Final Report for Period: 10/1997 - 09/2001**Submitted on:** 03/21/2002**Principal Investigator:** Oechel, Walter C.**Award ID:** 9730004**Organization:** San Diego State Univ Fdn**Title:**TECO: Patterns and Controls of Temporal Variation in CO₂ Sequestration and Loss in Arctic Ecosystems**Project Participants****Senior Personnel****Name:** Oechel, Walter**Worked for more than 160 Hours:** Yes**Contribution to Project:****Name:** Vourlitis, George**Worked for more than 160 Hours:** No**Contribution to Project:****Name:** Hastings, Steven**Worked for more than 160 Hours:** Yes**Contribution to Project:**

DOE Patent Clearance Granted
MPDvorscak
Mark P Dvorscak
(630) 252-2393
E-mail mark.dvorscak@ch.doe.gov
Office of Intellectual Property Law
DOE Chicago Operations Office
Jan 13, 2003
Date

Post-doc**Name:** Panikov, Nikolai**Worked for more than 160 Hours:** Yes**Contribution to Project:**

Collaborator from Stevens Institute of Technology, New Jersey. Was a subcontracted researcher involved with certain aspects of the experiment involving underground soil processes. (1999, 2000)

Name: Ebert, Tom**Worked for more than 160 Hours:** No**Contribution to Project:**

Subcontracted researcher, SDSU, working at an independent site on plant demography. (1999, 2000)

Graduate Student**Name:** Kinoshita, Glen**Worked for more than 160 Hours:** Yes**Contribution to Project:**

Graduate research assistant, SDSU, responsible for managing data collection and processing. (1999, 2000, 2001)

Name: Kwon, Hyojung**Worked for more than 160 Hours:** Yes**Contribution to Project:**

Graduate research assistant, SDSU, assisted in data collection. (1999, 2000, 2001)

Undergraduate Student**Name:** Reed, Clay**Worked for more than 160 Hours:** Yes**Contribution to Project:**

Undergraduate research assistant, SDSU, assisted in data collection

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Name: Ramos, Alejandra

Worked for more than 160 Hours: Yes

Contribution to Project:

Undergraduate research assistant, SDSU, assisting in data collection. (2000)

Name: Chapman, Robert

Worked for more than 160 Hours: Yes

Contribution to Project:

Undergraduate research assistant, SDSU, assisting in data collection. (2000)

Name: Lambert, Phillip

Worked for more than 160 Hours: Yes

Contribution to Project:

Undergraduate research assistant, SDSU, assisting in data collection. (2000)

Name: Sanchez, Leticia

Worked for more than 160 Hours: Yes

Contribution to Project:

NSF-UMEB participant, SDSU, assisting in data collection and conducting independent field research project. (2001)

Name: Perl, Michelle

Worked for more than 160 Hours: Yes

Contribution to Project:

NSF-UMEB participant, SDSU, assisting in data collection and conducting independent field research project. (2001)

Technician, Programmer

Name: Bryant, Pablo

Worked for more than 160 Hours: No

Contribution to Project:

Research associate, SDSU, responsible for equipment construction. (1999, 2000, 2001)

Other Participant

Name: Zamolodchikov, Dmitri

Worked for more than 160 Hours: Yes

Contribution to Project:

Researcher at Moscow State University, assisted with data collection. (1999, 2000, 2001)

Name: Karolin, Dmitri

Worked for more than 160 Hours: Yes

Contribution to Project:

Researcher at Moscow State University, assisted with data collection. (1999, 2000, 2001)

Research Experience for Undergraduates

Organizational Partners

NOAA Atmospheric Turbulence and Diffusion Div

Other Collaborators or Contacts

John A. Gamon

Professor

Center for Environmental Analysis (CEA-CREST)

& Department of Biological Sciences
California State University, Los Angeles

Dr. K. Fred Huemmrich
Joint Center for Earth Systems Technology (JCET)
University of Maryland Baltimore County

Gary J. Michaelson
Research Associate
University of Alaska, Fairbanks
Agricultural and Forestry Experiment Station

Activities and Findings

Research and Education Activities:

Research activities:

Activities from 1997 to 2001 were to determine seasonal and interannual patterns of net ecosystem CO₂ flux from wet coastal and moist tussock tundra ecosystems using eddy covariance. This took place during all years in Barrow and Prudhoe Bay, AK and a tower system was installed in Atkasuk, AK in 1998 and run continuously to the present.

Another major research activity from 1999-2001 was to install a reliable system for elevating soil temperatures and manipulating soil water tables and from there, quantify whole ecosystem CO₂ fluxes for the summer growing season between the treatments. This was to determine the possible effects of global climate change on the tundra ecosystem and how this might affect the carbon budgets of this region. Along with CO₂ fluxes, nutrient cycling, plant growth and demography, and effects on soil nutrients were to be examined with simulated climate change. The experimental site was installed in the beginning of the 1999 summer growing season and maintained until October of 1999. It was reactivated at the beginning of the 2000 growing season and maintained until September of 2000. The site was reactivated again at the beginning of the 2001 growing season and ended in September of 2001, where the experiment was ended with the removal of all equipment from the site. A total harvest was done at this time, as were soil cores to look at the effects of manipulation over three successive seasons.

Research was also conducted to link ecosystem physiological responses to canopy reflectance data. This was done in association with John Gamon of Cal State Los Angeles, who utilized his equipment and expertise to gather reflectance data both at small plot level scales and larger regional scales through the mounting of instrumentation on the SDSU Sky Arrow research aircraft.

Science Education and Outreach:

This project has worked diligently to promote K-16 science education and outreach. For example, Dr. Oechel obtained a GK-12 grant the PISCES Project (Partnerships to Improve Science Curriculum in Elementary Schools; an NSF GK-12 program project) to further K-6 science education through the use of science graduate and undergraduate students (the Science Corps) in K-6 classrooms. This is co-funded by OPP to involve Alaskan North Slope K-6 classrooms and university students. In April of 2000, Steve Hastings and Adrienne Marriott from PISCES attended an ARCUS sponsored workshop in Fairbanks, AK on science education in the Arctic. Mr. Hastings met with teachers and the Principle of Ipalook Elementary school in Barrow after the workshop. A number of programs were set up for summer 2000 involving researchers and PISCES science Corps participants.

Alejandra Rios, a PISCES Science Corps student from San Diego worked with students at Ipalook Elementary School in the summer of 2000. Ms. Rios's activities in Barrow continued as she worked with the Inupiat Heritage Center on a culturally relevant Global Change Exhibit. This allows a direct connection of NSF OPP funded Global Change Research to a local context with very high visibility. In January, 2001 Ms. Rios returned along with Maggie Reinbold (also a PISCES Science Corp participant) to instruct the elementary and middle school classes in Global Change Science. This was culminated in a sharing of Western science and traditional knowledge with Inupiat Elders and school children at Ipalook Elementary and Hobson Middle Schools. Local school children had the opportunity to question Western Scientists and Inupiat Elders on their perceptions of past climate change and the importance of future global change led by Dr. Walter C. Oechel and Ms. Nancy Taylor. Glen Kinoshita received tuition reimbursement and a stipend for his involvement in the PISCES program over the Spring and Fall of 2001 where he taught science in K-6 San Diego schools in partnership with elementary teachers using inquiry based science kits. Glen is in the last stages of completing his masters thesis which focuses on the effects of heating and a changes in water table on the annual flux of coastal tundra in the barrow area, initiated in 1998. In January of 2002, he will participate in a science educational experience for Barrow school children along with other PICES members. His first hand knowledge of the ecology of the Barrow area by way of four years of doing research in the

Arctic will help to make the educational experience for the native and non-native children of Barrow especially relevant.

During the summer of 2001 a number of educational outreach activities took place during the summer field season. Chris Donovan, a high school teacher at Desert View High School Tucson, Arizona participated in collecting data over the summer at Barrow as part of the NSF Teachers Experiencing the Arctic and Antarctic. Ms. Donovan worked side by side with SDSU researchers and maintained a daily log of her activities to share with her class in Tucson as well as participating TEA's teachers and classrooms. Her web page can be found at http://tea.rice.edu/tea_donovanfrontpage.html.

Undergraduate education was specifically targeted as part of the NSF UMEB: Integrating Independent Research and Group Learning in Environmental Biology. SDSU undergraduates Leticia Sanchez and Michelle Perl carried out independent studies in the summer of 2001 at Barrow on soil respiration and below ground root and microbial activity respectively. During the Spring semester of 2001 they had regular meetings with other UMEB participants where developed their projects and presented their proposals for their summer research activity. NSF Course, Curriculum, and Laboratory Improvement (CCLI) grant provided additional eddy covariance equipment such that the Arctic carbon flux data gathered at Barrow could be shared in a near real time format to be used in K-6 science education as part of the PISCES program. Web pages presenting the data can be found at <http://fs.sdsu.edu/project/met1.html> where comparisons with chaparral and desert ecosystems can be made. Linkages with elementary education is being developed in the form of web based lessons for elementary school classes currently posted at <http://fs.sdsu.edu/piscs/>.

A number of presentations were given to various groups in Barrow and Atkasuk including at Meade River School (Hastings). Other presentations and briefings were made on Barrow Public Radio (Oechel), to the U.S. Women's Press Corp (Zulueta) and representatives of the U.S. House appropriations committee (Oechel et al.) among others. Barrow High School Science class visited the OPP flux aircraft for a tour. Results of the research have appeared in the popular press and magazines, on All Things Considered, NPR (Oechel), a BBC documentary (Oechel, Zulueta, et al.) on global change which aired in Britain and the U.S. (PBS).

In 1991, the SDSU Biology Department received a Howard Hughes Medical Institute grant to increase the numbers of undergraduate students, especially those from historically underrepresented populations, preparing for graduate studies in biology. In 2000, Alejandra Rios and Alejandra Ramos worked on our projects in Barrow. We have had six students from the Hughes program involved in summer research activities and our educational grants. Rommel Zulueta, currently a Ph.D. student involved in the research proposed here, and pilot of our SDSU 650 ERA flux aircraft, first started working with the Global Change Research Group by way of the Howard Hughes Program in 1993.

A review of the Arctic Science education activities can be found at <http://gcrcl.sdsu.edu/%7Episcs/ArcticPPT/index.html> while the summer of 2000 and 2001 research activities can be found at <http://gcrcl.sdsu.edu/~jverfail/AK2000Web/index.htm> and <http://gcrcl.sdsu.edu/~jverfail/AK2001Web/index.html>.

Findings:

The tundra manipulation experiment was run from 1999 to 2001. During this time water table and soil temperatures were manipulated to look at the effects of simulated climate change.

In the 1999 season, heating the soil at 5 cm depth to 5°C above ambient caused the soil thaw depths to increase to double that of the control plots. Water table in the elevated water plots was maintained at soil saturation, while plots with lowered water tables were maintained at least 10 cm below the controls. The effect on CO₂ fluxes was as follows: net flux showed stronger sink activity with elevated water tables, while strong source activity was seen with elevated soil temperatures. Lowering the water table alone did not affect CO₂ fluxes when compared to the controls. Whole ecosystem respiration was increased with elevated temperatures, but not with only water table manipulation. Gross ecosystem exchange was higher for elevated soil temperature and elevated and lowered water table treatments, with other treatments only showing small deviations from the controls.

In the 2000 season, heating the soil at 5 cm depth to 3°C above ambient caused the soil thaw depths to increase to double that of the control plots. Water table in the elevated water plots was maintained at soil saturation, while plots with lowered water tables were maintained at least 10 cm below the controls. The effect on CO₂ fluxes was as follows: net flux values were similar between the control plots and lowered water table plots being overall sinks. Elevating the water tables caused those plots to become stronger sinks. Soil heating caused those plots to become sources, with the heated soil plots showing the greatest source activity. Heating the soil and elevating and lowering the water table showed weaker source activity. Whole ecosystem respiration was similar between the controls and other ambient temperature water treatments, but with elevated soil temperatures, higher respiration values were seen, with all heated soil treatments showing similar total ecosystem respiration values. Gross ecosystem exchange for the treatments when compared to the controls only showed minor deviations, with the elevated water table treatment, heated soil with elevated water table, and heated soil with lowered water table treatments showing small increases. Heating the soil alone showed a slight decrease when compared to the controls.

Continuing into the 2001 season, heating the soil at 5 cm depth to 3°C above ambient caused the soil thaw depths to increase to double that of the control plots. Water table in the elevated water plots was maintained at soil saturation, while plots with lowered water tables were maintained at least 10 cm below the controls as in the previous two seasons. Elevating the water table increased the sink activity when compared to the controls while lowering the water table didn't have an appreciable effect. Heating the soil caused the plots to become weak sources, but with the addition of elevated water table, strong sink activity was observed over the season. Whole ecosystem respiration increased for all treatments when compared to the controls. The heated soil treatments and heated soil with lowered water table treatments showed the highest ecosystem respiration values. Gross ecosystem exchange values were also higher for all treatments when compared to the controls. Elevating the water table and the heated soil with lowered water table treatments showed similar increases, but elevating the soil temperature and either elevating or lowering the water table showed the greatest increase in gross ecosystem exchange.

The utilization of reflectance data has shown to be useful in the small scale in looking at differences of water table and heating manipulation and on the larger scale, differentiating between vegetation types and topographic features when mounted on an aircraft.

Measurement Year - 1999

Site Locations: Barrow and Atqasuk

Climatic Conditions

Table 1 shows meteorological data such as average air temperature, average soil temperature at three different levels and precipitation from January to December, 1999 at Barrow and Atqasuk sites. From January to December, average air temperature was $\bar{13.5}^{\circ}\text{C}$ and average soil temperatures at 0, -5, and $\bar{10}$ cm were $\bar{13.6}^{\circ}\text{C}$, -13.5°C and $\bar{14.2}^{\circ}\text{C}$, respectively. Rain started in May and intensive rain mainly happen in August and total precipitation was 70.9 mm. At Atqasuk site, air temperature was much lower than soil temperature at two different levels (0 cm and $\bar{5}$ cm) from January to April. Air temperature and soil temperature at 0 cm and $\bar{5}$ cm increased up to 18.0°C , 16.7°C and 10.1°C , respectively during the growing season (June $\bar{8}$ August). Annual average air temperature was $\bar{12.4}^{\circ}\text{C}$ and soil temperatures at 0 cm and $\bar{5}$ cm were $\bar{6.5}^{\circ}\text{C}$ and $\bar{6.7}^{\circ}\text{C}$, respectively and total precipitation was 93.8 mm.

Seasonal Pattern of CO₂ and H₂O fluxes

Fig. 1 shows seasonal change in daily variation of CO₂ flux during the growing season at Barrow (Fig. 1a) and Atqasuk (Fig. 1b) sites. Net CO₂ flux at Barrow and Atqasuk showed sink during daytime in April and May. Net CO₂ flux at Atqasuk showed stronger sink than that at Barrow. Sink of net CO₂ flux in April and May may be caused by the photosynthesis of Alge and Lichen under snow cover, which could be activated with low sun light. After snow melted (June), net CO₂ flux at both sites turned to source from sink in daytime by soil respiration. Sink level of net CO₂ flux increased up to $\bar{0.1}$ g C m⁻² hr⁻¹ and $\bar{0.03}$ g C m⁻² hr⁻¹ in July and August at Barrow site and Atqasuk site, respectively in July and August. The reason that Atqasuk site showed less sink of net CO₂ flux than Barrow site during the growing season is assumed that the rate of soil respiration is higher than that of photosynthesis by plant at Atqasuk site. Seasonal change in daily variation of H₂O flux at both Barrow and Atqasuk site is depicted in Fig. 2. Net H₂O flux at both sites showed source from April to August. Source level of net H₂O flux increased to 44.5 mg m⁻² s⁻¹ in July and decreased in August at Barrow. At Atqasuk, net H₂O flux increased up to 92.7 mg m⁻² s⁻¹ in June and decreased from late June to August. Net H₂O flux at Atqasuk generally showed stronger source than that at Barrow

Measurement Year - 2000

Site Locations: Barrow and Atqasuk

Climatic Conditions

Table 2 shows climatic condition of average air temperature, average soil temperature at three different levels and precipitation from January to December, 2000 at Barrow and Atqasuk sites. From January to December, average air temperature was $\bar{9.0}^{\circ}\text{C}$ and average soil temperatures at 0, -5, and $\bar{10}$ cm were $\bar{11.8}^{\circ}\text{C}$, -12.6°C and $\bar{13.1}^{\circ}\text{C}$, respectively. Rain started in May and intensive rain mainly happen in August and total precipitation was 97.3 mm

(Table 2). At Atqasuk site, average air temperature was $\bar{12.3}^{\circ}\text{C}$ and soil temperatures at 0 cm

and $\bar{5}$ cm were $\bar{8.3}^{\circ}\text{C}$ and $\bar{8.7}^{\circ}\text{C}$, respectively. Rain started in May and intensive rain mainly happen in August and total precipitation was 124.0 mm.

Seasonal Pattern of CO₂ and H₂O fluxes

The cumulative net CO₂ exchange at Barrow showed strong sequestration carbon compared to that at Atqasuk (Fig. 10). The seasonal integrated carbon uptake from the atmosphere was 60 gC m⁻² from the atmosphere in Barrow and 66 gC m⁻² in Atqasuk. As mentioned earlier, the main explanation for the difference in amplitude of the seasonal carbon exchange between Barrow and Atqasuk is caused by the contribution of soil respiration to carbon exchange. The Atqasuk site is warmer and drier than Barrow, while Barrow site is wetter and colder than Atqasuk. The environmental condition at Atqasuk stimulates high microbial activity and results in high CO₂ efflux from soil. These results here implicates that reductions in soil moisture and an increase in air temperatures will play a role predominant role in controlling soil respiration and change the net CO₂ activity from sink to source. Potential increases in thaw depth would tend to exacerbate the differences as the climate warmed.

Site Locations: Lavrentia

Climatic Conditions

The local climate and atmosphere motion are monsoon in general and ocean water masses circulation stands for the main climate forming factor here. Marine strong winds bring a cool and cloudy weather with frequent fogs in warm season of a year. In summer the predominant wind direction in the coastal zone is from the sea to the mainland, whereas in winter it is opposite. The oceanic type of climate is characterized with high humidity and small range of intra-diurnal and monthly air temperatures. According to the stationary long-term (1951 - 85) observations in Lavrentiya weather station (Scientific-applied reference book on climate of USSR, 1990), the average annual air temperature

here is -5.8°C , which is one of the highest in Eurasia tundra zone. Mean air temperature in July as the warmest month is $+8.1^{\circ}\text{C}$, and in February as the coldest is -18.7°C . The beginning of the frost-free period in a year averaged at June 21, lasting till 4th of September with the duration of the frost-free period of 74 days.

Seasonal Pattern of CO_2 and H_2O fluxes

In the section below we analyzed the results of continuous micrometeorological measurements of net CO_2 fluxes at diurnal and seasonal scales. Periodical diurnal chamber-based measurements of canopy-level carbon dioxide fluxes were used for independent comparison with long-term tower-based data. As the eddy-covariance method doesn't distinguish between GPP and GER carbon fluxes, chamber-based data on these two constituents of the net flux were also recruited for the analysis of its controls.

The diurnal dynamics of carbon fluxes in tundra ecosystems is mainly affected by ambient conditions, namely, temperature and PAR, whereas phenological changes in phytomass standing crops or differences in phytomass structure are the main controls of seasonal dynamics (Zamolodchikov et al., 2000a).

Within the second half of the snow-free season one could set off the most characteristic periods in the carbon net flux diurnal dynamics. In the last 7-day period of July tundra was functioning as a carbon sink (Fig. 15) more than 15 hours a day (5:00 - 20:30). Maximum carbon sink was about $-8 \text{ gC m}^{-2} \text{ day}^{-1}$ in the midday hours. In the night time efflux seldom exceed $2 \text{ gC m}^{-2} \text{ day}^{-1}$, which resulted in diurnal carbon sink near $2 \text{ gC m}^{-2} \text{ day}^{-1}$. Amongst the abiotic factors PAR has demonstrated the best correlation with CO_2 flux ($R = -0.87$, $P < 0.05$, $n = 336$), which is easy to explain. At the end of July, at the peak season, the photosynthetic organs of vascular plants are the most developed. GPP flux considerably exceeds GER ($\text{GER} \ll \text{GPP}$) and contributes significantly to diurnal dynamics of the net flux ($\text{NF} = \text{GPP} - \text{GER}$). In its turn GPP is rigidly controlled with PAR and thus the NF should also correlate with PAR.

In mid-August the period of day-time carbon sink decreased to 10 hours from 8:00 till 18:00 (Fig. 16) with maximal rate at about $-4 \text{ gC m}^{-2} \text{ day}^{-1}$. Shortening of the sink period is due to seasonal decrease of diurnal light phase, whereas the decrease of the maximum rate of NF resulted from seasonal degradation, senescence and leaf-fall in vascular plants. The carbon dioxide emission in the night-time averaged at $1.5 \text{ gC m}^{-2} \text{ day}^{-1}$ i.e. its rate slightly decreased as compared to the end of July. At that period tundra kept the carbon sink pattern with the average rate of $-0.5 \text{ gC m}^{-2} \text{ day}^{-1}$.

Measurement Year - 2001

Site Locations: Barrow, Atqasuk, Prudhoe Bay, and Quartz Creek

Climatic Conditions

Barrow, Alaska

The 2001 summer season (June-September) on the Barrow coastal plain was also colder and drier than in 2000. Weather conditions in early-June were cold with periods of light snow and an average air and soil surface temperature of 0°C and -3°C respectively. Complete snow melt occurred in mid-June. Maximum recorded air and soil surface temperature was in August with 10.2°C and 5.2°C respectively. Total precipitation was 84.6 mm. Predominant wind directions were from the NW to NE with wind speeds averaging 4.9 m s^{-1} and varying from 1.8 m s^{-1} to 8.7 m s^{-1} . Maximum active layer depth was measured in late-August at -33.3 cm .

Atqasuk, Alaska

The 2001 summer season (June-September) in the Atqasuk area was colder and drier than in 2000. Average air temperature between June-September was 4.2°C . Average monthly temperatures were 4.3°C , 7.6°C , 4.3°C , and 0.7°C for June, July, August, and September respectively. Soil surface temperatures were close to freezing in early June, increasing through July to a maximum recorded temperature of 18.6°C . Total summer precipitation for this time period was 88.9 mm, considerably lower than the 120.6 mm recorded for the previous summer. Monthly precipitation values were 10.2 mm, 35.7 mm, 33.2 mm, and 9.8 mm for June, July, August, and September respectively. The maximum recorded active layer depth in late-August was -39 cm . Winds were predominately from the NW to NE with an average summer wind speed of 4.4 m s^{-1} .

Prudhoe Bay, Alaska

The average air temperature for July-September in Prudhoe Bay was 9.2°C with a maximum recorded air temperature of 14.4°C . Mean surface soil temperature was 7.2°C . Total precipitation was 147.1 mm with intensive rain events occurring between mid-July to mid-August. Total monthly precipitation was 30.0 mm, 116.8 mm, and 0.3 mm for July, August, and September respectively. Average wind speed was 4.9 m s^{-1} with the predominant wind direction from the NW to NE.

Quartz Creek, Seward Peninsula, Alaska

The Quartz Creek area was on average cooler (9.5°C) in 2001 compared to the 8-year mean (1992-2000: 10.7°C). This was mainly due to the lower average air temperatures in June (8.6°C) and July (10.6°C). The only summer snowfall event was on June 14th. The last night of frost in the spring was on June 17th and the first fall frost being on August 21st. There were 26 days with rain events and a total precipitation of 94.5 mm. This is close to the 8-year average (1992-2000: 98.7 mm). The average wind speed was 3.7 m s^{-1} coming predominately from the S, SW

and W. Thaw started after the completion of snow melt (estimated at June 1) with the maximum active layer depth measured at -53 cm (-44 cm in the intertussocks).

Seasonal Pattern of CO₂ and H₂O fluxes

The general direction and amplitude of net CO₂ flux for Barrow, Atqasuk, UPAD and Quartz Creek during the growing season were as follows. The diurnal amplitude of net CO₂ flux varied markedly in July and August at Barrow, July at Atqasuk and June, July and August at Quartz Creek. Net flux was relatively constant over the day at Barrow in June and in August at Atqasuk. Net flux at UPAD was generally constant over the season. The direction of the net CO₂ exchange for all sites was a sink during the growing season. At the Barrow site, net source activity was strong between 22:00 and 4:00 h, while net sink activity peaked between 10:00 and 15:00 h. Maximum midday uptake of CO₂ was $0.01 \text{ gC m}^{-2} \text{ hr}^{-1}$ in June. The intensity of midday uptake of CO₂ increased to $0.11 \text{ gC m}^{-2} \text{ hr}^{-1}$ in July and $-0.15 \text{ gC m}^{-2} \text{ hr}^{-1}$, decreasing to $1.1 \text{ gC m}^{-2} \text{ hr}^{-1}$ in August with an average daily CO₂ flux ranging from $0.72 \text{ gC m}^{-2} \text{ d}^{-1}$ to $-1.18 \text{ gC m}^{-2} \text{ d}^{-1}$. The low source activity of CO₂ flux in June at Barrow is assumed to be caused by the small contribution of soil respiration due to snow cover, and frozen soils, with CO₂ being released as the snow started to melt. Plant activity (other than moss and lichens) was minimal due to dormancy and cold temperatures. Carbon exchange in Atqasuk and UPAD showed relatively weak sink activity in July and August compared to the sink activity of Barrow and Quartz Creek. The magnitude of midday uptake of CO₂ flux at Atqasuk reached a maximum in July with $-0.8 \text{ gC m}^{-2} \text{ hr}^{-1}$ and in August with $-0.3 \text{ gC m}^{-2} \text{ hr}^{-1}$. At UPAD site, the maximum net CO₂ flux varied from -0.3 to $-0.6 \text{ gC m}^{-2} \text{ hr}^{-1}$. Average daily CO₂ flux was $-0.62 \text{ gC m}^{-2} \text{ d}^{-1}$ at Atqasuk and $0.03 \text{ gC m}^{-2} \text{ d}^{-1}$ at UPAD in July and $0.01 \text{ gC m}^{-2} \text{ d}^{-1}$ at Atqasuk and $-0.35 \text{ gC m}^{-2} \text{ d}^{-1}$ at UPAD in August. Daily fluctuation of net CO₂ flux at Quartz Creek reached its maximum magnitude at 0.30 in July and decreased as the growing season processed. Average daily flux ranged from $-1.74 \text{ gC m}^{-2} \text{ d}^{-1}$ to $-3.09 \text{ gC m}^{-2} \text{ d}^{-1}$ throughout the growing season.

The diurnal pattern of water vapor exchange generally showed same the trend in Barrow, Atqasuk, UPAD and Quartz Creek with a maximum peak of water vapor exchange at midday (from 10:00 to 15:00 hr) and a minimum value over the night time (from 22:00 to 4:00 hr) (Fig. 22). Average daily water vapor flux ranged from 0.47 to 0.89 mm d⁻¹ for Barrow and from 0.60 to 0.95 mm d⁻¹ for Atqasuk. Average daily water vapor flux were a range of 0.75 mm d⁻¹ to 0.97 mm d⁻¹ for UPAD and of 0.23 mm d⁻¹ to 0.35 mm d⁻¹ for Quartz Creek. Water vapor flux at Atqasuk and UPAD was larger than that at Barrow and Quartz Creek.

The net CO₂ flux was a small source following snowmelt in early June at Barrow. Net sink activity began to increase in late June and decreased in early July. The sink activity gradually started to increase again in mid-July and remained till late August. The trends of net CO₂ flux at Atqasuk and UPAD were relatively weak sink activity during the growing season. The maximum net CO₂ fluxes at Atqasuk and UPAD were $-1.2 \text{ gC m}^{-2} \text{ d}^{-1}$ in late June and $-0.96 \text{ gC m}^{-2} \text{ d}^{-1}$ early August, respectively. The sink strength diminished after late June at Atqasuk and after early August at UPAD and net CO₂ flux gradually decreased and turned to a weak source in late August. At Quartz Creek, net CO₂ flux was a small net source in early June. Net sink activity increased rapidly between mid June and early July with a peak net sink of $-6.5 \text{ gC m}^{-2} \text{ d}^{-1}$. Sink strength steadily decreased after mid July and net CO₂ flux remained as weak sink as the growing season came to a close.

Seasonal patterns of water vapor flux for all sites. Water vapor flux increased in early June and reached the maximum of water vapor flux at 1.5 mm d⁻¹ in mid-June. Water vapor flux stayed around 1.4 mm d⁻¹ from mid-June and late-July and decreased after August. The magnitude of water vapor flux decreased when air temperature was low owing to precipitation from mid-June to early July. The maximum water vapor fluxes for Atqasuk and for UPAD were 1.4 mm d⁻¹ in early July and 1.4 mm d⁻¹ in early August, respectively and water vapor flux for Atqasuk and UPAD steadily decreased as the growing season processed. Quartz Creek indicated the lowest water vapor flux out of four sites, showing the maximum water vapor flux was 0.5 mm d⁻¹.

Site Locations: Lavrentiay

Climatic Conditions

The summer was characterized by a cold June, a sunny and warm July, with August and September being quite typical for the region. Average air temperature for the last third of July was higher (11.9°C) than the same time in 2000 (5.7°C). Mean August temperatures for 2000 and 2001 were about the same, at 6.5°C and 6.4°C respectively. September was on average slightly higher in 2001 (3.7°C) than in 2000 (2.4°C). Average wind speeds (3m height) were 3.8 m s⁻¹, 4.8 m s⁻¹, and 5.7 m s⁻¹ for July, August, and September respectively. Thaw depth dynamics were similar in both 2000 and 2001 with measured maximum active layer depth in September being -66.7 cm and -67.7 cm respectively. However, the mean water table depth (from soil surface) was much deeper in 2001 (-20.4 cm) as compared to 2000 (-11.0 cm). Water table depths were greatest beginning in August.

Seasonal Pattern of CO₂ and H₂O fluxes

This is the second season of eddy covariance flux measurements for this site. A portable tower in 2000 was used between July 22-October 16, 2000. This season the tower was re-established at the same location on June 18, 2001 and is now a year-round eddy covariance measurement site. The start of the vegetative growing season for the Lavrentiya area was between June 19-28 with the peak season occurring between July 9-29. The fall senescence began around mid-August with the onset of winter around the last week in October. The Lavrentiya tundra ecosystem acted as a net carbon sink between June 19-August 28 with an average uptake rate of $-0.81 \text{ gC m}^{-2} \text{ day}^{-1}$. Following August 28, the ecosystem became a net source of carbon to the atmosphere and between August 28-October 27, the ecosystem was a net carbon source of

+0.78 gC m⁻² day⁻¹. A net sink of -57.8 gC m⁻² occurred during the vegetative season (June 19-August 28) and there was a net loss of +22.3 gC m⁻² during the fall to winter (August 29-October 27). The seasonal net ecosystem carbon exchange for 2001 (June 19-October 27) was -35 gC m⁻² season⁻¹.

Training and Development:

The objective of this project was to establish, operate, and maintain instrumentation that could determine the annual pattern of CO₂ flux of a wet, coastal plain and a moist tussock tundra ecosystem type. By maintaining three towers in three geographically different regions in the north slope of Alaska, this task was accomplished along with establishing a baseline data set for regional CO₂ flux patterns that is relevant for global climate change research interests.

The eddy covariance system has been developed to be a portable method of measuring landscape level CO₂ fluxes and has been transported to another arctic region in the Russian far east where the instrumentation has been in place in Laurentia, Russia for over the past two years. Such measurements are the first of their kind and will be important when making intercontinental comparisons in CO₂ fluxes.

The in-situ tundra manipulation experiment has been a large focus for collaboration, with researchers from Moscow State University and California State University, Los Angeles taking part in research, both in learning sampling techniques and exploring new methods of data collection such as in linking reflectance measurements to small scale physiological responses. This experiment has also been a source of undergraduate level research experience with students from San Diego State University, where students have taken part in ongoing research and added independent projects as required.

Dr. Oechel is also PI on an NSF GK-12 project to use university undergraduate and graduate science students to improve science education in K-8 classrooms with an emphasis on San Diego County and Barrow, AK. The PISCES project currently involves approximately 20 graduate and undergraduate Science Corps students who reach about 60 K-8 classrooms, and about 1,500 students per year. The project goal is to improve the quality and quantity of science education in the elementary schools. The data streams from the eddy covariance towers are featured prominently in real-time science lessons complete with live video of sites in Alaska and California to bring about a more unique learning experience when exploring issues related to environmental processes.

PISCES activities with teachers via in-service training and elementary students via classroom instruction include the use of near-real time data and imaging from the towers from Barrow, AK, San Diego, CA, and La Paz, Mexico, teachers and students are given an inviting entrance into the larger environmental and global change issues that can be addressed with data such as this. It allows education in ecological and environmental issues, and hopefully increases both K-8 and university student interest in pursuing careers in science.

Outreach Activities:

In the 1999 field season, Glen Kinoshita worked with two researchers from Moscow State University in Russia, Dr. Dimitri Zamolodchikov and Dr. Dimitri Karolin. Their purpose of working in this project was to learn technical and field techniques that would be of use to their research in the Russian arctic.

Outreach activities included three interviews for video documentaries. One was for an Italian children's science program (Giga), a BBC climate change documentary (Warnings From the Wild), and an NSF-LAI documentary covering research activities in the Alaskan arctic filmed by KUAC (the local television station), which was sponsored by ARCUS. There was also a presentation for Hopson Middle School in Barrow, AK for students to show them the research activities taking place in their area.

In the 2000 field season, a research team headed by Dr. John Gamon of California State University, Los Angeles, began a nearby project to determine the relationship between optical and physiological characteristics and seasonal changes in tundra. He also utilized the tundra manipulation experiment as another source of data for his research. A presentation was also made to Hopson Middle School outlining research activities in their area.

In the 2001 field season, two participants, Leticia Sanchez and Michelle Perl, in the NSF-UMEB (Undergraduate Mentoring in Environmental Biology) program participated in ongoing research in Barrow, AK as well as initiated their own research projects supervised by Glen Kinoshita. Leticia Sanchez monitored soil CO₂ fluxes in the field while Michelle Perl worked with root fungal associations with two species of shrub. A participant in the NSF-TEA (Teachers Experiencing the Arctic) program also participated in ongoing research. Christina Donovan of Desert View High School from Tucson, AZ worked with SDSU researchers to gain research experience to take back to her school and incorporated that into her teaching. Collaboration with Dr. John Gamon also continued in a second season of data collection with his project.

An outreach presentation in conjunction with the PISCES Project was also done at Hopson Middle School detailing research activities around Barrow, AK.

Journal Publications

Baldocchi, D, Falge, E, Gu, L, et. al., "FLUXNET: A New Tool to Study the Temporal and Spatial Variability of Ecosystem-Scale Carbon Dioxide, Water Vapor, and Energy Flux Densities", Bulletin of the American Meteorological Society, p. 2415, vol. 82 (11), (2001). Published

Oechel WC, Vourlitis GL, Hastings SJ, Zulueta RC, Hinzman L, and Kane D, "Acclimation of ecosystem CO₂ exchange in the Alaskan Arctic in response to decadal climate warming", Nature, p. 978, vol. 406, (2000). Published

Oechel WC, Vourlitis GL, Verfaillie J Jr., Crawford T, Brooks S, Dumas E, Hope A, Stow D, Boynton B, Nosov V, and Zulueta R, "A scaling approach for quantifying the net CO₂ flux of the Kuparuk River Basin, Alaska", *Global Change Biology*, p. 160, vol. 6, (1999). Published

Vourlitis GL, Harazono Y, Oechel WC, Yoshimoto M, and Mano M, "Spatial and temporal variations in landscape-scale net CO₂ exchange, respiration, and gross primary production in arctic tundra ecosystems", *Functional Ecology*, p. 203, vol. 14, (2000). Published

Vourlitis GL, Oechel WC, Hope A, Stow D, Boynton B, Verfaillie J Jr., Zulueta R, and Hastings S., "Physiological models for scaling plot-measurements of CO₂ flux across an arctic tundra landscape", *Ecological Applications*, p. 60, vol. 10, (2000). Published

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McMichael CE, Hope AS, Stow DA, Fleming JB, Vourlitis GL, and Oechel WC, "Estimating CO₂ exchange at two sites in Arctic tundra ecosystems during the growing season using a spectral vegetation index", *Int. Journal of Remote Sensing*, p. 683, vol. 20(4), (1999). Published

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Harazono Y, Mano M, Yoshimoto M, Vourlitis GL, and Oechel WC., "CO₂ Budget of the Wet Sedge Tundra Ecosystems in Alaska, analyzed by Continuous Flux Measurements and a Tundra CO₂ Budget Model (TCBM).", *Proceedings of the Sixth Symposium on the Joint Siberian Permafrost Studies between Japan and Russia in 1997*. Sapporo, p. 159, vol. , (1998). Published

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Oechel WC, Vourlitis GL, Brooks S, Crawford TL, and Dumas E, "Intercomparison among chamber, tower, and aircraft net CO₂ and energy fluxes measured during the Arctic System Science Land-Atmosphere-Ice Interactions (ARCSS_LAII) Flux Study", *Journal of Geophysical Research*, p. 28,993, vol. 103:28, (1998). Published

Walker DA, Bockheim JG, Chapin FS III, Eugster W, King JY, McFadden JP, Michaelson GJ, Nelson FE, Oechel WC, Ping CL, Reeburg WS, Regli S, Shiklomanov NI, Vourlitis, "A major arctic soil pH boundary: Implications for energy and trace-gas fluxes", *Nature*, p. 469, vol. 394, (1998). Published

Books or Other One-time Publications

Oversight Group for the Ecosystems Panel, "Global Change Ecosystems Research", (2000). Book, Published
Collection: Report to the National Research Council
Bibliography: National Academy Press, Washington, DC

Mano, M., Harazono, Y., Miyata, A., Zulueta, R.C., and Oechel, W.C., "Measurements of Carbon Dioxide and methane Fluxes over an Arctic Coastal Tundra Ecosystem in 2000 Growing Season", (2001). poster, Published
Bibliography: . Second Wadati Conference on Global Change and the Polar Climate, Japan, March 7-9, 2001

Oechel, W.C., Kinoshita, G.Y., Zulueta, R.C., Vourlitis, G.L., and Hastings, S.L, "An Experiment to Determine the Effects of in situ Manipulation of Soil Moisture and Temperature on Net Ecosystem CO₂ Flux at Barrow, Alaska", (1999). poster, Published
Bibliography: Arctic System Science Land-Atmosphere-Ice Interactions (ARCSS LAII) 1999 Science Workshop Record of the Meeting, Seattle, WA. March 11-13, 1999.

Oechel, W.C., Zulueta, R.C., Vourlitis, G.L., Hastings, S.J., and Kinoshita, G.Y, "Preliminary Landscape-Scale CO₂ and H₂O Vapor Fluxes at Barrow, Alaska, 1998", (1998). poster, Published
Bibliography: Arctic System Science Land-Atmosphere-Ice Interactions (ARCSS LAII) 1999 Science Workshop Record of the Meeting, Seattle, WA. March 11-13, 1999.

Panikov NS, Oechel WC, Mastepanov MA, Zulueta RC, Hastings SJ, Christensen TR, and Flanagan PW, "Microbial respiration occurs in frozen soils to below -400C: Explaining significant winter CO₂ emission", (2000). manuscript, manuscript
Bibliography: manuscript

Vourlitis GL and Oechel WC, "A phenomenological model for assessing the importance of meteorology, phenology, and acclimation on arctic tundra net CO₂ flux", (2000). manuscript, manuscript
Bibliography: manuscript

Mano, M, Harazono, Y, Miyata, A, Zulueta, RC, and Oechel, WC, "Measurements of Carbon Dioxide and Methane Fluxes over an Arctic Coastal Tundra Ecosystem in 2000 Growing Season", (2001). manuscript, Published
Bibliography: Second Watadi Conference Proceedings. Tsukuba, Japan. March 7-9, 2001

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Bibliography: The Annual Meeting of Japanese Society of Agricultural Meteorology. Matuyama, 29-30 July

Web/Internet Site

URL(s):

<http://www.sci.sdsu.edu/GCRG/>

<http://www.sdsa.org/pisces>

Description:

Other Specific Products

Product Type: Data or databases

Product Description:

CO₂ flux data taken under conditions of in-situ manipulation of elevated soil temperature and water table lowering and elevation to simulate conditions of climate change.

Sharing Information:

This data will be useful to workers in arctic ecosystem sciences and climate modellers in looking at the potential effect of climate change on arctic ecosystems.

Product Type: Instruments or equipment developed

Product Description:

We developed a system that will increase soil temperature and manipulate water table under field conditions that can be replicated in arctic tundra ecosystems to simulate climate change.

Sharing Information:

This system will be useful to any field workers seeking a method of simulating climate change in the arctic region on a plot level of experimentation.

Product Type: Software (or netware)

Product Description:

The software used to collect CO₂ flux data was converted from a DOS based program over to a Windows based system. This will allow for enhanced usage by enabling the software to be utilized by more powerful computer platforms.

Sharing Information:

The software is freely available to any who inquire.

Product Type: Instruments or equipment developed

Product Description:

A portable, self contained eddy correlation system has been assembled that can be transported to remote sites by as few as two persons has been developed for use in very remote sites.

Sharing Information:

This system can be easily transported and installed, unlike previous systems, enabling greater coverage and easier data collection.

Product Type: Data or databases

Product Description:

CO₂ flux data from three sites on the Alaskan north slope: Barrow, Atkasuk, and Prudhoe Bay are available on our website.

Sharing Information:

The data is available on: <http://www.joss.org>.

Product Type: Data or databases

Product Description:

Near real-time data is available on the website for use in instructional purposes. This data includes meteorological data and CO₂ flux data from Barrow, AK.

Sharing Information:

The data is available on: <http://www.sci.sdsu.edu/GCRG/>

Product Type: Teaching aids

Product Description:

Ecological and environmental science lessons for grades K-6 have been developed linking real-time data with lesson plans.

Sharing Information:

These lessons are available on: <http://www.sdsa.org/piscs>

Contributions

Contributions within Discipline:**Contributions to Other Disciplines:****Contributions to Human Resource Development:**

This project has given research experience opportunities to graduate and undergraduate students to further their development in careers in science. This project, through the related educational efforts with near real-time data and PISCES have also shown to be effective in attracting new students in careers in environmental and ecological sciences.

Contributions to Resources for Research and Education:

Dr. Oechel is a PI on an NSF GK-12 project to use university undergraduate and graduate science students to improve science education in K-8 classrooms with an emphasis on San Diego County and Barrow, Alaska. The PISCES project currently involves about 20 graduate and undergraduate Science Corps students who reach about 60 K-8 classrooms, and about 1,500 students each year. The project goal is to improve the quality and quantity of science education in the elementary schools. The data produced by this project in the form of near real-time data and live on site webcams are utilized to enhance the classroom experience.

PISCES activities with teachers via in-service training and elementary students via classroom instruction include the use of near-real time data and imaging from eddy correlation towers and the research aircraft. By presenting this data from Barrow, AK, San Diego, CA, and La Paz, Mexico, teachers and students are given an inviting entrée into the larger environmental and global change issues addressed with this project. It also allows education in ecological and environmental issues, and hopefully increases both K-8 and university student interest in pursuing careers in science.

Contributions Beyond Science and Engineering:

The ability to collect carbon and vegetation data over large spatial scales may allow more informed decisions to be made about land use, water conservation, and regulatory aspects relating to carbon emissions. This information could be used to assist in fire prevention planning and policies as well. On a larger scale, it provides the type of information that is becoming increasingly important as debates continue about addressing carbon emissions in countries around the world. The Kyoto treaty is a prime example of a global rise in concern over national carbon emissions.

Categories for which nothing is reported:

Contributions: To Any within Discipline

Contributions: To Any Other Disciplines