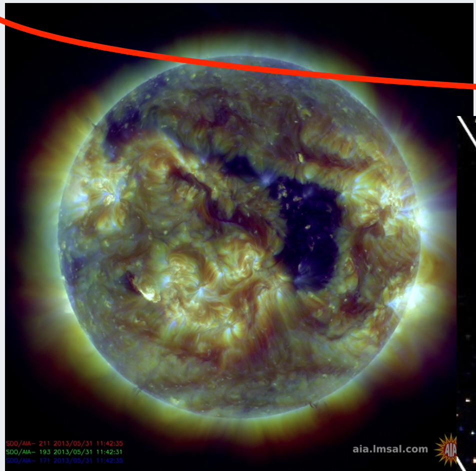
Ionization and NO production in the polar mesosphere during high speed solar wind streams

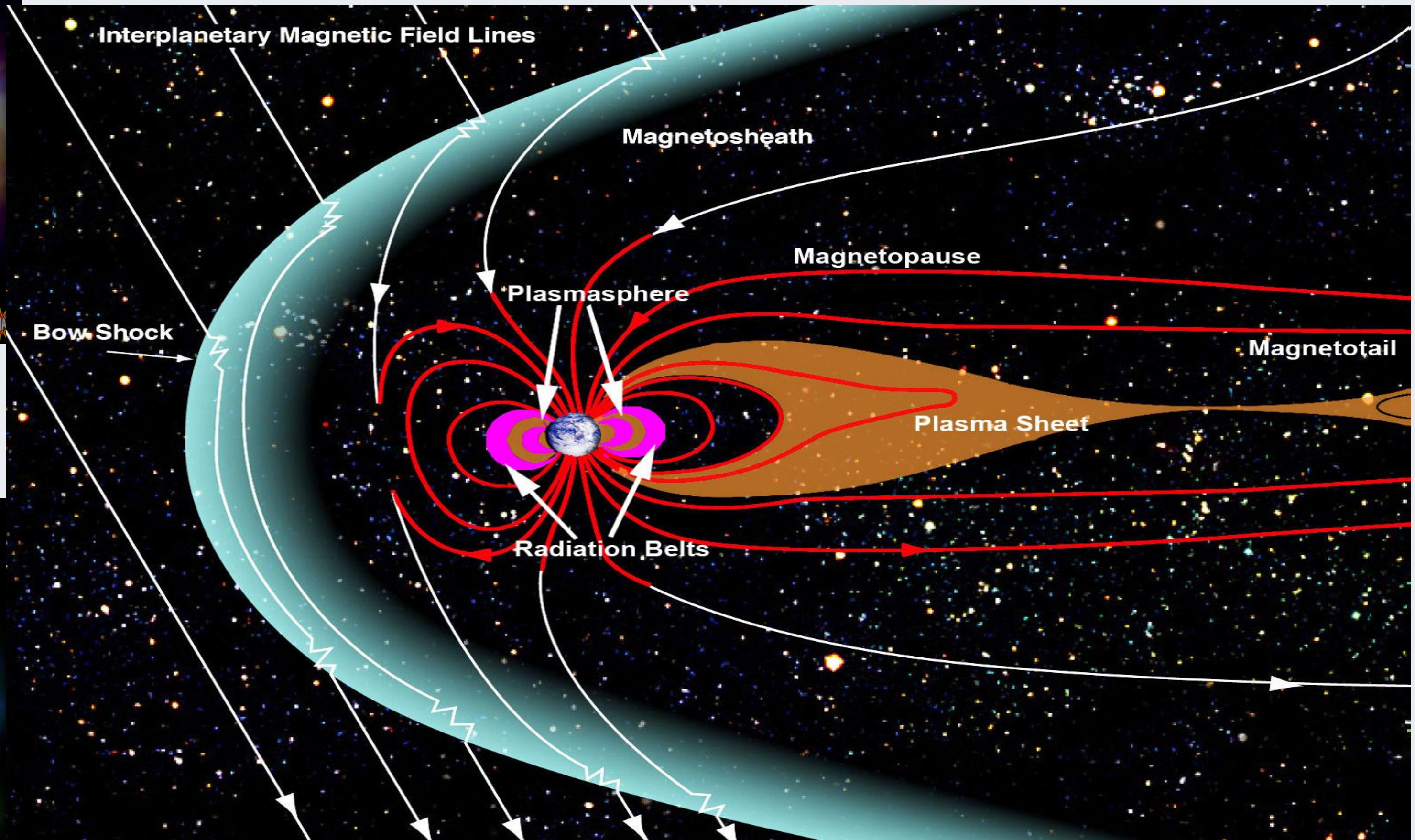
Sheila Kirkwood[1],
With contributions from : Evgenia Belova[1], Young-Sook Lee[2],
Alya Osepian[3], Kristell Pérot[4], A.K. Sinha[5], Jo Urban[4]

[1]Polar Atmospheric Research, Swedish Institute of Space Physics, Kiruna, Sweden
[2]Korea Astronomy and Space Science Institute, Daejeon, Korea
[3]Polar Geophysical Institute, Murmansk, Russia
[4]GEM, Chalmers University, Göteborg, Sweden
[4]Indian Institute of Geomagnetism, Mumbai, India

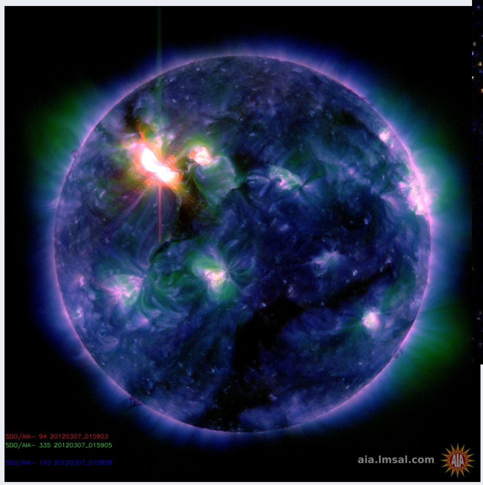
Coronal holes -> high-speed solar wind streams (HSS)



-> electrons from the magnetosphere precipitate to the atmosphere

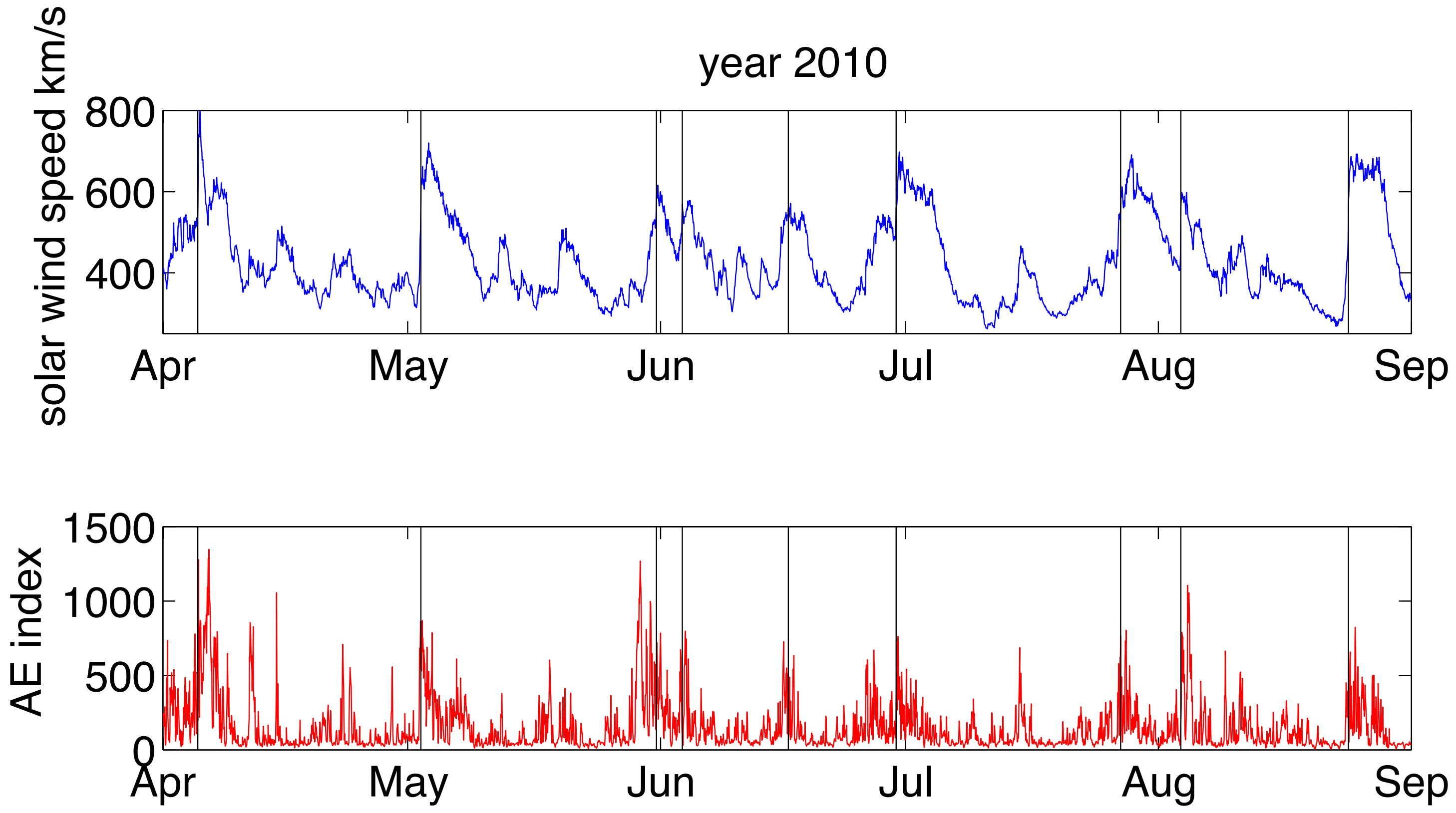


The Sun

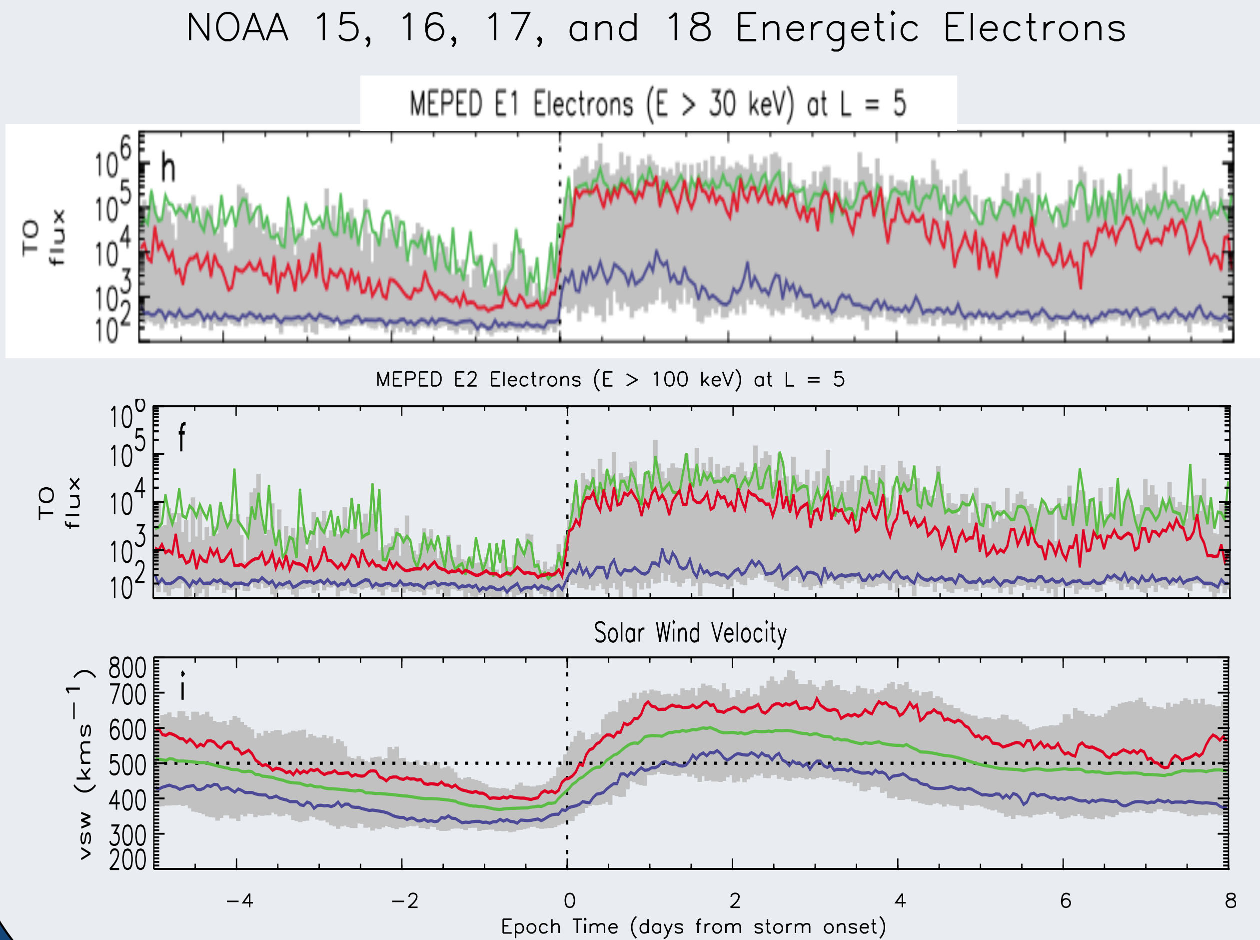


Coronal mass ejections -> solar protons precipitate to the atmosphere

high-speed solar wind streams – HSS

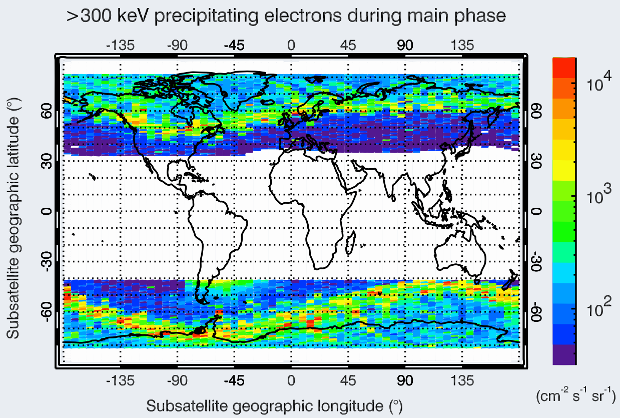


Statistical studies of energetic electrons (using satellite in-situ sensors) show several days of enhanced electron precipitation (EEP) following HSS



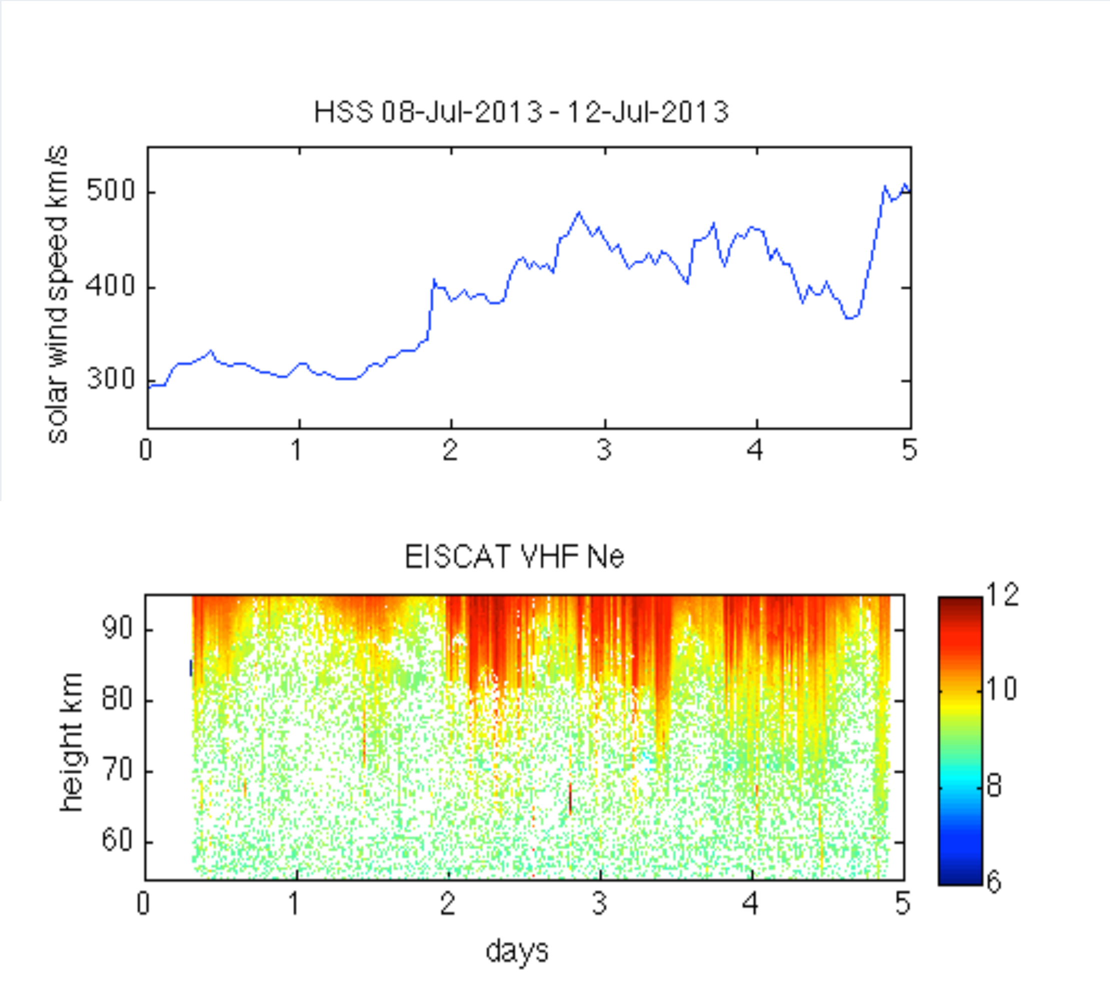
Meredith et al., JGR, 2011

Only integral EEP fluxes available, uncertainties due to e.g. loss-cone sampling and low counts



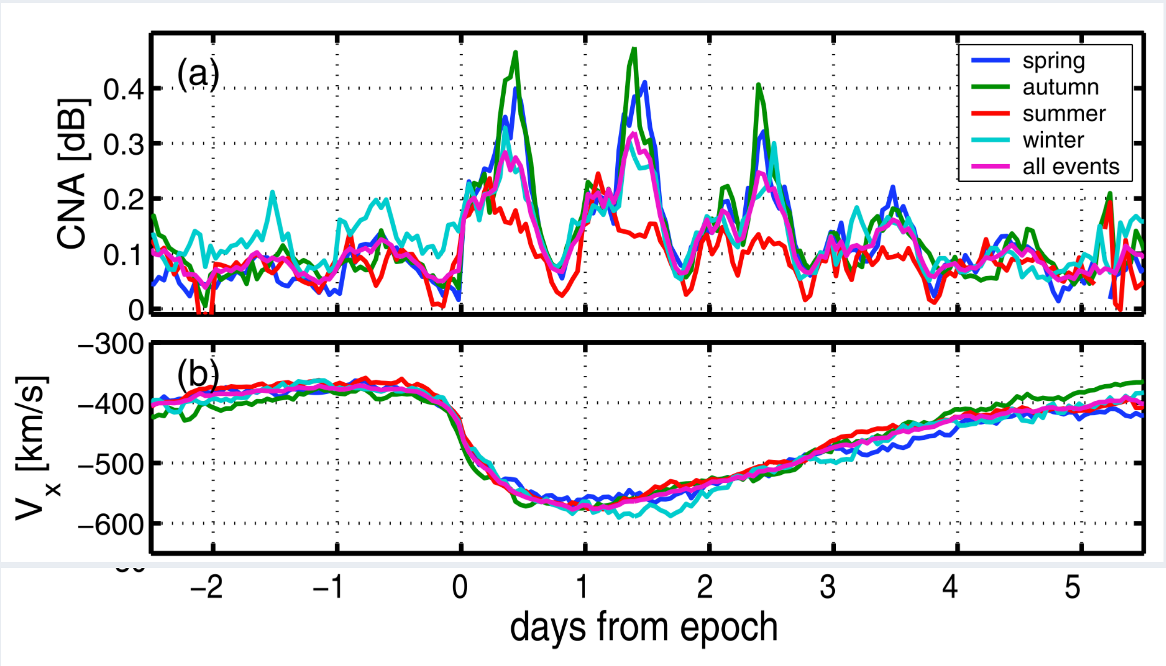
Horne et al., 2009

EEP increases electron densities in the mesosphere : e.g. seen by EISCAT incoherent scatter radar, Tromsö, cgm 66°N



Unfortunately, EISCAT cannot measure the low electron densities (Ne $<10^9$ m^{-3}) at low heights which are the result of the most energetic EEP

EEP leads to changes in cosmic noise absorption (CNA) by the ionosphere



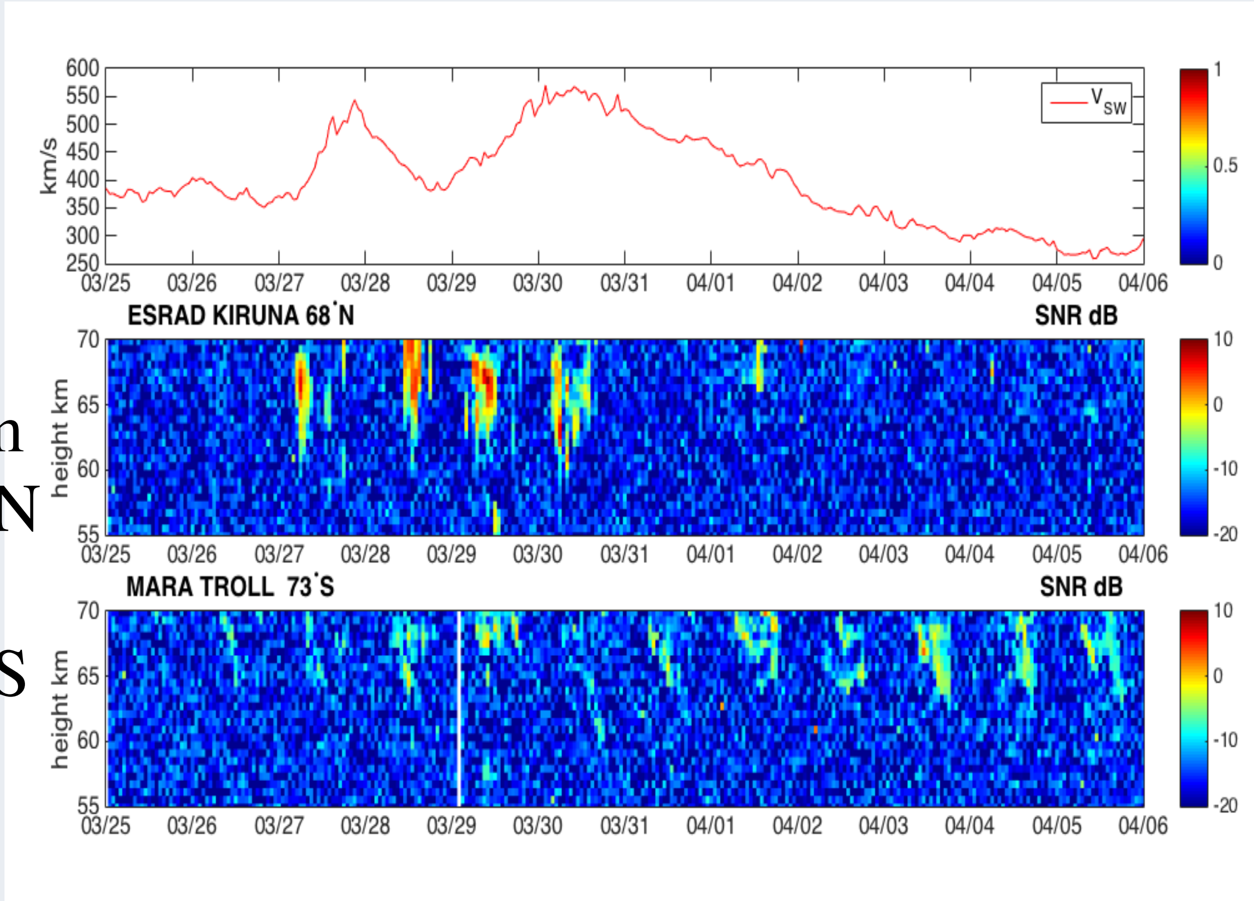
CNA measures height-integrated effects and cannot tell us the height distribution of the EEP effects

Superposed epoch analysis for HSS by Kavanagh et al., 2012

EEP causes strong VHF radar echoes ("PMWE") from the mesosphere (in both hemispheres, lasting several days)

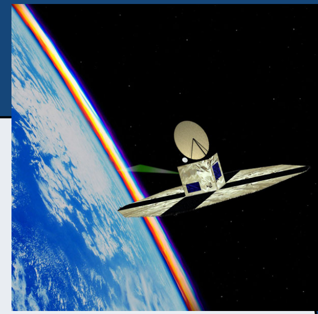
cgm
65 N

63 S



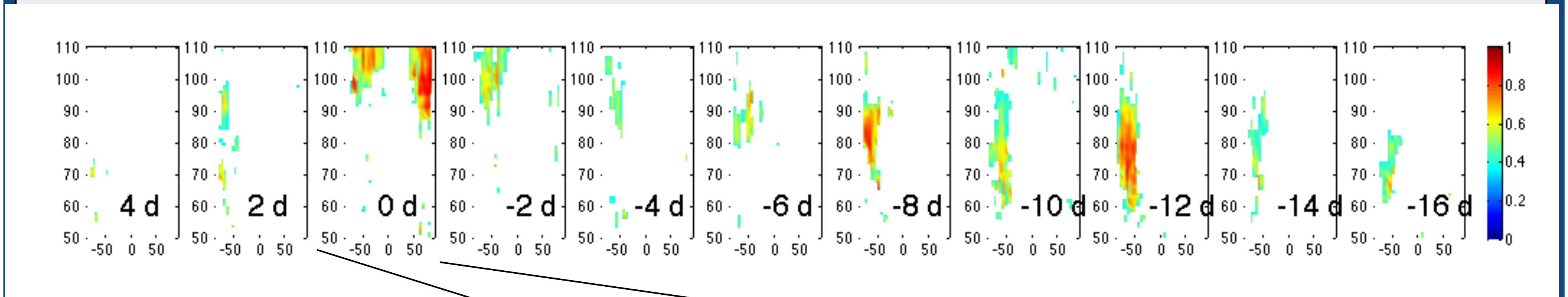
VHF radar echoes show effects of EEP down to 53 km but cannot be used to quantify the ionisation rates

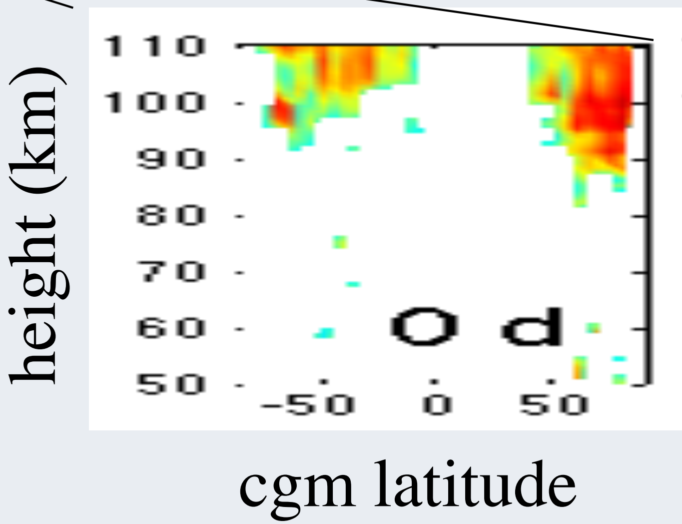
Kirkwood et al, 2015b



EEP leads to enhanced NO_x in the mesosphere

e.g. seen in a correlation between Odin-SMR NO and solar-wind speed in southern hemisphere winter (lagged +4 to -16 days)





ODIN-SMR NO amounts are very small and close to detection thresholds. Transport or direct production ?

To quantify the HSS-EEP NOx / Ne production in the polar mesosphere we need a model :

ionisation sources :

- energetic electrons (EEP)
- (energetic protons – not used here)
- solar X-ray, EUV, Lyman alpha
- cosmic rays, nightglow

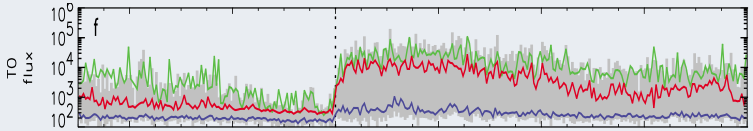
major neutrals : MSIS, background NO : Odin-SMR

estimated NO production rate = 1.25 x ion production rate

for Ne, simplified ion chemistry:

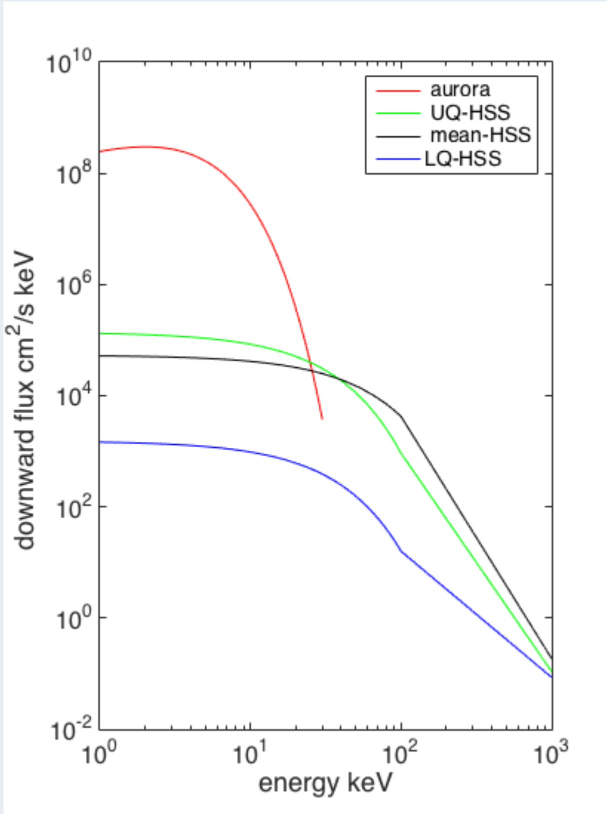
- minor neutrals : models (O, O_3, H_2O)
- 2 molecular ions
- 4 cluster ions
- 2 negative ions (ref Osepian, Kirkwood etc 1995-2015)

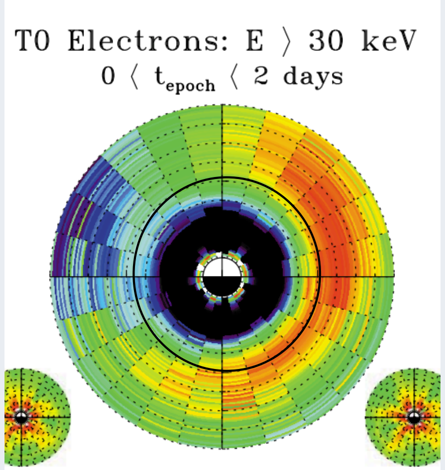
EEP flux-energy spectra based on statistical studies



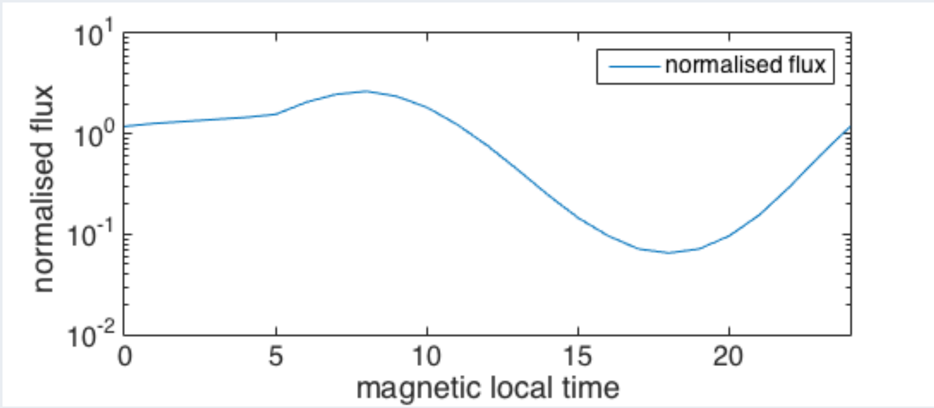
Meredith et al., JGR, 2011

exponential with
power-law tail

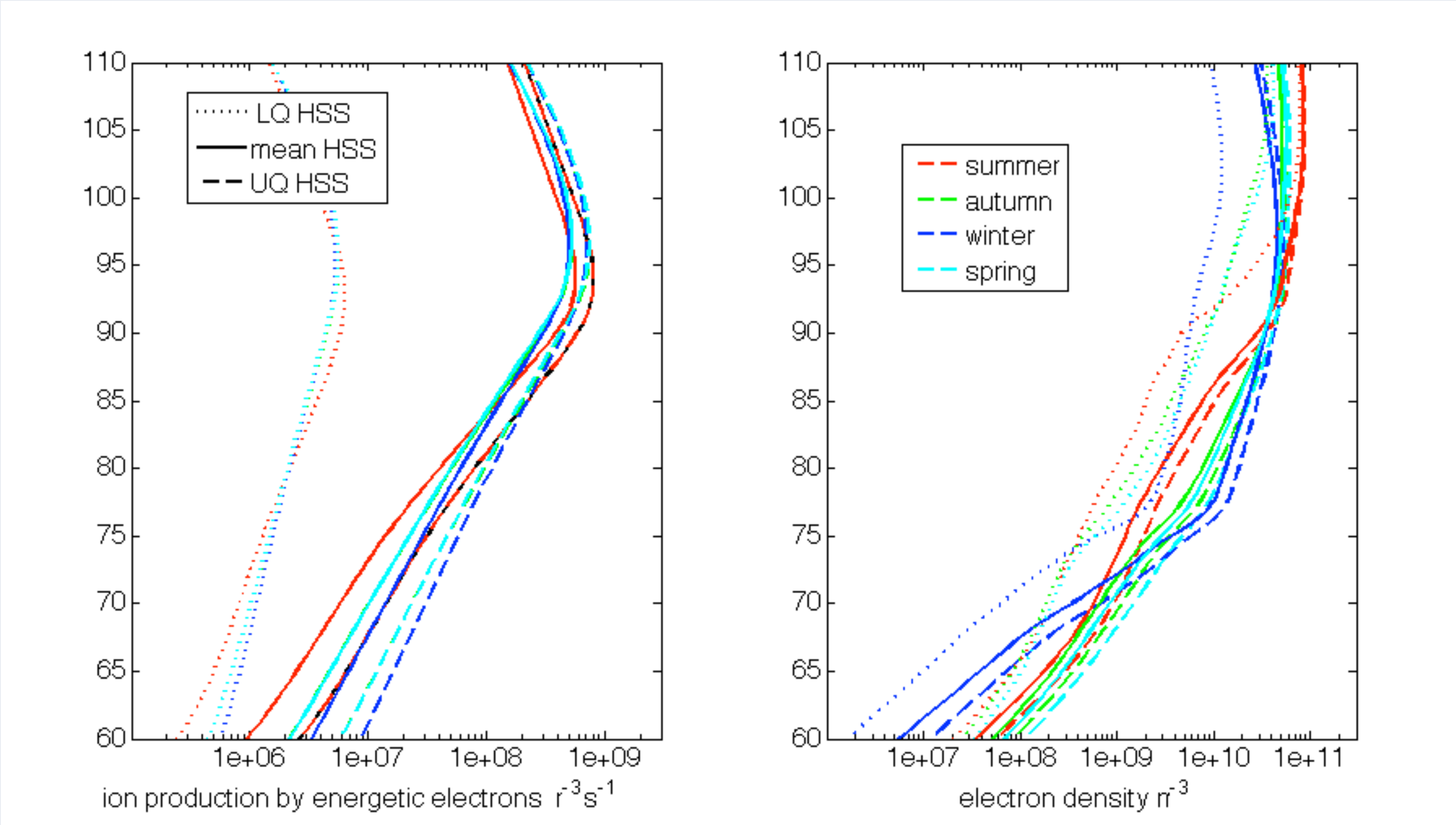




Meredith et al., 2011

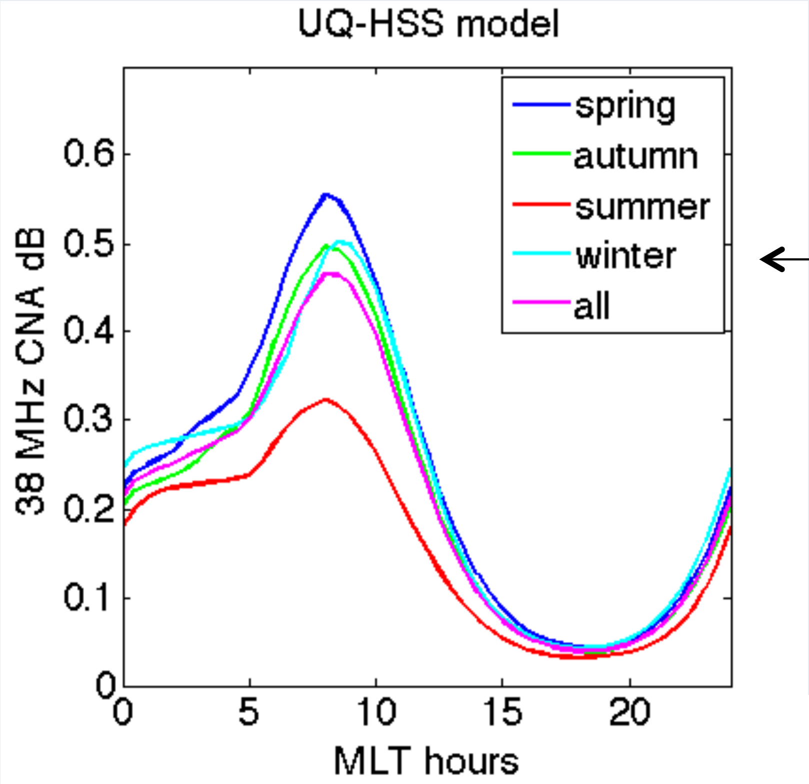


Model results :
ion (and NO) production rate and electron density profiles



model : $q_{NO} = 1.25\ q_{ion}$

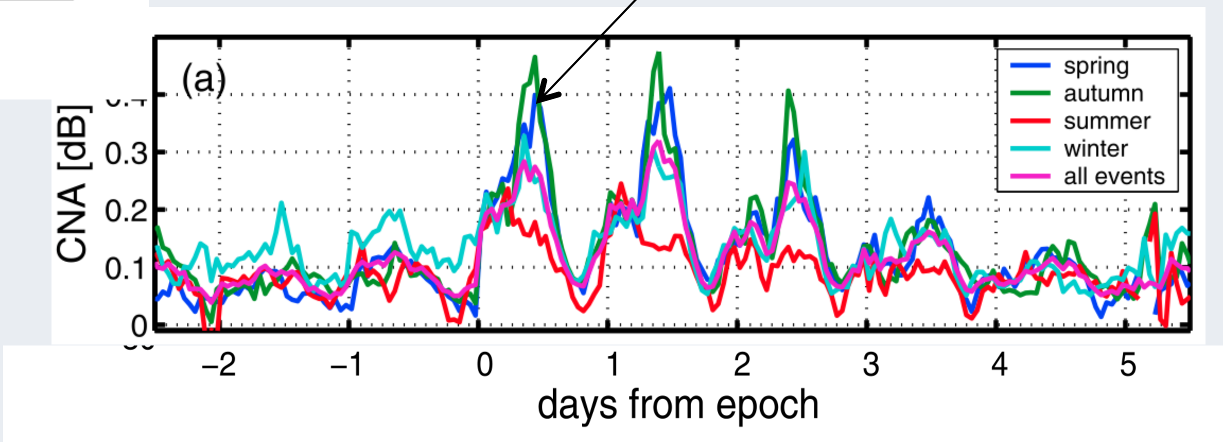
Kirkwood et al., 2015a



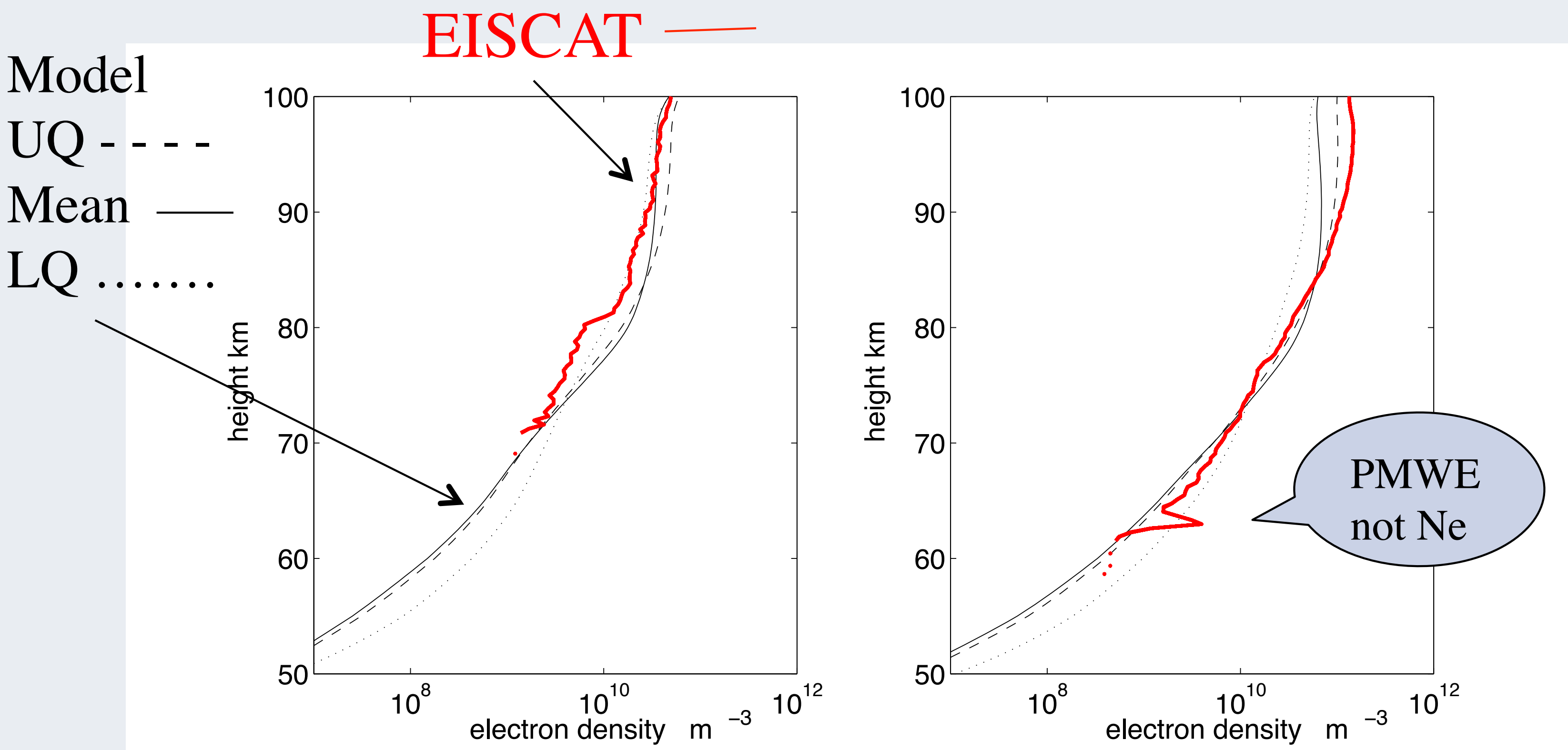
First test of the model :

Model CNA

Observed CNA
(Kavanagh et al., 2012)

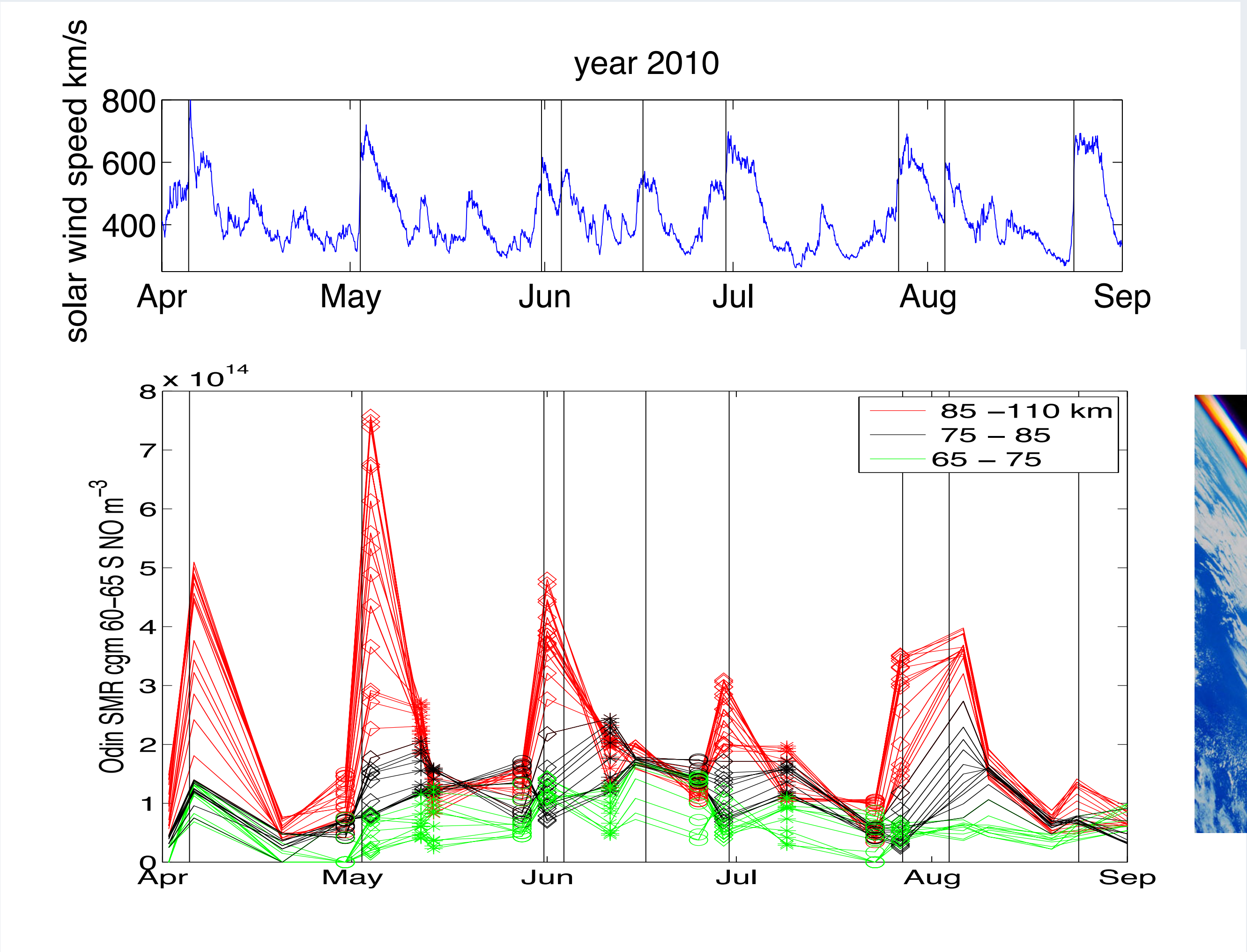


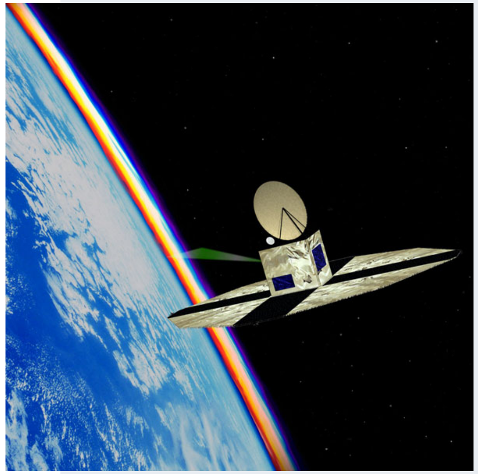
Second test of model :
Model fluxes scaled to fit observed instantaneous CNA
Profile shape compared with EISCAT



Kirkwood et al., 2015b

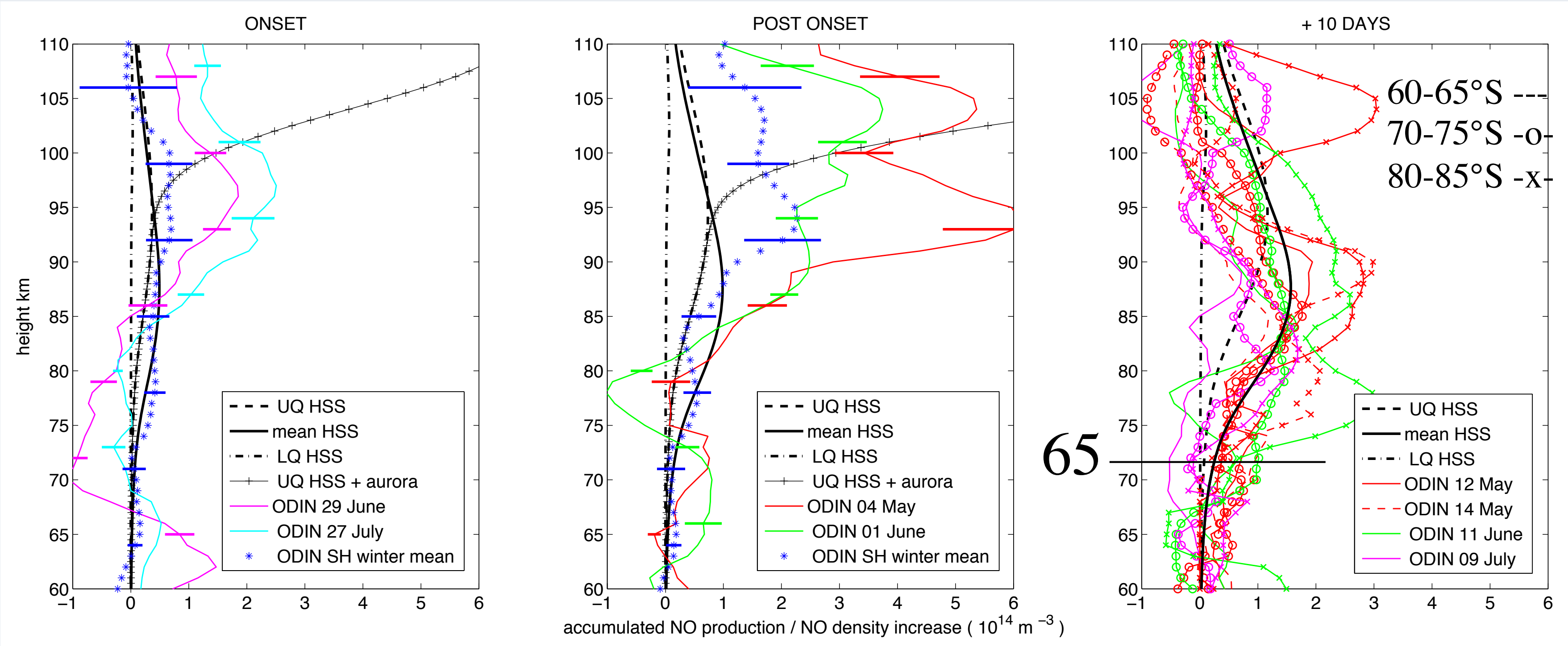
Test case : NO enhancements in the mesosphere cgm 60-65 ° S, following HSS, observed by ODIN-SMR





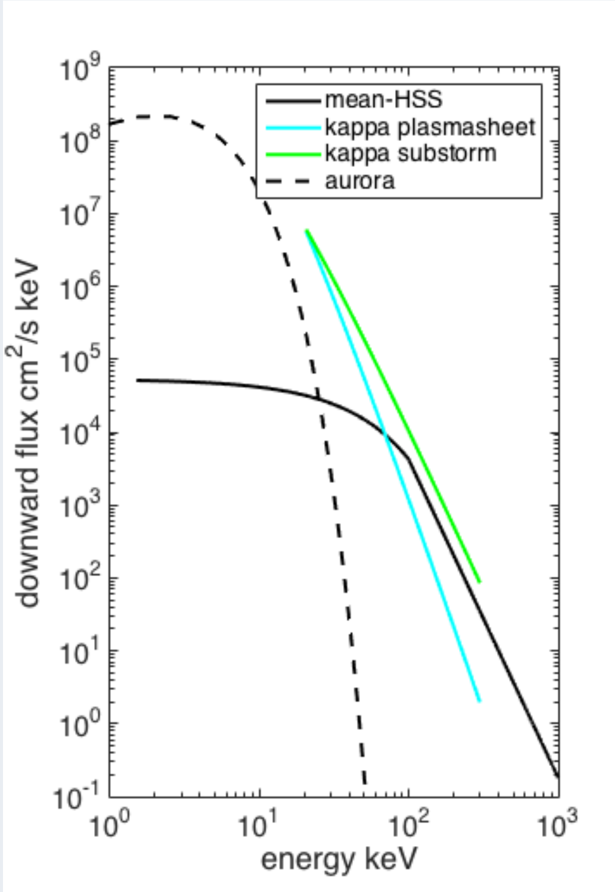
Comparison ODIN-SMR NO observed increase with model NO accumulated production

(+ very simple horizontal transport)

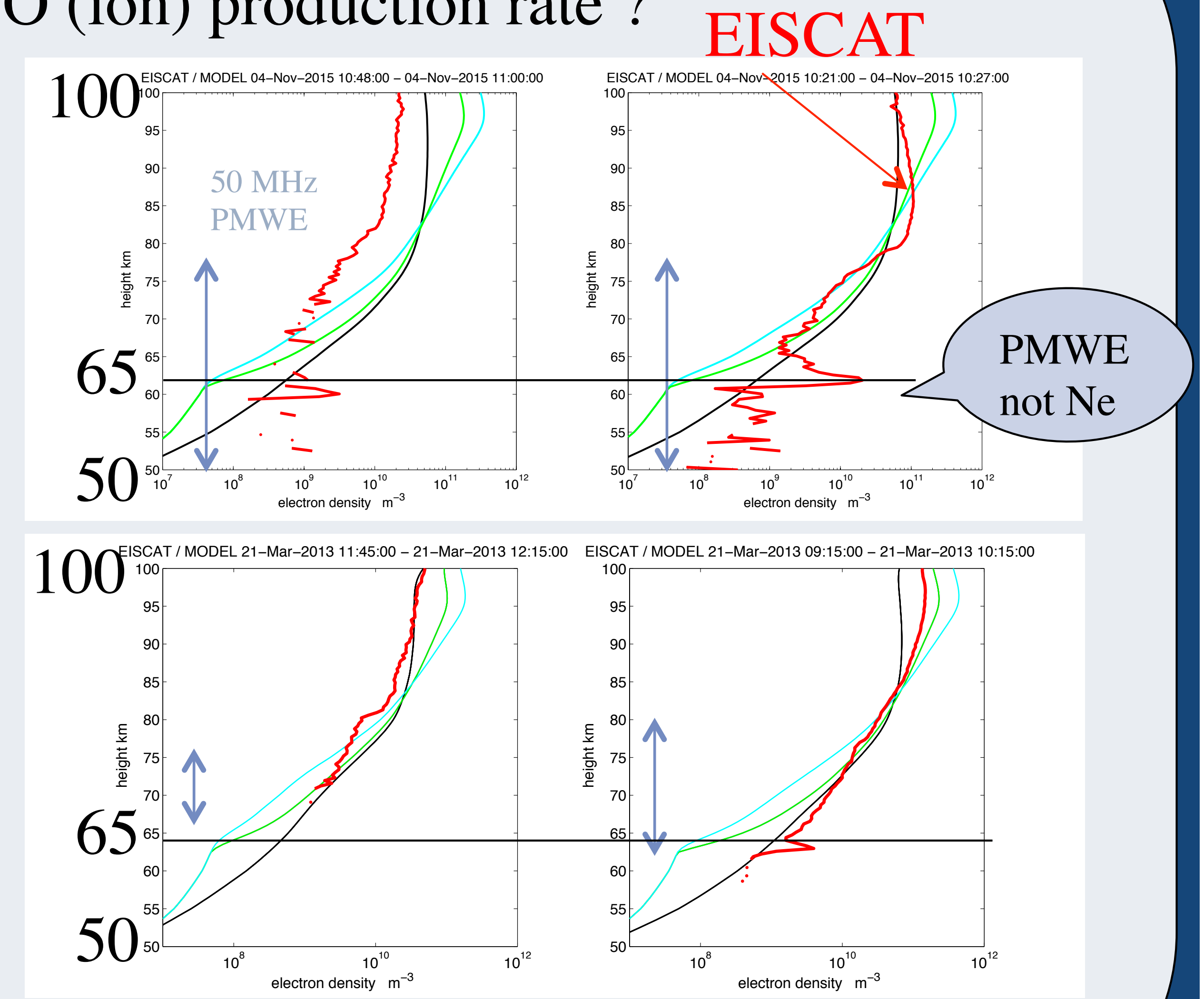


Kirkwood et al., Ann. Geophys. 2015a

Does this model overestimate mesospheric NO (ion) production rate ?

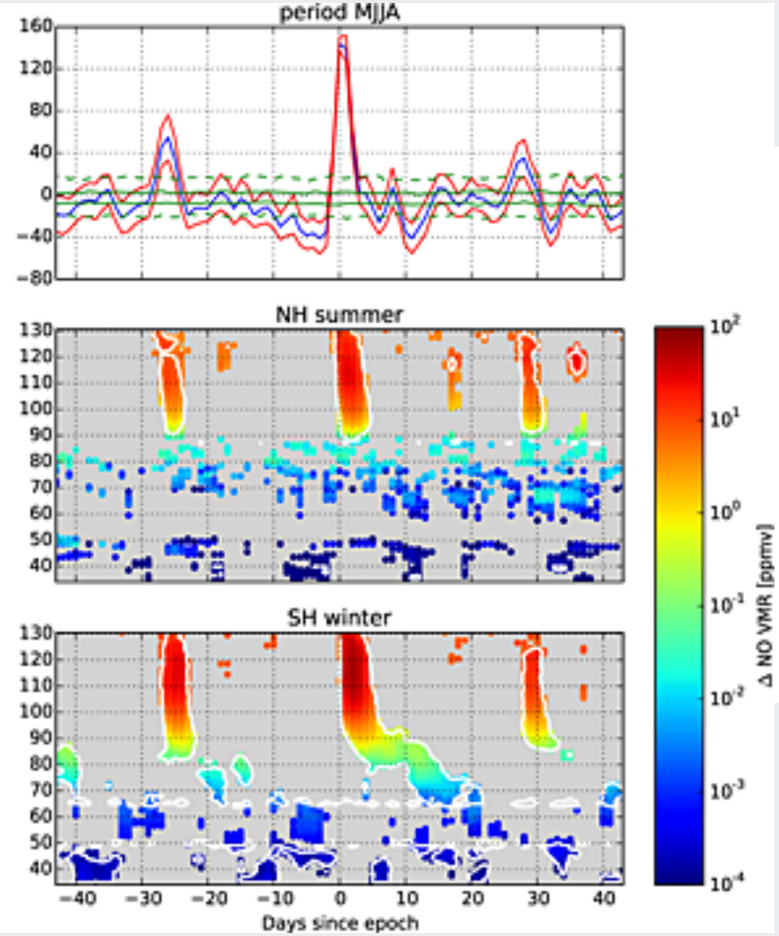


kappa models following Beharrell et al., 2015

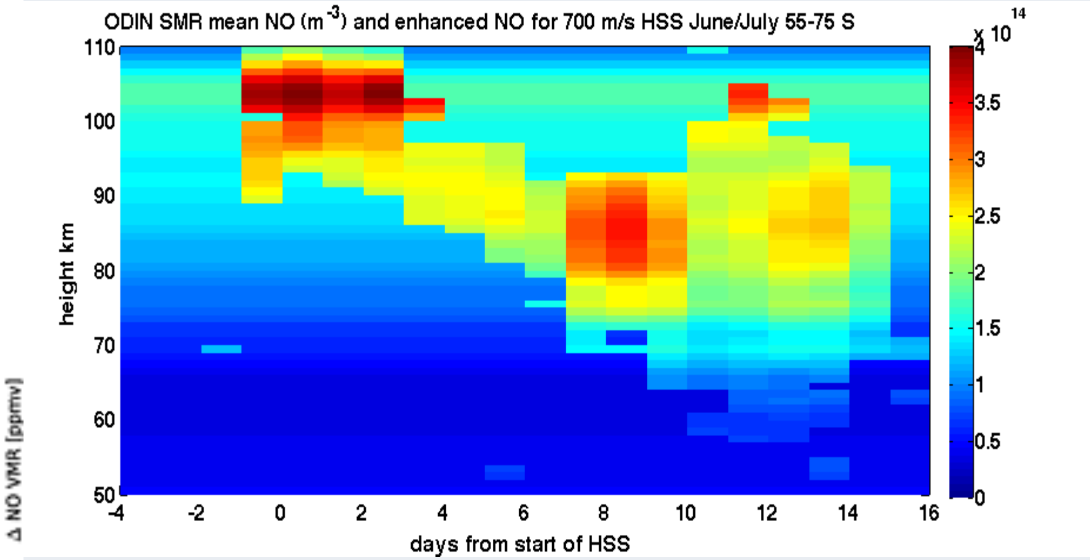


Does the pattern of NO increase suggests downward transport ?

AIM-SOFIE / AE-index



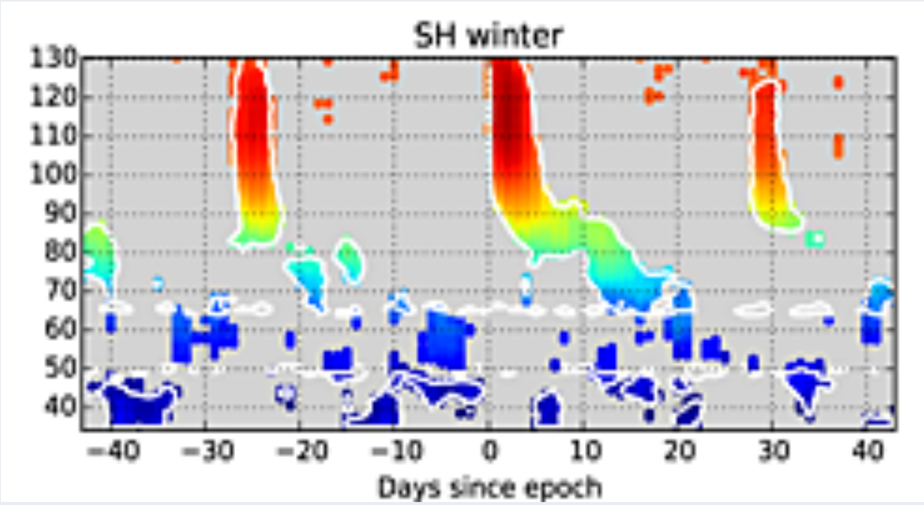
ODIN-SMR / HSS
SH winter



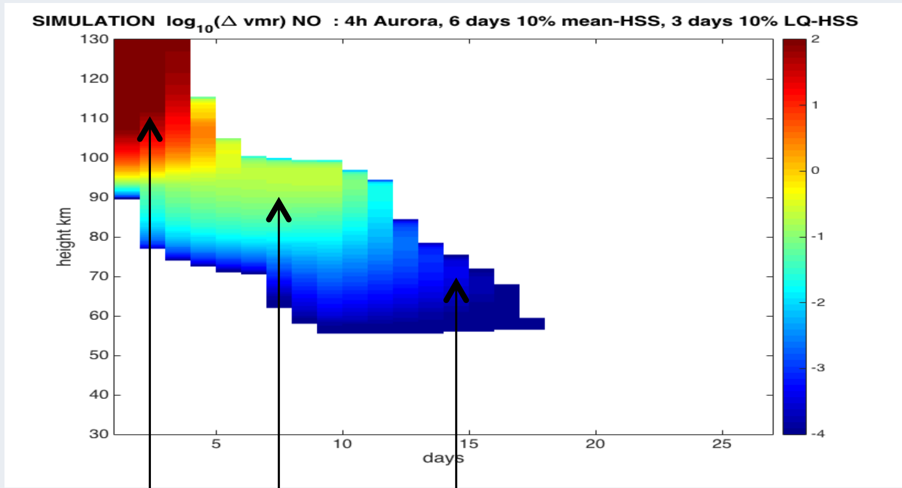
Hendrickx et al., J. G. R., 2015

Not neccessarily– the same pattern can result from increasing spectral hardness with time and increasing NO lifetime towards lower altitudes

AIM-SOFIE



Model log(ΔVMR)– no transport



4h Aurora

10% mean-HSS

10% LQ-HSS

Conclusions

- Effects of EEP in the mesosphere following the arrival of HSS are clear in many observed parameters – CNA, electron density profiles, VHF radar echoes (PMWE), enhancements of NO concentration – and can be detected for several days after the arrival.

- A model using statistical HSS-related EEP fluxes as input can quantitatively explain observed CNA, electron density and NO enhancements above ~ 65 km height, and qualitatively explain PMWE appearance down to ~ 53 km height.

- Apparent signatures of vertical transport in NO, can be reproduced, without transport, by hardening of the energy spectrum of EEP over several days, coupled with height-dependent NO lifetimes.