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| 1a.Describewhat is science and explain the scientific method “in a nutshell”, illustrating your explanation with a straightforward e.g |
| Science aims to further our understanding of the natural world using the scientific mtd  Scientific mtd: Observe, Explain, Test explanation  Science is self-correcting: keep repeating scientific mtd  Cadaverous Poisoning: Childbed Fever(fever after mother gave birth or miscarriage): Dr Semmelweis observed childbed fever occurring at higher rate in his clinic compared to midwives. Dr saw his friend died after being pricked by a scalpel using by a student doctor after performing an autopsy, with similar symptoms as childbed fever. Doctors attend to mothers after performing autopsies: Hypothesise due to "cadaver matter"(germ) being picked up during autopsies. Tried making people wash hands with chlorinated lime -> mortality rates drop |
| 1b. Describethe roles scientific observations play in the scientific method. |
| 1. help identify relevant facts about the phenomena  2. Provide clues to what might explain phenomena  3. Provide evidence to determine if explanations succeed or fail |
| 1c. Explainwhat are the main concerns that should be addressed when making scientific observations. |
| 1. Do we have a clear sense of what the relevant phenomena are?  2. Have we overlook anything?  3. Do we know for sure what is based on fact and what on conjecture or assumption?  4. Are our observations free of bias? (not contaminated by expectation or belief; confirmation bias)  5. Have we considered any necessary comparative(similar) info?  Galileo ignored Aristotelian view(4) and look closely at behaviour of objs slowing and coming to rest. Realised that Aristotelian view that obj nature was inherently stationary was not a fact(3). Realised that how much a obj move depends on type of surface contact(2). Realised influence on motion was due to contact btw obj and surface and not the nature of object(1). Test out by observing how much obj travel (released from fixed height) by varying the slope obj has to travel up |
| 1d. Explainwhy anomalous phenomena are important for science, illustrating your explanation with some examples from the scientific revolution. |
| Ptolemy, an astronomer devised a complicated system for the motion of the planets according to the assumption that the Sun and moon orbited around earth  1543- Nicolaus Copernicus wrote about how planets orbited the Sun and not Earth and Earth rotated. This contrasted the then accepted idea of everything rotated about Earth. However, Copernicus system wasn't better at predicting where the planets would be than Ptolemy system, as he also assumed that planets and moon must move in perfect circular orbits with uniform speed. Copernicus also stated his idea shouldnt be taken as real as he knew he could get executed for his radical idea. (concerns 3, 4)  Late 1500s: Galileo Galilei performed observations to test Copernicus idea. He built powerful telescopes possessing magnification of 30x (next best was 3x). New instruments allow us to make obsevations that couldnt be made before. These can turn up anomalies (something that can't be explained with current understanding).  He saw moon was bumpy and cratered, not a smooth sphere (Aristotelian view), moving sunspots on Sun (meaning Sun was not a complete sphere, and it rotated), 4 moons orbiting Jupiter (contrasting view that all things orbit Earth and recorded all phases of Venus (which shouldnt be possible if Venus orbited earth) -> Aristotelian view must be wrong and that the Sun was the center of the universe  Galileo got arrested and charged with heresy, then was let off when he claimed that he was mistaken in his idea.  Kepler ignored the explanation that planets orbited in circle, and came up with idea that planets orbited the Sun in ellipses, and now could produce the most accurate predictions of that time.  Bacon convinced scientific community that only way to get to truth of a explanation was by testing through observation or experimentation. Scientists should not accept a explanation as true but should doubt it and try to disprove it through observation (empiricism)  Isaac Newton integrated the work of Galileo on how objs move and Kepler work on how heavenly bodies move, along with his own experimentations. He presented his 3 laws of motion, connected how motions of things on earth were similar to how heavenly bodies move (unfamilar idea at that time) |
| 1e. In the context of the scientific revolution, discussthe difference between an evidence-based understanding of the natural world versus one based on authority. |
| Authority based: People would have only followed what Aristotle said, not doubting his views  Evidence-based: People only follow what their evidence point to, leading to new discoveries and understanding  Community in science is needed so individual work can be cross-checked as own work can be contaminated by own beliefs. |
| 1f. Discussthe steam engine’s contribution to the industrial revolution and its impact on population growth  in industrialized nations. |
| Industrial revolution: resulted from discoveries in the Scientific revolution.  From relying on muscle power, now use machines to do work. Discovery of energy, heat, work and second law of thermodynamics lead to construction of the steam engine  Occurred around late 1700s and started in Britain and Europe. Steam engine could manufacture items in far greater nums, having the most impact on textiles (e.g. through mechanised cotton spinning). Iron production also greatly increased as steam engine was used to blast air into furnaces, using coal (much cheaper than previously used charcoal). Industrialization was all about manufacturing on large scale in factories and powered mostly by steam engines. Average income increased, SOL increased, and population increased.  In Britain, coal was abundant (unlike charcoal which was obtained from trees). People mine for coal more -> have to go deeper to mine. New problem as the deeper the mine, the more likely it fills with water -> inaccessible. To deal with this, they pump the water out with the steam engine, fueled by the very coal it mined.  Roads also improved to make transportation of coal more reliable and efficient. Steam engine powered trains and ships incr efficiency of transporting materials, including food which was now in great demand in growing cities.  The improvement to agriculture, just prior to industrial revolution, coupled with new machinery now greatly reduced famine across Western Europe.  But now pollution from coal burning and throwing of human waste onto streets made cities living conditions very bad. No one knew about germs then hence hygiene was nonexistent. Outbreaks of cholera, typhoid, typhus and tuberculosis were common. Despite these, mortality rate still drop as people survive longer due to more food being produced, improvements in distributing food and building of sewage systems (slightly improving sanitation) |

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| Listthe tools in the baloney toolkit. | | |
| 1. How reliable is the source of the claim?  2. Does the source make similar claims?  3. Have the claims been verified by somebody else?  4. Does this fit with the way the world works?  5. Has anyone tried to disprove the claim? | 6. Where does the preponderance of evidence point?  7. Is the claimant playing by the rules of science?  8. Is the claimant providing positive evidence?  9. Does the new theory account for as many phenomena as the old theory?  10. Are personal beliefs driving the claim? | |
| CRAAP Test (Support rule 1 of baloney toolkit) | | |
| *C*urrency: *The timeliness of the information*. • When was the information published or posted?  • Has the information been revised or updated? • Is current infor required, or will older sources work as well?  - Are the links functional?  *R*elevance: *The importance of the information for your needs*. • Does the information relate to your topic or answer your question?  • Who is the intended audience? • Is the information at an appropriate level (i.e. not too elementary or advanced for your needs)?  • Have you looked at a variety of sources before determining this is one you will use? • Would you be comfortable citing this source in your research paper?  *A*uthority: *The source of the information.* • Who is the author/publisher/source/sponsor?  • What are the author's credentials or organizational affiliations? • Is the author qualified to write on the topic? • Is there contact information, such as a publisher or email address?  - Does the URL reveal anything about the author or source? examples: .com .edu .gov .org .net | | *A*ccuracy: *The reliability, truthfulness and correctness of the content.*  • Where does the information come from?  • Is the information supported by evidence? • Has the information been reviewed or refereed? • Can you verify any of the information in another source or from personal knowledge?  • Does the language or tone seem unbiased and free of emotion? • Are there spelling, grammar or typographical errors?  *P*urpose: *The reason the information exists*. • What is the purpose of the information? Is it to inform, teach, sell, entertain or persuade?  • Do the authors/sponsors make their intentions or purpose clear? • Is the information fact, opinion or propaganda? • Does the point of view appear objective and impartial? • Are there political, ideological, cultural, religious, institutional or personal biases? |
| Apply the baloney toolkit in an online investigation concerning human population growth over time. | | |
| |  | | --- | | Wikipedia. Sources easily verified (3 baloney, accuracy CRAAP). Data goes far back enough for our purpose (relevance CRAAP). | | Our World in Data. Graph similar to Wikipedia (relevance CRAAP). Sources easily verified | | Worldometers. Data didnt go far back enough. Broken weblink for source. (Not reliable or relevant) | | Census.gov. Estimates were common with Wikipedia and Our World in Data | | Jstor.org. Too detailed and in-depth for our purposes (relevance CRAAP) | | Statista.com. .com implies not that good (authority CRAAP). Sources could not be verified without paying $ so cannot be confirmed(3 baloney, accuracy CRAAP) | | Worldpopulationhistory.org. As is .org, need check who is presenting the info (10 baloney, purpose CRAAP). But source cannot be found easily | | Gapminder: Answers all our qn (relevance CRAAP). Source from 2012 UN report, but ok for our purpose (currency CRAAP). Site is independent Swedish foundation with no affiliations, all material under creative commons license and no advertisements (purpose CRAAP). Video by Prof Hans Rosling but not expert in demographics -> can fact-check by looking at sources (accuracy CRAAP, 1 baloney). Although nums abit overestimate, but still ok if rounded up (6 baloney) as many diff researchers estimating pop at diff times. Stated pop will level off at 11 billion, Mr John Wilmoth, director of UN Pop Division also appeared in video, adding credibility to site and videos (authority CRAAP). Although fertility rates drop, pop still climb rapidly until 11 billion.  How many children born, and how fertility rate will change in future make pop predictions uncertain. | | Pop depends on fertility and mortality rate. During Industrial Revolution, fertiliy rates remain high and unchanged, but mortality rates drop. Pop also increase after 1945 as mortality rate in Asia and Latin America drop due to improvements in public health, sanitation and nutrition imported from developed countries. Food production and improvement in nutrition played the biggest role in decreasing mortality. Science and tech started the "green revolution"/3rd agricultural revolution. During 1950s and 60s, food production increased mainly due to use of synthetic fertilizers. Plants need Nitrogen (a limiting nutrient) which is too stable for plants to break down. Main form of nitrogen in atmosphere cannot be directly processed in plants. | | Haber-Bosch Process: made possible to mass-produce inexpensive nitrogenous fertilizers which only really took off after WW2. Fertilizer along with pesticides and new breeds of wheat and rice, increase crop yields. Half of the world is dependent on the Haber-Bosch process. Further evidenced by drop in ppl dying due to famine from 1960s onwards. Haber-Bosch require a lot of energy due to high temp and pressure needed, 1% of world energy production used for this process. Getting Hydrogen (required for Haber-Bosch) also creates CO2 and accounts for 1.4% of world CO2 emission. Fertilizer also inefficient as Nitrogen can get lost in water, soil erosion or evaporate. | | | |
| Explain r/s btw science & tech, and its impact on human society & environment, illustrating explanation with world pop growth. | | |
| 8000BC: 1st agricultural revolution: switch from hunter-gatherers to agriculture  1543-1632: Scientific revolution: many discoveries and lead to industrial revolution  1760-1840: Industrial revolution: steam engine -> dependence on fossil fuels, created internal combustion engine and electricity (still needing fossil fuels to produce)  1700s: 1st pop surge in Europe and Northern America due to 2nd agricultural revolution + Industrial revolution  1950s-60s: Green revolution (3rd agricultural revolution): fertilizer from Haber-Bosch -> mortality rates decrease in Asia and Latin America -> 2nd pop surge  End of 21st century: pop stabilise at 11 billion, Africa catches up | | |

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| Define a scientific explanation and discuss the 2 basic ways in which a theory differs from a hypothesis |
| Scientific explanation is an account of how or why something is the case and must be testable.  Hypothesis is tentative/unproven, it hasn't been subject to any testing. Could be just a vague hunch about what might be gg on, or could be finely detailed (but still speculative) of why something is the case.  Theory (in regular English is the hypothesis in science) is characterized by the breadth and depth of its explanatory power. It is a conceptual framework for providing explanations. Will be well-tested, and have confirmed rules and principles.  Well-established theories have been tested numerous times in many ways and are till passing all the tests. E.g. Newton's 3 laws of mation and law of gravitation can predict motions of virtually all objs on earth and space and only break down under the most extreme conditions.  Obsolete or Superseded theories often were though to be correct at the time. E.g. Aristotelian world view. (Demonic theory -> Punitive theory -> Miasmatic Theory and Theory of the 4 humors, now germ theory has replaced these theories)  Although these are now known to br wrong, they are still called theory  Novel or Newly Proposed Theories can not only explained phenomena already explained by well-established theories, but also hope to explain the anomalies that the current theory have a hard time supporting. They are still being subjected to testing |
| Explain the diff btw 2 events being correlated and being related as cause and effect |
| Cause always precedes the effect. Causal explanation may allow us to understand why such phenomenon exist, but may not be that straighforward or simple.  1. Combination of causes leading to an effect -- Multiple factor combining to produce a single effect  2. Cause and effect can refer to groups -- Rather than about individuals. (E.g. smoking causes lung cancer means lung cancer occurs more frequently among those who smoke)  3. More than one cause can result in a specific effect -- we cannot pinpoint which cause it is as there are multiple factors  4. An effect might not result from a given causes in every case -- Cause doesn't result in the effect all the time (Some people smoke but dont get lung cancer)  5. Causal explanations can be negative -- e.g. wearing a maske help Prevents COVID transmission  6. Causal explanations can involve a series of linked causes and effects -- A cause B, and B cause C. Hence A is a remote cause of C  Correlation is the degree to which 2 properties, traits move in coordination/in sync. (Taller man tend to have larger shoe size)  1. Perfect correlation is when there is 1 to 1 correspondence btw changes in the 2 properties. (Age of tree in years perfectly correlated to number of rings in the tree's trunk) (All data points are on the best-fit line)  2. Positive correlations: when one qty goes up, the other goes up  3. Negative correlations: when one qty goes up, the other falls  Strong correlation when data isn't scattered very far from the line, weak correlation the opp  No significant correlation: data are all random  - When there is a cause for an effect, we expect there to be some correlation (+ve or -ve). But 2 things that are correlated != there is causal relationship |
| Discuss the basic features of the following types of scientific explanations: (a) cause and effect, (b) causal mechanism, (c) underlying processes, (d) laws, (e) function |
| a. Cause and effect -- cause occurring leads to effect occurring. Does not explain how it causes  b. Causal Mechanism -- linked chain of causes starting from the remote cause. Sometimes, this chain is still under investigation, so we will say a link has been established. (We know smoking causes lung cancer, but not how carcinogens in cigarette smoke cause uncontrolled cell growth in lungs). Knowing the causal mechanism provides us with a means of reducing the effect if it is bad, enhancing it if it is good.  c. Underlying process -- tries to describe the phenomenon is a more fundamental process (reductionist approach). Brownian motion where motion of particles is haphazard. We now know its due to particles colling with one another (explain what is happening in "simpler terms")  d. Laws -- Laws are just generalized descriptions of regularities that have been found to occur in nature (formula). Boyle's Law where if temp remain fixed, pressure of gas varied in inverse proportion to vol or Newton's laws. Laws tend to be thought of as universal and there is a tendency for it to occur more often than not  e. Function -- Also explain a phenomenon according to the purpose/function it fulfills. (why do we have a heart? It is the organ needed to pump blood around the body)  These types of explanations can be interrelated. E.g. Boyle's Law. Gases are made of huge num of molecules, they strike the walls and bounce off. These collisions produces a outward force resulting in pressure. This explains the underlying process. |
| Explain Occam's Razor, illustrating its use with an example |
| Often there can be more than one explanation for a phenomenon. (and we can test all of them, but this is unnecessary)  Occam's Razor is a methodology that we follow, we choose the explanation that is least complex (there is no good reason to use a explanation that introduce more complex ideas)  E.g. Copernicus model of solar system much simpler than Ptolemy and both had around the same accuracy. Using Occam's razor, we would just use Copernicus idea, which was what Galileo did.  Of course, the simpler explanation may not always be right, but it is easier to test the simpler explanation and move on if it is wrong |
| Discuss what is a scientific model, the diff types and their purpose, and explain the diff btw a model and a theory illustrating your explanation with an e.g. |
| Models can be considered a type of explanation, can be used to test those explanations, make predictions and projections and enhance our understanding of nature.  Scientific model is a cut-down and simplified representation of world objs, systems or events. They are idealizations of reality, with irrelevant parts of reality ignored.  a. Physical Models -- Represents a physical obj, can be used to help analyze and study the real system they represent. e.g. globe, architectural models of buildings. To better understand reality, the models can be augmented with instruments to make measurements of what's happening in and around the model (help assist in optimization and design of equipment or processes) E.g. Model placed inside a wind tunnel or wave tank to measure external flow of air or water around buildings/ppl/vehicles. An impt thing is to get the scale right, as forces and laws may not scale proportionally. Models can also be larger (making large models of DNA/atoms)  b. Conceptual Models -- cut down versions of reality with only parts of interest included. (maps, circuit diagram, free body diagram, chemical diagram). Only contains relevant info and may actual obj may not be exactly the same as models (molecules in diagram and real world are diff). Conceptual models can also represent processes  c. Mathematical/Computer Models -- Computer does all the tedious calculation needed to apply the mathematics. (Boyle's law, graph out the inverse relationship of pressure and vol). Since many laws can be expressed in mathematical formula, we can input them in computers to better see their relationship.  Projections differ from predictions in that they utilize "what if" scenarios. (COVID-19 model to project the num of deaths if no SMM were taken). Diff types of models can complement each other (physical model with instruments to read data, then fed into computer model to predict how obj would behave in real world)  Models are created from concepts and principles provided in a theory. Hence result of the models can be used to test a hypothesis/theory |

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| Describe the basic process of experimentally testing a scientific explanation and explain the importance of eliminating false confirmation and rejection from an experimental test. |
| page2image65247120Observe: A. Explain: B,G. Test: C,D,E,F,H,I  Models can help test an explanation. (H,I,D)  E.g. Big-bang theory. Model predicted that there is weak background radiation (remnant of the big-bang). Model predictions and experimental test matches -- explanation is true.  False confirmation -- believing results of experiment support explanation when it doesn't. E.g. cold fusion. Experiment was flawed leading to false confirmation. Another e.g. is polywater, there was fear that polywater could contaminate regular water. Scientist tested it but could not replicate results all the time. Realised that could be due to contamination of water. With thoroughly cleaned glassware, anomalous properties disappeared. => Poorly controlled experiment can lead to false confirmation  False rejection -- Believed results of experiment and falsely reject explanation. E.g. PC troubleshooting. 1st HDMI wasn't functioning, if did not try another HDMI cable, would just assumed that PC motherboard or graphics card was faulty.  Scientific community can help test your experiments |
| Discuss how contemporary scientific research is conducted and its relationship to testing explanations. |
| Observe: Observe some anomaly -> wonder why it happens -> research topic area (as could just be a phenomenon you don't know about / others have provide some explanation but you disagree with them / they found something you overlook)  Explain: There is some testable explanation that you can check through experiments  page9image65443936Test: 1) Use the process in earlier diagram. Experiments can be costly (building safe labs, costly equipments, engineers, technicians needs to be emplyed, consumables, travel to diff locations). Research funding at unis comes from grants from govt/private sector. Corporate funding from companies. Funding proposals need to be prepared, submitted, reviewed and then awarded. 2) Analyse data from instruments, surveys, historical documents/artifacts, videos. 3) Report conclusions  Publishing results is also difficult. Important step as scientist can make mistakes too. Guidelines on how research is conducted. (ethical guidelines). Need to provide referees to review manuscript. Manuscript then sent for peer review. Since there is rigorous peer review process -> source would be reputable. |
| Explain the meaning of meaning of accuracy, trueness, precision and uncertainty illustrating your explanation with examples. |
| Precision is how close together diff measurements are to each other. High precision means tighter grouping.  Uncertainty is the spread of readings. Higher precision means smaller uncertainty. Uncertainty usually ±. Random error  Accuracy: common defn: How close measurements are to true value. Poor aim = systematic error/bias. (E.g. Not calibrated)  Internation Organization Standard 5725-1 defn: Accuracy must be both accurate and precise. (Inacccurate instruments could lead to untrue measurements either due to random or systematic error) |
| Explain the relevance of experimental and control groups and the purpose of randomized controlled double-blind experiments. |
| To establish a casual relation, need control grp (nothing done) and experimental grp (cause applied). At the end, see if effect has occur/made a huge diff.  E.g. Salk Field Trial of 1954. Test of polio vaccine. Ethical issue of who should get the vaccine (experimental grp) and who shouldn't (control grp). Need to ensure 2 groups are as similar as possible.  A not so well-controlled trial: those whom parent consented to allow vaccine would be vaccinated and was in P2. If more kids were infected in this grp, bias AGAINST the vaccine would be introduced. If less kids infected, bias FOR the vaccine would be introuduced. Also, those parents that consented tend to come from higher income families and were more likely to get polio, so results would be biased against vaccine. (Children in higher income would be more hygenic, less chance to develop antibodies)  A well-controlled trial: No diff made btw P1, P2 and P3 kids. Half of kids from consenting parents were vaccinated and other half were not. (given placebo instead). Random selection as to which kids get vaccine -- radomized controlled trial. Those administering and diagnosing treatment were also not told which grp the kids belong to. THis is known as double-blind study / randomized controlled double-blind trial.  Rate of infection was lower among vaccine group. Not so well-controlled trial have results that were less significant than well-controlled trial |
| Explain the meaning of the following terms, (a) margin of error, (b) confidence level, (c) statistically significant, (d) effect size. |
| Margin of error provides the range of possible value for the result, instead of just 1 value.  To find a margin of error, need to spcify the confidence level -- how confident you are that the experiment would contain the true value in range given by margin of error.  E.g. Toss a coin. Flip 50 times and land on heads 40%. At 95% confidence level for 50 flips, margin of error is ±14%. so confidence interval is 26% to 54%. With higher confidence level, margin of error is greater and CI is larger.  Applying to Salk Field Trial, CI for the well-controlled test does not overlap for experimental and control grp -> 95% sure that vaccine works. Unlikely that diff is due to luck  Statistically significant: whether there is significant overlap in CI at high confidence level.  Pfizer efficacy = (rate in control grp - rate in exp grp)/(rate in control grp)  Larger sample size also reduce margin of error. Rough estimate: to reduce margin of error by half, need 4x more samples  By taking larger sample, some effect can become statistically significant as CI no longer/slightly overlap. But just because something is statistically significant, doesn't mean there is a practical diff.  Effect size: statistical significance ≠ practical diff is large, important or has a big effect |
| Apply the 3 rules of thumb to decide if a study has established a statistically significant difference between an experimental and control group. |
| 1) If there's no overlap in CI, then diff is statistically significant at 95% confidence lvl  2) If overlap < 1/3 of range covered by the 2 CI, then diff could be statistically significant  3) If overlap > 1/3 of range covered by the 2 CI, then diff is probably not statistically significant |

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| Epistemic responsibility |
| Every citizen has an epistemic responsibility to base their beliefs on sufficient evidence. (William Kingdon Clifford). (William James argue the opp). Climate change has causal origins. Sun heats Earth, that then heats atmosphere, that heats Earth further. Earth heating atmosphere is due to presence of greenhouse gases (gg), and by burning more fossil fuels, atmosphere will be hotter. This explains the greenhouse effect and climate change through a deterministic causal mechanism. |
| Discovery of the greenhouse effect |
| |  |  |  |  |  | | --- | --- | --- | --- | --- | | Empedocles of ancient Greece | 1st to argue that all matter was composed of the classical elements of water, earth, air and fire. | | | "Love" mix these elements  "Strife" separate these elements | | French mathematician, Jean-Baptiste Joseph Fourier | 1st to establish that atmosphere plays a role in controlling climate | Earth receive energy from source, but Earth must also radiate energy, now known as infra-red radiation. He calculated Earth's temp = -18, way below the 15 we observe. Realised that atmosphere was missing from calculations. The atmosphere must act as an insulator to prevent radiant heat from escaping to space and returning that radiant heat to further warm the Earth's surface. This is now known as the greenhouse effect | | | | Swedish meteorologist, Nils Gustaf Ekholm | | | ≈ 1900s | Coined the term greenhouse effect | |
| Nature of the atmosphere |
| |  |  |  | | --- | --- | --- | | Underlying process of global warming (gw)**.** The atmosphere is **≈** 78% nitrogen, 21**%** O2 and 1% argon with trace amounts of other gases and most importantly CO2. Water vapour is also impt and can contribute up to 4% of atmospheric composition. | | | | Italian polymath, Leonardo da Vinci | 1452-1519 | Air composed of: 'fire-air' that supports combustion and life & 'foul-air' that does not  Portion of air is consumed during combustion and respiration | | English chemist and physiologist, John Mayow | 1641-1679 | Fire requires a part of air (spiritus nitroaereus).  Placing a mouse / lit candle in closed container over water caused water to rise and replace 1/14 of the air's vol before extinguishing the subjects.  Concluded that nitroaereus is consumed in both respiration and combustion | | Flemish scientist, Jan Baptiste van Helmont | 1630 | Coined the term gas to describe vapours (sylvestre) given off when burning wood. Recognised that CO2 was produced in fermentation of wine. (Founder of pneumatic chem) | | Scottish physician, Joseph Black | 1756 | Proved gas discovered by van Helmont is naturally present in the atmosphere, confirming that atmosphere is not a single substance  Heated magnesium carbonate, collect CO2 (fixed air). Found that gas turn lime water milky. Original purpose to find cure for gallstones. Identified that CO2 was present in exhaled breath. Respiration and combustion return carbon from biosphere to atmosphere | | Reverend Stephen Hales | 1727 | Published work on plant transpiration: loss of water from leaves. Noted that plants probably draw through their leaves some part of their nourishment from the air | | Dutch scientist, Jan Ingenhousz | 1796 | Confirmed Hales work that plants draw CO2 from air. Respiration just another form of combustion. Photosynthesis return carbon from atmosphere to biosphere. | |
| Problem of combustion |
| |  |  |  | | --- | --- | --- | | Combustion was completely misunderstood by alchemists and early chemists. It was known that air was needed to sustain combustion and life, and that when a metal was heated in air, it changed and gained weight. | | | | Germans, chemist Joachim Becher and chemist Georg Ernst Stahl | 1667 | Theory states that all combustible materials were made of 2 parts. Phlogiston: given off when substance containing it was burnt and dephlogisticated part: thought to be the substance's true form (calx). If something gave off a lot of heat rich in phlogiston. Growing plants absorb phlogiston air does not spontaneously combust, and why plant burns easily (biogeochemical cycle). But theory did not recognise the role of air in combustion and increase in weight of metal after combustion phlogiston has -ve mass | | Polish alchemist, Michael Sendivogius | 1604 | 1st discovered O2 (cibus vitae / 'food of life'). Recognised this substance = gas released when potassium nitrate (saltpetre) is heated. (collected saltpetre from public urinals) | | Dutch engineer and scientist, Cornelis Jacobszoon Drebbel | 1621 | Purified air to get O2 and used it to sustain 12 men in a submarine for 1-3 hrs as they rowed from Westminister to Greenwich down River Thames. King James I became 1st monarch to travel underwater | | Swedish pharmacist, Carl Wilhelm Scheele | 1771/  1772 | Produced O2 by heating mercury oxide and various nitrates, calling O2 'fire-air' (same as da Vinci and Mayow) | | English theologian, Joseph Priestley | Aug 1774 | Person most frequently associated with discovery of O2. Focused sunlight on mercury oxide in a glass tube and called the resultant gas 'dephologisticated air'. Noted candles burn brighter and mice more active and live longer in this gas. Discovered fizzy drink. | | French chemist, Antoine-Laurent Lavoisier | Oct 1774 | Claimed that he discovered O2 independently even though Priestley and Scheele has relayed their findings to him. But he was 1st to understand importance of O2, and responsible for naming this gas as oxygen. | | He stated that combusting is always and only to do with O2. In a collab with his wife andPierre-Simon de Laplace, they proved that animal respiration is a slow form of combustion with consumption of O­2 and release of CO2. In noting that weight gained by a substance in combustion is lost by air, he established the Law of Conservation of Mass. (Father of Modern Chem) | | | | Discovery of O2 is most frequently credited to Scheele, Priestley and Lavoisire. Scheele was first to isolate gas, Priestley first to publish and Lavoisier first to understand the discovery.  Using Occam's Razor, it should however be Sendivogius who discovered O2 more than a century before their births. | | | |
| Role of the atmosphere |
| |  |  |  | | --- | --- | --- | | Irish physicist, John Tydall | 1859 | Credited with explaining the greenhouse effect. He investigated how a number of gases absorb radiation. Built the ratio spectrophotometer, measured extend which infrared radiation is abosrbed by gas in tube. Realised importance of water vapour in absorption of terrestrial radiation. He determined that CO2 is 90 times more effective at absorbing infra-red radiation than air, methane 403 times and water vapour 16000 times. Realised that such gases keep our planet warm by interfering with escaping radiation. | | Eunice Foote | 1856 | conducted experiments in which she filled glass jars with water vapour, CO2 and air and compared how much they heated up in the sun. She found the highest increase in CO2 (carbonic acid gas). Noted how container holding the gas also become heated, and required more time to cool. Foote speculated that concentrations of CO2 could influence global temps. | |
| Calculating the greenhouse effect |
| |  |  |  | | --- | --- | --- | | Swedish geologist, Arvid Högbom | 1890s | Attempted to quantify the natural sources of emissions of CO2 to understand the global carbon cycle. Found that estimated carbon production from industrial sources, mainly burning of coal, was comparable to natural sources | | Swedish chemist, Svante August Arrhenius | 1896 | Inspired by Högbom. Considered effect of changing amts of CO2 in atmosphere. Calculated that doubling of CO2 would raise ave global temp by 5-6. Expected the warming would take thousands of years, hence suggest that such warming might be beneficial to humanity | | English engineer and inventor Guy Stewart Callendar | 1938 | 1st to suggest that increasing CO2 might be having an observed effect. Argued that Earth's surface temp increasing over last 50 years was due to increasing CO2 concentrations. However, he also thought that warming would be beneficial, delaying a "return of the deadly glaciers" | | American scientist, Charles David Keeling | 1958 | Collected CO2 samples at the Mauna Loa Observatory in Hawaii some 3000m above sea level. By 1961, produced data showing CO2 levels rising steadily, 'Keeling Curve'. In 1963, National Science Foundation use this data to warn of rapidly increasing amounts of heat-trapping gases. | | US president Lyndon B. Johnson | 1965 | His Science Advisory Committee warn of harmful effects of fossil fuel emissions. "carbon dioxide is nearly transparent to visible light, but it is a strong absorber and back radiator of infrared radiation". Declared rise in CO2 level to be direct result of burning fossil fuel. Concluded that human activities were sufficiently large to have significant, global impact. | | American scientist, James Hansen | 1981 | Following advent of computer models, published a study saying effects of climate in 21st century include creation of drought-prone regions in North America and central Asia as part of shifting of climatic zones, erosion of West Antartic ice sheer, with rise in sea level. In 1988, Hansen said that it was 99% certain that warming trend was not a natural variation, but a build-up of CO2 and other artificial gases in atmosphere. Said gw has reach a level that we can ascribe with a high degree of confidence a cause and effect r/s btw greenhouse effect and observed warming. | |
| On metaphors |
| Greenhouse effect: process that causes the surface to be warmer than it would have been in absence of an atmosphere  GW: expected in magnitude of greenhouse effect, whereby Earth's surface will be inevitably hotter than it is now.   |  |  | | --- | --- | | Greenhouse effect | Blankets | | atmosphere enables convection | keep us warm by suppressing convection (same as greenhouses) | |  | Heat from body cannot escape | | more gg means warmer planet (anomaly like sulphate aerosols from volcanic eruptions, would cool Earth) | more blankets means warmer person | | Correct explanation for surface of Earth being warmer than without atmosphere: Earth receives energy from Sun & atmosphere | | |
| Building a model |
| To determine temp of Earth in absence of atmosphere, assume Earth emits radiation characteristic of a black body of temp, TE. i.e. obj absorbs all radiation, and assuming at thermal equilibrium, emits a spectrum of radiation determined by its temp alone. Further assume Sun is black body. Assume 'solar constant' (energy from Sun reaching top of atmosphere per m2 every second), S = 1370 W m-2. Assume energy impacting Earth's surface = that being emitted. Assume Earth absorbs solar energy over an area πR2 (cross-sectional area facing the Sun) but emits energy from its entire surface, area of 4πR2.  Energy per unit area = intensity = Stefan–Boltzmann constant, σ \* fourth power of the temp, T4. (σ = 5.67 × 10−8 W m−2 K−4)  So energy into the Earth system/s = 1370 × πR2 = σTE4 \* 4πR2 = energy out/s  TE4 = = . TE = 279K = 6. A bit chilly, but liveable.  To correct the assumption Earth is black body, need to consider that only 70% is absorbed, the rest is reflected either by surface, clouds or atmosphere itself. Fraction of solar radiation that is reflected is referred to as Earth's albedo, A = 0.3  TE4 = = . Then TE = 255K = -18, same temp calculated by Fourier, aka planets's effective temp |
| Modelling the atmosphere |
| Spectral distribution, i.e. intensity of radiation emitted by the black body at different wavelengths, is simply determined by its temp. Wien’s law describes this r/s; it states that the of peak of the spectral distribution is inversely proportional to its temp.  Atmospheric_Transmission.pngThe solid red and blue line show the spectral distributions, or black-body curves, for the Sun behaving as a black-body radiator at 5525 K and the Earth behaving as a black-body radiator at 255 K. The solar distribution peaks at approximately 0.5 microns, or 500nm, in the visible region of the EM spectrum. The terrestrial distribution peaks at ≈ 15 microns in the infra-red region of the EM spectrum.  The solid red and blue areas in the top panel identify effect of atmospheric absorption on both solar radiation and terrestrial radiation.  1. atmosphere cannot absorb and radiate at all and , so cannot be treated as a black body.  2. atmosphere let visible light through. At shorter in UV, atmosphere absorbs all radiation due to O2 and ozone, preventing mutagenic radiation from reaching the biosphere. Most infra-red is absorbed, but there are some not absorbable, leading to presence of 'atmospheric windows', which will escape to space.  Simplest way to extend our physical model is to include an atmosphere with a layer of uniform temp. Let global ave solar flux, i.e. energy per unit area per unit time, impacting top of the atmosphere = Fs. Fluxes from the ground and atmosphere = Fg and Fa. Defining transmittance as the fraction of radiation that isn’t absorbed, solar transmittance = τs and terrestrial transmittance = τg. Total emission from atmosphere = 2Fa. So, amt of solar radiation that passes through the atmosphere to be absorbed by Earth’s surface = Fs × τs. Similarly, amt of terrestrial radiation that passes through atmosphere to space = Fg × τg.  FS = = = 240 W/m2 At Earth’s surface, Fs \* + Fa = Fg. At top of atmosphere, Fs = Fg \* + Fa Fg = .  If solar flux (Fs) or solar transmittance () or terrestrial transmittance () , terrestrial flux (Fg) will . Since Earth is black body, Earth’s temp will  = 0.8, = 0.1. Fg = = 240 = 393 W/m2. = 6.93 x 109. = 289 K = 16°C  This means Earth’s surface is 34 K warmer than it would be without an atmosphere. This is the magnitude of the greenhouse effect. |

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| Climate Change and the Scientific Consensus |
| |  |  | | --- | --- | | Weather | Climate | | combination of temp, humidity, precipitation, cloudiness, visibility, and wind, that we experience at a particular location in the short-term, reflecting the short-term conditions of the atmosphere | describes the typical weather conditions in an entire region for a very long time | | what we get | what we expect | | Climate change is a shift in those ave conditions, and includes both the gw driven by human-induced emissions of gg, and the resulting large-scale shifts in weather patterns. Can also think of gw as being the cause, and cc as the effect. | |   The Intergovernmental Panel on Climate Change (IPCC), reported that temps have risen by more than 1°C since the 1850–1900 global average, and describes the ways in which Earth’s climate has changed due to human activity as “unprecedented” and unequivocal, with some of the changes being inevitable and “irreversible”. This is the current scientific consensus.   |  |  |  | | --- | --- | --- | | Colloquially consensus | Science | Scientific consensus | | General agreement of opinion | Objective framework. Facts explained by a hypothesis, which can be tested and retested until it is refuted.  As scientists gather more observations, they will add details to complete the picture. Eventually, a group of hypotheses might be integrated and generalised into a scientific theory, a scientifically acceptable general principle or body of principles offered to explain phenomena. | Achieved when the great majority of scientists of a given field agree upon a position based on a large amt of evidence. Consensus is not just a general agreement, but is dependent on the expertise of the scientists in qn and is based on the accumulation and verification of evidence.  Helps to inform public policy. | | Climate change is real because very careful measurements confirmed by many scientists have shown that it is happening. | | | |
| Establishing the Scientific Consensus |
| |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | | When and how was the scientific consensus on climate change established?  To build a scientific consensus, we need a huge num of scientists making measurements, developing conceptual and mathematical models, verifying each other’s work. | | | | | | | | Svante Arrhenius |  | | | | 1st mathematical model to predict the effect on global temp of increasing CO2. Built upon the conceptual work of Joseph Fourier, and the experimental analysis of John Tyndall and Eunice Foote. Viewed the temps as being a good thing. | | | Guy Callendar | 1938 | | | | 1st voiced concerns about gw. Believed nearly all CO2 produced by fossil fuel combustion had remained in atmosphere. Suggested in CO2 may account for the observed slight of ave temp in northern latitudes in the last 50 years. Didn't continue his research for 20 years due to war in Europe. | | | Other scientists | Agreed CO2 was a gg and if atmospheric concentrations it might affect the climate, but argued that water vapour is a gg and much more water vapour than CO2, hence sceptical that small in CO2 could have a big effect and didn't continue Callendar's research. | | | Using the (red blue) diag in the last lecture, shows the atmospheric absorption due to different gases. Water vapour and CO2 do not absorb at the same . in CO2 will thus significantly absorption of infra-red radiation at these and ultimately affect Earth surface temps. So, water vapour will not overwhelm the absorption due to CO2. | | | | | | | | Roger Revelle & Hans Suess | | 1957 | | | 1st to recognise there was a need to return to Callendar's work. Published a paper recognising the importance of studying the Callendar effect, and further recognised the inadequacy of current data. | | | Charles Keeling | 1 July 1957 - end of 1958 | | | | During International Geophysical Year, received the funding, pushed for by Revelle and Suess, to measure CO2 at Mauna Loa in Hawaii. Results from Mauna Loa (Keeling curve), showed instruments had the sensitivity to accurately measure small changes in CO2 concentrations in the atmosphere. Showed that btw 1958 and 1965, CO2 conc had by some 1% or 3 parts per million by volume (or ppmv). | | | Revelle and Keeling | 1965 | | | Asked to chair the President’s Science Advisory Committee (SAC), publishing the report, ‘Restoring the Quality of our Environment’, warning that, “By 2000, about 25% more CO2 in atmosphere than at present [and] this will modify the heat balance of the atmosphere that marked changes in climate…could occur”. | | | | President Lyndon Johnson | | | 1970s | | | Reported scientific consensus from his SAC to congress. In U.S. the impact of rising CO2 on climate affected national policy in terms of energy, national security and the economy. | | National Academy of Sciences | end of 1970s | | | | Reported, "many studies from diverse sources indicates a consensus that cc will result from man’s combustion of fossil fuels and changes in land use.” Latter due to deforestation & changes in agricultural practice. Not just Consensus of conceptual understanding: CO2 influences Earth surface temp, but was consensus of expectation: continuing to burn fossil fuels, then cc and Earth surface temp, will result. | | | Yes, consensus that burning fossil fuels will lead to cc, but no consensus about when this cc will occur. | | | | | | | |
| Not a question of if, but when |
| |  |  |  |  | | --- | --- | --- | --- | | Most scientists at that time thought that changes would not begin to become detectable until the 21st century.  Determining when cc would be detectable required sophisticated climate models: mathematical descriptions of the climate coded into computer models. These models coupled atmosphere and oceans and varied amts of gg. Predicted changes gave rise to different future scenarios. Key to knowing when cc would be detectable was estimating the natural climate variability. | | | | | James Hansen & co-workers | 1988 | | Published paper providing the 1st estimate of this variability. Used observed surface temps to argue that this variability in global ave temp was about 0.13°C s.t. an observed rise of about 0.4°C in the global ave 99% confidence that gw had been observed. Claimed this would “constitute convincing evidence of a cause and effect r/s, i.e., a ‘smoking gun’”.Further found that his model showed a similar variability, giving credence to the model’s predictions of climate change. | | IPCC |  | | Although Hansen’s 1988 paper predicted that this 0.4°C threshold would likely be witnessed in the 1990s, he told U.S. Congress gw was “happening now”. This was followed by further studies by other scientists using different climate models. IPCC formed to systematically evaluate these studies. Intergovernmental body of the UN mandated to provide objective scientific information relevant to understanding human-induced cc, its natural, political, and economic impacts and risks, and possible response options. | | 1st Assessment Report | 1990 | | Stated “global mean surface air temp has by 0.3 to 0.6°C over the last 100 years”. Further noted that this “is broadly consistent with predictions of climate models, but it is also of the same magnitude as natural climate variability”. | | 2nd Assessment Report | 1995 | | Noted “The balance of evidence suggests a discernible human impact on global climate”. In the 5 years btw the 2 reports, scientific consensus had shifted from [an understanding that the greenhouse effect is well understood, gg are increasing (due largely to human activity), and therefore should lead to significant gw], to [a greater understanding that gw continues and is most likely due to human activity.] | | 3rd Assessment Report | 2001 | | Stated “Human activities…are modifying the concentrations of atmospheric constituents…that absorb or scatter radiant energy. [M]ost of the observed warming over the last 50 years is likely to have been due to an in gg concentrations.” | | Public arena | After 3rd report | | Scientific consensus was that human-induced cc through burning fossil fuels was being identified in the observational record. Yet, after the 3rd Assessment Report, doubt and scepticism of this scientific consensus arose in the public arena.  The Gallup environment poll showed that in 1997 only 48% of U.S. public believed that “most scientists believe that gw is occurring”. 2001: 61%. 2006: 65%. 2010: 52%. 2021: 68%. | | Naomi Oreskes | 2004 | | Found that in the 928 papers published in the 10 years between 1993 and 2003 that talked about gw not one rejected the scientific consensus. | | John Cook & co-authors | | 2013 | 11,944 abstracts from peer-reviewed journals 97.1% agreed with the scientific consensus that human-induced climate change is real and happening. | | There is a disconnect btw the public perception of the level of consensus present among scientists studying cc and the consensus among scientists themselves. This scientific consensus is represented in the reports of the IPCC and is the position of every national and international scientific body. | | | | |
| Average global Temperature rising |
| |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | | 1951-1980 as baseline for temp change. Ave pairwise correlation btw 5 datasets = 99.04%. Diff due to sources of data – collected at thousands of meteorological stations, buoys and ships around the globe. | | | | | | | | 1st reason for diff | Coverage | | While there are plenty of weather stations on land, there are big gaps over the oceans, polar regions, and even parts of Africa and South America. Each temp record deal with it differently | | | | | 2nd reason for diff | Adjustments to records | | To correct for issues, such as missing data, changes in instrumentation, movement of stations, and human or technical error. This process = homogenisation. Despite being a well-understood scientific practice, is used by climate-sceptics as evidence that scientists are “fiddling” the data to overstate the amount of warming. | | | | |  | 1659 | only for Central England | | | | Longest running record | | US NASA | 1880 | Worldwide | | North America | slightly higher | Interpolates even more aggressively—areas with gaps are interpolated from the nearest station up to 1,200 km away—and offers 99% coverage | | US NOAA | 1880 | North America | middle | Use nearby stations to interpolate temps in areas that lack stations, having 93% coverage | | UK HadCRUT | 1850 | Europe | Leave out areas, covering ≈ 86% of Earth’s surface | | Japan Met. | 1891 | Asia | slightly lower | Leave out areas without plenty of temp stations out of their analysis, covering ≈ 85% of the globe. | | Berkely Earth | 1850 | North America |  |  | | Why unable to use satellite data | Only start from 1979 | | | | | | | Raw satellite data has to go through a more extensive “adjustment” process. Satellites do not directly measure temps, and have large systemic biases due to orbital decay, diurnal sampling drifts, changes in the satellite used. Correcting for these biases is not straightforward, and diff choices in correction parameters can lead to diff trends during the period from 1979 to the present day. | | | | | | | 4 major datasets with 1951–1980 baseline: btw 0.75 and 1°C depending on the dataset. Arguably, effect of industrialisation is already present in the baseline. If use the 1850–1900 period as a proxy for pre-industrial temps, then temp rise is even greater. Berkeley Earth dataset: of slightly higher than 1.2°C. The IPCC in the Sixth Assessment Report: 1.1°C | | | | | | | |
| Temp rise is Unprecedented |
| |  |  |  |  | | --- | --- | --- | --- | | Medieval Warm Period | | 950 to 1250 | Evidenced by historical documents, botany and extant temp measurements. However, little to no evidence that it can be seen in the global temp record. While the North Atlantic was unusually warm, other regions, were colder than normal. The ave global temps have no signal of this localised warming. This shows the danger of relying on data from a limited region and extrapolating that data to infer a global phenomenon. | | ‘Proxy methods’: in which a var which correlates with the target var is measured, and then used to infer the value of target var. Proxy methods can be used to study climate, beyond times when direct measurements of temps are available. Most proxy records have to be calibrated against indp temp measurements, or against a more directly calibrated proxy, during their period of overlap to estimate the r/s btw temp and proxy. The longer history of the proxy is then used to reconstruct earlier temps. | | | | | 1. Dendro-climatology | | Width of tree rings. Tree rings are wider when conditions favour growth, and narrower when times are difficult. By combining multiple tree-ring studies (cross dating), scientists can estimate past regional and global climates. One advantages of tree-ring studies is the ease with which tree rings can be dated. | | | 2. Coral reefs | Coral grows in warm, shallow waters. Corals add seasonal layer, which appear as bands in their hard calcium-carbonate shells. Bands in the coral’s shell can change in thickness with changes in temp, water clarity, or nutrient availability. Depending on how the 3 factors are related, interpretation of records varies. Cool water rising from ocean floor brings extra nutrients in many areas, so shells are often thicker when the water is cool. In other areas, the cold may slow growth. Scientists have to couple their observations of patterns in the seasonal bands to other measurements, including modern observations of coral growth, to determine what the bands say about cc. | | | | 3. Ice cores | Ice cores are one of the best available climate proxies. Ice core: core sample that is typically removed from an ice sheet or a high mountain glacier. Since ice forms from the incremental build-up of annual layers of snow, lower layers are older than upper. Ice cores can reach depths of > 3.2 km, and contain ice up to 800,000 years old. Since scientists cannot directly measure temps from ice cores, they measure the oxygen isotope, oxygen-18, in water, which is correlated with temp, if somewhat imperfectly. | | | | From cores drilled at Vostok Station, a Soviet research station in Antarctica founded during the International Geophysical Year, we know the last interglacial period ended about 120,000 years ago. Thereafter, was an ice age that ended about 11,500 years ago. Since then, Earth has been in an interglacial period called the Holocene.  The glacial–interglacial cycles revealed in ice-core temp record are caused by Milankovitch cycles, i.e. variations in eccentricity, axial tilt and precession that result in cyclical variations in the solar radiation reaching the Earth system. All data shows that current temps have not been witnessed in the last 100,000 years. What is striking about the long-term temp record is how unusual the recent rise in temp is. Although temp rises of 10°C characterise the transition from glacial to interglacial periods, the rate of the temp seen recently is far more rapid than has been seen in the last 800,000 years. | | | | |
| Concomitant rise in Greenhouse gases |
| |  |  |  | | --- | --- | --- | | CO2 is an important trace gas in Earth's atmosphere. It is an integral part of the carbon cycle, i.e. the biogeochemical cycle in which carbon is exchanged btw the Earth's atmosphere, oceans, soil, rocks and biosphere.  Keeling curve shows atmospheric CO2 conc from 315 ppmv in 1958 to in excess of the 415 ppmv levels today. But seasonal variation in CO2 conc. | Biosphere is represented as phytoplankton conc over the ocean and the vegetation index over land. CO2 conc are from Mauna Loa in Hawaii. As each year progresses, greening of the land moves south to north, then north to south. This coincides with CO2 content falling during Northern Hemisphere summer when photosynthesis surpasses respiration and decomposition. It then rises during the late autumn to early spring when respiration and decomposition of the previous season’s crop of leaves exceeds photosynthesis. These are the seasonal oscillations in the CO2 graph. More poetically, this shows Earth breathing, in and out, once per year. | | | CO2 conc, and conc of other gases, determined from composition of air in bubbles trapped in the ice cores.  Throughout Pleistocene: {during deep glaciations: 180ppmv, during interglacial periods: 280ppmv}  Pre-industrial conc: 280 ppmv  Current conc of CO2 not seen in last 2 million years  Rate of of CO2 since Industrial Revolution also unprecendented. | | Methane conc: {pre-industrial: ≈ 600 ppbv  Current: > 1800 ppbv—a 3-fold increase}  Nitrous oxide conc from ≈ 270 ppbv to 338 ppbv today. | | Clear that in temps since beginning of Industrial Revolution has been accompanied by in the conc of gg. The current conc of gg have not been witnessed in the last several 100 000 years. Rapidity of these also unprcedented in our record of gg conc. | | | |
| Anthropogenic or natural rise in CO2 |
| |  |  |  |  | | --- | --- | --- | --- | | Carbon cycle is 1 of the biogeochemical cycles. Relies on fact nature recycles: atoms within living organisms came from inorganic, non-living matter; same atoms will exit living organisms as inorganic matter.  Carbon is a constituent of all organic molecules. | Biogeochemical cycle traces movement of chemicals essential to life through Earth sys. Cycles can be described in terms of reservoirs and exchange fluxes btw reservoirs. Global carbon cycle describes movement of carbon btw carbon reservoirs in Earth's sys. Imbalance in exchange flux change in size of reservoir. Burning fossil fuels exchange flux of carbon into atmosphere, in atmospheric carbon reservoir. | | | | Greatest physical reservoir of carbon is not atmospheric CO2, but is located in Earth’s crust and not easily accessible to biological organisms. But source of virtually all carbon in living organisms is CO2 either in atmosphere or dissolved in water. | | | Before human activities, such as land use changes and industrial processes, had a sig impact, global carbon cycle was roughly balanced. However, CO2 has by ≈ 50% from 280 ppmv in 1750 to the current levels of over 415 ppmv. | | Diagram  Description automatically generated with medium confidenceNums represent carbon reservoirs in Petagrams of Carbon and the annual exchanges in PgC/year. Petagram = 1 billion metric tonnes. Black nums and arrows: pre-industrial reservoirs and fluxes. Red nums and arrows: ave additional fluxes caused by human activities from 2000–2009, including emissions due to burning of fossil fuels, cement production and land use change (in total ≈ 9 PgC/year). Some of this additional anthropogenic carbon is taken up by land and the ocean (≈ 5 PgC/year) while remainder is left in atmosphere (4 PgC/year), explaining the atmospheric conc of CO2. The red numbers in the reservoirs show the cumulative changes in anthropogenic carbon from 1750–2011; a +ve change indicates that the reservoir has gained carbon. | | | | | This accountancy of the carbon budget is difficult and fraught with uncertainty. | Hence, many climate change deniers claimed that these studies are flawed and do not show that burning fossil fuels has atmospheric carbon reservoir. | | | | However, scientists have shown that in CO2 in atmosphere is due to burning fossil fuels, by measuring atmospheric conc of carbon-14. Carbon-14 is formed in the upper atmosphere through impact of cosmic radiation. It is eventually oxidised to CO2 and through photosynthesis, is incorporated into biosphere. Carbon-14 is radioactive and decays with half-life ≈ 5730 years. Can use measurements of carbon-14 to date materials (radiocarbon dating) | | Hans Suess, realised burning fossil fuels would dilute amt of carbon-14 in atmosphere. Fossil fuels are devoid of carbon-14 as they are formed from fossilised remains of life that died 100s of millions of years ago primarily in Carboniferous period. Any carbon-14 present in these fossil fuels will have decayed. He realised this dilution would affect the accuracy of radiocarbon dating. Suess effect has been used to argue that the in CO2 in the atmosphere is due to burning fossil fuels. | | | Chart, histogram  Description automatically generatedFig shows per mille change in carbon-14 in atmosphere. Small dilution of carbon-14 in the shaded green area is due to Suess effect. There was a dramatic in carbon-14 in the mid-1950s to early 1960s, due to open-air testing of atomic weapons. Following the Limited Nuclear Test Ban treaty in 1963, prohibiting nuclear weapons tests in atmosphere or under water, carbon-14 conc dramatically. Drop was not due to radioactive decay, as half-life = 5730 years and would not be noticeable on the timescale in this fig. Instead drop was due to dilution through burning of fossil fuel. The rate of decay can be shown to match exactly that which would be expected given the in atmospheric CO2 through the burning of fossil fuels. There is simply no other mechanism that can explain this decay in carbon-14. | | | | | Human-caused disruption to the carbon-14 amt in atmosphere through testing of nuclear weapons is used to mark the transition from the Holocene to the current period where humans have become a dominant force of global environmental change. Paul Crutzen, named this period – Anthropocene. Start of Anthropocene = 16 July 1945 (Trinity atomic bomb test conducted) | | | | |
| On the nature of Scientific understanding of human-induced climate change |
| |  |  | | --- | --- | | Scientists achieve understanding of a phenomenon *P* if they construct an appropriate model of *P* on the basis of a theory *T*. Henk de Regt identifies the Criterion for Understanding as such: A phenomenon *P* is understood scientifically, iff, there is an explanation of *P* that is based on an intelligible theory *T* and conforms to the basic epistemic values of empirical adequacy and internal consistency. | Using the relevant physical, chemical and biological theories, scientists have built mathematical models based on the conceptual models that describe how each part of the Earth system is inter-connected, which are realised as computer-based climate models. Aim of these climate models is to attempt to quantitatively explain the in temp witnessed since the Industrial Revolution. | | In Sixth Assessment Report of IPCC, fig shows observed changes in global surface temp over the past 170 years (black), relative to an 1850–1900 baseline. This is compared to the CMIP6 climate model simulations of the temp response to both human and natural drivers (brown), and to only natural drivers, i.e. solar and volcanic activity (green). Solid coloured lines = multi-model average, and coloured shades = likely range of simulations.  Note brown solid line closely follows the observed temp record indicated by black line. But green solid line show no warming across entire period. Conclusion is that it is impossible to reproduce the observed warming in global surface temp without including the in gg due to burning of fossil fuels (human factors) | | | CMIP6 = 6th iteration of the Coupled Model Intercomparison Project. Consists of simulations from ≈ 100 distinct climate models produced across 49 different modelling groups. These models simulate the physics, chemistry and biology of the atmosphere, land and oceans, and require some of the largest supercomputers in the world to generate their climate projections. | | | Models provide convincing evidence that we do understand human-induced cc with a great deal of fidelity. Hence, the scientific community reached the consensus position that human-induced cc is happening. | | |

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| The Art of Doubt |
| |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | | US President Lyndon Johnson | | 1965 | | 1st affirm the scientific consensus on human-induced climate change. Affirmation of the scientific consensus by U.S. Presidents became a tradition | | | President George H. W. Bush | 1992 | | Affirmed this consensus when signing the UN Framework Convention on CC at the Earth Summit. Spoke of need to take “concrete action to protect the planet.”. Yet, no binding targets and timeline for emissions reduction. There was a strong disconnect btw the political rhetoric and commitment to action as Bush said, “The American way of life is not up for negotiations. Period.” Why was there a disconnect? | | | | Bush Chief of Staff, John Sununu | PhD in mechanical engineering from MIT | | | | Despite no training in climate science, felt qualified to pass judgement on James Hansen's work, Director of NASA's Goddard Institute for Space Studies. Described Hansen’s work as “technical poppycock.” Claimed the science underlying the link btw gw and combustion of fossil fuels, was insufficient to warrant government action or societal expense. | | James Hansen | 1989 | | Wanted to clarify that gw would not just cause more heat waves, but also other extreme events like floods. As was protocol for a govt scientist, he submitted his remarks to the White House’s Office of Management and Budget. Sununu then had the testimony heavily edited. Hansen described these edits as leaving his testimony “meaningless”. Although this effort at censorship was exposed, Sununu’s efforts to oppose cc policy and any regulations limiting CO2 emissions that would stifle economic growth continued. | | | | 400 officials from 65 countries | 1989 | | Met in Netherlands to discuss for a global treaty on gg emissions. Most of the delegations were prepared to endorse the Dutch proposal to freeze emissions at 1990 levels by 2000, and a reduction of 20% by 2005. Sununu appointed a cc sceptic to the US negotiating team, giving orders to prevent any U.S. commitment to limits. No agreement was forged. | | | | Sununu | 2018 | | In an interview, said “It couldn’t have happened, because frankly, the leaders of the world at that time were at a stage where they were all looking at how to seem like they were supporting the policy without having to make hard commitments that would cost their nations serious resources.” Sununu’s next sentence is chilling. “Frankly, that’s about where we are today.” Rest of Bush presidency continued this doctrine of not limiting CO2 emissions and rest of the world followed suit | | | | This further illustrates the importance of questioning the authority of a source. | | | | | | |
| When Scientists know Sin |
| |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | | Naomi Oreskes & Erik Conway | | | | | | Wrote book, Merchant of Doubt. Explain why and how doubt on scientific consensus (present in the opinions and beliefs of politicians and officials at the highest lvl of govt), permeate into public arena | | George C. Marshall Institute (MI) | | | 1984 | | | Non-profit conservative think tank established with focus on science and public policy. Founders were all physicists who made their names in the Cold War working on U.S. rocketry and weapons programmes. | | Robert Jastrow, founding Director of NASA’s Goddard Institute for Space Studies, (James Hansen’s boss) | | William Nierenberg, nuclear physicist working on the Manhattan Project, and later Directorship of the Scripps Institute of Oceanography in 1965, which made him Charles Keeling’s boss. | | Frederick Seitz, 17th President of the U.S. National Academy of Sciences, and later 4th President of the Rockefeller University. | | 3 scientists create the MI to defend the Strategic Defense Initiative (Star Wars) in the face of what they believed was Soviet strength and U.S. weakness. Oppose govt regulation | | Carl Sagan & Nobel Laureate, Hans Bethe | | | | | | Led the scientific community opposition against the Star Wars initiative. Saw the Star Wars initiative as politically destabilising because it implied a winnable nuclear war. Over 6500 scientists and engineers signed a petition pledging not to work on the Strategic Defense Initiative. | | Marshall Institute | | | For supporting Star Wars, insisted on equal air-time on news media to confront the opposition. If they weren’t given equal air-time as Sagan and Bethe (represented over 6500 scientists and engineers) whereas MI (representing 3 scientists), they threatened to sue under the Fairness Doctrine (threat work). This however, gave the appearance that debate around Star Wars was being waged by sides of similar size. | | | | | Fall of Berlin Wall | | | 1989 | | | Became clear that concerns about Soviet strength were unfounded. MI needed a new enemy which they called “environmental extremism”, viewing environmentalism as socialism. This association was made as the issues of concern to environmentalists at that time, included acid rain, ozone hole, pesticide DDT, and cc, required govt intervention.  Govt intervention is the antithesis of the free market, i.e. neo-liberalism. The downfall of the Soviet Union only strengthened the political consensus that neo-liberalism was correct.  For MI, a return to the regulation required to combat environmental concerns, like cc, was an anathema to their neo-liberal ideology. For them, regulation = loss of freedom; giving up economic freedom by allowing the govt to regulate the market place, means only a matter of time before losing other freedoms. | | Tobacco industry | | | 1950s | | | Another national concern was “second-hand smoke”. Industry launched a strategy that refuted and ridiculed the science linking smoking to health issues, including lung cancer. | | Frederick Seitz | | | 1979 | | | Hired by R. J. Reynolds Tobacco Company and learnt many tricks of the trade, especially around doubt-mongering. These would prove useful in his efforts to cast doubt on the science of cc. | | Fred Singer | | 1994 | | | Environmental physicist, & 1st Director of the U.S. National Weather Satellite Service. Joined MI in their battle against regulating second-hand smoke. Tgt with Kent Jeffreys, wrote a report criticising the Environmental Protection Agency’s 1993 study about cancer risks of second-hand smoke, calling it “junk science”. On 2nd page of report, Singer writes, “…if we do not carefully delineate the government’s role in regulating…dangers there is essentially no limit to how much government can ultimately control our lives.” This confirms that the anti-environmental contrarianism of MI, was driven by a political agenda to thwart govt regulation. | | | MI | Applied the tobacco industry playbook to the environmental issues of the time, casting doubt on the science behind many environmental issues.Argued chlorofluorocarbons were not responsible for ozone loss in stratosphere, wrote papers questioning link btw UV-B and skin melanoma, argued that sulphur dioxide released by coal-fired power plants was not responsible for the acid rain that was destroying forests but due to volcanic emissions.  For cc, argued that gw was caused by natural variations in solar radiation; that any warming caused by greenhouse emissions is swamped by natural climate variations. Claimed that there was no scientific consensus, and there were benefits to increased CO2 in atmosphere through higher agricultural productivity. | | | | | | | U.K | 2007 | | | Promoters of the contrarian position were able to have a polemical documentary film, The Great GWSwindlereleased on national tv. Singer appeared in film, denying the scientific consensus about the reality and causes of cc. Film's critics argued that it had misused and fabricated data, relied on out-of-date research, employed misleading arguments, and misrepresented the position of the IPCC. Although the U.K. broadcasting regulatory agency upheld complaints of misrepresentation, damage was already done. | | | | Frank Luntz | 2002 | | | While public trust in science and scientific consensus around cc was being damaged, the political rhetoric was changing. Luntz (political & communications consultant), wrote a memo to the President George W. Bush White House, that contained a damning statement: “Voters believe that there is no consensus about gw within the scientific community. Should the public come to believe that the scientific issues are settled, their views about gw will change accordingly. Therefore, you need to continue to make the lack of scientific certainty a primary issue in the debate, and defer to scientists and other experts in the field.” This encapsulates the continuing approach of those peddling in the contrarian position both inside and outside of politics. Large portion of public accepts the deniers’ allegations as true, or are confused by them, and hence dk what or whom to trust. | | | | Science has effectively been undermined, eroding public support for the decisive action needed to avoid the worst effects of gw. | | | | | | | |
| Climate Change Myths "Climate's Changed before" |
| |  |  |  | | --- | --- | --- | | Richard Lindzen | July 2009 | Wrote article in the Quadrant saying, “Climate is always changing. We have had ice ages and warmer periods when alligators were found in Spitzbergen. Ice ages have occurred in a hundred thousand year cycle for the last 700 thousand years, and there have been previous periods that appear to have been warmer than the present despite CO2 levels being lower than they are now. More recently, we have had the medieval warm period and the little ice age.” | | Currency | 6th Assessment Report of IPCC just published, and article written before 5th Assessment Report. Article is dated, but content isn’t inconsistent with current research. Also references, for that time, recent research articles. X | | | Relevance | Article is relevant to a search about whether climate has changed in the past. PPP | | | Authority | Lindzen was a Professor of Meteorology at the MIT. Also lead author of Chapter 7 of the IPCC's 3rd Assessment Report. Lindzen thus has the credentials. PPP | | | Accuracy | Previous climates can be explained by natural causes, while current cc can only be explained by an excess of CO2 released by fossil fuel burning. Records of past climates indicate that change happened on time scales of thousands to millions of years. But curr global rise in temp has occurred over the past 170 years is unprecedented. XXX | | | Purpose | Lindzen is widely known as a contrarian, but is a highly-respected scientist. After retiring from MIT, took a position at the Cato Institute, an organisation founded by and largely funded by the Koch brothers who have actively sought to limit cc legislation. Lindzen also took a contrarian view on the issue of second-hand smoke. XX | | | In terms of the CRAAP Test, it fails on the basis of Accuracy and to a lesser extent Purpose and Currency. | | | | Single Cause Fallacy (SCF) | Myth that current cc is natural assumes that because climate has changed from natural causes before, it can only be changing from natural causes now. SCF is when a phenomenon is falsely attributed to a single cause, even though other causes are possible. Similar to saying that smoking cannot cause cancer because people were getting cancer before cigarettes were invented. | | |
| Climate Change Myths "It's the Sun" |
| |  |  |  |  |  | | --- | --- | --- | --- | --- | | David Whitehouse | | 2004 | | Published article on BBC News website “Sunspots Reaching 1000-year High". Says “Over the past few 100 years, there has been a steady in the nums of sunspots, at the time when the Earth has been getting warmer. The data suggests solar activity is influencing the global climate causing the world to get warmer.” | | Currency | Report from 2004. Should have more recent articles. XXX | | | | | Relevance | Discusses the mechanisms by which Sun influences the Earth’s climate. PPP | | | | | Authority | BBC News is widely-respected and is world's largest broadcast news organisation. BBC is required by its charter to be free from political and commercial influence. Whitehouse has Ph.D. in astrophysics, so ok to report on science issues, including cc. Report accurately represented work of scientists at Institute for Astronomy in Zurich. PP | | | | | Accuracy | In last 35 years of gw, Sun has shown a slight cooling trend. Sun and climate have been going in opp dirn. In the past century, the Sun can only explain some of the in global temps, but only a relatively small amount. XXX | | | | | Purpose | Article over 500 words long but didn’t mention possibility of human-influence on cc until the penultimate paragraph. Whitehouse left BBC in 2006 and has since written articles with a contrarian view of cc. He currently holds a position on the Academic Advisory Council of the contrarian GW Policy Foundation. X | | | | | Article fails the CRAAP Test on Currency, Accuracy and Purpose. | | | | | | Fallacy of incomplete data | | | In trying to blame Sun for cc, deniers cherry pick data. Only show data from periods when solar and climate data track together. Draw false conclusion by ignoring the last few decades when the data shows opp result. | | |
| Climate Change Myths "The Earth's Cooling" |
| |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | | Henrik Svensmark | 2009 | | Published article in Danish newspaper, Jyllands Posten, “While The Sun Sleeps”. Translation of article was published on website, Watts Up With That? Says, “gw has stopped and a cooling is beginning. No climate model has predicted a cooling of the Earth. This means that projections of future climate are unreliable.” | | | | | | Currency | Article is a little dated. However, similar claims can be found in more recent articles. XX | | | | | | | | Relevance | Answers qn whether cc is happening. PP | | | | | | | | Authority | Article states that Svensmark approved the translation. Svensmark is a physicist at the Centre for Sun-Climate research with the Danish National Space Institute at the Technical University of Denmark. Has been working and publishing his research in the area of cc throughout his career. PPP | | | | | | | | Accuracy | When looking for evidence of gw, there are many different indicators that we should look for. Beside air temps, a more thorough examination would include; snow cover, ice melt, air temps over land and sea, and sea temps. XXX | | | | | | | | Purpose | Website where translation was posted is a known purveyor of cc denial, but Svensmark seems to be following his research. Svensmark argues that while the role of gg in cc is considerable, solar variations play a larger role. P | | | | | | | | The article fails the CRAAP Test on Currency and Accuracy. | | | | | | | | | Cherry-picking data | | Qn of gw stopping is often raised in the light of a recent weather event—a big snowfall or drought-breaking rain. For cc, it is the long-term trends that are impt; measured over decades or more, and those long-term trends and diff indicators show that the globe is still warming. (Rely on preponderance of evidence) | | | | | | | 1. Land surface air temp | | | | | | Weather stations show . Cc deniers argue temp is biased due to urban heat island effect, badly-sited weather stations, stations dropped from use in temp record,... | | | 2. Sea surface temp | | | | | | . Same as land temp, longest record start from 1850 and last decade is warmest | | | 3. Air temp over oceans | | | | | | . | | | 4. Lower troposphere temp | | | | | | Satellites measurements for 50 years show . Each of last 4 decades was warmer than previous. | | | 5. Ocean heat content | | | | | Records over last 50 years show . > 90% of extra heat from gw gg into ocean, contributing to sea lvl . | | | | 6. Sea level | | | | | | . Tide gauge records from 1870, sea level at accelerating rate | | | 7. Specific humidy | | | | | | in tandem with temp | | | 8. Glaciers | | | | | | Retreating. Alaska's melt rates highest on planet, Columbia glacier retreating at ≈ 35m/year. Glaciers are melting faster, losing 31% more snow and ice per year than 15 years ago | | | 9. Nothern Hemisphere snow cover | | | | | | |  | | 10. Arctic sea ice | | | | Satellite measurements from 1979 & shipping records from 1953, shows Sep sea ice extent has by 35% | | | | | 11. Flora and fauna | | | | | | Migrating polewards and upward | | |
| Climate Change Myths "Animals and Plants can Adapt" |
| |  |  |  | | --- | --- | --- | | Hudson Institute | 2007 | Wrote article on Heartland Institute website,“Challenge to Scientific Consensus on GW”. Article writes that “corals, trees, birds, mammals, and butterflies are adapting well to the routine reality of cc.” | | Currency | Article too old. XXX | | | Relevance | Article does not expand on this single statement, beyond stating that conclusion is drawn from research published in journals. Does not identify whether animals and plants can adapt to cc. XX | | | Authority | Cc is not in Hudson Institute areas of interest. No staff are expert in climate science. XXX | | | Accuracy | Science says that human-caused cc is occurring too rapidly for species to be able to adapt. Plants and animals are currently dying off at a rate that is 100 to 1000 times faster than the ave rate of extinction over geological timescales. Mounting evidence that we are heading towards a mass extinction event. XXX | | | Purpose | Article appears to be a puff piece promoting the book “Unstoppable GW Every 1,500 Years” by Fred Singer and Dennis Avery. Avery was also a Senior Fellow at the Hudson Institute. XXX | | | This article fails the CRAAP Test by every measure. | | | |
| Climate Change Myths "It's not Us" |
| |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | | Neil Frank | 2010 | | Wrote article on Houston Chronicle, “Climategate: You Should Be Steamed”. Says, “What do the skeptics believe? First, they concur with the believers that Earth has been warming since the end of a Little Ice Age around 1850. The cause of this warming is the qn. Believers think warming is man-made, while skeptics believe warming is natural and contributions from man are minimal and certainly not potentially catastrophic à la Al Gore.” | | | | | | | Currency | | Article is a little dated, but has similar claims to those written more recently. XX | | | | | | | | Relevance | | Discusses cc in light of the hacking of emails from the Hadley Centre’s Climate Research Unit, (“Climategate”). If qn was whether cc is human caused, then the article lacks depth. But if qn was about what scientists had said in the hacked emails, then article is relevant. P | | | | | | | | Authority | | Frank has Ph.D. in meteorology from Florida State University. Was Director of U.S. National Hurricane Center. PPP | | | | | | | | Accuracy | | Science says gw is human caused, because it has our “fingerprints” all over it. Proving gw is due to humans is about establishing causation. Many evidence that gw can be attributed to human-induced emissions of gg. XXX | | | | | | | | Purpose | | The polemical style of the article is revealing. It calls the climate scientists that are identifying the dangers of cc as being “alarmists”. Argues that the emails reveal a conspiracy between U.S. and U.K. climate scientists to adjust the data to make it look as if gw is real. This language is a red flag. XXX | | | | | | | | The article fails the CRAAP Test on Currency, Accuracy and Purpose. | | | | | | | | | | Ad hominem fallacy | | | | | Article was more an ad hominem attack on climate scientists (personal attack) | | | | | “fingerprints” all over gw: | | | | 1st | | 2nd | 3rd | 4th | | Evidence that humans are raising CO2 | | | | Humans emitting ≈ 30 billion tonnes of CO2 into atmosphere/year | | O2 levels are falling as carbon is being burnt to form CO2 | This carbon is in form of fossil fuels—this is the Suess effect | Corals absorbing this fossil carbon more recently. | | CO2 absorbing more infra-red radiation. | | | | | Satellites are measuring less infra-red radiation escaping to space at which CO2 absorbs | | Surface measurements reveal that this radiation is returning to Earth to warm surface | | | Observed pattern of warming is consistent with what is predicted | | | | Warming due to solar activity: stratosphere, atmosphere warm Warming due to greenhouse effect: stratosphere cool as IR radiation is trapped in the troposphere.  Satellite measurements show stratosphere is cooling | | Increased greenhouse effect would make nights warm faster than days, and has been observed | Combination of a warming troposphere and cooling stratosphere should cause the tropopause, which separates them, to rise, which was observed | Predicted that the ionosphere would shrink, and it is indeed shrinking | |
| Cognitive Bias |
| |  |  |  | | --- | --- | --- | | Fossil fuel industry, political lobbyists, media & individuals have spent ≈ 30 years casting doubt on reality of cc. World’s 5 largest publicly-owned oil and gas companies spend ≈ US$200 million/year on lobbying to control, delay or block binding climate policy. | | | | a. Science denial | | That science of cc is not settled, there is no consensus and it is just part of the natural cycle. | | b. Economic denial | That cc is too expensive to fix. This is a form of self-fulfilling prophecy. Economists estimate that fixing cc now need 1% of world GDP. By 2050, need over 20% of world GDP. Shows need for intergenerational equity. | | | c. Humanitarian denial | That cc is good for us. Longer, warmer summers make farming more productive, more CO2 can be fertiliser for plants, warmer winters = fewer deaths. This denial only considers effect on people living in temperate climates, and not those living in tropical climates. This is not even true, and points to the need for international equity. | | | d. Political denial | That we cannot take action because other countries are not taking action. This denial ignores the historic legacy of gg emissions. Further highlights the ethical responsibility of developed nations to take action first. | | | e. Crisis denial | That we shouldn’t rush into committing to binding international agreements, given the uncertainty and myths. | | | Individuals accept these forms of denial due to our susceptibility to cognitive bias. | | | | 1. Time-discounting bias (TDB) / tendency to discount the future | Despite claiming we want to leave world in good cond for future gen, ppl intuitively discount future to a greater deg than can be rationally defended. Ppl tend to focus on short-term considerations. Over-discounting future can lead to overharvesting of oceans and forests & failure to invest in new tech to address cc. We discount the future when it is uncertain, distant, and when involving intergenerational distribution of resources. Ppl advocate that earth’s resources should be preserved when thinking about their descendants. But when consumptive opp arise today that would inflict environmental costs on future gen, they then view “descendants” as a vague group of ppl living in a distant time. From a societal perspective, overweighting present concerns is both foolish and immoral, as it robs future generations of opportunities and resources. | | | 2. Illusory truth effect (ITE) / positive illusions | +ve illusions lead us to conclude that energy problems do not exist or are not severe enough to merit action. We tend to see ourselves, our environment, and future in a more +ve light than is objectively the case. 1. Unrealistic optimism leads us to believe and act as if effects of cc will be far less severe than the scientific community predicts. 2. Illusion of control leads us to believe that scientists will invent new tech to solve the problem. All this serves as excuses for the failure to act today. | | | 3. Self-serving bias (SSB) / egocentrism | We interpret events in a self-serving manner – tendency to expect others to do more than we do. Egocentrism causes all parties to believe that it is fair for them to bear less responsibility for reversing cc than an independent party would judge as fair. Prob is worsened not by a desire to be unfair but by an inability to view information objectively. | | | These three biases can have an interactive effect. Deniers no longer arguing that cc does not exist, that humans do not contribute to cc, or that others are to blame for the problem, they now argue that it would be too costly to respond to the prob. This transition– SSB (a. scientists are wrong) ITE (a. cc dont exist, humans not to blame & c. cc is good) SSB (d. others to blame) TDB (b. too costly to fix & e. future generations benefit) | | | |

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| Reliability of Models |
| |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | | Cc deniers have moved the goalposts as to what is required as evidence before we enact policies to mitigate cc.   |  |  |  |  | | --- | --- | --- | --- | | Climate models | Projections | Prediction | Scenario | | These computer programs | model-derived estimates of future climate | when a projection is branded “most likely” | coherent, internally consistent and plausible description of a possible future state of the world |   Mathematical models incoporating our understanding of Earth sys are expressed in the form of computer programs that can calculate climate and change in climate.  Reason for diff btw projection & prediction is that many of the climate simulations calculated are for future scenarios that are seen as possible. Scenarios have a demographic, socio-political, economic and technological storyline. | | |  |  |  |  | | --- | --- | --- | --- | | Hindcasting | Initial-value models | Natural forcings | Anthropogenic forcings | | Reproducing past observations | Models of past climate | incorporating solar variations and volcanic activity | changes in gg, sulphate aerosols, and land-use |   Can develop confidence in models by testing models (hindcasting) against past observations. Model shouldn't be tuned to reproduce past observations, as this would greatly limit the confidence in any such model for forecasting the future.  Initial-value models are given an initial state, then allowed to freely run forward in time. Models do not correct themselves using past surface temps. Model should be able to reproduce random variations in the climate system. However, it will not be able to reproduce the observed changes in Earth surface temp and need to be forced by natural and anthropogenic changes  From models calculations in 6th Assessment Report, in temp can only be explained by anthropogenic forcings | | Despite using some of the most powerful supercomputers, climate models need to divide the planet up into grid cells to make calculations more manageable at any one time, model is calculataing the ave climate of each grid cell. However, there are many processes in the climate system and on Earth’s surface that occur on scales within a single cell. E.g. topography will be averaged across a whole grid cell in the model, overlooking details of physical features such as mountains and valleys. Similarly, clouds can form and dissipate at scales that are much smaller than a grid cell. | | To solve this problem, these variables are “parameterised”, i.e. their values predefined in computer code rather than calculated by model. Parameterisations may also be used as a simplification where a climate process isn’t well understood. Parameterisations are 1 of the main sources of uncertainty in climate models. Each research group will approach the parameterisation of a climate process in a slightly diff way climate models in the IPCC reports give diff answers even if they are initialised with the same climate state. The variance in the global ave temp from these diff models gives us a sense of the uncertainty in the model calculations. Hence, there is no one 'best' model | | Hindcast calculations give confidence that climate models “understand” the climate processes that led to the in temp since the Industrial Revolution. It could be argued that future climate projections represents an extrapolation beyond the climate states. To resolve this, scientists constructed paleoclimate models that attempts to reproduce the proxy temp records for much earlier climates, when temp were vastly outside the envelope witnessed since the Industrial Revolution.  Hadley Centre Coupled Climate Model ver 3 (early ver used by UK Met Office) able to reproduce temp during last 800,000 years. | | Studying paleoclimates provides opp to better understand the sensitivity of models to changes in gg, glacial and sea-level, etc.  While ability to simulate past and current climate does not guarantee ability to simulate future climate, it is an impt precursor. Today’s climate models can accurately reproduce current climate; their predictions being observed in recent years. Many of the processes driving climate are well understood and ability to capture these processes in models has been tested and constantly improved. Climate models are not perfect, but are the best tool we have for explaining the current behaviour of our climate and predicting likely changes to the planet’s future climate. | |
| Feedback |
| |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | | Feedback can lead to substantial uncertainties in climate models | | | | | | | | | | positive feedback loop | lead to instability via exponential growth. (input , instability ) | | Mass of ice sheet and elevation of ice sheet. If ice sheet melts, then ice sheet will move to a lower elevation where it is warmer and will melt faster. This loop will not stabilise and will continue until entire ice sheet has melted. | | | | | even num of -ve couplings | | negative feedback loop | output of a system is fed back in a manner that reduces the fluctuation in the output. Stabilise the system. (input , stability ) | | | | Photosynthetic rate of plants and conc of atmospheric CO2. photosynthetic rate of plants by planting more trees, then atmospheric CO2 (). in atmospheric CO2 leads to in the photosynthetic rate of plants (). This stabilises the system. | | | odd num of -ve couplings | | +ve coupling | |  | | | () in one elem leads to () in the connected elem. | | | | | -ve coupling | |  | | | () in one elem leads to () in a connected elem. | | | | | Couplings are visual representation of a causal link. Photosynthesis rate and atmospheric CO2 are causally -ve correlated (-ve coupling). Atmospheric CO2 is causally +ve correlated with photosynthesis rate. If 2 vars are correlated but not causally linked, then vars are interchangeable. If 2 vars are causally linked, underlying process explaining this coupling may not be bidirectional. | | | | | | | | | | Set of feedback loops btw surface temp & water | | 1st feedback loop: +ve feedback loop  in surface temp evaporation water vapour in atmosphere an enhanced greenhouse effect greater surface temp. All of the couplings are +ve. | | | | 2nd feedback loop: -ve feedback loop.  in surface temp greater evaporation cloud cover in albedo (as clouds are reflective). However, albedo in surface temp, completing a -ve feedback loop. Note that this loop includes a single -ve coupling. | | | | If CO2 conc were doubled instantaneously terrestrial infra-red radiation absorbed (i.e. terrestrial transmittance, ) outgoing radiation at top of atmosphere [Fs - (Fa + Fg x )] ≈ 3.7 W/m2 imbalance btw amt of radiation entering and leaving Earth sys (aka radiative forcing). Since energy entering > leaving, Earth will warm up until balance is restored (≈ 1.25°C) | | | | | | | | | | However, temp will change other things. As explained before, in surface temp evaporation and water vapour. The +ve feedback loop will the initial temp rise by a further 60%. | | | | Other feedback loops include melting of ice allowing surface underneath to absorb sunlight instead reflecting back to space. Melting ice and exposing the underlying surface the albedo, A. This +ve feedback loop the initial temp rise by a further 20%. | | | If the water vapour nucleates to form clouds then it is possible for there to be a -ve feedback loop. However, effect of clouds is uncertain and depends on the altitude at which the clouds form. | | | Climate sensitivity (cs) = net effect of the initial warming due to doubling CO2 and the feedbacks in the Earth sys. Best estimate of cs in 6th Assessment Report is 3°C with a likely range of btw 2.5°C and 4°C. Range of cs has as climate models improved. | | | | | | | | | | Note that the in temp due to cs is the expected when Earth sys reaches equilibrium. It doesn’t happen overnight. Most of the imbalance in energy goes into heating up the oceans. Oceans take a long time to heat up and so there is a lag btw reaching the expected equilibrium surface temp and current surface temp. E.g. current in Earth surface temp from 1850–1900 baseline is ≈ 1.1°C. However, the current levels of atmospheric CO2 would imply an equilibrium Earth surface temp to be over 1.7°C. Avoiding such an equilibrium temp requires us to not only stop adding to the atmospheric CO2 concentration, but to reduce it. | | | | | | | | | |
| Models of the Past |
| |  |  |  |  |  | | --- | --- | --- | --- | --- | | Syukuro Manabe | 2021 | | Climate scientist awarded Novel Prize in Physics for climate modelling & reliably predicting gw. Although Arrhenius 1st to estimate in surface temp due to doubling of CO2, Manabe 1st to perform computational experiment for doubling CO2. 1 of the first to use realistic distribution of land masses and a mixed-layer model of the very upper ocean in modelling and show how parameterising clouds had large effect of model cs. | | | James Hansen & colleagues | | 1988 | | Reported climate model simulations for 3 diff emission scenarios. Scenario A: continued exponential gg growth (worst case), Scenario B: reduced linear rate of growth (most likely), Scenario C: rapid decline in gg emissions around the year 2000 (best case).  Data from 1958 to 1984 represent a hindcast, and after 1984 represent a forecast. Actual gg emissions is closest to Scenario B, Scenario B has a 0.26°C/decade temp trend, whereas the observed GISTEMP temp trend = 0.19°C. Scenario B has overestimated the temp trend in the forecast period. | | |  |  |  | | --- | --- | --- | | Reasons for overestimate | slightly overestimated how much atmospheric gg would | | | Model had a rather high cs of ≈ 4.2°C for a doubling of atmospheric CO2 | Actual cs ≈ 3.4°C. This is within the likely range of cs values listed as 2.5–4°C by the IPCC for a doubling of CO2. This would be just a little bit higher than the most likely value currently widely accepted as 3°C. | | Conclusion is that projections were not wrong but Hansen’s study is another evidence that cs is in the IPCC range of 2.5–4°C. | | | | | | | | | Hansen's model however correctly projected amplified warming in the Arctic, hot spots in northern and southern Africa, west Antarctica, and more pronounced warming over the land masses of the northern hemisphere, among other things. | | | | | | Modern climate models have a grid resolution of a degree or less. Hansen’s model grid was 8° × 10° (worse). Given the effect that grids have on the need to parameterise climate processes, we can understand the source of Hansen’s model’s high cs. | | | | | |
| Narratives of the Future |
| |  |  |  |  | | --- | --- | --- | --- | | IPCC | | 1990s | Published Special Report on Emissions Scenarios. Scenarios constructed to explore future developments in the global environment**,** highlighting the main scenario characteristics and dynamics, and r/s btw key driving forces. The 4 storylines combine 2 sets of divergent tendencies: one set varying btw strong economic values and strong environmental values, the other set btw increasing globalisation and increasing regionalisation. (Outdated) | | The most recent attempt to narrate future cc is the development of a Scenario Matrix Architecture which was used in the recent Sixth Assessment Report of the IPCC. The construction of this framework was two pronged. | | | | | 1st | |  |  | | --- | --- | | Representative Concentration Pathways (RCP) described diff lvl of gg and radiative forcings that might occur in future. | | | RCP1.9 | Limits gw to below 1.5°C, the aspirational goal of the Paris Agreement. Require very stringent mitigation efforts and -ve net carbon emissions around 2050 | | RCP2.6 | “Very stringent” pathway requiring CO2 emissions to start declining by 2020 and go to zero by 2100 | | RCP4.5 | “Intermediate” scenario that requires emissions to peak around 2040, then decline | | RCP7.0 | Baseline outcome rather than a mitigation target—(no concerted international effort to address cc) | | RCP8.5 | Very high emissions scenario – unlikely to occur, but might be possible as feedbacks are not well understood | | | | | 2nd | |  |  | | --- | --- | | Shared Socioeconomic Pathways (SSPs) described how socioeconomic factors (pop, education, urbanisation, economic growth, and rate of technological development) may change and how world might evolve in absence of climate policy | | | SSP1 | Gradual shift toward a more sustainable path, emphasizing more inclusive development (equality) that respects perceived environmental boundaries.(RCP1.9, RCP2.6) | | SSP2 | Social, economic, and tech trends do not shift markedly from historical patterns.(RCP4.5) | | SSP3 | World descends into resurgent nationalism, where concerns about competitiveness, security, and regional conflicts push countries to increasingly focus on domestic issues.(RCP7.0) | | SSP4 | Highly unequal investments in human capital, combined with increasing disparities in economic opp and political power, lead to inequalities and stratification both across and within countries. | | SSP5 | World places increasing faith in competitive markets, innovation and participatory societies to produce rapid tech progress and development of human capital as the path to sustainable development.(RCP8.5) | | | | | SSP1 and SSP5: relatively optimistic trends for human development, with substantial investments in education & health, rapid economic growth, and well-functioning institutions. SSP5 assumes this will be driven by an energy-intensive, fossil fuel-based economy, while in SSP1 there is an shift toward sustainable practices.  SSP3 and SSP4: more pessimistic in future economic and social development, with little investment in education or health in poorer countries, coupled with a fast-growing population and inequalities.  SSP2: middle scenario in which historical patterns of development are continued | | | | | Not all RCP can be achieved under all SSP  Figure shows a combination of SSP and RCP model runs, with RCPs listed in order of mitigation and SSPs in the rough order of mitigation difficulty.  Ratios in each cell = num of models that succeeded in making the scenario “work” out of the total numof models used. Note that the models have significant difficulty in achieving RCP1.9 and RCP2.6 targets in either an SSP3 world or SSP5 world. The RCP1.9 mitigation target can only be achieved by all models used under an SSP1 narrative. | | | | |
| Projections of Climate Change |
| |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | | |  |  | | --- | --- | |  | IPCC 6th Assessment Report | | Global | Ave surface temp , Sep Arctic sea ice area , ave sea level , and ocean surface pH . All indicators of global cc. | | SG | Annual mean temp from 1972: 26.6°C to 2019: 28.4°C (largely due to urban heat island effect). Has intense thunderstorms, flash floods, dry spells. Longest dry spell in 2014, since records begin in 1869 | | SEA | in hot extremes and high confidence is due to human influence. in heavy precipitation although low confidence is due to human influence. Low agreement in type of change in agricultural and ecological drought that is happening, (assessment based on observed and simulated changes in total column soil moisture). | | | The level of confidence terminology introduces in IPCC reports is based on a combination of the level of agreement and the quality of evidence. Low degree of confidence = 20% chance of being correct, a medium degree of confidence = 50% chance, and a high degree of confidence = 80% chance of being correct.  For model projections, IPCC use diff terminology as show by Fig  IPCC in 6th Assessment Report focused on 5 scenarios: SSP1-1.9, SSP1-2.6, SSP3-7.0, SSP2-4.5, and SSP5-8.5. Simulations begin to be forced by these scenarios in 2015 |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | | IPCC | SSP1-1.9 (very low gg emissions) | | SSP1-2.6 (low gg emissions) | SSP2-4.5 (middle gg emissions) | SSP3-7.0 (high gg emissions) | SSP5-8.5 (very high gg emissions) | | CO2 emissions | net zero ard 2050, further | | net zero ard 2075, further | constant until 2050 then | double ard 2100 | double ard 2050 | | Surface temp (1850 - 1900 baseline) | 2081-2100 higher by 1.0°C to 1.8° | | 2081-2100 higher by 1.8°C to 2.1° | 2081-2100 2.1°C to 3.5°C | 2081-2100 3.3°C to 5.7°C | | | Sep Arctic Sea Ice projections | Won't be practically ice-free | | | Practically ice-free near 2080 | Practically ice-free near 2050 | | | Ocean pH level  Since Industrial Revolution, pH has by 0.1 units ≈ 30% in acidity, since pH scale is logarithmic | | recovery of pH before the end of the century | | pH continued which further impact many ocean species like oysters and corals that make hard shells and skeletons by combining calcium and carbonate from seawater. If the pH gets too low, shells and skeletons can even begin to dissolve. | | | | Ave sea level relative to 1900 | By 2100, by 0.48–0.78m | | Rising | | By 2100, by 0.79–1.17m. 2m possible due to uncertainty in ice sheet processes. | | | In the longer term, sea level expected to for centuries to millennia due to continuing deep ocean warming and ice sheet melt, and will remain elevated for thousands of years. Sea level greater than 15m by 2300 cannot be ruled out in the very high emissions scenario. | | | | | | | Last time global surface temp was ≥ 2.5°C higher than 1850–1900 was over 3 million years ago. Simulations indicate that global surface temp will continue to until at least the mid-century under all emissions scenarios. Gw of 1.5°C and 2°C will be exceeded during the 21st century unless deep reductions in CO2 and other gg emissions occur in the coming decades. | | | | | | |  |  |  | | --- | --- | | Irish Centre for High-End Computing simulations | | | Ave global temp  (baseline 1850-1900) | Amt of warming is not equal in all areas of the world. | | Simulations shows oceans warm more slowly than land as it takes much more heat to warm water than land. | | Middle of continents warm more than coastal areas. Regional topography (mountain ranges) will influence this too. | | At high latitudes (near Arctic), temp warming faster than places near equator. Arctic 2x faster than global ave. | | SG projected to see 1–2°C in temp (low gg emissions scenario) or 4–5°C (very high gg emissions scenario) | | Annual precipi-tation (baseline 1981- 2010) | Although global ave precipitation by btw 3% to about 10%, it is not distributed evenly around the globe. | | in precipitation expected to occur at high latitudes. snowfall near both poles may offset some of the melting of glaciers and ice sheets by adding fresh ice to the tops of these features. Some places in Antarctica are even gaining more snow via precipitation than they are losing to melting caused by temp. | | Some regions may receive a net in rainfall, but the may come in form of more frequent heavy downpours punctuated by longer dry spells. This change in precipitation patterns is likely to cause a greater incidence of flooding, especially in combination with land use changes such as deforestation. | | However, regions near equator and mid-latitudes expected to see in precipitation. Areas in low- and mid-latitude regions expected to suffer from more frequent and severe droughts. Dry conditions, warmer temp that produce longer "fire seasons", and changes in ecosystems expected to generate more and larger wildfires in some areas. | | Some presently dry regions may be glad to see rainfall, just as drier conditions may benefit some currently very wet places. However, heavy rainfall that causes flooding as well as extended or more frequent droughts are likely to be disruptive to ecosystems and agriculture in the afflicted regions. | |
| Principles to Govern International Action |
| |  |  |  | | --- | --- | --- | | Science can inform public policy, but it cannot define public policy. | | | | UN General Assembly | 10 Dec 1948 | Universal Declaration of Human Rights was proclaimed by UN in Paris. In Preamble to the Declaration, it says “recognition of the inherent dignity and of the equal and inalienable rights of all members of the human family is the foundation of freedom, justice and peace in the world”. Reference to “all members of human family” has both spatial and temporal dimensions, bringing peoples of all countries and gens within its scope. Reference to “equal and inalienable rights” affirms the basic equality of all people across all gens. | | |  |  | | --- | --- | | Principles that should govern international action. | | | 1. Pre-cautionary Principle | States that lack of scientific certainty should not prevent appropriate action being taken. Acknowledged in Article 3.3 of UN Framework Convention on Climate Change (UNFCCC). Included as in 1992, threats of cc were seen as dangerous and potentially catastrophic. Meant to spur international action, and lack of full scientific certainty should not reason for postponing cost-effective measures to prevent environmental degradation. | | 2. Polluter Pays Principle | Polluters should pay for the damage of their pollution. Recognises that gg are global pollutants, and affect the global commons.Acknowledged in Principle 16 of the Rio Declaration on Environment and Development. Some developing countries asking for reparations from rich countries for the cc impacts they are already suffering. | | 3. Principle of Equity | Intergenerational and international equity. Recognised in Universal Declaration of Human Rights. Intergenerational equity: past, present and future gens should have same natural environment.  Acknowledged in Article 3.1 of UN Framework Convention on CC, saying developed countries should take the lead in combatting cc partly as many such countries have a legacy of historical emissions. | | Of the three principles, the most difficult to apply is that of equity. Currently, the richest half, i.e. high and upper-middle income countries = 86% of global CO2 emissions. The bottom half, i.e. low and lower-middle income countries = 14%. Yet countries who contribute least to gg emissions will be most impacted by cc.  Map of per capita emissions shows Sweden and Switzerland, (high-income countries) emit less on per capita basis than global ave. However, when imported emissions are considered, Sweden's emissions by two-thirds and Switzerland's by a factor of 3 | | | | | | One proposal by the Global Commons Institute is called Contraction and Convergence. Proposes stabilisation of atmospheric CO2 at an agreed level (e.g. 450 ppmv ≈ 2°C in global ave temp over pre-industrial levels). ‘Contraction’ part: world agrees to follow the envelope curve. ‘Convergence’ part: by 2030, CO2 emissions should be allocated to countries so as to share the emissions equally. Emissions need to converge to their 2030 allocations.  This proposal view international equity = emissions shared on per capita basis.  There is a third part that allows for trading of emissions. Those that have more than needed can sell to those wanting to emit more. This move money from developed to developing nations to help developing nations industrialise using non-fossil fuel energy systems. | | | |
| Climate Change Mitigation |
| |  | | --- | | Suppose we want to limit gw to 2°C over pre-industrial levels. To achieve this without -ve CO2 emissions, have to limit the cumulative amt of carbon emitted since beginning of the Industrial Revolution to 1 trillion tonnes ≈ 3.7 trillion tonnes of CO2. Such a limit supposedly would avoid the worst impacts of cc. However, recent projections suggests 1.5°C limit may be required.  There is roughly linear r/s btw temp rise and total amt of carbon emitted. Only the very low and low gg emissions scenarios avoid a total carbon emission of 1 trillion tonnes being exceeded by 2050 | | World has enough fossil fuel to go beyond this budget of 1 trillion tonnes. To keep under this budget, need to limit future carbon consumption to ≈ 400 billion tonnes. At current pace of consumption, will exceed budget by around 2045.  Divvying up the carbon budget on basis of GDP would leave little for developing countries, but give more to developed countries, who are better able to create value from burning carbon. Doing it on basis of pop would give developing countries a chance to develop with fossil fuels, but it leaves little time for carbon-intensive economies to switch to renewable energy sources. | | Early debate saw mitigating cc as needing a ‘silver bullet’: a single, optimum tech that could get us from today’s carbon-glutinous energy sys to a carbon-free energy sys. Steven Pacala and Robert Socolow argued that instead of finding a silver bullet, we should take a more diversified approach. In this approach we can think of any single tech that would lower carbon emissions as an “emissions stabilisation wedge,” which by itself, could 1 billion tonnes of carbon emissions/year. (We currently emit ≈ 10 billion tonnes of carbon/year.) While no single 1-billion tonne wedge would be adequate to avoid dangerous cc, a combination of stabilisation wedges could be. Figure imagines the need for nine such wedges to stabilise emissions. | | |  |  |  |  | | --- | --- | --- | --- | | Pacala and Socolow recognised that the technology already exists. Such technology wedges could be achieved through | | | | | 1. Efficiency. Double fuel efficiency of cars, num of car miles travelled by half, more efficient buildings, produce curr coal-based electricity with 2x efficiency. | 2. Biomass fuels. ethanol production 12x by creating biomass plantations with area = 1/6th of world cropland. | 3. Carbon capture and storage. Store carbon captured in power plants H2 production, and 180 coal-to-synfuels plants. Produce H2 from coal at 6x rate. | 4. Natural sinks. Eliminate tropical deforestation, or adopt conservation tillage in all agricultural soils worldwide. | | 5. Fuel switching. Replace 1400 coal electric plants with natural gas-powered plants. | 6. Solar. solar capacity, or use solar panels to produce H2 for fuel cell cars. | 7. Wind. wind electricity capacity by 10x, for a total of 2 million large windmills. | 8. Nuclear. Double curr global nuclear capacity | | | Carbon capture and storage is expensive. Blue H2 (production of H2 from fossil fuels, through processes like steam reforming) has high carbon footprint. Green H2 (H2 produced from renewable energy sources and electrolysis of water) has less carbon footprint. | | In addition to technology wedges, we may need behavioural wedges, such as cutting driving in half, cutting projected meat consumption by a third, or cutting projected miles flown by a third. | |
| The Danger of Certainty |
| It was the space engineer and journalist, James Oberg, who said, “Keep an open mind, but no so open that your brains fall out”.  A useful approach to new knowledge that challengs our preconceived notions might be to consider Bayes’ Theorem. P(A|B) = = . Suppose frequency of disease = 0.1%. Test will correctly identify 99% of people who have the disease (TPR). P(A|B) = ≈ 0.0902 = 9%. Suppose you took a 2nd test and got +ve, and that the two tests are independent of one another. P(C|D) = ≈ 0.9075 = 91%. Sensitivity = TPR. Specificity = TNR  We are all susceptible to bias, to take on different forms of denial. Recognising that our opinions are fallible, being willing to acknowledge our fallibility, and to make lasting change to behaviour.  Jacob Bronowski, in his book “The Ascent of Man”, said, “Science is a very human form of knowledge. We are always at the brink of the known, we always feel forward for what is to be hoped. Every judgment in science stands on the brink of error, and is personal. Science is a tribute to what we can know although we are fallible. Oliver Cromwell said: ‘I beseech you, in the bowels of Christ, think it possible you may be mistaken’.” There is a real danger to have absolute certainty, to dogma that closes the mind. Be open to test your reality, don’t fall to the arrogance of knowing the truth. |

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| What is the significance of the Singapore Green Plan 2030? (SGP2030) |
| 1 Feb 2021. "A Whole-of-Nation Sustainability Movement". Multi-agency effort spearheaded by MOE, MND, MTI, Ministry of Sustainability and Environment, and Ministry of Transport. Prof Wiston feel it's not enough.  While sustainability awareness has , understanding of biodiversity has not. Land use change neglected prioritising leaving pockets of young secondary forest where possible or retaining connectivity. Biodiversity in a point of focus in SGP2030. Pillars of SGP2030: City in Nature, Energy Reset, Sustainable Living, Green Economy, Resilient Future |
| What is a "City in Nature"? |
| LKY started planting tree movement in 1963. In 1300s, primeval SG largely forests. In 1819, rapid deforestation by British. In 1900, 90% of primeval forest cleared for agriculture (40% rubber plantations in 1935). 1959: rapid urbanisation & large-scale land reclamation with independence. 1973: <30% land area is natural vegatation. 1990: 99% of original forest lost and >50% SG is urbanised.   |  |  | | --- | --- | | 1963 | Vision I - Garden City (Economical development, First World image) | | 1988 | Vision II - City in a Garden (Recreational spaces, enhancing urban areas) | | 2011 | Vision III - Biophilic City in a Garden (Connectivity, natural heritage protection, community involvement) | | ≈20% natural vegetation + 30% managed vegetation. Connectivity btw nature parks, par connectors, streetscapes is most extensive. Enhancement of nature reserves – buffer parks and habitat enhancement. Acquisation of Rail Corridor. 1st naturalised waterway at Bishan-AMK Park | | 2017 | Vision IV - City in Nature (Conserving and restoring natural ecosystems, world class parks and gardens, ecological connectivity) |   Waterways: SG has 17 reservoirs to collect and store rainwater and used water. 4 national taps: reservoirs, imported water, NEWater, desalinated water  Concern about cross-island line (2013) gg across cenctral catchment nature reserve.  Coastal and marine environment: Mandai mangroves and mutflat now a nature reserve, 2018  50% increase in nature park land by 2030   |  |  |  |  | | --- | --- | --- | --- | | City in Nature by 2030: | Conserve and restore natural ecosystems | Establish world-class gardens and parks with nature | Restore nature into urban landscape | | Strngthen island-wide ecological and recreational connectivity | Enhance veterinary care and animal management | Build science and tech and industry capacity | Inspire communities to co-create and be stewards of nature | |
| Are all green spaces alike? |
| |  |  |  |  | | --- | --- | --- | --- | | Types of Green: | Grasslands - grass dominated | Scrubland - grass + shrubs | Woodlands - sparse tree canopy | | Forests - dominated by trees and woody vegetation | Primary rainforests (10% left by 1900) "virgin" forests | | | Mature secondary forest (later stages of growth) 40-100 years  (Central catchment, Bukit Timah, SG Botanic Gardens rainforest) | | | Young secondary forests (recovering from agriculture and settlements) <30 years | | | Exotic dominated secondary forests (mostly non-native species) | |   Our forests are mostly young. Source-sink model suggests forest seeds from older forest can reach younger ones, if they are connected |
| What is ecological connectivity and why is it critical? |
| Wildlife in forests can interact with other animals and perform ecosystem functions including seed dispersal. Fragmented habitats isolate animal and plant populations. Bukit Timah still fragmented.  Sources of disturbance: Roads, Paths, Human traffic (trail compaction; illegal night walks), Quarries, Condominiums (mosquito fogging), Compounded by size  Impact of edge effect: with drying of forest edges, more light penetration is received, leading to further fragmentation of a fragment. Globally, 70% of remaining forests is 1km from forest edge. Biodiversity reduction: 13 - 75%; and biomass reductions  BTNR very fragmented. 2014: limited access for repair works. But public demand was acute, so Summit Trail reopened  Connectivity impt for aerial, arboreal, terrestrial, fossorial and aquatic animals. Urban avoider: confined to natural habitats. Urban adapter: occur at margins or partly naturalised urban areas, occasionally straying into urban areas. Urban exploiters: e.g. commensals. Can improve genetic resilience of isolated pop of wildlife  Tengah forest could connect Western Catchment to Central Catchment. But 2019, plans to develop tengah forest revealed. |
| Will the OneMillionTree movement (OMT) help? |
| Through Ecological Profiling Exercise (EPE), NParks had identified source habitats and nature corridors in Clementi-Ulu Pandan area. Findings show 2 main ecological connectivity btw BTNR and Southern Ridges  Engagements have increased: Specific site engagements with agencies, Friends of Parks for ground up planning, Scientific Advisory Panel (part of NParks's islandwide EPE), URA Long Term Plan Review  OMT is a national effot to plant average of 100,000 plants per year for 10 years.  NUS planting commitment (2018) commit planting of 100,000 trees (10% of OMT) |
| What can you observe on the ground and realise? (Field Trip & Workshop) |
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| Where do native ecosystems survive in SG? |
| Forests: BTNR, CCNR, Labrador NR, Pulau Tekong, Pulau Ubin, Sungei Buloh Wetland Reserve (SBWR), Western Catchment  Terrestrial forests: Western Catchment, Central Catchment & Bukit Timah, Pulau Ubin, Pulau Tekong  Old forest: BTNR + CCNR  Mangrove: SBWR, Pulau Tekong, Pulau Ubin, Berlayer Creek, Khatib Bongsu, Mandai Mangrove and Mudflat, Pasir Ris Park, Pandan  Beaches: Labrador Park, St John Island, Changi Beach, ECP  Sheltered Coast -> more mangroves; exposed coast less. |
| How do we know about landuse change? |
| Berlayer Creek. 1914, Freshwater swamp at foothills of Mount Faber and Berlayer River meanders through valley of mangroves to Keppel Harbour. 1930, freshwater swamp drained, Berlayer River canalised, mangroves intact. |
| What can we do about ecosystem degradation? |
| OMT, currently planted 272, 232 trees. Growing a forest, habitat enhancement, coastal cleanups.  SBWR restoration plan at Kranji Coastal Nature Park. Secondary rainforest allow for natural recruitment of mangrove seedlings, planting of dominant species where seed source not available, planting of framework species (nitrogen-fixing and fruit-bearing trees) to fix nitrogen to modify disturbed soil and attract dispersers such as birds to bring in species from adjacent forests  Partnership with various organizations  Habitat enhancement not just tree-planting: soil prep, tree-planting, seedling protection activity (leaf litter). Is a long term commitment to establish or enhance a forest  Soil prep: weed clearance, soil exposure, soil loosening, soil digging, soil enhancement, tree hole readiness  Chestnut Nature Park, Rail Corridor |
| What solutions can we offer for ecosystem connectivity? |
| Culverts, Rope bridges, Ecolink, Nature ways |
| Human-Wildlife Interactions |
| Tap expertise of ground up working groups (WG) – NGOs, researchers, interest groups. (Marine Turtle WG SG, Pangolin WG, Freshwater Crab WG SG, Otter WG SG, Banded Leaf Monkey WG SG, Urban Wildlife WG, Long-tailed Macaque WG)  Public, Wildlife Reserves Singapore, Otterwatch, NUS, NParks, LTA, PUB, ACRES, AVA |
| Biodiversity Conservation for climate change requires more than science |
| Growing Community through Shared Use and Forest Stewardship. Need get science correct / assisting nature the right way and involve all stakeholders in the community. |

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| Sources of Climate Change btw countries |
| Inherent inequalities. Most gg emissions from energy sector, then (agriculture, forestry & land use), then industry. High human development countries produce more gg emissions. Country overshoot days very nearer for developed countries.  Ecological footprint of individuals most in excess of world's biocapaacity are mostly from affluent countries.  Pop of economies most vulnerable to cc contribute least to accumulation of gg  Climate risks disproportionately affect the poorest countries and people, who are more exposed and vulnerable to their impacts.  To fulfil objective of limiting temp incr to 2, need to limit warming to 1.5. Paris Agreement associates principle of equity with goals of poverty eradication and sustainable development. Recognise that effect response to cc require global collective effort guided by 2015 UN Sustainable Development Goals (SDG)  SDG are goals under the 2030 Agenda for Sustainable Development, global development framework agreed by all countries at UN Sustainable Development Summit in 2015. Comprises 17 SDGs with 169 targetsand 247 indicators to measure progress towards reaching targets. Rebranded as The Global Goals   |  |  |  |  |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | | No Poverty | Zero Hunger | | | Good Health & Well-being | | | Quality Education | | Gender Equality | | Clean Water & Sanitation | | | Affordable & Clean Energy | | Decent Work & Economic Growth | | | Industry, Innovation & Infrastructure | | Reduced Inequalities | | | Sustainable Cities & Communities | | Responsible Consumption & Production | | Climate Action | | | Life Below Water | | | Life On Land | | Peace & Justice Strong Institutions | | | Partnerships for the Goals | | |
| What is the hinterland? |
| Remote areas of country away from the coast or banks of major rivers. Rural area economically tied to an urban catchment area. Rural ares which supply city with natural capital and food.  Metropolis: large poverful urban community. Hinterland: surrounding territory which metropolis dominates through mainly economic means. |
| What spaces are we dependent on in SG? |
| |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | | Food | Food security prioritised over sustainable food sources.  2019 – due to cc and pop, world set to face 56% shortfall in food nutrition by 2050. Shortfall in food needed to feed world in 2050 likely to be exacerbated by global shortage of ≈ 600 million hectares of agricultural land.  SG food security: production of vegetables, fruit, poultry and fish. Import over 90% of food supply. Vulnerable to disruptions in transport routes, export bans, cc. Redundancy in supply.By 2030, aims to produce 30% of nutritional needs from curr 10%  82% of our food imported from over 170 countries (AVA 2017).   |  |  | | --- | --- | | Sources of vegetables: Malaysia, China, Australia | Potatoes, Onions, Cabbages | | Sources of fruits: Malaysia, China, US | Watermelons, Bananas, Oranges |   SG remain food secure by political/economic/legal: diversify import food sources, tech: high-tech farms, social: reduce food waste | | Water | World Meteorological Organization's State of Climate Services (2021): global water stress hotspots affect 25% of pop  2015 El Niño: SG consumes 400 million gallons of water.3 districts in Johor underwent water-rationing, affecting > 640,000 industrial and household consumers for a month. Hence desalination and NEWater plants freshwater production and very few people noticed the water shortage.  Our tap water quality is well within SG Environmental Public Health Regulations and WHO Guidelines for Drinking-water Quality. Water is safe for drinking directly from tap without any further filtration.  Curr: 45% domestic water, 55% non-domestic. NEWater supply 40%, desalinated water up to 30%  By 2030: 40% domestic, 60% non-domestic. NEWater 50%, desalinated water up to 30%  By 2060: 30% domestic, 70% non-domestic. NEWater 55%, desalinated water up to 30%  By 2010, SG has 17 reservoirs. | |
| Does it help that more than half of world's pop are in cities? |
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| Provide examples of scientific inquiry within the area of climate change by relating concepts and/or content from block 2 to block 1. |
| |  |  |  |  |  | | --- | --- | --- | --- | --- | | Observe, Explain, Test | | | Traditionally, theoretician = someone who developed testable theories. Nowadays, theoretician = putting together mathematical, and computer models. These models make predictions that can be tested against observation. So, theoreticians are in charge of explaining and testing, but leave observation to scientists skilled in this area.  Fourier 1st to realise that we cannot explain the temp of the Earth surface if we don't consider the atmosphere. Found that if we only considered radiation from the sun or from the interior of Earth, Earth would be much cooler than it is. He correctly identified that atmosphere must play a role, and he did this by making use of a metaphor. He said that “the Earth is kept warm because air traps heat, as if under a pane of glass”. We now know that this  is not quite right, but the essential element that we need to consider the atmosphere was correct. | | | Authority | |  |  | | --- | --- | | Scientific Consensus & Authority | Colloquially, authority = person or organization having political or administrative power & control  In science, consensus is achieved when the great majority of scientists of a given field agree upon a position based on a large amt of verified evidence. Something can only be science if it is verifiable.  There is a danger that scientific consensus could be seen as an arg from authority. (frequently articulated by cc deniers). Scientific consensus is not the general opinion of scientists. Few things in science have been verified more than the position that cc is happening. | | Pseudo-authority | Authority can be abused. John Sununu, Chief of Staff in the George H. W. Bush White House, who attempted to undermine the work of climate scientists and ultimately the international community in fighting cc. He argued from authority that global warming was “poppycock”. | | Authority as an expert, but still wrong | But it isn’t just educated people in the wrong field. Sununu did not have the required authority that is in CRAAP test to speak on issues of cc. However, Richard Lindzen, a professional climate scientist, has the authority to speak on issues of cc. And it is important that his voice is heard. However, his ideas for a solar source to rising temperatures are not confirmed by experiment and so his ideas are not part of the scientific consensus. Authority and consensus are different. | | | | | | Scientific Revolution | | | Paradigm found in the alchemical writings of Becher and Stahl were replaced with the ideas of Lavoisier. This transformation in thinking led to the development of chemistry as a rational and distinct scientific discipline. This chemical revolution centred on understanding nature of O2, and in particular, the role that O2 plays in combustion. Lavoisier established our modern understanding of combustion through recognizing that mass is conserved, that the O2 lost from air during combustion of a metal can be found in the metal oxide product. The law of conservation of mass underpins all of chemistry which is why Lavoisier is rightly called the Father of Chemistry. | | | Invention of new instrument leads to new discoveries | | | Ratio spectrophotometer built by Tyndall was critical in determining the relative importance of diff gg.  However, most impt instrument in climate science has been the computer. 1st attempt at performing a meteorological forecast through computation was conducted by Lewis Fry Richardson in 1922, before the advent of the modern computer. Not only did his 6-hour forecast take months to calculate, but it was also full of errors that no one repeated such calculations for 30 years. Without computers or the supercomputers used in climate modelling, we would not be able to project the effects of cc. It would simply not be possible to couple together all of the diff parts of the Earth sys, or indeed even understand isolated elements of the Earth sys. | | | Scientific Community | | | With a community in place such a thing as a scientific consensus becomes possible. The scientific societies that arose during scientific revolution became the model for open and frank discourse today. It was climate scientists being brought together to evaluate the emerging evidence that led to the consensus position around cc.  The Royal Society of London was an early example of such a scientific society. It was greatly influenced by Francis Bacon and his vision of experimental science. Bacon stated that the ultimate goal of scientific inquiry was power over nature. I fear this tradition is responsible for the current state of our climate. | | | Industrial Revolution | | | 1850 to 1900 was used as proxy for ave global temp for pre-industrial period. However, the industrial revolution, , was from the mid-to-late 1700s to mid-1800s.  We use ave temp btw 1850-1900 as a proxy for pre-industrial temps is because: 1st, we don’t have reliable instrumental records to construct a global ave prior to this; 2nd, we don’t believe CO2 emissions from the coal burnt btw the advent of the industrial revolution and this period would have significantly influenced global temps. | | | Scientific Observ-ations | | | When making proper scientific observations, we must consider any necessary comparative information. This was critical to Dr Semmelweis’ work and later when we discussed control groups.  This method of difference that dates back to William of Ockham is very common in science. We subtracted baseline temps, such as the 1850–1900 ave, from global temp measurements to reveal changes in temp. Also compared CO2, methane and nitrous oxide measurements to past levels to reveal differences. These were used to argue that gw was happening and that the suspected cause, i.e. gg, were also increasing. | | | Pre-ponderance of Evidence | | | | For cc we didn't just look at 1 instrumental temperature record but 4 – NASA, NOAA, the UK Met Office and the Japan Meteorological Agency. All treated data slightly differently and thus produced slightly diff temp records. However, all agreed extremely well and showed that global ave temps are . | | When looking at whether recently temp rises were unusual, scientists had to estimating temp prior to the instrumental temp record and used proxy mtds, including tree rings, coral rings and ice cores. All these proxy mtds agree and show that rapid in temp is unprecedented at least in the last several thousand years. | | Projections and analysis found in the IPCC Sixth Assessment Report come from 100 climate models developed from 49 distinct research groups. The preponderance of evidence from these model simulations is that global temps will , sea levels will , ocean pH will fall, and Arctic sea ice will continue to decline. | | Cc is happening due to human fingerprints. Again, we are not relying on single pieces of evidence we are looking at evidence found throughout the Earth system. This convergence of evidence is part of the process of verification and the establishment of scientific consensus. | | Testing an Explanation | | | In Baloney Toolkit, one of the tools is “Has anyone tried to disprove the claim?”.  Scientists have tried to disprove the claims that cc is happening and that it is human caused. They have studied whether temp could be natural variability, but no evidence. Scientists have attempted to prove that the temp is due to solar variability and changes in volcanic activity and again no evidence to support. Only explanation that scientists have failed to disprove is that the in temp is due to the in gg, in particular, CO2. | | | Scientists also attempted to prove that in CO2 is not human caused, but a variety of evidence has shown that it is. 1 evidence is of carbon-14 (more accurately the ratio of carbon-14 to carbon-12), in atmosphere after open-air testing of atomic weapons. Rate of dilution of ratio of carbon-14 to carbon-12 can only be explained by the emission of CO2 from burning of fossil fuels which are devoid in carbon-14. In fact, the amt of CO2 released through burning of fossil fuels is exactly that required to achieve the dilution observed. | | | Misinfo-mation, Falsehoods and Lies | | | Cc denial was influenced by political lobbyists and this influence permeated into the political discourse. Vested interests by fossil fuel industry, and doubt mongering by political lobbyists and contrarian scientists deeply damaged the prospects of action. Advent of internet in 1990s, 24/7 news cycle, and pervasiveness of social media divided opinion on a topic with no serious debate in scientific community. Political lobbyists mainstream their contrarian positions using techniques they picked up in the fight to limit regulation in the tobacco industry.  We all have biases, and are susceptible to these biases, but recognizing that you have biases and are susceptible is the first step to critically evaluate information that you might prefer to deny. | | | Theories & Hypotheses | | | Phlogiston theory states, that a metal is made of what Becher and Stahl called calx (metal’s true form), and phlogiston. When metal is heated the calx is revealed and the phlogiston is seen to leave the metal. At the time, this was a very popular scientific theory. Indications that there might be problems with the theory were found not least by Boyle in 1673, Lémery in 1675, and Freind in 1709, that showed that the metal gained weight when heated. Advocates of phlogiston theory then argue that the phlogiston liberated in combustion has “negative weight”. Phlogiston theory also limited a proper understanding of the role of O2 in combustion. Lavoisier recognize that combustion is solely about the reaction with O2. Many scientists did not see as clearly, blinded as they were to their adherence of the phlogiston theory. Lavoisier’s theory explained the appearance of water when hydrogen is burnt and also helped in our understanding of respiration. | | | Cause & Effect, Causal Mechanism | | | James Hansen at Senate hearing in 1988 wanted to state that a cause and effect r/s existed btw the greenhouse effect and observed warming. Gw is cause and cc is the effect; i.e. heating of Earth causing changes in diff areas. | | | In feedback loops, diff elements can be connected to one another. -ve couplings = -ve correlation. Similarly, +ve couplings describe situations in which elements are +ve correlated. These couplings directly describe cause and effect r/s, and feedback loops describe forms of causal mechanisms. | | | Certain effects can have many causes. Believing that a effect can only have a single cause = single cause fallacy. Cc deniers used this to argue that because cc has happened before, cc that is happening now can’t be due to us. | | | Underlying Processes, Laws & Functions | | | When talking about greenhouse effect, it was the gg (CO2), that absorb long-wave infra-red radiation from Earth and prevents that radiation escaping to space. This is an underlying process and was discussed by Tyndall & Foote. | | | Statistical law. This was used to suggest that we are all susceptible to cognitive biases. Some people might be more susceptible to self-serving bias, others to time-discounting bias. | | | Function of plants in the carbon cycle. Plants take up carbon dioxide from the atmosphere in order to photosynthesise. Plants also function as the source of food for certain animals. | | | Correlation | | | There are correlations btw the diff proxy mtds, such as the tree-ring widths, coral band widths and temp. Without these correlations these mtds wouldn’t work. Another correlation that I shared was the breathing earth. We saw the seasonal variation in atmospheric CO2 -ve correlating with the rates of photosynthesis in the biosphere, particularly the northern hemisphere forests. | | | Correlations are also used by cc deniers. The apparent +ve correlation btw temp and solar variation up until around 1980 was used to argue that gw was natural and due to changes in solar radiation. But the +ve correlation has disappeared in the last 30 years and if anything there is a -ve correlation. | | | Scientific Models | | Models are absolutely essential in science. Some mathematical models, like the single-layer atmosphere model, are not really used to do science but for teaching. Nowadays, almost all models are computer models. The phenomena that models are designed to explain are so complex that they can only be modelled in computer simulations. | | | | Contempo-rary Scientific Research | | | Research isn’t free and can sometimes be quite expensive. Supercomputers for climate models are also extremely expensive and their energy costs are very demanding, i.e. carbon footprint of climate model simulation very high. Unless simulation can truly add something to our understanding of climate science or how cc will evolve, it may be morally wrong to do the simulation. | | | Un-certainty & Confidence Levels | | | In late 1980s. James Hansen argued on the basis of the magnitude of natural variability that it was virtually certain that cc had happened.  Another issue that arose was in the language used in IPCC reports. There was conscious effort by climate scientists to convert the jargon around confidence and likelihood into language that could be readily understood by policy makers. Terminology like “very likely” and “virtually certain” converted to probability of occurring. | | |
| Explain the relationship between the each of the tools in the Baloney Detection Toolkit and Science. |
| |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | | How reliable is source of claim? | | Same as “Authority” check in CRAAP test. In any scientific endeavour, scientists must be able to rely upon the relevant data and the work of past researchers. While conducting a literature search scientists must use reliable sources, typically primary literature from well-respected peer-reviewed scientific journals. This generally, but not always, ensures reliability. Scientist research area also important. In the wider context, used to figure out if claimant even knows what they are talking about, or at least cites “CRAAP test passed” references to back up their claim – which adds to their credibility and reliability. | | | | | | | | Does source make similar claims? | | Tool is really referring to extraordinary claims. To figure out if source is biased. In science the equivalent qn would be “Does source consistently take a contrarian position?”. If yes, then may have motive other than objective evaluation and interpretation of evidence. Else, could be attempting to parse scientific results as objective but are in fact biased. Proper science is objective and unbiased. | | | | | | | | Have claims been verified by somebody else? | | | | | In science this is referred to as “reproducibility”, and not “repeatability”. Repeatability = researcher repeats a measurement many times, perhaps to establish uncertainty of their measurement. But reproducibility = when another independent research group can reproduce what the original researchers found. | | | | | Does this fit with the way the world works? | | | | In science this means: Does it conform to our curr understanding of the natural world? If observation, or claim, is at odds with what we currently understand about the natural world, then it is an anomaly. But most anomalies turn out to be not anomalous at all. If something is reported as an anomaly, then it will need further investigation to sort it out. | | | | | | Has anyone tried to disprove the claim? | | | | | | | This is directly asking if the claim has been tested – the foundational third step of our scientific method in a nutshell. An explanation must be falsifiable then tested to see if, indeed, it is falsified. | | | Where does preponderance of evidence point? | | | | This tool is intimately linked to scientific consensus. IPCC is a body set up to evaluate where the preponderance of evidence points with regard to cc. Evidence in science constitutes a test of an explanation, the more evidence, then the more tests we have, the surer we are that explanation isn’t wrong. Well established theories all have a preponderance of evidence supporting them. A preponderance of evidence forms the basis for an objective and honest understanding of the world. | | | | | | Is claimant playing by the rules of science? | | | | | | | | No need to dwell on this tool. It is asking if the scientific method is being properly followed in all the detail we have provided in this module | | Is claimant providing positive evidence? | Providing evidence directly supporting explanation or claim. Alternative explanations are wrong != evidence to support some other untested explanation. Eliminating alternative explanations, so that only one remains != one remaining is true. This is a fallacy because there may be yet another true explanation for the phenomenon that we dk. For a claim or explanation to be supported we need to find evidence that directly supports it. This is fundamental to testing all scientific explanations. | | | | | | | | | Does new theory account for as many phenomena as the old theory? | | | | | | This tool can readily be applied to conspiracy “theories”. Such “theories” often provide alternative explanations for events, but often ignore specific pieces of evidence, or misrepresent it when it is at odds with the theory. For an alternative explanation to be fully supported by the evidence in science it must account for all known evidence other testable explanations have no issues accounting for. | | | | Are personal beliefs driving the claim? | | | Check if science reported is objective. One of five concerns that must be addressed when making scientific observations – “Have our observations been contaminated by expectation of beliefs?”. Also includes interpretation of data. CRAAP test – “P” of the test for purpose. Without objectivity, false conclusions can be drawn and wrong explanations for phenomena incorrectly accepted as supported. | | | | | | |
| Describe each of the eight fallacies put forth in the name of science, providing examples to illustrate their meaning. |
| |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | | Fallacy = flawed reasoning or logic, incorrect or improper use of scientific method, or a deliberate act to misrepresent something. | | | | | | | False Anomalies | | | Genuine anomalies are important for science as they can lead to either more evidence to support a currently established theory, or may require revision of a theory, or even create an entirely new scientific field.  With false anomalies, claimant typically present some phenomenon as being mysterious, not explicable by science, then provide their own explanation, which often is an extraordinary claim. Slight-of-hand occurs when they leave out evidence in support of a regular scientific explanation, or misrepresent or falsify evidence. | | | | E.g. Crop circles: large, symmetrical geometric figures, circular and otherwise. “Mysteriously” appeared in wheat and corn fields in Southern England and have since been observed in many other countries. Made out to be anomalies with advocates suggesting there is no explanation for how they could be generated. Patterns are often found in middle of crop fields where there were no obvious signs of human intrusion. Then the extraordinary claim is made that the patters were made by aliens or their spaceships. | | | | However, what is purposefully disregarded are “tramlines”, which are either near or run through these patterns. Tramlines are indentations made by tractors as they travel through crop fields. Has been demonstrated that a hoaxer can simply walk down these tramlines, and with a few tools, create these circles quickly and easily. | | | | Questionable Arguments by Elimination | | | | | Same as tool 8 of Baloney Toolkit – “Is the claimant providing positive evidence?”. Here the claimant considers evidence that an alternative explanation is wrong to be actual evidence in support of their explanation. | | E.g. extrasensory perception (ESP). Often, strategy used to “prove” that someone can read another person’s mind is to show that ability cannot be explained by random guessing/ luck. E.g. ESP sensitive can tell what card someone else is looking at. Under tightly controlled experimental conditions, it can rule out possibility of luck at guessing the card, but does NOT prove that person has ESP. If there were only 2 possible explanations for what is observed. 1) Claimant has ESP or 2) Claimant is just lucky, then ruling out luck can conclude claimant has ESP. | | Else, eliminating luck explanation does not provide +ve evidence for ESP as can provide another explanation.  E.g. a magical invisible imp, indicating to person claiming to have ESP which card the other person is thinking about. There is just as much evidence that claimant has ESP as there is for the magical invisible imp. In fact, only conclusion we can draw is that something quite interesting is occurring that isn’t fully understood.  What we can NOT conclude here is that we HAVE evidence for ANY explanation for the phenomenon yet – all we have shown is that luck isn’t the explanation. So just by eliminating rival explanations doesn’t provide evidence for your favourite explanation. One needs to find positive evidence directly in support of it. | | Illicit Causal Inferences | | | Correlation doesn’t imply causation. OR it could be that some out of the ordinary occurrence precedes some other out of the ordinary occurrence, so one jumps to the conclusion that there is some causal link btw the two | | | | E.g. you’re thinking of a friend and then the phone rings, and it was the exact same person you were think about! Perhaps it means you have ESP, but it’s far more likely that it’s just coincidence. Think of how many times you’ve thought about your friend, and they didn’t call you, or how many times they called you and you weren’t thinking of them. That the two events should occur in close proximity every so often seems not all that unusual. | | | | E.g. just because you enter a lift as someone else exits it and then you smell something quite bad in the lift doesn’t mean that the person that just left the lift had anything to do with the stench. | | | | Unsupported Analogies & Similarities | | | | | Scientists sometimes use analogies to something that is well understood to help explain something puzzling. However, this can be exploited when the fact that an explanation works in one case is given as evidence for the correctness of a similar explanation in another case. This is because, a well-chosen similarity guides us to a possible explanation; it should not be thought of as providing evidence that the explanation is correct. Only careful testing can provide such evidence. | | E.g. astrology, which is a pseudoscience. Astronomy is science normally, but astrology is not. Astrology proports that positions of stars and planets at the time of our birth can influence our personalities or even our choices of profession. So, because the moon influences the tides on Earth, and sunspot activity can disturb radio transmissions on Earth, we can conclude that positions of the planets have an impt influence on formation of the human personality? Of course not. There is zero evidence to be found in the analogy and similarity that the positions of the planets have any important influence on the formation of the human personality. | | Untestable Explanations & Predictions | | | | E.g. “fate” as an explanation for something occurring, or the “dragon in my flat” conversation with Prof Lee.  If an explanation cannot be experimentally shown to be false, then it isn’t a scientific explanation. It could be the explanation, but there’s no way to check. When accepting some explanation, should ask ourselves: “Under what conditions would we be willing to set aside the explanation on the grounds that it is false?” If you can’t think of any such conditions, then the explanation you have isn’t a scientific explanation. | | | Many conspiracy “theories” fall under this category, and can seem plausible as they are immune to falsification. They can be circular in their “evidence” for their theory. E.g. These “theorists” believe they have uncovered various anomalies in the 9-11 attacks, then provide an explanation involving powerful government conspirators, and when asked for evidence, simply rehash the anomalies they believe they uncovered in the first place. There is no body of independent evidence. An anomaly isn’t evidence. An anomaly requires a falsifiable explanation.  Any real evidence that their theory is wrong is claimed to be fabricated by the conspirators, and lack of evidence they also claim is actual evidence of their conspiracy because all the evidence has been disposed of and covered up! Such explanations are not scientific as they are not falsifiable. | | | Empty Jargon | Science itself is full of jargon, so that communication btw scientists can be brief without having to constantly explain concepts and objects the jargon represents. However, conmen can highjack this language and string together a bunch of terms, which means nothing, in order to try and convince you that something is scientifically established. | | | | | | Ad Hoc Rescues | | It is normal in science for an experiment to give -ve results when a diff outcome was expected. Maybe we have a flawed experiment, and are about to falsely reject our explanation, or maybe we just need to make some minor adjustments and we will get the expected results. | | | | | But there must be a point where no matter what one tries, hypothesis cannot be verified. At this point we have to admit that hypothesis is wrong. However, if one continues to refuse to admit that they’re wrong, then this is an ad hoc rescue. i.e. still accepting something as true despite a lot of evidence that it isn’t. If there isn't any point where we will admit our explanation or claim as false, then this explanation or claim is untestable and thus not scientific. | | | | | Exploiting Uncertainty | | | | Doubt mongering around well- established causal links btw lung cancer & cigarette smoking, CFC emissions & stratospheric ozone hole, UVB radiation & skin cancer and SO2 emissions from coal burning power plants producing acid rain that in turn destroys forests, and finally attacking cc. | | | The clearest e.g. is by Frank Luntz who states that their position against the scientific consensus on cc is closing. Luntz said that “you need to continue to make the lack of scientific certainty a primary issue in the debate”. | | | Science is fraught with uncertainty. Even in a simple measurement, there is a ± associated with the reading, we also have confidence levels in science. We also know that conclusions regarding explanations can be wrong because of errors due to false confirmation or rejection, and that what once was a well- established scientific theory can be overturned and become obsolete as new evidence comes to light and a new theory established. | | | Far from being a weakness, this uncertainty is Science’s major strength. Science IS self-correcting because of this uncertainty. If there comes a point where science was able to state some scientific conclusion with absolute certainty, then it's no longer science but an authoritarian world view. | | | However, just because something isn’t 100% certain doesn’t mean that it isn’t certain for all practical purposes. E.g. A third +ve test = 99.9% certain we have the disease instead of 91% from two +ve tests. E.g. Salk vaccine field trial, can be confident that something is correct to an extremely high degree. And great preponderance of evidence for something provides confidence and credibility in conclusions drawn and explanations given. | | | It’s the merchants of doubt that want to recast tiny levels of uncertainty into large ones – turning somethings that has 99.99% confident into a 50-50 conclusion either way. | | |
| *Explain* the three ways that we cannot use to distinguish science from pseudoscience, and the four features that do distinguish science from pseudoscience. |
| |  |  | | --- | --- | | Pseudoscience isn’t actual science, it’s fake science. Pseudoscience often uses the fallacious methods we discussed in the last section in an attempt to establish credibility when there is little to none present. | | | Nothing to do with “hard” & “soft” sciences. | Sometimes, people say pseudoscience is soft science, which is wrong. Soft and hard science just refer to diff fields of study. Hard science: fields of physical, chemical and biological sciences. Soft sciences: fields engaged in the study of human behaviour like sociology, anthropology, psychology, political science  Both soft and hard sciences aim at explaining phenomena of the natural world. All fields use the rigorous mthds for observing, explaining and testing, so none deserve the label of pseudoscience. | | Nothing to do with lines of scientific discipline. | Cannot distinguish btw science & pseudoscience just because hypothesis, theory or claim exist within one of the hard or soft sciences. E.g. just because something is in the field of astronomy, doesn’t automatically mean that its science. This is because nonsense can be promulgated in any subject area.  Textbook e.g. Immanuel Velikovsky, in 1950s hypothesized that Venus was created out of an enormous volcanic eruption on Jupiter. Speculated that during its voyage from Jupiter to is current orbit, as it passed by the Earth, it caused several cataclysmic events. There is zero evidence to support such a claim. Nevertheless, this nonsensical hypothesis lies within astronomy, so a hypothesis being within a respected scientific discipline ≠ science. | | Nothing to do with basis of the results each produces. | Can’t claim something is a pseudoscience based on the fact that ultimately it turned out to be wrong. Phlogiston Theory, which became an obsolete theory after Lavoisier’s work. Lavoisier was one of those scientists that then established a new theory in its place – Caloric theory, but also ended up becoming obsolete.  Both obsolete theories were considered “well-establish” theories for their time with various scientific evidence in support of them and having been subjected to the all the rigours of the scientific method. The fact that these theories ultimately ended up being wrong, doesn’t make them a pseudoscience. |   Ways to differentiate science and pseudoscience   |  |  | | --- | --- | | Science | Pseudoscience | | Is self-correcting | Not self-correcting | | As a scientific discipline develops, will gradually produce a maturing body of explanatory or theorectical findings | Produces very little theory | | Findings, theoretical or otherwise are open to revision | Rarely do pseudoscientific claims change over time | | Embraces skepticism  Motto of the Royal Society: Nullius in verba. Scepticism is ever present in science, which is why the testing part of the scientific method in a nutshell is required. | Tends to view skepticism as narrow-mindedness  Narrow-mindedness isn’t a valid argument not to test an explanation, nor to provide proper scientific evidence in support of it. | | Note that anecdotal evidence, or testimonials, or eyewitness accounts, carries little to zero weight in science. | |  |  |  |  |  |  | | --- | --- | --- | --- | --- | | Pseudoscience | | | Concerns | | | Astrology | | | Predictions of human affairs and events by studying movements of heavenly bodies | | | Ufology | Aliens visit us in their spaceships. Not the same as SETI program (science devoted to search for extra-terrestrial life) | | | | | Parapsychology | | | Study of alleged psychic phenomena (ESP, telepathy, precognition, clairvoyance, telekineses, etc.) and other paranormal claims | | | Immanuel Velikocsky's Work | | | | Volcano on Jupiter creates Venus and causes various cataclysmic events. Also involved in pseudohistory | | Crytozoology | | Study of existence of entities like Big Foot, Loch Ness Monster, Yeti, Chupacabra, Bukit Timah Monkey Man, etc) | | | |