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Balloon-borne cryogenic frost point hygrometer observations over Syowa Station, Antarctica

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Abstract: Regular balloon-borne cryogenic frostpoint hygrometer observations were conducted at Syowa Station, Antarctica, from 2013 to 2022 to monitor long-term variations in water vapor concentration in the upper troposphere and lower stratosphere over Antarctica. The data was screened and published in Ascii format for research purposes. This is the only regular balloon-borne hygrometer observation in the Antarctic region and is expected to be used for various purposes, such as climate change monitoring, research on water vapor transport processes, and validation of satellite observations.

1. Background and Summary

Variations of water vapor concentration in the upper troposphere and lower stratosphere (UTLS) have a significant impact on the Earth's radiation budget[1, 2] despite its low concentration, so that the water vapor increase in the UTLS plays a substantial role in driving the surface global warming[3, 4]. On the other hand, stratospheric water vapor increase cools stratosphere through enhanced infrared radiation[5], which also causes a circulation change in the stratosphere and troposphere[6]. In addition, the air in the Antarctic stratosphere is subject to dehydration due to

extremely low temperature inside the winter polar vortex, which contributes to the generation of the ozone hole through the formation of polar stratospheric clouds[7].

Despite the essential and unique nature of water vapor variability in the Antarctic UTLS, few long-term monitoring observations have been conducted. Commonly used radiosondes cannot accurately measure the water vapor concentration in the UTLS because of its low temperature and low water vapor concentration[8]. Rapid changes in water vapor concentration across the tropopause hinder accurate measurements of water vapor concentration from satellites because of their insufficient vertical resolution[9]. Observations using high-precision balloon-borne hygrometers have been conducted at McMurdo and South Pole Stations on a campaign basis in the 1990s[10]. However, there were no regular water vapor observations in the Antarctic UTLS.

We have started regular balloon-borne hygrometer observations at Syowa Station, Antarctica, since 2013[11, 12]. Here, we present a dataset of water vapor concentration in the Antarctic UTLS obtained by Cryogenic frost point hygrometer (CFH) observations with fine vertical resolution and high precision.

2. Location

Balloon-borne hygrometer observations have been performed at Syowa Station (WMO station number 89532; 69.0°S, 39.6°E), Antarctica. The elevation of the balloon release point is 18.4 m until 2021 and 21.6 m after 2022. Syowa Station is located on East Ongul Island, which is 4 km away from the Antarctic continent (Figure 1).

The tropopause over Syowa Station is mainly located at an altitude of 8–10 km throughout the year, and its seasonal variation is small[13]. The subtropical jet (in the case of a single jet) and the subpolar jet (in the case of a double jet) in the Southern Hemisphere are located north of Syowa Station throughout the year[14], and extratropical cyclones pass to the north of Syowa Station. In austral winter, when the polar vortex develops, Syowa Station is basically located inside the polar vortex, but it sometimes moves out of it due to its deformation and displacement[15].

3. Measurements and Methods

The CFH is a balloon-borne hygrometer that has been developed by the University of Colorado for high-precision water vapor observations in the UTLS region[16, 17]. The CFH measures the frost point temperature of ambient atmosphere using a chilled mirror technique. The CFH has equipped with the Meisei RS-06G or RS-11G radiosonde (Figure 2), which transfers the frost point temperature data together with the pressure, temperature, and relative humidity data measured by the radiosonde, to the receiver at the ground every 1 s (i.e., assuming the ascent rate is about 5 m/s, the nominal vertical resolution is about 5 m). To minimize contamination due to evaporation of water

droplets from the balloon envelope during ascent, the balloon and CFH are separated by 50 m by an unwinder.

The sounding software (named MGPS_R) applies several kinds of corrections and filtering to the data to suppress effects of solar/infrared radiation, time-lag error, heat spike error, etc.[18]. The Hyland and Wexler equation[19] is used for derivation of the saturation mixing ratio from the frost point temperature. Then it is converted to water vapor volume mixing ratio using the ambient temperature. After the data screening due to mirror reflectivity, ascent/descent comparison, visual inspection, etc., the error flag, which indicates data quality: good (=0) or bad (=1), was assigned to the CFH data.

The CFH observations have been performed from 2013 to 2022 except for 2014 and 2015. In addition, intensive observation campaigns in which several CFHs are released in a month have been performed in July 2016 and July 2018. However, because CHF_3, which was used as a refrigerant for CFH, was restricted by the Kigali Amendments of the Montreal Protocol in 2016[20], CFH observations at Syowa Station were terminated after the last observation in February 2022. The number of CFH observations and available datasets for each month and year is shown in Table 1. A total of 43 CFH observations were made, of which 37 are publicly available. Unavailable six observations consisted of three cases of poor reception of radio waves, two cases of unstable photodetector signal, and one case of instrument failure due to the collision with the ground at the time of balloon release. Most of the data are available up to an altitude of 20 km or higher (Figure 3).

4. Data Records

The CFH data for each observation is provided as a text file named in the format of CFHyyyymmdd.dat (i.e., CFH20130728.dat). The first six lines are the header section, where the station name, observation date, height, latitude, longitude, and type of hygrometer and radiosonde used are recorded. The subsequent lines are data sections in which the following quantities are recorded.

Time (UTC) in a format of hh:mm:ss
Pressure (unit: hPa)
Height (unit: m)
Latitude (unit: degree)
Longitude (unit: degree)
Wind Direction (unit: degree)
Wind Speed (unit: m/s)
Zonal Wind (unit: m/s)
Meridional Wind (unit: m/s)
Temperature (unit: degC)

Detector Signal (unit: V)

Optics Temperature (unit: degC)

Battery (unit: V)

Relative Humidity observed by RS-06G/11G radiosonde (unit: %)

Mirror Temperature (i.e., corresponding to frost point temperature) (unit: degC)

Relative Humidity over ice observed by CFH (unit: %)

Volume Mixing Ratio of Water Vapor observed by CFH (unit: ppmv)

Flag indicating which data to use (=0) and which ones not to use (=1)

Note that -999.0 is a missing value.

5. Technical Validation

The uncertainty of CFH measurements is estimated to be 0.51 K in frost point temperature, which is no more than 10% in terms of water vapor mixing ratio in the stratosphere below an altitude of 25–28 km[16, 17]. Tomikawa *et al.* (2015a)[11] performed a comparison of water vapor mixing ratio between the CFH and coincident Aura/MLS observations in 2013 and showed that they agreed within the accuracy of their observations.

Although the water vapor data in this observation is flagged as available or unavailable based on careful data screening, the possibility of (remaining) outliers cannot be ruled out. For example, when a balloon passes through thick clouds, water droplets may adhere to the balloon's envelope and evaporate in the stratosphere, causing contamination in the CFH data during ascent. In fact, such a situation occurred during the observation on July 28, 2013, and data above about 20.5 km altitude were flagged based on comparison of ascending and descending data and comparison with the Aura/MLS observation. The water vapor concentration was also highly variable above 10 km altitude on December 28, 2020. This observation was performed near the summer solstice, and the balloon was released just before local noon, so it is possible that sunlight reached the photodetector and contaminated the stratospheric water vapor concentration[16]. On the other hand, balloon payloads are known to oscillate with a period corresponding to the length of the unwinder, which in this observation is about 15 seconds[21]. Furthermore, the response time of CFH in the stratosphere is estimated to be about 10 seconds[17]. Therefore, it is desirable to perform averaging and/or filtering in the altitude direction (synonymous with the time direction) before using this data for analysis.

6. Figures

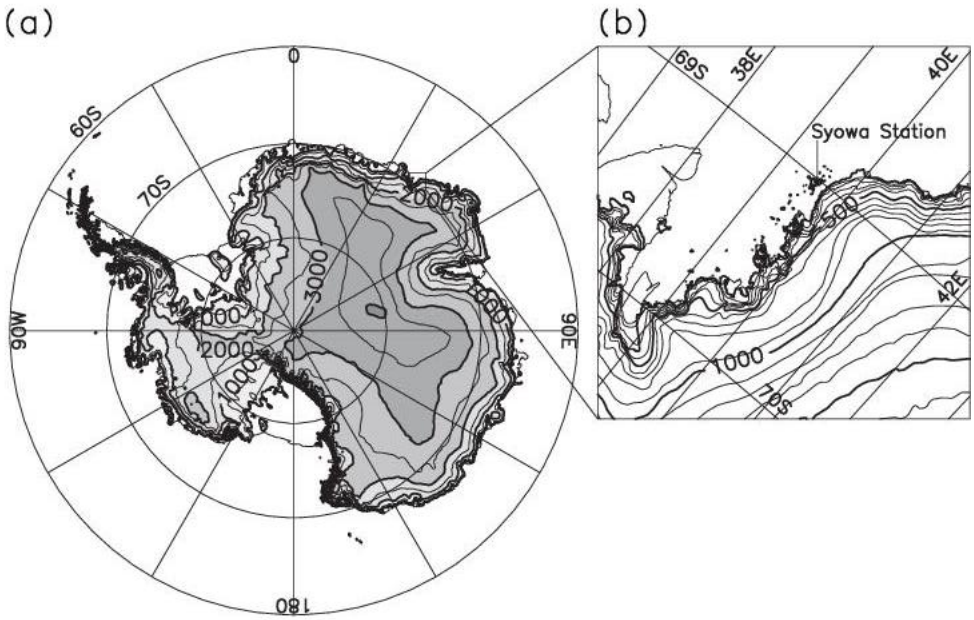

Figure 1. (a) Antarctic topography with contour intervals of 500 m. (b) Inset of (a) showing the coastal region around Syowa Station with contour intervals of 100 m. Adapted from Figure 1 of Tomikawa et al. (2015b)[22].

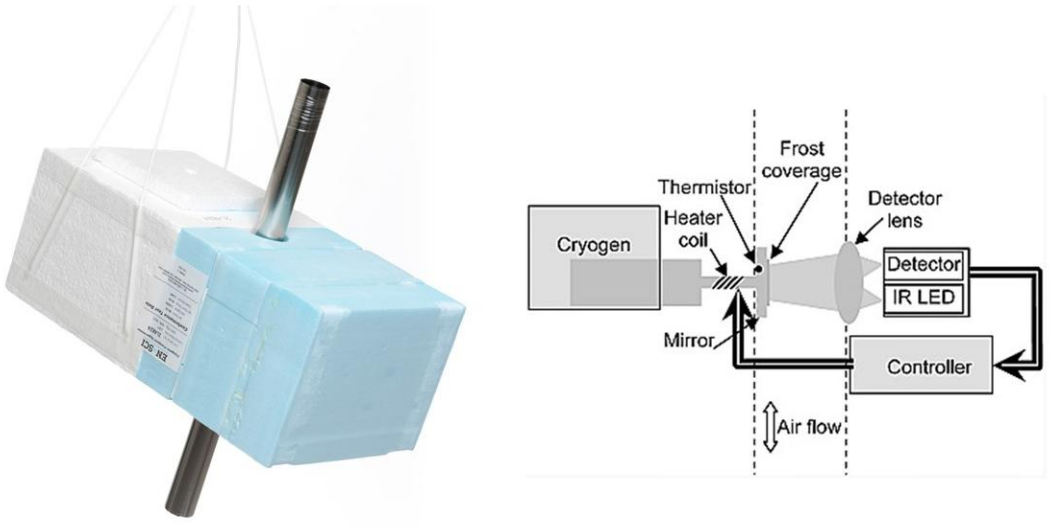

Figure 2. (left) photo of the CFH sensor adapted from https://www.en-sci.com/product/cryogenic-frost-point-hygrometer/ and (right) schematic of the CFH sensor adapted from Figure 1 of Vömel et al. (2007)[16].

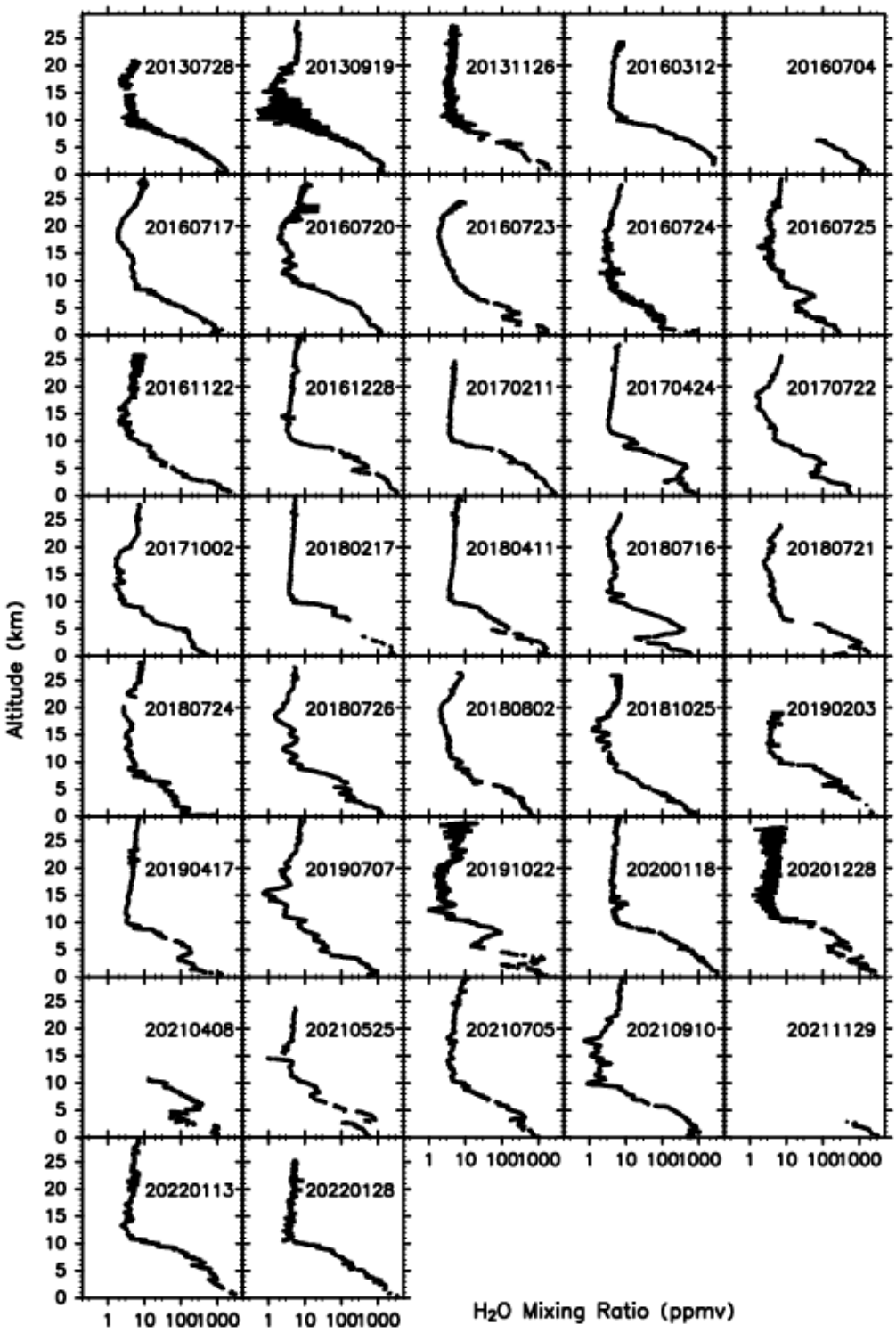

Figure 3. Vertical profiles of water vapor mixing ratio obtained by CFH observations at Syowa Station. The number in each plot shows the observation date.

7. Tables

Table 1. The number of CFH observations and available datasets (shown by brackets) as a function of year and month.

Year Month	2013	2016	2017	2018	2019	2020	2021	2022	Total
1						1(1)		2(2)	**3(3)**
2			1(1)	1(1)	1(1)			1(0)	**4(3)**
3		1(1)							**1(1)**
4			1(1)	1(1)	1(1)	1(0)	1(1)		**5(4)**
5							1(1)		**1(1)**
6						1(0)			**1(0)**
7	1(1)	7(6)	1(1)	5(4)	1(1)		1(1)		**16(14)**
8				1(1)					**1(1)**
9	1(1)						1(1)		**2(2)**
10			1(1)	1(1)	1(1)	1(0)			**4(3)**
11	1(1)	1(1)					1(1)		**3(3)**
12		1(1)				1(1)			**2(2)**
Total	**3(3)**	**10(9)**	**4(4)**	**9(8)**	**4(4)**	**5(2)**	**5(5)**	**3(2)**	**43(37)**

Author contributions

Yoshihiro Tomikawa organized the CFH observations at Syowa Station, created the data files, and performed their quality check. Naohiko Hirasawa, Masaki Tsutsumi, Takuji Nakamura, Masashi Kohma, and Kaoru Sato contributed to the establishment of this project and research using this dataset.

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