Radiation belt electron precipitation due to geomagnetic storms: significance to atmospheric ozone chemistry

Craig J. Rodger[1], **Mark A. Clilverd**[2], Annika Seppälä[2,3], Neil R. Thomson[1], Rory J. Gamble[1], Michel Parrot[4], Jean-André Sauvaud[5] Thomas Ulich[6] and Jean-Jacques Berthelier[7]

1. Department of Physics, University of Otago, Dunedin, New Zealand
2. British Antarctic Survey, Cambridge, United Kingdom
3. Finnish Meteorological Institute, Helsinki, Finland
4. Laboratoire de Physique et Chimie de l'Environnement et de l'Espace, Orleans, France
5. Centre d'Etude Spatiale des Rayonnements, Toulouse, France
6. Sodankylä Geophysical Observatory, University of Oulu, Sodankylä, Finland
7. Laboratoire Atmosphères, Milieux, Observations Spatiales/IPSL, Paris, France

Craig J. Rodger
Department of Physics
University of Otago
Dunedin
NEW ZEALAND

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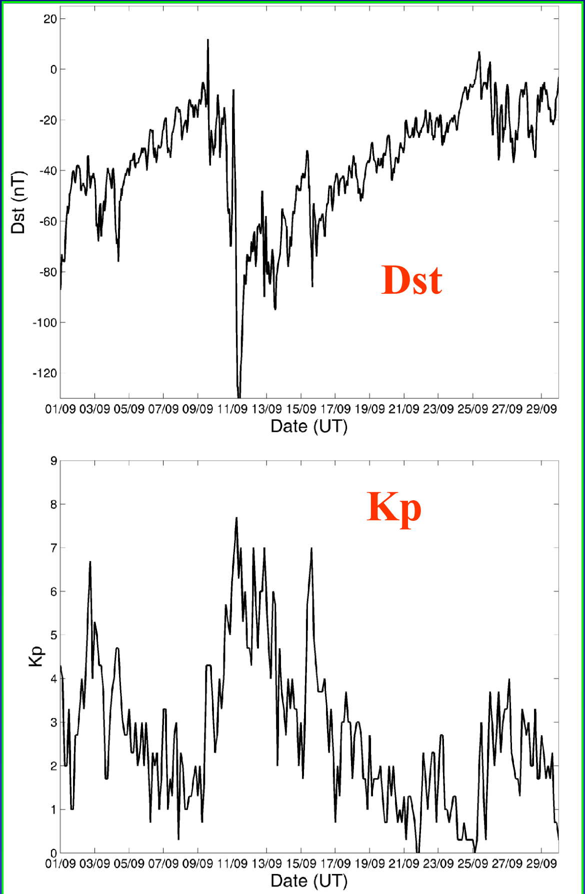
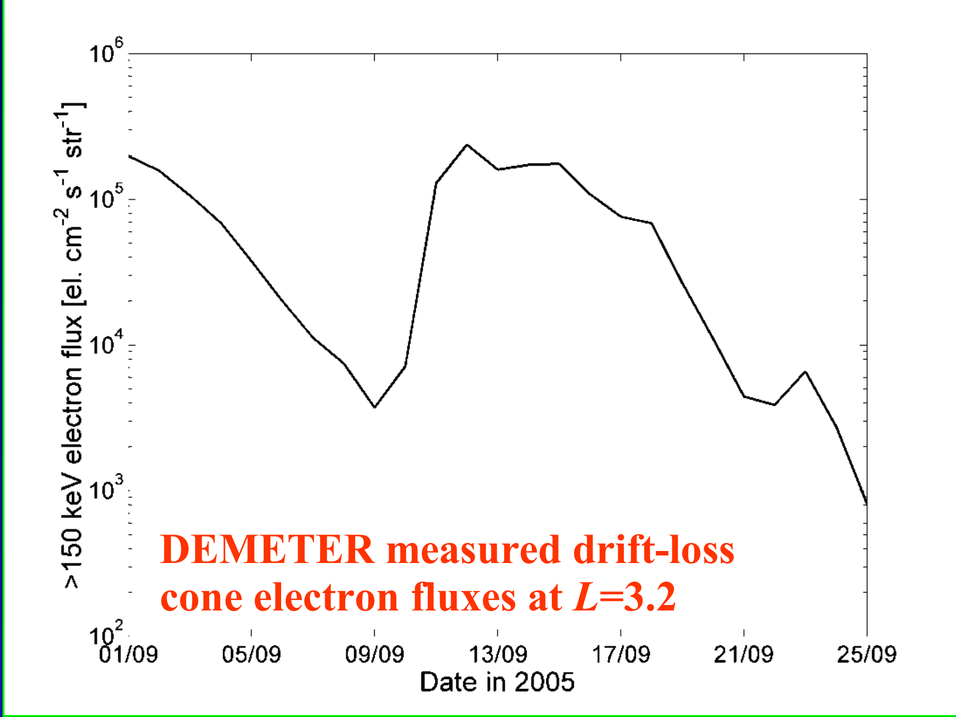
Radiation Belt Electron Precipitation following a geomagnetic storm (probably driven by Plasmaspheric Hiss):

A storm case study





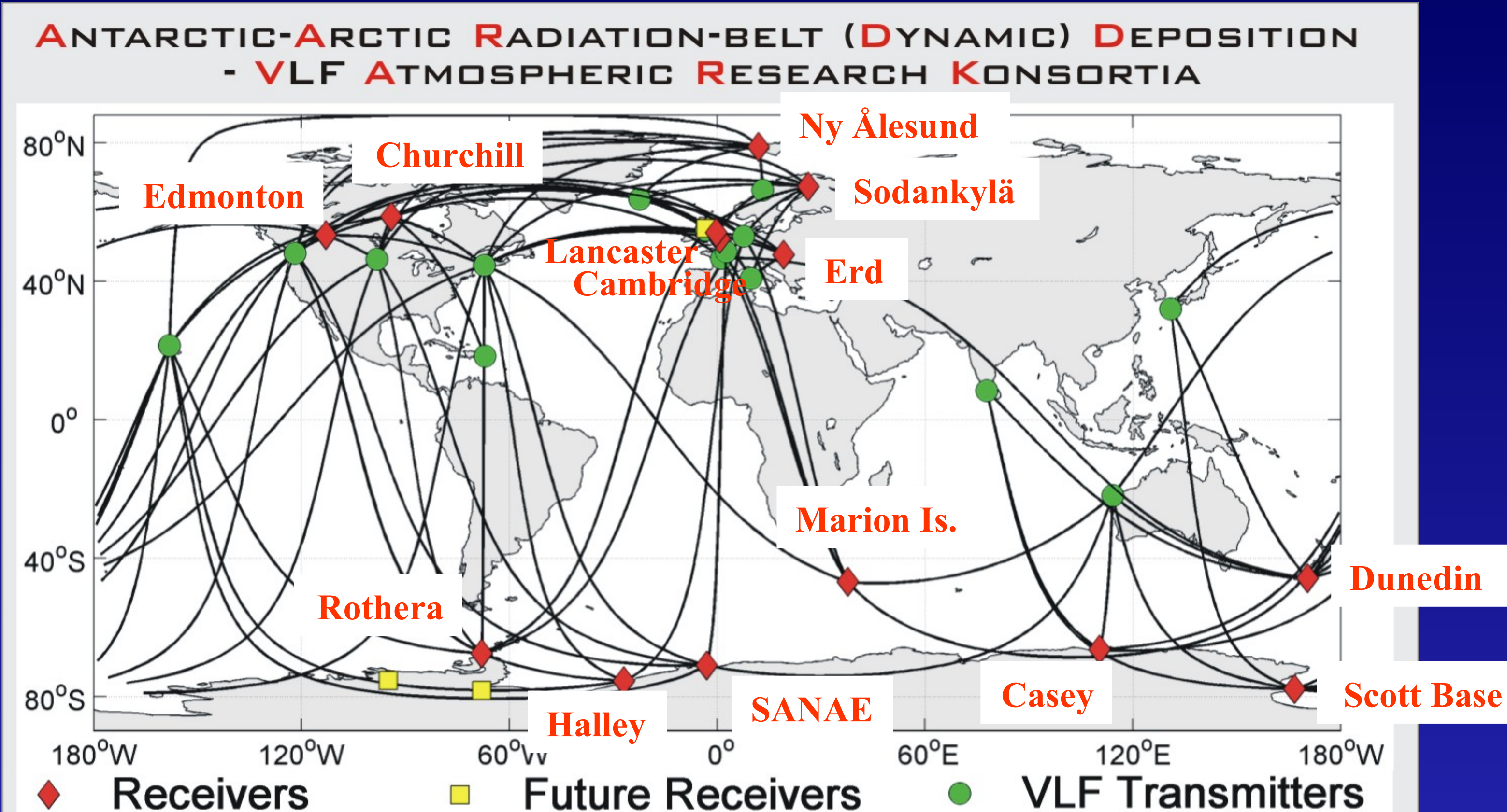
Geomagnetic storm of 11 Sept 2005 led to an increase in the energetic electron population in the inner edge of the outer radiation belt

1000 times ambient

100 above pre-storm levels

Decays over ~14 days to pre-storm levels (and 5 times above ambient), after which there is a DEMETER data-gap

Our AARDDVARK

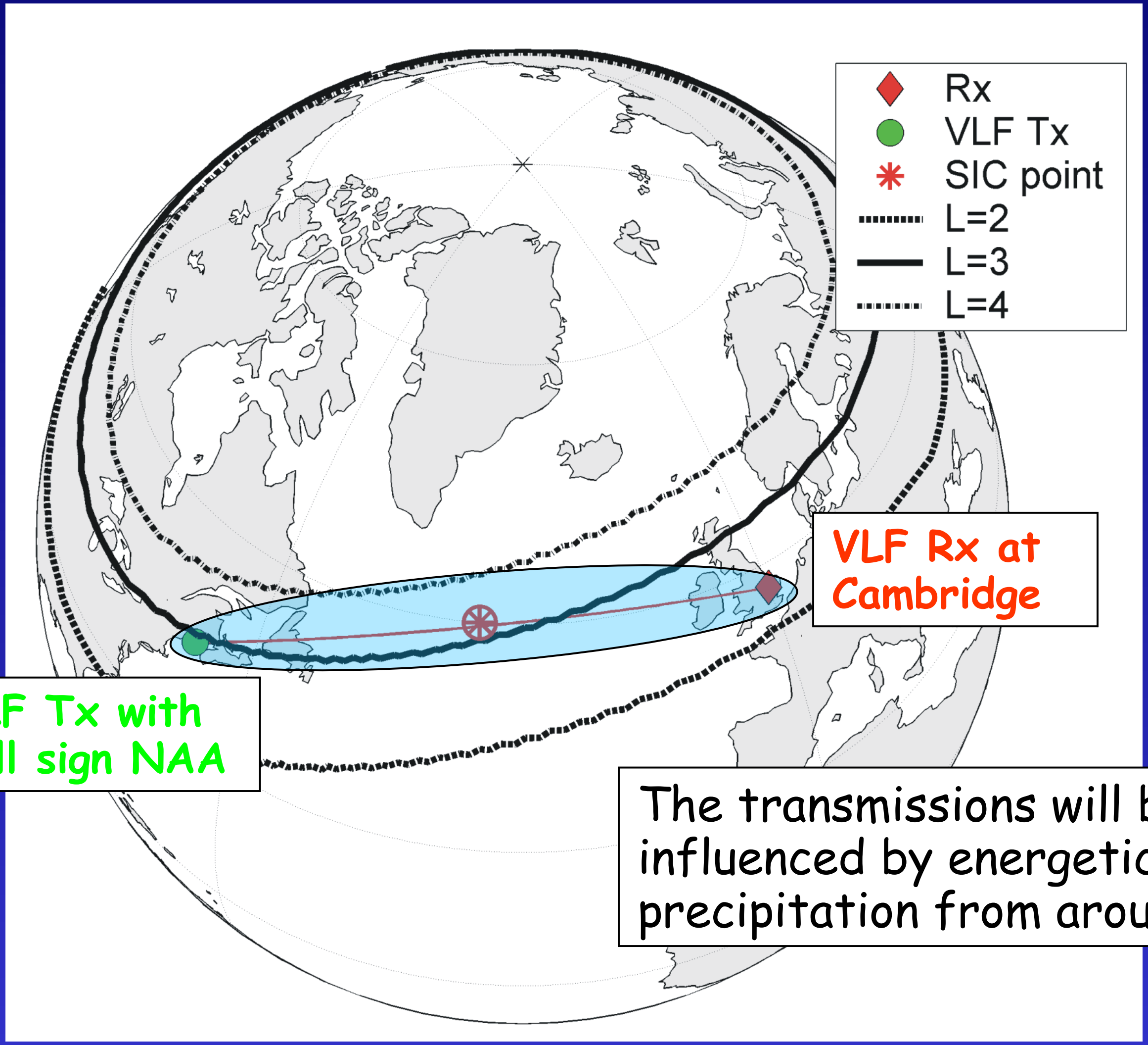


An aarmory of AARDDVARKs. This map shows our existing network of sub-ionospheric energetic precipitation monitors.

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

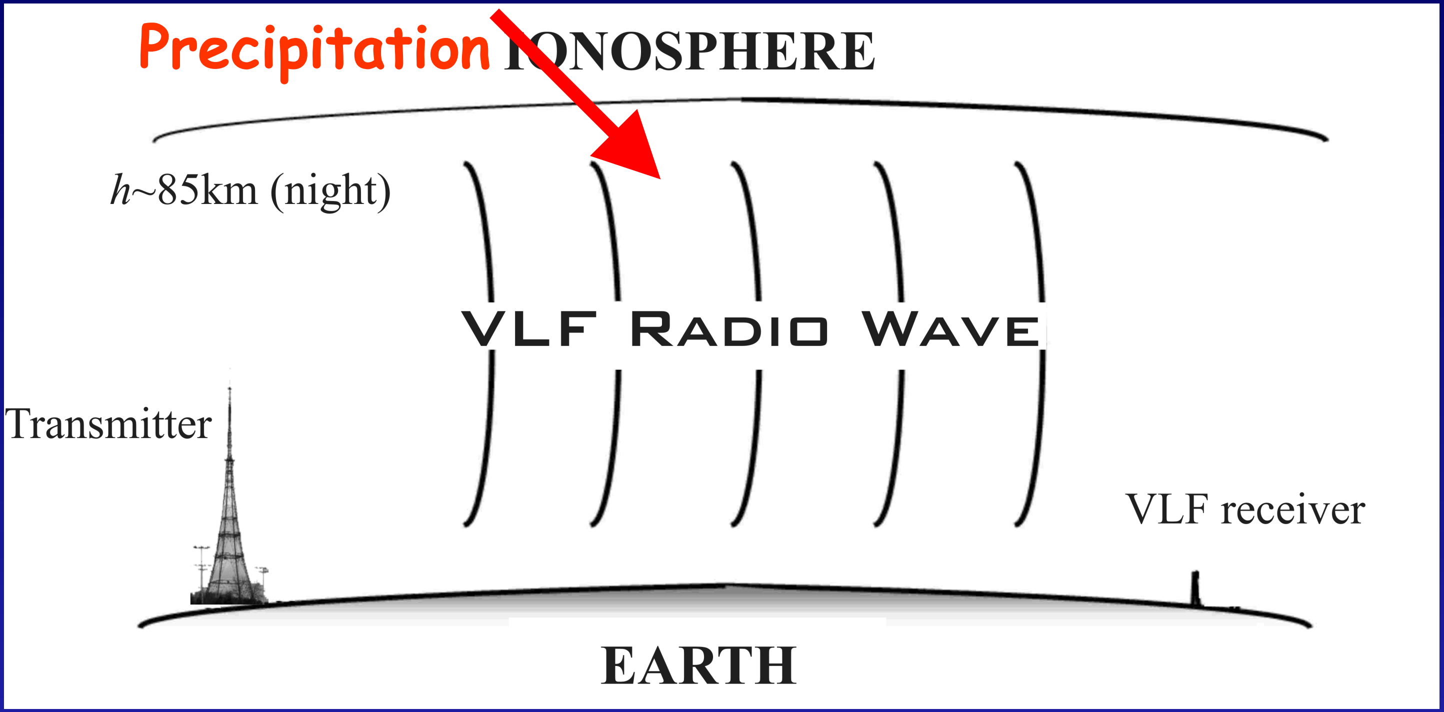
AARDDVARK Subionospheric Observations

In our study we make use of AARDDVARK subionospheric observations made by our receiver (Rx) running at the Cambridge (CAM) , during September 2005. Focus on observations from NAA.



The transmissions will be influenced by energetic electron precipitation from around L=3.2.

Subionospheric Radio Wave Propagation

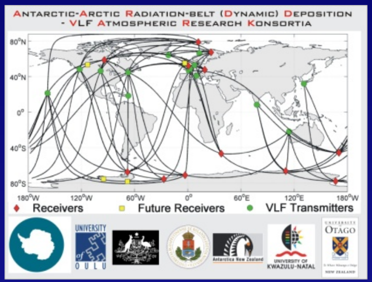


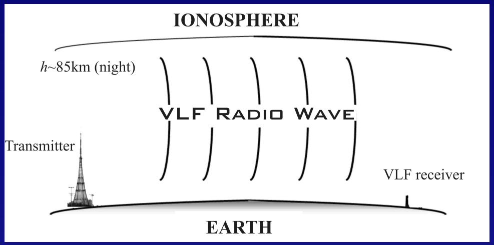
Radio transmissions at Very Low Frequencies (VLF) largely trapped between the conducting ground (or sea) and the lower part of the ionosphere (70-90 km), forming the Earth-ionosphere waveguide.

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!

Our Goal.

AARDDVARK VLF → Electron Precipitation Fluxes





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We are working towards extracting electron precipitation flux measurements from the AARDDVARK subionospheric VLF observations. While satellites may struggle to measure the whole Bounce Loss Cone, this is what the atmosphere "sees", and hence what AARDDVARK responds to.

This talk is talking about extracting fluxes for days-weeks, and their significance to the ionosphere and neutral atmosphere.

Here I am building on and expanding what we did in an earlier study

[R-2007; Rodger et al., JGR, A11307, doi:10.1029/2007JA012383, 2007].

This current work has been published as: **Rodger et al., *JGR*., 115, A11320, doi:10.1029/2010JA015599, 2010.**

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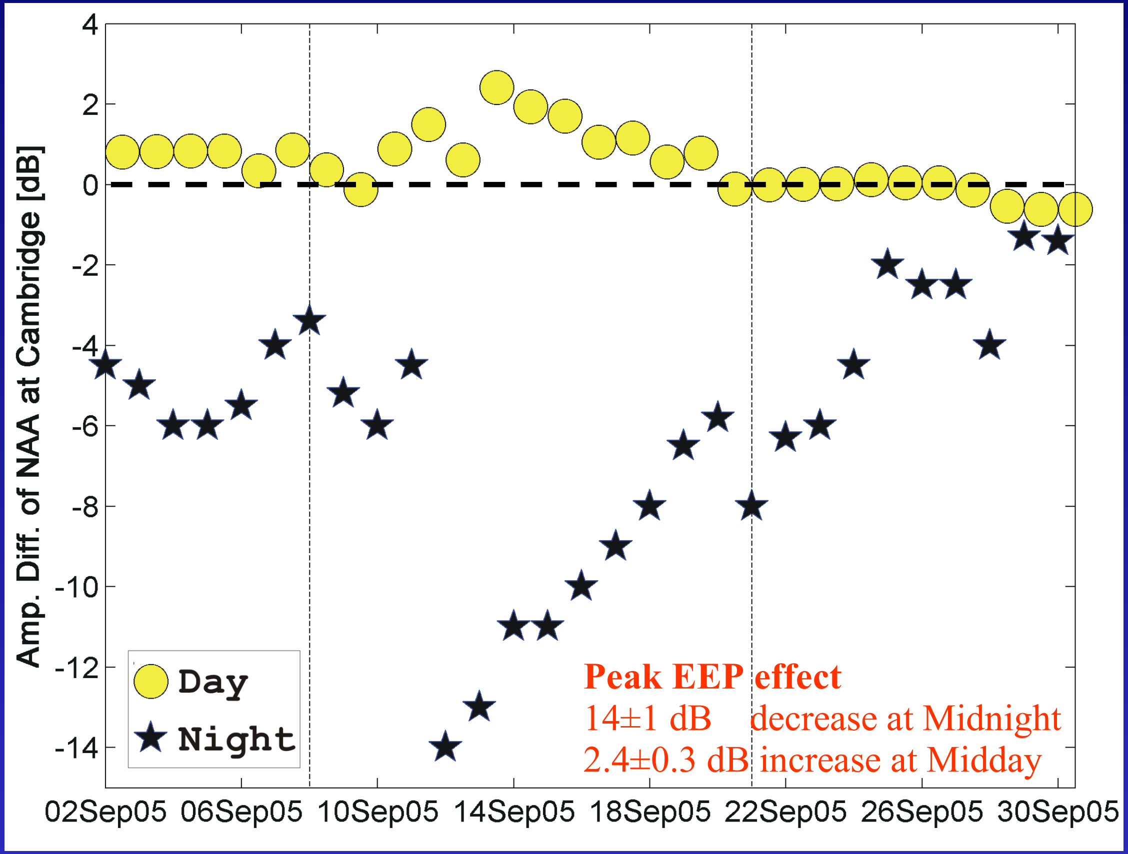
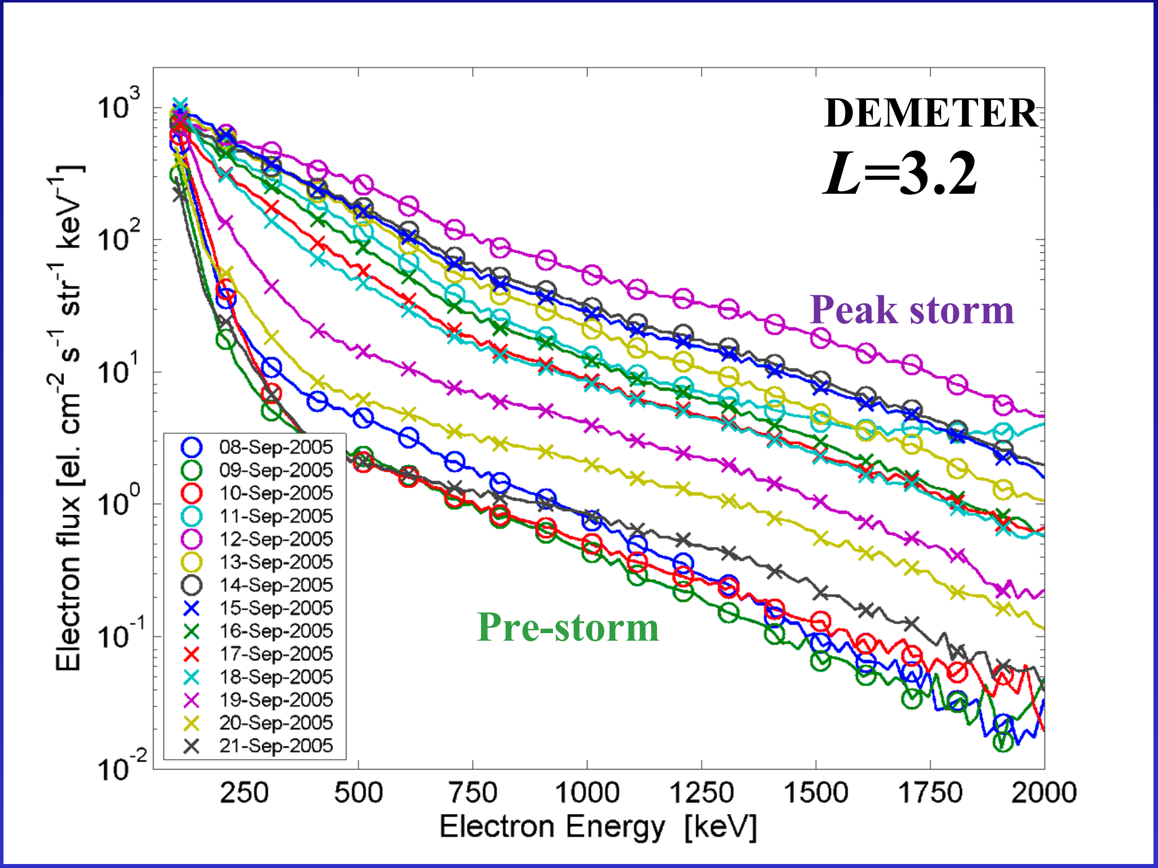


We do not have observations before this period from CAM, but we know from comparison to the QDC that there was already precipitation taking place (in agreement with DEMETER).

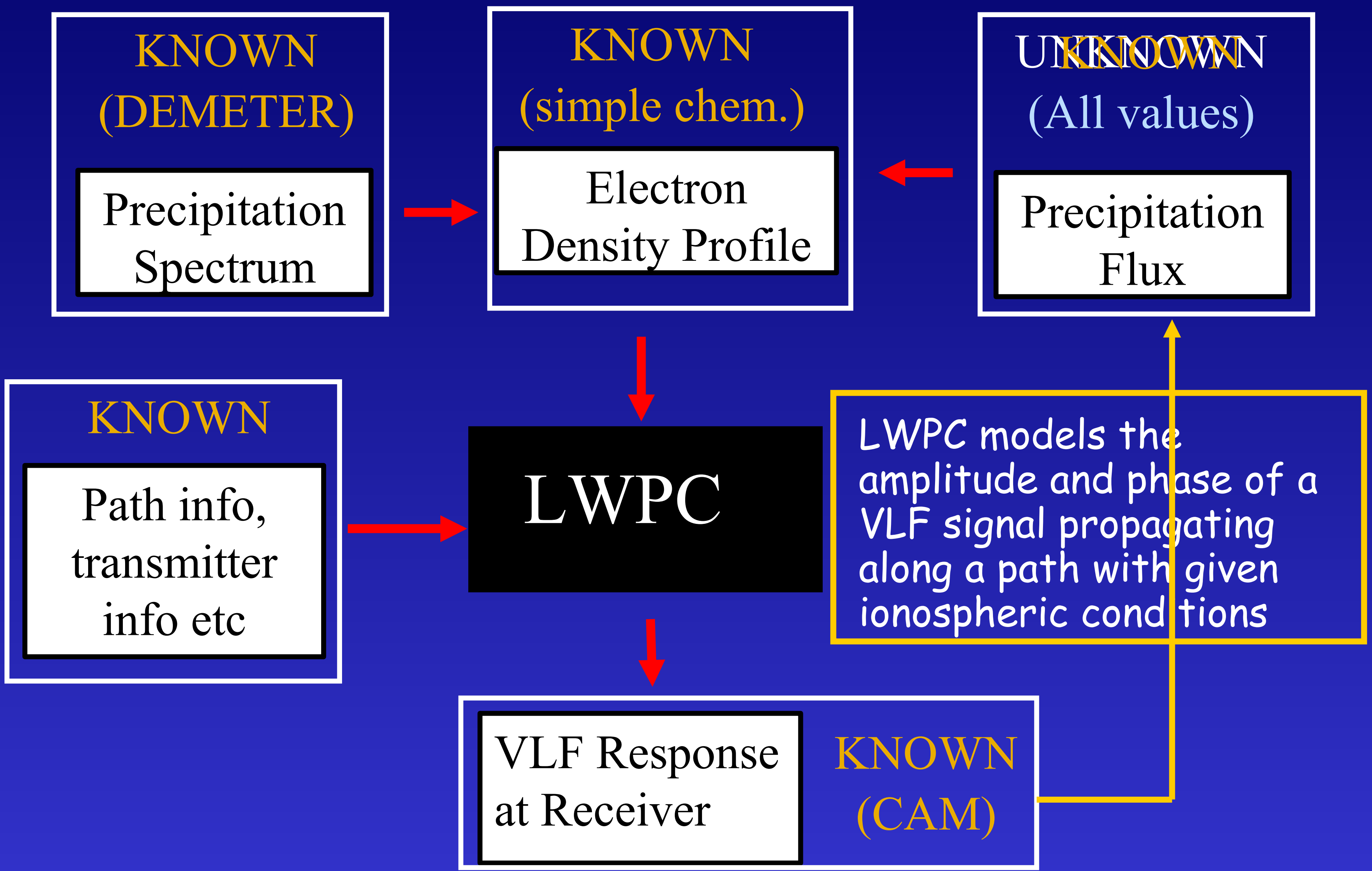
Our 2010 study – expand DEMETER data

We are particularly interested in how significant the electron precipitation in this period would be for driving neutral atmospheric changes.

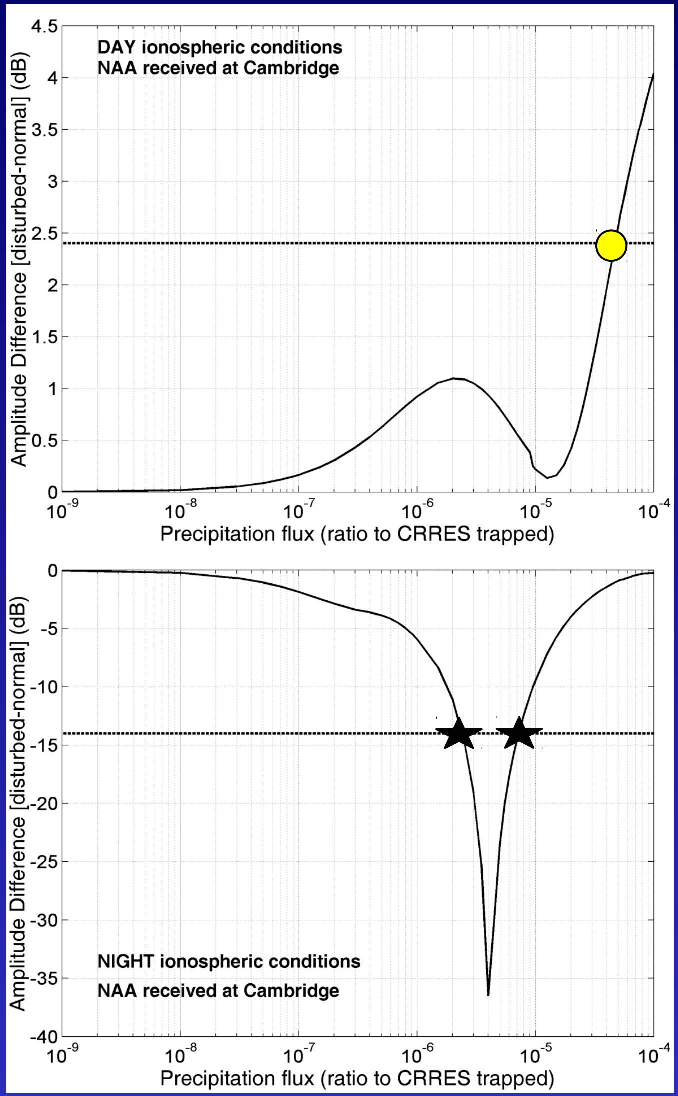
As part of examining this, we updated the R-2007 work to have a DEMETER-observed energy spectrum appropriate for each day.

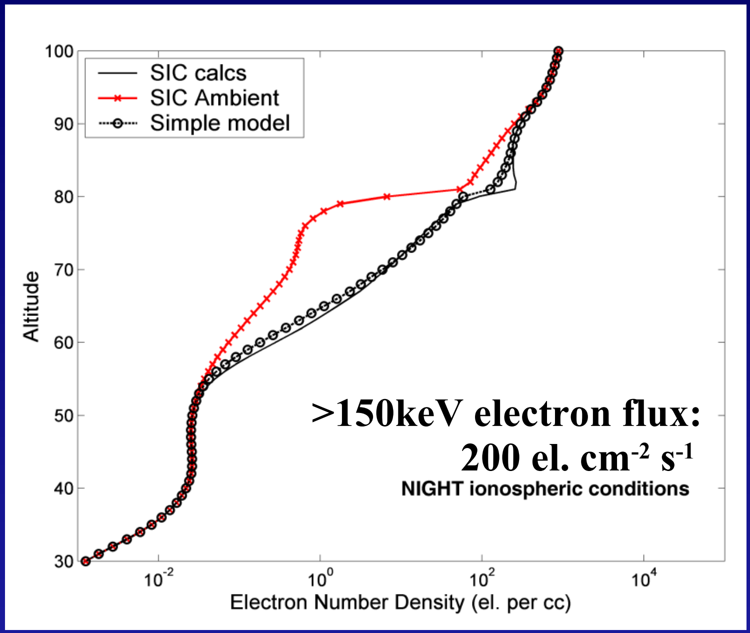


Schematic of Modelling Approach



Model the ionospheric changes



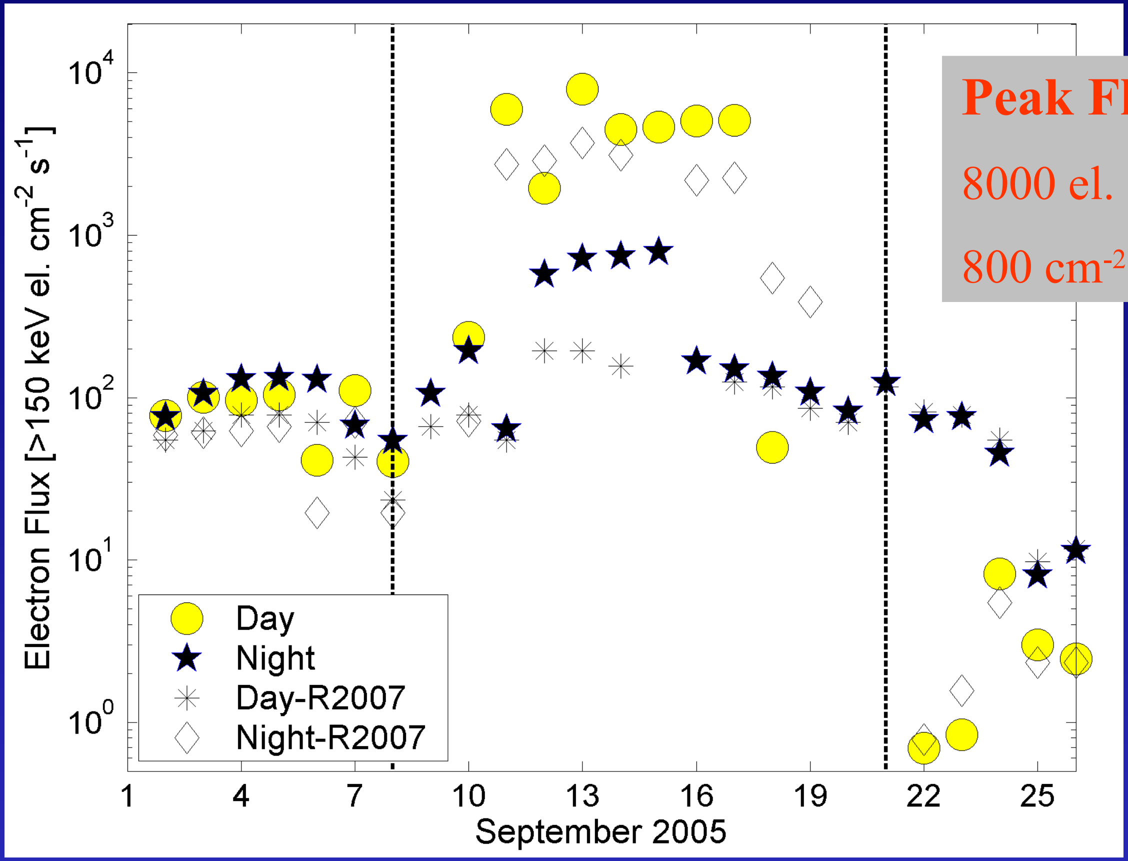


- Sweep through range of precip. fluxes
- Use a simplified ionospheric chemistry scheme to determine the D-region electron density after precipitation (checked by the Sodankylä Ion Chemistry Model)
- Use this as an input for the subionospheric propagation code LWPC

HENCE we predicted the expected change in amplitude for a given precipitation along our NAA-CAM path, and determined an EEP flux into the atmosphere.

Updated Electron Precip. Flux Values

Precipitation fluxes required to reproduce the changes in subionospheric propagation observed (NAA -> CAM).



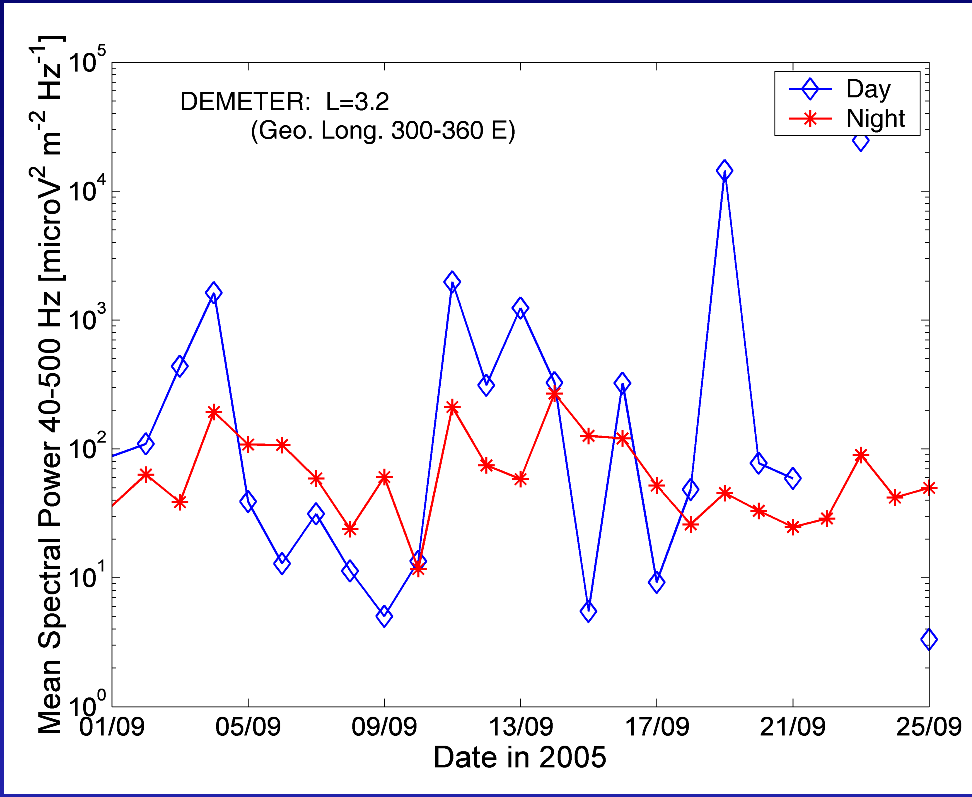
Peak Fluxes:

8000 el. cm^{-2}s^{-1} at midday

800 cm^{-2}s^{-1} at midnight.

We should note that there is fairly weak dependence on the choice of energy spectra used (fixed in R-2007 and daily varying here), although this is more significant during the peak storm period and during the nighttime.

DEMETER observations of plasmaspheric hiss



- At L=3.2 resonances

  500 Hz waves with 160keV electrons

  ~40 Hz waves with 1 MeV electrons

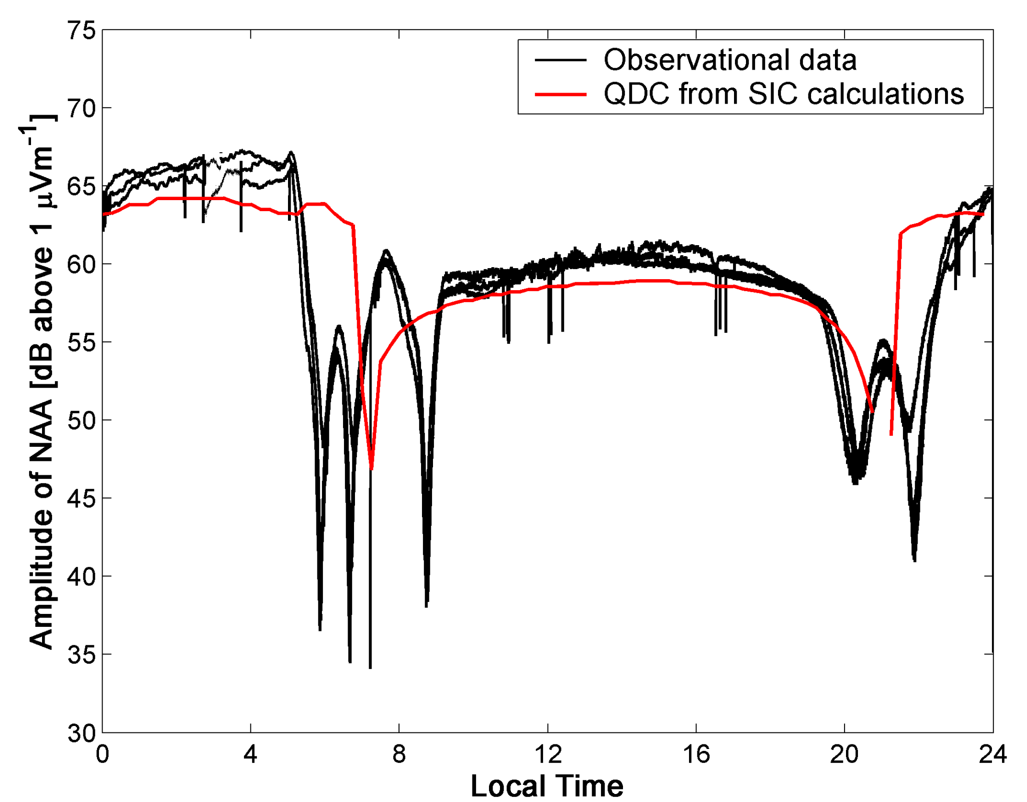
- Use DEMETER to look at this wave range and L-range above our transmitter-receiver Great Circle Path.

- **Both wave and particles show a factor ~200 increase during 9-11 Sept.**
- **Daytime wave powers ~10 times nighttime in post-storm period, much like seen in the precipitating particle measurements.**

Dawnside equatorial chorus does not reproduce the day-night differences seen in our precipitation fluxes, as it has peak intensities on the morning and evening sides. Off-equatorial chorus is 100 times stronger on day than night.

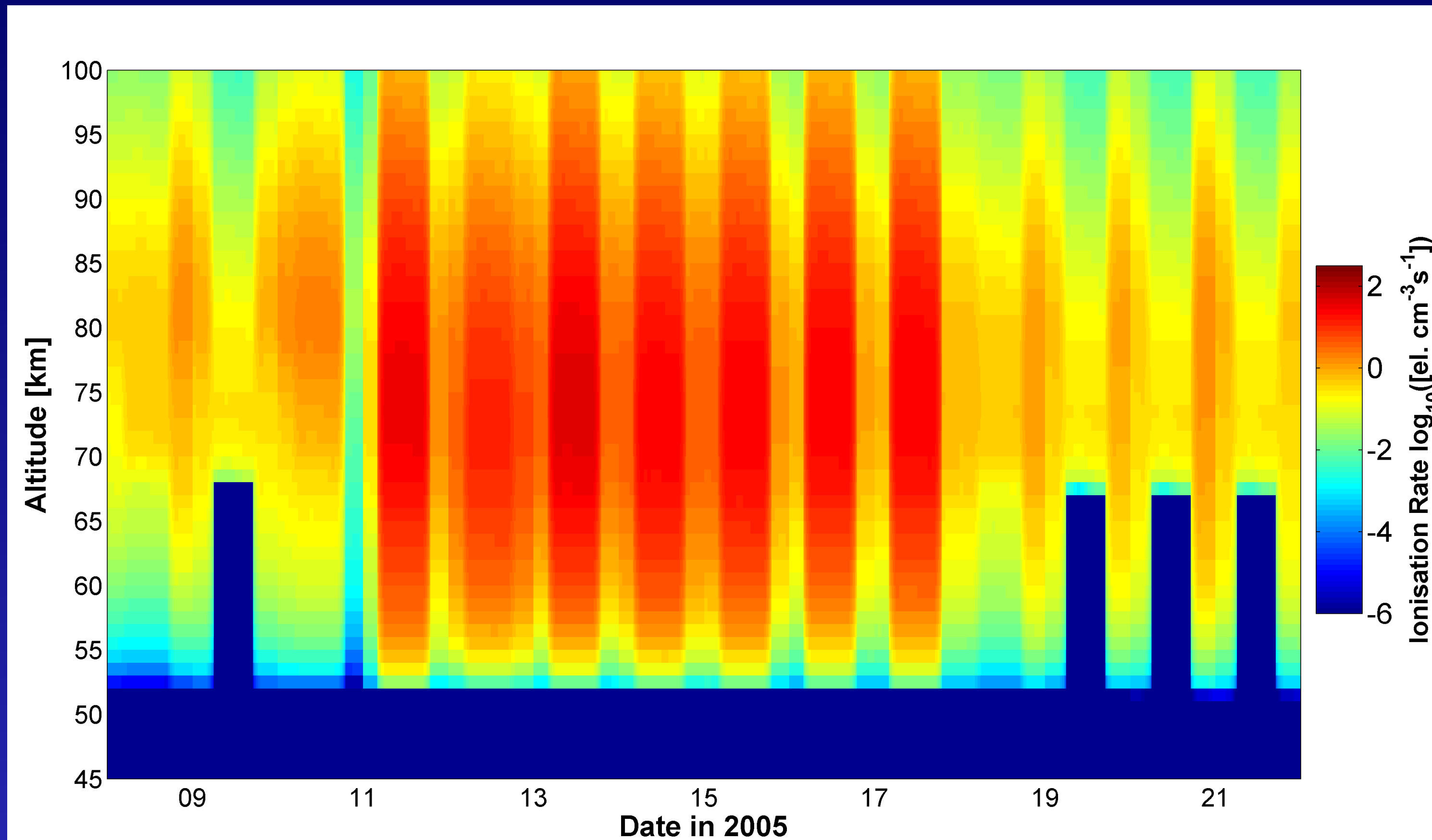
Model the ionospheric changes - with SIC

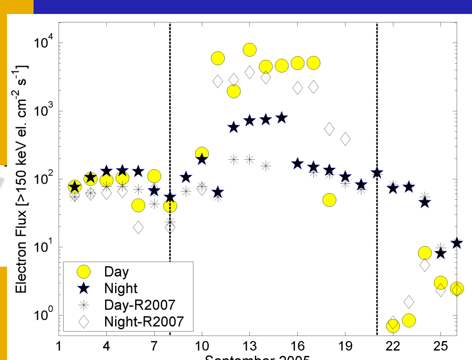
In order to determine the significance of this precipitation to the neutral atmosphere, we feed the EEP fluxes into the Sodankylä Ion and Neutral Chemistry Model (SIC).



First of all, we show that the ambient/non-forced/quiet time conditions are well reproduced by the SIC model, by feeding the electron density outputs into LWPC.

Hit the ionosphere with that EEP!

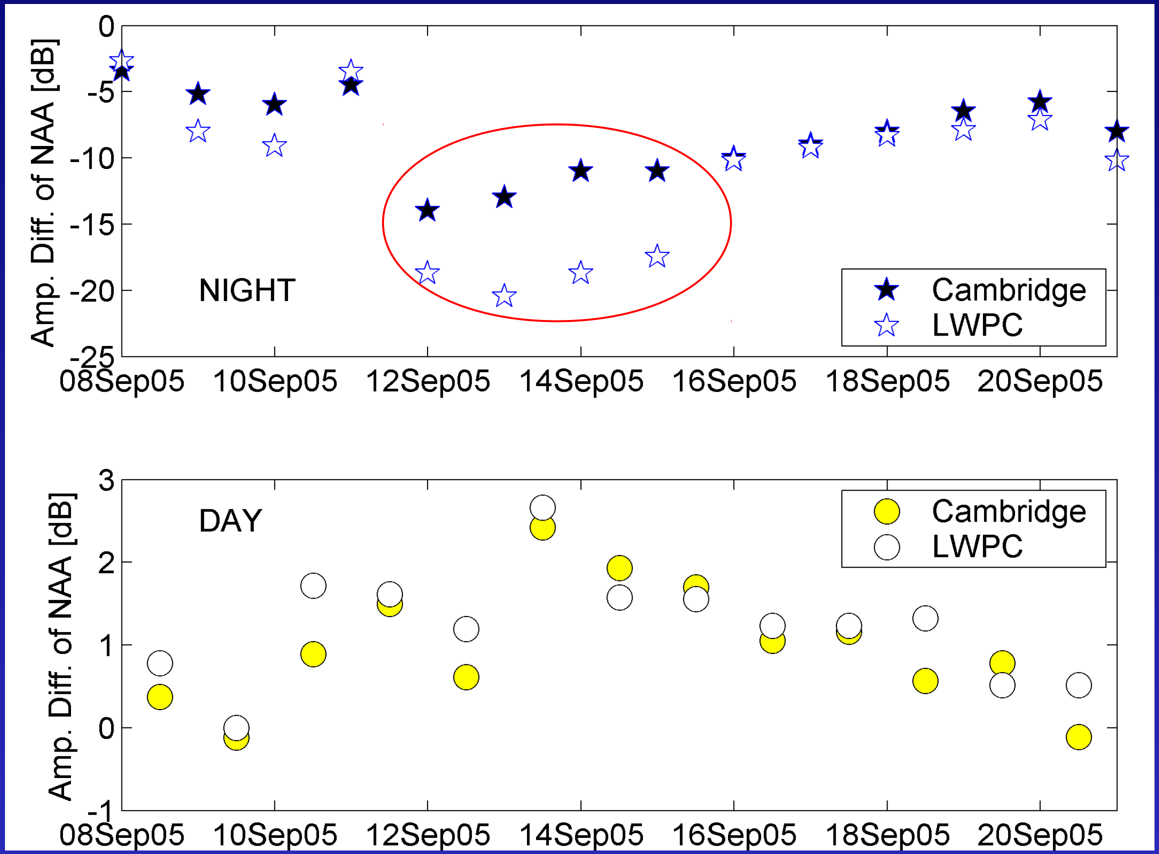




We then determine the ionisation rates expected for those electron precipitation fluxes (with that spectra), with which we can "force" the SIC model and look for changes away from the no-precipitation "control" case.

Test if the SIC outputs make sense

SIC produces modified electron density profiles, which we can run back through LWPC to see how well the EEP fluxes+SIC reproduce the observed AARDDVARK amplitude changes NAA-CAM.

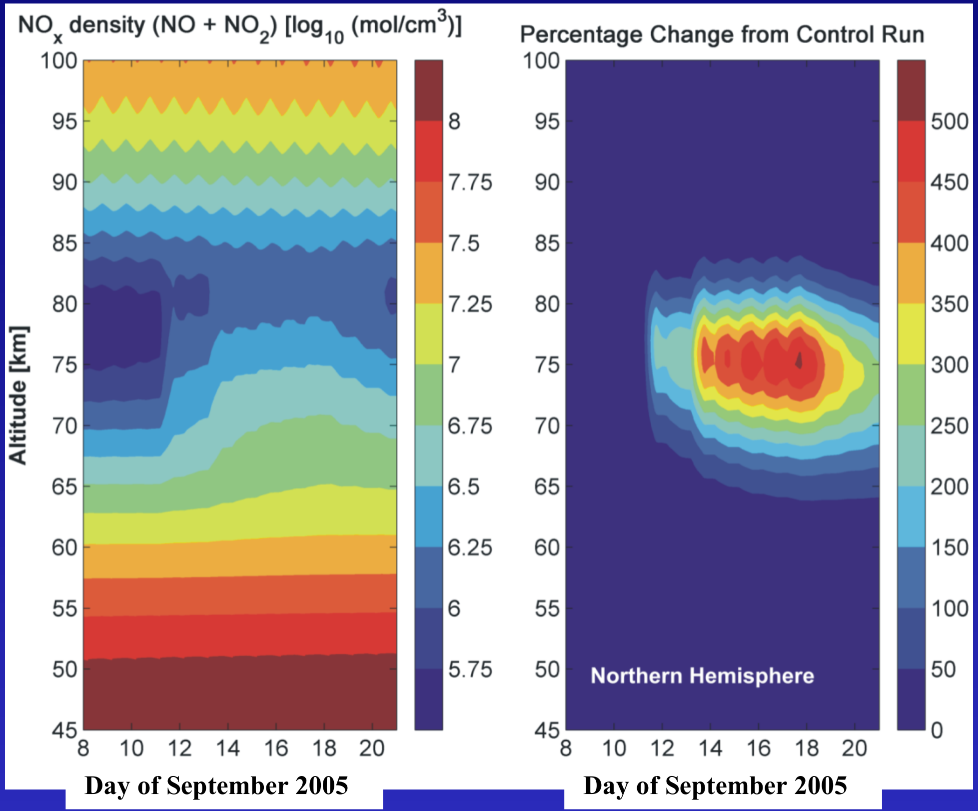


Very sensitive combination of parameters here, only a ~25% change in EEP flux gives an extra -5dB amp. change.

Most cases there is a strong agreement, pretty good given how many models are coupled together and then tested. Given we want a neutral atmosphere significance check, it suggests our tools are accurate enough.

Model the neutral atmosphere changes: NOx

Energetic electron precipitation results in the enhancement of odd nitrogen (NO_x) and odd hydrogen (HO_x), which play a key role in the ozone balance of the middle atmosphere. Using SIC, we can look at the electron precipitation produced changes, during this storm period.



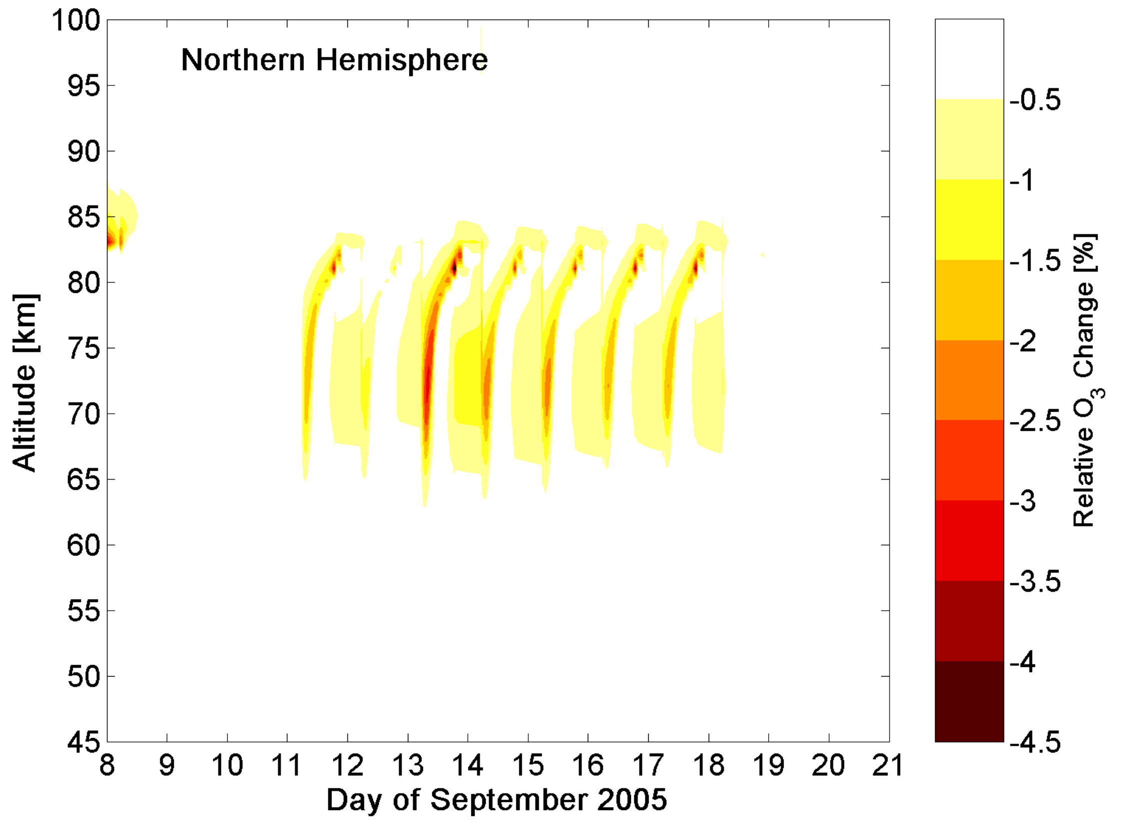
Factor of 5-6 increase that is most significant in the ~65-85 km altitude range

Looks impressive, but it is important?

The NO_x increase builds up primarily across the time-span when the >150 keV electron precipitation fluxes peak, and then start to recover due to photodisocciation.

Model the neutral atmosphere changes: O_3

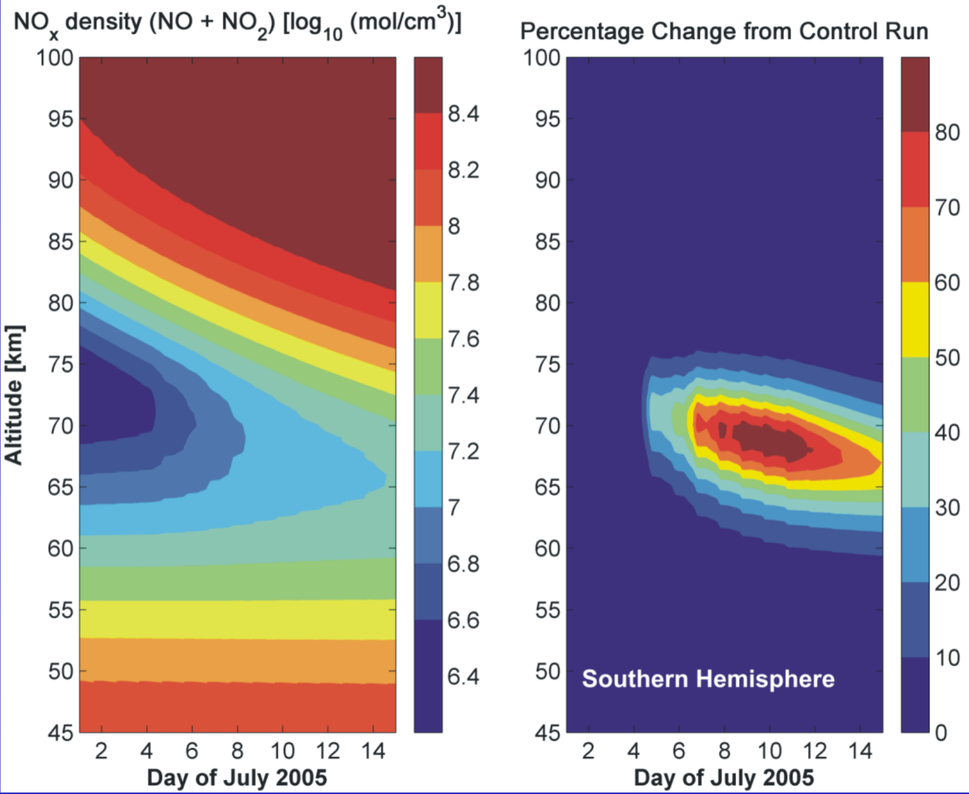
NO_x and HO_x increases caused by energetic particle precipitation have been associated with in-situ ozone loss in the polar middle atmosphere. This has been experimentally observed during Solar Proton Events. So what about for electron precipitation?



In the case studied here there is an **essentially insignificant level** of ozone loss (<1% most of the time, brief peaks at ~3%).

Model the neutral atmosphere changes: NOx

However, we considered the Northern Hemisphere during late summer-early autumn. The dark atmosphere, particularly the polar winter atmosphere, is very different. So lets take a Southern Hemisphere case (same *L*-shell) in deep SH winter.

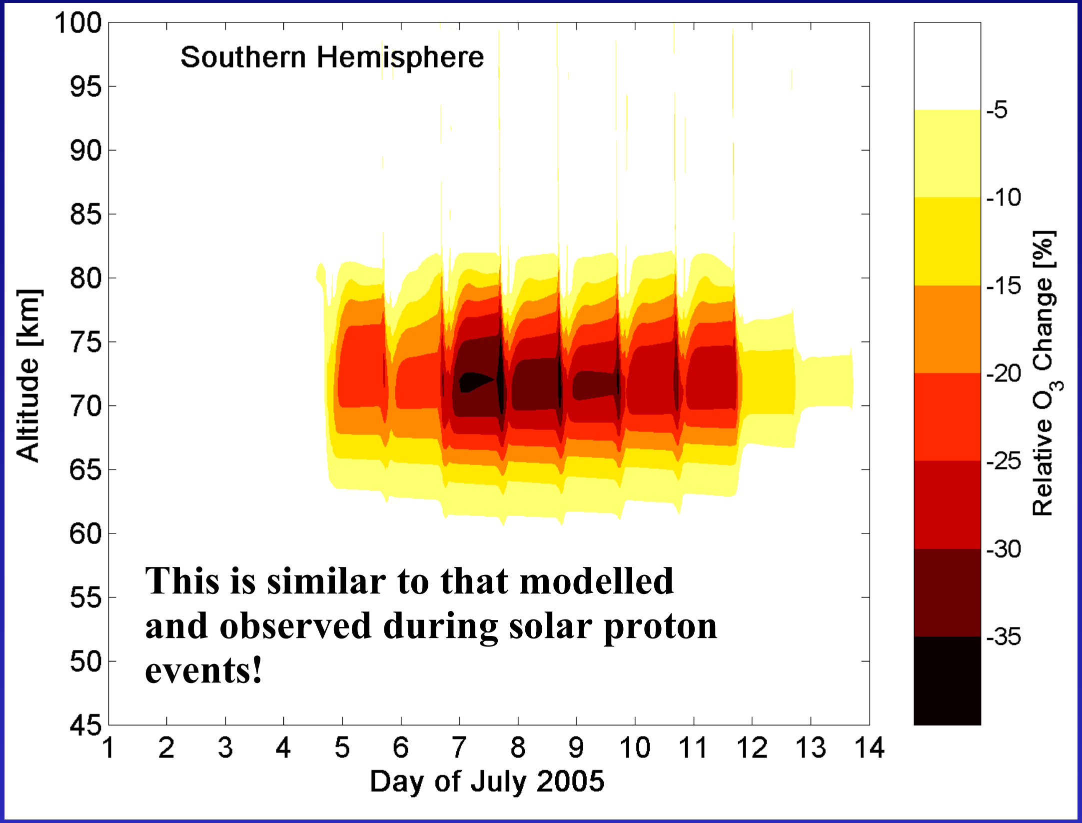


While the percentage change is not so big, the absolute changes are larger, and persist longer.

Again, looks a bit impressive, but it is important?

Model the neutral atmosphere changes: O_3

We know the response to particle precipitation is dependent upon hemisphere and season (this has also been experimentally observed during Solar Proton Events). So if we look at the Southern Hemisphere and winter, then yes, it's a very different picture!



In this case, because of seasonal asymmetries in background chemical composition, we get a **significant *in-situ* O_3 change**!

Summary and Conclusions

After the 11 September 2005 geomagnetic storm the >150 keV electron fluxes in the drift loss cone at L=3.2 increased by a factor of ~1000 above ambient conditions.

The fluxes decayed to within a factor of 5 of the ambient levels over the following 14 days. Plasmaspheric hiss (PH) observations show reasonable agreement with precipitating particle behaviour, suggesting PH with freqs <500 Hz can drive electron losses outside storm periods.

We can use AARDDVARK subionospheric VLF + DEMETER observations to estimate the energetic electron precipitation fluxes into the atmosphere through this ~1 month period.

The peak precipitated fluxes of >150 keV electrons into the atmosphere were 8000 el. $cm^{-2}s^{-1}$ at midday and 800 el. $cm^{-2}s^{-1}$ at midnight.

The energetic electron precipitation creates significant increases in NOx and HOx in the middle atmosphere.

These increases have an insignificant influence on ozone in the northern hemisphere (late summer). Had the EEP struck the polar atmosphere during the winter, significant *direct* ozone losses are predicted.

The calculations suggest that electron precipitation from the radiation belts can be as important to the middle atmosphere as (some) solar proton events!

UNIVERSITY of OTAGO
Te Whare Wānanga o Otāgo
NEW ZEALAND

ILMATIETEEN LAITOS
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UNIVERSITE PAUL SABATIER
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Thankyou!

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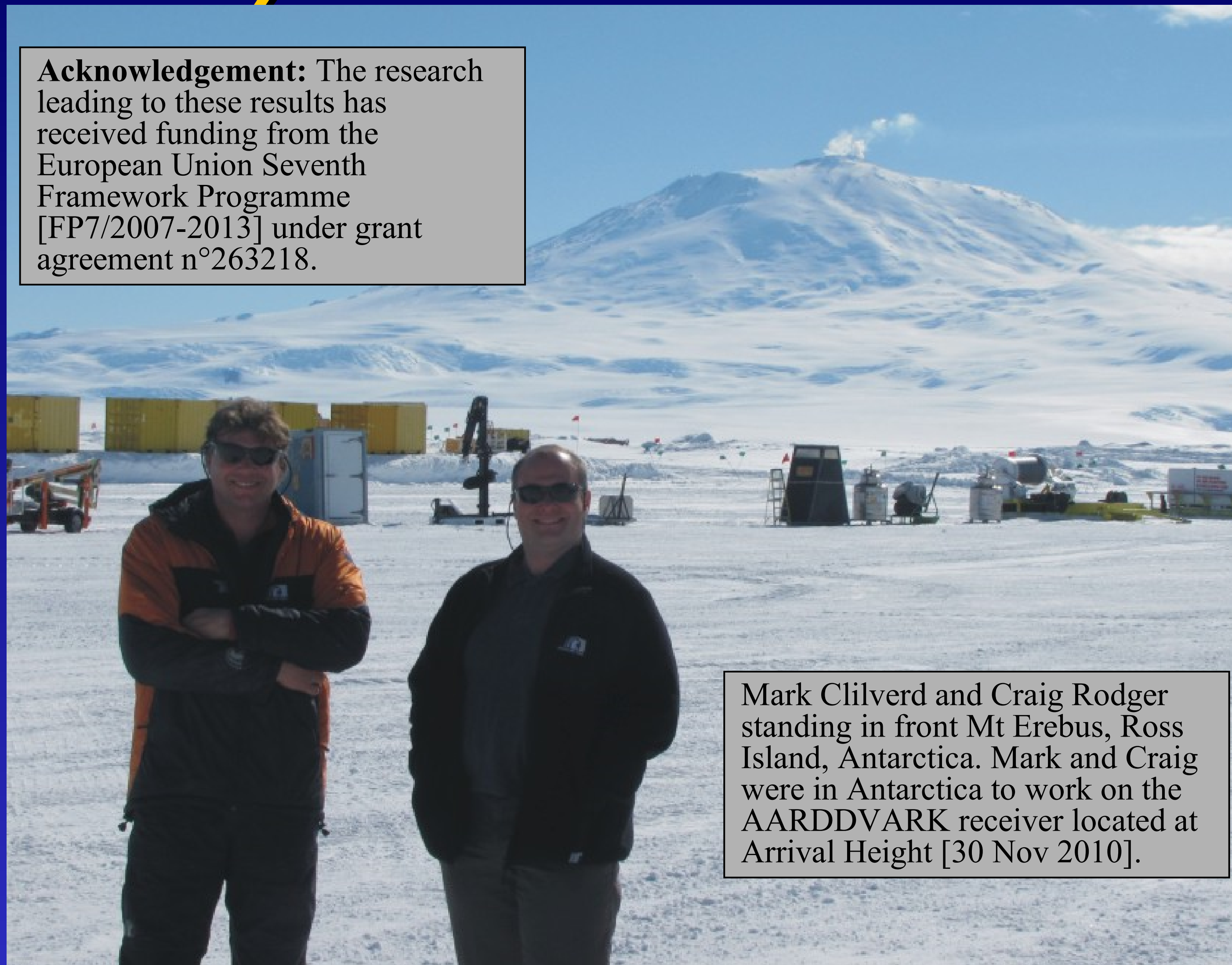

Mark Clilverd and Craig Rodger standing in front Mt Erebus, Ross Island, Antarctica. Mark and Craig were in Antarctica to work on the AARDDVARK receiver located at Arrival Height [30 Nov 2010].

Are there any questions?