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REMOTE INFRARED ATMOSPHERIC PROFILING SYSTEM (RIAPS)

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report describes the development of an infrared sensor operating in the 11 to 20 micron region using computerized inversion programs to yield tempera- ture and water vapor profiles of the earth's atmosphere up to 6 km. The development of the sensor system hardware and software is summarized for the period 1975 through 1981. Atmospheric profiles acquired and processed are presented.		

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SECTION 1

SUMMARY

The development of the Remote Infrared Atmospheric Profiling System (RIAPS) began in 1968 as a General Dynamics IRAD project. RIAPS was carried through initial theoretical, software work and laboratory model development and into the testing phase by the end of 1971. General Dynamics Engineering Research Reports documented that development effort. Beginning in January 1972, the continued development of the RIAPS was sponsored by the Office of Naval Research under Contract N00014-72-C-0175 with General Dynamics Electronics Division. A detailed account of the continued development from January 1972 through February 1975 is contained in the final report "Remote Infrared Atmospheric Profiling System," published in February 1975. Since 1975 the RIAPS development has been continued under a new ONR Contract N00014-75-C-0940. This report briefly summarizes the entire contract activity. Section 2 describes the RIAPS system and test results. Section 3 contains a complete list of publications generated by this contract. Finally several recommendations for future work are included in Section 4.

The current Remote Infrared Atmospheric Profiling System (RIAPS II) is a grating spectrometer radiometer capable of acquiring vertical atmospheric temperature and water vapor profiles. Eight (8) temperatures are calculated from the surface to 6 km. Five (5) water vapor mixing ratios are calculated from the surface to 4 km. Temperature accuracy versus a rawinsonde is $\pm 1.5^{\circ}\text{C}$ while water vapor mixing ratio accuracy is $\pm 20\%$. The profile data is acquired by the radiometer over a two (2) minute interval followed by a two (2) minute calibration procedure. Atmospheric and calibration data are then processed by an on-line computer and outputted on a Teletype. Under the direction of the Office of Naval Research, the RIAPS II system and the computer and peripheral equipment associated with the predecessor RIAPS I system have been shipped to: New Mexico Institute of Mining and Technology, Campus Station, Socorro, New Mexico 87801, Attn: Professor Charles Moore.

SECTION 2

RIAPS SYSTEMS AND TEST RESULTS

There are three systems supported under these contracts. Sensor 1 which was a laboratory research model was designed and built under a General Dynamics IRAD project. It was modified and field tested during 1972 and 1973 as the initial contract effort. Later RIAPS I and II were consequently developed and field tested. There had been a series of difficulties in obtaining a suitable and reliable detector for the RIAPS II system. The field tests conducted during the contract period using the RIAPS II system were very limited and of questionable scientific value.

An optical layout of the RIAPS I is shown in Figure 1 and the electronic block diagram is included in Figure 2. Figures 3 and 4 show the constructed instrument and the associated data processing unit. The band centers (Table I) chosen for the temperature and humidity profile inversions have been evolved for optimum sensor performance and maximum information retrieval. Initially the temperature profile alone is retrieved while a crude water vapor distribution (two parameters) is estimated to correct the transmission function in the 15 μm region. This program for temperature profile retrieval is summarized in Table II and an example of the retrieval profiles is shown in Figure 5. Later an independent water vapor profile inversion program was developed following the procedure outlined in Table III. These two programs are combined using the iterative algorithm described in Table IV which was implemented in the RIAPS I and II systems to retrieve both water vapor and temperature distributions. Typical profiles taken at Point Mugu compared with rawinsonde data are shown in Figures 6 and 7. The resultant temperature profiles have an accuracy comparable to that of rawinsonde with an overall RMS error of 1.6 $^{\circ}\text{C}$. The water vapor profile is in general within 20% of the rawinsonde except near the ground where large variations of the vertical profile cause substantial discrepancies.

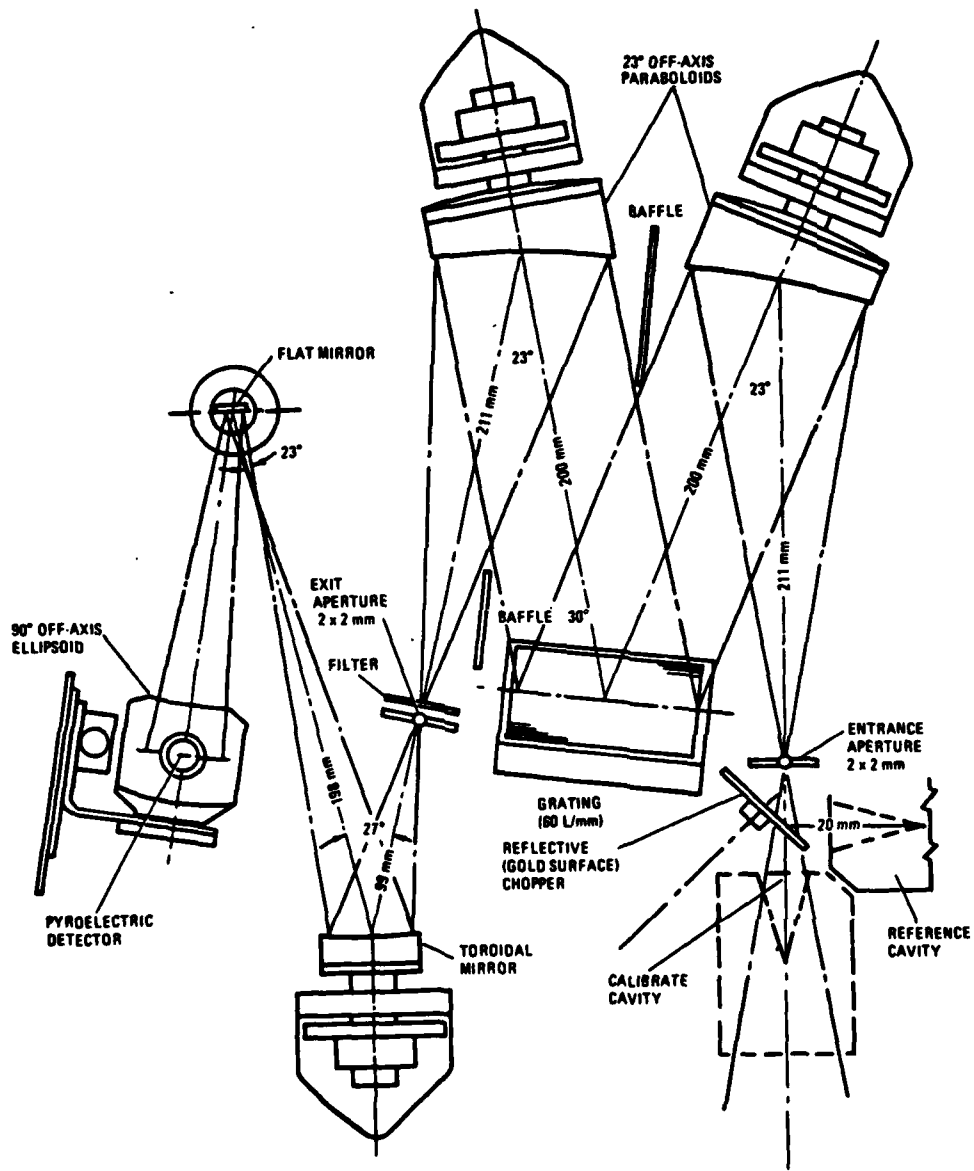


Figure 1. RIAPS optical layout.

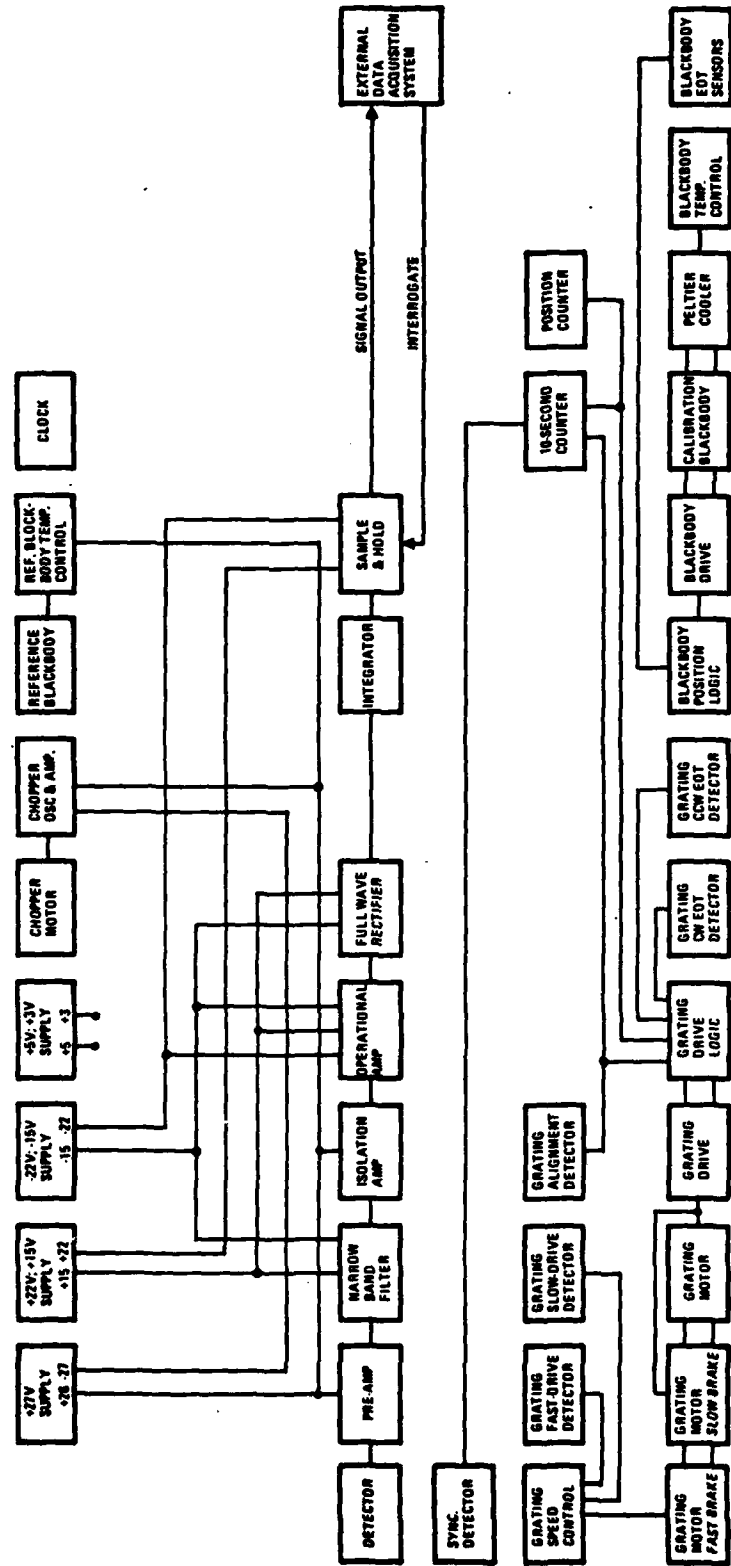
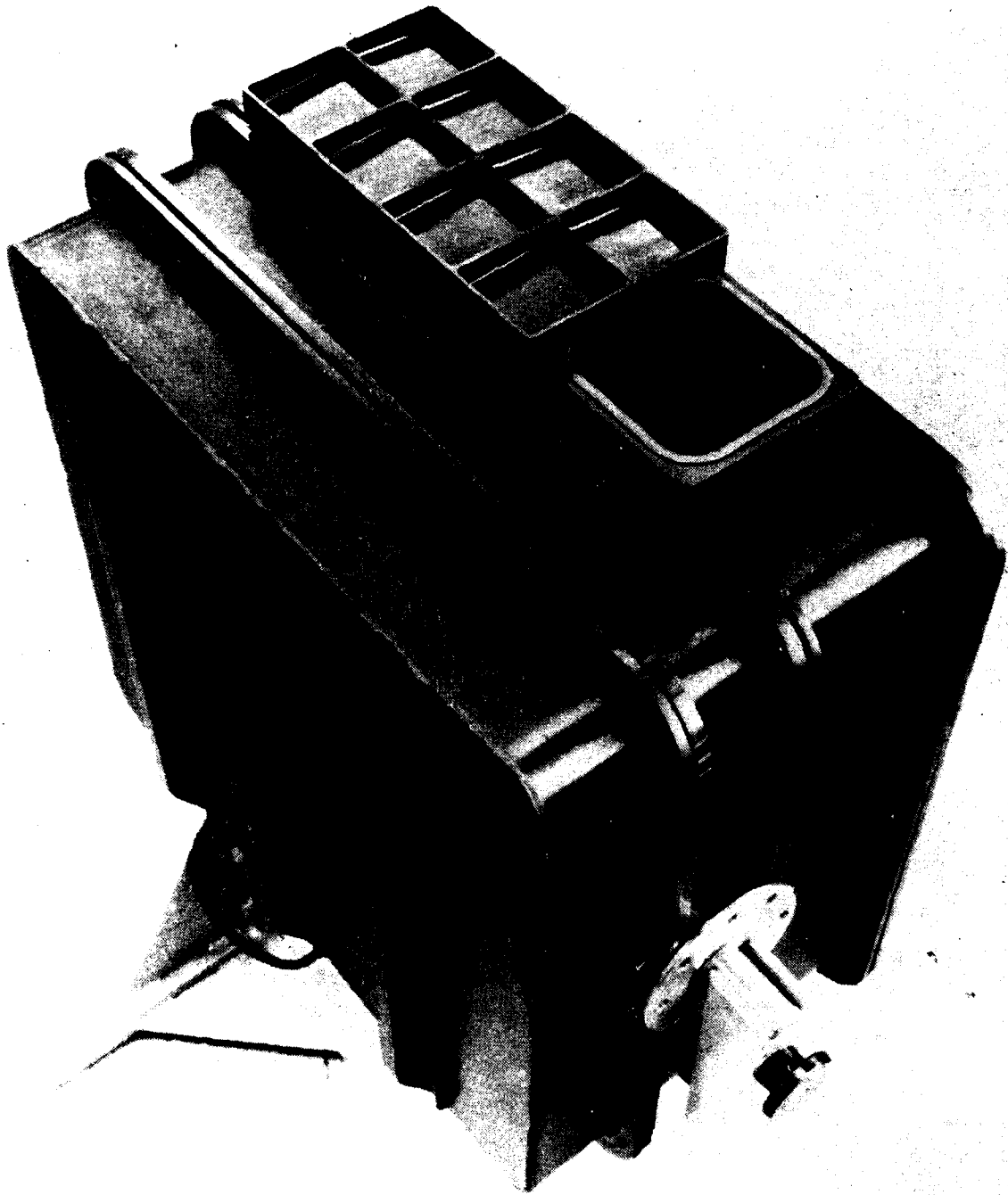


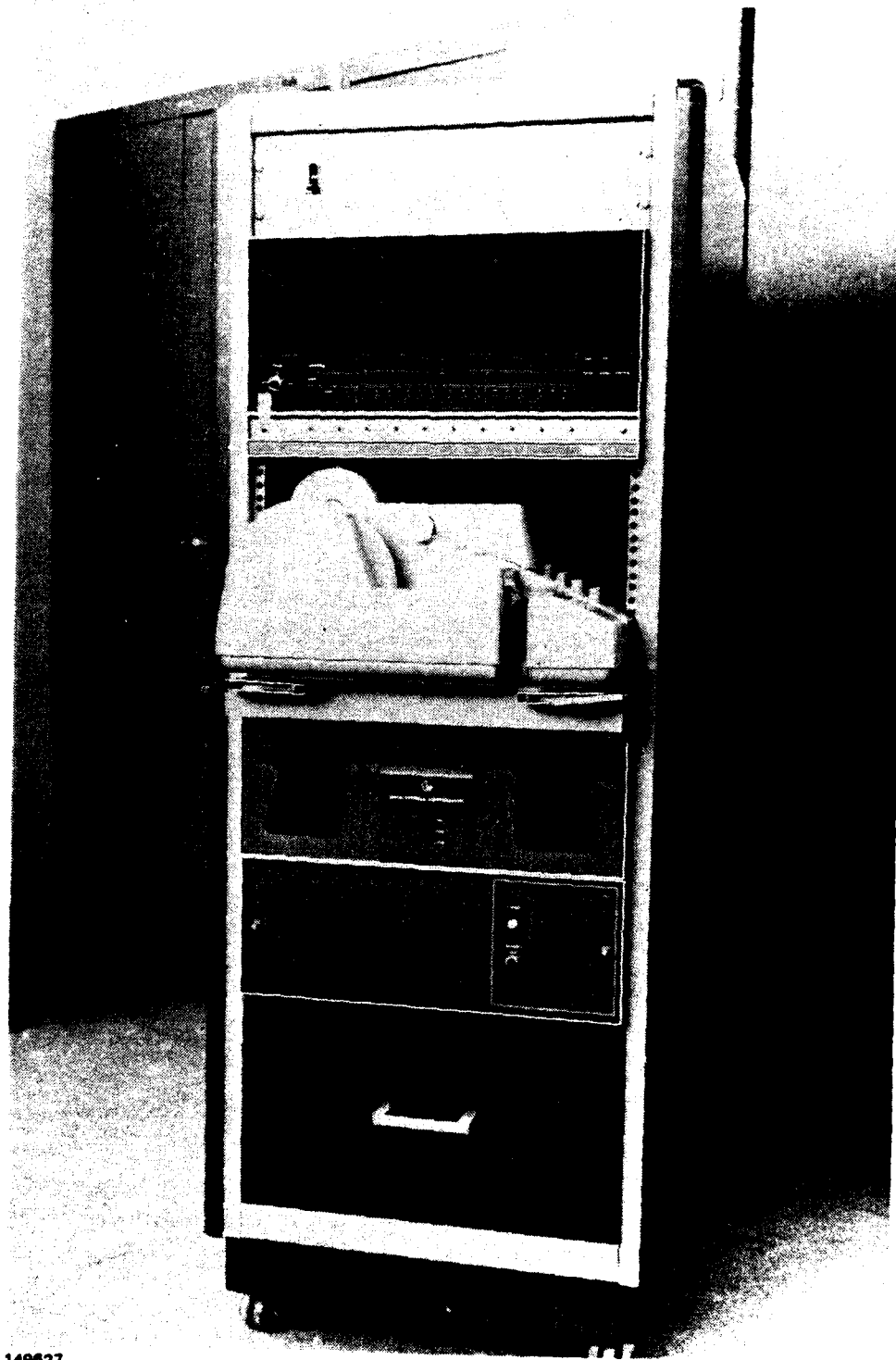
Figure 2. Temperature profiler block diagram.



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Figure 3. RIAPS instrument.



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Figure 4. Data processor.

TABLE I. BAND CENTERS

<u>REGION</u>	<u>INITIAL</u> cm ⁻¹	<u>BREADBOARD - SENSOR 1</u> cm ⁻¹	<u>RIAPS I</u> cm ⁻¹
11μ WINDOW	898	899	899.0
15μ CO ₂	728.5	730	730.5
	720	724	726.7
	711.5	711.5	722.5
	703	700	716.3
	694.5	693	711.7
	686	688	699.8
	677.5	677.5	688.0
	669	669	668.0
18μ H ₂ O	560	570	563.4
	522	540	548.3
	510	520	538.5
		527.5	533.1
			528.0
			493.6

TABLE II. TEMPERATURE INVERSION PROGRAM

1. LINEAR APPROACH USED
2. EIGHT LAYER ATMOSPHERIC MODEL IS USED
3. THEORETICAL RELATIONSHIPS AMONG
 - A. RADIANCE AT EARTH SURFACE
 - B. BLACKBODY RADIANCE AS FUNCTION OF WAVELENGTH AND TEMPERATURE
 - C. TRANSMISSIVITY AS FUNCTION OF WAVELENGTH AND ALTITUDE ARE USED
TO DEDUCE TEMPERATURE FROM A SET OF MEASUREMENTS
4. TRANSMISSIVITY FUNCTIONS USED ARE BASED ON PUBLISHED TRANSMISSION
CURVES
5. WATER VAPOR DISTRIBUTION MODEL IS USED TO MAKE CORRECTIONS TO
TRANSMISSION FUNCTIONS
6. PROGRAM ITERATES UNTIL THE CALCULATED WATER VAPOR RADIANCE APPROACHES
MEASURED RADIANCE.

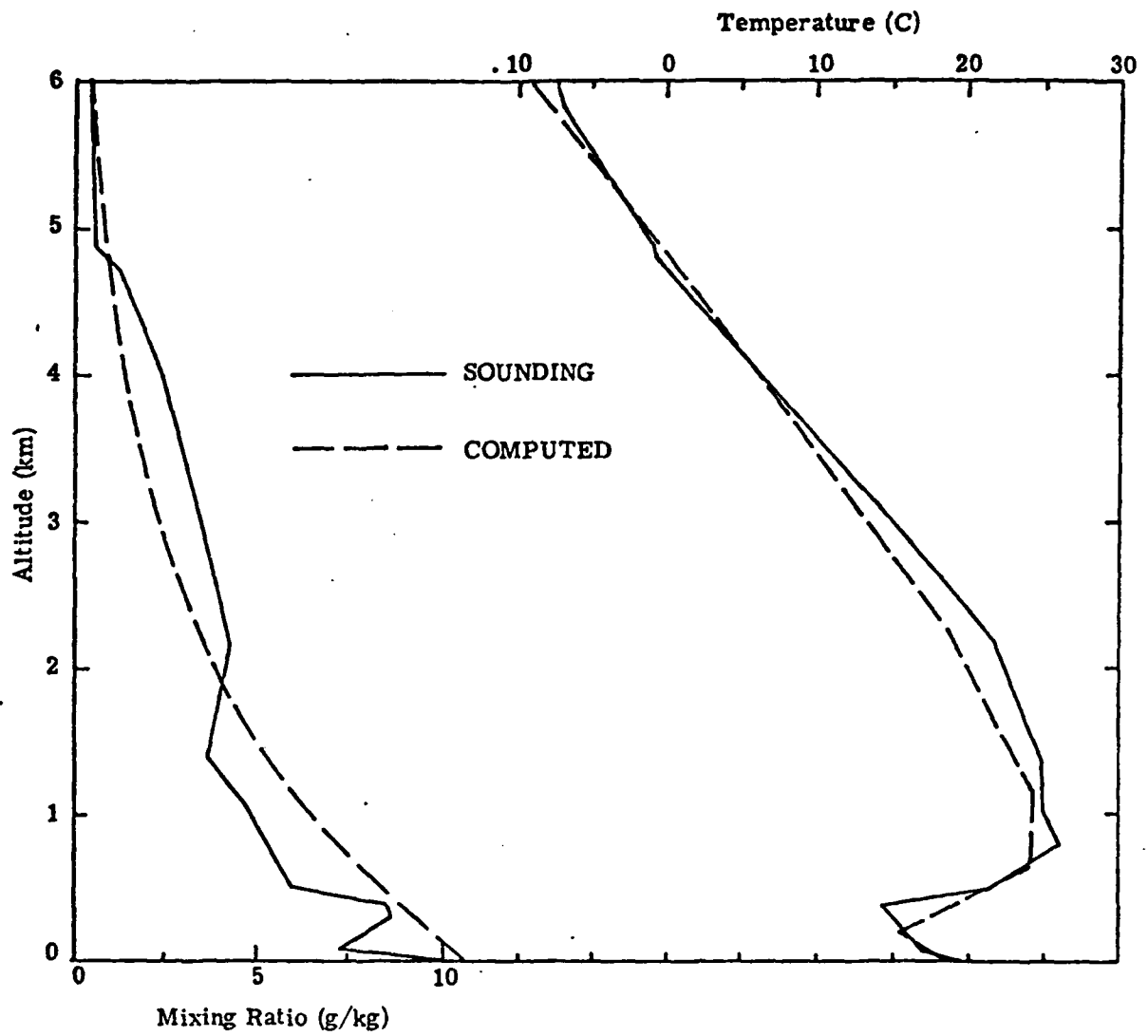


Figure 5. Comparison of infrared and radiosonde temperature profiles 23 June 1971, 2400Z.

TABLE III. WATER VAPOR INVERSION PROGRAM

1. NON-LINEAR APPROACH USED.
2. FOUR LAYER MODEL USED.
3. SIX DATA POINTS MEASUREMENT.
4. TRANSMISSION FUNCTIONS USED ARE BASED ON PUBLISHED DATA -40 cm^{-1} .
5. DEDUCED TEMPERATURE PROFILE CORRECTS ASSUMED WATER VAPOR PROFILE.
6. PROGRAM ITERATES UNTIL THE RESIDUES OF RADIANCE APPROACHES THE NOISE LEVEL.

TABLE IV

RIAPS TEMPERATURE/WATER VAPOR INVERSION PROGRAM

1. LINEAR APPROACH TO TEMPERATURE PROFILE
2. NON-LINEAR APPROACH TO WATER VAPOR PROFILE
3. EIGHT LAYERS FOR TEMPERATURE; FOUR LAYERS FOR HUMIDITY
4. TRANSMISSION FUNCTIONS FOR TEMPERATURE AS NOW USED
5. TRANSMISSION FUNCTIONS FOR WATER VAPOR TO BE DETERMINED FROM A 7 cm^{-1} MODEL
6. WE START WITH
 - A. MEAN TEMPERATURE PROFILE
 - B. ASSUMED WATER VAPOR PROFILE
7. CALCULATE TEMPERATURE PROFILE
8. USE TEMPERATURE PROFILE AND MEASURED $18\mu\text{m}$ RADIANCE TO IMPROVE WATER VAPOR PROFILE.
9. USE CALCULATED WATER VAPOR PROFILE TO IMPROVE TEMPERATURE PROFILE.
10. ITERATION CONTINUES UNTIL TEMPERATURE PROFILE LAYER SEVEN (MOST UNSTABLE) DOES NOT CHANGE MORE THAN 1°C .

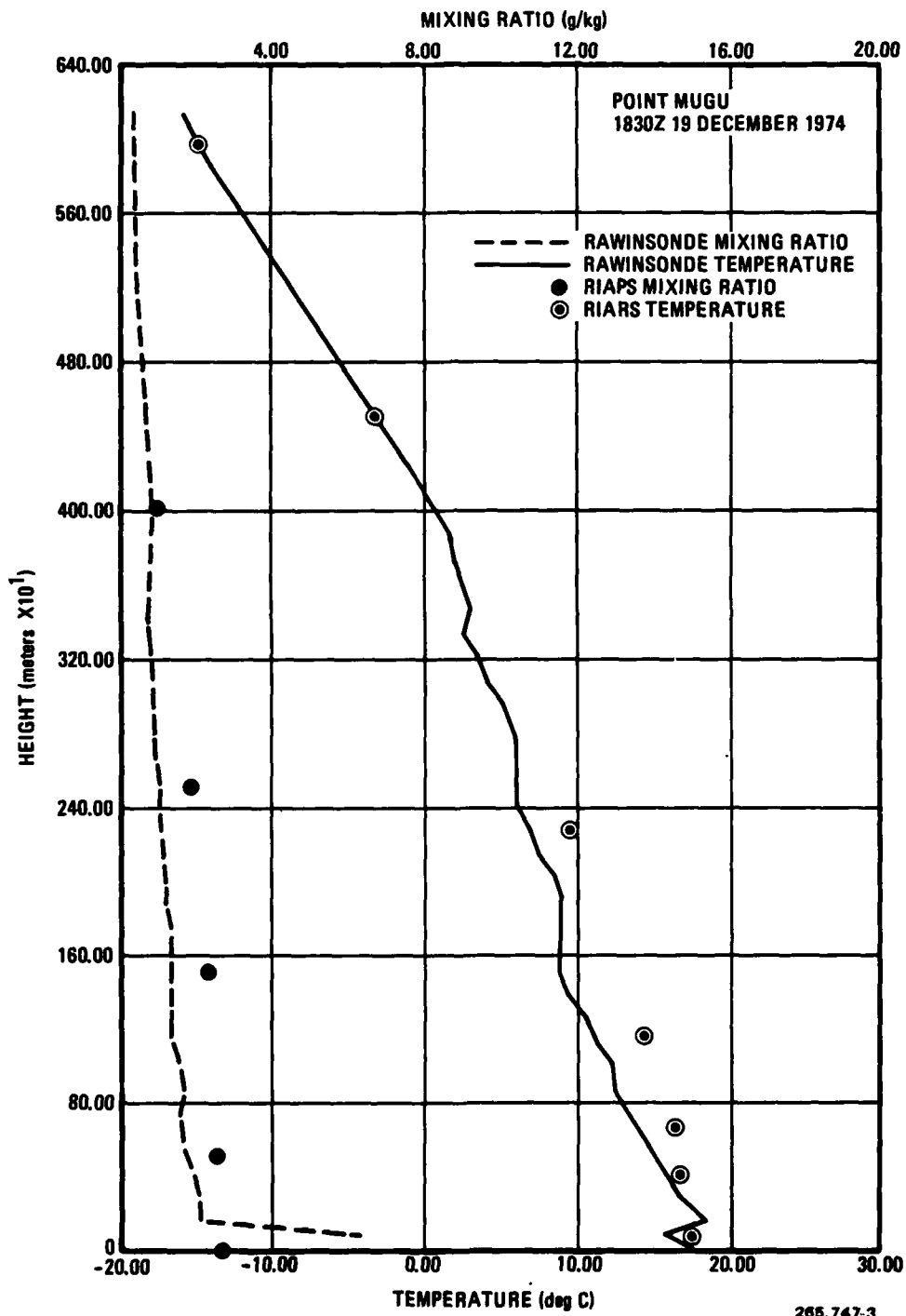


Figure 6. Typical RIAPS profile.

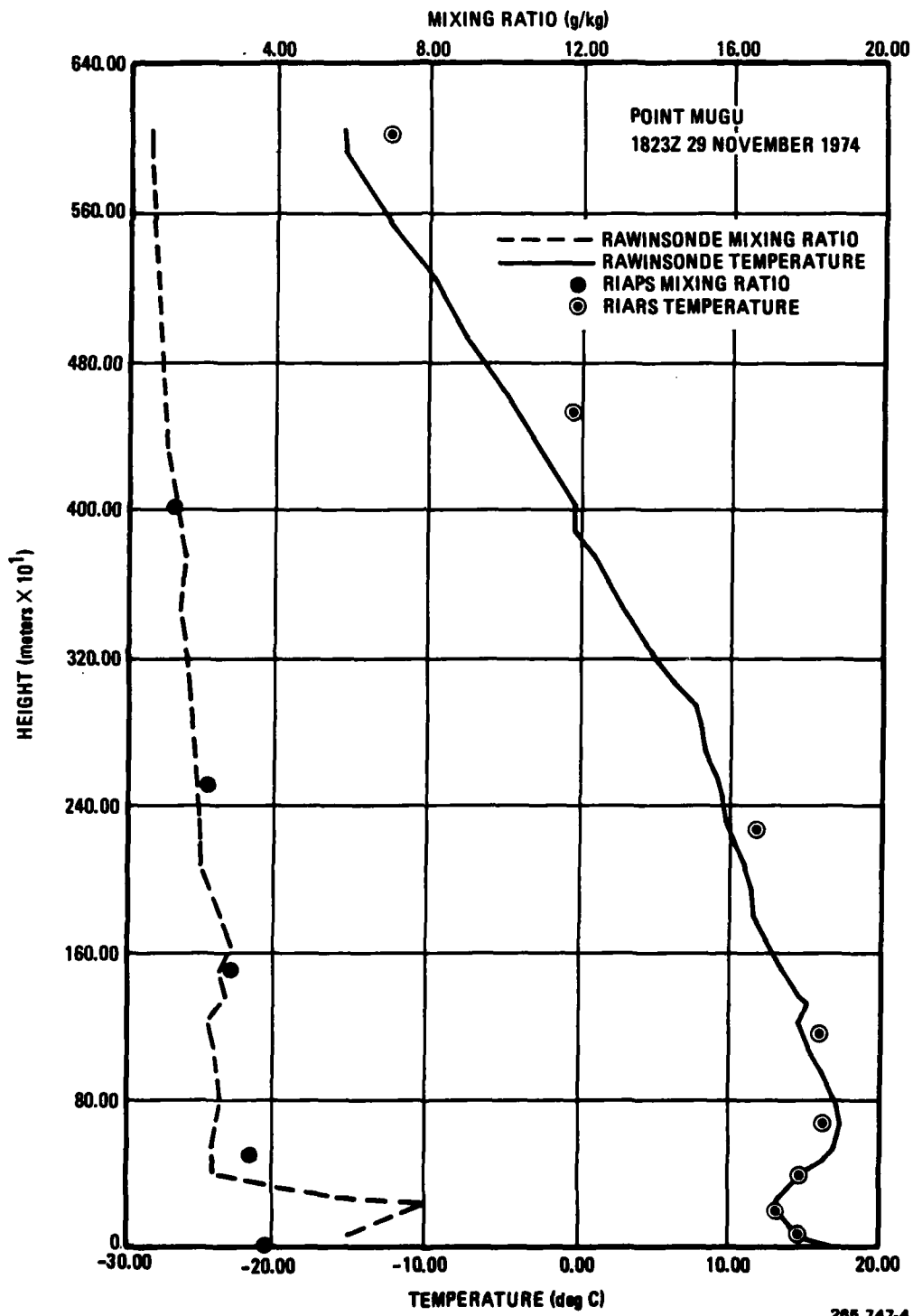


Figure 7. Typical RIAPS profile.

SECTION 3

TECHNICAL PUBLICATIONS

Publications

1. "On the Estimation of Low-Altitude Water Vapor Profiles from Ground-Based Infrared Measurements," by J. Y. Wang, *Journal of the Atmospheric Sciences*, 31, 513 (1974).

Abstract

Information on atmospheric constituents is contained in the remotely measured spectral radiances. Two iteration methods, linear and nonlinear, are presented to demonstrate the possibility of inferring the water vapor profile from ground-based measurements. The linear inversion method which linearizes the radiative transfer equation is found to have a narrow range of convergence. A study of the vertical resolution of the inferred profile through the linear inversion technique indicates that fine-scale detailed structure of the profile cannot be reconstructed. The nonlinear iteration procedure, which minimizes the root-mean-squares residual of the random noise along the direction of "steepest" descent, is found capable of inferring a reasonably stable solution with wide range of convergence and is proven in numerical stability superior to the linear technique. The effects of the errors both in radiance measurements and in temperature profile on the inferred profile are also presented.

2. "Measurement of Lower Atmospheric Temperature Profiles from Ground-Based Infrared Observations," by J. Y. Wang, C. R. Claysmith, and M. Griggs, *Journal of Applied Meteorology*, 14, 308 (1975).

Abstract

A ground-based infrared spectroradiometer has been used to measure the vertical temperature profile of the lower atmosphere from 0 to 6 kilometers. Eight measurements in the 15- μm carbon dioxide band have been used for the inversion in addition to three measurements in the 18- μm water vapor band for the water vapor corrections. One additional observation in the 11- μm window region is used to determine the presence of cloud. Twenty-one sets

of clear sky data obtained in the summer of 1971 are used to verify the inversion technique. The resultant profiles have an accuracy comparable to that of radiosondes with an overall RMS error of 1.58C.

3. "Temperature Effect on the Atmospheric Transmission Function in the 15- μ m Region," by J. Y. Wang, *Optics Letters*, 2, 169 (1978).

Abstract

The method of first-order Taylor expansion is used to study the temperature effect on the transmission function for several narrow spectral intervals in the 15- μ m CO₂ absorption region with direct application to the problem of thermal remote sounding. Numerical analysis indicates that the computed transmittances are in good agreement with those obtained by line-by-line calculation, especially for spectral intervals with relatively strong temperature dependence.

Presentations

1. "Remote Sensing of Low-Altitude Atmospheric Parameters," by J. Y. Wang, *Optical Society of America Spring Conference, Anaheim, California* (1975).
2. "Remote IR Profiling System," by C. R. Claysmith and J. Y. Wang, *Workshop on Remote Sensing of the Marine Boundary Layer, Vail, Colorado* (1976).

Reports

1. "Remote Infrared Atmospheric Profiling System (RIAPS)," by C. R. Claysmith, *Annual Report* (1973).
2. "Remote Infrared Atmospheric Profiling System (RIAPS)," by C. R. Claysmith, *Final Report, R-75-073* (1975).
3. "Remote Infrared Atmospheric Profiling System (RIAPS)," by J. Y. Wang, *Annual Report* (1978).

SECTION 4

RECOMMENDATIONS FOR FUTURE WORK

An extensive effort has been conducted which produced a RIAPS system capable of real time, vertical, low resolution atmospheric temperature and water vapor profiles. This analytical, hardware and software development has not realized its full potential. A number of techniques for improvement on the basic concept have been developed but not implemented while other ideas have not yet been explored. The items listed below are recommended for future work:

1. The grating instrument currently employed in the RIAPS system takes considerable time to complete one cycle of measurements in the 15- μm and 18- μm region. It is suggested that a new all-bandpass filter configuration for the temperature/humidity profiler be considered. An alternate approach is to provide a detector array having a detector element and preamplifier for each of the wavelengths to be measured. The first approach to an improved hardware design requires very narrowband filters for each wavelength. The alternate approach requires an expensive detector array and each detector element must be independently preamplified.
2. Current RIAPS software supports only ground based vertical looking applications of the profiler. An analytical and software development program which will allow profiling along a slant path should be considered in support of systems requiring this type of profiles. Laser weapon systems effectiveness is highly dependent on slant path water vapor.
3. All RIAPS bandcenters have identical bandwidths of approximately 7 cm^{-1} . Initially this was by design and is now dictated by the grating spectrometer configuration of the hardware. Some recent thinking on methods to improve on the technique has led to the belief that identical bandwidths are not optimum. It is suggested that theoretical and software development be initially considered to perform a numerical simulation of the optical design to optimize the bandcenters and bandwidths.

4. Currently the on-line software assumes a trial profile shape that is isothermal to 1.5 km and adiabatic above. This assumption degrades the system accuracy as the trial profile function closest to the actual profile results in the best accuracy. Software exists which uses current data to generate the trial profile and the resultant profiles using this trial profile function are improved over those obtained using RIAPS. This program approach was never implemented into the on-line RIAPS system for the lack of memory capacity. Current technology microprocessor-based computers readily provide the memory capacity and speed requirements for an adaptive trial profile processor for RIAPS at very reasonable cost.