Temperature Sensitivity of Eppley Broadband Radiometers

by W.L. Smith Jr., Stephen K. Cox, Vince Glover

FIRE Series No. 5

Funding Agencies: National Science Foundation
National Aeronautics & Space Administration

Atmospheric Science
PAPER NO.
423

DEPARTMENT OF ATMOSPHERIC SCIENCE
COLORADO STATE UNIVERSITY
FORT COLLINS, COLORADO

TEMPERATURE SENSITIVITY OF EPPLEY BROADBAND RADIOMETERS

FIRE Series No. 5

by
W.L. Smith Jr.,[1] Stephen K. Cox[1]
Vince Glover[2]

February, 1988

Atmospheric Science Paper No. 423

---

[1] Affiliation - Department of Atmospheric Science, Colorado State University, Fort Collins, CO 80523

[2] Affiliation - Research Aviation Facility of the Atmospheric Technology Division,
National Center for Atmospheric Research, Boulder, CO 80307

TABLE OF CONTENTS

TEMPERATURE SENSITIVITY OF EPPLEY BROADBAND RADIOMETERS

Abstract

Eppley Laboratory Inc. model PIR pyrgeometers and model PSP pyranometers have built in temperature compensation circuitry designed to limit relative errors in the measurement of radiation to +/- 2% for a temperature range of -20 C to +40 C. A procedure developed to verify this specification and to determine the relative sensitivity to temperatures below -20 C is described. Results of this calibration and application to data correction are also presented.

1. INTRODUCTION

Broadband radiometers manufactured by Eppley Laboratory Inc. are commonly used to measure irradiance from both ground-based and aircraft platforms. Namely, the precision pyranometer (Model PSP) measures irradiance in the .3-3 micron spectral region while the pyrgeometer (Model PIR) senses energy in the 4-50 micron region. The two instruments have a similar thermopile construction but different optical filters to achieve the appropriate spectral selection.

The precision pyranometer has been described by Albrecht and Cox (1976) and Robinson (1966). These instruments are typically sent to the manufacturer for calibration relative to a group of reference standards. Calibration of the pyrgeometer is more complex and can be performed following the procedures of Albrecht and Cox (1977). For a description of this instrument, see Albrecht et al. (1974). Several other authors have made contributions in assessing the performance of pyrgeometers. For example, see Weiss (1981), Bradley and Gibson (1982) and Ryzner and Weber (1982). Foot (1986) points out that the main problem with achieving accurate irradiance measurements from the pyrgeometer is associated with errors caused by temperature gradients within the instrument itself. He suggests minimizing these errors by utilizing a newly constructed pyrgeometer which demonstrates a markedly reduced sensitivity to temperature gradients.

During the fall of 1986, the First ISCCP (International Satellite Cloud Climatology

Project) Regional Experiment (FIRE) commenced with the first cirrus Intensive Field Observation (IFO) conducted in central Wisconsin. Due to the nature of this field project, pyranometers and pyrgeometers manufactured by Eppley Laboratory Inc. were flown on NCAR's high altitude research aircraft, the Sabreliner. Inherent in the construction of these radiometers is temperature compensation circuitry designed to make the instrument sensitivity nominally constant (within +/- 2%) over a temperature range from -20 C to +40 C. Because the Sabreliner flew at high altitudes where temperatures were as cold as -70 C, it was necessary to determine the radiometers relative sensitivity to temperatures below -20 C and apply appropriate corrections to the FIRE radiation data set. A procedure to perform this calibration is outlined below. It is meant to serve as a supplement to the calibration procedures referenced above.

2. LABORATORY SET UP

Six Eppley Laboratory Inc. manufactured radiometers were flown on the NCAR Sabreliner during the FIRE first cirrus IFO. Of these six, only three were available for this particular calibration at NCAR's Research Aviation Facility (RAF) and included two pyranometers and one pyrgeometer. Because this calibration is concerned with radiometer thermopile characteristics only, the calibration procedure can be simplified by converting them all to visible radiometers. This conversion only requires that the domes be visibly clear. The three radiometers were mounted inside an environment chamber at NCAR's RAF so that they faced, and were encompassed in the field of view of, a plated glass window in the door. A light source was mounted directly in front of the radiometers but on the outside of the chamber. In addition, an extra pyranometer was mounted on the outside of the chamber to monitor any changes in the light source output. Signal wires connected to the radiometers were passed through a datalogger to a computer where thermopile output, chamber temperature, room temperature and the sink temperature of the pyrgeometer were recorded and monitored in real-time. For a more visual depiction of the laboratory set up, see figure 1.

3. CALIBRATION PROCEDURE

The temperature of the insulated environment chamber was controlled so that data could be sampled every 5 degrees celsius from +26 C to -63 C. Again, because we are concerned with thermopile characteristics only, the calibration procedure can also be simplified by ensuring that the radiometers are in thermal equilibrium when data is recorded. The sink temperature of the pyrgeometer is the best indication of the temperature of the thermal mass of the radiometer. So, at each calibration point (i.e. each 5 degree C chamber temperature increment), the sink temperature of the pyrgeometer was monitored with respect to the chamber temperature to determine when the pyrgeometer was in thermal equilibrium. While the temperature of the chamber's environment could be changed rather rapidly, it was found to take nearly an hour for the thermal mass of the pyrgeometer to achieve thermal stability. Since the pyranometers and pyrgeometer are nearly identical in construction and thermal mass, it was assumed that all radiometers in the environmental chamber reached thermal equilibrium at the same time.

The instrument output was sampled at 1 Hz and recorded in 10 second averages. The source was chopped at each calibration point by covering the plated glass window, thus shielding the radiometers from all shortwave radiation. This provided information concerning the dark current of the instruments. Because of the time it took for thermal equilibrium to be reached at each calibration point, it took several days to cover the entire temperature range from +26 C to -63 C using 5 degree intervals. At the beginning of each day, a room temperature calibration data point was recorded. This data relates the output voltage of each radiometer being calibrated to the output voltage of the pyranometer monitoring the source while all radiometers are at the same room temperature. So, for each instrument being calibrated,

$$V_m(T_r) = p(T_r) * [V_c(T_r) - V_d(T_r)]$$

where T_r = room temperature

V_m = voltage output of source monitor at T_r

V_c = voltage output of radiometer being calibrated at T_r

V_d = dark voltage of radiometer

p = function relating V_c to V_m at T_r.

Then, for each subsequent calibration point,

$$V_m(T_r) = q(T) * [V_c(T) - V_d(T)]$$

where T = temperature of chamber and consequently of the thermal mass of the radiometers being calibrated

q = function relating V_c at T to V_m at T_r

and the relative sensitivity is

$$K(T, T_r) = p(T_r)/q(T).$$

Thus, the relative sensitivity K(T,T_r) is normalized to express the temperature dependence of each radiometers thermopile given a constant source of energy and with respect to some reference temperature, taken here to be the room temperature (T_r) of 26 degrees C.

4. RESULTS

Results of this calibration for the available radiometers are shown in figure 2. Within the electronically compensated temperature range from +40 C to -20 C, our results depict nominal instrument sensitivity within about 2.5%, close to the Eppley Laboratory Inc. +/- 2% specification. Outside of this range (i.e. below -20 C), errors could be as large as 7% at -63 C. A third order polynomial proved to provide the best fit to these data. These curves are also shown in figure 2. The corresponding coefficients for these curves are listed in table 1 and have been used to correct the data collected on board the Sabreliner during FIRE. Since two of the pyranometers flown on the Sabreliner were unavailable for this post mission calibration, an average was taken of the two pyranometer curves that were developed and this third curve used to correct the data collected by the uncalibrated instruments. Similarly, one pyrgeometer was also unavailable, so the curve developed from the calibrated pyrgeometer was also applied to data collected by the uncalibrated pyrgeometer.

5. APPLICATION TO DATA CORRECTION

The application of this calibration to data correction is straight- forward because the original manufacturer's calibrations were done at room temperatures near the 26 C reference temperature used in this calibration. Eppley Laboratory Inc. states in their calibration documentation that the adopted calibration temperature for the pyranometer is 25 C. For the pyrgeometers, the calibration procedure following the methods of Albrecht and Cox (1977) dictates that the temperature of the radiometer thermopile is near the room temperature of the laboratory. Albrecht et al. (1974) report that the sink temperature is representative of the thermopile sensor temperature. This is because the temperature difference between the hot and cold junctions of the thermopile is, at most, 0.5 K for typical irradiance measurements in the atmosphere.

The relative sensitivity (K), determined in section 3, can be applied directly to the pyranometer measurements to get the corrected value. For example,

$$\mathrm{SWCORR} = 1/\mathrm{K}(T_s) * \mathrm{C} * \mathrm{V}$$

where V = pyranometer thermopile output voltage

C = calibration constant supplied by Eppley Laboratory Inc. to convert thermopile output voltage to units of irradiance (i.e. W/M**2)

$\mathrm{K}(T_s)$ = the relative sensitivity at a temperature T_s which is the sink temperature of an adjacent pyrgeometer

SWCORR = the corrected irradiance.

For the pyrgeometer, an equation derived by Albrecht et al. (1974) and Albrecht and Cox (1977) of the form

$$H = \frac{E}{\eta} + \epsilon\,\sigma\,T_s^4 - \beta\,\sigma\,(T_d^4 - T_s^4)$$

where

ϵ - emissivity of the thermopile (usually taken to be unity)

σ = Stefan Boltzmann constant

T_d, T_s = dome temperature and sink temperature, respectively

η, β = calibration constants

E = thermopile voltage

H = incoming irradiance

can be further corrected for temperature sensitivity by applying $K(T_s)$ to the first term such that

$$HCORR = \frac{1}{K(T_s)} * \frac{E}{\eta} + \epsilon\sigma T_s^4 - \beta\sigma(T_d^4 - T_s^4)$$

where H CORR is H but corrected for temperature sensitivity.

However, because the infrared irradiance (from the pyrgeometer) is a function of the summation of several terms, the effect of the temperature sensitivity correction will be somewhat less for the pyrgeometer data than for the pyranometer data. Several FIRE data sets were analyzed to determine the magnitude of error between corrected and uncorrected pyranometer and pyrgeometer measurements. Irradiance errors for the pyrgeometer were found to be, at most, 2-3 W/m**2 which is within the noise of the instrument. Because the temperature sensitivity correction is applied directly to the pyranometer measurements, errors could be as large as 7% of the uncorrected measurement at -63 C. In addition, errors as large as 10% were found in cloud fractional absorptance (CFA) calculations (See Ackerman and Cox (1981) for a description of CFA).

6. SUMMARY

A calibration procedure to correct Eppley Laboratory Inc. broadband radiometers for thermopile temperature sensitivity has been presented. This calibration should be performed prior to field work where radiometers of this type, particularly the pyranometer, may be exposed to temperatures beyond the range of the temperature compensation circuit.

7. ACKNOWLEDGEMENTS

The authors wish to express their appreciation to Mr. Christopher Johnson-Pasqua at Colorado State University and Mr. David McFarland at NCAR's RAF for their electronics expertise and assistance with the laboratory set up. Dr. Ron Schwiesow provided scientific guidance regarding the design of the laboratory experiment and Mssrs. Herminio Avila and Paul LeHardy devised and assembled the calibration fixtures. Special thanks are extended to Melissa Tucker for preparation of this manuscript. This research has been supported by the National Science Foundation under Grant ATM-8521214 and by the National Aeronautics and Space Administration under Grant NAG 1-554.

Table 1. Coefficients for the third order polynomial representation of the relation sensivity (K) for -63 $\leq T_s \leq$ +26 where

$$K(T_s) = a + b * T_s + c * T_s ** 2 + d * T_s ** 3$$

Radiometer Serial No.	a	b	c	d
14963F3	1.0212	-3.8166E-4	-2.2971E-5	1.1316E-7
12149F3	1.0201	-5.8376E-4	-1.6416E-5	1.8673E-7
12148F3*	1.0207	-4.8271E-4	-1.9694E-5	1.4994E-7
14962F3*	1.0207	-4.8271E-4	-1.9694E-5	1.4994E-7
12150F3	1.0123	-4.5256E-4	-7.7408E-6	1.9354E-7
12151F3*	1.0123	-4.5256E-4	-7.7408E-6	1.9354E-7

*indicates that radiometer was unavailable for this calibration T_s is sink temperature of nearest pyrogeometer

8. REFERENCES

Albrecht, B., and S.K. Cox, 1977: Procedures for improving pyrgeometer performance. *J. Appl. Meteor.*, **16**, 188-197.

Ackerman, S.A., and S.K. Cox, 1981: Aircraft Observations of the Shortwave Fractional Absorptance of Non-Homogeneous Clouds. *J. Appl. Meteor.*, **20**, 0128-0133.

Ackerman, S.A., M. Poellot and S.K. Cox, 1974: Pyrgeometer measurements from aircraft. *Rev. Sci. Instrum.*, **45**, 33-38.

Bradley, S.G., and R.G. Gibson, 1982: On the use of pyrgeometers in cloud. *J. Appl. Meteor.*, **21**, 1155-1159.

Foot, J.S., 1985: A new pyrgeometer. *J. Atmos. Oceanic Technol.*, **3**, 363-370.

Robinson, N., 1966: Solar Radiation, Elsevier, 347 pp.

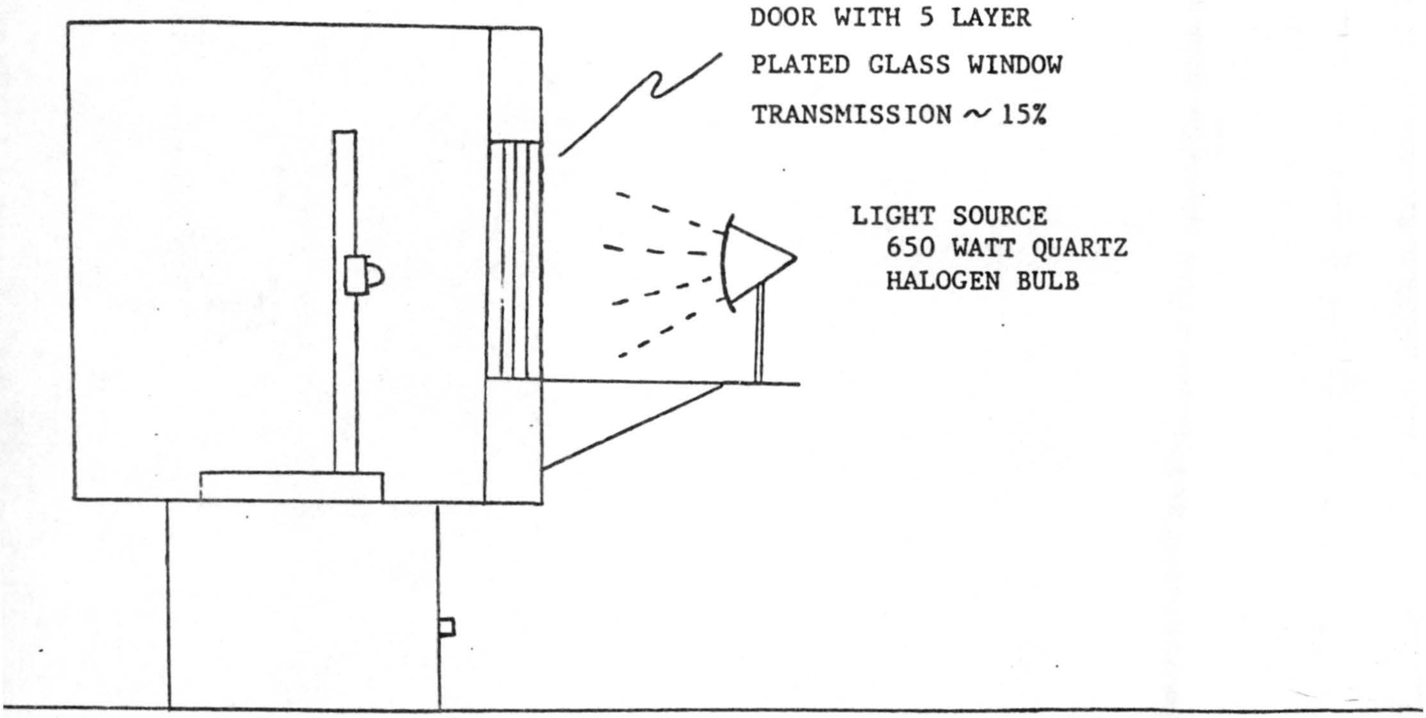
Ryzner, E., and M.R. Weber, 1982: Comments "On the performance of pyrgeometers with silicon domes." *J. Appl. Meteor.*, **21**, 1208-1210.

Weiss, A., 1981: On the performance of pyrgeometers with silicon domes. *J. Appl. Meteor.*, **20**, 962-965.

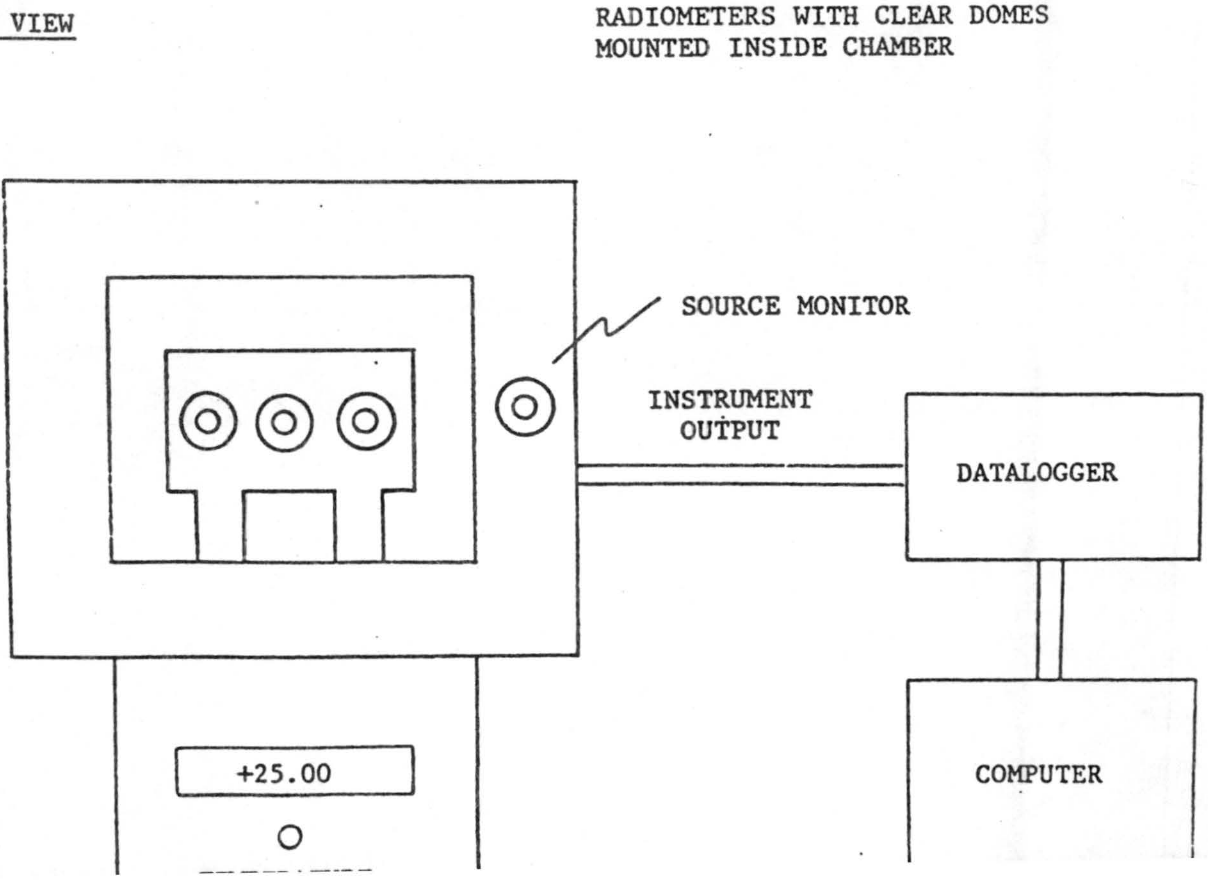
RE 1

NCAR (RAF) ENVIRONMENT CHAMBER

SIDE VIEW

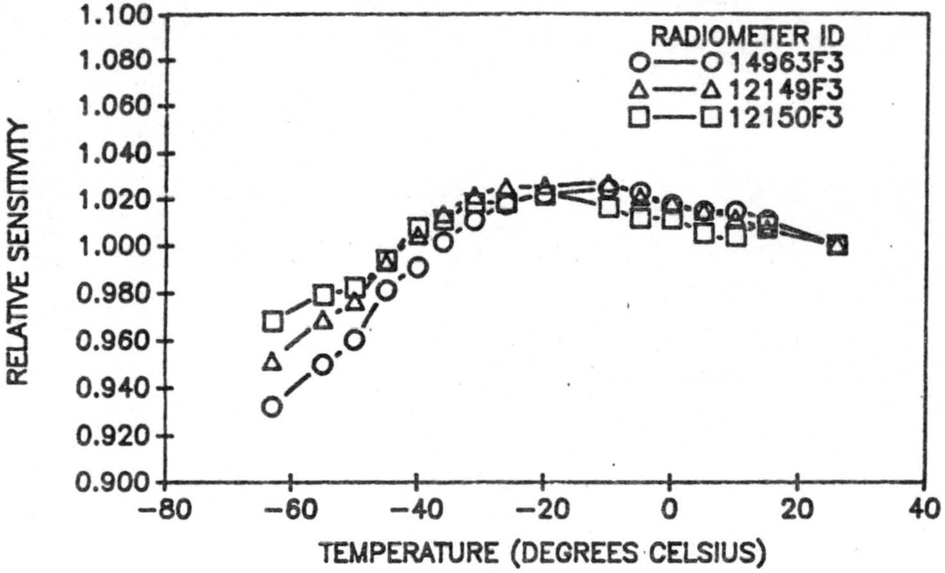


FRONT VIEW

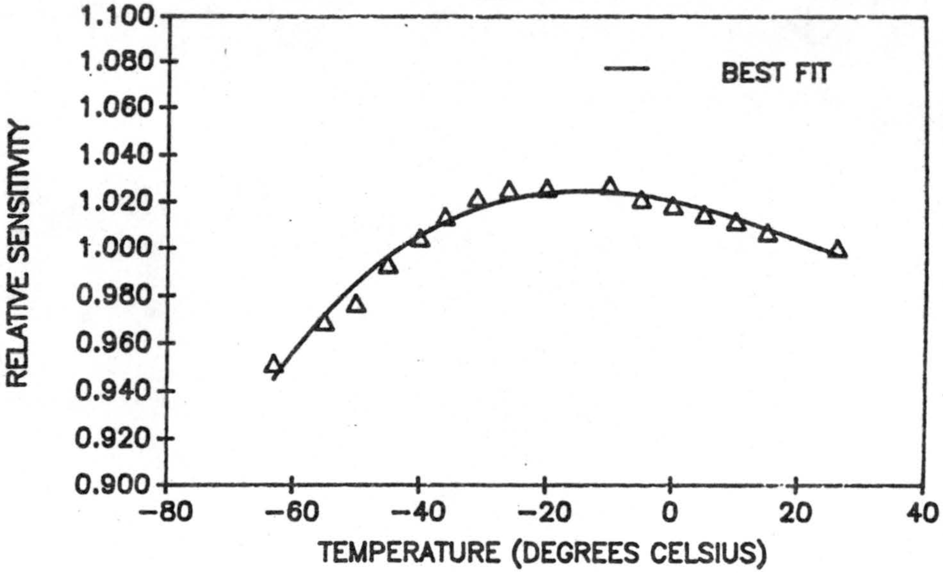


CSU–NCAR(RAF) CALIBRATI

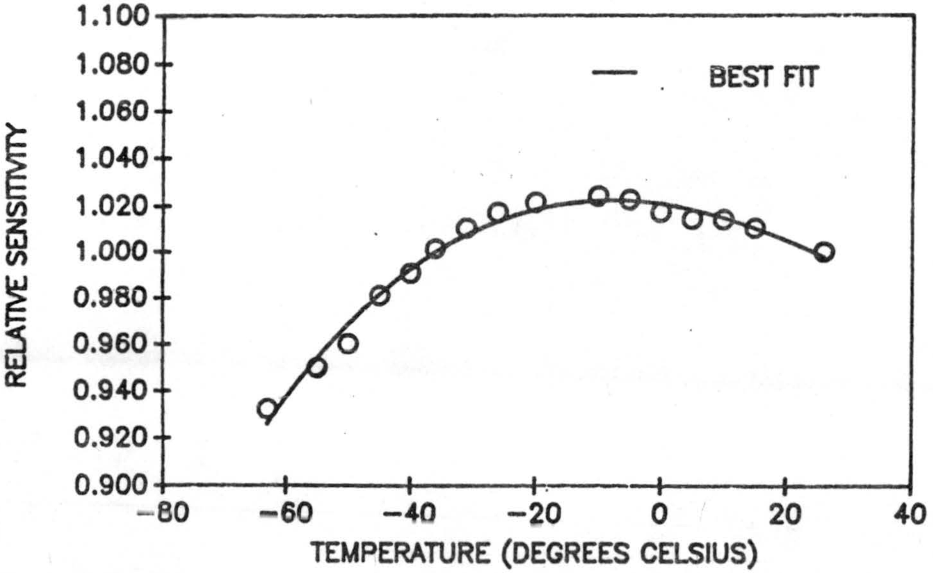
FALL 1987



PYRANOMETER #12149F3



PYRANOMETER #14963F3



PYRGEOMETER #12150F3