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SEARCHING OF OPTICAL EFFECTS INDUCED BY IONOSPHERIC HF HEATING

I. A. Kornilov[1], O. I. Kornilov, Yu.V. Fedorenko[1], E.V. Pigin[1], D. Wright[2], T. Yeoman[2]

[1]Polar Geophysical Institute, Apatity, Russia. kornilov@pgi.kolasc.net.ru
[2]Department of Physics and Astronomy, University of Leicester, LE1 7RH, UK.
Darren.Wright@ion.le.ac.uk, Tim.Yeoman@ion.le.ac.uk

Abstract

Optical effects in the ionosphere induced by high frequency heating are very weak. Maximum signal amplitude caused by Tromso HF heater was about 100 Rayleighs in 6300A emission, and usually artificial aurora is about 1-10 Rayleighs only. Especially difficult is a detection of heating effect in a presence of bright, high spatially and temporally dynamic natural aurora (10-50 kilo Rayleighs). We discuss different methods of image processing and searching of weak periodical signal using a prior information. Examples of applying those methods for different model noisy TV frames with addition of a small heating signal are presented. We also demonstrate some initial results of Spitsberben heating facility optical signal detecting.

Introduction

The excitation of airglow in the F-region of ionosphere by high frequency radio wave heating has been observed many times in the middle latitudes by photometers [Sipler and Biondi, 1972, Bernhard et al., 1991]. Atmospheric emissions (6300 and 5577 angstroms) are produced by plasma turbulence accelerated electrons, which then collide with the thermospheric neutrals. In auroral region (EISCAT heating facility) photometric measurements also revealed increasing of red and green emissions [Stubbe et al. 1982]. Disadvantage of photometric observations is a danger of parasitic influence of very powerful radio transmitter on the photometer electronics and photo multiplier (in all experiments photometer was not far from transmitter). From this point of view TV observations are much more preferable (camera produce two dimensional image, and any noise can not make a special parasitic influence only on the separate part of it. In 1993 Kornilov I.A. carried out the first successful TV camera observations of optical heating signal above EISCAT [Sergienko, Kornilov et al., 1996]. Amplitude modulation of transmitter power with a frequency 0.5 Hz was found in the optical signal after 20 minutes of TV data integration. Signal was detected in the region of TV frame, coinciding with the heating area on the sky, and signal was definitely smaller in other regions of TV frame. Resent results of high sensitivity digital TV camera observations of EISCAT facility optical heating effect are presented in [Kosch et al., 2000, Kosch et al., 2004]. No optical effects induced by ionospheric HF heating in the polar cap region (SPEAR heating facility at Spitsbergen) were found yet.

Instrumentation

For aurora study we use analog SIT-vidicon TV camera with Nikon all-sky lens (1:2.8, field of view 180 degrees). Camera operates in integral light, spectral range 4000 - 8000 angstroms, with maximum sensitivity about 5000 angstroms. Video output is a normal TV signal (interlaced 50 fields or 25 frames per second, 625 lines per frame), and so can be recorded by ordinary VHS videorecorder. Later we digitize recorded signal from videotape by D-Link framegrabber card (8-bits, 25 frames per second, 320*240 pixels). Analog camera and analog recording have a great advantage of preserving the smallest aurora intensity variations, even if take into account some stochastic noise, added by videorecorder (in digital camera everything less 1 bit is definitely lost absolutely and forever), and we can digitize recorded analog data many times in the different modes (for example, almost arbitrary amplify the signal and choose the levels of black and white before digitizing). Many effective methods of TV data integration and image filtering are also used.

Results of modeling and real heating experiment

To detect an extremely weak optical signal, TV data should be integrated, and information about the position of heating area, time interval of heating and period of heating cycles should be used. On January 26, 2006 SPEAR heating facility in Spitsbergen operated in a 4 minutes heating cycle (2 minutes transmitter ON, 2 minutes OFF). Experiment lasted 4 hours, so in recorded TV data we have 60 heating cycles total, and so have 360000 corresponding TV frames. There were about half of this amount computer synthesized TV frames with different uniform random noise addition for every frame, and addition for 'heating cycles' small periodical 'heating signal' approximately in the region of TV frame corresponding the position of heating area in the real experiment. So, in the pictures (Fig.1 and Fig.2) label '1000 $^{+}$- 1000 + 10' means that for gray TV frame (frame brightness is 1000 arbitrary unites) were added random noise with dispersion 1000 units and periodical 'heating signal' with intensity 10 units.

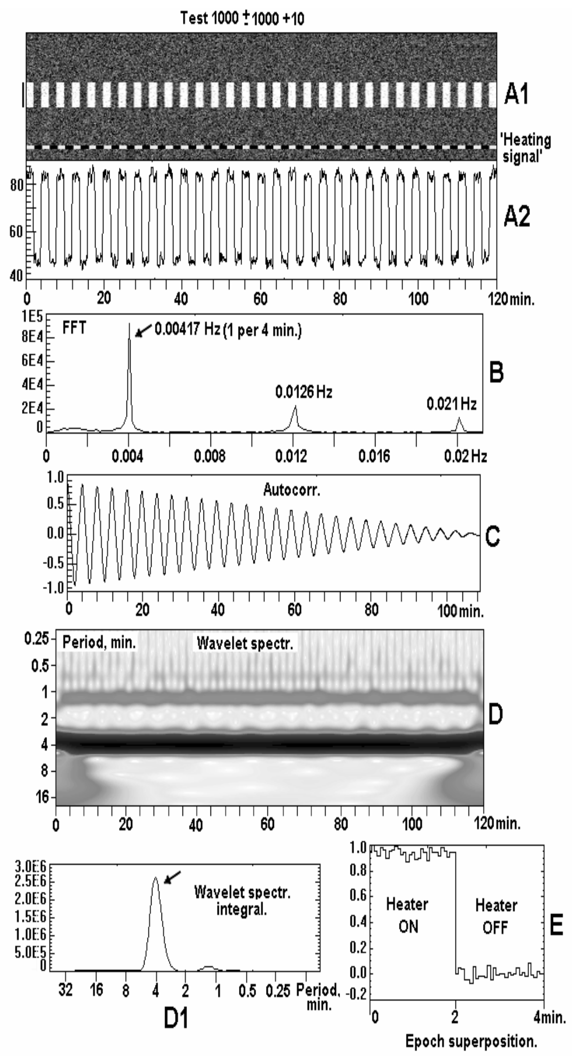

Fig.1

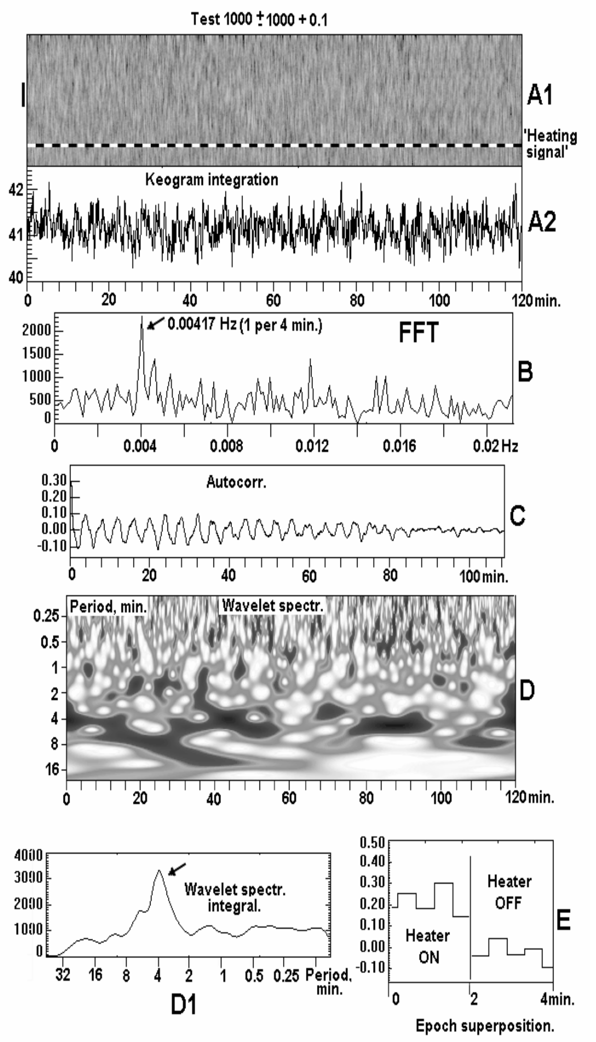

Fig.2

Results of model heating signal detecting. Keogram (A1), keogram integration (A2) in heating region, FFT-spectrum (B), autocorrelation function (C), functions, wavelet spectrum (D, D1), and epoch superposition (E).

In Fig.1 and Fig.2 one can see some results of computer simulated ‘heating experiment’ (30 ‘heating’ cycles, 180000 TV frames). In the left picture signal to noise ratio (S/N) in the model TV frames is about 0.005 (noise exceeds signal 200 times), and for the right plot noise exceeds signal 20000 times. Even for Fig.1 model heating signal is practically invisible in the individual TV frame (though slightly visible in film, i.e., frames animation), but cause of integration effect signal is very well detectible in keogram (A1), and in the plot, demonstrating result of keogram integration (A2), region of integration marked by vertical line left from keogram. For all TV frames signal was integrated inside square form region of ‘heating’, and FFT - spectrum fragment of the resulting one dimensional signal is shown in Fig.1, (B). Not only the main harmonic (4 minutes period), but also third and fifth harmonics of signal are well distinguishable. Autocorrelation function (C) also surely demonstrates the presence of model periodical signal. Three harmonics of model signal are well visible and in wavelet spectrum of integrated one dimensional signal (D, D1). The epoch superposition method is very useful for the searching of weak periodical signal. Integrated in the heating area TV data were summarized separately for intervals of ‘heating’, and intervals of ‘no heating’. One can see a sharp difference in signal intensity, definitely demonstrating the effect of ‘heating’ (E). We can see also almost the same results for the data presented in Fig.2, where S/N ratio is much worse, and the signal is absolutely invisible even in keogram (Fig.1, A1), but all other methods definitely detect the ‘heating signal’.

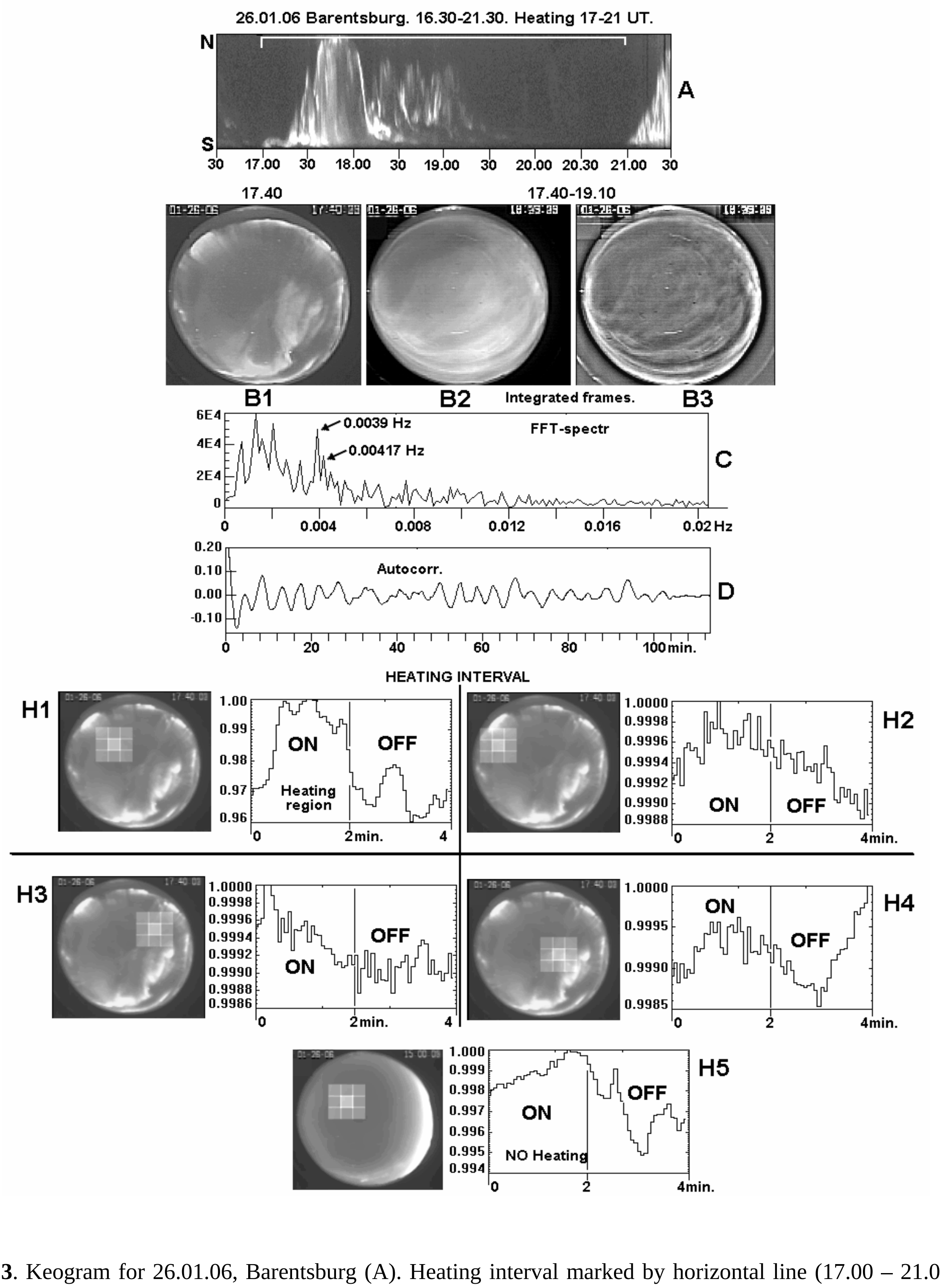

Fig.3. Keogram for 26.01.06, Barentsburg (A). Heating interval marked by horizontal line (17.00 – 21.00 UT). Individual (B1), and 1.5 hours integrated TV frames (B2, B3). Frame (B3) is high frequency filtered. FFT spectrum (C), and autocorrelation function (D) for 4 hours heating interval. Results of differential epoch superposition (H1-H5). H1 – for the region and time of heating, H2, H3, H4 – for the time interval of heating, but for NO heating regions. H5 – for the heating area, time interval without heating.

Keeping in mind the results of the model 'heating experiment', where signal is well detectable even in the presence of very strong random noise, one can optimistically conclude, that there is no problem to detect heating effect in the real heating experiment as well. Unfortunately, that is not truth. The problem is that aurora is not a phenomenon of random nature, and definitely has some regular temporal and spatial structure. Fig. 3 summarizes results of heating experiment at Spitsbergen (SPEAR heating facility). North – South keogram shows auroral situation above Barentsburg (about 50 km from SPEAR). Time interval of heating is marked by horizontal line (17.00 – 21.00 UT). One can see strong aurora activation between 17.00 and 19.00 UT. The breakup happened near the southern horizon, in auroral zone, and extended far to the North. Individual TV frame (B1) shows one example of positions and brightness of very dynamical auroral arcs. Absolutely no optical heating signal is visible not only in the individual TV frame, but in the frame either, integrated for 1.5 hours time interval (B2, B3), only traces of very weak fog, and Northern Star appeared in the filtered frame (B3). Problems of the heating signal detecting in presence of auroral activity are well seen in the plots presenting FFT spectrum and autocorrelation function (Fig.3, C and D), drawing in the same manner, as for the model experiment. Aurora has strong intensity variations (both changes of brightness and space motions), mostly concentrating in the frequency range 0.5 – 3.5 milliherz (periods about 5 – 30 minutes). And we can also see rather a strong peak at frequency 3.9 milliherz (period 4.3 minutes). So, the period of natural auroral variations can be very close to the heating period (4.17 millihertz, or 4 minutes), and can completely mask the searching signal (though peak of heating is also slightly visible in FFT spectrum). Autocorrelation function (D) also shows the presence of periodical signal, and long period beating of the function amplitude demonstrates interaction of two similar signals with the neighbor frequencies. Trying to suppress parasitic auroral intensity variations, we developed some modification of epoch superposition method. In TV frames (Fig 3., H1 – H5) one can see small bright square, corresponding to the heating area, and this square surrounded by squares with smaller brightness (8 reference areas). For every TV frame (360000 frames total for 4 – hours heating interval) TV signal was integrated inside the heating area, and inside 8 surrounding reference regions. Then all differences (8 numbers) between heating and reference signals were calculated and summarized, and for resulting numbers ordinary epoch superposition method (the same, as for the model experiment) was applied. This simple procedure allowed strongly (but of course, not ideally) suppresses parasitic effect of aurora. In Fig.3 (H1) one can see the results (data are normalized to 1) for heating region, and for time interval of heating. Optical signal starts to increase 20 seconds after heater ON, and slowly decreasing after heater OFF. The same procedure was also applied for the out of heating beam sky regions (H2, H3, H4), and for the heating region, but for time interval without heating (H5 - 2 hours before experiment, 2 hours data integration). The obvious difference in the amplitude of effect (see the difference in the vertical axis scales) gives us a hope, that small traces of heating effect were really detected.

Conclusions

Computer modeling demonstrates, that for the TV image, damaged by stochastic noise only, the simulated heating signal is well detectable even if S/N is less than 1/20000. But it is far not enough for the real heating experiments. Strong natural aurora and fog (can be very dynamical and several orders larger than the heating effect), make the detection of optical signal rather a difficult task A special procedure was developed (we called it the method of differential epoch superposition), allowing to detect a very small heating signal in presence of strong natural aurora.

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