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The noctilucent cloud region in the Earth's atmosphere - a natural dusty plasma laboratory.

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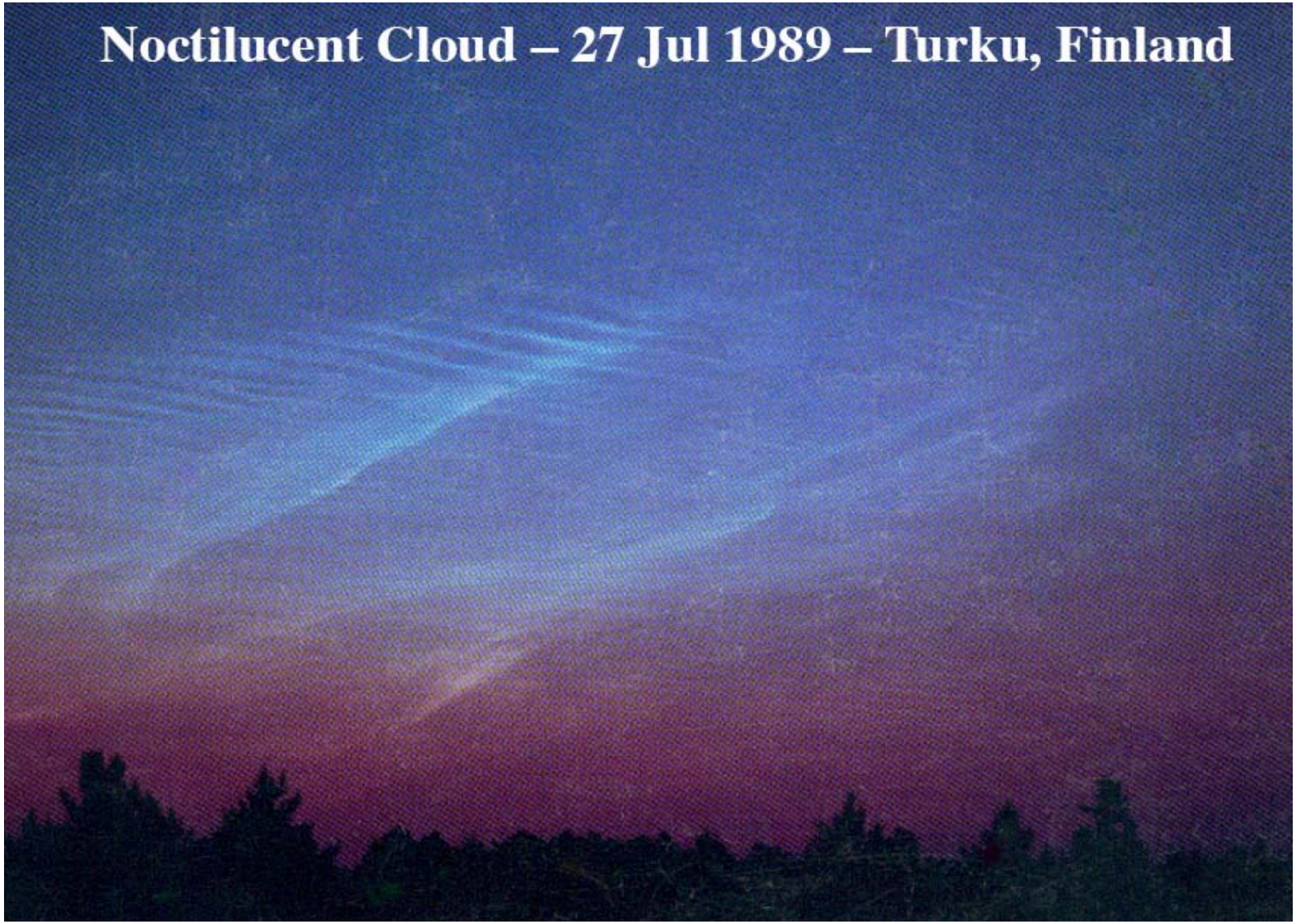
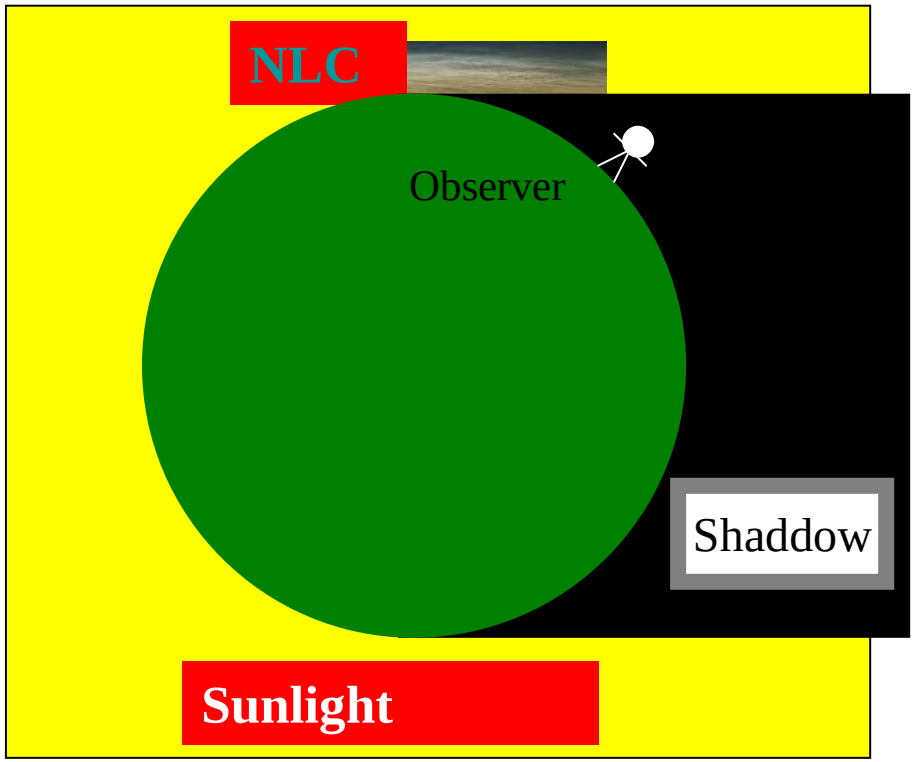
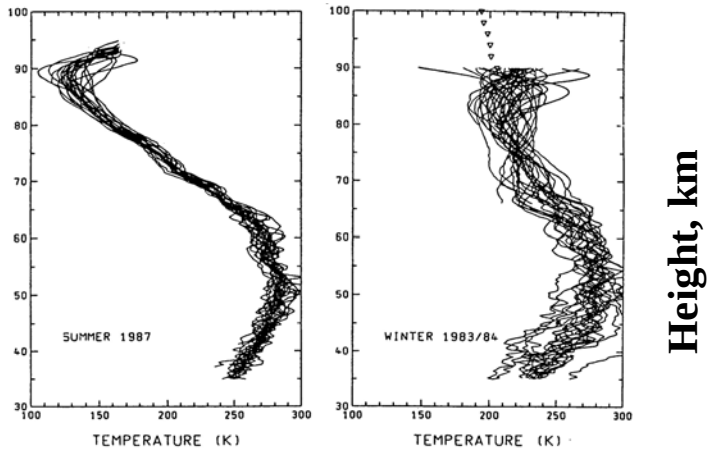
Abdus Salam – 20 August 2007


Noctilucent Cloud – 27 Jul 1989 – Turku, Finland

Noctilucent clouds (NLC) can only be seen by eye at twilight. Contains water ice particles (dust), with some metals?





(von Zahn and Meyer, 1989)

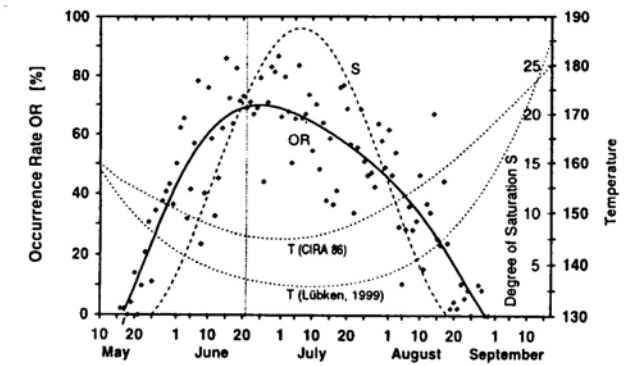
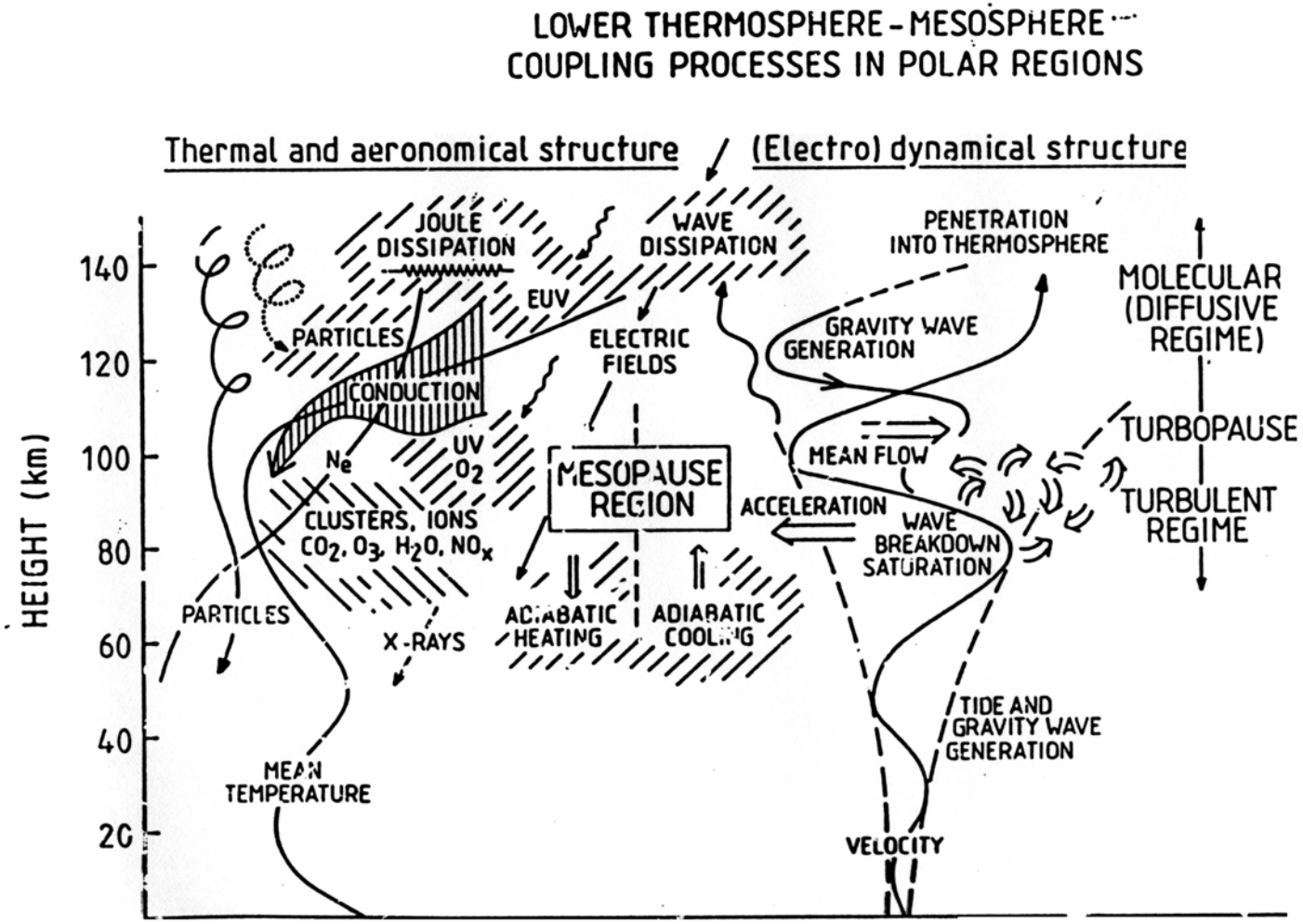


Figure 3. Seasonal variation of the mean occurrence rate of PMSE (OR, full curve) at Andenes during the interval 1994-1997 and of the degree of saturation (S,dashed curve) together with the temperature at 85 km altitude after *Lübken* [1999] and CIRA 86 (T, dotted lines).

(Hoffman, Singer and Bremer, 1999)

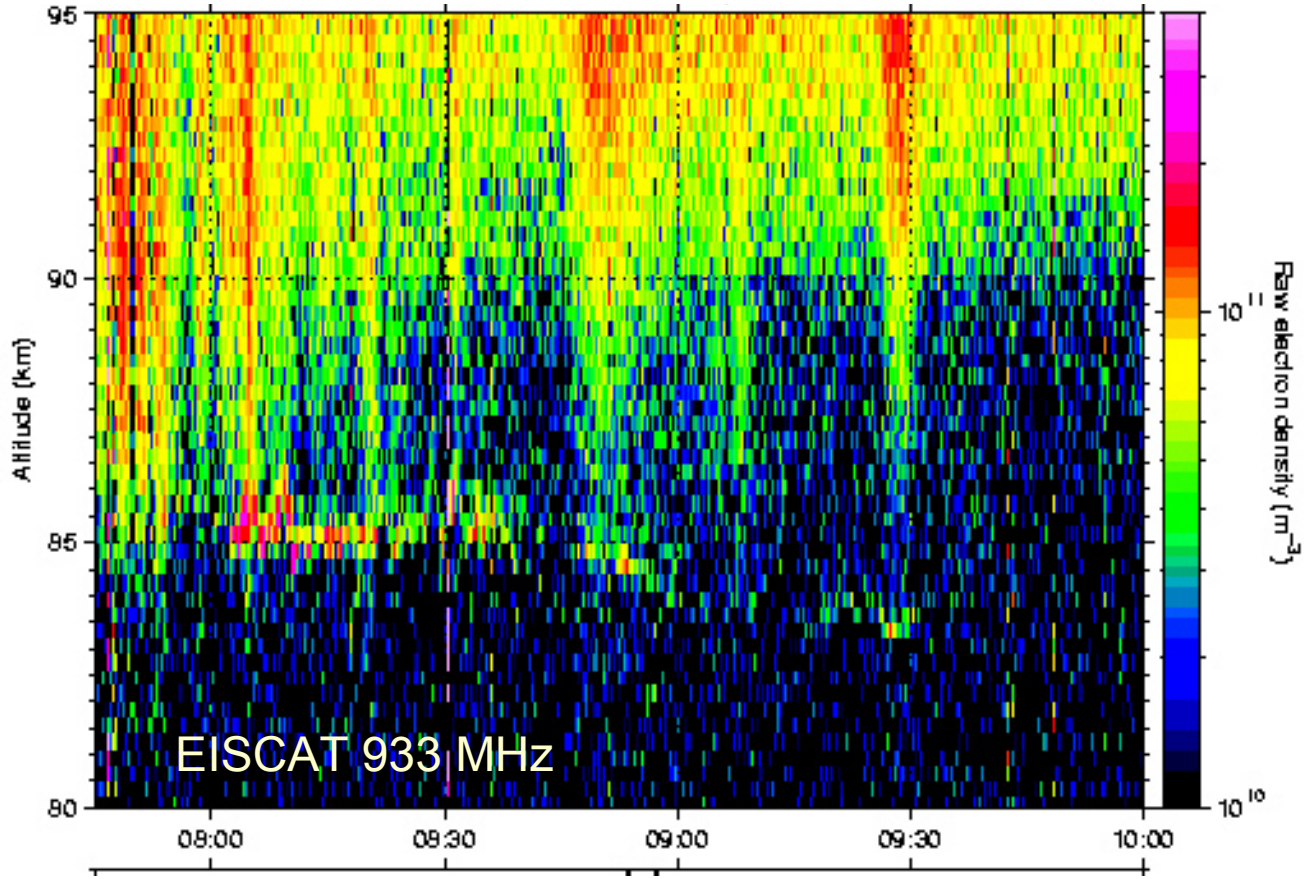
Many processes are important in the NLC region, it is a complex part of the atmosphere



Meteors “burn up” between 75 and 110 km height.

- They deposit metals in the mesosphere
- They most probably also deposit small (ca 1 nm ?) meteoric smoke particles.
- The smoke particles act as condensation sites for water/ice when the temperature becomes low enough in the mesosphere.

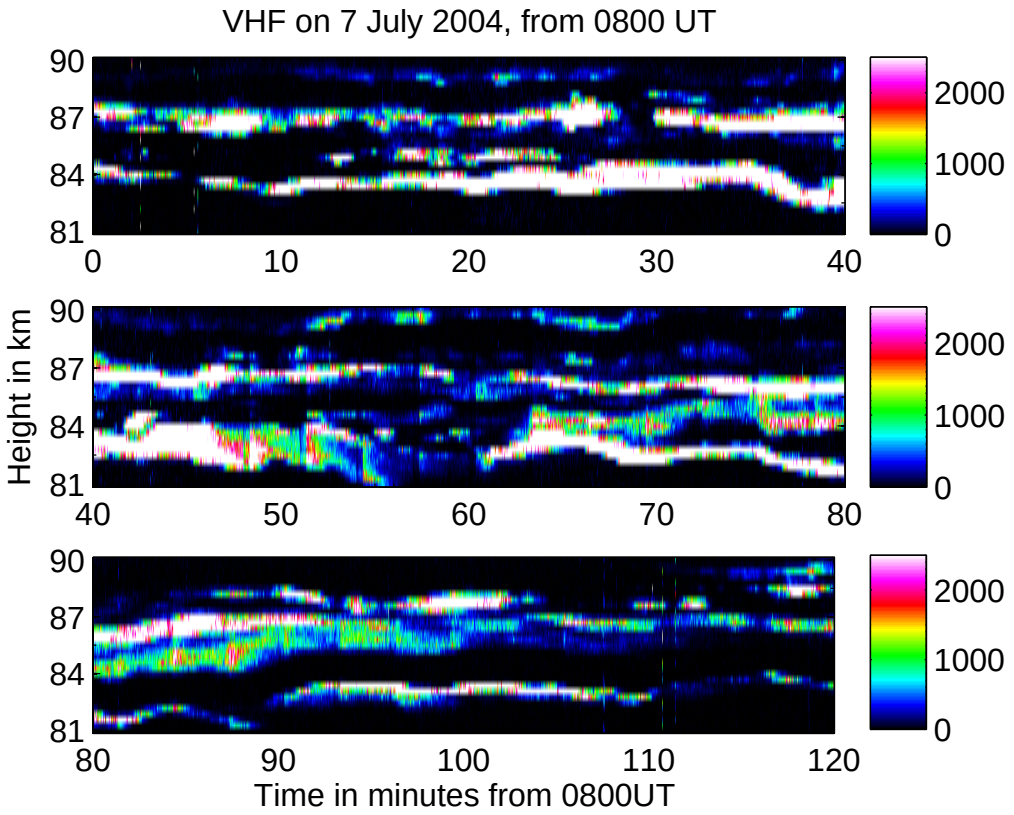
Energetic particle precipitation affects the Mesosphere charge balance



We also observe strong radar scattering layers (PMSE) in the mesosphere - they are strongly linked to the NLC

- PMSE (Polar Mesospheric Summer Echoes) were first observed at radar frequency ~50 MHz ($\lambda/2$ = 0.7 m)
- The have also been observed at frequencies around 1 GHz ($\lambda/2$ =0.15 m)
- The ocurrence rate and strength of PMSE is reduced (much) at higher frequencies.
- The PMSE is controlled by charged dust.

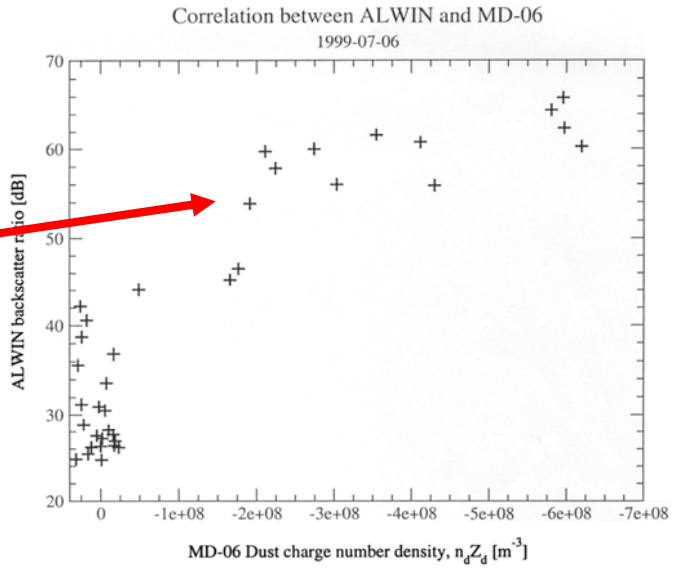
A complex PMSE

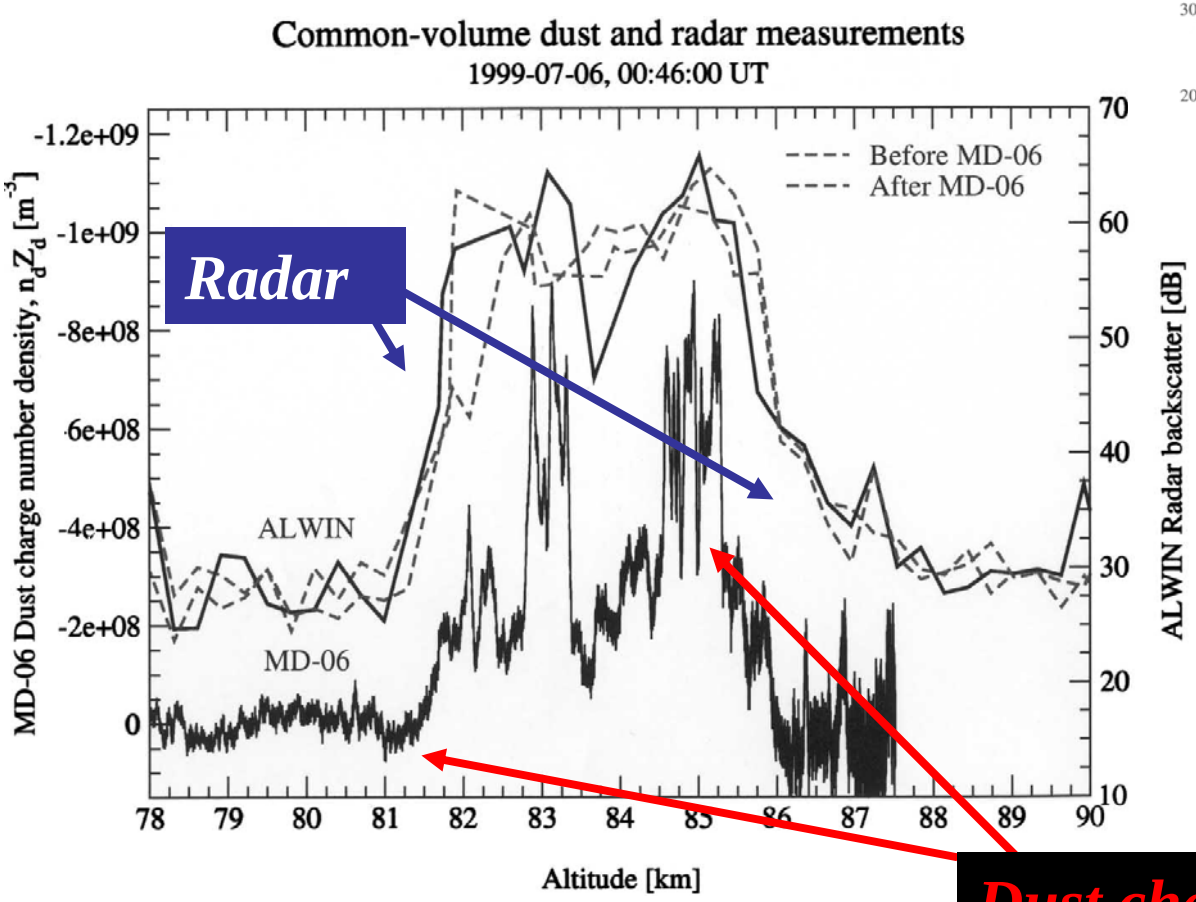


The radar PMSE layers – signatures of a DUSTY PLASMA

- Dust particles of sizes which apparently can be from a few nm (or less) to 50-100 nm.
- Most likely consisting of water ice.
- Do they also contain meteoric material (metals, smoke particles)?
- Densities up to 4000 particles per ccm.
- Charges –1e to –a few e.

Radar backscatter as function of dust charge density





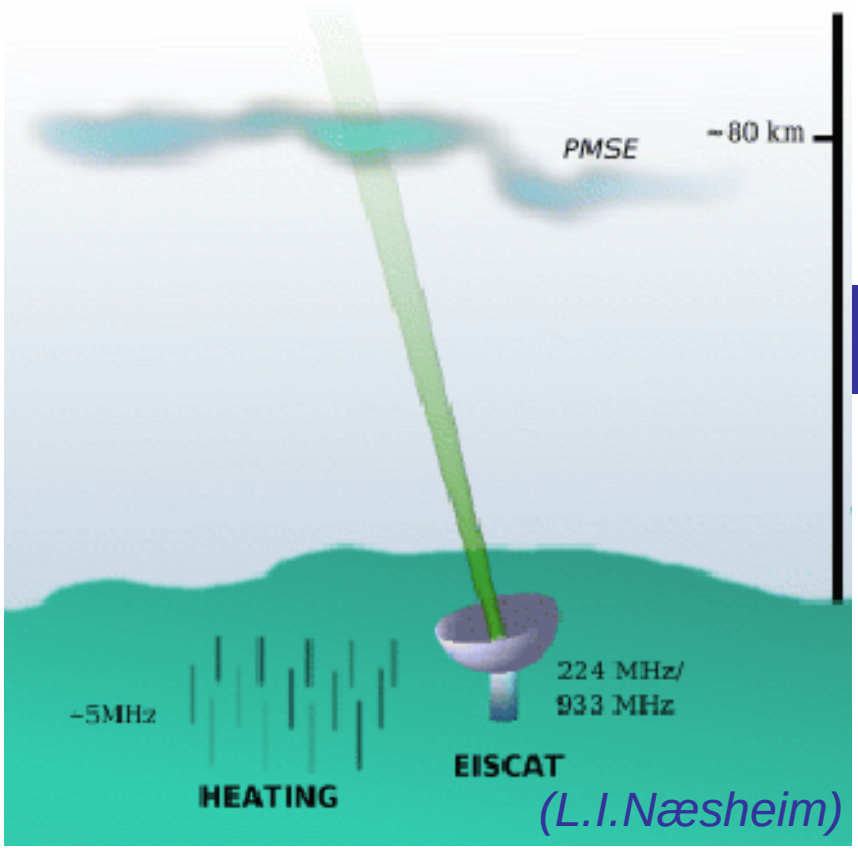
First common volume observation with radar (PMSE) and rocket (dust charge density) *(Havnes et al 2001).*

Dust charge density

We want to understand the radar phenomenon (PMSE) and also use it to monitor the conditions in the mesosphere

- We now (probably?) know why PMSE occur.
- However, so far the radar signals have yielded little information about the conditions in the mesosphere.
- Recent developments have opened up new possibilities for using the radars to diagnose the dusty plasma conditions in the mesosphere. *We can now actively modify the PMSE region.*

Observing (and modifying) PMSE by use of the EISCAT HEATING Facility with the VHF and UHF radars

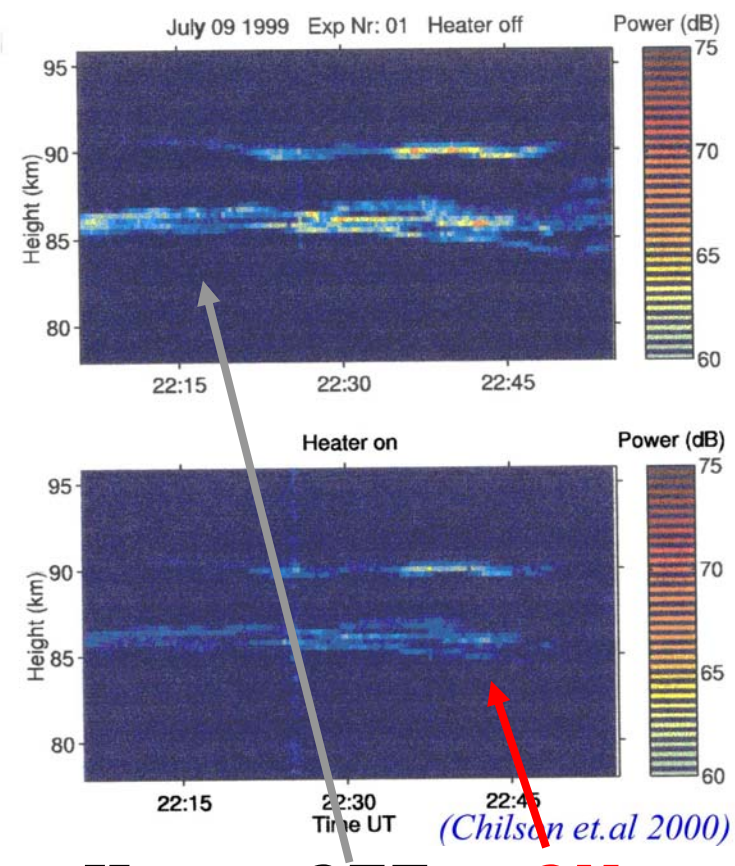


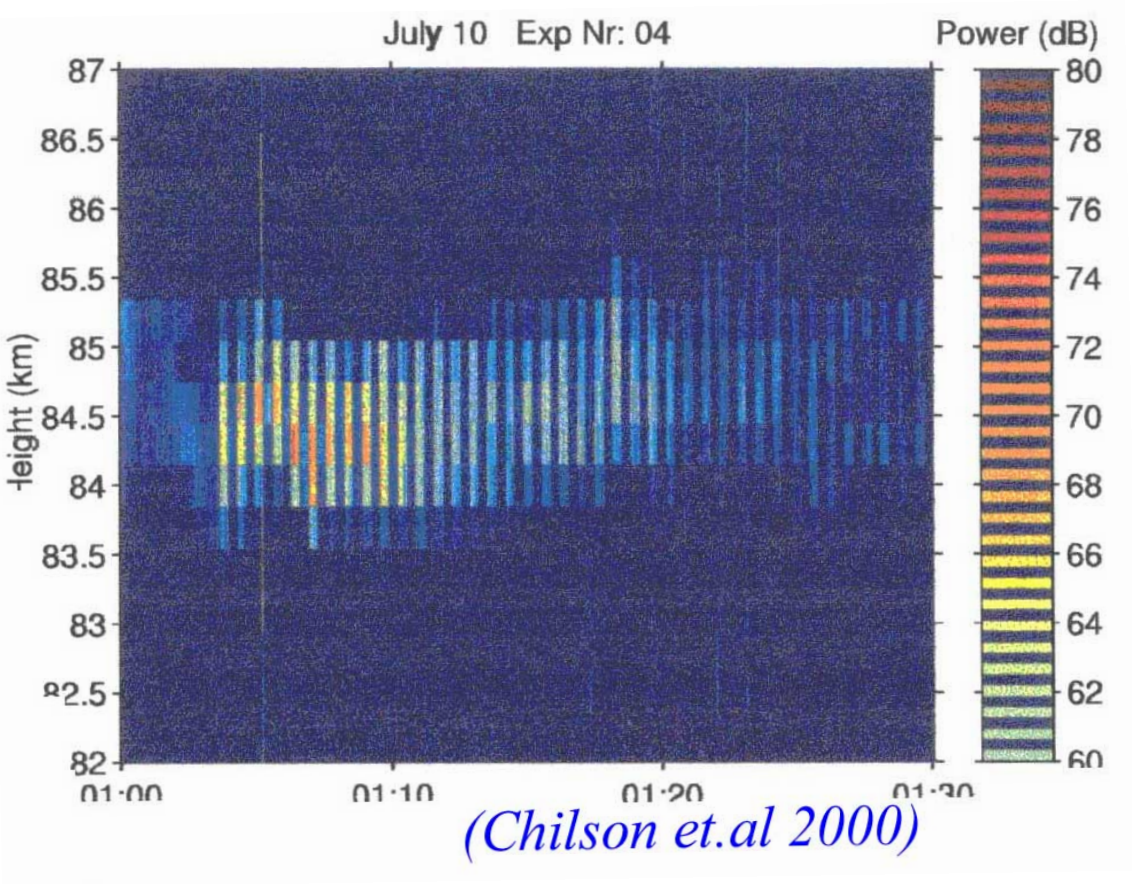
HF transmitter (Heating) at 4 to 8 MHz

Chilson et.al /2001) showed that the PMSE signal could be made to practically disappear by the use of artificial heating.

”**Old**” heating cycling (e.g 20 sec - 20 sec)

Discovery of the effect of running the EISCAT Heater during PMSE observations by EISCAT 224 MHz



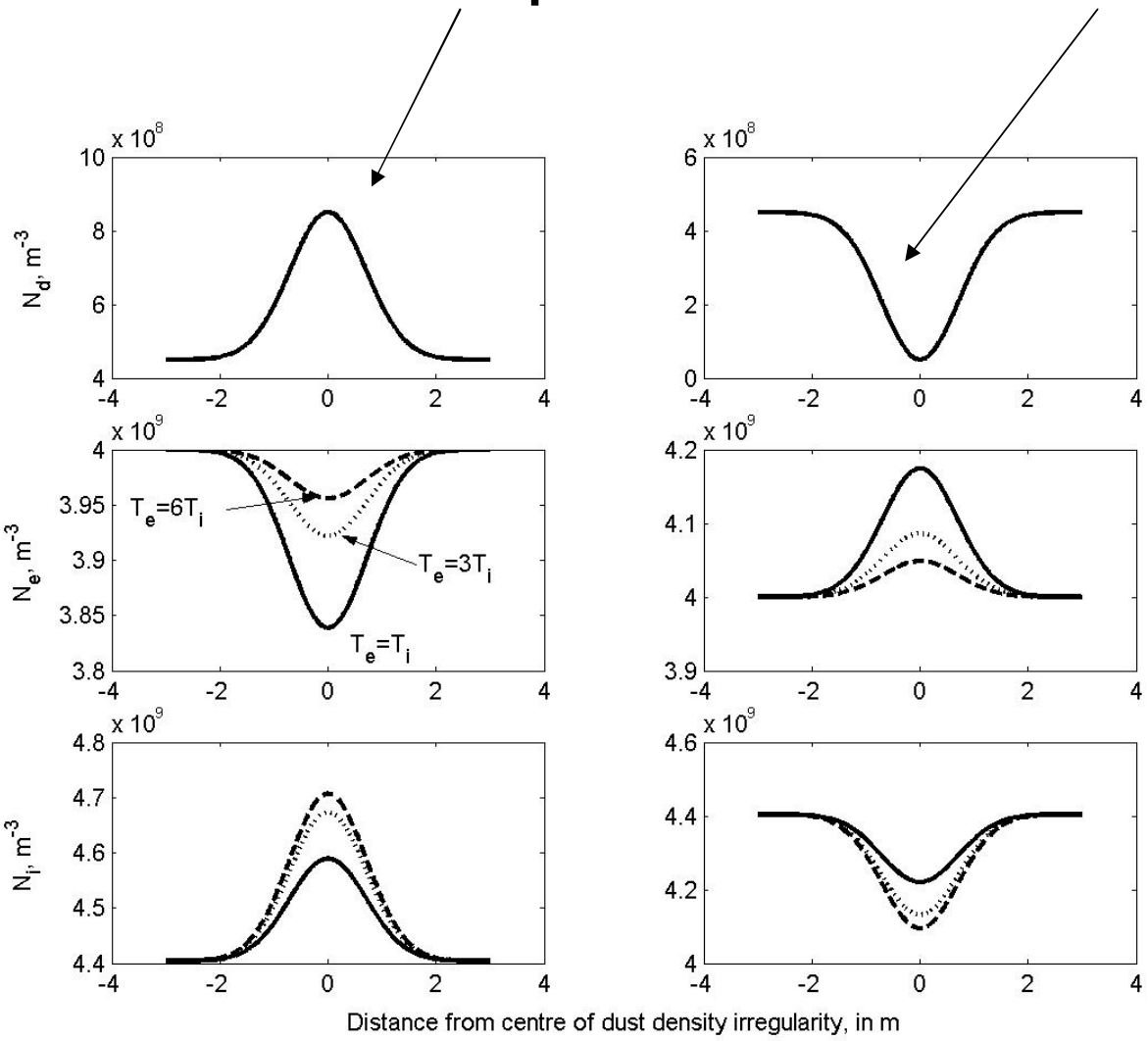


Heater: OFF ***ON***

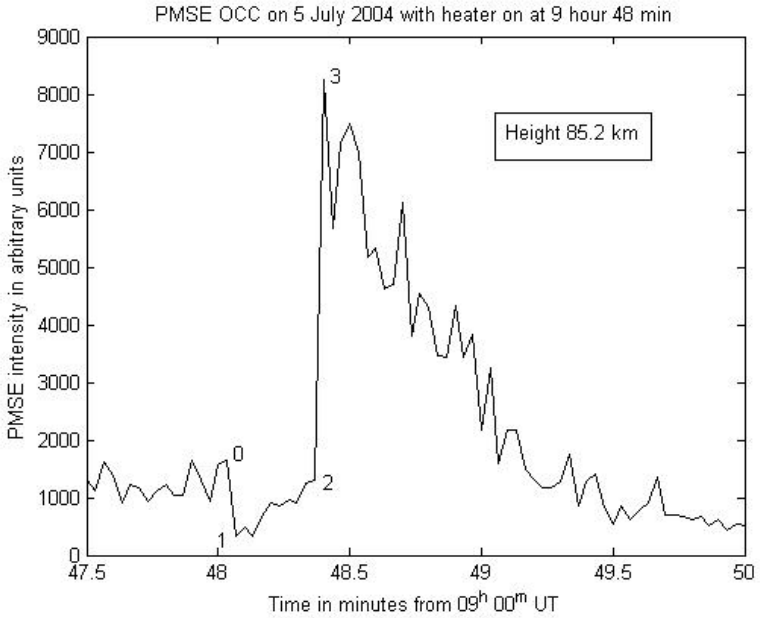
Heater : OFF 20 sec – ON 20 sec

The (likely) explanation for these variations was given by *Rapp and Lübken (2000,2003)*

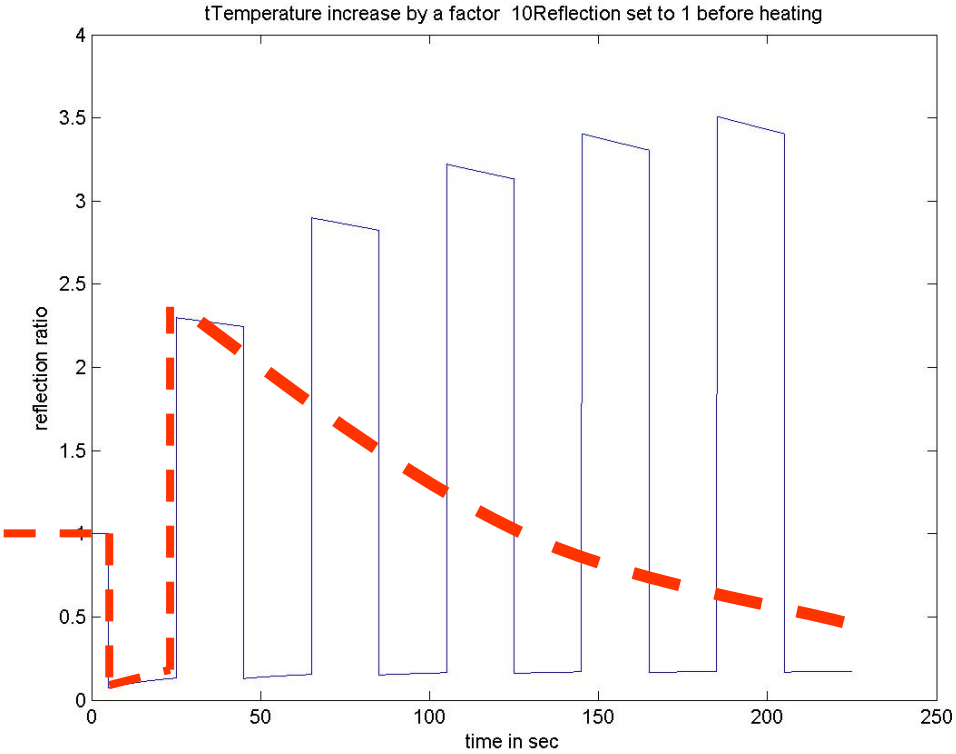
The redistribution of electrons take place both for dust clumps and dust ”holes”



How to create an Overshoot.

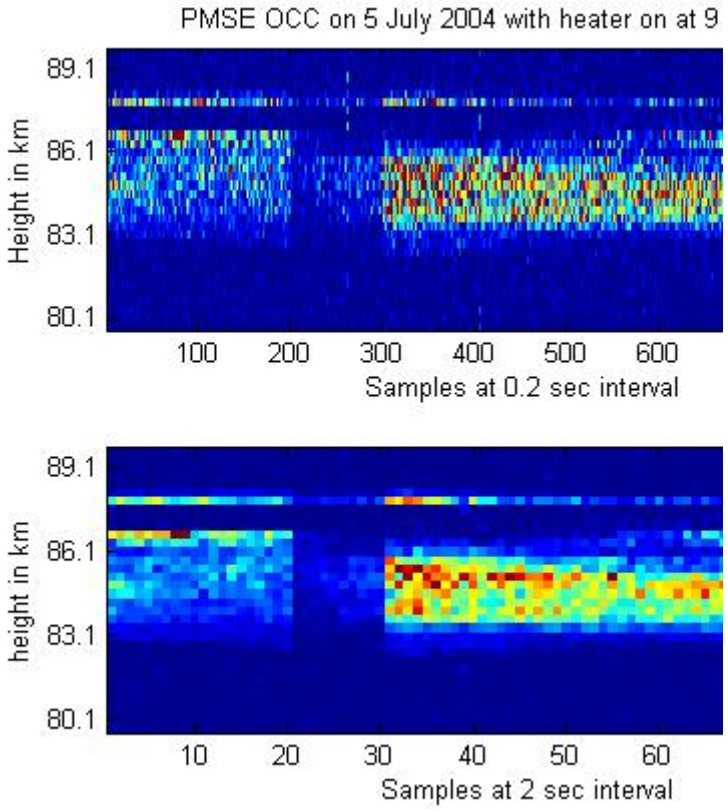


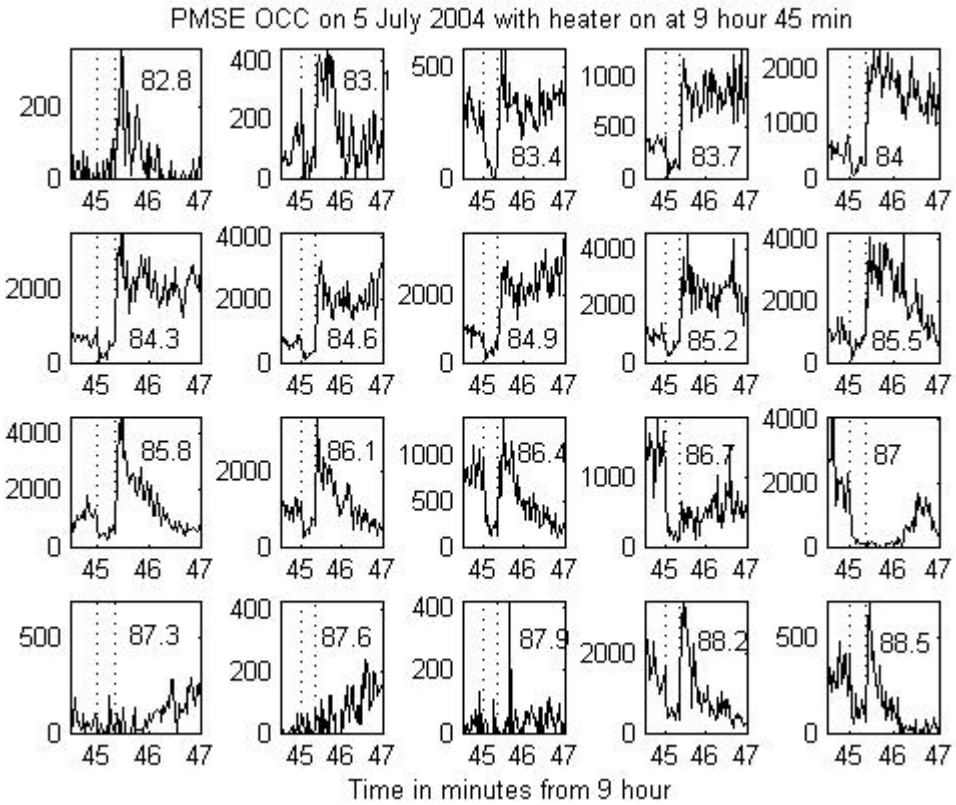
Kassa et.al (2005)



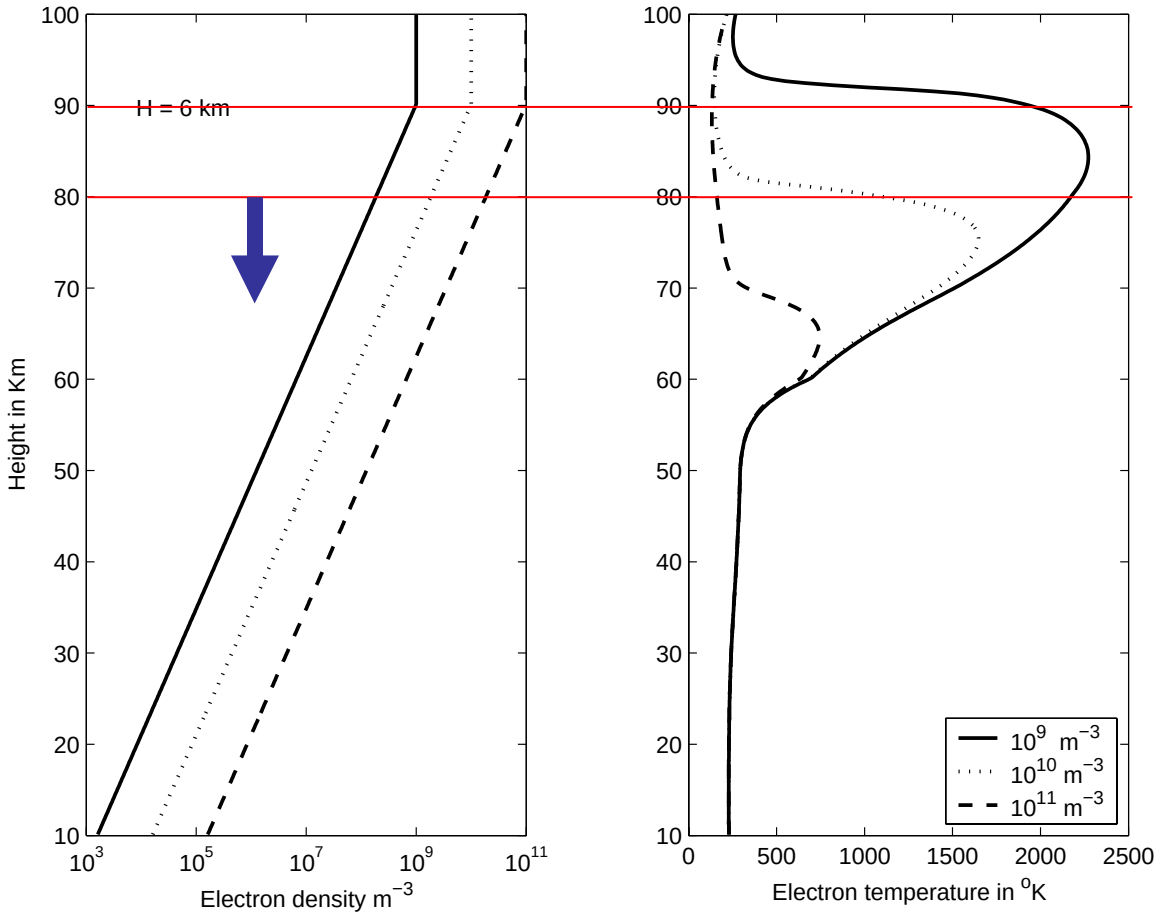
Havnes (2004)

Observation of one heating cycle: 20 sec ON, 160 sec OFF





The heater affects electrons only

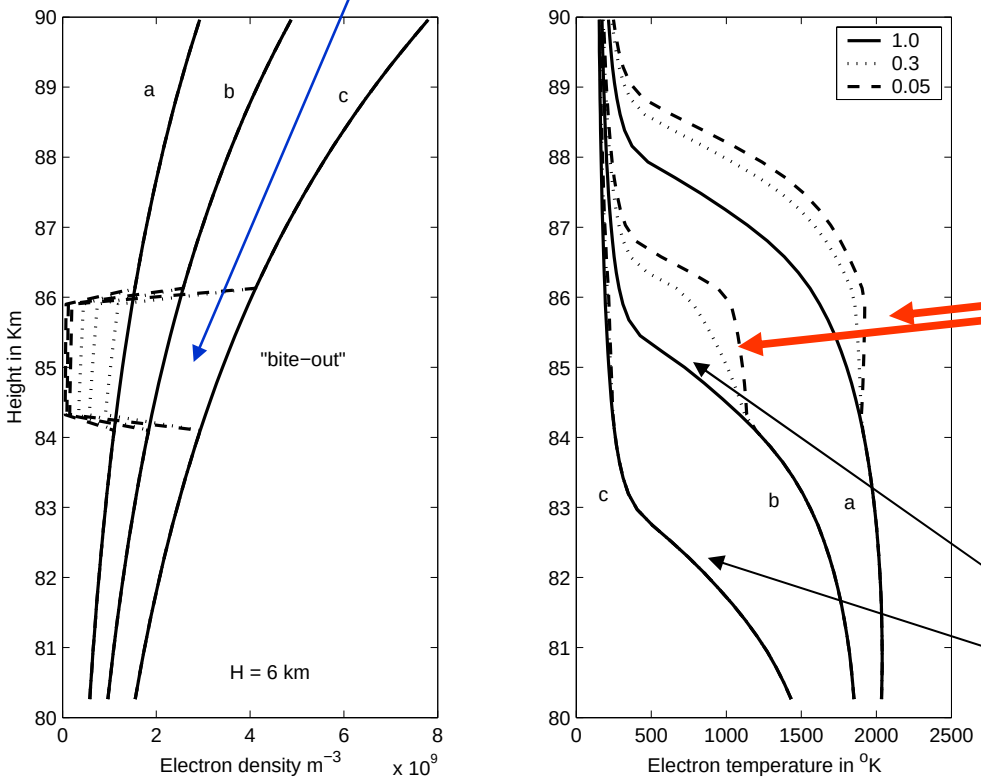


(Kassa, Havnes and Belova 2005)

- Electrons are heated within a few milliseconds
- The electron density below the PMSE layer control how much heater wave power which reach the PMSE layer.
- The electron heating in the PMSE layer may be (theoretically) from negligible to around 2500 – 3000 K.

Can the signature of exceptionally large dust densities be found in the observations?

They will produce electron “bite-outs”



- Bite-outs can affect the heating (as a function of height) by creating a plateau
- Without a bite-out we expect the temperature to always decrease with height

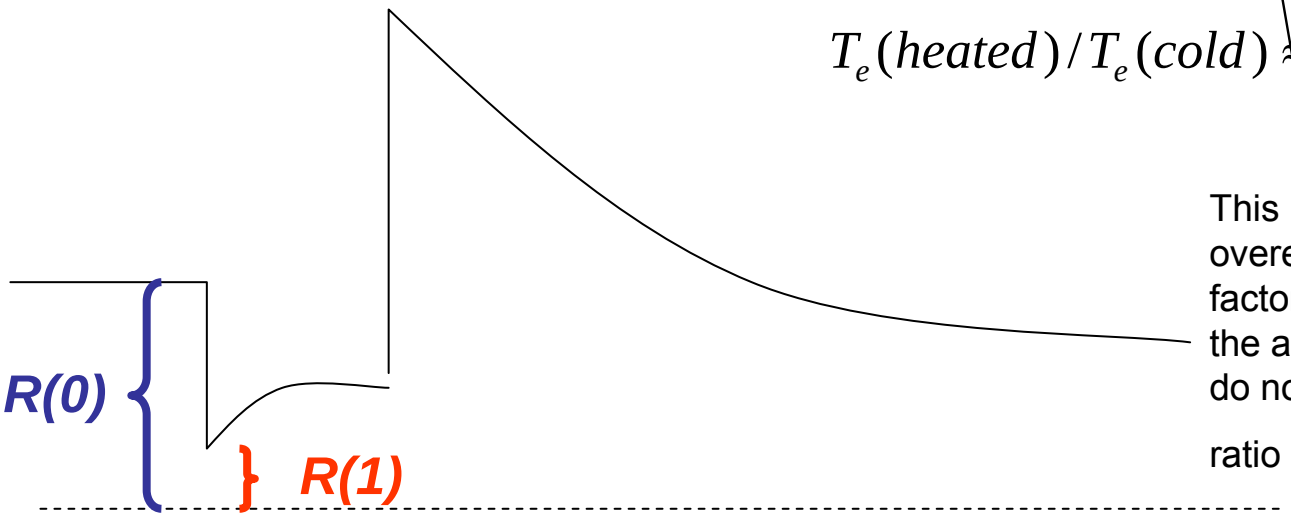
(Kassa, Havnes and Belova, 2005)

Based on that the plasma is Boltzmann distributed: $n_\alpha = n_{\alpha 0} \exp(eV / k_B T)$ we can find the heating factor

$$T_e(heated)/T_e(cold) \approx \frac{(1+n_{i0}/n_{e0} - \sqrt{R(1)/R(0)})}{(n_{i0}/n_{e0})\sqrt{R(1)/R(0)}}$$

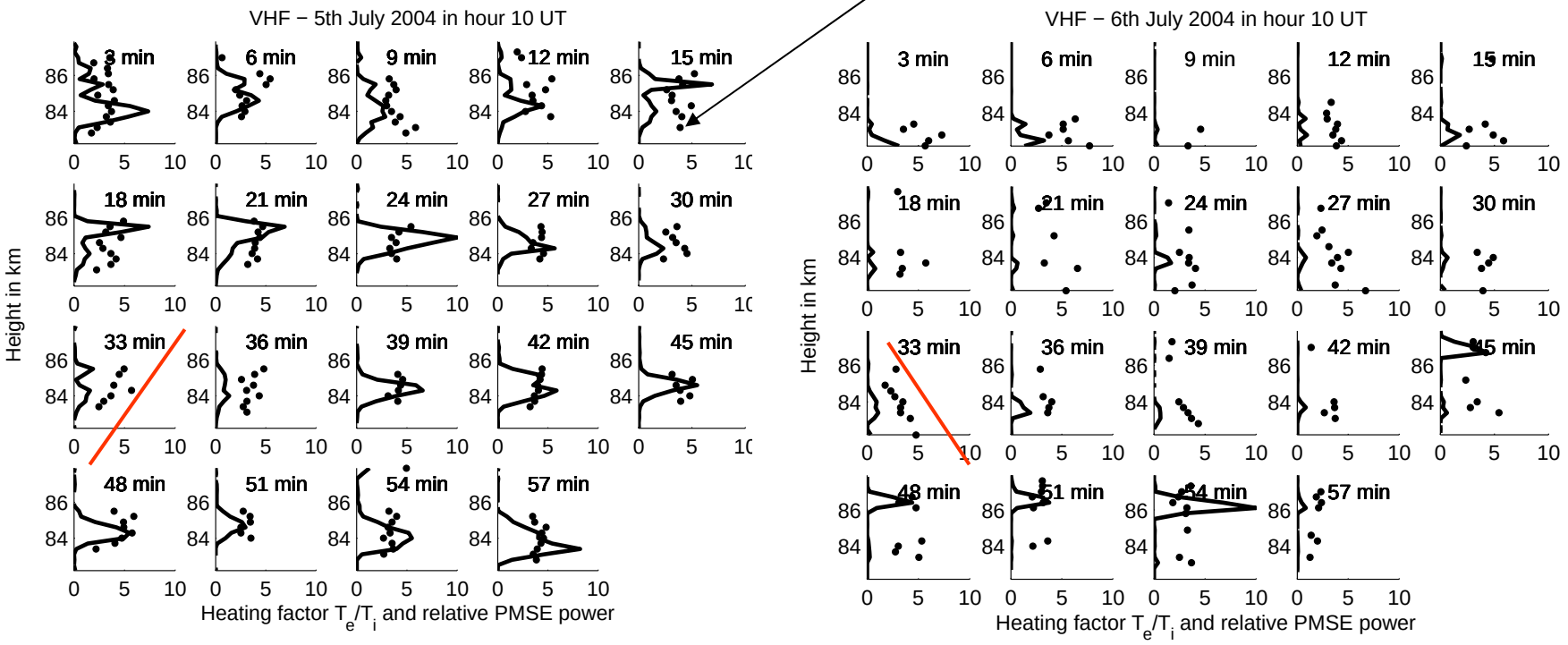
In situations with moderate amount of dust where $n_{i0}/n_{e0} \approx 1$ this becomes

$$T_e(heated)/T_e(cold) \approx \frac{2-\sqrt{R(1)/R(0)}}{\sqrt{R(1)/R(0)}}$$



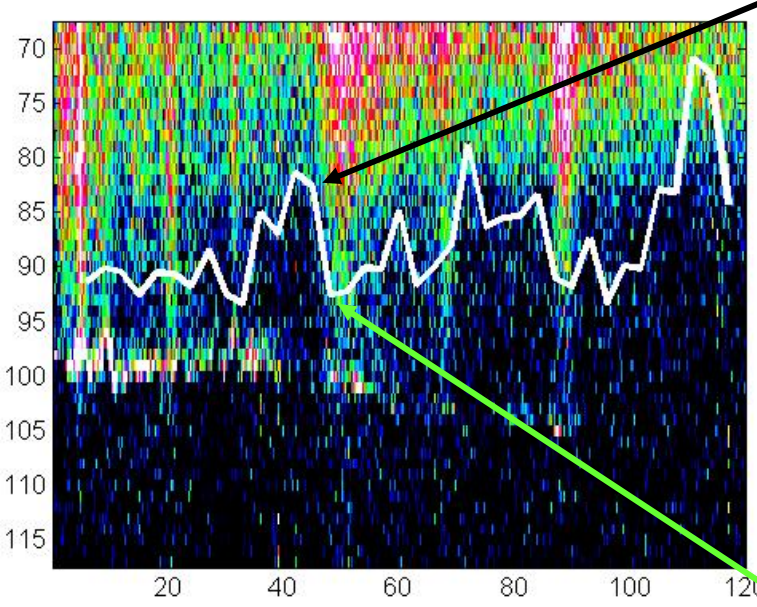
This relation (which overestimate the heating factor) will be a starting point in the analysis since we initially do not know the ratio n_{i0}/n_{e0}

Observed PMSE and the derived heating factors assuming $n_i / n_e \approx 1$

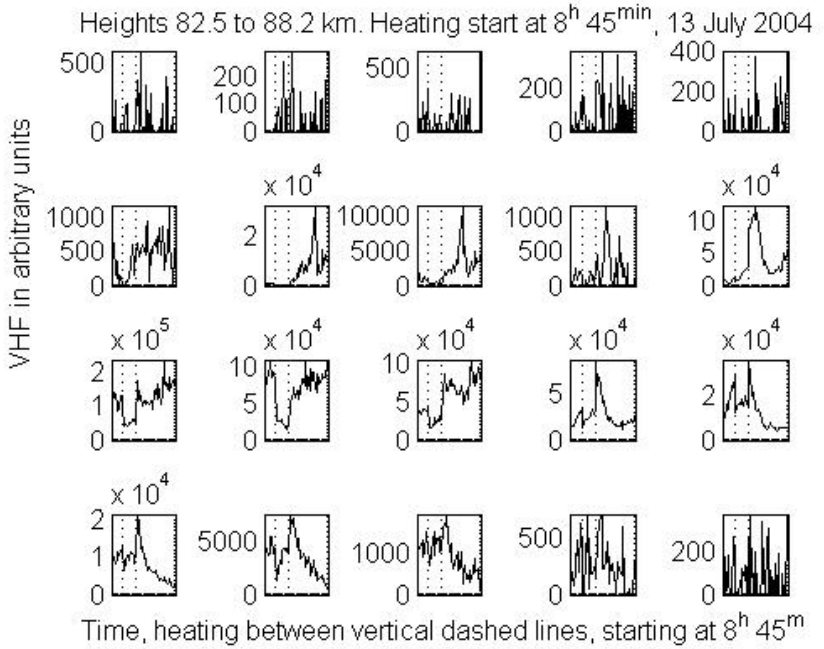


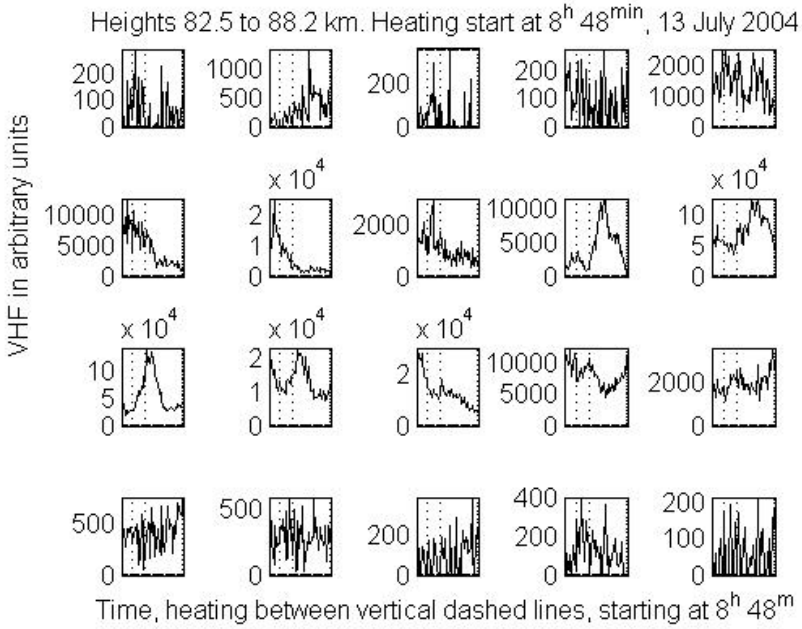
The heating as a function of height is different for these two days – why?

Computed heating factor – with VHF PMSE



UHF on July 13, 0800UT, 2004





Model for PMSE overshoot

- Heating is calculated – depends mainly on electron density height profile and neutral density.
- Overshoot profile depends on all factors: heating, plasma density, dust size and density.
- Main simplification : We assume that the plasma is instantaneously redistributed when the heater is switched on, and also when it is switched off – no diffusion effects.
- This simplification is probably fine for modelling the observations with the radars we now use but maybe not for our new radar at 56 MHz.

Model results for the overshoot

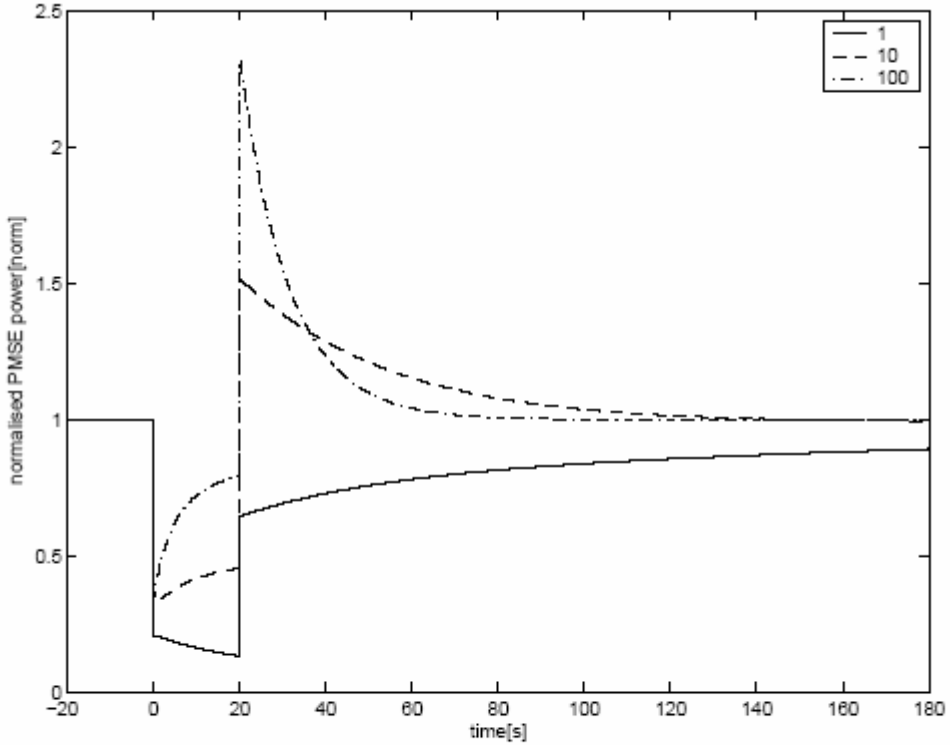


Fig. 5. Change of the OCC with change in the ion-electron pair production rate Q given in units of $\frac{1}{cm^3 s}$ for $r_d = 20nm$, $T_{eh} = 350K$, $N_{tot} = 500\frac{1}{cm^3}$ and $\alpha = 10^{-6}\frac{cm^3}{s}$.

Observed average profiles

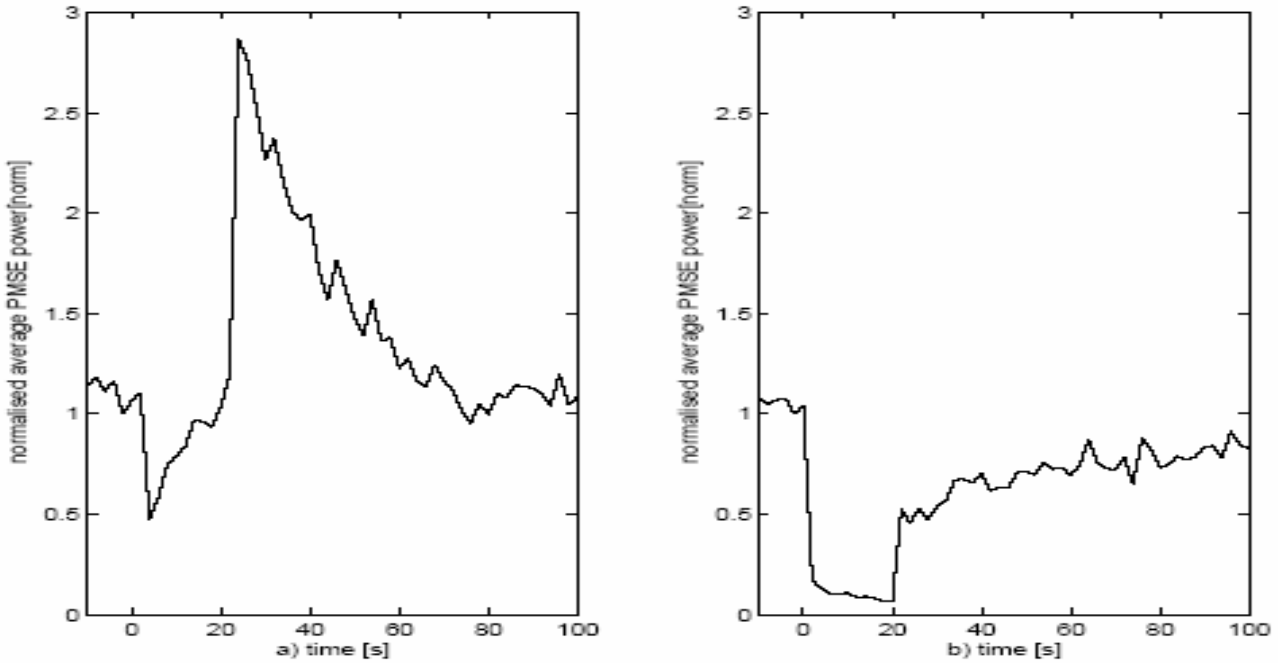
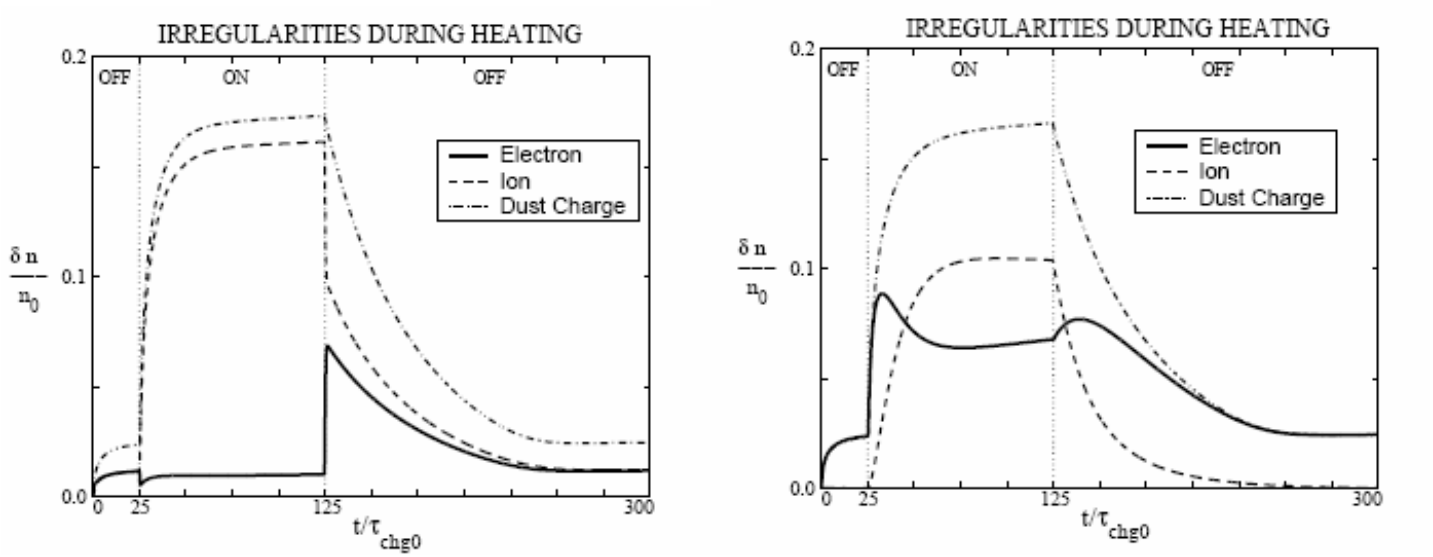


Fig. 8. Two experimental Overshoot Characteristic Curves from summer 2004. The curves have been obtained by averaging the PMSE backscatter power over one hour of measurement. Case a), year 04 month 7 day 12 hour 9, height range 84-84,3km: Clearly no considerable plasma particle absorption. Case b), year 04 month 7 day 5 hour 10, height range 85,5-85,8km: No overshoot, i.e. plasma particle absorption is present and important.

It has been predicted that the overshoot can look different at radar frequency < 50 MHz

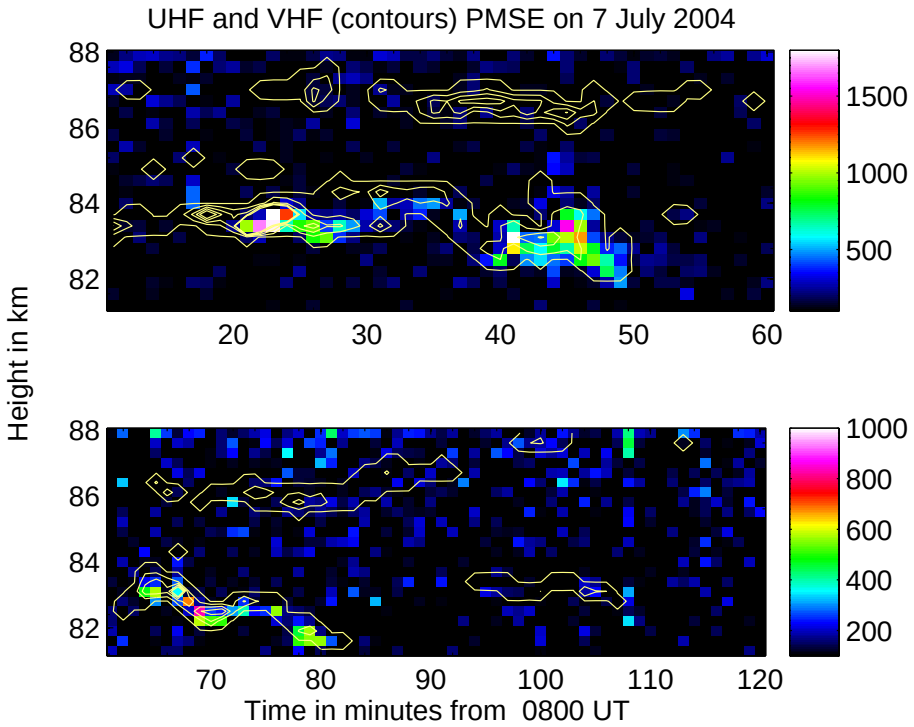


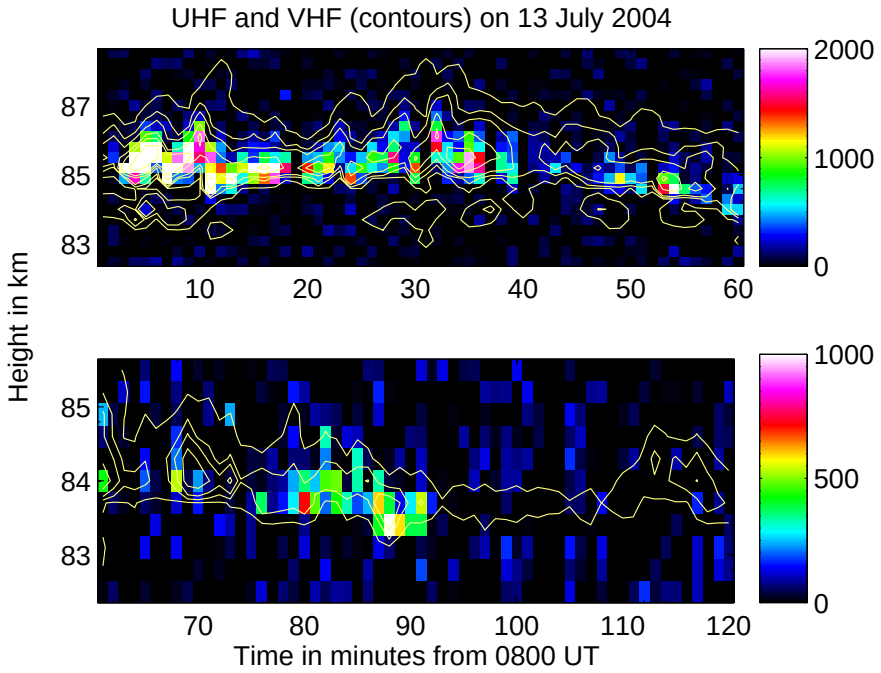
Chen and Scales, 2005

Site of new MORO (56 MHz) radar, operational October 2007

- The work to develop the dusty plasma diagnosis method based on the overshoot mechanism is proceeding but no definite results yet.
- By-products of our observations of the overshoot at the VHF (224 MHz) and UHF (930 MHz) is that it now is clear that only one mechanism is responsible for producing PMSE at all frequencies.

Simultaneous observation of PMSE at UHF and VHF





The overshoot effect is the same at VHF and UHF