DEMETER AND GROUND BASED OBSERVATIONS OF A LARGE-SCALE ELECTRON PRECIPITATION EVENT

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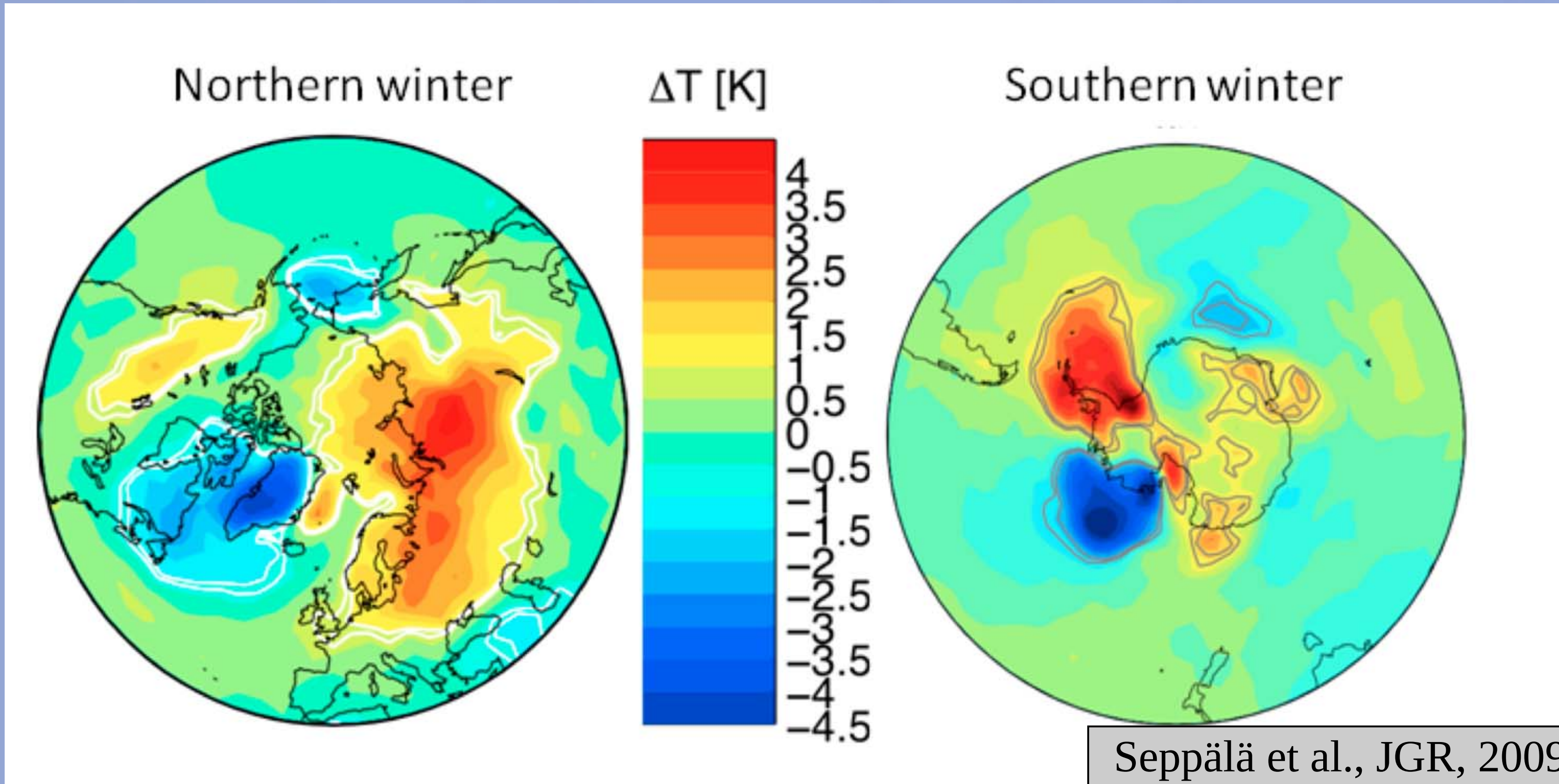
Overview

- Introduction and Motivation:
  - Why particle precipitation is important.
- Science background:
  - The drift loss cone and the bounce loss cone.
  - VLF measurements
  - VLF modelling
- Apply these methods to the January 2005 electron precipitation event.
- Determine flux and location of precipitation.

The Importance of Particle Precipitation



Seppälä et al., JGR, 2009

- Up to +/- 4⌖ polar surface temperature variation, statistically correlated to geomagnetic activity.

The Importance of Particle Precipitation

Particle precipitation
↓
Production of NO_x and HO_x
↓
Destruction of mesospheric and upper stratospheric O_3
↓
Change in radiation balance of mesosphere & <u>stratosphere</u>
↓
Climate

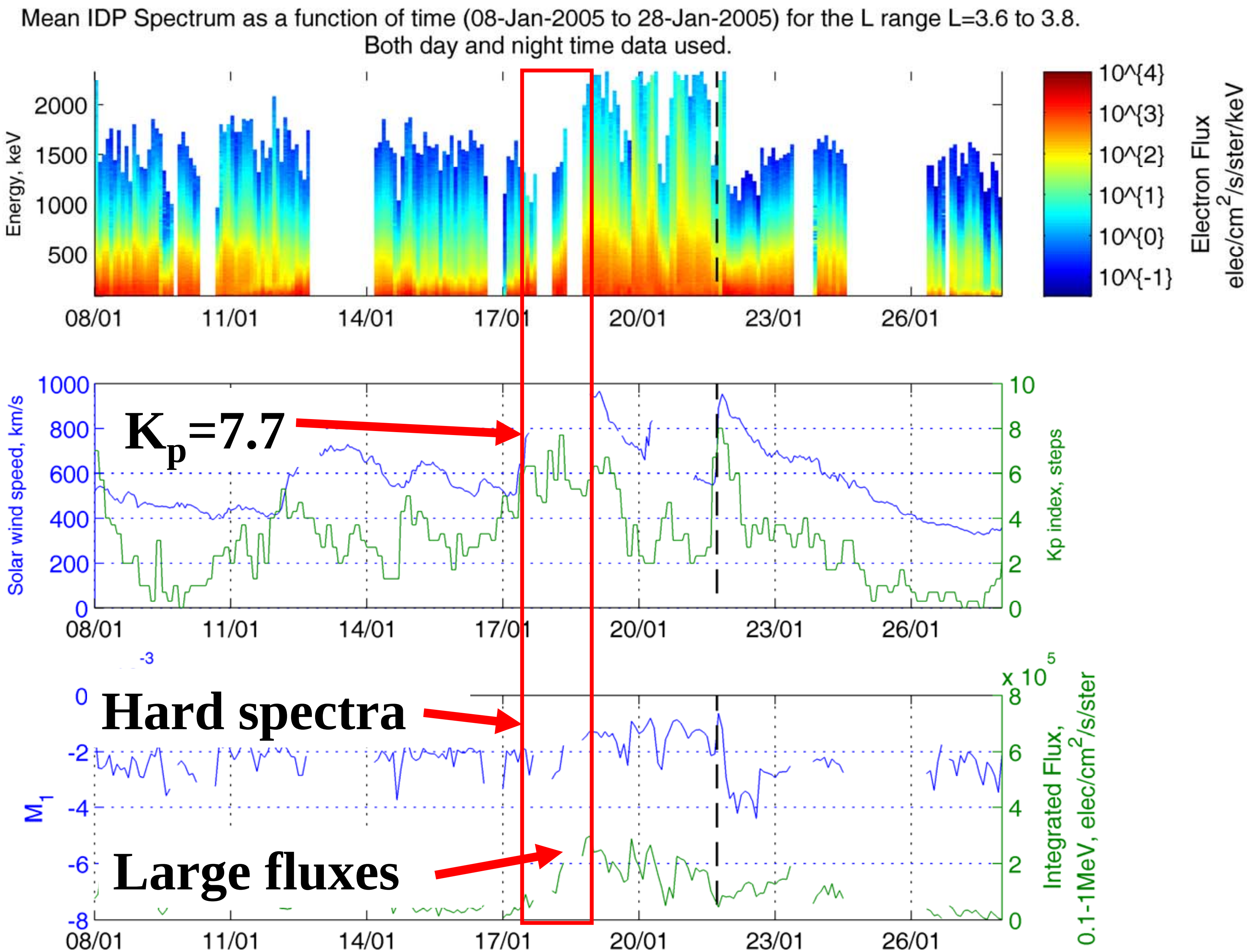
- Particle precipitation is one of the routes by which the Sun can link to the climate.
- Need to know about natural climate variation to say anything about human impacts on climate!

January 2005 Geomagnetic Storm

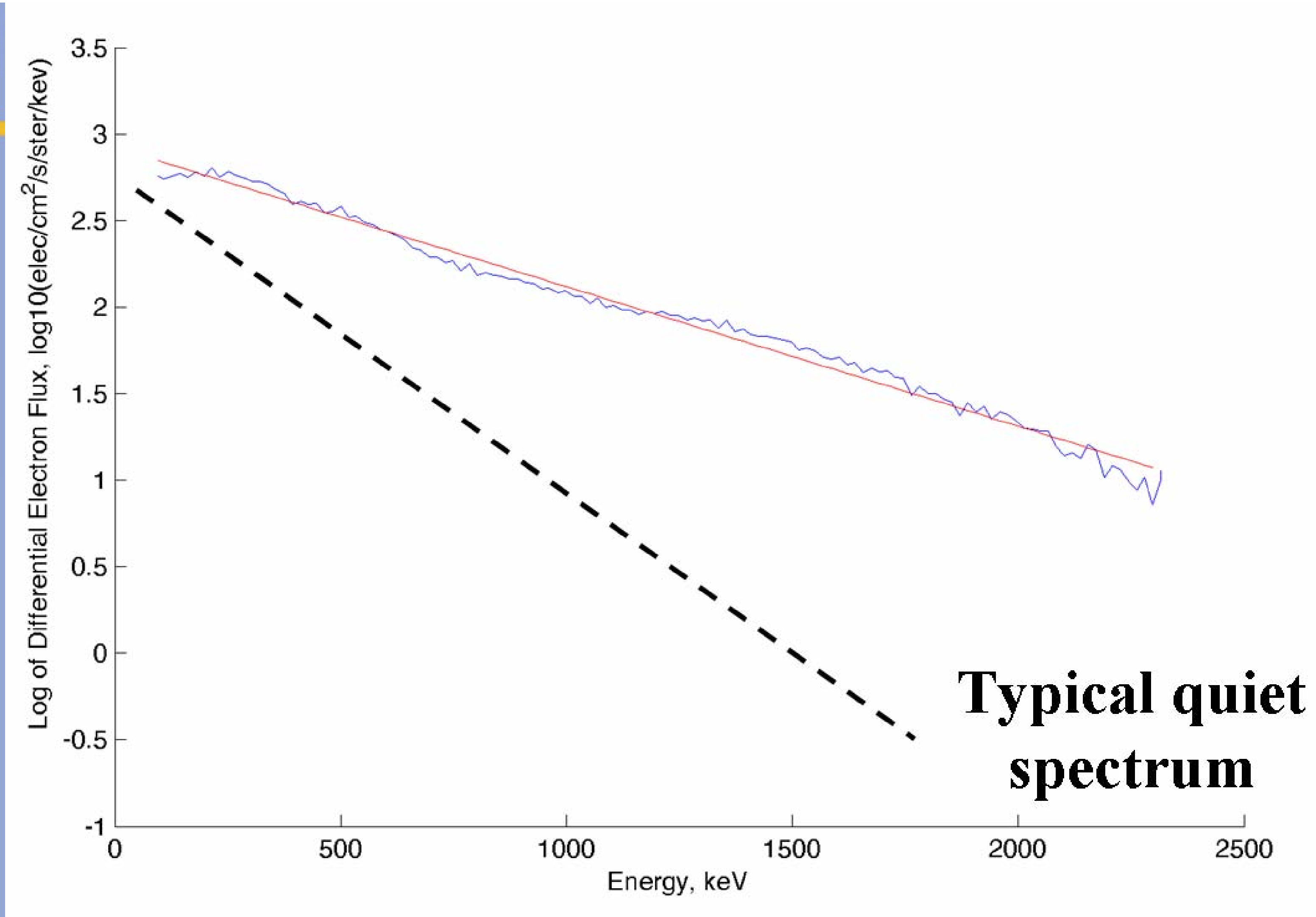
- Energetic electron precipitation event in January 2005.
- Precipitating electron energy spectrum (DEMETER)
- Subionospheric VLF (AARDDVARK).
- Combine with VLF modelling (LWPC).
- Determine nature of precipitation (size and location of region, precipitating flux, ionisation rate).

DEMETER Satellite

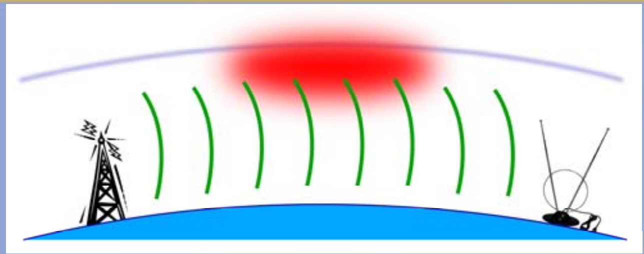
- In-situ measurements of radiation-belt electron spectra.
- Drift loss cone measurements up to L~7.
- Sees a strong response to storm.
- Drawbacks:
  - Single-point measurement, doesn’t give geographic extent.
  - Use drift-loss as proxy for loss cone: gives relative spectra, but doesn’t determine net flux of *precipitating* electrons…



Mean IDP Spectrum as a function of time (08-Jan-2005 to 28-Jan-2005) for the L range L=3.6 to 3.8.
Both day and night time data used.
Energy, keV
Electron Flux elec/cm^2/s/ster/keV
Solar wind speed, km/s
Kp index, steps
K_p=7.7
Hard spectra
Large fluxes
M_1
Integrated Flux, 0.1-1MeV, elec/cm^2/s/ster
08/01
11/01
14/01
17/01
20/01
23/01
26/01

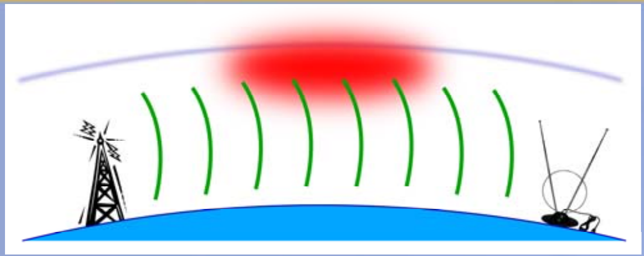


- Typical of large fluxes and hard spectra seen during 17-21 January storm period.
- Large flux: ~3×10^{8} elec/cm^2/s/ster (0.1-1MeV).
- Slope parameter: M_1~-8×10^{-4} elec/cm^2/s/ster/keV^2



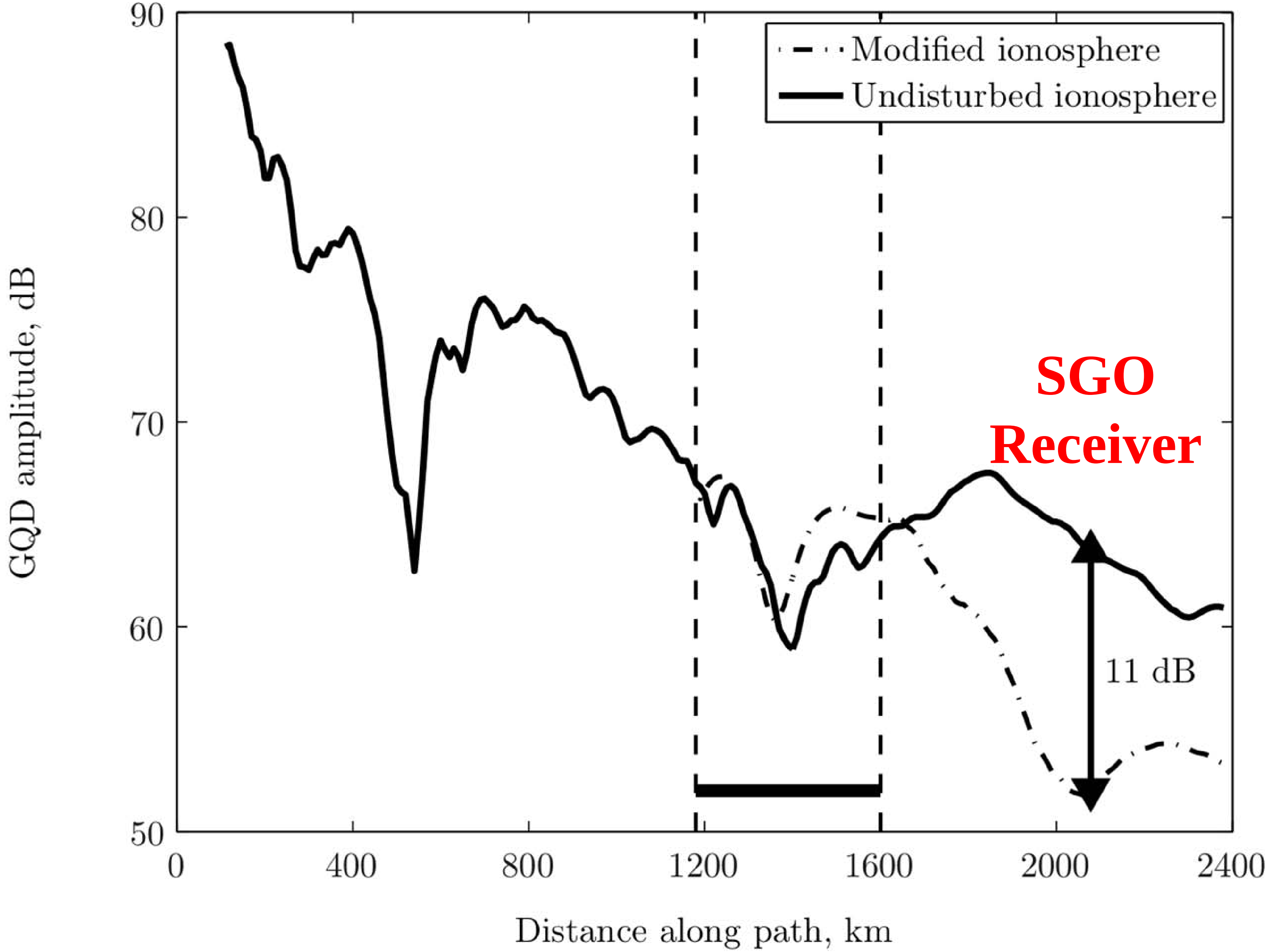
Subionospheric VLF

- VLF Waves trapped in ionosphere-Earth waveguide.
- Several modes propagate at once, combine at the receiver.
- Sensitive to precipitation in D-region and below (below 85 km altitude).
- Precipitation changes the mixture of modes present.
- Increase OR decrease in amplitude at receiver.



Subionospheric VLF

- Atmospheric precipitation causes changes in amplitude and phase at receiver.
- Can be used to infer geographic extent, net precipitation. (Compared to satellite)
- Drawbacks:
  - Results are indirect indicators – need to infer conditions from amplitude/phase perturbations



Modified ionosphere
Undisturbed ionosphere
SGO
Receiver
11 dB
GQD amplitude, dB
Distance along path, km
90
80
70
60
50
0
400
800
1200
1600
2000
2400

ANTARCTIC-ARCTIC RADIATION-BELT (DYNAMIC) DEPOSITION - VLF ATMOSPHERIC RESEARCH KONSORTIA

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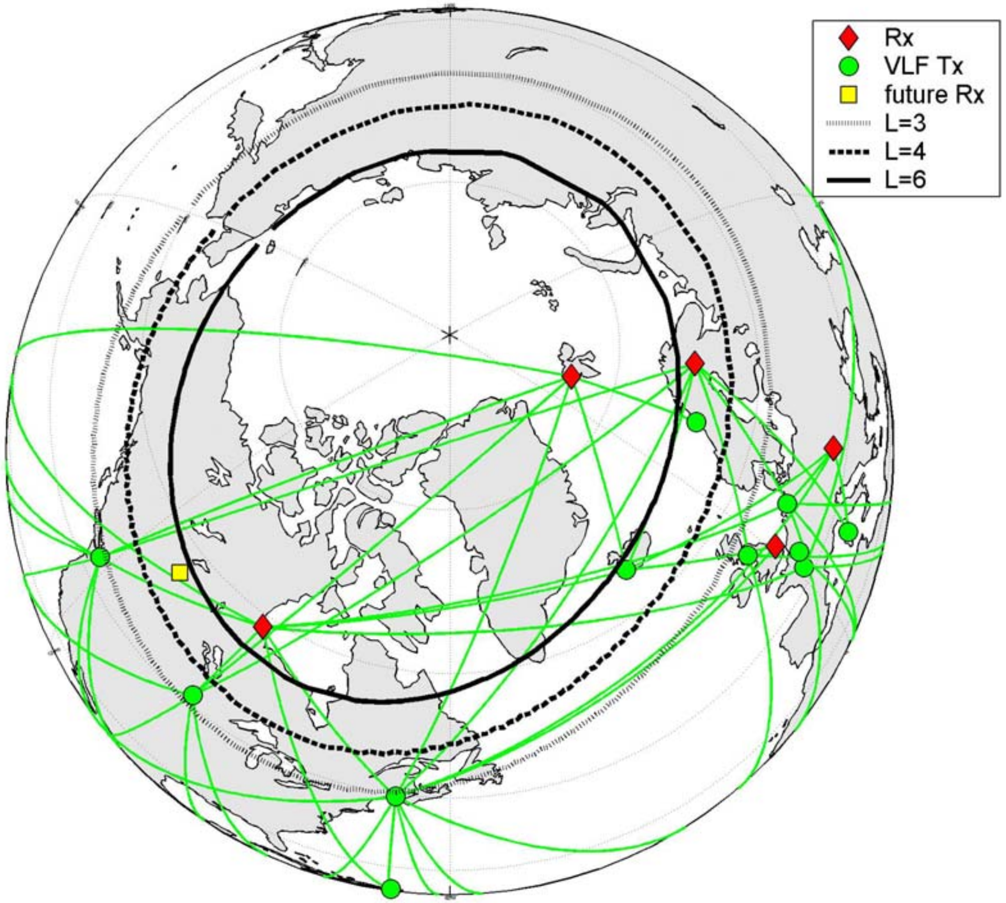
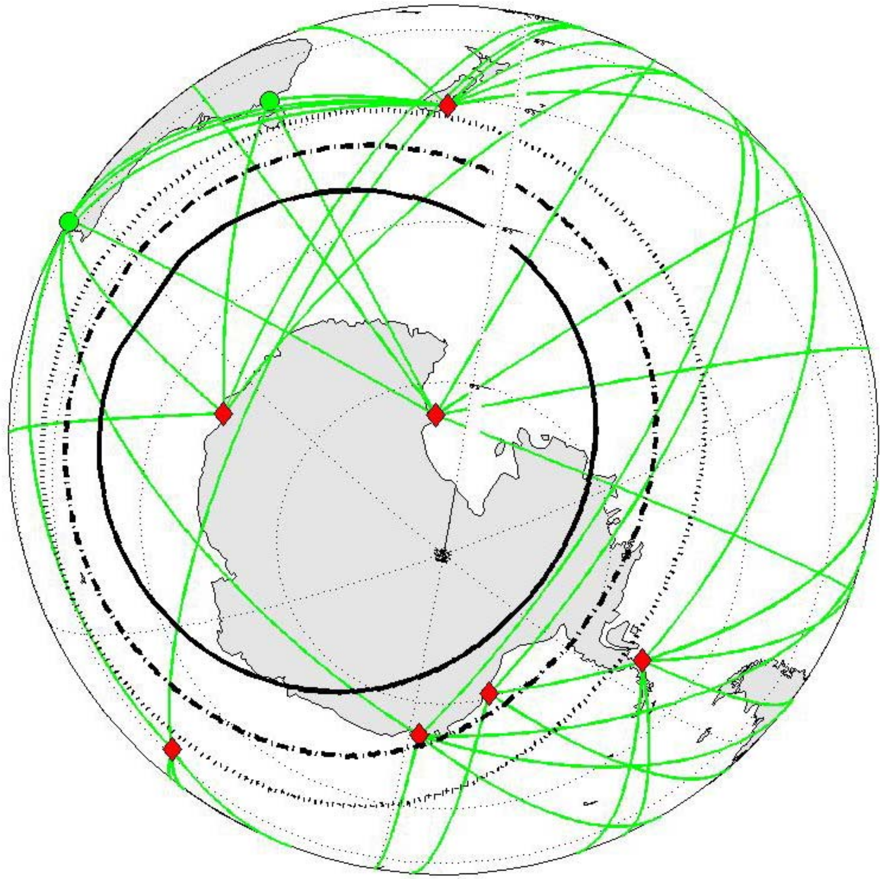
AARDDVARK Aarmory



AARDDVARK Aarmory



VLF Paths

- DHO Transmitter (Germany, 23.4 kHz, L=2.4)
- ICV Transmitter (Sardinia, 20.27 kHz, L=1.5)
- SGO AARDDVARK Receiver (Sodankylä, Finland, L=5.3)

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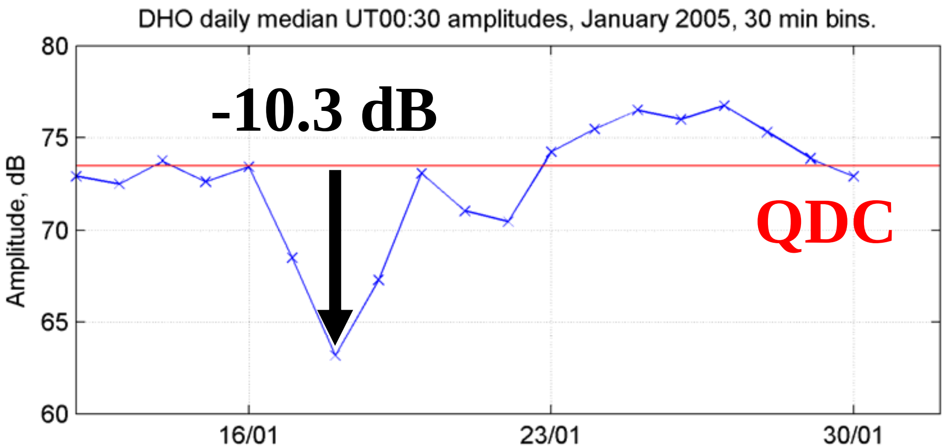
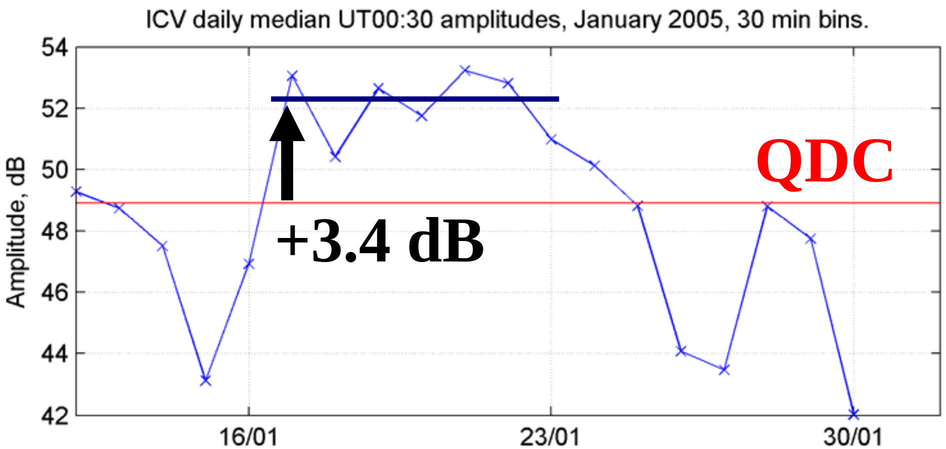
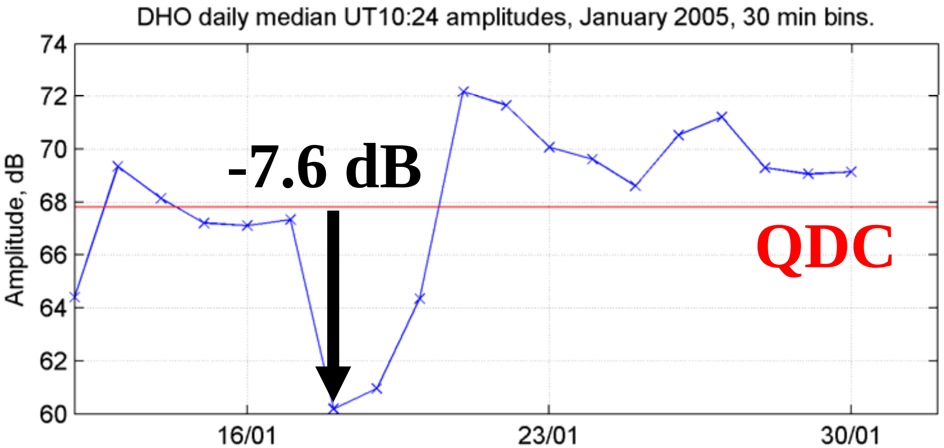


Germany, night



Italy, night



Germany, 'day'

(No clear response was seen for daytime ICV data.)

VLF Model: LWPC

- **L**ong **W**ave **P**ropagation **C**ode
- Models amplitude and phase of a VLF signal propagating along a path with given ionospheric conditions.
- Specify electron density altitude profiles along part of path (the precipitation region)
- Used to tie VLF and Demeter data together
- Profiles determined using a simple chemistry model…

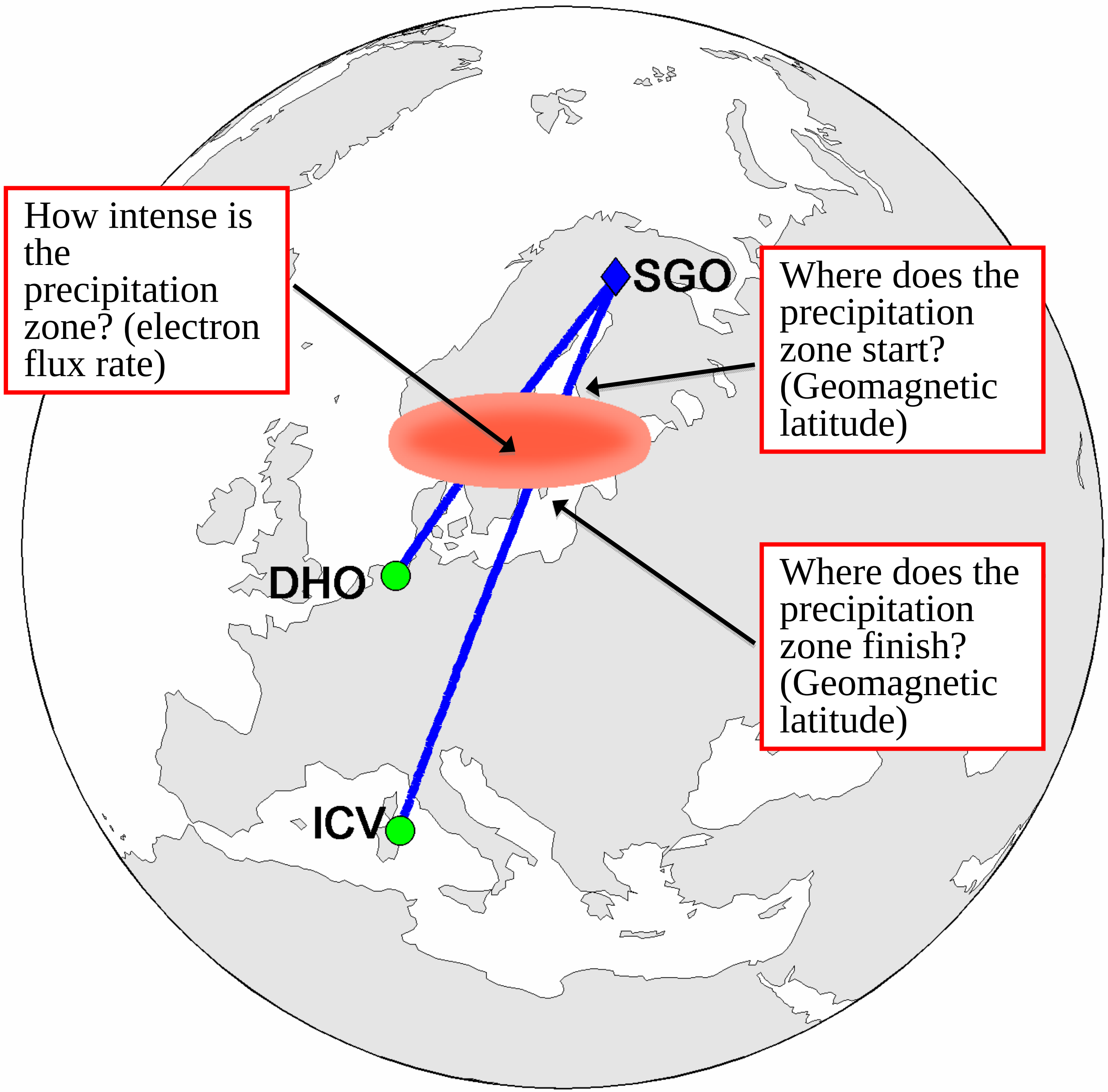
Neutral Chemistry Model

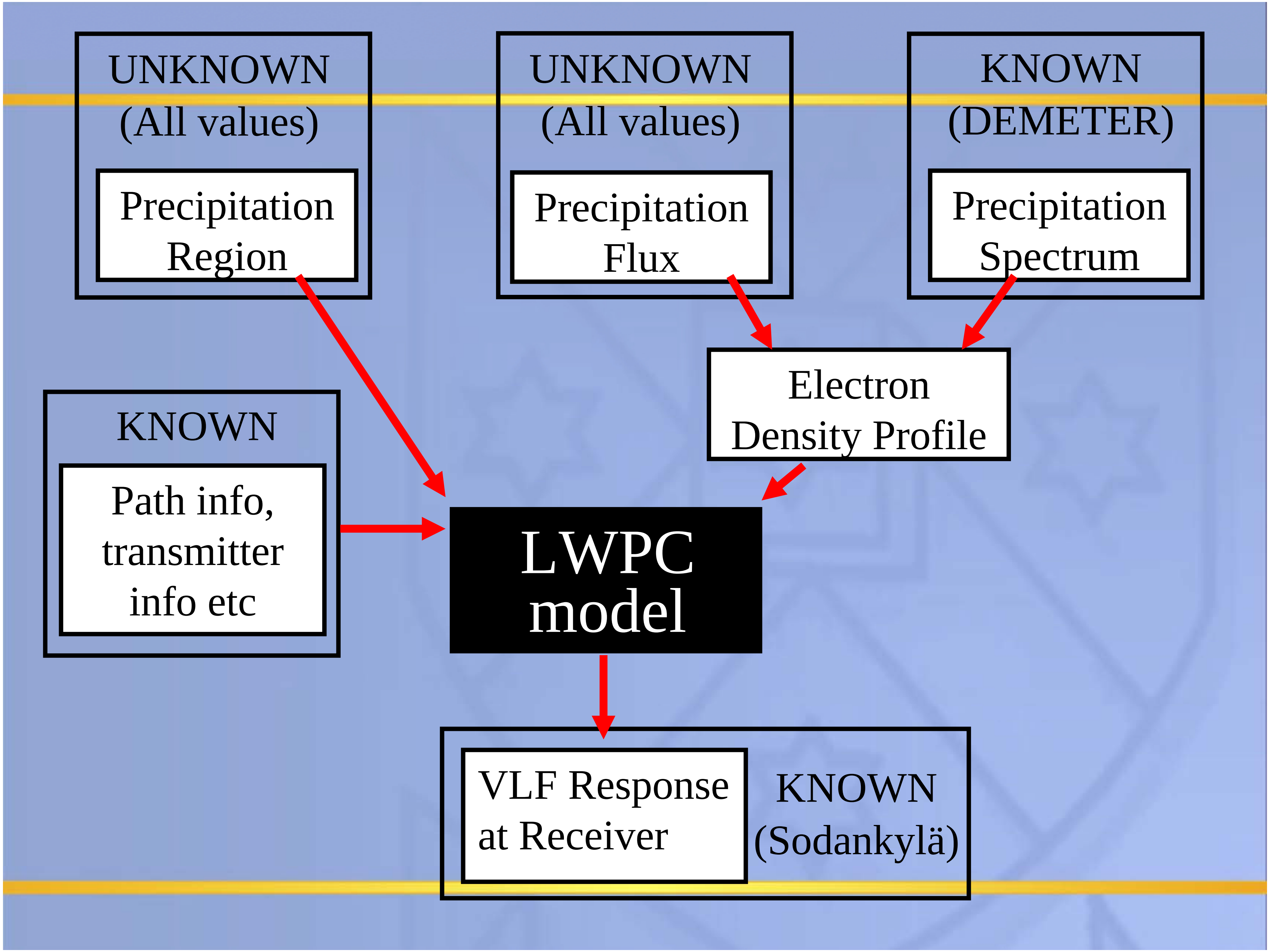
- Simple attachment and recombination model
  - Produces reasonably accurate results
  - Computationally fast
- Given a DEMETER electron spectrum, create electron density profile
- Net precipitating flux unknown, so use a range of values (from none up to 1× Demeter's fluxes)

Rodger et al (1998). Relaxation of transient ionization in the lower ionosphere. Journal of Geophysical Research, 103(A4), 6969-6975.

The Question:

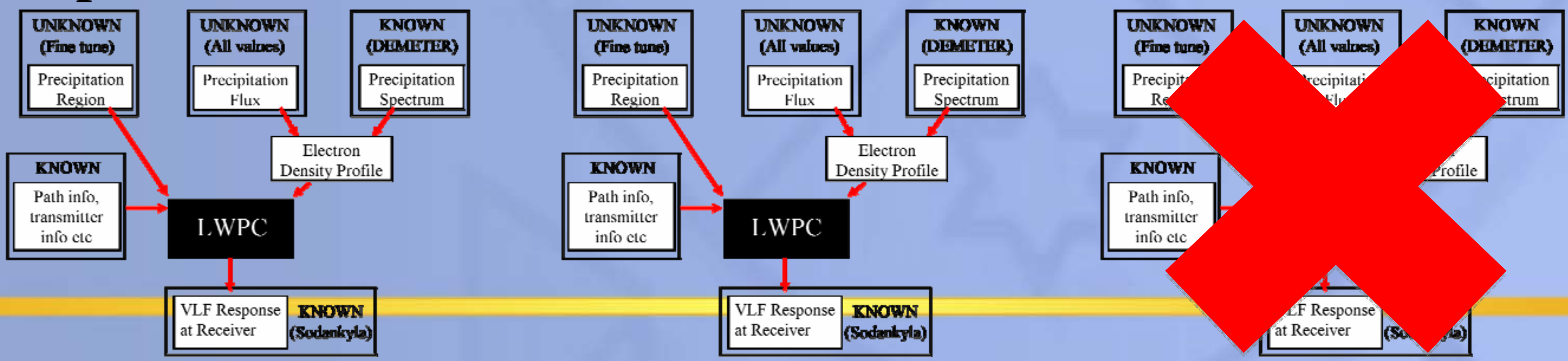
Can we reproduce the observed VLF signals by guessing the precipitation conditions?


How intense is the precipitation zone? (electron flux rate)
SGO
Where does the precipitation zone start? (Geomagnetic latitude)
DHO
ICV
Where does the precipitation zone finish? (Geomagnetic latitude)

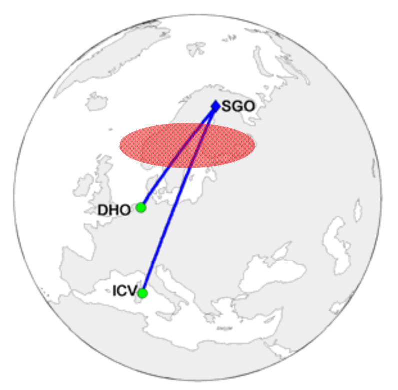

UNKNOWN
(All values)
Precipitation Region
UNKNOWN
(All values)
Precipitation Flux
KNOWN
(DEMETER)
Precipitation Spectrum
Electron Density Profile
KNOWN
Path info, transmitter info etc
LWPC model
VLF Response at Receiver
KNOWN
(Sodankylä)

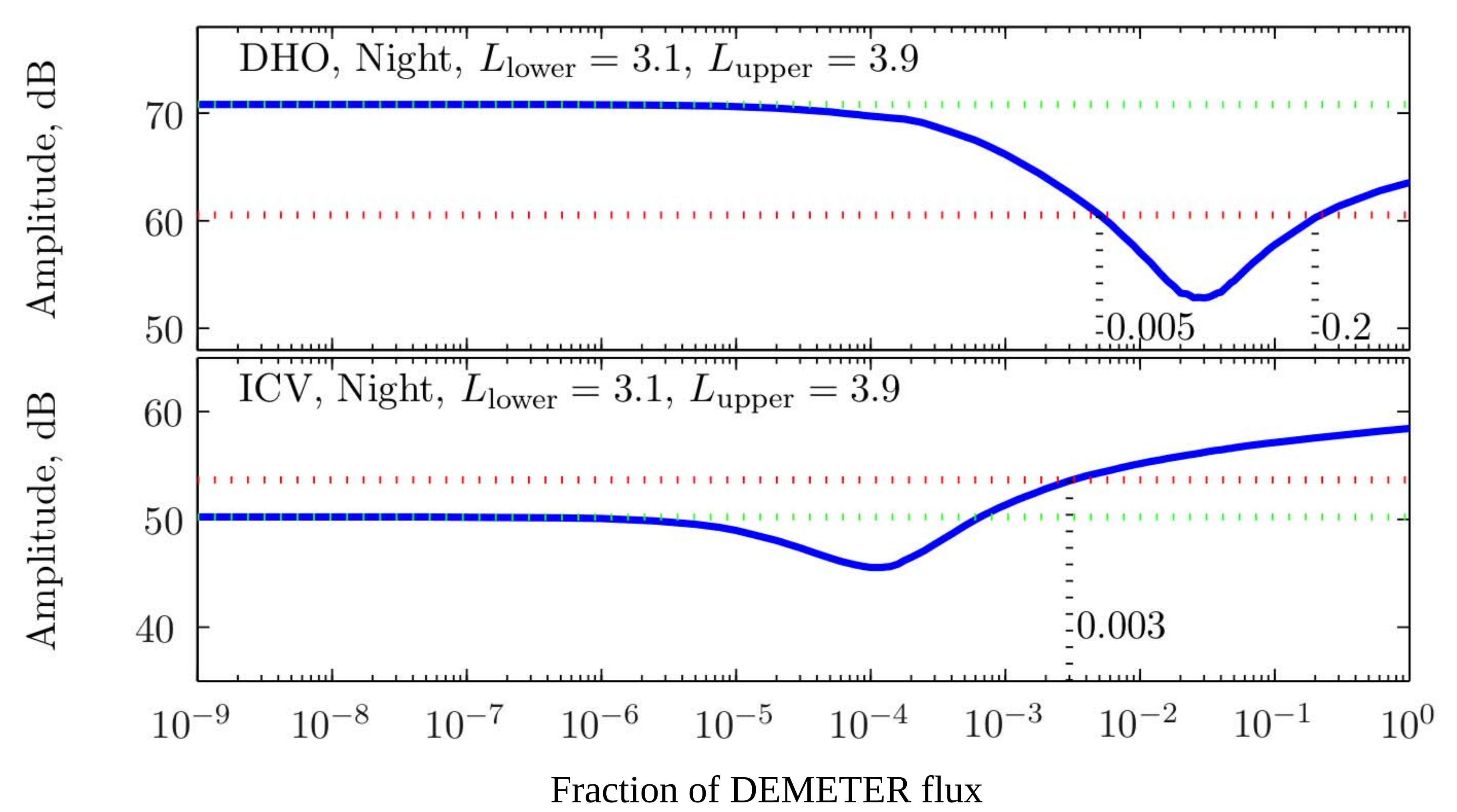
Combining all three…

- Use **model** to combine **VLF** and **satellite** data
- Unknowns:
  - Geographic size of precipitation zone (upper and lower L values).
  - Intensity of precipitation (ie fraction of Demeter flux)
- Model three cases independently, look for consistent parameters.



One successful candidate:



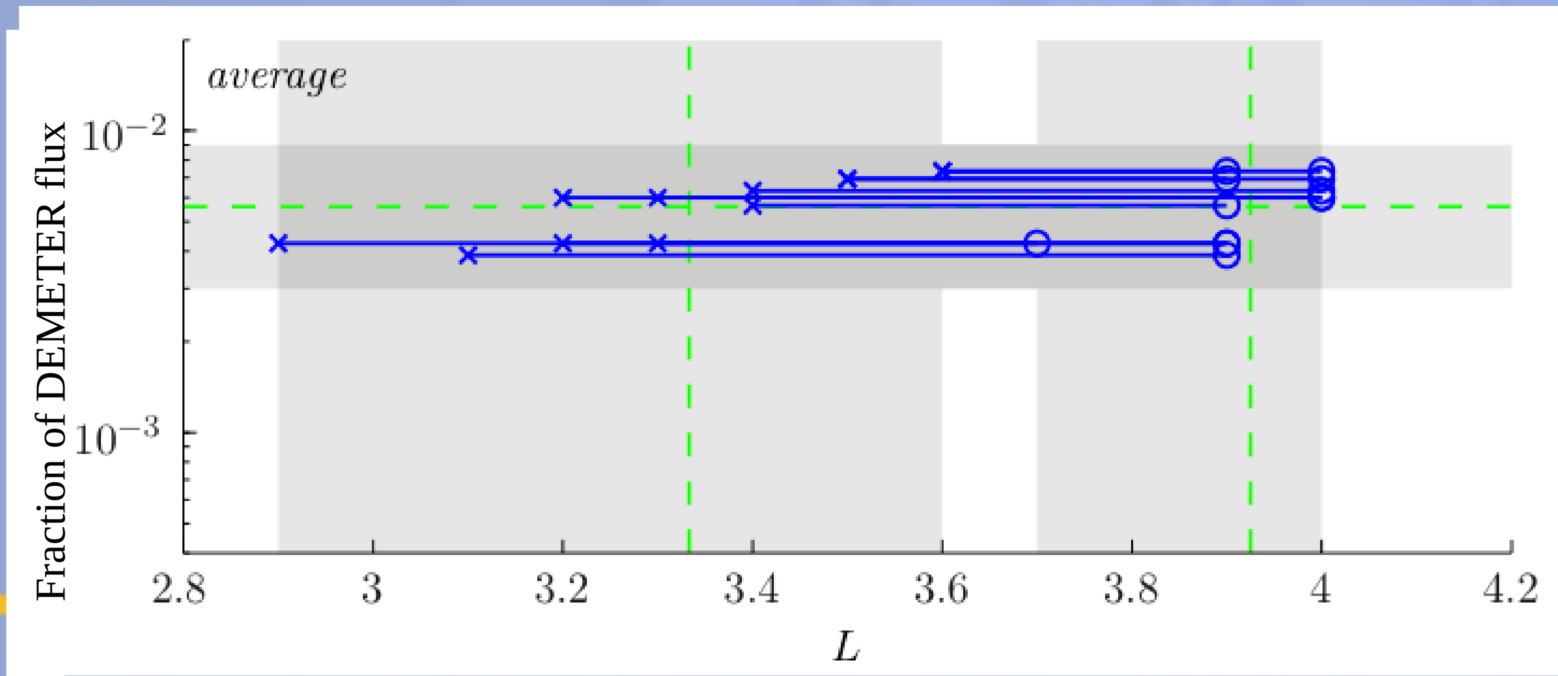


LWPC Modelling

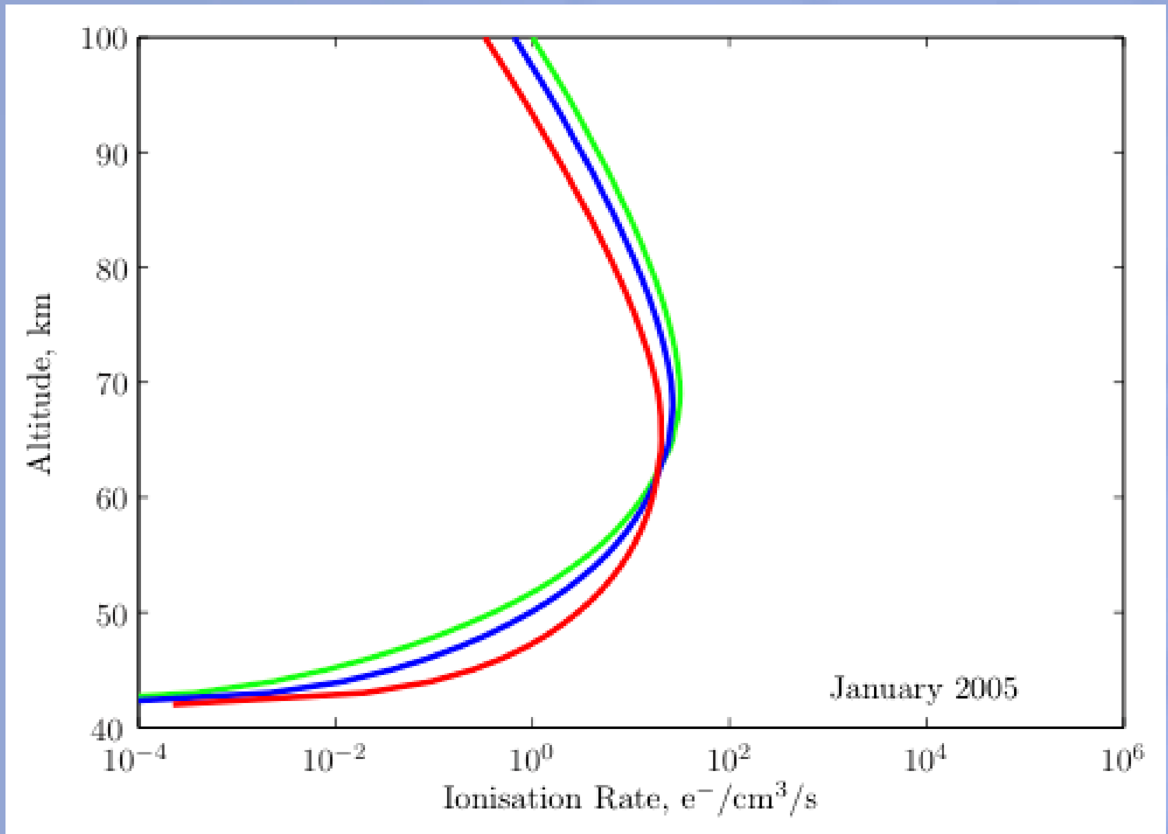
- However, this is just one set of parameters which works.
- Series of working models yields a **range** of answers.

Summary of working scenarios

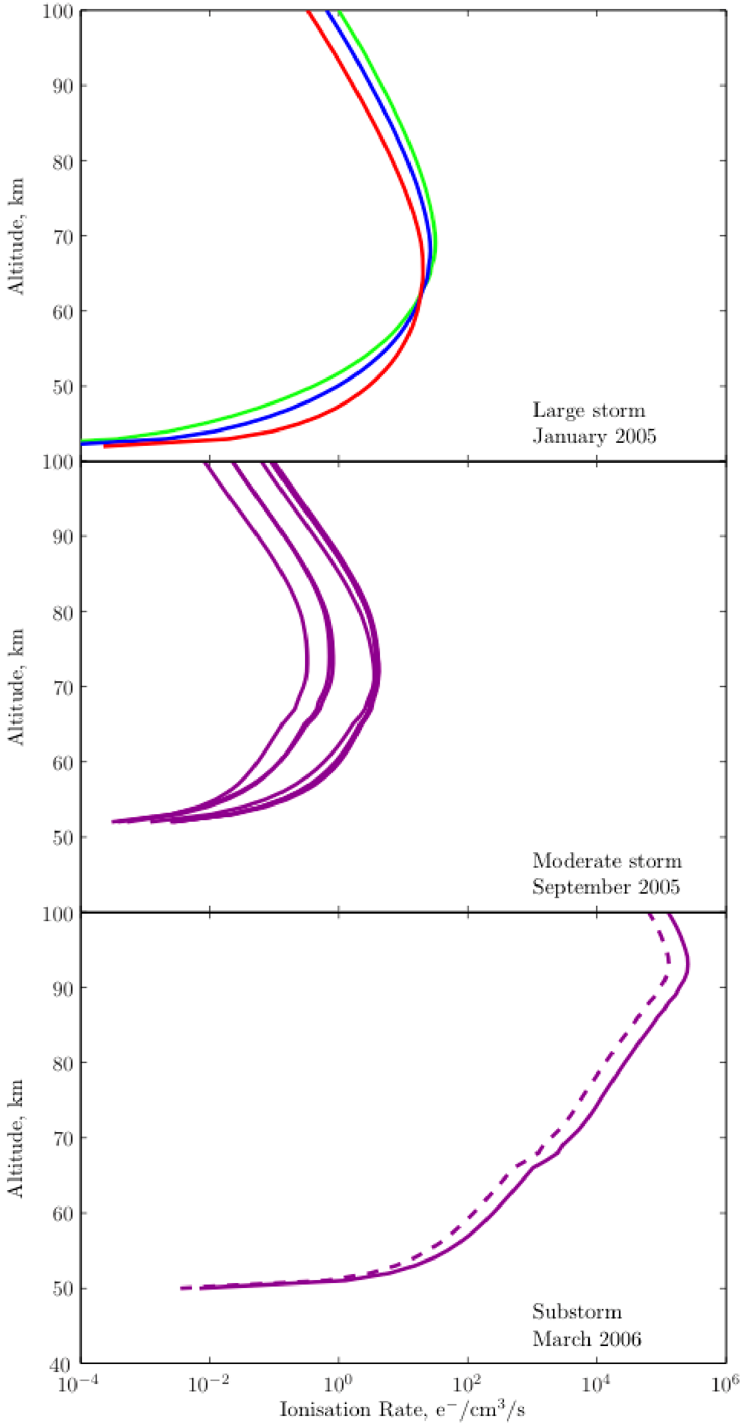
- L shells:
  - L_{lower} = 2.9 – 3.6
  - L_{upper} = 3.7 – 4.0
- Fraction of DEMETER flux:
  - 0.6% (0.3 – 0.9%) for night time
  - This corresponds to ~1.8×10^4 elec/cm^2/s precipitating flux (>150 keV electrons).



Resulting Ionisation



- Not very meaningful alone.
- Is this significant?



Comparison to other events.

- My work – ‘large’ geomagnetic storm,
- January 2005
- Significance to neutral atmosphere: ???

- Moderate geomagnetic storm, September 2005. (Rodger et al. JGR 2007, 2010)
- Lasted ~10∢ longer, ~10∢ less intense.
- 300% increase in NO_x.
- Occurred in polar **summer**: NO_x not persistent.
- -35% O_3 likely if **winter**.

- Substorm injection, May 2006. (Clilverd et al. 2008 , JGR 2008)
- 10^3 increase in NO_x at 60-70 km seen in similar events
- Jan 2005 not likely to be similar except at low altitudes

Conclusions

- Jan 2005 geomagnetic storms, focus on precipitation 17 January 2005.
- DEMETER sees very hard drift loss cone electron spectra during this time period.
- VLF responses from ICV and DHO transmitters received in Sodankylä show large response to precipitation.
- LWPC modelling indicates ~0.6% of DEMETER observed fluxes are precipitating onto L=2.9-4.0 of both propagation paths.
- VLF modelling provides agreement for nighttime data.
- Daytime data needs further constraints.
- Consequences for understanding dynamics of radiation belt loss processes and coupling into upper atmosphere.

Acknowledgements

- VLF data is courtesy of Sodankylä Geophysical Observatory, Finland.
- We are particularly grateful to Michel Parrot, Jean-André Sauvaud, Jean-Jacques Berthelier and the rest of the DEMETER team for their fine work and generously allowing us access to this great dataset.

  Without DEMETER my PhD and research would not have been possible!

Thank you!

Thanks for listening! Any questions?