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Relation between total ozone and sub-tropical jet stream

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सार— इस शोध पत्र में कुल ओज़ोन और उपोष्ण जेट धारा (एस. टी. जे.) के मध्य संबंध की जांच की गई है। निम्बस -7 उपग्रह के कुल ओज़ोन मानचित्र स्पेक्ट्रोमीटर (टी. ओ. एम. एस.) पत्र से कुल ओज़ोन आंकड़े प्राप्त किए गए हैं। इन आंकड़ों की जांच 90°-160° पू., 20°-50° उ. के क्षेत्र अर्थात् अक्तूबर 1982 से सितम्बर 1983 तक की अवधि में पूर्वी एशियाई एस. टी. जे. के प्रवेश क्षेत्र के आंकड़ों और मौसम विज्ञान के आंकड़ों के सहयोग से की गई है।

एस. टी. जे. उष्णकटिबंधी क्षोभ सीमा (सी ए 100 hPa) और निम्न उपोष्ण क्षोभ सीमा (सी ए 200 hPa) के मध्य परिसीमा बनाती है। शीतऋतु में यह देखा गया है कि कुल ओज़ोन समोच्च रेखाएं पवन की दिशा में लगभग समानांतर होती हैं और जैसे ही पवन गति में तेजी आती है, कुल ओज़ोन की क्षैतिज प्रवणता में वृद्धि होती है।

सामान्यतः एस. टी. जे. कुल ओज़ोन में तीव्र प्रवणता का संकेत देती हैं किन्तु वसन्त ऋतु में जेट धारा के पार कभी कभी बहुत छोटे प्रवणों सहित असंगत पैटर्न देखे गए हैं। इन घटनाओं का विशेष रूप से अध्ययन किया गया है इन घटनाओं का सबंध जेट धारा के अभिध्रुव की दिशा में लगभग 150 hPa (380 के.) पर अपेक्षाकृत कम किन्तु अचल समतापमंडलीय विभव भ्रमिलता (पी. वी.) की परत के साथ होता है। इससे यह पता चलता है कि इन घटनाओं का मार्च और अप्रैल में जेट कोड के ऊपर क्षोभमंडल से समतापमंडल तक वायु के स्थानान्तरण के साथ सामंजस्य है।

ABSTRACT. This article investigates the relationship between total ozone and subtropical jet stream (STJ). Total ozone data have been obtained from the total ozone mapping spectrometer (TOMS) instrument on the Nimbus - 7 satellite and have been examined in conjunction with meteorological data in the region 90° - 160°E, 20° -50°N, *i.e.*, the entrance region of the East Asian STJ from October 1982 to September 1983.

The STJ marks the boundary between the high tropical tropopause (ca. 100hPa) and lower subtropical tropopause (ca. 200hPa). In winter it has been found that the total ozone contours are almost parallel to the wind direction, and the horizontal gradient in total ozone increases as the wind speed strengthens.

The STJ normally marks a steep gradient in total ozone but in spring anomalous patterns are seen sometimes with very small gradients across the jet. A particular study has been conducted of these events, which are associated with a layer of relatively low but still stratospheric potential vorticity (PV) at around 150 hPa (380K) on the poleward side of the jet. This appears to be consistent with a transfer of air from troposphere to stratosphere above the jet core in March and April.

Key words — Subtropical jet stream, Potential vorticity, Total ozone.

1. Introduction

Total ozone has been measured from the ground using the Dobson spectrophotometer (Dobson and Harrison; 1926) and the distribution has been obtained from such measurements.

In the tropics, day to day ozone variations are small (like seasonal variations), but in middle and higher latitudes considerable variation occur on daily and seasonal time scales. Many of these variation are linked to meteorological features (*e.g.* Dobson and Harrison, 1926; Dobson *et al.* 1929 and 1930).

The total ozone column is a good indicator of the vertical air motion due to relative change in mixing ratio with height. The mixing ratio is small (~ 0.04 ppmv/km) and nearly constant in the troposphere, but immediately above the tropopause, it increases sharply with height to a maximum (~ 0.5 ppmv/km) near around 35 km. Thus any vertical displacement of the tropopause due to convergence or divergence produces a change in total ozone.

Ozone transport from stratosphere to troposphere was confirmed with the development of fast-responding ozone sensors for aircraft during the 1970s (Danielsen, 1985). Stratosphere-troposphere exchange of ozone was confirmed by tropopause folding due to rapid cyclogenesis (Danielsen *et al.* 1987); cut-off lows in the upper troposphere are also a possible agent of this exchange (Price and Vaughan, 1993). Diabatic heating also related stratosphere - troposphere exchange. Volkmar Wirth (1995) showed that tropospheric heating with a maximum of some $10Kd^{-1}$ underneath the lowered tropopause leads to the decay of the upper level vortex within a few days. During the decay air in the vortex centre which was initially a part of the lower stratosphere gradually turns into tropospheric air. The purpose of this work is to investigate the intrusion of tropospheric air into the stratosphere associated with the STJ and link between total ozone and any such intrusion for the period October 1982 - September 1983 by means of conventional tracers such as potential temperature and potential vorticity has also been reported in the present article. The use of a tracer (ozone, potential vorticity, water vapour) is the conventional means for observing troposphere-stratosphere exchange (*e.g.*, stratospheric air can be identified in the troposphere by its large values of PV). Ozone is almost an ideal tracer for this exchange because of the conservative property of air and distinct differences of PV between troposphere and stratosphere. Below 25 km ozone is transported poleward to the cyclonic side of the subtropical jet. In the lower stratosphere the largest vertical displacement with season in the mean ozone isopleths occurs in association with the seasonal variation of tropopause position (Herring, 1966).

2. Materials used

Daily grided ozone data were obtained from the TOMS instrument on the Nimbus-7 satellite for the period from October 1982 to September 1983 in the region 90° -160°E, 20° - 50°N. Wind speeds were obtained from global analysis fields supplied by the European Centre for Medium Range Weather Forecasts (ECMWF), Reading. Values of tropopause pressure were taken from the radiosonde tropopause reports.

3. Method of Analysis

TOMS measures near local noon and the nearest synoptic hour to the ozone measurements in the sector 90° - 160°E is midnight UTC with a time displacement of 3-6 hours from the Nimbus-7 overpass. Therefore, meteorological data for the 0000 UTC were used in this comparison. Data for the period from October 1982 to September 1983, combined into monthly means, are used in this study. Daily grided TOMS data are supplied at intervals of 1° in latitudes and 1.25° in longitude. Fleig *et al.* (1986) have reported that recent updates of ozone absorption cross-sections in the Huggins bands mean that the TOMS grided ozone values supplied for 1982-1983 should be increased by about 6%. This correction applies uniformly to the entire dataset used here and therefore should not affect statistical studies.

ECMWF data provide fields of zonal and meridional wind components, geopotential height and temperature on the 850, 700, 500, 300, 200, and 100 hPa surfaces. The data are available on a 2.5° * 2.5° latitude-longitude grid. For the results described here, the zonal and meridional wind components at 200 hPa were then combined to give a vector wind at each grid point daily. (Grid TOMS data were similarly averaged over a month at each grid point and contour charts were drawn for the monthly mean field points). To identify the subtropical jet for each day, 200 hPa wind speeds were examined.

To calculate isentropic potential vorticity (IPV), the absolute vorticity (on an isentropic surface), ξ_θ, and the stability of the atmosphere, $-\delta\theta/\delta p$, were known. To calculate ξ_θ, northward and eastward wind components were first linearly interpolated with height at each grid point to the desired isentropic surface, then ξ_θ was determined (as $\delta v/\delta x - \delta u/\delta y$) at each radiosonde position by fitting a bi-cubic spline to a 4*4 array of wind components surrounding each radiosonde station using a NAG routine. The ECMWF global analysis fields have sufficient horizontal resolution to determine ξ_θ, but lack the vertical resolution for precise determination of static stability ($-\delta\theta/\delta p$). Therefore, the static stability has been calculated directly from radiosonde profiles, after detecting and removing superadiabatic lapse rate and erroneous points and then filtering the profile with a non recursive low pass filter to remove structure on scales — less than 1 km in height. The smoothing reduces contamination of the stability values by small-scale gravity wave components, although any determination of $-\delta\theta/\delta p$ relying only on single radiosonde profiles cannot guarantee freedom from wave contamination. Thus IPV was calculated by a series of calculations involving the finite differentiation, interpolation and filtering of the data.

Vertical cross-section of wind speeds and potential temperature were then constructed from radiosonde observations across the jet entrance by using great circle method. This procedure gave cross-sections at 12 hours intervals (0000 and 1200 UTC) during March 1983. Because a discrepancy has been observed in March. It has been found that the higher STJ were sometimes associated with very low gradient of total ozone. Because of this, the March results

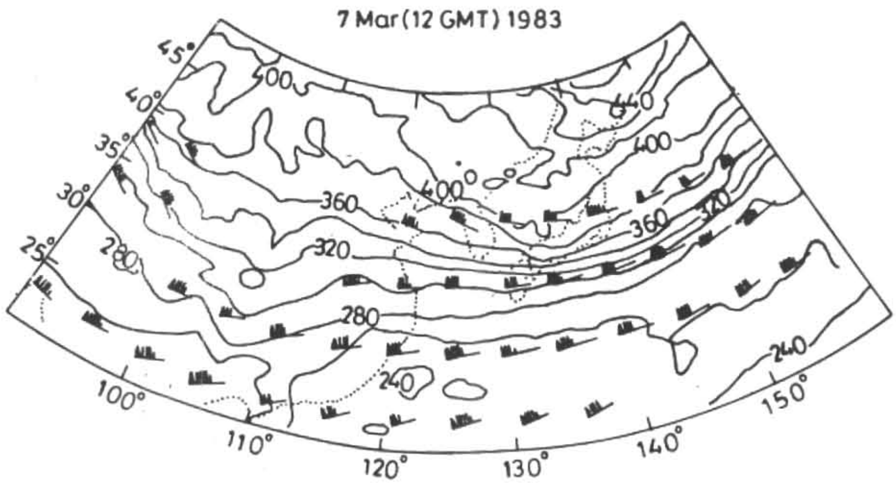

Fig. 1. Total ozone and 200 hPa winds (> 40m/s) for 7 March 1983 - an example with a steep ozone gradient across the jet

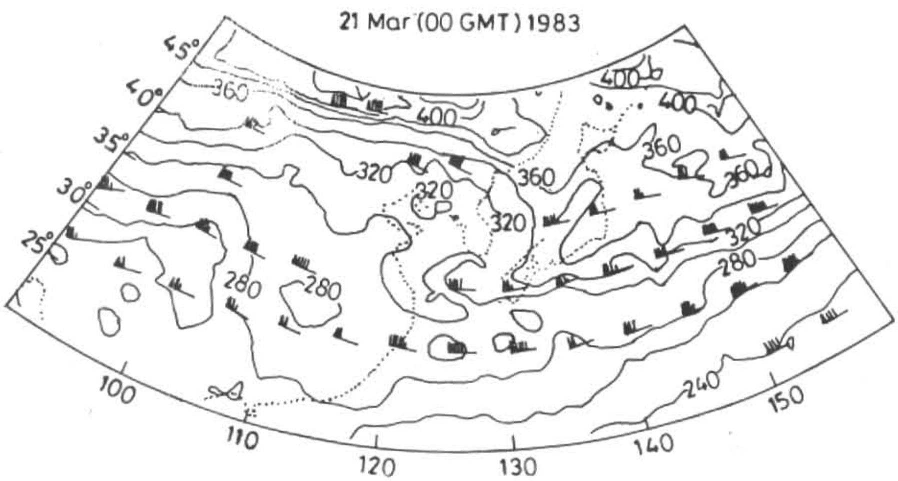

Fig. 2. As Fig. 1 for 21 March - showing a very small ozone gradient across the jet

were shown here specially to see whether there is any reason behind. Cross-sections were taken at different positions on different days because of variation in the positions of the STJ. Total ozone values were also analysed along the cross-sections.

PV and significant potential temperature variation along the tropopause are two important factors in the dynamics of the stratosphere-troposphere exchange. Hence IPVs were also calculated.

4. Results

(a) *Monthly mean total ozone contour (in DU) and 200 hPa winds*

From the monthly mean investigation of total ozone and 200 hPa wind fields, it was found that the total ozone contours are almost parallel to the wind direction in winter as the wind speed strengthens the gradient in total ozone increases. In winter and spring, a sharp gradient in total ozone is found on the cyclonic side of the STJ. This gradient of total ozone is pronounced in winter because of the strong Hadley circulation but as the Hadley cell ceases in summer, the jet weakens and horizontal gradients in total ozone become much smaller, disappearing almost entirely by the early autumn (Begum, 1993).

(b) *Jet maxima and total ozone gradient*

To find the relationship between the STJ and total ozone in section (a), an investigation was conducted to see whether the strength of the jet is related to the horizontal gradient of total ozone across it. To find the maximum wind speed and the corresponding ozone gradient, the 200 hPa wind field and total ozone data for each day of the year October 1982 - September 1983 were studied.

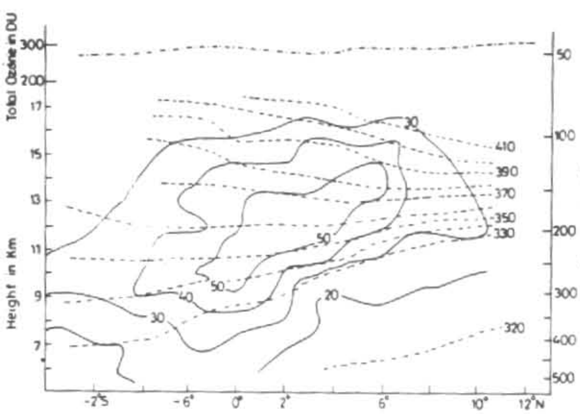

Fig. 3. Vertical cross-section from 112.5E, 27.5N to 115.0E, 40.0 N on 21 March 1983, 0000 UTC. Isentropes: dashed lines (K) isotachs: solid lines (m/s); total ozone dashed dotted line (DU)

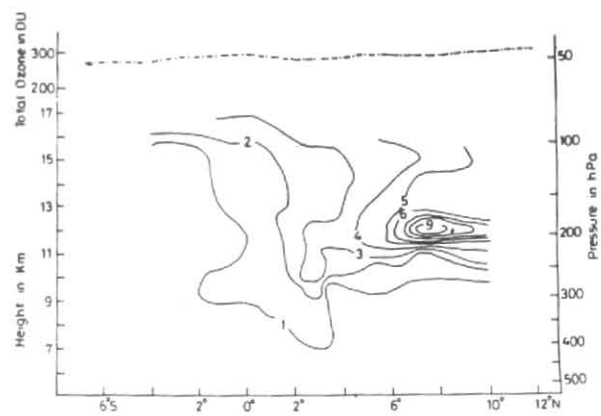

Fig. 4. Vertical cross-section showing PV isopleths (in units of 10^{-6} K m^2 kg^{-1} s^{-1}) for Fig. 3. PV : solid line; total ozone : dash dotted line (DU)

To deduce total ozone gradient accurately, a bi-cubic spline was fitted to a 6*6 array of ozone measurements surrounding the required point and the spline was evaluated at points 150 km apart either side of the maximum wind position using a NAG routine. This enabled an accurate determination of the total ozone gradient. To calculate the correlation coefficients for each month, daily pairs of maximum wind speed and total ozone gradient were combined. The results are shown in Table 1, where the correlation coefficients r>0.4 represent the significant coefficients at the 95% level or greater. For winter months (except December and February), significant correlations are found. The correlations for the summer months are insignificant probably due to the Hadley cell. The main generator of the STJ, is much weaker in this period. Thus, during the period when a strong jet is present its strength does appear to be weakly in relation with the total ozone gradient.

(c) *Spring anomaly in total ozone gradient across the STJ*

It was found that high wind speeds were nearly always accompanied by a steep gradient in total ozone (Fig. 1). In early spring one exception to this rule was observed, when the Hadley circulation (and therefore, the jet) was weakening. In the entrance region of the jet, latitudinal gradients of total ozone were often found to be very small in March (Fig. 2) and occasionally in April, although the corresponding 200 hPa wind speeds were high. These anomalously small gradients of total ozone in early spring have been further examined to see if they correspond to anomalously low IPV values in the lower stratosphere poleward of the jet (possibly indicating an intrusion of tropospheric air). Wind and temperature cross-section were studied when the latitudinal gradients of total ozone was anomalously small.

(d) *Results of cross-section analysis for March 1983*

The division between troposphere and stratosphere is observed by a change in the vertical gradient of potential temperature. A rapid change of tropopause level occurs to the north of the jet core, while to the south of the jet there is an almost uniformly high tropopause level (θ ~ 380K, P ~ 100 hPa). The values of PV in the lower stratosphere increased rapidly with height in most of the cases. Very often the layer of the strongest wind speeds sloped upward and northward on the cyclonic side of the jet. Near the jet entrance a different pattern was found, particularly in regions where the latitudinal gradient in total ozone was anomalously small. On the cyclonic side of the jet, just above the tropopause the values of PV usually increased very rapidly with height but then decreased at around 380 K for a while before increasing again (Fig. 3).

The large values of ($-\delta\theta/\delta p$) on the northward of the jet core characteristic of the stratosphere combine with relatively high absolute vorticity to give large PV. Fig. 3 shows the division of stratosphere and troposphere at a jet core by the strong horizontal wind shear near the jet. On the cyclonic side of the jet around 150 hPa, the values of ($-\delta\theta/\delta p$)are lower *i.e.* less stable with respect to the air beneath. This shows up in the PV cross-section (Fig. 4) as a horizontal layer of lower PV. In many cases, this type of feature is related with smaller gradient of total ozone along the cross-section. Another example is shown in Fig. 5, where the change of total ozone is monotonic. The distributions of wind speed and potential temperature are almost similar to Fig. 3, but there is no low PV layer found in the stratosphere. Corresponding PV chart (Fig. 6) shows that PV increases with height. Here total ozone is found to increase monotonically across the jet.

(e) *Results of cross-section analysis - layer of low PV*

For different values of the depth (difference in PV with respect to adjacent layer) the number of occurrence of layers with low PV near 380 K for different values of the depth are shown in the bar diagram (Fig. 7) for 0000 UTC and for 1200 UTC. It can be concluded that the depth of a layer is nearly limited to 4 units of PV. The number of layers deeper than

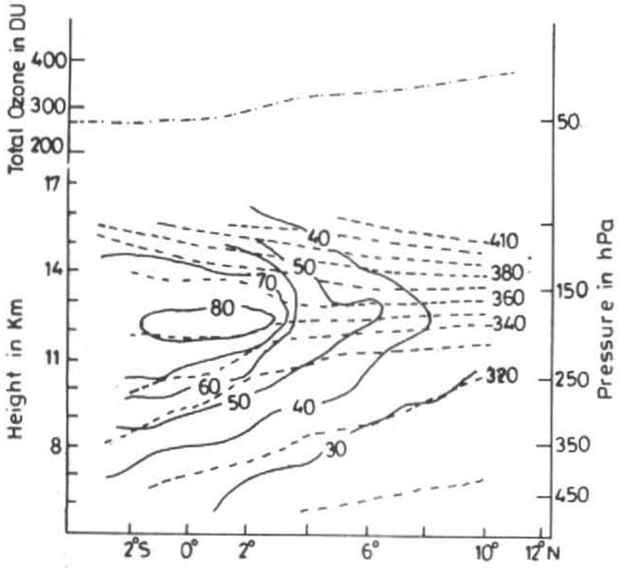

Fig. 5. Vertical cross-section from 120.0E, 27.5N to 117.0E, 37.5N on 7 March 1983, 1200 UTC. Symbols are the same as in Fig. 3 .

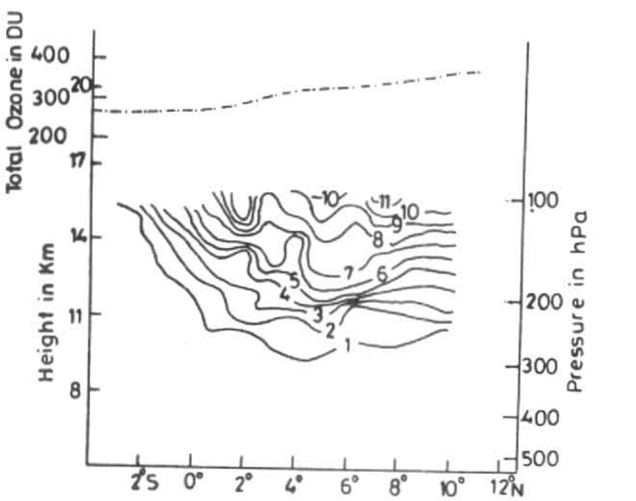

Fig. 6. Vertical cross-section as in Fig. 5, showing isopleths of PV (in units of 10^{-6} K m^2 kg^{-1} s^{-1}) and total ozone. Key as for Fig. 4.

4 PV unit is very small and a residual influence of gravity waves on the radiosonde ascents cannot be discounted in these cases. The correlation between a layer of low PV and a small latitudinal gradient in total ozone is demonstrated in the Table 2.

5. Conclusions

(*i*) From the monthly mean total ozone and 200 hPa wind fields it was found that in winter, the total ozone contours are almost parallel to the wind direction and the horizontal wind gradient in total ozone increases as the wind speed strengthens. In winter and spring a sharp gradient in total ozone is found on the cyclonic side of the STJ may be because of Hadley circulation.

(*ii*) In winter months (except December and February) significant correlation coefficients between the maximum wind speed (200 hPa) and the corresponding total ozone gradient were found.

(*iii*) In the entrance region of the jet, the latitudinal gradient of total ozone were, sometimes, very small. In contrast, the vertical change of PV was monotonic, where total ozone increased significantly across the jet.

The above evidence is consistent with notion that some air is transported into the 'midlatitude lower stratosphere' above the jet core at the entrance of the STJ, when the Hadley circulation weakens.

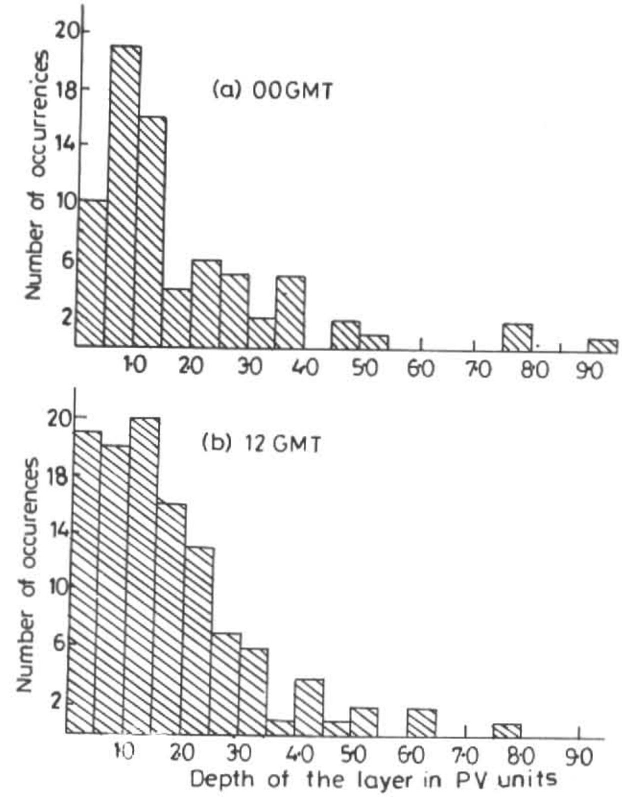

Fig. 7. Histogram showing the frequency distribution of PV layers of various depths. The depth is taken as the difference between PV in the layer and PV in adjacent layers.

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TABLE 1

Correlation between maximum wind and total ozone gradient

Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Cor. Coeff	0.70	0.44	0.02	0.47	-0.08	0.43	0.07	0.14	0.26	-0.23	0.01	0.22

TABLE 2

Coincident occurrence of layers of low PV and anomalously small total ozone gradient at jet entrance, March 1983

Day	0000 UTC		1200 UTC	
	L/N	H/S	L/N	H/S
1	N	H	-	-
3	L	S	L	S
4	N	H	L	H
5	-	-	L	H
7	N	H	N	H
8	L	H	L	H
9	L	H	-	-
10	N	H	N	H
11	L	H	L	H
12	L	S	L	H
13	L	S	L	S
14	-	-	N	S
15	L	S	L	S
16	L	S	L	S
17	L	S	L	S
18	N	S	-	-
19	N	S	-	-
21	L	S	L	S
22	L	S	-	-
24	L	S	L	S
25	L	H	L	S
26	N	H	L	S
27	L	S	L	S
28	-	-	L	S
29	N	H	-	-

In total: L:S = 21, N:S = 3, L:H = 9 & N:H = 8

L→ Layer present, N→ No layer, H → High gradient of ozone and

S → Less gradient of ozone. Note: Due to missing ozone data and lack of radiosonde observations over the region chosen for cross-section, some days are missing in Table 2.

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