Tropical and Subtropical Atmospheres

ALLEN E. COLE AND ARTHUR J. KANTOR[1]

Air Force Cambridge Research Laboratories, Bedford, Mass.

(Manuscript received 17 May 1962, in revised form 21 September 1962)

ABSTRACT

Atmospheres typical of the tropics (15N) and subtropics (30N) have been prepared as members of a family of atmospheres, supplemental to the 1962 U. S. Standard Atmosphere; they provide information on latitudinal and seasonal changes in atmospheric structure up to 90 km.

Temperature gradients for various segments are linear with geopotential height. Humidity is incorporated into the lowest 10 km of each atmosphere. Figures and tables depict temperature, relative humidity, pressure and density.

1. Introduction

Atmospheric structure typical of Tropical and Subtropical portions of the Northern Hemisphere is defined in this report by a single Tropical Atmosphere and summer and winter Subtropical Atmospheres. The Tropical Atmosphere is derived from observations near 15 deg latitude and the Subtropical Atmospheres are based on data from locations near 30N.

These atmospheres are members of a family of Supplemental Atmospheres, prepared at the request of the U. S. Committee on Extension of the Standard Atmosphere. They are intended to provide specialized information required by designers and engineers for the design of re-entry vehicles, missiles and aircraft on latitudinal and seasonal changes in atmospheric structure.

2. Requirements

Meeting in January 1961, the Working Group of the U. S. Committee on Extension of the Standard Atmosphere agreed that the family of Supplemental Atmospheres should be mutually consistent, and should be constructed in the same general manner as the 1962 U. S. Standard Atmosphere for 15 deg latitude intervals. Each Supplemental Atmosphere would use, in geopotential computations, the value of gravity appropriate to the latitude. For the Tropical and Subtropical Atmospheres, sea-level gravity is assumed to be 978.381 and 979.324 cm sec^{-2}, respectively, decreasing with height according to W. D. Lambert's (1951) formula.

Although the ICAO and 1962 U. S. Standard Atmospheres are dry, in the Supplemental Atmospheres humidity is specified where appropriate. As a result, densities are computed according to the assumed moisture content, and the vertical pressure distribution is determined using the appropriate virtual temperature. Thus the Supplemental Atmospheres are more typical of actual conditions than is the Standard. In particular, the Tropical Atmosphere described here has a sharp tropopause inversion at 16.5 gp km, −80C, with no isothermal layer (and hence no stratosphere, *sensu strictu*) although routine averaging of available data would indicate an isothermal layer some 2 km thick.

3. Temperature

The mean annual temperature-height profile for the Tropical and mean seasonal profiles for the Subtropical Atmospheres up to approximately 30 km were based on radiosonde temperature-height summaries for stations located near latitudes 15 and 30N in the Caribbean and southern United States (Ratner;[2] Jordan, 1958), Pacific and Atlantic Oceans (U. S. Weather Bureau, 1956–61; McDonald, 1959; U. S. Navy, 1955–56) and Africa and Asia (McDonald, 1959; Pisharoty, 1959; Goldie *et al.*, 1958; Faust and Attmannspacher[3]). Realistic Northern Hemisphere means for latitudes 15 and 30N were sought by giving equal weight to observed or interpolated data at each longitude.

Latitude 15 deg lies within the heart of the trade wind belt, which is characterized by a trade wind inversion throughout most of the year. Study of 3800 Caribbean radiosonde observations at 6 locations

[1] Applied Climatology Branch, Meteorological Development Laboratory.

[2] Ratner, B., 1957: Upper-air climatology of the United States, Part I—Averages for isobaric surfaces. U. S. Weather Bureau Technical Paper No. 32, 199 pp.

[3] Faust, H., and W. Attmannspacher, 1959: Cell structure of the atmosphere. Final Rpt., Parts I and II, Contract DA/91/508/EUC/387, Deutscher Wetterdienst, Zentralamt, Offenbach A. M., Germany, 80 pp.

(Gutnick, 1958) showed this inversion on 85 per cent of the days during January and 45 per cent during July. Temperature differences between the top and base of the inversion were as much as 10C, but roughly half were less than 0.5C in summer and less than 1C in winter. In the eastern North Atlantic (Riehl, 1954) the temperature difference is 3 to 5C between the bottom and top of the inversion. Over the eastern North Pacific, the height of the inversion varies from a few hundred meters to several thousand meters. (Crozier and Sabransky[4]; Neiburger *et al.*, 1961).

Undoubtedly the height, thickness and strength of these inversions vary greatly with both longitude and season at this latitude. Mean Tropical temperature-height profiles presented by Palmer *et al.* (1955), Pisharoty (1959), and Department of Defense (1957) show no trade wind inversion. Apparently they were constructed from mean monthly values, which smooth out small-scale features in the atmosphere.

In the preparation of an annual atmosphere for 15N, consideration of the predominantly oceanic surface and of the trade wind inversion provided a profile typical of actual conditions, that would also represent mean annual conditions at all longitudes. The temperature-height profile selected has a 0.8C temperature inversion between 2250 and 2500 m.

Differences in mean annual temperature between 15N and the equator are no larger than between various longitudes along 15N. Consequently, the Tropical Atmosphere is considered representative of the area between the equator and at least 15N. At 30N, longitudinal variations in the mean January and July temperatures are slightly larger than those around the annual mean at 15N. The largest differences above 4 km (4 to 5 deg) occur at 10 to 12 km over the western Pacific.

The three atmospheres also provide a good representation of conditions up to at least 26 km at 15 and 30 deg south latitude, as shown by comparisons of their temperature-height profiles with available radiosonde data for the Southern Hemisphere (U. S. Weather Bureau, 1956–61; Hofmeyer, 1961; Schwerdtfeger, 1960; Dupont and Grosjean, 1951).

Above 30 km the temperature-height profiles are based on observations made from rockets and instrumentation released from rockets (Court *et al.*, 1962). The rockets were fired at ranges in California, Florida, Virginia, and Guam (all between 13 and 38N), in Australia at 33S, and at the equator.

The only high-altitude temperature data available closer to the equator than 30 deg are from 9 rocket-grenade ascents at Guam (13.5N), all in November 1958 and one rocket-pressure gage flight at the equator in May 1950. These, together with the more numerous observations near latitude 30 deg, were used in deriving a temperature-height profile for the Tropical Atmosphere (Fig. 1). Presented in this same figure are temperature-height curves for four other atmospheres:

(a) MIL-STD 210A Tropical Atmosphere (Department of Defense, 1957);
(b) Tropical Atmosphere proposed by Pisharoty (1959);
(c) A low-latitude atmosphere prepared by Nordberg and Stroud[5] (1961);
(d) 1962 U. S. Standard Atmosphere.

All four tropical atmospheres are in close agreement, reflecting the homogeneity of the tropical climate.

The temperature profile above 30 km for the winter and summer Subtropical Atmospheres are compared in Fig. 2 to the 1962 U. S. Standard Atmosphere.

4. Humidity

The air is moist below the trade wind inversion at 15N; above it dry. Relative humidities selected for the lower portion of the Tropical Atmosphere reflect the presence of this inversion. Humidities based on 10-yr averages (Gutnick, 1958; Ratner[6]; U. S. Navy, 1956) are:

Altitude, geopot. km:	0	1	2.25	2.5	4	6	8	10
Rel. humidity, per cent:	75	75	75	35	35	35	30	20

Relative humidities for the Subtropical Atmospheres, based on longitudinal averages which take into consideration the land and ocean effects at 30N (Ratner[7]; U. S. Weather Bureau, 1956–61; U. S. Navy, 1956; Bunker[8]) are:

Altitude (km)		0	1	2	3	4	6	8	10
RH	Summer	80	65	60	60	50	40	40	30
	Winter	80	70	50	45	35	30	30	30

5. Pressure

Sea-level pressures for each atmosphere were estimated from monthly normal sea-level charts for the Northern Hemisphere based on a 40-yr period of record (U. S. Weather Bureau, 1952) and from 5-day

[4] Crozier, A. L., and F. A. Sabransky, 1954: Upper-air data for Southern California. Res. Rpt. 542, U. S. Navy Electronics Lab, San Diego, Calif., 30 pp.

[5] Nordberg, W., and W. G. Stroud, 1961: Seasonal, latitudinal, and diurnal variations in the upper atmosphere. NASA Technical Note D-703, 16 pp.

[6] *Op. cit.* See footnote 2.

[7] *Ibid.* See footnote 2.

[8] Bunker, A. F., 1962: Water vapor distribution in the sub-cloud trade wind air. Tech. Rpt. 47 Contr. Nonr-1721(00) (NR-082-021) Woods Hole Oceanographic Institution, Woods Hole, Mass., 20 pp.

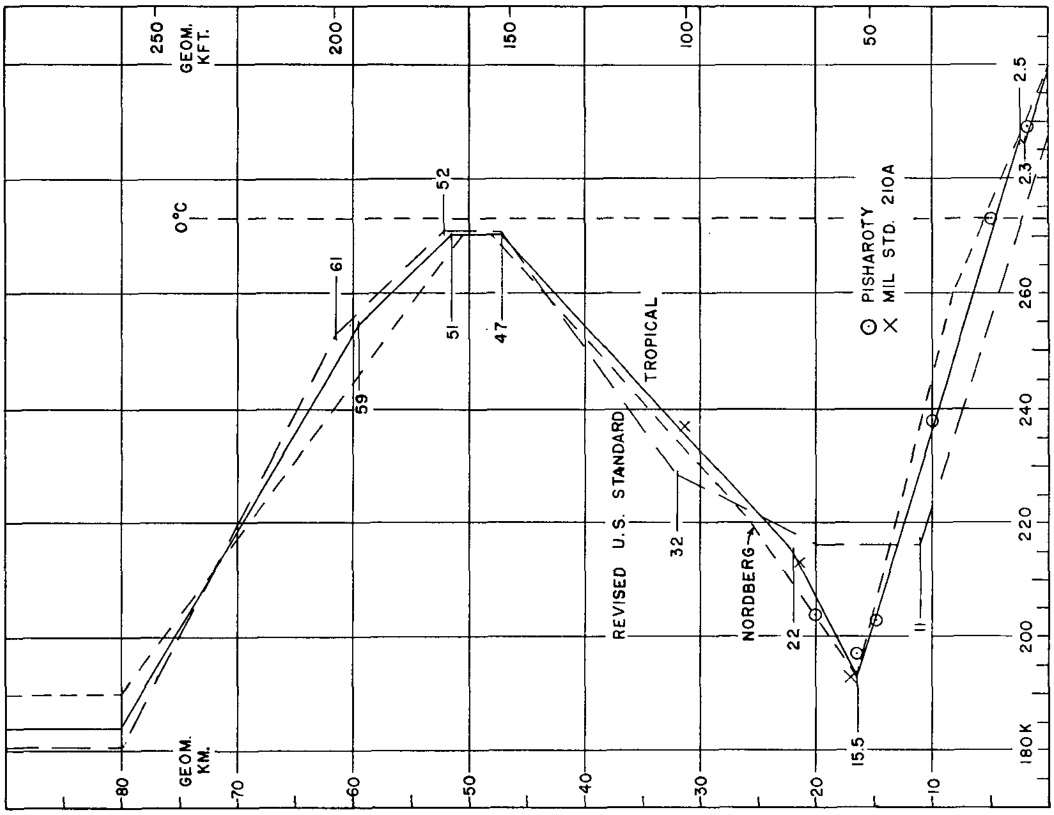

FIG. 1. Temperatures of proposed Tropical Atmosphere (15N) 1962 U. S. Standard and three low-latitude model atmospheres.

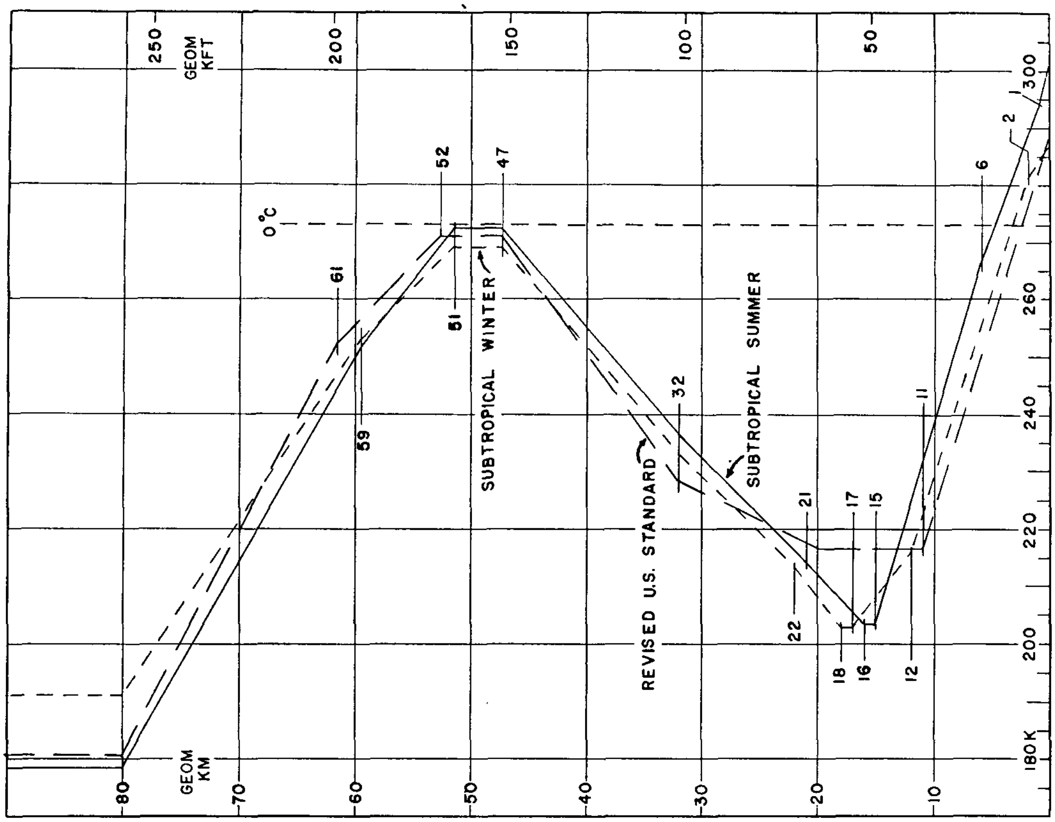

FIG. 2. Temperatures of proposed Subtropical (30N) winter and summer, and 1962 U. S. Standard Atmospheres.

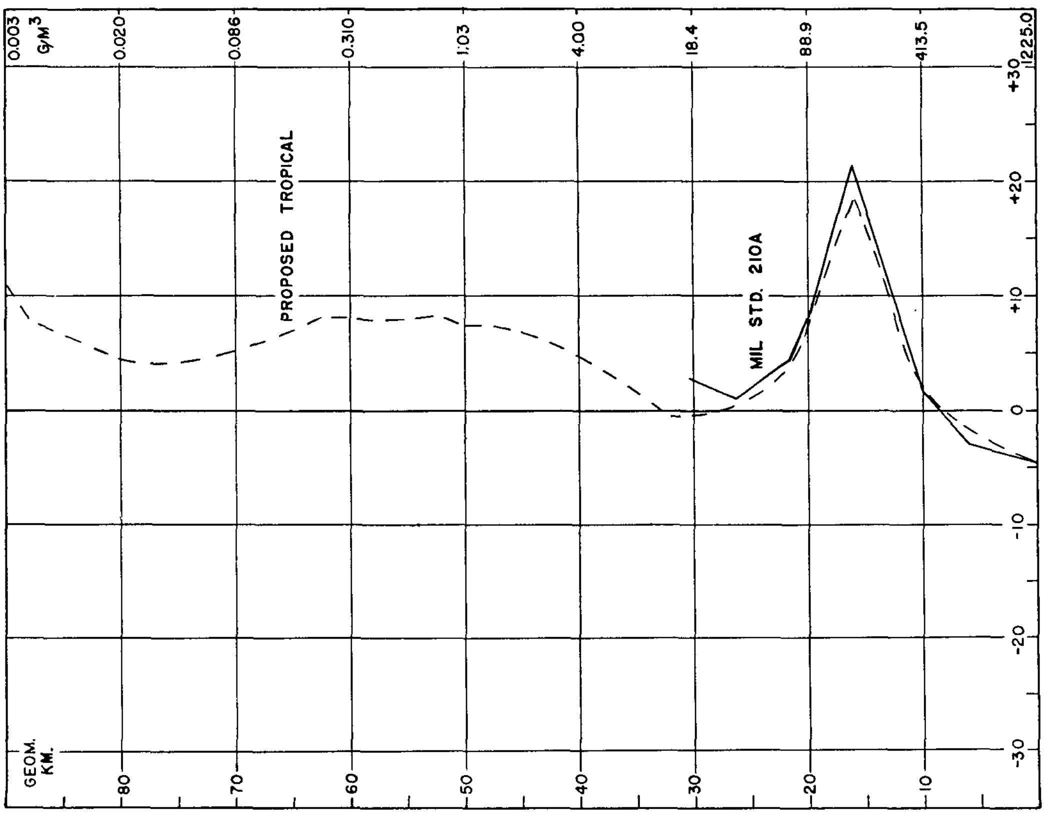

FIG. 3. Per cent departure of densities of proposed Tropical (15N) and MIL-STD 210A Tropical Atmospheres from 1962 U. S. Standard.

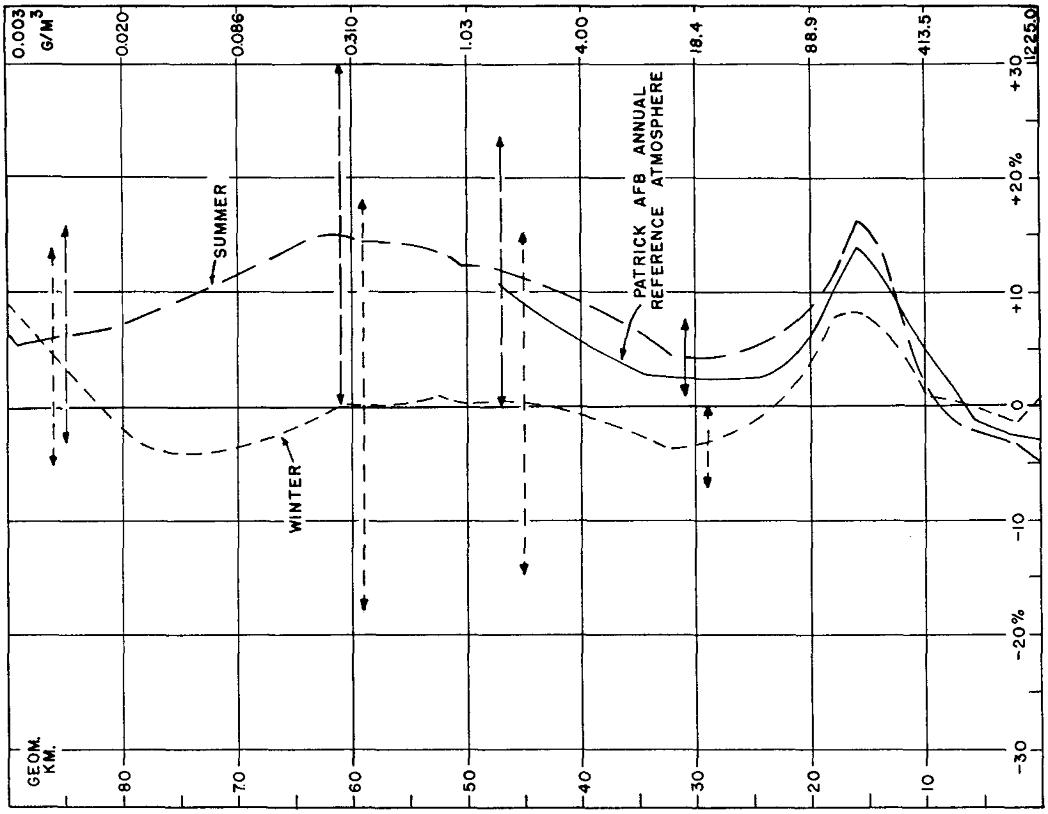

FIG. 4. Per cent departure of densities of proposed Subtropical (30N) summer and winter and Patrick Reference Atmospheres from 1962 U. S. Standard.

TABLE 1. Properties to 90 km of Tropical (15N) Atmosphere. Linear virtual temperature gradient assumed between tabulated altitudes, based on relative humidity of 75 per cent up to trade-wind inversion at 2 km, 35 per cent 2–6 km, and less than 30 per cent above.

Kilometers		Temperature		Pressure		Density	
Geomet.	Geopot.	Grad.	Kelvin	mbs	*	g/m³	*
90.000	88.597	0.0	184.15	1.8620	−3	3.5224	−3
89.388	88.000	0.0	184.15	2.0796		3.9342	
87.330	86.000	0.0	184.15	3.0113		5.6966	
85.272	84.000	0.0	184.15	4.3603		8.2487	−3
83.214	82.000	0.0	184.15	6.3137		1.1944	−2
81.156	80.000	0.0	184.15	9.1422	−3	1.7295	
80.130	79.000	xxx	184.15	1.1001	−2	2.0811	
79.104	78.000	−3.5	187.65	1.3215		2.4534	
77.052	76.000	−3.5	194.65	1.8878		3.3786	
75.000	74.000	−3.5	201.65	2.6630		4.6006	
72.949	72.000	−3.5	208.65	3.7128		6.1989	
70.898	70.000	−3.5	215.65	5.1199		8.2710	−2
68.852	68.000	−3.5	222.65	6.9881		1.0934	−1
66.806	66.000	−3.5	229.65	9.4466	−2	1.4330	
64.761	64.000	−3.5	236.65	1.2655	−1	1.8629	
62.717	62.000	−3.5	243.65	1.6809		2.4033	
60.673	60.000	−3.5	250.65	2.2148		3.0783	
59.652	59.000	xxx	254.15	2.5351		3.4749	
58.634	58.000	−2.0	256.15	2.8974		3.9404	
56.595	56.000	−2.0	260.15	3.7730		5.0524	
54.556	54.000	−2.0	264.15	4.8935		6.4536	
52.518	52.000	−2.0	268.15	6.3221		8.2135	
51.498	51.000	xxx	270.15	7.1756		9.2534	−1
50.480	50.000	0.0	270.15	8.1405	−1	1.0497	0
48.448	48.000	0.0	270.15	1.0477	0	1.3511	
47.432	47.000	xxx	270.15	1.1886		1.5328	
46.416	46.000	+2.2	267.95	1.3492		1.7542	
44.384	44.000	+2.2	263.55	1.7437		2.3049	
42.352	42.000	+2.2	259.15	2.2633		3.0425	
40.320	40.000	+2.2	254.75	2.9510		4.0355	
38.293	38.000	+2.2	250.35	3.8654		5.3788	
36.267	36.000	+2.2	245.95	5.0874		7.2061	
34.242	34.000	+2.2	241.55	6.7291		9.7049	0
32.217	32.000	+2.2	237.15	8.9464	0	1.3142	+1
30.192	30.000	+2.2	232.75	1.1958	+1	1.7898	
28.171	28.000	+2.2	228.35	1.6072		2.4519	
26.150	26.000	+2.2	223.95	2.1726		3.3797	
24.131	24.000	+2.2	219.55	2.9546		4.6884	
22.113	22.000	xxx	215.15	4.0430		6.5466	
20.096	20.000	+4.0	207.15	5.5838		9.3903	+1
18.081	18.000	+4.0	199.15	7.8106	+1	1.3663	+2
16.570	16.500	xxx	193.15	1.0137	+2	1.8284	
16.067	16.000	−6.7	196.50	1.1063		1.9613	
14.054	14.000	−6.7	209.90	1.5474		2.5682	
12.043	12.000	−6.7	223.30	2.1200		3.3074	
10.032	10.000	−6.7	236.70	2.8516		4.1965	
8.023	8.000	−6.7	250.10	3.7733		5.2545	
6.016	6.000	−6.7	263.50	4.9201		6.4996	
4.009	4.000	−6.7	276.90	6.3303		7.9509	
2.505	2.500	xxx	286.95	7.5861		9.1845	
		(+3.2)					
2.254	2.250	xxx	286.15	7.8133		9.4604	
2.004	2.000	−6.0	287.65	8.0475		9.6896	+2
1.002	1.000	−6.0	293.65	9.0417		1.0645	+3
0.000	0.000	−6.0	299.65	10.1325	+2	1.1666	+3

* Power of 10 by which preceding figures should be multiplied.

TABLE 2. Properties to 90 km of Subtropical (30N) Atmosphere, winter and summer. Linear virtual temperature gradient assumed between tabulated altitudes, based on relative humidity of 80 per cent at surface, decreasing to less than 30 per cent at 12 km.

Kilometers		Temperature Gradient		Temperature Kelvin		Pressure Millibars			Density (g/m³)		
Geomet.	Geopot.	Win	Sum	Win	Sum	Win	Sum	*	Win	Sum	*
90.000	88.680	0.0	0.0	191.15	178.65	1.8916	1.7297	−3	3.4474	3.3729	−3
89.301	88.000	0.0	0.0	191.15	178.65	2.1357	1.9695		3.8923	3.8411	
87.244	86.000	0.0	0.0	191.15	178.65	3.0518	2.8856		5.5619	5.6270	
85.188	84.000	0.0	0.0	191.15	178.65	4.3608	4.2277		7.9476	8.2441	−3
83.133	82.000	0.0	0.0	191.15	178.65	6.2314	6.1941		1.1357	1.2079	−2
81.078	80.000	0.0	0.0	191.15	178.65	8.9044	9.0752	−3	1.6228	1.7697	
80.053	79.000	xxx	xxx	191.15	178.65	1.0644	1.0985	−2	1.9399	2.1421	
79.028	78.000	−3.1	−3.7	194.25	182.35	1.2705	1.3270		2.2785	2.2352	
76.978	76.000	−3.1	−3.7	200.45	189.15	1.7954	1.9151		3.1203	3.5160	
74.928	74.000	−3.1	−3.7	206.65	197.15	2.5104	2.7251		4.2320	4.8153	
72.879	72.000	−3.1	−3.7	212.85	204.55	3.4757	3.8277		5.6887	6.5190	
70.830	70.000	−3.1	−3.7	219.05	211.95	4.7673	5.3120		7.5818	8.7311	−2
68.786	68.000	−3.1	−3.7	225.25	219.35	6.4815	7.2892		1.0024	1.1577	−1
66.742	66.000	−3.1	−3.7	231.45	226.75	8.7389	9.8981	−2	1.3154	1.5207	
64.699	64.000	−3.1	−3.7	237.65	234.15	1.1689	1.3309	−1	1.7135	1.9801	
62.657	62.000	−3.1	−3.7	243.85	241.55	1.5520	1.7732		2.2172	2.5574	
60.615	60.000	−3.1	−3.7	250.05	248.95	2.0460	2.3420		2.8505	3.2773	
59.596	59.000	xxx	xxx	253.15	252.65	2.3431	2.6833		3.2244	3.6999	
58.578	58.000	−2.0	−2.5	255.15	255.15	2.6798	3.0692		3.6589	4.1906	
56.541	56.000	−2.0	−2.5	259.15	260.15	3.4941	3.9998		4.6971	5.3562	
54.504	54.000	−2.0	−2.5	263.15	265.15	4.5374	5.1865		6.0068	6.8144	
52.468	52.000	−2.0	−2.5	267.15	270.15	5.8691	6.6926		7.6535	8.6304	
51.450	51.000	xxx	xxx	269.15	272.65	6.6654	7.5890		8.6273	9.6966	−1
50.432	50.000	0.0	0.0	269.15	272.65	7.5661	8.6006	−1	0.9793	1.0989	+0
48.401	48.000	0.0	0.0	269.15	272.65	0.9749	1.1046	+0	1.2619	1.4114	
47.385	47.000	xxx	xxx	269.15	272.65	1.1067	1.2519		1.4324	1.5996	
46.370	46.000	+2.4	+2.4	266.75	270.25	1.2570	1.4195		1.6416	1.8298	
44.340	44.000	+2.4	+2.4	261.95	265.45	1.6271	1.8314		2.1639	2.4035	
42.311	42.000	+2.4	+2.4	257.15	260.65	2.1164	2.3738		2.8672	3.1727	
40.282	40.000	+2.4	+2.4	252.35	255.85	2.7665	3.0916		3.8192	4.2096	
38.258	38.000	+2.4	+2.4	247.55	251.05	3.6348	4.0468		5.1152	5.6156	
36.233	36.000	+2.4	+2.4	242.75	246.25	4.8014	5.3246		6.8905	7.5327	+0
34.209	34.000	+2.4	+2.4	237.95	241.45	6.3777	7.0440		0.9337	1.0163	+1
32.186	32.000	xxx	xxx	233.15	236.65	8.5207	9.3710	+0	1.2732	1.3795	
30.163	30.000	+2.0	+2.0	229.15	232.65	1.1447	1.2534	+1	1.7403	1.8768	
28.144	28.000	+2.0	+2.0	225.15	228.65	1.5458	1.6848		2.3918	2.5670	
26.125	26.000	+2.0	+2.0	221.15	224.65	2.0986	2.2767		3.3059	3.5306	
24.108	24.000	+2.0	+2.0	217.15	220.65	2.8652	3.0932		4.5966	4.8836	
22.092	22.000	xxx	+2.0	213.15	216.65	3.9346	4.2261		6.4307	6.7955	
21.084	21.000	+2.5	xxx	210.65	214.65	4.6219	4.9505		7.6437	8.0345	
20.077	20.000	+2.5	+2.3	208.15	212.35	5.4398	5.8083		9.1043	9.5287	+1
18.064	18.000	xxx	+2.3	203.15	207.75	7.5803	8.0377		1.2999	1.3478	+2
17.057	17.000	xxx	+2.3	203.15	205.45	8.9665	9.4809	+1	1.5376	1.6076	
16.052	16.000	−2.6	xxx	205.75	203.15	1.0595	1.1204	+2	1.7939	1.9213	
15.046	15.000	−2.6	xxx	208.35	203.15	1.2493	1.3253		2.0889	2.2727	
14.041	14.000	−2.6	−7.0	210.95	210.15	1.4700	1.5632		2.4276	2.5914	
12.031	12.000	xxx	−7.0	216.15	224.15	2.0235	2.1405		3.2613	3.3267	
10.023	10.000	−6.5	−7.0	229.15	238.15	2.7494	2.8758		4.1798	4.2062	
8.016	8.000	−6.5	−7.0	242.15	252.15	3.6728	3.7987		5.2830	5.2458	
6.010	6.000	−6.5	xxx	255.15	266.15	4.8326	4.9422		6.5961	6.4619	
4.005	4.000	−6.5	−5.5	268.15	277.15	6.2717	6.3508		8.1407	7.9634	
2.002	2.000	xxx	−5.5	281.15	288.15	8.0375	8.0778		9.9341	9.7192	+2
1.001	1.000	−3.0	xxx	284.15	293.65	9.0652	9.0770	+2	1.1072	1.0698	+3
0.000	0.000	−3.0	−7.5	287.15	301.15	1.0210	1.0170	+3	1.2328	1.1632	+3

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

normal sea-level charts[9] based on a 20-yr period of record.

Vertical pressure distributions were computed from the hydrostatic equation for pressure in terms of geopotential height:

$$P/P_b=\begin{cases} T_b^*/(T_b^*+L^*h)g/RL^* & L^*\neq 0,\\ \exp(-gh/RT_b^*) & L^*=0,\end{cases}$$

where P and P_b are the pressures at the top and bottom of a layer of thickness h (difference in geopotential heights), T_b^* is the virtual temperature (K) at the base of the layer, L^* is the virtual temperature gradient (rate of *increase* of temperature with increasing height), g is the acceleration of gravity, and R is the gas constant for dry air. Pressures for all levels between the surface and 90 km are tabulated in Tables 1 and 2 for the Tropical and Subtropical Atmospheres.

6. Density

Density (ρ) was computed at each level from the perfect gas law, $\rho=P/RT^*$.

Density values for the proposed Tropical Atmosphere are tabulated in Table 1 and plotted in Fig. 3 as per cent departures from the 1962 U. S. Standard Atmosphere. Densities for the Department of Defense (1957) Tropical Atmosphere also are presented in Fig. 3 as departures from the Revised Standard.

These comparisons are based on densities at even geopotential altitudes. The geometric height of a given geopotential surface decreases with increasing latitude. The 50,000 geopotential meter surface at latitudes 15, 30, and 45 deg occurs at 50,480, 50,432 and 50,365 geometric meters, respectively. Densities computed from the same temperature-height curve but at different latitudes will be the same at a given geopotential surface, if surface pressure remains constant, but will not agree at geometric altitudes.

The percentages departures shown in Fig. 3 for densities at geopotential heights are slightly different than those at geometric heights. At 90 km, the altitude where the largest discrepancy would exist, the difference in departure from the Revised U. S. Standard is 2 to 3 per cent.

Densities for the Subtropical Atmospheres are presented in Table 2 and plotted in Fig. 4 as percentage departures from the Revised U. S. Standard at geopotential heights. This figure also includes densities from a Reference Atmosphere prepared by Smith[10] for Patrick AFB.

7. Discussion

A mean annual rather than seasonal profile was adopted for 15N, since the temperature-height structure remains relatively constant throughout the year. The largest seasonal variation (2 to 3 deg) in temperature at 15N occurs near the tropopause, which is approximately 1 km higher in January than in July. Routine averaging of mean monthly temperatures would result in a 1 to 2 km isothermal layer above 16 km. The profile selected as being representative of actual conditions in this region has a sharp tropospheric inversion at 16.5 km.

Seasonal differences are more pronounced at 30N. The seasonal variation in the height of the tropopause, 15 to 17 km, is twice as large as in the Tropics. Temperatures at 30N (Fig. 2) in winter are colder than in summer at all altitudes below 58 km, except for a 3–4 km layer near the tropopause. The largest difference, 14C, occurs at the surface. Above 58 km, where the two temperature height profiles intersect, winter temperatures are warmer. The maximum difference, 12.5C, occurs above 80 km. Differences between atmospheric density in winter and summer at 30N range from near zero at the isopycnic level (8 km), to roughly 15 per cent at 60 km. A second isopycnic level may exist between 80 and 90 km, where mean seasonal density profiles at all latitudes appear to approach or cross each other (Cole, 1961); the limited number of observations available at this altitude also indicates a decrease in interdiurnal variability. The horizontal arrows in Fig. 4 are estimates, based on rocket and searchlight observations of the day to day variability exceeded less than 5 per cent of the time at altitudes above 30 km. Data on which to base similar estimates for 15N are not available.

From latitudinal pressure gradients computed from the Tropical and Subtropical Atmospheres, January and July geostrophic zonal wind components were estimated for various altitudes between 25 and 30 deg latitude. These estimates are compared in Fig. 5 with Meteorological Rocket Network observations (1959–61) of zonal winds above 30 km over Patrick AFB (28N), and with serially-complete tabulations of rawin observation at Patrick for the period 1951–56[11] below 30 km.

The change in direction of the zonal components at 85 km agrees with theory, as well as with observations from Project Firefly (1960) experiments (high-altitude chemical releases) at Elgin AFB, 30N. The geostrophic winds computed, using seasonal data at both 15 and 30N, are lighter and agree more closely with the ob-

[9] Lahey, J. F., R. A. Bryson and E. W. Wahl, 1958: Atlas of five-day normal sea-level pressure charts for the northern hemisphere. Contract AF 19(604)–992, Scientific Rpt. No. 7, University of Wisconsin Press, 75 pp.

[10] Smith, O. E., 1960: A reference atmosphere for Patrick AFB, Florida (Annual). NASA TN D–555, 44 pp.

[11] Charles, B. N., 1959, Upper-wind statistics from USWB-FCDA data. U. S. Weather Bureau-Sandia Corp. Cooperative Project in Climatology, Final Rpt.

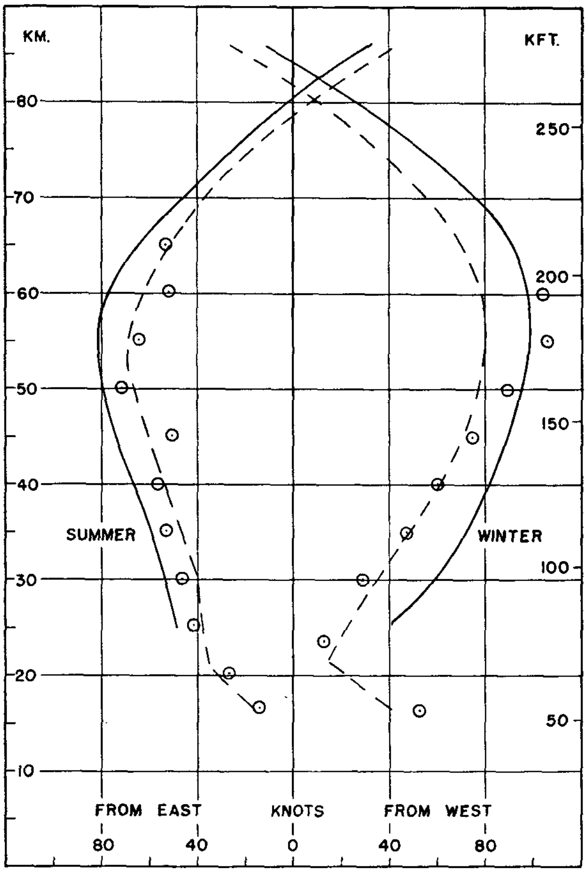

FIG. 5. Comparison of observed and computed zonal wind components for 25–30N. Solid line, geostrophic zonal wind components based on Proposed Tropical (annual) and Subtropical (seasonal) Atmospheres; dashed lines, geostrophic zonal winds based on seasonal atmospheres at both 15 deg and 30 N; circles, observed mean seasonal zonal wind components at Patrick AFB.

served data than those computed from mean annual pressures at 15N and seasonal values at 30N.

Recent investigations of the stratospheric wind fields in the tropics (Reed *et al.*, 1961) indicate a 26-month, rather than an annual, equatorial wind oscillation. Such a circulation pattern would require two types of pressure-height distribution, each effective for 13 months.

The relatively small differences previously mentioned in currently available seasonal and annual values of the temperature-height distribution of 15N do not appear to warrant the development of seasonal atmospheres at 15N at this time. Perhaps when more data become available for the region above 25 km, additional atmospheres for this region may be developed.

8. Conclusions

The Tropical Atmosphere represents mean annual conditions at 15N, a region with little seasonal variability, and the Subtropical Atmospheres represent mean conditions in winter and summer at latitude 30N. For all three atmospheres, pressures, temperatures and densities versus geopotential and geometric altitude are provided for altitudes up to 90 km.

Significant seasonal and latitudinal variations in atmospheric structure occur at altitudes up to and above 90 km. Recent studies have found little seasonal or latitudinal variations at altitudes above 150 to 200 km. Above 200 km, the variability is due primarily to changes in solar activity (active or quiet sun) and to the position of the sun relative to the earth (diurnal effects). Consequently, mean annual conditions above 150 to 200 km, given in the U. S. Standard Atmosphere (1962), modified for solar activity and diurnal effects, may be used at all latitudes and during all seasons. Additional research, however, is required to extend the Tropical and Subtropical Atmospheres, upward to merge with the Revised U. S. Standard at an altitude where seasonal and latitudinal effects are negligible. Such extension eventually will provide mutually consistent atmospheres for the Tropical and Subtropical region from the surface to 700 km.

Acknowledgments. The data used in this study were obtained from many sources and represent the efforts of many persons. The computational assistance provided by Patrick Keeney (University of California at Los Angeles), Paul Nee (Northeastern University), and John Barclay (Boston University), is gratefully acknowledged. Murray Gutnick and Arnold Court provided helpful discussions and suggestions.

REFERENCES

Cole, A. E., 1961: Suggestion of a second isopycnic level at 80–90 km over Churchill, Canada. *J. geophys. Res.*, **66**, 2773–2778.

Court, A., A. J. Kantor and A. E. Cole, 1962: Supplemental Atmospheres. AFCRL Research Note 62-899, 20 pp.

Department of Defense, 1957: Climatic extremes for military equipment. MIL–STD 210A, U. S. Govt. Printing Office, 41–46.

Dupont, G., and P. V. Grosjean 1951: Atmosphere standard provisoire pour le Congo. Service Meteorologique du Congo Belge, *Bulletin*, **7**, 9–32.

Goldie, N., J. G. Moore and E. E. Austin, 1958: Upper air temperatures over the world. *Geophys. Mem.* **101**, Meteor. Office, London, 228 pp.

Gutnick, M., 1958: Climatology of the trade-wind inversion in the Caribbean. *Bull. Amer. meteor. Soc.*, **39**, 410–420.

Hofmeyer, W. L., 1961: Statistical analysis of upper air temperatures and winds over tropical and subtropical Africa. *Notos* (Pretoria), **10**, 16–20.

Jordan, C. L., 1958: Mean soundings in the West Indies area. *J. Meteor.*, **15**, 91–97.

Lambert, W. D., 1951: Acceleration of gravity. Tables 167–168, *Smithsonian meteorological tables*, Sixth Revised Edition.

McDonald, J. E., 1959: Mean upper-air-data for selected world stations. *Mon. Wea. Rev.*, **87**, 299–300.

Neiburger, J., D. D. Johnston and C. W. Chien, 1961: *Studies of the structure of the atmosphere over eastern Pacific Ocean in summer, I. The inversion over eastern North Pacific.* University California Press, 20 pp.

Palmer, C. E., C. W. Wise, L. J. Stempson and G. H. Duncan, 1955: The practical aspects of tropical meteorology. *Air Weather Service Manual*, 105–48.

Pisharoty, P. R. 1959: A standard atmosphere for the tropics (msl to 20 km). *Indian J. Meteor. Geophys.*, **10**, 243–254.

Reed, R. J., W. J. Campbell, L. A. Rasmussen and D. G. Rogers, 1961: Evidence of a downward-propagating annual wind reversal in the equatorial stratosphere. *J. geophys. Res.*, **66**, 813–818.

Riehl, H., 1954: *Tropical meteorology*. New York, McGraw-Hill, 56–60.

Schwerdtfeger, W., 1960: *Cortes verticales meridionales del viento zonal y de la temperatura en la atmosfera libre sobre sud America, Resumenes mensuales del tiempo,* Vol. I. Publication H 408 del Servicio de Hidrografia Naval, Secretaria de Marina, Buenos Aires, Argentina, 13 pp.

U. S. Navy, 1955–56: *Marine climatic atlas*, Vol. I, North Atlantic, NAVAER 50-IC 528, Vol. II, North Pacific, NAVAER 50-IC, 529 pp.

U. S. Weather Bureau, 1956–61: *Monthly climatic data for the world.*

U. S. Weather Bureau, 1952: Normal weather charts for the northern hemisphere. USWB Technical Paper No. 21.