Ground-based estimates of outer radiation belt energetic electron precipitation fluxes into the atmosphere

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

Energetic Particle Precipitation

There are multiple "important" questions which need to be answered to understand RB-losses & the significance of Energetic Particle Precipitation.

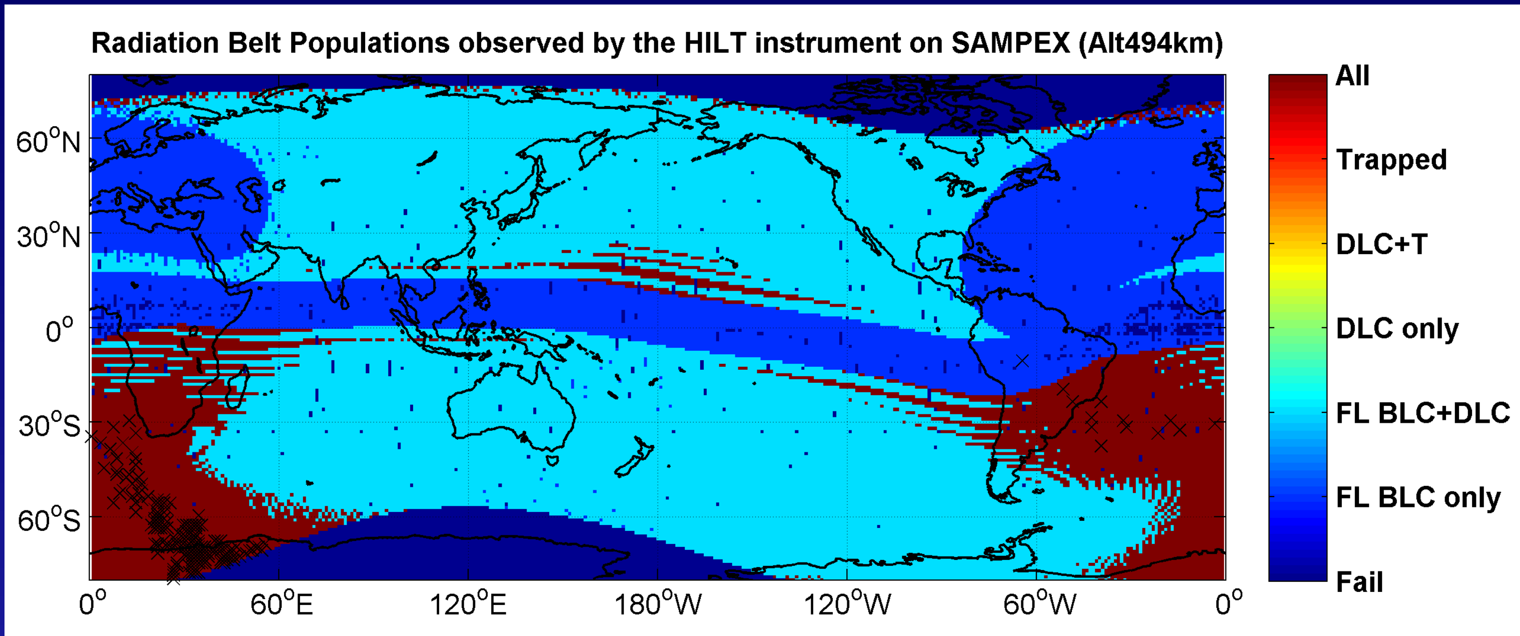
In order to drive atmospheric, ionospheric and coupled chemistry models, researchers would like access to long-time scale databases of time resolved particle precipitation measurements. **There is a gap for observations of precipitation of electrons at energetic (>10keV) and relativistic (>300keV) energies.**

Ones first instinct is to turn to satellites to provide these.

However, there is currently no appropriate satellite database available!

Tricky because of the complexity in measuring electron fluxes unambiguously in the whole bounce-loss cone without contamination from fluxes in the drift-loss cone or trapped fluxes.

SAMPEX and DEMETER

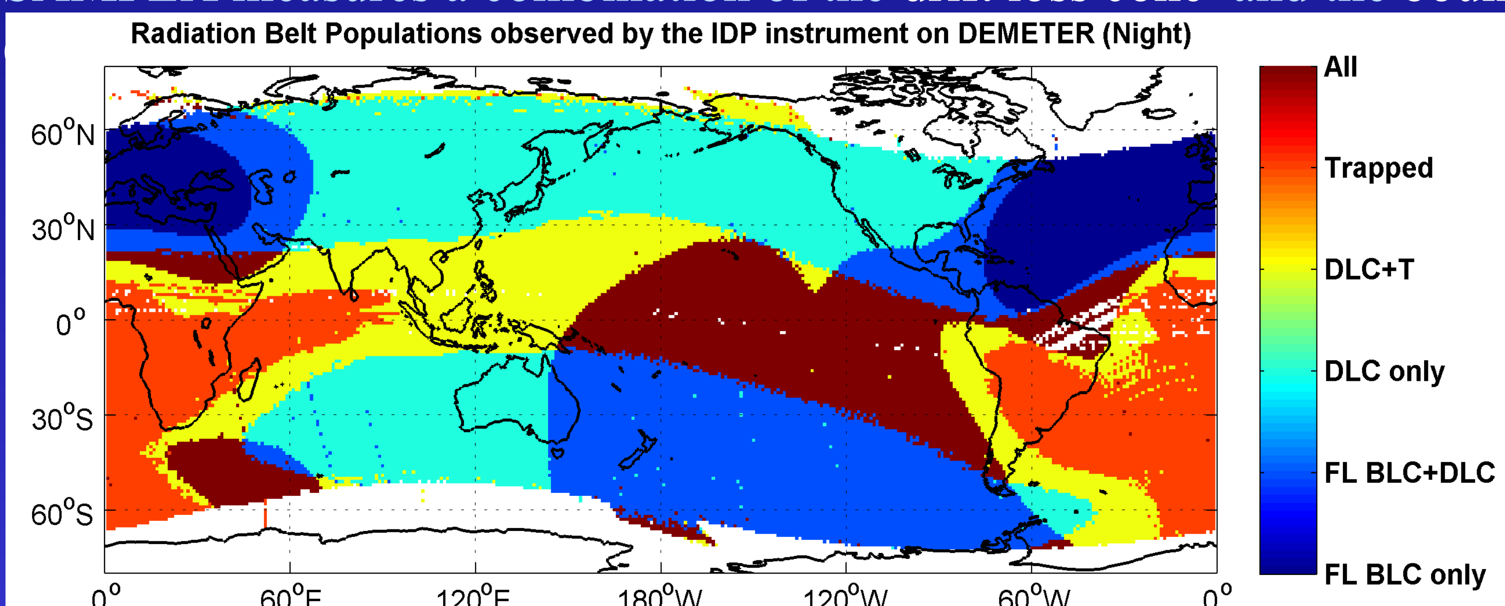


T=Trapped

DLC=Drift Loss Cone

FL BLC=Field Line Bounce Loss Cone

SAMPEX measures a combination of the drift loss cone and the bounce loss cone



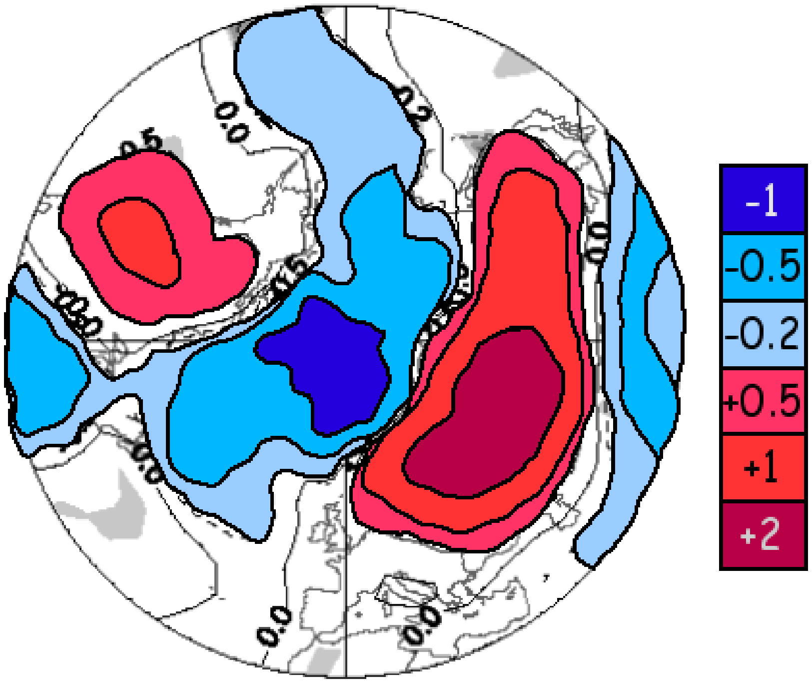
High Ap – low Ap

Why do we care?

The data: North

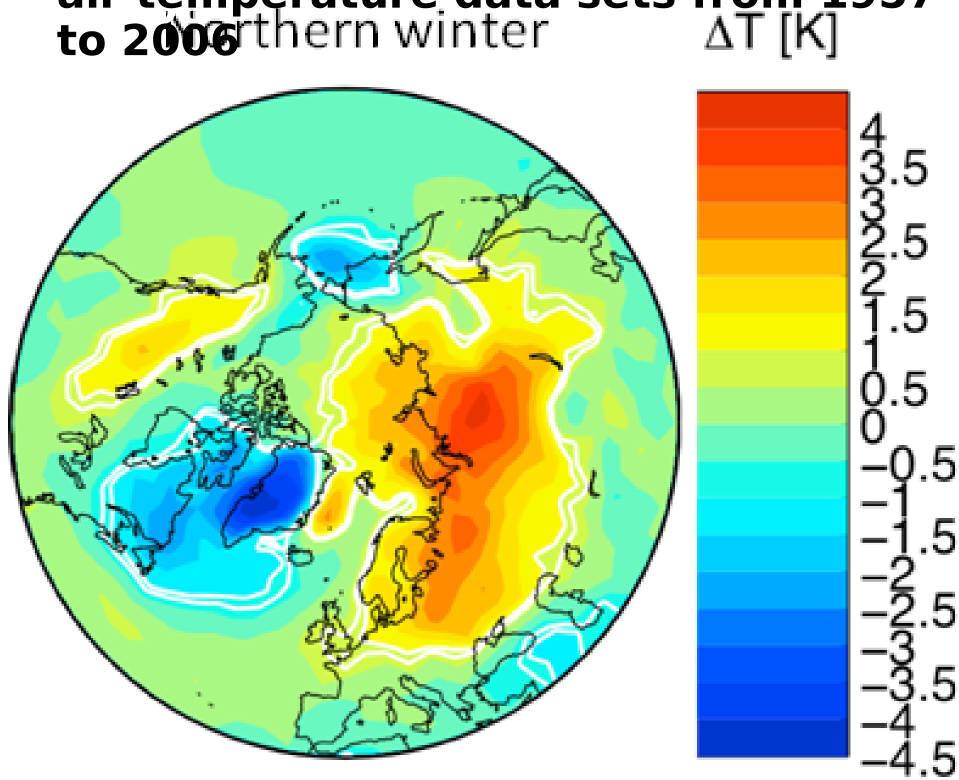
Model results

Northern Winter



Rozanov et al., 2005

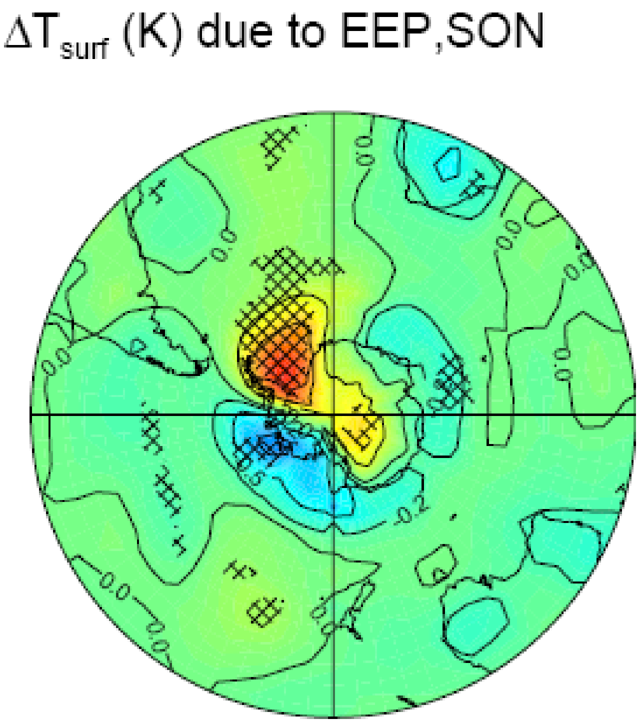
ERA-40 and ECMWF operational surface level air temperature data sets from 1957 to 2006

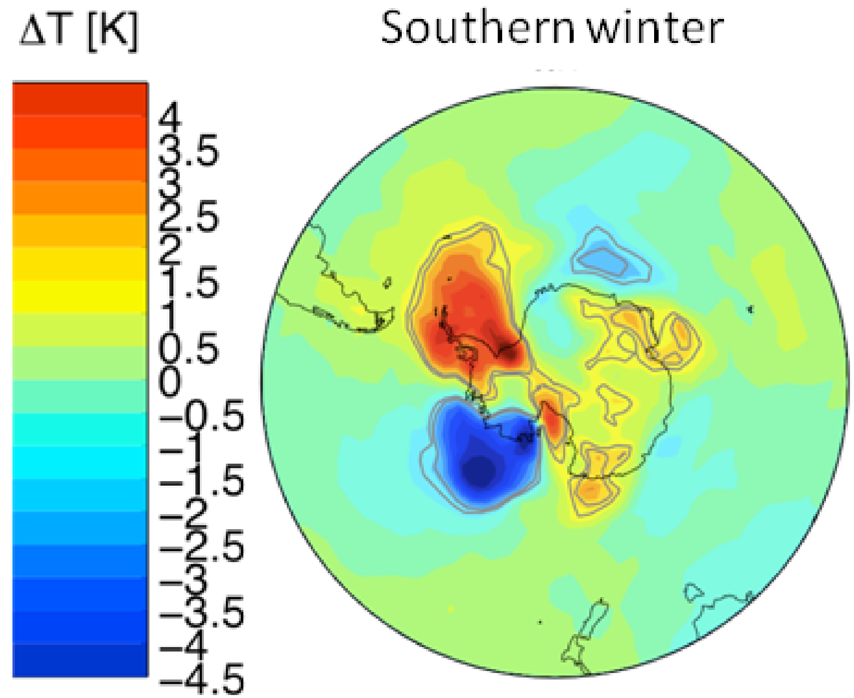


Seppälä et al., 2009

The data: South

High Ap – low Ap

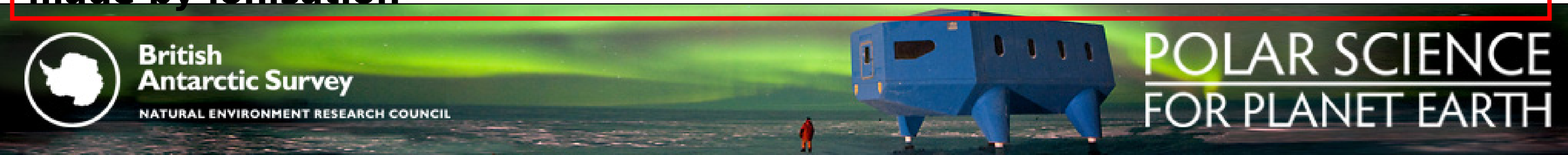




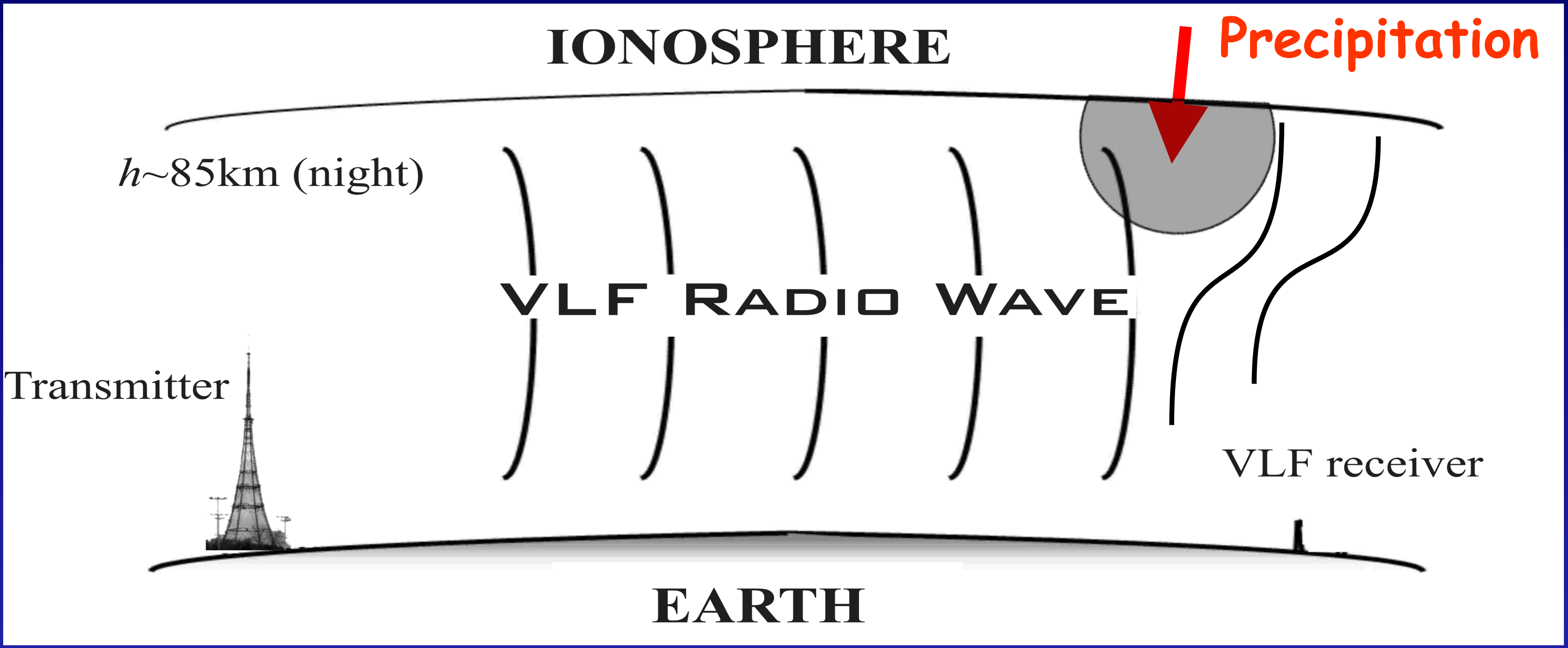
Based on Rozanov et al., 2005

Seppälä et al., 2009

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



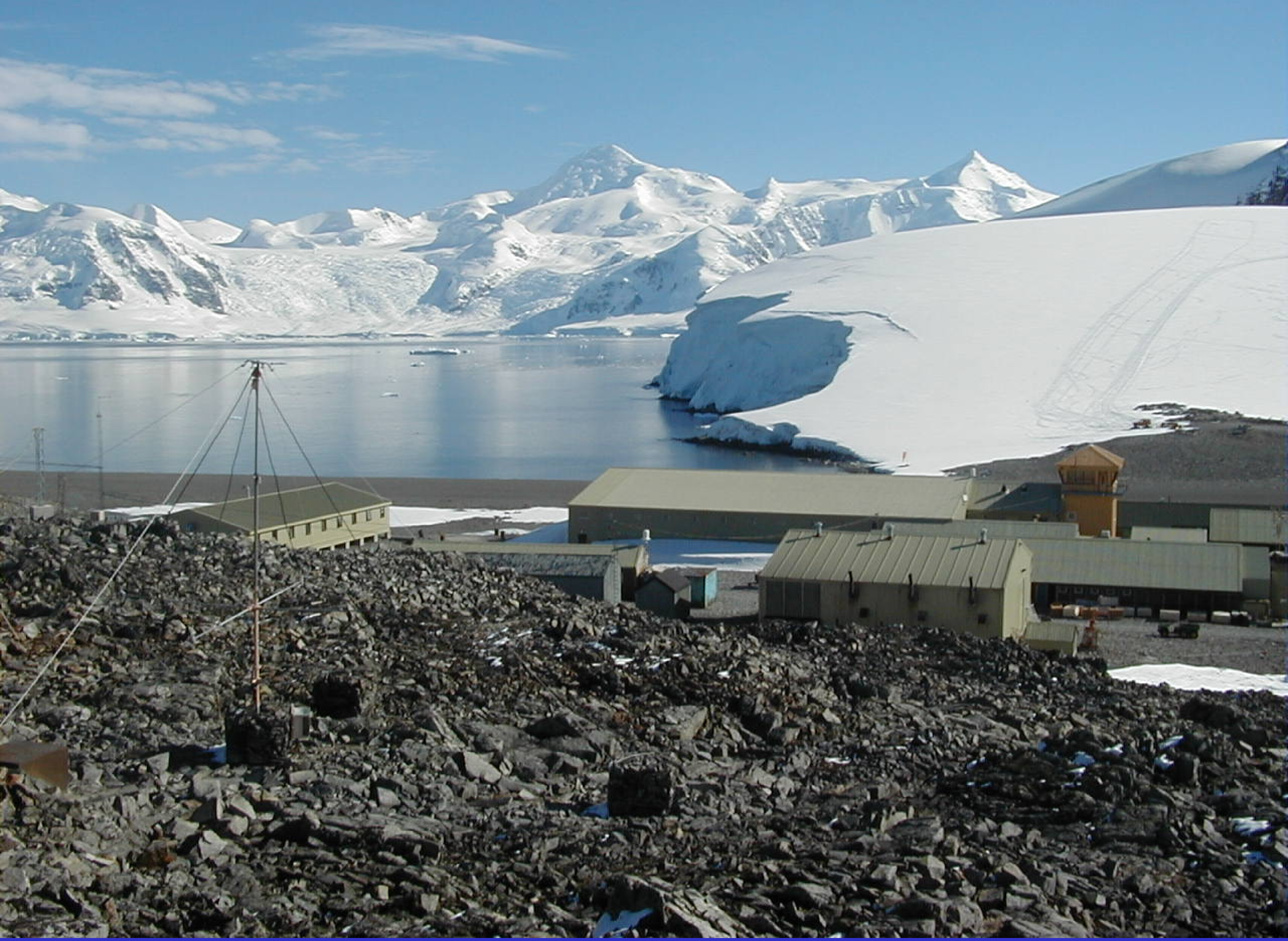
Lets use the ionosphere as a precipitation detector: Subionospheric Radio Wave Propagation



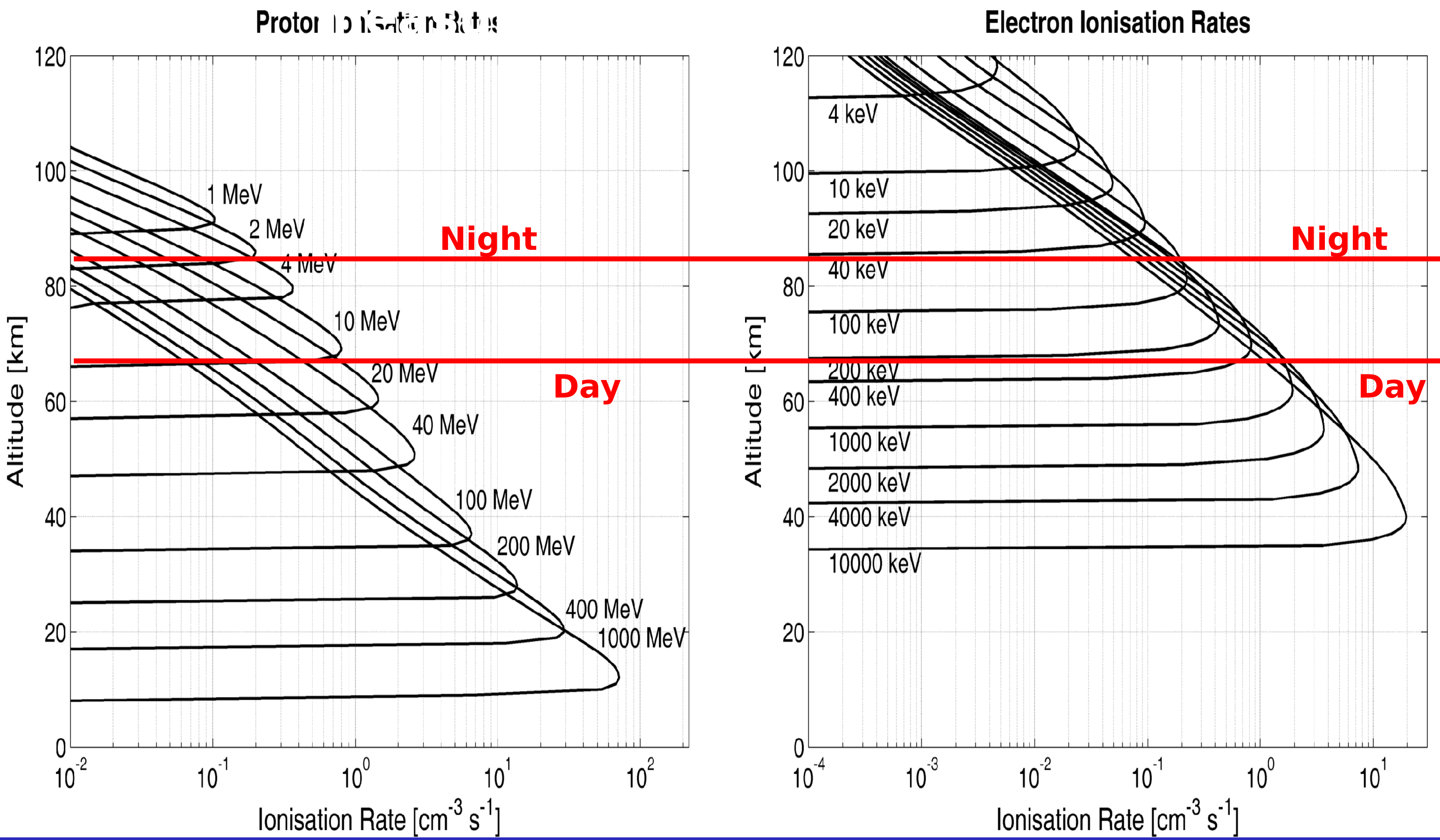
Radio transmissions at Very Low Frequencies (VLF) largely trapped between the conducting ground (or sea) and the lower part of the ionosphere (70-90 km) , forming the Earth-ionosphere waveguide.

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!

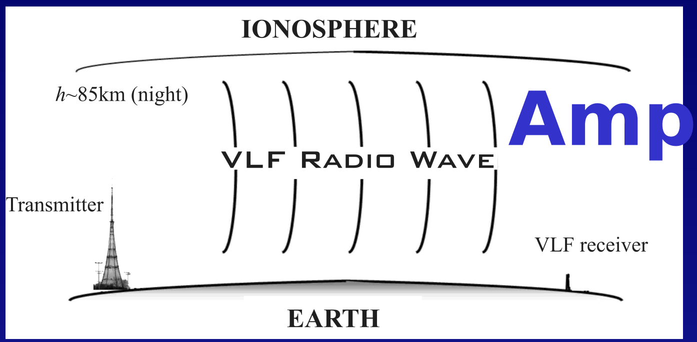
The NAA transmitter
24.0 kHz
1 MW output power
Big, expensive!



What energies do we



Our Goal: AARDDVARK VLF → Electron Precipitation Fluxes



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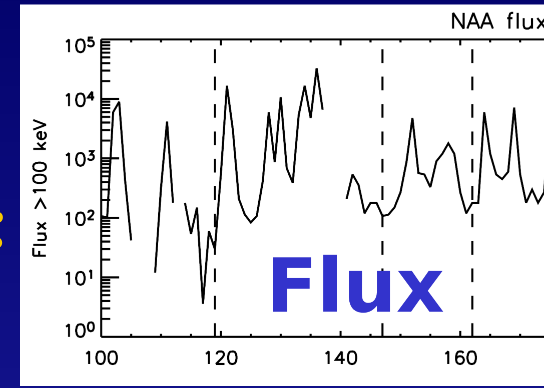


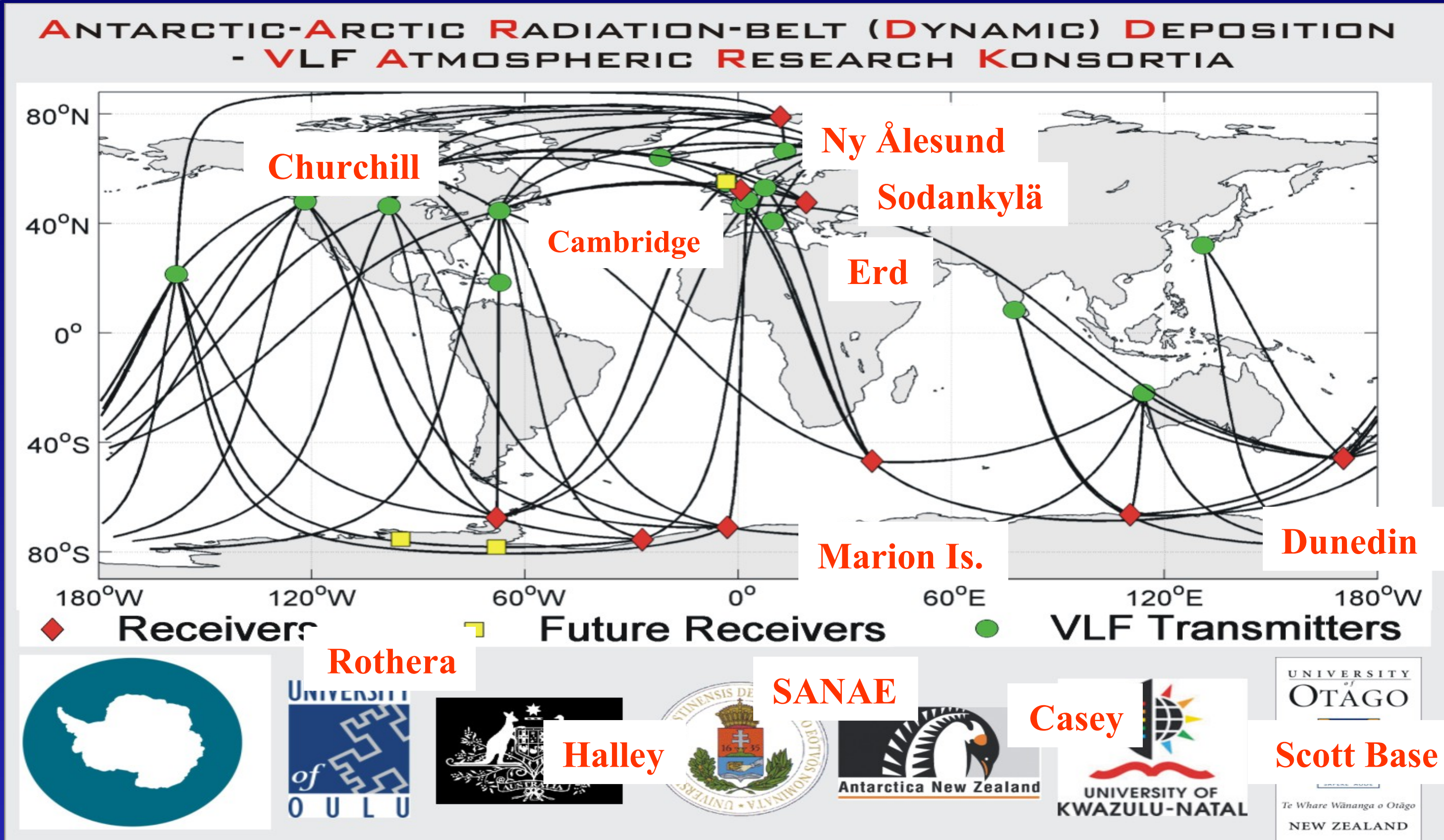
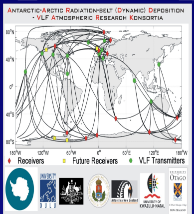
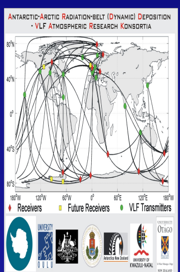
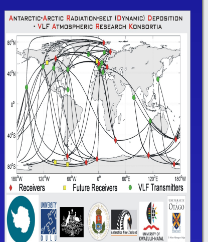
We are working towards <u>extracting</u> electron precipitation flux measurements from the AARDDVARK subionospheric VLF observations.

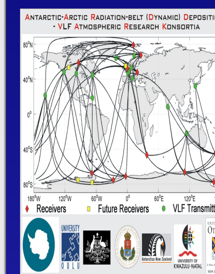
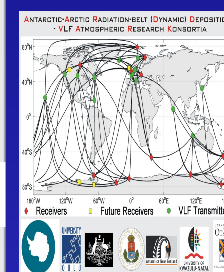
While satellites may struggle to measure the whole Bounce Loss Cone, the atmosphere is a detector of the true precipitation levels, and that is what AARDDVARK responds to.

Now working towards long-term continuous monitoring.

Clilverd et al., Ground-based estimates of outer radiation belt energetic electron precipitation fluxes into the atmosphere, JGR, doi:10.1029/2010JA015638, 2010.

Our AARDDVARK network of sub-ionospheric energetic precipitation monitors :

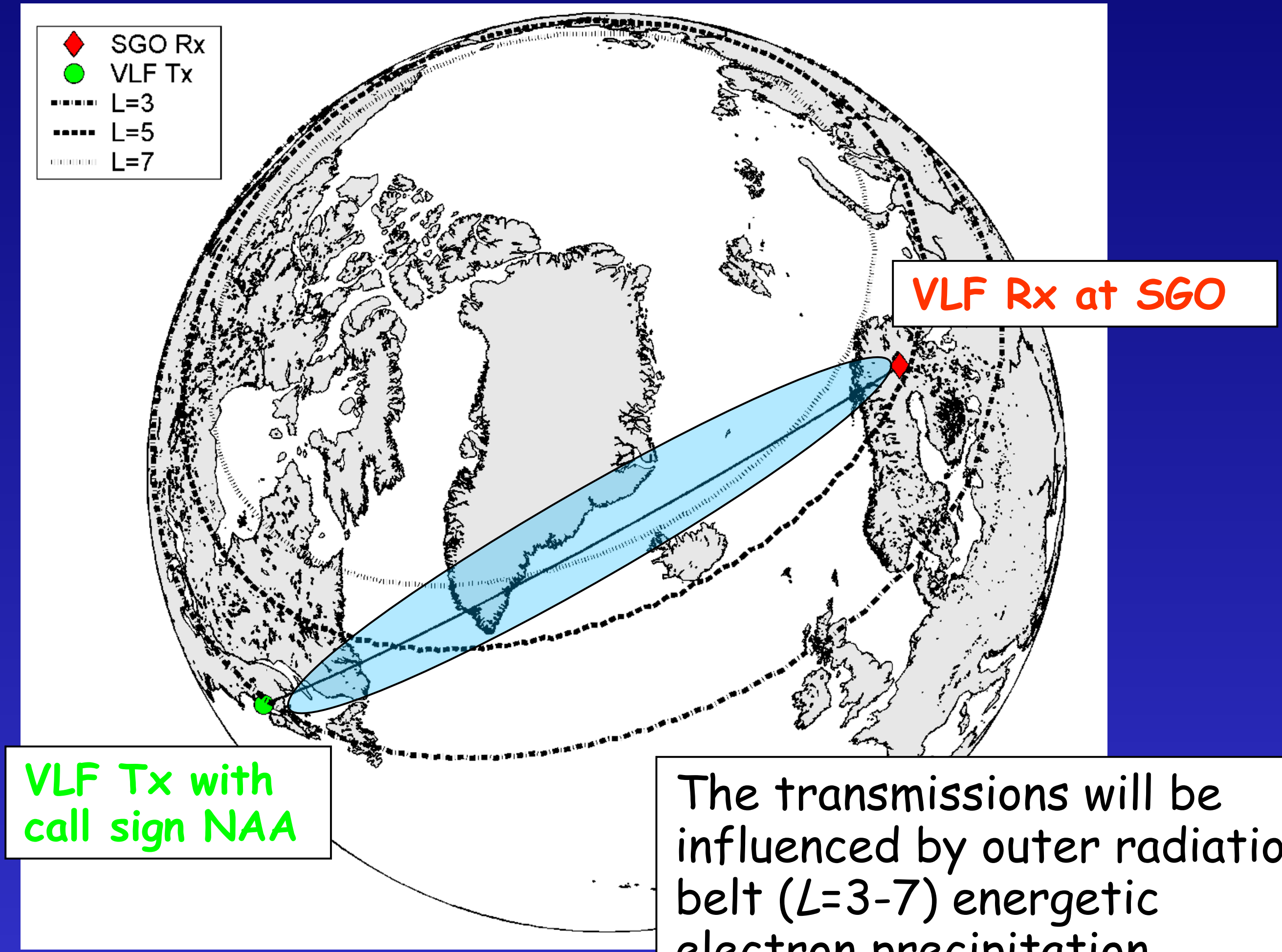




MORE INFORMATION:
www.physics.otago.ac.nz\space\AARDDVARK_homepage.htm

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

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.

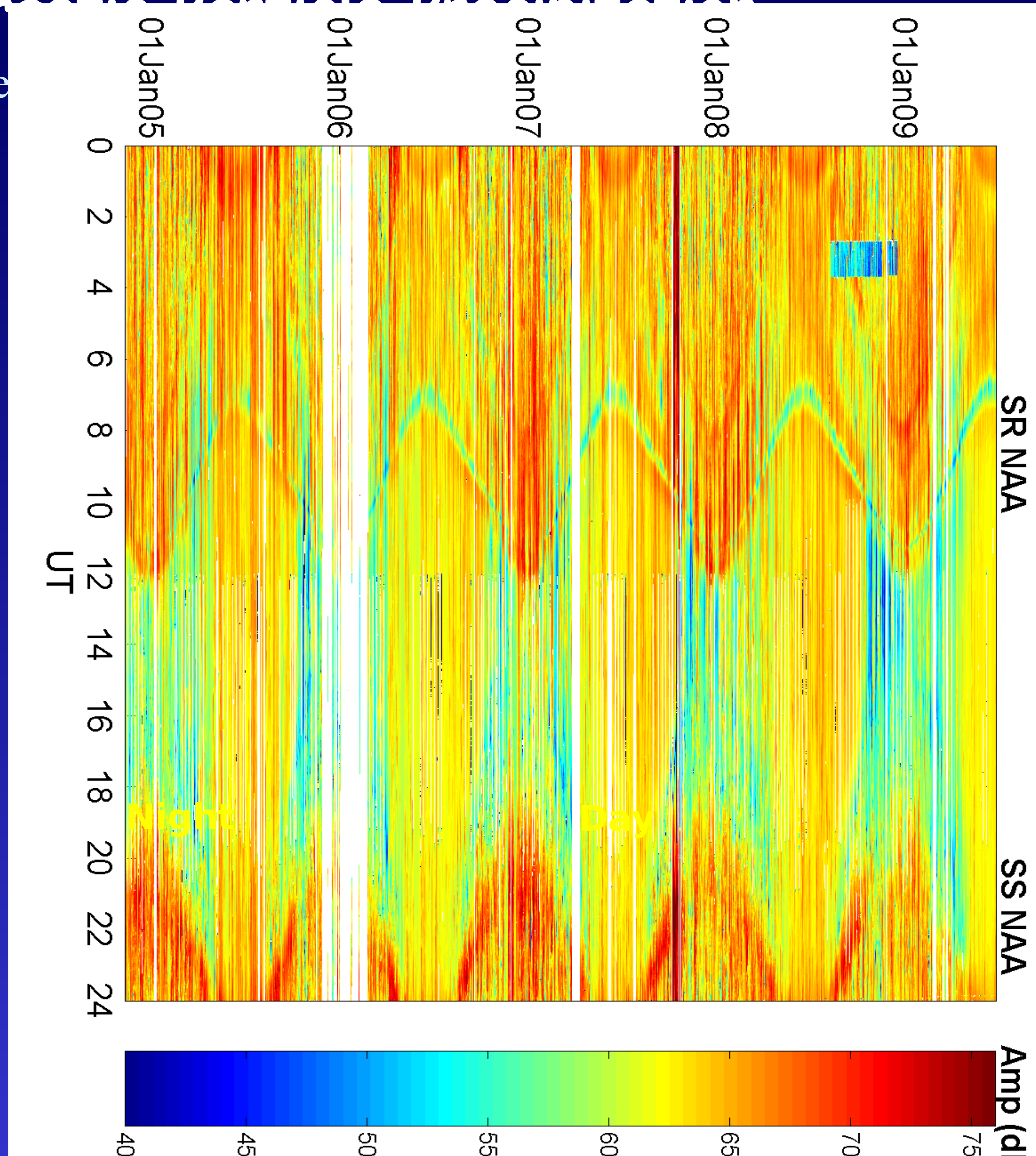
Ener

Amplitude of NAA rece … s.

SR NAA= Sunrise NAA

SS NAA = Sunset NAA

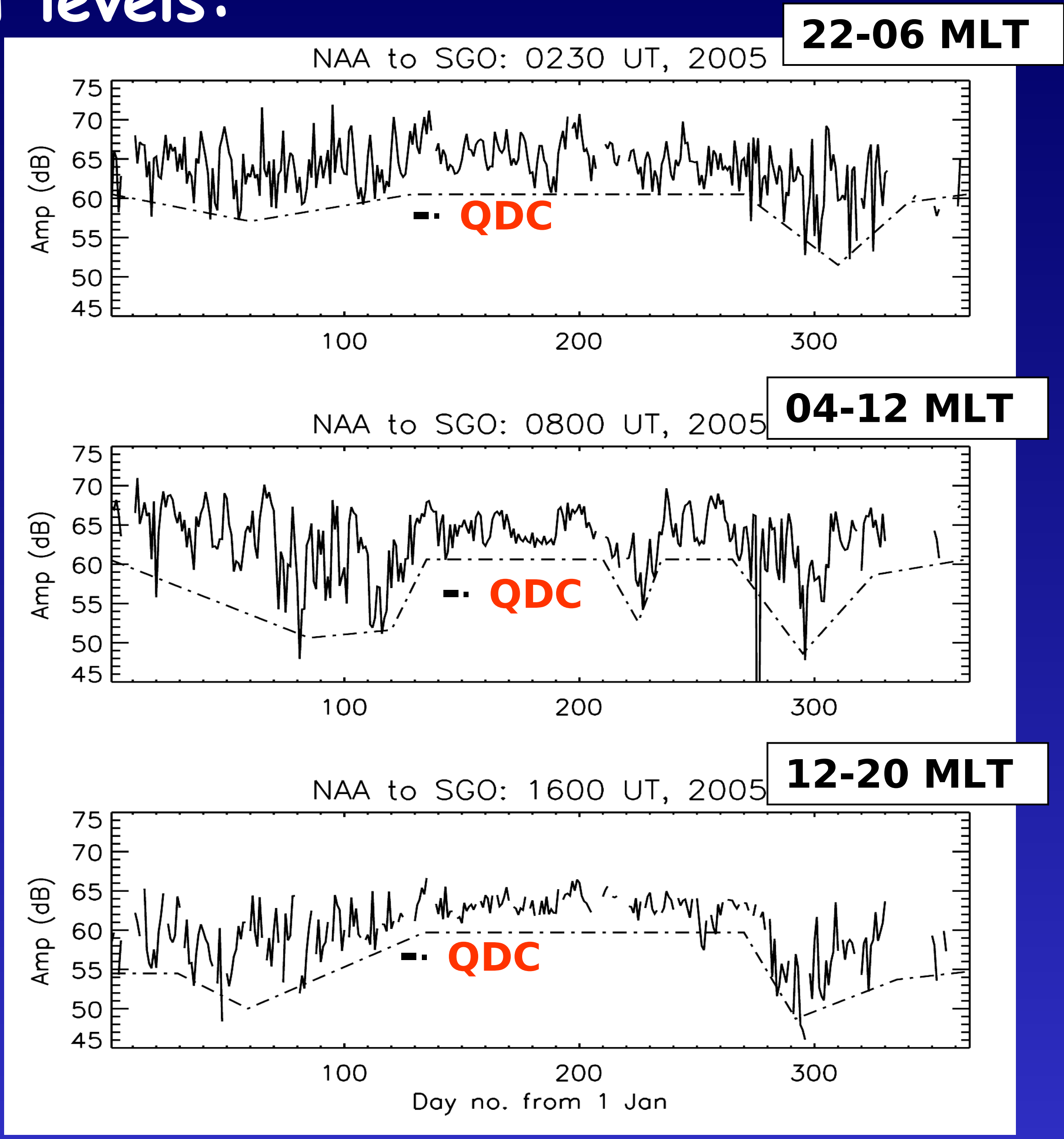
Challenge is to extract changes produced by e-precipitation from the normal seasonal variation!



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).

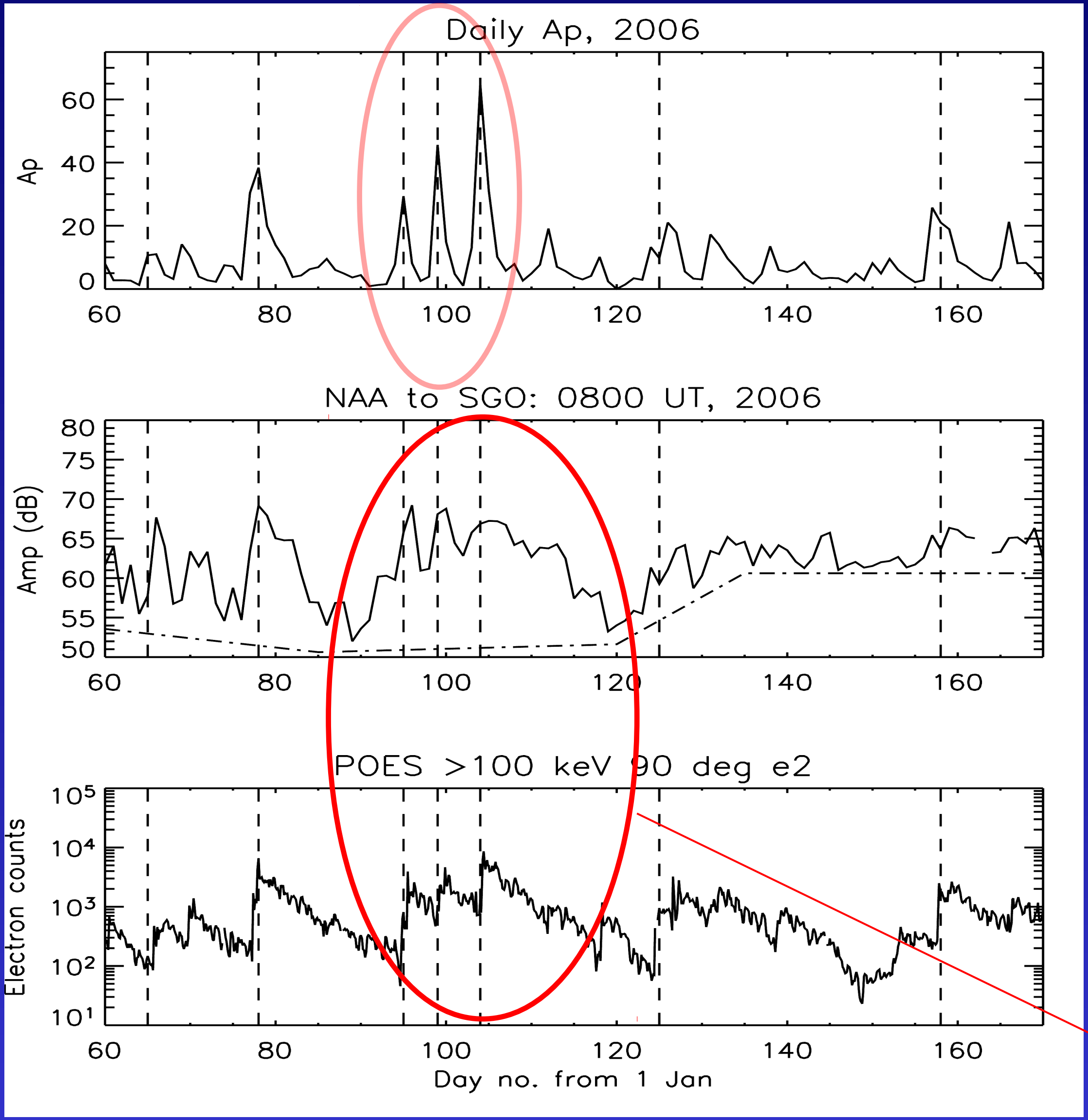
During the "summer months" the QDC is essentially the same for all times at ~60.5dB.



e⁻ precipitation leads to amplitude increases of up to 9-10dB.

Example of 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.

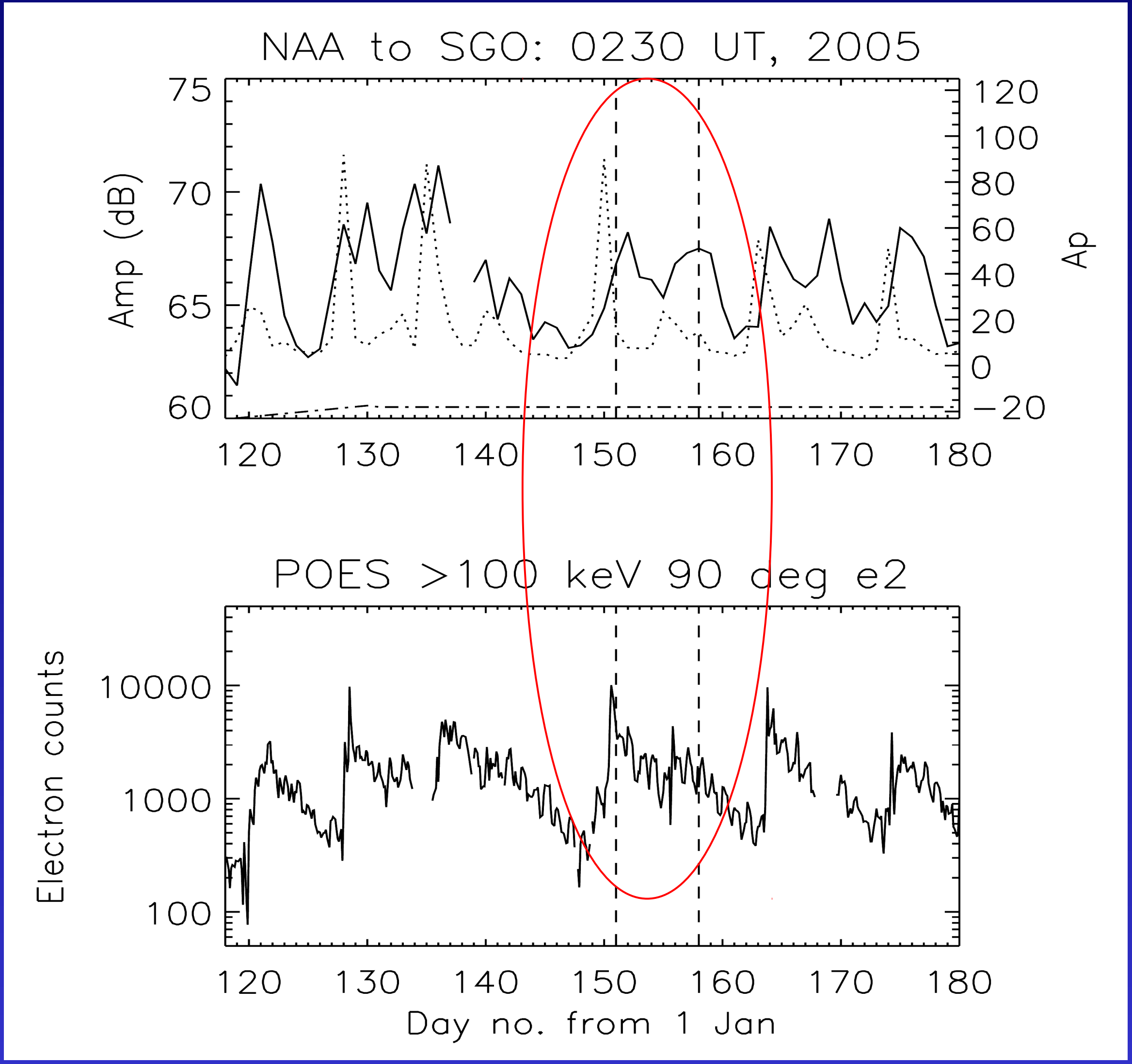
NAA-SGO variation in 8UT hourly amplitudes

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

Ap recovers but electron precipitation and POES enhancements take

Another example of responses

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.

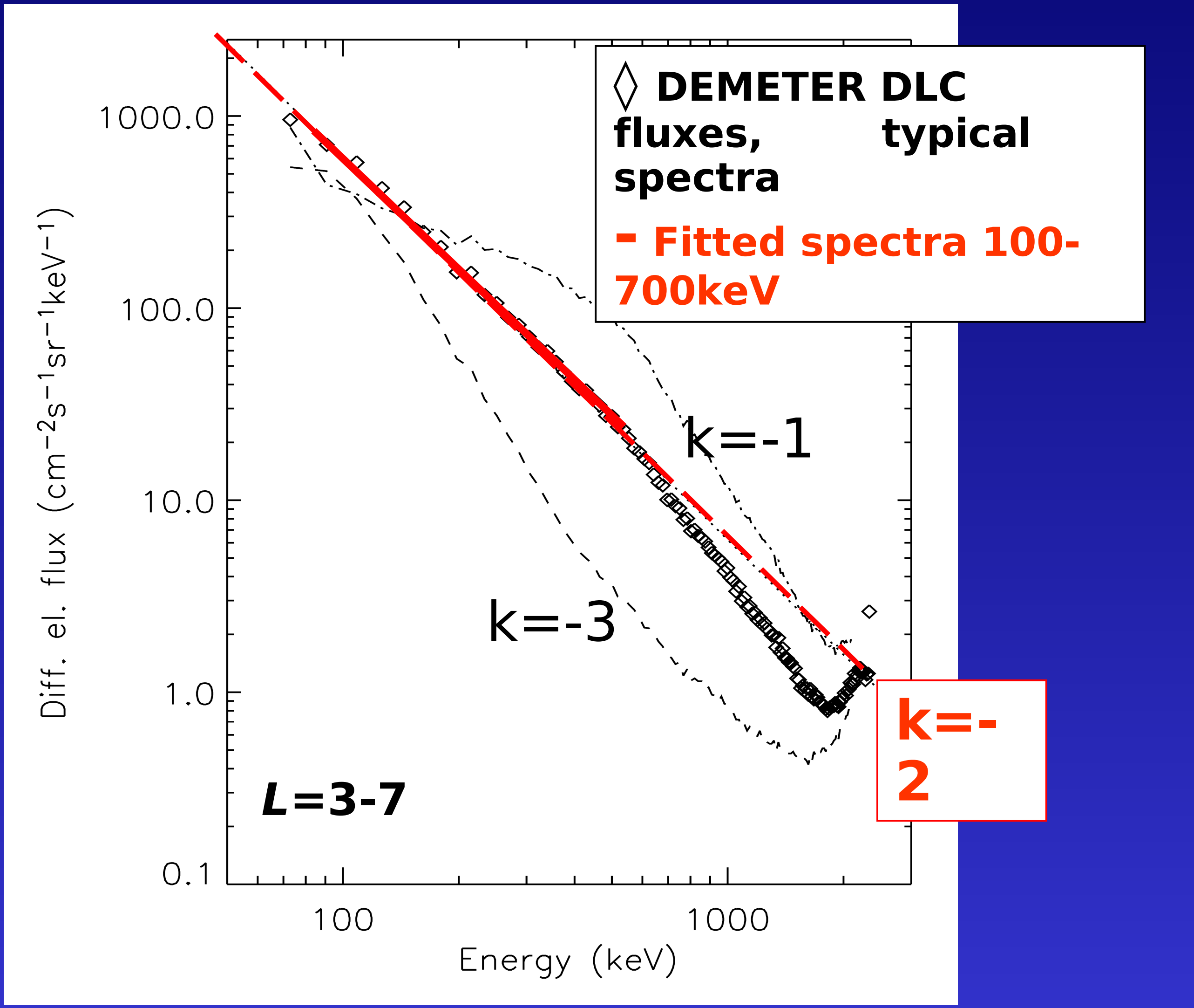
It is not clear Ap is a good proxy to represent accurately energetic electron precipitation inside atmospheric models (sometimes done).

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:

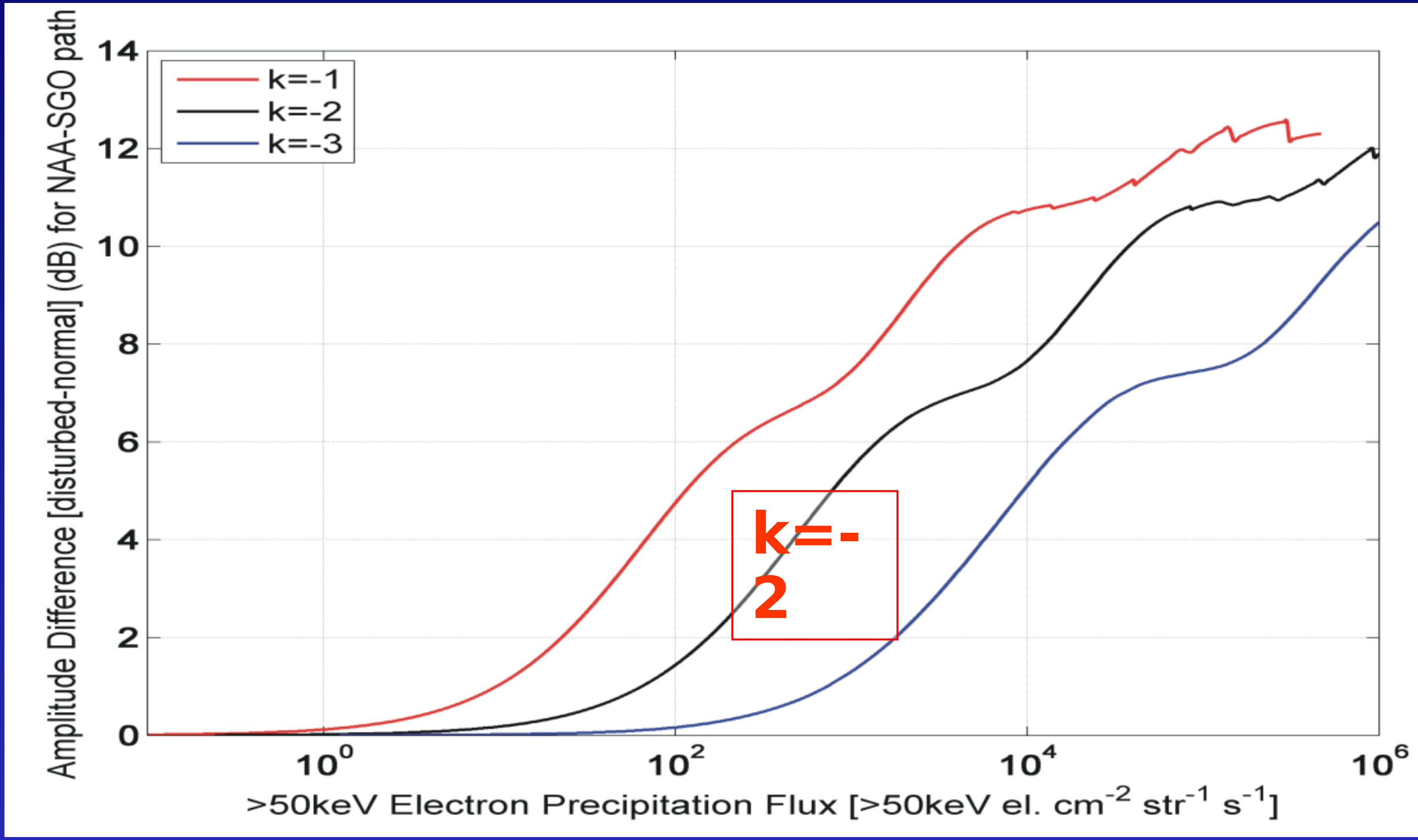
Two unknowns - spectra and flux



Flux ∝ $10^{k \log(E)}$

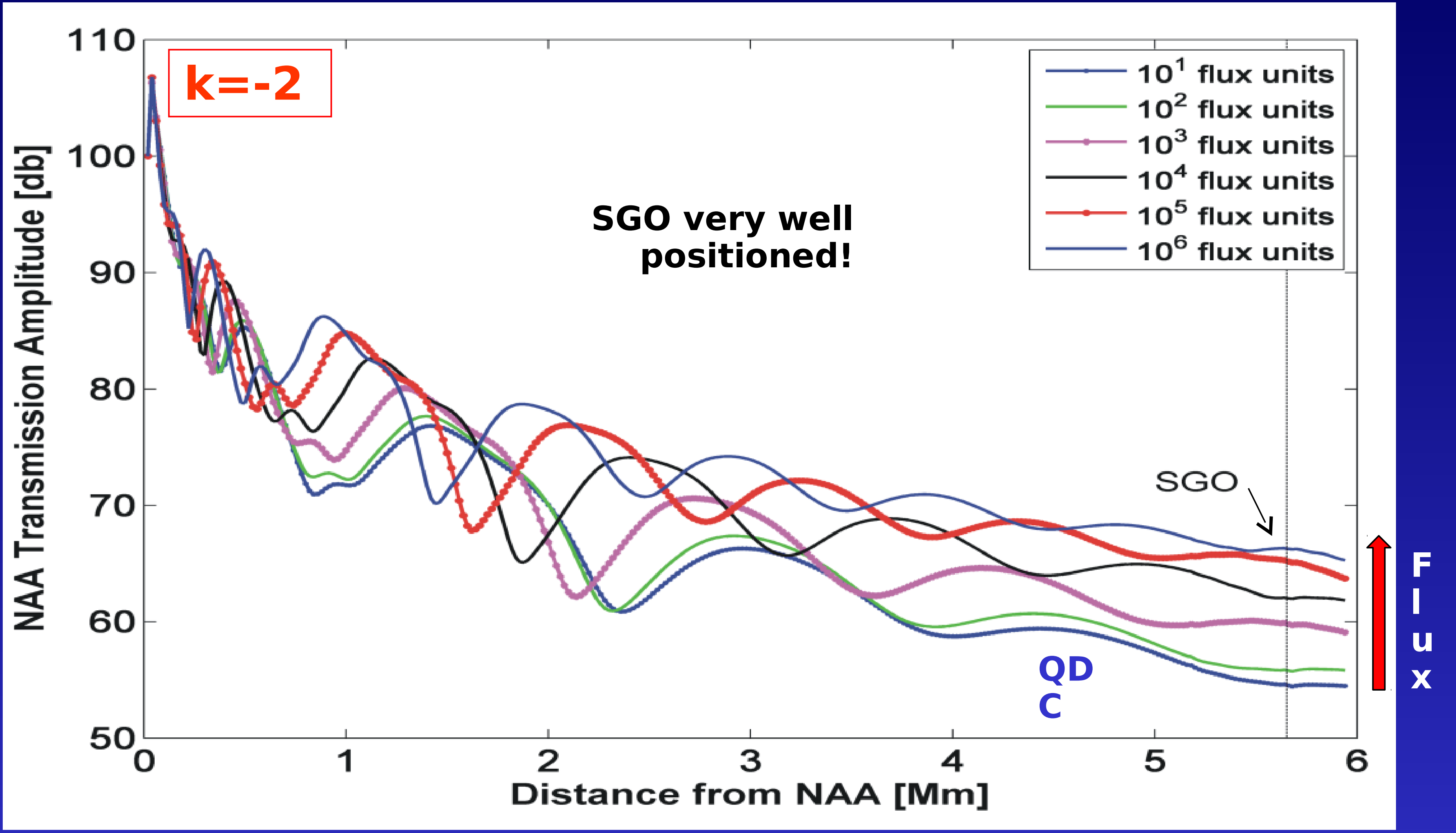
Modelled Response to Precipitation

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.

Modelled Response to Precipitation

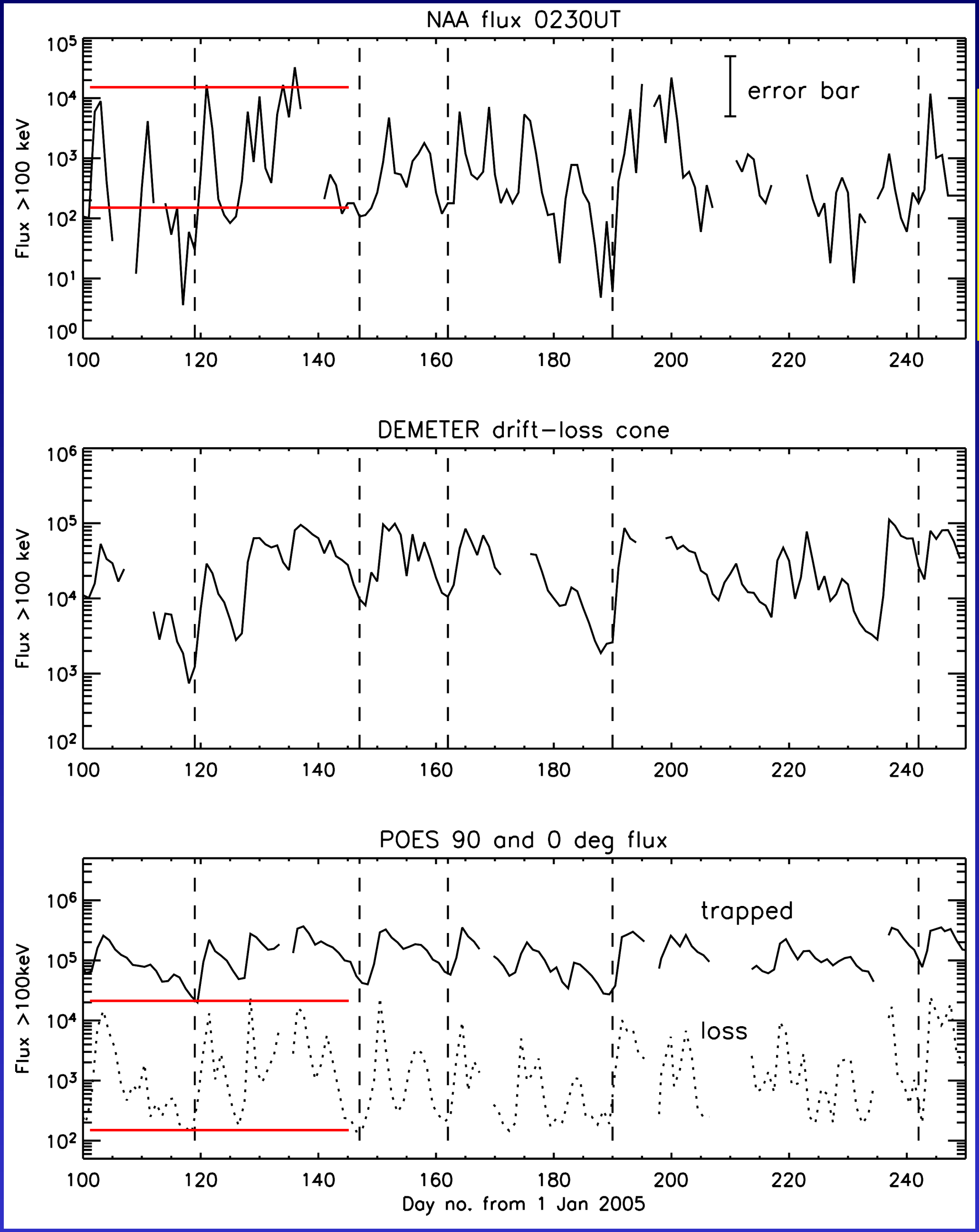


Some distances have jumbed responses to flux increases, but not SGO, or ~1 Mm

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.

What needs to be improved?

Is the precipitation spectrum always going to be *k* = -2?

Need a model to describe *k* as a function of time.

Average DEMETER spectra is 0-360 deg longitude: should use 280 deg E – 20 deg E (NAA-SGO).

What is the spectral gradient for Canadian longitudes?

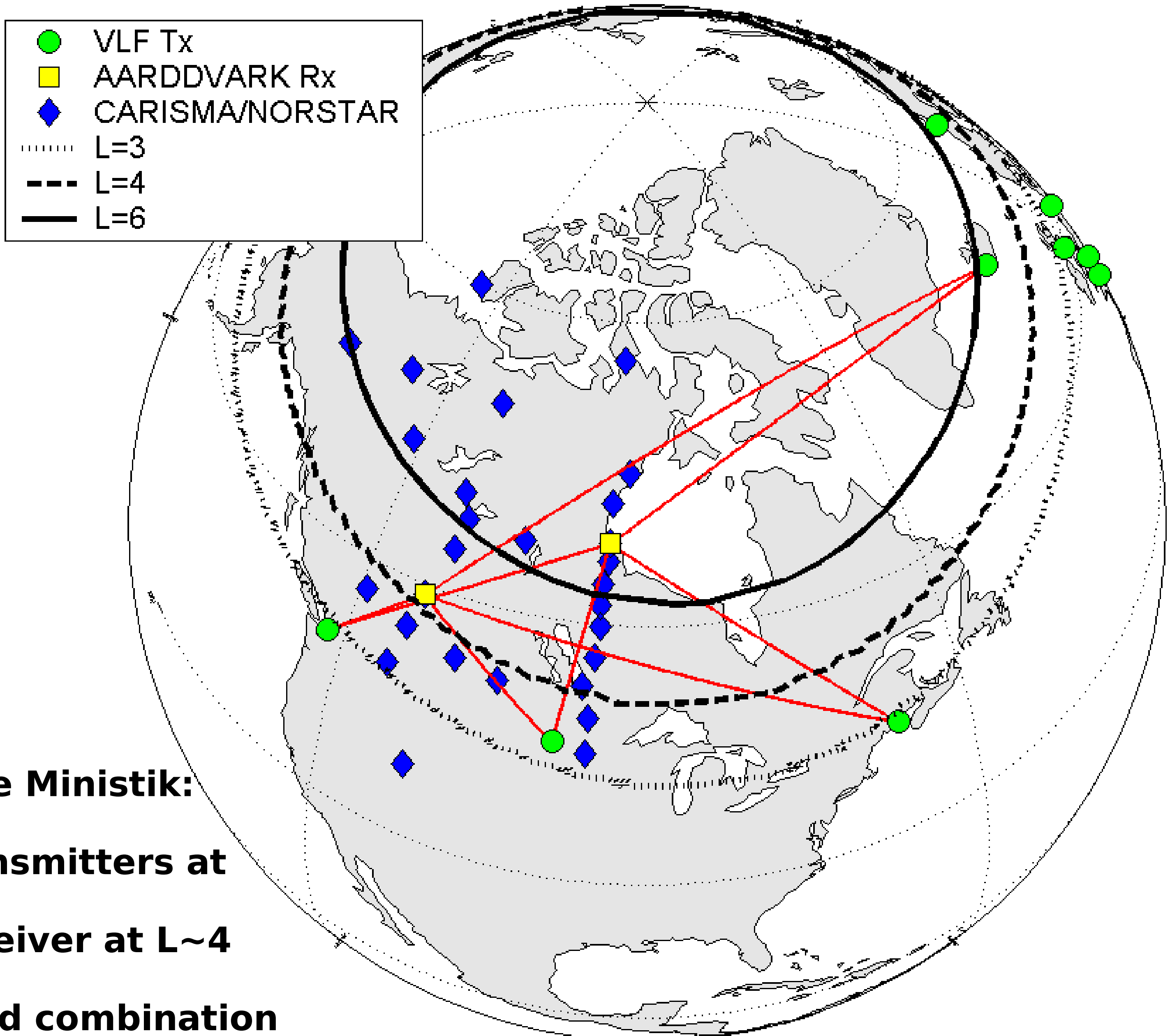
Will the precipitation fluxes be greater or less at Canadian longitudes?

NAA-SGO provides an integrated flux from L= 3 – 7.

Is there any variation with L-shell?

NAA-SGO has a large MLT window. Can we make it smaller?

AARDDVARK-Selected Canada Paths

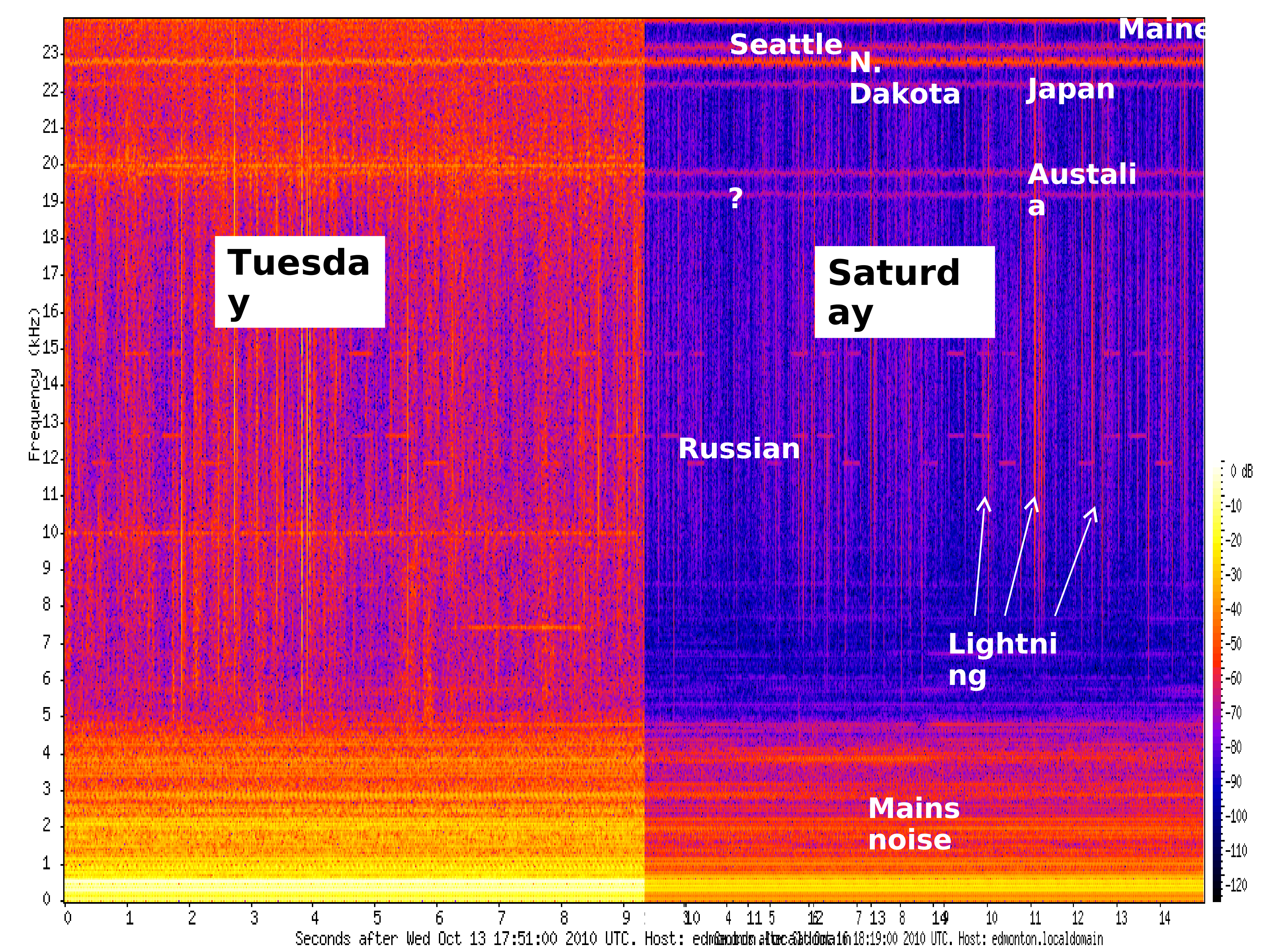


Lake Ministik:

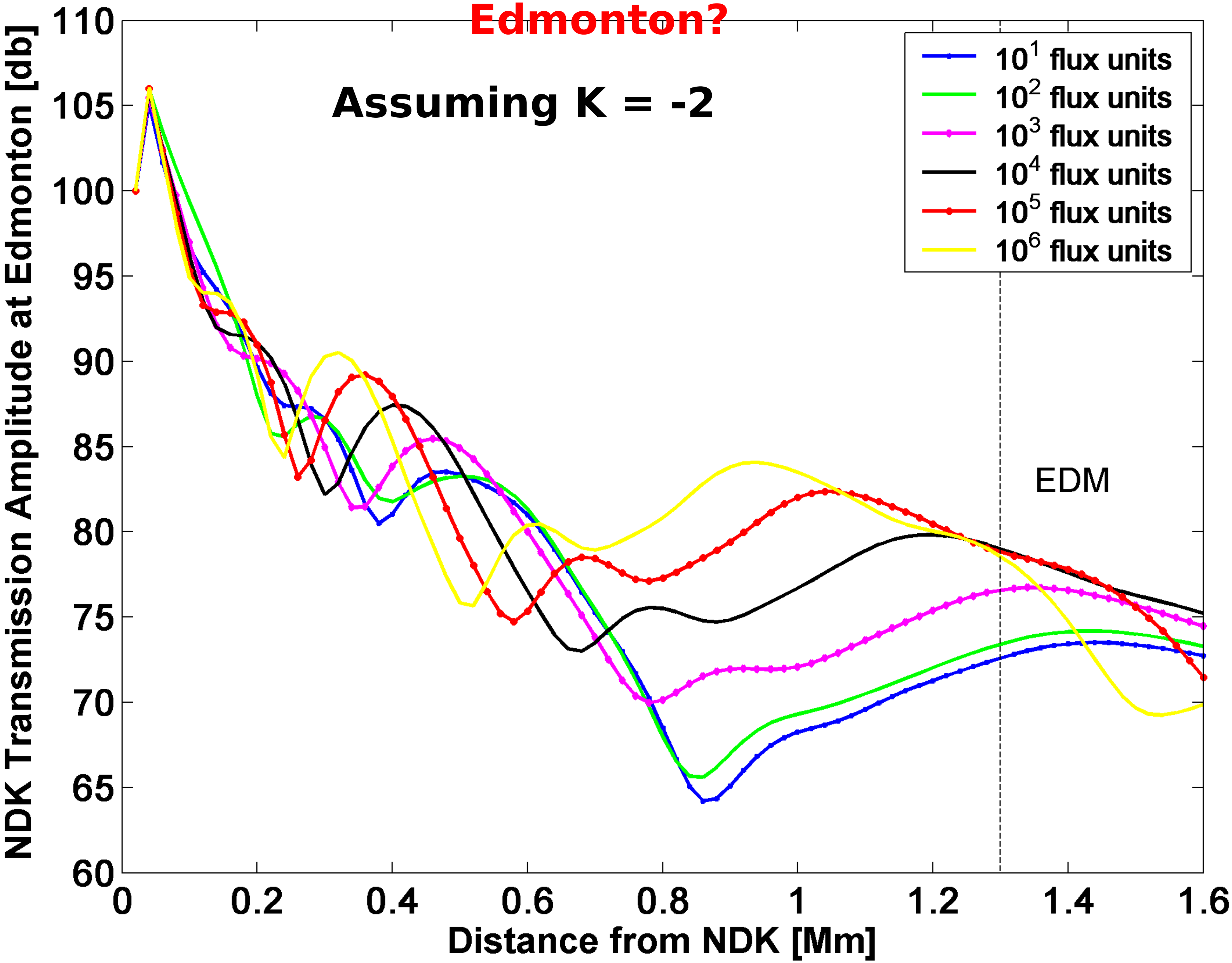
Transmitters at L~3
Receiver at L~4

Good combination with Churchill

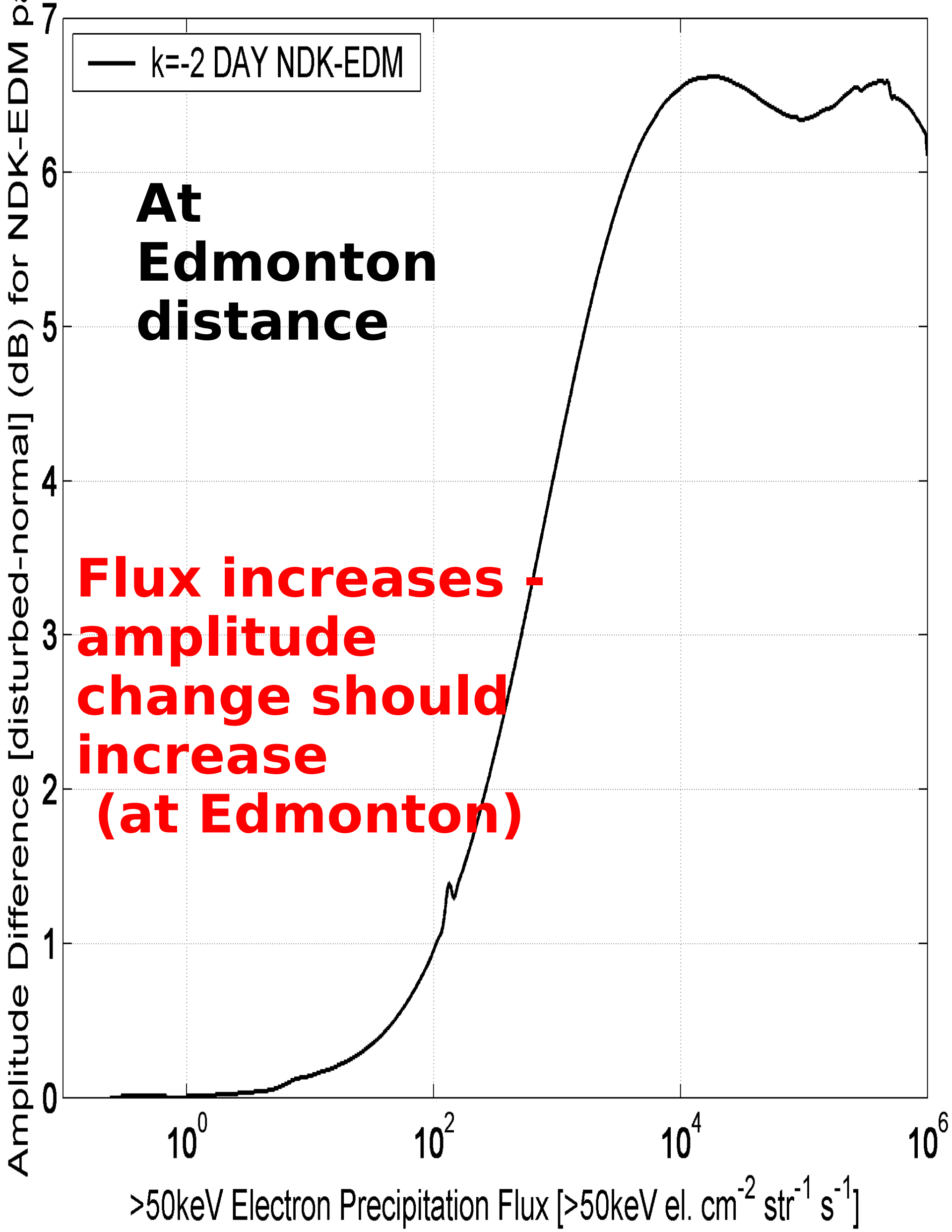

Lake Ministik:
Receiver operational from 17 October 2010


Seattle
N. Dakota
Maine
Japan
Austali a
?
Tuesda y
Saturd ay
Russian
Lightni ng
Mains noise
Frequency (kHz)
0 dB
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
Seconds after Wed Oct 13 17:51:00 2010 UTC. Host: edmonton.localdomain

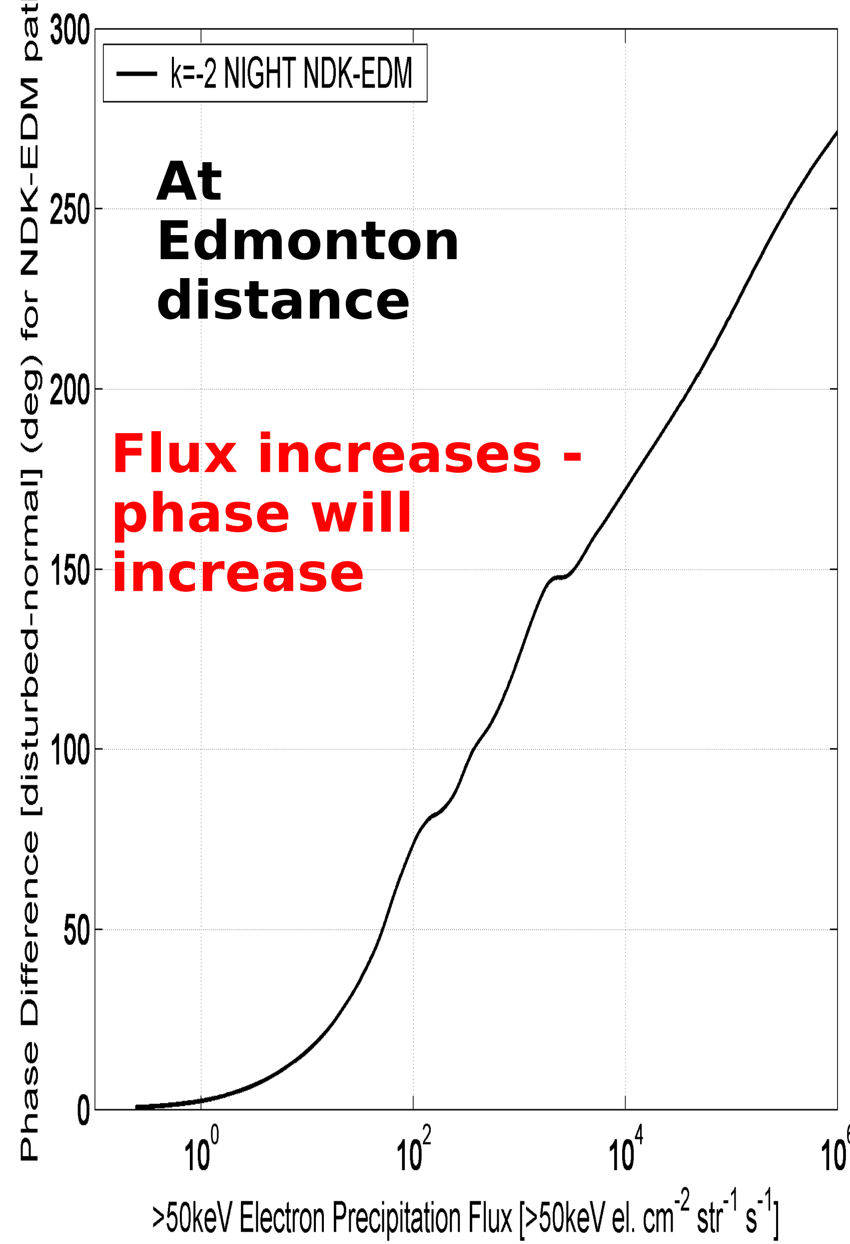
What should we see happening at Edmonton?



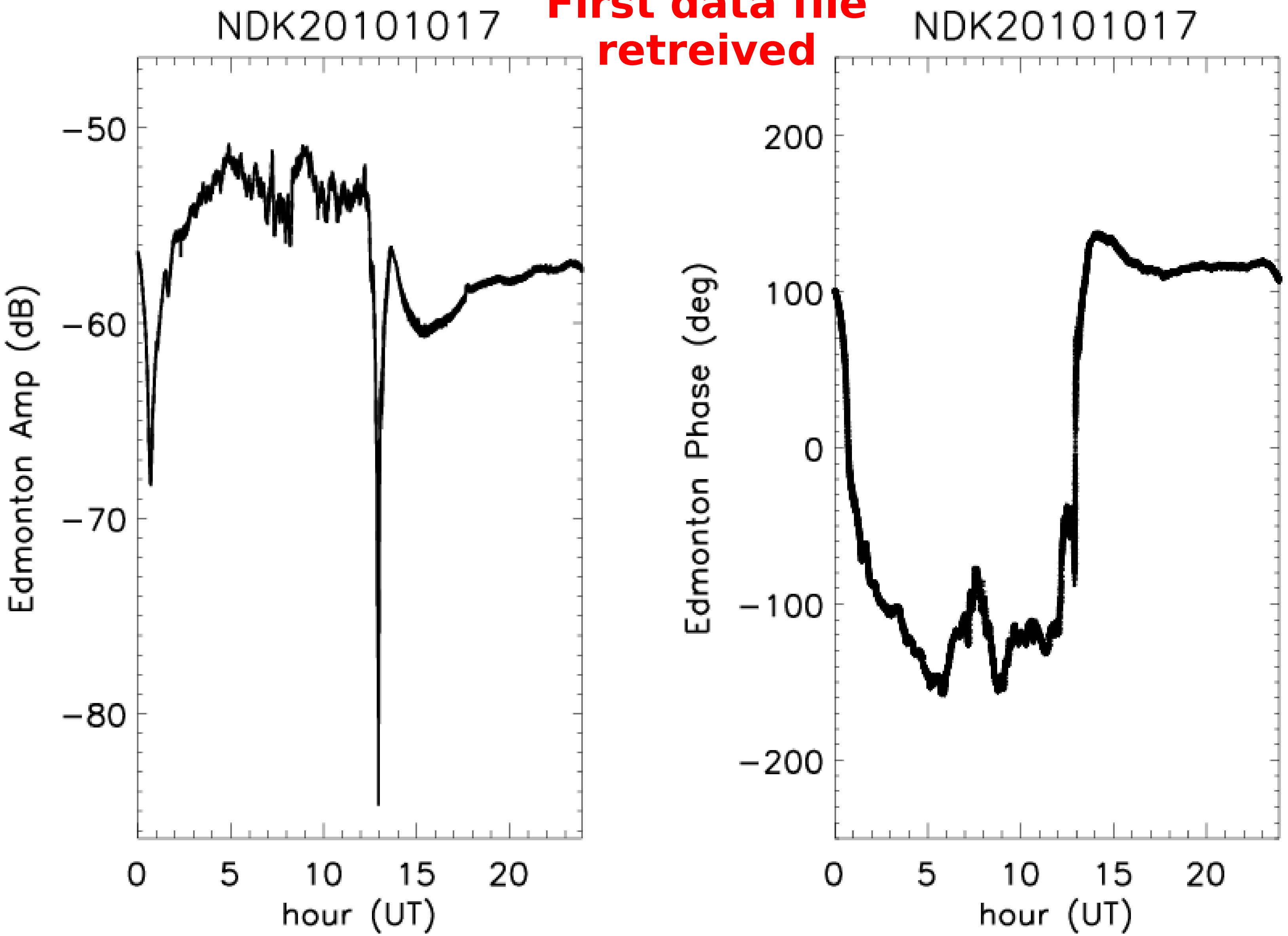
Amplitude



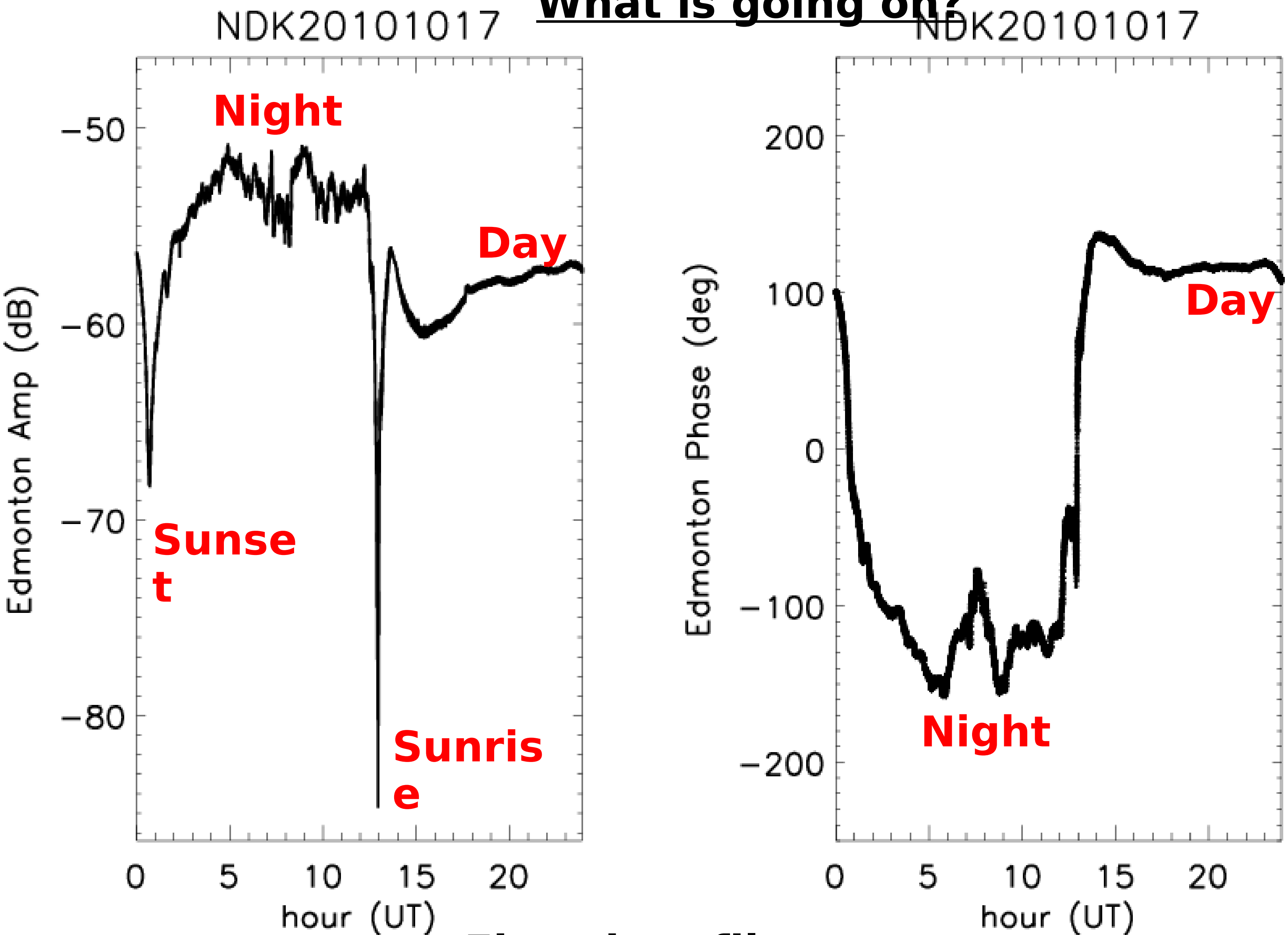
Phase



First data file retreived



What is going on?



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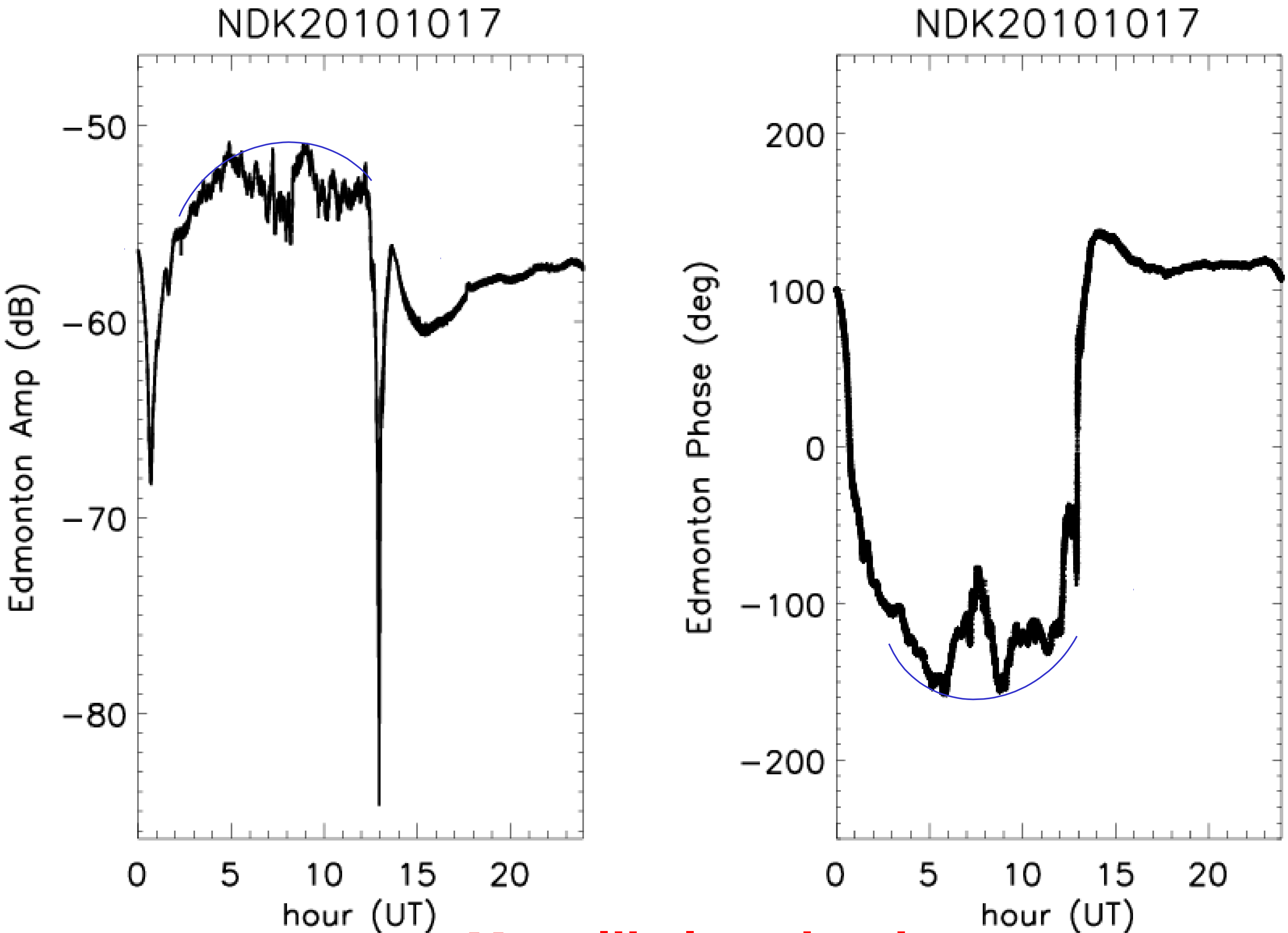
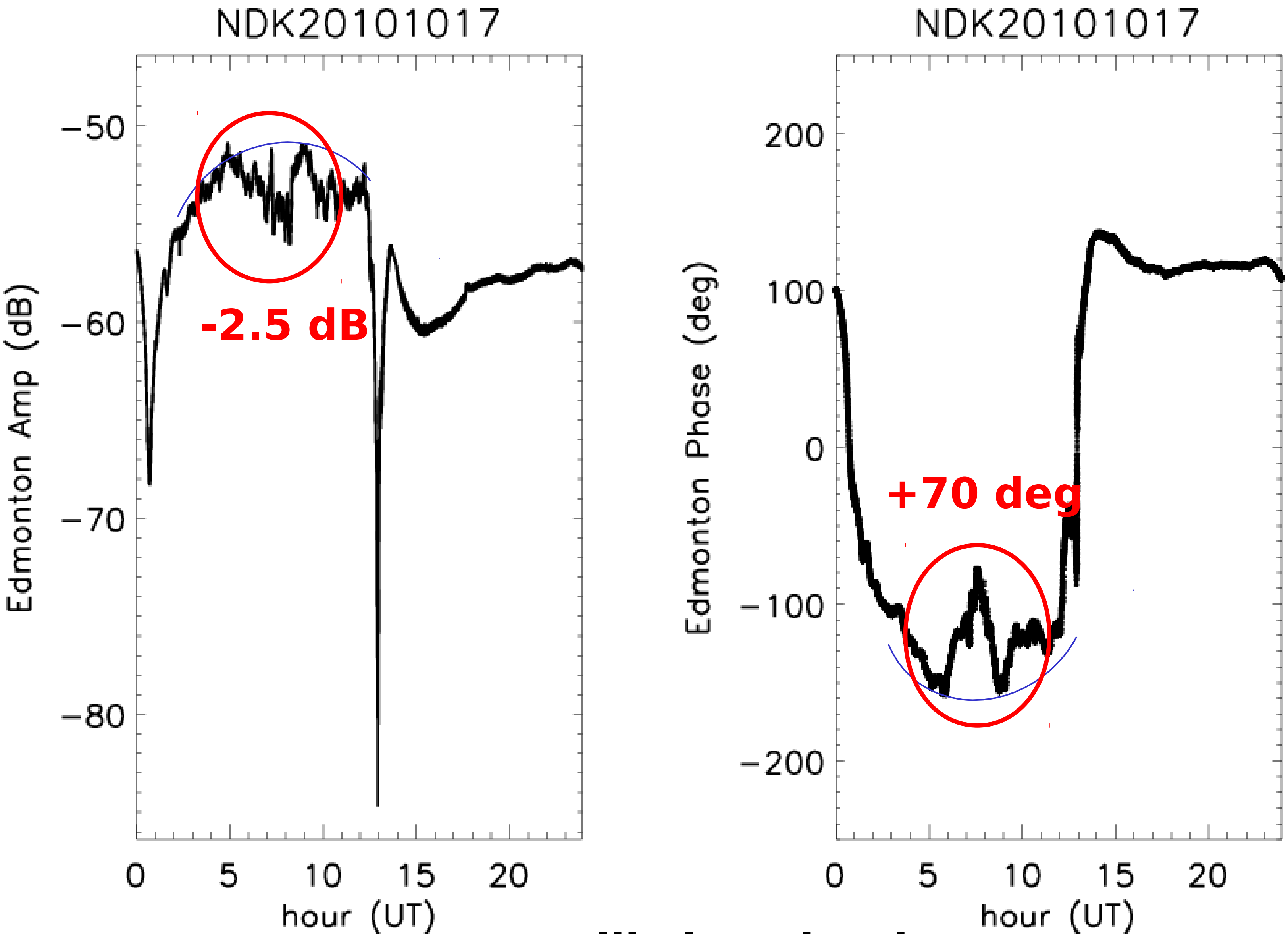
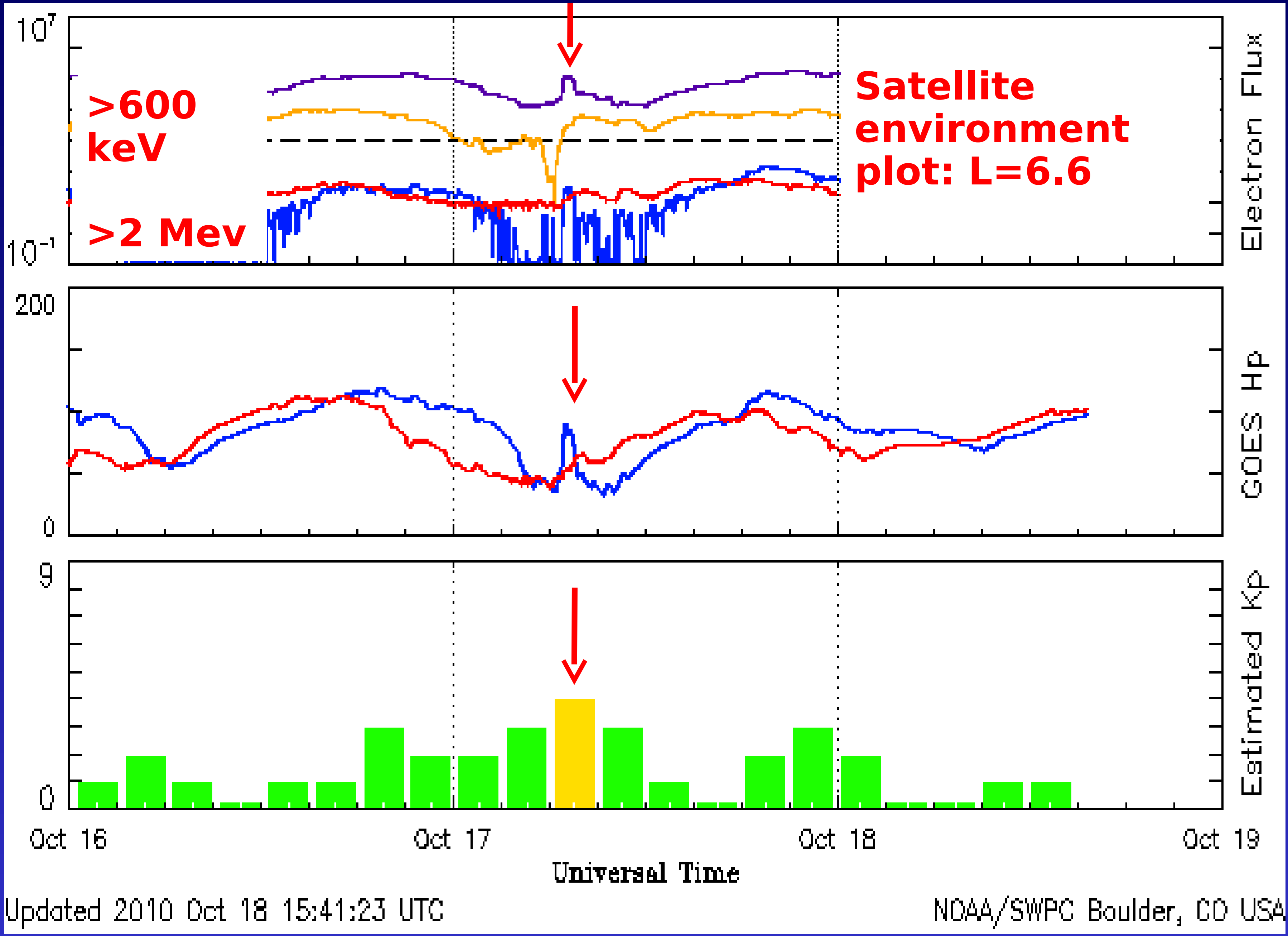


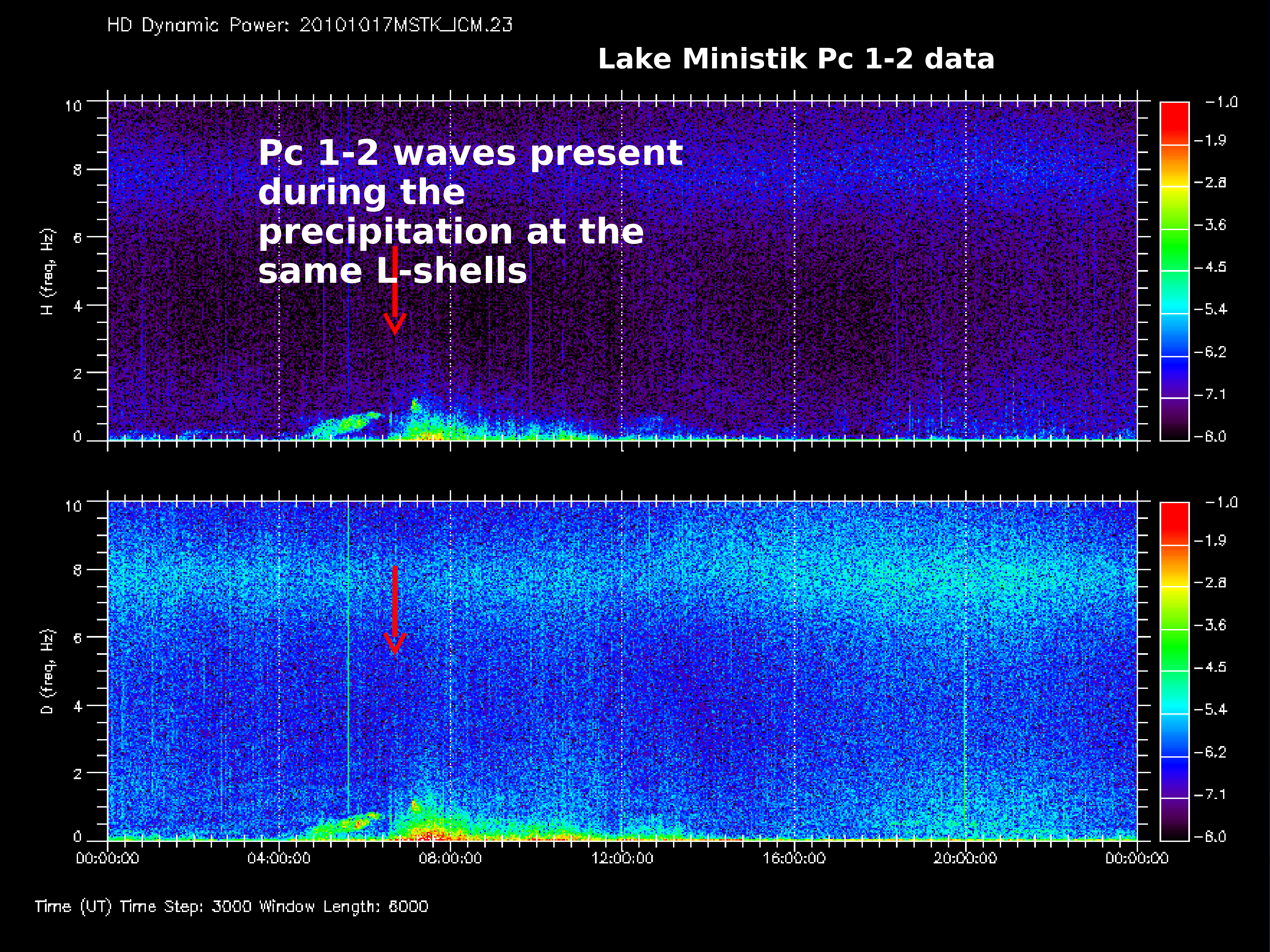
Most likely quiet day curve



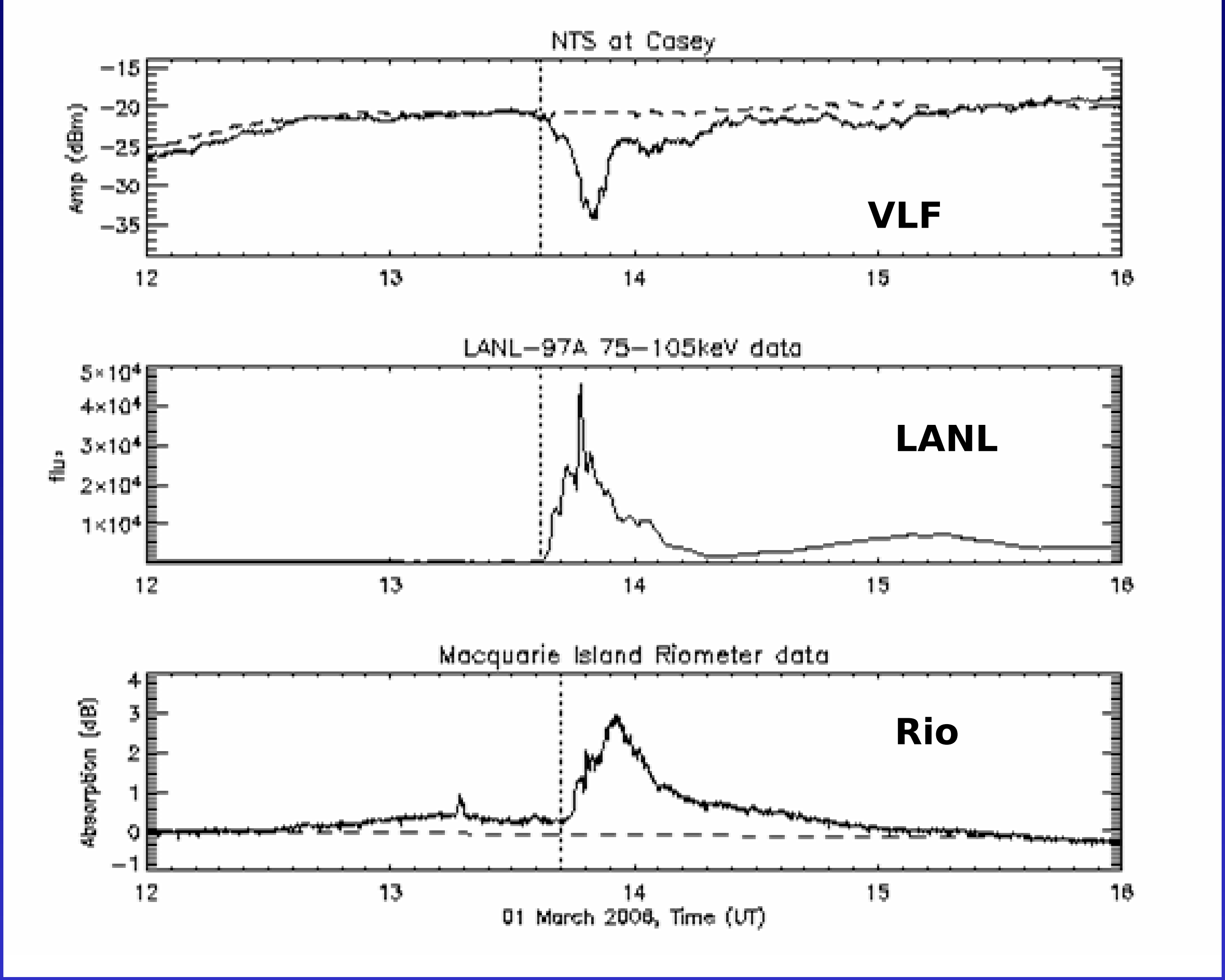
Most likely quiet day curve



10^7
10^-1
>600 keV
>2 Mev
Satellite environment plot: L=6.6
Electron Flux
200
0
GOES Hp
9
0
Estimated Kp
Oct 16
Oct 17
Oct 18
Oct 19
Universal Time
Updated 2010 Oct 18 15:41:23 UTC
NOAA/SWPC Boulder, CO USA


HD Dynamic Power: 20101017MSTK_ICM.23
Lake Ministik Pc 1-2 data
Pc 1-2 waves present during the precipitation at the same L-shells
H (freq, Hz)
D (freq, Hz)
0
2
4
6
8
10
-1.0
-1.9
-2.8
-3.6
-4.5
-5.4
-6.2
-7.1
-8.0
00:00:00
04:00:00
08:00:00
12:00:00
16:00:00
20:00:00
00:00:00
Time (UT) Time Step: 3000 Window Length: 6000

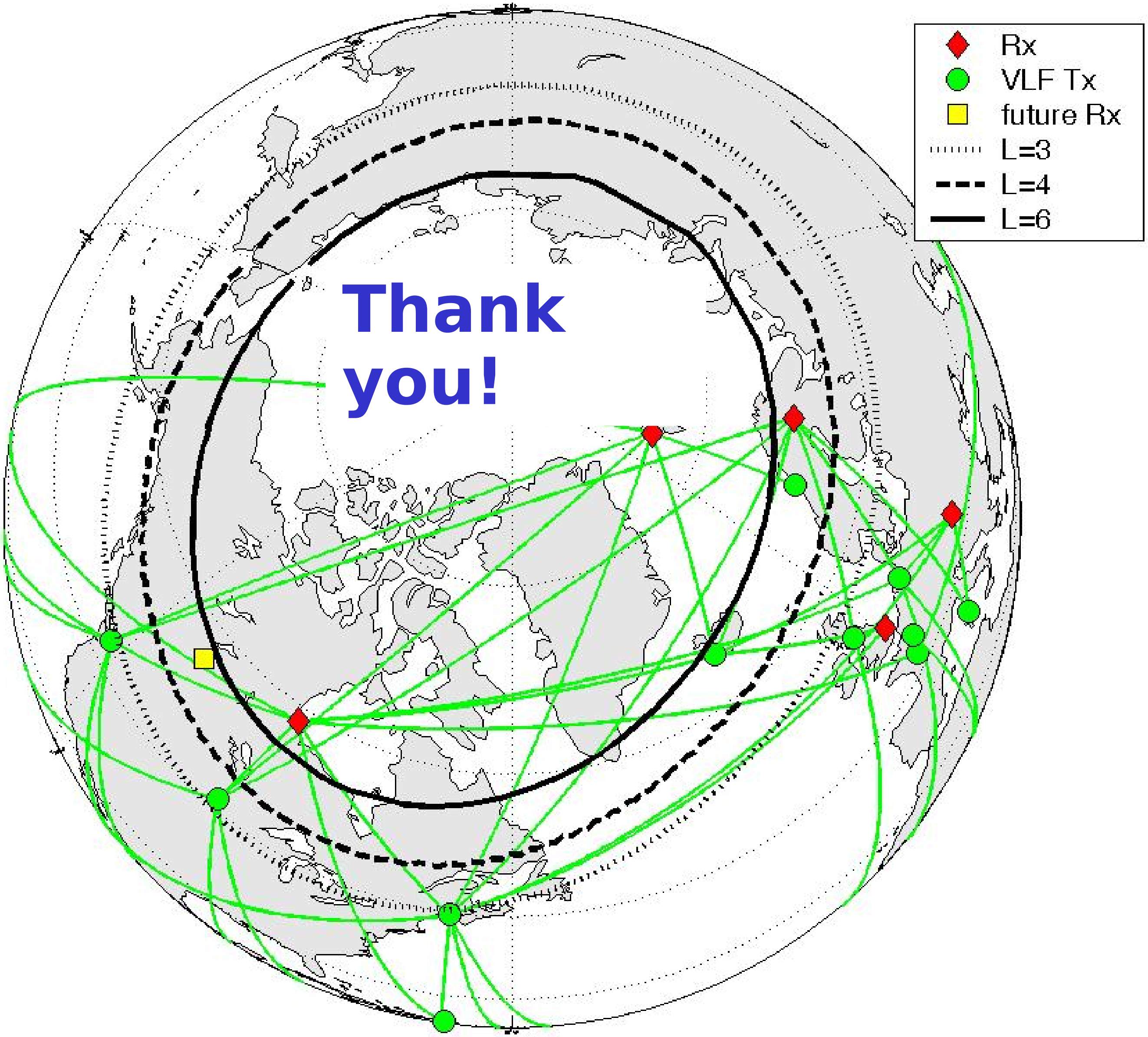
An example of VLF and Riometer effects during a substorm



Summary and Next Steps

- **The analysis of NAA@SGO amplitude variability has the potential of providing a detailed, near real-time, picture of energetic electron precipitation fluxes from the outer radiation belts.**
- 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.**
- **Great opportunity to collaborate together to study wave and particles in the radiation belts, looking at acceleration and loss processes.**

AARDDVARK Network



Thank you!