5-2012

Paleoclimatic variation of Lac du Sommet over the past 1000 years inferred from diatom analysis

Kristen Karnes
University of Arkansas, Fayetteville

Paleoclimatic Variation of Lac du Sommet for the Past 1000 Years Inferred from Diatom Analysis.

Kristen Karnes[*] *and Sonja Hausmann*[†]

ABSTRACT

There has been an increase in storm activity over the past 250 years in the Northeastern United States. In order to find the driving forces for the recent increase of wind activity, a lake sediment core was analyzed for diatoms. Lac du Sommet, in the boreal forest near Quebec, Canada, was used to help determine if either greenhouse gases or solar activity was the driving force for an increased abundance of diatoms. Diatom abundance and diatom productivity in Lac du Sommet is an indicator for previous turbulent water conditions. Prior research has shown that the diatom *Fragilaria virescens* is commonly seen in sediment samples when there were large amounts of lake circulation and windiness. Lac du Sommet had an increase in *Fragilaria virescens* populations over the past 250 years. However, a comparison with high temporal analysis of the diatoms, greenhouse gas changes, and solar activity (the cosmogenic isotopes ^{14}C and ^{10}Be) helped determine CO_2 to most likely be the cause for recent storm increases at the study site.

*Kristen Karnes is a 2012 graduate with a major in Environmental, Soil, and Water Science.
†Sonja Hausmann is an assistant professor and faculty mentor in the Geosciences Department

INTRODUCTION

Climate change can be defined as the variability in climate patterns over an extended period of time. Changes in the atmospheric concentrations of greenhouse gasses and solar radiation alter the energy balance of the climate system, driving climate change (Solomon et al., 2007). Sunspots are dark spots on the sun's surface that typically have an 11-year cycle**.** Solar activity influences the production of cosmogenic isotopes (Chambers and Ogle, 2002). These isotopes are recorded in ice cores, allowing for a correlation between ^{10}Be and sunspot data (Bard and Frank, 2006). Variations in the cosmogenic isotopes ^{14}C and ^{10}Be are used for past solar variation reconstruction (Hoyt and Schatten, 1997). Ice cores or tree rings can be used to trace past ^{14}C concentrations (Crowley, 2000).

Crowley (2000) found through climate models that past decadal-scale temperature variations were due to changes in solar irradiance. Before 1850, about 41% to 61% of pre-anthropogenic decadal-scale temperature variations were caused by solar irradiance. The Maunder Minimum was a period with fewer sunspots, resulting in below average global temperatures. This period occurred during 1645-1715, and temperatures were low because sunspots were uncommon (Crowley, 2000). Temperature responds almost linearly to the estimated changes in radiative forcing (Crowley, 2000). The Little Ice Age (LIA) occurred between 1550-1850, during the Maunder Minimum. Diatoms were used to determine if greenhouse gases (CO_2) or solar activity was the key driving force for diatom variation during the past 1000 years, specifically during the LIA.

Diatoms are single cell algae with a silica shell that are deposited in lake sediments over time. They are microscopic organisms found in all aquatic environments and soil whose siliceous shells are well fossilized in sediment (Stoermer and Smol, 1999). Since they have a very short generation interval, the species populations can drastically change in response to environmental influences such as the following: change in lake level, duration of ice cover, stratification, and different nutrient ratios (Smol, 1990 and Lamb et al., 1995). Therefore, diatoms are used to understand past lake and climate dynamics. Previous studies and models have shown a relationship between climate change, nutrient change and species-specific diatom response (ter Braak et al., 1993, Hausmann and Pienitz, 2009).

Hausmann and Pientiz (2007, 2009) and Hausmann et al. (2011) showed that diatoms could be used to reconstruct past summer winds. Their sediment trap study along elevation gradients showed the relative abundances of the wind-indicating diatom *Fragilaria virescens* (Figure 1) and how there was a relationship with this diatom and water column circulation (Hausmann and Pientiz, 2007 and 2009). However during the Anthropocene, the wind indicator increased up to 50% and the diatom flux was around four standard deviations above the Holocene, the past 10,000 years (Hausmann et al., 2011). Therefore, the recent increase in storms is abrupt and irregular. This experiment explores the explanation for this recent increase in *Fragilaria virescens* populations by statistically comparing previously measured greenhouse gases and cosmogenic isotopes archived in ice cores to the diatom flux (Hausmann et al., 2011).

The objective of this study was to determine if solar activity as indicated by ^{10}Be data or greenhouse gases as indicated by CO_2 data was better correlated with *Fragilaria virescens* counts. The diatoms can help determine if solar activity and sunspots were really the cause for increased windiness or if CO_2 was also the main factor.

MATERIALS AND METHODS

Core acquirement and dating

Samples were collected from Lac du Sommet (830 m. aslf. 47˚43'N, 70˚40'), a small boreal lake located in the Laurentian Mountains near Quebec City, Canada. A 30 cm sediment core was taken in 2001 with a Renberg corer. The sediment from the top 10 cm was then segmented into 2.5 mm intervals and below that in 5 mm intervals (Hausmann and Pientiz, 2009). The samples were sent for ^{210}Pb anaylsis to the University of Toronto. Plant macrofossils from seven depths were sent for AMS radiocarbon dating to Florida's BETA Analytic laboratory and then converted to years (Hausmann et al., 2011). Approximately 1 cm represents around 16 years, but varies with depth (Fig. 2).

Diatom analysis

In order to test for reproducibility, 3 samples were prepared per depth and approximately 300 key diatom species were identified. There were 43 available sediment depths from the sediment core. Therefore, there were a total of 129 samples prepared. Empty test tubes were weighed; the sediment was added to the test tubes and then dried in the oven at 105°C over night and reweighed. The known weights of dry sediment samples were oxidized with hydrogen peroxide (30%) in order to remove organic matter. The test tubes with sediment were placed on a hot plate to boil (100°C) until the samples were clear. Deionized water was added to each sample and the samples were placed in the refrigerator (4°C) overnight. Excess water was removed using a vacuum adapter and pipette tip. A known number of microbeads (250 µL) at the concentration of 754059.4 spheres/µL (diameter of 6 µm) were added in order to calculate absolute diatom abundance. Using a pipette, each sample's water and microbeads were decanted and placed on a slide. The slide was made with new, round cover slips and clean slides to air-dry overnight. A drop of Naphrax and toluene were then applied to mound the diatom to the slides. The diatoms were identified using a DMRB microscope with differential interference contrast (DIC), 1000x magnification, and oil immersion.

Out of the 129 samples, between 100 and 500 valves were counted for each slide. Freshwater diatom species were identified by grouping them into periphytic and planktonic species according to the taxonomy of Krammer and Lange-Bertalot (1991a) and Camburn and Charles (2000). A ratio of all diatoms per microspheres was used in order to calculate the concentrations in each slide. Using the already published chronology the diatom concentrations were converted to diatom flux (valves/cm2/year).

The diatom flux was calculated from the number of valves/year/cm^2 from three samples, gathered from each sediment depth. CO_2 was inferred from organic carbon concentrations (Etheridge et al., 1996). Sunspot activity was determined through past Coronal Mass Ejections (CME) data (Lean et al., 1995). The diatom flux was compared to the relative abundance of *Fragilaria virescens*, to past solar activity and to greenhouse gas data (Crowley, 2000). The ^{14}C, ^{10}Be, and CO_2 concentrations and dates for the years 1096-1954 were compared to the past *Fragilaria. virescens* fluctuations counted from the slides.

RESULTS AND DISCUSSION

Diatom fluctuation was compared to temperature, solar radiation, and CO_2 concentrations. These were compared through correlation coefficients (Table 1). The degrees of freedom were 62 for the diatom flux. The p value was 0.42 for the *Fragilaria virescens* (%) compared to diatom flux and 0.89 for the *Fragilaria virescens* (%) compared to diatom flux from Hausmann and Pientiz (2011). The diatom flux corresponded best with greenhouse gases (CO_2). According to these data, diatom flux was less related to ^{10}Be and ^{14}C concentrations. The diatom flux correlated to CO_2 is most explained by the Little Ice Age (LIA:1550-1850) (Figures 3-5). During the Medieval Warm Period (950-1250), the ice-free period was longer. This warm period allowed diatoms to flourish. Fewer diatoms were produced during the LIA. The LIA was a period with the following sun spot minima: Spoerer Minimum (1460 – 1550), Maunder Minimum (1645 - 1715) and Dalton (1790 - 1830). One additional possibility for the increased diatoms production during higher CO_2 concentrations might be the redistribution of nutrients through wind. Greenhouse gases may have enhanced surface winds at the study site, by displacing the Jetstream northward through expansion of the Hadley cell (Crowley, 2000). The *Fragilaria virescens* began to increase during the LIA around A.D. 1500. *Fragilaria virescens* is an indicator for an unstable water column and this diatom increased towards the present, indicating more wind (Figures 3-5).

The current diatom flux data are from two different investigators. Therefore, the data from Hausmann et al. (2011) did not correlate with this data because of a difference in microsphere solution concentrations. Therefore, the cause for increase in the diatom flux was greenhouse gases in this study and solar radiation in Hausmann et al. (2011). Further comparison by counting a higher quantity of diatoms could help decrease the data points with larger error bars. This may help the data to better correlate to Hausmann et al. (2011). The relationship between the two could help to justify if greenhouse gases, solar activity, or a combination of the two activities was the cause for diatom flux and increased windiness.

ACKNOWLEDGEMENTS

The authors would like to thank the Dale Bumpers College of Agricultural, Food and Life Sciences for providing financial support through the undergraduate research program. We would like to thank Reinhard Pientiz, CEN, ULAVAL, Canada for assisting us with sediment core collection and data. We would also like to thank Drs. Duane Wolf, Curt Rom, and Thad Scott.

LITERATURE CITED

Bard, E., G.M. Raisbeck, F. Yiou, and J. Jouzel. 1997. Solar modulation of cosmogenic nuclide production over the last millennium: comparison between ^{14}C and ^{10}Be records. Earth Planet. Sci. Lett. 150: 453–462 .

Bard, E., G. Raisbeck, F. Yiou, and J. Jouzel. 2000. Solar irradiance during the last 1200 years based on cosmogenic nuclides. Tellus B. 52(3): 985-992.

Bard, E. and M. Frank. 2006. Climate change and solar variability: What's new under the sun? Earth Planet. Sci. Lett. 248: 1-15.

Chambers, F. and M. Ogle. 2002. Climate Change: Critical Concepts in the Environment. Routledge. New York, NY.

Crowley, T. 2000. Causes of climate change over the past 1000 years. Science. 289:270-277.

Etheridge, D.M., L.P. Steele, R. L. Langenfelds, R.J. Francey, J.M. Barnola, and V.I. Morgan. 1996. Natural and anthropogenic changes in atmospheric CO_2 over the past 1000 years from air in Antarctic ice and firn. J. Geophy. Res. 101(D2): 4115- 4128.

Hausmann, S. and R. Pienitz. (2007) Seasonal climate inferences from high-resolution modern diatom data along a climate gradient: A case study. J. Paleolimnol. 38: 73-96.

Hausmann, S. and R. Pientiz. 2009. Seasonal water chemistry and diatom changes in six boreal lakes of the Laurentian Mountains (Quebec, Canada): Impacts of climate and timber harvesting. Hydrobiologia, 635: 1-4.

Hausmann, S., I. Larocque, P.J.H. Richard, R. Pienitz, G. St-Onge and F. Fye. 2011. Diatom inferred wind activity at Lac du Sommet, southern Québec, Canada: Adding coherence to a multi-proxy paleoclimate reconstruction based on diatoms, chironomids and pollen for the past 9500 years. The Holocene. 21(6): 925-930.

Hoyt, D. and K. Schatten. 1997. The Role of the Sun in Climate Change. Oxford University Press, Inc. NY, New York.

Solomon, S., et al. (eds.) 2007. IPCC Assesment Report. 4th ed. Cambridge University Press, Cambridge, United Kingdom and New York, NY.

Kilham, S., E.C. Theriot, and S.C. Fritz. 1996. Linking planktonic diatoms and climate change in the large lakes of the Yellowstone ecosystem using resource theory. Limnol. Oceanogr. 45(5): 1052-1062.

Krammer, K. and H. Lange-Bertalot. 1991a. Bacillariophyceae. 3. Teil: Centrales, Fragilariaceae, Eunotiaceae. In: Ettle, H., J. Gerloff, H. Heynig, and D. Mollenhauer (eds). Sußwasserflora von Mitteleuropa, Band 2/2. Jena: Gustav Fischer Verlag.

Lamb, H.F., et al., 1982. Relation between century-scale Holocene arid intervals in tropical and temperate zones. Nature. 373: 134-137.

Lean, J., J. Beer, R. Bradley. 1995. Reconstruction of solar irradiance since 1610: Implications for climate change. Geophys. Res. Lett. 22(23): 3195-3198.

Mann, M.E., R.S. Bradley, M.K. Hughes. 1999. Northern hemisphere temperatures during the past millennium: Inferences, uncertainties, and limitations. Geophys Res. Lett. 26(6) 759-762.

Smol, J. 1990. Paleolimnology: Recent advances and future challenges. Mem Ist. Ital. Idrobiol. 47: 253-276.

Stoermer, E.F. and J.P. Smol. 1999. The diatoms: Applications for the environmental and earth sciences. 1st ed. Cambridge University Press, Cambridge, United Kingdom.

ter Brakk C.J., F.S. Juggins, H.J.B Birks, and H. Van der Voet. 1993. Weighted averaging partial least squares regression (WA-PLS): Definition and comparison with other methods for species-environment calibration. Chapter 25 in: Multivariate Environmental Statistics, G.P. Patil, and C.R. Rado (eds). Amsterdam: Elsevier Science Publisher B.V. (North-Holland), pp. 525-560.

Table 1. Correlation coefficients of diatoms archived in the sediments of Lac du Sommet and radiative forcings: solar forcing (Lean et al., 1995), ^{10}Be from ice cores (Bard et al., 1997), ^{14}C from tree ring records (Bard et al., 2000, and Lean et al., 1995), CO_2 (Etheridge et al., 1996), and temperature (Mann et al., 1999).

	^{10}Be/Lean splice	^{14}C Bard/Lean splice	CO_2	Temperature
Fragilaria virescens (%)	0.66	0.46	0.84	0.62
Sum centric (%)	0.20	0.12	0.11	0.01
Periphytic (%)	-0.73	-0.57	-0.82	-0.59
Diatom Flux (valves/cm^2/year)	0.51	0.21	0.79	0.29

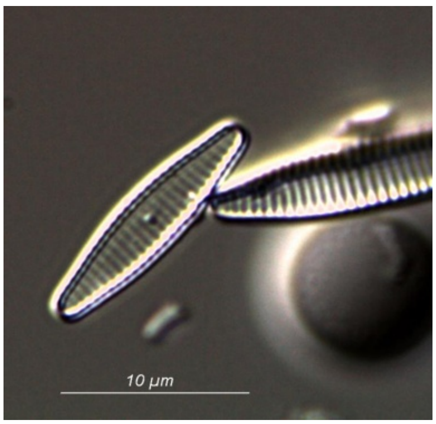

Fig 1. *Fragilaria virescens* compared to a microbead under a microscope at 10μm.

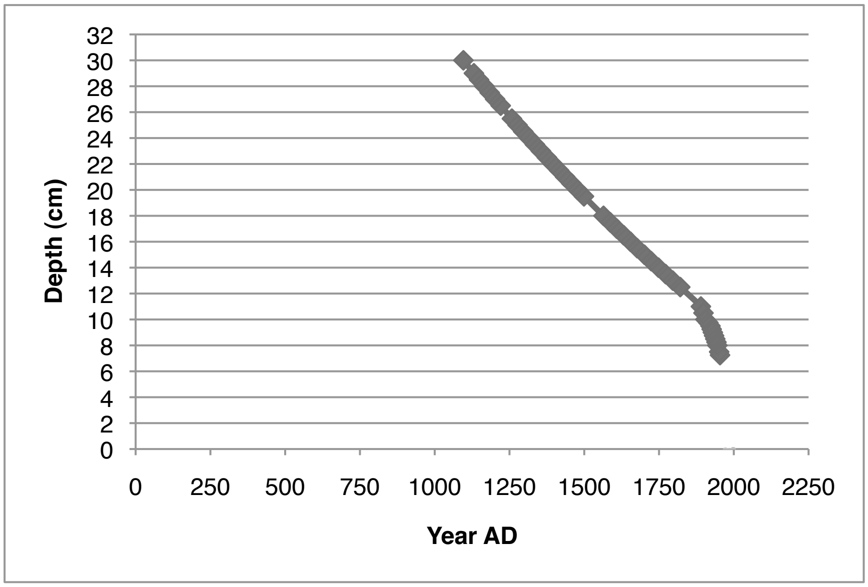

Fig 2. Average year per depth found after radiocarbon dating for the diatom samples analyzed.

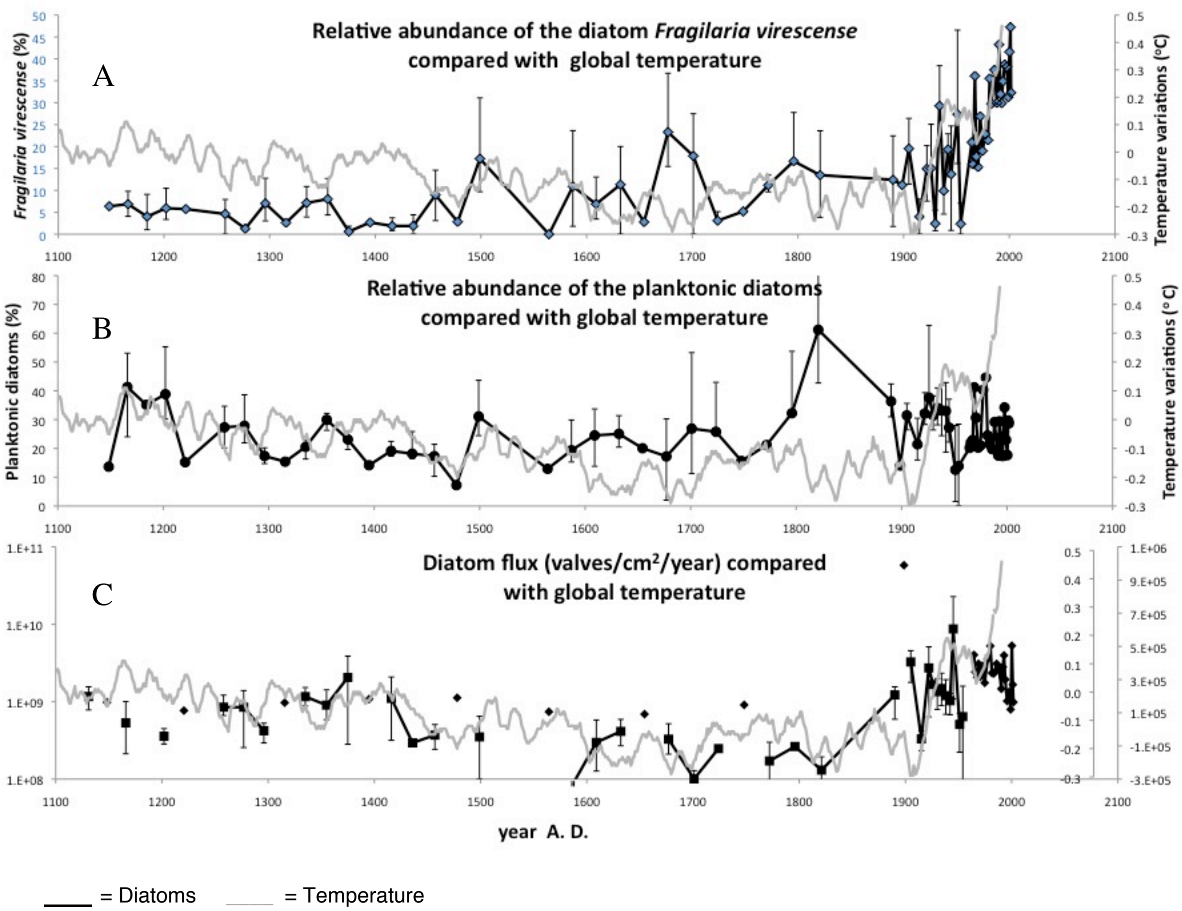

Fig 3. Comparison of the number of diatoms (planktonic or *Fragilaria virescens*) to global temperature over the past 1000 years. Temperature's correlation (Table 1) with the *Fragilaria virescens* or diatom flux. (A) *Fragilaria virescens* compared to global temperature (Crowley, 2000). (B) Planktonic diatoms other than *Fragilaria virescens* compared to global temperature. (C) During the Little Ice Age (1550-1850), there was a decrease in diatom flux (valves/cm^2/year) and a decrease in temperature.

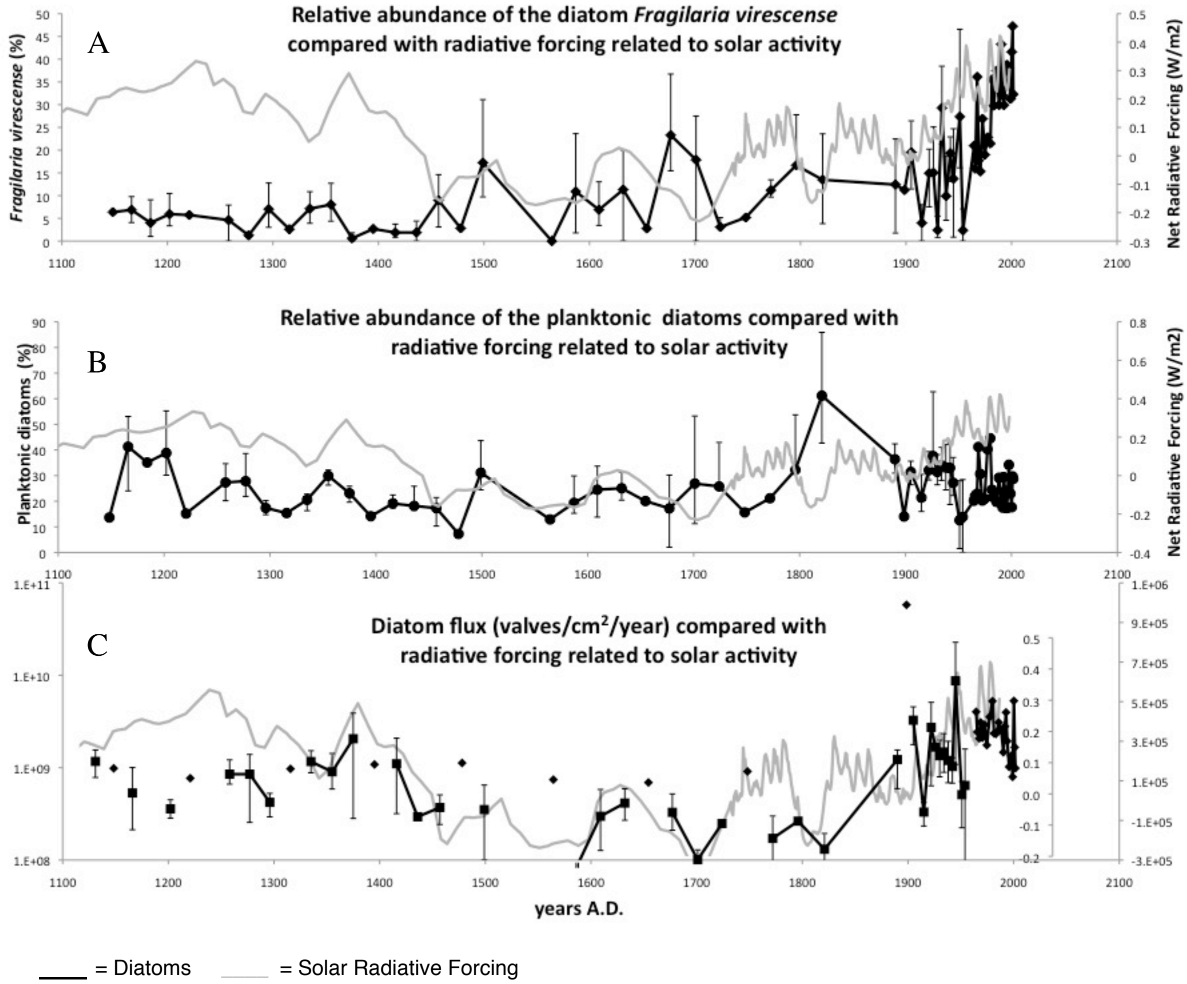

Fig 4. Comparison of the number of diatoms (planktonic or *Fragilaria virescens*) to radiative forcing over the past 1000 years. Solar activity (Table 1) compared with the *Fragilaria virescens* or diatom flux. (A) *Fragilaria virescens* compared to solar activity (Bard et. al, 1997 and Crowley, 2000). (B) Planktonic diatoms other than *Fragilaria virescens* compared to radiative forcing. (C) The diatom flux (valves/cm^2/year) and radiative forcing relationship.

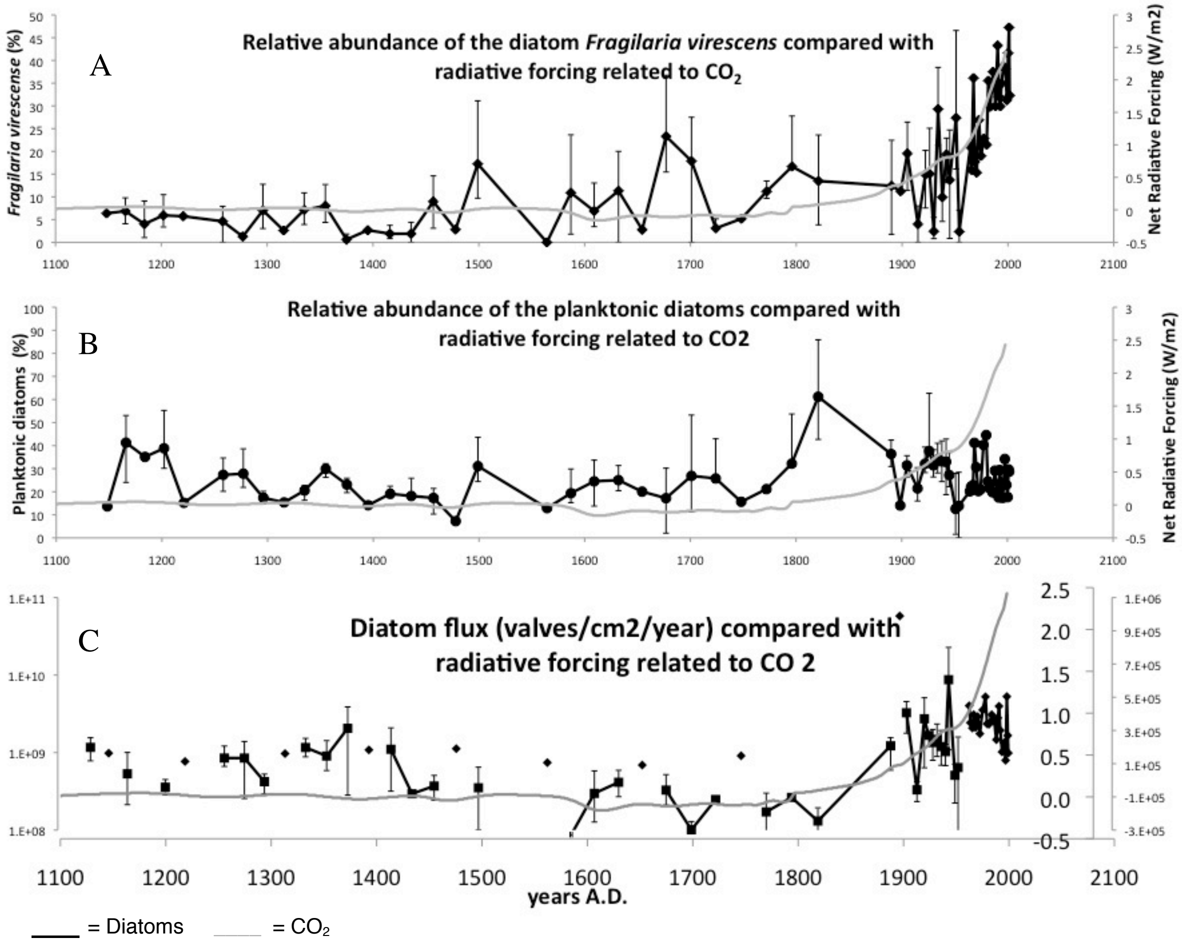

Fig 5. Comparison of the number of diatoms (planktonic or *Fragilaria virescens*) to changes in CO_2, or greenhouse gases over the past 1000 years. Greenhouse gases are best correlated (Table 1) with the *Fragilaria virescens* and diatom flux. (A) *Fragilaria virescens* compared to CO_2 fluctuations (Crowley, 2000 and Etheridge et al., 1996). (B) Planktonic diatoms other than *Fragilaria virescens* compared to greenhouse gases. (C) Diatom flux (valves/cm^2/year) and CO_2 relationship (Table 1).