temperatures for frequencies between 192 and 260 GHz [20]. Experimental uncertainties are not discussed, the extreme environmental conditions may have played a role. On the other hand, 335 - 420 GHz field data (included in Figure 15), that were reported by another group from the Soviet Union [21], [22] agree remarkably well with MPM predictions.

Attenuation data at 94 GHz have been recorded in a coastal region of the Netherlands [23]. Data, when presented in Figure 18 versus absolute humidity v, display significant random excess attenuation over MPM predictions. The same data plotted versus RH places all excess attenuation at RH > 98%. Haze and fog conditions probably were present as evident from optical transmission data. The highest excess of 0.8 dB/km requires $w \approx 0.16$ g/m^3, a value typical for heavy fog.

Figure 19 presents atmospheric noise temperatures measured against zenith at two different sites simultaneously at 10, 33, and 90 GHz [24]. Predictions with the MPM radio path program reproduce the frequency correlations quite correctly, which tends to confirm the f^2 assumption made for H_2O continuum absorption (10). In addition, model data set a limit for total precipitable water vapor V[mm] carried by the air mass. Noise exceeding this limit probably originates from suspended droplets. Data trends stemming from differences in the f-dependence of moist air and SWD absorption support such assumption.

5. CONCLUSIONS

Radio properties of the atmosphere are both a barrier and a boon to applications in the 10-1000 GHz spectral range. The first part of this report gave a somewhat detailed description of a laboratory experiment that had to apply latest advances in digital electronics and cryogenic detection to derive at 138 GHz two attenuation coefficients, k_s and k_f (8). At first sight, these two quantities describe the attenuation rate of moist air over a rather inconspicuous range from 0.1 to 10 dB/km; however, a more detailed analysis revealed the k-formulation provides conclusive evidence on temperature and pressure dependence of the water vapor continuum. Attaching an f^2 dependence to the 138-GHz results turned a frequency limited (< 1 THz) propagation model into a useful tool capable of operating in frequency, humidity, and pressure domains of the atmosphere.

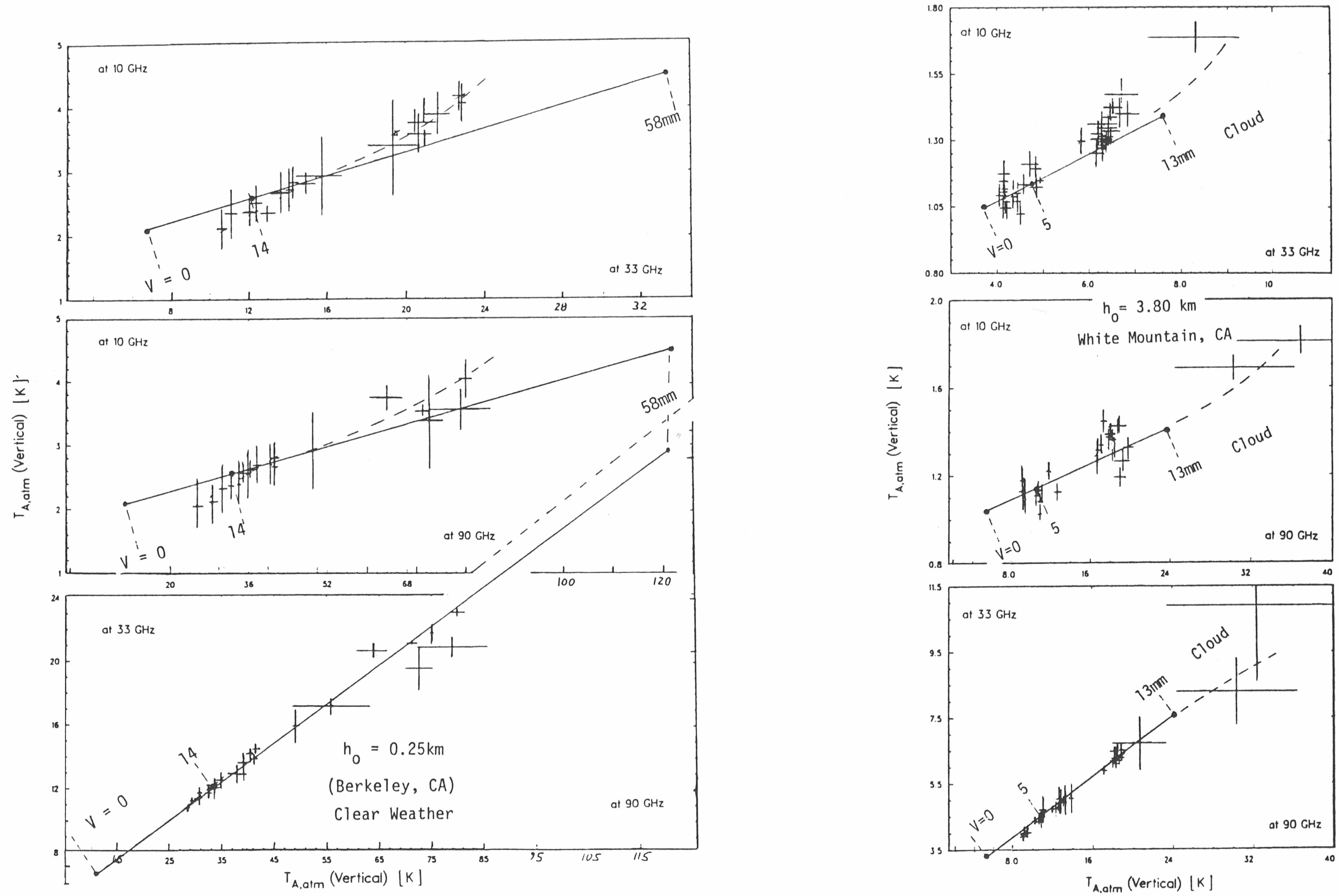

Figure 19. Correlated vertical atmospheric noise temperatures T_A at the frequency pairs 10/33, 10/90, and 33/90 GHz. Path-integrated water vapor is $V = \int v dh$ mm. The measurements were conducted from two sites located at height levels h_o = 0.25 and 3.30 km: data points [24]; solid lines, MPM with a mean July height profile (0-30 km) of P, T, RH for San Francisco, CA [3].

The report discussed details of contributions to modeling atmospheric MMW properties, foremost the attenuation calibration of MPM employing new laboratory results on moist air. Water vapor continuum absorption and, above RH = 90%, droplet attenuation are both affected by relative humidity RH. For haze formation, the range up to RH = 99.9% was modeled. So far, in fog and cloud situations, when RH exceeds 100 percent, values for w cannot be model-generated from the atmospheric water vapor content.

The code MPM was readily accepted by radio scientists and engineers. About 90 requests for copies of MPM have been honored since January 1986. Quotes from received comments were encouraging: "MPM proved of considerable value," -- "documentation is about the best I have ever seen," -- "technical flow, model development and general visibility for application efforts is superior," etc. The Microwave Group of the International Radiation Commission largely adopted MPM as atmospheric transmission code [25].

Although MPM was found capable of predicting atmospheric NMMW propagation limitations, several shortcomings still exist. They are, for example, the missing confirmation for a physical basis of water vapor continuum absorption (e.g., [7], [13]) dominating transmission in atmospheric window ranges centered at 90, 140, 220, 340 GHz and higher; needed measurements of spectroscopic parameters (i.e., shape, strength, width and shift) for spectral lines of the main absorbers (O_2 and H_2O) over the full atmospheric temperature range (300-200 K); and a lack for reliable subfreezing transmission data to clarify the problems that are indicated by Figure 17. Further parametric (frequency, pressure, humidity, temperature, gas composition such as H_2O + AIR) studies are proposed to realize the benefits obtainable from the high-humidity performance of the spectrometer that has been perfected to overcome a great deal of difficulties. Pressure-broadening of the 183-GHz line uniquely identifies monomer behavior (see Table 6). A comparative study of wing (f_0 ±6 GHz) and far-wing (220 GHz) responses to T and v(RH) variations would allow an apportioning of local line (known) and continuum (unknown) contributions.

6. ACKNOWLEDGMENTS

The authors wish to thank J. P. Stricklen for his skillful programing efforts, and Dr. T. Manabe for a most beneficial cooperation.

The work was supported in part by the Naval Ocean Systems Center (Ref: RA35 G80), and the experimental portion (Section 2) by the U. S. Army Research Office under Contract ARO 107-86.