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Reference atmospheres for aerospace use

ADDENDUM 2 : Air humidity in the Northern Hemisphere

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Australia	Egypt, Arab Rep. of	South Africa, Rep. of
Austria	France	Spain
Belgium	Germany, F.R	Sweden
Brazil	Ireland	United Kingdom
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No member body expressed disapproval of the document.

0 Introduction

The moisture content of air is very small, about 4 % by mass being the maximum. Nevertheless it has a strong influence upon the earth's biosphere, on meteorological processes and also upon the operation of aircraft. A knowledge of the distribution and variations of this important meteorological quantity is required for the design and operation of aerospace vehicles.

Water in the atmosphere is found in three states, as vapour, liquid and solid. Water vapour is of greatest interest in the present context, although the other states of water are important for aviation, for example as in clouds and fog, with the consequent poor visibility, icing, and so on.

The moisture content of the atmosphere decreases rapidly with increasing height, the main mass of water being contained in the atmospheric boundary layer. On average over the Northern Hemisphere, 60 % of the total water content is in the lowest 2 km of the atmosphere, and 99 % in the lowest 10 km.

This International Standard gives values of the humidity at heights up to 10 km above sea level, the region for which reasonably reliable radiosonde data are available.

To satisfy most potential users, the humidity of the atmosphere is expressed in three measures, namely

- humidity mixing ratio, r;
- vapour pressure (partial pressure), e';
- dew-point temperature, t_d.

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1 General aspects of the humidity distribution in the atmosphere

Moisture enters the atmosphere as a result of evaporation from oceans, lakes, rivers, vegetation and moist surfaces. The main sources are the oceans of the tropics, where the high temperature leads to intense evaporation. Air currents then transport the moisture to all parts of the globe.

In the troposphere the moisture content of the air is largely dependent upon the temperature. For a given temperature, there is a definite maximum quantity of water vapour that can be held in a given volume. The amount of water vapour required to saturate a given volume increases with increasing temperature. If the amount of water vapour in a given volume remains constant, a change of temperature alters only the degree of saturation — the relative humidity. During the course of the year, the moisture content of the atmosphere increases from winter to summer as a result of rising temperatures and consequently increase of evaporation rates. The largest annual variation appears above the continents, where the moisture influx into the atmosphere increases considerably in the summer as a result of evaporation from vegetation and water surfaces.

The moistest zone of the Northern Hemisphere lies between the equator and latitude 10 to 15° N. Very high humidity values occur locally over South America, the north coast of the Indian Ocean (the Indian subcontinent, Indo-China) and the near equatorial islands of the Pacific Ocean. Very low values of humidity in the Northern Hemisphere occur over Algeria, Jakutija (north-east Siberia, and northern Canada in the winter.

2 Definitions and formulae for calculation of humidity characteristics

The water vapour content of the air can be expressed by a number of physical terms which are related to each other — humidity mixing ratio, vapour pressure, dew-point temperature, and others.

It is convenient to use the humidity mixing ratio as the main humidity characteristic, since it is the most conservative. It remains invariable during vertical or horizontal air movements unless condensation or evaporation occurs, and it determines uniquely the water vapour content in the air.

2.1 The humidity mixing ratio, r, of moist air is the ratio of water vapour mass, m_v, to the mass of dry air, m_a, in the same volume. Since in practice $m_v \ll m_a$, the humidity mixing ratio is often reduced by a factor of 10^3 and is expressed in terms of grams per kilogram. The equation is

$$r = \frac{m_v}{m_a} \qquad \ldots (1)$$

where m_v is expressed in grams and m_a in kilograms.

2.2 The vapour pressure, or partial pressure of water vapour, e', is that part of the total atmospheric pressure which is exerted by water vapour. It is measured in the same units as the atmospheric pressure.

The vapour pressure, e', in moist air at total pressure p, and with mixing ratio r is defined by the equation

$$e' = \frac{r}{621{,}98 + r} \times p \qquad \ldots (2)$$

The unit of e' and p is millibars or another pressure unit, r is given in grams per kilogram.

Before dew-point temperature and relative humidity can be defined, the concept of saturation must be introduced. Moist air at a given temperature and pressure is said to be saturated if its mixing ratio, r_w, is such that the moist air can exist in neutral equilibrium with the associated liquid phase at the same temperature and pressure, the surface of separation being plane. An analogous statement applies to saturation with respect to ice, but this addendum deals only with relationships with respect to the liquid phase.

The saturation vapour pressure with respect to water e'_w, of moist air at pressure p and temperature t is defined by the equation

$$e'_w = \frac{r_w}{621{,}98 + r_w} \times p \qquad \ldots (3)$$

The unit of e'_w and p is millibars or another pressure unit, r_w is given in grams per kilogram.

The saturation vapour pressure may be conveniently expressed as a function of the air temperature. The following approximation gives satisfactory accuracy for saturation vapour pressure over a flat surface for the air temperature $-20\ °C < t < 30\ °C$:

$$e'_w = 6{,}107 \times 10^{\frac{a\,t}{b+t}} \qquad \ldots (4)$$

where $a = 7{,}5$ K, $b = 237{,}3$ K; if $t < 0$ °C, then over an ice surface $a = 9{,}5$ K, $b = 265{,}5$ K.

2.3 The dew-point temperature, t_d, of moist air at pressure p and with mixing ratio r is the temperature at which moist air, saturated with respect to water at the given pressure, has a saturation mixing ratio, r_w, equal to the given mixing ratio, r.

The dew-point temperature may be calculated with reasonable accuracy by the use of the equation

$$t_d = \frac{237{,}3 \times \log_{10} \dfrac{e'}{6{,}107\,0}}{7{,}5 - \log_{10} \dfrac{e'}{6{,}107\,0}} \qquad \ldots (5)$$

The unit of t_d is degrees Celsius, e' is given in millibars.

2.4 Relative humidity, U, is a percentage of the actual vapour pressure in the moist air to the saturated vapour pressure at the same temperature and pressure. Relative humidity is calculated by the equation

$$U = 100 \times \left(\frac{e'}{e'_w}\right)_{p,\,t} \qquad \ldots (6)$$

where the subscripts indicate that each term is subject to identical conditions of pressure, p, and temperature, t.

3 Humidity models

3.1 The humidity distribution at heights up to 10 km in the atmosphere of the Northern Hemisphere is depicted in four sets of tables :

a) the median values of humidity mixing ratio, vapour pressure and dew-point temperature for latitudes 10°, 30°, 50° and 70° N for January, July and the whole year (see table 1);

b) the median values of mixing ratio for January and July along the 0°, 80° E, 180° and 80° W meridians (see table 2);

c) the values of humidity mixing ratio, vapour pressure and dew-point temperature exceeded on 20 %, 10 %, 5 % and 1 % of occasions in the most humid areas, and the values not attained on 20 %, 10 %, 5 % and 1 % of occasions in the driest areas (see table 3);

d) the humidity characteristics of the atmosphere above two very dry and two very moist stations in the Northern Hemisphere (see table 4).

Three measures of humidity are given in table 1 and are averaged round each latitude circle for January, July and the whole year from data given in [1-10]. The tabulated values above a height of 8 km should be regarded as approximate because the amount of data here is insufficient. Meridional cross-sections (see table 2) are based on data from [1-3].

Percentiles of mixing ratio, vapour pressure and dew-point temperatures extremes for stations within the areas of high and low humidity, defined according to [4], and taking into account data from [10], are given in table 3. For the areas of low humidity, the values which are not reached on 1 %, 5 %, 10 % and 20 % of occasions are given. For low humidity associated with very low temperatures, a relative humidity of 90 % was assumed. The dry one-percentile values of humidity for heights up to 8 km, and the five- and ten-percentile values at heights of 1 and 2 km were found in January over northern Canada. The moist one-percentile values at the surface occur in July and August around the Persian Gulf, particularly at Abadan, Iran, and the five- and ten-percentile values at the surface were found in Honduras (Central America) during August. The moist extremes for all levels occurred over northern India.

The mean values of humidity for four stations representative of dry and moist regions of the Northern Hemisphere are given in table 4. They are Tamanrasset (North Africa) — January; Zhigansk (East Siberia) — January; Calcutta (India) — July and Truk (Pacific Islands) — January. In this table moisture values are given for isobaric levels.

Table 1 — Median values of humidity characteristics in the Northern Hemisphere

h, km	10° N								
	January			July			Annual		
	r, g/kg	e', mbar	t_d, °C	r, g/kg	e', mbar	t_d, °C	r, g/kg	e', mbar	t_d, °C
0	12,63	20,10	17,6	16,96	26,89	22,2	14,87	23,66	20,2
1	8,82	12,60	10,4	12,11	17,24	15,1	10,70	15,27	13,3
2	5,85	7,48	2,8	8,73	11,12	8,5	7,66	9,77	6,7
3	3,95	4,50	− 4,1	6,26	7,11	2,1	5,23	5,94	− 0,5
4	2,78	2,81	− 10,3	4,23	4,26	− 4,9	3,51	3,55	− 7,3
5	1,99	1,78	− 15,9	2,87	2,56	− 11,4	2,40	2,14	− 13,6
6	1,40	1,10	− 21,5	1,94	1,53	− 17,7	1,71	1,35	− 19,1
7	0,97	0,67	− 26,6	1,34	0,93	− 23,5	1,19	0,82	− 24,8
8	0,63	0,38	− 33,0	0,84	0,53	− 29,8	0,76	0,48	− 30,6
9	0,40	0,21	− 39,0	0,51	0,27	− 35,8	0,45	0,24	− 37,0
10	0,25	0,10	− 45,4	0,31	0,14	− 42,0	0,27	0,12	− 43,1

h, km	30° N								
	January			July			Annual		
	r, g/kg	e', mbar	t_d, °C	r, g/kg	e', mbar	t_d, °C	r, g/kg	e', mbar	t_d, °C
0	6,05	9,83	6,7	14,80	23,56	20,1	9,55	15,38	13,4
1	3,96	5,72	− 0,9	8,50	12,18	9,9	6,41	9,22	5,8
2	2,69	3,45	− 7,6	5,82	7,44	2,7	4,30	5,51	− 1,4
3	1,91	2,17	− 13,4	4,21	4,79	− 3,3	2,99	3,40	− 7,8
4	1,30	1,30	− 19,5	3,07	3,10	− 9,0	2,06	2,08	− 14,0
5	0,83	0,73	− 26,1	2,26	2,01	− 14,4	1,39	1,24	− 20,1
6	0,50	0,39	− 32,8	1,65	1,30	− 19,6	0,96	0,75	− 25,8
7	0,34	0,23	− 38,1	1,22	0,84	− 24,6	0,66	0,45	− 31,3
8	0,23	0,14	− 43,1	0,84	0,53	− 29,6	0,42	0,25	− 37,3
9	0,17	0,09	− 48,0	0,56	0,30	− 35,5	0,24	0,14	− 42,6
10	0,12	0,06	− 49,2	0,37	0,16	− 40,7	0,15	0,08	− 48,0

Table 1 — Median values of humidity characteristics in the Northern Hemisphere (*concluded*)

h, km	50° N								
	January			July			Annual		
	r, g/kg	e', mbar	t_d, °C	r, g/kg	e', mbar	t_d, °C	r, g/kg	e', mbar	t_d, °C
0	1,97	3,22	− 8,5	8,47	13,62	11,5	4,84	7,85	3,5
1	1,64	2,36	− 12,4	6,41	9,19	5,8	3,69	5,29	− 2,0
2	1,23	1,56	− 17,4	4,82	6,15	0,1	2,67	3,39	− 7,8
3	0,89	0,99	− 22,7	3,51	3,97	− 5,8	1,86	2,09	− 13,9
4	0,59	0,58	− 28,6	2,47	2,46	− 11,9	1,25	1,24	− 20,1
5	0,42	0,36	− 33,6	1,72	1,52	− 17,7	0,87	0,75	− 25,8
6	0,29	0,22	− 38,5	1,30	1,01	− 22,5	0,58	0,44	− 31,5
7	0,20	0,13	− 43,5	0,84	0,57	− 28,8	0,41	0,27	− 36,5
8	0,16	0,09	− 46,9	0,52	0,31	− 35,1	0,27	0,15	− 42,2
9	0,16	0,08	− 47,8	0,29	0,16	− 41,6	0,23	0,12	− 44,7
10	0,23	0,10	− 45,6	0,16	0,08	− 48,0	0,20	0,09	− 46,8

h, km	70° N								
	January			July			Annual		
	r, g/kg	e', mbar	t_d, °C	r, g/kg	e', mbar	t_d, °C	r, g/kg	e', mbar	t_d, °C
0	0,67	1,09	− 21,6	5,24	8,45	4,6	2,18	3,55	− 7,2
1	0,80	1,14	− 21,1	4,72	6,73	1,3	1,97	2,81	− 10,2
2	0,59	0,72	− 27,2	3,51	4,42	− 4,4	1,44	1,80	− 15,7
3	0,41	0,44	− 31,5	2,23	2,48	− 11,8	0,93	1,02	− 22,4
4	0,25	0,24	− 37,7	1,54	1,50	− 17,9	0,63	0,60	− 28,2
5	0,12	0,10	− 46,0	1,07	0,91	− 23,7	0,44	0,37	− 33,3
6	0,09	0,06	− 50,5	0,71	0,53	− 29,8	0,29	0,21	− 39,0
7	0,11	0,07	− 48,8	0,48	0,31	− 35,1	0,18	0,11	− 45,1
8	0,16	0,08	− 47,6	0,34	0,19	− 40,0	0,21	0,11	− 42,7
9	0,21	0,09	− 46,5	0,23	0,11	− 45,4	0,22	0,10	− 46,0
10	0,28	0,10	− 45,6	0,16	0,07	− 50,6	0,22	0,08	− 48,1

Table 2 — Median values of the mixing ratio (in grams per kilogram), for January and July along 0°, 80° E and 180°, 80° W

h, km	0°							
	January				July			
	10° N	30° N	50° N	70° N	10° N	30° N	50° N	70° N
0	7,06	3,60	3,43	1,84	15,85	7,67	8,36	5,39
1	5,43	2,53	2,34	1,26	9,70	5,62	6,31	3,73
2	4,07	1,76	1,67	0,79	6,24	4,02	4,42	2,71
3	2,90	1,28	0,94	0,54	4,77	3,34	2,84	2,02
4	1,59	0,92	0,60	0,33	3,46	2,37	1,87	1,38
5	1,25	0,68	0,37	0,26	1,88	1,69	1,22	0,85
6	0,91	0,50	0,27	0,23	1,37	1,15	0,73	0,57
7	0,57	0,33	0,22	0,20	0,90	0,74	0,43	0,35
8	0,29	0,23	0,20	0,18	0,52	0,40	0,28	0,18
9	0,21	0,18	0,16	0,19	0,29	0,24	0,20	0,15
10	0,19	0,16	0,15	0,20	0,09	0,09	0,07	0,04

h, km	80° E							
	January				July			
	10° N	30° N	50° N	70° N	10° N	30° N	50° N	70° N
0	12,09	—	—	0,42	18,47	—	—	7,40
1	9,54	—	—	0,52	13,20	—	—	4,58
2	6,65	2,32	1,82	0,53	10,20	9,44	4,97	3,46
3	3,85	1,75	0,81	0,31	7,64	8,17	4,21	2,59
4	2,77	1,26	0,69	0,20	4,95	6,70	3,26	1,90
5	2,32	0,80	0,56	0,11	3,67	5,12	2,20	1,41
6	1,90	0,46	0,43	0,07	2,67	3,75	1,55	0,95
7	1,56	0,30	0,25	0,08	1,96	2,61	1,16	0,59
8	0,98	0,22	0,16	0,14	1,48	1,73	0,81	0,32
9	0,57	0,16	0,16	0,15	1,06	1,08	0,38	0,15
10	0,52	0,15	0,16	0,15	0,96	0,60	0,17	0,15

Table 2 — Median values of the mixing ratio (in grams per kilogram), for January and July along 0°, 80° E and 180°, 80° W (*concluded*)

h, km	180°							
	January				July			
	10° N	30° N	50° N	70° N	10° N	30° N	50° N	70° N
0	13,45	6,05	2,52	0,58	15,85	14,24	8,26	5,10
1	10,45	5,70	1,99	0,71	11,94	9,50	5,81	4,14
2	6,91	3,53	1,14	0,66	8,58	6,55	4,32	3,31
3	4,02	1,90	0,71	0,41	5,64	4,01	3,34	2,54
4	2,43	1,30	0,44	0,26	3,65	2,64	2,27	1,77
5	2,09	0,83	0,33	0,17	2,58	1,73	1,64	1,22
6	1,73	0,59	0,29	0,17	1,78	1,20	1,27	0,75
7	1,01	0,37	0,21	0,16	1,16	0,78	0,78	0,43
8	0,67	0,29	0,16	0,17	0,75	0,52	0,43	0,28
9	0,33	0,20	0,16	0,17	0,53	0,28	0,22	0,16
10	—	—	—	0,16	0,26	0,09	0,09	0,09

h, km	80° W							
	January				July			
	10° N	30° N	50° N	70° N	10° N	30° N	50° N	70° N
0	12,42	4,78	0,50	0,25	17,46	15,25	7,07	4,16
1	10,45	4,97	0,86	0,27	12,63	11,19	5,52	3,34
2	6,83	3,27	0,84	0,30	8,83	7,76	4,32	2,40
3	3,85	2,38	0,68	0,33	6,30	5,59	3,14	1,77
4	2,69	1,76	0,42	0,23	4,39	3,96	2,37	1,23
5	2,08	1,33	0,32	0,12	3,01	2,66	1,59	0,81
6	1,57	0,91	0,17	0,07	1,95	1,66	0,89	0,53
7	1,15	0,59	0,11	0,06	1,39	1,09	0,61	0,31
8	0,66	0,35	0,16	0,09	0,95	0,73	0,37	0,16
9	0,31	0,20	0,16	0,15	0,64	0,54	0,15	0,11
10	0,08	0,08	0,08	0,20	0,58	0,51	0,14	0,10

Table 3 — Percentiles of humidity in extremely dry and moist areas and seasons

h, km	Low percentiles in extremely dry regimes											
	1 %			5 %			10 %			20 %		
	r, g/kg	e', mbar	t_d, °C	r, g/kg	e', mbar	t_d, °C	r, g/kg	e', mbar	t_d, °C	r, g/kg	e', mbar	t_d, °C
0	0,005 9	0,008 2	−62	0,008 7	0,014 1	−58	0,012 9	0,020 9	−55	0,018 9	0,030 7	−52
1	0,044 2	0,063 4	−50	0,107 0	0,153 0	−42	0,132 0	0,188 9	−40	0,179 0	0,256 7	−37
2	0,045 4	0,057 7	−51	0,087 3	0,110 8	−45	0,121 0	0,153 0	−42	0,165 0	0,208 8	−39
4	0,032 1	0,032 1	−56	0,041 2	0,040 6	−54	0,046 4	0,045 8	−53	0,052 2	0,051 3	−52
6	0,013 6	0,010 3	−65	0,015 6	0,011 8	−64	0,017 7	0,013 4	−63	0,020 1	0,015 2	−62
8	0,003 9	0,002 1	−76	0,044 9	0,002 6	−75	0,005 2	0,003 0	−74	0,006 0	0,003 4	−73

h, km	High percentiles in extremely moist regimes											
	1 %			5 %			10 %			20 %		
	r, g/kg	e', mbar	t_d, °C	r, g/kg	e', mbar	t_d, °C	r, g/kg	e', mbar	t_d, °C	r, g/kg	e', mbar	t_d, °C
0	29,0	44,8	31	27,3	42,3	30	25,7	39,9	29	24,2	37,8	28
1	27,4	37,8	28	25,8	35,5	27	24,3	33,5	26	22,8	31,7	25
2	22,9	28,1	23	21,5	26,3	22	18,9	23,3	20	16,6	20,6	18
4	17,7	17,0	15	15,5	14,9	13	13,6	13,1	11	11,8	11,5	9
6	8,8	6,56	1	8,18	6,09	0	7,59	5,67	−1	7,05	5,27	−2
8	5,92	3,35	−8	4,66	2,63	−11	4,30	2,43	−12	3,90	2,25	−13

Table 4 — Mean values of atmospheric humidity in dry and moist stations of the Northern Hemisphere

Station			Month	Isobaric levels, mbar	r, g/kg	e', mbar	t_d, °C
				Dry areas			
Tamanrasset			January	—	—	—	—
φ	λ	h, m		850	0,81	1,11	−21,4
22° 47′ N	05° 31′ E	1378		700	0,34	0,38	−33,0
				500	0,28	0,23	−38,1
				300	0,08	0,04	−54,0
				200	—	—	—
Zhigansk			January	1000	0,07	0,11	−42,7
φ	λ	h, m		850	0,35	0,48	−30,5
66° 46′ N	123° 24′ E	58		700	0,29	0,33	−34,5
				500	0,09	0,07	−49,2
				300	0,02	0,01	−64,9
				200	0,02	0,01	−64,9
				Moist areas			
Calcutta			July	1000	19,78	30,83	24,5
φ	λ	h, m		850	14,44	19,29	16,9
22° 39′ N	88° 27′ E	6		700	9,70	10,74	8,0
				500	2,52	2,01	−14,4
				300	0,09	0,04	−54,0
				200	0,09	0,03	−56,3
Truk			January	1000	15,36	24,01	20,5
φ	λ	h, m		850	9,96	13,39	11,3
07° 28′ N	151° 51′ E	2		700	4,61	5,15	−2,3
				500	1,73	1,39	−18,8
				300	0,16	0,08	−48,0
				200	—	—	—

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