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CALCULATIONS OF ATMOSPHERIC TRANSMITTANCE IN THE 11 μM WINDOW FOR ESTIMATING SKIN TEMPERATURE FROM VISSR INFRARED BRIGHTNESS TEMPERATURES

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ABSTRACT

An algorithm is presented for calculating the atmospheric transmittance in the 10 to 20 μm spectral band from a known temperature and dewpoint profile, and then using this transmittance to estimate the surface (skin) temperature from a VISSR observation in the 11 μm window. Parameterizations are drawn from the literature for computing the molecular absorption due to the water vapor continuum, water vapor lines, and carbon dioxide lines. FORTRAN code is documented for this application, and the sensitivity of the derived skin temperature to variations in the model's parameters is calculated. VISSR calibration uncertainties are identified as the largest potential source of error.

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Section 1

INTRODUCTION

A common procedure for estimating the underlying skin temperature from an infrared window observation is to use a radiation transfer correction for the intervening atmosphere. The experience of previous workers with this physical inversion technique has not been encouraging (Weinreb and Fleming, 1974; Aoki and Inoue, 1982). Sea surface temperatures (SST) are usually a few degrees less than the satellite-derived ones, and one cannot distinguish between problems due to thin clouds, emittance uncertainties, faulty transmittance estimates, and calibration errors. Operationally, sea surface temperatures are derived empirically at low space-time resolution by using regression between multispectral satellite and ground truth observations (Strong and McClain, 1984). Experimentally, multi-channel satellite data have been used with physical models to derive mesoscale gradients and relative changes in either skin temperature (Zandlo et al., 1982) or low-level moisture (Chesters et al., 1983), over both land and sea. Estimates based upon the VISSR 11 μm window <u>alone</u> are limited by calibration uncertainties in the geosynchronous imagery, and by the ambiguity in determining whether radiance arises from the surface or the atmosphere. Nevertheless, local skin temperature gradients and short-term changes should be measureable with fair relative accuracy from VISSR infrared data by using a physical model for the radiation transfer properties of the overlying atmosphere, with absolute accuracy provided by "tuning" to ground truth.

Exact molecular absorption calculations for the transmittance through the atmosphere are too computationally intensive for practical applications. Several approximations for the water vapor continuum, water vapor lines, and carbon dioxide lines have been published which provide accuracy better than ±1% (Roberts et al., 1976; McMillin et al., 1976, 1977, 1979 and 1980; Aoki, 1979 and 1980; Chou, 1981; Weinreb et al., 1980 and 1981). The absorption models by Roberts et al. (1976) and Aoki (1980) are adopted because they have an economical formulation and published values for all of the coefficients required within 11 μm window. Roberts et al. (1976) calculate the water vapor continuum absorption with separate terms for water vapor concentration, temperature, and wavenumber. Aoki (1980) calculates the water vapor and carbon dioxide line absorption with a semi-random band approximation whose intertwined pressure- and temperature-dependence is calculated from eight coefficients which are fitted at 50 cm^{-1} spectral intervals to line-by-line molecular absorption spectra. Aoki's model accounts for the variance in the line spacings, the line intensity distribution, and the contribution made by lines lying outside of the interval.

This report presents an algorithm for calculating the atmospheric transmittance in the 10 to 20 μm spectral band from a known temperature and dewpoint profile, and then using this transmittance to estimate the surface (skin) temperature from a VISSR observation in the 11 μm window. Section 2 outlines the abstract radiation transfer model for estimating skin temperature from infrared observations. Several possible empirical "tuning" factors are described which can adjust the algorithm to ground truth data. Section 3 presents the data processing algorithm with explicit coefficients and formulas for the absorption due to each molecular species, so that transmittance can be calculated for any temperature and dewpoint profile viewed from geosynchronous station. In Section 4, the algorithm is tested upon the US Standard Atmosphere, and a skin temperature is estimated from a simulated VISSR observation. The sensitivity of this estimate with respect to probable errors in various parameters is computed, and the largest sources of error are identified. The appendix documents a FORTRAN program which is available for use at the Goddard Laboratory for Atmospheric Sciences at NASA/GSFC.

Section 2

RADIATION TRANSFER

2.1 ABSTRACT FORMULATION

Satellite radiance observations in the 11 μm window are used to estimate the skin temperature by adjusting its value in a radiation transfer model until the calculated and observed radiances agree for the colocated satellite, surface, and atmospheric conditions.

$$Robs = Rcalc(Tskin) \quad (1)$$

VISSR radiance observations are available as brightness temperatures, T*obs, at an effective wavelength of 11.4 μm (Bauer and Lienesch, 1975).

$$Robs = B(veff, T^*obs) \quad erg/etc. \quad (2)$$

$veff = 1/(11.4\ \mu m) = 877.2\ cm^{-1}$

$B(v,T) = av^3/[\exp(bv/T) - 1]$

B is radiance, erg cm^{-2} sec^{-1} $sterradian^{-1}$ $(cm^{-1})^{-1}$ = erg/etc.
T is temperature, Kelvin (K)
v is wavenumber, cm^{-1}

$a = 2hc^2 = 1.1910636E-5$
$b = hc/k = 1.4388318$

The calculated radiance can be written as a surface term and an atmospheric term, both of which depend upon the transmittance properties of the entire atmosphere integrated over the 10 to 13 μm bandpass. The surface term includes a spectral emittance factor, e(v), which can be significantly unpredictable for vegitation at 11 μm.

$$
\begin{aligned}
\text{Rcalc} &= \text{Rsfc}(\text{Tskin}) + \text{Rair} \\
\text{Rsfc}(\text{Tskin}) &= \int dv\ f(v)\ [e(v)\ B(v,\text{Tskin})\ t(\text{Psfc},v)] \\
\text{Rair} &= \int dv\ f(v)\ [\ dP\ B(v,T(P))\ dt(P,v)/dP] \\
f(v) &= \text{normalized spectral response, } \int dvf(v)=1
\end{aligned}
\tag{3}
$$

Transmittance, $t(P,v)$, can be considered as the probability of a photon at wavenumber v escaping from level P. Consequently, the total transmittance is the product of the individual transmittances for each type of absorber. Transmittance is calculated from the optical depth, $s(P,v,\text{type})$, which is the integrated effect of all types of absorption, controlled by the pressure, temperature, absorber amount, and viewing angle in the layers between the field-of-view (FOV) and the satellite. An effective transmittance, $<t(P)>$, averaged over the spectral response, is not an accurate approximation for most wide band channels.

$$
\begin{aligned}
<t(P)> &= \int dv\ f(v)\ t(P,v) \\
t(P,v) &= \prod_{\text{type}} t(P,v,\text{type}) \\
t(P,v,\text{type}) &= \exp[-s(P,v,\text{type})] \\
s(P,v,\text{type}) &= \int_{P}^{0} ds(P',v,\text{type and } T(P'),D(P'),\sec\theta,dP')
\end{aligned}
\tag{4}
$$

$\sec\theta$ = airmass = secant of zenith angle from FOV to satellite
type = H_2O continuum, H_2O lines, CO_2 lines

The differential optical depth, ds, must be computed for each absorbing species at each level in the atmosphere as a function of wavelength. Optical depth is accumulated through the atmosphere and converted to transmittance. Then, the product of the transmittances is substituted into the radiation transfer equations, which are iterated to estimate the underlying skin temperature.

2.2 RADIANCE "TUNING"

Physical retrievals of SST derived from geosynchronous 11 μm window data alone are a few degrees less than ground truth observations (Aoki and Inoue, 1982). Most workers adopt some purely empirical factor to "tune" either their calculations or the infrared observation in order to match ground truth SST. "Tuning" factors may be applied to either the radiance observations, the effective wavenumber, the surface emittance, and/or the atmospheric transmittance.

$$T^{*\prime}obs = T^{*}obs - DT^{*} \tag{5}$$

$$v'eff = veff + Dv(T^{*}obs)$$

$$e'(v) = e(v) - De$$

$$t'(P,v) = [t(P,v)]^{(1+g)}$$

DT*, Dv, De, g = possible "tuning" factors

Because the 11 μm channel was originally designed only to make infrared images of cloud locations at night, VISSR calibration is not performed with high absolute accuracy for infrared data from the SMS and GOES satellites launched before 1980. Infrared calibration errors are on the order of ±3 K in brightness temperature (W. Shenk, private communication), and the channel's spectral response is merely characterized by an effective wavelength of 11.4 μm (Bauer and Lienesch, 1975). The GOES satellites launched after 1980 have an improved radiometer, with 11 μm calibration errors on the order of ±0.5 K, and the spectral response is well documented (Chesters and Robinson, 1983). Consequently, radiance and wavenumber "tuning" is definitely recommended for VISSR data from the satellites launched before GOES-4.

In the 10 to 13 μm band, the surface emittance, e(v), is approximately constant with wavelength. Values of e(v) from 0.98 to 1.00 are commonly used over bare land and open water, while values as low as 0.90 may apply to vegetation.

ESTIMATING TRANSMITTANCE

3.1 DISCRETE COORDINATES

Practical calculations are made on a computer at a discrete set of wavenumbers, v_k for k=1,...,Nv, and use atmospheric values averaged between radiosonde measurements at discrete levels, P_i for i=1,...,Np.

(6)

$$\mathrm{Rcalc} = \mathrm{Rsfc(Tskin)} + \mathrm{Rair}$$

$$\mathrm{Rsfc(Tskin)} = \sum_{k=1}^{Nv} f_k \, [e_k \, B(v_k, \mathrm{Tskin}) \; t_{ik}]$$

$$\mathrm{Rair} = \sum_{k=1}^{Nv} f_k \sum_{i=1}^{Np} [B(v_k, \langle T_i \rangle) \; Dt_{ik}]$$

$\langle T_i \rangle$ = average temperature between ith and i+1th level
t_{ik} = transmittance from the ith level for the kth wavenumber
$Dt_{ik} = t_{i+1,k} - t_{ik}$, for $i < Np$
$= 1 - t_{ik}$, for $i = Np$

satellite data:
f_k = normalized spectral response at kth wavenumber, $\Sigma f_k = 1$
v_k = kth wavenumber, cm^{-1}
Nv = number of wavenumbers, k=1,...,Nv
SATloc = longitude of geosynchronous subsatellite point, °W

surface data:
FOVloc = location of FOV, longitude °W and latitude °N
e_k = spectral emittance at kth wavenumber

atmospheric data:
P_i = pressure at the ith level, $P_{i+1} < P_i$ mb
T_i = temperature at the ith level, K
D_i = dewpoint at the ith level, °C
Np = number of radiosonde levels, i=1,...,Np
(i=1 is the surface,
i=Np is the top)

3.2 TRANSMITTANCE AND OPTICAL DEPTH

The radiation transfer equation is summed over optically thin layers, Dt<0.1, so that layer averages are valid. Both t and Dt depend upon the overlying atmospheric conditions and upon the zenith angle, θ, from the FOV to the satellite. The differential optical depth, Ds, depends only upon the local properties of the atmosphere -- pressure, temperature, amount of the absorber, and layer thickness as viewed by the satellite. Layer averages are used for the radiosonde values in the layer above level P_j.

(7)

$$<t_i> = \sum_{k=1}^{Nv} f_k \, t_{ik}$$

$$t_{ik} = \prod_{type} \exp[-s_{ik} type]$$

$$s_{ik} type = \sum_{j=i}^{Np} Ds_{jk} type$$

$$Ds_{jk} type = Ds(<P_j>, v_k, type; <T_j>, <D_j>, \sec\theta, DP_j)$$

$$\begin{array}{llll}
DP_j = P_j - P_{j+1} & \text{for } j<Np, & = 0.5P_j & \text{for } j=Np \\
<P_j> = 0.5[P_j + P_{j+1}] & \text{for } j<Np, & = P_j & \text{for } j=Np \\
<T_j> = 0.5[T_j + T_{j+1}] & \text{for } j<Np, & = T_j & \text{for } j=Np \\
<D_j> = 0.5[D_j + D_{j+1}] & \text{for } j<Np, & = D_j & \text{for } j=Np
\end{array}$$

3.3 HOMOGENEOUS LAYERS

The effective thickness of a homogeneous layer, DL_j above level j, is the projection of the hydrostatic thickness onto the line-of-sight.

$$DL_j = DP_j \, \frac{RO \; Tvirt(\langle T_j \rangle, \langle P_j \rangle, \langle D_j \rangle)}{\langle P_j \rangle \; mdry \; g} \sec\theta \qquad \text{cm} \tag{8}$$

$$Tvirt(T,P,D) = T/[1-(1-mH2O/mdry)\,(Psat(D)/P)] \qquad \text{K}$$

$$Psat(D) = 6.11 \exp[7.5 \ln(10)\; D/(D+237.5^\circ C)] \qquad \text{mb}$$

g = acceleration of gravity at 45°N = 980.616 cm sec^{-2}
NO = Avagadro's constant = 6.0225 $mole^{-1}$
RO = universal gas constant = kNO = 8.3143E7 erg K^{-1} $mole^{-1}$
PO = 1 atm = 1013.6 mb = 1.0136E6 dyne cm^{-2}
mO = 1 AMU = 1.67E-24 gm
mH2O = mass of water molecule = 18.0 AMU
mdry = mass of "dry" air molecule = 28.9 AMU

The airmass, secθ, for the extra path length viewed through a plane-parallel slab at local zenith angle θ is estimated from the difference between the subsatellite and FOV locations.

$$\sec\theta = [x^2 - 2xy + 1]^{1/2}/[xy - 1] \tag{9}$$

x = Rs/Re = 6.6134
y = sin(a) cos(b)

Re = radius of earth = 6378 km
Rg = radius of geosynchronous orbit = 42180 km

a = colatitude of field-of-view from the north pole
= 90 ° - (FOV latitude °N)

b = longitude difference between FOV and subsatellite point
= (FOV longitude °W) - (satellite longitude °W)

3.4 FORMULAS FOR MOLECULAR ABSORPTION

3.4.1 Water vapor continuum

Roberts et al. (1976) has parameterized the homogeneous absorption due to the water vapor continuum from data observed from 400 to 1200 cm^{-1} under a variety of field and laboratory conditions. The accuracy of this data when extrapolated to the relatively low temperatures and pressures in the middle and upper troposphere is untested. The most important characteristic about the water vapor continuum absorption is that it is proportional to the <u>square</u> of the water vapor content, so that it dominates molecular absorption at 11 μm in the boundary layer.

$$\mathrm{Ds}_{jk}\mathrm{H2Oc} = C(v_k)\ C(<T_j>)\ \mathrm{nH2O}_j\ \mathrm{PH2O}_j\ \mathrm{DL}_j \tag{10}$$

$$C(v_k) = 1.25\mathrm{E}{-22} + 2.34\mathrm{E}{-19}\ \exp(-8.30\mathrm{E}{-3}\ v_k)\ \mathrm{cm}^2\ \mathrm{atm}^{-1}/\mathrm{molecule}$$

$$C(<T_j>) = \exp[1800\ \mathrm{K}(1/<T_j>-1/296\ \mathrm{K})]$$

$$\mathrm{nH2O}_j = (1000\ \mathrm{Psat}(<D_j>))/(\mathrm{m0\ R0}\ <T_j>)\quad \mathrm{molecules\ cm}^{-3}$$

$$\mathrm{PH2O}_j = \mathrm{Psat}(<D_j>)/1013.6\quad \mathrm{atm}$$

3.4.2 Water vapor lines

Aoki (1980) has parameterized the homogeneous optical depth for the water vapor lines in 50 cm^{-1} intervals from 0 to 2050 cm^{-1} by fitting a semi-random band model to line-by-line simulations for tropospheric conditions. Aoki and Inoue (1982) list special values for the H2O line parameters *which were explicitly computed for the 11 μm channel on the* Japanese Geosynchronous Weather Satellite (GWS). Both sets of coefficients are listed below; the GWS coefficients are not a simple interpolation or convolution of the spectral coefficients.

$$Ds_{jk}H2Ol = [(C1(v,t)p')^2 + C2(v,t)C3(v,x)]^{1/2} - C1(v,t)p' \tag{11}$$

$$\begin{aligned}
v &= v_k \\
t &= \ln(\langle T_j\rangle/270\ K) \\
p' &= \exp[(1-c4(v))\ \ln(\langle P_j\rangle/1013.6)] \\
x &= \ln[p'\ PH2O_j\ DL_j]
\end{aligned}$$

$$PH2O_j = Psat(\langle D_j\rangle)/1013.6 \quad atm$$

$$\begin{aligned}
C1(v,t) &= c1(v)\ \exp[c6(v)t] \\
C2(v,t) &= c2(v)\ \exp[c7(v)t + c8(v)t^2] \\
C3(v,x) &= \exp[c3(v)x + c5(v)x^2]
\end{aligned}$$

$c1(v),\ldots,c8(v)$ = interpolations of Aoki's (1980) coefficients

TABLE 1

Coefficients for H2O line absorption near 11 μm

	800 cm^{-1}	850 cm^{-1}	900 cm^{-1}	950 cm^{-1}	1000 cm^{-1}
c1	0.021382	0.025245	0.034435	0.041589	0.031116
c2	0.56845E-5	0.29921E-5	0.14193E-5	0.05885E-5	0.09268E-5
c3	0.96754	0.99808	1.0153	1.1221	1.0320
c4	-0.08635E-2	-0.11122E-2	-0.09704E-2	-0.04544E-2	-0.20808E-2
c5	-0.03411E-2	-0.01399E-2	-0.18391E-2	-0.62568E-2	-0.00879E-2
c6	-0.43471	0.22454	0.35091	0.15582	0.07572
c7	8.7939	9.5119	10.7720	10.2056	10.3424
c8	-0.87402	-1.66808	-1.81940	-1.20720	-2.09283

	GWS channel
c1	0.0276185
c2	0.191647E-5
c3	1.02476
c4	-5.47816E-2
c5	-0.07084E-2
c6	0.665602
c7	9.71290
c8	-1.56049

3.4.3 Carbon dioxide lines

Aoki (1980) has parameterized the homogeneous optical depth for the carbon dioxide lines in 50 cm^{-1} intervals from 500 to 1050 cm^{-1} by fitting a semi-random band model to line-by-line simulations for tropospheric conditions.

$$Ds_{jk}CO21 = [(C1(v,t)p')^{2} + C2(v,t)C3(v,x)]^{1/2} - C1(v,t)p' \tag{12}$$

$$v = v_k$$
$$t = \ln(\langle T_j\rangle/270\ K)$$
$$p' = \exp[(1-c4(v))\ \ln(\langle P_j\rangle/1013.6)]$$
$$x = \ln[p'\ PCO2_j\ DL_j]$$

$$PCO2_j = 330.0E\text{-}6\ \langle P_j\rangle/1013.6 \quad \text{atm}$$

$$C1(v,t) = c1(v)\ \exp[c6(v)\,t]$$
$$C2(v,t) = c2(v)\ \exp[c7(v)\,t + c8(v)\,t^{2}]$$
$$C3(v,x) = \exp[c3(v)\,x + c5(v)\,x^{2}]$$

$c1(v),\ldots,c8(v)$ = interpolations of Aoki's (1980) coefficients

TABLE 2

Coefficients for CO2 line absorption near 11 μm

	800cm^{-1}	850cm^{-1}	900cm^{-1}	950cm^{-1}	1000cm^{-1}
c1	0.18465	0.60353	0.30581	0.13287	0.14893
c2	0.76362E-5	0.33103E-5	1.4291E-5	0.56096E-5	0.95598E-5
c3	1.2516	0.98463	1.1318	1.3890	1.1242
c4	-0.063233	-0.000349	-0.047875	-0.021649	-0.020353
c5	-0.017441	-0.0002027	-0.0065872	-0.020444	-0.0080091
c6	0.93946	0.04220	0.52813	0.22125	0.55908
c7	10.02969	13.33342	11.61556	9.78332	9.72914
c8	-1.28317	-4.23887	-2.83714	-1.25705	-1.58241

Aoki (1980) finds good agreement between his parameterized transmittances and exact line-by-line calculations, except for the CO2 Q-branch between 800 and 850 cm^{-1}. One can indeed see irregular behavior in all of the coefficients from 800 to 900 cm^{-1} in the above table. The parameterized CO2 transmittances are systematically too tranparent at these wavelengths. Fortunately, the CO2 line absorption in the 11 μm window is weak enough for these errors to be relatively unimportant for application to VISSR observations.

3.5 SPECTRAL RESPONSE FUNCTION FOR THE 11 µM WINDOW

Each geosynchronous satellite has a different spectral response within the broad window centered near 11 µm. In general, response is designed to be small at 13 µm (800 cm^{-1}) in order to avoid the 15 µm carbon dioxide band, and also small at 10 µm (1000 cm^{-1}) in order to avoid the 9.6 µm ozone band. Absorption by the water vapor continuum dominates the 11 µm window, especially at the longwave end. The spectral response curve for the 11 µm window on GOES-4 is listed below, drawn at 20 cm^{-1} intervals from a more detailed tabulation (Chesters and Robinson, 1983).

TABLE 3

Spectral response for the 11 µm window on GOES-4

ν, cm^{-1}	f (ν)
800	0.01
820	0.40
840	0.67
860	0.96
880	0.99
900	0.94
920	0.86
940	0.83
960	0.77
980	0.15
1000	0.01

Section 4

SAMPLE VALUES

4.1 TRANSMITTANCE AND SKIN TEMPERATURE

Response-averaged transmittances, $\langle t(P)\rangle = \int f(v)\,t(P,v)\,dv$, are listed below for the GOES-4 11 μm window, simulating a FOV at 40°N and 90°W with GOES-EAST at 75°W, viewed through the US Standard Atmosphere at the appropriate angle. Fully one-quarter of the photons from the surface are absorbed by this relatively dry atmosphere in the 11 μm "window" channel. Within the 11 μm bandpass, the transmittance spectrum varies considerably from t=0.83 at 1000 cm^{-1} to t=0.65 at 800 cm^{-1}. Transmittance values for each species are listed in Appendix A; they demonstrate that most of the absorption is due to the water vapor continuum. A skin temperature of 290.56 K is retrieved for this case, if the emittance is 0.99 and the observed brightness is 285 K.

TABLE 4

Transmittance estimates for the US Standard Atmosphere

i	P mb	T K	D °C	<t(P)> H20 cont.	<t(P)> H20 lines	<t(P)> CO2 lines	<t(P)> total
8	100	217	-82	1.000	1.000	1.000	1.000
7	200	217	-66	1.000	1.000	0.999	0.999
6	300	229	-49	1.000	0.999	0.999	0.999
5	400	241	-35	0.999	0.999	0.999	0.999
4	500	252	-24	0.998	0.998	0.999	0.995
3	700	269	-8	0.978	0.992	0.997	0.968
2	850	279	0	0.925	0.976	0.995	0.898
1	1000	287	7	0.826	0.947	0.992	0.776

Calculated for $\sec\theta = 1.52$ and $f(v)$ = GOES-4 11 μm window.
If $e(v) = 0.99$ and Tobs = 285.00 K, then Tskin = 290.56 K.

4.2 SENSITIVITY TO ERRORS

The values for the above simulation were computed using the computer program listed in the appendix. By rerunning the program with key parameters slightly changed, the sensitivity of the skin temperature estimate to normal uncertainties in the data is determined.

TABLE 5

Sensitivity of skin temperature to typical uncertainties

parameter	change	DTskin
e(v)	+0.01	-0.64 °C
T*obs	+1.0 K	+1.29 °C
veff	+10 cm^{-1}	-1.39 °C
f(v)	δ(v-veff)	-2.62 °C
veff	<v>=$\int$vf(v)dv	-2.74 °C
D(P)	+1.0 °C	+0.49 °C
T(P)	+1.0 K	-0.30 °C
P	+1%	+0.01 °C
s(P,v)	+10%	+0.38 °C
Ds_{jk} H20 lines	GWS coeff.	+0.21 °C
t(P,v)	<t(P)>	-0.95 °C

The algorithm is more sensitive to uncertainties in the satellite values than in the atmospheric profile or the transmittance model. The largest errors arise from uncertainties in calibration and spectral response. For instance, the expected ±3 K absolute calibration errors in VISSR data translate into ±4°C errors in skin temperature, and uncertainties in the assignment of an effective wavelength translate into 1° to 3°C biases, depending upon the spectral characterization selected. Uncertainties in the radiosonde data or absorption coefficients translate into smaller errors in skin temperature, less than ±1°C.

Section 5

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Appendix A

A COMPUTER PROGRAM FOR THE 11 μM WINDOW

This appendix lists the FORTRAN code which was used to make the skin temperature retrieval and the estimates of sensitivity to parametric uncertainties described in Section 4. Variables are named to resemble the algebra in Section 3. The code is written in FORTRAN 66 for transportability, and functions are modularized for easy modification. Output from a sample run is listed, for comparison.

In order to apply the code to other conditions, the user must introduce satellite data in subroutine GETSAT, surface conditions in GETSFC, and atmospheric conditions in GETATM. The default conditions are for GOES-EAST at 75°W using the GOES-4 11 μm filter to observe a typical brightness temperature of 285 K from a 99% emitting surface in Illinois, which is initially estimated to be 290 K (skin) temperature, viewed through the US Standard temperature (K) and dewpoint depression (K) profile at the manditory pressure levels from 1000 to 100 mb. After the atmospheric transmittance spectrum is calculated for continuum and line absorption, Newtonian iteration of the radiation transfer equation is employed over the 11 μm filter (specified at 20 cm^{-1} intervals), adjusting the skin temperature until the calculated radiance equals the observed radiance, at 290.56 K. The program is available for use on the SACC, NHSCF and VAP computers utilized by the Goddard Laboratory for Atmospheric Sciences at NASA/GSFC.

A.1 THE FORTRAN CODE

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C AOKI AND ROBERTS TRANSMITTANCE FOR THE VISSR 11 MICRON WINDOW
C    DENNIS CHESTERS/NASA/GSFC/915--09MAY84
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      COMMON /LOOPS/ NV,NP,ICASE,NCASE
      COMMON /SATEL/ VEFF,TOBS,SATLOC(2),F(42),V(42)
      COMMON /ATMOS/ P(40),T(40),D(40),
     &               DP(40),PP(40),TT(40),DD(40),DL(40)
      COMMON /SITE / FOVLOC(2),E,TSKIN
      COMMON /TRANS/ SECANT,TAU(40,42,4)
      COMMON /RADS / ROBS,RAIR,RSFC,RCALC,TCALC
      NCASE=1
      DO 100 ICASE=1,NCASE
      CALL GETSAT
      CALL GETSFC
      CALL AIRMAS
      CALL GETATM
      CALL MAKTAU
      CALL RXFER
      CALL SKINIT
      CALL REPORT
  100 CONTINUE
      STOP
      END
```

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE GETSAT
      COMMON /LOOPS/ NV,NP,ICASE,NCASE
      COMMON /SATEL/ VEFF,TOBS,SATLOC(2),F(42),V(42)
      DIMENSION VVAS(42),FVAS(42)
      DATA NVAS /11/
      DATA VVAS/800.,820.,840.,860.,880.,900.,920.,940.,960.,980.,1000./
      DATA FVAS/0.01,0.40,0.67,0.96,0.99,0.94,0.86,0.83,0.77,0.15,0.01/
C SET TO VAS VALUES ON GOES-EAST
      SATLOC(1)=75.0
      SATLOC(2)=00.0
      VEFF=1.E4/11.4
      NV=NVAS
      SUMF=0.0
      DO 100 K=1,NV
      V(K)=VVAS(K)
      F(K)=FVAS(K)
  100 SUMF=SUMF+F(K)
      DO 110 K=1,NV
  110 F(K)=F(K)/SUMF
      TOBS=285.0
      RETURN
      END
```

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE GETSFC
      COMMON /LOOPS/ NV,NP,ICASE,NCASE
      COMMON /SITE / FOVLOC(2),E,TSKIN
C SET TO MIDWEST
      FOVLOC(1)=90.0
      FOVLOC(2)=40.0
      E=0.990
      TSKIN=290.
      RETURN
      END
```

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE AIRMAS
      COMMON /LOOPS/ NV,NP,ICASE,NCASE
      COMMON /SATEL/ VEFF,TOBS,SATLOC(2),F(42),V(42)
      COMMON /SITE / FOVLOC(2),E,TSKIN
      COMMON /TRANS/ SECANT,TAU(40,42,4)
      A=90.0-FOVLOC(2)
      B=FOVLOC(1)-SATLOC(1)
      X=42180./6378.
      PI=3.141592653
      Y=SIN(PI*A/180.)*COS(PI*B/180.)
      SECANT=SQRT(X**2-2.*X*Y+1.)/(X*Y-1.)
      RETURN
      END
```

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE GETATM
      COMMON /LOOPS/ NV,NP,ICASE,NCASE
      COMMON /ATMOS/ P(40),T(40),D(40),
     &               DP(40),PP(40),TT(40),DD(40),DL(40)
      COMMON /TRANS/ SECANT,TAU(40,42,4)
      DIMENSION PFOV(40),TFOV(40),DFOV(40)
      DATA NPFOV/8/
      DATA PFOV /1000.,850.,700.,500.,400.,300.,200.,100./
      DATA TFOV / 287.,279.,269.,252.,241.,229.,217.,217./
      DATA DFOV /  7.0, 0.0,-8.0,-24.,-35.,-49.,-66.,-82./
C LOAD RAOB PROFILE FOR FOV
      NP=NPFOV
      DO 100 I=1,NP
      P(I)=PFOV(I)
      T(I)=TFOV(I)
      D(I)=DFOV(I)
  100 CONTINUE
C CREATE RUNNING DIFFERENCES AND MEANS
      P(NP+1)=0.0
      T(NP+1)=T(NP)
      D(NP+1)=D(NP)
      DO 200 I=1,NP
      DP(I)=P(I)-P(I+1)
      PP(I)=(P(I)+P(I+1))/2.
      TT(I)=(T(I)+T(I+1))/2.
      DD(I)=(D(I)+D(I+1))/2.
      PSATD=6.11*10.**(7.5*DD(I)/(DD(I)+273.5))
      TVIRT=TT(I)/(1.0-(1.0-18.0/28.9)*(PSATD/PP(I)))
      DL(I)=DP(I)*SECANT*(8.3143E7*TVIRT)/
     &                      (PP(I)*28.9*980.616)
  200 CONTINUE
      RETURN
      END
```

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE MAKTAU
      COMMON /LOOPS/ NV,NP,ICASE,NCASE
      COMMON /TRANS/ SECANT,TAU(40,42,4)
      DO 50 ITYPE=1,4
      DO 50 K=1,42
      DO 50 I=1,40
   50 TAU(I,K,ITYPE)=1.0
      CALL H2OCON
      CALL H2OLIN
      CALL CO2LIN
      DO 100 K=1,NV
      DO 100 I=1,NP
  100 TAU(I,K,1)=TAU(I,K,2)*TAU(I,K,3)*TAU(I,K,4)
      RETURN
      END
```

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE H2OCON
      COMMON /LOOPS/ NV,NP,ICASE,NCASE
      COMMON /SATEL/ VEFF,TOBS,SATLOC(2),F(42),V(42)
      COMMON /ATMOS/ P(40),T(40),D(40),
     &               DP(40),PP(40),TT(40),DD(40),DL(40)
      COMMON /TRANS/ SECANT,TAU(40,42,4)
      DIMENSION CV(42),CP(40)
C USE ROBERTS ET AL. (1976), VALID FOR 400 TO 1300 CM-1
      DO 100 K=1,NV
      CV(K)=0.0
      IF(V(K).LE.400.0 .OR. V(K).GT.1300.0) GO TO 100
      CV(K)=1.25E-22+2.34E-19*EXP(-8.30E-3*V(K))
  100 CONTINUE
      DO 200 I=1,NP
      CT=EXP(1800.*((1./TT(I))-(1./296.)))
      PSATD=6.11*10.**(7.5*DD(I)/(DD(I)+237.5))
      H2ON=(1000.*PSATD)/(1.67E-24*8.3143E7*TT(I))
      H2OP=PSATD/1013.6
      CP(I)=CT*H2ON*H2OP
  200 CONTINUE
      DO 300 K=1,NV
      S=0.0
      DO 300 I=1,NP
      J=NP-I+1
      DS=CV(K)*CP(J)*DL(J)
      S=S+DS
      TAU(J,K,2)=EXP(-S)
  300 CONTINUE
      RETURN
      END
```

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE H2OLIN
      COMMON /LOOPS/ NV,NP,ICASE,NCASE
      COMMON /SATEL/ VEFF,TOBS,SATLOC(2),F(42),V(42)
      COMMON /ATMOS/ P(40),T(40),D(40),
     &               DP(40),PP(40),TT(40),DD(40),DL(40)
      COMMON /TRANS/ SECANT,TAU(40,42,4)
C USE AOKI (1980) COEFFICIENTS AT V=000,050,100,...,2000,2050 CM-1
      DIMENSION C(42,8),C1(42),C2(42),C3(42),C4(42),
     &                  C5(42),C6(42),C7(42),C8(42),CV(8),GWS(8)
      EQUIVALENCE  (C(1,1),C1(1)),(C(1,2),C2(1)),(C(1,3),C3(1)),
     &             (C(1,4),C4(1)),(C(1,5),C5(1)),(C(1,6),C6(1)),
     &             (C(1,7),C7(1)),(C(1,8),C8(1))
      DATA C1/.041998,.092223,.075728,.053753,.045314,
     &        .030196,.019314,.040225,.022761,.038508,
     &       .041330,.019655,.025841,.018003,.017488,
     &         .023402,.021382,.025245,.034435,.041589,
     &       .031116,.027587,.035354,.084901,.108790,
     &         .115250,.100190,.057167,.043479,.053011,
     &       .113780,.045058,.060933,.059544,.077740,
     &         .049796,.040851,.023565,.034289,.032469,
     &       .038948,.049833/
      DATA C2/.33532E-1,.73169,.81907,.51514,.39653,
     &        .11834,.63845E-1,.39191E-1,.55465E-2,.31008E-2,
     &       .17226E-2,.39553E-3,.17034E-3,.79938E-4,.31328E-4,
     &         .17940E-4,.56845E-5,.29921E-5,.14193E-5,.58849E-6,
     &       .92684E-6,.64879E-6,.33642E-5,.22943E-4,.77877E-4,
     &         .51276E-3,.29276E-2,.12247E-1,.15613E-1,.63473E-1,
     &       .22031,.51172E-1,.55366E-1,.13296,.95819E-1,
     &        .36980E-1,.11226E-1,.20414E-2,.22467E-2,.46036E-3,
     &       .16181E-3,.42423E-4/
      DATA C3/.95930,.10322E+1,.98916,.10181E+1,.93772,
     &        .99425,.10008E+1,.91257,.99383,.99275,
     &       .10128E+1,.10876E+1,.10521E+1,.10282E+1,.99322,
     &        .10268E+1,.96754,.99808,.10153E+1,.11211E+1,
     &       .10320E+1,.11028E+1,.10671E+1,.10020E+1,.98005,
     &        .97035,.97839,.97952,.10565E+1,.10068E+1,
     &       .10012E+1,.94804,.10304E+1,.10219E+1,.10168E+1,
     &        .10566E+1,.10404E+1,.10661E+1,.99595,.10261E+1,
     &       .10344E+1,.10627E+1/
```

```
 DATA C4/-.91454E-2,-.98319E-2,-.44953E-2,-.14185E-1,-.46059E-2,
&          -.15621E-1,-.25494E-1,-.47444E-2,-.15901E-1,-.69590E-2,
&         -.11820E-1,-.13635E-1,-.29322E-2,-.13961E-2,-.14661E-2,
&          -.11491E-2,-.86349E-3,-.11122E-2,-.97038E-3,-.45444E-3,
&         -.20808E-2,-.64715E-2,-.28998E-1,-.99276E-2,-.66671E-2,
&          -.30364E-1,-.52805E-1,-.40833E-1,-.43125E-1,-.40016E-1,
&         -.25563E-1,-.33621E-1,-.22112E-1,-.21701E-1,-.15822E-1,
&          -.20913E-1,-.20071E-1,-.23985E-1,-.18801E-1,-.28728E-1,
&         -.33485E-1,-.42419E-1/
 DATA C5/-.37839E-1,-.17290E-2,-.20660E-2,-.10511E-3,-.16759E-1,
&          -.15908E-3,-.13413E-3,-.40980E-2,-.14633E-3,-.87257E-4,
&         -.30110E-3,-.15225E-3,-.65968E-3,-.29567E-3,-.14027E-3,
&          -.34657E-2,-.34111E-3,-.13990E-3,-.18391E-2,-.62568E-2,
&         -.87926E-4,-.97954E-4,-.14919E-3,-.65263E-3,-.10428E-2,
&          -.25773E-3,-.83324E-2,-.27798E-2,-.16955E-3,-.66676E-3,
&         -.71190E-3,-.18466E-1,-.24837E-3,-.14121E-3,-.15256E-3,
&          -.14590E-3,-.10532E-3,-.14246E-3,-.19701E-3,-.15485E-3,
&         -.14375E-3,-.15296E-3/
 DATA C6/-.17136,-.04406,.25395,.40202,.12155,
&          .65488,.72494,.14525,.29936,.19062,
&         .29378,1.43326,.50286,.28133,.25011,
&          .24613,-.43471,.22454,.35091,.15582,
&         .07572,-.03850,.49841,.21488,.21833,
&          -.49067,-1.17866,-.41061,.15930,.69690,
&         .39747,.37997,.49863,.28927,.34280,
&          .63085,.34498,1.41368,.74723,1.48141,
&         1.36339,2.09282/
 DATA C7/1.0643,2.5126,3.1319,4.0704,3.5912,
&          4.9048,5.4988,5.6218,7.0913,7.4134,
&         7.2168,7.7716,8.0488,7.8089,8.4474,
&          8.2915,8.7939,9.5119,10.7720,10.2056,
&         10.3424,10.0839,9.2890,7.3673,7.1788,
&          7.0972,5.6239,5.2652,4.6582,3.4433,
&         3.4458,1.9749,1.9530,2.3889,3.2042,
&          4.0455,4.3753,4.5972,4.8526,5.6121,
&         6.8722,8.2266/
 DATA C8/-.19040,-.24306,-.27868,-.41036,-.37553,
&           -.50397,-.56753,-.63833,-.75103,-.27426,
&         -.46691,-.84266,-1.42339,-.172181,-1.19561,
&           -.96755,-.87402,-1.66808,-1.81940,-1.20720,
&         -2.09283,-2.67175,-.96213,-.97576,-.26443,
&           -.45219,-.60283,-.57719,-.47750,-.36057,
&         -.35798,-.20712,-.20529,-.24958,-.32391,
&           -.41384,-.30872,-.55061,-.48158,-.59724,
&         -.84702,-.93563/
 DATA GWS /0.0276185,0.191647E-5,1.02476,-5.47816E-2,
&           -0.07084E-2,0.665602,9.71290,-1.56049/
```

```
C INTERPOLATE TO EACHWAVNUMBER WITH MODULUS ARITHMETIC (BASE 0, STEP 50)
      DO 100 K=1,NV
      IF(V(K).LE.-00.1 .OR. V(K).GE.2050.1) GO TO 100
      INTV=V(K)
      MODV=1+((INTV-000)/50)
      DELV=(V(K)-000)-(MODV-1)*50
      FRACT=DELV/50.
      DO 110 IC=1,8
      CV(IC)=(1.-FRACT)*C(MODV,IC)  + FRACT*C(MODV+1,IC)
C --- CV(IC)=GWS(IC)
  110 CONTINUE
      S=0.0
      DO 200 I=1,NP
      J=NP-I+1
      TJ=ALOG(TT(J)/270.)
      PJ=(PP(J)/1013.6)**(1.-CV(4))
      PSATD=6.11*10.**(7.5*DD(J)/(DD(J)+237.5))
      XJ=ALOG(PJ*(PSATD/1013.6)*DL(J))
      C1VT=CV(1)*EXP(CV(6)*TJ)
      C2VT=CV(2)*EXP(CV(7)*TJ + CV(8)*TJ**2)
      C3VX=      EXP(CV(3)*XJ + CV(5)*XJ**2)
      DS=SQRT((C1VT*PJ)**2 + C2VT*C3VX) - C1VT*PJ
      S=S+DS
      TAU(J,K,3)=EXP(-S)
  200 CONTINUE
  100 CONTINUE
      RETURN
      END
```

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE CO2LIN
      COMMON /LOOPS/ NV,NP,ICASE,NCASE
      COMMON /SATEL/ VEFF,TOBS,SATLOC(2),F(42),V(42)
      COMMON /ATMOS/ P(40),T(40),D(40),
     &               DP(40),PP(40),TT(40),DD(40),DL(40)
      COMMON /TRANS/ SECANT,TAU(40,42,4)
C USE AOKI (1980) COEFFICIENTS AT V=500,550,...,950,1000,1050 CM-1
      DIMENSION C(12,8),C1(12),C2(12),C3(12),C4(12),
     &                  C5(12),C6(12),C7(12),C8(12),CV(8)
      EQUIVALENCE (C(1,1),C1(1)),(C(1,2),C2(1)),(C(1,3),C3(1)),
     &            (C(1,4),C4(1)),(C(1,5),C5(1)),(C(1,6),C6(1)),
     &            (C(1,7),C7(1)),(C(1,8),C8(1))
      DATA C1/.41298,.19878,.24468,.22422,.24895,.31271,
     &         0.18465,0.60353,0.30581,0.13287,0.14893,0.23225/
      DATA C2/.25760E-4,.17819E-2,.12824,.12397E+1,.42854E-1,.96466E-3,
     &     .76362E-5,.33103E-5,.14291E-4,.56096E-5,.95598E-5,.38838E-4/
      DATA C3/.10850E+1,.10134E+1,.89209,.10150E+1,.95768,.96888,
     &         1.2516,0.98463,1.1318,1.3890,1.1242,1.1416/
      DATA C4/-.39586E-1,-.19271,-.10890,-.83364E-1,-.78617E-1,-.078185,
     & . -.63233E-1,-.34863E-3,-.47875E-1,-.21649E-1,-.20353E-1,-.064135/
      DATA C5/-.11029E-1,-.19114E-1,-.15428E-1,-.13951E-3,-.14599E-2,
     &          -.81506E-2,
     &      -.17441E-1,-.20266E-3,-.65872E-2,-.20444E-1,-.80091E-2,
     &         -.13155E-1/
      DATA C6/.59002,.81508,1.16764,1.64471,1.18913,.69803,
     &         0.93946,0.04220,0.52813,0.22125,0.55908,0.79438/
      DATA C7/9.30501,7.46916,4.65691,3.11361,6.39635,8.88405,
     &         10.02969,13.33342,11.61556,9.78332,9.72914,9.65031/
      DATA C8/-1.30012,-0.61854,-0.39070,-0.20007,-0.62010,-1.17213,
     &         -1.28317,-4.23887,-2.83714,-1.25705,-1.58241,-0.98902/
```

```
C INTERPOLATE TO EACHWAVNUMBER WITH MODULUS ARITHMETIC (BASE 500 STEP 50
      DO 100 K=1,NV
      IF(V(K).LE.499.9 .OR. V(K).GE.1050.1) GO TO 100
      INTV=V(K)
      MODV=1+((INTV-500)/50)
      DELV=(V(K)-500)-(MODV-1)*50
      FRACT=DELV/50.
      DO 110 IC=1,8
  110 CV(IC)=(1.-FRACT)*C(MODV,IC) + FRACT*C(MODV+1,IC)
      S=0.0
      DO 200 I=1,NP
      J=NP-I+1
      TJ=ALOG(TT(J)/270.)
      PJ=(PP(J)/1013.6)**(1.-CV(4))
      PC02=330.E-6*PP(J)
      XJ=ALOG(PJ*(PC02/1013.6)*DL(J))
      C1VT=CV(1)*EXP(CV(6)*TJ)
      C2VT=CV(2)*EXP(CV(7)*TJ + CV(8)*TJ**2)
      C3VX=      EXP(CV(3)*XJ + CV(5)*XJ**2)
      DS=SQRT((C1VT*PJ)**2 + C2VT*C3VX) - C1VT*PJ
      S=S+DS
      TAU(J,K,4)=EXP(-S)
  200 CONTINUE
  100 CONTINUE
      RETURN
      END
```

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE RXFER
      COMMON /LOOPS/ NV,NP,ICASE,NCASE
      COMMON /SATEL/ VEFF,TOBS,SATLOC(2),F(42),V(42)
      COMMON /ATMOS/ P(40),T(40),D(40),
     &               DP(40),PP(40),TT(40),DD(40),DL(40)
      COMMON /SITE / FOVLOC(2),E,TSKIN
      COMMON /TRANS/ SECANT,TAU(40,42,4)
      COMMON /RADS / ROBS,RAIR,RSFC,RCALC,TCALC
C LOCAL PLANCK FUNCTION AND INVERSE BRIGHTNESS TEMPERATURE
      B(V,T)=1.1910636E-5*(V**3)/(EXP(1.4388318*V/T)-1.0)
      TB(V,R)=1.4388318*V/ALOG(1.0+1.1910636E-5*(V**3)/R)
C CONVERT VAS OBS
      ROBS=B(VEFF,TOBS)
C INTEGRATE ATMOSPHERE
      RAIR=0.0
      DO 100 K=1,NV
      RV=0.0
      DO 110 I=1,NP
      IF(I.LT.NP) DRV=B(V(K),TT(I))*(TAU(I+1,K,1)-TAU(I,K,1))
      IF(I.EQ.NP) DRV=B(V(K),TT(I))*(1.0-TAU(I,K,1))
      RV=RV+DRV
  110 CONTINUE
      RAIR=RAIR+F(K)*RV
  100 CONTINUE
C SURFACE AND TOTAL RADIANCES
      RSFC=0.0
      DO 200 K=1,NV
      RSFC=RSFC+F(K)*E*B(V(K),TSKIN)*TAU(1,K,1)
  200 CONTINUE
      RCALC=RSFC+RAIR
      TCALC=TB(VEFF,RCALC)
      RETURN
      END
```

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE SKINIT
      COMMON /LOOPS/ NV,NP,ICASE,NCASE
      COMMON /SATEL/ VEFF,TOBS,SATLOC(2),F(42),V(42)
      COMMON /ATMOS/ P(40),T(40),D(40),
     &               DP(40),PP(40),TT(40),DD(40),DL(40)
      COMMON /SITE / FOVLOC(2),E,TSKIN
      COMMON /TRANS/ SECANT,TAU(40,42,4)
      COMMON /RADS / ROBS,RAIR,RSFC,RCALC,TCALC
C SIMPLE NEWTONIAN ITERATION TO MAKE RCALC(TSKIN)=ROBS
      DTSKIN=1.0
      DO 100 KOUNT=1,8
      IF(DTSKIN.GT.-0.001 .AND. DTSKIN.LT.0.001) GO TO 100
      TSKINO=TSKIN
      RCALCO=RCALC
      TSKIN=TSKIN+1.0
      CALL RXFER
      DRDT=(RCALC-RCALCO)/(TSKIN-TSKINO)
      DTSKIN=(ROBS-RCALCO)/DRDT
      TSKIN=TSKINO+DTSKIN
      CALL RXFER
  100 CONTINUE
      RETURN
      END
```

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE REPORT
      COMMON /LOOPS/ NV,NP,ICASE,NCASE
      COMMON /SATEL/ VEFF,TOBS,SATLOC(2),F(42),V(42)
      COMMON /ATMOS/ P(40),T(40),D(40),
     &               DP(40),PP(40),TT(40),DD(40),DL(40)
      COMMON /SITE / FOVLOC(2),E,TSKIN
      COMMON /TRANS/ SECANT,TAU(40,42,4)
      COMMON /RADS / ROBS,RAIR,RSFC,RCALC,TCALC
      DIMENSION TAUNET(40,4)
C INTEGRATE TRANSMISSION OVER BANDPASS
      DO 100 ITYPE=1,4
      DO 100 I=1,NP
      TAUNET(I,ITYPE)=0.0
      DO 100 K=1,NV
  100 TAUNET(I,ITYPE)=TAUNET(I,ITYPE)+F(K)*TAU(I,K,ITYPE)
C
      WRITE(6,1111) ICASE,NCASE,
     &              TSKIN,TOBS,TCALC,VEFF,E,SECANT,
     &              SATLOC,FOVLOC,
     &              ROBS,RCALC,RAIR,RSFC
 1111 FORMAT('1'/' RESULTS FOR CASE = ',I3,' OF ',I3,' CASES.'//
     & ' TSKIN =  ',F10.2/' TOBS =   ',F10.2/' TCALC =  ',F10.2/
     & ' VEFF =   ',F10.2/' E =      ',F10.2/' SECANT = ',F10.2/
     & ' SATLOC = ',2F10.2/' FOVLOC = ',2F10.2/
     & ' ROBS =   ',F10.2/' RCALC =  ',F10.2/' RAIR =   ',F10.2/
     & ' RSFC =   ',F10.2///
     & 2X,'J',6X,'P(J)',6X,'T(J)',6X,'D(J)',4(4X,'TAU(J)')/
     & 3X,8X,'MB',9X,'K',9X,'C','     TOTAL','  H2O CONT',
     &                          '  H2O LINE','  CO2 LINE'/
     & 33X,'  TYPE = 1','  TYPE = 2','  TYPE = 3','  TYPE = 4')
C
      DO 200 I=1,NP
      J=NP-I+1
      WRITE(6,3333) J,P(J),T(J),D(J),(TAUNET(J,ITYPE),ITYPE=1,4)
 3333 FORMAT(1X,I2,3F10.1,4F10.4)
  200 CONTINUE
C
      WRITE(6,2222) NV,((K,V(K),F(K)),K=1,NV)
 2222 FORMAT(/' SPECTRAL RESPONSE AT ',I3,' WAVENUMBERS'/
     &       9X,'K',6X,'V(K)',6X,'F(K)'/(I10,F10.1,F10.4))
C
```

```
      WRITE(6,9999)
 9999 FORMAT('1')
      DO 300 ITYPE=1,4
      WRITE(6,4440) ITYPE,(K,K=1,NV)
 4440 FORMAT(' TRANSMITTANCE OF TYPE = ',I3/6X,'K = ',20I5/(10X,20I5))
      WRITE(6,4442)  (V(K),K=1,NV)
 4442 FORMAT(3X,'V(K)  = ',20F5.0/(10X,20F5.0))
      WRITE(6,4443)
 4443 FORMAT('  J','  P(J) ')
C
      DO 400 I=1,NP
      J=NP-I+1
      WRITE(6,4444) J,P(J),(TAU(J,K,ITYPE),K=1,NV)
 4444 FORMAT(I3,F6.0,1X,20F5.2/(10X,20F5.2))
  400 CONTINUE
C
  300 CONTINUE
C
      RETURN
      END
```

A.2 SAMPLE OUTPUT

```
RESULTS FOR CASE =   1 OF   1 CASES.

TSKIN =       290.56
TOBS =        285.00
TCALC =       285.00
VEFF =        877.19
E =             0.99
SECANT =        1.52
SATLOC =       75.00       0.0
FOVLOC =       90.00      40.00
ROBS =         97.08
RCALC =        97.08
RAIR =         18.65
RSFC =         78.43


 J       P(J)         T(J)          D(J)     TAU(J)     TAU(J)     TAU(J)     TAU(J)
           MB            K             C      TOTAL   H20 CONT   H20 LINE   CO2 LINE
                                           TYPE = 1   TYPE = 2   TYPE = 3   TYPE = 4
 8      100.0        217.0         -82.0     0.9999     1.0000     1.0000     1.0000
 7      200.0        217.0         -66.0     0.9999     1.0000     1.0000     0.9999
 6      300.0        229.0         -49.0     0.9997     1.0000     1.0000     0.9998
 5      400.0        241.0         -35.0     0.9991     0.9997     0.9998     0.9996
 4      500.0        252.0         -24.0     0.9960     0.9979     0.9988     0.9992
 3      700.0        269.0          -8.0     0.9675     0.9780     0.9917     0.9976
 2      850.0        279.0           0.0     0.8980     0.9248     0.9755     0.9954
 1     1000.0        287.0           7.0     0.7759     0.8257     0.9469     0.9922

SPECTRAL RESPONSE AT  11 WAVENUMBERS
           K       V(K)       F(K)
           1      800.0     0.0015
           2      820.0     0.0607
           3      840.0     0.1017
           4      860.0     0.1457
           5      880.0     0.1502
           6      900.0     0.1426
           7      920.0     0.1305
           8      940.0     0.1259
           9      960.0     0.1168
          10      980.0     0.0228
          11     1000.0     0.0015
```

```
TRANSMITTANCE OF TYPE =    1
      K =      1    2    3    4    5    6    7    8    9   10   11
   V(K) =  800. 820. 840. 860. 880. 900. 920. 940. 960. 980.1000.
  J  P(J)
  8  100.  1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
  7  200.  1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
  6  300.  1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
  5  400.  1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
  4  500.  0.99 0.99 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
  3  700.  0.94 0.95 0.96 0.96 0.97 0.97 0.97 0.97 0.97 0.97 0.98
  2  850.  0.83 0.85 0.87 0.89 0.90 0.91 0.91 0.91 0.91 0.92 0.92
  1 1000.  0.65 0.69 0.72 0.75 0.78 0.80 0.80 0.80 0.80 0.82 0.83
TRANSMITTANCE OF TYPE =    2
      K =      1    2    3    4    5    6    7    8    9   10   11
   V(K) =  800. 820. 840. 860. 880. 900. 920. 940. 960. 980.1000.
  J  P(J)
  8  100.  1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
  7  200.  1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
  6  300.  1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
  5  400.  1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
  4  500.  1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
  3  700.  0.97 0.97 0.97 0.97 0.98 0.98 0.98 0.98 0.98 0.98 0.99
  2  850.  0.88 0.89 0.91 0.91 0.92 0.93 0.93 0.94 0.94 0.95 0.95
  1 1000.  0.74 0.76 0.78 0.80 0.82 0.83 0.84 0.86 0.86 0.87 0.88
TRANSMITTANCE OF TYPE =    3
      K =      1    2    3    4    5    6    7    8    9   10   11
   V(K) =  800. 820. 840. 860. 880. 900. 920. 940. 960. 980.1000.
  J  P(J)
  8  100.  1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
  7  200.  1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
  6  300.  1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
  5  400.  1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
  4  500.  1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
  3  700.  0.98 0.98 0.99 0.99 0.99 1.00 0.99 0.99 0.99 0.99 0.99
  2  850.  0.95 0.95 0.96 0.97 0.98 0.99 0.98 0.98 0.98 0.98 0.98
  1 1000.  0.90 0.91 0.92 0.94 0.95 0.97 0.96 0.95 0.95 0.95 0.96
TRANSMITTANCE OF TYPE =    4
      K =      1    2    3    4    5    6    7    8    9   10   11
   V(K) =  800. 820. 840. 860. 880. 900. 920. 940. 960. 980.1000.
  J  P(J)
  8  100.  1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
  7  200.  1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
  6  300.  1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
  5  400.  1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
  4  500.  1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
  3  700.  1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 0.99 1.00 1.00
  2  850.  0.99 1.00 1.00 1.00 1.00 0.99 0.99 0.99 0.99 0.99 0.99
  1 1000.  0.99 1.00 1.00 1.00 1.00 0.99 0.99 0.99 0.98 0.99 0.99
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An algorithm is presented for calculating the atmospheric transmittance in the 10 to 20 μm spectral band from a known temperature and dewpoint profile, and then using this transmittance to estimate the surface (skin) temperature from a VISSR observation in the 11 μm window. Parameterizations are drawn from the literature for computing the molecular absorption due to the water vapor continuum, water vapor lines, and carbon dioxide lines. FORTRAN code is documented for this application, and the sensitivity of the derived skin temperature to variations in the model's parameters is calculated. VISSR calibration uncertainties are identified as the largest potential source of error.

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