Intensive Ozonesonde Observation at Fairbanks and Comparison with Three-Dimensional Chemical Transport Model

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An observation campaign including intensive launches of ozonesondes was conducted at Fairbanks (64.8 N, 147.9 W), Alaska, during 23–30 August 2003. The objectives are validation of data from Improved Limb Atmospheric Spectrometer-Ⅱ (ILAS-Ⅱ) on board the Advanced Earth Observing Satellite-Ⅱ (ADEOS-Ⅱ) with Alaska Project ground-based instruments and examination of small-scale ozone variation in the upper troposphere and lower stratosphere. Observed small-scale structures in ozone are compared with high-resolution fields reconstructed from 3-dimensional chemical transport model using the reverse domain filling technique.

Keywords
Stratospheric ozone, Ozonesonde, Fine structure in ozone distributions, ILAS-Ⅱ, Chemical transport model

1 Introduction

The stratospheric ozone layer plays an important role in protecting living organisms on Earth from harmful ultraviolet radiation. The destruction of the ozone layer in the polar regions due to anthropogenic substances such as chlorofluorocarbons has become a serious global environmental issue, and efforts are currently underway to monitor the ozone on a global scale. The stratospheric ozone layer also acts as a heat source in the terrestrial atmosphere and significantly affects the temperature and wind fields in the middle atmosphere.

Since the 1970s, it has been recognized that the ozone distribution displays a laminated structure on small vertical scales in the lower stratosphere. This fine structure of ozone distribution in the lower stratosphere (at altitudes of approx. 15–25 km), where ozone is a photochemically long-lived species, is believed to have been generated by dynamical processes, that is, by the transportation of air parcels originating in different latitudes or altitudes to the observation point in the presence of a north-south or vertical concentration gradient. Some candidates that have been proposed as the cause of the laminated structure are the breaking of Rossby waves, chaotic advection, and gravity waves. The former two attribute the formation of the laminated structure to quasi-horizontal advection, while the latter attributes it to vertical advection. Since these different proposed causes occur on different time scales, the resulting laminated structure should similarly display different temporal and spatial scales. Furthermore, the respective contributions of these mechanisms to transport in the middle atmosphere may also be distinct.

The ILAS-Ⅱ was placed aboard the ADEOS-Ⅱ satellite and launched in December 2002. Routine operations began in April 2003,

and until the abrupt termination of ADEOS-Ⅱ in October 2003 due to failure of its solar panel, the ILAS-Ⅱ collected data on the various chemical species involved in the destruction of the ozone layer[1]. Figure 1 shows the time series of the latitudes (limited to the northern hemisphere) measured by the ILAS-Ⅱ. The Poker Flat Research Range, which is the observation site for the Alaska Project[2], is included in the latitudinal band, and the observation over the latitude band took place in April and August 2003. Taking advantage of this opportunity, we participated in the cooperative validation experiments of ILAS-Ⅱ, and an ozonesonde observation campaign was conducted at Fairbanks in August 2003 as part of the validation experiment. The aim of the campaign was to perform a validation assessment of the ILAS-Ⅱ as well as to resolve the formation mechanism of the small-scale vertical structure of ozone.

In the present paper, we will report on the ozonesonde observation campaign, and then compare the acquired high-frequency ozonesonde data with a three-dimensional chemical transport model. The readers are referred to reference[3] for a validation of the ILAS-Ⅱ data using the data collected during the Alaska Project, which includes the ozonesonde data.

2 The observation campaign

The ozonesonde observation campaign was conducted at Fairbanks (64.8 N,147.9 W), Alaska, from August 23–30, 2003. During that period, a total of 22 electrochemical concentration cell (ECC) ozonesonde observations were conducted, including a synchronized observation with the ILAS-Ⅱ near Fairbanks (conducted daily, at 04 UTC) and intensified observation performed every 3 hours (from 18 UTC 26 to 04 UTC 28 August). The En-Sci 2Z-GPS ozonesonde used in the experiment was equipped with a GPS receiver, and was able to provide horizontal wind velocity data based on positioning data, in addition to the ozone concentration, temperature, and humidity data from the ground up to an altitude of 30 km. Further, GPS radiosonde (Vaisala RS 80–15 GH) observations were carried out at 07, 10, and 13 UTC on August 26, 19 UTC on August 28, and 01 UTC on August 29. Since ECC ozonesonde observation requires a couple of hours for preparation before each balloon release and to complete a sounding, few high-frequency observation attempts have been made in the past. However, in the present experiment, we were able to obtain data having high temporal and vertical resolutions over a 36-hour period.

Figure 2 presents the vertical profile of the

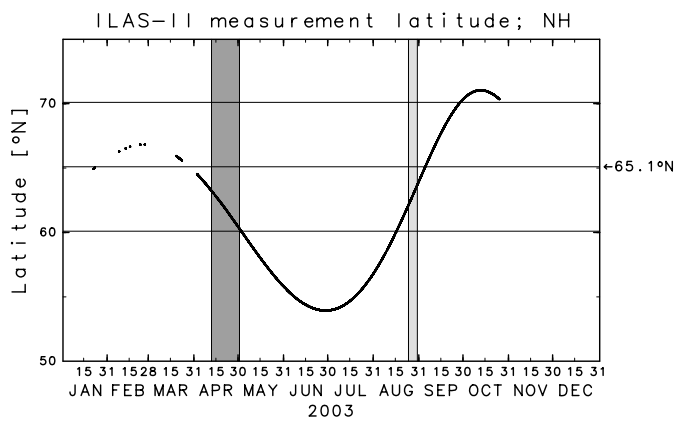

Fig.1 *Time-series of ILAS-Ⅱ measurements, by latitude (limited to the northern hemisphere)*

ozone mixing ratio obtained in these observations. Each profile has been shifted by 2 ppmv per day based on the time elapsed since 20 UTC on August 23. Several notable features emerge from Fig. 2. One such feature is seen in the structure at an altitude of approximately 25–30 km. During the first half of the observation period, the ozone concentration near the 28-km altitude is small, and maxima are seen at two heights: 26 and 33 km. In the latter half of the period, the vertical profile features only a single maximum, near 33 km. Furthermore, at altitudes of 11–17 km, just above the tropopause, a maximum or a minimum of approx. 1 km is continually present. The sections that follow will focus on the latter.

3 Laminated structure in the region directly above the tropopause

Figure 3 is a time-altitude cross-sectional diagram of the ozone mixing ratio at altitudes

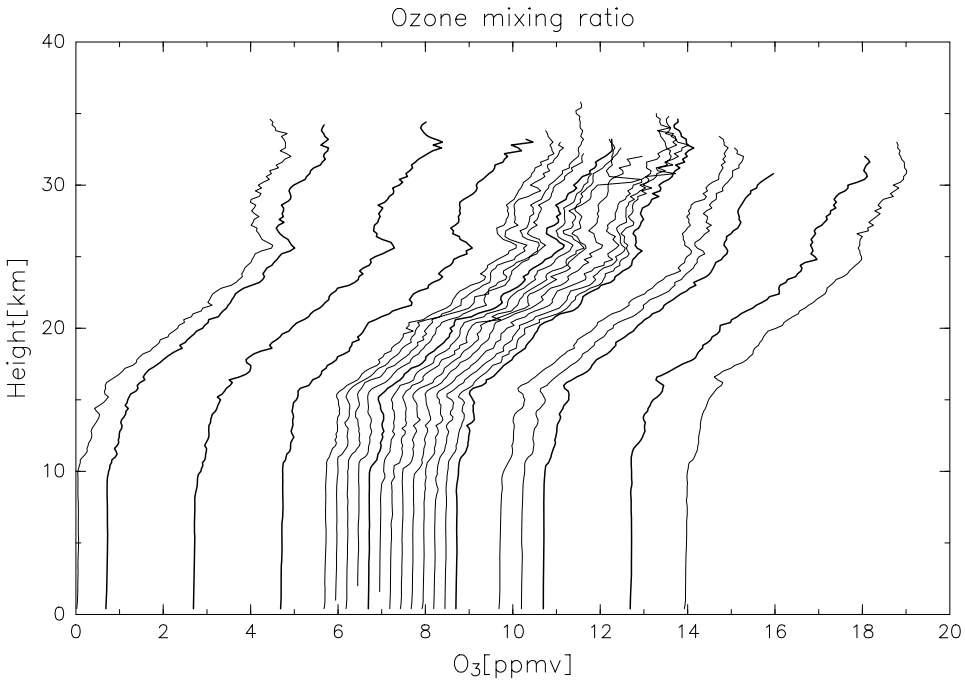

Fig.2 *Vertical profiles of ozone mixing ratio obtained by ozonesondes*

Each profile has been shifted by 2 ppmv per day based on the time elapsed since 20 UTC on August 23. The thick line represents the vertical profile used in ILAS-Ⅱ validation.

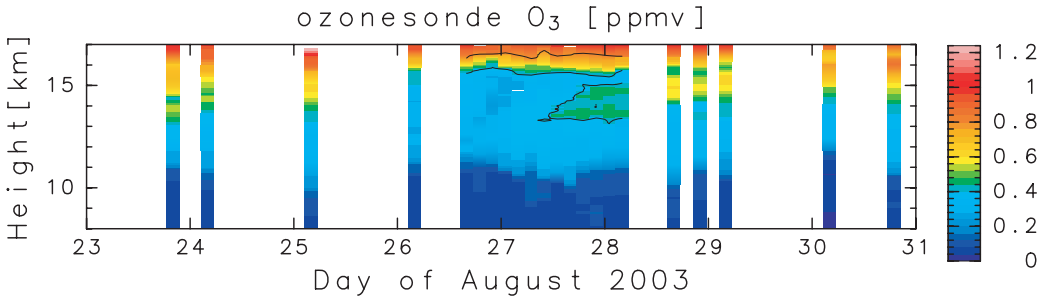

Fig.3 *Time-altitude cross-sectional diagram of the ozone mixing ratio obtained by ozonesonde observation (altitudes of 8–17 km)*

of 8–17 km. Here we see a layer with thickness from several hundred meters to 1 kilometer, in which the ozone concentration either increases or decreases. Maxima are observed near 13.5 km and 14.7 km on August 28, while minima are found near 14.0 and 15.2 km. These features seem to persist even after the intensive observation period (in which observations were made at 3-hour intervals). At this time and altitude, ozone is sufficiently long-lived photochemically so that its distribution should be dependent on its transportation. In other words, air parcels that are transported from ozone-rich regions will have high ozone concentrations, and those from ozone-poor regions will have lower concentrations.

From August 27 to 29, the tropopause above Fairbanks was positioned to the east of an upper-level low pressure, and the prevailing wind was northward. On the other hand, the overall latitudinal gradient of ozone at these altitudes was positive (i.e., with higher concentrations toward the pole). Advection from the south is considered to result in a negative deviation, and at a glance, seems to be inconsistent with the observation results. Three-dimensional chemical transport data was used to investigate the cause of this structure.

4 Comparison with Three-Dimensional Chemical Transport Model data

4.1 The Three-Dimensional Chemical Transport Model

Since the ozone distribution in the lower stratosphere is dominated by the effects of transport, information on the 3-D distributions of ozone mixing ratio and wind velocity fields are essential for interpreting vertical ozone profiles from single-point observations. We used 3-hourly output fields calculated by the stratospheric ozone reanalysis system developed by the Meteorological Research Institute. This system consists of a combination of the Chemical Transport Model (CTM)[4] and the General Circulation Model (GCM). In order to reproduce a realistic atmospheric field, the wind velocity field of NCEP/NCAR reanalysis and the total ozone of the Total Ozone Mapping Spectrometer (TOMS) are both incorporated into the system[5]. The resolution is T42L68 (horizontal resolution is approx. 300 km and vertical resolution in the lower stratosphere is 500 m to 2 km). Using a fine vertical grid for the lower stratosphere where a large vertical ozone gradient is observed, the system has succeeded in reproducing the atmospheric field with significantly higher precision than conventional methods.

4.2 Reverse Domain Filling (RDF) method

Since the model data and the ozonesonde data feature different spatial resolutions and representation, straightforward comparison of fine structures cannot be made. In fact, the laminated structure is not observed in the time-altitude cross-sectional diagram of the ozone mixing ratio near Fairbanks for the model data (Fig. 4). However, since ozone is sufficiently long-lived photochemically in the lower stratosphere so that it can be regarded as a tracer, a high-resolution distribution was created using the backward trajectory in accordance with the following procedure. (See Figure 5 for a schematic representation of this procedure).

(1) The backward trajectory is calculated from time t and position x, and the position of the air parcel x_0 at time $t-\Delta t$, for which the tracer distribution is known, is estimated.
(2) The mixing ratio of the tracer at time $t-\Delta t$ and position x_0 is used to represent the value at time t and position x.
(3) By assigning the initial positions of the trajectory calculations at high density, a high-resolution distribution is obtained.

This method is called Reverse Domain Filling (RDF)[6]. The advantage of RDF is that it produces a distribution with a resolution higher than that of the original data. However, it must be noted that the effects of mixing in

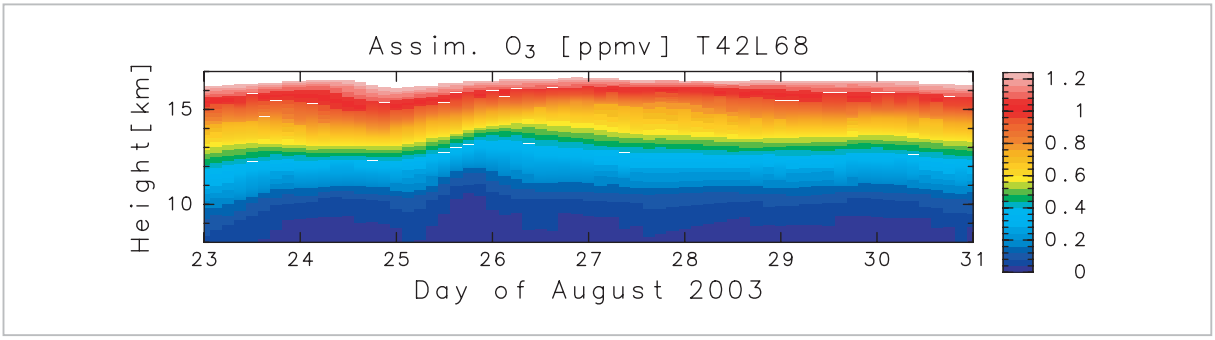

Fig.4 *Time-altitude cross-section diagram of ozone mixing ratio obtained by interpolation from the four grid points near Fairbanks by CTM*

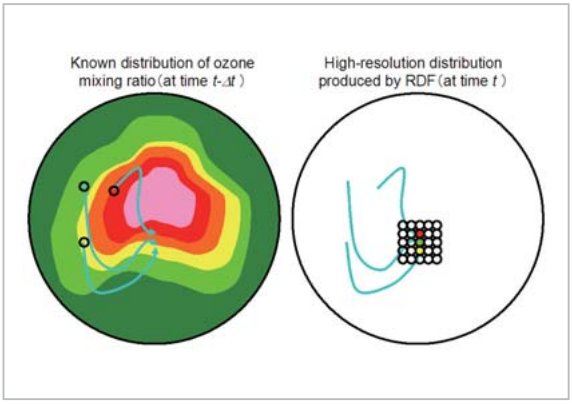

Fig.5 *Schematic illustration of RDF*

the actual atmosphere, which arise on scales smaller than the model resolution, will not be reflected in the results.

The trajectory calculations were made using the meteorological fields obtained from the reanalysis system every 3 hours, and assume an adiabatic process.

4.3 Comparison

Figure 6 is a time-altitude cross-sectional diagram with high vertical resolution produced by RDF. The diagram was created based on the ozone mixing ratio 14 days prior to the date of observation, and the backward trajectories were calculated from each altitude (at approx. 0.1-km intervals) above Fairbanks. The characteristics of the laminated structure, shown in Fig. 3, such as the time and altitude of appearance, were sufficiently reproduced. However, the following inconsistencies are noted: (1) the value of the ozone mixing ratio in Fig. 6 is generally 10 % higher than the observed value; and (2) compared to Fig. 3, the diagram in Fig. 6 appears to have a finer structure in the vertical direction.

A high-resolution horizontal distribution of the ozone mixing ratio was also produced by RDF. Examination of the time evolution showed that an air parcel having high ozone concentration originating in the polar region was stretched thinly by the counter-clockwise flow around upper-level low pressure and was transported to the region above Fairbanks from the south.

5 Discussion

The features of the time-altitude cross section produced by RDF were generally consistent with the laminated structure found in ozonesonde observations, which suggests that the layered ozone structure observed is created by advection caused by the large-scale flow field resolved in the model. The fine vertical structure seen in Fig. 6 may result from the fact that the effect of vertical diffusion present in the actual atmosphere is not reflected in the distribution produced by RDF.

It is believed that ozone is preserved for about two weeks in the 8–17 km altitude range. To confirm this assumption, we performed an integration of the change caused by chemical reactions of an odd-oxygen species (ozone and atomic oxygen) calculated by the model along the trajectory. The results showed that the proportion of these species in the ozone mixing ratio was lower than 3 %.

In the RDF conducted in the present study, the backward integration period is set at 14

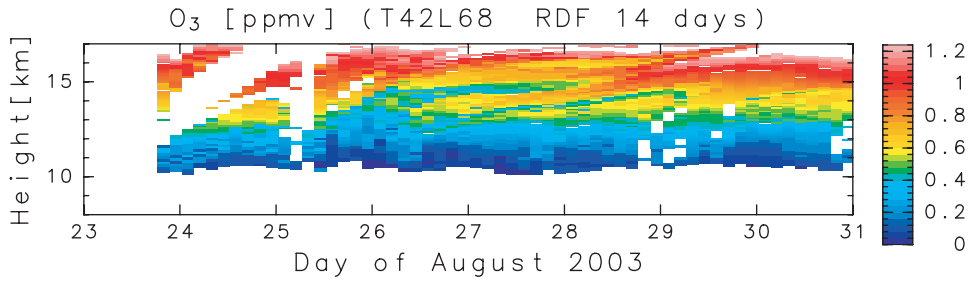

Fig.6 *High-resolution time-altitude cross-section diagram of ozone mixing ratio obtained by RDF*

days. Obviously, the distribution obtained by RDF will display finer features for longer backward integration periods. Thus it will be necessary to determine the most suitable integration period. Conversely, the optimal length of backward integration should provide some information on the extent of mixing in the lower stratosphere.

6 Conclusions

The ozonesonde observation campaign was conducted in August 2003 with the aims of providing a validating assessment of the ILAS-Ⅱ and investigating the fine vertical structures of ozone distribution in the lower stratosphere. By performing an unprecedented intensive high-frequency observation every 3 hours, we succeeded in resolving the time evolution of the laminated structure with thickness ranging from several hundred meters to 1 kilometer directly above the tropopause. The observed laminated structure was reproduced in the high-resolution ozone distribution obtained by the RDF method using data from the three-dimensional chemical transport model. These results imply that the observed layer structure was produced by the large-scale flow field resolved in the model.

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The trajectory calculations were performed using the National Institute of Polar Research (NIPR) trajectory model [7].

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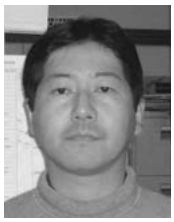

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