36 at 15.2 km and 48 ppb in flight 39 at 18.9 km. These results imply HNO_3 plus NO_2 mixing ratios greatly exceeding those for the unperturbed stratosphere. Also, our results show higher mixing ratios for these nitrogen constituents at 15.2 km than at 14.0 km in flight 36. This is another indication of the nonuniform distribution in the plume.

Measurements were also made of ^{222}Rn from samples from flights 36 and 39 (*7*). The measured radioactivity for the 16.5-km sample from flight 36 was 0.13 ± 0.02 disintegration per minute per liter (at standard pressure and temperature), where the error limit is 3 standard deviations. The flight 39 sample from 18.9 km, which was collected 26 days later in the predicted trajectory of the plume sampled in flight 36, showed that the radioactivity was 0.018 ± 0.002 disintegration per minute per liter. From the ^{222}Rn time constant of 3.8 days, the radioactivity is calculated to have decayed to about 1.4×10^{-4}. The background level of ^{222}Rn activity of the unperturbed stratosphere must be better known before the difference between the measured and calculated results can be properly interpreted.

Measurements of N_2O, $CFCl_3$, CF_2Cl_2, and CO_2 showed that the concentrations were within the range of mixing ratios previously measured in unperturbed stratospheric air in locations at similar latitudes (*8*).

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Changes in Stratospheric Water Vapor Associated with the Mount St. Helens Eruption

Abstract. *A frost point hygrometer designed for aircraft operation was included in the complement of instruments assembled for the NASA U-2 flights through the plume of Mount St. Helens. Measurements made on the 22 May flight showed the water vapor to be closely associated with the aerosol plume. The water vapor mixing ratio by mass in the plume was as high as 40×10^{-6}. This compares with values of 2×10^{-6} to 3×10^{-6} outside of the plume.*

Stratospheric water vapor—its concentration, variability, sources, and sinks—has been the subject of considerable interest and controversy ever since Brewer and co-workers (*1*) made measurements in the late 1940's. To obtain new data on this water vapor, we assembled a frost point hygrometer for use on the U-2 aircraft.

Table 1. Stratospheric water vapor mixing ratios in parts per million (ppm) measured over Moffett Field, California, 15 May 1980.

Altitude (km)	Mixing ratio (ppm)	
	Average	Range
15	1.5	1.1 to 2.0
16.5	1.4	1.0 to 1.9
18	1.4	1.0 to 1.6
19.5	1.9	1.7 to 2.1

The instrument, based on the design used by Mastenbrook (*2*) in his balloon program, consists of a small mirror that is controlled by temperature at the frost point. The mirror is connected through a moderate thermal resistance to a liquid nitrogen reservoir and has an electrical heater attached to it. The temperature is controlled by balancing the electrical heat input with the thermal conduction to the cold reservoir. The presence of frost on the mirror is measured optically and is used to servo control the temperature. A knowledge of the frost point yields the absolute humidity and the water vapor mixing ratio.

The instrument was installed in the wing tank of the U-2. Ambient air was taken in through a Rosemont probe mounted on the skin of the wing tank; it flowed across the mirror surface and was exhausted at the back of the tank. The major concern in any water vapor measurement is that the ambient air is not contaminated in the sampling process. The flow through our system is fairly high (1.6 liters per minute), and metal tubing is used throughout.

After fabrication and testing of the unit in late April and flight testing on the U-2 during May, the first flight with the unit was made on 15 May. When Mount St. Helens erupted on 18 May provision was made to fly the frost point unit on several flights into the volcanic cloud. Data were obtained on 22 and 27 May and 14 and 17 June 1980.

The water vapor mixing ratios, measured during the 15 May flight over NASA's research center at Moffett Field, California, are given in Table 1. Both average mixing ratios and the ranges for each altitude are shown. At this time, because of the limited data base with the instrument, we are not able to separate the fluctuations due to measurement precision from those due to water vapor variability. The figures are included for comparison with data obtained during penetration of the volcanic cloud on 22 May (Table 2). The time range for the measurements is included so that the water vapor data can be compared with measurements made by other sensors aboard the U-2 and decribed in accompanying reports.

Our data indicate that the aircraft was in the cloud at 1845 Universal Time (*3*). The water vapor data show a marked decrease in mixing ratio associated with the increase in aircraft altitude at 1925 and a sharp increase in mixing ratio when the aircraft descended again at 2000. The mixing ratio by mass decreases significantly after 2015 and appears to reach a background level of 3×10^{-6} at an altitude of 20.2 km by 2030. A background of 2.6×10^{-6} at 19.8 km was measured on the 15 May flight. These data confirm that significant amounts of water vapor were injected into the stratosphere by the 18 May eruption. On the flight of 22

Table 2. Stratospheric water vapor mixing ratios in parts per million (ppm) measured in the plume of Mount St. Helens on 22 May 1980.

Time	Altitude (km)	Mixing ratio range (ppm)
1845 to 1920	18.6 to 20.1	15 to 40
1930 to 1955	20.7	2.5 to 5.0
2000 to 2015	20.1	3.0 to 25
2030 to 2115*	20.1	2.0 to 3.5

*These data were obtained well away from the plume and represent unperturbed background mixing ratios.

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May the plume was well defined, and the water vapor mixing ratio in the plume was at least an order of magnitude above background concentrations.

Data obtained on the other three flights through the volcanic plume with the frost point hygrometer show larger variations in water vapor mixing ratios than observed during the 15 May flight, but the higher mixing ratios are generally only a factor of 2 or so above background. These increases are not as easily correlated with the time when the aircraft was in the plume. On the 27 May flight the range in mixing ratio by mass was from 1.5×10^{-6} to 4.5×10^{-6}; the highest readings were obtained between 0200 and 0215, the time during which the pilot was in the area where the cloud was predicted to be. High readings were also observed around 0245 when the aircraft was over Washington state but thought to be out of the plume.

The data obtained during the 14 June flight also showed great variability in comparison with the 15 May flight. Water vapor mixing ratios by mass ranged from 1.5×10^{-6} to 5.2×10^{-6}. There seemed to be no extensive areas where the mixing ratio was higher than that in surrounding areas; rather the regions appeared to be patchy.

The data obtained during the 17 June flight show practically no increase in water vapor mixing ratio anywhere along the flight path except for one brief period around 2135. At that time the mixing ratio reached 6.0×10^{-6}. During the rest of the flight the mixing ratio was between 2.0×10^{-6} and 2.5×10^{-6}.

From the data obtained with the frost point hygrometer it is evident that a large amount of water vapor was injected into the stratosphere by the 18 May eruption. It is less evident that the later eruptions carried much water vapor into the stratosphere. During the flight of 22 May, the enhanced water vapor mixing ratios were well correlated with the plume, and the plume size determined by Danielson (*4*) can be used to estimate the total amount of water injected by the eruption. Danielson gives the volume of the plume as $\simeq 2 \times 10^6$ km^3. From an average mixing ratio in the plume of 2×10^{-5}, it appears that a total mass of 3.2×10^9 kg of water was injected by the eruption. The injected water could come either from the volcano or from entrained tropospheric air. If the only source of water is tropospheric air, with a mixing ratio of 2 g/m^3, it would require the entrainment of 1.6×10^3 km^3 of tropospheric air to account for the water vapor measured in the plume on 22 May. This appears to be too large a volume, and thus some of the water vapor probably had to come from the volcano. If the source is totally volcanic, 3.2×10^{-6} km of liquid water would be required which, in view of the size of the 18 May eruption, appears reasonable. The water vapor mixing ratios measured after the other eruptions were not enhanced enough to argue for major injections of water from the weaker eruptions.

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Measurements of Cloud Condensation Nuclei in the Stratosphere Around the Plume of Mount St. Helens

Abstract. *Measurements of cloud condensation nuclei were made from small samples of stratospheric air taken from a U-2 aircraft at altitudes ranging from 13 to 19 kilometers. The measured concentrations of nuclei both in and outside the plume from the May and June 1980 eruptions of Mount St. Helens were higher than expected, ranging from about 100 to about 1000 per cubic centimeter active at 1 percent supersaturation.*

The eruptions of Mount St. Helens in May and June 1980 injected significant amounts of gases and particles into the stratosphere. We measured cloud condensation nuclei (CCN), the part of the aerosol capable of nucleating water vapor condensation at supersaturations of the order of 1 percent (relative humidity of 101 percent).

Rather elaborate projections of the effects of volcanic aerosol on the earth's climate have been made in recent years, such as that of Pollack *et al.* (*1*). Whether stratospheric CCN are important in the total picture of global weather depends on (i) the numbers of CCN available in the stratosphere, (ii) the rate at which they enter the troposphere, and (iii) the way in which they affect weather systems in the troposphere. Our measurements relate to the first of these three aspects. The second may involve any of eight mechanisms described by Shapiro (*2*). Once in the troposphere, CCN of stratospheric origin could modify cloud microstructure, leading to two possible effects upon climate: alteration of precipitation processes and alteration of the scattering and absorption of solar radiation by clouds (*3*).

To the best of our knowledge, our CCN data are the first reported from altitudes above the local tropopause. An indication of the CCN count, however, can be gained from the measurements of Rosen and Hofmann (*4*) taken between 10 and 20 percent supersaturation before June 1980, and more recently at 200 percent supersaturation, in numerous balloon ascents over Laramie, Wyoming. These investigators reported evidence of both anthropogenic and volcanic increases in stratospheric sulfates (*5*). Our measurements are taken as a function of two to three supersaturations within the range of those found in actual clouds; if compared to tropospheric counts, they should help to resolve questions of whether or not the stratosphere can ever be a significant source of CCN.

We analyzed four 1-liter samples of stratospheric aerosol collected by a NASA U-2 aircraft. These samples, although well suited for their original purpose of trace gas analysis, presented a serious concern with respect to our CCN measurements. It was expected that losses due to Brownian diffusion to the walls might cause unacceptably rapid depletion of the CCN present in the small sample containers, which were stainless steel cylinders with rounded ends (radius, 5 cm; length, 20 cm). Laboratory simulations of the experiment with similar containers showed that the loss of CCN active at 1 percent supersaturation was a rather consistent 35 ± 5 percent per hour. (No attempt was made to establish stable thermal stratification of the container contents.)

The 1-liter sample containers were cleaned and evacuated before each flight and were opened by pilot activation of motor-driven valves at the specified horizontal and vertical coordinates. All samples were obtained from a sample entry system designed for gas analysis. Diffusion losses of CCN were probably neg-

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