'Detecting Space Weather with an AARDDVARK'

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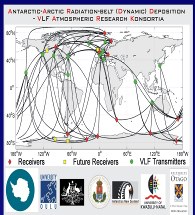
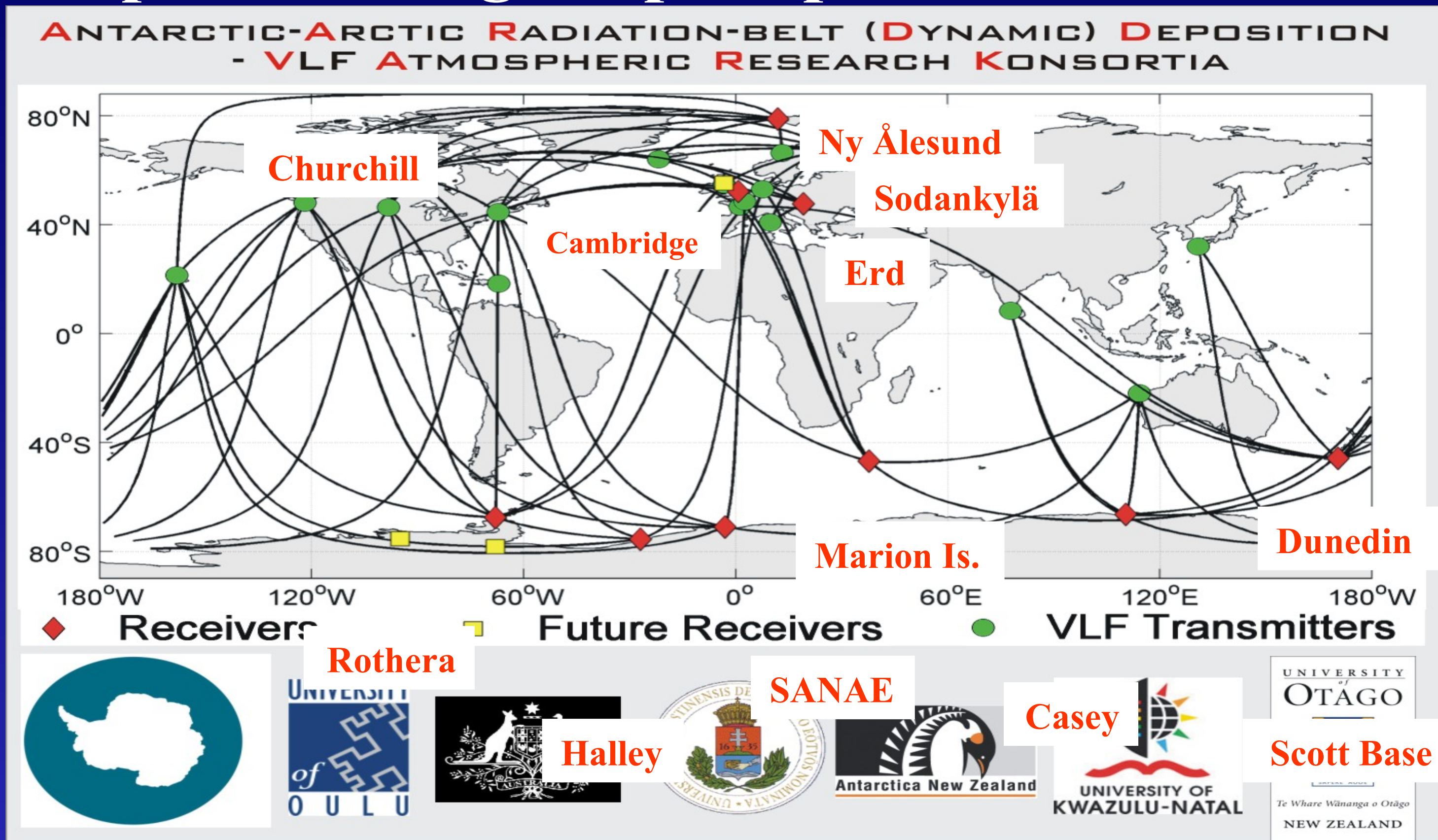
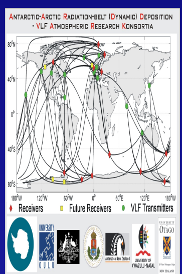
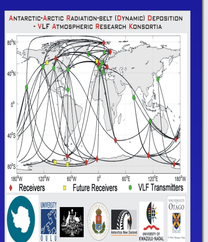
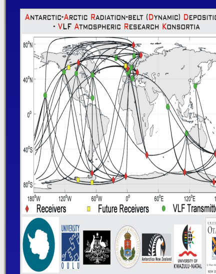
What is an AARDDVARK? Our AARDDVARK network of sub-ionospheric energetic precipitation monitors :

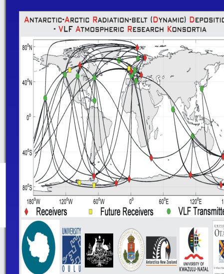


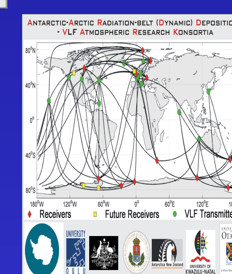








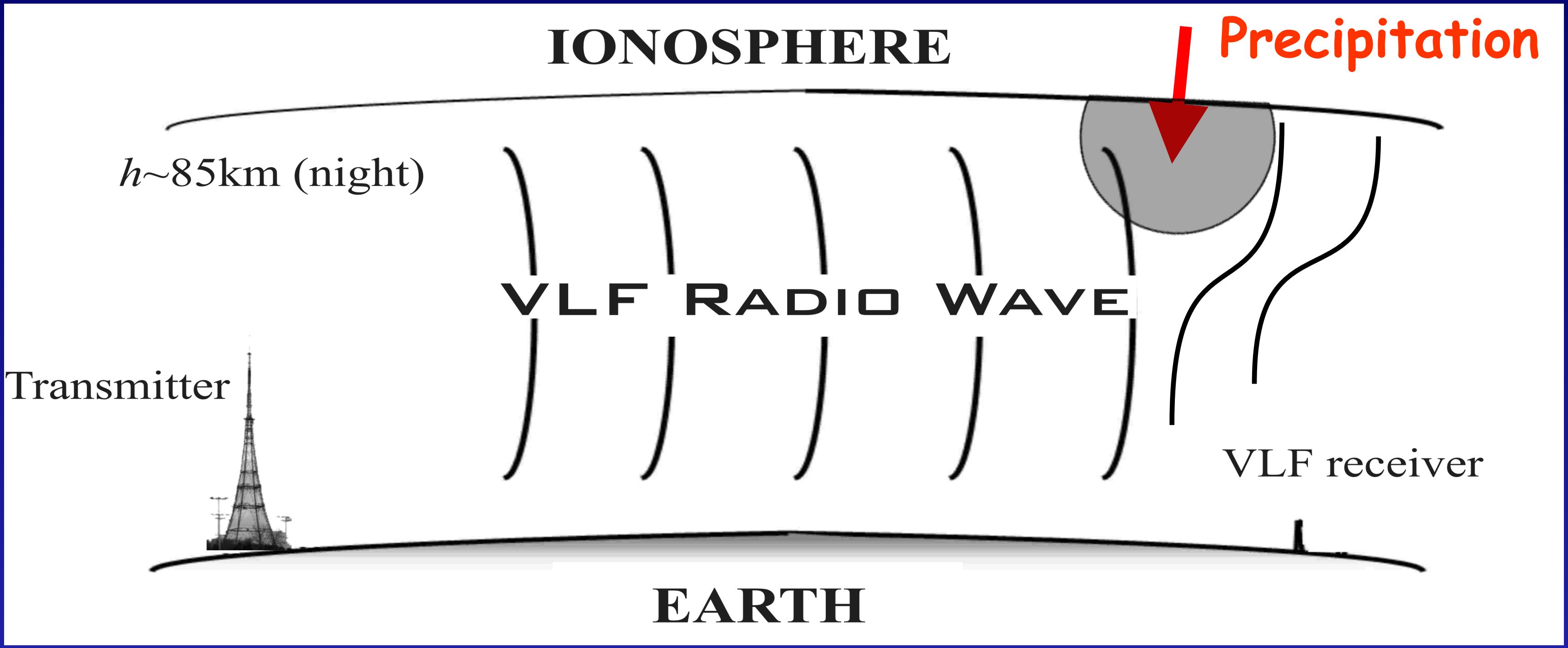




MORE INFORMATION:
www.physics.otago.ac.nz\space\AARDDVARK_homepage.htm

Reference: Clilverd et al., Remote sensing space weather events: the AARDDVARK network, Space Weather, 7, 2009.

We use the ionosphere as a precipitation detector: 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!

The NAA transmitter
24.0 kHz
1 MW output power.
Big, high maintenance, expensive!

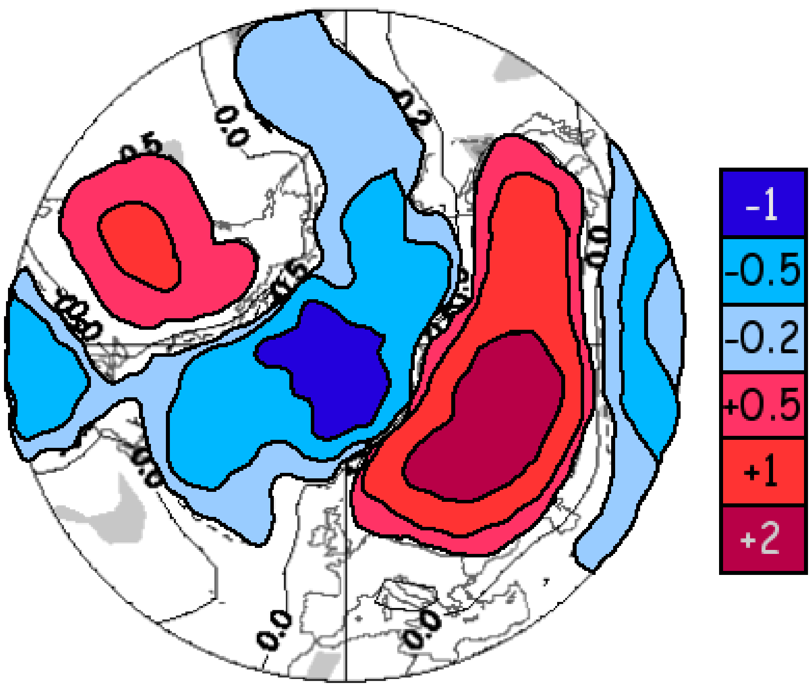

The VLF receiver
Small, low maint., low cost

Why do we care?

The data: North

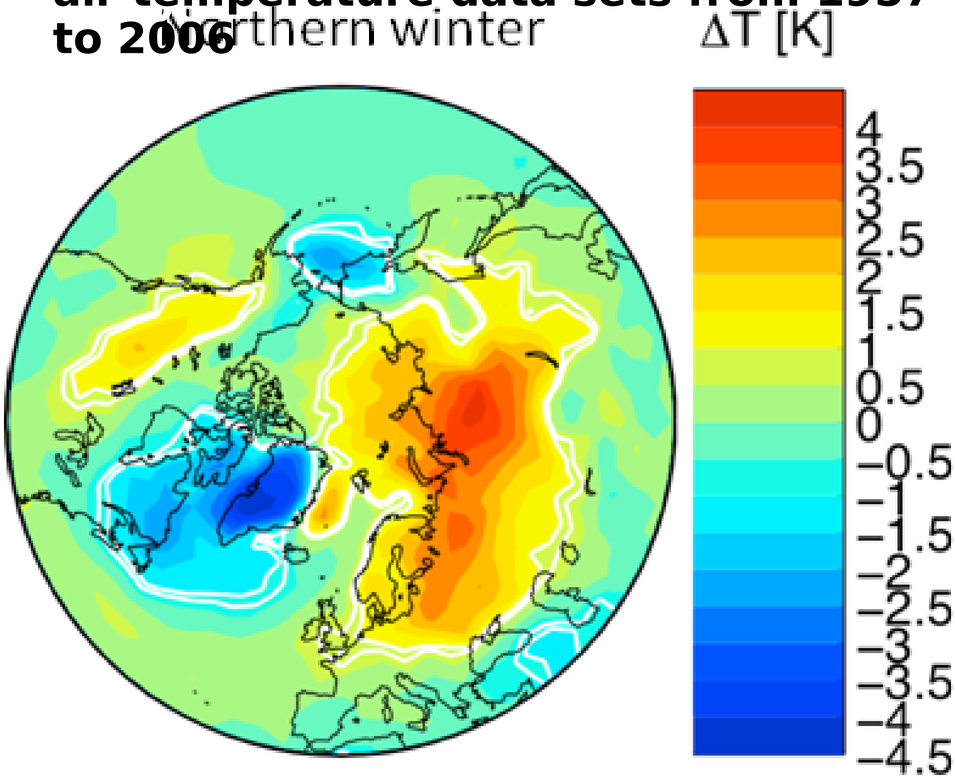
High Ap – low Ap [*Space Weather*]

Model results
Northern Winter



Rozanov et al., 2005

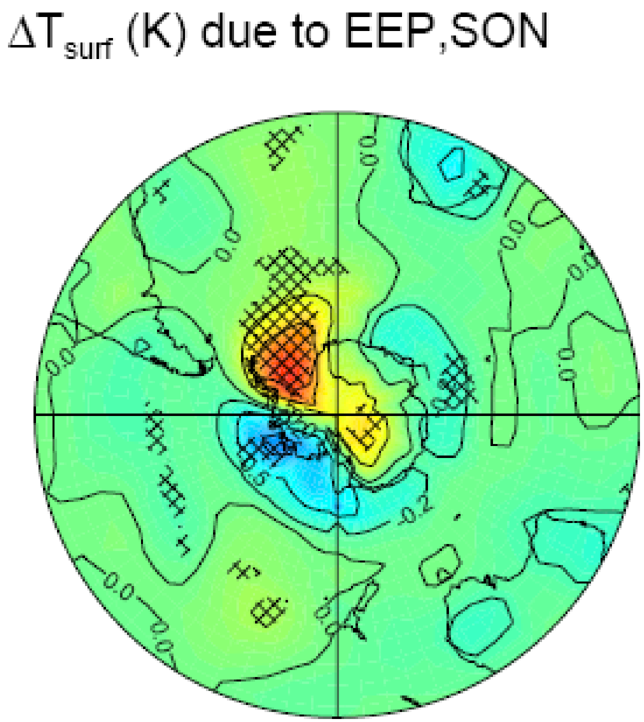
ERA-40 and ECMWF operational surface level air temperature data sets from 1957 to 2006

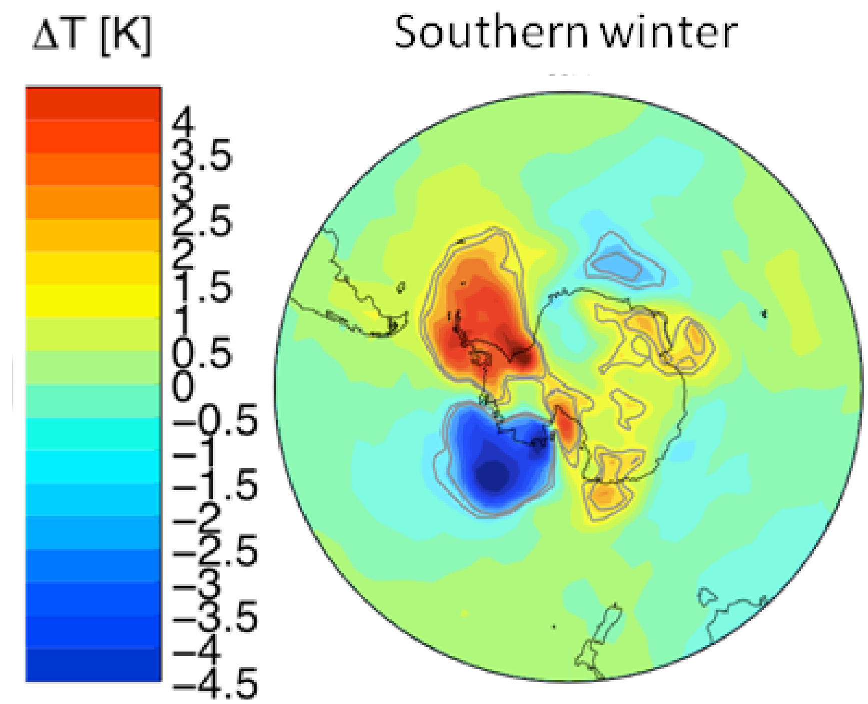


Seppälä et al., 2009

The data: South

High Ap – low Ap [*Sp*… *We*…

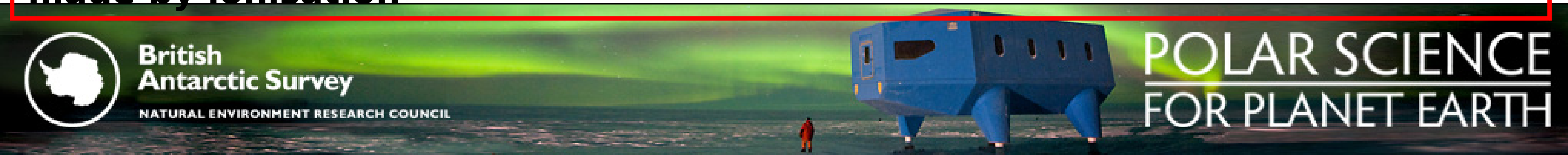




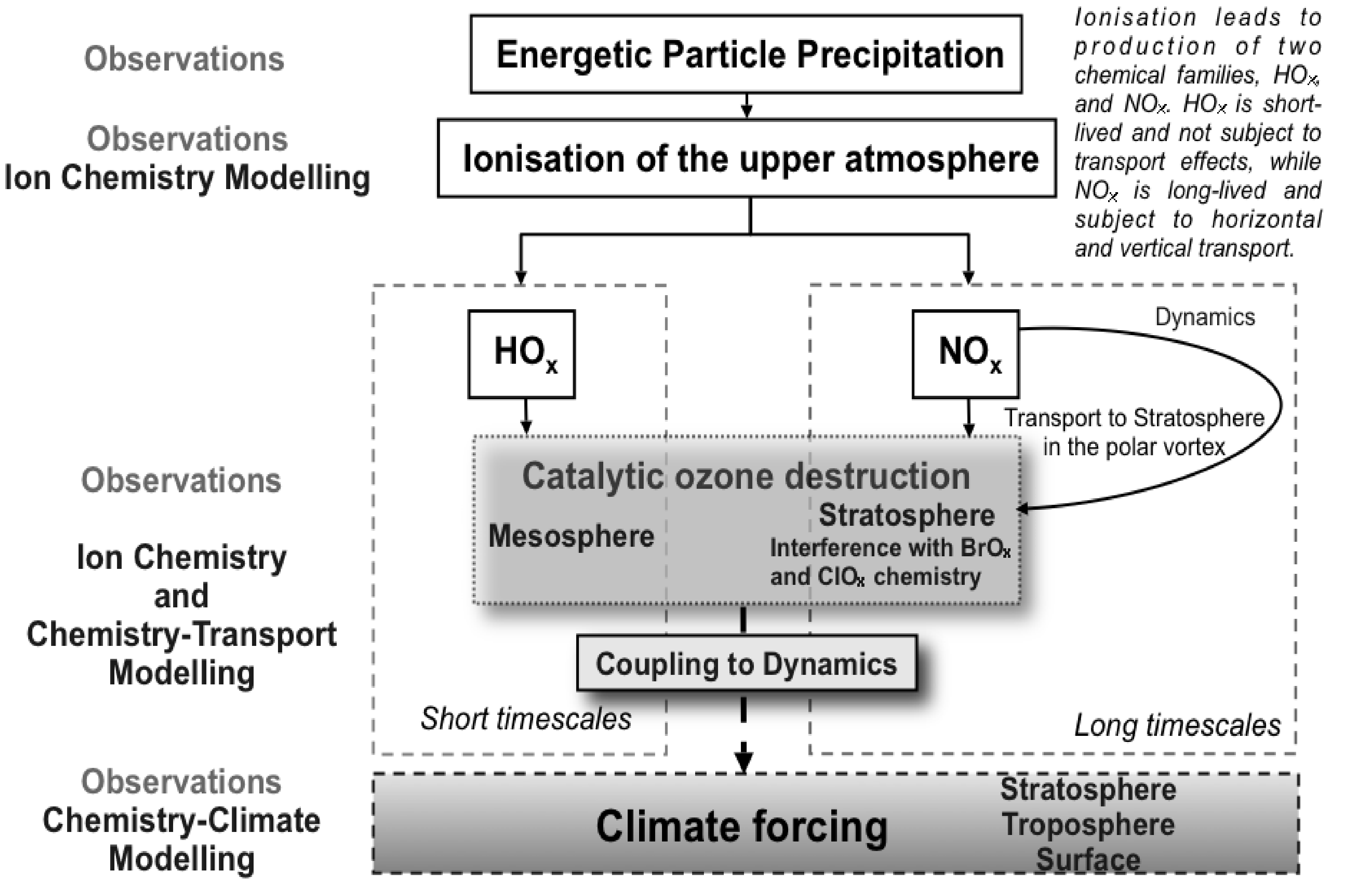
Based on Rozanov et al., 2005

Seppälä et al., 2009

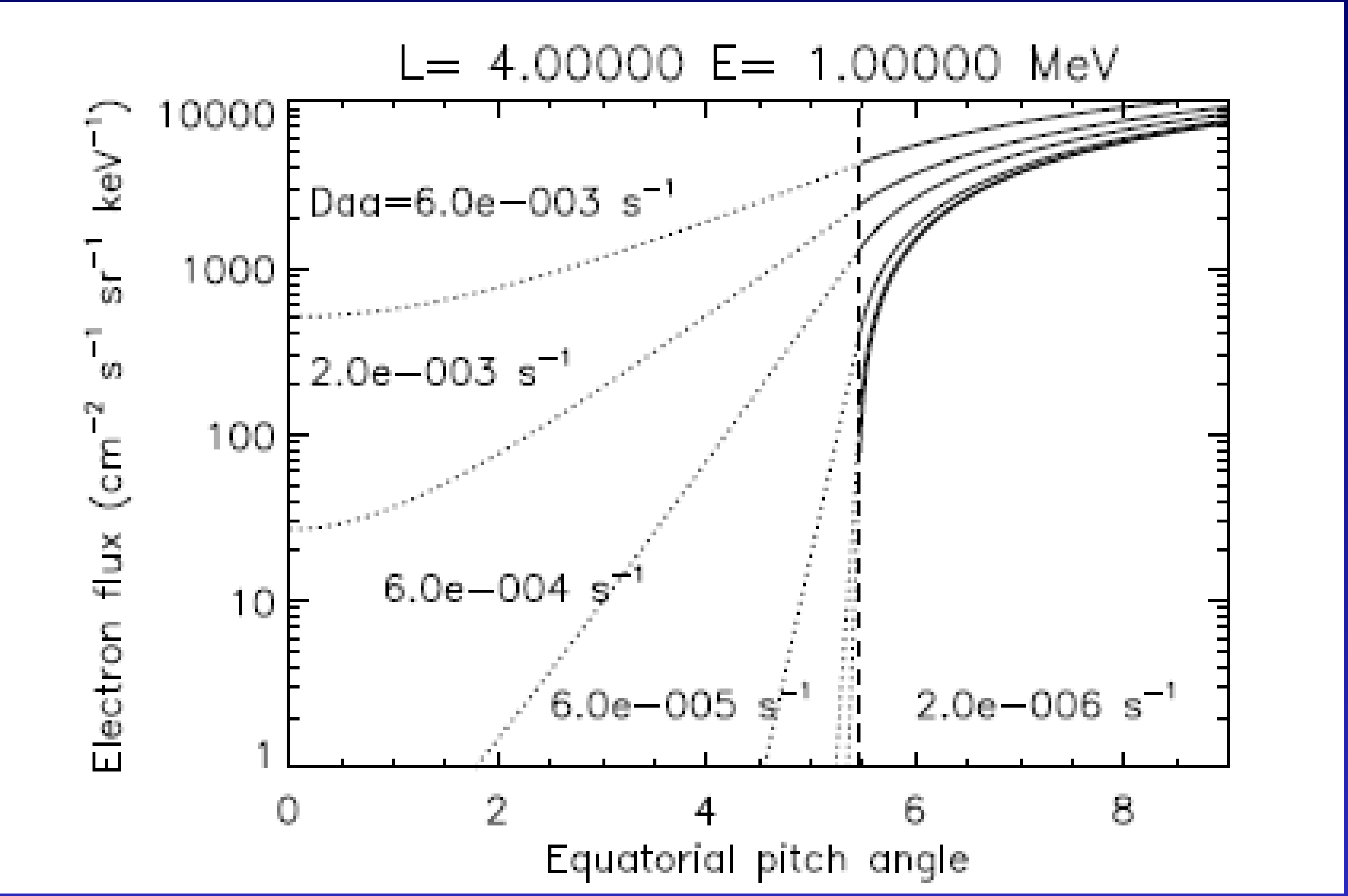
These results are generated by adding NOx at 80 km to the SOCOL model – made by ionisation



How does Space Weather do this?



What Satellites see of the electron precipitation.



The effect of Space weather on strong/weak diffusion conditions – Richard Horne.

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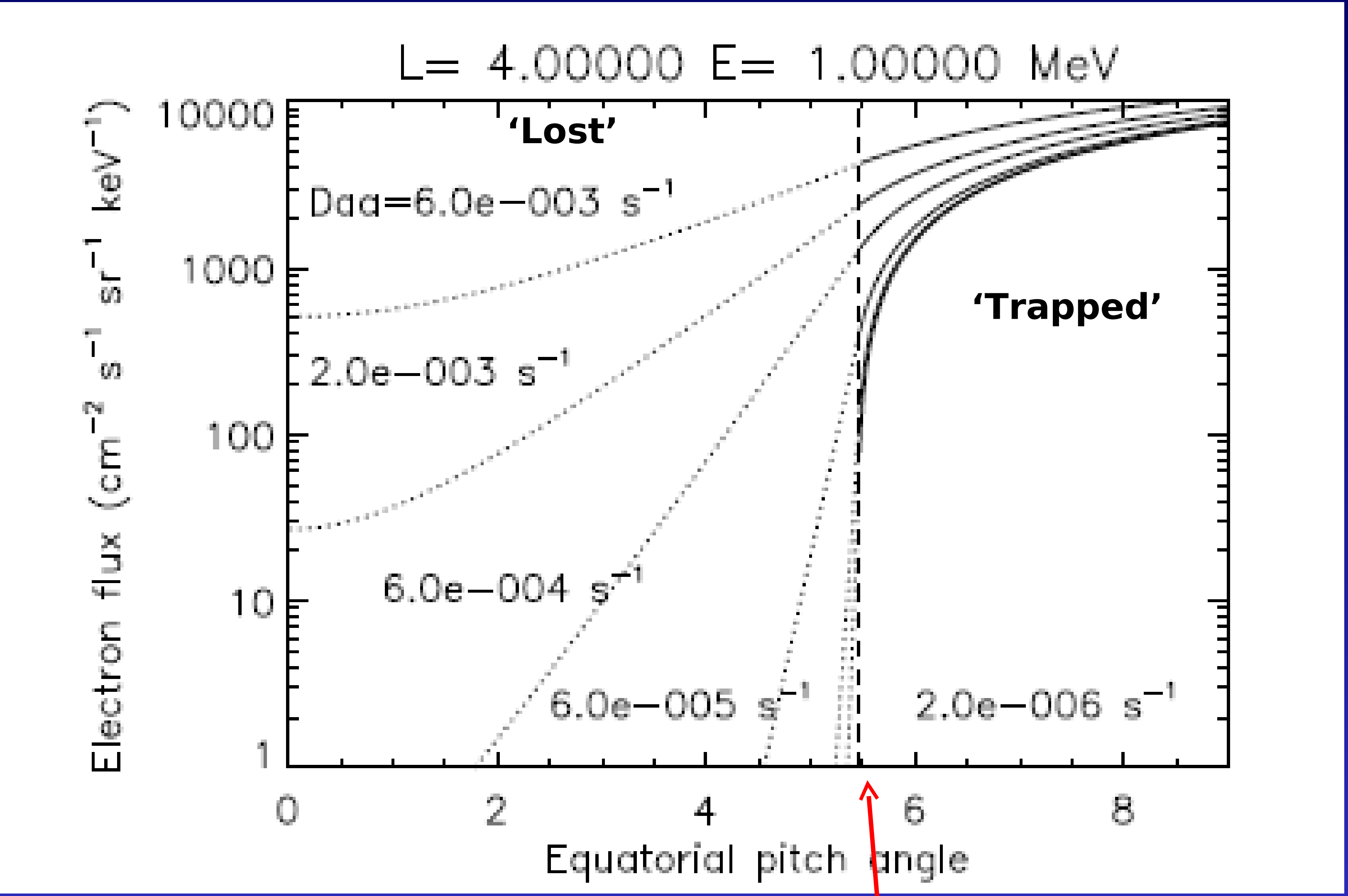
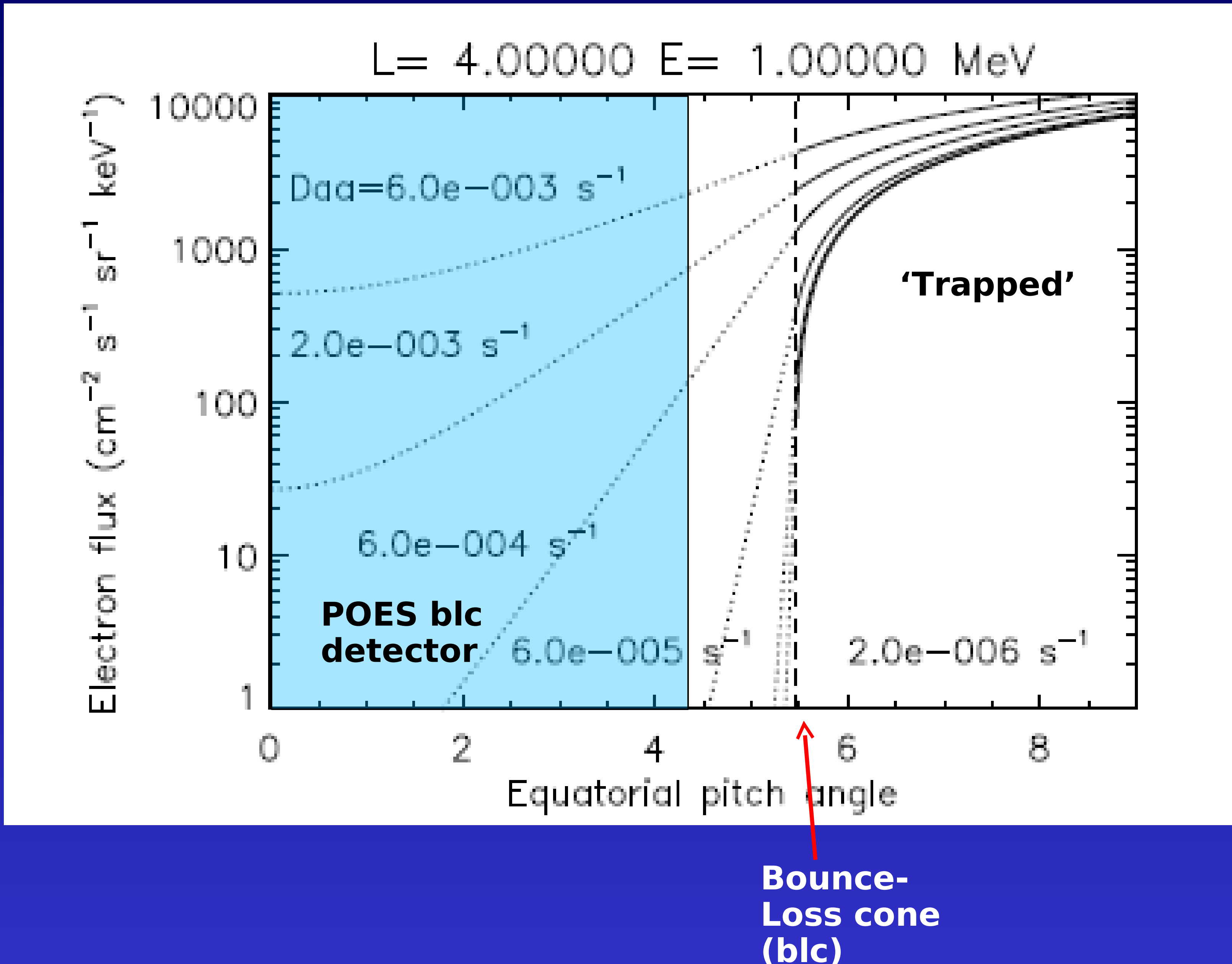


Bounce-
Loss cone
(blc)

What Satellites see of the electron precipitation.



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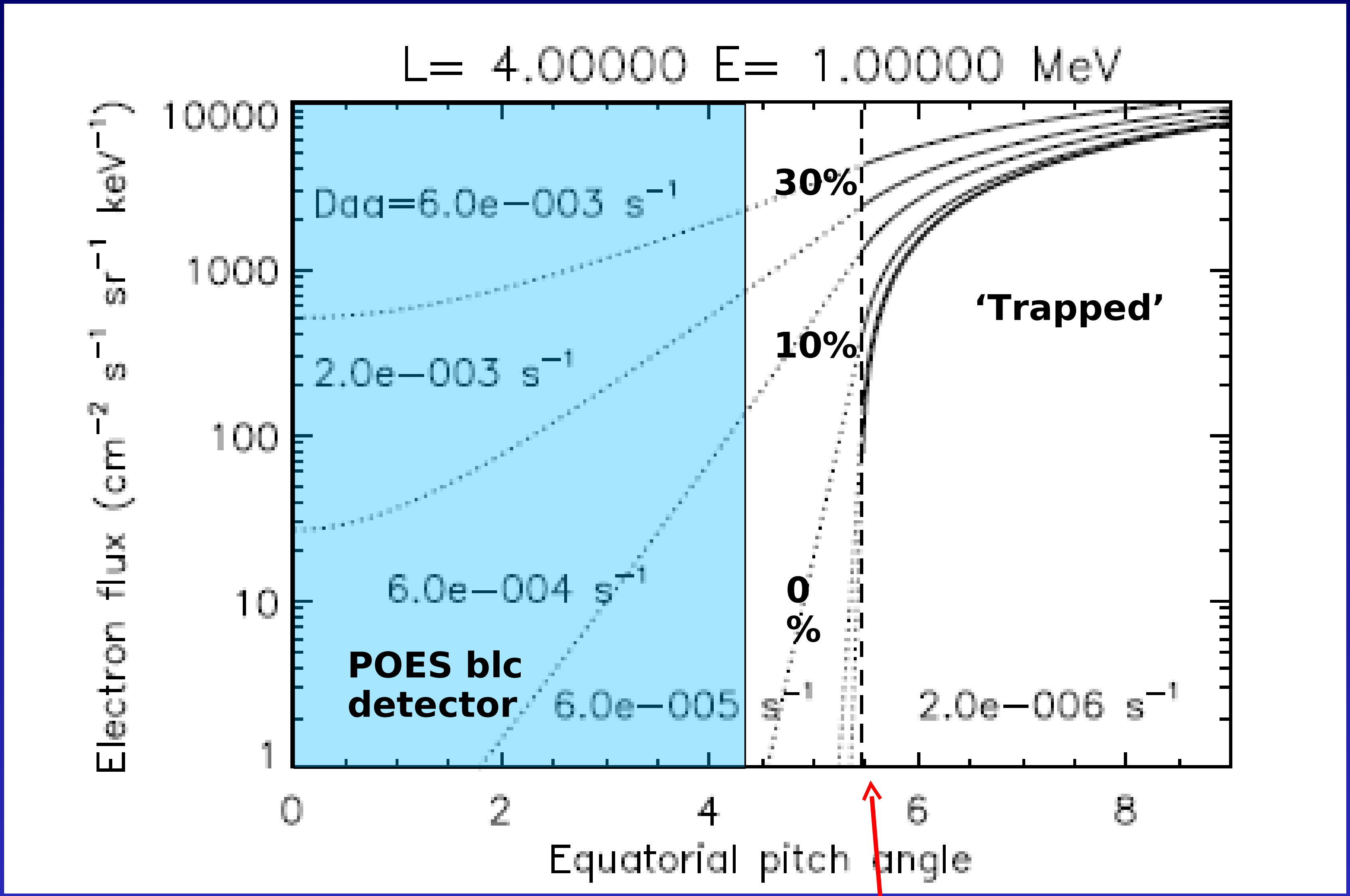
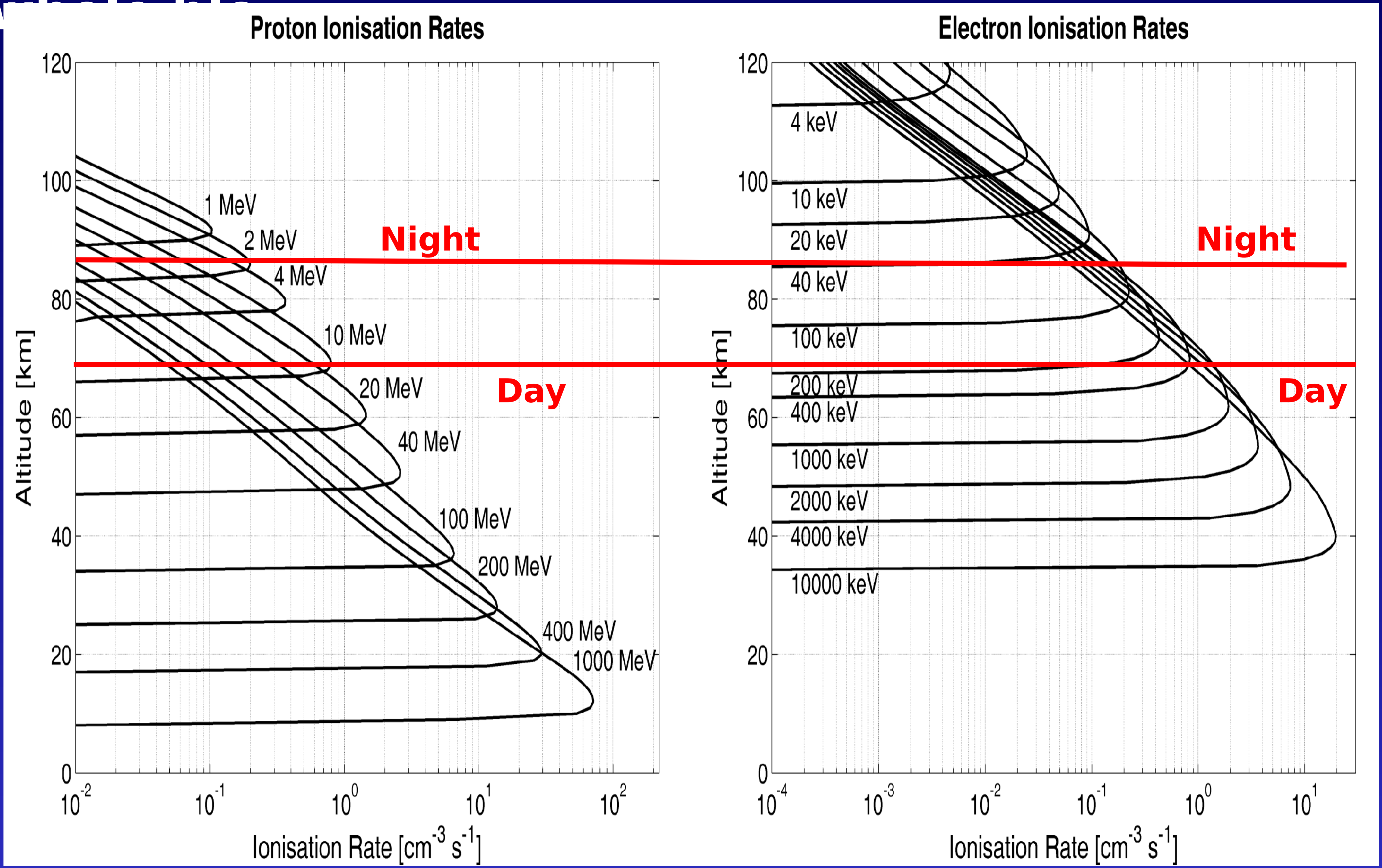
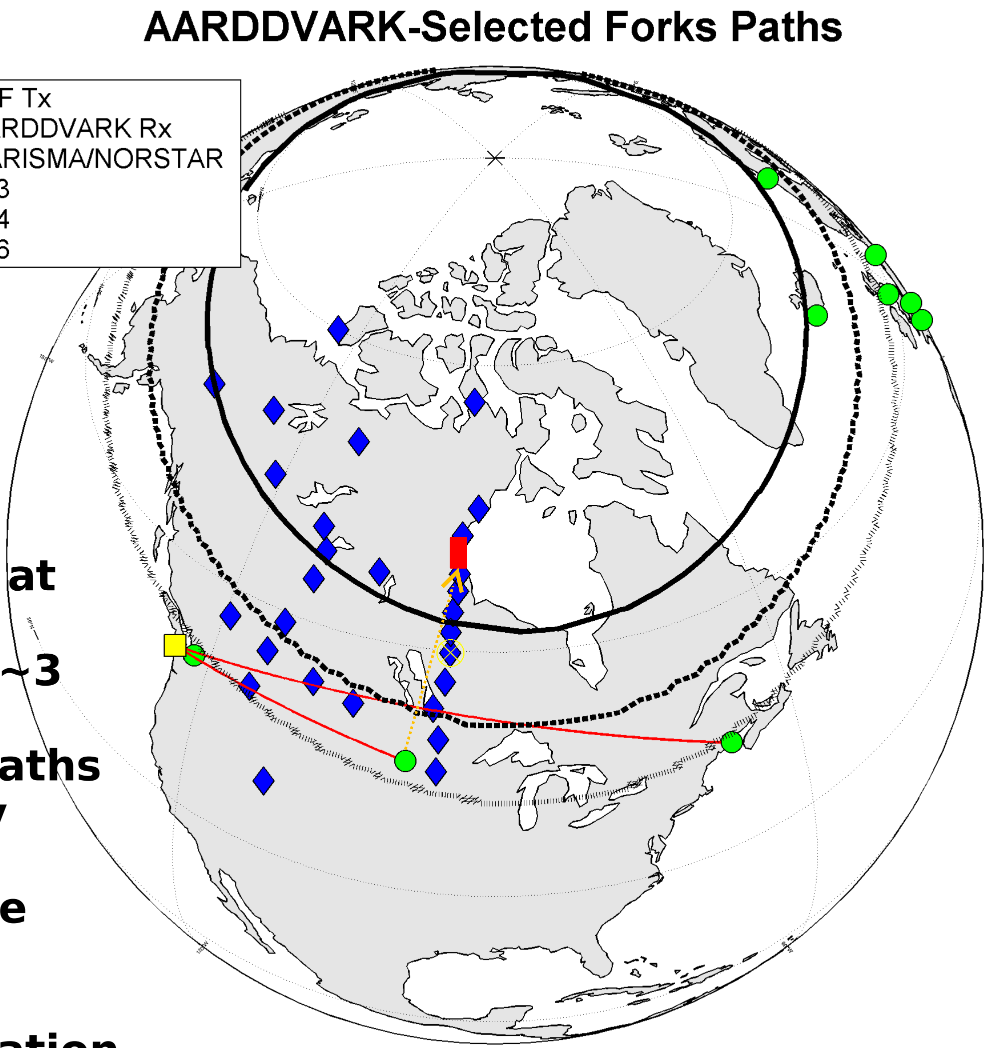


AARDDVARK uses the ionosphere to measure the



What can a Forks AARDDVARK measure?



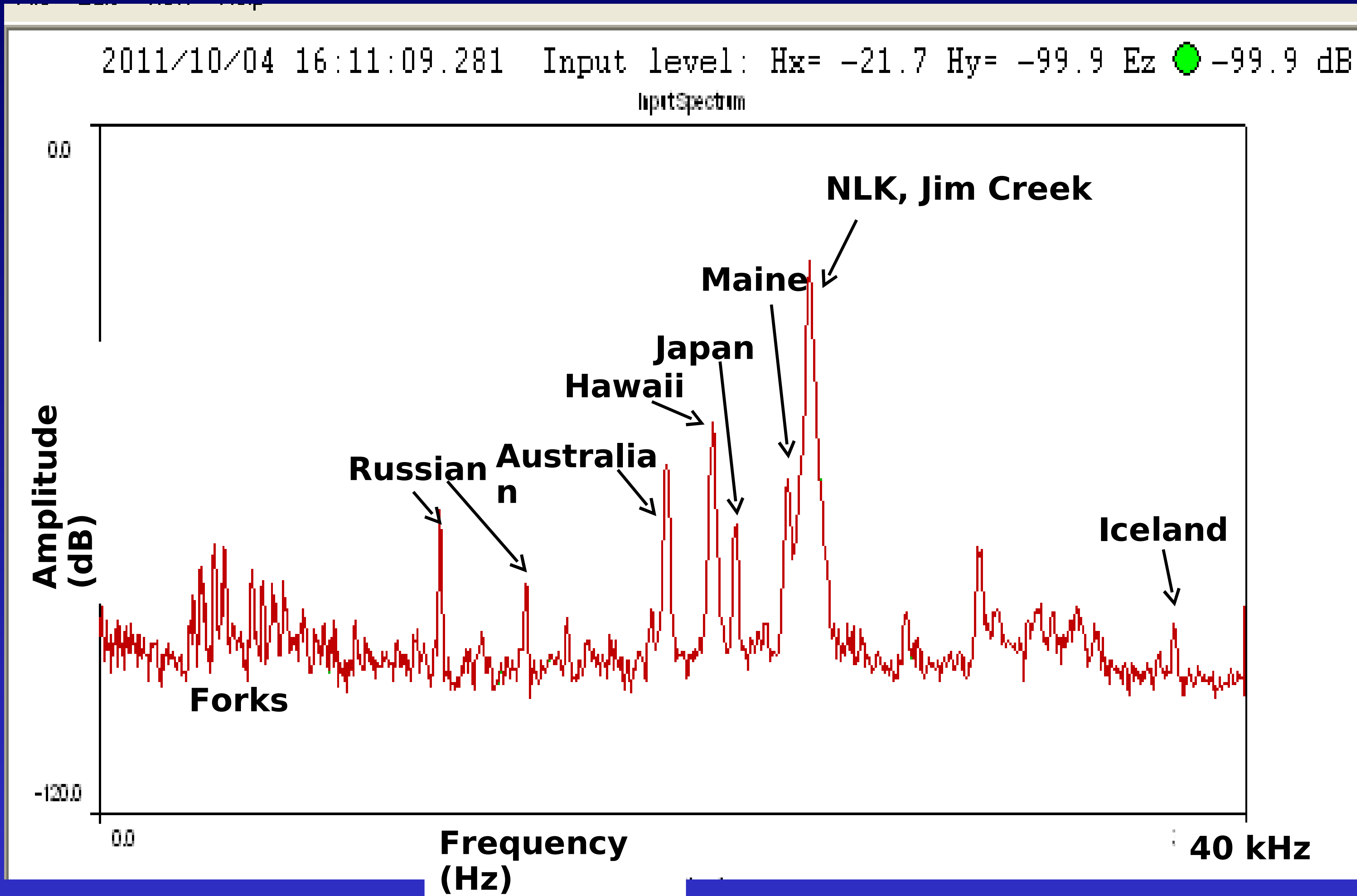
Forks :

Transmitters at L~3
Receiver at L~3

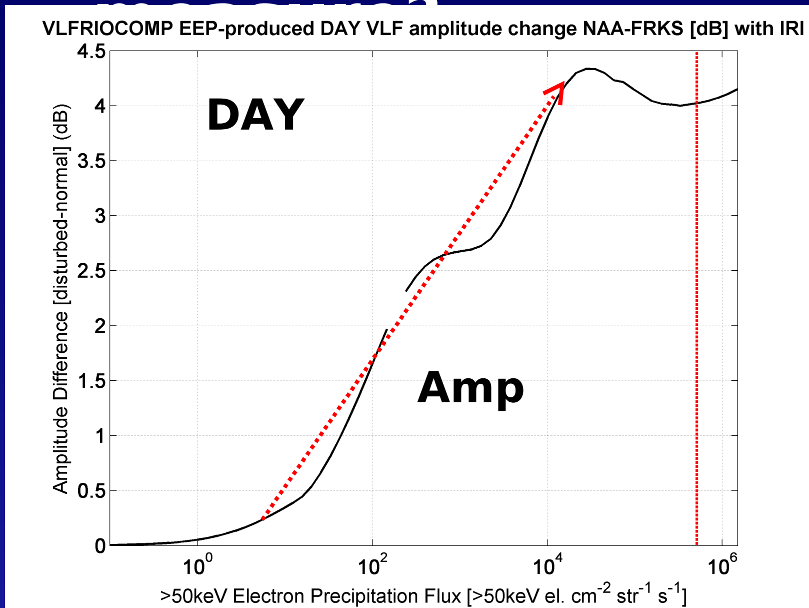
Low L-shell paths influenced by plasmaphere wave –particle interactions

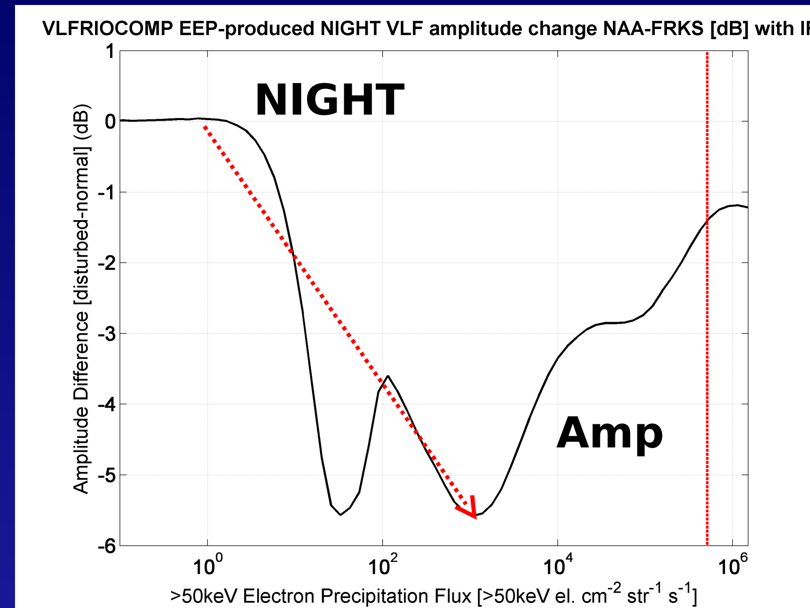
Good combination with Churchill

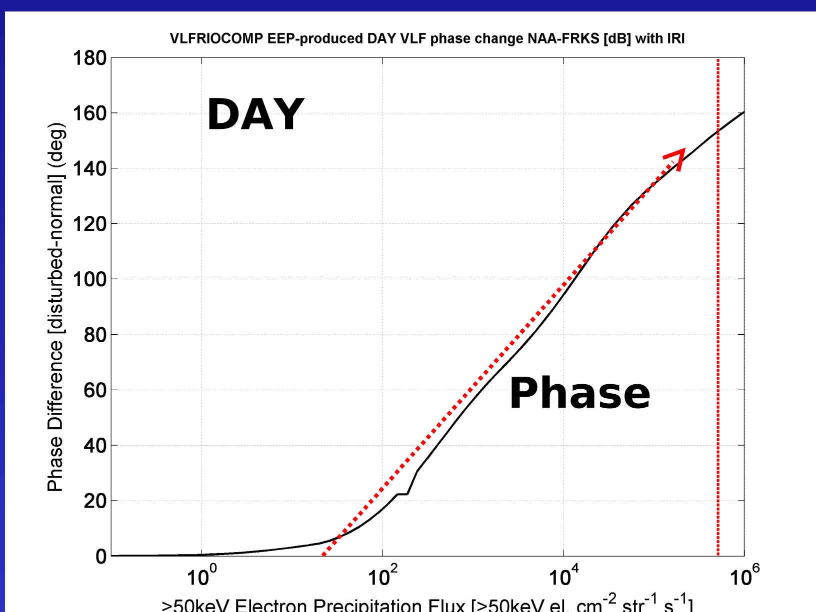
What can a Forks AARDDVARK measure?

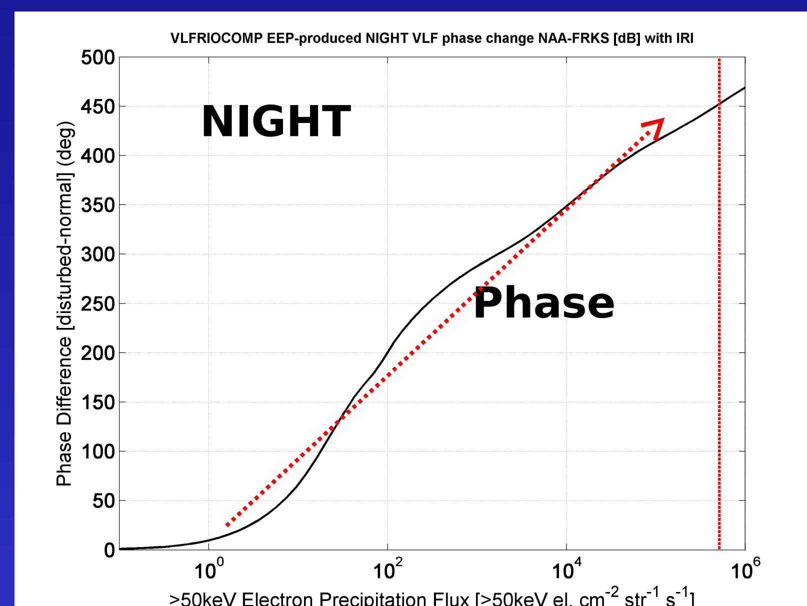


What electron fluxes will a Forks AARDDVARK measure?



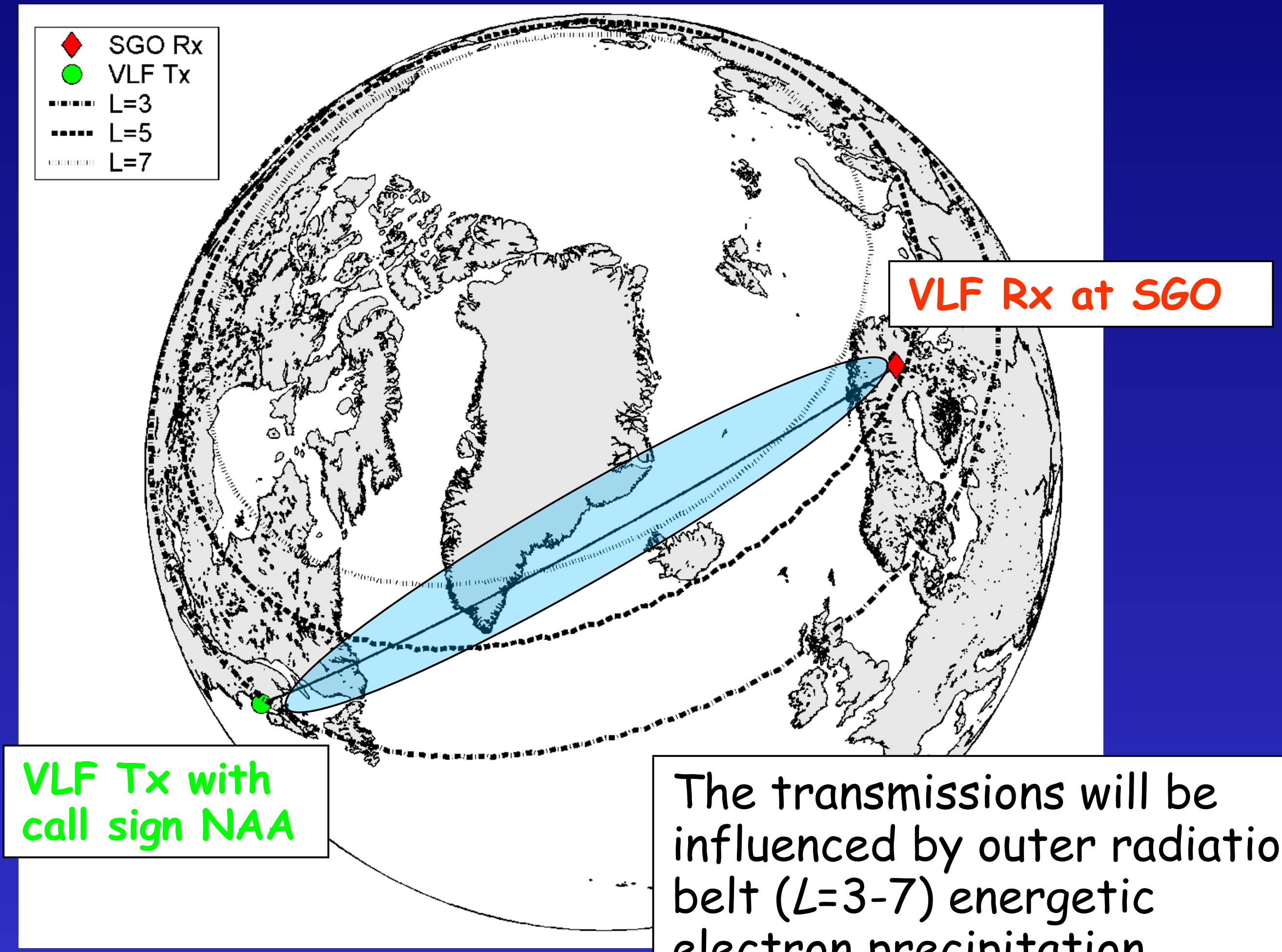






Concentrate on NAA-SGO Path

In our study we make use of AARDDVARK subionospheric observations made by our receiver (Rx) running at the Sodankylä Geophysical Observatory (SGO). Focus on observations from NAA.



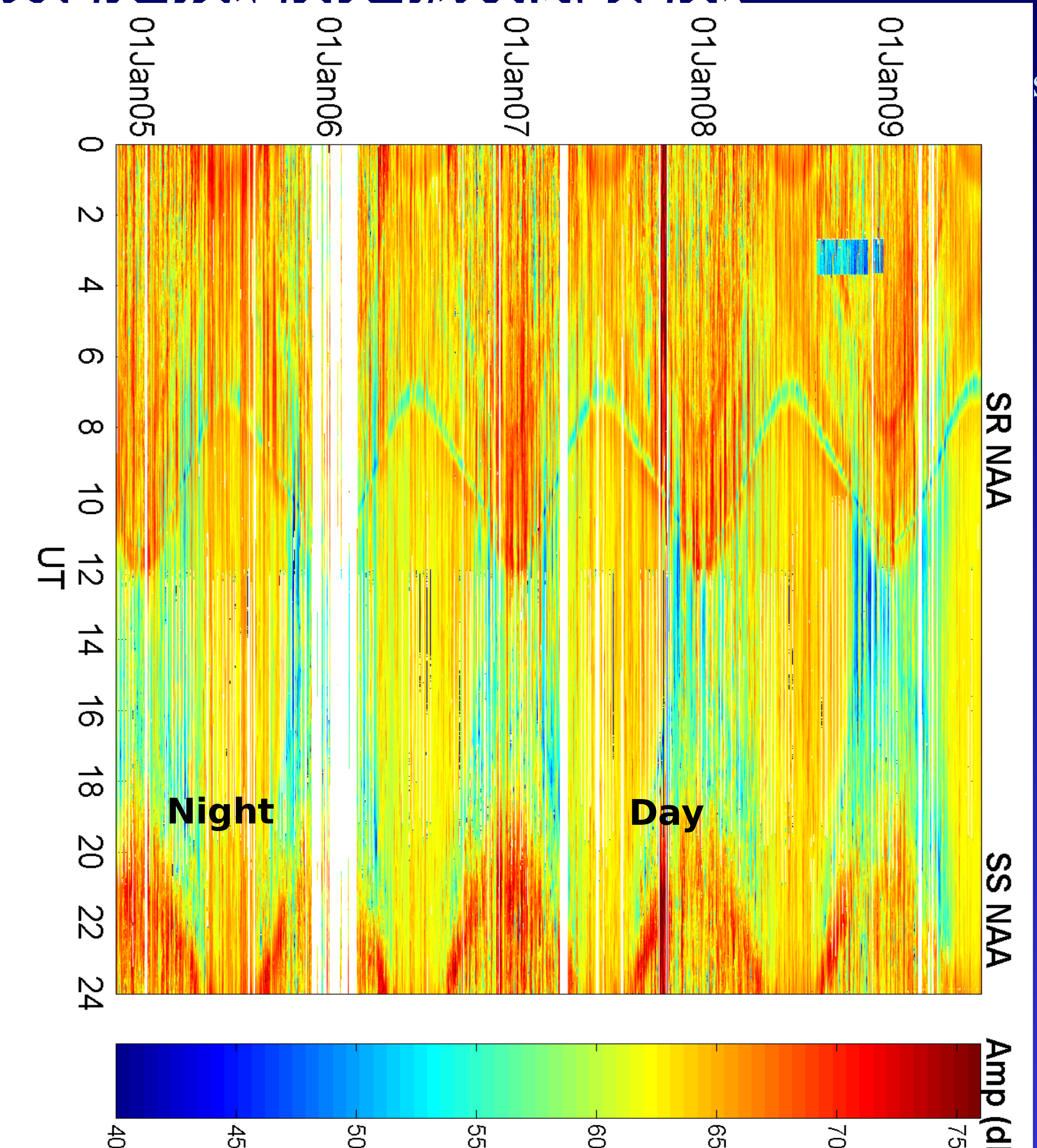
The transmissions will be influenced by outer radiation belt (L=3-7) energetic electron precipitation.

Ener

Amplitude of NAA rece s.

SR NAA= Sunrise NAA

SS NAA = Sunset NAA



Challenge is to extract changes produced by e-precipitation from the normal seasonal variation!

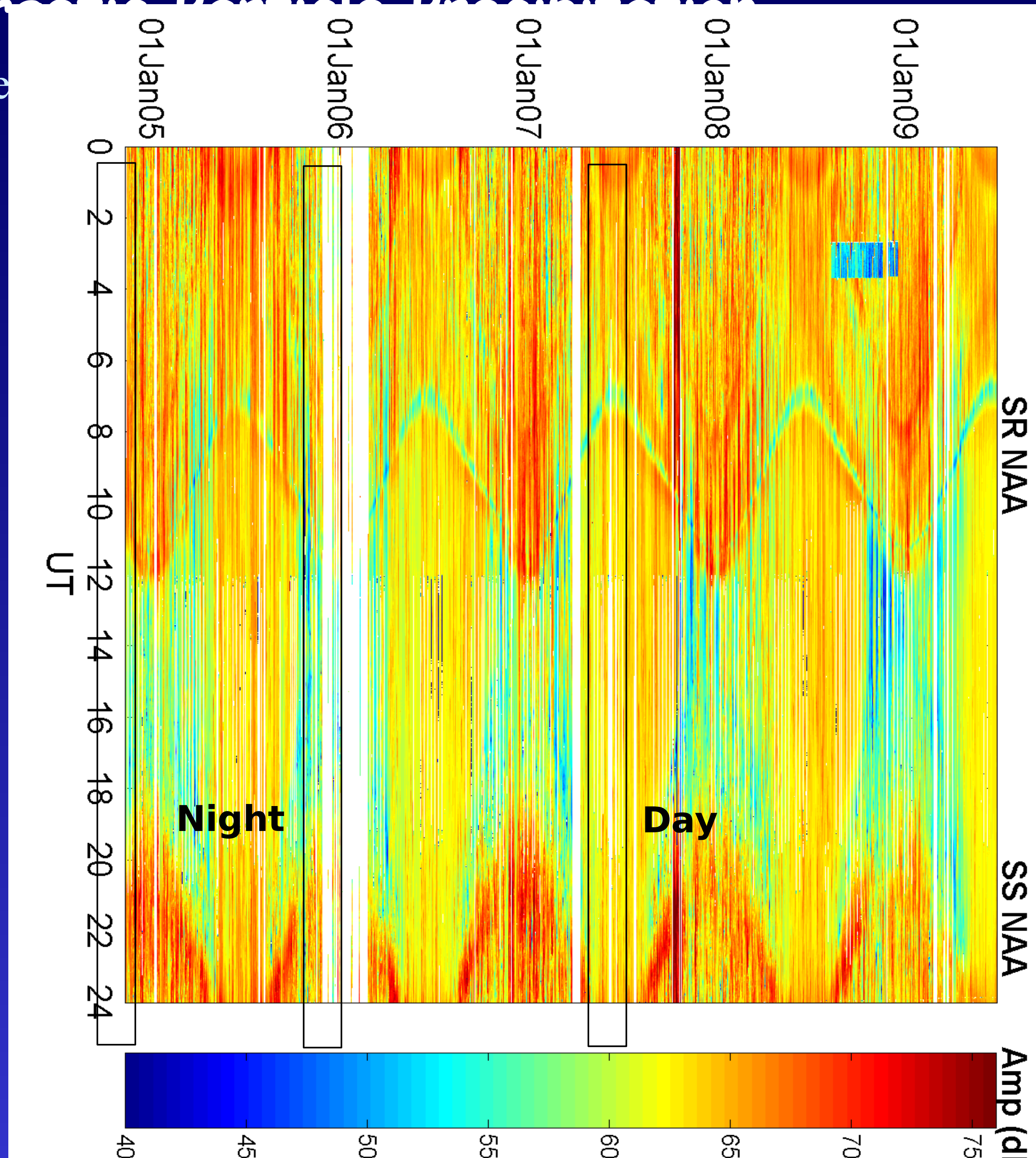
Energetic Particle Precipitation

Amplitude of NAA rece ... s.

SR NAA= Sunrise NAA

SS NAA = Sunset NAA

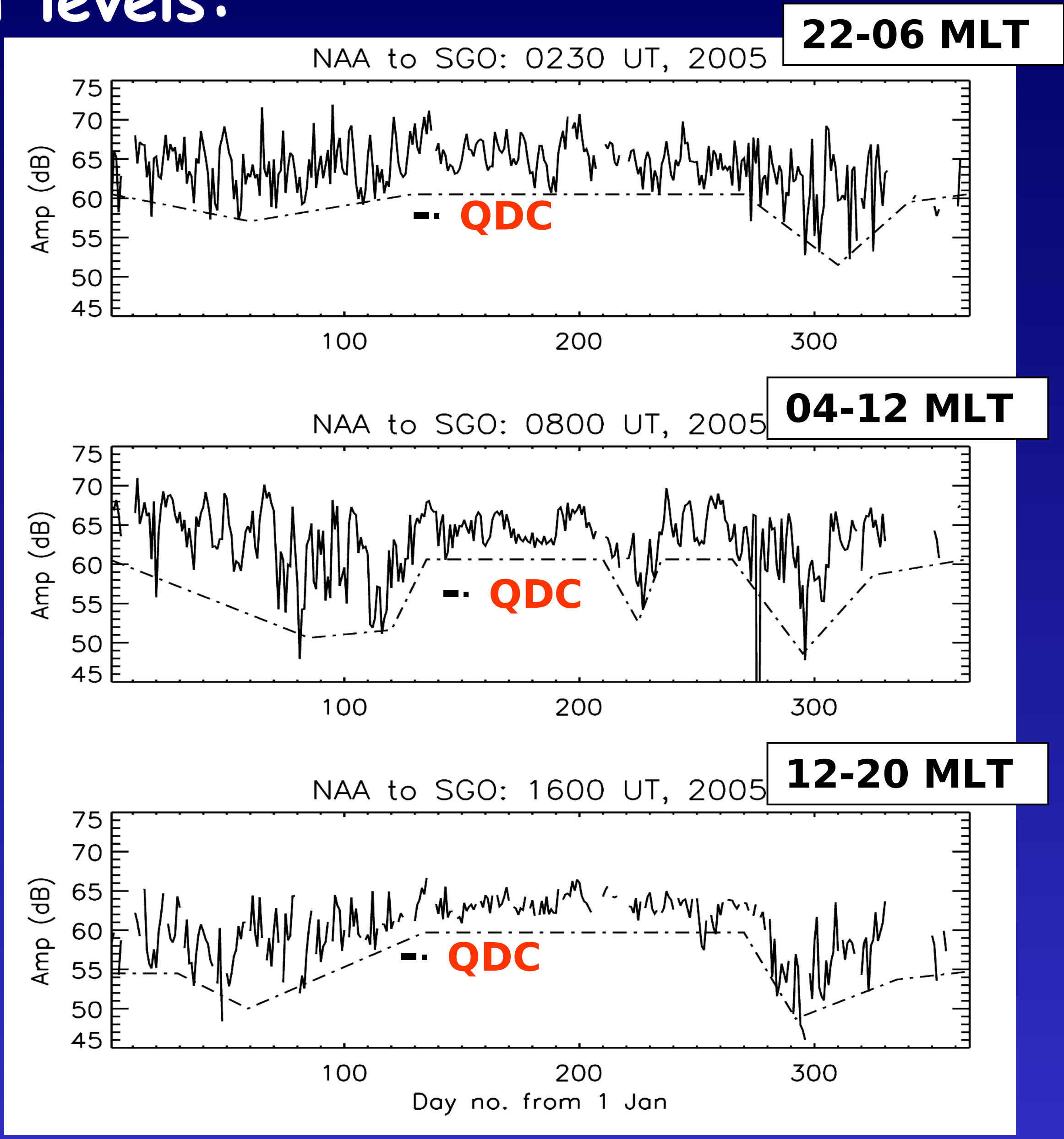
Challenge is to extract changes produced by e-precipitation from the normal seasonal variation!



Identify the Quiet levels:

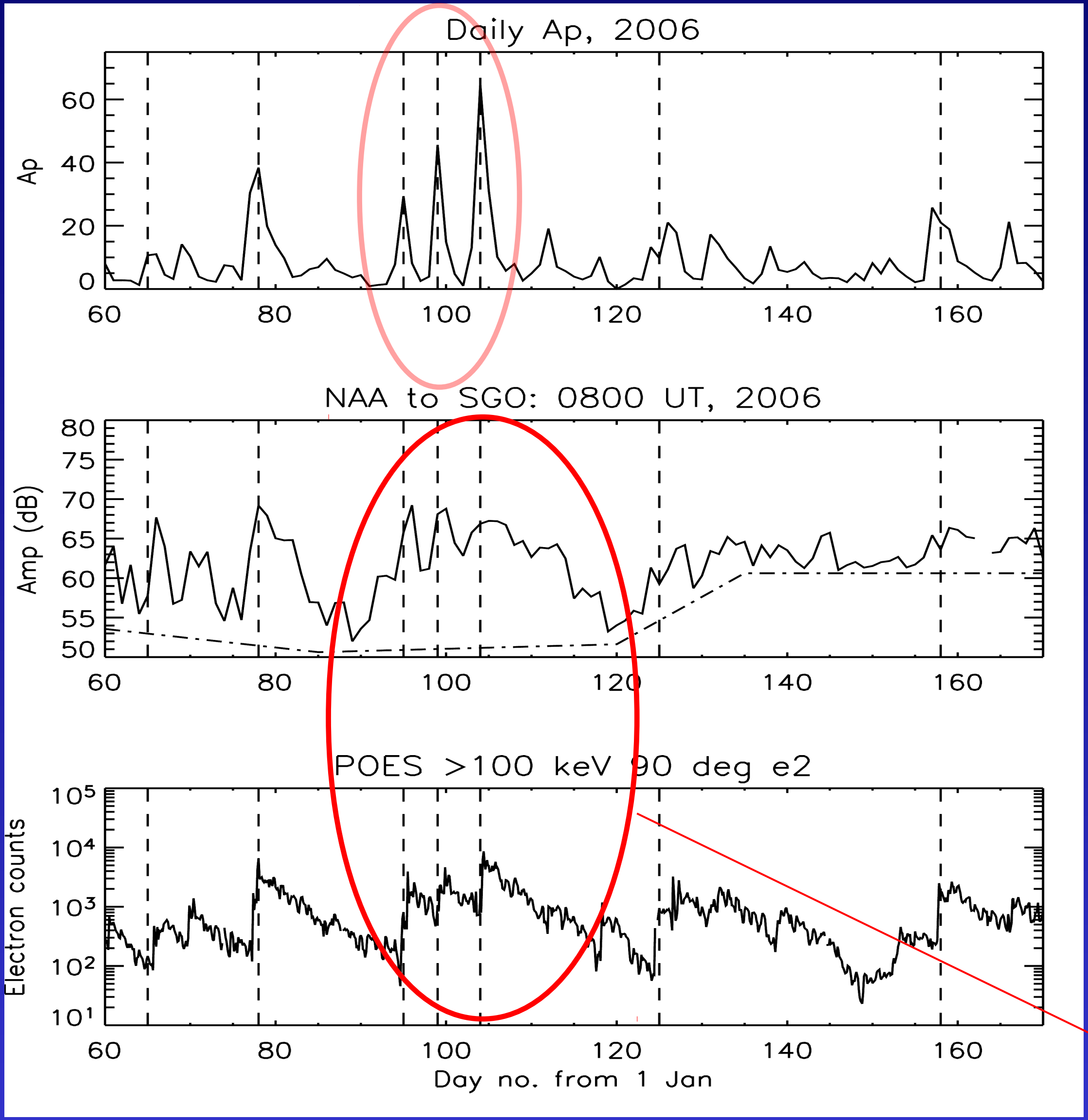
To determine the changes in received amplitude caused by particle precipitation, we need to identify the "Quiet Day Curve" (QDC), the seasonal variation in quiet time amplitudes. We do this from the 2005-2008 data during truly quiet times (minimal precipitation).

During the "summer months" the QDC is essentially the same for all times at ~60.5dB.



Example of Space weather (storm) responses

Geomagnetic storms (through Ap) lead to enhanced radiation belt fluxes (in the POES 90° telescope) and appear in the NAA-SGO observations as enhanced amplitudes.



Mean Ap, correlates well with start of RB enhancement and precipitation but not the intensity or duration.

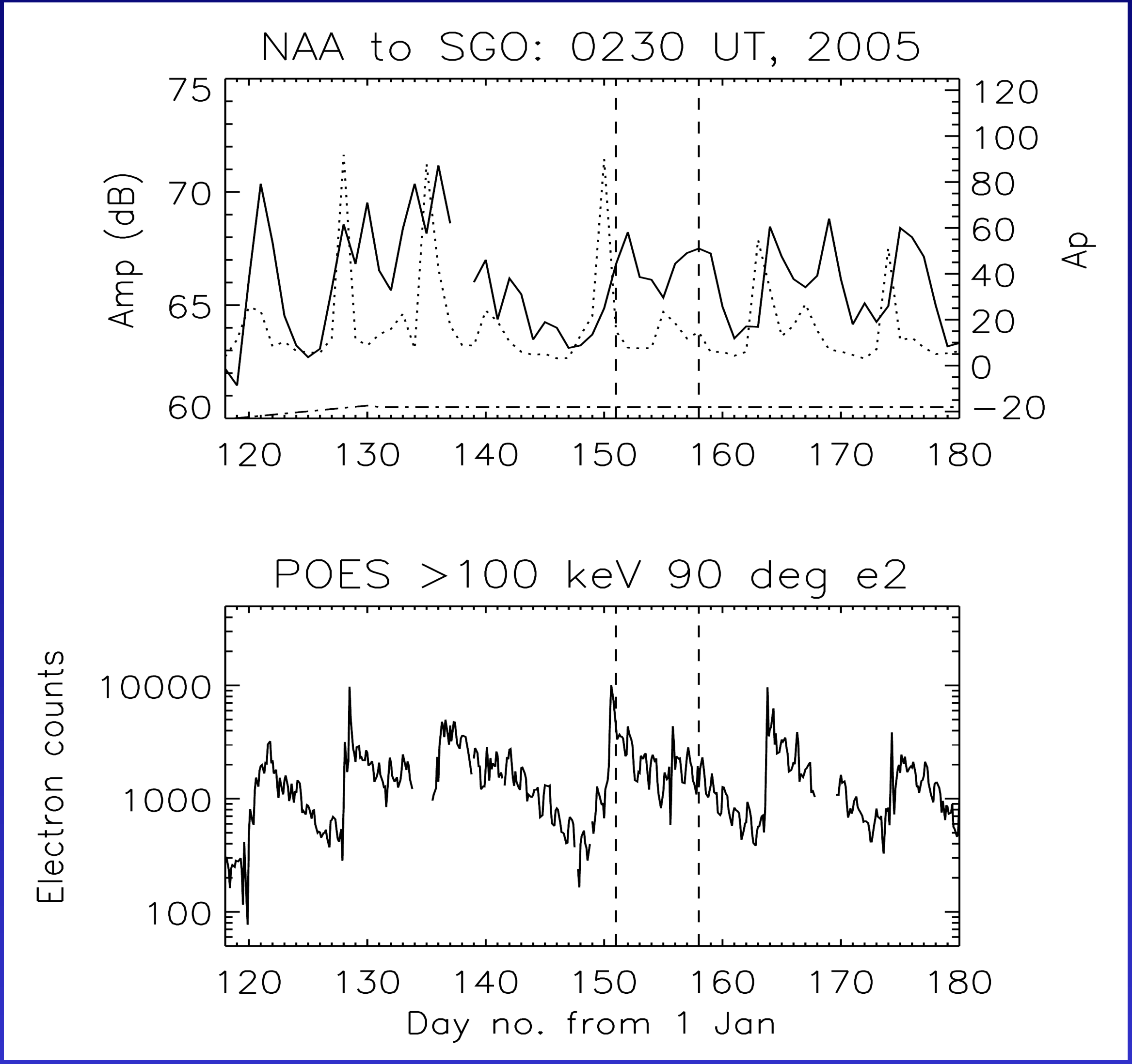
NAA-SGO variation in 8UT hourly amplitudes

POES *L*=3-7 trapped and quasi-trapped fluxes (>100keV).

Ap recovers but electron precipitation and POES enhancements take

Another example of Space Weather

NAA-SGO precipitation monitor and the POES “trapped” fluxes can respond to big and small changes in geomagnetic activity (Ap), and the time-duration is very poorly represented by Ap.



Mean Ap is dotted, solid is NAA-SGO amplitude.

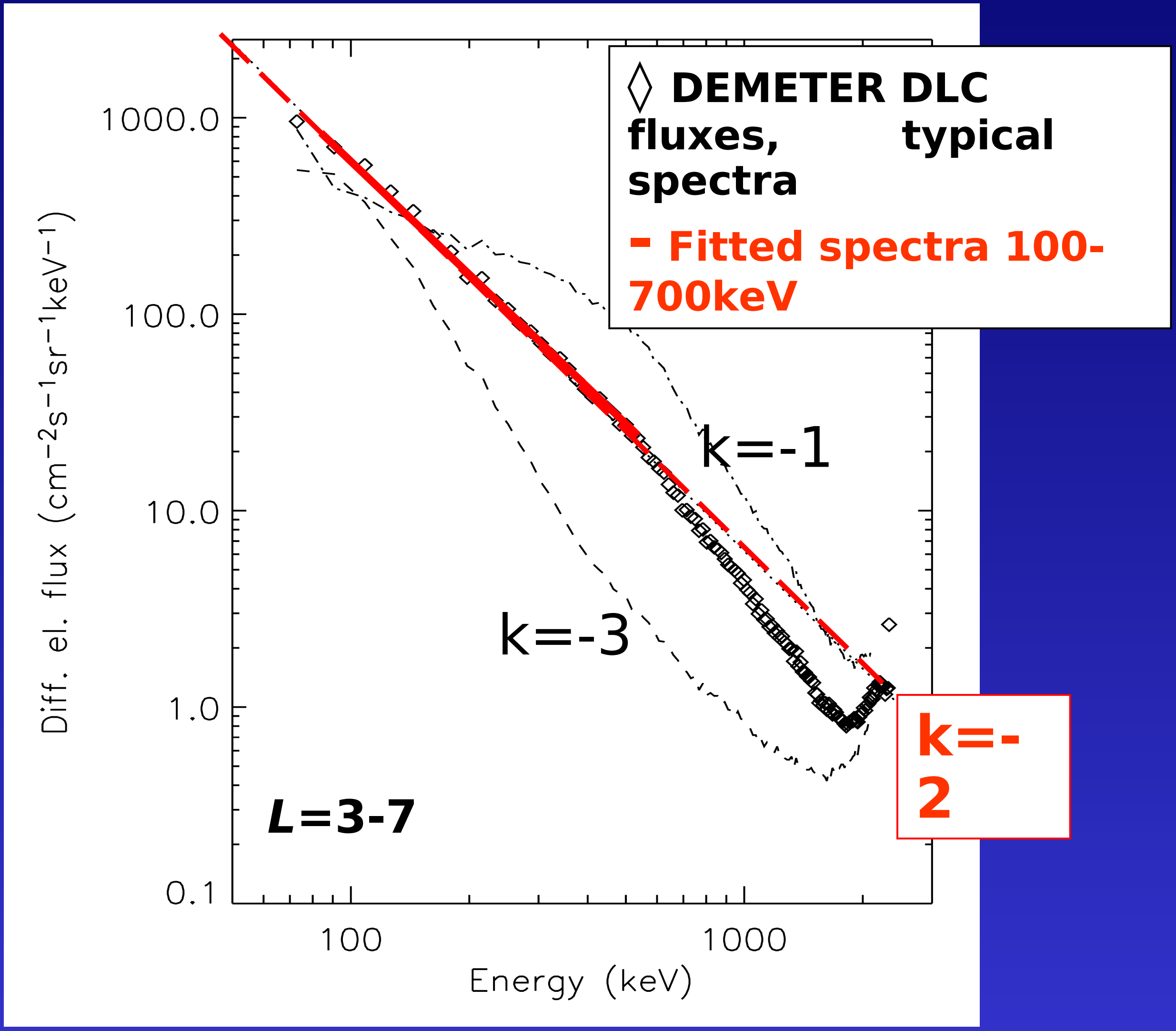
It is not clear Ap is a good proxy to represent accurately energetic electron precipitation inside atmospheric models (sometimes done).

Precipitation Energy Spectra from DEMETER

We fit the DEMETER 3<L<7 DLC fluxes by a power law, and find that the typical flux variation with energy up to 700keV is best described through a power law with slope of k=-2 ±1.

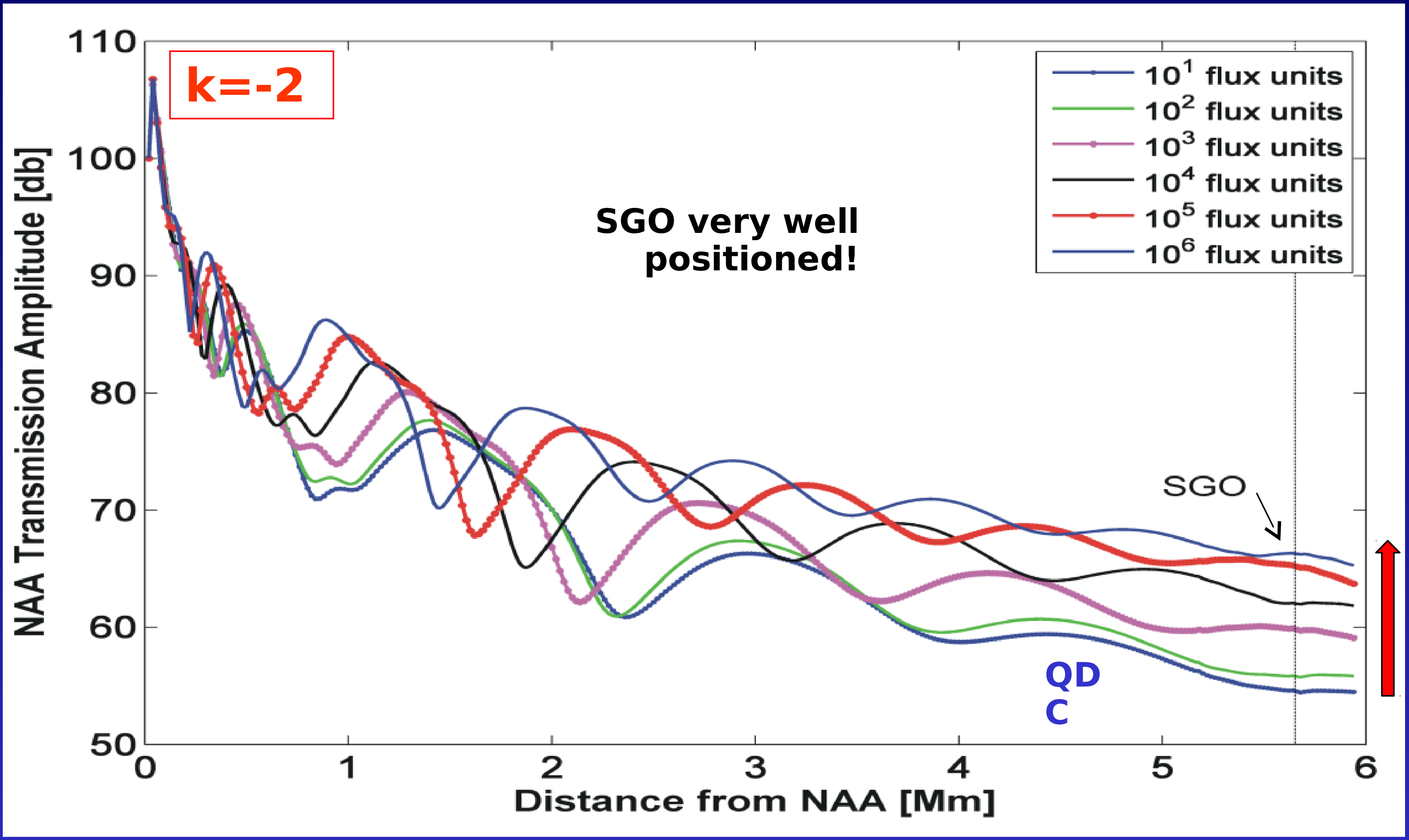
Now we need to convert NAA amplitude to fluxes:

Two unknowns - spectra and flux



Flux ∝ $10^{k \log(E)}$

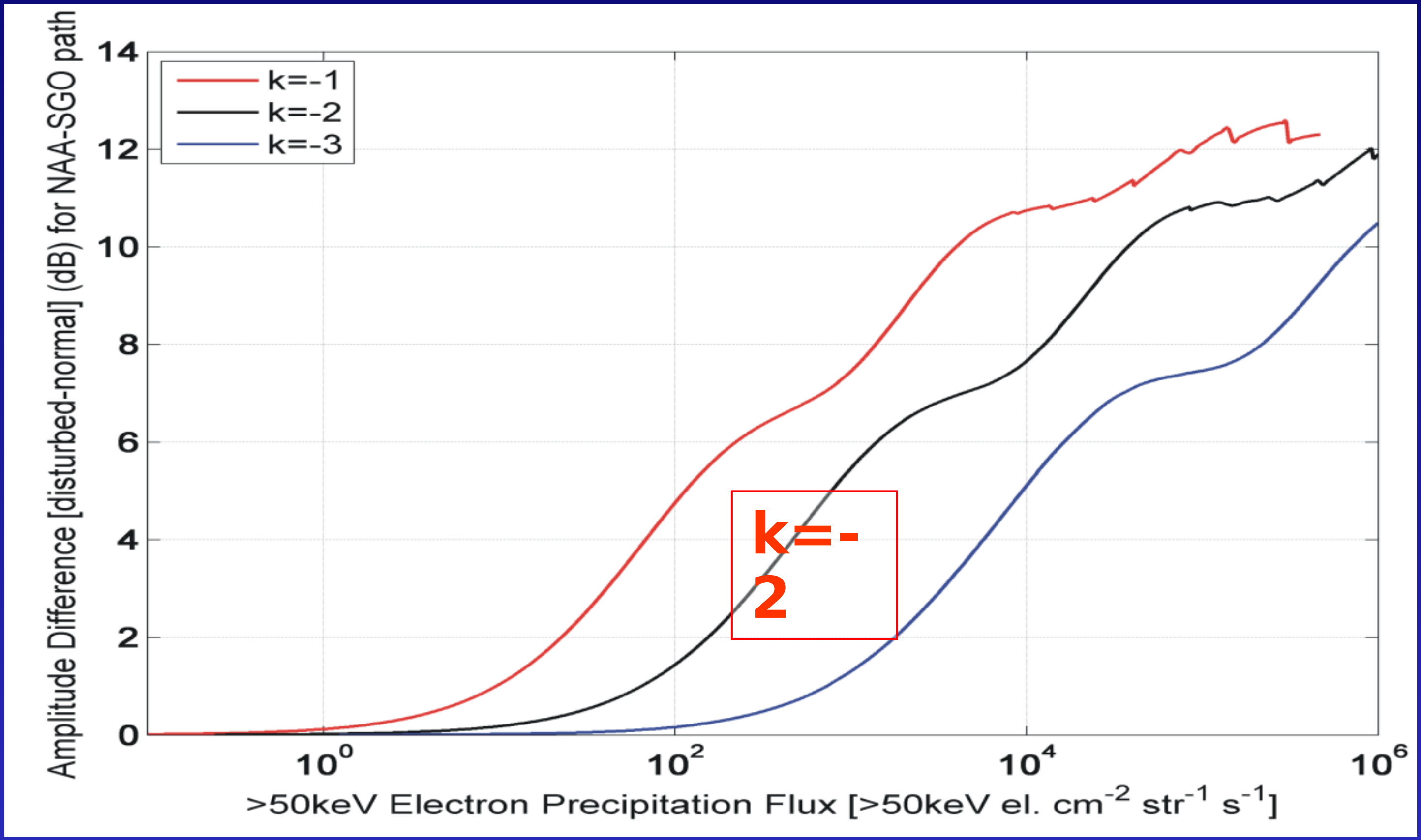
Modelled Response to Precipitation



Some distances have jumbed responses to flux increases, but not SGO, or ~1 Mm

Modelled Response to Precipitation

Use LPWC propagation code and simple ionospheric chemistry model to determine the expected NAA@SGO amplitude response to differing electron precipitation flux magnitudes.

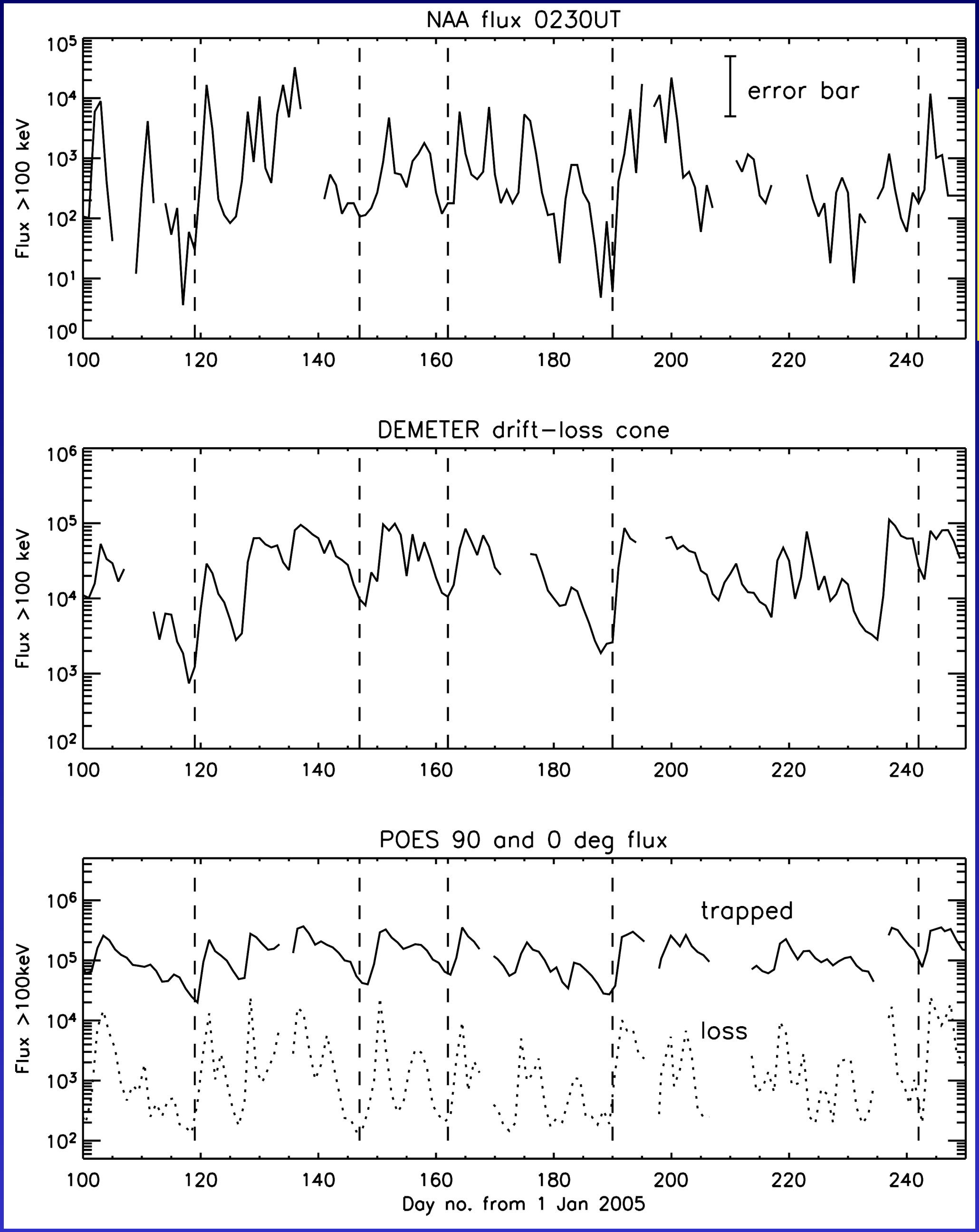


From this well behaved behaviour we can construct a lookup table, which tells us what amplitude change corresponds to what precipitation flux.

Resulting Precipitation Fluxes from NAA@SGO

k=-2

NAA@SGO precipitation fluxes are larger and smaller than POES loss fluxes



150 days of precipitation flux measurements from the AARDDVARK receiver at SGO.

Variation in the DEMETER DLC electron fluxes in the same period.

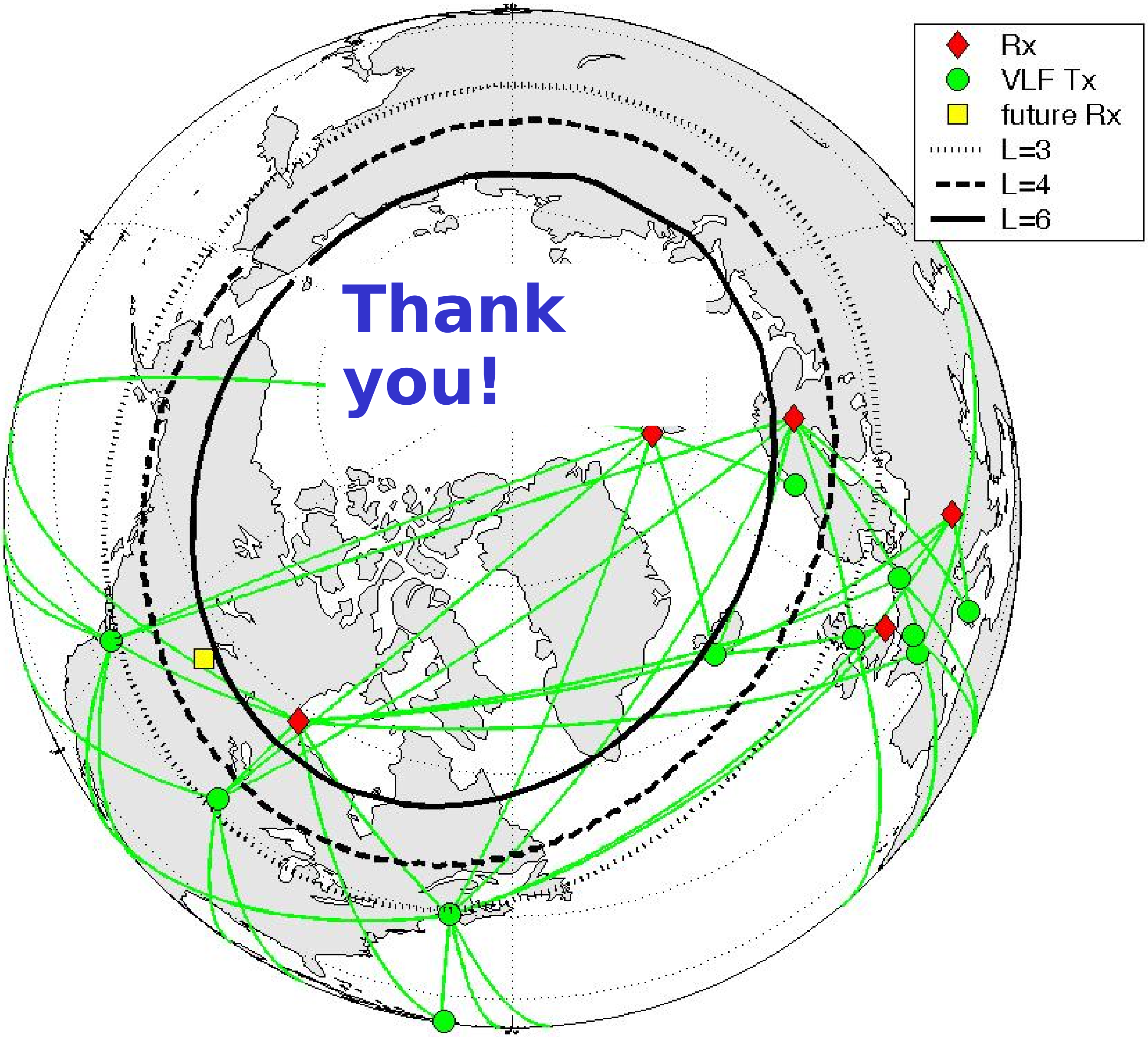
Variation in the POES "trapped" and BLC electron fluxes in the same period.

Global not regional fluxes

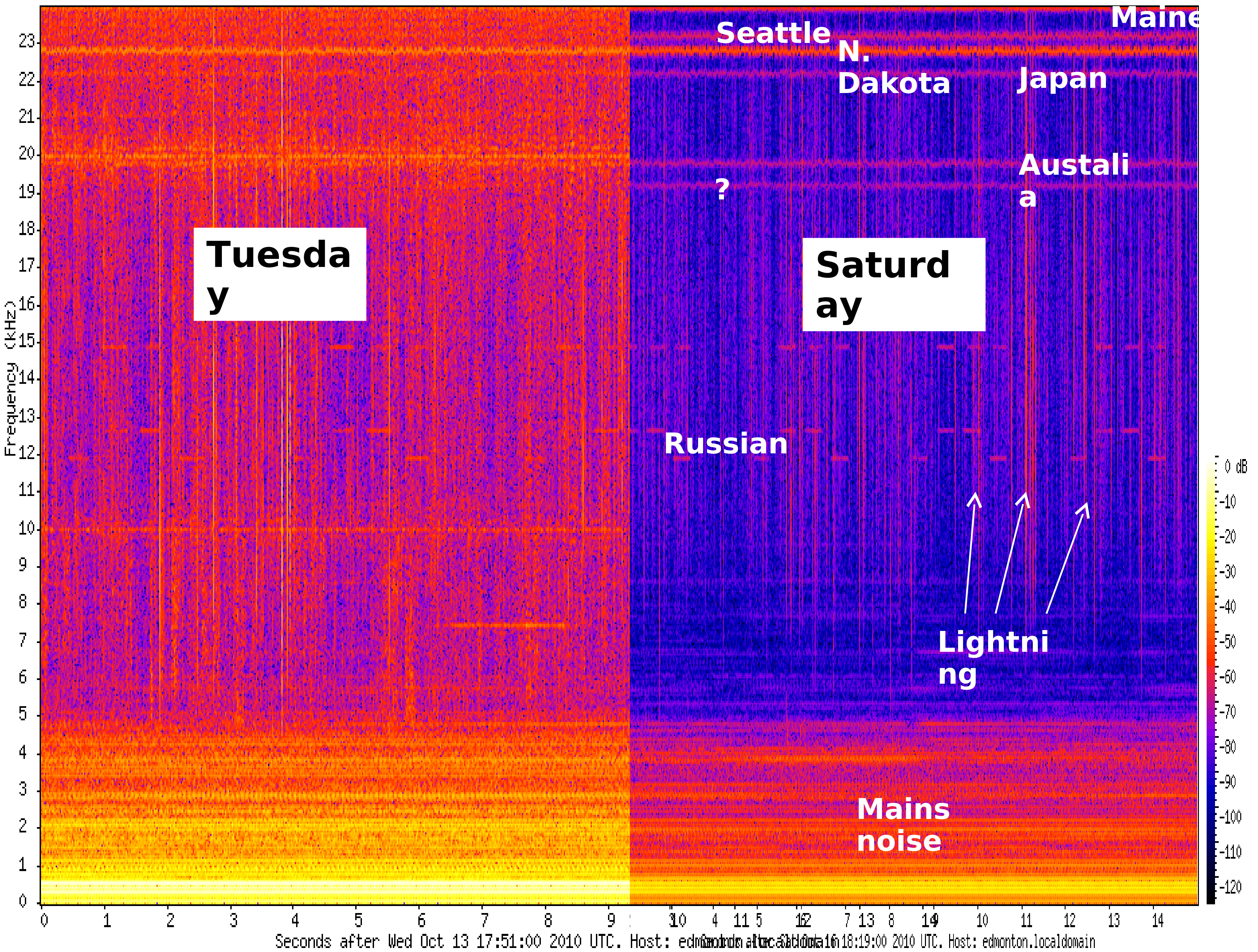
Summary and Next Steps

- **The analysis of AARDDVARK amplitude variability has the potential of providing a detailed, near real-time, picture of energetic electron precipitation fluxes from the outer radiation belts – good for atmospheric modelling.**
- Test the precipitation fluxes derived from the AARDDVARK NAA-SGO measurements against other instruments which can detect precipitation (like riometers).
- **Work towards the goal of making a "LEVEL2" product – a near-real time precipitation monitor available on the world wide web from this data source.**
- AARDDVARK: a great opportunity to study loss processes in the radiation belts, and the generation of excess ionisation in the D-region, through the impacts of Space Weather.

AARDDVARK Network



Thank you!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