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DETERMINATION OF THE TOTAL OUTGOING RADIANCE OF THE EARTH-ATMOSPHERE SYSTEM

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GODDARD SPACE FLIGHT CENTER
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Musa Pasternak

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ABSTRACT

Utilizing eighty atmospheric models, the equivalent blackbody temperatures for the 6- 7, 10-11, 15-16 and the 20-24 μm spectral regions, corresponding to the Nimbus 3 Medium Resolution Infrared Radiometer were computed. The blackbody temperatures for the 5-30 μm channel and the total outgoing radiances for these atmospheres were also computed. It was found that the total radiation can be estimated from the 10-11 μm channel alone with a standard error of 2.2 watts/meter^2 sr.

The standard error can be reduced to 0.50 watts/meter^2 sr or less if one uses the 10-11 and 14-16μm channels in conjunction with either of the 6-7μm or 20-24μm water vapor channels. The theoretical relationships given in this report between the total infrared radiation and the various channels are useful for radiation studies.

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DETERMINATION OF THE TOTAL OUTGOING RADIANCE OF THE EARTH-ATMOSPHERE SYSTEM

INTRODUCTION

The Nimbus 3 Medium Resolution Radiometer measures the long-wave radiation in four narrow band spectral regions. The problem was to find how accurately the long-wave outgoing radiance can be theoretically obtained, using the energy from different combinations of one, two, three, or all of these spectral intervals.

To solve this problem, the equivalent blackbody temperatures and the effective radiances for the spectral regions corresponding to the Nimbus 3 MRIR channels and the 5-30 μm spectral region from Nimbus 2 were computed at vertical incidence for 80 atmospheric profiles. The total outgoing radiance for these atmospheres was also computed. Equations of the total radiance (0.2-500μm) were obtained as a function of the blackbody temperatures or filtered radiances of different channel combinations. The type of polynomial generally least-square fitted was a third degree in the first channel variable, a second degree in the second channel variable, and linear fits in the third and fourth variables, if used.

METHOD

The equivalent blackbody temperatures and effective radiances for the 6-7, 10-11, 14-16, and the 20-24 μm spectral regions corresponding to the Nimbus 3 MRIR channels and the 5-30 μm spectral region from the Nimbus 2 MRIR and the total outgoing radiances were computed at vertical incidence for 80 atmospheric profiles. The atmospheric profiles consisted of ten basic models of temperature and ozone. Each basic model had water vapor profiles of 10% and 50% humidity; and atmospheres having no clouds, and clouds at 3, 6 and 9 kms. This made a total of 80 atmospheric profiles in all*.

The Nimbus channels for which the filtered energy was computed receive the following radiation:

Nimbus 2: 5-30 μm channel

Measures most of the emitted longwave infrared energy.

Nimbus 3: (The half-power channel bandwidths are noted in parentheses)

Channel 1: 6-7 μm (6.35-7.72 μm):

Receives radiation from the upper troposphere water vapor.

Channel 2: 10-11 μm (10.1-11.2 μm):

Operating in the atmospheric window, this channel measures surface or near-surface temperatures over clear portions of the atmosphere.

*The atmospheric models were supplied by E. Raschke, Rohr Universität, Bochum, Germany.

Channel 3: 14-16 μm (14.5-15.8 μm)

Receives radiation which emanates primarily from the stratosphere.

Channel 4: 20-24 μm (20.8-23.2 μm)

Receives radiation from the lower tropospheric water vapor.

The atmospheric computation program used the absorption coefficients from Mueller and Yamanoto for wave numbers 200-1925 cm^{-1}: (1) the water absorption coefficients from Yamamoto for 0-200 cm^{-1}: (2) and the Green and Griggs band-model coefficients beyond 1925 cm^{-1}.

The computer program to obtain the radiance was an extensively revised version of that by V. Kunde. A computer program was written to obtain the least-square fits of the total outgoing radiance (0.2-500 μm) as a function of the equivalent blackbody temperatures or effective radiances of different channel combinations. The type of polynomial generally fitted was: Total Outgoing Radiance = $A + BV + CV^2 + DV^3 + EX + FX^2 + GY + HZ$, where V, X, Y and Z represent blackbody temperatures or filtered radiances from the different channels. A to F are constants obtained by the least-square fit. Obviously some of the constants E to H will be zero if the corresponding channels are not considered. The total outgoing radiance was then calculated from each equation using the effective channel blackbody temperatures or effective radiances for the 80 atmospheric models. For each equation the maximum difference between the calculated and the theoretical total radiances and the standard error of estimate were obtained. Thus one could have some measure of the accuracy of the different least-square fits.

RESULTS

The effective blackbody temperatures and the outgoing radiance for each atmosphere are tabulated in Table A-1. Also the average values for the outgoing radiances and the filtered channel energies and their standard deviations are listed in Table A-2.

The Nimbus blackbody temperatures and total outgoing radiances obtained for 10% humidity are shown versus a number representing their atmosphere (Figure 1). Each of the ten basic atmospheres of ozone and temperature was arbitrarily given a number for identification purposes (Appendix A-1). The results are shown for the non-cloudy atmosphere and for 3, 6 and 9 km cloud heights.

One can see that there is an interaction between temperature changes of the channels at the same cloud height and humidity. The linear correlation coefficients of the 10-11 μm channel with the 6-7 and 20-24 μm channels were calculated to be 0.79 and 0.95, respectively. The 14-16 μm channel had the lowest correlation with the other three channels. The correlation coefficients are listed in Table 1.

The total outgoing radiances (total intensities) are shown as a function of the Nimbus 3 equivalent blackbody temperatures used in Figures 2a and 2b. Thus one can see graphically the correlation between the total radiance and the channel temperatures.

The Nimbus 2 5-30 μm temperature had an extremely high correlation coefficient of 0.998 with the total intensity. Thus the total intensity can be calculated very accurately using the channel alone. Because of the high correlation, it is assumed that the empirical results showing the limb-darkening changes of the Nimbus 2 5-30 μm temperature as a function of zenith angle are equivalent to limb-darkening changes of the total intensity. This is not the case with the other channels.

In the Nimbus 3 radiometer, the 10-11 μm temperature has the highest correlation with the intensity (0.991) and the 14-16 μm temperature the lowest (0.499).

The model atmosphere computer program also computed the equivalent theoretical temperatures for each 25 cm^{-1} wavelength interval at the top of the earth-atmosphere system. Temperatures whose midpoints corresponded to those of the Nimbus 3 channels give similar correlations with the 5-30μm Nimbus 2 temperatures. This implies that even if the filters corresponding to the different channels deviate slightly, the conclusions in this report would still hold about the best combinations of wavelength intervals used to compute the intensity.

The results of the correlation analysis are summarized in Table 1. The standard formula used to obtain the correlation ρ_{yx} between the variables y and x was:

$$\rho_{yx} = \frac{V_{yx}}{D_x D_y}$$

where V_{xy} is the variance of variables y and x

D_y and D_x are standard deviations of y and x.

The formula used to calculate the deviation of any variable Z is:

$$D_z = \sqrt{\frac{\Sigma\,(\overline{z} - \bar{z})^2}{N}}$$

where $\bar{z}$ is the average value and N is number of samples

The variance of y and x is:

$$V_{yx} = \overline{xy} - \bar{x}\,\bar{y}$$

The correlation coefficients of the channels' filtered energies and total intensity may help one to realize the best combinations of the different channels to use in order to compute the total radiance.

The total radiance was least-square fitted as different combinations of the channel energies. First the intensity was obtained as a function of one channel.

Because of the correlation between the intensity and the 5-30 μm bandwidth, the intensity can be obtained as a third degree polynomial of the Nimbus 5-30 μm channel alone. This accuracy was comparable to that of obtaining the intensity using three Nimbus 3 channels.

The intensity was also least-square fitted as third-degree and fourth-degree polynomials of the 10-11μm channel which of the Nimbus 3 channels had the highest correlation to the intensity. These did not give too accurate results. One such fit gave a standard deviation of 2.25 watts/meter^2 comparable to a 10-11 μm temperature error of 2.97 K. The fourth-degree polynomial did not give more accurate results than the third degree.

The total radiance was also least-square fitted as a function of two Nimbus 3 channels. The more accurate such combinations had a third-degree polynomial of channel 2 and a second-degree polynomial of the other water vapor channels. One such equation gave a standard deviation of about 1.3 watts/meter^2 (approximately 1.7 K in channel 2 temperature). The maximum errors were more than 4 watts/meter^2.

The total radiance was also obtained using three Nimbus 3 variables. Equations having the least standard deviation used the 10-11 μm, 20-24 μm, and the 14-16 μm channels. This gave a standard deviation of about 0.23 watts/meter^2 sr. The maximum error for this case was about 0.6 watts/meter^2 sr.

This accuracy compared favorably with that obtained using the 5-30 μm channel alone and that using all four channels.

The deviation was increased when one used the 20-24 μm channel in place of the 6-7 μm channel. However, it may be that the theoretical intensity thus calculated is more accurate, since the absorption coefficients in the 6-7 μm range may be more precisely known.

It is significant to note that using the two Nimbus 3 water vapor channels 1 and 4 in a three variable equation is not as satisfactory as using the 14-16 μm channel in conjunction with the 6-7 μm channel.

Using the two Nimbus 3 water vapor channels in a three variable equation increases the errors by a factor of five over that in using the 14-16 μm channel in conjunction with the 6-7 μm channel. This may be because channels 2 and 4 are more highly correlated than 2 and 3. Thus the use of channel 3 provides additional information about the atmospheric intensity.

The total radiation was also obtained as a function of all four channels. Using the 10-11 μm or 20-24 μm channels as a third-degree polynomial and the Nimbus 3 channels as linear functions could give standard deviations and maximum errors of approximately 0.20 and 0.45 watts/meter^2 sr respectively.

The constants of the different equations obtaining the total radiance as a function of the temperature or radiance are shown in Tables 2 and 3. The tables also tabulate for a given least-square fit the standard deviations and the maximum deviations between the calculated and theoretical intensities for the 80 atmospheres.

In evaluating the accuracy of the equations it should be realized that errors of 2 watts/meter^2 sr or less are within the accuracy of the theoretical calculation. A study had been made between the intensities obtained from our atmospheric computation program and that employed by Wark and Lienesch. The same 80 atmospheric profiles were used. Our calculated intensities were an average of 2 watts/meter^2 sr greater, giving an average intensity of 65 watts/meter^2 sr. The differences between the intensities calculated by these two programs was attributed to limits in the state of the art in calculating the atmospheric transmission coefficients precisely.

Equations calculating the blackbody temperatures of one channel in terms of the others were also determined. The 20-24 μm temperature can be theoretically calculated from the other three channel temperatures within a 1 K error of estimate. The other Nimbus 3 temperatures were obtained less accurately. The results are shown in Table 4.

CONCLUSION

As previously known, one obtains the total outgoing radiance very accurately from the 5-30 μm Nimbus 3 channel alone, whose bandwidth includes practically all of the atmospheric longwave radiation. However, the Nimbus 3 radiometer does not have this channel. Using the 10-11 μm channel by itself is not so accurate, giving a standard deviation of 2.25 watts/meter^2 sr. By adding either of the water vapor channels to the equation the standard deviation is reduced by 1 watt/sq meter sr. An error of 1 watt is certainly within the limits of accuracy in determining the total radiances, since the absorption coefficients are not precisely known. Using three channels, and adding the 14-16 μm channel to the 20-24 and 10-11 μm channels, one obtains a very small standard deviation of 0.2 watts. This is just as good an accuracy as obtained by using the 5-30 μm bandwidth alone. Using the 14-16 μm channel in place of another water vapor channel reduced the deviation by a factor of five and gave accuracies equivalent to using all four channels. Similar small deviations appeared in all the appropriate three channel equations tested, whether filtered radiances or temperatures were used.

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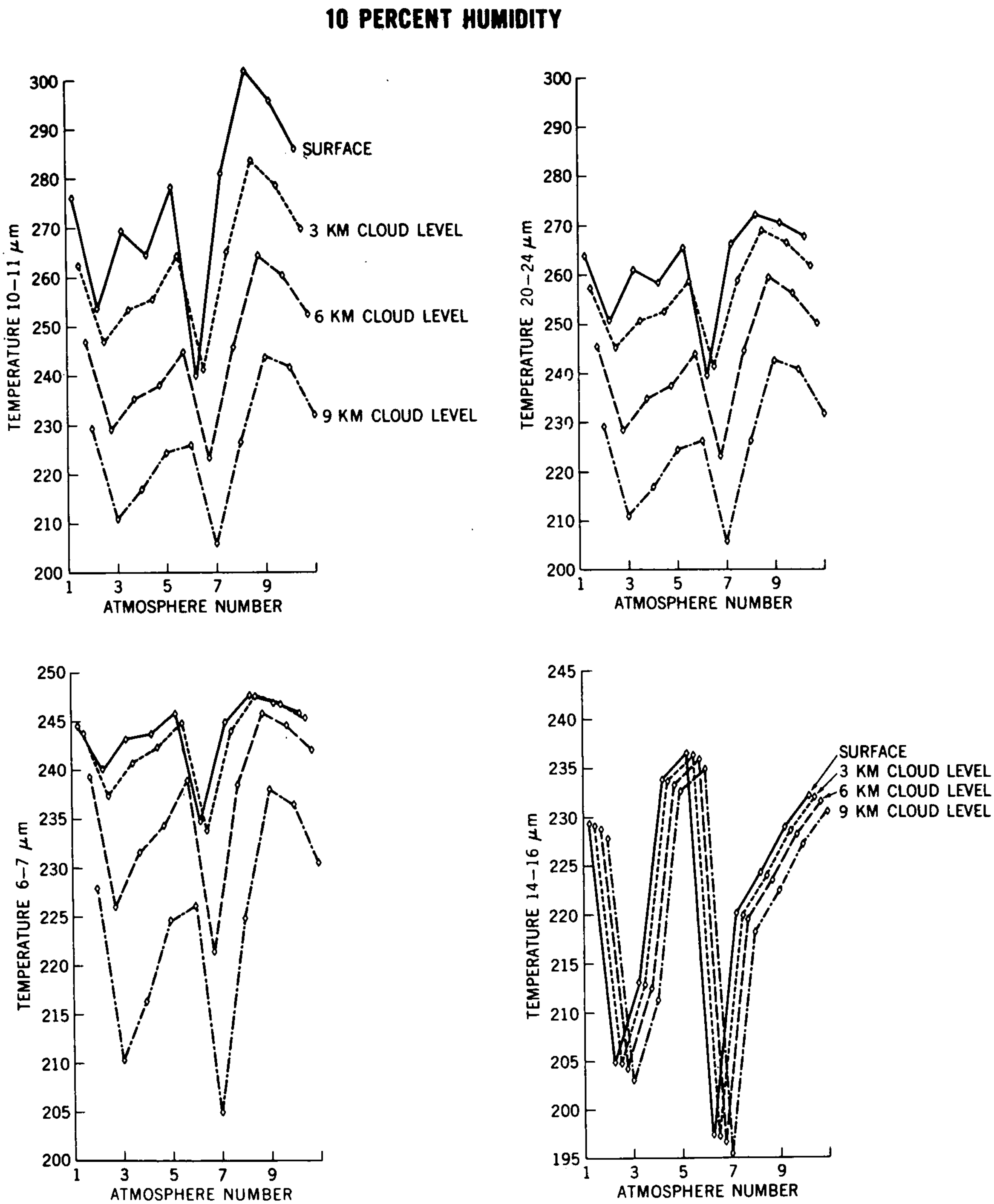

Figure 1. Nimbus 3 Temperatures vs. Atmosphere. Each of the basic atmosphere profiles of ozone and temperature had been assigned a number 1 to 10.

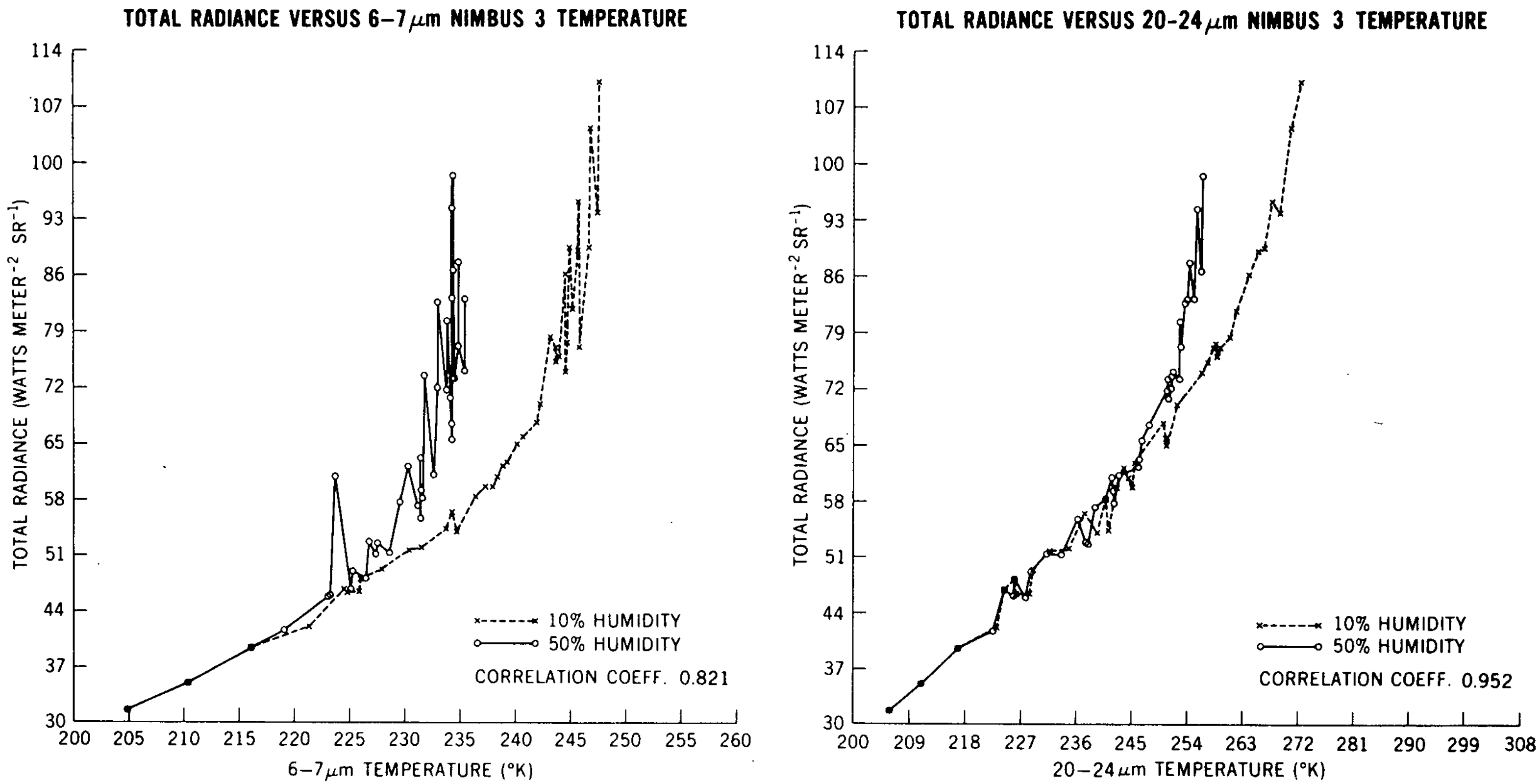

Figure 2A. Total Radiance vs. Nimbus 3 Temperatures

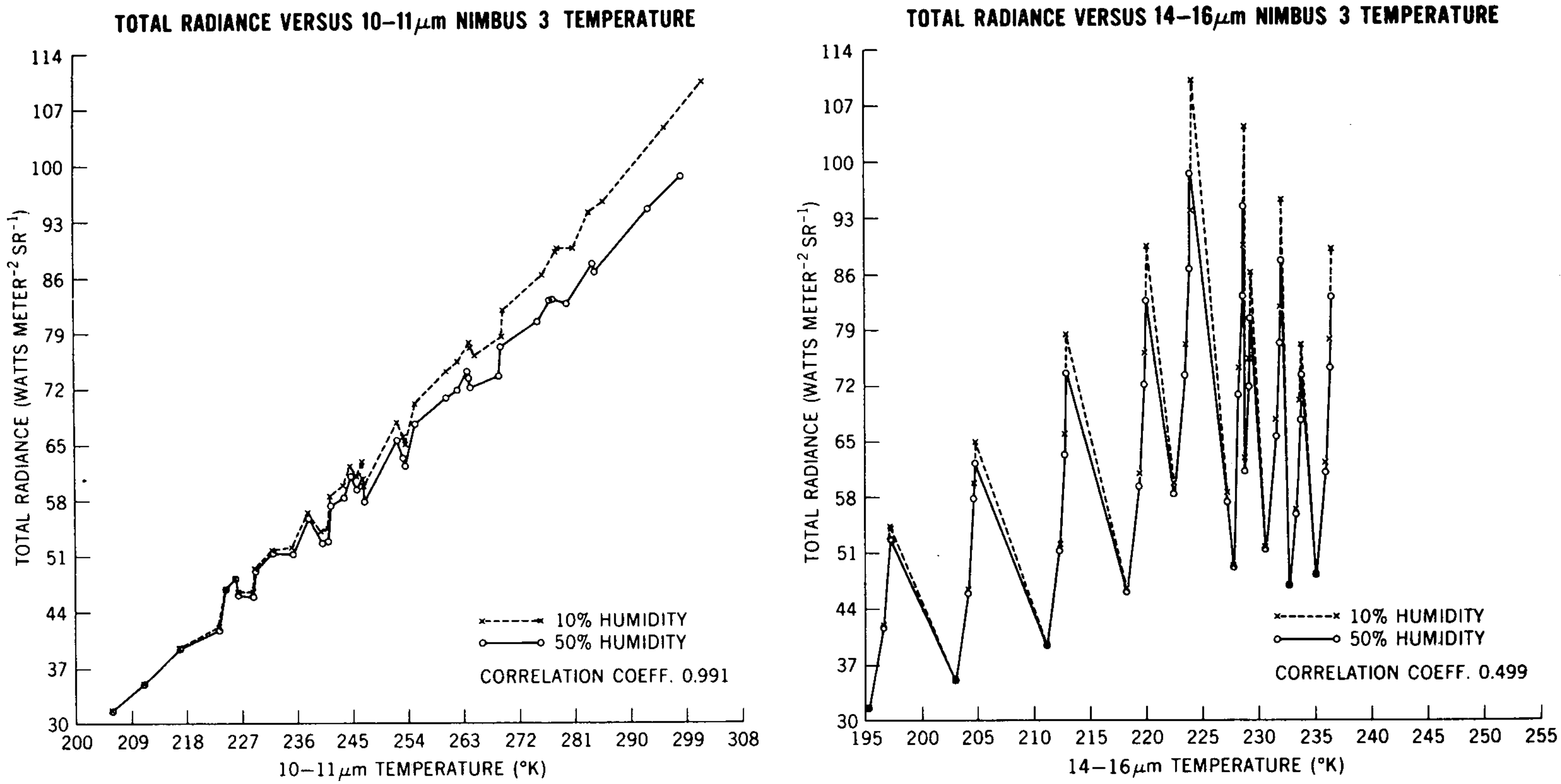

Figure 2B. Total Radiance vs. Nimbus 3 Temperatures

Table 1

Correlation Coefficients from 80 Atmospheric Models

(A)

Correlation Coefficients of Blackbody Temperatures of Nimbus 3 channels with each other

Channel 1		Channel 2		Channel 4	
With Channels	Corr. Coeff.	With Channels	Corr. Coeff.	With Channels	Corr. Coeff.
2	0.793	1	0.793	1	0.928
3	0.512	3	0.442	2	0.947
4	0.928	4	0.947	3	0.469

(B)

Correlation of total outgoing radiance with Nimbus 3 channels

Nimbus 3 Channel	Corr. Coeff. for Blackbody Temperature	Corr. Coeff. for Effective Radiance
1 (6-7 μm)	0.821	0.826
2 (10-11 μm)	0.991	0.984
3 (14-16 μm)	0.499	0.485
4 (20-24 μm)	0.952	0.959

Table 2A

Total Intensity (watts/meter^{2}sr) as a Function of Equivalent Blackbody Temperature from Least-Square Fits

No.	Function	CONSTANTS A	B	C	D	E	F	G	H
ONE CHANNEL: TOTAL INTENSITY = $A+BU+CU^2+DU^3+EU^4$									
1	$F(T_2)$	27.639	0.699658 (2)	$-0.908792*10^{-4}$ (2)	$0.795619*10^{-5}$ (2)	--	--	--	--
2	$F(T_2)$	27.920	0.66081 (2)	$0.140151*10^{-2}$ (2)	$-0.13429*10^{-4}$ (2)	$-0.13429*10^{-4}$ (2)	--	--	--
TWO CHANNELS: TOTAL INTENSITY = $A+BU+CU^2+DU^3+EV+FV^2$									
1	$F(T_2, T_1)$	29.2186	0.258639 (2)	$0.426007*10^{-2}$ (2)	$-0.699097*10^{-5}$ (2)	0.231002 (1)	$0.24930*10^{-2}$ (1)	--	--
2	$F(T_2, T_4)$	29.034	-0.46286 (2)	$0.881739*10^{-2}$ (2)	$-0.131498*10^{-4}$ (2)	0.98784 (4)	$-0.39623*10^{-2}$ (4)	--	--
3	$F(T_2, T_3)$	28.1418	0.57644 (2)	$0.129067*10^{-2}$ (2)	$0.24899*10^{-5}$ (2)	0.110229 (3)	$0.476888*10^{-3}$ (3)	--	--
4	$F(T_4, T_2)$	27.5066	0.779764 (4)	$-0.613776*10^{-2}$ (4)	$0.444888*10^{-4}$ (4)	$-0.618134*10^{-1}$ (2)	$0.464663*10^{-2}$ (2)	--	--
5	$F(T_4, T_1)$	30.9292	-4.66708 (4)	0.103769 (4)	$-0.49907*10^{-3}$ (4)	5.12742 (1)	$-0.830311*10^{-1}$ (1)	--	--
THREE CHANNELS: TOTAL INTENSITY = $A+BU+CU^2+DU^3+EV+FV^2+GW$									
1	$F(T_2, T_1, T_3)$	30.4424	0.807411 (2)	$-0.45885*10^{-2}$ (2)	$0.371556*10^{-4}$ (2)	-0.504167 (1)	0.115532 (1)	0.118574 (3)	--
2	$F(T_2, T_1, T_4)$	28.300	-0.40408 (2)	$0.10901*10^{-1}$ (2)	$-0.321206*10^{-4}$ (2)	0.636244 (1)	$-0.639709*10^{-2}$ (1)	0.37736 (4)	--
3	$F(T_2, T_4, T_3)$	29.271	-0.110172 (2)	$0.455591*10^{-2}$ (2)	$0.300864*10^{-5}$ (2)	0.563988 (4)	$-0.46265*10^{-3}$ (4)	0.122583 (3)	--
4	$F(T_2, T_4, T_1)$	28.443	0.97907 (2)	$-0.52327*10^{-2}$ (2)	$0.313609*10^{-4}$ (2)	-0.695677 (4)	$0.70729*10^{-2}$ (4)	0.33960 (1)	--
5	$F(T_4, T_2, T_3)$	29.1930	0.6123 (4)	$-0.13376*10^{-2}$ (2)	$0.52435*10^{-5}$ (4)	-0.14920 (2)	$0.51627*10^{-2}$ (2)	0.12245 (3)	--
6	$F(T_4, T_2, T_1)$	27.310	-0.11713 (4)	$0.33314*10^{-2}$ (4)	$0.644848*10^{-4}$ (4)	0.554607 (2)	$0.116838*10^{-2}$ (2)	0.318169 (1)	--
a) FOUR CHANNELS: TOTAL INTENSITY = $A+BU+CU^2+DU^3+EV+FW+GZ$									
1	$F(T_2, T_4, T_1, T_3)$	29.2559	-0.0492526 (2)	$0.419172*10^{-2}$ (2)	$0.330433*10^{-5}$ (2)	0.46894 (4)	$0.368204*10^{-1}$ (1)	0.120166 (3)	--
b) FOUR CHANNELS: TOTAL INTENSITY = $A+BU+CU^2+DU^3+EV+FV^2+GW+HZ$									
1	$F(T_2, T_1, T_3, T_4)$	29.4075	0.0530822 (2)	$0.28927*10^{-2}$ (2)	$0.909311*10^{-5}$ (2)	-0.052167 (1)	$0.147351*10^{-2}$ (1)	0.121321 (3)	0.43676 (4)
2	$F(T_2, T_4, T_1, T_3)$	29.178	0.0940577 (2)	$0.258547*10^{-2}$ (2)	$0.918820*10^{-5}$ (2)	0.325856 (4)	$0.108108*10^{-2}$ (4)	0.0500736 (1)	0.119644 (3)
3	$F(T_4, T_2, T_1, T_3)$	29.1283	0.497577 (4)	$-0.107746*10^{-2}$ (4)	$0.879867*10^{-5}$ (4)	-0.0656325 (2)	$0.469053*10^{-2}$ (2)	0.0420485 (1)	0.119422 (3)

U, V, W and Z are Nimbus 3 blackbody temp. minus 200°K. The Nimbus 3 channel pertaining to term is written in parenthesis. The channels cover the following wavelength: 1 (6-7 μm), 2 (10-11 μm), 3 (14-16 μm), 4 (20-24 μm).

Table 2B

Errors of Estimate

No.	Function	No. of Channels in Equation	Maximum Deviation	Standard Deviation
		One Channel	(K)	(K)
1	$F(T_2)$		4.78	2.25
2	$F(T_2)$		4.84	2.25
		Two Channel		
1	$F(T_2, T_1)$		5.30	1.30
2	$F(T_2, T_4)$		3.67	1.35
3	$F(T_2, T_3)$		3.07	1.29
4	$F(T_4, T_2)$		4.20	1.78
5	$F(T_4, T_1)$		11.98	3.12
		Three Channels		
1	$F(T_2, T_1, T_3)$		1.64	0.521
2	$F(T_2, T_1, T_4)$		2.52	1.22
3	$F(T_2, T_4, T_3)$		0.814	0.227
4	$F(T_2, T_4, T_1)$		4.97	1.22
5	$F(T_4, T_2, T_3)$		0.471	0.227
6	$F(T_4, T_2, T_1)$		4.88	1.207
		a) Four Channels		
1	$F(T_2, T_4, T_1, T_3)$		0.4715	0.216
		b) Four Channels		
1	$F(T_2, T_1, T_3, T_4)$		0.773	0.209
2	$F(T_2, T_4, T_1, T_3)$		0.4715	0.216
3	$F(T_4, T_2, T_1, T_3)$		0.448	0.217

Table 3A

Total Intensity (watts/meter^{2}sr) as a Function of Effective Radiance From Least-Square Fits (Radiance in watts/meter^{2}sr)

No.	Function	CONSTANTS A	B	C	D	E	F	G	H
ONE CHANNEL: TOTAL INTENSITY = A + BU + CU^2 + DU^3									
1	$F(\bar{N}_{5-30})$	0.46387	1.79024 (5-30μm)	-0.008960 (5-30μm)	-0.008960 (5-30μm)	0.68934 $*10^{-4}$ (5-30μm)	-	-	-
2	$F(\bar{N}_2)$	12.999	15.0662 (2)	-1.07634 (2)	0.0406255 (2)		-	-	-
TWO CHANNEL: TOTAL INTENSITY = A + BU + CU^2 + DU^3 + EV + FV^2									
1	$F(\bar{N}_2, \bar{N}_1)$	18.0997	9.3445 (2)	-0.40090 (2)	0.013479 (2)	26.769 (1)	4.8074 (1)	-	-
2	$F(\bar{N}_2, \bar{N}_4)$	-34.741	-9.4307 (2)	1.77191 (2)	-0.071077 (2)	41.525 (4)	-3.335762 (4)	-	-
3	$F(\bar{N}_2, \bar{N}_3)$	8.436	13.5946 (2)	-0.921179 (2)	0.035336 (2)	3.77872 (3)	-0.23633 (3)	-	-
4	$F(\bar{N}_4, \bar{N}_2)$	-235.439	221.19 (4)	-62.640 (4)	5.807 (4)	11.3059 (2)	-0.4094 (2)	-	-
THREE CHANNELS: TOTAL INTENSITY = A + BU + CU^2 + DU^3 + EV + FV^2 + GW									
1	$F(\bar{N}_2, \bar{N}_1, \bar{N}_3)$	13.936	11.7049 (2)	-0.76959 (2)	0.03070 (2)	-7.9196 (1)	46.9534 (1)	2.27295 (3)	-
2	$F(\bar{N}_2, \bar{N}_4, \bar{N}_3)$	-7.72142	-0.12634 (2)	0.538575 (2)	-0.0191539 (2)	17.0772 (4)	-0.71590 (4)	2.3575 (3)	-
3	$F(\bar{N}_2, \bar{N}_4, \bar{N}_1)$	-15.5424	-2.91206 (2)	1.04526 (2)	0.0434417 (2)	26.6856 (4)	-2.26812 (4)	14.4083 (1)	-
4	$F(\bar{N}_4, \bar{N}_1, \bar{N}_3)$	30.96	-9.747 (4)	-0.5739 (4)	1.0709 (4)	123.46 (1)	-289.86 (1)	3.0118 (3)	-
5	$F(\bar{N}_4, \bar{N}_2, \bar{N}_3)$	0.352	10.442 (4)	-0.24896 (4)	0.037092 (4)	3.4158 (2)	0.07734 (2)	2.4113 (3)	-
6	$F(\bar{N}_4, \bar{N}_2, \bar{N}_1)$	-18.879	33.082 (4)	-9.0552 (4)	0.82698 (4)	7.8207 (2)	-0.14789 (2)	26.461 (1)	-
7	$F(\bar{N}_2, \bar{N}_1, \bar{N}_4)$	10.402	3.4923 (2)	0.23045 (2)	-0.010314 (2)	36.889 (1)	-29.294 (1)	6.1748 (4)	-
a) FOUR CHANNELS: TOTAL INTENSITY = A + BU + CU^2 + DU^3 + EV + FW + GZ									
1	$F(\bar{N}_2, \bar{N}_4, \bar{N}_1, \bar{N}_3)$	2.84756	3.45916 (2)	0.114626 (2)	-0.0024949 (2)	8.78379 (4)	5.21506 (1)	2.34702 (3)	-
b) FOUR CHANNELS: TOTAL INTENSITY = A + BU + CU^2 + DU^3 + EV + FV^2 + GW + HZ									
1	$F(\bar{N}_2, \bar{N}_1, \bar{N}_3, \bar{N}_4)$	2.87688	3.50946 (2)	0.109769 (2)	-0.0022991 (2)	5.01140 (1)	0.361816 (1)	2.34756 (3)	8.75678 (4)
2	$F(\bar{N}_2, \bar{N}_4, \bar{N}_3, \bar{N}_1)$	-2.47294	1.65391 (2)	0.34251 (2)	-0.0117588 (2)	13.0639 (4)	-0.43164 (4)	2.32862 (3)	4.18774 (1)
3	$F(\bar{N}_4, \bar{N}_2, \bar{N}_1, \bar{N}_3)$	-2.7168	14.2818 (4)	-2.13805 (4)	0.212206 (4)	4.57218 (2)	0.018970 (2)	7.60691 (1)	2.30869 (3)

U, V, W, and Z are effective radiances of channels. The Nimbus 2 5-30μm or Nimbus 3 channel pertaining to term is written in parenthesis. The Nimbus 3 channels cover the following wavelengths: 1 (6-7μm), 2 (10-11μm), 3 (14-16μm), 4 (20-24μm).

Table 3B

Errors of Estimate

No.	Function	No. of Channels in Equation	Maximum Deviation (watts/m^2 sr)	Standard Deviation (watts/m^2 sr)
		One Channel		
1	$F(\bar{N}_{5\text{-}30})$		0.576	0.350
2	$F(\bar{N}_2)$		5.09	2.23
		Two Channels		
1	$F(\bar{N}_2, \bar{N}_1)$		4.9	1.28
2	$F(\bar{N}_2, \bar{N}_4)$		3.1	1.29
3	$F(\bar{N}_2, \bar{N}_3)$		4.76	1.72
4	$F(\bar{N}_4, \bar{N}_2)$		5.15	2.15
		Three Channels		
1	$F(\bar{N}_2, \bar{N}_1, \bar{N}_3)$		1.39	0.467
2	$F(\bar{N}_2, \bar{N}_4, \bar{N}_3)$		0.562	0.230
3	$F(\bar{N}_2, \bar{N}_4, \bar{N}_1)$		2.83	1.233
4	$F(\bar{N}_4, \bar{N}_1, \bar{N}_3)$		13.37	2.79
5	$F(\bar{N}_4, \bar{N}_2, \bar{N}_3)$		0.555	0.241
6	$F(\bar{N}_4, \bar{N}_2, \bar{N}_1)$		4.408	1.196
7	$F(\bar{N}_2, \bar{N}_1, \bar{N}_4)$		4.59	1.23
		a) Four Channels		
1	$F(\bar{N}_2, \bar{N}_4, \bar{N}_1, \bar{N}_3)$		0.455	0.1995
		b) Four Channels		
1	$F(\bar{N}_2, \bar{N}_1, \bar{N}_3, \bar{N}_4)$		0.454	0.1995
2	$F(\bar{N}_2, \bar{N}_4, \bar{N}_3, \bar{N}_1)$		0.495	0.201
3	$F(\bar{N}_4, \bar{N}_2, \bar{N}_1, \bar{N}_3)$		0.619	0.199

Table 4

The Energy of One Nimbus 3 Channel in Terms of the Other Channels

Equation	Errors of Estimate Max. Dev.	Stand. Dev.
Channel 4 (20-24 μm)		
$T_4 = 202.292 + 1.80489\ t_2 - 0.184149*10^{-1}\ t_2^2 + 0.70888*10^{-4}\ t_2^3 - 1.11008\ t_1 + 0.24051*10^{-1}\ t_1^2 - 0.465958*10^{-2}\ t_3$	2.80 K	1.10 K
Channel 2 (10-11 μm)		
$T_2 = 200.670 + 2.55885\ t_4 - 0.113586*10^{-1}\ t_4^2 + 0.110500*10^{-3}\ t_4^3 + 0.295481\ t_3 - 0.50946*10^{-4}\ t_3^2 - 1.5991\ t_1$	20.60 K	4.85 K
$T_2 = 204.961 - 5.80895\ t_4 + 0.143336\ t_4^2 - 0.772256*10^{-3}\ t_4^3 + 6.3804\ t_1 - 0.111284\ t_1^2 - 0.886046*10^{-3}\ t_3$	15.86 K	3.86 K
Channel 1 (6-7 μm)		
$T_1 = 201.471 + 2.71897\ t_4 - 0.63248*10^{-2}\ t_4^2 - 0.82158*10^{-4}\ t_4^3 - 1.96957\ t_2 + 0.111088*10^{-1}\ t_2^2 + 0.67018*10^{-1}\ t_3$	10.92 K	1.69 K
Channel 2 $\overline{N}_2$ (10-11 μm)		
$\overline{N}_2 = 118.352 - 97.860\ \overline{N}_4 + 23.412\ \overline{N}_4^2 - 1.70788\ \overline{N}_4^3 + 90.9088\ \overline{N}_1 - 151.50\ \overline{N}_1^2 + 0.138671\ \overline{N}_3$	3.94 watts/m^2 sr	0.99 watts/m^2 sr
Nimbus 2 5-30 μm temp. as a function of Nimbus 3 channel temp. 2 and 4		
$T_{(5-30)} = 199.219 + 0.28228\ t_2 + 0.17402*10^{-2}\ t_2^2 + 0.146683*10^{-7}\ t_2^3 + 0.714293\ t_4 - 0.312691*10^{-2}\ t_4^2$	2.73 K	1.56 K
Nimbus 2 5-30 μm temp. as a function of Nimbus 3 channel temp.		
$T_{(5-30)} = 199.798 + 0.53901\ t_2 - 0.10207*10^{-2}\ t_2^2 + 0.89260*10^{-5}\ t_2^3 + 0.321233\ t_4 - 0.820861*10^{-4}\ t_4^2 + 0.197029*10^{-1}\ t_1 + 0.141489\ t_3$	0.597 K	0.207 K
In equations temperature T is channel blackbody temperature; temperature $\underline{t}$ = T - 200 K, and $\overline{N}$ is filtered channel radiance - 200 K.		

APPENDIX A

A-1

Table A-1

Total Outgoing Intensity and Nimbus Channel Temperatures for Each Atmosphere

No.	Atmosphere Type	Water Vapor (gms/kilogrm) at ground level	Surface Temp. (at cloud height)	Nimbus 3 Channel Temp. (K) Channel 1 6-7μm	Channel 2 10-11μm	Channel 3 14-16μm	Channel 4 20-24μm	Nimbus 2 Temp. (K) 5-30μm	Total Intensity watts/meter^2 sr	Cloud Ht. Km.	Humidity %
1a	60° N	2.50	277.00	233.90	275.02	229.20	252.86	259.90	80.28	0	50
			262.75	233.86	262.00	229.09	250.78	252.27	71.68	3	50
			247.00	232.67	246.60	228.71	242.94	241.92	61.10	6	50
			229.25	225.34	229.16	227.75	228.72	228.47	49.07	9	50
1b	60° N	0.50	277.00	244.61	276.07	229.27	263.95	263.82	85.08	0	10
			262.75	243.76	262.31	229.14	257.30	254.60	75.18	3	10
			247.00	239.33	246.70	228.73	245.35	242.87	62.69	6	10
			229.25	227.91	229.16	227.75	229.04	228.62	49.31	9	10
2a	70° S June	0.42	254.00	230.36	253.50	204.83	246.10	243.06	62.18	0	50
			247.25	229.63	246.88	204.72	242.09	238.36	57.71	3	50
			229.00	223.07	228.85	204.18	227.85	224.36	45.86	6	50
			211.00	210.35	210.90	203.03	210.89	209.63	34.96	9	50
2b	70° S June	0.084	254.00	240.20	253.66	204.85	250.65	244.81	64.88	0	10
			247.25	237.37	246.95	204.73	245.06	239.65	59.65	3	10
			229.00	225.93	228.85	204.18	228.49	224.64	46.36	6	10
			211.00	210.44	210.90	203.02	210.91	209.64	34.98	9	10
3a	60° S May	1.50	270.00	231.83	268.71	212.93	251.42	253.85	73.47	0	50
			253.75	231.48	253.20	212.77	246.27	244.05	63.22	3	50
			235.50	227.41	235.20	212.29	233.71	230.91	51.16	6	50
			217.00	216.10	216.77	211.20	216.86	215.86	39.38	9	50
3b	60° S May	0.30	270.00	243.20	269.36	212.97	260.92	257.24	78.32	0	10
			253.75	240.74	253.35	212.79	250.56	245.72	65.77	3	10
			235.50	231.57	235.20	212.39	234.78	231.35	51.96	6	10
			217.00	216.24	216.77	211.20	216.88	215.87	39.40	9	10
4a	80° N May	1.0	265.00	234.49	263.96	233.72	250.85	253.64	73.16	0	50
			255.75	234.29	255.16	233.55	247.89	248.29	67.46	3	50
			238.00	231.47	237.79	233.26	236.30	235.97	55.66	6	50
			224.40	225.20	224.20	232.57	224.47	225.62	46.79	9	50
4b	80° N May	0.20	265.00	243.71	264.40	233.75	258.24	256.26	77.00	0	10
			255.75	242.31	255.30	233.67	252.32	250.03	69.94	3	10
			238.00	234.35	237.80	233.27	237.35	236.40	56.34	6	10
			224.40	224.54	224.20	232.50	224.37	225.56	46.70	9	10

Table A-1 (Continued)

No.	Atmosphere Type	Water Vapor (gms/kilogrm) at ground level	Surface Temp. (at cloud height)	Nimbus 3 Channel Temp. (K)				Nimbus 2 Temp. (K) 5-30μm	Total Intensity watts/meter^{2}sr	Cloud Ht. Km.	Humidity %
				Channel 1 6-7μm	Channel 2 10-11μm	Channel 3 14-16μm	Channel 4 20-24μm				
5a	80°N	2.81	279.00	235.52	277.02	236.42	253.93	262.06	83.03	0	50
	July		264.50	235.47	263.70	236.31	251.76	254.34	74.05	3	50
			245.00	223.80	244.70	235.91	241.85	241.66	60.88	6	50
			226.00	226.50	225.82	234.99	226.00	227.27	48.11	9	50
5b	80°N	0.56	279.00	245.70	278.15	236.48	265.40	266.15	88.98	0	10
	July		264.50	244.75	264.10	236.35	258.65	256.80	77.63	3	10
			245.00	238.96	244.73	235.92	243.73	242.38	62.11	6	10
			226.00	226.04	225.82	234.99	225.95	227.24	48.05	9	10
6a	85°S	0.085	240.00	227.58	239.96	197.16	237.97	232.53	52.55	0	50
	July		241.25	226.84	241.02	197.22	237.50	232.82	52.77	3	50
			223.50	219.12	223.23	196.61	222.65	218.91	41.60	6	50
			206.00	204.85	205.72	195.29	205.85	204.13	31.56	9	50
6b	85°S	0.017	240.00	234.74	239.93	197.27	239.40	233.19	53.92	0	10
	July		241.25	233.80	241.04	197.23	241.25	233.75	54.32	3	10
			223.50	221.38	223.23	196.61	223.11	219.14	41.99	6	10
			206.00	205.03	205.72	195.29	205.85	204.14	31.59	9	10
7a	45°S	3.50	282.00	233.05	279.78	219.99	253.68	261.60	82.60	0	50
	May		265.00	233.01	264.13	219.34	251.39	252.54	72.00	3	50
			246.00	231.55	245.66	219.38	242.07	240.00	59.20	6	50
			226.50	223.31	226.26	218.22	225.91	224.63	46.02	9	50
7b	45°S	0.70	282.00	244.96	281.00	220.07	266.37	266.30	89.40	0	10
	May		265.00	243.98	265.00	219.89	258.76	255.17	75.95	3	10
			246.00	238.44	245.71	219.40	244.42	240.92	60.82	6	10
			226.50	224.85	226.50	218.23	226.23	224.78	46.28	9	10
8a	30°N	13.93	304.00	234.46	298.38	223.95	256.43	273.29	98.39	0	50
			284.25	234.46	284.36	223.85	256.20	264.83	86.55	3	50
			264.50	234.33	264.00	223.45	252.80	253.63	73.16	6	50
			243.75	231.65	243.61	222.41	240.79	238.93	58.20	9	50
8b	30°N	2.79	304.00	247.64	301.91	224.17	272.33	280.87	110.07	0	10
			284.25	247.55	283.59	224.00	269.10	269.67	93.78	3	10
			264.50	245.88	264.29	223.52	259.37	256.05	77.01	6	10
			243.75	237.98	243.62	222.43	242.64	239.76	59.62	9	10

Table A-1 (Continued)

No.	Atmosphere Type	Water Vapor (gms/kilogrm) at ground level	Surface Temp. (at cloud height)	Nimbus 3 Channel Temp. (K)				Nimbus 2 Temp. (K) 5-30μ m	Total Intensity watts/meter^{2}sr	Cloud Ht. Km.	Humidity %
				Channel 1 6-7μ m	Channel 2 10-11μ m	Channel 3 14-16μm	Channel 4 20-24μm				
9a	45°N	9.43	297.50	234.39	292.99	228.67	255.56	270.61	94.27	0	50
			279.00	234.39	277.46	228.56	255.10	262.20	83.11	3	50
			260.50	234.18	260.19	228.16	250.95	251.45	70.70	6	50
			241.50	231.24	241.42	227.17	239.06	237.80	57.19	9	50
9b	45°N	1.89	297.50	246.88	295.74	228.84	270.71	277.10	104.27	0	10
			279.00	246.70	278.44	228.68	266.62	266.28	89.37	3	10
			260.50	244.63	260.40	228.22	256.35	253.44	73.95	6	10
			241.50	236.50	241.43	227.18	240.62	238.47	58.35	9	10
10a	60°N	4.92	287.00	234.94	284.08	231.97	254.31	265.54	87.58	0	50
			270.00	234.94	269.07	231.86	253.02	257.13	77.15	3	50
			252.50	234.34	252.23	231.50	246.72	246.28	65.48	6	50
			232.00	228.64	231.93	230.51	231.29	231.10	51.30	9	50
10b	60°N	0.98	287.00	245.80	285.85	232.07	267.73	270.79	95.12	0	10
			270.00	245.29	269.66	231.92	261.81	260.30	81.71	3	10
			252.50	242.03	252.33	231.53	250.11	247.63	67.57	6	10
			232.00	230.46	231.93	230.52	231.71	231.28	51.62	9	10

Table A-2

Average Filtered Energies and Standard Deviations from Eighty Atmospheric Models

Variable	Temperature (K)	Stand. Dev.	Effective Radiance watts/meter^{2}sr	Stand. Dev.
Nimbus 3				
1: 6-7μm	233.06	9.5	0.3115	0.1078
2: 10-11μm	251.32	22.8	5.102	2.4168
3: 14-16μm	221.36	2.8	2.685	0.6167
4: 20-24μm	243.84	2.6	3.807	0.6828
Nimbus 2				
4: 5-30μm	243.74	17.5	42.025	
Total Outgoing Radiance		17.6	64.98	