551.5 (213)

A Standard Atmosphere for the Tropics (m.s.l. to 20 km)

P. R. PISHAROTY

Meteorological Office, Poona

(*Received 9 March 1958*)

ABSTRACT. The mean geopotential heights and temperatures of the standard isobaric surfaces over the Asian, the Carribean and the Southwest Pacific areas are examined. The examination reveals —(*i*) that sufficient uniformity prevails over these regions to justify the drawing up of specifications for a Standard Atmosphere for the Tropics, and (*ii*) that the conditions over the tropics are sufficiently different from the ICAN, ICAO and NACA Standard Atmospheres to warrant the drawing up of a separate set of specifications.

Specifications for a Standard Atmosphere for Asian Tropics (SAAT) and slightly different specifications for a Standard Atmosphere for Tropics for Universal use (SATU) are presented in the paper. Two computed tables, one showing the distribution of pressure and temperature with height, and the other showing the heights and temperature of standard isobaric surfaces, for both the proposed standard atmospheres are presented.

1. Introduction

Aviators, aircraft engineers and meteorologists are familiar with the Standard Atmosphere adopted by the International Commission for Air Navigation (ICAN), based primarily on the average conditions over the middle latitudes of the Northern hemisphere. Many countries use this atmosphere, with or without minor changes, as a standard for the calibration of altimeters, and in other applications including weather analysis. The NACA and the ICAO standard atmospheres very closely resemble the ICAN atmosphere. Enough data have now accumulated over the tropics to show that the mean conditions here differ considerably from those of the extra-tropical regions.

The main uses of a 'Standard Atmosphere' are to represent the synoptic sequence of events in terms of deviations from the standard and to furnish information about the mean climatic state of the atmosphere. As none of the standard atmospheres, specified so far, are satisfactory for either of the above purposes over the tropical areas, it is time that specifications are drawn up for a 'Standard Tropical Atmosphere' and the requisite tables giving the temperature and pressure distribution along the vertical drawn up. Once such tables are available, the day-to-day data need not be referred to the station mean values, which sometimes undergo changes as data are collected for longer periods. Analysis of upper air temperatures and contour heights of isobaric surfaces over the tropics, and the possible use of *D*-values (the differences between actual and indicated heights) expected to be received from high-flying aircraft over the tropics, make the necessity of specifying such a standard atmosphere rather urgent for the synoptic meteorologist.

Proposals regarding the specifications of such a Standard Atmosphere for the Asian Tropics (SAAT), and tables computed on the basis of these proposed specifications are given in this paper. The same specifications, with a few small modifications above 5 km, appear to be satisfactory for defining a Standard Atmosphere for the entire Tropics (Lat. 25° N to 25° S) for Universal use (SATU). Tables based on these specifications are also given in this paper.

2. Specifications of the current Standard Atmospheres (m.s.l. to 20 km)

The details of the various current standard atmospheres have been specified up to a height of 20 km (ICAN 1938, NACA 1925, ICAO 1954—*see references*).

Neglecting the minor variations in the values assumed for the composition of air, the absolute temperature corresponding to 0°C, and the acceleration due to gravity, the principal specifications regarding the temperature distribution with height are the same in both the ICAO and the ICAN atmospheres. These are—a mean sea level pressure of 1013·25 mb, a mean sea level temperature of 15°C, a lapse rate of 6°·5C per km upto 11 km—the level of the tropopause, and an isothermal stratosphere of —56°·5 C aloft. In the case of the NACA standard Atmosphere the differences are in the slightly lower height of the tropopause, namely, 10,769 metres, and in the slightly higher temperature of the isothermal stratosphere, namely,—55° C. In all these standard atmospheres, the specifications are made only upto the 20-km level.

3. Mean data for the Indian area along and near Lat. 12° N

The NACA atmosphere (otherwise called the U. S. Standard Atmosphere), was arrived at by considering the mean conditions at latitude 40°N. Considering the tropics, as lying between Lat. 25° N and 25° S, the ideal standard tropical atmosphere should be specified by considering the mean conditions prevailing at nearly Lat. 12° N and 12° S. The analysis of easterly waves, which primarily affect the weather over the Bay Islands and the States of Madras, Mysore and Kerala during the winter months also requires a standard atmosphere applicable to a latitude belt centred along latitude 12° N. With these ends in view, the monthly mean upper air data of the following four stations were examined —Port Blair (11° 40′ N, 92° 43′ E), Madras (13° 00′ N, 80° 11′ E), Trivandrum (08° 30′ N, 76° 59′ E) and Visakhapatnam (17° 42′ N, 83°18′ E). (The mean latitude of these four stations is 12° 32′ N).

The annual mean geopotential heights and temperatures at standard isobaric levels as well as the mean for the four months October, November, December and January derived from *Upper Air Normals* of the India Meteorological Department (1955) are entered in Table 1. The annual mean geopotential heights of the standard isobaric levels given in Table 1 were plotted against the corresponding annual mean temperatures. An extrapolation of the curve to the sea level gives a surface temperature of nearly 27°C. The mean annual isotherms for the world given by Riehl (1954) are also in agreement with this value. This procedure was adopted deliberately, as the temperature at the station level, varies considerably between morning and evening, and as the lapse rates in the lowest one kilometre are not representative of the lapse rate in a deeper layer. The mean curve thus drawn shows a lapse rate very close to 5°·4 C per km upto 5 km at which level, the temperature falls to 0° C, and a steeper lapse rate very close to 6°·5 C per km, up to a height of at least 16 km (see Fig. 1).

4. Comparison with other Tropical areas

An examination of the data for Bangkok (Lat. 13° 44′ N, Long. 100° 30′ E), Saigon (Lat. 10° 49′ N, Long. 106° 40′ E) and Songkla (Lat. 7° 11′ N, Long. 100° 37′ E) shows that conditions are not very different at these stations also. Table 2 gives the mean conditions for these three stations, over a period of a few years (not the same for all stations) as deduced from the *Monthly Climat Tables* published by the U. S. Weather Bureau. The mean temperatures over Aden (Lat. 12° 50′ N, Long. 45° 01′ E) are higher upto 700 mb by a couple of degrees. The mean data for Aden deduced from the same source as above are also entered in Table 2. (It is remarkable that for all these tropical stations, the geopotential heights of the isobaric surfaces are slightly higher in winter than in summer. The winter tropopause also apparently occurs at a slightly greater height than the summer tropopause).

In Table 3 are entered the annual mean values given in Table 1, along with the mean values (September and October) for the

TABLE 1

Mean geopotential heights and temperatures of standard isobaric surfaces for four Indian stations along and near Lat. 12° N (Port Blair, Visakhapatnam, Madras and Trivandrum)

Pressure level	Aunnal mean		Annual range of the monthly means		Mean for the four months Oct, Nov, Dec and Jan	
(mb)	Geopotential height in gpm (nearest decametre)	Temperature (°A)	Geopotential height in gpm (nearest decametre)	Temperature (°A)	Geopotential height in gpm (nearest decametre)	Temperature (°A)
850	1500	292	90	9	1510	290
700	3140	283	70	5	3150	283
600	4410	276	50	4	4420	276
500	5870	268	60	4	5870	267·5
400	7590	257·5	70	9	7590	257
300	9700	244	120	7	9700	243
200	12490	224	320	8	12470	223
150	14330	212	370	6	14320	211
100	16810	201	600	8	16770	200

TABLE 2

Mean geopotential heights and temperatures for the three stations Bangkok, Songkla and Saigon as well as for Aden (deduced from monthly Climat Tables)

Pressure level	Annual mean for the three stations		Annual mean for Aden		Annual mean for the four Indian stations along and near Lat. 12°N	
(mb)	Geopotential height in gpm (nearest decametre)	Temperature (°A)	Geopotential height in gpm (nearest decametre)	Temperature (°A)	Geopotential height in gpm (nearest decametre)	Temperature (°A)
850	1530	291	1500	295	1500	292
700	3150	283	3160	285	3140	283
500	5940	268	5880	297	5870	268
300	9800	242	9710	242	9700	244
200	12480	220	12440	221	12490	224

TABLE 3

Mean geopotential heights and temperatures for Tropical India (Table 1), for the Southwest Pacific, for the Carribean area and in the ICAO Atmosphere

Pressure surface	Indian area		S.W. Pacific area		Carribean area		ICAO atmosphere		Mean of Indian, S.W. Pacific and Carribean areas	
	Geopotential height	Temperature	Geopotential height	Temperature	Geopotential height	Temperature	Geopotential height	Temperature	Geopotential height	Temperature
(mb)	(gpm)	(°A)	(gpm)	(°A)	(gpm)	(°A)	(gpm)	(°A)	(gpm)	(°A)
850	1500	292	1510	290	1530	290	1457	279	1510	291
700	3140	283	3140	282	3170	282	3012	268	3160	282
600	4410	276	4400	274	4420	274	4206	271	4410	275
500	5870	268	5850	266	5870	266	5575	252	5870	267
400	7590	257·5	7570	255	7590	255	7185	241	7590	256
300	9700	244	9650	240	9680	241	9164	228	9680	242
200	12490	224	12350	217	12390	218	11785	216·5	12410	220
150	14330	212	14140	204	14180	205	13609	216·5	14220	207
100	16810	201	16530	196	16550	196	16178	216·5	16630	198

Southwest Pacific (Colon 1953), for the Carribean area (Schacht 1946) and for the ICAO (1954) standard atmosphere. The mean of the values for the Indian, Southwest Pacific and the Carribean areas are also entered in the same table. The large agreement with the values of the various tropical mean atmospheres, and their large departure from the ICAO atmosphere (which is practically the same as the ICAN and NACA atmospheres) are well brought out by Table 3.

Data pertaining to the level of the tropopause and the lower stratosphere are inadequate for the four stations Port Blair, Madras, Visakhapatnam and Trivandrum, so that it has not been feasible to compute normals. However, a study of the radiosonde ascents over Trivandrum (Krishna Rao and Ganesan 1953), an examination of the India Meteorological Department (1955) Mss data regarding the tropopause observations over Port Blair, Madras, Visakhapatnam and Poona, and a study of the Upper Air Data for Aden (Lond. met. Office 1954), suggest—

(*i*) that the tropical tropopause is between 16 and 17 km, often nearer to 17 km;

(*ii*) that the temperature at the tropopause generally varies between 190° A and 200° A ;

(*iii*) that there is a sharp inversion in the lower stratosphere beginning with the tropopause; and

(*iv*) that the temperature at 20 km generally varies between 200° A and 210° A.

Although not directly referring to the Asian Tropics, the statements of Koteswaram (1952) regarding the inversion in the lower stratosphere of the tropical atmosphere and its absence in the lower stratosphere of the other atmospheres, are important.

An examination* of the height of the level of 0°C over Port Blair, Madras, Visakhapatnam, Trivandrum and other Indian stations,

* The author is grateful to Shri A. Krishnan, Meteorological Office, Poona for showing him the unpublished analysis on this subject

reveals that the mean mode and median of the height values lie in the range 5000—5100 m or in the range 4900—5000 m, for all the months of the year. Hence on the average, the freezing level can be taken as 5 km for the Asian tropical atmosphere.

5. A proposed Standard Atmosphere for the Asian Tropics (a.s.l. to 20 km)

Based on the data outlined in Sections 3 and 4 above, the author would propcse a Standard Atmosphere for the Asian Tropics (SAAT) with the following specifications—

Sea level pressure	=1013·25 mb
Sea level temperature	=27° C
Lapse rate for the first 5 km	=0°·0054C per m
Freezing level (0°C)	=5000 m
Lapse rate for the layer 5 to 17 km	=0°·0065C per m
Level of the tropopause	=17 km
Temperature at the tropopause	=−78°C
Inversion or counter lapse rate in the lower stratosphere	=0°·003C per m
Temperature at 20 km	=− 69°C

(As in the cases of the other standard atmospheres the specifications are given only upto 20 km a.s.l.)

This sea level pressure of 1013·25 mb does not correspond to the mean annual atmospheric pressure over the Asian latitude belt along 12° N. On the basis of the extrapolation of the observed mean geopotential heights at the 600, 700 and 850-mb levels, this mean sea level pressure works out to be about 1011 mb. On the basis of the observed values of the station level pressures, the annual mean for the Asian Tropics works out to be nearly 1004 mb, and is subjected to the well-known marked semi-diurnal variation characteristic of the tropics. However, the Physical Sciences have defined the Standard Atmospheric Pressure at mean sea level as $1 \cdot 01325 \times 10^6$ dynes/cm² (Smithsonian Physical Tables 1956). Hence a proposal to define a different standard atmospheric pressure at mean sea level for the tropics is likely to be unacceptable.

Fig. 1 depicts the height temperature curve for the proposed Standard Atmosphere for Asian Tropics (SAAT) as well as the observed mean annual height and temperature data along and near Lat. 12° N of the Indian area and over the Southwest Pacific. The mean values for the Carribean area (summer months) practically coincide with those over the Southwest Pacific area. For comparison, the ICAO standard atmosphere is also depicted in the same figure. The annual mean heights and temperatures of the standard isobaric surfaces averaged over the four stations—Veraval (Lat. 20° 55′ N), Nagpur (Lat. 21° 09′ N), Calcutta (Lat. 22° 39′N) and Allahabad (Lat. 25° 27′ N), whose mean latitude is 22° 32′ N, are also represented in Fig. 1.

6. Numerical tables for the proposed SAAT

The computation of the latest ICAO tables (1954), makes use of the following physical and geophysical constants—

Gas constant for air, R
$=2 \cdot 8704 \times 10^6$ ergs gm^{-1} (°K)$^{-1}$

Melting point of ice, $T_0 = 273 \cdot 16$°K

Acceleration due to gravity, g
$=980 \cdot 665$ cm sec^{-2}

Computations for the proposed Standard Atmosphere for the Asian Tropics (SAAT), were made with the following relationships—

(1) *Sea level to 5 km*

$$\frac{p_z}{1013 \cdot 25} = \left(\frac{298 \cdot 16 - 0 \cdot 0054 z}{298 \cdot 16} \right)^{n_1} \qquad (6 \cdot 1)$$

$$\text{where } n_1 = \frac{9 \cdot 80665}{0 \cdot 0054 \times 287 \cdot 04}$$

(2) *5 to 17 km*

$$\frac{p_z}{p_{5000}} = \left(\frac{273 \cdot 16 - 0 \cdot 0065\ (z - 5000)}{273 \cdot 16} \right)^{n_2} \qquad (6 \cdot 2)$$

$$\text{where } n_2 = \frac{9 \cdot 80665}{0 \cdot 0065 \times 287 \cdot 04} = 5 \cdot 2561$$

(3) *17 to 20 km*

$$\frac{p_z}{p_{17000}} = \left(\frac{195 \cdot 16}{195 \cdot 16 + 0 \cdot 003\ (z - 17000)} \right)^{n_3} \qquad (6 \cdot 3)$$

$$\text{where } n_3 = \frac{9 \cdot 80665}{0 \cdot 003 \times 287 \cdot 04} = 11 \cdot 3883$$

In all the three formulæ given above, the height z is in metres; the numerical values have been adjusted to this unit of length. They are all based on the simple hydrostatic equation applied to layers of the atmosphere in which the temperature changes linearly with height. It is assumed that the acceleration due to gravity is $980 \cdot 665$ cm sec $^{-2}$ and that it does not vary with height, which is justifiable as the computations extend only upto 20 km. Therefore, the values of z would be the exact geometrical heights only at places where the acceleration due to gravity has the above value. The values of z would be numerically equal to the geopotentials of the various pressure surfaces at other places also, provided the unit is a *standard* geopotential metre, which is $9 \cdot 80665/9 \cdot 80 = 1 \cdot 00068$ of the usual geopotential metre. Consequently the values thus computed, should be increased at the rate of about 7 m for every 10,000 m, if they are to be compared with the geopotential heights expressed in units of the usual geopotential metre. The computed values of height, temperature and pressure for the SAAT are given in Table 4. The geopotential heights of the standard isobaric surfaces and their temperatures are given in Table 5. The corresponding values in the ICAO (ICAN) atmosphere are also given in Tables 4 and 5.

7. An unofficial U.S. Standard Atmosphere for the Tropics

In the *U. S. Weather Bureau Training Paper No. 1* the workers in the Carribean area have suggested a tropical atmosphere with the following specifications—

Mean sea level pressure	$=1013 \cdot 25$ mb
Mean sea level temperature	$=28°$ C
Lapse rate for the first 8 km	$=0° \cdot 006$ C per m
Lapse rate between 8—15 km	$=0° \cdot 0075$ C per m
Height of the tropopause	$=15$ km
Temperature at the tropopause	$= -72° \cdot 5$ C
Lapse rate in the lower stratosphere, 15-20 km	=Nil (Isothermal stratosphere).

It is not known whether numerical tables have been computed for such an atmosphere and whether the values are in daily use.

A temperature of 28° C at the sea level, appears to be a bit too high for a standard tropical atmosphere, most of which lies over oceanic areas. The mean annual world isotherms given by Riehl (1954), do not suggest this high value. When the sea level air temperature over vast oceanic areas becomes 28°C, the water temperature is likely to be slightly above 28°C—a condition very favourable for the development of tropical revolving storms. As discussed by Koteswaram (1952) and pointed out earlier by Ramanathan (1929) an isothermal stratification of the lower stratosphere is not typical of a tropical atmosphere.

8. Specifications for a Standard Atmosphere for the Tropics, Universal (SATU)

It is quite likely that the mean conditions over the Asian Tropics, subjected to pronounced monsoonal effects, are not fully representative of the mean upper air conditions over the entire tropical zone,

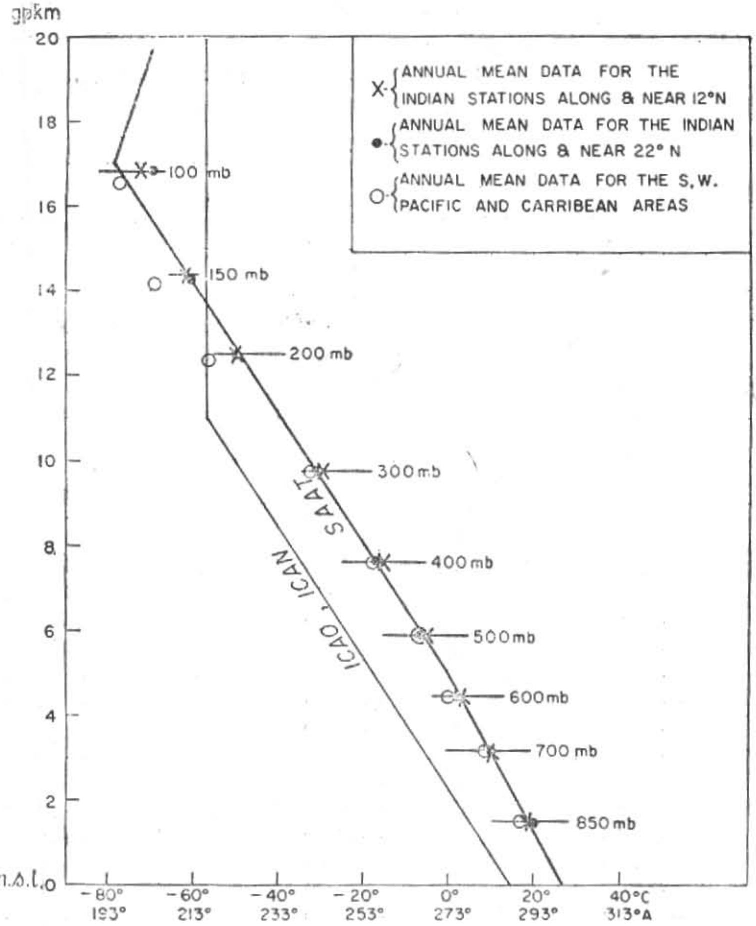

Fig. 1. Height—temperature distribution in the proposed Standard Atmosphere for the Asian Tropics (SAAT) and in the ICAO (ICAN) atmosphere

Lat. 25° N to 25° S of the earth. The mean monthly temperatures at the standard isobaric levels over the zonal circles of latitudes 20°N, 10°N, equator, 10°S and 20°S, for the four representative months January, April, June and October are given by Goldie, Moore and Austin (1958). These figures, as well as the mean annual values derived from these figures are given in Table 6. (The negligible variation in the monthly mean temperatures of these pressure surfaces over the tropics during the year is clearly brought out by Figs. 5, 6 and 7 in the above publication).

These mean values suggest a somewhat steeper rate in the upper troposphere. The mean geopotential heights of the standard isobaric surfaces, computed on the basis of these annual mean temperatures are plotted in Fig. 2. An examination of the meagre tropical tropopause data and stratospheric data over the different parts of the world, as well as the Figs. 15, 16, 17 and 18 and plates 33 to 40 of Goldie *et al.* (1958) giving the vertical cross-section across longitudes 80°W, Greenwich Meridian, 80°E and 140° E, and the average pressures and temperatures at the tropopause for the four months

TABLE 4

Values of height, temperature and pressure in (1) the proposed Standard Atmosphere for Asian Tropics (SAAT), (2) the proposed Standard Atmosphere for Tropics, Universal (SATU) and (3) the ICAO Standard Atmosphere

Height (in standard gpm)	SAAT (Asian Tropics)		SATU (Tropics, Universal)		ICAO	
	Temp. (°C)	Pressure (mb)	Temp. (°C)	Pressure (mb)	Temp. (°C)	Pressure (mb)
m.s.l	27·00	1013·25	27·00	1013·25	15·00	1013·25
500	24·30	956·95	24·30	956·95	11·75	954·61
1000	21·60	903·30	21·60	903·30	8·50	898·74
1500	18·90	852·22	18·90	852·22	5·25	845·56
2000	16·20	803·58	16·20	803·58	2·00	794·95
2500	13·50	757·31	13·50	757·31	— 1·25	746·82
3000	10·80	713·29	10·80	713·29	— 4·50	701·08
3500	8·10	671·46	8·10	671·46	— 7·75	657·64
4000	5·40	631·70	5·40	631·70	—11·00	616·40
4500	2·70	593·95	2·70	593·95	—14·25	577·28
5000	0	558·12	0	558·12	—17·50	540·20
5500	— 3·25	524·09	— 3·50	524·07	—20·75	505·07
6000	— 6·50	491·76	— 7·00	491·70	—24·00	471·81
6500	— 9·75	461·06	—10·50	460·93	—27·25	440·35
7000	—13·00	431·93	—14·00	431·72	—30·50	410·61
7500	—16·25	404·32	—17·50	404·00	—33·75	382·51
8000	—19·50	378·15	—21·00	377·72	—37·00	356·00
8500	—22·75	353·37	—24·50	352·81	—40·25	330·99
9000	—26·00	329·92	—28·00	329·22	—43·50	307·42
9500	—29·25	307·74	—31·50	306·91	—46·75	285·26
10000	—32·50	286·79	—35·00	285·82	—50·00	264·33
10500	—35·75	267·01	—38·50	265·89	—53·25	244·74
11000	—39·00	248·35	—42·00	247·09	—56·50	226·32
11500	—42·25	230·76	—45·50	229·36	—56·50	209·16
12000	—45·50	214·19	—49·00	212·65	—56·50	193·30
12500	—48·75	198·60	—52·50	196·93	—56·50	178·65
13000	—52·00	183·94	—56·00	182·15	—56·50	165·10
13500	—55·25	170·17	—59·50	168·26	—56·50	152·59
14000	—58·50	157·25	—63·00	155·23	—56·50	141·02
14500	—61·75	145·13	—66·50	143·01	—56·50	130·33
15000	—65·00	133·78	—70·00	131·57	—56·50	120·45
15500	—68·25	123·16	—73·50	120·88	—56·50	111·31
16000	—71·50	113·24	—77·00	110·88	—56·50	102·87
16500	—74·75	103·97	—76·00	101·65	—56·50	95·08
17000	—78·00	95·32	—75·00	93·24	—56·50	87·87
17500	—76·50	87·36	—74·00	85·56	—56·50	81·21
18000	—75·00	80·12	—73·00	78·54	—56·50	75·05
18500	—73·50	73·53	—72·00	72·13	—56·50	69·36
19000	—72·00	67·52	—71·00	66·27	—56·50	64·10
19500	—70·50	62·04	—70·00	60·92	—56·50	59·24
20000	—69·00	57·05	—69·00	56·01	—56·50	54·75

TABLE 5

Geopotential heights and temperatures of isobaric surfaces in the SAAT, SATU and ICAO atmospheres

Pressure level (mb)	SAAT		SATU		ICAO	
	Height (gpm)	Temp. (°A)	Height (gpm)	Temp. (°A)	Height (gpm)	Temp. (°A)
1013·25	0	300	0	300	0	288
1000	116	299	116	299	111	287
850	1523	292	1523	292	1457	279
700	3158	283	3158	283	3012	268·5
600	4421	276	4421	276	4206	271
500	5874	267	5873	267	5575	252
400	7586	256	7580	255	7185	241
300	9693	242	9672	240	9164	228·5
200	12462	225	12408	221	11785	216·5
150	14319	212	14228	208	13609	216·5
100	16746	196	16607	196	16178	216·5

TABLE 6

Average temperatures* at standard isobaric surfaces between 20°N and 20°S

	Average temperatures (°A) at standard isobaric surfaces					
	700 mb	500 mb	300 mb	200 mb	150 mb	100 mb
			JANUARY			
20°N	279·9	263·8	237·6	219·2	209·0	198·4
10°N	282·4	267·1	240·4	219·3	206·1	193·7
Equator	282·8	268·2	241·5	219·1	205·4	192·8
10°S	282·6	268·0	242·0	219·7	205·8	193·5
20°S	282·2	267·0	241·3	220·2	207·7	196·8
			APRIL			
20°N	281·4	265·3	238·9	218·9	209·0	200·0
10°N	282·9	267·4	241·8	220·2	206·8	194·8
Equator	282·9	268·1	242·6	220·8	206·4	193·9
10°S	282·7	267·7	241·8	220·5	206·6	194·8
20°S	281·4	265·6	239·5	219·7	207·9	198·1
			JULY			
20°N	283·8	267·7	241·7	220·0	207·8	199·0
10°N	282·7	267·3	241·3	218·9	206·2	196·7
Equator	281·9	267·0	241·1	218·8	206·4	197·0
10°S	280·9	266·3	240·5	219·6	207·6	198·7
20°S	278·3	263·6	238·6	220·4	210·2	202·8
			OCTOBER			
20°N	282·1	266·6	240·7	219·6	206·6	198·1
10°N	283·1	267·4	241·7	219·7	204·9	194·9
Equator	282·9	267·3	241·8	219·5	204·6	194·6
10°S	282·3	266·9	241·0	219·4	206·0	197·0
20°S	280·2	264·5	238·7	219·4	208·7	202·5
Mean	282·0	266·6	240·7	219·6	207·0	196·9

*Extracted from *Upper Air Temperatures over the World* by Goldie *et al.* (1958)

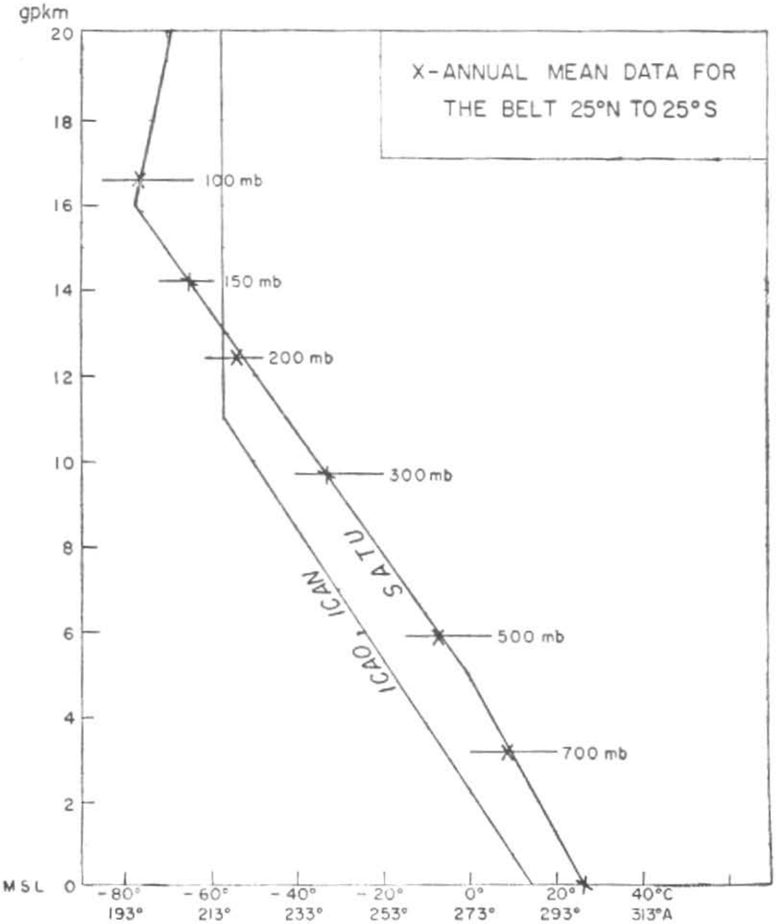

Fig. 2. Height—temperature distribution in the proposed Standard Atmosphere for the Tropics for Universal use (SATU) and in the ICAO (ICAN) atmosphere

January, April, July and October, suggest a mean tropical tropopause at a level somewhat below the 100-mb surface with a temperature between —75° and —80°C.

Based on these, the author would propose the following specifications, for a Standard Atmosphere for Tropics for Universal use (SATU), Fig. 2—

Mean sea level pressure =1013·25 mb

(About this there is no choice as physical sciences have defined it)

Mean sea level temperature =27°C

Lapse rate in the lowest 5 km =0°·0054C per m

Freezing level (0°C) =5 km

Lapse rate in the upper troposphere, 5-16 km =0°·007C per m

Level of the tropopause =16 km

Temperature at the tropopause =—77°C

Lapse rate in the lower stratosphere, 16-20 km $= -0^\circ \cdot 002$C per m

Temperature at 20 km $= -69^\circ$C

Computations have been carried out with the above specifications and the physical and geophysical constants mentioned in Section 6. The corresponding relationships between pressure and height for the various layers are —

(*i*) *Sea level to 5 km*

same as equation (6·1).

(*ii*) *5 to 16 km*

$$\frac{p_z}{p_{500}} = \left(\frac{273 \cdot 16 - 0 \cdot 007\ (z - 5000)}{273 \cdot 16}\right)^{n'_2} \quad (8 \cdot 2)$$

where $n'_2 = \dfrac{9 \cdot 80665}{\cdot 007 \times 287 \cdot 04}$

(*iii*) *16 to 20 km*

$$\frac{p_z}{p_{16000}} = \left(\frac{196 \cdot 16}{196 \cdot 16 + \cdot 002(z - 16000)}\right)^{n'_3} \quad (8 \cdot 3)$$

where $n'_3 = \dfrac{9 \cdot 80665}{0 \cdot 002 \times 2 \cdot 8704 \times 10^2}$

The computed values of height, temperature and pressure for the SATU are given in Table 4. The geopotential heights of the standard isobaric surfaces and their temperatures for the SATU are given in Table 5. The values are in good agreement with the world contours of standard isobaric surfaces for January and July given in the two papers by Heastie (1957).

9. Concluding Remarks

It is gratifying that the mean data over areas as widely separated as the Carribean, the Southwest Pacific and India show a close agreement, strongly suggesting that a standard atmosphere for the entire tropics 25°N to 25°S is a feasible proposition. Another remarkable feature of the tropical atmosphere appears to be the insignificant variation in the monthly mean temperatures and the monthly mean heights of most of the isobaric surfaces during the course of the year. The marked variations between the summer and the winter so characteristic of the extra-tropical latitudes appear to be absent in the tropical atmosphere. It is realised that the day-to-day soundings over the different portions of the vast tropics, cannot lie close to any standard specification.

The objectives to be kept in view in suggesting any specifications are—(*a*) simplicity of the specifications and (*b*) fairly close agreement to the mean conditions in the different months and areas, so that departures would not be large enough to suppress the temporal and spacial changes. Increase in the network of upper air temperature observations in the tropics, the preparation of vertical section analyses over extended areas and the possible availability of reports of *D*-values from high altitude aircraft flying over unrepresented areas of the tropics in the near future, all make the necessity of specifying such a standard atmosphere urgent.

Either of the two standard atmospheres, the SAAT or the SATU appears to be suitable for use in the tropics. For the reasons explained in Section 8, there may be a general preference for the use of the SATU. However, this is a point which requires discussions at an international level. It is hoped that the present paper would serve to initiate discussion on this important problem of specifying a standard atmosphere for the tropics for universal or regional use.

10. Acknowledgement

I am thankful to Shri A. Thiruvengadathan and to Shri R. Chellappa for computational help, and to Shri K. V. Rao for useful discussions. I am grateful to the Deputy Director General of Observatories (Climatology) for giving me access to unpublished Mss data, and to the Deputy Director General of Observatories (Forecasting), for giving me all facilities for carrying out the work outlined in this paper.

REFERENCES

Colon, J. A.	1953	*Bull. Amer. met. Soc.*, **34**, pp. 333-334.
Goldie, N., Moore, J. G. and Austin, E. E.	1958	*Geophys. Mem., Lond.*, 101.
Heastie, H.	1957	*Met. Res. Pap.*, 1045 and 1066, Met. Res. Comm., Air Ministry, London.
I. C. A. N.	1938	International Commission for Air Navigation, *Official Bulletin No. 26*, Resolution No. 1053, December 1938. *Cf.* also *Smithsonian Met. Tables*, sixth revised edition, Washington D.C., 1951, p. 268.
I. C. A. O.	1954	International Civil Aviation Organisation, *Doc. 7488, Manual of ICAO Standard Atmosphere*, Montreal.
India met. Dep.	1955	*Upper Air Normals*, Mss data.
	1952	*Tropopause data over India*, Mss data.
Koteswaram, P.	1952	*Indian J. Met. Geophys.*, **3**, 1, p. 30.
Krishna Rao, P. R. and Ganesan, V.	1953	*Ibid.*, **4**, 3, p. 193.
London met. Office	1954	*Upper Air Data, Aden.*, M.O. 555 (Part 5), H.M.S.O. London.
N.A.C.A.	1925	National Advisory Committee for Aeronautics, *Report No. 218*. A summary is given in *Smithsonian Met. Tables*, sixth revised edition, Washington D.C., 1951.
Ramanathan, K. R.	1929	*Nature*, **123**, pp. 834-35.
Riehl, H.	1954	*Tropical Meteorology*, pp. 392. McGraw Hill, London.
Schacht, E. J.	1946	*Bull. Amer. met. Soc.*, **27**, pp. 324-327.
Smithsonian Institute	1956	*Smithsonian Physical Tables*, ninth revised edition, Washington D.C.
U. S. Weather Bureau	1948	*Hurricane Notes*, Weather Bureau Training Paper No. 1, Washington D. C.