Mid-Latitude Humidity to 32 km[1]

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ABSTRACT

The results of 17 northern California soundings of humidity up to 25–30 km, generally a month apart, utilizing a highly sophisticated alpha-radiation hygrometer and associated balloon sounding equipment are described. The stratosphere was never found to be near saturation as has been suggested by some investigators, nor was it as dry and completely devoid of variability as is indicated by the most accepted circulation theory. A very dry layer was found above the tropopause, followed by a slight increase in humidity up to an average altitude of about 25 km. Above this level a general decrease in water vapor with altitude was deduced. Variability in this region of the lower stratosphere approached a factor of 10. Spasmodic transfer of water vapor upward through the tropopause is suggested and speculation related thereto provided.

1. Introduction

Starting more than 20 years ago British scientists (Dobson *et al.*, 1946; Brewer, 1949, 1955; Helliwell *et al.*, 1956, 1957, 1960), reporting upon initial aircraft investigations of humidity in the lower stratosphere, presented evidence that the tropopause acts as a cap to water vapor, which enters the atmosphere from the earth's surface, preventing it from penetrating into the stratosphere. This finding was presented in conjunction with a circulation theory which indicated that tropospheric air passes into the stratosphere only over equatorial regions from where it moves northward. It sinks back into the troposphere at higher latitudes, closing the cycle.

Tropical tropospheric air, having a higher moisture content than all other surface level air, following this route into the stratosphere would have to pass through the very cold tropopause of the tropics, less than −80C, where the water vapor density would be forced down to a value lower than elsewhere due to condensation. As this air departs upward from this level, the mixing ratio (the weight of water per unit weight of dry air) must remain constant if there is no source or condensation of water vapor. The mixing ratio most closely depicted by these British findings is 0.002 gm kg^{-1} which may be interpreted as 2 parts per million (ppm). It follows that water vapor density, i.e., the absolute humidity, must become monotonically lower as atmospheric density falls off with altitude. Frost point (and dew point) has a 1:1 relationship with absolute humidity and thus would have a parallel decrease with altitude. The British findings were considered quite authoritative for many years and have not been completely contradicted to date, although evidence to be presented herein and by others (Murcray *et al.*, 1966; Pybus, 1966[2]; Brown and Pybus, 1964) indicates some modification may be in order. Many slightly earlier investigations in England, Japan and the United States (Mastenbrook and Dinger, 1961), summarized by Gutnick (1962), indicated much higher humidities at 15–30 km. Some current parallel investigations (Mastenbrook, 1963,[3] 1965a,b, 1968; Williamson and Houghton, 1965) are providing evidence more in keeping with the British theory. Some of the wetter findings appear to be definitely unrealistic, e.g., the rocket observations of Fedynskii *et al.* (1967) of nearly 1 part per hundred at 75 km. Also, some of their earlier wet soundings were later disclaimed by the investigators, after changing their sounding technique (Mastenbrook, 1964[4]; Brown and Pybus, 1964). Therefore, those accepting the dry, nonvarying stratospheric humidity theory view with mistrust all data showing mixing ratios other than those near the average value speculated by the British, i.e., 2 ppm. However, quite recent British findings from an aircraft carrying man-monitored frost-point instrumentation equivalent to that flown during early experiments, but to higher altitudes, provided moist layers in the lower stratosphere not in agreement with the dry theory (Murgatroyd, 1967[5]). Unfortunately, the aircraft crashed during these experiments and the findings have not been published.

In 1965, a program supported by AFCRL's Laboratory Director through special funding (Grantham *et al.*,

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[1] This research was supported by the Air Force In-house Laboratory Independent Research Fund.

[2] Private communication, including frost-point profiles for Grand Turk Is., Bahamas; McMurdo Sound, Antarctica; and Palestine, Tex.

[3] Paper presented at Upper Atmosphere Meteorological Symposium, 21 August, Berkeley. Calif.

[4] Paper presented of Fifth Conference on Applied Meteorology, Amer. Meteor. Soc., 4 March, Atlantic City, N. J.

[5] Private communication including flight cross sections and preliminary data analyses.

1965) was initiated to help shed light on this quandary which had been aptly described by Gutnick (1961) in a widely acclaimed paper, "How Dry the Sky?"

The planned program involved flights of two frost-point soundings per month for one year from the surface to about 27 km from Chico, Calif., with the alpha-radiation hygrometer.

The alpha-radiation hygrometer, invented by John G. Ballinger, is an automatic frost-point instrument (Ballinger *et al.*, 1964, 1965a) in which the temperature of a polonium surface is controlled by a servomechanism which strives to maintain a stable deposit of frost on it. Brousaides and Morrissey (1967) have recently summarized Honeywell's development of this equipment for the Air Force Cambridge Research Laboratories. The polonium emits alpha radiation which is monitored by a Geiger-Mueller detector. The frost point is recorded by a miniature thermistor embedded in the polonium. The accuracy of the sensor in this instrumentation varies with true frost point, atmospheric pressure, and time allowed for the sampled air to reach equilibrium with the sensor. Poorest performance, 2–3C errors in frost point, is found near 100 mb when the frost point is between −80 and −90C because of the low mass transfer rates of the very few water molecules in the relatively high density of air molecules. At the top of the soundings the sensor error is only a fraction of a degree, but the recorder limits readings to about 1C. Fig. 1 depicts the frost-point error band for this sensor determined from a laboratory test cell. It may be noted that a frost point of −90C is the practical lower limit of this equipment. Fortunately, this did not prove to be a detriment in these experiments.

Balloons of 500,000 ft^3 with controlled valving and ballasting for obtaining desired vertical velocities were employed. A total payload of 450 lb included the alpha-radiation hygrometer which, when sealed with a recorder and dry ice in a desiccated stainless steel container, weighed 75 lb. The sensor package was lowered 2000 ft from the load bar on a hydraulic reel shortly after launch to separate it from water vapor, which may be outgassed from the surface of the balloon, and associated command and control equipment on the load bar.

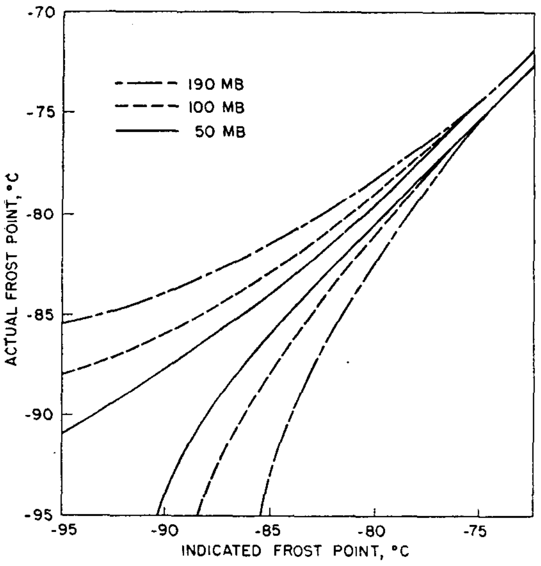

FIG. 1. Frost-point error curves for the alpha-radiation hygrometer.

Response time to anticipated humidity changes in the atmosphere dictated that the vertical velocity of the instrumentation be less than about 800 ft min^{-1} at the most critical altitudes with the optimum rate about 200–300 ft min^{-1}. The total flight time for a sounding was limited by FAA flight regulations which require that balloon flights commence and terminate during daylight hours. Since greater emphasis was to be placed on the descent portion of the flights, balloon ascent rates were increased to 600–700 ft min^{-1} so that descent rates could be maintained at the optimum value. On most flights, descent was begun as soon as the float altitude was attained. The normal flight configuration lasted between six and eight hours, well within designed battery and heat-sink coolant life.

An analog strip recorder, housed within the hygrometer package, was keyed by a commutator to register, each minute, six frost-point temperatures, two instrumentation calibrations, and one each of the following measurements: ambient air temperature, atmospheric pressure, heat-sink temperature, and internal hygrometer package temperature. In reducing the frost-point data, 5-min running averages were used to average the servo-cycle of the hygrometer.

As a further precaution against contamination, balloons were packaged dry, instead of being dusted with cornstarch, the usual lubricant. However, after two successful flights, a series of balloon bursts during ascent indicated the desirability of dusting the folds of the balloon with lubricant. Teflon powder was chosen because of its extremely low moisture absorption qualities.

2. Findings

Of the planned 24 flights, 17 soundings were obtained which provided useful data into the stratosphere but one of these was for only a very short distance above the tropopause. Dates of the 17 successful soundings are listed in Table 1.

Fig. 2 depicts the first sounding. Despite the extensive precautions to prevent contamination, its presence on ascent is quite apparent. In the stratosphere, ascent

TABLE 1. Dates of humidity soundings, Chico, Calif.

8 Jan. 1965
10 Jan. 1965
24 Feb. 1965
23 Mar. 1965
22 Apr. 1965
22 May 1965
22 Jun. 1965
25 Jun. 1965
22 Jul. 1965
21 Sep. 1965
23 Sep. 1965
25 Oct. 1965
27 Oct. 1965
7 Dec. 1965
27 Feb. 1966
25 Apr. 1966
27 Apr. 1966

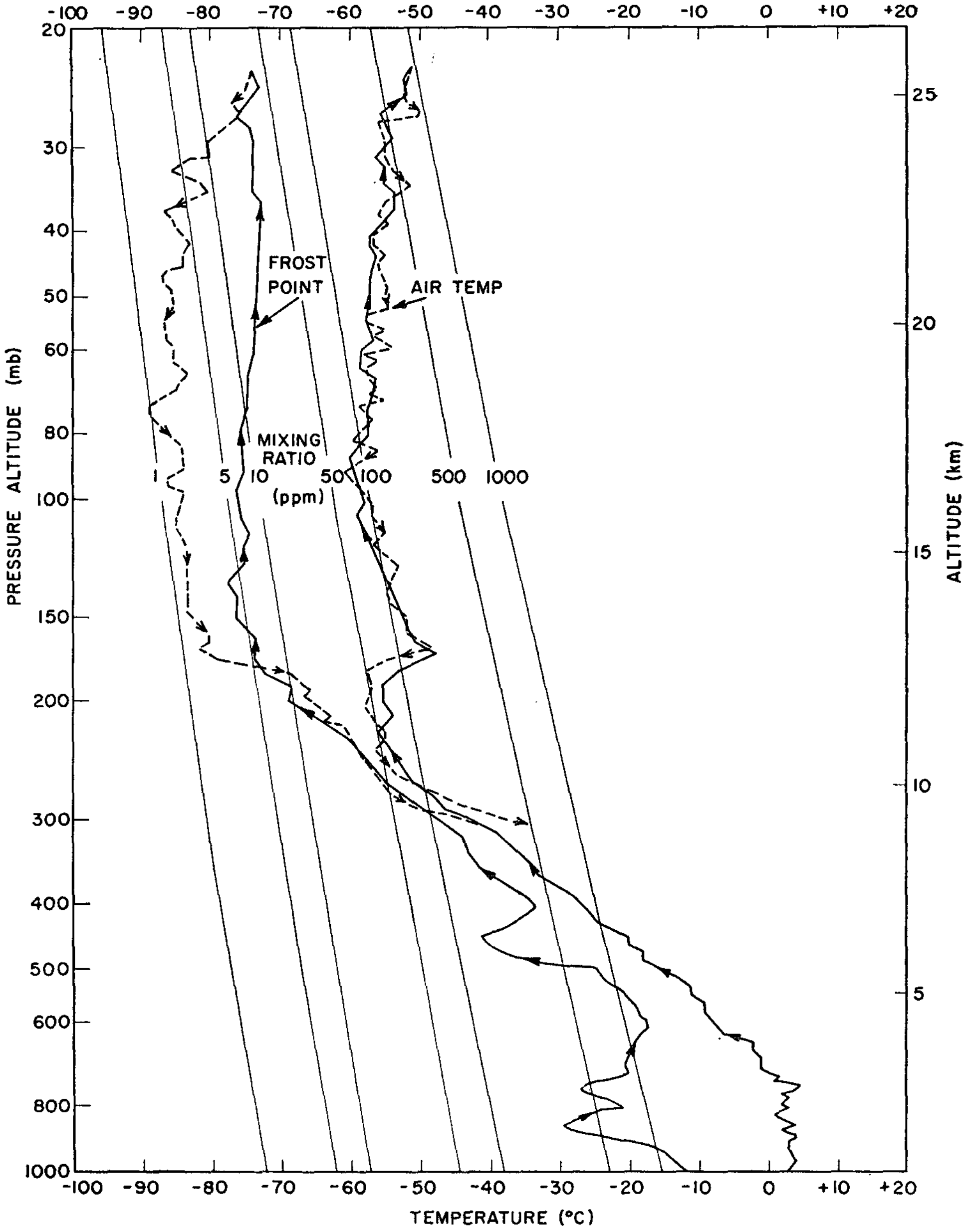

FIG. 2. Ascent and descent sounding of 8 January 1965, Chico, Calif.

frost points averaged around −75C, while frost points were colder by 10C or more during descent. This amounts to a factor of 5 in the water vapor density at these temperatures. This early finding lead to careful study of the configuration of the sounding system as shown in Fig. 3. The geometry of the sensor in the stainless steel container A, which was lowered 2000 ft from the hydraulic reel B, still had one shortcoming. Air passing over the instrument container could sweep molecules of water vapor off its surface and then be sucked into the sensor intake which protrudes directly beneath it. Though the bottom and walls of the cylindrical container were stainless steel, a relatively nonhygroscopic material, the top had to be constructed of heavy gage aluminum which is more prone to surface absorption. It was quite apparent that our ascent data could not be considered as truly representative of the stratosphere with this defect. The remedy was to bend the stainless steel intake tube 90° and lengthen it slightly to get it out of the boundary layer. Since the tube in itself was a possible source of contamination (Ballinger *et al.*, 1965b), it had to be kept as short as possible. The electronic command and control equipment is contained in C. It was permitted to breathe through a vapor trap. The container for dessicated ballast is D. A radiosonde instrument E was used to provide

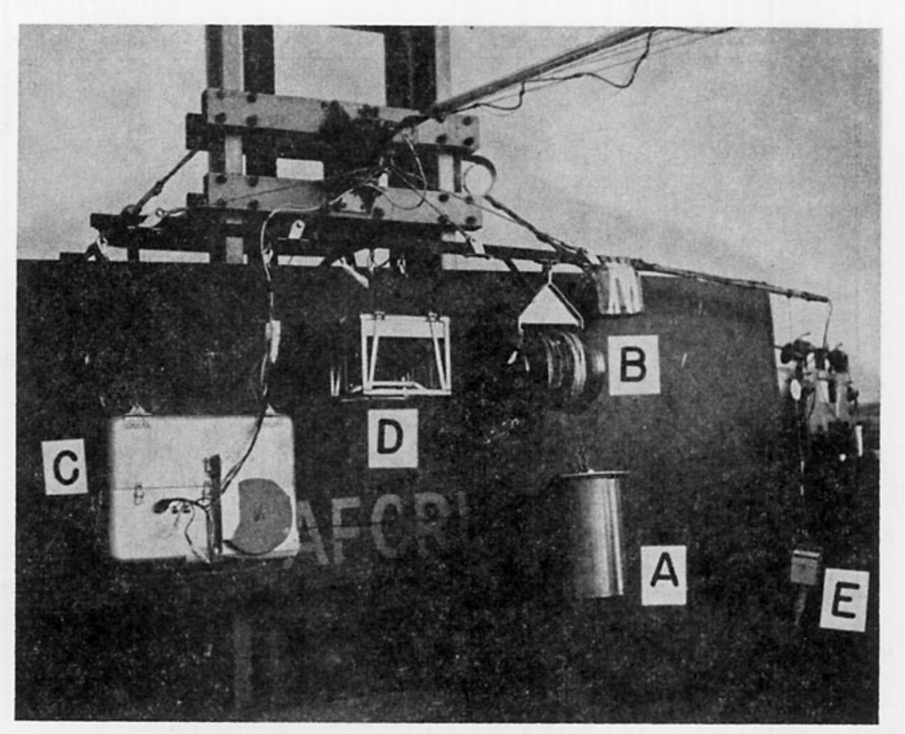

FIG. 3. Stratospheric humidity sounding system: A, hygrometer and recorder container; B, hydraulic reel; C, electronic command and control equipment; D, ballast container; and E, radiosonde.

flight support data and serve as a tracking beacon. Radiosonde pressures, corrected for 2000-ft separation, were used to specify altitude.

The effectiveness of this configuration was proven several flights later as shown in Fig. 4. In this case the air encountered in ascent was actually drier than that encountered in descent in the stratosphere and upper troposphere at most levels. During the several hours of flight the balloon had moved a considerable distance across a mountain range, and was sampling a different air mass. This flight effectively provided two independent soundings, since a bias toward wetter ascent, which appeared in all earlier flights even when ascent and desent were widely separated, was no longer present. Also apparent in this figure is the horizontal stratification (layering effect) in the frost-point profile, several lamina being observed on both ascent and descent portions of the sounding, e.g., the layers at 140 and 50 mb. These stratified layers range in depth from a few hundred meters up to over a kilometer. Similar layering effects in other atmospheric constituents have been observed by other investigators (Hering and Borden, 1967; Pittock, 1966). Pittock, for instance, reported a remarkably stable thin (0.5 km) layer of ozone and volcanic debris in tropical air which had been quasi-horizontally advected from about 8S (originating from the Mt. Agung volcanic eruption) to 40N. It was present over Boulder, Colo., at 50 mb for at least a month.

Fig. 5 shows the monthly summary of all data found acceptable. Frost points are averages through the pressure levels indicated. There appears to be an annual cycle for layers higher in altitude than 100 mb ($\sim$16 km). A maximum is reached in the late winter, a minimum in the summer. However, there is probably little significance in deducing such systematic variation from this limited data sample. The range of the 5 data points obtained during April above 60 mb (2 in 1965, 3 in 1966) is nearly as great as that of the range of the annual cycle. Though such an annual cycle has been suggested in a theoretical study of ozone and water vapor in the stratosphere by Roney (1965), a harmonic analysis revealed that cycles depicted by the Chico data are not statistically significant.

As indicated earlier in this report, the humidity that can best be attached to the nonvarying dry British stratosphere is 2 ppm by weight, i.e., a mixing ratio of 0.002 gm kg^{-1}. The values obtained in this study near the 100–150 mb layer, which is the maximum altitude of the original British aircraft data, are in good agreement with this nominal value. Our data ranged from 1–10 ppm at this level. However, it can be noted from the scale on the far right of Fig. 5, that while the annual cycle appears to be damping out with altitude, the proportion of water vapor appears to be increasing, attaining some 10–40 ppm near the top of the soundings. This increase is sufficient to increase the frost point from about -81C at 18 km to about -79C at 25 km.

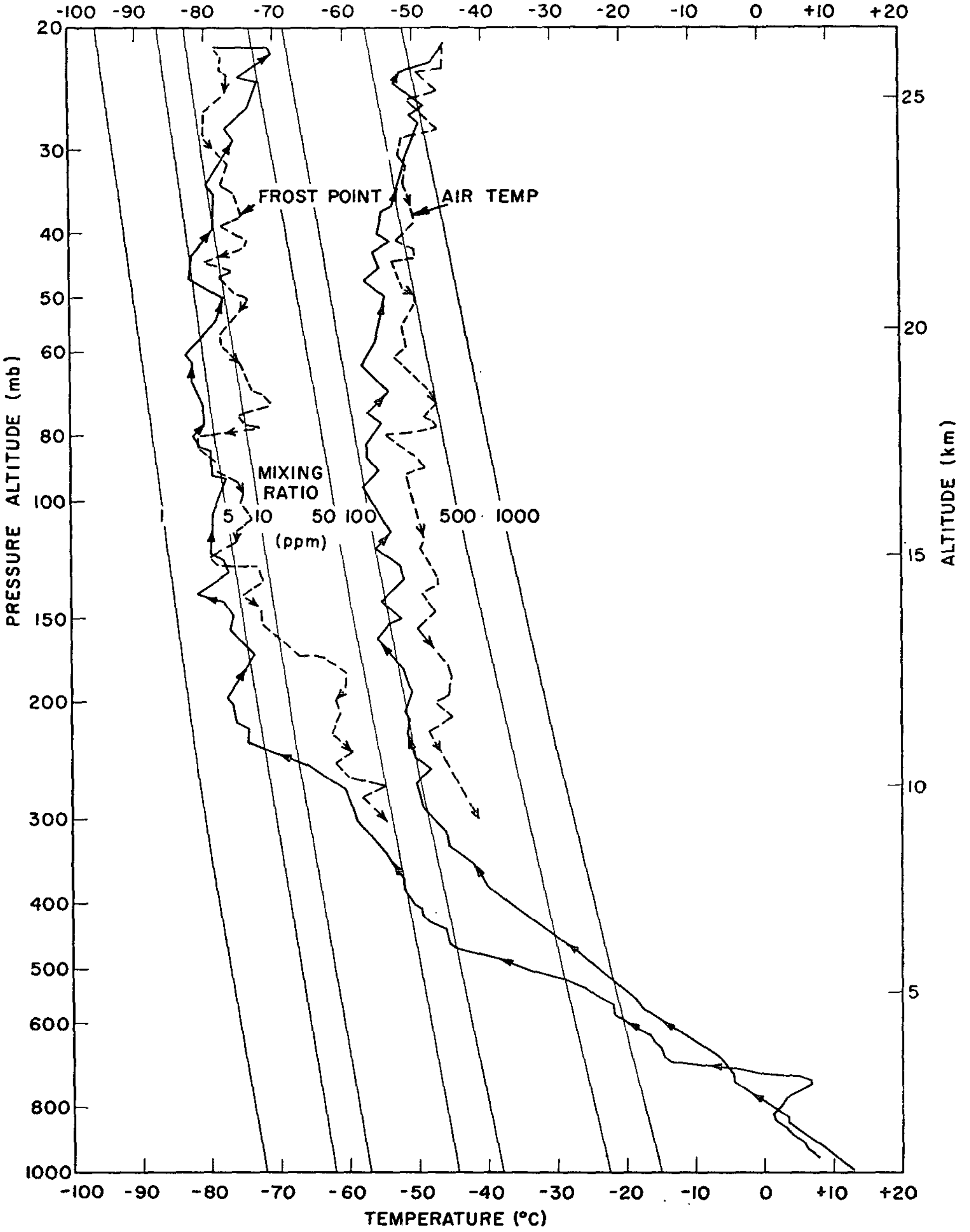

Fig. 4. Ascent and descent sounding of 22 April 1965, Chico, Calif.

This trend can make the reliability of these data suspect. If continued upward, the partial pressure of the water vapor at some altitude would exceed total atmospheric pressure. This is not physically possible.

For this reason a special experiment was arranged to carry the equipment to higher altitudes. This sounding (Fig. 6) reached a pressure of 8–9 mb (~32 km) as compared to the usual 25 km. The lower 25 km of this sounding differs little from the earlier soundings. Once above the tropopause, the frost point decreases to a −84C [illegible] and increases to a maximum of −75C at 23 [illegible] (~25.5 km). However, above this point a trend is established toward lower frost-point values. At 9 mb it dips to −82C, lowering the mixing ratio to 27 ppm, still 10 times that at the base of the stratosphere.

A convincing factor in this high-altitude sounding that provides confidence in the presence of a slightly more moist layer at 25 km than immediately above or below this level is that it is seen in both the ascent and descent. There are some differences due to time and space, since about 3 hr elapsed between ascent and descent through the 25-mb level. If contamination were thought to be the reason for the maximum in humidity on ascent, it would be difficult to argue that this is the

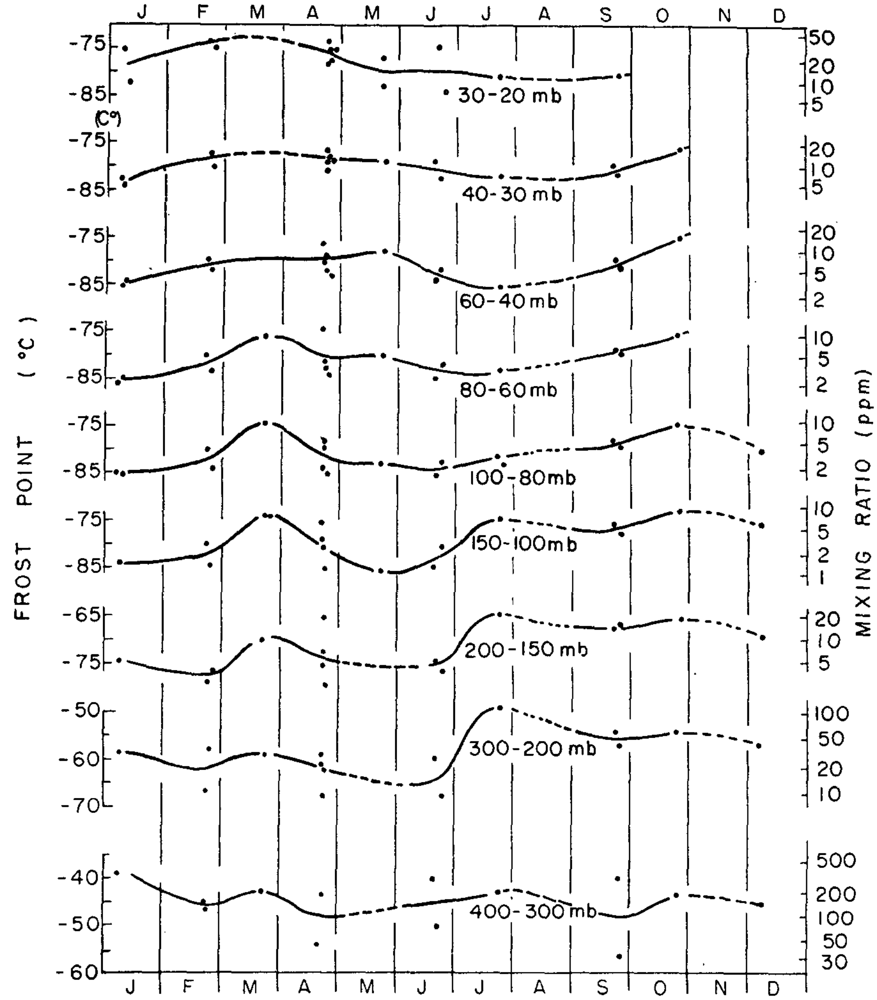

FIG. 5. Mean frost points within selected layers by months.

cause of the maximum on descent, since the system had dried out at higher altitudes as evidenced by the lower humidities with higher temperatures. Also, the air sampled in descent is less likely to have had any contact with the boundary layer air of the balloon system than on ascent. The fact that the sensor had the range to attain much colder frost points, which were observed both above and below this layer, also establishes confidence in the instrumentation and the slightly increased humidity at 25 km.

To further verify this relative maximum in humidity at about 25 km an additional sounding was made on 26 April 1967. The results of this flight were a disappointment, however, since due to an apparent equipment malfunction early in the sounding, in either the heat sink, the electronics, or both, frost-point temperatures appear to be 5–10C too warm at all altitudes. However, the vertical gradients in the frost-point profile appear to be valid and are very similar to those in Fig. 6. After a humidity minimum above the tropopause, the frost point increases gradually to a maximum at about 22 km. (In Fig. 6 the maximum is at 25 km.) Above this maximum, the frost-point gradient is about $-1\mathrm{C\ km^{-1}}$ up to the top of the sounding at 32 km. The frost-point lapse rate in the top portion of this 26 April 1967 flight is essentially the same as that depicted above 25 km in Fig. 6. The descent data was valid only down to about 27 km but in the 5-km descent, the frost-point temperature trace closely followed the ascent profile.

Fig. 7 is presented as further support for the tendency of a humidity maximum at ≈25 km, at least over mid-latitudes. (This is also the altitude of nacreous clouds which generally form to the leeward of mountains during periods of strong upper air flow across the range.) This 14 June 1965 sounding was obtained at Holloman AFB in New Mexico during investigations of the frost-point sounding system contamination (Ballinger *et al.*, 1965b). The alpha-radiation, frost-point hygrometer was flown on the load bar in these studies (rather than at 2000 ft beneath it as in Chico) and usually showed much less contamination than in the flight pictured in this figure. Presumably, this is be-

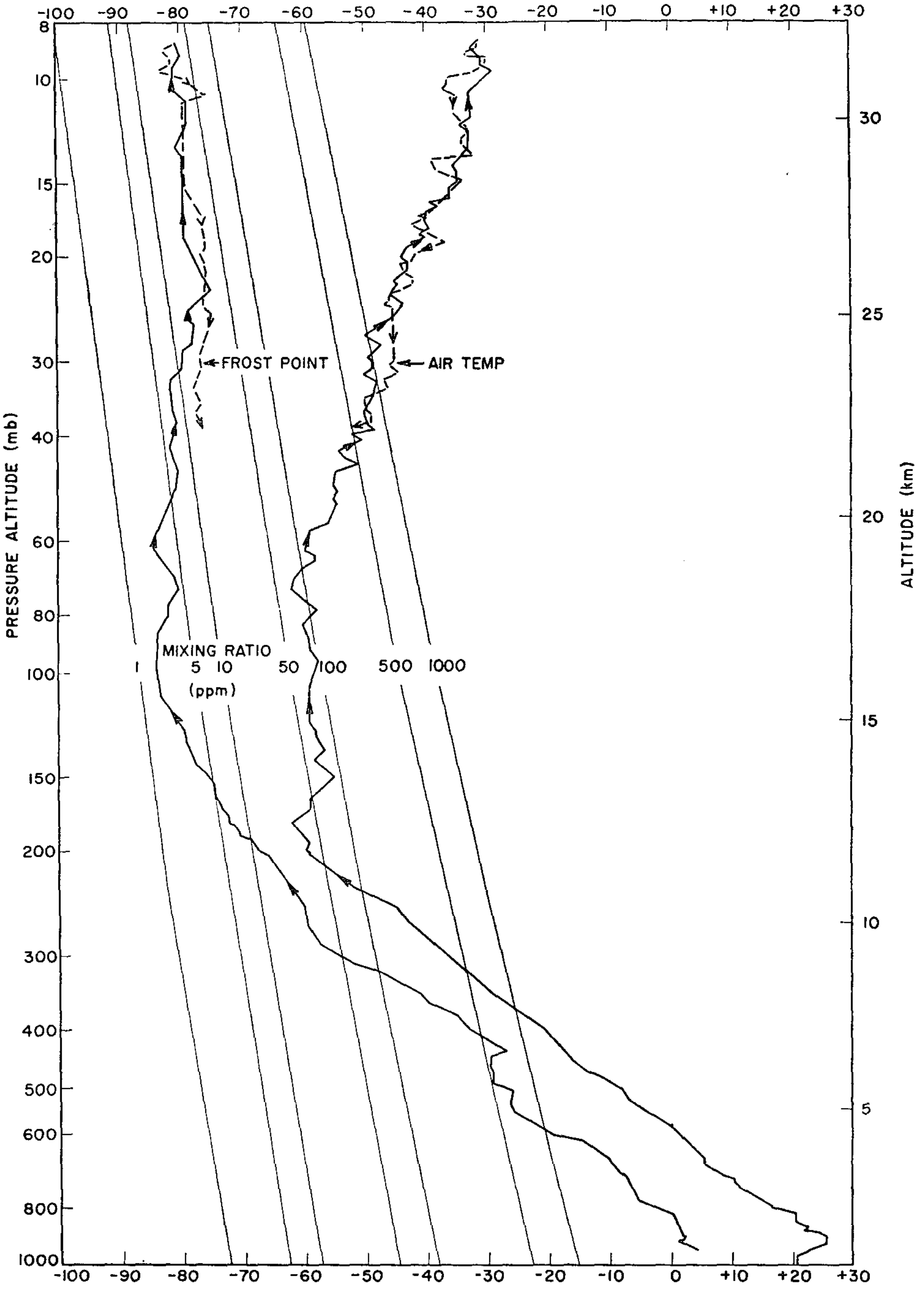

Fig. 6. Ascent and descent sounding of 25 April 1966, Chico, Calif.

cause of the drier surface and troposphere conditions of the New Mexico desert. However, both ascent and descent of this Holloman flight also showed a tendency for the slight increase in moisture at 25 mb.

How this gradient in frost point of −1C km^{-1} above 25 km is related to water vapor at the mesopause was next considered. Probably, the only information in which one can place great confidence regarding water vapor in a layer at high altitude was derived from an experiment in which noctilucent cloud particles, captured by a rocket at the 80-km mesopause level, included ice (Soberman, 1963; Michaels, 1965). This finding implies the existence of saturated water vapor through a layer at this high altitude. Such clouds are not found at tropical and mid-latitudes where temperatures are seldom colder than −100C (Cole and

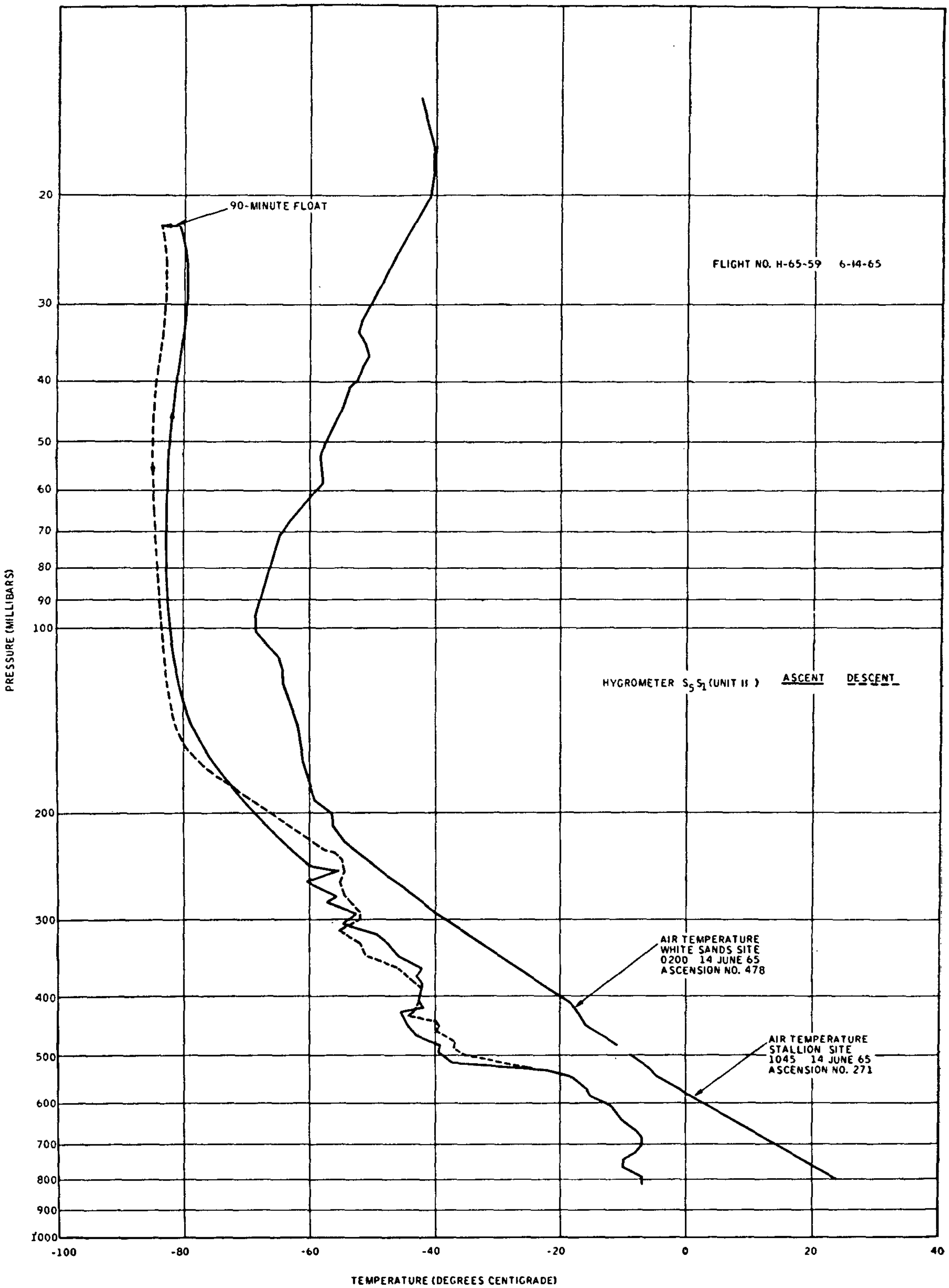

FIG. 7. Contamination study sounding of 14 June 1965, Holloman, N. M.

Kantor, 1963) at this level. They are only seen at high latitudes in the summer where extremely cold mesopause temperatures are usual. During one experiment (Anon., 1963) at which such clouds were physically sampled, the temperature observed was −143C. During another sampling when the clouds had dissipated, a temperature of −120C was measured. If the mixing ratio of 27 ppm at 30 km, the top level of our highest sounding (Fig. 6) were considered to hold uniformly up to 80 km (~0.01 mb), the frost point would only be −115C, not cold enough. However, the frost point in this sounding had fallen 7C in the highest 6.5 km, a gradient of about -1C km^{-1}. At this rate, 48 km are required to lower the frost point from −82C (the value at 32 km in Fig. 6) to −130C, a nominal value for noctilucent clouds suggested by the experimental data (Anon., 1963). Since these clouds are found about 48 km above the top of this sounding, the trend in humidity in the 25–32 km altitude region provided by the Chico sounding appears to support the values of humidity which must be present at altitudes of noctilucent clouds.

Now the problem remains of explaining the relatively moist layers at 20–25 km. Mixing ratios in this layer are five times those at the base of the stratosphere and can only be considered credible if a source for such a "spiking" of the stratosphere can be presented. The British and other investigators (Mastenbrook, 1965b, 1968) had noted near saturation in the upper troposphere and a sharp drying out upon passing upward through the tropopause. The Chico data corroborates these findings. In Fig. 8 the average change in frost-point depression below free air temperature during penetration of the tropopause for this series of soundings is shown. The drop in frost point from −63.9C at the tropopause to −80.4C in 2.8 km lowers the water content by a factor of 12. The tropopause certainly seems to act as a barrier.

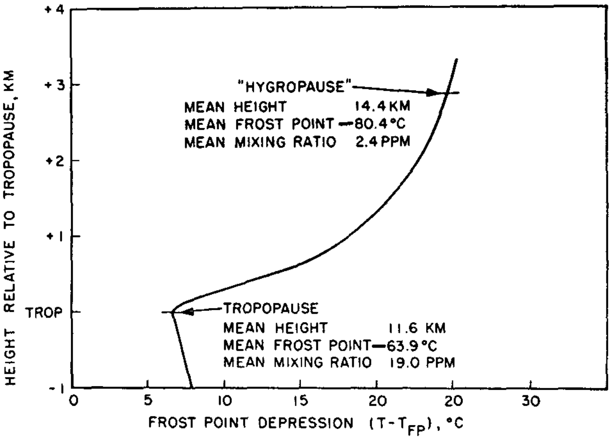

FIG. 8. Mean frost-point spread at vicinity of tropopause level.

However, there are exceptions which if not present would have made these average rates of decrease even more dramatic. In Fig. 9 the graph at the left displays a sharp temperature tropopause (the solid curve), and a very sharp decrease in the frost point (the dashed curve). At the right of Fig. 9, for another weather situation, the tropopause is not well defined (solid curve) and the parallel frost point decreases were far less dramatic (dashed curve). This example suggests that with less intense tropopause inversions, such as are encountered frequently at mid-latitudes when there is overlapping or leafing of tropical and polar tropopauses, there will be occasional transfer of moister tropospheric air into the stratosphere. For example, over the Gulf of Alaska where such leafing action could be forced by well-developed cyclones regularly entering the Aleutian low (the tropopause is known to rise and fall as cyclones pass), the tropopause temperature remains between −50 and −55C (Ratner, 1957, 1958) throughout the year. This air is about 25C warmer than in equatorial regions and can contain nearly 100 times more vapor before becoming saturated. Small amounts of saturated

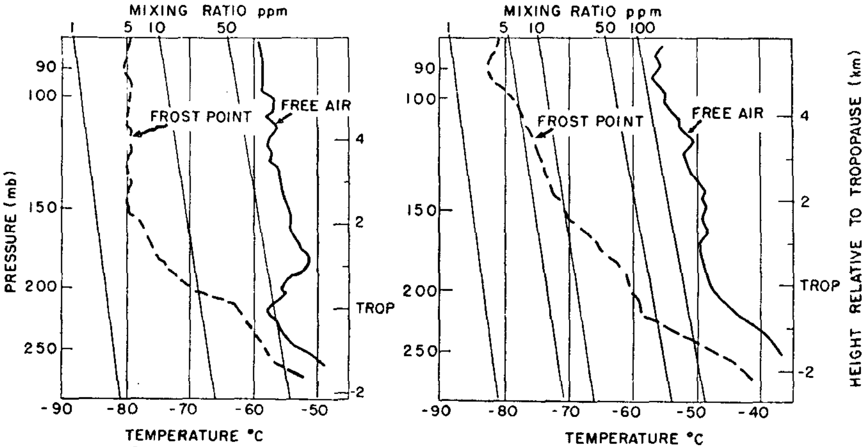

FIG. 9. Frost-point profiles at vicinity of tropopause.

tropospheric air being mixed upward could add considerably to the water vapor of higher level warmer air, even if most of this higher altitude air had entered the stratosphere over the equator, as suggested by Brewer (1949). Corroborating this speculation, extensive cloudiness through a deep layer well above the tropopause over Anchorage, Alaska, was noted by an Air Weather Service forecaster (Ehrlich, 1966).[6] Though a well-defined polar tropopause was present at 25,000 ft, jet aircraft were unable to top all cloudiness after climbing to 39,000 ft. This happened during a transition season and was associated with the passage of a not unusually strong, extratropical cyclone. Crutcher (1963) also summarized much evidence of clouds in the stratosphere in an address on problems of supersonic aircraft. He quoted Capt. Joseph W. Kittenger, a USAF investigator/parachutist who upon jumping from a balloon at 102,800 ft stated: "I am making an exciting discovery. There are clouds at my altitude. They are so thin I see them only when my vision comes within 30° of the sun, but they reflect the sun with dazzling whiteness."

Passage of water vapor into the stratosphere during leafing of multiple tropopauses at mid-latitude and higher is a possible, but not necessarily an exclusive, explanation. Another possibility is vaporization of the ice crystals of convective clouds which penetrate into the stratosphere over continental mid-latitudes in the warmer half of the year. These have been observed to attain altitudes of 22 km by aircraft and radar (Grantham and Kantor, 1967; Long, 1966) over the center of the United States with greater frequency than has heretofore been considered likely. They must evaporate to dissipate and thus also add vapor to the air. Since at this level, the upper winds flow from the east during the summer, this water vapor could very well be carried over Chico.

There are no known reliable direct measurements of humidity in the upper stratosphere and mesosphere, consistent with noctilucent cloud data, which can be compared to the suggested extension of the Chico profile. However, comparison with indirect measurements such as spectrographic analyses are possible. A balloonborne spectrometer experiment was conducted from Holloman AFB, N. M., in September 1965 by The Johns Hopkins University. Special care was taken to remove the influence of the water being outgassed from the floating balloon from the reduced data. The results of this experiment, based on analysis of absorption of solar energy in 50 cm^{-1} wide spectral intervals, indicated a mean mixing ratio of 10.5 ppm above the 34-mb float level (Zander, 1966). This value was later revised (Zander and Bottema, 1967) to 5.4 ppm after stronger emphasis was placed on individual spectral line analysis. In order to compare these findings with the extension of the Chico data to the mesopause suggested by the discussions of frost point in noctilucent clouds, a nominal mean humidity profile was developed for Chico (Fig. 10) which is the average of all soundings up to 25 km. Above 25 km the frost-point lapse rate is that provided by the two soundings attaining 32 km. The British "Dry Sky" concept and Gutnick's (1962) average of data available before 1962 are shown.

The mean mixing ratio (details shown in Table 2) for the layer 34–0.01 mb (25–85 km), based on the extension of Chico data, is 14.7 ppm. Although this value is higher than the revised (Zander and Bottema, 1967) value of 5.4 ppm, it is only slightly higher than the original value of 10.5 ppm. Regardless of which of the two New Mexico values are accepted, it cannot be considered in great conflict with the Chico findings. There is far less likelihood that water vapor injected into the stratosphere through the tropopause over Pacific cyclones will reach New Mexico in September than will reach Chico on a year round basis. Also, while the New Mexico sounding (Fig. 7) does show a tendency for a slight maximum near 25 km in June, the Zander sounding at 24 km in September may have been above such a maximum, or near the top of it. Chico soundings revealed that this slight maximum had a range in altitude of a few kilometers about an average altitude of 25 km. Therefore, the arguments for explaining the small, but measurable, amount of water vapor up to 25 km at Chico can be logically used to estimate a lesser amount over New Mexico, where the tropopause inversion is stronger.

TABLE 2. Basis for obtaining mean mixing ratios above 34 mb at Chico.

Layer (mb)	Weighting factor	Mean mixing ratio for Chico extension (ppm)
34 –25	9	13.0
25 –15	10	17.0
15 –10	5	17.0
10 – 6	4	15.5
6 – 3	3	14.0
3 – 1	2	10.4
1 – 0.5	0.5	6.8
0.5– 0.01	0.5	1.8

3. Conclusions

1) A nominal mid-latitude yearly average humidity profile is provided by the average of 17 Chico, Calif., soundings shown in Fig. 10. The dashed extension is a result of only one sounding plus corroboration in the gradient from a malfunctioning second attempt to reach 32 km. The curve reveals a stratospheric humidity minimum above the tropopause near 15 km, a slight maximum near 25 km, and a gradual decrease upward. This rate of decrease provides a frost point of −130C at the mesopause (80 km), which is in reasonable agreement with temperatures observed while trapping noctilucent cloud particles which contained water. The mid-latitude maximum required a physical explanation,

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[6] Private communication.

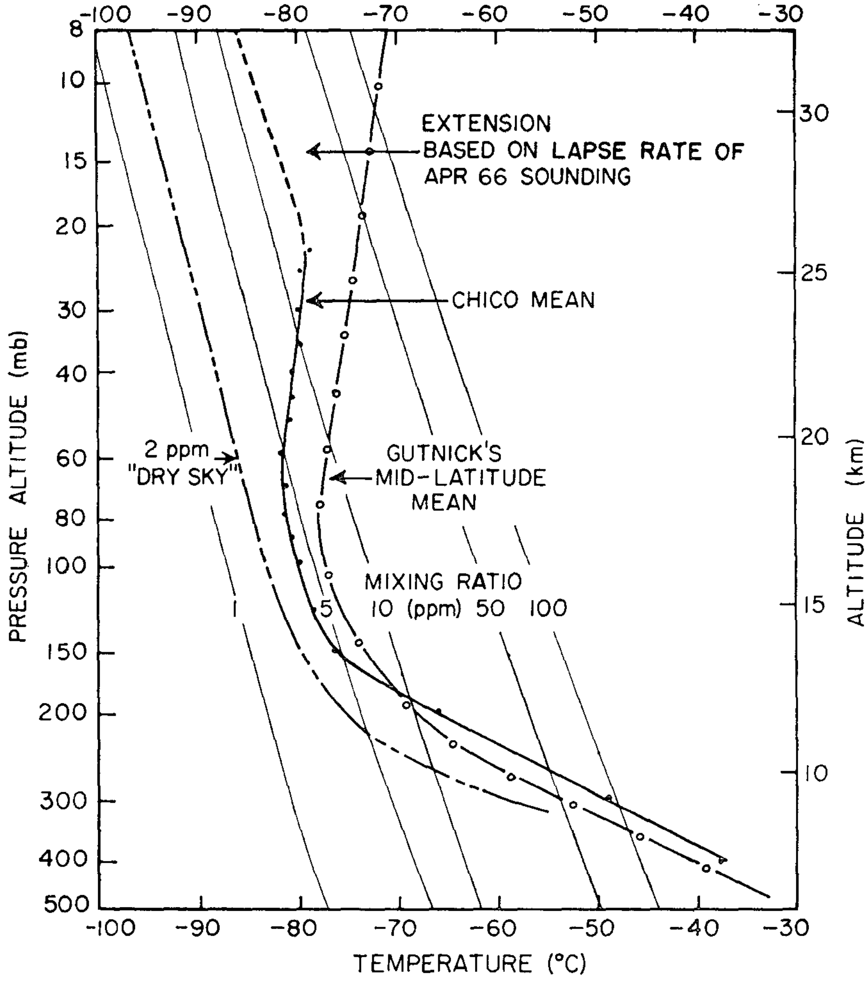

Fig. 10. Comparison of frost-point profiles. See text for explanation.

a water source, to make it plausible. Two mechanisms have been suggested.

2) The curve on the left of Fig. 10 is representative of the frost points that could be expected if the mixing ratio remained constant at 2 ppm, the value suggested by early British investigators and still considered valid by many. This curve yields a frost point of −125C at the altitudes of noctilucent clouds, which is still within the range for agreement with experimental noctilucent cloud data i.e., −120C with no cloud, −143C with cloud present, obtained by the 1963 United States-Swedish rocket experiments. Having a nominal profile of humidity such as this over tropical areas would not be inconsistent with the nominal mid-latitude profile inferred from the Chico soundings if the suggested mechanism for injection of water vapor into the stratosphere in the mid-latitudes is acceptable.

3) The curve on the right, prepared in 1962 (Gutnick, 1962), shows the mean conditions observed up to that time after screening out data thought to be erroneous through subjective examination. This water content profile could not be reasonably extrapolated upward since it would require noctilucent clouds over most of the earth and result in a partial pressure of water vapor which exceeds the total pressure of the atmosphere at some altitude.

4) Since the processes that introduce water vapor into the stratosphere are sporadic, there is a variability of nearly tenfold in the lower stratosphere at mid-latitudes. Systematic variability, such as associated with seasons, also appears to be present but much more evidence is required to substantiate it.

5) Finally, none of the Chico experimental data support speculation that the lower to middle stratosphere is sometimes nearly saturated.

Acknowledgments. Lt. Col. Robert W. Cowne was responsible for monitoring the development and procurement of the instrument package and in supervising some of the early flights. The efforts of M/Sgt. John E. Bowers, Instrument Technician, in preparing and maintaining flight instruments also merit special recognition. Special thanks are due to Messrs. S. Rohrbough and J. Ballinger, of Honeywell, Inc., for design of the sensor package and field aid during initial flights. The balloon systems were designed by AFCRL's Balloon Research Branch and flown under the supervision of the Balloon Flight Requirements Analysis Branch.

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