LIGHTNING AND CLIMATE: THE WATER VAPOR CONNECTION

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ABSTRACT

The amplitude of future global warming will depend strongly on how upper tropospheric water vapor (UTWV) changes in response to greenhouse gas forcings. However, monitoring long-term changes in water vapor is very difficult, and no single method is in place, or planned, to deal with this problem. In this paper new evidence is presented showing the close link between UTWV variability and global lightning activity. Continental deep convective storms that transport large amounts of water vapor into the upper troposphere dominate the variability of global UTWV, while also being the storms that produce the majority of our planet's lightning. Furthermore, integrated global lightning activity can be continuously observed from a single location on the earth's surface via the Schumann Resonances (SR), an electromagnetic phenomenon in the atmosphere produced by global lightning.

INTRODUCTION

Tropospheric water vapor is a key element of the earth's climate. It has direct effects as a greenhouse gas, as well as indirect effects through the interaction with clouds, aerosols, and tropospheric chemistry. Small changes in upper tropospheric water vapor (UTWV) have a much larger impact on the greenhouse effect than small changes in water vapor in the lower atmosphere [1]. Both climate models and observations support the idea that higher temperatures will increase the amount of UTWV [2, 3]. Recent observations indicate that UTWV may already be increasing [4]. Some climate models predict UTWV to increase by 20% for every 1 K increase in surface temperatures [3]. This sensitivity is greater than that predicted by the Clausius-Clapeyron equation (6% per 1 K at 300 K) since UTWV is influenced not only by temperature, but also by transport from the lower atmosphere. As a result, the water vapor feedback could amplify the surface temperature change due to a doubling of carbon dioxide by 60% [5].

UTWV is transported aloft by deep convection, to be later redistributed zonally and meridionally in the upper atmosphere [6]. The stronger the updrafts, the deeper these cloud and precipitation particles are transported into the upper levels of clouds. Not only does the intensity of the convection influence the volume of water transported aloft, but it simultaneously influences the electrification processes in these convective clouds. The eventual sublimation of the large ice-filled anvils results in a major source of water vapor into the upper troposphere [7].

In this paper a new diagnostic is presented for studying global UTWV variability. It involves using the global atmospheric electric circuit that is regulated by global lightning activity. The use of the global electric circuit to monitor climate variability has previously been suggested [8]. However, previous studies focused on using the global electric circuit and lightning activity to study tropical and global surface temperature changes. Here we build on a previous study by [9] and consider the connection between global lightning and UTWV.

METHODOLOGY

A relatively simple and cheap method for continuously observing global lightning variability is via the Schumann Resonance (SR) [10]. Each lightning discharge emits electromagnetic radiation at all frequencies and in all directions. The lower the frequency of the radiation, the less the attenuation of the electromagnetic waves in the atmosphere, and the greater the propagation distance. At extremely low frequencies (ELF: 1Hz$<f<$100Hz) the radiation can propagate a few times around the globe before dissipating. This is achieved by electromagnetic waves being trapped in the earth-ionosphere waveguide. The resonant frequencies are excited by lightning discharges in the lower atmosphere, and since there are approximately 50-100 lightning flashes per second around the globe, the variability of the SR intensity represents a continuous measure of the variability of global lightning activity [11]. Simultaneous measurements on opposite sides of the globe show remarkable agreement (Figure 1), implying that a single station can be used to track global lightning variability. At present a SR observation site in the Negev Desert, Israel, is continuously providing magnetic and electric field data. There are a number of other stations around the world that also continuously monitor the SR, including Rhode Island (USA), Japan, Hungary, Alaska (USA), and California (USA). The global nature of the SR is demonstrated below by the amazing agreement between the independent daily measurements in Israel and California over a 25-day period.

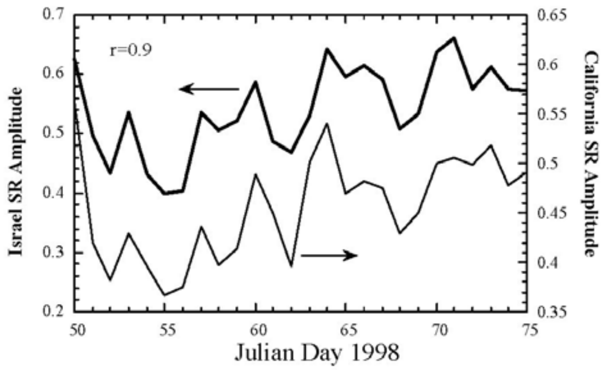

Figure 1: The simultaneous daily measurements of the 8 Hz horizontal magnetic field amplitude in Israel and California.

At the Negev SR station we monitor the two horizontal magnetic components of the ELF field (north-south and east-west) together with the vertical electric field. Since our field station is globally located north of tropical Africa, west of tropical Asia, and east of tropical America (great circle paths) as shown in Figure 2a, it is possible to separate out the different source regions by using different magnetic components at different times during the day. Even though the north-south magnetic detector is sensitive to both South American and Southeast Asian thunderstorm activity, the Asian thunderstorms peak around 08 UT (4 pm local time), while South America peaks at 20 UT (4pm local time) (Figure 2b). The African activity can be monitored using the east-west magnetic component at 14 UT (4pm local time).

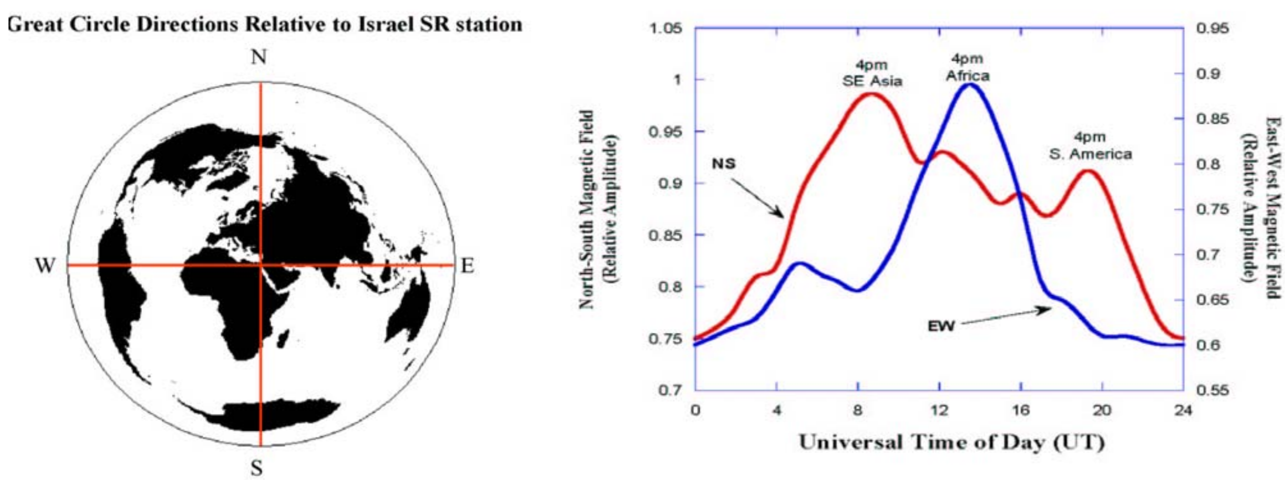

Figure 2a. The location of the Negev SR site relative to the different thunderstorm regions of the world showing the great circle paths to the station; and b. the monthly mean diunal amplitude of the SR signal in the NS and EW horizontal magnetic components, showing the 3 peaks related to the 3 main regions of thunderstorm activity (SE Asia, Africa and S. America).

The primary data set used for studying UTWV was obtained from the NOAA NCEP/NCAR reanalysis [http://wesley.wwb.noaa.gov/reanalysis.html]. This data set is a combination of model and historical data that provides the best global meteorological data set at 6-hourly intervals, many vertical layers, and covering the last 40 years. The model is used to generate data when observations are not available, while the model is also forced to match the observations in regions where data is available. For our study, we have used the specific humidity parameter (grams of water vapor/kg of air) at the 300 mb level representing the upper troposphere.

Our present analysis covers a 2-month period from 20 October – 20 December, 1998. Since lightning activity occurs mainly over continental areas, we used a land-sea mask to eliminate the UTWV over the oceans, and considered only the continental UTWV over tropical Africa (Fig. 3a) and tropical South America (Fig. 4a). Figure 3a shows the 2-month mean specific humidity at 1200UT over Africa. This time was chosen since it is closest to the 1400UT maximum in the SR signal originating from Africa. Figure 3b shows the daily values of the SR amplitude (1200 UT EW magnetic component) together with the daily values of the specific humidity *shifted* by one day. The lightning activity represented by the SR measurements peaks one day *before* the specific humidity peaks in the upper troposphere. The specific humidity plot is shifted one day to show the remarkable agreement between these two totally independent parameters (r=0.82). The dominant periodicity of both the SR and the UTWV time series over Africa is 3.5 days, with a weaker 5 day periodicity.

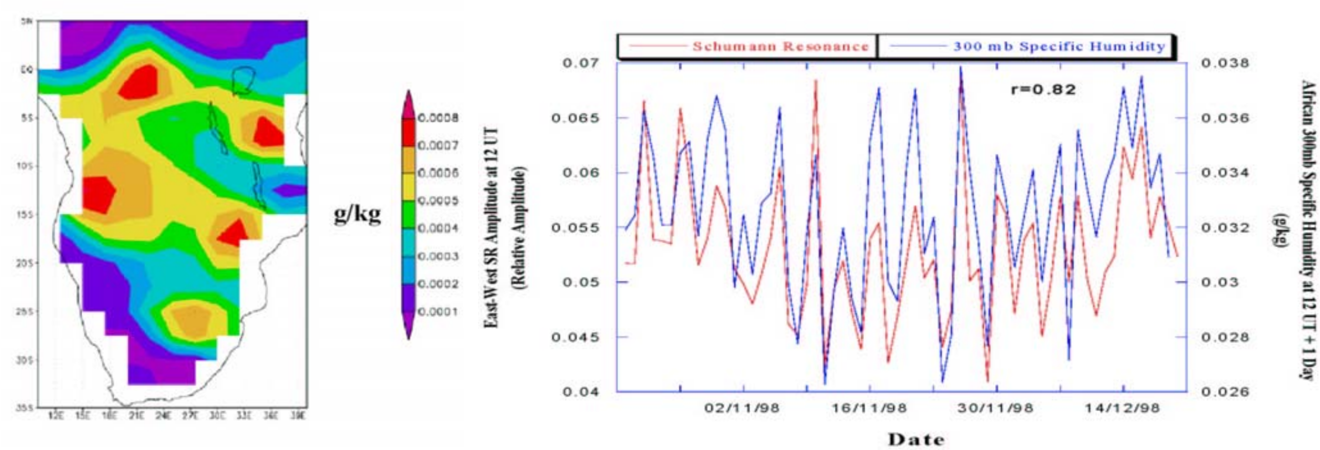

Fig.3a. The 2-month mean specific humidity above Africa at 300 mb at 1200 UT; b. the daily variations of lightning and water vapor above Africa. Note that the specific humidity data is shifted by one day to show the good agreement.

In Figure 4a we show a similar 2-month mean specific humidity at 300 mb, however at 1800UT, the closest NCEP time to the 2000UT lightning maximum from South America. Fig. 4b shows the daily 1800 UT values of the SR (NS magnetic component) together with the shifted 1800UT 300 mb specific humidity. Here too the specific humidity peaks one day *after* the lightning activity peaks. This lag in the maximum water vapor can be explained by the slow sublimation of thunderstorm anvils, followed by the advection horizontally away from cloudy regions. Satellite data used in the NCEP reanalysis can only observe UTWV in clear-sky regions. The correlation coefficient for S. America is 0.79. The dominant periodicity of both the SR and the UTWV time series over S. America is 9 days, with a weaker 5 day periodicity.

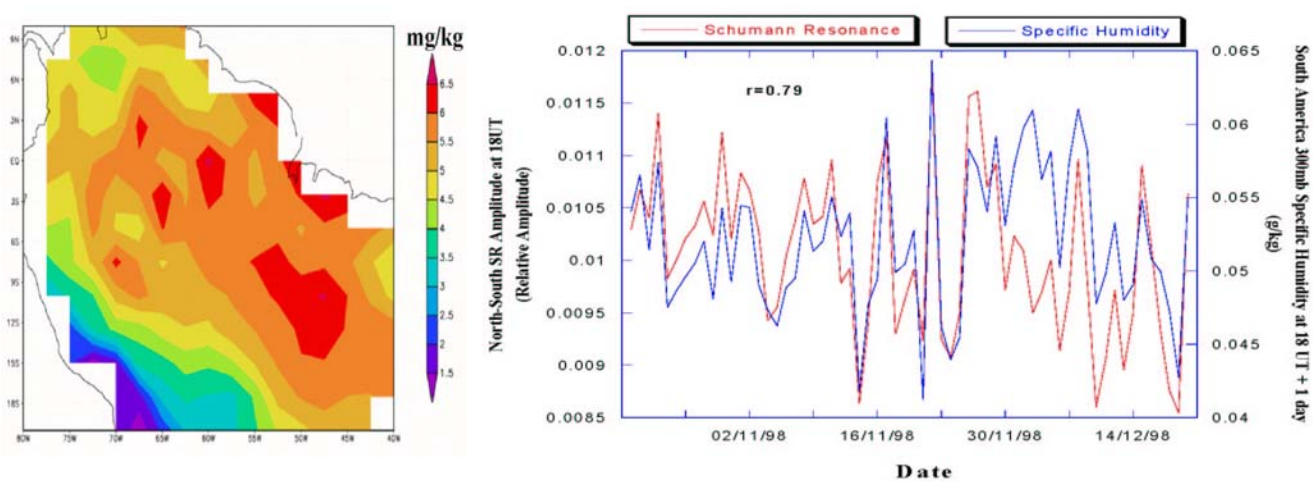

Fig. 4a and b. As in Fig. 3 however above South America at 1800 UT.

Using a different UTWV data set we have also looked at the *global* variability of UTWV and lightning activity, which is shown in Figure 5 [9]. Even though the UTWV data set used in this plot has many problems, and the SR data used here is for 10 Hz instead of 8 Hz, here too we see the close connection between global lightning activity and variations in the UTWV (r=0.76). In addition, we also see the one-day delay between the peak lightning activity and the peak UTWV. Hence, the relationship between lightning and upper tropospheric water vapor appears to be quite robust on many different spatial and temporal scales.

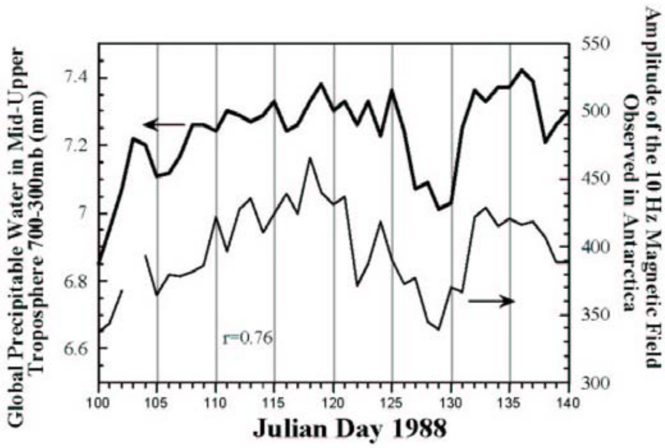

Figure 5. A comparison between daily globally integrated UTWV from the NVAP project, and the 10Hz SR signal monitored at Arrival Heights, Antarctica [12].

CONCLUSIONS

Water vapor is the most important greenhouse gas in the earth's atmosphere. Without it the average temperature of the earth would be $-17^{o}C$. Any future global warming will be strongly influenced by how tropospheric water vapor concentrations change in the future. In particular, the earth's climate is extremely sensitive to changes in the amount of upper troposphere water vapor (UTWV). The agreement between the variability of regional/global lightning activity (ELF SR intensities) and regional/global UTWV concentrations suggests that single-station measurements of the Schumann resonance could supply a cheap, continuous, long-term measure of the variability of UTWV. This is particularly important due to the present difficulty in monitoring UTWV over long periods of time using satellites. Not only are the quantities of UTWV extremely small, but satellites normally have a lifetime of only a few years. Changes in satellites normally result in shifts in long-term trends. On the other hand, SR measurements can be done over periods of decades with regular absolute calibration of the signals.

REFERENCES

[1] Hansen, J. *et al*., in *Climate Processes and Climate Sensitivity* (eds Hansen, J.E., and Takahashi, T.) 130-162 (American Geophysical Union), Washington, D.C., 1984.

[2] Rind, D. *et al*., Positive water vapour feedback in climate models confirmed by satellite data. *Nature*, **349**, 500-502, 1991.

[3] Rind, D., Just add water vapor. *Science*, **281**, 1152-1153, 1998.

[4] Oltmans, S.J., and Hofmann, D.J., Increase in lower-stratospheric water vapor at a mid-latitude Northern Hemisphere site from 1981-1994. *Nature*, **374**, 146-148, 1995.

[5] Climate Change 1995: IPCC Assessment Report (eds Houghton, J.J *et al*., Cambridge University Press, UK, 1996.

[6] Newell, R.E., et al., Walker circulation and tropical upper tropospheric water vapor, *J. Geophys. Res.,* **101**, 1961-1974, 1996.

[7] Kent, G.S., et al., Surface temperature related variations in tropical cirrus cloud as measured by SAGE II. *J. Climate*, **8**, 2577-2594, 1995.

[8] Williams, E.R., The Schumann Resonance: a global tropical thermometer. *Science*, **256**, 1184-1186, 1992.

[9] Price, C., Evidence for a link between global lightning activity and upper tropospheric water vapor, Nature, 406, 290-293, 2000.

[10] Schumman, W.O., Uber die strahlungslosen eigenschwingungen einer leitenden kugel, die von einer luftschicht und einer ionospharenhulle umgeben ist*. Zeitschr. f. Naturf.,* **7a**, 149-162, 1952.

[11] Heckman, S.J., E. Williams and B. Boldi, Total global lightning inferred from Schumann Resonance measurements. *J. Geophys. Res.*, **103**, 31775-31779, 1998.

[12] Fraser-Smith, A.C. *et al*., Global measurements of low-frequency radio noise. In *Environmental and Space Electrodynamics*, (ed Kikuchi, H.) 191-200 (Springer, Tokyo), 1991.