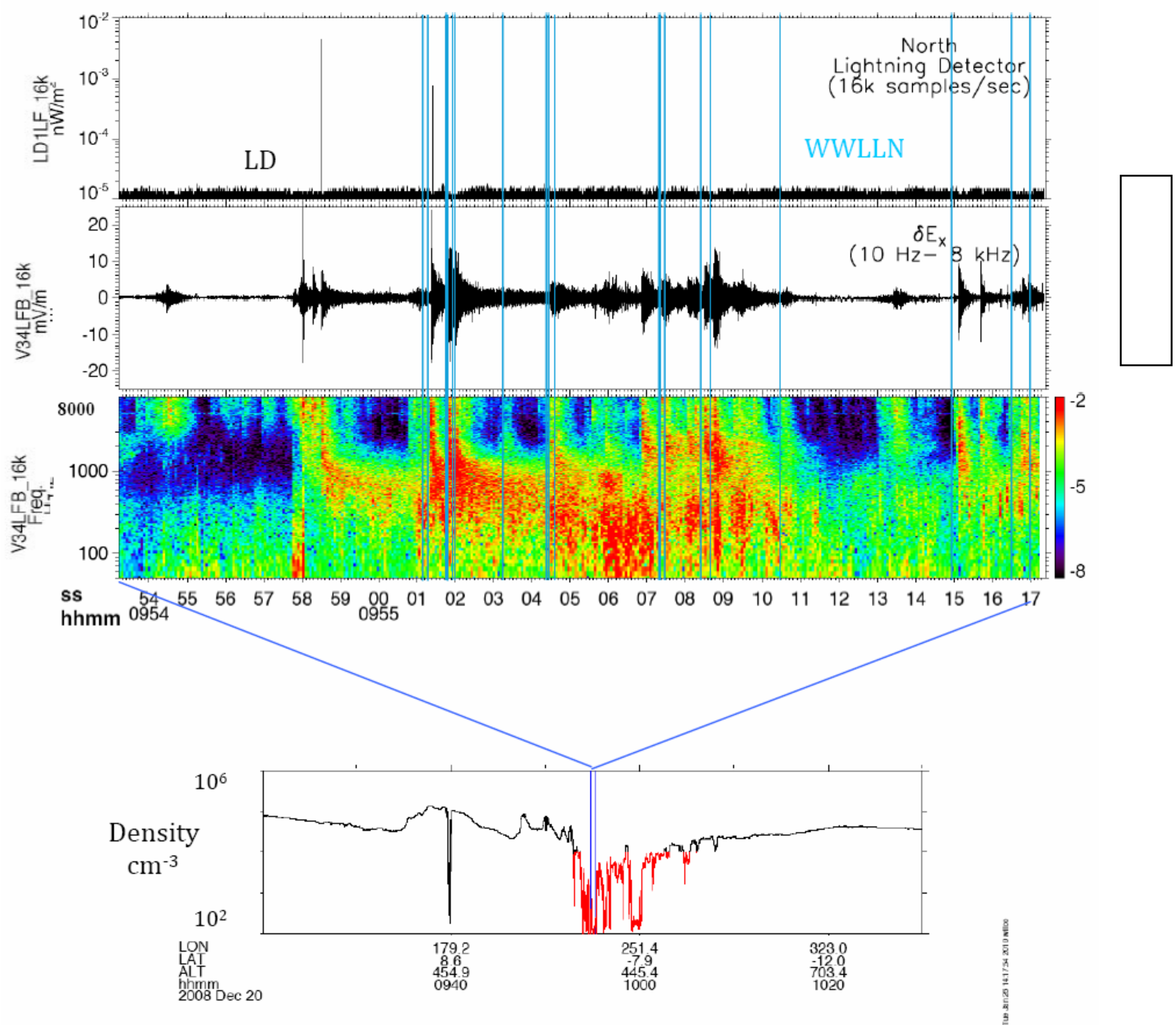
# Lightning Influence on Ionosphere and Magnetosphere Plasma

**Lightning Whistler Wave Characteristics**. Lightning is one of the most powerful natural phenomena, with energy release rates of which can be over $10^{11}$ Watts . We have known about ionospheric and magnetospheric VLF (Very Low Frequency) plasma whistler waves since the 1950s and 1960s (see Helliwell, 1965), and even about lightning-generated ion whistler waves since the early years of the space program (see Gurnett et al, 1965). The well developed theory of the coupling of electromagnetic waves from lightning into whistler mode electromagnetic plasma waves, and the subsequent propagation in the ionosphere and magnetosphere has allowed the use of whistlers to study magnetospheric dynamics. For instance, one can use whistler duct motion to estimate magnetospheric electric fields (Helliwell, 1965). For these studies, it was shown that the whistlers propagated in plasma ducts within the magnetosphere and then coupled back into an electromagnetic wave to reach the ground based receiver. It was assumed that this required some wave amplification process for significant magnetospheric propagation, so the lightning whistler waves were consider like 'test' waves which were amplified in the unstable plasma at the expense of free energy in the particle distributions (through strong coupling to the trapped electron populations, for instance.). These ducted whistler waves were relatively rarely detected (compared to the number of lightning strokes), and therefore our main knowledge of these waves required both a duct and magnetospheric amplification, in order for the waves to be detected on the ground, or to cause particle pitch angle scattering resulting in precipitation such as 'Trimpi' events (Carpenter et al, 1984).

**High Amplitude Lightning Waves Detected**. The first vector electric field experiment on ionospheric rockets, flown directly over thunderstorms, was reported in 1985 (Kelley et al, 1985) where it was reported that the measured, lightning-generated whistler mode waves were much larger in amplitude than predicted (e.g. Park and Dejnakarintra, 1973). Since then several rocket flights have been conducted over thunderstorms to study the upward coupling of lightning generated emissions into the ionosphere. Li (1993) showed that over 85% of lightning events within 1,500 km of a rocket subtract resulted in upward going whistler waves detected at the rocket. Helliwell (1965) had already shown that these waves, once coupled into a whistler mode plasma wave, would refract into the vertical because of the strongly horizontally stratified ionospheric electron density. Indeed, the whistler waveforms detected by Kelley et al (1985) and all subsequent such experiments, generally showed that the whistlers were very coherent, having only a single monofrequency at each moment of time, thus indicating that there had been only one path to the rocket - namely vertically straight up. So, the picture emerged that every lightning event generates strong electromagnetic wave in the earth-ionosphere waveguide which couples into whistler mode waves over large areas (at least 2500 km, see Holzworth et al, 1999.) Indeed, the low frequency part of these waves (between, say, 500 Hz and 2 kHz, say) can propagate right out to the magnetopause (Holzworth et al, 1999). The vast majority of these waves are found to be propagating as oblique whistlers, and are not necessarily captured in any magnetospheric plasma duct. Note that once inside the magnetosphere, these whistler mode waves do not easily couple back down to the ground, but rather can bounce around between the ionosphere and the magnetopause and become completely phase mixed as they combine with other such lightning generated VLF waves.

**Recent Advancements.** Results from the Demeter (cf. Berthelier et al, 2008) and C/NOFS (Holzworth et al, 2010) are providing new evidence for the importance of lightning to ionosphere and magnetosphere plasma processes. We have known since 1982 (Woodman and Kudeki, 1982) that lightning can trigger explosive ionospheric plasma density perturbations called Spread-F (where the ionospheric radar returns echos from multiple layers simultaneously with the same frequency.) Indeed the study of these ionospheric irregularities is a major reason for the C/NOFS satellite (De la Beaujardiere et al, 2004).

Now the importance of lightning to the irregularities is becoming stronger with results showing that lightning can be the largest electric




Electric field, optical lightning and density measurements on C/NOFS at 450 km Altitude. Blue lines are WWLLN lightning times. Electron density was < 100/cc in the event.

Field signal in deep density cavities associated with spread-F. This implies that lightning may be a more important stimulator of ionospheric irregularities than previously anticipated. Such perturbations are thought to be a primary driver for radio scintillation which affects radio communication and GPS signals as they pass through the ionosphere.

**Suggestion for Future Work**. Lightning has been shown to be much more important to ionospheric and magnetospheric phenomena than previously considered. Lightning is very powerful, happens all the time (40 to 80 strokes per second globally), penetrates the ionosphere with every stroke, and propagates as plasma wave energy all the way to the magnetopause. Yet traditionally, space scientists have not considered lightning to be energetically important to ionospheric and magnetospheric dynamics.

Consider that some of the strongest plasma waves in the magnetosphere are so called hiss waves (banded whistler mode emissions around a few kHz.) The plasmaspheric hiss is likely strongly linked to phase mixed, and multiple reflected lightning-generated whistler waves. Yet, we do not know what is the energy input into the magnetosphere from lightning. These waves may be the dominant source of pitch angle scattering and subsequent precipitation of energetic, trapped particles in the magnetosphere: i.e. a major loss mechanism for the radiation belts. These strong plasma waves may be important in other wave particle interactions such as reconnection at the magnetopause, or triggering of stimulated emissions in the magnetosphere and ionosphere.

**References**:


J.-J. Berthelier*, M. Malingre, R. Pfaff, E. Seran, R. Pottelette, J. Jasperse, J.-P. Lebreton and M. Parrot, Lightning-induced plasma turbulence and ion heating in equatorial ionospheric depletions, Nature Geoscience V.1, Feb 2008

de La Beaujardiere, et al, C. ,C/NOFS: a mission to forecast scintillations, *Journal of Atmospheric and Solar-Terrestrial Physics*, v 66, n 17, Nov. 2004, p 1573-91

Carpenter, D.L.; Inan, U.S.; Trimpi, M.L,. Helliwell, R.A.; Katsufrakis, J.P. Perturbations of subionospheric LF and MF signals due to whistler-induced electron precipitation bursts, *Journal of Geophysical Research*, v 89, n A11, 9857-62, 1 Nov. 1984

Gurnett, D. A., S. D. Shawhan, N. M. Brice and R. L. Smith, Ion Cyclotron Whistlers, J. Geophys. Res. 70(7), 1965.

Helliwell, R. A, Whistlers and related ionospheric phenomena, Stanford U. Press, 1965.

Holzworth, R. H., R. M. Winglee, B. H. Barnum and YaQi Li, Lightning whistler waves in the high-latitude magnetosphere, J. Geophys. Res., 104, 17369, 1999

Kelley, M. C, et al, Electrical Measurements in the Atmosphere and in the Ionosphere over an Active Thunderstorm, 1. Campaign Overview and initial ionospheric results, J. Geophys. Res., 90, 9815-23, 1985

Li, Ya Qi, Ionospheric VLF waves and optical phenomena over active thunderstorms, Ph.D. thesis, Univ. of Washington, 1993.

Park, C.G. Dejnakarintra, M., Penetration of thundercloud electric fields into the ionosphere and magnetosphere. I. Middle and subauroral latitudes *Jl of Geophysical Research*, v 78, n 28, p 6623-33, 1 Oct. 1973

Turman, B.N., Detection of Lightning Superbolts, J. Geophys. Res., 82, 2566, 1977.

Woodman, R. F. And E. Kudeki, A causal relationship between lightning and explosive spread F, Geophys. Res. Lett., v 11, n 12, p 1165-7, Dec. 1984