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Temperature drives inter-annual variability of growing season CO_2 and CH_4 fluxes of Siberian lowland tundra

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Due to the logistic and technical difficulties associated with experimental work in high latitudes, long-term measurements of CO_2 and CH_4 fluxes from arctic ecosystems are still rare, and published trace gas balances often rely on measurements from one or few growing seasons. The inter-annual variability of environmental conditions such as temperature, precipitation, snow cover, and timing of snow melt can be high in the Arctic, especially for regions which are influenced by both continental and maritime climates, such as the Siberian arctic lowlands. For these ecosystems, we must also expect a great inter-annual variability in the balance of trace gases. Multi-annual data sets are needed to investigate this variability and its drivers. Here we present multi-annual late summer CO_2 and CH_4 flux data from the Lena River Delta in the Siberian Arctic (72°N, 126°E). The study site Samoylov Island is characterized by polygonal lowland tundra, a vegetation dominated by mosses and sedges, a soil complex of Glacic, Turbic and Histic Cryosols, and an active layer depth of on average 0.5 m. Seasonal flux measurements were carried out with the eddy covariance technique during the 13-year period 2002 - 2014. Within this period, CO_2 flux data overlaps during 37 days (20 July - 25 August) for 12 years, and CH_4 flux data overlaps during 25 days (28 July - 21 August) for 9 years. Cumulative net ecosystem CO_2 exchange (NEE) during the late summer overlap period is fairly consistent for 9 out of 12 years with a CO_2 uptake of 1.9 ± 0.1 mol m^{-2}. Three years show a clearly smaller uptake of <1.5 mol m^{-2}. A correlation analysis reveals a quadratic relationship between air temperature and NEE, which suggests the existence of a temperature optimum where the balance of photosynthesis and ecosystem respiration leads to maximum CO_2 net uptake. Both photosynthesis and ecosystem respiration probably benefit initially from higher temperatures, however, in the highest temperature range ecosystem respiration outbalances photosynthesis. Median CH_4 fluxes during the overlap period ranged between 36 and 64 μmol m^{-2} hr^{-1} and were found to be positively linearly correlated to the date of thaw and soil temperature at 10 cm depth in wet polygon centers. This suggests that (i) higher soil temperatures enhance CH_4 production more than CH_4 oxidation, and (ii) a long thaw period may allow a stronger accumulation of CH_4 in soil pore space by methanogens and thus enhance transport processes which bypass oxidation (ebullition, plant-mediated transport). The obtained results indicate that the Siberian polygonal tundra will emit more greenhouse gases in a warming climate - at least on the short term. On the longer term, an adaptation of the vegetation or effects of higher evapotranspiration on the hydrology may counteract these effects. Our findings can be used to evaluate and train deterministic climate-carbon cycle models for the circumpolar permafrost regions.