LLS2024 Part 4 — A Brief Primer on Global Warming

As Presented

By Vincent S. Cronin, revised October 12, 2024

SLIDE 1 Lecture series title slide.

SLIDE 2 Topic title slide.

SLIDE 3 The year that I was born, most geoscientists thought that Earth was in an interglacial period, and that the global mean surface temperature would eventually cool as we slipped into another "ice age" characterized by expanding glaciers and decreasing sea levels.

SLIDE 4 It was assumed that the ice age cycle was controlled more-or-less exclusively by Milenkovich cycles dominated by planetary processes: cyclical variation of gravitational attraction by other planets that causes our orbit to vary in its eccentricity on a 100,000-year cycle, slight variations in the tilt of Earth's spin access on a 41,000-year cycle, and precession of the equinoxes on a 26,000 year cycle.

SLIDE 5 Elsewhere across the landscape of science, other folks studied the atmosphere and its chemistry. The history of this quiet scientific development is well told by Spencer Weart in an online resource hosted by the American Institute of Physics website. The link is shown at the bottom of this slide, and is also accessible from this lecture's website. Simply recounting the story of climate research would take all of our time today, so I will minimize the history in favor of the data.

A large impetus for this research was concern over air pollution. Coal was introduced in London as a fuel for lime kilns and forges by 1228 CE and was banned by King Edward I in 1306 to curb the negative health effects of air pollution. (The ban lasted only a couple of decades.) A few years before I was born, the people of modern London experienced an atmospheric inversion that, for 5 days in December 1952, caused a deadly concentration of smog that killed thousands.

SLIDE 6 A connection between the atmosphere and surface temperature was first described by Joseph Fourier in work published in 1824 (and enhanced by Claude Pouillet in 1827 and 1838) indicating that Earth's atmosphere acts to trap radiation from the sun, and warm Earth's surface.

SLIDE 7 In 1856, Eunice Newton Foote wrote a paper, published under her husband's name, in the American Journal of Science and Arts titled "On the heat in the Sun's rays." Eunice reported results of her experiments that solar heating of gas [1] increased with increasing gas density, [2] increased with increasing water vapor, and [3] increased with increasing "carbonic acid gas" or carbon dioxide. She prominently noted in her conclusions that an increase in carbon dioxide in the atmosphere would cause an increase in temperature.

These scientific advances are now considered the dawn of our understanding of greenhouse gases and the atmospheric contributions to climate change.

SLIDE 8 Let me introduce you to two of my most important mentors as a student geologist: Mason Hill and A.O. Woodford. Woody founded the Geology Department of Pomona College just over a century ago. Mase was one of its earliest graduates in 1926, and along with Tom Dibblee was the first to demonstrate large-scale slip along the San Andreas Fault. He coined the term "strike-slip fault." He was a co-discoverer of the first commercial oil field in Alaska. Woody drew many students into geology over his decades of teaching, including this fellow...

SLIDE 9   Roger Revelle earned his bachelors degree in Geology at Pomona College in 1929, and began working at Scripps Institution of Oceanography in 1931. He rose to become its director in 1950, and remained an exceptional researcher throughout his career. In particular, his paper with Hans Suess in 1957 proved that the atmospheric concentration of carbon dioxide was increasing over time, and that increase was largely due to the combustion of fossil fuels. That influential paper in Tellus closed with the following sentence: "Human beings are now carrying out a large scale geophysical experiment of a kind that could not have happened in the past nor be reproduced in the future."

SLIDE 10   Revelle hired Dave Keeling in 1956 to collect a definitive dataset concerning the concentration of CO2 in the atmosphere. As a result, we now have a continuous 67-year history of CO2 collected at the Mauna Loa Observatory in Hawai'i.

SLIDE 11   Our current understanding is based on the work of many scientists and thousands of peer-reviewed published papers.

The result of all this work over two centuries is that we now know from direct measurement that Earth's climate is warming and that the concentration of greenhouse gases in the atmosphere is increasing. The predominant reasons for the increase in greenhouse gases above natural variation are associated with human activity.

A significant number of people reject this knowledge without understanding it. They think that this knowledge might cause a change in the status quo business environment that would threaten our prosperity.

But, you see, Nature doesn't care about how we feel about reality. And in the game of reality, Nature always bats last.

Our challenge as scientists is to usefully characterize that reality so that society can base its decisions on reliable information.

SLIDE 12   Geoscientists are called upon to use their knowledge and skills to deal with natural hazards that, in a warming world, are predicted to increase in frequency, intensity, and complexity as they interact with each other to form compound disasters.

We are living during an interglacial period. We have long assumed that our climate would be constant and predictable — constant in the sense of changing very slowly within a rather narrow range of conditions.

We see that assumption in, for example, the way we define a 100-year flood plain, which has informed how society develops land adjacent to rivers and lakes.

We now know that the assumption of static climate is wrong — that the climate is warming and will be warming for the foreseeable future. So we can no longer look to the past as the key to the present & future. Mean global and oceanic temperature, precipitation, water supply, sea level, droughts, and storm frequency will not just exist within a static bell curve of past experience.

SLIDE 13 There is an ethical dimension of our work as geoscientists that extends well beyond research integrity, spanning a very broad array of issues. But at a fundamental level, our job is to seek the truth bounded by the uncertainties that are always present in our work. As C.P. Snow wrote, "The only ethical principle which has made science possible is that the truth shall be told all the time."

Many talks about the effects of climate change just scare the willies out of us. Geoscientists need to approach these issues with knowledge, respect, determination, and hope.

SLIDE 14 I humbly suggest we have three general tasks ahead of us that we should approach with hope, positivity, enthusiasm, and care to remain good scientists acting in the public interest.

SLIDE 15 First, we need to become and remain informed about the underlying science of climate change so that we will be prepared to offer expert advice to society as it confronts the many challenges of a warming climate. Preparation is a prerequisite for success.

SLIDE 16 Second, we need to communicate knowledge of climate change and its impact on society and the engineered environment in ways that are clear, accurate, useful, and positively directed toward solving problems. Many of us need to learn how to communicate in this way.

SLIDE 17 And third, we need to make decisions and recommendations in light of knowledge of how climate change will affect whatever we are working on over the coming decades. Take the time and the energy you might expend in worrying about the problem and channel that energy into learning about the problem and developing, proposing, and implementing solutions.

The realignment of our perspective to consider a world whose climate is warming provides us with exceptional opportunities to serve society as geoscientists. We have a lot of work ahead of us, and that will support a lot of wonderful careers. A life of service — of science applied in the public interest — is a good life.

This afternoon, I would like to give you a brief primer on global warming, to give you a bit of a push along the first of the tasks I just described — becoming informed.

But first, I want to tell you a story.

SLIDE 18 This fella, Michael Fahey, was born in 1844 in Ireland. His homeland was about to be devastated by a great famine that would lead to about one million deaths by starvation or disease. Another million left the island during the famine.

At the time of his birth, an ocean and a continent away, the little village of El Pueblo de Nuestra Señora, la Reyna de los Angeles in the Mexican province of Alta California had a population of about 5,000 people.

The human population of Earth then was just under 1.2 billion, having crossed the 1 billion threshold around 1800.

SLIDE 19 Here's Michael in 1894 after he emigrated to California (now part of the United States) to work on the railroads. He and his Irish wife have just welcomed their baby, John, into the world. Earth's population was about 1.6 billion.

SLIDE 20 John grew up, survived a World War in France, and worked summers in Yosemite, where he met his soon-to-be bride, Dorothy Kibler.

It's 1919 and Earth's population was about 1.8 billion.

SLIDE 21 John and Dorothy settled in Los Angeles and raised a family at the base of the Hollywood Hills.

It's 1948. About 4 million people lived in Los Angeles County — up from 5000 a century earlier — and Earth's population was about 2.5 billion.

SLIDE 22 Their oldest daughter, Dottie, met and married an army vet named Gil. They raised four kids in the house where Dottie had grown-up. The baby in Gil Cronin's arms is me.

It's 1957 -- the beginning of the International Geophysical Year in which the first measurements of atmospheric CO_2 would be collected at the new Mauna Loa Observatory in Hawaii. Earth's population was about 2.9 billion.

SLIDE 23 It's 1997 and a new family has emerged, with Cindy Ellis Cronin and our descendants Kelly and baby Connor.

Earth's population was about 5.9 billion — doubling since the previous photo was taken in 1957.

SLIDE 24 Today, the population of Los Angeles County is over 10 million. During the timespan of 5 generations, the number of people living in LA County increased by a factor of about 2000.

SLIDE 25 Earth's population has passed the 8 billion mark, increasing by a factor of almost 7 since this timeline began with Michael Fahey in 1844.

SLIDE 26 Today in another branch of this family, my sister's daughters and daughter-in-law all have children, and some of these are at early childbearing age. Those young adults and their anticipated children will be the sixth and seventh generations of this family's story.

The idea that we bear a debt to the legacy of those who came before and a responsibility to those who are to come can supply a humbling and useful context for our actions.

The Chief of the Onondaga Nation, Oren Lyons, wrote that it is a mandate that chiefs make every decision relate to the welfare of the seventh generation to come.

SLIDE 27 Plotting the growth of Earth's human population since 1844, and including some of the family birthdays, we see a curve whose slope steadily increases with time. This is a classic "hockey-stick" curve. It took more than 200,000 years for the human population to reach 1 billion. In the time since my birth, Earth's population has almost tripled.

SLIDE 28 Here's a UN plot of human population growth since 1950. While we can fit an exponential equation to the past population growth, that equation merely describes the data but does not govern the process. People who study such things infer that Earth's human population will likely peak at around 10 to 12 billion sometime after 2080, although the uncertainties are substantial.

SLIDE 29 Every one of those persons needs potable water, food, energy for cooking and warmth, shelter, and the freedom to form community with others. The basic needs in industrialized societies are more extensive, of course.

When we view things from the vantage point of a single life, the world appears to be a rather static place apart from seasonal changes and occasional extraordinary events.

When we change our vantage point to a higher elevation, as in this photograph of Earth, or to a longer timeline like that of seven generations in a family, what we see isn't static at all. We see dynamic change.

SLIDE 30 Science is a human activity in which reliable knowledge is based on reproducible observations and testable hypotheses.

Understanding uncertainty in our data and hypotheses is an essential part of our work.

Our understanding is always contingent or provisional — subject to new data and better hypotheses.

Eventually, clarity emerges from the fog. Only reliable knowledge is useful to society.

SLIDE 31 Scientists aspire to be truth-tellers. We tend to be shy about using the word "truth" because of its rather fluid definition elsewhere in society. Einstein had a clear definition that is consonant with the scientific method. "Truth is what stands the test of experience," he wrote in an essay on ethics in science. In science, our truths are not absolute — they always include uncertainty and are constrained by reproducible data.

So I challenge you to continue learning about the causes and consequences of global warming so you can use this knowledge in your work for the benefit of society. As Louis Pasteur once said, "Opportunity favors the prepared mind."

SLIDE 32 I want to spend a few minutes touching on the reproducible data, testable hypotheses, and still-evolving models related to climate change.

Let's start with greenhouse gases in the atmosphere.

SLIDE 33 The lower atmosphere's temperature is controlled by solar radiation and several gases, including water vapor that condenses in the atmosphere and some other gases that do not condense in the atmosphere — SLIDE 34 — mostly carbon dioxide or CO2, methane, nitrous oxide, ozone, and human-made fluorinated gases like chlorofluorocarbons, hydrochlorofluorocarbons, nitrogen trifluoride, and sulfur hexafluoride.

SLIDE 35 These are called greenhouse gases. They absorb solar radiation that has reflected or radiated from Earth's surface, and radiate some of that energy back to the surface, increasing the surface temperature.

CO2 is the most abundant of these non-compressing greenhouse gases and can persist in the atmosphere for centuries or longer.

Methane is less abundant in the atmosphere, where it breaks down into CO2 within about a decade. Methane is about 80 times more potent as a greenhouse gas than CO2, compared kilogram for kilogram over 20 years.

About 60% of the methane in the atmosphere was generated by human-controlled sources — fossil fuel production and use, biomass-biofuel, and agricultural sources like rice and livestock.

Reducing the introduction of new methane into the atmosphere could have a significant positive effect on slowing greenhouse warming in the coming decades.

SLIDE 36 Warming the atmosphere causes an increase in water vapor, adding to the warming effect.

SLIDE 37 In contrast, tiny aerosol particles in the air, such as soot and volcanic ash, have a cooling effect on the atmosphere's temperature.

SLIDE 38 For example, the massive eruption of Mt. Pinatubo in the Philippines in 1991 resulted in a measurable reduction in global temperature for almost two years.

SLIDE 39 We know the basics about how greenhouse gases work from laboratory observations. What about observations made in Nature?

Have we made enough reproducible measurements of CO2, methane, or nitrous oxide in the atmosphere, so we have reliable knowledge of those concentrations and whether they are changing over time?

SLIDE 40 Yes, we have. The first systematic and sustained measurement of atmospheric carbon dioxide began around the time I was born, made by Dave Keeling and his coworkers from the Scripps Institution of Oceanography, led by Roger Revelle. Dave began collecting and analyzing gas samples at the Mauna Loa Observatory at an elevation of about 11,135 feet above sea level (which is about 2500 feet below the volcano summit) in 1958.

SLIDE 41 This graph is called the Keeling curve and has the atmospheric concentration of carbon dioxide in parts per million on the vertical axis and years on the horizontal axis. The red curve shows the variation in CO2 concentration over time. The sawtooth pattern is due to annual cycles of high and low values.

SLIDE 42 The atmospheric concentration of CO2 has increased at an increasing rate between 1958 and today. In 1880, the CO2 concentration in the atmosphere was around 290 ppm. Keeling's first monthly average, for March 1958, was 316 ppm. On May 12, 2024, it reached 428.05 ppm — the highest in human history.

This increase contributes to atmospheric warming.

SLIDE 43 This graph shows the atmospheric concentration of methane in parts per billion on the vertical axis and years on the horizontal axis. The red sawtooth curve shows the variation in methane concentration over time.

SLIDE 44 This curve tells the same story as the CO2. In April of 2024, the methane concentration had risen to 1931.41 ppb — the highest methane level we've recorded. This increase contributes to atmospheric warming.

SLIDE 45 This graph has the atmospheric concentration of nitrous oxide in parts per billion on the vertical axis and years on the horizontal axis. The red curve shows the variation in nitrous oxide concentration over time.

SLIDE 46 This is the third major greenhouse gas that shows the same trend. In April of 2023, the nitrous oxide concentration had risen 337.63 parts per billion.

Direct measurements of atmospheric greenhouse gases show that they have increased, mostly at increasing rates, over the past decades.

SLIDE 47 So where does all of this additional carbon dioxide and methane come from? About 10% of the nitrous oxide, 33% of the methane and 87% of the carbon dioxide originate in the combustion or production of fossil fuels.

SLIDE 48 Since 1850, we have emitted about 700 million tons of additional carbon into the Earth system from previously sequestered fossil fuels and deforestation. That carbon load is now in the atmosphere, land, and oceans. The atmospheric part leads to global warming. The oceanic part leads to ocean acidification.

SLIDE 49 The last year, global emissions of CO2 were the greatest in history. Most of that additional carbon came from fossil fuels.

SLIDE 50 British Petroleum's annual energy outlook report for 2024 included this graphic. <describe diagrams>. The good news is that they predict peak CO2 emissions around 2030. By 2050, the emissions will be back at around 1995 levels. The bad news is that my descendants will live in a much warmer world even if a miracle occurs and we finally commit to accelerating the energy transition away from fossil fuels.

SLIDE 51 <show video> In addition to analysis of collected samples, NASA’s Orbiting Carbon Observatory satellite and instruments placed on the International Space Station have complimentary orbits that, together, cover the entire Earth. Their mission is to measure carbon dioxide and methane, and identify their sources.

SLIDE 52 With new data comes new opportunities to understand the sources, distribution and flow of greenhouse gases in the atmosphere. <show video>

SLIDE 53 <show video>CO2 concentration in the atmosphere rises and falls with the seasons because of the annual cycles of photosynthetic plants. As plants green up in the summer, they absorb CO2 causing the atmospheric concentration to decrease. The process reverses with the onset of the fall and winter every year. Peak concentrations of CO2 at the Mauna Loa observatory are in mid-May.

SLIDE 54 What does the global temperature record show?

SLIDE 55 This is a visualization of the monthly global surface temperature, starting in 1880 and continuing to 2024, based on the current version of the GISS Surface Temperature Analysis or GISTEMP 4. <show video>The reference period is the three decades between 1951 and 1980. <quiet till the end> The surface temperature increases steadily from the 1970s to present time, and 2023-24 is the hottest year in the record.

SLIDE 56 Here's the global temperature anomaly time series from 1880 to date, as compiled by five independent climate groups using direct measurements. All show an increase in temperature over time, totaling about 1.2°Celsius of warming in the last 143 years.

SLIDE 57 <show video>The same story emerges from looking at the global surface temperature record month by month.

SLIDE 58 <show video>The same story shown using a thermometer temperature scale. The 1880s world is blue — the current world is yellow to red.

SLIDE 59 <show video>The same story shown focusing on latitudinal or zonal variations in temperature over time. <pause> Notice that the polar regions and especially the north polar region is warming more than temperate and equatorial areas. This is a problem for the great continental glaciers on Greenland and Antarctica.

SLIDE 60 The sea-surface temperature anomaly since 1880 shows the same warming trend. Here's a reminder of one reason why ocean warming is important.

SLIDE 61 This NASA map shows the hot sea-surface temperature in the western Atlantic, Caribbean Sea and Gulf of Mexico on September 23, as Hurricane Helene gained energy and moved from offshore Nicaragua toward Florida. What about the deeper ocean?

SLIDE 62 Since we started measuring it in the late 1950s, the heat content of the upper 2000 meters of the world's oceans has also increased. Ocean warming is not just a surface phenomenon, and can have a dramatic effect on ocean ecosystems.

SLIDE 63 Where can we obtain data to allow us to reconstruct a longer climate record?

SLIDE 64 Geoscience has gained the ability since the mid-20th Century to collect deep-sea cores and ice cores that contain information about temperature, plant and animal life, the chemistry of the ocean and atmosphere, volcanic eruptions, and many other important aspects of Earth history.

For example, tiny bubbles in ice cores from Greenland and Antarctica contain microsamples of the atmosphere when the ice was formed from compacting snow. Ash layers in the cores contain datable minerals, allowing us to associate air chemistry with radiometric dates. Careful analysis of data from ice cores and marine sediment cores has revolutionized our understanding of Earth's climate history.

SLIDE 65 This graph presents data for a much longer time span of over 2,000 years —from year zero of the common era to the present time.

A slide presented earlier showed the temperature record from 1880 to the present. Here, that shorter record is shown in the yellow box on the right side of the graph.

For about the first 95% of this record, the temperature was a little bit above or a little bit below the average temperature between 1951 and 1980.

Then, around the year 1900, the temperature begins to rise above the average, reaching temperatures much higher than any in the previous two thousand years. Another hockey-stick curve.

SLIDE 66 The lower graph shows the concurrent trend in CO2 concentration in the atmosphere. Rising global temperature largely correlates with rising CO2 levels. More hockey-sticks.

SLIDE 67 Some of the increased CO2 in the atmosphere is absorbed by the oceans, making them more acidic. Increased acidity affects the ability of organisms like this tiny pteropod to form or maintain its carbonate shell. These plankton are an important part of the ocean food chain, so disrupting them can have devastating effects on the marine ecosystem.

SLIDE 68 One last stretch to the horizontal time scale shows us how concentrations of CO2 and methane correspond to global mean surface temperature over the past 800,000 years, using data from ice cores. The deeper past is to the left of the graph, and the present is to the right. The vertical pink stripes indicate interglacial warm periods.

The reproducible peer-reviewed data shown here demonstrate that atmospheric CO2 levels are now significantly greater than at any time in the last 800,000 years. Current understanding is CO2 has not been this abundant in the atmosphere for about 3 million years.

SLIDE 69 Atmospheric methane levels are now significantly greater than at any time in the last 800,000 years.

SLIDE 70 And the global mean surface temperature is greater than at any time in the last 125,000 years. It's rising at an unprecedented rate, geologically speaking.

SLIDE 71 Because of its long average residence time in the atmosphere, much of the CO2 already in the atmosphere will persist for centuries unless we find effective ways to capture and trap, or sequester, atmospheric CO2.

The mean global surface temperature will continue to increase beyond the year 2100 because of the greenhouse gases that are already in the atmosphere.

SLIDE 72 As global surface temperature increases over time, sea level rises.

SLIDE 73 Local and global sea levels are measured routinely using tide gauges, robotic floats, and orbital satellites. They produce a flood of data, much of which is freely accessible to the public.

SLIDE 74 Here are some of the orbital satellite systems that contribute to our understanding of global sea level. Some measure sea level using radar. Some use lasers. Some respond to mass anomalies that are reflected in variations in gravitational acceleration. There are NASA web resources devoted to each of these systems, and relevant links are available on the web page associated with this talk.

SLIDE 75 The record developed with data from satellite systems clearly indicates an increase in the global mean sea level over the past 30 years, and the rate of increase is accelerating.

SLIDE 76 <show video>The global mean sea level has risen steadily by about 10 cm during the last three decades.

SLIDE 77 Another approach to collecting sea-level data is to use robotic floats like those used in the ARGO program.

SLIDE 78 At any given time, about 4,000 ARGO floats are distributed across the world's oceans, initially spaced about 300 km apart, and then they drift on the currents.

SLIDE 79 Each one starts on the surface where its position is determined using GPS. After about one to three days, it descends to a depth of 1000 m where it drifts for 10 days. Then it descends to its profiling depth of from 2000 m to 6000 m, followed by an ascent to the sea surface over the course of about an hour per 1000 m depth, collecting data all the way up. Once on the surface, Argo determines its location using GPS, establishes satellite communication, and uploads its data.

All Argo floats measure temperature and salinity. Some also measure acidity (pH); oxygen, nitrate, and chlorophyll concentrations; and other biogeochemical data.

SLIDE 80 The variation in global mean sea level over time, relative to the 2005 level, is plotted on this graph of summary data from Argo floats. The black curve shows increasing total global mean sea level, while the orange curve shows the portion of the total that is attributed to melting of the Greenland and Antarctic ice sheets.

SLIDE 81 We closely monitor the ice mass of both Antarctica and Greenland using instruments on several orbital satellites, and by other means. Antarctica lost an average of 125 billion tons of ice per year between 2002 and 2016, and that meltwater contributes to sea level rise.

SLIDE 82 In contrast, Greenland's smaller ice sheet lost an average of 281 billion tons of ice per year during that same time interval — more than twice as much as Antarctica. Meltwater lost from Antarctica and Greenland accounts for about 2/3 of the increase in total global mean sea level.

SLIDE 83 The World Glacier Monitoring Service has documented the decline in mountain glaciers and ice caps around the world. A warmer world leads to melting glaciers, with all of the adverse consequences that flow from that.

SLIDE 84 Most of the rest of the total global mean sea level is attributed to the warming of the ocean and the dilution of seawater salinity by fresh water from melting ice — both of which reduce the density and increase the volume of seawater.

SLIDE 85 Local relative sea level is measured routinely by automatic tide gauges. They include small stations like the one on the left that use an acoustic sensor to measure the water level every six minutes. On the right is one of the large Sentinel tide gauges located offshore and designed to withstand major hurricanes. Water-level data from these NOAA tide gauges are transmitted to data centers soon after they are collected. Processed data are then posted in web-accessible datasets.

SLIDE 86 One way to access these data is NOAA's Sea Level Trends website, which provides graphical summaries of sea levels around the US coast and worldwide. Arrows that point up indicate that sea level is rising at that site. The length and color of the arrow indicate the rate of rise. All the arrows aren't equal because the land surface at a given site might be rising or subsiding due to geological or hydrological conditions onshore.

SLIDE 87 Here's the summary map for the Gulf Coast, and the big red arrow I've circled in the middle is from Grand Isle, Louisiana. If you click on the arrow, ...SLIDE 88...a data box opens that provides a summary of sea-level data for the site, and links to other information about the site.

SLIDE 89 For example, here is the time series of sea-level data from the site in graphical form, with links to the numerical data below. Relative to this tide gauge, sea level is rising at more than 9 mm/year, which is equivalent to about 3 feet every century.

SLIDE 90 Here's another graph of useful information from that site. It indicates that by the end of this century, sea level at Grand Isle will have risen between 3 and about 9 feet.

SLIDE 91 Global warming affects humans as well as our communities and infrastructure worldwide.

SLIDE 92 Society depends on geoscientists to understand and mitigate the effects of global warming.

SLIDE 93 How can geoscientists help society meet the challenge of a changing climate?

First, we need to engage in the professional development of the knowledge and skills needed to create sustainable solutions to these problems. Ignorance is not useful.

SLIDE 94 Second, we need to communicate effectively with the public and specifically with people and groups who have the power to effect change. Establish our profession as a source of reliable information and solutions to the problems, at all scales, posed by a warming climate. We need to teach through words and actions — including our personal example.

SLIDE 95 And third, we need to make decisions and recommendations in light of knowledge of how climate change will affect whatever we are working on over the coming decades. We need to devote our time and energy to help develop, propose, and implement solutions to the problems of a warming world.

SLIDE 96 Looking ahead, the projected increase in global mean sea level in the year 2100 is at least 2 feet, and could be much higher if the atmospheric concentration of greenhouse gases continues to increase. The future rate of melting in Antarctica and Greenland is a significant wildcard in these projections.

It is important to remember that the year 2100 is not the finish line. Sea level will continue to increase beyond 2100 because of the carbon dioxide that is already in the atmosphere. Where sea level will be seven generations from now depends on our action or inaction today.

For more information about this topic, visit https://CroninProjects.org/Oct2024/Climate