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Observation of ¹⁷O anomaly in stratospheric CO₂

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Long-term observation of mass-independent oxygen isotope anomaly in stratospheric CO₂

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Abstract

Anomalous oxygen isotopic compositions of stratospheric CO₂ were first reported in 1989, although their detailed behavior in the middle atmosphere is still open question. We collected 60 stratospheric air samples over Sanriku, Japan from 1991 to 2004 and Kiruna, Sweden in 1997. Using these accumulated air samples, we performed long-5 term observations of triple oxygen isotope compositions of stratospheric CO₂. It is the first simultaneous observation in the stratosphere of both relations between $\Delta^{17}O_{CO2}$ and [N₂O], and $\delta^{18}O_{CO2}$ and $\delta^{17}O_{CO2}$, accurately. Observations confirmed simultaneous linear correlations between $\delta^{18}O_{CO2}$, $\Delta^{17}O_{CO2}$, and [N₂O] within [N₂O]>50 ppbv: the correlations faded away along with decreasing [N2O] from 50 ppbv. For dividing 10 observation results by $[N_2O]=50$ ppbv, the divided datasets show that 1) both $\Delta^{17}O_{CO2}$ and $\delta^{18}O_{CO2}$ are conservative parameters within the N₂O-rich division, 2) the slope of least squares regression on $\delta^{18}O - \delta^{17}O$ plot for the N₂O-rich division is significantly steeper than that of the N₂O-depleted one, and 3) the N₂O-depleted division shows a discrepancy with recent model calculations, suggesting unconsidered isotope fractionation processes on complicated oxygen interactions in the CO₂-O₃-O₂ system in the upper stratosphere and mesosphere.

1 Introduction

Although δ^{17} O values vary during most isotopic fractionation processes, relationship between δ^{17} O and δ^{18} O values are usually conserved according to a mass-dependent relation of δ^{17} O=0.516× δ^{18} O (Matsuhisa et al., 1978; Santrock et al., 1985). Recently, mass-independent triple oxygen isotopic fractionation processes, which bring non-zero Δ^{17} O (= δ^{17} O-0.516 × δ^{18} O) values, so-called ¹⁷O anomaly, have been found in photochemical reactions, such as in the photochemical production of O₃ from O₂ (Thiemens and Heidenreich, 1983; Mauersberger, 1987).

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Tropospheric CO₂ has a almost constant $\delta^{18}O_{VSMOW}$ value (+41‰) with no ¹⁷O anomaly through a rapid oxygen isotope exchange with seawater (Thiemens et al., 1991). On the contrary, anomalously heavy $\delta^{18}O$ and positive ¹⁷O anomaly have been observed in the stratospheric CO₂ over Texas and New Mexico (Thiemens et al., 1991), ⁵ southern high-latitudinal regions (Thiemens et al., 1995a), Kiruna in Sweden (Alexander et al., 2001; Lämmerzahl et al., 2002), Aire-sur-l'Adour in France (Lämmerzahl et al., 2002), and northern high-latitudinal regions (Boering et al., 2004). A positive ¹⁷O anomaly in CO₂ has been also observed in upper stratosphere and lower mesosphere over New Mexico (Thiemens et al., 1995b). It is generally thought that the ¹⁷O anomaly observed in the stratospheric CO₂ is brought through a series of reactions, where O₃ is a source of extra heavy $\delta^{18}O$ and $\Delta^{17}O$ anomaly (Mauersberger, 1987; Yung et al.,

1991):

$$O_3 + h\nu(< 310 \text{ nm}) \rightarrow O_2 + O(^1\text{D})$$
 (R1)

$$CO_2 + O(^1D) \rightarrow CO_3^* \rightarrow CO_2 + O(^3P)$$
(R2)

¹⁵ In parallel with the field observations, several laboratory experiments and model calculations have been conducted to elucidate detailed mechanism of the mass-independent oxygen isotope fractionation of CO₂, O₃, and O₂ in the middle atmosphere (e.g. Chakraborty and Bhattacharya, 2003; Liang et al., 2007).

Although several observations have reported anomalous oxygen isotopic compo-

²⁰ sitions in stratospheric CO₂, only limited number of samples or parameters, which makes further detailed quantitative analysis difficut, has been obtained in each observation. For example, results from only few stratospheric air samples (less than 10) were presented (Thiemens et al., 1991, 1995a; Alexander et al., 2001). Only Lämmerzahl et al. (2002) and Boering et al. (2004) have reported a notable correlation of $\Delta^{17}O_{CO2}$ respectively with other tracers, such as $\delta^{18}O_{CO2}$ over Aire-sur-l'Adour and Kiruna (Lämmerzahl et al., 2002) and with N₂O mixing ratio ([N₂O]) over the northern high-latitudinal region (Boering et al., 2004).

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Interactive Discussion

Since 1985, we have continued stratospheric whole air sampling over Sanriku, Japan. This is so far the only long-term stratospheric whole air sampling and a portion of the δ^{18} O data in the lower stratospheric CO₂ has been reported (Gamo et al., 1989, 1995). In this paper, we report triple oxygen isotope compositions and its relationship to [N₂O] obtained in the past 14 years long-term sampling in addition to a stratospheric air sampling carried out over Kiruna in February 1997, when the sampling area was inside a polar vortex. A novel analytical method we recently developed was used to determine $\Delta^{17}O_{CO2}$ (Kawagucci et al., 2005).

2 Sampling and analysis

¹⁰ During 1991–2004, vertical samples of stratospheric whole air were collected during seven observations in early or late summer over Sanriku, Japan (39° N)(Table 1) using a balloon-borne cryogenic sampler developed by the Japan Aerospace Exploration Agency (JAXA). Utilizing the same sampling system, an additional vertical sampling was carried out at Kiruna, Sweden (68° N) on 22 February 1997 (Table 1). The air sampling system is capable of collecting whole air samples with little transformation of chemical and isotopic compositions. Detailed descriptions of the sampler and sampling procedures have been reported elsewhere (Nakazawa et al., 1995; Honda et al., 1996; Aoki et al., 2003).

After taking aliquots from the sampled whole air in the sampler, both $\delta^{18}O_{CO2}$ and $\delta^{17}O_{CO2}$ values in the sampled stratospheric air were simultaneously analyzed using a continuous-flow isotope ratio mass spectrometer, which requires no preparation processes such as separation of CO₂ from other components and fluorination conversion of CO₂ to O₂ in determining $\Delta^{17}O_{CO2}$ in a small amount of whole air sample (Kawagucci et al., 2005). Analytical precisions for the analyzed $\delta^{18}O_{CO2}$, $\delta^{17}O_{CO2}$, and $\Delta^{17}O_{CO2}$ in this study were estimated at most, ±0.05‰, ±0.5‰, and ±0.5‰, respectively. In ad-

dition, the N_2O mixing ratios were also determined using other aliquots from the same

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stratospheric air samples. Some of the $\delta^{18}O_{CO2}$, $\delta^{17}O_{CO2}$, and N₂O mixing ratio data have been already reported previously (Aoki et al., 2003; Kawagucci et al., 2006).

3 Results

3.1 Sanriku

⁵ 49 whole air samples in the stratosphere, including four samples just below or around the tropopause, were obtained during seven launches in the past 14 years (Table 1). Figure 1 plots vertical profiles of $\Delta^{17}O_{CO2}$. Significantly positive ¹⁷O anomalies in CO₂ with at most +7.6‰ were found over Sanriku, although no ¹⁷O anomaly was observed near the tropopause. The long-term observations over Sanriku confirm that no clear year-to-year variation exists in vertical profiles of $\Delta^{17}O_{CO2}$ for the past 14 years beyond small fluctuations, which is caused by natural air transport, although vertical profiles of the CO₂ mixing ratio in the stratosphere show a clear increasing trend by a ratio of ca. 1.4 ppmv per year (Aoki et al., 2003).

Figures 2a, b show correlations of $\Delta^{17}O_{CO2}$ and $\delta^{18}O_{CO2}$ to $[N_2O]$. All data obtained ¹⁵ during the past 14 years are plotted. Both $\Delta^{17}O_{CO2}$ and $\delta^{18}O_{CO2}$ exhibit almost negative linear correlations with $[N_2O]$ and no year-to-year variation was observed. The observed negative linear correlation between $\Delta^{17}O_{CO2}$ and $[N_2O]$ supports the first observation about the correlation over northern high-latitudinal region (Boering et al., 2004), while the linear correlation between $\delta^{18}O_{CO2}$ and $[N_2O]$ is first observed in this study. Additionally, the $\delta^{18}O$ and $\delta^{17}O$ values in stratospheric CO_2 exhibit an almost positive linear trend with no year-to-year variation (Fig. 3).

3.2 Kiruna

We obtained 11 whole air samples from the stratosphere over Kiruna, including one sample collected around the tropopause (Table 1). A vertical profile of the $\Delta^{17}O_{CO2}$

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(Fig. 1) showed that above 20 km altitude ¹⁷O anomalies became much larger with increasing altitude compared to those below 20 km altitude. The profile is similar to the typical one observed for long-lived tracers within a polar vortex, where upper stratospheric air descends into lower stratosphere because of strong downward advection (Waugh and Hall, 2002). As a result, air with characteristics of upper stratosphere could be observed even in lower stratosphere in this region (Waugh and Hall, 2002). In our observation, $\Delta^{17}O_{CO2}$ at 25.6 km height was +12.2‰ (Table 1), which is as large as previously observed in the mesosphere (Thiemens et al., 1995b). Therefore, we consider that the observed lower stratospheric air above 25 km height in Kiruna had been brought from mesosphere by a strong downward advection. One should 10 notice that correlations of $\Delta^{17}O_{CO2}$ and $\delta^{18}O_{CO2}$ to [N₂O] changed significantly at a $[N_2O] \sim 50$ ppbv (Fig. 2). At a condition of $[N_2O] > 50$ ppbv, both $\Delta^{17}O_{CO2}$ and $\delta^{18}O_{CO2}$ showed linear correlations similar to those observed over Sanriku, however, at the condition of [N₂O]<50 ppbv, the correlations faded away along with decreasing [N₂O] from 50 ppbv. 15

4 Discussion

It has been known that physical height (altitude) is not a conserved parameter to describe vertical structure in the stratosphere because of the complex air mass transition in different times and locations. For this reason, it is not possible to compare $\Delta^{17}O_{CO2}$ values among different years and locations based on sampling altitudes. In contrast, N₂O is known to be used as a tracer of air mass in the lower stratosphere since N₂O is a long-lived trace gas and emitted only from earth's surface (Waugh and Hall, 2002). The observed negative linear correlation between $\Delta^{17}O_{CO2}$ and [N₂O] within [N₂O]>50 ppbv over Sanriku and Kiruna suggests that the $\Delta^{17}O_{CO2}$ value is also regarded as a long-lived tracer. Similar linear correlation between $\Delta^{17}O_{CO2}$ and [N₂O] has been also reported in the northern high latitudinal region (Boering et al., 2004).



In addition, we also found the negative correlation between $\delta^{18}O_{CO2}$ and $[N_2O]$ in the lower stratospheric air (i.e., air masses with $[N_2O] > 50$ ppbv), suggesting that $\delta^{18}O_{CO2}$ is also a long-lived tracer like N_2O in the lower stratosphere. These observed linear relationship of $\Delta^{17}O_{CO2}$ and $\delta^{18}O_{CO2}$ to $[N_2O]$ within air containing $N_2O > 50$ ppbv indicate that both $\Delta^{17}O_{CO2}$ and $\delta^{18}O_{CO2}$ undergo physicochemical processes similar to those long-lived N_2O undergoes in the air mass with $N_2O > 50$ ppbv in the stratosphere. Namely, in-situ photochemical reactions as suggested previously (e.g., R2) are not responsible for the mass-dependent and mass-independent oxygen isotope fractionations in CO_2 , but simple physical mixing of different air masses is responsible for the 10 fractionation within air masses containing $N_2O > 50$ ppbv in the stratosphere.

On the other hand, the correlations of $\Delta^{17}O_{CO2}$ and $\delta^{18}O_{CO2}$ to $[N_2O]$ in the air masses containing $[N_2O] < 50$ ppbv over Sanriku and Kiruna showed a relationship which is different from those observed in the air mass with $[N_2O] > 50$ ppbv (Fig. 2). Similar change at $[N_2O] \sim 50$ ppbv in the correlations of $\Delta^{17}O_{CO2}$ and $\delta^{18}O_{CO2}$ to $[N_2O]$ have been observed in the upper stratosphere and lower mesosphere over New Mex-

ico (Thiemens et al., 1995b) as plotted with our observations in Fig. 2. One should notice that the data observed over New Mexico quite nicely overlap with our observation. Therefore, we divided our observation results over Sanriku and Kiruna at [N₂O]=50 ppbv and referred air masses in the N₂O-rich division (>50 ppbv) as "lower stratosphere-like air" and those in the N₂O-depleted division (<50 ppbv) as "upper

stratosphere/lower mesosphere-like air."

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Figure 3 plots a correlation between δ^{18} O and δ^{17} O, which is useful to discuss massindependent isotope fractionation processes since vertical deviation from the terrestrial fractionation line (TFL: slope = 0.516) corresponds to ¹⁷O anomaly. Using a least-

square regression analysis, slopes of the correlation lines in the lower stratospherelike air and the upper stratosphere/lower mesosphere-like air were calculated (Fig. 3). Their slopes were 1.75±0.17 (lower stratosphere-like air) and 1.17±0.24 (upper stratosphere/lower mesosphere-like air), respectively, which shows there is a clear difference 7, 15723–15737, 2007

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in the slopes. Even if $[N_2O]=30$ ppbv or 70 ppbv was employed as a dividing point of the air mass type, the difference qualitatively remained similar. It should be pointed out that the slope in the lower stratosphere-like air in this study agrees well with that observed in the lower stratosphere over Aire-sur-l'Adour and Kiruna (1.71±0.03) (Lämmerzahl

- et al., 2002), while the upper stratosphere/lower mesosphere-like air observed in this study agrees well with that observed in upper stratosphere and mesosphere over New Mexico (1.21±0.19) (Thiemens et al., 1995b). The clear difference in slopes suggests presence of isotope fractionation process(es) for triple oxygen isotope compositions in the upper stratosphere/lower mesosphere-like CO₂ in addition to those for the lower
 stratosphere-like CO₂, which is long-lived and its triple oxygen isotope compositions is
 - controlled by only physical process such as air mass movement.

Characteristic oxygen isotope fractionation in CO₂ through the stratosphere and mesosphere has been proposed in a recent model calculation study (Liang et al., 2007), which considered O₂ photolysis as a dominant O(¹D) source on (R2) above upper mesosphere (~70 km height), while in the current observation only air masses in the stratosphere and the lower mesosphere below 60 km height have been sampled. The model calculation also qualitatively reproduced observed relationships of $\delta^{18}O_{CO2}-\delta^{17}O_{CO2}$ in the stratosphere (see Figs. 4 and 5 in Liang et al., 2007), however, the deviation of the model calculation from the observations including current study gradually increased as [N₂O] decreased, resulting in underestimated $\Delta^{17}O_{CO2}$ value in both $\delta^{18}O_{CO2}-\delta^{17}O_{CO2}$ plot and $\Delta^{17}O_{CO2}-[N_2O]$ plot. These deviations in the low [N₂O] conditions suggests existence of process(es) during oxygen isotope exchanges in CO₂-O₃-O₂ system in the upper stratosphere and mesosphere, which is not considered in the current model study.

25 5 Conclusions

Our observations revealed and reconfirmed following new and important facts related to stratospheric CO₂.



- 1) Simultaneous observation of $\delta^{18}O_{CO2}$, $\Delta^{17}O_{CO2}$, and $[N_2O]$ confirmed a negative linear correlation between $[N_2O]$ and $\Delta^{17}O_{CO2}$, and newly revealed a similar correlation between $[N_2O]$ and $\delta^{18}O_{CO2}$ within $[N_2O]$ >50 ppbv, indicating that $\Delta^{17}O_{CO2}$ and $\delta^{18}O_{CO2}$ are long-lived.
- 2) No clear year-to-year variation was found in the correlations of $\Delta^{17}O_{CO2}$ to altitude, [N₂O], and $\delta^{18}O_{CO2}$.

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- 3) Relationship between $\delta^{18}O_{CO2}$ and $\delta^{17}O_{CO2}$ found to be divided into two different linear ones when the samples are divided at $[N_2O]=50$ ppbv, suggesting existence of oxygen isotope fractionation process of CO₂ in the N₂O-depleted air.
- 4) Discrepancy between observations and the recent model calculation was found in the N₂O-depleted air, suggesting existence of oxygen isotope fractionation(s) during complicated oxygen interactions in CO₂-O₃-O₂ system at the upper stratosphere and mesosphere.

Present study confirmed several features of oxygen isotope behaviors in stratospheric ¹⁵ CO₂ which have been previously reported and also found possible existence of unaccounted oxygen isotope fractionation process(es). However, detailed oxygen isotope fractionations in a CO₂-O₃-O₂ system at the stratosphere and mesosphere have not yet fully understood and still remain an open question.

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- Alexander, B. M., Vollmer, K., Jackson, T., Weiss, R. F., and Thiemens, M. H.: Stratospheric CO₂ isotopic anomalies and SF₆ and CFC tracer concentration in the Arctic polar vortex, Geophy. Res. Lett., 28(21), 4103–4106, 2001.
- Aoki, S., Nakazawa, T., Machida, T., Sugawara, S., Morimoto, S., Hashida, G., Yamanouchi, T., Kawamura, K., and Honda, H.: Carbon dioxide variations in the stratosphere over Japan, Scandinavia and Antarctica, Tellus B, 55(2), 178–186, 2003.
 - Boering, K. A., Jackson, T., Hoag, K. J., Cole, A. S., Perri, M. J., Thiemens, M. and Atlas, E.: Observations of the anomalous oxygen isotopic composition of carbon dioxide in the lower
- stratosphere and the flux of the anomaly to the troposphere, Geophy. Res. Lett., 31 (3), L03109, doi:10.1029/2003GL018451, 2004.
 - Chakraborty, S. and Bhattacharya, S. K.: Experimental investigation of oxygen isotope exchange between CO2 and O(D-1) and its relevance to the stratosphere, J. Geophys. Res., 108(D23), 4724, doi:10.1029/2002JD002915, 2003.
- Gamo, T., Tsutsumi, M., Sakai, H., Nakazawa, T., Tanaka, M., Honda, H., Kubo, H., and Itoh, T.: Carbon and oxygen isotopic ratios of carbon dioxide of a stratospheric profile over Japan, Tellus B, 41, 127–133, 1989.
 - Gamo, T., Tsutsumi, M., Sakai, H., Nakazawa, T., Machida, T., Honda, H., and Itoh T.: Long-Term monitoring of carbon and oxygen-isotope ratios of stratospheric CO₂ over Japan, Geonby Res Lett. 22(4) 397–400, 1995

²⁰ phy. Res. Lett., 22(4), 397–400, 1995.

Honda, H., Aoki, S., Nakazawa, T., Morimoto, S., and Yajima, N.: Cryogenic air sampling system for measurements of the concentrations of stratospheric trace gases and their isotopic ratios over Antarctica, J. Geomagn. Geoelectr., 48, 9, 1145–1155, 1996.

Kawagucci, S., Tsunogai, U., Kudo, S., Nakagawa, F., Honda, H. Aoki, S. Nakazawa, T., and

- ²⁵ Gamo, T.: An analytical system for determining δ^{17} O in CO₂ using Continuous Flow-Isotope Ratio MS, Anal. Chem., 77(14), 4509–4514, 2005.
 - Lämmerzahl, P., Röckmann, T., Brenninkmeijer, C. A. M., Krankowsky, D., and Mauersberger, K.: Oxygen isotope composition of stratospheric carbon dioxide, Geophy. Res. Lett., 29(12), 1582, doi:10.1029/2001GL014343, 2002.
- Liang, M. C., Blake, G. A., Lewis, B. R., and Yung, Y. L.: Oxygen isotopic composition of carbon dioxide in the middle atmosphere, P. Natl. Acad. Sci. USA, 104, 21–25, 2007.
 Matsuhisa, Y., Goldsmith, J. R., and Clayton, R. N.: Mechanism of hydrothermal crystallization

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of quartz at 250°C and 15 kbar, Geochim. Cosmochim. Ac., 42, 173–182, 1978.

Mauersberger, K.: Ozone Isotope Measurements in the Stratosphere, Geophy. Res. Lett., 14(1), 80–83, 1987.

Nakazawa, T., Machida, T., Sugawara, S., Murayama, S., Morimoto, S., Hashida, G., Honda,

- ⁵ H., and Itoh, T.: Measurements of the stratospheric carbon dioxide concentration over Japan using a balloon-borne cryogenic sampler, Geophy. Res. Lett., 22(10), 1229–1232, 1995.
 - Santrock, J., Studley, S. A., and Hayes, J. M.: Isotopic analyses based on the mass spectrum of carbon dioxide, Anal. Chem., 57, 1444–1448, 1985.

Thiemens, M. H. and Heidenreich, J. E.: The Mass-Independent Fractionation of Oxygen -

- A Novel Isotope Effect and Its Possible Cosmochemical Implications, Science, 219(4588), 1073–1075, 1983.
 - Thiemens, M. H., Jackson, T., Mauersberger, K., Schueler, B., and Morton, J.: Oxygen Isotope Fractionation in Stratospheric CO₂, Geophy. Res. Lett., 18(4), 669–672, 1991.

Thiemens, M. H., Jackson, T., and Brenninkmeijer, C. A. M.: Observation of a mass indepen-

dent oxygen isotopic composition in terrestrial stratospheric CO_2 , the link to ozone chemistry, and the possible occurrence in the Martian atmosphere, Geophys. Res. Lett., 22(3), 255–258, 1995a.

15

20

- Thiemens, M. H., Jackson, T., Zipf, E. C., Erdman, P. W., and Vanegmond, C.: Carbon-Dioxide and Oxygen-Isotope Anomalies in the Mesosphere and Stratosphere, Science, 270, 969– 972, 1995b.
- Waugh, D. and Hall, T.: Age of stratospheric air: Theory, observations, and models, Rev. Geophys., 40(4), 1010, doi:10.1029/2000RG000101, 2002.
- Yung, Y. L., Demore, W. B., and Pinto, J. P.: Isotopic Exchange between Carbon-Dioxide and Ozone Via O(¹D) in the Stratosphere, Geophy. Res. Lett., 18(1), 13–16, 1991.

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Table 1. Measured oxygen isotopic compositions of CO₂ are shown with the sampling location, date, and altitude. Several samples indicated by * are obtained just below or around the tropopause. Errors of δ^{18} O, δ^{17} O, and Δ^{17} O are estimated respectively as, at most, 0.05‰, 0.5‰, and 0.5‰.

Location Date Attitude A ¹⁰ O b ¹⁰ O b ¹⁰ O (m) (%) (%) (%) (%) Sanniku 29 Aug 91 33.3 46.37 30.8 6.9 (39'N) 31 Aug 94 18.2 41.89 22.6 1.0 20.4 42.92 23.2 1.4 22.4 41.29 23.2 1.4 22.4 41.29 23.2 1.6 24.7 43.67 25.8 3.0 26.8 43.75 25.6 3.0 29.2 43.25 25.7 3.2 31.1 44.29 27.8 5.5 8 June 95 20.3 41.75 27.6 4.2 22.3 41.92 23.1 1.47 24.5 45.33 24.1 4.7 26.7 45.21 27.9 4.5 28.4 64.13 30.5 6.6 32.4 47.50 31.3 6.8 31.6 44.50 25.0 0.7 16.7 41.97 27.6 4.5 28.8 40.13 30.5 6.6 32.4 47.50 31.3 6.8 33.8 46.73 30.3 6.1 7.7, 1 41.97 27.6 4.5 20.9 42.2 25.0 2.7 18.7 45.21 27.9 4.5 28.8 40.13 30.5 6.6 32.4 47.50 31.3 6.8 32.4 47.50 31.3 6.8 33.8 46.73 30.3 6.1 7.7, 1 41.80 22.3 0.7 18.7 41.97 27.1 4.4 30 May 01 14.9 41.22 27.1 4.4 30 May 01 14.9 41.22 27.1 4.4 30 May 01 14.9 41.22 27.1 7.50 27.6 42.24 21.6 -0.2 2 7.6 42.24 21.6 -0.2 2 7.6 42.24 21.6 -0.2 2 7.6 42.24 21.6 -0.2 2 7.6 43.18 02.0 3.7 15.2 42.24 21.6 -0.2 2 7.6 43.18 02.0 3.7 15.2 42.24 21.6 -0.2 2 7.7 41.7 27.50 4 Sep 02 15.2 42.24 21.6 -0.2 2 7.7 41.7 25.0 5.1 18.7 42.15 23.1 1.3 20.6 43.16 25. 6.9 15.2 42.24 21.6 -0.2 2 7.7 41.7 25.0 5.1 18.7 42.15 23.1 1.3 20.6 43.16 25. 6.9 15.2 42.24 21.6 -0.2 2 7.7 5.0 27.6 43.28 25.5 1.3 30.4 34.02 37.7 5.0 27.7 41.7 28.2 5.1 13.0 43.67 22.0 0.5 18.7 42.27 23.0 5 27.7 3.4 7.79 28.2 5.1 30.3 45.68 30.5 6.9 21.2 42.24 21.6 -0.2 2 22.4 43.39 25.7 4.1 22.9 44.03 37.1 1.5 40.47 30 2.5 6.9 1.5 42.17 1.2 4.5 1.5 2.4 2.24 21.6 -0.2 2 7.7 5.0 2.7 3.0 4.5 62.4 3.1 2.0 5 6.9 3.0 4.5 6.9 3.0 4.5 6.9 3.0 4.5 6.9 3.0 4.5 6.9 3.0 4.5 6.9 3.0 4.5 7.7 5.0 2.1 4.2 2.2 1.5 5 2.1 4.5 2.2 5.1 3.0 5 6.9 3.0 4.5 7.7 4.1 2.2 6.5 1.2 2.8 3.2 1.1 5.8 3.1 5.6 42.4 3.1 3.2 6.6 3.1 0.1 3.2 6.6 3.3 7.1 3.2 6.6 3.3 7.1 3.2 6.6 3.3 7.1 3.2 6.9 3.7 3.3 6.6 45.0 3.3 7.1 3.4 4.7 7.7 4.7 2.2 2.5 1.2 5 3.5 4.2 4.2 4.0 1.7 1.5 4.2 4.2 2.8 5.1 3.5 4.5 4.7 4.8 6.8 3.2 8.6 46.8 3.4 3.7 2.4 4.5 2.9 2.4 2.8 3.2 4.2 4.5 2.5 7.4 3.9 2.4 4.5 5.8 7.4 4.5 9.1 3.5 4.5 7.4 3.9 2.							
(km) (%k) (%k) (%k) Samriku 29 Aug 91 33. 46.37 30.8 6.9 31 Aug 94 18.3 46.37 30.8 6.9 31 Aug 94 18.2 41.89 28.2 1.4 20.4 24.29 22.2 1.4 20.4 42.29 22.4 2.6 6.8 24.7 43.67 25.8 3.3 25.2 43.75 27.6 4.5 21.4 42.9 2.6 1.1 42.7 43.67 24.8 2.3 31.4 42.9 2.6 1.1 44.75 27.6 4.5 3.3 34.7 44.75 27.6 4.5 30.6 46.31 30.5 6.6 32.4 47.50 3.3 8.6 20.6 49.73 30.3 6.1 21.7 4.4 30.3 6.5 32.8 46.73 30.3 6.1	Location	Date	Altitude	δ ¹⁸ O	$\delta^{17}O$	$\delta^{17}O$	
Samiku 29 Aug 91 33.3 46.37 30.8 6.9 (39'N) 31 Aug 94 18.2 41.18 22.8 1.0 21.3 Aug 94 18.2 41.18 22.8 1.0 22.3 4.222 22.4 1.4 22.3 4.222 2.4 22.3 4.222 2.4 4.223 3.1 4.429 2.6 31.1 44.29 2.7 3.2 3.1 4.429 2.8 5.0 31.1 4.429 2.8 1.4 2.4 5.6 5.0 31.1 4.429 2.8 1.4 7.5 5.6 5.0 31.1 4.429 2.1 1.4 7.5 2.6 4.53 3.0 6.6 32.4 4.53 3.0 6.6 3.6 6.6 3.6 6.6 3.6 6.6 3.6 6.6 3.6 6.6 3.6 6.6 3.6 6.6 3.6 6.6 3.6 6.6 3.			(km)	(‰)	(‰)	(‰)	
(39'N) 38.3 44.16 29.8 6.5 31 Aug 94 38.3 44.16 29.8 6.5 31 Aug 94 21.4 41.89 22.6 1.4 20.4 24.29 2.2 1.4 20.4 42.29 2.2 1.4 20.4 42.29 2.2 2.1 4.4 2.4 2.6 1.0 24.7 43.67 2.8 3.3 3.6 8.3 3.6 8.3 3.6 3.1 4.4 2.7 8.0 2.1 1.4 4.29 2.6 1.1 4.4 5.7 3.2 3.1 1.4 4.24 7.4 7.3 3.6 5.5 2.8 4.1 3.6 5.5 3.6 6.6 3.6 7.4 5.21 2.7 4.5 2.8 3.6 5.5 2.8 4.13 3.6 6.7 3.5 6.6 3.2 3.6 7.7 1.6 3.6 3.6 7.7 1.6 3.6 3.6 7.7	Sanriku	20 Aug 01	33.3	46.37	30.8	6.9	
(a) (b) (b) (b) (b) (b) (b) (b) (b) (b) (b	(39° NI)	23 Aug 31	35.3	45.18	20.8	6.5	
Si Kaj Si 20.4 4.229 25.2 1.4 20.4 4.229 25.2 1.4 24.7 34.22 24.8 2.6 24.7 34.67 25.8 3.3 28.2 43.50 25.7 3.2 31.1 44.29 25.6 3.0 29.2 43.50 25.7 3.2 31.1 44.29 25.8 1.1 44.7 44.75 27.6 4.5 22.3 41.92 23.1 1.4 22.3 41.92 23.1 1.4 22.3 41.92 23.1 1.4 26.7 45.21 27.9 4.5 28.4 61.3 30.5 6.6 32.4 47.50 31.3 6.8 29.9 42.92 25.0 2.9 29.9 42.92 25.0 2.9 20.9 42.92 25.0 2.9 21.1 41.02 21.7 0.4<	(03 14)	31 Aug 94	18.2	/1 80	22.6	1.0	
22.3 42.2 24.9 2.6 24.7 43.67 28.8 3.3 25.8 43.57 28.8 3.3 26.8 43.57 28.8 3.3 28.8 43.57 28.8 3.3 21.1 44.50 27.7 5.0 31.1 44.20 27.7 5.0 31.1 44.20 27.8 5.0 31.1 44.20 28.7 2.3 24.3 44.52 28.1 1.7 26.7 45.3 30.3 6.6 32.4 46.13 30.3 6.8 32.4 47.50 31.3 6.8 32.4 47.50 31.3 6.8 32.4 47.50 31.3 6.8 32.4 47.50 31.3 6.8 32.4 47.50 31.3 6.8 32.4 47.50 31.3 6.8 32.4 47.50 31.3 6.8		01 Aug 34	20.4	42.20	23.2	1.0	
24.7 44.67 44.67 56.8 3.3 28.2 44.57 25.6 3.0 29.2 44.57 25.6 3.0 31.1 44.29 25.7 3.2 31.7 44.75 27.6 4.5 22.3 41.92 25.1 1.4 22.3 41.92 25.1 1.4 22.3 41.92 25.1 1.4 22.3 41.92 25.1 1.4 26.7 45.21 27.9 4.5 28.4 47.50 31.3 6.8 30.6 46.31 30.5 6.6 32.4 47.50 31.3 6.8 20.9 42.92 25.0 7.9 21.7 1.4 -0.0 7.1 41.80 20.9 42.92 25.0 2.9 2.3 21.7 4.4 4.00 2.0 -0.1 1.4 30 May 01 14.9 41.2 1.7 4.4 <td></td> <td></td> <td>20.4</td> <td>42.20</td> <td>24.0</td> <td>2.6</td> <td></td>			20.4	42.20	24.0	2.6	
26.8 43.75 25.6 3.0 28.8 43.75 25.6 3.0 31.1 44.29 27.7 3.0 31.1 44.29 27.8 5.0 31.1 44.29 27.8 5.0 31.1 44.29 27.8 5.5 20.3 43.67 24.8 2.3 24.5 49.22 3.1 1.4 24.5 45.35 28.1 4.7 24.5 45.33 28.1 4.7 26.7 45.21 27.9 4.5 30.6 46.31 30.5 6.6 32.4 47.50 31.3 6.8 20.4 47.50 31.3 6.8 30.8 46.13 30.5 6.6 32.4 47.50 31.3 6.8 20.9 22.9 22.0 2.9 22.7 43.22 2.5 4.14 -0.7 18.4 10.02 5.0.2 2.7			22.3	40.22	24.9	2.0	
28.0 43.50 25.7 3.2 29.2 43.50 25.7 3.2 31.1 44.29 27.8 5.5 31.1 44.29 27.8 5.5 31.1 44.29 27.8 5.5 23.3 44.67 24.31 1.4 22.3 44.67 24.31 1.4 22.3 44.67 24.31 1.4 26.7 45.21 27.9 4.5 28.4 45.13 30.6 6.6 32.4 47.50 33.3 6.6 32.4 47.50 33.3 6.6 32.4 47.50 33.3 6.6 24.4 7.50 5.00 7 17.1 41.80 22.3 0.7 17.1 41.80 22.3 0.7 17.1 41.80 22.3 0.5 20.9 42.22 2.5 2.9 22.7 42.23 0.5 0.0 1.4			24.7	43.07	25.6	3.3	
49.2 43.20 27.8 5.2 31.1 44.29 27.8 5.2 34.7 44.75 27.6 5.2 34.7 44.75 27.6 5.2 34.7 44.75 27.6 5.2 22.3 41.62 24.8 2.3 1.4 24.5 45.35 28.1 4.7 26.7 45.21 27.9 4.5 28.8 46.13 30.6 6.6 32.4 47.50 31.3 6.6 32.4 47.50 31.3 6.6 32.4 47.50 31.3 6.6 32.4 47.50 31.3 6.6 32.4 47.50 31.3 6.6 32.4 47.50 31.3 6.8 16.7 41.97 21.4 -0.3 20.9 22.7 43.23 25.6 4.3 30 May 01 14.9 41.22 21.7 0.4 41.8 40.0			20.0	40.00	25.0	3.0	
31.1 44.75 27.8 3.15 34.7 44.75 27.8 2.3 8 June 95 20.3 43.67 24.8 2.3 24.7 44.75 27.9 4.5 24.7 46.31 30.5 6.6 32.4 44.75 30.3 6.1 38.8 47.73 30.3 6.1 38.8 47.50 30.5 6.0 34.4 44.53 20.3 6.5 34.4 47.50 30.5 6.0 11.1 41.80 22.3 0.7 11.7 41.80 22.3 0.7 11.7 41.80 22.4 3.1 20.9 42.92 2.6 2.9 22.7 44.23 2.17 -0.0 16.8 41.04 2.17 0.5 18.7 40.02 2.05 -0.2 - 18.8 40.02 2.05 -0.2 - 18.7 42.03 </td <td></td> <td></td> <td>29.2</td> <td>43.50</td> <td>25.7</td> <td>3.2</td> <td></td>			29.2	43.50	25.7	3.2	
8 June 95 20.3 43.67 24.8 2.3 22.3 43.67 24.8 2.3 1.4 24.5 43.67 23.1 1.4 24.5 45.37 23.1 1.4 24.5 45.37 23.3 6.5 28.6 46.13 30.5 6.8 32.4 47.50 31.3 6.8 32.4 47.50 31.3 6.8 32.4 47.50 30.3 6.1 71.1 41.80 22.3 0.1 - 17.1 41.87 21.4 -0.3 20.9 22.5 4.41.3 27.1 4.4 - 20.7 42.22 25.0 2.9 22.5 4.41.3 27.1 4.4 -			31.1	44.29	27.0	5.U	
a Julie y5 20.3 41.92 23.1 1.4 24.5 45.33 28.1 1.4 26.7 45.21 29 4.5 26.8 46.13 30.3 6.6 30.6 46.31 30.3 6.6 30.6 46.31 30.5 6.6 30.6 46.31 30.5 6.1 28.8 46.13 30.5 6.1 30.4 47.75 31.3 6.1 11.1 14.80 20.3 2.0 7 11.1 41.80 20.3 2.0 7 20.9 42.92 2.6.0 2.9 2.7 21.7 14.80 20.5 -0.2 9 21.7 14.4 30 May 01 14.9 41.22 2.1 1.4 30 May 01 14.9 41.2 7.0 5 1.8 21.6 42.00 2.7 5.0 -0.2 1.8 4.002 2.05		0. 1	34.7	44.75	27.0	4.5	
24.5 4 45.35 25.1 1.7 24.5 45.35 25.1 4.7 26.7 45.21 27.9 4.5 26.8 46.13 30.3 6.5 26.8 46.13 30.5 6.6 32.4 47.50 31.3 6.8 32.4 47.50 31.3 6.6 32.4 47.50 31.3 6.8 22.7 42.92 25.0 0.7 18.7 41.80 22.3 0.7 18.7 41.80 22.3 0.7 20.9 22.5 4.41.3 27.1 4.4 30 May 01 14.9 41.22 21.7 0.4 16.8 40.02 20.5 -0.2 2 27.6 42.26 2.5 4.31 2.7 4.50 0.7.7 5.0 2.7 1.1 20.6 42.16 2.1.1 1.3 2.0 27.6 42.24 2.16 <td></td> <td>o Julie 95</td> <td>20.3</td> <td>43.07</td> <td>24.0</td> <td>2.0</td> <td></td>		o Julie 95	20.3	43.07	24.0	2.0	
24-3 45-21 27.9 4.5 28.7 45.21 27.9 4.5 28.8 46.13 30.3 6.1 30.6 46.31 30.3 6.1 30.6 46.31 30.3 6.1 28.8 46.13 30.3 6.1 28.9 46.31 30.3 6.1 28.9 47.97 41.97 21.4 -0.3 11.1 41.80 22.3 0.7 1 20.9 42.92 25.0 2.9 2.2 2.2 2.9 20.7 44.23 27.1 4.4 30 44.03 27.1 4.4 30 May 01 14.9 41.22 21.7 0.4 40.02 2.05 -0.2 1.8 4561 40.02 2.05 -0.2 1.8 40.02 2.05 -0.2 1.8 4590 21.5 42.80 8.01 1.3 2.06 3.7 11.7 42.16 <t< td=""><td></td><td></td><td>22.3</td><td>41.92</td><td>23.1</td><td>1.4</td><td></td></t<>			22.3	41.92	23.1	1.4	
Kiruna (68 ⁺ N) 22,6 46,13 30,3 6,5 28,8 46,13 30,3 6,5 30,6 46,31 30,5 6,6 32,4 47,50 31,3 6,8 32,4 47,50 31,3 6,6 32,4 47,50 31,3 6,6 32,4 47,50 31,3 6,6 32,4 47,50 31,3 6,8 30,4 6,73 30,3 6,1 11,1 41,80 22,3 0,7 18,7 41,97 21,4 -0,3 20,9 42,92 25,0 2,9 22,4 4,12 2,17 0,4 30 May 01 14,9 41,22 2,17 0,4 4,4 0,27 5,0 27,6 42,58 25,4 3,1 1,3 4,002 20,5 -0,2 - 16,8 41,04 21,7 0,5 18,2 4,002 20,5 -2,7 5,0 2,1 1,1 3,0 4,002 3,0 <			24.5	45.35	20.1	4.7	
48.8 46.31 30.3 6.8 30.6 46.31 30.5 6.8 32.4 47.50 31.3 6.8 32.4 47.50 31.3 6.8 32.4 47.50 31.3 6.8 32.4 47.50 31.3 6.8 32.4 47.50 31.3 6.8 31.6 6.07 20.7 42.7 0.7 17.7 44.80 22.3 0.7 1 20.9 22.7 42.23 2.6 2.9 22.7 43.23 25.6 -0.3 3.4 30 May 01 14.9 41.22 2.17 0.4 30 May 01 16.8 41.02 2.7 0.5 18.8 41.02 2.7 0.5 -0.2 - 4560 26.4 40.02 2.7 5.0 - - - 4 Sep 02 15.2 42.24 2.16 -0.2 - 1			20.7	45.21	27.9	4.5	
30.6 40.31 30.5 6.0 32.4 475.0 31.3 6.8 33.8 467.73 30.3 6.1 33.8 467.73 30.3 6.1 17.1 41.80 22.3 0.7 18.7 41.97 21.4 -0.3 20.9 42.22 25.0 2.9 22.7 43.23 25.4 3.1 30 May 01 14.9 41.22 21.7 0.4 16.8 41.04 21.7 0.5 18.4 30 May 01 15.2 42.26 25.4 3.1 20.6 42.92 25.0 2.9 2.7 21.6 42.52 2.5.4 3.1 1.2 16.8 40.02 20.5 -0.2 1 16.4 40.42 2.8 -0.1 1 20.6 43.16 25.1 2.8 -1.1 20.6 3.16 25.1 2.8 5.1 3			20.0	40.13	30.3	0.5	
32.4 4.7.3 33.3 6.0 33.8 4.67.3 33.6 6.1 28 Aug 00 15.0 39.71 20.5 0.0 * 17.1 14.80 22.3 0.7 * * * 20.9 42.92 25.0 2.1 + - - * 20.9 42.92 25.0 2.1 + - <td></td> <td></td> <td>30.6</td> <td>46.31</td> <td>30.5</td> <td>6.6</td> <td></td>			30.6	46.31	30.5	6.6	
33.8 40,73 30.3 6.1 33.8 40,73 30.3 6.1 17.1 41.80 22.3 0.7 18.7 41.97 21.4 -0.3 20.9 42.92 25.0 2.9 22.9 42.92 25.0 2.9 22.7 43.23 25.4 3.1 30 May 01 14.9 41.32 27.1 4.4 40.02 20.5 -0.2 7 5.0 18.8 40.02 20.5 -0.2 7 16.8 40.02 20.5 -0.2 1 16.4 40.02 20.5 -0.2 1 16.4 40.04 21.7 0.5 1 20.6 43.10 25.1 1.3 2 21.2 42.03 0.5 1.2 2 22.9 43.30 26.7 1.1 2 24.0 43.19 22.6 5.1 2 30.			32.4	47.50	31.3	0.0	
28 Auguo 15.0 39.7 20.5 0.0 17.1 41.80 22.3 0.7 18.7 41.97 21.4 -0.3 20.9 42.92 20.6 2.9 22.7 43.23 25.4 3.1 30 May 01 14.9 41.12 21.7 0.4 16.8 41.02 21.7 0.4 0.6 21.6 4.022 1.7 0.4 16.8 41.02 21.7 30 May 01 14.9 41.02 21.7 0.5 0.2 2.6 3.4 20.6 24.4 40.02 2.0 7 5.0 2.6 3.4 20.6 4.00 40.8 0.0 1.1 3 3.4 20.6 4.16 40.44 20.6 0.7 1.1 3 215.2 42.29 24.0 8.0 7.1 4 3.0 3.6 5.1 2.5 3.7 1.5 3.7 1.5 3.7			33.8	46.73	30.3	6.1	
Hind 41.90 22.3 0.7 18.7 41.97 21.4 -0.3 20.9 42.92 25.0 2.9 22.7 43.23 25.4 3.1 30 May 01 14.9 41.32 27.1 4.4 30 May 01 14.9 41.22 21.7 0.4 16.8 41.04 21.7 0.5 18.8 40.02 20.5 -0.2 1 18.8 40.02 20.5 -0.2 4 6.4 4.03 7.7 5.0 21.6 44.03 27.7 5.0 2.8 4.4 0.2 7.6 0.2 1 1.3 20.6 3.16 2.8 2.1 1.3 20.6 3.16 2.8 -0.1 1 2.4 4.03 2.7 4.1 2.4 4.03 2.6 5.1 1.3 2.6 5.1 2.8 5.1 2.5 7.8 3.5 5.6 9 1.6 4.4 7.0 3.12		28 Aug 00	15.0	39.71	20.5	0.0	-
18.7 41.97 21.4 -0.3 20.9 42.92 25.0 2.9 22.7 42.82 25.4 3.1 20.9 42.92 25.4 3.1 21.6 41.13 27.7 44.23 25.4 3.1 30 May 01 14.9 41.22 21.7 0.4 16.8 41.04 21.7 0.4 16.8 41.02 21.7 0.4 18.8 41.02 21.7 0.4 16.8 41.02 21.7 0.4 18.8 40.02 20.5 0.2 -0.2 27.6 42.50 25.4 3.0 4 Sep 02 16.2 42.50 25.1 1.5 0.2 -0.1 2.5 22.9 43.90 26.7 4.1 2.4 0.6 0.1 -0.1 22.9 43.90 26.7 4.1 2.6 3.7 1.7 44.9 44.04 44.04 42.6 3.7 1.7 4.79			17.1	41.80	22.3	0.7	
20.9 43.23 25.8 4.13 30 May 01 14.9 25.8 4.13 27.1 4.4 30 May 01 14.9 11.22 21.7 0.4 16.8 41.04 21.7 0.5 18.8 40.02 20.5 -0.2 27.6 42.58 25.4 3.1 27.6 42.58 25.4 3.4 20.6 44.03 27.7 5.0 2.2 16.4 40.44 20.8 -0.1 -0.1 18.7 42.15 23.1 1.3 -0.1 20.6 43.16 25.7 4.1 -0.1 20.4 43.19 26.0 3.7 -0.1 21.7 44.77 28.2 5.1 -3.3 30.3 45.68 30.5 6.9 -1.4 24.0 4.319 22.6 5.1 -3.5 18.7 42.17 22.2 0.5 18.7 21.2 42.290			18.7	41.97	21.4	-0.3	
Z2,7 43,23 25,4 3,1 25,8 44,13 27,1 4,4 30 May 01 14,9 41,22 21,7 0,4 16,8 41,00 21,7 0,5 0,4 18,8 41,00 21,7 0,5 0,2 27,6 6,100 21,7 0,5 0,2 27,6 6,200 25,4 3,4 0,2 5,5 0,2 28,4 44,03 27,7 5,0 1 2,24 4,24 1,6 -0,2 2,6 3,1 1,3 20,6 43,16 25,1 1,3 2,8 2,29 4,403 2,7,7 5,0 1,5 2,8 3,0 3,6 6,8 3,7 2,1 1,3 2,8 2,29 4,310 2,6,7 4,1 2,6 1,3 3,1 2,6 1,3 3,1 2,6 1,3 3,1 2,2 0,5 2,1 2,8 3,1 2,4 4,3,0 2,4 4,3			20.9	42.92	25.0	2.9	
2b.8 44.13 27.1 4.4 30 May 01 14.9 41.22 27.7 0.4 16.8 41.04 21.7 0.5 0.5 18.8 40.02 20.5 -0.2 - 18.8 40.02 20.5 -0.2 - 14.8 40.02 20.4 44.03 7.7 5.0 29.4 44.03 7.7 5.0 -0.2 - 16.4 40.44 20.8 -0.1 - - 16.4 40.44 20.2 - - 1.6 - 1.1 - 20.6 - 1.1 - 1.2 - 1.2 2.1 1.3 2.0 - 1.1 - 1.2 - 1.1 - 1.2 2.9 4.3 92.6 5.1 1.3 3.0 3.6 6.0 3.16 - 1.1 - 1.1 - 1.1 - 1.1 2.2 0.5 1.1 2.1			22.7	43.23	25.4	3.1	
30 May 01 14.9 41.04 21.7 0.4 16.8 41.04 21.7 0.5 27.6 42.00 22.5 -0.2 27.6 4258 25.4 3.4 29.4 44.03 27.7 5.0 4 Sep 02 15.2 42.24 16.4 -0.2 16.4 40.44 20.8 -0.1 * 18.7 42.15 23.1 1.3 22.9 20.6 43.16 25.1 2.8 22.9 21.5 23.0 43.16 25.1 2.8 22.9 43.90 26.7 4.1 26.0 3.7 27.7 44.79 25.1 2.8 30.3 45.68 30.5 6.9 30.3 45.68 30.5 2.6.9 1.5 2.6.1 5.8 11.6 4.17 41.63 21.4 2.5 5.1 21.7 42.69 2.7 3.1 5.5 2.6.1 5.8			25.8	44.13	27.1	4.4	
H6.8 41.04 21.7 0.5 18.8 40.02 20.5 -0.2 - 27.6 42.58 25.4 3.4 - 29.4 44.03 7.7 5.0 - 2.2 - 15.2 42.24 41.6 -0.2 - </td <td></td> <td>30 May 01</td> <td>14.9</td> <td>41.22</td> <td>21.7</td> <td>0.4</td> <td></td>		30 May 01	14.9	41.22	21.7	0.4	
H8.8 4002 20.5 -0.2 27.6 4258 24 42.40 27.7 5.0 4 Sep 02 15.2 42.24 16.40 27.7 5.0 4 Sep 02 15.2 42.24 16.40 20.4 42.03 27.7 5.0 18.7 42.24 14.6 -0.2 22.4 42.03 27.7 5.0 18.7 42.15 23.1 1.3 20.6 43.16 25.1 2.8 22.9 43.90 25.7 4.1 28.2 3.7 27.7 27.7 44.79 28.2 5.1 3.3 35.68 30.5 6.9 30.3 45.68 30.5 6.9 34.0 47.08 31.2 6.9 1 Sep 04 47.08 31.6 7.6 25.5 21.2 2.5 21.7 23.4 43.79 25.1 2.5 25.7 21.2 2.5 25.7 30.5 44.64 73.8 8.8 <td< td=""><td></td><td></td><td>16.8</td><td>41.04</td><td>21.7</td><td>0.5</td><td></td></td<>			16.8	41.04	21.7	0.5	
27.6 42.58 25.4 3.4 29.4 4403 27.7 5.0 2.4 4403 27.7 5.0 2.4 24.4 40.3 2.7 5.0 2.4 21.6 -0.2 * 16.4 40.44 20.4 40.4 20.4 21.6 -0.2 * 18.7 42.15 23.1 1.3 20.6 43.16 25.1 2.8 22.9 43.90 26.7 4.1 24.0 43.19 26.0 3.7 27.7 44.79 28.2 5.1 3.3 45.68 30.5 6.9 30.3 45.68 30.5 6.9 3.7 4.7 4.0.1 -0.1 7.6 34.0 47.08 31.2 6.9 1.7 2.2 0.5 1.5 18.7 41.63 42.7 22.8 0.1 7.1 2.2 0.5 18.7 43.59 25.0 2.5 2.5 2.5 2.5 2.5 <td></td> <td></td> <td>18.8</td> <td>40.02</td> <td>20.5</td> <td>-0.2</td> <td></td>			18.8	40.02	20.5	-0.2	
29.4 44.03 27.7 5.0 4 Sep 02 15.2 42.24 16.4 -0.2 42.16 -0.2 1 16.4 40.44 20.8 -0.1 * -			27.6	42.58	25.4	3.4	
4 Sep 02 15.2 42.24 21.6 -0.2 * 16.4 40.44 20.8 -0.1 * 18.7 42.15 23.1 1.3 * 20.6 43.16 25.1 2.8 * * 24.0 43.19 26.0 3.7 * <			29.4	44.03	27.7	5.0	
16.4 40.44 20.8 -0.1 * 18.7 42.15 23.1 1.3 20.6 43.16 25.1 2.8 22.9 43.90 26.7 4.1 24.0 43.19 25.0 3.7 27.7 44.79 28.2 5.1 30.3 45.68 30.5 6.9 34.0 47.08 31.2 6.9 1 5ep 04 47.08 31.2 6.9 16.5 42.11 22.9 0.5 21.2 0.5 21.7 42.90 2.7 23.4 43.79 25.1 2.5 21.7 42.90 2.7 30.5 21.2 2.5 2.5 21.7 43.64 27.3 4.7 30.5 2.1 5.8 25.7 43.55 20.2 1.5 3.15 46.47 30.8 6.8 30.5 45.11 2.1 1.8 3.15 46.61 31.6 7.6 </td <td></td> <td>4 Sep 02</td> <td>15.2</td> <td>42.24</td> <td>21.6</td> <td>-0.2</td> <td></td>		4 Sep 02	15.2	42.24	21.6	-0.2	
18.7 42.15 23.1 1.3 20.6 43.16 25.1 2.8 22.9 43.90 26.7 4.1 24.0 43.19 26.0 3.7 27.7 44.79 28.2 5.1 30.3 45.68 30.5 6.9 34.0 47.08 31.2 6.9 15.6 42.11 22.2 0.5 16.5 42.11 22.2 0.5 18.7 44.379 28.2 5.1 25.7 43.55 25.0 2.5 27.8 43.64 37.0 2.5 28.4 43.79 28.1 2.5 28.4 43.66 13.6 7.6 30.5 45.11 29.1 5.8 31.5 46.47 30.8 6.8 32.8 46.61 31.6 7.6 35.6 45.11 29.1 5.8 31.5 44.27 23.8 2.1			16.4	40.44	20.8	-0.1	•
20.6 43.16 25.1 2.8 22.9 43.90 26.7 4.1 24.0 43.90 26.0 3.7 27.7 44.70 28.2 5.1 30.3 45.68 30.5 6.9 34.0 47.08 31.2 6.9 1 Sep 04 14.7 41.63 21.4 -0.1 16.5 42.11 22.9 0.5 21.2 0.5 21.2 42.90 4.47 42.90 2.7 23.4 43.79 25.1 2.5 25.7 43.64 27.3 4.7 30.5 45.11 2.9 1.5 30.5 45.11 2.8 3.6 45.00 3.5 1.5 46.47 30.8 6.8 3.3 7.1 5.5 2.6 5.0 2.5 (68'N) 13.0 42.07 2.9 1.2 1.5 43.64 27.3 4.7 3.6 6.8 3.2 2.1 1.			18.7	42.15	23.1	1.3	
22.9 43.90 26.7 4.1 24.0 43.19 26.0 3.7 27.7 44.79 28.2 5.1 30.3 45.68 30.5 6.9 1 50.0 47.08 31.2 6.9 1 56.0 42.11 22.2 0.5 16.5 42.11 22.2 0.5 18.7 44.379 28.2 5.1 2.2 0.5 18.7 42.27 22.3 0.5 2.1.2 42.90 24.9 2.7 2.3.4 43.79 25.7 43.56 25.0 2.5 2.7.8 43.64 37.0 8.7 4.1 1.5 8.3 31.5 46.11 1.5 8.8 31.5 46.13 7.1 8.7 8.1 3.7 1.7 (68'N) 10.2 43.67 22.6 0.1 * 4.3 7.6 3.7 1.7 4.379 22.9 1.2 1.5 4.363 2.6<			20.6	43.16	25.1	2.8	
24.0 43.19 26.0 3.7 27.7 44.79 22 5.1 30.3 45.68 30.5 6.9 34.0 47.08 31.2 6.9 1 Sep 04 14.7 41.63 21.4 -0.1 16.5 42.11 22.05 5.1 2.5 21.2 42.90 2.7 22.3 0.5 21.4 42.90 2.7 22.9 0.5 21.4 42.90 2.49 2.7 3.4 3.79 25.1 2.5 25.7 43.55 25.0 2.5 2.5 3.6 45.00 3.1 7.1 30.5 45.11 2.9 1.5 3.5 5.6 3.6 46.00 3.3 7.1 30.5 45.61 2.8 2.1 1.6 3.6 46.61 3.6 8.8 32.8 46.61 31.6 7.6 3.1 1.7 1.6 4.362 2.6 1.0 1			22.9	43.90	26.7	4.1	
27.7 44.79 28.2 5.1 30.3 456.8 30.5 6.9 34.0 47.08 31.2 6.9 1 Sep 04 14.7 41.63 21.4 -0.1 15.5 42.11 22.2 0.5 - 18.7 42.27 23.0 5 - 23.4 43.79 25.1 2.5 - 2.7 23.4 43.79 25.1 2.5 - 2.7 23.4 43.79 25.7 43.55 25.0 2.5 27.8 43.64 7.3 4.7 - 3.6 - 30.5 45.11 29.1 5.8 -			24.0	43.19	26.0	3.7	
30.3 45.68 30.5 6.9 34.0 47.08 31.2 6.9 1 Sep 04 14.7 41.63 21.4 -0.1 * 1 Sep 04 14.7 41.63 21.4 -0.1 * 1 Sep 04 14.7 42.03 22.0 0.5 21.2 42.90 2.7 22.3 0.5 21.4 42.09 2.7 23.4 43.79 25.1 2.5 25.7 43.56 25.0 2.5 2.5 3.6 45.01 2.5 30.5 45.11 2.9 1.5 3.6 4.60 31.6 7.6 30.5 45.11 2.1 5.8 3.2 4.61 31.6 7.6 30.5 45.11 2.9 1.2 5.8 3.2 6.8 3.3 7.1 - (68'N) 13.0 42.07 2.9 1.2 - 4.363 25.6 3.2 (68'N) 13.0 4			27.7	44.79	28.2	5.1	
34.0 47.08 31.2 6.9 15 sep 04 14.7 41.63 21.4 -0.1 16.5 42.11 22.2 0.5 18.7 42.27 23.0 0.5 21.2 42.90 24.9 2.7 23.4 43.79 25.7 43.55 25.0 2.5 27.8 43.64 27.3 4.7 3.6 31.5 46.17 30.5 45.11 29.1 5.8 31.5 46.47 30.8 6.8 33.7.1 5.8 31.5 46.47 30.8 6.8 (68"N) 10.2 43.66 27.6 0.4 -6.1 -7.6 3.7.1 (68"N) 10.2 43.67 22.6 0.1 -1 -1.7 -1.1 1.9 -1.1 (14.1 42.21 23.8 2.1 -1.5 -1.4 -1.7 -1.4 -1.7 -1.5 -1.4 -1.7 -1.4 -1.7 -1.4 -1.7 -1.4			30.3	45.68	30.5	6.9	
1 Sep 04 14.7 41.63 21.4 -0.1 * 16.5 42.11 22 0.5 0.5 0.5 0.5 21.2 42.90 2.7 22.3 0.5 0.5 21.2 42.90 2.7 23.4 43.79 25.1 2.5 25.7 43.56 25.0 2.5 2.5 0.5 0.5 20.6 45.11 2.9 0.7 43.67 20.8 6.8 30.5 46.147 30.8 6.8 32.8 46.61 1.6 7.6 (68"N) 13.0 42.07 22.9 1.2 * * 15.9 43.23 24.0 1.7 16.4 43.63 22.6 0.0 * (68"N) 13.0 42.07 22.9 1.2 * * 16.4 43.63 25.6 3.1 1.7 * 3.2 2.1 * (68"N) 14.1 42.12 43.29			34.0	47.08	31.2	6.9	
Kiruna 22 Feb. 7 43.70 22.20 0.5 18.7 42.27 22.3 0.5 21.2 42.29 22.3 0.5 21.2 42.29 2.23 0.5 23.4 43.79 25.1 2.5 25.7 43.55 25.0 2.5 27.8 43.64 27.3 4.7 30.5 45.11 29.1 5.8 31.5 46.47 30.8 6.8 32.8 46.61 31.6 7.6 35.6 46.90 31.3 7.1 13.0 42.07 22.9 1.2 (68"N) 13.0 42.07 22.9 1.2 15.9 43.22 24.0 1.7 1.59 15.9 43.22 24.0 1.7 1.6.4 16.4 43.63 25.6 3.1 17.2 43.79 25.4 2.8 3.2 20.1 45.62 27.4		1 Sep 04	14.7	41.63	21.4	-0.1	•
IB.7 42.27 22.3 0.5 21.2 42.90 2.49 2.49 2.49 2.7 23.4 43.79 25.1 2.5 2.5 25.7 43.56 25.0 2.5 27.8 43.64 27.3 4.7 30.5 45.11 2.8 2.1 5.8 31.5 46.47 30.8 6.8 32.8 46.61 31.6 7.6 (68'N) 70 70.7 71.4 42.21 2.8 2.1 7.8 (68'N) 14.1 42.21 2.8 2.1 7.8 3.6 6.8 3.2 3.6 1.7 1.6 4.363 2.6 1.7 1.6 4.363 2.6 1.7 1.6 3.2 2.1 1.7 1.6 3.2 2.1 1.7 1.6 4.362 2.5.8 3.2 2.1 3.2 2.1 3.2 2.1 3.2 2.1 3.2 2.1 3.2 2.2 2.1			16.5	42.11	22.2	0.5	
21.2 42.90 24.9 2.7 23.4 43.79 25.1 2.5 23.4 43.79 25.1 2.5 27.8 43.56 25.0 2.5 27.8 43.64 27.3 4.7 30.5 45.11 29.1 5.8 31.5 46.47 30.8 6.8 32.8 46.61 31.6 7.6 35.6 46.90 31.3 7.1 (68"N) 10.2 43.67 22.6 0.1 15.9 43.22 24.0 1.7 1.5 16.4 43.63 25.6 3.1 1.7 15.9 43.22 40.1 1.7 1.6.4 43.63 25.6 3.1 17.2 43.79 25.6 3.1 1.7 2.40 1.7 16.4 43.63 25.6 3.1 1.7 2.40 1.7 16.4 43.65 25.4 2.8 3.2 2.01 4.52			18.7	42.27	22.3	0.5	
23.4 43.79 25.1 2.5 25.7 43.55 25.0 2.5 27.8 43.64 27.3 4.7 30.5 45.11 2.8 2.1 5.8 31.5 46.47 30.8 6.8 32.8 46.61 31.6 7.6 (68'N) 70 13.0 42.07 22.9 1.2 (68'N) 14.1 42.21 23.8 2.1 7.8 15.9 43.25 26.6 3.1 7.1 2.5 (68'N) 14.1 42.21 28.21 1.7 15.9 43.28 2.66 3.1 1.7 16.4 43.63 25.6 3.2 2.8 2.1 17.2 43.39 25.4 2.8 2.1 3.2 20.1 45.62 27.4 3.9 2.1 3.2 2.9 21.8 45.56 29.4 5.9 23.6 6.8 3.2 21.8			21.2	42.90	24.9	2.7	
25.7 43.55 25.0 2.5 27.8 43.64 27.3 4.7 30.5 45.11 29.1 5.8 31.5 46.47 30.8 6.8 32.8 46.61 31.6 7.6 35.6 46.90 31.3 7.1 (68"N) 10.2 43.67 22.6 0.1 11.0 42.07 22.9 1.2 1.5 (68"N) 13.0 42.07 22.9 1.2 1.5 15.9 43.22 24.0 1.7 1.6.4 43.63 25.6 3.1 17.2 43.79 25.6 3.1 1.7.2 3.7 2.1 15.9 43.23 24.0 1.7 1.6.4 43.63 25.6 3.1 17.2 43.79 25.6 3.1 1.7.2 4.32 24.0 1.7 20.1 45.62 27.4 3.9 21.8 45.58 2.4 5.9 23.6			23.4	43.79	25.1	2.5	
27.8 43.64 27.3 4.7 30.5 45.11 2.8 1.5 5.8 31.5 46.47 30.8 6.8 32.8 46.61 31.6 7.6 Kruna 22.Feb. 97 10.2 43.67 22.6 0.0 (68*N) 13.0 42.07 22.9 1.2 1.2 (58*N) 14.1 42.21 23.8 2.1 1.7 16.9 43.23 2.40 1.7 1.6 4.363 25.6 3.1 17.2 43.79 25.4 2.8 2.1 1.7 1.6 4.322 2.40 1.7 16.4 43.63 25.6 3.1 1.7 2.4 2.8 2.1 17.2 43.79 25.4 2.8 3.2 2.0.1 45.62 7.4 3.9 21.8 45.56 27.4 3.9 2.3.6 45.36 5.9 23.6 45.35 29.4 5.9 2.3.6			25.7	43.55	25.0	2.5	
30.5 45.11 29.1 5.8 31.5 46.47 30.8 6.8 32.8 46.61 31.6 7.6 35.6 46.90 31.3 7.1 (68"N) 10.2 43.67 22.6 0.0 13.0 42.07 22.9 1.2 15.9 43.23 24.0 1.7 16.4 43.63 25.6 3.1 17.2 43.79 25.6 3.1 17.2 43.79 25.8 3.2 20.1 45.62 27.4 3.9 21.8 45.58 29.4 5.9 23.6 48.34 3.6 8.7 25.6 52.49 39.3 12.2			27.8	43.64	27.3	4.7	
31.5 46.47 30.8 6.8 32.8 46.61 31.6 7.6 35.6 46.90 31.3 7.1 Kiruna 22 Feb. 97 10.2 43.67 22.6 0.0 (68'N) 13.0 42.07 22.9 1.2 1.2 16.9 43.23 24.0 1.7 16.4 43.63 25.6 3.1 17.2 43.79 25.4 2.8 1.1 1.7 16.4 3.28 2.1 16.9 43.22 24.0 1.7 16.4 43.63 25.6 3.1 17.2 43.79 25.4 2.8 1.1 1.2 1.2 18.2 43.82 25.8 3.2 2.1 3.9 2.1.8 45.52 2.4 3.9 23.6 45.34 3.6 8.7 3.9 3.3 1.2			30.5	45.11	29.1	5.8	
32.8 46.61 31.6 7.6 35.6 46.90 31.3 7.1 Kiruna 22 Feb. 97 10.2 43.67 22.6 0.0 * (68"N) 13.0 42.07 22.9 1.2 * <td< td=""><td></td><td></td><td>31.5</td><td>46.47</td><td>30.8</td><td>6.8</td><td></td></td<>			31.5	46.47	30.8	6.8	
35.6 46.90 31.3 7.1 Kiruna 22 Feb. 97 10.0 43.67 22.6 0.0 (68'N) 13.0 42.07 22.9 1.2 14.1 42.21 23.8 2.1 15.9 43.23 24.0 1.7 16.4 43.63 25.6 3.1 17.2 43.79 25.4 2.8 18.2 43.82 2.58 3.2 20.1 45.62 27.4 3.9 21.8 45.85 29.4 5.9 23.6 45.43 3.6 6.7 25.6 52.49 3.9.3 12.2			32.8	46.61	31.6	7.6	
Kiruna 22 Feb. 97 10.2 43.67 22.6 0.0 * (68'N) 13.0 42.07 22.9 1.2 (68'N) 13.0 42.07 22.9 1.2 (68'N) 11.0 42.01 1.7 1.1 42.21 23.8 2.1 1.59 43.23 24.0 1.7 1.6 43.63 25.6 3.1 1.7 1.7.2 43.79 25.4 2.8 2.2 2.0.1 45.62 27.4 3.9 2.1.8 45.65 2.4 2.8 2.1 4.36 2.6.6 5.9 2.3.6 4.5.9 2.3.6 6.8 3.9 2.3.6 6.8 7.7 3.9 2.3.6 6.8 7 2.2.6 5.249 39.3 1.2.2			35.6	46.90	31.3	7.1	
$ \begin{array}{c} (68^\circ\text{N}) & 13.0 & 42.07 & 22.9 & 1.2 \\ 14.1 & 42.21 & 23.8 & 2.1 \\ 15.9 & 43.22 & 24.0 & 1.7 \\ 16.4 & 43.63 & 25.6 & 3.1 \\ 17.2 & 43.79 & 25.4 & 2.8 \\ 18.2 & 43.82 & 25.8 & 3.2 \\ 20.1 & 45.62 & 27.4 & 3.9 \\ 21.8 & 45.56 & 29.4 & 5.9 \\ 23.6 & 48.34 & 33.6 & 8.7 \\ 25.6 & 52.49 & 39.3 & 12.2 \\ \end{array} $	Kiruna	22 Feb. 97	10.2	43.67	22.6	0.0	•
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	(68° N)		13.0	42.07	22.9	1.2	
$\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$			14.1	42.21	23.8	2.1	
$ \begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$			15.9	43.23	24.0	1.7	
$\begin{array}{cccccccccccccccccccccccccccccccccccc$			16.4	43.63	25.6	3.1	
18.2 43.82 25.8 3.2 20.1 45.62 27.4 3.9 21.8 45.56 29.4 5.9 23.6 48.34 33.6 8.7 25.6 52.49 39.3 12.2			17.2	43.79	25.4	2.8	
20.1 45.62 27.4 3.9 21.8 45.58 29.4 5.9 23.6 48.34 33.6 8.7 25.6 52.49 39.3 12.2			18.2	43.82	25.8	3.2	
21.8 45.58 29.4 5.9 23.6 48.34 33.6 8.7 25.6 52.49 39.3 12.2			20.1	45.62	27.4	3.9	
23.6 48.34 33.6 8.7 25.6 52.49 39.3 12.2			21.8	45.58	29.4	5.9	
25.6 52.49 39.3 12.2			23.6	48.34	33.6	8.7	
			25.6	52.49	39.3	12.2	

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Observation of ¹⁷O anomaly in stratospheric CO₂

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Fig. 1. Vertical profiles of $\Delta^{17}O_{CO2}$ values. Datasets over Sanriku are categorized by the sampling year and season (open symbols, late summer; filled symbols, early summer) and that over Kiruna is represented by a filled star. A vertical dashed line indicates no ¹⁷O anomaly. Analytical precisions of 0.5‰ are represented as horizontal bars.

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Fig. 2. (a) $\Delta^{17}O_{CO2}-N_2O$ mixing ratio plot. **(b)** $\delta^{18}O_{CO2}-N_2O$ mixing ratio plot. Vertical axes for the N₂O mixing ratio are in reverse. Open circles and squares in both figures respectively represent observations over Sanriku and Kiruna. Black circles in (a) and gray circles in (b) represent datasets from Boering et al. (2004). Black squares in both figures represent datasets obtained from Thiemens et al. (1995b). Analytical precisions for each parameter are represented as cross bars; errors are comparable to symbol sizes in some instances.

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Fig. 3. $\delta^{18}O_{CO2} - \delta^{17}O_{CO2}$ plot. A terrestrial fractionation line (TFL: slope = 0.516) is shown as a solid line. Our observations over Sanriku and Kiruna are divided based on N₂O mixing ratios, such as open circles ([N₂O]>50 ppbv) and solid circles ([N₂O]<50 ppbv). Dashed lines represent least square fittings, which have slopes of 1.75±0.17 (N₂O-enriched) and 1.17±0.24 (N₂O-depleted). Open and solid squares respectively represent datasets from Lämmerzahl et al. (2002) and Thiemens et al. (1995b). Analytical precisions for each parameter are represented as cross bars; errors are comparable to symbol sizes in some instances.

ACPD 7, 15723–15737, 2007 Observation of ¹⁷O anomaly in stratospheric CO₂ S. Kawagucci et al. **Title Page** Introduction Abstract Conclusions References **Figures** Back Full Screen / Esc **Printer-friendly Version** Interactive Discussion