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Evaluation of the linkage between Schumann Resonance peak frequency values and global and regional temperatures

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ABSTRACT: Lightning-generated extremely low frequency electromagnetic energy (the Schumann Resonance) could be a sensitive indicator of tropical or global temperature. In this investigation, we analyze the relationship between Schumann Resonance peak frequency data and various daily and monthly temperature datasets. Our results show that daily and monthly lower-tropospheric temperature estimates made from satellites and monthly thermometer-based temperature measurements are significantly related to the Schumann Resonance peak frequency data collected in Rhode Island. Further analyses reveal that the temperatures from subtropical and tropical latitudes dominate the relationship with daily and monthly Schumann Resonance peak frequency variations. Our results further our understanding of the linkage between temperature patterns, latitudinal shifts in thunderstorms, and Schumann Resonance peak frequencies.

KEY WORDS: Schumann Resonance · Temperature variations

1. INTRODUCTION

One of the simplest yet most important questions in the global warming/greenhouse debate centers on whether or not the planetary temperature is currently rising, falling, or remaining unchanged. Some datasets suggest that the planet is currently warming while others have not been able to confirm such a warming trend over recent decades (Houghton et al. 1996, Santer et al. 2000, Wallace et al. 2000). During the 1990s, several scientists suggested that lightning-generated extremely low frequency electromagnetic energy—the Schumann Resonance—may be an additional indicator of variations and trends in planetary temperature (Williams 1992, 1994, Sátori & Zieger 1996, 1999, Sentman 1996, Reeve & Toumi 1999).

While the underlying physics of the processes may be complex, the idea is relatively simple and is based on the well-known fact that thunderstorms and lightning strokes in the tropical regions are related to temperatures in the lower atmosphere. Higher temperatures generally produce more lightning strokes while lower temperatures tend to depress lightning activity (Williams 1992, Price 1993, Price & Rind 1994, Watkins et al. 1998). As shown recently by Sátori & Zieger (1999), the latitudinal position of lightning activity, which impacts the peak frequency of the Schumann Resonance as measured at a point, may be related to global temperatures as well.

Lightning discharges occurring anywhere in the world produce electromagnetic pulses that spread radially away from the source. Much of the energy is degraded quickly, but some of the energy produced by the lightning falls in the extremely low frequency/long wavelength domain of the electromagnetic spectrum, and at these long wavelengths near 8 Hz, the energy from a lightning stroke is able to circumnavigate the earth without serious degradation. The resonance properties of this extremely low frequency/long wavelength energy were first predicted by Schumann (1952) and are therefore called Schumann Resonances.

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Furthermore, virtually all of the energy in these wavelengths measured at the surface of the earth originates from thunderstorm activity.

Sátori & Zieger (1999) recently suggested that the peak frequency of the vertical electric field component of the Schumann Resonance, as measured at only 1 observation site in Hungary, should be related to the latitudinal position of the dominant thunderstorm activity, and the latitudinal position of the storms should be controlled in part by planetary temperature. It is known that the Schumann Resonance peak frequencies are mainly, but not only, determined by the source-observer geometry. In the first Schumann Resonance mode of the magnetic field component, near 8 Hz, the peak frequency should vary directly with distance from the source.

Sátori & Zieger (1999) used January data to avoid contamination in their measurements from thunderstorms occurring in the European region. They compared January Schumann Resonance peak frequency data from 2 El Niño periods (1994, 1998), when the planetary and especially tropical temperatures were relatively high, to 2 La Niña periods (1996, 1997), when the planetary and tropical temperatures were relatively low, and found a significant shift in the peak frequency values. The El Niño months revealed peak frequencies approximately 0.05 Hz higher than the La Niña months, and Sátori & Zieger interpreted the result as a southward (poleward) shift of 4° to 8° latitude during the warmer periods in the southern-hemispheric-dominant January thunderstorm activity. Because their measurements were made in Europe, their results were impacted most by thunderstorm activity in Africa due south of their observation site. Their study suggests that variations in Schumann Resonance peak frequency may be a useful indicator of variations in tropical and/or global temperature. Furthermore, Nickolaenko & Rabinowicz (1995) have shown that the frequency range of Schumann Resonances during a day (maximum–minimum) is inversely related to the size of the source region (the area producing lightning).

In this investigation, we further examine the statistical relationship between daily Schumann Resonance peak frequency data and daily and monthly satellite-based lower-tropospheric temperatures and monthly thermometer-based near-surface air temperatures. Based on the findings of Sátori & Zieger (1999) and others, we expected to find a significant and positive relationship between the peak frequency and temperature data, and we expected to find the strongest relationship with temperature records from the lower latitudes. Our analyses explore the concept that the latitudinal movement of thunderstorm bands is temperature dependent, and that the movement of these thunderstorms is detectable in the Schumann Resonance data.

2. SCHUMANN RESONANCE DATA

The original primary data for this study consisted of measurements of Schumann Resonance magnetic fields collected in the north-south and east-west directions; we focus our study on the peak frequency of the first mode near 8 Hz. The measurements are carried out continuously at the Massachusetts Institute of Technology field station in West Greenwich, Rhode Island, and the dataset is considered one of the best available at this time in terms of quality and completeness. The instruments are in a wooded area approximately 5 km from the nearest major road. Two identical magnetometers with permalloy cores, each 2.13 m long and 7.7 cm in diameter, are buried with sandbags and aligned with geographical north-south and east-west directions. These coils have built-in low noise pre-amplifiers and a flat frequency response for magnetic field from 2 to 120 Hz. Calibration analyses of the instruments (Heckman et al. 1998) suggest that the absolute error in magnetic field measurement is less than 5%.

The pre-amplified signals are routed over 200 m of shielded twisted pair cable to final amplifiers and 60 Hz notch filters at an equipment shelter. Every sequential set of 4096 digital samples is Fourier transformed to compute the power spectral density $P(k)$ of each measured scalar field F. With a sampling rate of 350 Hz, 12 s elapse while 4096 points are collected. Once every 12 min, the last 60 transforms are averaged, and this average is archived. Any points that appear to be narrow-band contamination from man-made sources are eliminated.

These north-south and east-west magnetic peak frequency data (the frequency with the strongest Schumann Resonance signal near 8 Hz) were averaged into 'global' estimates for the magnetic field. These values were then averaged for the entire day to provide an estimate of daily Schumann Resonance peak frequency (v_{mx}) near 8 Hz. In addition, the range in the peak frequency values (Δv_{mx}) for each day was determined by subtracting the minimum value from the maximum value.

The Schumann Resonance data used in this study extended from 1 January 1994 to 31 December 1998, but to minimize the possible contamination caused by local lightning activity, all May through September days were eliminated from further consideration leaving 558 days for analysis (Fig. 1). The selection of low-sun months in the Northern Hemisphere reduced the possibility of the measurements being dominated by

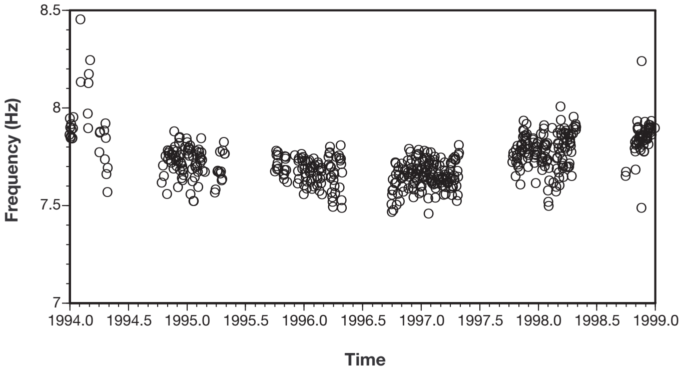

Fig. 1. Peak frequency variations of Schumann Resonance magnetic fields near 8 Hz over 558 days from 1 January 1994 to 31 December 1998

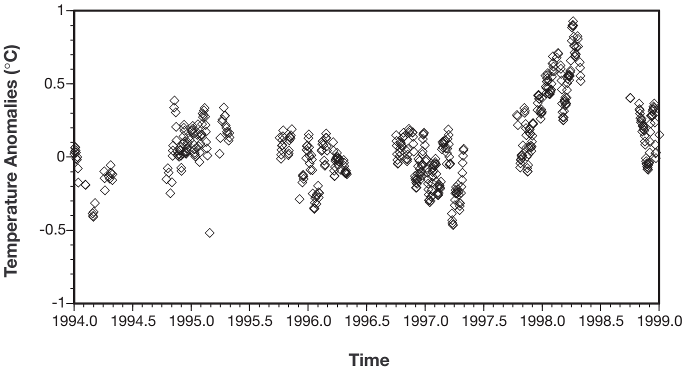

Fig. 2. Satellite-based global temperature anomalies over 558 days from 1 January 1994 to 31 December 1998

thunderstorms near Rhode Island and provided an opportunity to detect movements of storms in the active intertropical convergence zone which in those months is largely in the Southern Hemisphere. The position of the instruments in Rhode Island also meant that thunderstorms to the south, in South America, would have the greatest impact on the measured peak frequencies.

3. TEMPERATURE DATA

The satellite-based lower-tropospheric daily temperatures for the globe, Northern Hemisphere, Southern Hemisphere, and each of sixty-seven 2.5° latitudinal bands from 82.5° S to 82.5° N were assembled for each of these 558 days. Polar-orbiting satellites measure microwave emissions from molecular oxygen in the lower 8 km of the atmosphere, and the results provide a measure of lower-tropospheric temperatures (Spencer et al. 1990, Wallace et al. 2000). The temperature data used in this study had been corrected to account for small effects of orbital decay and other potential contaminants to the record (Christy et al. 1998, Wentz & Schabel 1998). All values were expressed as anomalies (deviations from normal) based on a 1979 to 1998 'normal' period (Fig. 2).

A second 'global' temperature dataset was available from near-surface thermometer measurements made in many places around the world. These temperatures were available for each month from many 5° latitude by 5° longitude grid cells around the globe, and they were derived from the land surface air temperature data developed and described by Jones (1994) and the oceanic data generated and described by Folland & Parker (1995). Jones et al. (1999) provided an excellent description of this dataset.

4. ANALYSES

After assembling all Schumann Resonance and temperature data, we plotted all data and examined the time series for questionable values. After finding none, we tested each time series for normality by calculating the standardized coefficients of skewness and kurtosis and the Kolmogorov-Smirnov 1-sample test. No significant departures from a normal distribution were found for the temperature data, but both the peak frequency data and the range in peak frequency data revealed a statistically significant positive skewness. We found that a square-root transformation was required to 'normalize' the data. In all of our subsequent analyses we found that the use of the raw data versus the transformed data did not significantly impact the results.

We used multiple regression analysis to determine the portion of variance in daily planetary temperatures, T_g, that could be explained by the variations in Schumann Resonance peak frequency and the range in the peak frequency values. The intercorrelation between these 2 'independent' variables was 0.01, indicating essentially no multicollinearity among the predictor variables.

We assumed in our analyses that the following multivariate equation was valid to link latitudinal temperature (either near-surface and lower-tropospheric) variations to the Schumann Resonance parameters:

$$T'(L,t) = a(L) + b_1(L) \cdot \nu_{\mathrm{mx}}(t) + b_2(L) \cdot \Delta\nu_{\mathrm{mx}}(t)$$

where $T'(L,t)$ is the estimated temperature anomaly at latitude L at time t, $\nu_{\mathrm{mx}}(t)$ is the peak frequency of the first Schumann Resonance mode measured in Rhode Island, $\Delta\nu_{\mathrm{mx}}(t)$ is the range of these frequencies, $b_1(L)$ and $b_2(L)$ are the latitude-dependent partial regression coefficients, and $a(L)$ is the latitude-dependent intercept value. At the global scale and consistent with Sátori & Zieger (1999), we anticipated a positive value

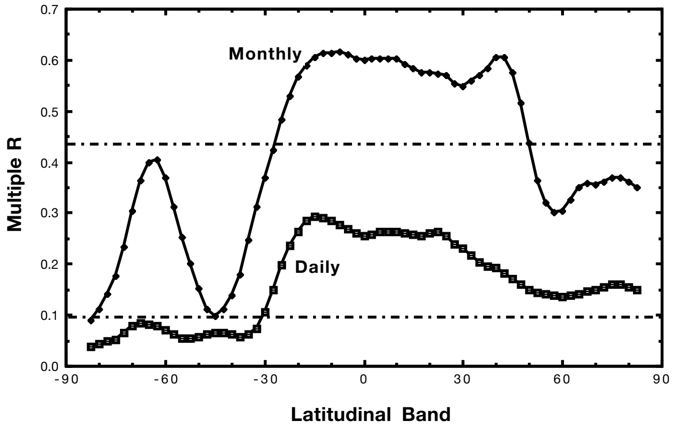

Fig. 3. Multiple R values for regression analyses comparing October–April daily and monthly satellite-based temperatures in latitudinal bands to the Schumann Resonance frequency data. Values greater than 0.10 and 0.43 are significant at the 0.05 level of confidence for the daily and monthly values, respectively

of b_1 as warmer temperature should shift the southern-hemispheric-dominant October to April thunderstorms poleward (farther from Rhode Island), thereby increasing the v_{mx} values. Similarly, we anticipated a negative b_2 value based on the findings of Nickolaenko & Rabinowicz (1995). This simple model could be compromised by many potential feedbacks, including the possibility that cloud cover associated with active convection zones could cool the lower atmosphere and actually reverse the expected relationships.

The regression analysis produced a multiple R value of 0.276 ($\rho = 0.000$) for predicting daily planetary temperature from daily Schumann Resonance peak frequency data. The standardized partial regression coefficient was 0.221 for the peak frequency values and 0.176 for the range in the values. The result verified that a statistically significant positive relationship exists between global temperature and the peak frequency values. The positive relationship between temperature and the range of peak frequencies was at odds with the findings of Nickolaenko & Rabinowicz (1995). However, the multiple R^2 value indicated that only 8% of the variance in daily planetary temperature was 'explained' by the Schumann Resonance data.

The same analyses were conducted for the hemispheric temperature values; the multiple R for the Northern Hemisphere was 0.276 ($\rho = 0.000$) and for the Southern Hemisphere 0.196 ($\rho = 0.000$). The 2 R values were not significantly different, and in both cases, the standardized regression coefficients indicated that the peak frequency was more important than the range in peak frequencies in explaining variance in daily temperatures.

Regression equations were then developed for the daily temperature time series for each of the 2.5° latitudinal bands. The multiple R values showed a pattern with highest values in the tropical and subtropical latitudes and lowest values in high latitudes (Fig. 3). The multiple R values for the daily data were not statistically significant in latitudes south of 30° S, but significant and positive at all other latitudes. Generally, the higher multiple R values were found in areas of the world with the highest lightning activity; the highest values were found near 20° S, which corresponds to the approximate position of thunderstorms in South America during the October to April time period used in this study.

All of these analyses were repeated using monthly satellite-based data over 31 months with complete or nearly complete data. The regression equation for the monthly global temperature had a multiple R value of 0.664 ($\rho = 0.000$). The multiple R values for the Northern and Southern Hemispheres were 0.672 and 0.476, and again, the values were not significantly different. A plot of R values for the latitudinal bands was generally similar to the pattern found for the analyses of the daily values (Fig. 3), with significant values found between 30° S and 50° N.

The monthly analyses were repeated using the 5° by 5° near-surface air temperature data described in Jones et al. (1999). Over the 31 months used in this study over the period 1994 to 1998, the correlation coefficient between the thermometer-based and satellite-based record of temperature anomalies was 0.77.

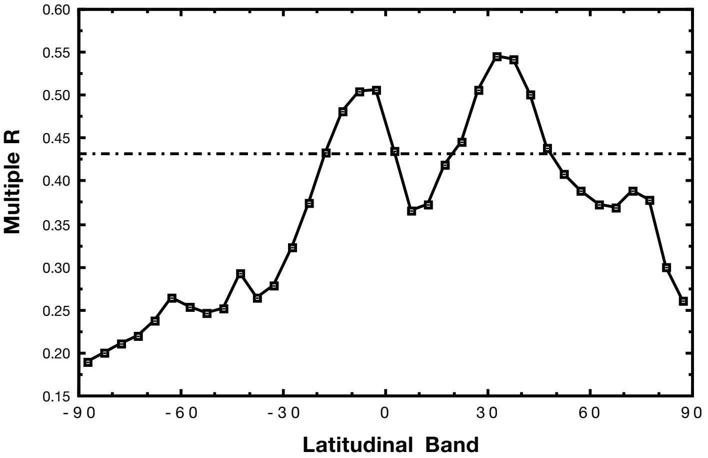

Fig. 4. Multiple R values for regression analyses comparing October–April monthly thermometer-based temperatures in latitudinal bands to the Schumann Resonance frequency data. Values greater than 0.43 are significant at the 0.05 level of confidence

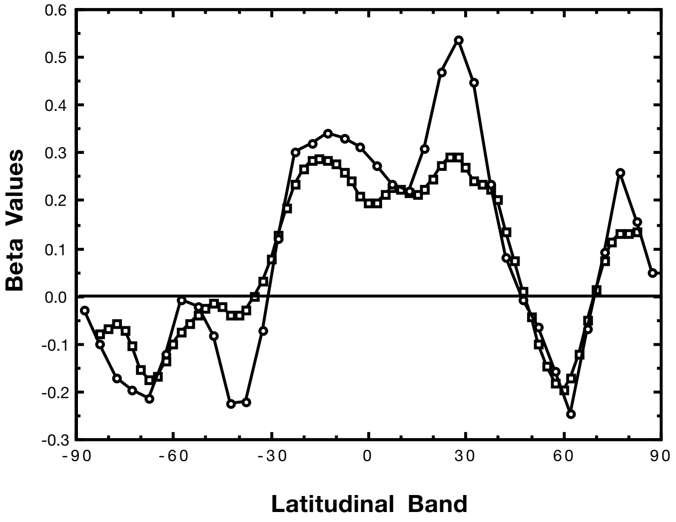

Fig. 5. Latitudinal standardized partial regression coefficients linking peak frequency data to daily satellite-based temperature anomalies (□) and monthly near-surface temperature anomalies (○)

The regression equation for the monthly global temperature anomalies had a multiple R value of 0.591 (ρ = 0.002). The multiple R values for the Northern and Southern Hemispheres were 0.520 and 0.523, and again, the values were not significantly different. A plot of R values for the latitudinal bands (Fig. 4) revealed a pattern with highest values in the low latitudes (particularly the subtropics) and lowest values in the high latitudes; the pattern was similar to the one determined for the satellite data (Fig. 3). The only significant values appeared between 20° S and 40° N.

Finally, we examined the pattern in the partial regression coefficients that link the peak frequency values to the daily satellite-derived latitudinal temperature data and the monthly near-surface air temperature values. The standardized partial regression coefficients ('beta values' associated with the $b_1(L)$ values) showed high similarity in their latitudinal pattern (Fig. 5). Significant values (generally greater than 2.0) were found in the low latitudes between 30° S and 45° N; few significant negative values appeared in the analyses. In addition, the $b_2(L)$ partial regression coefficients were generally not significant and they did not produce a coherent latitudinal pattern.

Obviously, planetary temperature was not 'dependent' upon the Schumann Resonance peak frequency values, and therefore, we re-conducted all analyses with the temperature values as independent variables and the Schumann Resonance peak frequency as the dependent variable. The results were very similar to the findings described above. The relationship between Schumann Resonance frequency data and the thermometer-based and satellite-based temperature records continued to show highest R values (and significant values) in the low latitudes of both hemispheres and the subtropics of the Northern Hemisphere.

5. CONCLUSIONS

The analyses conducted in this investigation comparing Schumann Resonance peak frequency data measured in Rhode Island to various daily and monthly temperature values were preliminary, but encouraging. We found that daily and monthly satellite-based lower-tropospheric global temperature measurements were significantly and positively related to Schumann Resonance peak frequency values. The relationship was particularly strong in low latitudes (not necessarily near the equator), where most lightning occurs. We also found that monthly global and regional near-surface air temperature measurements from thermometers worldwide revealed the same basic patterns seen in the analyses with the satellite-based temperature records. All of these findings are consistent with idea that the latitudinal position of dominant thunderstorms is temperature dependent and detectable in the Schumann Resonance peak frequencies measured in Rhode Island.

All of our analyses add empirical support to the theoretical predictions that global and tropical temperatures should be related to Schumann Resonance measurements. In addition, the analyses represent a test for both the near-surface air temperature and the satellite-based lower-tropospheric temperature databases. Given the interest in 'reconciling' differences between these important datasets (e.g., Santer et al. 2000, Wallace et al. 2000), it is noteworthy that they produced highly similar latitudinal patterns with respect to their relationship to the Schumann Resonance parameters, despite their different temporal and spatial resolutions.

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