Global AARDDVARK Measurements of Energetic Electron Precipitation

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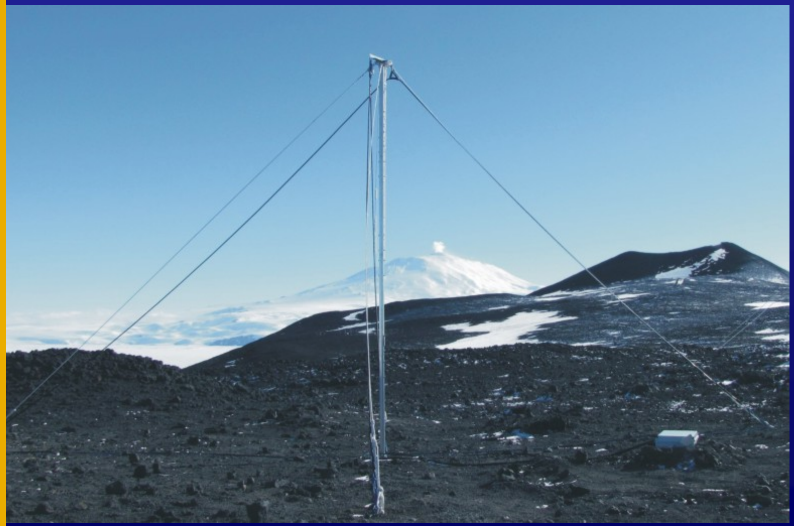


VLF receiver in Antarctica (Ross Sea)

HEPPA 2009

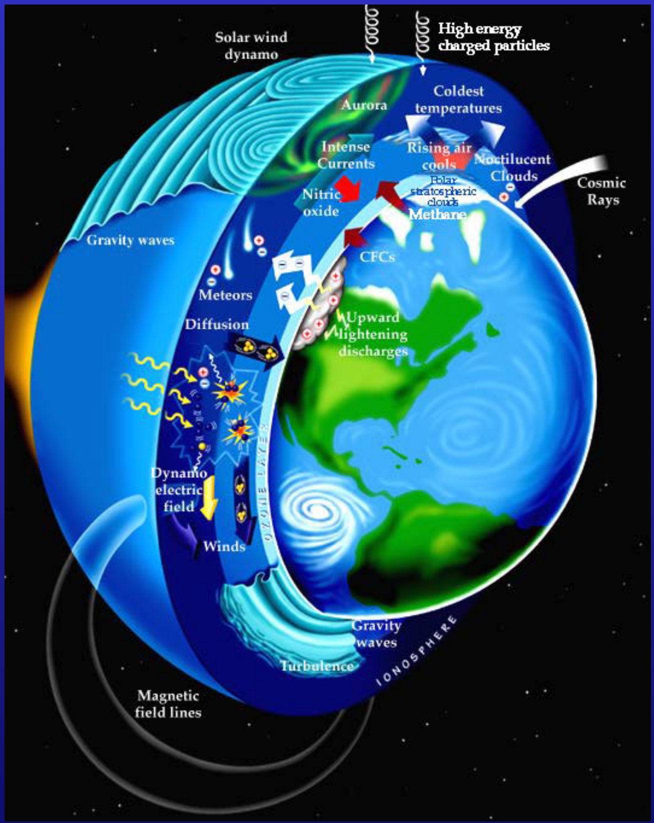
EPP effects on the Thermosphere & Ionosphere

14:35-1450 Tuesday 6 October 2009

Energetic Particle Precipitation

Losses: overall response of the RB to geomagnetic storms are a "delicate and complicated balance between the effects of particle acceleration and loss". [*Reeves et al.*, GRL, 2003].

Thus while there has been a lot of focus on the acceleration of radiation belt particles, it is also necessary to understand the losses to understand the RB.



Space Weather links to the atmosphere (and beyond?). In addition, particle precipitation is one way that changes at the Sun, and around the Earth, can couple into the atmosphere - and possible into the climate.

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

How can we observe these drivers?

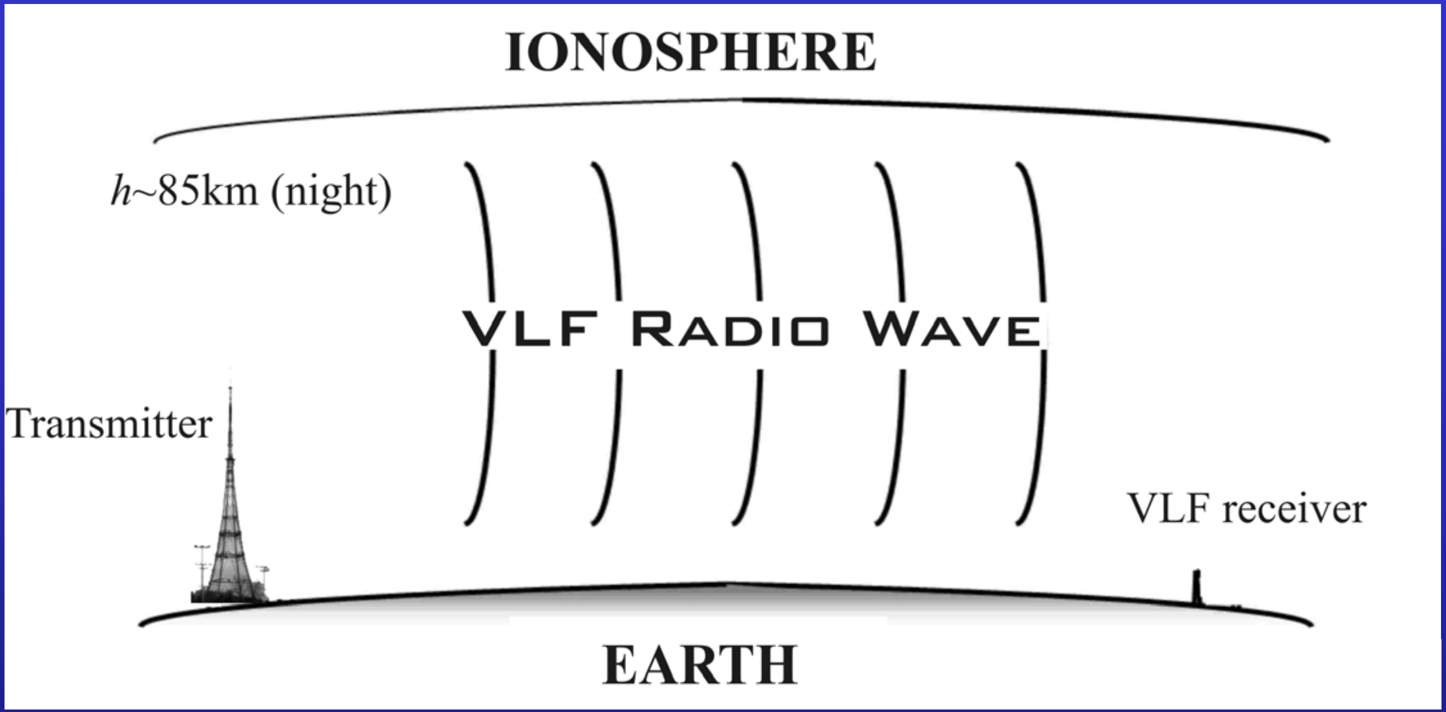
From space, obviously! But from the ground, instruments in the polar regions are best, and the altitudes sensed define the energy range of the precipitating particles, as the atmosphere acts like an energy spectrometer.

EXAMPLES:

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

VLF receiver at Ny Alesund

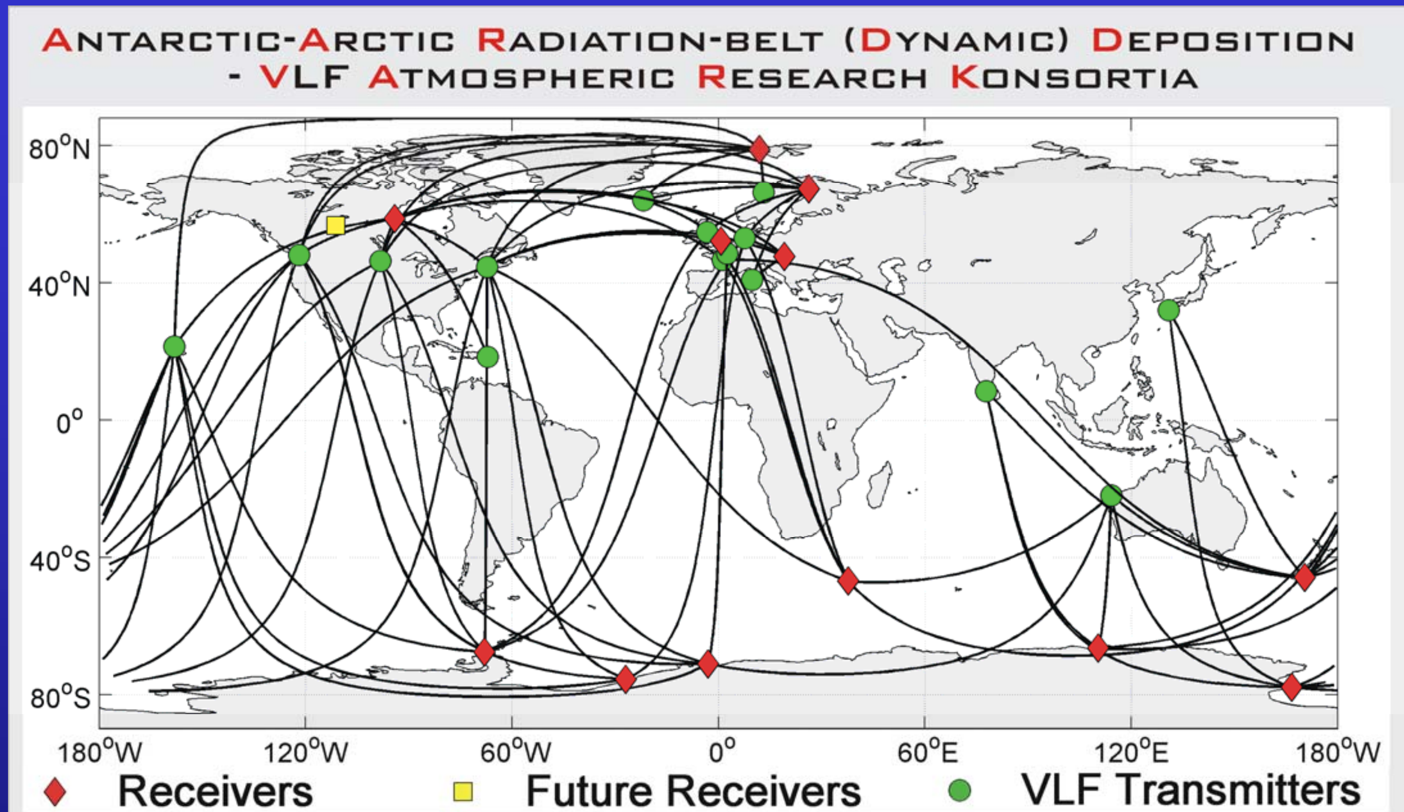
Subionospheric Radio Wave Propagation



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 causes 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



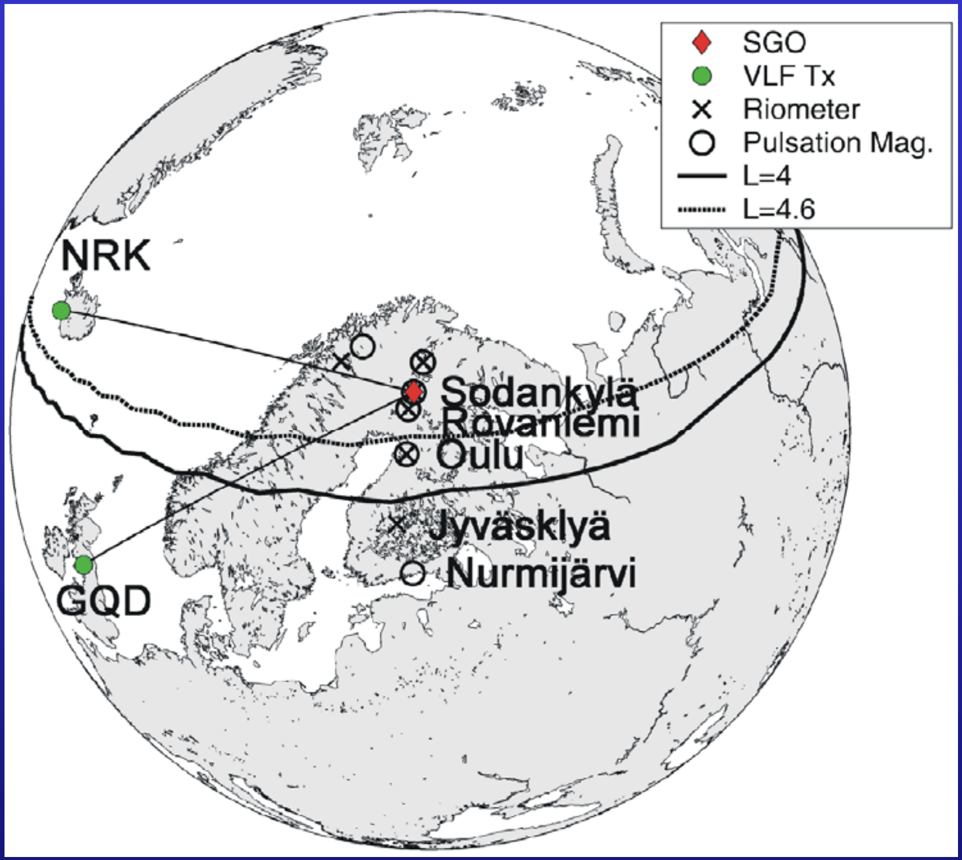
An aarmory of AARDDVARKs. This map shows our existing network of sub-ionospheric energetic precipitation monitors.

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

1. EMIC wave driven relativistic precipitation

Theoretical modeling has shown that electromagnetic ion cyclotron (EMIC) waves should play an important role in the loss of relativistic electrons from the radiation belts, through precipitation into the atmosphere.

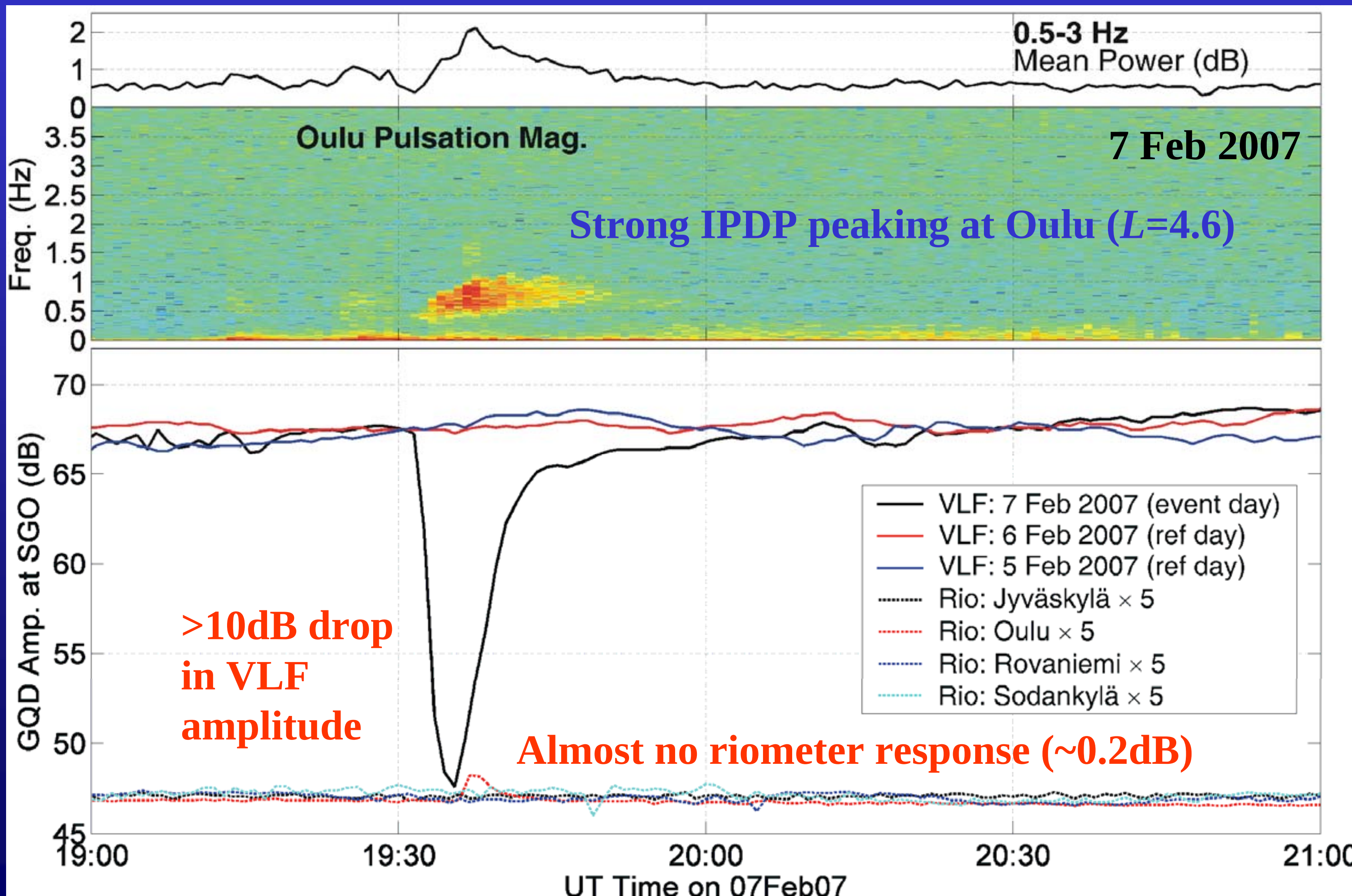
Up to now there has been limited experimental evidence for relativistic electron precipitation driven by EMIC waves.



Rodger, C. J., T. Raita, M. A. Clilverd, A. Seppälä, S. Dietrich, N. R. Thomson, and Th. Ulich, Observations of relativistic electron precipitation from the radiation belts driven by EMIC Waves, *Geophys. Res. Lett.*, 35, L16106, doi:10.1029/2008GL034804, 2008.

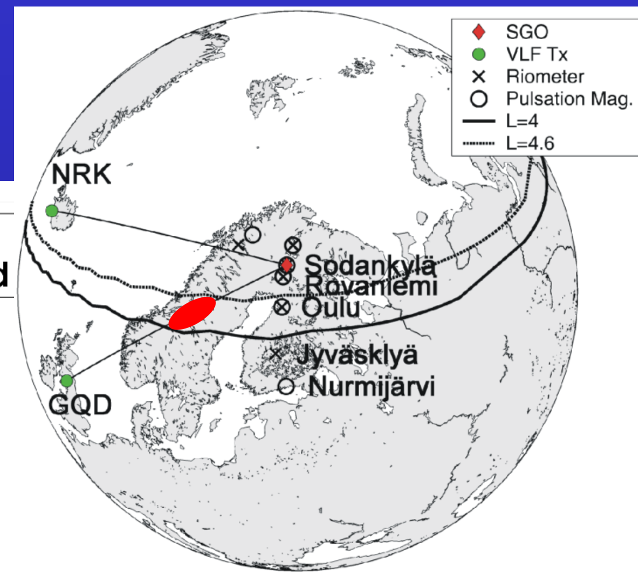
1. EMIC wave driven relativistic precipitation

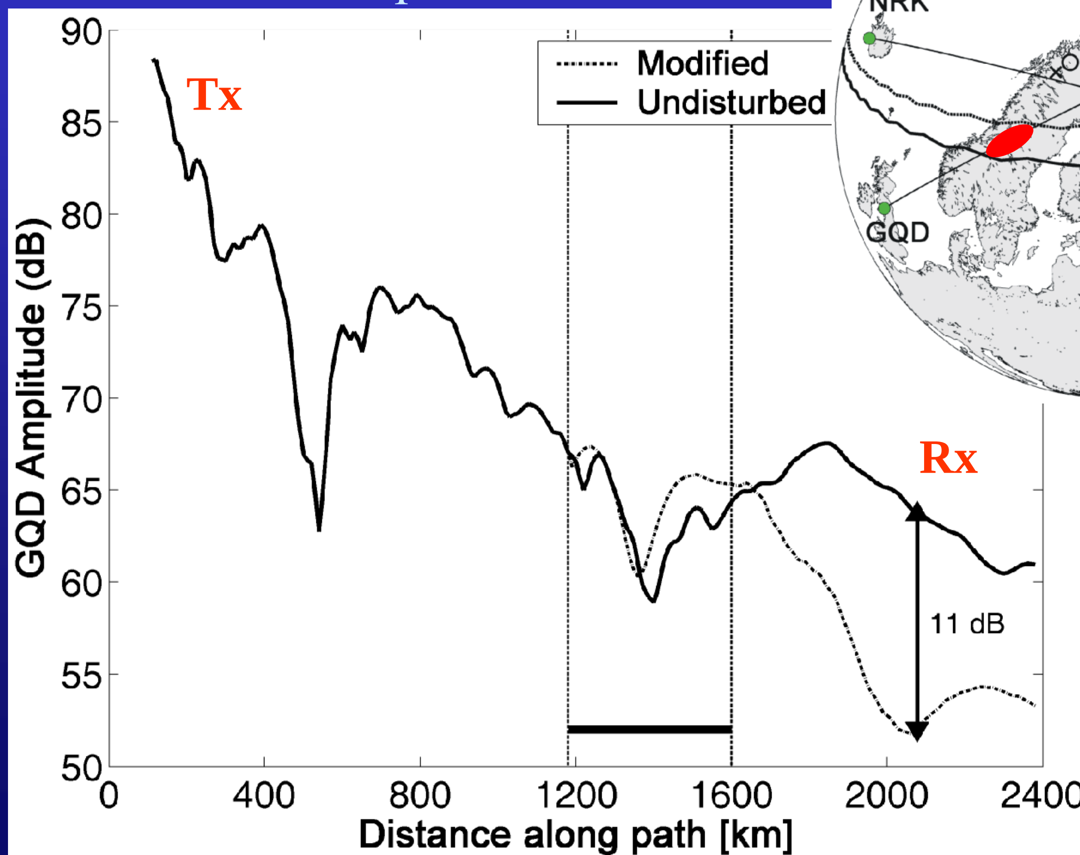
Our recent case study considered events occurring during quiet to weakly disturbed geomagnetic conditions, leading to very clear linkages between the wave activity and precipitation.



1. EMIC wave driven relativistic precipitation

Modeled with a "representative" monoenergetic beam of 1.5MeV electrons with flux 500 el. $cm^{-2}s^{-1}str^{-1}keV^{-1}$, into a location suggested by the pulsation magnetometer observations, produces an ionospheric modification which peaks at ~60km.





Resulting riometer absorption 0.15dB, as mostly below altitudes where riometers are most sensitive. Follow up statistical study being undertaken.

2. Relativistic Microburst Precipitation

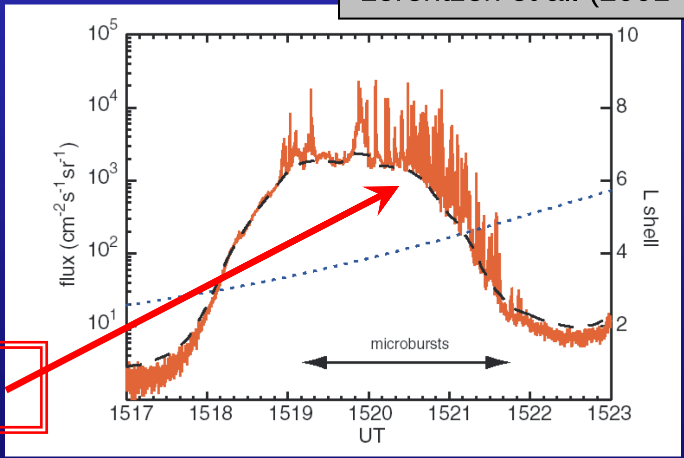
RELATIVISTIC MICROBURSTS

- >1 MeV microbursts lasting <<1 s (*L*=4-6)
- typically observed at the outer edge of the radiation belt
- observed at all local times, but predominantly in the morning sector
- each burst less than "several tens of gyro-radii" ($r_B \approx$ 0.2km) in *L*
- Thought to be associated with VLF chorus waves

[*Blake et al.*, 1996; *Lorentzen et al.*, 2001]

Plot taken from:
Lorentzen et al. (2001

SAMPEX satellite observed fluxes show that microburst precipitation losses could essentially "flush out" the entire relativistic electron population during the main phase of the storm.

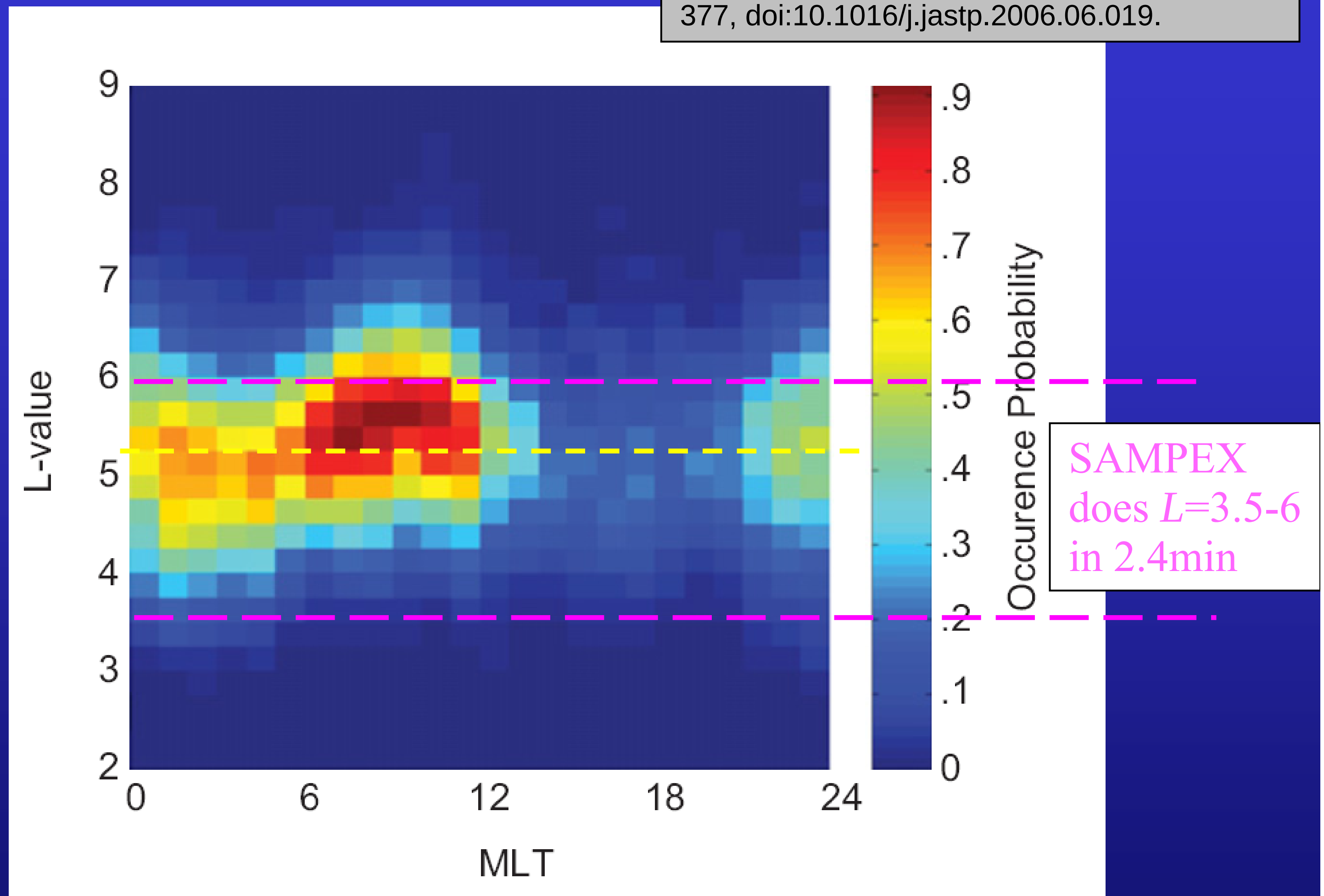


These pulses here!

However, the global loss estimates are based upon the assumption that the microburst flux is isotropic & constant over given *L* & MLT ranges. Ground based observations would complement the space-based point measurements, but to date no ground based observations.

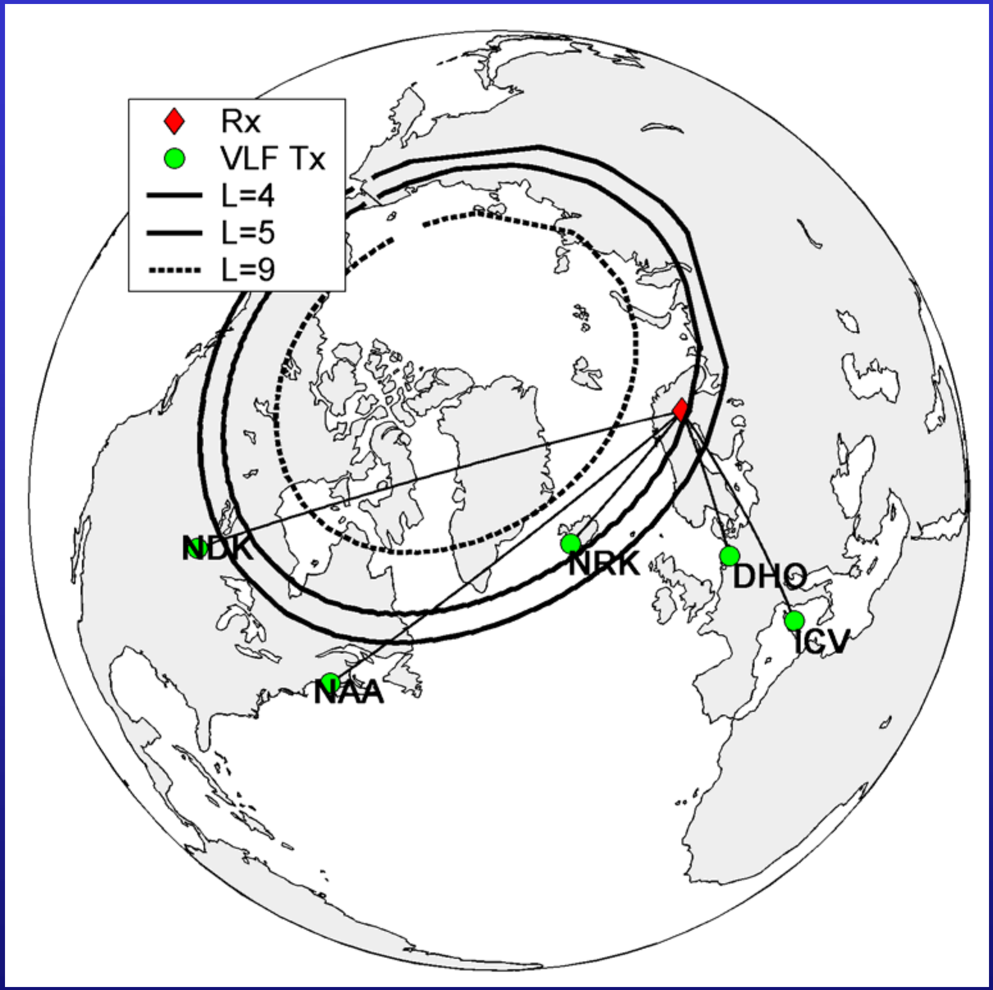
2. REP Microbursts

Plot taken from:
Millan & Thorne (2006), *JASTP*, 69(3), 362-377, doi:10.1016/j.jastp.2006.06.019.



Occurrence probability for relativistic microbursts observed by SAMPEX (this plot made by T.P. O'Brien).

Observation setup



Focusing on the time period from December 2004 to June 2005 and the AARDDVARK data from the Sodankylä Geophysical Observatory (SGO) receiver.

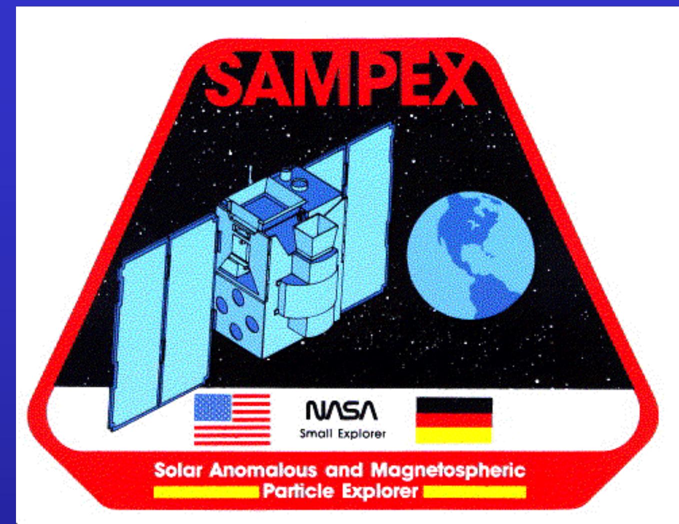
Experimental Observations

Ground Based Observations from Sodankylä (SGO)

Position: 67° 22' N, 26° 38' E

$L \approx 5.2$

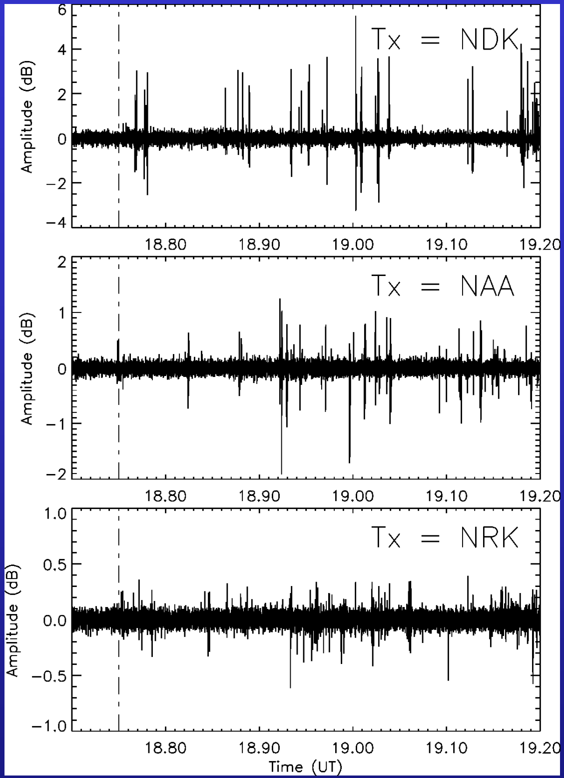
AARDDVARK instrument (subionospheric VLF receiver)



Space Based Observations from SAMPEX

Orbit: 520 × 670 km altitude and 82º inclination, orbit period is ≈96 min. HILT measures RB electrons >1 MeV.

Examples of FASTREP in SGO data



The majority of the FAST perturbations are not simultaneous with FAST perturbations on other paths even though they occur during the same periods.

However, a very small fraction, on the order of ~1-2% appear to be simultaneous on multiple paths. This behaviour is consistent with ionospheric changes with small spatial size, occurring near to the Sodankylä receiver.

Modelling of the time decay of the perturbation shows they are mostly likely caused by bursts of ~1.5MeV electrons.

A useful analogy is a rainstorm, with many small raindrops, each representing a burst of precipitating electrons, produced by the same physical process spanning a much larger spatial region.

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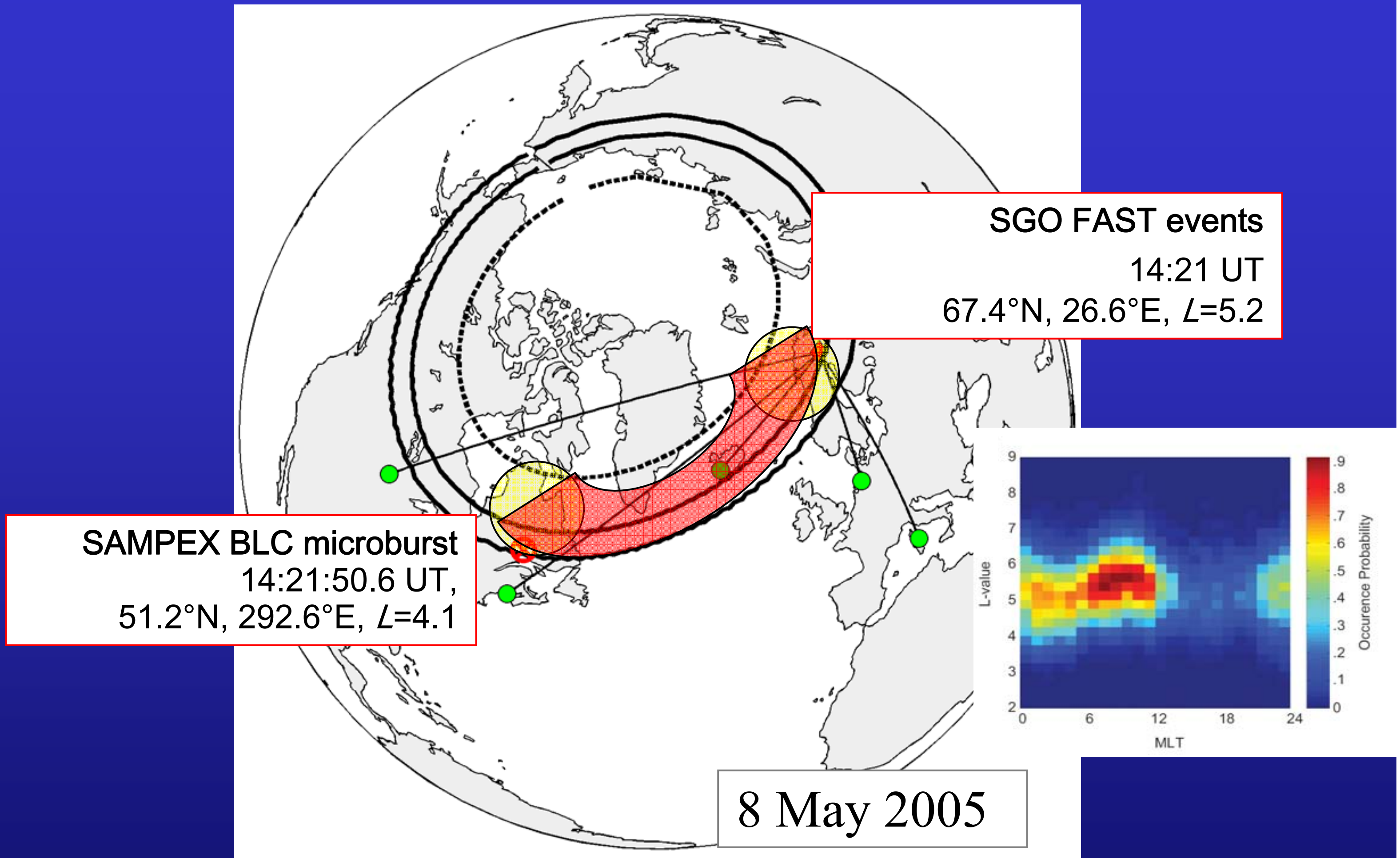
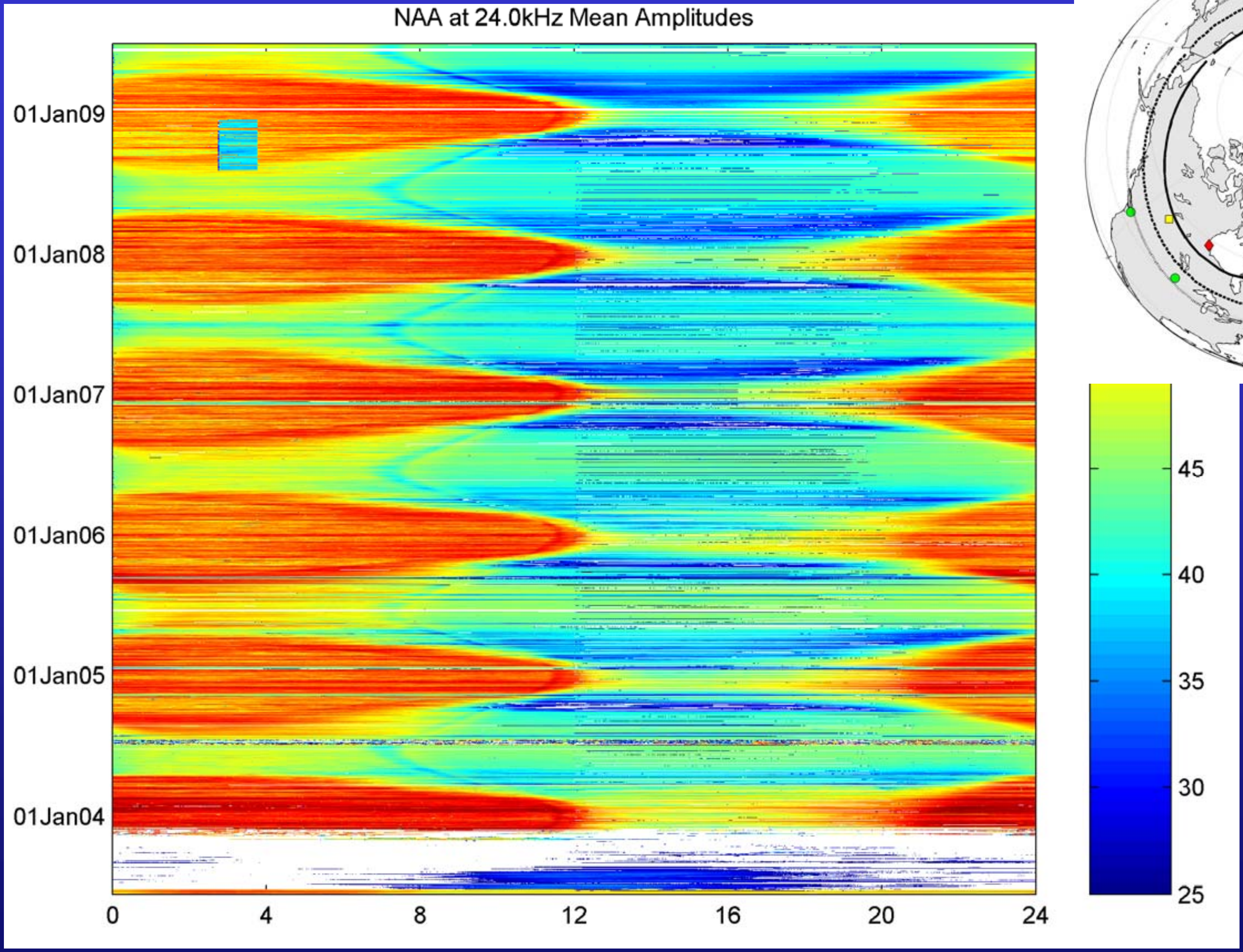
Looking for size of REP microburst "storm"

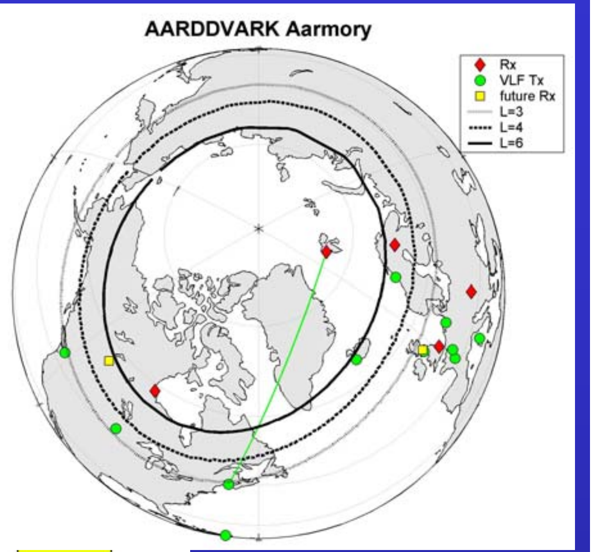


Look at time-periods when we have SGO FAST events and check for microbursts also reports by SAMPEX in the BLC. The biggest longitude difference is at 14:21UT on 8 May 2005, which is 94°.

Of course this does assume a single "storm" system.

3. The Future?





Over the next few years we plan to determine long-term particle precipitation fluxes into the atmosphere along some of our paths, providing a new near-continuous space weather monitor and support for RB missions (RBSP, ORBITALS, BARREL).

Conclusions

- AARDDVARK provides a network of continuous long-range observations of the lower-ionosphere in the polar regions.
- The network of sensors detects changes in ionization levels from ~30-90 km altitude, globally, continuously, and with high time resolution, with the goal of increasing the understanding of energy coupling between the Earth's atmosphere, the Sun, and space.
- A recent study have shown that EMIC-waves can drive intense bursts of relativistic electrons into the atmosphere, confirming long reported theoretical calculations.
- The VLF perturbation decay time is consistent with short-lived bursts of REP (~1.5 MeV electron). Such bursts have been previously observed by satellites as relativistic microbursts. SAMPEX and AARDDVARK data combined suggest the region over which REP microburst storms are at least as large as 90 degrees in longitude.
- The AARDDVARK modelling tools have advanced to the point that we can estimate precipitation fluxes from the observations, to test against other experiments and eventually feed models.

Mark Clilverd and Craig Rodger at the summit of Helvellyn, the 3rd highest mountain in England (950m above sea level). [September 2009].

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Thankyou!

Are there any questions?

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