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AUTHOR(S): Paul Weber, SST-7, Los Alamos National Laboratory

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Los Alamos Los Alamos National Laboratory
Los Alamos, New Mexico 87545

Small Satellite Radiometric Measurements*

Paul G. Weber**

Los Alamos National Laboratory, Los Alamos, NM 87545

A critical need for the Mission to Planet Earth is to provide continuous, well-calibrated radiometric data for the radiation budget. This paper describes a new, compact, flexible radiometer which will provide both spectrally integrated data and data in selected spectral bands. The radiometer design is suitable for use on small satellites, aircraft, or remotely piloted vehicles (RPVs).

Introduction

Understanding of global climate changes demands, at the very least, accurate measurements of the power fluxes through the top of the atmosphere as a function of space and time, and covering the full range of atmospheric conditions. Indeed, a measure of the success of global circulation models (GCMs) is to compare the predicted energy balance from the code with actual observations¹. Information on the global energy balance was provided by the Earth Radiation Budget Experiment (ERBE) series of instruments². However, the ERBE scanners are no longer providing data, and the follow-on experiment, CERES, is scheduled to fly no earlier than 1997. Thus a large data gap exists in measuring the global radiation balance at this critical time.

A further issue is to investigate power fluxes over a given site, combined with a full complement of measurements of ambient conditions. This would lead to a better understanding of the processes which underlie the observed fluxes, and to better parameterizations for inclusion into climate

models. Such a study is being undertaken by the DOE Atmospheric Radiation Measurements Program (ARM), with the first site to be located in the mid-Western USA. Operation at this first site is scheduled to start in 1992.

This paper introduces the design of the Los Alamos Radiometric Instrument (LARI): a new, compact, flexible radiometer for these important measurements, together with some potential applications. The instrument includes well-calibrated total, shortwave, and contiguous, spectrally resolved channels, thus providing important information to the community³. The design allows implementation on a satellite, an aircraft, or remotely piloted vehicle (RPV) with relatively minor modifications. However, the design philosophy for satellite, aircraft, and RPV radiometers is the same: namely, to provide a compact, low power, well-calibrated instrument with the desired spatial and wavelength coverages.

Design Considerations

Accurate measurements of the Earth's radiation balance are required for understanding of the processes which control that balance. The measurement requirements are discussed in detail by the National Research Council's Committee on Earth Sciences³ (NRC/CES). The spectral cov-

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** Staff Member, Space Science and Technology Division, MS D466, LANL, Los Alamos, NM 87545.

erage needs to include the range from about 0.3 to 4 μm for albedo studies, and approximately 4 to 100 μm for the longwave flux. Some spectral resolution is desired to establish the actual composition of the atmosphere at the time of measurement. The required accuracy is extreme: as a simple basis, consider that doubling the CO_2 concentration in the atmosphere is predicted to have a net effect of only a few Wm^{-2} compared to an annual average insolation of $\sim 340\text{Wm}^{-2}$. The data also are to be sufficiently accurate to detect decadal climate trends. The mean accuracies suggested by the NRC/CES are 5% for the short-wave and 5Wm^{-2} for the long-wave over annual cycles with 1-month resolution.

Because of variations in solar zenith angle, temperature, humidity, clouds and atmospheric composition, one needs to make observations over the full earth in a sufficiently short timescale⁴. Continuity and overlap of measurements is also important to uncover any systematic offsets between satellite instruments. Thus, this problem is an excellent match to small satellites, with their attributes of relatively low cost and flexibility of launching. One can conceive of a set of three small satellites providing full diurnal, global coverage simultaneously.

Instrument Description

The version of the Los Alamos Radiometric Instrument design shown in Figure 1 is optimized for aircraft applications: the satellite version can be considerably simpler. (The aircraft version needs to operate in rather rapidly changing conditions as the aircraft flies through various volumes.) The input optic (lower left side of Fig. 1.) consists of a pair of mirrors, mounted on a rotating scanner drum, and oriented at 45° to each other to provide almost complete cancellation of polarization effects. In addition to observing the desired scene, this scanner also accesses the on-board calibration sources (shown

schematically as a rectangle near the scanner drum), thereby providing a complete instrument calibration on every scan. The modified Gregorian telescope determines the instantaneous field-of-view (IFOV) and allows separation between the input section of the telescope and the spectral analysis and detection volume (at the upper right of Fig. 1). These volumes are linked by a small aperture, allowing thermal and environmental stability for the prisms and detectors over long time-scales. A chopper is used at this aperture, since the pyroelectric detectors observe only changes in power: thus each individual measurement is referred to the chopper blade, with a full instrument calibration referenced to the on-board calibration sources on every complete scan. Nominal design values for LARI in a 700-800 km orbit include a pixel size of some 20-40 km, with cross-track scanning to 2000 km from nadir; the scan rate is sufficiently fast to spatially oversample.

After passing through the aperture, the radiation is recollimated, and then divided into several channels. The first channel is the total radiation channel, in which a geometrically determined fraction of the input power is directly incident on a detector, which, therefore, measures the wavelength integral over the entire range of 0.2 to $>50\ \mu\text{m}$ (this range being determined by the characteristics of the optics and detectors). A parallel "short-wave" channel is identical, except the detector is filtered with a Suprasil (or similar) window, selecting radiation in the 0.2 to $\sim 5\ \mu\text{m}$ range. These two channels duplicate the most frequently used ERBE channels; the wavelength integrated long-wave radiation is typically obtained by subtracting the wavelength integrated short-wave channel from the total.

While these two broad channels allow a separation of "solar" and "thermal" radiation, one requires spectral resolution to point to the causes of changes in these integrals. For example, with

even crude spectral resolution, one can separate the black-body equivalent temperature and the major absorption features due primarily to CO_2 , O_2 , O_3 , H_2O , etc.. This radiometer includes this capability. Part of the radiation (physically above the wavelength integrated channels) is dispersed by side-by-side prisms, and is then incident upon a linear array of detectors, with the dispersion and detector dimensions chosen to give wavelength bands with specific dominant influences in each band. Figure 2 shows an example of such a selection: there are four contiguous bands (labelled 1,2,3,4) in the "short-wave"; there are five contiguous bands (5-9) in the "long-wave" region with dominant absorbing species indicated. The prisms are made of different optical materials, (e.g. quartz and CsI) to enable coverage of the full spectrum (0.2 to $>50 \mu m$) in transmission.

Light in the upper atmosphere can be highly polarized⁵. The LARI optical system is designed for low sensitivity to polarization: in addition to the polarization cancelling input scanner, the optics are used at small (near-normal) angles.

Pyroelectric detectors have been chosen for a number of reasons. They are thermal detectors, which, with appropriate coatings, can cover the full wavelength region with uniform responsivity. They do not require cooling, the chopping frequency is selectable over a reasonable range, sensitivity is more than adequate for our application, and linearity is excellent. Electrical Substitution Radiometers using pyroelectric detectors have proven accurate at the $< 1\%$ level with excellent stability over many years⁶. Pyro-electric detectors have been used successfully both in space^{7,8} and in aircraft radiometers⁹. Recent advances in material science and processing have permitted the production of both linear and two-dimensional arrays¹⁰.

Accuracy of measurement is of paramount im-

portance. The stated requirement for accuracy is one percent for the total and short-wave channels. The radiometer will first be calibrated in a laboratory facility, using well-characterized blackbodies, sunlight, tungsten lamps in an integrating sphere geometry, and other spectral sources. The calibrations will be ultimately referenced to a cryogenic electrostatic substitution radiometer¹¹, and to self-trapping diodes¹². The details of the on-board calibrations are dependent on the specific application, but will consist of at least one blackbody (preferably two) plus lamp(s) for the shorter wavelengths. The calibration requirements are "state-of-the-art"; they are facilitated slightly by the simultaneously available spectral information and built-in redundancy of checking that the sum of the spectrally resolved channels equals the total channels.

Summary

LARI is a versatile radiometer for climate studies. The instrument is compact ($\sim 0.1m^3$), low power ($\sim 35W$), and, as shown by system studies, eminently suited to use on a small satellite, RPV, or aircraft. In addition to providing similar measurements to ERBE, a number of new features, including spectral decomposition are provided. The capability exists to use this instrument, with others as appropriate, on a number of small satellites, and thus provide both a continuation of Earth radiation budget information as well as new insights based on the addition of some spectrally resolved data.

Acknowledgments

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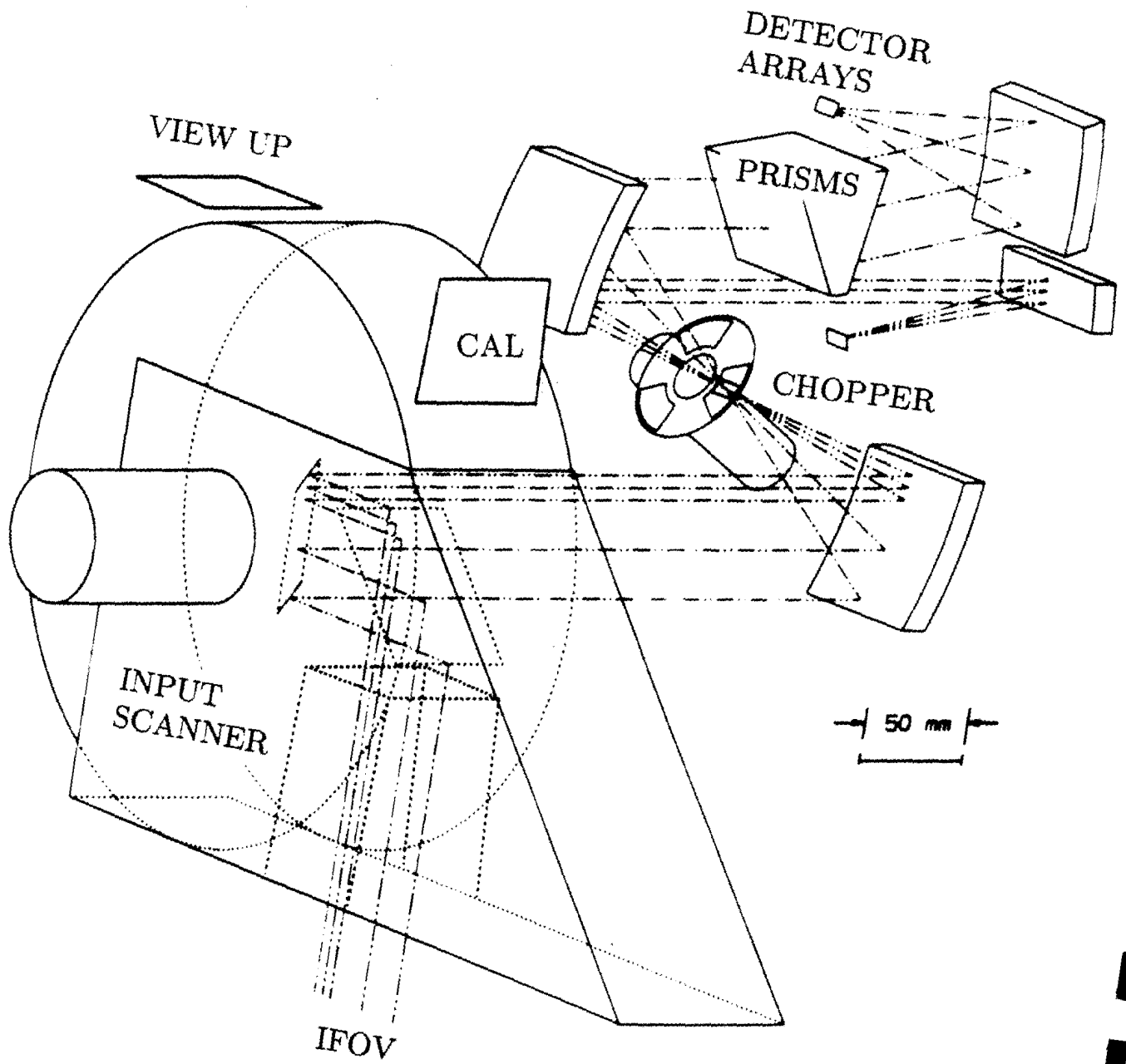


Fig. 1: Isometric view of the LARI instrument.

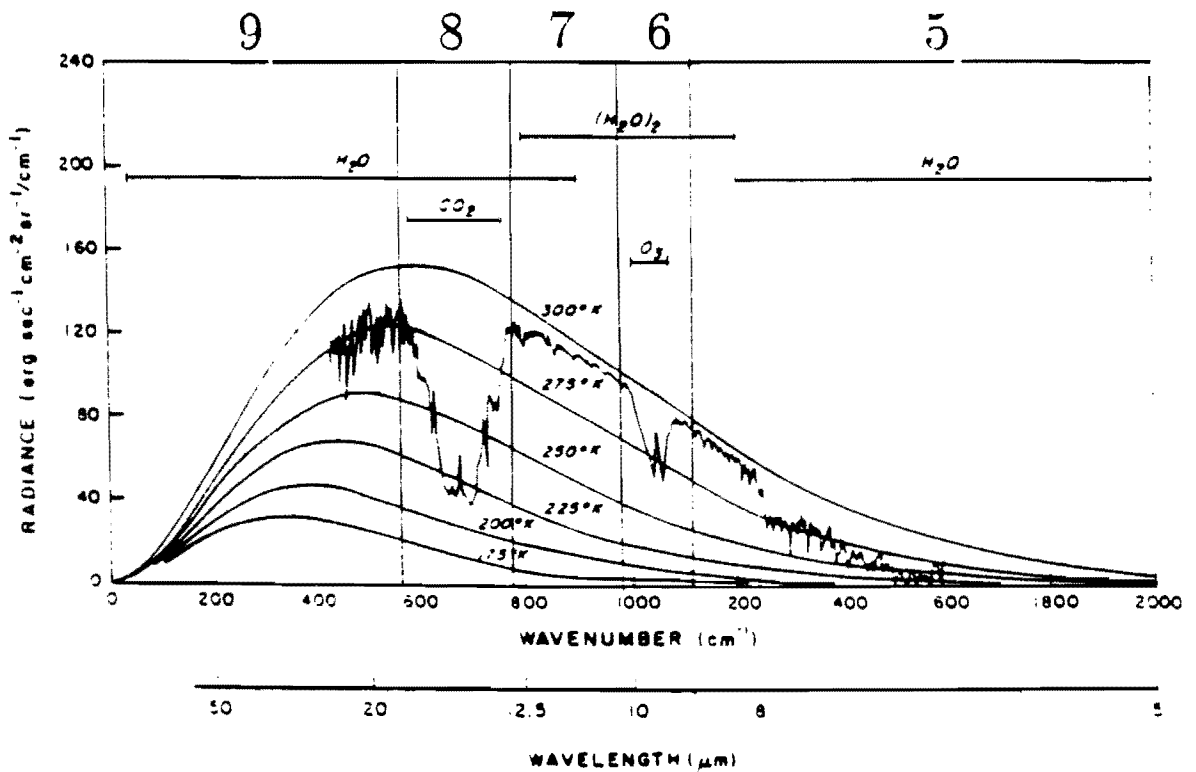
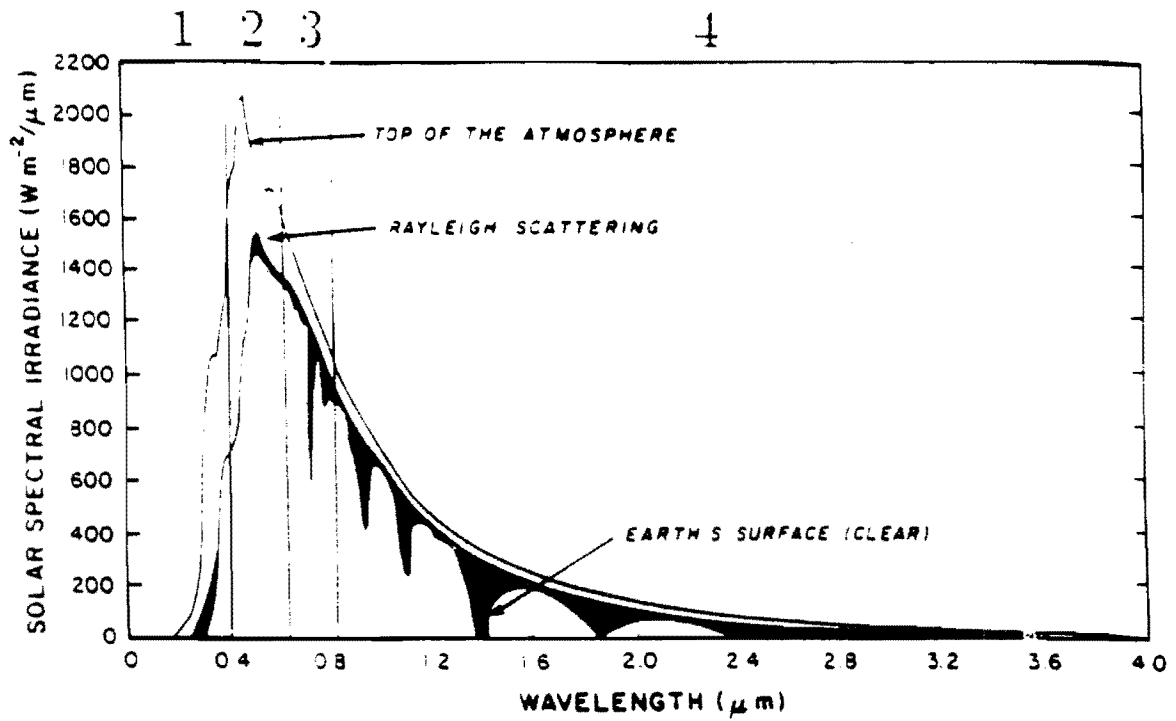


Fig. 2: Example of selected contiguous wavelength bands.