A Balloon-Borne Platform for Measuring Vertically Resolved Concentrations of Black Carbon in the Troposphere

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Objective

The primary goal of this project is to develop and promote a balloon-borne method for routine measurement of the vertical distribution of black carbon and other air quality and climate-relevant aerosols in the atmosphere. The project will: i) demonstrate, using currently available technology, the feasibility of measuring the variation in black carbon concentrations in the troposphere with a balloon-borne package small enough to be deployed without FAA restriction; ii) develop low-cost and lightweight instruments for measuring different types of aerosols; iii) launch and retrieve several balloon-borne packages to measure the seasonal variability in the vertical profile of aerosols in California; and iv) seek collaboration with other institutions for simultaneous measurement of aerosols, greenhouse gases, and radiation flux. A longer-term goal is the wide adoption and frequent deployment of balloon-borne aerosol measurements that will provide the information needed to improve representation of aerosols in climate models, improve satellite aerosol retrieval algorithms, and better distinguish long-range transported and locally generated aerosol pollution.

Background

Sunlight-absorbing black carbon (BC) particles emitted during combustion of fossil and biomass fuels contribute to climate change. Recent studies estimate that emissions of BC are the second strongest contributor to current global warming, after carbon dioxide[1,2]. One of these studies finds that the global average BC radiative forcing is as much as 55% of the carbon dioxide forcing and is larger than the forcing due to the other greenhouse gases[2]. The BC forcing in this study is larger than many other estimates (including IPCC) because it prescribes peak BC concentrations at 2 km above the surface [3,4], whereas in most general circulation models they are concentrated close to the surface[5]. BC at a higher altitude may significantly enhance solar absorption because it absorbs sunlight reflected by low clouds [6,7].

Several other modeling studies agree that the climate impacts of aerosols depend on their vertical distribution in the troposphere [2,4,6,8-10]. For example, if BC aerosol layers are located above clouds, they exert two to five times the forcing of the same amount of BC beneath cloud cover [10]. The vertical distribution of BC tells us where solar radiation is being absorbed and thus what layers of the atmosphere are being heated, which has implications for cloud formation and sensible heat transport [6,8]. Further, the altitude where BC exists influences the length of its atmospheric lifetime and how far it may be transported from the original source: a higher altitude means longer lifetime and farther transport. Chemical transport models coupled to climate models show that aerosols emitted at the surface can be lofted to altitudes over 5 km and transported great distances [11-14].

A major gap in our understanding of how aerosols impact climate and air quality exists because there are no routine methods for measuring the vertical distribution of aerosols in the troposphere. The vertical profiles of light-absorbing aerosols provided by satellites have a very high level of uncertainty [15] and satellite retrievals of atmospheric aerosols are nearly impossible when clouds are present [16]. The occasional multi-agency (including DOE) sponsored field campaign combines satellite, aircraft, and ground based measurements to provide snapshots of the vertical profile of BC and other aerosols [13,17-23], but this approach is prohibitively expensive for widespread and routine measurements. Another approach is the use of small instrumentation flown on unmanned aerial vehicles [24], but these platforms are also very expensive. Moreover, they are limited in altitude to a few kilometers and the FAA severely restricts their use to only a few remote areas.

We are developing an alternate approach – a balloon-borne method – including the development of low-cost and lightweight instruments for routine measurements of BC and other aerosols throughout the troposphere. Wide adoption of this approach will improve our understanding and prediction of the climate and air quality impacts of aerosols.

Progress and next steps

In late spring of 2011, we launched a micro-aethalometer – a commercially available and small instrument for measuring BC – on a hobbyist's weather balloon, which reached an altitude of 40 km and a minimum temperature of -60ºC. Upon recovery four hours after launch, the micro-aethalometer was still operating and the internally stored data was in-tack. While this first flight demonstrated the feasibility of launching and recovering balloons in California and the durability of the micro-aethalometer when exposed to conditions of low temperature and pressure, the poor quality of the data demonstrated that this instrument needed modification to produce meaningful data. Our team is currently working with the manufacturer of the micro-aethalometer to customize it for our next balloon-borne measurements this spring 2012. Modifications include an increase in the sampling flow rate to increase sensitivity, firmware reconfiguration to increase optical stability, and temperature/humidity controls at the instrument's inlet..

Additionally, we have been developing a balloon instrument platform that includes a GPS and meteorology (T, P, RH) instrument communication package, with the capability of transmitting data and payload position in real time. A first flight to test the communication and tracking capabilities is planned for the week of March 26 – 30th, 2012. The customized micro-aethalometer will be integrated into the instrument platform once we confirm that the data logger and communication system are operational.

In the second year of the project, we plan to expand the capabilities of the package by adding instruments that measure aerosol light extinction and particle number concentration, which are climate relevant aerosol property. The combination of BC, light extinction, and particle number concentration measurements can be used to determine the radiative forcing from atmospheric aerosols throughout the atmospheric column. We will plan to periodically launch instrumented balloons at several sites in California to quantify the geographical and seasonal variation of the aerosol distribution in the atmosphere above California. These measurements will be of interest to CARB (California Air Resources Board), which presently seeks data to support climate policy. The proposed measurements could help distinguish between locally emitted aerosols and those transported from Asia, which is also policy relevant as it speaks to the relative importance of local vs. distant emissions in affecting air quality and climate. As appropriate, we will communicate our research with CARB and pursue future funding (as noted below). We will attempt to coordinate with the National Weather Service so that our measurements will be concurrent with radiosonde deployments that measure vertical profiles of temperature, pressure, and relative humidity, as a means of verifying our measurements of these parameters.

To demonstrate the value of our balloon-borne technique, we will seek opportunities to include our vertical-profiling measurements into field campaigns where aircraft and satellite measurements are planned, such as those often administered by DOE and NOAA.

Significance

Our limited understanding of how aerosols impact climate is the largest source of uncertainty in current climate model predictions [25]. Based on recent estimates of the importance of BC, policy to control BC has been proposed as a short-term means of mitigating global warming [26]. The importance of measuring vertical profiles of aerosols is recognized as crucial to reducing the significant uncertainty in climate models [7,10,27,28]. As noted above, satellite retrieval algorithms carry a high level of uncertainty and are presently incapable of vertically resolving aerosols when clouds are present or over ice, snow, or bright desert. For example, satellite born instruments like MODIS and CALIOP have been used to obtain the total aerosol optical thickness (AOT) and the vertically resolved AOT respectively, but the data retrievals are robust only for moderate aerosol loading and when the ground cover is sufficiently dark and no clouds are present. Furthermore, atmospheric aerosols can obscure the satellite retrievals of greenhouse gases. Large aircraft campaigns are too costly to be practical for routine measurements at several locations.

Our proposed balloon-based approach for routinely measuring aerosol vertical profiles can provide the data that is necessary for improving and validating satellite based measurements and refining aerosol benchmarks for chemical transport models that currently rely on surface measurements. Given that chemical transport models are coupled to general circulation models (i.e., climate models), these measurements will be valuable in reducing the large uncertainty that atmospheric aerosols represent in climate change predictions. In addition, when used in conjunction with transport models and air mass back trajectories [29], the data will provide better estimates of the fraction of aerosols in the western US originating from long-range transport from Asia as opposed to local emissions, which is relevant for air quality and climate mitigation policy.

Due to its short atmospheric lifetime, on the order of weeks compared to centuries for CO_2, BC mitigation has recently become a focus for policy makers and climate solution strategists [8,26]. Increased measurement of BC throughout the atmosphere will lead to better understanding the how BC affects climate and will allow for the most effective policies at mitigating climate change.

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