5.4 METEOROLOGY AND OCEANOGRAPHY COME TOGETHER IN COLLEGE COURSES

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1. INTRODUCTION

Long-range weather forecasts, from seasonal changes in weather patterns to decadal changes in climate, requires the merger of data and concepts from oceanography, meteorology, and other disciplines within earth-system science. Students in meteorology, oceanography, and environmental science all need to understand the interactions between the ocean, atmosphere, and land, and how these interactions influence the earth system on many different time scales. In particular, we are seeing a closer integration of meteorology with other parts of earth-system sciences.

I discuss how "Bridging the Studies of Weather and Climate" has influenced my teaching of undergraduate courses in oceanography and environmental science.

2. TEACHING OCEANOGRAPHY IN A NEW ERA

The increasing importance of changing climate and weather patterns, the increasing student interest in these problems, and the importance of earth-system science at the heart of these problems, has strongly influenced my teaching. I now include modules highlighting the connections among meteorology, oceanography, and earth-system science in all my courses.

The courses include:

1. Environmental Geoscience for incoming majors in environmental geoscience and environmental studies degrees;
2. Interdisciplinary Oceanography for upper-division undergraduates in many majors, especially meteorology; and
3. Introduction to Physical oceanography for upper-division meteorologists and ocean engineers.

The first two courses are problem-based. Both include a module on the role of the ocean in climate, including global warming and abrupt climate change. The second includes an additional module on the role of the ocean in weather patterns (El Niño) and the influence of the ocean on transient events such as Hurricane Katrina of 2005. The third, the physical oceanography course, is a more traditional course built around processes not problems. Still, it includes much information on abrupt climate change, El Niño, heat fluxes, and the influence of the ocean on atmospheric processes.

Although physical processes are important, biological processes, such as the influence of marine phytoplankton on earth's carbon budget, cannot be neglected.

In the coming year I will add modules on the influence of the ocean on drought in mid-continental areas of north America, including the influence of the Pacific Decadal Oscillation and the Atlantic Multidecadal Oscillation. Next I will add a module on the controversy surrounding the importance of global warming and sea-surface temperature on global hurricane statistics. Are hurricanes getting stronger or more frequent?

I find that these problems motivate students to delve deeper into meteorology, physical oceanography, and environmental science. The problems are relevant to the students' lives, and they want to know more.

3. KEY CONCEPTS

Students in meteorology and atmospheric science increasingly need to know about parts of the earth system not usually included in their curriculum. It is impossible to understand global warming and climate change without understanding processes in the ocean and on land. Oceanic processes dominate the atmospheric processes.

Some of the key concepts include:

1. The ocean dominates earth's carbon cycle. There is 50 times more CO_2 in the ocean than the atmosphere.
2. Atmospheric CO_2 concentration is influenced by physical and biological processes in the ocean. A quantity of carbon equal to all the carbon in the atmosphere cycles through the ocean in 8–9 years.
3. Half of the CO_2 put into the atmosphere by human activity is quickly absorbed into the ocean. Part will be stored for hundreds of years in the deep ocean, part will be stored for millions of years in oceans sediments.
4. We know little about the circulation in the ocean that determines how long carbon is stored in the deep ocean.
5. The oceans, not sunlight, warms the atmosphere. Two heat sources are important: latent heat of evaporation, which warms the atmosphere when water vapor condenses in clouds; and infrared radiation from the ocean absorbed by water vapor in the lower troposphere. Most of the heat comes from the tropical ocean.

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I found that most upper-division meteorology students did not know what warmed the atmosphere. When asked, they tended to say either the sun or land.

6. The ocean transports about half the heat from the tropics to mid-latitudes.
7. If earth had a static atmosphere and no ocean, the greenhouse effect would warm earth's surface to a average temperature of 67°C. The oceans and atmosphere combine to reduce the average surface temperature to 15°C. Failure to understand this concept has led to much confusion in global warming discussions.
8. Rain that falls on land comes mostly from the tropical ocean. Water vapor is carried in narrow jets out of the tropics to mid and high latitudes.
9. Changing weather patterns such as enhanced winter rains in the US southeast, tornado frequencies, hurricane patterns, and great plains drought are due to changing oceanic conditions, sometimes in areas far from the US. El Niño is the most well known, but the Pacific Decadal Oscillation and the Atlantic Multidecadal Oscillation also contribute.
10. Abrupt climate change, which influences atmospheric circulation for hundreds of years, has been tied to changes in the ocean's circulation.
11. Oxygen in the atmosphere comes from the burial of reduced carbon in sediments, mostly in the ocean. This too is a widely misunderstood concept. Most texts state oxygen comes from plants on land and in the ocean.

Students also need to understand several other important concepts:

1. Much of our understanding of complex systems comes from a combination of coupled atmosphere-ocean-land numerical models constrained by data and theory. Models, data, and theory are all critical.
2. Data sources are important. Some are good, some are not as good. There are criteria for determining which are good.
3. We are always data limited. Sampling errors dominate. Yet most students do not know about sampling errors.
4. The *Tragedy of the Commons* is important for understanding human influences on the environment.
5. Scientific, economic, political, and legal issues are equally important in the climate-change debate. The issues cannot be separated.

4. RESULTS

I find, based on four years of teaching these concepts, that:

1. Students prefer problem-based courses. Too many of their courses are based on processes, and they see no connection to the real world or their life. Climate problems seem remote and beyond their control.
2. Once meteorology students see how problems in their field are tied to other parts of the geosciences and to economics and politics they are much more interested in taking such courses. Some required core courses became much more interesting.
3. Students in environmental geosciences became more interested in learning about atmospheric sciences.
4. Students see how a number of different fields of learning are needed to solve important problems, including the climate problem.
5. They are surprised to learn that most important problems, such as global warming, do not have a technological solution.
6. Students in a large university, where geology, oceanography, geographic-information systems, and meteorology are taught in different departments, came to understand the underlying unity of the geosciences.

5. SOME CONSEQUENCES

As a result of changing my teaching, I have become much more of a generalist. I know more about many subjects. This has implications for graduate teaching in meteorology.

1. Graduate students in meteorology interested in a university teaching career need to know much more about other parts of the geosciences and liberal arts.
2. The *Report of the Panel on Oceanography by the President's Science Advisory Committee* stated in 1996 that:

   "The Panel questions the wisdom of granting Ph. D.'s in oceanography *per se* and feels education should be focused on a broad spectrum of environmental sciences, incorporating basic sciences. ... The close linkage of oceanography with other environmental sciences and with basic sciences has been illustrated throughout this report and supports the thesis that classical Ph. D. training in oceanography will not serve the purposes of ocean science and technology in the years ahead."

   The same could be said of meteorology today. Just substitute *meteorology* for *oceanography* and *ocean sciences* in the above quote.

6. REFERENCE

Panel on Oceanography (1966). Effective Use of the Sea. *Report of the Panel on Oceanography of the President's Science Advisory Committee*. The White House. xvi + 144 pp.