1. Understanding Climate Change
    a. This presentation is meant to communicate critical gaps in our knowledge of climate change. It is by no means comprehensive but is meant to be a framework to understand some of the science behind studying climate change. The presentation is most appropriate for middle to high school groups and was written to help teach students the impact of climate change on natural ecosystems especially coral reefs. If you have any questions, suggestions or comments you can contact the author, Raphael Ritson-Williams at raphswall@gmail.com. Raphael is a PhD student at the University of Hawaii who studies coral ecology, evolution and conservation. He is funded by STAR Fellowship Assistance Agreement # FP917660 awarded by the U.S. Environmental Protection Agency (EPA). This presentation has not been formally reviewed by EPA. The views expressed in this presentation are solely those of the authors, and EPA does not endorse any products or commercial services mentioned in this publication.
2. Where do trees get their mass?
    a. Where do trees get their mass? Many people will say nutrients/soil, but it is actually CO_2 from the air. Photosynthesis relies on CO_2 as a source of carbon. Most of the carbon in plants is extracted from the air. Any carbon that is fixed into mass is called a carbon **sink**. Any carbon that is released into the atmosphere is considered a **source**.
3. CO_2 Sources and Sinks
    a. We are changing the carbon cycle. By changing **sinks** to **sources** humans are increasing the concentrations of carbon dioxide in the atmosphere. Carbon dioxide can be found in short-term sinks/sources (plants, forests) and long-term sinks/sources (petroleum, coal). Removing vegetation (deforestation and harvesting trees) creates a source of CO_2 that is approximately 20% of the CO_2 we release. These are easy to sink back into forests and vegetation over years to decades through photosynthesis. This is comparable to a checking account where you spend money and you deposit money (but you maintain a stable balance). Using these short-term sources does not contribute very much to climate change because these sources are relatively easy to sink back into the environment in relatively short time periods.
4. CO_2 Sources and Sinks
    a. Long-term sinks were created millions of years ago and are now in the form of coal and oil, both of which are dead plants that have been compressed. Even though it is also plant derived carbon it has been stored under the land and ocean and has been removed from the carbon cycle for millions of years. This is comparable to a retirement savings account, the CO_2 is put away for long-term storage.

5. CO_2 Sources and Sinks
    a. Currently we are consuming long-term sinks to make gas, plastics, burning coal for electricity, etc. By extracting oil we have created a source where there used to be a stable sink (we are spending our retirement account). These long-term sources are very difficult to sink back into the environment. We currently do not have any technology to sink this long term CO_2, so now it is accumulating in the atmosphere and oceans. Of the CO_2 we release 30% rapidly sinks back into plants in the environment, 45% remains in the atmosphere and 25% is absorbed by the oceans.
6. Measuring CO_2 in the Air
    a. The Mauna Loa Observatory in Hawaii is one research station where scientists are measuring atmospheric CO_2 concentrations. This observatory is a great location to measure the atmosphere because it is on an island in the middle of the ocean far from large cities and local sources of CO_2 that obscures long-term trends.
7. Measuring CO_2 in the Air
    a. The concentrations of CO_2 also change on an annual cycle. This can be attributed to weather not climate. In this graph you can see that CO_2 concentrations fluctuate up and down during the year. The lowest point in a year is during the summer in the northern hemisphere and is due to increased plant growth (photosynthesis) removing CO_2 from the atmosphere (the northern hemisphere has more land mass so there are more plants consuming CO_2).
8. Changing CO_2 in the Air
    a. Scientists use air trapped in bubbles in ice to measure historical CO_2 concentrations. We can use historical data to determine how much variation in CO_2 concentrations is natural. In this graph you can see that during the last 650,000 years CO_2 concentrations in the atmosphere have never been as high as they are now. In 2013 CO_2 concentrations reached 400 parts per million (ppm). We know that increased concentrations of CO_2 traps more heat on the planet.
9. Measuring CO_2 in the Oceans
    a. Carbon dioxide also dissolves into the oceans. The purple points on this graph are the CO_2 concentrations in the oceans. You can see that as CO_2 concentrations increase in the atmosphere there is the same rate of increase in the oceans.
10. Measuring pH in the Oceans
    a. As CO_2 concentrations increase in the oceans it changes the pH of seawater. You can see this in the graph with the blue points (axis on the right). This is referred to as ocean acidification. Notice that the purple and blue graphs have inverse slopes, there is a direct (inverse) relationship between the CO_2 concentrations in the oceans and the pH in the oceans.

11. The pH Scale
    a. The pH of the oceans has already decreased, referred to as "ocean acidification". pH is a logarithmic scale and ranges from 14 which is the most basic to 0 which is the most acidic. Acidic things like lemon juice are around 2 on the pH scale and natural seawater was 8.12.
12. Changing pH in the Oceans
    a. Since 1700 the pH has gone down approximately 0.11 units (since it is on a log scale this is a large change in pH). As seawater chemistry changes it is more difficult for the calcifying organisms to extract calcium carbonate out of seawater to make their shells and skeletons. This threatens many different animals including plankton, oysters and clams, and corals that build islands and protect shorelines.
13. Coral Killers-Ocean Acidification
    a. As seawater absorbs more carbon dioxide the pH and alkalinity change. Coral reefs are especially threatened by climate change and as pH decreases coral skeletons can dissolve; however, it is important to know that the research for dissolving skeletons tests corals at very acidic pH values probably more extreme than those seen in the next 300 years.
14. Coral Killers-Ocean Acidification
    a. We are still studying the impacts of Ocean Acidification on coral communities. Preliminary studies show that some coral species can't grow and have reproductive failure in OA conditions. In natural CO_2 seeps in Papua New Guinea we see that some corals will survive OA conditions but other do not, suggesting that we will lose the diversity of corals on reefs and instead will be left with few corals and more algae.
15. Coral Killers-Rising Temperatures
    a. Global climate change can also stress and kill corals. More carbon dioxide in the atmosphere increases the temperature of the atmosphere and the temperature of the sea surface (shallow zones of the ocean). Increased sea temperature causes bleaching which is a break down in symbiosis. Corals thrive at ocean temperatures between 26-27 °C (79-81 °F). This graph shows the mean of sea surface temperatures from around the world between 1971-2000 (indicated as the blue line at 0), the orange line is the amount of change from the mean. See how the temperatures used to be below the mean and now they are consistently above the 0 line. You can see that temperatures have consistently been above average during the recent decades. Sea surface temperatures have been higher in the last 3 decades than at any other time since 1880.
16. Coral Killers-Bleaching
    a. Corals live together with algae. This symbiosis gives the algae a home and the algae give the coral food in the form of sugar. Coral bleaching is a stress response of corals where they lose their algae, greatly reducing their food supply.

b. Higher temperature means the algae can not produce as much sugar and they start to release toxins instead, so the coral releases the algae from its tissues. An analogy is a tenant (the algae) stops paying rent to it's landlord (the coral) and gets kicked out of it's home. Once the algae are gone, the coral has a white appearance and is said to be "bleached." In this slide you can see how the same species of coral looks when it is bleached and healthy.

17. Coral Killers-Bleaching
    a. During bleaching photosynthesis in zooxanthellae stops working well. Instead of sugar the zooxanthellae make reactive oxygen species (superoxide radicles and hydrogen peroxide) that are toxic to the corals. Thus the corals kick the zooxanthellae out of its tissue much like you would evict a renter that destroyed your house.
18. Coral Killers-Bleaching
    a. In extreme cases whole reefs can be bleached. Coral bleaching can kill corals, but it depends on the species of coral and how long the bleaching stress persists. Coral can survive for a little while without algae (weeks to months), but if high seawater temperatures persist the coral colonies will die.
19. Coral Killers-Bleaching
    a. Major bleaching events have been recorded in 1998 and 2005 both of which had El Nino weather patterns. This year (2015) is forecast to be another extreme El Nino year. Watch the popular press for stories of coral bleaching across the Pacific Ocean.
20. Interacting Stressors
    a. As coral bleaching is becoming more frequent and sever we are starting to see that this stressor combined with other local stressors (overfishing, competition with algae, water quality and pollution) can cause more stress and death than either stressor alone. We are just beginning to understand the complexity of how multiple stressors interact to harm natural ecosystems.
21. Global Value of Reefs
    a. These limestone reefs are really important to us (people) since they provide habitat for diverse species, seafood that we eat, protection of coastlines from wave damage, and a sustainable source of revenue from tourism. Globally, the estimates of coral reef economic values range widely but the values shown here are a conservative estimate. Already there are 2 medicines made from coral reef animals, but the potential to find novel medicines is huge. Sponges and soft corals contain many different types of medicinal compounds that may be effective treatment for cancer and have antibacterial activity.
22. Hawai'ian Coral Reefs
    a. The reefs in Hawaii are valued at $800 million a year, mostly from the tourist dollars that they attract to the islands.

23. Recovering Reefs
    a. But there is hope. There are still coral reefs like this on the planet. High coral diversity and healthy colonies.
24. Recovering Reefs
    a. Healthy reefs provide homes for fish and food and tourism for people from many cultures. We should be doing all we can to preserve coral diversity and reefs on a local and global scale.
25. Things you can do to help
    a. In the face of all these threats, it is important to remember that we can save coral reefs. Coral and algae have a unique partnership that forms the basis of coral reef ecosystems, but for corals to survive, we need to be good partners as well. Remember that coral reef conservation begins on land, and we need to change some of our own activities in order to help. Here is a list of things we can do to protect coral reefs.