Continuous bio-aerosol monitoring in a tropical environment using a UV fluorescence and light scattering instrument.

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Abstract

This paper describes an instrument designed to achieve the continuous monitoring of ambient bio-aerosol concentrations. The instrument is a compact, relatively low-cost, UV aerosol spectrometer that monitors and classifies the ambient aerosol by simultaneously recording from individual airborne particles both a 2×2 fluorescence excitation-emission matrix and multi-angle spatial elastic scattering data. The former can indicate the possible presence of specific biological fluorophores within the particle whilst the latter provides an assessment of particle size and shape. Taken together, these parameters can facilitate discrimination between biological and non-biological particles and potentially allow classification of biological particle types. Example measurements are given illustrating magnitude and temporal fluctuations in the biological fraction of aerosol within the Borneo tropical rain forest.

1 Introduction

Sensors that are able to provide continuous real-time monitoring for potential bio-aerosol hazards are required in both civilian and military environments. Where real-time response and reagent-free operation are required, techniques based on the measurement of optical and/or spectroscopic properties of individual airborne particles can offer advantages. In general, the greater the number of such parameters measured, the higher the level of detection confidence and the lower the risk of false-positive detection.

Whilst most bio-aerosol detectors/monitors have to-date been developed to meet the growing potential threat of deliberate bio-hazard release, there is growing interest in their deployment in the fields of atmospheric and climate research. Biological particles such as bacteria and pollen are known to be very efficient ice nucleators [1] and thus can influence cloud microphysical and radiative processes. However, their role remains poorly understood, in part through the lack of quantitative data relating to bio-aerosol fluxes and distributions in the atmosphere.

During the Summer of 2008, a major atmospheric research field campaign is being undertaken in Borneo as part of the ACES (Aerosol Cycle in the Earth System) experiment [2].This experiment is primarily concerned with understanding the fundamental processes involved in the formation of aerosols from the chemical processing of natural hydrocarbons emitted from forested regions. However, the campaign initially lacked instrumentation to monitor the temporal behaviour of bio-aerosol concentrations, and as a

consequence, a prototype bio-aerosol sensor developed by the authors for the UK DSTL (Defence Science and Technology Laboratory) was commissioned for inclusion in the study.

2 The prototype FAB sensor

This sensor, referred to as Fluorescence Aerosol Bio-sensor (FAB), is the latest version of a series of prototype real-time biological particle monitors [3,4]. It continuously samples ambient air at a rate of ~2.35 l/min through a delivery system that filters ~2.1 l/min of the air and re-introduces this as a sheath around the remaining ~250 ml/min sample flow. Particles within this sample flow column are aerodynamically constrained to single file as they intersect the beam from a continuous-wave 635 nm diode laser. Each individual particle, down to ~0.5 μm in size, produces a scattered light pattern that is recorded by a multi-channel photodetector used to derive particle shape and size information (see below). The scattered light signal also provides a trigger signal to initiate the sequential firing (~10 μs apart) of two xenon discharge tube sources that irradiate the particle with UV pulses centred upon ~280 nm and ~370 nm wavelength, optimal for excitation of the common bio-fluorophores tryptophan and NADH respectively. For each excitation wavelength, fluorescence is detected across two bands (300-400nm and 420-650nm) embracing the peak emissions of the same two bio-fluorophores. These data are summarised in Table 1. Particle classification may be achieved by evaluating these spatial scatter and fluorescence data to appropriately 'position' the particle within multiparameter space. Particles are measured at rates up to ~125 particles/s (limited by the xenon recharge time), corresponding to all particles for concentrations up to ~2.5×10^4 particles/l.

Table 1: Summary of FAB data parameters.

Source	Data parameter
Laser diode, 635 nm	Forward scattered light in four spatial regions. Side-scatter at 90º +/- 36º.
Xenon 1 @ 280 nm	Fluorescence in band ~300-400 nm. Fluorescence in band ~420-650 nm.
Xenon 2 @ 370 nm	Fluorescence in band 300-400 nm is discarded since the elastically scattered light at xenon 2 excitation wavelength saturates the detector. Fluorescence in band ~420-650 nm.

The forward scattered light from each particle is captured by a quadrant photomultiplier detector that covers the scattering angle range Θ = 6 - 25º; $\varnothing$ = 0 - 360º. The quadrant is orientated at 45º to the direction of the sample airflow through the laser beam, such that elongated particles (that tend to align axially with the airflow as a result of the aerodynamic confinement) scatter predominantly to the horizontally-opposed pair of quadrants. An *Asymmetry Factor, Af,* for each particle is determined by evaluating the root-mean-squared variation in the azimuthal light distribution received by the four quadrant detector elements. This is scaled such that a spherical particle (that scatters equally to all four quadrants) has an asymmetry factor of 0, whilst elongated particles such as fibres have an Af approaching 100. The sum of the four detector outputs is used in an estimate of particle size (spherical equivalent size for non-spherical particles), based on scattering intensities from known calibration microspheres.

Preliminary Results

There are numerous potential methods of combining the multiple data parameters obtained with this instrument in order to achieve particle characterisation and discrimination between different particle types. Typically, unknown particles are positioned within a multiparameter space defined by their fluorescence, size, and shape (Af) values, and classified by comparison with results from know particle types (vegetative bacteria and bacterial spores, pollens, fungal spores, etc). These will be described in more detail in the presentation.

By example here, we provide in Fig.1 the results of a simple discrimination between particles deemed biological and those deemed non-biological on the basis of the magnitude of their fluorescence signals in the two detection bands listed above. The 'biological particle' threshold for each fluorescence band (assuming appropriate particle size and Af values) was set arbitrarily in this case to 2.5*st.dev of baseline data. (The baseline data is the fluorescence signal level recorded when each xenon tube is deliberately fired in the absence of a particle. This signal level results from a number of sources including background fluorescence in the instrument scattering chamber, possible sub-0.5µm particles in the sample airstream, fluorescence filter breakthrough, etc).

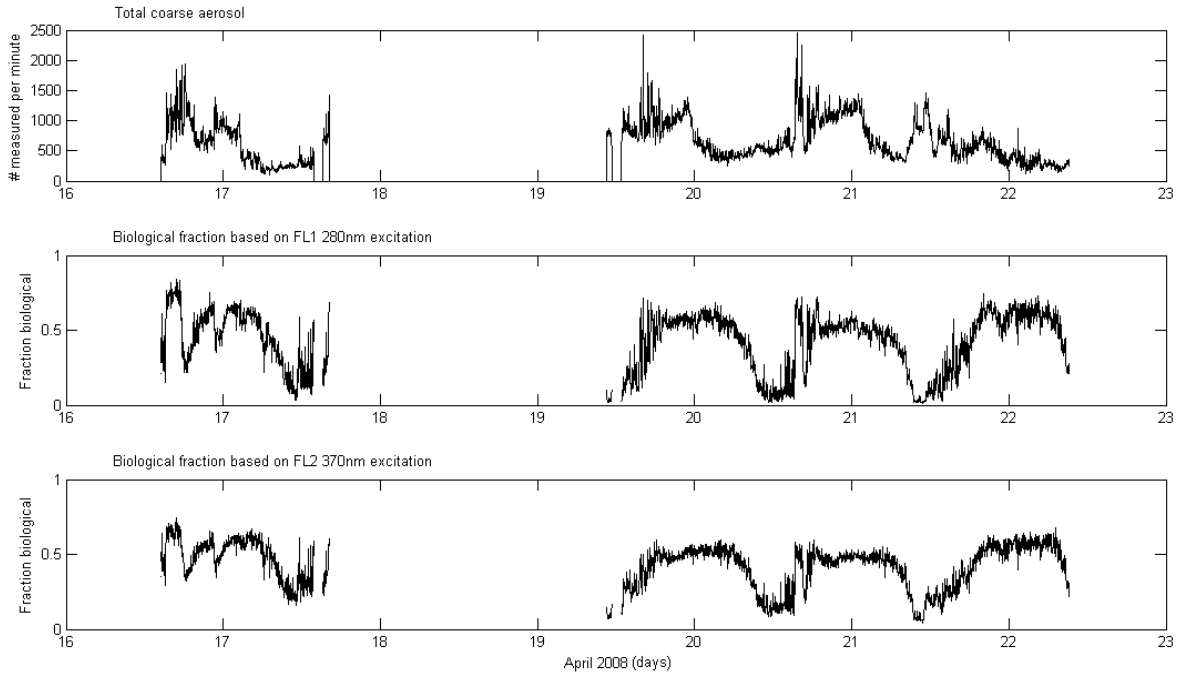

Figure 1: FAB sensor data recorded in ACES tropical rain forest campaign.

The bio-aerosol data presented in Fig. 1 were recorded with the FAB instrument at an elevation of 1.7m from the forest floor in the South-East Asian tropical rain forest. The clear diurnal cycles of increased proportions of biological particles during the night periods are consistent with predictions of nocturnal pollen release/sporulation at the location. Sunset and sunrise are around 6.30am and 6.30pm. (The gaps on the data are a result of 'power-outs' at the monitoring station).

Figure 2 shows a diurnal average of these data, comparing the number of particles deemed biological with those deemed non-biological. Decreased proportions of biological particles around mid-day are again evident, whilst detail in the periodic cycle of the fluorescence data could potentially arise from different pollenating species. (Further data analysis is being carried out to investigate this possibility).

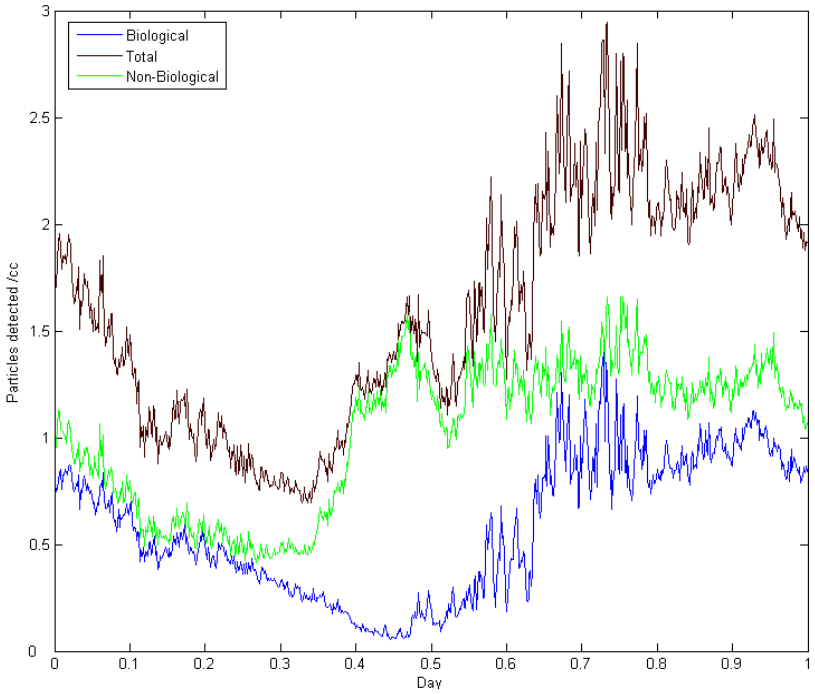

Figure 2: Diurnal average of biological and non-biological aerosol recorded in ACES Week 1. (0 on the x-axis corresponds to midnight)

4 Conclusion

These results are just one example that shows the ability and potential of the multiparameter bio-aerosol sensor to assist in the detection and characterisation of bio-aerosol both naturally occurring and produced by human activity. The rain forest deployment is part of an ongoing process of detailed characterisation of the FAB instrument involving both laboratory and field experiments with aerosols of bacteria, pollens, fungal spores, biological simulants, and a variety of non-biological materials. It is anticipated that these results will ultimately provide it with the capacity to efficiently classify the biological components of ambient environmental aerosols in real-time.

Acknowledgments

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References

[1] G. Vali, *Nucleation and Atmospheric Aerosols,* 271-279 (Pergamon, 1996).

[2] See http://ncasweb.leeds.ac.uk/appraise/ .

[3] P. H. Kaye, E. Hirst, V. E. Foot, J. M. Clark, and K. L. Baxter, “A low-cost multi-channel aerosol fluorescence sensor for networked deployment,” in Optically Based Biological and Chemical Sensing for Defence. J. C. Carrano and A. Zukauskas, eds. Proc. SPIE 5617, 388-398 (2004).

[4] P. H. Kaye, W. R. Stanley, E. Hirst, E. V. Foot, K. L. Baxter and S. J. Barrington, “Single particle multichannel bio-aerosol fluorescence sensor,” Opt. Express **13**, 3583-3593 (2005).