Math and Physics in Nature

Sabbatical Report for Art Peck
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Eugene, OR

Introduction:

My goal for this sabbatical project at the outset were to:

1: Deepen and expand my knowledge and understanding of natural phenomena.
2: Hone my techniques for effectively conveying my new and existing insights about math and physics in a way that helps students develop their own "mind's eye".
3: Inspire students to appreciate math.
4: Get people off couches and screens and into the outdoors!
5: Rekindle my passion for storytelling through film and animation.
6: Gain more experience with quality, engaging video production for future use in my teaching.
7: Better address and accommodate a wider variety of learning styles in my teaching.

My plan was to create a series of videos to make available on You-tube for students and the general public to view and learn from. Even as I was writing my original proposal, the topic I found myself most enthusiastic about was understanding and explaining the subtleties of ocean tides. I knew this would require a lot of learning on my part, while some of the other topics in my proposal were more about teaching concepts that I already felt I had a grasp on. As it turned out, I ended up putting about 90% of my time and effort into the Tides project, and am thrilled to have gotten to learn even more than I had expected to about the somewhat predictable complexity of tides around the world. I find it interesting that I was so drawn to the experience of being a "student" again after many years of identifying mainly as a teacher.

Another unstated objective was to experience rejuvenation after two years of teaching during the Covid pandemic by spending as much time as possible out in the natural world, which has always proven to be deeply healing for me. I felt quite satisfied in this regard, and am very grateful to have had the opportunity at this particular time in my career.

The idea of using situations in nature to explore and convey some physics and math concepts was a key element of this project, and I feel satisfied with having achieved that goal. When the sabbatical committee accepted my application, they noted that it seemed a bit overly ambitious in terms of the number of topics I wanted to create videos for. They were correct, in that I was not able to cover everything I had originally proposed. Still, I am pleased with what I was able to cover, especially the topic of tides.

For some of the other video topics, I started out with the objective of passing along my accumulated knowledge of certain aspects of nature for the benefit of my own children as well as for anyone else who might find it useful. As I delved into the project, however, it occurred to me that the approach, attitude, and mindset with which I explore the natural world might be more valuable to convey than any of the specific facts that I might share. The concept of "Camping Like a Scientist" arose from this realization, and I hope that my children and others might benefit from and emulate the enjoyment I get from approaching the world with curiosity, wonder, and a striving to understand and seek more general patterns and principles behind particular phenomena. I hope this comes across in the videos.

Process:

At the beginning of my sabbatical term I was issued a digital video camera and tripod from Media Services at LCC. I was also pleased to discover that the college has a site license for the Adobe Suite of editing software, including Premier Pro for video, which they helped me load onto my laptop.

My first excursion was to the Oregon Coast near Yachats, where I shot lots of video footage of waves and tides, explaining to the camera as I filmed. Interestingly, some of my explanations from that trip were later proven incorrect as I learned more about the details of tides, for instance, and my understanding became more nuanced.

My second trip was into the Cascade foothills in early April. The spring in western Oregon this year was unusually wet and cold, and I encountered much more snow on this and subsequent trips than I had expected to. Luckily, I was able to incorporate this into the topics I covered. The rains, however, kept me from getting out to the woods as much as I had planned until later in the summer.

I collected more video footage and researched ocean tides throughout the spring and summer, making several more trips with the camera both to the mountains and to the coast. There were several other trips that I decided not to risk taking the camera on, but I was constantly thinking of topics to include and observing my own thought process about the math and physics of nature.

I got a lot of valuable help and tips from colleagues for websites, simulations, and information on specific topics that I wanted to understand and convey. I have special appreciation for Andrea Goering, Paul Bunson, Dennis Gilbert, and Ahmad Rajabzadeh for pointing me in the right directions to find answers to my questions and find tools for conveying my findings.

It really wasn't until August that I delved into the editing part of the video projects. I had gotten some help on video editing tips from Media Services earlier in the spring, but Premier Pro is quite a sophisticated program with lots of controls to learn about. There are simpler programs available that probably would have sufficed for my project, but I decided it would be worth the investment of time and effort to learn this program that is the industry standard for professional video production. I do plan to continue using it for future educational videos. The Premier Pro tutorials and You-tube how-to videos were a great resource for learning the basics of what I needed to achieve my video goals. There are many more effects and tools that I would use to enhance my projects if I had the time to figure them out. Perhaps I will for future projects. One of the hardest parts of this process is to decide what is "good enough" and to stop editing. I find I am still making adjustments right up to the day of my sabbatical presentation.

A lot of my preliminary research on ocean tides came from the book Tides: The Science and Spirit of the Ocean by Jonathan White, an author, sailor, and surfer who lives on Orcas Island. I was able to find answers to many of my preliminary questions in that text, and it also introduced me to several aspects of tidal behavior that were completely new to me. I ended up fleshing out my understanding of this information through internet websites, educational videos, and academic papers. In order to convey this information to my audience I sought out computer simulations, animations, and video clips that I could incorporate into my video project. I made a lot of Quicktime screen recordings using these tools with voiceover to illustrate various concepts, and I'm quite pleased with the results. I am grateful to have found several simulations that are almost exactly what I was imagining creating myself that would have required a lot of technical learning on my part to achieve.

Findings:

Tides: There are some aspects of ocean tides that I already had a good grasp on, some that I thought I had a good grasp on but was mistaken (as I imagine many people are), and some aspects that were completely new to me. The approaches for understanding the various tidal phenomena seem to fall into two categories; astronomical influences, which are somewhat complicated but still highly predictable into the far future, and terrestrial geography, which is quite a bit more "messy" and changing.

I started out with a list of questions to address about ocean tides for myself and my audience. Below is that list, with the answers that I either already understood or discovered during my research, with a few that still remain unanswered for me:

1) *Why are there tides? What does the moon have to do with it?*

There seem to be two main approaches to this question, both having to do with gravitational attraction. One is that the moon and Earth are orbiting a common center of mass, called the barycenter, causing the earth to "wobble". The oceans on the side of the earth facing the moon experience a greater gravitational attraction, while the oceans farthest from the moon experience the greatest centrifugal effect and are drawn away from the moon. (I'm reluctant to use the term "centrifugal force" because in this rotating system the effect doesn't fit the strict physics definition of a force. The same is true of the Coriolis effect that I also mention in this video.)

The other approach to this question relies on Newton's Law of Gravitation, which states that the strength of a gravitational force is dependent on the proximity of the two objects experiencing a gravitational attraction. Since the oceans closer to the moon experience a slightly stronger gravitational force than the center of the earth and the oceans on the far side experience a weaker force, the near oceans undergo a greater centripetal acceleration, drawing them closer to the moon, while the far oceans have lesser acceleration, drawing them away.

2) *Why are there tides in the ocean and not lakes, ponds, or glasses of water?*

It is important to realize that this tidal effect from the moon (and also from the sun, to a lesser effect) is very weak – about 1 ten-millionth as strong as the effect of Earth's own gravity on the oceans. It also operates on a continental scale, so that the effect is pretty much equal on every part of a lake, swimming pool, or glass of water, so there is no tendency to bulge in any particular area. The Great Lakes are large enough that there is a measurable tide, but only a matter of inches between the highest part and the lowest part, which is easily dwarfed by even minor ripples or waves. The only reason there are tides on the oceans is that they are connected and water is able to flow into the regions of slightly reduced weight from other regions where the weight of water is not alleviated.

3) *Why 2 tides a day?*

It turns out that this is not true everywhere and at all times! While the Pacific Northwest typically experiences this "semidiurnal" behavior, there are many locations on Earth that experience only one high and one low tide per "lunar day" due to other factors. For those regions that do experience semidiurnal tides, see the explanation from question 1: There is a tidal bulge facing the moon and another facing opposite the moon. As the earth rotates relative to these (theoretical) bulges, any given location on the earth will pass through 2 high-water regions and 2 low-water regions in the course of a day. Note that as the earth rotates, the moon is also moving along in the same direction about $1/28^{th}$ of a revolution, so that it takes about 24 hours and 50 minutes for the moon to be directly overhead again relative to a point on earth.

4) *Why tide level is slightly different from day to day (every other high tide)?*

The moon's orbit is not directly aligned with the earth's equator. Just as the apparent path of the sun across the sky varies from day to day due to the tilt of the earth's axis, following its highest possible path on the summer solstice and lowest path on the winter solstice, the moon also follows a different path each day. This creates a different influence on the tidal bulges, sometimes drawing them farther north of the equator and sometimes farther south. Because the moon goes through its entire orbit in about 28 days, its apparent path through the sky changes much more rapidly each day than the sun's path. I invite you to observe this! The moon's path changes from its highest to its lowest in just 2 weeks.

5) *Why are the two tides sometimes very different in the same day?*

By the model just described, when the moon is passing highest in the sky the bulge facing the moon will be drawn farther north while the bulge opposite the moon will occur farther south. In theory, for those of us in the northern hemisphere, this would create more extreme high tides as we pass under the moon and less extreme high tides half a day later, when the moon is on the opposite side of the earth. This would be reversed when the moon has a low passage through the sky.

6) *What are spring tides and neap tides, and why do they occur?*

The sun creates a tidal influence in the same manner and for the same reasons that the moon does. Because the tides rely on the *difference* in gravitational attraction on the different sides of the earth, the percentage change from one side to the other due to the sun's gravity is less than for the moon's gravity, even though the *overall* gravitational attraction between sun and earth is much greater. Even without the moon, the earth would still have tides due to this effect from the sun, but a little less than half as strong. With these influences from the sun and moon operating simultaneously, they can sometimes work together, as during a full moon or new moon and create more extreme tides, called spring tides (nothing to do with the season of spring). When the sun and moon are at right angles relative to the earth, as during the 1st quarter or 3rd quarter moon, they are pulling the oceans in opposite directions so the sun's influence diminishes the moon's tidal effect, causing less extreme high and low tides, called neap tides.

7) *What are King tides and why do they occur?*

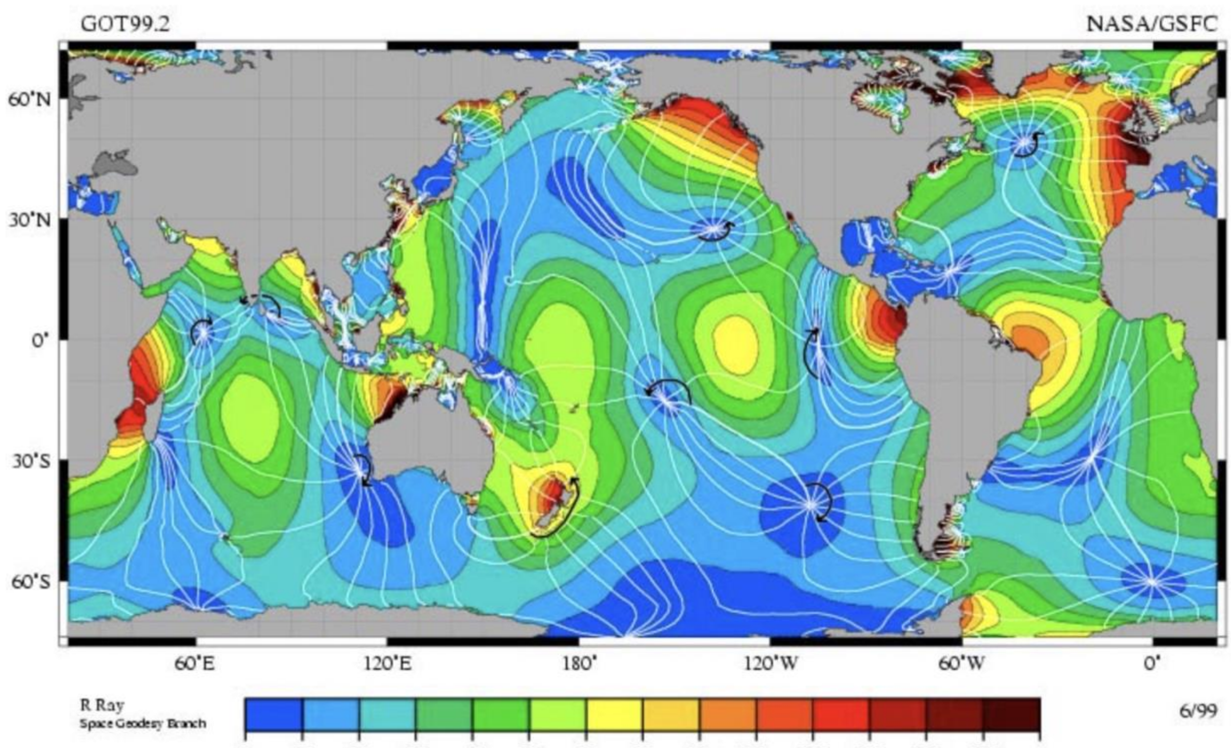
King tides are extreme high tides, caused by a number of the factors that accentuate the tides all occurring simultaneously. The alignment of sun, moon, and earth (spring tide) is one of these factors. Two more have to do with the elliptical orbits of the earth around the sun and the moon around the earth, causing these bodies to get closer together at times and farther apart at other times. Both orbits lead to more extreme tides when the bodies are closer together. If the moon is at the closest point in its orbit to the earth (which occurs once every 28 days) and the earth is at its closest point to the sun (which occurs in January), and the moon happens to be full or new, this "perfect storm" of conditions can lead to an extra-high spring tide. The severity of a king tide depends on how precisely these factors align. King tides give a glimpse into the future of what normal high tides might look like in the future as sea levels rise, serving as a reminder of the urgency of mitigating climate change through swift and decisive action recommended by the scientific community.

8) *Why does driftwood get moved way up the beach in winter but not in summer?*

See King tides, which occur in January. At least in Oregon, winter also tends to be when there are more severe storms with increased flooding of coastal rivers and larger ocean waves.

9) *Why is the timing and depth of the tide different in locations with the same longitude?*

In exploring this question, I discovered what are called "Amphidromic Systems". Most of the world's tides involve some "sloshing" of the water in various ocean basins and sub-basins that are connected but have their own oscillatory behavior. Whenever there is a mass movement of fluid in a north-south direction it is subject to the Coriolis effect. This is due to the fact that the rotating earth is thicker at the equator, so that all objects and substances that are rotating with the earth near the equator are moving faster than the ones farther north or farther south. If something travels from one region to another it experiences what appears to be a sideways push as it interacts with the faster-moving (or slower-moving) surroundings. This is what causes hurricanes to rotate, and it also causes the tidal "sloshing" to rotate, typically counterclockwise in the northern hemisphere. At the center of these rotating sloshing cells is an Amphidromic Point, where the water *level* stays relatively constant (though it may be flowing laterally). Locations farther from the Amphidromic point tend to have more extreme tides. The Amphidromic system affecting Oregon is centered in the Pacific Ocean west of Baja California and has a counterclockwise rotation. (See diagram)



This means that Los Angeles will experience a particular high tide before San Francisco, and then Oregon, then Washington, British Columbia, and Alaska. A few hours later, low tide will make its way up the same coast, followed by the next high tide, etc.

Another factor is the river estuaries, where the tidal water can flow in and out, affecting the timing of the highest and lowest water levels.

10) Why are charts from 19 years apart nearly identical, nearly everywhere in the world?

This is a question that I generated after learning of this phenomenon in my research. I learned that the moons orbit around the earth is not aligned with the earth's equator but is also not aligned with the earth's orbit around the sun. I learned that it maintains a tilt of about 5 degrees relative to the plane of the earth's orbit around the sun, which is called the "plane of the ecliptic", and is the plane that the sun appears to stay in as we see it pass through the sky. This means that the moon sometimes appears 5 degrees higher in the sky than the sun does at summer solstice, and sometimes the moon's highest path of the month is 5 degrees lower than the sun gets at summer solstice. Furthermore, the orientation of this 5-degree tilt slowly rotates as the earth-moon system orbits the sun. It takes about 18.6 years for this orientation to return to its original position, so every 19 years the path of the moon's orbit around the earth all year is very close to what it was before, kind of re-setting the cosmic clock so that at least the astronomical influences are similar.

11) Who generates the tide charts? What are they based on? Do they all agree?

I have not yet found a complete answer to this series of questions. It appears that each nation has its own tidal authority, using a combination of astronomical predictions and historical data collected at monitoring stations around the world's coastlines. The nearest monitoring station to Eugene is in Waldport, in the Alsea Bay. Other locations along the coast are given adjustments in both tidal height and timing relative to the official station in Waldport, presumably based on historical data.

Other Findings:

Tidal bores: I had never heard of these before, but there are about 60 locations on Earth where the incoming tide arrives all at once as a giant, rapid wavefront. These seem to be at a river mouth near a fairly large ocean tide, where the incoming water gets "focused" by the surrounding geography into an intense wall of water moving up the river channel.

Timing: I was under the impression before I started this project that a good rule of thumb for predicting the tides was to consider the position of the moon. I believed that high tide would occur at any location when the moon is at its highest point on its arc through the sky, and low tides would occur when the moon is on either horizon. It turns out that this is not a reliable concept. The timing of the tides can be either ahead of the moon or behind it by up to several hours. The tidal "sloshing" is much more complicated than I had realized.

Conclusion:

I find that I have met most all of my goals in completing this sabbatical. I have certainly gained a much deeper understanding of the various phenomena surrounding ocean tides. I have also benefitted greatly from the exercise of exploring and articulating the multitude of examples of math and physics in nature.

I have gained a deeper appreciation for the role of math and physics principles in making sense of natural phenomena, from melting snow and wet firewood to the fire-prone forests throughout the West. From the strength of tree roots in soil and the power of waves to the cosmic forces of gravitational attraction and planetary motion. I trust that my understanding and enthusiasm will be infectious among my students and colleagues, inspiring them to pursue similar explorations.

I have been pleasantly surprised by how much I enjoyed learning video editing and production, despite the setbacks, glitches, and sheer amount of time and effort involved. Many of my friends have been fascinated with my research. One group demanded that I present a lecture of my findings on tides during a camping trip in the San Juan Islands in September, which was enthusiastically received. It has been quite exciting and gratifying to convey my knowledge in the form of video presentations. I do expect to use these skills in my future teaching to reach students with a variety of learning styles. There are many math concepts that lend themselves to visual representation and animation, and I feel better equipped now to illustrate those.

I am very grateful to the many people and organizations that made this sabbatical possible. It has been truly enlivening and invigorating for me, and hopefully by extension for my students, friends, and colleagues.

My sabbatical videos can be viewed here:

Tides: https://youtu.be/wli7bxAscj8

Camping Like a Scientist series:
https://youtu.be/2cC_DCoMmgU
https://youtu.be/BhRb3VwWgSM
https://youtu.be/VP7Ccb-2bek
https://youtu.be/43cJtdVl2sc

Resources:

Tides: The Science and Spirit of the Ocean by Jonathan White, Trinity University Press, 2017

Major Lunar Standstill by Dr. Judith S. Young
Dept. of Astronomy
Univ. of Mass., Amherst
Updated December 2010