Environmental Science Institute
THE UNIVERSITY OF TEXAS AT AUSTIN

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Visualizing Cyclone Mechanics

Lesson plan for grades 9-12
Length of lesson: 1 class period, 75 minutes
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SOURCES AND RESOURCES:

- The Theory of Hurricanes
  Emanuel, K. A. The theory of hurricanes. Annu. Rev. Fluid Mech. 23, 179–196 (1991)
- University of British Columbia: Hurricane in a Box
  - http://outreach.phas.ubc.ca/phys420/p420_04/sean/
- Physics of Hurricanes
  - http://webphysics.iupui.edu/warmup/iupui_archive/hurricanes.html
- Thermal Expansion Definition
  Paul A., Tipler; Gene Mosca (2008). *Physics for Scientists and Engineers, Volume 1*(6th ed.). New York, NY: Worth Publishers. pp. 666–670. ISBN 1-4292-0132-0.
- ABC Australia: Classic Candle Experiment
  http://www.abc.net.au/science/surfingscientist/pdf/lesson_plan10.pdf
- Discovery News: "Global Warming - Hurricane Link To Climate Change Explained"
  http://news.discovery.com/earth/global-warming/does-climate-change-mean-more-or-stronger-hurricanes-120907.htm
- Kerry Emanuel, Ragoth Sundararajan, and John Williams: Hurricanes and Global Warming - Results from Downscaling IPCC AR4 Simulations:
  ftp://texmex.mit.edu/pub/emanuel/PAPERS/Emanuel_etal_2008.pdf

POTENTIAL CONCEPTS TEKS ADDRESSED THROUGH THIS LESSON:

- §112.32.c Aquatic Science Grade 10-12: 8A, 8B
- §112.35.c Chemistry, Grade 10-12: 4B, 4C, 9A-C, 11A-E
- §112.36.c Earth and Space Sciences, Grade 11-12: 9A, 11E, 13B, 14C, 15A, 15E
- §112.37.c Environmental Systems, Grade 11-12: 8A, 8E
- §112.38.c Integrated Physics and Chemistry, Grade: 9, 10: 9A, 9B, 9D, 9E
- §112.39.c Physics, Grade 9-12: 4A, 4B, 6A-G

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PERFORMANCE OBJECTIVES:

Students will be able to:

- Identify, in words, favorable conditions for hurricane genesis such as tropical latitudes, warm water regions, and low wind shear.
- Identify the heating of ambient air by the ocean as an energy source for hurricanes.
- In words, describe the anatomy of a hurricane, from the rising of warm air to the creation of clouds due to condensation, the creation of low pressure zones, and a positive feedback mechanism created with radial inward movement of air masses.
- Report, in words, the effects of global warming on hurricane power dissipation over time and possible effects on frequency of hurricanes.

MATERIALS (per group of three):

- 1 sheet of Easel Pad Paper (any size)
- 2-3 washable markers
- 3 copies of the article “Global Warming - Hurricane Link To Climate Change Explained” [included above under resources]
- Student evaluation sheets (located at the end of this lesson plan)

PREPARATION:

- Have all student copies (articles, evaluation sheets) ready
- Have all videos booted and prepared (if needed)

CONCEPTS & TERMS:

- **Boiling point** is defined as the temperature at which the vapor pressure of a liquid is equal to the atmospheric pressure.
- **Thermal expansion** is the tendency of matter to change in volume in response to a change in temperature.
- **Hurricanes** refer to tropical cyclones in the Atlantic and East Pacific ocean whose winds reach winds in excess of 32 metres per second, or 74 MPH sustained winds.
- **Hurricanes** develop in conditions of low latitudes under conditions of warm oceans and low wind shear conditions.
- A **mature hurricane** is driven by **thermodynamic disequilibrium** between warm tropical oceans and the surrounding atmosphere.
- **Pressure** is defined as a force over an area and is measured in Newton•Metres (N•m) or Pascals (Pa)
- **Coriolis force: The tendency for water or air masses moving in a forward trajectory to turn to the right in the Northern Hemisphere, and to the left in the Southern Hemisphere as a result of the Earth’s rotation**

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BACKGROUND:

Hurricane physics brings together the fields of meteorology, atmospheric science, fluid dynamics, and thermodynamics. At the high school level, most students in the sciences are exposed to the kinetic theory of ideal gases and the ideal gas law. The current aim of this lesson is to use students' existing experiences with boiling water and pressure in everyday circumstances such as in tires and in balloons. In an extension of this, the students will apply their shared experiences to the large-scale structure of an idealized hurricane storm to identify disequilibrium between sea and atmosphere as the 'fuel' driving these storms. Students should be informed that this is *not* a closed (meaning inactive, or fully explored) discipline but rather one of fertile, active, and critical importance in research.

Today, the study of hurricanes remains of critical importance in public safety, as the records document various catastrophic events tied to these natural disasters including Hurricanes Katrina (2005) and "Galveston" (1900) among the most destructive and deadliest in the US alone. From a fluid dynamics standpoint, the complex nature of these cyclones leave many unanswered scientific questions including the genesis of these storms. In this lesson, one approach to the theory of hurricanes advanced by Dr. Kerry Emmanuel of the Massachusetts Institute of Technology is explored with an emphasis on sea-air-wind energy exchange and pressure gradient effects.

ENGAGE:

This lesson begins with an assortment of demonstrations, but the instructor is free to modify any combination of these. The author includes three demonstrations to emphasize a key concept: the powerful effects of pressure difference.

As a first demonstration is the classic can crushing demonstration in which the instructor carefully brings a small amount of water to boiling in an ordinary aluminum soda can and then promptly inverting the can over a beaker of room-temperature water. The rapid condensation of the internal water vapor appreciably causes a drop in pressure inside the can whereby the external atmospheric pressure crushes the can. The key idea for the purpose of this lesson is that the boiling water and the vapor created in the can displaces a significant amount of air within the can much like how a warm equatorial areas of the pacific interacts with surrounding air, causing it to rise higher in the atmosphere.

Secondly, there is the equally timeless candle in a jar experiment. Instructions for this experiment are contained in the sources above, and the author recommends using the "Teacher Demo 2: Cooling Air Contracts" demonstration near the end of the instructions in order to focus student attention on the changes in air temperature and pressure. The author of the demonstration includes this version to help clarify the common misconception that the candle in the jar consumes *all* of the oxygen in the bottle; for this lesson, the flame is not essential to demonstrate the desired concepts of pressure differences.

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Finally, there is the ingenious “Hurricane in a Box” demonstration as outlined by the University of British Columbia (UBC) Physics and Astronomy department (included in sources above). The specs for constructing are contained therein, but the author of this lesson recommends showing videos of experiments by the department also linked on their page. Their apparatus functions much like the previous two demonstrations, but only now water is allowed to boil freely into the ambient air. There are four offset slits in their box which allow surrounding room air to enter the box and fill the low pressure region left by the rising warm vapor; the separation of the slits is such as to set the hot vapors spinning (to replicate the Coriolis force – see CONCEPTS AND TERMS). The UBC team has even perfected their experiment by also adding small amounts of liquid nitrogen to their boiling water plate in order for the desired vortex to be visible to students. This demonstration is also a demonstration of the effects of pressure differences and is a model of hurricane genesis.

Sample dialogues/possible probing questions for the instructor during demonstration (after introducing demos and stating class objectives):

- What is happening now as I’m heating the water inside this can? How can you tell?
- Predict (either in words, or in writing) what will happen when I place this can over this beaker of water.
- [after can demonstration] Someone tell me what they think just happened. Was this what you predicted earlier? How is it different?
- What happened when I inverted this hot flask over this plate of water? *Why* did the water rise? Is there anything else you’ve seen before that does this?
- [hurricane in a box] What’s going on in this video? What’s in the center of the box? What are some *observations* we can make about this group’s experiment? Does it look like anything you’ve seen before?

Model Transition: All three of these experiments are intimately connected, and things like them happen all the time in nature. Since we have our “scientists and engineers” hats on today, let’s break up into groups and see if we can work out some of the science at play here.

<u>EXPLORE</u>:

Overview:

During this section, the instructor may choose to assign or randomize groups of no more than three. Students will be working in small groups to develop their own hypothesis behind one of the above demonstrations. Using supplied easel pad paper and markers, each group will illustrate their ideas and present to the class after a set amount of time.

Collaborative Learning:

In order to promote *collaborative learning* and focus, the author recommends assigning roles such as “illustrator,” “recorder”, and “material manager” within each group. Each group member should have a

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responsibility, and it should be communicated to each group that each group member is accountable and equally likely to present group ideas at the end of this section.

The teacher may choose also to break up each demonstration such that in a model classroom of 24 students with groups of three, two groups may work (separately) on the can experiment, two groups may work on the bottle demonstration, and three groups may work on the more complicated vortex demo. The use of a timer (ten to fifteen minutes) is encouraged but at the instructor's discretion for this step.

Instructions:
These are instructions the teacher may wish to communicate to the students prior to the activity and also have on display throughout:

1. In your groups, develop a *hypothesis* to explain your assigned demonstration.
2. Use as much scientific terms as possible, be specific!
3. Draw and record your group's ideas on the provided paper.
4. Be ready to share your ideas; presenters from each group will be randomized.

Teacher Guidance:
The objectives of this lesson are around the science of hurricanes, where they form, what sustains them, and how they become so potentially destructive. Students should be encouraged to employ scientific vocabulary amongst each other as much as possible and to have prepared, scientific ideas for their models. For example, students may be familiar with terms like density, pressure, temperature, boiling, and condensation. The instructor at this point should not provide definitions, but it may help to listen how students use these terms.

It is very important to describe how the sun's energy is heating both air and water masses, and have a special section on why climate change and GHGs are thought to be driving the intensity of storms through increase differences in pressure.

Sample Dialogues/Questions:

- What ideas does [your] group have about the [say, can-crushing demonstration] so far?
  - Student: We think the boiling water vapor pushes the air out of the can, and then the pressure crushes it when the opening is closed off.
  - Teacher: Why does your group think the vapor pushes the air out?
  - Student: You could see some steam coming out of the top of the can when it was over the fire.
  - Teacher: I see. And you mentioned something about the pressure; tell me more about that.
  - Student: Maybe the can can't hold back the air pressure anymore when it's covered up like that, so it gets crushed.

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   - Teacher: These are very interesting ideas, and I think you might be onto something. But, I'm wondering how your group would explain why the empty can isn't crushed when it's *not* heated. That might be something to think about.
- How about the second demonstration with the heated flask; why *did* the water level in the flask rise when [I] flipped it over on that plate?
   - What was inside the flask before and after I flipped it over?
   - How is this similar to the aluminum can? How is it different?
   - Why did the can get crushed and not the flask? *Should* it have? Why/not?
   - [If student mentions air *first* inside the flask], what do you know about the properties of air?
      - What happens when air is cooled? When it's heated? Are there examples you can think of?
      - How about air and metals? How do metals behave when they are heated or cooled?
- So, what was in the center of that box in the video?
   - Student: It looked like a hot plate with some water and [other stuff] in the middle.
   - Teacher: That's right, and how does your group explain what happened?
   - Student: We're not really sure. It looked like a small tornado.
   - Teacher: It did look like a tornado, yes. So, maybe, it might help to think of what caused that shape in the first place. Have you seen anything like this around school before? Or perhaps near buildings? It might help your group to think about just how that box was designed.

EXPLAIN :

After the allotted time, students should return all markers to their respective containers and should be in their assigned seats. The teacher may begin gathering student feedback by selecting one group member from each station to present each hypothesis. One way the author has seen this done is to have a set of cards labeled "1", "2", and "3," and then having the three members from each group draw face down cards. Since it is randomized, the teacher may select all "2s" from each group to be the presenters for the day.

With each presentation, the instructor should record student ideas on either a separate easel pad or on a board/projector. The author recommends a traditional two-column method with student hypotheses on one side and key words on the other. This helps keep track of all ideas for later comparison and also aids in the introduction of formal labels and definitions *in terms of* provided student explanations.

At this time, it is suitable to introduce terms like **relative density, buoyancy, partial vacuum, thermal expansion, Coriolis force,** as they are appropriate.

ELABORATE:

One of the key points of Dr. Emanuel's talk was the effects of global warming on future hurricane risk assessment (minute 32:02 of the talk). He contrasted the notion of constant variables in climatology over time

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with increasing global temperatures (minute 33:19) and even demonstrated how power dissipation of hurricanes have doubled with rising sea temperatures in the Atlantic ocean (minute 23:34). The summary of the latter portion of his presentation left us with the following message: **global warming increases the incidence of intense, destructive hurricanes and this is reflected in model projections of increased risk of high winds (minute 28:00), surges, and floods (minute 30:28) associated with Texas hurricanes (minute 32:05).** With a shared experience in the mechanics and conditions required to create a hurricane, the students now will have an opportunity to extend and apply this knowledge to current science and events. Namely, in the resources section of this lesson plan is an interview published in September 2012 with the leading atmospheric scientist and speaker on this disk, Dr. Kerry Emanuel.

Each student should receive a copy of the article, and it is for the instructor to decide how this article should be read: in sections by groups and then presented to the class, independently, as class, etc. This article give a very accessible introduction to the work of Dr. Emanuel in atmospheric science and how it stands today with society's concerns of deadly, destructive storms in the future. Key points to highlight are the effects of global warming on hurricane frequency and intensity. Dr. Emanuel makes comment to the fact that increasing wind shears due to climate change could potentially signal a decrease in overall amount of hurricanes but nevertheless a higher intensity of the destructive 3, 4, 5 category hurricanes. He terms these a seemingly strange juxtaposition of "two contradictory things going on." Additionally, one may choose to emphasize Dr. Kerry's response to hurricane science as still an open science with much more work required to be able to make predictions that currently are outside its realm (e.g. how many hurricanes will reach the coast in a given year?). For greater details on the effects of global warming on hurricanes, the author has also included a more technical, but directly related, article by Emanuel, Sundararajan, and Williams (2008) treating these questions of increasing wind shear, predictive models, and increasing intensity in much more detail.

EVALUATE:
Please use the evaluation sheet provided in the Materials section.

Name: ______________________________ Date: ______________________

Please answer the following questions in complete sentences.

1. What are the favorable conditions for a hurricane to form, according to scientists?

2. What powers a hurricane? Describe or illustrate and label how this energy is used to form a hurricane.

3. Using your own observations, please interpret the graph below of Atlantic sea surface temperatures and storm dissipation over 141 years. Please explain your reasoning.