HAARP-Induced Artificial Ionospheric Ducts

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Motivations

- Naturally induced field aligned irregularities of the plasma density exhibit enhanced refractive indices and act as ducts that guide waves in the whistler range between the two hemispheres.

- HF heating of the ionosphere creates density perturbations that may propagate into the plasmasphere, thus produce artificial ducts.

Objectives

- **To present the observations of the density perturbations caused by the HF-heating of the ionosphere by HAARP and detected by Demeter and DMSP satellites.**

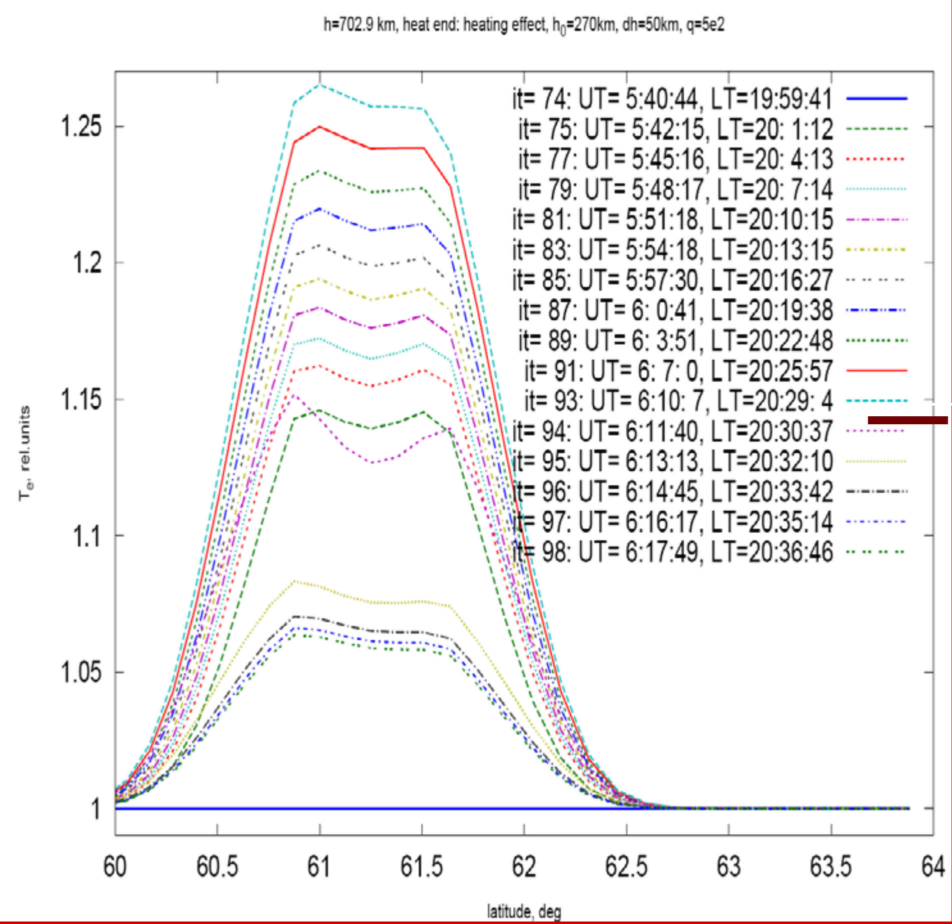
- **To check the observations against a model of the artificial ducts due to HF-heating of the ionosphere.**

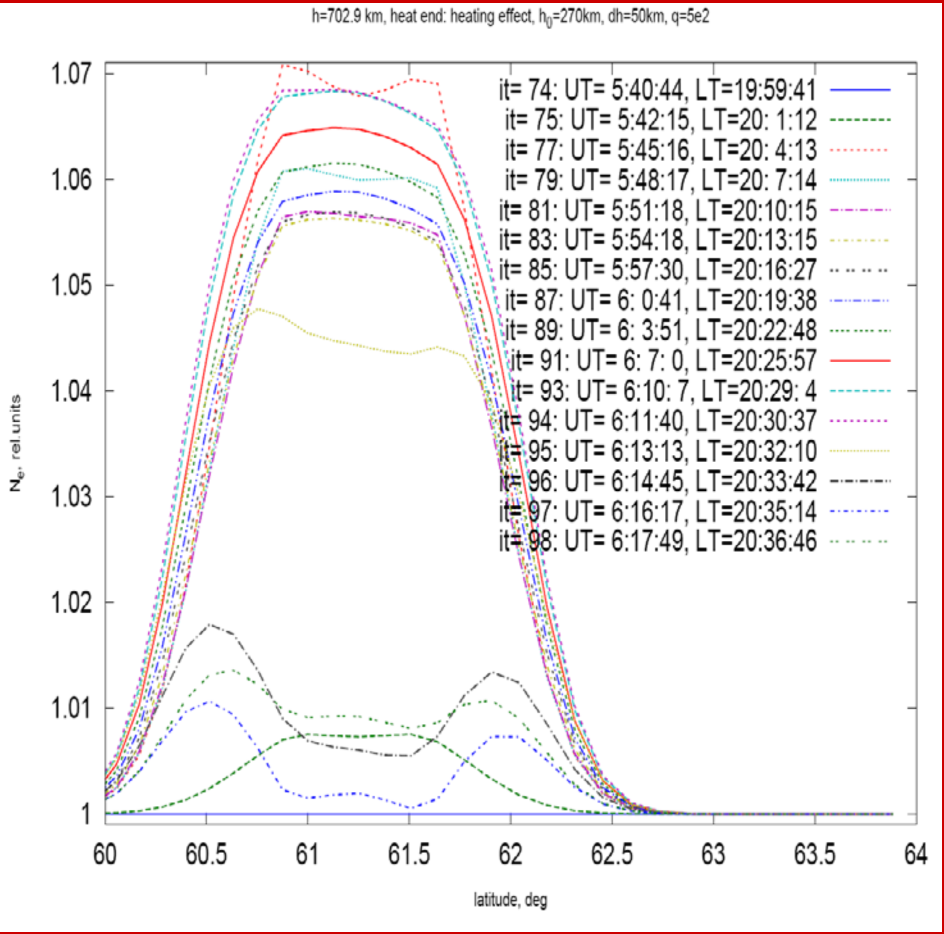
The model of artificial ducts in the ionosphere

- It is based on the SAMI2 model of the ionosphere [Huba, et al., 2000] which describes evolution of the ionospheric plasma confined by a bunch of the geomagnetic field lines.
- We use the latest version of the code (release 0.99) which describes high latitudes, and includes effects from ExB drift.
- The SAMI2 model was modified, namely a flexible local source of the electron HF-heating was introduced in the form of the localized heating rate per electron:

$$q = \mu P / V n_e \approx 2\times 10^4 \mu \,(K/s)$$

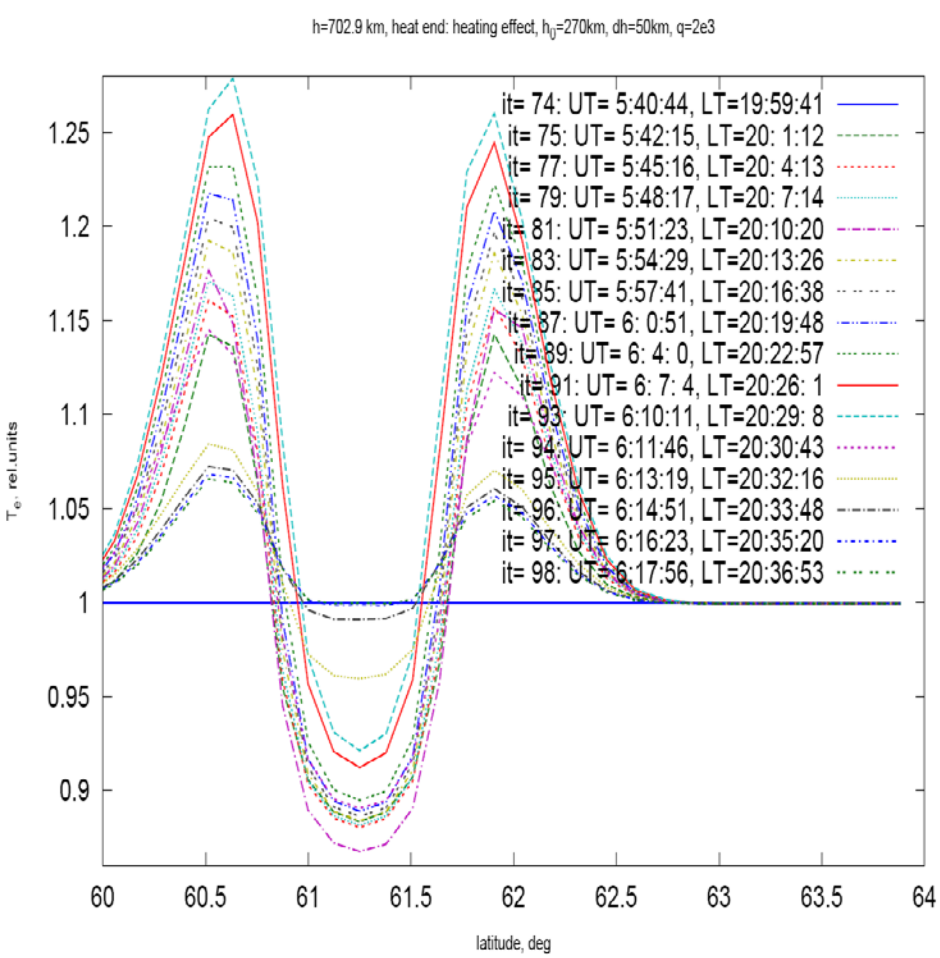
Model of HF-heating effects due to HAARP

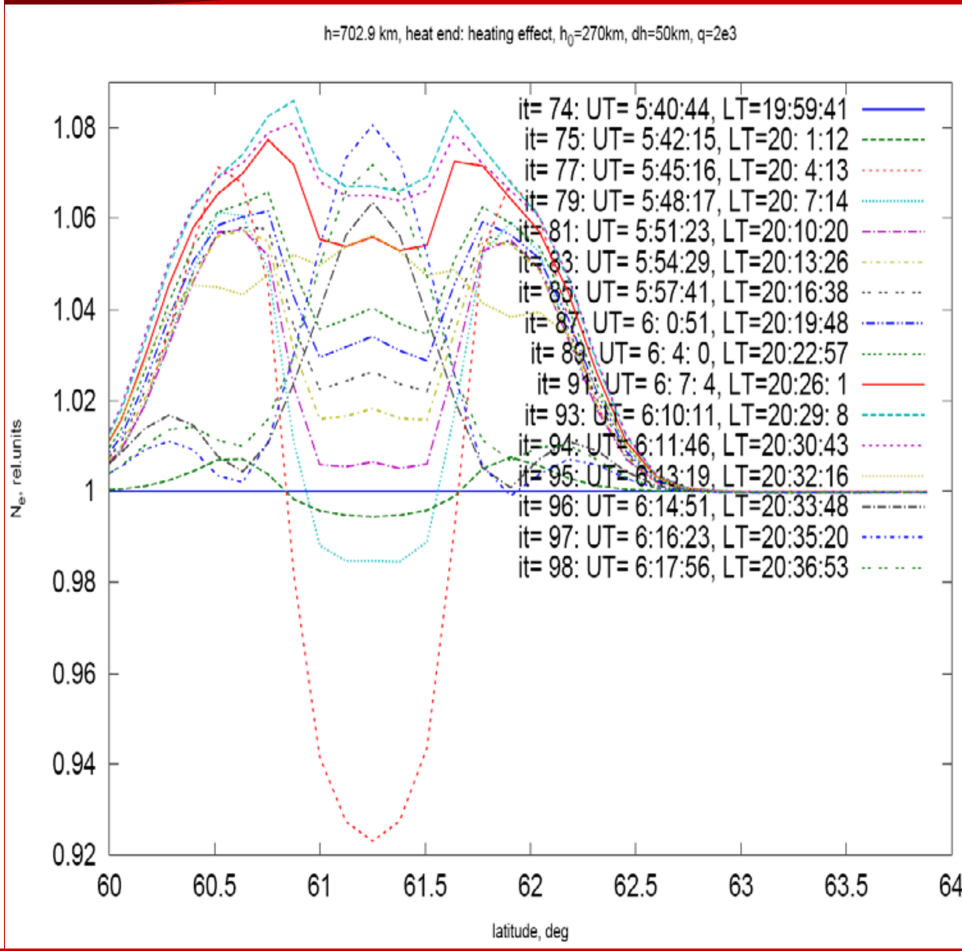




Variations of the electron temperature & density along the DEMETER orbit at 700 km. The “HF-heating” was conducted during 20:00 – 20:30 LT (drift is not included).

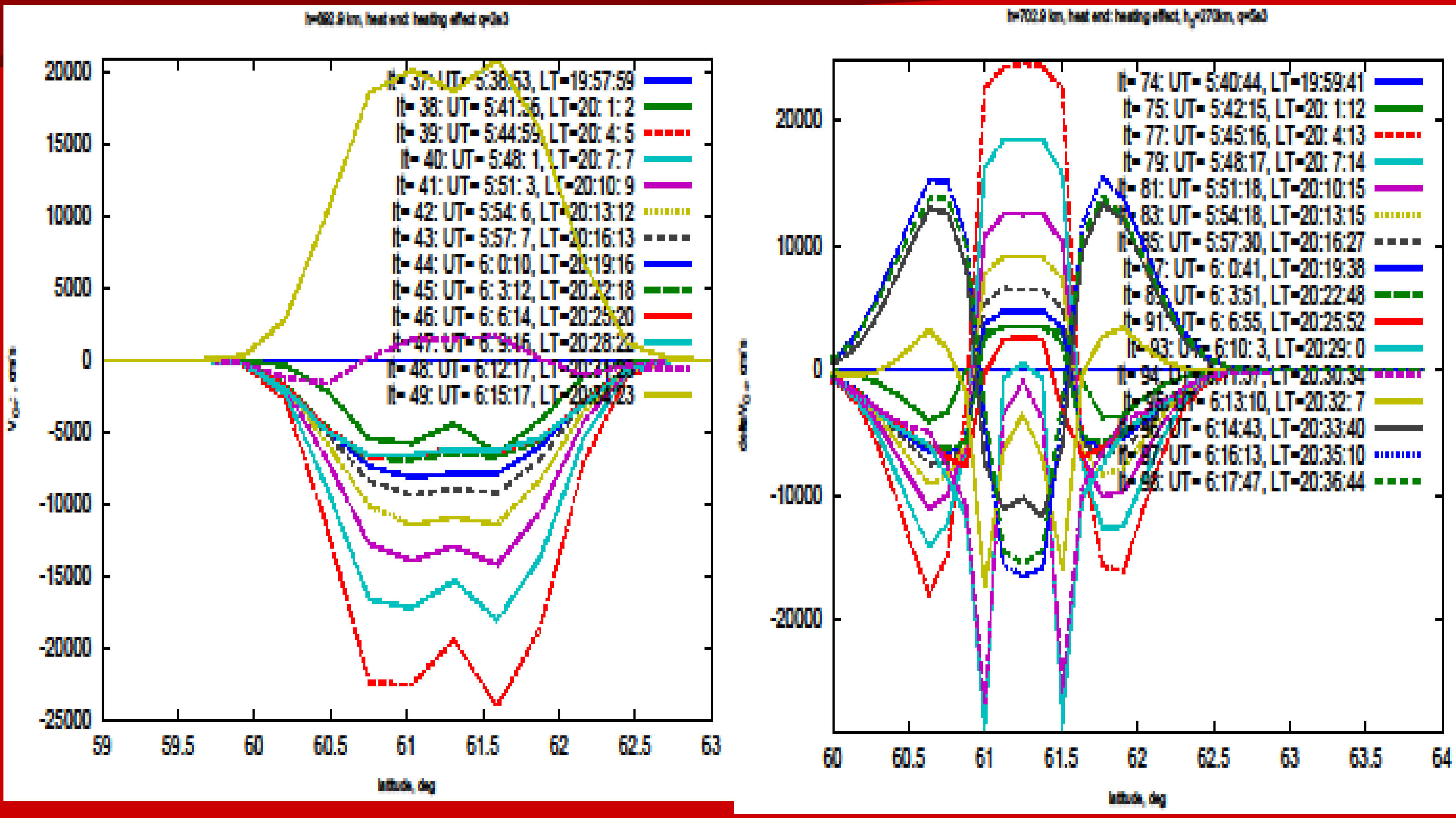
Model of HF-heating effects due to HAARP





Variations of the electron temperature & density along the DEMETER orbit at 700 km. The “HF-heating” was conducted during 20:00 – 20:30 LT (drift is not included).

Model of HF-heating effects due to HAARP



Variations of the ion velocity along the DEMETER orbit. “HF-heating” was conducted during 20:00 – 20:30 LT (q=2e3 K/s and 5e3 K/s at the left and right panel).

Analysis of the Demeter Observations

• Demeter over-flies HAARP twice a day, at nighttime and daytime. The ionospheric ducts were detected only during the nighttime passes.

• Altogether about 20 observations of the ionospheric ducts were made.

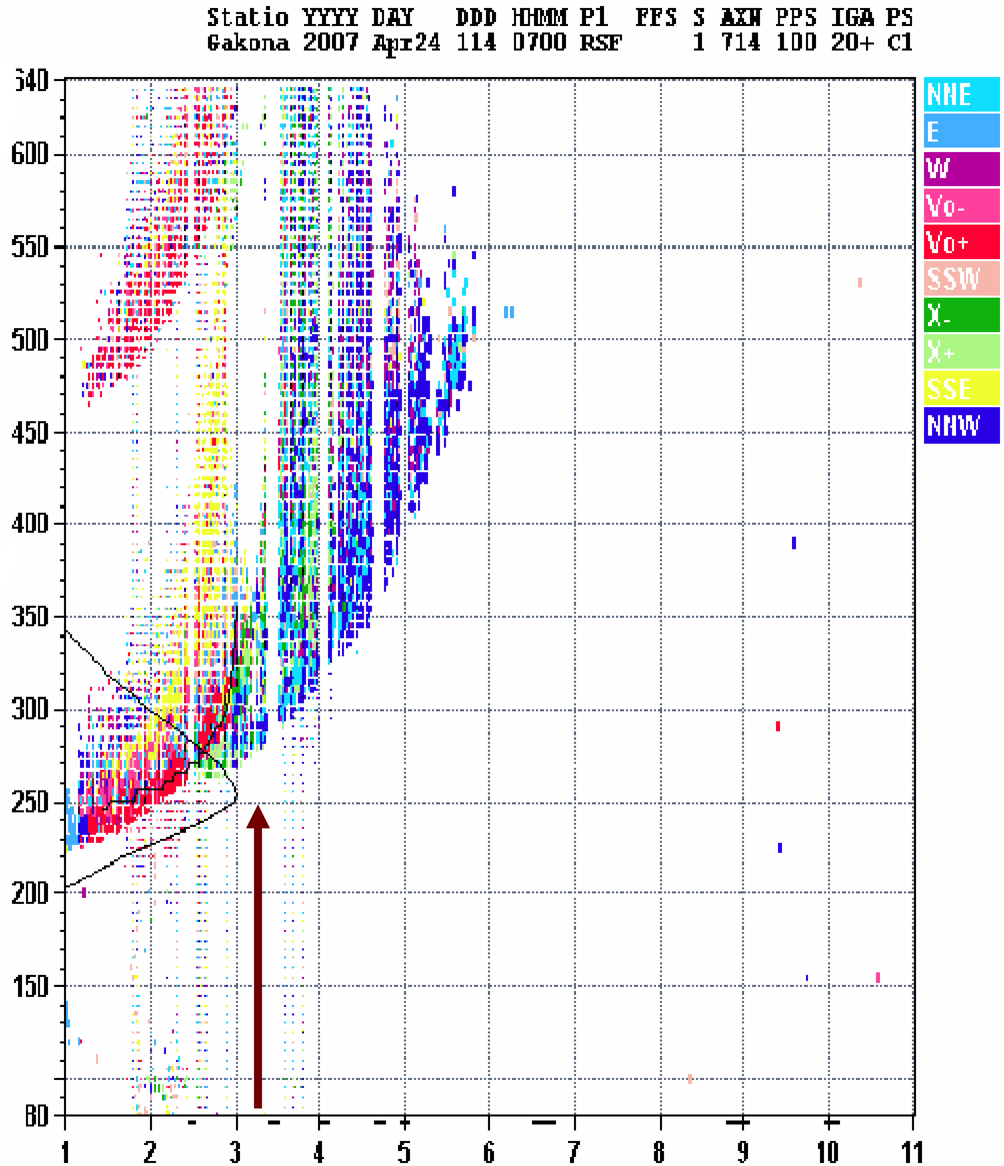
• We separate them into three group:

(a) Over-dense ionosphere $f < f_0 F_2$

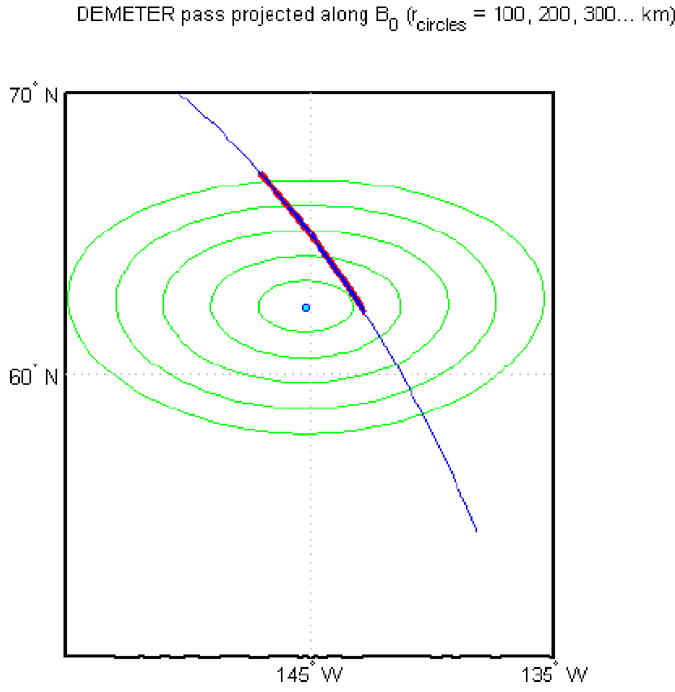
(b) Under-dense ionosphere $f > f_0 F_2$

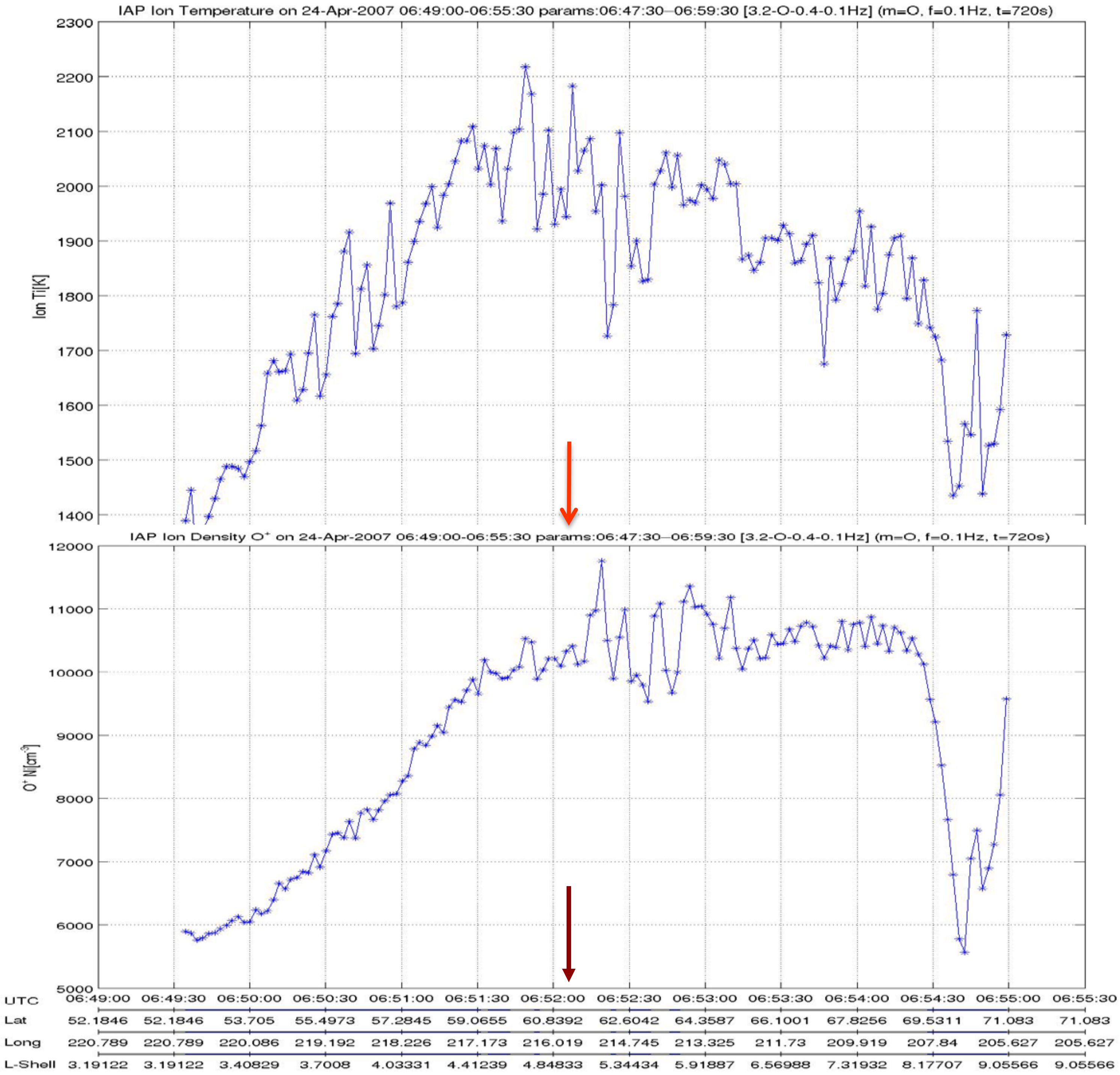
(c) A weak ionosphere $f_0 F_2$ is not available

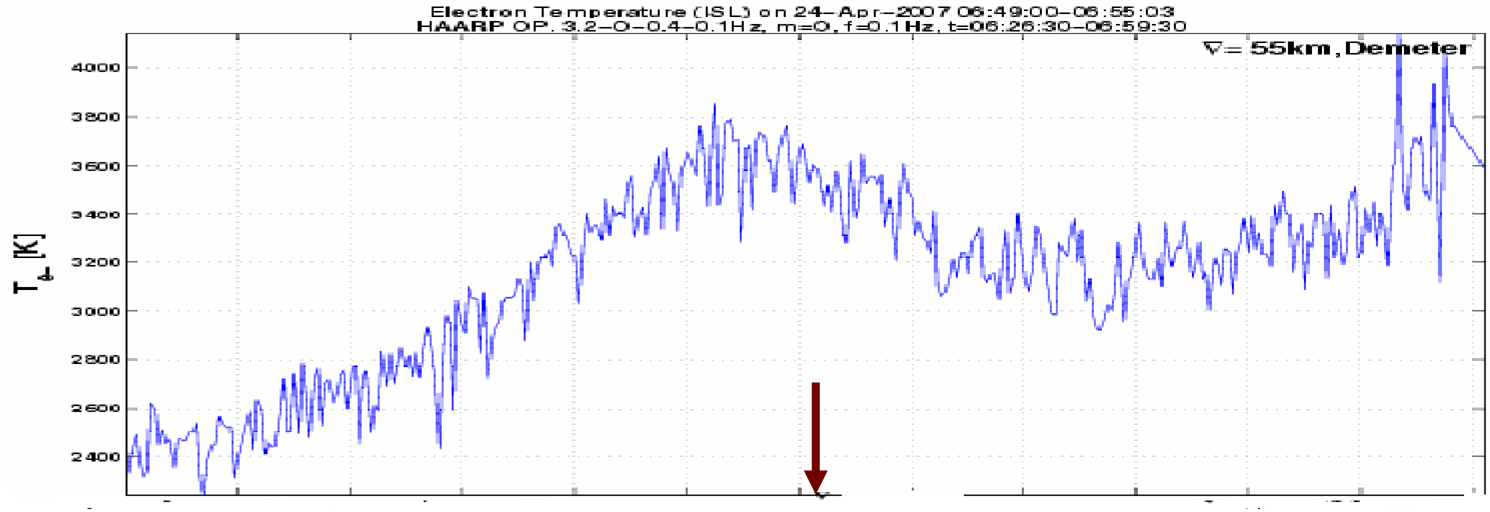
Three following DEMETER observations represent each of these groups

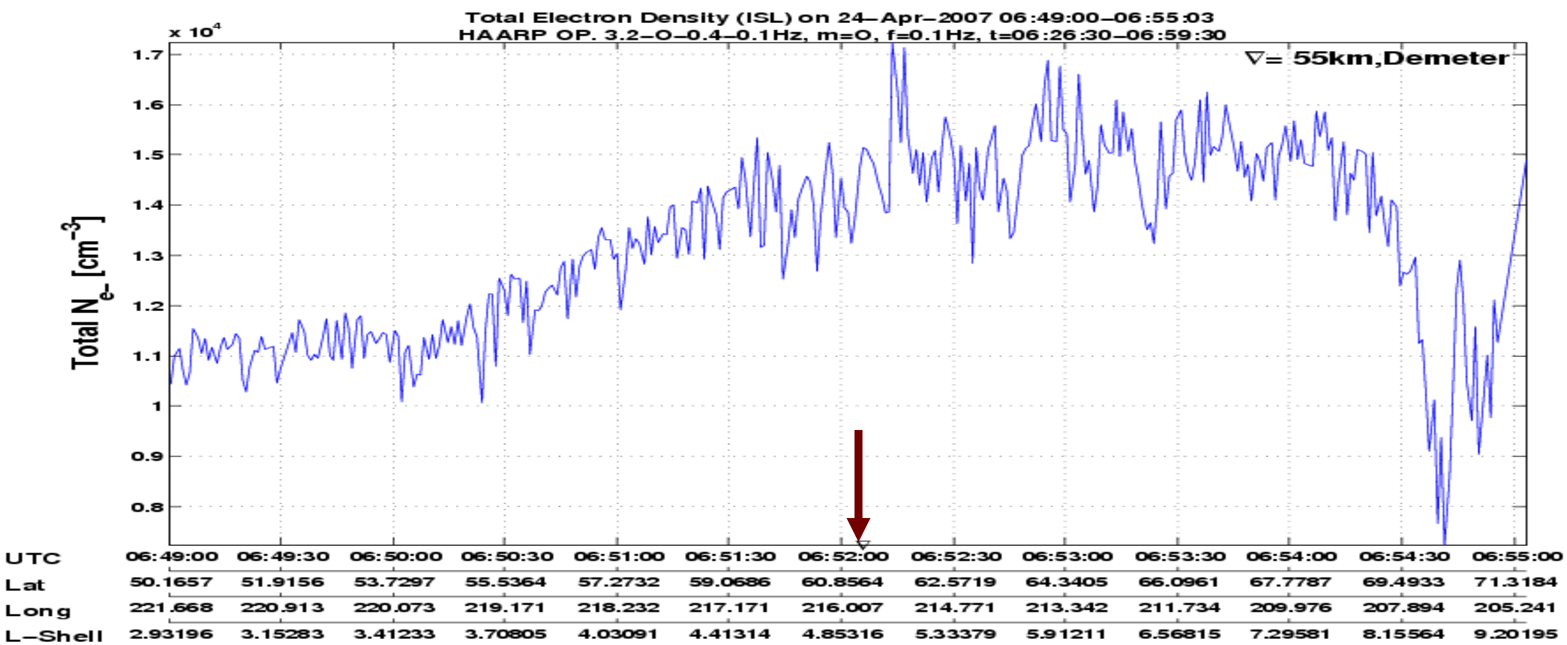


04/24/07
f=3.2 MHz
O-mode
0.1 Hz
Magn. Zen.
No electrojet

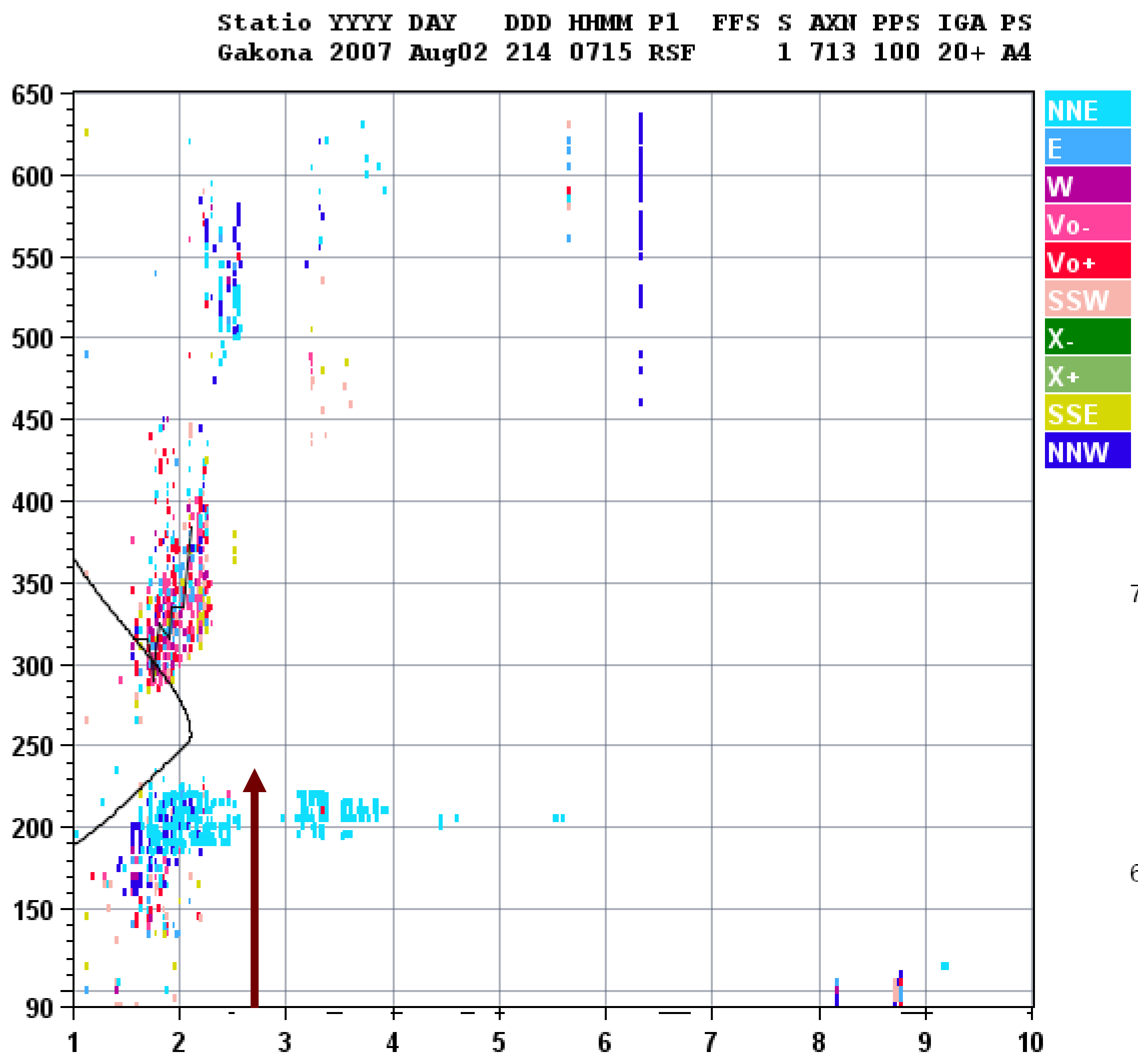


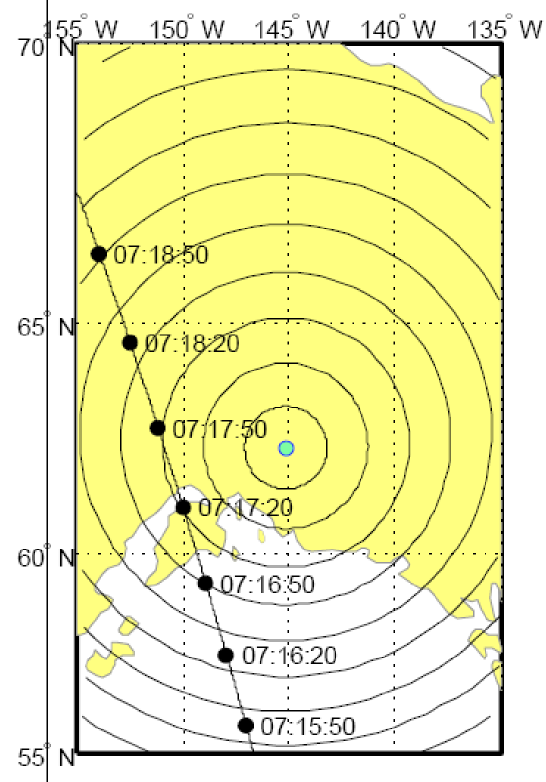

IAP Ion Temperature on 24-Apr-2007 06:49:00-06:55:30 params:06:47:30–06:59:30 [3.2-O-0.4-0.1Hz] (m=O, f=0.1Hz, t=720s)
Ion Ti[K]
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
IAP Ion Density O+ on 24-Apr-2007 06:49:00-06:55:30 params:06:47:30–06:59:30 [3.2-O-0.4-0.1Hz] (m=O, f=0.1Hz, t=720s)
O+ N[cm-3]
12000
11000
10000
9000
8000
7000
6000
5000
UTC 06:49:00 06:49:30 06:50:00 06:50:30 06:51:00 06:51:30 06:52:00 06:52:30 06:53:00 06:53:30 06:54:00 06:54:30 06:55:00 06:55:30
Lat 52.1846 52.1846 53.705 55.4973 57.2845 59.0655 60.8392 62.6042 64.3587 66.1001 67.8256 69.5311 71.083 71.083
Long 220.789 220.789 220.086 219.192 218.226 217.173 216.019 214.745 213.325 211.73 209.919 207.84 205.627 205.627
L-Shell 3.19122 3.19122 3.40829 3.7008 4.03331 4.41239 4.84833 5.34434 5.91887 6.56988 7.31932 8.17707 9.05566 9.05566

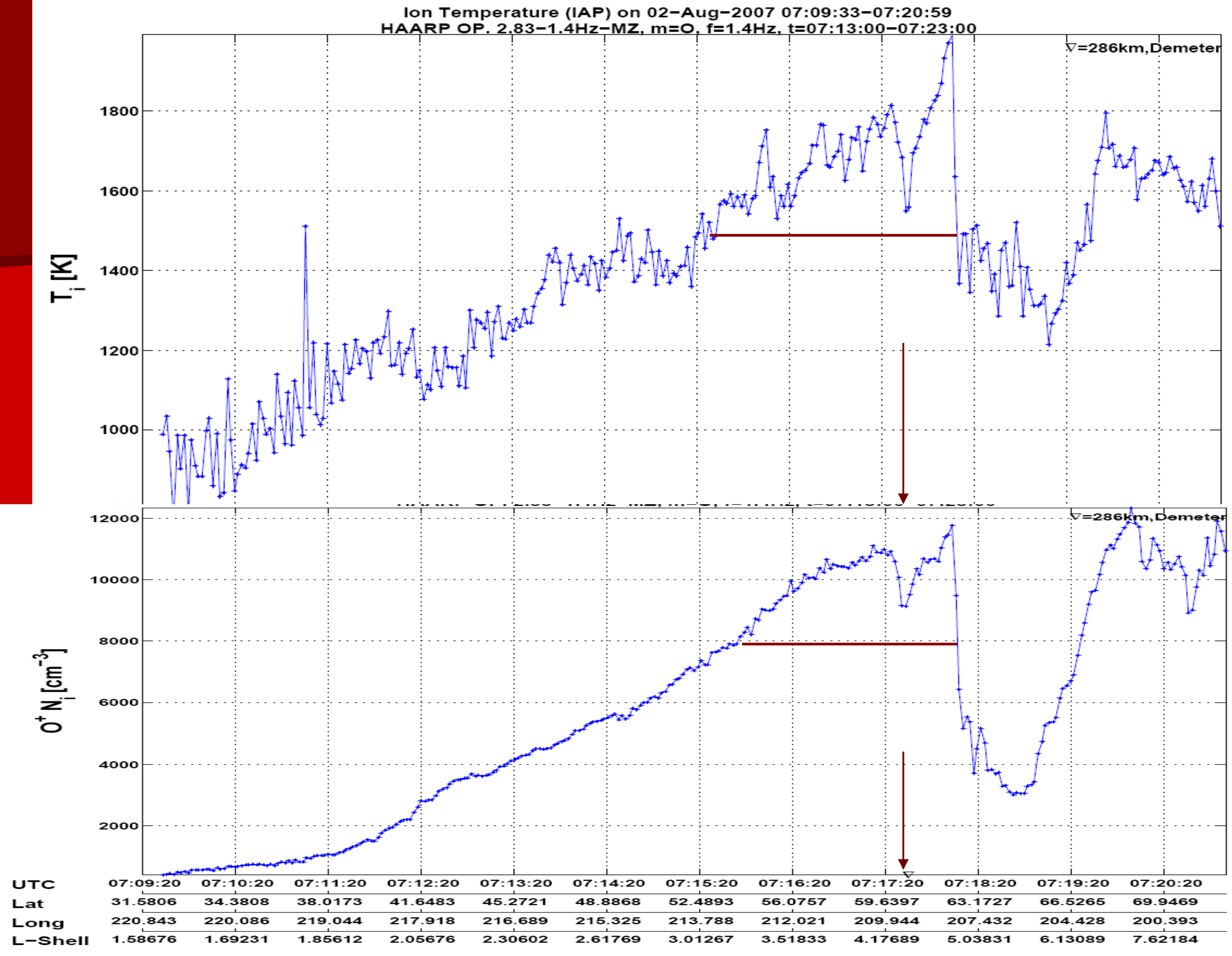

Electron Temperature (ISL) on 24-Apr-2007 06:49:00-06:55:03
HAARP OP. 3.2-O-0.4-0.1Hz, m=0, f=0.1Hz, t=06:26:30-06:59:30
∇= 55km,Demeter
T⊥ [K]
4000
3800
3600
3400
3200
3000
2800
2600
2400


Total Electron Density (ISL) on 24-Apr-2007 06:49:00-06:55:03
HAARP OP. 3.2-O-0.4-0.1Hz, m=0, f=0.1Hz, t=06:26:30-06:59:30
x 10^4
∇= 55km,Demeter
Total Ne- [cm-3]
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
UTC 06:49:00 06:49:30 06:50:00 06:50:30 06:51:00 06:51:30 06:52:00 06:52:30 06:53:00 06:53:30 06:54:00 06:54:30 06:55:00
Lat 50.1657 51.9156 53.7297 55.5364 57.2732 59.0686 60.8564 62.5719 64.3405 66.0961 67.7787 69.4933 71.3184
Long 221.668 220.913 220.073 219.171 218.232 217.171 216.007 214.771 213.342 211.734 209.976 207.894 205.241
L-Shell 2.93196 3.15283 3.41233 3.70805 4.03091 4.41314 4.85316 5.33379 5.91211 6.56815 7.29581 8.15564 9.20195

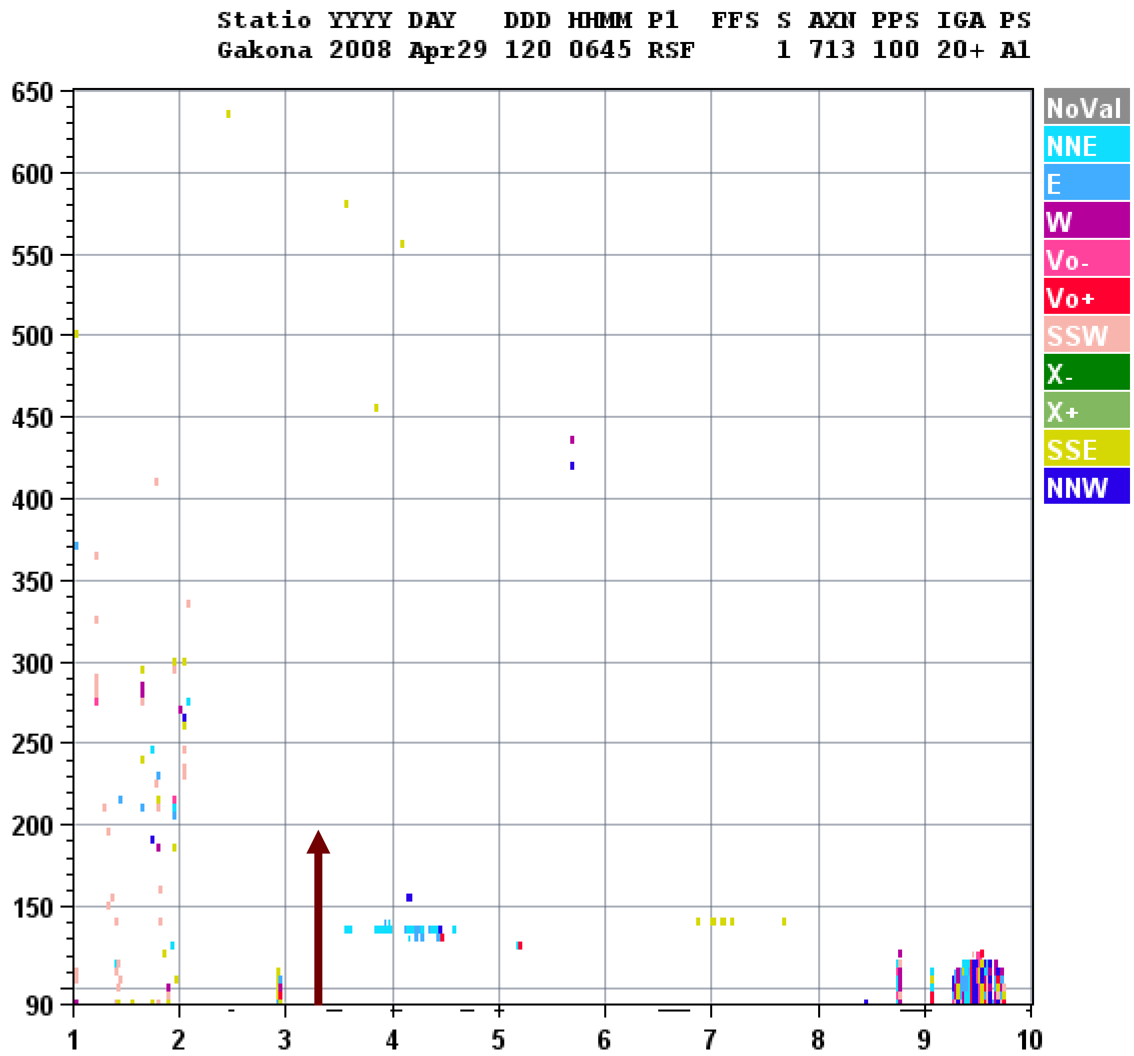
08/02/07
F=2.83MHz
O-mode
1.4 Hz
Mag. Zen.

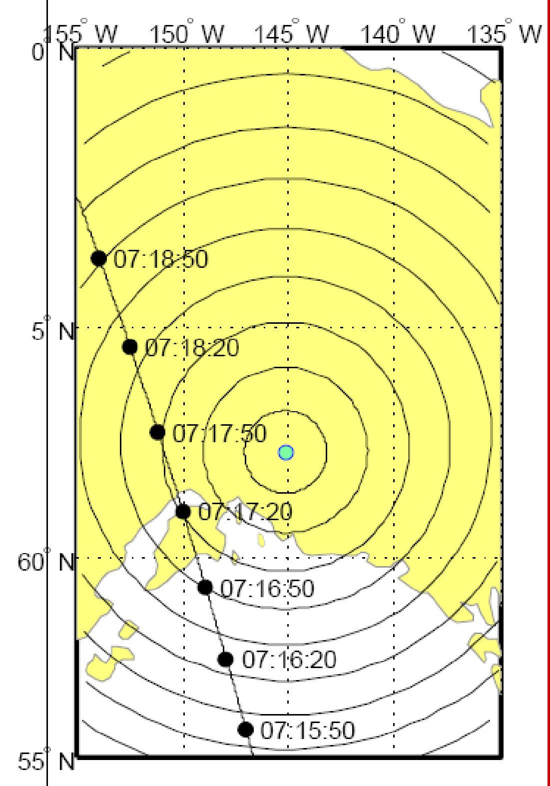


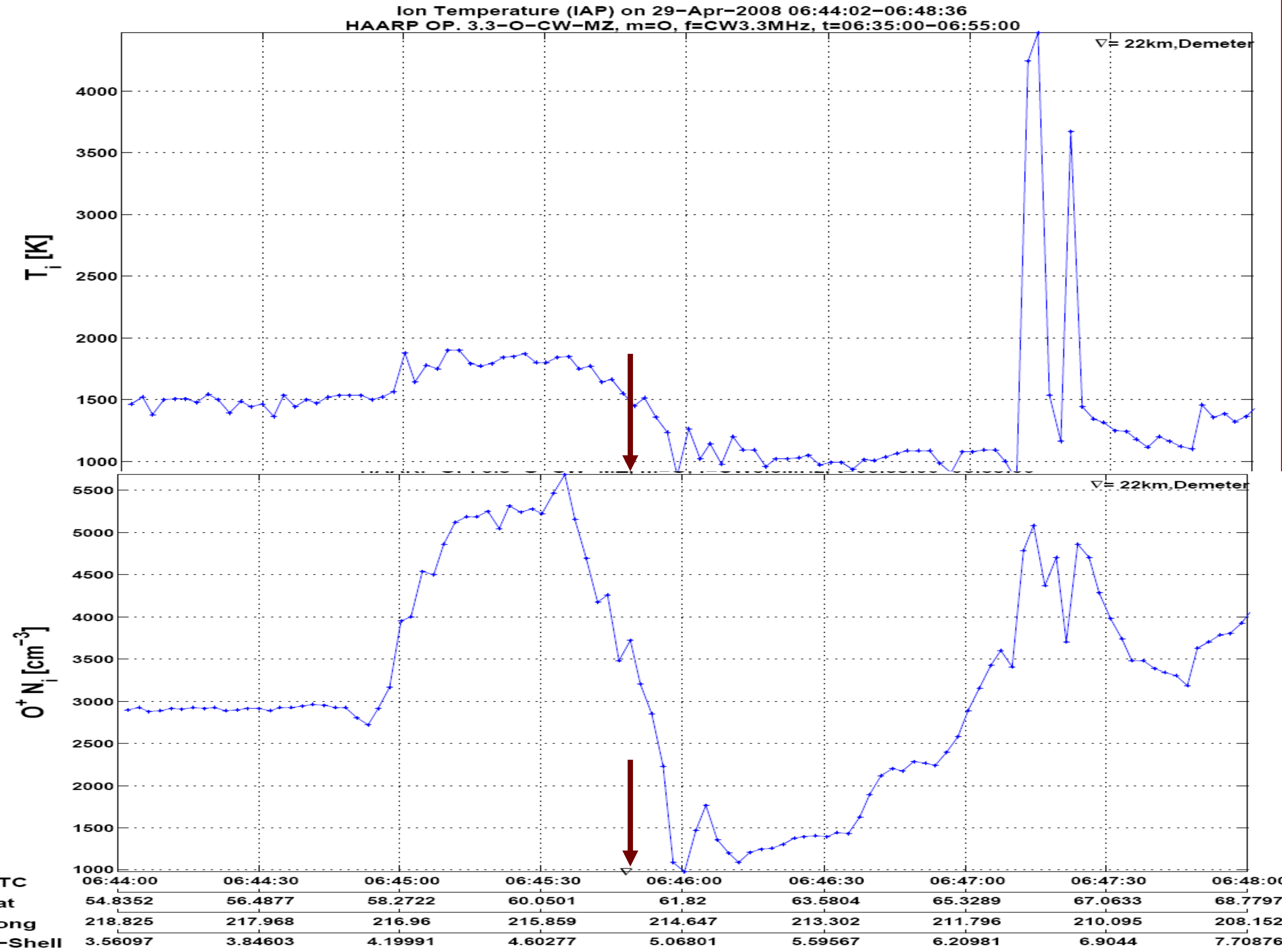


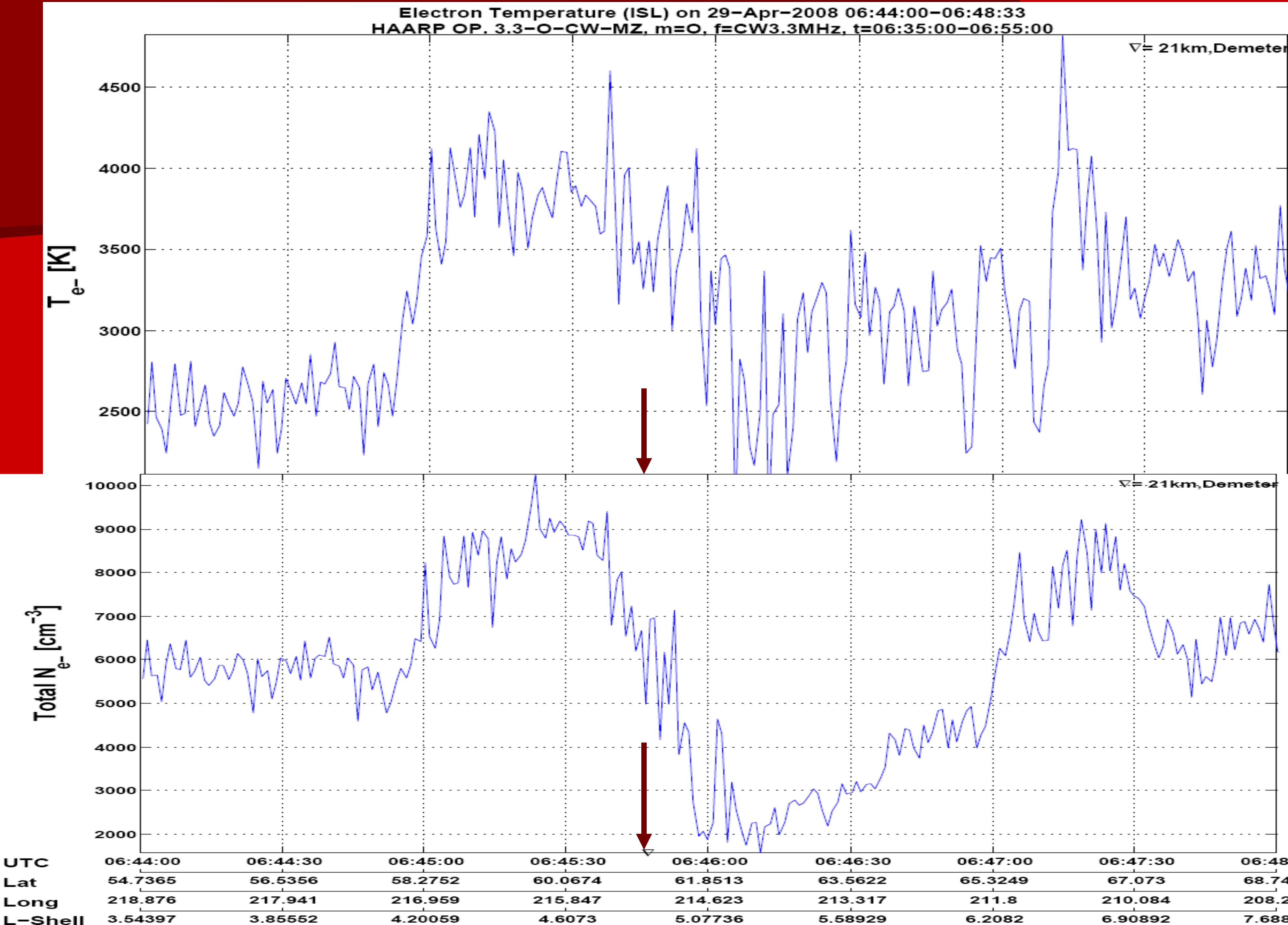

Ion Temperature (IAP) on 02−Aug−2007 07:09:33−07:20:59
HAARP OP. 2.83−1.4Hz−MZ, m=O, f=1.4Hz, t=07:13:00−07:23:00
▽=286km,Demeter
T_i [K]
1800
1600
1400
1200
1000
▽=286km,Demeter
O+ N_i [cm−3]
12000
10000
8000
6000
4000
2000
UTC
07:09:20
07:10:20
07:11:20
07:12:20
07:13:20
07:14:20
07:15:20
07:16:20
07:17:20
07:18:20
07:19:20
07:20:20
Lat
31.5806
34.3808
38.0173
41.6483
45.2721
48.8868
52.4893
56.0757
59.6397
63.1727
66.5265
69.9469
Long
220.843
220.086
219.044
217.918
216.689
215.325
213.788
212.021
209.944
207.432
204.428
200.393
L−Shell
1.58676
1.69231
1.85612
2.05676
2.30602
2.61769
3.01267
3.51833
4.17689
5.03831
6.13089
7.62184

04/29/08
F=3.3MHz
O-mode
CW
Mag. Zen.

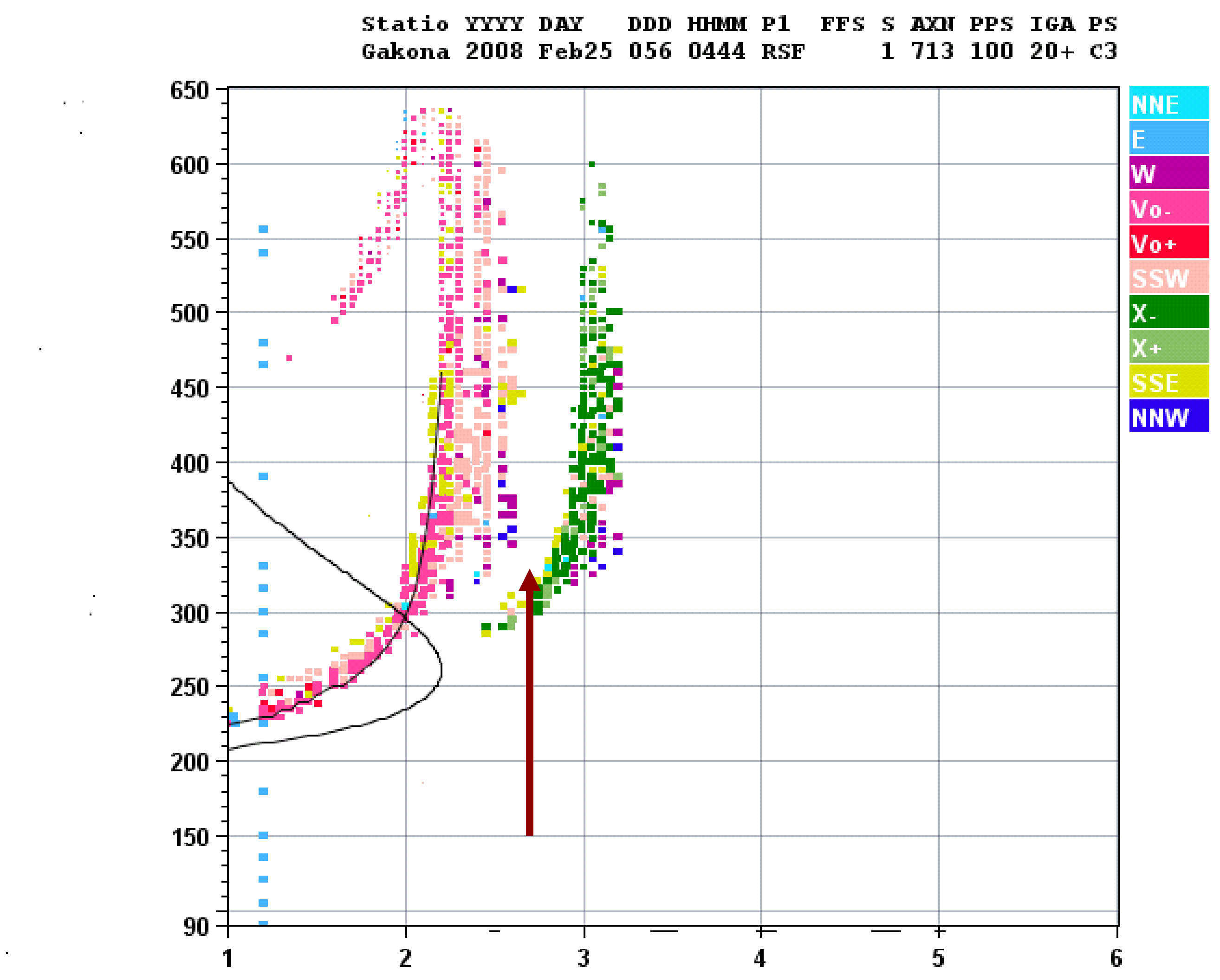




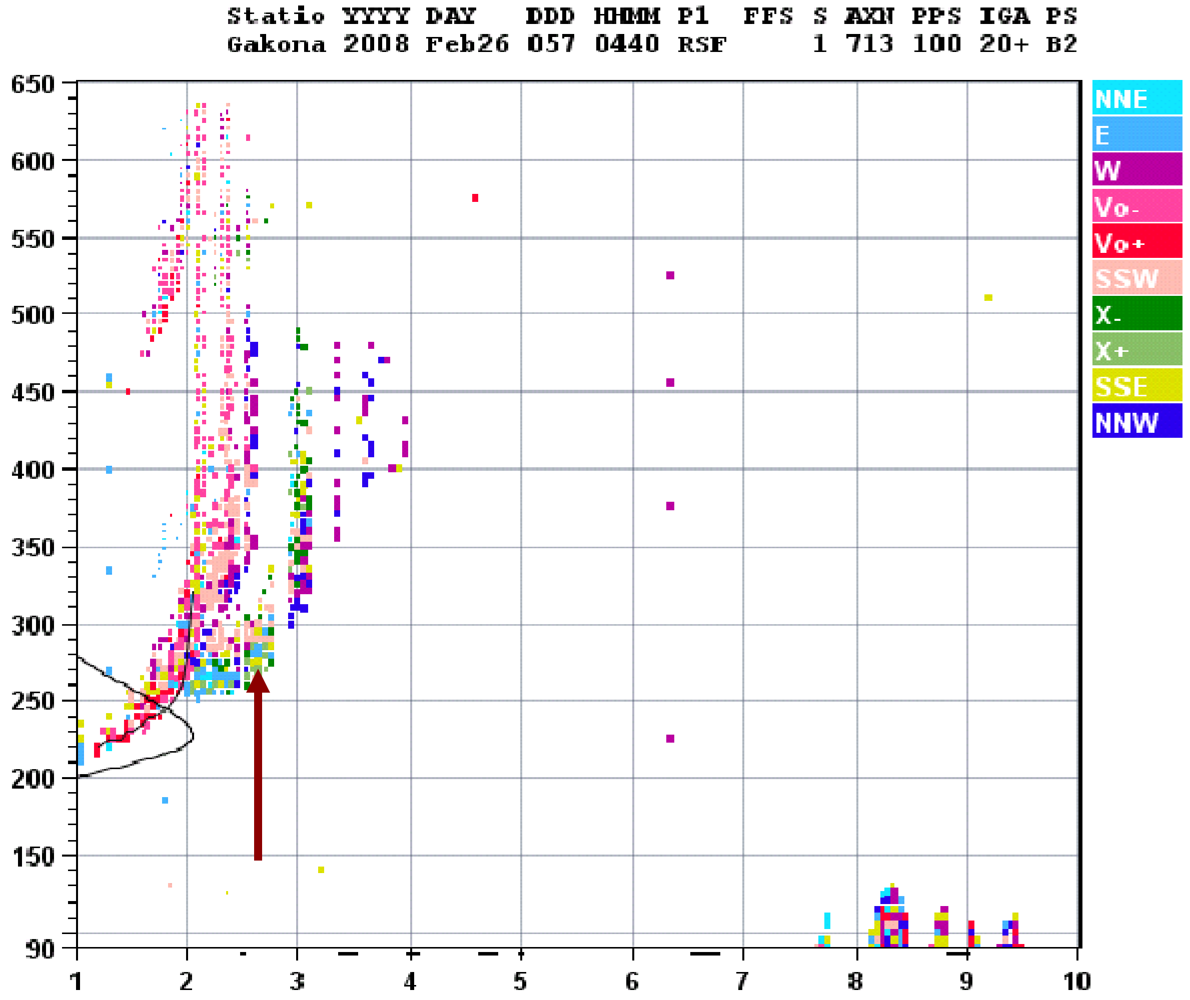

Ion Temperature (IAP) on 29−Apr−2008 06:44:02−06:48:36
HAARP OP. 3.3−O−CW−MZ, m=O, f=CW3.3MHz, t=06:35:00−06:55:00
∇= 22km,Demeter
T_i [K]
1000
1500
2000
2500
3000
3500
4000
∇= 22km,Demeter
O+ N_i [cm−3]
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
TC
06:44:00
06:44:30
06:45:00
06:45:30
06:46:00
06:46:30
06:47:00
06:47:30
06:48:00
at
54.8352
56.4877
58.2722
60.0501
61.82
63.5804
65.3289
67.0633
68.7797
ong
218.825
217.968
216.96
215.859
214.647
213.302
211.796
210.095
208.152
-Shell
3.56097
3.84603
4.19991
4.60277
5.06801
5.59567
6.20981
6.9044
7.70876


Electron Temperature (ISL) on 29-Apr-2008 06:44:00-06:48:33
HAARP OP. 3.3-O-CW-MZ, m=O, f=CW3.3MHz, t=06:35:00-06:55:00
∇= 21km,Demeter
T_{e-} [K]
4500
4000
3500
3000
2500
∇= 21km,Demeter
Total N_{e-} [cm^{-3}]
10000
9000
8000
7000
6000
5000
4000
3000
2000
UTC 06:44:00 06:44:30 06:45:00 06:45:30 06:46:00 06:46:30 06:47:00 06:47:30
Lat 54.7365 56.5356 58.2752 60.0674 61.8513 63.5622 65.3249 67.073
Long 218.876 217.941 216.959 215.847 214.623 213.317 211.8 210.084
L-Shell 3.54397 3.85552 4.20059 4.6073 5.07736 5.58929 6.2082 6.90892

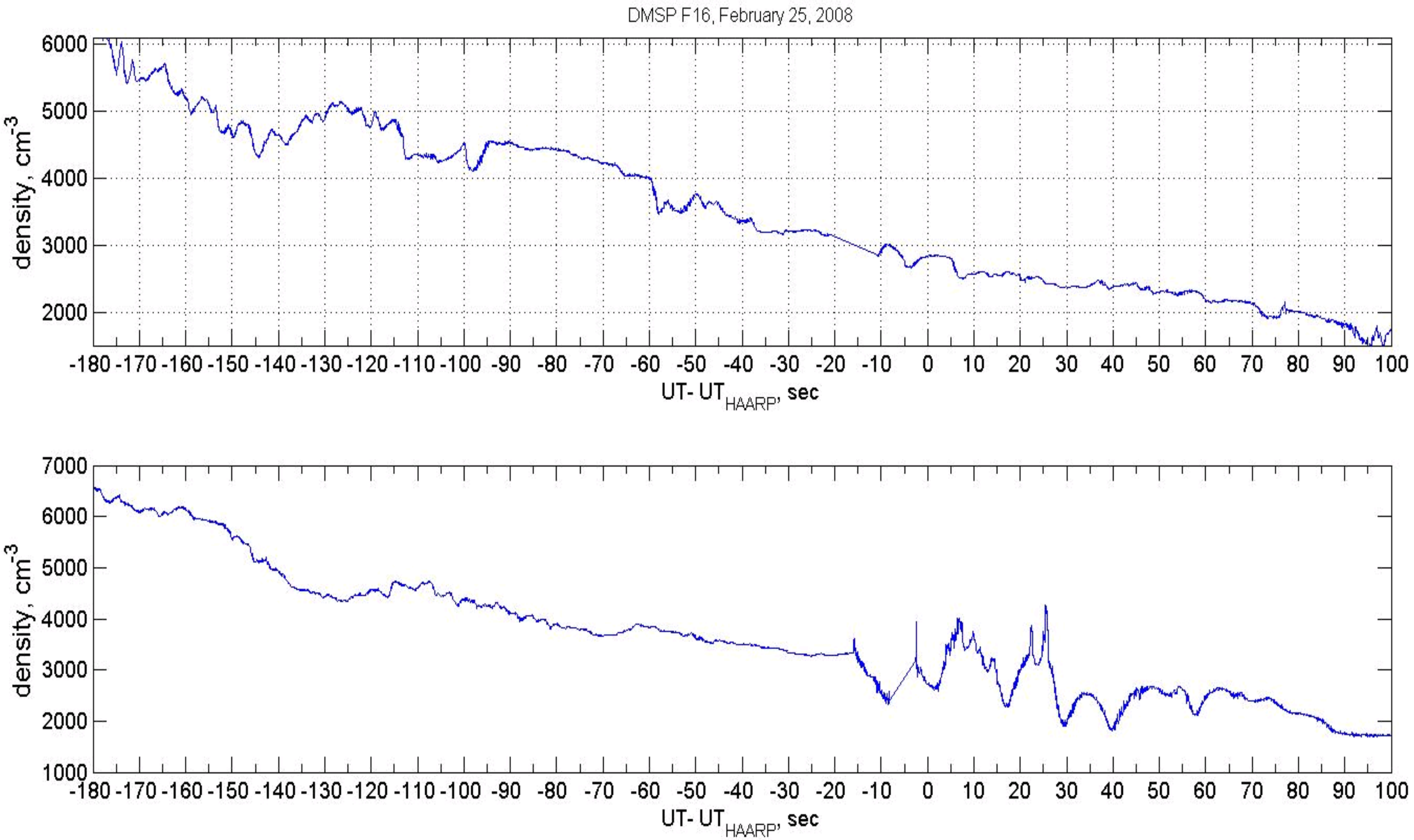
HAARP & DMSP F16 Experiments



02/25/08
f=2.85 MHz,
O-mode,
Magn. Zen.
No electrojet

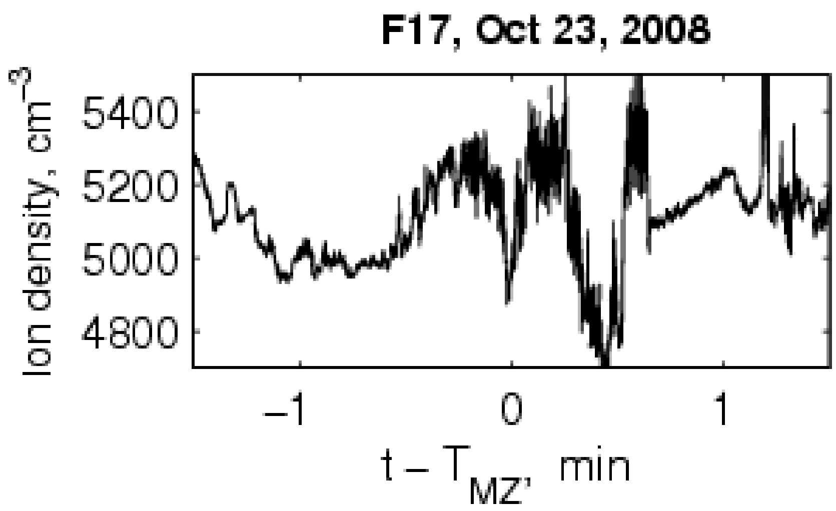


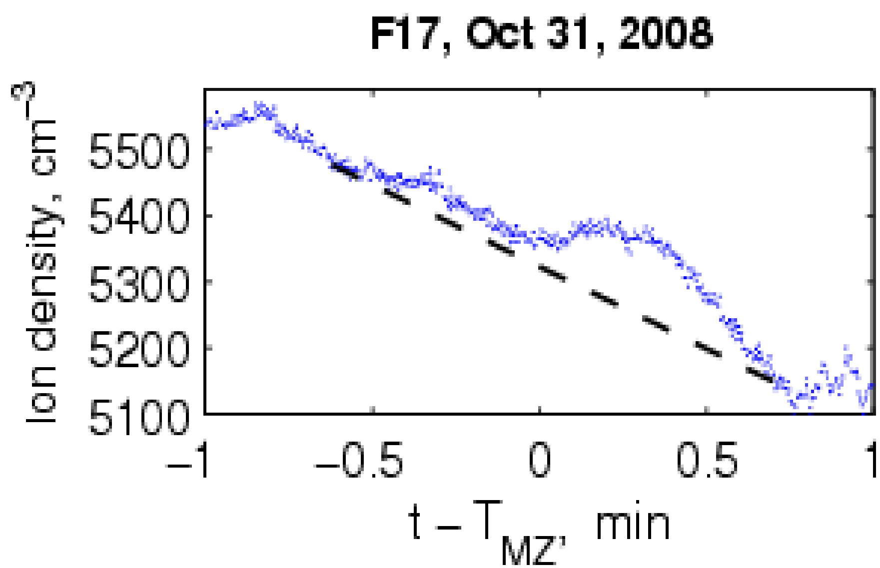
02/26/08
F=2.85 MHz,
O-mode,
Magn. Zen.,
No electrojet



Measurements by DMSP F16 during the HAARP winter 2008 campaign, made 02/25 (top) and 02/26 (bottom). Zero time corresponds to the shortest distance from the F16 foot point to HAARP which is 500 km (02/25) and 300 km (02/26).

Recent observations of ducts by DMSP





Here zero time is when F17 overflies HAARP. It is a daytime (2 UT or 17 LT), and pretty dense ionosphere.

Ducts detected at mid-latitude
[Frolov et al. JETP Lett. , 2008]

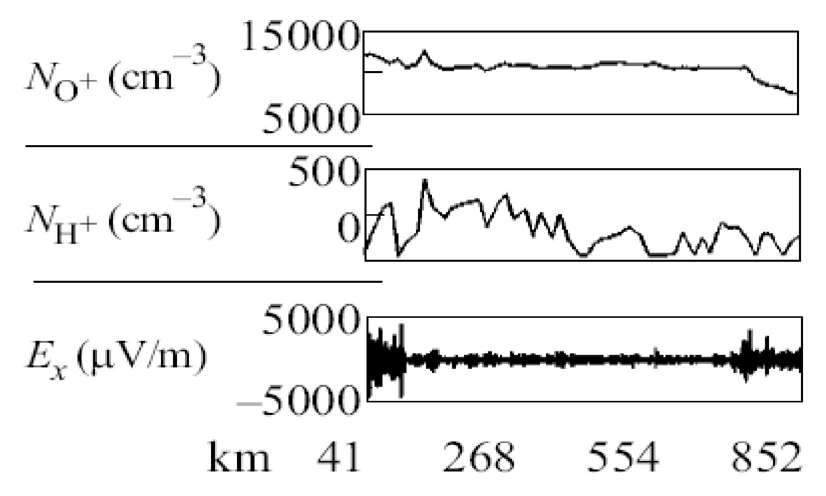
- Ducts generated by the SURA facility (56ºN, 46ºE) were detected by DEMETER and DMSP satellites.
- DEMETER observed 3 cases when $\delta n_e / n_e \leq 25 - 30\%$

It occurred when $f < f_0F_2$, at ERP=40 MW, CW.

Followed by oscillations of E_x.

- DMSP observed 2 cases with $\delta n_e / n_e \leq 2 - 5\%$

Shown are the Demeter observations made 05/01/06 when overflying SURA.



	$N_i^o (cm^{-3})$	$N_i^{peak} (cm^{-3})$	$T_i^o (K)$	$T_i^{peak} (K)$	$T_e^o (K)$	$T_e^{peak} (K)$	$L_x (km)$
Over-dense ionosphere	4730	6800	1450	2250	2830	3980	510
Under-dense ionosphere	3520	4300	1190	1360	2480	3780	250
Weak ionosphere	1670	2730	1430	1470	2770	3230	510

Table 1.Results of DEMETER measurements averaged over 20 HAARP over-flights.

Estimates of energy flux into ducts: $F_{peak} = (\delta N_i \delta T_i + \delta N_e \delta T_e) \times \mathrm{v}$

Estimates of power pumped into ducts: $P_{ducts} = (\delta N_i \delta T_i + \delta N_e \delta T_e) \times \mathrm{v} \times \mathrm{Area}$

	$F_{peak}\left(\frac{\mu w}{m^2}\right)$	F_{peak}/F_{HAARP}	$\overline{P}(kW)$	$\overline{P}/P_{HAARP}$
Over-dense Ionosphere	5.65×10^{-2}	3.1×10^{-4}	2.3	7.2×10^{-4}
Under-dense ionosphere	1.6×10^{-2}	1.4×10^{-4}	0.32	10^{-4}
Weak ionosphere	0.74×10^{-2}	0.6×10^{-4}	0.3	10^{-4}

Conclusions

- Ion outflow due to the ionospheric heating by HAARP was detected by Demeter & DMSP F16, F17.
- Modified SAMI2 model provides qualitative predictions of the outflows amplitude.
- The power pumped into ducts was estimated as been in the range 0.01- 0.1% of the HAARP power.
- The best conditions for generation of ducts occurred when matching F2 peak in the absence of the electrojet. The worst case scenario occurs when the radio wave is strongly absorbed in the E-layer.