TERRESTRIAL NON-THERMAL CONTINUUM RADIATION: WIND OBSERVATIONS

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Abstract

We present new results on terrestrial non-thermal continuum radiation from WIND observations. Direction-finding analyses of the WIND data suggest that some continuum radiation may originate in the magnetopause. We generally find little evidence for polarization of the trapped component, except when banded structures are present indicating that WIND is close to the source region. We often observe significant circular polarization for the escaping component. We find that the location of the source of enhanced continuum radiation is different from the source of normal trapped continuum radiation.

1 Introduction

Terrestrial non-thermal continuum (NTC) radiation, also known as terrestrial myriametric radiation, is a common but relatively weak component of Earth's low-frequency electromagnetic spectrum [Gurnett and Shaw, 1973; Gurnett, 1975]. For a critique of the terminology as well as an insightful review see Kurth [1992]. Terrestrial NTC radiation consists of two distinct components. One component in the frequency range from ~5 kHz to 30–80 kHz is characterized by a smooth frequency spectrum. The upper frequency limit depends on conditions in the near Earth solar wind at the time of the measurement. This component represents radiation that is trapped within Earth's magnetospheric cavity. A second higher-frequency component is characterized by drifting narrow banded frequency structures and represents continuum radiation escaping from Earth's magnetospheric cavity [Kurth et al., 1981a]. In addition to the normal NTC radiation, an enhancement is often observed in the low-frequency trapped continuum that is usually correlated with the substorm AE index [Filbert and Kellogg, 1989]. NTC radiation is believed to originate in the plasmapause by a mode conversion of electrostatic waves near the upper hybrid resonance (UHR) [Gurnett, 1975]. Some NTC radiation may also originate in the magnetopause [Jones, 1987].

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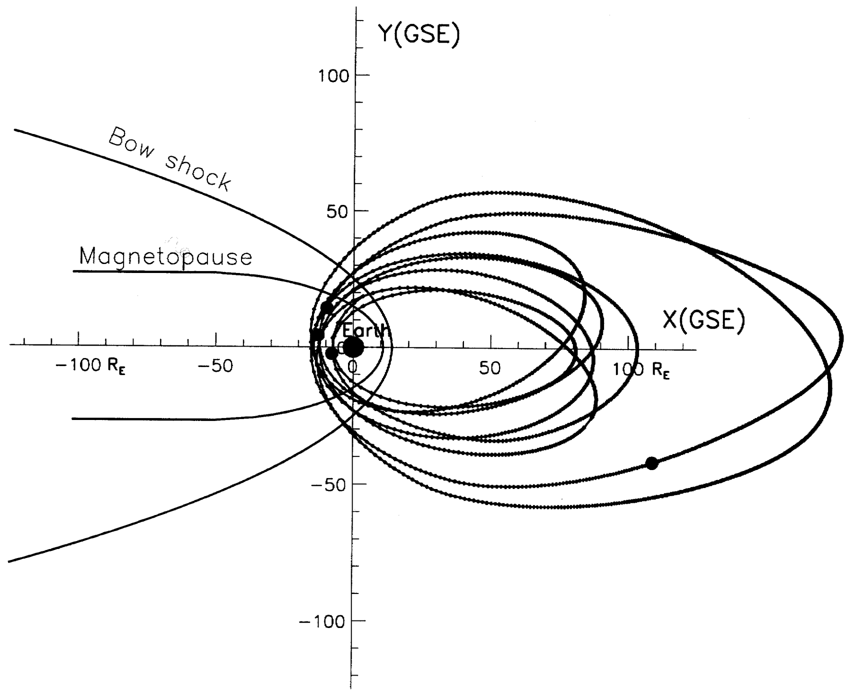

Figure 1: Orbit of WIND from August 2, 1995 to May 10, 1996.

Because of its unique orbit the WIND spacecraft was able to measure both trapped and escaping continuum from a number of different perspectives during numerous perigee passes. Figure 1 shows the near ecliptic plane orbit of WIND from August 2, 1995 to May 10, 1996. Note that during its perigee passes, WIND was never closer than 7.5 R_E to Earth, so it probably never passed through the continuum source region. The dots on the orbits in Figure 1 indicate the locations of WIND at the times of the examples of continuum emission that will be considered here. One of the examples occurred when WIND was in the solar wind outside the bow shock and the others occurred when WIND was inside the magnetospheric cavity. WIND observed NTC radiation at other times as well.

2 Trapped Continuum

Figure 2a shows an example of trapped continuum emission observed on November 28, 1995. The data shown are from the thermal noise receiver (TNR) of the WAVES experiment on WIND. The TNR measures the electric field strength over a total frequency range

Figure 2: (plate, next page) (a) Dynamic spectrum of the radio emission measured by WIND on November 28, 1995. The intense emission from 5–35 kHz is the trapped non-thermal continuum radiation. (b) Dynamic spectrum of the radio emission measured by WIND on August 20, 1995. Note the "banded" structure of the trapped continuum emission.

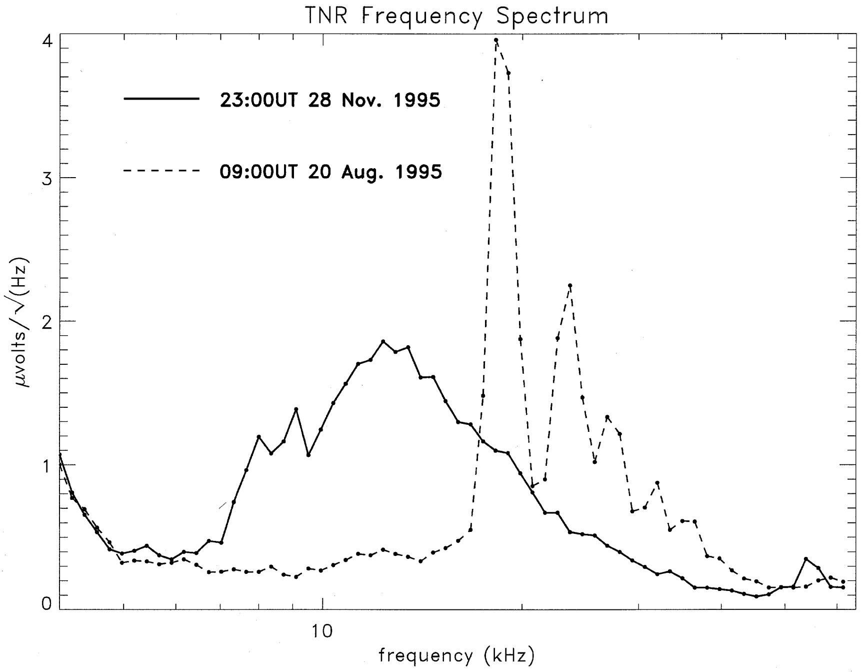

Figure 3: Frequency spectra for the measured NTC radiation on September 28, 1995 and August 20, 1995.

from 4 to 256 kHz. The electric sensors consist of a wire dipole antenna (50 m elements) in the spacecraft spin plane and a spin axis dipole (with elements presently extended 4.3 m). The data in Figure 2a are presented in the usual dynamic spectrum format, i.e., the observed radio intensity, indicated by the color scale, is plotted as a function of time along the horizontal axis and frequency along the vertical axis. The time spans 10 hours, from 14:00 to 24:00 UT, and the frequencies shown range from 4 to 64 kHz.

As WIND entered the magnetospheric cavity at about 17:00 UT, trapped continuum radiation was observed in the frequency range from ~5 to 25–35 kHz. At this time WIND was at (-7.9, 17.9, 1.4)R_E(GSE), ~19.6 R_E from Earth. Figure 3 shows that this continuum radiation, at 23:00 UT, exhibits a relatively smooth frequency spectrum from about 7 to 35 kHz. This is typical of the frequency spectra measured during this time period. The low-frequency cut off is determined by the plasma density at the spacecraft.

The direction-finding capabilities on WIND were used to determine the direction of arrival of this trapped continuum radiation observed as WIND entered into the magnetospheric cavity. The results at 40 kHz are shown in Figure 4. The lowest panel in Figure 4b shows the measured radio intensity from 16:00 to 24:00 UT. The middle panel shows the measured source azimuth. The dashed line indicates the direction to Earth. The upper panel in Figure 4b shows the source colatitude as measured from WIND. The source colatitude indicates that the NTC radiation source was near but slightly to the north of Earth's direction.

The source azimuth from 17:00 to ~19:30 UT was steady at 20° from the WIND-sun line. At ~20:00 UT the azimuth increased suddenly from 20° to 55°. The direction of arrival of the NTC radiation implied by the measured azimuths at the times indicated by the

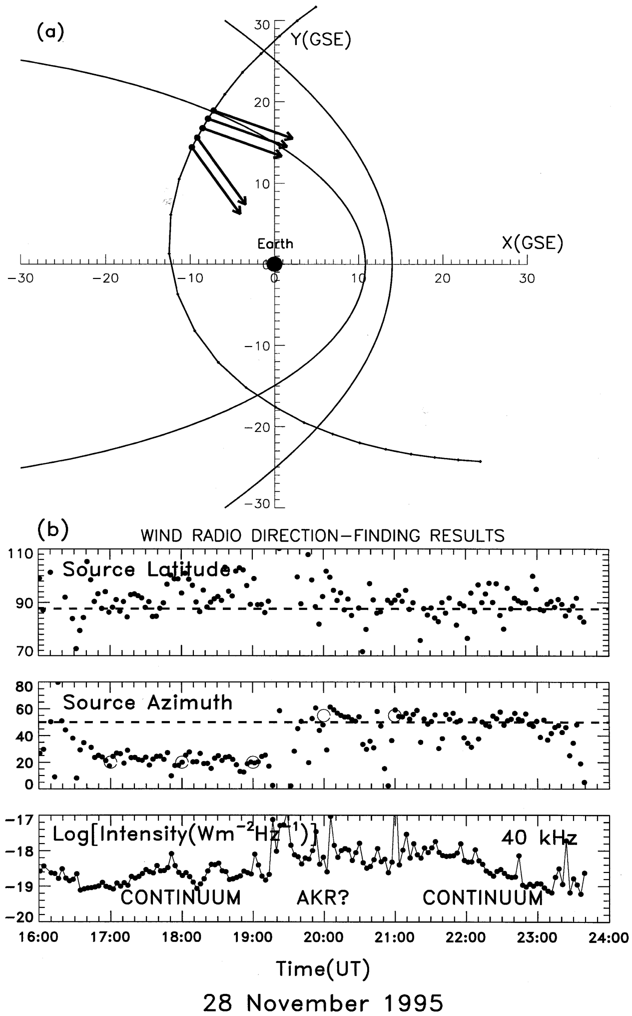

Figure 4: (a) Cartoon showing the orbit of WIND on November 28, 1995. The arrows indicate the measured direction of arrival of the NTC radiation as WIND entered the magnetospheric cavity. (b) Results of the WIND direction-finding analysis from 16:00 to 24:00 UT on November 28, 1995.

open circles in Figure 4b is shown by the arrows on the portion of the WIND orbit shown in Figure 4a. Typical magnetopause and bow shock boundaries are also indicated. As WIND entered the magnetospheric cavity from the magnetopause, the NTC radiation was observed to come from the direction of the magnetopause. As it entered more deeply into the magnetospheric cavity, the NTC radiation appeared to come from the direction

Figure 5: (plate, next page) (a) Dynamic spectrum of the radio emission measured by WIND on September 27–28, 1995. The escaping component consists of frequency drifting bands of emission above the $2f_p$ emission line. (b) Dynamic spectrum of the radio emission measured by WIND on May 10, 1996. Note the enhancement in the trapped continuum radiation at about 04:00 UT and again at about 15:00 UT.

of the plasmapause and/or Earth. These results indicate that at least some of the NTC radiation may originate in the magnetopause.

Of course, from these direction-finding results alone we can not rule out the possibility that this radiation originated at the plasmapause and was subsequently refracted by the magnetopause. However, in this latter scenario, we have to explain why radiation of equal intensity did not also reach WIND directly from the plasmapause, in which case we should expect the measured radio centroid of these two radiation sources, one direct, the other refracted, to lie somewhere between the two sources. To explain the observed azimuths, we would have to make the unlikely argument that the direct radiation was prevented from reaching WIND at this time. Thus the above observations provide a fairly convincing case that this initial (weaker) radiation originated in the magnetopause.

A second example of trapped continuum measured by WIND on August 20, 1995 is shown in Figure 2b. Here the time spans 6 hours, from 4:00 to 10:00 UT, and the frequency ranges from 4 to 64 kHz. WIND entered the magnetospheric cavity at about 23:00 UT on August 19 and exited the cavity at about 17:00 UT on August 20. This period is of interest because of the banded structure in the trapped NTC radiation that is observed between 07:00 and 10:00 UT and between ~17 and 40 kHz, suggesting that even trapped continuum often exhibits a banded structure. The frequency spectrum measured at 09:00 UT on August 20, 1995 is also shown in Figure 3. At this time WIND was closer to the plasmapause, (-7.9, -2.4, 0.5)R_E(GSE), 8.27 R_E from Earth (see Figure 1), but there is no evidence (intense Langmuir waves) to indicate that WIND was passing through the source region at this time. Nevertheless, this banded frequency structure suggests that WIND may have been very close to the NTC radiation source region.

In addition to measuring the source direction, the radio receivers on WIND also measure the complete polarization state, i.e., the four Stokes parameters, even when the signal is weak. Although we generally found no significant polarization associated with normal trapped continuum radiation, we did find a significant amount of circular polarization associated with this banded structure in the trapped continuum. The polarization was found to be predominantly left-hand circular.

3 Escaping Continuum

Figure 5a shows an example of escaping continuum radiation from September 27–28, 1995 when WIND was in the solar wind ~110 R_E upstream of the bow shock (see Figure 1). The local plasma frequency line at ~37 kHz and the second harmonic $2f_p$ emission from the electron foreshock region at ~74 kHz are clearly visible. Above the $2f_p$ emission line, weaker drifting banded structures, apparently drifting both upward and downward in frequency, represent escaping continuum emission. This emission was observed from ~19:00 UT on September 27 to ~01:30 UT on September 28 and from about 80 to 250 kHz. For another case that was observed on April 28, 1996, the escaping continuum emission was observed to frequencies greater than 400 kHz.

We found that the banded structures observed before ~21:00 UT were predominantly right-hand circularly polarized and those after ~21:00 UT were predominantly left-hand circularly polarized. The degree of circular polarization of the frequency bands tended to increase with increasing frequency.

4 Enhanced Continuum

Figure 5b shows an example of enhanced continuum radiation. This example from May 10, 1996 shows two clear enhancements at ~04:00 UT and again at ~15:00 UT. Both of these enhancements were associated with terrestrial substorms and with a sudden decrease in the CL electrojet index. At this time, WIND was in the magnetospheric cavity near perigee at 13.6 R_E.

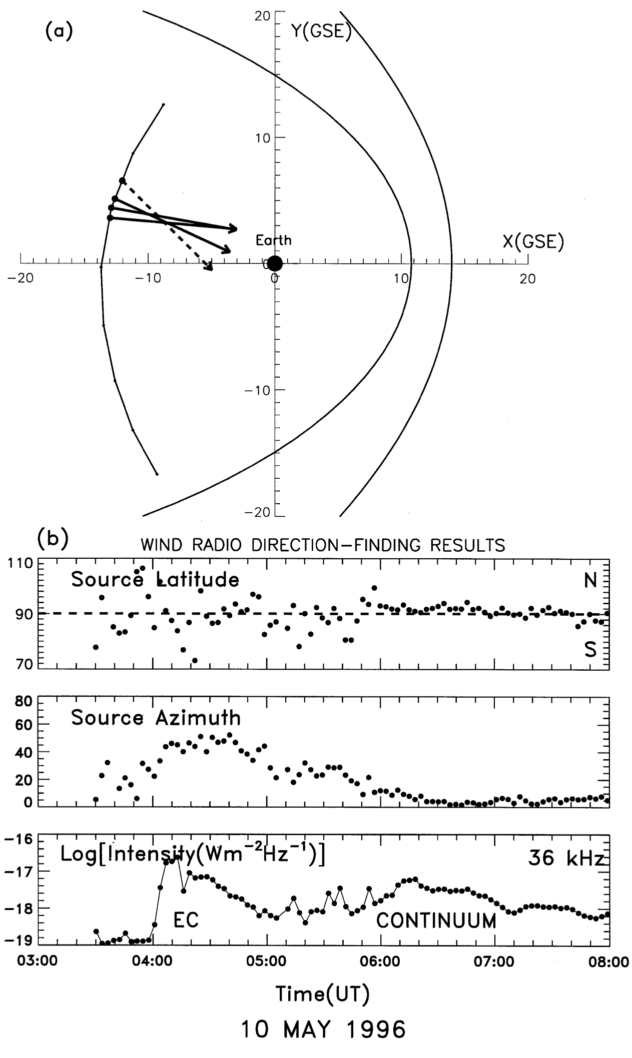

Figure 6: (a) Cartoon showing the orbit of WIND on May 10, 1996. The arrows indicate the measured direction of arrival of the continuum radiation from inside the magnetospheric cavity. (b) Results of the WIND direction-finding analysis from 03:00 to 08:00 UT on May 10, 1996.

Figure 6 shows the direction-finding analysis for the enhanced continuum emission at ~04:00 UT. As before, the bottom panel of Figure 6b shows the intensity of the radiation from 03:00 to 08:00 UT and the middle panel shows the azimuth angle. During this time period, there was a significant change in the measured source azimuth. At the time of the enhanced continuum at 04:00 UT the source azimuth was ~45° and was directed toward the dawn side of Earth as indicated by the dashed arrow in Figure 6a. Later as WIND observed the normal continuum emission between 06:00 and 08:00 UT, the azimuth decreases until by 6:20 UT it was ~5° and therefore was directed toward the dusk side of Earth. These measured azimuths indicate that the enhanced continuum source location was different from that of the normal trapped continuum source. The source colatitude was close to the colatitude of Earth as shown in the top panel of Figure 6b.

5 Conclusion

As these preliminary results illustrate, the WIND spacecraft, with its unique orbit and direction-finding and polarization capabilities, offers an opportunity to shed new light on some of the outstanding questions regarding non-thermal continuum radiation. The WIND observations may help to pinpoint exactly were on the plasmasphere the NTC radiation source lies. They hopefully will provide conclusive evidence for, and location of, any source or sources that may originate in the magnetospause. They may provide an understanding of the relationship between the enhanced and normal continuum radiation. Finally, the WIND observations may provide a complete polarization characterization of the NTC radiation source.