

INFRARED DEVICE FOR MEASUREMENT OF CARBON DIOXIDE FLUCTUATIONS UNDER FIELD CONDITIONS

III. Adaptation to Infrared Hygrometry

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INTRODUCTION

Two models of infrared device for measurement of CO₂ fluctuations have been described in previous papers (Ohtaki and Seo 1976a, 1976b). The improved model with a double beam system has proved to be adequately sensitive and stable for fluctuation measurements. It is shown that the instrument can be applied to measure water vapor fluctuations with interchange of filters.

MODIFICATION OF PROTOTYPE MODEL

A schematic diagram of Fig. 1 shows the optical system of the modified model. The modifications taken here are as follows: (1) replacement of the 4.3 μm filter by a 2.6 μm filter, (2) replacement of the 3.9 μm filter by a 2.2 μm filter, and (3) removal of the wide-band filter in front of the detector. The electronics remained unchanged except that cutoff frequencies of the two low pass filters succeeding A/D converters have been changed from 1 Hz to 10 Hz (Ohtaki and Seo 1976b). Some design considerations are described below.

Absorption bands of water vapor are centered at 1.9, 2.7 and 6 μm in the intermediate infrared region. The 6 μm band is outside the long-wave threshold of the spectral response of the cooled PbSe detector (Optoelectronics, OTC-11-52-T) employed in the present device.

The 2.7 μm band is preferred for the following reasons. (1) The radiant source is operated at about 1000°K, yielding a larger output at 2.7 μm than at 1.9 μm . Relative to the peak value at about 3 μm , the available radiant power is 0.5 at 1.9 μm and 0.9 at 2.7 μm . It is mentioned for reference that the relative power is 0.7 at 4.3 μm , i. e., the wavelength of the CO₂ measurement band. (2) The 2.7 μm absorption band is more intense than the 1.9 μm band. (3) It is more adjacent to the measurement wavelength 4.3 μm of the prototype.

The 2.7 μm band is overlapped by a CO₂ absorption band. Under normal atmospheric conditions, the CO₂ absorption in this band is one order of magnitude less than the water vapor absorption, and its possible interference is practically eliminated by shifting the measurement

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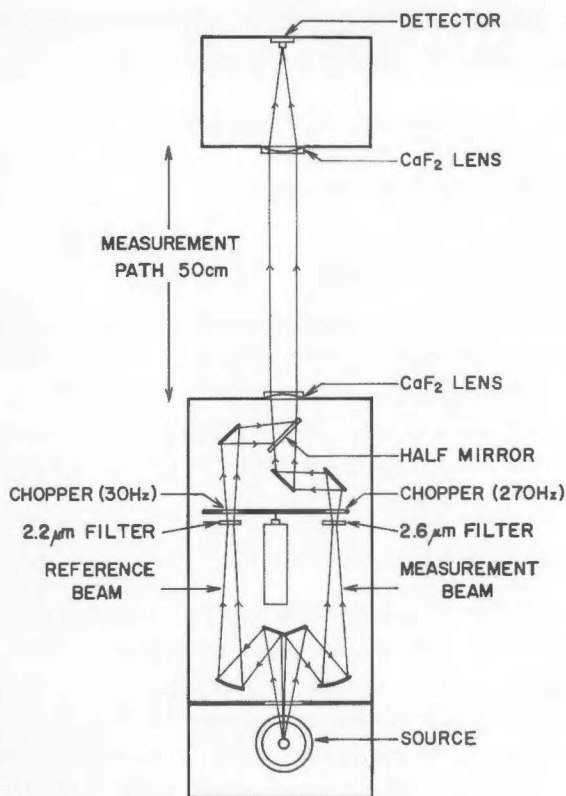


Fig. 1. Optical system of infrared device for measurement of humidity fluctuations.

band to $2.6 \mu\text{m}$. This is achieved by the use of a $2.6 \mu\text{m}$ filter with narrow bandwidth.

The water vapor absorption at $2.6 \mu\text{m}$ is assessed from the table calculated by Wyatt, Stull and Plass (Jamieson et al. 1963). Averaged over the filter pass-band specified by the half width ($2.55\text{--}2.63 \mu\text{m}$), it is about 20% for the specific humidity of 15 g/kg and the path length of 50 cm . This is commensurate with the CO_2 absorption at $4.3 \mu\text{m}$ for the concentration of 300 ppm and for the same path length.

The original $3.9 \mu\text{m}$ reference band might have been retained. The reference band is shifted, however, from $3.9 \mu\text{m}$ to $2.2 \mu\text{m}$, because the $2.2 \mu\text{m}$ band is more close to the selected H_2O absorption band.

Specifications of the filters employed are given below.

| | 2.6 μm filter | 2.2 μm filter |
|------------------------------------|--------------------------|--------------------------|
| center frequency (μm) | 2.591 | 2.186 |
| peak transmission (%) | 77 | 67.5 |
| half width (μm) | 0.079 | 0.093 |

In the original model, the detector is shielded from ambient radiation by a wide-band filter with pass band of 2.88 to 5.98 μm . The selection of 2.2 μm and 2.6 μm bands for humidity measurement requires removal of the wide-band filter.

It is remarked that the combination of 2.2 μm and 2.6 μm enables the glass optics to be used in an eventual IR hygrometer design.

PERFORMANCE TEST

A field test of the infrared hygrometer was made by comparison with a thermocouple psychrometer. The experiment was conducted on a grass surface in the meteorological enclosure of the Institute on 21 October 1975. The duration of the run was 29 min starting at 14h47m.

The thermocouple is a copper-constantan thermocouple. The air temperature junction is made from 0.1 mm ϕ wire and the wet junction from 0.05 mm ϕ wire. The measuring junctions are 5 cm long and stretched between plastic supports. The time constant of the psychrometer is approximately 1 sec at wind speeds of several tens of cm s⁻¹.

The measurement path of the IR hygrometer was set vertical, extending from 55 cm to 105 cm above the grass surface. The measuring junctions of the psychrometer were positioned at a height of 80 cm in proximity to the sensing path.

Preamplified outputs of the instruments were logged on an analog tape recorder. The data were digitized at the laboratory by a computer-controlled A/D converter at the sampling rate of 10 Hz.

Fig. 2 compares on the basis of 16.8 sec averages the output of the IR hygrometer with the specific humidity as determined from the psychrometer. The two series of data show remarkable similarity in the modes of time variation. The correlation coefficient calculated from the raw data is 0.82. It is noticed that a rising trend toward the end of the period is somewhat steeper in the hygrometer data than in the psychrometer data.

Fig. 3 illustrates more details of the variations on the basis of 0.3 sec averages. It is seen that the fluctuations are not so strongly correlated at high frequencies as at lower frequencies.

Power spectra calculated by the use of Tukey's scheme are shown in Fig. 4. At lower frequencies below 0.7 Hz, both instruments give approximately equal values of normalized spectral density. At higher frequencies the result from the psychrometer is affected by noise. The power spectrum from the IR hygrometer shows reasonable fall-off with increasing frequency. It is noted that the frequency response of the instrument is limited by the cutoff frequency 10 Hz of the low pass filter in the electronic block and the line averaging over the sensing path.

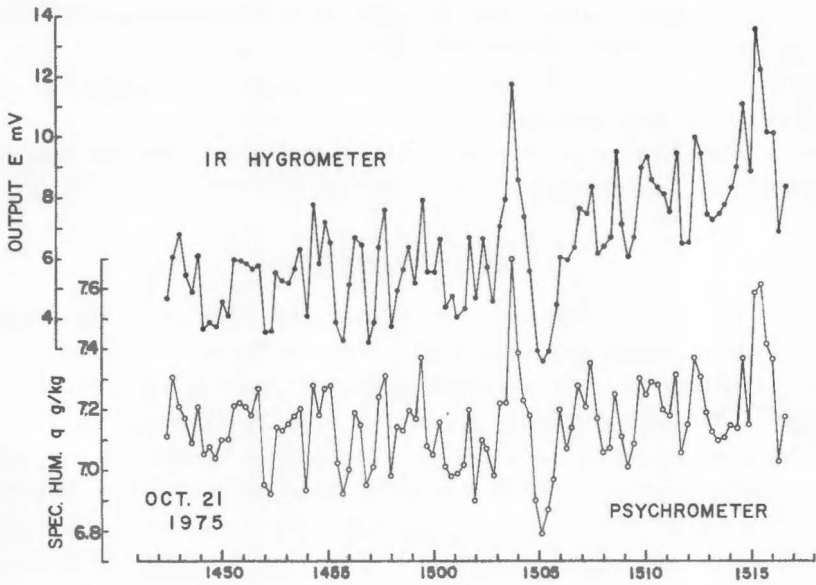


Fig. 2. Output of IR hygrometer E compared with specific humidity q from thermocouple psychrometer. Plot of 16.8 sec averages.

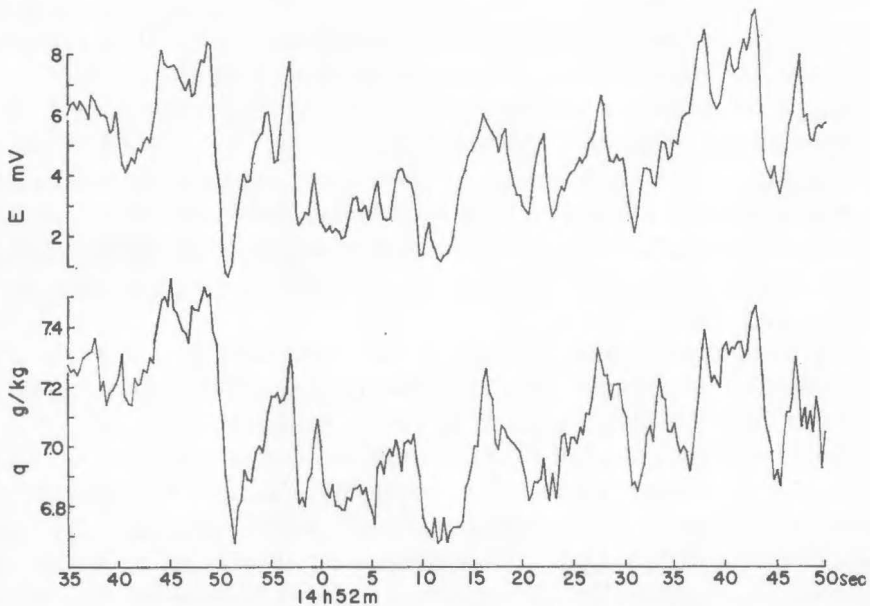


Fig. 3. Output of IR hygrometer E compared with specific humidity q from psychrometer, illustrating details of fluctuations in expanded time scale. Plot of 0.3 sec averages.

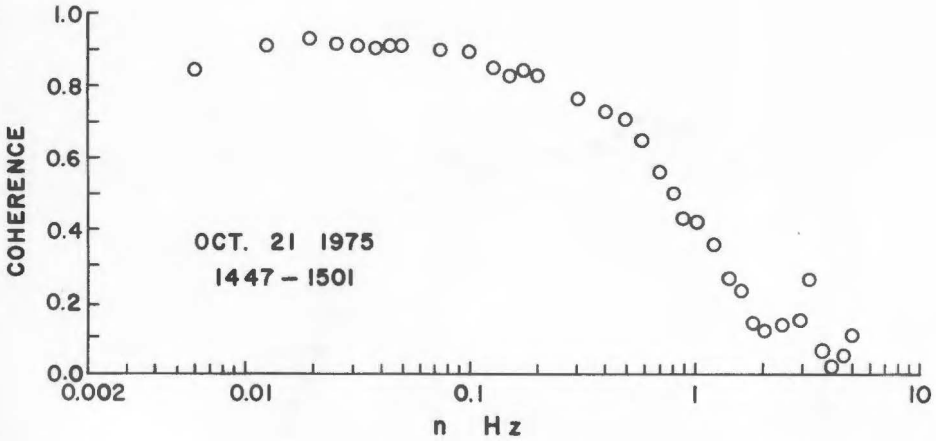


Fig. 5. Coherence between IR hygrometer output and specific humidity derived from psychrometer measurement.

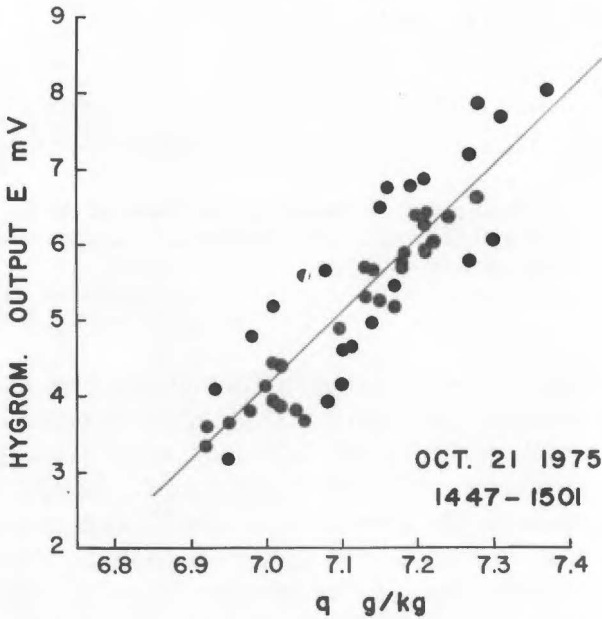


Fig. 6. Output of IR hygrometer E as a function of specific humidity q as determined by psychrometer. Data are taken from the first 14 min of the test run.

From the data given in Fig. 2, the difference between contiguous two values is taken successively. The resulting time variations Δq and ΔE over 16.8 sec are compared in Fig. 7. The data can be fitted by the regression equation:

$$\Delta E = 9.61\Delta q + 0.059.$$

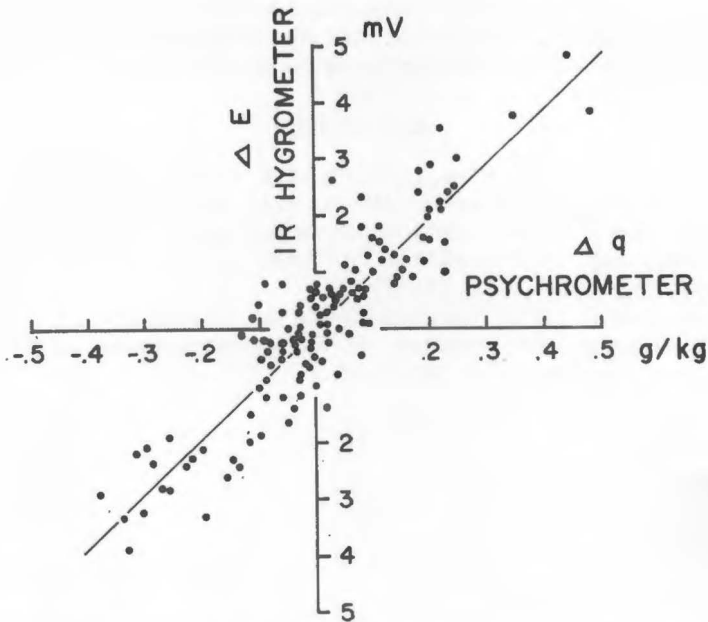


Fig. 7. Time variations (differences between contiguous two values from the data given in Fig. 2) compared between IR hygrometer and psychrometer. Time interval=16.8 sec. Data from the total 29 min run.

The sensitivity obtained here ($9.61 \text{ mV/g kg}^{-1}$) is in good agreement with that derived above ($9.74 \text{ mV/g kg}^{-1}$).

The noise at the output of the prototype model is of the order of 0.1 mV (Ohtaki and Seo 1976b). Inspection of the records has indicated that the noise for the hygrometer is of the same order. With reference to the sensitivity given above, this noise voltage is equivalent to the variation of the order of 0.01 g/kg in specific humidity.

CONCLUSIONS

It has been demonstrated that the infrared device for measurement of CO₂ fluctuations can be modified to measure humidity fluctuations. The tested IR hygrometer is adequate in sensitivity for the fluctuation measurement. The newly developed IR device combined with a sonic anemometer will make it possible to determine the turbulent fluxes of water vapor and carbon dioxide by the eddy correlation technique. Further improvements required are as follows: (1) The sensing path needs to be shortened to a length compatible with the 20 cm path of the standard sonic anemometer. (2) Reduction of zero drift is necessary for a long term measurement. It can be achieved by making more stringent the sealing and purging of the housings.

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