Introduction

Primary biogenic aerosol particles (PBAP) are used by organisms including fungi, pollinating plants, bacteria and viruses as a means to propagate their genetic material, either by transport of organisms themselves or their reproductive components. Many studies have suggested PBAP might be important for initiation of cloud formation and subsequent precipitation evolution by acting as cloud condensation nuclei (CCN) or possibly as ice nuclei (IN). This link is inferred from laboratory studies (e.g. Diehl et al, 2001) demonstrating the high activation efficiency of PBAP at warm temperatures, coupled with observations that biological particles are ubiquitous in the atmosphere. Despite more than two hundred years of research (e.g. Ehrenberg, 1830) information on the abundance, composition and more importantly the sources and heterogeneity of PBAP on global scales is still lacking.

We present new observations of PBAP below and above the canopy of a South-East Asian tropical rain forest in Sabah, Malaysia, using the WIBS-3: a novel real-time aerosol spectrometer (Kaye et al., 2005). The observations were validated using Environmental Scanning Electron Microscope (ESEM) analysis of bioaerosol that were collected onto Nucleopore filters in the same locations.

Previous PBAP emission estimates

The first estimates of global average PBAP emission rates, based on observations in Amazonia and budget calculations, were provided by Elbert et al. (2007) (referred to as E2007) and demonstrate that fungi contribute a major fraction of the observed PBAP PM$_{10}$ mass (particles with diameters from 1 – 10 µm). Particularly abundant were Ascomycota (AAM) and Basidiomycota (ABM), which are commonly seen in tropical regions. Some species belonging to these divisions release wet spores via active discharge mechanisms. Passive dispersal mechanisms require external mechanical action in order to function but may also be important contributors on a seasonal time scale. Wet discharged Basidiospore (ABS) emissions were traced using specific compounds (e.g. alcohol manitol) to calculate global average spore emission rates for ABM. E2007 calculate a value of ~17 Tg yr$^{-1}$ for ABM, consistent with observed concentrations of ABS that typically range from $10^3$ - $10^4$ m$^{-3}$ by number ($~0.1$ - $1$ µg m$^{-3}$ by mass), although PBAP abundance varies widely as a result of spatial and temporal sensitivity to meteorological variables.

Wu et al. (2004), Fuzzi et al. (2006) and Kellog & Griffith (2006) suggest a background contribution of $~6.5$ µg m$^{-3}$ for PBAP in the size range $0.2 < D_p < 50$ µm. This size range includes pollen grains, fern spores and large fungal spores. Penner et al. (1995) estimated a PM$_{2.5}$ PBAP emission rate of 56 Tg yr$^{-1}$. E2007 subsequently estimated the global average
ambient mass and emission rate for all fungal spores to be \( \sim 1 \ \mu g \ m^{-3} \) and \( \sim 50 \ \text{Tg yr}^{-1} \) respectively: a 3 times higher than for their detailed calculations involving only ABS spores.

**Tropical Rain Forest Observations**

Measurements were performed beneath the tropical rainforest canopy in the Danum Valley, within the Yayasan Sabah Forestry Division, which is located in the Sabah Federal State of Malaysia. The measurement site was located at \( \sim 4^\circ 58.562^\prime \ N, 117^\circ 51.478^\prime \ E \) at an elevation of 196 m ASL. PBAP in the size range \( 0.8 < D_p < 20 \ \mu m \) were identified in real-time using the WIBS-3: a novel single-particle, dual-channel UV fluorescence spectrometer (Kaye et al., 2008). Inside the instrument ultra-violet pulses excite fluorescence in two tracers, known as biofluorophores, normally found in viable material: the metabolic product NADH and the amino acid Tryptophan. Particle optical diameter and sphericity are measured using elastically scattered light from a diode laser beam. Above-canopy measurements were made to compare with the below-canopy observations and in order to derive flux estimates. Supporting measurements from a range of aerosol and turbulence instruments were also made and PM\(_{10}\) filter samples of the ambient aerosol in these locations were collected for subsequent PBAP identification using ESEM.

Number size distributions for PBAP and non-PBAP were derived based on whether or not each sampled particle exhibited fluorescence. The time evolution of the number size distribution shows that PBAP in the size range \( 2 < D_p < 4 \ \mu m \) dominate the total coarse concentration at night through transient spikes in number concentration, most likely fungal sporulation events, one of which occurs in late afternoon and is normally followed by multiple events before and after midnight. PM\(_{10}\) PBAP number peaks at \( 2 \times 10^3 \ \text{I}^{-1} \) in the late evening, representing 90% of the total PM\(_{10}\) number at that time. Fluorescing particles were also found to have a larger modal diameter and asphericity than those with no detectable fluorescence, indicating a different morphology. Laboratory asymmetry calculations using sample spores from forest floor fungi yielded comparable asphericity results. ESEM analysis of coincident PM\(_{10}\) filter samples revealed spores with shapes ranging from approximately spherical to highly elongated, primarily in the size range \( 2 < D_p < 4 \ \mu m \). The above-canopy PM\(_{10}\) PBAP number concentration exhibits more day-to-day variation than below the canopy but also reaches a maximum of \( \sim 4 \times 10^3 \ \text{I}^{-1} \) in the late evening. The recorded PBAP number above-canopy has few transient spikes at night and is 4 - 5 times smaller than that found below-canopy, indicating the forest floor and canopy are likely to be sources. Profile measurements of aerosol number size distribution show a negative vertical gradient at night in the same size range, suggesting a possible PBAP source in the canopy.