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Combined space and ground based observations of electron precipitation during a substorm [K060]

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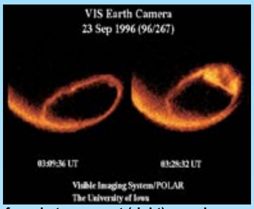
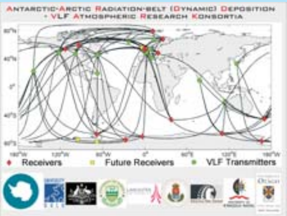
"Substorms" are brief (2-3 hour), yet common, disturbances in the space around the Earth which occur when variations in the solar wind cause a mini or partial storm. The localised merging of the magnetic field lines of the solar wind with those of the Earth lead the transfer of energy and particles from the solar wind into the Earth's magnetosphere and ultimately into the atmosphere. Observations from ground-based magnetometers in Scandinavia indicate that one polar longitude region experiences a mean substorm rate of 500 per year.

While generally recognised through auroral signatures or magnetic field disturbances, we have previously shown that substorms are associated with intense electron precipitation from space into the atmosphere, occurring over a large spatial region.



Example of a substorm event (right) seen in auroral images taken from an Earth-orbiting satellite).

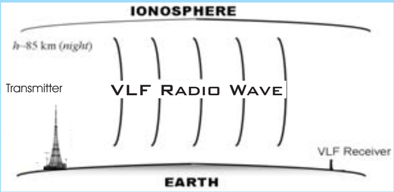
Here we combine observations from two Antarctic locations, one satellite, and one sub-Antarctic island to examine the energetic electron precipitation occurring during a substorm on 28 May 2010.

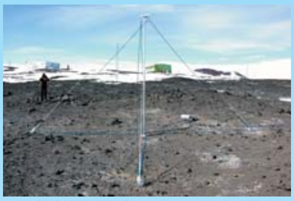


The **Antarctic-Arctic Radiation-belt (Dynamic) Deposition - VLF Atmospheric Research Konsortium (AARDDVARK)** is currently operating near-continuously in both hemispheres of the globe, with 14 receiving stations currently operational, and several new polar stations on-line soon.

AARDDVARK network 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,◆).

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.

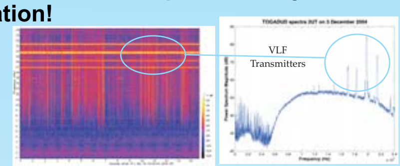




Our AARDDVARK VLF receiver at Arrival Heights.

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.



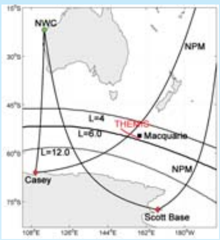
Example of a 15 second VLF spectra recorded in Dunedin, New Zealand. The manmade VLF communications transmitters are clear in the spectra (left) and power spectral density (right).

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.

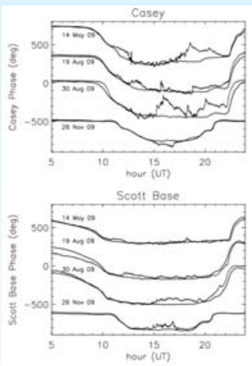
Reference: Clilverd, M A, C J Rodger, N R Thomson, J B Brundell, Th Ulich, J Lichtenberger, N Cobbett, A B Collier, F W Menk, A Seppälä, P T Verronen, and E Turunen, Remote sensing space weather events: the AARDDVARK network, Space Weather, 7, S04001, doi: doi:10.1029/2008SW000412, 2009.

Experimental Configuration

The figure to the right shows the experimental configuration. This includes map of the subionospheric VLF propagation paths from the NWC and NPM transmitters (marked by green circles) to the Casey and Scott Base receivers in Antarctica (red diamonds). Contours of constant magnetic latitude are show by the *L*-shellsfor *L*=4, 6, and 12 (blue lines).



The locations of the southern hemisphere footprint of the THEMIS-E satellite during the substorm events studied here are included (red line). Finally an AAD riometer instrument on Macquarie Island (solid square), which we use for additional ground-based observations, is also indicated.



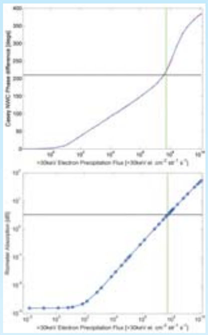
Substorm produced phase changes

Three examples of the NWC nighttime phase variation at Casey & Scott Base. The solid lines represent the nightime data on 28 June 2009, 30 August 2009, and 28 May 2010 as labelled. The dotted lines represent the typical undisturbed behaviour of the phase, taken from geomagnetically quiet days close to the event days.

At 17 UT on 28 June 2009, 16 UT on 30 August 2009, and 12 UT on 28 May 2010 phase increases of ~ 200°are observed at Casey, with corresponding changes of ~40° at Scott Base. The enhancement of phase during these events typically lasts 1-3 hours, with the phase returning to near undisturbed values by the end of the events. These changes are caused by substorm driven precipitation.

Modelling the phase changes

To determine the magnitude of the precipitation into the atmosphere, we undertake modelling of the VLF propagation in order to produce a 200° phase change on the NWC-Casey path during the 28 May 2010 event.



At the same time we constrain our modelling by the need to reproduce the response of the Macquarie Island riometer (an absorption increase of 3.2 dB) observed at the same time. Our modelling is also constrained by the energy spectra observed by the THEMIS spacecraft, which was ideally positioned during this substorm. The precipitation flux level identified by the vertical dashed line (>30 keV electron flux of 5.6×10^{7} el.cm^{-2} sr^{-1} s^{-1}).

Putting this into context

- To date there have been very few measurements of the energetic (>10 keV) electron precipitation during substorms - most observations have focussed on the vastly softer electrons which lead to the auroral displays.
- The precipitation flux levels identified here are <u>very</u> large in comparison with those seen coming from the radiation belt during geomagnetic, being ~10-100 times greater than a big storm.
- While short-lived, this level of precipitation flux is large enough to cause significant (100-1000 times) increases in atmospheric chemical species at 60-70km (e.g.,NOx) which drive O_3 losses.

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

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