

working from the point of view of getting beauty in one's equations, and if one has really a sound insight, one is on a sure line of progress. If there is not complete agreement between the results of one's work and experiment, one should not allow oneself to be too discouraged, because the discrepancy may well be due to minor features that are not properly taken into account and that will get cleared up with further development of the theory" [Farmelo, 2009]. This is slightly different from what we deal with here but, nevertheless, addresses the same sort of problem.

What Is Needed?

To make progress in the field requires a broad research community that includes many different perspectives and has a healthy, respectful divergence of opinions. Each of the global numerical experiments and analytical models has its drawbacks and strengths. On one hand, the global models incorporate a wider range of processes. On the other hand, simple analytical and numerical models are more amenable to analysis and are valuable for their illumination of any changes that take place in response to other variations. Favoring one approach over the other will move us backward rather than forward.

It took meteorologists decades to arrive at the current state where we can make

relatively reliable forecasts several days in advance. It may take the same amount of time, if not more, to make comparable progress in climate prediction. To be successful, we need to attack the problem from all angles with a variety of methods and a hierarchy of models. While predictions should obviously be made for planning purposes, some of us would prefer to see the global numerical models used more often for sensitivity studies (i.e., examining the behavior of one variable as others are changed) than for predictions, as at this stage, we need to understand what it is that has to be parameterized better.

It is worth noting a crucial difference between global climate modeling and weather prediction. In weather prediction, one finds out fairly quickly if the forecast was poor. Examining a "skill score" keeps the weather prediction community honest. Because of the different timescales, there is no such score for global climate models and it is not at all obvious how global climate models can be rigorously validated (or invalidated).

I am not sure that I can propose easy solutions to the above situation. However, the first step is to recognize that there is a problem. It is, of course, the job of those of us who use simple models to convince the global modelers of the significance of simple models and of their ability to shed light on what the global models show. Unfortunately, our success in that aspect so far has been very limited.

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MEETINGS

Assessing the State of the Art of Ocean Internal Wave Research

Is There an Internal Wave Continuum in the Ocean?
Seattle, Washington, 3–4 October 2008

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Heavily studied in the 1970s and 1980s in part for their relevance to submarine detection and acoustic propagation, internal gravity waves are now of central interest in the physical oceanographic community for their role in global ocean energy cycles and mixing the oceans at great and shallow depths. Though the small time and space scales of internal waves may forever prevent their explicit resolution in global circulation models, their effects must be properly parameterized for reliable predictions of key quantities such as meridional heat transport.

To evaluate the state of the art of this field and formulate future directions, an international group of physical oceanographers recently gathered and discussed the current state of scientists' understanding of oceanic

internal gravity waves and associated wave-breaking processes. The meeting (http://www.apl.washington.edu/projects/PIMS_at_APL_Oct08/index.html) was sponsored by the Pacific Institute for Mathematical Sciences and held at the Applied Physics Laboratory of the University of Washington in Seattle.

Discussion focused on a pioneering semiempirical model known as the Garrett-Munk (GM) spectrum, which formed the basis for skillful parameterizations of the turbulent mixing of internal waves in the 1980s and 1990s. These represented a great advance because internal waves are much more easily mapped and included in large-scale models than is turbulence itself. These parameterizations treat the internal wave field as a uniform "sea" of waves of many frequencies and wave numbers, referred to as the spectral continuum. The waves interact

to transfer energy from large input scales to small scales, where breaking waves contribute to mixing and dissipation.

Recent work presented at the meeting also focused on strongly directional, narrowband motions at specific frequencies—called "near-inertial waves" and "internal tides"—which play a special role because they rise prominently above the continuum. Most recently, it has been further suggested that the continuum arises primarily from Doppler shifting of these few spectral lines by horizontal and vertical motions. This discretized interpretation of the wavefield calls for a different energy cascade, potentially invalidating some of the assumptions of the continuum-based parameterizations. More generally, failures of the parameterizations in high-energy regions lead to the devil's advocate question: Are the parameterizations only applicable where mixing is too weak to matter?

In the end, most meeting participants agreed that a continuum view is useful but that Doppler shifting is critical to the time variability of shear, strain, and mixing processes. Exciting recent theoretical work on the nonlinear interactions between the continuum waves reveals regional and seasonal differences in spectral level and slope, in contrast to the "universal" GM spectrum. These differences need to be catalogued at all scales, attendees agreed. Further, they determined that more work

is also needed to understand not only the geography and energetics of the large-scale waves but also the processes governing energy transfer from them to the smaller breaking scales.

Exciting recent advances in our ability to model internal waves, particularly in more realistic, eddy-rich, numerical oceans, will greatly improve experiment

design and data interpretation, according to conference participants. Additionally, field measurements will continue to be critical in addressing specific questions pinpointed through meeting discussions, and in quantifying energy sources for the continuum. Researchers in this field are challenged to further develop these concepts, instruments, and eventual

parameterizations in order to maintain a rapid rate of progress.

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What Do Lakes and Reservoirs Tell Us About Climate Change?

Chapman Conference on Lakes as Sentinels, Integrators, and Regulators of Climate Change; Incline Village, Nevada, 8–10 September 2008

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Where are scientists likely to find the clearest signals of climate change so that they can predict future impacts? The question of where we focus our sampling efforts is not a trivial one due to the complex nature of the landscape of the Earth and the wide and varied impacts of both humans and natural processes on the landscape. As the lowest point in the landscape and as hot spots of carbon cycling, lakes and reservoirs may provide an answer. These inland waters play a disproportionate role in informing us about climate change. They also play an important role in regulating climate change by their contributions to the global carbon cycle.

In early September, 92 scientists and 17 students from 18 countries gathered on the shores of Lake Tahoe at a Chapman Conference. Four working groups examined the role of lakes and reservoirs as sentinels, integrators, and regulators of climate change. They also discussed how to incorporate inland waters into global climate models. The results will be published in a special issue of *Limnology and Oceanography*, the journal of

the American Society of Limnology and Oceanography.

The sentinel value of lakes comes from their clear responses to changes in air temperature, precipitation, snowpack, and glacial meltwater, conference speakers reported. Signals include decreases in the duration of winter ice cover by 12 days in the past 100 years. Impoundment of water by humans accounts for a 0.55-millimeter-per-decade underestimate of sea level rise. Climate is also modifying the phenology of aquatic organisms, leading to a temporal mismatch between consumers and their food resources.

Discussions at the meeting highlighted that the sediments of lakes and reservoirs effectively integrate past signals of climate change. Sedimentary diatom assemblages from lakes in arctic, alpine, and temperate regions indicate warming over the past 150 years. Records from the sediments of remote alpine lakes show dramatic shifts in diatom community structure in recent decades. When coupled with neocological experiments, these paleosignals provide information about the relative role of climate change, nitrogen deposition, and other natural and anthropogenic forcing.

Lakes and reservoirs are also important regulators of climate change. Although they represent only about 3% of the land surface area of the Earth, they play an important role in the global carbon cycle as processors of the organic carbon from terrestrial ecosystems. Conference speakers pointed out that annual rates of carbon dioxide emissions from lakes and reservoirs are similar to rates of absorption of this gas by the world's oceans, while annual rates of organic carbon burial are greater than those in the world's oceans. Further, anthropogenic nutrient inputs and construction of impoundments may increase the occurrence of harmful algal blooms and anoxic "dead zones" in lakes as well as increase the production of potent greenhouse gases such as methane.

Attendees noted that past modeling efforts have ignored the role of smaller lakes in global climate models. Recognition of lakes and reservoirs as hot spots in the carbon cycle combined with a doubling of the estimated area that lakes occupy in the global landscape has stimulated active efforts to develop fully coupled atmosphere/land surface/lake climate models that incorporate lakes and reservoirs.

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