CGER-M003-'93

ANNUAL REPORT ON GLOBAL ENVIRONMENTAL MONITORING

- 1993 -

Center for Global Environmental Research

National Institute for Environmental Studies
Environment Agency of Japan

Foreword

In recent decades, scientific evidence from long-term monitoring has revealed the creeping destruction of ecosystems upon which human existence depends. Recognition of this destruction is changing the international policies used to manage our planet. Vast quantities of information regarding the status of the global environment is necessary in order to achieve a solid consensus among nations for environmental policies. To detect global change early, systematic monitoring with coverage of the entire surface of the earth should be implemented under close coordination among countries and researchers from different disciplines. The resulting precise and accurate measurements should be integrated in a timely fashion into an internationally coordinated database which will be available to the decision makers.

In view of this concept, the Center for Global Environmental Research was established in 1990 and started work on monitoring, data management, modeling and their integration. CGER's field of monitoring covers the stratosphere, troposphere, fresh water, marine and terrestrial ecosystems. Groups of researchers are organized to design and conduct the monitoring. After intensive examination by these researchers, the resulting data are compiled into this report to be used in academic society as well as to serve decision makers. In 1993 two series of monitoring data reached this stage of publishing. This report contains the results of the Ozone Lidar Monitoring Program and the Japan-Korea Marine Biogeochemical Monitoring Program.

The Center for Global Environmental Research very much appreciates both the research staff of these programs for their long-term and patient measurements and the advisory members for their valuable recommendations to the staffs. Those researchers who wish to examine and utilize the raw or primary data are strongly encouraged to contact the Monitoring Section of the center.

September, 1993

Tsuguyoshi Suzuki, M.D., D.M.S.
Executive Director,
Center for Global Environmental Research
National Institute for Environmental Studies

Preface

The Center for Global Environmental Research coordinates its own monitoring projects. Each project is implemented by an executive group which consists of core researchers, technical support unit, advisory members, and data users. Core researchers are scientists of the National Institute for Environmental Studies. Initially projects are proposed by researchers and evaluated by the steering committee for global environmental monitoring. After a proposal is approved, the project is executed in three steps. The first step is a feasibility study for one year (Phase 2). The second step, a preliminary monitoring stage, lasts for three years (Phase 4). The final step, a long-term monitoring, continues for 10 to 20 years (Phase 6). When the project goes one step forward and every 5 years during Phase 6, progress is evaluated by the steering committee for global environmental monitoring. A science leader from among the core researchers is in full charge of the execution of the project. Monitoring projects should establish routine procedures during Phase 2 and Phase 4. When projects enter Phase 6, responsibility for execution is transferred to technical support unit and the science leader becomes responsible for maintaining the data quality over the long-term.

This annual report on global environmental monitoring (1993) collates the data which has been obtained through December 1991. The reliability of the data was endorsed by a subcommittee organized by the core researchers and the secretariat of the CGER Monitoring Section. Data quality assurance takes about one and a half years. The data will be made available to the public in the annual report as soon as the data quality is assured.

September, 1993

N. Furuta

Naoki Furuta, D.Sc.
Research Program Manager
Center for Global Environmental Research
National Institute for Environmental Studies

Secretariat of Monitoring Section:

Research Programme Manager*	Naoki Furuta, D.Sc.
Chief Administrator**	Yoshiyuki Yoichi
Administrator***	Kenji Fukuzawa

Editing members:

Editor-in-chief	Naoki Furuta, D.Sc.
Assistant	Kikue Oguri

Mailing address:

Monitoring Section
Center for Global Environmental Research
National Institute for Environmental Studies

16-2, Onogawa, Tsukuba, Ibaraki 305, Japan
Telephone: +81-298-51-6111 Ext. 377 or 374
Facsimile: +81-298-58-2645

*	~ 1990 - 1991	Gen Inoue, D.Sc.
*	1991 - 1992	Takashi Uehiro, D.Sc.
**	~ 1990 - 1993	Shin-ichi Araki
***	~ 1990 - 1992	Takao Ohashi

Contents

1. Ozone Lidar Monitoring

Hideaki Nakane, Sachiko Hayashida, Nobuo Sugimoto, Ichiro Matsui, and Yasuhiro Sasano

Global Environment Research Division, Atmospheric Environment Division, and
Center for Global Environmental Research,
National Institute for Environmental Studies
16-2, Onogawa, Tsukuba, Ibaraki 305, Japan

An ozone lidar system was installed at the National Institute for Environmental Studies (36°N, 140°E) in March, 1988 and observation of ozone profiles commenced from August 1988. The lidar system consists of XeCl, XeF and KrF excimer lasers, 2 m and 56 cm telescope optics and data processing systems. Since the Ozone Lidar Monitoring Program of the Center for the Environmental Research started in October 1990, frequent measurements (more than 50 times per year) have been made. After checking the statistical and systematic errors, the ozone profiles were archived. Comparisons between the lidar data and SAGE II satellite data were done for mutual validation and gave good results. Seventy four vertical profiles of ozone archived for the period from August 1990 through December 1991 are presented in this report. The seasonal and altitudinal variations of stratospheric ozone distribution can be explained by generally understood transport and photochemical reaction processes. Longer term monitoring is required to detect trends in the vertical profile of ozone.

1.1 Background

The ozone layer plays important roles in the atmosphere. Solar ultra-violet radiation, which is harmful to plants and animals, including humans is absorbed in the ozone layer. The second important role of the ozone layer is a heat or energy source in the stratosphere and the mesosphere (middle atmosphere). The temperature profile and general circulation in the middle atmosphere should be influenced by changes in the ozone layer. Ozone also exhibits greenhouse effects in both the troposphere and the lower stratosphere. Thus, variations in the ozone layer will influence life directly and/or indirectly.

Though natural variations of ozone are very large and important, trends could occur in the total column ozone and/or the vertical profile of ozone. Since the 1970s, it has been postulated that chlorofluorocarbons (CFCs) and halons could deplete stratospheric ozone. However, discerning the influence of those manmade pollutants has proven difficult. Studies on the ozone hole and the report of "The International Ozone Trends Panel 1988" provided for the first time evidence of the possibility of irreversible changes in the ozone layer caused by anthropogenic substances. Efforts to assess trend in the ozone layer have continued, and the most recent results were reported in the "Scientific Assessment of Ozone Depletion: 1991" (WMO, 1992), (Table 1).

Table 1 Total ozone trends in percent per decade with 95% confidence limits (WMO, 1992)

Season	TOMS:1979 - 91 45°S	Equator	45°N	Ground-based:26°N - 64°N 1979-1991	1970-1991
Dec-Mar	-5.2±1.5	+0.3±4.5	-5.6±3.5	-4.7±0.9	-2.7±0.7
May-Aug	-6.2±3.0	+0.1±5.2	-2.9±2.1	-3.3±1.2	-1.3±0.4
Sep-Nov	-4.4±3.2	+0.3±5.0	-1.7±1.9	-1.2±1.6	-1.2±0.6

Trends of the vertical profile of ozone are much more difficult to estimate and discrepancies remain among the measurement methods used. The reported assessment of ozone profile trends is shown in Fig. 1.

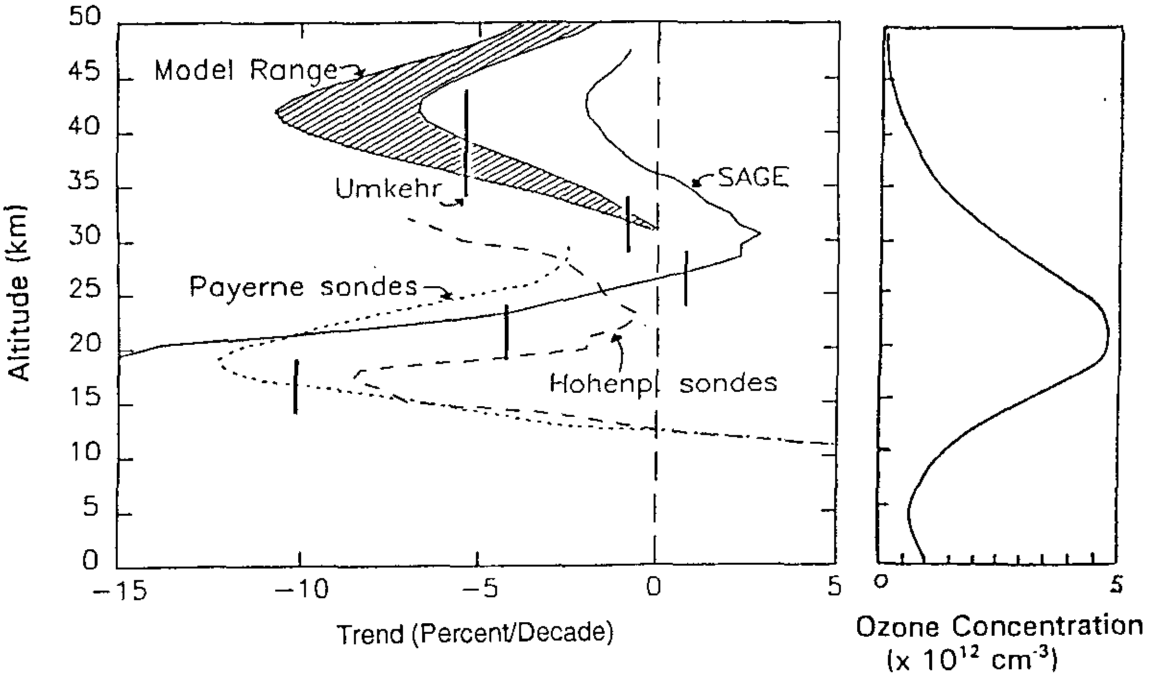

Fig. 1 Comparison of ozone profile trends estimated from several different measurement systems (WMO, 1992)

1.2 Network for the Detection of Stratospheric Change (NDSC)

The data used in the reports of the assessment panels mentioned above were obtained by the Global Ozone Observing System (GO3OS), organized by the World Meteorological Organization (WMO), and/or by such satellite sensors as the Total Ozone Mapping Spectrometer (TOMS) and the Stratospheric Aerosol and Gas Experiment (SAGE). Another network for observing the ozone layer with high technology instruments has been developed recently. This is the "Network for the Detection of Stratospheric Change" (NDSC), which consists of a set of high-quality, ground-based, remote-sensing research stations that will observe ozone, key ozone-related chemical compounds and other parameters, such as temperature. Instruments recommended, chemical species and parameters to be measured are shown in Table 2. The "primary stations" of the NDSC are located so as to cover the globe latitudinally, as shown in Table 3.

It is well-known that the longitudinal distribution of ozone and ozone trends are not homogeneous. As a consequence, secondary or complementary station are required to extend the network longitudinally. This is one reason that the NDSC called for complementary measurements. Deployment of the secondary or complementary stations was also recommended in the "International Implementation Plan" of the "Stratospheric Processes and their Role in Climate (SPARC)", project of the World Climate Research Program (WCRP). They are especially required in the Asia-West-Pacific Region, where the Japanese station is the only candidate for the NDSC type station. Efforts to develop the NDSC instruments and to deploy stations in Japan are therefore important. In this context, the "NDSC Workshop in Japan", attended by both the Chairman and Vice-chairman of the NDSC Steering Committee, was held on November 19, 1992, at the National Institute for Environmental Studies (NIES).

Table 2 NDSC instruments and species to be measured (from NDSC brochure, 1992)

Species	Altitude Range	Instrument
O_3 column	total column	Dobson, Brewer, UV/visible spectrometers
O_3 Profile	0 - 20 km 15 - 45 km 25 - 75 km	YAG lidar excimer lidar microwave
temperature	0 - 45 km	lidar
ClO	25 - 45 km	microwave
H_2O	0 - 30 km	balloon hygrometer
	>20 km	microwave
aerosols	0 - 30 km	lidar
NO_2	stratospheric column	UV/visible spectrometers
HCl	stratospheric column	Fourier transform infrared spectrometer (FTIR)
CH_4	stratospheric column	FTIR
N_2O	20 - 50 km	microwave, FTIR
HNO_3	stratospheric column	FTIR
$ClONO_2$	stratospheric column	FTIR
OH	40 - 60 km	UV fluorescence excimer lidar
HO_2	30 - 60 km	microwave

Table 3 NDSC primary stations (from NDSC brochure, 1992)

1. Arctic station: Eureka (80°N, 86°W), Thule (76°N, 69°W), Ny Ålesund (78.5°N ,12°E).

2. Alpine station: Observatoire de Haute Prvence (44°N, 6°E), Jungfraujoch (46°N, 7°E), Plateau de Bure (44°N, 6°E).

3. Mauna Loa and Mauna Kea (20°N, 155°W)

4. Lauder, New Zealand (45°S, 170°E)

5. Antarctic station: Dome C (74.5°S, 124°E), beginning in 1995. Interim sites at McMurdo (77.8°S, 166°E) and Dumont D'Urville (67°S, 140°E).

1.3 Ozone Lidar at the National Institute for Environmental Studies (NIES)

Lidars (Laser Radars) play important roles in NDSC, since they are expected to measure vertical profiles of ozone, aerosols and temperature with both the high accuracy and good height resolution. NIES has been developing various lidars since the 1970s. Among others these include a scanning lidar with a 1.5 m telescope to measure horizontal and vertical distributions of aerosols, a small lidar to measure mixed layer height, mainly in the urban areas, a differential absorption lidar (DIAL) to measure the vertical profiles of nitrogen dioxide, and a three-wavelengths lidar to obtain precise information about aerosol profiles.

In March 1988, NIES installed an ozone lidar (DIAL) system to measure the ozone profiles from the troposphere to the upper stratosphere (~45 km). Observations have been conducted since August 1988, and quality-checked data archived. In this report, the NIES ozone lidar, data processing, the data obtained, and variations of ozone are described.

1.4 Principle of Ozone Lidar

The absorption cross-section of ozone changes drastically around 300 nm. A laser beam emitted from the ground can hardly reach the stratosphere when the wavelength is shorter than 290 nm. When the wavelength of the laser beam is 308 nm, it is mildly absorbed by ozone and can reach the upper stratosphere. Absorption by ozone is negligible around 350 nm. An ozone lidar emits two pulsed laser beams, one of which is absorbed by ozone and the other not and receives the scattered light due to air molecules and aerosols with a telescope. The height at which the laser beam is scattered by air molecules and aerosols is calculated using the time delay between the emission of the laser pulse and the receipt of the scattered light. If the scattering due to aerosols can be ignored, the signal intensity of the unabsorbed (off-resonant) light (e.g. 351 nm) decreases gradually with altitude and that of the absorbed (on-resonant) one (e.g. 308 nm) decreases more rapidly where ozone density is high. The vertical profile of ozone can be calculated by comparing the two signals (Fig. 2).

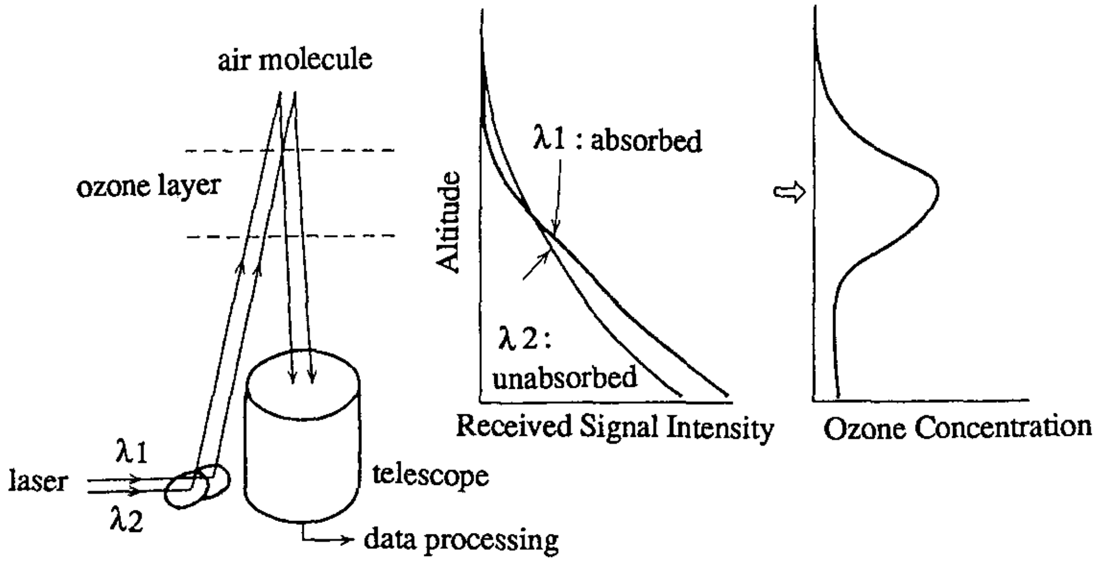

Fig. 2 Principles of ozone lidar

Since this calculation is very simple and the height of the ozone is determined directly, in principle the lidar measurement is highly accurate. The main source of the systematic errors is backscattering and extinction due to aerosols. Additional laser light with a different wavelength could correct for the systematic errors due to aerosols, the effects of which are usually negligible above 30 km.

1.5 Hardware of NIES ozone lidar system

The NIES ozone lidar system consists of two subsystems; a high altitude system (HA system) and a low altitude system (LA system). Because the validated data at present are obtained by the HA system at present, this system is described here. Table 4 shows the specifications of the lidar system and Fig. 3 is a block diagram of it (Sugimoto *et al.*, 1989). An injection-locked XeCl excimer laser (Lambda Physik EMG160TMSC) is used as the light source for the on-resonant wavelength (308 nm). Another injection-locked excimer laser, a XeF laser, emits the light with the off-resonant wavelength (351 nm). A Raman shifter with deuterium generates another off-resonant 339 nm laser beam from the 308 nm laser beam. The intensity of the 339 nm radiation is adjusted by the pressure of the deuterium to give comparable signal intensity to that of 308 nm at an altitude of about 40 km.

Table 4 Specification of ozone lidar

Transmitter			
laser	XeF excimer laser	XeCl excimer laser with deuterium Raman shifter	
wavelengths	351 nm	308 nm	339 nm
output energy	75 mJ	140 mJ	adjustable
pulse repetition rate	250 Hz (maximum)	94 Hz (typical)	
beam divergence	0.07 mrad	0.07 mrad	
Receiver			
telescope diameter		2 m	
field of view		0.6 mrad (typical)	
filter bandwidth	2 nm	2 nm	2 nm
total optical efficiency	<20%	<10%	<20%
chopper		750 Hz	
Detector			
photomultipliers	Hamamatsu R3235 (6 channels)		
gate width	1-200 μs		
preamplifiers	100 MHz		
Signal processor			
photon counters	1μs gate time, 2048 segments (6 channels)		
Data processor	PDP 11/53		

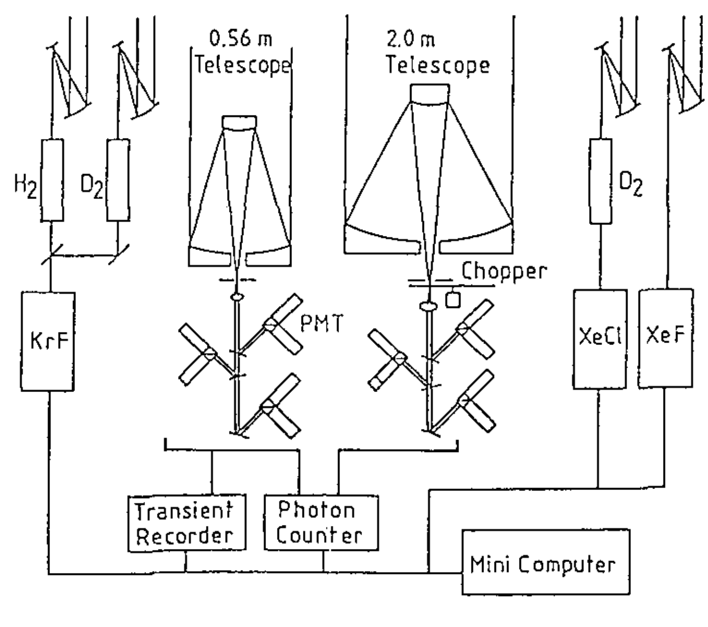

Fig. 3 Block diagram of the ozone lidar (Sugimoto *et al.*, 1989)

The Raman shifter has a convex lens with a 60 cm focal length at the entrance and a flat window at the exit. The diverging beam from the Raman shifter is collimated with an off-axis parabolic mirror with a 2 m focal length. A concave lens is used for the XeF laser beam and a similar off-axis parabolic mirror collimates the diverging beam. In this way, the two laser beams with three wavelengths are expanded 3.3 times. The directions of these beams transmitted are the same for 308 nm and 339 nm. The direction of these beams and that for 351 nm can be independently adjusted. Therefore, the alignment of the laser beams can be checked by comparing the 339 nm signal and 351 nm signal, when the effects of aerosols are negligible.

The backscattered light is collected by the 2 m telescope and then focused on a chopper blade for cutting the strong light scattered at the lower altitudes. The lenses just before and after the chopper were formerly single plano-convex lenses, but in June 1990 those were replaced by achromatic lenses. This improvement produced better alignment and higher accuracy, especially in the lower altitude region. Dichroic mirrors, color glass filters and interference filters are used for wavelength separation. Beams separated are then divided by beam splitters (ratio: 95 to 5 %). The signals from the 95% and 5% channels are called high sensitivity (HS) and low sensitivity (LS) channels, respectively. The signals of the HS and LS channels are combined to make signals with a larger dynamic range. The split beams are finally focused on the photomultipliers (Hamamatsu R3235) with electrical gates and pre-amplifiers. Signals are processed with the discriminators, photon-counters and a minicomputer (PDP 11/53). Typical signals obtained are shown in Fig. 4.

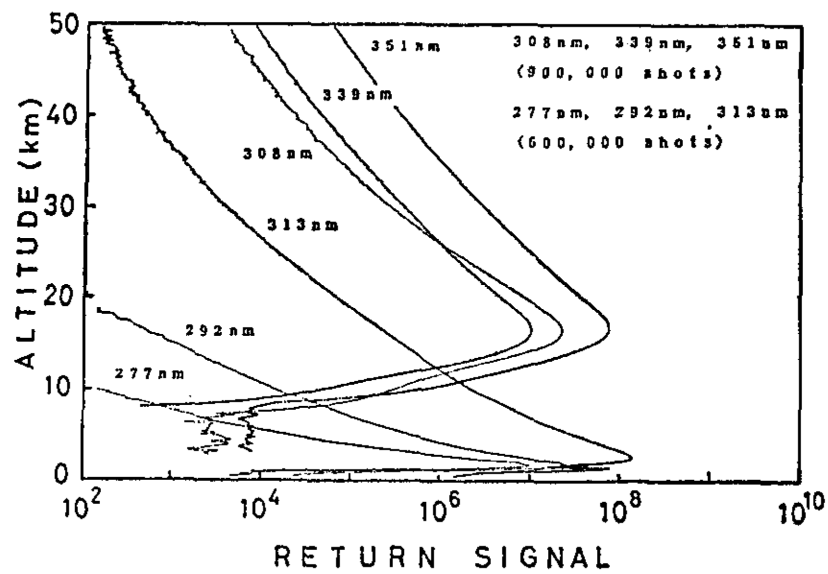

Fig. 4 Typical received signals at 277, 292, 308, 313, 339 and 351 nm (Sugimoto *et al.*, 1989)

1.6 Data check and data processing

The main sources of systematic errors are misalignment of transmitting or receiving optics, dead time of photon counters (saturation of photon counters) and aerosol effects (Sasano *et al.*, 1989). The ratios between the HS and LS signals for the same wavelength are suitable for checking dead time effects and determining the minimum height of the signals without distortion. The minimum height for the LS channel signals is much lower than those for the HS channels. Therefore combining the signals for HS and LS channels at the minimum height of the HS channel signals extends the dynamic range of the measurements. The ratios between 339 nm and 351 nm signals can be used to check the alignment of the laser beams transmitted, because they are independently adjusted. Aerosol effects can be also detected using this ratio when the deviation of this ratio from the constant value correlates with the aerosol profile. Comparison between the calculated ozone profiles using different off-resonant signals (wavelength: 339 nm and 351 nm) provides a similar check.

The vertical profiles of ozone were calculated based on the conventional DIAL equation from the lidar signals:

$$N(z) = \frac{1}{2\{\sigma_{on}(T) - \sigma_{off}(T)\}} \left[\frac{d}{dz} \left\{ -\ln \frac{n_{on}(z)}{n_{off}(z)} \right\} + B + E \right] \qquad \textbf{Eq(1)}$$

$$B = \frac{d}{dz} \ln \frac{\beta_{on}(z)}{\beta_{off}(z)}$$

$$E = -2 \{\alpha_{on}(z) - \alpha_{off}(z)\}$$

where n(z) is the photoelectron number, ß(z) and $\alpha(z)$ the backscattering coefficient and extinction coefficient due to aerosols and air molecules at the altitude of z, $\sigma(T)$ the temperature dependent absorption cross-section of ozone, T the temperature, and N(z) the number density of ozone molecules. When aerosol effects are negligible in the range of interest, terms B and E are estimated from the air molecule profile, given in aerological data or atmospheric models.

Parameters used for the ozone profiles presented in this report are as follows: Temperature dependent absorption cross-sections of ozone are used at 307.96 nm, 339.2 nm (Bass and Pauer, 1985; Pauer and Bass, 1985) and 351.1 nm (Cacciani *et al.*, 1989), which are 12.94, 0.10 and 0.019 ($10^{-24}m^2$) at 0°C, respectively. Quantities related to air molecules and the temperature profile are given by the US Standard Atmosphere (1976).

The differentiation in the DIAL equation given above is done by applying a numerical filter generated from a least-square third-order polynomial fitting to the discrete data points. The width of fitting defines the range resolution.

Statistical errors for ozone number densities calculated are estimated by assuming that the statistical errors are determined only by the shot noise of the received signals, and that the shot noise is equal to the square root of the number of photoelectrons detected. The final error (standard deviation) can be expressed by a linear combination of shot noise according to the noise propagation theory. The coefficients (weights) for the linear combination are related to the numerical filter for the differentiation.

1.7 Estimation of systematic errors

Systematic errors are usually estimated by comparisons between independent measurements. We are comparing the ozone profiles derived from a pair of signals for 308 nm and 339 nm, and 308 nm and 351 nm. Figure 5 provides an example of these comparisons. The agreement is very good and it is difficult to distinguish the two profiles. This means (1) that the effects of stratospheric aerosols on the ozone lidar measurements are negligible within the statistical errors, and (2) that the alignment of the laser beam transmitted is probably good, as mentioned above. This is a typical example for ozone profiles measured under good atmospheric conditions before arrival of the stratospheric aerosols due to the eruption of Mt. Pinatubo.

Another comparison was performed with data provided by the satellite sensor SAGE II. SAGE II data were selected based on the criteria of spatial and temporal differences between the lidar and SAGE II measurements: 5° of latitude and 15° of longitude within one day before or after the lidar measurements (individual comparison), and a latitudinal band from 31°N to 41°N within three or five days (zonal-mean profile comparison). Results showed good agreement for both the individual and zonal-mean profiles (Fig. 6). Estimated differences between ozone profiles measured with the ozone lidar and with the SAGE II were about 10 % over the stratosphere (Nakane *et al.*, 1993).

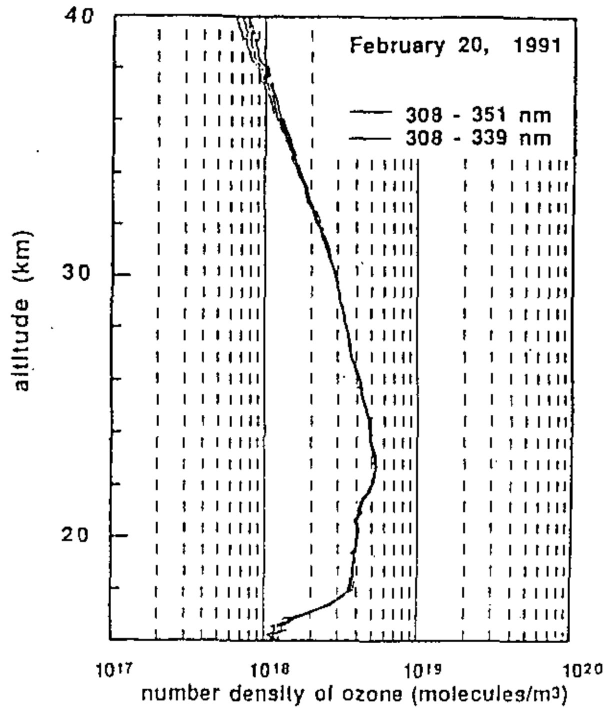

Fig. 5 Ozone profiles with statistical errors derived from a pair of signals for 308 nm and 339 nm (thin curves), and 308 nm and 351 nm (bold curves).

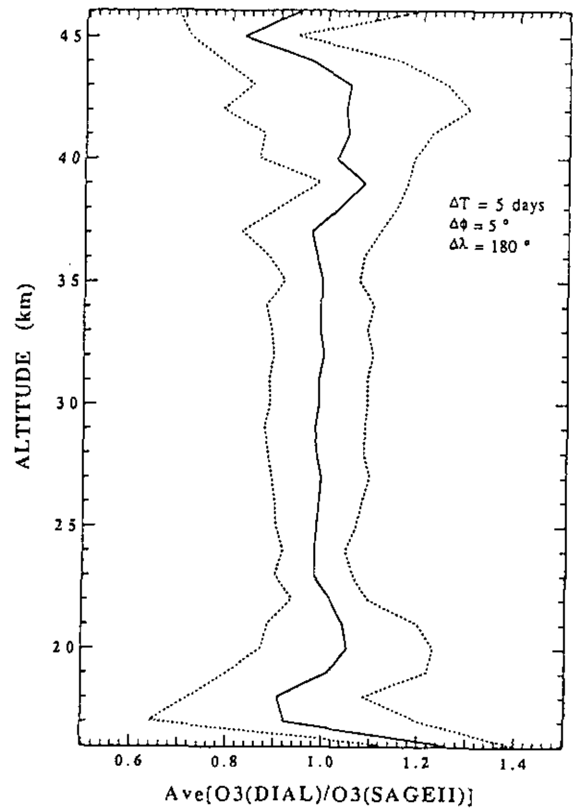

Fig. 6 The average of the ratios and its variability for zonal-mean profile comparisons. The time differences are five days and the difference in latitude is five degrees (Nakane *et al.*, 1993).

1.8 Archived data

Lidar observation of ozone profiles with the NIES Ozone Lidar started in August 1988. Temporal variations of ozone at 20, 25, 30, 35, and 40 km since then are depicted in the Fig. 7.

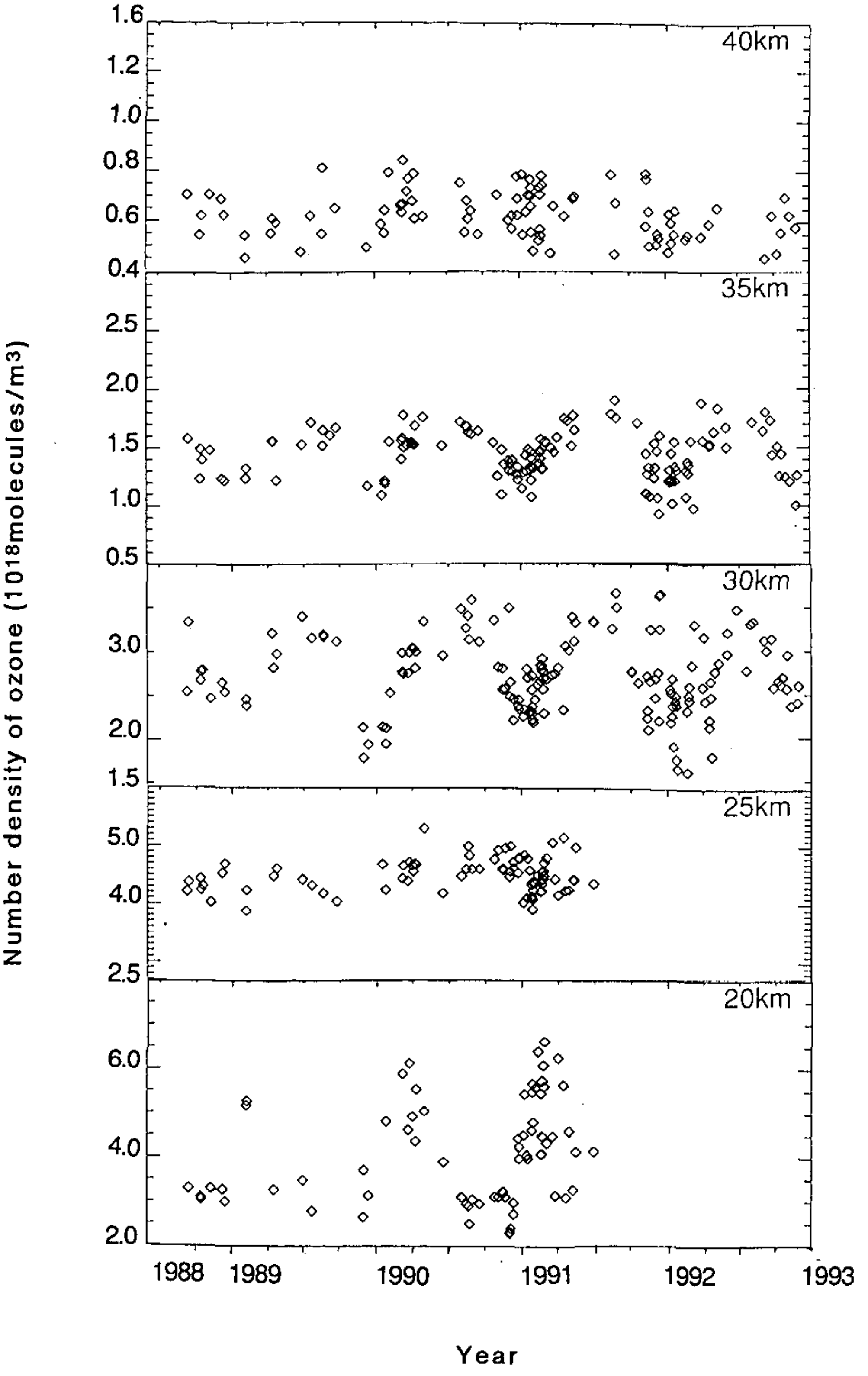

Fig. 7 Variations of ozone at an altitude of 20, 25, 30, 35, and 40 km

Seasonal variations differ with altitude. Ozone density is high in winter and low in summer at 20 km and high in summer and low in winter at 30 and 35 km. This is consistent with the mechanism of seasonal variation in the lower and upper stratosphere which is generally understood: Transport effects are dominant in the lower stratosphere and photochemical effects are dominant in the upper stratosphere. Figure 8 shows the difference of ozone profiles in summer and winter and their intra-seasonal variation in winter. The phase of the seasonal variation interchanges at about 23 km.

As mentioned above, in June 1990 a considerable improvement was made in the receiving optics and observation after this improvement started on August 3, 1990. On October 1, 1990 the Center for Global Environmental Research was established and financial supports for ozone lidar monitoring began. Since then frequent, high accuracy measurements (more than 50 times per year) have been made. Accurate vertical profiles of ozone have been obtained during the period August 3, 1990 - December 16, 1991 (Fig. 9). After the arrival of the "Pinatubo aerosols" data below 30 km were not shown, because they caused systematic errors. The wavelength pair used for Fig. 8 and 9 is the 308 nm and 351 nm pair, because they give the smallest statistical errors.

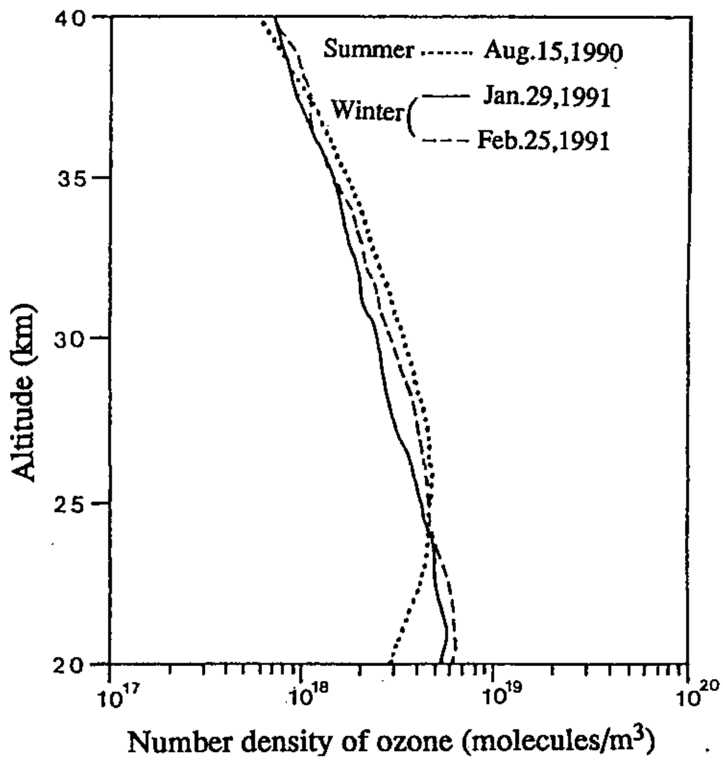

Fig. 8 Ozone profiles in summer and winter

1.9 Conclusion

Vertical profiles of ozone have been observed with the NIES Ozone Lidar since August 1988, and accurate data have been archived. Since October 1990, observations have been conducted within the framework of the "Ozone Lidar Monitoring Program "of the Center for Global Environmental Research. Because the lidar system has high power excimer lasers and large telescope, measurements of the vertical profile of ozone up to an altitude of 45 km are possible under good atmospheric conditions. The multi-wavelength and multi-channel configuration of the lidar system permits various checks of the accuracy of the signals and the ozone profiles, in which the ratios of signals or ozone profiles with different wavelengths and/or channels are used. Comparisons between the lidar data and SAGE II satellite data were done for mutual validation, and gave good results. Seasonal variations seen clearly at altitudes of 20, 30 and 35 km , result form the effects of transport and photochemical changes in the stratosphere, depending on altitude. Longer term monitoring is required to detect trends in the vertical profile of ozone.

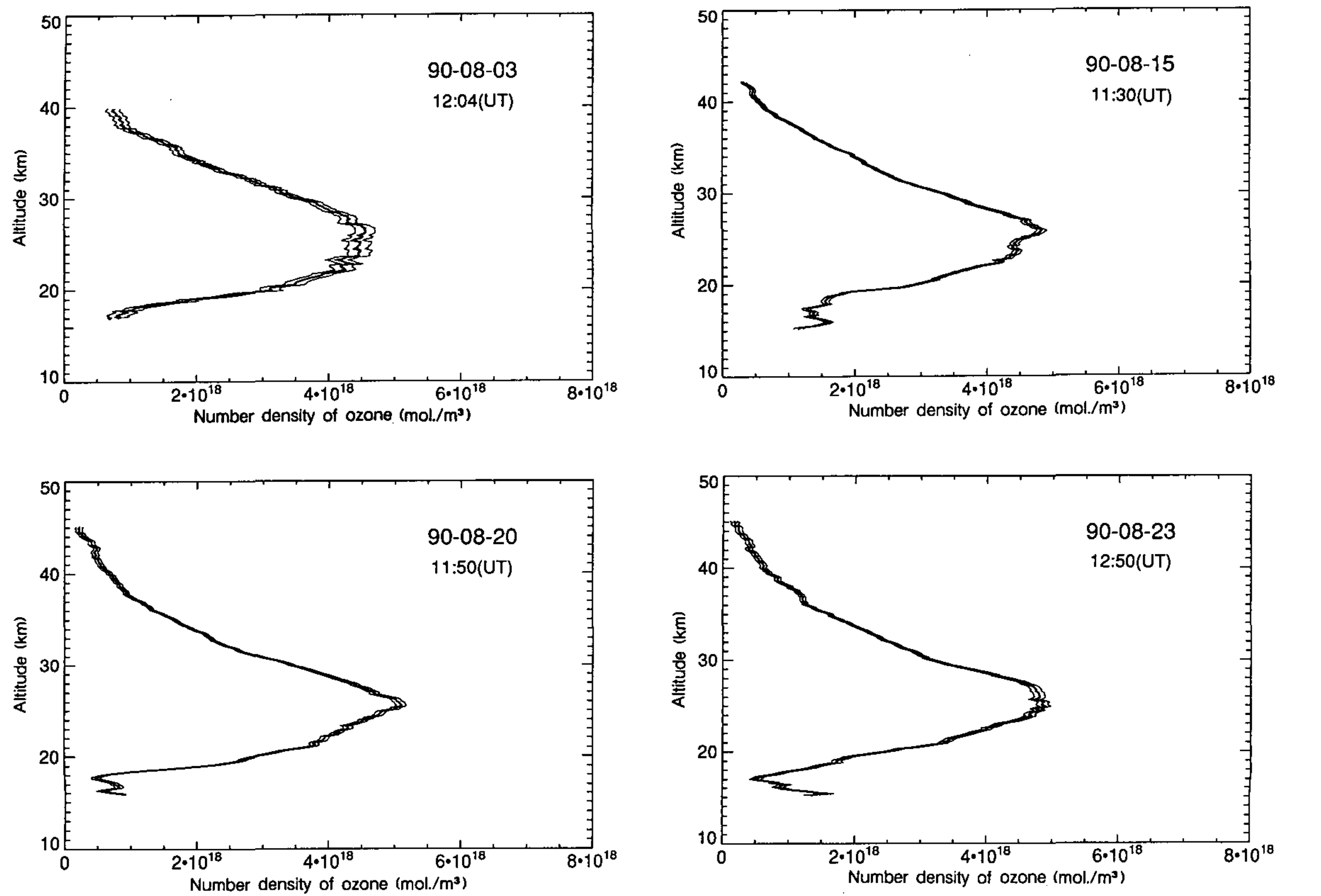

Fig. 9 Vertical profiles of ozone from August 3, 1990 through December 16, 1991

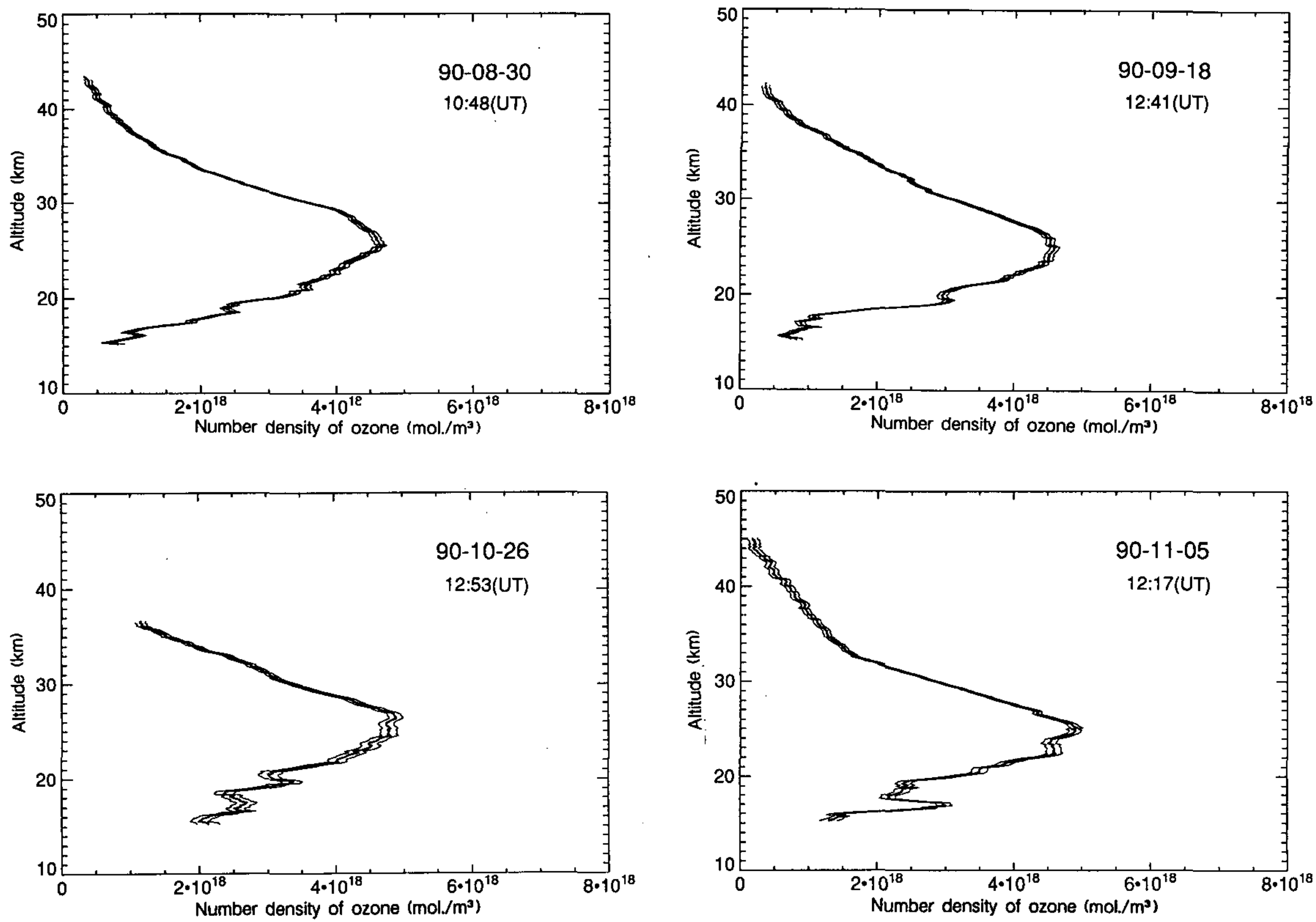

Fig. 9 (continued)

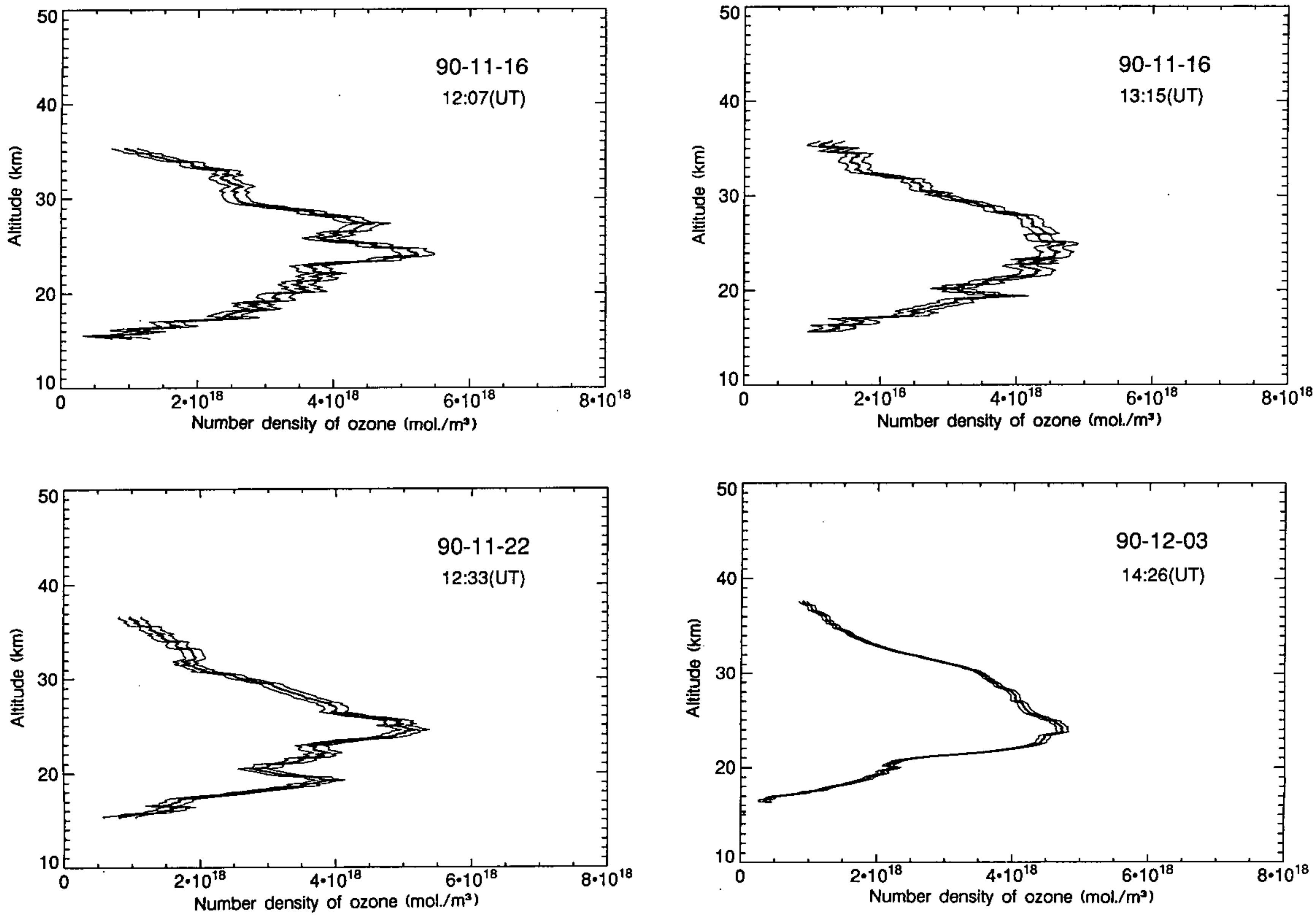

Fig. 9 (continued)

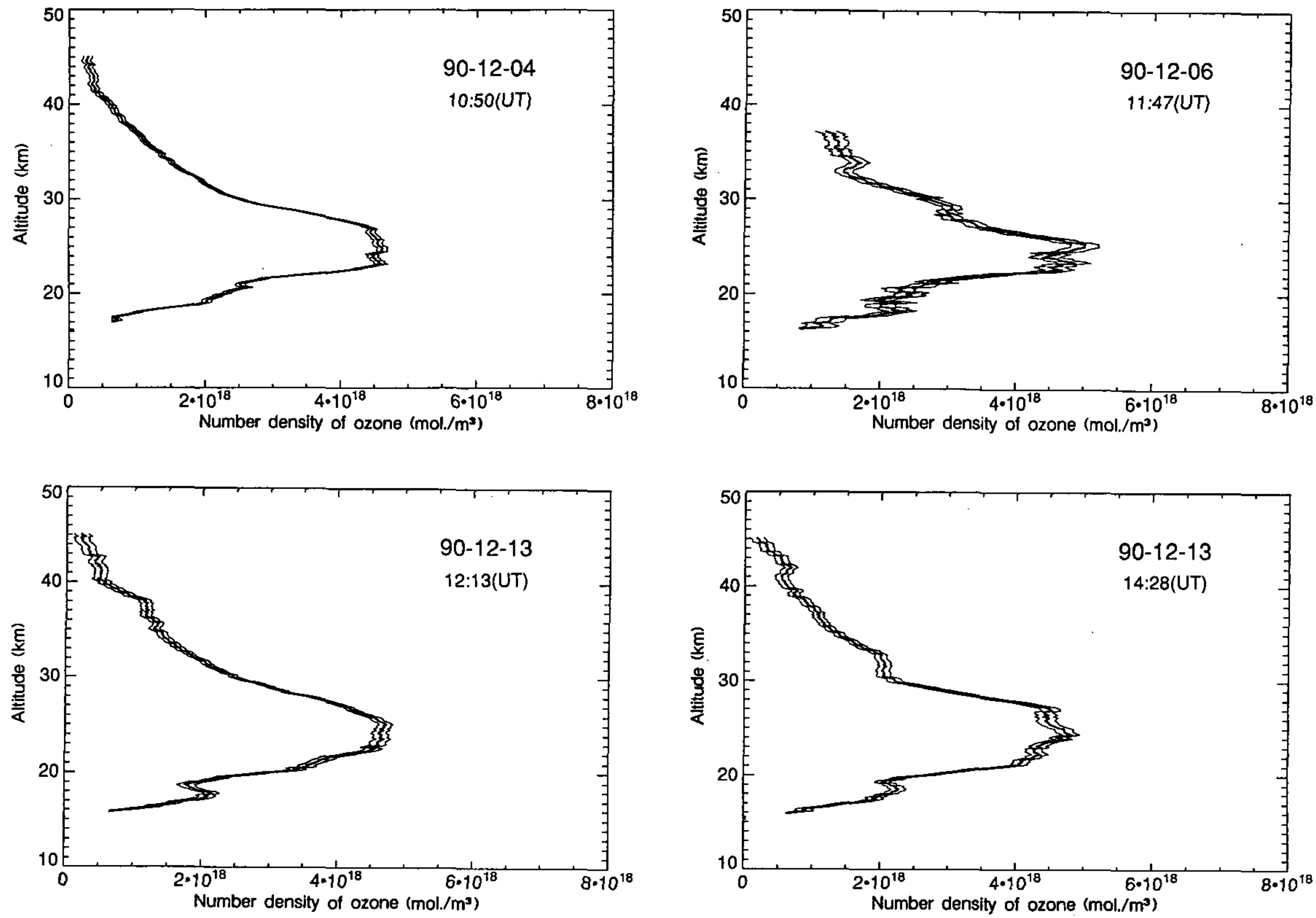

Fig. 9 (continued)

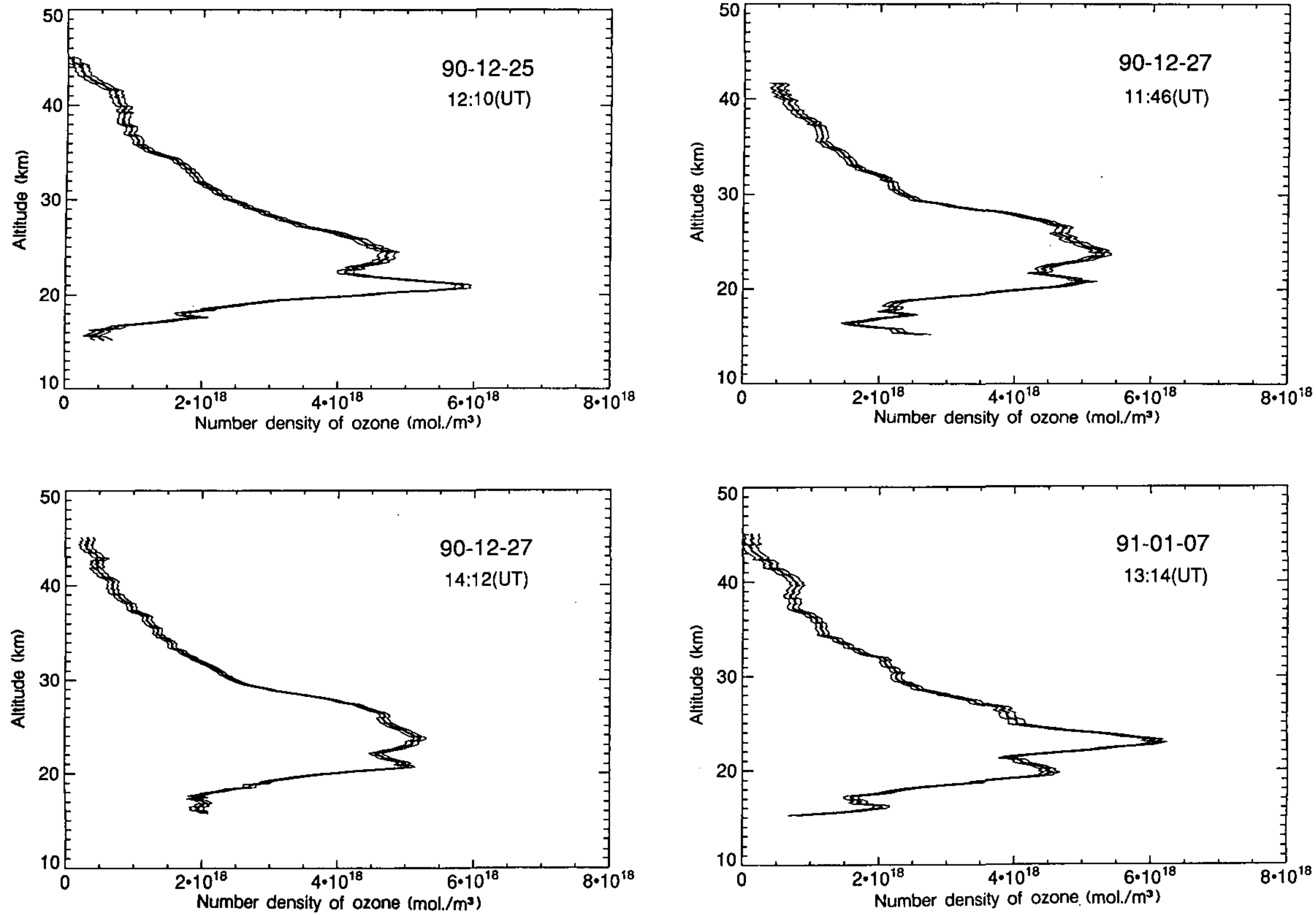

Fig. 9 (continued)

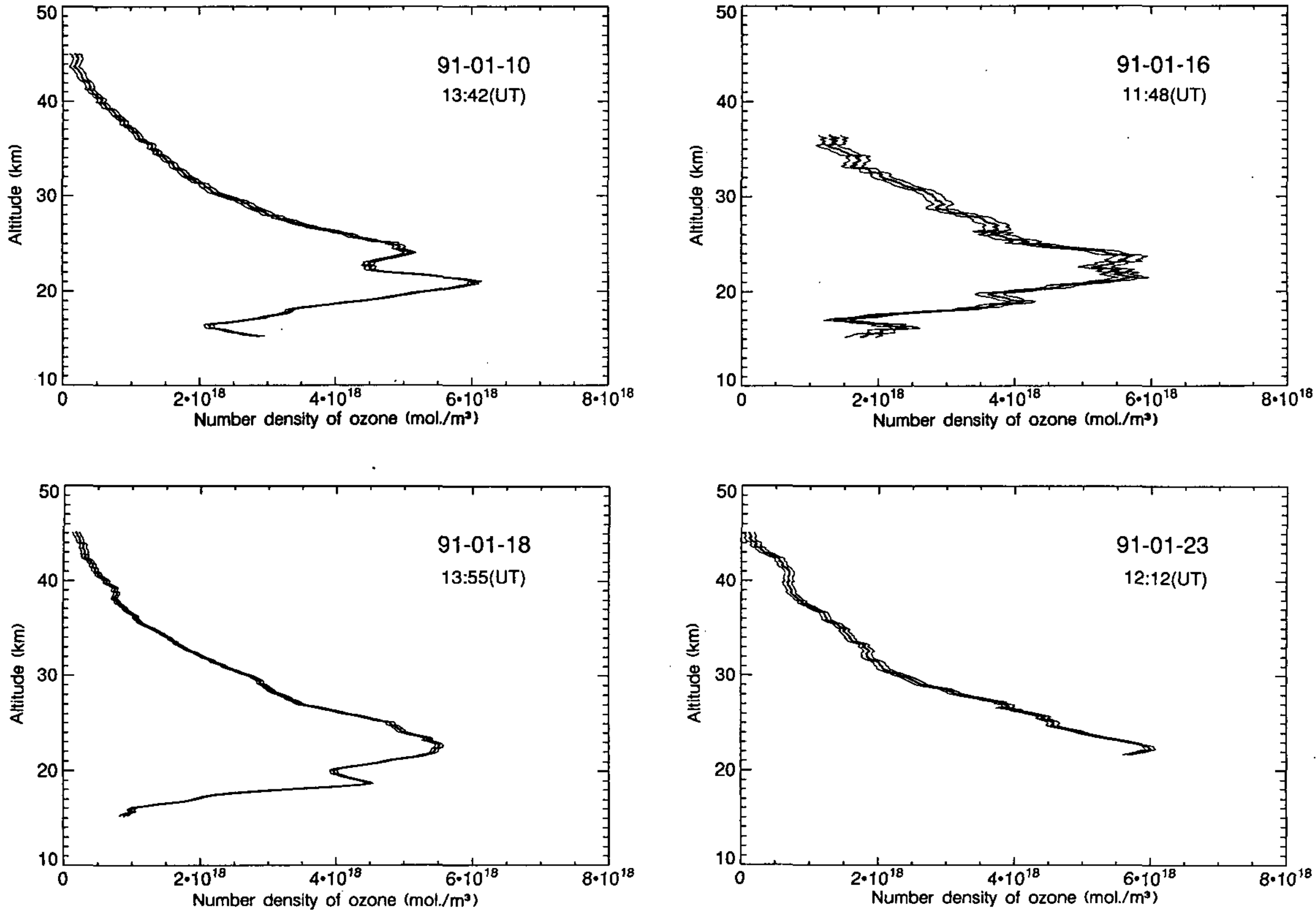

Fig. 9 (continued)

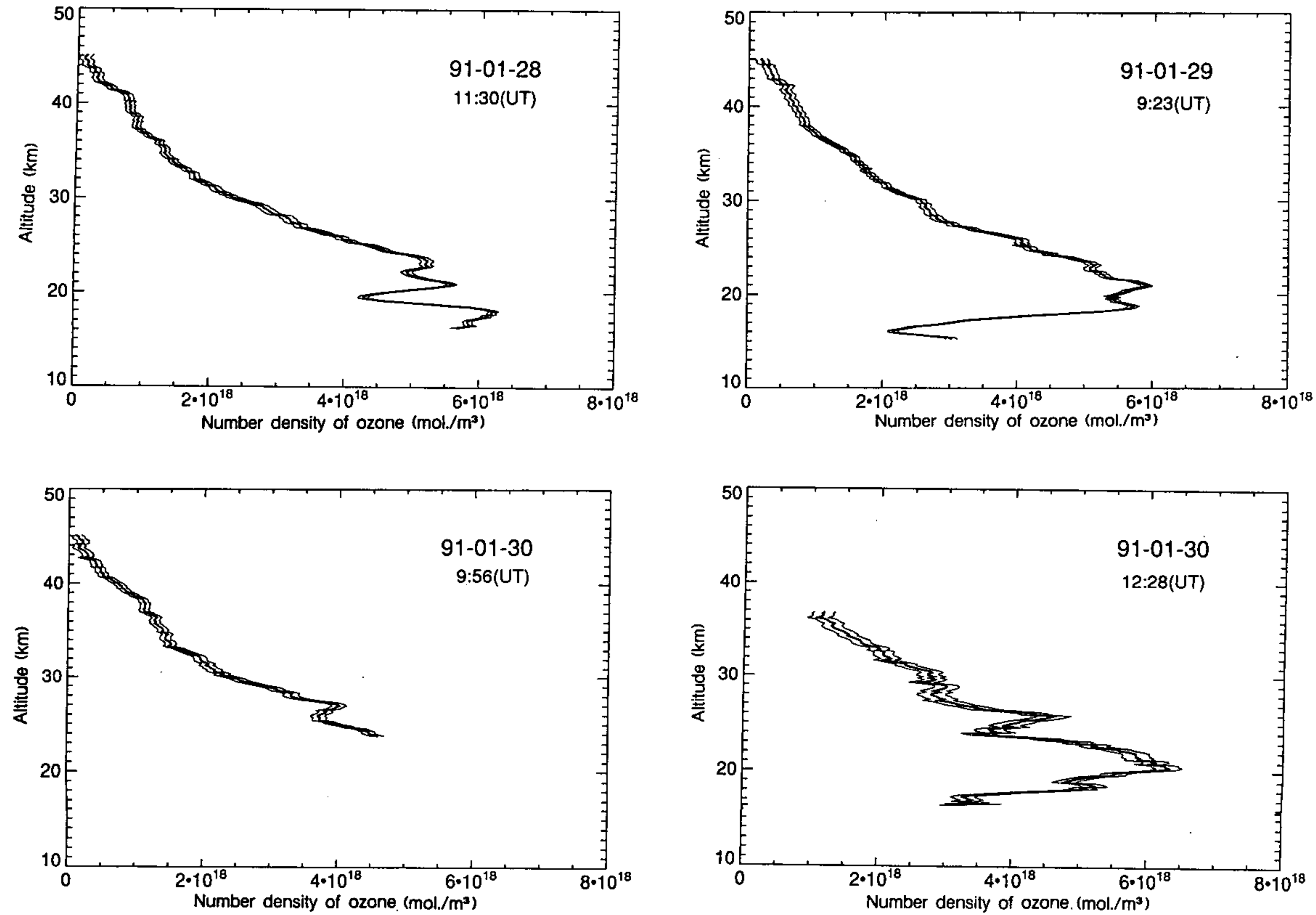

Fig. 9 (continued)

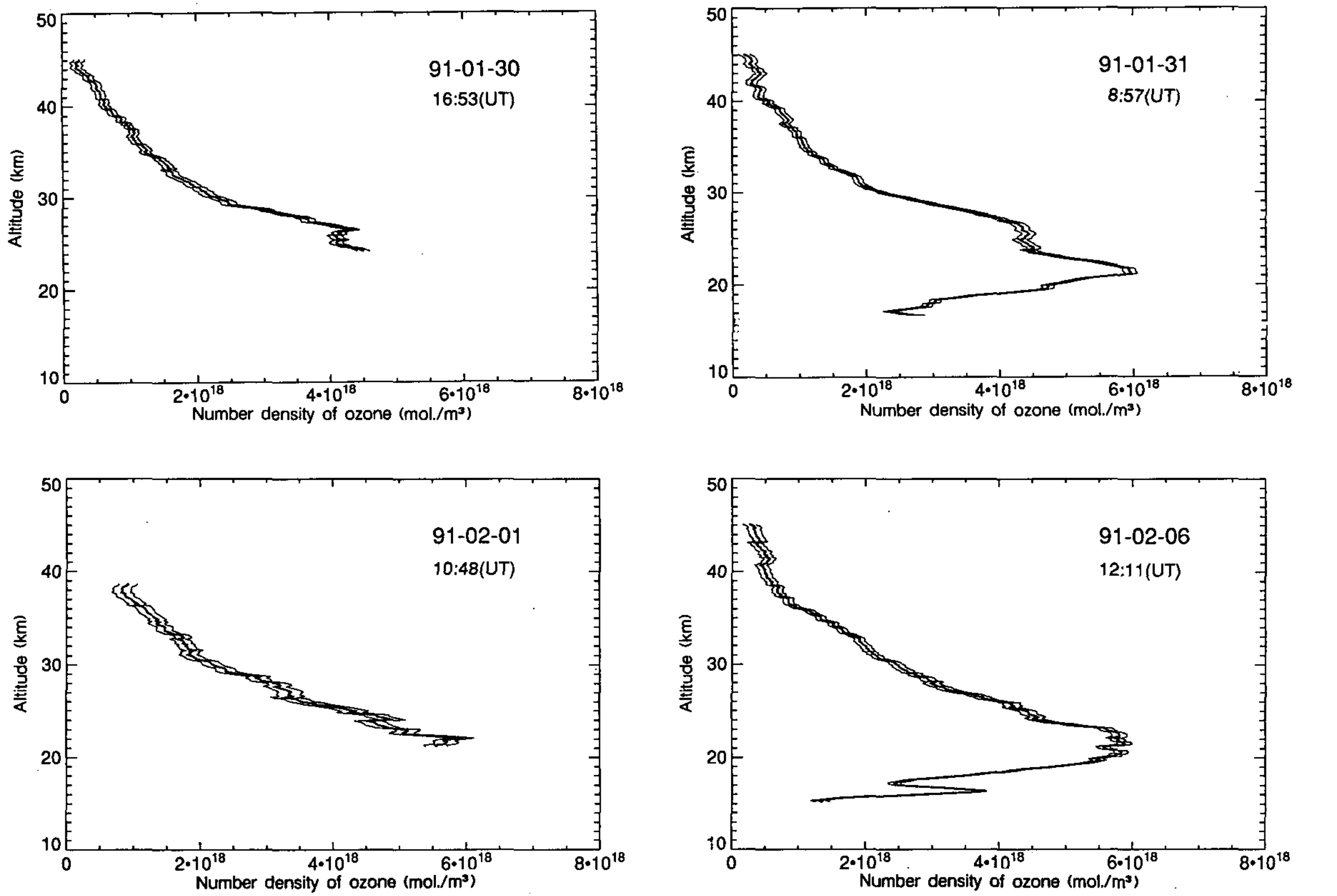

Fig. 9 (continued)

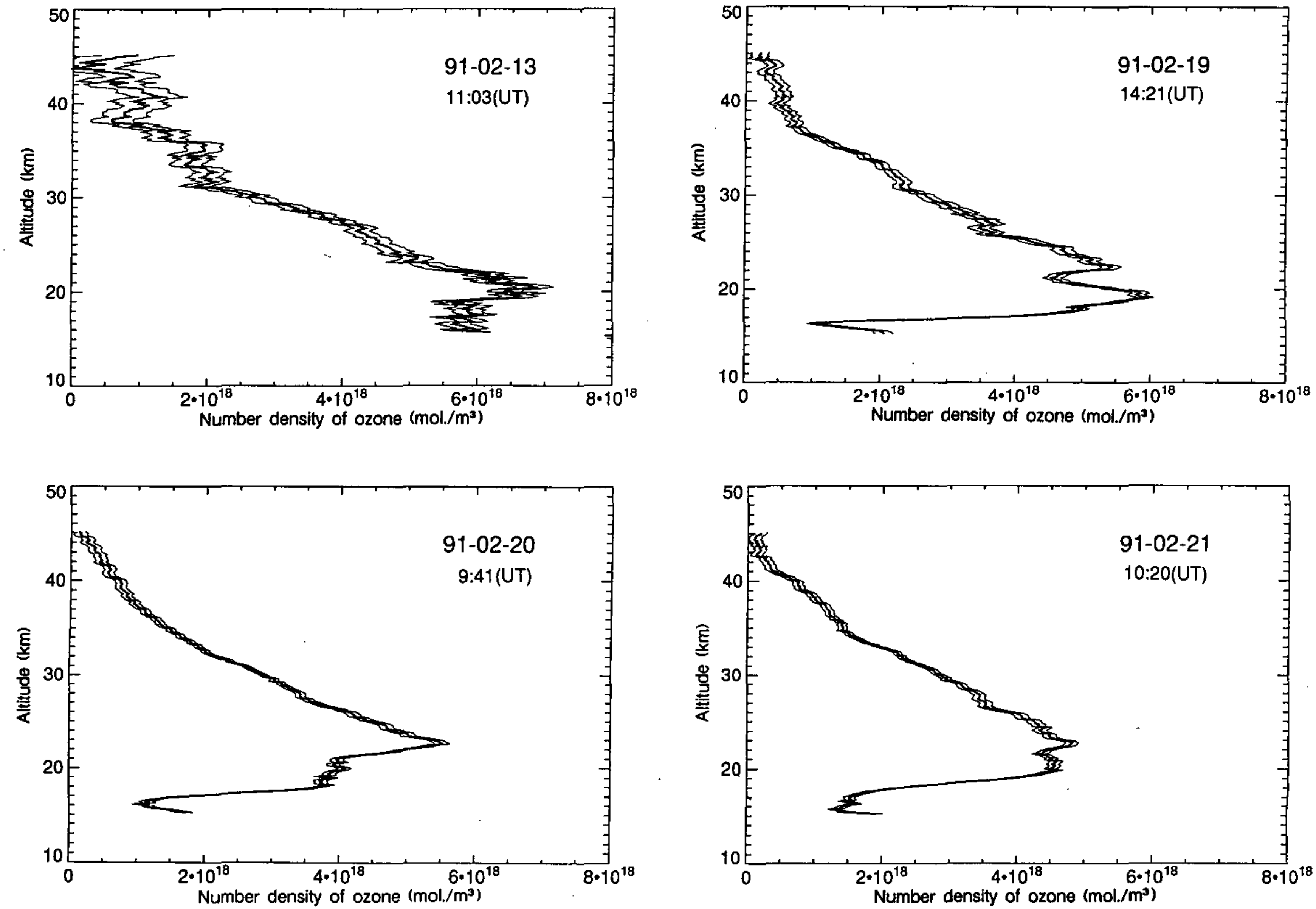

Fig. 9 (continued)

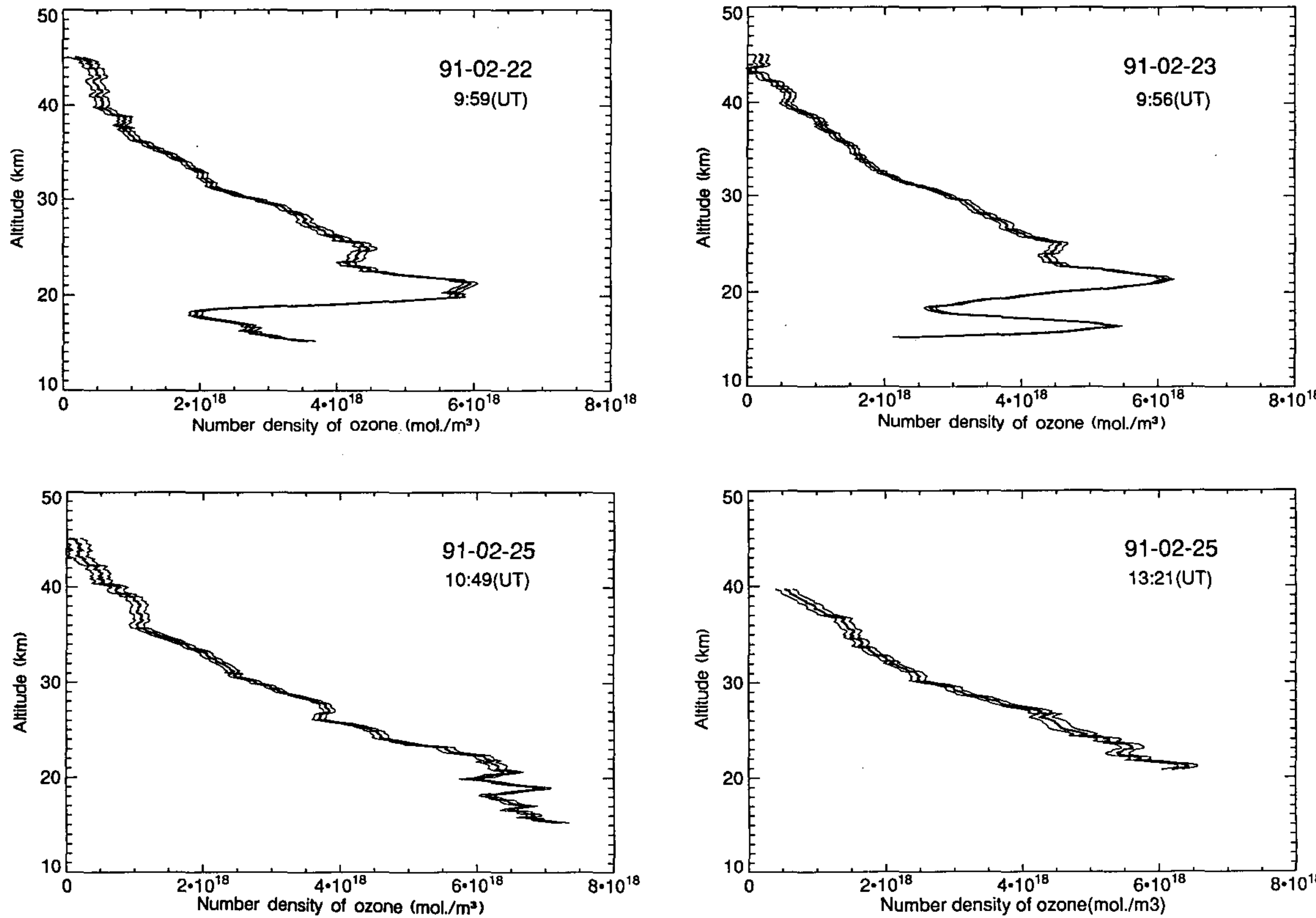

Fig. 9 (continued)

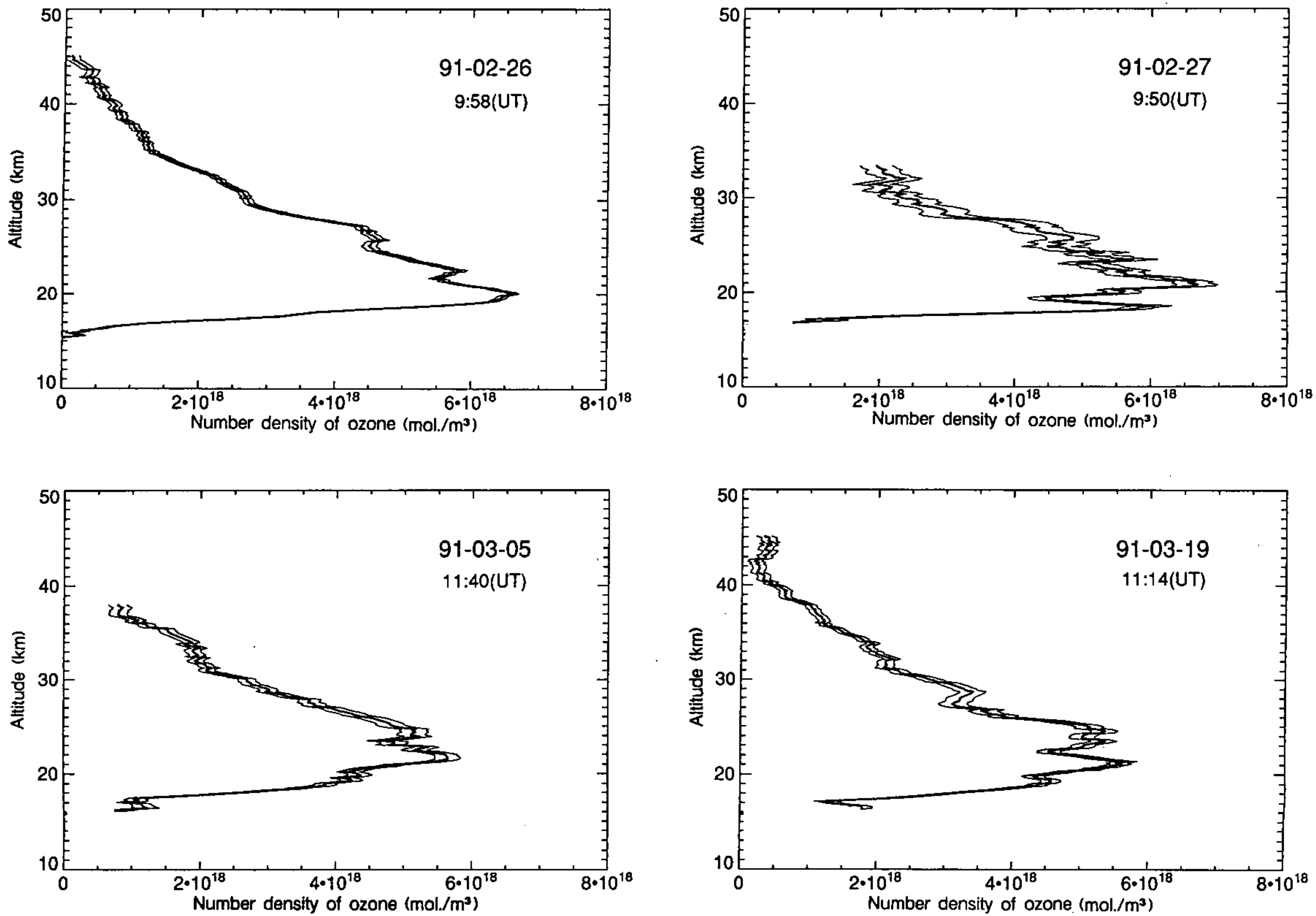

Fig. 9 (continued)

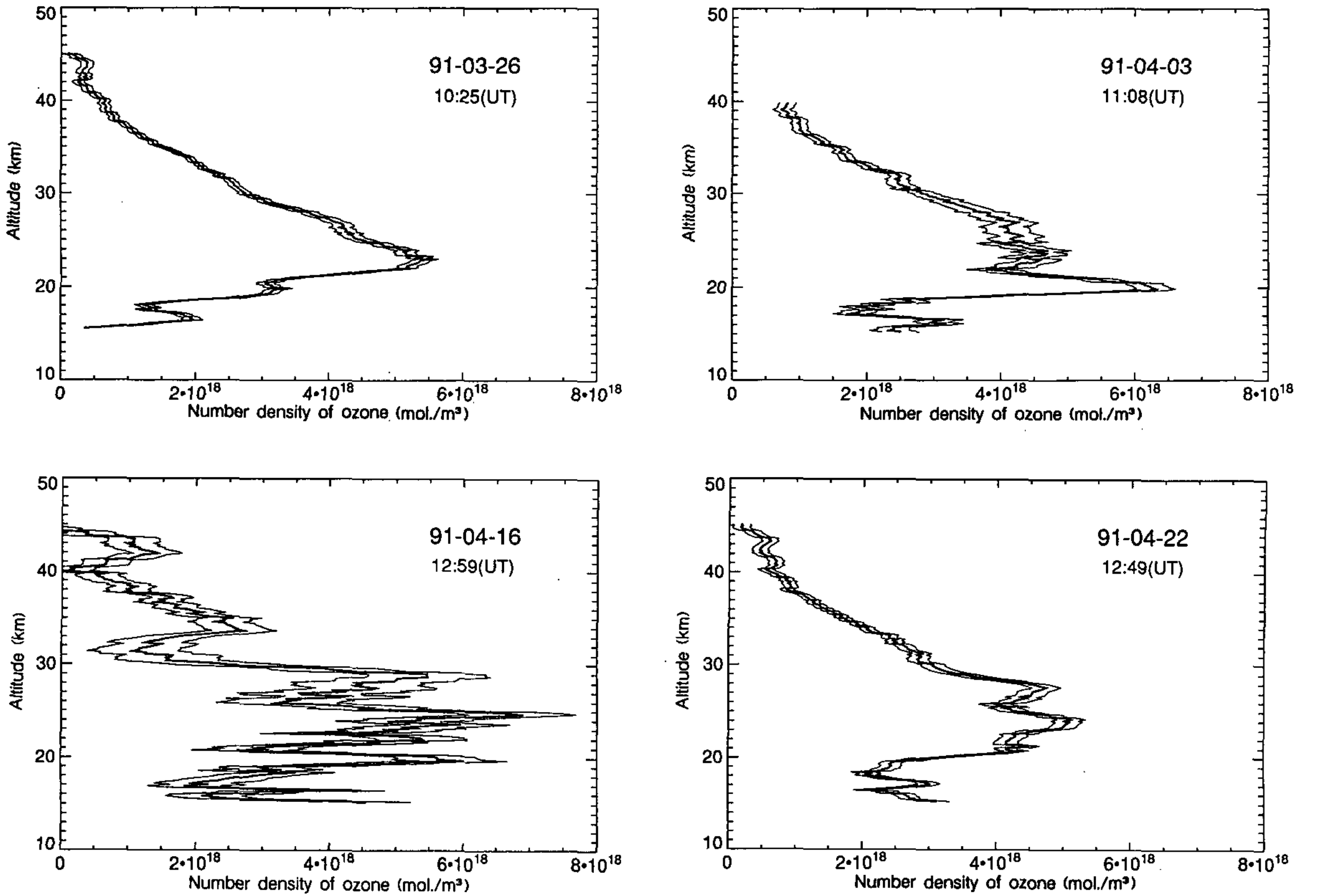

Fig. 9 (continued)

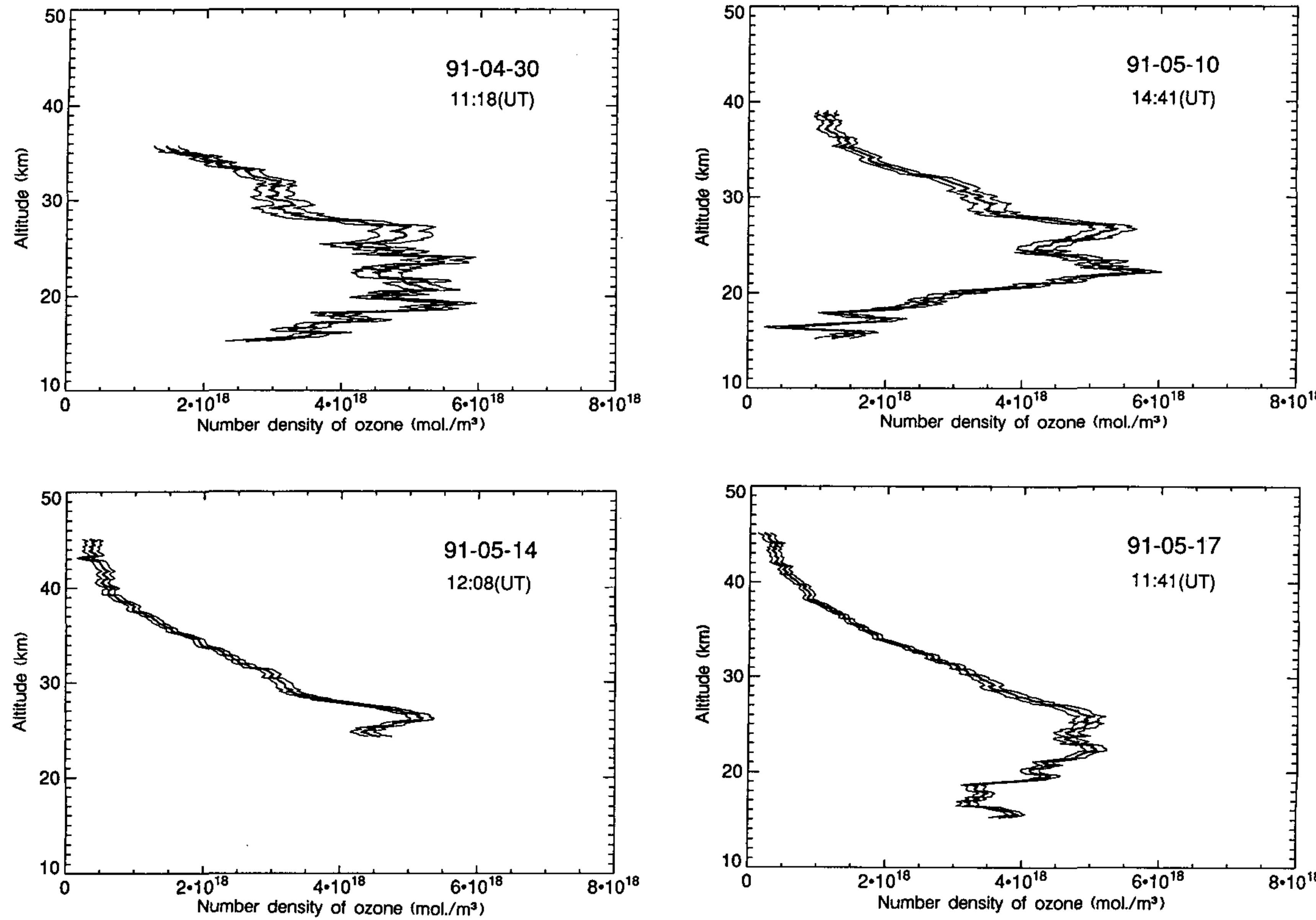

Fig. 9 (continued)

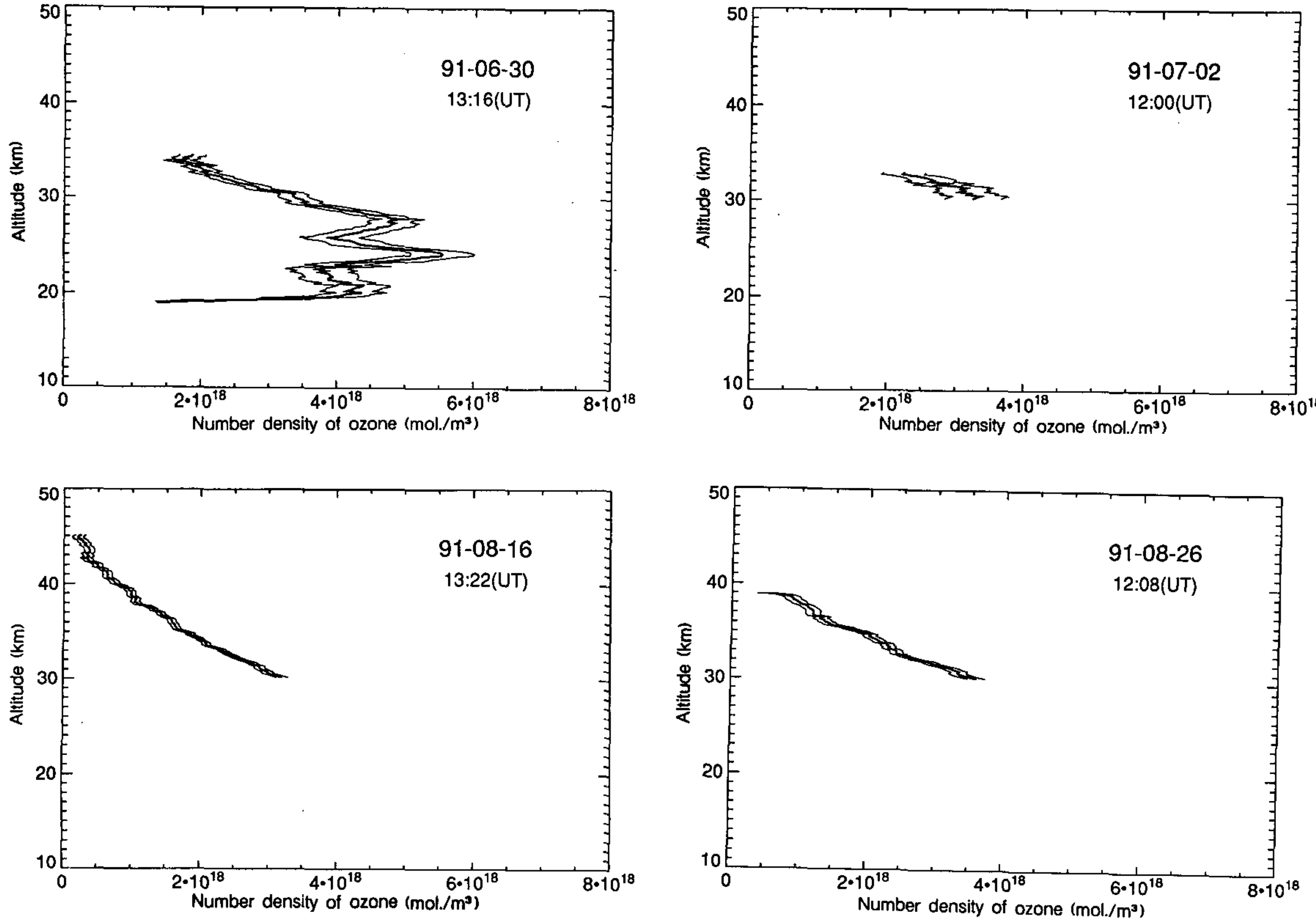

Fig. 9a (continued)

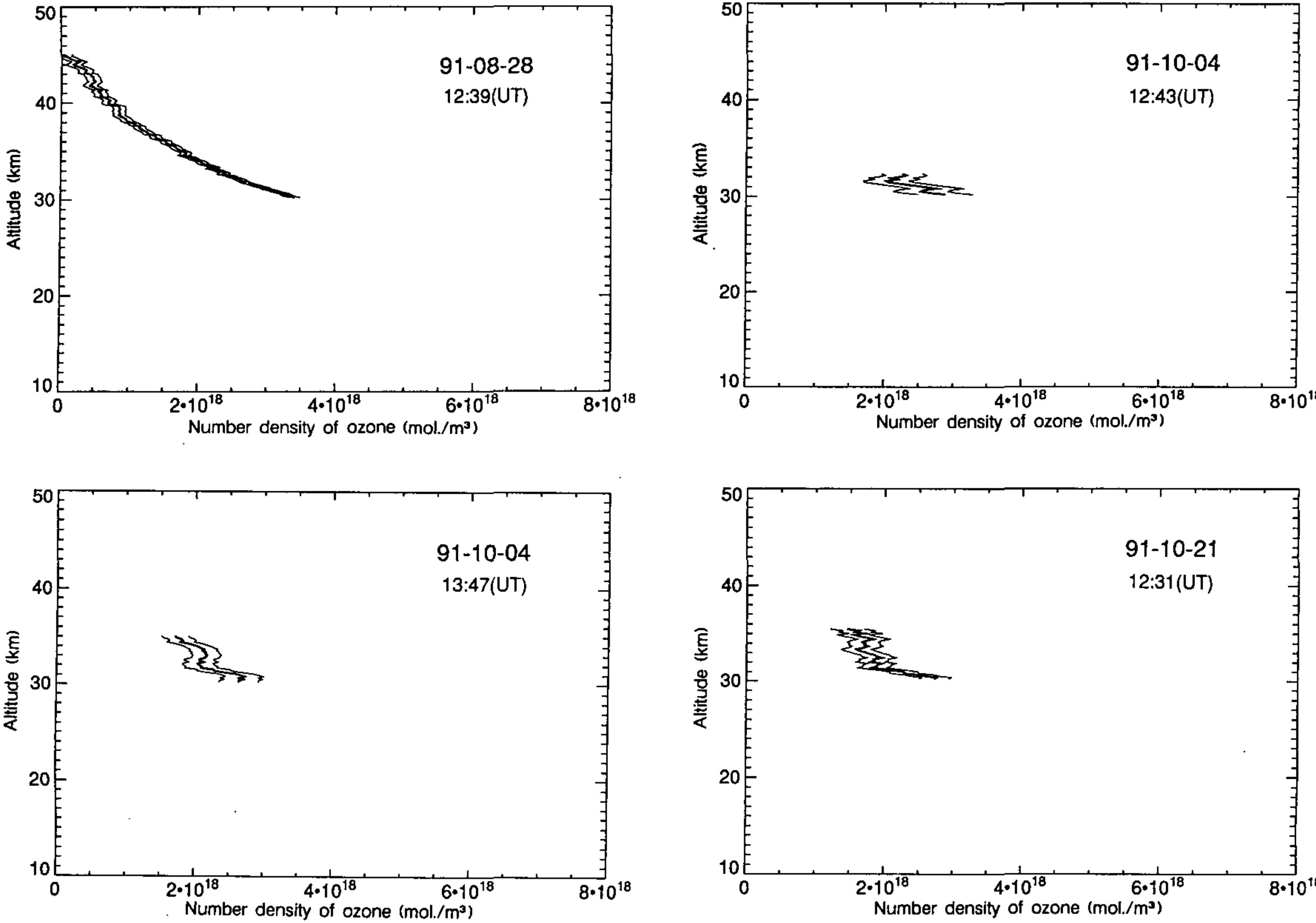

Fig. 9 (continued)

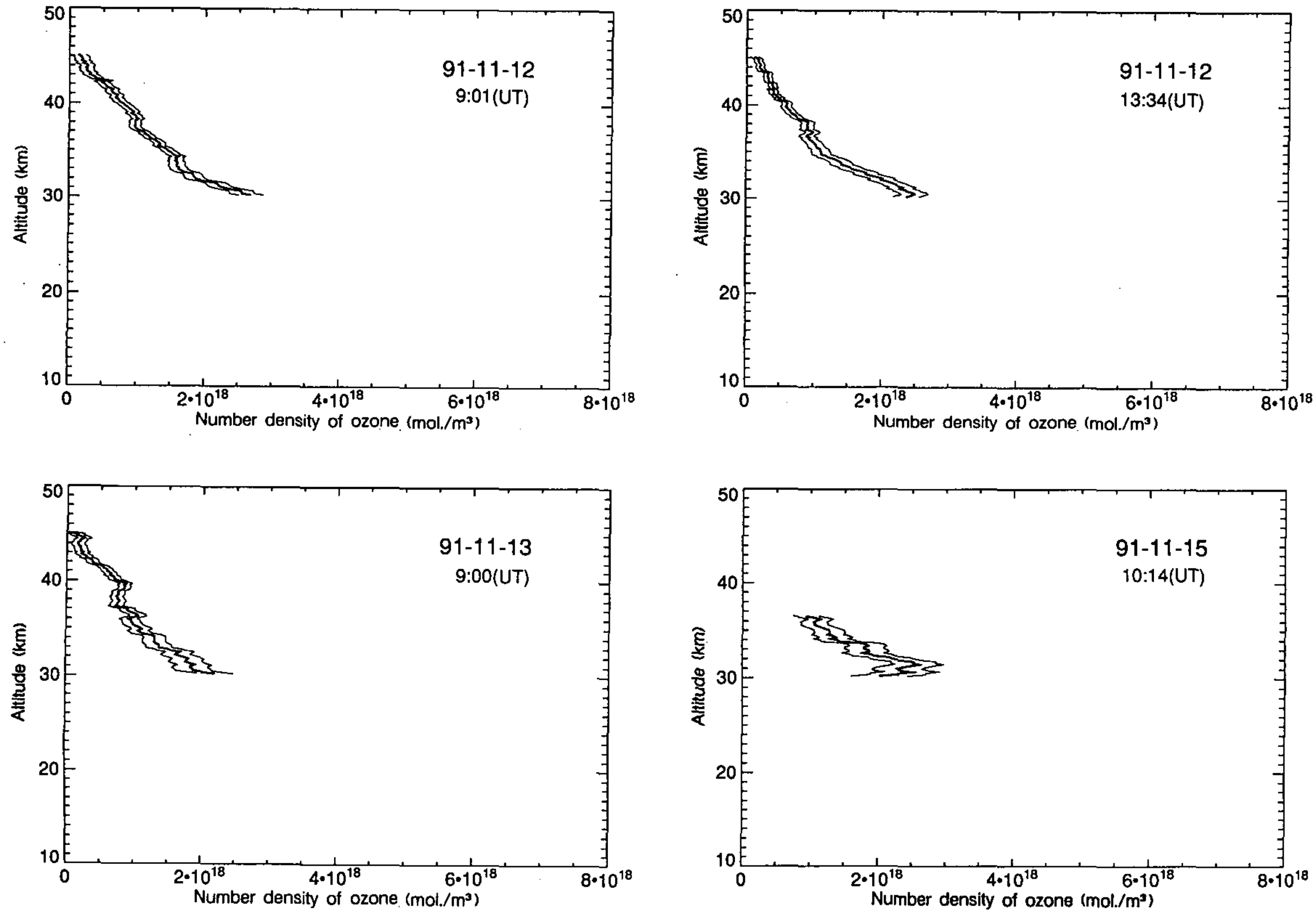

Fig. 9 (continued)

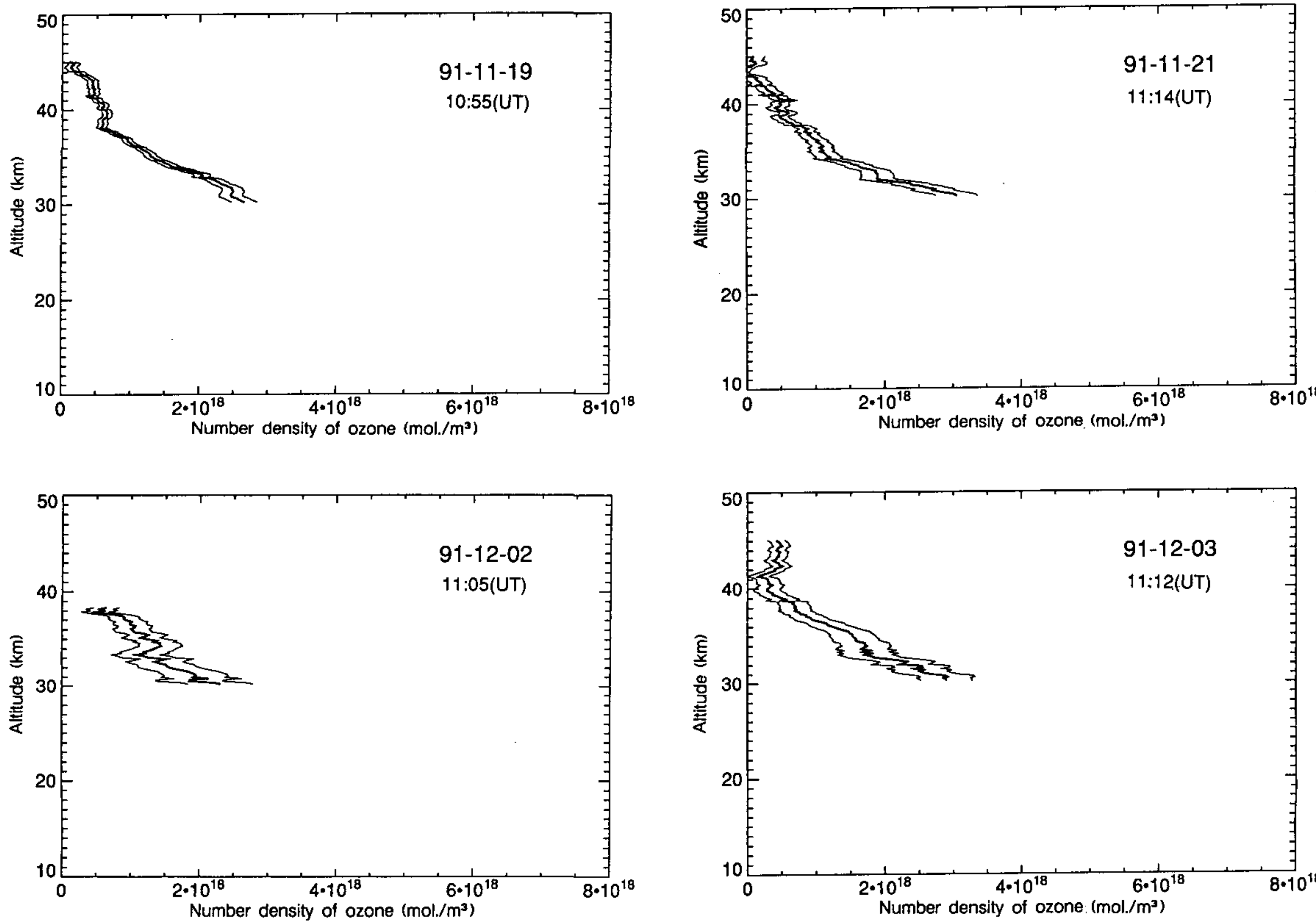

Fig. 9 (continued)

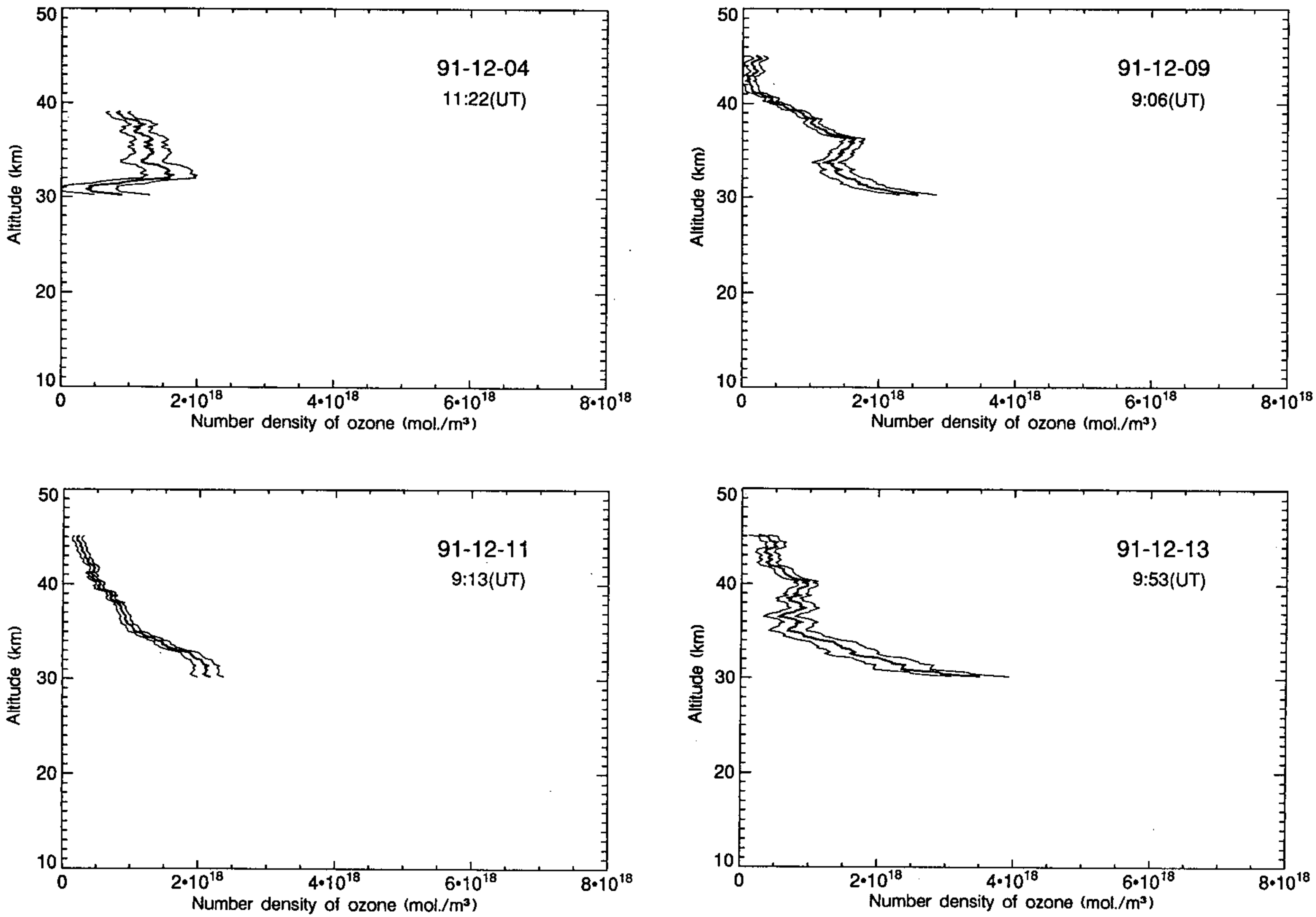

Fig. 9 (continued)

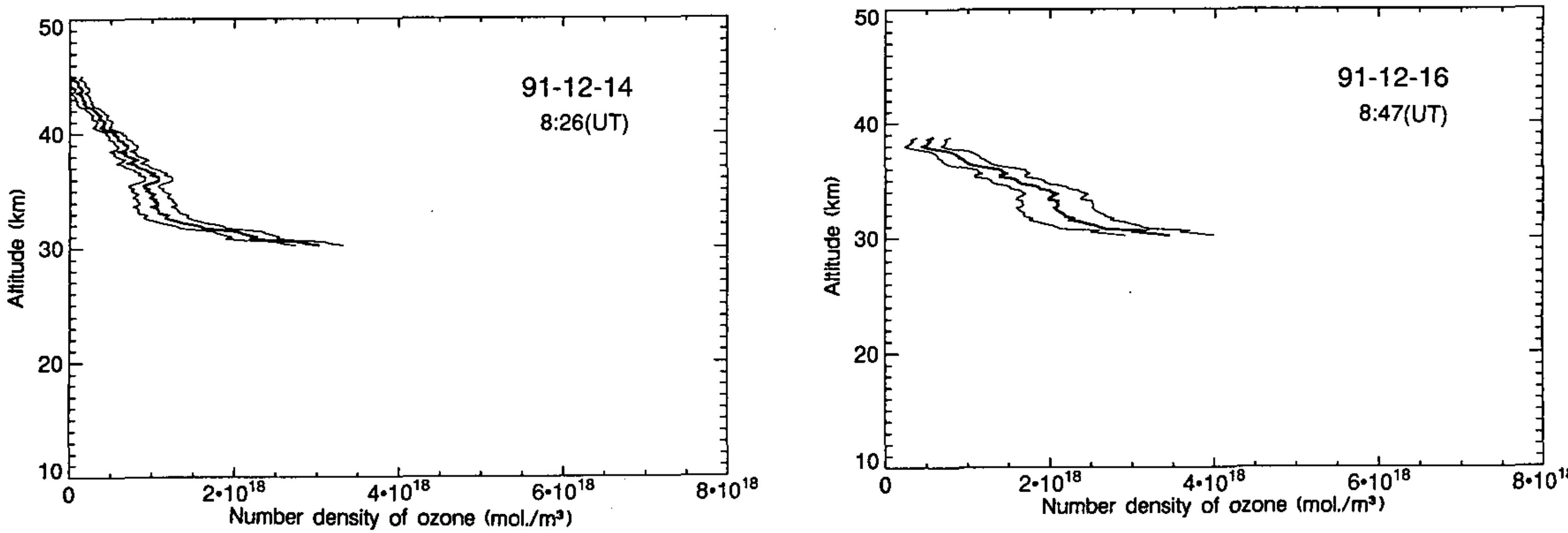

Fig. 9 (continued)

1.10 Acknowledgements

The authors wish to express their thanks to Dr. Hiroshi Shimizu, who had initiated construction of the ozone lidar system. Mr. Fumio Sakurai and Mr. Yoshitsugu Sato, of FIT, are appreciated for their assistance in the operation and data processing. They also thank Spectra Technology Inc. for its efforts in building the ozone lidar system.

The project has been managed based on discussions among the members of the subcommittee for Ozone Lidar Monitoring which has been organized by NIES-CGER.

Subcommittee members for Ozone Lidar Monitoring:

Y. Iwasaka (Nagoya University) : Chairman
T. Ogawa (The University of Tokyo)
H. Nakane (NIES)
S. Hayashida (NIES)
N. Sugimoto (NIES)
I. Matsui (NIES)
Y. Sasano (NIES)

Secretariat:

G. Inoue (NIES-CGER)
T. Uehiro (NIES-CGER)
N. Furuta (NIES-CGER)
S. Araki (NIES-CGER)
Y. Yoichi (NIES-CGER)

References

Bass A. M. and R. J. Pauer (1985): The ultraviolet cross-sections of ozone: I. The measurements, in Atmospheric Ozone Proceedings of the Quadrennial Ozone Symposium, Halcadiki, Greece, Zerefos, C. S. and A. Ghazi (*eds.*), 606-610.

Cacciani, M., A. Sarra, F. Fiocco and A. Amoruso (1989): The ultraviolet cross-sections in the UV at wavelength used as reference in ozone DIAL systems, in Atmospheric Ozone Proceedings of the Quadrennial Ozone Symposium 1988 and Tropospheric Ozone Workshop.

Nakane, H., S. Hayashida, Y. Sasano, N. Sugimoto, I. Matsui, and A. Minato (1992): Vertical profiles of temperature and ozone observed during DYANA campaign with the NIES ozone lidar system at Tsukuba, J. Geomag. Geoelectr., **44**, 1071-1083.

Nakane, H., Y. Sasano, S. Hayashida -Amano, N. Sugimoto, I. Matsui, and A. Minato (1993): Comparison of ozone profiles obtained with NIES DIAL and SAGE II measurements, J. Meteorol. Soc. Japan, **71**, 153-159.

Pauer R. J. and A. M. Bass (1985): The ultraviolet cross-sections of ozone: II. The results and temperature dependence, in Atmospheric Ozone Proceedings of the Quadrennial Ozone Symposium, Halcadiki, Greece, Zerefos, C. S. and A. Ghazi (*eds.*), 611-616.

Sasano Y., N. Sugimoto, H. Nakane, S. Hayashida-Amano, I. Matsui, and A. Minato (1989): Multiple-wavelength differential absorption lidar (DIAL) for measuring the ozone profiles in the stratosphere and the troposphere, Abstracts of First Tsukuba Workshop on Ozone DIAL.

Sugimoto, N., Y. Sasano, H. Nakane, S. Hayashida-Amano, I. Matsui, and A. Minato (1989): Multiple-wavelength laser radar for measuring stratospheric and tropospheric ozone profiles, Oyobutsuri, **56**, 1385-1397 (in Japanese).

US Standard Atmosphere (1976): U.S. Government Printing Office, Washington, D.C. WMO, Scientific Assessment of Ozone Depletion: 1991 (1992): Global ozone research and monitoring project, Rep. **25**, Geneva.