Radiometer Exhibit – Birch Aquarium

05/30/2016

Capstone Executive Summary

Climate Science & Policy MAS Program

Scripps Institution of Oceanography

May 31, 2016

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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.

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 w/m^2).

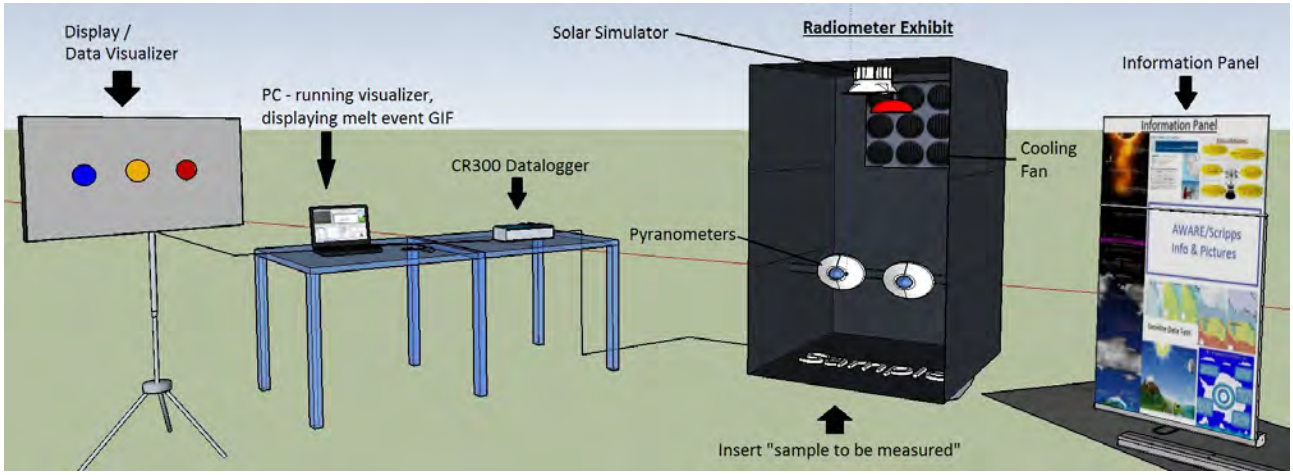
Exhibit Overview

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.

Learning Objectives for Audience

1. Convey the importance of A*lbedo* 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 Tb = epsilon*Tp, where Tb is brightness temperature, epsilon is emissivity, and Tp 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-infared 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.

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

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

Total Budget List

Component	Cost per Unit	Quantity	Price	Notes	Link
CR300 Datalogger	$552.00	1	$552.00	See Campbell Scientific sales quote	https://www.campbellsci.com/cr300
Power Supply	$28.80	1	$28.80	See Campbell Scientific sales quote	
Solar Simulator					
LED Bulb: LC LED 200W 5700K	$49.95	6	$293.70	Standard screw size (E26/E27), converts to mogul size using E26/27 to E39/E40 adapter	http://www.amazon.com/LC-LED-Commercial-Residential-Non-Dimmable/dp/B017XC2LQ0/ref=sr_1_1?ie=UTF8&qid=1461884793&sr=8-1&k
Halogen Bulb: Bulbrite 150 Watt, 120 Volt T0 Clear Halogen Bulb	$8.99	4	$35.96	Color Temperature 3000K, Base Medium (E26)	http://www.bulbs.com/product/Q150CL-EDT?refId=22
Bulb Fixtures: One Light Adjustable Wall or Ceiling Heat Lamp Fixture with Black Baffle, White Finish	$50.50	4	$202.32	Uses One BR40 Medium Base Lamp, 250W Maximum. Base Medium (E26)	http://www.bulbs.com/product/P6397-307?refId=572
TEDCO Radiometer	$11.99	1	$11.99	Display Radiometer	http://www.amazon.com/TEDCO-01800-Radiometer/dp/B0007YFII2
Total			$1,124.77		

4. Exhibit Label

RADIOMETER INTERACTIVE

Birch Aquarium

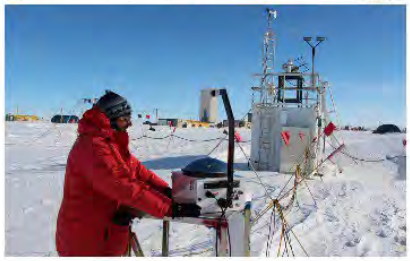
SCRIPPS INSTITUTION OF OCEANOGRAPHY

Secrets of the Cryosphere

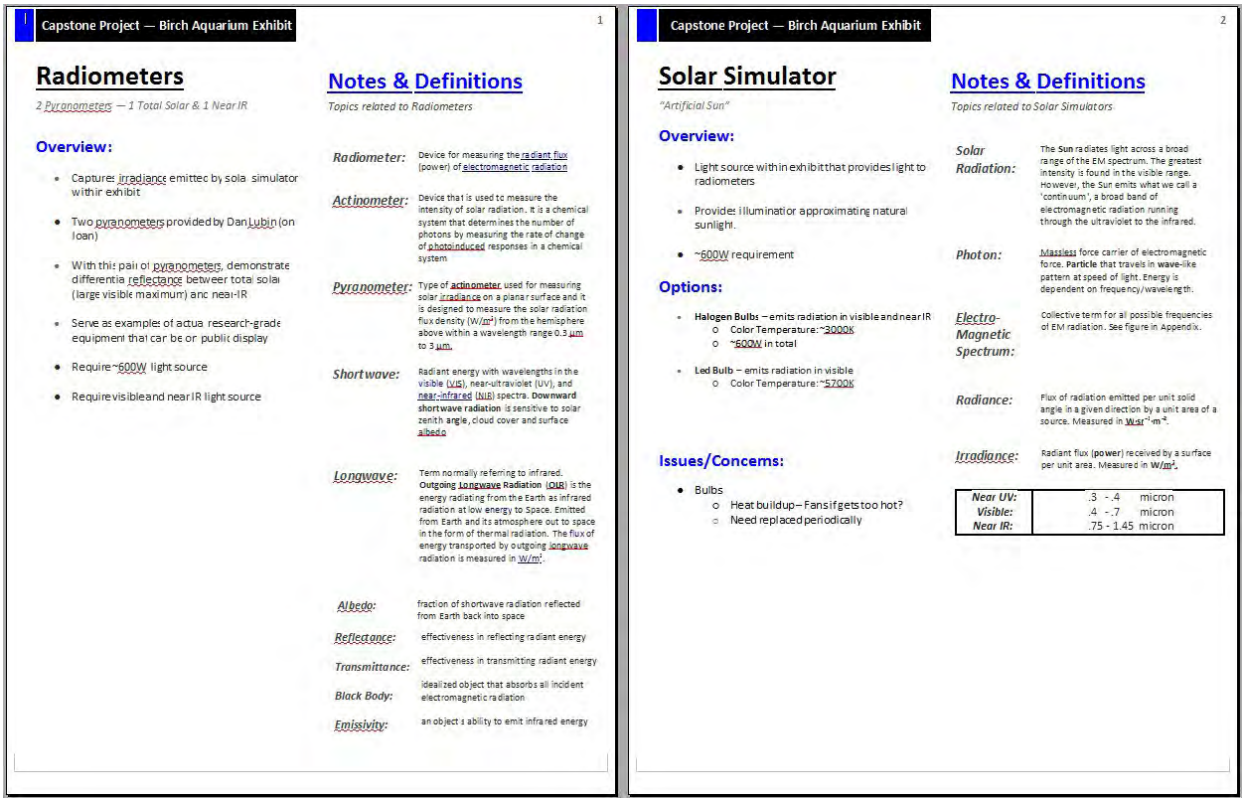
FROM THE FIELD: AWARE *(ARM West Antarctic Radiation Experiment)*

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



Capstone Project — Birch Aquarium Exhibit 1

Radiometers

2 Pyranometers — 1 Total Solar & 1 Near IR

Overview:

- Captures irradiance emitted by solar simulator within exhibit
- Two pyranometers provided by Dan Lubin (on loan)
- With this pair of pyranometers, demonstrate differential reflectance between total solar (large visible maximum) and near-IR
- Serve as examples of actual research-grade equipment that can be on public display
- Require ~600W light source
- Require visible and near IR light source

Notes & Definitions

Topics related to Radiometers

Radiometer: Device for measuring the radiant flux (power) of electromagnetic radiation

Actinometer: Device that is used to measure the intensity of solar radiation. It is a chemical system that determines the number of photons by measuring the rate of change of photoinduced responses in a chemical system

Pyranometer: Type of actinometer used for measuring solar irradiance on a planar surface and it is designed to measure the solar radiation flux density (W/m^2) from the hemisphere above within a wavelength range 0.3 μm to 3 μm.

Shortwave: Radiant energy with wavelengths in the visible (VIS), near-ultraviolet (UV), and near-infrared (NIR) spectra. **Downward shortwave radiation** is sensitive to solar zenith **angle**, cloud cover and surface albedo

Longwave: Term normally referring to infrared. **Outgoing Longwave Radiation** (OLR) is the energy radiating from the Earth as infrared radiation at low energy to Space. Emitted from Earth and its atmosphere out to space in the form of thermal radiation. The flux of energy transported by outgoing longwave radiation is measured in W/m^2.

Albedo: fraction of shortwave radiation reflected from Earth back into space

Reflectance: effectiveness in reflecting radiant energy

Transmittance: effectiveness in transmitting radiant energy

Black Body: idealized object that absorbs all incident electromagnetic radiation

Emissivity: an object's ability to emit infrared energy

Capstone Project — Birch Aquarium Exhibit 2

Solar Simulator

"Artificial Sun"

Overview:

- Light source within exhibit that provides light to radiometers
- Provides illumination approximating natural sunlight.
- ~600W requirement

Options:

- **Halogen Bulbs** – emits radiation in visible and near IR
  - Color Temperature: ~3000K
  - ~600W in total
- **Led Bulb** – emits radiation in visible
  - Color Temperature: ~5700K

Issues/Concerns:

- Bulbs
  - Heat buildup – Fans if gets too hot?
  - Need replaced periodically

Notes & Definitions

Topics related to Solar Simulators

Solar Radiation: The **Sun** radiates light across a broad range of the EM spectrum. The greatest intensity is found in the visible range. However, the Sun emits what we call a 'continuum', a broad band of electromagnetic radiation running through the ultraviolet to the infrared.

Photon: Massless force carrier of electromagnetic force. **Particle** that travels in **wave**-like pattern at speed of light. Energy is dependent on frequency/wavelength.

Electro-Magnetic Spectrum: Collective term for all possible frequencies of EM radiation. See figure in Appendix.

Radiance: Flux of radiation emitted per unit solid angle in a given direction by a unit area of a source. Measured in $W \cdot sr^{-1} \cdot m^{-2}$.

Irradiance: Radiant flux (**power**) received by a surface per unit area. Measured in W/m^2.

Near UV:	.3 - .4	micron
Visible:	.4 - .7	micron
Near IR:	.75 - 1.45	micron

Datalogger

Campbell Scientific Datalogger

Overview:

- Collects data from pyranometer, making it available over various networks and delivers it using your preferred protocol
- Needed to measure millivolts from pyranometers
- Records readings from sensors in mV
- Campbell Scientific uses CRBasic programming language.
- Model Used: Campbell Scientific CR300

Notes & Definitions

Topics related to Datalogger

PAR: Photosynthetically Active Radiation (PAR) represents the fraction of sunlight with a spectral range from 400 to 700 nm, usually expressed in μmol (photons) m^{-2} s^{-1}.

Volt: Derived unit for electric potential, electric potential difference (voltage), and electromotive force.

Software

Outputs data in a comprehensible & intuitive format

Overview:

- Using mV reading, software will convert and display values corresponding to irradiance, transmittance, and reflectance
- Use software "fudge factors" as necessary to transform the actual output of the lamp into the balance between total solar and NIR that exists in the actual solar spectrum
  - Converting the lamp's irradiance, probably <600 W/m², to the solar constant
- Helps visitors make comparisons and draw conclusions about cause and effect/impacts of different color/texture surfaces or albedo.
- Wire-based coding (Labview & Epic Unreal Engine)
- Epic Unreal Engine– game design environment which will allow for real-time data visualization
- Epic Games Unreal Engine
  - https://www.youtube.com/watch?v=RtEGsdHy55U

Terms & Definitions

Solar Constant: the average rate at which radiant energy is received from the sun by the earth's atmosphere per unit area (S = 1367 W/m² total, or 342 W/m² when averaged at top of atmosphere)

Fudge Factor: a figure included in a calculation to account for error or unanticipated circumstances, or to ensure a desired result

Watts: amount of energy per second

Luminosity: total amount of energy emitted by an astronomical object per unit time. Measured in joules per second or watts. Values for luminosity are often given in the terms of the luminosity of the Sun, which has a total power output of 3.846×10^{26} W. The symbol for solar luminosity is $L_{\odot}$

Information Panel

Supplemental data to explain background concepts of exhibit

Goal:

- To tie in all scientific concepts demonstrated by exhibit
- Effectively and intuitively communicate complicated scientific subjects
- Exhibit Label
  - Brief explanation of AWARE and its importance

Data Analysis:

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

Infographs:

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

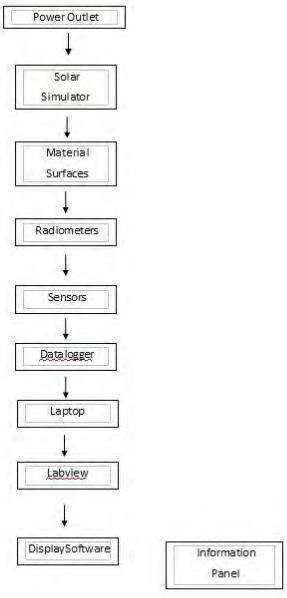
Terms & Definitions

Remote Sensing: the scanning of the earth by satellite or high-flying aircraft in order to obtain information about it.

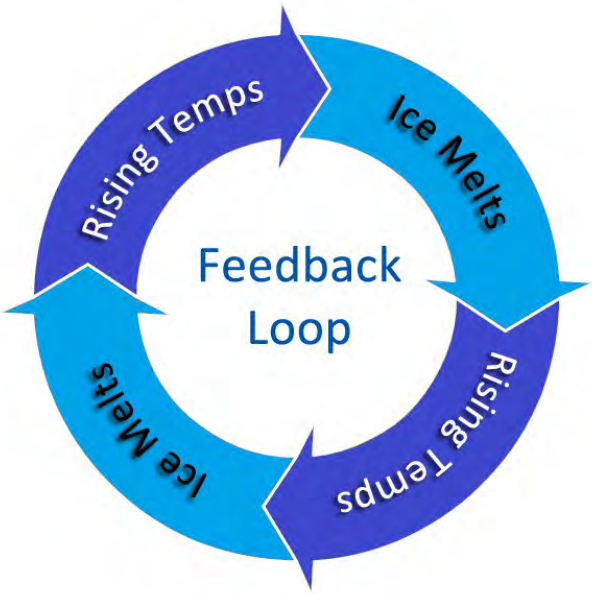
GIS: A geographic information system (GIS) lets us visualize, question, analyze, and interpret data to understand relationships, patterns, and trends.

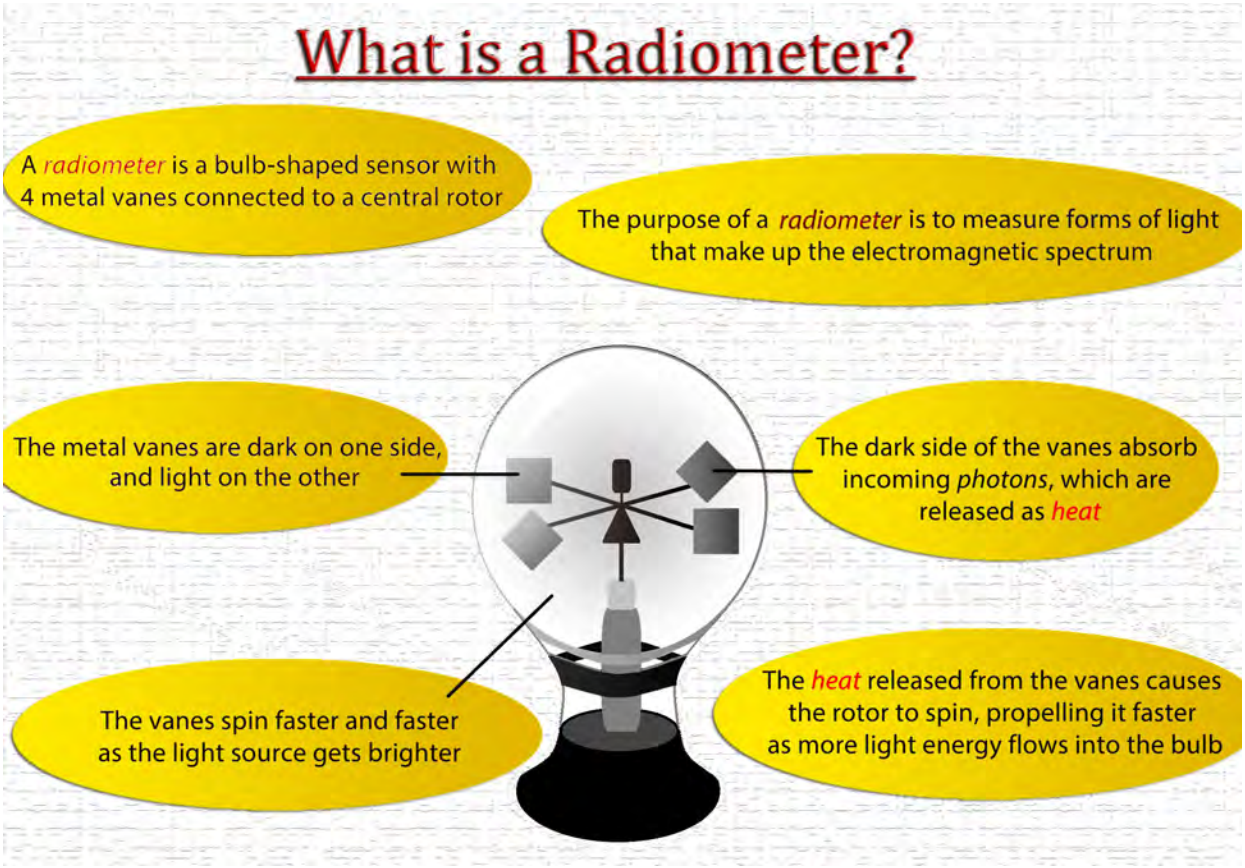
MODIS: *Moderate-resolution imaging spectroradiometer* – a scientific instrument attached to the Aqua & Terra satellites orbiting Earth. Captures data in 36 spectral bands ranging in wavelength from 0.4 μm to 14.4 μm and at varying spatial resolutions (2 bands at 250 m, 5 bands at 500 m and 29 bands at 1 km)

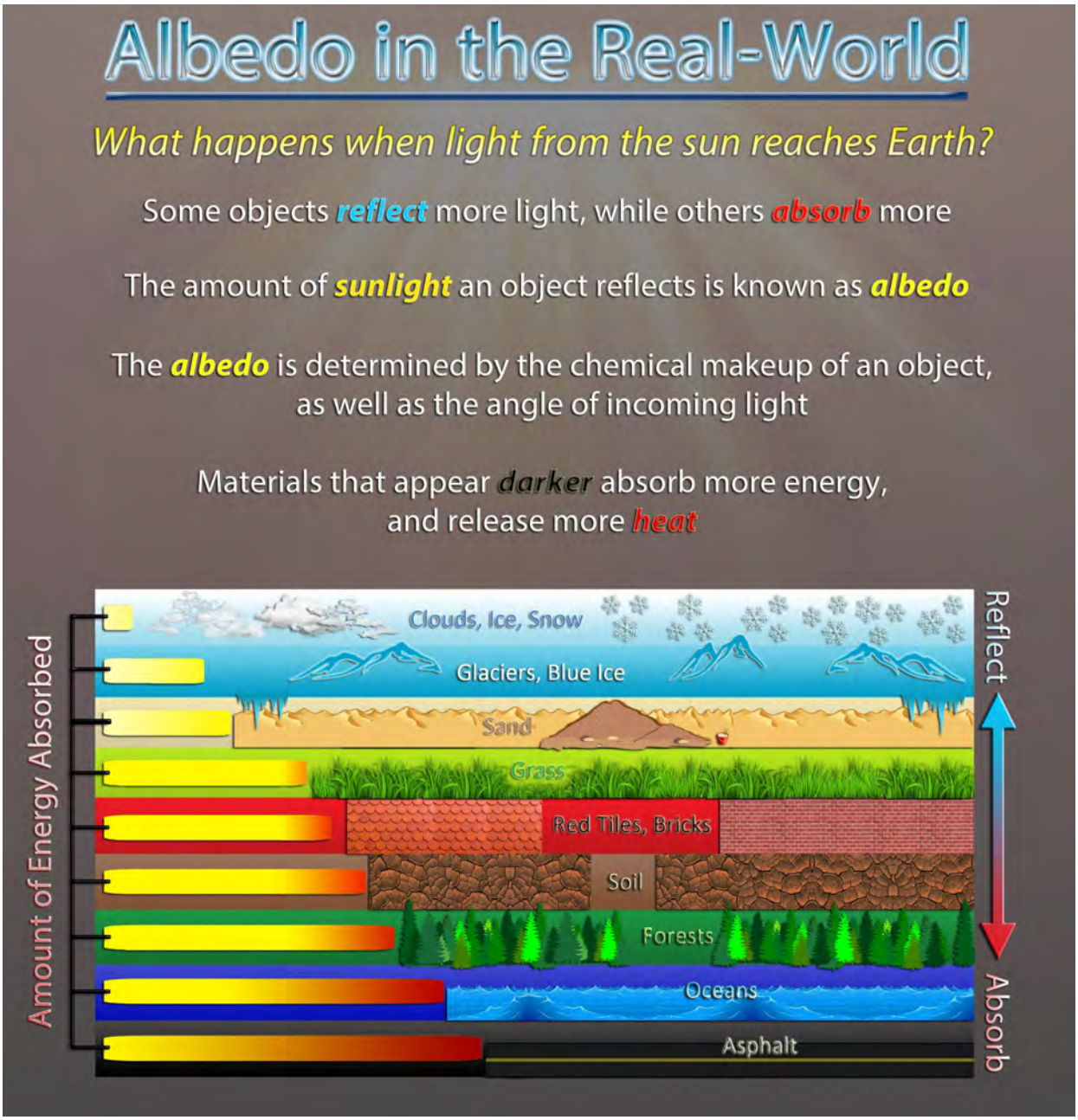
Exhibit Flowpath

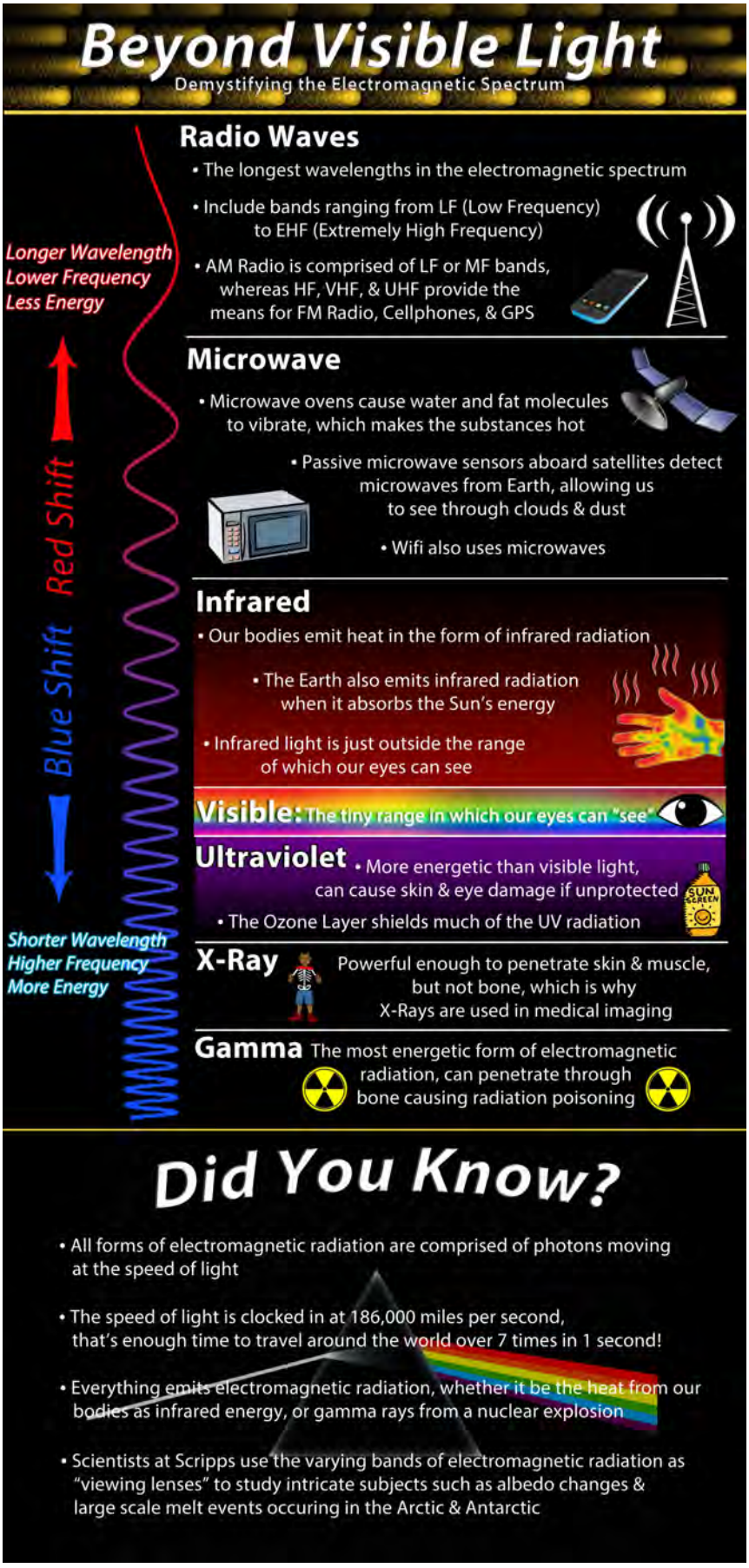


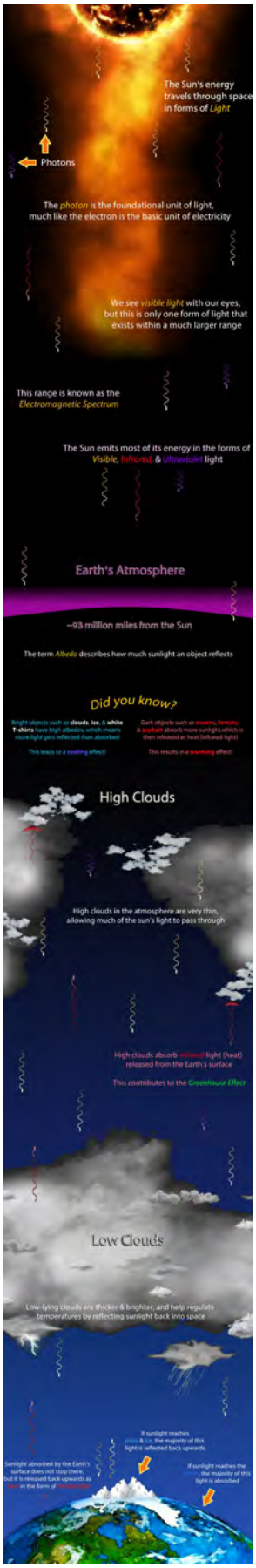
6. Infographs


Rising Temps
Ice Melts
Rising Temps
Ice Melts
Feedback Loop

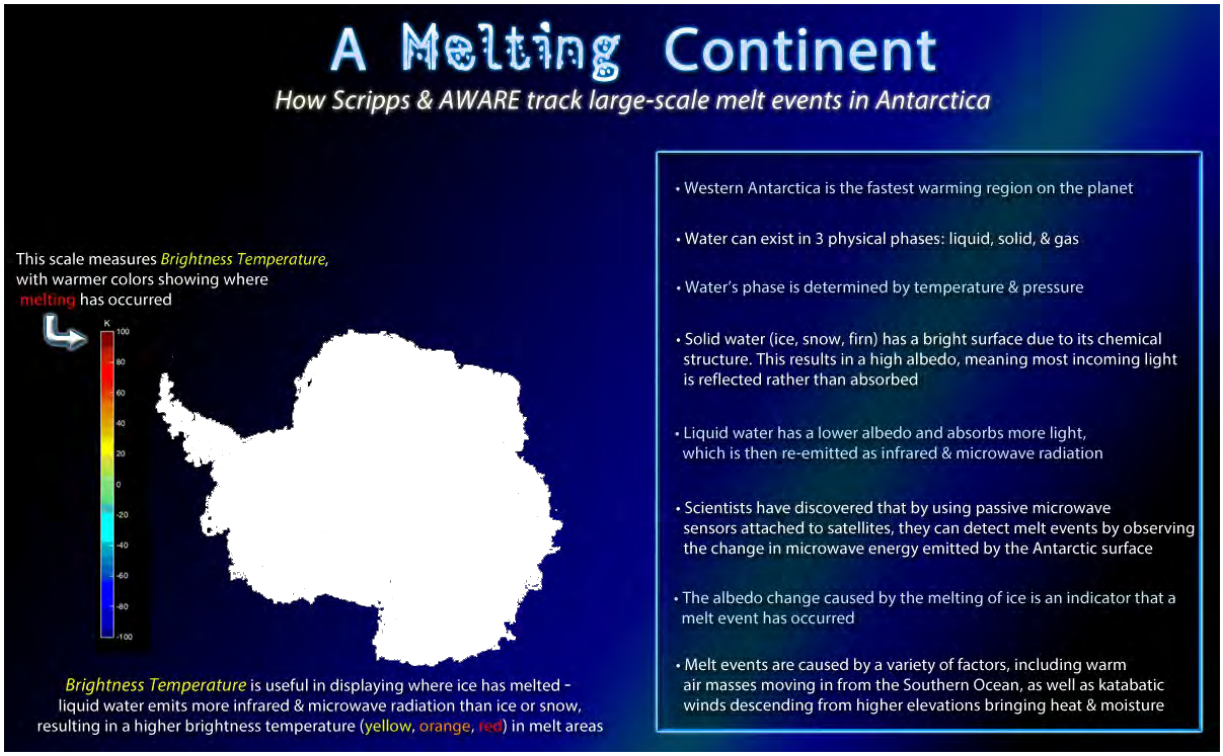

What is a Radiometer?
A radiometer is a bulb-shaped sensor with 4 metal vanes connected to a central rotor
The purpose of a radiometer is to measure forms of light that make up the electromagnetic spectrum
The metal vanes are dark on one side, and light on the other
The dark side of the vanes absorb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

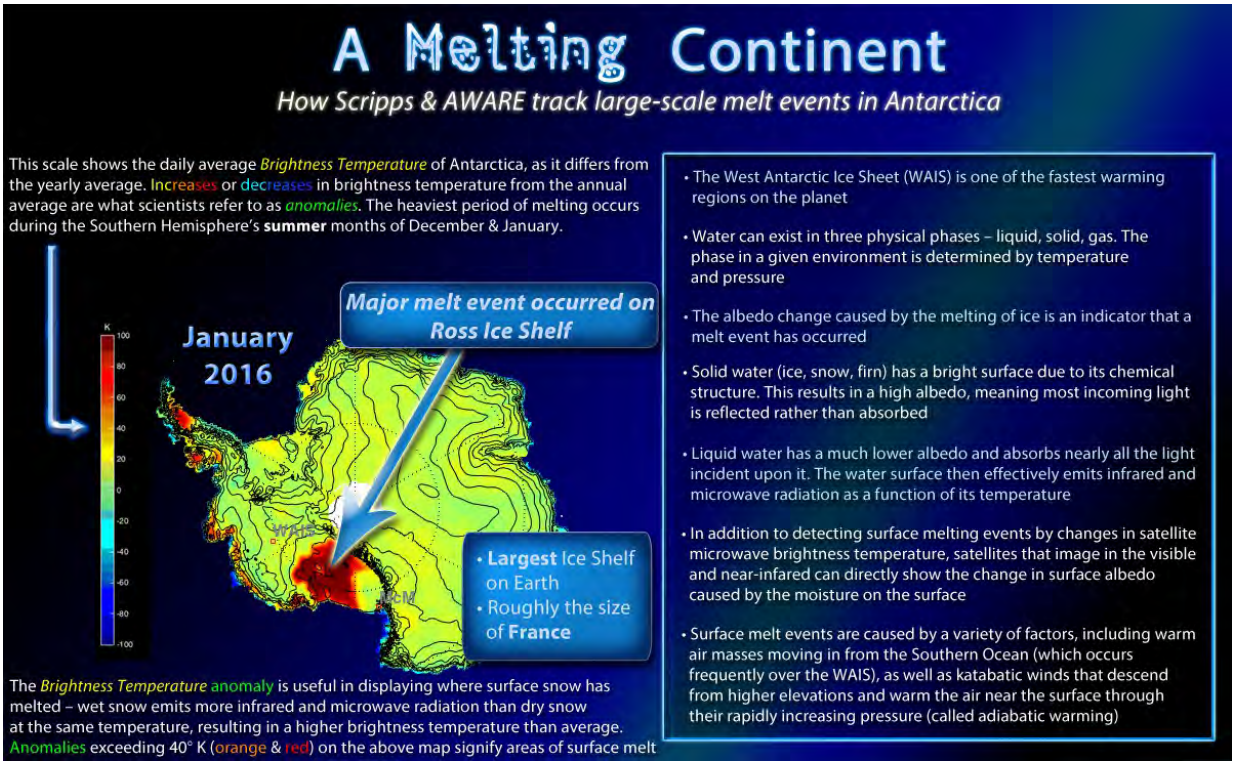

Albedo in the Real-World
What happens when light from the sun reaches Earth?
Some objects reflect more light, while others absorb more
The amount of sunlight an object reflects is known as albedo
The albedo is determined by the chemical makeup of an object, as well as the angle of incoming light
Materials that appear darker absorb more energy, and release more heat
Amount of Energy Absorbed
Clouds, Ice, Snow
Glaciers, Blue Ice
Sand
Grass
Red Tiles, Bricks
Soil
Forests
Oceans
Asphalt
Reflect
Absorb


Beyond Visible Light
Demystifying the Electromagnetic Spectrum
Longer Wavelength
Lower Frequency
Less Energy
Red Shift
Blue Shift
Shorter Wavelength
Higher Frequency
More Energy
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
SUN SCREEN
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 occuring in the Arctic & Antarctic


The Sun's energy travels through space in forms of Light
Photons
The photon is the foundational unit of light, much like the electron is the basic unit of electricity
We see visible light with our eyes, but this is only one form of light that exists within a much larger range
This range is known as the Electromagnetic Spectrum
The Sun emits most of its energy in the forms of Visible, Infrared, & Ultraviolet light
Earth's Atmosphere
~93 million miles from the Sun
The term Albedo describes how much sunlight an object reflects
Did you know?
Bright objects such as clouds, ice, & white T-shirts have high albedos, which means more light gets reflected than absorbed
This leads to a cooling effect!
Dark objects such as oceans, forests, & asphalt absorb more sunlight, which is then released as heat (infrared light)
This results in a warming effect!
High Clouds
High clouds in the atmosphere are very thin, allowing much of the sun's light to pass through
High clouds absorb infrared light (heat) released from the Earth's surface
This contributes to the Greenhouse Effect
Low Clouds
Low-lying clouds are thicker & brighter, and help regulate temperatures by reflecting sunlight back into space
If sunlight reaches snow & ice, the majority of this light is reflected back upwards
Sunlight absorbed by the Earth's surface does not stop there, but it is released back upwards as heat in the form of infrared light
If sunlight reaches the ocean, the majority of this light is absorbed

7. Satellite Data Analysis GIF Template & Example





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