SECOND IN A SERIES

The Science of Climate Change

By John Brodman

As we approach the upcoming global conference on climate change set to begin in Paris this November, we can expect a media storm of increased coverage about climate change. What are we to make of so many conflicting claims? This is the second part of a series of articles about global warming. Part I in last month's *Shoreline* explained the components of the United Nations Framework Convention on Climate Change (UNFCCC) and its processes. The third and final part will appear next month and will explore the expected outcomes of the Paris meeting.

Simplified overview. The earth's climate is a chaotic system with multiple variables and non-linear feedback loops that are constantly changing, interacting with each other and producing the wide range of variability we observe in the weather and climate over different periods of time. We know that natural variations in the sun's energy, changes in the earth's orbit and tilt on its axis, volcanoes, earthquakes, asteroids, forest fires, currents, ocean oscillations (like *el Nino*) and ocean/atmosphere interactions can all have a significant impact on the earth's climate over time frames ranging from a few months to millennia. While the earth's climate is a dynamic system that is always changing, many scientists believe this natural variability in the climate system alone cannot explain the observed warming of the planet during the past century. Mainstream climate science attributes most of the observed warming during the last 100 years to increases in greenhouse gas concentrations caused by human activity (anthropogenic global warming). Other scientists believe that we don't know enough about all the forces at work to separate the "natural variability" in our climate from human influences. This is what climate science is all about.

The greenhouse effect is the term often used to describe the impact of rising concentrations of greenhouse gases (GHGs) in the atmosphere on the radiative balance of the earth. As the sun shines, it radiates short wave energy to the earth. Some of the sun's short wave energy is immediately reflected back into space, and some is absorbed by the earth (land and water) and radiated back into space in the form of long-wave, infrared radiation. The term "albedo" refers to the percentage of solar radiation that gets immediately reflected back into space, and the earth as a whole has an albedo of about 30% to 35%, depending on cloud cover and some other factors. This means that about 70% of the sun's energy that reaches the earth is initially absorbed by our land, water and atmosphere, and is then reradiated back in the form of long-wave infrared radiation.

Greenhouse gases in the atmosphere absorb some of this long-wave energy, preventing the loss of heat to space. These gases effectively trap the heat, like a blanket, and warm the earth's atmosphere. Under normal circumstances, these radiative forces are pretty much in balance, creating more or less stable temperatures over long periods of time. In a balanced system, GHGs, which by definition are gases that are able to absorb infrared radiation, trap enough of the sun's heat to make the earth a habitable place. Without them, scientists estimate that the earth's average temperature would be 60 degrees cooler than it is, so having some amount of these gases in our atmosphere is a good thing. We couldn't survive without them.

Emissions and concentrations. Concentrations of GHGs in our atmosphere have been accumulating at an increasing rate as a result of human activity since the beginning of the industrial era. Annual emissions of GHGs now exceed the earth's natural ability to remove them, causing concentrations of these gases in our atmosphere to rise. A common analogy is the water level in a bathtub. If the faucet (annual emissions of GHGs) is allowing water to run into the tub faster than the drain lets it run out, the water level in the tub rises (increasing GHG concentrations). Increasing concentrations of GHGs in the atmosphere trap more of the outgoing infrared radiation (heat), causing the planet to warm. Attempts to model this process have produced a wide range of results in the timing and amount of warming we can expect with a given increase in GHG concentrations.

Greenhouse gases. The main greenhouse gases include water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (NO_2), ozone (O_3) and halocarbons (CFCs, HFCs, HCFCs, PFCs and SF_6, together called the "F" gases). In addition, there are particles, like dust, soot, sulfur compounds and ground level smog in the atmosphere (called aerosols), that can both absorb and reflect some of the sun's energy, depending on where they are in the atmosphere, having both warming and cooling effects. Not all these GHGs are the same; some are more powerful than others, they interact with each other to form new compounds and they remain in the atmosphere for different periods of time. For the purposes of accounting, scientists convert measures of each of these gases into their carbon dioxide equivalents (CO_2e), based on their "global warming potential" (GWP).

The GWP of a gas is the warming over a 100-year period caused by the emission of a given amount of the gas relative to the warming caused by emission of the same amount of CO_2. The GWP of CO_2, by definition is 1, but methane has a GWP of 25, and nitrous oxide, a very powerful GHG, has a GWP of 298, meaning that a ton of NO_2 has 298 times the warming impact as a ton of CO_2, Why CO_2 equivalents? Because, other than water vapor (H_2O), carbon dioxide is the most prevalent GHG, accounting for approximately 80% of all GHG emissions on an equivalent basis. CO_2 and CO_2e are often used interchangeably in the popular press, even though they are quite different. All GHGs have different GWPs for different periods of time.

GHG concentrations in our atmosphere are higher than they have been at any time during the last million years or so, and they are still rising. Concentrations of CO_2 in the atmosphere have risen 40% from around 280 to 300 parts per million (ppm) in the 1850 to 1900 period, to just over 400 ppm today. Methane, a very powerful GHG in our atmosphere, is up 250% from the pre-industrial era. Nitrous oxide concentrations are up about 20% from pre-industrial levels. The "F" gases (halocarbons) are a relatively small part of overall GHG concentrations, but they are very powerful and they remain in the atmosphere for a long time. Aerosols are a bit of a mystery, as they can react with water vapor and other components of the atmosphere to form clouds and a range of compounds that both absorb and reflect energy. At the planetary level, these aerosols are thought to offset about 20% to 35% of the warming caused by the other GHGs.

CO_2 is absorbed and emitted naturally as part of the **carbon cycle,** which involves plant and animal respiration, decay and growth, volcanic activity, forest fires and ocean/atmosphere interactions. CO_2 emissions have risen from about five gigatons per year in the pre-industrial era to about 37 gigatons per year today. Eighty percent of the extra (human related) CO_2 entering our atmosphere (equivalent to two-thirds of all GHGs) comes from the production and use of fossil fuels, and the other 20% comes about as a result of changes in land use patterns, deforestation and agricultural practices. Methane enters the atmosphere from natural sources like wetlands, decaying plant and animal materials, natural leakages of methane from oil and gas deposits and coalbeds. Human sources of methane include landfills, energy production, processing and transportation, mining, animal feedlots and other agricultural practices. Nitrous oxide comes primarily from fossil fuel burning and the use of fertilizers.

GHGs remain in the atmosphere for a long time. About one-third of the GHGs emitted today will remain in the atmosphere 100 years from now. About 45% of the GHGs we have emitted so far this century will remain in the atmosphere in 2100, so even if we immediately ceased emitting all GHGs right now (an impossibility), our past emissions will go on warming the climate for several hundred years before a new equilibrium is established. Annual GHG emissions have risen from 27 gigatons CO_2e in 1970, to about 55 gigatons CO_2e in 2014 (there are ranges associated with all these figures). Total concentrations of GHGs in the atmosphere are now estimated to be close to 465 ppm CO_2e (with a range of 440 to 485 ppm, without adjustment for the effects of aerosols).

Tipping points. The UNFCCC has agreed to try and limit future warming to no more than two degrees Celsius (C) by 2100, as an "insurance policy" against the largely unpredictable consequences of global warming. While no one knows for sure what the impacts will be, the fear is that rising temperatures may create a

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