REMOTE SENSING SPACE WEATHER EVENTS THROUGH IONOSPHERIC RADIO : THE AARDDVARK NETWORK

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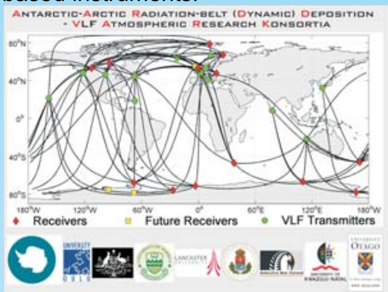
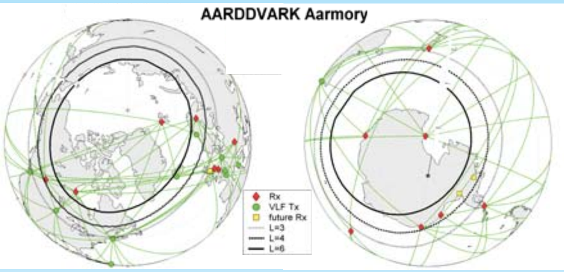
We have recently developed a global-scale network of sensors that monitors powerful VLF communications transmitters, measuring the precipitation of >100 keV electrons into the atmosphere from the inner and outer radiation belts. The network is well suited to providing observations complementary to other ground-based and space-based instruments.

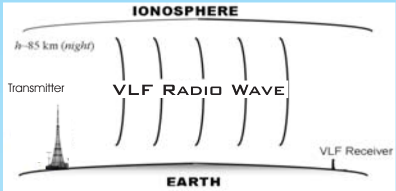


The **Antarctic-Arctic Radiation-belt (Dynamic) Deposition - VLF Atmospheric Research Konsortium (AARDDVARK)** is currently operating near-continuously in both hemispheres of the globe, with 14 receiving stations and nearly 100 different transmitter-receiver paths monitored.



Polar views of the coverage - our network monitors the state of the upper atmosphere along the green great circle paths between the observed VLF communications transmitters (Tx, ●) and the receiver sites (Rx,◆). Also shown are the contours of the magnetic latitude (*L*-shells).

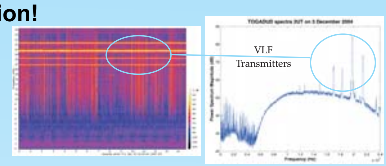
One of the few experimental techniques that can probe the altitude range from ~50-90 km uses very low-frequency (VLF) electromagnetic radiation, trapped between the lower ionosphere (~85 km) and the Earth; these signals can be received thousands of kilometres from the source.



Our AARDDVARK VLF receiver at Arrival Heights, Antarctica (located near Scott Base).

The nature of the received radio waves is determined by propagation inside the waveguide, with variability largely coming from changes at and below the lower ionosphere. **One source of this variability is the additional ionisation produced by impacting particle precipitation!**

We make use of powerful fixed-frequency VLF communication transmitters. These are ideal research tools, due to the known transmitter-receiver locations, very high radiated powers, and the fact these transmitters generally operate near constantly.



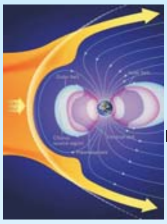
Example of a 15 second VLF spectra recorded in Dunedin, New Zealand. The manmade VLF communications transmitters are clear in the spectra (left) and power spectral

Actually, the majority of these transmitters are operated to communicate with military submarines - **but we don't care**, and nor do we need to! The signals are highly encrypted, we focus on the carrier.

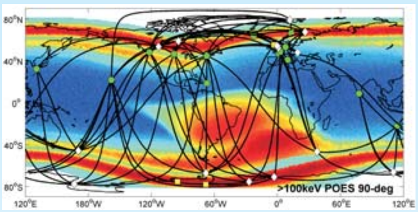
Reference: Clilverd, M A, C J Rodger, N R Thomson, J B Brundell, Th Ulich, J Lichtenberger, N Cobbett, A B Collier, F W Menk, A Seppälä, P T Verronen, and E Turunen, Remote sensing space weather events: the AARDDVARK network, Space Weather, 7, S04001, doi: doi:10.1029/2008SW000412, 2009.

Examples of what we are using the AARDDVARK network to study

For electrons with energies >100keV, the bulk of the precipitated energy is deposited into the lower ionosphere (~50-90 km), creating local increases in ionisation density detected by AARDDVARK.



The network of sensors is particularly well placed to study electron precipitation from the outer radiation belts.

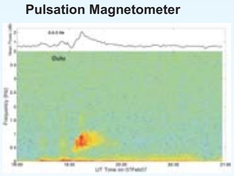


Trapped and quasi-trapped median >100 electron counts from the SEM-2 instrument on the Polar-orbiting Operational Environmental Satellite (POES) NOAA-18 observed across the entire of 2008.

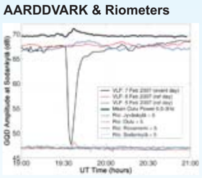
1. Relativistic Electron Precipitation from EMIC waves

For many years it has been predicted that EMIC waves should lead to precipitation of relativistic electrons. This has recently been confirmed through AARDDVARK observations undertaken during weakly disturbed geomagnetic conditions, where a one-to-one correspondence between EMIC wave activity and large VLF amplitude changes have been observed without a corresponding riometer response. Modelling shows the VLF and riometer responses are consistent with a monoenergetic beam of 1.5 MeV electrons with flux 500 el. $cm^{-2}s^{-1}str^{-1}keV^{-1}$.

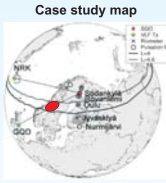
Pulsation Magnetometer



AARDDVARK & Riometers



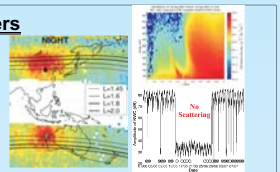
Case study map



Reference: Rodger, C J, T Raita, M A Clilverd, A Seppälä, S Dietrich, N R Thomson, and Th Ulich, Observations of relativistic electron precipitation from the radiation belts driven by EMIC Waves, Geophys. Res. Lett., 35, L16106, doi:10.1029/2008GL034804, 2008.

2. Electron Precipitation Driven by VLF Transmitters

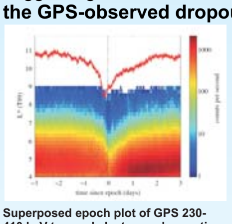
DEMETER data shows that the large VLF transmitter operating in Australia (NWC) regularly scatters electrons into the loss cone during the local night. When NWC is broadcasting, DEMETER sees enhanced scattering >80% of the time. When NWC is not broadcasting, the scattering feature disappears.



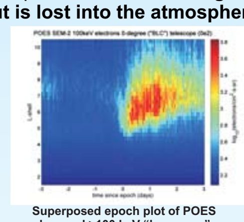
Reference: Gamble, R J, C J Rodger, M A Clilverd, J A Sauvaud, N R Thomson, S L Stewart, R J McCormick, M Parrot, and J-J Berthelier, Radiation belt electron precipitation by manmade VLF transmissions, J. Geophys. Res., 113, A10211, doi: 10.1029/2008JA013369, 2008.

3. GPS observed "sudden" at solar wind stream interfaces.

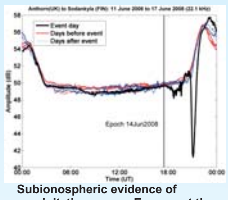
Superposed epoch analysis of ~300keV trapped electron data observed by GPS satellites show that there is a sudden dropout in fluxes at the time of Solar wind stream interfaces [*Morley et al.*, 2010]. Recent work with the POES satellites has confirmed that there is an increase in bounce loss cone fluxes at these times, suggesting loss into the atmosphere. **We are working to quantify what fraction of the GPS-observed dropout is lost into the atmosphere.**



Superposed epoch plot of GPS 230-410 keV trapped electrons observations from Morley et al. [Fig. 2, 2010].



Superposed epoch plot of POES observed >100 keV "loss cone" electrons for the Morley epochs.



Subionospheric evidence of precipitation across Europe, at the time of one of the Morley epochs.

Reference: Morley, S K, R H W Friedel, E L Spanswick, G D Reeves, J T Steinberg, J Koller, T Cayton, E Noveroske, Dropouts of the outer electron radiation belt in response to solar wind stream interfaces: global positioning system observations, *Proc. R. Soc. A*, doi:10.1098/rspa.2010.0078, 2010.

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AARDDVARK Website: **www.physics.otago.ac.nz/space/AARDDVARK_homepage.htm**