Distinguishing a magmatic CO_2 degassing signature from a biogenic CO_2 signature

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PURPOSE: Using CO_2 degassing fluxes to infer the presence of a magmatic CO_2 signature in the Northern Appalachian Anomaly area.

Introduction

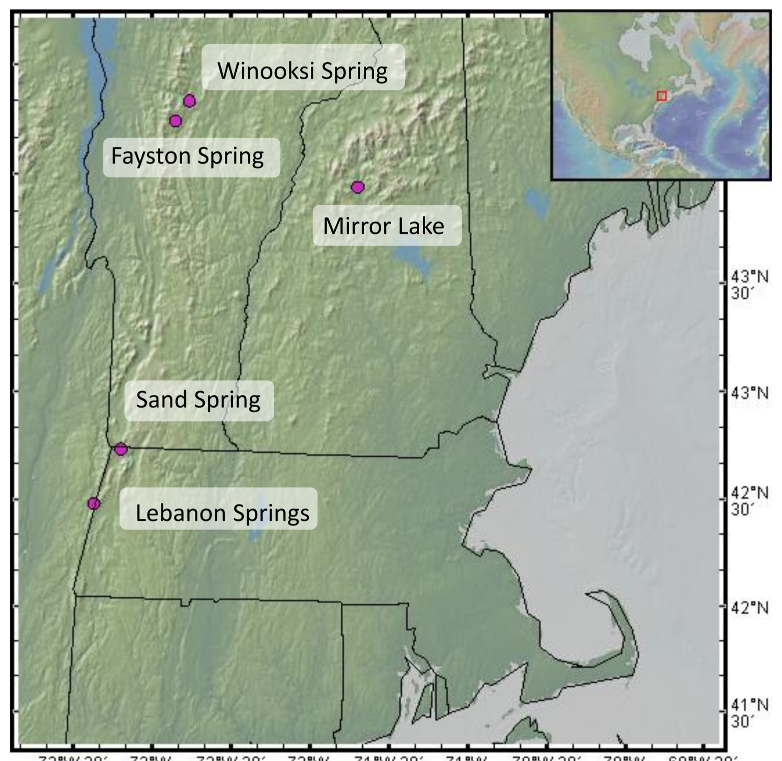


Figure 1. Locus map showing where the Northeastern Coastal USA CO_2 flux data was taken with an EMG-5 CO_2 Gas Analyzer.

- The Northern Appalachian Anomaly is a thermal anomaly inferred from shear wave velocities beneath New England and interpreted as a mantle plume.
- Possible evidence of magmatism is investigated here by analyzing soil CO_2 flux emissions in areas surrounding regional springs in NY, MA, NH and VT.
- To test the presence of magmatism at depth, we measured the flux of diffusely degassing soil CO_2.
- Areas where springs are present were sampled, because the water traveling from within the Earth's crust, and sometimes deeper, exploit the easiest pathway to reach the surface, and we expect that CO_2 would exploit similar paths.

Vegetation Type	g CO_2 m^{-2} d^{-1}
Tundra	0.6 ± 0.06
Mediterranean woodlands and hearth	0.94 ± 0.16
Tropical savannas and grasslands	2.25 ± 0.38
Northern bogs and mires	3.23 ± 0.31
Tropical moist forest	4.15 ± 0.76
Desert Scrub	4.44 ± 0.78
Croplands, fields, etc.	5.46 ± 0.8
Temperate deciduous forests *	6.31 ± 0.53
Marshes	6.5 ± 0.51
Tropical dry forests	6.76 ± 1.35
Boreal forests and woodlands	6.84 ± 0.95
Temperate grasslands	7.16 ± 0.88
Temperate coniferous forests	12.7 ± 0.57
Biogenic Component (This study)	17.6 ± 7.65
Magmatic Component (This study)	48.6 ± 21.9

Table 1. Soil respiration rates for different vegetation types (Raich, J.W., 1992) in comparison to the data presented in this study from the Northeastern Coastal USA. Data from this study is presented with a purple background, the vegetation type of NE Coastal USA is presented with a grey background.

*Including mixed broad-leaved and needle-leaved forests

Sara (left) using the EGM-5.

Arianna (right) in front of a spring! (Spring pictured was not used in this study)

CO_2 Data Analyses

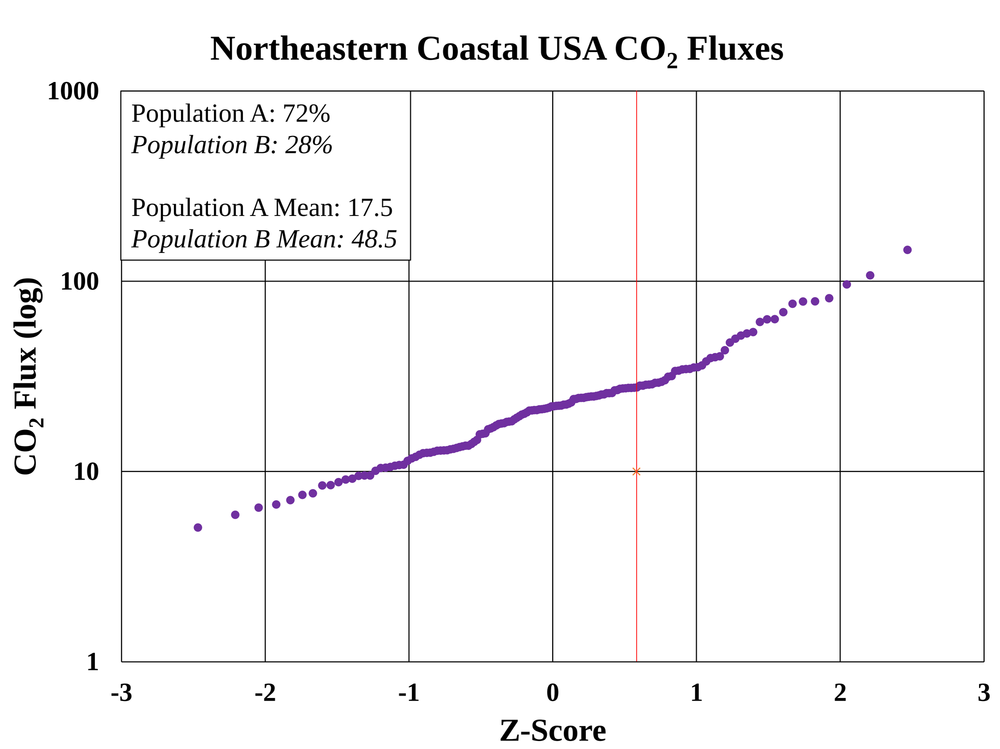
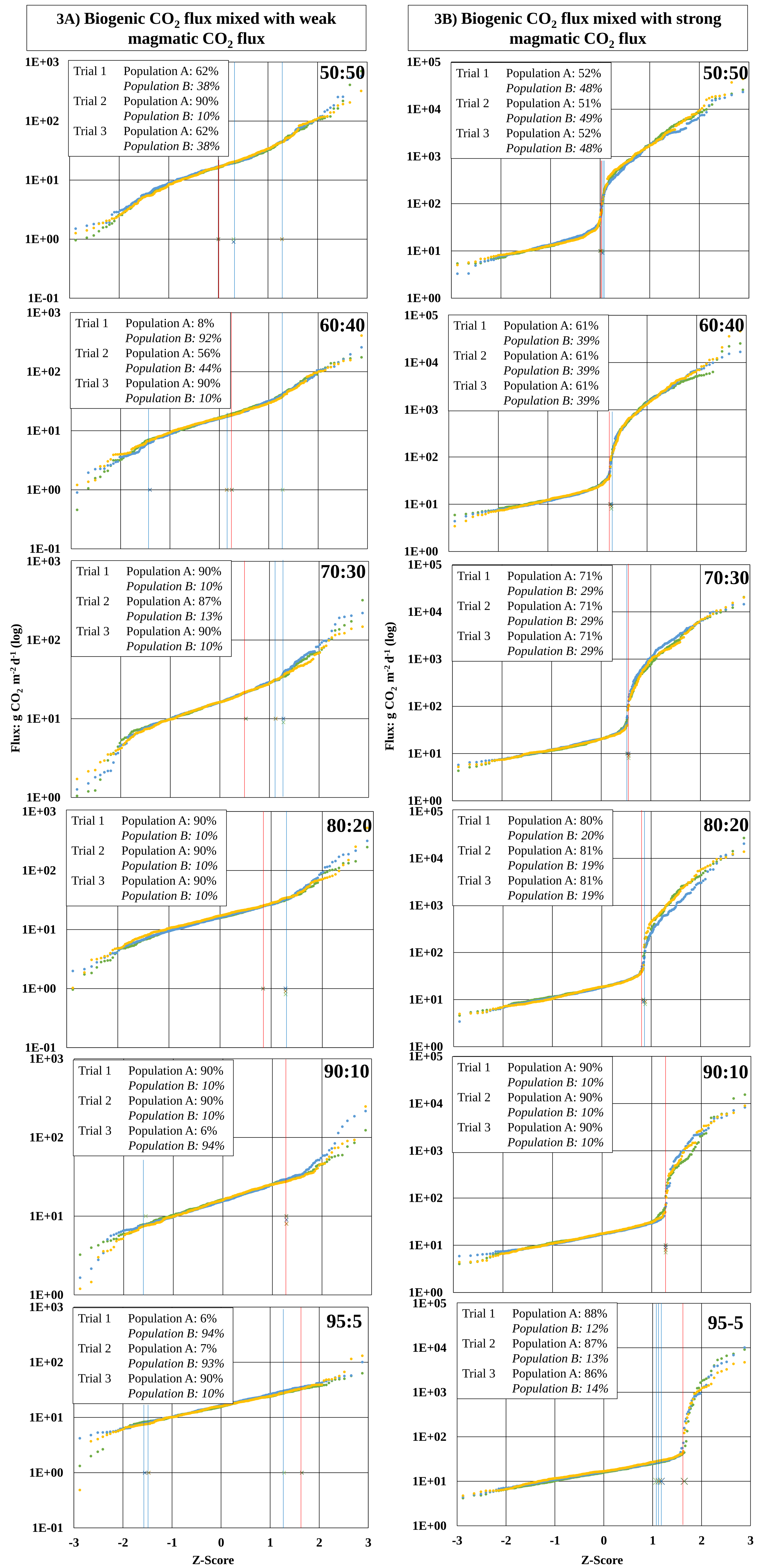


Figure 2. Log probability plot of the CO_2 flux data collected in the Northeastern Coastal USA. The "x" and the red line shows the placement on the graph where population A ends and Population B begins.

- CO_2 concentrations and Linear Flux (gCO_2 m^{-2} h^{-1}) were taken with an EGM-5 Portable CO_2 Gas Analyzer.
- The EGM-5 was used to cover a geographic area ranging from ~0.1-1.0 miles^2 surrounding 5 different locations (Figure 1).
- A code was used to statistically discriminate the possible presence of two geochemical populations.
- Two distinct populations have been found indicating the presence of a biogenic CO_2 signature and magmatic CO_2 signature in the Northeastern Coastal USA region.



Data Modeling

- The CO_2 fluxes in the Northeast Coast of the United States are quite high (mean CO_2 flux of 26 g m^{-2} d^{-1}), similar to magmatic fluxes observed in regions of weak magmatic CO_2 degassing (e.g., Natron Basin, Tanzania). Population A of the Northeastern Coastal USA CO_2 fluxes (Figure 2) was used as the biogenic component in the modeling.
- To investigate the potential range of magmatic fluxes that could be discriminated from these high background values, we generate several synthetic datasets using MATLAB.
- Each dataset represents biogenic and magmatic CO_2 flux components based on data obtained in this study and known regions with magmatic CO_2 fluxes (Natron Basin, Tanzania and Mammoth Mountain, USA).
- The two magmatic components selected have different signatures. Data from Lake Natron (Tanzania) display weak fluxes (mean CO_2 flux of 30 g m^{-2} d^{-1}) and are treated here as a weak magmatic component.
- CO_2 fluxes from Mammoth Mountain (USA) are considerably higher (mean CO_2 flux of 1,991 g m^{-2} d^{-1}) and are treated as an example of a strong magmatic component.
- The synthetic datasets are created and ran through a code on MATLAB. The code is a "Statistical approach for discriminating CO_2 flux populations" created by Emily Judd and her colleagues at the University of Syracuse.
- The code was generated using a similar approach to the Sinclair (1974) paper on discriminating between two geochemical populations.

Figure 3. Log Probability Plots graphically showing the comparisons between three trial runs (1-green, 2-blue, 3-yellow) to simulate the distribution of CO_2 fluxes obtained by mixing two controlled populations. Multiple trials are run to see how reliable the method is. Population A represents a background signal, in this study, the biogenic CO_2 flux, while Population B represents a magmatic CO_2 flux.
3A) Biogenic CO_2 flux mixed with weak magmatic CO_2 flux. This dataset appears to be a straight line, if a kink is not present it is not immediately evident, yet the code is identifying two populations.
3B) Biogenic CO_2 flux mixed with strong magmatic CO_2 flux. This dataset displays a distinctive kink. Also in this instance, two populations are observed, a magmatic population and a biogenic population.
The actual percent contribution used to generate the dataset is reported as a red line and a ratio in the top right corner. The obtained percent contributions are shown as a blue line.

Results

- The errors obtained while using the strong magmatic signal are consistently low <1% and only increase to ~9% when the magmatic contribution is 5%.
- The errors obtained while using the weak magmatic signal are widely variable ranging between 0 and 17% (excluding the anomalous samples) indicating that the program is able to find the two populations but the obtained % are not quite as reliable when the biogenic signal is similar to the magmatic signal.
- Additionally, four anomalous readings have been observed, with errors as high as 89%, while using weak magmatic signal. These extremely high errors are observed especially when the magmatic contribution is 10% or less.

Conclusions

- Synthetic datasets confirm our ability to identify magmatic signatures with both strong and weak signals.
- We hypothesize that these errors occurred due to the similar mean of the biogenic signal and the weak magmatic signal which creates a large overlap of the two populations.
- A second population has been identified in the Northeastern Region of the United States based on CO_2 degassing fluxes.
- The second population could be a mantle CO_2 signal, consistent with the mantle anomaly identified based on seismic data, or the signal could have been produced by different types of vegetation.

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References:
Cardellini, C., Chiodini, G., & Frondini, F. (2003). Application of stochastic simulation to CO2 flux from soil: mapping and quantification of gas release. Journal of Geophysical Research: Solid Earth, 108(B9).

Levin, V., Long, M. D., Skryzalin, P., Li, Y., & López, I. (2017). Seismic evidence for a recently formed mantle upwelling beneath New England. Geology, 46, 87– 90. https://doi.org/10.1130/G39641.1

MATLAB and Statistics Toolbox Release 2019b, The MathWorks, Inc., Natick, Massachusetts, United States.

Muirhead, J.D., Fischer, T.P., Lazier, A., Oliva, S. J., Judd, E.J., Lee, H., Kazimoto, E., Kianji, G., Ebinger, C.J., Sharp, Z. D., Dufek, J., 2018, Constraining variability in mantle CO2 flux along the East African Rift System: GeoPRISMS Newsletter, Issue No. 41.,

Muirhead, J.D. et. al, Statistical approach for discriminating CO2 flux populations. 2019 wordpress

Sinclair, A., 1974, Selection of threshold values in geochemical data using probability graphs: Journal of Geochemical Exploration: 1974, 3: 129-149.