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DISTRIBUTION OF THERMODYNAMIC PROPERTIES OF THE ATMOSPHERE BETWEEN 30 AND 80 KM

Allen E. Cole

Air Force Cambridge Research Laboratories
L. G. Hanscom Field, Massachusetts

10 August 1972

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AIR FORCE SYSTEMS COMMAND
United States Air Force

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13. ABSTRACT

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Abstract

Recently acquired rocket observations from U. S. and USSR stations in arctic and subarctic regions are used to expand and update information published in AFCRL Environmental Research Paper No. 330, Extreme Temperature, Pressure and Density Between 30 and 80 km. A revised set of estimated world-wide extremes of temperature, pressure and density are provided, together with frequency distributions of observed temperatures and densities at levels between 30 and 80 km for latitudes 30°, 45°, 60° and 80° N during June-July and December-January. Distributions around the annual mean are given for 15° N.

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1. INTRODUCTION

Recently acquired rocket observations from U. S. and USSR stations have been used to expand and update information published in AFCRL Environmental Research Paper No. 330 Extreme Temperature, Pressure and Density Between 30 and 80 km (Cole, 1970) A revised set of world-wide extremes of temperature, pressure and density for levels between 30 and 80 km are presented for use in the revision of MIL-STD-210A. Climatic Extremes for Military Equipment. Frequency distributions of observed temperatures and densities at levels between 30 and 80 km are also presented for latitudes 30°, 45°, 60° and 80° N during June-July and December-January. Distributions around the annual mean are given for 15° N.

In determining the world-wide extremes, June-July observations were used to represent one extreme of the annual cycle of temperature, pressure and density and December-January the other. The warmest and coldest mean monthly temperatures and the highest and lowest densities and pressure at levels between 30 and 80 km occur over the summer and winter poles. The use of data for two calendar months, rather than one, greatly increased the sample size and the reliability of the estimates with little effect on extreme values.

The frequency distributions of temperature and density at levels between 30 and 80 km for latitudes 30°, 45°, 60° and 80° N are also based on June-July and December-January observations. Although the maximum and minimum mean

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monthly temperatures between 30 and 80 km do not occur at all latitudes in the same month, the June-July and December-January observations provide a good indication of the magnitude of the seasonal and latitudinal temperature variability at these levels. June-July and December-January are also the months with the highest and lowest densities.

The annual temperature cycle at levels between 30 and 80 km is largest near the poles, decreasing toward the equator. Semiannual and biennial cycles are largest near the equator, decreasing toward the pole. The phases as well as the amplitudes change with latitude and altitude. The semiannual oscillation produces two pronounced maxima and minima within the yearly temperature cycle in tropical and sub-tropical regions. North of 30° latitude, however, there is normally one pronounced maximum and minimum within the yearly temperature cycle. The combined annual and semiannual components occasionally shift the time of the maximum temperature in the upper stratosphere to early June or May, and the minimum to early December or November. However, in cases where the maximum mean monthly temperatures occur in May rather than December or January, the difference between the May-and-June and the November-and-December values are only a few degrees.

In tropical areas the amplitudes of the temperature cycles are relatively small in comparison to those at mid-and-high-latitudes. Consequently, distributions of temperature and densities for 15°N are given around the annual rather than the seasonal mean.

2. DATA

Data for determining distributions of temperature, pressure, and density at levels between 30 and 80 km are from meteorological and experimental rocket observations taken primarily in the Northern Hemisphere. Unfortunately, observational sites are not evenly distributed throughout the hemisphere. Most of the observations are from sites in North America. There is a considerable gap in the data between 40° and 60°N and a sharp decrease in the number of available observations for levels above 55 km, especially in tropical areas.

Meteorological Rocket Network (MRN) observations (World Data Center A, 1965-70) for the years 1965-69 and Russian rocket observations (USSR, 1967-71) for the years 1965-1969 were used to determine the frequency distributions of observed temperature, pressure and density at levels between 30 and 55 km. The measurements considered were taken within a few hours of local noon at locations given in Table 1.

The frequency distributions at levels between 55 and 90 km are based primarily on data derived from grenade, falling sphere and pitot static tube experiments (USSR, 1967-71; Smith et al, 1964, 1966, 1967, 1968, 1968-70; Groves, 1965, 1968; Faire and Champion, 1965-69) performed between 1958 and 1970 at the locations listed in Table 2.

Table 1 Data Analyzed in Determining Temperature and Density Distributions Between 30 and 55 km

Observation Site	Location	
Ascension	7°59'S	14°25'W
Antigua	17°09'N	61°47'W
Barking Sands	21°54'N	159°35'W
Cape Kennedy	28°27'N	80°32'W
Wallops	37°50'N	75°29'W
Volgograd	48°41'N	44°21'E
West Geirinish	57°21'N	7°22'W
Churchill	58°44'N	93°49'W
Ft Greely	64°00'N	145°44'W
Thule	76°33'N	68°49'W
Heiss Island	80°37'N	58°03'E

Table 2. Data Analyzed in Determining Temperature and Density Distributions Between 50 and 80 km

Observation Site	Location	
Ascension	7°59'S	14°25'W
Natal	5°55'S	35°10'W
Woomera	30°57'S	136°31'E
White Sands	32°23'N	106°29'W
Eglin	30°23'N	86°42'W
Wallops	37°50'N	75°29'W
Volgograd	48°41'N	44°00'E
Churchill	58°44'N	93°49'W
Point Barrow	71°21'N	156°59'E
Heiss Island	80°37'N	58°03'E

The World-wide pressure extremes are based on observations taken at Thule Point Barrow and Heiss Island. The maximum and minimum pressures were observed at these locations

3. DATA ACCURACY

The equipment used by the Meteorological Rocket Network consists of parachute-borne telemetering sets with bead thermistors to sense temperature. They are ejected from rockets at altitudes of 60 to 65 km. Errors associated with aerodynamic heating during ascent and ejection and with solar radiation on the bead during descent by parachute have not been completely resolved. The current opinion (Ballard and Rofe, 1969) is that little correction is needed below 50 km. In addition to possible biases, measurements include random errors. Estimated rms (root-mean-square) instrumental errors in MRN density and temperature measurements are given below.

Temperature – less than 1°K at levels below 50 km (Ballard and Rofe, 1969)

Density – 2-to 3-percent at 50 km decreasing with altitude (Cole, 1968)

Estimated rms instrumentation errors in the temperature and density measurements taken by USSR rocketsondes at Heiss Island and Volgograd (USSR, 1967-71) are:

Temperature – 3°K at 40 km
5°K at 50 km
7 to 10°K at 60 to 80 km

Density – 10 to 15% at 60 to 80 km

There are insufficient data on which to base statistical estimates of the observational errors in temperatures, densities and pressures derived from grenade, falling sphere and pitot-static tube experiments. The accuracy of grenade measurements is related to (1) altitude; (2) height increment over which temperatures are averaged, normally 2.5 to 5.0 km; and (3) the arrangement of microphones that are used to detect the arrival of sound waves at the ground. Determining the arrival time of sound waves at the ground is the major source of error. Inaccurate time measurements can result in temperature errors ranging from 1°C at 40 km to 15°C at 90 km (Smith et al, 1964). Since the errors are random, they will have little effect on the mean values but will tend to increase the range of extreme values. It is difficult to assess the magnitude of the effect of these errors on the estimated extremes of temperature, pressure and density since they are based on theoretical studies which give only a range of possible errors.

4. PROCEDURE

Temperature, pressure and density observations at 5-km intervals between 30 and 80 km for June-July and December-January at each site were ordered from the smallest to the largest and plotted on probability paper using the following formula suggested by Kimball (1960):

$$Pi = (i-3/8)/(N+1/4)$$

where P is the probability of a value being equalled or exceeded, i is the sequence of observations, and N is the number of observations. Smoothed lines were drawn through the points on the probability paper and the curves were used as estimates of the true distributions. The values equalled or exceeded 1, 10, 20, 50, 80, 90 and 99-percent of the time were determined from the probability curves for each site and plotted on linear graph paper as a function of latitude. Smoothed curves extending from the equator to 85°N at levels below 50 km and from 30° to 85°N at levels above 50 km were subjectively fitted to the data points. Curves representing the distributions (by latitude) of temperature and densitites which are equalled or exceeded 1-, 10-, 50-, 90- and 99-percent of the time are shown in Figures 1 and 2.

5. DISCUSSION

5.1 Temperatures

At mid-and high-latitudes, the warmest median temperatures between 30 and 60 km occur in June-July and the coldest in December-January. The latitudinal temperature gradients are weak in summer with temperatures increasing toward the pole. The magnitude of the day-to-day variability about the seasonal medians as indicated by the 1- and 99-percent values, Figure 1, remain relatively constant between equator and pole in June-July. The reversal in the latitudinal temperature gradients between 75° and 80°N is based on Heiss Island data. Extrapolation of U. S. data for June-July would show increasing temperature from equator to pole. The decrease suggested by the Heiss Island data may not be real since the U. S. and USSR temperature measurements were taken with different types of sensors. It is possible that the Russian instruments may be biased toward colder and/or the U. S. sensors toward warmer temperatures.

The December-January temperature distributions between 30 and 60 km, Figure 1, are nearly normal and the range of observed values relatively constant from the equator to 30°N. At higher latitudes, temperature distributions are bi-modal. Sudden warmings and coolings of the upper stratosphere in arctic and subarctic regions produce large day-to-day changes in the vertical temperature distribution. As a result temperatures are usually colder or much warmer than the seasonal medians. The extremely warm temperatures, values equalled or exceeded 1- and 10- percent of the time, deviate consideratly more from the median than the extremely cold temperatures. At some locations, the 1- and 10-percent December-January temperatures are warmer than the corresponding June-July values for the same level. There is considerable variation with longitude in the 1- and 10- percent temperatures in arctic and subarctic regions as the frequency and magnitude of the winter warmings varies with longitude. The 1 percent 45 km temperature at West Geirinish (57 N^{o} $7^{o}W$) during December-January, for example, is 304 K compared to 1 percent values of 264 and 275 at Ft Greely ($64^{o}N$ $164^{o}W$) and Churchill ($59^{o}N$ $95^{o}W$) which are at approximately the same latitude. The 99-, 90-, and 50- percent December-January temperatures between 30 and 60 km decrease rapidly with latitude between 30^{o} and $80^{o}N$ with the lowest temperature occurring near the pole. Longitudinal variations in the 99- and 90-percent temperatures are relatively small.

There is a level of minimum seasonal and latitudinal variability in monthly median temperatures at 60 and 65 km. Day-to-day variations at this level, however, are much larger in winter than in summer at both mid- and high-latitudes. The latitudinal temperature gradients at levels above 65 km are the reverse of those at the lower levels. The coldest temperatures occur in June-July and warmest in December-January, with the more extreme values occurring in polar regions. Although the median temperature curves are relatively smooth for levels above 60 km, the 1- and 10-percent curves are very irregular, particularly at 75 and 80 km. Part of this irregularity is undoubtedly due to the extremely small sample of observation and larger measurement errors associated with observations at the higher levels.

In the tropics, 0^{o} to 25^{o} latitude, the temperature cycle is dominated by a semiannual oscillation at levels between 30 and 80 km. Both mean monthly temperatures and densities at these levels are highest in the spring and lowest in winter, with secondary maximum and minimum values occurring in the fall and summer respectively. The amplitudes of the semiannual oscillations, however, are relatively small when compared to annual variations at high latitudes. The temperature and density distributions given for tropical regions are computed around the annual rather than seasonal medians for levels up to 50 km. Sufficient observations are not available in tropical areas for estimating the day-to-day distributions of temperature and density about the seasonal or annual medians above 50 km.

5.2 Densities

The annual variability of density at levels between 30 and 80 km increases with latitude. The highest and lowest values occur near the poles in June-July and December-January respectively. The seasonal range increase with altitude up to approximately 70 km and then decreases slightly between 70 and 80 km.

In June-July, densities increase gradually from equator to pole and the range of the day-to-day variability about the median values as depicted by the 1- and 99-percent curves, Figure 2, remains relatively constant with latitude except for a slight increase between 60° and 80°N.

In December-January there is a rapid decrease in the median densities and a relatively large increase in the day-to-day variability between 30°N and the pole. The irregularity of the latitudinal density curves between 30 and 60 km in subarctic regions is a reflection of the longitudinal variability in the structure of the atmosphere and the intensity of winter warmings of the stratosphere.

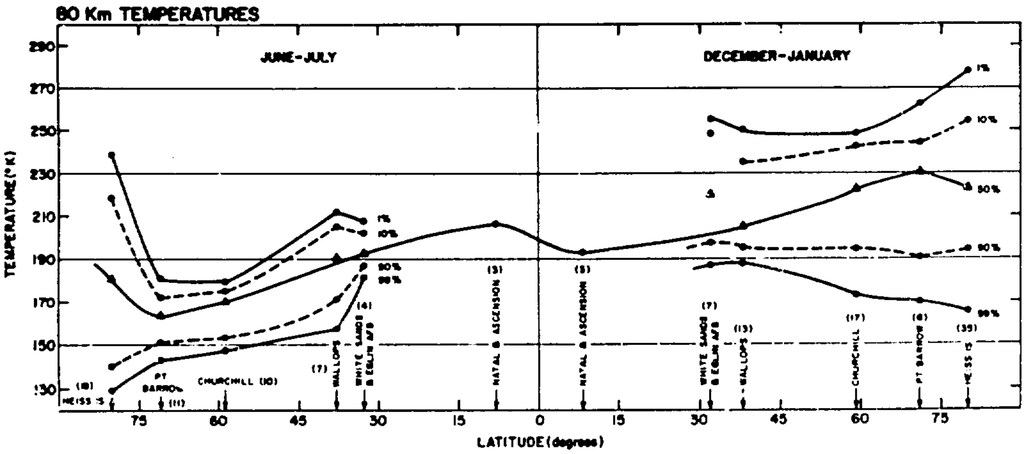
6. DISTRIBUTIONS OF TEMPERATURE AND DENSITY AT SPECIFIC LATITUDES

Median temperatures and densities with maximum and minimum values which are equalled or exceeded 1-, 10-, and 20-percent of the time during June-July and December-January are given for levels between 30 and 80 km in Tables 3 and 4 for 30, 45, 60 and 80°N. Densities are shown as percent departure from the U. S. Standard Atmosphere, 1962. In areas where there is considerable longitudinal varability (arctic and subarctic regions), values for a specific latitude are from the region reporting the most extreme conditions.

7. WORLD-WIDE EXTREMES

High and low temperatures, pressures and densities for various levels between 30 and 80 km that have a 1-, 10- and 50- percent likelihood of being equalled or exceeded during the worst season (two month period) at the worst location (antarctica excluded) are presented in Tables 5, 6 and 7. At most levels the 1 percent world-wide extremes are based on extrapolated data and are more extreme than observed conditions. Due to the sparsity of data at the higher levels, confidence in the 1- and 10-percent values decreases rapidly with altitude above 50 km.

TEMPERATURES



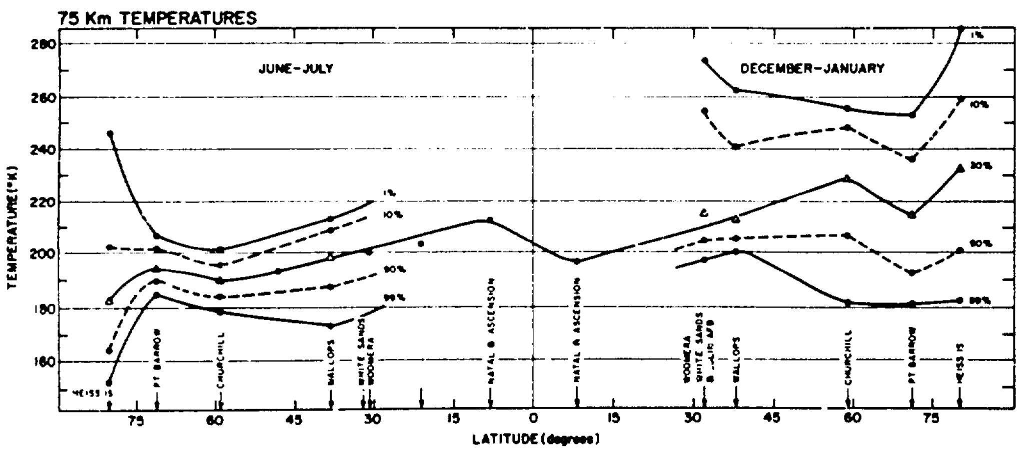


Figure 1. Longitudinal Plots of Temperatures Which Are Equalled or Exceeded 1-, 10-, 50-, 90- and 99-percent of the Time During June-July and December-January. Triangles represent median values and circles seasonal mean values. Number of available observations is given in brackets at the 80- and 60- km levels

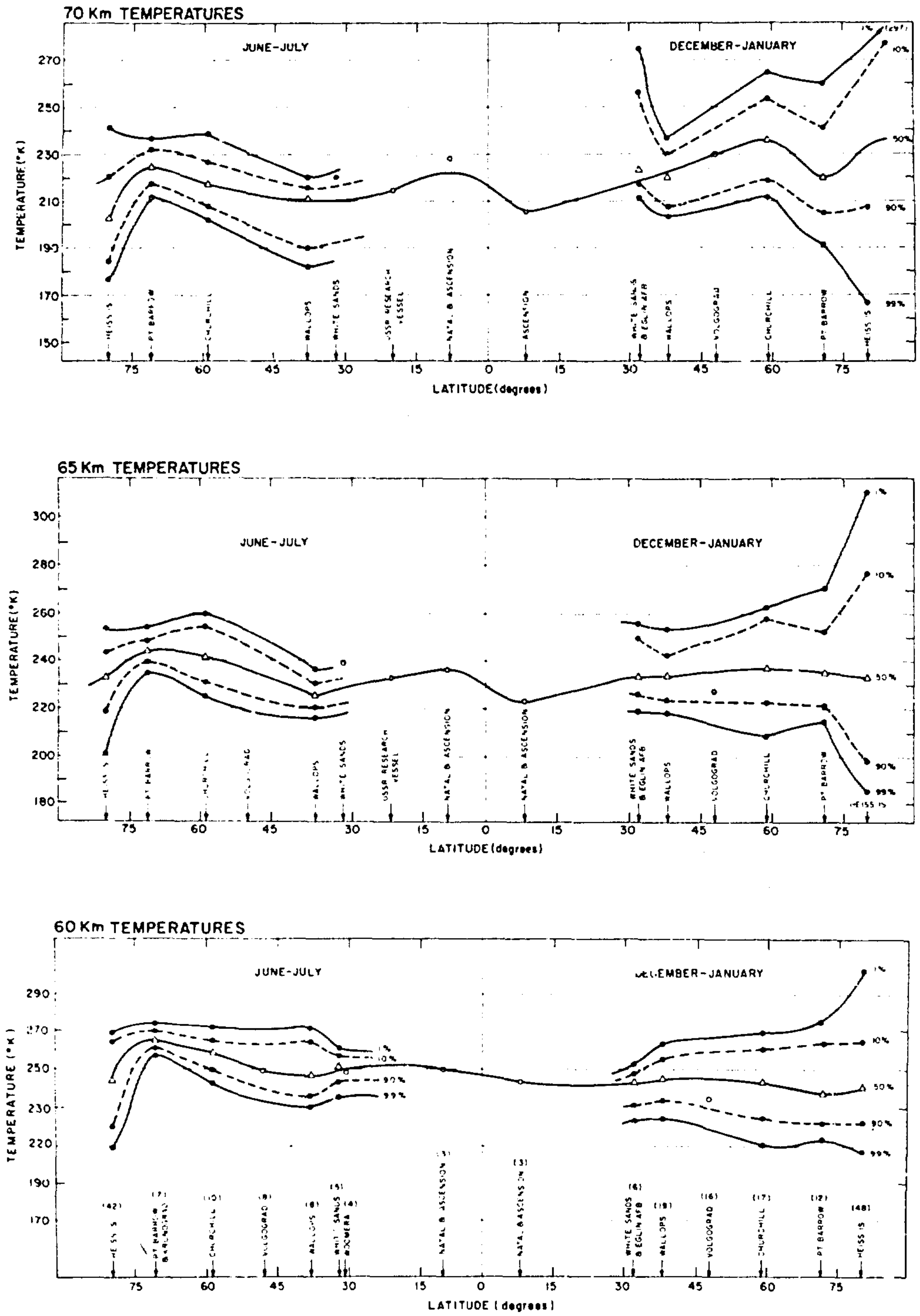


Figure 1 (Contd.). Longitudinal Plots of Temperatures Which Are Equalled or Exceeded 1-, 10-, 50-, 90- and 99-percent of the Time During June-July and December-January. Triangles represent median values and circles seasonal mean values. Number of available observations is given in brackets at the 80- and 60- km levels

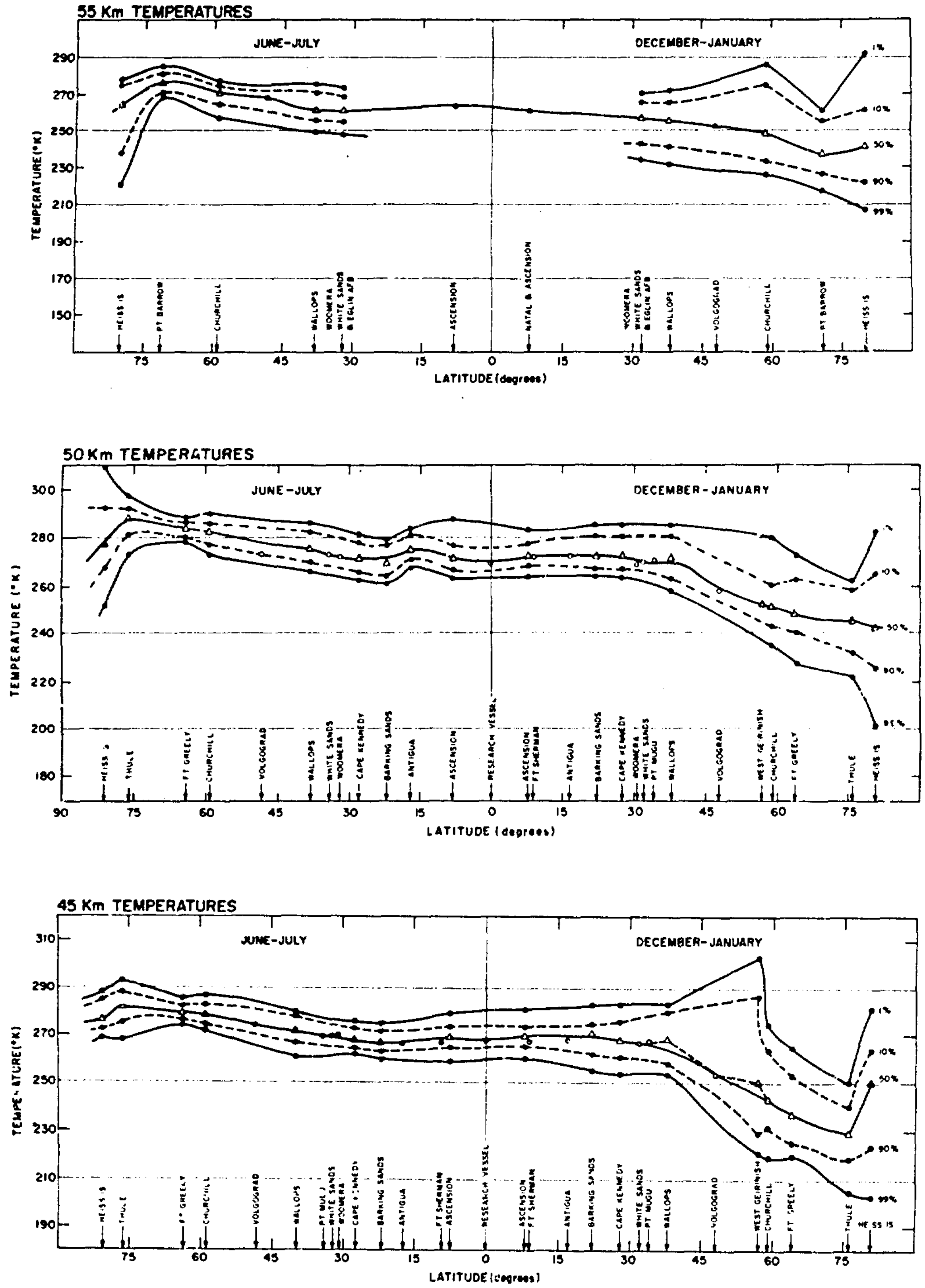
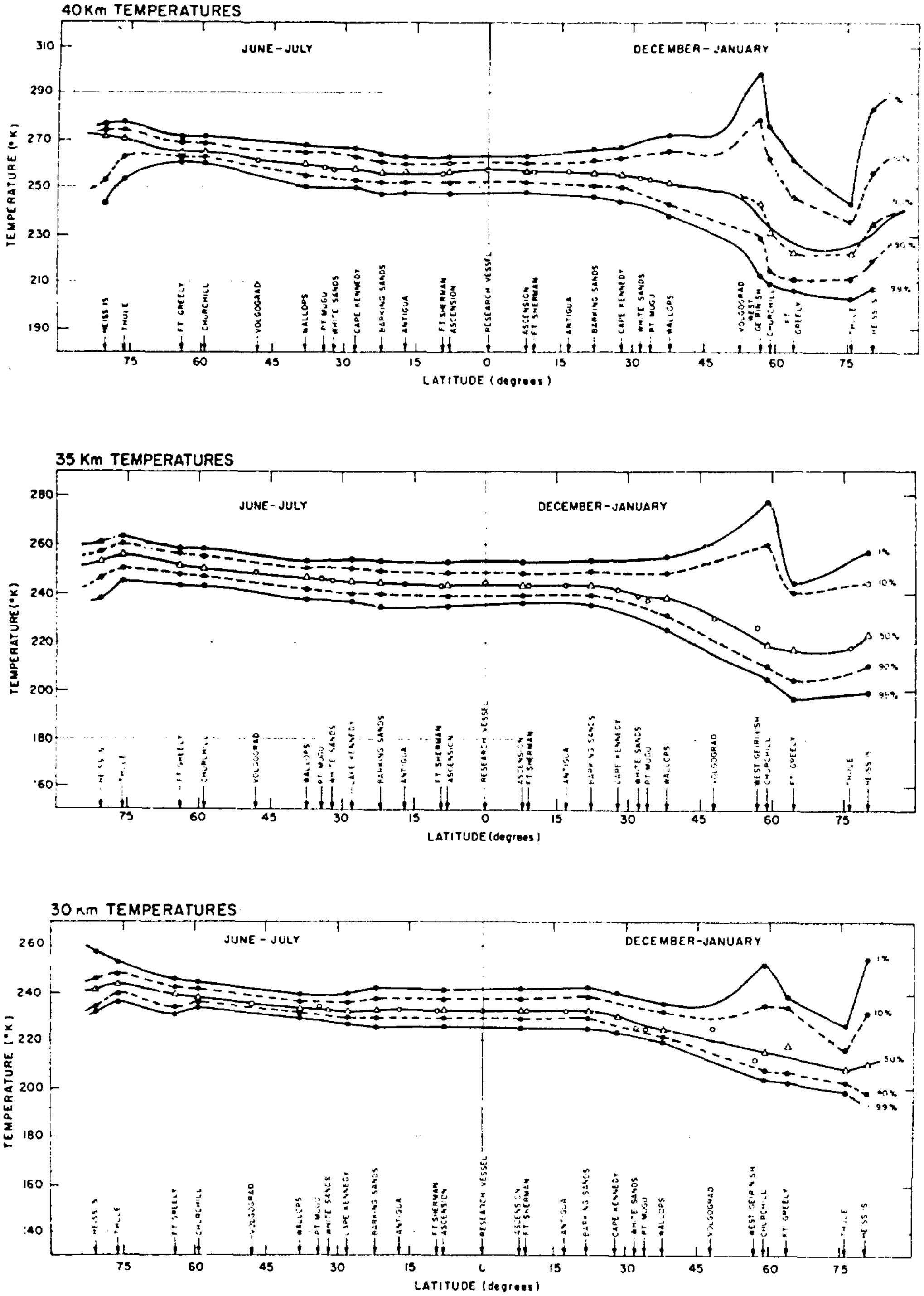


Figure 1 (Contd.). Longitudinal Plots of Temperatures Which Are Equalled or Exceeded 1-, 10-, 50-, 90- and 99-percent of the Time During June-July and December-January. Triangles represent median values and circles seasonal mean values. Number of available observations is given in brackets at the 80- and 60- km levels



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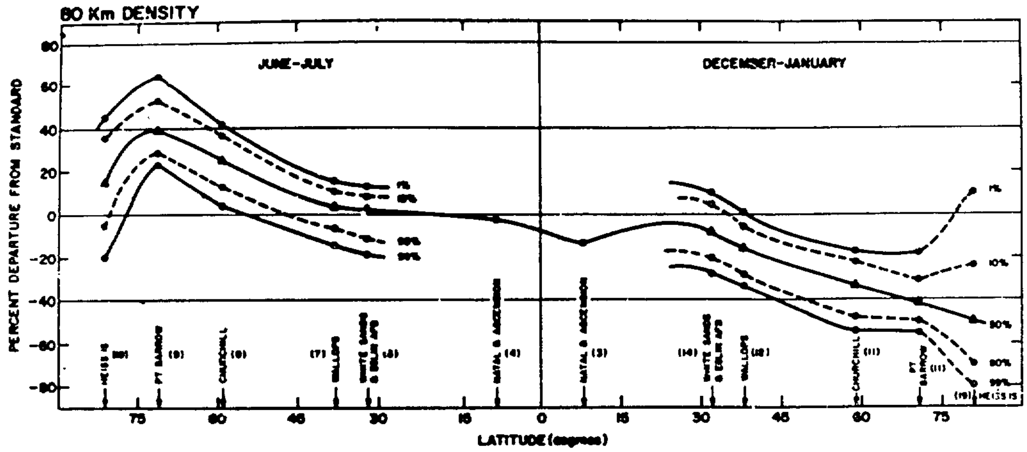
DENSITY



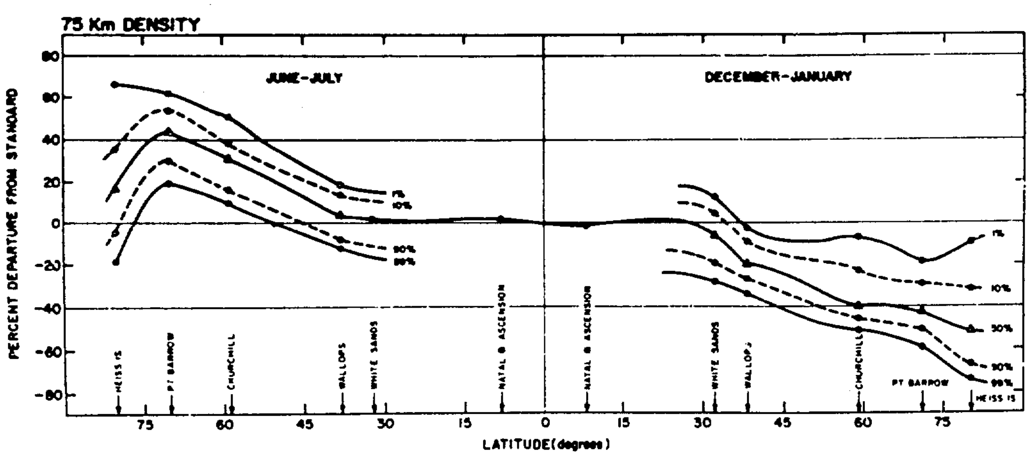
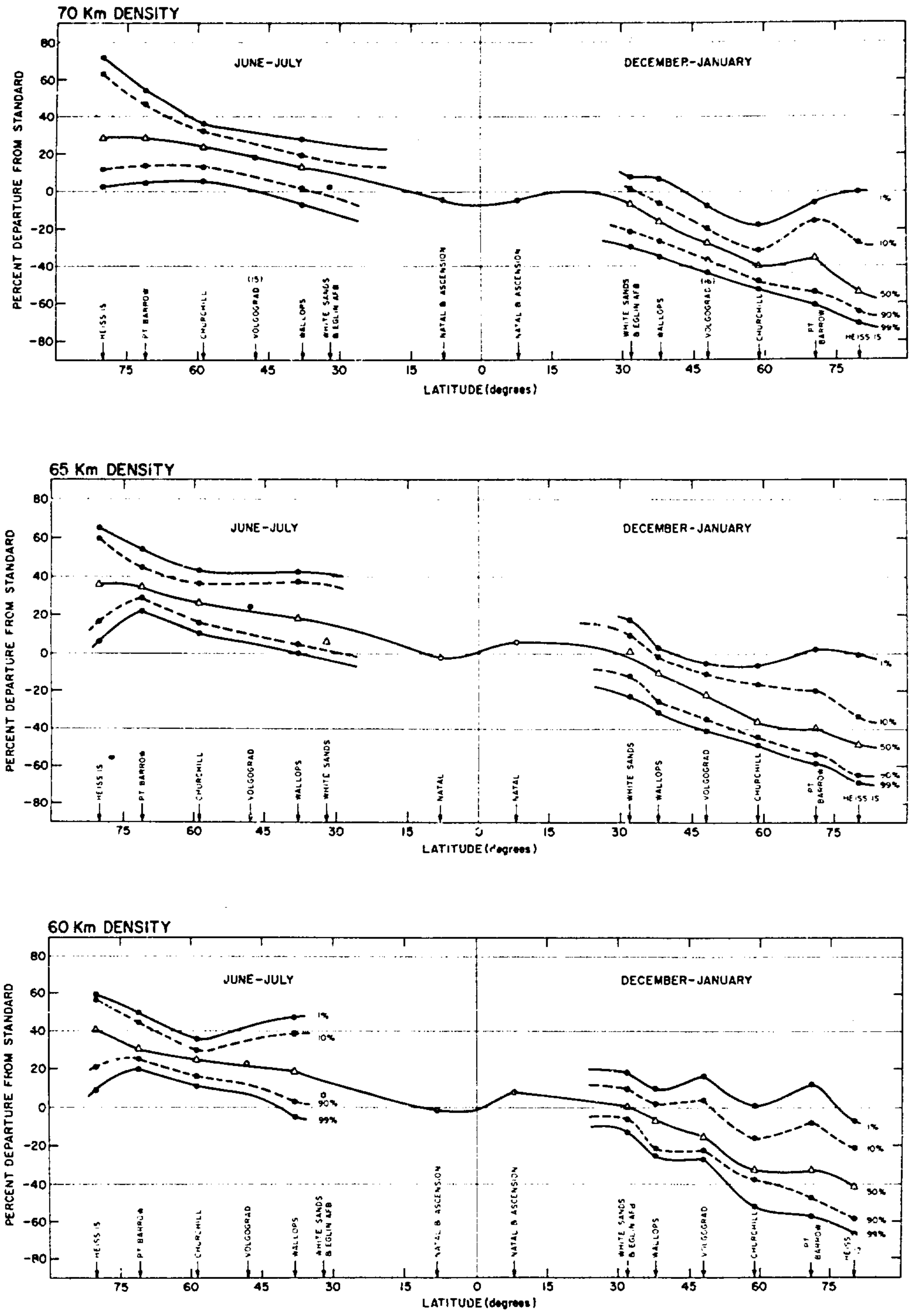


Figure 2. Longitudinal Plots of Densities Which Are Equalled or Exceeded 1-, 10-, 50-, 90- and 99- percent of the Time During June-July and December-January. Triangles represent median values and circles seasonal mean values. Number of available observations is given in brackets at the 80- and 50- km levels.



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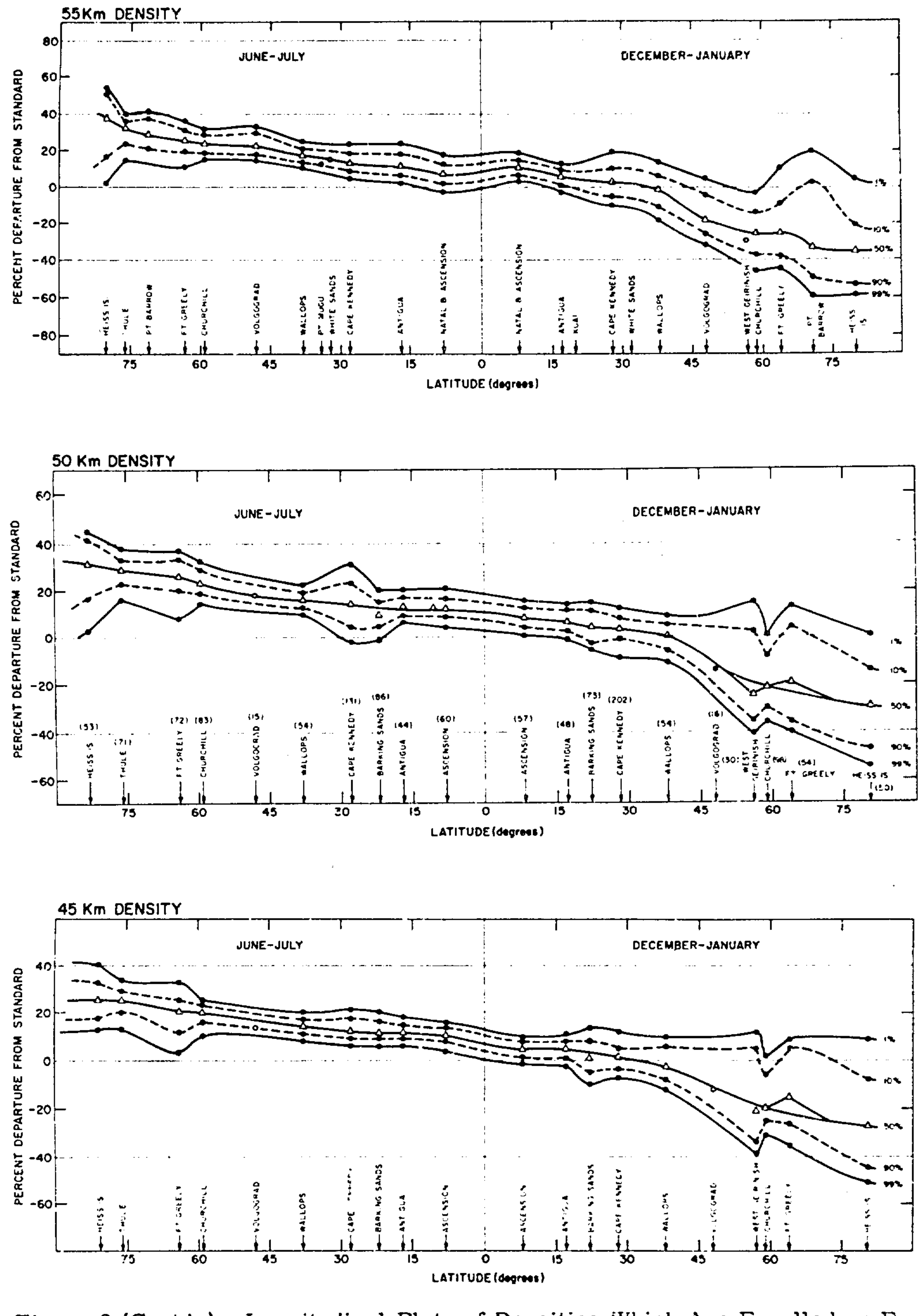

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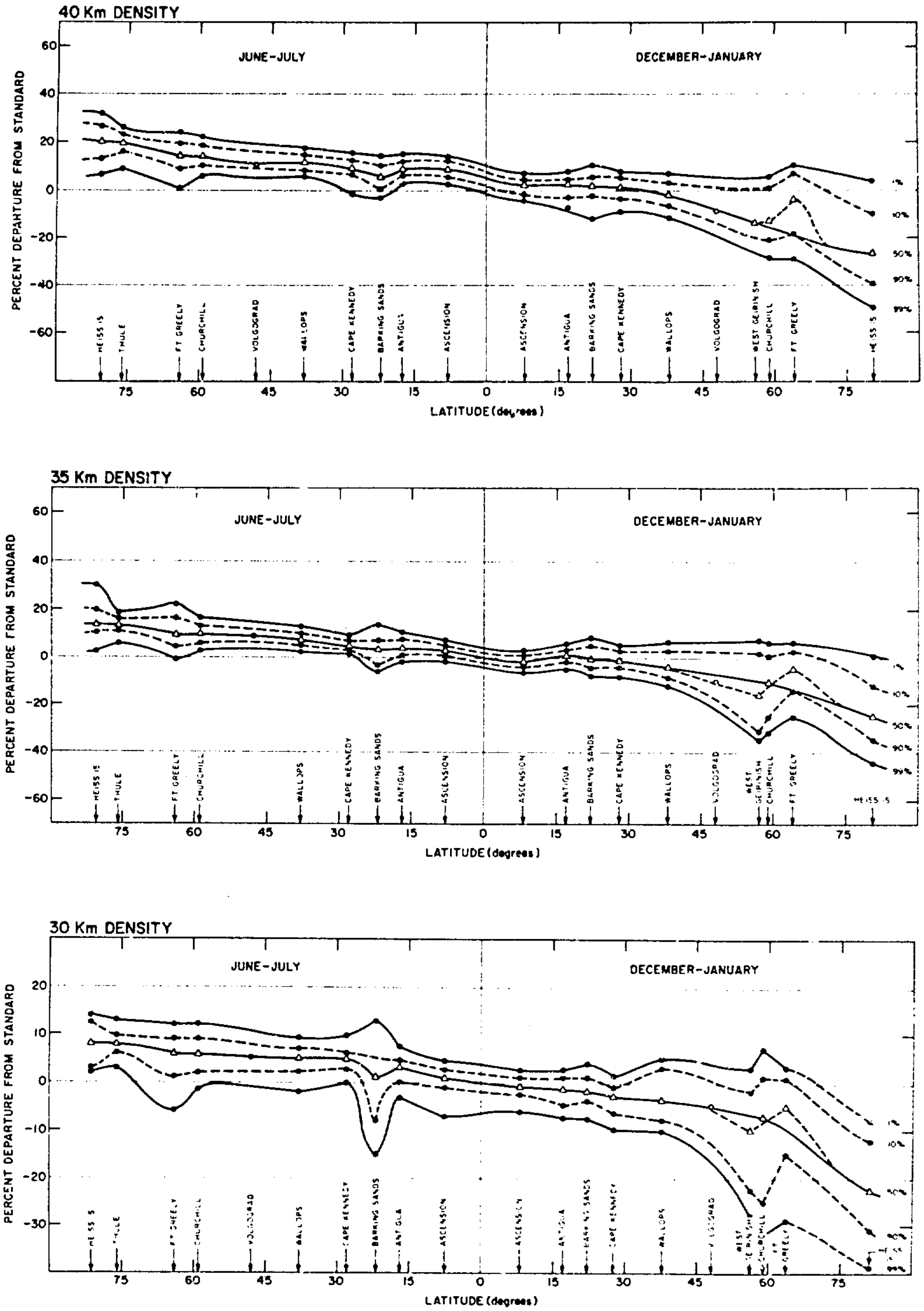

Figure 2 (Contd.). Longitudinal Plots of Densities Which Are Equalled or Exceeded 1-, 10-, 50-, 90- and 99-percent of the Time During June-July and December-January. Triangles represent median values and circles seasonal mean values. Number of available observations is given in brackets at the 80- and 50- km levels

Table 3. Median and Maximum and Minimum Temperatures Equalled or Exceeded 1-, 10- and 20-percent of the Time During June-July and December-January at 80°, 60°, 45° and 30°N and During the Year at 15° Latitude

80°N

Season	Altitude (km)	Median Temp (°K)	Variations 1% Max	1% Min	10% Max	10% Min	20% Max	20% Min
June-July	30	242	262	233	246	234	243	236
	35	253	260	238	256	246	255	249
	40	271	275	243	272	261	270	263
	45	276	288	269	286	273	284	275
	50	277	312	252	293	266	288	272
	55	264	278	221	275	238	272	249
	60	244	259	208	255	219	253	228
	65	232	253	200	243	217	236	219
	70	202	241	175	220	184	212	189
	75	182	246	153	202	164	196	171
	80	181	239	128	219	140	197	154
December-January	30	210	255	194	231	198	224	202
	35	223	256	199	244	210	236	213
	40	235	284	207	256	219	248	224
	45	250	281	203	264	224	260	233
	50	242	282	201	265	225	259	229
	55	241	291	208	262	221	253	226
	60	241	303	206	263	213	255	219
	65	233	310	186	277	202	263	209
	70	233	297	166	277	201	261	207
	75	233	289	183	259	201	251	207
	80	223	277	165	254	194	240	201

Table 3 (Contd.). Median and Maximum and Minimum Temperatures Equalled or Exceeded 1-, 10-, and 20-percent of the Time During June-July and December-January at 80°, 60°, 45° and 30°N and During the Year at 15° Latitude

60°N

Season	Altitude (km)	Median Temp (°K)	Variations 1% Max	1% Min	10% Max	10% Min	20% Max	20% Min
June-July	30	236	245	232	243	234	241	235
	35	249	258	243	256	247	253	248
	40	263	272	259	269	263	268	262
	45	278	287	271	283	274	280	275
	50	282	290	273	286	277	284	27[illegible]
	55	272	278	257	275	264	273	266
	60	262	273	242	265	250	263	253
	65	240	259	225	253	230	248	233
	70	216	239	202	226	208	222	211
	75	192	202	178	196	182	194	186
	80	169	180	140	176	153	174	155
December-January	30	216	253	203	235	208	225	210
	35	219	277	204	259	204	238	214
	40	230	300	206	278	211	246	219
	45	242	303	219	282	225	255	231
	50	251	289	227	280	240	271	245
	55	248	283	225	275	233	256	238
	60	243	271	210	261	224	253	234
	65	238	262	208	258	218	249	222
	70	233	264	212	253	219	249	225
	75	228	255	180	249	203	246	213
	80	223	248	173	243	195	239	204

Table 3 (Contd.). Median and Maximum and Minimum Temperatures Equalled or Exceeded 1-, 10- and 20-percent of the Time During June-July and December-January at 80°, 60°, 45° and 30°N and During the Year at 15° Latitude

45°N

Season	Altitude (km)	Median Temp (°K)	Variations 1% Max	1% Min	10% Max	10% Min	20% Max	20% Min
June-July	30	235	246	231	243	233	240	234
	35	247	255	241	251	245	250	246
	40	259	270	253	267	257	264	258
	45	271	282	263	279	266	275	268
	50	277	288	268	283	272	281	274
	55	267	275	251	271	257	269	260
	60	255	270	233	265	240	260	244
	65	234	245	216	241	223	238	220
	70	213	226	188	219	196	216	202
	75	197	210	175	205	186	201	190
	80	182	203	154	195	163	191	170
December-January	30	220	235	214	230	217	226	219
	35	231	257	218	251	224	243	226
	40	244	270	232	263	238	256	240
	45	257	290	241	282	251	271	254
	50	263	284	250	275	256	270	258
	55	257	275	229	267	239	263	245
	60	249	266	220	263	230	257	241
	65	239	255	216	246	223	243	228
	70	229	246	206	238	211	234	217
	75	219	261	297	245	205	235	210
	80	208	248	185	237	197	228	202

Table 3 (Contd.). Median and Maximum and Minimum Temperatures Equalled or Exceeded 1-, 10- and 20-percent of the Time During June-July and December-January at 80°, 60°, 45° and 30°N and During the Year at 15° Latitude

30°N

Season	Altitude (km)	Median Temp (°K)	Variations 1% Max	Variations 1% Min	Variations 10% Max	Variations 10% Min	Variations 20% Max	Variations 20% Min
June-July	30	232	240	227	237	230	235	231
	35	244	254	237	250	240	247	242
	40	256	267	250	263	253	261	254
	45	268	276	261	273	265	260	266
	50	273	282	262	278	266	276	268
	55	264	273	247	269	253	267	256
	60	251	265	235	257	243	254	245
	65	232	240	218	236	222	234	225
	70	212	222	186	218	194	214	199
	75	202	218	178	214	192	209	196
	80	193	207	182	200	189	198	191
December-January	30	230	239	222	236	225	234	227
	35	239	253	231	248	235	245	237
	40	251	268	243	262	249	258	250
	45	264	283	254	277	261	274	263
	50	270	285	260	280	264	276	268
	55	258	272	231	267	243	263	248
	60	245	255	231	248	240	246	242
	65	233	254	218	242	226	238	228
	70	220	235	198	227	204	225	210
	75	209	253	197	237	203	227	208
	80	198	243	187	230	194	217	197

15°N

Annual	30	231	243	226	239	229	236	230
	35	244	256	236	253	240	250	242
	40	248	270	251	265	254	263	256
	45	269	278	258	274	263	272	265
	50	272	285	263	277	267	275	269

Table 4. Median Densities and High and Low Values Equalled or Exceeded 1-, 10- and 20-percent of the Time (given as percent departure from U. S. Standard Atmosphere, 1962) During June-July and December-January at 80°, 60°, 45° and 30°N and During the Year at 15° Latitude

80°N Densities

Season	Altitude (km)	Median Density	Variability 1% Max	Variability 1% Min	Variability 10% Max	Variability 10% Min	Variability 20% Max	Variability 20% Min	U. S. Std Atmosphere, 1962 (kgm^{-3})
June-July	30	+ 8	+18	+ 5	+15	+ 6	+13	+ 7	1.8410^{-2}
	35	+13	+30	+ 3	+20	+10	+18	+11	8.4634^{-3}
	40	+20	+32	+ 6	+26	+13	+24	+15	3.9957^{-3}
	45	+25	+41	+ 7	+33	+17	+30	+18	1.9663^{-3}
	50	+30	+47	+ 2	+42	+16	+39	+22	1.0269^{-3}
	55	+38	+53	+ 2	+51	+16	+48	+26	5.6075^{-4}
	60	+40	+59	+ 9	+56	+21	+52	+28	3.0592^{-4}
	65	+36	+65	+ 6	+60	+16	+53	+20	1.6665^{-4}
	70	+28	+70	+ 2	+62	+11	+53	+17	8.7535^{-5}
	75	+20	+66	-20	+35	- 6	+37	0	4.335^{-5}
	80	+20	+50	-15	+39	- 0	+30	+10	1.999^{-5}
December-January	30	-23	- 8	-39	-12	-31	-17	-28	1.8410^{-2}
	35	-25	+ 1	-44	-12	-35	-17	-32	8.4634^{-3}
	40	-27	+ 4	-50	-10	-40	-15	-38	3.9957^{-3}
	45	-27	+ 9	-51	- 8	-45	-14	-39	1.9663^{-3}
	50	-31	0	-55	-15	-47	-21	-44	1.0269^{-3}
	55	-36	+ 5	-59	-21	-53	-25	-51	5.6075^{-4}
	60	-41	- 7	-66	-21	-59	-31	-56	3.0592^{-4}
	65	-49	- 1	-69	-34	-65	-38	-61	1.665^{-4}
	70	-54	0	-71	-28	-65	-37	-62	8.735^{-5}
	75	-52	-10	-74	-32	-66	-40	-63	4.335^{-5}
	80	-49	+ 8	-78	-34	-66	-35	-65	1.999^{-5}

Table 4 (Contd.). Median Densities and High and Low Values Equalled or Exceeded 1-, 10- and 20-percent of the Time (given as percent departure from U. S. Standard Atmosphere, 1962) During June-July and December-January at 80°, 60°, 45° and 30°N and During the Year at 15° Latitude

60°N Densities

Season	Altitude (km)	Median Density	Variability						U. S. Std Atmosphere, 1962 (kgm^{-3})
			1%		10%		20%		
			Max	Min	Max	Min	Max	Min	
June-July	30	+ 7	+12	- 1	+ 9	+ 2	+ 8	+ 4	1.8410^{-2}
	35	+10	+17	+ 1	+14	+ 6	+12	+ 7	8.4634^{-3}
	40	+14	+23	+ 5	+18	+10	+16	+11	3.9957^{-3}
	45	+19	+33	+ 6	+25	+11	+23	+14	1.9663^{-3}
	50	+24	+37	+ 9	+33	+17	+30	+22	1.0269^{-3}
	55	+24	+32	+14	+29	+19	+27	+21	5.6075^{-4}
	60	+25	+37	+12	+30	+17	+28	+20	3.0592^{-4}
	65	+26	+43	+10	+37	+16	+33	+20	1.6665^{-4}
	70	+24	+38	+ 5	+33	+14	+30	+17	8.7535^{-5}
	75	+32	+51	+10	+40	+17	+37	+22	4.335^{-5}
	80	+29	+43	+ 5	+38	+15	+35	+20	1.999^{-5}
December-January	30	- 9	+ 7	-32	+ 2	-25	- 2	-15	1.8410^{-2}
	35	-12	+ 8	-35	+ 3	-32	- 3	-19	8.4634^{-3}
	40	-16	+10	-36	+ 7	-32	- 4	-20	3.9957^{-3}
	45	-20	+12	-39	+ 5	-34	-10	-24	1.9663^{-3}
	50	-22	+15	-42	+ 2	-36	-14	-28	1.0269^{-3}
	55	-27	+ 2	-46	-14	-38	-21	-34	5.6075^{-4}
	60	-32	0	-53	-16	-39	-23	-37	3.0592^{-4}
	65	-38	- 7	-51	-18	-46	-26	-43	1.6665^{-4}
	70	-40	-17	-53	-31	-49	-34	-49	8.7535^{-5}
	75	-41	- 8	-53	-25	-47	-30	-45	4.335^{-5}
	80	-34	-18	-53	-23	-47	-28	-43	1.999^{-5}

Table 4 (Contd.). Median Densities and High and Low Values Equalled or Exceeded 1-, 10- and 20-percent of the Time (given as percent departure from U. S. Standard Atmosphere, 1962) During June-July and December-January at 80°, 60°, 45° and 30°N and During the Year at 15° Latitude

45°N Densities

Season	Altitude (km)	Median Density	Variability 1% Max	Variability 1% Min	Variability 10% Max	Variability 10% Min	Variability 20% Max	Variability 20% Min	U. S. Std Atmosphere, 1962 (kgm^{-3})
June-July	30	+ 6	+10	- 1	+ 8	+ 2	+ 7	+ 3	1.8410^{-2}
	35	+ 9	+14	+ 4	+12	+ 6	+11	+ 7	8.4634^{-3}
	40	+13	+18	+ 6	+15	+10	+14	+12	3.9957^{-3}
	45	+16	+22	+ 9	+19	+13	+18	+14	1.9663^{-3}
	50	+18	+25	+12	+22	+16	+21	+17	1.0269^{-3}
	55	+21	+30	+11	+25	+15	+24	+16	5.6075^{-4}
	60	+22	+44	+ 5	+37	+11	+32	+14	3.0592^{-4}
	65	+23	+41	+ 4	+35	+10	+31	+14	1.6665^{-4}
	70	+22	+30	- 4	+25	+ 6	+23	+10	8.7535^{-5}
	75	+18	+29	- 7	+21	0	+19	+ 6	4.335^{-5}
	80	+14	+22	- 8	+20	- 2	+16	+ 3	1.999^{-5}
December-January	30	- 5	+ 5	-14	+ 2	-11	- 1	- 9	1.8410^{-2}
	35	- 7	+ 7	-17	+ 2	-12	- 2	-10	8.4634^{-3}
	40	- 8	+ 6	-17	+ 2	-12	- 2	-10	3.9957^{-3}
	45	-10	+11	-20	+ 6	-16	- 1	-14	1.9663^{-3}
	50	-12	+ 9	-24	+ 4	-18	- 2	-16	1.0269^{-3}
	55	-13	+ 7	-30	0	-25	- 5	-21	5.6075^{-4}
	60	-15	+ 7	-27	- 3	-24	- 7	-21	3.0592^{-4}
	65	-19	- 5	-40	-10	-35	-14	-30	1.6665^{-4}
	70	-20	- 4	-41	-15	-34	-17	-30	8.7535^{-5}
	75	-20	-11	-42	-15	-36	-19	-32	4.335^{-5}
	80	-17	- 9	-42	-14	-36	-15	-31	1.999^{-5}

Table 4 (Contd.). Median Densities and High and Low Values Equalled or Exceeded 1-, 10- and 20-percent of the Time (given as percent departure from U.S. Standard Atmosphere, 1962) During June-July and December-January at 80°, 60°, 45° and 30°N and During the Year at 15° Latitude

30°N Densities

Season	Altitude (km)	Median Density	Variability 1% Max	1% Min	10% Max	10% Min	20% Max	20% Min	U. S. Std Atmosphere 1962 (kgm^{-3})
June-July	30	+ 5	+10	0	+ 7	+ 3	+ 6	+ 4	1.8410^{-2}
	35	+ 7	+11	+ 2	+ 9	+ 4	+ 8	+ 5	8.4634^{-3}
	40	+ 9	+15	- 2	+13	+ 6	+12	+ 7	3.9957^{-3}
	45	+13	+21	+ 6	+17	+ 9	+18	+11	1.9663^{-3}
	50	+14	+28	- 2	+22	+ 4	+15	+ 7	1.0269^{-3}
	55	+14	+23	+ 6	+19	+10	+17	+12	5.6075^{-4}
	60	+14	+48	-10	+39	0	+26	+ 6	3.0592^{-4}
	65	+14	+40	- 6	+34	0	+23	+ 5	1.6665^{-4}
	70	+ 9	+25	-13	+15	- 4	+14	0	8.7535^{-5}
	75	+ 2	+14	-18	+10	-13	+ 7	- 8	4.335^{-5}
	80	+ 2	+13	-19	+ 8	-12	+ 6	- 8	1.999^{-5}
December-January	30	- 3	+ 2	-10	0	- 7	- 1	- 6	1.8410^{-2}
	35	- 2	+ 5	- 8	+ 3	- 4	+ 1	- 2	8.4634^{-3}
	40	+ 1	+ 6	- 9	+ 4	- 4	+ 3	- 2	3.9957^{-3}
	45	+ 1	+11	- 8	+ 5	- 4	+ 4	- 2	1.9663^{-3}
	50	+ 3	+12	- 9	+ 8	- 1	+ 7	+ 1	1.0269^{-3}
	55	+ 3	+19	-10	+10	- 6	+ 8	- 2	5.6075^{-4}
	60	+ 2	+19	-10	+10	- 5	+ 7	- 3	3.0592^{-4}
	65	+ 2	+20	-20	+11	-11	+ 7	- 7	1.6665^{-4}
	70	- 4	+11	-28	+ 4	-20	+ 2	-15	8.7535^{-5}
	75	- 5	+14	-30	+ 6	-18	+ 2	-15	4.335^{-5}
	80	- 6	+12	-26	+ 6	-18	+ 2	-15	1.999^{-5}

15°N Densities

Annual	30	- 1	+ 4	- 6	+ 1	- 3	0	- 2	1.8410^{-2}
	35	+ 1	+ 7	- 4	+ 5	- 1	+ 3	0	8.4634^{-3}
	40	+ 4	+10	- 2	+ 7	+ 1	+ 6	+ 3	3.9957^{-3}
	45	+ 6	+13	+ 1	+10	+ 4	+ 8	+ 5	1.9663^{-3}
	50	+ 9	+17	+ 4	+15	+ 6	+12	+ 7	1.0269^{-3}

Table 5. Median and Extreme Temperatures Which Are Exceeded 50-, 10- and 1-percent of the Time During Months With Highest Values and 50-, 90- and 99-percent of the Time During Months With Lowest Values at Locations With Highest and Lowest Temperatures Between Equator and Pole (Antarctica excluded)

Altitude (km)	High Temperatures			Low Temperatures		
	Median	10%	1%	Median	90%	99%
30	244	249	262	208	198	194
35	255	260	$\underline{276}$	216	210	199
40	271	$\underline{278}$	$\underline{298}$	222	211	203
45	282	$\underline{288}$	$\underline{303}$	229	219	203
50	287	293	310	243	224	203
55	276	281	$\underline{292}$	237	221	209
60	265	270	$\underline{302}$	238	221	209
65	243	$\underline{276}$	$\underline{310}$	225	198	186
70	$\underline{236}$	$\underline{277}$	$\underline{297}$	$\underline{203}$	$\underline{183}$	$\underline{166}$
75	$\underline{233}$	$\underline{259}$	$\underline{289}$	$\underline{183}$	$\underline{163}$	$\underline{153}$
80	$\underline{230}$	$\underline{254}$	$\underline{278}$	$\underline{164}$	$\underline{140}$	$\underline{128}$

NOTE: Underlined values indicate levels where temperatures are highest in December-January and lowest in June-July. Extreme high temperatures in the upper stratosphere (30 to 45 km) occur at West Geirinish (57°21'N, 7°22'W) during winter warmings of the atmosphere. Extremes at other levels occur at Pt. Barrow (71°21'N, 156°59'W) or Heiss Island (80°37'N, 56°03'E). The only exceptions are at levels between 65 and 70 km where extremes often occur at midlatitudes.

Table 6. Median and Extreme Densities (given as percent departure from the U. S. Standard Atmosphere, 1962) Which Are Exceeded 50-, 10- and 1-percent of the Time During Months With Highest Densities and 50-, 90- and 99-percent of the Time During Months With Lowest Densities at Locations With Lowest and Highest Densities Between the Equator and Pole(Anarctica excluded)

Altitude (km)	High Densities			Low Densities		
	Median	10%	1%	Median	90%	99%
30	8	12	14	-23	-31	-39
35	13	20	29	-25	-35	-44
40	20	26	32	-27	-40	-50
45	25	36	42	-27	-45	-51
50	30	42	44	-30	-47	-55
55	38	51	54	-36	-54	-59
60	40	56	59	-41	-59	-67
65	36	60	65	-49	-65	-69
70	29	62	72	-54	-65	-71
75	43	54	66	-52	-67	-74
80	40	52	64	-50	-70	-80

NOTE: Extreme values are based primarily on observations taken at Heiss Island (80°36'N, 58°03'E), Pt Barrow (71°21'N, 156°59'W) and Thule (76°33'N, and 68°49'W).

Table 7. Median and Extreme Pressures (given as Percent Departure from U. S. Standard Atmosphere, 1962) Which Are Equalled or Exceeded 50-, 10- and 1-percent of the Time During Months With Highest Values and 50-, 90- and 99-percent of the Time During Months With Lowest Values at Worst Locations in the World (Antarctica excluded)

Altitude (km)	High Pressure			Low Pressure		
	Median	10%	1%	Median	10%	1%
30	16	21	24	-32	-38	-42
35	22	29	33	-34	-41	-47
40	28	37	42	-36	-42	-48
45	38	46	50	-41	-47	-55
50	43	50	56	-44	-51	-61
55	44	54	66	-47	-58	-64
60	42	56	72	-48	-60	-67
65	36	53	70	-51	-63	-69
70	30	46	55	-53	-63	-70
75	32	36	48	-50	-58	-68
80	19	29	42	-45	-55	-66

NOTE: Extreme values are based primarily on observations taken at Heiss Island (80°37'N, 58°03'E), Pt Barrow (71°21'N, 156°59'W) and Thule (76°33'N, and 68°49'W).

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