SEA LEVEL EXPERIMENTS FOR CLIMATE SCIENCE OUTREACH

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ABSTRACT

The motivation for this outreach effort is to establish an experimental curriculum for high school students. Several experiments are performed in a sequence, designed to spark interest in the scientific method and the testing of theories, leading students to some predictable and non-trivial results in sea level science. Two aspects of scientific theory are tested experimentally: salinity distribution in the ocean and the impact of fresh water influx on local sea levels. The learned concepts are used to understand basics of altimetry, determination of mean sea level and computation of mean dynamic topography. The students are also taught the basics of scientific experimentation, data collection, analysis and reporting. A logical chain of experiments builds knowledge about state of the ocean and use of radar for ocean remote sensing. The learning process emphasizes the role of altimetry in monitoring sea level and the state of the Earth's climate system.

Model Altimeter

A model altimeter can be easily and inexpensively constructed from an Arduino microcontroller and an ultrasonic range finder (Fig. 1). The rangefinder incorporates a simple ultrasonic sensor with a microcontroller. The sensor sends out a burst of ultrasound and then listens for the echo when it bounces off an object. The working range of this rangefinder is between 2 centimeters and 3 meters. The microcontroller is connected to a laptop, and the data from the sensor can be read into MATLAB for data visualization and analysis. This inexpensive rangefinder can be used for a variety of simple experiments, such as making range measurement of students walking towards and away from the sensor. A nadir altimeter can be modeled by making range measurements to the surface of water in a container.

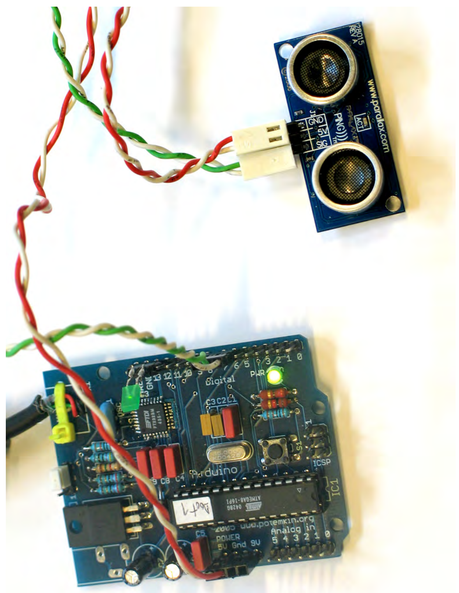
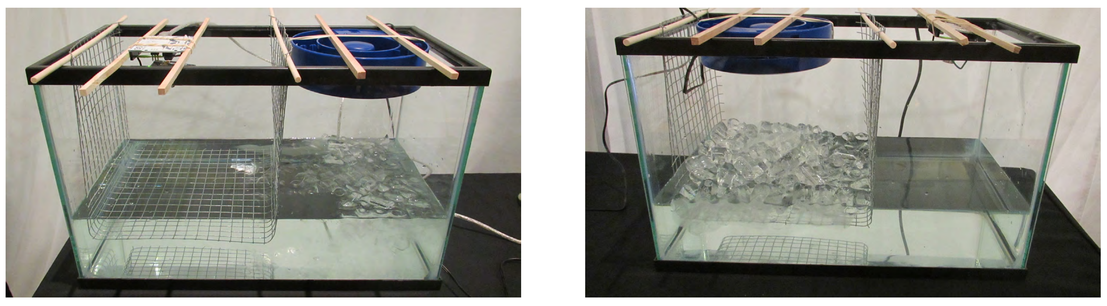


Fig. 1: Model altimeter constructed from an Arduino mini controller and an ultrasonic rangefinder.

Fig. 2: Experimental setup to compare the differences between the contribution of melting sea ice (left) and melting continental ice (right) to sea level rise.



Contribution of Melting Sea Ice and Continental Ice to Sea Level

The model altimeter can be used to explore the difference between melting sea ice and melting continental ice in terms of their contribution to sea level change. The increase of water level in two separate containers, one container where ice is floating in tap water to simulate sea ice (Figure 2, left panel) and one where ice is suspended just above the surface of the tap water to simulate continental ice (Figure 2, right panel). A fan is used to expedite the melting of the ice. The experiment is run for 20 minutes, and the results are read directly into MATLAB for further analysis. Once the experiment has been completed MATLAB is used to analyze the results to determine whether sea ice or continental ice contributes more to sea level rise when it melts. The results (Figure 3) show that melting "continental" ice causes the water level to change significantly more than melting "sea" ice. This classroom lectures accompanying this experiment, the experiment itself, and statistics describing the educational outcomes are described in Hamlington and Leben (2012).

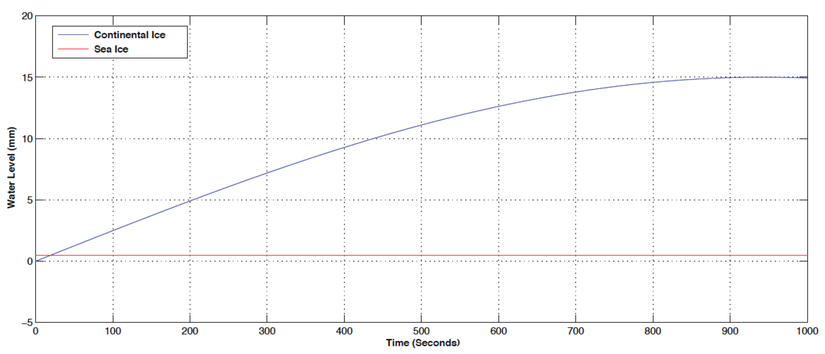


Fig. 3. Results of ice experiments that show that melting "continental ice" (blue) contributes significantly more to sea level rise than melting "sea ice" (red).

Contribution of Melting Sea Ice to Sea Level

It was common lore that the melting of floating ice does not change sea level until Noerdlinger and Brower (2007) correctly pointed out that the melting of floating ice actually raises sea level. A more advanced experiment exploring this "halosteric" contribution of melting sea ice to sea level can be performed based on a similar experiment described in Noerdlinger and Brower (2007). The demonstration uses a saturated solution of sodium chloride with blue dye added and a 1000 ml graduated cylinder with an adhesive metric ruler attached. The saturated salt solution, which is 26% salt by weight, was made by adding 3 lbs. of sea salt to one gallon of heated distilled water. Various recipes for making the solution can be found with a web search of "how to make a saturated salt solution". Ice cylinders slightly smaller than the diameter of the graduated cylinder were made using forms made from PVC tubing and end caps available a local hardware store. The "halosteric" contribution of melting ice floating in a saline solution is clearly shown. The effect for salinity values in the earth's ocean is such that the increase in ocean volume when floating sea ice melts is equal to 2.6% of the seawater volume initially displaced by the ice.

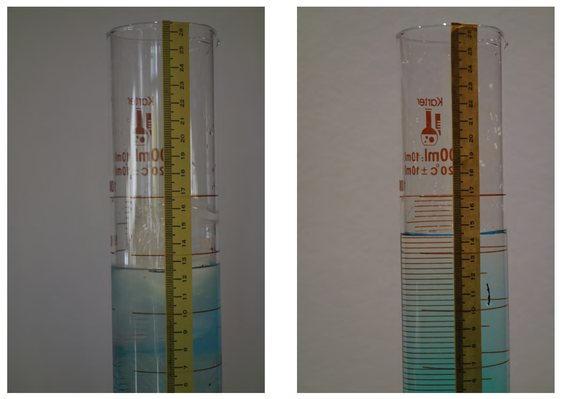


Fig. 4. The initial experiment was performed starting with 600 ml of salt solution in the graduated cylinder and a reference height of 3.3 cm on the metric ruler. A total of 333 grams of ice was added, increasing the water level to 12.5 cm (left). Melting overnight raised the water level to 14.4 cm (right).

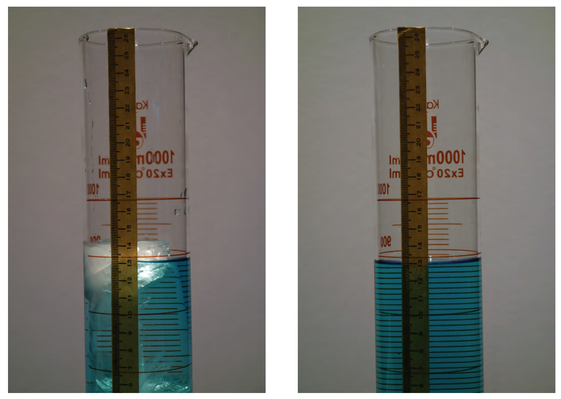


Fig. 5. The experiment was repeated, this time using distilled water instead of the saturated salt solution. A total of 290 grams of ice was added to the graduated cylinder, increasing water level to 13.9 cm (left). Melting overnight resulted in no change in the water level from the initial height of 13.9 cm (right).

Relative Sea Level Change

Salinity in the Earth's ocean varies depending on fresh water inflow and evaporation rates, as well as mixing processes due to diffusion and advection. This affects sea level. An experimental apparatus was constructed of two interconnected cylinders, designed to simulate change in salinity levels in interconnected vessels. Basic hypotheses of water level change due to salinity changes were explored. By introducing ice into one of the cylinders, partially filled with brine solution, students observed that initially, water levels equilibrate. After some time has passed, the ice completely melts and the temperature of water equilibrates, but the water levels became distinctly different. This can be explained by difference in specific density and the long equilibration path to be traversed by the salt ions. Length of the diffusion path prevents the fluid within the interconnected cylinders from equilibrating in salt concentration.

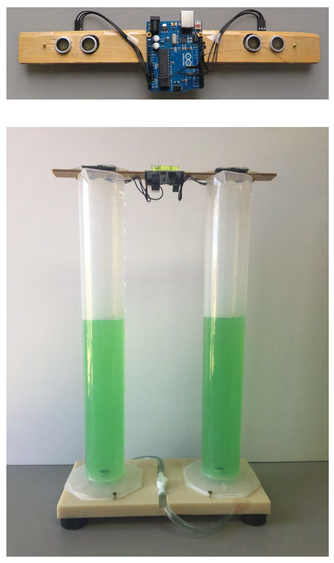


Fig. 6. Double altimeter/cylinder configuration.

What about SWOT?

Nadir radar altimetry is a relatively simple concept to teach in the classroom. The primary SWOT instrument is an interferometric altimeter, which is a swath instrument capable of measuring/imaging ocean topography along a swath 120-km wide. We are exploring the use of an augmented reality sandbox as a demonstration tool for this technology. An example is shown to the left.

Fig. 7. Augmented reality sandbox based on the Microsoft Kinect projecting realtime topography (Reed et al., 2014; Kreylos, 2015; SUNY, 2014).

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Acknowledgement

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