Studying the Biosphere

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ESPM 2: Fall, 2017

How do we know what we know about the Biosphere? To answer this question we need to know how we Measure components of Biosphere? We need to know how the sensors work? What they measure? How representative and direct are they? Do they measure scalars or fluxes? At what scale to we make measurements and how do we add them up?

Outline

- Scientific Method and Philosophy of Science
- How We Study the Biosphere
- Challenges to Studying the Biosphere
- Challenges to Interpreting the Biosphere
- Survey of Methods Used
  - Scalars
  - Fluxes
- Instruments

How We Know What We Know?: The Science of Science

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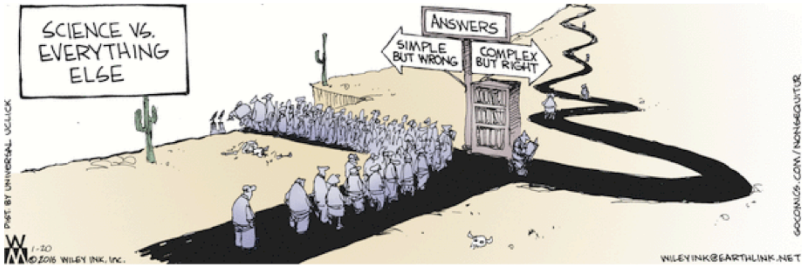
This lecture will Focus on the Science of Science, not really called Scientology, but this Center is near my step-sons home in Hollywood and thought it would be a good provocative introduction to the topic



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Science is Not Magic!

‘Any sufficiently advanced technology is indistinguishable from magic’

Arthur C Clarke, science fiction author

‘It's not magic! It's physics…’

Deborah Bull, Dancer

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It is important to know where the knowledge we study comes from and why we accept the results. First of all I want to Stress Science is NOT Magic…

And even Magic is not ‘magic’, once we look behind the curtain and see how it is done. It too obeys the laws of physics, chemistry and biology.

Similarly with science we have to look under the hood at the principles on which we measure and study complex systems like the Biosphere.

This lecture is important because it takes the magic away from the lessons we will teach. You will get a back ground and understanding on where the data come from, how they are collected and measured and what are their uncertainties and limits.

Big Questions?

How Do We Study the Biosphere?

What Quantities do we Measure?

What Tools and Methods do We Use?

How Accurate and Uncertain are they?

How Representative are They, in Time and Space?

These are the questions we ask ourselves as scientists when we make measurements, design experiments and interpret our results. There is no one way, or perfect sensor to study the biosphere. From the get-go we have to adopt a multi-disciplinary, multi-scaled, hierarchal approach

Sometimes the Science of the Biosphere is Not Cook Book; It is more Like Sausage Making

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A bunch of happy Italians making sausage, really. Nonna Baldocchi, Mom, Zio Guido, Zia Eva, Appy, Tonia, Dad.

But the point I want to make is studying the Biosphere can be messy. Often there is not a clear and distinct answer to your question or a simple and precise measurement. The world is changing about us, so signals are varying and trending with time. There is much spatial variabilty, so the quantity measured at one point may differ greatly at another. Knowing how to assemble and distill all this information is part of the art of the science of studying the biosphere. It is why it is such a challenging, interesting and fun topic and profession.

I want to stress it is not cook book, and when I talk to the best and most creative scientists almost all of them note their approaches can be a bit haphazard, looking for serendipity. That is were the real discoveries are made and you have to be ready, willing and able to detect serendipity when it occurs

Difficulty of Studying the Biosphere

- We have only One Replicate
- We cannot Manipulate the Biosphere and Compare it with an Unaltered Control
- The Record is Complicated by Super-positioning of Many processes that are correlated or lag with one another and operate across a spectrum of fast to slow time scales

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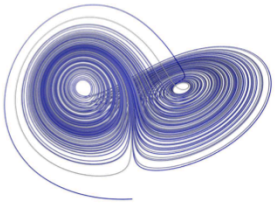
As an alternative, we can use measurements back in time to infer how the Earth system may behave to different conditions. Proxies in the paleo-record, stable and radioactive isotopes, stored in rocks, sea and lake sediments and tree rings are an example. How to upscale this information is a question? How representative these measurements are to other parts of the biosphere are also raised? We can also use mathematical models to probe the biosphere. But there remain issues to the accuracy of the models, how well they represent all the processes, and how the models are parameterized. Finally we have to ask our selves how good is good enough. Simple models can often be good enough if you are willing to accept given levels of error. Yet models can be vulnerable to criticisms to skeptics and deniers who will never accept good enough. But the truth is we cannot model or simulate the biosphere perfectly and accurately.

The other alternative is to use Earth System Simulation modeling. This approach is currently being used to assess the state of the planet in the future with continued greenhouse gas emissions. Models must be validated with past conditions, parameterizes with information from experiments and assumed to be valid in the future, and not to suffer from issues like scale emergent properties.

Difficulty in Interpreting Biosphere Data and Information:

Complexity and Chaos Causes Answers to Complex Systems to be:

NOT Black or White



But some Value within a Phase-Space Attractor,
that may Switch Phase Quickly and Expectantly;
Answers are Conditional

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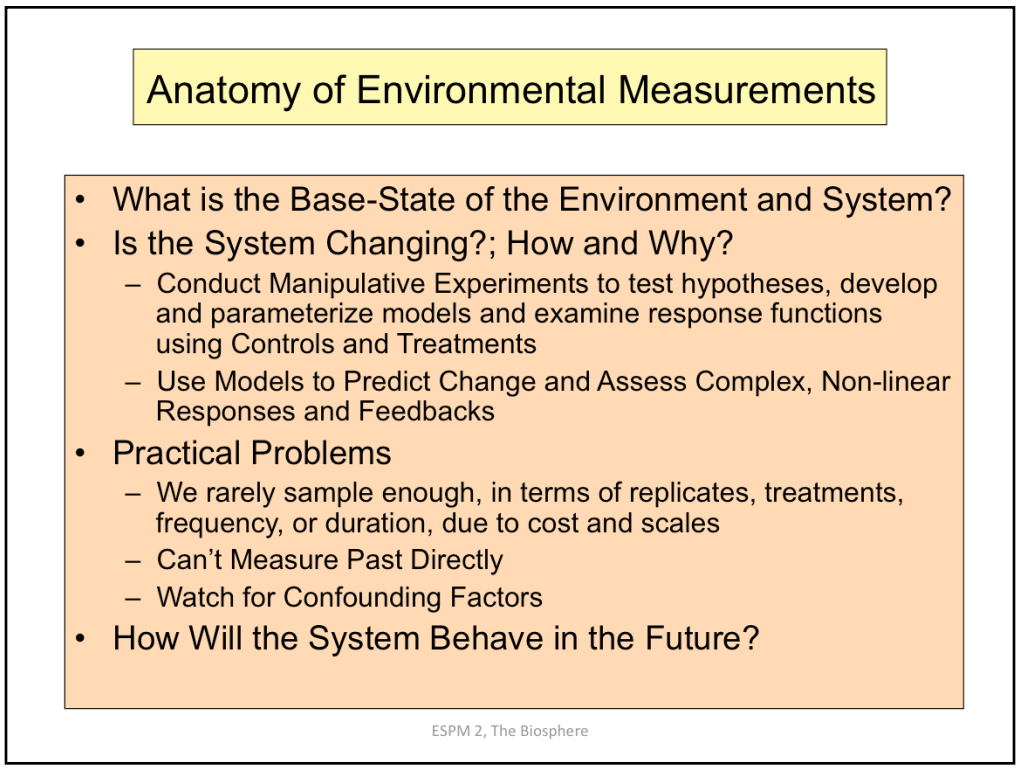
No measurement is perfect, nor any model is perfect, since both are based on assumptions, theory laden or their presence may alter the system they are trying to study. The answer also depends upon the time and space scale of the inquiry. Consequently, we tend to rely on convergence of information, consistency of data and arguments using multiple constraints and a hierarchy of modeling and measurement approaches.

In addition the answers may be conditional. Many systems respond to forcings in a non linear manner so Process A may be greater than B for condition X1, but vice versa for condition X2.

The consequence of complex systems is that they produce chaotic, seemingly noisey time series. These may appear random, but they are deterministic. They are hard to predict because they are very, very sensitive to initial conditions, which we don't know well. Bottom line is that environmental measurements tend to be noisy and we have to work with that noise.



It is difficult to conduct experiments in the natural world that controls everything. Scientists often conduct experiments that compare the response of a set of treatments or manipulations with a control. These experiments should be sufficiently randomized, designed to remove or minimize artifacts and repeatable.

Big Picture Question
on Predicting and Quantifying the State of the Biosphere:

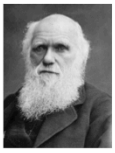
- **How can We Produce Information about the Biosphere that is:**

  'Everywhere, All of the Time?'

As a biosphere scientist it is one of the goals of my work to be able to assess information on the biosphere everywhere all of the time. Yet as you will see there is no one perfect sensor or instrument system that allows or enables us to do this. We must work with multiple systems.

Wedding at Cana, by Veronese, the Louvre, Paris

Who Are Scientists?



Common Denominator, Insatiable Curiosity

Top, Newton, Darwin, Einstein, Curie, Watson & Crick

Bottom, UCB Nobel Laureates, Lawrence, Calvin, Schekman, Perlmutter

Sure they are all very smart, but some were smarter than others, some more ambitious than others, some more persistent than others and some more clever. Yet they all made land mark discoveries and changed the way we think and view the world.

Who Are Scientists?, v2

'The Fox knows many things,
but the Hedgehog knows one big thing'

Isaiah Berlin, Philosopher, 1909-1997

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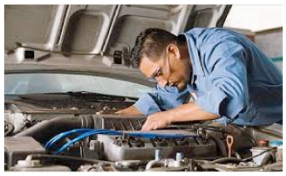
Scientists are human and have human traits. From their personalities, backgrounds and educations they tackle the study of the biosphere from multiple angles. As someone who has mentored many students and postdocs and worked with many colleagues I have come to accept that they fall into broad categories first identified by Isaiah Berlin, Foxes and Hedgehogs.

Sir Isaiah Berlin is noted for his fox and hedgehog analogy, to distinguish great thinkers and writers from one another. This concept does apply to many of our scientific colleagues. Some are quite happy buried in their data and laboratory studying one aspect of the world in great details. Others gravitate towards being big thinkers and integrators, but may not be so good on falling up on details. Neither is good or bad, right or wrong. In reality we need an ecosystem of scientists with a variety of skills, personality traits and attributes to advance knowledge.

Traits/Personalities of Scientists

'Stamp Collectors'

Collect, curate and catalogue data



Mechanics

Study Processes and Curious How things Work

Puzzle Solvers

Strive to Know the Unknown; Practitioners of Consilience

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As I talk with colleagues and mentors, I've become aware of a slightly different mix of personality types who make scientists. Scientists and naturalists like Linnaeus could be considered to be stamp collectors, giving names, ranking and order to the different species. Scientist like Melvin Calvin (UCB Nobel Laureate) could be considered to be a mechanic with his quest to define the mechanisms of the carbon cycle of photosynthesis. Scientists like Hubble, Einstein and Watson and Crick could be considered puzzle solvers, as they asked big questions about the fabric of the universe in terms of space and time and structure of DNA

Biosphere Scientists in the 21st Century

Multi-Disciplinary Teams
Collaboration, Across Institutes/the Globe
Need for Data Sharing and Transparency

Methods of Inquiry and 'Story-Telling'

- Journalist
  - Who?
  - What?
  - Where?
  - When?

- Scientist
  - What?
  - When?
  - How?
  - Why?
  - Will Be?

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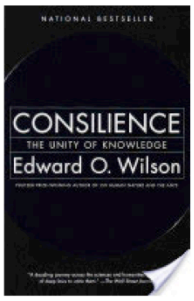
Many non scientists are better versed at reading the newspaper and magazines and can be intimidated with scientific reports. Scientists don't connect well with the public, and students, because we often bury our knowledge and lessons at the end of long complicated manuscripts. Gory detail is given before the crux of the finding is discussed. Journalists are adept at story telling and describing conflicts, differences in opinions. They tell you the crux of the story at the beginning then elaborate with more detail. We need to do a better job communicating with the public, students and our peers. We can do so by applying some lessons from journalists. But there is more, too.

And science endeavors to do more than just tell a story. The goal of scientific research is to answer questions generated by innate curiosity, low how something works and why. Scientists are less interested in differences in opinions and concentrate more on the facts that best explain results

In today's world where so many are becoming science-phobic, it is more and more important to herald the importance and power of science and the scientific method. So much of our life depends upon science and the technology derived from it, like medical treatments for cancer and heart disease, new plant varieties, cell phones, computers, airplanes, modern automobile, energy generation and transmission system, etc

And with sufficient information one should be able to predict behavior. Classic examples are how well physics can predict the movement of the planets, stars, comets and the tides on Earth. Simulation models of airplanes are developed before airplanes are manufactured and those that are built, indeed fly.

Discovery by Consilience



Definition of CONSILIENCE:

the linking together of principles from different disciplines especially when forming a comprehensive theory

"Literally a 'jumping together' of knowledge by the linking of facts and fact-based theory across disciplines to create a common groundwork of explanation." EO Wilson

Consilience was written by EO Wilson, a famous naturalist and biologist at Harvard.

The word lends itself to our practice of studying the biosphere with multiple constraints. No one method is perfect, but by observing the system from multiple viewpoints or perspectives we grab a better understanding of its functioning

Serendipity

the occurrence and development of events by chance in a happy or beneficial way.

‘Be Prepared to Expect the Unexpected’

'Proof ' in Science is Different from the Law and Journalism

- Law: Prosecutor has to prove guilt beyond 'reasonable doubt'
  - 'If the glove don't fit, we must acquit', Johnnie Cochran
  - innocent people are often convicted and guilty ones set free
- Journalism: Tells both sides of a Story, despite relative differences in importance, e.g. false equivalence
  - It attempts to be 'Politically-Correct' or 'Fair and Balanced'
  - Should climate deniers be given the same voice as climate science?
- Science: Hypotheses are Testable, and Expt. must be Repeatable
  - Falsified hypotheses are relegated to the 'Dustbin of History'; they are not given equal voice just because they exist or can be articulated
  - Science is Not Democratic or a 'Beauty Contest', e.g ideas with the most votes do not necessarily win.

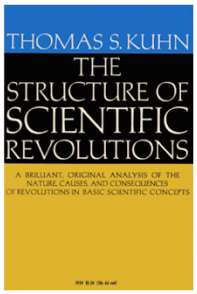
An example of false equivalence is the comparison of journalistic coverage of Hilary Clinton's connection to Benghazi or her email server which was covered ad nauseum vs the tepid coverage of Trumps possible collusion with the Russians, lack of transparency of his business and earnings and outright string of lies, starting with the birther arguments about Obama.

Scientific Method

- Identify a Question or Problem
- Perform Background-Scholarly Search on What has been done in the Past
- Propose a Rational and Meaningful Hypothesis
- TEST Your Hypothesis by Performing Controlled Experiments, Paired Measurements, or Numerical Computations
- Analyze Your Data, Quantify Systematic and Sampling Errors, Test for Null Hypothesis, and Draw a Conclusion
- Use Information to Produce Mathematical Model and Use it to Predict
- Modify and Refine Hypothesis, Re-Test

Science is Testable and Good Theories and Hypotheses are Repeatable; Bad theories can be Falsified. Religious explanations rely on faith, are not tested, and instead rely on anecdotal observations that are not repeatable.

How Science Progresses/Evolves



Pre-Paradigm Phase, data are collected, hypotheses proposed

Normal Science, Data accumulate to support Paradigm, but exceptions exist.

Crisis in Knowledge and Understanding may arise, as New data, New instruments, New insights are forged

Scientific Revolution, new Paradigm arises

Post Revolution, the New Paradigm becomes Normal and Cycle continues

Kuhn, Structure of Scientific Revolutions

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Science is not perfect, but it has proven to be the best way of knowing that we know

Size evolves as information is accumulated and a better understanding is gained. Sometimes this can be disrupted, as when there is a Paradigm Shift. But this is normal and an exciting aspect of science. It strives to get better. Science is not supported by dogma. Science and learning is not inflexible.

What is a good example of a paradigm shift? Plate tectonics is a good one. Prior to the 1960s this idea was not strongly supported.

Science

- Science may not be perfect, but it has been demonstrated time and time again it is our best possible way of knowing
- Computers and Iphones, airplanes, medicine, weather forecasting, electrical power are all examples of how science had made our lives better

Interpreting Data:

Science, Opinion and Society

'Everyone is entitled to his own opinion, but not his own facts'

Attributed to Daniel Patrick Moynihan

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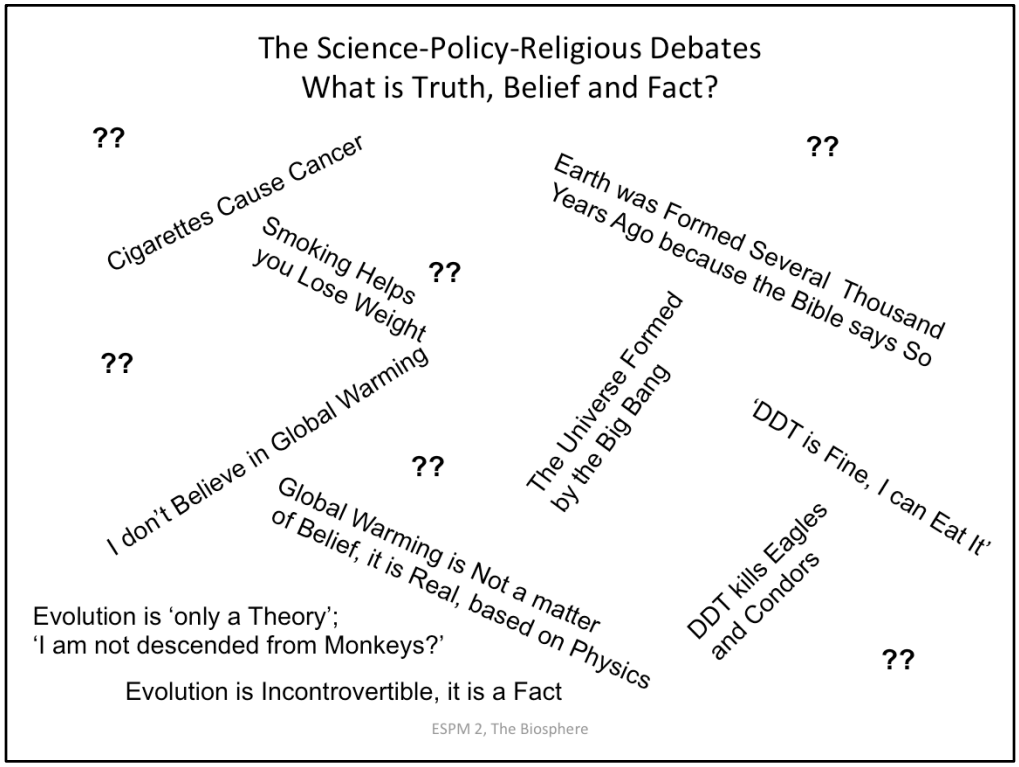
Wish I did not have to stress this obvious point, but in today's world with fake news and alternative facts, it is probably more important than ever; though if one does look back at history we see it repeats itself; remember the Scopes Monkey Trials in the 1920s over evolution. The trial and condemnation of Galileo by the Church; condemnation and imprisonment of Roger Bacon (1200s). Those in power or the status quo are often threatened by knowledge produced by science

There is a lot of miss-information in the press and in the sphere of public debate because people either don't fully understand science and the scientific method or they are miss-using it deliberately to support their causes and claims, that would otherwise not be supported with rigorous scientific scrutiny.

There is also the philosophical questions and debates in how scientists should interact with society. Many hold we should be unbiased arbitrators of data and information; To this point I concur. It gets more complicated to what degree we should engage with the formation of policy. Do we lose our objective perspective when doing so? This question is harder to answer and there are often lines not to be crossed (see next slide Merchants of Doubt). Some scientists insist we should remain separate from society. Others argue we should be engaged as Pandora has opened the proverbial box and society is better off relying on scientific data and information, than misinformation and psuedoscience. The reality is that we as scientists are part of society too and benefit or suffer from decisions that use or misuse scientific data, such as the ongoing climate debates and others with vaccines and gmos…

Daniel Patrick Moynihan, late Senator from New York;



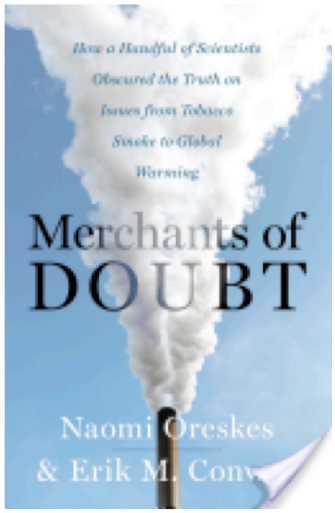
Belief: confidence in the truth or existence of something not immediately susceptible to rigorous proof

Science: We can disprove a hypothesis, but it is difficult to prove one

Caveat Emptor: Watch for Science deniers who have vested interests and misuse science to bolster their arguments. Aspect of Fallacious Logic

See book on Merchants of Doubt, Naomi Oreskes, http://www.merchantsofdoubt.org/

Merchants of Doubt



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It is important to understand the scientific method as there are those politically motivated to misuse and abuse scientific thought, theory and data to push their agenda for economic, political or religious reasons, on both the left and right. Examples today include fossil fuel emissions, fracking, cigarette smoking, vaccines, gmos. We will see that there are issues of fallacious logic, to avoid. Yet many of these merchants of doubt are masters of using and abusing fallacious logic to push their ideas. Yet under the same scrutiny they apply to science, their ideas are bound to collapse.

Merchants of Doubt tells the story of how a loose-knit group of high-level scientists and scientific advisers, with deep connections in politics and industry, ran effective campaigns to mislead the public and deny well-established scientific knowledge over four decades. Remarkably, the same individuals surface repeatedly-some of the same figures who have claimed that the science of global warming is "not settled" denied the truth of studies linking smoking to lung cancer, coal smoke to acid rain, and CFCs to the ozone hole. "Doubt is our product," wrote one tobacco executive. These "experts" supplied it.

‘Belief’ is confidence in the truth or existence of something not immediately susceptible to rigorous proof

Belief is not Proof, as it is Not Testable

Lacks Self-Criticality and can suffer from tenets of Fallacious Logic

90% of Americans Believe in God and Afterlife
90% of Scientists in the National Academy of Science are Atheists or Agnostic

Theory of Falsification

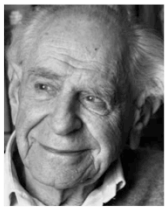
We cannot Prove a Hypothesis, as We Don't Know what We don't Know

We can Disprove a Hypothesis that is Incorrect with a single experiment or set of observations

e.g. Testing the null hypothesis

Ronald Fisher
1890-1962

Donald Rumsfeld



Karl Popper
1904-1992

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Your dataset may not be large enough, it may not have a Gaussian or normal distribution, causing you not to sample important but rare extreme events. The Black Swan.

Ironically, the ignorant person is happy to just 'know' what he/she thinks, without going further and learning more. This is the conflict we have in a democratic society trying to do what is best for the whole, while respecting the opinions of the individuals.

Proving Theories

- One Can Never Prove a Theory, But one can Falsify or Disprove a theory
  - "No amount of experimentation can ever prove me right; a single experiment can prove me wrong", Einstein
  - Case 1, The Earth is the Center of the Solar System
    - Disproved by Copernicus, Kepler and Galileo
  - Case 2, The Universe formed from a Big-Bang
    - The Big Bang theory is strong, supported by multiple and independent lines of evidence; it has not been disproven or falsified
  - Case 3, Life on Earth originated on Mars or space, panspermia
    - Open to Debate and More data, not proven nor falsified, yet
  - Case 4, Santa Claus brings Christmas presents.
    - I think you know the answer

Karl Popper is a 20th Century Philosopher who advanced the Falsification theory.

Science cannot prove a theory or hypothesis. But it can falsify one with rigorous and thoughtful experimentation. The power of the Scientific method is it is subject to scrutiny and must be consistent among multiple lines of inquiry. Hence it evolves towards a better truth and is repeatable.

Proving/Falsifying Biosphere Theories Fall in the Gray Area

- What is Global Photosynthesis?
  - No Perfect Metric to Compare with Many Estimates Exist, Which is Right?; Which is Wrong?
- All Models are Wrong, Some are Useful
  - How Good is Good Enough?

Watch for and Avoid Fallacious Logic

- *Ad hominem* attack
  - 'the theory is wrong because Dr. Bozo is a jerk and ugly'
- Appeal to Authority
  - the theory that the 'earth is flat' is correct because Dr. Peabody, a Nobel Laureate, says so.
- Appeal to Motive
  - 'climate change is a hoax', the oil lobby
  - 'Buying carbon offsets that plant trees every time you fly will prevent global warming', the green lobby
- Cherry Picking, An unrepresentative sample (e.g. anecdotal evidence)
  - The homeopathic remedy worked because Betty Sue got well.
  - All Dutch Scientists are Tall (e.g. Han Dolman, Bart Kruijt, Bert Holtslag, Bart van den Hurk, but Cor Jacobs and Marten Scheffer are not)
- Magical Thinking, Correlation does not prove Causation
  - Super Bowl-Stock Market Index predicts up-market if NFC or former NFL team wins, and down-market if AFC team wins; it has been correct 32 out of 40 years, and was correct 28 out of first 31 years
- Begging the Question
  - 'Elephants weigh a lot because elephants are big' , naïve naturalist

A lot of confusion about science in the public space occurs because advocates have vested interested and use fallacious logic to make their cases. In other words their arguments are based on a 'fallacy', an argument that uses poor reasoning. This slide lists some examples of fallacious logic.

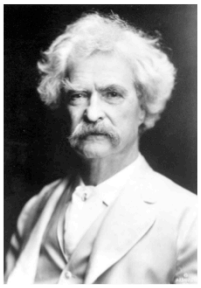
If you are interested in this topic here is a web site with some discussion
http://www.nizkor.org/features/fallacies/

https://www.logicallyfallacious.com/tools/lp/Bo/LogicalFallacies/11/Ad-Hominem-Tu-quoque

http://www.unc.edu/depts/wcweb/handouts/fallacies.htm

Begging the question involves circular logic, Claim X assumes X is true; then X is true. Eg *Paranormal activity is real because I have experienced what can only be described as paranormal activity.*

There are three kinds of lies:
lies, damned lies, and statistics."



Who else, but by Mark Twain

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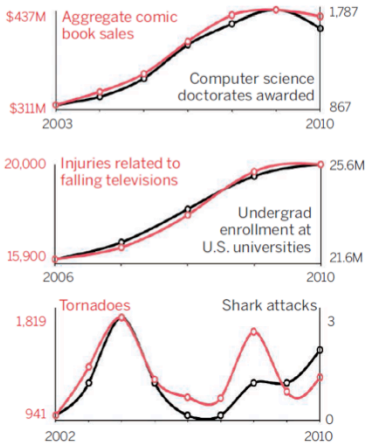
Mark Twain (Samuel Clements) attributed the quote to Benjamin Disraeli (1804-1881), Prime Minster of Great Britain.

We rarely sample enough, in terms of replicates, treatments, frequency, or duration, due to cost and scales. Consequently, we must make due with imperfect information to advance scientific knowledge. I think you see this reality with political polls. They often sample a 1000 people on their opinion or likelihood to vote for someone, and then the election comes out differently.

Correlation Does Not Prove Causation:
Watch for Spurious Correlations



Correlations are critical in scientific analysis, but given enough data, it is possible to find things that correlate, even when they shouldn't. More examples of how not to use statistics can be found on the author's website, tylervigen.com.

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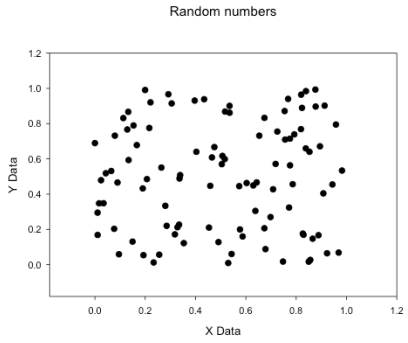
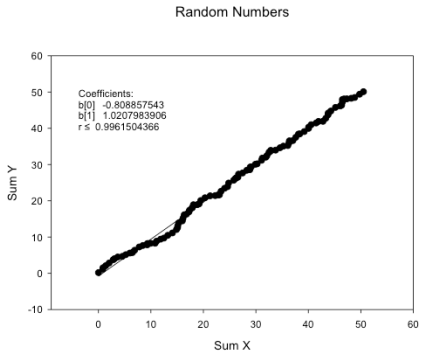
Many correlations between two unrelated variables can be shown, but they can be meaningless. Correlation does not prove causation, but it is a step towards doing so.

Often cumulative statistics tend to be correlated. For example, compare two sets of accumulating random numbers.

http://www.sciencemag.org/content/348/6238/980.2.full.pdf

Accumulated Random Numbers are Correlated!





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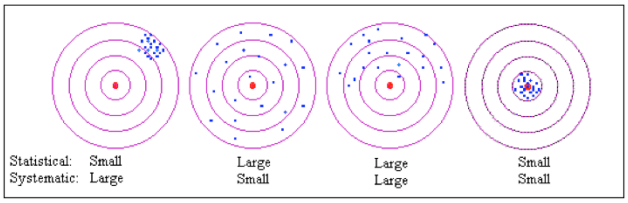
Good example of the false correlation between 2 sets of random numbers as one compares their sums!! Sadly there are too many science papers and theories based on summed quantities and their originators have not been astute or self critical enough to challenge their thinking.

Uncertainty due to Systematic Bias and Sampling Error

Accuracy and Precision



Here is terminology about how well we measure something. It could be precise, but in error. It can be accurate, on average, but very imprecise. It can be imprecise and inaccurate, or precise and accurate. It is important to read the specification of an instrument to know about its accuracy, sensitivity, precision, drift, resolution, signal to noise

Because measurement systems may have biases it is often better to make 'differential measurements' using the same sensor, this way bias errors cancel. You will see an application of this idea next in testing the null hypothesis

Null Hypothesis, H_0

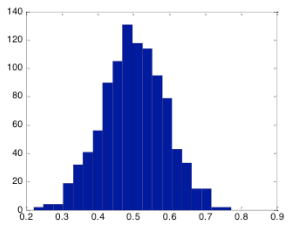
- Formulate a Meaningful Null Hypothesis
  - H_0: $\langle x_1 \rangle = \langle x_2 \rangle$,Test if the Differences in the Populations is zero
  - H1, Avocadoes are Denser than Tomatoes?
  - H1, Boys are Taller than Girls?
- Determine Means and Variances of the Two Populations
- If Differences Exist, Test if they are Real (95/100) or by Chance (5/100), also called a false positive
- If Real, Reject H_0 and Accept H_1

R.A. Fisher is a 20th Century Statistician who advanced the idea of testing the null hypothesis. He is famous for his paper in the 1930s called the 'lady, tea testing experiment'. A women was asked to tell if the tea was infused with cream before or after the tea was poured, from random sampling of tea. The test was whether her ability was better than random sampling.

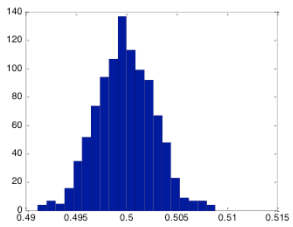
Some hypotheses are conditional.. What if we sampled a group of 17 year old girls and 10 year old boys?; clearly the girls would be taller than the younger boys, while a group of 17 year old boys will probably be taller than the 17 year old girls. So how you formulate your hypothesis is important, too.

Is the sample Large enough to Detect an Answer Significantly different from Random?

Precision Increases with Sample Size



1000 samples of the ave of 10 Random numbers



1000 samples of the ave of 10000 Random numbers

A Curse of Biosphere Studies is that Variables we Study are Noisy and we Tend to Under-Sample due to High Cost, $$ and Limited Time and Staff; So We Tend to Under Sample Populations

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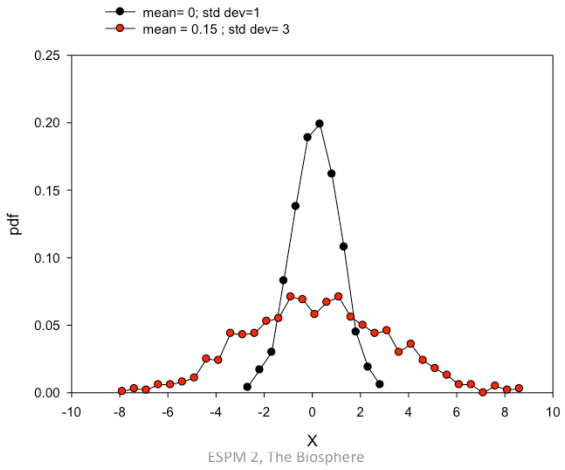
Note that the distribution on the left ranges between 0.2 and 0.8. The pool of binned numbers is small (10) so the probability distribution in this histogram is large

In the second case we polled much larger groups of numbers (10000), so here the distribution is much closer to the average random number (0.5) with a distribution between 0.49 and 0.51.

Why is this all important? Not only does it affect your ability to study the biosphere, but to interpret data in the newspaper on issues about health, the environment, consumer safety, product comparisons, etc.. This can lead to conflicting results in follow-up studies.

Two Populations with Means that are Numerically Different;
Mean 1 = 0 and Mean 2 = 0.15.

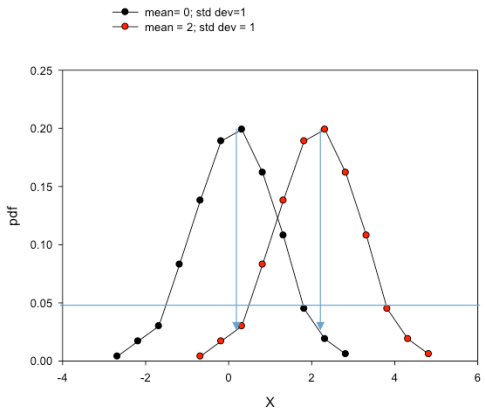
We Cannot Reject the Null Hypothesis, H_0, because the Populations are Not significantly different, at the 5% Probability Level (P<0.05)



Just because two means are numerically different does not mean they are statistically different. Statistical differences depend on the standard deviation and the number of samples. Precision and accuracy of the measurement and natural variability of the system affect how well we can tell if a treatment is different from a control. In the case shown here I produced two data sets that are numerically different, on average. But statistically there is no difference between population 1 and 2 because the probability distribution of population two overlaps population one.

Precision increases with the number of samples because the sampling error is a function of the standard deviation divided by the square root of the number of samples

Two Populations with means significantly different, at P<0.05;



Be circumspect of Anecdotal Evidence
Note the populations overlap and there are instances where members of Population 1 (Black Dots) > Population 2 (Red Dots); Hence, be circumspect of Anecdotal Evidence

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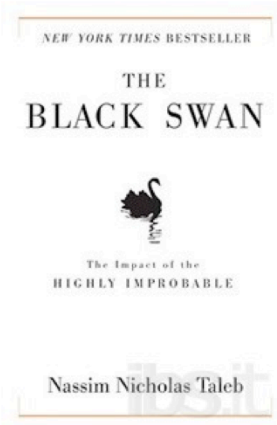
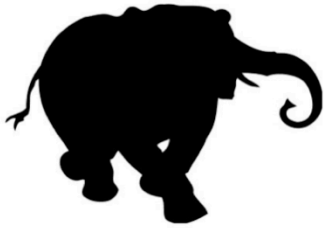
In this case the two populations are statistically different from one another, e.g. population 1 (black) is less than population 2 (red). But also realize there are situations when population 1 is greater than population 2. Classical example is the case where the fastest men out run the fastest women in a Marathon, but many women run faster than many of the men, within the population of runners. So watch out for anecdotal evidence that may arise from sub sampling the probability distributions.

Watch for Black Swan/Black Elephant Events





BLACK ELEPHANT: "A cross between "a black swan" (an unlikely, unexpected event with enormous ramifications) and the "elephant in the room" (a problem that is visible to everyone, yet no one still wants to address it) even though we know that one day it will have vast, black-swan-like consequences."

Tom Friedman distilling Adam Sweidan

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The theory was developed by Nassim Nicholas Taleb to explain:

The disproportionate role of high-profile, hard-to-predict, and rare events that are beyond the realm of normal expectations in history, science, finance, and technology.

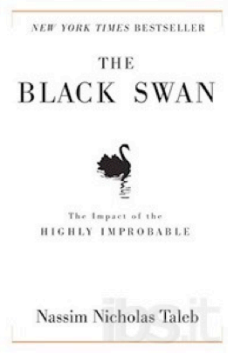
The non-computability of the probability of the consequential rare events using scientific methods (owing to the very nature of small probabilities).

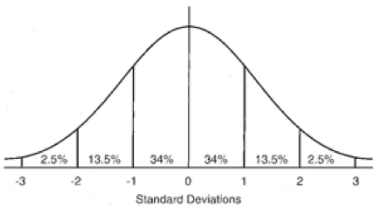
The psychological biases that blind people, individually and collectively, to uncertainty and to a rare event's massive role in historical affairs.

The statistical properties of Nature can be very Non-Gaussian

Their Histograms can be described as having Long Tails,
not the classic Bell Curve of a Normal Distribution

Rare or Extreme Events can
Have Large Consequential Effects on the State of the Biosphere





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Black swan events are outliers from normal distributions that have high or extreme impacts. Crash of stock markets are one example. Think of some rare, long tailed events that affect the Biosphere. With weather it could be a tornado or hurricane. With ecosystems a fire. With the land a land slide, flood or earthquake. With Earth it could be a meteor impact. Key ideas: extreme events can and do occur. Some positive, others negative. We should build robust systems to endur the negative black swan events (good example may be collapse of ice sheets or loss of carbon from tundra/permafrost as the planet warms from greenhouse gases. In my world of measuring turbulent gas exchange, 80% of the exchange may occur by events 10 times the mean that happen less than 10% of the time.

Is a big advocate of using fractal theory of Mandlebrot to describe them. Power laws are important to describe the distribution, like book sales and number of books published. Best sellers are few and far between, but dominate total sales. Problem is identifying the best seller. Hard to do, so many books are published with hope of a black swan event. Black Swan theory is highly critical of using normal distributions to gauge risk.

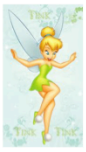
In 2017 the 50 inch deluge of rain on Houston from Hurricane Harvey, is clearly a Black Swan event, something that is supposed to occur once in every 500 years; yet Houston, in recent years experience a number of storms with more than 10 inches of rain

Outliers and Anomalies

- Sometimes, They can Be Important and Reveal new Insights
- Other times, they can be Erroneous , due to poor or sloppy measurements, instrument artifacts
- Extraordinary results need Extraordinary Explanations
  - Always be self-critical of your results

Key Points

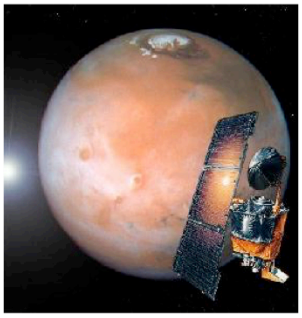
- Scientific Method Provides a Testable and Repeatable Way to Dis Knowledge and Predict
- Avoid Fallacious Logic
- There is no Perfect Truth
  - Measurements and Experiments are Imperfect, Complex systems are Noisy and we often Under Sample Nature
  - We can Falsify Weak Hypotheses
- Science is Iterative and is Self-Critical, so It Evolves and Self-Corrects; it is not Democratic and subject to Vote or Opinion
- Knowledge produced by Science is at the opposite end of the spectrum of Knowledge produced by Faith and Belief
- 'Belief' is confidence in the truth or existence of something not immediately susceptible to rigorous proof
  - Belief is not Proof, as it is Not Testable, Lacks Self-Criticality and can suffer from tenets of Fallacious Logic
  - 90% of Americans Believe in God and Afterlife
  - 90% of Scientists in the National Academy of Science are Atheists or Agnostic



Consequently, I never say 'I believe in global warming'. It is not a subject matter to faith or belief. It is based on fundamentals, based on sound physics, like the fact that gases like CO2 and CH4 absorb infrared radiation at selected wavelengths, and this absorbed energy is re-radiated to the surface and warms the surface. These ideas have been subjected to numerous tests over time.

Units Matter

- **NASA's metric confusion caused Mars orbiter to Crash**



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In the US the old British system of feet, pounds and degrees Fahrenheit is used by commerce and engineers. Scientists, working with international colleagues use units of the System International

http://physics.nist.gov/cuu/Units/

Key Points on Environmental Measurements

- Requires inputs from many fields of knowledge
  - Electrical and Mechanical Engineering, Computer Science (software and data systems), Chemistry and Physics for instrument design and fabrication
  - Scientific Technicians for deployment, calibration, data acquisition
  - Scientists for Experimental Design and Analysis

Discussion Topics

- What set of skills and knowledge are needed by the next generation of scientists and technologists to perform biosphere studies?
- Discuss some of the sensors covered in the notes that may not have been covered in lecture
- How can you frame your educational experience to contribute to this endeavor?
- What Gaps exist in the Current Framework?
  - How would you conduct studies relating to animal, insect or fish populations, organisms that move, are hard to find or are under Extreme Conditions?

Unique Aspects in Interpreting Information on the Biosphere

- It is a complex system, so predictions are sensitive to initial conditions
- Its components span multiple time and space scales, processes behave in a non-linear manner to external forcings and the system has many positive and negative feedbacks and Hysteresis
- Systems experiences lots of natural variability, so it may take a long time or many samples before a signal evolves above the noise

Examples are discussed below

Summary: Take Home points, pt 1

- Scientific Method
- Fallacious Logic
- Proving vs Falsifying Hypotheses
- Complexity/Pitfalls in Interpreting Environmental Data
- Watch for Under Sampling, non-normal distributions and Extreme Events when interpreting natural data

Fallacious Logic

- **Ad hominem (abusive)**
- **Description:** Attacking the person making the argument, rather than the argument itself, when the attack on the person is completely irrelevant to the argument the person is making
- **Logical Form:**
- *Person 1 is claiming Y.*
- *Person 1 is a moron.*
- *Therefore, Y is not true.*

https://www.logicallyfallacious.com/tools/lp/Bo/LogicalFallacies/1/Ad-Hominem-Abusive

Appeal to Authority
argumentum ad verecundiam

- **Description:** Using an authority as evidence in your argument when the authority is not really an authority on the facts relevant to the argument. As the audience, allowing an irrelevant authority to add credibility to the claim being made.
- **Logical Form:**
- *According to person 1, Y is true.*
- *Therefore, Y is true.*

https://www.logicallyfallacious.com/tools/lp/Bo/LogicalFallacies/21/Appeal-to-Authority

Cherry Picking

- **Description:** When only select evidence is presented in order to persuade the audience to accept a position, and evidence that would go against the position is withheld. The stronger the withheld evidence, the more fallacious the argument.
- **Logical Form:**
- *Evidence A and evidence B is available.*
- *Evidence A supports the claim of person 1.*
- *Evidence B supports the counterclaim of person 2.*
- *Therefore, person 1 presents only evidence A.*

https://www.logicallyfallacious.com/tools/lp/Bo/LogicalFallacies/65/Cherry-Picking

Magical Thinking, Correlation is Causation

- **Description:** Making causal connections or correlations between two events not based on logic or evidence, but primarily based on superstition. Magical thinking often causes one to experience irrational fear of performing certain acts or having certain thoughts because they assume a correlation with their acts and threatening calamities.

https://www.logicallyfallacious.com/tools/lp/Bo/LogicalFallacies/123/Magical-Thinking

Moving the Goal Posts

- **Description:** Demanding from an opponent that he or she address more and more points after the initial counter-argument has been satisfied refusing to conceded or accept the opponent's argument.
- **Logical Form:**
- *Issue A has been raised, and adequately answered.*
- *Issue B is then raised, and adequately answered.*
- *.....*
- *Issue Z is then raised, and adequately answered.*
- *(despite all issues adequately answered, the opponent refuses to conceded or accept the argument.*

https://www.logicallyfallacious.com/tools/lp/Bo/LogicalFallacies/129/Moving-the-Goalposts

Appeal to Motive; Ad Hominem (Circumstantial)
argumentum ad hominem

- **Description:** Suggesting that the person who is making the argument is biased or predisposed to take a particular stance, and therefore, the argument is *necessarily* invalid.
- **Logical Form:**
- *Person 1 is claiming Y.*
- *Person 1 has a vested interest in Y being true.*
- *Therefore, Y is false.*