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TECHNICAL REPORT

A balloon for microclimate observations within the forest canopy

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Summary

We describe the construction of an inexpensive balloon and its use as a platform for microclimate observations within the forest canopy. It is easily made, portable and rugged, allowing access to regions of the forest not previously available. To illustrate the balloon's utility we present some examples of within-canopy light measurements.

Key-words: canopy access, helium balloon, photosynthetically active radiation, spatial variation, transmittance.

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Introduction

Because of access difficulties, observations on forest canopy environments are often restricted to those obtainable from the ground or from remote-sensing platforms. Most within-canopy observations are taken from fixed positions masts or towers (Parker, Smith & Hogan 1992; Moffet 1995). For several spatially variable attributes of forest canopies (e.g. the fields of radiation or temperature), the capacity of single locations to represent canopy environments is questionable. Few observations have been made within the three dimensions of canopy space. Consequently, there is little appreciation of the variability in the canopy physical environment and its influence on the biological components.

Balloons are one way to counter the limitations of gravity. While often employed in upper atmosphere measurements (e.g. Lenschow & Johnson 1968) or near-surface aerial photography (Mims 1990; Davis & Johnson 1991; Nagano 1990), balloons are rarely used within the canopy (see Hladik & Hladik 1980; Safranyik *et al.* 1992). This is because the familiar pressurized balloons made of latex are easily ruptured by sharp objects in canopies, or because the sizes of canopy spaces that accommodate balloons might limit the payload.

These disadvantages may be surmounted. Various light and durable fabrics are available and small payloads can often be used to advantage. The objectives of the present work were to describe the construction of an inexpensive balloon as a platform for some within-canopy measurements, and to illustrate its use with spatially detailed measurements of the photosynthetically active radiation (PAR) environment.

Methods

MATERIALS

The balloon fabric is a metallized biaxially oriented nylon laminate with a polyethylene inner coating, most commonly available in 94·5-cm-wide rolls (Allied Signal, Morristown, NJ). This material is widely used for novelty balloons, which are typically small (maximum lift *c.* 50 g). The fabric, about 0·03 mm thick and weighing 29·1 g m^{-2}, has a low permeability to helium, is stretch- and puncture-resistant and easily heat-bonded. The aluminum exterior coating aids in gas retention (Mike Bost, Allied Signal, personal communication). However, the fabric is rather easily torn when shock-loaded. We first tried metallized mylar as the balloon material but it sealed poorly and tended to puncture more easily than the nylon laminate.

A seaming iron (Veraseal model 510 heat sealing iron, Aristo-craft, New York), often used for applying fabric to model aircraft and available at most hobby shops, seals two layers of fabric by their polyethylene-coated inner surfaces.

CONSTRUCTION

The balloon we describe has the shape of an inverted square pyramid (ISP, Fig. 1). This shape was chosen for its dynamic stability and simplicity of construction. Only two shapes are needed for the main parts: a square top panel (sides 94·5 cm) and four triangular side panels (base side 94·5 cm, height 210 cm; Fig. 2). The panels are readily shaped by cutting with a sharp blade.

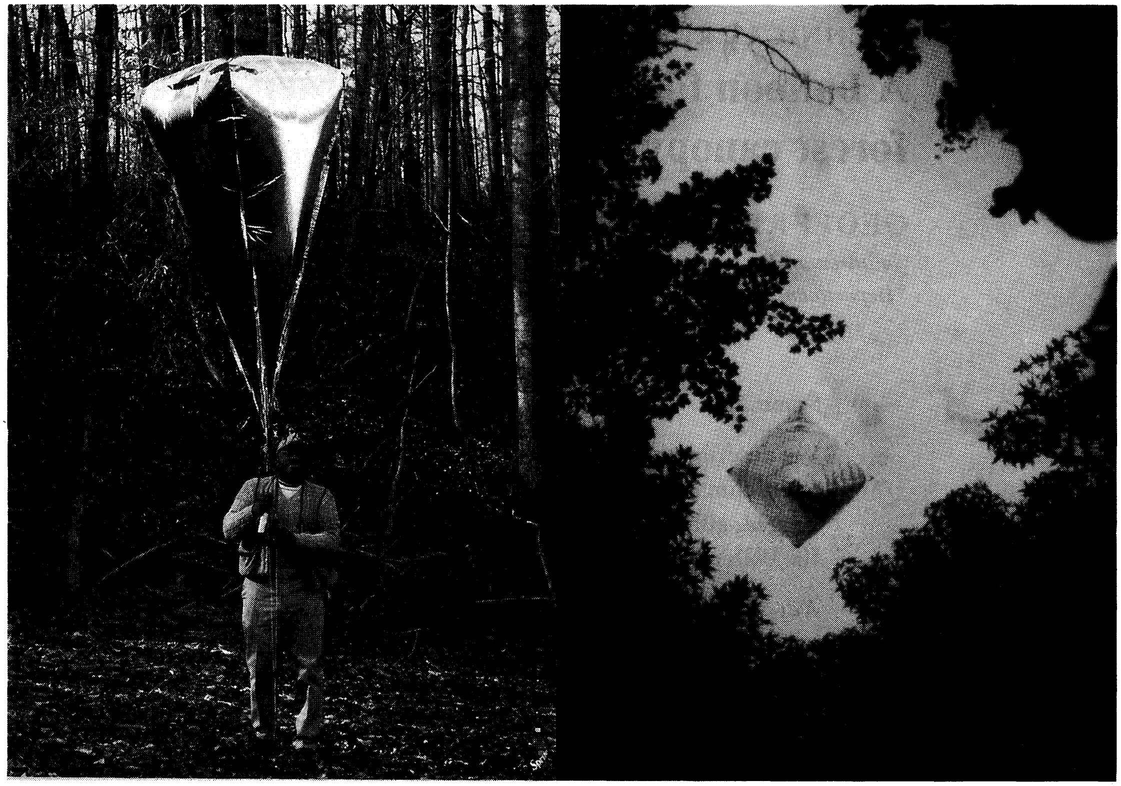

Fig. 1. Inflated balloon at the ground (left panel) and within a gap in a deciduous canopy (right).

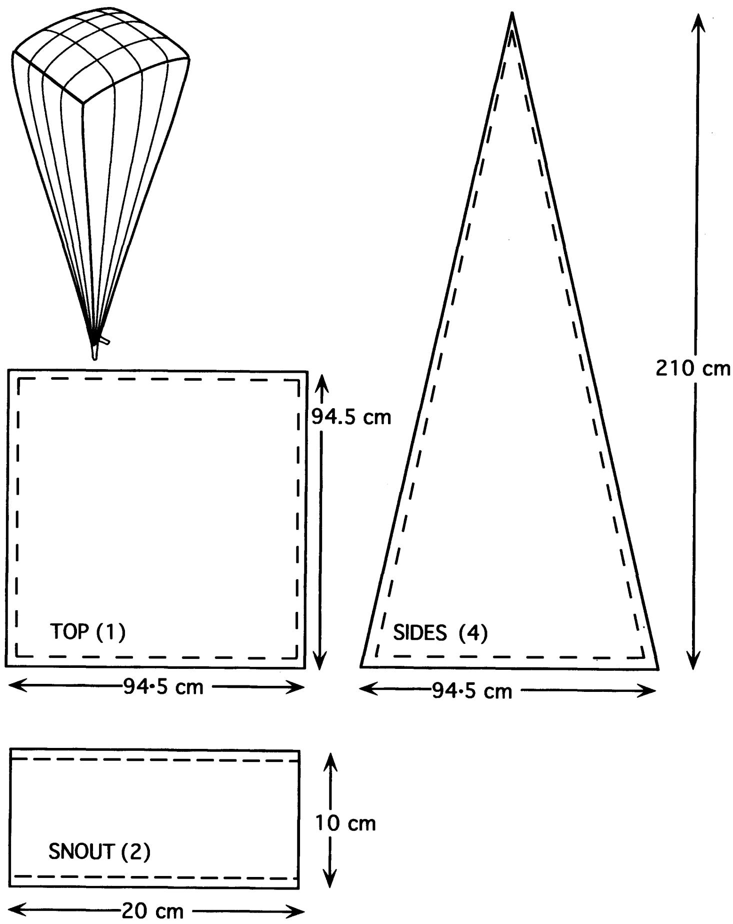

Fig. 2. Schematic plan of the balloon components.

Journal of Applied Ecology, **33**, 173–177

The triangular side panels are sealed together along their long edges. A setting of 3 on the sealing iron (*c.* 230 °C) produces a satisfactorily tight seal. Each seam is sealed on both sides. For greater strength the width of the seam tapers from 1·5 cm wide at the bottom to 2·5 cm at the top. The side seams are sealed beginning 20 cm from the narrow end of the balloon, stopping 5 cm from the broad end. After all four sides are connected, the square top piece is sealed to the four triangular sides, with 2·5-cm-wide seams. The top seams may be reinforced with tape.

Gas is introduced to the balloon through two closable inlet tubes (snouts) at the base (Fig. 2). The snouts are made from 10 × 20-cm rectangles of fabric, folded and sealed along their long sides. One tube is inverted and sealed into a side seam about 20 cm from the balloon base. The other is sealed into the bottom, where all four sides meet. The lower snout acts as an attachment point for the four corners, an inflation port, and a connection for the tether and instrument cable. The upper snout allows the addition of helium in the field without untying the tether. To tether the balloon we used a braided nylon mason's twine (about 1·2 g m^{-1}). The tether is simply tied to the lower snout and marked at 1-m intervals to measure working height.

When used to make light measurements, the balloon's top panel is painted flat black to reduce reflection. A light sensor (model LI-189 quantum sensor, Li-Cor, Lincoln, Nebraska, USA) is attached to the centre of the top with velcro and the sensor cable taped to the side of the balloon. If the sensor cable is strong, e.g. RG-174 coaxial wire (weighing *c.* 10·8 g m^{-1}), it can also serve as the lifting line and the tether may be removed.

The cost of materials for an ISP balloon lifting *c.* 0·5 kg is about US $9·00 (Table 1). The balloon requires, after some practice, about 5 h to make. A seamed ISP balloon of ideal shape is about 0·537 m^3 in volume, giving 453 g lift (596 g lift for the helium minus 143 g for the weight of the fabric). However, since the balloon can be overfilled, the actual lift is usually somewhat more.

Results

PERFORMANCE

Figure 3 illustrates the capacity and variation that may be expected of the ISP balloon, as demonstrated by the decay of lift in balloons made by different individuals. The initial lift of balloons of this design could attain 530 g and declined at 1·5–1·7 g h^{-1}. Note that modifications to reduce lift loss (0·1 g h^{-1}; trace 'G' in Fig. 3) required wider seams which also reduced the initial lift.

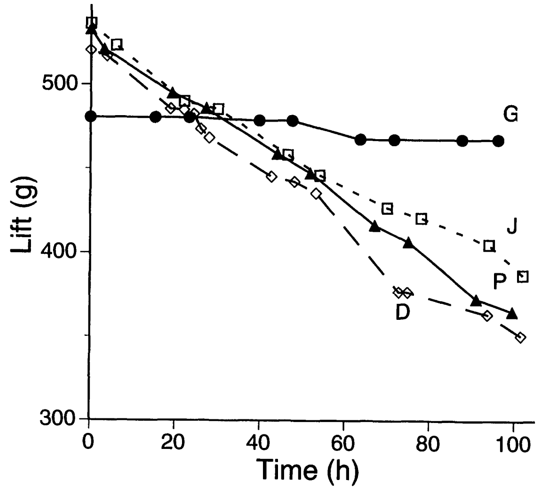

Fig. 3. Loss of lift since initial filling of four ISP balloons built by different individuals (letter codes).

TECHNIQUES FOR DEPLOYMENT

Before filling with helium, the balloon should be purged of air that may have entered during construction or storage. The balloon should not be over filled because solar heating will cause the helium to expand and stress the seams. Canopy spaces are complex, so the balloon cannot be inserted everywhere easily. However, we found that many places can be accessed indirectly by manoeuvring the balloon around obstacles. The balloon may become caught or snagged when aloft but gentle tugging to one side will usually dislodge it. Avoid sharp jerking actions which can tear the fabric at the tethering point. In some cases it may be preferable to allow a caught balloon to ascend above an obstacle before retrieving it. If the balloon is punctured it will lose lift slowly; such holes are readily repaired with tape (*c.* 45 g m^{-2}). Even though the metallized outer coating can decay, the balloon is quite rugged and may be reused repeatedly: one balloon used in dozens of ascents is still quite serviceable.

Table 1. Weight and costs of material for the ISP balloon for use to 40-m height. Negative weights are lifts

Material	Unit cost	Unit weight	Required	Cost (US$)	Weight (g)
Fabric	0·0088 $ g^{-1}	29·1 g m^{-2}	4·9 m^2	1·26	143
Tether	0·021 $ m^{-1}	1·2 g m^{-1}	40 m	0·84	48
Helium	11·60 $ m^{-3}	−1110 g m^{-3}	0·58 m^3	6·75	−643
Total				8·85	−452

EXAMPLE OF CAPABILITIES

Figure 4 shows several vertical profiles of PAR transmittance in a tall, mixed species forest (described by Parker, O'Neill & Higman 1989) made using the ISP balloon. This figure demonstrates the enormous spatial variability of light profiles, especially in the outer canopy. Not shown are results on the diurnal variation in vertical transmittance obtained by repeated ascents at one location and a comparison of transmittance profiles in stands of different structure. To obtain these data by conventional means would require a rather extensive system of supports, time, and effort.

Discussion and conclusions

The balloon has some drawbacks as a platform for canopy observations. Its use is restricted to calm conditions (mean above-canopy wind $< 2\,m\,s^{-1}$). The size of the balloon limits access to some canopy spaces, e.g. the very near bole and other regions can only be accessed with some effort. The balloon may rip or tear when caught. However, it is reusable, easily repaired, and quite rugged overall. We expect it will find applications where fixed towers or masts are untenable (for logistical, cost, or commitment reasons), where surveys are of interest, or where supplemental measurements to those at fixed positions are desired (Table 2).

The basic design presented here is readily modified. For example, other shapes are easily devised: they need only be dynamically stable (recover balance when displaced from the vertical) and not too large for canopy spaces. Lift can be increased somewhat through the use of hydrogen (about 1·2 g lift dm^{-1} balloon volume at STP) rather than helium (1·1 g dm^{-1}), but hydrogen is explosive and can be difficult to work with.

Though we have demonstrated its utility for measurements of canopy PAR, the balloon has other uses. Other sensors, for variables such as temperature and humidity, could be lifted. We have employed a

Table 2. Qualitative comparison of the benefits and drawbacks of balloons and fixed structures as instrument platforms

Criterion	Balloons	Fixed structures
Portability	good	poor
Cost	good	poor
Capacity	poor	very good
Installation	good	poor
Repair	good	poor
Tolerance of extremes	poor	good

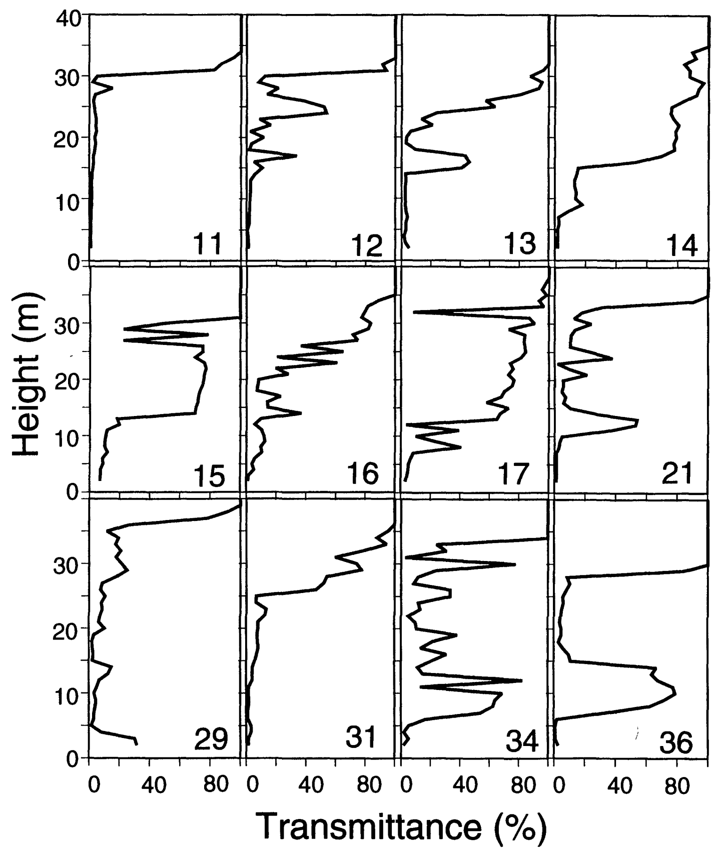

Fig. 4. Spatial variation in the vertical profile of midday PAR transmittance taken at 12 stations in a tall, mixed-species forest on the Maryland coastal plain (numbers are location codes).

similar balloon to take air samples by replacing the sensor cable with a gas sampling tube. Another larger version was used to lift a video camera. Finally, the balloon can be used to attach lines to high canopy limbs not easily reached by climbing.

The balloon we describe provides a stable platform for small environmental sensors in the middle and upper canopy. This mobile 'tower' can be employed to extend the understanding of spatial variability in canopy environments in an inexpensive manner.

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