



Remote sensing space weather events through ionospheric radio: the AARDDVARK network

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Drivers of Ionisation in the Middle Atmosphere

In the lower ionosphere/middle atmosphere there are multiple drivers leading to changes in ionisation levels. An understanding of these will allow us to describe the coupling of processes which may start on the Sun and link all the way into the Earth's atmosphere.

•The Sun

Space Weather drivers

- •Solar flares
- •Solar Proton Events
- •Radiation belt electron precipitation
 - -Dynamics during geomagnetic storms
 - -Wave-particle interactions driving precipitation
 - •Chorus waves
 - •Plasmaspheric hiss waves
 - •Ion-cyclotron waves (EMIC)
 - •Magnetosonic waves
 - •Man-made transmitter waves



Particle access to the upper atmosphere

Losses: The outer radiation belt deposits energy into the polar atmosphere in both the Antarctic and Antarctic (primarily due to waveparticle interactions with ULF & VLF waves).





Radiation Belt Precipitation



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How can we observe these drivers?

From space, obviously! But from the ground, instruments in the polar regions are best, and the altitudes define the energy range primarily focused upon, as the atmosphere acts like an energy spectrometer.

EXAMPLES:

- Riometers
 - Point measurement
 - -30-200 keV el., ~85 km alt
 - -1 s resolution
- Ionosondes
 - Point measurement, high altitudes (>80 km),
 - $-\sim 1$ min resolution
- VLF Radiowaves
 - spatially integrated measurement
 - 50 keV >2 MeV
 - 30-90 km altitudes
 - high time resolution (0.05 s)





Radio transmissions at Very Low Frequencies (VLF) largely trapped between the conducting ground (or sea) and the lower part of the ionosphere (70-90 km), forming the Earth-ionosphere waveguide.

Changes in the ionosphere cause changes in the received signal. There is very low attenuation in this frequency range, such that transmissions can propagate for many 1000km's - long range sensing of the upper atmosphere!

Our AARDDVARK



An aarmory of AARDDVARKs. This map shows our existing network of subionospheric energetic precipitation monitors.

MORE INFORMATION: www.physics.otago.ac.nz\space\AARDDVARK_homepage.htm







Examples of recent AARDDVARK contributions to Space Weather Topics

Relativistic Microbursts/Chorus driven wave-particle interactions Dietrich, S. L., et al., *J. Geophys. Res.*, 115, A12240, doi:10.1029/2010JA015777, 2010.

Plasmaspheric Hiss driven wave-particle interactions Rodger, C. J., et al., *J. Geophys. Res.*, 115, A11320, doi:10.1029/2010JA015599, 2010.

Long Term measurements of radiation belt electron precipitation Clilverd, M. A., et al., *J. Geophys. Res.*, 115, A12304, doi:10.1029/2010JA015638, 2010

Precipitation during recurrent solar-wind stream driven activity Clilverd, M. A., et al., *J. Geophys. Res.*, 115, A0832, doi:10.1029/2009JA015204, 2010.

Wave-particle interactions driven by manmade VLF transmissions Rodger, C. J., et al., *J. Geophys. Res.*, 115, A12208, doi:10.1029/2010JA015880, 2010

Characterising the "ambient" D-region Thomson, N. R., et al., *J. Geophys. Res.*, 116, A03310, doi:10.1029/2010JA016248, 2011.

Substorms

Clilverd, M. A., et al., J. Geophys. Res., 113, A10311, doi: 10.1029/2008JA013220, 2008.

Neutral Atmospheric change driven by energetic electron precipitation Clilverd, M. A., et al., *J. Geophys. Res.*, 114, A04305, doi:10.1029/2008JA013472, 2009.





I promised we were trying to do this during the Chicago URSI in 2008!

The Future?

Over the next few years we plan to determine long term particle



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01-Jul-2005

01-Apr-2005 01-Jan-2005

0

4

8

12



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1. Long term observations of Energetic Electron Precipitation from the Radiation Belts

We are working to determine the long term particle precipitation fluxes into the atmosphere along some of our paths, providing a new near-continuous space weather monitor and support for space missions (RBSP, DSX, BARREL, ERG, **RESONANCE**).



precipitation.

This appears to work, we now moving towards validation, establishing uncertainties and improving our modelling.

Clilverd, M A, C J Rodger, R J Gamble, Th Ulich, T Raita, A Seppälä, J C Green, N R Thomson, J A Sauvaud, and M Parrot, Ground-based estimates of outer radiation belt energetic electron precipitation fluxes into the atmosphere, J. Geophys. Res., 115, A12304, doi:10.1029/2010JA015638_2010



Schematic of Modelling Approach









Resulting Precipitation Fluxes from SGO



60 Ap 40 28 205 190 195 200



150 days of precipitation flux measurements from the AARDDVARK receiver at SGO. Note 3 order of magnitude dynamic range!

All MLTs show increased precipitation after a Kp=6+ geomagnetic storm on 9 July 2005.

Largest fluxes in midnight magnetic sector (22-06 MLT), then morning side (0330-1130 MLT) finally afternoon Evidence of varying precipitation sector (1130-expected, but good to see evidence of MLT) has abs













2. Wave-particle interactions driven by manmade VLF transmissions

Previous work has shown that manmade VLF transmitters can produce strong loss signatures (driving inner belt electrons into the drift loss cone).

However, there has been confusion as to the relative role of ducted waves (originally broadcast from the transmitters) and nonducted waves.



Rodger, C J, B R Carson, S A Cummer, R J Gamble, M A Clilverd, J-A Sauvaud, M Parrot, J C Green, and J-J Berthelier, Contrasting the efficiency of radiation belt losses caused by ducted and non-ducted whistler mode waves from ground-based transmitters, J. Geophys. Res., 115, A12208, doi:10.1029/2010JA015880, 2010







FROM DUNEDIN SUBIONOSPHERIC DATA1 August-11 December 2006NWC onNPM on1 August-11 December 2007NWC offNPM on



We can therefore look for the signature of ducted transmissions (NWC) and non-ducted (NPM) over this time period!





NWC on NPM on

Strong scattering signature seen starting at NWC in the "night" orbits (5LT), but not the day ones (17LT). This is as expected, of course.

RATIO plot (day/night) suggests the enhancement peaks at the green star (L=1.8) rather than the red star (L=2).

Suggests some disagreement with non-ducted model, but the location is consistent with scattering from ducted propagation.

Is NPM doing anything? Hard to tell, might be masked!



NWC off NPM on

2.5

1.5

0.5

-0.5

0

3 2.5

2

1.5

0.5

-0.5

0

POES N-15 >100 keV

₀(counts s ⁻¹)]

OES N-15 >100 keV [log

10 (South/North)]

Ratio [log 1

-1.5

0.5

0

2

RATIO plot (day/night) fails to show any evidence of an NPM produced enhancement in DLC electron fluxes.

While modelling indicates these fluxes will be 1-7 times weaker than NWC fluxes in L=1.7-1.9), in practise any scattering which is being produced by NPM is at least 50 times weaker.

At this point we do not have conclusive evidence of any non-ducted scattering by NPM, and evidence for only weak occasional ducted scattering.



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3. Radiation Belt drop-outs during High Speed Solar Wind <u>Streams</u>

Recently Morley et al. [2010] used particle monitors on the GPS spacecraft to examine 67 examples where the highenergy electron flux in the radiation belts which surround the Earth "dropped out".

They showed that the dropout was very fast, and suggested one possibility to explain the loss was precipitation to the atmosphere.







May 2010







In-situ observations of the dropouts

However, if one examines Bounce Loss Cone (BLC) observations undertaken from LEO spacecraft, and undertakes a superposed epoch analysis on the same Morley events, we find a lot of loss has already happened before any precipitation starts showing up.

Loss caused by magnetopause shadowing (initially) with atmospheric precipitation playing a role later?

Work in progress! Aaron Hendry (University of Otago Honours student) Summer project Jan-February 2011









Determine the magnitude of the precipitated fraction

Even if atmospheric precipitation is not the dominant loss mechanism, we need to determine its magnitude to describe the dropout <u>and</u> to describe the atmospheric impact of these common, repeatable events.

This is current student project being undertaken at Otago in collaboration with Steve Morley (LANL) and Mark Clilverd (BAS).





Work in progress! Aaron Hendry (University of Otago Honours student) current project.





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Plasmaspheric Hiss driven wave-particle interactions

All AARDDVARK publications, both in press and published are available from the AARDDVARK webpage

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Thankyou!

Are there any questions?

http://www.physics.otago.ac.nz/space/AARDDVARK_homepage.htm