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The Vertical Distribution of Water Vapor Over Kwajalein Atoll, Marshall Islands

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ABSTRACT

Five balloon flights with a frostpoint hygrometer sounding instrument provided measurements of the vertical distribution of water vapor over Kwajalein, in the Marshall Islands, during the month of November 1963. A consistent water vapor distribution is observed, showing a moist surface layer beneath the trade-winds inversion, a dry trade-wind layer above the inversion, and near saturation conditions in the upper troposphere. The stratospheric distribution approximates a constant water-vapor-to-air mixing ratio in the range of 1 to 4 parts per million.

PROBLEM STATUS

This is a final report on one phase of the problem; work on the problem is continuing.

AUTHORIZATION

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THE VERTICAL DISTRIBUTION OF WATER VAPOR OVER KWAJALEIN ATOLL, MARSHALL ISLANDS

INTRODUCTION

The state of knowledge on the vertical distribution of water vapor in the low-latitude regions of the tropics has been limited to that data acquired through routine meteorological soundings of the atmosphere, and this data, due to the limitations of the sensors, is representative only for the lower half of the troposphere. The distribution at the higher levels bears directly upon such meteorological problems as the general circulation and the radiative transfer of the atmosphere, and recently has assumed importance to military problems as well.

In November 1963 the Naval Research Laboratory and the Pacific Missile Range joined in an effort to measure the water vapor distribution at higher altitudes in the tropics. The measurements were made at Kwajalein, an atoll in the Marshall Islands, at a latitude of 9 degrees north. This was a first attempt at direct measurement this near to the tropical convergent zone where the frequency of convective activity poses a special problem of instrument contamination.

INSTRUMENTATION AND SOUNDING PROCEDURE

The measurements of water vapor distribution were obtained using automatic frostpoint hygrometers (1) which were carried to stratospheric heights and returned using controlled expansible balloons. The flight configuration is shown in Fig. 1. The support vehicle was a 7000-g neoprene balloon equipped with a gas valve. In sequence beneath the balloon were a 17-ft parachute, corner reflector, deployment reel, battery pack, and, at the bottom, the frostpoint hygrometer.

The sounding procedure was as follows: During the first few minutes after launch, the hygrometer was deployed 900 ft below the rest of the flight train. When the ascending balloon reached the 12-millibar (mb) pressure level, a pressure-activated control opened the balloon valve, allowing helium to escape. As the buoyancy decreased, a maximum altitude was achieved, which was then followed by a descent at an accelerating rate until ram pressure at the valve opening became equal to the overpressure of the balloon and valving ceased. The following stratospheric descent was at a decelerating rate, from a maximum rate of about 2000 ft/min to a rate of approximately 1000 ft/min. The parachute became operative at stratospheric levels only in the event of balloon failure, and it provided a descent rate of 4000 ft/min at the 100,000-ft level.

RESULTS

Five soundings were made during the period from Nov. 15 through 23, 1963, which provided data for analysis. The flight data are shown graphically as pressure vs altitude plots of frostpoint and ambient temperature in Figs. 2(a) through (e). The data points of frostpoint temperature were extracted from the flight record at 1/2-min intervals and constitute running means of 15 sec at tropospheric level and 30 sec at stratospheric levels. The plots show a close agreement between the ascent and descent curves of frostpoint at tropospheric levels, providing a detailed delineation of the moisture distribution.

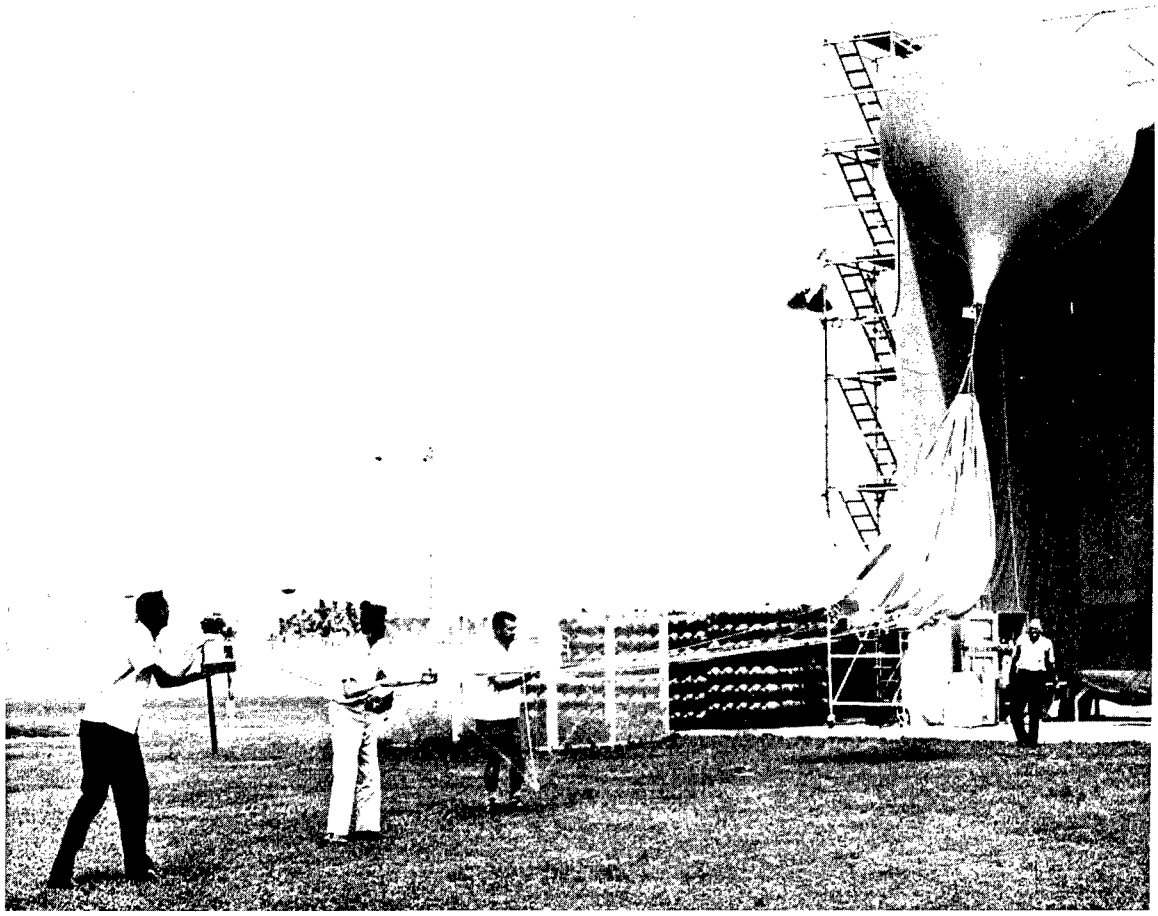

Fig. 1 - Launching of a water-vapor sounding system from Kwajalein, Marshall Islands

At the stratospheric levels the ascent distributions of frostpoint are substantially higher than the descent distributions, a direct consequence of sampling from the lowest position of the flight train; under the circumstances, the ascent observations are taken in the contaminated wake of the balloon, while the sampling during descent is in front of the wake and free of this source of contamination. The first few thousand feet of descent are accompanied by a rapid decrease in frostpoint. At this point an instrumental problem is apparent, which seriously affected three of the four stratospheric descents and resulted in a complete loss of representativeness for two of the flights and a reduction in the representativeness of a third. At the very low frostpoint temperatures encountered in the high stratosphere, the instrument control was less responsive and tended to lose control, with a drift of the mirror temperature toward the limiting heat-sink temperature. Later laboratory studies determined the problem to be principally one of collection efficiency, and in subsequent flights adequate coupling of the mirror with the atmosphere was achieved by increasing the flow rate past the mirror. The condition of no control is readily determined in the continuous recording of the frostpoint temperature by the complete absence of oscillations,

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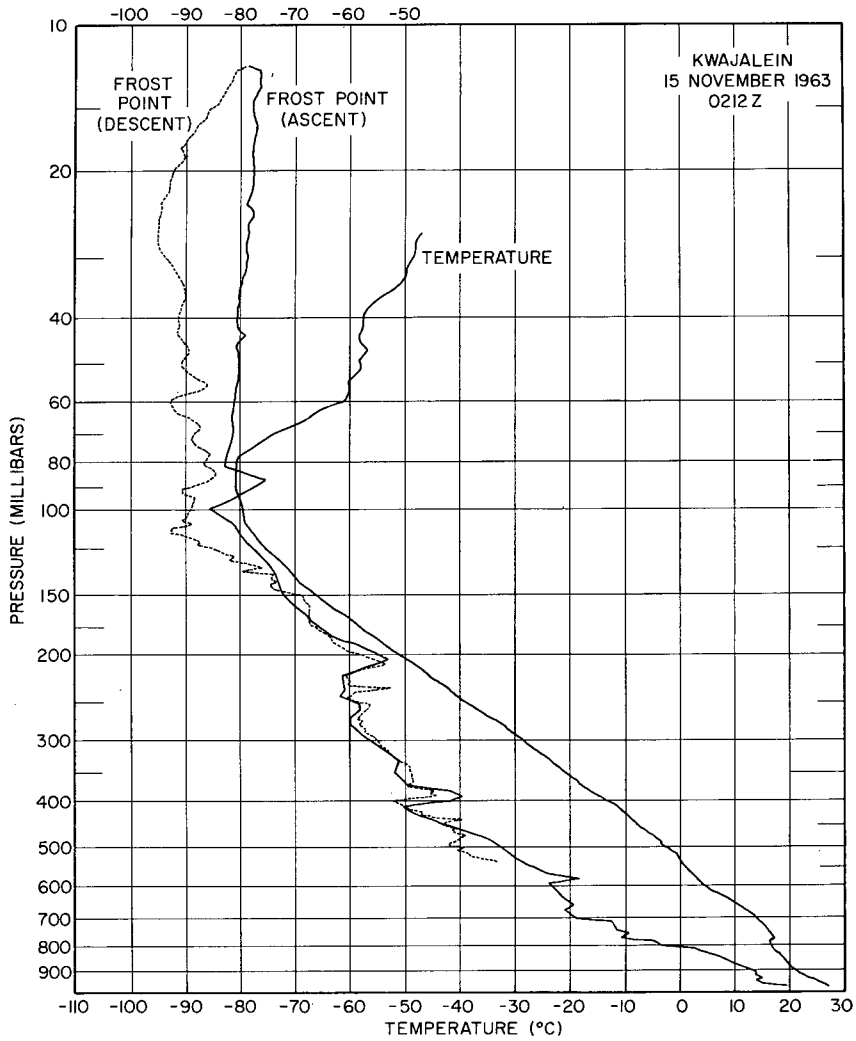
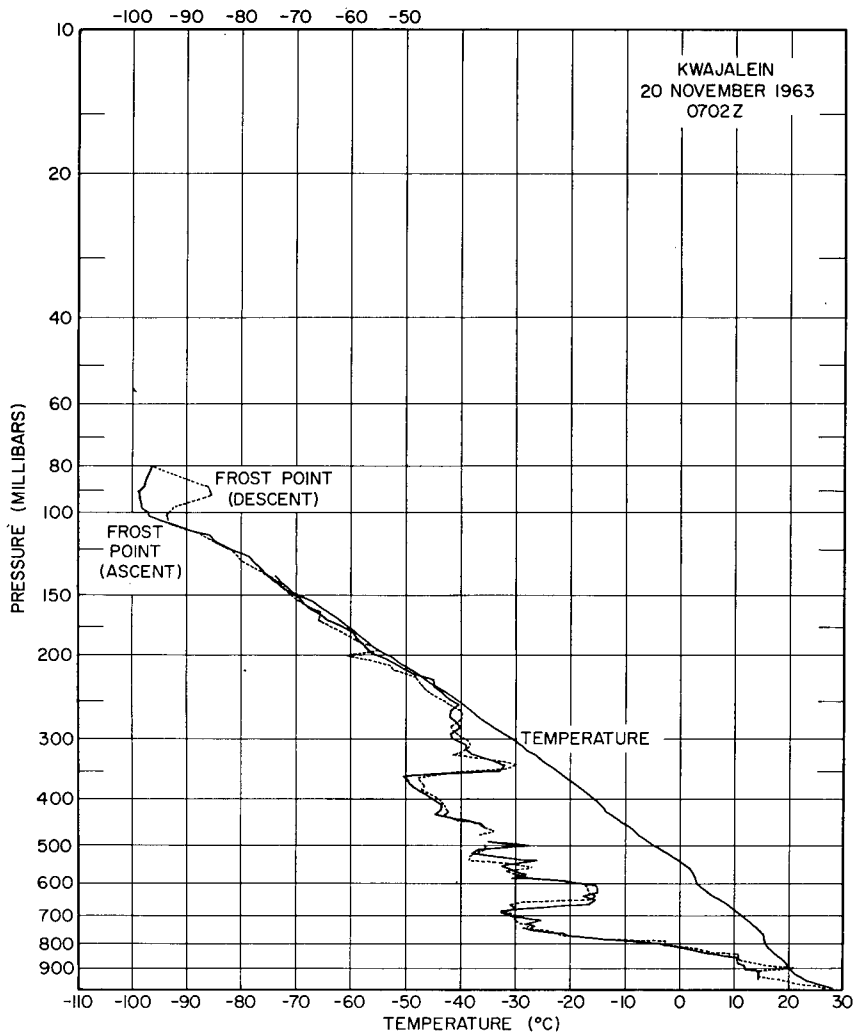


(a)

Fig. 2 - Frostpoint hygrometer soundings over Kwajalein showing the distribution of frostpoint temperature and air temperature in terms of pressure (height) for (a) Nov. 15, (b) Nov. 20, (c) Nov. 21, and (d) and (e) Nov. 23, 1963. The ascent (solid line) and descent (dotted line) frostpoint temperature data were taken from the flight records at 1/2-min intervals.

which are characteristic of the servo control when following the frostpoint temperature of the sample. On these grounds, the stratospheric descents of the two flights of Nov. 23 are not regarded as representative; the stratospheric descent of Nov. 15 exhibited marginal control, tending to drift too cold at times, and the descent of Nov. 21 was continuously controlled.

All of the flights show a loss of control at the tropopause level during ascent, lasting for a period of about 3 min. This may be attributed to instrument drift and low collection

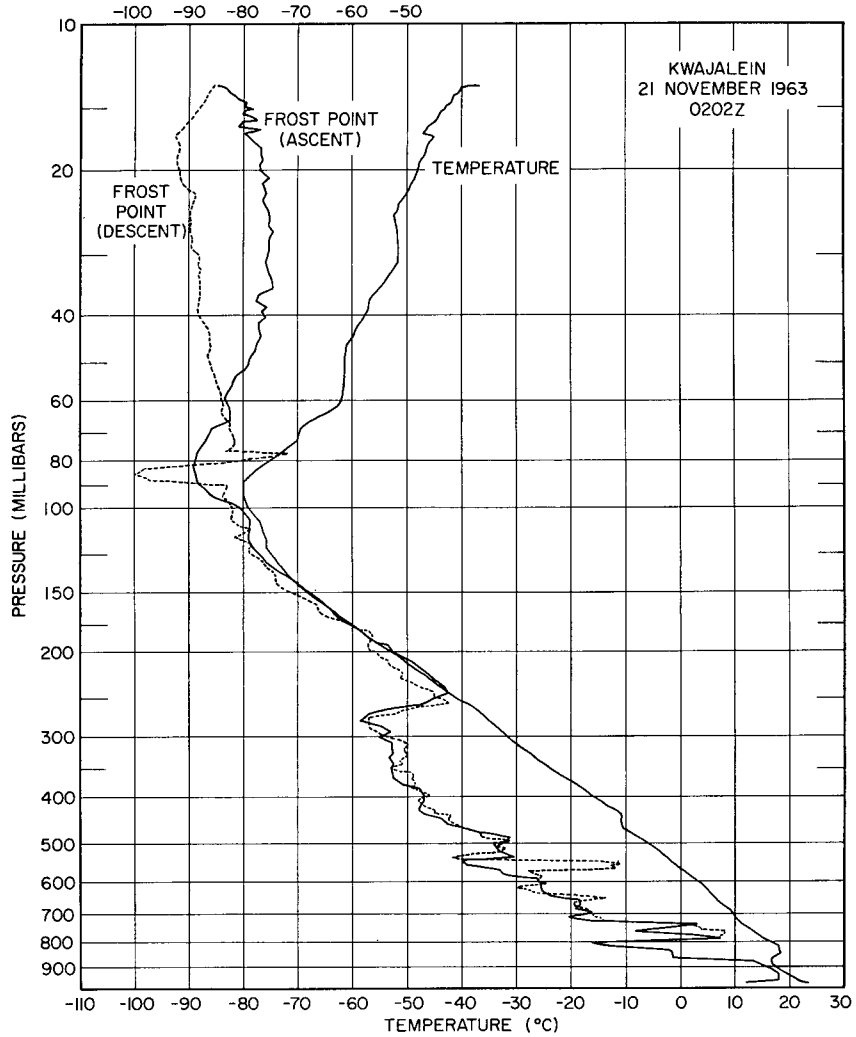


(b)

Fig. 2 (cont'd) - Frostpoint hygrometer soundings over Kwajalein showing the distribution of frostpoint temperature and air temperature in terms of pressure (height) for (a) Nov. 15, (b) Nov. 20, (c) Nov. 21, and (d) and (e) Nov. 23, 1963. The ascent (solid line) and descent (dotted line) frostpoint temperature data were taken from the flight records at 1/2-min intervals.

efficiency, aggravated by ascent rates approaching 3000 ft/min at the top of the troposphere and an accompanying rapid decrease in ambient air temperature to a low of -80°C.

Two of the flight descents were by parachute due to balloon rupture. The descent of the flight of Nov. 20 began at 58,000 ft with an initial descent rate of 2000 ft/min, which was less than the ascent rate for the same altitude. The descent of the flight of Nov. 23 at 1915Z began at 114,000 ft with a descent rate close to 20,000 ft/min initially, decreasing to 9000 ft/min at 50,000 ft. A 17-ft parachute was not available for this flight and a 6-ft buoy deployment parachute was substituted; the resulting descent rate was much too high



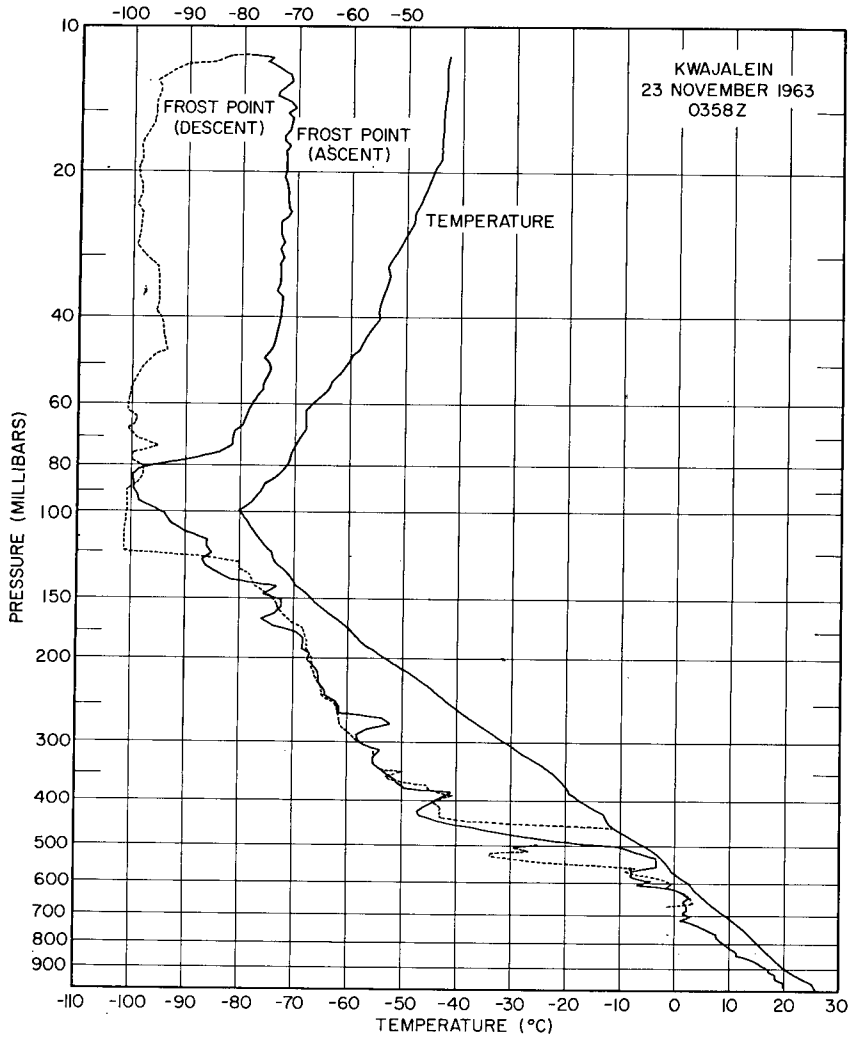
(c)

Fig. 2 (cont'd) - Frostpoint hygrometer soundings over Kwajalein showing the distribution of frostpoint temperature and air temperature in terms of pressure (height) for (a) Nov. 15, (b) Nov. 20, (c) Nov. 21, and (d) and (e) Nov. 23, 1963. The ascent (solid line) and descent (dotted line) frostpoint temperature data were taken from the flight records at 1/2-min intervals.

for the response capability of the instrument at stratospheric levels and the frostpoint values shown in Fig. 2(e) are only indicative of this condition. Below 45,000 ft, however, the ascent and descent curves are in close agreement, indicative of the faster instrument response at the higher frostpoint temperatures.

DISCUSSION

The water vapor soundings over Kwajalein can best be discussed by considering the stratospheric and tropospheric observations separately. At tropospheric levels, the



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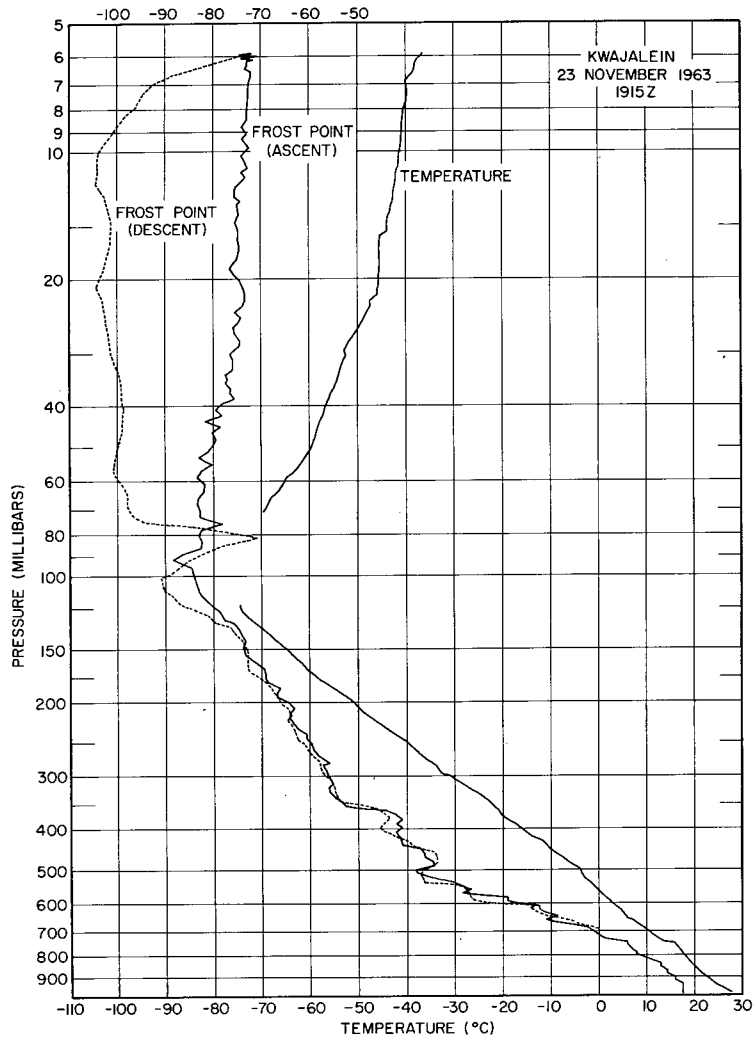
frostpoint temperatures fall easily within the measuring capabilities of the frostpoint hygrometer and the contribution of moisture contamination does not assume significant proportions. This is readily apparent in the close agreement between the ascent and descent observations (see Fig. 2).

At the stratospheric levels the data must be treated subjectively. The ascent observations are regarded as more indicative of the level of extraneous moisture evolved from the flight train than the real moisture content of the stratosphere. The observations are useful to the extent that they indicate the moisture content from the combined sources and place an upper limit to the real atmospheric moisture content.



(e)

Fig. 2 (cont'd) - Frostpoint hygrometer soundings over Kwajalein showing the distribution of frostpoint temperature and air temperature in terms of pressure (height) for (a) Nov. 15, (b) Nov. 20, (c) Nov. 21, and (d) and (e) Nov. 23, 1963. The ascent (solid line) and descent (dotted line) frostpoint temperature data were taken from the flight records at 1/2-min intervals.

A subjective sorting of the descent observations at stratospheric levels is necessary to eliminate those flights which do not show clear evidence of servo control. The flights of Nov. 15 (Fig. 2(a)) and Nov. 21 (Fig. 2(b)) show sufficient evidence of a control performance to be considered as relating to the real moisture distribution. Of the two soundings, the flight of Nov. 21 exhibited the tighter control. The data from these flights are shown in Fig. 3 as a vertical plot of frostpoint temperature and mixing ratio. The excursion at the 80-mb level appears as a sudden upset of the control balance rather than a delineation of the distribution at this level; the impingement of particulates on the mirror of the hygrometer or a sudden alteration of frost deposit could produce this effect.

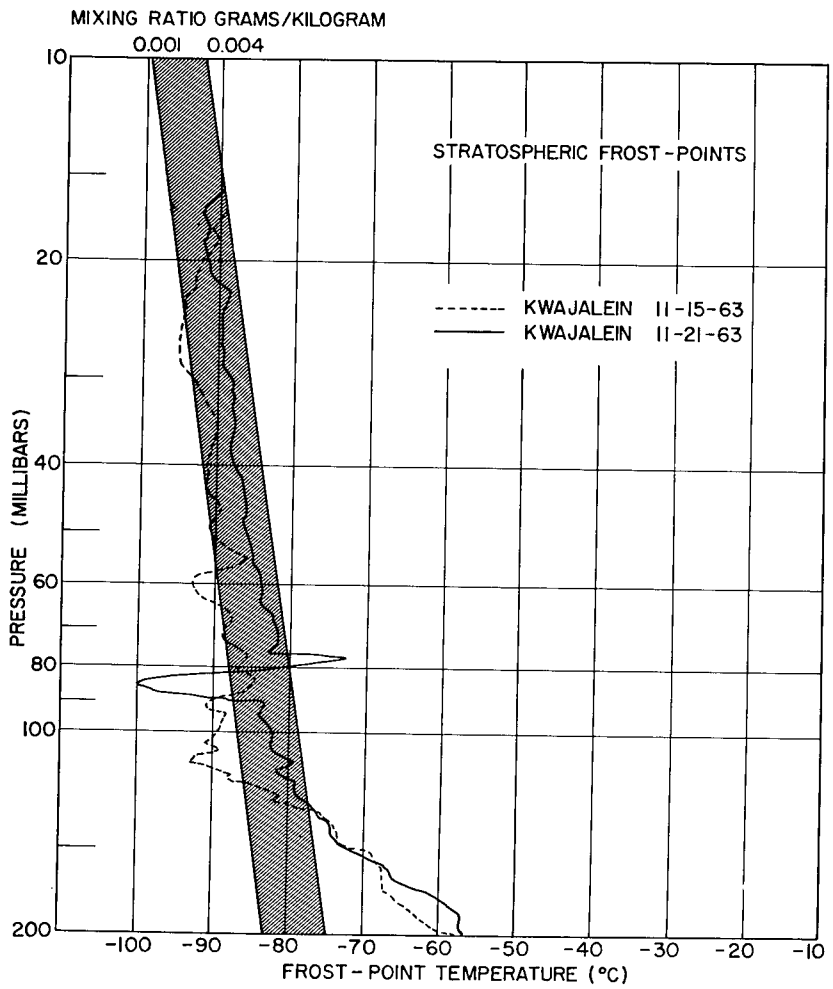


Fig. 3 - Frostpoint temperature and water-vapor-to-air mixing ratio distribution in the stratosphere over Kwajalein

The salient feature of the distributions of Fig. 3 is the constancy of mixing ratio within the stratosphere, which falls generally within the limits of 0.001 to 0.004 g/kg. Two descent soundings of the previous year over the United States, employing an earlier model of the hygrometer that was used at Kwajalein, show similar stratospheric distributions (Fig. 4) lying within the 0.001- to 0.004-g/kg range. These four flights, showing a near-constant concentration of water vapor for stratospheric levels up to 80,000 ft, are at variance with earlier balloon soundings (2,3) which indicate higher and more variable moisture contents for the stratosphere, with the concentration generally increasing with height.

The distributions of frostpoint temperature at tropospheric levels for the five Kwajalein flights are shown in Fig. 5. All of these November flights are observed to fit a common distribution pattern. The surface layers beneath the trade-wind inversion are moist, with high relative humidities. The middle tropospheric levels are dry, with relative humidities of less than 10 percent. Overlying the dry layer is a layer extending to the tropopause level, where the frostpoint temperatures approach ambient temperatures and near-saturation

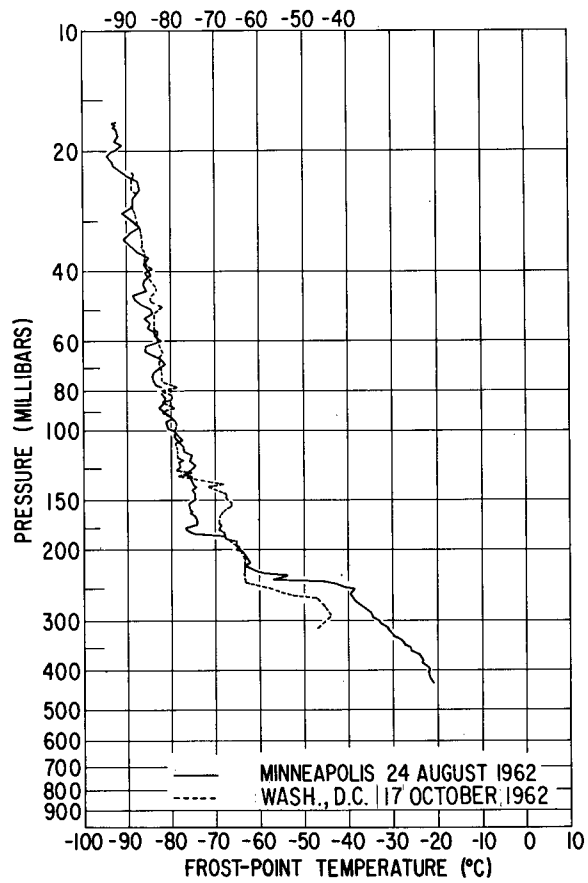


Fig. 4 - Frostpoint temperature distribution over Minneapolis, Minn., and Washington, D.C., 1962

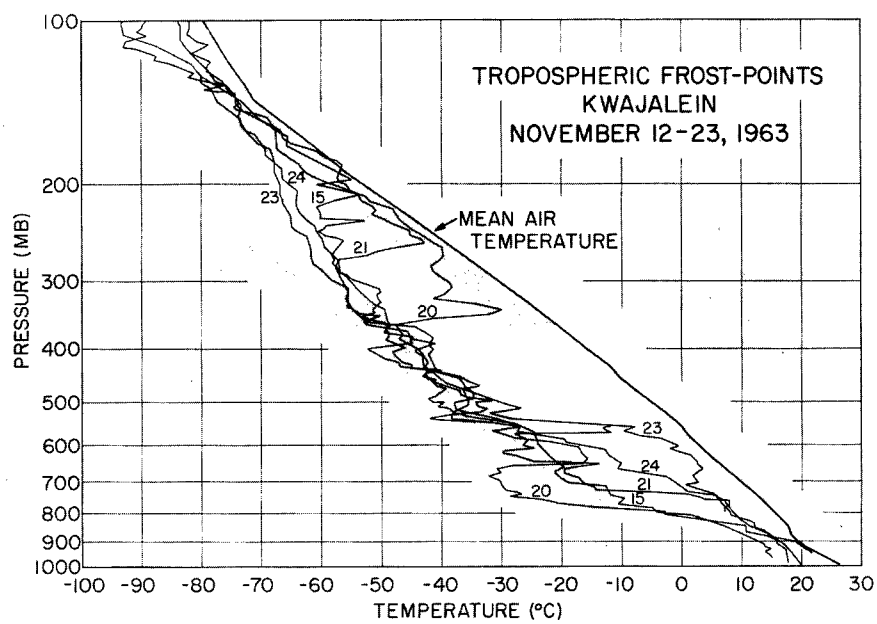


Fig. 5 - Frostpoint temperature distribution in the troposphere over Kwajalein for Nov. 12-23, 1963

conditions prevail. The transition layer between the dry midtroposphere and the moist upper troposphere varies from a few thousand feet to more than 10,000 ft. In Fig. 6, the moisture layering, which is apparent in Fig. 5, is superimposed on a time plot of the winds. The dry layer coincides with the layer of persistent north-east trade winds, while the winds of the moist upper troposphere are light and variable and apparently do not relate to an organized circulation pattern.

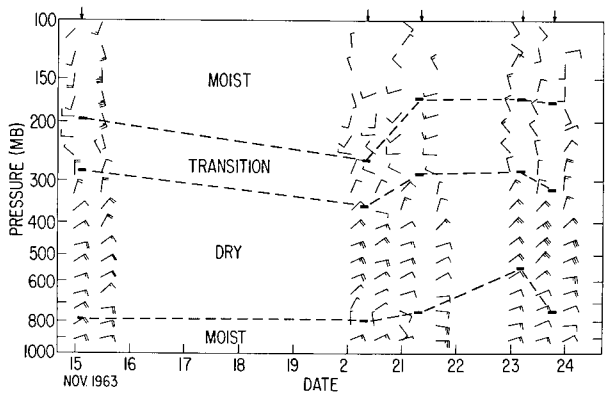


Fig. 6 - Time plot of winds over Kwajalein and a delineation of moisture layers

During the period of water vapor measurements at Kwajalein, the Pacific Missile Range was also measuring the vertical distribution of ozone using the chemiluminescent ozonesonde developed by V. Regener (4). The ozone sounding of Nov. 14 was made within eight hours of the time of a water-vapor sounding, and the two soundings are compared in Fig. 7. Due to difficulties of calibration, the absolute values of ozone are uncertain, but the relative concentrations are considered valid. A general correspondence between the layering of ozone and water vapor in the troposphere is apparent. The dry mid-troposphere has an ozone content which is relatively high, while the moist upper troposphere is essentially devoid of ozone.

CONCLUSIONS

The five water-vapor soundings over Kwajalein show a consistent pattern in the vertical distribution of tropospheric water vapor during the month of November 1963. The surface layer beneath the trade-wind inversion was moist. Above the inversion, and extending to the top of the trade-wind layer, the moisture content was low, with relative humidity generally less than 10 percent. Overlying the dry layer and extending to the tropopause was a moist layer where near saturation conditions prevailed. A single comparison of an ozone sounding and a water-vapor sounding shows a relatively high ozone content for the dry trade-wind layer, and less than measurable amounts of ozone for the moist upper troposphere.

At stratospheric levels, the response of the water-vapor sounding instrument was marginal, and only two of the flights exhibited acceptable response characteristics. The two stratospheric distributions approximate a constant water-vapor-to-air mixing ratio in the range of 1 to 4 parts per million.

ACKNOWLEDGMENT

I am indebted to Mr. Walter Hoehne of the Pacific Missile Range for his active participation in the field operations which resulted in the successful collection of the data contained in this report.

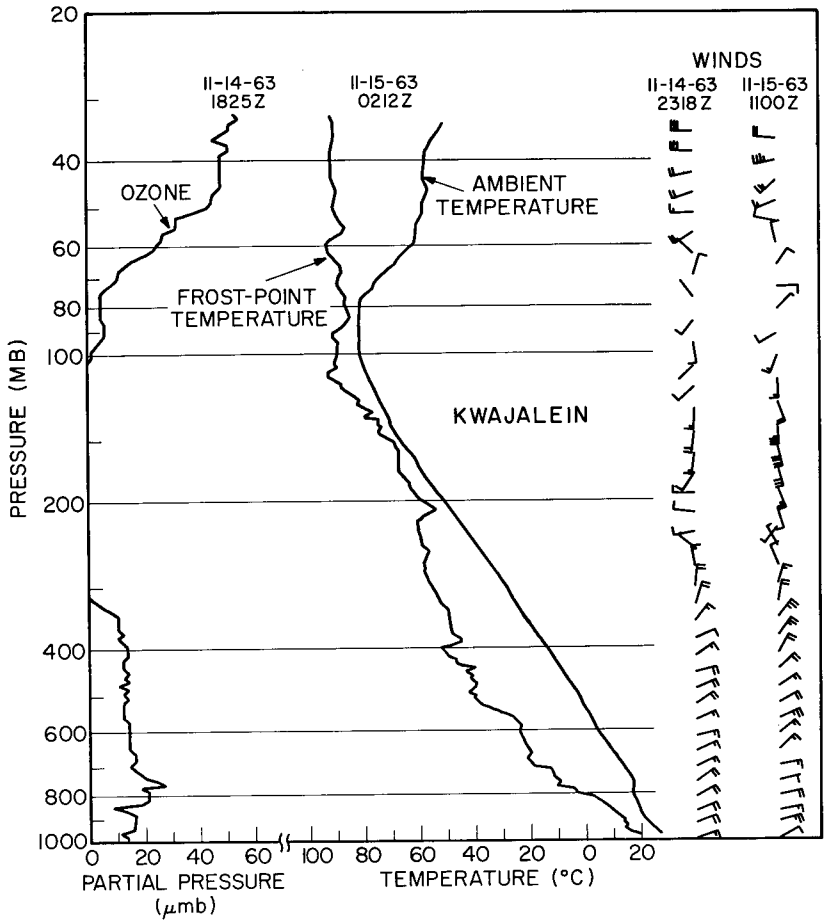


Fig. 7 - Comparison of the ozone sounding of Nov. 14, the water-vapor sounding of Nov. 15, and wind soundings

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