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THERMAL EMISSION SPECTRA OF THE EARTH AND ATMOSPHERE OBTAINED FROM THE NIMBUS 4 MICHELSON INTERFEROMETER EXPERIMENT

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JUNE 1970

GSFC

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

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ABSTRACT

Thermal emission spectra of the earth and atmosphere in the spectral range 400 to 1500 cm^{-1} with a resolution equivalent to 2.8 cm^{-1} have been obtained with the Michelson interferometer flown on the Nimbus 4 satellite. A study of selected samples indicate that the spectra are of sufficiently high quality to permit the recovery of atmospheric temperature, humidity, and ozone profiles on a global basis, as well as the study of surface reststrahlen effects and other geophysical and meteorological phenomena.

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The meteorological research satellite Nimbus 4, launched on April 8, 1970, carried, among other instruments, a Michelson interferometer similar to one placed in orbit by Nimbus 3 approximately a year earlier[1]. The infrared emission spectra of the earth and its atmosphere recorded by Nimbus 4 represent an improvement over the earlier results. Instrumental advancements include (1) a higher spectral resolution corresponding to 2.8 cm^{-1} compared to 5 cm^{-1}, (2) a narrower field-of-view of 5° compared to 8°, and (3) a lower noise equivalent radiance, particularly noticeable at the higher wavenumber end of the spectrum. The upper wavenumber limit was chosen at 1500 cm^{-1} (6.7 μm), in part to permit the higher spectral resolution without a change in the data interface to the Nimbus spacecraft. The lower limit of 400 cm^{-1} (25 μm) for the recorded spectral range is the same as on Nimbus 3.

The scientific objectives of this experiment are similar to those of the earlier IRIS experiment, i.e., the vertical soundings of atmospheric temperatures, humidities and ozone concentrations. In addition, the recording of the complete spectrum between 400 and 1500 cm^{-1} has permitted other scientific investigations, e.g., studies of surface conditions[2]. In the first IRIS experiment, emphasis was placed on the demonstration of the principles of atmospheric soundings of temperature and composition. Application of the large body of data to circulation studies and other meteorological tasks is now beginning. The higher spectral and spatial resolution and better signal-to-noise ratio of the Nimbus 4 interferometer will permit considerable refinements in these techniques.

Figure 1 shows three spectra selected from the Nimbus 4 data to illustrate their quality and usefulness. Included are the coldest spectrum and the warmest spectrum recorded on orbit 29 (April 10, 1970), along with a mid-latitude case taken over the Mediterranean. Each spectrum is computed from a single interferogram recorded by the instrument within a 13 second interval. The instrumental technique used and the on-board calibration procedures are discussed elsewhere[3].

While the spectra of Figure 1 were processed using an apodization or smoothing function employed to reduce the side lobes of the instrument function, the same spectra are shown in Figure 2 without smoothing. The spectral resolution in this case is almost twice as high, corresponding to about 1.5 cm^{-1}. When the data are processed in this fashion, the instrument function has more pronounced side lobes; therefore, for a radiometric analysis such as that required in obtaining atmospheric temperature profiles, the apodized spectrum is preferred. However, for line identification, the higher resolution of the unapodized spectrum has a distinct advantage.

The warmest spectrum of the three shown in Figures 1 and 2 was recorded over the Sahara Desert. The field-of-view of the instrument has been superimposed on a television picture (Figure 3), taken by the Nimbus Image Dissector

Camera System at the same time. The data show the features of CO_2, H_2O, O_3 and CH_4 as indicated in Figure 1. In addition, the effects of the residual ray phenomenon originating from the SiO_2 in the surface result in brightness temperatures approximately 10°K lower in the window region on the high wavenumber side of the 1042 cm^{-1} (9.6 μm) ozone band than those on the low wavenumber side. The maximum brightness temperature of 320°K (47°C) in the atmospheric window is consistent with a poor heat conducting material at the surface, such as dry sand.

The Mediterranean spectrum was recorded shortly thereafter. The maximum brightness temperature of 285°K (12°C) is close to the water surface temperature. The coolest spectrum recorded over the Antarctic plateau indicates a surface temperature of 190°K (-83°C). The CO_2, O_3, and H_2O features appear in emission, indicating a warmer atmosphere above a colder surface. The inferred surface temperature is extremely low, but shelter temperatures of -80°C along with strong surface inversions have been recorded at Plateau Station located in the same general region.

Estimates of temperature and humidity profiles obtained from the spectrum taken over the Mediterranean are shown in Figure 4a and 4b, respectively, where they are compared with data from a radiosonde launched from Gibralter. The ozone profile inferred from the same spectrum is shown in Figure 4c. The techniques employed for obtaining the temperature and humidity profiles have been discussed by Conrath, et al.[2] and the method for calculating ozone profiles has been given by Prabhakara, et al.[4] Because of the interesting behavior of the Antarctic spectrum, an estimate of the temperature profile for this case has been made (Figure 5) even though no radiosonde data are available for comparison. The profile can be anticipated intuitively from an examination of the spectrum (Figures 1 and 2). The warmer upper atmosphere is associated with the Q-branch of the CO_2 band at 667 cm^{-1} where the highest radiances in the band occur, while the approximately isothermal portion of the profile is associated with the more transparent portions of the CO_2 band and the stronger lines of the water vapor rotation band. The cold surface temperature results in the relatively low radiances found in the window region and between the water vapor lines.

These preliminary results indicate that the interferometer experiment on Nimbus 4 is providing high quality infrared spectra of the earth and atmosphere. The low noise equivalent radiance, high spectral resolution, and broad spectral coverage make these data ideally suited for studies of atmospheric radiative transfer as well as the analysis and development of remote sensing techniques. In addition, the experiment provides a body of data which can be employed in a variety of geophysical and meteorological investigations. Temperature and humidity profiles derived from the spectra on a global basis will be useful in numerical modeling experiments of the atmospheric circulation.

ACKNOWLEDGMENTS

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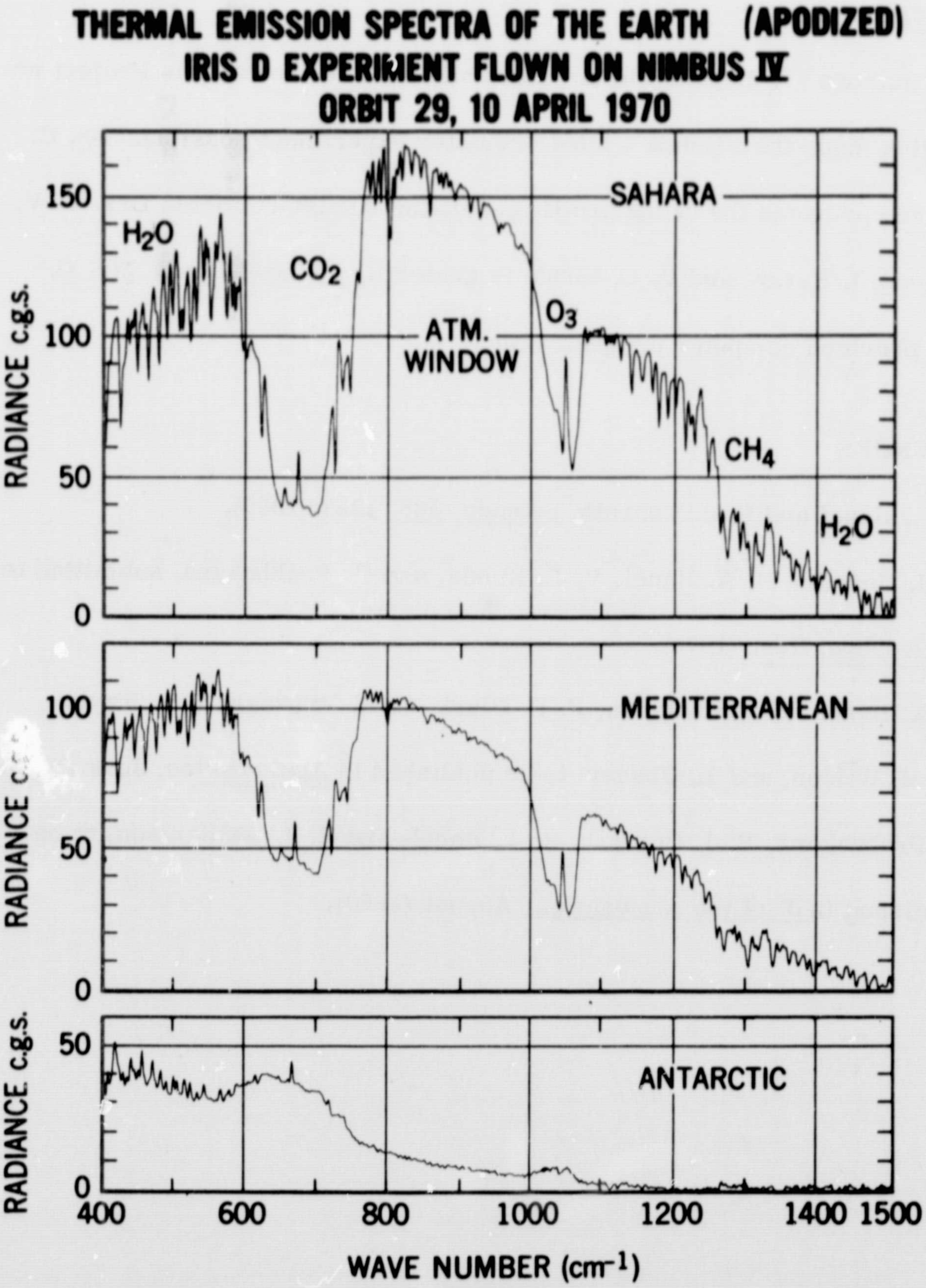

Figure 1. Selected spectra obtained with the Michelson interferometer flown on the Nimbus 4 satellite. The three spectra shown here, obtained over the Sahara Desert, the Mediterranean, and the Antarctic, are apodized, resulting in a resolution equivalent to 2.8 cm $^{-1}$. Atmospheric constituents responsible for the various absorption features are indicated in the upper spectrum.

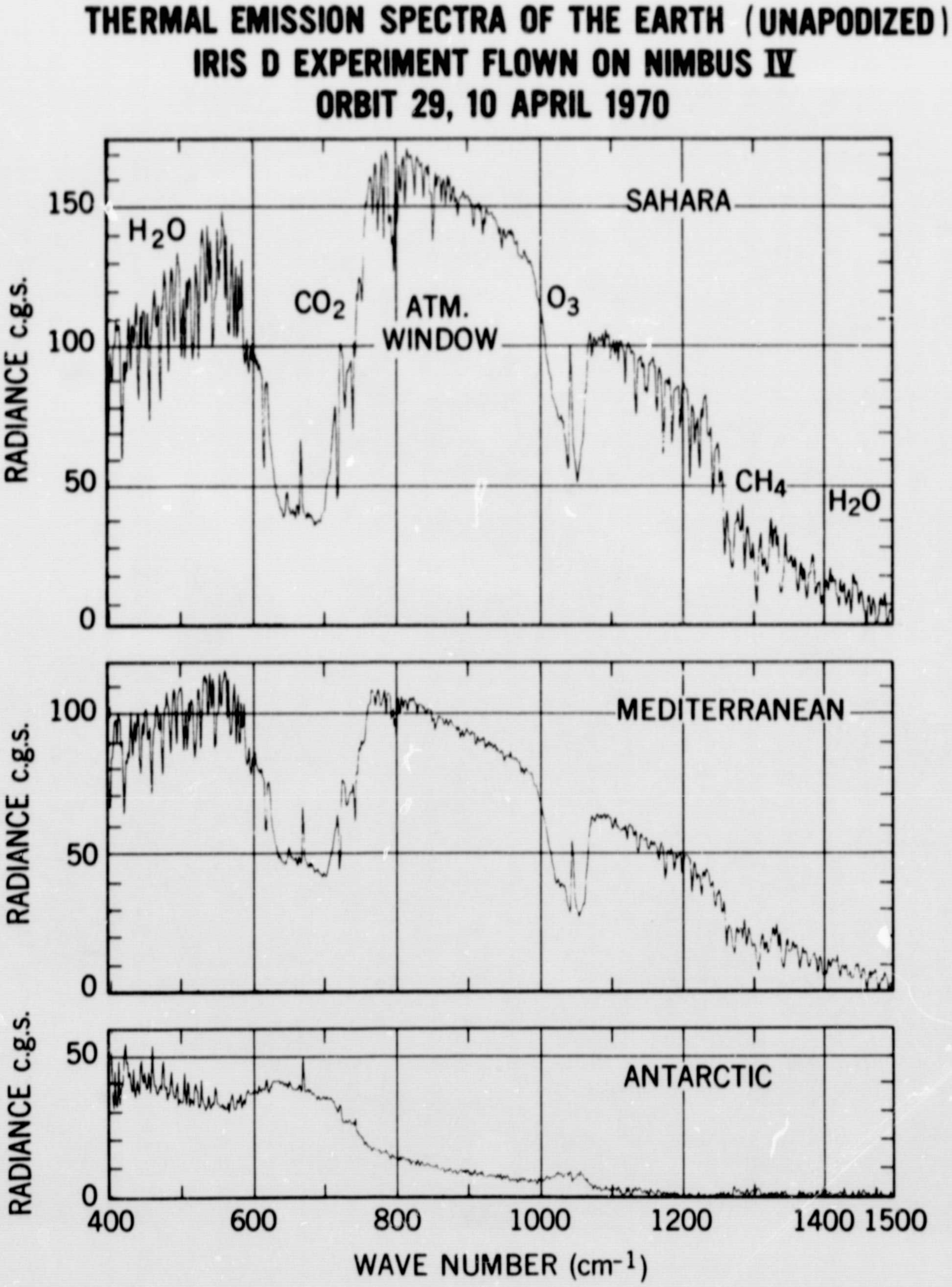

Figure 2. The same spectra shown in Figure 1 are here given in their unapodized form with a resolution equivalent to 1.5 cm^{-1}.

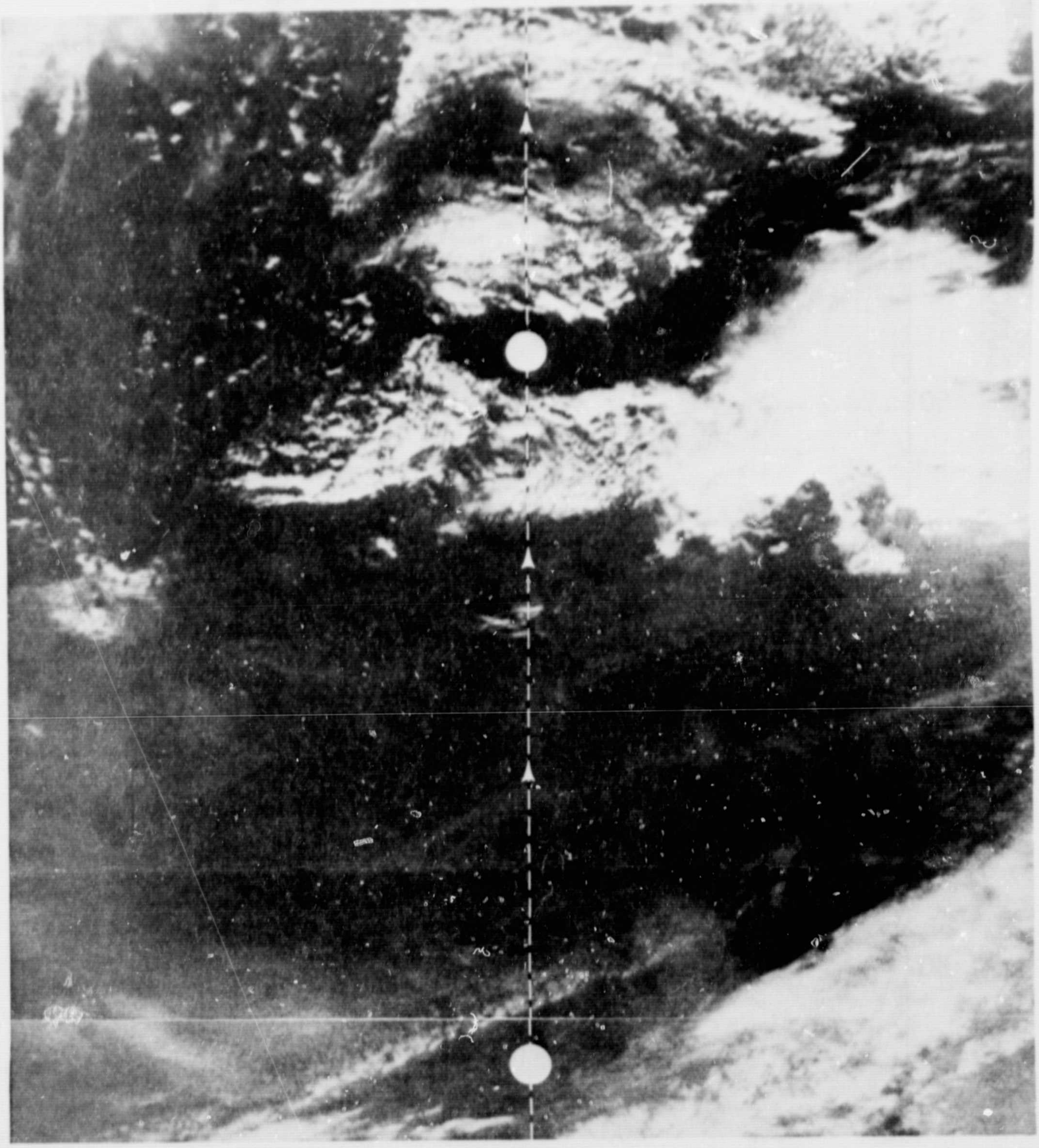

Figure 3. Television picture obtained from the Nimbus 4 satellite. The fields-of-view of the Michelson interferometer, corresponding to the Sahara and Mediterranean spectra given in Figures 1 and 2, are indicated by the circles, and the subsatellite path is indicated by the broken line.

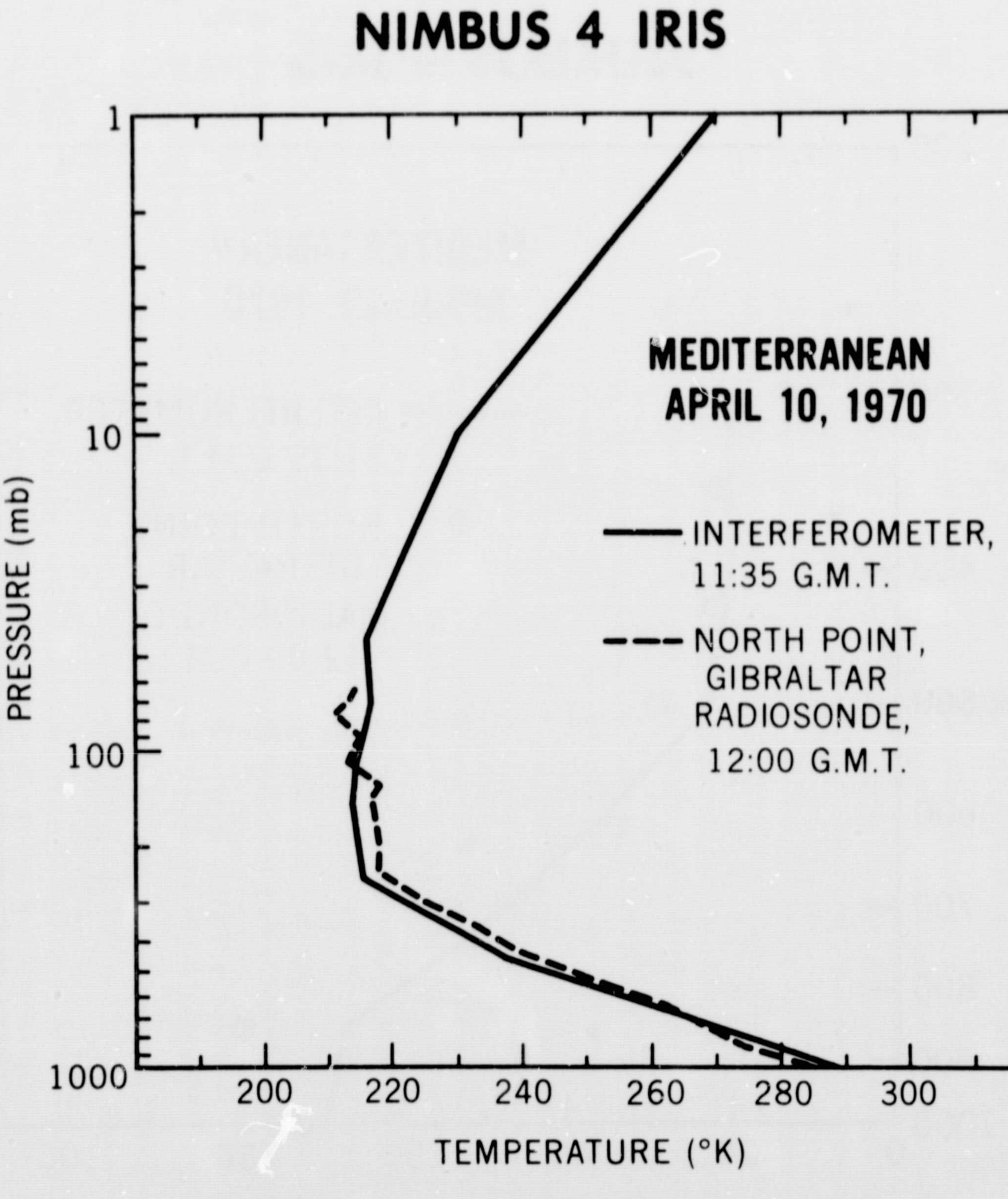

Figure 4. Vertical profiles of atmospheric parameters obtained from the Mediterranean spectrum shown in Figure 1. The profiles include (a) temperature, (b) relative humidity, and (c) ozone. Measurements of temperature and humidity obtained from a nearby radiosonde are shown for comparison.

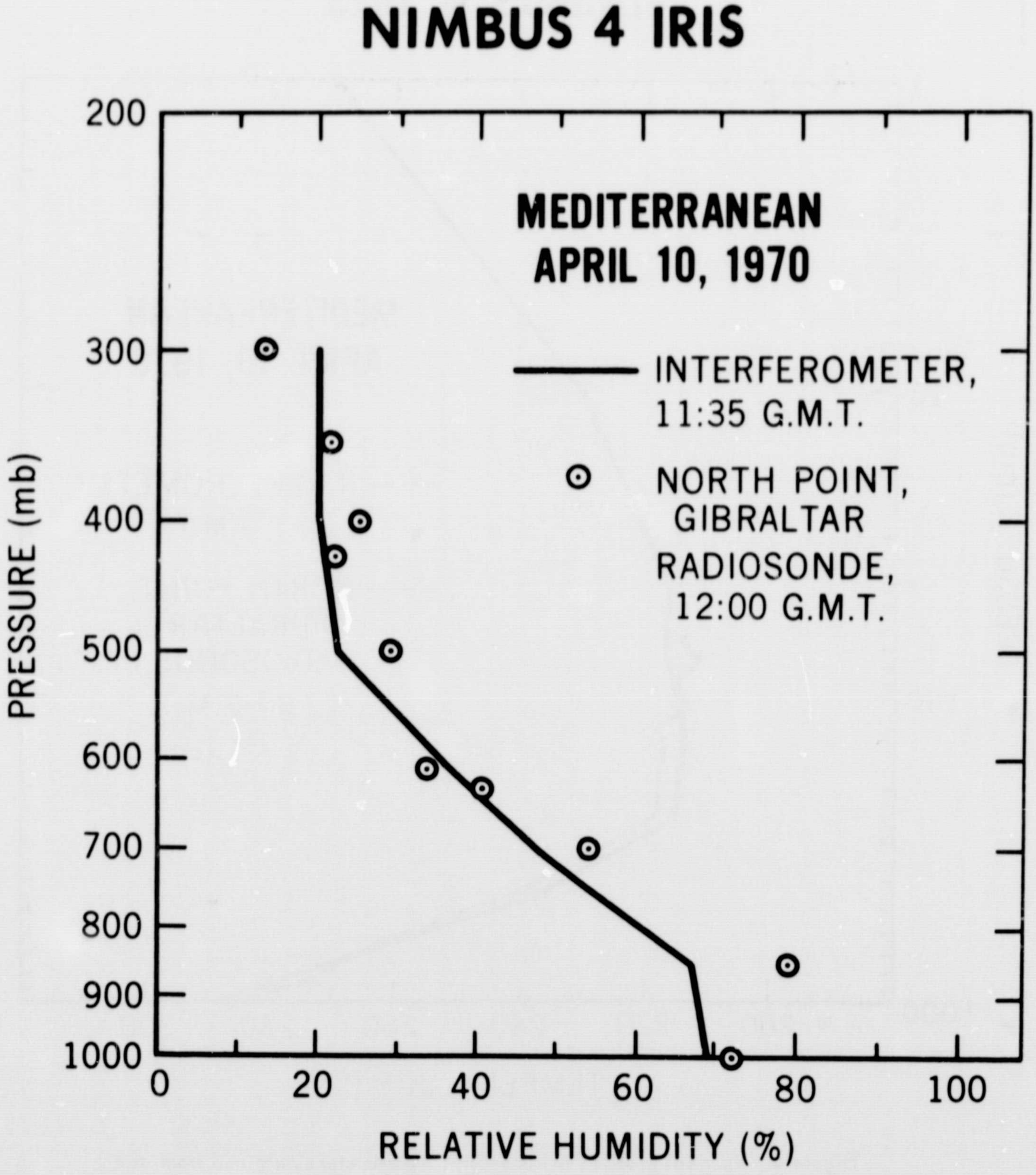
NIMBUS 4 IRIS
MEDITERRANEAN
APRIL 10, 1970
INTERFEROMETER, 11:35 G.M.T.
NORTH POINT, GIBRALTAR RADIOSONDE, 12:00 G.M.T.
PRESSURE (mb)
200
300
400
500
600
700
800
900
1000
0
20
40
60
80
100
RELATIVE HUMIDITY (%)

Figure 4 (b)

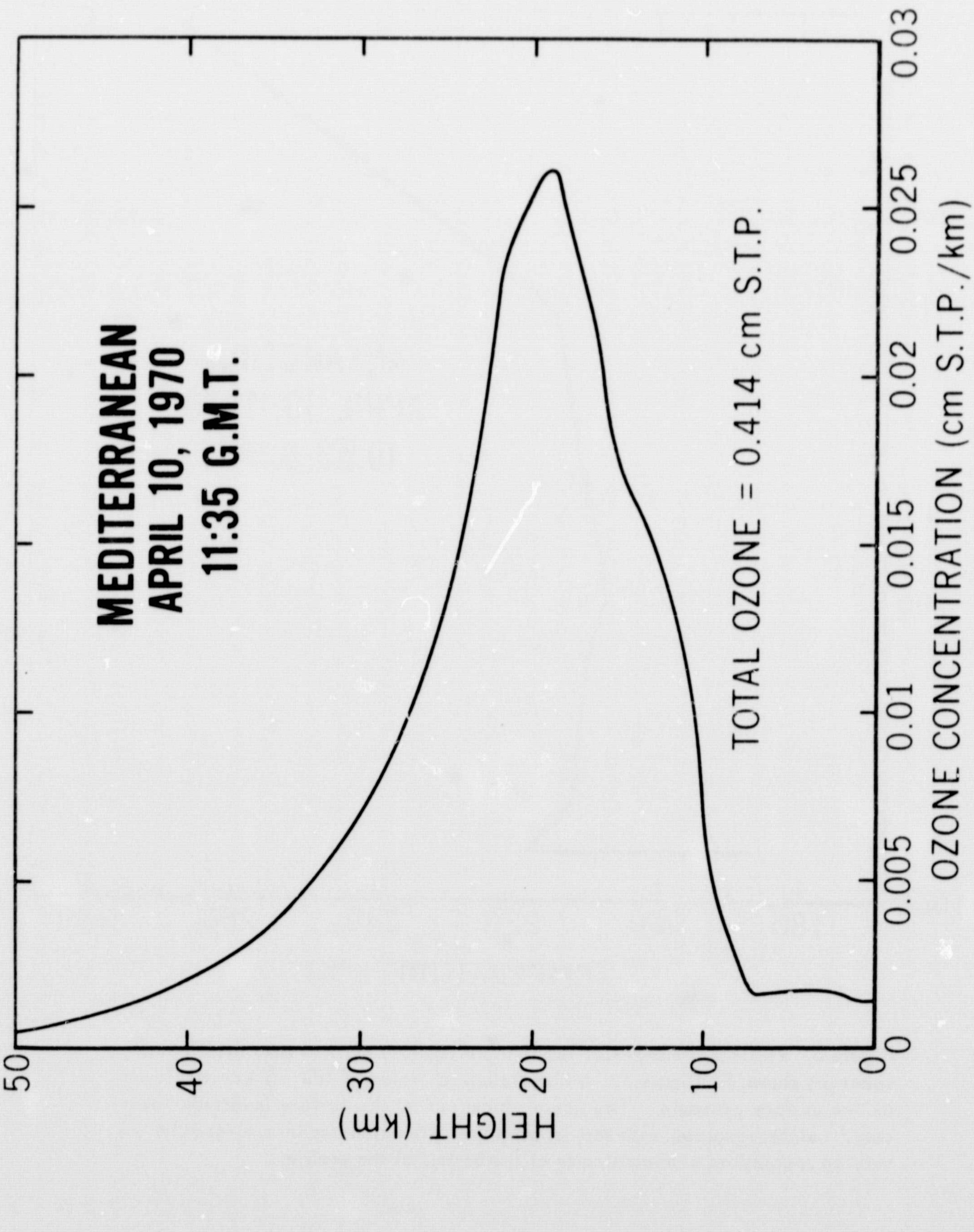
MEDITERRANEAN
APRIL 10, 1970
11:35 G.M.T.
TOTAL OZONE = 0.414 cm S.T.P.
HEIGHT (km)
0
10
20
30
40
50
OZONE CONCENTRATION (cm S.T.P./km)
0
0.005
0.01
0.015
0.02
0.025
0.03

Figure 4 (c)

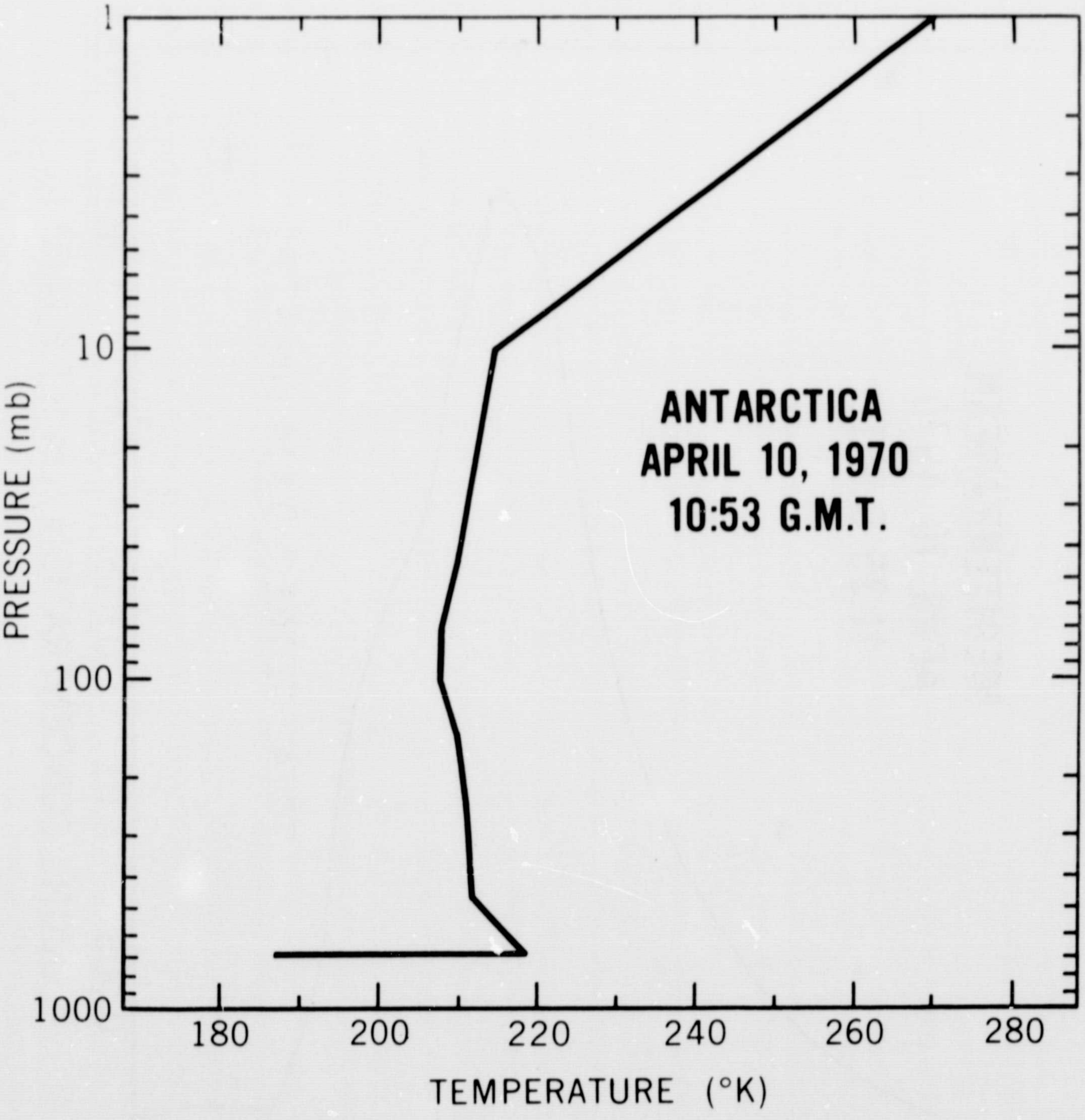

Figure 5. Vertical atmospheric temperature profile obtained from the Antarctic spectrum shown in Figure 1. A climatologicsl value of 700 mb was employed as the surface pressure. The actual thickness of the surface inversion layer could not be resolved with the temperature estimation technique, and the inversion appears as a discontinuity at the bottom of the profile.