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

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URSI GA Istanbul 2011
Abstract #1382, Session H11.4
09:00 Saturday 20 August 2011
Topkapi B

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.

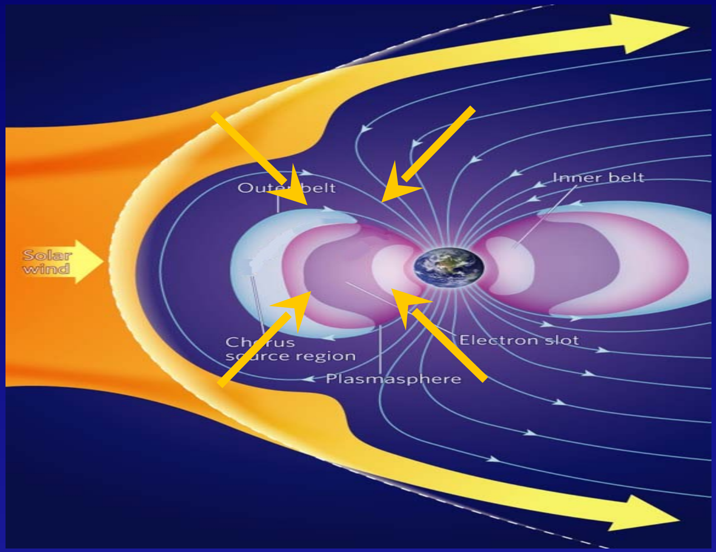
- The Sun

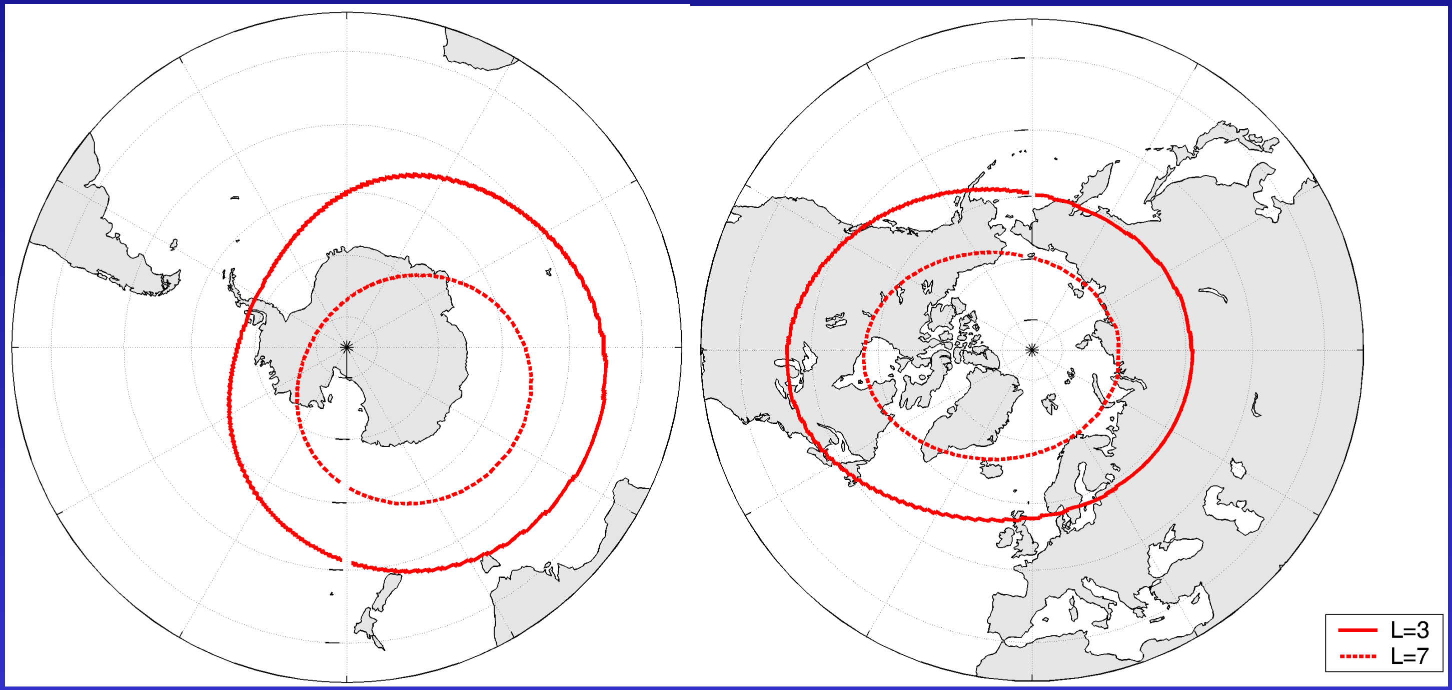
Space Weather drivers

- 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 wave-particle interactions with ULF & VLF waves).





Radiation Belt Precipitation

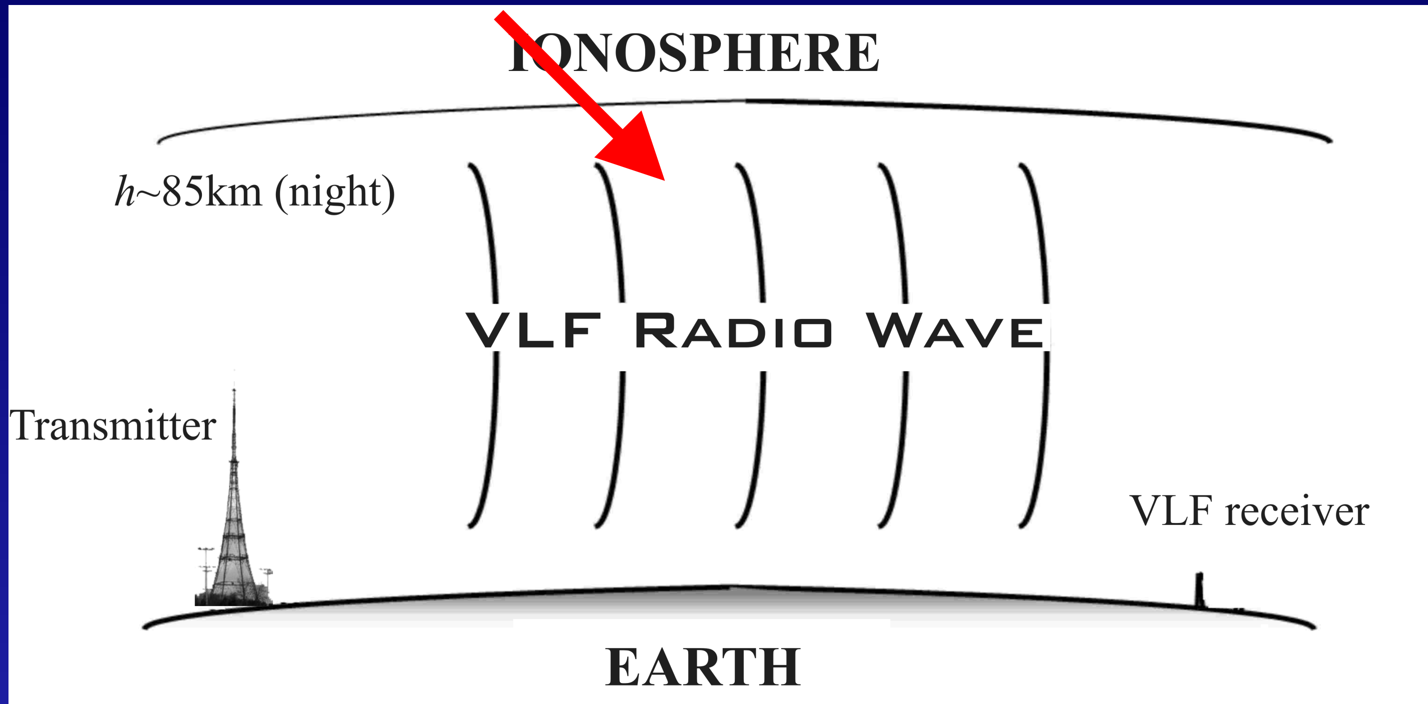
How can we observe these drivers?

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),
  - ~1 min resolution
- **VLF Radiowaves**
  - spatially integrated measurement
  - 50 keV - >2 MeV
  - 30-90 km altitudes
  - high time resolution (0.05 s)

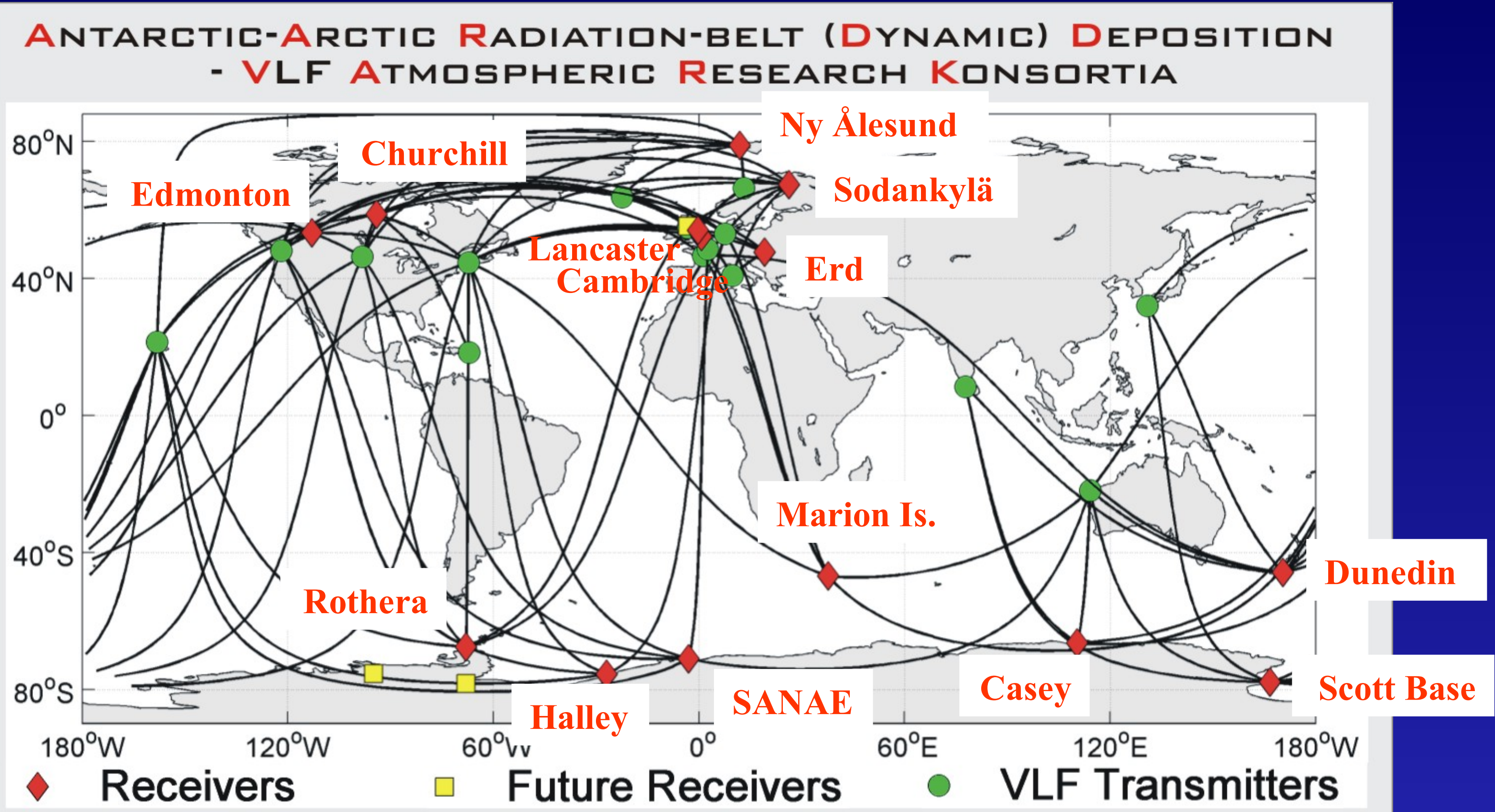
Subionospheric Radio Wave Propagation



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!

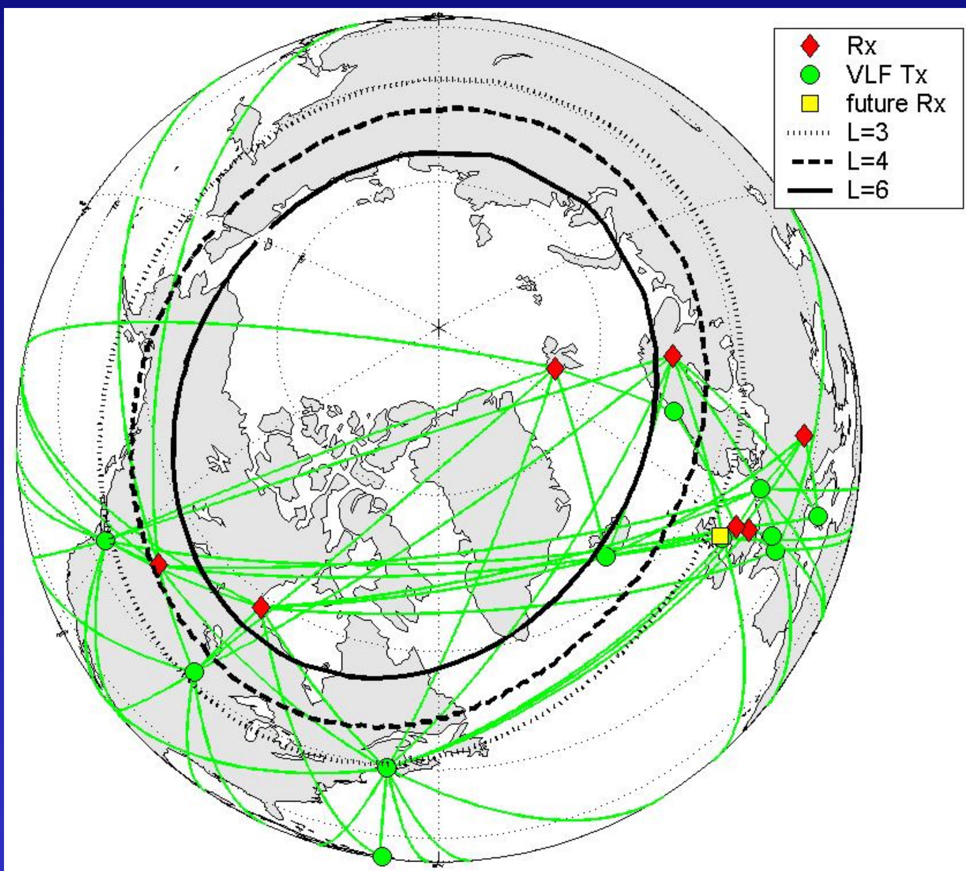
Our AARDDVARK

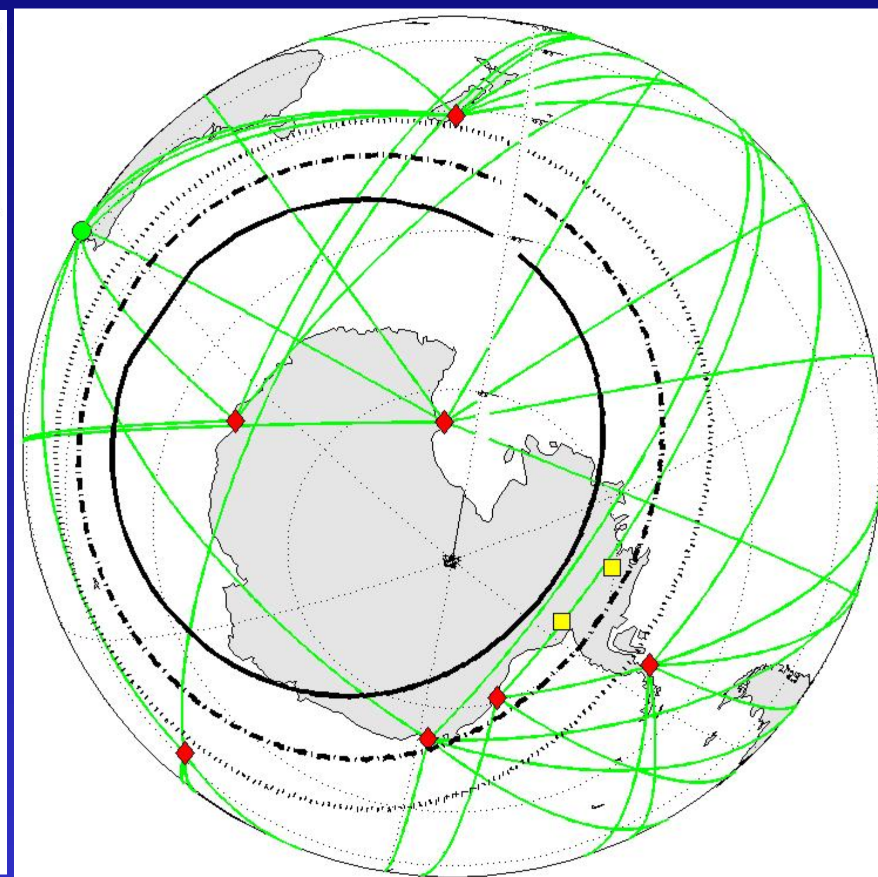


An aarmory of AARDDVARKs. This map shows our existing network of sub-ionospheric energetic precipitation monitors.

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

Antarctic-Arctic Radiation-belt (Dynamic) Deposition - VLF Atmospheric Research Konsortia





Examples of recent AARDDVARK contributions to Space Weather Topics

Relativistic Microbursts/Chorus driven wave-particle interactions

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Plasmaspheric Hiss driven wave-particle interactions

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1.

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.

2.

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

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Substorms

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Neutral Atmospheric change driven by energetic electron precipitation

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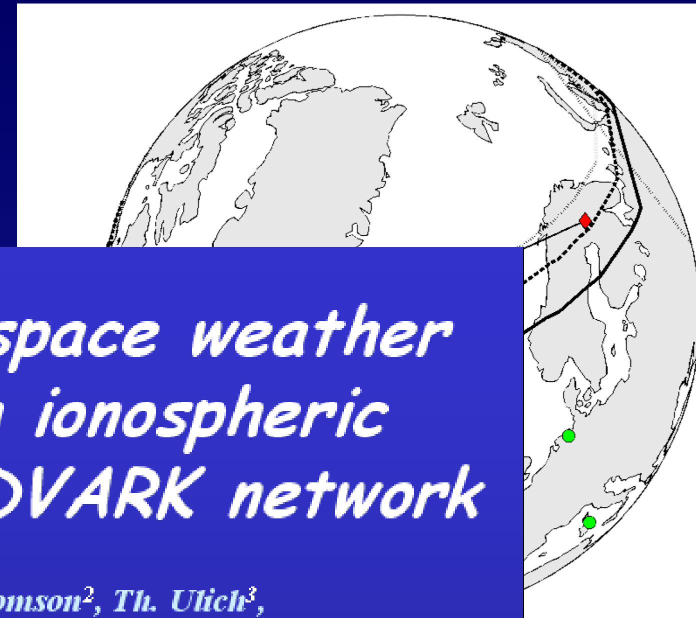
The Future?

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



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

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2. Physics Department, University of Otago, Dunedin, NEW ZEALAND.
3. Sodankylä Geophysical Observatory, Sodankylä, FINLAND
4. Space Research Group, Department of Geophysics, Eötvös University, Budapest, HUNGARY.
5. Hermanus Magnetic Observatory, Hermanus, SOUTH AFRICA

URSI GA Chicago 2008
Abstract #1382, Session H03.5
16:00 Wednesday 13 August 2008
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I promised we were trying to do this during the Chicago URSI in 2008!

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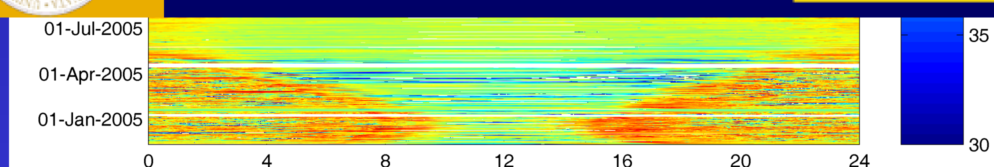
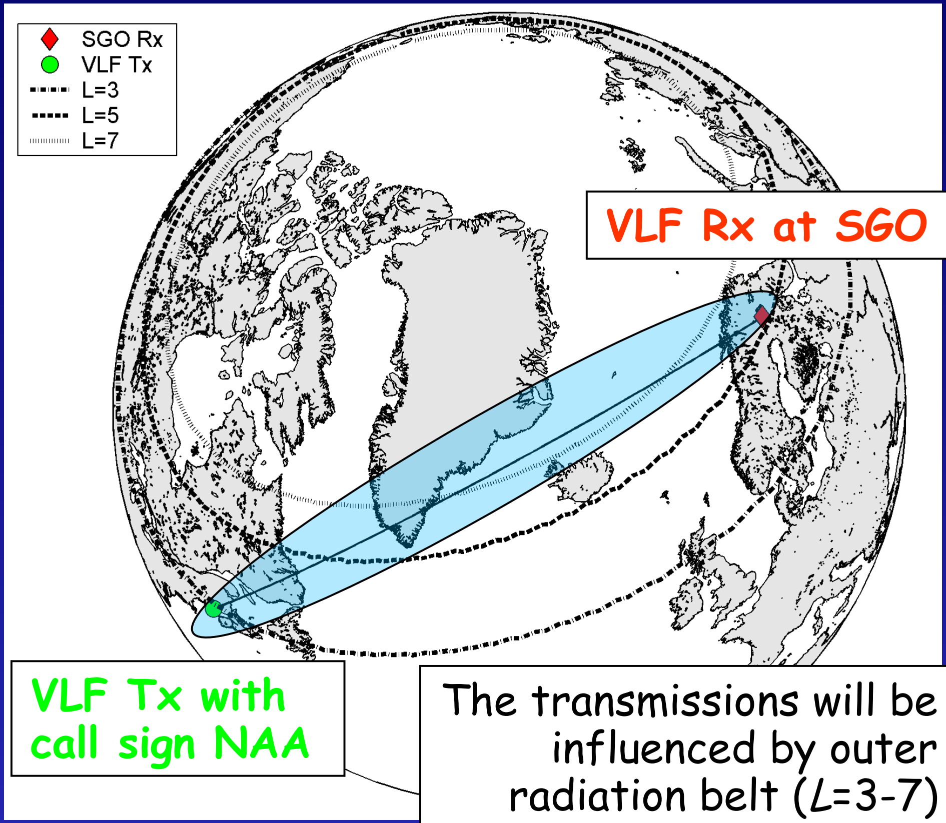
paths planned.



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).



The transmissions will be influenced by outer radiation belt (L=3-7) energetic electron precipitation.

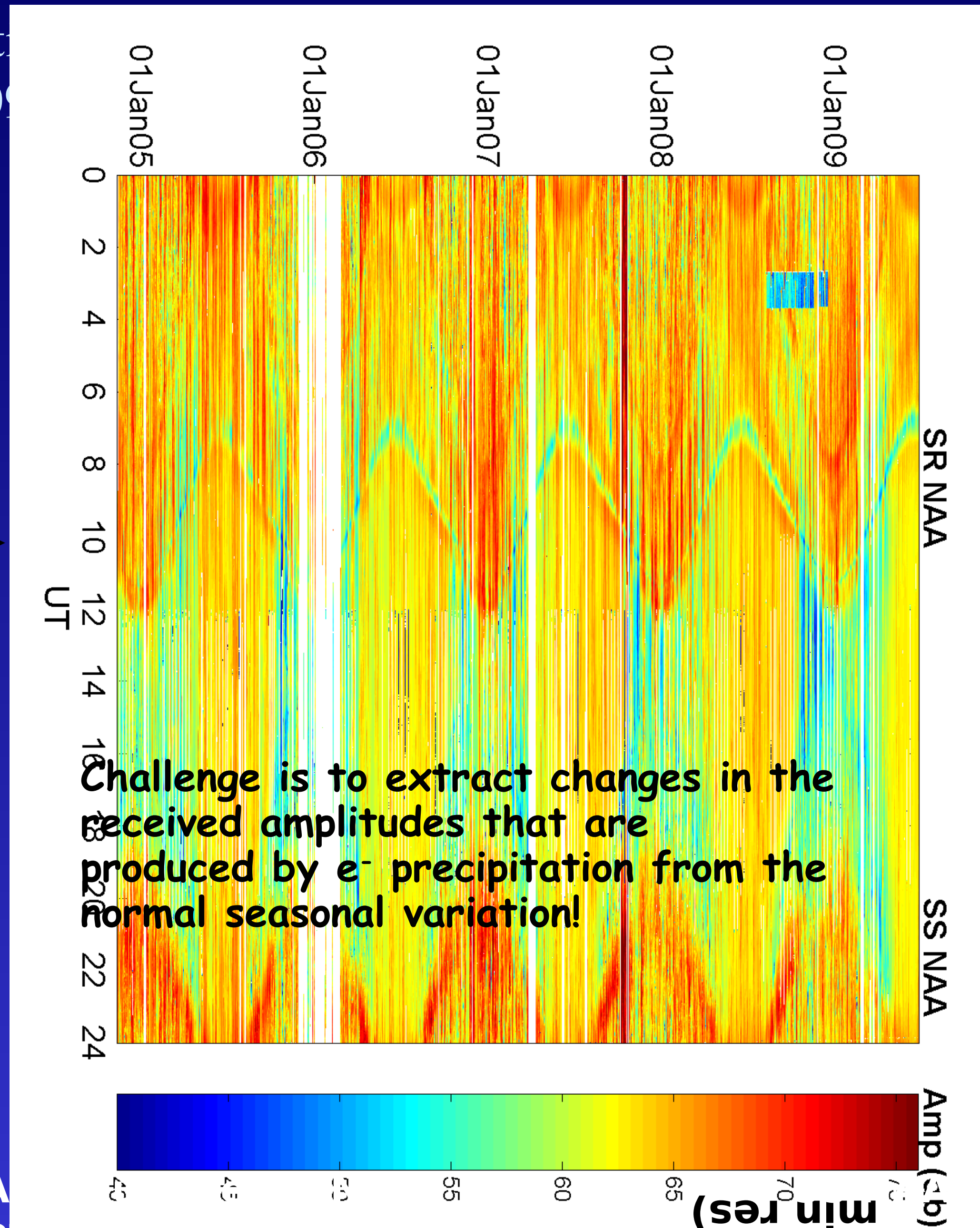
This appears to work, we now moving towards validation, establishing uncertainties and improving our modelling.

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.

Energetic Particle Precipitation

Observat… 2004 to May 200…

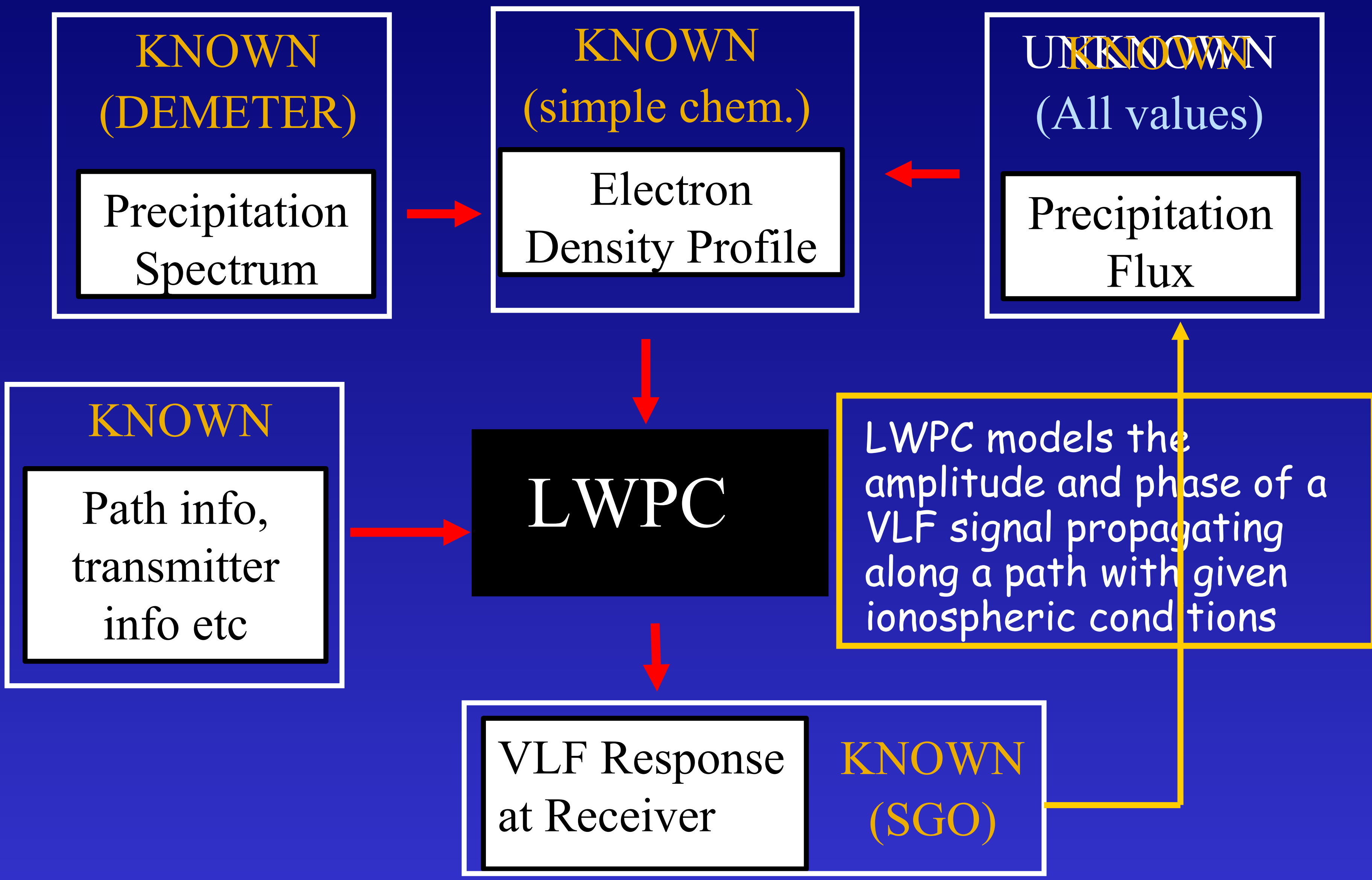
Example



Challenge is to extract changes in the received amplitudes that are produced by e^- precipitation from the normal seasonal variation!

SR NA…
Sunse…

Schematic of Modelling Approach



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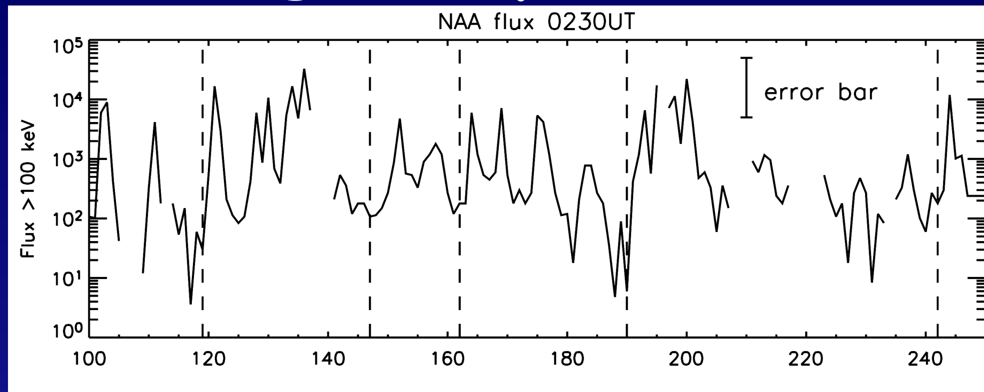
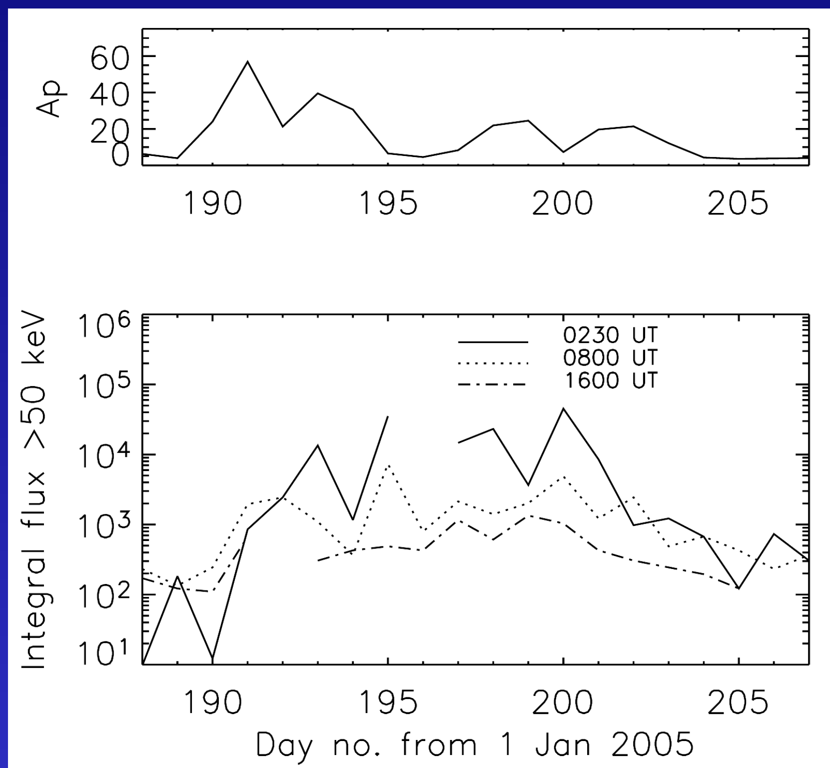
Resulting Precipitation Fluxes from SGO



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 sector (1130-1930 MLT) has the lowest.

Evidence of varying precipitation with MLT (to be expected, but good to see evidence for this!).

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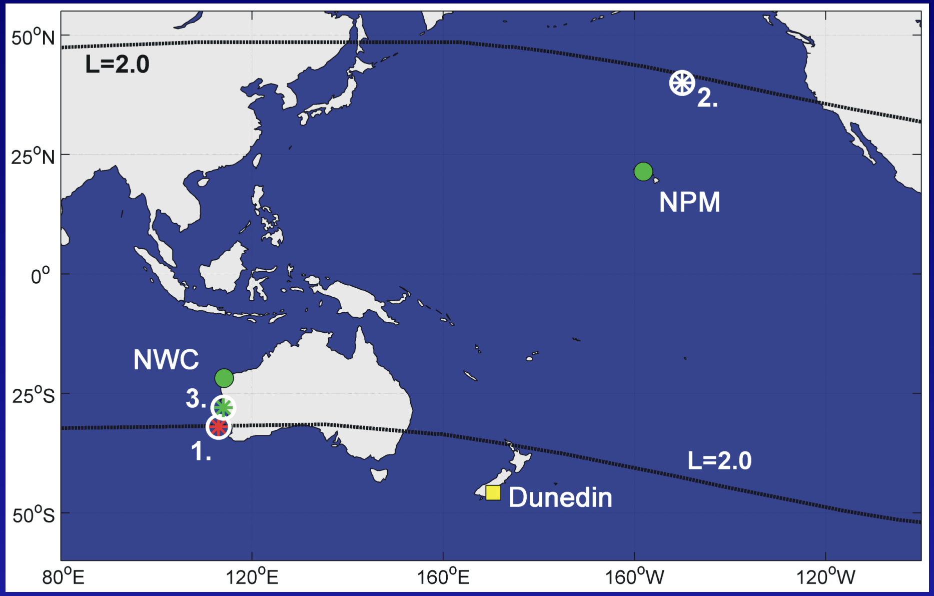
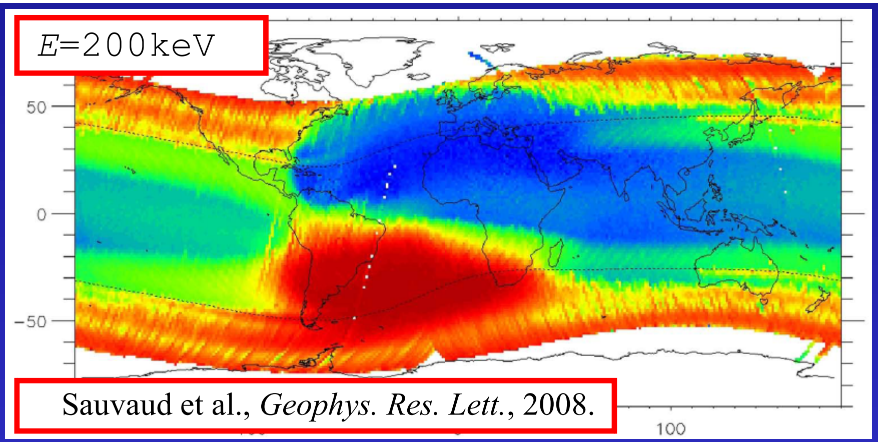
2. Wave-particle interactions driven by manmade VLF transmissions

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

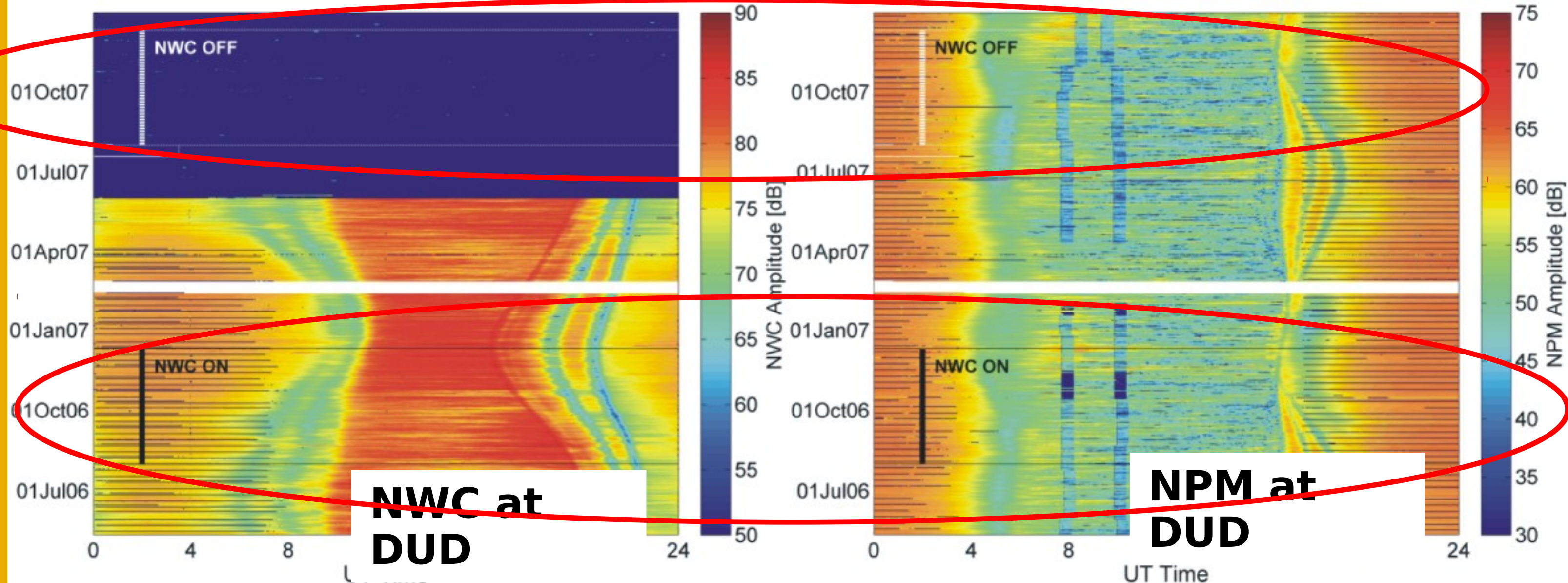
However, there has been confusion as to the relative role of ducted waves (originally broadcast from the transmitters) and non-ducted waves.





Sauvaud et al., *Geophys. Res. Lett.*, 2008.

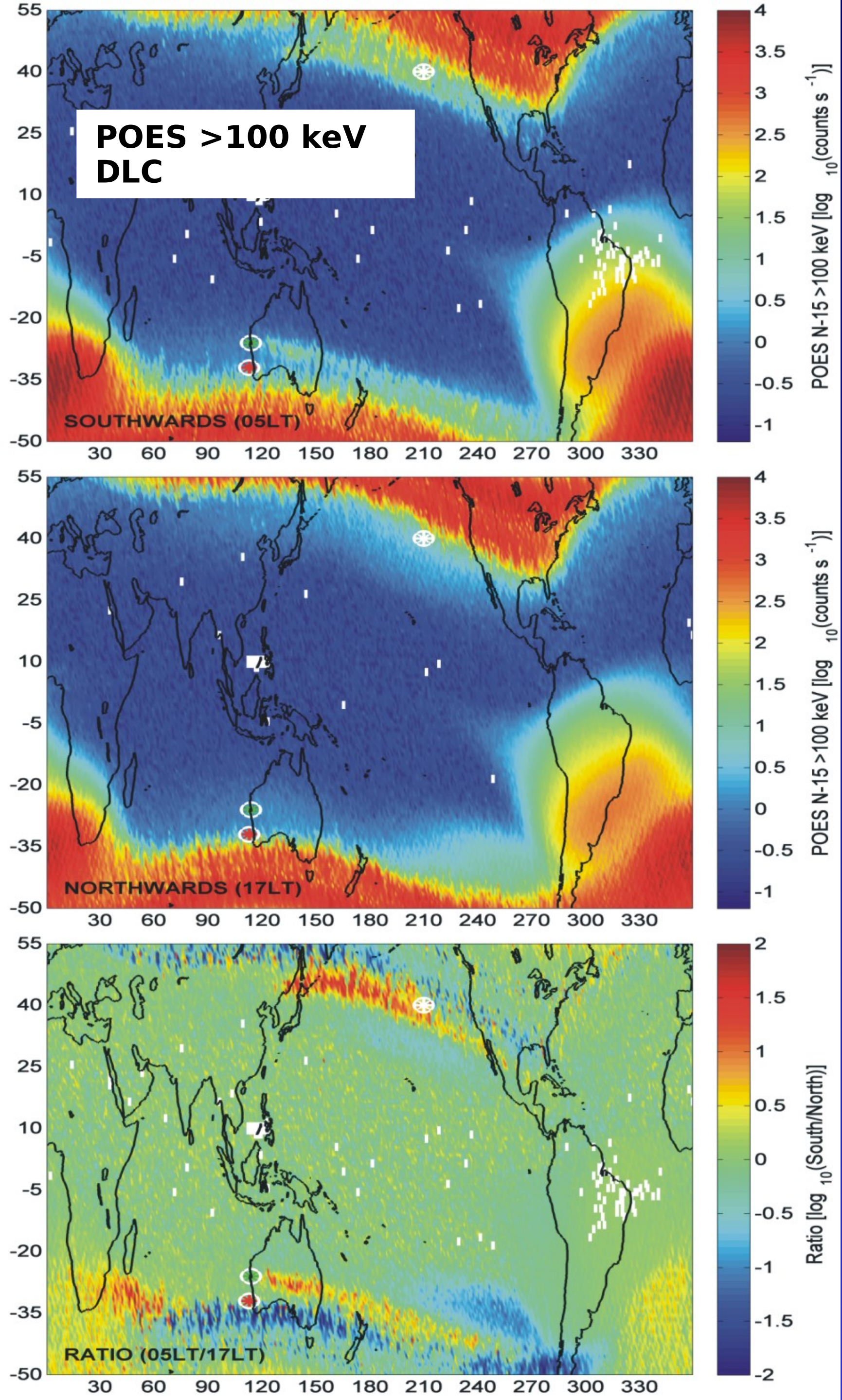
Rodger, C J, B R Carson, S A Cummer, R J Gamble, M A Clilverd, J-A Sauvaud, M Parrot, J C Green, and J-J Berthelier, Contrasting the efficiency of radiation belt losses caused by ducted and non-ducted whistler mode waves from ground-based transmitters, J. Geophys. Res., 115, A12208, doi:10.1029/2010JA015880,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



FROM DUNEDIN SUBIONOSPHERIC DATA

1 August-11 December 2006	NWC on	NPM on
1 August-11 December 2007	NWC off	NPM 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!

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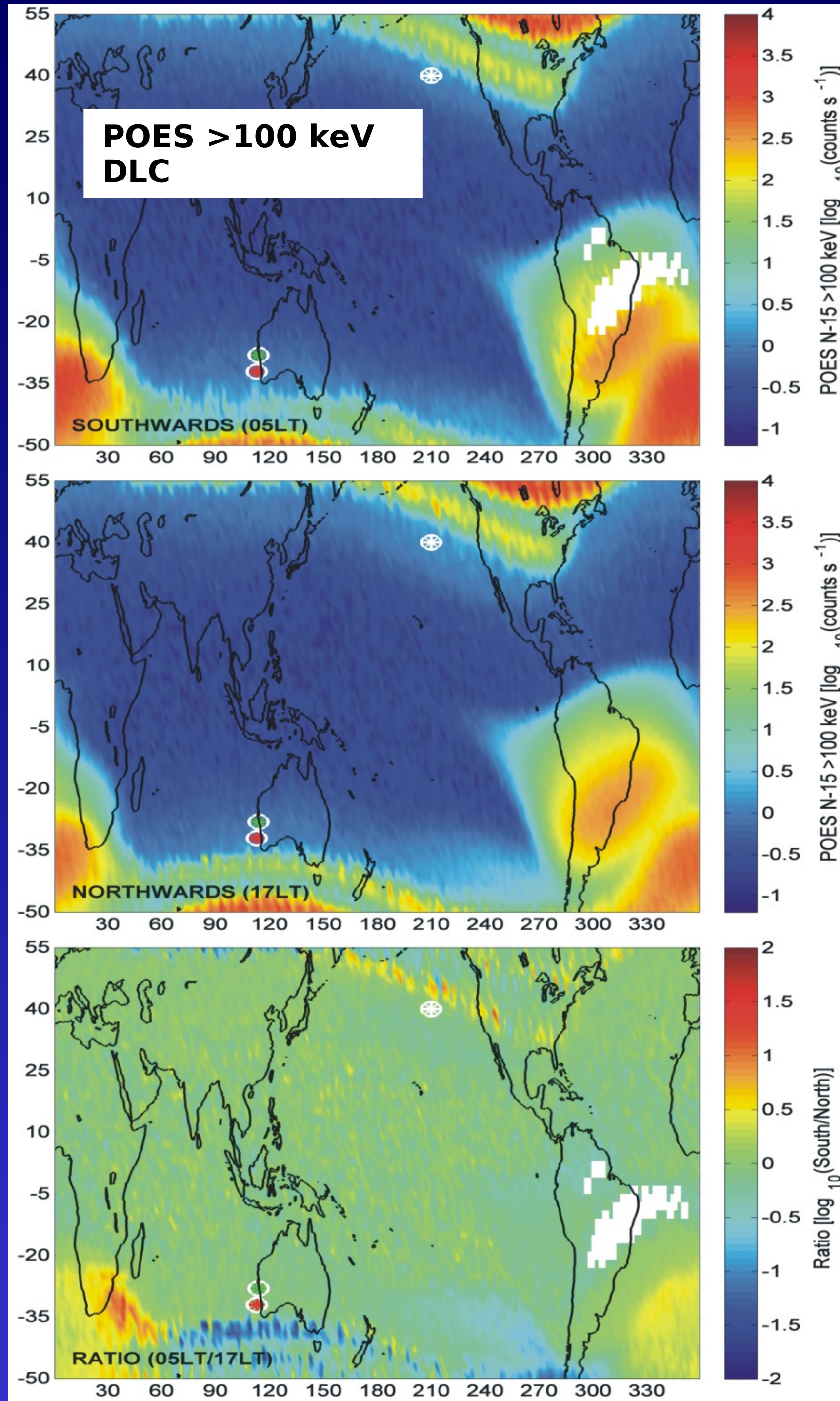


NWC off NPM on

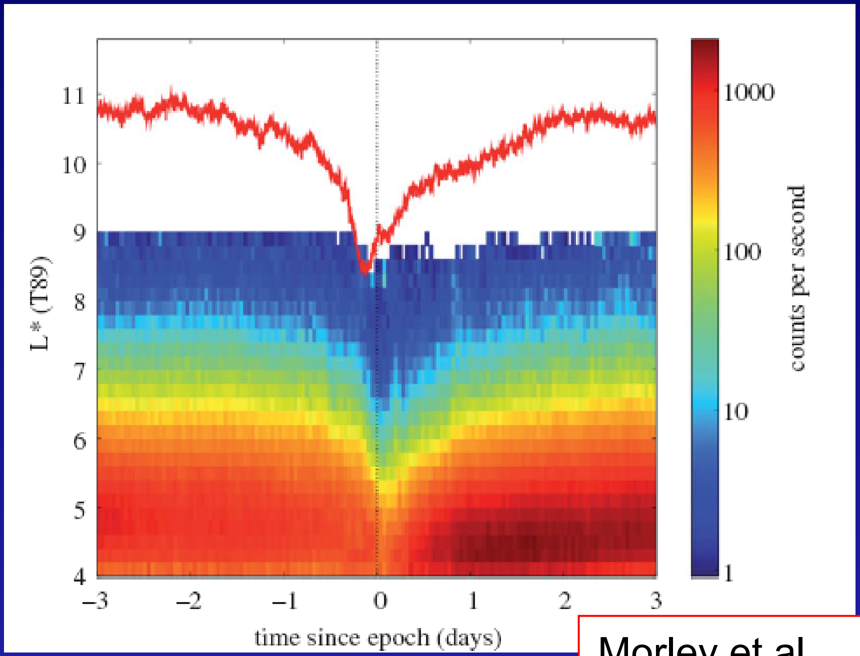
RATIO plot (day/night) fails to show any evidence of an NPM produced enhancement in DLC electron fluxes.

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.

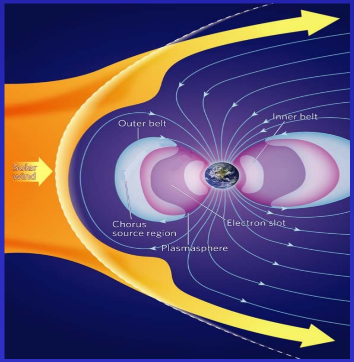
3. Radiation Belt drop-outs during High Speed Solar Wind Streams

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



Morley et al., *Proc. R. Soc. A*, May 2010

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



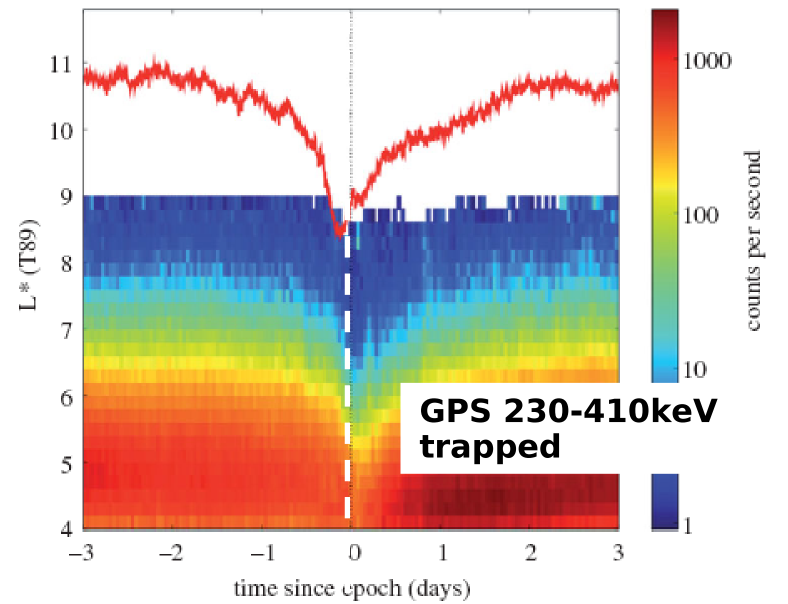
Work in progress! Much of this work is being undertaken by Aaron Hendry, 2011 University of Otago Honours student.

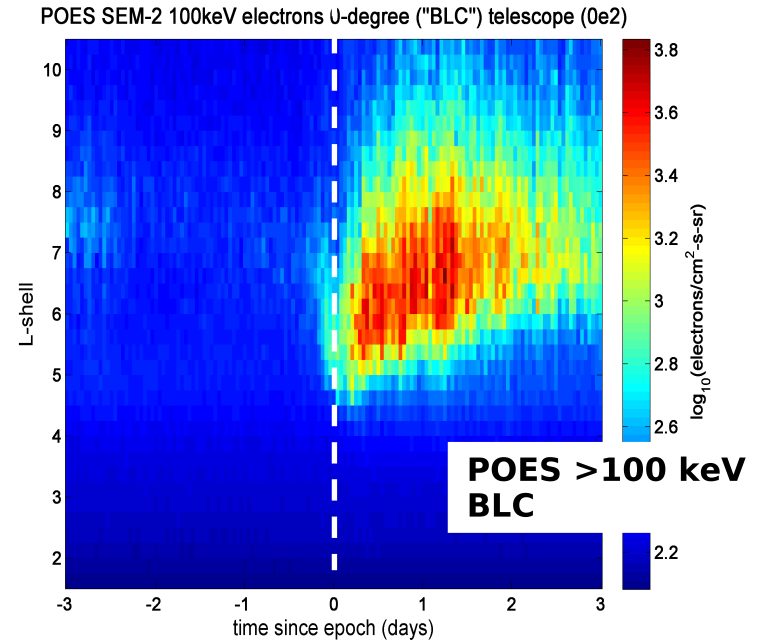
In-situ observations of the dropouts

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?

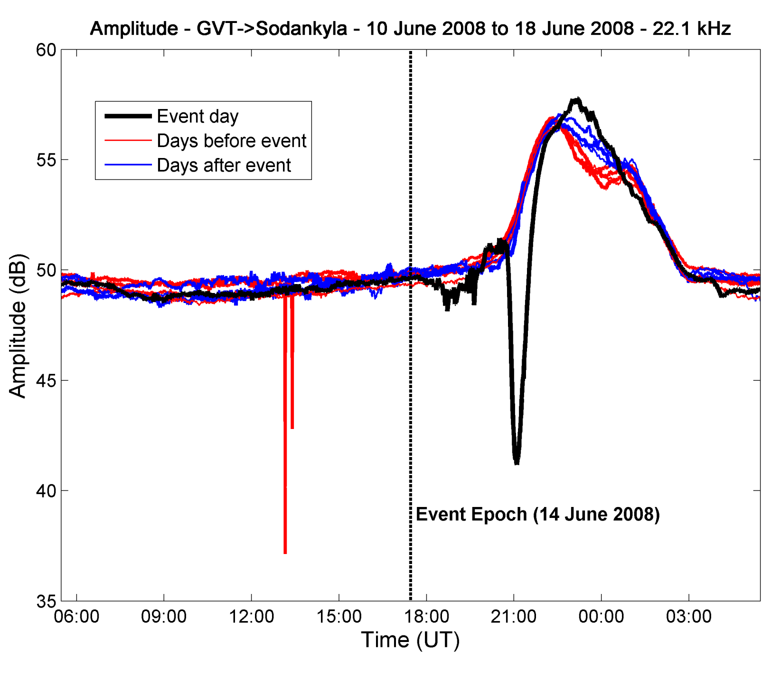
Work in progress! Aaron Hendry (University of Otago Honours student) Summer project Jan-February 2011



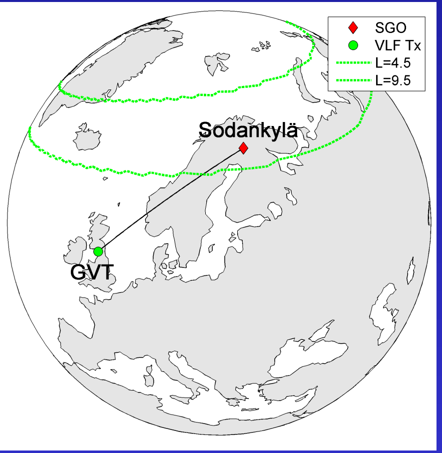


Determine the magnitude of the precipitated fraction

Even if atmospheric precipitation is not the dominant loss mechanism, we need to determine its magnitude to describe the dropout and 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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All AARDDVARK publications, both in press and published are available from the AARDDVARK webpage

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

Clilverd, M. A., et al., *J. Geophys. Res.*, 115, A0832, doi:10.1029/2009JA015204, 2010.

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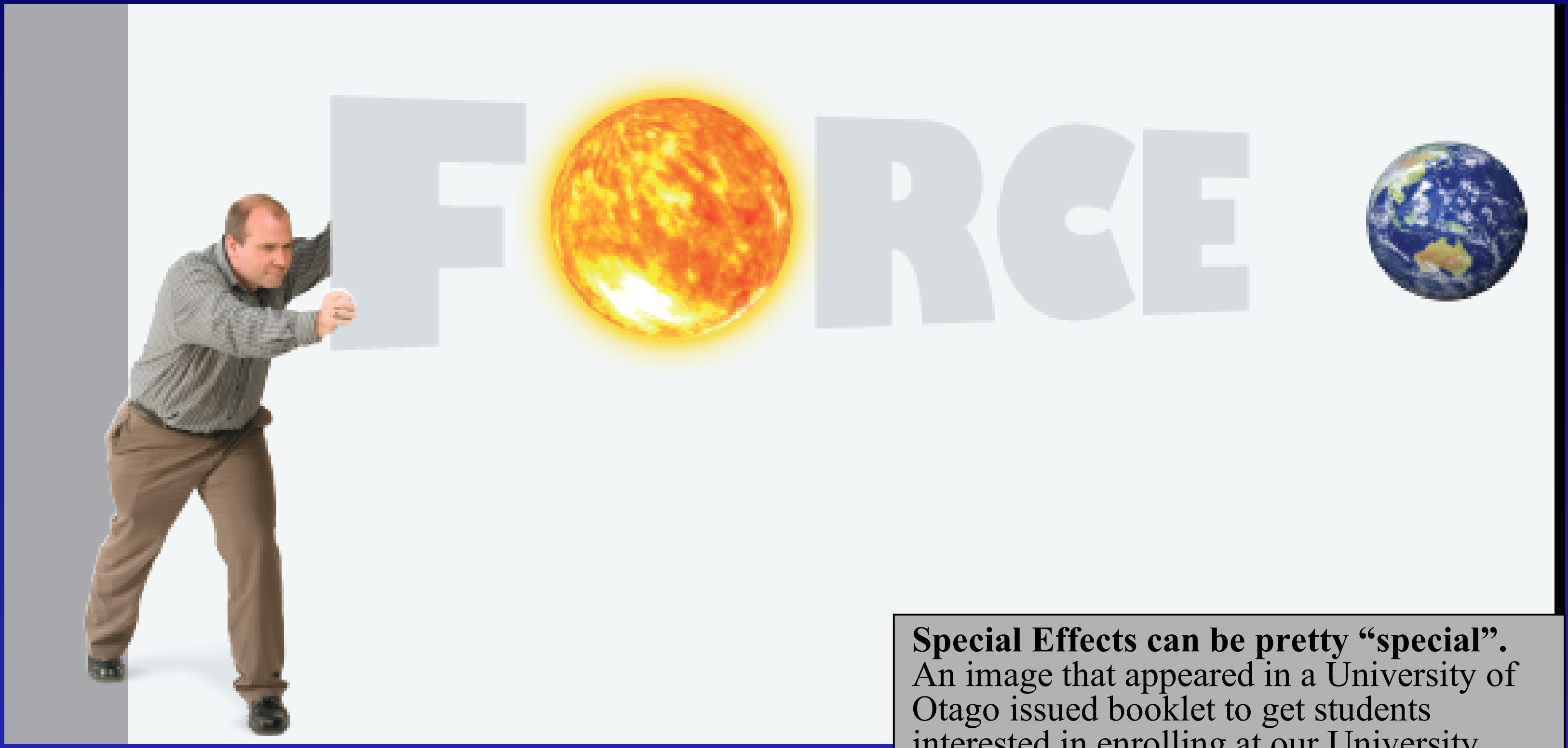
Acknowledgement: The research leading to these results has received funding from the European Union Seventh Framework Programme [FP7/2007-2013] under grant agreement n°263218.



Special Effects can be pretty "special". An image that appeared in a University of Otago issued booklet to get students interested in enrolling at our University.

Thankyou!

Are there any questions?

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