atmospheric CO2 associated with El Nino phenomena is predominately caused by exchanges with land biota. We also present evidence for a global increase in ocean ventilation and associated uptake of O2 by the oceans commencing in 1999.

GC62A-08 1540h

Decadal Changes in Global Ocean Primary Production: Relationships to Climate Change

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An evaluation of decadal changes in global ocean primary production has not previously been possible due to incompatibilities between the CZCS (1978-1986) and the modern SeaWiFS (1997-present). Revision of the historical CZCS record has permitted a quantitative determination of decadal changes from the early 1980's to the present. Results indicate that global ocean annual primary production has declined over the two decadal time segments. Large decreases were observed in the high latitudes. In the northern high latitudes, these reductions in primary production were associated with increases in sea surface temperature and decreases in atmospheric iron deposition to the oceans. Three of four low latitude basins indicated decadal increases in annual primary production. These results show global and regional changes in ocean photosynthetic carbon uptake and how they may be related to climatic influences.

GC62A-09 1555h

Ocean carbon transport and atmospheric CO_2

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The oceanic transport of carbon by the large-scale ocean circulation and the associated air-sea exchange of CO_2 are a significant factor controlling the distribution of atmospheric CO_2, from which major inferences are made with regard to global-scale sources and sinks of CO_2. We present here new estimates of pre-industrial and present CO_2 air-sea exchange, their implied ocean carbon transport, and their impact on atmospheric CO_2 on the basis of an ocean inverse modeling method that uses ocean interior observations of dissolved inorganic carbon (DIC) and associated anthropogenic CO_2 estimates. The inversely estimated pre-industrial air-sea fluxes of CO_2 reveal the expected pattern of CO_2 uptake by the oceans in the mid to high latitudes and release back into the atmosphere in the low latitudes. By contrast, the air-sea flux of anthropogenic CO_2 is found to be into the ocean everywhere, totaling about 1.8 Pg C yr^{-1}. The pre-industrial CO_2 flux results imply a net oceanic transport of carbon in pre-industrial times from the high latitudes to the low latitudes and a corresponding transport in the opposite direction in the atmosphere. We find, however, a strong asymmetry between the two hemispheres. This asymmetry is largely caused by the Atlantic Ocean, where CO_2 is taken up at high latitudes and transported across the equator into the southern hemisphere with magnitudes in agreement with estimates derived from direct hydrographic inversions. This Atlantic transport gives rise to a modest cross-equatorial transport of about 0.4 PgC yr^{-1}. Our inversely estimated pre-industrial air-sea CO_2 fluxes nevertheless produce a south pole to north pole gradient of atmospheric CO_2 in pre-industrial times of nearly 1 ppm. Although this south-north interhemispheric gradient is significant, it is too small to negate the need for a large northern hemisphere land carbon sink in order to explain the currently observed atmospheric CO_2 gradients.

GC62A-10 1610h

Modeling the Combined Effects of CO2, Climate and Land Use on the Carbon Stocks of Plants and Soils

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A terrestrial carbon cycle component of the Integrated Science Assessment Model (ISAM) is used to examine the response of plant and soil carbon stocks to historical changes in land cover, land use management, atmospheric CO2 concentration and climate. This geographically-explicit implementation of ISAM simulates the carbon fluxes to and from different compartments of the terrestrial biosphere with 1-by-1 degree spatial resolution (longitude and latitude). Each 1-by-1 degree cell contains thirteen land coverage classifications, which represent both highly managed land uses and less managed biomes. Changes in areas between land cover classifications are driven by land uses that have resulted in, e.g., shifting-agriculture, afforestation, deforestation, and reforestation. Within each grid cell and land-coverage classification, the modeled carbon cycle includes feedback processes such as CO2 fertilization and temperature effects on photosynthesis, and respiration. Plant and soil carbon stocks for land-coverage classifications are also influenced by agriculture and forest management practices including, e.g., soil amendments and tillage. For the historical time period (1765 through 1990), CO2 sources and sinks are derived using the observed temperature change and CO2 concentrations along with surveys of past land cover change and shifts in management practices. After 1990, carbon fluxes are estimated based on the AOGCM based temperature distributions and ISAM based CO2 concentrations. The results are compared to other highly resolved models.

GC62A-11 1625h

Responses of Carbon Uptake to Uncertain Climatic and Economic Parameters in an Integrated Global Systems Model (IGSM)

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Significant uncertainty exists about the magnitude of carbon uptake in the next century. This uncertainty comes from a variety of factors, including economics of future emissions, ocean processes, temperature change, and ecosystem processes. The MIT IGSM contains detailed submodels to address each of these critical factors in the carbon cycle. A previous study showed that oceanic vertical mixing, parameterized by Kv, the coefficent of vertical diffusion, is the dominant uncertain parameter in the ocean component of the IGSM. In this new work we examine the relative contributions of the uncertainty in Kv, economic uncertainty, and climate sensitivity to the final values of carbon uptake by the ocean and the ecosystem. In a case where only climate parameters were allowed to vary and an economic scenario designed to achieve 550 ppm stabilization was used, regression analysis showed that about 96% of the ocean uptake resulted from variation in Kv. When uncertainty in the economic model was addressed, with the assumption of no climate policy, uncertainty in carbon dioxide emissions yielded about 55% of the variation in ocean uptake in 2100. Only about 40% of the variance was due to uncertainty in the coefficient of vertical diffusion. Therefore, the impact of climate sensitivity must be less than 5%. Under a sample policy regime based on extending the Kyoto protocol, emissions became more certain, and the dependence of the uncertainty on Kv increased to about 90%.

GC62A-12 1640h

A Comprehensive GCM-Based Climate and Carbon Cycle Model: Transient Simulations to Year 2100 Using Prescribed Greenhouse Gas Emissions

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We use an interactive global climate and carbon-cycle model to perform simulations of climate change from 1870 AD to 2100 AD forced by anthropogenic emissions of greenhouse gases. The goal of this effort is to produce a simulation tool capable of improved realism in future climate predictions. In particular, we seek to include and better understand feedbacks between the climate system and the carbon cycle. We use the Parallel Climate Model 2 (PCM-2) developed at NCAR as our climate model. The PCM-2 includes a version of NCARs CCM3 for the atmospheric GCM and a version of the POP model for the ocean GCM. The horizontal resolutions for atmosphere and ocean are T42 truncation (about 280 km) and 0.7 degrees (about 75 km), respectively. The ocean carbon model is based on OCMIP protocols, but modified to eliminate the phosphate-restoring restriction. The terrestrial biosphere model is IBIS-2 which simulates biophysical and biogeochemical surface fluxes and includes a dynamic vegetation model. The model is integrated to a pre-industrial equilibrium using a prescribed atmospheric CO2 concentration of 290 ppmv. This equilibrated state serves as the starting point for three transient simulations. The Control Case assumes zero net anthropogenic emissions and is used as a reference for model drift. The Full Interaction case assumes historical greenhouse emissions up to year 2000, then uses SRES A1B emissions up to year 2100. A Carbon Cycle Only Case is the same as the Full Interaction case, except that the greenhouse radiative forcing of climate is held fixed at preindustrial values. We will discuss the models simulation of the twentieth century climate and atmospheric CO2 concentrations, the strength of carbon cycle feedbacks, and compare our simulation results to those of Cox et al. (2000) and Friedlingstein et al. (2001).

GC72A MCC: Hall D Sunday 1330h

Carbon Cycle and Climate: Past, Present, and Future Posters III *(joint with A, B, H, OS, PP)*

Presiding: **N Zeng,** University of Maryland**; M Heiman,** Max-Planck-Institut fuer Biogeochemie**; N Gruber,** University of California, Los Angeles

GC72A-0201 1330h POSTER

Coupling Between Atmospheric $[CO_2]$ and Temperature During the last Millennium

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The Little Ice Age climate deterioration is the most recent cool pulse of a series of recurrent climate fluctuations throughout the Holocene. Within the ongoing discussion on the coupling of CO_2 and temperature, documentation of both parameters on a high temporal resolution is needed. Recent Northern Hemisphere temperature reconstructions based on tree-ring chronologies reveal a higher amplitude for temperature fluctuations during the last millennium than proposed so

far. Ice core atmospheric [CO_2] records already demonstrate low amplitude fluctuations associated with the Little Ice Age. In this study an alternative high resolution CO_2 record is obtained by means of stomatal frequency analysis of (sub-) fossil oak (*Quercus robur*) leaves. The leaf material is derived from a four meter long sediment core consisting of laminated clayey gyttja taken in an oxbow lake in the southern Netherlands. The derived CO_2 reconstructions show a series of distinct shifts of higher amplitude than documented in Antarctic ice core records. The stomatal frequency based CO_2 record for the last millennium suggests a dynamic atmospheric CO_2 regime parallelling the temperature deviations during the last millenium referred to as the Little Ice Age and the late Medieval Warm Period.

GC72A-0202 1330h POSTER

Atmospheric CO_2 Dynamics During the Holocene Revealed by Stomatal Frequency Analysis

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A variety of land plants are capable of sustained adjustment of the number of leaf stomata (gas pores) to changing atmospheric CO_2 concentrations. Measured on fossil leaves, and calibrated against modern training sets, stomatal frequency data are increasingly applied as a proxy for palaeo-atmospheric CO_2 reconstructions. These data demonstrate with high temporal resolution and accuracy that century-scale CO_2 fluctuations contributed to Holocene climate evolution.

We here present a composite record of Holocene atmospheric CO_2 concentrations based on stomatal frequency analysis. The CO_2 estimations are derived from fossil leaf assemblages preserved in peat and lake deposits in Europe, Canada and the USA. The leaf material studied originates from deciduous trees, conifers and shrubs.

Independent of site locality and plant species studied, CO_2 reconstructions from the individual sections correspond well in the overlapping parts of the records. The combined data sets provide convincing evidence for a highly dynamic atmospheric CO_2 regime during the Holocene.

A fast CO_2 increase occurs at the Younger Dryas / Holocene transition. Short-term CO_2 reductions are associated with three major cool pulses known from marine and terrestrial records: the Preboreal Oscillation, the 8.2 kyr event and the Little Ice Age.

GC72A-0203 1330h POSTER

The terrestrial biosphere: a missing C sink during the Mid-Miocene climate change?

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The current rise in atmospheric CO_2 concentration is thought to be mitigated in part by carbon sequestration in the terrestrial biosphere, soils, or the oceans so that the buildup of CO_2 in the atmosphere will reduce or slow. Understanding how long-term CO_2 "sinks" perform is of utmost importance for the development such measures. The Mid-Miocene is from the geological record the youngest period which may well serve as a model for the present day scenario, in which after a period of warmth with elevated CO_2 levels large amounts of C has been naturally sequestered in the marine or terrestrial realm. This period is characterized by the transition from the Miocene climatic optimum to the Late Cenozoic cool mode. In the marine record a marked positive C isotope excursion indicates enhanced biological productivity and burial of organic carbon, which in turn may have resulted in a drastic depletion in CO_2. Excessive C sequestration is evident from the marine organic rich Monterey Formation in the Pacific realm. Tectonic uplift may have resulted into increased weathering as an additional C sink. However, virtually nothing is known about the role of the terrestrial biosphere as a sink for atmospheric CO_2. Intriguingly, the Miocene is also a time of extensive coal formation in Europe, Australia and Asia. It is hypothesized that widespread formation and the substantial size of these coal deposits may have contributed to the drawdown of atmospheric CO_2. In order to corroborate this hypothesis pCO_2 has been reconstructed by means of stomatal frequency analysis, a terrestrial proxy that is independent of changes in the marine realm. The pCO_2 curve shows a prominent drawdown, which coincides with the positive C isotope excursion and the periods of enhanced C burial in the marine and terrestrial sedimentary record. Comparison of the C and S isotope records allows a first order approximation of the proportion of the marine and terrestrial C burial. However, perhaps the most striking feature of the stomata based CO_2 reconstruction is that the main phase of CO_2 depletion occurs during the Miocene climatic optimum. If CO_2 were a dominant climate determinant, one would expect that cooling should have accompanied the CO_2 drawdown. Decoupling suggests that other climatic factors temporarily compensated for the diminished greenhouse effect of CO_2 that are still not well understood.

GC72A-0204 1330h POSTER

Implications of ice core smoothing for inferring CO_2 flux variability

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Air extracted from polar ice allows reconstruction of atmospheric levels of CO_2 prior to direct atmospheric measurements. These ice core records are commonly used to infer information about past variability of CO_2 fluxes. Due to processes involved in storing this air in ice, ice core records are a smoothed representation of the actual past atmospheric variations. As such, there is a limit to how much information ice core measurements can contain about flux variability on some time scales. With a numerical model of the firn processes we quantify this smoothing, and discuss implications for inferring CO_2 flux variability from the high time resolution Law Dome ice core record. In particular we look at results from the CCMLP model intercomparison of terrestrial models over the 20th century. The firn model smoothes concentrations more than a 10-year running mean does, so conclusions about how well the results match the ice core record require careful consideration of the smoothing.

GC72A-0205 1330h POSTER

The Significance of Sulphuric Acid Induced Chemical Weathering on Long Term Fluxes of CO_2 Between the Atmosphere-Ocean and Rocks: Evidence From River Chemistry and Carbon Isotopes in the Canadian Cordillera.

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It has been proposed that a negative feedback between silicate chemical weathering rates and climate has maintained relatively constant surface temperatures over much of the Earth's history by modulating geological fluxes of CO_2. Attempts to validate this hypothesis have focused on quantifying rates and relative proportions of carbonate versus silicate weathering. Here we demonstrate that quantification of chemical weathering induced by sulphuric acid is also required to accurately calculate the CO_2 flux between the atmosphere-ocean and geological reservoirs.

Carbonic acid is formed by the dissolution of CO_2 in water. Sulphuric acid is formed by the chemical weathering of sulphide minerals. Silicate dissolution by carbonic acid causes a net transfer of CO_2 to the geological reservoir. Carbonate dissolution by carbonic acid causes no net transfer of CO_2 between the two reservoirs over geological timescales (>100,000 y). Silicate weathering by sulphuric acid does not involve carbon. However, importantly carbonate dissolution by sulphuric acid causes a net transfer of CO_2 from the geological reservoir to the atmosphere-ocean reservoir.

River chemistry and isotopic data from major drainages in the Canadian Cordillera, including the Fraser, Skeena and Nass rivers are used to calculate weathering rates of silicate, carbonate, and sulphide minerals and the related CO_2 fluxes for the different geomorphological regions of the Canadian Cordillera. The magnitude of the CO_2 flux due to carbonate dissolution by sulphuric acid is shown to be highly significant and therefore should be included in carbon balance models.

GC72A-0206 1330h POSTER

Silicate, Diatoms and Atmospheric CO2 During the Last Glacial Cycle: A Comparison of Core Data and Model Results.

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Increased nutrients, especially silicate have been invoked as a mechanism to increase new and export production and cause the lower atmospheric levels of CO2 observed during glacial periods. However, for most of the last glacial cycle, opal deposition and atmospheric CO2 varied together rather than in opposition as would be expected if increased diatom productivity resulted in decreased atmospheric CO2. This decrease in opal deposition during glacial periods has been termed the opal paradox (Berger et al.,1994). The direct relationship in opal deposition as observed in an equatorial core (WG8402A-14GC) and atmospheric CO2 measured in the Vostok core, has an analog in a model of the modern equatorial ecosystem (COSINE) where a phase occurs in which decreasing source silicate concentration results in decreased diatom activity, increased non-siliceous phytoplankton and decreased surface nitrate and TCO2. The conclusion from comparing the model output and core data is that diatoms through the silicate pump create HNLC conditions in open ocean upwelling systems and a consequent net flux of CO2 to the atmosphere from these regions of the oceans. Low silicate conditions during ice buildup reduce the influence of diatoms and the non-siliceous phytoplankton are able to use all available nitrate and so reduce surface concentrations of CO2. This hypothesis is consistent with changes observed in natural abundances of nitrogen and carbon isotopes.

GC72A-0207 1330h POSTER

Carbon Budget and Carbonate Saturation in Global Paleo-ocean

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The relationships between the global carbon cycle and paleo-climates on short and long time scales have been based on studies of accumulation rate of different components of the sedimentary carbon reservoir, as well as reconstructions of the geographic distributions of

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carbon burial. Variations in the rate and proportion of carbonate burial through Phanerozoic time have been attributed to the influence of tectonics on eustasy, atmospheric CO2 concentration, MOR hydrothermal flux, and weathering and riverine flux. Variability in biologic production (Corg and Ccarb) through geologic time also had a significant impact on surface ocean chemistry and the sedimentary carbon record. In this study, a geochemical model with Phanerozoic atmospheric pCO2 and surface ocean temperature reconstructions from the literature was used to estimate the history of variations in surface-ocean chemistry (degree of saturation with respect to calcite and aragonite). The results show that, using present-day values of ocean salinity and alkalinity, the Early Paleozoic and Middle Mesozoic oceans were undersaturated with respect to CaCO3. For the present-day values of supersaturation (IAP/Ksp) of 3.0 to 4.5, paleo-alkalinity of ocean water would have been up to 2.5 times greater than at present, although the pH values of surface ocean water would have been somewhat lower than the present value. This alkalinity factor is consistent with a higher calcium concentration (up to 2.5x) due to increased MOR circulation and also higher salinity (up to 1.5x) attributed by other authors to segments of the geologic past. Our model results indicate that pCO2 was a contributing factor to shifts between calcite and aragonite saturation of seawater, however, additional changes in alkalinity were also needed to maintain supersaturation. In addition to MOR circulation, continental weathering of crystalline and older carbonate rocks was likely an important mechanism for maintaining supersaturation of surface-ocean water, particularly during times of increased carbonate storage.

GC72A-0208 1330h POSTER

New Mechanism for Tropical Ocean Influence on the Marine Carbon Cycle and atmospheric CO2

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The tropical ocean plays an important role in the transfer of organic carbon and calcite to the deep sea; and the exchange of carbon between the atmosphere and ocean. This is particularly true for the eastern equatorial Pacific (EEP, east of 120 W); where a substantial fraction of open ocean biological production occurs. Fluxes of organic carbon and calcite to the deep sea were reconstructed for the EEP from the last glacial maximum (LGM) to the Present to examine changes during the major reorganization of the marine carbon cycle at the deglacial. Organic carbon annual flux and seasonality were reconstructed using transfer functions and benthic foraminiferal assemblages. Calcite flux was reconstructed using 230Th normalized sediment calcite accumulation rates and a new proxy for %calcite dissolved at the seabed. This approach yields Holocene fluxes close to the expected and LGM values that satisfy a carbonate diagenesis model using expected LGM conditions. We find that LGM fluxes for both organic carbon and calcite were lower than at Present by 25 to 35%. At the LGM the molar ratio of organic carbon to CaCO3 fluxes was about 1.0. Both began to increase at about 18ckyr (calendar kiloyears) with organic carbon flux stabilizing at 16ckyr but calcite flux continuing to rise into the Holocene. This implies that at 16ckyr there was a decrease in the org. C/calcite flux ratio. The timing of this shift coincides with a strong reduction in the seasonality of production as indicated by the benthic foraminiferal proxy. The flux ratio shift would result from the decrease in f-ratio that occurs in planktonic communities as seasonality of production is reduced. It has been proposed that atmospheric CO2 content could be controlled by changes in the deep ocean org C/calcite flux ratio. The changes we document are in the right sense and timing to provide positive feedback on the increase in atmospheric CO2 recorded for the deglacial. This feedback is driven by changes in production seasonality which we propose is linked to shifts in the position of the ITCZ.

GC72A-0209 1330h POSTER

A New Box-Model to Explain Glacial/Interglacial Atmospheric CO_2 Variation

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During the last glacial era, the partial pressure of atmospheric carbon dioxide (CO_2) was around 200 ppmv. This is approximately 80 ppmv less than the preindustrial value of atmospheric CO_2. Estimates suggest that the ocean is the only reservoir large enough to account for such dramatic change in the carbon budget over these time scales.

The distribution of total CO_2 (dissolved CO_2, carbonate and bicarbonate) throughout the ocean, is controlled by air-sea exchange, the strength of the thermohaline flow, mixing between the surface and the deep water, and by the particulate flux of organic matter sinking to the bottom of the ocean. There is debate over the roles played by high and low latitude oceans in the storage of CO_2, and their relative importance in the process: box models of the CO_2 cycle have been proposed which suggest that conditions in the high latitude oceans greatly determine the amount of CO_2 the ocean is able to store. However, general circulation models (GCMs), indicate that the low latitude oceans influences CO_2 storage to a degree greater than the box models suggest.

We propose a box model which to a large extent resolves the debate. It does so while also retaining consistency with the fundamental fluid and thermodynamic equations governing this flow. We will describe this carbon dioxide preserving model, and will show that by changing the forcing the model yields glacial and interglacial solutions when realistic parameter values are used.

GC72A-0210 1330h POSTER

A Theory For The Influence Of The Subtropical Thermocline On The Solubility Pump Of Carbon

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We examine the abiotic carbon cycle in a single hemispheric basin and propose a new, quantitative theory relating atmospheric pCO_2 to the amplitude of surface wind stress and the diapycnal diffusivity. At the zeroth order, high latitude surface water controls atmospheric pCO_2 by dominating dissolved inorganic carbon (DIC) of the deep ocean reservoir as explained by classical 3-box models. At the next order the thermocline determines the ocean carbon inventory, where warm, thermocline waters are depleted in DIC relative to the deep ocean. In this study, we examine the impact of this thermocline inventory on atmospheric pCO_2. Assuming that the total amount of carbon in the atmosphere and in the ocean is conserved, a simple analysis predicts that atmospheric pCO_2 will scale linearly with the product of the thermocline depth and DIC concentration. The theory shows that atmospheric pCO_2 increases with surface wind stress because (1) the warm thermocline deepens with stronger Ekman pumping, and (2) the thermocline waters become increasingly undersaturated as the western boundary current is intensified and subduction occurs before equilibration with the atmosphere. The theory suggests that atmospheric pCO_2 scales as $w_{ek}^{1/2}$ or $w_{ek}^{3/2}$ depending on the intensity of the wind forcing. This is confirmed by experiments with the numerical basin model. Atmospheric pCO_2 is also enhanced by higher diapycnal diffusivity which increases the thickness of the thermocline. Both theory and basin model suggest that atmospheric pCO_2 scales as $\kappa^{1/3}$ in the diffusive thermocline limit. In the numerical experiments, over a reasonable range of parameters, the thermocline inventory itself can modulate atmospheric pCO_2 by up to 30 [ppmv] with this abiotic mechanism. Finally, we examine the sensitivities of a more complex global abiotic carbon cycle model and discuss how this simple theory might help understand the response of such models to the imposed forcing parameters.

GC72A-0211 1330h POSTER

Role of Siberian Permafrost in the Global Atmospheric Carbon Budget

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The large (80-100 ppmv; 200 Pg) fluctuations in atmospheric CO_2 that coincide with past glacial cycles reflect biospheric feedbacks triggered by changes in solar input. These feedbacks are poorly understood but will likely influence the response of the Earth System to recent increases in global temperature and atmospheric CO_2. Siberian permafrost contains a large pool (ca. 700 Pg) of sediment carbon that is similar to the quantity of the carbon in the global atmosphere. Laboratory incubations, field measurements, and chemical analyses indicate that this carbon is highly labile and decomposes quickly when permafrost melts. A continuation of recent warming trends could trigger release of this carbon through either direct temperature effects on active-layer thickness and decomposition or increased frequency of forest fires, which cause a three- to five-fold increase in thaw depth. Similarly, melting of permafrost in Europe and Southern Siberia at the end of the Pleistocene may have released more than 400 Pg of CO_2-carbon to the atmosphere. This release could have contributed substantially to the increase in atmospheric CO_2 at the Pleistocene-Holocene boundary. These observations suggest that melting of Siberian permafrost could play a globally significant role in the past and future changes in Earths climate.

GC72B MCC: Hall D Sunday 1330h

Carbon Cycle and Climate: Past, Present, and Future Posters IV *(joint with A, B, H, OS, PP)*

Presiding: **N Zeng,** University of Maryland**; M Heiman,** Max-Planck-Institut fuer Biogeochemie**; N Gruber,** University of California, Los Angeles

GC72B-0212 1330h POSTER

Refinements in the Spatial and Temporal Resolution of Fossil-Fuel CO_2 Emissions Data

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Increasing sophistication of inverse models of the carbon cycle and more detailed understanding of carbon fluxes require finer spatial resolution and seasonal or greater temporal resolution of fossil-fuel CO_2 emissions data. Increasing pressure to formulate a feasible greenhouse-gas emissions policy for the USA requires spatial resolution of CO_2 emissions at scales much finer than national totals. We have calculated preliminary estimates of fossil-fuel CO_2 emissions for the entire USA on a month-by-month basis, and for each state on an annual basis, for the most recent 20 years. The methodology for obtaining the emissions estimates is similar to what we have used previously to estimate global and national annual totals, but relies on more detailed data by fuel type and end use. Efforts are underway to provide similar estimates of CO_2 emissions for the rest of North America.