AGU BOOKSHELF

Surface Ocean–Lower Atmosphere Processes

No system exists in isolation, and the ocean is no different. Understanding the mechanics directing a system as complicated as the ocean takes an interdisciplinary effort and well-controlled studies. The Surface Ocean–Lower Atmosphere Study (SOLAS) program is an international effort to make sense of the physical and biogeochemical interactions that take place between the air and the sea. Having scientists ready to dissect these interactions will be increasingly important as the world begins to consider deliberately manipulating the system in an attempt to combat climate change. The AGU Monograph *Surface Ocean–Lower Atmosphere Processes*, edited by Corinne Le Quéré and Eric S. Saltzman, looks at the increasingly important interactions occurring at the boundary between these two systems. In this interview, *Eos* talks to Corinne Le Quéré.

Eos: *Why is the boundary between the surface ocean and the lower atmosphere so important?*

Le Quéré: The ocean absorbs about one quarter of the carbon dioxide emitted every year, and to see how this is going to change in the future, you have to know how the biogeochemistry and physical interactions function.

But, in addition to carbon dioxide, there are gases such as dimethyl sulfide (DMS) that play an important role in ocean-atmosphere interactions. DMS is a gas that is produced in the ocean by phytoplankton, and when it gets emitted to the atmosphere, it cools the atmosphere by producing nuclei around which cloud droplets can condense. So this particular gas has an origin in the marine ecosystem, but it has a control on climate.

There are also interactions that originate in the atmosphere, for instance, iron deposition over the ocean. Iron is found in desert dust, which gets transported over oceans by wind. When iron gets deposited into the ocean, it enhances phytoplankton productivity and the cycling of nutrients and thus changes the entire marine biogeochemistry. So all of these interactions are very important for climate, and they involve a lot of processes that take place both in the atmosphere and in the ocean.

Eos: *The book is based on lectures from the SOLAS summer school program. What is the SOLAS summer school program? How did it get started?*

Le Quéré: Surface ocean–lower atmosphere science is quite complicated because you need to have knowledge of ocean physics, atmospheric physics, cloud physics, and chemistry, as well as biogeochemical cycles in general. It's very rare to meet a scientist who has all of the required knowledge. Véronique Garçon from the Laboratoire d'Etudes en Géophysique et Océanographie Spatiales and I proposed to do a 2-week summer school where international students would come and experienced scientists would give crash courses in multidisciplinary research around air-sea interactions. We started the program in 2003. It was very successful with the students, and we decided to repeat it on a 2-year cycle to reach new students, ideally as they start their Ph.D.s. The next course will be in August 2011.

Eos: *Each chapter of the book presents an overview of a different critical process in the ocean-atmosphere system. How was the book put together? Who would find it useful?*

Le Quéré: After the third summer school we felt that we had quite a good set of lectures. It provided broad enough knowledge, but then we thought that the students may not have taken very much information with them once the school was finished. We thought that if we transposed the lectures into a book, it would not only be useful for the students who attend the school, but it would also allow students who were not able to attend the summer school to access important information.

All of the authors have lectured in one of the summer schools, so they knew exactly the right level to write each chapter so that students can reap the most benefits.

Eos: *In addition to the ocean carbon cycle, dust and cloud condensation nuclei, and an analysis of dimethyl sulfide, what is another interaction covered in the book? Why did you choose that issue?*

Le Quéré: Another topic we chose to cover was the biogeochemistry of the coastal ocean. There are many processes that are specific to the coastal ocean because they are heavily influenced by anthropogenic behaviors, like river fluxes of nutrients. Coastal oceans are important locally but could also potentially have a large role globally. For example, if nutrient loads increase in the coast from erosion or from excess fertilizers used by agriculture, their use locally can lead to an expansion of the low-oxygen zones in the coast and generate emissions of nitrous oxide (N_2O, a potent greenhouse gas) to the atmosphere. The excess coastal nutrients are then transported to the open ocean where they can be used by phytoplankton and alter the biogeochemical cycles. We chose topics that the students absolutely must know in order to fully understand air-sea interactions.

Eos: *How were research techniques covered in the monograph?*

Le Quéré: In the book and in the summer school we have made quite a lot of effort to talk about methods. The ones that made it into the book are remote sensing, data assimilation, and biogeochemical modeling. One thing that is required in this kind of field is that people use a range of tools. Often with the more complicated

Coastal Mediterranean waters surrounding the Cargèse Institute of Scientific Studies (Corsica, France), which hosted the summer schools of the Surface Ocean–Lower Atmosphere Study during 2001–2009. Photo courtesy of Georgia Bayliss-Brown.

tools, like global biogeochemical models, people can get a bit intimidated. We tried to cut down on the complex details and explain the essence of modeling and data assimilation in a way that is more accessible and could encourage people to widen their approaches when looking at different problems.

Eos: *In addition to providing a resource for students, did you have a bigger goal in mind when creating this monograph?*

Le Quéré: We are always faced with simple questions about things that are close to our field but not firmly in our field. We did think that such a monograph would be really, really useful for more experienced scientists who don't have time to read 10 books on these topics but would have time to browse through a book, have a look at the figures, and get the highlights of the topic very quickly. The group of lecturers who put the SOLAS summer school together thought we would like to have such a book on our bookshelves, and I actually use it quite a lot myself. As an ocean scientist, I find it very useful to read the atmospheric chapters, or the dimethyl sulfide chapter, or things that are a little bit apart from my field. The chapters clearly articulate the complex science, but they don't provide a lot of depth.

Eos: *Throughout the monograph—and especially in a chapter that discusses the impacts of iron fertilization on phytoplankton growth—the complexity in ocean-atmosphere dynamics is heavily emphasized, as is the level of uncertainty that remains in our understanding. What level of confidence does this lend to plans to deliberately engineer the Earth's climate?*

Le Quéré: With current knowledge the level of confidence is relatively low. We know more about the impact of iron fertilization to stimulate growth of phytoplankton than any other geoengineering option proposed so far. There have been maybe 15 experiments where ships have gone and put iron in the ocean, and we know that phytoplankton bloom. This is relatively well understood, and it can be repeated, so this gives some confidence.

But what we don't know is what happens after that; how much of that biomass is then eaten by zooplankton, how much of the biomass and carbon sinks to depth, what are the changes in the ecosystem, how much DMS is produced. All of these secondary reactions are very, very poorly known. There are not an infinite number of things to understand, and it is possible to actually devise experiments to test different hypotheses and to quantify what the feedbacks are, but it has to be done systematically, and this takes a long time. There is a lot of talk about geoengineering, but the scientific knowledge is not ready to support the technical geoengineering implementation.

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—Colin Schultz, Staff Writer

RESEARCH SPOTLIGHT

Highlighting exciting new research from AGU journals

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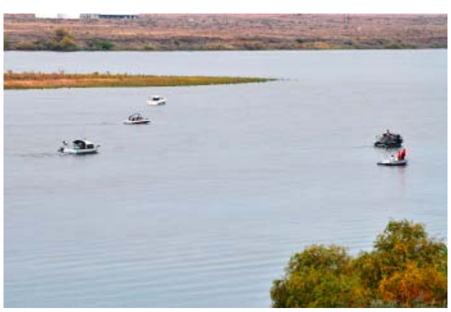
Potential pathways of radioactive contaminants to surface waters

From the 1940s to the end of the Cold War, the U.S. Department of Energy maintained production facilities for manufacturing nuclear weapons along the Columbia River north of Richland, Wash. Known as the Hanford Site, the Rhode Island–sized area contains more than 53 million gallons of radioactive waste and is the location of a massive environmental cleanup. Of particular concern is that when the facility was active, fluids containing 33–59 tons of uranium were discharged into the shallow subsurface aquifer underneath Hanford. Studies suggest that this pollution is pervasively moving with the groundwater in the direction of the Columbia River.



US DOE

The Columbia River near the Hanford Site, pictured above, is a potential location where groundwater contaminated with uranium could discharge into surface waters.

Slater et al. wondered where and when groundwater contaminated with uranium would show up in the surface waters of the Columbia River. Understanding this requires detailed knowledge of the exact nature and location of links between groundwater and surface water. Capitalizing on the contrast in electrical properties between the permeable aquifer and underlying, less permeable materials, the authors towed a long string of electrodes back and forth close to the riverbank along the Columbia River near Hanford and recorded the variations in resistance along the river. From this they built a detailed map of the geology beneath the river bottom and identified regions where sediments underlying the river—formations into which nuclear waste was discharged farther inland—are likely more permeable and in contact with surface water.

Focusing on the areas identified as more permeable, the authors deployed fiber-optic temperature sensors on the riverbed. Capable of taking thousands of simultaneous measurements every minute along cables more than a kilometer in length, the fiber-optic data set revealed subtle changes in river bottom temperature along the river corridor: Certain locations on the riverbed were relatively warm in winter and cool in summer when compared to the surrounding riverbed, indicating that groundwater—which maintains a relatively constant temperature year-round—was discharging into surface waters. The authors suggest that continuous monitoring of the river at these sites of groundwater to surface water exchange near Hanford will allow researchers to know when and where uranium is likely to discharge into surface waters. (*Water Resources Research*, doi:10.1029/2010WR009110, 2010)

North and south components of Saturn's radio emissions reversed

Saturn is known to emit intense radio emissions at kilometer wavelengths from its auroral regions. Observations in recent years found that the Saturn kilometric radiation (SKR) emission from the northern auroral region has a clocklike modulation with a period of about 10.6 hours, while the SKR emission from the southern auroral region has a period of about 10.8 hours. Analyzing more recent observations from the Cassini spacecraft, *Gurnett et al.* have now found that the rotational modulation rates of the southern and northern components reversed shortly after Saturn's equinox on 11 August 2009, so that the southern hemisphere SKR now has the shorter rotation period. They also analyzed data from the Ulysses spacecraft to show that a similar reversal occurred during the previous equinox, in November 1995.

The authors suggest that these changes are probably driven by seasonal changes in incident solar radiation to the two hemispheres as the planet orbits the Sun. The changing incident solar radiation could lead to changes in the upper atmosphere, which could in turn affect how Saturn's magnetosphere slips with respect to its internal rotation. The changes in the magnetosphere could cause the observed changes in the rotational modulation of Saturn's radio emissions.