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STABILIZED PLATFORM FOR TETHERED BALLOON SOUNDINGS OF BROADBAND LONG- AND SHORT-WAVE RADIATION

J. M. Alzheimer
G. A. Anderson
C. D. Whiteman

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Pacific Northwest Laboratory
Richland, Washington 99352

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STABILIZED PLATFORM FOR TETHERED BALLOON SOUNDINGS OF BROADBAND LONG- AND SHORT-WAVE RADIATION

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1. INTRODUCTION

In the past few decades, changes in the composition of trace gases in the earth's atmosphere have been reported by many observers, and a general concern has been expressed regarding possible changes to the earth's climate that may be caused by radiatively active gases introduced into the earth's atmosphere by man's activities. Radiatively active trace gases produce temperature changes in the earth's atmosphere through changes in radiative flux divergence. Our knowledge of and means of measuring radiative flux divergence is very limited. A few observations of vertical radiative flux divergences have been reported from aircraft (Ackerman and Cox, 1987), from radiometersondes (Suomi and Kuhn, 1958; Kuhn et al., 1967), from towers (Funk, 1963), and from large tethered balloons (Slingo et al., 1982; Duda and Stevens, 1989). Each of these measurement techniques suffers from one or more drawbacks, including shallow sounding depths (towers), high cost (aircraft), complicated logistics (large tethered balloons), and limitation to nighttime hours (radiometersondes).

Changes in radiative flux divergence caused by anthropogenic trace gases are expected to be quite small, and will be difficult to measure with existing broadband radiative flux instruments. The emphasis of present research in global climate change is thus being focused on improving radiative transfer algorithms in global climate models. The radiative parameterizations in these models are at an early stage of development and information is needed regarding their performance, especially in cloudy conditions.

The impetus for the research to be reported in this paper is the need for a device that can supplement existing means of measuring vertical profiles of long- and short-wave irradiance and radiative flux divergence. For this purpose, we have designed a small tethered-balloon-based system that can make radiometric soundings through the atmospheric boundary layer (Figure 1). This paper discusses the concept, the design considerations, and the design and construction of this sounding system. The performance of the system will be tested in a series of balloon flights scheduled for the fall and winter of 1992.

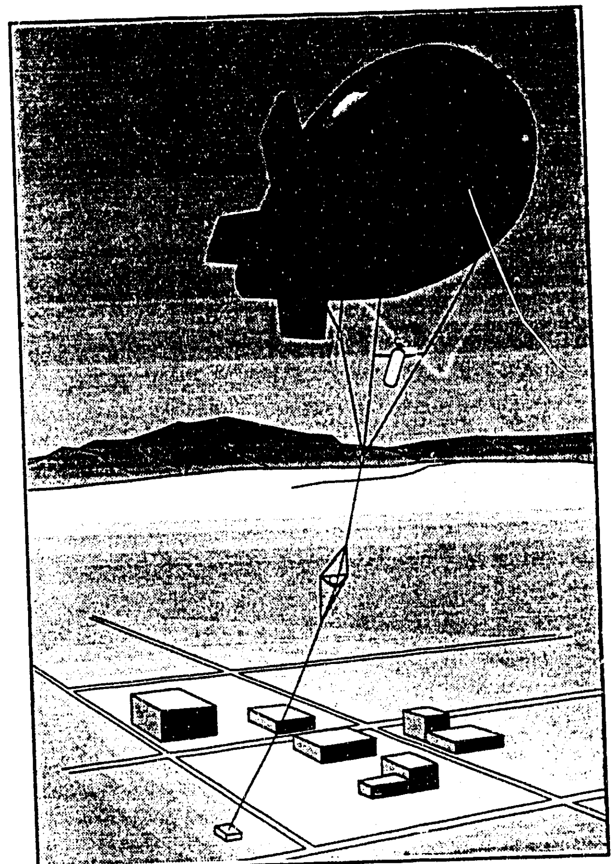

Figure 1. Radiometric sounding system.

2. CONCEPT

The project concept is to develop the capability of obtaining vertical profiles of upward- and downward-directed short- and long-wave irradiance from a small tethered balloon. Radiometric instruments would be carried on a commercially available tethered balloon meteorological sounding system whose altitude is controlled from a ground-based level-wind electric winch. Soundings would be made during times of special interest, with ascents to depths of 1.5 km AGL taking approximately 30-45 minutes. Radiometric data would be supplemented by meteorological data from the sounding system.

Since the atmospheric sounding system is presently available commercially, the major task in our project is to develop a stabilized platform to keep a radiometric instrument package level despite motions of the balloon-tetherline system. This levelness requirement arises because of the desire to measure vertical radiative flux divergence and to carry radiometers that perform angular and spectral integrations of the radiance fields.

It was recognized at the outset that the tethered balloon system will have distinct operating limitations. It is unsuitable for use in certain weather conditions and is also subject to operating restrictions by aviation authorities. Despite these limitations, radiative flux data from a balloon profiler are expected to provide important new data for environmental and global climate change research.

3. DESIGN CONSIDERATIONS

Several important design considerations were identified at the beginning of the project.

- The mounting platform would need to be capable of keeping the radiometers level within rather small tolerances.
- The system would have to be inexpensive, since balloons are occasionally lost due to tether component failures and accidents.
- The radiometric platform would have to be lightweight in order to use a small tethered balloon system that could be handled by one operator.
- The radiative effects of the balloon, tetherline, and radiometric platform would have to be minimized.
- The radiative sounding system would need to be capable of operating over a broad range of environmental conditions.

Many platform design concepts and leveling methods were evaluated. Because of anticipated problems in stabilizing platform motions at the balloon under turbulent conditions and because of radiometer exposure problems near the balloon, a decision was made to design a stabilized platform that would be carried on the balloon's tetherline. This platform would have an active control system and need sensors to detect when the instruments were off-level. A drive system with control circuits would correct the platform's attitude automatically.

Several design questions arose immediately. 1) How level must the platform be in order to maintain acceptable radiation measurement accuracy?, 2) How far below the balloon must the platform be in order to reduce the radiative effect of the balloon?, 3) When the platform is located on the tetherline, how can an attitude-correcting torque be applied to return the platform to level when the tetherline itself provides insignificant resistance?, and 4) How can we determine the motion frequency characteristics of the tetherline/platform system in order to properly close the automatic control loop?

The first question above is being answered with a mathematical model of measurement errors caused by the tilting of a net radiometer. This model, described by Shaw and Whiteman (1993), accounts for long- and short- wave radiance distributions on the upper and lower measurement surfaces of a net radiometer as well as oscillatory radiometer motions. The model shows that a non-level net radiometer can be seriously in error during daytime when the shortwave radiation stream is directed, but is less susceptible to error during nighttime ascents when the longwave radiation is more isotropic. Oscillations of the radiometer about the level are less serious than a mean tilt angle. Our design goal is a maximum deviation of plus or minus two degrees from the level and an average deviation of plus or minus one quarter degree.

The second question was answered by calculating the solid angle subtended by balloons of different equivalent spherical diameters from a point various distances below the balloon. The calculations showed that a distance of 30 m was sufficient to reduce the solid angle of the tethered balloon to a negligible fraction of the hemispherical solid angle.

The third question was answered by the design of a harness inserted in the tetherline which levels the platform. The design is described further below.

The fourth question was given a preliminary answer by constructing and exercising a mathematical model of the dynamics of the platform including the details of the drive system. A longer term solution involves the actual measurement of the motions to which the platform will be subjected on the tetherline under various meteorological conditions. For this purpose, a special motion sensing platform has been designed to fly in place of the stabilized platform. This platform will be described along with other components of the radiometric sounding system in the next section.

4. COMPONENTS OF THE RADIOMETRIC SOUNDING SYSTEM

The components of the radiometric sounding system include a tethered balloon meteorological sounding system, a stabilized radiometric platform, and a motion sensing platform.

4.1 Tethered Balloon Meteorological Sounding System

The radiometric sounding capability is developed around an existing commercial tethered balloon meteorological sounding system*[1]. This tethered balloon system is capable of making frequent vertical ascents through the atmospheric boundary layer to heights of 1 to 2 km (depending on payload, size of balloon, and wind speed) to measure profiles of basic meteorological data. The sounding system consists of an electric winch with 2 km of 110-kg test tetherline, an airborne meteorological instrumentation package carried on the tetherline several meters below a helium-filled, blimp-shaped balloon, and a ground receiving station. The balloon, which is small enough to be managed by one person, has a displacement of 7.5 m^3, a free lift of 5.7 kg, and is 6.6 m long and 1.8 m in diameter. As the balloon ascends and descends under control of the electric winch, the airborne sensor package telemeters multiplexed temperature, wet bulb temperature, pressure, wind direction and wind speed data to the ground on a frequency of 403 MHz. The elevation of the instrumentation package is obtained from the hypsometric equation using the pressure, temperature and humidity data.

4.2 Sky Platform

A triangular frame radiometric platform, called the Sky Platform, is carried in a harness inserted within the tetherline and leveled by an automatic control system. The harness connecting the upper and lower tetherline attachment points consists of three lines, one for each frame corner. One line is fixed to the frame while the other two lines are connected to pulleys of the drive system. The automatic control system keeps the platform level by driving two corners of the frame up and down the harness lines. Figures 2 and 3 show the Sky Platform and identify the major components. A system block diagram is shown in Figure 4. Power is supplied by eight 1.2-V Nicad batteries. A flux gate magnetometer*[2] is used to measure the heading of the Sky Platform, and will be used to assess system performance. The present Sky Platform is instrumented with two modified Q*6 net radiometers*[3], but a future version will carry an upward- and downward-looking total hemispherical radiometer and an upward- and downward-looking pyranometer. These two instruments will be mounted in the same positions as the two net radiometers and will have about the same size and mass. The Sky Platform will then measure the upward and downward directed short- and long-wave irradiances (Kup + Lup and Kdn + Ldn, respectively) and the upward and downward shortwave irradiances (Kup and Kdn, respectively). Upward and downward longwave radiation can be obtained by subtraction, and net shortwave, longwave, and all-wave radiation can then be determined. The basic data would then be vertical profiles of the measured and derived radiometric quantities. The data acquisition and storage computer*[4] contains a 12-bit analog-to-digital converter (ADC) and a real time clock. Data are processed by the computer's ADC and recorded on a credit-card-size memory module during the flight. The memory module can hold up to an hour's worth of data if eight channels of data are sampled once per second. After the flight, the data is uploaded to a personal computer for processing and display. On-board data storage produces significant weight and power savings relative to data transmission by telemetry. The total weight of the Sky Platform is 1.2 kg.

Each of the two drive systems contains control circuitry, a DC motor with gearhead, and an enclosed pulley. The Sky Platform uses two solid state, linear accelerometers*[5] for sensing level. One accelerometer is associated with each of the two independent control circuits. The active direction of each accelerometer is parallel to one side of the triangular frame so as to decouple the two control circuits. When the platform is level, both accelerometers are oriented such that they undergo zero g's in the active direction. When the platform is not level, each accelerometer undergoes an acceleration proportional to the sine of the tip angle about one side of the frame. Several other level sensors were investigated but none were as light,

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[1] Model TS-3-A
Atmospheric Instrumentation Research,
8401 Baseline Road
Boulder, CO 80303

[2] Model C100
KVH Industries Inc.
110 Enterprise Center
Middletown, RI 02840

[3] Model Q*6
Radiation Energy Balance Systems, Inc.
P. O. Box 15512
Seattle, WA 98115-0512

[4] Tattletale 2B-1M; PR-1A Breadboard
Onset Computer Corp.
P. O. Box 1030
North Falmouth, MA 02556-1030

[5] Model NAS-0026
NovaSensor
1055 Mission Court
Fremont, CA 94539

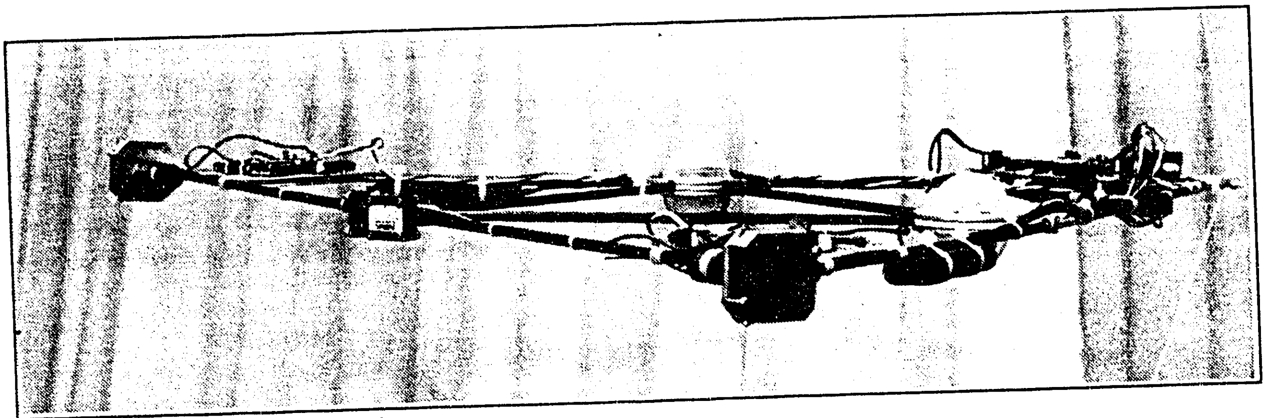

Figure 2. Side view of Sky Platform.

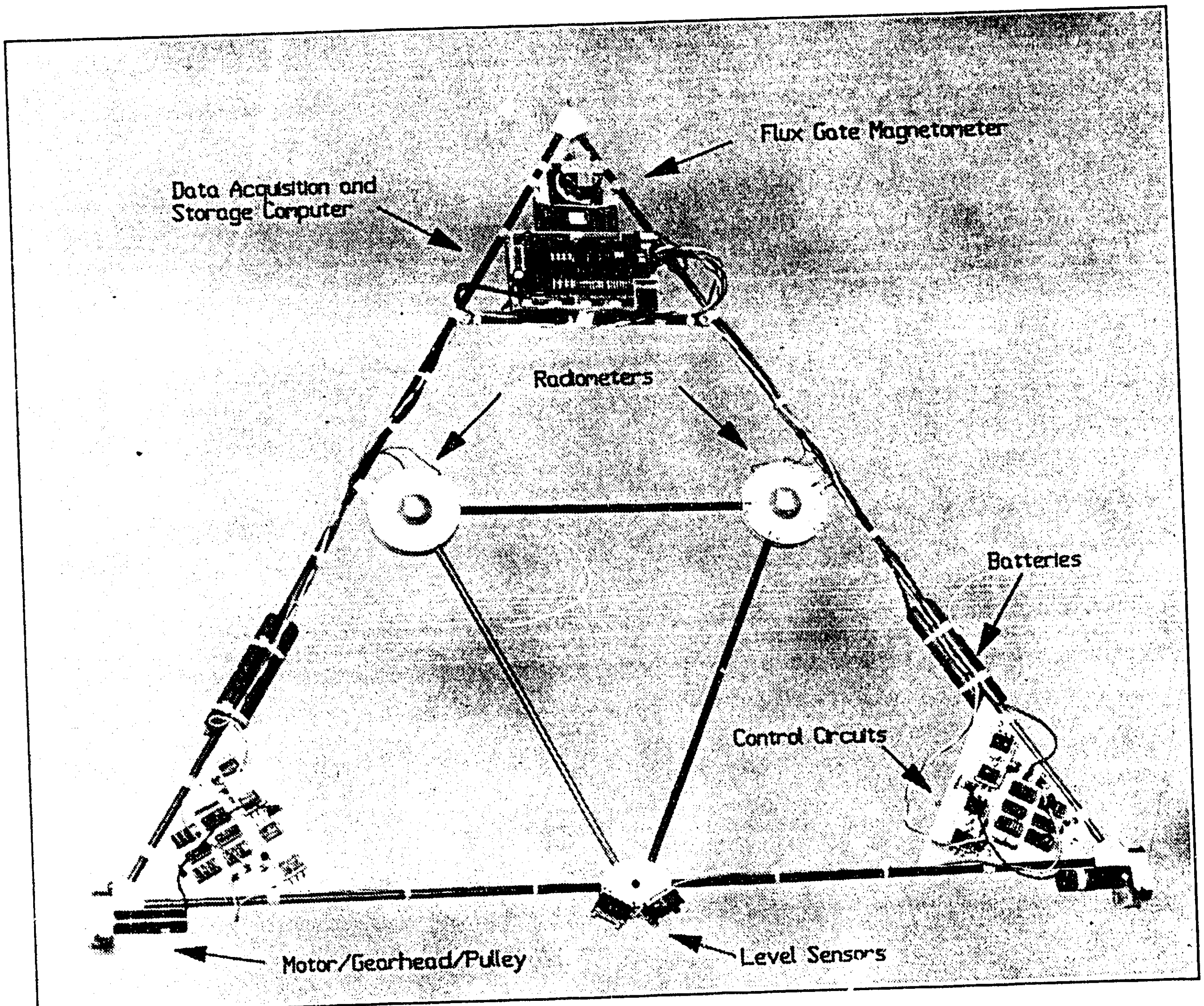

Figure 3. Plan view of Sky Platform.

small, inexpensive and rugged as the linear accelerometers. A disadvantage of the linear accelerometers is they are affected by lateral accelerations. However, errors due to high frequency lateral accelerations are damped by the slow response of the platform and mechanical components of the drive system. If, in further testing, the linear accelerometers prove unacceptable, a rate sensor based system may be substituted.

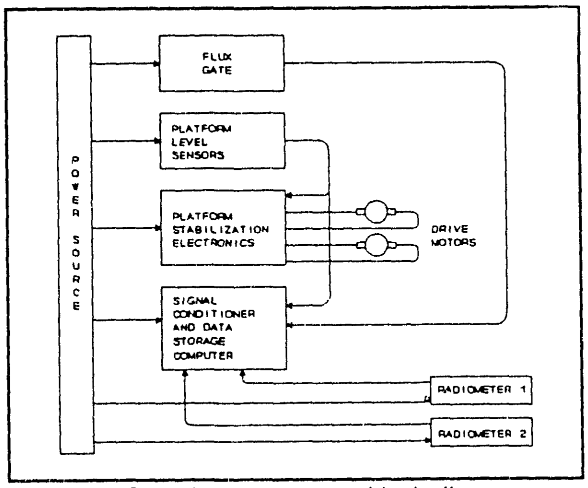

Figure 4. Sky Platform system block diagram.

4.3 Motion Sensing Platform

A Motion Sensing Platform (MSP) is designed to fly in place of the Sky Platform to characterize its operating environment by measuring lateral and angular accelerations, velocities, and displacements. Information obtained from the MSP is used to optimize components of the automatic control loop in the Sky Platform. In keeping with this function, the MSP does not have a leveling system or carry radiometric sensors.

The MSP (Figure 6) contains an array of nine accelerometers, two solid state rate sensors, a flux gate magnetometer, and a data acquisition and storage computer. Its tetrahedral frame is designed to carry the nine accelerometers in a three-dimensional orthogonal coordinate system, as indicated in Figure 5.

When the kinematics equations are solved for this arrangement of linear accelerometers using the method of Hu (1977), the following angular acceleration equations are obtained:

$$\dot{\omega}_x = (a7-a3)/2r_y - (a9-a2)/2r_z$$

$$\dot{\omega}_y = (a8-a8)/2r_z - (a5-a3)/2r_x$$

$$\dot{\omega}_z = (a4-a2)/2r_x - (a6-a1)/2r_y$$

where ai's are the measured linear accelerations and r_x, r_y and r_z are the distances between the accelerometer arrays on the various axes. Angular velocities and displacements can be obtained by integration. Note that these linear equations are inherently stable and require no knowledge of angular velocity time histories.

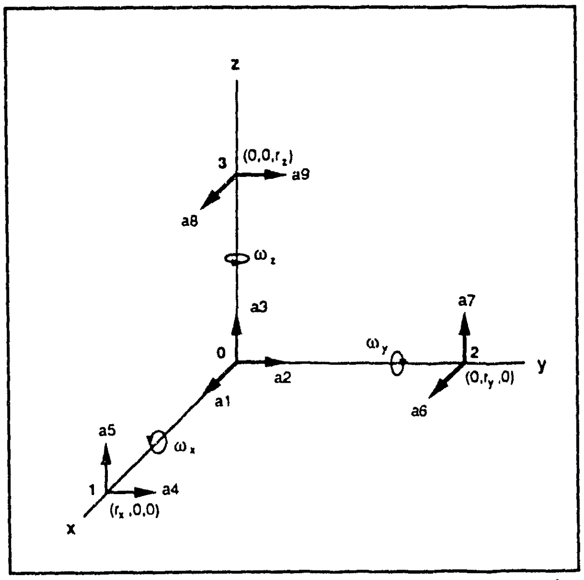

Figure 5. Coordinate system and arrangement of nine linear accelerometers on the Motion Sensing Platform.

The two solid state angular rate sensors[6] on the MSP permit the direct measurement of two of the angular velocities. These measurements are used to confirm the results of the accelerometer-based calculations. These rate sensors can also be used as the heart of a level sensing system which is insensitive to lateral accelerations. Electronic circuits are used to integrate the angular rate signals and obtain angular position. The long-term stability (drift) of the instruments can be corrected using a linear accelerometer. Such a system will be used to confirm the adequacy of the linear accelerometer-based level sensing system presently on the Sky Platform.

5. SYSTEM PERFORMANCE

As of this writing (September 1992), early prototype versions of the Sky and Motion Sensing Platforms have been flown under varying wind conditions. The two platforms described in this

[6] Model RT01-0604-1
Humphrey, Inc.
9212 Balboa Avenue
San Diego, CA 92123

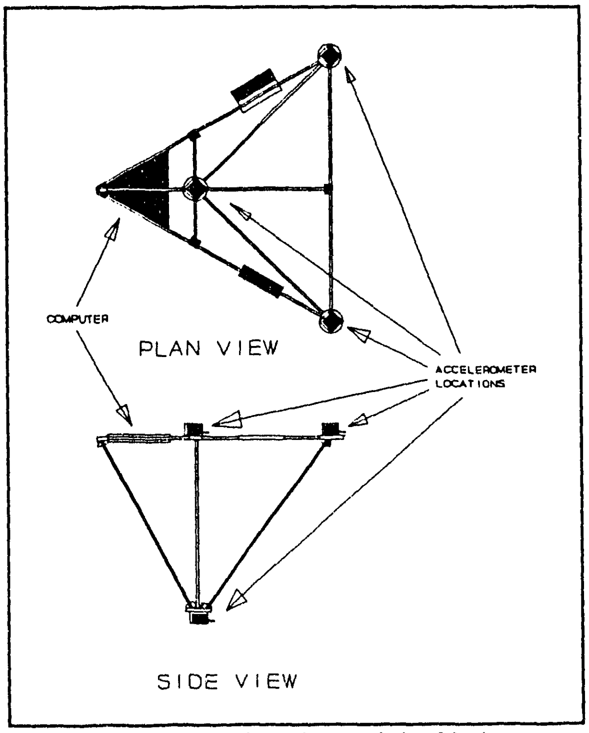

Figure 6. Side and plan views of the Motion Sensing Platform.

paper have benefited from this early testing and will be tested extensively during fiscal year 1993. We expect to be able to report the results of the flight tests at a later date.

6. ACKNOWLEDGMENTS

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