summary of symposium and meeting of the American Meteorological Society Committee on Radiation Energy (CRE)

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1. Introduction

This AMS Committee held its first meeting in Newport, R. I., during the period 25–27 March 1968. The sessions took three forms:

- a) scientific presentations and general discussions on an informal basis,
- b) a formal meeting of committee members on Monday evening (25 March), and
- c) an experimental comparison program of representative North American standard pyrheliometric instruments.

About 30 invited scientists attended. These scientists represented many agencies with a wide scope of radiation interests. Most of the participants are shown in the accompanying group photograph.

The following preliminary program was drawn up, by the outgoing CRE chairman (Drummond), as a basis for up-to-date discussion:

- 1) Review of the requirements regarding radiation measurements, with particular reference to the increasing demands in the fields of atmospheric and space sciences;
- 2) The present state of instrumentation for the measurement of solar and terrestrial radiation;
 - a) Spectral measurements of solar radiation (especially in the ultraviolet region), and the related problems involved in the calibration and interpretation of such records;
 - b) Infrared radiometry, with emphasis on the coordination of outdoor measurement programs with laboratory-based calibration procedures;

Front row: J. R. Latimer, E. Flowers, P. M. Kuhn, E. G. Laue, W. J. Scholes, A. J. Drummond, M. Rosa, A. R. Karoli, J. S. Nader, J. R. Hickey. Middle row: R. A. Hanel, W. Morrison, M. Kuhn, R. M. Marchgraber, F. Griffin, W. E. Marlatt, S. Fritz, A. N. Hill, A. R. Dennett. Back row: H. A. Wade, R. Linton, G. Stanhill, H. Yates, W. H. Klein, P. P. Starke, R. Anderson, J. H. Brown. (CRE chairman: outgoing Drummond, incoming Fritz.)

- 3) Instrumentation design for spacecraft and space simulation applications and associated basic calibrations;
- 4) The coordination of pyrheliometric calibrations in North America on a continuing basis.

As can be seen, the program was devoted essentially to experimental radiometry. When the attendees had assembled, the topics were expanded to embrace measurement requirements in the fields of photobiology, agriculture and forestry; environmental problems introduced by atmospheric pollutants were also considered.

The scientific sessions were held in the Eppley Foundation for Research and are summarized here in chronological order.

2. Satellite measurements

On Monday morning three associated opening talks were given by Drs. Hanel, Fritz and Kuhn (P.). The first speaker outlined the NASA-Goddard meteorological satellite program. In addition to the now well-known radiometric results from TIROS VII, Hanel described the possibilities of obtaining information on wind velocity, water vapor and gaseous constituents in the upper atmosphere. The plans for the forthcoming NIMBUS B satellite were discussed, especially his own experiment to determine the vertical profile of temperature from measurements of the emission by carbon dioxide (in the 15 micrometer band), by interferometer methods.* This led into future NIMBUS programs involving new microwave exploratory techniques and suggested supplementary *in-situ* detectors on balloons or buoys with satellites as interrogators. Changing topics, Hanel then outlined the work which he had been doing the previous summer at Harvard Observatory with its 61-inch telescope, using a Michelson interferometer capable of resolving one wavenumber. He reported preliminary results of the emission spectra of Venus in the 750–1250 cm^{-1} region by Fourier techniques. His measured brightness temperature of about 250K is slightly higher than most previous estimates.

Fritz was then asked to insert his thoughts on the problems that exist in some of Hanel's topics. He first pointed out that operations which might work well in the absence of clouds can be hampered by the presence of clouds; for example, cirrus clouds are not opaque since their opacity may range from near 0 to 100% according to particle distribution and vertical extent. Moreover, the opacity of cirrus clouds is different for 6- μm and 10- μm radiation. His next subject was that of the necessity for the use of satellites in the assembly of heat budget information on a global scale, which brought up the question as to whether or not the planet Earth is in radiative balance over a day. Other matters to which he drew attention were the laws of angular scatter in dealing with the interpretation of energy back-scattered from clouds; and

* Unfortunately the NIMBUS B launch failed in May 1968. But a substitute NIMBUS B(2) will be launched in Spring 1969.

the importance of on-board instrument calibrations in space vehicles. A discussion followed on the aspects of precision and accuracy required in the various satellite measurement programs.

3. Balloons, rockets, aircraft

Kuhn's subject was concerned with observations from balloons, rockets and aircraft. His opening remarks were directed at the questions already posed regarding high-level cirrus (and aerosol). By illustration, he described his experiences on the NASA CV-990 research aircraft, when he measured with his infrared zenith-looking sky radiometer—here the problem is one of asking if cirrus is invisible to the eye, does its presence affect an IR measurement? His balloon program is complementary in that such passes are attempted above and below cirrus to examine whether the "blackness" is different. Efforts are being made to improve his basic IR radiometric standards, particularly in view of the projected new comparisons (in the 5.5–7 and 8–12 micrometer bands) between the upper air ascents and overflying satellites.

4. Antarctic surface measurements

M. Kuhn, from Innsbruck (Austria) but temporarily attached to the U. S. Army Natick Antarctic project, devoted the remaining time of the session to Earth-bound problems in radiation meteorology. He spoke on the difficulties of measuring solar and terrestrial radiation in the hostile Antarctic environment. Associated is the interpretation of the results, which entails assessment of the diverse instrument calibration errors. Kuhn went on to describe his experiences, at the plateau station, with drifting snow and frost formation on radiometer performance. Another point made was that the albedo measurements are not typical of isotropic conditions since the reflected radiation depends upon the nature of the snow surface and on the elevation of the Sun; sky polarization measurements did not explain the observed distribution. In the general discussion, it was agreed that polar (clean air) locations are valuable references with regard to changes in atmospheric transmission.

5. Plants, agriculture, forestry

In the afternoon, there was a very different type of program in which the emphasis was placed upon solar radiation influences in ecology. Here, Drs. Klein, Stanhill and Reifsynder presented a series of contributions in biological and agricultural sciences. Klein led off with an introduction to the general mechanisms by which radiant energy regulates and controls the development of higher plants; viz., by conversion of large amounts of radiant energy to chemical energy (i.e., photosynthesis) and by the activation of regulating systems by small amounts of radiation. He pointed out that there are processes which are responsive to the ultraviolet-blue regions of the spectrum and others which are controlled mainly by red and far red absorptions. Although there is the question of the photoreception of animals, his interest and that

of his colleagues at the Smithsonian Institution is primarily with seed plants. Since there is limited information available as to the daily, monthly, etc., changes in the spectral quality of daylight, most knowledge of radiation influences has been gained from laboratory studies with artificial sources. He concluded by describing his present program for correlating environmental control facilities for growing plants with, simultaneously, carefully obtained outdoor spectral measurements in absolute energy units, employing the filter pyranometer technique.

Stanhill continued with an outline of the use of radiation measurements in agriculture, as viewed from requirements in Israel. Because of the limited and almost fully exploited water resources there, research has so far concentrated on the relationship between radiation and evaporation. He was therefore concerned with both short-wave and long-wave energy fluxes to investigate local differences used to compute larger scale yearly trends. Slides were shown illustrating the various types of vegetation and other terrain features. The measurements of the components of the radiation balance above these surfaces indicated that there were large differences in the relationship between the components and the total radiation of the different surfaces; the short- and the long-wave characteristics are equally important in determining these relationships. Stanhill concluded by emphasizing the need for such locally observed values rather than inference from generalized material such as was assembled during the IGY.

The third speaker of this afternoon session, Reifsynder of Yale University, moved the theme into forestry. He described his research program in the New Haven area, in which the main object is the investigation of the thermal budget and water vapor transport in forest stands. Special problems here are imposed by the height and non-uniformity of the cover. Of still greater difficulty are solar radiation measurements under canopies of trees. In this experiment, short-wave total and diffuse radiation is sampled at 20 random points by matched pairs of pyranometers mounted side by side. The receiver of one unit is screened by a shadow band of local construction. Radiometer output is recorded at 5-minute intervals on a data acquisition system; the time cycle for 42 signals is about 1-1/2 minutes. The routine radiation measurements are made with simplified detectors but these are "controlled," at a central point, by more precise instrumentation. An outline was then given of the roles of sunlight and shade on the ecology of the stands (principally hardwood and pine) and why such measurement programs are necessary to improve our knowledge in this field.

6. Instrumentation requirements

Next morning, the topics revolved mainly around instrumentation requirements for radiation measurements particularly in aircraft and, remotely, in satellite and spacecraft.

7. Solar constant

Laue opened with a general account of the JPL-Eppley solar constant measurement experiment employing high-altitude aircraft. To date, eight successful flights (apart from several test flights) have been conducted, seven on the NASA B-57B and CV-990 jets, and, most important, on a USAF/NASA X-15 rocket research aircraft. He explained the background of the project and briefly described the instrumentation. This led into the problems which can arise in the undertaking of solar radiation measurements of this nature. There are quite different types involved; viz., adherence of the radiometer-readout system in its flight performance to the basic calibration; instrument mounting and radiometer solar orientation with regard to the particular aircraft facilities and safety regulations stipulated; effect of aircraft speed on the measurements, to mention a few. An important point made was the extremely thorough (and highly accurate) pyrheliometric calibration programs carried out, before and after flights, at Table Mountain (California) and Parhump (Nevada). The opportunity was taken to distribute, to the attendees, copies of a preprint of a recent article giving the final results obtained so far.

8. Satellite instruments

The next address was given by Yates, of NESC, who first of all drew attention to the difficulties in performing onboard calibrations, to obtain quantitative information from the satellite radiometers. Experience has shown that in the infrared region, it is easier to achieve the desired reference than is the case in the visible and ultraviolet regions. In the absence of this information, the sampled data must be related to "ground truth" or, alternatively, to simultaneously similar measurements from underflying aircraft. He mentioned the Sun as an ideal calibration source of satellite solar detectors. Another experimental problem discussed (distinct from those of the TIROS-NIMBUS series) was that of determination of cloud-top altitude from surface brightness measurements, where the need for calibrated diffusers is paramount. Efforts are therefore being made to obtain highly stable reflectance standards in the wavelengths of interest. Finally, Yates stressed the desirability of introducing instrumentation of higher resolution and also of more rapid methods of data acquisition from satellite radiometers.

9. Filters

Complimentary was Hickey's summary of the present state-of-the-art in filter radiometry and its correlation with monochromator techniques. Much of the information he provided was drawn from the work of the Eppley team, in this field, over the last five or six years. In large measure, the new requirements to evaluate, with the maximum attainable certainty, the spectral quality of the artificial sun in space simulation systems contributed to this advancement. Essential features have been the development of greatly improved optical nar-

row (interferential) bandpass filters and the evolution of compatible spectral radiation standards for use with monochromators. An important innovation has been the employment, routinely, of broad (colored glass) bandpass filters, with unique transmission characteristics, to control the narrower filters where the filter factor is a function of the source emission distribution. The examples given included the calibration, at Newport, of the NASA-Ames earth albedo experimental package, of the OSO satellite series, intended to measure the intensity of reflected sunlight at discrete wavelengths from about 300 to 800 nanometers. The problems in dealing with a multichannel filter-photomultiplier type radiometer viewing both the Sun directly and the Earth diffusely were outlined.

10. Air pollution

A broad switch in topics was then made by Nader who spoke on radiometric versus chemical methods for the investigation of atmospheric pollution. A pilot study of ultraviolet radiation in Los Angeles at the time of the smog season, in October 1965, was conducted by the Division of Air Pollution of the U. S. Public Health Service, jointly with several other organizations. The objectives of the 4-week program were to measure, concurrently, by both physical and chemical techniques (a) incoming UV radiation from 300 to 390 nanometers for representative environmental conditions in downtown L.A. and on Mt. Wilson, and (b) outgoing reflected radiation detected from aircraft over the city at various elevations from 1300 to 6300 ft. The new radiometric instrumentation employed was described.

11. Radiometry

The fourth and last session of this impromptu symposium was held on Wednesday morning. Dr. Marchgraber, of the U. S. Army Research Laboratories at Fort Monmouth, outlined some original ideas concerning the dynamic response of calorific radiometers to an environment of changing temperature. A transient appears at the output of the radiometer causing an error in the integration of the measured fluxes. This error depends only on the amplitude of the change in the environmental temperature and not on its time function. Proper instrument design minimizes the error. He also discussed the limitations in the use of calorific radiometers for the measurement of rapidly changing fluxes as encountered, for example, in albedo measurements from airborne platforms. If one succeeds in finding a differential equation which describes quantitatively the radiometer, an analogue technique allows the reduction of the apparent time constant; the bandwidth of undistorted measurements of temporal variations of radiant energy can be considerably increased.

This was followed by a presentation by Karoli on absolute radiometry. It was pointed out that most radiometric instrument calibrations can be ultimately

traced to a standard (either source or detector) which has been evaluated absolutely using the Stefan-Boltzmann constant (σ). The prevailing lack of agreement between the derived and experimentally determined values of σ was discussed. A brief review of the design of blackbody radiators used in fundamental radiometry was given, followed by a description of several sources of both high and low temperature currently available. Attention was called to the possible errors arising from emissivity calculations and temperature measurements. Data were introduced showing the excellent agreement (within $\pm 1\%$) between the IPS and NBS references, recently achieved, at Newport, with a group of thermopiles as the transfer instruments.

12. Arctic measurements

After the coffee break, Brown (of the U. S. Navy Electronics Laboratory) described the micrometeorological programs of the Arctic Sciences Division in high latitudes. He pointed out that in the detailed type of energy balance investigations with which he is concerned, the computer models are still not completely ready. With regard to the basic mathematical concepts he referred to the early work of Priestley's Australian group. It is well recognized that oceans are very important in climatic studies; and data over sea ice sheets are quite different from those over land and ocean. The proposed new work will utilize an icebreaker for one and hopefully two months in the Arctic. He went on to describe the short- and long-wave pyranometers which will be employed there. Other problems discussed were concerned with the measurement of evaporation, humidity and wind under these conditions. Brown also mentioned his recent associated work at the University of California, at Davis, in Coulson's (formerly Brooks') laboratory.

13. Tropics measurements

In contrast, Stroschein described the forthcoming U. S. Army sponsored research program in tropical environmental studies in Thailand. This will include microclimatological aspects for South-East Asia, which have not been treated up to present. He confined his discussion here to the proposed pyranometric measurements which will embrace incoming and outgoing (reflected) short-wave radiation, integrally and in well-defined spectral bands. A series of recently developed hemispherical interference filters will be employed to separate out narrow bands in this energy exchange, supplementing the more standard broad bandpass filters which have sharp cutoff transmission characteristics. Records of global ultraviolet radiation and the natural illumination of daylight will also be maintained, as well as instrumentation for the measurement of direct solar radiation and the corresponding spectral components. Measurements are planned on top of a high tower above the forest canopy and likewise under the foliage.

14. Pyrheliometric intercomparisons

As explained earlier, the parallel effort to the symposium took place in the Eppley Laboratory, where the pyrheliometric/pyranometric comparisons were made. The extensive outdoor meteorological facility was supplemented by the indoor integrating hemisphere (artificial sky). For the first time, the principle standards of pyrheliometry of the Canadian Meteorological Service, the U. S. Weather Bureau and the Eppley Laboratory were intercompared in this country. It is understood that the three primary Ångström-type instruments agreed very closely. Comparisons were made of representative working standard pyranometers. This work program was under

the direction of Latimer (Toronto), aided by Wade (Newport) and Wright (Washington).

Tuesday afternoon was purposely left free to allow the visitors to see something of the facilities of the Eppley Laboratory. This was arranged in small groups according to individual interests.

By the courtesy of Roy Anderson, President both of the Eppley Laboratory and the Eppley Foundation for Research, participants were entertained to luncheon on Monday and Tuesday, as guests of the Eppley Foundation for Research. On Tuesday evening, Andy and Renee Drummond entertained the group to cocktails at their home.

news and notes

Environmental Sciences Institute at San Jose

Dr. Jen-Yu Wang, professor of meteorology at San Jose State College, has been appointed director of the college's new Environmental Sciences Institute. Dr. Wang was appointed by college President Dr. Robert D. Clark, and in his new position is associated with Dr. David G. Barry, dean, School of Natural Sciences and Mathematics. Dr. Barry is chairman of the Institute's Board of Councilors and Advisory

Committee.

The Institute will have international implications and will attempt to answer questions necessary to solve long-range environmental problems. Objectives of the Institute are: To develop environmental models for the prediction and control of the changing environment; develop a repository of scientific data to serve the public in decision making;

coordinate environmental research of various agencies and individuals by acting as a clearing house for information developed by each; develop a research center that will promote research by educational and private research institutions, government, and industry; and lastly, disseminate information in California and elsewhere by means of advisory groups, conferences, symposia, workshops and publications.

Dr. Wang, considered an outstanding environmental scientist, is a member of numerous scientific and professional societies, including the China Academy of Science. In past years he was on the Editorial Board of the International Society of Biometeorology and is a consultant to many private and governmental agencies, including the Stanford Research Institute and the U. S. Weather Bureau. His work in crop-prediction, air pollution research, and instrumentation for micro-meteorological survey has had international recognition.

Dr. Wang received his B.S. in physics and chemistry from Funkien Christian University and his M.S. and Ph.D. in meteorology from the University of Wisconsin.

(More news and notes on page 35)

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