Photometer and spectrometer search of the oxygen green and red lines during artificial ionospheric heating in the auroral zone

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ABSTRACT. During four campaigns in 1980/81 the oxygen green and red lines have been observed for several hours with the heating transmitter operating during obviously quiet ionospheric periods. There has been no period with intensity modulation which could unambiguously be due to ionospheric heating caused by the continuous RF radiation. We expect that the main reason for the absence of intensity modulation is most likely insufficient energization of the atmospheric electrons. Secondly, the possibly excited $O(^1D)$ atoms can be dispersed over wide areas by thermospheric winds before they radiate. These hindrances have most likely prevented the resulting red line to increase to a detectable level for our instruments.

Key words : transmitted power, optical observations, lifetime, thermospheric wind, attenuation.

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INTRODUCTION

The ionospheric heating experiments at mid-latitude in Colorado, USA have demonstrated that the intensity of the forbidden oxygen green and red lines are modified by RF radiation, and that such measurements could be used to study excitation and loss processes, energy conversion and dynamics of the ionosphere (Haslett and Megill, 1974). With the heating facility installed by the Max-Planck-Institut für Aeronomie, Lindau, West-Germany at Ramfjordmoen near Tromsø, Norway, similar experiments were intended to be performed in the auroral zone (Stubbe and Kopka, 1979). As part of the collaboration between the Max-Planck-Institut and the Auroral Observatory, Tromsø one meridian scanning photometer, MSP, and two spectrophotometers were installed at Ramfjordmoen and one meridian scanning photometer at Kiruna to measure the oxygen green and red lines during operation of the heating transmitter. The spectrometers were two 0.5 mf/5 Littrow spectrophotometers. All the optical instruments had a comparable field of view ~ 5°, much less than the beam width from the antenna of the heating transmitter. The spectrometers were mostly pointing in one direction 8° north of zenith during operation of the heating transmitter, since it was expected that the area of enhanced emissions would occur in that direction.

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MEASUREMENTS

Simultaneous observations from Ramfjordmoen and Kiruna have been carried out during four periods with the heating transmitter in operation, and we have not been able to detect any enhancement or depression of the green or red line emissions which could definitely be due to the RF radiation. There are requirements which must be fulfilled to a certain degree before the conditions for detecting modified emissions are satisfactory — quiet ionosphere after sunset, no clouds, no moonlight, no auroral activity, little or at least stable natural airglow background — and these conditions seldom fully coincide, as mentioned by Stubbe *et al.* (1982). Since these conditions have been reasonably satisfied several times during the observing periods, the main difficulty is likely due to internal conditions of the auroral ionosphere.

In addition to optical/ionospheric limitations the optical equipment at Ramfjordmoen were intermittently directly influenced by the RF radiation, and then the resulting records showed features which erroneously could be related to variations in the green and red lines emitted from the ionosphere. This interference occurred quite unpredictably on each spectrometer and the meridian scanning photometer as well, but the disturbances did not always effect all the instruments simultaneously.

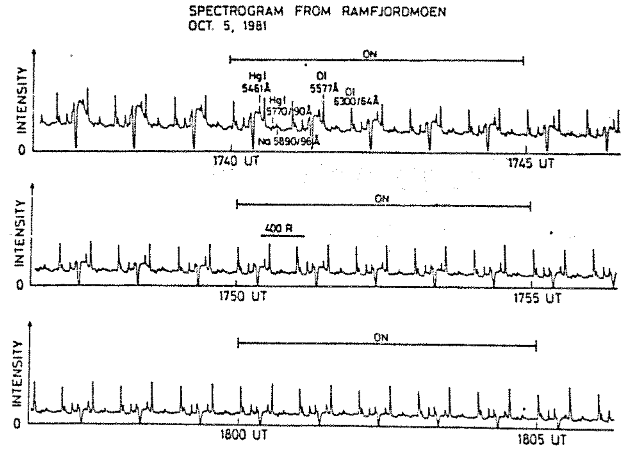

Figure 1

Spectrograms from Ramfjordmoen on Oct. 5, 1981 *scanning the wavelength region from* 5450 Å *to* 6400 Å *in* 1 min *including flyback. Wavelength resolution is about* 30 Å. *The intensity response is linear, and the deflection of* 400 R *for line emissions is plotted into one spectrogram. Before each spectral scan started the signal drops to zero, indicating the zero level and splitting each scan on the analog records. During this period the heating transmitter operates at full power with a frequency of* 5.423 MHz *in the* O-*mode. The* 5-min *intervals with the transmitter switched on are marked, and the spectrometer is pointing into the ionospheric region where the* RF *heating of the ambient electrons is expected to be strongest.*

It came as somewhat of a surprise that no intensity modulations occurred during periods when the conditions for observing enhanced emissions were apparently good. One such period was on Oct. 5, 1981 from ~ 1730 to ~ 2100 UT. Then the heating transmitter was operating at a frequency of 5.423 MHz in the O-mode and with full power, twice as much as during the Colorado experiments. The transmitter at Ramfjordmoen was continuously emitting in a sequence of 5 min. and switched off for the next 5 min. during the 3.5 hrs operation period on Oct. 5, 1981.

Comparing with the results of the Colorado experiments (Haslett and Megill, 1974), we optimistically expected to see intensity enhancements being as much as ~ 100 R for the green line and ~ 600 R for the red line, and these intensities are 5 and 30 times higher than the detection threshold of the MSP at Ramfjordmoen. The detection threshold for the spectrometers are below 10 R for the green and red lines. However, our spectrometers and MSP at Ramfjordmoen could not detect any modulation of the oxygen green and red lines throughout this period.

The MSP were simultaneously measuring the green and red lines, and one spectrophotometer was fixed on the wavelength of the red line. The other spectrophotometer was scanning the wavelength interval from 5450 Å to 6400 Å, pointing 10° north of zenith, and the spectrograms from this scanning instrument during the period from 1736 UT until 1806 UT are shown in figure 1. The green and red oxygen lines are distinct in these spectrograms. They are not affected by the on-off cyclus of the heating transmitter, and this result disagrees with the photometric observations obtained at Ramfjordmoen on Oct. 5, 1981 by Stubbe *et al.* (1982). The background light level in figure 1 is slowly decreasing due to decreasing twilight. Some intensity variations can be stated by the Hg I line at 5461 Å, originating from surrounding city light, and these changes indicate changes in a mist cover above Ramfjordmoen. The intensity levels of the 5577 Å and 6300 Å lines are ~ 200 R around 1750 UT, but the intensity of the red line decreases somewhat as the twilight decreases.

The MSP at Ramfjordmoen was scanning in the meridian plane from 60° north of zenith to 60° south of zenith on Oct. 5, 1981. In order to detect an eventual small heated area in the meridional plane the field of view of this MSP was limited to 2°. For this instrument the intensity of the variations in the green and red lines must exceed 20 R before the light changes could be clearly seen above the noise level. With this restriction in mind we state that there was no observable effect on the MSP records.

Unfortunately, a dense cloud cover at Kiruna prevented MSP operation from Kiruna on Oct. 5, 1981. The threshold of sensitivity of this instrument is quite close to the MSP at Ramfjordmoen, and the Kiruna MSP has been most of the time scanning the *E*- and *F*-layer above Ramfjordmoen. No observable heating related effect from the oxygen green and red lines has so far been detected by this instrument.

There are still large uncertainties associated with absolute calibration of photo- and spectrometers, and we estimate that the accuracy of our absolute intensity values is within a factor of two. On the other hand the stability of our instruments was so high that intensity modulations exceeding 5 % could be detected.

CONCLUDING REMARKS

Until now we have concentrated our observations to zenith and in the meridian plane around zenith. In Colorado the area of enhanced airglow could intermittently occur eastward of the transmitter (Haslett and Megill, 1974). If such a displacement is more common in the auroral zone, another MSP should scan in the E-W direction. Therefore a slight possibility exists that we have missed observing the area of enhanced airglow.

Generally seen, it has become evident from the optical observations performed at Ramfjordmoen and Kiruna that it is more difficult in the auroral zone to see any modulation of the intensity of the oxygen green and red lines than at mid latitudes. Similar experience is gained in USSR, where the Polar Geophysical Institute, Apatity for several years has been performing heating experiments on the Kola Peninsula (S. Chernouss, private communication, 1982).

In contrast to mid latitudes the drift of the oxygen atoms in the *F*-layer can be of the order of several hundred meters per second during quiet periods (R. W. Smith, 1982, private communication). According to the measurements of Haslett and Megill (1974) there could occasionally be a delay time of 2 or 3 min from turn on of RF radiation until the 6300 Å intensity began to increase. We consider this delay mainly as a consequence of indirect delayed excitation taking part in generating $O(^1D)$ atoms combined with the 110 s radiative lifetime of the ^1D state as found for the auroral green line at

5577 Å in active aurora (Henriksen, 1973). It is a well-known feature of active auroral displays that the red line is delayed 2-3 min relative to the permitted N_2^+ band at 4278 Å (cf. Stoffregen and Derblom, 1960). We find it pertinent to point out the similarity of delay observed by artificial airglow modification and in auroral displays. If a 3 min delay between excitation and emission appeared in the auroral zone, the excited $O(^1D)$ atoms could be ~ 100 km away from the heated area due to thermospheric wind transport, and outside the field of view of the instruments pointing 10° north of zenith.

The $O(^1S)$ atoms have a radiative lifetime close to 1 second, and the excitation energy is 4.17 eV. If the ambient electrons were sufficiently energized, the emission of the 5577 Å photons would have appeared within the field of view of the optical instruments even if F-region winds exceeded 1000 m/s, assuming that the expected heating of the electrons occurred within a few milliseconds of the turn on of the high-power RF transmission, even with indirect delayed excitation processes were contributing significantly to the ^1S excitation.

The auroral absorption for frequencies below 6 MHz can be severe even if it is not detectable by standard riometers at 30 MHz. Sometimes the lower ionosphere acts as a nonlinear attenuator with increasing heater power (Utlaut and Violette, 1974). Both of these effects are a hinderance for the RF radiation to reach the F-layer, and can play an important part at auroral latitudes.

According to recent investigations the reflection point of the heating wave is shifted downwards due to generation of small-scale field aligned striations, and at the reflection point the electric field flips from being field aligned to being perpendicular to the magnetic field (T. Hagfors, 1982, private communication). Then it can be expected that the energization of the electrons is most efficient when the heating frequency is twice and higher orders of the electron gyrofrequency. However, this idea seems to be in contradiction to the explanations of the observations at mid latitudes where the red line enhancements were observed for a range of frequencies as long as the heater frequency was below the critical frequency of the F_2-layer (Haslett and Megill, 1974), and the electric field of the heating wave, accelerating the electrons, believed to be along the geomagnetic field.

Simultaneous EISCAT observations at Ramfjordmoen show that the plasma line can be detected only 0.1-0.2 s at the beginning of each heating period (T. Hagfors, 1982, private communication), and we consider that the electrostatic waves responsible for electron energization are efficient only during the periods when the plasma line is detectable. The EISCAT observations, therefore, indicate that energization period for the electrons is too short, at least to give significant red line enhancements, and this shortening of energization period is expected to be due to generation of D- and E-region attenuation by the RF-radiation itself.

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