Spatial Variations in Late Summer Tundra Methane Flux on the North Slope of Alaska

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Abstract:

Scientific evidence indicates wide-scale changes in Arctic climate. Predicting future changes in Arctic climate is complicated by multiple, intersecting feedback loops. The Arctic contains large expanses of tundra with permafrost, or permanently frozen subsoil. The thawing of tundra has the potential to enhance biogenic methane (CH_4) production in thawed, active soils or release methane (CH_4) trapped in or below the permafrost. Methane is a highly effective greenhouse gas so CH_4 released from melting tundra constitutes a potential positive feedback to Arctic climate change. In August, 2013 the U.S. Naval Research Laboratory (NRL-6114) led an expedition to investigate late-summer tundra CH_4 concentrations and fluxes on the North Slope of Alaska near Prudhoe Bay. Permafrost cores were collected to measure CH_4 concentrations and soil parameters and a series of gas traps were deployed to measure tundra CH_4 flux at 9 stations over an area of ~1800 km^2. Results show large differences in tundra CH_4 concentrations with depth and fine-scale variability in daily CH_4 flux over a small spatial area. These observed differences and variability are likely a result of multiple factors such as CH_4 source and soil organic matter content, soil density and water content, and active layer depth. Further research is required to quantify and predict tundra CH_4 flux in order to better understand the potential impact it will have on Arctic climate. Such an understanding will enhance the U.S. Navy's ability to develop policy, strategy, force structures, and planning for a future that may include increased operations in the Arctic maritime environment.

Study Area and Methods:

Figure 1. Google Earth view of Prudhoe Bay in North Slope Borough, Alaska. Green markers denote the locations that were sampled between 17-21AUG13. Note: A total of 3 gas traps and 1 core were retrieved from all stations except Station 1, in which only 3 gas trap samples were collected.

Figure 1 shows study area near Prudhoe Bay, AK and indicates sampling locations for tundra cores and gas traps. **Figure 2** details core collection process and trap deployment. Traps were deployed for 24-54 hours prior to sampling. After collection, core samples and gas samples from traps were transported to the laboratory (NRL-6114) for analysis of CH_4 concentrations and tundra soil parameters.

Figure 2. Top left: Drilling hole into permafrost for core extraction. **Top right:** Trap insertion via PVC pipes for CH_4 flux measurements. **Bottom left and right:** Core samples were extracted from permafrost, measured, and separated into air-tight containers for further analysis at Naval Research Laboratory in Washington, DC**.** 10 mL samples were inserted into a Shimadzu GC-14A gas chromatograph to obtain concentrations.

Tundra Core Results:

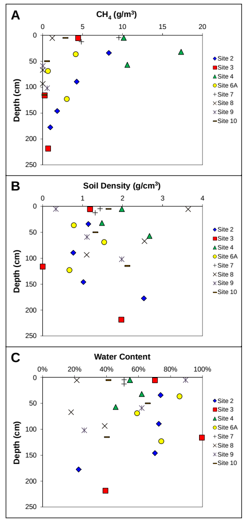

Figure 3. Various parameters measured in relation to depth of cores extracted from all stations: (**A**) Methane (g/m^3) versus depth (**B**) Soil density (g/cm^3) versus depth (**C**) Water content versus depth.

Figure 3 shows measured CH_4 concentrations, soil density, and water content vs. depth for the tundra cores. Methane concentrations were highly variable and ranged from 0.03 to 17.32 g/m^3 with an average concentration of 3.65 g/m^3. These values are in the same range, or slightly higher than those measured by other studies on the North Slope and other tundra areas (Michaelson et al., 2011; Mastepanov et al., 2013; Surtevant and Oechel, 2013). Observed differences are likely due to differences in methane sources at each site combined with differences in main soil parameters like density (**Fig. 3B**) and water content (**Fig. 3C**).

Tundra Flux Results:

Table 1. Recorded active layers (AL) depth and calculated methane flux for each station with standard deviation (n=3).

Site	LAT	LONG	Deployment Date	Deployment Time (hrs)	Active Layer Depth (cm)	Methane Flux (mg/m^2-hr)	Standard Deviation (+/-, n = 3)	Methane Flux (mg/m^2-d)	Standard Deviation (+/-, n = 3)
1	70.085	148.572	8/17/2013	38.0	63.6	8.81	8.57	211.50	205.79
2	70.172	148.645	8/17/2013	38.3	45.6	2.69	0.40	64.61	9.48
3	70.342	148.681	8/18/2013	51.5	31.8	0.71	0.26	17.12	6.18
6A	70.280	148.752	8/18/2013	53.5	39.3	2.85	0.81	68.30	19.37
7	70.313	149.127	8/21/2013	52.1	40.9	1.05	0.50	25.14	12.06
9	70.408	149.428	8/20/2013	53.1	50.6	3.02	1.12	72.53	26.81
10	70.294	149.501	8/20/2013	39.9	44.6	3.12	2.86	74.91	68.72
				Max.	63.6	8.81		211.50	
				Min.	31.8	0.71		17.12	
				Avg.	45.2	3.18		76.30	

Table 1 shows measured daily CH_4 flux and AL, or melt layer, depth for each station. Methane flux varied between stations from 6.04 to 211.50 mg/m^2-d with an average of 61.79 mg/m^2-d. The AL depth also varied between stations from 31.8 to 73.1 cm with an average of 50.1 cm. Values are similar or slightly higher than those measured by others (Michaelson et al., 2011; Mastepanov et al., 2013; Surtevant and Oechel, 2013). **Figure 4** shows a 2-D spatial plot of daily CH_4 flux between stations.

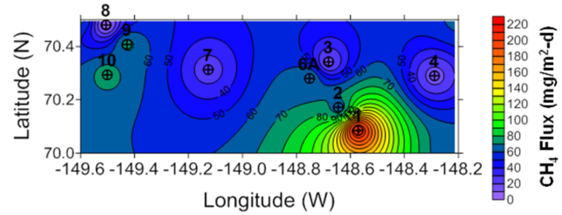

Figure 4. 2-D CH_4 flux spatial distribution from each sample station created using a 1/R^2 interpolation with Surfer 11 contouring and surface mapping software.

CH_4 Flux Spatial Distribution and Discussion:

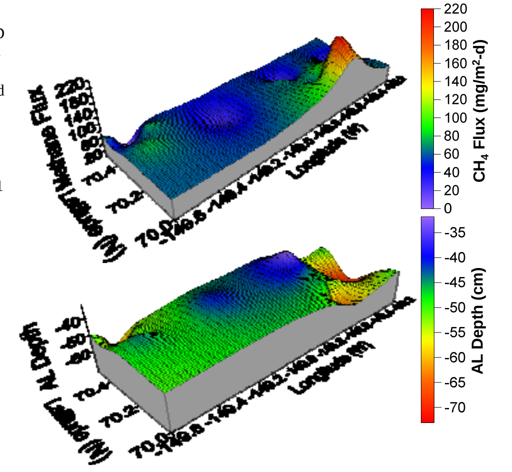

Figure 5. 3-D contour maps of CH_4 flux (mg/m^2-d) and AL depth (cm) created using a 1/R^2 interpolation with Surfer 11 contouring and surface mapping software.

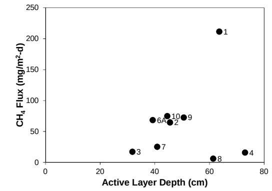

Figure 6. Active layer depth versus methane flux for all stations. There is a significant correlation between active layer depth and CH_4 flux with the exception of Stations 4 & 8.

Figure 5 is 3-D contour maps of CH_4 flux and AL depth. The highest CH_4 flux was at Station 1, which has a deep AL. **Figure 6** shows AL depths vs. CH_4 flux for all stations. Station 4, was along the coast near a river bank and the core hole filled with water after extraction. Station 8 was also located in a coastal area with high soil density and low water content indicative of a coastal bluff environment, not tundra. The average $\delta^{13}CH_4$ value for all sites was -73.8‰ indicating a biogenic CH_4 source. If the flux measurements at Station 4 and 8 are treated as outliers, then the AL depth and tundra CH_4 flux correlation makes sense given the CH_4 source.

Conclusions:

- ***Observed late-summer tundra CH_4 concentrations and fluxes in the Prudhoe Bay region of the North Slope of Alaska were similar or slightly higher than values found in previous research.***
- ***Measured CH_4 concentrations and fluxes were spatially variable and are likely influenced by factors such as: geographical location, CH_4 source, soil density & water content, AL depth, and fluid advection.***
- ***The total integrated flux for the study area was ~ 1.1 x 10^5 gCH_4/d which, if constant, would result in a release of ~ 4 x 10^7 g of CH_4/yr.***
- ***Future studies should be aimed towards investigating environmental factors controlling tundra CH_4 flux and quantifying and predicting year-round tundra CH_4 flux in order to better understand the potential impact it will have on Arctic climate.***

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