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The Short Wave Aerostat-Mounted Imager (SWAMI): A novel platform for acquiring remotely sensed data from a tethered balloon

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Abstract

We describe a new remote sensing system called the Short Wave Aerostat-Mounted Imager (SWAMI). The SWAMI is designed to acquire co-located video imagery and hyperspectral data to study basic remote sensing questions and to link landscape level trace gas fluxes with spatially and temporally appropriate spectral observations. The SWAMI can fly at altitudes up to 2 km above ground level to bridge the spatial gap between radiometric measurements collected near the surface and those acquired by other aircraft or satellites. The SWAMI platform consists of a dual channel hyperspectral spectroradiometer, video camera, GPS, thermal infrared sensor, and several meteorological and control sensors. All SWAMI functions (e.g. data acquisition and sensor pointing) can be controlled from the ground via wireless transmission. Sample data from the sampling platform are presented, along with several potential scientific applications of SWAMI data.

Keywords: Short Wave Aerostat-Mounted Imager; SWAMI; Tethered balloon; GPS; Trace gas flux scaling; Hyperspectral remote sensing; Unmanned aerial vehicle; UAV

1. Introduction

Remote sensing is an indispensable tool for studying terrestrial biophysical and biogeochemical processes from the local to global scale. Flux towers are being used to study material and energy exchanges between the biosphere and the atmosphere over landscape scales. Although advances in multispectral and hyperspectral remote sensing technology over the past three decades have enabled the study of ecosystem structure and function across a wide range of spatial and temporal scales, there still exists a gap between canopy scale processes and landscape level satellite remote sensing measurement.

To derive biophysical parameters relevant to ecosystem structure and function from coarse-scale spectral data, it is often necessary to use algorithms developed from in situ spectral reference data acquired at the plot level. Reference data collection methodologies can be separated into two categories. In the first approach, often employed where the vegetation canopy top is relatively low (< 1.5 m), spectral data is gathered near the ground using portable spectrometers positioned above specific surface plots. Biophysical characteristics (e.g. photosynthetic and non-photosynthetic biomass, leaf angle distribution, leaf area index) of these entire plots can then be thoroughly quantified to develop empirical relationships with the observed spectra (e.g. Asrar et al., 1986; Middleton, 1991). A main drawback to this sampling approach is that the instrument ground instantaneous field of view (GIFOV) is limited in size, and often is too small to investigate spectral changes associated with varying densities and other characteristics of larger plant functional groups (i.e. trees and shrubs) at a scale coars enough to link spectral data with biogeochemical measurements such as watershed-scale hydrology and ecosystem–atmosphere trace gas fluxes.

To characterize areas containing taller plant canopies (i.e. trees and large shrubs), a second type of field sampling approach is often employed. Biophysical characteristics are measured at a greater number of locations without concurrent ground-based spectroradiometric measurements, but close in

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time to sensor overflight (e.g. Cohen et al., 2003). The measurement locations are later co-registered with the overflight image, and relationships between the image data and ground parameters are derived. However, inherent to this approach are errors that stem from the fact that the exact amount of overlap between pixel and sample plot locations is often impossible to quantify due to geometric and radiometric constraints. Furthermore, because vegetation water status and biosphere–atmosphere material fluxes often vary as a function of hour and day, improving correlations between fluxes and spectral data requires concurrent measurement at the appropriate scale within the tower footprint (Rahman et al., 2003). Given these considerations, it is important to develop new remote sensing techniques to bridge the spatial gap between ground measurements and high-altitude aircraft or spaceborne observations, as well as to narrow the temporal gap that may limit the applicability of locally derived spectral algorithms to predict fluxes at regional and global scales (e.g. Gamon et al., 2004).

Remote sensing instruments capable of flying on the tether line of a sturdy tethered balloon can help bridge such sampling gaps. Because the flight altitude of a tethered balloon can be precisely controlled and rapidly changed, a balloon-mounted remote sensing platform can acquire surface spectral data at a variety of nested spatial scales ranging from the plot level (<5 m diameter GIFOV) to the level of moderate resolution satellite sensors (ca. 500 m diameter GIFOV). In addition, tethered balloon remote sensing allows for continuous data collection above a fixed ground location as the sun angle changes over the course of a day, therefore serving as a cost-effective method for acquiring experimental data with which to evaluate, validate, and improve canopy radiative transfer models. In this paper, we describe the Short Wave Aerostat-Mounted Imager (SWAMI), a new remote sensing system that can be mounted to the tether line of a tethered balloon. The SWAMI is designed to acquire quantitative hyperspectral, photographic, and a suite of ancillary data that can be used to study both basic remote sensing questions (e.g. Chen & Vierling, 2006-this issue) as well as to link ecosystem level trace gas fluxes with spatially appropriate spectral observations in real time.

1.1. Background

The use of tethered balloons in remote sensing science dates to the birth of aerial remote sensing itself, when in 1858 Gaspard Felix Tournachon manually collected an aerial photograph near Paris while aboard a tethered hot air balloon. Numerous aerial photographic surveys using manned tethered balloons followed in the 1860s, establishing this method as a viable means for collecting airborne data for municipal, military, aesthetic, and scientific purposes (Newhall, 1969). Timed and remote methods of camera shutter control have enabled smaller unmanned tethered balloons to be employed for remote sensing science. Expanded application of such data in recent years includes photogrammetric quantification of periglacial geomorphology (Boike & Yoshikawa, 2003), measurement of the area of melt ponds perched upon sea ice (Derksen et al., 1997), and quantitation of plant biomass and vegetated canopy area (e.g. Buerkert et al., 1996; Friedli et al., 1998; Gerard et al., 1997). Although tethered balloons do present some unique deployment challenges, their continued use to conduct remote sensing science for more than 140 years attests to the many advantages of tethered balloons over other airborne platforms, including: (1) extended flight duration (allowing continuous observations to be made over a given location for an indefinite amount of time, ranging from hours to weeks), (2) the highly controllable flight altitude (i.e. GIFOV size), (3) ease of use in remote and/or international locations, where logistical and/or political constraints may preclude the use of other aircraft, (4) relative low cost, (5) relative ease of moving the platform (e.g. Buerkert et al., 1996 used a camel harnessed by a tow rope to guide their balloon across the Sahelian landscape), (6) no high-frequency vibration as with helicopter platforms, and (7) wireless target selection and spectrometer control from the ground, enabling unmanned data collection and its inherent safety benefits. However, while numerous studies have employed relative radiometric methods for gathering and classifying surface information via tethered balloons using both RGB and IR-sensitive films and charge coupled devices (CCDs), to our knowledge no such systems have ever before been deployed to quantify absolute hyperspectral or multispectral radiance or reflectance. The SWAMI carries instrumentation that can image an area using videography, as well as gather hyperspectral radiometric measurements that can be precisely co-located with the imagery. Some applications of these data are described in detail in this paper.

In addition to their utility for collecting remote sensing data, measurements collected with tethered balloons can also fill a critical scale gap in the quantification of landscape level trace gas fluxes. Pioneering tethered balloon work to quantify meteorological variables throughout the planetary boundary layer (Emmitt, 1978; Wylie & Ropelewski, 1980) has been combined with advances in atmospheric trace gas sampling to derive trace gas fluxes representing upwind footprints of tens to hundreds of square kilometers (e.g. Davis et al., 1994; Zimmerman et al., 1988). Over the past decade, fluxes of methane (Beswick et al., 1998; Choularton et al., 1995), non-methane hydrocarbons (Davis et al., 1994; Greenberg et al., 1999; Guenther et al., 1996; Spirig et al., 2004; Zimmerman et al., 1988), and carbon dioxide (Kuck et al., 2000) have been calculated using measurements from tethered balloons. Collecting remote sensing data from balloons, therefore, can allow for simultaneous spectral and flux measurements representing large flux footprints collected via balloons and towers. This explicit link between spectra and fluxes at the landscape scale may allow improved scaling of flux tower results from the local to landscape scale.

Here, we provide details pertaining to the design and manufacturing of the SWAMI, as well as the tethered balloon platform currently used to fly the platform. Fundamental elements of the mechanical design and construction are presented. Electrical and computer systems that enable sensor stability control, communications routing, and remote operation of the spectrometer are also described. Sample data are presented in the context of their applications for conducting