Scott Doney
Woods Hole Oceanographic Institute

I've always been interested in the ocean. I' grew up along the coast in California and I got to explore the tide pools and go diving in the ocean. But I got into climate when I was an undergraduate. I did an internship at a NASA lab where Jim Hansen was. That was right when the whole story of climate change was starting to break and come out and I just found it a really fascinating field, in part because it was so controversial. You know there were a lot of people who didn't really value it as a science, didn't think it was truly scientific. And that got me intrigued as to what was actually there — what was real and what wasn't. So that's how I got into the whole climate change story.

My work looks at the carbon cycle. Basically when we burn fossil fuel, such as oil, carbon, natural gas, we release carbon dioxide into the atmosphere. And that's one of the main gases driving climate change and climate warming. I'm interested in what the fate of carbon dioxide is and where it ends up and what the impact of that is. So in terms of tipping points, one question is, "are there big sources of carbon that might be released into the atmosphere in the future if the planet gets warmer?" So we are looking at various different sources of carbon. It might be the Amazon forest. It might be the peat lands and the tundra up in the Arctic or it might be methane clathorate. There is methane trapped in ice, underneath marine sediments that if it got warm enough could be released and that could cause climate warming to accelerate.

[There are different sources of carbon.] There is the carbon that you're used to. The carbon that is in your gasoline or oil or coal, but there is also carbon stored in vegetation. There is carbon stored in the ocean in inorganic form. There is basically a lot of carbon dissolved in the ocean. So one of the things we look at is, "what happens when we release fossil fuel carbons?" Some of it goes into the ocean, but there is also the possibility that some of the carbon that is already in the ocean could go back to the atmosphere.

One of the things that scientists really weren't looking at was "what happens when carbon dioxide gets in the ocean?" About a third of all the carbon that we emit into the atmosphere – from chopping down forests in the Amazon and burning them or for running our cars – actually gets removed from [the air] by the ocean and that is actually slowing down climate change. In that sense it's a good thing, but it's also when the carbon gets into the ocean that it's actually changing ocean chemistry. So one of the main areas I've been looking at is, "what happens when you change the chemistry of the ocean?" What happens to all the plants and the animals that live in the ocean when we are fundamentally changing ocean chemistry?

One of the things we've learned is that we're making the ocean more acidic. Carbon dioxide gets into the ocean and it combines with water and forms carbonic acid. And that carbonic acid is lowering the pH or making the water more acidic. All the plants and animals that build shells out of calcium carbonate [are affected.] Think if you went to a chalkboard and picked up a piece of chalk, that is actually a piece of calcium carbonate. Corals, shellfish, like lobsters and clams, and lots of little plankton – the microscopic

plants and animals that float on the ocean's surface – all build shells out of calcium carbonate and these shell-forming plants and animals have a real problem when the acidity of the ocean increases.

Since we started burning fossil fuels, the acidity [of the oceans] has increased by about 30%. What's really striking and what is really discouraging is that we're on a trajectory of changing that by another factor of two or three before the middle of this century. We just [have] a lot more people and we're burning a lot more fossil fuels. That's going to lead to a much larger impact on ocean chemistry.

The way that changing ocean chemistry – or acidification – impacts plants and animals is that it makes it harder for them to build shells. A good example is corals. Corals are actually small little animals, but they build a skeleton out of calcium carbonate. When you change the pH of the ocean and you make the water more acidic it's harder for the corals to build that shell. And that leads to mortality. It leads to lower reproduction rates. Basically the coral itself isn't able to grow as fast. But it's not just the coral that's affected. There are lots of different plants and animals that depend upon the structure of a coral reef. And so if the corals begin to degrade and can't maintain their structure – can't build a reef – then all the other plants and animals on a tropical reef will also begin to suffer.

What is different now is the rate that we're adding carbon dioxide. Yes, carbon dioxide in the atmosphere has varied in the past but in comparison we're changing the levels in the atmosphere about 100 to 1000 times faster than [during] past geological events. You really have to go back tens of millions of years when there were major extinction events to see such a rapid change in ocean chemistry and atmospheric composition. And one of the things that is so worrying is [human behavior may cause] a major extinction event in the geological history.

I'm not particularly optimistic – particularly about coral reefs – because coral reefs are also threatened by several other factors, one of which is just warming. When you have sharp warming events, the coral tends to bleach. As I said, corals are small little animals, but inside them they have little symbiotic algae and they need those algae. The algae are photosynthesizing and they supply food to the coral. When you have a sharp period of warming they tend to lose those algae and they turn white. Those bleaching events, those warming driven bleaching events are also threatening coral. And so you are basically hitting them with a double hammer. You are hitting them with warming and you are hitting them with acidification at the same time.

I get asked all the time, "So how do we solve the acidification problem?" In the end, we have to reduce our emissions of carbon into the atmosphere. We either need to switch to renewable fuels or we need to somehow capture the carbon that we would normally emit say from a power plant or from a car and put it someplace safe. One of the ways that's being discussed is to pump it down into geological reservoirs like old oil wells or [house it in] salt domes. That is going to be really tough. Energy pervades our economy and fossil fuels are basically the lubricant that has led to rapid development around the globe.

So it's not some simple. It's not something so simple that we can flip a switch and suddenly no longer emit carbon into the atmosphere. We have to change in many ways the entire way we live as a human society.

Corals reefs are fundamental to the economy, particularly for a lot of tropical developing countries. So some of the pain isn't going to be hitting [the U.S.] It's going to be hitting people who are already living basically hand-to-mouth. That is, they depend upon coral reefs for tourism. They depend upon coral reefs for fishing. But these are also some of the most diverse, biologically rich systems in the world. [If you say,] "I don't care about coral reefs," it is basically [the same as saying,] "I don't care about the Amazon." Let's just chop it all down. We can pave it over and plant grass. Well you are losing a biological richness and you're also losing I think an aesthetic richness. I guess one of the ways I view it is we're making choices that future generations are going to have to live with and I don't really think it's our choice to destroy something that they are never going to get to see.

One of the things we've been talking about is corals, but there are lots of other plants and animals that are affected by acidification. So we actually have been looking at the fish catch within the U.S. – you know looking at all the different species and all the different places around the country. And when you add it all up, about half of the total value of fish catch in the U.S. comes from shellfish – things like crabs, lobsters, mollusks, and scallops. Those are all threatened by acidification. So this isn't just the tropical problem. This is also going to directly affect a lot of consumers and a lot of people who depend upon the seafood industry.

Another question is about climate and the water cycle. A lot of people when they think about climate [change] they only hear from the press, "well, it's going to get a little warmer" and "well, you know I'll wear shorts more in the summer" or "we'll have to air condition more." But probably the place that is going to be most impacted by climate change in a lot of people's lives is changes in the water supply. As we warm the plant, we're going to be speeding up the hydrological cycle, [which is the process by which] water gets evaporated out of the ocean and it forms rainfall on land. Some places are going to see striking increases in the amount of rainfall. Other places are actually going to get drier – particularly places like the U.S. southwest are projected to get drier. Now these are already places with a growing population where they are already having severe water crises. And what we are seeing in the future is those are likely to get worse. Droughts may be extended in time and stronger in intensity and so one of the problems is all of human society – particularly our use of water for agriculture and water for household use – has all been premised and built on what the current conditions are. If those conditions are going to change, we just don't have the infrastructure set up to do well under a future climate. At least that seems to be what the models are suggesting.

I haven't really looked much into [the issue of over-fishing] cod, but I will say there have been a number of studies looking at the large pelagic fish, such as tunas, sharks and some of the apex predators. They're basically the lions of the sea; they're the biggest thing out there. And the [studies] have essentially looked at where we have fished and in places

where we have been fishing these species they tend to be fairly slow growing and they live a long time and when you look at current populations they are only about 10% of what they were when people started fishing. So at least for some set of species, it's fairly clear that we have essentially vacuumed out the large fish in the ocean.

One of the things that people ask is, "you know where is the threshold beyond which we don't want to go?" And sometimes it's raised as a tipping point — a point that if we go beyond [things] are just going to go downhill really fast. One obvious one for corals is the bleaching events and we may already be experiencing a tipping point. The coral reefs in the Caribbean have essentially been decimated by bleaching events. We don't yet know whether acidification is contributing to that or if it will just make it harder in the future for the reefs to survive. So I think biologically we are already starting to see major shifts and the ocean will survive. There will still be life in the sea, but it's going to be different than what we are used to and a lot of things we're used to benefiting from may not be there any more.

People have been trying to figure out how are we going to adapt to climate change. You know there is climate mitigation, which is "how can we slow climate change?" And then there is adaptation, [which is] "what can we do to live within the climate change that is almost inevitable?" At this point, some amount of climate change, some amount of acidification is inevitable. And people have been talking about various scenarios. One is growing coral in tanks and replanting them. The Australians are even talking about trying to shift the Great Barrier Reef south. As the planet warms, the corals will be lost closer to the tropics, but maybe we can cause the reef to move further south. I think a lot of these are fairly desperate measures and they're going to be fairly expensive to maintain small amounts of habitat. I think probably better measures at this point are trying to protect the reefs we have and reduce the other human influences. Reduce pollution, reduce over fishing, and reduce dredging to give the reef at least some chance to survive under climate change. Whether we could engineer whole new reefs and reef systems is a really tough. I think that's going to be a really tough and expensive problem.

The oceans have been heavily impacted by humans in a way that we haven't fully appreciated yet.

Coral reef bleaching is a serious tipping point, a serious warning. The disappearance of a lot of fish — particularly long-lived fish that we really shouldn't be going after in the first place — is a warning. I live close to sea level. My house is only a few feet above sea level. I am very concerned about the melting of the glaciers in Greenland and Antarctica. Those are striking tipping points. They are melting much faster than anybody had expected. And the disappearance of sea ice in the Arctic is astonishing. The rate is much faster than any of the models had predicted and I think that should be a warning sign to anyone who is interested in the health of the ocean and the climate of the planet.

I grew up body surfing in the ocean and playing in tide pools and skin diving and I unfortunately became a chemist in the sense that you know chemistry isn't as exciting as

biology. But I have been able to work my way back into looking at how chemistry affects ocean life and how chemistry plays an important role in our global climate system.

All these problems about climate change and acidification go back to energy use and where our energy comes from and how much we use and so yes, you make a hundred decisions every day whether it's to flip off the light switch or to take the bus or when you are buying a new car or whether to insulate your house. So I think there are lots of decisions that can be made that can improve the ocean. But you have to sort of think about how you are living and what your impact is on the planet.

I get asked all the time, "So, what can individual people do?" Well remember climate change and acidification all comes back to energy use. How much energy we use and where it comes from and whether we are releasing carbon into the atmosphere and so you have to think when you look at your daily life, "how are you using energy?" "Do you need to leave a light switch on?" "Are you going to take the bus rather than a car?" "What kind of car are you going to drive?" "Are going to insulate your house or not?" All those decisions feed into how much carbon we emit to the atmosphere.
So I think there are lots of little things we can do. It's not just as simple as choosing one choice of going to the store and buying one thing or not. It's all your decisions that you make impact how much energy and how much carbon you release.