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Carbon Release from the Permafrost Soils of the Arctic; NASA's Project: CARVE

The Gelisols of Alaska, soils that reside in areas with permafrost, have been accumulating their horizons for thousands of years. Alan Buis (2013), of NASA's Jet Propulsion Laboratory in Pasadena, California, explains how researchers at NASA are currently undertaking the monumental task of mapping the concentrations of greenhouse gases (GHGs) in the soils of permafrost regions of the Artic. Buis' article "Is a Sleeping Climate Giant Stirring in the Arctic" details the project, Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE), which is scheduled to last five years. The NASA team, with the collaboration of many research groups, is recording data in the tundra region where the permafrost is 10s of meters deep. The quickly thawing soils of the regions to the north may have a considerable impact on the speed with which GHGs accumulate in the atmosphere. Which GHG is released, carbon dioxide (CO_2) or methane (CH_4), may also affect the speed of warming the climate undergoes (Buis, 2013).

According to Buis (2013), CARVE began initial project preparation flights in 2011, and data collection flights in 2012. The NASA crew, which contains research scientist Charles Miller of NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California, utilizes a specially equipped C-23 Sherpa aircraft for the mission. The plane flies very low (500 feet) above the surface of the tundra in its flights to collect data from the thawing permafrost, which the scientist are using to study climate change and how the carbon cycle in the Arctic is changing. The Sherpa is equipped with instruments that "sniff" for the concentrations of methane (CH4), carbon dioxide (CO2), and carbon monoxide (CO), which includes a super-sensitive spectrometer that analyzes Earth's reflected sunlight. The unit functions similarly to Carbon Observatory-2, NASA's orbiting satellite that is scheduled to launch in July of 2014. Samples of air are captured from outside the plane and later transported to the University of Colorado's Institute for Arctic and Alpine Research Stable Isotope Laboratory and Radiocarbon Laboratory in Boulder for testing GHG sources. Conditions data, such as basic weather and flight navigation information, is transferred within 12 hours of each flight (Buis, 2013).

The Permafrost Potential

Buis (2013) states that the permafrost soils (Fig. 1) release stored GHG's during the warmer months of the year when anywhere from 10 cm to several meters of layers near the interface with the atmosphere thaw. Plant life is able to prosper in these thawed regions for several months of the year. The problem, which has been developing for over a hundred thousand years, is that this plant life is unable to decompose once it dies at the end of the growing season. The majority of the carbon waiting to be released in the Arctic regions resides in the top few meters of soil. According to Buis (2013), "… an estimated 1,400 to 1,850 petagrams of it" (carbon) "(a petagram is 2.2 trillion pounds, or 1 billion metric tons). That's about half of all the estimated organic carbon stored in Earth's soils." The total carbon placed into the atmosphere by human means, such as fossil fuel burning, between the year 1850 and the present is around 350 petagrams total. How much of this stored carbon, and which gas, CO_2 or CH_4, is released, may depend on anthropogenic forcings that are contributing to the initial warming of the permafrost.

Charles Miller of the CARVE project was quoted as saying, “Permafrost soils (Fig. 1) are warming even faster than Arctic air temperatures – as much as 2.7 to 4.5 degrees Fahrenheit (1.5 to 2.5 degrees Celsius) in just the past 30 years, ….” The effect climate change may have on permafrost is not factored in to present prediction models. Greater understanding of the overall permafrost cycle, as it functions in the present, must be obtained in order to create more efficient models (Buis, 2013).

Figure 1: The above map indicates the area and degree to which permafrost exist. According to Buis (2013) permafrost covers “nearly a quarter of the exposed land area of the Northern Hemisphere…” Ahlenius, H. Cited in Buis, A. (2013, June 10).

Methane is More Harmful than Carbon Dioxide

The good thing about methane is that it has a much shorter residence time than carbon dioxide. With the amounts of carbon stored in the permafrost it may become very critical which gas is released, methane or carbon dioxide. According to Buis (2013), “…methane is 22 time more potent as a greenhouse gas than carbon dioxide on a 100-year time scale, and 105 times more potent on a 20-year timescale.” The high moisture content from the melting permafrost, along with warmer temperatures, may lead to more of the carbon being released as methane (Fig. 2). The higher temperature earlier in the year could have effects on the net release or storage of carbon in normally colder areas. The positive forcing of the carbon release may be heightened by water vapor feedback as warmer temperatures lead to more evaporation. Many other factors, one of which is tundra fires, have adverse effects on the way carbon is stored and released in the Arctic.

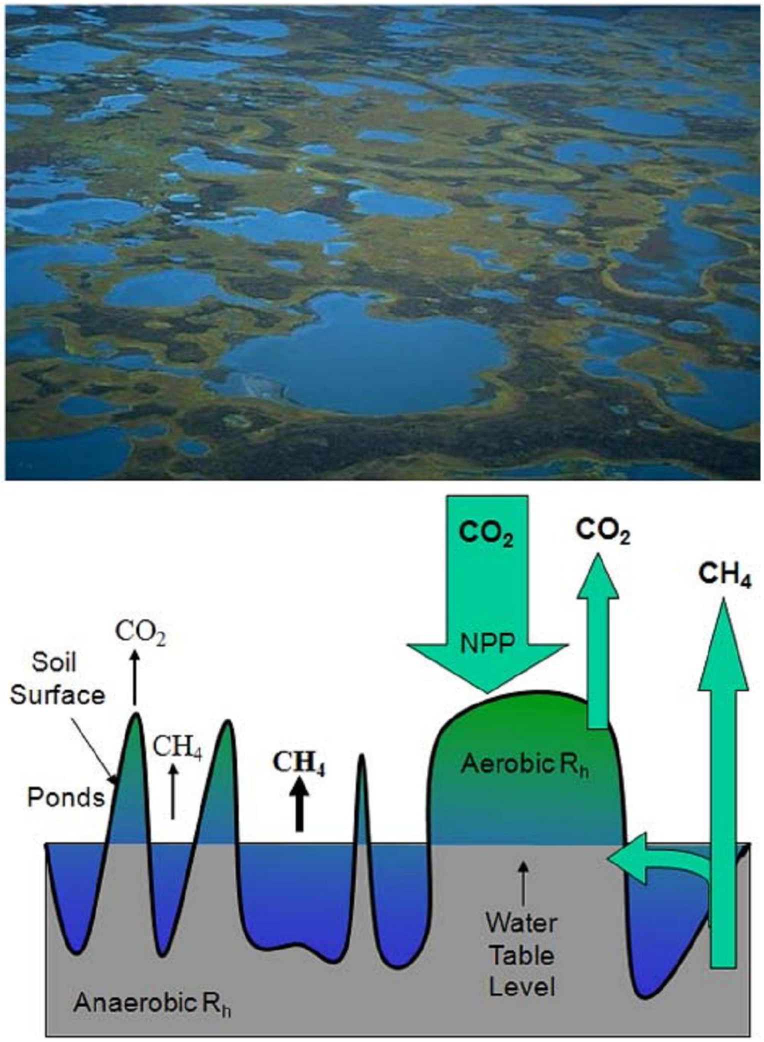

Figure 2: "Ubiquitous thermokarst wetlands exemplify the inseparable linkage between the Arctic carbon hydrologic cycles. Micro-topography, water table level, and active layer depth dictate the partitioning of soil respiration in aerobic (CO_2 release) and anaerobic (CH_4 release) processes. Seasonal and inter-annual variation in water availability and wetlands extent leads to high uncertainty in the CO_2/CH_4 partitioning of carbon fluxes from Arctic ecosystems (Miller and Denardo, 2012, p. 2)." Miller, C.E.; Dinardo, S.J., "CARVE: The Carbon in Arctic Reservoirs Vulnerability Experiment," Aerospace Conference, 2012 IEEE , vol., no., pp.1,17, 3-10 March 2012, doi: 10.1109/AERO.2012.6187026.Retrieved from http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6187026&isnumber =6186985

The Multiple Aspects of the CARVE project

CARVE is not only looking at the effects of the thawing tundra, the team is also evaluating the increase in forest fires in boreal areas in the recent decades. Charles E Miller and

Steven J. Dinardo discussed the CARVE mission in detail in their paper "CARVE: The Carbon in Arctic Reservoirs Vulnerability Experiment," which was published in *Aerospace Conference, 2012 IEEE.* Miller and Dinardo (2012) listed the following three objectives:

> (1) Directly testing hypotheses attributing the mobilization of vulnerable Alaskan Arctic carbon reservoirs to climate warming;
> (2) Delivering the first direct measurements and detailed maps of CO_2 and CH_4 sources in regional scales in the critical Alaskan Arctic ecozone; and
> (3) Demonstrating new remote sensing and modeling capabilities to quantify feedbacks between carbon fluxes and carbon cycle-climate processes in the Alaskan Arctic region.

Miller and Dinardo's (2012) hypothesis for objective 1 is as follows: "There exist early warning signatures that identify the tipping point for rapid release of vulnerable Arctic C reservoirs into the atmosphere". Miller and Denardo referenced previous data in the explanation of 0°C being the "tipping point" when the phase change occurs and ice becomes water. The project will involve determining relationships between temperature and the release of CO_2 and CH_4 in the interface region of the atmosphere and Earth's surface, and the effects the concentrations have. The hypothesis of the second objective, as stated by Miller and Denardo is, "Local surface-atmosphere fluxes of CO_2 (or CH_4) correlate with coincident surface controls or atmospheric concentrations of CO_2 (or CH_4)." For the approach to objective 2 Miller and Denardo stated "CARVE will make coincident measurements of soil moisture, inundation state, freeze/thaw state, and surface temperature along with total column CO_2 and CH_4 on spatial scales ≤ 1 km to test the hypothesis". The third hypothesis Miller and Denardo list is, "Fires in boreal forest or tundra will accelerate permafrost thaw, mobilizing vulnerable C reservoirs into dynamic carbon cycling and increasing the seasonal amplitude of high latitude atmospheric CO_2 concentrations." Data will be collected in the vicinity of fires within the region of study to determine cause and effect. The group will also evaluate the sites of previous fires to determine the regeneration of environments at various post-fire ages (Miller and Denardo, 2012, p. 2-5).

Effects of Tundra Fires on the Ecosystem

According to Mack et al. (2011), in "Carbon loss from an unprecedented Arctic tundra wildfire," the Arctic has had a lack of fire prior to the last century, but has seen a dramatic increase in fire events in the last several decades. A total of 1,039 square kilometers were burned in the 2007 Anaktuvuk River fire. This Alaskan Arctic slope fire, which was started by lightning, is the largest documented event of the region and burned an area equal to all other fires between 1950 and the present. The carbon release during the Anaktuvuk fire was estimated at 2016 g C m^2 and normal release is 450 g C m^2. Also, huge amounts of stored nitrogen (N) were lost in the fire. Based on present accumulation rates, it is estimated "the fire emitted 400 years of N accumulation". Nitrogen is crucial for healthy, productive soils and the lack of sufficient amounts may impede restoration of the burn area. Mack et al. (2011) comments that "As much as 18% of the one-meter-depth soil C pool in Arctic tundra may be vulnerable to direct loss through combustion because it is contained in surface organic horizons." During a fire, atmospheric CO_2 greatly increases, mass amounts of carbon storage is removed, and warming in the Arctic is magnified.

Mack et al. (2011) also pointed out some of the other effects of fire that are possible in the tundra regions. The earth's albedo, the ability to reflect incoming energy may be altered, this alteration varies, at times positive and others negative. Spring thaw may be affected by the lack of vegetation protecting the permafrost, allowing the release of more than normal amounts of either CO_2 or CH_4 from deeper layers of organic matter. After a fire the ecosystem may morph in varying ways including changes in producing vegetation. Mack et al. (2011) claimed:

> Another future scenario is that fire will act as a mechanism for threshold change such that graminoid [grasses] tundra is replaced by shrub tundra after fire. A shift to shrub tundra has been independently occurring across Arctic Alaska[30], and vegetation transition from graminoid to shrub has been linked to fire in some palaeoecological studies[3].

Not only is shrub tundra more susceptible to fire, it also has an increased yield and less ability to store carbon, as well less albedo compared to graminoid tundra. The Anaktuvuk River fire's modifications to the tundra surface are believed to have reduced albedo in the area by 50 to 71 %. Based on data accumulated over the last 50 plus years concerning fires in the tundra regions, an increase in tundra fires has occurred in the last 20 years. This increase is parallel with rising temperatures and the loss of cryosphere that has been documented. Further, data concerning the Anuktuvuk River fire soils indicate the massive amount of carbon that can be removed from storage and emitted to the atmosphere episodically. The majority of the information leads to speculation that these episodic occurrences will lead to increases in rates of temperature rise (Mack et al. 2011).

The Analysis Tools of the CARVE

As mentioned earlier, CARVE utilizes a C-23 Sherpa aircraft for the mission. Miller and Denardo (2012) describe the various scientific analysis equipment housed on board the Sherpa aircraft in "CARVE: The Carbon in Arctic Reservoirs Vulnerability Experiment." The *Passive Active L-band System (PAL*S) belonging to JPL is capable of "… remotely sensing soil moisture, inundation state, temperature, and freeze/thaw state. This instrument consists of a polarimetric radiometer and radar that time-share a single planer-array antenna." The ground values are determined by "microwave radiance and radar backscatter coefficients in multiple polarizations." The *Fourier Transform Spectrometer (FTS)* "…acquires high-resolution near-infrared spectra of solar radiance reflected from the Earth's surface, from which column abundance of CO_2, CH_4, and CO are retrieved using algorithms…" The *In Situ Gas Analyzer (ISGA)* "…contains a Piccarro G1401 analyzer for continuous in situ measurement of CO_2, CH_4, and CO, and a number of 12-flask Programmable Flask Packages (PFPs) to acquire whole air samples. The *ISGA* complements… *FTS* spectra, and delivers high-precision, in-situ concentrations of 50 other gases and isotopologues" (Miller and Denardo, 2012, p. 5 and 6).

CARVE Ground Analysis Stations

Miller and Denardo also emphasize the existence of many ground stations collecting continuous data for the CARVE program. This data serves many purposes for the program, including continuous collection for long term analysis. The data is also useful in the formation of "sub-grid-scale dynamics for model validation, and to establish a context for up-scaling observations from local to regional scales." The ground sites perform as check-in points for the Sherpa, giving conformation to readings and instrument standardization. The Barrow AK (BRW) facility, which was established by NOAA (National Oceanic and Atmospheric Administration) in 1973, is positioned in an area that is subjected to very little, if any, human generated GHGs, making it ideal for CARVE's check-in purposes (Miller and Denardo, 2012, p. 7).

CARVE is Comprised of Various Organizations

Miller and Denardo (2012) state in a responsibility table that they are accompanied in the endeavor by many organizations. Most of the organizations are within the Unites States, and some are from other countries. NASA's Jet Propulsion Laboratory is the lead in the project, but NOAA maintains a large part of the data analysis responsibilities. NOAA's Earth System Research Laboratory and Cooperative Institute for Research in Environmental Sciences, which is affiliated with the University of Colorado, both of which are in Boulder, Colorado are involved in various aspects of data analysis. Several Universities have personnel working on the project in various data analysis positions. Included in those involved universities are: the City College of New York, the University of California at Berkeley, the University of California at Santa Barbara, Caltech, the University of California at Irvine, Harvard, and San Diego State University. The Lawrence Berkeley National Laboratory and the University of Melbourne in Victoria, Australia also have personnel involved in the CARVE project (Miller and Denardo, 2012, p. 5).

What CARVE has Determined in the First Year of Flights

Buis (2013) indicates data processing of the previous year's flights by the CARVE researchers is currently in progress. The findings to date suggest the possibility of a serious situation developing. Miller states, "We saw large, regional-scale episodic burst of higher-than-normal carbon dioxide and methane in interior Alaska and across the North Slope during the spring thaw, and they lasted until after the fall freeze." Miller also added that methane readings that were "650 parts per billion higher than normal background levels" existed in the Innoko Wilderness swamp areas in July of 2012 and that these levels are comparable to a huge metropolis. According to Miller, the findings are greatly dissimilar from existing models. The CARVE team aspires to determine if the permafrost has reached the point of no return, were carbon and methane releases will quickly escalate, leading to more warming and higher levels of release (Buis 2013).

Thoughts at This Time

Although the CARVE program is still in the early stages, initial data indicates the program will be able to confirm correlation, and presumably causation, between increasing temperatures and the increase in GHGs in the permafrost regions. As more data is collected and analyzed, better models for predicting rates of change in the region should become available. It is unknown what actions, if any, will materialize from the acquired knowledge. Based on the data collected from the Anuktuvuk River fire, it seems prudent to make preparations to reduce the longevity and the severity of future fires if possible. It is known that fire is part of nature and some believe that fire should be allowed to run its course. With the delicate ecosystem of the permafrost regions, and the great stores of carbon that are released, along with the accumulations of nitrogen that are lost, this should be avoided in the Arctic. Loss of permafrost regions and their ability to store carbon may be catastrophic for the future of the planet. Warming conditions will enhance the release of methane in wetter areas, which does have a shorter residence time, but much larger effect on the warming of the climate. This positive forcing from CH_4 may lead to additional evaporation causing a positive water vapor feedback, which will add additional warming to the region. Human contributions are believed to be responsible for the accelerated warming that has been seen in recent decades. This warming is accelerating the release of GHGs in the permafrost regions of the northern latitudes. How much of the carbon in the region is released, and at what speed the carbon is released, will hopefully be determined by CARVE in coming years.

References

Buis, A. (2013, June 10). *Is a sleeping climate giant stirring in the arctic*. Retrieved from http://www.nasa.gov/topics/earth/features/earth20130610.html

Mack, M. C., Bret-Harte, M. S., Hollingsworth, T. N., Jandt, R. R., Schuur, E. A. G., Shaver, G. R., & Verbyla, D. L. (2011). Carbon loss from an unprecedented arctic tundra wildfire. *Nature*,*475*(7357), 489-792. doi: 10.1038/nature10283. Retrieved from http://www.nature.com/nature/journal/v475/n7357/full/nature10283.html

Miller, C.E.; Dinardo, S.J., *CARVE: The Carbon in Arctic Reservoirs Vulnerability Experiment*, Aerospace Conference, 2012 IEEE , vol., no., pp.1,17, 3-10 March 2012, doi: 10.1109/AERO.2012.6187026.Retrieved from http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6187026&isnumber=6186985