A- 1.2.3 Analysis of Ozone change with ozonesonde observations at Tsukuba

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Abstract

A special campaign of ozonesonde observation was carried out at the Aerological Observatory (Tsukuba) from winter through spring to make clear the mechanism of ozone layer variation in the mid-latitudes. In the northern high latitudes a severe ozone loss was observed due to the steady polar vortex in spring of 1997. A layer with less ozone was also observed over Tsukuba when a patch of broken polar vortex passed over Tsukuba in May. Such a large ozone depletion was not found in spring of 1998 and 1999 in the northern high latitudes.

However, in 1999 a relatively large ozone decrease is observed over Tsukuba. Backward trajectory analysis proved that the cause is different from that of 1997, due to advection of air with less ozone from the low latitudes. Effects of quasi-biennial oscillation(QBO) are suggested.

Key Words Ozone change, Ozonesonde, Polar Vortex

1. Introduction

A large ozone loss is often observed in the northern high latitudes (in the polar vortex) in 1990s, presumably due to the same mechanism proceeding in the antarctic ozone hole. The Aerological Observatory (Tsukuba) has been continuing ozonesonde observation since 1968, providing valuable data showing a long-term trend. The data show that ozone over Tsukuba is decreased in the altitude range between 300 and 30 hPa. A decrease in ozone is remarkable in spring with a trend of 20 % or more per decade at 200hPa (1). Though this may be an influence of polar ozone depletion, the relation of polar and mid-latitude ozone has not been clarified yet.

2. Research Objective

Ozone in the mid-latitudes is supposed to be influenced by polar ozone variation through advection of air parcels originating in the polar vortex. In this study the process of ozone variation in the mid-latitudes is examined experimentally with ozonesonde, and analytically by various kinds of meteorological data.

3. Research Method

At the Aerological Observatory a special campaign of ozonesonde observation was carried out from winter through spring in addition to the routine observation to get ozone profile with finer time resolution. By analyzing these data coupled with other data obtained in special campaigns at Yakutsk and Hokkaido, we can examine ozone loss mechanism in the polar vortex and its influence on mid-latitude ozone.

4. Result

4.1 Ozone depletion in the northern high latitudes and its affection over Tsukuba

Figure 1 shows the daily lowest temperature at 50 hPa in the northern high latitudes in 1997-1999. In winter and spring of 1996/1997 temperature was very low because the polar vortex was steady, and low temperature below -78 ℃ (threshold for an appearance of the polar stratospheric clouds: PSCs) continued from January to March. As a consequence a severe chemical ozone destruction occurred in the polar vortex following heterogeneous reactions on the PSCs. The Total Ozone Mapping Spectrometer(TOMS) data show that total ozone in the northern high latitudes in March and April was less than the normal of 1979-1992 [2)] by 30 % or more.

By defining a region of high potential vorticity as extent of the polar vortex, we could find that the shape of polar vortex got distorted and broken in May, and one of the broken patches of high potential vorticity region moved toward Japan. When the center of one of the high potential vorticity regions approached Hokkaido on 12 May, ozonesonde observation was made at Sapporo and Tsukuba. Figure 2 shows profiles of ozone on 12 May at Sapporo and Tsukuba. Both profiles show that partial pressure of ozone at an altitude near 22 km is less than the normal with more than a standard deviation. This decrease in ozone corresponds to a passage of a region with high potential vorticity.

Figure 3 shows the result of a backward trajectory analysis that traces an air parcel backward. With this figure it is clear that the air that passed over Tsukuba between 21 and 23 km on 12 May passed through Siberia, where the polar vortex hadbeen. These facts show the evidence of an influence of chemically depleted ozone in the polar region on mid-latitude ozone.

In figure 2 another low ozone region near 15 km altitude can be seen at both stations. With a trajectory analysis it is proved that this low ozone is not transported from the polar region, but from the lower latitudes, where ozone is poor.

4.2 Ozone decrease in March 1999

In winter of 1997/1998 and 1998/1999 there was no continuous period of low temperature necessary for the formation of PSCs (figure 1). So the severe ozone depletion as in 1997 was not seen in the northern high latitudes. However, monthly mean total ozone in March 1999 over Tsukuba was the second lowest ever since the beginning of observation. This decrease is distributed over latitudinal zone of 30 degree north obviously in TOMS data (figure 4).

The ozonesonde observation over Tsukuba in March shows that ozone partial pressure is generally low at an altitude between 300-20 hPa referenced to the normal (figure 5). A similar decrease was seen at Kagoshima and Naha.

Figure 6 shows results of backward trajectory analysis that traces an air parcel at an altitude of 23 km over Tsukuba for all days in March 1998 and March 1999. While in March 1998 most air parcels moved from the latitude zone between 30 and 60 degree north, in March 1999 many parcels moved from the south of 30 degree north. The mean latitude of the position of 10 days before passing over Tsukuba is 37 degrees north for March 1998 and 31 degrees north for March 1999. All air parcels of altitudes between 5 and 27 km came from the lower latitude zone in March 1999 than in 1998. In this altitude range ozone partial pressure is generally lower in the lower latitudes. So the low ozone in March 1999 is interpreted as being due to advection of air with less ozone from the lower latitudes.

In March 1999 distinguishable phenomena are also observed in aerological data over Tsukuba. The component of south wind at 30 hPa is largest ever since the beginning of observation. Temperature is high in the troposphere and low in the stratosphere, with the lowest record at 125-40 hPa. Figure 7 shows temperature at 500 and 50 hPa, total ozone over Tsukuba, and zonal wind at 50 hPa over Singapore as an index of quasi-biennial oscillation (QBO). Total ozone and temperature at 50 hPa over Tsukuba varies in correspondence with zonal wind at 50 hPa over Singapore. The period of low total ozone over Tsukuba coincides with that of low temperature at 50 hPa and high at 500 hPa over Tsukuba, and with the period of changing from east wind to west wind over Singapore. These facts suggest that a decrease in ozone in March 1999 over Tsukuba may be induced by the QBO.

5. Discussion

For 1997-1999 the lowest temperature in the stratosphere in the northern high latitudes was examined. Among these 3 years temperature in 1997 was continuously lower than the threshold for the PSCs formation (-78 ℃) in the northern polar vortex from January through March. Simultaneously severe ozone depletion was observed in the northern polar region. This is considered to be caused by chemical ozone destruction through heterogeneous reactions on PSCs. In May 1997 a layer with less ozone was observed over Tsukuba. The air parcel in this layer was found to be transported from the polar vortex. So we can say that ozone in the mid-latitudes is influenced by chemical destruction in the polar region.

In March 1999 a layer of less ozone was found in the lower stratosphere, and its origin was found in the lower latitudes, not in the polar region. It is suggested that transport of low ozone from the lower latitudes might be a result of perturbation of circulation accompanied by the QBO. However, the mechanism of changes in circulation and its relation to mid-latitude ozone has not been clarified yet.

In conclusion ozone in the mid-latitudinal zone is affected both by the lower latitudes and the higher latitudes. More extensive research is necessary.

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2) Japan Meteorological Agency, 1998; Annual report of ozone layer monitoring: 1997.

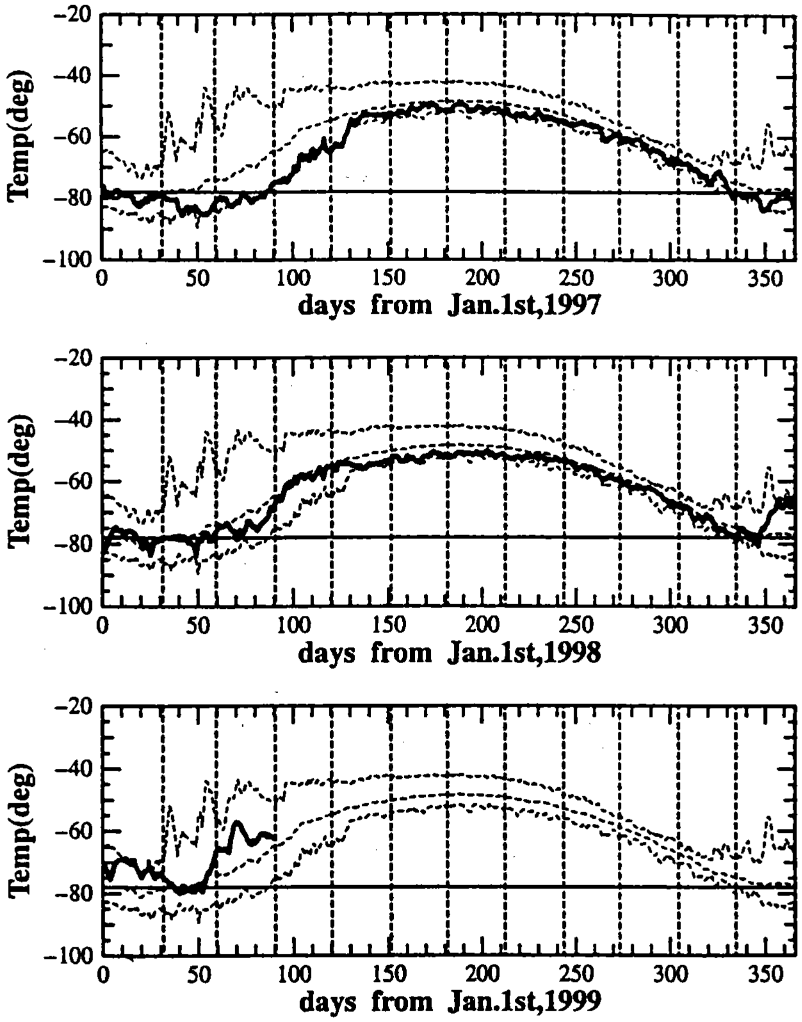

Fig.1 Time sequence of daily lowest temperature at 50 hPa in the 60-90N latitude zone in 1997,1998 and 1999. Three broken lines show the maximum, average, and minimum in the statistical period (1988-1998).

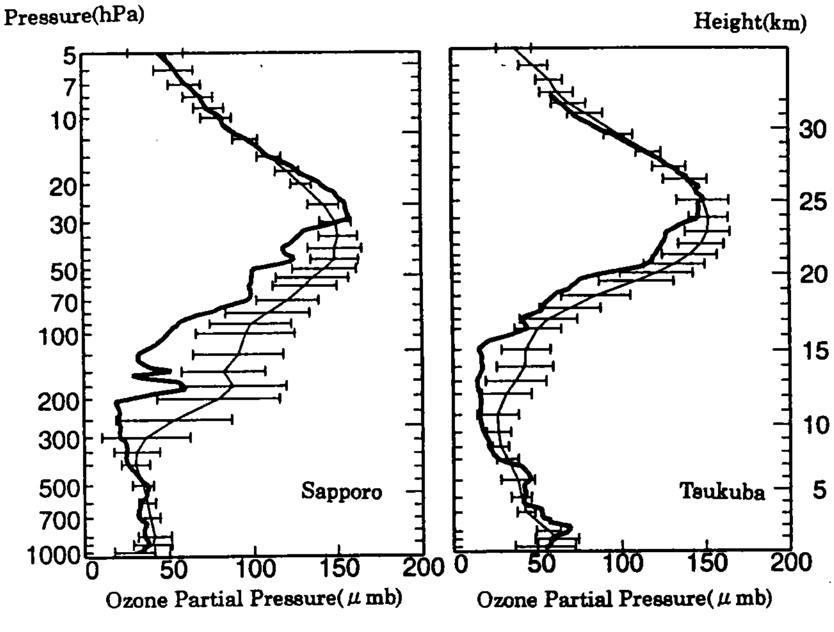

Fig.2 Vertical profiles of ozone partial pressure observed on 12 May in 1997 at Tsukuba and Sapporo. The thin lines show the normals (1968-1996) and their standard deviations.

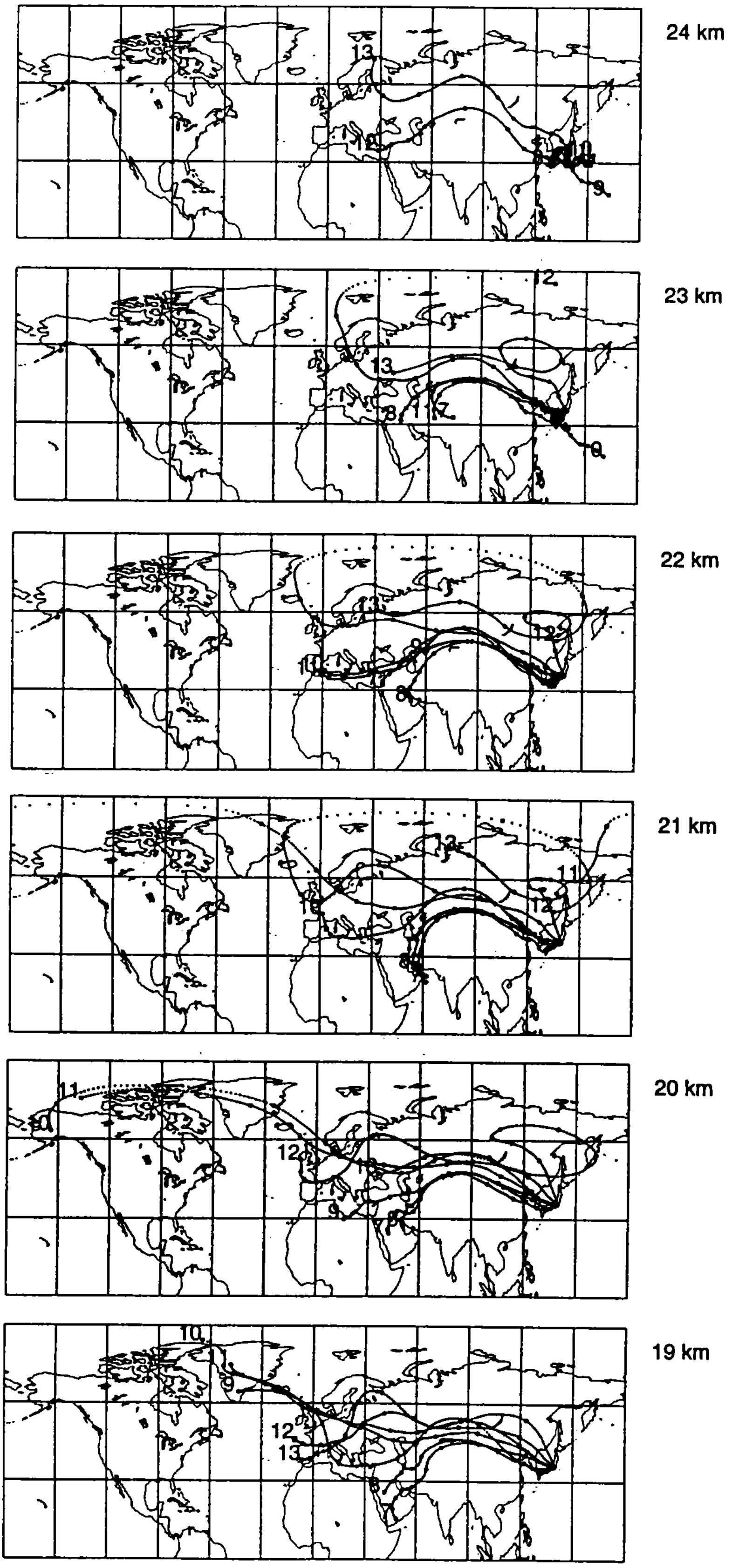

Fig.3 Ten-day backward trajectories over Tsukuba at 19-24km since 1 May to 13 May, 1997. The numbers show date of arrival at Tsukuba.

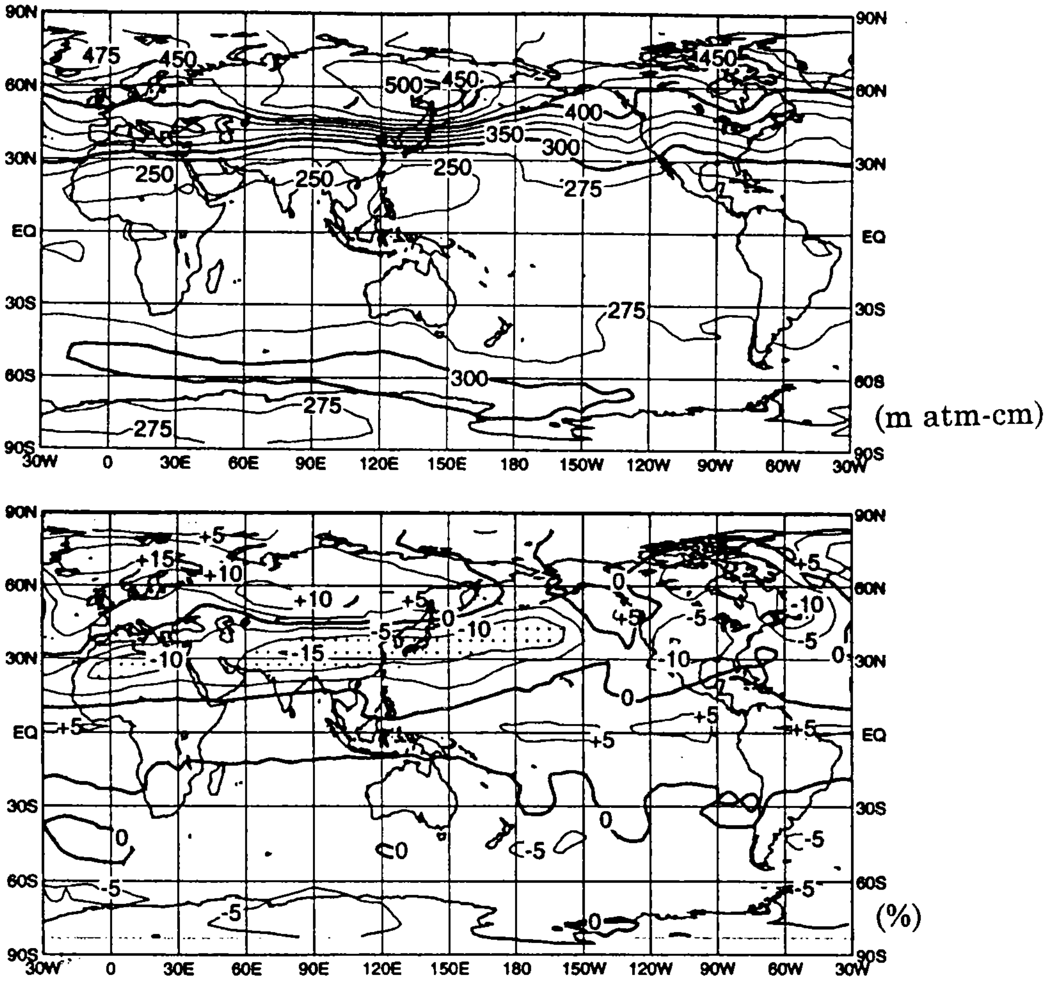

Fig.4 Monthly mean amounts of total ozone and its anomalies observed with TOMS in March 1999. The TOMS data supplied by the NASA.

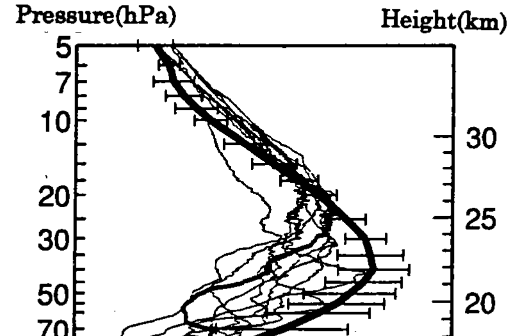

Fig.5 Vertical profiles of ozone partial pressure observed in March 1999 over Tsukuba. Thin lines : all observations; thick line :29 March ; the heavy thick line with bars: normal(1968-1996) and their standard deviations.

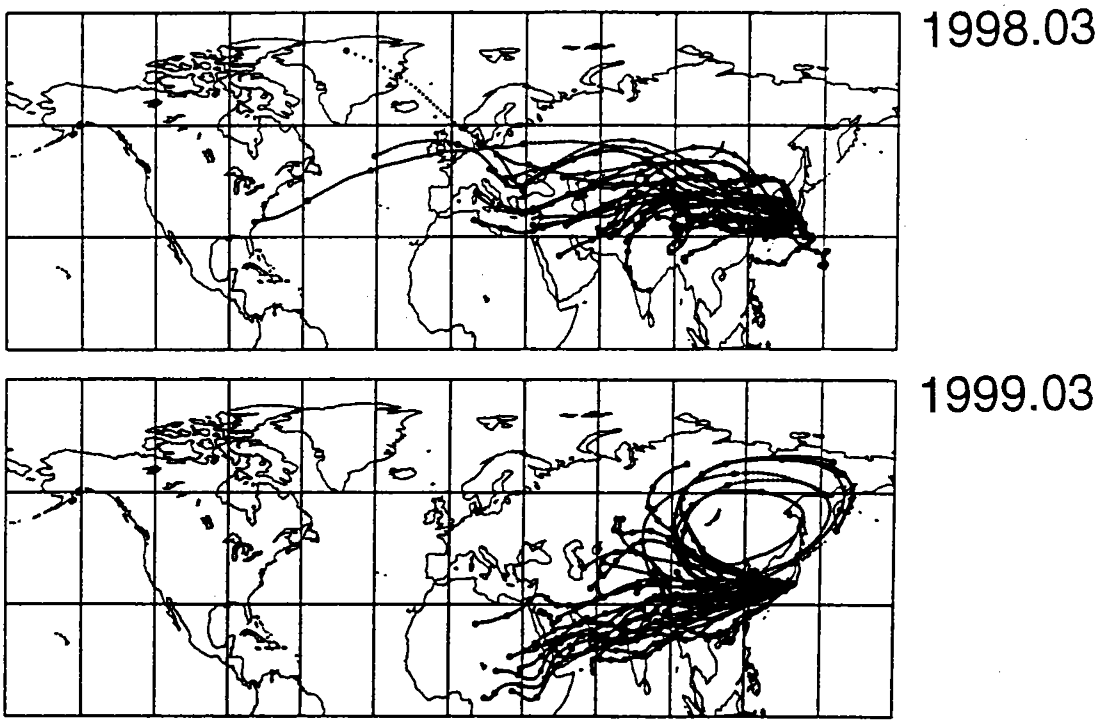

Fig.6 Ten-day backward trajectories over Tsukuba at 23km during March 1998 and March 1999.

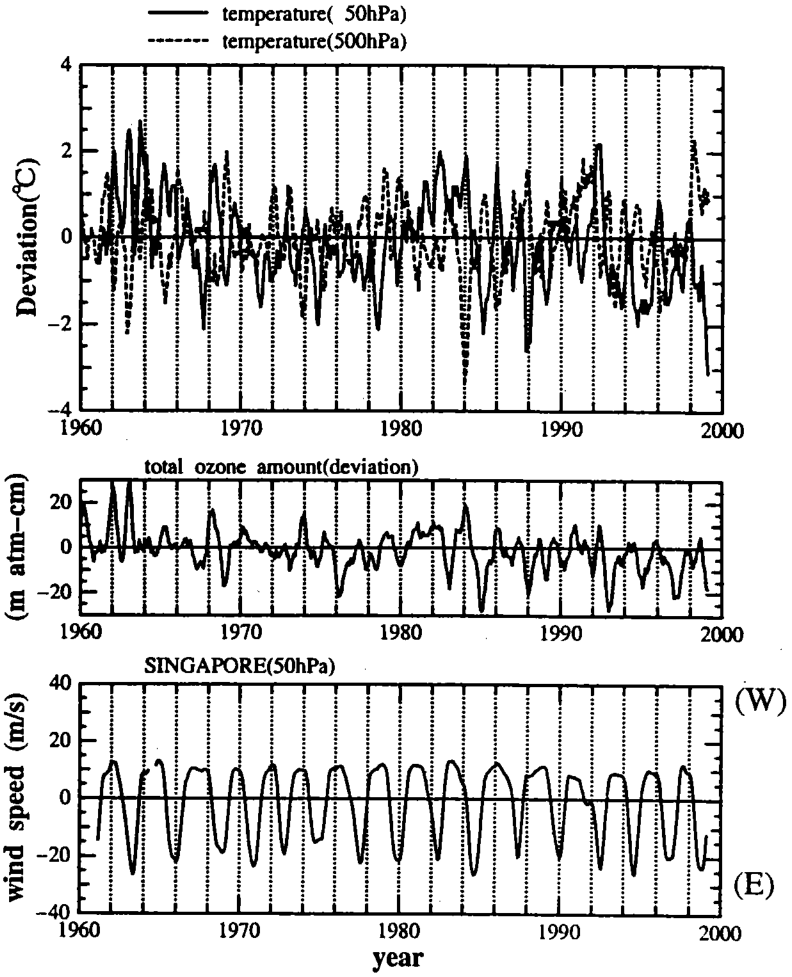

Fig.7 Time sequence of deviation of temperature at 500hPa and 50hPa over Tsukuba (upper panel), total ozone over Tsukuba (middle panel), and zonal wind at 50hPa over Singapore (lower panel). All values are 5-month running mean.

1.2.4 Effects of polar-mid latitude interactions on ozone trends

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Abstract.

As the initial stage of the study of long termed ozone trends combined with the analysis of polar vortex behavior, the deseasoned QBO model was developed. The data of 40-years NCAR/NCEP Reanalysis Project (zonal component of equatorial winds) have been treated using harmonic analysis technique.

Keywords:

QBO (Quasi-biennial Oscillations), ozone trends, polar vortex, solar activity, NCEP Reanalysis data.

The mechanism of the ozone depletion in the Arctic polar vortex is essentially same as that in the Antarctic Ozone Hole and the ozone loss rate of it is also as large as that in the Antarctic Ozone Hole (e.g. Rex et al.,1998). Therefore, the negative trend of ozone in the northern hemisphere, which is largest in winter/spring, should be affected by the ozone depletion in the Arctic polar vortex. Taking the above effects into account, we need the following procedures for trend analysis of ozone in the northern hemisphere:

(1)to remove seasonal variation,
(2) to remove the effects of the Quasi Biennial Oscillation (QBO),
(3) to remove the effects of the variation of solar activity,
(4) to choose the data affected by the polar vortex,
(5) to apply trend analysis.

We apply a multiple regression model including seasonal variation, QBO, the solar activity. A sinusoidal model for the seasonal variation and the 10.7 cm solar flux for the solar activity can be used for the multiple regression analysis. As we also need the QBO to carry out the multiple regression analysis, in this report we will show the details of QBO modeling. As to the effects of polar vortex, we used the method developed by Ninomiya and Nakane (1998).

The interannual variability of the vertical distribution of stratospheric ozone is affected by several factors among which the seasonal variations and the Quasi-biennial oscillations are dominating. The latter phenomena is closely linked with the behavior of stratospheric tropical wind, namely its zonal component. Different approaches to QBO modeling have been applied (see SPARC (1998) and the references herein), but the problem is still far from being completely investigated. In particular, it is important to separate the seasonal and QBO influence to ozone distribution.

The author was proposed to compile the model for the clean QBO-signal using the data provided by National Center for Environmental Prediction and National Center for Atmospheric Research (Kalnay E. et al.(1996)). The most comprehensive archive contains data saved on 2.5° long.×2.5° lat. grid on 17 pressure levels (including 200, 150, 100, 70, 30, 20, and 10 hPa) with 6-hr time step for 40 years period (1958—1997). The zonal component of equatorial wind over Singapore is the subject of the following analysis.

An example of the data set under discussion is shown on Fig. 1 (total of 14579 points, only daily averaging of data applied). The straight dashed line represents the trend. On the first look on the plotted time series the Fourier analysis of these data suggests itself.

Fig. 2 shows the first 100 amplitudes of discrete Fourier spectrum for these time series after prior removal of trend component (the lower plot). The maximal signal corresponds to period of about 860±30 days, or 2 years and 3--5 months, which is usually treated as the period of QBO. The second clear peak (index 40) has 364±5 days period. This is annual component.

The part of the spectrum selected to build the demonstrative QBO model is marked with red dots. Having been inversely transformed, it provides the smooth sinusoid-like curve presented (also in red) on the upper plot of fig. 2. The blue curve shows the sum of reconstructed QBO signal and the seasonal (annual and semiannual) components.

Fig. 3 allows to compare the changes of spectrum with height. Height decreasing, the QBO peak becomes smaller. The annual component remains almost the same, the semiannual one becoming more clear. Neither trend removal nor different averaging procedures do not affect these signals quality and distribution.

These results agree well with other empirical approaches to QBO modeling. For example, in Randel et al. (1995), weighted average of zonal winds with the following weights is used: 10 mbar (0.24), 15 mbar (0.51), 20 mbar (0.60), 30 mbar (0.50), 40 mbar (0.26), 50 mbar (0.04), 70 mbar (-.09). The largest weight is prescribed to 20 mbar level, seen as the largest peak on figs. 2 and 3.

We have not found references for Fourier analysis application to QBO modeling. It was possibly due to the absence of long-termed equi-spaced data. Instead, the most of researches use regression technique, as in Stolarski et al. But the information contained in Fourier spectrum is useful for both regression model design and as a final representation of the signal under study.

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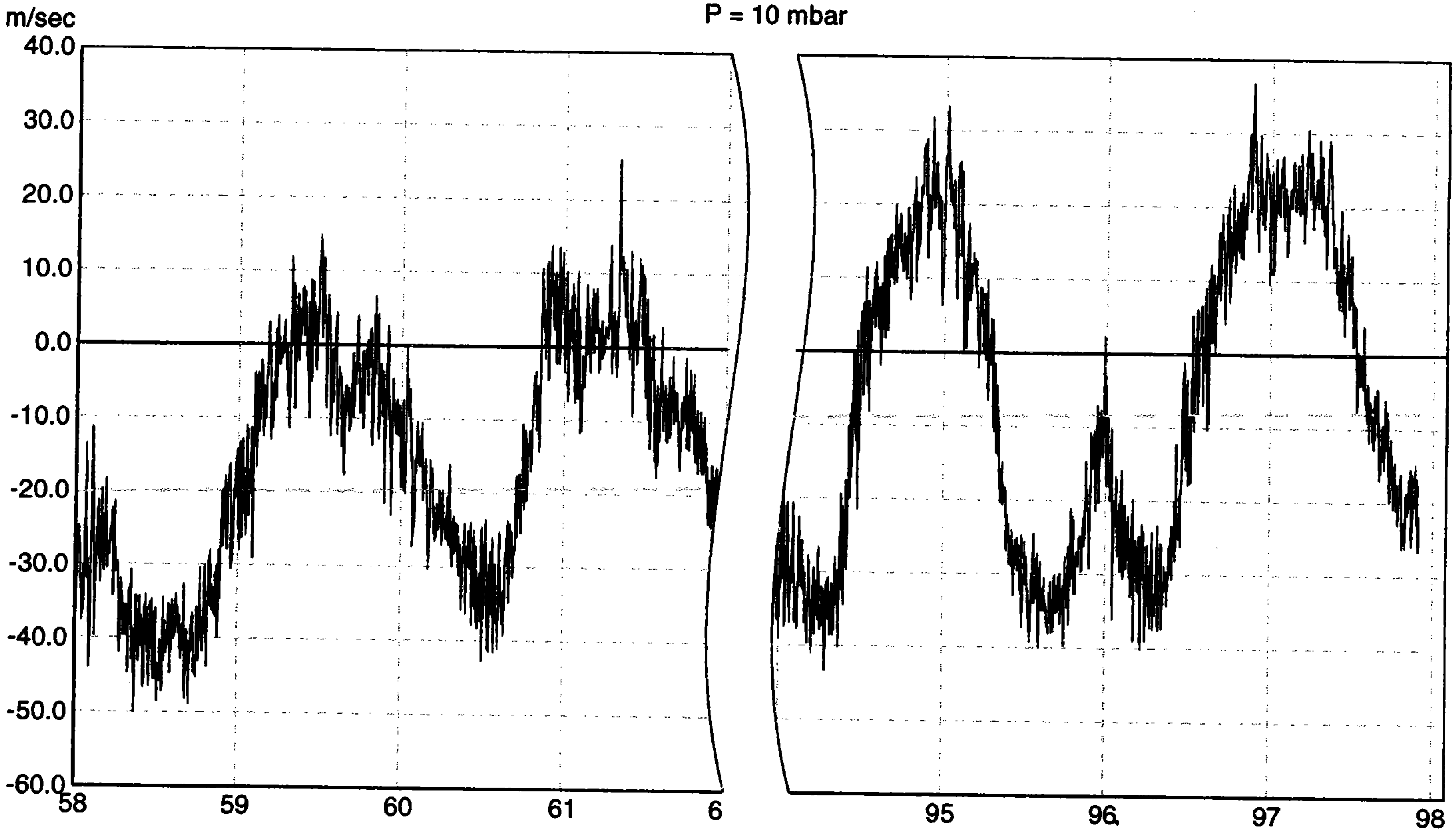
P = 10 mbar
m/sec
40.0
30.0
20.0
10.0
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
-60.0
58
59
60
61
6
95
96
97
98

Fig. 1

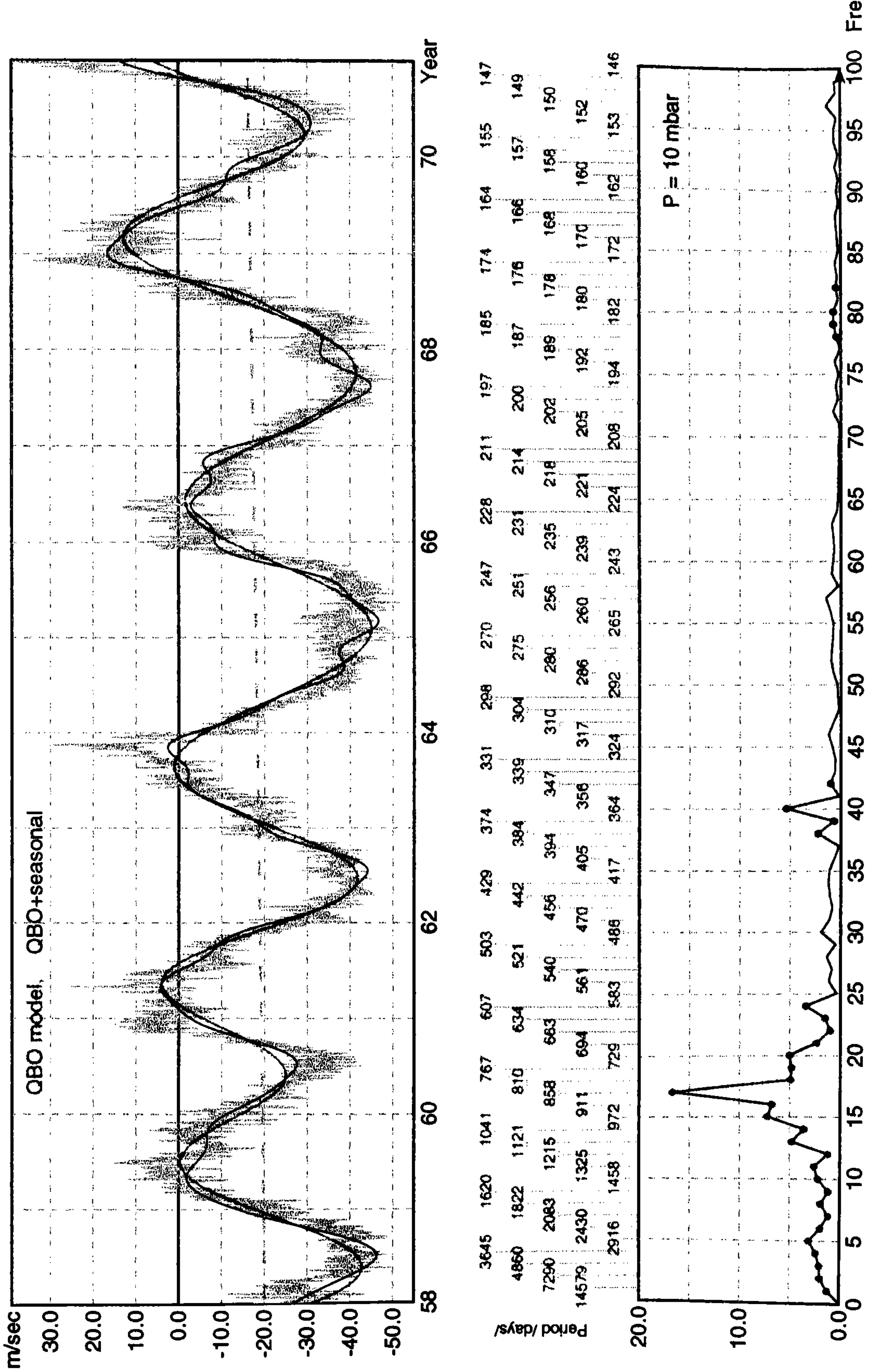
QBO model, QBO+seasonal
m/sec
30.0
20.0
10.0
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
58
60
62
64
66
68
70
Year
Period /days/
3645 1620 1041 767 607 503 429 374 331 298 270 247 228 211 197 185 174 164 155 147
4860 1822 1121 810 634 521 442 384 339 304 275 251 231 214 200 187 176 166 157 149
7290 2083 1215 858 663 540 456 394 347 310 280 256 235 218 202 189 178 168 158 150
14579 2430 1325 911 694 561 470 405 356 317 286 260 239 221 205 192 180 170 160 152
2916 1458 972 729 583 486 417 364 324 292 265 243 224 208 194 182 172 162 153 146
P = 10 mbar
20.0
10.0
0.0
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
Freq

Fig. 2

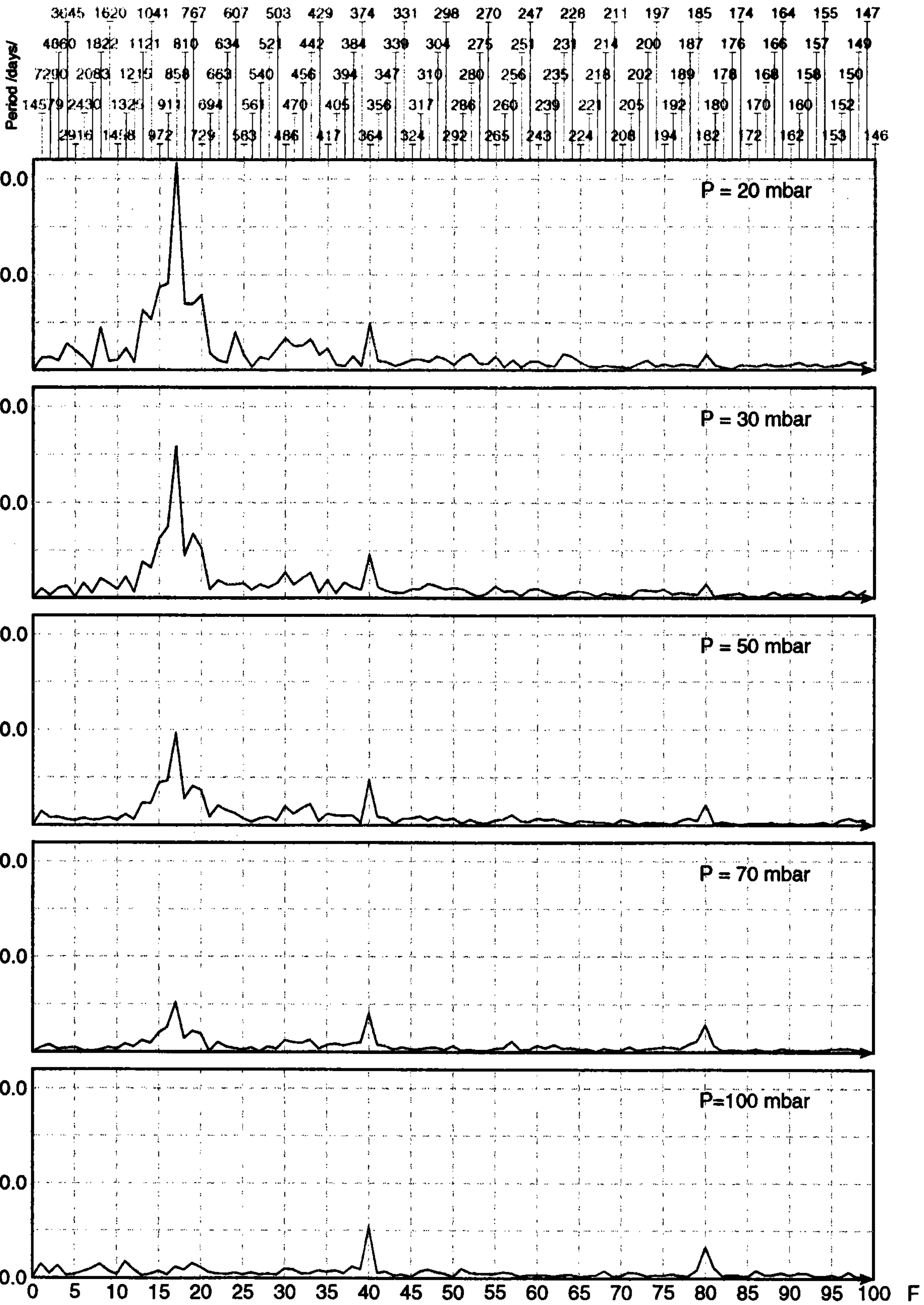
Period /days/
3645 1620 1041 767 607 503 429 374 331 298 270 247 228 211 197 185 174 164 155 147
4860 1822 1121 810 634 521 442 384 339 304 275 251 231 214 200 187 176 166 157 149
7290 2083 1215 858 663 540 456 394 347 310 280 256 235 218 202 189 178 168 158 150
14579 2430 1325 911 694 561 470 405 356 317 286 260 239 221 205 192 180 170 160 152
2916 1458 972 729 583 486 417 364 324 292 265 243 224 208 194 182 172 162 153 146
P = 20 mbar
P = 30 mbar
P = 50 mbar
P = 70 mbar
P=100 mbar
20.0
10.0
0.0
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
F

Fig. 3