The Interaction of Oceans and Climate

Interview with Anand Gnanadesikan
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BARRY REICHENBAUGH: This is Barry Reichenbaugh with the NOAA Research Communications Office. I'm here in Princeton, New Jersey at the Geofluid Physical Dynamics Laboratory with Anand Gnanadesikan. Anand, can you first start by just telling us what your title is here and what it is you do?

ANAND GNANADESIKAN: I'm an oceanographer in the Biospheric Processes Group here. We look at ourselves as bringing life to the heart of GFDL. We are a bunch of oceanographers, a few ecologists. And, what we're really interested in is the interaction between the living world and the physical world both in the oceans and on land.

But, my training personally is as a physical oceanographer. That is, a marine physicist studying the circulation of the ocean and trying to understand the processes that drive it.

BARRY REICHENBAUGH: There must be some interesting conversations here with climatologists and oceanographers and the variety of backgrounds.

ANAND GNANADESIKAN: This is a really interesting lab because we're all, at some level, trying to predict and understand the earth as a system. And so, one of the fun things here is that you can have a seminar on atmospheric dynamics and the oceanographers will show up. Or, you'll have a seminar on ocean dynamics or Mars and people from very different fields will show up. And, it's a really remarkable environment in that sense.

BARRY REICHENBAUGH: My first question has to do with that topic. How does the ocean affect climate?

ANAND GNANADESIKAN: Well, there's really three ways in which the ocean affects climate. The first is that it stores a lot of heat. If you were to go and jump into the ocean, off a dock, and with your hands up above your head, just as your hands pass the surface, from your feet to the top of your hands, that column of water would have as much heat in it as the entire atmosphere above you.

And so, very small changes in the temperature of that water can have big impacts on the temperature of the atmosphere especially since winds and waves stir the oceans in much greater depth than that -- about two meters of that would cover your body.

And, that means that how warm your summer is and how cold your winter is -- it's really determined by how close you are to the ocean. Most people have experience of that if you live in a place like San Diego, you know that there is relatively little change in temperature between summer and wintertime.

If you live in Minnesota, you know the winters are really cold and the summers can get really hot. And, a lot of that is due simply to how far away you are from the ocean.

The second way in which the ocean is important is because it stores so much heat, it can move it around relatively easily. And so, the oceans are responsible for moving most of the heat away from the tropics.

And, that has some pretty big impacts. It moves heat away from the tropics and into the polar regions and, interestingly, it seems to be the second part, the moving the heat into the polar regions that's really important.

A few years ago, one of my colleagues here, Mike Winton, did an experiment where he turned the transport of heat into the polar regions off. And, the result of that was that as the heat got -- the heating from the ocean got turned off, sea ice formed. And, that sea ice reflected more heat back to -- more of the sunlight back to space and that cooled the surface still further and more sea ice formed. And, he ended up producing a planet that was completely glaciated.

So, ocean heat transport actually can have a pretty significant impact on climate, especially through its interactions with the cryosphere, with ice.

Now, the third way, which I think we may talk a bit more about later is that the ocean actually influences the composition of the atmosphere. So, the amount of carbon dioxide in the atmosphere, as well as gases like dimethyl sulfide which affect cloudiness, sea salt, which is an aerosol, which also affects cloudiness, all of these are determined in part by the ocean.

BARRY REICHENBAUGH: Can we turn that around? How does the climate affect the ocean?

ANAND GNANADESIKAN: Well, there's actually quite a lot of ways. One of the features of climate that really seems to matter a lot for the ocean, one that we've worked a lot on here at GFDL, is the role of winds. So, we have some evidence from paleoclimatic studies, distribution of trees, chemicals in ice cores and things like that, that winds have changed in the past.

The area that we are particularly interested is the southern ocean. The southern hemisphere jet stream can shift by hundreds of kilometers and it turns out that those shifts can have a big impact on ocean circulation.

And, that's one of the main results to come out of the ocean group in this lab in the past, say, 20 years. We've really been trying to figure out how that works.

The reason it's important is that those winds act as a sort of pump for the whole ocean circulation, bringing up dense water to the surface where it can get freshened and warmed. And so, you can turn dense water into light water.

And, that acts like a pump. You can think of it as the faucet on your bathtub that if the light waters of the ocean, which basically are, in the tropics, are about 3,000 feet deep. That top 3,000 feet of warm water really got its start in the southern ocean. That pumping and freshening is like turning on a faucet and filling up that bowl 3,000 feet deep with warmer, fresher water.

Now, the drain for that is in the northern hemisphere. And, it's part of the Gulf Stream-North Atlantic Current system that brings warm water northwards and means that the North Atlantic, off of Newfoundland or Iceland, is actually warmer than the North Pacific at the same latitude.

So, that whole system, we think, is really pumped by the winds and slowed down by precipitation. And, how exactly that happens and how those opposing forces may change in the future is really one of the key topics that we try to understand with our climate models.

BARRY REICHENBAUGH: That sort of leads me into the next question. What are some of the things we still don't understand about the ocean-climate relationship?

ANAND GNANADESIKAN: Well, we know that the ocean and atmosphere and sea ice system is coupled. And, what we mean by that is that changes in the one affect the other.

If you've ever had watched small children at play, you know how this works. Sometimes they'll wind each other up and you have to step in before someone gets hurt. And, sometimes they'll just calm each other down. And, the thing is that, just as with children, you don't exactly know what it is that's going to start them fighting, that's going to wind them up. And, we don't always know what's going to wind up the climate system or what is going to calm it down.

So, one of the changes that we're looking at right now is the role that marine plants play in changing the depth at which sunlight is absorbed. If you think about it, sunlight comes into the ocean and it penetrates to depth and it gets absorbed. And, as it gets absorbed, it heats the ocean. So, if it penetrates deeper, you'd expect that the surface would be colder and that the ocean at depth would be a little bit warmer.

But, it turns out that the system isn't as simple as that. It turns out that that warm water gets drawn up to the surface in places by the winds. And so, it turns out that small changes in heating will actually get amplified maybe by a factor of two or three. So, that's an example where the climate system winds itself up and involves life.

Another change that we're looking at or another process that we're looking at is the role of eddies in the ocean. We know that the ocean has a lot of what are basically the equivalent of storms in the atmosphere. They can be maybe five, ten, 20, maybe even 100 miles across.

Now, there are high and low pressure systems and they tend to form at the edges of currents. Now, one of the things that we've been looking at is whether specifically modeling those eddies makes a difference to the climate.

And, one of the things that we're finding is that it seems to actually tamp changes down so that if you were to increase the winds, the eddies would act to oppose the changes in circulation that would be caused by those changes in winds rather.

And so, that's another area of future research in the lab because it's very expensive to model eddies. Most of the models that we run to try to understand how the climate is going to change in the future or changed in the past tried to represent the effects of those eddies but they don't actually model the eddies themselves.

And so, that's an area where we still don't understand a great deal. In general, from the point of view of the ocean, the interesting questions are all about how the ocean interacts with its boundaries, the top and the bottom.

And, there are many physical processes that we don't understand there. And so, there's quite a lot of opportunity to try to figure out what kinds of measurements we need to understand those processes.

BARRY REICHENBAUGH: Can you describe the ocean carbon cycle?

ANAND GNANADESIKAN: Okay. So, we know that the atmosphere holds about 800 billion tons of carbon dioxide. So, that's about 150 tons for each human being, about the size of a small ship. But, the ocean holds almost 50 times that amount. So, perhaps the size of a small ocean liner.

On the very long time scales of many millennia, it's really the ocean that controls how much carbon dioxide there is in the atmosphere.

Now, there's two reasons why the ocean holds so much carbon. The first is that they contain a lot of dissolved chalk, calcium carbonate, basically the same calcium carbonate that you would find in chalk or Tums.

And, additional reasons that marine plants, what we call phytoplankton, drifting marine plants, very small algae, in the surface of the ocean -- when they grow, they take up carbon dioxide to build their tissues. And then, when they die, some of them fall into the deep ocean and they rot. And so, the deep ocean has a little bit more carbon dioxide than the surface ocean.

And so, taken together, those two processes mean that the ocean holds a lot of carbon dioxide. Now, we think actually that it's the changes in the biological cycle, or at least in the efficiency with which the biological cycle stores carbon, that account for many of the changes that have been seen over the past 400,000 years or a million years and how much carbon dioxide there is in the atmosphere.

One of the big questions in environmental geosciences is, why was carbon dioxide so much lower in the atmosphere during the Ice Ages? And, we really think that one of the major players in that is the efficiency with which carbon that's pumped into the deep ocean by sinking biological materials, basically dead plants, how efficiently that's retained in the deep ocean.

And, we have some ideas that that may, in fact, be connected to these changes in winds in the southern ocean. But, that continues to be a real exciting idea that's subject to a lot of future research.

BARRY REICHENBAUGH: What's the most significant impact of climate change on the ocean?

ANAND GNANADESIKAN: That's a good question. The impact that people are most worried about is the changes in what's called the North Atlantic Overturning Circulation, the flow of warm waters into the Greenland, Iceland, and Norwegian seas that warm that region, and that if there is significant melting of glaciers, that circulation could shut down as it has in the past. That's one.

In some ways, it's not clear that that's the one that we should be most worried about. Sea level rise is, of course, a big impact. But, from the ocean's point of view, it doesn't matter all that much where its boundaries are.

It matters a great deal to us, of course, whether the ocean sees Logan Airport (Boston, MA) or not. Or, Kennedy Airport (New York City) or not. In fact, since many of our airports are right on the water, that's one of the major possible costs of climate change.

But, from the ocean's point of view, one thing that we are quite worried about is the effects of acidification, and that arises because carbon dioxide is a very weak acid. We know that the pH of the ocean is changed, that it has become less basic and more acidic over the past 150 years.

And, recent work in which we participated in, but which was led by Dick Feely of PMEL, has shown that those changes could have impacts on marine plants that have chalky shells. Basically, if you think of Tums as an antacid, calcium carbonate is an antacid because when you swallow it, it dissolves and neutralizes the acid in your stomach. And so, if plants -- marine plants or marine animals -- have shells that's made of calcium carbonate, chalk, and the ocean becomes more acidic, their shells will start to dissolve.

And, that's been seen to happen in a number of cases and it's really a question of a lot of concern because we have no idea really how such changes would ripple through ecosystems and cause changes in food chains, food webs, and in general ecosystem structure.

BARRY REICHENBAUGH: Let's shift topics and talk about science careers a little bit.

ANAND GNANADESIKAN: Sure.

BARRY REICHENBAUGH: What got you into science?

ANAND GNANADESIKAN: Well, in many ways, my getting into oceanography in particular is quite tightly related to this lab. I was an undergraduate here at Princeton. In my sophomore year, I took a course in physical oceanography from Jorge Sarmiento who is a faculty member in the program in Atmospheric and Oceanic Sciences, which we run jointly with Princeton.

And, I was taking Physical Oceanography and I was taking Quantum Mechanics. And, I was told that in Quantum Mechanics, there were three or four problems that you could do exactly and we would spend the entire year doing them, and that was going to be it whereas in Physical Oceanography, we would have a class in which we would say "derive the Gulf Stream."

And, I would look at the derivation and say, "Well, how well does it work?" I was told, "Well, it doesn't work all that well for explaining some pretty basic things like why does the Gulf Stream leave the coast at Cape Hatteras?" That's a research question. And so, I realized that as a sophomore in college, I could ask research questions.

And, I also realized that, in physics, it would probably be another three or four years before I could really ask questions that would push the frontiers of the field.

Now, in some ways, it's a bit ironic. I often tell this story about the Gulf Stream separation being a research question. It's ironic because getting the Gulf Stream to separate properly has been one of the banes of my existence for the past five years because it's one of the things that we still can't do very well in the models.

But then, the summer after taking that course, I spent a summer at Woods Hole Oceanographic Institution as a summer intern and went to sea and actually ended up going to sea with the person who would be my graduate advisor, my Ph.D. advisor. I spent two summers working here at GFDL as a summer intern and worked on my first paper while I was an intern here and really got a lot of exposure to the range of questions that people ask here.

And, also to the culture of the field and of the lab. This lab has a very remarkable culture. One of the things that was amazing was to be an undergraduate student, working in the lab, and to have Suki Manabe, who is really the founder of climate modeling, a member of the National Academy, winner of the Blue Planet Prize, comes charging into the lab every two or three days when he'd learn something new. And, he just had to tell somebody.

And so, here I was getting to hear the latest results from the person who founded the field. And, it was really an incredible experience. I think this lab is a very special place.

BARRY REICHENBAUGH: What would you say to a young person who is thinking about a career in science?

ANAND GNANADESIKAN: Well, I think we live in a privileged time in history and if you look at even the 1930's, if you look at Germany before Hitler came to power, there were about 60 professors of physics in the entire country. Fortunately for the U.S., half of them came here. We live at a time where there are hundreds of professors of physics in the United States, thousands even. Thousands of professors of geology and geoscience. And, where the scientific enterprise is such that people can actually get paid to be curious about the world.

One of the things I do is help run a competition called "Science Olympiad." And, at the Olympiads, you have maybe 700 students from dozens of schools participating.

And, I look around that auditorium and every one of those students has the opportunity to go on and make a career that involves science, whether it's being a scientist, or teaching science in a high school, or going into medicine, or going to into patent law for that matter.

We live in such a highly technological society that we really need people to go into science. Now, if you were to do the same thing at a sports tournament, one or two of those students would be able to go on and make a career in sports. And so, what I would tell students in the sciences is that there really are opportunities for people who want to learn about the world and want to teach others about how that world works.

For the environmental sciences, for oceanography and atmospheric sciences, what I would is most of our students in the program -- in our graduate program -- have gone to college, they've earned degrees in one of the hard sciences, physics, mathematics, chemistry, biology. Primarily physics and mathematics, and sometimes also in engineering.

Relatively few of our students actually earn degrees in marine and atmospheric sciences and we find that actually getting that good grounding in the physical sciences and in mathematics is really important for doing graduate work in our field.

So, that's part of the advice that I give students who are interested in going on to a career in environmental sciences is learn biology or chemistry or physics really well and then apply it. And, if you do that, you actually come in with a whole bunch of tools that are useful.

BARRY REICHENBAUGH: Well, Anand, thanks very much for joining me and it has been a pleasure talking to you and learning a little bit more about how ocean and climate interact. And, I think we're gonna wrap things up. Thank you.

ANAND GNANADESIKAN: Thank you. Thank you very much, Barry.