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Investigation of cave-air CO_2 source

Problem Formulation

I am currently working on a research project with Dr. Dan Breecker, in which we are investigating the major source of carbon in cave-air CO_2, and by extension in speleothem calcite. Currently, the two major sources of cave-air CO_2 are considered to be atmospheric air and soil respiration (which comprises root and microbial respiration). However, data that I have been collecting appears to refute that soil air significantly contributes to cave air. Instead, we propose that respiration occurring in the bedrock is contributing significantly to cave air.

The main difference between respiration from these two sources is that soil gas undergoes diffusion, whereas air traveling through the bedrock does not undergo diffusion, but rather undergoes advection in the fracture network. We attempt to identify whether cave air has undergone diffusion in order to understand whether or not soil air is a major component of cave air. In doing so, we rely on the fact that diffusion changes the molecular ratios and isotopic composition of gases. By using the respiratory quotient (RQ, which is the number of moles of CO_2 produced per mole of O_2 consumed, defined here in relation to atmospheric air) of cave air compared to soil gas, it appears that cave air has not undergone diffusion.

In order to confirm these results, we also look at the stable carbon isotopic composition of cave-air CO_2 compared to soil gas CO_2. In order to conduct these comparisons, we subtract the atmospheric and diffusive components from soil gas, and compare these values to (1) cave air with atmospheric and diffusive components subtracted, and (2) cave air with atmospheric, but not diffusive components subtracted. If (1) is more similar to our calculated soil gas, this would indicate that soil gas is indeed a major contributor to cave air. On the other hand, if (2) is more similar to our calculated soil gas, this would corroborate our results obtained from RQ, which indicates that soil gas is not a major contributor to cave air, and that respiration from the bedrock is likely a major source of cave-air CO_2.

Oddly enough, the data I (and Breecker et al., 2014) have gathered is the case of (1), as described above. This poses a mystery, as two different methods of identifying whether or not air has undergone diffusion yield contradictory results. In effort to gain insight into this mystery, I created two maps for Natural Bridge Cavern South, and two maps for Inner Space Cavern. One of the two maps created for each cave contains a cave outline showing the differences between the carbon isotope values of soil and cave air, with atmospheric and diffusive components subtracted for both. The other map created for each cave was identical to this first map, except that only the atmospheric component was subtracted from the cave air, and not the diffusive component. The purpose of these maps is to identify whether there is a spatial trend between the different cave sites within each cave, which would indicate that there may be environmental variables affecting the proportion of respiration originating from the soil or bedrock. Such environmental variables could include soil permeability or abundance of bedrock fractures.

Data Collection and Preprocessing

Each map that I have created contains five layers in the end product: a satellite image, a cave outline, points showing cave air collection sites, a circle encompassing soil gas collection sites, and an interpolation (spline) of the values manually entered into the cave air collection points. The satellite image was obtained from the TNRIS GIS data website, in which the image contained coordinate points. The cave outline was a tiff file containing no spatial reference and needed to be georeferenced to the satellite image. The cave and soil collection sites were manually entered into ArcMap by creating a file geodatabase, and then a feature class. Prior to interpolation, two columns of data were entered into the attribute table of the cave air collection sites. The data entered is from measurements and calculations stored on excel spreadsheets that I have compiled from my research project. Using these data, I organized the data and calculated values specifically for this GIS project. I entered values in per mil (‰) in one column of the attribute table, of the difference between soil and cave values both corrected for atmospheric and diffusive components. The other column contained values, also in per mil, of the difference between soil values corrected for atmospheric and diffusive components, and cave values corrected for only the atmospheric component. An average of all soil stable carbon isotopic values was subtracted from respective isotopic values measured from each cave site. Each of the two columns was used for a single map (i.e. one column per map; two maps per cave). The spline tool was then used to create a raster which interpolated the values between each of the cave air collection sites.

ArcGIS Processing

Here are the ArcGIS processing steps that I took:

Load a satellite image from TNRIS GIS data containing the cave location **(figure 1)** → find and zoom into the specific cave location with the help of Google Earth **(figure 2)** → load the tiff file containing the cave outline **(figure 3)** → georeference the cave outline to the satellite image → create a file geodatabase → create a polygon feature class → digitize the cave outline so that the background color from the tiff image is not present **(figure 4)** → create a point feature class → label cave and soil sites with points on the cave outline, using Meyer et al. (2014) and Breecker et al. (2012) for a reference of cave site locations **(figure 5)** → calculate necessary values in excel **(figure 6)** → create a new floating point field in the attribute table of the cave air collection sites, and manually enter the values into the attribute table **(figure 7)** → create a new data frame containing the exact same layers of the first data frame → open the spline spatial analysis tool, for both data frames **(figure 8)**: under environments, open raster analysis and set a mask to the cave trace so that the interpolation stays within the cave boundary, and change the pyramid resampling technique from nearest neighbor to bilinear since the interpolation values should be continuous; for one data frame, choose values from one of the created columns in the cave site

attribute table, and for the other data frame choose values from the other column → change the spline symbology from "classified" to "stretched," and then change the stretch type to "minimum-maximum," in order to change the minimum and maximum values so that they are the same for both maps from the same cave, which enables the viewer to more easily see the difference between the two maps **(figure 9)** → label the cave sites by their room name (e.g. NBWS = Natural Bridge Well Shaft room).

All of these steps were used twice: once for Natural Bridge Cavern South, and once for Inner Space Cavern.

Data Presentation

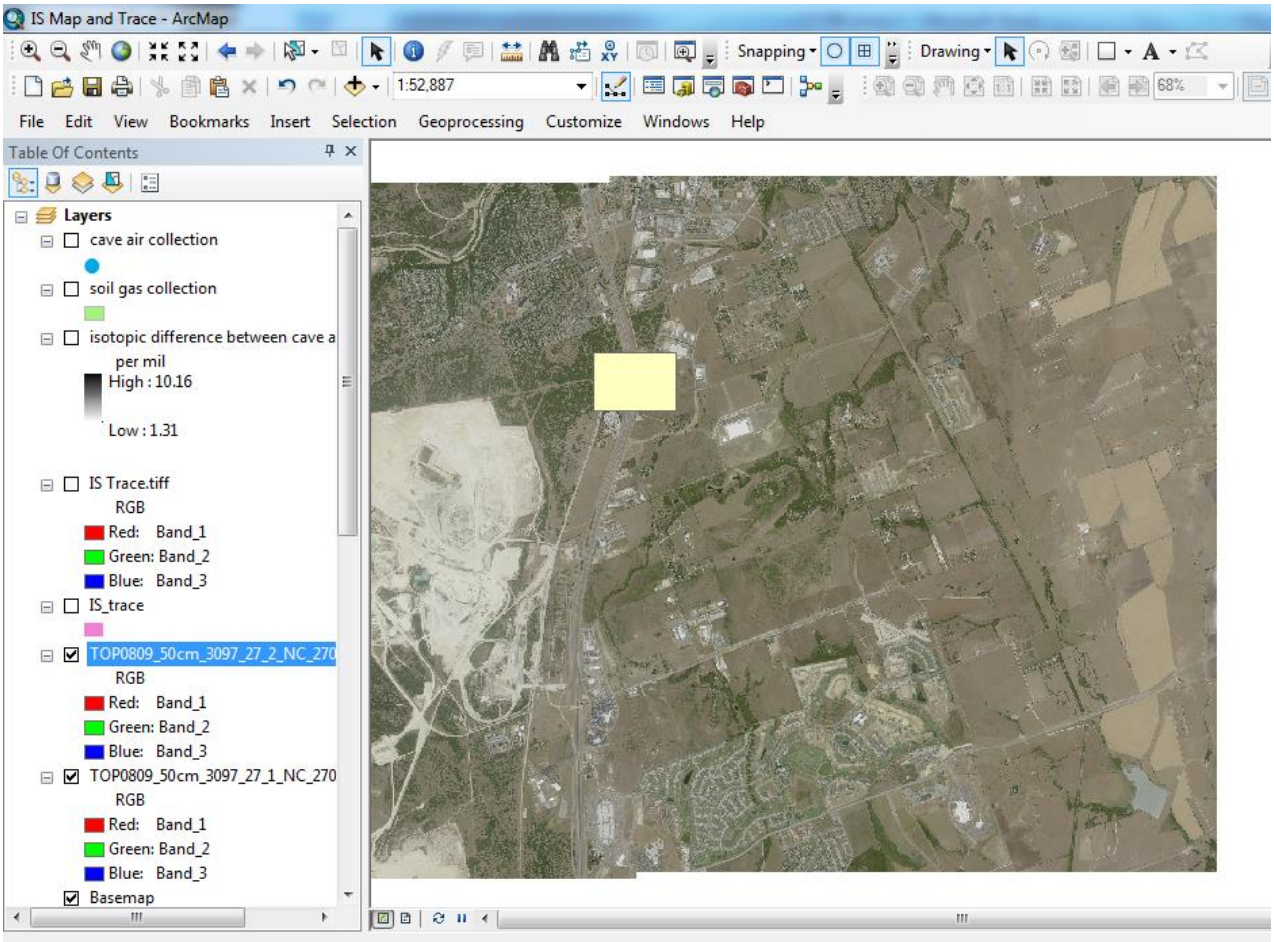


Figure 1: The full downloaded image from TNRIS GIS data. The white square in the southwest of the image shows the area covered by Inner Space Cavern in Georgetown, Texas.

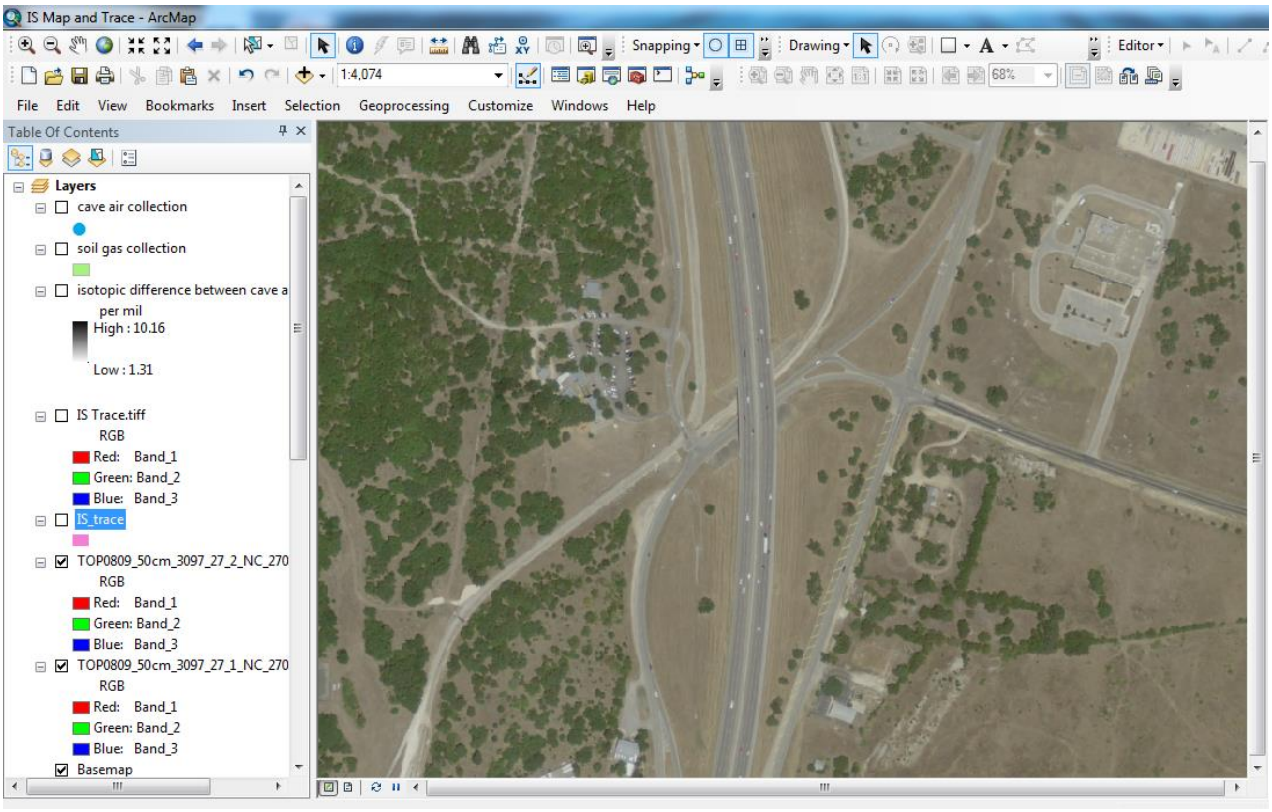


Figure 2: This is the close-up of the location shown in the white box from figure 1.

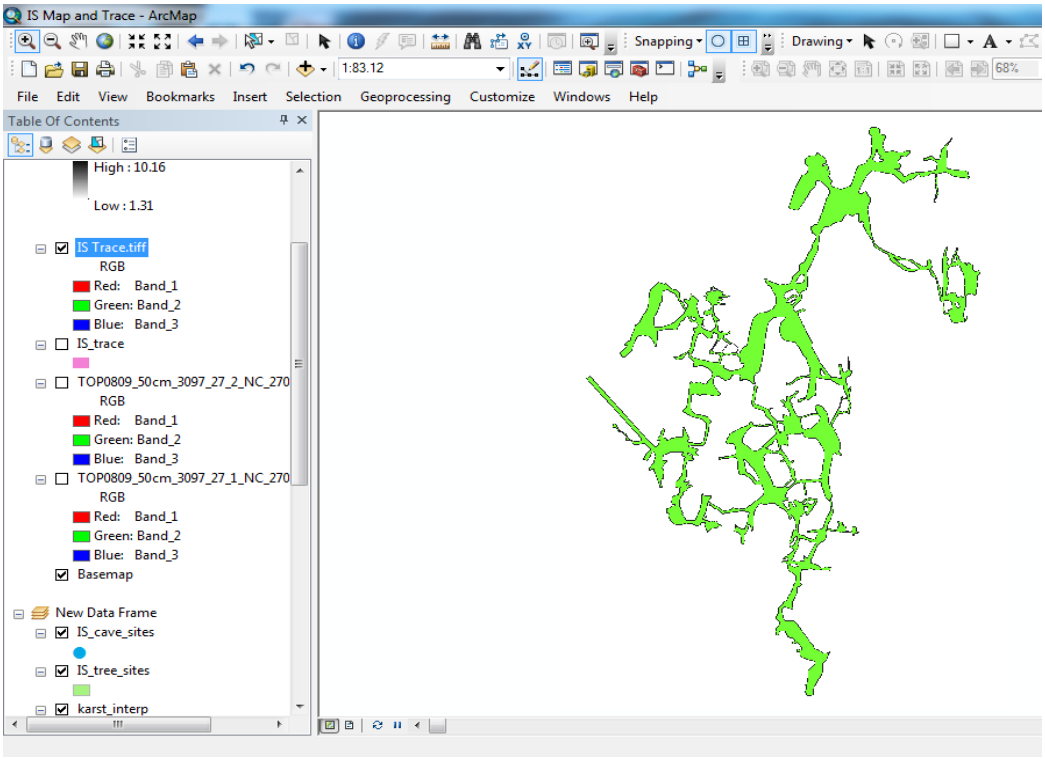
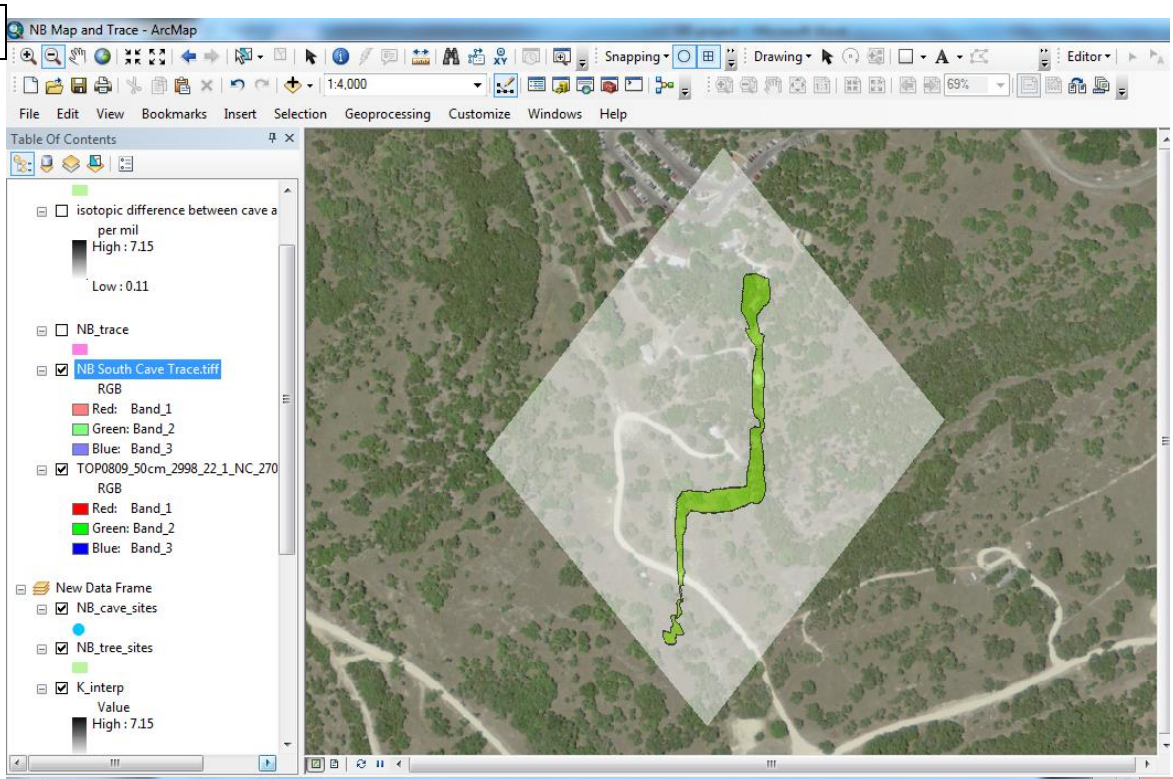


Figure 3: Tiff file of the trace of Inner Space Cavern, with no spatial reference.

A



B

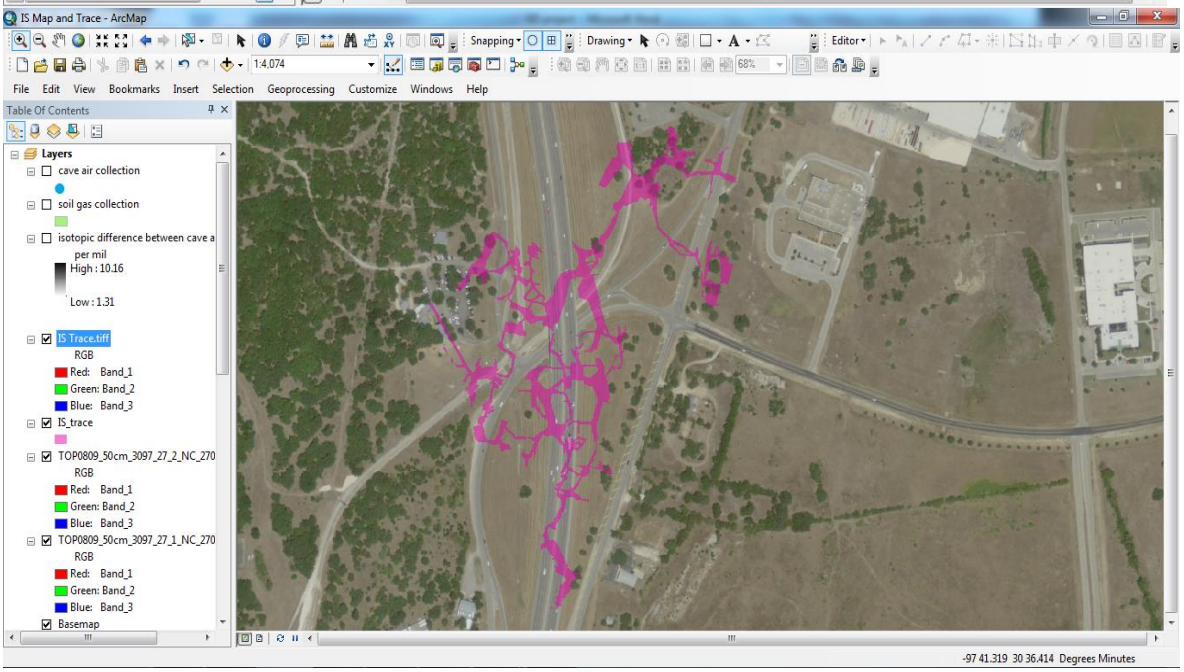


Figure 4: (A) shows the Natural Bridge Cavern South tiff file after being georeferenced to the satellite image. (B) shows Inner Space Cavern after being digitized. Natural Bridge is chosen for (A) because the Inner Space georeferenced tiff file may have accidentally been deleted.

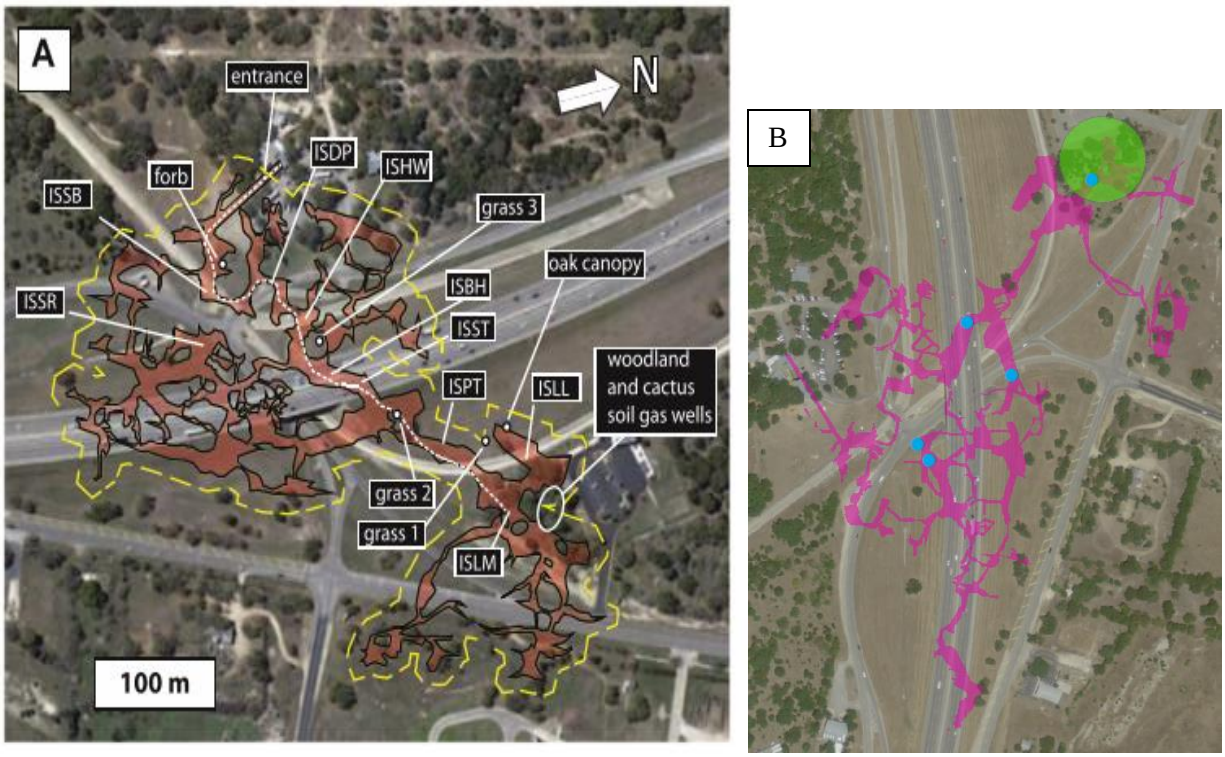
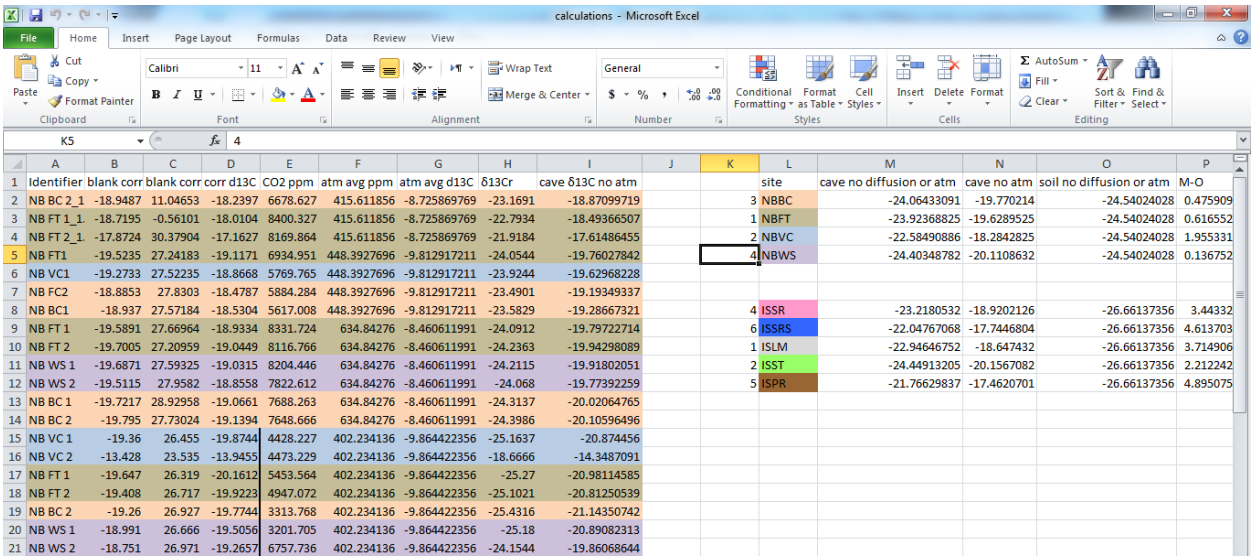


Figure 5: (A) shows a figure from Breecker et al. (2012) that was used to reference cave and soil collection sites for Inner Space. (B) Shows my cave collection sites as blue dots, and soil collection sites within the green circle. North points directly upward in (B).



calculations - Microsoft Excel

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Identifier	blank corr	blank corr	corr d13C	CO2 ppm	atm avg ppm	atm avg d13C	δ13Cr	cave δ13C no atm			site	cave no diffusion or atm	cave no atm	soil no diffusion or atm	M-O
2	NB BC 2_1	-18.9487	11.04653	-18.2397	6678.627	415.611856	-8.725869769	-23.1691	-18.87099719		3	NBBC	-24.06433091	-19.770214	-24.54024028	0.475909
3	NB FT 1_1.	-18.7195	-0.56101	-18.0104	8400.327	415.611856	-8.725869769	-22.7934	-18.49366507		1	NBFT	-23.92368825	-19.6289525	-24.54024028	0.616552
4	NB FT 2_1.	-17.8724	30.37904	-17.1627	8169.864	415.611856	-8.725869769	-21.9184	-17.61486455		2	NBVC	-22.58490886	-18.2842825	-24.54024028	1.955331
5	NB FT1	-19.5235	27.24183	-19.1171	6934.951	448.3927696	-9.812917211	-24.0544	-19.76027842		4	NBWS	-24.40348782	-20.1108632	-24.54024028	0.136752
6	NB VC1	-19.2733	27.52235	-18.8668	5769.765	448.3927696	-9.812917211	-23.9244	-19.62968228							
7	NB FC2	-18.8853	27.8303	-18.4787	5884.284	448.3927696	-9.812917211	-23.4901	-19.19349337							
8	NB BC1	-18.937	27.57184	-18.5304	5617.008	448.3927696	-9.812917211	-23.5829	-19.28667321		4	ISSR	-23.2180532	-18.9202126	-26.66137356	3.44332
9	NB FT 1	-19.5891	27.66964	-18.9334	8331.724	634.84276	-8.460611991	-24.0912	-19.79722714		6	ISSRS	-22.04767068	-17.7446804	-26.66137356	4.613703
10	NB FT 2	-19.7005	27.20959	-19.0449	8116.766	634.84276	-8.460611991	-24.2363	-19.94298089		1	ISLM	-22.94646752	-18.647432	-26.66137356	3.714906
11	NB WS 1	-19.6871	27.59325	-19.0315	8204.446	634.84276	-8.460611991	-24.2115	-19.91802051		2	ISST	-24.44913205	-20.1567082	-26.66137356	2.212242
12	NB WS 2	-19.5115	27.9582	-18.8558	7822.612	634.84276	-8.460611991	-24.068	-19.77392259		5	ISPR	-21.76629837	-17.4620701	-26.66137356	4.895075
13	NB BC 1	-19.7217	28.92958	-19.0661	7688.263	634.84276	-8.460611991	-24.3137	-20.02064765							
14	NB BC 2	-19.795	27.73024	-19.1394	7648.666	634.84276	-8.460611991	-24.3986	-20.10596496							
15	NB VC 1	-19.36	26.455	-19.8744	4428.227	402.234136	-9.864422356	-25.1637	-20.874456							
16	NB VC 2	-13.428	23.535	-13.9455	4473.229	402.234136	-9.864422356	-18.6666	-14.3487091							
17	NB FT 1	-19.647	26.319	-20.1612	5453.564	402.234136	-9.864422356	-25.27	-20.98114585							
18	NB FT 2	-19.408	26.717	-19.9223	4947.072	402.234136	-9.864422356	-25.1021	-20.81250539							
19	NB BC 2	-19.26	26.927	-19.7744	3313.768	402.234136	-9.864422356	-25.4316	-21.14350742							
20	NB WS 1	-18.991	26.666	-19.5056	3201.705	402.234136	-9.864422356	-25.18	-20.89082313							
21	NB WS 2	-18.751	26.971	-19.2657	6757.736	402.234136	-9.864422356	-24.1544	-19.86068644							

Figure 6: Some of my data in excel, which I entered into the cave air collection site attribute table.

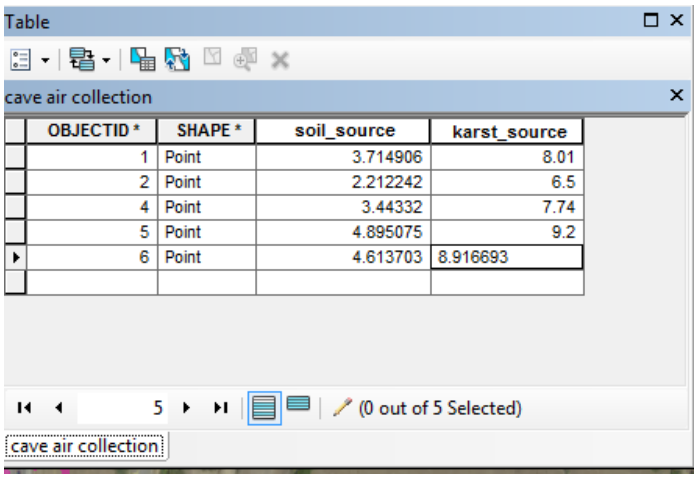


Figure 7: The attribute table of the cave collection points of Inner Space, after I have entered all of the necessary data.

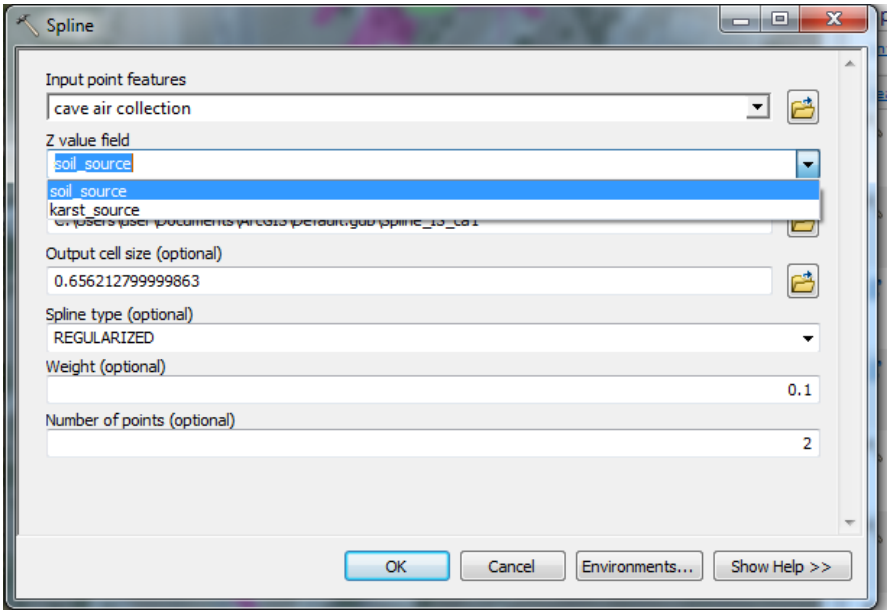


Figure 8: Spline tool.

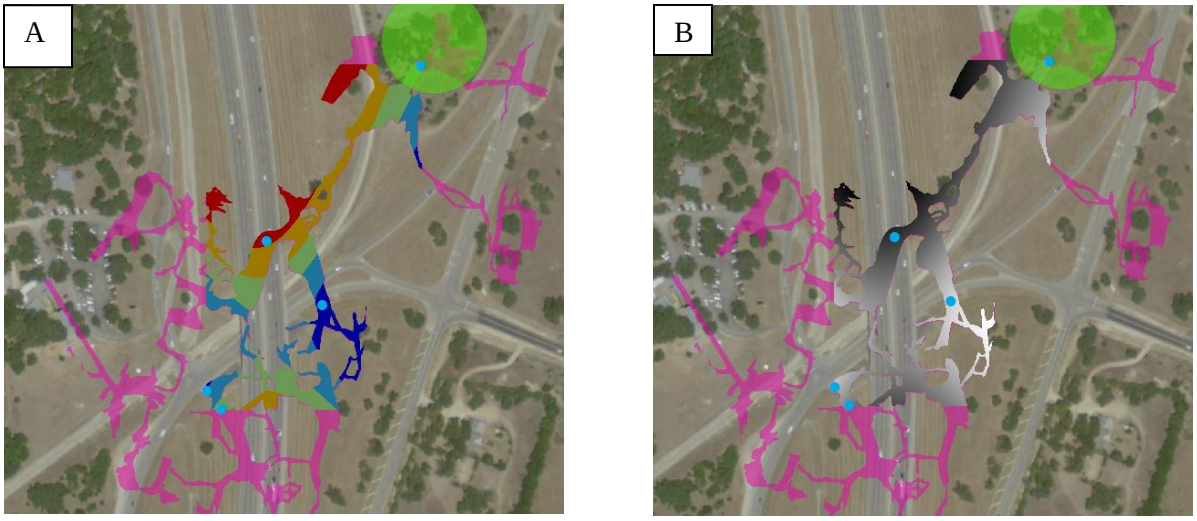


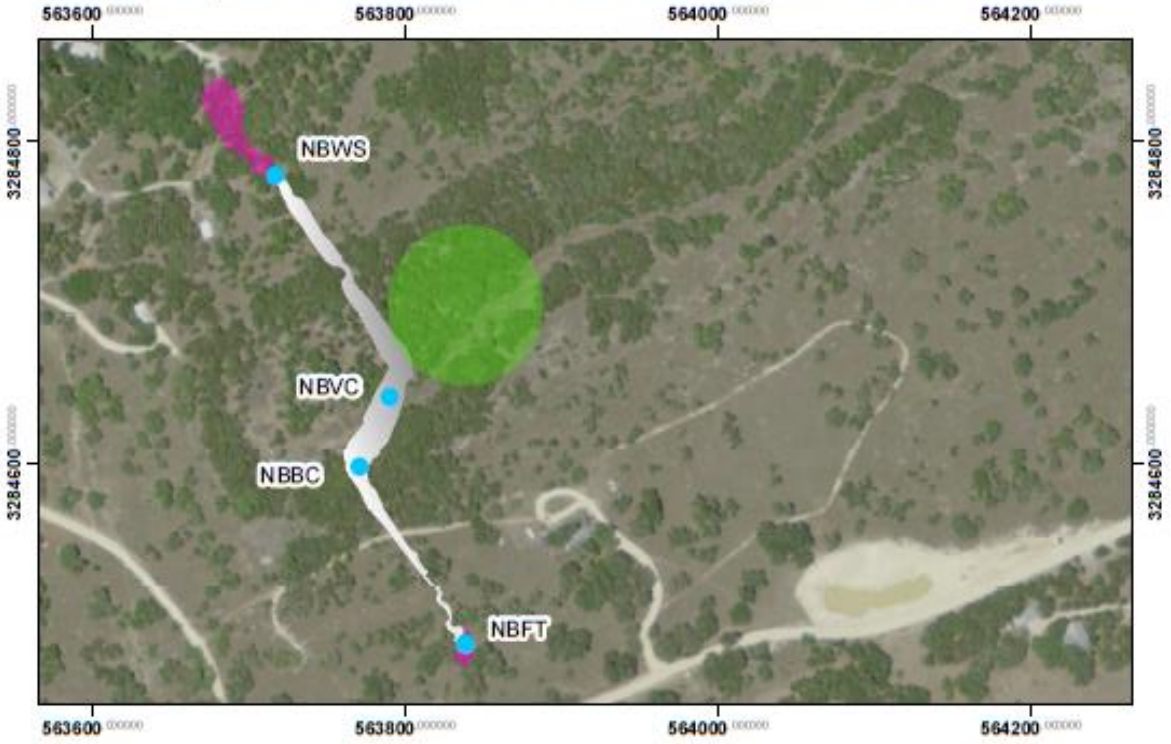
Figure 9: (A) shows the initial output from the spline tool, and (B) shows the same output, but with changed symbology. Only regions contained within a rectangle formed by the points are able to be interpolated.

Summary and Conclusion

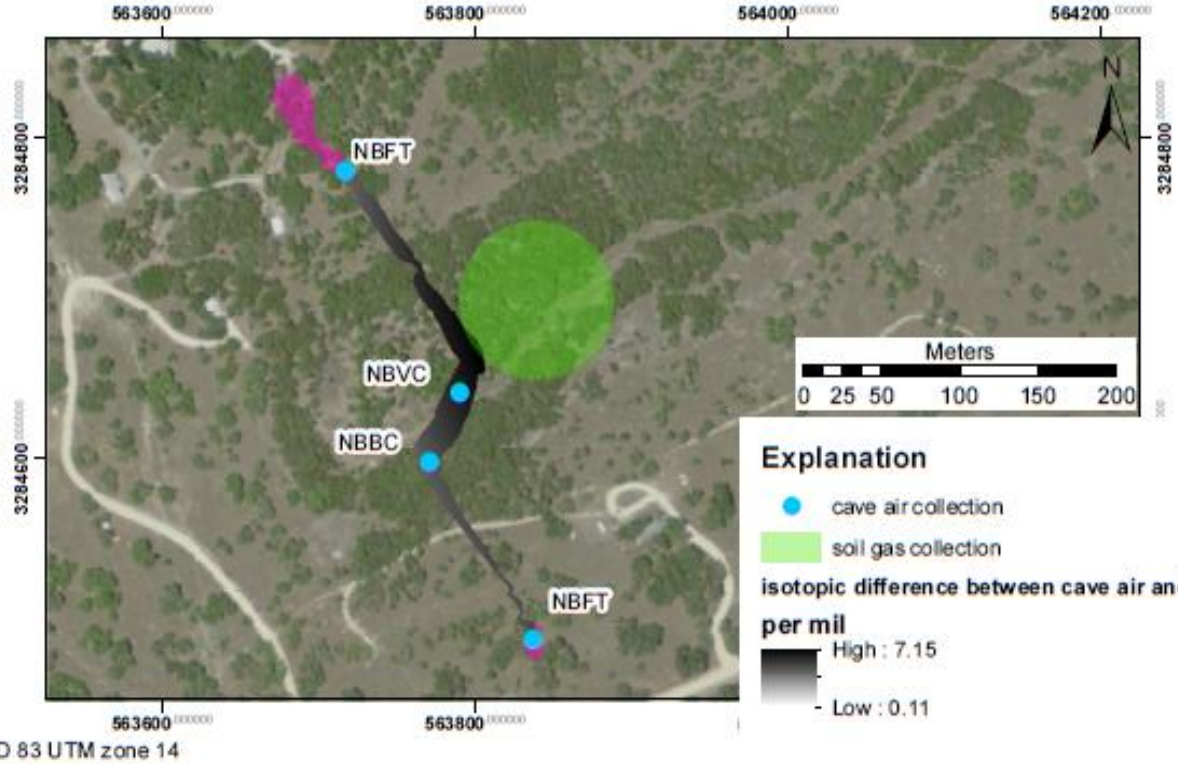
The question that I aimed to address by producing these maps is whether or not there is a spatial trend in the difference between corrected soil and cave air stable carbon isotopic values. I produced two maps from each of two caves, for a total of four maps. One map per cave addresses whether a spatial trend exists when cave air is corrected for both atmospheric and diffusive alterations. The other map addresses whether a spatial trend exists when cave air is corrected for the atmospheric input, but not for diffusive alterations.

It is clear from the maps that (1) cave air values are most similar to corrected soil gas values when cave air is corrected for both atmospheric input and diffusive isotopic alterations, (2) there is no strong spatial trend within a single map, and (3) general trends are similar from both caves, although the magnitudes are different. (1) had already been noted by simply observing the values in excel; however, the visualization strengthened the comprehensibility of the numerical observations. (2) rules out the possibility that there are local environmental differences within the area of one cave that influence the proportion of soil or bedrock respiration entering the cave. (3) is interesting in the sense that the differences between soil and cave air are larger in both corrections at Inner Space than at Natural Bridge. The reason for the difference between the two caves needs to be further explored in order to understand the reason for the magnitude differences. However, some possibilities explaining the variation may be due to higher urbanization and impermeable cover at Inner Space than Natural Bridge, or vegetative history. Most known characteristics of both cave locations are similar, such as amount of precipitation, atmospheric and cave temperature, and host rock units.

Carbon isotope comparison between soil and cave air corrected for atmosphere and diffusion at Natural Bridge Cavern South, TX



Carbon isotope comparison between soil gas corrected for atmosphere and diffusion and cave air corrected for only atmosphere at Natural Bridge Cavern South, TX



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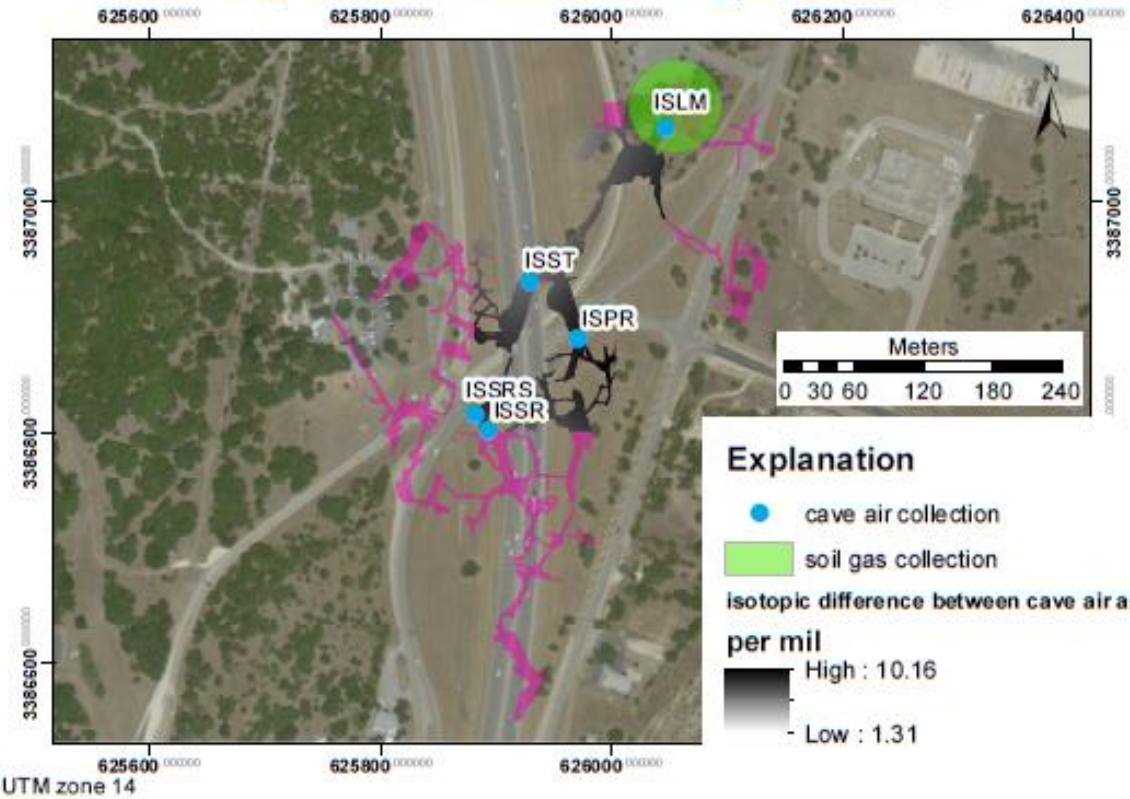
Carbon isotope comparison between soil gas corrected for atmosphere and diffusion and cave air corrected for only atmosphere at Inner Space Cavern, TX

Carbon isotope comparison beween soil and cave air corrected for atmosphere and diffusion at Inner Space Cavern, TX



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