Reconstructing Historical Temperature Records on the Bocas del Toro Reef Complex

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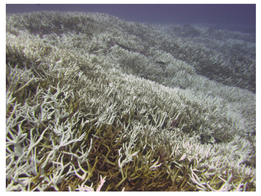
Introduction

Problem:

- Coral around the world are facing death and erosion
  - Negatively impacted by increasing temperatures and ocean acidification (Gattuso et al., 2015)
- The decline in coral health is easy to see through bleaching - when algae is expelled from coral tissue that surrounds their skeleton
  - Leaves coral without color or food, leading to death



Significance:

- Coral are crucial part of the ecosystem
  - Habitat for millions of marine species
  - Support rich biodiversity
- Humans feel benefits of coral reefs as well
  - Source of food
  - Protective barriers for coastlines
    - Reduce impact from waves/storms

Isotope Clumping

How it works:

- Light isotopes are significantly more common than heavier ones
  - Carbon-12 makes up 98.9% of carbon isotopes, Carbon-13 makes up 1.1%
- Random distribution of isotopes to isotopologues would result in:
  - Light isotopes only **(vast majority)**
  - Light isotopes and one heavy isotope **(significant amount)**
  - Multiple heavy isotopes **(very rare)**
- Isotopologues with multiple heavy isotopes are more stable than their lighter counterparts (Eiler, 2007)
  - Vibrate slower and have lower energy
  - Thermodynamic forces drive heavier isotopes to 'clump' together in isotopologues
    - Has less of an effect at higher temperatures
- Find difference between expected and measured abundance of isotopologues with multiple heavy isotopes to find what's known as Δ47 values
  - Deviation decreases as temperature increases so you can find temperature from Δ47 values (Affek, 2012)

Why this method:

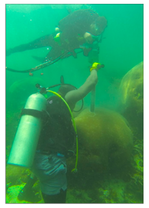
- Previous methods require isotope compositions of both the carbonates and surrounding water to find changes in temperature. (Ghosh, 2006)
  - There are no records of the isotopic composition of water in Panama

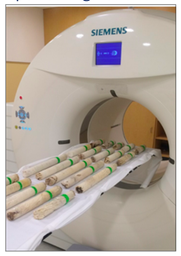
Hypothesis

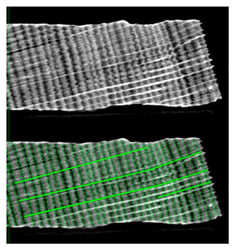
Hypothesis: The measured decline in coral growth in the Bocas del Toro Reef Complex in Panama is the result of increasing average temperatures over the last 50 years.

Methods

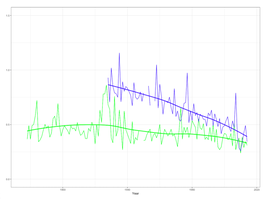
- Coral skeletal cores are extracted using a hydraulic drill
  - Study species: *Siderastrea siderea*
- Alternating density growth bands in coral cores are visualized using computed tomography (CT)
  - Skeletal extension rates are found by measuring the thickness of paired high and low density bands



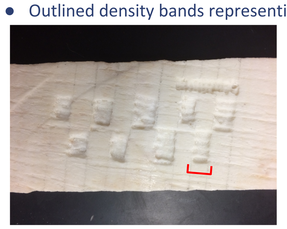




- We graphed the skeletal extension rates for the the coral cores over time
  - Chose two coral cores to use, one from inshore and offshore
  - Decided to investigate the years 1971-1979 and 2007-2015



- Outlined density bands representing our chosen years on each core



- Used a drill to mill across individual sections
- Collected samples from each year
- Samples were run three times through a mass spectrometer to measure the abundance of CO2 isotopologues for each year
- We will produce Δ47 values for each year by measuring the difference, in per mil, between measured and expected abundances of isotopologues (Eiler, 2007)

Additional Analysis

- We also took 15 samples along a short segment of the core to run through the mass spectrometer
  - Rather than looking at isotopologues, we were simple looking at the amount of Oxygen-18 isotopes present in the samples
    - Oxygen-18 isotopes correlate strongly with seasonal changes (Guzmán, 1998)

Results

- At this stage in the project our samples have been put in queue for the mass spectrometer, so we do not have final data

CO_2 mass	CO_2 isotopologue	Relative abundance
44	$^{12}C^{16}O_2$	98.40%
45	$^{13}C^{16}O_2$	1.11%
	$^{12}C^{17}O^{16}O$	748 ppm
46	$^{12}C^{18}O^{16}O$	0.40%
	$^{13}C^{17}O^{16}O$	8.4 ppm
	$^{12}C^{17}O_2$	0.142 ppm
47	$^{13}C^{18}O^{16}O$	44.4 ppm
	$^{12}C^{17}O^{18}O$	1.5 ppm
	$^{13}C^{17}O_2$	1.6 ppb
48	$^{12}C^{18}O_2$	3.96 ppm
	$^{13}C^{17}O^{18}O$	16.8 ppb
49	$^{13}C^{18}O_2$	44.5 ppb

TABLE 1.— Relative abundance of CO2 isotopologues assuming the surrounding water follows the VSMOW standard (standard isotopic composition) and isotopes are randomly distributed among isotopologues (Affek, 2012).

- Table 1 shows the expected abundances of CO2 isotopologues
  - We will compare the results from our sample with the isotopologue abundance outlined in red to create Δ47 values
    - We compare these isotopologues because the one outlined in red is the most abundant isotopologue with multiple heavy isotopes, making it easier to measure
- While our samples are waiting to be run through the mass spectrometer, we created a graph to show what our data might look like. Therefore, the following is not real data, but represents the expected outcome

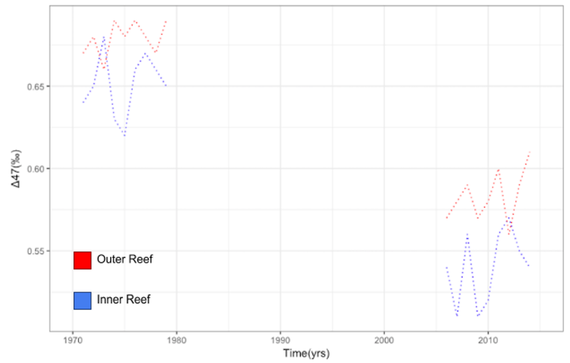


Figure 1.— Plot of Δ47 values for inner and outer reef corals for the years 1971-1979 and 2007-2015. Samples were gathered from two coral cores and run through a mass spectrometer. Δ47 values were found by comparing expected isotopologue abundance with actual result

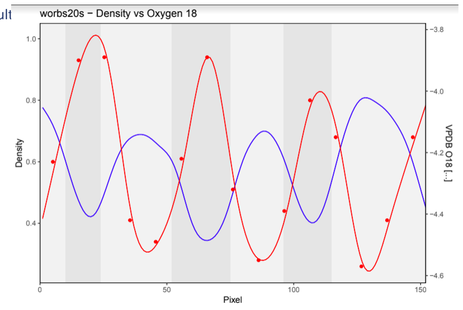


Figure 2.— Plot of Density vs. Oxygen-18 isotopes in samples, showing how density correlates with isotopic composition, which correlates with season changes like temperature. Oxygen-18 values were given by a mass spectrometer and density values were derived from the CT scans

Discussion/Conclusion

- The stability of heavy isotopologues is what causes deviation between measured and expected isotopologue abundance. At higher temperatures, the stability has less of an effect, which causes the deviation from expected to decrease (Eiler, 2007). Δ47 values represent the deviation from expected, so if they decrease, temperature has increased.
  - Figure 1 shows an expected drop in Δ47 values over time for both coral cores. These results would support our hypothesis: temperature has risen over the last 50 years.
  - We can also analyze Figure 2 to compare conditions in the inner and outer reef. In Figure 1, for most years the inner reef has lower Δ47 values. Therefore, we expect the inner reef to experience hotter conditions on average throughout the year.
- This project is important for refining the clumped isotope technique and will hopefully give us a better understand of the relationship between coral growth and temperature
- Our additional analysis (Figure 2) shows the relationship between Oxygen-18 and Density.
  - We know Oxygen-18 has a strong inverse correlation with temperature (Guzman, 1998)
  - When Oxygen-18 measurements are high, temperature is low, and density is low, so the CT scan shows a dark band.
    - This supports our hypothesis about light and dark growth bands
- In the future, other researchers can build off of this project by creating a more complete record over time. In addition, future research projects could measure sub-annual temperatures instead of a yearly average. This could provide valuable insight into historical seasonal conditions, which is beyond the scope of this analysis.

References

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