Calculation of levels of relative contribution of the carbon-dioxide channel radiance from TIROS VII in the case of a large-scale stratospheric warming in January 1964

Giaque, Larry Lee

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CALCULATION OF LEVELS OF RELATIVE CONTRIBUTION OF THE CARBON-DIOXIDE CHANNEL RADIANCE FROM TIROS VII IN THE CASE OF A LARGE SCALE STRATOSPHERIC WARMING IN JANUARY 1964

LARRY LEE GIAUQUE
THESIS

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OF THE CARBON-DIOXIDE CHANNEL RADIANCE FROM
TIROS VII IN THE CASE OF A LARGE-SCALE
STRATOSPHERIC WARMING IN JANUARY 1964

by

Larry Lee Giauque

Thesis Advisor: F. L. Martin

September 1971

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Calculation of Levels of Relative Contribution of the Carbon-dioxide Channel Radiance from TIROS VII in the Case of a Large-scale Stratospheric Warming in January 1964

by

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Lieutenant Commander, United States Navy
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Submitted in partial fulfillment of the requirements for the degree of

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from the

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September 1971
ABSTRACT

A case study of a winter stratospheric warming in the western hemisphere in January 1964 between 60° and 40° north latitudes was conducted. Utilizing TIROS VII radiance data and analyzed height fields, a stepwise regression equation was determined to specify lower stratospheric layer temperatures. These temperatures were used with standard atmospheric temperatures to construct a sounding for use in a radiance computer program. Finally, this computed radiance was compared to regression values to determine if prediction and study of stratospheric warmings are valid and useful.
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<thead>
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<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_i$</td>
<td>Regression coefficients</td>
</tr>
<tr>
<td>$B(\lambda, T)$</td>
<td>Planck intensity function at wavelength $\lambda$ and temperature $T$</td>
</tr>
<tr>
<td>$\text{CO}_2$</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>$C$</td>
<td>Degrees Celsius</td>
</tr>
<tr>
<td>$F_k$</td>
<td>F-ratio upon entry at step $k$</td>
</tr>
<tr>
<td>$g$</td>
<td>Acceleration of gravity</td>
</tr>
<tr>
<td>GMT</td>
<td>Greenwich Mean Time</td>
</tr>
<tr>
<td>$I_\lambda$</td>
<td>Outgoing monochromatic radiance</td>
</tr>
<tr>
<td>$K$</td>
<td>Degrees Kelvin</td>
</tr>
<tr>
<td>$\text{km}$</td>
<td>Kilometer</td>
</tr>
<tr>
<td>$m$</td>
<td>Meter</td>
</tr>
<tr>
<td>$\text{mb}$</td>
<td>Millibars</td>
</tr>
<tr>
<td>$N$</td>
<td>Detected radiance</td>
</tr>
<tr>
<td>$p$</td>
<td>Atmospheric pressure</td>
</tr>
<tr>
<td>$q$</td>
<td>Specific constituent mixing ratio</td>
</tr>
<tr>
<td>$R$</td>
<td>Multiple regression coefficient</td>
</tr>
<tr>
<td>$R_d$</td>
<td>Dry air gas constant</td>
</tr>
<tr>
<td>$S_{W}(10)$</td>
<td>Warm hemisphere sample of 10 January 1964</td>
</tr>
<tr>
<td>$S_{K}(10)$</td>
<td>Cold hemisphere sample of 10 January 1964</td>
</tr>
<tr>
<td>$S_{W}(15)$</td>
<td>Warm hemisphere sample of 15 January 1964</td>
</tr>
<tr>
<td>$S_{K}(15)$</td>
<td>Cold hemisphere sample of 15 January 1964</td>
</tr>
<tr>
<td>$T$</td>
<td>Temperature</td>
</tr>
<tr>
<td>$X_i$</td>
<td>Regression predictors</td>
</tr>
<tr>
<td>$Y$</td>
<td>Regression predictand</td>
</tr>
</tbody>
</table>
$\hat{y}$  Regression predictand test values

$\psi$  Weighting function as a function of $\ln p$

$h$  Height above mean sea level

$\tau(h)$  Transmittance of the atmosphere to the outgoing 15-$\mu$ band of CO$_2$, between the levels $Z = h$ and $Z = \infty$

$\phi_{\lambda}$  Filter function centered at wavelength $\lambda$, spanning the increment $\Delta \lambda$

$\lambda$  Wavelength

$\mu$  Microns, identical to $10^{-4}$ cms

$\Delta Z$  Thickness of atmospheric layer

$1-\alpha$  The significance of the predictor added expressed as a probability
ACKNOWLEDGEMENTS

The author wishes to express his appreciation to his advisor, Professor F. L. Martin, for his suggestions, advice, guidance and support in this research.

Appreciation is also expressed to the W. R. Church Computer Facility of the Naval Postgraduate School.
I. INTRODUCTION

The launch of the TIROS VII meteorological satellite on 19 June 1963 led to the remote sensing of stratospheric temperatures on a quasi-global scale. The orbits of TIROS VII were almost circular and had an average height of 635 km. The plane of the satellite orbit was inclined to the equitorial plane at an angle $58^\circ$, which resulted in scan-coverage between $60^\circ$ north and $60^\circ$ south latitudes. TIROS VII was equipped with a five-channel scanning radiometer, one of which measured the filtered thermal radiation of CO$_2$ in the half-power wavelength range 14.8 to 15.5$\mu$m [Staff members, 1964]. The CO$_2$ in the stratosphere should emit at the same temperature as the air (of which it is a part), thus the observed intensities can be interpreted in terms of a weighted-mean, equivalent black-body temperature in the stratosphere. Radiation transfer theory leads to the radiance from the 15-$\mu$m band [Warnecke, 1967] as

$$N_{15} \lambda_2 \int_{\lambda_1}^{\lambda_2} \int_{p=1000}^{p=0.1} \frac{\partial \tau(\lambda, \ln p)}{\partial (\ln p)} B(\lambda, T(\ln p)) \, d(\ln p) \, d\lambda$$

In (1), the 15-$\mu$m band is assumed opaque to the surface radiation. If the weighting function $\psi(\ln p)$ is defined as

$$\psi(\ln p) = \int_{\lambda_1}^{\lambda_2} \hat{\psi}(\lambda) B(\lambda, T(\ln p)) \frac{\partial \tau(\lambda, \ln p)}{\partial (\ln p)} \, d\lambda$$

the integral (1) reduces to
Thus the contribution of each layer to the radiance, \( N \), sensed by the radiometer can be determined as a function of pressure. Radiative transfer theory applied to model atmospheres by Nordberg et al. [1965] indicates that maximum radiation, \( \psi (\ln p) \), in the 15-\( \mu \) range is emitted by the low stratosphere. The maximum weighting contribution at small nadir angles originates at about 25 km but the 15-\( \mu \) temperature corresponds to different heights from time to time because the temperature structure in the stratosphere changes with time [Belmont et al., 1968]. Radiance should also then be statistically related to the mean temperature or thickness between various pressure levels in the stratosphere. The latter conjecture was the originating hypothesis of this investigation.

Several studies have appeared in the literature which strongly support a relationship with 15-\( \mu \) temperatures at pressure levels in the stratosphere. Belmont et al. [1968], Nordberg et al. [1965], Warnecke [1967] and Teweles [1966] indicated that 15-\( \mu \) temperatures depict some of the large scale horizontal wave activity in the thermal fields of the lower stratosphere. In addition, Kennedy [1966], has compiled an atlas of ten-day mean isotherm charts recorded by the 15-\( \mu \) channel of TIROS VII for the period June 1963 through July 1964. These charts were presented by Kennedy as indicative of the spatial temperature distribution of the lower stratosphere during the total period of analysis of TIROS VII. Between 60° north and 60° south
latitudes these charts depict, for example, the proper seasonal
distribution of stratospheric isotherms at about 25 km.

Dense cloud bands will cause a decrease in the 15-\(\mu\) temperature
and will raise the peak elevation of its radiance weighting function.
Although data presented in the Kennedy Atlas were not corrected for
cloud contamination, nevertheless, the reduction to ten-day mean 15-\(\mu\)
temperatures was considered by Kennedy to have eliminated the cloud
contamination effect. This atlas served as a source for grid point
15-\(\mu\) temperature data for the case studies investigated in this
dissertation.

Since the 15-\(\mu\) temperatures are weighted over an indefinite thickness range in the stratosphere, Belmont et al. [1968] has raised the
question, "which pressure level in the stratosphere does the 15-\(\mu\)
temperature best represent?" Moreover, Shen et al. [1968] have shown
the usefulness of 15-\(\mu\) temperature fields in detecting stratospheric
warming events in the Southern Hemisphere polar winter. This paper
seeks to relate statistically the various layer-contributions to the
15-\(\mu\) temperature in the case of a winter stratospheric warming in the
polar latitudes of the Western Hemisphere. This case was centered
II. DATA PROCESSING

The 15-μ temperatures were extracted from the Kennedy Atlas [1966] of stratospheric mean 15-μ isotherms, using charts 42 (10 January 1964) and 43 (15 January 1964). Grid points values for 60°, 50°, and 40° north and every 5° of longitude around the globe were carefully interpolated to the nearest whole degree Kelvin. These 216 grid points were further divided into two hemispheres: that between 70° west and 110° east longitude corresponding to the "cold" sample since it approximated the sector of the winter cold vortex. The "warm" hemisphere between 110° east and 70° west longitude (the "Western" Hemisphere) contained the warm stratospheric anticyclone. There were 108 grid points located in each sample.

Thickness values at each of the 216 grid points were noted and for both dates of interest were determined from the Northern Hemisphere analyses of 10, 30, 50, 100 and 300 mb contour charts. These charts were found in the January 1964 series of map analyses of the Institute of Meteorology and Geophysics of the Free University of Berlin [1964]. Contour values from each pressure level and at each grid point were differenced to determine four thicknesses in the stratosphere and upper troposphere:

10 - 30 mb thickness, denoted $X_1(i,j)$
30 - 50 mb thickness, denoted $X_2(i,j)$
50 - 100 mb thickness, denoted $X_3(i,j)$
100 - 300 mb thickness, denoted $X_4(i,j)$

Finally, the dependent variable is the 15-μ temperature and is denoted hereafter as $Y(i,j)$. 
The statistical model is then to be expressed in the multiple-regression form

\[ Y = A_0 + A_1 X_1 + A_2 X_2 + A_3 X_3 + A_4 X_4 \]  

(4)

where the coefficients \( A_0, A_1, A_2, A_3 \) and \( A_4 \) are to be determined by the least squares techniques. All of the variables for input into equation (4) were encoded onto punched cards in a format consistent with the requirements of the stepwise regression program, BMD02R [Dixon, 1966]. This program is available in the Library of the W. R. Church Computer Center of the Naval Postgraduate School.
III. STATISTICAL PROCEDURES AND INTERPRETATIONS

A. DEFINITION OF DATA SETS

As noted previously, it was necessary to stratify the data for the two map-times into cold and warm stratospheric "hemispheres". According to the stratospheric contour and temperature analyses of the Free University of Berlin, the warming anticyclone had reached its peak intensity in the Western Hemisphere on 15 January 1964, with a well-defined cold hemisphere adjacent. The stratospheric warming was still in a developing stage on 10 January 1964. This led to the four substratifications of sample data, which for simplicity will be denoted in Table I.

<table>
<thead>
<tr>
<th>Date</th>
<th>Warm</th>
<th>Cold</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 January</td>
<td>$S_W(10)$</td>
<td>$S_K(10)$</td>
</tr>
<tr>
<td>15 January</td>
<td>$S_W(15)$</td>
<td>$S_K(15)$</td>
</tr>
</tbody>
</table>

Actually the last two, $S_W(15)$ and $S_K(15)$ were used to generate the multiple regression equations of type applicable to the warm and cold hemispheres, respectively. These equations were then to be tested for diagnostic significance by applying them to the independent samples $S_W(10)$ and $S_K(10)$. Each of the four stratifications had 108 data sample sets.

The BMD02R regression analysis not only generates a multiple regression equation similar to (4) but also performs a step-wise
screening in the process: it first determines that independent variable
X_1 which explains the highest percentage variance of Y. Then at step
two, it determines the X_j in the remaining predictor set that explains
the largest percentage of the residual variance unexplained by the
first variable, and so forth, for steps three and four.

The BMD02R program also computes for each step the F-statistic
upon-entry of the kth variable selected, where F_k is expressible at
step k as [Dixon, 1966]

\[ F_k(1,n-k-1) = \left[ \frac{\text{\% cum. expl. var., step } k}{} - \left( \frac{\text{\% cum. expl. var., step } k-1}{} \right) \right] \]

In the present problem, two tests were to be made using X_1, X_2, X_3 and
X_4 with a total sample size of n=108 in the warm and cold cases S_W(15)
and S_K(15), respectively. Based upon the magnitude of F_k of (5), Table
II indicates the order of entry of the predictors selected and the
corresponding F_k-statistic with which they entered.

For each predictor tested, its significance at step k may be
assessed by comparison of its F_k value with a Critical F^c_k defined
after Miller [1962] as

\[ F^c_k = F_{\alpha/p-k+1} \left( 1,n-k-1 \right), \alpha = 0.05 \]  \hspace{1cm} (6)

in order that the over all regression be assured of significance at the
1-\alpha confidence level. The set of Critical F^c_k values to be used for
comparison are adjoined to Table II.

The four-predictor regression equations having the form of (4) are
as follows:

\[ S_W(15), \ Y=112.213 - .04842X_1 + .03686X_2 + .18648X_3 + .07498X_4 \]  \hspace{1cm} (7)
TABLE II

Stepwise order of entry of variables in the regression equation (4), including $F_k^k$ upon-entry at step $k$, the test statistic $F_k^c$, and multiple correlation coefficient $R_k$ at each step

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>k=1</td>
<td>$X_3$</td>
<td>179.13</td>
<td>.7926</td>
<td></td>
<td>$X_3$</td>
<td>14.81</td>
<td>.4252</td>
</tr>
<tr>
<td>2</td>
<td>$X_1$</td>
<td>54.20</td>
<td>.8688</td>
<td></td>
<td>$X_1$</td>
<td>8.42</td>
<td>.4905</td>
</tr>
<tr>
<td>3</td>
<td>$X_4$</td>
<td>39.20</td>
<td>.9066</td>
<td></td>
<td>$X_4$</td>
<td>4.21</td>
<td>.5083</td>
</tr>
<tr>
<td>4</td>
<td>$X_2$</td>
<td>4.36</td>
<td>.9106</td>
<td></td>
<td>$X_2$</td>
<td>1.72</td>
<td>.5201</td>
</tr>
</tbody>
</table>

$S_k(15)$, $Y=171.927 + .04872X_1 + .06728X_2 + .10750X_3 - .07642X_4$  \( (8) \)

Table II shows that all thickness predictors entered at a confidence level of 95 percent for each entry in equation (7). On the other hand, for the cold case, the order of entry was identical to that of $S_w(15)$ but the levels of significance for $X_4$ and $X_2$ were subcritical. However, in the cold case, the standard error of estimate continued to decrease from step three to step four, so the full four predictor equation (8) was retained for testing against the independent sample $S_k(10)$. A more complete justification for retaining the full set of predictors can be found at the end of III-C.

B. TEST ON AN INDEPENDENT DATA SAMPLE

In order to test the validity of equations (7) and (8) developed from $S_w(15)$ and $S_k(15)$, the coefficients from these samples were
combined through the matrix multiplication (9) to form the estimator-predictand of the independent data

\[
\hat{Y} = (A_0, A_1, A_2, A_3, A_4) \begin{pmatrix} 1 \\ X_1 \\ X_2 \\ X_3 \\ X_4 \end{pmatrix}
\] (9)

using the sets \(S_W(10)\) and \(S_K(10)\). The regression between \((Y,Y)\) for the independent sample gave the results listed in Table III as compared to the dependent case.

**TABLE III**

Comparison of explained variance between the dependent sample and independent sample

<table>
<thead>
<tr>
<th>Dependent Sample</th>
<th>Independent Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>(%) Expl. Variance</td>
<td>(%) Expl. Variance</td>
</tr>
<tr>
<td>(S_W)</td>
<td>82.92</td>
</tr>
<tr>
<td>(S_K)</td>
<td>27.05</td>
</tr>
</tbody>
</table>

There was a sizeable shrinkage in explained variance in the warm case when applying the regression from the \(S_W(15)\) case to the independent data set. However, in this case the F-test still indicated confidence well over the 95 percent level of belief in spite of the shrinkage. The result of the regression for the cold case showed a significant improvement in the explained variance of \(T_{15}\) in the independent sample, an unexpected result which will be discussed below.
C. STATISTICAL INFERENCES OF THE TEST

The stratospheric warming which seemed to reach its maximum magnitude over the entire "warm" hemisphere on 15 January, had also spread to some extent into the "cold" hemisphere. The fact that the warming process had encompassed the entire warm sector and a part of the cold sector may explain the wide range of explained variance between the two sectors on 15 January including the rather low explained variance in $S_K(15)$.

A statistical reason for the observed shrinkage in explained variance in passing from the dependent equation (7) to the independent sample of 10 January may be ascribed to the incomplete development of the full warm hemisphere as of this date, so that the sample of 10 January actually consisted of a mixture of warm and cold data points. In other words, the warm hemisphere of 10 January seems not to have been as clearly stratified as a warm hemisphere as that of 15 January.

The phenomenon of an increased percentage explained variance in passing from equation (8) to the independent cold sample of 10 January was subject to a similar conjecture. The relatively small multiple regression coefficient resulting from $S_K(15)$ seemed to indicate that a stratospheric warming effect had also begun to spread into the "cold" hemisphere, and in consequence only 27.05 percent of the variance of $Y$ was explained by the specification equation (8). On the other hand, the much larger percentage of the variance explained by (8) applied to $S_K(10)$ seems to indicate that the cold stratification for the 10 January case was more uniform than the dependent case chosen for 15 January.
In retrospect, a more flexible sampling procedure which might have improved the results should have involved more care in delineating the stratifications of the areas of warm and cold stratospheres, respectively. For example, it now seems reasonable to limit the warm area sample to those stratospheric grid points having anticyclonic contour curvature and not necessarily assigning an entire hemisphere to the sample. Similar considerations, with regard to cyclonic curvature might well have afforded a better criterion for the cold stratification in both the dependent and independent cases.

It was now possible to offer a more complete statistical reason for retaining all four predictors in the right side of equation (8). Even though the dependent cold sample from which equation (8) was derived seems to have been not uniformly stratified, the use of the resulting predictand was well verified \( R(Y, Y) = .8753 \) on the more stable stratified cold hemisphere of 10 January.

It was also noteworthy that a choice of \( S_K(10) \) as the dependent cold sample gave the same order of entry for variables as indicated in Table II, with all individual predictors significant at well above the 95 percent confidence limit.

With \( Y \) based upon equation (8), the ensuing regression between \( Y \) and \( Y \) for 10 January was

\[
Y = -95.3142 + 1.4298 Y, \quad R(Y, Y) = .8753
\]

(10)

so that by equation (10) all predictors would have had the same coefficient matrix apart from the constant multiplier, 1.4298. Thus equations (7) and (8) are adopted as the representative regression equations for the warm and cold stratospheric samples, respectively.
Since the regression equations just listed must be satisfied by the sample means, it is useful to list the mean properties of these two atmospheric samples $S_w(15)$ and $S_K(15)$. Table IV is a compilation of the means and standard deviations of all variables which appear in equations (7) and (8) for 15 January 1964.

**TABLE IV**
Means and standard deviations of 15-μ temperatures and predictor thicknesses for samples $S_w(15)$ and $S_K(15)$

<table>
<thead>
<tr>
<th>Vrbl.</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Mean</th>
<th>Std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{15}$</td>
<td>226.16K</td>
<td>3.68923</td>
<td>217.96K</td>
<td>4.79275</td>
</tr>
<tr>
<td>$X_1$</td>
<td>7298.1 gpm</td>
<td>327.7286</td>
<td>6796.5 gpm</td>
<td>268.4886</td>
</tr>
<tr>
<td>$X_2$</td>
<td>3356.1</td>
<td>126.8544</td>
<td>3149.4</td>
<td>100.4864</td>
</tr>
<tr>
<td>$X_3$</td>
<td>4520.6</td>
<td>165.8544</td>
<td>4221.9</td>
<td>162.5060</td>
</tr>
<tr>
<td>$X_4$</td>
<td>7017.0</td>
<td>125.0733</td>
<td>6998.1</td>
<td>138.5645</td>
</tr>
<tr>
<td>Y</td>
<td>226.16K</td>
<td>3.68923</td>
<td>217.96K</td>
<td>4.79275</td>
</tr>
</tbody>
</table>

The standard deviation of $X_1$ (the 10 to 30 mb thickness) was considerably larger than the other levels; however, it is a layer subject to more radiosonde error than those below it. Also interpolation of contour height to grid points was more subjective at 10 mb due to stronger gradients than existed at lower levels in the stratosphere.

Because of the equivalence of thickness to mean temperature of an isobaric layer through the integrated form of the hydrostatic equation
it is possible to ascribe a mean temperature to each of the four isobaric layers of thicknesses hitherto denoted $X_1$, $X_2$, $X_3$ and $X_4$. These mean temperatures corresponding to the mean thicknesses already listed in Table IV are given in Table V for the warm and cold stratospheres respectively, along with other relevant statistics used in the specification of the $15-\mu$ temperature. The statistic $R(Y,X_i)$ is the simple correlation between $T_{15}$ and the $i$th layer-thickness.

TABLE V
Layer mean statistics for the warm and cold cases $S_W(15)$ and $S_K(15)$

<table>
<thead>
<tr>
<th>Layer (mb)</th>
<th>Mid-point press.</th>
<th>Warm Case</th>
<th>Cold Case</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$R(Y,X_i)$</td>
<td>Layer mean temp.</td>
<td>Layer mean temp.</td>
</tr>
<tr>
<td>$X_1$: 10 - 30</td>
<td>17.32 mb</td>
<td>.195</td>
<td>226.96K</td>
</tr>
<tr>
<td>$X_2$: 30 - 50</td>
<td>38.73</td>
<td>.663</td>
<td>224.40</td>
</tr>
<tr>
<td>$X_3$: 50 - 100</td>
<td>70.71</td>
<td>.793</td>
<td>222.82</td>
</tr>
<tr>
<td>$X_4$: 100 - 300</td>
<td>173.20</td>
<td>.656</td>
<td>218.22</td>
</tr>
</tbody>
</table>

D. CONSTRUCTION OF WARM AND COLD MODEL STRATOSPHERES

From the mean temperatures listed in Table V, stratospheric model temperature-pressure distributions were constructed for the warm and cold cases in Figure 1: A-B-C-D showing the lower stratosphere temperatures in the warm case and A'-B'-C'-D' showing the lower stratosphere temperatures in the cold case at 17.3, 38.7, 70.7 and 173.2 mb
respectively. The lowest points D and D' lie within a half degree Celsius of one another, at the 173.2 mb level.

Since no mean temperatures were available from this study below 173.2 mb, the cold and warm cases were adjoined to the Cold and Warm Supplemental Standard Atmospheres [Dubin et al., 1966] at latitude 60° north in January. The cold and warm January standard profiles below 300 mb were virtually identical and for the purpose of the modeling done here were taken as the unique curve E-F-G in Figure 1. This led to a minor inconsistency in the mean temperatures to be expected in the layer 100-300 mb in the cold and warm cases, respectively.

The expected temperature at 10 mb for the warm and cold models were obtained by extrapolating the lines B - A and B' - A' in Figure 1 to the 10 mb level. This technique led to the results listed in Table VI:

<table>
<thead>
<tr>
<th>Warm</th>
<th>Cold</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 mb, model</td>
<td>-43.65C</td>
</tr>
<tr>
<td>Jan. 60N Supp.</td>
<td>-43.75C</td>
</tr>
</tbody>
</table>

It is clear that the lower stratospheric temperatures from the warm sample are in good agreement with the January warm standard, while the cold sample was not as clearly definitive of the cold standard for the reasons already cited in III-C.

The remainder of the model above the 10 mb level was fitted in both models by extending linearly the T-ln p profile from 10 mb upward to
Fig. 1. Warm and cold model atmospheres
the listed stratopeaks of the Warm and Cold Supplemental Standards [Dubin et al., 1966]. These peaks occur over the range:

\[ p = 0.7 \text{ to } 0.423 \text{ mb where } T = -5^\circ C \]
\[ p = 0.44 \text{ to } 0.26 \text{ mb where } T = -17^\circ C \]

Above the top of these levels, the listed lapse rate above the stratopeak was used to extend the T-ln p models to the level p=0.1 mb, which is commonly taken as the top of the atmosphere in radiative-transfer theory.

The simple correlation coefficients listed in Table V give some indication of the layers contributing most heavily to the specification of \( T_{15} \). The results in the warm case (Table V) indicate a maximum influence or weight from the layer 50-100 mb centered at 18.1 km (70 mb). However, there is considerable additional influence from the 30-50 mb and 100-300 mb layers (at 26.4 and 12.2 km, respectively). Note that the influence from the layers \( X_2, X_3 \) and \( X_4 \) as indicated by \( R(Y, X_1) \) seem significant. This will be discussed further in IV.

On the other hand, the cold model atmosphere has the maximum influence detectable from this study in view of the high correlation coefficient \( R(Y, X_1) \), (Table V), attributable to the layer 10-30 mb and this influence decreases systematically below this level. The significant negative correlation in the lowest level (100-300 mb) is apparently due to the low warm tropopause which is synoptically expected with a cold stratospheric vortex situation. The overlying deep cold layer (100-10 mb) apparently acts as an effective absorber, and relatively low-emittance re-radiator of the CO\(_2\) radiation started in the high troposphere. In other words, this negative correlation in the lowest layer is apparently related to the relatively steep lapse
rate between the lowest part of the stratosphere and the warm
tropospheric layer immediately below.
IV. A NUMERICAL RADIATIVE COMPUTATION

A brief discussion of the upwelling radiance from an arbitrary planetary atmosphere having a temperature distribution \( T = T(p) \) and constituent distributions \( q_i = q_i(p), \) for \( i = 1, \ldots, 3 \), is given. V. Kunde [1967] prepared a detailed theoretical study of a number of planetary atmospheres detailing the necessary theoretical computations for the upwelling radiances sensed by various medium resolution infrared radiometers. Kunde's theory [Kunde, 1967] made use of spherically horizontal symmetry of all sounding properties in the atmosphere, and computed the transmitted radiative contributions from each level \( p \) to \( p + dp \). Thus he made use of the generalized formula for outgoing radiance

\[
dI_\lambda = B_\lambda [\lambda, T(ln p)] \frac{d\tau}{d(ln p)} d(ln p)
\]

(12)

in the case of a satellite sensor having optical filter response \( \phi_\lambda = 1.0 \). In equation (12), the transmittance \( \tau \) is the constituent product-transmissivity at pressure \( p \), and \( \tau \) must be a decreasing function of pressure. The Curtis-Godson approximation is used for correcting the vertical absorber mass distribution, and for deducing the resultant pressure-effect upon line broadening.

When \( \text{CO}_2 \) is the main emitter and the earth's 15-µm band the main source of outgoing radiation, the surface may be considered black in the terrestrial spectrum (reflectivity zero). The problem was further simplified by assumed constancy of the mixing ratio of \( \text{CO}_2 \) at \( q = 0.477 \text{ gm/kg} \). The details of the vertical variation of water vapor and ozone mixing ratios, which are highly variable for each gas, were supplied in the form of a sounding distribution of each. These
gases are distributed relative to height or, equivalently to the pressure \( p = p(h, T) \).

Based on the results of III-D, two model vertical profiles \( T(p) \) were determined from Figure 1 with sufficient vertical resolution (about thirty significant levels) to cover the entire range of pressure from \( p = 1013.5 \) mb to \( p = 0.1 \) mb, for both the warm and cold cases in Figures 2 and 3.

The vertical distributions of water vapor and ozone enter the computation of \( N_{15} \) only in a very secondary manner since there is only slight overlap between the water vapor rotational band wings and the 14.0-16.3\( \mu \) response function placed upon the sensors of the 15-\( \mu \) channel of TIROS VII. The sensor response function \( \hat{e}(\lambda_j) \) associated with the jth subinterval, \( \Delta \lambda_j \), of the 15-\( \mu \) channel are listed in the TIROS VII Radiation Data Catalog and Users' Manual [Staff, 1965].

The water vapor and ozone mixing ratio distributions with height actually used were listed for Maniwaki, Quebec (46N, 76W) based upon the real time radiosonde observations taken on 29 September 1958 at 1200 GMT. The Maniwaki surface values (at 996.0 mb) of mixing ratio were considered identical to those at 1013.5 mb of the present models atmospheric base level.

The integral \( \psi(\ln p) \) of equation (2) represents the contribution to the total filtered radiance at a point in space in \( \text{watts/m}^2/\text{ster} \) of depth and includes the Planck-Kirchhoff transmittance attributed to a small pressure increment \( dp \), as essentially specified by the radiosonde (including the constituent mixing ratios).

The Kunde radiative transfer theory [Kunde, 1967] was applied to both of the model atmospheres as input, and with the model-invariant
Fig. 2. Proposed model warm atmospheric sounding
Fig. 3. Proposed model cold atmospheric sounding
mixing ratio distributions of $q_{H_2O}(p)$ and $q_{O_3}(p)$. The Kunde computer program is listed in the Appendix. The program was designed to give the total filtered N and the corresponding $T_{15}$ computed by five-point interpolation from the laboratory calibration of N vs $T_{15}$. In this theoretical program no instrument degradation need be considered.

Finally the first important output of the program gives N and the effective $T_{15}$ for the model atmospheres. It also gives a pressure-height weighting function essentially equivalent to $\psi(\ln p) = dN/d(ln p)$ appropriate to the contribution to N for equal increments of $\ln p$.

The results of the model-atmosphere radiance computation after Kunde [1967] applied to the warm and cold models (and the implied soundings, Figures 2 and 3) led to the following results for calculated N and the resultant $15-\mu$ temperatures.

**TABLE VII**

Comparison of $15-\mu$ temperature computed from the sample-mean and the model atmosphere radiance calculations

<table>
<thead>
<tr>
<th></th>
<th>$N$(watts/m$^2$/ster)</th>
<th>$T_{15}$ [Kunde]</th>
<th>$\bar{T}_{15} = Y$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_w(15)$</td>
<td>3.048</td>
<td>228.9K</td>
<td>226.2K</td>
</tr>
<tr>
<td>$S_K(15)$</td>
<td>2.460</td>
<td>218.1K</td>
<td>217.9K</td>
</tr>
</tbody>
</table>

In Table VII the corresponding values are in columns 3 and 4, whereas the contrast between the model atmospheres is to be seen by comparing row 2 against row 3. It is to be noted that the warm case emits a greater N than the cold sample, and that the model atmospheres adopted reproduce the respective sample mean $\bar{T}_{15}$ temperatures effectively.
Another important output of the Kunde program is the percentage of total \( N \) associated with increments of \( \ln p \) between \( p = 0.1 \) and \( p = 1013.5 \text{ mb} \). This output was listed in the Kunde program by kilometer intervals and at equivalent pressure levels for the warm and cold model atmospheres and the results summed to give the weight functions \( \psi (\ln p) \) in the form of block-diagrams on a \( \ln p \) scale (Figures 4 and 5). These block diagrams were subsequently smoothed preserving equal areas of \( \psi (\ln p) \) from block-to-block and the results appear as Figures 6 and 7.

It is now useful to reconsider the simple correlation coefficients between \( T_{15} \) (and therefore \( N \)), and the layer thicknesses given in Table V. For the cold atmosphere, the negative correlation attributable to the layer 100-300 \text{ mb} has been explained by the compensating cool shielding layer \( C'B' \) which occurs even when a temperature rise occurs at or near 300 \text{ mb}. However, the correlation coefficient of 0.750 between the 10-30 \text{ mb} thickness and the total radiance was due to sampling variations in temperature of \( B'A' \) about the mean profile \( T(p) \) of Figure 1, with a warmer than average upper layer able to contribute more radiance to space than if the layer were sampled as relatively cold. This result verifies the positive correlation \( R(T_{15}, X_1) = 0.750 \) found for the cold case.

A similar argument was applied to the warm case where the lapse rate from the upper troposphere to the stratopause was continuously of an inversion nature. Any layer sampled in \( S_w(15) \), if warmer than the mean, tends to have greater emittance to space, whereas it will have smaller emittance when cooler than normal accounting for the positive correlations in Table V. This effect is especially prominent near the level of
Fig. 4. Carbon-dioxide channel radiance contributions for equal increments of $\ln p$ (warm model atmosphere)
Fig. 5. Carbon-dioxide channel radiance contributions for equal increments of ln p (cold model atmosphere)
Fig. 6. Warm case equal area weighting curve corresponding to Fig. 4
Fig. 7. Cold case equal area weighting curve corresponding to Fig. 5
maximum weighting function $\psi (\ln p)$, which occurs in the range 50-100 mb.
V. CONCLUSIONS

The results of this study of a northern hemisphere stratospheric warming indicate that a polar-orbiting satellite with a 15-μ sensor can be used as a tool to study stratospheric warming processes. The layers of the lower stratosphere which are initially affected can be identified by comparison of regression values to normal soundings for that of the anticyclonic area or the vortex area. Although this study was concerned only with one stratospheric warming, the correlation coefficients are large enough to seem significant. This was especially true in the $S_W(15)$ sample which was particularly well stratified with respect to the warming.

A daily synoptic analysis of the CO$_2$ channel radiance information from a polar-orbiting satellite should provide initial indications of when a stratospheric warming is beginning. The development of such a warming may easily be followed as it progresses around the globe. Future operational study in this area by use of smaller sectors, using successive-day swath continuity might allow enough data-definition to follow such a warming as it develops in the vertical and could become a tool for the study of stratospheric warmings.
FORMAT(1H0,4(1PE13.6,5X)/)
16 FORMAT(1H0,4HPLK=1PE13.6)
17 FORMAT(1H0,5HSE=F7.3)
18 FORMAT(1H0,10X,F12.3,3X,F12.6,3X,F12.6,3X,F12.6,3X,F12.6,3X,F12.6,3X,F12.6)
19 FORMAT(1H1,13X,16H UT-BTLAY ,15H AVEP(H20) ,15H AVEP(H2)
10 ),15H DEPTH(H20),15H AVEP(O3),15H AVEP(O3),15H DEPTH(O3)
2 DEPTH(O3)
23 FORMAT(F8.6,F4.2,F4.2,11)
24 FORMAT(1H1,8HMID-HT,19H MID-TEMP,12H MID-PRESS,8H RHO ,11H
1 PEP1 ,19H AVEP1 ,11H AVEP1 ,12H DEPTH1-BLAY,7H RHO ,11H
2 PEP2 ,19H AVEP2 ,11H AVEP2 ,12H DEPTH2-BLAY/50X,13H(WATER
3 VAPOR),29X,17H( OZONE ) )
25 FORMAT(1H0,10X,3H00 24X,4H00 = F11.7,3X,7H C1 = F4.2,3X,7H C2 = F
14.2)
1,1X,F9.6,4X,F9.3,3X,F6.1,3X,F5.1,3X,F8.3,3X,F11.4)
28 FORMAT(5(3X,F5.2,2X,F9.4))
29 FORMAT(1H1,10X)62H OUTGOING ATMOSPHERIC RADIATION SECT 1 OPTIC
31 AL PATH LENGTH)
32 FORMAT(6F12.5)
33 FORMAT(12F6.2)
34 FORMAT(5X,14,F10.2,E15.5,E12.4,E10.5,E10.5)
35 FORMAT(5X,10.5,F10.5)
36 FORMAT(5X,15,F15.5,F10.5,F12.4)
37 FORMAT(1H,105X,1THIS SPECTRAL INTERVAL IS OUT OF RANGE OF ABSORPTI
1ON TABLES OF HTB --- WAVE NUMBERS = 1, F10.2)
40 FORMAT(1H0,6X,4HPLAV,3X,7HSTUF PR,3X,8HS1) TEMP,2X,6HPADIUS,2X,9HG
1AS CONST,1X,4PDRLX,2X,4HR GAS,1X,4HGCAS,1X,4HIATM,1X,4HIATM,1X,2HLA
2)
41 FORMAT(1H ,E10.4,2F10.3,E11.4,F6.3,2I5,2I4)
50 FORMAT(5F6.2,2I15.3,F5.2)
101 FORMAT(1H ,15.2,F10.4)
905 FORMAT(1H0,10X,15(2X,F6.1))
915 FORMAT(1H ,3X,F7.3,15(2X,F6.4))
5601 FORMAT(1H1)
5610 FORMAT(12F6.1)
5611 FORMAT(F6.1,F6.1,F6.1)
5612 FORMAT(10F10.4)
5613 FORMAT(1H0,20H6.3MICRON GEN ABSRPP)
5614 FORMAT(1H1,17HMODEL ATMS INPUT)
5615 FORMAT(1H0,20H9.6MICRON GEN ABSRPP)
5616 FORMAT(1H0,21HROTATIONAL GEN ABSRPP)
5617 FORMAT(1H0,20HCONTINUUM GEN ABSRPP)
5618 FORMAT(1H ,10X,3HD3 ,4X,4H K = F11.7,3X,7H C1 = F4.2,3X,7H C2 = F
14.2)
5619 FORMAT(1H0,7X,02HHT,8X,4HTEMP,4X,8HPRESSURE,3X,9HEFF PRESS,5X,11HP
14TH LENGTH
5620 FORMAT(1H,5X,F7.3,3X,F7.2,3X,F6.4,3X,F9.4,5X,F8.4,4(1X,E10.4,1X))
1
5621 FORMAT(1H,1,20X,49HALL QUANTITIES REFER TO BOTTOM OF LAYER CO2 GA)
15)
5622 FORMAT(1H,20X,34HEET EFF PRESS AT LAYER MIDPOINT)
5624 FORMAT(1H,0.26H15.0 MICRON CO2 GEN ABSORPTION)
5625 FORMAT(2F6.2)
5626 FORMAT(1F10.4,1F10.2)
5627 FORMAT(1H,10.2,3X,F12.6,3X,F10.4)
5628 FORMAT(1H,13.4,3(2X,1P10.4,1X),3F10.4,F10.2,F8.2,2F10.4)
5629 FORMAT(1H,20X,24HATMOSPHERIC TRANSMISSION)
5630 FORMAT(1H,15X,11HWPVE NUMBER,5X,17HSPECTRAL RESPONSE)
5631 FORMAT(1H,15X,F8.2,15X,F6.4)
5632 FORMAT(1H,10X,4HT MP,10X,4HDNAR)
5633 FORMAT(1H,0.28X,F6.2,0.08X,F12.6)
5634 FORMAT(1H,10X,4HT SURFACE LAYES,5X,4HDNAR,10X,3HTBR)
5635 FORMAT(1H,10X,62HOUTGOING ATMOSPHERIC RADIATION)
1
5636 FORMAT(1H,18A4)
5637 FORMAT(1H,3I10,2F10.2)
5638 FORMAT(1H,0.39.3,2(1X,F12.6),2F8.2,5(1X,F12.6))
5639 FORMAT(1H,0.40,F10.2,F10.2,410)
5640 FORMAT(1H,0.53,F9.3,2F10.2,110)
5641 FORMAT(1H,0.54,F10.4,4.3 "MICRON H2O GEN ABSORPTION")
5642 FORMAT(1H,0.55,F10.4,4.3 "MICRON CH4 ABSORPTION")
5643 FORMAT(6F10.2)
5644 FORMAT(1H,0.56,'SUFF HT',01X,'SUFF TEMP',02X,'GRD TRAN',03X,
1 'GRD PDR',04X,'ATM RAD',05X,'TOT RAD',06X,'PER TOT',07X,'TBB',
102X,'WAVE',03X,'LAMBRAD',05X,'PHI')
5645 FORMAT(1H,0.10X,'TOTAL VERTICAL CO2 CONTENT BY PRESSURE INTEGRATION
1 = ',1F10.2)
5646 FORMAT(1H,0.57,F9.3,2F10.2,110)
5647 FORMAT(1H,0.58,3(2X,F12.6,2X))
5648 FORMAT(1H,11X,'WAV',10X,'PHL',06X,'LAYER CONTRIBUTION',05X,'PER CENT OF
1ATM',05X,'PER CENT OF TOTAL ATM',05X,'LAYER CONTRIBUTION',05X,'PER CENT OF
1TOTAL CO2 PATH = ',1F7.3,'CM-ATM',05X,'TOTAL PATH = ',1F10.2,'CM-ATM',05X)
5649 FORMAT(1H,10X,'TOTAL H2O PATH = ',1F7.3,2X,'PR-CM',15X,'TOTAL Q3 PATH = ',1F10.2,'CM-ATM',05X)
1P')
UNDER = 1.1,P-30
UNDER = UNDER*UNDER
WRITE(3,5601)
C DATE--TABLE OF WAVE NUMBER VS LOG10(GEN ABS COEFF),IZE--TOTAL NO**
READ(2,3) IXE
READ(2,5610) (WAVEZ(I),DATE(I),I=1,IXE)
WRITE(2,5612) (WAVEZ(I),DATE(I),I=1,IXE)
C DATE--TABLE OF LOG(LAM) VS TRANSMITTANCE, IZF--TOTAL NO OF POINTS
READ(2,3) IXF
READ(2,5610) (XLUF(I),DATE(I),I=1,IXF)
WRITE(3,5612) (XLUF(I),DATE(I),I=1,IXF)
C DATK-CONTINUUM H2O, WAVE NO VS LOG10(GEN ABS COEFF), IXK-TOTAL NO OF POINTS**********
READ(2,3) IXK
READ(2,5610) (XLUK(I),DATK(I),I=1,IXK)
WRITE(3,5612) (XLUK(I),DATK(I),I=1,IXK)
C DATK-9.603, WAVE NUMBER VS LOG10(GEN ABS COEFF), IXK TOTAL NO OF PTS
READ(2,3) IXK
READ(2,5610) (WAVEK(I),DATK(I),I=1,IXK)
WRITE(3,5615) (WAVEK(I),DATK(I),I=1,IXK)
C DATK-9.603, LOG10(L*U) VS TRANS, IXK-TOTAL NO OF PTS**********
READ(2,3) IXK
READ(2,5610) (XLUK(I),DATL(I),I=1,IXK)
WRITE(3,5612) (XLUK(I),DATL(I),I=1,IXK)
C DATK-15.002, WAVE NUMBER VS LOG10(GEN ABS COEFF), IXK-TOTAL NO OF *
READ(2,3) IXK
READ(2,5610) (WAVEK(I),DATL(I),I=1,IXK)
WRITE(3,5624) (WAVEK(I),DATL(I),I=1,IXK)
C DATK-15.002, LOG10(L*U) VS TRANS, IXK-TOTAL NO OF POINTS**********
READ(2,3) IXK
READ(2,5610) (XLUK(I),DATM(I),I=1,IXK)
WRITE(3,5612) (XLUK(I),DATM(I),I=1,IXK)
CALL O2ONE(I,1,1,1,0)
C 3.2 H2O--WAVE NUMBER VS LOG10(GEN ABS COEFF)*****************************
READ(2,3) IXU
READ(2,5610) (WAVEU(I),DATU(I),I=1,IXU)
WRITE(3,5640) (WAVEU(I),DATU(I),I=1,IXU)
C 3.2 H2O--LOG(L*U) VS TRANS*****************************
READ(2,3) IXU
READ(2,5610) (XLUU(I),DATUU(I),I=1,IXU)
C 4.3 CO2 -- WAVE NUMBER VS LOG10(GEN ABS COEFF)*******************************
READ(2,3) IXV
READ(2,5610) (WAVEV(I),DATV(I),I=1,IXV)
WRITE(3,5641)
WRITE(3,5612) (WAVEV(I),DATV(I),I=1,IXV)

C 4.3 CO2 -- LOG (L + U) VS TRANS**************************************
READ(2,3) IXV
READ(2,5610) (XUV(I),DATUV(I),I=1,IXV)
WRITE(3,5612) (XUV(I),DATUV(I),I=1,IXV)

C 3.3 CH4 -- WAVE NUMBER VS W******************************
READ(2,3) IXV
READ(2,5643) (WAVEV(I),WEE(I),I=1,IXV)
WRITE(3,5643)
WRITE(3,5643) (WAVEV(I),WEE(I),I=1,IXV)
READ(2,8) (SPWORD(I),I=1,18)
READ(2,3) IPHI
READ(2,5625) (WAVSP(I),FHI(I),I=1,IPHI)
READ(2,3) ITAR
DO 9020 I=1,ITAR
READ(2,5626) XNBAR(I), TEMPBB(I)
WRITE(3,5626) XNBAR(I), TEMPBB(I)
9020 CONTINUE
READ(2,5611) WAVE,DWAVE,INTER
WRITE(3,5639) WAVE,DWAVE,INTER
INTER=FLOAT(INTER)
WAVE=WAVE + INTER*Dwave - 5.
TATV=C
NUM=0.
HT2=0.0
READ(2,3) NUM
NUM=NUM

20 READ(2,50) RAD, XMIN, DEKR, HT, HT4, LAYER1, LAYER2, THLAY1, THLAY2, THLAY3
READ(2,10) (ANGLE(I),I=1,18)
READ(2,13) G0, SUM, PD, XMOL, R1, R2, R3
READ(2,23) XMOL, C1H2, C2H20, IGAS
CONC2=XMOL/(12.4519*18.)
READ(2,23) CONC2, C1O2, C2CO2, IGAS
CONC2=CONC2*(1.54*05)
READ(2,23) CONC3, C1O3, C2O3
CONC3=CONC3*(1.54*05)

C OCH4=2.4PPM(BOWMAN), 1.1PPM(GOLDBERG), AVERAGE = 1.75PPM**********
OCH4=(1.75E-6)*(1.54*05)
ON20=(0.28E-05)*(1.54*05)
IDELVE=50
**IDELVE = 20**
**IDELFP = FLOAT(IDELVE)/100.**
**IVERT=-1**
**IE(IVERT) 60,60,70**

**C**
**HEIGHT VS TEMPERATURE READ IN, IVERT=-1**************************************************************************

**C**
**DATA TABLE OF H VS TEMP, IXA-TOTAL NO OF POINTS**************************************************************************

**C**
READ(2,3)IXA
WRITE(3,5614)
DO 61 IXA=1,IXA
READ(2,5599) PRESS(I), TEMP(I), OOH27(I), HETTEM(I), OOCO2(I)
DO 62 J=1,IXA
HETTEM(J) = HETTEM(J)*1.E-03
HETH2O(J) = HETTEM(J)
62 HETCO2(J) = HETTEM(J)
IXA = IXA
IXC = IXA
F1 = PRESS(I)
HS = HETTEM(1)
HT4 = HETTEM(IXA)
IZHT4 = (HT4 + .005)*100.
IZHT2 = (HS + .005)*100.
IVERTN = (IZHT4-IZHT2)/IDELVE
IVERTN = IVERTN - 1
WRITE(3,28) (HETTEM(I), TEMP(I), I=1,IXA)
**C**
**PRESSURE VS TEMPERATURE READ IN, IVERT=-1**************************************************************************

**C**
CONTINUE
READ(2,3) IXA
READ(2,31) (PRESS(I), I=1,IXA)
READ(2,32) (TEMP(I), I=1,IXA)
**C**
**CONVERSION FROM PRESSURE TO HEIGHT**************************************************************************

**C**
HMIN(1)=.0
CONST=8.3175+07/(XMOL*50)
DO 100 I=2,IXA
TERM = (CONST*(TEMP(I)+TEMP(I-1))*(PRESS(I)-PRESS(I-1)))/(PRESS(I)+PRESS(I-1))
PRESS(I-1) = TERM+1.E-05
HMIN(I) = HMIN(I-1)+TERM
WRITE(3,33) I, TEMP(I), PRESS(I), CONST, TERM, HMIN(I)
100 CONTINUE
DO 115 I=1,IXA
Hh(I)=HMIN(IXA)-HMIN(I)
DATA(I)=TEMP(I)
WRITE(3,34) Hh(I), DATA(I)
115 CONTINUE
DO 120 I=1,IXA
IXA=IXA+1-I
IXA1=2*I-1
IXA2=2*I
DATA(IXA1)=HH(I)
DATA(IXA2)=TEMP(I)
PRES(I)=PRESSH(I)
PRESH(I)=1013.25*PRES(I)
WRITE(3,35)I,IXAA,IXA1,IXA2,PRESH(I),DATA(I)
CONTINUE
120
 C DATA-TABLE OF H VS H2O DIST, IXB-TOTAL NO OF POINTS***************
C WRITE(3,29) (HH=H2O(I),IXC=IXC(I),I=1,IXB)
 C DATA-TABLE OF H VS OT DIST, IXC-TOTAL NO OF POINTS***************
C WRITE(3,28) (H=H2O(I),IXC2=IXC2(I),I=1,IXC)
READ(2,3) IUP
READ(2,32) (H=H2O(I),I=1,IUP)
JTA=1
C ANG = ANGLE(JTA)*0.017453294
ITA=0
NUM1 = NUM1 + 1
IDELR1 = (DELR*1000./2.)*.05
SH=0
K=E+XMINH)*SIN(ANG)
SUM=0.
SUMBOT = 0.0
C PRESSURE INTEGRATION****************************************************
WRITE(3,5601)
DELR=0
N=1
IHS = (HS + .0005)*1000.
IH = IHS
IH = IH+IDELR
IH1 = IH+IDELR1
IDELP=DELR*1000.+5
X=N=FLOAT(IH)/1000.
X1(N)=FLOAT(IH1)/1000.
DEL=DELL
H1=X1(N)
H=\text{X}(N)

608 \text{T1=TIMAS(H1\text{, }\text{HETTEM\text{, }TEMP\text{, }IXA\text{, }1})}
\text{TH30T=TIMAS(H\text{, }\text{HETTEM\text{, }TEMP\text{, }IXA\text{, }1})}
\text{X1T(N)=T1}
\text{XT2(N)=TH30T}
\text{GR=GO*\{RAD/(H1+RAD)\}**2}
\text{GR30T=GO*\{RAD/(H+RAD)\}**2}
\text{I=(N\text{, }GT\text{, }1) GO TO 609}
\text{BZAP = DELP/2.}
\text{SUM=SUM+GR30T*(GR*XMOL)*(1.0+5)/(RD*TH30T)}
\text{GO TO 607}

609 \text{CONTINUE}
\text{SUM=SUM+DELL*\{GR*XMOL\}*(1.0+5)/(RD*TH1)}
\text{SUMBOT=SUMBOT + DEL*\{(GR30T*XMOL\}*(1.0+5)/(RD*TH30T)}
\text{GO TO 607}

607 \text{XP(N)=P1*(2.71828182**(-SUM))}
\text{XP30T(N)=P1*(2.71828182**(-SUMBOT))}
\text{P=RAD+X(N) \hspace{1cm} I=P-RAD \hspace{1cm} 610\text{, }610,612}

610 \text{R=R0-RAD}
\text{I=I+1000.}
\text{GO TO 605}

612 \text{XDEL(N)=(3/\text{SQRT(R**2-R0**2)})*DELL}
\text{HT=(HT-DELF)*1000.}
\text{N=N+1}
\text{IF (N - IVERIN ) 605,604,604}

604 \text{NCLAY=N-1}
\text{HT4=X\{NCLAY\}}
\text{HT = HT4}
\text{HT3=HT4}
\text{WRITE(3,5638) HT4}
\text{IPR1=0}
\text{IFP=IPR1+55}
\text{WRITE(3,29)}
\text{WRITE(3,14) NUM1}
\text{WRITE(3,8) \{WORDS(I),I=1\text{, }18\}}
\text{WRITE(3,9) ANGLE(JT4),XMINH,HT2}
\text{WRITE(3,6) COH20,C1H20,C2H20}
\text{WRITE(3,25) CCONO2,C1C02,C2C02}
\text{WRITE(3,5618) CNO3,C1O3,C2O3}
\text{WRITE(3,40) IGAS,JGAS,ITM,JTM}
\text{WIHT=3,24}
\text{DELT=0.}
\text{TSUM1=0.}
\text{PSUM1=0.}
\text{SUM2=0.}
DO 650 M=1,NCLAY
N=NLAY-M+1
H=X(N)
H1=X1(N)
TH1=XT1(N)
PR=XP(N)

RHO1 = TINAS(H1,HETH2O,POH2O,1X8+1)
RHOJ = TINAS(H1,HETCO2,POCO2,1X8+1)

CALL PRSEV(RHO1,PR,ICAS,CONH2O,PEP=1)
SUM4=DELS*RHO1*((PR/PO)**C1H2O)**((TO/TH1)**C2H2O)
DELU1=SUM4*CONH2O
DELU=DELU1+DELU1
USUM4=DELS*RHO1*((PR/PO)**(TO/TH1))**((TO/TH1)

DELU2=USUM4*CONH2O
DELU=DELU1+DELU1
TSUM1=TH1*DELU1+TSUM1
PSUM1=PRPR1*DELU1+PSUM1
SUM2=SUM2+SUM4
DEPT1=CONH2O*SUM2
AVET1=TSUM1/DELU
AVET1=PSUM1/DELU

C OPTICAL DEPTH COMPUTATION******************************************************************

DELU2=SUM44*H01*((PRATIO)**C1O3)**((TO/TH1)**C203)
USUM44 = DELS*H01
UDELU2 = USUM44*CON03
UDELUU = UDDELUU + UDDELU2
TSUM2=TH1*DELU2+TSUM2
SUM22=SUM22+SUM44
DEPT2=CON03*SUM22
P1*P2=PR
PSUM2=PSUM2*DELU2+PSUM2
AVET2=TSUM2/DELUU
AVEP2=PSUM2/DELUU
PRA=PF/P0

C CARBON DIOXIDE OPTICAL PATH LENGTH

PHOC2=1.0
CALL PFEV(RHOC2,PR,JSAS,CONCO2,PEE=CO2)
SUM44=DELS*((PEeCO2/P0)**C102)*((TO/TH1)**C202)
DECO2=DECO2+DECO2
SUM22=SUM22+SUM44
DEPO2=CONCO2*SUM22
SUMCO2 = DELS*(PP/P0)*(TO/TH1)
SUMCO2 = SUMCO2 + SUMCO
SUMCO2 = SUMCO2*CONCO2
UCO2(M) = DEPCO2
PCO2(M) = PEPCO2
CO2L = (.00031444.01*1.01325E+06)/(1.9769-E-03*980.665*28.97)
UCO2(M) = SUMCO*CONCO2
CDL = CO2L*1.5*03
PCO2(M) = CDL*[(XPROT(N) - XPROT(N+1))

C METHANE OPTICAL PATH LENGTH

SUMCH = DELS*(CH4*(PR/P0)*(TO/TH1)
SUMCH4 = SUMCH4 + SUMCH
SUMCH4 = SUMCH4 + SUMCH*(FR/985.)
UCH4(M) = SUMCH4
USCH4(M) = SUMCH4

C N2O OPTICAL PATH LENGTH

SUMN2 = DELS*N2O*(PR/P0)*(TO/TH1)
SUMN20 = SUMN20 + SUMN2
SUMN0 = SUMN0 + SUMN2*(PR/P0)*SORT(TO/TH1)
USN20(M) = SUMN0
UNN20(M) = SUMN20

780 IPR1(IPR2-IPR1) 782,782,784
782 IPR2(IPR1+1)
784 WRIT:(3,26) H1,TH1,PR,RHO1,PEEF1,AVET!,AVEP1,DEPT1,RHOJ,PEEF
AVET2,AVEP2,DEPT2
IH = (H+.0005)*1000.
IHT3 = (HT3+.0005)*1000.
IF(TH-IHT3) 750,750,650

C OPTICAL DEPTH MATRIX
WRITE(3,18) (((XTA(KT,MT,NT),KT=1,7),MT=1,LA),NT=JTA,JTA)
WRITE(3,5601)
WRITE(3,5647)(XTA(1,MT,1),XTA(9,MT,1),XTA(10,MT,1),MT=1,LA)
IF(JTA-JTAN)720,708,708
720 JTA=JTA+1
GO TO 30
708 CONTINUE
C DETERMINATION OF TRANS FROM GEN ABS COEF
C
C INTA-H VS TEMP
C INTB-H VS H2O DIST
C INTI-H VS O3 DIST
C INT0-3 H2O, WAVE NUMBER VS LOG10(L)
C INTG-ROTATIONAL H2O, WAVE NUMBER VS LOG10(L)
C INTH-ROTATIONAL H2O, LOG10(L) VS TRANS
C INTJ-CONTINUUM H2O
C INTL-9.6 OZONE, WAVE NUMBER VS LOG10(L)
C INTM-9.6 OZONE, LOG10(L) VS TRANS
DO 1101 IJ=1,JTAN
   KIKI = 0
   JTA = IJ
   DO 735 J=1,INTER
      XJ=FLOAT(J)
      WAVG=WAVE(I)+((XJ-1.)*DWave
      WAVW(IJ)=WAVEO
      IHRI=+10
      IHRI=-10
      IF(IHRI)1847,1840,1840
      IF((WAVEO,LT,2360.) OR (WAVEO,GT,3100.)) GE TO 1841
      GO TO 1847
1840 IF((WAVEO,LT,2360.) OR (WAVEO,GT,3100.)) GE TO 1841
      GO TO 1847
1841 WRITE(3,37) WAVEO
      GO TO 735
1847 GENH52 = TIMAS(WAVEO,WAVEE,DATE,IXE,1)
GENST5 = TIMAS(WAVEO,WAVEE,DATI,IXE,1)
GENH7T = TIMAS(WAVEO,WAVEE,DATJ,IXE,1)
GENH96 = TIMAS(WAVEO,WAVEK,DATK,IXK,1)
GENC42 = TIMAS(WAVEO,WAVEW,DATM,IXM,1)
GENH32 = TIMAS(WAVEO,WAVEU,DATU,IXU,1)
GENC43 = TIMAS(WAVEO,WAVEV,DATV,IXV,1)
   DC 715 N=1,LA
   IF(IHRI)1861,1861,1848
   C N2O--BASED ON LINEAR PORTION OF CURVE OF GROWTH
   1848 IF(WAVEO,GE,2426.) GO TO 1849
   TPA20(IN) = 1.0

GO TO 1859
1849 IF(WAVE0.GE.2496.)GO TO 1851
TRN20(N) = 1. - ((11.5*XTA(10,N,JTA))/70.)
GO TO 1859
1851 IF(WAVE0.GE.2518.)GO TO 1853
TRN20(N) = 1.0
GO TO 1859
1853 IF(WAVE0.GE.2608.)GO TO 1855
TRN20(N) = 1.0 - ((44.*XTA(10,N,JTA))/90.)
GO TO 1859
1855 TRN20(N) = 1.0
1859 CONTINUE
1861 REDH20=XTA(4,N,JTA)
REDCO2=XTA(8,N,JTA)
XLUH63=ALGO10(REDH20) + GENH63
XLUROT=ALGO10(REDH20) + GENROT
XLUOC2=ALGO10(REDCO2) + GENC02
XLUH32 = ALGO10(REDH20) + GENH32
XLUOC3 = ALGO10(REDCO2) + GENC03
RED03=XTA(7,N,JTA)
IF(RED03=0.00) EC8, EC8, 809
808 XLU96=-15.
GO TO 811
809 XLU96 = ALGO10(RED03) + GEN096
811 CONTINUE
TR463(N) = TINAS(XLUH63,XLUF,DATF,IXF,1)
TRROT(N) = TINAS(XLUROT,XLUF,DATH,IXH,1)
ARGU= 
(GENETA*SORT(REDH20) + GENBET*REDH20)
TRCON(N)=EXP(ARGU)
TRCON(N)=1.0
TRC96(N) = TINAS(XLU96,XLUL,DATL,IXL,1)
CALL GZONE(WAVE0,RED03,XTA(6,N,JTA),TRD96(N),2)
TRD02(N) = TINAS(XLU96,XLUN,DATN,IXN,1)
TRH32(N) = TINAS(XLUH32,XLUU,DATUU,IXUU,1)
TRC43(N) = TINAS(XLUC43,XLUV,DATUV,IXV,1)
WE = TINAS(WAVE0,WAVE0,WE,1XW,1)
TRH33(N) = EXP(-XTA(9,N,JTA)/WE)**0.56
C
TRAM(N) = TRG43(N)*TRH32(N)*TRH33(N)*TRN20(N)
TRAM(N) = TRG02(N)*TRD95(N)*TRD02(N)*TRROT(N)*TRF65(N)
TRAM(N,N) = TRAM(N)
715 CONTINUE
KI1=KI1+1
WAVE(KI1)=WAVE0
GO TO (805,810,815,820,825,830,835,840,845,850,855,860,865,870,-
1875),K11
805 DO 807 N=1,LA
807 T1(N)=TRAM(N)
GO TO 716
810 DO 812 N=1,LA
812 T2(N)=TRAM(N)
     GO TO 716
815 DO 817 N=1,LA
817 T3(N)=TRAM(N)
     GO TO 716
820 DO 822 N=1,LA
822 T4(N)=TRAM(N)
     GO TO 716
825 DO 827 N=1,LA
827 T5(N)=TRAM(N)
     GO TO 716
830 DO 832 N=1,LA
832 T6(N)=TRAM(N)
     GO TO 716
835 DO 837 N=1,LA
837 T7(N)=TRAM(N)
     GO TO 716
840 DO 842 N=1,LA
842 T8(N)=TRAM(N)
     GO TO 716
845 DO 847 N=1,LA
847 T9(N)=TRAM(N)
     GO TO 716
850 DO 852 N=1,LA
852 T10(N)=TRAM(N)
     GO TO 716
855 DO 857 N=1,LA
857 T11(N)=TRAM(N)
     GO TO 716
860 DO 862 N=1,LA
862 T12(N)=TRAM(N)
     GO TO 716
865 DO 867 N=1,LA
867 T13(N)=TRAM(N)
     GO TO 716
870 DO 872 N=1,LA
872 T14(N)=TRAM(N)
     GO TO 716
875 DO 877 N=1,LA
877 T15(N)=TRAM(N)
     WRITE(3,5620)
     WRITE(3,905) (WA(I),I=1,15)
     GO TO 716
910 WRITE(3,915) XTA(1,N,JTA),T1(N),T2(N),T3(N),T4(N),T5(N),T6(N),T7(N)
                     ,T8(N),T9(N),T10(N),T11(N),T12(N),T13(N),T14(N),T15(N)
                      ,KIX=0.6
716 CONTINUE
CONTINUE
DC 1823 N=1, NOLAY
M = NOLAY - N + 1
L = N - 1
HINTERG(N) = X(M)
TMINT173(N) = XT1(M-1)
CONTINUE
IVERIN = NOLAY
GO TO 1826
C INTEGRATION OF RADIATIVE TRANSFER EQUATION
IH = (IH4 + .005)*100.
DO 1825 I=1, IVERIN
H = FLOAT(IH)/100.
H1 = H - DSLVER/2.0
H2 = H - DELVER
T111 = TIMES(H, HETTEM, TEMP, IXA, 1)
T121 = TIMES(H2, HETTEM, TEMP, IXA, 1)
TMINT173(I) = (T111 + T121)/2.0
HINTERG(I) = H
IH = IH - DELVE
CONTINUE
DO 1826 CONTINUE
WRITE(3, 11) NOLAY, IVERIN
WRITE(3, 5635)
WRITE(3, 14) NUM1
WRITE(3, 14) WORDS(I), I=1, 18
WRITE(3, 19) ANGLE(IJ), XMINH, HT2
WRITE(3, 6) COMP20, C1H20, C2420
WRITE(3, 25) CONCO2, C1CO2, C2CO2
WRITE(3, 5618) CONO3, C1O3, C2O3
WRITE(3, 40)
WRITE(3, 41) GO, PL, TC, RD, RO, DELR, IGA5, JGAS, IATM, JTAN
WRITE(3, 5636) SPWORD(I), I=1, 18
WRITE(3, 5630)
WRITE(3, 5631) WAVSP(I), PHI(I), I=1, IPHI
WRITE(3, 5632)
WRITE(3, 5633) (TEMPR(I), XNRAR(I), I=1, 13, 2)
C IPRT = +1, PRINT INTERIM DATA FOR EACH SPECTRAL INTERVAL FOR EACH
C ATMOSPHERIC LAYER
C IPRT1 = +1, PRINT OUTGOING RAD DATA FOR EACH SPECTRAL INTERVAL
IPRT = +1
IPRT = -1
IPRT1 = +1
IPRT2 = +1
DO 1100 J=1, IU
DO 1049 I=1, IVERIN
1049 SUMLAI(1) = 0.0
SUMR = 0.0
SUMGDF = 0.0
IF(IERPT)1058,1008,1007
1007 WRITE(3,5644)
1008 CONTINUE
DO 1056 K=1,INTER
WAVG = WAWW(K)
PHII = TINAS(WAVEO,WAVSP,PHI,IPHI,1)
IF(PIII) 1050,1050,1009
1009 DO 1010 N=1,1A
MZ = LA + 1 - M
TRANV(M) = TRAMM(MZ,K)
1010 HLT(M) = XTA(1,MZ,JTA)
C TDF LAYER***********************************************************************************************************************************************
PUP = 0.0
ITRANU = (TRANU + .000005)*100000.
HU = HINTG(1)
HL = HINTG(2)
ITRANL = (TRANL + .000005)*100000.
TH = TMINDIN(1)
CALL PLANK(WAVEO,DWAVE,TH,BBFW,BBFWO)
ITRAN = ITRANU - ITRANL
DTRAN = FLOAT(ITRAN)/100000
TRANL = FLOAT(ITRANL)/100000.
OLIVER = DTRAN*BBFW*PHII
SUM = OLIVER
SUMP = SUMP + OLIVER
SUMHTU(1) = HU
SUMHTL(1) = HL
SUMLAY(1) = SUMLAI(1) + OLIVER
WAV = WAVEO
IF(IERPT) 1870,1870,1865
1865 WRITE(3,5638)HU,HL,TRANU,TRANL,TH,WAV,BBFW,BBFWO,CLIVER,SUM,DTTRAN,DTRAN,DTRAN
C ATMOSPHERIC LAYERS***********************************************************************************************************************************************
1870 IVER = IVER+1 - 2
M = 900 M = 1,IVER
HU = HINTG(M+1)
HL = HINTG(M+2)
TH = TMINDIN(M+1)
TRANU = TRANL
ITRANU = ITRANL
TRANL = TINAS(HL,HET,TRANV,LA,1)
ITRANL = (TRANL + .000005)*100000.
CALL PLANK(WAVEO,DWAVE,TH,BRFW,BBFWO)
TDFTRAN = ITRANU - ITTRAN
DTRAN = FLOAT(TDFTRAN)/100000
TRANL = FLOAT(TDFTRAN)/100000.
TRANU = FLOAT(ITRANL)/100000.
OLIVER = DTRAN*BRFW * PHI
SUM = SUM + OLIVER
SUMR = SUMR + OLIVER
SUMHTU(M+1) = HU
SUMHTL(M+1) = HL
SUMLAY(M+1) = SUMLAY(M+1) + OLIVER
WAV = WAVEO
IF(TERT) 1880, 1880, 1875
1875 WRITE(3,5638) HU,HL,TRANU,TRANL,TH,WAV,BRFW,OLIVER,SUM,DTRAN,DTRAN
1880 IF(HL-HROT(J)) 901,901,900
900 CONTINUE
901 CONTINUE
RADATM = SUM
C SURFACE CONTRIBUTION******************************************************************************

H = HL
TH = TINAS(H,HETTEM,TEMP,IXA,1)
TRANS = TINAS(H,HST,TRANV,LA,1)
CALL PLANK(WAVEO,DWAVE,TH,BRFW,BBFWO)
RADGRD = TRANG*PEM * PHI
RA = RA + RADATM + RADGRD
SUMGRD = SUMGRD + RADGRD
PER = RA + NGRD/RA
CA = 1.1999*12
CP = 1.43879
TBR = (CA*WAV)/ALOG(DWAVE*CA*WAV**3/RAT1+1.0)
XXLAM = 1.1*04/WAV
IF(TPT1) 1050, 1050, 1040
1040 WRITE(3,5628) H,TH,TRANS,PADGRD,FADATM,RA,PER,TBB,WAV
1,XXLAM,PHI
1050 CONTINUE
TOT = SUMR + SUMGRD
TOT = TOT*1.5*04
TBB = TINAS(TOT,XNBAR,TEMPBB,IBAR,1)
WRITE(3,5634)
WRITE(3,5627) H,TOT,TBB
IF(TPT2) 1100, 1093, 1093
1093 IVVVV = IVVR + 1
WRITE(3,5648)
WRITE(3,11) IVVV
DO 1097 JL = 1,IVVV
PPER = SUMLAY(JL)/(SUNR+SUMGRD)
PPER = SUMLAY(JL)/SUMR
}
1097 WRITE(3,5646) SUMTU(JL),SUMTL(JL),SUMLAY(JL),PERR,PRT,JL
1100 CONTINUE
1101 CONTINUE
   NUM=NUM-1
   IF(NUM).EQ.710,710,20
1173 CONTINUE
710 STOP
END

SUBROUTINE CZONE(WAVE0,XMASS,PEAR,TAU,IFIRST)
DIMENSION SDD(30),ADD(30),WAV(30),XKK(30)
GO TO (50,90),IFIRST
50 CONTINUE
READ(2,103) (ADD(I),I=1,27)
READ(2,103) (XKK(I),I=1,27)
103 FORMAT(14F5.1)
   TAU = 1.
RETURN
90 CONTINUE
   PO = 1013.25
   PI = 22.73
   PRT1 = -1
   WAV(1)=940.
   WAV(27)=1100.
   DO 130 K=2,26
130 WAV(K) = 955.*+FLOAT(K-1)*5.
   SDD(1) = .004
   SDD(2) = .018
   SDD(3) = .036
   SDD(4) = .068
   SDD(5) = .120
   SDD(6) = .211
   SDD(7) = .376
   SDD(8) = .687
   SDD(9) = 1.15
   SDD(10) = 1.82
   SDD(11) = 2.82
   SDD(12) = 4.07
   SDD(13) = 5.89
   SDD(14) = 7.24
   SDD(15) = 8.13
   SDD(16) = 9.13
   SDD(17) = 7.24
   SDD(18) = 6.03
   SDD(19) = 6.03
   SDD(20) = 10.11
   SDD(21) = 10.115
SUBROUTINE PPEV(RHO, PR, IGAS, CAPK, PEFF)
PRL = 1.3
PRZ = 6.3
IF(IGAS = 2) 10, 20, 30
10 PEFF = PR * (PRL - 1.) * CAPK * 10. ** (-5) * PR
GO TO 40
20 PEFF = PR * (PRZ - 1.) * 10. ** (-3) * RHO * 12.45 * CAPK * PR
GO TO 40
30 PEFF = PR
40 RETURN
END

SUBROUTINE PLANK(WAVEO, Dwave, TH1, PADM, RADW)
DIMENSION PLK(5)
CA = 1.19868 - 12
CB = 1.43879
PADM = 0.
PADW = 0.
Dwave = WAVEO - 2.0 * Dwave / 5.0
DO 21 I = 1, 5
   PLK(I) = CA * CB ** 3 / (EXP(CB * Dwave / TH1) - 1.0)
   SF = 1.
   PADM = RADW * PLK(I) * SF
21 CONTINUE
RETURN
END

FUNCTION TINAS(A, X, Y, NX, KX)

ADKINS INTERPOLATION / EXTRAPOLATION

A = ARGUMENT
X = TABLE OF X'S
Y = TABLE OF Y'S  I.E.  Y(I) = F(X(I))
NX = NUMBER OF ENTRIES IN TABLE 'X'
KX = ORDER OF INTERPOLATION

NOTE: X(I) MUST BE LESS THAN X(I+1)

REAL *4 TINAS, A, X, Y, CX, CY
DIMENSION X(2), Y(2), CX(15), CY(15)
C----------
K = NO. POINTS TO USE

K = KX + 1

IF( K .GT. 15) K = 15

FIND NEAREST X(I)

DO 10 I = 1, NX

IF( A .LE. X(I) ) GO TO 20

10 CONTINUE

I = NX

CHECK FOR EVEN/ODD NO. POINTS

20 IF( MOD(K,2) .EQ. 1 ) GO TO 40

SET I SO PTS X(I) TO X(I+KX) = NEAREST POINTS TO 'A'

30 I = 1 - K/2

IF( I .LT. 1) I = 1

IF( (I+K) .GT. NX ) I = NX - K + 1

GO TO 50

K IS ODD. SET I SO MIDDLE POINT IS NEAREST TO 'A'

40 IF( I .EQ. 1 ) GO TO 50

40 J = I - 1

IF( A .LE. (X(I) + X(J)) * 0.5 ) ) I = J

GO TO 30

SET INITIAL CY, CX

50 DO 60 J = 1,K

50 CX(J) = X(I(J)) - A

50 CY(J) = Y(I(J))

60 I = I + 1

PERFORM INTERPOLATION

M = K - 1

DO 80 J = 1,M

70 CY(I+1) = ( CX(I+1)*CY(J) - CX(J)*CY(I+1) )/(CX(I+1)-CX(J))

80 CONTINUE

TINAS = CY(K)

RETURN
LIST OF REFERENCES


Meteorological Analyses, Institute for Meteorology and Geophysics of the Free University of Berlin, January-March 1964.


<table>
<thead>
<tr>
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<th>Name and Address</th>
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Calculation of Levels of Relative Contribution of the Carbon-dioxide Channel Radiance from TIROS VII in the Case of a Large-scale Stratospheric Warming in January 1964

A case study of a winter stratospheric warming in the western hemisphere in January 1964 between 60° and 40° north latitudes was conducted. Utilizing TIROS VII radiance data and analyzed height fields, a stepwise regression equation was determined to specify lower stratospheric layer temperatures. These temperatures were used with standard atmospheric temperatures to construct a sounding for use in a radiance computer program. Finally, this computed radiance was compared to regression values to determine if prediction and study of stratospheric warmings are valid and useful.
<table>
<thead>
<tr>
<th>KEY WORDS</th>
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<tr>
<td>Stratospheric Warming</td>
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<td>Channel Radiance</td>
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<tr>
<td>Stratospheric layer temperatures</td>
</tr>
<tr>
<td>TIROS VII radiance data</td>
</tr>
</tbody>
</table>
Calculation of levels of relative contribution of the carbon-dioxide channel radiance from TIROS VII in the case of a large-scale stratospheric warming in January 1964.