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The CIRA86aQ_UoG model: An extension of the CIRA-86 monthly tables including humidity tables and a Fortran95 global moist air climatology model

by

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1. Introduction

Atmospheric climatological models are of high utility for a variety of applications which need quick but reasonable mean estimates of the atmospheric state as determined by its fundamental variables such as temperature, humidity, pressure, and density. These applications include for example simulation studies in the field of atmospheric remote sensing, which are performed to learn about characteristics and the performance of sounding systems of interest. Simulations of electromagnetic signal propagation through a climatological model (e.g., by "ray tracing") help in this case to explore the potential of sensing techniques and data analysis methodologies.

Currently the most widely used climatological models for the lower atmosphere (surface to mesopause) are the tabular COSPAR (Committee on Space Research) International Reference Atmosphere CIRA-86 [*Fleming et al.*, 1988] and the MSISE-90 model [*Hedin*, 1991], the latter being a Fortran77 tool providing continuous fields directly based in the lower atmosphere on the CIRA-86 tabular model. MSISE-90 thus represents essentially the same lower atmosphere climatology as CIRA-86. While these models are generally of high utility, they are dry atmospheres, i.e., they do not include a humidity climatology.

Humidity, especially tropospheric humidity, is frequently needed in applications, however. One such application is the GNSS (GPS/GLONASS) based radio occultation technique [see, e.g., *Silvestrin and Ingmann*, 1997, or *Kirchengast and Ladreiter*, 1996, for an overview description], which is of particular interest to the authors. In fact studies on this technique prompted the development of the moist air global climatological model "CIRA86aQ_UoG" described in this report. It has been developed as part of the so-called End-to-end GNSS Occultation Performance Simulator (EGOPS) [see, e.g., *Kirchengast*, 1996 and 1998, for details]. As it has been found useful beyond EGOPS, it is described separately in this report, which can be distributed together with the model itself independent of EGOPS.

Briefly, the CIRA86aQ_UoG model involves as its core 12 monthly zonal-mean tables of temperature, humidity, and pressure, respectively, which are contained in a formatted ASCII file named *tqp.2DAtm*. In addition, it comprises a FORTRAN-95 software tool, contained in a file named *hlat2datm.f90*, which is an empirical model utilizing the *tqp.2DAtm* file for providing, by interpolation within the zonal-mean tables and by use of basic physical laws, the fundamental atmospheric variables (temperature, humidity, pressure, etc.) at arbitrary latitude-height-month locations. The name CIRA86aQ_UoG derives (i) from its roots in *CIRA-86*, (ii) from the addition of humidity, typical symbol *q* or *Q*, fields (*aQ* = and Q = +Q) to CIRA-86, and (iii) from being developed at the IMG/*UoG*.

The following description comprises two main sections with various subsections. In section 2, the CIRA86aQ_UoG monthly tables as contained in file *tqp.2DAtm* are described, documenting which modifications of the existing CIRA-86 tables have been performed. In section 3, the CIRA86aQ_UoG Fortran95 model is described, documenting its interface, code structure and algorithms as well as including graphical examples of temperature and water vapor fields computed by the model.

2. The CIRA86aQ_UoG Monthly Tables (File *tqp.2DAtm*)

The CIRA86aQ_UoG file *tqp.2DAtm* roots in the CIRA-86 ASCII file *twp.lsn*, which contains monthly means of temperature, zonal wind, and pressure for a dry climatological zonal mean atmosphere on a fixed latitude-height grid. The range covered by each of the 12 monthly tables in *twp.lsn* is from –80 deg to +80 deg (10 deg steps) in latitude and from 0 km to 120 km (5 km steps) in height, respectively. (Exception: The pressure tables range from 20 km to 120 km, since it was decided for CIRA-86 not to include mean tropospheric pressure values.) The CIRA-86 model has been documented by *Fleming et al.* [1988] and is also addressed, with providing further references, in the overview on solar-terrestrial models by *Bilitza* [1992]. Information on the Internet, including the possibility to download the model, is available via the NSSDC (National Space Science Data Center, U.S.A.) webpage *http://nssdc.gsfc.nasa.gov/space/model/atmos* through the link "COSPAR International Reference Atmosphere: 0 km to 120 km".

Using the file *twp.lsn* obtained from the NSSDC, the file *tqp.2DAtm* was produced at IMG/UoG, mostly as part of the M.Sc. thesis by *Hafner* [1997] supervised by G. Kirchengast. While closely following the format of the file *twp.lsn*, the file *tqp.2DAtm* modifies the former in four major aspects:

1. Instead of the height range of 20 km to 120 km of the *twp.lsn* pressure tables, the *tqp.2DAtm* pressure tables range from 0 km to 120 km (surface to 120 km as all other tables).
2. The wind tables of *twp.lsn* have been dropped and specific humidity tables have been added in *tqp.2DAtm*. These new specific humidity tables, which constitute the major extension to the dry atmosphere CIRA-86, range in height from 0 km to 15 km, in 1 km steps.
3. In line with the range and stepsize for the new humidity tables, also the temperature and pressure tables have been changed within 0 km to 15 km from 5 km steps to 1 km steps.
4. Instead of the latitudinal span of –80 deg to +80 deg of the *twp.lsn* tables, the *tqp.2DAtm* tables range from –90 deg to +90 deg (pole to pole).

Each of these modifications is described separately in subsections 2.1 to 2.4 below. Subsection 2.5 provides exemplary tables which directly illustrate the modifications.

2.1. Extension of CIRA Pressure Height Range to 0km-to-120km Range

The original CIRA-86 pressure (p) tables extending from 20 km to 120 km were extrapolated from the p(20km) value downwards by hydrostatic integration as described in detail by *Hafner* [1997], Appendix C. The values p(15km), p(10km), p(5km), and p(0km) have been computed in this way. Briefly summarized this was done as follows. The hydrostatic equation in integral form,

$$p(z \le 20\mathrm{km}) = p_{20\mathrm{km}} \exp\left(\int_{20\mathrm{km}}^{z} \frac{dz}{H(z)} \right), \quad H(z) = \frac{R^* T(z)}{\overline{M}\, g}, \tag{1}$$

was employed for the heights $z \in \{15\mathrm{km}, 10\mathrm{km}, 5\mathrm{km}, 0\mathrm{km}\}$. $H(z)$ is the atmospheric scale height involving the general gas constant, $R^* = 8.3145$ J mol^{-1}K^{-1}, the mean molar mass of air, $\overline{M} = 28.964$ g mol^{-1}, the temperature profile, $T(z)$, and the acceleration of gravity, g. The $T(z)$ profile was taken at any given latitude and month from the corresponding CIRA-86 temperature table and it was assumed to change linearly within the 5-km intervals between the available values. For g the (surface) values of the International gravity formula at any given latitude were used.

2.2. Extension of CIRA-86 by Monthly Humidity Tables

While the CIRA-86 mean zonal wind speed tables have been dropped in CIRA86aQ_UoG (if required, they could be readily added back into the file *tqp.2DAtm*, i.e., one could create an extended file *tqpw.2DAtm*), specific humidity tables have been added in order to expand CIRA-86 from a dry air to a moist air climatological model. As the extension of the pressure tables this was mostly performed as part of the work of *Hafner* [1997] and described in detail there. A summary description of this most significant extension to CIRA-86 is given below.

The main basis for the humidity modeling was the set of analytical climatological water vapor density profiles, $\rho_w(z)$, given by *Damosso et al.* [1983]. This set contains five empirically determined tropospheric $\rho_w(z)$ profiles, (i) annual-mean tropical (15°N), summer mid-latitude (45°N), winter mid-latitude (45°N), summer high-latitude (60°N), and winter high-latitude (60°N), respectively. We assumed the 45°N and 60°N profiles equally valid, but with summer and winter interchanged, for the southern hemisphere. In addition, in order to extend this basic set to polar latitudes, we complemented it by three simple exponential profiles of the form

$$\rho_w(z) = \rho_{w0} \exp\left(\tfrac{z}{H_w}\right) \tag{2}$$

for the latitudes (70°N, 80°N, 80°S), applicable to (northern) winter. Roughly following the water vapor climatology information given by *Ajayi et al.* [1996], the values (0.5 g m^{-3}, 0.1 g m^{-3}, 2 g m^{-3}) and (1.5 km, 1 km, 1.5 km) were chosen for ρ_{w0} and H_w, respectively, for the selected auxiliary latitudes (70°N, 80°N, 80°S). We assumed these profiles equally valid for (northern) summer, given northern and southern latitudes interchanged, i.e., for the latitudes (70°S, 80°S, 80°N).

Horizontal linear interpolation within this set of analytical $\rho_w(z)$ profiles was then performed both for winter and summer in order to obtain water vapor density tables for January and July, respectively, spanning the latitude range from –80 deg to +80 deg in 10 deg steps and the height range from 0 km to 15 km in 1 km steps. At the equator (0 deg) the profile extrapolated southward from 15°N does not exactly match the one extrapolated northward from 15°S. Thus the 0 deg profile values were taken to be the average of the southward and northward extrapolations. Given the 0 deg profile and the original ±15 deg profiles, the ±10 deg profiles were finally obtained by horizontal linear interpolation between the former profiles.

Next, the two (January and July) water vapor density tables were converted to water vapor pressure tables by utilizing the equation of state for water vapor. The temperature profiles required for this were taken from the corresponding CIRA-86 temperature tables vertically interpolated to the 1-km humidity grid by natural cubic spline interpolation [e.g., *Press et al.*, 1992]. Based on the water vapor pressure tables for January, e_{jan}, and July, e_{jul}, the seasonal cycle was then modeled in that the cosine variation

$$e_i = e_0 + \left(\frac{e_{jan} + e_{jul}}{2} \right) + \frac{2}{\sqrt{3}} \left(\frac{e_{jan} - e_{jul}}{2} \right) \cos\left(\frac{\pi (i-2)}{6} \right) \tag{3}$$

was applied at each latitude-height location in the table. The subscript $i \in (1,...,12)$ denotes the months from 1=January to 12=December, $e_0 = e_{jan}$ in the northern hemisphere, and $e_0 = e_{jul}$ in the southern hemisphere. In line with climatological knowledge on the annual variation [e.g., *Ajayi et al.*, 1996], the phase factor (i – 2) ensures that the extrema are reached in February/August, and the cosine amplitude factor $2/\sqrt{3} > 1$ ensures that the extreme values in February/August are slightly higher than the prescribed January/July values. Note that at the equator $e_{jan} = e_{jul}$ holds, thus there is no annual variation in the 0 deg profile.

The 12 monthly water vapor pressure tables obtained as described have been checked against super-saturation by use of the Clausius-Clapyron equation for saturation water vapor pressure (with invoking the corresponding temperature tables). The very few values detected with relative humidity > 98 % have been set back to match this relative humidity. After this step, finally, the water vapor pressure tables were converted to the specific humidity tables contained in *tqp.2DAtm*, q [g kg^{-1}], by using the standard relation of q and e (with invoking the corresponding pressure tables).

2.3. Densification of Temperature and Pressure Table Grids Below 15 km

As noted in the above subsection, the humidity tables new in CIRA86aQ_UoG have been prepared at a vertical grid ranging from 0 km to 15 km with 1 km steps, while the original temperature and pressure tables exhibit 5 km steps within this height range. In order to align the temperature and pressure vertical grids with the humidity grid, also these have been refined to 1 km steps.

This was performed for both temperature and pressure by interpolating, for each latitude in each table, the 5-km grid to a 1-km grid using natural cubic spline interpolation [e.g., *Press et al.*, 1992]. The interpolation was applied to the temperature values directly but for pressure ln(p) values were interpolated and the resulting values converted back to $p = \exp(\ln p)$. The latter is a standard measure to improve vertical interpolation of air pressure profiles given their near-exponential structure arising from the barometric law.

2.4. Extension of CIRA Latitude Range to a Pole-to-Pole Range

The CIRA-86 –80 deg to +80 deg range was extended to the CIRA86aQ_UoG –90 deg to +90 deg range for the three variables temperature, humidity, and pressure as follows:

Temperature: In each monthly table the temperature profiles at –90deg/+90deg were set to be equal to the temperature profiles at –80deg/+80deg, i.e., temperature was extended towards the poles in a spherically symmetric manner (no horizontal variation).

Humidity: Given the very low specific humidities already at –80deg/+80deg (see subsection 2.2 above) the humidities have been set to zero at all height levels at –90deg/+90deg in each monthly table, i.e., humidities have been considered to fall off to negligible magnitude towards the poles.

Pressure: Each monthly pressure table has been extended in exactly the same way as temperature, i.e., pressure was extended towards the poles assuming a perfectly stratified atmosphere (no horizontal variation).

2.5. Exemplary Tables: The January Tables of CIRA86aQ_UoG and of CIRA-86

In order to provide a direct documentation and illustration on how the extension from CIRA-86 to CIRA86aQ_UoG changed the monthly tables, we included below print-outs of the January tables from both the file *tqp.2DAtm* of the new CIRA86aQ_UoG model and the file *twp.lsn* of the original CIRA-86 model, respectively. Table 1 illustrates the new tabular model, Table 2 the original one.

Table 1: The temperature, humidity, and pressure tables of *tqp.2DAtm* for January

January ZONAL MEAN TEMPERATURE (K)

HEIGHT	LATITUDE																		
(km)	90S	80S	70S	60S	50S	40S	30S	20S	10S	EQ	10N	20N	30N	40N	50N	60N	70N	80N	90N
120	391.2	391.2	390.6	389.7	388.5	386.9	385.2	383.2	381.1	379.0	376.8	374.7	372.7	371.0	369.4	368.2	367.3	366.7	366.7
115	318.1	318.1	318.8	319.1	318.1	315.4	311.0	305.7	300.6	296.6	294.3	293.7	294.1	294.5	293.9	291.9	289.2	286.9	286.9
110	293.9	293.9	287.9	279.1	268.7	257.7	247.0	237.3	229.0	222.8	219.3	218.8	221.6	226.8	233.0	238.6	242.5	244.6	244.6
105	246.1	246.1	240.0	231.9	223.3	215.3	208.5	202.8	198.2	194.7	192.5	192.2	194.3	198.5	204.4	210.8	216.3	220.0	220.0
100	189.1	189.1	188.3	187.4	186.8	186.8	187.3	187.9	188.1	187.7	187.0	186.7	187.4	189.6	193.2	197.6	201.9	204.9	204.9
95	152.2	152.2	155.3	160.0	166.0	172.5	178.7	183.5	186.4	187.3	187.0	186.6	187.2	189.1	192.2	196.0	199.5	202.1	202.1
90	142.9	142.9	147.6	154.8	163.9	173.3	181.5	187.1	189.7	190.5	190.6	191.3	193.5	196.9	201.3	205.6	209.1	211.6	211.6
85	147.9	147.9	152.7	160.1	170.1	180.6	189.4	194.6	196.5	197.5	198.6	200.5	204.1	208.6	213.7	217.8	220.3	222.2	222.2
80	171.7	171.7	173.6	176.9	184.1	192.9	200.7	204.7	204.8	205.5	206.3	207.7	211.5	215.8	221.4	224.4	224.6	225.8	225.8
75	200.1	200.1	199.8	199.8	201.6	204.6	208.4	210.8	210.6	211.1	211.4	212.3	215.6	219.3	223.8	226.3	225.6	226.8	226.8
70	226.4	226.4	224.8	222.7	219.0	215.2	214.1	215.9	217.8	218.3	217.7	217.5	219.5	221.2	225.0	227.7	227.3	229.3	229.3
65	248.3	248.3	245.3	241.5	235.5	229.8	227.5	230.4	233.8	235.1	233.1	230.7	227.8	226.3	226.2	229.6	232.6	236.4	236.4
60	266.7	266.7	262.9	258.7	252.8	247.4	245.0	247.7	252.6	252.9	250.2	244.5	238.7	232.5	230.7	235.0	241.9	247.2	247.2
55	281.1	281.1	276.8	272.1	266.3	261.1	258.7	259.4	263.3	264.6	262.9	258.3	251.9	245.2	241.7	244.2	250.7	255.5	255.5
50	288.5	288.5	284.4	279.7	275.4	271.4	268.7	267.4	267.8	267.8	267.9	267.0	263.4	259.2	253.5	253.5	255.0	255.4	255.4
45	286.1	286.1	283.4	280.0	275.8	272.8	269.5	267.1	264.0	263.8	264.5	265.8	264.4	260.6	254.4	252.3	252.0	251.0	251.0
40	276.2	276.2	274.1	271.2	267.6	264.1	260.2	256.5	254.9	255.2	255.2	255.8	254.0	250.0	246.4	246.5	246.7	246.9	246.9
35	261.8	261.8	260.5	258.1	254.6	250.6	246.8	244.1	242.3	242.5	242.1	241.7	239.2	237.4	235.4	235.7	236.3	236.6	236.6
30	244.5	244.5	244.1	243.7	240.7	236.1	232.0	228.9	227.8	227.2	228.0	228.1	228.5	227.5	226.2	224.7	221.7	219.1	219.1
25	235.6	235.6	233.8	232.6	229.0	225.4	222.1	219.2	218.1	217.5	218.0	218.3	219.3	219.6	218.2	213.8	207.8	202.0	202.0
20	234.6	234.6	233.2	229.6	222.8	215.5	210.2	207.4	205.3	204.3	204.6	206.7	210.0	214.5	216.8	215.5	211.4	205.9	205.9
15	232.5	232.5	231.3	227.3	220.3	212.3	206.0	202.0	199.8	199.3	199.7	202.2	208.1	214.7	217.9	217.0	214.1	211.2	211.2
14	231.1	231.1	229.6	226.0	220.1	213.9	209.4	206.6	204.9	204.6	204.8	206.3	210.4	214.9	217.4	216.4	213.7	211.3	211.3
13	229.5	229.5	227.8	224.6	220.2	216.5	214.5	213.2	212.2	212.0	212.0	212.3	213.7	215.4	216.8	215.7	213.3	211.4	211.4
12	228.0	228.0	226.2	223.7	221.0	220.0	220.7	221.2	220.9	220.8	220.6	219.5	217.9	216.5	216.5	215.4	213.2	211.7	211.7
11	227.1	227.1	225.3	223.6	222.8	224.4	227.7	229.8	230.1	230.2	229.7	227.4	222.9	218.4	217.1	215.7	213.7	212.4	212.4
10	226.9	226.9	225.5	224.8	225.9	229.8	235.0	238.3	239.0	239.2	238.6	235.4	228.6	221.6	218.8	217.1	215.2	214.0	214.0
9	227.8	227.8	227.1	227.6	230.5	236.1	242.3	246.1	247.0	247.2	246.7	243.0	234.8	226.2	222.0	219.8	217.9	216.6	216.6
8	229.7	229.7	230.0	231.8	236.2	242.9	249.5	253.3	254.1	254.3	253.9	250.2	241.5	231.9	226.5	223.7	221.5	219.9	219.9
7	232.6	232.6	233.9	236.8	242.6	250.1	256.5	259.9	260.6	260.8	260.5	257.0	248.3	238.5	231.9	228.4	225.7	223.8	223.8
6	236.3	236.3	238.6	242.5	249.3	257.1	263.1	266.1	266.6	266.7	266.6	263.5	255.1	245.5	238.0	233.6	230.3	227.9	227.9
5	240.8	240.8	243.7	248.3	255.8	263.8	269.4	271.9	272.3	272.4	272.4	269.6	261.8	252.5	244.5	239.1	234.8	231.9	231.9
4	245.9	245.9	249.1	254.0	261.7	269.8	275.3	277.5	278.0	278.1	278.1	275.4	268.2	259.3	251.1	244.6	239.1	235.7	235.7
3	251.5	251.5	254.7	259.4	267.1	275.2	280.7	283.0	283.6	283.7	283.6	281.1	274.3	265.9	257.7	250.1	243.1	239.1	239.1
2	257.5	257.5	260.4	264.8	272.1	280.2	285.9	288.4	289.3	289.3	289.1	286.5	280.2	272.2	264.3	255.5	246.9	242.4	242.4
1	263.8	263.8	266.2	270.0	276.8	284.9	291.0	293.7	294.9	295.0	294.6	291.8	286.0	278.5	271.0	261.0	250.5	245.5	245.5
0	270.2	270.2	272.0	275.2	281.4	289.5	295.9	298.9	300.5	300.6	300.0	297.1	291.7	284.7	277.7	266.4	254.1	248.6	248.6

January spec. HUMIDITY (g/kg)

HEIGHT	LATITUDE																			
(km)	90S	80S	70S	60S	50S	40S	30S	20S	10S	EQ	10N	20N	30N	40N	50N	60N	70N	80N	90N	EXPON
15	0.000	0.523	0.305	0.089	16.489	19.163	10.948	3.668	0.000	0.000	0.000	0.158	0.119	0.076	0.036	0.000	0.000	0.000	0.000	1.E-03
14	0.000	0.875	0.660	0.440	22.333	26.292	15.660	6.059	0.000	0.000	0.000	1.205	0.783	0.323	0.049	0.000	0.000	0.000	0.000	1.E-03
13	0.000	1.461	1.663	1.829	31.687	38.049	24.860	12.798	4.554	0.000	4.554	5.836	3.656	1.345	0.069	0.000	0.000	0.000	0.000	1.E-03
12	0.000	2.441	4.518	6.453	47.105	57.842	43.242	29.861	21.948	19.317	21.939	19.530	12.022	4.256	0.103	0.014	0.000	0.000	0.000	1.E-03
11	0.000	4.077	12.038	19.565	73.267	90.839	77.447	65.416	61.291	65.488	61.374	49.576	30.118	10.445	0.160	0.043	0.026	0.000	0.000	1.E-03
10	0.000	0.681	2.974	5.159	11.835	14.451	13.572	12.855	13.194	14.830	13.245	10.524	6.711	2.954	0.916	0.633	0.176	0.003	0.000	1.E-02
9	0.000	1.160	6.838	12.324	20.190	23.714	23.499	23.520	25.151	28.784	25.237	19.926	12.941	6.117	2.327	1.555	0.305	0.005	0.000	1.E-02
8	0.000	1.977	14.216	26.194	34.535	38.780	39.553	40.659	44.212	50.802	44.346	35.146	23.375	11.974	5.451	3.646	0.525	0.011	0.000	1.E-02
7	0.000	3.367	26.851	50.117	58.243	63.177	65.575	68.426	74.982	86.083	75.180	60.017	40.898	22.536	11.730	8.034	0.900	0.024	0.000	1.E-02
6	0.000	0.573	4.649	7.109	9.576	10.244	10.812	11.440	12.627	14.491	12.656	10.158	7.049	4.087	2.314	1.637	0.153	0.005	0.000	1.E-01
5	0.000	0.976	6.290	9.517	15.263	16.489	17.789	19.166	21.394	24.627	21.435	17.201	12.018	7.110	4.175	3.032	0.260	0.011	0.000	1.E-01
4	0.000	1.704	9.282	13.441	23.809	26.440	29.353	32.380	36.708	42.600	36.780	29.325	20.440	12.024	7.028	5.117	0.445	0.026	0.000	1.E-01
3	0.000	2.973	13.333	18.552	31.630	41.550	47.593	53.810	62.033	72.691	62.155	49.040	33.775	19.300	10.768	7.596	0.759	0.059	0.000	1.E-01
2	0.000	0.518	1.868	2.506	4.099	6.324	7.424	8.549	9.983	11.790	10.002	7.811	5.298	2.910	1.500	0.975	0.129	0.014	0.000	1.E+00
1	0.000	0.903	2.557	3.319	5.224	8.905	10.804	12.463	14.586	17.267	14.615	11.349	7.605	4.042	1.905	1.065	0.221	0.032	0.000	1.E+00
0	0.000	1.572	3.425	4.314	6.555	10.968	14.136	15.829	18.197	21.366	18.233	14.215	9.499	5.009	2.219	0.975	0.377	0.075	0.000	1.E+00

January ZONAL MEAN PRESSURE (mbar)

HEIGHT	LATITUDE																			
(km)	90S	80S	70S	60S	50S	40S	30S	20S	10S	EQ	10N	20N	30N	40N	50N	60N	70N	80N	90N	EXPON
120	2.714	2.714	2.702	2.682	2.657	2.623	2.583	2.540	2.497	2.456	2.418	2.384	2.353	2.325	2.299	2.277	2.260	2.250	2.250	1.E-05
115	4.264	4.264	4.238	4.201	4.155	4.104	4.052	3.998	3.945	3.889	3.835	3.781	3.731	3.689	3.656	3.634	3.622	3.616	3.616	1.E-05
110	7.174	7.174	7.158	7.142	7.136	7.144	7.167	7.195	7.213	7.201	7.146	7.039	6.904	6.760	6.639	6.562	6.526	6.518	6.518	1.E-05
105	1.294	1.294	1.311	1.338	1.374	1.415	1.460	1.505	1.542	1.567	1.570	1.547	1.500	1.439	1.379	1.333	1.303	1.288	1.288	1.E-04
100	2.727	2.727	2.796	2.901	3.030	3.171	3.315	3.452	3.572	3.658	3.686	3.632	3.495	3.301	3.097	2.925	2.804	2.735	2.735	1.E-04
95	7.250	7.250	7.368	7.534	7.730	7.928	8.133	8.338	8.552	8.733	8.814	8.694	8.341	7.803	7.212	6.694	6.313	6.089	6.089	1.E-04
90	2.307	2.307	2.264	2.205	2.142	2.087	2.051	2.043	2.064	2.101	2.122	2.093	1.995	1.843	1.675	1.526	1.418	1.353	1.353	1.E-03
85	7.222	7.222	6.796	6.263	5.727	5.286	5.004	4.886	4.891	4.953	4.976	4.868	4.597	4.198	3.777	3.435	3.169	3.008	3.008	1.E-03
80	1.590	1.590	1.504	1.408	1.290	1.186	1.129	1.119	1.123	1.130	1.118	1.083	1.033	0.960	0.890	0.861	0.815	0.781	0.781	1.E-02
75	3.903	3.903	3.680	3.421	3.069	2.737	2.537	2.486	2.503	2.514	2.480	2.391	2.253	2.060	1.880	1.806	1.714	1.639	1.639	1.E-02
70	8.541	8.541	8.080	7.545	6.786	6.067	5.592	5.440	5.473	5.484	5.408	5.206	4.854	4.392	3.956	3.769	3.591	3.417	3.417	1.E-02
65	1.730	1.730	1.647	1.552	1.417	1.288	1.195	1.152	1.148	1.146	1.136	1.099	1.025	0.928	0.831	0.784	0.745	0.703	0.703	1.E-01
60	3.321	3.321	3.189	3.032	2.814	2.597	2.426	2.319	2.282	2.273	2.267	2.219	2.101	1.926	1.733	1.616	1.513	1.410	1.410	1.E-01
55	6.130	6.130	5.940	5.710	5.372	5.019	4.713	4.483	4.359	4.333	4.346	4.320	4.163	3.893	3.532	3.262	2.993	2.749	2.749	1.E-01
50	1.107	1.107	1.081	1.049	0.998	0.942	0.890	0.847	0.818	0.812	0.816	0.817	0.797	0.757	0.695	0.640	0.582	0.531	0.531	1.E+00
45	1.989	1.989	1.956	1.913	1.835	1.747	1.658	1.584	1.537	1.525	1.531	1.531	1.503	1.443	1.345	1.244	1.130	1.033	1.033	1.E+00
40	3.624	3.624	3.579	3.524	3.410	3.266	3.127	3.006	2.935	2.912	2.922	2.914	2.872	2.786	2.636	2.447	2.224	2.037	2.037	1.E+00
35	6.791	6.791	6.737	6.677	6.509	6.288	6.081	5.892	5.776	5.724	5.747	5.735	5.690	5.572	5.313	4.932	4.473	4.099	4.099	1.E+00
30	1.326	1.326	1.318	1.311	1.288	1.260	1.231	1.203	1.184	1.174	1.178	1.177	1.173	1.154	1.106	1.030	0.937	0.861	0.861	1.E+01
25	2.700	2.700	2.690	2.675	2.654	2.628	2.595	2.560	2.528	2.512	2.516	2.512	2.497	2.462	2.372	2.235	2.071	1.935	1.935	1.E+01
20	5.563	5.563	5.571	5.591	5.633	5.669	5.678	5.652	5.613	5.593	5.596	5.568	5.499	5.382	5.187	4.944	4.686	4.487	4.487	1.E+01
15	1.155	1.155	1.160	1.176	1.213	1.257	1.290	1.300	1.300	1.298	1.298	1.282	1.244	1.190	1.133	1.085	1.044	1.017	1.017	1.E+02
14	1.339	1.339	1.346	1.367	1.415	1.473	1.516	1.529	1.530	1.528	1.528	1.509	1.462	1.394	1.325	1.270	1.225	1.196	1.196	1.E+02
13	1.554	1.554	1.562	1.589	1.650	1.722	1.776	1.793	1.795	1.792	1.793	1.771	1.714	1.633	1.550	1.486	1.436	1.406	1.406	1.E+02
12	1.803	1.803	1.814	1.848	1.922	2.010	2.074	2.095	2.096	2.092	2.095	2.070	2.005	1.910	1.812	1.738	1.684	1.651	1.651	1.E+02
11	2.093	2.093	2.107	2.148	2.237	2.340	2.413	2.437	2.438	2.433	2.437	2.411	2.339	2.230	2.116	2.032	1.972	1.938	1.938	1.E+02
10	2.430	2.430	2.446	2.494	2.597	2.716	2.797	2.822	2.822	2.815	2.821	2.796	2.719	2.599	2.468	2.373	2.308	2.271	2.271	1.E+02
9	2.821	2.821	2.838	2.892	3.008	3.141	3.228	3.253	3.251	3.242	3.250	3.227	3.149	3.021	2.874	2.768	2.697	2.658	2.658	1.E+02
8	3.271	3.271	3.290	3.349	3.475	3.619	3.710	3.732	3.728	3.716	3.727	3.708	3.634	3.500	3.339	3.222	3.146	3.105	3.105	1.E+02
7	3.788	3.788	3.807	3.868	4.003	4.154	4.246	4.265	4.257	4.242	4.256	4.244	4.176	4.043	3.869	3.741	3.662	3.620	3.620	1.E+02
6	4.377	4.377	4.394	4.455	4.596	4.752	4.842	4.855	4.843	4.825	4.842	4.837	4.782	4.652	4.467	4.332	4.252	4.210	4.210	1.E+02
5	5.042	5.042	5.056	5.115	5.258	5.416	5.503	5.508	5.490	5.468	5.489	5.495	5.455	5.331	5.138	4.998	4.922	4.884	4.884	1.E+02
4	5.788	5.788	5.797	5.851	5.994	6.152	6.234	6.230	6.205	6.179	6.204	6.222	6.200	6.084	5.884	5.745	5.680	5.650	5.650	1.E+02
3	6.626	6.626	6.626	6.672	6.813	6.968	7.043	7.030	6.996	6.965	6.996	7.027	7.024	6.919	6.714	6.582	6.539	6.520	6.520	1.E+02
2	7.567	7.567	7.556	7.592	7.725	7.876	7.943	7.918	7.874	7.837	7.874	7.922	7.940	7.847	7.640	7.523	7.512	7.511	7.511	1.E+02
1	8.630	8.630	8.604	8.624	8.747	8.889	8.945	8.907	8.850	8.807	8.852	8.918	8.962	8.884	8.678	8.585	8.618	8.643	8.643	1.E+02
0	9.835	9.835	9.790	9.790	9.897	10.025	10.067	10.013	9.942	9.892	9.945	10.033	10.108	10.050	9.848	9.789	9.881	9.939	9.939	1.E+02

Table 2: The temperature, wind, and pressure tables of *twp.lsn* for January

JANUARY ZONAL MEAN TEMPERATURE (K)

HEIGHT									LATITUDE								
(km)	80S	70S	60S	50S	40S	30S	20S	10S	EQ	10N	20N	30N	40N	50N	60N	70N	80N
120	391.2	390.6	389.7	388.5	386.9	385.2	383.2	381.1	379.0	376.8	374.7	372.7	371.0	369.4	368.2	367.3	366.7
115	318.1	318.8	319.1	318.1	315.4	311.0	305.7	300.6	296.6	294.3	293.7	294.1	294.5	293.9	291.9	289.2	286.9
110	293.9	287.9	279.1	268.7	257.7	247.0	237.3	229.0	222.8	219.3	218.8	221.6	226.8	233.0	238.6	242.5	244.6
105	246.1	240.0	231.9	223.3	215.3	208.5	202.8	198.2	194.7	192.5	192.2	194.3	198.5	204.4	210.8	216.3	220.0
100	189.1	188.3	187.4	186.8	186.8	187.3	187.9	188.1	187.7	187.0	186.7	187.4	189.6	193.2	197.6	201.9	204.9
95	152.2	155.3	160.0	166.0	172.5	178.7	183.5	186.4	187.3	187.0	186.6	187.2	189.1	192.2	196.0	199.5	202.1
90	142.9	147.6	154.8	163.9	173.3	181.5	187.1	189.7	190.5	190.6	191.3	193.5	196.9	201.3	205.6	209.1	211.6
85	147.9	152.7	160.1	170.1	180.6	189.4	194.6	196.5	197.5	198.6	200.5	204.1	208.6	213.7	217.8	220.3	222.2
80	171.7	173.6	176.9	184.1	192.9	200.7	204.7	204.8	205.5	206.3	207.7	211.5	215.8	221.4	224.4	224.6	225.8
75	200.1	199.8	199.8	201.6	204.6	208.4	210.8	210.6	211.1	211.4	212.3	215.6	219.3	223.8	226.3	225.6	226.8
70	226.4	224.8	222.7	219.0	215.2	214.1	215.9	217.8	218.3	217.7	217.5	219.5	221.2	225.0	227.7	227.3	229.3
65	248.3	245.3	241.5	235.5	229.8	227.5	230.4	233.8	235.1	233.1	230.7	227.8	226.3	226.2	229.6	232.6	236.4
60	266.7	262.9	258.7	252.8	247.4	245.0	247.7	252.6	252.9	250.2	244.5	238.7	232.5	230.7	235.0	241.9	247.2
55	281.1	276.8	272.1	266.3	261.1	258.7	259.4	263.3	264.6	262.9	258.3	251.9	245.2	241.7	244.2	250.7	255.5
50	288.5	284.4	279.7	275.4	271.4	268.7	267.4	267.8	267.8	267.9	267.0	263.4	259.2	253.5	253.5	255.0	255.4
45	286.1	283.4	280.0	275.8	272.8	269.5	267.1	264.0	263.8	264.5	265.8	264.4	260.6	254.4	252.3	252.0	251.0
40	276.2	274.1	271.2	267.6	264.1	260.2	256.5	254.9	255.2	255.2	255.8	254.0	250.0	246.4	246.5	246.7	246.9
35	261.8	260.5	258.1	254.6	250.6	246.8	244.1	242.3	242.5	242.1	241.7	239.2	237.4	235.4	235.7	236.3	236.6
30	244.5	244.1	243.7	240.7	236.1	232.0	228.9	227.8	227.2	228.0	228.1	228.5	227.5	226.2	224.7	221.7	219.1
25	235.6	233.8	232.6	229.0	225.4	222.1	219.2	218.1	217.5	218.0	218.3	219.3	219.6	218.2	213.8	207.8	202.0
20	234.6	233.2	229.6	222.8	215.5	210.2	207.4	205.3	204.3	204.6	206.7	210.0	214.5	216.8	215.5	211.4	205.9
15	232.5	231.3	227.3	220.3	212.3	206.0	202.0	199.8	199.3	199.7	202.2	208.1	214.7	217.9	217.0	214.1	211.2
10	226.9	225.5	224.8	225.9	229.8	235.0	238.3	239.0	239.2	238.6	235.4	228.6	221.6	218.8	217.1	215.2	214.0
5	240.8	243.7	248.3	255.8	263.8	269.4	271.9	272.3	272.4	272.4	269.6	261.8	252.5	244.5	239.1	234.8	231.9
0		272.0	275.2	281.4	289.5	295.9	298.9	300.5	300.6	300.0	297.1	291.7	284.7	277.7	266.4	254.1	248.6

JANUARY ZONAL MEAN ZONAL WIND (m/s)

HEIGHT									LATITUDE								
(km)	80S	70S	60S	50S	40S	30S	20S	10S	EQ	10N	20N	30N	40N	50N	60N	70N	80N
120	-0.8	-1.5	4.0	8.6	10.4	8.2	-15.3	-26.0	12.1	34.9	14.8	-14.2	-23.6	-37.9	-28.3	-11.2	-5.7
115	-0.7	-1.2	4.7	10.4	13.9	14.3	-4.6	-14.7	15.6	31.5	10.3	-16.9	-25.8	-40.2	-30.4	-12.7	-6.5
110	0.7	1.5	9.5	18.1	25.6	31.3	21.6	12.9	27.8	29.1	6.9	-14.3	-21.7	-36.1	-27.1	-11.2	-5.6
105	4.4	8.9	19.6	30.7	40.5	48.5	44.5	36.2	40.1	29.9	7.5	-6.6	-11.7	-25.3	-18.4	-5.4	-2.7
100	7.2	14.1	25.9	37.1	46.3	54.1	50.6	42.2	42.2	28.8	8.4	-1.1	-3.6	-16.4	-10.7	0.2	0.0
95	5.8	11.3	21.7	31.0	37.6	43.2	39.2	32.2	34.2	24.4	8.0	2.4	2.4	-9.1	-3.8	5.3	2.5
90	0.6	1.2	7.5	13.2	17.2	22.3	20.2	17.5	24.8	21.1	10.5	9.3	11.6	1.0	4.6	11.0	5.5
85	-5.3	-10.3	-16.6	-14.2	-12.3	-4.0	5.1	7.6	24.0	27.3	19.5	24.4	24.9	13.4	9.8	15.6	7.8
80	-8.9	-17.0	-37.6	-44.4	-46.8	-30.3	-3.8	6.6	25.7	31.7	27.3	38.6	38.5	22.6	10.3	17.7	8.9
75	-11.2	-21.9	-48.7	-63.5	-68.9	-45.7	-7.8	10.9	28.1	37.5	37.5	50.0	51.4	27.6	11.5	17.1	8.8
70	-11.9	-23.6	-51.5	-67.5	-74.2	-52.3	-13.6	9.1	26.1	39.7	45.8	59.0	60.4	31.8	13.1	17.0	8.6
65	-11.1	-22.0	-47.7	-61.8	-69.5	-56.5	-27.1	-4.9	11.2	32.5	46.6	61.2	62.5	36.0	16.7	19.5	9.7
60	-9.3	-18.4	-42.1	-54.5	-63.5	-61.6	-45.9	-26.2	-9.9	15.1	36.0	54.3	58.0	39.8	23.9	26.0	12.8
55	-6.9	-13.8	-36.1	-46.9	-57.7	-64.3	-62.7	-48.8	-30.1	-6.0	19.3	41.7	50.5	43.3	32.2	34.4	17.0
50	-4.3	-8.6	-30.1	-39.9	-52.0	-63.0	-69.5	-61.1	-41.5	-17.8	7.6	31.2	43.2	43.7	36.6	39.5	19.8
45	-2.0	-4.0	-24.5	-33.8	-45.5	-56.6	-63.0	-54.8	-37.5	-15.4	4.9	23.8	34.5	39.3	36.5	39.9	20.4
40	-0.1	-0.3	-19.1	-27.3	-37.5	-46.0	-50.3	-44.2	-33.4	-11.4	4.9	16.3	25.1	33.8	35.7	39.2	19.9
35	1.4	2.5	-14.1	-20.5	-28.2	-34.3	-37.9	-38.0	-35.3	-12.1	1.6	8.8	18.4	30.1	36.0	37.8	19.3
30	1.4	2.7	-9.5	-13.3	-18.0	-23.2	-27.3	-29.9	-30.6	-11.2	-0.8	4.9	14.7	26.7	34.2	33.7	17.5
25	-0.8	-1.7	-4.7	-6.6	-9.2	-12.9	-17.9	-21.3	-19.5	-6.7	1.2	5.6	12.9	21.9	27.6	25.5	13.4
20	-0.3	-0.5	1.7	2.7	1.3	-2.7	-8.6	-11.8	-10.3	0.6	7.7	11.1	15.8	19.0	20.7	18.0	9.3
15	1.9	3.7	9.6	16.3	17.6	12.1	4.5	-0.5	-1.5	12.9	24.5	28.2	26.6	20.6	17.6	13.2	6.8
10	1.7	2.5	9.6	19.9	21.6	14.4	4.2	-2.2	-2.5	4.6	21.4	33.4	26.0	16.0	10.2	7.2	3.6
5	0.1	0.4	8.0	15.7	13.4	6.2	0.1	-1.6	-3.3	-1.8	8.3	15.4	14.8	10.3	6.2	4.1	2.3
0		-0.2	2.6	5.4	2.6	-2.3	-4.0	-1.8	-2.0	-5.1	-4.1	1.1	3.5	2.5	0.5	0.2	-1.2

JANUARY ZONAL MEAN PRESSURE (mb)

HEIGHT									LATITUDE									
(km)	80S	70S	60S	50S	40S	30S	20S	10S	EQ	10N	20N	30N	40N	50N	60N	70N	80N	EXPONENT
120	2.714	2.702	2.682	2.657	2.623	2.583	2.540	2.497	2.456	2.418	2.384	2.353	2.325	2.299	2.277	2.260	2.250	E-5
115	4.264	4.238	4.201	4.155	4.104	4.052	3.998	3.945	3.889	3.835	3.781	3.731	3.689	3.656	3.634	3.622	3.616	E-5
110	7.174	7.158	7.142	7.136	7.144	7.167	7.195	7.213	7.201	7.146	7.039	6.904	6.760	6.639	6.562	6.526	6.518	E-5
105	1.294	1.311	1.338	1.374	1.415	1.460	1.505	1.542	1.567	1.570	1.547	1.500	1.439	1.379	1.333	1.303	1.288	E-4
100	2.727	2.796	2.901	3.030	3.171	3.315	3.452	3.572	3.658	3.686	3.632	3.495	3.301	3.097	2.925	2.804	2.735	E-4
95	7.250	7.368	7.534	7.730	7.928	8.133	8.338	8.552	8.733	8.814	8.694	8.341	7.803	7.212	6.694	6.313	6.089	E-4
90	2.307	2.264	2.205	2.142	2.087	2.051	2.043	2.064	2.101	2.122	2.093	1.995	1.843	1.675	1.526	1.418	1.353	E-3
85	7.222	6.796	6.263	5.727	5.286	5.004	4.886	4.891	4.953	4.976	4.868	4.597	4.198	3.777	3.435	3.169	3.008	E-3
80	1.590	1.504	1.408	1.290	1.186	1.129	1.119	1.123	1.130	1.118	1.083	1.033	0.960	0.890	0.861	0.815	0.781	E-2
75	3.903	3.680	3.421	3.069	2.737	2.537	2.486	2.503	2.514	2.480	2.391	2.253	2.060	1.880	1.806	1.714	1.639	E-2
70	8.541	8.080	7.545	6.786	6.067	5.592	5.440	5.473	5.484	5.408	5.206	4.854	4.392	3.956	3.769	3.591	3.417	E-2
65	1.730	1.647	1.552	1.417	1.288	1.195	1.152	1.148	1.146	1.136	1.099	1.025	0.928	0.831	0.784	0.745	0.703	E-1
60	3.321	3.189	3.032	2.814	2.597	2.426	2.319	2.282	2.273	2.267	2.219	2.101	1.926	1.733	1.616	1.513	1.410	E-1
55	6.130	5.940	5.710	5.372	5.019	4.713	4.483	4.359	4.333	4.346	4.320	4.163	3.893	3.532	3.262	2.993	2.749	E-1
50	1.107	1.081	1.049	0.998	0.942	0.890	0.847	0.818	0.812	0.816	0.817	0.797	0.757	0.695	0.640	0.582	0.531	E 0
45	1.989	1.956	1.913	1.835	1.747	1.658	1.584	1.537	1.525	1.531	1.531	1.503	1.443	1.345	1.244	1.130	1.033	E 0
40	3.624	3.579	3.524	3.410	3.266	3.127	3.006	2.935	2.912	2.922	2.914	2.872	2.786	2.636	2.447	2.224	2.037	E 0
35	6.791	6.737	6.677	6.509	6.288	6.081	5.892	5.776	5.724	5.747	5.735	5.690	5.572	5.313	4.932	4.473	4.099	E 0
30	1.326	1.318	1.311	1.288	1.260	1.231	1.203	1.184	1.174	1.178	1.177	1.173	1.154	1.106	1.030	0.937	0.861	E 1
25	2.700	2.690	2.675	2.654	2.628	2.595	2.560	2.528	2.512	2.516	2.512	2.497	2.462	2.372	2.235	2.071	1.935	E 1
20	5.563	5.571	5.591	5.633	5.669	5.678	5.652	5.613	5.593	5.596	5.568	5.499	5.382	5.187	4.944	4.686	4.487	E 1

3. The CIRA86aQ_UoG Fortran95 model (File *hlat2datm.f90*)

The CIRA86aQ_UoG FORTRAN-95 model, contained in a file named *hlat2datm.f90*, utilizes the tabular fields in file *tqp.2DAtm* in order to conveniently provide continuous monthly fields of the fundamental atmospheric variables temperature, specific humidity, water vapor pressure, (total) pressure, mass density, and refractivity as well as of the 1st vertical derivative of refractivity and the 2nd vertical derivative of refractivity, respectively. Either dry air modeling or moist air modeling is selectable, the former assuming humidity to be zero. The provision of continuous fields, i.e., of values for arbitrary latitude-height-month locations (within the prescribed height range), is achieved by interpolation, whereby the type of interpolation (linear or cubic splines) is also selectable by the user. This allows to choose the best trade-off between performance and accuracy for any given application.

The description below is organized into model interface description (subsection 3.1), model source code structure and how-to-compile description (subsection 3.2), and model algorithms overview description (subsection 3.3), respectively. The final subsection 3.4 complements the description in showing exemplary model output fields of temperature and humidity for the months January (winter), April (spring), July (summer), and October (fall), respectively.

3.1. Model Interface

The FORTRAN-95 subroutine name of the CIRA86aQ_UoG model is `Hlat2DAtmModel` (for "height/latitude two-dimensional atmospheric model"). It can be invoked by the user in his/her calling program via

```
CALL HLat2DAtmModel(h,phi,mon,InterpType,AtmType,Par, &
                    N,dNdz,d2Ndz2,T,p,rho,q,e) ,
```

where the input/output (I/O) parameters are defined as follows:

Input parameters:

```
         h = height [km] for which a variable is desired
       phi = latitude (-90 to +90)/[deg] for which a variable is desired
       mon = month (1=Jan to 12=Dec)/[mon no.] for which output is desired
InterpType = 'vLin+lLin', 'vSpl+lLin', or 'vSpl+lSpl', specifies which
             interpolation (Spline or Linear) shall be used vertically
             (v) and latitudinally (l), respectively; setting should be
             chosen to reflect accuracy requirements for field continuity.
   AtmType = 'Dry Atm.' or 'Moist Atm.', specifies whether dry or
             moist atmospheric conditions shall be modeled.
       Par = one of {'N','N+dNs','T','p','rho','q','e'}, specifies
             which atmospheric variables shall be returned (N, dNdz, and
             d2Ndz2 for 'N+dNs')
```

Output parameters:

```
     N (optional) = Refractivity [N]
  dNdz (optional) = Vertical gradient of refractivity [N/km]
d2Ndz2 (optional) = Vertical curvature of refractivity [N/km2]
     T (optional) = Temperature [K]
```

```
     p (optional) = (total) pressure [mbar]
   rho (optional) = (total) mass density [kg/m3]
     q (optional) = specific humidity [g/kg]
     e (optional) = water vapor pressure [mbar]
```

The parameter `mon` is of type INTEGER, the parameters `InterpType`, `AtmType`, and `Par` are of type CHARACTER(LEN=*), all other parameters are of type DOUBLE PRECISION.

In addition to the correct supply of the I/O parameters, the file *tqp.2DAtm* described in section 2 above has to be available to the model, since it accesses this file during execution.

We note, finally, that the file *hlat2datm.f90* itself contains besides brief CIRA86aQ_UoG background information detailed interface information, including some remarks on useful settings of input parameters such as `InterpType`.

3.2. Model Source Code Structure (structure of *hlat2datm.f90*) and Compilation

Within the file *hlat2datm.f90*, a MODULE block *HLat_2DAtmosphere* contains on top the main SUBROUTINE *HLat2DAtmModel(...)*, which provides the external interface of CIRA86aQ_UoG (see subsection 3.1 above) and is the driver subroutine for the computations performed.

This main subroutine utilizes a series of internal routines, which are also contained in the MODULE block (see in *hlat2datm.f90* the CONTAINS list at the beginning of the MODULE bock). These auxiliary routines, performing specific computational subtasks required for the modeling, are separated in code from the main routine for structural needs and convenience.

Regarding compilation, this can either be performed using FORTRAN-95 or FORTRAN-90 compilers; the code is compatible with both standards. We confirmed seamless compilation using Fujitsu f95, NAG f95, DEC f95, NAG f90, and SGI f90 compilers. No further auxiliary files are required by *hlat2datm.f90* when producing an executable, since *hlat2datm.f90* is self-contained, i.e., comprises the complete set of routines constituting the model. When running an executable involving the model, the file *tqp.2DAtm* needs to be available in a subdirectory /COEFFS of the directory holding the executable, since the model uses the command

```
OPEN(10, FILE = 'COEFFS/tqp.2DAtm', STATUS = 'OLD', ACTION = 'READ', &
              FORM = 'FORMATTED')
```

for opening *tqp.2DAtm*. If desired, this file path is readily changed by the user in the cited open statement, which resides in the auxiliary subroutine *Read_TQPFile*.

3.3. Model Algorithms Overview

Input to the algorithms: The input parameters received via the parameter list are height, latitude, month, interpolation type for linear/spline interpolation, type of atmosphere (dry or moist), and type of output parameter(s) desired. Input data received from file *tqp.2DAtm* are the tables of temperature, humidity, and pressure for the selected month (out of 1 to 12).

These are loaded into memory (RAM) by routine *Read_TQPFile* during the first call of the model by the calling routine, so that while the calling routine remains active all subsequent calls can take the data directly from RAM. Together with loading the atmospheric tables, also the corresponding tables of refractivity and its 2nd vertical derivatives are prepared (by routine *PrepareAtmData*) for the selected type of atmosphere (dry or moist). The Smith-Weintraub refractivity formula [e.g., *Gorbunov and Sokolovsky*,1993] is used for this purpose; the 2nd vertical derivatives are computed (by routine *Spline_2D*) in form of cubic spline coefficients based on the refractivity profiles.

Computation of refractivity as basis: Either for dry air or moist air, as selected, one of the output parameters refractivity (optionally plus 1st and 2nd vertical derivative), density, pressure, temperature, water vapor pressure, and specific humidity is then computed for the desired location. The basis for all of these computations is that the refractivity (optionally plus 1st and 2nd vertical derivative) is generated for the desired location by interpolation on the prepared refractivity grid. This is done using the auxiliary subroutine *Refr*.

The interpolation in *Refr* is performed, dependent on the interpolation type selected, either linear in latitude and height, linear in latitude and natural cubic spline in height, or bi-cubic splined in latitude and height. The interpolation algorithms (routines *SplineInt_1D, SplineInt_2D, Spline_1D*) follow *Press et al.* [1992]. In view of satellite-to-satellite and satellite-to-ground ray-tracing applications, the refractivity (optionally plus 1st and 2nd vertical derivative) is available via extrapolation also beyond 120 km into deep space (see code of subroutine *Refr*).

Considerable care has been taken to provide complete continuity in refractivity and its derivatives throughout the entire model domain for allowing to achieve millimetric excess phase accuracy in high-accuracy ray-tracing through the model. Extensive application of CIRA86aQ_UoG in the context of the EGOPS software confirmed that such accuracy is indeed obtained.

Computation of desired atmospheric variables: The actual formulae employed for computation of the output variables of interest are well readable in the code of the main subroutine *HLat2DAtmModel* within the code segment with the structure

```
IF (AtmType = 'Dry Atm.') THEN
   SELECT CASE (Par)
            ...dry air formulae/routine calls...
   END SELECT
ELSE IF (AtmType = 'Moist Atm.') THEN
   SELECT CASE (Par)
            ...moist air formulae/routine calls...
   END SELECT
END IF.
```

Thus these formulae shall only be commented on, but not repeated in writing here.

Refractivity: For both dry and moist air, refractivity follows immediately from the interpolation and is thus directly available for output.

Other variables if 'Dry Atm.': For dry air, density is simply proportional to refractivity. Pressure is derived from refractivity (in effect density) by hydrostatic integration from top downward (by routine *HydroPresN*, which does this integration by Simpson's rule – for efficiency on a special non-equidistant height grid). Temperature is obtained readily (locally) from pressure and density employing the equation of state. Humidity values are trivially zero in dry air.

Other variables if 'Moist Atm.': For moist air (below 15 km height in case 'Moist Atm.' was selected), first the temperature profile is derived just as described above for dry air at a 0.5km-spaced height grid extending from the desired height up to 15 km. Also, the moist air refractivity is computed at the same grid. Using these two input profiles, the density, pressure, and humidity profiles are consistently computed (by routine *Wet_rhopqe* and its auxiliary routines *HydroPresT* and *TempFunct*) following the iterative "moist air profiles retrieval scheme" after *Gorbunov and Sokolovskiy* [1993]. The lowermost profile values, those at the desired heights, are the final output values for density, pressure, and humidity profiles in moist air.

Concluding Note: One may wonder why the atmospheric variables are not computed by direct interpolation within the respective CIRA86aQ_UoG tables (which would in fact be significantly more efficient, especially for moist air), but rather all via the interpolated refractivity field. The reason is that the tables are too "coarse grained" to have rigorous thermodynamic+hydrostatic consistency ensured among the variables at any possible location if each variable is interpolated separately. This consistency is required, however, for accurate self-consistent forward-inverse simulations. Favorably, the perhaps computationally most demanding application of CIRA86aQ_UoG, high-accuracy ray-tracing, uses refractivity directly and is thus not further loaded by any burden beyond the refractivity interpolation itself.

3.4. Exemplary Model Output Fields: Temperature and Humidity for Jan/Apr/Jul/Oct

In order to provide an illustration of the model fields computed by the CIRA86aQ_UoG Fortran95 model, we included below a few exemplary Figures showing temperature and specific humidity fields. Each Figure depicts temperature in the upper panel (computed at a 10 deg x 5 km grid reflecting the grid of the underlying table), and specific humidity in the lower panel (computed at a 10 deg x 1 km grid also reflecting the underlying table), respectively. The model of course allows output at arbitrarily sampled locations, e.g., on much finer grids, which would lead to very smoothly curved iso-contour lines in the panels if spline interpolation were used.

In the Figures below, however, we deliberately want to visually reflect the original tabular resolution. Figure 1 shows January fields illustrating winter conditions, Figure 2 April fields illustrating spring conditions, Figure 3 July fields illustrating summer conditions, and Figure 4 October fields illustrating fall conditions, respectively. Note that Figure 1 is a direct graphical illustration of the *tqp.2DAtm* temperature and humidity tables of Table 1 in section 2 above.
The Figures have been produced with the "Visualize Volume Data" functionality of the EGOPS software [*Kirchengast*, 1996 and 1998] mentioned in the introduction.

Figure 1: Temperature and humidity fields of the CIRA86aQ_UoG model for January

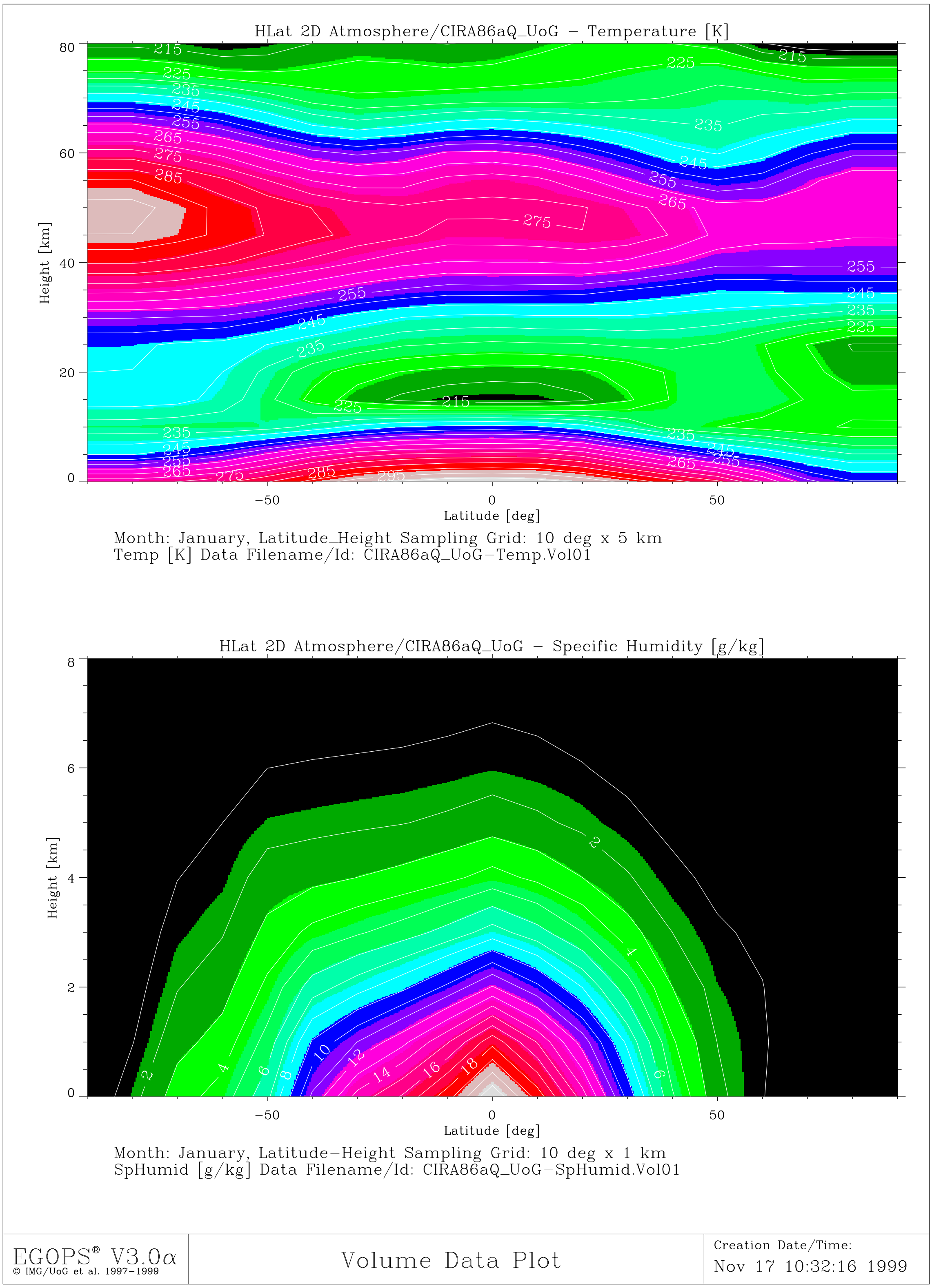
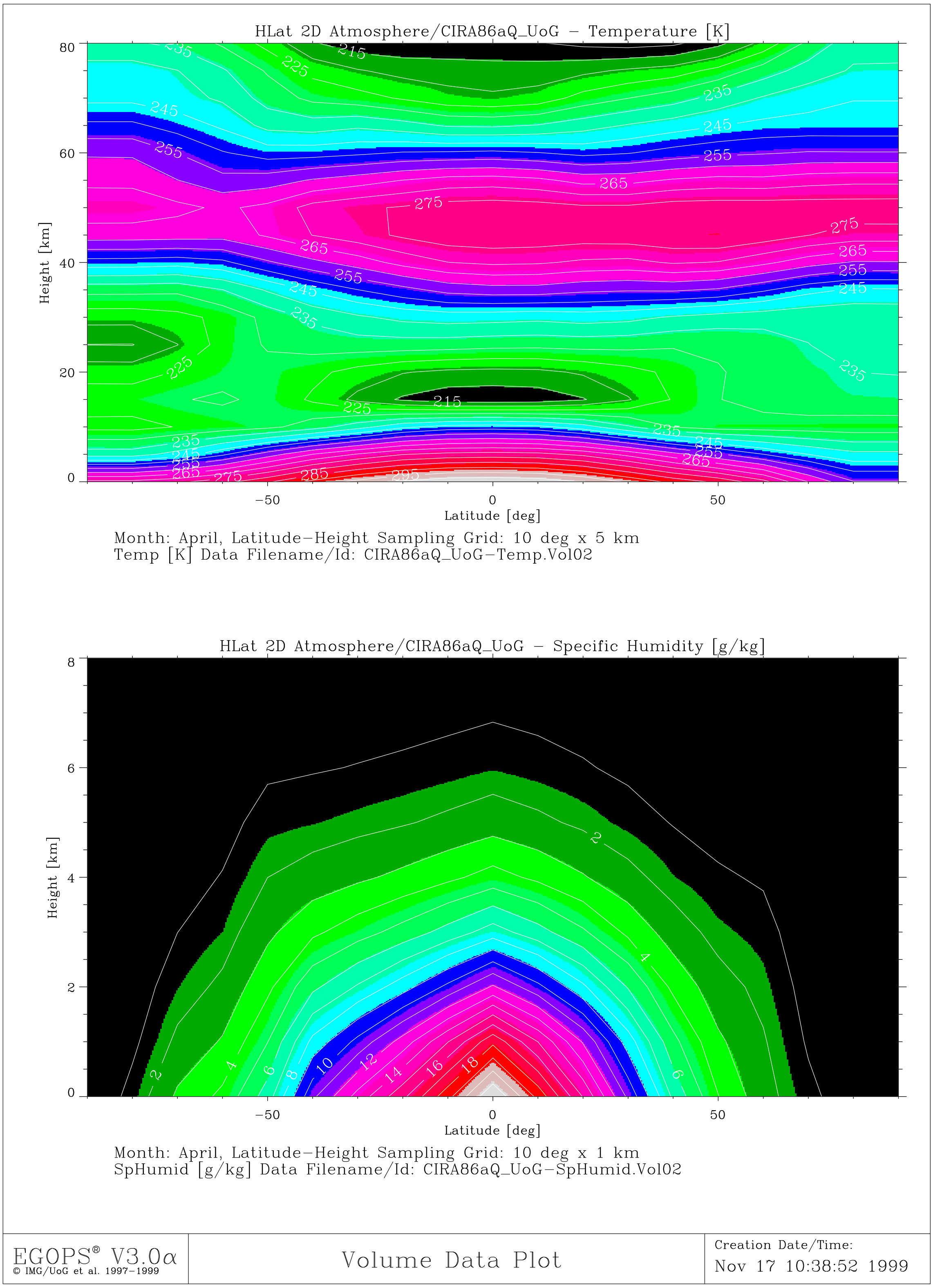


Figure 2: Temperature and humidity fields of the CIRA86aQ_UoG model for April



HLat 2D Atmosphere/CIRA86aQ_UoG – Temperature [K]

Month: April, Latitude–Height Sampling Grid: 10 deg x 5 km
Temp [K] Data Filename/Id: CIRA86aQ_UoG–Temp.Vol02

HLat 2D Atmosphere/CIRA86aQ_UoG – Specific Humidity [g/kg]

Month: April, Latitude–Height Sampling Grid: 10 deg x 1 km
SpHumid [g/kg] Data Filename/Id: CIRA86aQ_UoG–SpHumid.Vol02

EGOPS® V3.0α
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Volume Data Plot

Creation Date/Time:
Nov 17 10:38:52 1999

Figure 3: Temperature and humidity fields of the CIRA86aQ_UoG model for July

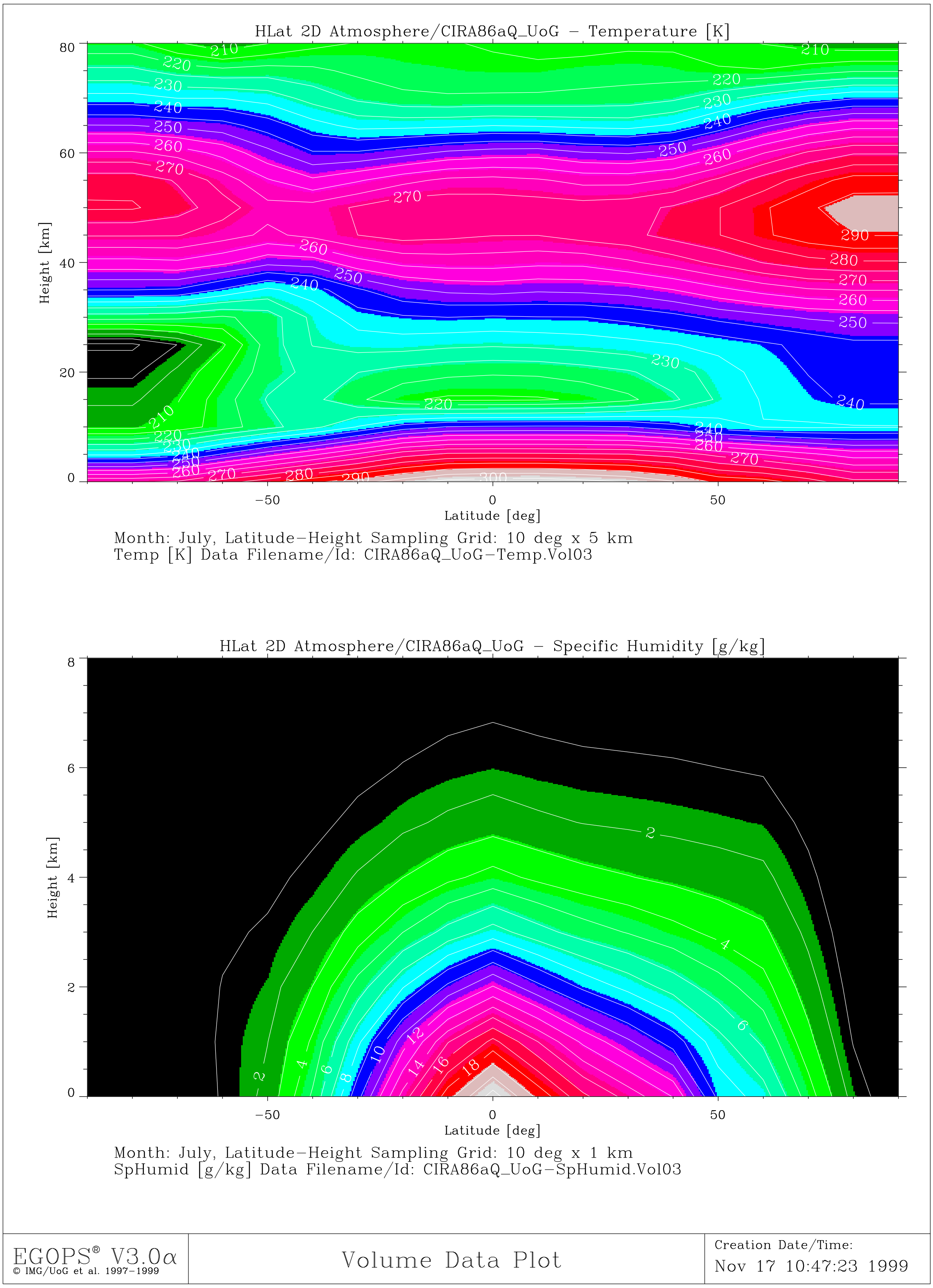
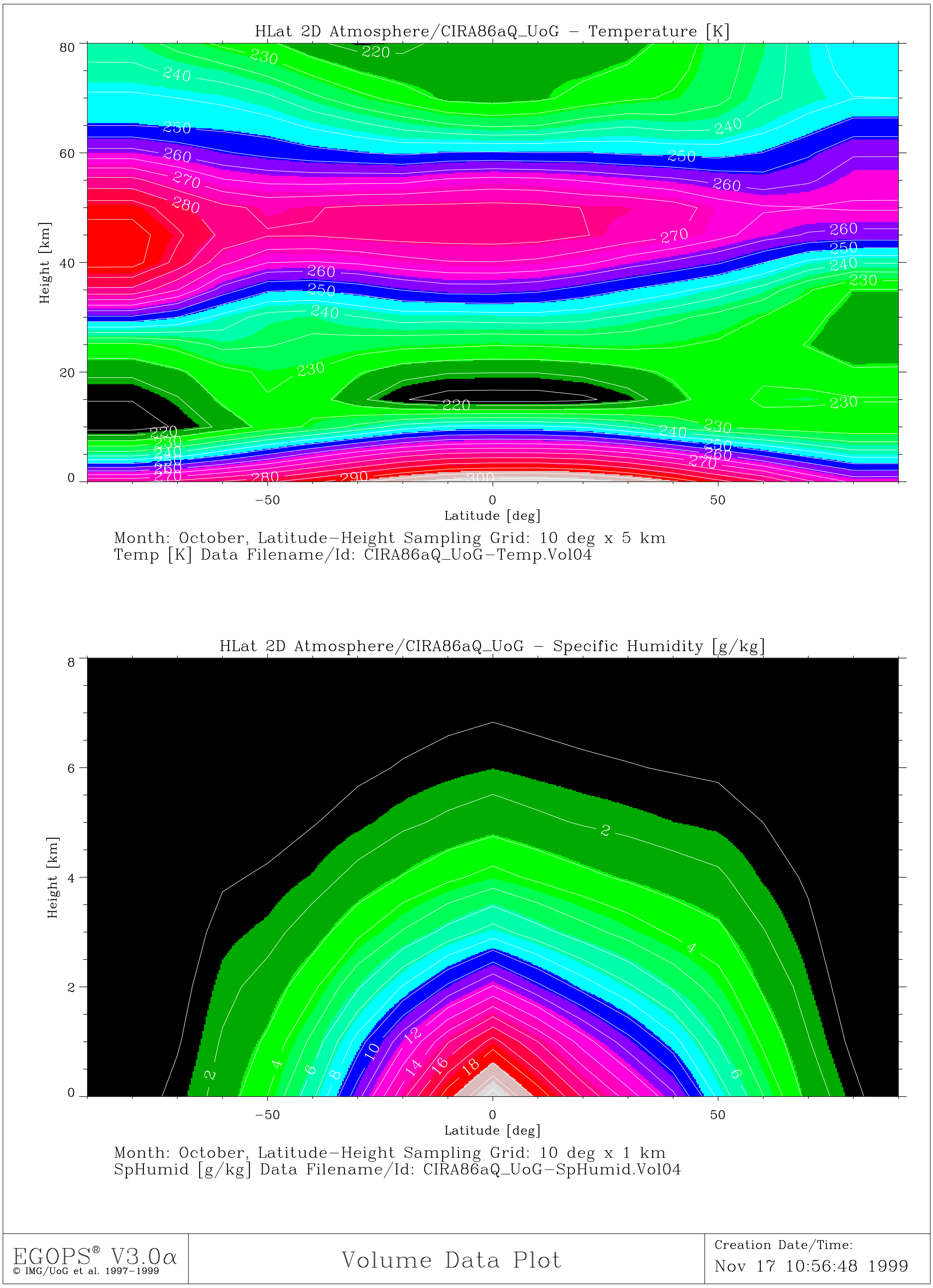


Figure 4: Temperature and humidity fields of the CIRA86aQ_UoG model for October



Month: October, Latitude–Height Sampling Grid: 10 deg x 5 km
Temp [K] Data Filename/Id: CIRA86aQ_UoG–Temp.Vol04

Month: October, Latitude–Height Sampling Grid: 10 deg x 1 km
SpHumid [g/kg] Data Filename/Id: CIRA86aQ_UoG–SpHumid.Vol04

4. Acknowledgments

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