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Stratospheric layer thicknesses from TIROS-N SSU data

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सार — टाइरोस-एन (TIROS-N) उपग्रह में लगे समतापमण्डलीय जांच एकक (S.S.U.) के आंकड़े श्रीहरिकोटा स्थित भू-केन्द्र पर VHF संकेत ग्रहण प्रणाली द्वारा प्राप्त किये गये और उससे समतापमण्डलीय पट्टी की मोटाई की गणना की गई है जो कि उर्ध्व वायुमण्डलीय स्थिर दाब के चार्ट तैयार करने में सहायक है। यह गणना हाथ से मापक समाश्रयण गुणांक एवं समोचित अंश शोधन प्रयोग करके प्राप्त किया गया है। संगणना की विधि में पूर्व-प्रक्रम के समस्त प्रकार समोचित रूप से संयोजित किये गये हैं जिससे विधि का पूर्व रूप से सत्यापन किया जा सके। इस प्रपत्र में यह पूर्ण विधि संक्षेप में बताई गई है और कुछ आंकड़ों से संगणना भी दर्शाई गई है।

ABSTRACT. Data from Stratospheric Sounding Unit (SSU) on board TIROS-N satellite received at ISTRAC, SHAR *via* VHF telemetry has been used in a preliminary attempt to derive stratospheric layer thicknesses which are useful to generate upper air constant pressure charts. For this purpose hand calculations have been done using standard regression coefficients for two selected scan lines with proper calibration. The preprocessing aspects of demultiplexing, calibration, limb correction and earth location etc have been done manually to validate the methodology before its computerisation. Various steps involved in the retrieval of stratospheric layer thicknesses from the raw TIROS Operational Vertical Sounder (TOVS) telemetry data pertaining to SSU are briefly explained in this paper and the preliminary results obtained on two selected lines of a TIROS-N pass are presented here.

1. Introduction

TIROS-N, the first satellite on the new TIROS/NOAA satellite series carried aboard a complement of vertical sounding instruments capable of providing global coverage of vertical temperature data between the surface and the stratopause known collectivily as TIROS Operational Vertical Sounder (TOVS). The TOVS instrumentation for atmospheric sounding comprises the Stratospheric Sounding Unit (SSU), the High resolution Infrared Sounder (HIRS) and the Microwave Sounding Unit (MSU). Using the data from SSU on board TIROS-N received at ISTRAC station SHAR, an attempt has been made to derive stratospheric layer thicknesses which are useful to generate upper air constant pressure charts (NASA, 1976). Various steps involved and preliminary results obtained are briefly discussed in this paper. The stratospheric layer thicknesses derived in this paper are useful to generate upper air charts which have multiple applications, *e.g.*, determining the trajectory of constant-level balloons, and providing a data base (climatological and synoptic) for evaluating environmental effects on aerospace vehicles. In addition, such maps are also useful for verification of the performance of numerical circulation models.

2. SSU characteristics

The Stratospheric Sounding Unit (SSU) is a 3-channel infrared radiometer designed by U.K. to measure the radiance emitted by stratospheric carbon dioxide (CO_2) with the selective chopping principle. The spectral characteristics of each channel are determined by the pressure in a CO_2 gas cell in the optical path. The amount of CO_2 in the cells determines the heights of the weighting function peaks in the atmosphere. The SSU channel characteristics are given in Table 1, while the SSU instrument characteristics are shown in Table 2. The three optical channels of SSU centred at 15, 5 and 1.5 mb, each of which has a field of view of 10° diameter, view the atmosphere by way of a shared mirror. This mirror can be rotated in 10° steps to direct the fields of view through eight positions (8 spots) across the satellite's orbital track spanning $\pm 40°$ from nadir (Fig. 1).

The r.m.s. noise on the radiances in 15, 5 and 1.5 mb channels on board TIROS-N are about 0.3, 0.5 and 40° mw/m^2 sr cm^{-1} respectively. While the noise level for the 15 and 5 mb channels are well within requirements, the 1.5 mb channel developed a fault during launch of TIROS-N and has, thus, become useless (Miller *et al.* 1980).

3. SSU data processing

The SSU data on board the spacecraft is handled by a TIROS Information Processor (TIP). The TIP incorporates the spacecraft telemetry and low bit rate instrument data from SSU, HIRS, MSU, SEM and DCS, the

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TABLE 1

SSU channel characteristics

Ch. No.	Central wave No. (cm^{-1})	Wave-length (um)	Cell pres-sure (mb)	Pressure of weighting function peak (mb)	Corres-ponding height (km)	NE$\triangle T$ (mw/m^2 sr. cm^{-1})
1/25	669.988	14.926	100	15	29	0.35
2/26	669.628	14.934	35	5	37	0.70
3/27	669.357	14.940	10	1.5	45	1.75

TABLE 2

SSU instrument characteristics

Parameter	Value
Calibration	Stable black body and space background
Cross-track scan	$\pm$ 40° ($\pm$ 737 km)
Scan time	32 seconds
No. of steps/spots	8
Step angle	10°
Step time (spot dwell period)	4 seconds
Ground resolution (IFOV) (at nadir)	147.3 km
Ground resolution (IFOV) (at scan end)	244 km cross-track by 186.1 km along-track
Distance between IFOVs	210.1 km along-track at nadir
Data rate	480 bps

combined data rate being 8.32 kbs. The various steps in processing SSU data at the ground include demultiplexing, calibration, nadir correction, earth location and stratospheric layer thickness retrieval.

3.1. *Demultiplexing of SSU data*

The TIP data are output as serial digital words. There are 320 (0-319) minor frames in each TIP major frame and each TIP minor frame consists of 104 eight-bit words cycling from 0-103 which is transmitted in 0.1 seconds. Each TIP minor frame contains six 8-bit words of SSU data and each two words when taken together as one 16-bit word represent one data sample of either telemetry or radiometric data. Thus, each TIP minor frame contains 3 SSU data words.

An SSU scan is 32 seconds in duration (one TIP major frame or 320 TIP minor frames) beginning at each minor frame 0. The SSU provides a complete sampling of data every second. Recalling that each TIP minor frame is 0.1 second in duration and, that each minor frame contains three SSU data words, this provides 960 data words/scan, at a rate of 30 words/second. Each

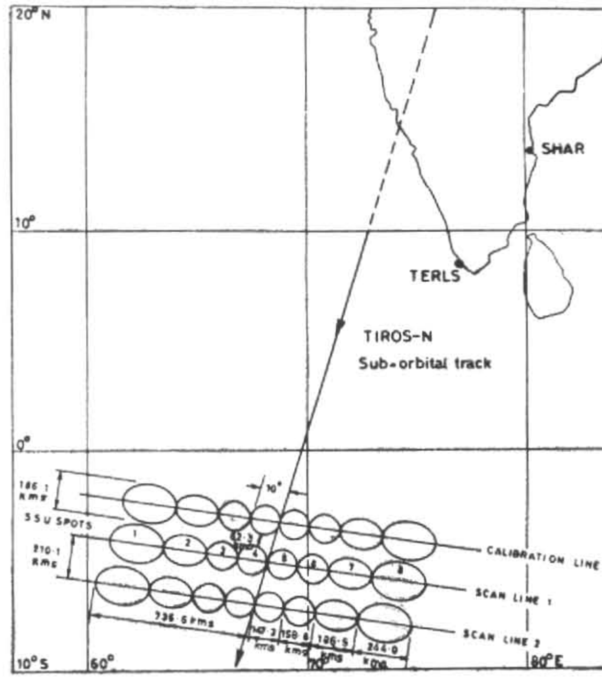

Fig. 1. A typical SSU scan pattern for TIROS-N orbit No. 15126 on 11 October 1979 at 2337 GMT from SHAR

second of data (30 words) contains two radiometric data samples for each channel.

Details reported by Lauritson *et al.* (1979) regarding location of SSU instrument data, its quality check, its arrangement according to instrument geometry and the identification of calibration/earth view data have been implemented in demultiplexing the SSU words from TIP data stream and a matrix of 32 $\times$ 30 SSU words starting with beginning of every SSU scan line has been generated. The main thrust in demultiplexing has been to put as many cross checks as possible so as to maximize usable data without allowing misplacement of data.

An SSU scan line consists of eight, 4-second earth/calibration dwell periods as shown in Fig. 1 for a typical TIROS-N pass. During each dwell period, eight radiometric data samples are taken for each channel. These eight radiometric data samples require additional processing, *i.e.*, converting them into RAMP (counts/sec) as discussed in subsection 3.2 on SSU calibration. The RAMP values of each spot (counts/sec) are then converted into radiance values using the derived calibration coefficients discussed below.

3.2. *SSU calibration*

During normal operations, the SSU instrument repeats a calibration cycle every eight lines (256 seconds). A calibration cycle consists of one line of radiometric data samples taken while the instrument views space and the internal calibration target. The remaining seven scan lines contain radiometric earth view data samples.

The SSU calibration line contains four dwell periods of space data followed by four dwell periods of internal target data. Each dwell period of the calibration line or the earth view line contains 8 radiometric data samples per channel spaced according to the following timing chart :

Samples (s)	*Time (t)*	*Sample(s)*	*Time (t)*
1	0.4 sec	5	2.4 sec
2	1.0 sec	6	3.0 sec
3	1.4 sec	7	3.4 sec
4	2.0 sec	8	4.0 sec

The accumulation of these samples over a four second dwell period produces a linear relationship between output samples (counts) and time (seconds). The slope of this line is defined as a RAMP (counts per second).

This RAMP is computed using the least square equation :

$$\text{RAMP} = \frac{8\,\Sigma\, t.s \; - \Sigma\, t\, \Sigma\, s}{8\,\Sigma\, t^2 - (\Sigma\, t)^2} \tag{1}$$

where all the summations are over the eight samples and '*s*' is the count output value from a data sample at time '*t*'. An average of the four RAMP values from the space view and an average of the four RAMP values from the internal target view are used in the calculation of calibration coefficients.

The temperature of the internal target can be calculated from the black body Platinum Resistance Thermometer (PRT) data samples of the last 12 seconds of the calibration line and during the entire 32 seconds of the other 7 scan lines, its average count value represented by $\bar{X}$. The PRT provides the most precise measure of the internal target temperature. However, should the blackbody PRT fail, the data samples from the two blackbody thermistors and the thermistor reference may be used to derive the internal target temperature by using the following equations :

(a) *Black body PRT* :

The target temperature T (K) is :

$$T(\text{K}) = a_0 + a_1 \bar{X} + a_2 \bar{X}^2 \tag{2}$$

where $a_0 = 284.1571$, $a_1 = 4.75532 \times 10^{-3}$ and $a_2 = 6.34256 \times 10^{-9}$ are the known temperature conversion coefficients, and $\bar{X}$ is the average counts of the PRT data samples obtained from the last 12 seconds of the calibration line and the entire 32 seconds of the other 7 scan lines.

(b) *Black body thermistor*

The target temperature T (K) is :

$$T\,(\text{K}) = \tfrac{1}{2}\,[(b_0 + b_1 \bar{X} + b_2 \bar{X}^2 + b_3 \bar{X}^3) + (c_0 + c_1 \bar{Y} + c_2 \bar{Y}^2 + c_3 \bar{Y}^3)] \tag{3}$$

where, $b_0 = c_0 = 375.969$, $b_1 = c_1 = -203.161$,

$b_2 = c_2 = 179.13$, $b_3 = c_3 = -85.16$

are the known constants, and $\bar{X}$, $\bar{Y}$ are the average count values of two blackbody thermistors.

The internal target temperature is converted to radiance (N_T) using Planck's equation :

$$B(v, T) = \frac{c_1\, v^3}{e^{c_2 v/T} - 1} = N_T \tag{4}$$

where, $c_1 = 1.1910659 \times 10^{-5}$ mw/m^2 sr. cm^{-4}, and $c_2 = 1.43883$ cm K are the known constants and T is the internal target temperature (°K) and v is the SSU wave number for each channel. The SSU channel gains are then calculated using the following equation :

$$G = \frac{N_{SP} - N_T}{\overline{\text{RAMP}}_{SP} - \overline{\text{RAMP}}_T} \tag{5}$$

where G is the gain of channel, N_{SP} and N_T are the radiance of space and internal target respectively and $\overline{\text{RAMP}}_{SP}$ and $\overline{\text{RAMP}}_T$ are the average ramp values for the space and the internal target views.

Channel intercepts are calculated by :

$$I = N_{SP} - G.\, \overline{\text{RAMP}}_{SP} \tag{6}$$

The gains and intercepts as computed for the SSU instrument above are then used to convert earth view radiometric samples (RAMP_E values in counts per second for each of 8 SSU spots per scan line) to calibrated radiance values (N_E) using the equation :

$$N_E = G.\, \text{RAMP}_E + I \tag{7}$$

The above calibrated radiance values N_E do not, however, include corrections for atmospheric attenuation, slant path corrections, or other atmospheric phenomenon.

3.3. *Nadir correction*

The nadir correction scheme is introduced to compensate for the upward vertical shift of the weighting functions as the radiometers scan away from a nadir view. Using historic data sample from about 1200 rocket soundings, simulated radiances are calculated at nadir and at 10° and 30° off nadir. Regression coefficients are then calculated which enable the bias offset in radiance, for a particular angle from nadir due to a vertical shift of the weighting function in a non-isothermal atmosphere, to be estimated from the values of the off nadir radiances simultaneously measured in the available channels. The lower channels cannot give a good estimate of the mean lapse rate across the higher weighting function. It is the mean lapse rate which determines the size and sign of the basis error with scan angle. The accuracy required for this correction is such that an unzoned and nonseasonally adjusted set of coefficients is adequate.

3.4. *Earth location*

The earth location of the data can be found out from the suborbital track using APT predict messages. For example, from the APT predicts we find that the orbit No. 15126 of TIROS-N has equatorial crossing time as 22 hr 36 min 37 sec (GMT) and the corresponding equatorial crossing longitude is 69.50°E in the descending node, *i.e.*, south bound pass. The APT predicts for this particular pass also show that there is about 3.5° latitude shift and about 0.9° longitude shift per minute from the equator. From this information we can find out the positions of each scan line for a particular pass. The suborbital track of TIROS-N pass, orbit No. 15126, on 11 October 1979 and the corresponding SSU scan pattern of a calibration line '0', earth view line '1' and earth view line '2' are shown in Fig. 1. The exact locations of the centres of the scan lines '0', '1' and '2' for, TIROS-N orbit No. 15126 shown in Fig. 1 are at 3.39°S, 68.63°E; 5.25°S, 68.15°E; 7.11°S, 67.67°E respectively.

TABLE 3

Stratospheric layer thicknesses in geopotential decametres (dm)

Spot No.	Layer 1 (100-20 mb)	Layer 2 (100-10 mb)	Layer 3 (100-5 mb)	Layer 4 (100-2 mb)	Layer 5 (100-1 mb)
			(a) Scan line 1		
1	1072.06	1603.84	2183.54	2971.72	3554.30
2	1063.07	1595.10	2167.96	2956.34	3540.25
3	1071.02	1600.53	2176.26	2958.88	3538.80
4	1068.25	1597.39	2173.81	2958.90	3540.44
5	1066.38	1596.65	2176.24	2967.14	3551.87
6	1064.13	1592.14	2168.44	2955.43	3538.49
7	1076.83	1610.72	2192.13	2980.54	3562.57
8	1074.89	1607.59	2187.64	2974.95	3556.69
			(b) Scan line 2		
1	1065.19	1595.00	2174.25	2965.21	3550.13
2	1059.89	1586.57	2162.39	2950.79	3535.15
3	1061.24	1589.02	2166.31	2956.28	3541.25
4	1065.52	1593.80	2169.91	2955.91	3538.28
5	1065.99	1594.98	2172.25	2959.78	3542.86
6	1059.12	1586.69	2164.66	2956.75	3543.08
7	1056.99	1583.17	2159.50	2950.13	3536.02
8	1079.19	1602.82	2182.66	2917.49	3554.52

3.5. *Stratospheric layer thicknesses retrieval*

A multichannel linear regression scheme has been used to retrieve stratopsheric layer thicknesses from the radiances similar to the method used by the British Meteorological Office. For regression coefficients we have taken the standard values used by NOAA/NASA, USA (which are used on a catalogue of about 1200 rocketsonde temperature profiles. These profiles (600 rocket profiles each with two different tie-on sondes) compiled by NOAA/NMC, USA have an even spread of summer, winter, polar and tropical profiles.

The regression coefficients used in this paper are for the tropical belt 30°N-30°S for all seasons. Using the available rocketsonde data from TERLS, Trivandrum for the period 1970-1980 we are contemplating to derive our own region specific and season specific regression coefficients for deriving stratospheric layer thicknesses over the Indian region.

4. Results and discussions

Preliminary results on stratospheric layer thicknesses derived from the SSU data recorded at ISTRAC/SHAR of a typical TIROS-N pass, orbit No. 15126 dated 11 October 1979 for each of the 8 spots of two earth view scan lines shown in Fig. 1, are presented in Table 3 (a & b). The stratospheric thicknesses in geopotential decametres have been derived for the layers 100-20 mb, 100-10 mb, 100-5 mb, 100-2 mb, 100-1 mb. Limb corrections for the off-nadir views have also been incorporated in these results.

While the radiances determined from channels 1 (or 25) and 2 (or 26) in this investigation were found to be quite stable for all the 8 spots of each SSU scan line (Fig. 1), the radiances from the chanel 3 (or 27) were found to be highly variable for 8 spots of the same scan line. This is due to the fact that the channel 3(27) on board the TIROS-N satellite started malfunctioning after the launch as also indicated by a large r.m.s. noise of 40 mw/(m^2 sr. cm^{-1}). The r.m.s. noise of channels 1(25) and 2(26) were 0.3 and 0.5 mw/(m^2 sr. cm^{-1}) well within the specified requirements. Due to the faulty channel 3(27), only two channels, *viz.*, 1(25) and 2 (26) of the SSU were used for deriving stratospheric layer thicknesses from the TIROS-N given in Table 3 (a & b). With all the three SSU channels working all right on board the NOAA-6 satellite, the accuracies of the stratospheric layer thicknesses from NOAA-6 are expected to be better than TIROS-N. If we add into these thicknesses the geopotential height of the reference level 100 mb, about 1600 dm, we get the geopotential heights of the constant pressure surfaces 20 mb, 10 mb, 5 mb, 2 mb and 1 mb. For spot 1, scan line 1, the geopotential height of the constant pressure surface of 20 mb is 2672 dm which is close to the value from literature.

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References

Campbell, J.S. and Pick, D.R., 1979, Retrieval of stratospheric data from the sounders on the TIROS-N series of operational satellites during the first year of operation, Met 019 Branch, Memo. No. 54, British Met. Office.

Houghton, J.T. and Smith, S.D., 1970, *Proc. R. Soc. Lond.*, **A 320**, 23-33.

Lauritson, L., Nelson, J. and Porto, W., 1979, Data extraction and calibration of TIROS-N/NOAA radiometers, NOAA Tech. Mem. NESS 107.

Miller, D.E., Brownscombe, J.L., Carruthers, G.P., Pick, D.R. and Stewart, K.H., 1980, Operational temperature sounding of the stratosphere, *Phil. Trans. R. Soc. Lond.*, **A296**, pp. 65-71.

NASA Special Report (NASA SP-3102), 1976, Synoptic analysis, 5.2 and 0.4 millibar surfaces for July 1973 through June 1974, A joint NOAA/NASA publication.

Quiroz, R.S. and Gelman, M.E., 1972, Direct determination of stratospheric layers from single channel satellite radiance measurements, *Mon. Weath. Rev.*, **100**, pp. 788-795.

Schwlab, A., 1978, The TIROS-N/NOAA-G series of satellites. NOAA Tech. Memo. NOAA TM NESS 95. NOAA, Wash. D.C., 75 pp.

The Middle Atmosphere Program, 1980, Proposal for Indian participation, MAP-1-1-1980 ISRO Headquarters, Bangalore.