Capstone Executive Summary
Climate Science & Policy MAS Program
Scripps Institution of Oceanography
May 31, 2016

Kris Scarci
Executive Summary

Introduction

As a leading science educator in Southern California, Birch Aquarium of La Jolla, CA, has approved plans to modernize a portion of its exhibit space. The goal of this new space is to create an immersive environment focused on real-world, scientific expeditions – specifically “Polar” and “At-Sea” research stations. New exhibits will cater towards “creative interactivity”, vice the old standard of hard-science presentations of data.

We live in an age of exponential technological advancement. Mountains of information lie in waiting at the beck and call of nimble fingertips. This luxury has morphed into a modern necessity, as children are immersed and indoctrinated to advanced technology at younger ages. As scientific researchers and educators, our role has never been more important, and has never had more opportunity to take advantage of the communication capabilities of modern technology. Inventions such as computers, cell phones, and the Internet, are the future of scientific public outreach and can be used as a seamless conduit for public awareness by way of innovative scientific communication.

Institutions like Birch Aquarium provide a means to take this technology a step further, by providing the platform designed to fully engage a broad audience with the most recent discoveries in modern science. The vision of the new exhibit space at Birch is to harmoniously entwine science, art, and interactivity into one cohesive educational experience. Modern technology and software play on the instant gratification mechanisms of an individual’s psychological reward system. We experience short bursts of joy through the release of the reward neurotransmitter “dopamine”; by varying means such as conquering the final boss of a video game or googling the correct answer during a heated debate with a friend.

The current wave of technology shows that captivation by instantaneous feedback and information is happening at increasingly – or rather decreasingly – younger ages. Most children are now perpetually engrossed in technology of all kinds. This provides a unique reactionary stimulus that can be used to deliver effective science communication. This same mechanism can be similarly tapped into with an interactive science exhibit; one that communicates science in a fun and digestible way, as well as possessing a controllable element that provides tactile feedback along with visually appealing responses to user-input. “Game-culture” is growing increasingly in popularity, and parallels the rise of what many call the “technological singularity”.

These methods of scientific communication are not limited to children and young adults, but can also be used to educate those in the corporate sector. The new exhibit spaces have potential to spur interest in the design and construction of more energy efficient and environmentally-friendly buildings. Interested enthusiasts in the corporate world can use the science-based information in the exhibits at Birch aquarium to make decisions regarding sustainable engineering and building material types – e.g. what materials best reflect light or absorb heat – in order to achieve optimal passive energy efficiency for a building. By means of effective science communication of concepts such as “albedo”, economic and financial efficiency can be achieved through more sustainable approaches of doing business and solving large-scale problems.
Executive Summary

The renovation will consist of four exhibit spaces total:

1. Expedition Staging Area
2. Polar Research Expedition
3. At-Sea Research Expedition
4. Ocean Acidification

Each space will be designed to simulate the real-world counterpart with the goal of being as immersive as possible, allowing visitors to step into the shoes of scientists on research expeditions. Each exhibit will be designed in an intuitive way to effectively communicate information rooted in science, while remaining comprehensible to all. Of the four exhibit spaces, the radiometer exhibit will be included in the Polar Research Expedition space. A commonly used instrument of research in polar regions – in particular, Antarctica – is the radiometer.

Radiometer Exhibit – Birch Aquarium

As an affiliate of Birch Aquarium, Scripps Institution of Oceanography acts as a key scientific resource with a rich history in the many disciplines of Earth Science, as well as being a hub for numerous scientific expeditions around the world. As new director of Birch Aquarium, Harry Helling’s vision is one that seeks to capture the imagination of visitors through inquisitive, tangible engagement coupled with cutting-edge scientific research provided by Scripps. The overall effort is in pursuit to better communicate science to the public.

The goal of my capstone project is to design an interactive exhibit centered on radiometry techniques applied in Antarctica. The mission of the exhibit is to educate visitors on subjects that affect the energy balance of our planet, specifically topics such as:

- Earth Energy Balance & the Solar Forcing
- Explanation of Albedo
- Importance of Cryosphere
- Electromagnetic Spectrum Basics
- Importance of projects such as AWARE

A radiometer is an instrument used to measure the radiant flux of incoming electromagnetic radiation. Radiometers come in all shapes and sizes, with varying mechanistic purposes and designs. A basic Crookes radiometer consists of a glass bulb harboring a stem connected to a pinwheel, granting a rotational axis for four suspended vanes. Each vane is dark on one side, and light on the other, providing an absorptivity differential for incoming photons. This thermodynamic property, in combination with the low pressure / near vacuum inside the bulb, causes the vanes to spin along the low-friction rotational axis, effectively providing a measurement of incident radiant energy (radiance in \( \text{w/m}^2 \)).
Executive Summary

Exhibit Overview

The radiometers to be used in the exhibit are a more complex variant of the Crookes radiometer. The exhibit will use two “pyranometers” – one to detect near-infrared radiation and the other to detect shortwave radiation. A pyranometer is a type of radiometer that is designed to be sensitive to visible, near-infrared, and near-ultraviolet wavelengths of light. Providing a complete hemispheric range to incoming irradiance, a pyranometer is typically disc-shaped and can be attached to a planar surface. The pyranometer also exhibits a directional response to the angle of incoming light, which is ideal when modeling daily solar irradiance.

The next essential component for the exhibit is the “solar simulator”. Sometimes referred to as an “artificial sun”, a solar simulator is a man-made light-source designed to output a spectral irradiance curve to approximate sunlight. This curve includes electromagnetic radiation in the forms of visible light, near-infrared, and near-ultraviolet. Since solar simulators are a relatively new scientific tool, those available on the market are quite robust and expensive, and mainly used for the testing of solar panels. However, with the right combination of halogen and LED light bulbs, it is possible to achieve an approximate spectral match of the sun.

The exhibit design will take the shape of an enclosed rectangular booth with an opening near the bottom. The bottom opening will allow visitors to insert a sample object to be measured. The measurement of radiant energy will be conducted by two pyranometers, situated near the opening. A combination of LED and halogen light bulbs will be used to simulate the sun’s spectral output. The energy radiance level captured by the pyranometers will be recorded by a datalogger. Hidden from the exhibit in an inaccessible location to the public, the datalogger will connect to a laptop where the radiance levels will be accumulated and processed. The datalogger will be connected to a computer, which will run data visualization software to the main exhibit display monitor. Using Epic Games Unreal Engine game design environment, I was able to create a trial version that parses and visualizes input-data in real-time. My current plan is to design the scripting language of the visualizer to display colored spheres of magnitude to correlate objects with higher albedos to blue-toned spheres, and objects with lower albedos to red-toned spheres. The goal of the software is to provide a visually appealing yet informative representation of the physical mechanisms occurring as the light shines on materials of varying reflectance and absorptivity. An information panel will be placed alongside the exhibit, to provide supplemental information related to exhibit concepts.
Mockup

Target Audience

Birch Aquarium receives visitors of all ages from young children to adults. Harry Helling desires to capture the imagination of this broad audience. Field trips to Birch Aquarium from local schools are a common occurrence, with the highest percentage of ages hovering around the “middle school” years. These formative years of educational development provide an excellent opportunity to imprint a realistic interpretation of the natural world to children. However, it must be done in a way that is both engaging as well as educational. Children today are well integrated with technology at early ages, and have become accustomed to the gratification of near instantaneous information/feedback. The radiometer exhibit will cater towards these mechanisms, and use the appeal demonstrated by game-culture to capture attention and catalyze curiosity.
Executive Summary

**Learning Objectives for Audience**

1. Convey the importance of *Albedo* as a major regulator in Earth’s energy balance. Educate visitors on subjects that affect the energy balance of our planet, as well as modern research methods in the field. Topics will include, but are not limited to:
   - Solar Radiation
   - Radiometry
   - Reflectivity (Explanation of Albedo)
   - Absorptivity (Correlate to colors in the visible light spectrum)
   - Emissivity (Black Body Radiation)
   - Shortwave / Longwave Difference
   - Earth Energy Balance
   - Forcings / Feedbacks
   - Electromagnetic Spectrum

2. Use infographs to distill complicated scientific subjects into digestible formats, and provide foundational knowledge for concepts demonstrated by exhibit.
   - Energy Balance & the Solar Forcing
   - What is a Radiometer?
   - The Importance of Ice
   - Demystifying the Electromagnetic Spectrum
   - Albedo in the Real-World

3. The scientific importance of Scripps/AWARE research
   - Use satellite data (PMW & MODIS) to demonstrate how satellites can directly show the change in surface albedo caused by surface moisture (16 years of melt events in Antarctica)
   - Better inform the public
   - Environmental protection
   - Scripps/AWARE/Birch brand awareness
**Data Analysis: 16 Years of Melt Events in the Antarctic**

How microwave emissivity can be used as an indicator of melt events

Using passive microwave data provided by the National Snow & Ice Data Center, Scripps graduate student Ryan Scott created GIFs displaying the daily deviation of Antarctic brightness temperature from the annual mean in the summer months of December and January for a span of 16 years. Due to regional warming events over temporal scales, these anomalies show shifts in the amount of microwave radiation emitted by the Antarctic surface from 1990 to 2016. The colors orange and red on the map demonstrate an increase in daily brightness temperature from the annual mean, with melting occurring once the threshold of 40°K is surpassed.

The increase in microwave emission is due to the change in phase from ice to liquid. Liquid water has a microwave emissivity coefficient close to 1, whereas the coefficient for ice is much lower. In the microwave range, the exponential in the denominator of the Planck function can be expanded in a Taylor series to derive what is known as the Rayleigh Jeans approximation, which ultimately yields the relationship \( T_b = \epsilon T_p \), where \( T_b \) is brightness temperature, \( \epsilon \) is emissivity, and \( T_p \) is the physical temperature in units of K. Liquid water alters the dielectric properties of surface firn, reducing its reflective properties while increasing microwave emission, resulting in a greater microwave signature when liquid water is present at the surface.

The occurrence of melt is marked by an increase in microwave brightness temperature caused by the presence of moisture in the Antarctic surface firn. Surface melt events are caused by a variety of factors, including warm air masses moving in from the Southern Ocean (which occurs frequently over the WAIS), as well as katabatic winds that descend from higher elevations and warm the air near the surface through their rapidly increasing pressure – known as adiabatic warming.

In addition to detecting a melt event by changes in satellite microwave brightness temperature, satellites that image in the visible and near-infrared can directly show the change in surface albedo caused by the moisture on the surface. Instruments such as MODIS (moderate-resolution imaging spectroradiometer) are attached to satellites and provide imagery in the visible spectrum which optically shows a direct change in the Antarctic surface albedo due to melt.
Executive Summary

Appendix:

1. Deliverable Checklist

Finished:

- Capstone Documents
  - Memo, Proposal, Approved Budget List, Final Presentation, Executive Summary
- Exhibit Mockup via Sketchup
- Exhibit Label
- Curator’s Notes & Definitions
  - Background knowledge for Birch Aquarium facilitators
- Antarctica 20 Year Melt Event GIF Template
- Infographs
  - Energy Balance & the Solar Forcing
  - What is a Radiometer?
  - The Importance of Ice
  - Demystifying the Electromagnetic Spectrum
  - Albedo in the Real-World

Still to Come:

- Radiometer Exhibit (beta)
  - Surveys
  - Evaluation Period Data – public impressions, wear-and-tear issues, safety concerns
- Finalized GIF showing correlation between PMW & MODIS data
  - Requires the manual combination of 16 years of satellite imagery with GIF template
  - Roughly ~1000 images: 16 years of data containing daily images during the Antarctic summer months of December & January
- Data Visualizer
  - Visually appealing display of exhibit/datalogger output
- Provide experiential data for 2016 CSP media class
- Finalized Radiometer Exhibit at Birch Aquarium
Executive Summary

2. Capstone Advisors

Dan Lubin - Research Physicist
- Lead Scientist - AWARE Project
- Satellite remote sensing of Earth's polar regions
- Application of global climate model simulation to the polar regions

Cheryl Peach - Director, Scripps Educational Alliances
- Incorporating satellite remote sensing data in high school curricula
- Workshop coordinator for high school science teachers
- Coordinator for new Polar Exploration exhibit at Birch Aquarium

3. Total Budget List using Capstone Funds

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost per Unit</th>
<th>Quantity</th>
<th>Price</th>
<th>Notes</th>
<th>Link</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar Panel</td>
<td>$150.00</td>
<td>3</td>
<td>$450.00</td>
<td></td>
<td>[Link]</td>
</tr>
<tr>
<td>Battery</td>
<td>$120.00</td>
<td>2</td>
<td>$240.00</td>
<td></td>
<td>[Link]</td>
</tr>
<tr>
<td>Inverter</td>
<td>$350.00</td>
<td>1</td>
<td>$350.00</td>
<td></td>
<td>[Link]</td>
</tr>
<tr>
<td>Generator</td>
<td>$500.00</td>
<td>1</td>
<td>$500.00</td>
<td></td>
<td>[Link]</td>
</tr>
<tr>
<td>Solar Tracking System</td>
<td>$200.00</td>
<td>2</td>
<td>$400.00</td>
<td></td>
<td>[Link]</td>
</tr>
<tr>
<td>Total</td>
<td>$1,120.00</td>
<td>1</td>
<td>$1,120.00</td>
<td></td>
<td>[Link]</td>
</tr>
</tbody>
</table>
Executive Summary

4. Exhibit Label

RADIOMETER INTERACTIVE

FROM THE FIELD: AWARE (ARM West Antarctic Radiation Experiment)
Location: West Antarctica
Lead Scientist: Dan Lubin - Scripps Institution of Oceanography
Purpose: Polar Energy Balance & Cloud Microphysics
Start Date: November 2015 - Ongoing

On November 5th 2015 the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Climate Research Facility launched the ARM West Antarctic Radiation Experiment (AWARE), with equipment deployed to the West Antarctic Ice Sheet (WAIS) and McMurdo Station. As a collaborative project between DOE and the National Science Foundation (NSF), which manages the U.S. Antarctic Program, AWARE scientists will collect and analyze data covering the atmospheric energy balance, cloud microphysics, precipitation, and aerosol chemistry. AWARE is deploying the Second ARM Mobile Facility (AMF2), which is the most advanced and complete set of equipment for atmospheric and climate science ever sent to Antarctica. Dan Lubin, a research physicist at Scripps, leads the AWARE campaign in conducting unprecedented research on polar air masses, cloud radiative forcing, and surface energy balance.
5. Curator's Notes
Executive Summary

Datalogger

Overview:
- Collects data from aquariums, making it available even when networks are down.
- Used in monitoring equipment.
- Easy to use.
- Compares with scientific literature.
- Model: Oceanlab Scientific (OLS).

Notes & Definitions

- **Power User:** A power user is someone who uses a system extensively and in complex ways.
- **Data Logger:** A device that records measurements or events at periodic intervals and typically stores the data internally.

Software

Overview:
- Used for gathering, storing, and analyzing data.
- Easy to use, accessible without programming knowledge.
- Outputs in a comprehensive and intuitive format.
- User-friendly interface.

Terms & Definitions

- **Solar Constant:** The average rate at which radiation enters the Earth from the Sun in the form of electromagnetic radiation.
- **Lumen:** A unit of luminous flux.
- **Watt:** A unit of power in the International System of Units (SI).

Information Panel

- **Goal:**
  - To engage in scientific concepts demonstrated by exhibit.
  - Effectively and intuitively communicate complex scientific subjects.
  - Exhibit label.

Data Analysis:

- **20 Year Antarctica Melt Event GIFs**
  - Show the gradual effect of warming, particularly in Western Antarctica over the last 20 years.

Infographics:

- **Importance of Ice**
- **What is a Radiometer?**
- **The Sun & Energy Balance**
- **Importance of Albedo**
- **Beyond Visible Light**

Terms & Definitions

- **Albedo Sensing:** The process of measuring the reflectivity of the Earth's surface to determine the amount of solar radiation that is reflected back into space.
- **GEO:** Global Environmental Observation System.

Exhibit Flowchart

- **Power Outlet**
- **Solar Simulator**
- **Tiles/Textured Surface**
- **Radiometer**
- **Sensors**
- **Display Software**
- **Information Panel**
6. Infographs

The Importance of Polar Ice

1. Ice covers 98% of the Antarctic surface, and contains about 61% of the Earth's total freshwater.

2. Ice reflects light from the sun back into the atmosphere & space. This reflective property is known as "albedo".

3. When ice melts, darker surfaces take the place of the brighter ice, causing more heat from the sun to be absorbed by the Earth. This kicksstarts what is called a "feedback loop".

4. A feedback loop is a self driving cycle. Once set in motion, each action fuels a reaction, and vice-versa. In this case, the warmer it gets, the more ice melts, and so on...

5. Multiple events that continuously enhance the effects of each other are known as "positive feedback loops", whereas "negative feedback loops" occur when events lessen each other's effect.
**Executive Summary**

**What is a Radiometer?**

A *radiometer* is a bulb-shaped sensor with 4 metal vanes connected to a central rotor. The purpose of a *radiometer* is to measure forms of light that make up the electromagnetic spectrum. The metal vanes are dark on one side, and light on the other. The dark side of the vanes absorb incoming photons, which are released as *heat*. The *heat* released from the vanes causes the rotor to spin, propelling it faster as more light energy flows into the bulb. The vanes spin faster and faster as the light source gets brighter.
Albedo in the Real-World

What happens when light from the sun reaches Earth?

Some objects reflect more light, while others absorb more.

The amount of sunlight an object reflects is known as albedo.

The albedo is determined by the chemical makeup of an object, as well as the angle of incoming light.

Materials that appear darker absorb more energy, and release more heat.
Executive Summary

Beyond Visible Light
Demystifying the Electromagnetic Spectrum

Radio Waves
- The longest wavelengths in the electromagnetic spectrum
- Include bands ranging from LF (Low Frequency) to EHF (Extremely High Frequency)
- AM Radio is comprised of LF or MF bands, whereas HF, VHF, & UHF provide the means for FM Radio, Cellphones, & GPS

Microwave
- Microwave ovens cause water and fat molecules to vibrate, which makes the substances hot
  - Passive microwave sensors aboard satellites detect microwaves from Earth, allowing us to see through clouds & dust
  - Wifi also uses microwaves

Infrared
- Our bodies emit heat in the form of infrared radiation
  - The Earth also emits infrared radiation when it absorbs the Sun’s energy
  - Infrared light is just outside the range of which our eyes can see

Visible: The tiny range in which our eyes can “see”

Ultraviolet
- More energetic than visible light, can cause skin & eye damage if unprotected
  - The Ozone Layer shields much of the UV radiation

X-Ray
- Powerful enough to penetrate skin & muscle, but not bone, which is why X-Rays are used in medical imaging

Gamma
- The most energetic form of electromagnetic radiation, can penetrate through bone causing radiation poisoning

Did You Know?
- All forms of electromagnetic radiation are comprised of photons moving at the speed of light
- The speed of light is clocked in at 186,000 miles per second, that’s enough time to travel around the world over 7 times in 1 second!
- Everything emits electromagnetic radiation, whether it be the heat from our bodies as infrared energy, or gamma rays from a nuclear explosion
- Scientists at Scripps use the varying bands of electromagnetic radiation as “viewing lenses” to study intricate subjects such as albedo changes & large scale melt events occurring in the Arctic & Antarctic
Executive Summary

The Sun emits light through a process called the Photosphere.

The photons (the light waves) travel through space at the speed of light.

These photons eventually reach the Earth's atmosphere.

The Earth's atmosphere consists of various layers, including:

1. **High Clouds**: These are high-altitude clouds that reflect a significant portion of sunlight. They are often found in temperate and polar regions.

2. **Low Clouds**: These are lower-altitude clouds that can affect visibility and weather patterns. They can also have a significant impact on sunlight reflection.

3. **Earth's Surface**: The Earth's surface reflects a small portion of sunlight, contributing to the overall energy balance of the planet.

The sunlight that reaches the Earth's surface is partially absorbed, with some reflected back into space. This interaction between sunlight and the Earth's atmosphere is crucial for regulating the planet's temperature and climate.
Executive Summary

7. Satellite Data Analysis GIF Template & Example

**A Melting Continent**

*How Scripps & AWARE track large-scale melt events in Antarctica*

- Western Antarctica is the fastest warming region on the planet
- Water can exist in three physical phases: liquid, solid, and gas
- Water's phase is determined by temperature and pressure
- Solid water (ice, snow, firn) has a bright surface due to its chemical structure. This results in a high albedo, meaning most incoming light is reflected rather than absorbed
- Liquid water has a lower albedo and absorbs more light, which is then re-emitted as infrared & microwave radiation
- Scientists have discovered that by using passive microwave sensors attached to satellites, they can detect melt events by observing the change in microwave energy emitted by the Antarctic surface
- The albedo change caused by the melting of ice is an indicator that a melt event has occurred
- Melt events are caused by a variety of factors, including warm air masses moving in from the Southern Ocean, as well as katabatic winds descending from higher elevations bringing heat & moisture

This scale measures **Brightness Temperature**, with warmer colors showing where melting has occurred.

**Brightness Temperature** is useful in displaying where ice has melted - liquid water emits more infrared & microwave radiation than ice or snow, resulting in a higher brightness temperature (yellow, orange, red) in melt areas.

This scale shows the daily average **Brightness Temperature** of Antarctica, as it differs from the yearly average. Increases or decreases in brightness temperature from the annual average are what scientists refer to as **anomalies**. The heaviest period of melting occurs during the Southern Hemisphere's summer months of December & January.

**A Melting Continent**

*How Scripps & AWARE track large-scale melt events in Antarctica*

- The West Antarctic Ice Sheet (WAIS) is one of the fastest warming regions on the planet
- Water can exist in three physical phases - liquid, solid, gas. The phase in a given environment is determined by temperature and pressure
- The albedo change caused by the melting of ice is an indicator that a melt event has occurred
- Solid water (ice, snow, firn) has a bright surface due to its chemical structure. This results in a high albedo, meaning most incoming light is reflected rather than absorbed
- Liquid water has a much lower albedo and absorbs nearly all the light incident upon it. The water surface then effectively emits infrared and microwave radiation as a function of its temperature
- In addition to detecting surface melting events by changes in satellite microwave brightness temperature, satellites that image in the visible and near-infrared can directly show the change in surface albedo caused by the moisture on the surface
- Surface melt events are caused by a variety of factors, including warm air masses moving in from the Southern Ocean (which occurs frequently over the WAIS), as well as katabatic winds that descend from higher elevations and warm the air near the surface through their rapidly increasing pressure (called adiabatic warming)
Executive Summary

References:


