Kathy
Copy 5

DOCUMENTATION

Soundings and Radiation Parameters From TIROS-N for Winter MONEX

David W. Martin

Space Science and Engineering Center
University of Wisconsin-Madison

Dhirendra N. Sikdar

Department of Geological Sciences/Atmospheric Sciences
University of Wisconsin-Milwaukee

January 1981

1. Winter MONEX

2. Soundings and Radiation Parameters from TIROS-N for Winter MONEX.

3. Data Archiving Agency: World Data Center-A
Robert Williams (704)258-2850 x-381
National Climatic Center
Federal Building
Asheville, NC 28801

4. Data Processing Agency: Space Science and Engineering Center
University of Wisconsin-Madison
David W. Martin (608)262-4363
1225 West Dayton Street
Madison, WI 53706

5. Data Collection Agency: Satellite Data Services Division
World Weather Building, Room 606
Washington, D.C. 20233

6. Data Set Description

a. General description: This data set consists of (i) soundings and (ii) radiation parameters both derived from observations of the TIROS-N satellite over the area 95° to 130°E, 20°S to 30°N.

b. Type of data:

i. Soundings

Temperature (°K), dewpoint temperature (°K); also HIRS brightness temperatures (°K) for channels 1-19 and MSU brightness temperatures (°K) for channels 1-4; also elevation (m), sea level pressure (mb), total precipitable water vapor (cm of water), total long wave flux (W/m^2), cloud amount (%), cloud pressure (mb), cloud temperature (°K), retrieval type((whether infrared plus microwave (HIRS + MSU) or microwave only (MSU)), and solar zenith angle (deg). These are given as a function of latitude and longitude (deg), pressure, and time. Soundings are irregularly spaced, depending on the distribution of clouds and rain.

ii. Radiation parameters

Cloud height (mb), cloud amount (%), cloud temperature (°K), long wave flux (W/m^2) and albedo (%); also solar zenith angle (deg). These are given as a function of latitude and longitude (deg). Radiation parameters are regularly spaced.

c. Period covered: 1-31 December 1978. No data were available for the mornings of 1, 9, 12, 14, and 16 December and the afternoon of 12 December; also individual orbits were missing on the morning of 30 December and on the afternoons of 1, 2, 4, and 17 December.

d. Resolution: Both morning and afternoon satellite passes were used whenever they were available.

Spatial resolution is determined by the field of view of the radiometer. For the HIRS the ground field view is 17.4 km in diameter at nadir and 58.5 km (cross track) by 29.9 km (along track) at the limits of the scan. For the MSU the ground field of view is 124 km at nadir and 323 km (cross track) by 179 km (along track) at the limits of the scan. Clear column and partly cloudy retrievals use HIRS plus MSU radiances whereas overcast cloud retrievals use only MSU radiances. The spacing between soundings depends partly on the distribution of clouds and rain and this is highly variable. On the average over the area of interest there is one sounding per six square degrees per half day. Radiation parameters use only HIRS radiances. Values were calculated for every spot and every line. Since scan lines are separated by 42 km, this resulted in an average spacing of ~40 km between adjacent values of radiation parameters. Because of limits on computer time, radiation parameters were not calculated for every orbit; however, insofar as possible they were calculated for at least one orbit each day.

e. Processing and quality control procedures: (This section is adapted from Smith (1978), Menzel et al (1978) and Winston et al (1972)). The raw radiance data were calibrated and located before being ingested into the McIDAS for meteorological interpretation. To generate retrievals the McIDAS terminal operator instructed the computer, through the keyboard, to display magnified data images for several channels of data (typically visible, infrared window, and lower troposphere microwave) and to produce vertical temperature and moisture profiles for every third element and third line. Automatically, two types of infrared-based soundings were attempted for each location: (1) a clear sounding from the single ~30 km field of view selected by the computer, and (2) a partly cloudy sounding which was obtained from data from two adjacent 30 km fields of view (the one selected by the computer and one of its neighbors). The algorithm for partly cloudy soundings assumed (a) only cloud coverage differed between the two fields of view and (b) the observed radiance (brightness temperature) of the mid-tropospheric microwave channel could be specified from a linear combination of the clear-column infrared radiances. The best partly cloudy result from the eight different neighboring fields of view surrounding the operator selected spot was specified on the basis of being in best r.m.s. agreement (sum of squares of temperature differences at several levels in the vertical) with a lower resolution sounding produced directly from the three microwave channel observations for the same area. A selection between the best "partly cloudy sounding" and the "clear sounding" for the area was made on the same basis. (The r.m.s. selection criterion is not believed to bias the infrared sounding result to the lower resolution microwave product since cloud-induced errors should always tend toward poorer agreement in a vertical r.m.s. sense.) Soundings were discarded completely if the r.m.s. difference was excessive, which is generally the case in heavily clouded areas. The operator, by means of a cursor, then added soundings to fill gaps in the field produced by the computer. Sometimes, when clouds were extensive over an image area, the automatic mode was simply skipped.

Retrievals were generated by means of multiple linear regression using coefficients determined from simulated radiances. These radiances were calculated from climatological soundings for the belt from 30°S to 30°N (see Section 7.1 in Smith et al., 1974).

The objective of editing is twofold: (1) to remove those soundings for which temperature at any tropospheric level is grossly in error, and (2) to achieve a field of temperature which fairly and accurately portrays the major synoptic thermal features. Editing procedures varied somewhat, depending on circumstances. In general they included the following steps, in the order listed.

(1) Display as a field of numbers differences in temperature between microwave and infrared retrievals for the same field of view at one pressure level. Delete soundings for which the temperature difference is large. Repeat for other levels.

7

(2) Display temperature at a level, as numbers and as contours. Delete soundings where (a) individual values are very high or very low, (b) gradients are large and show no vertical consistency, or (c) clear-column, partly cloudy and/or microwave soundings are systematically different. Repeat for several levels.

(3) Display fields of geopotential thickness, as numbers and as contours. Delete soundings as in (2) above. Repeat for several layers.

(4) In areas of extensive solid overcast, when rain is not implied in the lower troposphere channel, add microwave retrievals. Horizontal inconsistencies between these microwave soundings and their infrared neighbors were alleviated automatically by adding to the microwave result any systematic differences between microwave and infrared soundings in neighboring clear or partly cloudy areas. The differences were interpolated into the overcast region where the microwave soundings were generated.

(5) Selectively check temperatures and thicknesses again. Delete soundings as in (2) and (3).

With the exception of 12 December all processing was done by the same person (Lam). To insure that standards were uniform through the whole month, after all days had been processed, another person (Martin) reexamined and (where necessary) re-edited some of the first days processed (1,2,3,4, and 6 December).

Other things being equal, partly cloudy retrievals (which tended to be relatively warm in the lower troposphere) were removed before clear column retrievals. "Clear column" retrievals in areas that appeared to be partly cloudy were regarded with suspicion, also "partly cloudy" retrievals in mostly cloudy areas.

Using the radiative transfer equation, cloud pressure is determined from the ratio of deviations in cloud produced radiances and neighboring clear air radiances for two or more spectral channels (Menzel et al, 1978). The technique takes advantage of the property that different frequencies receive different radiative contributions from the same level of the atmosphere. Investigating the ratios at various pressure levels, a reasonably unambiguous cloud pressure may be determined, and, from a nearby retrieval, cloud top altitude and temperature. The method is most reliable for clouds whose tops are above the 700 mb level.

Effective cloud amount η is determined from cloud top pressure and window infrared radiance through the relation

$$\eta = \varepsilon N = \frac{I - I_{cl}}{I_{Bcd} - I_{cl}} .$$

N is the fractional cloud amount within the radiometer's field of view, I is the observed infrared radiance, I_{cl} is the observed infrared radiance from a nearby clear field of view and I_{Bcd} is the opaque cloud radiance. I_{Bcd} is calculated from the Planck function B(T(p)) where the temperature T is obtained from the cloud top pressure p through a nearby retrieval. ε is emissivity.

The flux F is computed from the radiances I_i and coefficients C_o and C_i obtained at any step n using the multiple linear regression equation:

$$F = C_o + \sum_{i=1}^{n} C_i I_i .$$

The window channel alone explains most of the variance of the total flux, presumably because the primary modulator is cloudiness. However, significant reductions of standard error are obtained with the addition of all the longwave (5 - 15μm) moisture and CO_2 channels. Coefficients of the regression are obtained for a sample of 100 climatological atmospheres expanded into 1700 simulated cloudy radiance profiles from which fluxes are calculated according to the method of Rodgers and Walshaw (1966). An example of the application of a similar model is given in Winston, Smith and Woolf (1972).

The albedo is derived from the observed radiance in the HIRS visible channel (0.69 μm), according to a model of Raschke et al (1973). The model takes into account sun angle and surface characteristics (land, sea, ice or snow).

Radiation parameters were not edited in any way.

f. Soundings and radiation parameters are supplied on computer tapes.

g. Tape format is as follows:

PHYSICAL CHARACTERISTICS:

1600 BPI, odd parity, phase encoded, 9 track, ASCII with parity-0.

TAPE LAYOUT:

```
         G          G          E          E E
    file O     file O  . . .   O    file  O O
         F          F          F          F F
        ---        ---        ---        -----
                                           ↑
                                         indicates logical end of data
```

FILE LAYOUT:

2880 8-bit bytes per physical records

720 8-bit bytes per logical record--'TIRET' (sounding) data

72 8-bit bytes per logical record--'RADIATION' data

1st logical record of each file is header record.

Remaining logical records are data.

Logical records which are fillers are entirely 9's.

All values occupy exactly 8 ASCIT bytes (sign included).

All values are scaled integers.

HEADER RECORD FORMAT:

Value 1	YYMMDD - year, month, day of data
Value 2	HHMMSS - Greenwich Mean Time for line 1, spot 1
Value 3	HHMMSS - Greenwich Mean Time for last line, spot 1
Value 4	number of lines in image
Value 5	satellite number: 1 = TIROS-N 2 = NOAA-6
Value 6	scan direction: 1 = N → S, 2 = S → N
Value 7	number of logical records of data

Remaining values not used.

'TIRET' DATA RECORD FORMAT:

Values	Contents	
1	Latitude, DDD.DD, W+S-	
2	Longitude, DDD.DD, W+E-	
3	Time, HHMM, hours & minutes	
4	Elevation, meters	
5-19	Mandatory level heights, geopotential meters, (1000-10mb)	
20-34	Temperatures, KKK.KK, (surface, 850-10mb); Kelvin	} IR+microwave
35-40	Dewpoints, KKK.KK, (surface, 850-300mb); Kelvin	
41-59	HIRS 1-19 Brightness temp, KKK.KK, °Kelvin	} Radiometric
60-63	MSU 1-4 Brightness temp, KKK.KK, °Kelvin	
64	Sea level pressure (mb)	
65	Orbit line number	
66	Scan element number	
67-81	MSU retrievals, KKK.KK	[Microwave (Air)]
82	Total precipitable water vapor, cm of water, CCCC.CCC	
83	Total long wave flux, W/m^2, LLL.LL	(IR)
84	Cloud amount, %	
85	Cloud pressure, mb	
86	Cloud temperature, KKK.KK, °Kelvin	
87	Retrieval type	
88	Solar zenith angle, DDD.DD, degrees	
89-90	Not used	

'RADIATION' DATA RECORD FORMAT:

Values	Contents
1	Latitude, DDD.DD, N+S-
2	Longitude, DDD.DD, W+E-
3	Solar zenith angle, DDD.DD
4	Cloud height, millibars
5	Cloud amount, %, 0-100
6	Cloud temperature, °K, TTT.TT
7	Long wave flux, W/m^2, LLL.LL
8	Albedo, %, 0-100
9	Not used

h. Input data are computer tapes of TIROS-N High Resolution Infrared Radiation Sounder 2 (HIRS/2) and Microwave Sounding Unit (MSU) raw radiances. Data were calibrated and earth located. These data are available from the Satellite Data Services Division (301/763-8111).

i. TIROS-N retrievals should be useful in describing temperature and moisture structure on a regional scale and smaller features of a marked thermodynamic signature. In a small number of comparisons, temperature from clear column retrievals most closely matched temperature from dropsondes. Clear column retrievals tended to be too cold, especially near the surface, partly cloudy retrievals tended to be too warm. The differences generally were less than 1.5°C. Owing to faulty microwave surface emissivity corrections along coastlines, partly cloudy retrievals have been found to be too warm in the lower troposphere. Not all of these bad retrievals were removed in editing, thus retrievals within 150 km of coastlines should be treated with special caution. This effect appears to be most pronounced along the coast of mainland China. In regions of extensive cloud, only microwave retrievals were possible. These suffer from poor vertical resolution and occasional contamination by cloud liquid water; they must be considered less reliable than adjacent clear column and partly cloudy retrievals.

TIROS moisture profiles tend to be too dry in the middle troposphere. Through an oversight dewpoint temperatures are given for microwave retrievals. These have no physical meaning and should be disregarded. Clear column and partly cloud precipitable water should be useful; however, because of the natural high variability of moisture and the deleterious effects of clouds in the field of view of the radiometer, individual dewpoint values cannot be taken too seriously.

j. There are 4 tapes, 2 for retrievals, 2 for radiation parameters. The first tape in each subset is nearly full, the second about one-half full.

k. Descriptions of the TIROS-N HIRS/2 and MSU instruments are available in references 3, 5, and 9.

l. Inventory is as follows:

1) Retrievals

TABLE OF CONTENTS FOR TAPE 101

FILE	DATE	TIMEBEGIN	TIMEEND	#LINES	S.C#	SCANDIR	#RECORDS
1	781201	55002	55524	48	1	1	145
2	781201	92202	[illegible]	22	1	1	23
3	781201	182301	[illegible]	142	1	2	[illegible]
4	781201	202452	201840	140	1	3	247
5	781202	70401	72451	140	1	1	217
6	781202	181202	[illegible]	[illegible]	1	1	141
7	781202	[illegible]	[illegible]	[illegible]	1	2	247
8	781203	44401	[illegible]	[illegible]	1	1	198
9	781203	[illegible]	[illegible]	56	1	2	214
10	781204	83303	84453	114	1	1	225
11	781204	150122	152025	68	1	2	129
12	781204	193403	194851	140	1	2	187
13	781205	63358	65448	140	1	1	154
14	781205	175302	175653	36	1	2	22
15	781205	192401	193851	140	1	2	168
16	781205	210502	211003	40	1	2	53
17	781206	63203	64453	140	1	1	147
18	781206	191302	192753	142	1	2	192
19	781206	205501	210301	76	1	2	147
20	781207	62201	63451	140	1	1	191
21	781207	[illegible]	81649	140	1	1	[illegible]
22	781207	204452	205803	146	1	3	187
23	781208	61104	62603	132	1	1	216
24	781208	75154	80643	140	1	1	184
25	781209	60401	61541	144	1	1	184
26	781209	74059	75543	140	1	1	192
27	781209	184200	185649	140	1	2	195
28	781209	222502	223953	140	1	2	143
29	781210	55803	62453	[illegible]	1	1	149
30	781210	70104	71553	140	1	1	[illegible]
31	781210	183158	184643	140	1	1	182
32	781210	201501	[illegible]	140	1	1	[illegible]
33	781211	[illegible]	[illegible]	[illegible]	1	1	123
34	781211	70103	72553	140	1	1	221
35	781211	[illegible]	[illegible]	32	1	1	62
36	781212	181501	182704	114	1	2	126

END OF FIRST TAPE DUMP

TABLE OF CONTENTS FOR TAPE 102

FILE	DATE	TIMEBEGIN	TIMEEND	#LINES	SAT#	SCANDIR	#RECORDS
1	781213	64200	65253	104	1	1	155
2	781214	65000	70449	140	1	1	177
3	781214	83159	84450	124	1	1	217
4	781214	193259	194743	140	1	2	157
5	781215	63958	65449	140	1	1	195
6	781215	82200	82653	140	1	1	219
7	781216	63400	64453	140	1	1	153
8	781216	81104	82553	140	1	1	203
9	781216	205501	210021	76	1	2	121
10	781217	62001	63451	140	1	1	177
11	781217	190203	191653	140	1	2	106
12	781217	204459	205001	96	1	2	155
13	781218	61000	63443	140	1	1	206
14	781218	185104	190553	140	1	2	227
15	781218	203400	204949	140	1	2	149
16	781219	60004	61423	104	1	1	152
17	781219	74001	75451	140	1	1	181
18	781219	184102	185552	140	1	2	133
19	781219	222358	223848	140	1	2	192
20	781220	73000	74449	140	1	1	166
21	781220	193101	194552	140	1	2	213
22	781221	55003	55302	30	1	1	92
23	781221	71958	73443	140	1	1	176
24	781221	90059	90502	40	1	1	53
25	781221	180001	181451	140	1	2	179
26	781221	200304	201753	140	1	2	124
27	781222	71003	72453	140	1	1	185
28	781222	181403	182852	104	1	2	223
29	781222	195158	200648	140	1	2	183
30	781223	94102	95004	96	1	1	243
31	781223	180731	182152	140	1	2	118
32	781223	194203	195653	140	1	2	171
33	781224	64902	70352	140	1	1	204
34	781224	83003	84431	132	1	1	234
35	781224	175901	180459	58	1	2	69
36	781224	193104	194553	140	1	2	234
37	781224	211400	211653	30	1	2	59
38	781225	63803	65253	140	1	1	161
39	781225	82001	83451	140	1	1	238
40	781225	175158	175659	48	1	2	115
41	781225	192102	193552	140	1	2	183
42	781225	210358	211003	52	1	2	120
43	781226	62801	64251	140	1	1	147
44	781226	81000	82449	140	1	1	209
45	781226	191101	192544	140	1	2	156
46	781226	205259	214001	96	1	2	203
47	781227	61900	63249	140	1	1	164
48	781227	75959	81449	140	1	1	188
49	781227	190001	191451	140	1	2	174
50	781227	204004	205501	114	1	2	188
51	781228	61000	62301	124	1	1	167
52	781228	75003	80453	140	1	1	187
53	781228	185000	190440	140	1	2	155
54	781228	203159	204649	140	1	2	177
55	781229	60000	61253	104	1	1	153
56	781229	74001	75451	140	1	1	152
57	781229	202203	203653	140	1	2	202
58	781230	55504	60302	66	1	1	102
59	781230	72903	74352	140	1	1	187
60	781230	193003	194452	140	1	2	132
61	781230	201104	202553	140	1	2	185
62	781231	54901	55205	42	1	1	67
63	781231	71901	73352	140	1	1	167
64	781231	90359	90642	48	1	1	88
65	781231	182059	183524	134	1	2	168
66	781231	200102	201552	140	1	2	193

END OF FIRST TAPE DUMP

2) Radiation parameters

TABLE OF CONTENTS FOR TAPE 123

FILE	DATE	TIMEBEGIN	TIMEEND	#LINES	SAT#	SCANDIR	#RECORDS
1	781201	55023	55524	48	1	1	2656
2	781201	92502	90724	23	1	1	1122
3	781201	182021	193750	140	1	2	7842
4	781202	72901	72251	140	1	1	7540
5	781202	181722	182435	68	1	2	3605
6	781202	195203	202453	140	1	2	7842
7	781203	84401	85259	86	1	1	4916
8	781203	180758	181900	96	1	2	5376
9	781204	83372	84455	114	1	1	6384
10	781204	180102	192025	65	:	2	3825
11	781204	193403	194853	140	.	2	7542
12	781205	63958	65446	140	1	1	7942
13	781205	175322	175659	38	1	2	2125
14	781205	192401	193851	140	1	2	7640
15	781206	63223	64453	140	1	1	7342
16	781207	62021	63451	140	1	1	7840
17	781207	204459	205605	106	1	2	5936
18	781208	61104	62502	132	1	1	7392
19	781208	75158	80648	140	1	1	7640
20	781209	74059	75549	140	1	1	6272
21	781209	184200	185549	140	1	2	7840
22	781210	55823	60459	66	1	1	2240
23	781210	73104	74553	140	1	1	5042
24	781210	201501	202952	140	1	2	7842
25	781211	72102	73552	140	1	1	7942
26	781212	181501	182704	114	1	2	6364
27	781213	84200	85259	104	1	1	5924
28	781214	65000	70449	140	1	1	7842
29	781214	83158	84459	124	1	1	6944
30	781214	193259	194749	140	1	2	7840
31	781215	63958	65448	140	1	1	7784
32	781216	63003	64453	140	1	1	7840
33	781216	81104	82553	140	1	1	7840
34	781217	204459	205501	96	1	2	5376
35	781218	203400	204549	140	1	2	7640
36	781219	74001	75451	140	1	1	7840
37	781220	73000	74449	140	1	1	7840

END OF RADIATION TAPE DUMP

TABLE OF CONTENTS FOR TAPE 104

FILE	DATE	TIMEBEGIN	TIMEEND	#LINES	SAT#	SCANDIR	#RECORDS
1	781221	55023	55302	30	1	1	1680
2	781221	71955	73446	140	1	1	7840
3	781221	182001	183451	140	1	2	7840
4	781221	200304	201753	140	1	2	7840
5	781222	71003	72453	140	1	1	7840
6	781222	195158	200548	140	1	2	7840
7	781222	180701	182150	140	1	2	7840
8	781223	194203	195653	140	1	2	7840
9	781224	83003	84401	132	1	1	7392
10	781224	175921	180459	55	1	2	3245
11	781224	193104	194553	140	1	2	7840
12	781225	63803	65253	140	1	1	7840
13	781225	82001	83451	140	1	1	7840
14	781225	192102	193552	140	1	2	7840
15	781226	81000	82449	140	1	1	7840
16	781226	191101	192544	140	1	2	7840
17	781227	75955	81446	140	1	1	7840
18	781227	190001	191451	140	1	2	7840
19	781227	204304	205501	114	1	2	6384
20	781228	75023	80453	140	1	1	7840
21	781229	60202	61259	104	1	1	5824
22	781229	74001	75451	140	1	1	7840
23	781229	202203	203653	140	1	2	7840
24	781230	72902	74352	140	1	1	7840
25	781230	183003	184453	140	1	2	7840
26	781230	201104	202553	140	1	2	7840
27	781231	54801	55205	40	1	1	2240
28	781231	71901	73350	140	1	1	7840
29	781231	90059	90600	48	1	1	2688
30	781231	182059	183504	134	1	2	7504

END OF RADIATION TAPE DUMP

m. These data were produced between March and December 1980.

n. Tapes were sent to World Data Center A on December 1980. Information on retrieval methods and quality are available in the following references:

1) Hayden, C. M., L. F. Hubert, E. P. McClain, and R. S. Seaman, 1979: Quantitative Meteorological Data from Satellites. Tech. Note No. 166 (WMO No. 531), World Meteorological Organization, Geneva, 1-32.

2) Kidwell, K. B., 1979: NOAA polar orbiter data (TIROS-N and NOAA-6) users guide (preliminary version). National Climatic Center Satellite Data Services Division, World Weather Building, Washington, D.C.

3) Phillips, N., L. McMillin, A. Gruber, and D. Wark, 1979: An evaluation of early operational temperature soundings from TIROS-N. Bull. Am. Meteor. Soc., 60, 1188-1197.

4) Schwalb, A., 1978: The TIROS-N/NOAA A-G satellite series. NOAA Tech. Mem. NESS 95, Environmental Science Information Center (D822), Environmental Data Service, NOAA, Rockville, MD, 75 pp. (NOAA-S/T 77-3012).

5) Smith, W. L., 1979: Processing and Utilization of Satellite Sounding Data in Meteorological Research. Symposium on the Use of Satellite Data in Meteorological Research, Tokyo, pp. 108-115. Available from the Meteorological Society of Japan, Tokyo.

6) Smith, W. L., H. M. Woolf, P. G. Abel, C. M. Hayden, M. Chalfant, and N. Grody, 1974: Nimbus-5 sounder data processing system. Part 1: Measurement characteristics and data reduction procedures. NOAA Tech. Mem. NESS 57, 99 pp.

7) Smith, W. L., C. M. Hayden, H. M. Woolf, H. B. Howell and F. W. Nagle, 1979: Satellite sounding applications to mesoscale meteorology. In (COSPAR) Remote Sounding of the Atmosphere from Space (H. J. Bolle, ed.), Pergamon Press, 33-47.

8) Smith, W. L., H. M. Woolf, C. M. Hayden, D. Q. Wark, and L. M. McMillin, 1979: The TIROS-N Operational Vertical Sounder. Bull. Am. Meteor. Soc., 60, 1177-1187.

9) Menzel, W. P., W. L. Smith and H. M. Woolf, 1978: A man interactive technique for specifying cloud heights from sounding radiance data. Preprint Volume: Third Conference on Atmospheric Radiation (Davis, Cal., 28-30 June), American Meteorological Society, Boston, 154-157.

10) Raschke, E., T. H. Vonder Haar, W. R. Bandeen and M. Pasternak, 1973: The annual radiation balance of the earth-atmosphere system during 1969-70 from Nimbus 3 measurements. J. Atmos. Sci., 30, 341-364.

11) Rodgers, C. D. and C. D. Walshaw, 1966: The computation of infrared cooling rate in planetary atmospheres. Quart. J. Roy. Meteor. Soc., 92, 67-92.

12) Winston, J. S., W. L. Smith and H. M. Woolf, 1972: The global distribution of outgoing long-wave radiation derived from SIRS radiance measurements. Proc. of the Conference on Atmospheric Radiation, (Fort Collins, Col., 7-9 Aug. 1972), 221-227.