

# HAARP-induced Ionospheric Ducts

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# *Motivation*

- **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.

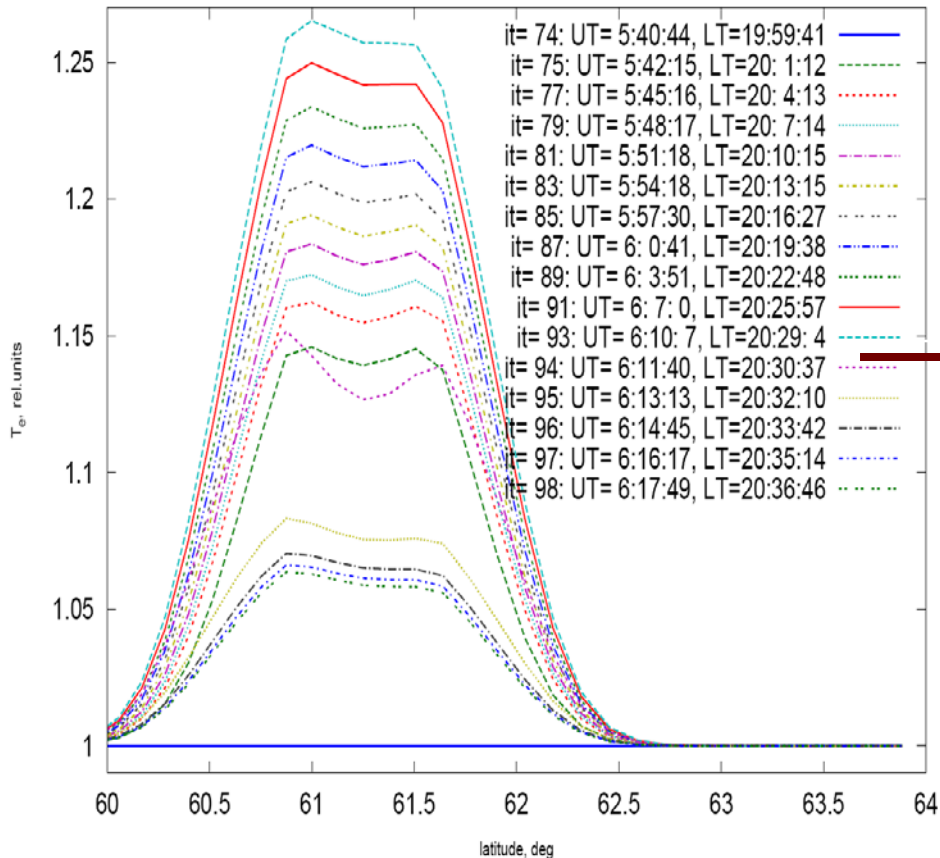
# *The model of artificial ducts in the ionosphere*

- 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:

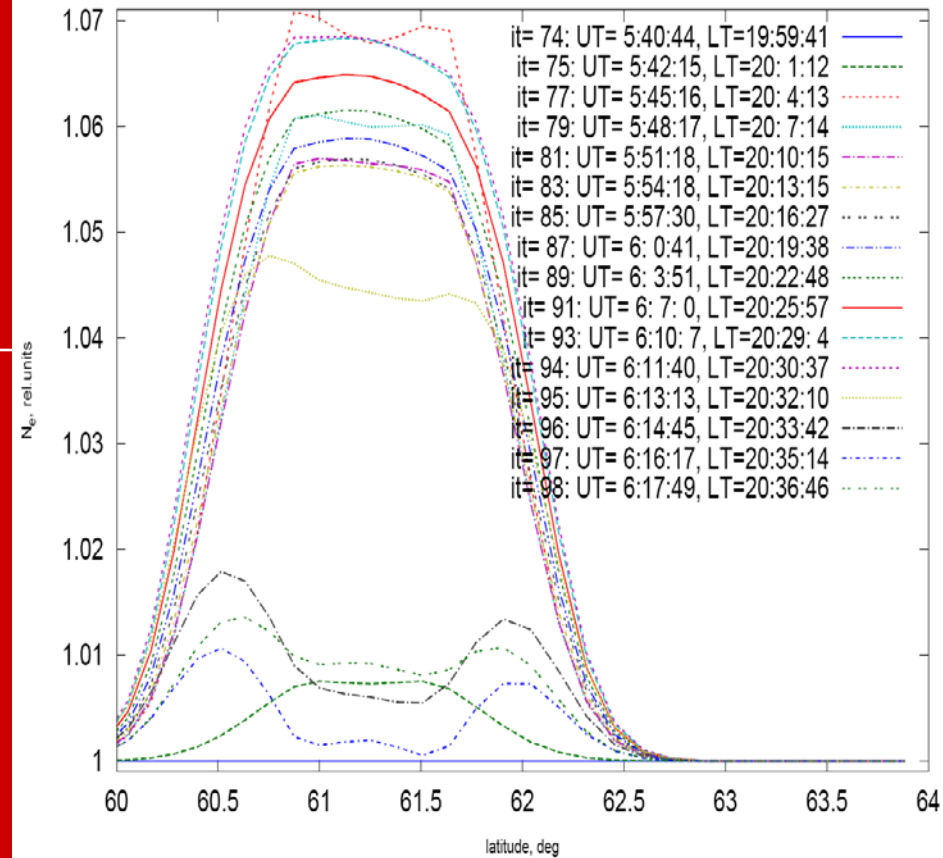
$$q = \mu P / V n_e \approx 2 \times 10^4 \mu (K / s)$$

# Model of HF-heating effects due to HAARP (low ERP)

h=702.9 km, heat end: heating effect,  $h_p=270$ km,  $dh=50$ km,  $q=5e2$



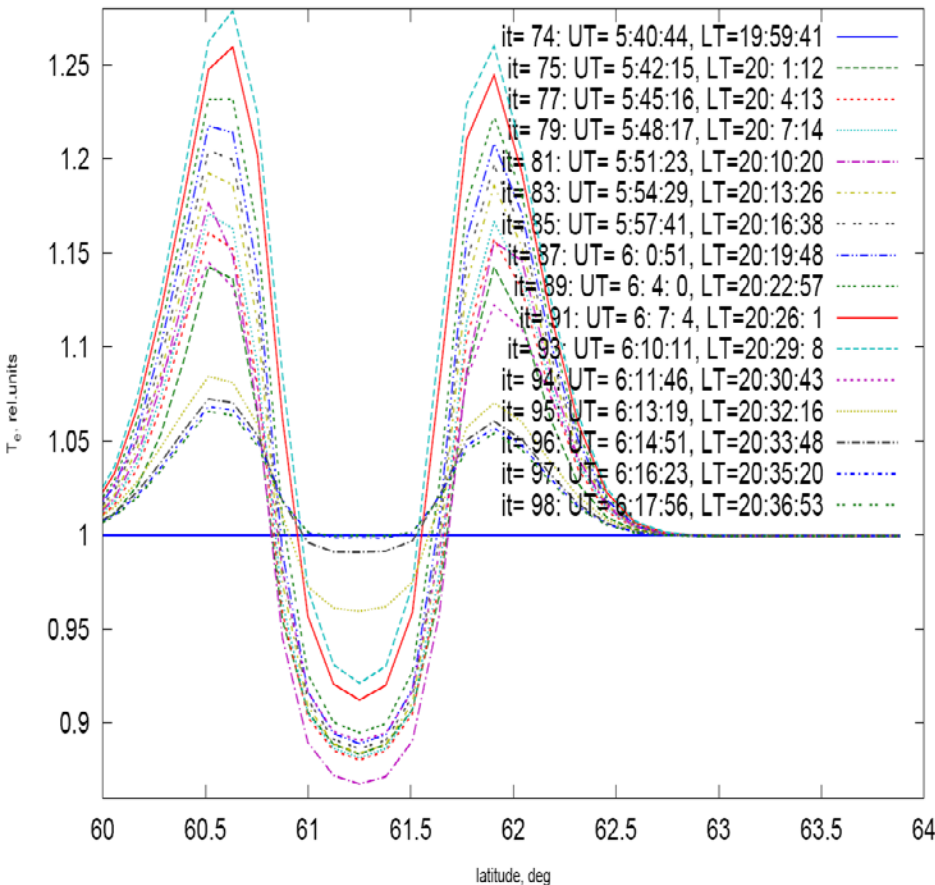
h=702.9 km, heat end: heating effect,  $h_p=270$ km,  $dh=50$ km,  $q=5e2$



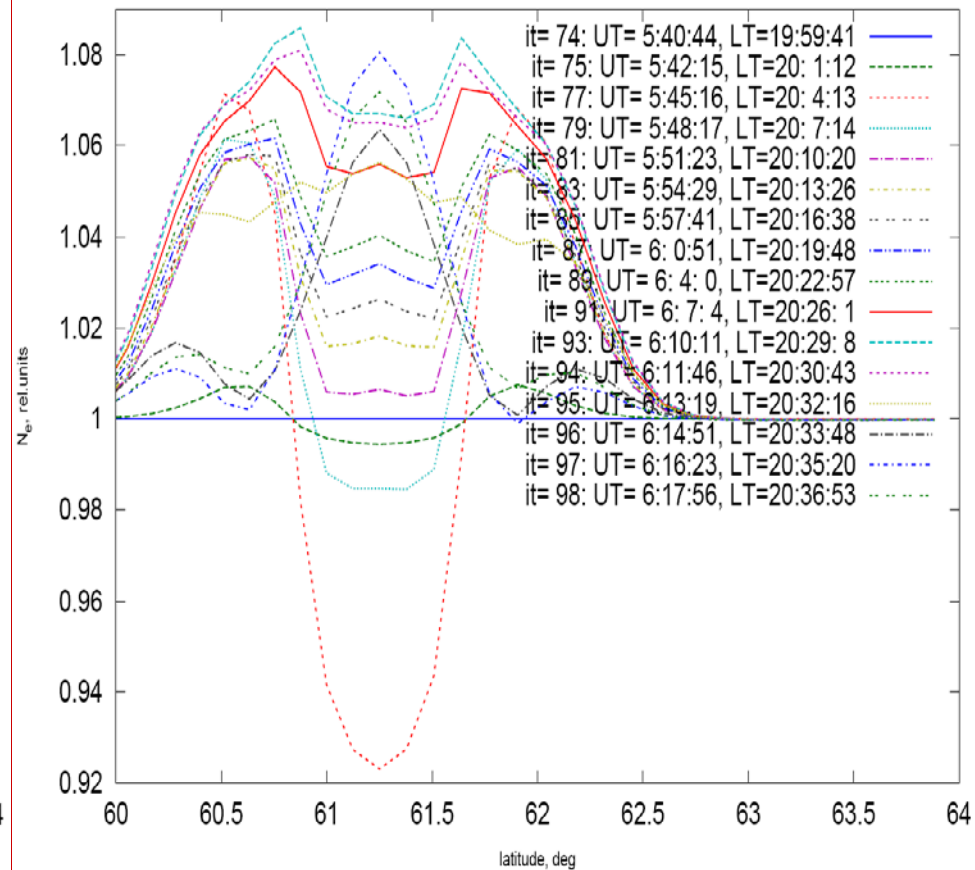
Variations of the electron temperature & density along the DEMETER orbit at 700 km. The “HF-heating” was conducted during 20:00 – 20:30 LT (drift is not included).

# Model of HF-heating effects due to HAARP (moderate ERP)

h=702.9 km, heat end: heating effect,  $h_0=270$ km,  $dh=50$ km,  $q=2e3$

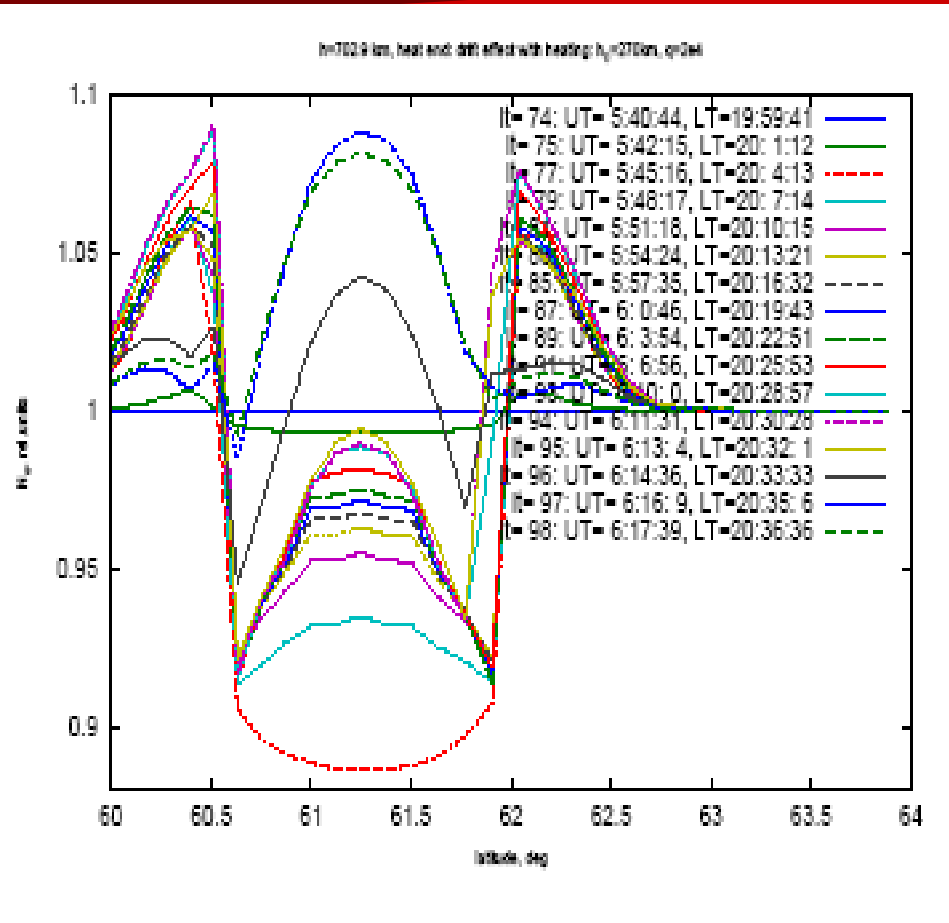
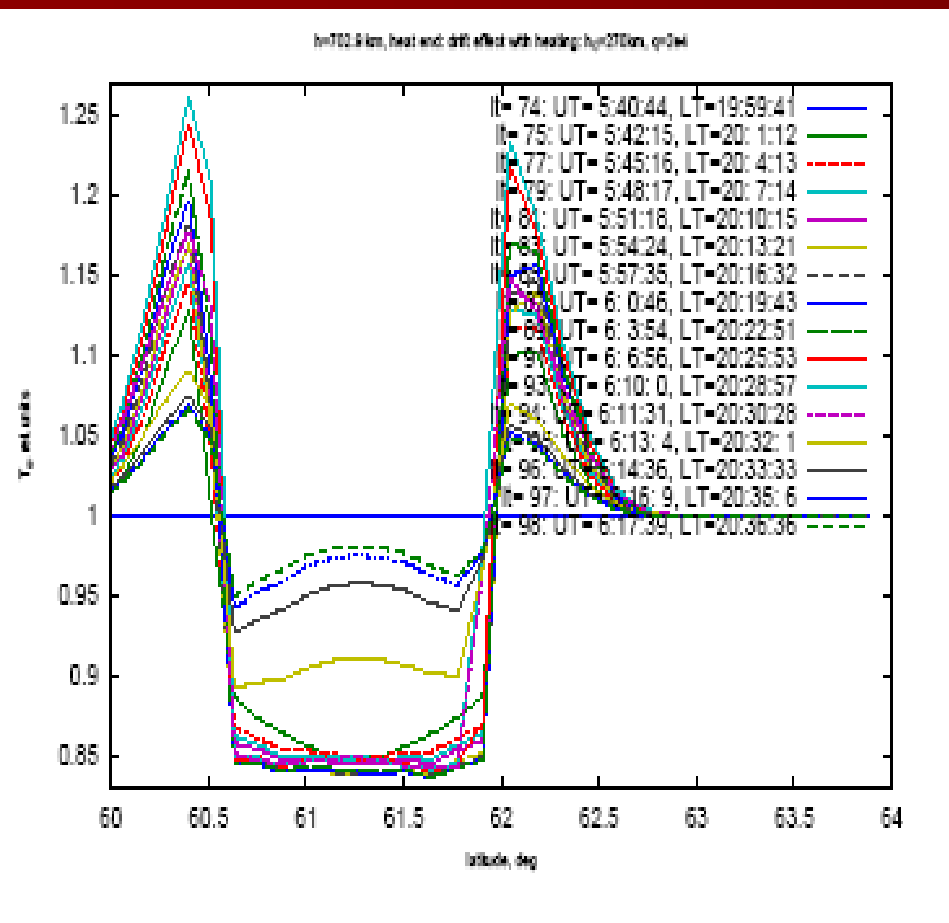


h=702.9 km, heat end: heating effect,  $h_0=270$ km,  $dh=50$ km,  $q=2e3$



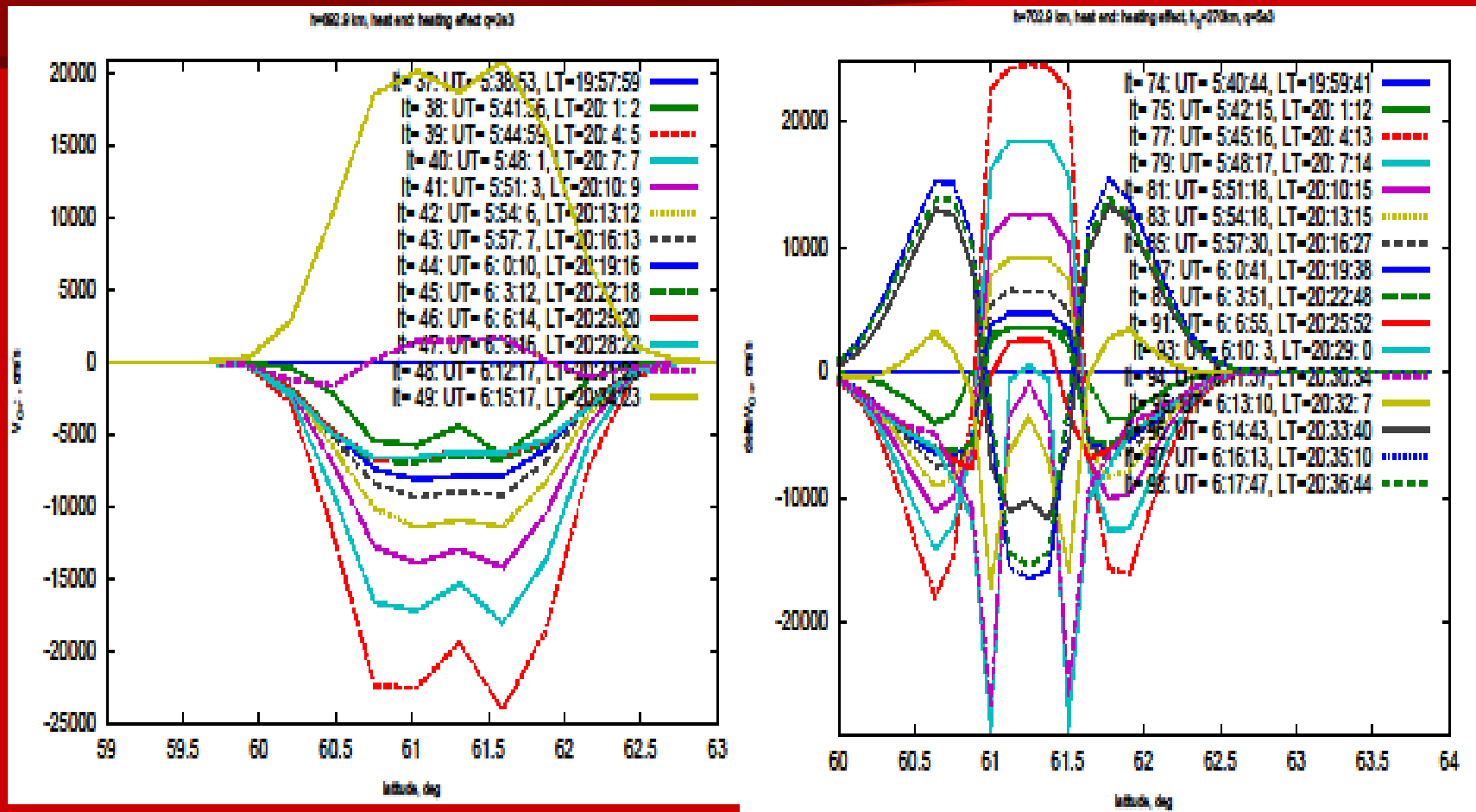
Variations of the electron temperature & density along the DEMETER orbit at 700 km. The “HF-heating” was conducted during 20:00 – 20:30 LT (drift is not included).

# Model of HF-heating effects due to HAARP (high ERP)



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 ( $q=2 \times 10^3$  K/s and  $5 \times 10^3$  K/s at the left and right panel).



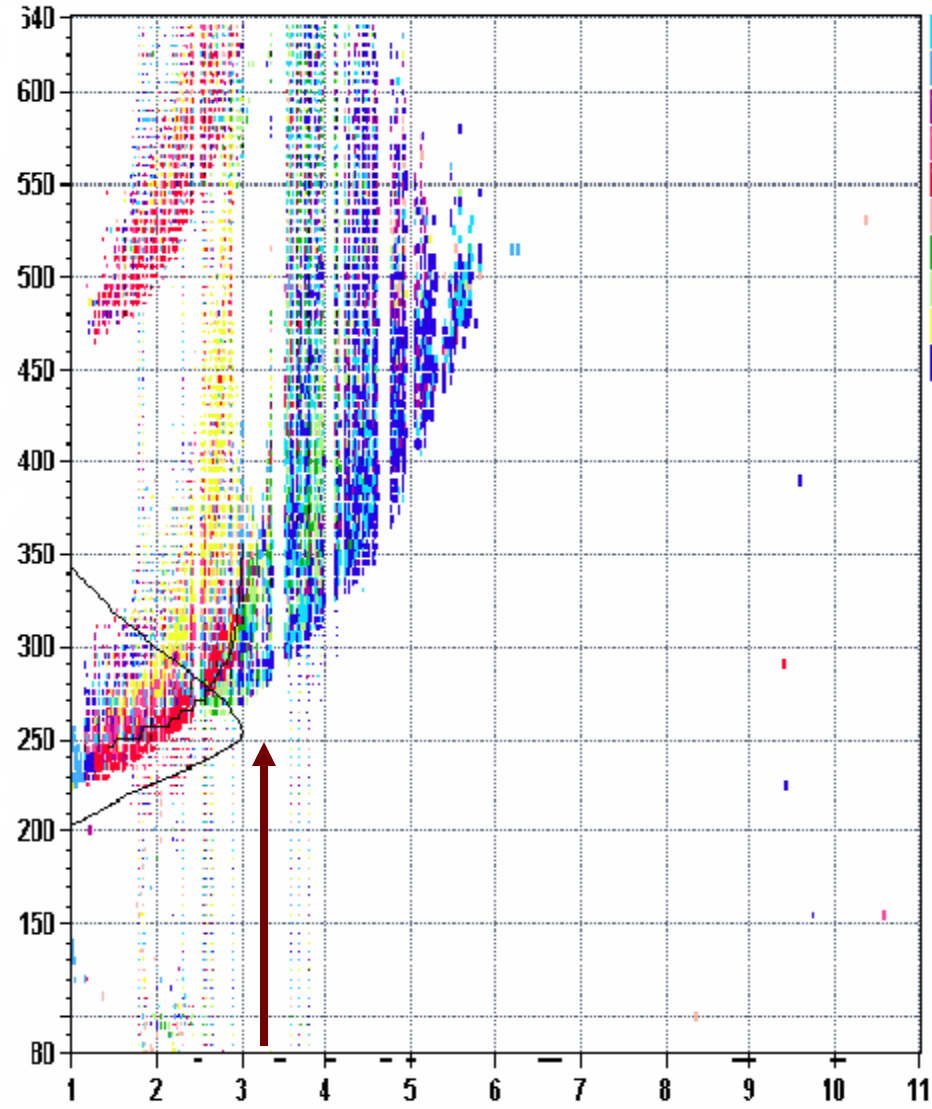
# Analysis of the Demeter Observations

- 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  $f < f_0F_2$
- (b) Under-dense ionosphere  $f > f_0F_2$
- (c) A weak ionosphere  $f_0F_2$  is not available

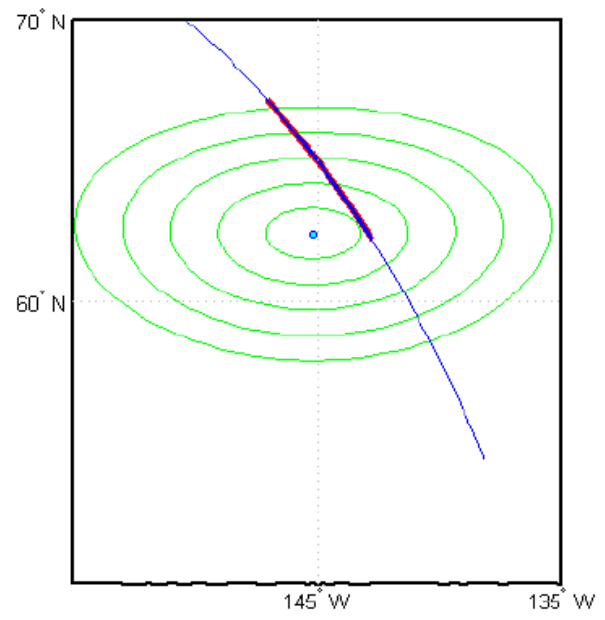
Three following DEMETER observations represent each of these groups

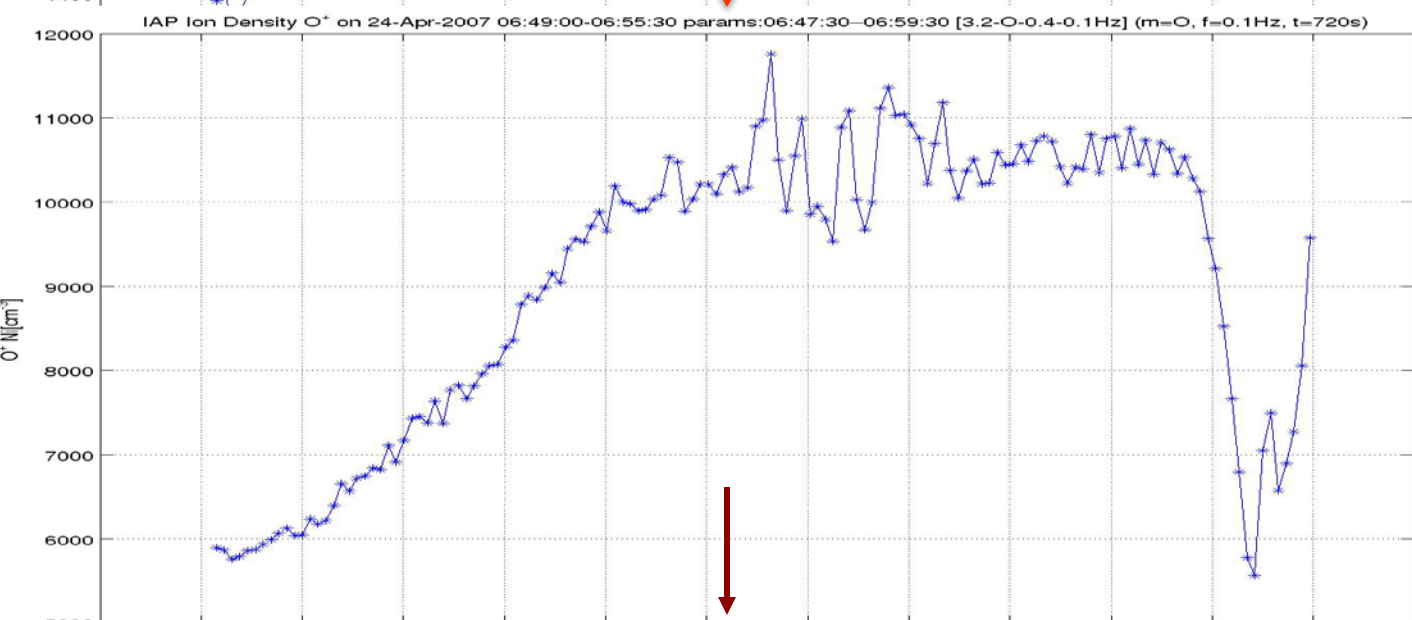
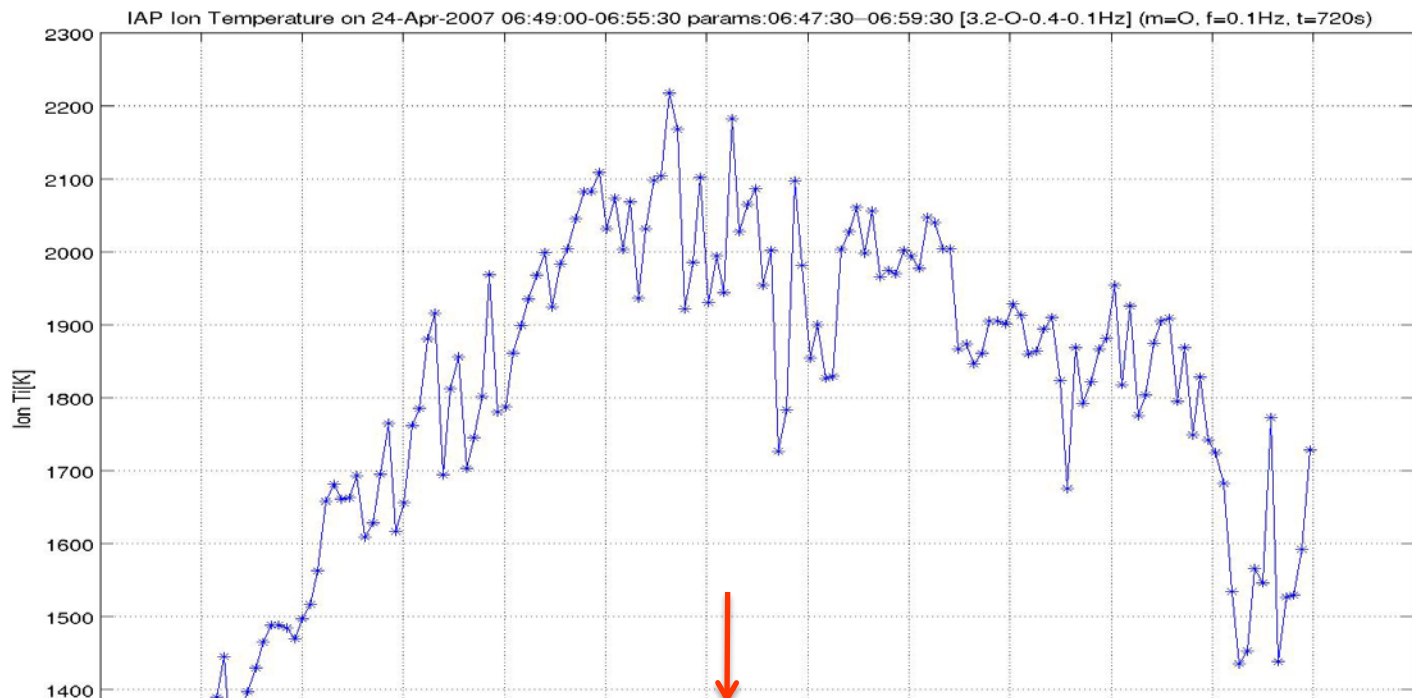
Statio YYYY DAY DDD HHMM P1 FPS S AXH PPS IGA PS  
Gakona 2007 Apr24 114 0700 RSF 1 714 100 20+ C1



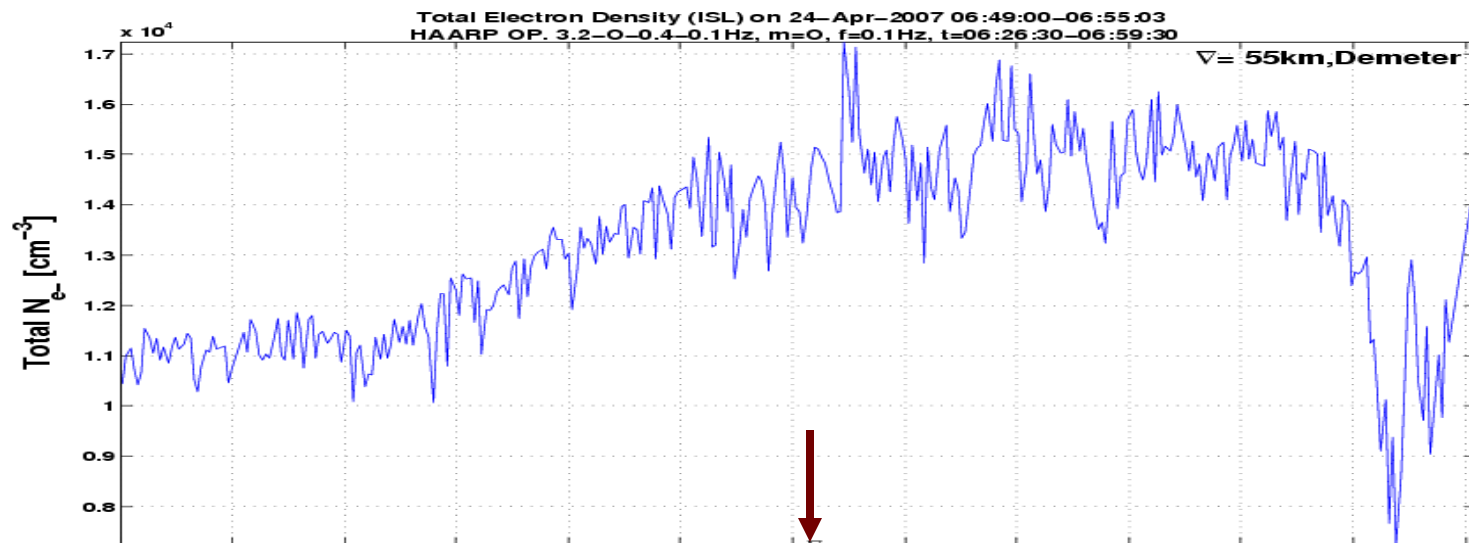
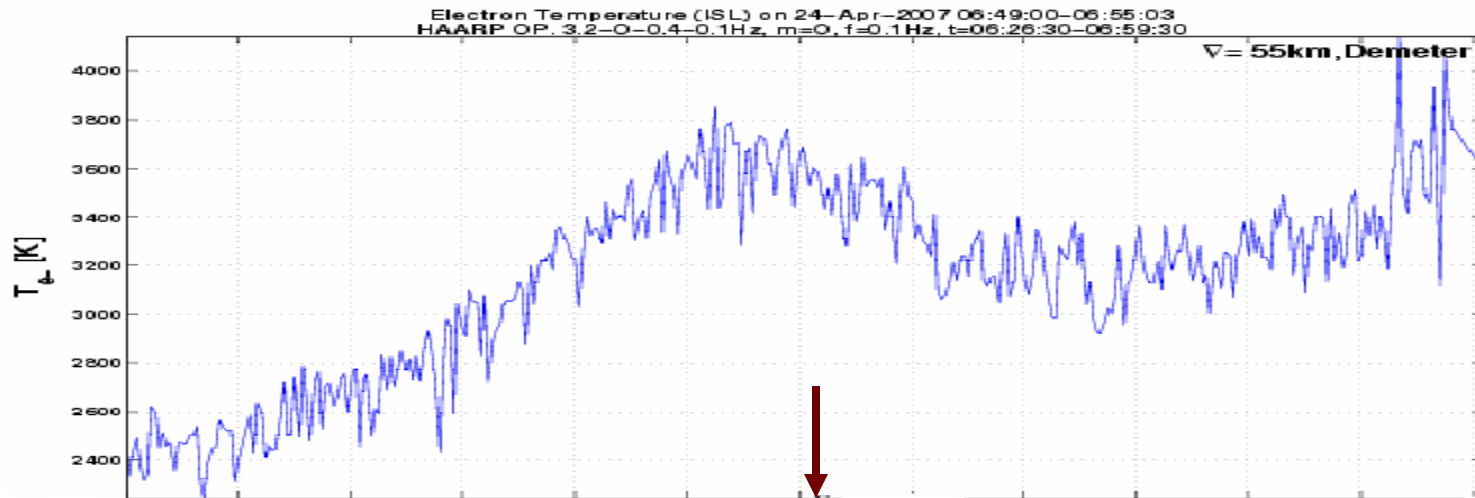
04/24/07  
f=3.2 MHz  
O-mode  
0.1 Hz  
Magn. Zen.  
No electrojet

DEMETER pass projected along  $B_0$  (r\_circles = 100, 200, 300... km)



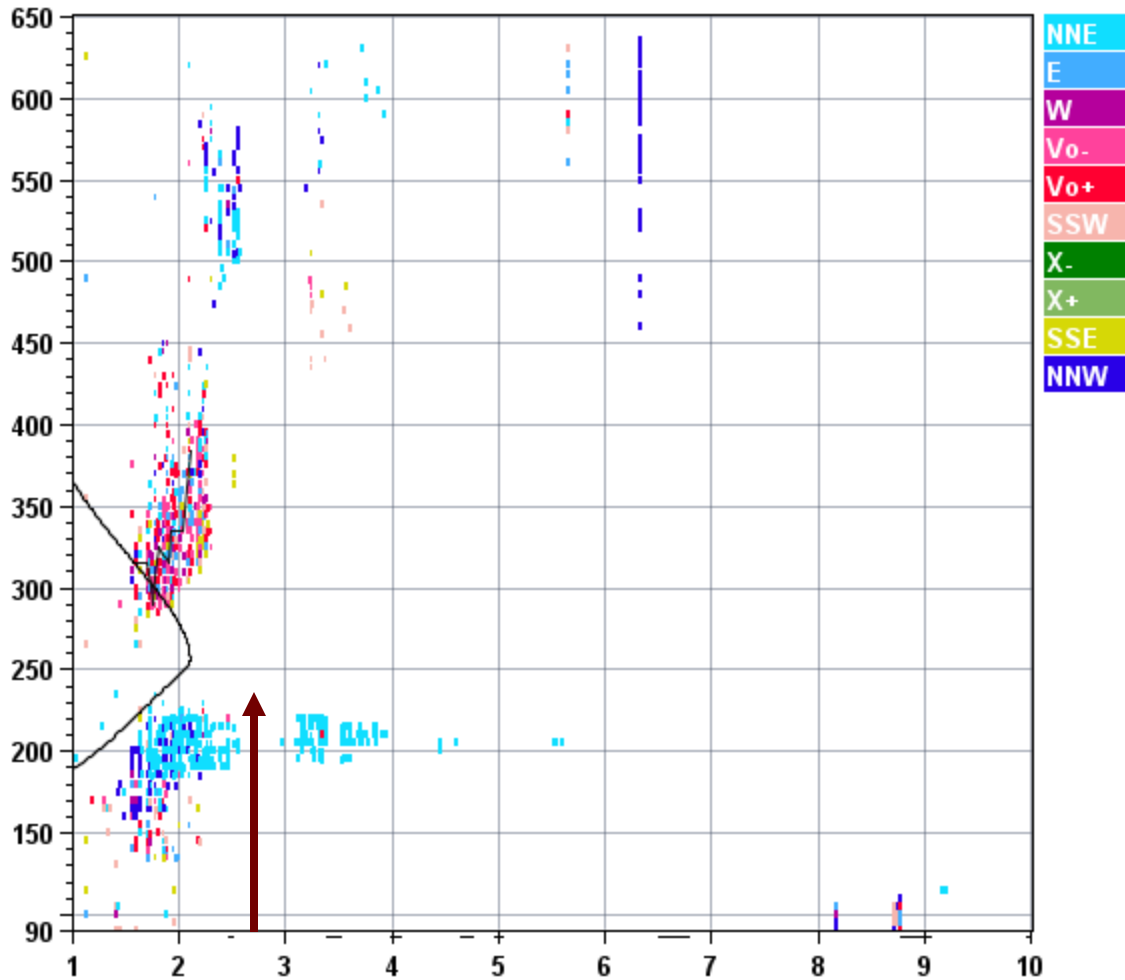


UTC	06:49:00	06:49:30	06:50:00	06:50:30	06:51:00	06:51:30	06:52:00	06:52:30	06:53:00	06:53:30	06:54:00	06:54:30	06:55:00	06:55:30
Lat	52.1846	52.1846	53.705	55.4973	57.2845	59.0655	60.8392	62.6042	64.3587	66.1001	67.8256	69.5311	71.083	71.083
Long	220.789	220.789	220.086	219.192	218.226	217.173	216.019	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

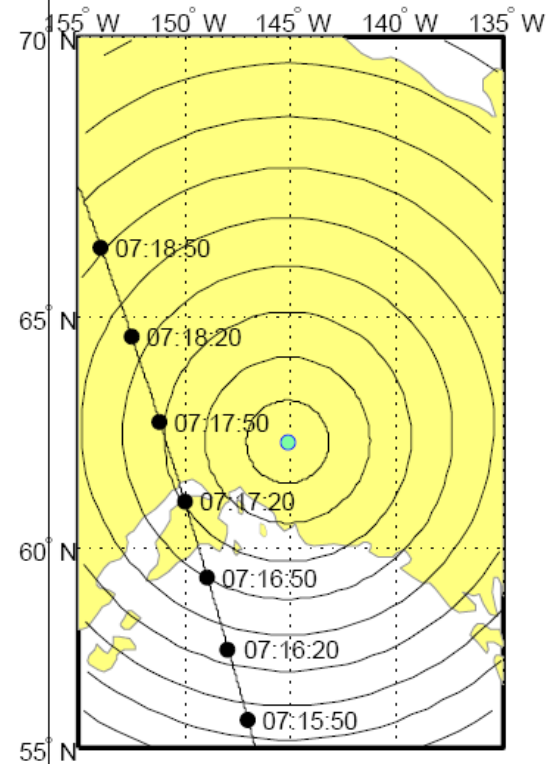


UTC	06:49:00	06:49:30	06:50:00	06:50:30	06:51:00	06:51:30	06:52:00	06:52:30	06:53:00	06:53:30	06:54:00	06:54:30	06:55:00
Lat	50.1657	51.9156	53.7297	55.5364	57.2732	59.0686	60.8564	62.5719	64.3405	66.0961	67.7787	69.4933	71.3184
Long	221.668	220.913	220.073	219.171	218.232	217.171	216.007	214.771	213.342	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

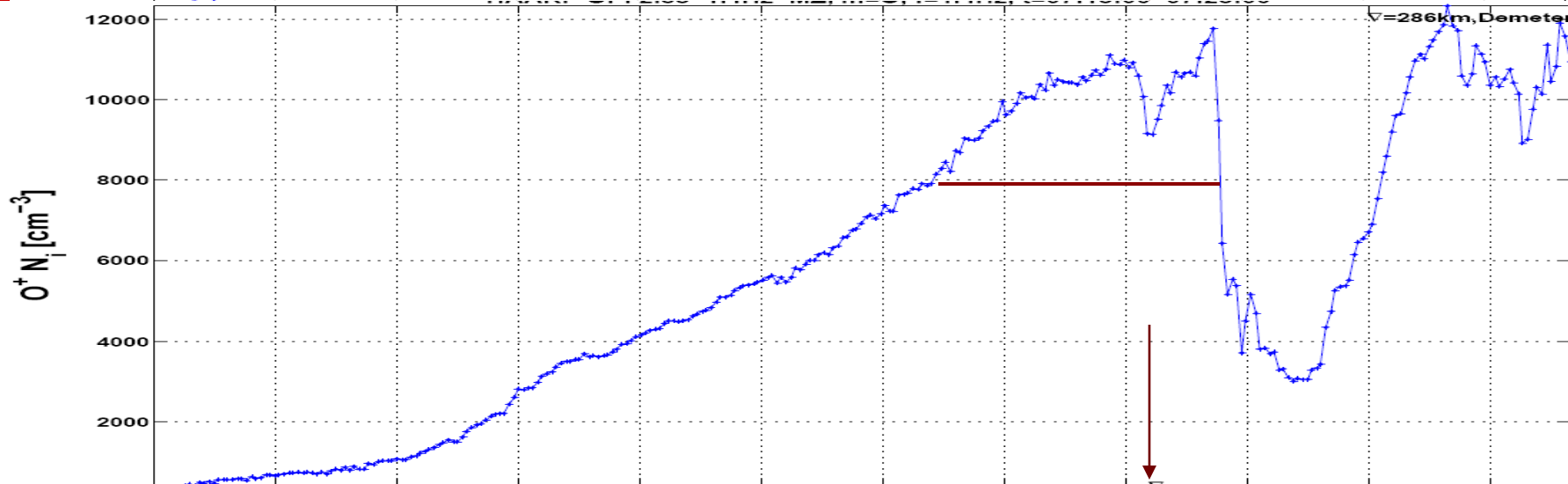
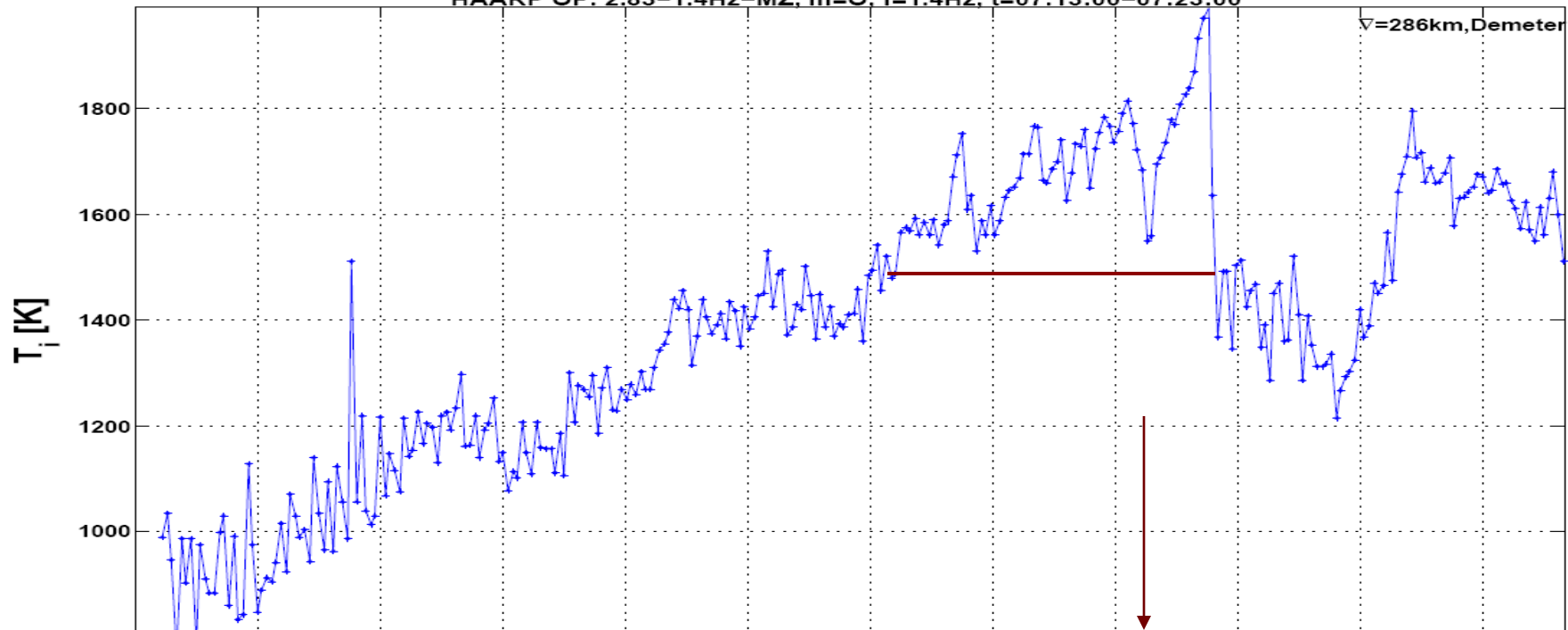
Statio YYYY DAY DDD HHMM P1 FFS S AXII PPS IGA PS  
Gakona 2007 Aug02 214 0715 RSF 1 713 100 20+ AA



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

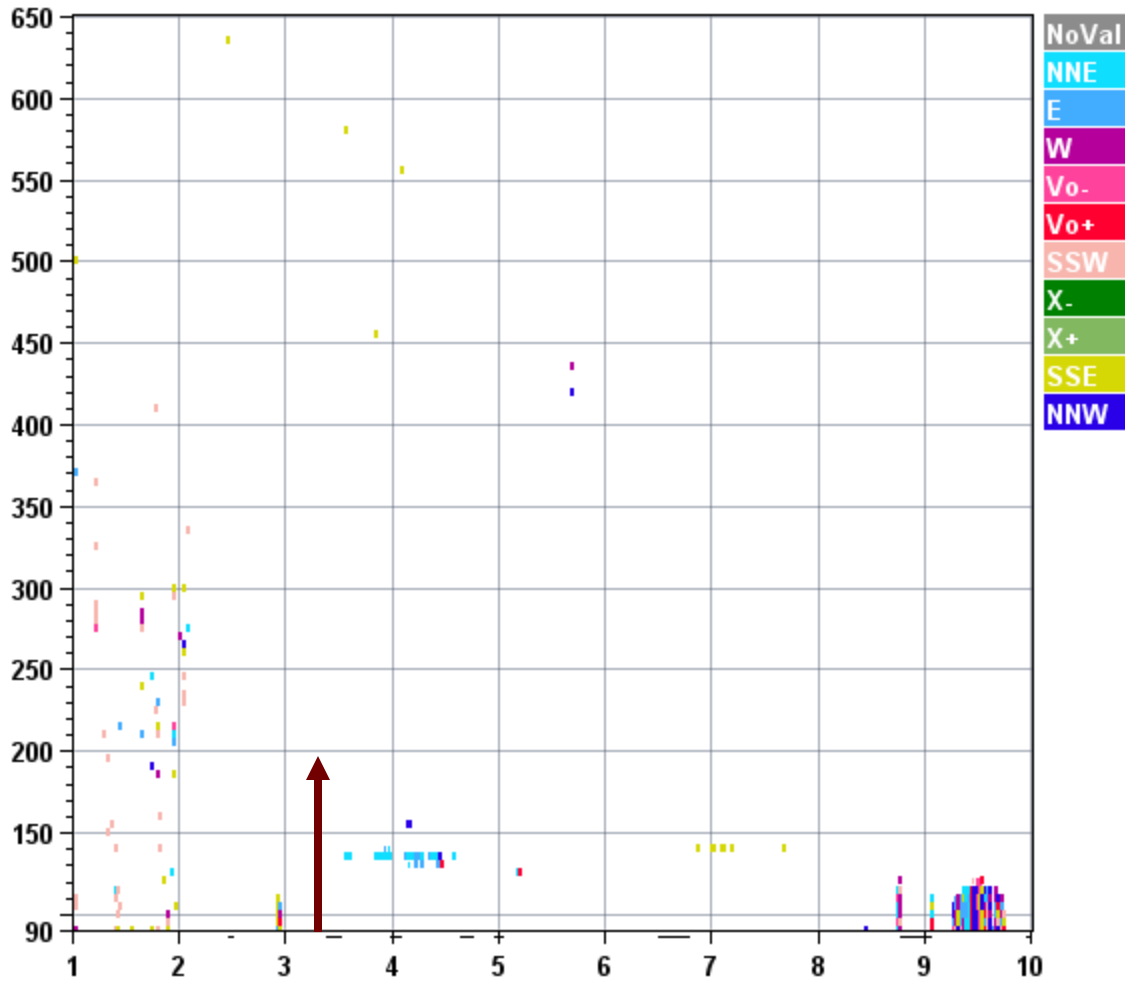


Ion Temperature (IAP) on 02-Aug-2007 07:09:33-07:20:59  
 HAARP OP. 2.83-1.4Hz-MZ, m=O, f=1.4Hz, t=07:13:00-07:23:00

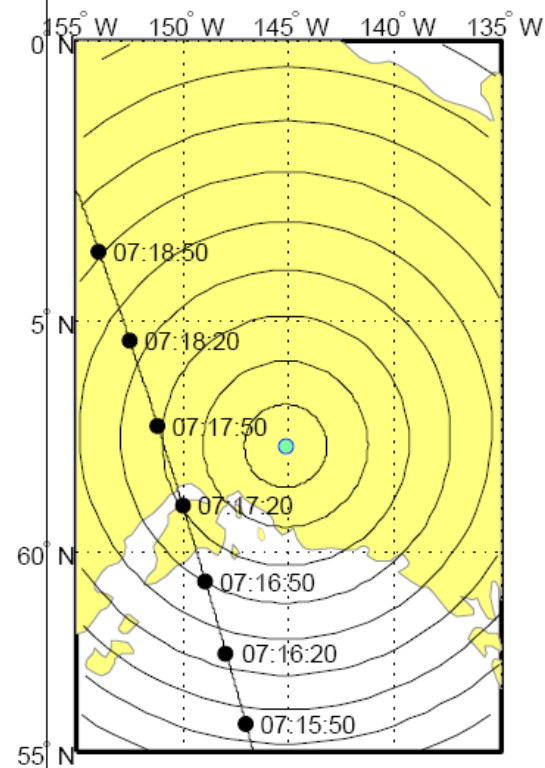


UTC	07:09:20	07:10:20	07:11:20	07:12:20	07:13:20	07:14:20	07:15:20	07:16:20	07:17:20	07:18:20	07:19:20	07:20:20
Lat	31.5806	34.3808	38.0173	41.6483	45.2721	48.8868	52.4893	56.0757	59.6397	63.1727	66.5265	69.9469
Long	220.843	220.086	219.044	217.918	216.689	215.325	213.788	212.021	209.944	207.432	204.428	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

Statio YYYY DAY DDD HHMM P1 FFS S AXI PPS IGA PS  
Gakona 2008 Apr29 120 0645 RSF 1 713 100 20+ A1



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



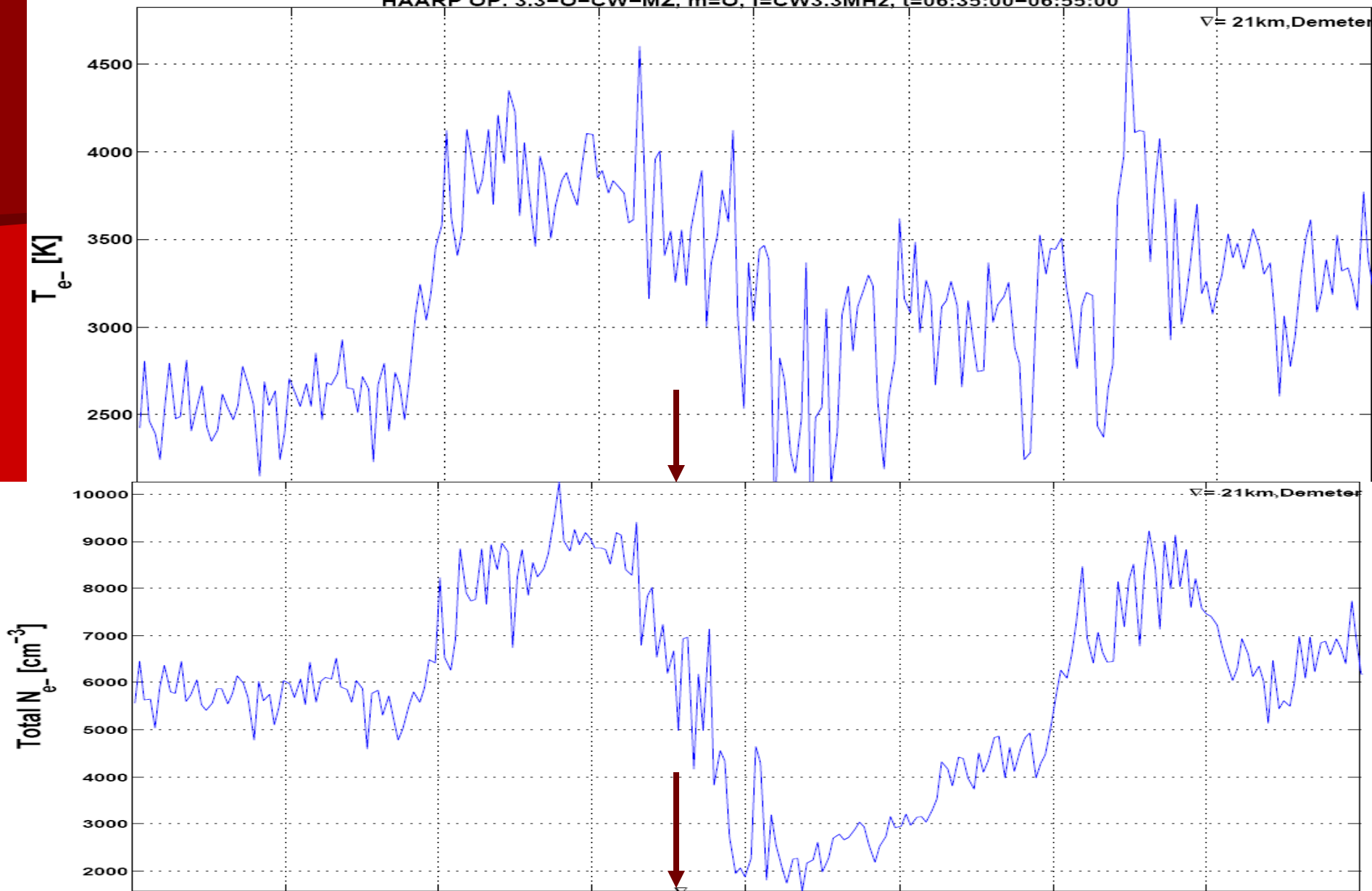
Ion Temperature (IAP) on 29-Apr-2008 06:44:02-06:48:36  
 HAARP OP. 3.3-O-CW-MZ, m=O, f=CW3.3MHz, t=06:35:00-06:55:00



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



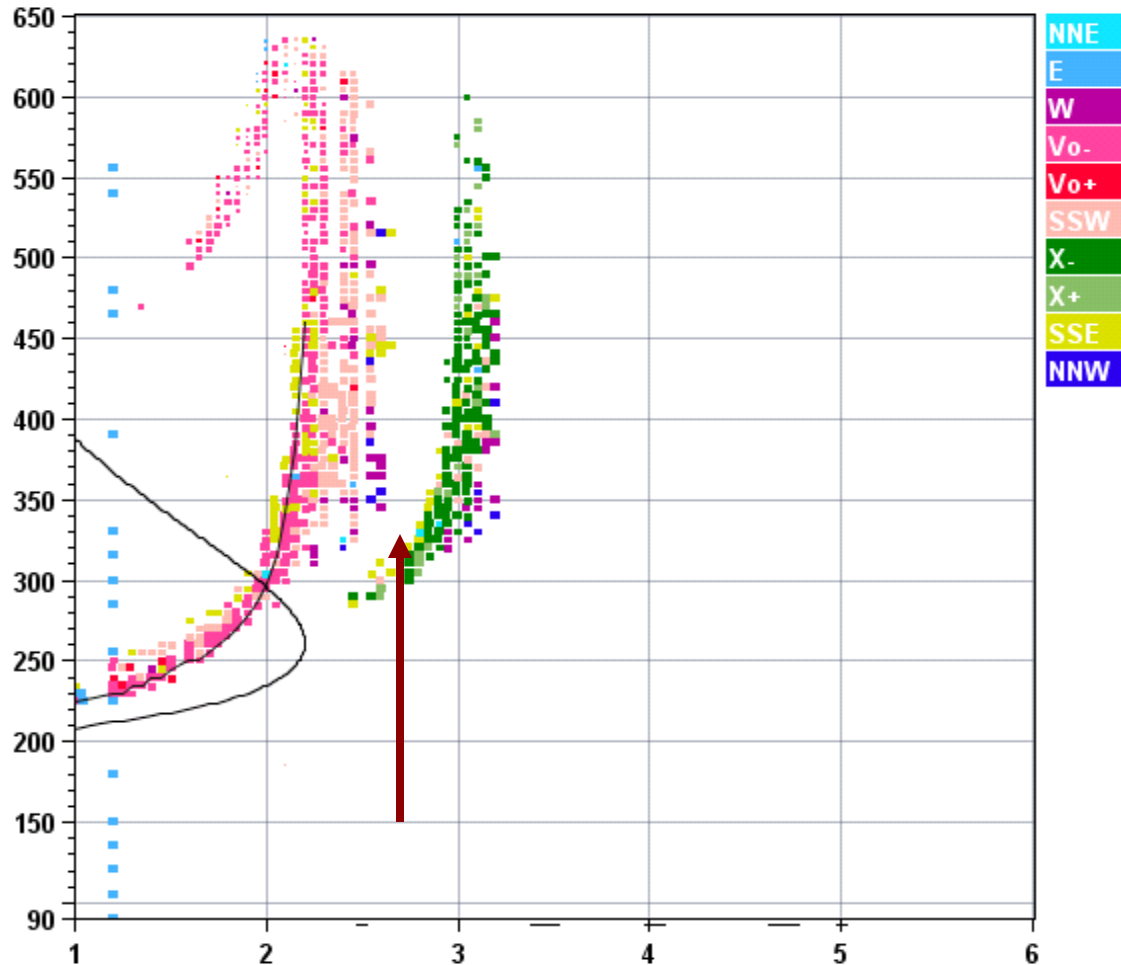
Electron Temperature (ISL) on 29-Apr-2008 06:44:00-06:48:33  
 HAARP OP. 3.3-O-CW-MZ, m=O, f=CW3.3MHz, t=06:35:00-06:55:00



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	06:48:00
Lat	54.7365	56.5356	58.2752	60.0674	61.8513	63.5622	65.3249	67.073	68.74
Long	218.876	217.941	216.959	215.847	214.623	213.317	211.8	210.084	208.2
L-Shell	3.54397	3.85552	4.20059	4.6073	5.07736	5.58929	6.2082	6.90892	7.68

# HAARP & DMSP F16 Experiments

Statio YYYY DAY DDD HHMM P1 FFS S AXI PPS IGA PS  
Gakona 2008 Feb25 056 0444 RSF 1 713 100 20+ C3



02/25/08

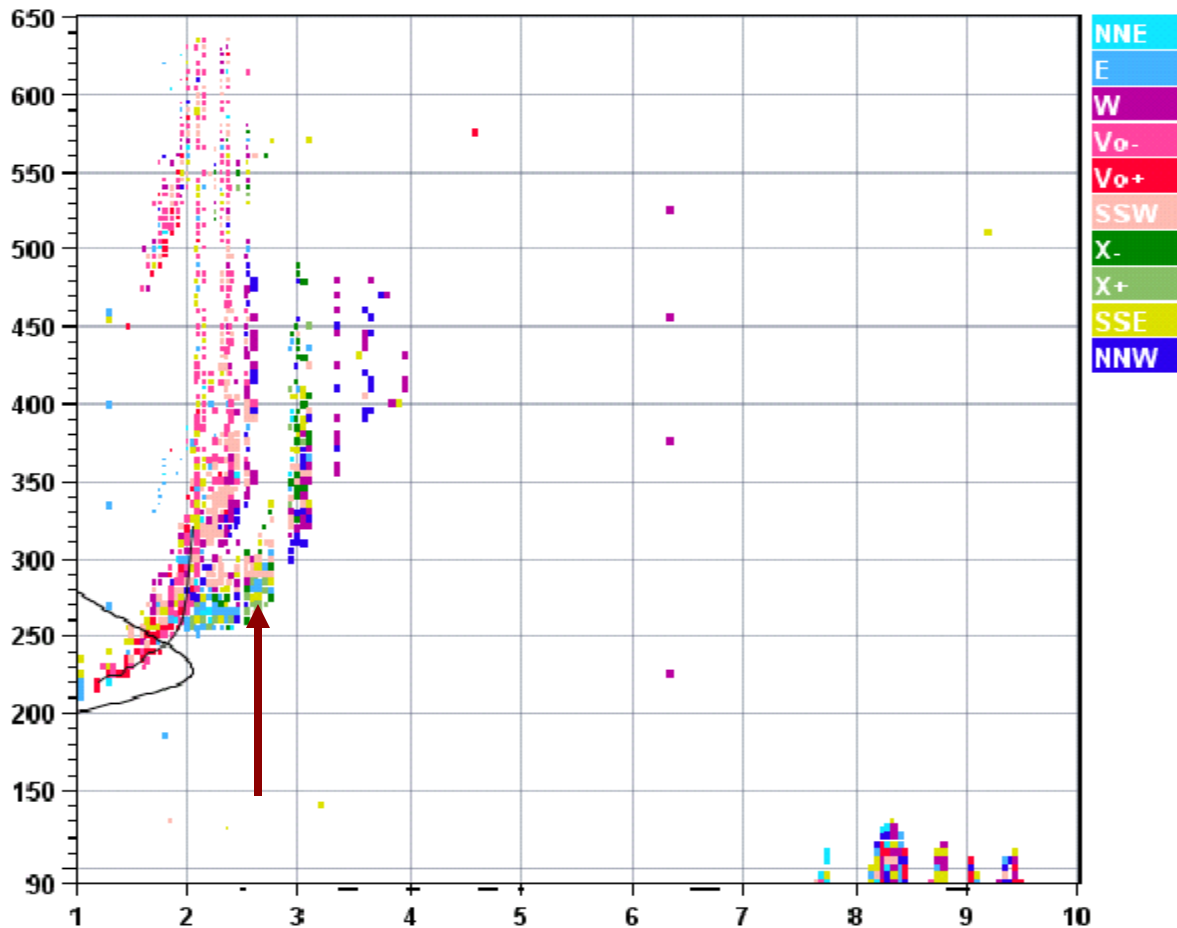
$f=2.85$  MHz,

O-mode,

Magn. Zen.

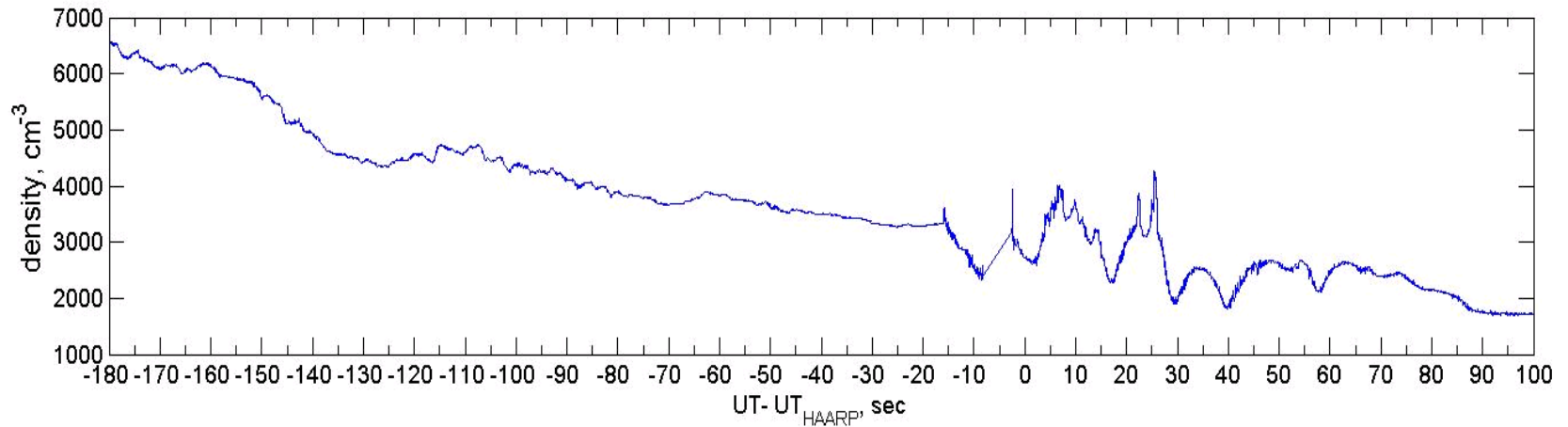
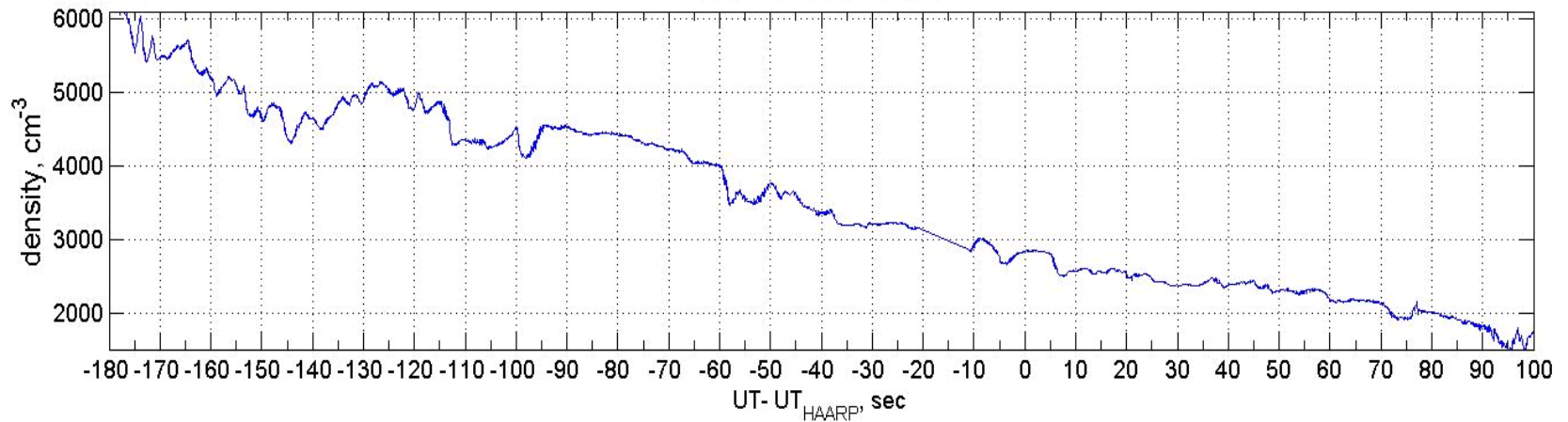
No electrojet

Statio YYYY DAY DDD HMM P1 FFS S AXN PPS IGA PS  
Gakona 2008 Feb26 057 0440 RSF 1 713 100 20+ B2



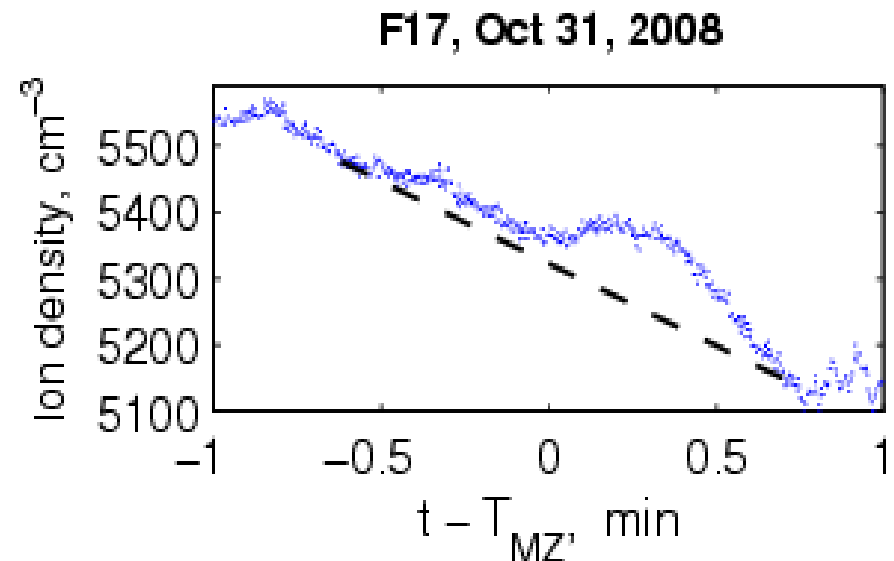
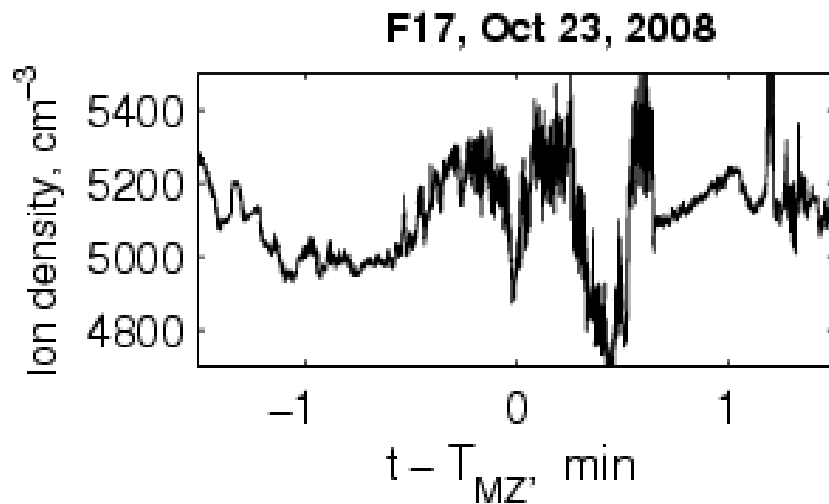
02/26/08  
F=2.85 MHz,  
O-mode,  
Magn. Zen.,  
No electrojet

DMSF F16, February 25, 2008



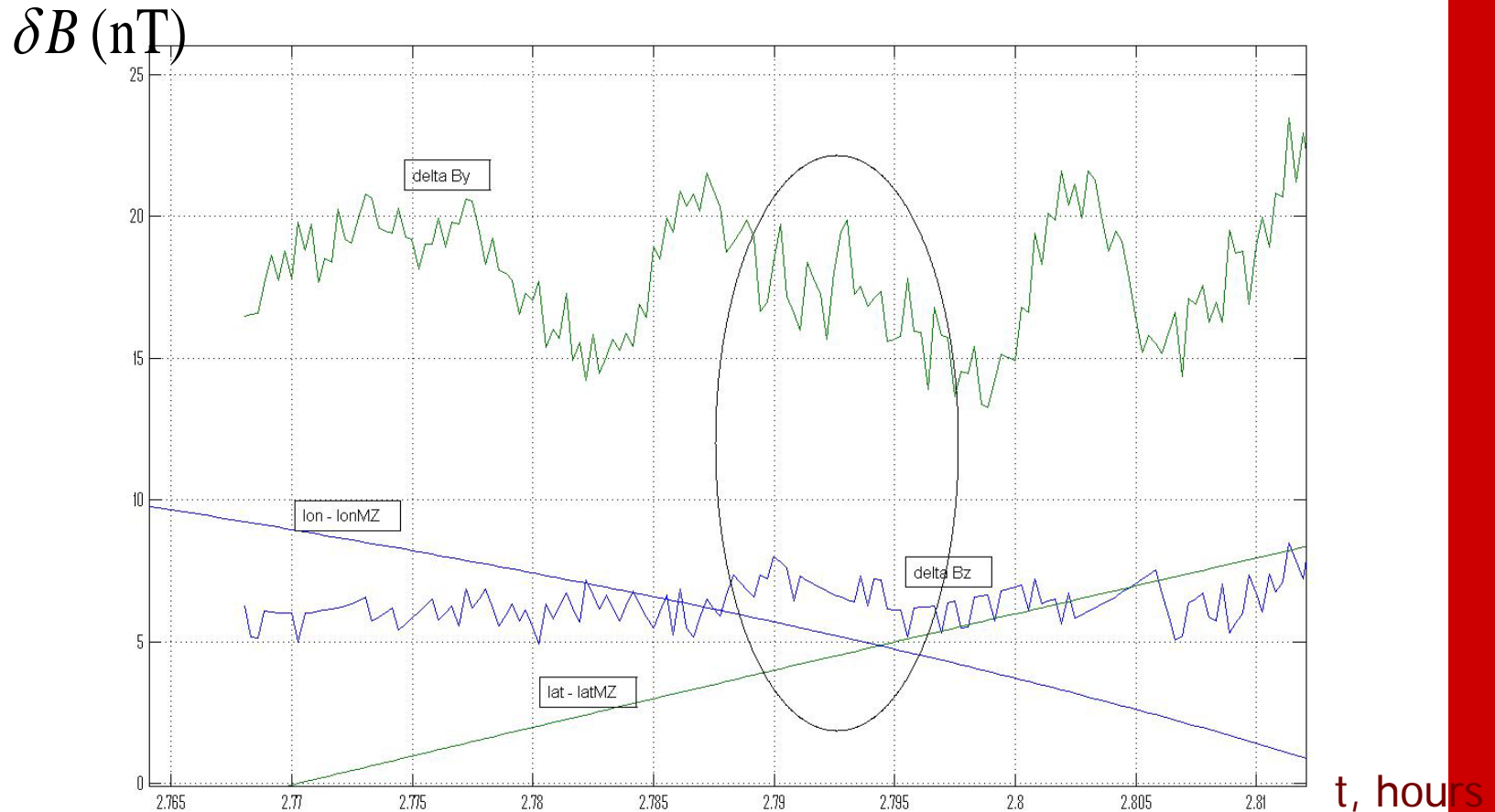
Measurements by DMSF F16 during the HAARP winter 2008 campaign, made 02/25 (top) and 02/26 (bottom). Zero time corresponds to the shortest distance from the F16 foot point to HAARP which is 500 km (02/25) and 300 km (02/26).

# Recent observations of ducts by DMSP



Zero time corresponds to F17 flew over HAARP. It is a daytime (2 UT or 17 LT), and pretty dense ionosphere.

# Magnetic field fluctuations observed 10/27/08 by F15



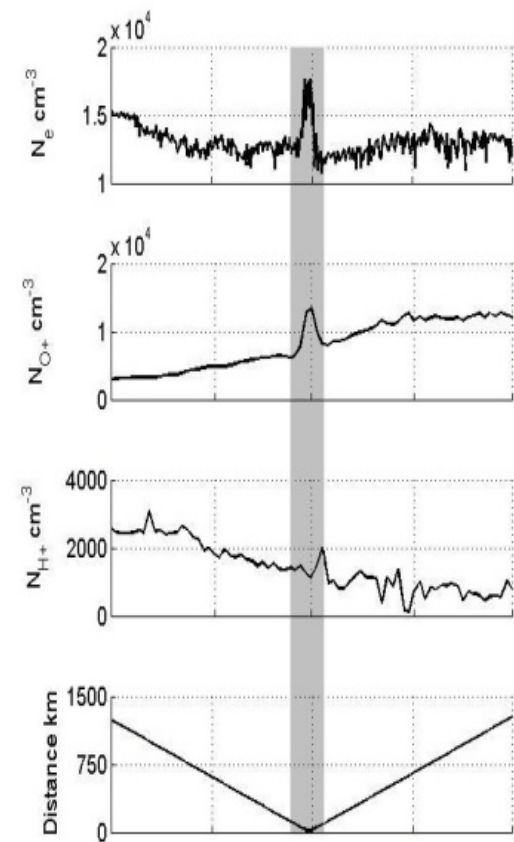
$B_y$ ,  $B_z$  fluctuations lasted for about 40 s which corresponds to 300 km.

# Mid-latitude Experiments SURA-DEMETER

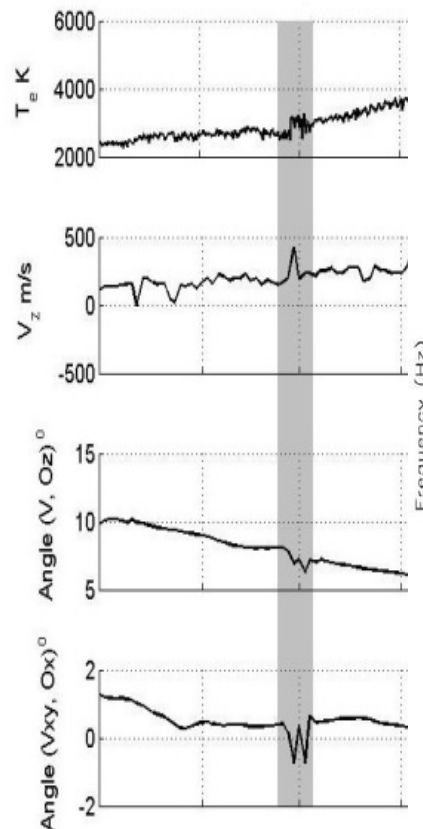
The artificial ducts were detected at nighttime, at orbit less than 50 km from the center of the heated region, lasted for 20-30 s,  $f=f_oF2 - (0.5-1)\text{MHz}$ ,  $\text{ERP} < 100\text{MW}$ .

On one occasion ducts correlated with increased electron precipitation (30-110 keV).

VLF waves were trapped by the ducts.

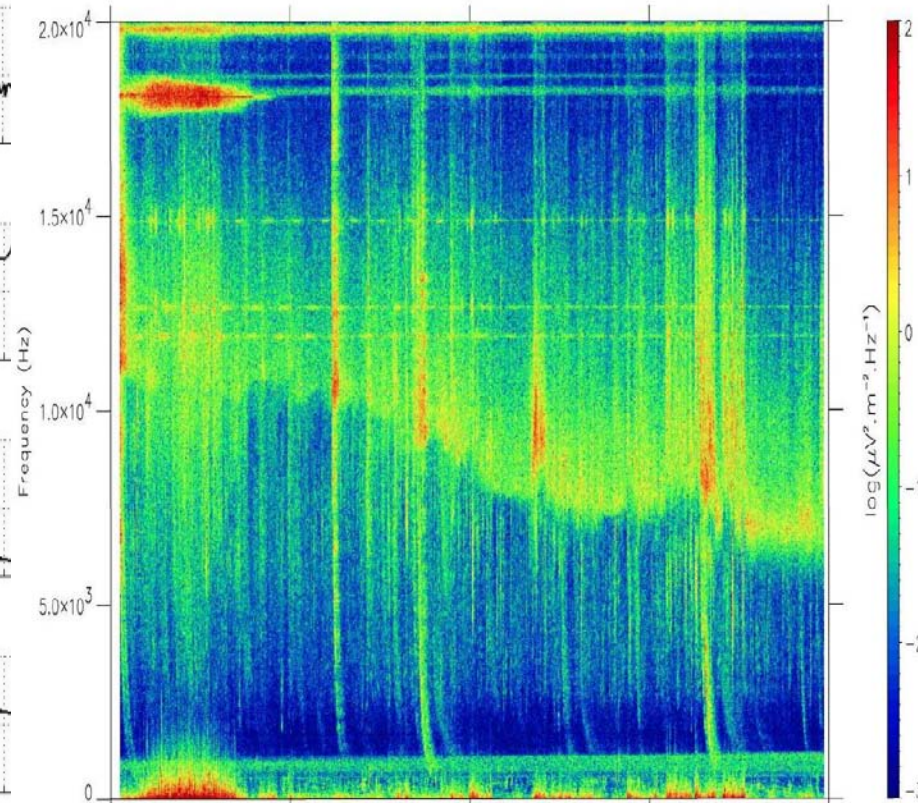


Longitude	49.8	47.9	45.8	43.1	39.6
Latitude	44.6	49.5	54.4	59.3	64.1
Time UT	18:13:46	18:15:08	18:16:30	18:17:52	18:19:13
Data	2008-05-12				



Longitude	49.8	47.9	45.8	43.1
Latitude	44.6	49.5	54.4	59.3
Time UT	18:13:46	18:15:08	18:16:30	18:17:52
Data	2008-05-12			

Date (y/m/d): 2006/05/01



LT	21:32	21:30	21:27	21:24	21:22
Lat.	53.70	55.04	56.38	57.71	59.04
Long.	45.83	45.16	44.46	43.71	42.92
L	2.53	2.68	2.85	3.03	3.23

# *Conclusions*

- Artificial ducts due to the ionospheric heating was detected by Demeter & DMSP F15, F16, F17 during nighttime.
- Modified SAMI2 model provides qualitative predictions of the outflows amplitude.
- 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.



Duct production in the auroral ionosphere require some help from the Almighty.  
Like what Moses transport company received.

