Bioaerosol distribution and detection by WIBS

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Introduction

The importance of studying bioaerosols (fungi, bacteria, viruses etc.) and their distribution in the atmosphere originates from their possible role as CCN and IN, as well as their effects on health. As there are still large uncertainties surrounding processes impacted by bioaerosols, data from a variety of climates, weather conditions, altitudes and environments needs to be collected. In the past many studies have been carried out using offline sampling methods which are limited in their temporal resolution. WIBS is a new online device that could provide a solution for the lack of knowledge. It detects FBAP based on their ability to fluoresce, which is used to distinguish bioaerosols against non-biological particles. [1]

WIBS

Wideband Integrated Bioaerosol Sensor (WIBS-4)

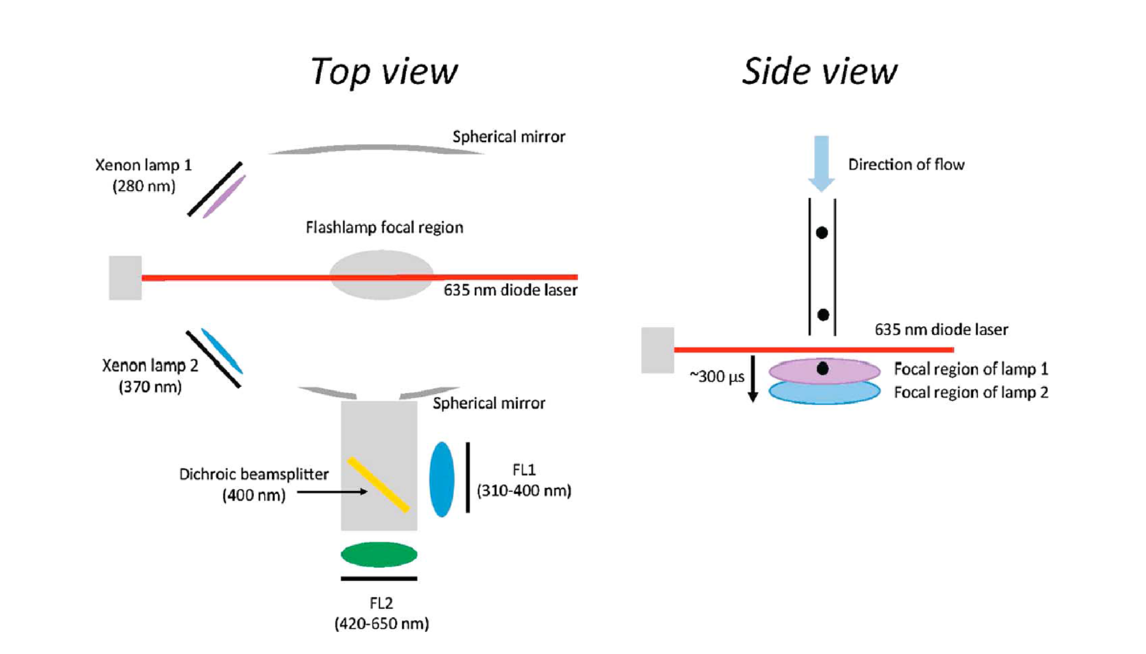

Figure 1. Schematic diagram of the WIBS detection cell as viewed from (left) above and the (right) side showing the orientation of the Xenon flash lamps, PMT detectors, red triggering laser, and spherical mirrors.

- detects FBAP in sizes from 1 μm to 10 μm in diameter
- uses UV-LIF (ultra violet light induced Fluorescence) with two Xenon lamps to excite at 280 nm and at 370 nm
- detects resulting fluorescence in two wavelength sections (310-400 nm, 420-650 nm)

The collected fluorescence signals are divided in channels

Table 1. The WIBS Excitation-Emission Matrix and the Fluorescent-Type Identities Discussed in the Text[a]

Excitation \ Emission		310–400 nm	420–650 nm
280 nm		Channel A	Channel B
370 nm		Detector Saturated	Channel C

[a]Type A = Signal in channel A only; Type B = signal in channel B only; Type C = signal in channel C only; Type AB = signal in channels A and B; Type AC = signal in channels A and C; Type BC = signal in channels B and C; and Type ABC = signal in channels A, B, and C.

Bacteria have two amino acids that fluoresce:

- Tryptophan: Channel A
- NADH: Channel C [2]

The combination of both channels (Type AC) was used in a one year study in Karlsruhe at the Nordcampus. [1]
With regard to the three fluorescent signals, there are seven possible spectral signatures which classify the bioaerosol types. Every particle can have a signal in one, two or three channels.

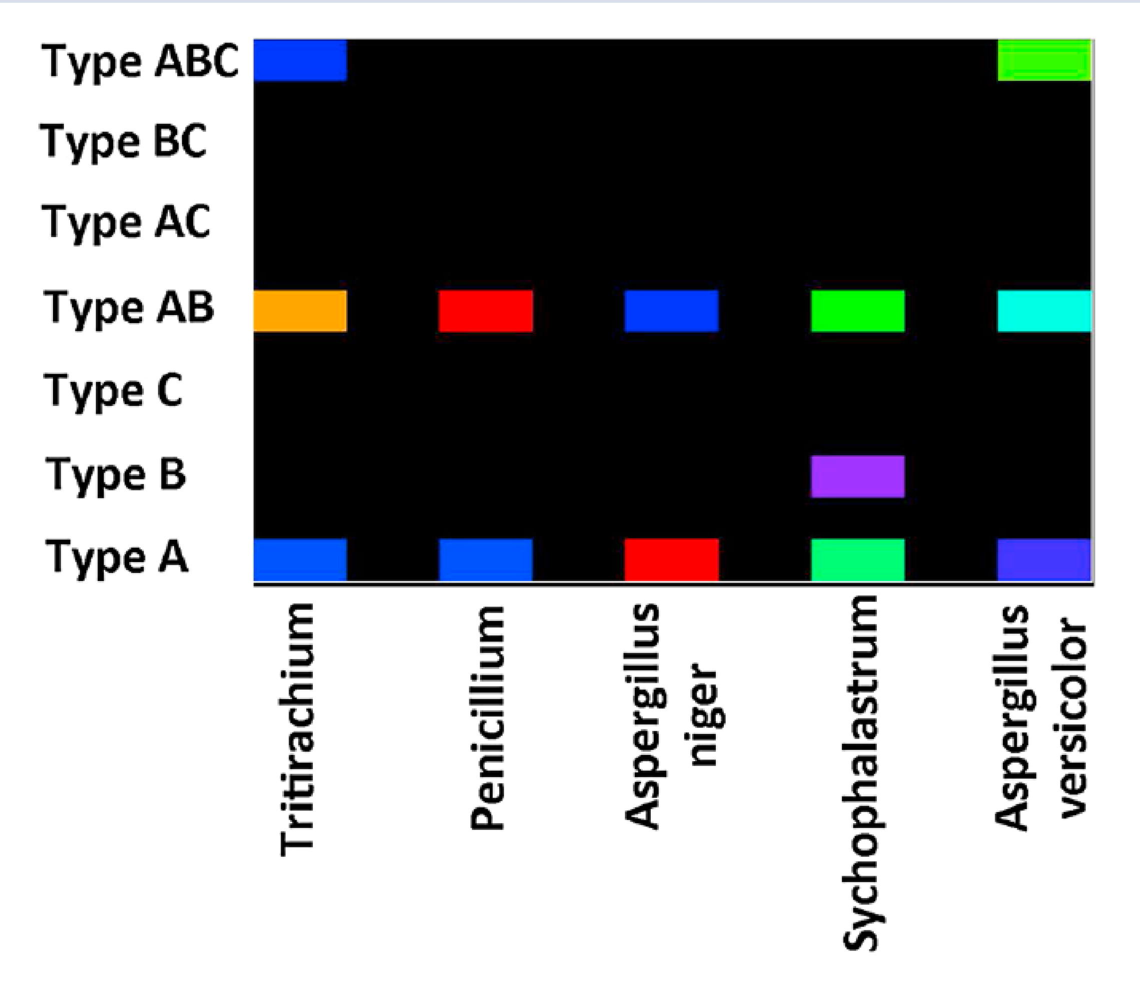

Figure 3. Type manifestations of known fungal spores in the NOAA WIBS during laboratory tests. The colors represent the fraction of that type of spore that appeared in the WIBS as a certain type.

Every type shows the presence of a particular particle population. Tritirachium for example manifests mainly in Type AB, but as well in Type A and Type ABC. All of the spores have a Type A signal, but differ at the other channels. This is used to identify the spores. [2] Type ABC was used to discriminate biological aerosol in an airborne study in the SEUS region. [3]

Temporal Variability

Seasonal cycle: one year study in Karlsruhe Nordcampus (semi-urban region)
→ Significant seasonal variability with the highest N_{FBAP} and f_{FBAP} in summer and lowest in winter

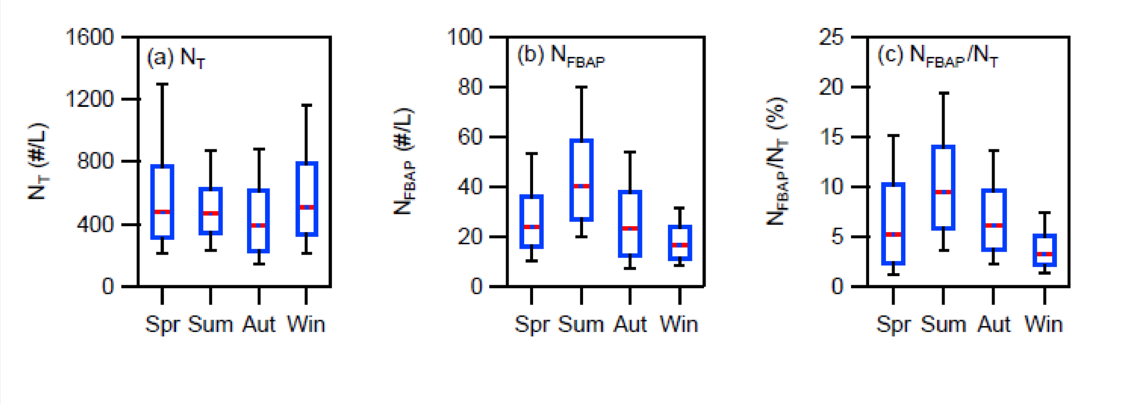

Fig. 8. Statistical representation of FBAP number concentrations and N_{FBAP}/N_T for different seasons as box-and-whisker plots. Red solid line represents median (50th percentile), lower and upper limits of blue box show 25th and 75th percentiles, respectively. The black error bars show 10th and 90th percentiles.

Links to Meteorological Conditions: airborne study in the SEUS region (figure 5):
Maximum N_{FBAP} at:

- no wind and no rain (6 September to 11 September)
- heavy rainfall and wind (14 August)

→ possibly due to different particles:
fungi spores are released at rainy conditions while bacteria emissions rise when it's dry and calm [3]

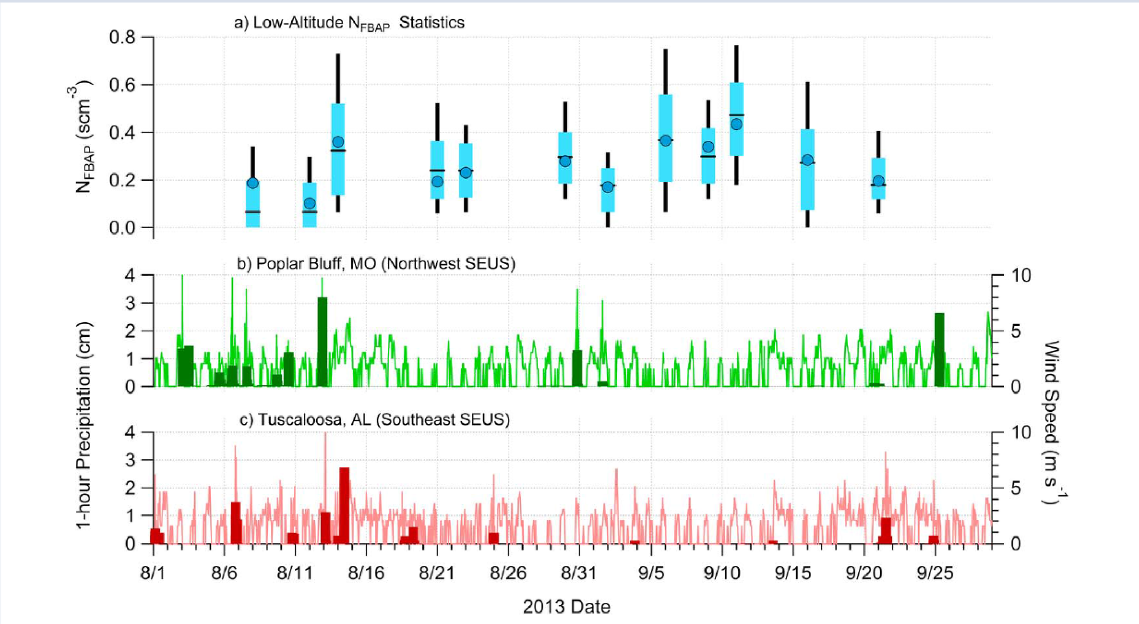

Figure 5. (a) Time series for flight-averaged N_{FBAP} statistics and meteorological parameters for (b) Poplar Bluff, MO and (c) Tuscaloosa, AL during SEAC[4]RS. For Figure 5a, circles are average values, horizontal lines are median values, the line extents are interdecile ranges (90th and 10th percentiles), and the box extents are the interquartile ranges (75th and 25th percentiles). All FBAP statistics reference low-altitude (less than 1 km pressure altitude) sampling. Dark bars (Figures 5b and 5c) are 1 h precipitation, and lines are wind speed.

Other studies: show dependency on relative humidity, [1,2], not found here

Spatial Variability

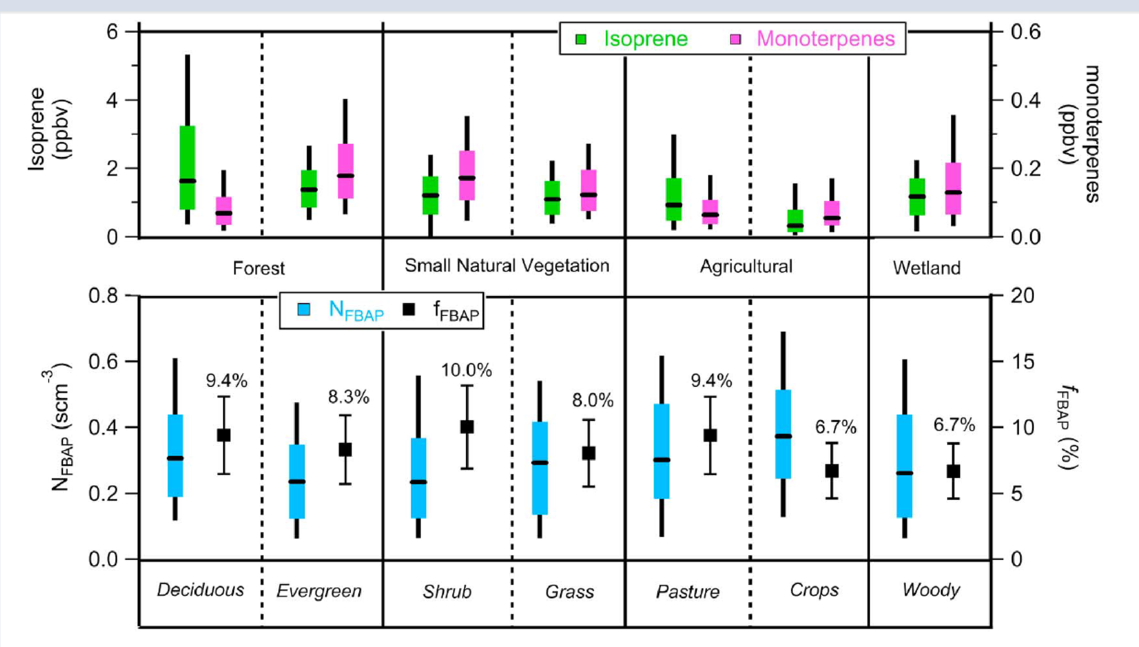

Figure 8. Campaign statistics for gas phase tracers (top, isoprene and monoterpenes) and (bottom) N_{FBAP}/f_{FBAP} are shown for the SEUS land types. Box and whisker values are shown for interquartile and interdecile values as in Figure 5a. Square symbols represent the calculated f_{FBAP} value for each land cover type with error bars representing the calculated uncertainty. Data are segregated by forests, natural vegetation, agricultural regions, and wetlands.

Low flights over various land cover:

- *Forests:* deciduous larger emissions than evergreen forests, mostly bacterial communities on leafy surfaces, large isoprene and monoterpene emissions
- *Small Natural Vegetation:* shrubs larger source than grasses, lack of coarse mode aerosol sources → high f_{FBAP} values
- *Agricultural Lands:* cropland largest emissions of FBAP → highest N_{FBAP} value, but also emission of mineral dust and other harvesting products → low f_{FBAP} values,
  isoprene and monoterpene emissions are suppressed
- *Woody Wetlands:* low f_{FBAP} → possibly source for non-fluorescent bio aerosols [3]

SEUS Region

Location where flights took place in the south east United States:

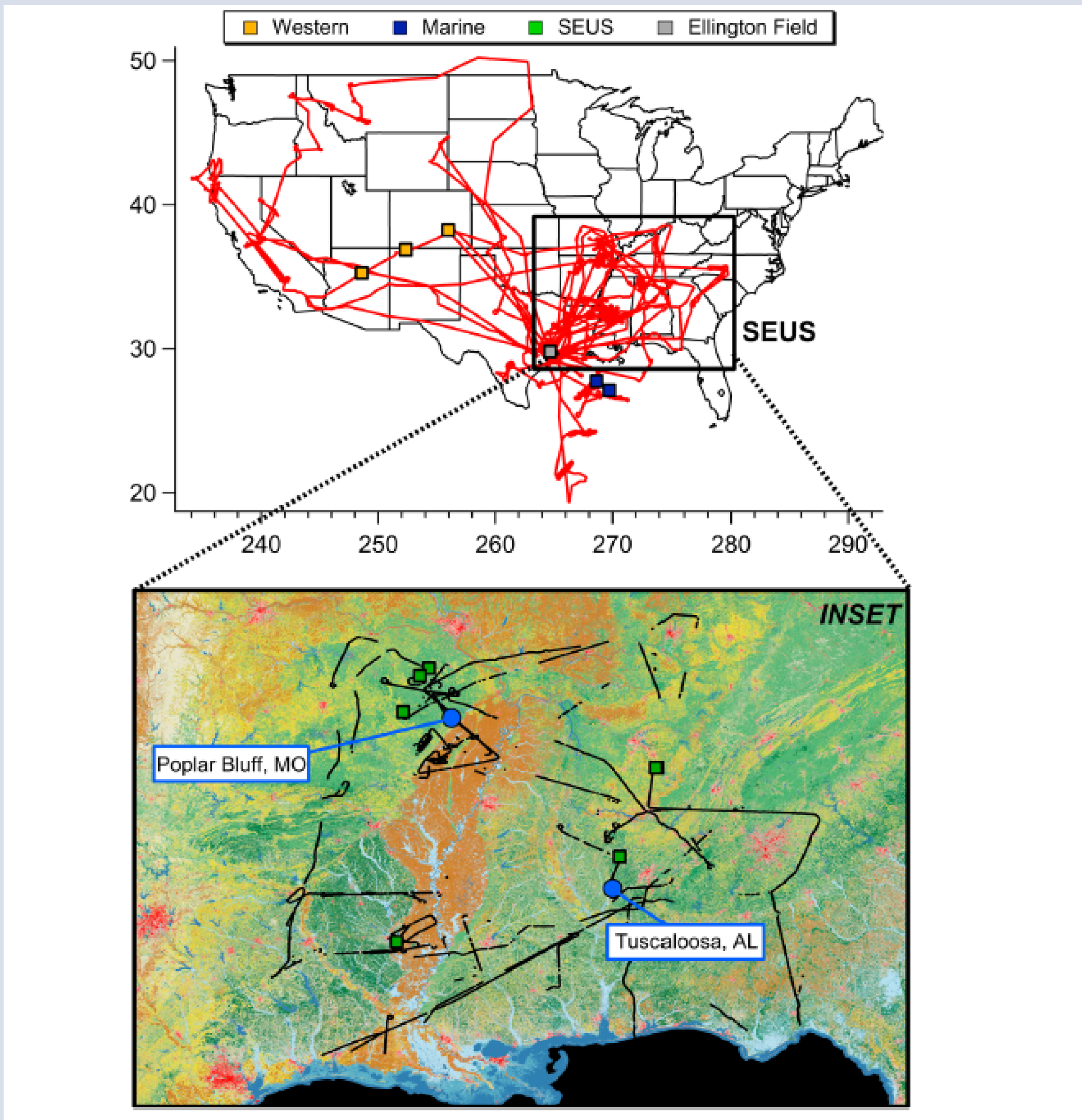

Figure 1. SEAC[4]RS flight tracks (red) and profile locations (squares). The targeted SEUS region is shown in the inset (bottom), with black lines representing low-altitude flight tracks. NLCD2011 land cover types are colored as follows in the inset: Developed land (red), evergreen forest (dark green), deciduous forest (light green), shrubs and grasslands (tan), pastures (yellow), cultivated crops (brown), and wetlands and open water (blue). Ground sites used for meteorological context in Figure 5 are shown as circles in the inset: Poplar Bluff, MO and Tuscaloosa, AL.

Vertical Variability

Quantification of vertical FBAP transport through vertical transport efficiency (VTE, right panel figure 8), with the effect of dilution corrected, calculated at each 0.5 km altitude step

$$VTE = \frac{\text{FBAP concentration at certain altitude}}{\text{ground-level FBAP concentration}} \quad (1)$$

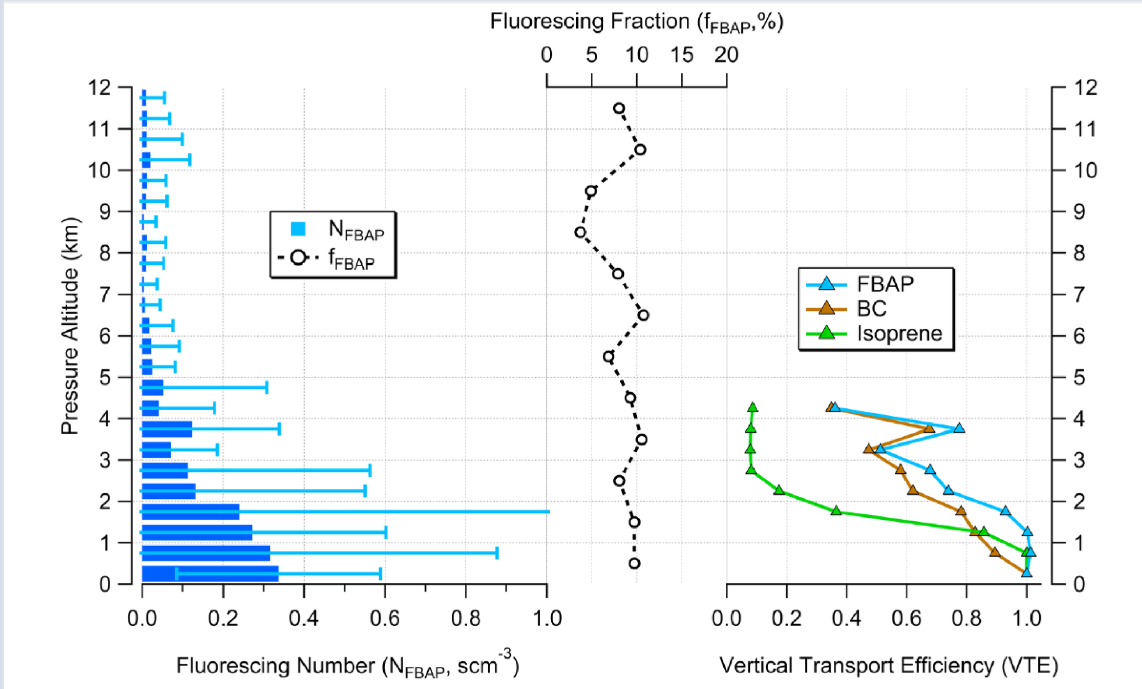

Figure 10. Average full-campaign vertical profiles from the SEUS region for (left) N_{FBAP}, (middle) f_{FBAP}, and (right) vertical transport efficiency. Error bars represent the average N_{FBAP} ±1 standard deviation.

f_{FBAP} and N_{FBAP}:

- Boundary layer (BL):
  main source of bio aerosols
  → largest N_{FBAP}
- Middle of the troposphere:
  genereal decrease of N_{FBAP} with increasing altitude but additional source through moderate convective lofting
- Free troposphere:
  low concentrations, but small secondary maxima at 8-8.5 km and 10-10.5 km [3]

VTE:

- FBAP transported similarly effective out of the BL as BC if not better
- although FBAP are large, they survive long enough to be transported out of source region in BL

Abbreviations

FBAP: Fluorescent bio aerosol particle
f_{FBAP}: Fraction of bio aerosols over total aerosol
N_{FBAP}: Number of particles per standard cubic centimeter
IN: Ice nuclei
CCN: Cloud condensation nuclei
BL: Boundary layer
BC: Black carbon
SEUS: Southeast United States
VTE: Vertical transport efficiency

References

[1] E. Toprak and M. Schnaiter, "Fluorescent biological aerosol particles measured with the waveband integrated bioaerosol sensor wibs-4: laboratory tests combined with a one year field study," *Atmospheric Chemistry and Physics*, vol. 13, no. 1, p. 225, 2013.

[2] A. E. Perring, J. P. Schwarz, D. Baumgardner, M. T. Hernandez, D. V. Spracklen, C. L. Heald, R. S. Gao, G. Kok, G. R. McMeeking, J. B. McQuaid, and D. W. Fahey, "Airborne observations of regional variation in fluorescent aerosol across the United States," *Journal of Geophysical Research: Atmospheres*, vol. 120, no. 3, pp. 1153–1170, feb 2015. [Online]. Available: http://doi.wiley.com/10.1002/2014JD022495

[3] L. D. Ziemba, A. J. Beyersdorf, G. Chen, C. A. Corr, S. N. Crumeyrolle, G. Diskin, C. Hudgins, R. Martin, T. Mikoviny, R. Moore, M. Shook, K. L. Thornhill, E. L. Winstead, A. Wisthaler, and B. E. Anderson, "Airborne observations of bioaerosol over the Southeast United States using a Wideband Integrated Bioaerosol Sensor," *Journal of Geophysical Research: Atmospheres*, vol. 121, no. 14, pp. 8506–8524, jul 2016. [Online]. Available: http://doi.wiley.com/10.1002/2015JD024669