Monthly Atmospheric Structure, Surface to 80 km

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ABSTRACT

Mean monthly atmospheric properties for latitudes 30, 45 and 60N are described. Temperature-height profiles were objectively derived from observed winds and temperatures, resulting in a family of atmospheres with internally consistent thermodynamic properties. The amplitude of seasonal changes in mean monthly temperatures and densities between 30 and 80 km increases with increasing latitude. The transition from one season to another of mean monthly atmospheric properties is relatively smooth except from late January to April in subarctic regions.

1. Introduction

A family of internally consistent mean monthly atmospheres for latitudes 30, 45 and 60N is described in this paper. These atmospheres present information on atmospheric structure to 80 km in greater detail than that provided in the U. S. Standard Atmosphere, 1962, and the U. S. Air Force Interim Supplemental Atmospheres.

Although meteorological rocketry has been employed for almost two decades and the Meteorological Rocket Network has been operating for more than four years, the amount of reliable rocket data for heights above 30 km remains severely restricted. Observations are poorly distributed with latitude, longitude and season, and the number of temperature reporting stations from latitudes 30 to 60N is limited to seven, primarily in North America (see locator table below). Consequently, details of the atmospheric models presented undoubtedly will be altered with the influx of additional data. However, these atmospheres, based on a minimal climatological sample which has been objectively extended to other regions, provide interim estimates of mean monthly atmospheric structure between latitudes 30 and 60N, from the surface to 80 km.

2. Data

Data utilized in defining these atmospheres consisted of summaries of radiosonde and rawinsonde observations at Northern Hemisphere stations near latitudes 30, 45 and 60N, and observations made from sensors released by rockets (see references) fired at the following ranges from November 1956 through March 1964:

Location	Latitude	Temp. Obs.
Cape Kennedy	28N	63
Eglin Gulf Test Range	30N	—
Kindley Air Force Base	32N	—
White Sands Missile Range	32N	199
Point Mugu	34N	98
Wallops Island	38N	34
Tonopah Range	38N	—
Fort Churchill, Canada	59N	68
Fort Greely, Alaska	64N	119
Woomera, Australia	31S	11

Although temperatures were not observed at Eglin, Kindley and Tonopah, wind data at all these stations and density data at Eglin were used in determining mean monthly atmospheric structure at 30N.

Sensors of the thermodynamic properties include thermistors, genades, falling spheres and pressure gages. Thermistor temperatures at these locations were modified above 40 km according to Wagner's (1964) corrections, and all observations taken within the same 24-hour period at any one location were averaged together and counted as one observation in the computation of the observed means. For heights above 30 km, observations are sporadic so that data are not necessarily available for specific months at any one location. At Fort Churchill, for example, no observations were taken from July 1962 through November 1962. Also, values for the thermodynamic properties were not available for all measurements of wind.

Sea level pressures for each atmosphere were estimated from monthly normal sea level charts for the Northern Hemisphere based on a 40-year record (U. S. Weather Bureau, 1952), and from five-day normal sea level charts based on a 20-year record (Lahey *et al.*, 1958). Sea level temperatures were determined from available U. S. and foreign atlases which are included in the references.

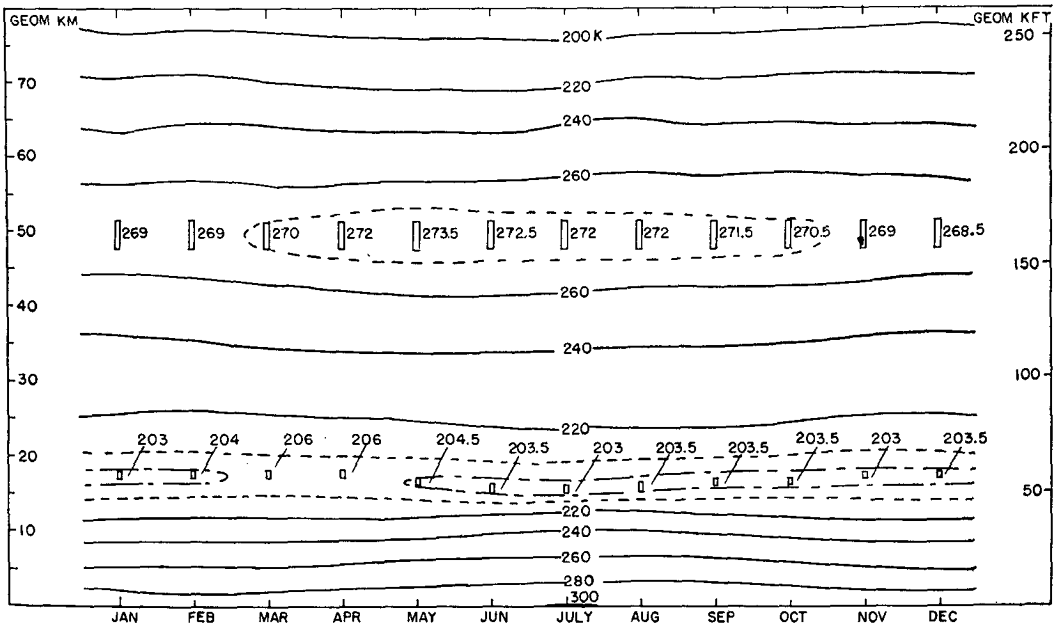

Fig. 1. Mean monthly temperature (deg K) at 30N, vertical bars isothermal.

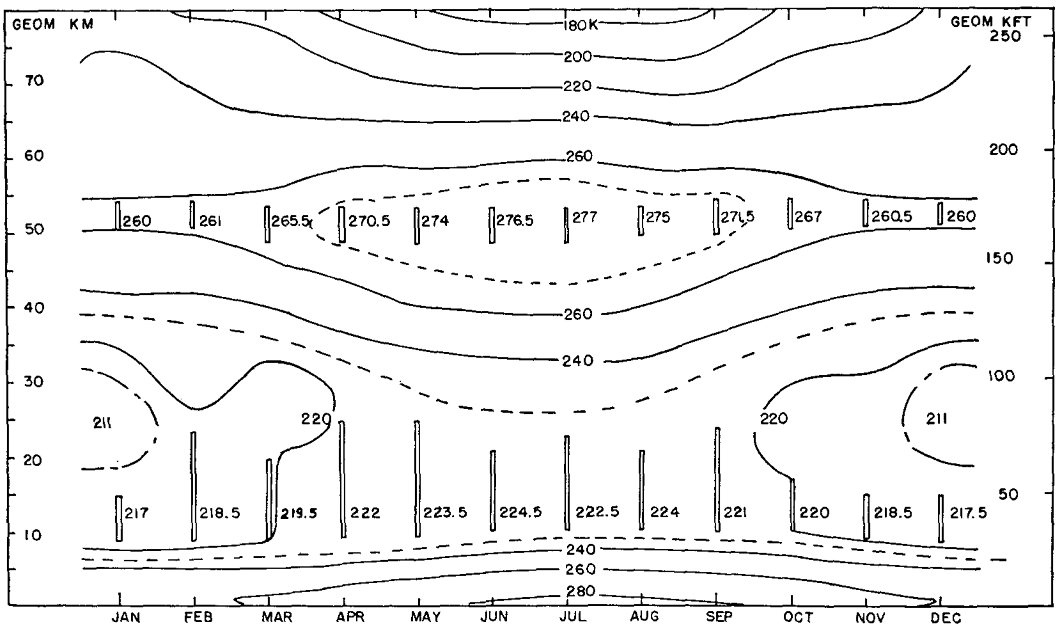

Fig. 2. Mean monthly temperature (deg K) at 60N, vertical bars isothermal.

As for the Standard and Supplemental Atmospheres, the latest internationally adopted values of the various thermodynamic and physical constants have been used for all computations of atmospheric properties. The defining parameter is atmospheric temperature presented by linear gradients in geopotential meters, exact to tenths of a Kelvin degree. Humidity has not been specified in these atmospheres. Resulting pressures and densities are everywhere within one per cent of the values that would have been obtained if the water vapor content of the atmosphere had been included in the calculations.

Monthly vertical pressure and density distributions were calculated from the barometric equations (U. S. Standard Atmosphere, 1962), using objectively derived mean monthly temperature-height profiles for latitudes

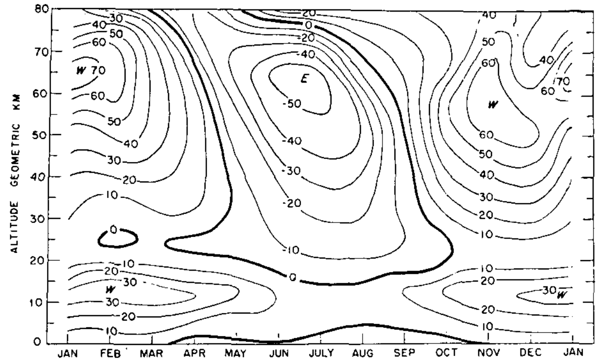

FIG. 3. Mean monthly zonal winds (m sec^{-1}) at 30N.

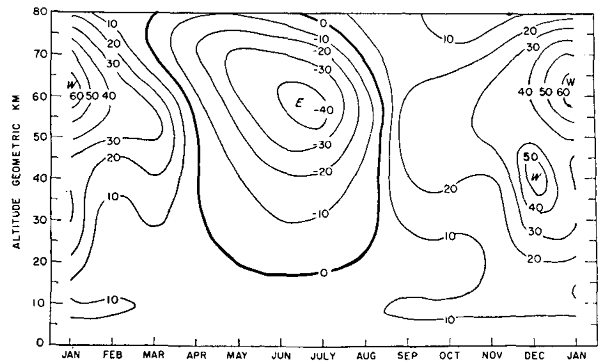

FIG. 4. Mean monthly zonal winds (m sec^{-1}) at 60N.

30, 45 and 60N. Resulting mean monthly temperatures, pressures and densities are provided at intervals of 5000 geopotential meters for latitudes 30, 45 and 60N (Tables 1, 2 and 3), respectively. Similar tables at geometric heights can be computed using the relation

$$Z=\frac{rH}{(g_0 r/G)-H},$$

where r is the effective earth's radius at the appropriate latitude (List, 1958), H the geopotential height, G the standard gravity constant (980.665 cm sec^{-2}), g_0 the acceleration due to gravity at 30N (979.324 cm sec^{-2}) and at 60N (981.911 cm sec^{-2}). For 45N, g_0 was taken as 980.665 cm sec^{-2}, the value adopted for the U. S. Standard Atmosphere, 1962.

3. Temperature and wind

Below 30 km, an abundance of world-wide radiosonde and rawinsonde data provided the basis for monthly temperature-height profiles and zonal winds at latitudes 30, 45 and 60N. Above 30 km, however, observations in numbers sufficient for analyses are limited primarily to locations near latitudes 30 and 60N (see locator table). Since all reporting stations at these levels are in or near North America (except Woomera), longitudinal differences at any one latitude could not be considered. Even at these locations and latitudes, data are not available for all months and heights. Near 60N, for example, temperature observations for April, May and June do not exist above 50 km. They were estimated by using observations at lower latitudes and altitudes, and by fitting annual temperature curves to the data available for other months of the year.

Monthly temperatures and zonal winds at latitudes 30 and 60N (Figs. 1, 2, 3 and 4) were constructed from available temperature and wind observations. The data sample for heights above 30 km, limited as described earlier, is considerably larger for 30N than for 60N. For this analysis, however, estimates of the annual march of temperature and wind for both latitudes have been considered equally representative.

Mean monthly temperature-height profiles to 80 km were determined at latitudes 30 and 60N from Figs. 1 and 2, and monthly zonal wind profiles were obtained from Figs. 3 and 4. Since essentially no data exist near 45N above 30 km, these monthly temperature and wind profiles were used with the thermal wind equation to compute horizontal temperature gradients between latitudes 30 and 45N and between latitudes 60 and 45N. These horizontal temperature gradients were applied to appropriate 30 and 60N temperature-height profiles, assuming linear dependence on latitude. The thermal wind relationship was used in the form:

$$\frac{\partial T}{\partial y}=-T^2\left(\frac{2\omega\sin\phi}{g}\right)\frac{\partial}{\partial z}\left(\frac{u}{T}\right), \quad (1)$$

where $\partial T/\partial y$ is the horizontal temperature gradient, T the mean temperature of the layer, ω the earth's angular rotation, ϕ the latitude, and u the zonal wind component. To further facilitate computations, 5 km increments of height were used from 30 to 80 km for 15 degrees of latitude, reducing Eq. (1) to:

$$\text{From}\begin{pmatrix}60\text{N}\\30\text{N}\end{pmatrix}:\begin{pmatrix}+\\-\end{pmatrix}\Delta T=0.005T^2\left(\frac{u_2}{T_2}-\frac{u_1}{T_1}\right)\sin\phi, \quad (2)$$

where T is the horizontal temperature change over 15 degrees of latitude, ϕ is the mean latitude (52.5 degrees and 37.5 degrees, respectively) and u_2 and T_2 are zonal winds and temperatures at heights 5 km above u_1 and T_1. Resulting 45N vertical temperature distributions for January, April, July and October are shown in Fig. 5. The profiles represent 45N temperatures which were averaged from the objectively derived temperatures. Circles are values computed from 30N and crosses values computed from 60N.

The 45N temperatures derived from 30N and those calculated from 60N exhibit greatest absolute dif-

Table 1. Mean monthly atmospheric properties, 30N.

Altitude (geop. m.)	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
						Temperature (K)						
0000	287.15	286.55	289.15	292.15	295.15	298.65	301.15	298.65	296.65	293.65	289.15	286.15
5000	261.65	264.15	262.65	267.15	271.15	272.65	271.65	272.15	272.15	268.65	266.15	261.25
10000	229.15	231.65	230.15	232.15	233.65	235.15	238.15	239.95	234.65	233.65	231.15	229.75
15000	208.35	209.95	210.55	210.95	208.15	203.65	203.15	206.95	207.65	207.65	208.75	209.05
20000	208.15	208.15	210.15	211.15	211.55	212.05	211.95	210.65	211.75	211.15	209.15	209.65
25000	219.15	218.15	220.15	221.65	223.05	222.55	222.15	220.65	222.25	221.25	219.65	219.85
30000	229.15	228.15	231.05	231.65	234.55	233.05	232.15	230.65	230.75	229.75	227.15	226.85
35000	240.35	239.65	242.55	242.85	246.05	245.15	243.35	242.15	241.65	240.65	237.95	237.45
40000	252.35	252.15	254.05	254.85	257.55	257.65	255.35	254.65	254.15	253.15	250.95	250.45
45000	264.35	264.65	265.55	266.85	269.05	270.15	267.35	267.15	266.65	265.65	263.95	263.45
50000	269.15	269.65	270.15	271.65	273.65	272.65	272.15	272.15	271.65	270.65	269.15	268.65
55000	261.15	263.65	262.15	261.55	263.65	262.65	264.15	266.15	263.65	264.65	263.15	262.65
60000	250.05	254.35	250.95	248.45	250.35	249.35	252.35	256.55	252.35	255.25	253.85	253.45
65000	234.55	237.85	234.95	232.45	233.85	232.85	233.35	238.55	235.85	238.25	237.35	237.45
70000	219.05	221.35	218.95	216.45	217.35	216.35	214.35	220.55	219.35	212.25	220.85	221.45
75000	203.55	204.85	202.95	200.45	200.85	199.85	195.35	202.55	202.85	204.25	204.35	205.45
79000	191.15	191.65	190.15	187.65	187.65	186.65	180.15	188.15	189.65	190.65	191.15	192.65
						Pressure (mb)						
0000	1.0210	1.0190	1.0180	1.0170	1.0155	1.0140	1.0135	1.0135	1.0150	1.0170	1.0190	1.0200+3*
5000	5.5020	5.4909	5.4860	5.5191	5.5530	5.5692	5.5700	5.5612	5.5556	5.5372	5.5208	5.4866+2
10000	2.7402	2.7540	2.7400	2.7812	2.8188	2.8385	2.8515	2.8540	2.8278	2.8017	2.7743	2.7334
15000	1.2437	1.2601	1.2499	1.2732	1.2888	1.2958	1.3127	1.3269	1.2953	1.2826	1.2638	1.2444
20000	5.4096	5.5011	5.4942	5.6030	5.6479	5.6768	5.7429	5.7963	5.6629	5.6032	5.5031	5.4289+1
25000	2.4342	2.4680	2.4834	2.5460	2.5729	2.5861	2.6146	2.6247	2.5826	2.5469	2.4887	2.4589
30000	1.1359	1.1478	1.1638	1.1981	1.2193	1.2216	1.2325	1.2310	1.2148	1.1940	1.1584	1.1444
35000	5.4820	5.5235	5.5654	5.8269	5.9888	5.9757	6.0030	5.9704	5.8846	5.7660	5.5450	5.4696+0
40000	2.7400	2.7572	2.8426	2.9327	3.0386	3.0286	3.0255	3.0012	2.9539	2.8863	2.7565	2.7151
45000	1.4143	1.4234	1.4727	1.5234	1.5881	1.5852	1.5736	1.5591	1.5327	1.4938	1.4195	1.3964
50000	7.4804	7.5365	7.8087	8.1051	8.4892	8.4673	8.3819	8.3041	8.1536	7.9284	7.5066	7.3756−1
55000	3.9351	3.9771	4.1177	4.2810	4.5052	4.4830	4.4410	4.4083	4.3150	4.1939	3.9566	3.8829
60000	2.0192	2.0602	2.1183	2.1925	2.3193	2.3019	2.2961	2.2977	2.2284	2.1779	2.0470	2.0063
65000	0.9975	1.0289	1.0484	1.0772	1.1450	1.1331	1.1359	1.1521	1.1065	1.0896	1.0208	1.0001
70000	4.6956	4.8878	4.9376	5.0310	5.3683	5.2945	5.2936	5.4721	5.2224	5.1789	4.8417	4.7491−2
75000	2.0914	2.1919	2.1962	2.2161	2.3707	2.3289	2.2980	2.4393	2.3242	2.3193	2.1671	2.1326
79000	1.0462	1.0999	1.0955	1.0956	1.1728	1.1480	1.1094	1.2115	1.1581	1.1606	1.0856	1.0731
						Density (kg/m³)						
0000	1.2387	1.2384	1.2265	1.2127	1.1986	1.1828	1.1724	1.1822	1.1920	1.2065	1.2277	1.2418+0*
5000	7.3255	7.2416	7.2764	7.1970	7.1344	7.1159	7.1431	7.1186	7.1116	7.1802	7.2263	7.3162−1
10000	4.1657	4.1416	4.1474	4.1734	4.2028	4.2051	4.1712	4.1435	4.1982	4.1773	4.1812	4.1447
15000	2.0796	2.0908	2.0680	2.1026	2.1570	2.2166	2.2510	2.2337	2.1731	2.1517	2.1091	2.0738
20000	9.0537	9.2069	9.1078	9.2441	9.3007	9.3262	9.4393	9.5858	9.3165	9.2444	9.1662	9.0209−2
25000	3.8694	3.9412	3.9297	4.0016	4.0184	4.0481	4.1002	4.1440	4.0481	4.0101	3.9472	3.8963
30000	1.7269	1.7525	1.7547	1.8018	1.8110	1.8261	1.8494	1.8593	1.8339	1.8104	1.7766	1.7574
35000	7.9457	8.0292	8.1242	8.3587	8.4792	8.4917	8.5937	8.5893	8.4833	8.3469	8.1181	8.0246−3
40000	3.7825	3.8093	3.8980	4.0089	4.1101	4.0950	4.1277	4.1057	4.0490	3.9720	3.8266	3.7766
45000	1.8638	1.8736	1.9320	1.9888	2.0563	2.0442	2.0505	2.0332	2.0024	1.9590	1.8735	1.8465
50000	0.9682	0.9737	1.0070	1.0394	1.0807	1.0819	1.0729	1.0630	1.0456	1.0205	0.9716	0.9564
55000	5.2494	5.2551	5.4719	5.6999	5.9528	5.9460	5.8570	5.7701	5.7016	5.5206	5.2379	5.1501−4
60000	2.8131	2.8217	2.9406	3.0743	3.2274	3.2160	3.1697	3.1201	3.0762	2.9725	2.8091	2.7577
65000	1.4815	1.5069	1.5545	1.6144	1.7058	1.6952	1.6958	1.6825	1.6344	1.5932	1.4983	1.4673
70000	7.4676	7.6926	7.8562	8.0971	8.6043	8.5252	8.6033	8.6434	8.2942	8.1544	7.6372	7.4709−5
75000	3.5794	3.7276	3.7699	3.8514	4.1119	4.0596	4.0980	4.1954	3.9915	3.9558	3.6944	3.6160
79000	1.9067	1.9993	2.0071	2.0339	2.1773	2.1426	2.1453	2.2432	2.1273	2.1207	1.9784	1.9405

* Power of ten by which preceding numbers should be multiplied.

ferences during January. This is understandable since during winter both the north-south temperature gradient and zonal wind speed and their variability with latitude are largest, causing the thermal wind relationship, based on observations at any one latitude, to provide relatively poor estimates of the horizontal temperature gradient over 15 degrees of latitude. Nevertheless, the 45N profile for January seems plausible. For example, the nearly isothermal layer near 65 km probably is associated with the warm mesosphere typical of higher latitude winter.

Between 45 and 55 km, the 45N December tempera-

TABLE 2. Mean monthly atmospheric properties, 45N

Altitude (geop. m.)	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
						Temperature (K)						
0000	272.15	273.15	274.15	279.15	284.65	288.15	294.15	292.15	288.15	284.15	278.15	273.15
5000	249.65	249.65	253.15	257.15	260.15	263.40	267.15	265.40	262.40	257.15	254.15	251.15
10000	219.65	217.15	223.15	224.65	225.15	231.90	235.15	231.90	230.90	227.15	224.15	218.65
15000	217.15	217.15	217.15	218.15	218.15	216.15	215.65	215.15	215.15	215.15	215.35	216.15
20000	215.15	217.15	217.15	218.15	218.15	219.45	219.25	218.75	217.65	215.15	214.65	216.15
25000	215.15	219.65	220.15	221.65	223.15	224.95	225.25	224.75	222.65	220.15	218.65	216.15
30000	219.90	224.65	225.15	228.65	231.65	233.15	233.65	233.15	227.65	225.15	222.65	216.15
35000	229.90	231.65	233.40	239.15	244.90	245.40	245.40	244.40	239.15	234.15	229.65	227.90
40000	240.65	242.15	246.65	252.40	258.40	259.15	258.40	257.40	251.90	246.90	241.90	241.40
45000	255.60	255.90	260.65	264.65	268.90	269.65	268.15	268.40	268.65	258.90	255.15	257.15
50000	264.40	263.40	266.65	269.40	272.40	273.40	271.65	271.40	269.40	265.40	262.65	265.40
55000	259.90	258.15	258.65	262.15	265.90	267.65	268.40	265.15	262.40	262.40	259.15	264.15
60000	247.65	247.90	244.15	251.15	253.15	254.65	256.65	253.15	248.40	251.90	249.65	255.65
65000	238.65	237.40	233.15	238.15	235.90	238.65	235.40	233.65	232.15	238.40	239.15	241.90
70000	232.15	227.40	225.40	222.90	216.90	216.40	212.15	213.15	213.65	223.65	225.15	226.65
75000	218.65	218.15	216.90	207.15	198.40	191.40	190.15	194.65	196.15	207.90	211.15	212.65
79000	206.65	210.95	209.30	193.55	182.80	173.40	171.85	177.85	183.35	195.50	201.55	203.85
						Pressure (mb)						
0000	1.0180	1.0165	1.0160	1.0150	1.0145	1.0130	1.0135	1.0150	1.0165	1.0175	1.0180	1.0180+3*
5000	5.3072	5.3097	5.3368	5.3928	5.4428	5.4709	5.5224	5.5176	5.4805	5.4178	5.3714	5.3316+2
10000	2.5602	2.5510	2.6024	2.6509	2.6888	2.7422	2.7963	2.7730	2.7393	2.6734	2.6271	2.5736
15000	1.1711	1.1617	1.1876	1.2143	1.2319	1.2614	1.2924	1.2721	1.2556	1.2189	1.1983	1.1730
20000	5.3098	5.2900	5.4080	5.5497	5.6300	5.7439	5.8760	5.7735	5.6891	5.5103	5.4085	5.3222+1
25000	2.4004	2.4144	2.4707	2.5442	2.5959	2.6627	2.7244	2.6722	2.6185	2.5137	2.4584	2.4148
30000	1.0898	1.1191	1.1471	1.1914	1.2211	1.2608	1.2919	1.2651	1.2262	1.1671	1.1335	1.0956
35000	5.0963	5.2839	5.4308	5.7231	5.9557	6.1632	6.3226	6.1799	5.8972	5.5287	5.3123	5.0765+0
40000	2.4649	2.5660	2.6616	2.8573	3.0225	3.1325	3.2098	3.1268	2.9442	2.7177	2.5693	2.4471
45000	1.2347	1.2905	1.3580	1.4758	1.5830	1.6441	1.6804	1.6351	1.5173	1.3834	1.2931	1.2328
50000	6.4418	6.7176	7.1345	7.8173	8.4457	8.7858	8.9418	8.7112	8.0229	7.2327	6.7035	6.4418−1
55000	3.3637	3.4996	3.7390	4.1224	4.4903	4.6867	4.7590	4.6185	4.2366	3.7965	3.4972	3.3829
60000	1.7211	1.7818	1.8943	2.1173	2.3265	2.4394	2.4905	2.3919	2.1708	1.9574	1.7862	1.7593
65000	0.8475	0.8812	0.9238	1.0554	1.1593	1.2210	1.2470	1.1899	1.0674	0.9750	0.8888	0.8851
70000	4.1199	4.2233	4.3841	5.0260	5.4425	5.7846	5.7972	5.5146	4.9601	4.6582	4.2643	4.2737−2
75000	1.9325	1.9611	2.0266	2.2728	2.3919	2.4938	2.4803	2.3908	2.1506	2.1094	1.9449	1.9579
79000	1.0162	1.0372	1.0672	1.1488	1.1673	1.1782	1.1648	1.1473	1.0463	1.0711	1.0028	1.0157
						Density (kg/m³)						
0000	1.3031	1.2964	1.2910	1.2667	1.2416	1.2247	1.2003	1.2103	1.2289	1.2475	1.2750	1.2983+0*
5000	7.4058	7.4093	7.3442	7.3058	7.2885	7.2357	7.2013	7.2425	7.2760	7.3396	7.3626	7.3954−1
10000	4.0606	4.0925	4.0627	4.1108	4.1604	4.1194	4.1426	4.1657	4.1329	4.1001	4.0830	4.1004
15000	1.8788	1.8636	1.9052	1.9392	1.9672	2.0330	2.0877	2.0598	2.0331	1.9737	1.9385	1.8905
20000	8.5976	8.4866	8.6760	8.8624	8.9907	9.1182	9.3364	9.1945	9.1059	8.9221	8.7778	8.5777−2
25000	3.8866	3.8292	3.9096	3.9988	4.0526	4.1236	4.2135	4.1420	4.0971	3.9777	3.9169	3.8919
30000	1.7265	1.7353	1.7749	1.8151	1.8364	1.8838	1.9262	1.8903	1.8764	1.8058	1.7736	1.7659
35000	7.7224	7.9462	8.1059	8.3368	8.4719	8.7492	8.9755	8.8089	8.5724	8.2256	8.0585	7.7599−3
40000	3.5683	3.6916	3.7593	3.9437	4.0748	4.2109	4.3274	4.2318	4.0718	3.8346	3.7002	3.5314
45000	1.6825	1.7568	1.8150	1.9426	2.0508	2.1241	2.1830	2.1223	2.0048	1.8615	1.7655	1.6700
50000	0.8488	0.8884	0.9321	1.0109	1.0801	1.1195	1.1467	1.1182	1.0375	0.9494	0.8891	0.8456
55000	4.5087	4.7226	5.0360	5.4783	5.8829	6.1002	6.1769	6.0680	5.6246	5.0403	4.7011	4.4615−4
60000	2.4210	2.5039	2.7029	2.9369	3.2016	3.3372	3.3806	3.2916	3.0444	2.7071	2.4925	2.3973
65000	1.2371	1.2931	1.3803	1.5438	1.7120	1.7824	1.8454	1.7741	1.6017	1.4248	1.2947	1.2746
70000	6.1810	6.4699	6.7759	7.8551	8.7414	9.3123	9.5195	9.0130	8.0878	7.2559	6.5981	6.5688−5
75000	3.0790	3.1318	3.2550	3.8222	4.1998	4.5390	4.5441	4.2789	3.8195	3.5346	3.2088	3.2075
79000	1.7130	1.7129	1.7763	2.0676	2.2246	2.3671	2.3626	2.2474	1.9881	1.9086	1.7334	1.7358

* Power of ten by which preceding numbers should be multiplied.

ture-height profiles were determined from the 30N temperatures and zonal winds. This was based on the assumption that at 60N the strong winds near 40 km, their decrease to 50 km and subsequent increase to 60 km (Fig. 4), do not reflect the zonal wind flow between latitudes 60 and 45N. These winds probably are related to the polar jet which is not so marked south of 60N. Also, since these winds are based on a limited number of 60N December observations, they may not be representative of the zonal winds which are envisioned as an elongated belt of strong west winds between 30 and 70 km rather than the two cells depicted

Table 3. Mean monthly atmospheric properties, 60N.

Altitude (geop. m.)	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
						Temperature (K)						
0000	257.15	256.65	261.65	269.15	276.65	282.65	287.15	284.15	281.15	275.15	266.15	259.15
5000	240.95	244.90	245.65	250.15	253.25	259.65	260.15	262.15	256.15	252.65	248.65	243.90
10000	217.15	218.65	219.65	222.15	223.65	224.65	225.15	224.15	221.15	220.15	218.65	217.65
15000	217.15	218.65	219.65	222.15	223.65	224.65	225.15	224.15	221.15	220.15	218.65	217.65
20000	214.15	218.65	219.65	222.15	223.65	224.65	225.15	224.15	221.15	218.35	216.65	214.15
25000	211.15	219.55	215.15	222.15	223.65	228.65	228.15	227.75	222.15	218.65	214.65	210.65
30000	216.15	222.55	217.65	225.65	231.15	233.65	235.65	232.25	227.15	221.15	219.65	212.65
35000	222.65	225.55	225.35	238.15	244.65	246.65	247.65	245.15	236.65	229.65	224.65	219.65
40000	235.15	236.15	240.85	250.65	259.65	261.65	262.65	260.15	249.15	242.15	235.65	233.15
45000	247.65	248.65	256.35	263.15	270.85	273.05	273.85	271.15	261.65	254.65	248.15	246.65
50000	260.15	261.15	265.65	270.65	274.15	276.65	277.15	275.15	271.65	267.15	260.65	260.15
55000	258.35	259.35	260.65	266.65	269.15	272.65	273.15	269.15	268.75	264.95	259.15	258.65
60000	250.65	251.15	248.15	256.65	256.65	260.05	260.45	252.85	253.35	253.65	251.65	251.15
65000	248.15	246.15	240.15	242.15	236.65	237.05	236.95	231.35	234.35	241.15	243.25	243.65
70000	244.75	240.35	234.15	224.65	216.65	214.05	213.45	209.85	215.35	228.65	231.25	236.15
75000	237.75	231.35	224.15	207.15	196.65	191.05	189.95	188.35	196.35	216.15	219.25	228.65
79000	232.15	224.15	216.15	193.15	180.65	172.65	171.15	171.15	181.15	206.15	209.65	222.65
						Pressure (mb)						
0000	1.0135	1.0140	1.0140	1.0130	1.0125	1.0105	1.0100	1.0105	1.0120	1.0110	1.0212	1.0125+3*
5000	5.1582	5.1916	5.2147	5.2668	5.3293	5.3952	5.4076	5.4051	5.3689	5.3034	5.2373	5.1866+2
10000	2.4160	2.4504	2.4793	2.5302	2.5771	2.6614	2.6715	2.6735	2.6211	2.5719	2.4940	2.4399
15000	1.1002	1.1219	1.1392	1.1728	1.2007	1.2442	1.2510	1.2477	1.2107	1.1838	1.1419	1.1131
20000	4.9826	5.1364	5.2341	5.4359	5.5940	5.8166	5.8583	5.8232	5.5922	5.4384	5.2092	5.0456+1
25000	2.2315	2.3528	2.3856	2.5196	2.6063	2.7338	2.7489	2.7309	2.5839	2.4827	2.3592	2.2576
30000	1.0031	1.0864	1.0834	1.1749	1.2296	1.3056	1.3159	1.2994	1.2079	1.1417	1.0743	1.0072
35000	4.5949	5.0684	4.9826	5.6237	5.9849	6.3943	6.4717	6.3355	5.7657	5.3288	4.9793	4.5697+0
40000	2.1782	2.4120	2.3938	2.7952	3.0392	3.2645	3.3127	3.2216	2.8535	2.5828	2.3655	2.1484
45000	1.0733	1.1920	1.2039	1.4375	1.6004	1.7274	1.7570	1.6983	1.4617	1.2983	1.1673	1.0539
50000	5.4764	6.0979	6.2852	7.6063	8.5635	9.2938	9.4652	9.0955	7.7204	6.7449	5.9638	5.3701−1
55000	2.8388	3.1690	3.2961	4.0389	4.5820	5.0033	5.1013	4.8755	4.1139	3.5568	3.0956	2.7839
60000	1.4488	1.6214	1.6840	2.1023	2.3923	2.6410	2.6959	2.5367	2.1399	1.8410	1.5858	1.4243
65000	0.7304	0.8157	0.8343	1.0623	1.1964	1.3277	1.3558	1.2521	1.0617	0.9228	0.7959	0.7140
70000	3.6558	4.0453	4.0647	5.1078	5.6282	6.2216	6.3457	5.7689	4.9647	4.4591	3.8736	3.5032−2
75000	1.8008	1.9605	1.9286	2.3144	2.4610	2.6746	2.7181	2.4442	2.1640	2.0682	1.8143	1.6797
79000	1.0066	1.0759	1.0367	1.1690	1.1921	1.2607	1.2743	1.1421	1.0487	1.0826	0.9592	0.9167
						Density (kg/m³)						
0000	1.3730	1.3764	1.3501	1.3112	1.2750	1.2454	1.2253	1.2389	1.2540	1.2800	1.3246	1.3611+0*
5000	7.4578	7.3850	7.3952	7.3347	7.3310	7.2386	7.2414	7.1827	7.3018	7.3126	7.3377	7.4082−1
10000	3.8759	3.9041	3.9322	3.9677	4.0142	4.1271	4.1335	4.1551	4.1288	4.0697	3.9737	3.9052
15000	1.7650	1.7874	1.8067	1.8391	1.8792	1.9294	1.9357	1.9392	1.9071	1.8732	1.8193	1.7816
20000	8.1054	8.1837	8.3014	8.5244	8.7136	9.0199	9.0644	9.0503	8.8091	8.6767	8.3763	8.2079−2
25000	3.6816	3.7333	3.8627	3.9512	4.0597	4.1652	4.1973	4.1772	4.0520	3.9556	3.8289	3.7335
30000	1,6167	1.7006	1.7340	1.8138	1.8532	1.9467	1.9454	1.9491	1.8526	1.7985	1.7038	1.6501
35000	7.1894	7.8282	7.7025	8.2264	8.5222	9.0313	9.1037	9.0030	8.4876	8.0836	7.7215	7.2477−3
40000	3.2270	3.5582	3.4624	3.8850	4.0777	4.3464	4.3939	4.3140	3.9898	3.7157	3.4970	3.2102
45000	1.5098	1.6700	1.6360	1.9030	2.0585	2.2039	2.2351	2.1820	1.9461	1.7761	1.6387	1.4886
50000	0.7333	0.8134	0.8242	0.9790	1.0882	1.1703	1.1897	1.1516	0.9901	0.8795	0.7971	0.7191
55000	3.8279	4.2567	4.4053	5.2766	5.9306	6.3928	6.5061	6.3105	5.3327	4.6766	4.1613	3.7496−4
60000	2.0137	2.2490	2.3641	2.8536	3.2473	3.5380	3.6060	3.4950	2.9425	2.5284	2.1953	1.9756
65000	1.0254	1.1544	1.2103	1.5282	1.7612	1.9512	1.9933	1.8854	1.5783	1.3332	1.1399	1.0209
70000	0.5204	0.5863	0.6048	0.7921	0.9050	1.0126	1.0357	0.9577	0.8031	0.6794	0.5835	0.5168
75000	2.6387	2.9521	2.9974	3.8922	4.3596	4.8770	4.9850	4.5207	3.8394	3.3333	2.8827	2.5592−5
79000	1.5105	1.6721	1.6708	2.1084	2.2989	2.5439	2.5937	2.3247	2.0168	1.8295	1.5939	1.4342

* Power of ten by which preceding numbers should be multiplied.

in Fig. 4. Above 30 km, other details in the temperature and wind cross sections, based on this limited sample, are subject to similar uncertainties.

The bi-modal temperature distribution in the arctic and subarctic winter mesosphere and stratosphere must be considered in defining details of atmospheric structure at 60N for December, January, and February, and to a lesser extent, March. The frequency of occurrence of cold and warm regimes was determined and observations were weighted accordingly in arriving at realistic mean monthly values for the winter months. Atmospheric properties associated with these cold and warm

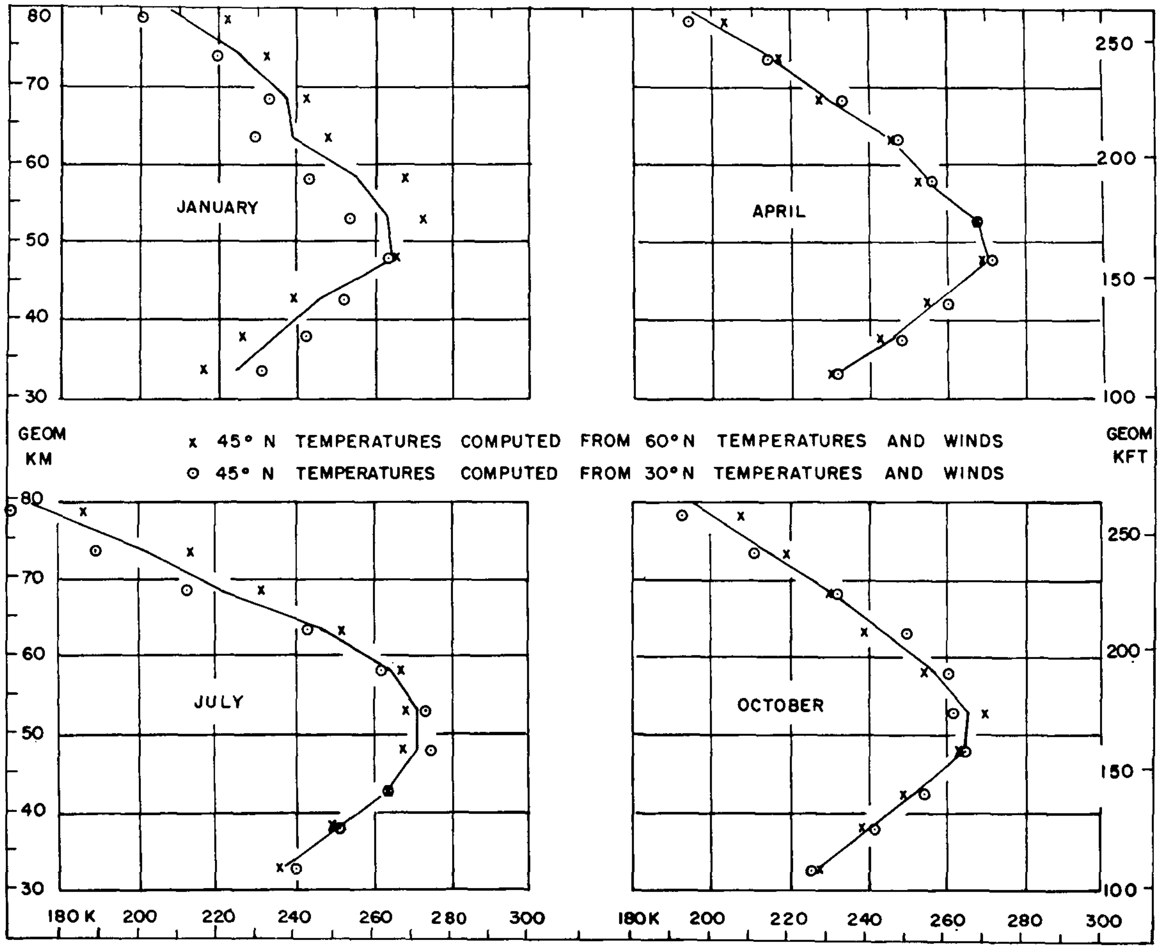

FIG. 5. Mean temperature-height profiles, 30 to 80 km, at 45N for January, April, July and October.

stratospheric conditions at latitudes 60 and 75N have been described by Cole and Kantor (1963).

4. Results

In Fig. 6, temperature-height profiles for latitudes 30, 45 and 60N are compared for January, April, July and October. Several features merit discussion. An inverse relationship exists between temperatures at the stratopause (50 km) and those near the mesopause (80 km) regardless of season and latitude. In other words, the warmest (coldest) stratopause is associated with the coldest (warmest) mesopause. Also, the change in temperature between latitudes 30 and 60N for any given height or month is not necessarily linear. The mathematically-defined 45N temperature-height profiles generally lie between, but not midway between, the 30 and 60N profiles. Temperatures in Tables 1, 2 and 3 (and Fig. 6) indicate that January and July are not extreme months at all heights and latitudes. At 30N, May displays the warmest and December the coldest temperatures at the stratopause; at 60N, June and July appear warmest and December and January (also November) are coldest near 50 km. The annual temperature range increases from 30 to 60N, ranging at the stratopause from 3.5K at 30N to 17K at 60N.

The major zonal wind patterns above 25 km, westerly in winter and easterly in summer, are apparent in Figs. 3 and 4 for latitudes 30 and 60N, respectively. Wind maxima appear generally between 55 km and 70 km, varying somewhat in strength and height with change in season and latitude. More detailed discussions of winds and wind variability in the stratosphere and mesosphere are contained in studies by Appleman (1963) and Kantor and Cole (1964).

Profiles of the vertical density distributions between 30 and 80 km for January, April, July and October are plotted in Fig. 7 as per cent departures from the density profiles of the U. S. Standard Atmosphere, 1962. These data indicate that a regular seasonal variation in density occurs at all heights between 30 and 80 km with highest densities in summer and lowest densities in winter. The maximum seasonal variation occurs near 70 km and ranges from roughly 130 per cent to 70 per cent of

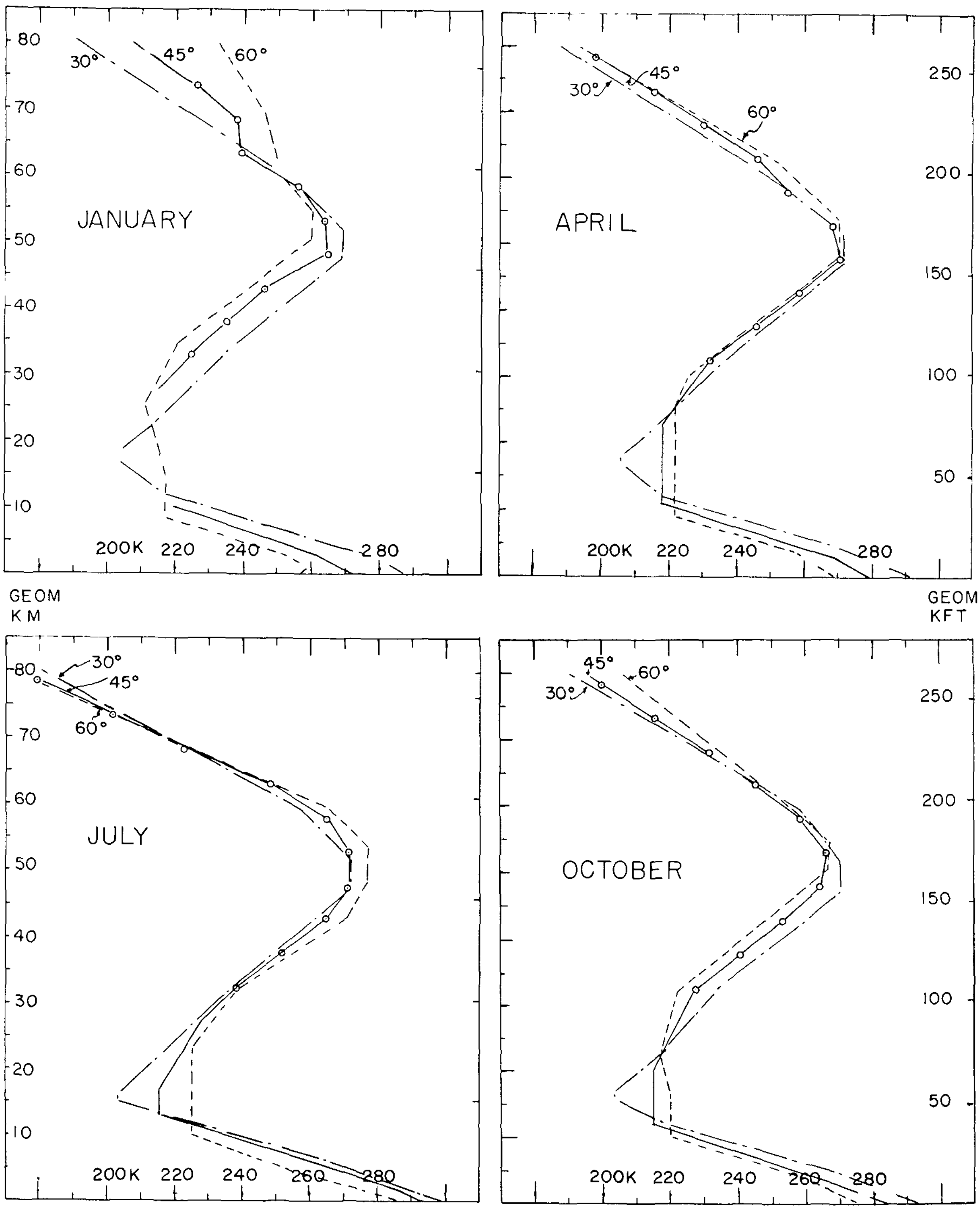

Fig. 6. Mean temperature-height profiles at 30, 45, and 60N for January, April, July and October.

standard at 60N, and from 110 to 95 per cent of standard at 30N. The seasonal variability at all three latitudes decreases at heights above and below 70 km.

The annual march of mean monthly densities for the 40, 50 and 60-km levels of the 30 and 60N atmospheres is compared to observed data in Fig. 8 as per cent departures from the U. S. Standard Atmosphere, 1962. Observed values for 30N are based on observations taken at White Sands, Eglin Air Force Base and Cape Kennedy, and those for 60N are based on observations at Fort Greely and Fort Churchill. All available falling sphere and grenade observations plus 1963 and January, February and March 1964 Meteorological Rocket Network thermistor observations were used. Again, observations taken within the same 24-hour period at any one location were averaged together and weighted as one observation in the computation of the observed means.

A distinct seasonal variation in both computed and observed density is evident at the three levels shown in Fig. 8. The highest densities occur in May and June at 30N and in June and July at 60N. The lowest densities occur in December and January at both latitudes. The amplitude of the seasonal variations, however, is much larger at 60N than at 30N. With the exception of the January, February and March portions of the density curves at 60N, monthly variations of density at these altitudes can be represented by relatively smooth curves at both latitudes. The irregularity in the 40, 50 and 60 km density curves (January through April) at 60N is undoubtedly associated with the sudden warmings which frequently take place in the subarctic stratosphere and mesosphere in late January or early February. At radiosonde heights (20 to 30 km) these warmings have accounted for temperature changes of as much as 40K within two or three days. The abruptness of the final stratospheric warming around the first of April (Dartt and Belmont, 1964) also contributes to this irregularity. The transition from summer to winter, however, is much smoother, as indicated by the July to December portions of the 60N curves in Fig. 8.

5. Conclusions

1. An inverse relationship is apparent between temperatures at the stratopause (50 km) and those near the mesopause (80 km). The warmest (coldest) stratopause is associated with the coldest (warmest) mesopause regardless of season and latitude.

2. The temperature change between latitudes 30 and 60N is not linear for all heights and months. Also, minimum and maximum values of monthly thermodynamic properties and zonal winds do not necessarily occur during either January or July at all levels and latitudes. At 30N, for example, the warmest stratopause is shown in May rather than in July and the coldest in December rather than in January.

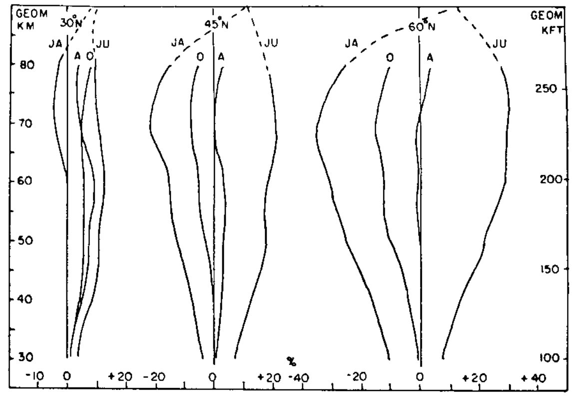

FIG. 7. Density departure (%) from 1962 Standard, 30 to 80 km, at 30, 45 and 60N for January, April, July and October.

3. The amplitude of seasonal changes in mean monthly temperatures and densities at altitudes between 30 and 80 km increases with increasing latitude.

4. The transition from one season to another appears to be relatively smooth at all latitudes with the exception of the period from late January to April in subarctic regions. Sudden warmings in the subarctic and arctic stratosphere and mesosphere are associated with marked irregularities in the annual temperature, density and wind curves for altitudes above 30 km during this period.

5. Additional observations between 30 and 80 km are required in equatorial and arctic regions as well as at middle latitudes, before definitive equator-to-pole cross sections of mean monthly temperature, pressure, density and wind can be constructed at these levels.

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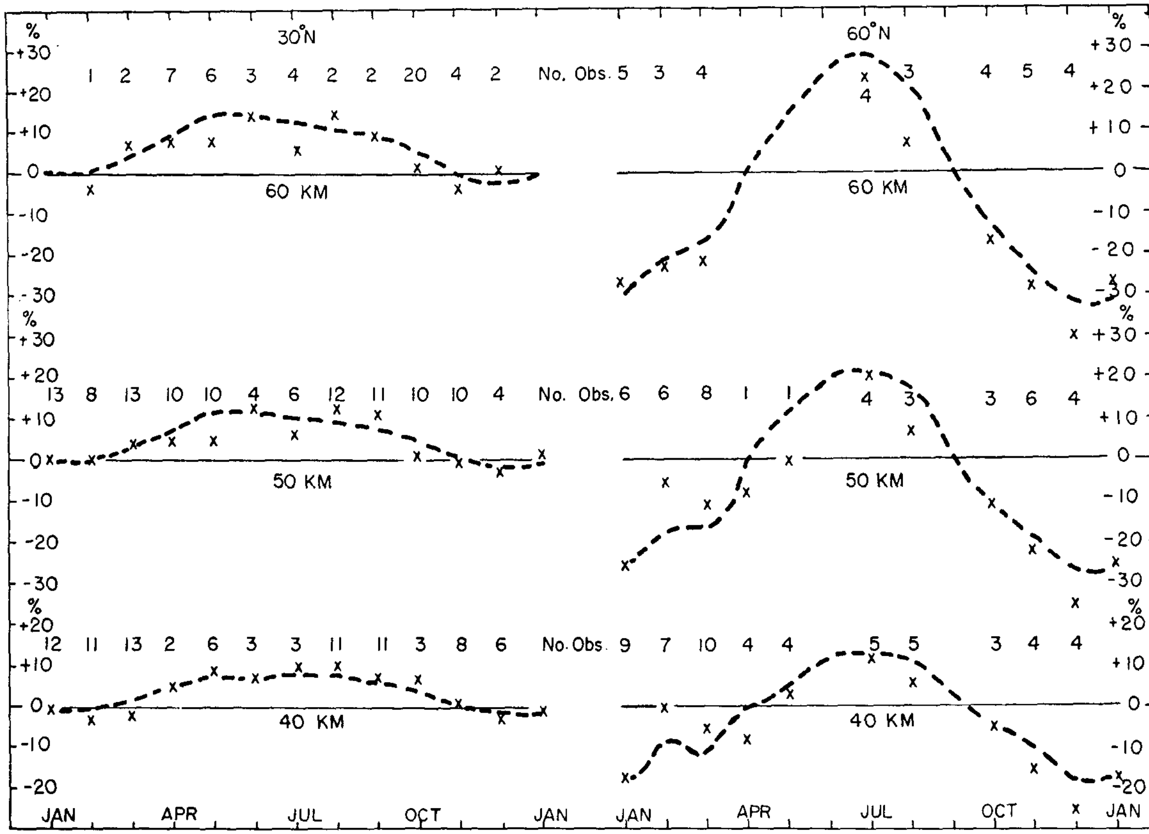

Fig. 8. Mean monthly density departure (%) from 1962 Standard, 40, 50 and 60 km, at 30 and 60N.

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