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Comparison of total ozone retrieved from NOAA satellite and measured from Dobson spectrophotometer over Indian region

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सार — आई० एम० डी० पी० एस०, नई दिल्ली सुविधा के आई० टी० पी० पी० सॉफ्टवेयर का प्रयोग करते हुए एच० आई० आर० एस० चैनल-9 के नोआ-12 उपग्रह से पुनः पता लगाए गए सकल ओज़ोन की तुलना भारतीय नेटवर्क केन्द्रों के परम्परागत डॉब्सन स्पैक्ट्मी प्रकाशमापी से पता लगाए गए सकल ओज़ोन के साथ करने का प्रयास किया गया है। भारतीय क्षेत्र के मार्ग की मौसम की बाधा को छोड़कर डॉब्सन से मापा गया सकल ओज़ोन 8 प्रतिशत की घटबढ़ के साथ उपग्रह से पता लगाए गए सकल ओज़ोन के अनुरूप पाया गया है। यह देखा गया है कि जब कभी पश्चिमी विक्षोभ उत्तर भारत तथा उसके पड़ोसी राज्यों से गुजरता है, तब उपग्रह से पता लगाए गए सकल ओज़ोन तथा डॉब्सन से पता लगाए गए सकल ओज़ोन में घटबढ़ 8 प्रतिशत (या ±20 डी० यू०) से अधिक होती है।

ABSTRACT. An attempt has been made to compare the total ozone retrieved from HIRS channel-9 of NOAA-12 satellite using ITPP software at the facility of IMDPS, New Delhi with that of conventional Dobson spectrophotometer over Indian network stations. The satellite-retrieved total ozone agrees within an accuracy of ±8% with that of Dobson-measured total ozone except during the passage of a weather system over the Indian region. It is seen that whenever, a western disturbance is passing over north India and neighbourhood, the difference between the satellite-retrieved and Dobson-measured total ozone becomes more than ± 8% (or ±20 DU).

Key words — Ozone, Retrieve, Satellite, Dobson's spectrophotometer, NOAA, D-values.

1. Introduction

Ozone is an important atmospheric constituent between 10 and 50 km above the surface of the earth. The ozone layer in the middle atmosphere absorbs the ultraviolet rays from the sun and protects the earth from its harmful effects (WMO 1992). It also has a great influence on the stratospheric temperature and winds which are responsible for controlling the general atmospheric circulation and climate. In view of the important role played by the atmospheric ozone, accurate measurements of ozone using ground-based balloon borne, rocket borne, and satellite borne instruments are essential. Satellite measurements of total ozone started in October, 1978, by using solar back-scattered ultraviolet (SBUV) and total ozone mapping sounder (TOMS). From the TIROS-N/NOAA series of satellites, the ozone amount is retrieved using 9.6 micrometre ozone absorption band, *e. g.*, channel 9 of HIRS (High Resolution Infra-Red Spectrometer) of TOVS (TIROS Operational Vertical Sounder) on board satellite.

The NOAA-11 and NOAA-12 satellite passes over India and its adjoining areas, are being tracked regularly by India Meteorological Department (IMD). The retrieval of total ozone and other parameters, like vertical temperature and moisture profiles, is done routinely using the International TOVS Processing Package (ITPP, version 4.0, Smith W. L. *et al.* 1983), developed at the Space Science and Engineering Centre of the University of Wisconsin in Madison, U.S.A. INSAT Meteorological Data Processing System (IMDPS), New Delhi has a facility for receiving and processing HRPT (High Resolution Picture Transmission) data on VAX-3400 computer system.

The total ozone measurements are also made by IMD at four network stations using Dobson spectrophotometer at standard international hours daily. The present paper is an attempt to compare the total ozone amounts retrieved from the NOAA-12 satellite TOVS data and Dobson spectrophotometer measurements for the six months period from November 1993 to April, 1994. NOAA-11 observations were not used for comparison to avoid any ambiguity in the results. The effect of passing weather systems on the total ozone measurements/retrievals is also examined with particular reference to Delhi.

2. Principle of total ozone measurement from NOAA satellite

The following fundamental radiative transfer equation is used to retrieve the total ozone from HIRS radiance measurements in the 9.6 micrometer spectral channel :

$$R(\nu, \theta) = B(\nu, Ts)\,\tau(\nu, \theta, Ps) - \int_0^{P_s} B(\nu, T)\left(\frac{\partial \tau(\nu, \theta, p)}{\partial p}\right) dp \qquad (1)$$

where,

$R(\nu, \theta)$ = Radiance at a particular wave number ν for a zenith angle of observation θ.

$B(\nu, T)$ = Planck's function

$\tau(\nu, \theta, p)$ = Transmittance from the pressure level P to the top of the atmosphere along the observation angle θ.

The subscript 's' denotes surface values, either ground or cloud.

The ozone amount is linked to radiance to space through the transmittance $\tau(\nu, \theta, p)$. In fact, the transmittances are not known accurately as a function of profiles of atmospheric absorbing gases and vertical temperatures (Kelkar *et al.* 1993). The retrievals are thus made by solving mathematically equation (1) and from observed radiances in different spectral channels. The total ozone is retrieved from equation (1), using the following successive steps (Marshall *et al.* 1989, Xia-Lin *et al.* 1984, and Smith *et al.* 1979).

2.1. An initial ozone guess profile is selected judiciously by using regression relations between the ozone concentration and the infrared brightness temperature observations of the stratospheric CO_2 emissions from HIRS channels (1 to 4). There exists an excellent correlation between these two quantities, as the dynamic processes, which are responsible for causing warm and cold stratospheric air, also cause maxima and minima of total ozone. The coefficients for the regression relations between ozone and brightness temperatures are derived from a set of conventional ozone and temperature sounding data.

The initial ozone guess profile is suitably adjusted in shape and in the vertical position of peak ozone mixing ratio with the help of brightness temperatures calculated from guess profile and brightness temperatures obtained in the 9.6 micrometre ozone spectral band, so that the true ozone profile resembles with the guess profile. These adjustments are made using two different empirical relations for low and mid-latitude zones respectively.

From the modified ozone guess profile, the brightness temperatures are again calculated which are then used alongwith the observed brightness temperatures from 9.6 μm HIRS channel, in the following equation :

$$\frac{u(P)}{u^n(P)} = \exp\left\{ \left[T_B(\nu) - T_B^n(\nu)\right] \left[\int_0^{P_s} W^n(\nu, p)\frac{dp}{p}\right]^{-1} \right\} \qquad (2)$$

to arrive at the final estimate of the ozone amount.

where,

$u(P)$ = ozone concentration.

$u^n(p)$ = nth estimate of the ozone concentration.

$T_B(\nu)$ = brightness temperature measured.

$T_B^n(\nu)$ = brightness temperature calculated for the nth estimate of the ozone profile.

and

$$W^n(\nu, P) = \left(\frac{\partial B(\nu, T)/\partial T}{\partial B(\nu, T_B)/\partial T}\right)\left(\frac{\partial T}{\partial \ln p}\right)\left(\frac{\partial \tau(\nu, P)}{\partial \ln u^n(P)}\right) \qquad (3)$$

where other quantities have their usual meanings.

The Eqn. (2) has been mathematically derived from Eqn (1) to retrieve true ozone concentration.

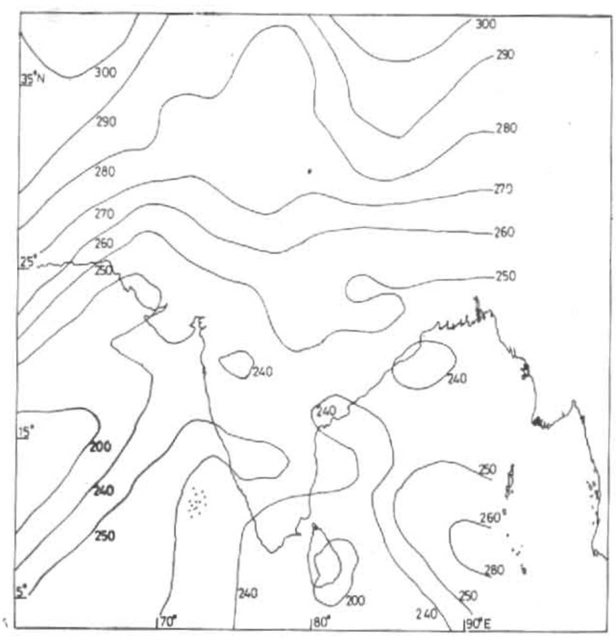


Fig. 1. A sample plot of total ozone

The Eqn. (2) is iterated till the difference between the calculated brightness temperatures and observed brightness temperatues is less than the measurement noise level (about 0.2°C).

3. Methodology

3.1. *Total ozone from Dobson spectrophotometer*

The observations of the total ozone are regularly taken from the Dobson spectrophotometer at four Indian stations. *viz.*, New Delhi. Varanasi. Pune and Kodaikanal at various hours of the day. The measurement of total ozone is made by using two different wavelengths. out of which one has maximum attenuation due to ozone layer of the atmosphere and the other wavelength remains unaffected by passing through ozone layer. The relative intensities of the two wavelengths are measured at the ground. The measure of relative intensities can be used in a mathematical formula. derived by Dobson. to find out the amount of total ozone present in the atmosphere at the location of observation. Mean values of the several total ozone observations. taken in one day are utilized in the present study. Data from all other Dobson stations is taken in a similar way.

3.2. *Total ozone from NOAA-12 satellite*

The total ozone data retrieved from ITPP package at IMDPS. for each pass of the NOAA-12 satellite is plotted by printer/plotter on a weather map (Pagano *et al.* 1993). The isopleths are drawn at an interval of 5 or 10 DU (Dobson Units) depending upon the range of the total ozone values obtained during a particular pass. The total ozone values over the four stations are. then. read from the isopleths passing over these stations or by interpolation technique in case the isopleths are not passing exactly over these stations. The plotting of ozone data is done so as to ensure the availability of total ozone values from each pass at each of the above mentioned stations. The total ozone values obtained from all the passes of NOAA-12 in one day were averaged to provide the daily means for these stations. A sample plot of total ozone taken at IMDPS facility is shown in Fig. 1.

3.3. *Comparison of total ozone amounts*

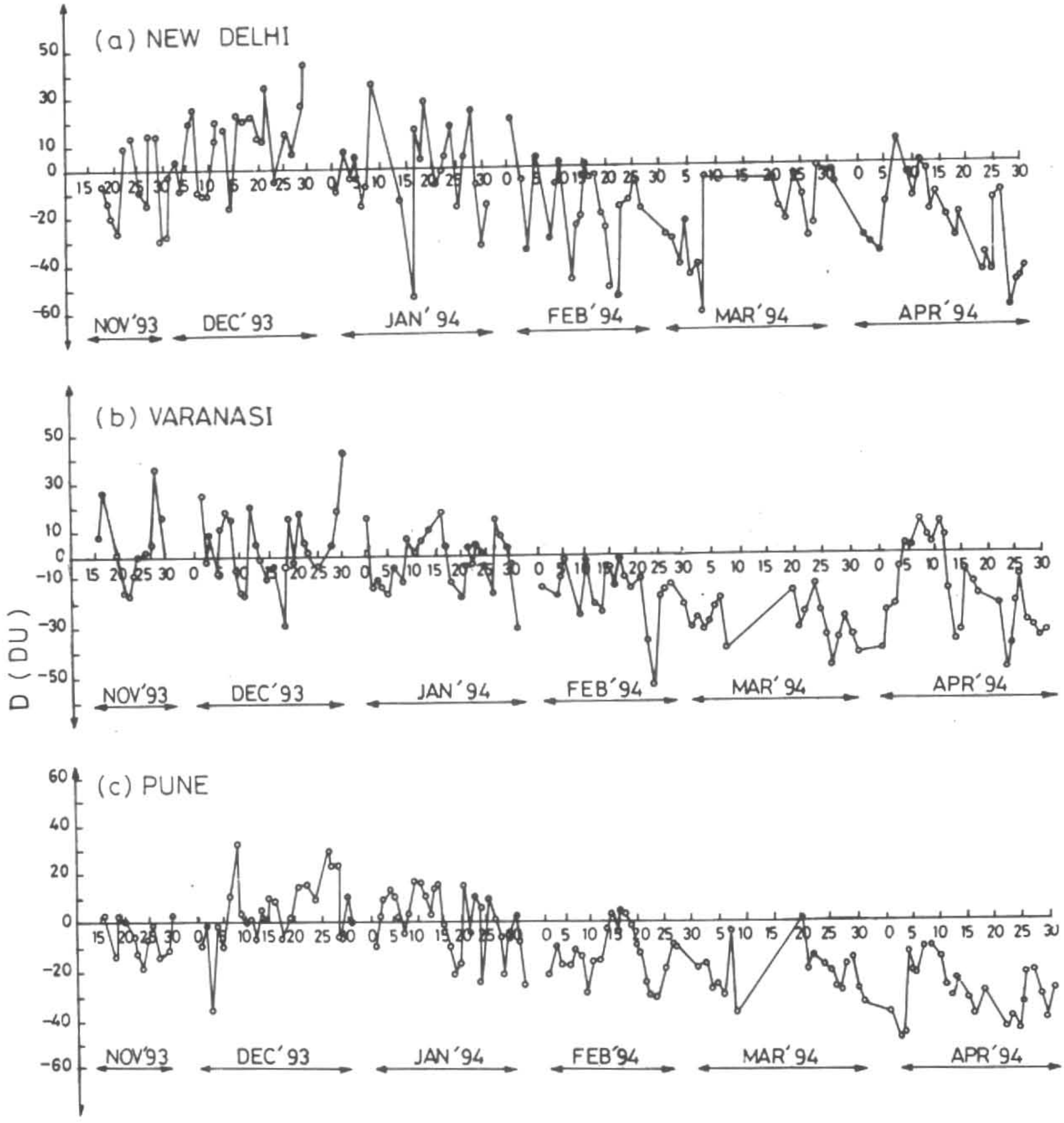
The values obtained from the two sources of data mentioned above were compared to yield difference (D) between daily means of satellite-measured total ozone and Dobson spectrophotometer total ozone. The D of total ozone was then plotted on all dates from 15 November 1993 to 30 April 1994 to depict D-curve of total ozone. Such curves for all the four network stations are shown in Figs. 2 (a-c) & Fig. 3.

4. Results

4.1. *Total ozone over New Delhi*

In the month of November 1993. the difference (D) values between satellite and Dobson-measured total ozone were more frequent on negative side with a maximum of −29 DU. On remaining occasions positive D values were observed with a maxima at +15 DU. The trend in the month of December. 1993 is reverse of November, 1993 as the differences were more frequent on positive side with a maximum at +43 DU and on remaining occasions differences were negative with a maximum of −17 DU. During January 1994, the difference values were equally distributed on the positive and negative sides showing maximum values of +36 DU and of −56 DU respectively.

During February, March and April 1994, the difference between the satellite-retrieved and Dobson-measured total ozone values were mainly on negative side having maxima at −57. −56 and −55 DU respectively.



Figs. 2 (a-c). D-curves of total Ozone for (a) New Delhi, (b) Varanasi and (c) Pune

4.2. *Total ozone over Varanasi*

During November and December 1993 and January 1994, the differences between the satellite and Dobson-measured total ozone values were equally distributed on both sides of the graph with maxima peaks at −18, +36, −30, +42, −32 and +17 DU respectively. In the months of February and March 1994, the differences were always on negative side having maxima at −56 and −46 DU. While in April 1994, this trend continued except on few occasions when it became positive. The maxima were obtained at −43 and +13 DU.

4.3. *Total ozone over Pune*

During November 1993, the differences in two methods of total ozone measurements, were more

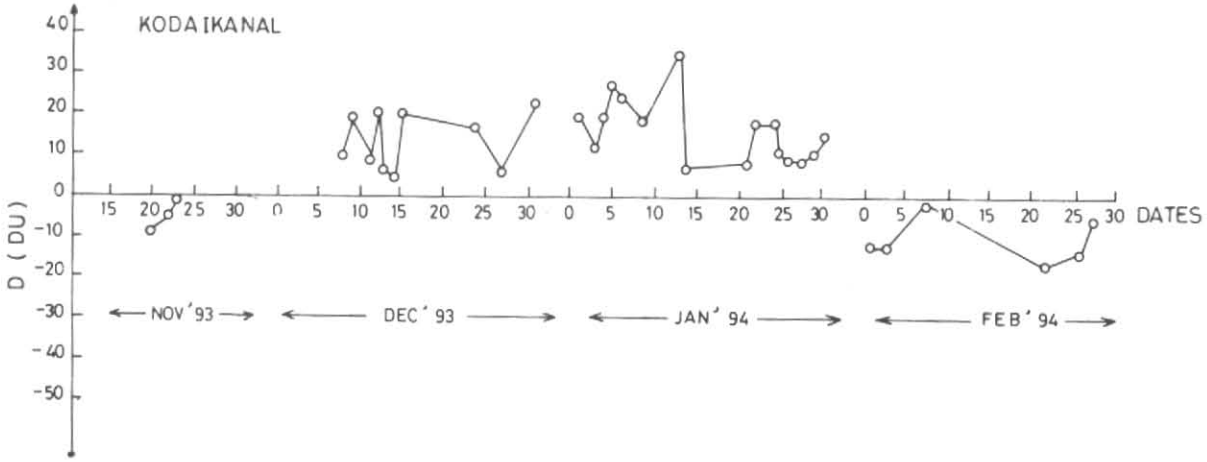


Fig. 3. D-curves of total ozone for Kodaikanal

biased towards negative side with a maximum difference of −17 DU and the positive D observed on few occasions have a maxima of +5 DU. In December 1993, the trends in differences were more frequent on positive side with peak at +33 DU, while rest had negative D values with maxima at −35 DU. During January 1994, the differences were equally distributed on both sides of the graph and had maxima at +18 and −24 DU. In the month of February 1994, the differences were more on negative side in comparison to positive side and had maxima at −31 and +5 DU respectively. During March and April 1994, the D values were always on negative side of the graph and had maxima at −34 and at −44 DU respectively.

4.4. *Total ozone over Kodaikanal*

The Dobson station at Kodaikanal has very limited observations of total ozone during the period under study as the weather was mostly cloudy. Therefore, the comparison of the satellite data with Dobson data could not be made for all days.

During November 1993, only two observations were available showing differences about −10 DU. During December 1993, on all the 9 days of observations, the difference values were positive with maxima at +22 DU. During January 1994, the D values were positve on all occasions with maximum value of +35 DU. In February 1994, the differences were opposite of January 1994 with maximum value of −17 DU. During March 1994, the Kodaikanal data were available only for seven days and the D values were negative with maximum of −23 DU. Dobson data of Kodaikanal for the month of April, 1994 was not available.

5. Discussion

It can be seen from the difference plots pertaining to four stations as shown in Figs. 2 (a-c) & Fig. 3, that total ozone values retrieved from NOAA satellite and measured by Dobson spectrophotometer are in good agreement within an accuracy of ± 8% or ± 20 DU except whenever, a weather system is passing over the region. A difference of ± 20 DU between satellite-retrieved and Dobson-measured total ozone has also been reported in WMO Report No. 18.

A study of weather summary during the period under consideration was made over north Indian region.The Table 1 contains a list of days whenever differences were higher than ± 20 DU, alongwith the associated weather systems over New Delhi as this station during winter season is mainly affected by western disturbances. It is evident from Table 1 that differences (D) higher than ± 20 DU are always associated with a passing weather system, a western disturbance or a cyclonic circulation etc.

The frequency of negative differences in the month of November, and of positive differences in the month of December, is higher over New Delhi and Pune, while in January month, the D values are equally frequent on positive as well as on negative side of the graph at New Delhi, Pune and Varanasi.

Typically, all the four ozone stations have shown positive drift during November and December

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TABLE 1

Difference in DU and associated weather systems

Station : New Delhi

Date	Difference in DU	Weather system
1993		
21 November	−26	WD over north India
30 November	−29	Do.
1 December	−27	Do.
6 December	+20	Do.
7 December	+26	Do.
12 December	+21	An U/A cycir over northwest Rajasthan
16 December	+23	Do.
17 December	+21	Do.
19 December	+22	WD over north India
22 December	+34	Cold wave conditions over north India
29 December	+26	WD over north India
30 December	+43	Do.
1994		
09 January	+36	Do.
16 January	−55	Do.
19 January	+28	Do.
28 January	+24	Do.
30 January	−33	Do.
1 February	+20	Do.
4 February	−36	Do.
9 February	−30	Do.
13 February	−50	Do.
14 February	−27	Do.
15 February	−22	Do.
19 February	−21	Do.
20 February	−27	Do.
21 February	−53	Do.
22 February	−56	Do.
27 February	−20	Do.
04 March	−22	Do.
05 March	−43	Do.
06 March	−38	Do.
07 March	−56	Do.

TABLE 1 (*Contd.*)

Date	Difference in DU	Weather system
26 March	−27	Do.
27 March	−23	Do.
01 April	−27	Do.
02 April	−30	Do.
04 April	−34	Do.
16 April	−29	Do.
17 April	−28	Do.
22 April	−41	Do.
23 April	−34	Do.
24 April	−40	Do.
27 April	−55	A cycir over Punjab & neighbourhood
28 April	−45	Do.
29 April	−44	A cycir over southwest Rajasthan
30 April	−40	Do.

WD : Western disturbance, U/A : Upper air.
DU : Dobson Units. Cycir : Cyclonic circulation.

months on more occasions and negative drift during February, March and April almost on all the days of observations. While drift is in both the directions during January, being transition month. Since the ozone distribution changes with season, more so near transition zone of 30 degrees latitude, this change in drift direction can be associated with the change of season from winter to spring. The effect of seasonal change is more pronounced in satellite data than Dobson data. At the time of constructing initial ozone guess profile, conventional ozone data and temperature profiles are used in the software programme covering Northern Hemisphere area. To construct a better guess profile, the initial input to the ITPP software requires certain changes in order to account for the change in drift direction by using more samples of conventional data over Indian region. However, the drift in both measurements became more prominent whenever any western disturbance passed over northern India, which can be attributed to the passing weather system.

6. Conclusion

Over Indian region, the total ozone retrieved from NOAA-12 satellite at IMDPS, New Delhi is within an accuracy of ± 8% of Dobson spectrophotometer measured mean values (typical 250 DU). This difference of ± 8% in mean values of total ozone is due to two different modes of measurements. The Dobson-measured value is representative of a single spot while the Physical Retrieval TOVS Package produces total ozone from HIRS radiances over a grid box of approx. 75 × 75 sq km. Another reason for difference between two methods could be due to the fact that both observations are not taken at the same timings of the day, as only daily means of total ozone values are compared. The error of ± 20 DU is also reported in WMO Report No. 18 and Li *et al.* 1991.

On the occasion of a passing weather system, the difference between the two ozone values becomes more than ± 20 DU. It seems that under the influence of moving weather system, the ozone profile gets disturbed in shape and in the position of the peak of ozone mixing ratio. Therefore, further fine tunings are required in ozone guess profile taking into consideration the presence of water vapour contents and cloudy conditions during the passage of a weather disturbance, because the HIRS channel ozone transmittance is influenced by them. The regression coefficients, which are input in the construction of the initial ozone guess profile and are derived from a set of conventional ozone and temperature profiles, may have to take into consideration the seasonal changes in weather over Indian region. Hence, the total ozone amount retrieved from NOAA-12 satellite, which in general, is less as compared to Dobson-measured total ozone amount, required suitable changes in ITPP software under disturbed weather conditions.

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