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A MODEL ATMOSPHERE FOR EARTH RESOURCES APPLICATIONS

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ABSTRACT

A computer subprogram set is described which permits the use of radiosonde data to provide model atmosphere data for earth resources applications.

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SUMMARY

All earth resources remote-sensing techniques are affected by the atmosphere lying between the target and the sensor. The computer program presented in this report offers a method of numerical use of radiosonde data so that atmospheric effects may be assessed and possibly removed from the signal.

INTRODUCTION

The objectives of the NASA Earth Resources Program are to determine the performance capabilities of various sensors, to discover signature criteria of resources, and to develop new sensors and systems that will eventually enable management of earth resources. To accomplish these objectives, certain absolutes which may be used to evaluate sensing systems and techniques must be established. The laboratory usually offers the best testing environment, but the type of target, the conditions of the path of the signal, and other testing parameters are limited. In general, the laboratory is so restrictive that a successful laboratory test of a remote sensor is necessary but not sufficient to ensure proper operation of the sensor in an application. Therefore, much of the testing is performed in the same environment in which the instrument is expected to operate. Testing under such conditions requires that the data concerning the environment between the instrument platform (e.g., an aircraft or a spacecraft) and the target be as accurate as possible. Thus, determination of the "ground truth" and description of the state of the atmosphere in the path of the electromagnetic signal are necessary.

Remote-sensing techniques are affected by the atmosphere lying between the target and the sensor. The amount of noise introduced into the signal by the interaction between the atmosphere and the signal depends upon the type of sensor, the wavelength employed, and the meteorological conditions prevailing at the time of the experiment. Since the NASA Earth Resources Program remote-sensing effort is in a developmental stage, the effects of this interaction are presently being determined, and hopefully, the model atmosphere for earth resources applications, presented in this paper, will facilitate analyses of such effects.

The computer subprogram set presented in this paper offers a self-consistent method for numerically calculating the state of the atmosphere based on radiosonde data given in terms of significant levels of pressure, temperature, and temperature-dewpoint depression. After data from the radiosonde closest to an aircraft or spacecraft remote-sensing target have been obtained and after these data have been inserted into the computer subprogram set, a programer has almost any desirable atmospheric parameter available for use in his computer programs. In particular, the subprogram set described in this paper makes available all the necessary quantities for calculation of infrared and microwave absorption or refraction, or both. However, no attempt has been made in this paper to include atmospheric absorption calculations in the model atmosphere; only the basic atmospheric data necessary for the previously mentioned calculations are provided.

The model atmosphere was written in the FORTRAN V computer language for the Univac 1108 computer. However, the program is also compatible with Control Data Corporation and IBM FORTRAN IV compilers. Copies of the computer cards are available upon request from David E. Pitts, TF8, Manned Spacecraft Center, Houston, Texas 77058.

SYMBOLS

C_{sound}	computer symbol ANS(4), speed of sound, m/sec
d	computer symbol DUM/D1, increment of the slant path from r to r', cm
e	computer symbol ANS(19), E(X), water-vapor pressure, mbar
e_s	computer symbol ANS(20), E(X), saturation water-vapor pressure, mbar
f_w	computer symbol F(P, X), correction for the departure of the air and water-vapor mixture, from ideal-gas law
g	computer symbol ANS(5), acceleration caused by gravity, f(Z), cm/sec^2
g_o	surface gravity, g at R_e, cm/sec^2
H	computer symbol H(I), geopotential altitude, m
H_a	computer symbol HA, HLOW, geopotential altitude at A, where $H_a < H_b$, m
H_b	computer symbol HB, geopotential altitude at B, m
H_p	computer symbol ANS(15), pressure scale height, km
H_ρ	computer symbol ANS(16), density scale height, km

M_i	mass percentage of the ith constituent
m	computer symbol ANS(7), molecular weight of the atmosphere, g/g-mole
m_b	molecular weight at H_b, g/g-mole
m_d	computer symbol XMO, molecular weight of the dry atmosphere, g/g-mole
m_o	computer symbol XMO, molecular weight at the surface, g/g-mole
m_w	molecular weight of water, g/g-mole
n'	computer symbol XN2, refractive index at $r' + (1/2)\Delta Z$
n''	computer symbol XN1, refractive index at $r'' + (1/2)\Delta Z$
n_{STP}	computer symbol ANS(17), refractive index of air at STP
$n(Z)$	computer symbol ANS(18), refractive index of air as a function of λ, T, and P
P	computer symbol ANS(1), atmospheric pressure, mbar
P_a	computer symbol PLOW, atmospheric pressure at H_a, mbar
P_b	computer symbol PHIGH, atmospheric pressure at H_b, mbar
q	computer symbol ANS(13), specific humidity, g/kg
q_s	computer symbol ANS(14), specific humidity at saturation, g/kg
R	computer symbol RO, universal gas constant, 8.31432×10^7 ergs/(mole °K)
R_e	computer symbol RE, mean radius of the earth, 6371.299 km
Rel	computer symbol ANS(12), relative humidity, percent
R_X	computer symbol XS-XL, X-component of $\left(\overrightarrow{r_{sp}' - r_l'}\right)$, km
R_Y	computer symbol YS-YL, Y-component of $\left(\overrightarrow{r_{sp}' - r_l'}\right)$, km
R_Z	computer symbol HS-HL, Z-component of $\left(\overrightarrow{r_{sp}' - r_l'}\right)$, km

r	computer symbol ANS(10), mixing ratio of the water in the atmosphere, g/kg
r'	computer symbol S2, distance to shell $Z + \Delta Z$ on the refracted path, km
r''	computer symbol S1, distance to shell Z on the refracted path, km
r_1'	distance from the center of the earth to a target, km
r_s	computer symbol ANS(11), mixing ratio required for the saturation of water in the atmosphere, g/kg
r_{sp}'	distance from the center of the earth to a spacecraft, km
S	computer symbol S, Sutherland's constant, 110.4° K
s	distance
T	computer symbol ANS(2), kinetic atmospheric temperature, °K
T^*	computer symbol ANS(6), virtual temperature, °K
T_a	computer symbol T( ), temperature at H_a, °K
T_a^*	computer symbol TVLOW, virtual temperature at H_a, °K
T_b	computer symbol ANS(2), temperature at H_b, °K
T_b^*	computer symbol TVHIGH, virtual temperature at H_b, °K
T_d	dewpoint temperature, °K
$T_{d,a}$	computer symbol TD( ), dewpoint temperature at H_a, °K
$T_{d,b}$	computer symbol ANS(9), dewpoint temperature at H_b, °K
T_m	molecular scale temperature, °K
TOS	computer symbol TOS, angle between r_1' and r_{sp}', rad
t	time
VV	identifier of the significant-level data set of radiosonde code
Z	computer symbol Z, geometric altitude, km

Z_l	computer symbol ZL, altitude of a target above the earth, km
Z_{sp}	computer symbol ZS, altitude of a spacecraft above the earth, km
β	computer symbol BETA, 1.458×10^{-6} kg/(sec °K m)
γ	ratio of specific heats
ζ	computer symbol PHI, angle from the zenith down to the tangent to the path at the target, rad
ζ''	computer symbol C(3), distance upward from a local station to a spacecraft, rad
η''	computer symbol C(2), distance eastward from a local station to a spacecraft, rad
θ_l	computer symbol THETAL, target longitude, input card, deg (internally, rad)
θ_{sp}	computer symbol THETAS, spacecraft longitude, input card, deg (internally, rad)
λ	computer symbol XLAMDA, wavelength, microns
μ	computer symbol ANS(8), coefficient of viscosity, kg/(msec)
ξ	computer symbol SUM1, dummy variable, rad
ξ''	computer symbol C(1), distance southward from a local station to a spacecraft, rad
ρ	computer symbol ANS(3), atmospheric density, g/cm^3
ρ_d	density of dry air, g/cm^3
ρ_w	density of water vapor, g/cm^3
ϕ'	computer symbol PHIPR, angle between r' and the path of the ray after refraction, rad
ϕ''	computer symbol PHI, angle between r'' and d, rad
ϕ_l	computer symbol PHIL, target latitude, input card, deg (internally, rad)

ϕ_{sp} computer symbol PHIS, spacecraft latitude, input card, deg (internally, rad)

ψ computer symbol PSI, angle between r' and d, rad

MODEL ATMOSPHERES

Model atmospheres for earth resources applications may be described as one of three types: preflight, flight, and postflight. Preflight model atmospheres include those which have been developed from aerospace flight-support models (refs. 1 and 2) and statistical models of cloud cover over the earth (ref. 3). The last of these indicates the probability of success on spacecraft- or aircraft-borne photographic missions for earth resources applications.

Flight model atmospheres are calculated from sounding-type remote-sensing devices aboard spacecraft or aircraft. Flight model atmospheres are not presently well developed, but when they are well developed, they will represent the ultimate in knowledge of the "air truth" until special-purpose instruments that will perform atmospheric noise extraction in real time are developed.

Postflight model atmospheres are based upon standard meteorological soundings and are used to assist in the development of flight model atmospheres. These postflight model atmospheres may be described as predictive and nonpredictive.

Predictive postflight model atmospheres use equations of motion, thermodynamics, and continuity and standard meteorological soundings to predict (in time and space) the state of the atmosphere near the target for a remote sensor mounted on an instrument platform. This type of model atmosphere is not presently well developed. Nonpredictive postflight model atmospheres offer a self-consistent method of calculating a model atmosphere at the position of a radiosonde which may be located near the experiment platform. The subprogram model atmosphere set discussed in this paper has the capability of performing either as a nonpredictive postflight model atmosphere or as a preflight model atmosphere, depending on the form of the input data.

EQUATIONS FOR THE MODEL ATMOSPHERE

The model atmosphere may generally be considered to be in a state of quasi-static equilibrium. That is, when the equations of motion, thermodynamics, and continuity are scaled and when closed sets are found, the large-scale (i.e., the first order) vertical-component solution will show that, except near clouds with high-velocity updrafts, the hydrostatic equation

$$\frac{\partial P}{\partial Z} = -\rho g \tag{1}$$

applies well. In equation (1), P is atmospheric pressure, Z is geometric altitude, ρ is atmospheric density, and g is the acceleration caused by gravity. At pressures and temperatures experienced in the atmosphere of the earth, the ideal-gas law is usually accurate to within 1 percent. The equation of state

$$\rho = \frac{Pm}{RT} \tag{2}$$

is a form of the ideal-gas law, where m is the molecular weight of the atmosphere, R is the universal gas constant, and T is the kinetic atmospheric temperature.

With certain reasonable and valid assumptions, the proper combination of the hydrostatic equation (eq. (1)) and the ideal-gas law (eq. (2)) results in equations (3) and (4), which are derived in detail in reference 4. If $\partial T^*/\partial H \neq 0$, where T^* is virtual temperature and H is the geopotential altitude, then

$$P_b = P_a \left(\frac{T_b{}^*}{T_a{}^*}\right)^{g_o m_d/[R(\partial T^*/\partial H)]} \tag{3}$$

and if $\partial T^*/\partial H = 0$, then

$$P_b = P_a \exp\left[\frac{-g_o m_d(H_b - H_a)}{RT_a{}^*}\right] \tag{4}$$

In equations (3) and (4), P_b is the atmospheric pressure at H_b, P_a is the atmospheric pressure at H_a, $T_b{}^*$ is the virtual temperature at H_b, $T_a{}^*$ is the virtual temperature at H_a, g_o is the surface gravity, m_d is the molecular weight of the dry atmosphere, H_a is the geopotential altitude at A, and H_b is the geopotential altitude at B. In the upper atmosphere, a fictitious temperature designated as molecular scale temperature T_m is defined in order to include variations in molecular weight (caused by molecular dissociation) and temperature in one variable.

$$T_m = T \frac{m_o}{m} \tag{5}$$

where m_o is the molecular weight at the surface. Similarly, in the lower atmosphere, a quantity designated as virtual temperature T^* is defined in order to include variations in molecular weight (caused by water vapor) and temperature in one variable.

$$T^* = T \frac{m_d}{m} \tag{6}$$

Therefore, T^* and T_m may be used interchangeably in equations (3) and (4); this fact enables the use of equations (3) and (4), which were derived for planetary atmospheres in reference 4.

As shown in appendix A, the proper combination of the equation of the state of dry air, the equation of the state of moist air, and equation (6) gives the exact expression of T^* as a function of temperature, pressure, and water-vapor pressure.

$$T^* = \frac{T}{\left(1 - 0.37803 \frac{f_w e}{P}\right)} \tag{7}$$

where f_w is the correction factor for the departure of the air and water-vapor mixture (from the ideal-gas law) and e is water-vapor pressure. Equations (3) and (4), which are the fundamental equations of subroutine MODATM calculations, are used in different forms to find the altitude of the significant levels and to find the pressure at a level between significant levels.

Subroutine MODATM

When atmospheric data at a particular altitude are desired, either geometric altitude is used as the calling variable, or pressure is used as the calling variable and a corresponding geometric altitude is calculated by using equations (3) and (4). Geopotential altitude H is calculated by

$$H = \frac{Z\left(R_e\right)}{R_e + Z} \tag{8}$$

where R_e is the mean radius of the earth. Geopotential altitude is then used to calculate temperature, virtual temperature, and molecular weight.

Temperature is calculated by

$$T_b = T_a + \frac{\partial T}{\partial H}\left(H_b - H_a\right) \tag{9}$$

where T_b is the temperature at H_b, and T_a is the temperature at H_a. Virtual temperature is calculated by

$$T_b{}^* = T_a{}^* + \frac{\partial T^*}{\partial H}\left(H_b - H_a\right) \tag{10}$$

Molecular weight is calculated by

$$m_b = \frac{m_d T_b}{T_b{}^*} \tag{11}$$

where m_b is the molecular weight at H_b.

When P and T* are known, a form of the equation of state (eq. (2))

$$\rho = \frac{Pm_d}{RT^*} \tag{12}$$

is used to calculate density. Then, additional quantities related to altitude, pressure, density, molecular weight, temperature, and virtual temperature are calculated. The equations for the speed of sound C_{sound}, acceleration of gravity g, coefficient of viscosity μ, saturation mixing ratio r_s, saturation specific humidity q_s, pressure scale height H_p, and density scale height H_ρ are as follows:

$$C_{sound} = \sqrt{\gamma \frac{RT^*}{m_d}} \tag{13}$$

$$g = g_o\left(\frac{R_e}{R_e + Z}\right)^2 \tag{14}$$

$$\mu = \frac{\beta T^{3/2}}{T + S} \tag{15}$$

$$r_s = \frac{0.62197 f_w e_s}{\left(P - f_w e_s\right)} \tag{16}$$

$$q_s = \frac{0.62197 f_w e_s}{\left(P - 0.37803 f_w e_s\right)} \tag{17}$$

$$H_p = \frac{RT^*}{m_d g} \tag{18}$$

$$H_\rho = \frac{1}{\frac{1}{H_p} + \frac{1}{T^*}\left(\frac{\partial T^*}{\partial Z}\right)} \tag{19}$$

where γ is the ratio of specific heats, β is 1.458×10^{-6}, S is Sutherland's constant, and e_s is the saturation water-vapor pressure. Equations (13), (15), (18), and (19) are derived in reference 1, equation (14) is derived in reference 4, and equations (16) and (17) are derived in reference 5. The f_w-factor is calculated by a function subprogram simulating tables 89 and 90 given in reference 6.

For calculations of variables describing the amount of water vapor in the atmosphere, dewpoint temperature T_d is calculated as follows:

$$T_{d,b} = T_{d,a} + \frac{\partial T_d}{\partial H}\left(H_b - H_a\right) \tag{20}$$

where $T_{d,b}$ is the dewpoint temperature at H_b, and $T_{d,a}$ is the dewpoint temperature at H_a. The equilibrium vapor pressure over a plane surface of water (ref. 6) is then calculated.

$$e = 1013.246 \times 10^{-7.90298\left[-1.0+\left(373.16/T_d\right)\right]+5.02808\log_{10}\left(373.16/T_d\right)-1.3816\times10^{-7}\left\{10^{11.344\left[1.0-\left(T_d/373.16\right)\right]}-1.0\right\}+8.1328\times10^{-3}\left\{10^{-3.4914\left[-1.0+\left(373.16/T_d\right)\right]}-1.0\right\}} \tag{21}$$

The formula for the vapor pressure over ice (ref. 6) may also be used.

$$e = 6.1071 \times 10^{-9.09718\left[-1.0+\left(273.16/T_d\right)\right]-3.56654\log_{10}\left(273.16/T_d\right)+0.876793\left[1.0-\left(T_d/273.16\right)\right]} \tag{22}$$

The choice of the temperature ranges during which each of the previously mentioned equations for e is used is determined by the programer (function E(X)). As presently set up, only equation (21) is used. Equations (21) and (22) are used for calculating e_s by using T in place of T_d.

With the previously discussed basic quantities available, the remaining atmospheric quantities may be calculated. The equations for the mixing ratio r, relative humidity Rel, specific humidity q, refractive index n_{STP} (in wavelength), and refractive index $n(Z)$ (in P, T, and wavelength) are as follows (ref. 5):

$$r = \frac{0.62197f_w e}{\left(P - f_w e\right)} \tag{23}$$

$$\mathrm{Rel} = \frac{r}{r_s} \times 100 \tag{24}$$

$$q = \frac{0.62197f_w e}{\left(P - 0.37803f_w e\right)} \tag{25}$$

For the infrared region (ref. 7)

$$n_{STP} = 1 + 10^{-8}\left(6432.8 + \frac{2949810.0}{146 - \frac{1}{\lambda^2}} + \frac{25540}{41 - \frac{1}{\lambda^2}}\right) \tag{26}$$

and

$$n(Z) = 1 + \left(n_{STP} - 1\right)\left(\frac{1 + \frac{288.15}{273.16}}{1 + \frac{T}{273.16}}\right)\frac{P}{1013.25} \tag{27}$$

where λ is wavelength. If the wavelength is in the microwave region ($\lambda >$ 12 500 microns, i.e., $\lambda >$ 1.25 centimeters), then

$$n(Z) = 1.0 + \left[1.0 \times 10^{-6}\left(77.6\,\frac{P}{T}\right)\right] + 373000.0\,\frac{e}{T^2} \tag{28}$$

as shown in reference 8.

The input variables of MODATM are included in the calling argument, and all output variables (i.e., the variables calculated by equations (3) to (28)) are stored in a "common block" in the array ANS. Detailed instructions on the use of subroutine MODATM are included in comment cards. For data-card information, see the discussion on subroutine INPUT in this report.

Subroutine INPUT

The purpose of subroutine INPUT is to read the input data cards necessary to set up the significant levels of various atmospheric parameters (i.e., altitude, pressure, temperature, and dewpoint temperature) for subroutine MODATM. Subroutine INPUT is initiated by MODATM whenever pressure (i.e., ANS(1)) is set equal to a number which is less than zero, and because of this fact, many sets of radiosonde data may be used successively, but not concurrently.

The input data may be of the form given in the significant levels (i.e., VV) of pressure, temperature, and temperature-dewpoint depression for a radiosonde. Table I shows an example of radiosonde data and the key to the radiosonde code. Table II gives the input data cards for the example shown in table I.

Subroutine INPUT is also constructed to accept input data other than radiosonde code VV. If the first data card encountered is blank, then each of the next data cards will be read in uncoded form (i.e., as altitude, temperature, and relative humidity). An example of the input data cards necessary to set up the 15° N annual model (ref. 2) is included in table III.

Levels of possible condensation are indicated by the word "condensation" in the print-out of the significant levels. This occurrence is determined by $T - T_d < 2^\circ$ K at 1500 meters and $T - T_d < 8^\circ$ K at 9000 meters, which is expressed by the approximate expression

$$T - T_d < 1.0 + 0.000777H \text{ (meters)} \tag{29}$$

Subroutine REFRAC

Subroutine REFRAC is included to assist in making refracted path calculations throughout the atmosphere. The basic equations are developed (ref. 9) from Snell's law

$$n' \sin \phi' = n'' \sin \psi \tag{30}$$

and from the law of sines

$$\frac{\sin \phi''}{r'} = \frac{\sin \psi}{r''} \tag{31}$$

as shown in figure 1. In equations (30) and (31), n' is the refractive index at $r' + (1/2)\Delta Z$, ϕ' is the angle between r' and the path of the ray after refraction, n'' is the refractive index at $r'' + (1/2)\Delta Z$, ψ is the angle between r' and d, ϕ'' is the angle between r'' and d, r' is the distance to shell $Z + \Delta Z$ on the refracted path, and r'' is the distance to shell Z on the refracted path.

The combination of equations (30) and (31) gives

$$\phi' = \sin^{-1}\left(\frac{n''r'' \sin \phi''}{n'r'}\right) \tag{32}$$

and

$$\psi = \sin^{-1}\left(\frac{r'' \sin \phi''}{r'}\right) \tag{33}$$

Thus, by using known values for r'', r', λ, and ϕ'' and by initiating MODATM to obtain values for n'' and n', the angles ϕ' and ψ are calculated. If a continuous path is desired, ϕ'' should be set equal to ϕ', and r'' and r' should be incremented. Then, subroutine REFRAC should be called again.

Slant-path calculations are also made available by using the law of sines to calculate the increment d of the slant path from r to r' as follows:

$$d = \frac{r'' \sin(\phi'' - \psi)}{\sin \psi} \tag{34}$$

Since subroutine MODATM is called by subroutine REFRAC and since subroutine MODATM is called last for the altitude corresponding to the middle of d, the array ANS may be used externally to calculate the amount of water vapor or the total atmospheric mass that was traversed over distance d. For the initial calculation at the target point, the angle ζ (i.e., ϕ'') is needed; therefore, subroutine PATH is provided to calculate ζ for the programer.

Subroutine PATH

The principal purpose of subroutine PATH is to calculate the angle ζ; however, while calculating ζ, it is also convenient to calculate the columnar mass and the precipitable water vapor along this path. These three quantities are stored in the array ANS. If subroutine PATH is called prior to the calling of subroutine MODATM, ANS(1) will be set equal to -1.0, and subroutine MODATM will be called such that subroutine INPUT is activated, eliminating the future need to call subroutine INPUT externally. Subroutine PATH is thus programed to be called only once for each radiosonde sounding.

The initial guess at ζ is calculated by finding $(\overrightarrow{r_{sp}' - r_1'})$, the vector from the target (1) to the spacecraft (sp), as shown in figure 2 and as developed in reference 10. The components of $(\overrightarrow{r_{sp}' - r_1'})$ are

$$R_X = \left(R_e + Z_{sp}\right) \cos \theta_{sp} \cos \phi_{sp} - \left(R_e + Z_1\right) \cos \theta_1 \cos \phi_1 \tag{35}$$

$$R_Y = \left(R_e + Z_{sp}\right) \sin \theta_{sp} \cos \phi_{sp} - \left(R_e + Z_1\right) \sin \theta_1 \cos \phi_1 \tag{36}$$

and

$$R_Z = \left(R_e + Z_{sp}\right) \sin \phi_{sp} - \left(R_e + Z_1\right) \sin \phi_1 \tag{37}$$

where θ_{sp} is the longitude of the spacecraft, θ_1 is the longitude of the target, ϕ_1 is the latitude of the target, ϕ_{sp} is the latitude of the spacecraft, Z_{sp} is the altitude of a spacecraft above the earth, and Z_1 is the altitude of the target above the earth.

The components (R_X, R_Y, and R_Z) are found by coordinate transformation in the coordinate system of the target to be ξ'', η'', and ζ'', which are the respective distances southward, eastward, and upward from a local station to the target.

$$\begin{bmatrix} \xi'' \\ \eta'' \\ \zeta'' \end{bmatrix} = \begin{bmatrix} \sin \phi_1 \cos \theta_1 & \sin \phi_1 \sin \theta_1 & -\cos \phi_1 \\ -\sin \theta_1 & \cos \theta_1 & 0 \\ \cos \phi_1 \cos \theta_1 & \cos \phi_1 \sin \theta_1 & \sin \phi_1 \end{bmatrix} \begin{bmatrix} R_X \\ R_Y \\ R_Z \end{bmatrix} \tag{38}$$

The unrefracted zenith angle

$$\zeta = \tan^{-1}\left[\frac{\sqrt{(\xi'')^2 + (\eta'')^2}}{\zeta''}\right] \tag{39}$$

can then be found. Next, the angle TOS between r_1' and r_{sp}' is calculated by using the definition of the dot product

$$TOS = \cos^{-1}\left(\frac{\overrightarrow{r_1'} \cdot \overrightarrow{r_{sp}'}}{|r_{sp}'| \cdot |r_1'|}\right) \tag{40}$$

so that the best refracted path from the target to the spacecraft (fig. 1) may be found by iteration.

Iteration of paths from the equations developed in the description of subroutine REFRAC is used to find ϕ' and ψ for each level, and since

$$\Delta\xi = \phi'' - \psi \tag{41}$$

integration proceeds until

$$\Sigma\, \Delta Z = Z_{sp} - Z_1 \tag{42}$$

Then, $\Sigma\,\Delta\xi$ is compared to TOS for the purpose of iterating on ζ as follows

$$\zeta(t + \Delta t) = \zeta(t) - \frac{(\Sigma\,\Delta\xi - \mathrm{TOS})}{2} \tag{43}$$

until $|\Sigma\,\Delta\xi - \mathrm{TOS}| \leq 0.0001$ radian (0.0057°). This procedure yields an accuracy on ζ of approximately 3×10^{-3} radian (0.17°). The quantities columnar mass and precipitable centimeters of water along this refracted path are calculated, respectively, in the following equations.

$$\int_{r_1'}^{r_{sp}'} \rho\, ds \simeq \Sigma\, \rho \cdot d \tag{44}$$

and

$$\int_{r_1'}^{r_{sp}'} q\rho\, ds \simeq \Sigma\, q\rho d \tag{45}$$

The increments on ΔZ are made to be multiples of 10 smaller than $Z_{sp} - Z_1$, such that

$$Z_{sp} - Z_1 = \Delta Z \cdot i \tag{46}$$

where i is 10, 100, 1000, et cetera and $\Delta Z \leq 0.2$ kilometer.

Subroutine ATMOS3

The subroutine ATMOS3 reproduces the U.S. Standard Atmosphere, 1962 (ref. 1). Subroutine ATMOS3 is called with geometric altitude from which geopotential altitude is calculated. The equations which are subsequently used for ATMOS3 are many of those developed for subroutine MODATM. Equations (3) to (5) and (8) to (15) are common to both subroutines. The main difference between subroutines ATMOS3 and MODATM is that in subroutine ATMOS3, all the significant levels are included in a data statement so that no data cards are necessary, and the output variables are more limited; that is, only the first eight variables in array ANS are available. These variables are pressure, temperature, density, speed of sound, acceleration of gravity, molecular scale temperature, molecular weight, and coefficient of viscosity. The main purpose for including subroutine ATMOS3 is that if atmospheric data above the maximum-altitude radiosonde data are required of subroutine MODATM, then ATMOS3 is automatically called. The main impact subroutine ATMOS3 has on analyses is that if the maximum usable radiosonde altitude is <10 kilometers, significant water vapor will be ignored since the subroutine ATMOS3 includes no water vapor. Instructions on the use of subroutine ATMOS3 are included in comment cards in the subprogram. The computer print-out, including all subroutines, is shown in appendix B.

CONCLUDING REMARKS

It is hoped that this nonpredictive model atmosphere for earth resources applications will fill the need for atmospheric data until predictive postflight or flight models can be developed.

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TABLE I. - LAKE CHARLES, LOUISIANA, RADIOSONDE AND CODE[a]

May 10 1969 0000Z

TT 60004 72240 99016 23266 01008 00146 21467 00512 85517
08463 35017 70118 04273 32033 50577 13571 29543 40743 26569
27572 30946 38567 27590 20217 519// 15400 589// 10650 673//
88999
66280 275950

VV 6000/ 72240 00016 23266 11970 18068 22831 06662 33813
11075 44609 02171 55400 26569 66290 40166 77243 461// 88227
451// 99193 535// 11100 673// 31313 25069 451// /////0

QQ 60000 72240 90012 01008 35512 35007 90346 36009 36013 34524
90789 33530 34031 33031 91246 31535 32539 31534 9205/ 29044
27582 9302/ 27588 275950

2nd Trans

WW 6000/ 72240 70866 661// 50071 633// 30391 551// 20653
497// 10115 411// 07358 403//
88950 681// /////
779990

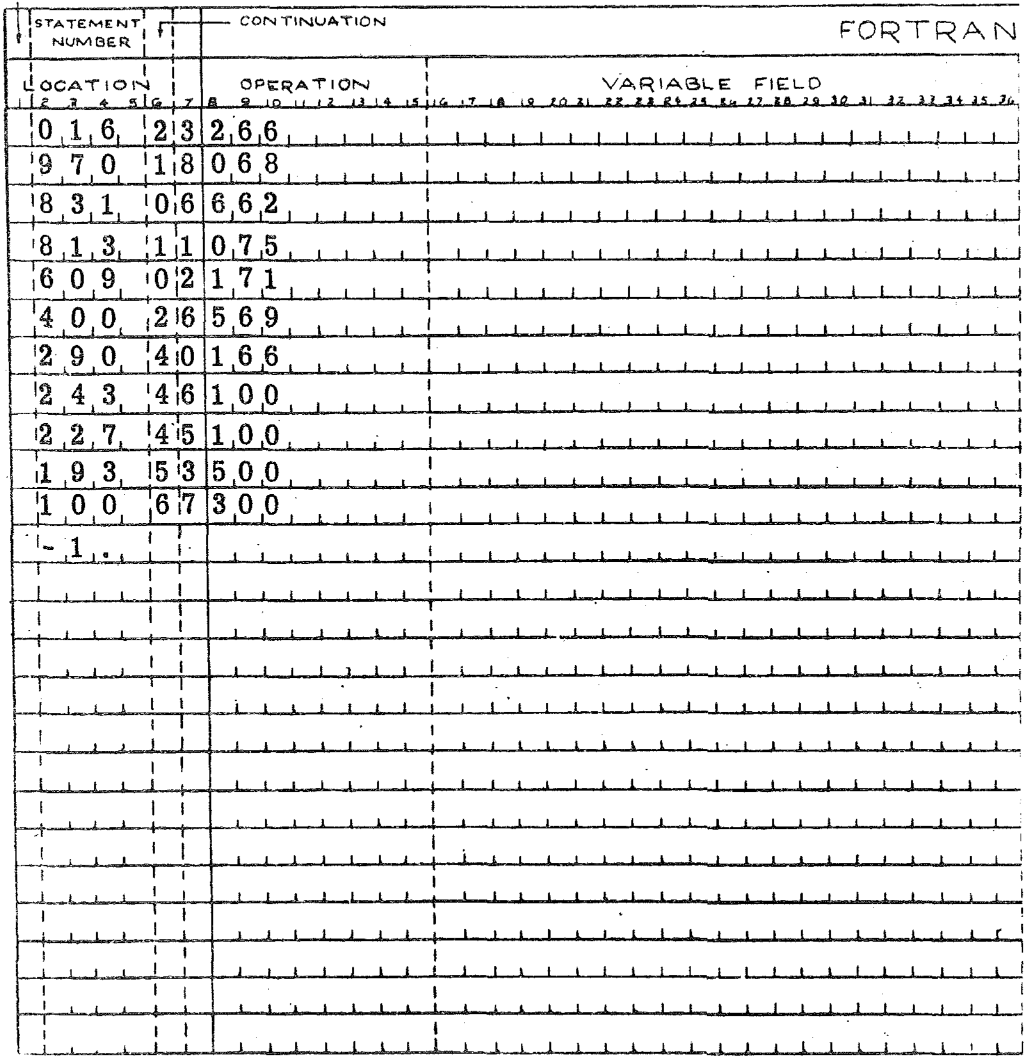
YY 6000/ 72240 11950 681// 22920 657// 33600 665// 44230
511// 55100 411// 66070 403//0

LL 60000 72240 XMTD0

---

[a] The significant level code is VV. For VV, the code is iippp TTTdd where
ii = identifier of a set of data; the two characters are identical (e.g., 00, 11, 22, 33).
ppp = pressure in mbar except the 4th character from the right is suppressed (e.g., 970 = 970 mbar, and 016 = 1016 mbar).
TTT = temperature, + if last digit is even, and - if last digit is odd.
dd = dewpoint temperature. If 00-49, multiply by 0.1 for °C; 50 = 5.0° C; 51-55, not used; 56-99, subtract 50 for °C.
That is, 02 = 0.2, 56 = 6.0, 60 = 10.)
Slashes indicate no data.

TABLE II. - INPUT DATA CARDS FOR LAKE CHARLES, LOUISIANA, RADIOSONDE DATA



FORTRAN

STATEMENT NUMBER / LOCATION	6 7	CONTINUATION / OPERATION	VARIABLE FIELD
016	23	266	
970	18	068	
831	06	662	
813	11	075	
609	02	171	
400	26	569	
290	40	166	
243	46	100	
227	45	100	
193	53	500	
100	67	300	
-1.			

TABLE III. - INPUT DATA CARD FORMAT FOR 15° N ANNUAL MODEL ATMOSPHERE

STATEMENT NUMBER — CONTINUATION — FORTRAN

LOCATION — OPERATION — VARIABLE FIELD

				← Blank Card
0.000E+00	1.013250E+03	299.65	75	
1.000E+03	9.039000E+02	293.65	75	
2.000E+03	8.043000E+02	287.65	75	
2.250E+03	7.809000E+02	286.15	75	
2.500E+03	7.580000E+02	286.95	35	
4.000E+03	6.323000E+02	276.90	35	
6.000E+03	4.911000E+02	263.50	35	
8.000E+03	3.764000E+02	250.10	30	
1.000E+04	2.843000E+02	236.70	20	
	-.100000E-05			

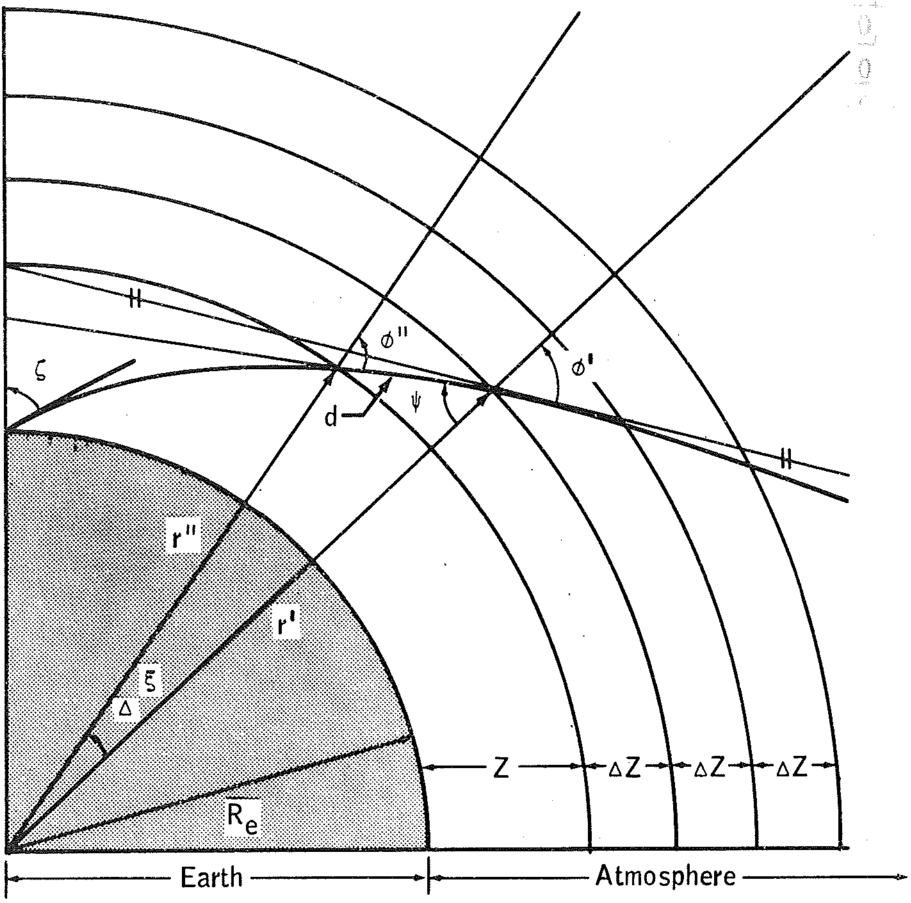


Figure 1. - Refraction-path geometry through a spherically symmetric atmosphere.

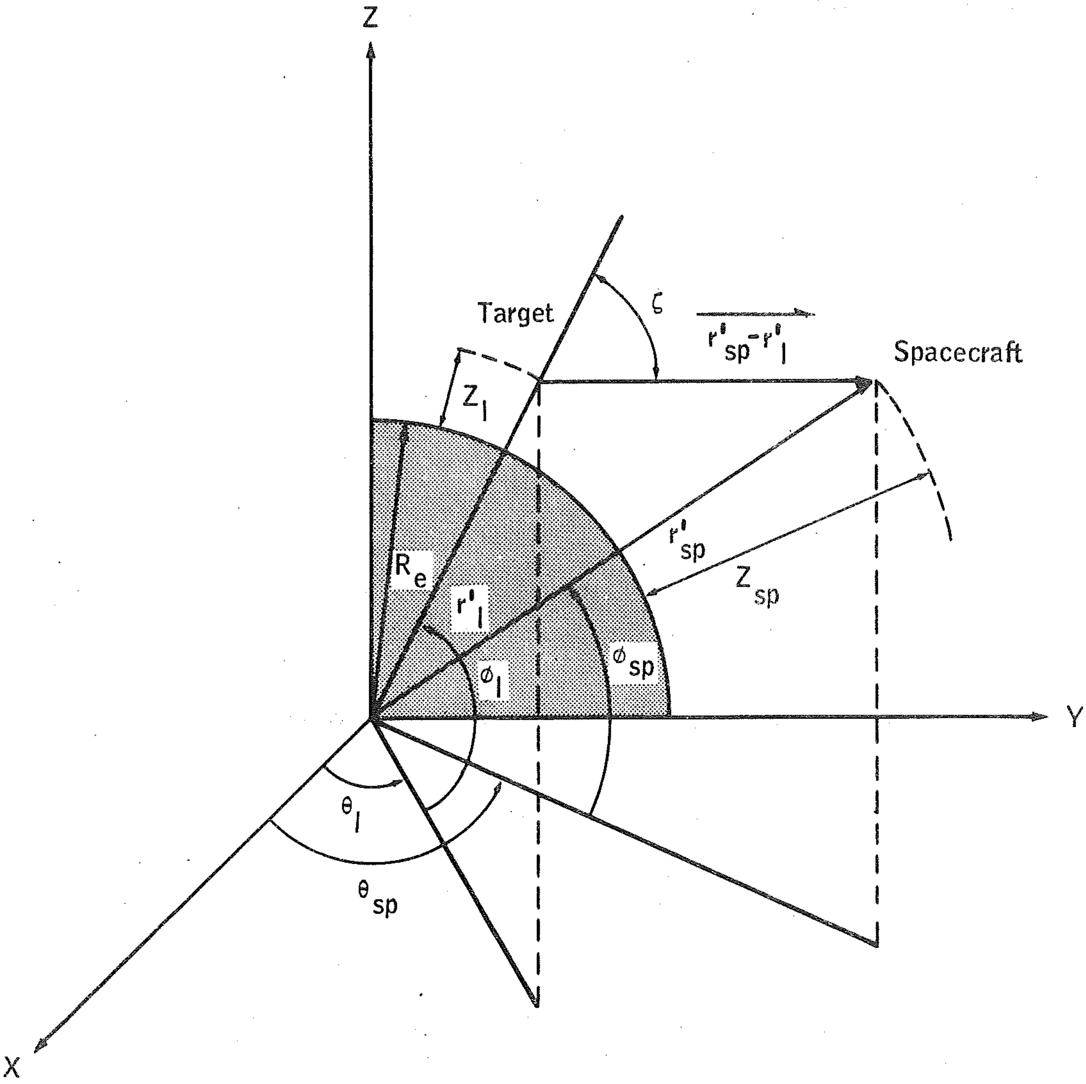


Figure 2. - Resultant vector from the target to the spacecraft in fixed-earth center coordinates.

APPENDIX A

DERIVATION OF VIRTUAL TEMPERATURE T*

The equations of the state of dry air

$$\rho_d = \frac{\left(P - f_w e\right) m_d}{RT} \tag{A1}$$

of water vapor

$$\rho_w = \frac{f_w e m_w}{RT} \tag{A2}$$

and of wet air

$$\rho = \rho_d + \rho_w = \frac{f_w e m_w}{RT} + \frac{\left(P - f_w e\right) m_d}{RT} \tag{A3}$$

can be used with the mass percentage formula for molecular weight

$$m = \frac{100}{\sum_i \frac{M_i}{m_i}} = \frac{\rho}{\frac{\rho_w}{m_w} + \frac{\rho_d}{m_d}} \tag{A4}$$

to give a formula for the relationship of temperature, molecular weight, pressure, and water-vapor pressure

$$m = \frac{\frac{f_w e m_w + \left(P - f_w e\right) m_d}{RT}}{\frac{f_w e + \left(P - f_w e\right)}{RT}} \tag{A5}$$

Equation (A5), when simplified, becomes

$$m = m_d \left[\frac{P + f_w e\left(\frac{m_w}{m_d} - 1\right)}{P} \right] = m_d \left(1 - 0.37803\, \frac{f_w e}{P}\right) \tag{A6}$$

By employing the definition of T^*

$$T^* = \frac{m_d T}{m} \tag{A7}$$

and by using equation (A6), the exact expression for T^* may be found in terms of T, e, and P

$$T^* = \frac{T}{\left(1 - 0.37803\, \frac{f_w e}{P}\right)} \tag{A8}$$

APPENDIX B

SUBROUTINES

```
00101                SUBROUTINE MODATM (Z,PP,TEST,XLAMDA)
00103                DIMENSION H(25),P(25),T(25),TD(25),ANS(35),TV(25)
00104                COMMON ANS
00105                DATA RO/8.31432E+07/,XMO/28.9664/,BETA/1.458E-06/,S/110.4/,RE/6.37
00105               11299E+03/,G/980.665/,CONN/-3.41631947E-02/
00105          C
00105          C**********************************************************************
00105          C
00105          C Z IS IN KM, PP IS IN MB
00105          C ANS IS OUTPUT VARIABLES
00105          C XLAMDA IS THE WAVELENGTH IN MICRONS FOR WHICH YOU ARE CALCULATING
00105          C     ATMOSPHERIC REFRACTION
00105          C IF TEST .EQ. PRES THEN PRESSURE IS USED AS HEIGHT INDICATOR
00105          C IF TEST.NE. PRES THEN GEOMETRIC ALTITUDE (KM) IS HEIGHT INDICATOR
00105          C     YOU MUST SET ANS(1)=-1.0 BEFORE ENTERING THE SUBROUTINE THE FIRST TIME
00105          C RO IS THE UNIVERSAL GAS CONSTANT BASED ON THE CARBON 12 ATOMIC WEIGHT
00105          C     SCALE IN ERGS/(DEG KELVIN-GM-MOLE)
00105          C XMO IS MOLECULAR WEIGHT OF AIR CALCULATED FROM THE COMPOSITION OF DRY
00105          C     AIR USING THE CARBON 12 ATOMIC WEIGHT SCALE.  FOUND IN THE U. S.
00105          C     STANDARD ATMOSPHERE 1962, PAGE 9.  GIVEN IN GM/(GM-MOLE)
00105          C BETA IS A CONSTANT USED IN SUTHERLAND'S VISCOSITY EQUATION.  GIVEN IN
00105          C     KG/SEC-M-(DEG KELVIN**1/2)
00105          C S IS SUTHERLAND'S CONSTANT IN DEG. KELVIN
00105          C RE = THE MEAN RADIUS OF THE EARTH IN METERS AS GIVEN BY THE SMITHSONIAN
00105          C     METEOROLOGICAL TABLES, SIXTH EDITION, PUBLICATION 4014, R. J.
00105          C     LIST, 1966
00105          C G IS ACCELERATION OF GRAVITY AT 0 EQUIPOTENTIAL SURFACE LEVEL GIVEN IN
00105          C     CM/SEC**2
00105          C CONN IS A CONSTANT GIVEN AS -M*G/RO WHERE M IS MASS AND G AND RO ARE AS ABOVE
00105          C
00105          C**********************************************************************
00105          C
```

```
00105    C THE FOLLOWING IS AN EXAMPLE OF A CALLING PROGRAM FOR MODATM AND PATH
00105    C      DIMENSION ANS(35)
00105    C      COMMON ANS
00105    C      XLAMDA=.6
00105    C      ZS=20.0
00105    C      PHIS=30.0
00105    C      THETAS=90.0
00105    C      ZL=0.0
00105    C      PHIL=30.0
00105    C      THETAL=90.0
00105    C      CALL PATH  (XLAMDA,ZS,PHIS,THETAS,ZL,PHIL,THETAL)
00105    C      WRITE (6,3) (ANS(K),K=21,23)
00105    C    3 FORMAT (1X,///,1X,1P3E14.4)
00105    C      TEST=4HPRES
00105    C      DO 1 I=1,20
00105    C      Z=I
00105    C      PP=1000.0-Z*50.
00105    C      CALL MODATM (Z,PP,TEST,XLAMDA)
00105    C    1 WRITE (6,2) TEST,Z,(ANS(N),N=1,24)
00105    C    2 FORMAT (1X,A4,4X,1P12E9.3,/,1P13E9.3,//)
00105    C      CALL EXIT
00105    C      END
00105    C
00105    C*************************************************************************************
00105    C
00115           CT=288.15/273.16+1.0
00115    C CT IS 1.0 + RATIO OF SURFACE TEMPERATURE TO ICE TEMPERATURE
00116           IF(ANS(1).GE.0.0) GO TO 15
00120           ANS(1)=0.0
00121           CALL INPUT (P,T,TD,H,TV,M)
00122        15 IF (TEST.EQ.4HPRES) GO TO 7
00124           HA= RE*Z/(RE+Z)*1000.0
00124    C HA IS GEOPOTENTIAL ALTITUDE IN METERS
00125        23 DO 11 I=1,M
00130           II=I
00131           IF(H(I)-HA) 11,12,13
00134        11 CONTINUE
00136         9 CALL ATMOS3(Z)
00137           ANS(9)=0.0
00140           GO TO 52
00141        13 I=II-1
00142           DH=H(I+1)-H(I)
00143           D=(TV(I+1)-TV(I))/DH
```

```
00144     76*          W=(T(I+1)-T(I))/DH
00145     77*          DW=(TD(I+1)-TD(I))/DH
00146     78*          DH=H(I)-HA
00146     79*     C
00146     80*     C*************************************************************************
00146     81*     C
00146     82*     C HEIGHT 'H' IS IN METERS
00146     83*     C HEIGHT 'Z' IS IN KM
00146     84*     C
00146     85*     C ANS( 1) IS PRESSURE
00146     86*     C PRESSURE IS IN MB
00146     87*     C
00146     88*     C ANS( 2) IS TEMPERATURE
00146     89*     C TEMPERATURE IS IN DEG KELVIN
00146     90*     C
00146     91*     C ANS( 3) IS DENSITY
00146     92*     C DENSITY IS IN GM/CC
00146     93*     C
00146     94*     C ANS( 4) IS SPEED OF SOUND
00146     95*     C SPEED OF SOUND IS IN M/SEC
00146     96*     C
00146     97*     C ANS( 5) IS ACCELERATION OF GRAVITY
00146     98*     C ACCELERATION OF GRAVITY IS IN CM/SEC**2
00146     99*     C
00146    100*     C ANS( 6) IS VIRTUAL TEMPERATURE
00146    101*     C TEMPERATURE IS IN DEG KELVIN
00146    102*     C
00146    103*     C ANS( 7) IS MOLECULAR WEIGHT
00146    104*     C
00146    105*     C ANS( 8) IS COEFFICIENT OF VISCOSITY
00146    106*     C VISCOSITY IS IN KG /(M SEC)
00146    107*     C
00146    108*     C ANS( 9) IS DEW POINT TEMPERATURE
00146    109*     C TEMPERATURE IS IN DEG KELVIN
00146    110*     C
00146    111*     C ANS(10) IS MIXING RATIO R
00146    112*     C MIXING RATIO IS IN PARTS/THOUSAND     I.E. (0/00)  GM/KG
00146    113*     C
00146    114*     C ANS(11) IS SATURATION MIXING RATIO RS
00146    115*     C SATURATION MIXING RATIO IS IN PARTS/THOUSAND I.E. (0/00) GM/KG
00146    116*     C
00146    117*     C ANS(12) IS RELATIVE HUMIDITY
```

```
00146     C RELATIVE HUMIDITY IS IN PERCENT (0/0)
00146     C
00146     C ANS(13) IS SPECIFIC HUMIDITY
00146     C SPECIFIC HUMIDITY IS IN GM/KG
00146     C
00146     C ANS(14) IS SATURATION SPECIFIC HUMIDITY
00146     C SATURATION SPECIFIC HUMIDITY IS IN GM/KG
00146     C
00146     C ANS(15) IS PRESSURE SCALE HEIGHT
00146     C PRESSURE SCALE HEIGHT IS IN KM
00146     C
00146     C ANS(16) IS DENSITY SCALE HEIGHT
00146     C DENSITY SCALE HEIGHT IS IN KM
00146     C
00146     C ANS(17) IS REFRACTIVE INDEX DEVELOPED BY EDLEN IN TERMS OF WAVELENGTH ALONE
00146     C INDEX IS FOR AIR AT 288 DEG KELVIN AND 760MM HG
00146     C
00146     C ANS(18) IS REFRACTIVE INDEX DEVELOPED BY PENNDORF IN TERMS OF
00146     C     WAVELENGTH, TEMPERATURE, AND PRESSURE
00146     C
00146     C ANS(19) IS THE WATER VAPOR PRESSURE IN MB
00146     C
00146     C ANS(20) IS THE SATURATION WATER VAPOR PRESSURE IN MB
00146     C
00146     C ANS(21) IS THE ZENITH ANGLE FROM GROUNDSTATION IN RADIANS
00146     C
00146     C ANS(22) = THE TOTAL GM/CM**2 OR COLUMNAR MASS ALONG THE SLANT PATH.
00146     C
00146     C ANS(23) = TOTAL GM/CM**2 OF WATER VAPOR ALONG THE SLANT PATH.  IT IS
00146     C     EQUIVALENT TO PRECIPITABLE CM OF WATER
00146     C
00146     C ANS(24) = TOTAL PATH LENGTH IN CM
00146     C
00146     C ANS(21) THRU ANS(24) ARE CALCULATED IN SUBROUTINE PATH.
00146     C
00146     C**********************************************************************
00146     C
00147           ANS(2)=T(I)-W*DH
00150           ANS(6)=TV(I)-D*DH
00151           ANS(9)=TD(I)-DW*DH
00152           ANS(1)=PRES(P(I),D,TV(I),ANS(6),DH)
00153           GO TO 14
```

```
00154         12 I=I1
00155            ANS(1)=P(I)
00156            ANS(2)=T(I)
00157            ANS(6)=TV(I)
00160            ANS(9)=TD(I)
00161         14 ANS(5)=G*(RE/(RE+Z))**2
00162            ANS(3)=ANS(1)*XMO/(RO*ANS(6))*1000.0
00163            ANS(4)=SQRT(1.4*RO*ANS(6)/XMO)/100.0
00164            ANS(7)=XMO*ANS(2)/ANS(6)
00165            ANS(8)=BETA*(SQRT(ANS(2)))**3/(ANS(2)+S)
00166         52 ANS(19)=E(ANS(9))
00167            ANS(20)=E(ANS(2))
00170            ANS(10)=R(ANS(19),ANS(1),ANS(2))
00171            ANS(11)=R(ANS(20),ANS(1),ANS(2))
00172            ANS(12)=(ANS(10)/ANS(11))*100.0
00173            ANS(13)=Q(ANS(1),ANS(9))
00174            ANS(14)=Q(ANS(1),ANS(2))
00175            ANS(15)=RO*ANS(6)/(XMO*ANS(5))*1.0E-05
00176            ANS(16)=ANS(15)/(1.0+RO/(XMO*ANS(5))*D*.01)
00177            IF (XLAMDA.GE.12500.00) GO TO 30
00177      C THIS MEANS IF XLAMDA IS .GE. 1.25 CM USE MICROWAVE REFRACTIVITY
00201            ANS(17)=1.0+1.0E-08*(6432.8+2949810./(146.-1./(XLAMDA**2))+25540./
00201           1(41.-1./(XLAMDA**2)))
00202            ANS(18)=1.0+(ANS(17)-1.0)*(CT/(1.0+ANS(2)/273.16))*ANS(1)/1013.25
00203            GO TO 31
00204         30 ANS(18) =1.0+1.0E-06*(77.6*ANS(1)/(ANS(2))+373000.0*ANS(19)/(ANS(2
00204           1)**2))
00205            ANS(17)=ANS(18)
00206         31 RETURN
00207          7 DO 16 I=1,M
00207      C     PRESSURE
00212            II=I
00213            IF(PP-P(I)) 16,41,17
00216         16 CONTINUE
00220            HA=0.0
00221            DHA=100.0
00222         51 DO 48 I=1,11
00225            HA=HA+DHA
00226            CALL ATMOS3(HA)
00227            IF (ANS(1).LE.0.0) GO TO 42
00231            IF (ANS(1) .LT. PP) GO TO 49
00233         48 CONTINUE
00235         42 DO 10 I=2,35
00240            IF (I.EQ.21.OR.I.EQ.22.OR.I.EQ.23.OR.I.EQ.24)  GO TO 10
00242            ANS(I)=0.0
00243         10 CONTINUE
```

```
00245   206*          ANS(17)=1.0
00246   207*          ANS(18)=1.0
00247   208*          Z=HA
00250   209*          RETURN
00251   210*       41 Z=H(II)*RE/(1000.0*(RE-H(II)/1000.0))
00252   211*          GO TO 12
00253   212*       49 IF (ABS(ANS(I)-PP) .LE. (.001*PP)) GO TO 50
00255   213*          HA=HA-DHA
00256   214*          DHA=DHA/10.0
00257   215*          GO TO 51
00260   216*       50 Z=HA
00261   217*          GO TO 9
00262   218*       17 I=II-1
00263   219*          D=TV(I+1)-TV(I)
00264   220*          IF(D) 20,21,20
00267   221*       20 D=CONN/ALOG(P(I+1)/P(I))*ALOG(TV(I+1)/TV(I))
00270   222*          ANS(6)=TV(I)*(PP/P(I))**(D/CONN)
00271   223*          HA=H(I)+(ANS(6)-TV(I))/D
00272   224*          GO TO 22
00272   225*    C HA IS IN METERS
00273   226*       21 HA=H(I)+TV(I)*ALOG(PP/P(I))/CONN
00274   227*       22 Z=HA*RE/(1000.0*(RE-HA/1000.0))
00275   228*          GO TO 23
00276   229*          END

          END OF UNIVAC 1108 FORTRAN V COMPILATION.     0 *DIAGNOSTIC* MESSAGE(S)
```

```
00101               SUBROUTINE ATMOS3 (Z)
00101         C SUBROUTINE FOR THE 1962 STANDARD
00101         C Z IS ALTITUDE IN KM
00103               DIMENSION H(23),T(23),P(23),ANS(35),A(23),ZZ(23)
00104               COMMON ANS
00105               DATA H/-5000.,0.0,11000.0,20000.0,32000.0,47000.0,52000.0,61000.0,
00105              179000.,88744.2,98452.,108129.8,117777.7,146543.8,156073.6,165574.3
00105              2,184488.55,221972.686,286486.49,376331.361,463556.85,548275.86,
00105              2630594.90/,T/320.65
00105              3,288.15,216.65,216.65,228.65,270.65,270.65,252.65,180.65,180.65,
00105              4210.65,260.65,360.65,960.65,1110.65,1210.65,1350.65,1550.65,1830.6
00105              55,2160.65,2420.65,2590.65,2700.65/,P/1.77687E+03,1.01325E+03,
00105              62.26320E+02,5.47487E+01,8.68014,1.10905,5.90005E-01,1.82099E-01,
00105              71.0377E-02,1.6438E-03,3.0075E-04,7.3544E-05,2.5217E-05,5.0617E-06,
00105              83.6943E-06,2.7926E-06,1.6852E-06,6.9604E-07,1.8838E-07,4.0304E-08,
00105              91.0957E-08,3.4502E-09,1.1918E-09/ ,A/320.650,
00105              1 288.15,216.65,216.65,228.65,270.65,270.65,252.65,180.65,180.65,
00105              2 210.02,257.0,349.49,892.79,1022.2,1105.5,1205.5,1321.7,1432.1,
00105              31487.4,1499.2,1506.1,1507.6/ ,ZZ/ -5000.,0.0,11000.,20000.,32000.,
00105              447000.,52000.,61000.,79000.,90000.,100000.,110000.,120000.,150000.
00105              5,160000.,170000.,190000.,230000.,300000.,400000.,500000.,600000.,
00105              6700000./
00113               DATA S/110.4/,CONN/-3.41631947E-02/,RE/6.36E+06/
00113         C
00113         C**********************************************************************************
00113         C
00113         C ZZ IS THE GEOMETRIC ALTITUDE FOR BREAKPOINTS ABOVE 90 KM
00113         C H(I) IS THE ALT IN GEOPOTENTIAL METERS FOR SIGNIFICANT LEVELS
00113         C D IS THE TEMPERATURE GRADIENT IN THE VERTICAL (DEG/GEOPM)
00113         C T(I) IS THE MOLECULAR SCALE TEMPERATURE AT A SIGNIFICANT LEVEL
00113         C A(I) IS THE KINETIC TEMPERATURE AT THE SIGNIFICANT LEVELS
00113         C P(I) IS THE PRESSURE IN LB/FT**2.  ACTUALLY IT WONT MATTER AND PRESSURE CAN
00113         C      BE IN ANY SET OF UNITS SINCE ONLY THE RATIO AT VARIOUS ALTITUDES RELATIVE
00113         C      TO P(2) IS USED
00113         C ANS(1) IS THE RATIO OF PRESSURES (P/PSL)
00113         C ANS(1)*1.01325E+03 FOR PRES IN MB
00113         C ANS(2) IS THE RATIO OF TEMPERATURE (T/TSL)
00113         C ANS(2)*288.15 FOR TEMP IN DEG K
00113         C ANS(3) IS THE RATIO OF DENSITIES
00113         C ANS(3)*1.225E-03 FOR DENSITY IN GM/CC
00113         C ANS(4) IS THE RATIO OF SPEED OF SOUND  (C/CSL)
00113         C ANS(4)*340.294 FOR SPEED OF SOUND IN M/SEC
00113         C ANS(5) IS THE ACCELERATION OF GRAVITY (G/GSL)
```

```
00113     C ANS(5)*980.665 FOR ACC UF GRAVITY IN CM/(SEC**2)
00113     C ANS(6) IS THE RATIO OS MOLECULAR SCALE TEMPERATURE
00113     C ANS(6)*288.15 FOR TEMP IN DEG K
00113     C ANS(7) IS THE MOLECULAR WEIGHT
00113     C ANS(8) IS THE RATIO OF COEF OF VISCOSITY (MU/MUSL)
00113     C ANS(8)*1.7894E-05 TO COEF IN KM/M-SEC
00113     C W IS THE VERTICAL KINETIC TEMPERATURE GRADIENT
00113     C THIS RADIUS 'RE' IS CHOSEN TO AGREE WITH THE U S STANDARD AT 40 KM, BUT IT
00113     C      ALSO IS A BEST FIT TO ALL LEVELS BELOW 90 KM.  ABOVE 90 KM THE LEVELS
00113     C      THAT ARE BREAK POINTS WERE CALCULATED FROM GEOMETRIC TO GEOP USING 'RE'
00113     C
00113     C************************************************************************
00113     C
00117           Z=Z*1000.0
00120           IF (Z-700000.0) 10,50,50
00123        10 CONTINUE
00124           HA=RE*Z/(RE+Z)
00125           ANS(5)=RE**2/((RE+Z)**2)
00126           DO 1 M=1,23
00131           I=M
00132           IF (H(I)-HA) 1,2,3
00135         1 CONTINUE
00137           GO TO 50
00140         3 I=I-1
00141           D=(T(I+1)-T(I))/(H(I+1)-H(I))
00142           W=(A(I+1)-A(I))/(H(I+1)-H(I))
00143           GO TO 4
00144         2 ANS(6)=T(I)/T(2)
00145           ANS(2)=A(I)/A(2)
00146           D=(T(I+1)-T(I))/(H(I+1)-H(I))
00147           GO TO 5
00150         4 IF (90000.0-Z) 7,7,9
00153         7 ANS(6)=(T(I)-(T(I+1)-T(I))/(ZZ(I+1)-ZZ(I))*(ZZ(I)-Z))/T(2)
00154           ANS(2)=(A(I)-(A(I+1)-A(I))/(ZZ(I+1)-ZZ(I))*(ZZ(I)-Z))/A(2)
00155           GO TO 5
00156         9 ANS(6)=(T(I)-D*(H(I)-HA))/T(2)
00157           ANS(2)=(A(I)-W*(H(I)-HA))/A(2)
00160         5 IF (90000.0-Z ) 8,6,6
00163         6 ANS(7)=28.9644
00164           GO TO 11
00165         8 ANS(7)=28.9644*ANS(2)/ANS(6)
00166        11 ANS(4)= SQRT(ANS(6))
```

```
00167     86*          ANS(8)=((T(2)+S)/(ANS(2)*T(2)+S))*SQRT((ANS(2))**3)
00170     87*          IF (D) 12,13,12
00173     88*       12 CONN=D*ALOG(P(I+1)/P(I))/(ALOG(T(I+1)/T(I)))
00174     89*          ANS(1)=P(I)/P(2)*(ANS(6)*T(2)/T(I))**(CONN/D)
00175     90*          GO TO 14
00176     91*       13 CONN=ALOG(P(I+1)/P(I))/(H(I+1)-H(I))*T(I)
00177     92*          ANS(1)=P(I)/P(2)* EXP(CONN*((HA-H(I))/(ANS(6)*T(2))))
00200     93*       14 ANS(3)=ANS(1)/ANS(6)
00201     94*          ANS(1)=ANS(1)*1.01325E+03
00202     95*          ANS(2)=ANS(2)*288.15
00203     96*          ANS(3)=ANS(3)*1.225E-03
00204     97*          ANS(4)=ANS(4)*340.294
00205     98*          ANS(5)=ANS(5)*980.665
00206     99*          ANS(6)=ANS(6)*288.15
00207    100*          ANS(8)=ANS(8)*1.7894E-05
00210    101*          Z=Z/1000.0
00211    102*          GO TO 53
00212    103*       50 DO 51 I=1,8
00215    104*       51 ANS(I)=0.0
00217    105*       53 RETURN
00220    106*          END

     END OF UNIVAC 1108 FORTRAN V COMPILATION.      0 *DIAGNOSTIC* MESSAGE(S)
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```
00101            SUBROUTINE INPUT (P,T,TD,H,TV,M)
00103            DIMENSION P(1),T(1),TD(1),H(1),TV(1)
00103      C
00103      C*****************************************************************
00103      C
00103      C THIS INPUT SUBROUTINE IS SET UP TO TAKE STANDARD PRINTOUT OF CODE VV ,
00103      C     (IE SIGNIFICANT LEVELS OF A RADIOSONDE) AND SET ALTITUDES, VIRTUAL TEMP,
00103      C     DEWPOINT TEMPERATURES, AND AMBIENT TEMPERATURES OR IF A BLANK CARD
00103      C     PRECEEDS THE DATA THE INPUT DATA IS OF THE FORM HEIGHT, PRESSURE,
00103      C     TEMPERATURE, AND RELATIVE HUMIDITY
00103      C
00103      C*****************************************************************
00103      C
00104            CONDE=5H
00105            NSATI=5H
00106            ON=5H
00107            M=0
00110            H(1)=0.0
00111            WRITE (6,25)
00113         25 FORMAT (1X,41X,'EARTH RESOURCES MODEL ATMOSPHERE,1969',
00113           1 ,//,        29X,'THE SIGNIFICANT LEVELS FOR THE MODEL ATMOSPHERE
00113           2ARE AS FOLLOWS',//,34X,'ALT',10X,'PRES',10X,'TEMP',9X,'TD',11X
00113           3,'TV',/,34X,'(M)',10X,'(MB)',10X,'(K)',10X,'(K)',10X,'(K)',/)
00113      C
00113      C*****************************************************************
00113      C
00113      C THIS SECTION INPUTS CODED DATA
00113      C
00114            DO 1 I=1,25
00117            READ(5,3) P(I),T(I),TD(I)
00117      C THIS IS THE FORMAT FOR READING RADIOSONDE DATA
00124      3     FORMAT(1X,F3.0,1X,F3.0,F2.0)
00124      C ALTITUDE IN METERS
00124      C PRESSURE IN MB
00124      C T AND TD IN DEG KELVIN
00125            IF (P(I).LE.0.0.AND.T(I).LE.0.0.AND.TD(I).LE.0.0) GO TO 11
00127            IF (P(I).LE.0.0) GO TO 2
00131            M=M+1
00132            IF(I .EQ. 1 .AND. P(I) .LT. 1000.0) P(I)=P(I)+1000.0
00134            IF (AMOD(T(I),2.0).GT.0.01) T(I)=-T(I)
00136            T(I)=T(I)*.1
00137            IF (TD(I) .GT. .01 .AND. TD(I) .LE. 50.0) TD(I)=TD(I)*.1
00141            IF(TD(I) .GE. 51.0 .AND. TD(I) .LE. 55.0) WRITE(6,4)
00144          4 FORMAT(1X,'INVALID TD INPUT DATA')
```

```
00145          IF (TD(I) .GE. 56.0  .AND. TD(I) .LE. 99.0) TD(I)=TD(I)-50.0
00147          IF (TD(I).LE..01) TD(I)=T(I)+273.16
00151          TD(I)=T(I)-TD(I)
00152          T(I)=T(I)+273.16
00153          TD(I)=TD(I)+273.16
00154        1 CONTINUE
00156          GO TO 2
00156    C
00156    C***********************************************************************
00156    C
00156    C THIS SECTION INPUTS NON-CODED DATA
00156    C
00157       11 M=0
00160          DO 12 I=1,25
00160    C  THIS IS THE FORMAT FOR READING SIGNIFICANT LEVELS IN NON-CODED FORM
00163          READ (5,13) H(I),P(I),T(I),TD(I)
00171       13 FORMAT (E9.3,E12.6,F7.2,F3.0)
00171    C TD(I) HERE, IS RELATIVE HUMIDITY UNTIL A TD(I) IS FOUND BY ITERATION
00172          DELT=100.0
00173          GUESS=50.0
00174          RI=R(E(T(I)),P(I),T(I))
00175     992 DO 990 L=1,11
00200          GUESS=GUESS+DELT
00201          REL=R(E(GUESS),P(I),GUESS)*100.0/RI
00202          Q=REL-TD(I)
00203          IF (Q) 990,991,995
00206     990 CONTINUE
00210          CALL EXIT
00211     995 GUESS=GUESS-DELT
00212          DELT=DELT/10.0
00213     991 IF (ABS(Q).GT..01) GO TO 992
00215          TD(I)=GUESS
00216          IF (P(I).LE.0.0) GO TO 2
00220          M=M+1
00221       12 CONTINUE
00221    C
00221    C***********************************************************************
00221    C
00223        2 DO 5 I=1,M
00226          IF(TD(I) .LE. 0.0) GO TO 7
00230          TV(I)=T(I)/(1.0-(0.37803*E(TD(I))*F(P(I),T(I))/P(I)))
00231          GO TO 5
00232        7 TV(I)=T(I)
00233        5 CONTINUE
```

```
00235     89*          DO 26 I=M,25
00240     90*          H(I)=H(M)
00241     91*       26 P(I)=P(M)
00243     92*          DO 6 I=1,M
00246     93*          IF (ABS(T(I)-TD(I)).GT.1.0+H(I)*.000777) GO TO 27
00250     94*          CONDE=5HCONDE
00251     95*          NSATI=5HNSATI
00252     96*          ON=5HON
00253     97*       27 WRITE (6,24) H(I),P(I),T(I),TD(I),TV(I),CONDE,NSATI,ON
00265     98*       24 FORMAT (26X,1P2E13.3,0P3F13.2,1X,3A5)
00266     99*          IF (CONDE.EQ.5H      ) GO TO 6
00270    100*          CONDE=5H
00271    101*          NSATI=5H
00272    102*          ON=5H
00273    103*        6 CONTINUE
00275    104*          WRITE (6,86)
00277    105*       86 FORMAT (//)
00300    106*          RETURN
00301    107*          END

      END OF UNIVAC 1108 FORTRAN V COMPILATION.      0 *DIAGNOSTIC* MESSAGE(S)
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```
00101      1*          SUBROUTINE REFRAC (Z1,Z2,XLAMDA,PHI,PHIPR,PSI,SLANT)
00103      2*          DIMENSION ANS(35)
00104      3*          COMMON ANS
00105      4*          DATA RE/6371.299/
00105      5*    C
00105      6*    C**********************************************************************
00105      7*    C
00105      8*    C IN ORDER TO CALCULATE A CONTINUOUS PATH YOU MUST EXTERNALLY SET  PHI=PHIPR
00105      9*    C Z1, Z2, PHI, AND XLAMDA ARE INPUT VARIABLES
00105     10*    C Z1 AND Z2 ARE IN KM  AND XLAMDA IS IN MICRONS
00105     11*    C PHIPR, PSI, AND SLANT ARE OUTPUT VARIABLES
00105     12*    C PHI, PHIPR, AND PSI ARE IN RADIANS  AND SLANT IS IN CM
00105     13*    C IF YOU WANT AMOUNT OF GM/CM**2 (COLUMNAR MASS) OF ATMOSPHERE FROM Z1 TO Z2
00105     14*    C      USE ANS(3)*SLANT.   GM/CM**2 OF WATER IS ANS(3)*SLANT*ANS(13)/1000.0.
00105     15*    C      SINCE ALL ANS ARRAY IS IN COMMON, YOU CAN DO THIS EXTERNALLY.
00105     16*    C
00105     17*    C**********************************************************************
00105     18*    C
00107     19*          S1=RE+Z1
00110     20*          S2=RE+Z2
00111     21*          DELT=(Z2-Z1)/2.0
00112     22*          CALL MODATM(Z2+DELT,PP,4HALTI,XLAMDA)
00113     23*          D2=ANS(3)
00114     24*          XN2=ANS(18)
00115     25*          CALL MODATM (Z1+DELT,PP,4HALTI,XLAMDA)
00116     26*          D1=ANS(3)
00117     27*          XN1=ANS(18)
00120     28*          PSI=SININV(S1*SIN(PHI)/S2)
00121     29*          PHIPR=SININV(S1*SIN(PHI)*XN1/(S2*XN2))
00122     30*          SLANT=S1*SIN(PHI-PSI)/SIN(PSI)*1.0E+05
00123     31*          RETURN
00124     32*          END

        END OF UNIVAC 1108 FORTRAN V COMPILATION.     0 *DIAGNOSTIC* MESSAGE(S)
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```
00101         SUBROUTINE PATH (XLAMDA,ZS,PHIS,THETAS,ZL,PHIL,THETAL)
00103         DIMENSION ANS(35),A(3,3),B(3),C(3)
00104         COMMON ANS
00105         DATA PI/3.14159265/,CON/.0174532925/,RE/6371.299/
00105   C
00105   C**********************************************************************
00105   C
00105   C QUANTITIES ENDING IN S ARE FOR THE SATELLITE
00105   C QUANTITIES ENDING IN L ARE FOR THE GROUND LOCAL
00105   C -Q1- AND -Q2- ARE DUMMY VARIABLES
00105   C -XS, YS, AND HS- ARE THE RECTANGULAR COORDINATES OF THE SPACECRAFT
00105   C -XL, YL, AND HL- ARE THE RECTANGULAR COORDINATES OF THE GROUND LOCAL
00105   C THE ANGLE ABD IS THE ANGLE BETWEEN THE SUBSATELLITE POINT AND TARGET.
00105   C ANGLE ABD IS FOUND BY USING THE DOT PRODUCT AND TAKING THE INVERSE COS
00105   C .0092833 RADIANS IS THE TOTAL REFRACTION ON A PASS THRU U.S. STANDARD
00105   C .SUM. IS THE TOTAL ANGLE CHANGE DURING REFRACTION
00105   C 'SUM1' IS THE SUM OF ALL DELTA XI CALCULATED BY LAW OF SINES
00105   C 'SUM2' IS PRECIPITABLE CM OF WATER OR GM/CM**2 OF WATER VAPOR
00105   C 'SUM3' IS THE TOTAL COLUMNAR MASS IN THE SLANT PATH
00105   C 'SUM4' IS THE TOTAL SLANT PATH IN CM
00105   C PHI IS IN RADIANS
00105   C
00105   C ANS(21) IS THE ZENITH ANGLE FROM GROUNDSTATION IN RADIANS
00105   C
00105   C ANS(22) = THE TOTAL GM/CM**2 OR COLUMNAR MASS ALONG THE SLANT PATH.
00105   C
00105   C ANS(23) = TOTAL GM/CM**2 OF WATER VAPOR ALONG THE SLANT PATH.  IT IS
00105   C      EQUIVALENT TO PRECIPITABLE CM OF WATER.
00105   C
00105   C ANS(24) = TOTAL PATH LENGTH IN CM
00105   C
00105   C**********************************************************************
00105   C
00111         PHIS=PHIS*CON
00112         THETAS=THETAS*(-CON)
00113         PHIL=PHIL*CON
00114         THETAL=THETAL*(-CON)
00115         DELT =ABS(ZL-ZS)
00116         DO 80 I=1,32000
00121         DELT=DELT/10.0
00122         L=I
00123         IF(DELT.LE.2.0) GO TO 81
00125      80 CONTINUE
00127         CALL EXIT
```

```
00130    45*       81 IF (L.LE.1) DELT=DELT/10.0
00132    46*          ANS(1)=-1.0
00133    47*          Q1=RE+ZS
00134    48*          Q2=COS(PHIS)
00135    49*          XS=Q1*COS(THETAS)*Q2
00136    50*          YS=Q1*SIN(THETAS)*Q2
00137    51*          HS=Q1*SIN(PHIS)
00140    52*          Q2=COS(PHIL)
00141    53*          Q1=RE+ZL
00142    54*          XL=Q1*COS(THETAL)*Q2
00143    55*          YL=Q1*SIN(THETAL)*Q2
00144    56*          HL=Q1*SIN(PHIL)
00145    57*          ABD=COSINV(((XS*XL)+(YS*YL)+(HS*HL))/(SQRT(XS**2+YS**2+HS**2)
00145    58*         1*SQRT(XL**2+YL**2+HL**2)))
00146    59*          DO 3 I=1,3
00151    60*        3 C(I)=0.0
00151    61*     C FROM HERE TO STATEMENT 4 FINDS THE VECTOR (C) FROM THE TARGET TO THE
00151    62*     C    SATELLITE
00153    63*          A(1,1)=SIN(PHIL)*COS(THETAL)
00154    64*          A(2,1)=-SIN(THETAL)
00155    65*          A(3,1)=COS(PHIL)*COS(THETAL)
00156    66*          A(1,2)=SIN(PHIL)*SIN(THETAL)
00157    67*          A(2,2)=COS(THETAL)
00160    68*          A(3,2)=COS(PHIL)*SIN(THETAL)
00161    69*          A(1,3)=-COS(PHIL)
00162    70*          A(2,3)=0.0
00163    71*          A(3,3)=SIN(PHIL)
00164    72*          B(1  )=XS-XL
00165    73*          B(2  )=YS-YL
00166    74*          B(3  )=HS-HL
00167    75*          DO 4 I=1,3
00172    76*          DO 4 M=1,3
00175    77*        4 C(I)=A(I,M)*B(M)+C(I)
00200    78*          PHIL=PHIL/CON
00201    79*          THETAL=THETAL/(-CON)
00202    80*          PHIS=PHIS/CON
00203    81*          THETAS=THETAS/(-CON)
00204    82*          PHI=ATAN2(SQRT(C(1)**2+C(2)**2),C(3))
00205    83*          IF (PHI.GT..017)PHI=PHI-.0092833
00207    84*          IF (PHI/CON.GT.90.0)WRITE (6,88)
00212    85*       88 FORMAT (///,1X,'WARNING,ZENITH ANGLE OF UNREFRACTED PATH EXCEEDS
00212    86*         190.0 DEG',/,1X,'IT IS HIGHLY PROBABLE THAT THE AIRCRAFT OR SPACE
00212    87*         2CRAFT CANNOT SEE THE TARGET',///)
00213    88*       89 CALL MODATM (ZL+DELT*.5,PP,4HALTI,XLAMDA)
```

```
00214    89*          PHIINT=PHI
00215    90*          Z1=ZL
00216    91*          D1=ANS(3)
00217    92*          WATER1=ANS(13)
00220    93*          XN1=ANS(18)
00221    94*          SUM=0.0
00222    95*          SUM1=0.0
00223    96*          SUM2=0.0
00224    97*          SUM3=0.0
00225    98*          SUM4=0.0
00226    99*          DO 1 I=1,32000
00231   100*          Z2=Z1+DELT
00232   101*          S1=RE+Z1
00233   102*          S2=RE+Z2
00234   103*          CALL MODATM (Z2+DELT*.5,PP,4HALTI,XLAMDA)
00235   104*          D2=ANS(3)
00236   105*          WATER2=ANS(13)
00237   106*          XN2=ANS(18)
00240   107*          PSI=SININV(S1*SIN(PHI)/S2)
00241   108*          PHIPR=SININV(S1*SIN(PHI)*XN1/(S2*XN2))
00242   109*          DUM=D1*S1*SIN(PHI-PSI)/SIN(PSI)*1.0E+05
00243   110*          SUM1=SUM1+PHI-PSI
00244   111*          SUM2=SUM2+WATER1*DUM/1000.0
00245   112*          SUM3=SUM3+DUM
00246   113*          SUM4=SUM4+DUM/D1
00247   114*          IF (Z2.GE.ZS) GO TO 82
00251   115*          SUM=SUM+ABS(PHIPR-PSI)
00252   116*          PHI=PHIPR
00253   117*          Z1=Z2
00254   118*          D1=D2
00255   119*          WATER1=WATER2
00256   120*        1 XN1=XN2
00260   121*          CALL EXIT
00261   122*       82 CONTINUE
00262   123*          Q=SUM1-ABD
00263   124*          PHI=PHIINT-Q/2.0
00264   125*          IF (ABS(Q).GE..0001) GO TO 89
00266   126*          ANS(21)=PHI
00267   127*          ANS(22)=SUM3
00270   128*          ANS(23)=SUM2
00271   129*          ANS(24)=SUM4
00272   130*          IF (PHI/CON.LE.90.0) GO TO 83
00274   131*          WRITE (6,87)
00276   132*       87 FORMAT (1X,///,1X,' THE ANGLE FROM ZENITH IS GREATER THAN 90.0')
```

```
00277    133*          ANS(22)=0.0
00300    134*          ANS(23)=0.0
00301    135*          ANS(24)=0.0
00302    136*       83 RETURN
00303    137*          END

      END OF UNIVAC 1108 FORTRAN V COMPILATION.      0 *DIAGNOSTIC* MESSAGE(S)
```

```
00101        1.            FUNCTION COSINV(A)
00101        2.     C THIS FUNCTION CALCULATES THE INVERSE COSINE OF 'A'.
00103        3.            COSINV=ATAN2(SQRT(1.0-A**2),A)
00104        4.            RETURN
00105        5.            END

        END OF UNIVAC 1108 FORTRAN V COMPILATION.      0 *DIAGNOSTIC* MESSAGE(S)
```

```
00101        1.            FUNCTION SININV(A)
00101        2.     C THIS FUNCTION CALCULATES THE INVERSE SINE OF 'A'.
00103        3.            SININV=ATAN2(A,(SQRT(1.0-A**2)))
00104        4.            RETURN
00105        5.            END

        END OF UNIVAC 1108 FORTRAN V COMPILATION.      0 *DIAGNOSTIC* MESSAGE(S)
```

```
00101        1.            FUNCTION Q(P,T)
00101        2.     C W = SPECIFIC HUMIDITY WITH UNITS OF   GM/KG
00101        3.     C SPECIFIC HUMIDITY=GM OF WATER VAPOR / (KG OF AIR,INCLUDING WATER VAPOR)
00103        4.            X=E(T)
00104        5.            Q=0.62197*X/(P-0.37803*X)*1000.0
00105        6.            RETURN
00106        7.            END

        END OF UNIVAC 1108 FORTRAN V COMPILATION.      0 *DIAGNOSTIC* MESSAGE(S)
```

```
00101         FUNCTION ALTITU (TVHIGH,TVLOW,PHIGH,PLOW,HLOW)
00101   C
00101   C******************************************************************************
00101   C
00101   C GIVEN THE TEMPERATURE AND PRESSURE AT EACH OF 2 POINTS AND THE ALTITUDE OF
00101   C     THE LOWER POINT, THIS FUNCTION CALCULATES THE ALTITUDE OF THE HIGHER POINT
00101   C ALTITU IS IN METERS.  CONN IS A CONSTANT =  -M*G/R
00101   C
00101   C******************************************************************************
00101   C
00103         DATA CONN/-3.41631947E-02/
00105         D=TVHIGH-TVLOW
00106         IF(D) 2,3,2
00111       2 D=CONN/(ALOG(PHIGH/PLOW))*ALOG(TVHIGH/TVLOW)
00112         ALTITU =HLOW+(TVHIGH-TVLOW)/D
00113         GO TO 6
00114       3 ALTITU =HLOW+TVLOW*ALOG(PHIGH/PLOW)/CONN
00115       6 RETURN
00116         END

     END OF UNIVAC 1108 FORTRAN V COMPILATION.      0 *DIAGNOSTIC* MESSAGE(S)
```

```
00101     1*          FUNCTION PRES(PLOW,D,TVLOW,TVHIGH,DH)
00103     2*          DATA CONN/-3.41631947E-02/
00103     3*    C
00103     4*    C**************************************************************************
00103     5*    C
00103     6*    C THIS PROGRAM CALCULATES PRESSURE -PRES- AT SOME POINT -DH- ABOVE A
00103     7*    C     POINT IN THE ATMOSPHERE HAVING PRESSURE -PLOW- WHERE -D- IS THE
00103     8*    C     TEMPERATURE GRADIENT AND -TVHIGH- AND -TVLOW- ARE CORRESPONDING
00103     9*    C     TEMPERATURES.  -CONN- IS CONSTANT = -M*G/R
00103    10*    C
00103    11*    C**************************************************************************
00103    12*    C
00105    13*          IF(D) 2,3,2
00110    14*        2 PRES=PLOW*(TVHIGH/TVLOW)**(CONN/D)
00111    15*          GO TO 4
00112    16*        3 PRES=PLOW*EXP(-CONN*DH/TVLOW)
00113    17*        4 RETURN
00114    18*          END

      END OF UNIVAC 1108 FORTRAN V COMPILATION.      0 *DIAGNOSTIC* MESSAGE(S)


00101     1*          FUNCTION E(X)
00103     2*          DATA TS/373.16/,TO/273.16/
00103     3*    C
00103     4*    C**************************************************************************
00103     5*    C
00103     6*    C THIS ROUTINE CALCULATES VAPOR PRESSURE OVER A PLANE SURFACE OF
00103     7*    C     WATER (C = 0.0) OR OF ICE (C = 273.16) BASED ON TEMPERATURE IN DEG
00103     8*    C     KELVIN.  E(X) IS IN MB
00103     9*    C SET C=273.16 IF YOU WANT VAPOR PRES OVER ICE USED BELOW 273. DEG K
00103    10*    C
00103    11*    C**************************************************************************
00103    12*    C
00106    13*          C=0.0
00107    14*          T=X-C
00110    15*          IF (X .LE. 1.0) GO TO 4
00112    16*          IF (T) 1,2,2
00112    17*    C   FORMULA FOR VAPOR PRESSURE OVER ICE
00115    18*        1 E=6.1071*10.0**(-9.09718* (-1.0+TO/X)-3.56654*LOG10(TO/X)+0.876793
00115    19*         1*(1.0-X/TO))
00116    20*          GO TO 5
00116    21*    C
00116    22*    C**************************************************************************
00116    23*    C
```

```
00116     24*    C  FORMULA FOR VAPOR PRESSURE OVER WATER
00117     25*       2 E=1013.246*10.0**(-7.90298*(-1.0+TS/X)+5.02808*LOG10(TS/X)-1.3816E
00117     26*        1-07*(10.0**(11.344*(1.0-X/TS))-1.0)+8.1328E-03*(10.0**(-3.4914*(-1
00117     27*        2.0+TS/X))-1.0))
00120     28*         GO TO 5
00121     29*       4 E=0.0
00122     30*       5 RETURN
00123     31*         END

        END OF UNIVAC 1108 FORTRAN V COMPILATION.      0 *DIAGNOSTIC* MESSAGE(S)
```

```
00101      1*         FUNCTION R(S,P,X)
00101      2*    C
00101      3*    C******************************************************************************
00101      4*    C
00101      5*    C THIS ROUTINE CALCULATES THE MIXING RATIO (GM OF H2O)/(KG OF DRY AIR)
00101      6*    C    BASED ON X WHICH IS TEMPERATURE IN DEG KELVIN
00101      7*    C R(S,P,X) =0/00 (IE PARTS PER THOUSAND)
00101      8*    C S IS VAPOR PRESSURE OF WATER
00101      9*    C P IS TOTAL ATMOSPHERIC PRESSURE IN MB
00101     10*    C
00101     11*    C******************************************************************************
00101     12*    C
00103     13*         IF (S) 7,6,7
00106     14*       7 CONTINUE
00107     15*         R=18.016*S*F(P,X)/(28.9664*(P-S*F(P,X)))*1000.0
00107     16*    C R IS IN GM/KG
00110     17*         RETURN
00111     18*       6 R=0.0
00112     19*         RETURN
00113     20*         END

        END OF UNIVAC 1108 FORTRAN V COMPILATION.      0 *DIAGNOSTIC* MESSAGE(S)
```

```
00101          FUNCTION F(P,X)
00103          DIMENSION TE(12),PE(11),U(12,11)
00104          DATA ((U(I,J),J=1,11),I=1,12) /0.,1.,2.,3.,6.,12.,18.,30.,42.,53.,
00104         165.,1.,1.,2.,3.,6.,11.,17.,27.,38.,49.,60.,1.,1.,2.,3.,6.,11.,16.,
00104         226.,36.,46.,55.,1.,2.,3.,4.,6.,11.,15.,24.,34.,43.,52.,1.,2.,4.,
00104         35.,7.,11.,15.,24.,32.,41.,49.,0.,2.,5.,6.,8.,12.,16.,24.,32.,40.,
00104         447.,4*0.,10.,14.,18.,25.,32.,40.,47.,4*0.,12.,16.,20.,27.,34.,41.,
00104         548.,6*0.,23.,30.,37.,44.,50.,6*0.,26.,34.,41.,48.,54.,7*0.,37.,45.
00104         6,52.,59.,8*0.,48.,56.,64./,TE/-50.,-40.,-30.,-20.,-10.,0.,10.,20.,
00104         730.,40.,50.,60./,PE/5.,10.,30.,50.,100.,200.,300.,500.,700.,900.,
00104         81100./
00104    C
00104    C*****************************************************************************
00104    C
00104    C 'F' IS THE CORRECTION FACTOR FOR THE DEPARTURE OF THE MIXTURE OF AIR
00104    C     AND WATER VAPOR FROM THE IDEAL GAS LAW.
00104    C X IS TEMPERATURE IN DEG KELVIN
00104    C P IS TOTAL ATMOSPHERIC PRESSURE IN MB
00104    C
00104    C*****************************************************************************
00104    C
00110          T=X-273.16
00111          DO 1 I=1,12
00114          IF (T.LE.TE(I)) GO TO 2
00116          II=I
00117        1 CONTINUE
00121          FA=1.0
00122          GO TO 3
00123        2 DO 4 J=1,11
00126          IF (P.LE.PE(J)) GO TO 5
00130          JJ=J
00131        4 CONTINUE
00133          FA=1.0
00134          GO TO 3
00135        5 I=II
00136          J=JJ
00137          F1=(U(I+1,J)-U(I,J))/10.0*(T-TE(I))+U(I,J)
00140          F2=(U(I+1,J+1)-U(I,J+1))/10.0*(T-TE(I))+U(I,J+1)
00141          FA=(F2-F1)/(PE(J+1)-PE(J))*(P-PE(J))+F1
00142          FA=1.0+FA*1.0E-04
00143        3 F=FA
00144          RETURN
00145          END

    END OF UNIVAC 1108 FORTRAN V COMPILATION.      0 *DIAGNOSTIC* MESSAGE(S)
```