Daily and seasonal variations of TID parameters over the Antarctic Peninsula

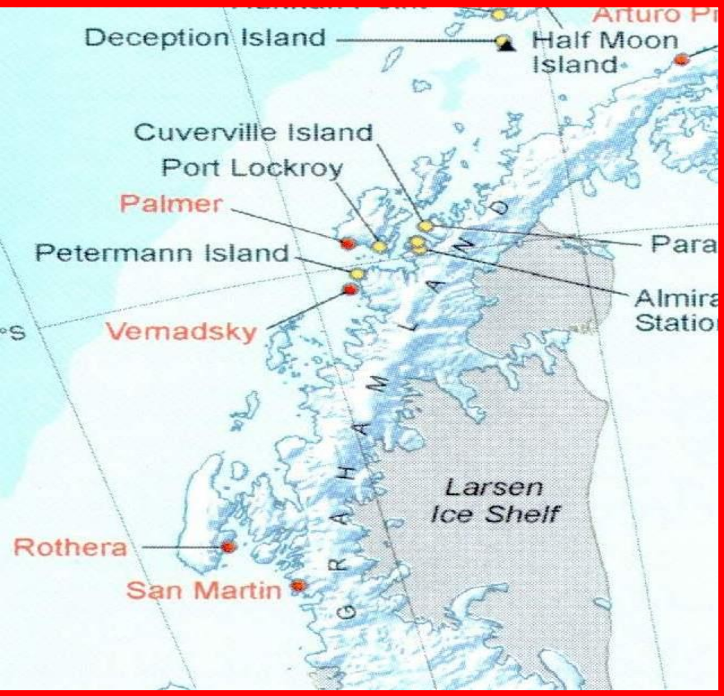
A. Zalizovski[1], Y. Yampolski[1], V. Paznukhov[2], E. Mishin[3], A. Sopin[1]

1. Institute of Radio Astronomy, National Academy of Sciences of Ukraine
2. Institute for Scientific Research, Boston College.
3. Air Force Research Laboratory/RVBXI

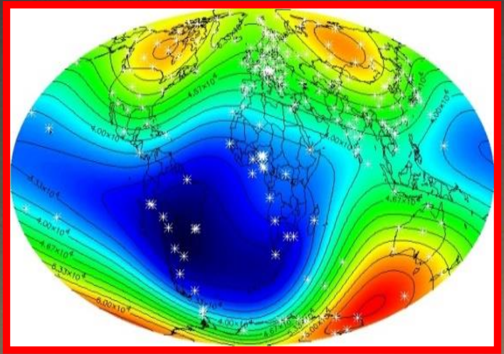
zaliz@rian.kharkov.ua

- **The results of diagnostics of AGW/TID phenomena over the Antarctic Peninsula obtained using two different RF remote sensing techniques are presented. One method is based on multi-positional GNSS TEC measurements. Another is bi-static HF Doppler ionospheric sounding.**
- **Two-position coherent HF system was installed at the *Akademik Vernadsky* (Ukraine) and *Palmer* (USA) Antarctic stations. Several GNSS receivers are located close to the HF diagnostic radio path.**
- **Quasi-periodic variations associated with TIDs were registered simultaneously in both types of data. Significant diurnal and seasonal variations of the TID time period and horizontal propagation direction are found.**

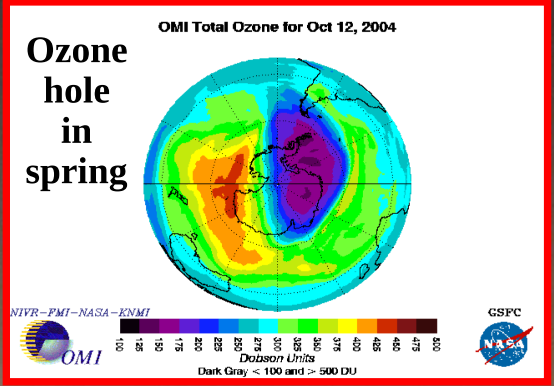
The Antarctic Peninsula is well-suited for exploring the troposphere-ionosphere energy transfer



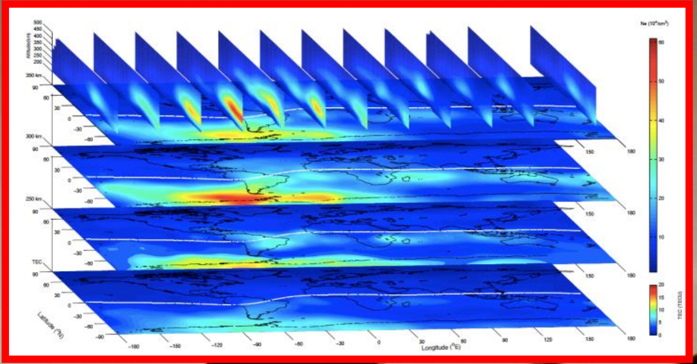
Magnetic anomaly (very low inclination)



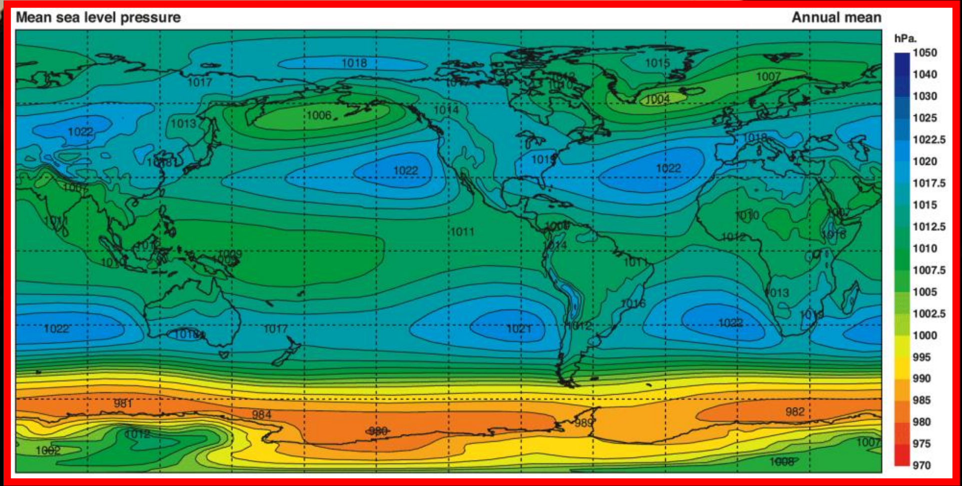
Ozone hole in spring



Weddell sea anomaly



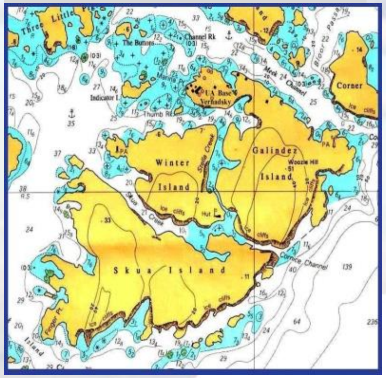
High cyclonic activity



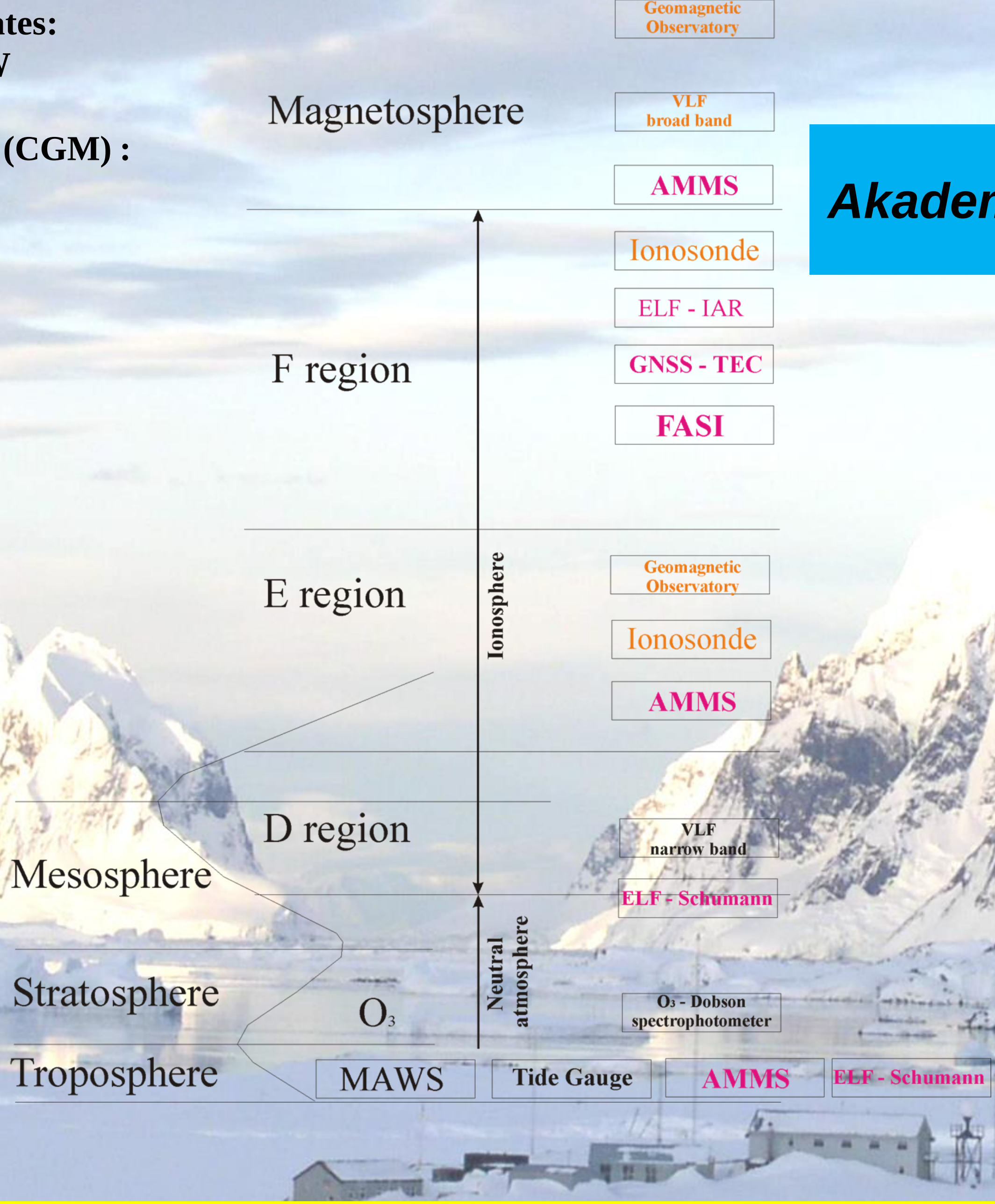
Geographic coordinates:
65.25° S, 64.27° W

Geomagnetic coordinates (CGM) :
50° S, 9° E

Argentine Islands Archipelago

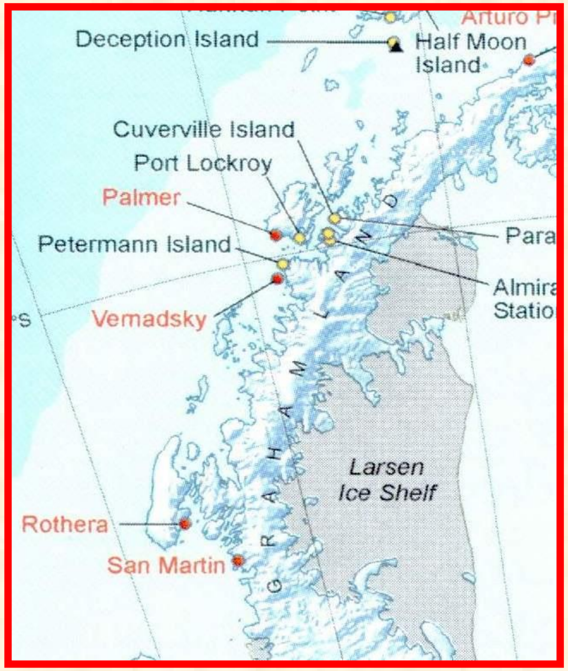


Akademik Vernadsky



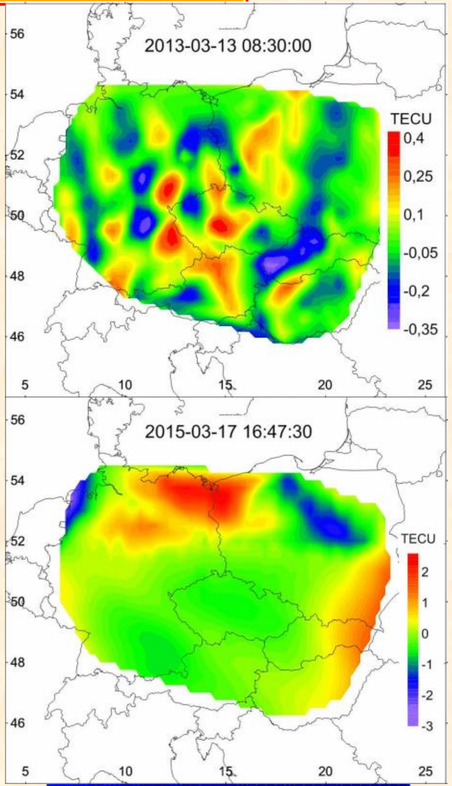
Analyses of long-term data sets obtained at the Ukrainian Antarctic station *Akademik Vernadsky* (former UK *Faraday*) have specified the weather impact on the dynamics of the E and F regions

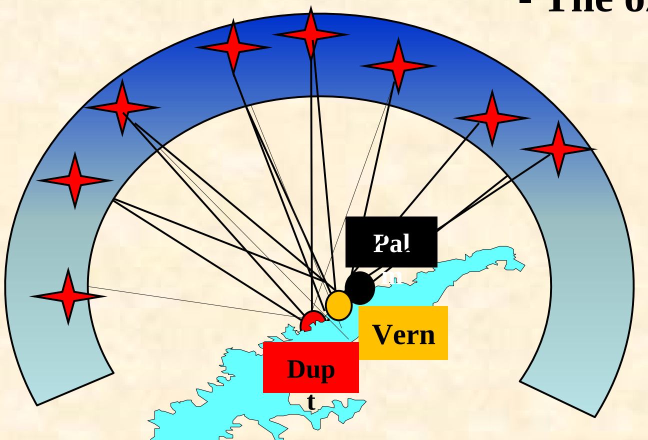
GNSS-TEC radioscopy of the ionosphere over the Antarctic Peninsula and Europa



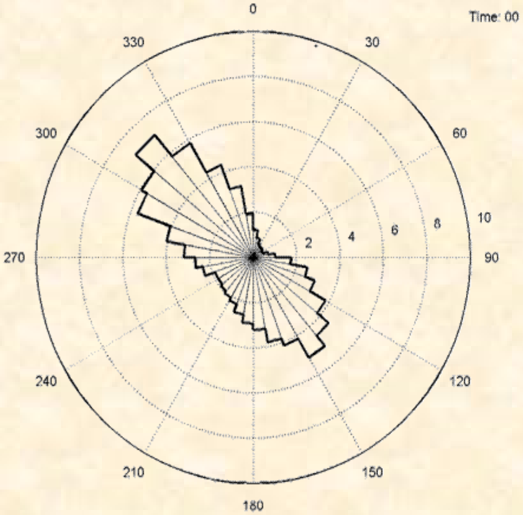
Advantages of Antarctic Peninsula for AGW/TID study

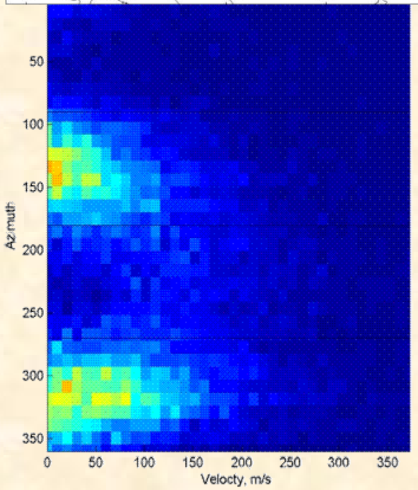
- Favorable interference situation
- Maximal difference between geomagnetic and geographic latitudes.
- Extreme cyclonic activity.
- Calm background conditions of mid latitudinal ionosphere.
- Geomagnetic anomaly.
- Weddell Sea ionospheric anomaly.
- The ozone hole.





Radioscopy of AGW/TID by signals of GNSS satellites





Diagnostics of Ionospheric Disturbances over the Antarctic Peninsula using GNSS TEC Measurements

Location of the GNSS stations in the Antarctic Peninsula region (http://sopac.ucsd.edu/map.shtm).

Coordinates of the GPS stations:

- **PALM** (Palmer station)	64.78 S, 64.05 W;
- **VNAD** (Vernadsky station)	65.25 S, 64.25 W;
- **DUPT**	64.81 S, 62.82 W;
- **PRPT**	66.01 S, 65.34 W;

GNSS TEC measurements

For TEC perturbations represented in the form:

$$I(x,y,t) = I(x(t)\sin\alpha + y(t)\cos\alpha - Vt)$$

Solution (azimuth and V) can be found as :

$$\gamma(t) = \pm\sqrt{\gamma_x^2(t) + \gamma_y^2(t)}$$

$$\sin\alpha(t) = \gamma_x(t)/\gamma(t)$$

$$V(t) = \frac{1}{\gamma(t)}\left[\gamma_x(t)\frac{dx_p(t)}{dt} + \gamma_y(t)\frac{dy_p(t)}{dt} - I'(t)\right]$$

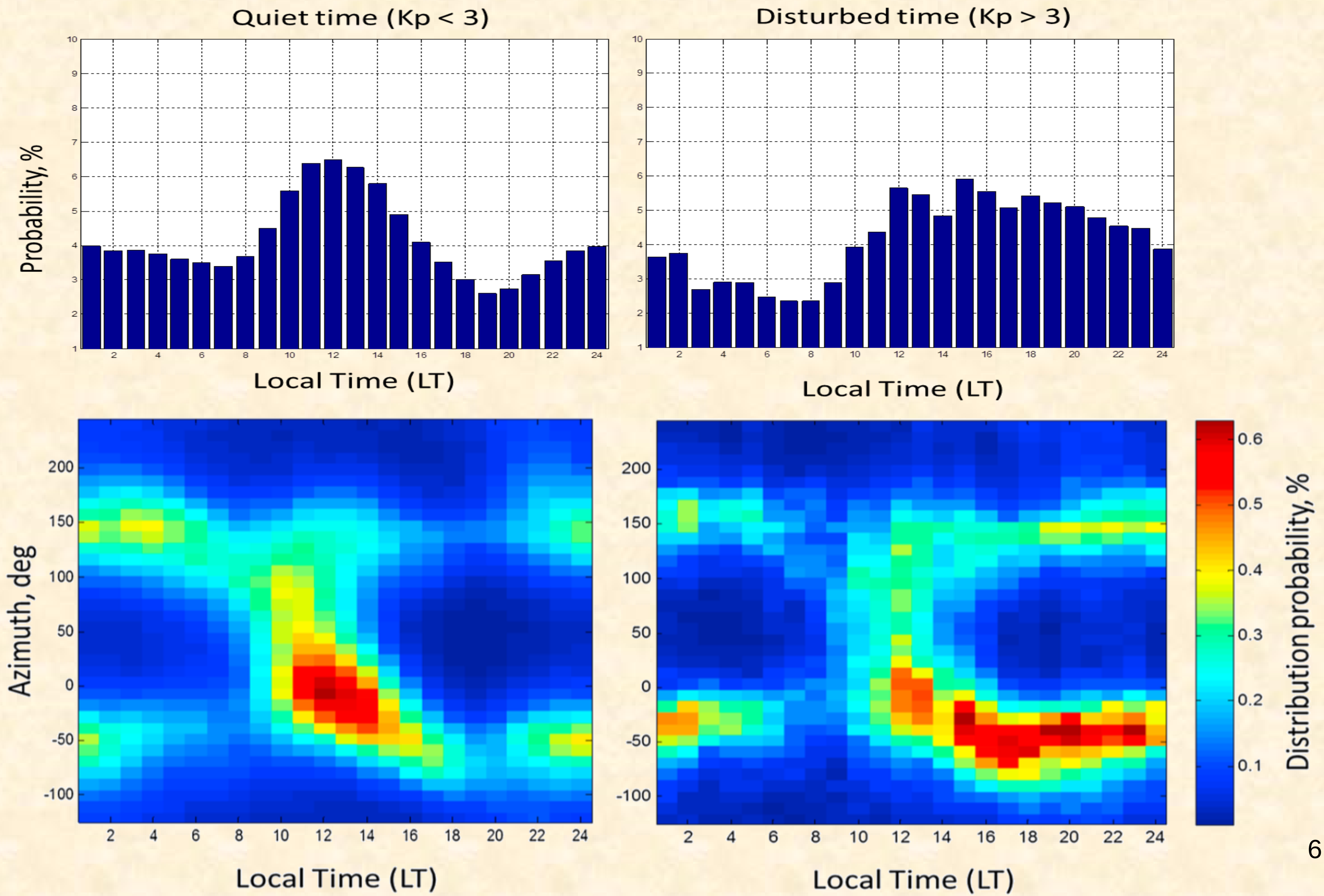
Spatial and temporal gradients numerically estimated as:

$$I_1'(t_n) \approx \frac{I_1(t_n) - I_1(t_{n-1})}{\Delta t}$$

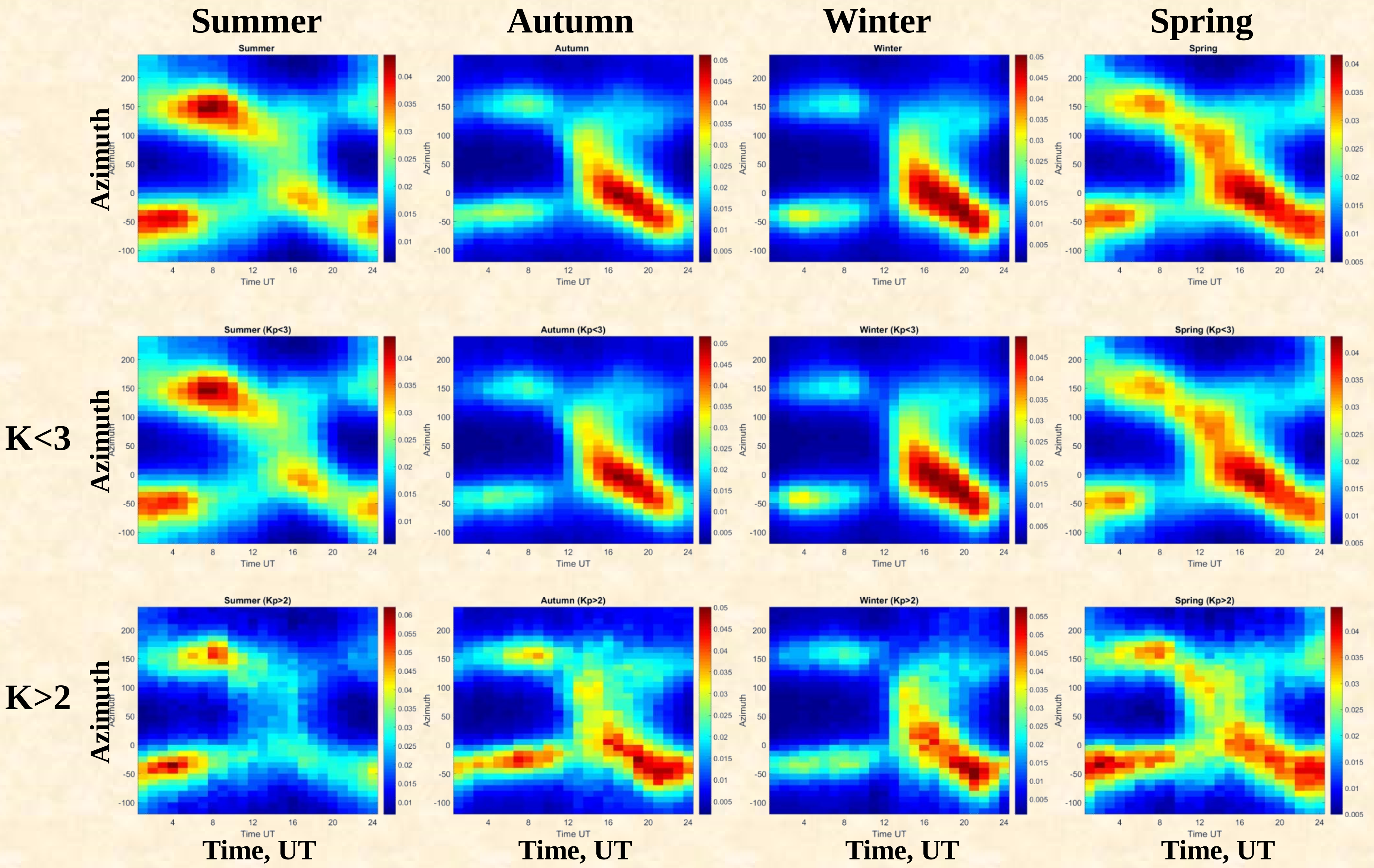
$$\gamma_x(t_n) \approx \frac{y_3\cdot(I_2(t_n) - I_1(t_n)) - y_2\cdot(I_3(t_n) - I_1(t_n))}{x_2y_3 - x_3y_2}$$

$$\gamma_y(t_n) \approx \frac{x_2\cdot(I_3(t_n) - I_1(t_n)) - x_3\cdot(I_2(t_n) - I_1(t_n))}{x_2y_3 - x_3y_2}$$

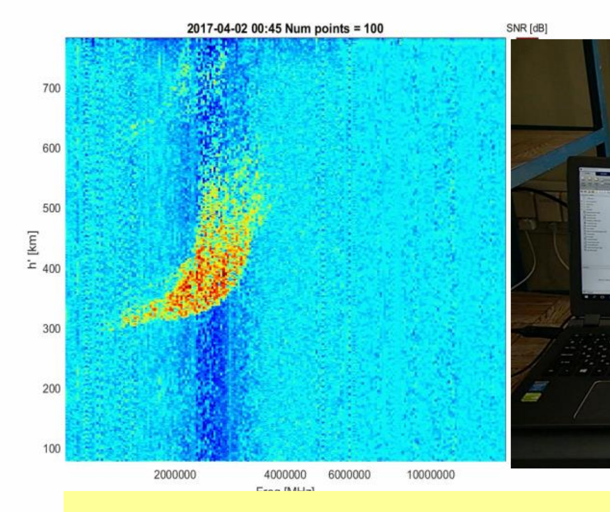
DIURNAL AND SEASONAL VARIATIONS OF AGW/TID PARAMETERS OBTAINED USING GNSS/TEC TECHNIQUE

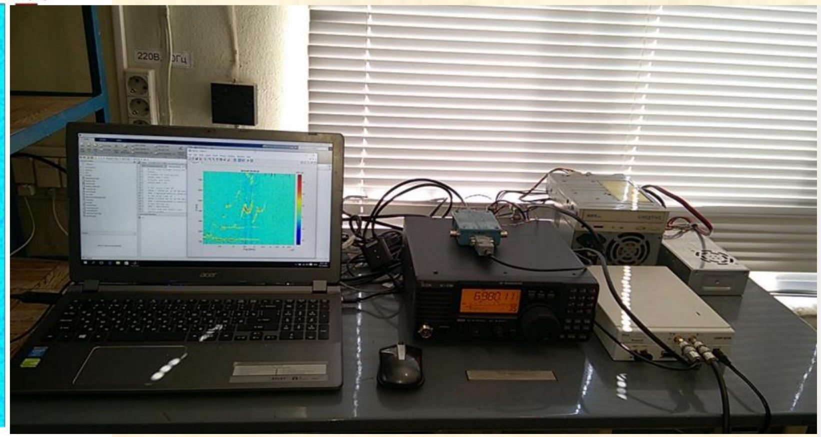


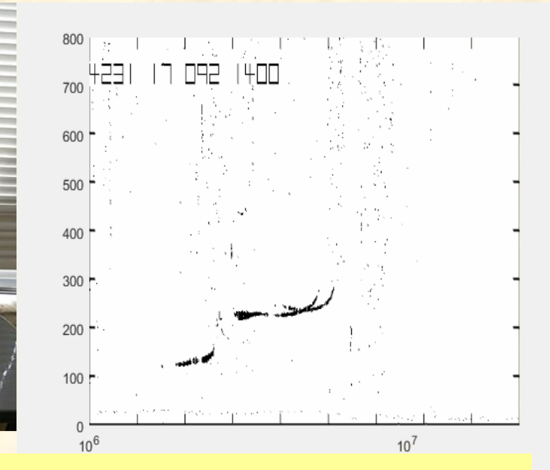
Seasonal variations of TID parameters for 2009-2015 from GNSS/TEC



RECENTLY-INSTALLED HF TOOLS

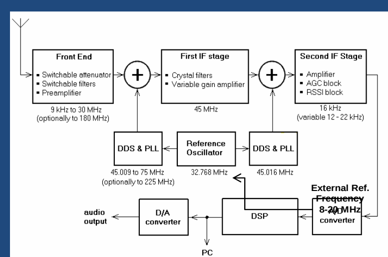






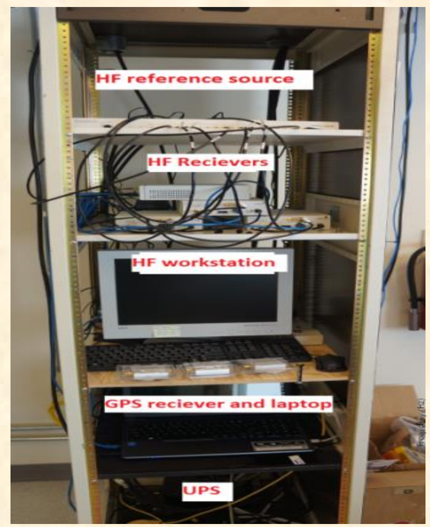
Digital Ionosonde Prototype since April 2017

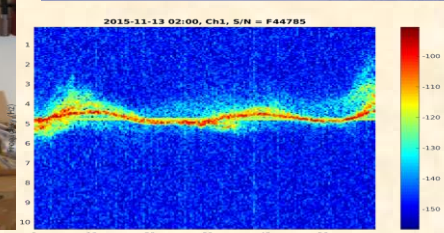
Automatic remotely controlled receiving HF facilities



Receiver type	DSP-based SDR
Frequency range	9 kHz - 30 MHz
Tuning resolution	1 Hz
Spurious-free dynamic range	95 dB
Bandwidth	1 - 15000 Hz (adjustable in 1 Hz steps)
Intermediate frequencies	IF1: 45 MHz IF2: 16 kHz (variable 12-22 kHz)
Roofing filter	2 x 4-pole 15 kHz crystal filter
Antenna input	50 ohm (SMA connector)
Form factor	2/3 length PCI card (PCI 2.2 compliant)
Weight	330 g

Unified HF installation, 2010-2015 (LFO, UAS, Svalbard, Tromso)

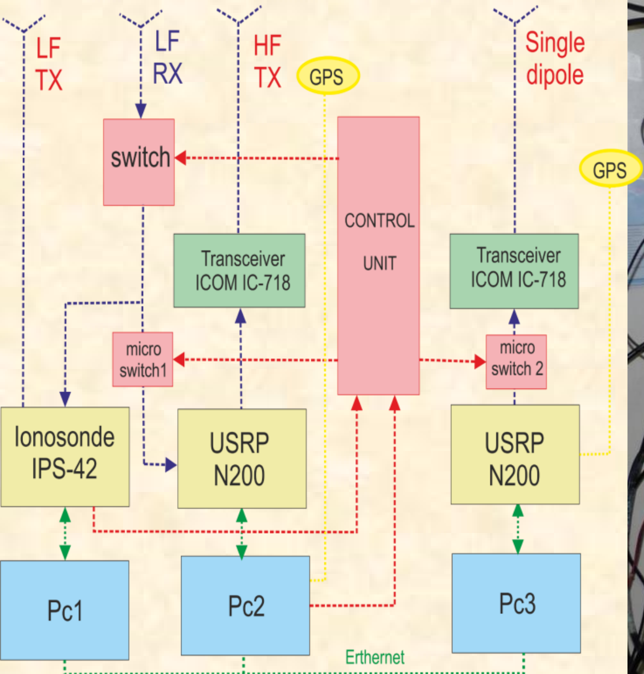


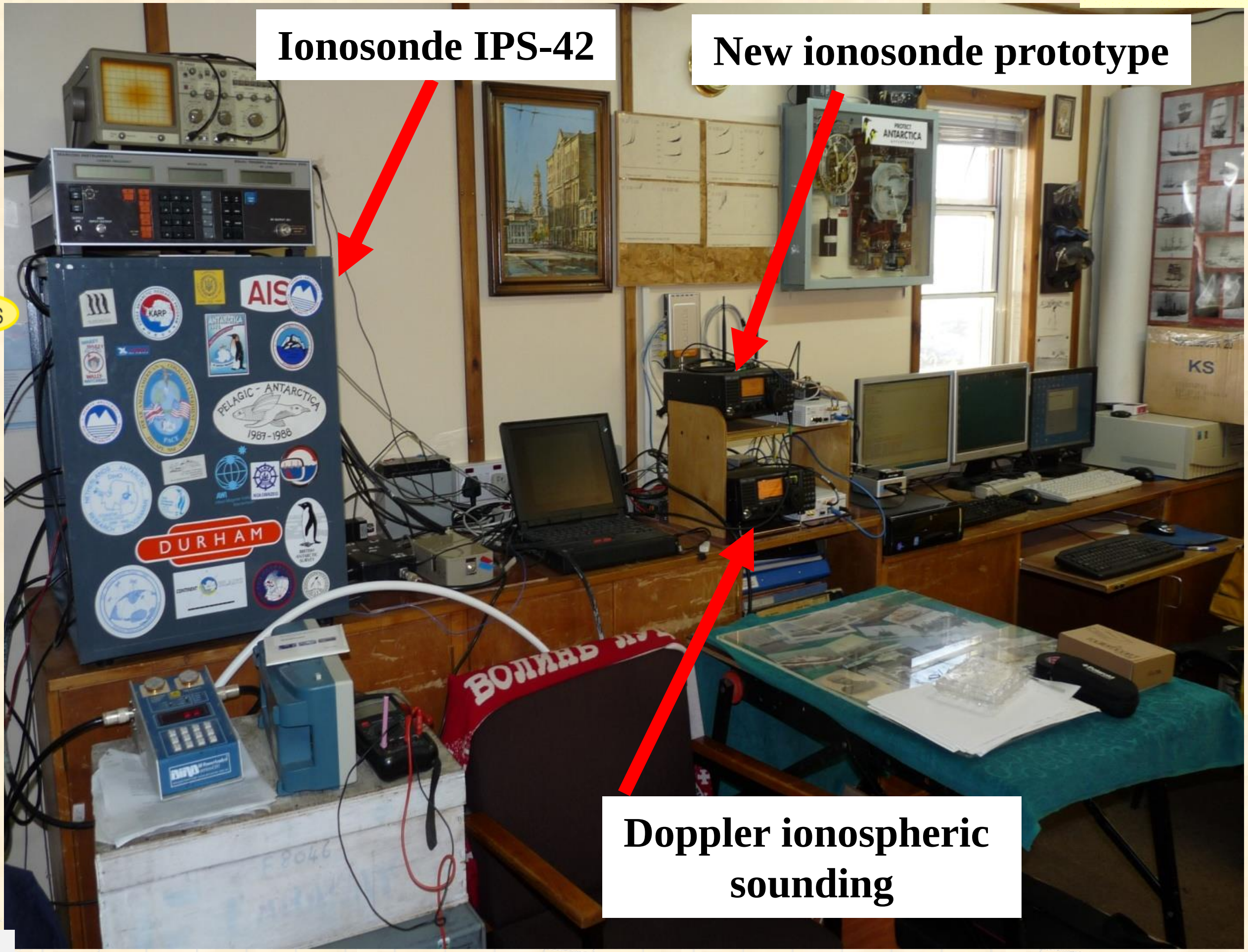


HF complex for Doppler ionospheric sounding at UAS-Palmer radio line since 2015 (IRA NASU – Boston College)

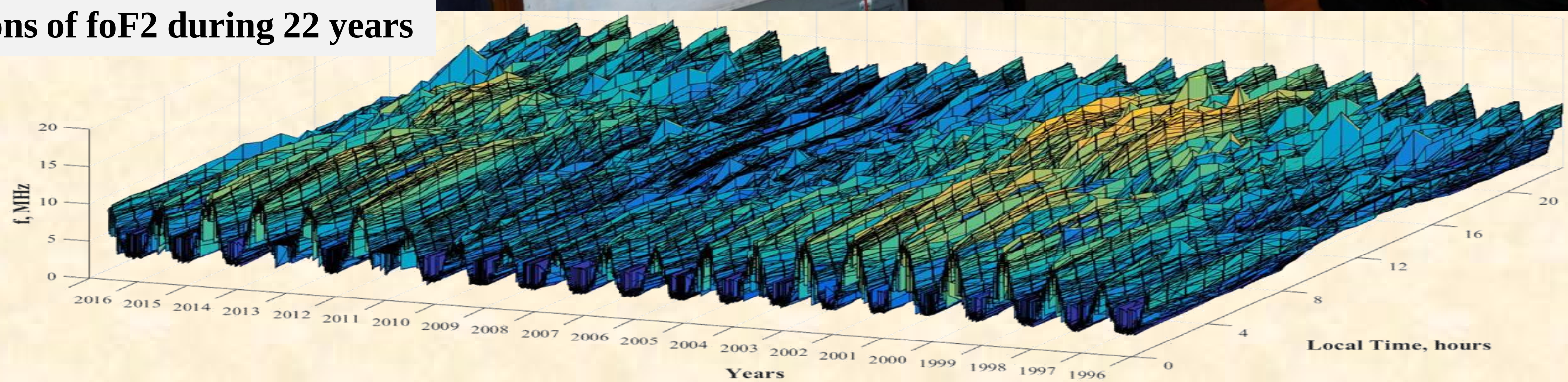
REMOTE SENSING TOOLS

Functional diagram



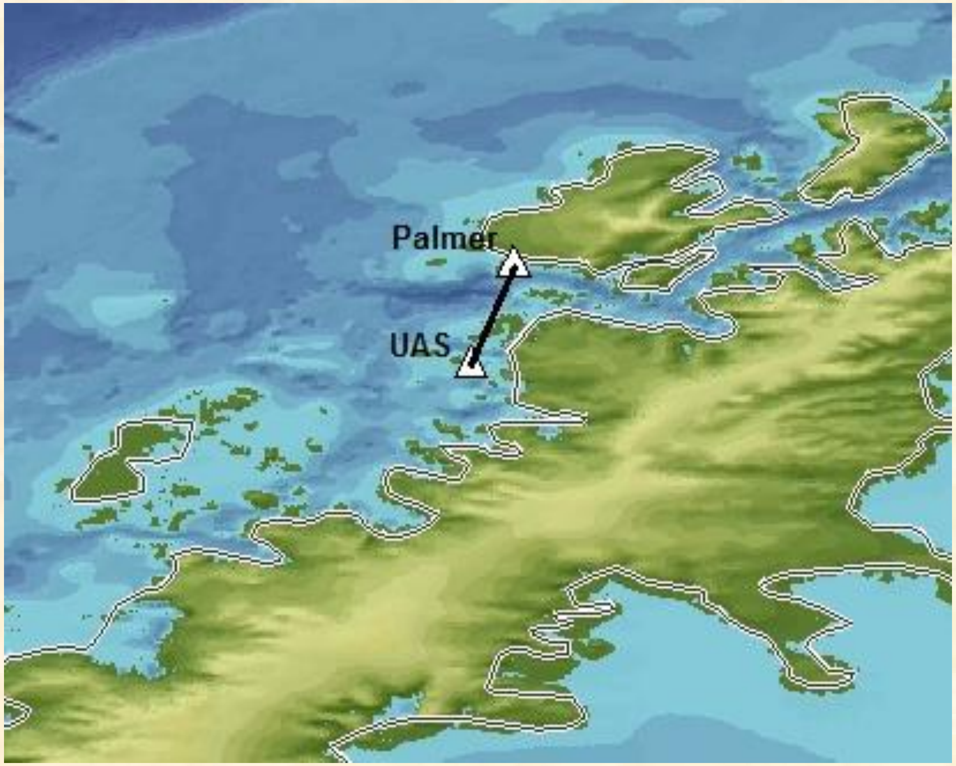


Variations of foF2 during 22 years

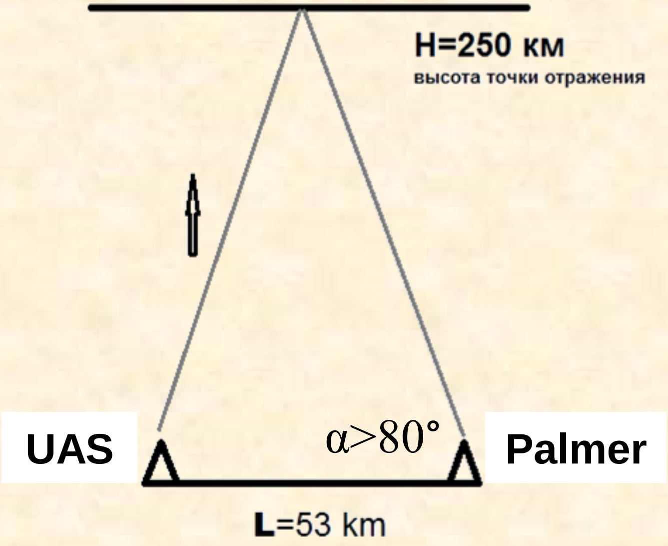


HF Doppler measurements

- **2-position coherent system for measuring the Doppler frequency shifts (DFS) of probing signals was implemented with assistance from Boston College. Transmitting and one receiving systems were installed at *Akademik Vernadsky* and another receiving system was installed at *Palmer* 53 km almost along the meridian.**
- **Systematic measurements of DFS started at both sites in May 2015. Quasi-periodic DFS variations stimulated by AGW/TID processes are found. Their parameters, such as time periods and projection of the wave vectors along the meridian are calculated and analyzed.**



The distance between UAS and Palmer:
L ~53 km.
Azimuth «UAS-Palmer» ~10°.

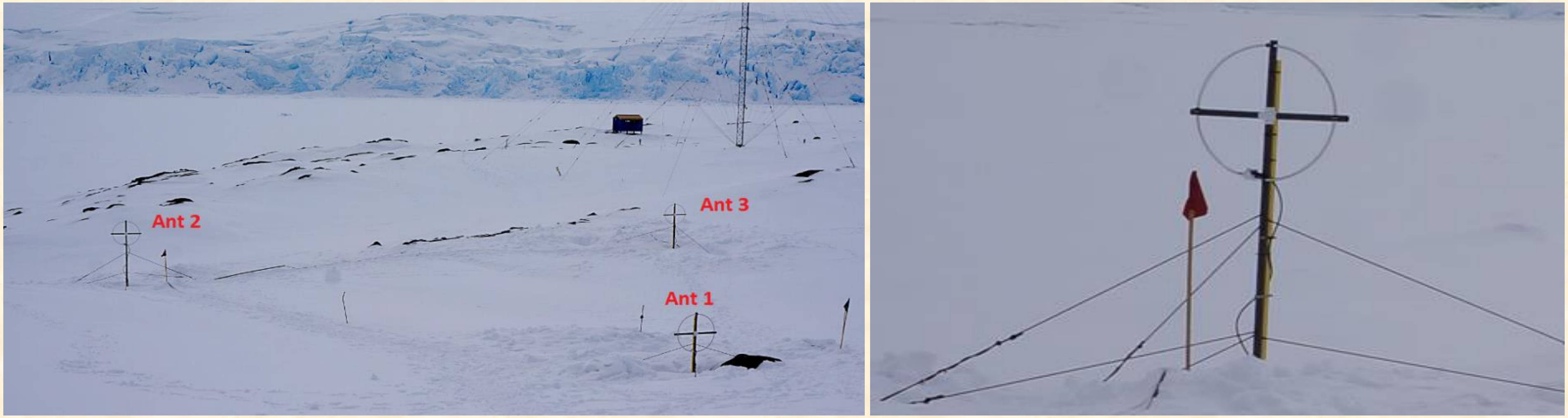


HF Doppler measurements

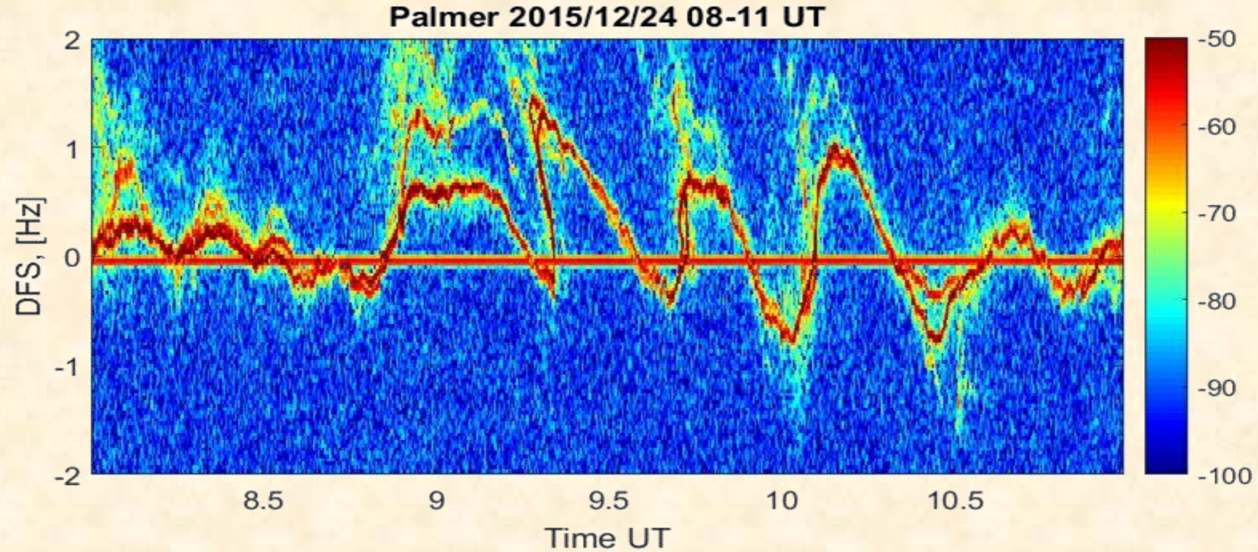
Receiving loop HF antennas at UAS

Terminated folded dipole transmit antenna at UAS

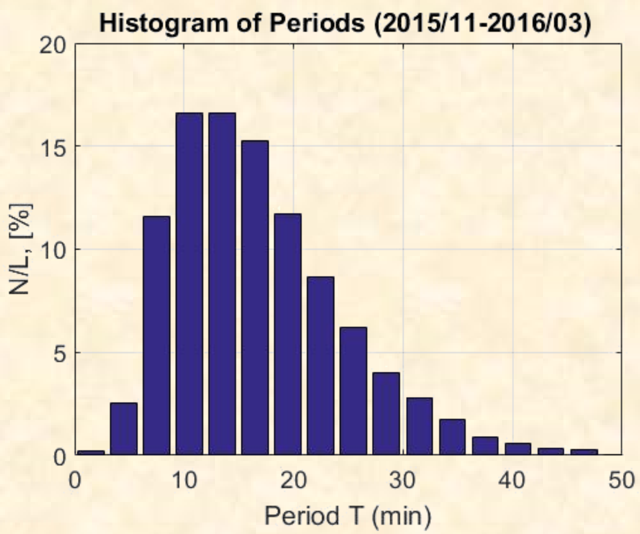
Receiving HF antennas at Palmer



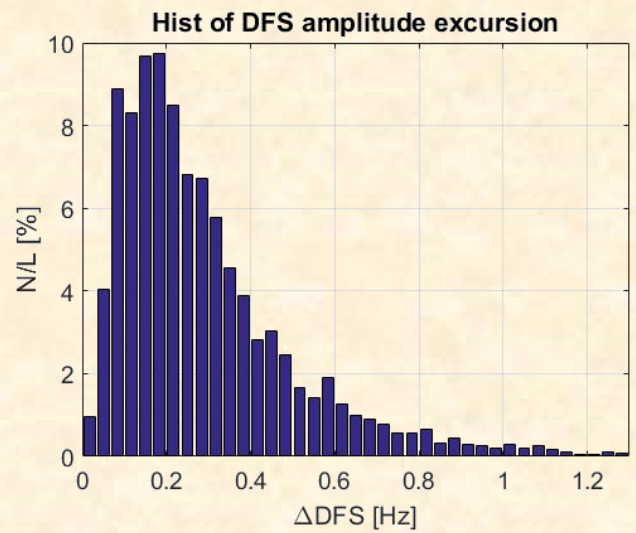
HF Doppler measurements



HF signal spectrogram recorded at *Palmer* station on 2015/12/24, 8:00-11:00 UT.



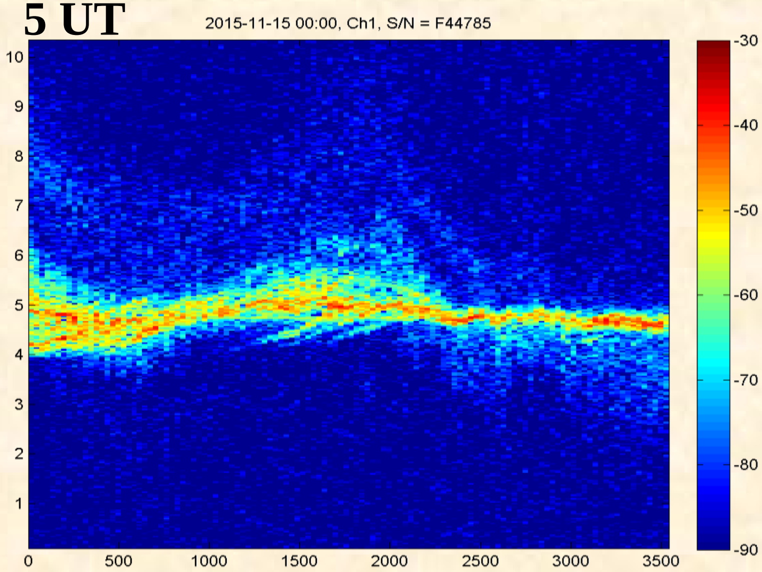
Distribution of periods of DFS variations



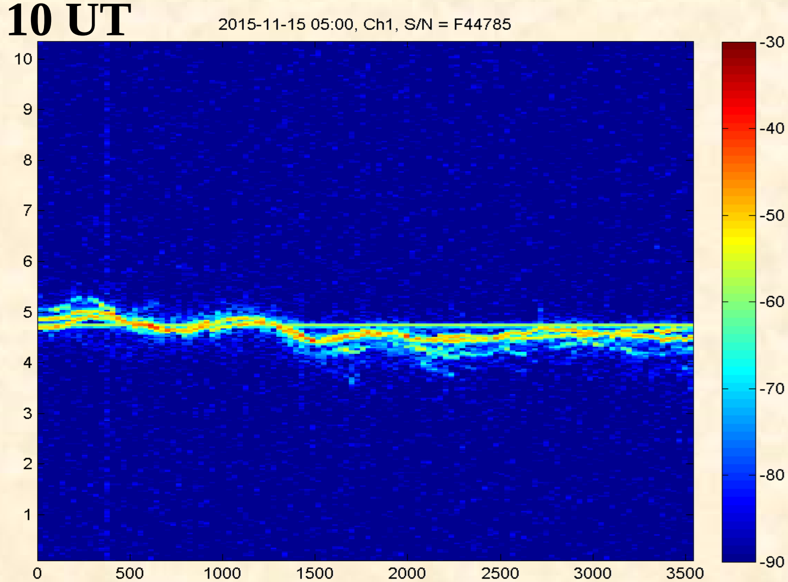
Distribution of amplitude excursion of DFS variations

AGW/TID periods over Antarctic Peninsula from HF Doppler sounding. November 15, 2015

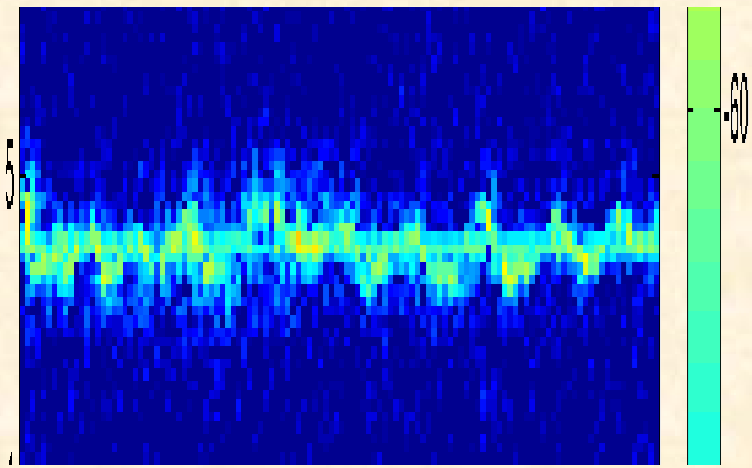
5 UT



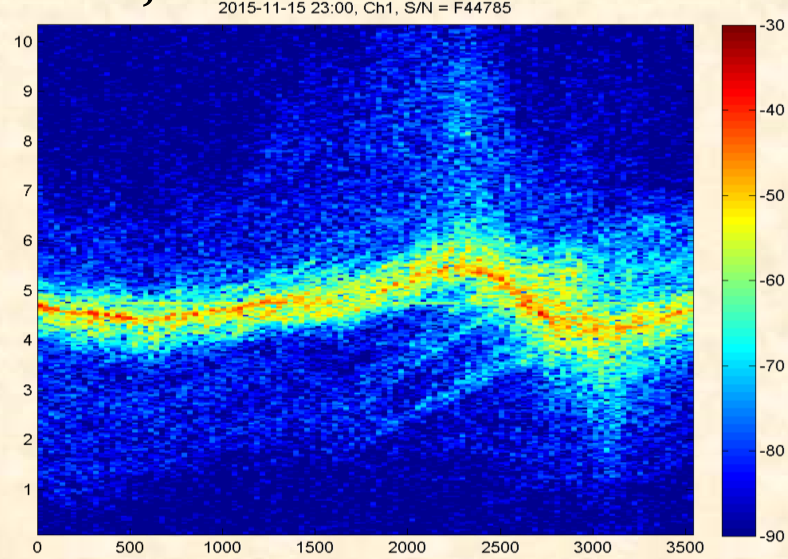
10 UT



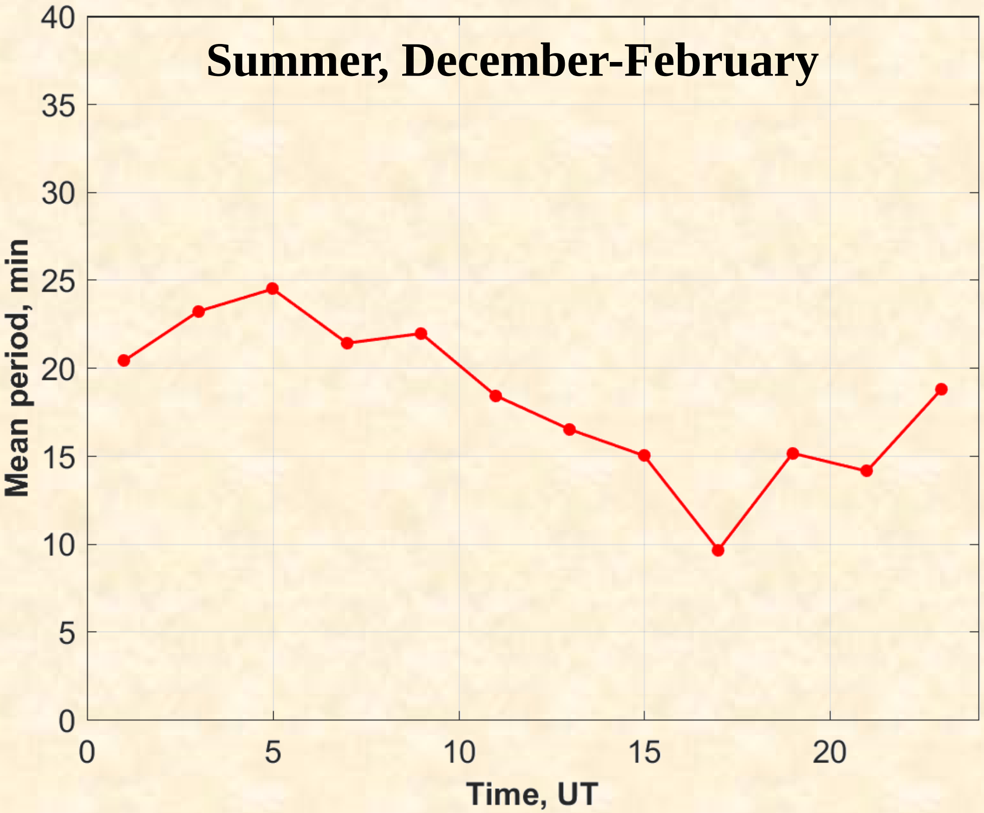
15 UT



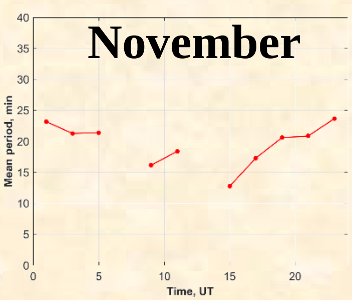
4 UT, Nov 16

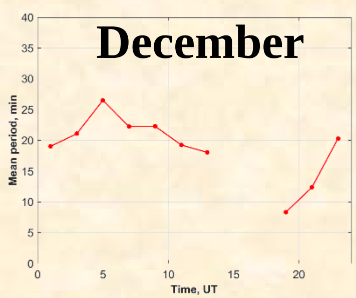


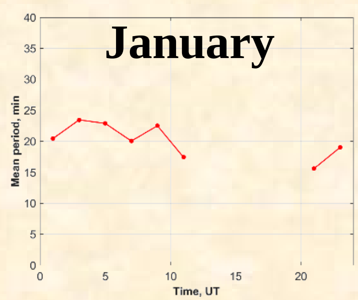
AGW/TID periods over Antarctic Peninsula from HF Doppler sounding. November, 2015 - February, 2016

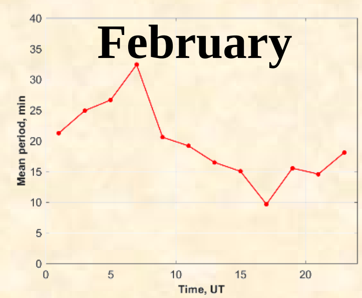


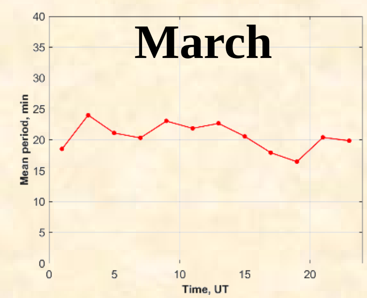
A statistical processing of AGW/TID periods estimated using DFS variations of probing HF signals for UAS-Palmer radio link was carried out for the time interval from November, 2015 to March, 2016. For the summer months in Southern hemisphere (December-February) the so strong daily variation of AGW/TID periods is observed with maximum at the night hours (25-30 minutes) and minimum at the daytime (10-15 minutes). Such dependence is probably associated with diurnal variations of reflection altitudes as well as value of Brunt-Vaisala frequency.



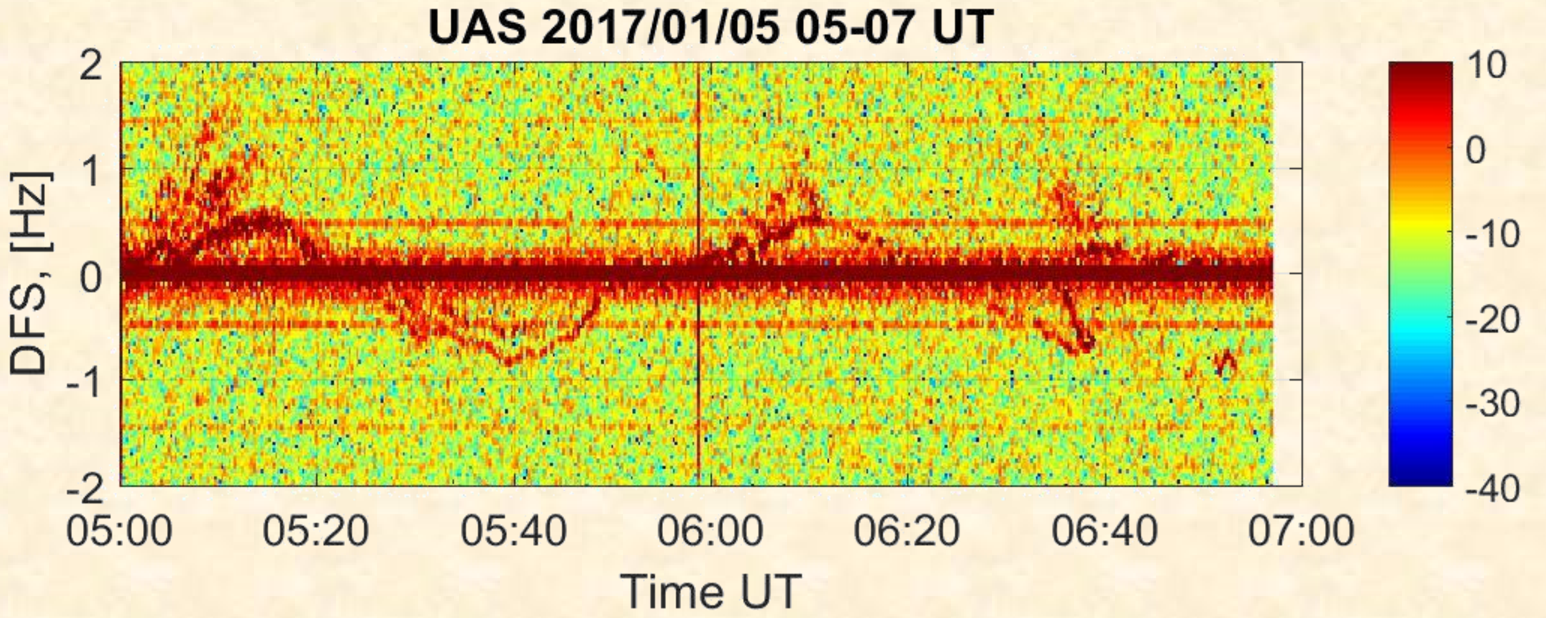


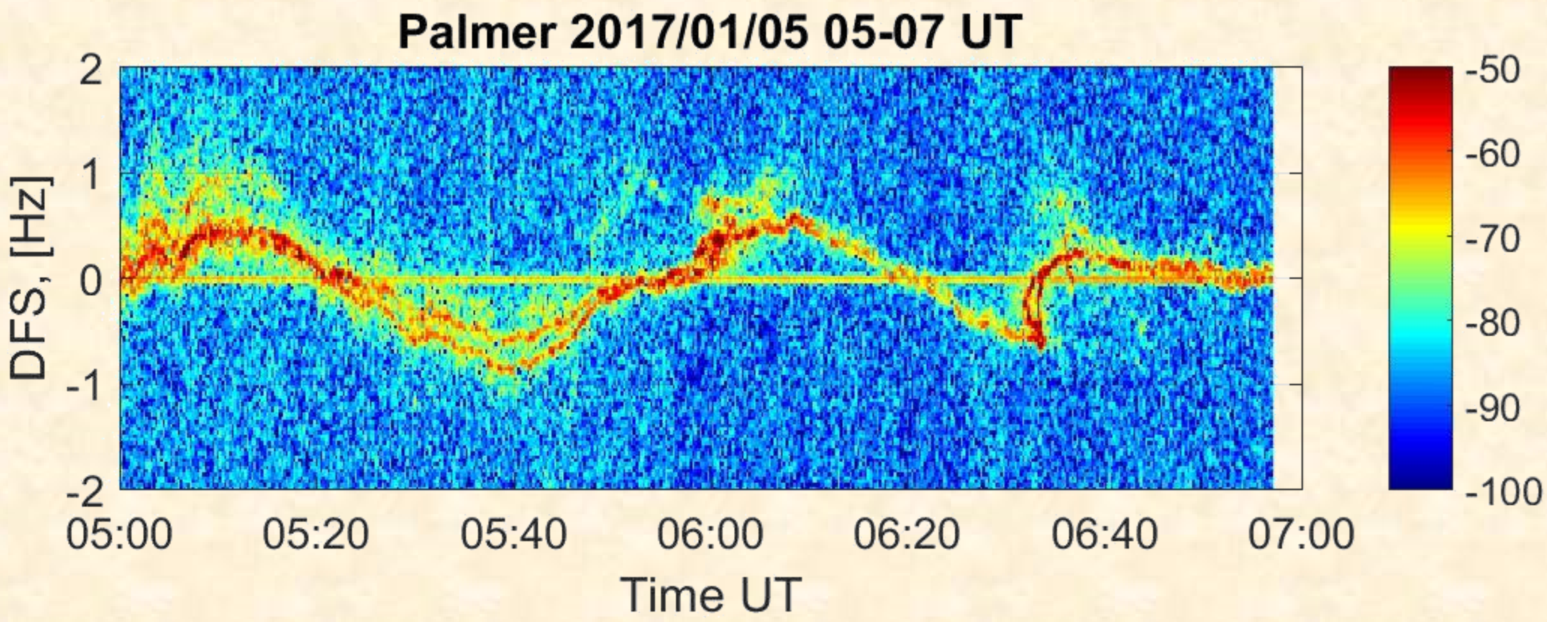




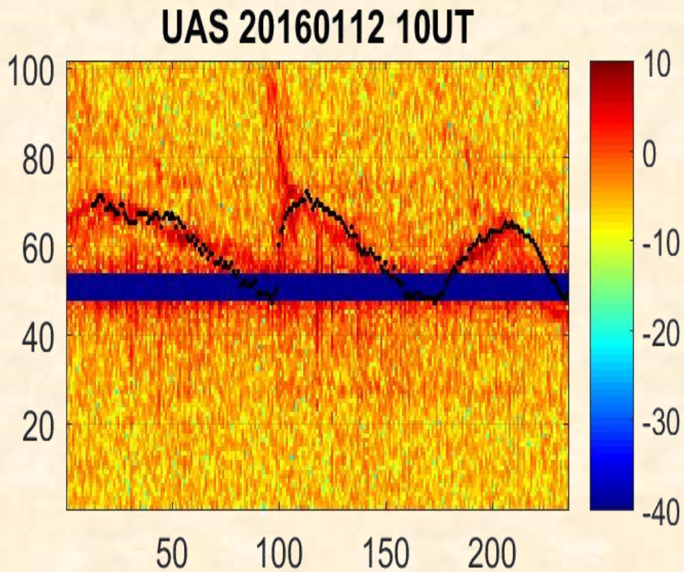


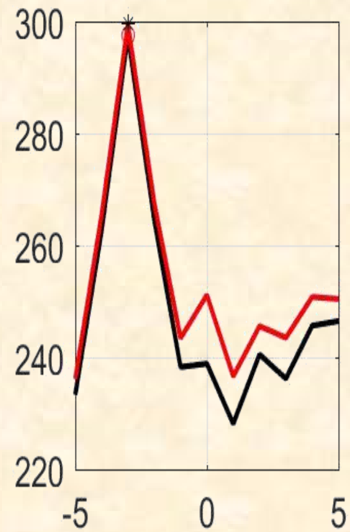
2-position HF Doppler sounding of TID at *Vernadsky-Vernadsky* and *Vernadsky-Palmer* radio paths

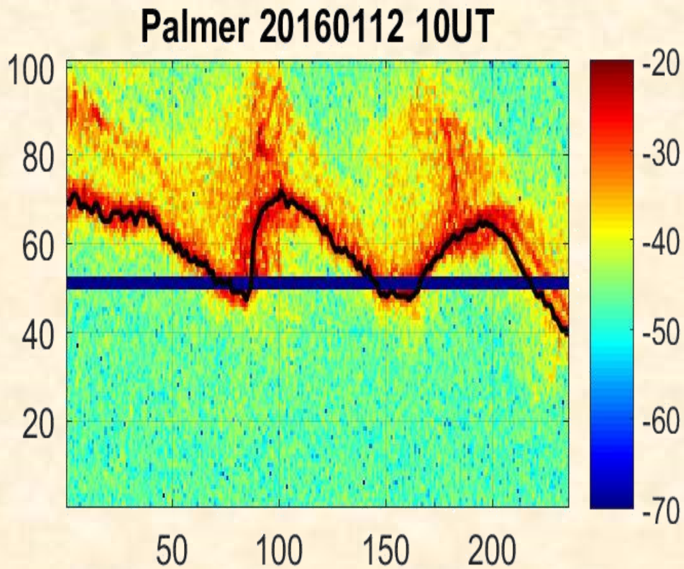




HF Doppler sounding of AGW/TID at UAS-UAS and *UAS-Palmer* radio path







dX= 15

dT= 4 HAND

dt= +11 t>0 (Palm>Uas)

---

dt -2 -1 0 +1 +2

v1 +13 + 6 + 3 + 0 + 4 SUM

v1 +13 + 6 + 3 + 0 +18

---

v1 100 95 90 85 76 CCF= 6

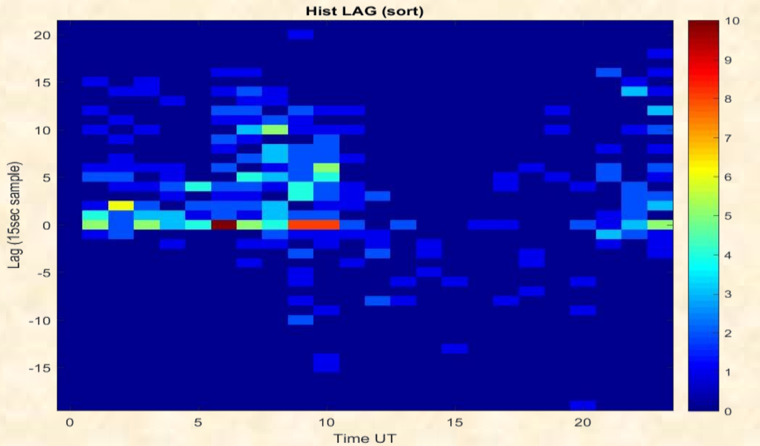
v1 100 95 90 84 75 t= -2

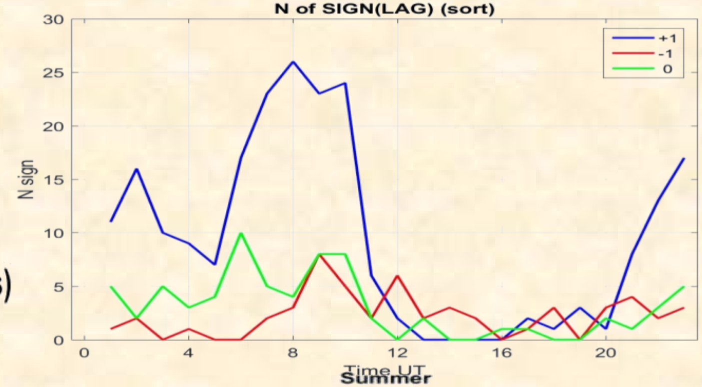
---

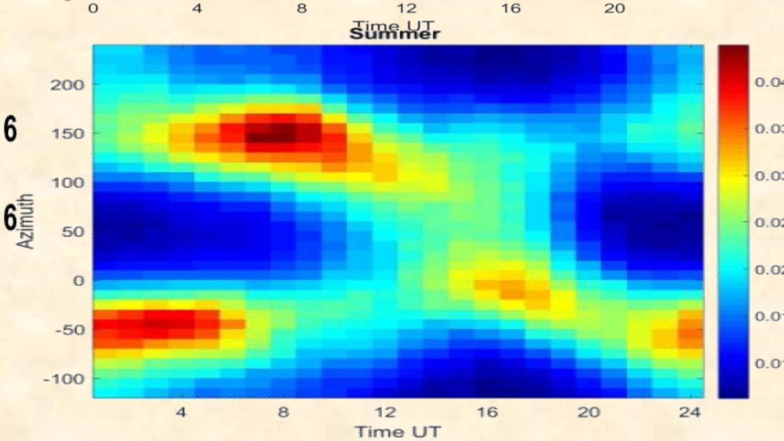
v1 + 10 + 10 + 10 + 13 + 14 CCF= 6

v1 + 6 + 6 + 6 + 1 + 10 t= -2

Diurnal variations of movement directions at November 2015-March 2016

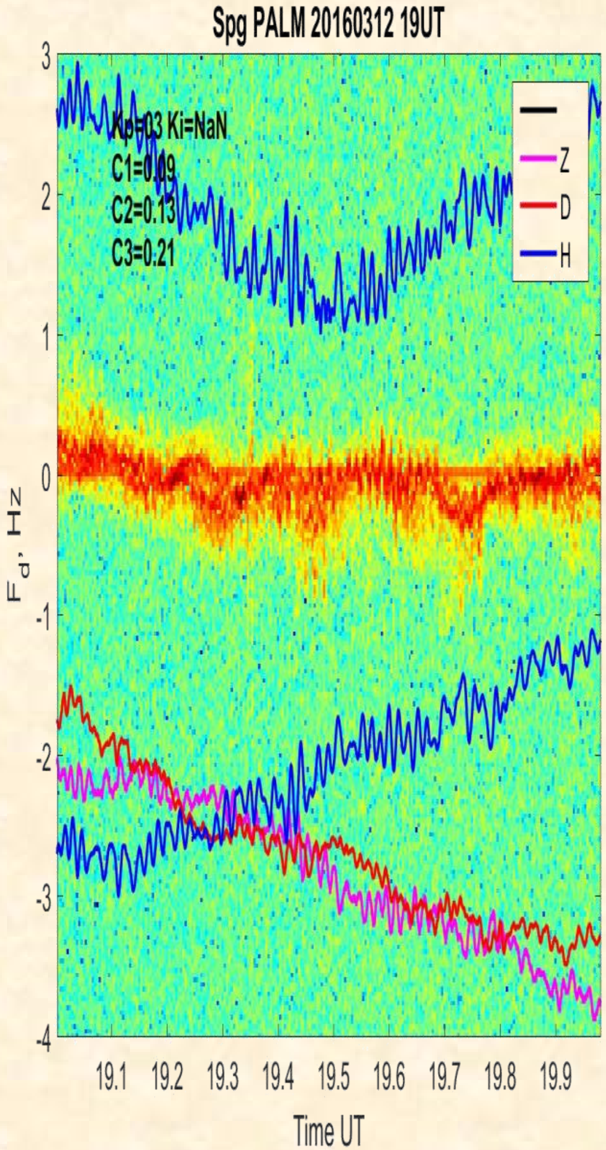




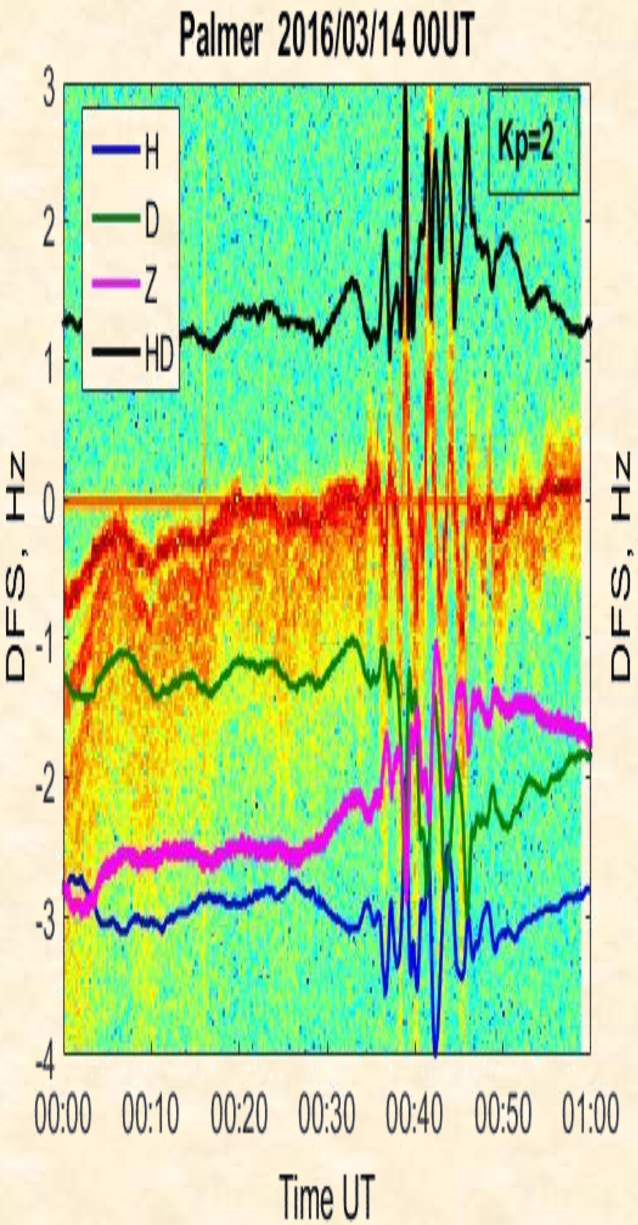


HF Doppler sounding of TID at *Vernadsky-Palmer* radio path. Examples of ionospheric disturbances associated with MHD waves

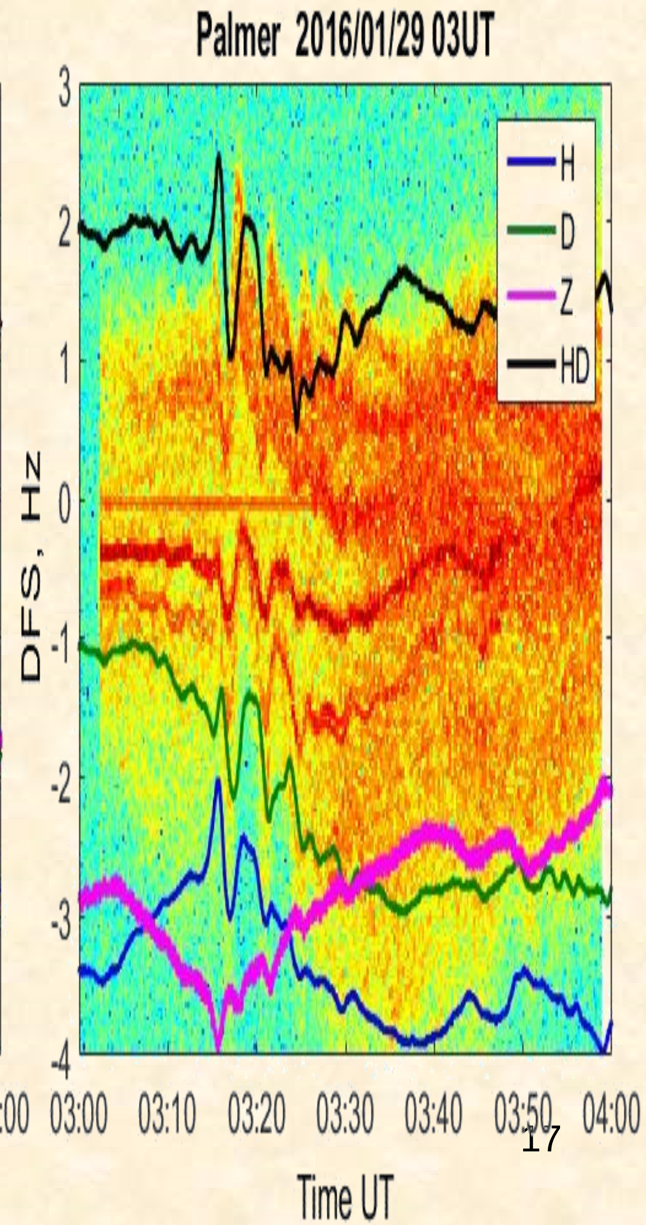
Pc3



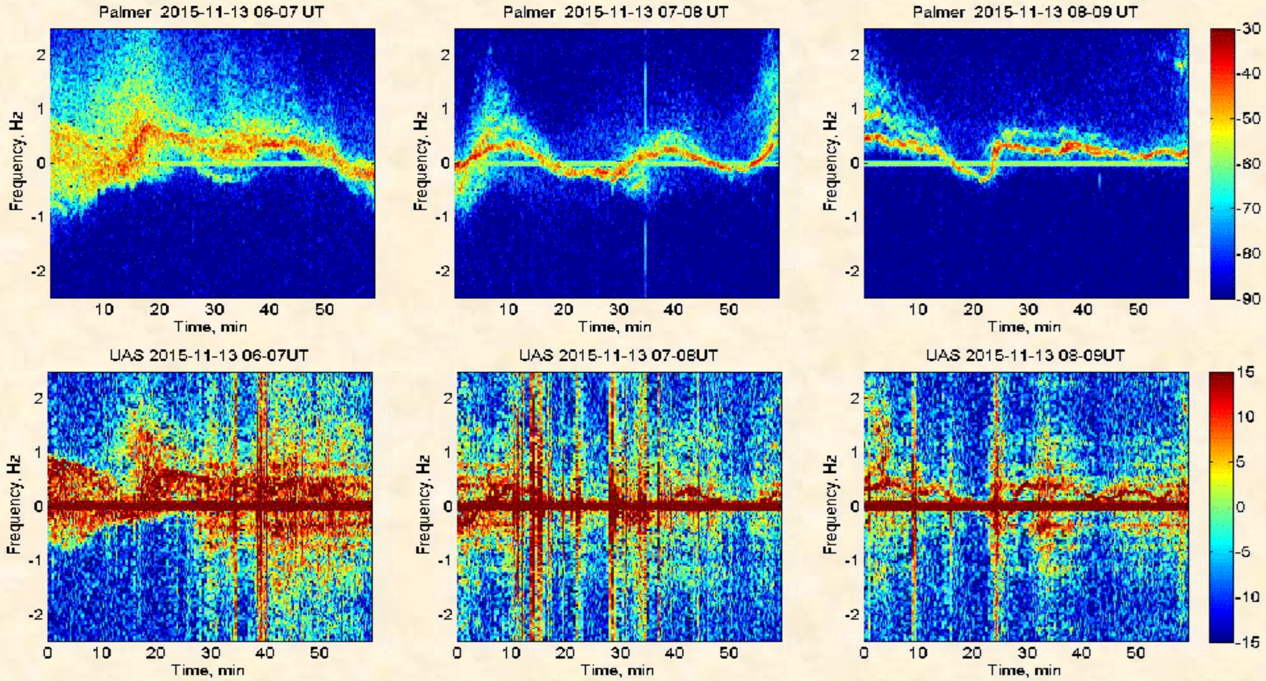
Pc4



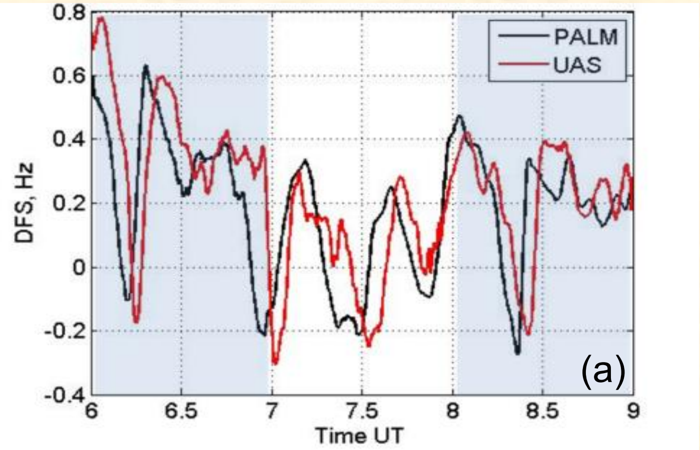
Pc5?

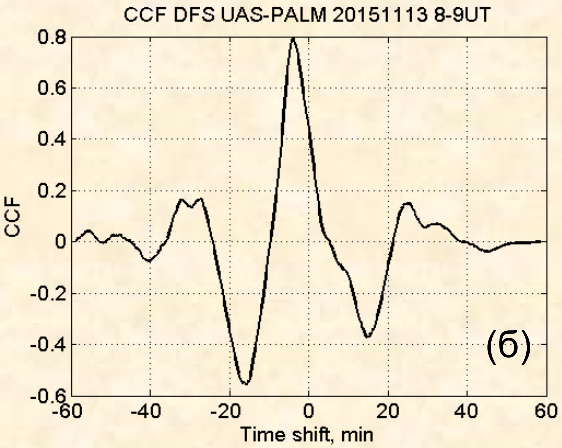


Diagnostics of Ionospheric Disturbances over the Antarctic Peninsula using both GNSS/TEC and Coherent HF Ionospheric Sounding



Spectrogram of HF signal (f_w= 5.555 MHz) recorded at Palmer (upper panel) and UAS (lower panel) stations on 2015.11.13, 6:00-9:00 UT.



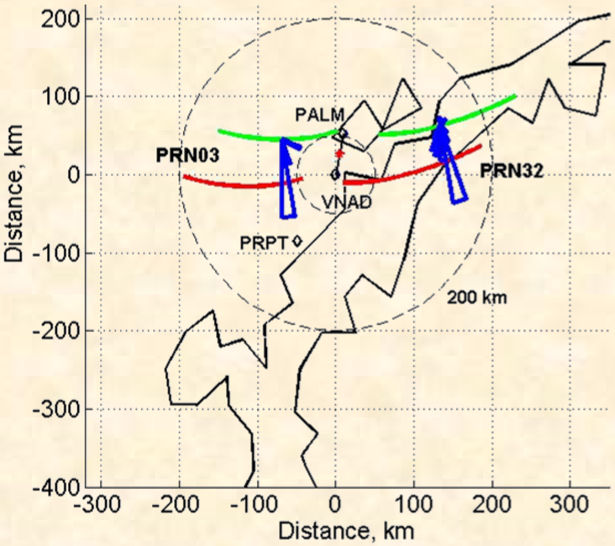


Time delay between DFS variations ~ 4 min.

Apparent velocity along UAS-Palmer direction ~112 m/s.

(a) Time variations of DFS of the HF signal recorded at Palmer and Vernadsky stations on 2015.11.13 at 6-9 UT.
(b) Cross-correlation function of DFS variations at UAS and Palmer during 8:00-9:00 UT.

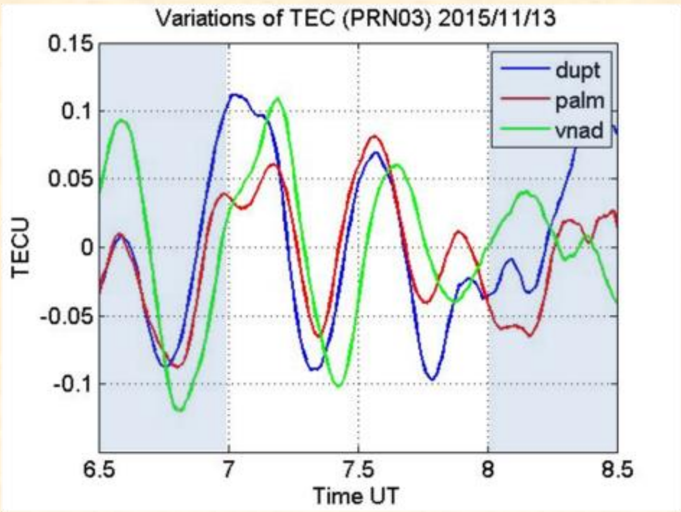
GNSS TEC measurements



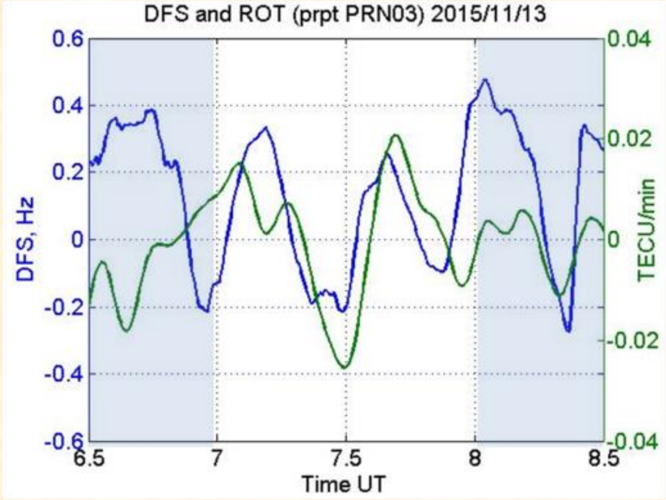
Trajectory of the IPP of the GPS satellites PRN03 and PRN32 for VNAD (green line) and PRPT (red line) on 13.11.2015 7-8 UT and the histogram of the reconstructed disturbance propagation direction (azimuths).

	TEC		HF
	PRN03	PRN32	DFS
T, [min]	27-35	32-34	~30
α	175°	165°	–
Vm, [m/s]	98	100	112
Λ, [km]	175-235	220-260	201

Parameters of TIDs estimated using GNSS (TEC) and HF (DFS) observations 2015.11.13 7-8 UT. Note that last column shows projections on the line of sight UAS-Palmer for wavelength and velocity.



TEC variations obtained from PRN03 at stations PALM, DUPT and VNAD on 2015.11.13 at 6:30-8:30 UT.



Variations of DFS (blue line) of HF signal received at Palmer station on 2015.11.13 at 6:30-8:30 UT and the rate of change of detrended TEC for GPS satellite PRN03 obtained at PRPT stations

Summary

The work presents the results of diagnostics of AGW/TID phenomena over the Antarctic Peninsula obtained using two different RF remote sensing techniques. The first one is based on multi-positional GNSS TEC measurements. The second technique is bistatic HF Doppler ionospheric sounding. Two-position coherent HF system was created at *Akademik Vernadsky* (Ukraine) and *Palmer* (USA) Antarctic stations. Spaced GNSS receivers are located close to HF diagnostic radio path.

A case study has shown that the spatial and temporal parameters of the ionospheric disturbances assessed by the two methods are in a good agreement. In the case under consideration the wavelike disturbances propagated almost in the meridional direction from North to South with the azimuthal angle of about 170 degrees. Their time period was 30 min; velocity and spatial scale were estimated to be about 100 m/s and 230 km, correspondingly.

The results demonstrate that the effectiveness and accuracy of the TID diagnostics could be significantly improved by performing simultaneous measurements using both Doppler HF and GNSS-TEC techniques. The proposed method will be used to determine regular variations of TID parameters and to establish the relationship between TID parameters and tropospheric weather and geomagnetic activities, and to identify their sources.

Quasi-periodic variations associated with propagation of TID were registered simultaneously in both types of the data. The significant diurnal and seasonal variations of time periods and propagation directions of TID were found.

Since the April 2017 we started the multi frequency HF Doppler sounding on *Vernadsky-Palmer* radio path which will permit us to obtained the vertical profiles of TID in the *F* region in addition to horizontal parameters.

Acknowledgments. This study was carried out with partial support of EOARD-STCU Partner project P667, and NSF project #1341557.


Thank you for your attention!