FINAL REPORT

Control of Methane Production and Exchange in Northern Peatlands
National Aeronautics and Space Administration Grant # NAGW-3774

to the University of New Hampshire
Patrick Crill, Principal Investigator
expired 6/30/97

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FINAL REPORT

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This proposal has successfully supported studies that have developed unique long term datasets of methane (CH_4) emissions and carbon dioxide (CO_2) exchange in order to quantify the controls on CH_4 production and exchange especially the linkages to the carbon cycle in northern peatlands. The primary research site has been a small fen in southeastern New Hampshire where a unique multi-year data baseline of CH_4 flux measurements was begun (with NASA funding) in 1989. The fen has also been instrumented for continuous hydrological and meteorological observations and year-round porewater sampling.

Multiyear datasets of methane flux are very valuable and very rare. Datasets using the same sampling techniques at the same sites are the only way to assess the effect of the integrated ecosystem response to climatological variability. The research has had two basic objectives: 1. *To quantify the effect of seasonal and interannual variability on CH_4 flux.* 2. *To examine process level controls on methane dynamics.*

Sites.

Sallie's Fen, NH is a small (1.7 hectare) poor fen perched on glacial till in Barrington, NH (Fig. 1). Its location in southeastern New Hampshire places the fen on the southern edge of the band of boreal peatlands that extend, with increasing frequency of occurrence to the Hudson Bay. Wieder and Yavitt (1994) suggest that peatland sites along the southern edge such as Sallie's Fen may provide important insight into functional changes in boreal peatlands under predicted global climate change scenarios. Peat depths at the fen are over 4 m in some areas and there is a strong pH gradient with the northern portion of the bog over two pH units more basic. This is because of a small stream that enters at the northern end. The low pH end of the fen is dominated by *Sphagnum* spp. and *Carex* spp. with scattered *Chamaedaphne calyculata, Kalmia angustifolia* and *Vaccinium oxycoccus*. At the high pH end, the ericacious shrubs become more evident with *Rhododendron canadense* and *Vaccinium corymbosum* appearing with the leather leaf and sheep laurel. The *Sphagnum* spp. have been carefully characterized within the fen and they appear to be particularly useful as indicators of the long term average water table position at a given site.

The fen (Fig. 1) has been instrumented with a meteorological tower and hourly averages of one minute measurements of the temperature profile using thermistors from 25 cm above to 90 cm into the peat, air temperature and relative humidity at 2 m above the surface, precipitation (tipping bucket), net radiation, photosynthetically active radiation (PAR), heat flow at 5 and 15 cm, wind speed at 2m, air pressure, and automatic water level are logged. There are four other water level wells installed along the boardwalk, weirs were installed at the outlet and inlet stream and an array of peizometers installed September 1992. There are also three porewater sampling stations that allow year round (through ice) removal of pore fluids for trace gas or other analyzes.

The research site was established in 1989 and maintained with NASA funding as part of a larger research effort investigating trace gas emissions from a broad range of northern peatlands. CH_4 fluxes and respiratory CO_2 emissions from the soil surface have been measured from at least four sites in the fen since 1989 (Fig. 1) from a boardwalk installed in that year and extended to a total length of nearly 300 m in the fen in subsequent years. Since 1994, there have been measurements at 9 long-term collar sites within the fen. Also in 1994, temperature controled transparent chambers (Carroll and Crill, 1997) were used to begin measurements of net ecosystem exchange (NEE) of CO_2 at the fen surface.

Another long-term CH_4 flux dataset has been developed at an upland forest site, College Woods in Durham, NH (Crill 1991) in order to better place Sallie's Fen into a regional landscape context. The forest soils consume atmospheric CH_4 and constantly emit CO_2. CH_4 oxidation processes play a role in the regional CH_4 budget and, in peatlands with unsaturated surface soil layers, may directly affect the magnitude of the net CH_4 flux by consuming a portion of the CH_4 production before it is released to the troposphere (Whalen and Reeburgh 1990, Fechner and Hemond 1992, Moosavi et al. 1996, Moosavi and Crill 1997 a, b).

Flux and trace gas dynamics measurements in Lemeta Bog, Fairbanks, Alaska, near Toolik Lake, north slope Alaska, Angie's Bog, New Durham, NH and in a number of different peatlands in Illomantsi, Finland have been supported. This has been to place the intensive measurement programs of the local NH sites into the broader context of northern peatlands.

Some Results from the Research.

The Alaskan work has been lead by Dean Moosavi (also with the support of the NASA Graduate Fellowship program) as part of his M.S. and Ph.D.research. It has yielded multi-seasonal datasets of CH_4 emissions across environmental gradients from central Alaskan and North Slope Alaska peatlands. It has been important in the development, evaluation and the use of a field method for the use of CH_3F as a competitive inhibitor of CH_4 oxidative processes in the aerobic zones of unsaturated peatlands. For the first time, it is possible to directly measure the contribution of oxidative processes in ameliorating the total CH_4 flux from a wetland to the atmosphere (Moosavi and Crill 1997b). Techniques developed and tested in Alaska were very usefully applied in our subsequent participation in the BOREAS project (e.g. Moosavi and Crill 1997a).

The Angie's Bog studies were accomplished by Dr William Schmid, a retired chemistry professor living in the woods of New Hampshire, have also resulted in multi-year datasets of CH_4 and CO_2 fluxes. Currently these data are being evaluated and integrated into our existing datasets. Angie's Bog sites are in a very productive lagg area of an ox-bow wetland with a controlled water level and so provide us with information on the possible range and the seasonality of fluxes from wetlands in NH.

The Finnish studies have lead to the development of ongoing collaborations with colleagues involved in northern peatland trace gas fluxes. Technically, our collaborations have been important in the development of automated chamber systems for high frequency flux measurements, NEE flux measurement techniques and correlation models of emissions. Scientifically, our collaboration has resulted in advances in our understanding of N_2O dynamics in northern peatlands (Martikainen et al. 1993a; Crill et al. 1994), water table effects on CH_4 emissions (Martikainen et al. 1993b) and the effects of different nitrogenous compounds on CH_4 oxidation in northern peat soils (Crill et al. 1994).

In order to understand the magnitudes and the processes that control trace gas dynamics in northern peatlands, our most continuously intense efforts have been directed at our local sites in Sallie's Fen and College Woods. CH_4 and respiratory CO_2 fluxes have been measured with static chamber techniques from at least four sites in the Fen since 1989 (Fig. 2) from a boardwalk installed in that year and extended to a total length of nearly 300 m in the fen in subsequent years. Since 1994, there have been measurements at 9 long-term collar sites within the fen. This long term data set shows the different effects of a warm, wet year (1990) when a beaver kept the water table abnormally high; a warm, dry year (1991); a cool, wet year (1992); and a warm, wet year without a beaver's influence (1994) on the water level and CH_4 fluxes (Fig. 2). The picture of the interannual variability also emerges. As expected perhaps, the highest emissions are generally coincident with the warmest months of July and August. August 1991 is an unusual month probably because Hurricane Bob came over the fen and apparently there was a rapid degassing of the fen due to the unusually low air pressure and a large influx of oxygenated freshwater (8 cm of rain in 12 hours). The result was that it took the CH_4 fluxes and porewater concentrations over a month to recover. This is a small example of how natural events (or experiments) like this make long term datasets so interesting and informative about processes. These data from Sallie's Fen have been used to develop empirical models (Frolking and Crill 1994) that have been used to evaluate climate effects of the global source of methane from northern peatlands (Harriss et al. 1993).

The annual average flux is 1258 kg CH_4 and has ranged from 890 to 2070 kg CH_4 y^{-1} from the entire fen (Fig. 3). The seasonally averaged data show winter fluxes to contribute about 3% of the total annual flux. Fig. 3 also illustrates the large variability observed in the year to year total flux but also in the seasonal distribution of those fluxes. There is also a high degree of variability of the CH_4 flux in the summer at Sallie's Fen. The reasons for this are unclear as are the reasons for interannual variability of the total CH_4 emissions. Some of the answer may be tied to winter effects of the phase change energies required for freezing and thawing surface ice and its effect on season length. The initial indications are that the energy required for the freeze/thaw cycle, which is highly variable from year to year, directly affects the annual energy balance of the peatland and may have a direct effect on its annual CH_4 and carbon budgets. This variability, which needs to be incorporated into the models, is observed in a number of more limited seasonal datasets (e.g. Whalen and Reeburgh 1992). Much of the variance can be explained statistically by the strong temperature correlation with flux that is observed especially when average monthly CH_4 fluxes are compared to expected, long-term average temperatures (Fig. 4).

Since 1994 we have quantified net ecosystem exchange of CO_2 and its relationships to CH_4 flux with chambers that have controlled temperature, light, humidity and CO_2 levels (Carroll and Crill 1997). Grab samples for CH_4 analyzes are taken routinely from these chambers as well. The field gradient studies were designed to address these controls in a quantitative manner.

Plant metabolism may be directly associated with CH_4 flux. It has been known from at least the 1960's that plant root exudates will stimulate soil microbial activity. Previous work in Alaskan tundra led us to a model (Crill and Sass, abstract 1991) that indicated that biomass production was correlated to CH_4 production and flux. Similar observations has been made in monospecific stands of graminoid species in the Everglades (Whiting et al., 1991) and in a subarctic fen (Whiting and Chanton 1992; Waddington and Roulet 1996). Both Whiting et al. And Waddington and Roulet use net ecosystem exchange of CO_2 (NEE) as a correlate of labile photosynthate supply to the microbial community where this organic supply directly stimulates CH_4 and flux.

NEE in a closed system, such as a chamber, is the sum of soil, root and plant respiration minus the C fixation of photosynthetic activity. We used NEE in order to assess the effect of biomass production rates on CH_4 flux. Fig. 5 illustrates NEE/respiration and CH4 flux data from individual collars in 1997. We are continuing to analyze these data. NEE versus photosynthetically active radiation (PAR) and temperature curves will be established. PAR was logged hourly at the meteorological tower throughout the year and these data, along with temperature, will be used to extrapolate to the annual C exchange in the fen. The link of CH_4 emissions to measure of net primary productivity such as NEE (e.g. Fig. 6) could be useful since these parameters can be remotely sensed on large scales and have an extensive literature correlating them to environmental variables.

Some studies have demonstrated strong correlations between temperature and CH_4 flux while others have not. This may be due to the confounding influence of water table. When the water table remains close to the bog surface a strong correlation with temperature is evident when the water table is variable the correlation with temperature is much less robust (Roulet et al. 1992). Only a few direct observations of the influence of water table on CH_4 flux have been published. As the water table falls, it creates an unsaturated zone above the CH_4 producing, water-saturated peats. This aerobic zone provides an environment for the establishment of CH_4 oxidizing microbial oxidizing communities. These communities may be capable of consuming all of the deeper CH_4 production before it reaches the atmosphere. Water table and precipitation were constantly monitored in Sallie's Fen. Counterintuitively perhaps, a weak anti correlation between water table height and CH_4 emission became apparent (Fig. 7). That is to say that lower fluxes were measured during periods of high water in the summer. This is probably due to frontal passage, and the addition of fresh oxygenated meteoritic water to the surface of the fen.

In a similar manner, a long term dataset of CH_4 uptake and respiratory CO_2 emissions has been developed for nearby drained upland forest soils (Fig. 8; Crill 1991). Seasonal dynamics have been consistent in the broadest sense from year to year, i.e. highest rates in the summer and lowest in the summer (Fig. 9). There are significant differences from year to year in the annual totals due to climatic differences that control soil moisture and temperature. Even though the CO2 emissions are very tightly correlated with temperature, CH4 uptake becomes decoupled from temperature in the summer. The rates of consumption become diffusion limited. This is apparent when monthly averaged uptake rates are compared to the soil gravimetric moisture (Fig. 10) and the effect of increasing moisture (and hence wfps) in inhibiting fluxes becomes evident.

The long term field measurements of Sallie's Fen and College Woods are significant in that they will reveal something about the nature of the immediate controls on CH_4 flux over short time scales and, because of the cumulative effect of a long term dataset they will reveal something about the interannual variability in emissions . There is a problem of scale, both in space and time, of extrapolating from the small scale (on the order of days and cm^2) to ecosystem gradients in the fen (on the scale of seasons or years and m^2). The goal is to develop testable hypotheses (roughly equal to models) that can provide information over regional or global areas on time scales of climate change and to test models that will anticipate the long-term integrated ecosystem response to changing controls on CH_4 flux.

We have generated a unique, continuous multiyear data set of CH_4 and CO_2 exchange at specific sites. Such a data set is the only way to assess the effect of the integrated ecosystem response to climatological variability. We will know more about peatland CH_4 and its interaction with CO_2 fixation and/or respiration and the effects of pH, and water and energy balance on the CH_4 flux. The complete dataset will provide a common testing ground for models for many years into the future.

This solid picture of CH_4 flux will provide the necessary context in which to assess the effect of seasonal and interannual climatological variability on emissions. We will have also examined in a quantitative manner the most important process level controls on CH_4 production and flux, namely temperature, substrate supply (if NEE is correlated), and moisture. Our measurement and manipulation program will be tightly linked to parallel efforts to develop models of CH_4 flux from peatlands. The result will be process level models of CH_4 exchange that will be tightly constrained by the hydrologic and energy flux balances in a quantitative manner.

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Data Management

The expected data products include CH_4 fluxes, CH_4 porewater concentrations, NEE, and all the ancillary data from the flux measurements (soil, air and chamber temperature, PAR the chamber) and all of the automated hydrometeorological data. The final checked numbers of all manual and automated systems have been or soon will be entered into relational databases for access and analysis. Particular attention will be paid to data documentation, organization and quality control. It is assumed that we will submit our finished data products to a publically accessible archive to be determined by discussions with the program manager and other users such as the Oak Ridge National Laboratory Distributed Active Archive Center. We have submitted datasets to the TRAGNET program in Boulder, CO. Of course, all our data are presently available directly from us to anybody who asks.

Theses and Dissertations:

The following theses and dissertations were accomplished in whole or in significant part with the support of NASA grant NAGW-3774 to the University of New Hampshire, Control of Methane Production and Exchange in Northern Peatlands

William De Mello, 1992, Ph.D., Factors controlling fluxes of volatile sulfur compounds in sphagnum peatlands, Univ. of New Hampshire.
Peter Czepiel, 1992, M.S., Methane Emissions from Urban Systems: A Model and Field Investigation, Univ. of New Hampshire.
Steve Frolking, 1993, Ph.D., Modeling Soil Climate Controls on the Exchange of Trace Gases between the Terrestrial Biosphere and the Atmosphere, Univ. of New Hampshire.
Sadredin Moosavi, 1994, M.S., Controls on Methane Flux from an Alaskan Boreal Wetland, Univ. of New Hampshire.
Leonard Rappoli, 1994, M.S., Nitrous oxide production in a New Hampshire freshwater peatland, Univ. of New Hampshire
Georgia Murray, 1994, M.S., The effects of acid deposition on sulfate reduction and methane production in peatlands, Univ. of New Hampshire
Paul Carroll, 1995, M.S., Carbon Cycling in a New Hampshire Fen, Univ. Of New Hampshire.
Peter Czepiel, 1995, Ph.D., Radiatively Active Trace Gas Emissions from Waste Management Systems, Univ. of New Hampshire.
Rae Melloh, 1996, M.S., Seasonal Hydrology and Winter Methane Dynamics in a Temperate Poor Fen, Univ. of New Hampshire.
Sadredin Moosavi, 1998, Ph.D. (pending),

Publications and Abstracts:

The following publications and presentations were accomplished in whole or in significant part with the support of NASA grant NAGW-3774 to the University of New Hampshire, Patrick Crill, PI, Control of Methane Production and Exchange in Northern Peatlands.

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Figure 1

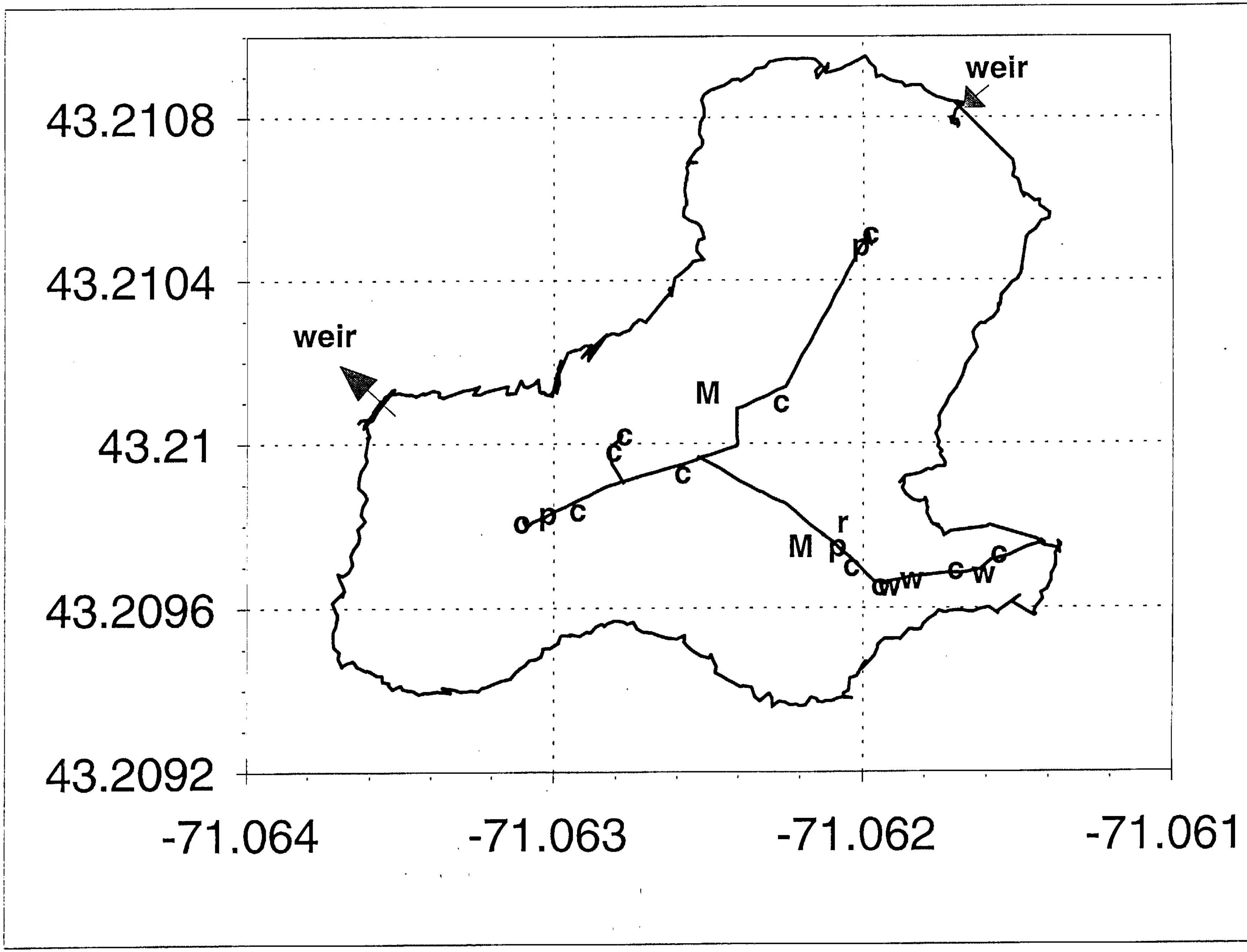
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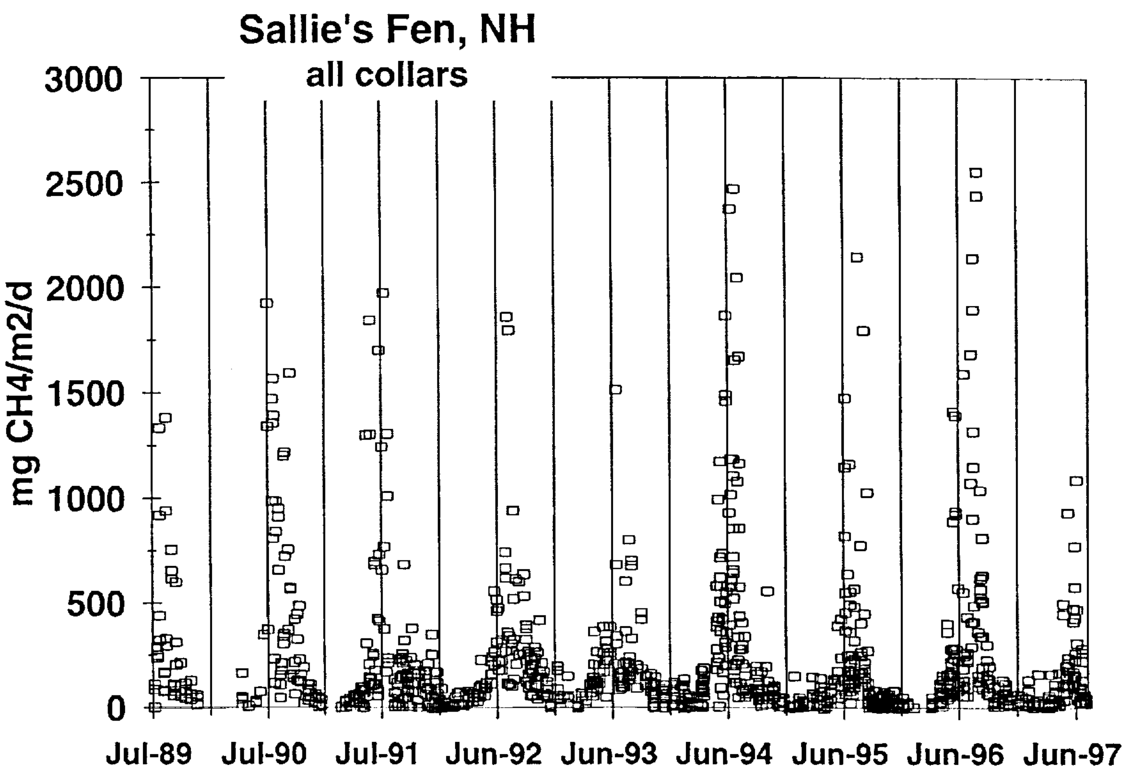
Figure 2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Jun-92
Jun-93
Jun-94
Jun-95
Jun-96
Jun-97

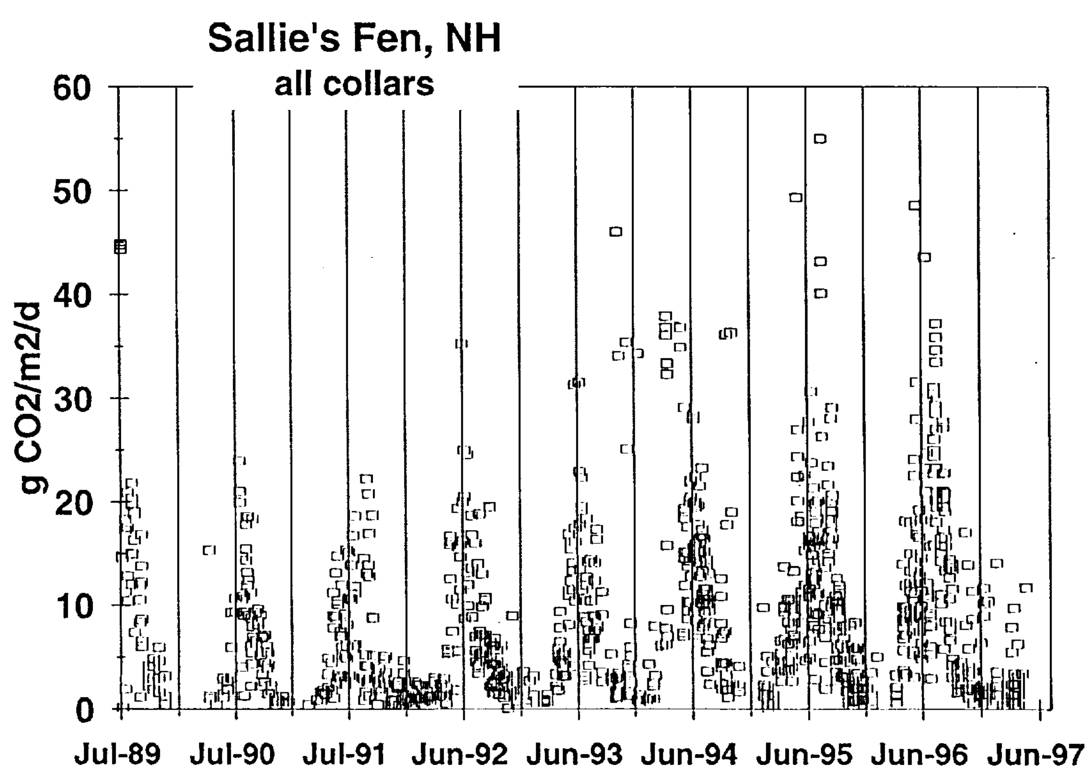

Sallie's Fen, NH
all collars
g CO2/m2/d
60
50
40
30
20
10
0
Jul-89
Jul-90
Jul-91
Jun-92
Jun-93
Jun-94
Jun-95
Jun-96
Jun-97

Figure 3

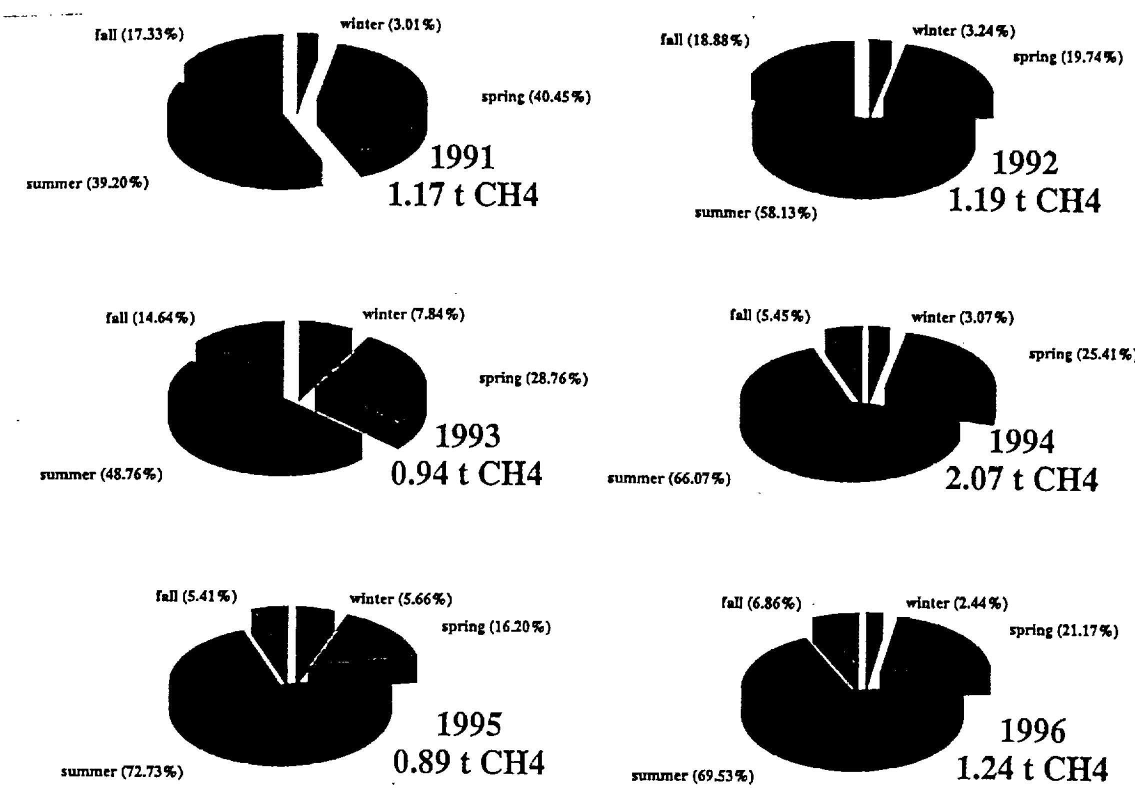


Figure 4

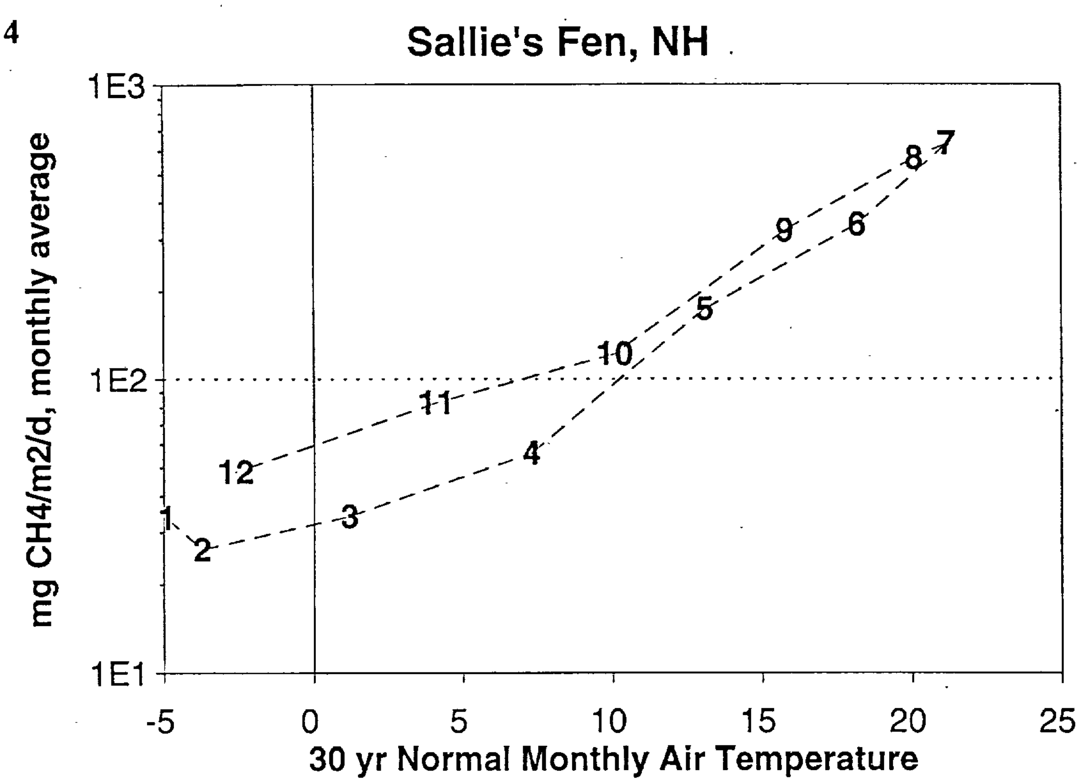


Figure 5

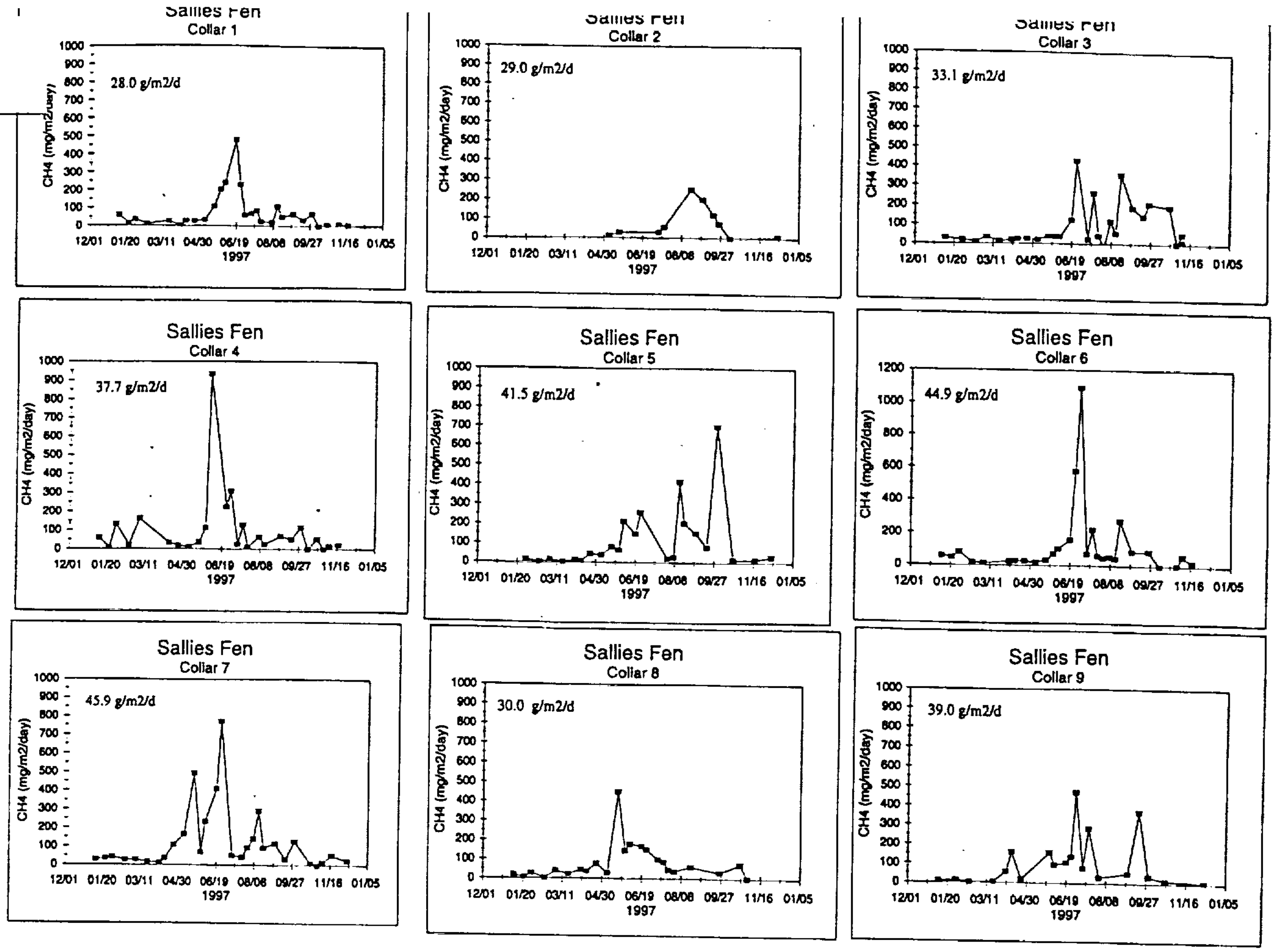


Figure 6

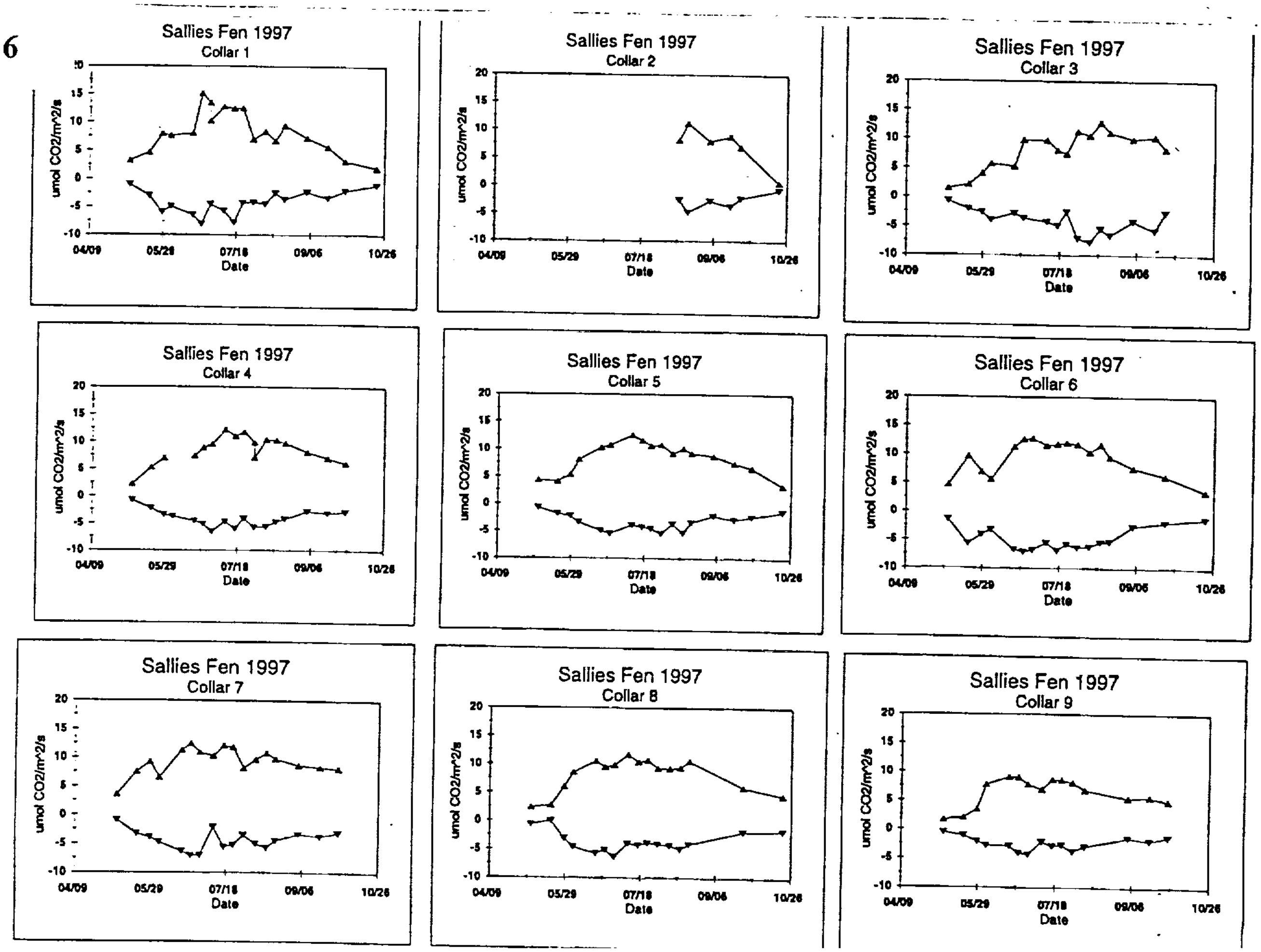
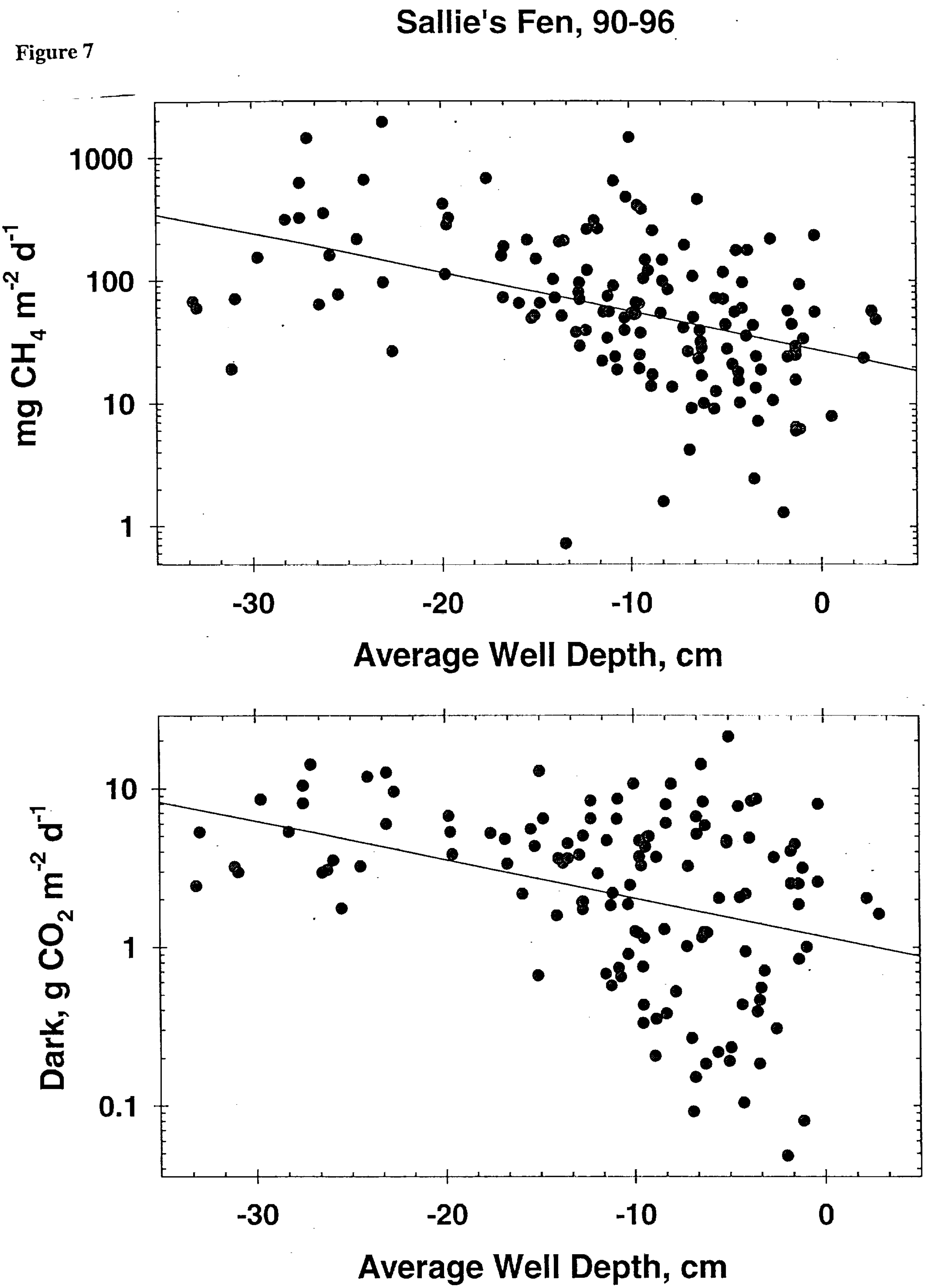


Figure 7



Sallie's Fen, 90-96
1000
100
10
1
mg CH_4 m^{-2} d^{-1}
-30
-20
-10
0
Average Well Depth, cm
10
1
0.1
Dark, g CO_2 m^{-2} d^{-1}
-30
-20
-10
0
Average Well Depth, cm

Figure 8

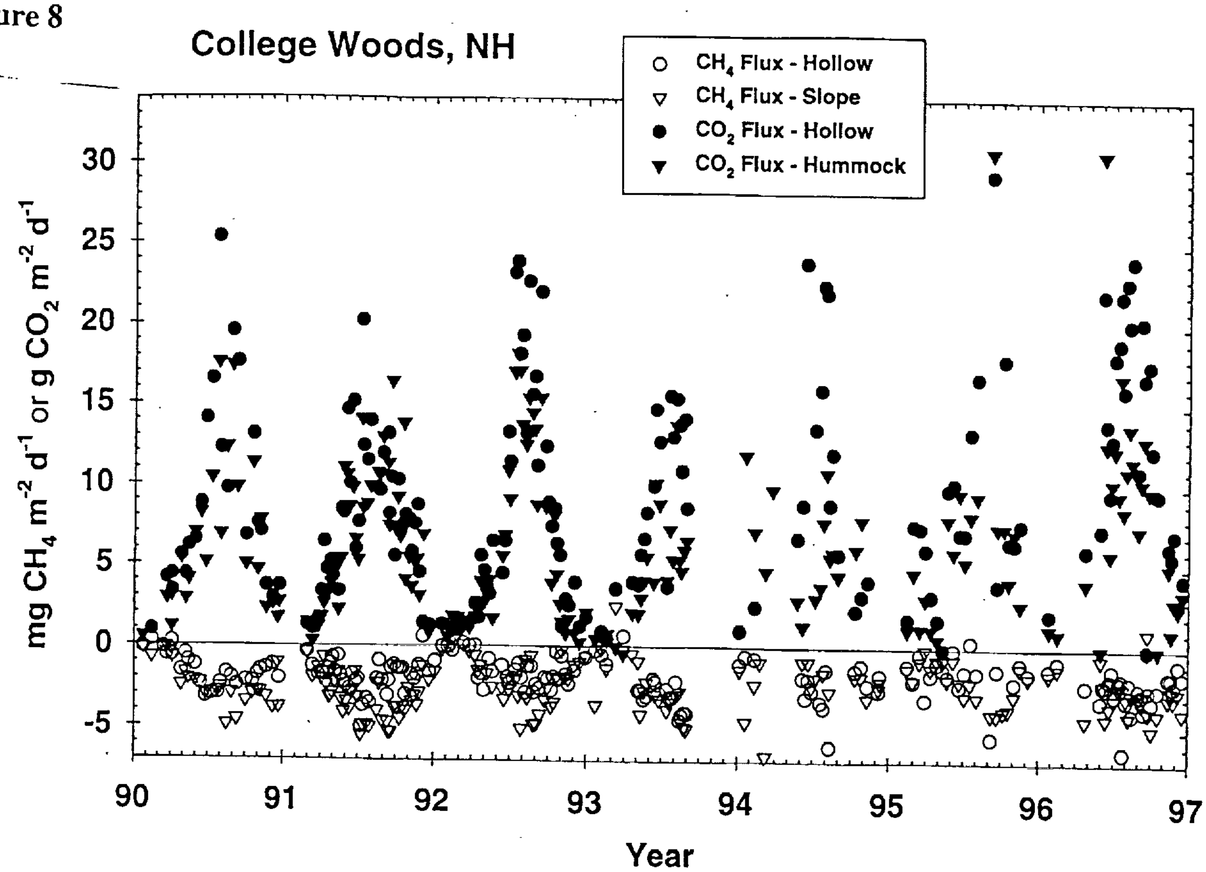
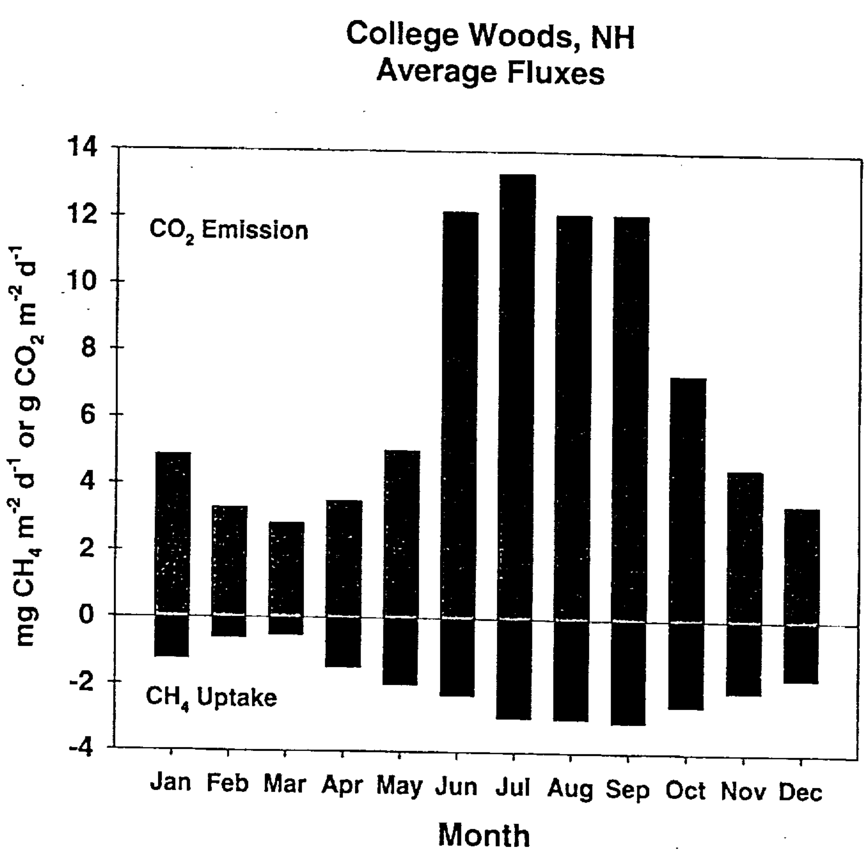


Figure 9



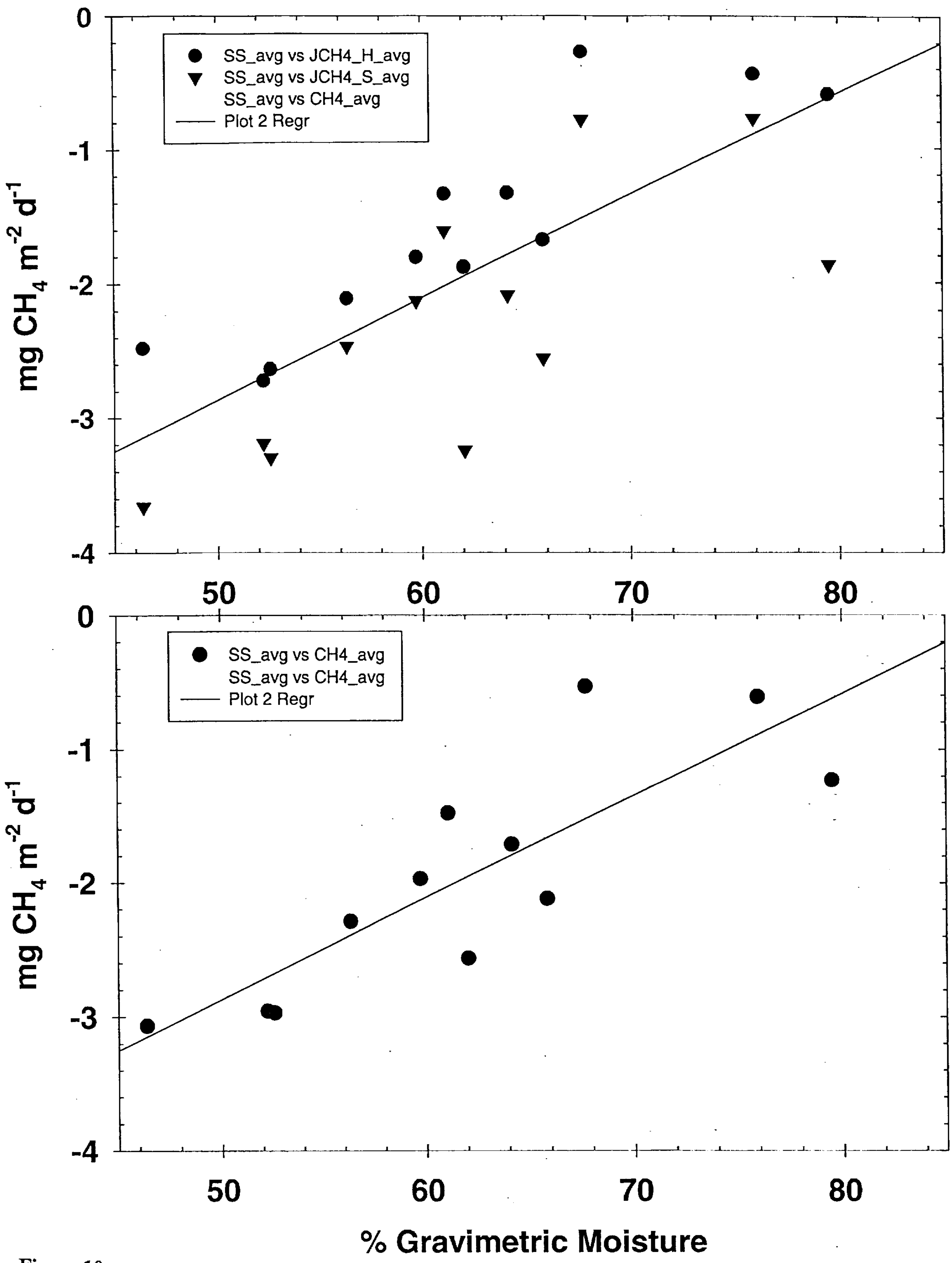

0
-1
-2
-3
-4
mg CH4 m-2 d-1
SS_avg vs JCH4_H_avg
SS_avg vs JCH4_S_avg
SS_avg vs CH4_avg
Plot 2 Regr
50
60
70
80
0
-1
-2
-3
-4
mg CH4 m-2 d-1
SS_avg vs CH4_avg
SS_avg vs CH4_avg
Plot 2 Regr
50
60
70
80
% Gravimetric Moisture

Figure 10