Atmospheric Research 92 (2009) 277–279

Contents lists available at ScienceDirect

Atmospheric Research

journal homepage: www.elsevier.com/locate/atmos

Short communication

Electric signals generated by tornados

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ARTICLE INFO

Article history:
Received 28 July 2008
Received in revised form 21 October 2008
Accepted 28 October 2008

Keywords:
Tornado
Ultra Low Frequency radiation
Early warning

ABSTRACT

Severe weather events generate electrical phenomena beyond those related to lightning discharges. In the present letter we suggest that as precipitation like rain, hail stones, and dirt move in the thunderstorm they generate an electrical signature that is characteristic for the rotation properties of the associated storm. A case study is offered which clearly demonstrates that this electrical signature is present and detectable, though it is quite weak. It can be observed that as the speed of rotation increases and diameter decreases the emitted frequency increases as would be anticipated. Comparison to synchronous radar, surface and visual data suggest that developing tornadoes in this way can be detected earlier than currently feasible weather surveillance radars.

1. Introduction

Several investigations hint to a link between thunderstorm electrification, lightning discharge distributions and tornado genesis. There is some indication of characteristic signatures with regard to lightning frequency and polarity in tornadic storms – for example missing lightning activity during tornados – but it is not encouraged to use lightning data as a basis for tornado warnings (Teittinen, and Maekelae, 2008); (Bluestein, and MacGorman, 1998). Electrification processes however also lead to electromagnetic Ultra Low Frequency (ULF) radiation (defined as $f<10$ Hz for this paper). ULF radiation is home to many natural phenomena. It is even suspected to be useful for earthquake prediction (Schmitter, 2006); (Ohta et al., 2001) but it also shows a complex correlation with storm behavior. In the presented study, the electric fields of a rotating and non-rotating supercell storm have been recorded and analyzed yielding supporting data sets. In that way monitoring the electric and/or magnetic component of rotating storms can lead to an increased understanding of the generating mechanisms, which in turn would transfer to shorter warning times for the public.

Triboelectricity (Greek origin of 'tribo' is 'to rub') is well known from solid state physics as contact electrification. The associated charge exchange is a quantum effect resulting from bringing the Fermi energy of two originally isolated grains to the same energy level upon contact. With respect to the atmosphere we can say that winds and mixing dusts produce triboelectricity. Electrification of contacting grains charges them oppositely.

Lighter grains (mostly negatively charged, (Ette, 1971)) are blown upward by convection.

So we get charge separation and a vertical electric dipole moment $M(t)$. Rotating or swirling grains cause moment variation in time $\mathrm{d}M/\mathrm{d}t$ which in turn is the source of electromagnetic radiation. Also the rotating charged particles act like a current flowing in a solenoid generating a magnetic dipole moment. See Section 3 for a short discussion of ULF generating processes.

Measurements of dust devil electrical properties have shown that dust devils of 10 m width and 100–200 m height can develop DC electric fields exceeding several hundred volts/meter (Freier, 1960). The charge concentration in these dust devils is 10^6 e/cm^3 and is comparable to the charge concentration of the terrestrial ionosphere (Crozier, 1964). So triboelectricity is seen as the most probable source of charge separation for thunderstorms and also for dust devils. As the

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doi:10.1016/j.atmosres.2008.10.029

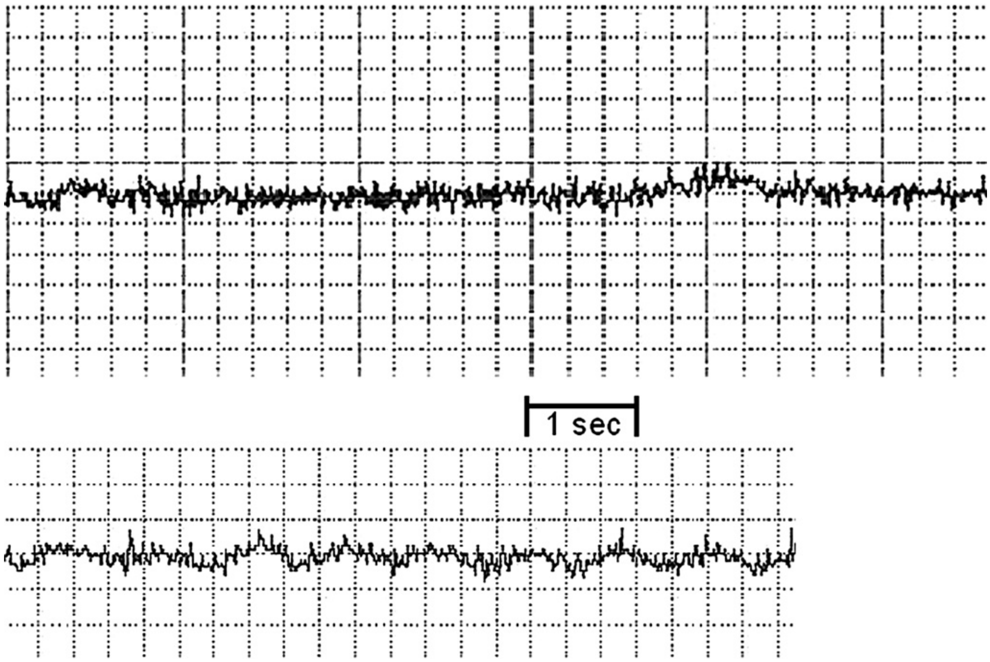

Fig. 1. ULF time signal from the non-rotating storm (upper trace) and after start of violent rotation with a single weak tornado (lower trace; ordinates in arbitrary units and abscissa time division is 1/3 s).

charged droplets, hailstones and/or dirt particles begin to rotate or move violently an electromagnetic signature is produced (cp. Section 3). Now the question is: can the signal be picked out in the mass of electromagnetic interference present in that environment? Fourier transform can be used to determine the effective frequency of this signature and to assess how severe or violent the rotation is. This allows the operator to see the storm scale become more concentrated.

2. Experimental setup and results

The signals discussed here have been received with a pan style antenna made of stainless steel to hinder corrosion. This is mounted on a PVC frame that is secured to the roof of the research vehicle. It is connected to an E-field receiver in the vehicle with a discharge tube and backup to prevent lightning damage. A profound difference is found in rotating and non-rotating super cells. A non-rotating storm produces nothing more than electrical noise on the monitor (Fig. 1, upper trace). The slight bump in the upper trace of Fig. 1 is generated by a passing semi-tractor truck. Vehicles and CB radios are determined to have a large effect on the E-field readings. The lower trace in Fig 1 shows the ULF signal near to violently rotating storm that is about 1/2 mile away from the receiving antenna that produced one weak tornado. The sampled storm occurred on May 31, 2008 just outside Guymon, Oklahoma. A brief tornado formed, but the storm was in the outer range for the weather service radars, so the radar resolution is very low and adds no understanding. Mobile Doppler vehicles were also collecting data, but were in the process of changing position when the tornado touched down, so no usable data was gathered. The signal persisted for a five minute interval. An oscillation can be seen with a period of about one second. The FFT analysis of the rotating signal (Fig. 2) with $2^{14}=16{,}384$ data points using a Hanning window exhibits a well defined spike around 1.2 Hz slightly increasing with shrinking funnel diameter. The sample rate was 240 per second, so the total FFT time period in this case is $2^{14}/240=68.3$ s. At the present time, this is the only case study on ULF emissions with our instrumentation. With more data it should be possible to determine an effective range to analyze the validity of this instrument for severe storm warning aid.

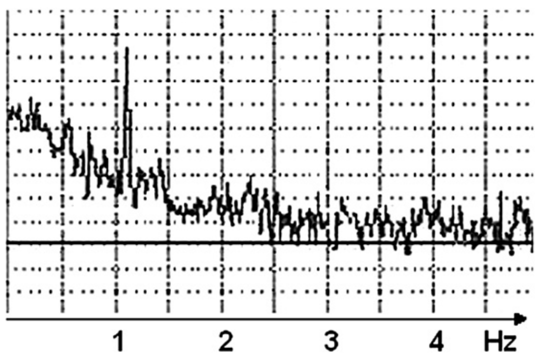

Fig. 2. Fourier analysis of the ULF signal during storm rotation. Displayed is the logarithmic power of the Fourier coefficients in arbitrary units vs. frequency showing a pronounced peak at 1.2 Hz.

3. Process models

Different process models for the generation of Ultra Low Frequency radiation from rotating storms spawning tornadoes have been discussed. According to (Farrell et al. 2004; Houser et al., 2003) triboelectrically charged particles moving in a vortex act like a current in a solenoid generating a magnetic moment which is proportional to the current, the number of 'turns' — i.e. the vertical extension of the helix and to the area of a 'turn'. So the magnetic moment varies with the volume of the funnel.

Radial as well as vertical oscillations of the funnel solenoid produce a periodically changing magnetic moment that in turn generates an electric field component orthogonal to the magnetic field and varying with the same time period (Jackson, 1962). In total an ULF signal with a frequency reflecting that of the vortex oscillation is emitted. This idea is consistent with the radial vibration model (Bedard et al., 2000) that was proposed to explain for infrasound signals in the 0.5 to 10 Hz range (Bowman and Bedard, 1971); (Bedard and Georges, 2000); (Bedard et al., 2000). According to this model parts of the rotating storm core and a fortiori tornado funnel cores perform radial oscillations with a fundamental frequency inversely proportional to the core radius, i.e. roughly: $f = 200/r$ (f in Hz, r in m). According to another idea vertical charge separation within the cone is a mechanism forming a vertical electric dipole moment pulsating with height variation of the funnel and so acting as an ULF antenna. In both cases – i.e. whether the origin of the radiation is an oscillating magnetic or electric dipole moment – its frequency reflects the natural period of funnel vibrations and so clearly indicates its onset and decay. Future measurements have to tell more detailed how ULF frequencies relate to the storm and vortex geometry.

4. Conclusion

Our case study shows and confirms that tornados can emit Ultra Low Frequency (ULF) radiation most probably caused by natural oscillations of the cone. Regarding the relative simplicity of building and operating ULF E-field receivers and the characteristically good propagation and penetration properties of ultra low frequency electromagnetic waves we are convinced of the potential of this method in a close cooperation with standard early warning systems. With more data it should be possible to determine an effective range to analyze the validity of this instrumentation for severe storm warning aid and get a better understanding for the generation mechanisms. This will provide an improvement over even a trained spotter as they cannot always get a clear picture of exactly what is happening in the area of rotation.

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