Engaging undergraduates in Ocean-Atmosphere experiments: From teaching to research and outreach

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Abstract

The Weather in a tank demonstrations (http://paoc.mit.edu/labguide/) are being implemented at a group of universities (UW Madison, Penn State, Millersville University, Johns Hopkins and UMass Dartmouth and MIT) to introduce many atmospheric and ocean circulation related concepts to students at various levels. An elegant and easily transportable rotating table has been designed for a series of experiments that simulate diverse processes in the atmosphere-ocean system. The experiments have been used very successfully in education at our university and partner universities. We discuss two aspects of these demonstrations: (1) the use of rotating fluid experiments in undergraduate education and how they can be used to engage physics undergraduates in research via a hands-on experience and (2) the use of experiments in outreach and general education. The implementation at UMass Dartmouth has led to the engagement of undergraduates in research, the prototyping of new lab experiments in collaboration with MIT, and to the publication of our results in a peer-reviewed journal. Demonstrations have also been used in outreach settings for the general public, as well as to attract incoming freshmen to our field. Engaging the audience by asking them to make predictions prior to the demonstrations, and linking them to atmospheric and oceanic flows, enhances their impact.

1 Weather in a Tank for Undergraduates

Though continuum mechanics is a part of classical mechanics, it is not generally covered well in the undergraduate physics curriculum. *Gollub*(2003) has forcefully recommended that physics curriculum would benefit from inclusion of continuum mechanics, though this has only happened at very few universities in the UK and the US. In a recent article in Physics Today, *Gollub*(2008) discusses introducing fluid motions in a more general context. There is an increase in interest on environmental physics among physics majors although the traditional physics curriculum does not teach enough continuum mechanics for the physics students to be able to pursue these interests.

In the absence of a formal continuum mechanics background, hands-on laboratory experiments can motivate students and help them connect with the theory as well as the data related to atmospheric and ocean dynamics. At UMass Dartmouth the "Weather in a Tank" setup (see Figure 1) by the lead institution (MIT) is used to introduce a few important concepts to Physics majors as well as non-majors via general education courses. We limit ourselves to the implementations at UMass Dartmouth below, but would like to alert the reader that different implementations happened at each of the partner universities and at MIT as the lead institution. *Illari et al.*(2009) contains a detailed article submitted to the Bulletin of the American Meteorological Society on this project. Collectively, we learned that these experiments can be implemented at many levels, from high school to graduate school, and from general education to specialized graduate courses. The website associated with the project has links to the experiments, the theory behind the experiment and the datasets that can be used to illustrate and quantitatively investigate the phenomenon. It also offers a wiki as well as resources for teachers. Formal assessments by an independent evaluator, Dr. Kathie Mackin showed that these experiments had a positive impact on student learning. In the discussion that follows, we discuss the implementation in four such courses at UMass Dartmouth.

The physics majors at UMass Dartmouth have to fulfill a senior lab requirement and we implemented four of the experiments in Spring 2007 as part of a seminar course. In Fall 2007 these demonstrations were used in a general education meteorology course. In Fall

Figure 1: This photograph shows the setup the weather in a tank. The platform is mobile, which allows it to be moved in and out of classrooms easily.

2008, a different set of experiments were used in a general education introductory course on climate change, as well as in a team taught sustainability topics course on “Coastal Zones”. In Fall 2007 and 2008, the implementation followed the Socratic questioning (suggested by John Marshall and Lodovica Illari; see Figure 2), which first questions the students to make and sketch their predictions for one or several conditions (slow/fast rotation or no rotation, presence/absence of thermal gradients etc.) and forces the students to think critically about their predictions soon after making them. This forces the class to be interactive, though many students do not like to make a prediction for the fear of being proven wrong. The positive part in our experience is that the students then have a stake in the outcome of the demonstration, and get more interested in the results of the demonstration. Building up some suspense in class is key! We typically list or write the possible predictions made by the class on the board before doing the demonstration.

In Fall 2008, in the climate change course the experiments were motivated specifically by in class discussions on poleward heat transport by the atmosphere and the ocean. The dye stirring experiment was used to introduce the class to the rotating table setup and the importance of rotation. This was followed up by experiments demonstrating frontal thermal wind balance via a cylinder collapse, and then annulus experiments demonstrating heat

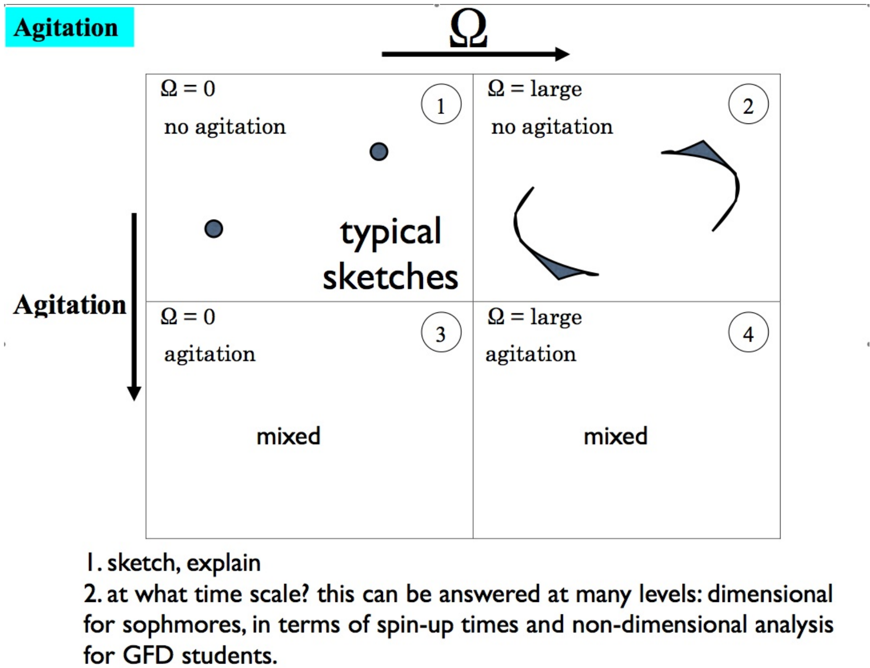

Figure 2: A sample of the teacher resource for the dye-stirring experiment showing some of the possible audience reactions. The level of the discussion can be suited to the audience readily, as indicated.

transport via Hadley cell and the eddies, in different rotation regimes.

In the coastal zone class different tank experiments were used. Firstly the students were shown how density stratification can be created (e.g. Marsigli's experiment) or destroyed (convection with beakers). The thermohaline experiment using a tilted bottom was used to illustrate how in absence of other forcing, the flow follows isobaths rather than flowing downhill, and the coastal downwelling and upwelling was illustrated via the Ekman upwelling and Eman suction experiment in different lectures. This led to spontaneous and stimulating questions from students on Peruvian Fisheries and El-Nino.

The general education implementation did not allow time for students to investigate the experiments or associated data on their own. However, for the physics majors seminar course, the in-class demonstrations were followed by requiring the students to do the demonstrations by themselves afterwards, and to link the experiments to the atmosphere or the ocean datasets (via links provided at the MIT Weather in a Tank website). The students also read up on the theory, which was subsequently discussed in class. This ensured that the theory,

Figure 3: This photograph shows the audience viewing the dye stirring experiment after having made their predictions at the New Bedford Waterfront festival in October 2008.

experiments and observations were all linked for a particular phenomenon. As part of their course project, the students were also required to think of one extension of one of the original demonstrations and write about it as a comprehensive lab report at the end of semester, linking it with either atmospheric or oceanic dynamics and making the results quantitative. In Spring 2007, the physics majors got very interested in doing the experiments themselves, and documented their results with an online album on a Flickr website, on their own.

2 Weather in a Tank for Outreach

The setup lent itself easily to illustrate counter-intuitive phenomenon during open house events in every semester since Spring 2007. It has also been used for outreach at the opening of a new research building at UMass Dartmouth, and at the New Bedford waterfront festival in Fall 2008. At the latter event, despite heavy rains, the dye stirring experiment proved to be a major draw for the visiting public, who were asked to make predictions. Many in the audience (see Figure 3) wanted to know more about the experiment as their predictions for dye mixing in the rotating frame turn out to be quite different from what the demonstration later shows. The setup was also used in a seminar to graduate students at the School for Marine Science and Technology (SMAST), where it proved to be very popular with students. We are now planning to collaborate with the New Bedford ocean explorium in further outreach efforts.

3 Involving Undergraduates in Research and prototyping new experiments

As part of the Physics seminar course, the students were required to think of extensions of the currently listed experiments. This gave rise to many exotic ideas such as trying the fronts experiments with density contrast achieved via an oil/water mixture, experiments in different parameter regimes, and a trial to test wind-driven effects in a rotating frame using computer cooling fans. The latter extension proved very useful, and was improved and prototyped over summer 2007. The fans easily attach to the edges of the tank and blow air over the waters surface. Thus they create currents in the tank that can be studied in the rotating frame. This technique is used for simple classroom demonstrations to model cyclones, anti-cyclones, and Ekman transport. To create the cyclone/anticyclone, two fans are attached to the edge of the tank. The wind driven circulation is observed using a combination of potassium permanganate crystals and floating particles at the surface. Depending on the direction of the fans and the direction of the tanks rotation, either convergence or divergence occurs at the surface as shown in Figure 4. The resulting circulation mimics that of an atmospheric cyclone. The anticyclone is created by reversing the direction of the fans. The experiments illustrate Ekman pumping and Ekman suction as well. For general education students, a discussion about the Great Pacific Garbage patch before this demonstration can be very motivating. The Ekman pumping and suction experiment was presented at the 2007 AMS student conference, and it resulted in a publication *Beesley et al.*(2008)*Beesley, Olejarz, Tandon, and Marshall* with undergraduate seniors David Beesley and Jason Olejarz as lead authors.

In Fall 2008, junior physics student Carter Chamberlain got involved in the project. Carter worked on some modifications to the table to allow fan controls on the main table. More importantly, he investigated the Ekman pumping and suction in a 2-layered system, as well as upwelling along a coast with a stright edge coast. The lower salty dense layer is dyed, and the motion of the interface is a very clear indication of the Ekman pumping and suction in a stratified system.This work is being presented at the 2008 AMS student conference, and it is being written up. Carter also considered various particle trackers such as mustard seeds and tapioca flakes, and has shown that tapioca flakes act as a great tracer for motion

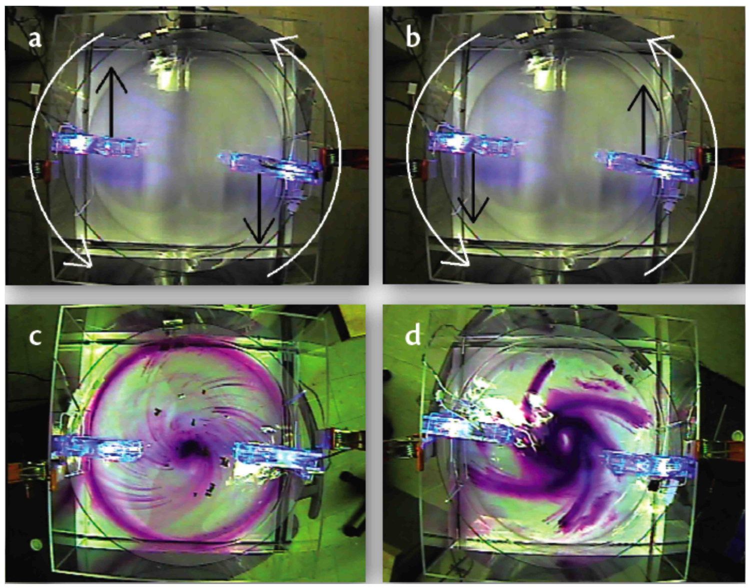

Figure 4: This figure shows the Ekman suction/upwelling demonstration in a homogeneous fluid layer, motivated by research with undergraduates in summer 2007. Top row: (a) Anticyclonic and (b) cyclonic circulation are induced by blowing air over the surface of a rotating tank of water using co-rotating fans. In both cases, the table rotates anticlockwise (cyclonically) as shown by white arcs in the top row. The fan arrangements provide an anticyclonic wind stress in the left panel (a) and a cyclonic wind stress in the right panel (b). Black arrows show the direction of the air blown from the fans. Bottom Row: (c) Anticyclonic (left) and (d) cyclonic (right) circulations set up by the applied wind stress revealed by potassium permanganate crystals resting on the bottom of the tank. Black paper dots floating on the surface reveal the sense of the upper (directly wind-driven) flow. Over time, the dots congregate in the middle of the anticyclone but on the periphery of the cyclone.

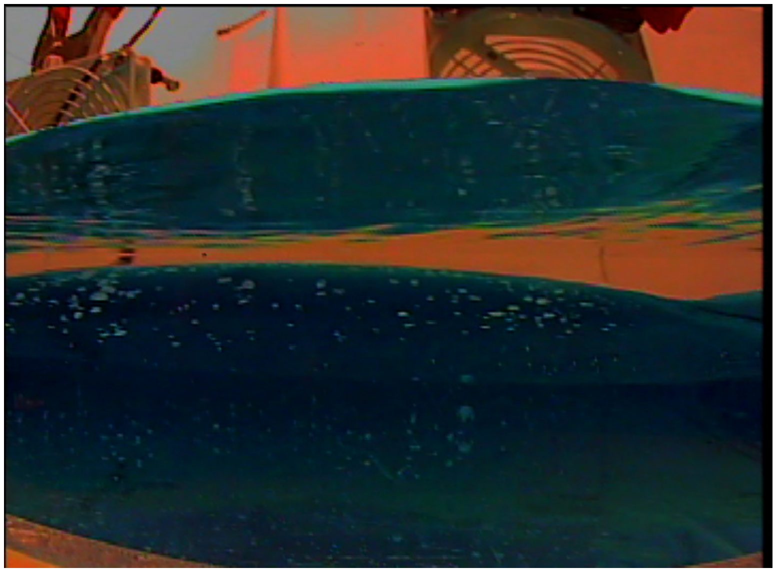

Figure 5: This figure shows an experiment carried out by undergraduate Carter Chamberlain, where the cyclonic windstress is setup at the surface of the tank by using computer cooling fans. The water in the tank has two layers, and the lower salty dense layer is dyed blue. The interface can be seen doming up at the center of the figure due to Ekman suction which gets setup at the surface. Tapioca flakes act as a tracer to mark the motion at the interface. Total internal reflection causes the false appearance of a blue layer which seems to be hiding the fans at the surface.

at the interface for demonstrations. Figure 5 shows the Ekman upwelling resulting in the doming up of the interface, and the tapioca flakes at the interface. Carter is also working on a model to quantify the interfacial height by mapping the dye intensity in an image with its depth.

4 Assessment and benefits for educators

Several assessment tools have been developed as part of this project. These include pre/post tests that test general knowledge of students about atmosphere, ocean and climate; weekly logs of instructors that are implementing the experiments; development of rubrics for evaluating oral and written student work related to the experiments; survey of student impressions on each of the experiments, as well as end of semester survey of instructors. Formal evaluation by an independent evaluator, Dr. Kathie Mackin suggests that the experiments are greatly appreciated by the students and lead to improvements in student learning. At

UMass Dartmouth, the lead author (Tandon) has found the experiments to be very motivating for both the instructor and the students, and have led to higher instructor satifaction. More information, including detailed results and implementations at other universities are available at the website http://paoc.mit.edu/labguide/ .

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