to 30,000 people could be affected on the densely populated island with popular tourist beaches.

Global Significance

Globally, many other forested volcanic islands have oversteepened and highly eroded edifices, where large landslides could cause significant harm to local communities and trigger tsunami. These sites are inherently difficult—and often dangerous—to survey via fieldwork. Google Earth™ provides a freely available and easy-to-use means of examining volcanic islands. Areas targeted as potentially hazardous can then be examined in more detail using archive aerial photographs and/or high-resolution optical satellite images (15–90 meter pixels). Satellite radar, which can operate through clouds or ash plumes, is particularly useful, and the RadarSat and TerraSAR-X satellites provide imagery with 1–3 meter pixels.

However, very high resolution satellite imagery (i.e., pixels less than 3 meters) remains expensive, typically in the US$1,000–10,000 range, which is problematic for low-income nations. The United Nations Charter on Space and Major Disasters has improved the situation, with free and rapid supply of satellite imagery to disaster-affected countries; however, it is a reactive system, limited to crisis response. The data cost problem still remains for low-income countries that are proactive and wish to produce disaster preparedness maps.

Another problem with mapping slope instability features on forested volcanic islands is that most types of remote sensing only show the top of vegetation cover. Fortunately, laser altimetry (or light direction and ranging (lidar)) can penetrate forest cover, revealing ground morphology. Airborne lidar has been used to map jungle-covered volcanic slopes on Lihir Island, Papua New Guinea [*Haneberg et al.*, 2005]. The Lihir lidar survey had an average laser strike spacing of 0.4 meter, which resulted in a 2-meter gridded elevation model, enabling the mapping of slope instability features. The cost of an airborne lidar survey over a remote island is high (at least $2000 per square kilometer) and beyond the budgets of most small island nations. However, where a major landslide hazard has been identified on a forest-covered volcanic island, the most effective hazard assessment strategy is an airborne lidar survey, supported by ground-based geomorphological mapping and geotechnical sampling.

This new study of landslide and tsunami hazards facing Dominica and Guadeloupe could stimulate some disaster risk reduction measures. For instance, an airborne lidar survey, supported by ground surveys of geomorphology and geotechnical conditions, would determine the severity of the north Dominica landslide hazard and enable improved estimates of the tsunami hazard. Given that a lidar survey of northern Dominica would be very expensive, an initial low-cost risk reduction strategy would be to reduce tsunami vulnerability on the southern coasts of Guadeloupe. Inhabitants and tourists in communities likely to be affected by tsunami should be alerted about how to recognize tsunami waves and be aware of local refuge sites, such as multistory reinforced-concrete buildings. Publicity about the potential tsunami hazard should help to raise the awareness of emergency planners, disaster managers, and the population of Guadeloupe.

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Ice Tank Experiments Highlight Changes in Sea Ice Types

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With the current and likely continuing reduction of summer sea ice extent in the Arctic Ocean, the predominant mechanism of sea ice formation in the Arctic is likely to change in the future. Although substantial new ice formation occurred under preexisting ice in the past, the fraction of sea ice formation in open water likely will increase significantly. In open water, sea ice formation starts with the development of small ice crystals, called frazil ice, which are suspended in the water column [*World Meteorological Organization,* 1985]. Under quiescent conditions, these crystals accumulate at the surface to form an unbroken ice sheet known in its early stage as nilas. Under turbulent conditions, caused by wind and waves, frazil ice continues to grow and forms into a thick, soupy mixture called grease ice. Eventually the frazil ice will coalesce into small, rounded pieces known as pancake ice, which finally consolidate into an ice sheet with the return of calm conditions. This frazil/pancake/ice sheet cycle is currently frequently observed in the Antarctic [*Lange et al.*, 1989]. The cycle normally occurs in regions that have a significant stretch of open water, because this allows for the formation of larger waves and hence increased turbulence. Given the increase of such open water in the Arctic Ocean caused by retreating summer sea ice, the frazil/pancake/ice sheet cycle may also become the dominant ice formation process during freezeup in the Arctic.

This brief report discusses a new series of laboratory experiments aimed at increasing our understanding of the processes underlying such new ice formation, under both turbulent and quiescent conditions.

The experiments were part of the project Understanding the Impact of a Reduced Ice Cover in the Arctic Ocean (RECARO), which involved more than 20 partners from 10 European countries, Japan, and the United States. The project consisted of two experimental phases: a 2-week experiment in November 2007 and a 1-week experiment in March 2008. By staggering the Arctic Environmental Test Basin (AETB) experiments in this manner, the consortium had time to analyze the data and adjust the experiments in phase 2 to fill in knowledge gaps remaining after the first round of experiments. RECARO studies complement the comprehensive basin-wide evaluation of sea ice processes performed under the European Union–funded Developing Arctic Modeling and Observing Capabilities for Long-term Environmental Studies (DAMOCLES) project. These experiments built on results from previous studies, most notably those of *Haas et al.* [1999], *Shen et al.* [2001], and *Doble et al.* [2003].

Experimental Layout

The experiments took place at the Hamburg, Germany, Ship Model Basin's (HSVA; http://www.hsva.de) Arctic Environmental Test Basin (AETB), which is 30 meters long, 6 meters wide, and filled with saltwater to a depth of 1.2 meters. To provide for the two scenarios of ice growth under quiescent and turbulent wave–dominated conditions, the AETB was divided into three separate tanks. Tank 1 was maintained as a turbulence-free zone, while tanks 2 and 3 were used to study ice formation under a wave-dominated environment. In these separate tanks, starting from open water, ice was grown under both turbulent and quiescent conditions, and associated atmospheric, cryospheric, and oceanographic variables were constantly monitored.

The identically sized tanks 2 and 3 each had a separate wave maker, and each ended in a raised beach. The object of the raised beach was to try to absorb the incoming wave energy and thus limit the amount of wave reflection back along the tanks. The tanks were isolated from each other by sealed wooden barriers. Figure 1 shows a schematic of the tanks.

A number of different sensors were placed in each tank, including (1) oceanographic sensors to measure temperature, salinity, turbulence, and wave field; (2) meteorological sensors to measure air temperature, humidity, and air pressure; and (3) cryospheric sensors to measure ice thickness, concentration, crystal structure, salinity and brine content, optical properties, and ice strength.

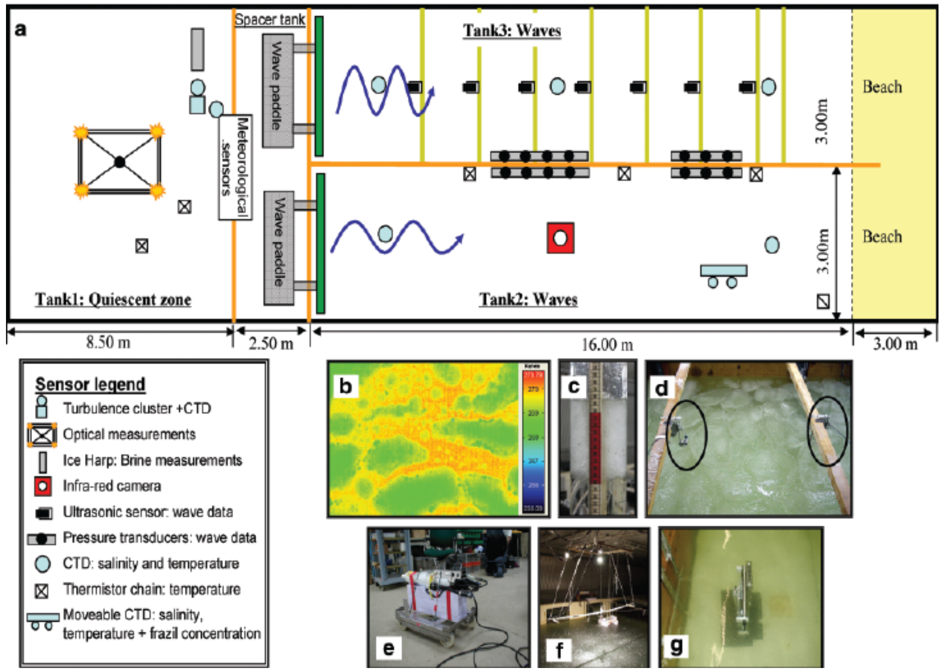

Fig. 1. (a) Schematic of the layout of the Arctic Environmental Test Basin. (b) Infrared image of developing pancake ice. (c) Measuring the frazil ice layer. (d) Ultrasonic sensors (circled) above pancake ice. (e) Movable conductivity-temperature-depth profiler. (f) Optical experiment in tank 1. (g) In-tank conductivity-temperature-depth profiler.

Experimental Program

A number of experiments involving waves of different frequencies and amplitudes were conducted at the AETB. The simultaneous measurements of the same oceanic and cryospheric parameters in all three tanks during the ice formation process should provide new insight into a large variety of questions relating to the different regimes of ice formation. These include the following:

Ice growth: Wave-induced frazil ice formation is thought to produce a greater and more sustained rate of ice growth than ice grown under quiescent conditions. What are the growth rates of each newly formed ice type?

Brine drainage: The natural result of enhanced ice formation will be enhanced salt release into the underlying ocean, which will influence the stability of the mixed layer. What are the brine expulsion rates for each ice type?

Pancake ice formation: Pancake ice formation only occurs when a wave field is present. What are the factors that control the evolution of frazil ice to pancake ice, and what controls the initial size of the pancakes?

Mechanical strength/crystal properties: An ice sheet formed from pancake ice has a different crystal structure than one formed from ice grown under calm conditions. How will this different crystal structure influence the strength and hence the stability of the ice sheet in its initial stages?

Wave attenuation: An increase in open water will lead to changes in the wave spectra, which will influence both new ice formation and the enhanced breakup of ice in the melt season. How will the change in the wave field influence the new ice formation regime? And what is the relationship between wave attenuation, ice thickness, and wave frequency and wave amplitude?

Optical properties: How does the increasing fraction of thin ice in the Arctic change surface albedo, absorption of energy, and transmission of light into the ocean? On the basis of radiation experiments, significant stages of new ice cover evolution can be derived.

Future Directions

The experiments described in this brief report could improve our understanding of the processes behind the two different ice formation regimes as well as their respective influences on the ocean and atmosphere. An improved understanding could allow for better characterization of the development of sea ice in the Arctic Ocean during freezeup—especially the optical and physical properties of new ice types, the associated brine drainage, and sea ice wave dynamics—and could guide the incorporation of these ice regimes into future coupled sea ice models.

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