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Atmospheric methane sources: Alaskan tundra bogs, an alpine fen, and a subarctic boreal marsh

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ABSTRACT

Methane (CH_4) flux measurements from Alaskan tundra bogs, an alpine fen, and a subarctic boreal marsh were obtained at field sites ranging from Prudhoe Bay on the coast of the Arctic Ocean to the Alaskan Range south of Fairbanks during August 1984. In the tundra, average CH_4 emission rates varied from 4.9 mg CH_4 m^{-2} d^{-1} (moist tundra) to 119 mg CH_4 m^{-2} d^{-1} (waterlogged tundra). Fluxes averaged 40 mg CH_4 m^{-2} d^{-1} from wet tussock meadows in the Brooks Range and 289 mg CH_4 m^{-2} d^{-1} from an alpine fen in the Alaskan Range. The boreal marsh had an average CH_4 emission rate of 106 mg CH_4 m^{-2} d^{-1}. Significant emissions were detected in tundra areas where peat temperatures were as low as 4 °C and permafrost was only 25 cm below the ground surface. Emission rates from the 17 sites sampled were found to be logarithmically related to water levels at the sites. Extrapolation of our data to an estimate of the total annual CH_4 emission from all arctic and boreal wetlands suggests that these ecosystems are a major source of atmospheric CH_4 and could account for up to 23% of global CH_4 emissions from wetlands.

1. Introduction

Since the last glacial retreat, boreal marshes and tundra wetland ecosystems have stored a significant amount of the Earth's carbon in organic soil and peat (Schlesinger, 1977; Armentano, 1980). An extensive zone of these organic deposits lies between 45° N and 65° N latitude in Alaska, Canada, the USSR, the United Kingdom, and Scandinavia. These deposits generally remain waterlogged throughout the year due to poor drainage of seasonal rain, melting snow, and thawing permafrost. Areal estimates of these northern wetlands are poorly defined and vary from 4 to 9.5×10^6 km^2 (Ajtay et al., 1979; Schlesinger, 1980; Gore, 1983). Since peat deposits in waterlogged boreal and tundra areas are likely to be under anaerobic conditions during the summer months and cover a globally significant area, these ecosystems could be an important source of methane to the global atmosphere.

The few available CH_4 flux measurements from marshes and bogs in boreal and tundra areas indicate the complexity and variability of the processes controlling biogenic gases in these systems (Svensson et al., 1975; Svensson and Rosswall, 1984). Characterization of fluxes from these wetlands thus requires detailed studies of the biological, chemical, and physical processes which control CH_4 production as well as extensive data on seasonal and geographic variability in these emissions. To date, insufficient flux data from the boreal regions has handicapped the efforts to estimate natural global CH_4 sources and sinks (Svensson, 1976; Ehhalt and Schmidt, 1978; Logan et al., 1981; Sheppard et al., 1982; Khalil and Rasmussen, 1983).

A major factor in the slow accumulation of CH_4 emission data from these isolated northern regions has been the problem of inaccessibility. In northern Alaska, this obstacle has diminished in recent years due to the opening of the North Slope Haul Road from Fairbanks to Prudhoe Bay, constructed along the Trans-Alaska Oil Pipeline. We present here the results of CH_4 measurements from major boreal and tundra wetland ecosystems, including coastal tundra, alpine meadows, bogs, fens, and boreal marshes at field sites from Prudhoe Bay (70.33° N, 149.06° W) south to the Alaskan Mountain Range. Most of our measurements were made along the North Slope Haul Road during August 1984 at a time of peak surface temperature. Extrapolation of these preliminary data to an estimate of the total annual CH_4 emissions from all arctic and subarctic wetlands verifies Svensson's (1976) assessment that these ecosystems are a major source of atmospheric CH_4.

2. Experimental methods

Methane flux across the air-soil interface was measured with a gas-filter correlation infrared absorption analyzer integrated with a 0.14 m^3 open bottom chamber. Details of the CH_4 analyzer design and calibration techniques can be found in Sebacher and Harriss (1982) and Sebacher (1985). In this integrated system, air is continuously recirculated from the sampling chamber, through the CH_4 analyzer, and back to the chamber. Any change in the CH_4 concentration in the enclosed chamber atmosphere is thus continuously monitored. Methane flux is calculated directly from the recorded CH_4 concentration change with time since the volume of the chamber and the interface area are known. If flux measurements are made over a water surface, floats are attached to the chamber to maintain a constant volume. This system has a detection limit of approximately 1×10^{-4} g $CH_4/m^2/d$ for a 15-min measurement period, the time interval usually used. The response time for the detection system was maintained at 3 s or less. Calibration of the system is carried out in the field using certified standards. Surface water provided a chamber seal at most waterlogged sites. When chamber-to-peat surface seals were difficult, a collar containing a water trough was preset at the site, allowing a quick seal for later measurements. Since CH_4 fluxes can be calculated with μg increases in the chamber CH_4 concentration, pressure changes inside the system were insignificant. Permafrost depth and peat thickness were measured by incremental coring, and peat temperature was probed using a shielded thermocouple sensor. Peat depth, peat surface temperature, and permafrost depth were generally consistent at each site, while surface water depth and CH_4 flux exhibit significant variability. Variations of water depth at each site are indicated in the tables.

3. Field study

3.1. General geological and ecological setting

Alaska is a region of diverse ecology and complicated geology where the majority of globally important types of boreal and tundra ecosystems are well represented. From the Arctic Ocean south to the foothills of the Brooks Range lies a broad, low relief, coastal plain called the North Slope, composed of recent sedimentary deposits and covered by arctic tundra vegetation devoid of trees. This area contains a multitude of small lakes, streams, fens, and bogs due to poor drainage of precipitation and melting permafrost during the summer months. Severe climatic conditions in this northern region have created a landscape dominated by the effects of permafrost, cryopedologic, and cryoturbation processes. Differential freezing, expansion, and thawing of soil materials results in the formation of such widespread landscape features as frost scars and boils, pingos, and ice-wedge polygons (Britton, 1957; Brown et al., 1980). In general, the coastal climate has long, dry, cold winters and short, moist, cool summers. Fog and clouds are common throughout the summer, and humidity consistently averages greater than 80% from June to September (Brown et al., 1980). Mean July temperatures range from 7 to 13 °C, and the vegetation growth period is approximately 60 days (Hultén, 1968).

The North Slope is separated from the Yukon basin to the south by the Brooks Range, whose rugged peaks exceed 2800 m. The northern foothills of the Brooks Range are overlain with spongy mosses and grassy meadows, which are commonly covered by several cm of water. Hummock formation is usually circular, but sometimes appears linear and parallel to the ridges of the surrounding hills. The Foothills Province is marked by an increase in both habitat diversity and plant species. Dry meadows are common in the southern section of the Province, while to the north and on lower, wetter slopes of glacial moraines and alluvial fens, tussock tundra or meadows are common (Britton, 1957).

Central Alaska is a plateau largely covered by boreal forest dominated by white spruce and paper birch, and also includes black spruce, poplar, fir, and pine species. Numerous muskegs, bogs, and fens occur in the interior in areas too wet for tree growth. Such areas can occur on old river terraces and out-washes, infilling ponds and old sloughs, and on gentle slopes facing to the north (Viereck and Little, 1972). Central Alaska is bounded on the south by the Alaskan Range, which contains large glacier-fed wetlands in extensive alpine valley systems. The valley-type peatlands common in southeastern and central Alaska are a variable wetland type and range from lakes rimmed by grasses and organic deposits to valley bottoms completely filled with water-logged *Sphagnum* and other boreal flora. Peat depths are generally greater in the Alaskan Range wetlands than in more northern regions since mean temperatures are higher during the summer and the growing season is longer. Wet-lands on the eastern side of the central plateau region begin to grade into a boreal marsh type more typical of central Canada, being grassy in aspect and generally lacking *Sphagnum* mosses.

More detail on various wetland types encountered in Alaska can be found in Dashnowski-Stokes (1941), Drury (1956), Britton (1957), Sellman (1968), and Hofstetter (1983). Overall similarities in characteristics between Alaskan peatlands and those in Minnesota, Canada, and Scandinavia are discussed in Drury (1956) and in Sjors (1961).

3.2. *Site locations for measurements*

Field site locations used for CH_4 emission measurements are illustrated in Fig. 1. The majority of our sites are concentrated along the North Slope Haul Road and are located in areas representative of most of the major boreal and tundra wetland ecosystems. The Haul Road begins approximately 120 km north of Fairbanks and is marked by milepost (MP) indicators from MP 1 to MP 416 at the northernmost point of the road near Prudhoe Bay. We have used these MP markers as indicators of the locations of our field sites since other points of reference in this remote area are lacking. Milepost markers were also used for field sites in an alpine fen near the Denali Highway and for a boreal marsh site along the Richardson Highway (Fig. 2).

A brief qualitative description of the field sites and the dominant flora at each site is given in the

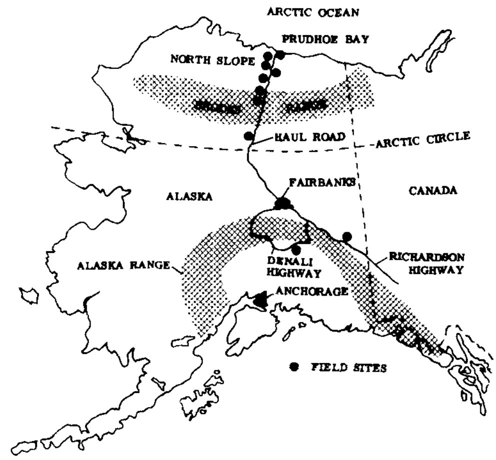

Fig. 1. Field measurement sites in Alaska.

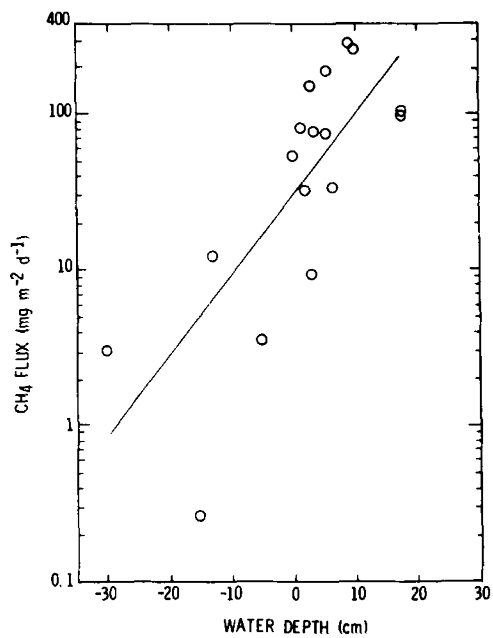

Fig. 2. Methane flux versus water depth for all sites in Alaska.

Appendix. Plant species were identified according to Hultén (1968) and Viereck and Little (1972).

4. Results and discussion

Average CH_4 fluxes measured during our survey of Alaskan tundra bogs, an alpine fen and a

Table 1. *North slope coastal tundra CH_4 fluxes*

Site location/haul Road mile post	Surface water depth (cm)	Peat surface temperature (°C)	Permafrost depth (cm)	Peat depth (cm)	Number of measurements	Mean CH_4 flux and standard error (mg CH_4 m^{-2} d^{-1})
361	3–10	8.2	53	53	5	33.7 ± 1.5
361	15–20	8.6	50	20	7	98.5 ± 10.5
371	3–8	4.3	42	42	6	75.2 ± 4.9
408	3–8	4.4	57	41	3	190 ± 35.3
408	5–15	—	57	—	5	266 ± 35.9
408	0–3	4.3	45	20	7	82.5 ± 9.9
416	0	2.4	30	30	7	53.7 ± 5.4
416	3	4.7	40	—	4	152 ± 8.5

(Wet: water level above or at peat surface).
Overall mean flux for wet coastal tundra = 119 ± 27.8 mg CH_4 m^{-2} d^{-1}.

Table 2. *North slope coastal and Brooks Range tundra CH_4 fluxes*

Site location/haul Road mile post	Surface water depth (cm)	Peat surface temperature (°C)	Permafrost depth (cm)	Peat depth (cm)	Number of measurements	Mean CH_4 flux and standard error (mg CH_4 m^{-2} d^{-1})
298	−30	7.5	27	27	3	3.1 ± 3.1
318	−15	3.6	40	5	3	0.27 ± 0.27
346	−13	10.5	43	18	2	12.5
401	−5	5.3	55	22	4	3.6 ± 2.2

(Moist: water level more than or equal to 5 cm below peat surface).
Overall mean flux for moist tundra = 4.9 ± 2.6 mg CH_4 m^{-2} d^{-1}.

subarctic boreal marsh are presented in Tables 1 through 4. Data have been divided into five categories covering the primary CH_4 producing ecosystems found in northern wetlands. Table 1 lists CH_4 fluxes and ancillary data from waterlogged sites in the North Slope coastal tundra. Mean flux values at these sites varied from 34 to 266 mg CH_4 m^{-2} d^{-1}, and the mean flux for all of the wet coastal measurements was 119 ± 28 mg CH_4 m^{-2} d^{-1}. Surface water depths ranged from 0 (at the soil-air interface) to 20 cm, and surface soil temperatures varied from 2.4 to 8.6 °C. The depth at which permafrost was found ranged from 30 to 57 cm, and peat thickness varied from 20 to 53 cm.

Measurements from sites in moist coastal tundra are presented in Table 2. These sites were classified as moist as opposed to wet when the water table was at least 5 cm below the peat surface, resulting in more aerobic conditions at the surface. Although peat temperatures and permafrost depths were similar to those observed in the waterlogged tundra, CH_4 fluxes measured from the moist tundra sites had a mean value for all of these measurements of only 4.9 ± 2.6 mg CH_4 m^{-2} d^{-1}. Peat thickness at the moist tundra sites, however, was somewhat lower than those at wet sites, averaging 17.9 cm versus 34.3 cm in the wetter sites and ranging from 5 to 27 cm. Additional emissions measurements (data not presented) were made at sites in elevated dry tundra areas within the coastal zone and in the uplands in the Brooks Range. In all of these cases, the dry, aerobic tundra produced a flux too low to be detected by our instrumentation (less than 0.1 mg CH_4 m^{-2} d^{-1}).

Three sites were established to quantify CH_4 emissions from wet meadow or tussock tundra in the foothills of the Brooks Range (Table 3). Emissions from these sites were lower than those from wet tundra on the Coastal Plain with an overall mean of 40 ± 20 mg CH_4 m^{-2} d^{-1}.

Table 3. *Brooks range meadow tundra CH_4 fluxes*

Site location/haul Road mile post	Surface water depth (cm)	Peat surface temperature (°C)	Permafrost depth (cm)	Peat depth (cm)	Number of measurements	Mean CH_4 flux and standard error (mg CH_4 m^{-2} d^{-1})
159	3	8.2	35	35	6	9.4±2.6
298	2	7.5	27	27	2	32.6
346	2–5	13.5	45	45	6	77.6±14.1

(Wet: water level above the peat surface).
Overall mean flux for Brooks Range wet meadow tundra = 39.9±20.0 mg CH_4 m^{-2} d^{-1}.

Table 4. *Alpine fen and boreal marsh CH_4 fluxes*

Site location/haul Road mile post	Surface water depth (cm)	Peat surface temperature (°C)	Permafrost depth (cm)	Peat depth (cm)	Number of measurements	Mean CH_4 flux and standard error (mg CH_4 m^{-2} d^{-1})
Alpine fen Alaskan Range Denali hwy MP 50	3–15	16	>60	>60	6	289±14.2
Boreal marsh Richardson hwy MP 1372	15–20	9	>60	>60	7	106±4.6

(Wet: water level above the peat surface.)

Environmental variables measured in the two regions were not significantly different, although soil temperatures in the Brooks Range were somewhat higher (a mean temperature of 9.7 versus 5.3 °C from wet coastal tundra). Since only a restricted number of sites were sampled in the Foothills area, additional data are required to confirm this apparent difference in flux between the two regions and to examine other possible environmental controls on flux.

The CH_4 emission data shown in Tables 1, 2, and 3 were obtained in areas above the Arctic Circle (Fig. 2), where permafrost was less than 60 cm below the ground surface. Two additional categories of northern wetlands sampled during our survey were an alpine fen and boreal marsh, located in regions below the Arctic Circle where permafrost occurs only sporadically or is too deep in the soil during the summer to be of significance to CH_4 production.

Six measurements were made at an alpine fen site in the Alaskan Range, with an average emission rate of 289 ± 14 mg CH_4 m^{-2} d^{-1} (Table 4). The elevated emissions observed at this site are related to stable water depths during the summer glacier thaw, higher peat temperatures, and a deeper unfrozen peat layer as compared to the North Slope region. Peat in alpine wetlands can accumulate to over 10 m in depth, and peat temperatures of 15.6 °C up to 30 cm below the surface were measured at our site. Actual peat thickness at the site is unknown as it extended beyond the maximum length of our probe (60 cm). In contrast, the Brooks Range muskeg-type bog near MP 159 had a thawed peat thickness of only 35 cm, and peat temperatures dropped from 8.2 °C at the surface of the peat to 3 °C at 30 cm below the surface. Surface water levels at the Brooks Range site were also significantly lower than those observed at the Alaskan Range site.

The fifth type of boreal wetland ecosystem surveyed during this experiment was sub-arctic marsh, located in southeastern Alaska at MP 1373 along the Richardson Highway. Seven measurements were made in this habitat type, characteristic of vast wetland areas occurring in boreal Canada, and an average CH_4 emission rate of 106 ± 5 mg CH_4 m^{-2} d^{-1} was obtained.

Correlation of measured fluxes with the environmental parameters (water level, temperature, depth at which permafrost occurs, and the thickness of the peat layer) revealed that emissions were only well correlated with water level (Fig. 2). Emissions were logarithmically related to water level (r^2 = 0.57; significant at the 99% confidence level). Multiple regression with the additional variables measured did not significantly reduce the variance. At sites where permafrost occurs at shallow depths (Tables 1–3), emission rates did correlate with the depth of the permafrost. However, because depth of permafrost and water level are cross correlated (90% confidence level), this relationship is likely to be an indirect response to water level or to a third variable such as drainage or climate and topography that controls these two parameters. Svensson (1976) also reports a correlation of flux with moisture levels for 6 sites within a single wetland and finds large variation in emission rates from apparently similar areas.

For sites covered with water (Tables 1, 3, and 4), emission rates were linearly correlated with water depths up to approximately 10 cm (r^2 = 0.54; significant at the 99% confidence level). This relationship is not significant for greater depths, suggesting that depths greater than 10 cm are unnecessary to create aerobic conditions promoting an additional increase, or that processes and variables such as water stratification effects (Sebacher et al., 1982) or CH_4 oxidation in the water column may be important in controlling flux.

Methane flux was found to be poorly correlated with soil temperature at our sites (r^2 = 0.04). The relatively high CH_4 emissions observed from these northern areas at low soil temperatures are, however, interesting in comparison to more temperate regions. Published relationships of flux to temperature from more temperate sites suggest that emissions at these low temperatures should be much lower than those we observed (Fig. 3). It is apparent from Fig. 3, however, that little seasonal flux data have been taken at low soil temperatures. Our preliminary data suggest that the soil temperature-to-flux relationship in northern regions may not be the same as that in more temperate areas. Flanagan and Bunnell (1980) report that the

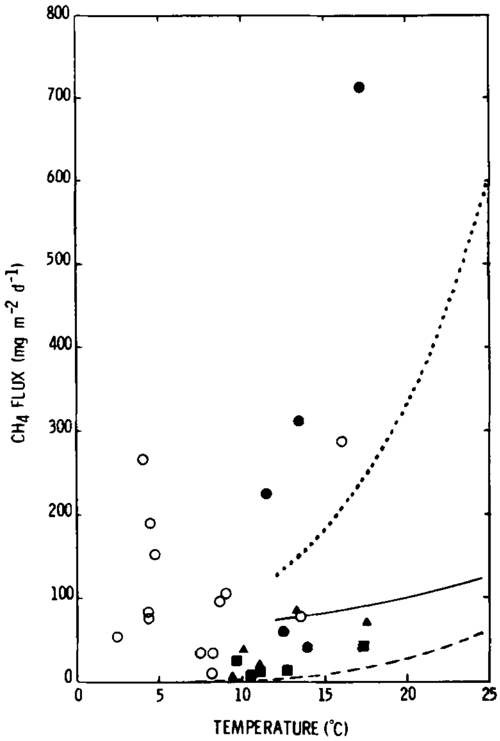

Fig. 3. Methane flux versus soil temperature for field studies in natural wetlands where significant flux to temperature correlations were reported. Data sources: ········ Baker-Blocker et al. (1977), Michigan ponds and swamp (air temperatures rather than soil temperatures were used). —— Sebacher (unpublished data), ponds in north Florida. ---- Harriss et al. (1982), Dismal Swamp, Virginia. Open circles: This study, Alaska. Mean data from water logged sites. Closed symbols: Svensson and Rosswall (1984), wet sites in a Swedish mire. Closed squares: their site #4, closed triangles: their site #5, closed circles: their site #6.

activities of many tundra microorganisms show a linear reponse to increasing temperature rather than the classic exponential response. They hypothesize a linear relationship to temperature to serve as an adaptation to the typically low temperature of the region by permitting a more rapid response to small temperature increases at low soil temperatures.

The presence of low-temperature-adapted bacteria is reported by Svensson (1984). In laboratory incubations of peat from a Swedish subarctic mire, the presence of several populations of low-temperature-adapted methanogens was demonstrated. One population appeared to have a temperature optimum at about 20 °C, and the other, with somewhat different nutritional requirements, had an optimum of between 24 and 28 °C. Temperature optimum previously reported for methanogen population growth in samples taken from more temperate regions lie in the range of 35 to 42 °C (Zeikus and Winfrey, 1976). Since the evidence indicates that methanogens may adapt to different temperature regimes, an intrasite temperature correlation may not be seen although there will be seasonal variations at each site.

Only limited data are available from other northern regions to compare the emission rates we report here. A relatively high average CH_4 flux of 337 ± 76 mg CH_4 m^{-2} d^{-1} is reported by Harriss et al. (1985) from a variety of northern Minnesota peatlands during August 1983 at soil temperatures ranging from 12.3 to 20.3 °C. The majority of these measurements were obtained in *Sphagnum* bogs and fens, and they range in magnitude from 3 to 1940 mg CH_4 m^{-2} d^{-1}. These data would be comparable to our fluxes from the alpine fen (289 mg CH_4 m^{-2} d^{-1}), from the muskeg-type bog at MP 159 (9.4 mg CH_4 m^{-2} d^{-1}), and from the boreal marsh site (an average of 106 mg CH_4 m^{-2} d^{-1}).

Svensson (1974), Svensson et al. (1975), and Svensson and Rosswall (1984) report CH_4 emission rates from ombrotrophic and minerotrophic sites in a Swedish wetland. Emissions varied widely (0.34–950 mg CH_4 m^{-2} d^{-1}) and appeared to partially correlate with moisture levels (Svensson, 1976), as was found for the Alaska sites reported here. Seasonal sampling during warmer months (June through early September) indicates that fluxes correlate with temperature, but only at the wetter sites sampled. Emissions from drier sites were poorly correlated with temperature. Spatial variability in flux from areas that appeared very similar in nature was also high. An annual estimate of 10 g CH_4 m^{-2} for this type of subarctic wetland was made based on these data by Svensson (1974) and Svensson et al. (1975).

Methane flux measurements in an English bog are somewhat smaller than those measured here. Clymo and Reddaway (1971) found emission rates varying from 9·6 to 70 mg CH_4 m^{-2} d^{-1} at a blanket bog site in the Moor House National Nature Reserve at a soil temperature of 11 °C. They also calculated that 1 to 6% of the net primary production of the bog in which they worked was lost to the atmosphere by CH_4 release. A similar estimate can be made for our data from the coastal wet tundra (Table 1) using primary production values measured for the coastal tundra at Barrow, Alaska (Miller et al., 1980). This calculation is necessarily only an approximation since flux is highly dependent upon the distribution of water and no primary production data exist for the specific sites at which our flux measurements were made. Miller et al. (1980) report net annual primary production for the tundra at Barrow (above and below ground production, averaged for the variety of vegetation types present) at 230 g dry wgt m^{-2}. Assuming a carbon to dry weight ratio of 0.45 (Chapin et al., 1980), this production corresponds to 104 g C m^{-2} yr^{-1}. Assuming our average flux of 119 mg CH_4 m^{-2} d^{-1} from the wet tundra occurs for approximately 100 days (Flanagan and Bunnell, 1980), annual releases of CH_4 to the atmosphere are on the order of 8.9 g C m^{-2}. Methane losses in the coastal tundra thus correspond to 8·6% of the net primary production. This value compares favorable to a similar calculation by Svensson (1983) for his minerothrophic site which resulted in a CH_4 loss of 11% of the primary production.

The importance of CH_4 emissions from the tundra and boreal region is illustrated by a consideration of the large geographic extent of these types of habitats and a comparison of the magnitude of our northern wetland data to other natural sources of CH_4 (Harriss et al., 1982; Cicerone et al., 1983; DeLaune et al., 1983; Seiler et al., 1984; Bartlett et al., 1985). If all of the mean emissions data from the five wetland ecosystems sampled here are averaged (83 fluxes from 17 sites), the overall emission rate would be 112 ± 39 mg CH_4 m^{-2} d^{-1}. Assuming a regional average of 100 days a year of active CH_4 emissions, our averaged flux corresponds to 11.2 g CH_4 m^{-2} yr^{-1}. This value is in agreement with the 10 g CH_4 m^{-2} yr^{-1} estimated by Svensson (1974) and Svensson et al. (1975). Using an areal estimate for northern wetlands of between 4×10^6 to 9.5×10^6 km^2 (Ajtay et al., 1979; Schlesinger, 1980; Gore, 1983) and our flux estimate of 11.2 g CH_4 m^{-2} yr^{-1}, we calculate the annual emission of CH_4 from all arctic and boreal wetlands is between 4.5×10^{13} and 10.6×10^{13} g CH_4 yr^{-1}. Ehhalt and Schmidt's (1978) estimate of the global biogenic production rate of atmospheric CH_4 is 4.7×10^{14} to 6.2×10^{14} g CH_4

yr^{-1} when enteric fermentation of animals is ignored. A comparison of our northern wetland production rates to Ehhalt and Schmidt's estimate indicates that these ecosystems may account for 7 to 23% of the total biogenic sources of atmospheric CH_4. Methane production from the tundra regions alone have been estimated to contribute up to 3% of the total global biogenic CH_4 (Svensson, 1976).

5. Concluding remarks

To improve our understanding of peatlands as a source of atmospheric CH_4, emission studies must continue on the vast areas of arctic and subarctic wetlands. This study shows that CH_4 fluxes from tundra are of the same magnitude as those measured from wetlands located in more temperate regions, even though the peat temperatures are much lower. In fact, some biogenic CH_4 production is shut down in temperate wetlands at the temperatures observed in the northern regions (Harriss et al., 1982). Of particular interest, significant emissions were measured from North Slope tundra when the peat temperatures were 2 to 4 °C and the permafrost was only 25 cm below the surface. Only limited data were obtained from subarctic marshes, which are considered to be of primary importance in southern Canada, and must be included in any future survey. Seasonal variations also need to be considered in these studies to refine our calculation of northern wetlands CH_4 production since a seasonal maximum was expected in August.

6. Acknowledgement

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7. Appendix: description of field sites

North Slope Haul Road

MP 159 Treeless muskeg bog south of the Brooks surrounded by stunted black spruce forest. Thick *Sphagnum* cover with irregular wet surface. Standing water over 50% of surface. Flora includes *Rubus chamaemorus* L. (Cloudberry), *Vaccinium vitis-idaea* L. (lingonberry or mountain cranberry), *Betula nana* L. (dwarf birch), *Ledum palustre* L. (Labrador tea), *Vaccinium uliginosum* L. (alpine or bog blueberry), *Carex aquatilis* wahlenb. (sedge), *Empetrum nigrum* L. (crowberry), caribou-antler lichen, and other lichens and mosses.

MP 298 Alpine meadow with small grassy hummocks in a valley of the Foothills Province. Thick *Sphagnum* cover with patches of grass. Flora includes *B. nana*, *Salix rotundifolia* Trauto. (willow), *Eriophorum* spp. (cotton grasses), *R. chamaemorus*, and a variety of other mosses, sedges and lichens.

MP 318 Moist alpine tussock tundra in Foothills Province, located at the upper boundary of a wet coastal valley with thick moss cover. Flora includes L. *palustre*, *B. nana*, *V. vitis-idaea*, caribou-antler lichen, and several mosses.

MP 346 Wet grassy meadow in Foothills Province on the north side of Brooks Range. Long linear hummocks parallel to ridge of nearby hills, which are covered with stunted willows. Flat area flora dominated by *Eriophorum vaginatum* L. and includes other grasses and mosses. At the foot of the slopes, plant species change to include *Dryas integrifolia* M. Vahl (entire-leaf mountain-avens), *Salix* spp. (willows), as well as the grasses. Up the slopes, the flora continues to change as grass-like species are lost and *Equisetum arvense* L. (horsetail), *Lupinus arcticus* S. Wats. (lupine), *S. rotundifolia*, *Arctostaphylos rubra* (Rehd. and Wilson) (bearberry), *D. integrifolia*, and moss species dominate.

MP 361 Grassy wet meadow on the North Slope Coastal Plain. Standing water between 3 and 20 cm deep (pH = 7.05) over a thick moss cover. Flora also includes *C. aquatilis*, *E. vaginatum*, *D. integrifolia*, and *V. uliginosum*.

MP 371 Coastal Plain wet grassy meadow. Moss covered hummocks up to 30 cm high with pools of water 7 cm deep between them. Hummocks have a cover of grasses, several moss species, and stunted willows. Other flora include *D. integrifolia*, *S. rotundifolia*, *Carex* spp., and *Dryas octopetala* L. (white mountain-avens).

MP 401 Similar to the site at MP 371 with the exception that the hummocks are only half as high.

MP 408 Coastal Plain wet grassy meadow with less distinct hummock formation. Water up to 10 cm deep (pH = 7.48). Flora includes *C. aquatilis*, *Salix* spp., *Pedicularis sudetica* Willd. (lousewort), *Eriophorum angustifolium*, Honck. and a variety of grass species.

MP 416 Two sites were studied in the Prudhoe Bay area. One was a wet grassy site with a thick moss cover about 300 m from the ocean coast. Only about 10% of the ground surface was water saturated. Flora includes *E. vaginatum*, *Poa arctica*, R. Br. moss species, and other grasses (pH = 7.22). Second site contained numerous small ponds approximately 30 m in diameter and was farther from the coastline. The surrounding area was a moist hummock grassland with an irregular surface and some polygon formation. Flora includes *C. aquatilis*, *D. integrifolia*, and several moss and grass species, including *Eriophorum* spp.

Denali Highway

MP 50 Fen in an alpine valley (altitude of 900 m), south of the Alaskan Range. Numerous large ponds in topographically low areas fed by melting glaciers. Thick spongy moss layer covered with water dense stands of *Carex* spp., *Arctagrostis latifolia* (R. Br.) Griseb. and (polar grass) around edge of ponds. Other flora includes *Potentilla palustris* (L) Scok. (marsh fivefinger), *Carex rostrata* Stokes (sedge), and several moss species.

Richardson Highway

MP 1373 Boreal marsh at low elevation near the southeastern border of Alaska with Canada and generally similar to Canadian boreal marshes found in taiga. Tall grasses up to 1 m high in 20 cm of water. No moss cover. Approximately 67% of area covered by *Carex* spp. and 33% by *latifolia* intermingled with submergent vegetation. Willows form a fringe around the marsh border and the bottom is mucky and irregular. Other plant species include *P. palustris*, and *Equisetum palustre* L. (horsetail).

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