Reply

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Our analysis of the comments of Drs. Staley and Herman indicates that, basically, they are questioning the following discussions in our publication:

- 1) References to computed and observed radiant flux.
- 2) Hygristor errors.

FIG. 1. Radiometersonde run for Barbados, 3 June 1969. Curves and symbols are as follows: $\times$'s represent humidity (gm kg^{-1}) along lower abscissa, $+$'s air temperature, Δ upward radiant flux, ∇ downward radiant flux, $\diamond$ net radiant flux, and $\circ$'s represent cooling along upper right-hand abscissa.

3) Rapid moisture decreases that could be related to static stability rather than to hygistor error.

4) Reconstruction of the humidity profiles by an "iterative" radiometric method.

5) Contributions of aerosol or haze and other trace gases to the downward radiant flux.

6) Radiative transfer model. (We believe they refer to a model rather than a computer calculation.)

1. Robinson's (1950) measurements and estimates of downward radiant flux referred to *surface* measurements although one might assume that he also implied a measured vs computed *profile* discrepancy. His work took place before the introduction of the radiometersonde (Suomi and Kuhn, 1958). Kuhn and Suomi (1965) detailed this downward radiative flux profile discrepancy between observations and calculations.

2. The problems of the possible hygistor error of the U. S. radiosonde appears to us to be well enough known not to necessitate a literature review or archival listing, and indeed, this was not a study to explicitly define hygistor errors as such. Examples cited in Kuhn and Stearns (1971, 1972), unfortunately not referenced in the original study, clearly indicate that on several occasions during BOMEX the radiosonde hygistor

was not functioning properly. A problem does exist and the radiometersonde observations combined with radiative transfer calculations are offered as a possible solution.

3. To assist in answering the questions raised on static stability we reproduce a temperature-moisture-radiation sounding cited as an example of hygistor deficiencies in our publication as Fig. 1. This figure, an ascent of 3 June 1969 at Barbados, does not display a correlation of rapid moisture decrease with static stability changes in the 1000–550 mb layer. Kuhn and Stearns (1971) reported and listed all BOMEX radiative transfer observations and calculations. In the subject report containing 151 temperature-moisture-radiation soundings, 49 cases of rapid moisture decrease with height were noted (32%). Of these only six (12%) could be related to static stability changes.

4. The term "iterative," cited in Section 2, refers to repetitive computer computations of the downward radiant flux by adjusting the amount of water vapor in the successive atmospheric layers until agreement is obtained between the observed and calculated flux. Input consists of three parameters—pressure, temperature, and water vapor mixing ratio. One of the series of

FIG. 2. Comparison of Ellingson-Gille and Kuhn-Cox models for radiative transfer of thermal flux in Canal Zone ascent.

iterations is made with a saturated water vapor profile above a point where the hygistor exhibited a sudden drop or cutoff (Fig. 4 of the original paper). Certainly, saturation would be a maximum estimate, and thus a limiting value to the calculated radiation profile. It also produced, as might be expected, a discontinuity from the original sounding with respect to moisture and hence was not considered the true moisture profile. Having established the minimum (original moisture sounding) and maximum (saturated) boundaries, we repeated the calculations by increasing the moisture using the Smith (1966) power law approximation from the level of rapid moisture decrease. When the difference between calculated and observed flux was within the convergence criterion, the iteration was stopped. As noted above, a moisture profile used as input to the calculations that produced a discontinuity from the original sounding at the level of rapid moisture decrease was disregarded. Only the smooth upward moisture profile was considered the best estimate of the final profile.

Since our publication could not be of text length, we obviously could not detail all information and explanations evidently required by Staley and Herman. These can better be communicated by personal contact. As for the Kuettner and Holland (1969) reference, the authors of the comments misconstrued our purpose in citing this reference. Our reference was to give proper

credit to those who supported the BOMEX radiation program and to briefly describe the effort, and not to imply that Kuettner and Holland were comparing radiative transfer calculations and observations.

5. With reference to the capability of Harmattan haze measurements in July to produce radiative divergences in June, the authors of the comments have mistaken our intent. It was stated that island (Barbados) observers reported the haze during the 3 June period. The comment on the July observations of the deep haze layer from the first high altitude aircraft (CV-990) was intended to emphasize the frequent presence and depth of the layer even through July.

During this research effort numerous observations and calculations of the effects of atmospheric haze were made for another project. We will report these conclusions employing mass absorption coefficients ($\text{cm}^2 \text{gm}^{-1}$) and volume absorption coefficients (cm^{-1}) for atmospheric cirrus and haze and atmospheric attenuation. However, in the subject publication four references to haze effects on the transfer calculations were made in Section 4.

6. The transmission model employed in the radiative flux calculations is basically the Elsasser (1960) periodic model. The absorption coefficients for water vapor are those of Möller and Raschke (1964), as stated, taken from Yamamoto (1952), covering the $6.3 \mu\text{m}$ band of water vapor, $1160\text{--}2120 \text{ cm}^{-1}$, and the rotational band of water vapor, $200\text{--}800 \text{ cm}^{-1}$. The absorption coefficients are listed in the cited reference. They are not the absorption coefficients upon which the Elsasser chart data are based.

In the spectral regions where active absorption bands of two or more absorbers overlap each other, $520\text{--}800 \text{ cm}^{-1}$ for carbon dioxide and water vapor, and $840\text{--}1140 \text{ cm}^{-1}$ for ozone and the water vapor window, the multiplicity formulation (Goody, 1964) is employed to determine the total transmissivity. The spectral transmissivity τ is determined by the product of the spectral transmissivities of the individual constituents

$$\tau_\nu = \tau_{\nu_1} \cdot \tau_{\nu_2} \cdot \tau_{\nu_3} \cdots \tau_{\nu_m}, \quad (1)$$

where the subscripts refer to the specific transmission functions of the n active gasses in the spectral interval ν . We did inadvertently omit the ozone integral in the original publication and it should have been listed in Eq. (1) as

$$\cdots \int_0^\infty \int_{\tau=1.0}^\tau B(\nu, T) d\tau (u_{\text{O}_3}) d\nu,$$

where the symbols are listed in the publication, and u_{O_3} refers to the optical mass of gaseous ozone (gm cm^{-2}). In computing the contribution of ozone to the total downward and upward flux we used the data of Walshaw (1957) giving the integrated absorption of the entire $9.6 \mu\text{m}$ band ($840\text{--}1140 \text{ cm}^{-1}$).

As for radiative contributions of trace gases neither our model nor the radiometer can bring such a contribution out of the general noise level. The pressure correction for the optical depth employed in the model used was that of Curtis-Godson in the form

$$p_{\text{eff}} = \int p du / \int du, \quad (2)$$

where p is pressure (mb) and u optical mass (gm cm^{-2}).

An error analysis of the calculations may be made by reference to Fig. 3 of the original publication. The calculated downward radiant emittance (CDE) is slightly more than 30% of the measured downward emittance (MDE). In view of the fact that we employ the Curtis-Godson pressure correction we (i) consider gaseous absorption overlap, (ii) do not use the Elsasser chart absorption data, and (iii) calculate emission from ozone; we assume a further error of 10% in our, or for that matter any, radiative transfer calculations. This appears to be one-half of the recovered radiant flux. Aerosol emission could account for one-half of the latter, or 5%. At the worst we could then have recovered 5% of the total flux discrepancy between measured and calibrated radiation and this recovery should be due to water vapor emission. Admittedly, error assessment without an accepted standard is difficult at best. We would suggest continued comparisons between more precise measurements and calculations and certainly serial radiometric profiles.

Finally, we compare two flux calculations employing the same pressure, temperature and water vapor mixing ratio profiles from a radiometersonde ascent of 7 May 1970 in the Caribbean at $12^{\circ}30'$ by $80^{\circ}00'W$ (see Fig. 2). The Ellingson-Gille, 57 interval (1972) model follows the approach of Rodgers and Walshaw (1966) while the Kuhn-Cox model (1972)¹ is a modified Elsasser and

Culbertson (1960) calculation. Ellingson and Gille included several trace gases in their model while we did not. The agreement is quite good in spite of the basic differences in the calculations. This might emphasize the fact that differences in independent models are less than measured-observed differences.

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¹ Personal communication.