Relativistic Microburst Storm Characteristics: Combined Satellite And Ground-Based Observations

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Topkapi B

Microbursts

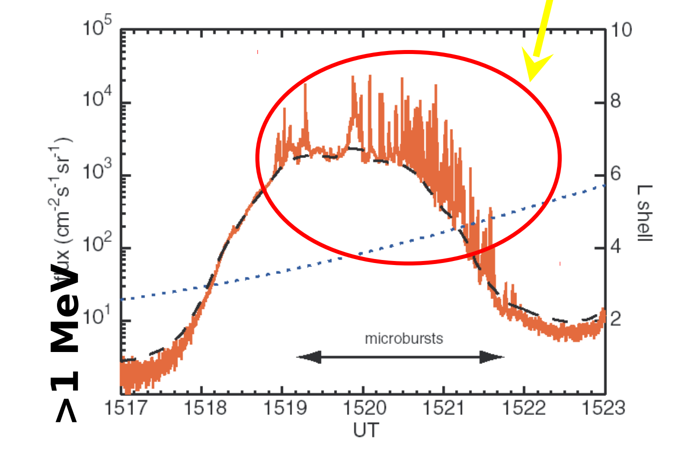
These pulses here!

RELATIVISTIC MICROBUSRTS

- >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]

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.



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 <u>no ground based observations</u>.

Plot taken from:
Lorentzen et al. (2001), *GRL*, 28(13), 2573-2576.

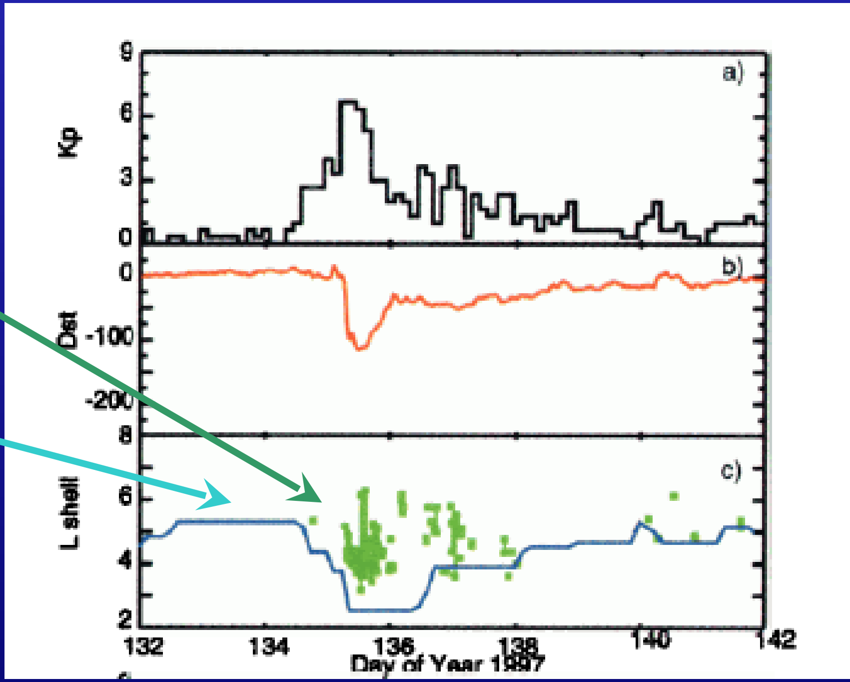
Microbursts

In addition:

SAMPEX observations have shown that relativistic microbursts occur during geomagnetic storms and at locations which are outside the plasmapause.

Microbursts are the green dots here!

Modelling plasmapause location provided by the blue line.



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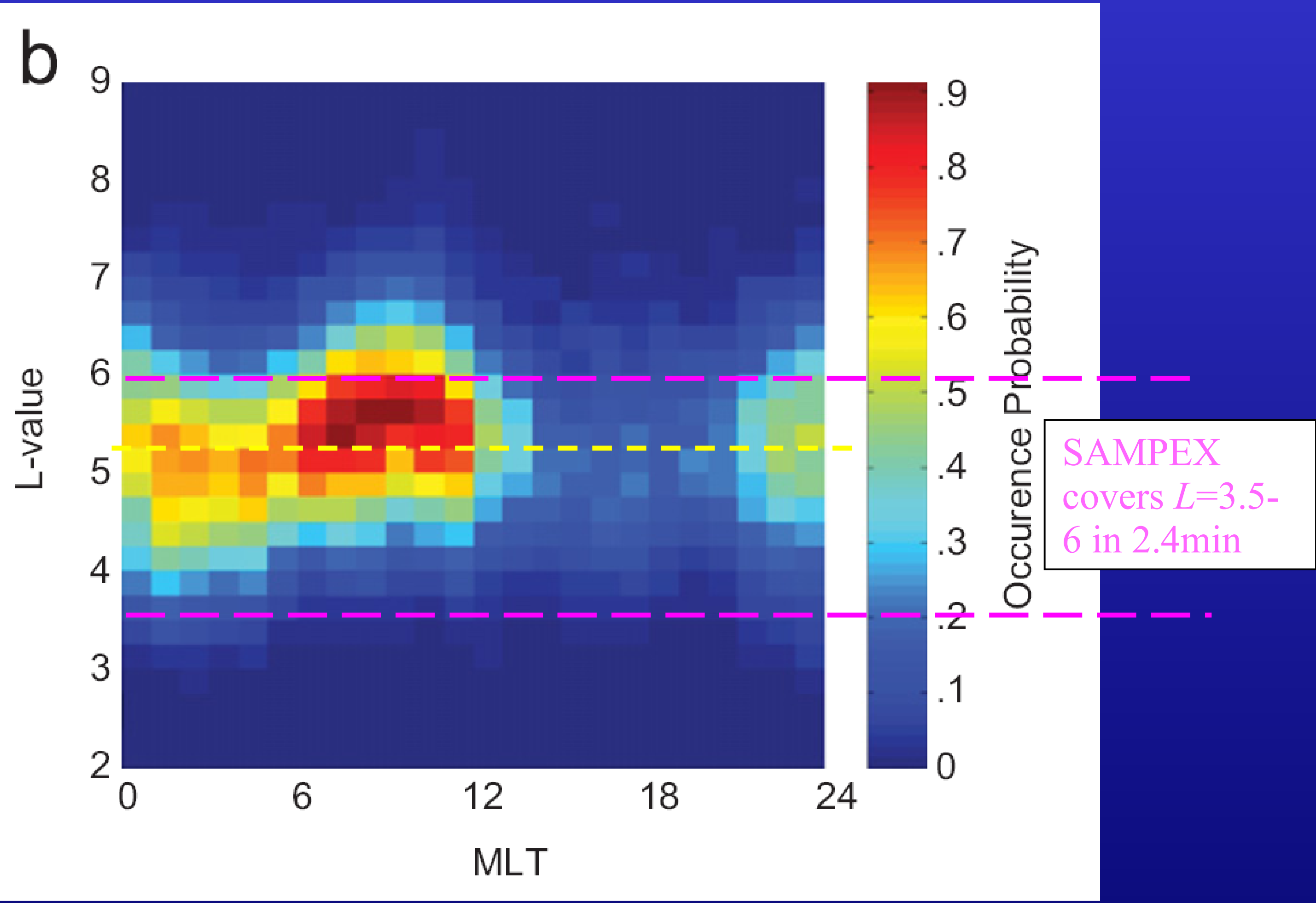
REP Microbursts



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

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

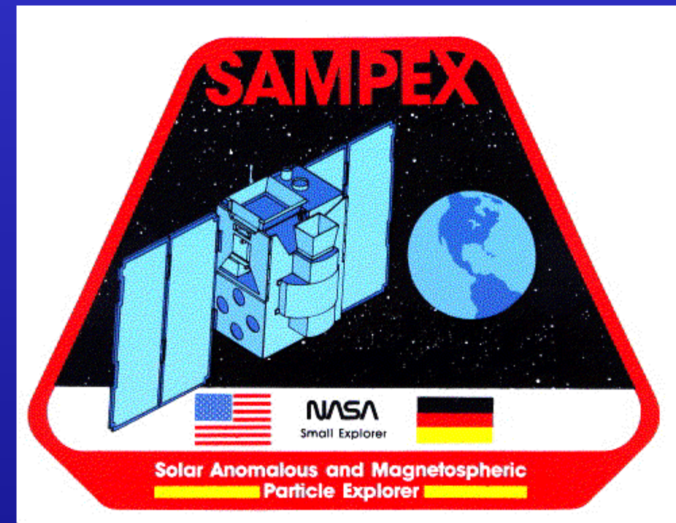
Experimental Observations

Ground Based Observations from Sodankylä (SGO)

Position: 67° 22' N, 26° 38' E

$L \approx$ 5.3

AARDDVARK instrument (subionospheric VLF receiver) located outside plasmapause.

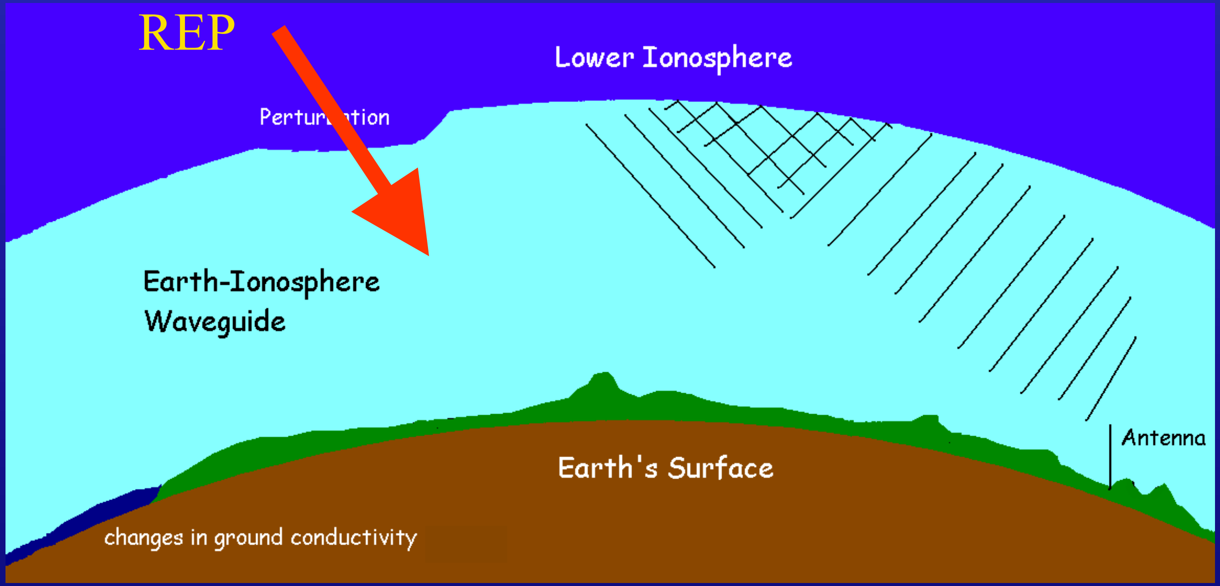


Space Based Observations from SAMPEX

Orbit: 520 × 670 km altitude and 82º inclination, orbit period is ≈ 96 min. HILT measures RB electrons >1.05 MeV.

Energetic Precipitation from the RB affects the lower ionosphere

For electrons >100keV, the bulk of the precipitated energy is deposited into the middle and upper atmosphere (30-100km), and can be detected through changes in subionospheric VLF propagation.

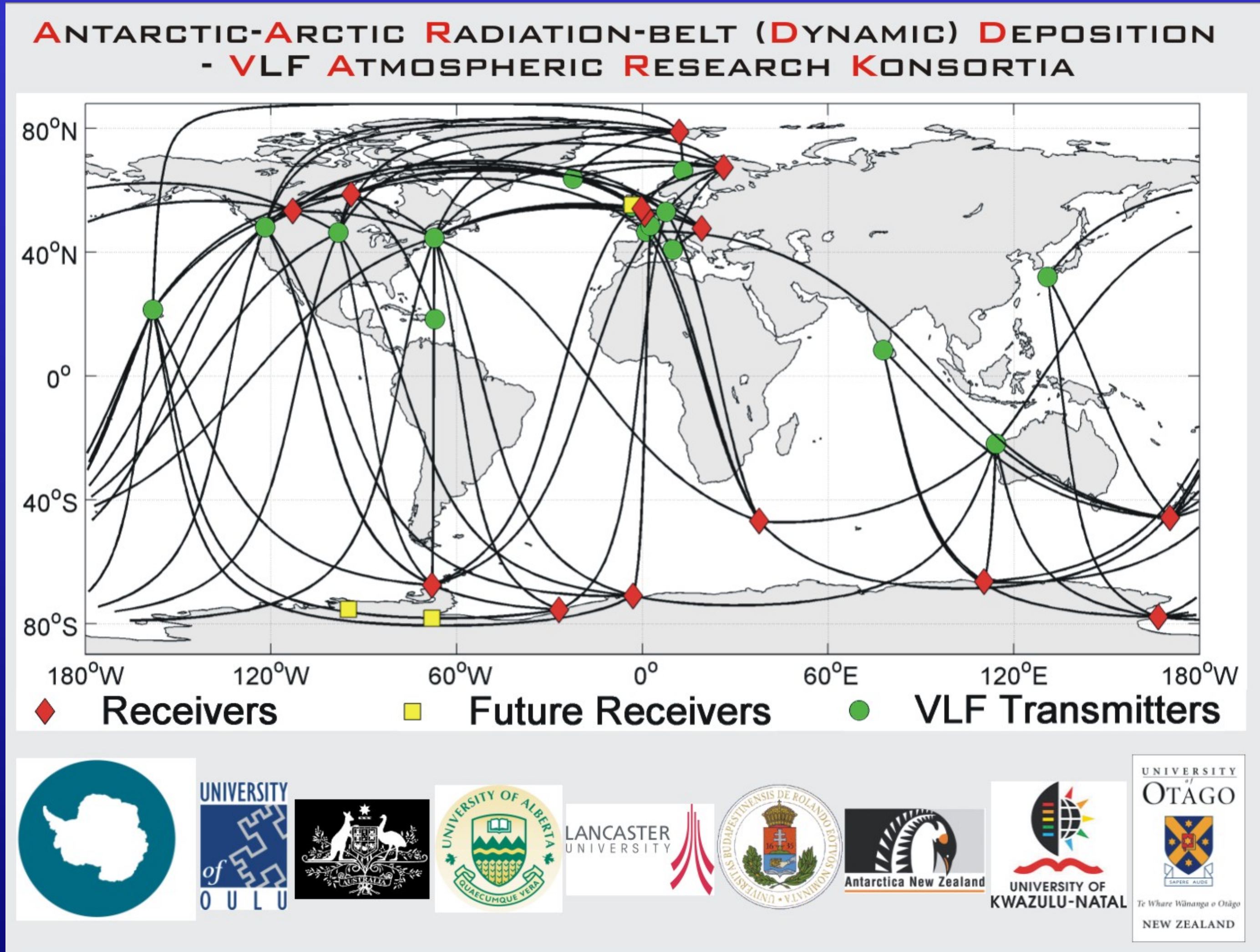


Subionospheric VLF signals reflect from the ionospheric *D*-region.

→ received radio waves are largely determined by propagation between the boundaries

→ Very-long range remote sensing is possible (1000's of km)!

Our AARDDVARK

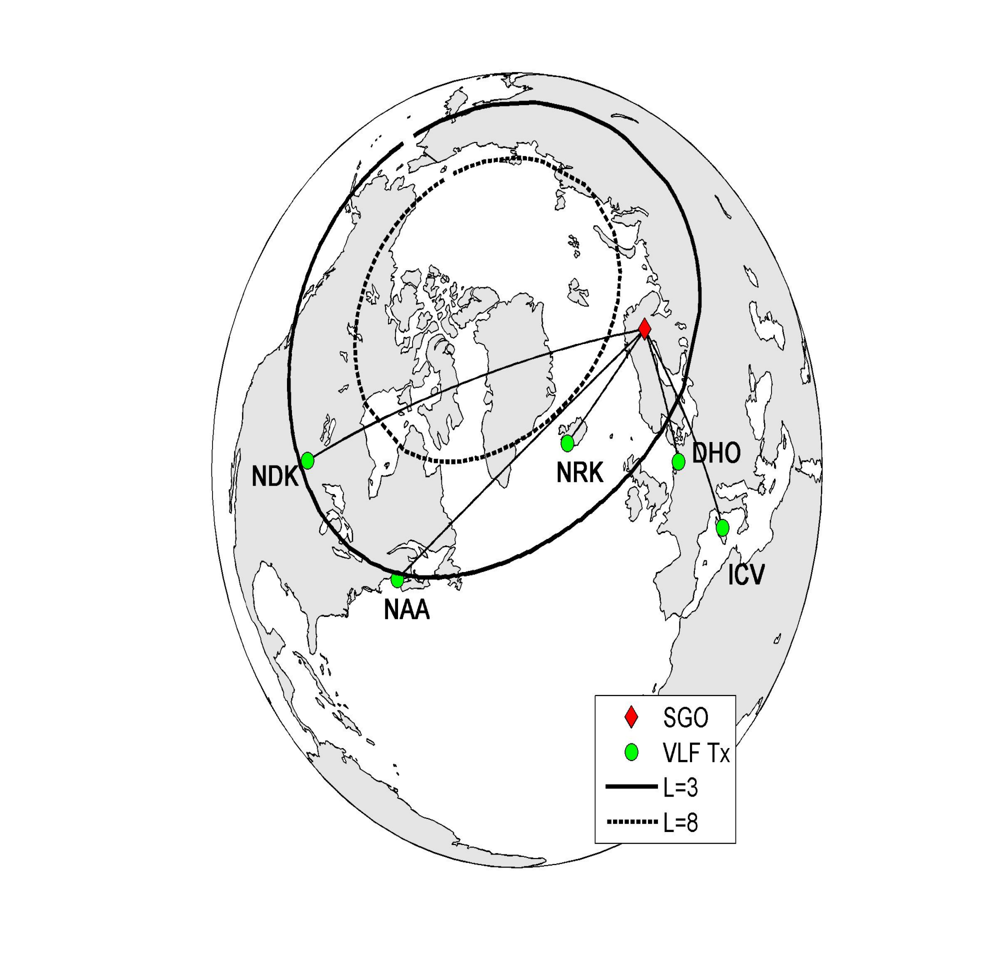


An aarmory of AARDDVARKs. This map shows our <u>existing</u> network of sub-ionospheric energetic precipitation monitors.

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

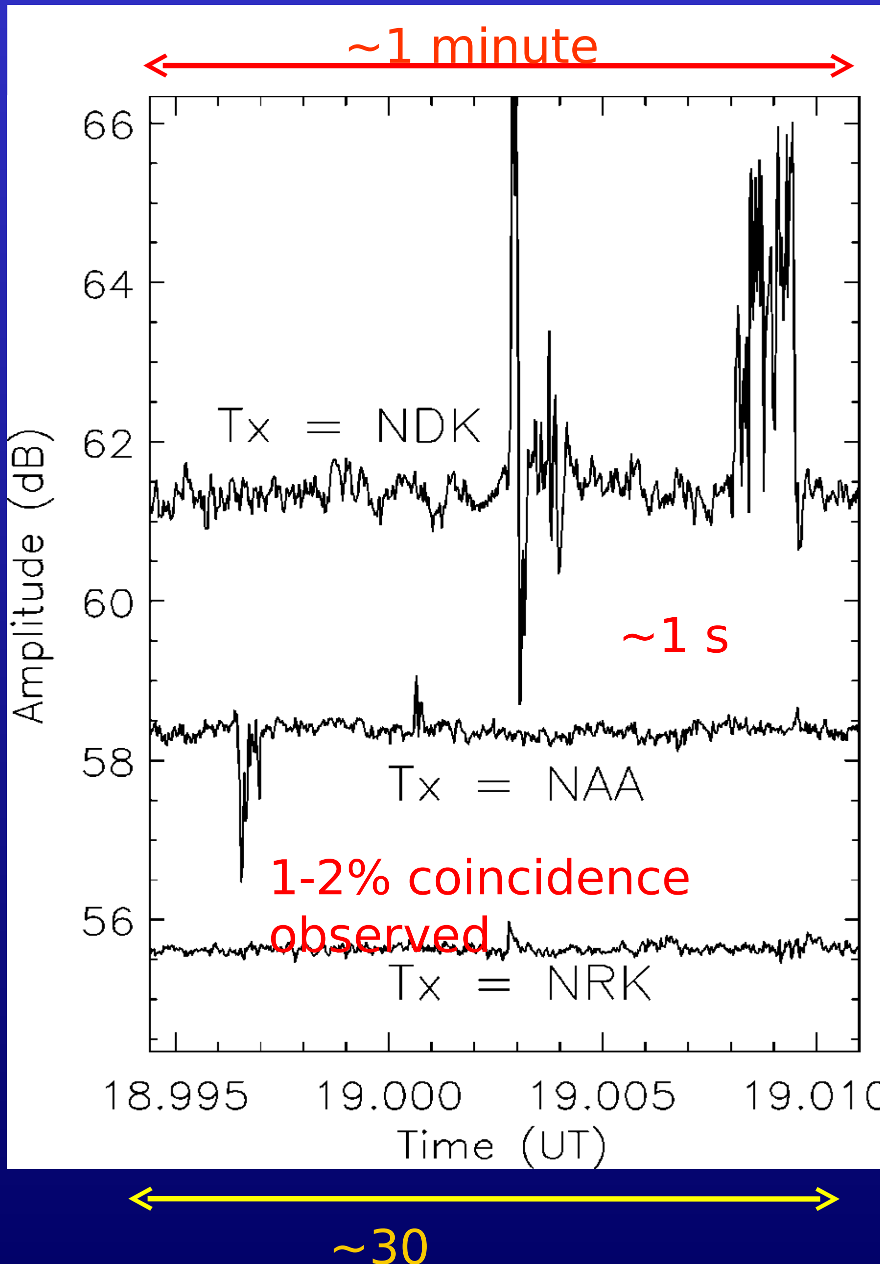
OR: Clilverd et al., Space Weather, 7, S04001, doi: doi:10.1029/2008SW000412, 2009.

Observation setup for this study



Focusing on the time period from December 2004 to June 2005 and the AARDDVARK data from the Sodankylä Geophysical Observatory (SGO) receiver. There were multiple big storms in this time. Our 5 “look directions” span around L=3-8.

Examples of FASTREP in SGO data



The residual amplitudes that remain after removing the smoothed background with a 5s filter, drawing out the rapid changes.

Shows many large short-lived spike events of 1-5 dB, both increases and decreases.

Approximately 99% of individual FAST events are <u>not</u> coincident across different received signals.

This suggests that FAST events are the result of a precipitation "rainstorm" producing spatially small (tens of km or less) REP "raindrop"s.

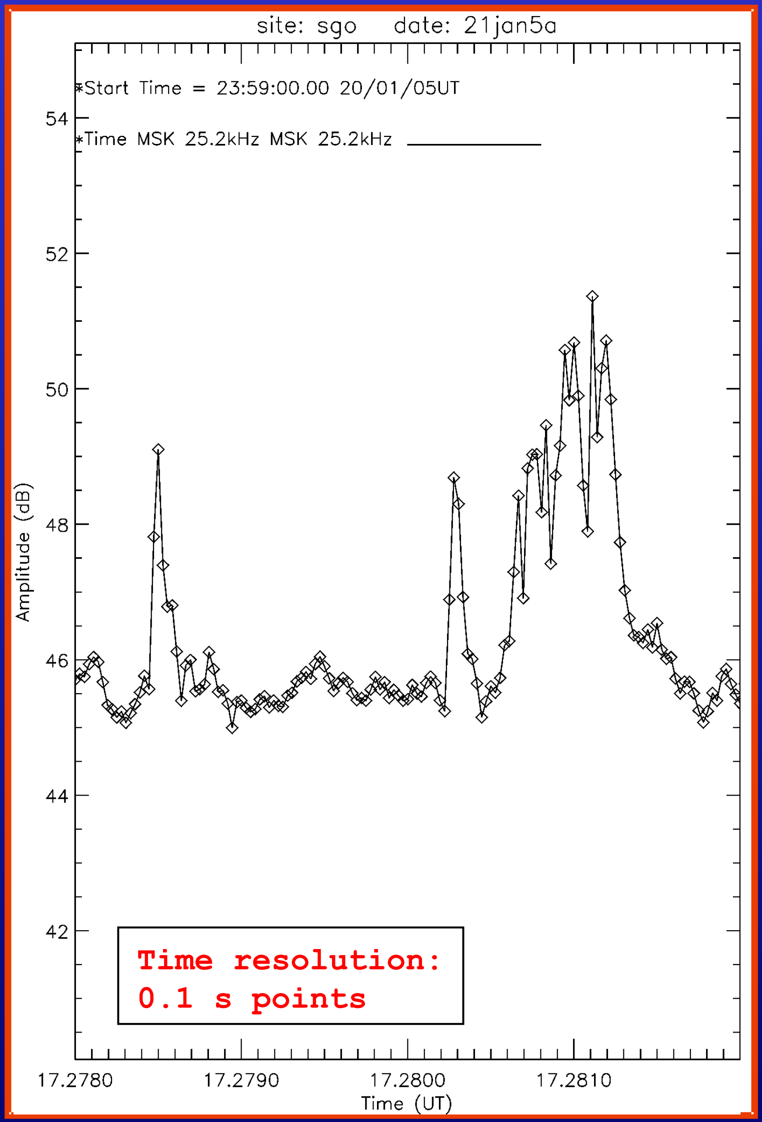
FASTREP events at SGO occur during high geomagnetic activity

	D/N	SPE	K_p	FAST	FAST Period	FAST Peak
May 8th	Day	N	8.3	Y	12:55-15:16	12:55-13:30
May 15th	Day	Y	8.3	Y	02:36-09:08	02:36-03:11, 05:55-06:30
Jan 21st	Night	Y	8.0	Y	17:12-19:50	17:12-17:20, 18:30-19:50
May 30th	Day	N	7.7	N		
Jun 12th	Day	N	7.3	N		
Apr 4th	Night	N	7.0	Y	20:50-02:30	00:00-02:30
Jun 23rd	Day	N	7.0	N		
Jan 19th	Night	Y	6.7	Y	01:16-06:14	04:10-04:36
Feb 18th	Night	N	6.3	N		

5 days in which we have FASTREP activity.

There is no hard and fast rule for the occurrence of FAST events in the SGO data with Kp, but geomagnetic activity is a clear indicator. A big storm (Kp over 6.7) is a minimum requirement.

Timescales of FASTREP

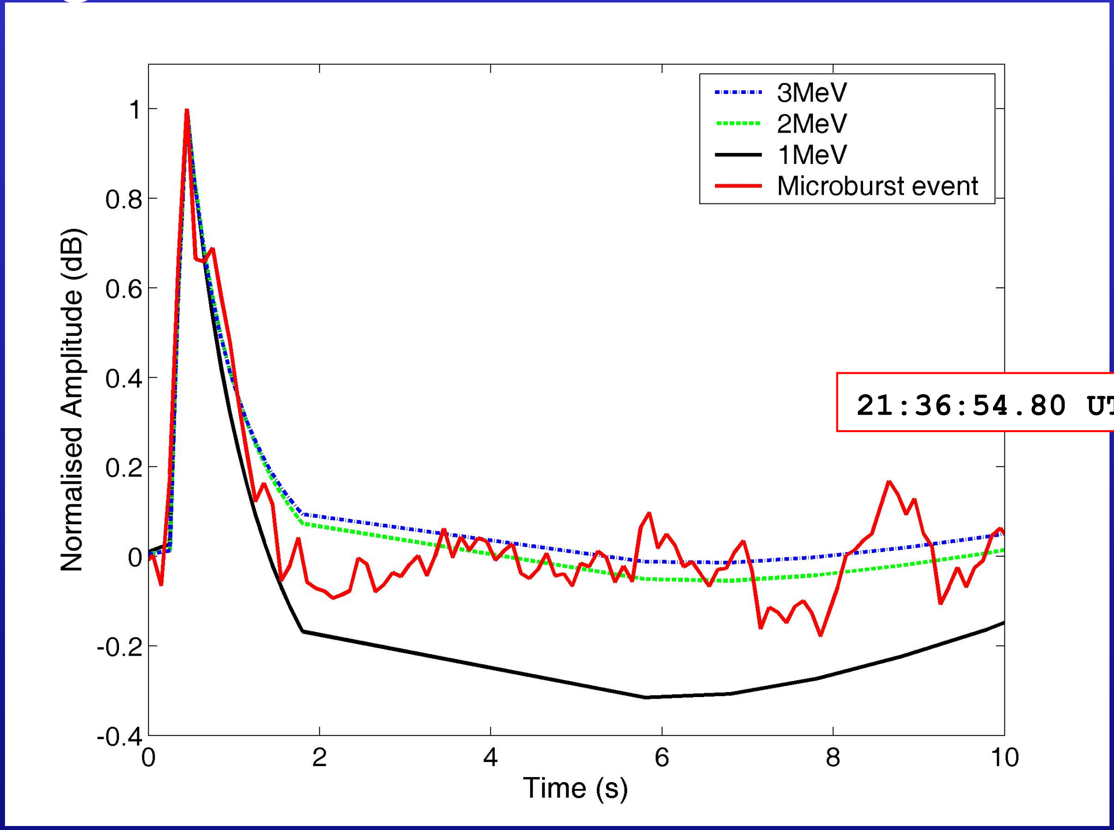


Example from 21 January 2005. On this day we generally see a ~0.2s risetime (which is equipment limited), following by a ~0.5s decay, but with some perturbations appearing to be made up of multiple events.

The rapid decay time is highly suggestive of a short-lived, highly energetic precipitation burst, producing significant additional ionization at ~60km altitude (peak ionization altitude for a ~1.5MeV electron).

We therefore conclude that the FAST subionospheric VLF perturbations are most consistent with the ionization signature caused by REP microbursts.

Modelled VLF perturbation from mono-energetic REP beams



21:36:54.80 UT, 5 April 2005

Try 0.1s monoenergetic beams with flux of 100 el.cm^{-2}s^{-1}sr^{-1} (similar to SAMPEX) and contrast with the same microburst decay time. We need a highly energetic beam with no significant electron flux less than ~1.5MeV to reproduce the decay time of our VLF perturbations. This is consistent with the satellite observations of the flux in relativistic REP microbursts.

Consistent Decay Timescales of SGO observed FASTREP events from 2005

	Day/Night	SPE Flux	Peak K_P	Decay Time
Jan 19th	Night	189.5	6.7	1.04
Jan 21st	Night	373.5	8.0	0.8
Apr 4th-5th	Night	0.451	7.0	1.2
May 8th	Day	0.1495	8.3	0.84
May 15th	Day	3790	8.3	0.63

Table 6.2: FAST event decay times for the five known FAST periods from December 2004 - June 2005 (inclusive).

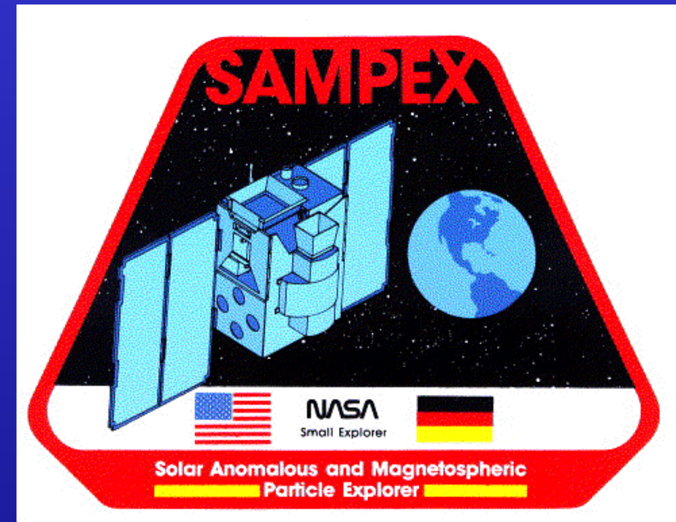
The decay times are consistent with a "cartoon model" as to how far the REP penetrates below the existing VLF reflection height:

day + SPE	only low altitude ionisation present (short decay time)
night + noSPE	more altitudes take part (longer decay time)

Microbursts hit the atmosphere → FAST events. 'Raindrop' versus 'rainstorm' – how big are either of these?

Experimental Observations

Ground Based Observations from Sodankylä (SGO)



Space Based Observations from SAMPEX

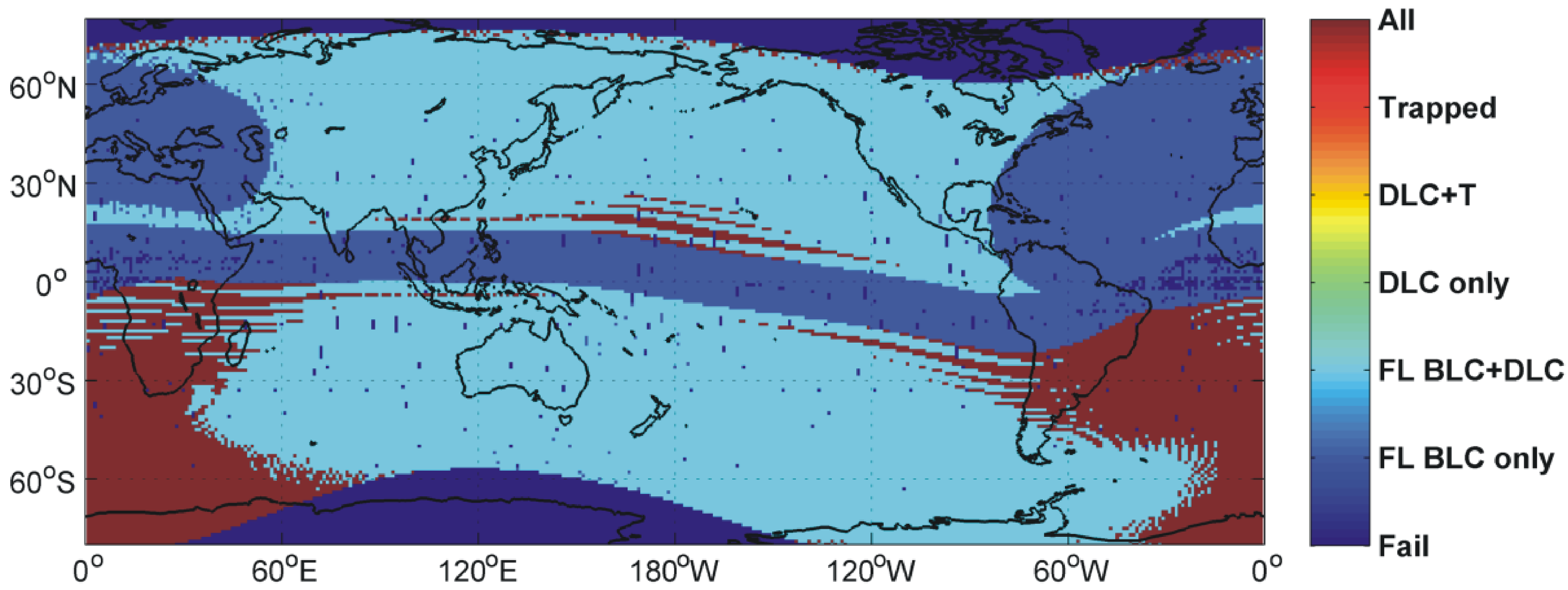
We have contrasted SAMPEX data with SGO FASTREP events to try and determine:

the size of a single REP microburst ("raindrop size")

the size of the region in which REP is occurring ("storm size")

SAMPEX does agree it is "raining" when SGO reports FAST events.

Radiation belt populations observed by SAMPEX's HILT instrument.

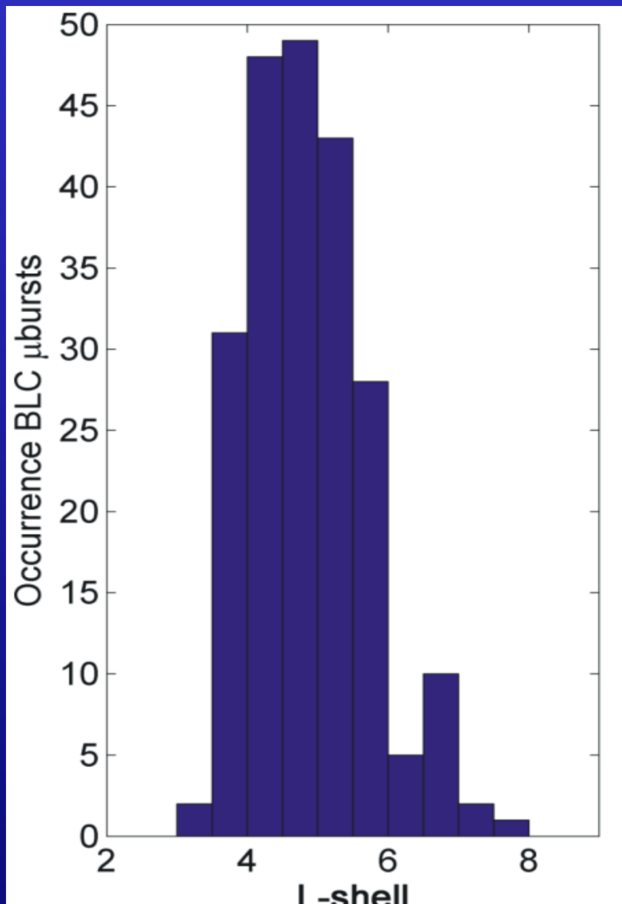


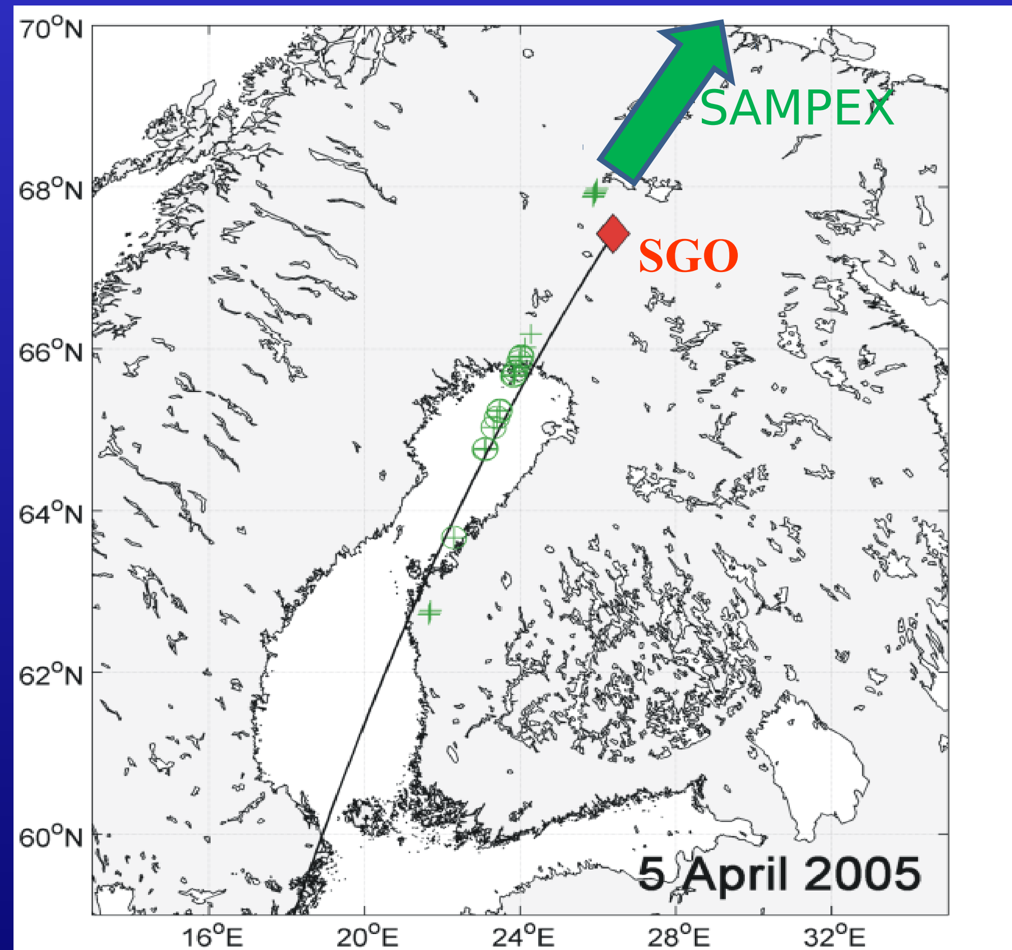
FROM: Dietrich et al. (2010), *JGR*, 115, doi:10.1029/2010JA015777, 2010.

'In the Northern Hemisphere from about 85°W to 55°E the HILT detects only BLC fluxes'.

Our ground-base observations map into SAMPEX 'Bounce Loss-Cone only' region (good for detecting microbursts that will reach the atmosphere).

SAMPEX microbursts seen during FAST events



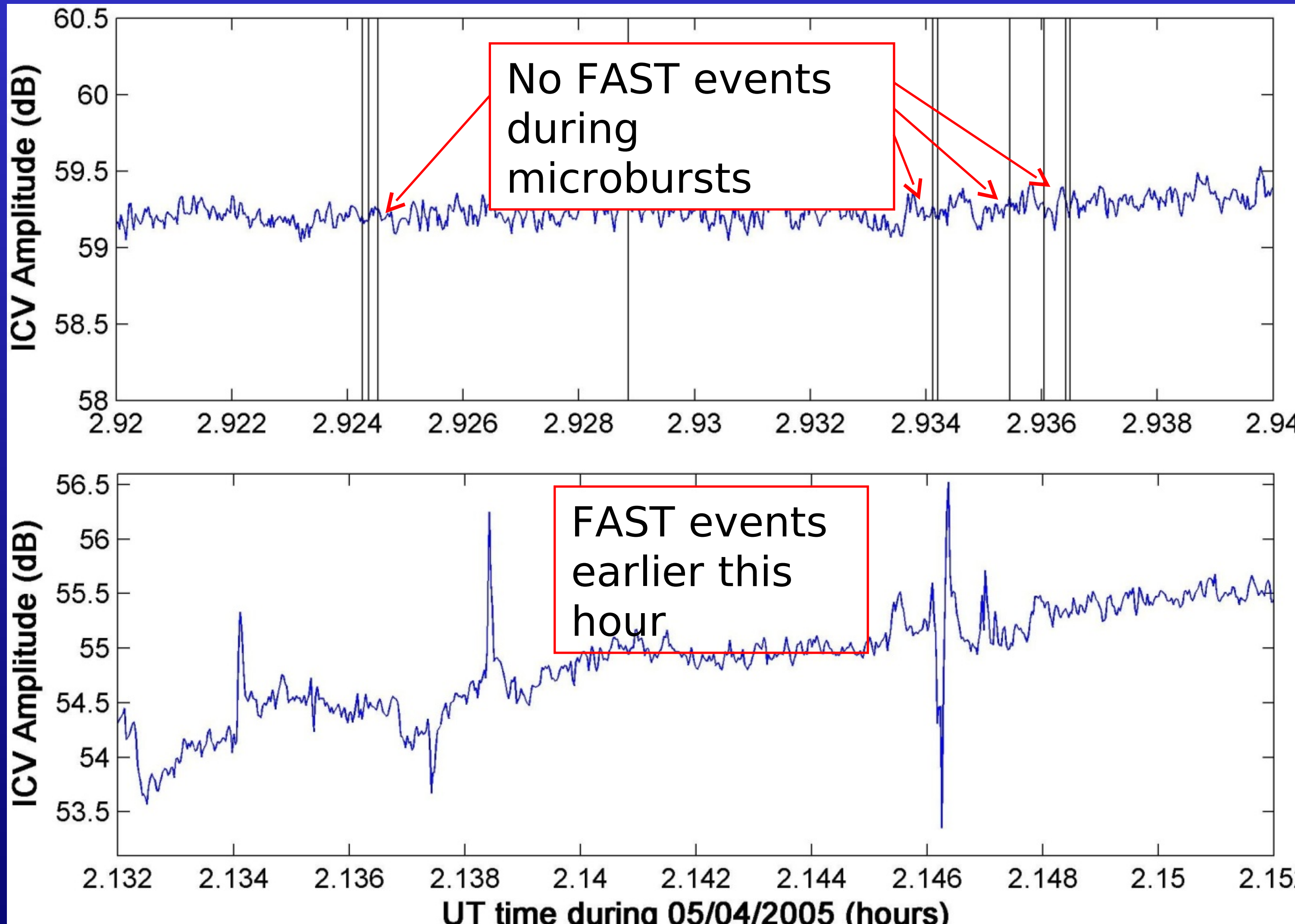


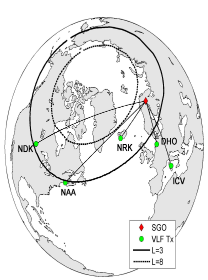
Normal L-shell values seen ($3<L<6$):
During FAST events periods SAMPEX sees typical

Some SAMPEX-observed microbursts (mapped down to 90km) hit very close to one of the Sodankylä look directions

Microbursts land close to a path

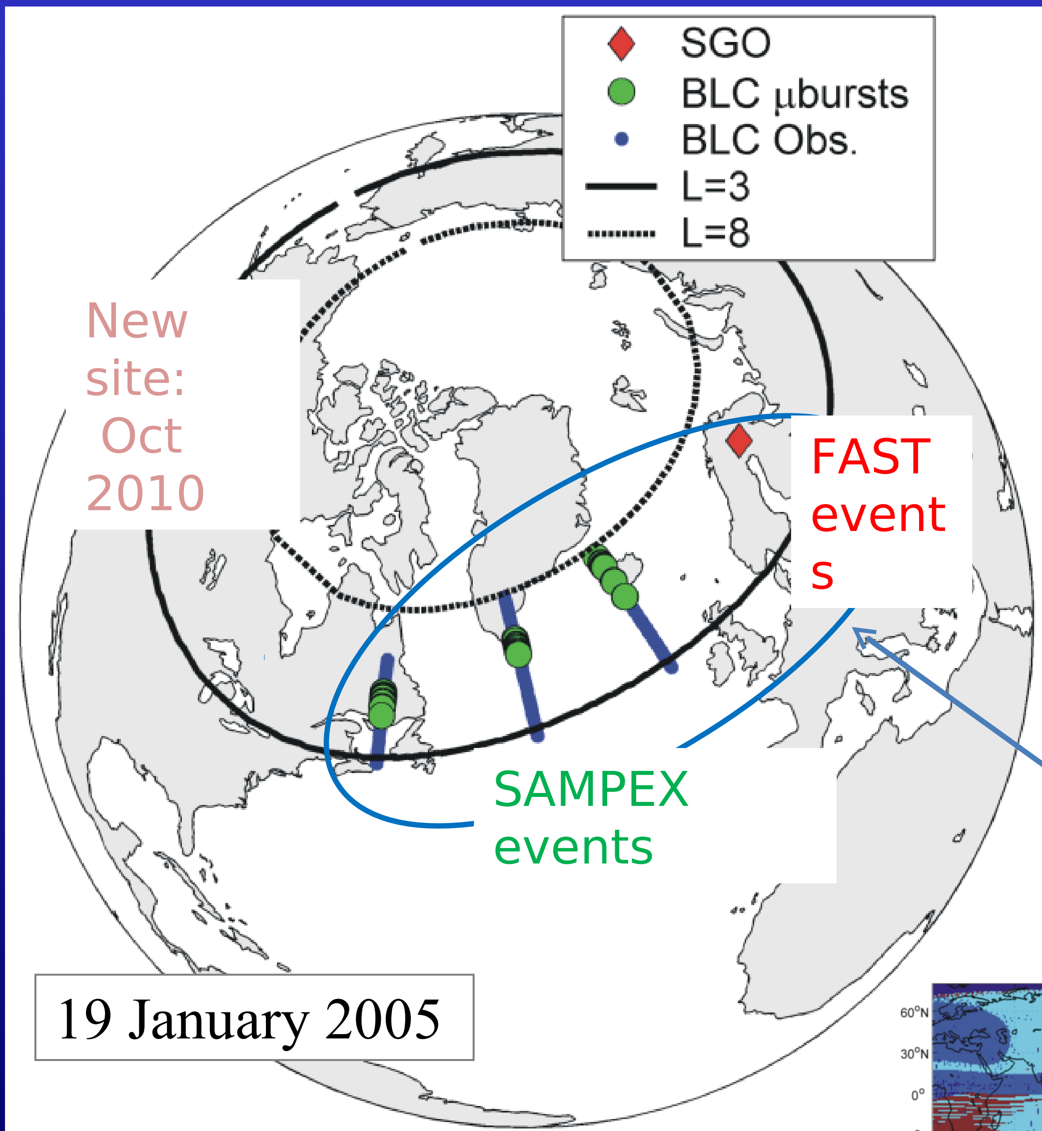
Like the balloon measure-ments of relativistic microbursts, we have not "caught a rain-drop“.





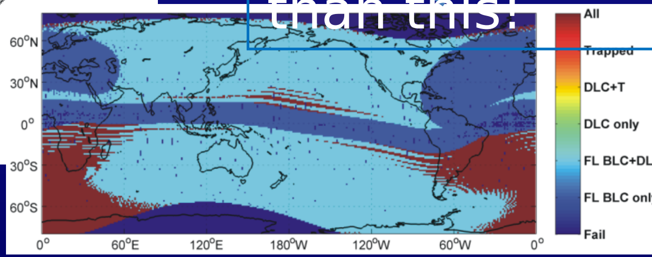
This suggests that ‘raindrops’ are very small, i.e., <10 km diameter

What about the rainstorm?

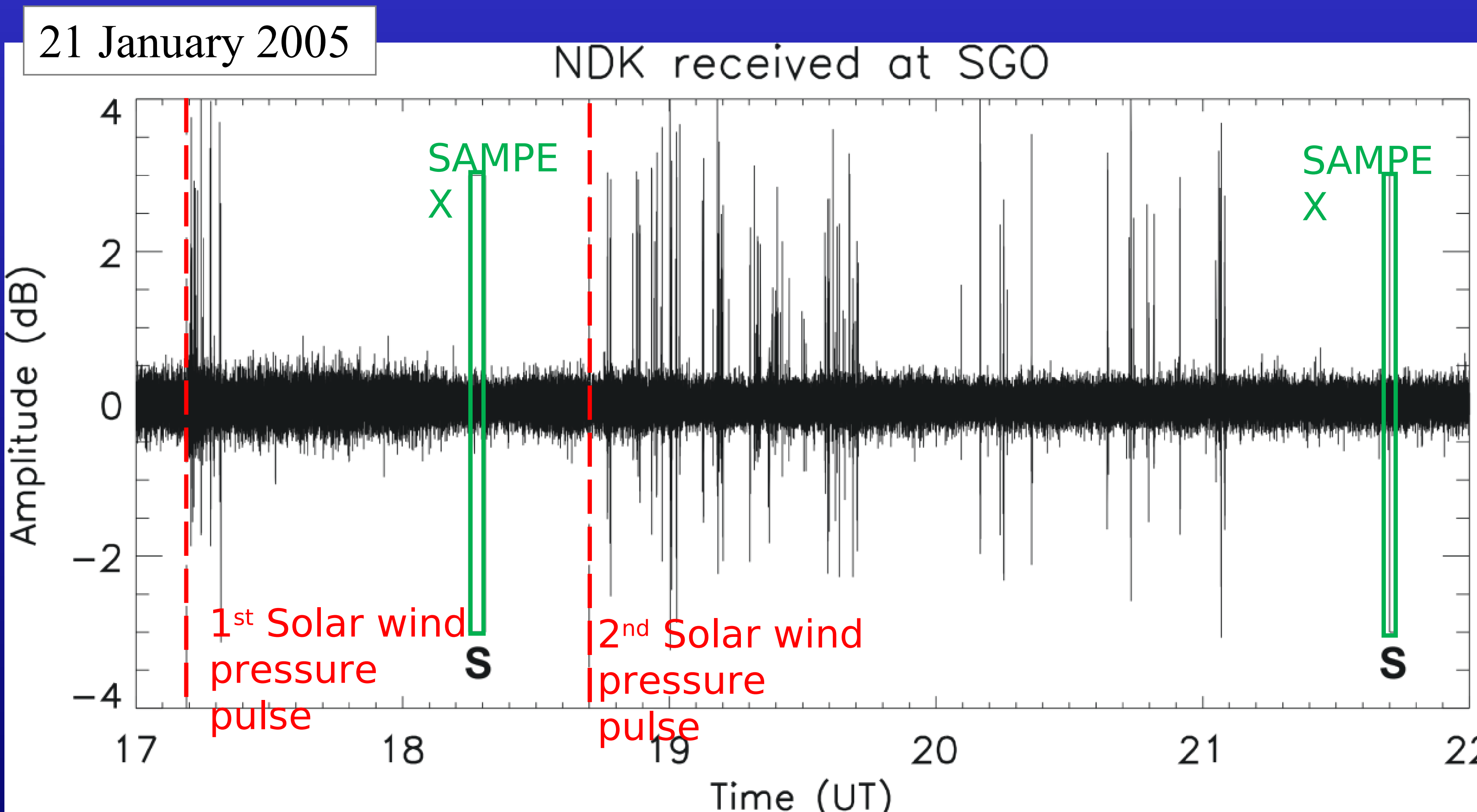


Microbursts and FAST events occur during the same time period, but over a wide range of longitudes

Typically microbursts are seen where SAMPEX observes in the BLC. Thus the 'rainstorm' might actually be bigger than this!



Advantage of continuous ground based observations



Dynamic drivers cause time-variations in ground-based FAST events, not observed with SAMPEX microburst observations

Summary

- When relativistic microbursts hit the atmosphere they are produce subionospheric VLF perturbations we term FAST events.
- The precipitation area of each relativistic microburst is small (<10 km diameter) → 'raindrop' size
- The precipitation region is very large (1000's of km and at least ~6 MLT) → 'rainstorm' size
- SAMPEX only sees BLC microbursts in a limited region. FAST events should be seen outside that region [we hope to provide new reports from Edmonton AARDDVARK].
- AARDDVARK should be able to provide additional insight into the response to geomagnetic drivers.
  ESPECIALLY for the time periods when SAMPEX is outside of the radiation belts. Here ground-based and balloon measurements will provide highly valuable complementary observations.

MSc graduate Sarah Dietrich with Craig at the conference dinner of the 2009 Annual Antarctic Conference of Antarctica New Zealand. The conference dinner took place inside Kelly Tarlton's Antarctic Encounter and Underwater World, Auckland (NZ), 2 July 2009

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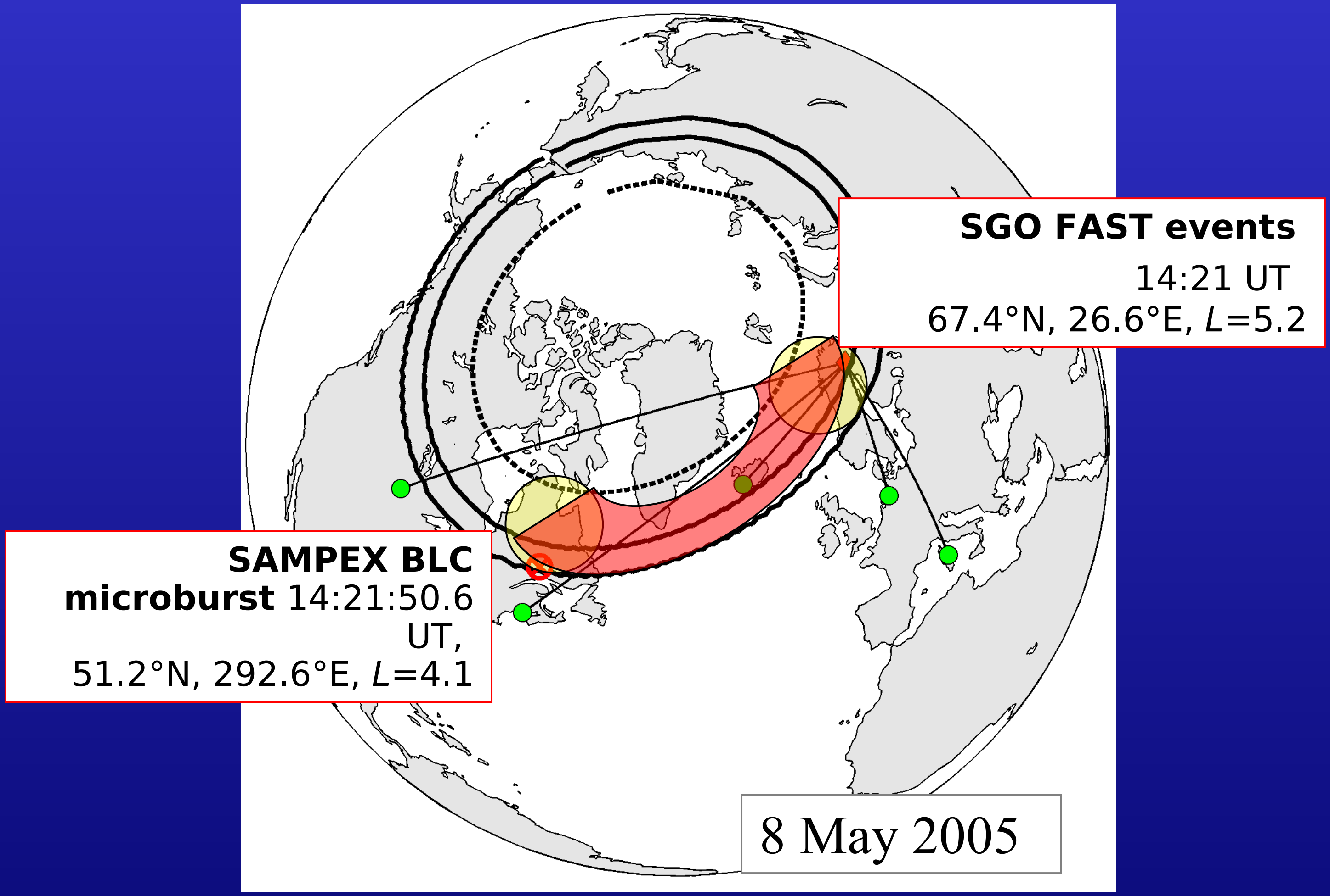
Thankyou!

Are there any questions?

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.

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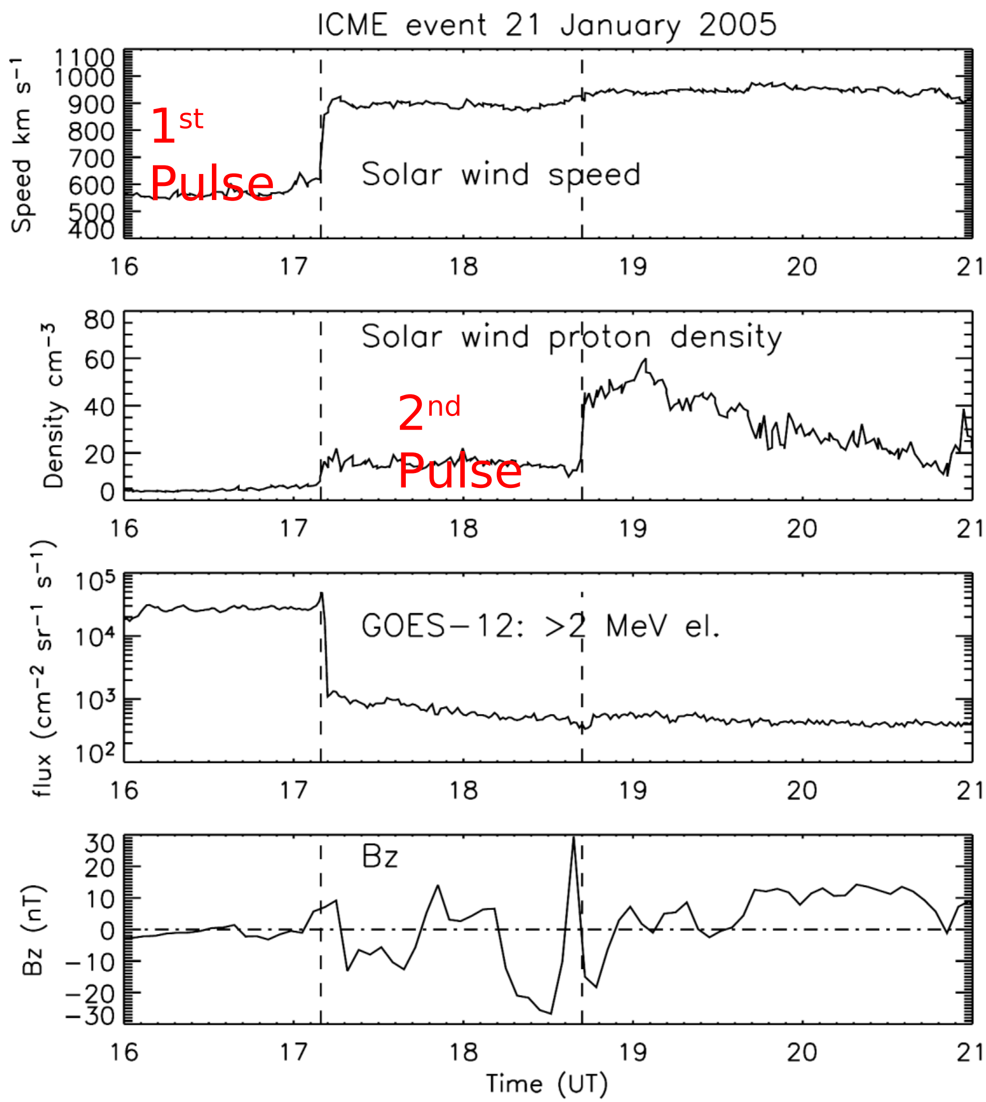
Response of the magnetosphere to solar wind
ses



ACE solar wind data shifted by 23 mins to estimate arrival time at the magnetosphere.

Two pulses, the first arrives at 17:12 UT, the second at 18:45 UT.

Can we see if any microbursts were generated?

Consistent Decay Timescales of SGO observed FASTREP events from 2005

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