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LATITUDE-DEPENDENT OSCILLATIONS IN GEOMAGNETIC FIELD INTENSITY AND ATMOSPHERIC CO_2 LEVELS

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ABSTRACT

Atmospheric CO_2 has a long-term, exponential increase in concentration as well as an annual oscillation. Observations reported here indicate that the intensity of the geomagnetic field (**F**) has annual trends similar to CO_2's yearly component. The annual amplitudes of both **F** and CO_2 are dependent on latitude, and the increases in amplitude as a function of latitude are essentially identical for **F** and CO_2. The interannual differences in **F**'s amplitude also show a high correlation with the solar cycle. The analysis presented in this study suggests an association between the intensity of the geomagnetic field and atmospheric CO2 levels, either directly or through interaction with a common modulator.

Keywords: Geomagnetic field, atmospheric carbon dioxide, amplitude, sunspots.

INTRODUCTION

Monthly atmospheric carbon dioxide (CO_2) levels collected from a network of worldwide sampling stations provide real-time monitoring of worldwide CO_2 (CDIAC, 2011; Conway *et al*., 2010). Data from these stations reveals a long-term, exponential increase in atmospheric CO_2 and a shorter-term, annual oscillation in CO_2 levels. The annual oscillation is predominantly observed in the northern hemisphere, and has been traditionally attributed to the growing season (Bacastow *et al*., 1985; Thoning *et al*., 1989). The amplitude of these oscillations increases with latitude, where that in the Arctic Circle is almost three times larger than the amplitude in the tropics (Keeling *et al*., 1996). Mirroring the long-term rise in CO_2 has been a decrease in the intensity (**F**) of the Earth's geomagnetic field (McNeil, 2011). This present study identifies a short term, yearly amplitude in **F,** compares it with those in CO_2, and analyzes the latitude-dependent similarities between these two parameters.

MATERIALS AND METHODS

Geomagnetic intensity (**F**) data was obtained from the World Data Center for Geomagnetism (WDC, 2011); atmospheric CO_2 data was obtained from the Carbon Dioxide Information Analysis Center (CDIAC, 2011) and the Carbon Cycle Cooperative Global Air Sampling Network (Conway *et al*., 2010). All amplitudes reported in this study are calculated using root mean square (*rms*) normalized to the yearly mean. For amplitude vs latitude comparisons (Fig. 3), an attempt was made to mimic CO_2 observatory locations used by Keeling and Worf (2004). Paired geomagnetic and CO_2 monitoring stations used for this section were separated by less than 5^o in longitude/latitude. Eight stations between 20^o-75^o N latitude were selected; CO_2 observatories located below 20^o N were excluded due to nominal amplitudes. Hourly data for at least a 4-year period was used to calculate the yearly amplitudes as a function of latitude; the time period was centered on the year 2000, which corresponds to a relatively calm period.

RESULTS AND DISCUSSION

In addition to the exponential increase in mean annual levels, atmospheric CO_2 also has a short-term sinusoidal component (Thoning *et al*., 1989), which increases in amplitude as a function of latitude (Tans and Conway, 2009). While these "seasonal" oscillations in CO_2 concentration appear to be smooth, the yearly amplitude of this sinusoidal effect varies dramatically. Figure 1 shows the familiar monthly trend of atmospheric CO_2 concentrations at Mauna Loa (Fig. 1a), and the yearly amplitude of these oscillations at this same station for three decades (Fig. 1b).

A recent report identified a temporal correlation between the exponential increase in CO_2 and the decrease in intensity (**F**) of the geomagnetic field for the last 400 years (McNeil, 2011). An analogous comparison is made here for the sinusoidal component of these parameters. Similar to the non-linearity in CO_2's amplitude (Fig 1b), interannual variability is also observed in the amplitude of the geomagnetic field intensity. Figure 2 shows the yearly amplitude in **F** from five observatories in the northwestern hemisphere, at latitudes between 20^oN and 75^oN. The amplitude of **F** varies widely from year to year for these stations, but are synchronized with respect to trends.

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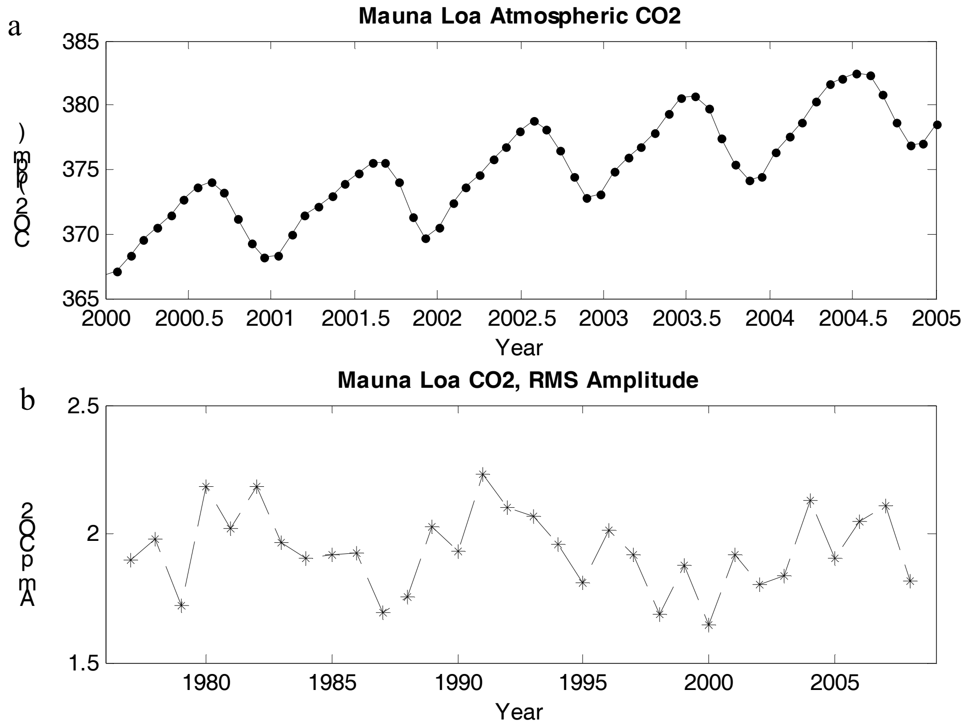

Fig. 1. Variability in CO_2 Amplitude at Mauna Loa. (a) Seasonal oscillations in atmospheric CO_2 from monthly collections at Mauna Loa. (b) Analysis of amplitude of these oscillations shows extensive interannual variability. The top panel is for a five-year period to show detail; the lower panel is from 1977 to 2008 [Data source: CDIAC, 2011].

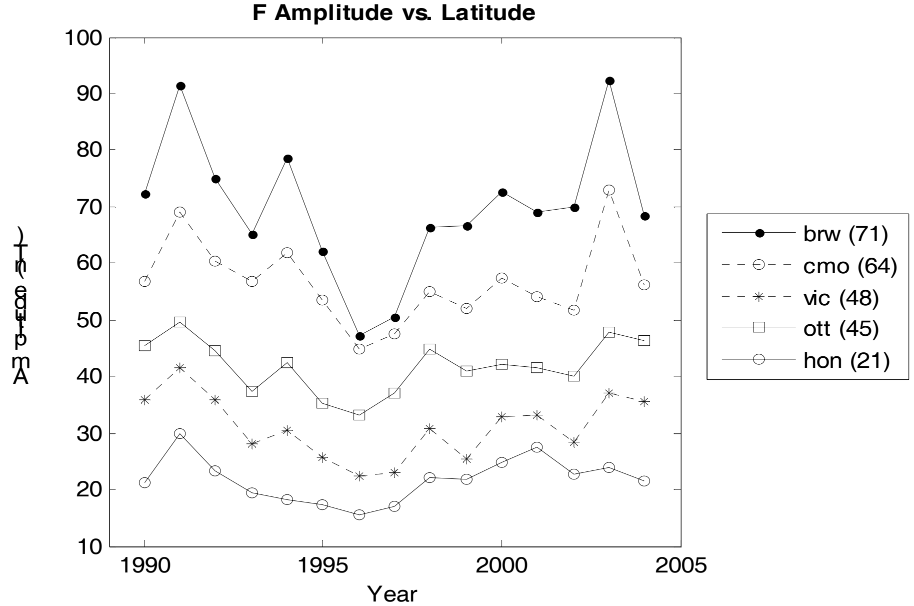

Fig. 2. Variability in F amplitude at increasing latitudes. Yearly amplitudes from magnetometer observatories at five latitudes are shown. Magnetometer observatories by abbreviations are: hon = Honolulu, HI; ott = Ottawa, Canada; vic = Victoria, Canada; cmo = College, Alaska; brw = Pt. Barrow, Alaska. Latitudes for each site are shown in parentheses. Each yearly data point represents the amplitude from ~8760 hourly readings.

To further compare the amplitudes in CO_2 and **F** as a function of latitude, eight magnetometer and CO_2 observatories were identified that were proximally located to one another. That is, the CO_2 observatory had a magnetometer station located within 5° longitude/latitude. Plotting yearly amplitude versus latitude for these paired

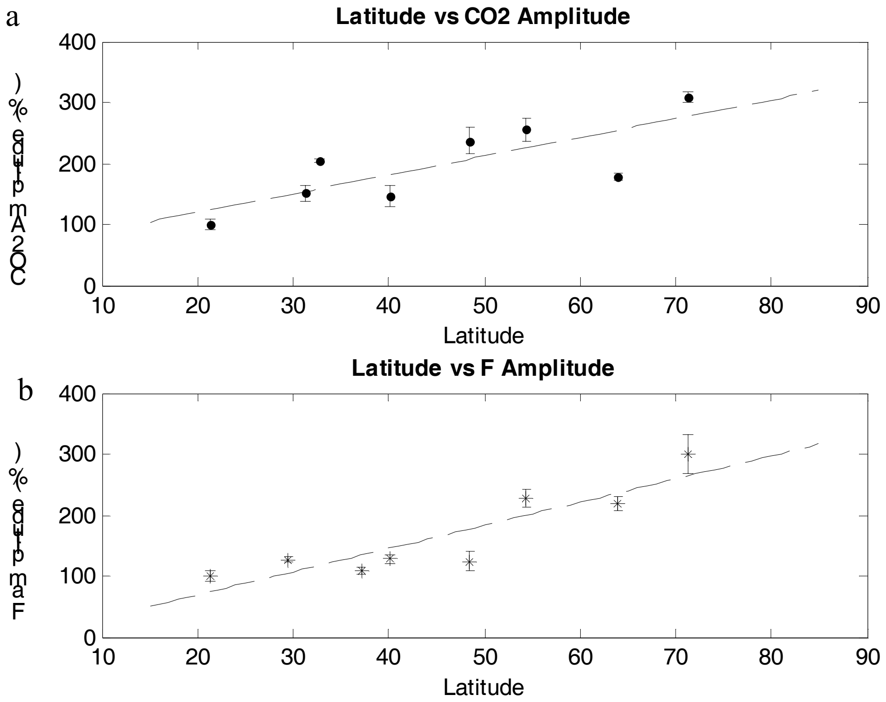

Fig. 3. Comparison of amplitudes versus latitude for CO_2 and F. (a) Amplitude of yearly CO_2 oscillations at various latitudes (b) Amplitude of yearly oscillations in **F** at similar latitudes. Plotted points represent the mean amplitude ± the standard deviation; Y-axis values are percentages normalized to recordings at Mauna Loa, Hawaii for CO_2 or Ewa Beach, Hawaii for **F**. Dotted lines represent the best fit by linear regression (MATLAB, R2008b); the slope for (a) and (b) are 3.1 and 3.8 percent per degree of latitude, respectively.

sites reveals similar slopes for CO_2 and **F** (Fig 3). Specifically, the rate of increase in CO_2's amplitude is 3.1 % per degree of latitude, compared to 3.8 % per degree of latitude for **F**. Whether this trend is conserved globally is unknown, as the rate of change in **F** is non-linear near Eastern Europe, throughout the Indian Ocean, and in the North Atlantic near the Southeastern United States (Rukstales and Quinn, 2001; USGS, 2011).

Simple harmonic motion has been used to model the oscillation in atmospheric CO_2 (Keeling *et al.*, 1976; Bacastow *et al.*, 1985). The year-to-year variability in the amplitude of the oscillation has previously been attributed to "unprecedented changes in the terrestrial biosphere" (Keeling *et al.*, 1996), but the postulated large swings in the growing season are not consistent with five decades of empirical data, in the form of worldwide agriculture production indices (FAOSTAT, 2011).

Since the 12-month periodicity in CO_2 does not change, the variability in the amplitude shown in Fig. 1 implies a change in energy of the harmonic system. Under these conditions, the change in mechanical energy (ΔE) of an oscillating system is proportional to the square of the difference in amplitudes:

$$\Delta E \;\alpha\; (A_2 - A_1)^2 \qquad \text{Eq1}$$

where A_2 and A_1 are the ending and beginning amplitudes, respectively. It follows then, that energy in the form of a driving force -- in resonance with the oscillation-- must be involved to push CO_2's amplitude away from equilibrium. Given the (i) matched natural frequency of CO_2 and **F** and (ii) amplitude vs. latitude slopes reported above, it is plausible that **F** contributes to the driving force in yearly CO_2 oscillations, albeit through an unknown mechanism.

It has long been established that the Earth's geomagnetic field is heavily influenced by the solar cycle (reviewed in Cliver, 1994; NRC, 2008). This interaction is more pronounced at higher latitudes, where solar coronal mass ejections result in auroras and intense geomagnetic storms. Solar activity was therefore compared with **F** at Pt. Barrow (latitude = 71° N) to determine if the former could be influencing the variability in amplitude of **F**. A plot of the solar cycle (i.e. sunspot number) versus the raw **F** data for Pt. Barrow for the last 25 years does not reveal an obvious interaction (Fig. 4a). The correlation becomes significant, however, when the amplitude of **F** at Pt. Barrow is analyzed against the solar cycle (Fig. 4b). More specifically, the peaks and troughs of **F**'s amplitude show close resemblance to the maxima and minima of solar cycle numbers 22 and 23. This correlation was not evident for a CO_2 vs. solar cycle comparison (data not shown).

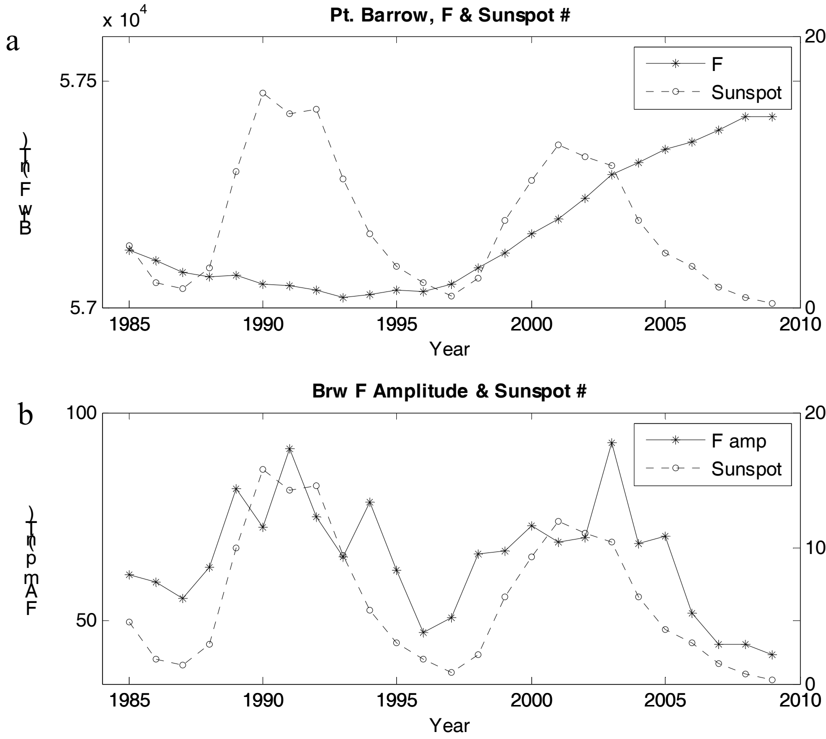

Fig. 4. Comparison of Magnetic Field Intensity with Solar Activity. (a) Annual mean **F** data from Pt. Barrow compared with yearly sunspot activity, for solar cycle numbers 22 and 23. (b) Yearly amplitudes in **F** from Pt. Barrow compared with yearly sunspot activity ($R^2 = 0.77$, $p < 0.001$). [Source for solar data: SIDC, 2011].

The observations reported here suggest a model where the geomagnetic field has trends similar to CO_2 for the "seasonal", short-term component. The yearly amplitudes of both **F** and CO_2 are dependent on latitude, as shown here for the Northwestern Hemisphere. Furthermore, the increases in amplitude as a function of latitude are essentially identical for **F** and CO_2. The interannual differences in **F**'s amplitude appear to be influenced by the solar cycle, through well-established interactions between Earth's geomagnetic field and solar activity (Cliver, 1994; NRC, 2008; USGS, 2011).

CONCLUSIONS

The data presented here suggest an association between the intensity of the geomagnetic field and atmospheric CO2 levels, either directly or through the interactions of a common modulator.

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COMPETING FINANCIAL INTERESTS

The author declares no competing financial interests.

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