Unusual Observation of Chorus at L=2.6

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Abstract

On the 4th August 2010, Very Low Frequency (VLF) chorus was observed on Marion Island ($L = 2.6$). This is a very unusual occurrence as chorus is thought to be generated outside the plasmapause, which would only extend to such low L during periods of severe geomagnetic activity. A similar event was observed at Palmer Station, Antarctica ($L = 2.44$) during the Halloween storms of 2003. The 2003 event had a minimum Dst of around $-350\mathrm{nT}$, while the 2010 event occurred after a significantly smaller storm (Dst $\sim -70\mathrm{nT}$). A further difference is that the 2003 event occurred during solar maximum, while the 2010 event occurred during a period where the Sun had been unusually inactive. The spatial extent of the 2010 event is discussed, and data from a broadband VLF ground receiver is presented. Empirical plasmapause location models reveal that Marion Island was just within the plasmasphere at the time of the event. Preliminary analysis of low resolution VLF data from another high latitude station shows that a similar emission was observed at that site, but at a slightly later universal time, which indicates that the generation region was moving. This movement is likely linked to the eastward drift of electrons, and also possibly to the plasmapause relaxing to its quiet time position.

1. Introduction

Chorus is a Very Low Frequency (VLF) emission which occurs as a result of Doppler Shifted Cyclotron Resonance between whistler mode waves and hot electrons. The generation of chorus is confined to the low density region outside the plasmasphere, to which these electrons are typically confined [1]. Chorus has been associated with the injection of energetic electrons into the dusk-midnight sector of the magnetosphere, either from a geomagnetic storm or substorm. Interaction between whistler-mode waves and these energetic electrons can result in amplification of the waves, which are detected on the gound as chorus. The eastward drift of the electrons towards dawn accounts for the observation of chorus in the midnight and dawn sectors (00 - 09 LT), with the most intense chorus usually occurring around 06:00 LT [2]. [3] have shown that there is dispersion which occurs in the eastward drift of electrons. The most energetic particles drift fastest, with the drift speed decreasing as energy decreases. This azimuthal dispersion can result in the

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maximum frequency of the chorus increasing with time, as less and less energetic electrons enter the chorus generation region.

A large geomagnetic storm can cause a dramatic reconfiguration of the Earth's radiation belts, where the outer radiation belt becomes depleted and there is a concurrent increase in plasma density closer to Earth, such as during the Halloween storms of 2003 [4]. During the Halloween storms, [5] observed chorus at Palmer Station, Antarctica ($L = 2.44$). The observation of chorus at such low L is extremely rare, as the plasmapause is usually found at higher L. In fact, they showed using the IMAGE Extreme Ultra-Violet (EUV) sensor, that the geomagnetic activity had moved the plasmapause to a sufficiently low L for Palmer to be outside the plasmasphere at the time of observation.

On the 4th August 2010 (Day 216) a moderate geomagnetic storm occurred. A K_p of 6.67 and a minimum Dst of $-65\mathrm{nT}$ were experienced. This storm was not as severe as the Haloween storm, but GPS electron flux data shows that a depletion of high energy ($> 1\mathrm{MeV}$) electrons occurred above $L = 4$.

2. Marion Island Event

The chorus observed at Marion Island ($L = 2.6$) started at 03:00 UT and continued until 07:00 UT (06:00 - 10:00 LT). The emission started as risers between $2\mathrm{kHz}$ and $4\mathrm{kHz}$. As the emission evolved the upper limit of the frequency range increased to $5\mathrm{kHz}$ at approximately 04:15 UT. After this the emission changed to plasmaspheric hiss at 04:40 UT. During this time the upper limit of the emission again reduced to $4\mathrm{kHz}$ at 05:05 UT, and then at 05:20 UT the hiss disappeared, and chorus was again observed. The evolution of the emission is shown in Figure 1. Each vertical slice corresponds to one minute of data, recorded at 5 minute intervals.

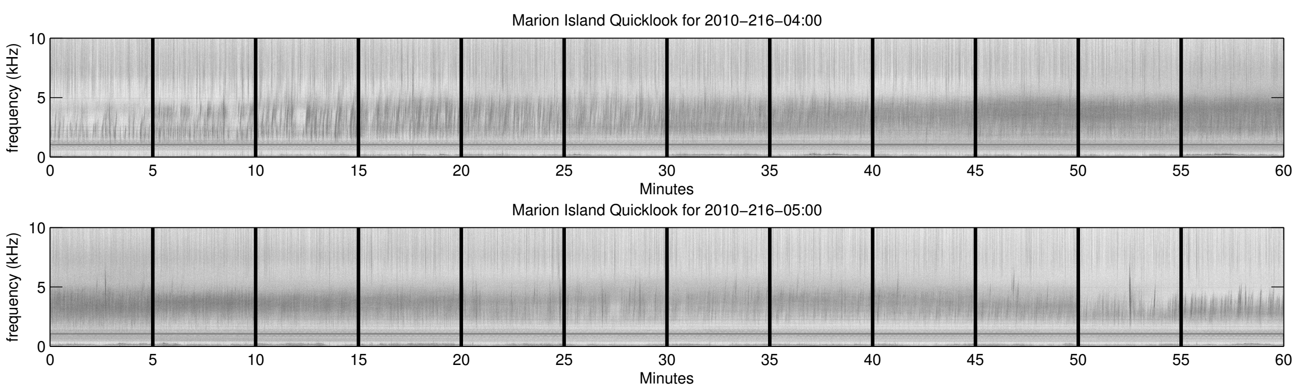

Figure 1: The evolution of the chorus at Marion Island from 04:00 – 06:00 UT on Day 216. Each vertical panel is 1 minute of data, and each panel is 5 minutes after the last

Chorus was also observed from 06:00 - 08:00 UT at the South African Antarctic base, SANAE IV (71.4°S 2.51°W, $L = 4.36$). The structure of this chorus from 06:00 to 07:00 UT is shown in Figure 2. One can see that this chorus has different spectral structure to that observed at Marion Island. The frequency range of the SANAE chorus is from $1\mathrm{kHz}$ to $2.5\mathrm{kHz}$.

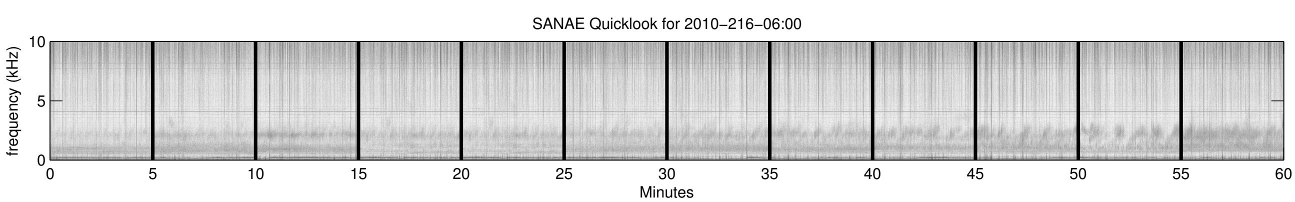

Figure 2: The evolution of the chorus at SANAE from 06:00 – 07:00 UT on Day 216. The data has the same structure as the Marion data.

Since chorus is generated outside the plasmasphere, one needs to establish whether Marion Island was indeed outside the plasmasphere during the event. There are various methods of inferring the location of the plasmapause, such as the observation of knee whistlers, direct observation of the plasma by satellite, or by the analysis of magnetic Field Line Resonances. However, there are also several models which have been developed for the determination of the location of the plasmapause. These models are generally based on geomagnetic indices, as the plasmasphere is usually compressed at higher levels of geomagnetic activity. A simple model, developed by Carpenter, is given by [6]

$$L_{pp} = 5.7 - 0.47K_{pmax} \tag{1}$$

where L_{pp} is the L-value of the plasmapause, and K_{pmax} is the maximal value of Kp obtained in the previous 12 hours. If we use (1), with $K_{pmax} = 6.67$, we determine the value of L_{pp} to be 2.56. This reveals that Marion Island was just outside the plasmasphere. (1) produces a spherical plasmapause, which is not accurate. It is well established that there is a bulge in the plasmapause on the dusk side of Earth [7], and (1) predicts the location of the dawn minimum most accurately. The bulge is reproduced by a series of models created by [8], one based on K_p, one on Dst and another on AE. We have employed the model based on K_p, which is given by

$$L_{pp} = -0.39(1 + (-0.34)\cos(\phi - 4.34))K_{pmax} + 5.6(1 + 0.12\cos(\phi - 0.7854)) \tag{2}$$

where ϕ is $2\pi(LT/24)$, and K_{pmax} is the maximal value of K_p obtained in the previous 36 hours. We plot the location in the equatorial plane of the plasmapause determined from (2) in Figure 3 in red. The radial axis has units of L, LT increases in an anti-clockwise direction and the blue circle represents the L-value of Marion Island ($L = 2.62$) mapped up to the geomagnetic equatorial plane. The two black radial lines signify the start (05:00 LT) and stop (09:00 LT) magnetic local times of the chorus at Marion Island.

3. Discussion

The observation of chorus (which is generated outside the plasmasphere) and plasmasheric hiss (which is generated inside) together indicate that Marion Island was close to the plasmapause during the emission. This is supported by the plot in Figure 3 from which one can see that Marion Island was close to the plasmapause during the event. Although a direct satellite observation (which was unavailable for the period of this emission) of the plasmapause location would be more definitive, the model does support the idea that Marion Island was close to the plasmapause.

Since the chorus observed at SANAE and Marion Island are distict one can conclude that they were generated at locations with significantly different L-values, as the maximum frequency of chorus elements tends to increase with decreasing L-value [2]. One can infer from the frequency of the chorus elements the maximum parallel energy of the resonating electrons (since $E \sim \Omega$ and $\Omega \sim 1/L^3$, and N, which is on the order of 10cm^{-3} outside the plasmasphere would not vary greatly with L), which shows that the energy of the resonating electrons is much higher at Marion Island. This also implies that during the brief period where the frequency of the chorus increased, there were more energetic electrons present in the generation region.

The fact that SANAE is some 3 magnetic local hours west, and 2 L south of Marion Island, and the conclusion that the generation regions of the chorus differ so significantly, indicate that the chorus generation region is drifting with time. The onset times of the emissions also shows that the generation region is moving eastwards, which is consistent with the usual eastward drift of electrons in the magnetosphere. It would be useful to see if chorus was observed at other stations, so that the drift pattern of the chorus generation region could be determined.

4. Conclusion

A moderate geomagnetic storm caused a dramatic reconfiguration of the Earth's radiation belts. This pushed the plasmapause as far inward as $L = 2.6$, which resulted in the observation of chorus at Marion Island. It seems that the chorus generation region was drifting eastwards with time.

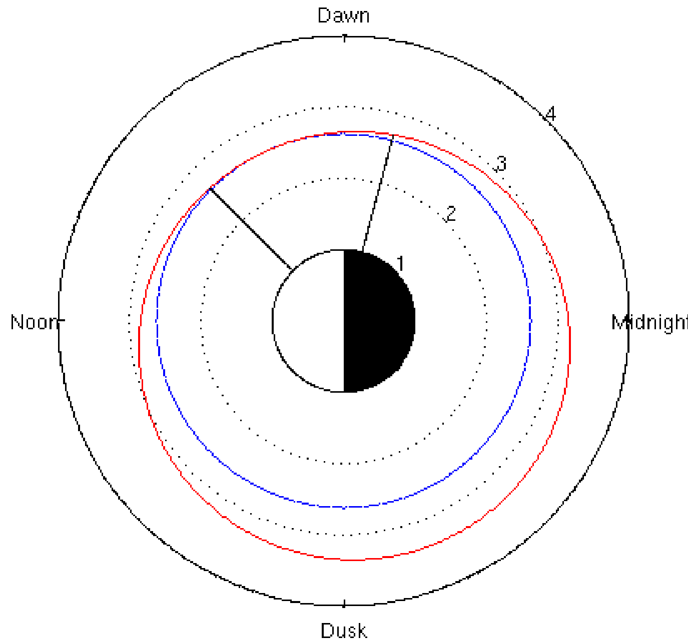

Figure 3: The location of the plasmapause in the geomagnetic equatorial plane obtained from (2) is plotted in red. The black radial lines signify the start and stop times of the emission at Marion Island. The radial axis has units of L. The L-value of Marion Island mapped back to the equatorial plane is plotted in blue.

5. References

[1] D. Summers, R. M. Thorne, and F. Xiao. Relativistic theory of wave-particle resonant diffusion with application to electron acceleration in the magnetosphere. *Journal of Geophysical Research*, 103, 1998:p. 20487.

[2] S. S. Sahzhin and M. Hayakawa. Magnetospheric chorus emissions: A review. *Planetary and Space Science*, 40(5), 1992:pp. 681–697.

[3] A. B. Collier and A. R. W. Hughes. Modelling substorm chorus events in terms of dispersive azimuthal drift. *Annales Geophysicae*, 22, 2004:pp. 4311–4327.

[4] D. N. Baker, S. G. Kanekal, X. Li, S. P. Monk, J. Goldstein, and J. L. Burch. An extreme distortion of the van allen belt arising from the halloween solar storm in 2003. *Nature*, 432, 2004:pp. 878–881.

[5] M. Spasojevic and U. S. Inan. Ground based VLF observations near L = 2 . 5 during the Halloween 2003 storm. *Geophysical Research Letters*, 32, 2005:pp. 2001–2004.

[6] D. L. Carpenter. Relations between the dawn minimum in the equatorial radius of the plasmapause and Dst, Kp, and local K at byrd station. *Journal of Geophysical Research*, 72(11), 1967:pp. 2967–2971.

[7] D. L. Carpenter and C. G. Park. On what ionospheric workers should know about the plasmapause-plasmasphere. *Reviews of Geophysics and Space Physics*, 11(1), 1973:pp. 133–154.

[8] M. B. Moldwin, L. Downward, H. K. Rassoul, R. Amin, and R. R. Anderson. A new model of the location of the plasmapause: CRRES results. *Journal of Geophysical Research*, 107(A11), 2002. doi:10:1029/2001JA009211.