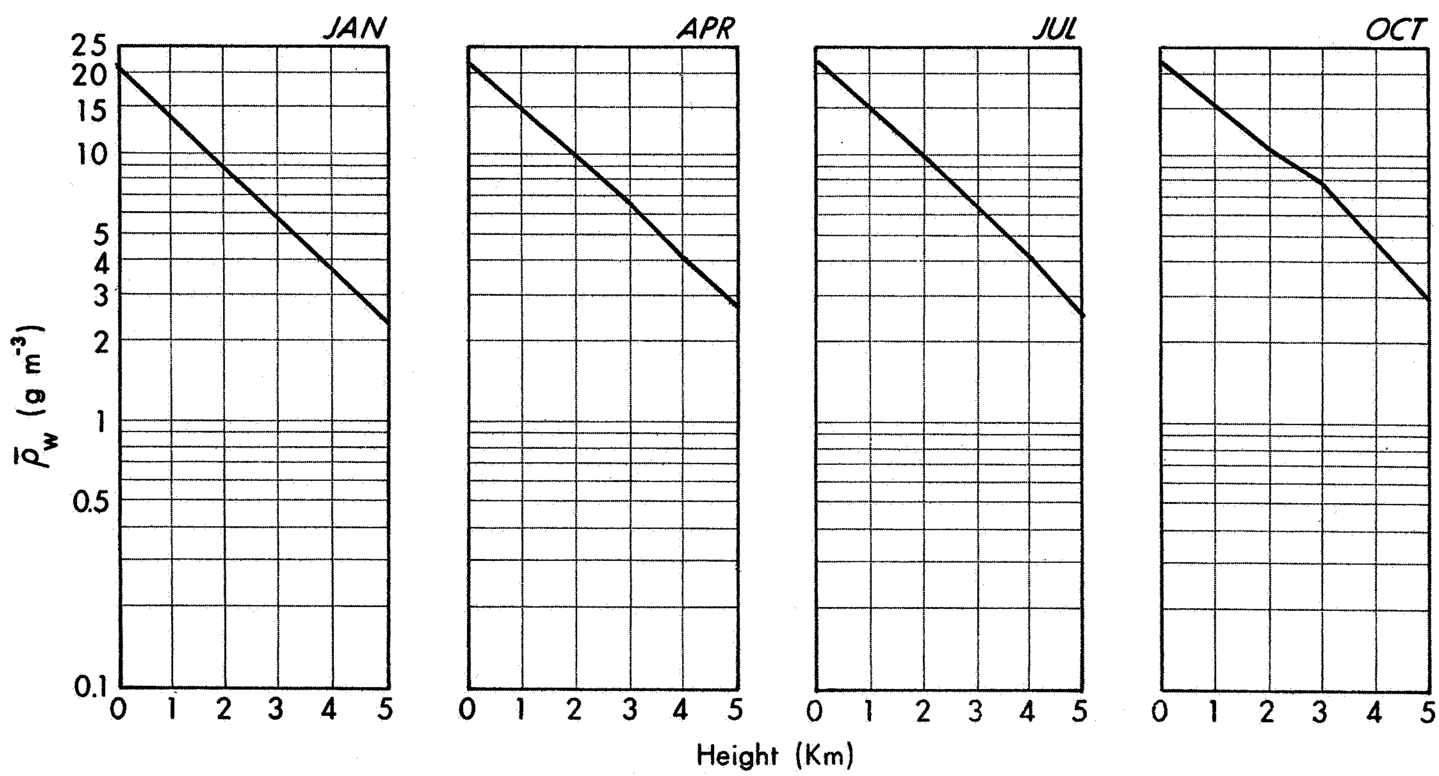


Figure A-24 Mean Absolute Humidity vs Height for Midseason Months - Region 24

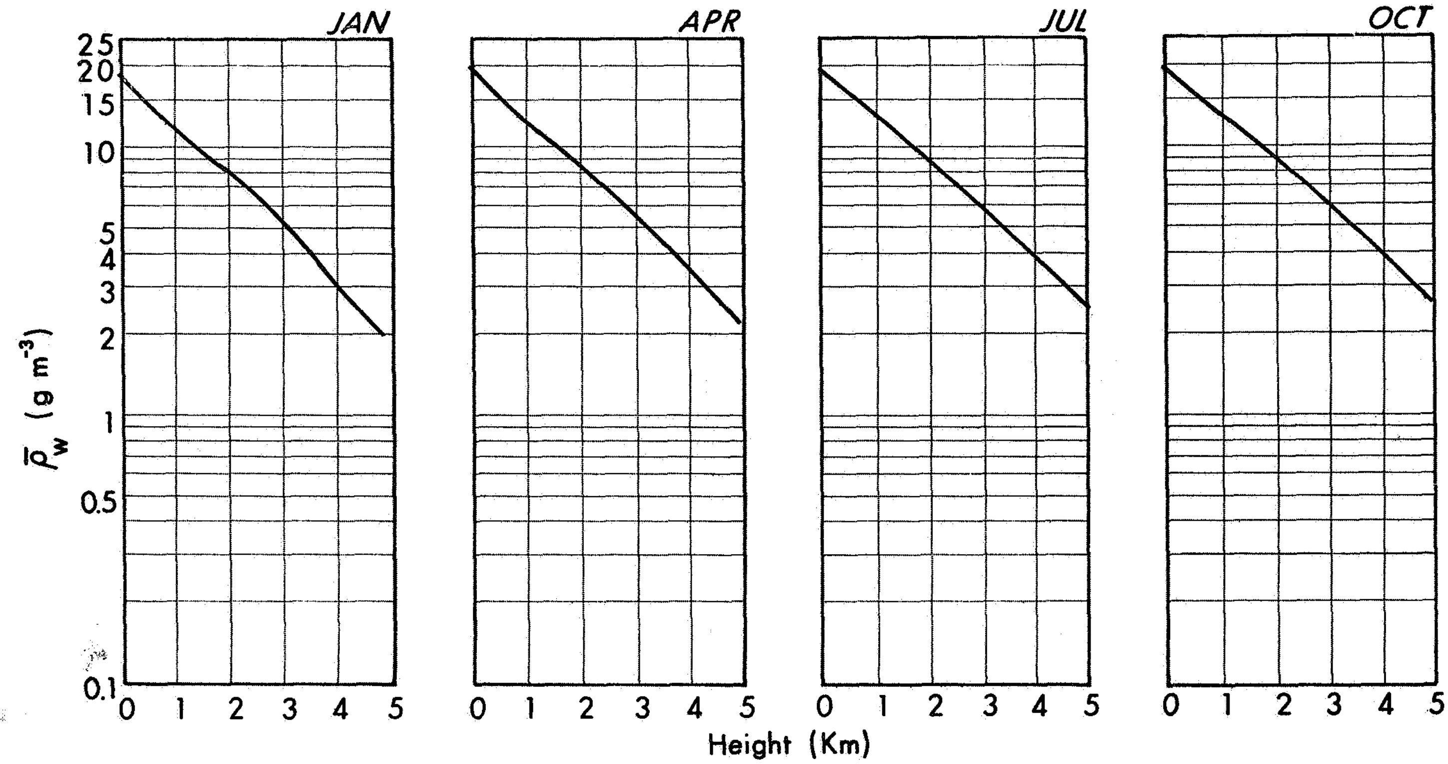


Figure A-25 Mean Absolute Humidity vs Height for Midseason Months - Region 25

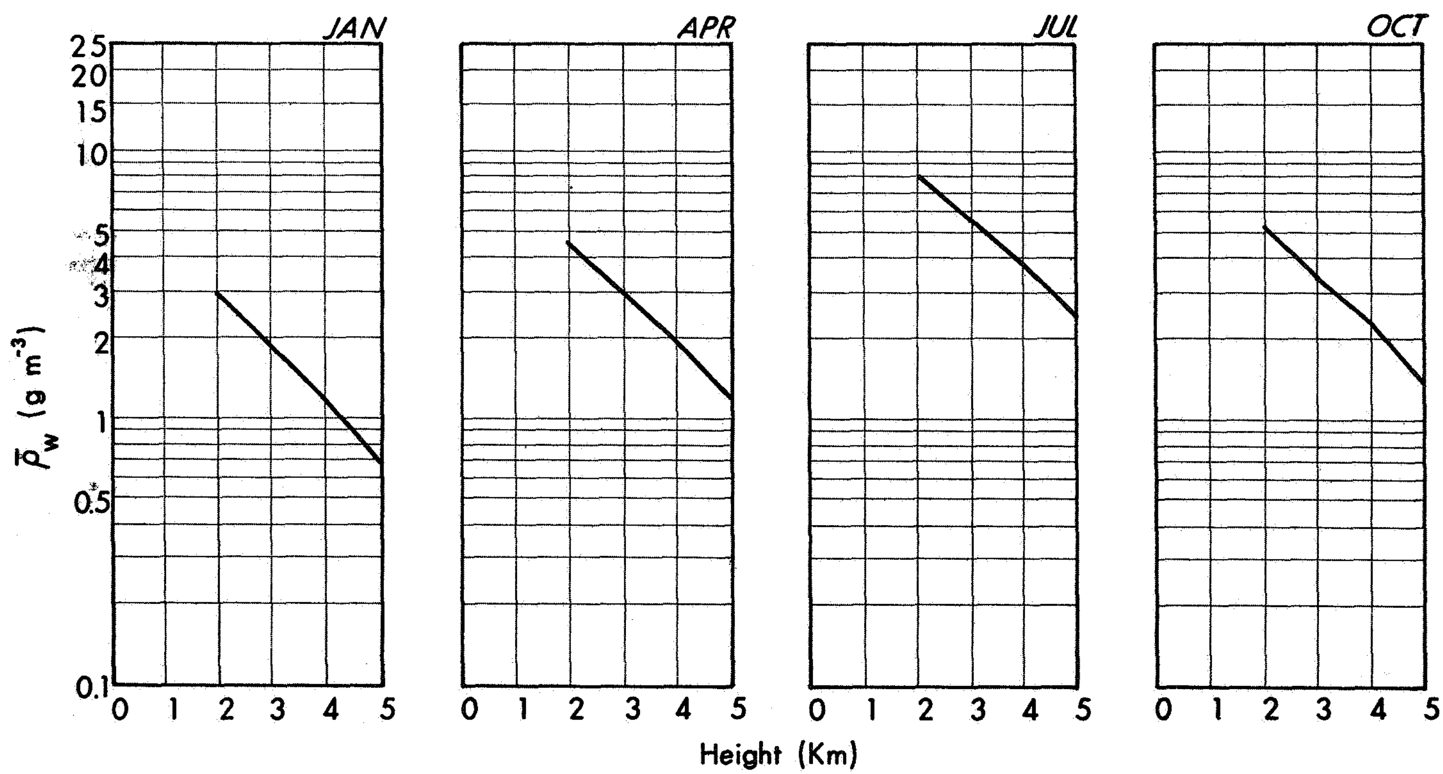


Figure A-26 Mean Absolute Humidity vs Height for Midseason Months - Region 26

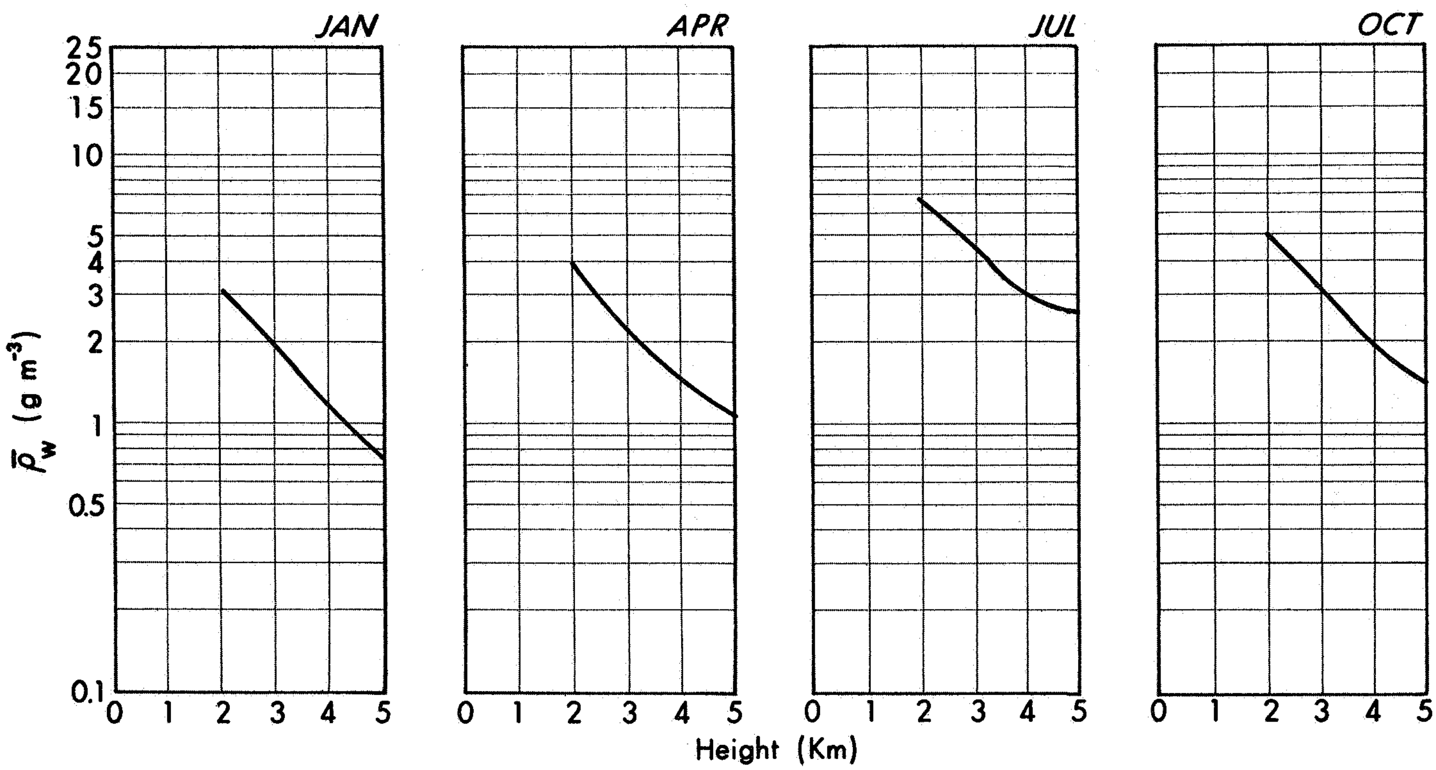


Figure A-27 Mean Absolute Humidity vs Height for Midseason Months - Region 27

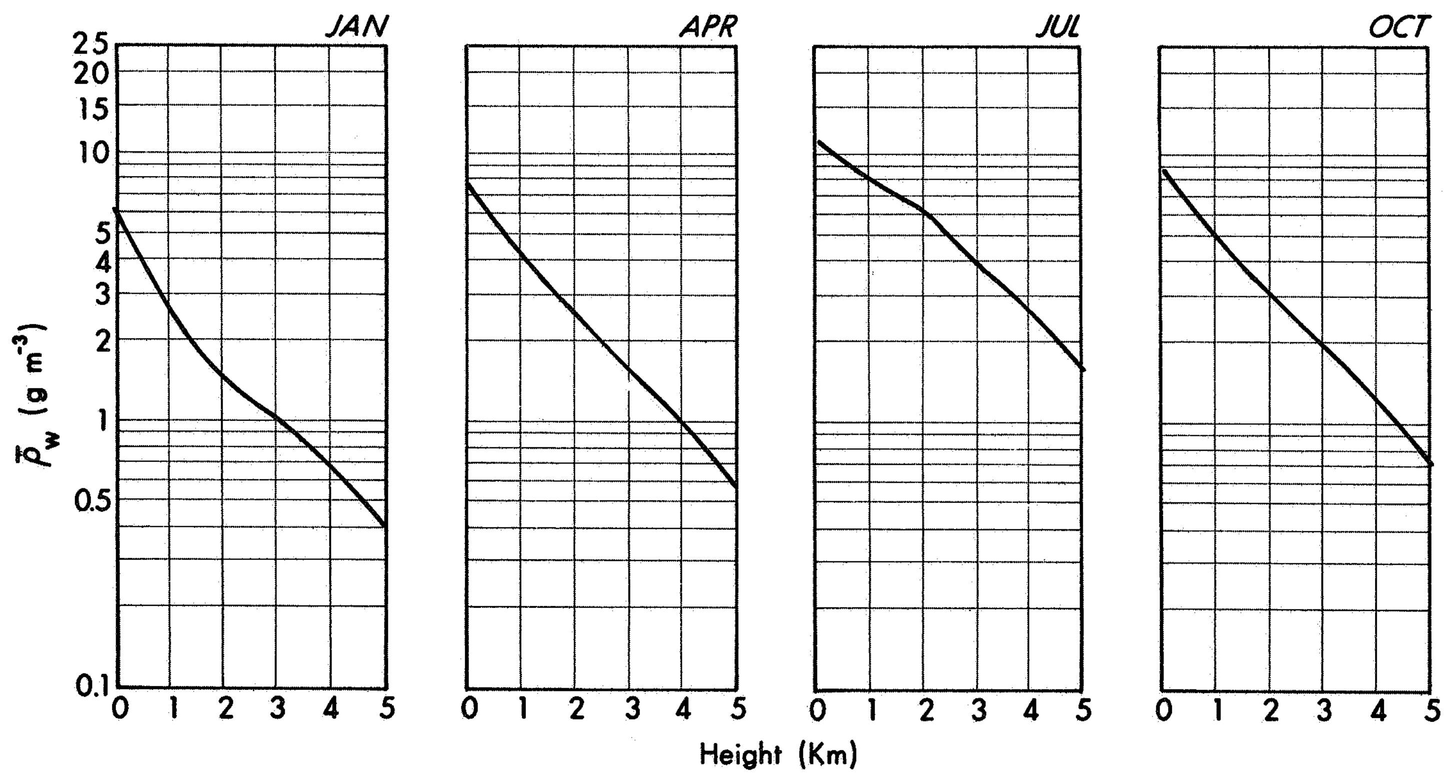


Figure A-28 Mean Absolute Humidity vs Height for Midseason Months - Region 28

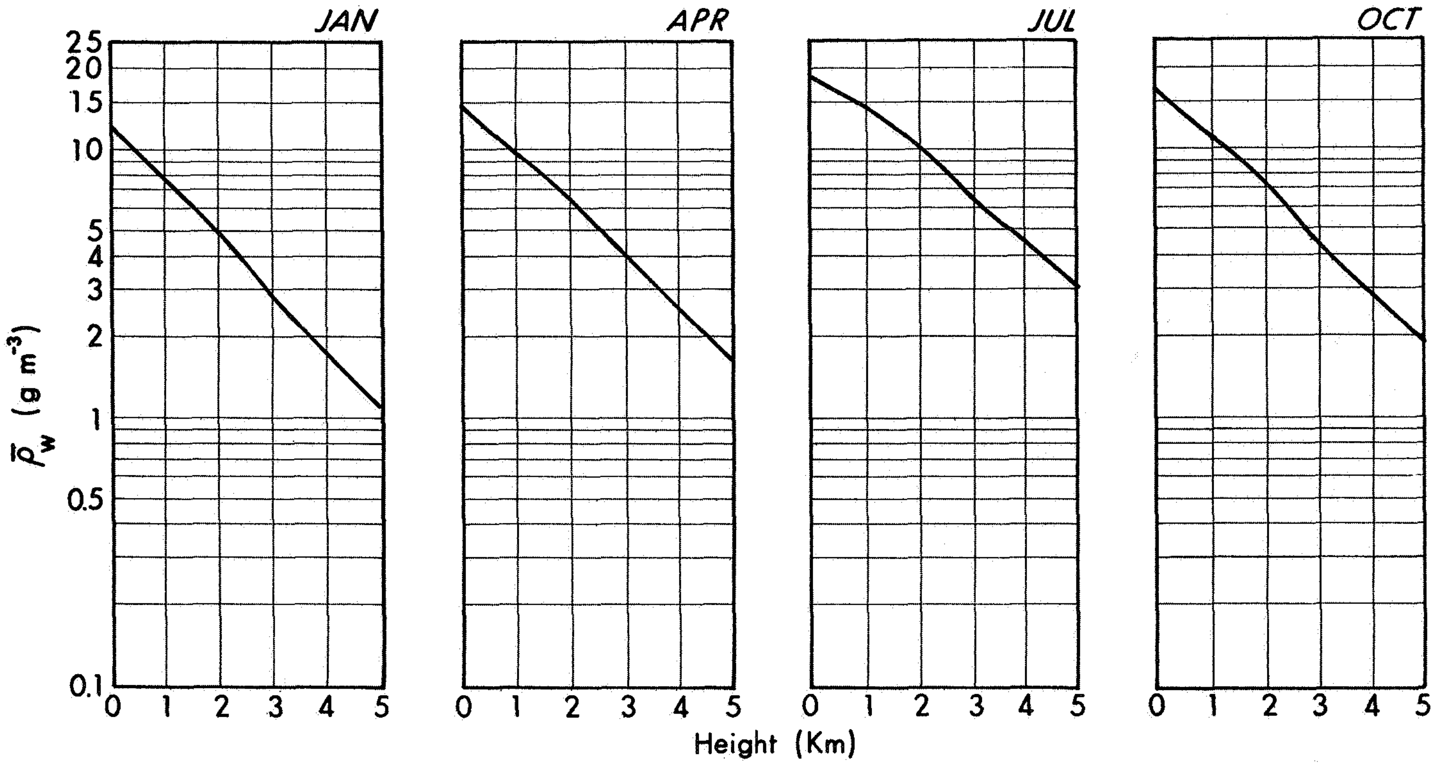


Figure A-29 Mean Absolute Humidity vs Height for Midseason Months - Region 29

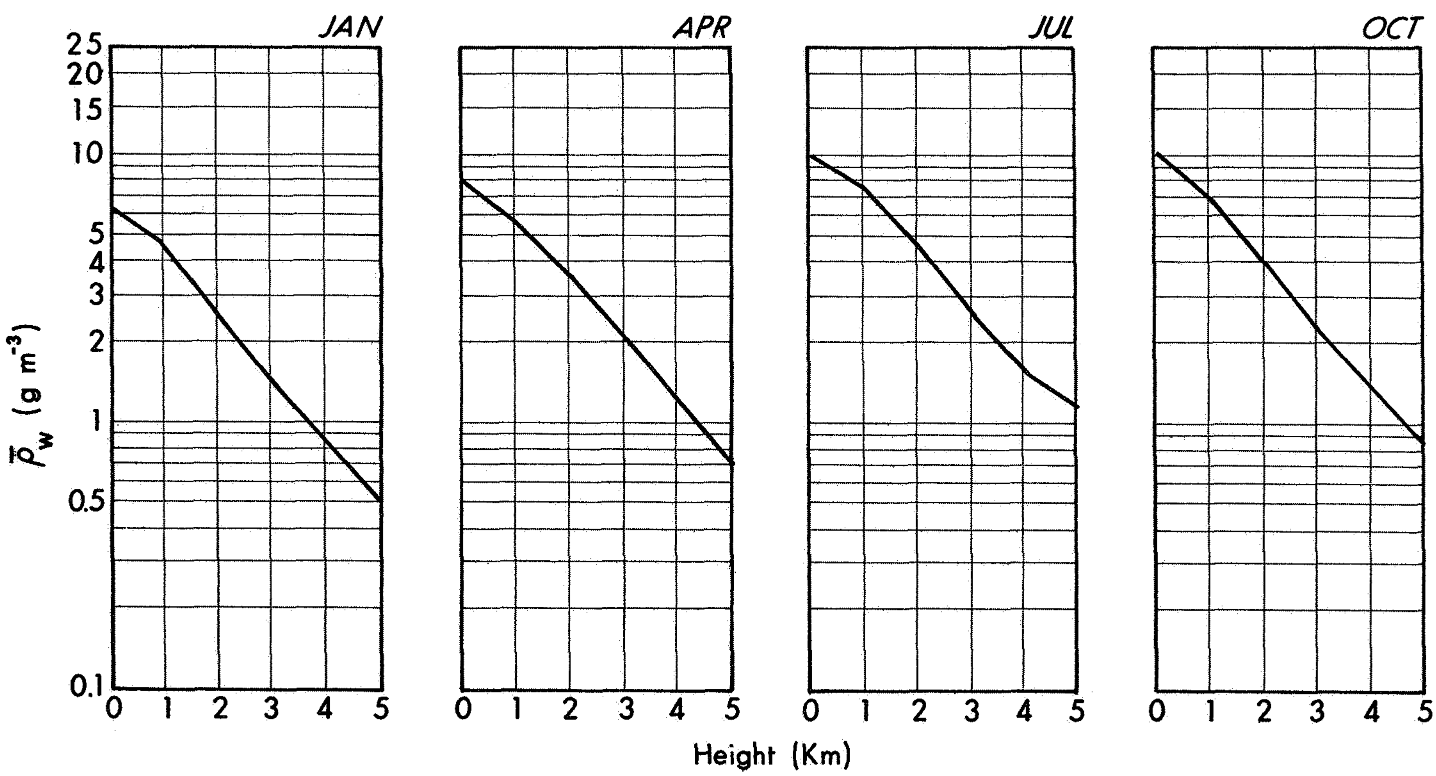


Figure A-30 Mean Absolute Humidity vs Height for Midseason Months - Region 30

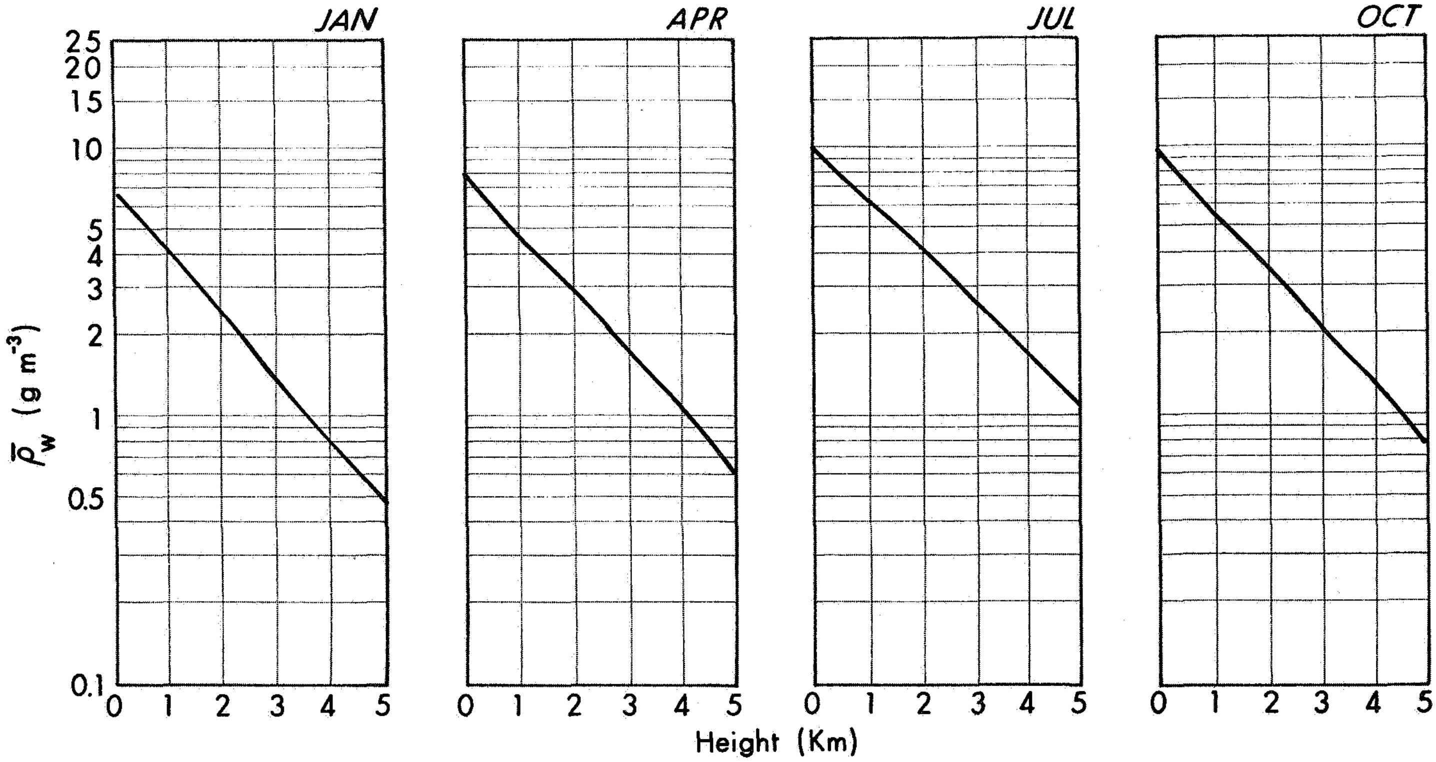


Figure A-31 Mean Absolute Humidity vs Height for Midseason Months - Region 31

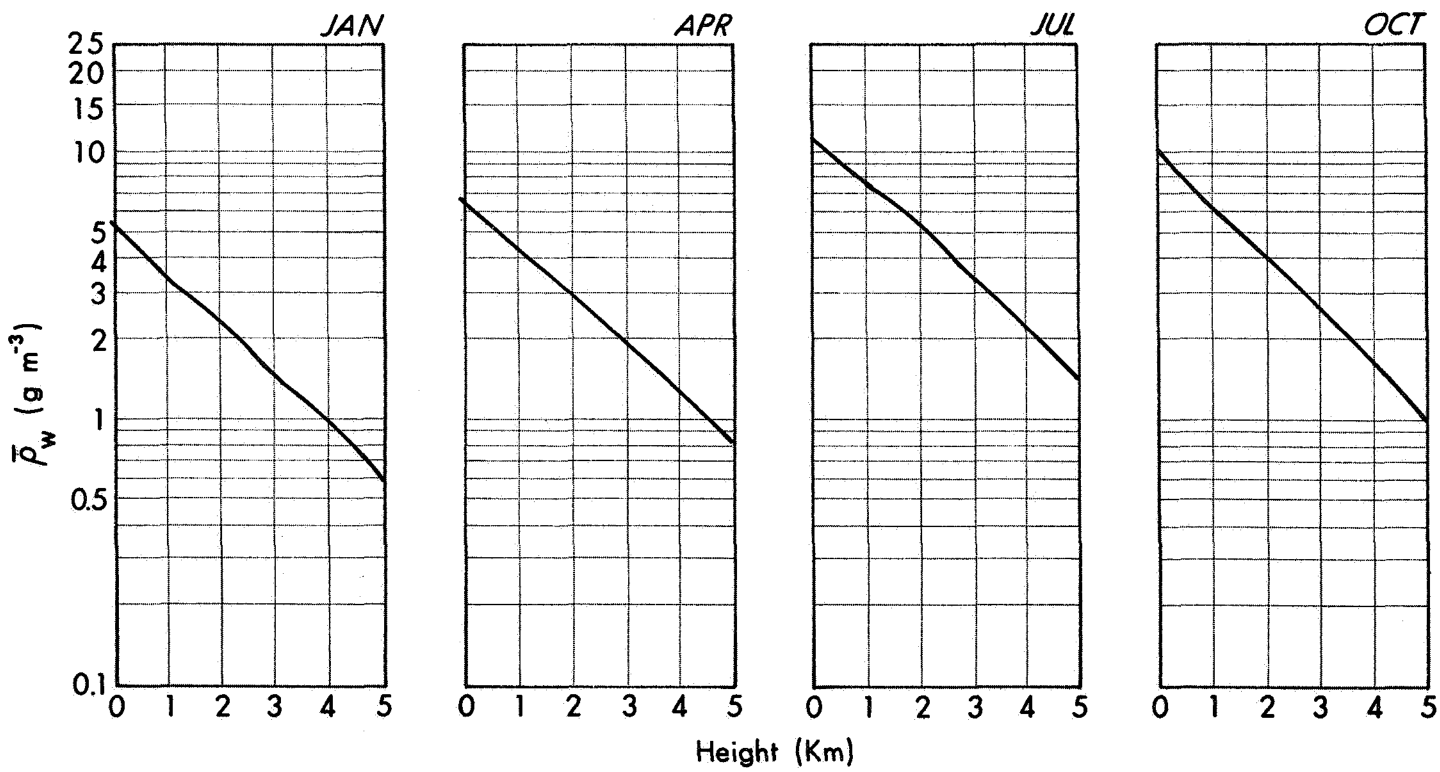


Figure A-32 Mean Absolute Humidity vs Height for Midseason Months - Region 32

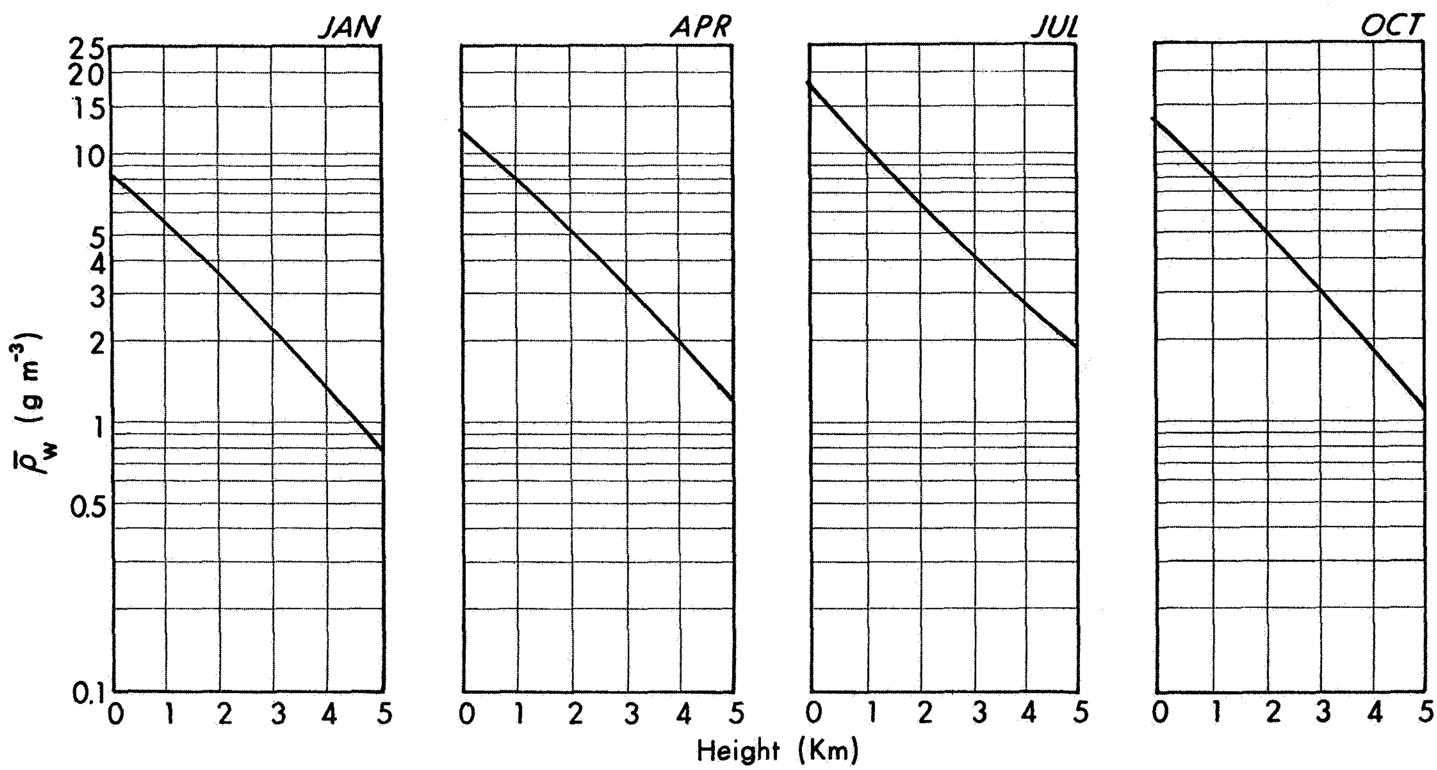


Figure A-33 Mean Absolute Humidity vs Height for Midseason Months - Region 33

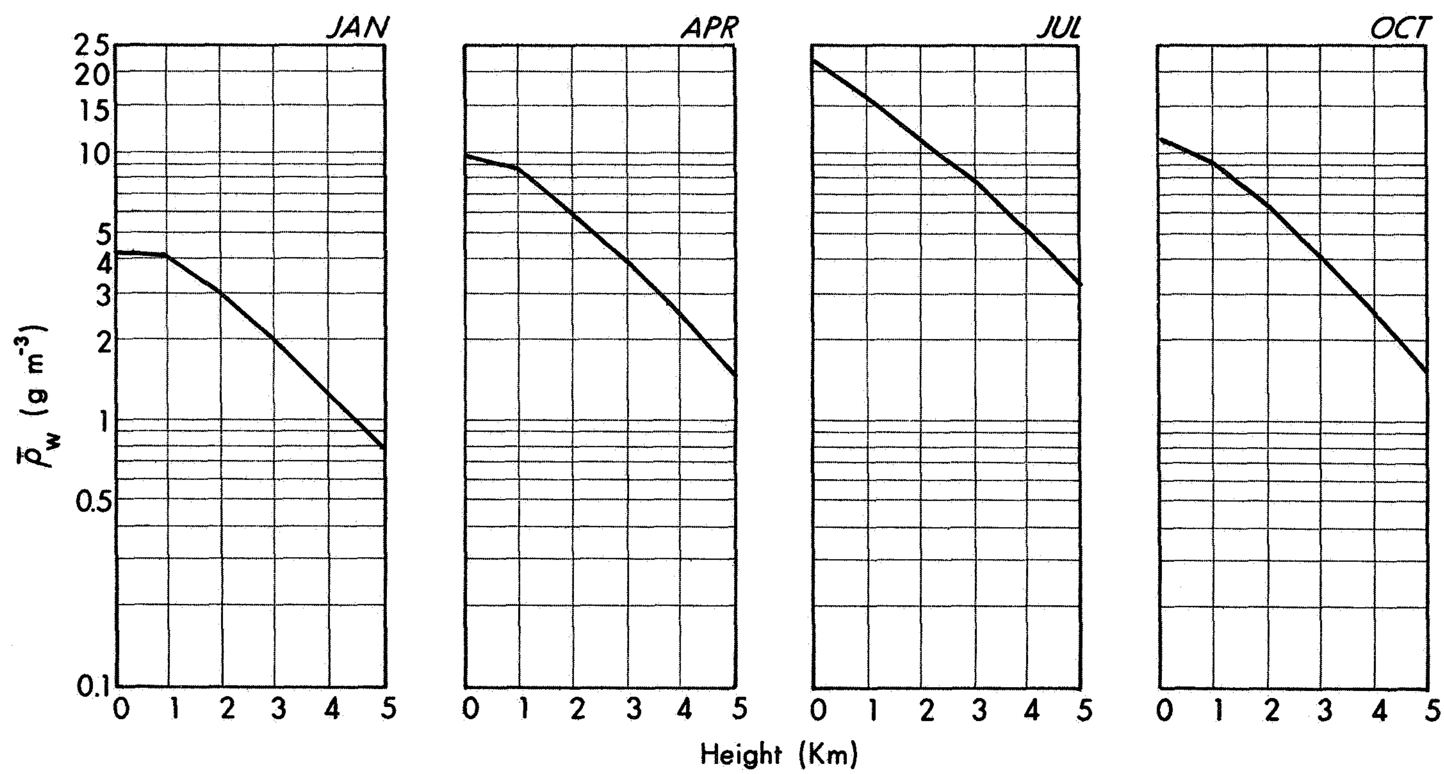


Figure A-34 Mean Absolute Humidity vs Height for Midseason Months - Region 34

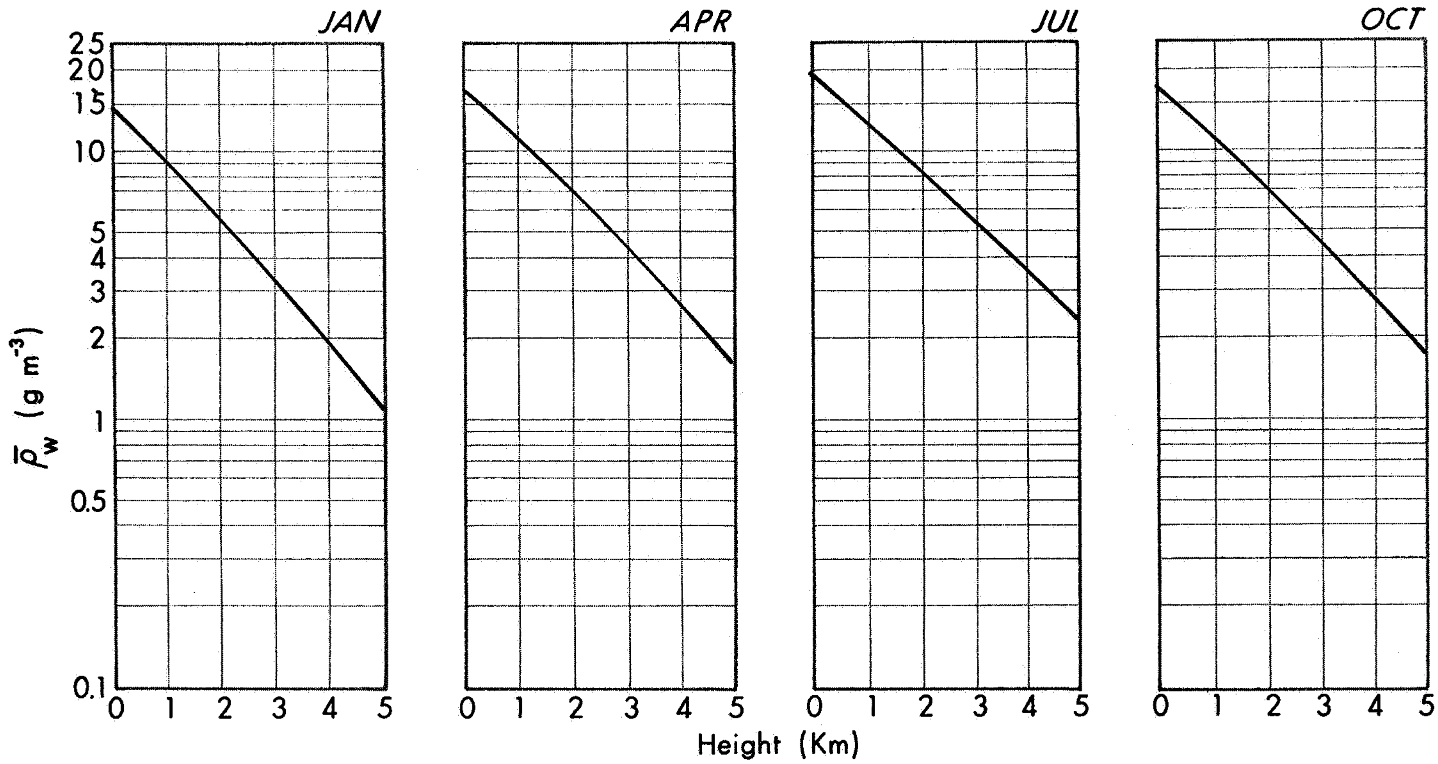


Figure A-35 Mean Absolute Humidity vs Height for Midseason Months - Region 35

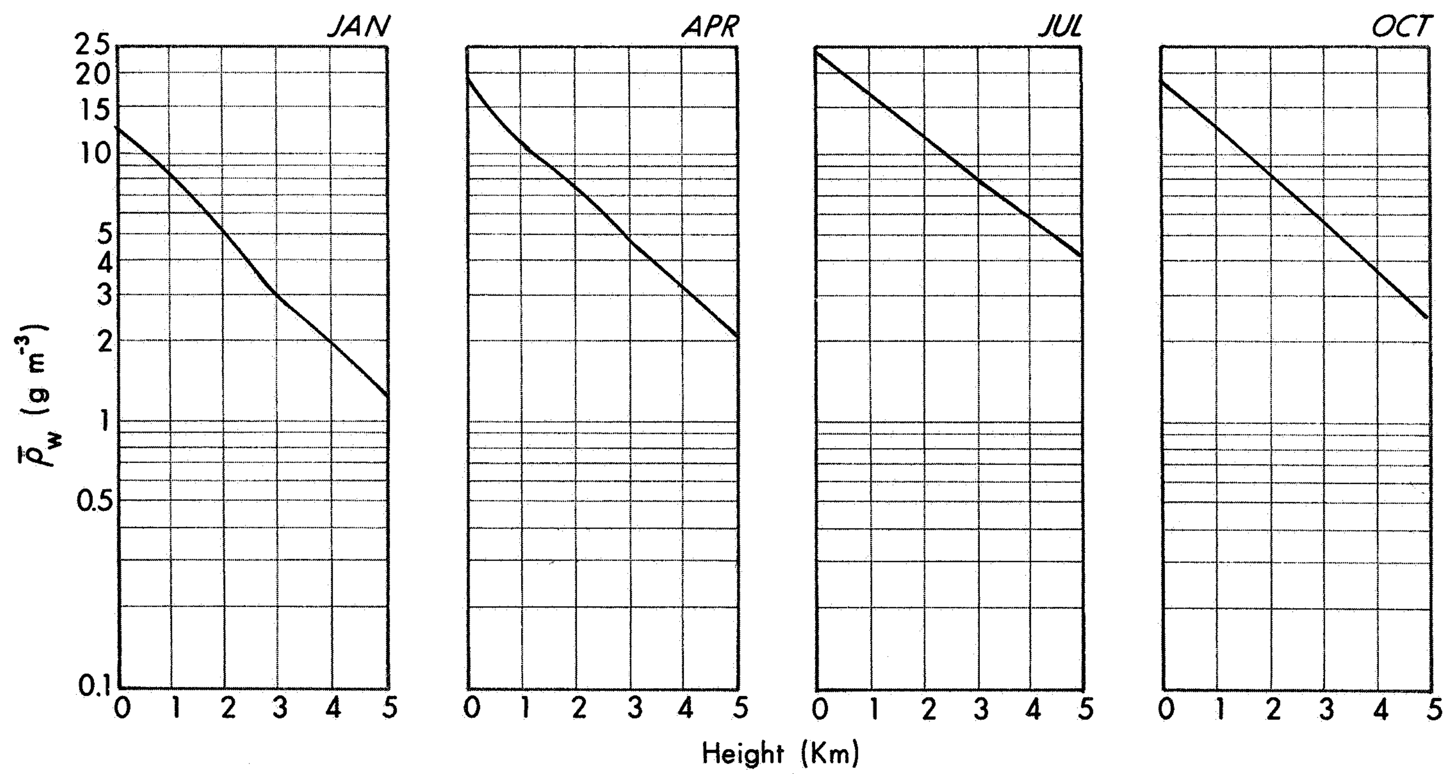


Figure A-36 Mean Absolute Humidity vs Height for Midseason Months - Region 36

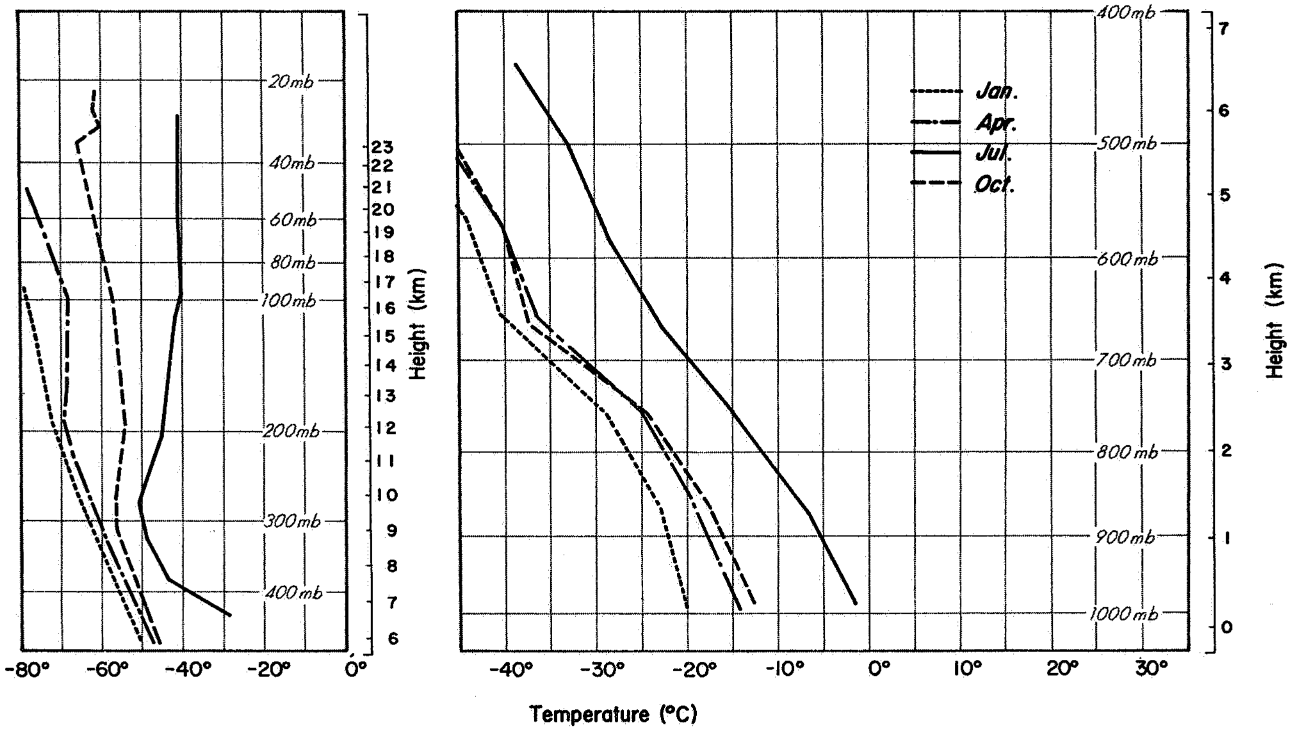


Figure A-37 Actual Mean Temperature Profile - Region 1

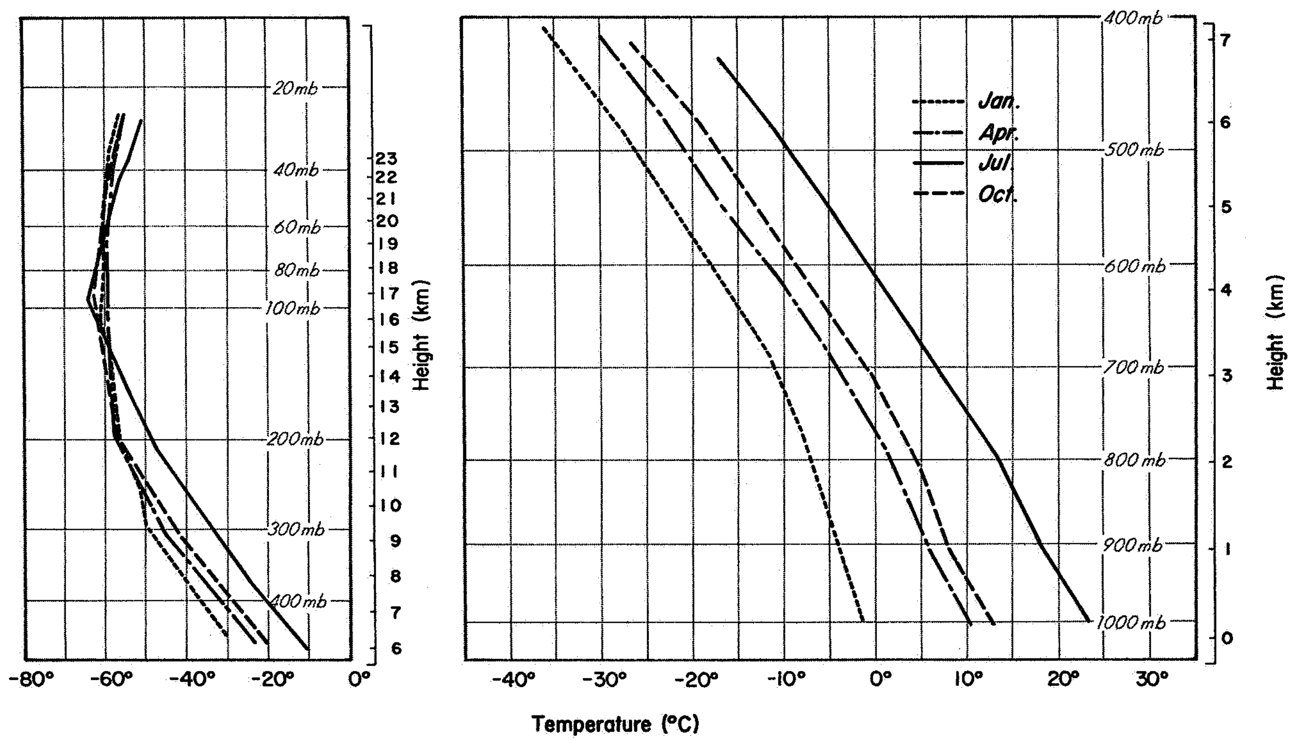


Figure A-38 Actual Mean Temperature Profile - Region 7

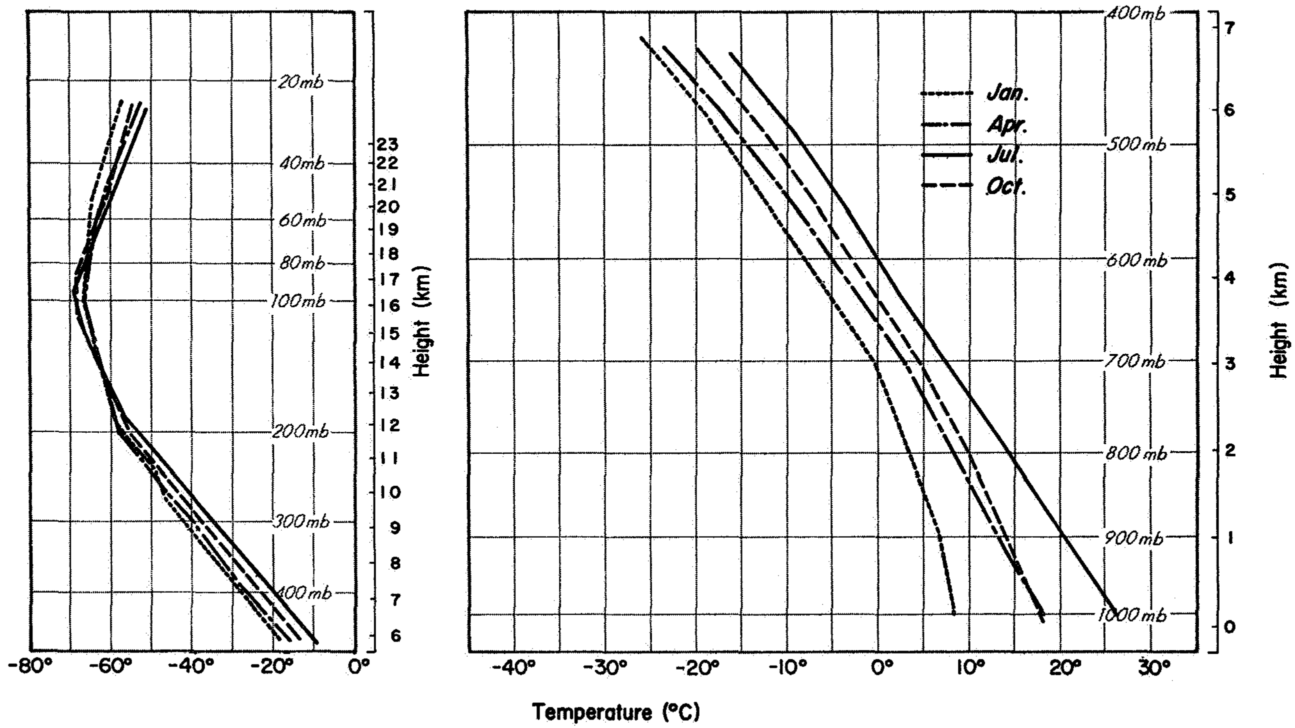


Figure A-39 Actual Mean Temperature Profile - Region 14

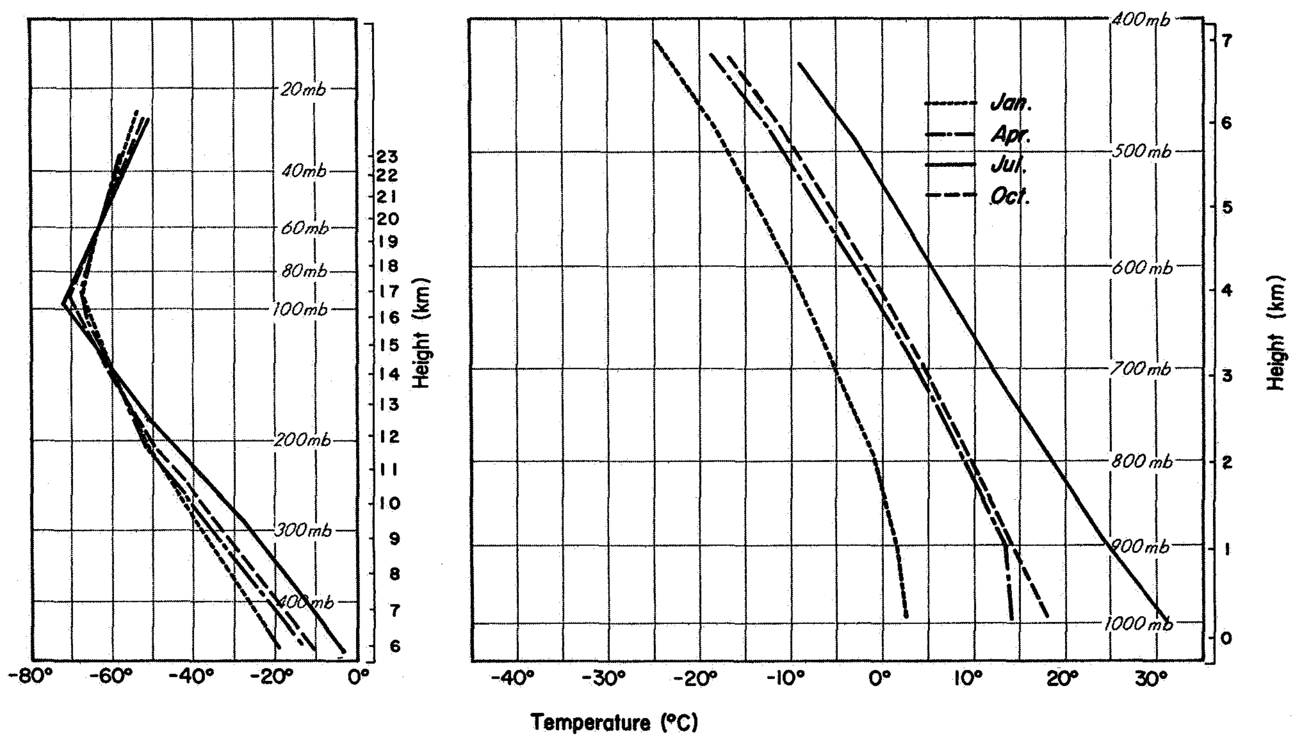


Figure A-40 Actual Mean Temperature Profile - Region 34

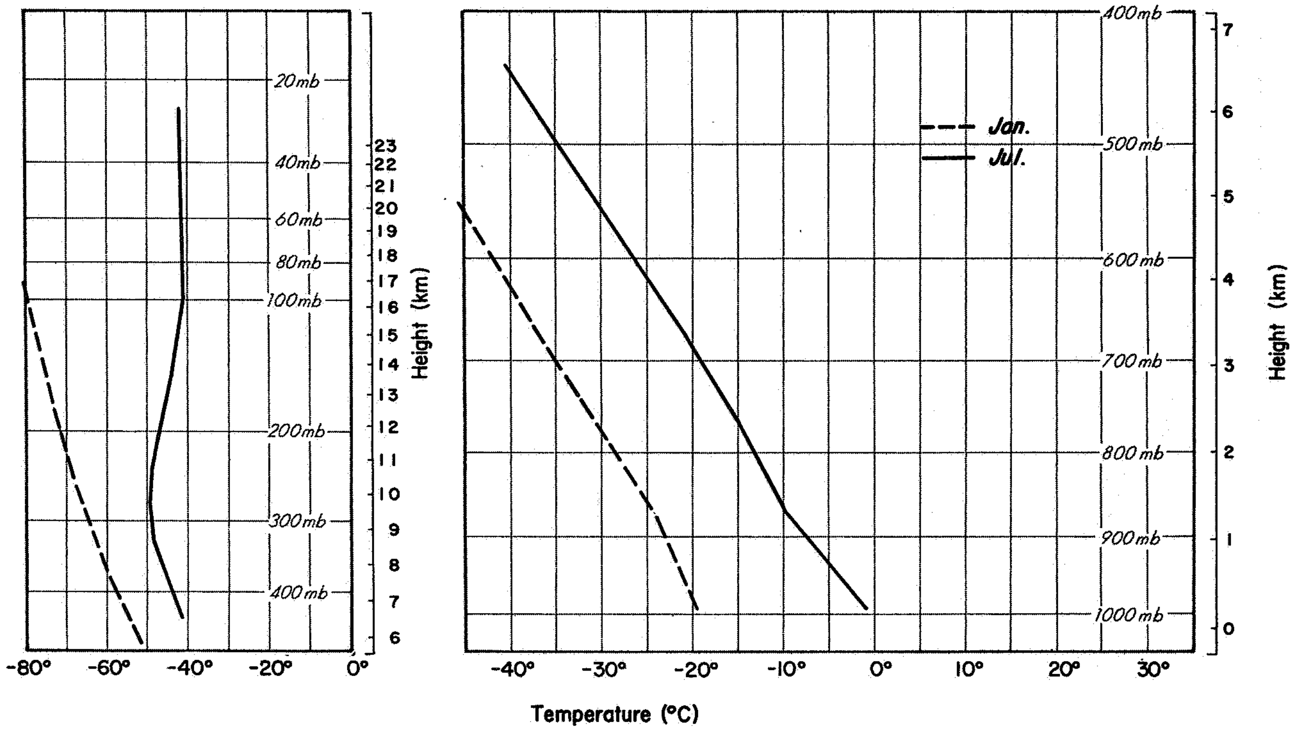


Figure A-41 Derived Mean Temperature Profile - Region 1

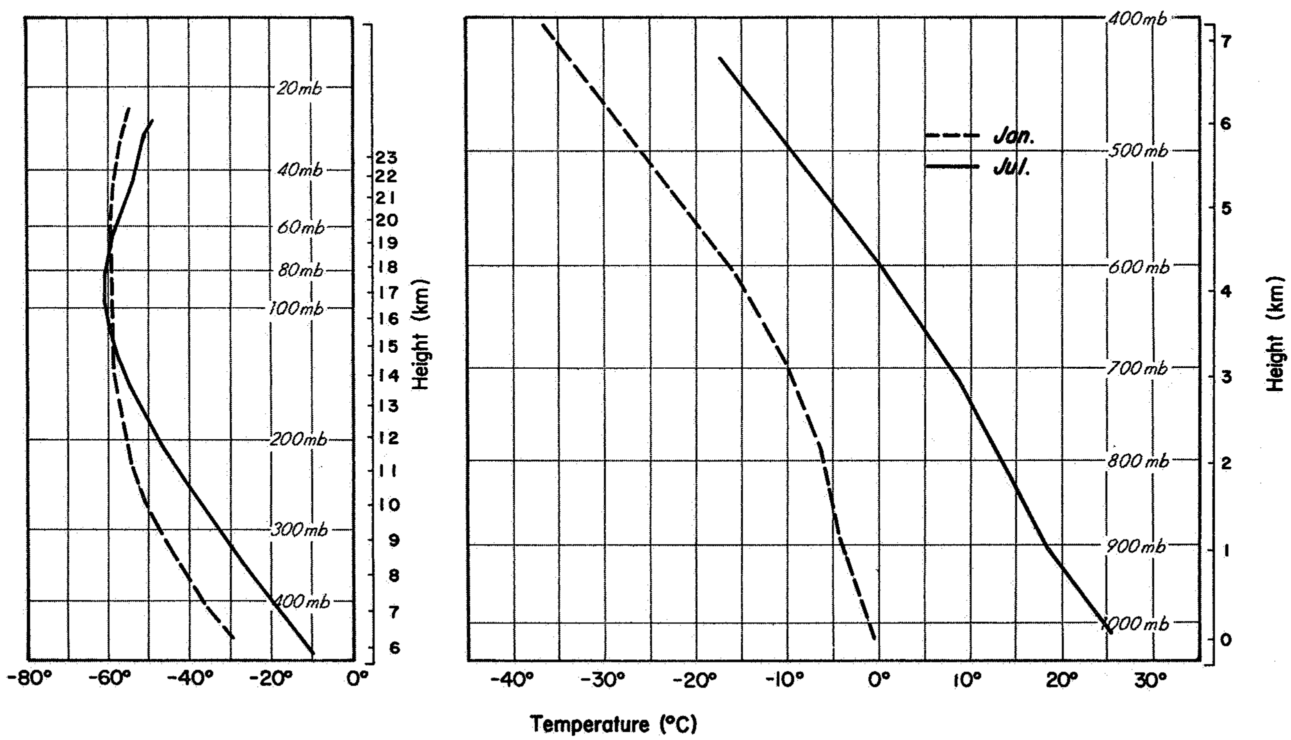


Figure A-42 Derived Mean Temperature Profile - Region 7

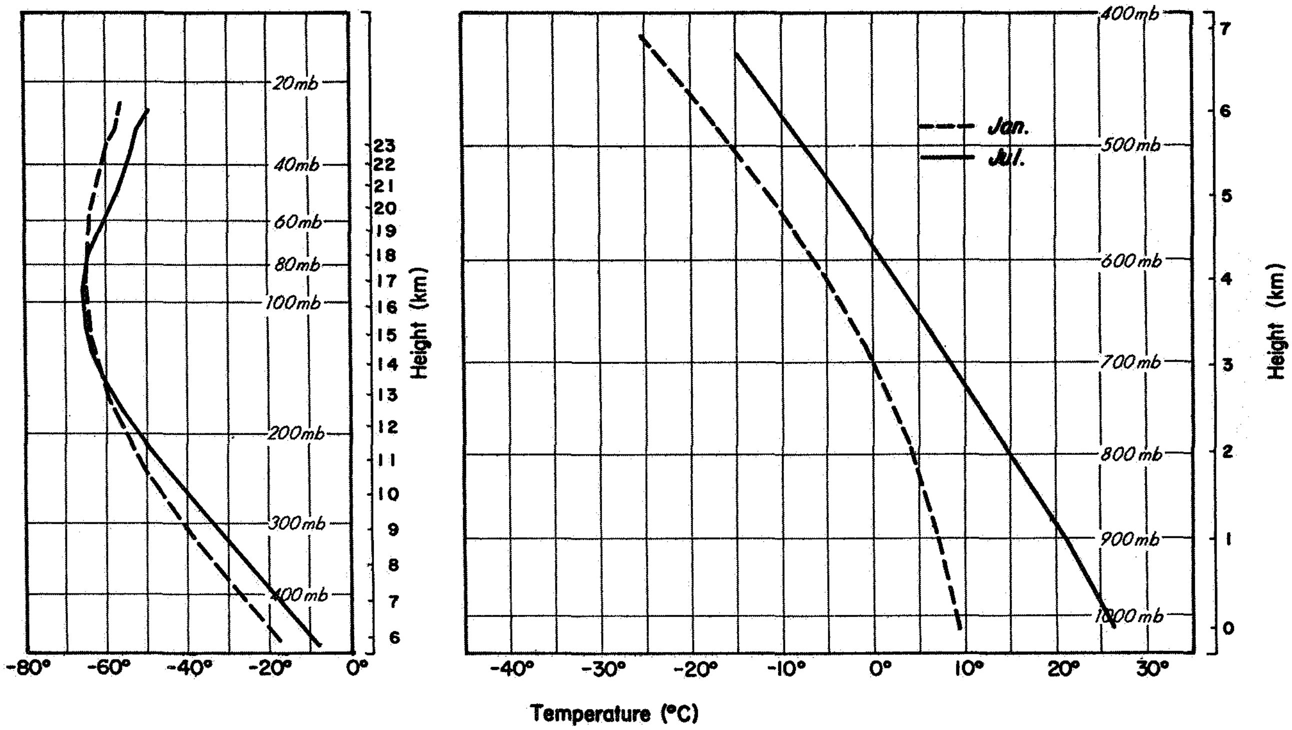


Figure A-43   Derived Mean Temperature Profile - Region 14

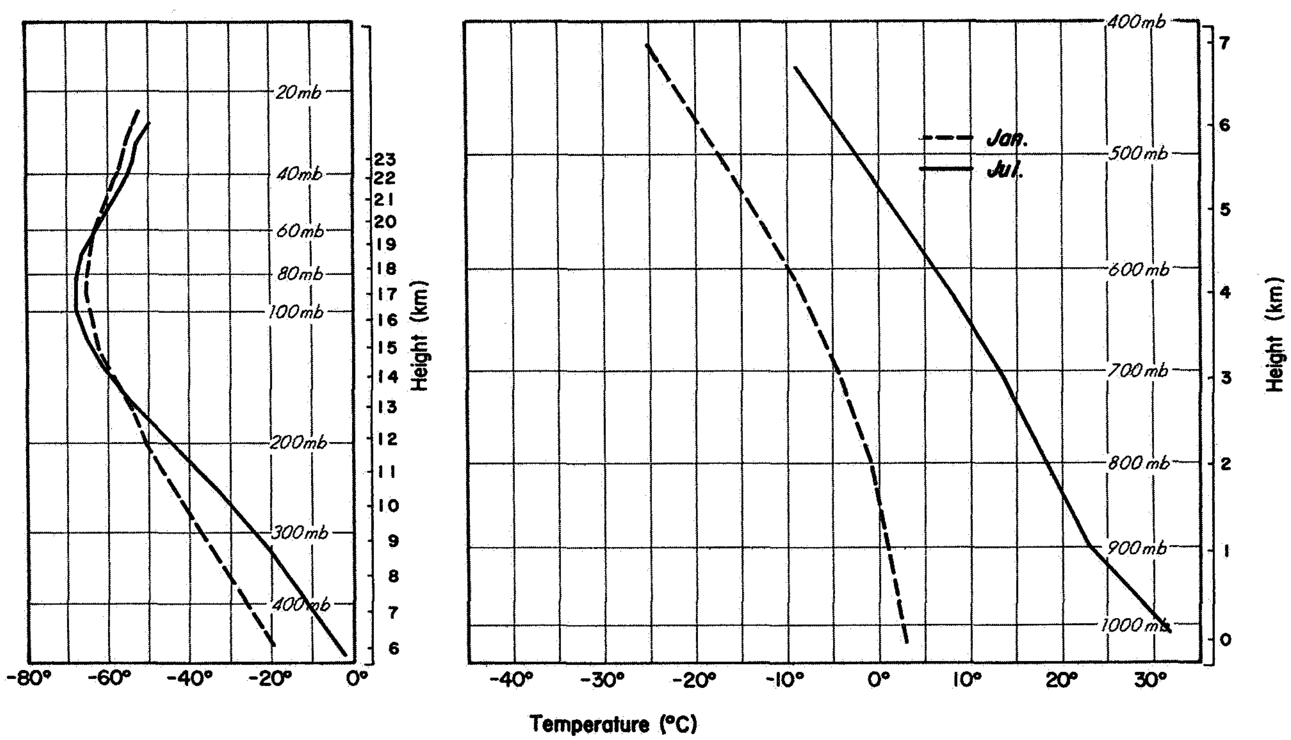


Figure A-44   Derived Mean Temperature Profile - Region 34

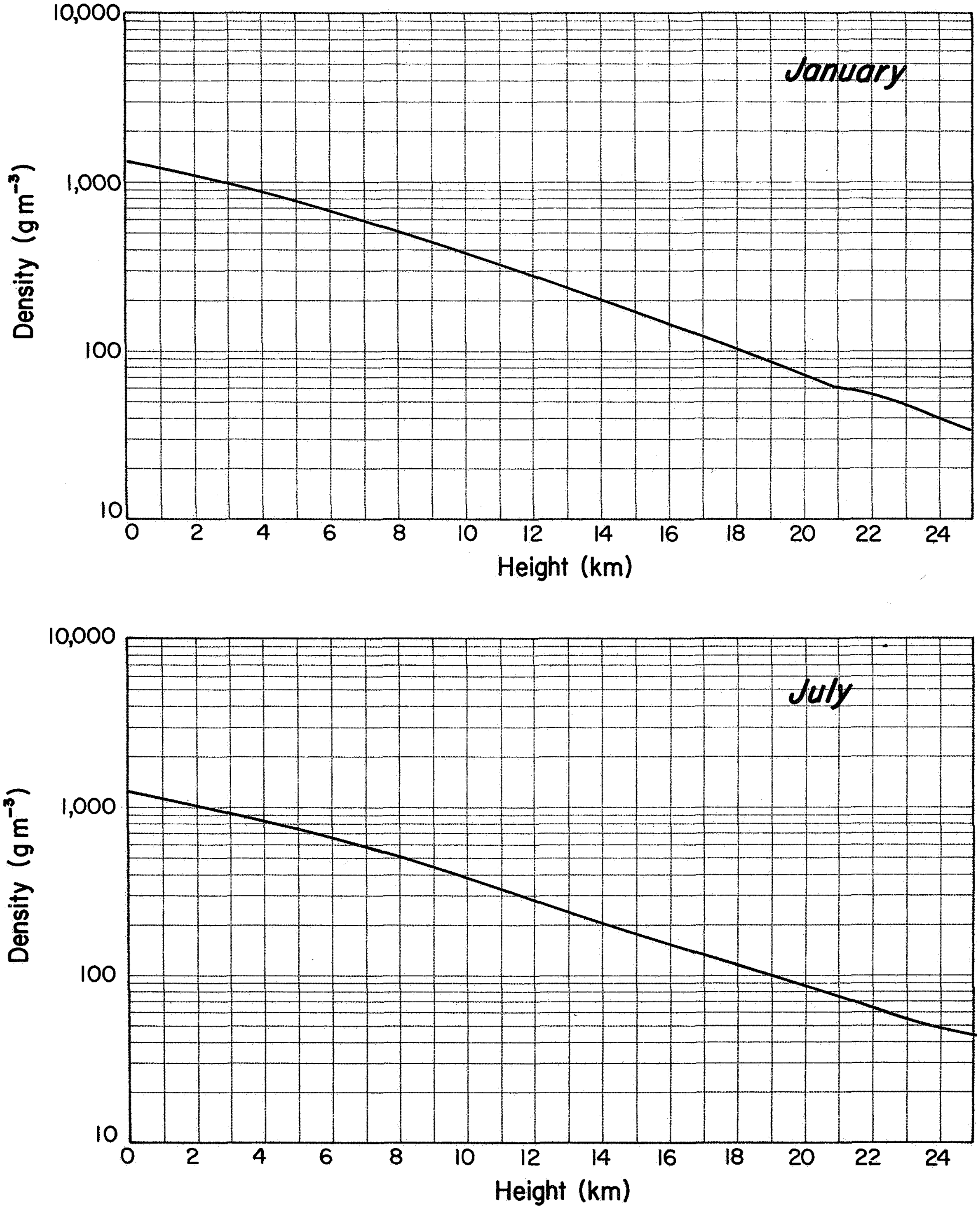
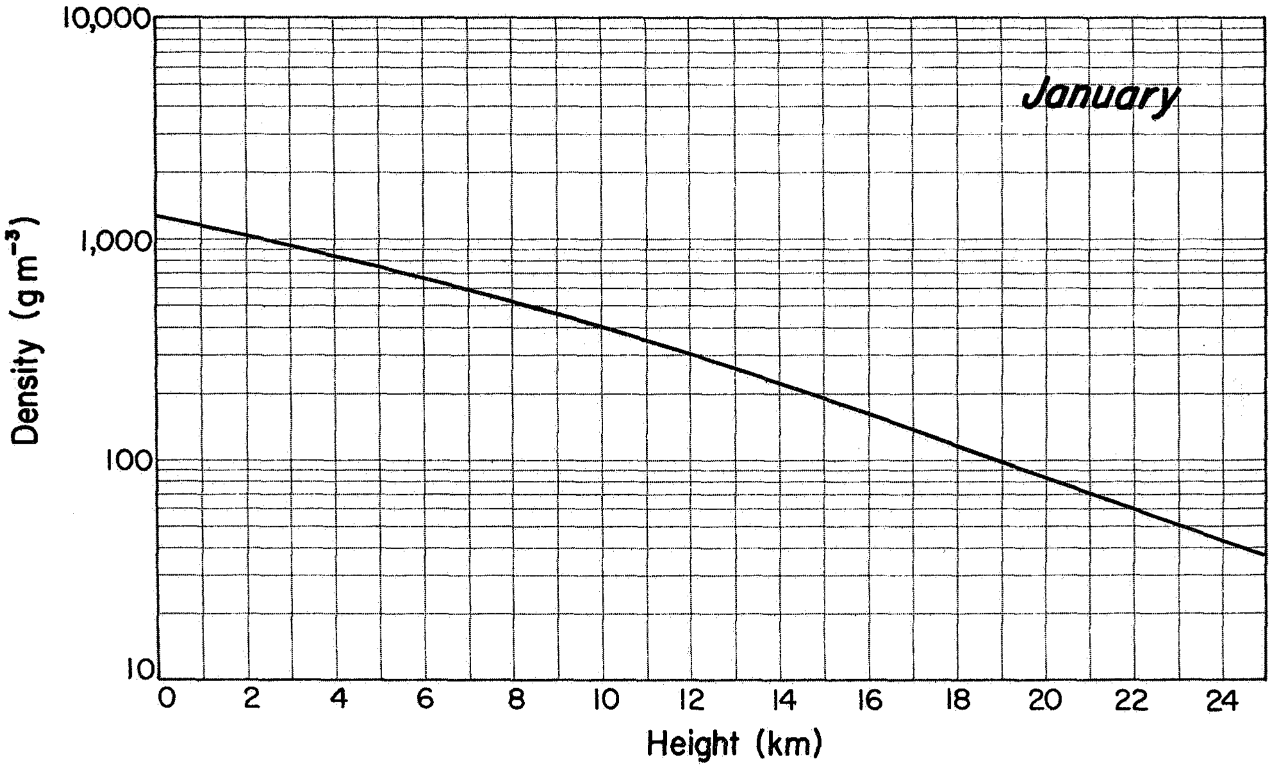


Figure A-45 Mean Density Profile - Region 1



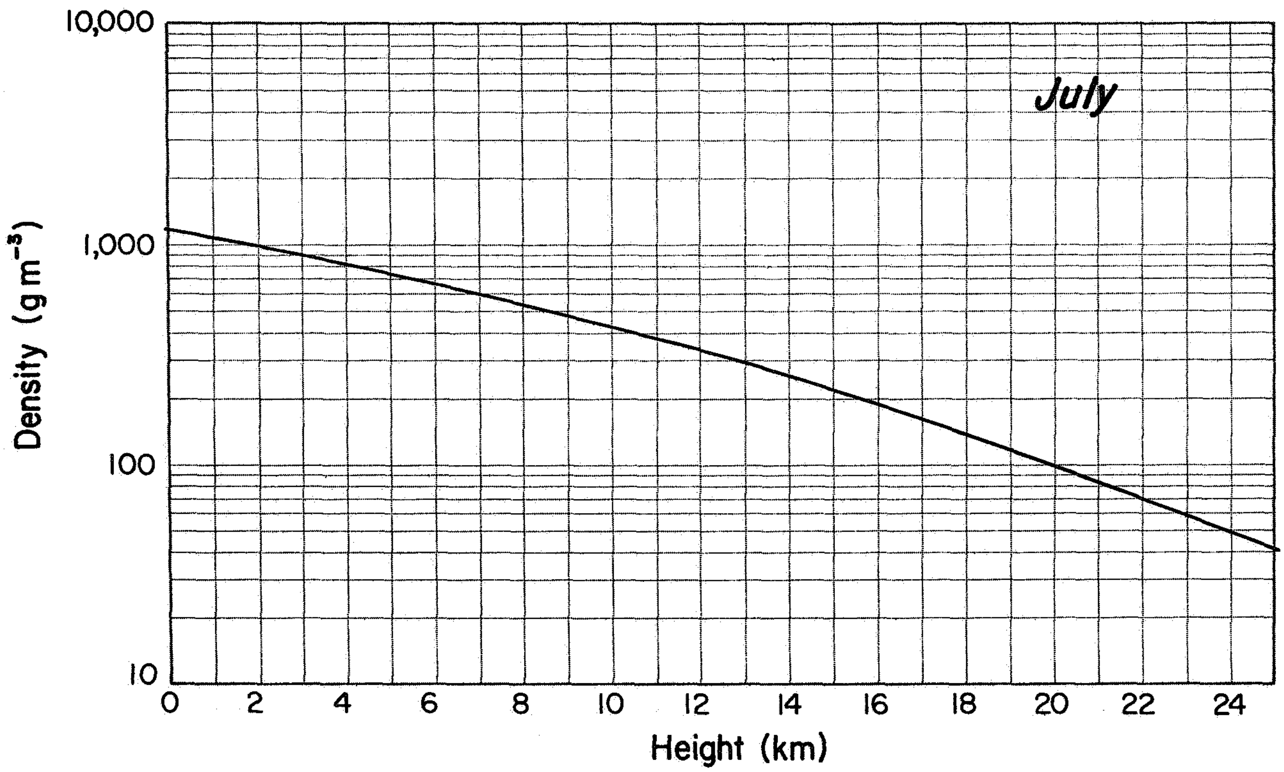


Figure A-46 Mean Density Profile - Region 7

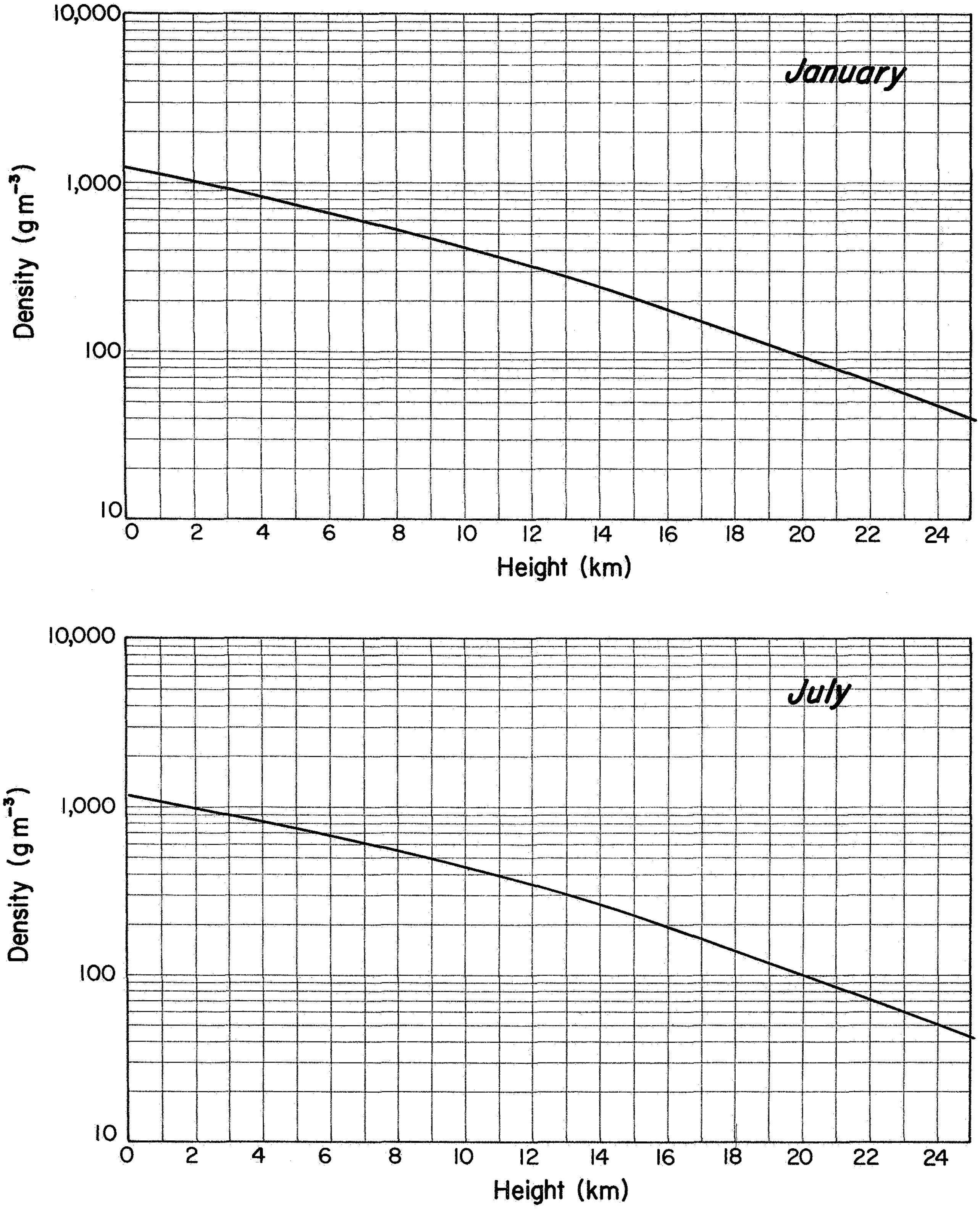


Figure A-47 Mean Density Profile - Region 14

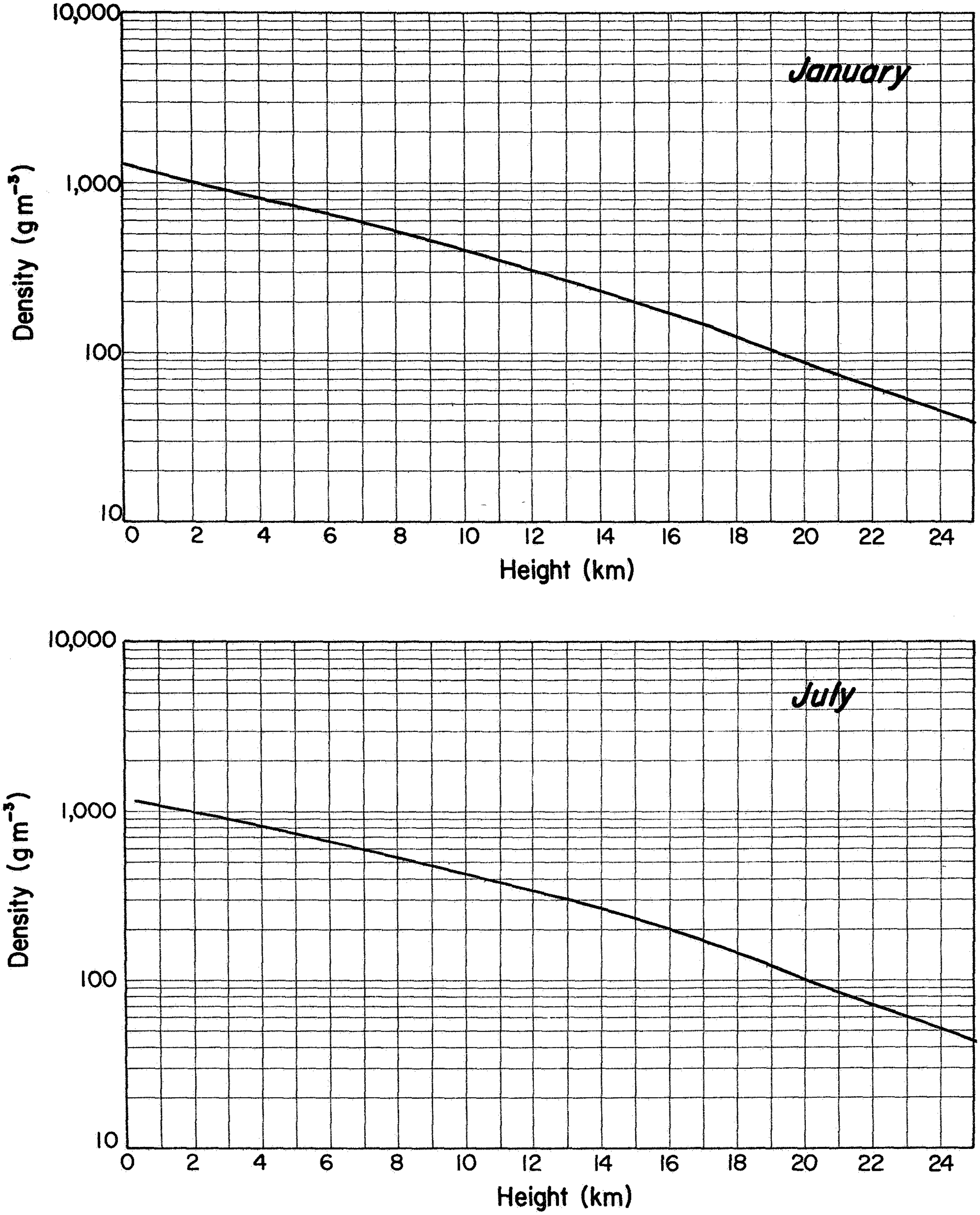


Figure A-48   Mean Density Profile - Region 34

APPENDIX B

9G81-15

USERS MANUAL FOR COMPUTER PROCESSING WITH FOUR-DIMENSIONAL ATMOSPHERIC MODELS

AUGUST 1971
CONTRACT NO. NAS 8-25618

JAMES H. WILLAND
MARY G. FOWLER

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
AERO-ASTRODYNAMICS LABORATORY
AEROSPACE ENVIRONMENT DIVISION
HUNTSVILLE, ALABAMA 35812

ARA ALLIED RESEARCH ASSOCIATES, INC.
VIRGINIA ROAD • CONCORD, MASSACHUSETTS

1. INTRODUCTION

The purpose of this manual is to describe in detail the procedures and programs necessary to derive monthly mean and daily variance profiles of moisture, temperature, density and pressure from the surface to 25 km for any location of the globe and for any month of the year. The final report on this study (Spiegler and Greaves, 1971) describes the concepts behind the study and the results. This manual should be used in conjunction with the information provided in the final report.

Section 2 discusses the background data processing in some detail to familiarize the user with the source data. Sections 3 and 4 describe how to use the computer programs and data to derive the desired atmospheric model profiles.

2. DATA PROCESSING

For the development of the 4-D models (see Final Report, Spiegler and Greaves, 1971), the following constant pressure data sets were available.

1) Daily values of temperature, dew point depression and heights for eight years on the National Meteorological Center (NMC) 1977 point grid. Temperatures and heights are from 1000 mb to 300 mb; dewpoint depressions from 850 mb to 500 mb (24 reels of tape).

2) Daily values of temperature and height from 100 mb to 10 mb for seven years on the NMC grid (7 reels of tape).

3) Monthly means and variances of temperature, dewpoint, and height from the surface to 100 mb (dewpoint, surface to 500 mb) on the 5° latitude-longitude grid for the northern hemisphere (1 tape).

4) Monthly means of temperature, dewpoint, and height from the surface to 100 mb (dewpoint to 500 mb) on the 5° latitude-longitude grid for the southern hemisphere (1 tape).

5) Midseason monthly variances of temperature, height and dewpoint from 850 mb to 100 mb (dewpoint to 500 mb) at every 5° latitude-longitude for the southern hemisphere (cards).

6) Daily variances of temperature, dewpoint and height from 850 mb to 100 mb (dewpoint to 500 mb) for latitudes 0° to 15° in the northern hemisphere (cards).

The first two data sets were processed to obtain means and daily variances of temperature, dewpoint and height. Conversion of these variances to a 5° latitude-longitude grid (using the 16-point Bessel interpolation scheme) allowed the computation of daily/monthly variance ratios for the northern hemisphere down to 20°N. Midseason southern hemisphere daily variances poleward of 20°S were then found by multiplying the variance ratios by the appropriate southern hemisphere monthly variances. For the southern hemisphere equatorial region, the northern hemisphere equatorial variances were used. The high altitude northern hemisphere daily variances, averaged around latitude circles, were applied to the southern hemisphere. Because northern hemisphere equatorial data and southern hemisphere means were not available above 100 mb, the data were extrapolated to 30 mb using regression equations.

The result of the processing to this point was a comprehensive data network at constant pressure levels. To interpolate all the data to kilometer levels as required by this study, the following equations were applied.

$$\overline{T}_{km} = \overline{T}_{p1} + \left(\overline{T}_{p2} - \overline{T}_{p1}\right)\left(\overline{Z}_{km} - \overline{Z}_{p1}\right) / \left(\overline{Z}_{p2} - \overline{Z}_{p1}\right) \quad (1)$$

$$\overline{TD}_{km} = \overline{TD}_{p1} + \left(\overline{TD}_{p2} - \overline{TD}_{p1}\right)\left(\overline{Z}_{km} - \overline{Z}_{p1}\right) / \left(\overline{Z}_{p2} - \overline{Z}_{p1}\right)$$

$$\overline{e}_{km} = 6.11 \times 10^{\left(\frac{7.5\, \overline{TD}_{km}}{\overline{TD}_{km} + 237.3}\right)}$$; the vapor pressure at a given dewpoint

$$\overline{\rho}_{w_{km}} = 216.7\, \overline{e}_{km} / \overline{T}_{km} \quad (2)$$

$$\overline{P}_{km} = 10^{\left(\log_{10} \overline{P}_{p1} - \left[\overline{Z}_{km} - \overline{Z}_{p1}\right] / \left[67.442\left(\overline{T}_{km} + \overline{T}_{p1}\right)/2\right]\right)} \quad (3)$$

$$\overline{\rho}_{km} = 348.3\, \overline{P}_{km} / \overline{T}_{km} \quad (4)$$

$$\sigma^2{}_{T_{km}} = \left(\sigma_{T_{p1}} + \left[\sigma_{T_{p2}} - \sigma_{T_{p1}}\right]\left[\overline{Z}_{km} - \overline{Z}_{p1}\right] / \left[\overline{Z}_{p2} - \overline{Z}_{p1}\right]\right)^2 \quad (5)$$

$$\sigma^2{}_{TD_{km}} = \left(\sigma_{TD_{p1}} + \left[\sigma_{TD_{p2}} - \sigma_{TD_{p1}}\right]\left[\overline{Z}_{km} - \overline{Z}_{p1}\right] / \left[\overline{Z}_{p2} - \overline{Z}_{p1}\right]\right)^2$$

$$\frac{d\left(\sigma_{\rho_{w_{km}}}\right)}{d\left(\sigma_{TD_{km}}\right)} = 4719.8\, \overline{\rho}_{w_{km}} / \left(273.3 + \overline{TD}_{km}\right)^2$$; the change in the standard deviation of absolute humidity with respect to the change in the standard deviation of dewpoint.

$$\sigma^2{}_{\rho_{w_{km}}} = \left(\frac{d\left[\sigma_{\rho_{w_{km}}}\right]}{d\left[\sigma_{TD_{km}}\right]}\right)^2 \sigma^2{}_{TD} \quad (6)$$

$$\sigma_{Z_{km}} = \sigma_{Z_{p1}} + \left(\sigma_{Z_{p2}} - \sigma_{Z_{p1}}\right)\left(\overline{Z}_{km} - \overline{Z}_{p1}\right) / \left(\overline{Z}_{p2} - \overline{Z}_{p1}\right)$$

$$\sigma^2{}_{P_{km}} = \left(\overline{\rho}_{km}\, g\right)^2 \sigma^2{}_{Z_{km}} \; ; \; g = .980 \times 10^{-4} \quad (7)$$

$$\sigma^2{}_{\rho_{km}} = \sigma^2{}_{T_{km}} \left(\overline{\rho}_{km} / \overline{T}_{km}\right)^2 . \quad (8)$$

where:

$\overline{T}$	=	mean temperature
$\overline{TD}$	=	mean dewpoint
$\overline{e}$	=	mean vapor pressure
$\overline{\rho}_w$	=	mean absolute humidity
$\overline{z}$	=	mean height
$\overline{P}$	=	mean pressure
$\overline{\rho}$	=	mean density
σ_T	=	standard deviation of temperature
σ_{TD}	=	standard deviation of dew point
σ_{ρ_w}	=	standard deviation of absolute humidity
σ_Z	=	standard deviaiton of height
σ_P	=	standard deviation of pressure
σ_ρ	=	standard deviation of density

Subscripts:

p1	=	the given pressure level at the bottom of an interpolation interval
p2	=	the given pressure level at the top of an interpolation interval
km	=	a given altitude

With the values at constant height levels, several other operations were performed to put the data in final form. The 5^{o} latitude-longitude means were converted to the NMC grid. Mean and variance profiles from 0 to 15^{o}N were retained to form the northern hemisphere tropical data set. The southern hemisphere midseason variances were applied to months on either side of the midseason months to complete that data set.

The final NMC data set consisted of a combination of the three groups of values available on that grid:

1) Means for all parameters from 1 to 16 km and means for surface moisture (from the original northern hemisphere 5^{o} latitude-longitude grid converted to the NMC grid).

2) Means for pressure, temperature and density at the surface and daily variances of all parameters from the surface to 10 km (from the daily data tapes on the NMC grid for levels up to 300 mb).

3) Means and daily variances of temperature, pressure and density from 17 to 25 km (from the daily high-altitude data tapes).

All missing values were then interpolated to complete the data set.

The final statistics produced consisted of approximately 9,000,000 values at constant height surfaces recorded on six tapes, as follows:

The NMC Data Set (3 Tapes)

NMCA1	Months 1 - 4	NMC Grid
NMCB1	Months 5 - 8	NMC Grid
NMCC1	Months 9 - 12	NMC Grid

These tapes contain means and variances for 1977 points; pressure, temperature, and density from surface to 25 km, moisture from surface to 5 km.

The Southern Hemisphere Data Set (2 Tapes)

SHA1	Months 1 - 6	5^o Lat-Long Grid
SHB1	Months 7 - 12	5^o Lat-Long Grid

These tapes contain means and variances for 1368 points; pressure, temperature, and density from surface to 23 km, moisture from surface to 5 km.

The Equatorial (0^o to 15^oN) Data Set (1 Tape)

EQN	Months 1 - 12	5^o Lat-Long Grid

This tape contains means and variances for 288 points; pressure, temperature, and density from surface to 23 km, moisture from surface to 5 km.

These tapes were all written in the same format of one point/record, one file/month. Each record consists of 210 36-bit integer words; the first 208 words contain data values multiplied by 100. Word 209 contains the point number, and word 210 contains the month number. The 208 data words are arranged as 26 levels of means and variances of pressure, temperature, moisture, and density, in that order. Thus word 1 contains the surface pressure mean; word 27, the surface pressure variance; word 208, the 25 km density variance. As the number of records in each file corresponds to the number of points per grid, the NMC tapes have 1977 records/file, the SH tapes have 1368 records/file, and EQN has 288 records/file. All tapes were written on a UNIVAC 1108 at 556 BPI binary.

Thirty-six regions were defined over the globe based upon the analysis of moisture data. Each data point was assigned to a given region. All the point means and variances were processed to develop region means and variances from the surface to 25 km. These were output onto tape NHSH, formatted identically to the above tapes, except that each record corresponds to a region rather than a point and the months are not separated by end-of-files.

3. FINAL DATA FORMATS AND COMPUTER PROGRAMS

3.1 Card Deck Description for the Four-Dimensional Atmospheric Model

Two card decks were assembled containing the data necessary to derive the monthly mean and variance profiles of moisture, temperature, density and pressure within "homogeneous" regions, defined on the basis of moisture (Spiegler and Greaves, 1971). The first card deck contains the homogeneous region numbers and boundaries. The second deck contains the necessary coefficients and constants for use with analytic functions to generate the atmospheric profiles.

3.1.1 Card Deck Containing Moisture Regions and Boundaries

Data for this deck were extracted from the map shown in Figure 3 of the final report (Spiegler and Greaves, 1971), as follows:

> The homogeneous moisture region boundaries were drawn along one-degree latitude-longitude lines to facilitate the problem of region boundary recognition by the computer. The area between 74°S and 80°N is divided into 155 rows extending from the Greenwich meridian (0° longitude) eastward for 360° of longitude, back to Greenwich. By scanning eastward along each row, the number of the region encountered and the value of its terminating longitude (numbers between 0 and 360) were recorded and punched on cards. Two cards were used to catalog one row, even though data for some rows did not extend into the second card. The card setup is illustrated in Figure 1.

3.1.2 Card Deck Containing Constants and Coefficients

Figure 2 illustrates the deck setup for cards containing the constants and coefficients for calculating the various atmospheric profiles. As can be seen, nine cards contain all the data for the analytic functions for each region. The top part of Figure 2 identifies each variable punched on the card and its location on the card. For example, the first of the nine coefficients to be used for calculating the standard deviation(s) of the pressure for Region 1 in January begins in column 1 of card 1, and is punched on the card in the familiar FORTRAN E format. (For example, 0.1138250E 02 represents the number $.1138250 \times 10^2$ or 11.38250.) The remaining coefficients extend from left to right onto the second card. The next three sets of nine coefficients are for calculating the temperature or pressure, standard deviation of the temperature, and the standard deviation of the density, respectively.

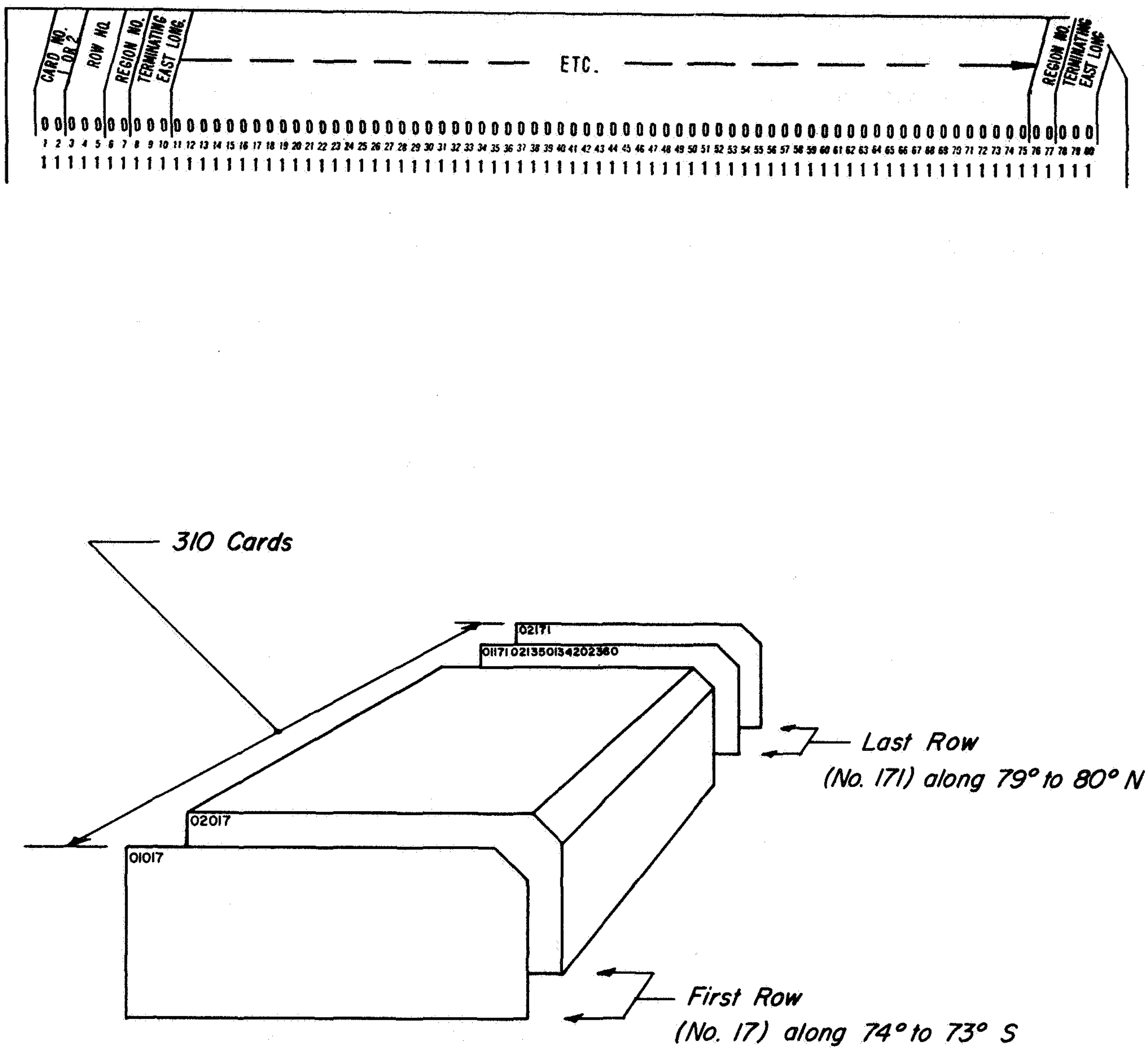


Figure 1 Deck Setup for Cards Combining Region Numbers and Terminating Longitudes

7807

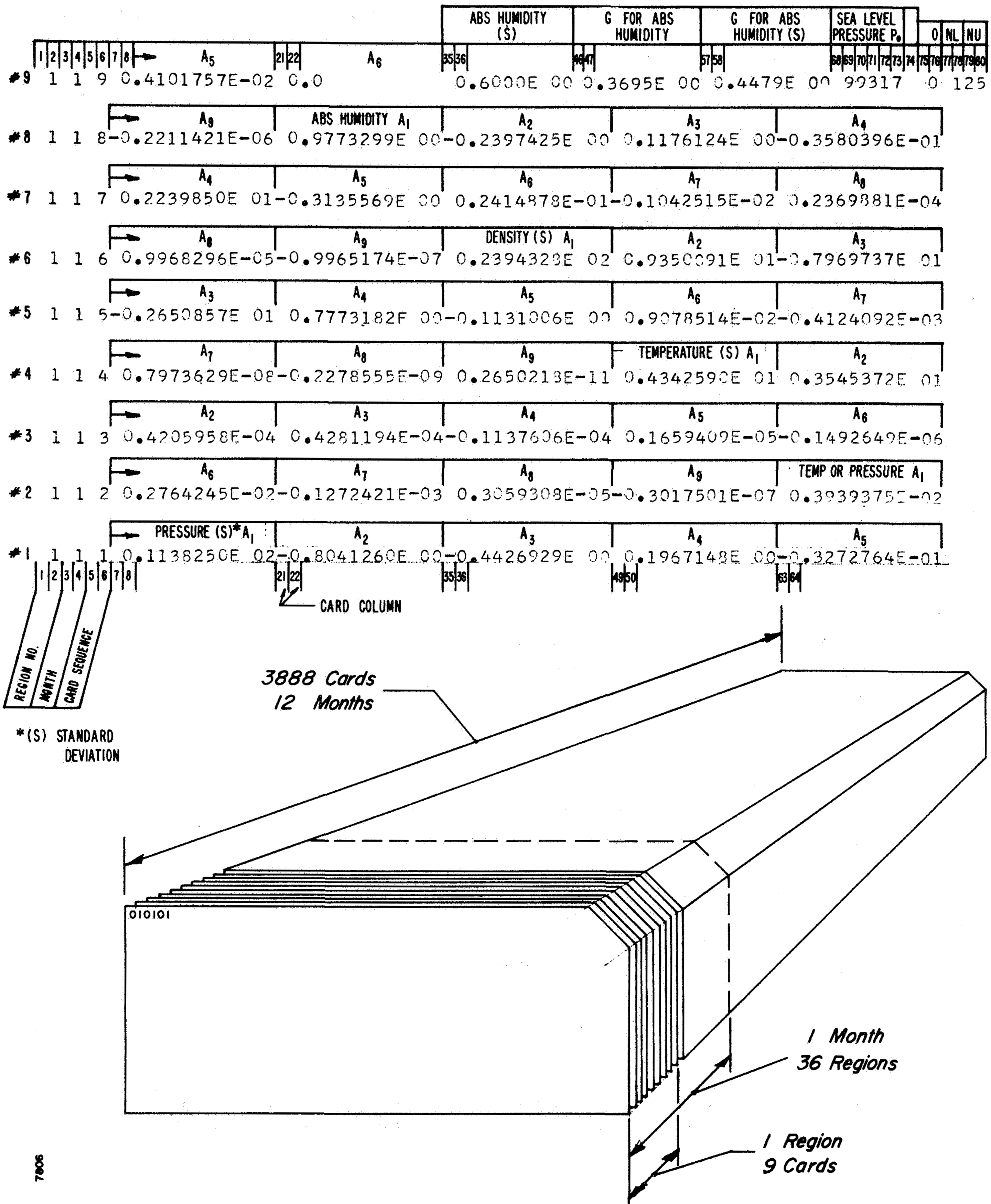


Figure 2 Deck Setup for Cards Containing the Constraints and Coefficients Defining the Analytical Functions for Calculating Various Atmospheric Parameters

Six coefficients then follow for calculating the absolute humidity. The next three values are constants punched in a shorter FORTRAN E format. The first is a single coefficient to be used for calculating the standard deviation of absolute humidity. The next two are G constants to be used in Eq. (12) below for calculating absolute humidity or its standard deviation, respectively. The sea-level pressure (P_o x 100) is punched as an integer constant in columns 68 through 73 of the ninth card. Column 76 is always zero. Two integer values (NL, NU) punched in columns 77 through 80 represent the lowest and the highest kilometer levels, respectively, that were encountered in the original data during the curve-fitting process.

3.2 Computations*

Equation (9) below, and the proper coefficients, may be used to calculate temperature (°K), and standard deviations of pressure, temperature and density.

$$Y = \left[\sum_{n=1}^{N} a_n z^{n-1} \right]^M . \tag{9}$$

Equation (10) may be used to calculate pressure in millibars.

$$p = p_o \exp \left[-(g/R) \sum_{n=1}^{N} a_n z^n/n \right]^M . \tag{10}$$

Note that the same set of coefficients used in Eq. (9) for calculating temperature are used in Eq. (10) for calculating pressure. The density can be calculated using the equation of state, Eq. (11):

$$\rho = p/(RT). \tag{11}$$

The absolute humidity or its standard deviation may be calculated using Eq. (12) below.

$$Y = \exp(-Gz) \left[\sum_{n=1}^{N} a_n z^{n-1} \right]^M . \tag{12}$$

Equation (13) below is used for determining absolute humidity above 5 km:

$$Y = Y_5 \exp(-G(z - 5)). \tag{13}$$

*Parts of Section 3.3 of the final report, explaining the analytic expressions derived for calculating the atmospheric profiles, are repeated in this section.

Variables for these equations are listed below.

Y is the atmospheric variable

N is the number of terms in the power series for each variable. $N = 9$ for temperature, pressure and the standard deviations of pressure, temperature, density. $N = 6$ for absolute humidity and $N = 1$ for its standard deviation.

G is a constant determined for each region and month

a_n are the appropriate coefficients

Z is altitude above sea level in kilometers

M is always +1 except when calculating temperature where $M = -1$

P is pressure (millibars)

P_o is sea level pressure (millibars)

g is acceleration due to gravity (.09807 km/sec^2)

R is the gas constant (.0028704 $^oK/sec/cm^2$)

ρ is density

Y_5 is computed absolute humidity at 5 km

The calculation of each parameter at sea level ($Z = 0$) presents a special case where values are calculated as follows:

$$T = \frac{1.0}{a_1}$$

$$P = \frac{P_o}{100.0}$$

Absolute humidity = a_1

Standard deviation of temperature = a_1

Standard deviation of pressure = a_1

Standard deviation of density = a_1

Standard deviation of absolute humidity = a_1

where

a_1 is the first coefficient for the variable being calculated.

T is temperature

4. COMPUTER PROGRAMS FOR CALCULATING ATMOSPHERIC PROFILES

Two computer programs were written to use the data punched on cards to calculate mean monthly atmospheric profiles and daily variances for specified areas of the world. The programs were specifically written to be used on the UNIVAC 1108 computer at NASA's Marshall Space Flight Center (MSFC) in Huntsville, Alabama.

4.1 Program No. 1

The first program reads in all of the data cards described in Section 3, verifies that all the cards are in proper order and outputs the data onto magnetic tape in binary format at 556 BPI. This tape is the data source for the second program which is described below. The resulting tape from this program contains 14 physical records.

- Record one is 156 words long containing the integer subscript addresses of the first region number and terminating longitude of a row.
- Record two is 2300 words long containing packed integer region numbers and terminating longitudes.
- Records three through fourteen contain all of the floating point constants and coefficients for computing profiles for each month and region. Each one of records three through fourteen is 1836 words long.

Each record is further broken down into 36 logical records, each of which contains 51 floating point words. The first word of each logical record is the region number and the second is the month. Words 3 through 51 are the coefficients stored sequentially. An end-of-file terminates the data on tape.

4.2 Program No. 2

The second program was written to calculate monthly mean and variance profile curves of moisture, temperature, density and pressure from sea level to 25 km for any location of the globe for any month of the year.

4.2.1 Program Input

The magnetic tape generated by Program No. 1 is required by this program as input for all coefficients for each region and month. The program also requires input cards containing data indicating the month(s) and region(s) for which the monthly means and variances are desired. Figure 3 illustrates where each input parameter is to be punched for each profile requested. These parameters are listed and explained below.

Input Parameter	Card Columns	Definition
Month	Integer 1 and 2 right-justified	This is the month for which the profile is to be derived.
Region	Integer 5 and 6 right-justified	This is the region for which the profile is to be derived. (This is optional.)
Latitude	Floating point 10 through 19	This is the latitude at which the profile is to be derived.
Longitude	Floating point 20 through 29	This is the east longitude at which the profile is to be derived.
First km level	Floating point 30 through 39	The first kilometer level of interest.
Last km level	Floating point	The last kilometer level of interest ($\leq$25 km).
Kilometer increment	Floating point 50 through 59	Incremental level of the profile

If the region number is punched on the card, the latitude and longitude need not be punched. If the region number is left blank, a latitude and longitude must be punched so that the program can find the proper region. All other parameters must appear on the card. The program has the additional capability for computing values at increments between (whole) km levels. Thus the kilometer values need not be whole numbers. All floating point numbers must be punched with a decimal point somewhere within the area allotted for the parameter. Any number of these input cards may be placed behind the source or object deck of Program No. 2.

4.2.2 Program Output

For each month and region requested, a table of pressure, temperature, absolute humidity and density means and variances for each kilometer level is calculated and printed on the printer.

Table 1 is included here as a sample output of the profile requested on the card in Figure 3. Below is a list of the units applicable to the profile parameters.

Profile Parameter	Units
Pressure	mb
Temperature	Kelvin
Absolute Humidity (water)	g/m^3
Density	g/m^3
Variances	$(\text{standard deviation})^2$
Level	km

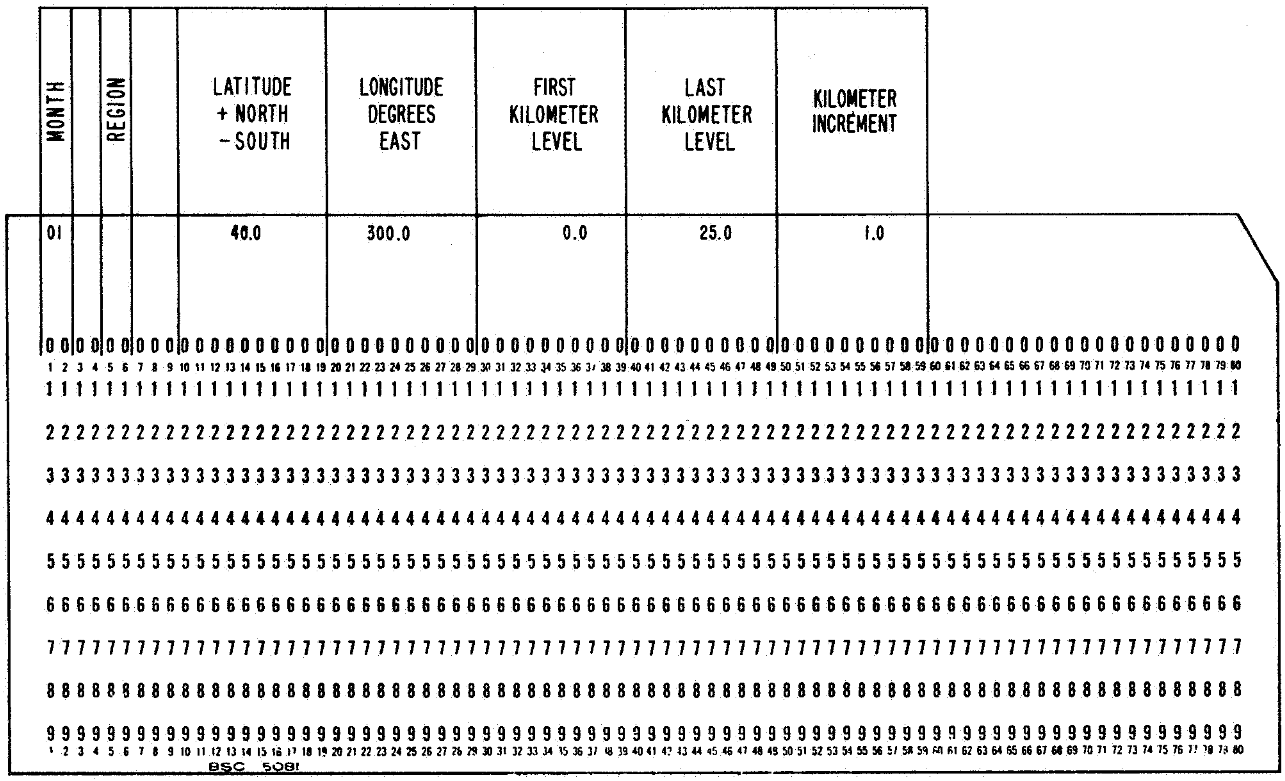


Figure 3 Input Card for Program 2

7808

TABLE 1

FOUR-DIMENSIONAL ATMOSPHERIC MODEL

MONTH = 1 LATITUDE = 40.00 LONGITUDE = 300.00 E REGION 11

LEVEL	PRESSURE	VARIANCE	TEMP (K)	VARIANCE	WATER	VARIANCE	DENSITY	VARIANCE
0.0 KM	1017.44	72.05	284.65	15.31	8.27	5.55	1245.24	297.68
1.00 KM	901.10	56.41	273.56	14.28	5.09	2.78	1126.97	237.26
2.00 KM	796.24	51.26	273.80	15.46	2.81	1.18	1013.12	212.87
3.00 KM	702.03	49.16	268.74	16.52	1.58	0.50	910.09	191.24
4.00 KM	617.36	47.40	262.82	16.68	0.94	0.21	818.35	164.41
5.00 KM	541.21	45.30	256.15	16.06	0.56	0.09	736.09	134.99
6.00 KM	472.75	42.92	249.12	15.21	0.32	0.04	661.12	107.90
7.00 KM	411.35	40.47	242.19	14.51	0.13	0.02	591.73	86.31
8.00 KM	356.54	37.97	235.75	14.19	0.10	0.01	526.89	70.78
9.00 KM	307.37	35.25	230.06	14.27	0.06	0.00	466.22	60.15
10.00 KM	264.96	32.01	225.27	14.56	0.03	0.00	409.75	52.55
11.00 KM	227.36	28.02	221.41	14.79	0.02	0.00	357.74	46.04
12.00 KM	194.64	23.24	218.44	14.67	0.01	0.00	310.42	39.16
13.00 KM	166.32	17.95	216.26	13.97	0.01	0.00	267.92	31.29
14.00 KM	141.93	12.67	214.76	12.67	0.00	0.00	230.23	22.78
15.00 KM	121.01	8.02	213.80	10.92	0.00	0.00	197.18	14.76
16.00 KM	103.11	4.47	213.26	9.01	0.00	0.00	168.45	8.30
17.00 KM	87.84	2.17	213.03	7.29	0.00	0.00	143.65	4.06
18.00 KM	74.82	0.95	213.03	5.99	0.00	0.00	122.36	1.84
19.00 KM	63.74	0.41	213.22	5.21	0.00	0.00	104.14	0.93
20.00 KM	54.31	0.24	213.59	5.03	0.00	0.00	88.58	0.67
21.00 KM	46.29	0.24	214.15	5.41	0.00	0.00	75.31	0.69
22.00 KM	39.47	0.28	214.89	6.29	0.00	0.00	64.00	0.70
23.00 KM	33.68	0.31	215.78	7.59	0.00	0.00	54.38	0.48
24.00 KM	28.76	0.25	216.72	9.46	0.00	0.00	46.23	0.22
25.00 KM	24.57	0.18	217.43	12.59	0.00	0.00	39.37	0.35

☆U.S. GOVERNMENT PRINTING OFFICE: 1971—745378/4025