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OBSERVATIONS OF THE OVERSHOOT EFFECT DURING THE 2004 EISCAT PMSE CAMPAIGN

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Abstract.

The radar phenomenon PMSE (Polar Mesospheric Summer Echoes), which is associated with charged dust particles, can be affected by artificial electron heating. Chilson et al. showed in 2000 that if the heater is run in a cycle with equal, and comparatively short (10-20 sec) off and on periods, the PMSE strength is observed to weaken when the heater is on, and recover to approximately the same strength when the heater is switched off. With a new heater cycling, where the heater is on for a short time and then off for a long enough time for the dusty plasma conditions to return to its undisturbed conditions, a PMSE "Overshoot" effect is produced. In the overshoot the PMSE strength, when the heater is switched off, can increase by a factor of several compared to what it was directly before the heater was switched on. By analysing the shape of the overshoot characteristic curve as the PMSE varies through a weakening as the heater is switched on, an overshoot as it is switched off and a subsequent relaxation back to an unaffected strength, we can obtain a considerable amount of information on the state of the PMSE dusty plasma.

In the present paper we will show results from a large EISCAT overshoot campaign in July 2004 where the PMSE overshoot was observed frequently. The shape of the PMSE power variations in each overshoot cycle is shown to vary considerably with height in the PMSE layer and also from cycle to cycle. We will show that very different PMSE overshoot shapes can occur at various occasions, and heights, and how they can be dependent on the local dust and plasma conditions.

1.Introduction. The radar phenomenon PMSE (Polar Mesospheric Summer Echoes, (Cho and Röttger 1997)), which occurs in the summer mesosphere between about 80 and 90 km, can be affected by artificial electron heating. A weakening of the PMSE can be produced and has been observed with the EISCAT VHF radar at 224 MHz (Chilson et al., 2000, Belova et al., 2003),and the EISCAT UHF radar at 933 MHz (La Hoz, personal communication), The EISCAT Heating facility (Rietveld et al., 1993) used in these experiments was run in equal and short on and off intervals (from 10 to 20 sec) and it was found in many, but not all, cases that the PMSE strength was rapidly weakened when the heater was turned on, and that it also returned rapidly (Belova et al.,2003) to approximately the pre-heater value when the heater was turned off again. A strengthening of the PMSE, after the heater was switched off compared to the value just before it was switched on, was predicted by Havnes (2004) to be possible when the heater was run in a cycle with a short on phase of typically 20 sec and a comparatively long off phase of 160 sec to allow the PMSE dusty plasma to relax back to its equilibrium state (Havnes et.al 2003, 2004). The phenomenon is called the "overshoot effect" and the increase in strength is often observed to be a factor of 2 to 3 and sometimes more. As the heater is switched on the PMSE is weakened as before but can also show a substantial recovery in strength during the heater on phase and then the rapid overshoot as the heater is switched off. The time variation of the PMSE strength during an overshoot heater cycling is called an Overshoot Characteristic Curve (OCC), and a typical form is shown in Figure 1 which shows the PMSE intensity at a given height throughout a heating cycle of 20 sec with the heater on and 160 sec off. We see clearly the drop in PMSE intensity as the heater is switched on at 09:12, some recovery during the phase when the heater is on and the large overshoot by a factor of approximately 4 as the heater is switched off with a subsequent relaxation back to the undisturbed conditions. The exact shape of the OCC depends on the parameters characterizing the dusty plasma – dust size and density and the plasma density (Havnes et.al 2003, 2004, Biebricher et.al 2004). We will show different cases of OCC as observed in a large overshoot campaign in July 2004 involving the EISCAT Heater and radars. In the present paper we concentrate on the "normal" overshoot cycling (20 sec with heater on and 160 sec off) and demonstrate the large variety of OCC's which can occur. We also show modelling results of OCC for conditions with different amounts of dust present and how this predict the different OCC which are observed. We will not discuss in any detail the physics behind the suggested model for the overshoot, and how the various overshoot shapes reflect the dusty plasma conditions in the PMSE, but refer to the papers by Havnes et.al (2004) and Biebricher et.al (2004) for this. Most of the other results from the campaign, the UHF results and the effects of varying the heater transmitter power, mode and frequency and the cycling period have not been properly analyzed and will be taken up in subsequent papers. The results shown in this paper are for transmitter frequency 5.423 MHz in the X-mode.

2. The observational campaign.

After the observation of the overshoot effect in 2003 (Havnes et.al 2003) it became clear that in order to exploit the phenomenon more fully in investigations of the PMSE conditions, it was necessary to obtain observations at a large variety of PMSE conditions and to investigate what effects changes in the parameters of the heater could have on the overshoot effect. Also, it would be desirable to increase the radar sampling time below the 5 sec used in 2003 to better resolve details in the OCC. These problems were addressed in the EISCAT 2004 Overshoot campaign involving groups from EISCAT, Germany, Norway, Sweden and UK. The campaign lasted from July 5 to 15 with observations on 4 to 5 hours per day. PMSE was observed most of the time at VHF (224 MHz) and occasionally also at UHF (933MHz). The following observing schemes were applied on one or more of the observing days.

1. The time resolution was 0.2 sec on all days.
2. Heater cycle with 20 sec on and 160 sec off.
3. Heater cycle with 10 sec on and 110 sec off.
4. Heater cycle with 20 sec on and 100 sec off.
5. Varying the heater power from 100%, in steps of 20% at subsequent heater cycles, down to 20% of full power.
6. In a (“pump-up”) mode with a heater cycling with 5 consecutive 10 sec on and 2 sec off and thereafter 120 sec off.
7. Varying between heater transmitting in X and O mode in subsequent heating cycles with 20 sec on and 160 sec off.

8. Most often the transmitter frequency was 5.423 MHz but a frequency of 6.96 MHz was also used.

3. Preliminary results from the 2004 EISCAT overshoot campaign and some interpretation of their OCC.

The preferred heater cycling was as in point 2 above. It appeared that the 100 or 110 sec relaxation time of heater cycling 3 and 4 could sometimes be on the short side so that a complete return to the equilibrium undisturbed plasma condition might not always have taken place.

In Fig.2 we show the raw data for the observations of one hour PMSE overshoots, with the cycle 20s-160s, where clear overshoots are present in practically every heater cycle and throughout most of the height gates where PMSE is observed by the radar. The PMSE in Fig.2 is a moderately strong one with a total vertical width of up to 5 km with much internal structure. To better show the presence of the overshoot during the whole hour we show in Fig.3 the PMSE strength at one height (85.2 km) throughout the whole hour. The overshoot was present during the whole observation period that day from $07^h\ 36^m$ to $11^h\ 00^m$ UT.

Since the PMSE structures can move considerably in height, as can be seen from Fig.2, the constant height scan can be somewhat misleading since it can miss the PMSE in certain time intervals. To show in detail the height variation of the overshoot we have picked one heater cycle where the heater was switched on at $09^h\ 45^m$ and show the results for both the 0.2 and 2 sec sampling in Fig.4. We see the clear overshoot in practically all height gates (300m height sampling) where the PMSE is apparent and also in the thin PMSE layer above the main layer. Fig.5 show the PMSE intensity as a function of time for height gates from 82.8 to 88.5 km where the PMSE intensity has been corrected for variations in the radar transmitter effect since this is affected somewhat by the heater activity.

In the examples shown in Figs 1 to 5 the overshoot shapes are most often close to the original shapes which where modelled by Havnes et.al (2003) assuming that the dust was not a dominant charge carrier in the PMSE, so that absorption by dust could be neglected. This is probably often the situation for PMSE (Havnes et.al 2001) but it is also clear that conditions where this is not the case, and where electron bite-outs are produced (Pedersen et.al 1969, Ulwick et.al 1988) caused by the presence of dust particles (Havnes et.al 1996), is not uncommon. Biebricher et.al (2004) show that in cases where the dust charge density is no longer small compared to the electron density, so that absorption of free electrons by the dust particles play a role in deciding the undisturbed plasma densities, the electron absorption efficiency increase as the electrons are heated. This will counteract the overshoot effect since it will lead to an overall reduction of the electron density when the heater is on so that the overshoot is reduced, or in some cases wholly removed. In Fig.6 we present model calculations with the PMSE model from Biebricher et.al (2004) for three cases, all with a dust radius of 10 nm, and with low to high dust density as given in the figure.

The overshoots in Figs 1 to 5 appear to correspond mostly to cases with moderate to low dust charge density, as shown by the moderate to low dust density cases of Fig.6. The comparatively large overshoot factors which are present indicate an electron heating which is larger than used in Fig.6 while the moderate recovery of the PMSE during the 20 seconds the heater is on indicate that the dust particles are of medium PMSE sizes. If we look at the same type of experiments on July 6, as shown in Fig.7, the situation is different. On this day the PMSE layer consisted of many relatively parallel weak layers. Although the effect of the heater is apparent in all the PMSE layers, the overshoot effect is very often weak or apparently not present. If we concentrate on one cycle, again choosing the cycle where the heating starts at 09^{h} 45^{m}, we see the results for this cycle in Fig 8 for the raw data and in Fig.9 we show the PMSE intensity variations with time corrected for transmitter variations, for all the height gates. There will certainly be arbitrary intensity variations, brought about by structures being brought out of or into the radar beam by horizontal winds during the heater cycle, but it appears that we often have cases corresponding to the high density case of Fig.6 where the PMSE is constant or weakened when the heater is on and the overshoot is weak or absent. This does not necessarily mean that the dust charge density is large but that it is comparable to, or larger than, the electron density.

From the observations of the 20 sec-160 sec heater cycling which we have examined, totalling by now about 12 hours of observations, it appears that the heater in most of the cycles has some effect on the VHF PMSE. Although the effect in some cases can be small or absent, in different cycles or at different heights, it is surprising that the heating and overshoot effect often is clearly present over very large height ranges.

In Fig.10 we show one hour observation where we have varied the heater transmitter power as described in the figure text. The PMSE consists two weak layers with the strongest at the bottom. Although the layers sometimes are 8-9 km apart the heating can be clearly seen in both layers. In Fig.11 we show, as in Figs.5 and 8, the PMSE profiles for different heights. We focus on the lower and upper layer and see clear heating effects from the gate at 81.3 km to the one at 89.7 km, corresponding to a height span of 8.4 km. The overshoot effect is not present at all gates where the heater effect is seen but is most pronounced in the upper part of the layer. In the lower layer the profiles may correspond to the high dust density cases.

If we look at Fig.9 we see that the heating effect is present in the majority of the cases, also when the heating transmitter power is low. In fact, a closer inspection show that the heater effect is without doubt present at 40% of the power and that also some indications of its effects are also seen in the cycles where the power is only 20% as can be seen from Fig. 12.

4. Discussion.

It is apparent, both from the overshoot observations from 2003 (Havnes et.al 2003), and the results from the 2004 overshoot campaign, that the reaction of the PMSE to the artificial electron heating can very different on different occasions and also at different heights at the same time. Since this occurs also when the transmitter and radar characteristics are kept constant the changes of the OCC must be caused by physical differences of the PMSE within the different radar sampling volumes. This should therefore open up for the possibility of using the PMSE overshoot to diagnose the PMSE dusty plasma conditions, as earlier predicted and modelled (Havnes et.al 2004, Havnes 2004, Biebricher et.al 2004). According to the modelling of the overshoot, the dust sizes and their densities, compared to the plasma densities, are most important in determining the OCC. With a knowledge of the electron densities, which sometimes probably can be obtained from UHF measurements or other instrumentation, we should be able to extract information both of the dust sizes and their radius. These parameters are normally not available except on sites where multicolour lidars are available (von Cossart et.al 1999), or with direct sampling by rocket dust probes (eg Havnes et.al 1996). In addition to this the lidars normally require comparatively large dust particles for reliable detection.

It is also clear from the observations that to find the OCC from observations is not always straightforward, unless the PMSE layers are slowly varying in strength and height, since large variations of PMSE can occur on timescales comparable or shorter than the heater cycling we have used. Efforts should therefore be directed at the OCC for such variations. While this most likely can be done for PMSE varying at a time scale not very much shorter than the heater cycling period of 3 min, the large variations we observe also from sampling to sampling both at 0.2 and 2 sec represent a more serious problem. They can seriously affect the determination of the reduction in PMSE intensity as the heater is switched on and off, and the shape of the PMSE during the heater on phase which all are very important in a comparison with PMSE models.

The many different observations we have obtained represent a challenge for the existing models for the PMSE and the overshoot effect in that they have to explain and extract information on the different physical conditions. While, as discussed before, many of the observed OCC fit well into the classes of shapes which have been predicted, we also find several cases which apparently have OCC different from the model results. Some such cases are shown in Fig.13 for one heater cycle where we see cases where the effect on the PMSE as the heater is switched on is small, so that little or no heater on effect is present but where still the overshoot is considerable. This indicates that the comparatively simple models for the heating and overshoot which have been presented until now should be improved.

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Figure Captions

Fig.1. An example of a strong overshoot at the height of 84.9 km. The radar samples with a resolution of 300 m and the PMSE layer in this case extended from about 83 to 87 km. The heater was switched on at 09h 12m UT and off at 09h 12m 20s.

Fig.2. The raw data of PMSE observations with overshoot heating cycles of 3 min periods (20 sec heater on and 160 sec off) with heater on starting at 09h 00m. The PMSE intensity is in an arbitrary scale.

Fig.3. The PMSE overshoot intensity at constant heights.

Fig.4 The raw data for one overshoot heater cycle shown with 0.2 sec and 2 sec sampling. The heater is switched on at sample number 200, respectively 20, and off at 300 or 30, corresponding to a heater on period of 20 sec.

Fig.5. As for Fig.4 but showing the PMSE intensity variation with time at 20 height gates. The heater is on between the dotted lines.

Fig. 6. Three cases of overshoot cycles for dust particles of radius 10 nm with 3 different dust densities given in the figure (in particles cm-3). The electron temperature, as the heater was switched on at 0 sec, was assumed to go from 150 to 450 oK.

Fig.7. As in Fig.2 but for the 6th of July, 2004.

Fig. 8. As for Fig. 4 but on July 6, 2004.

Fig. 9. As for Fig.5 but for July 6, 2004.

Fig 10. In this one hour observation the heater transmitter power is varied from 100% power at each 15 min, starting at 10h 00m, with the power reduced in equal steps down to 20% at the fifth heating cycle. After this we repeat the same 15 min cycle.

Fig. 11 show the PMSE power variations at different heights where we have concentrated on the two layers, the low and the high. In this heating cycle the heater transmitter power is at 80% of full power.

Fig 12. PMSE time profiles for one heater cycle at different heights from 81 to 88.5 km. The transmitter power is 20% of full power.

Fig 13. PMSE variations at different heights during one heater cycle.

Figure 1, B&W
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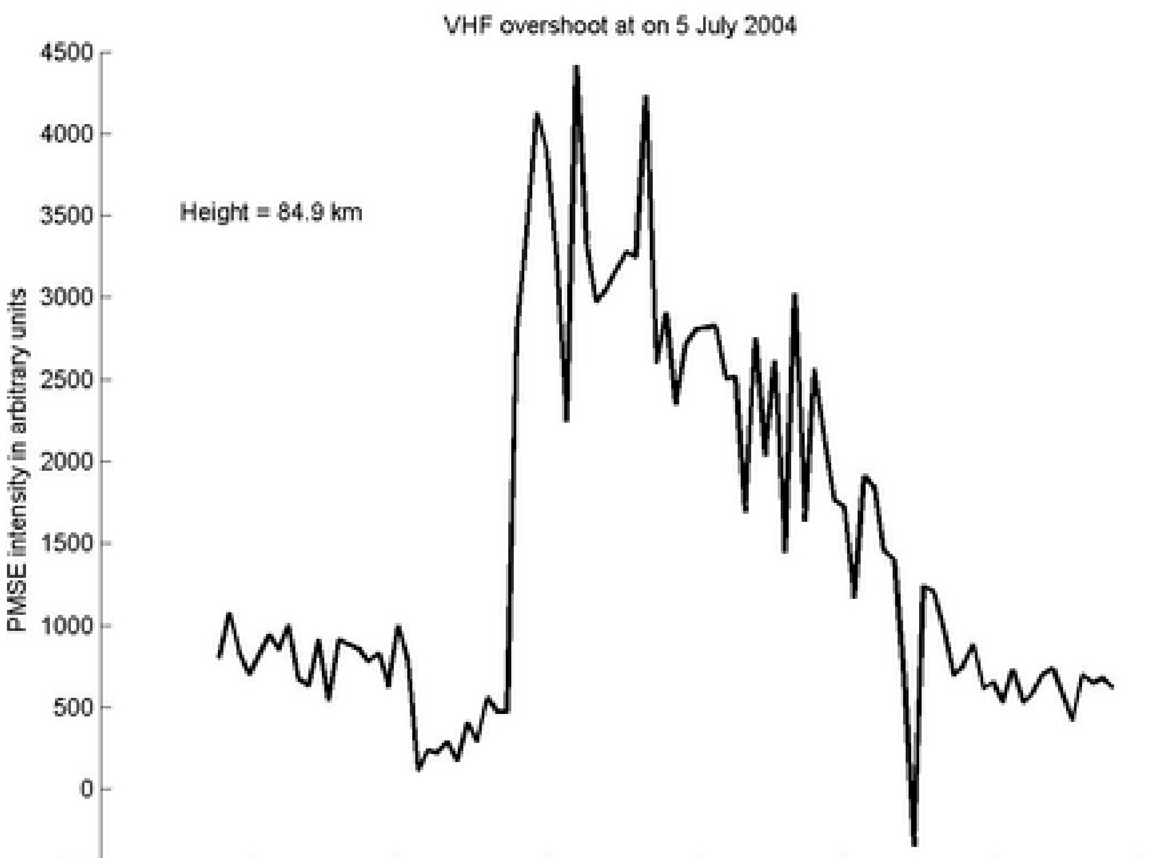

Figure 2 , colour

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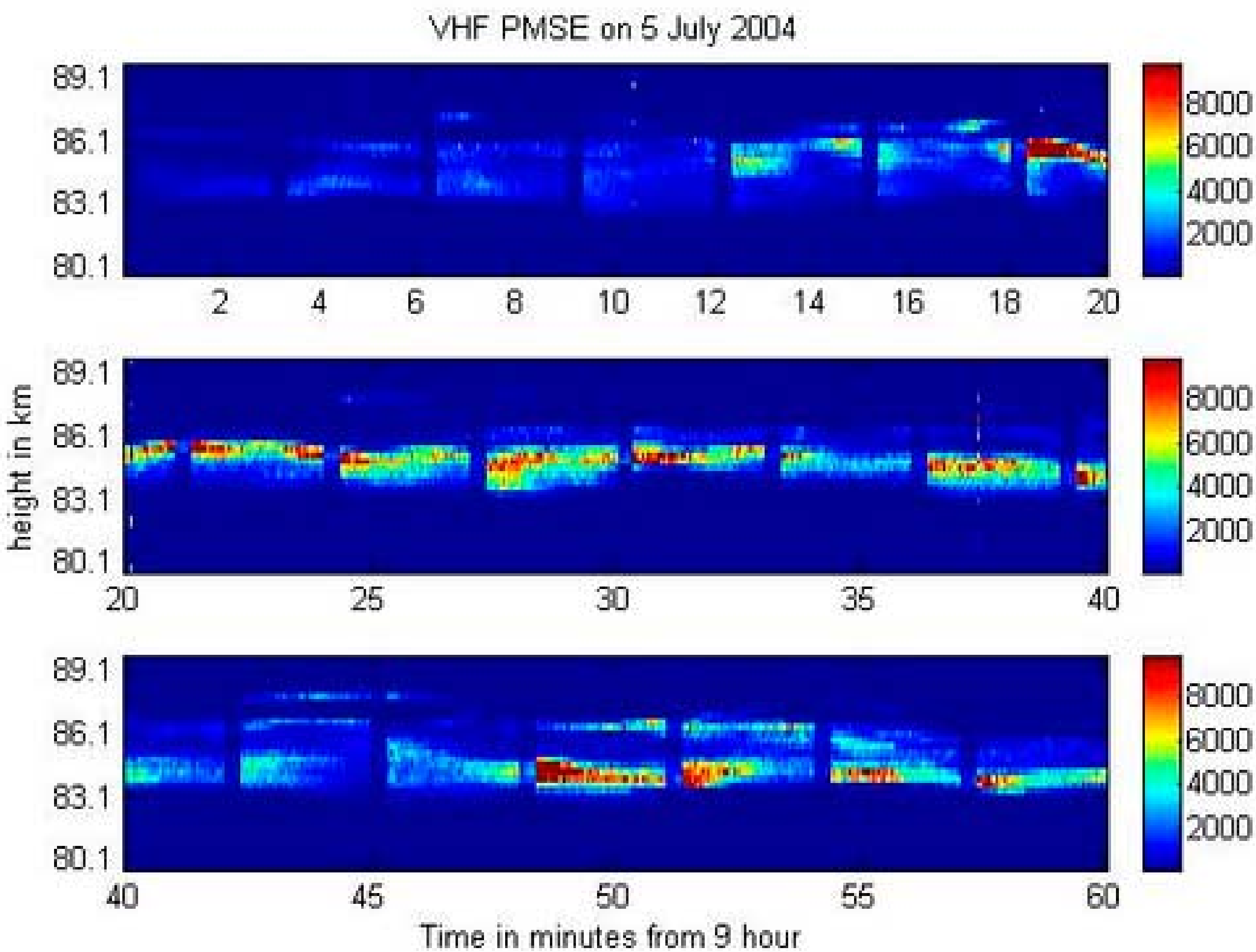

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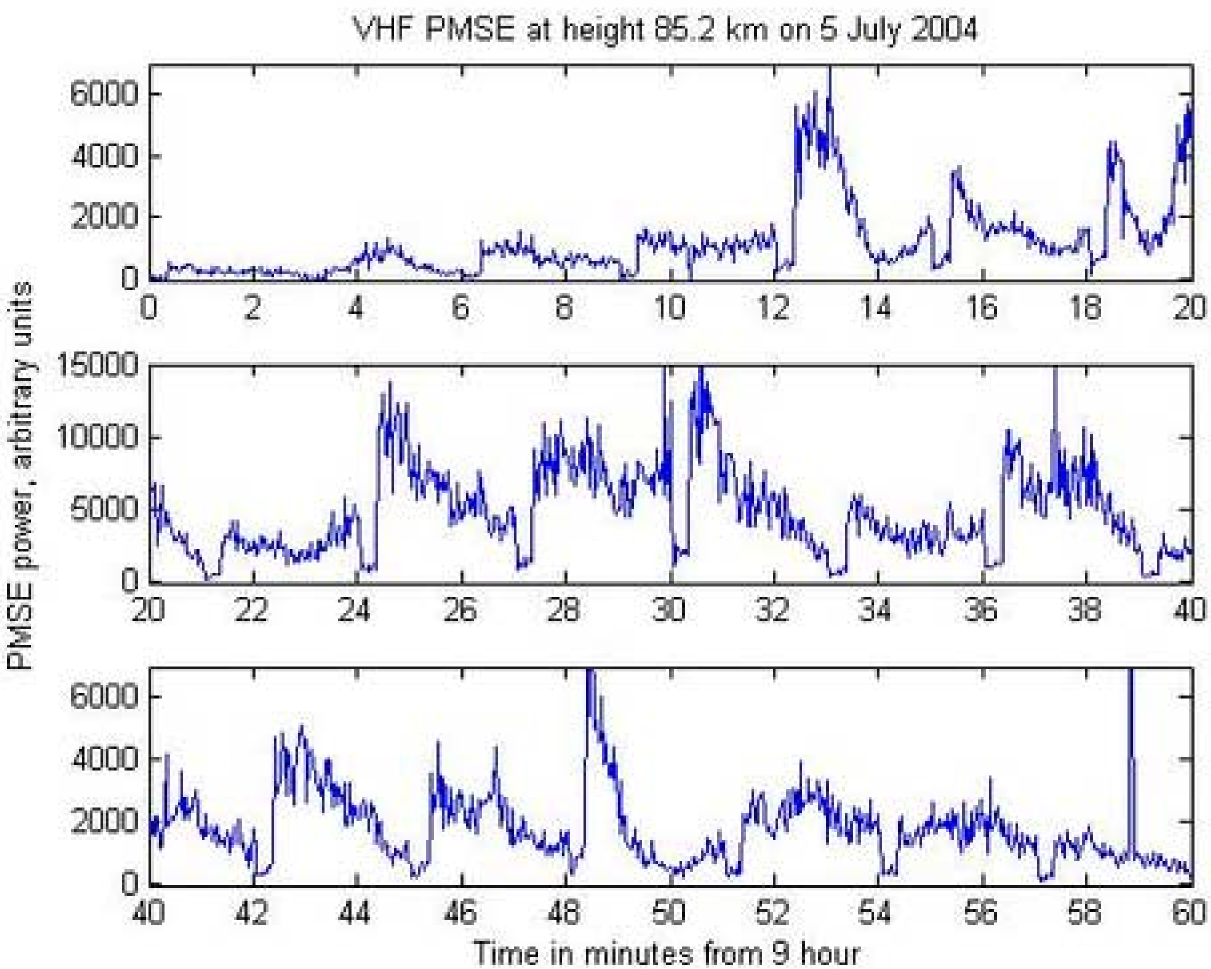

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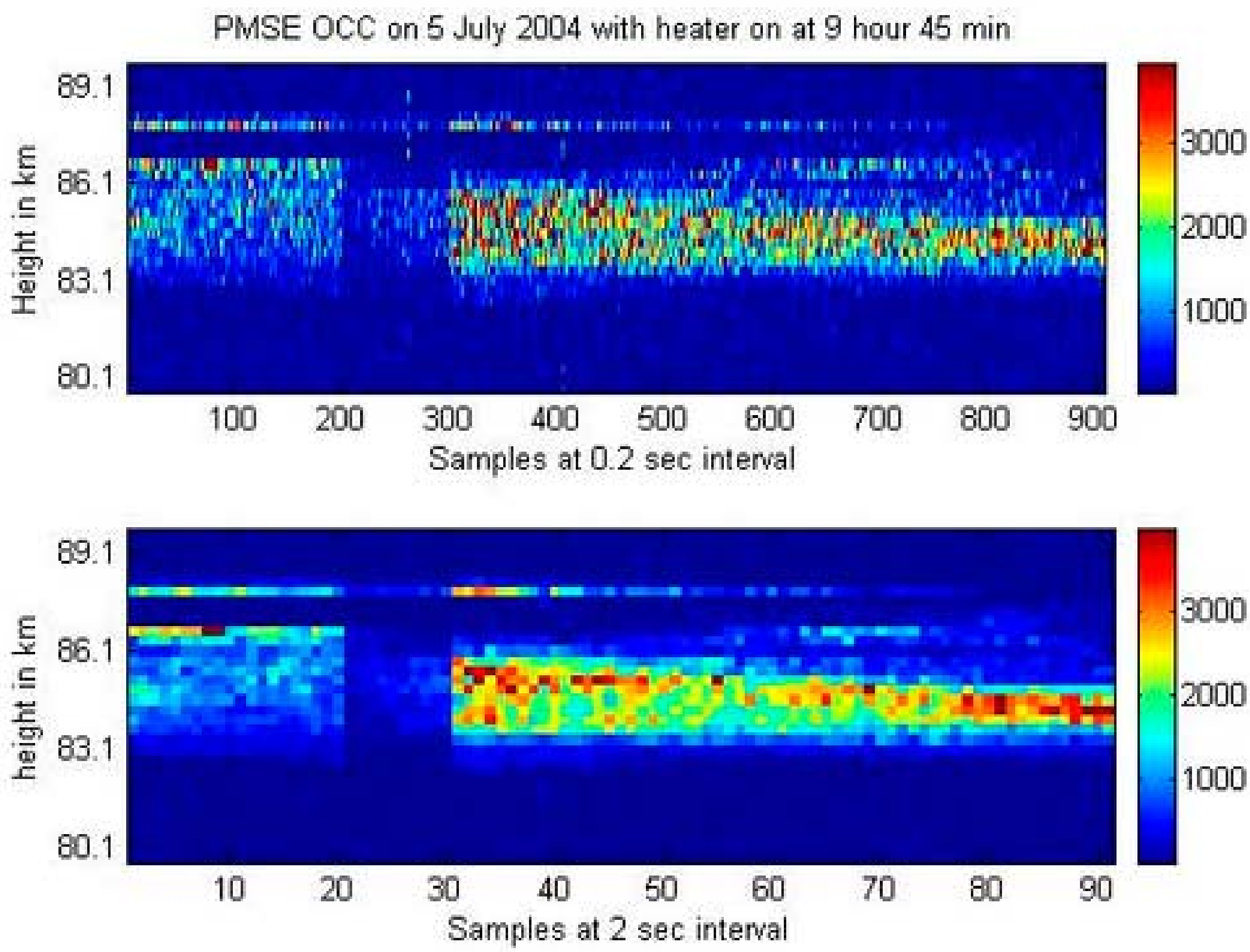

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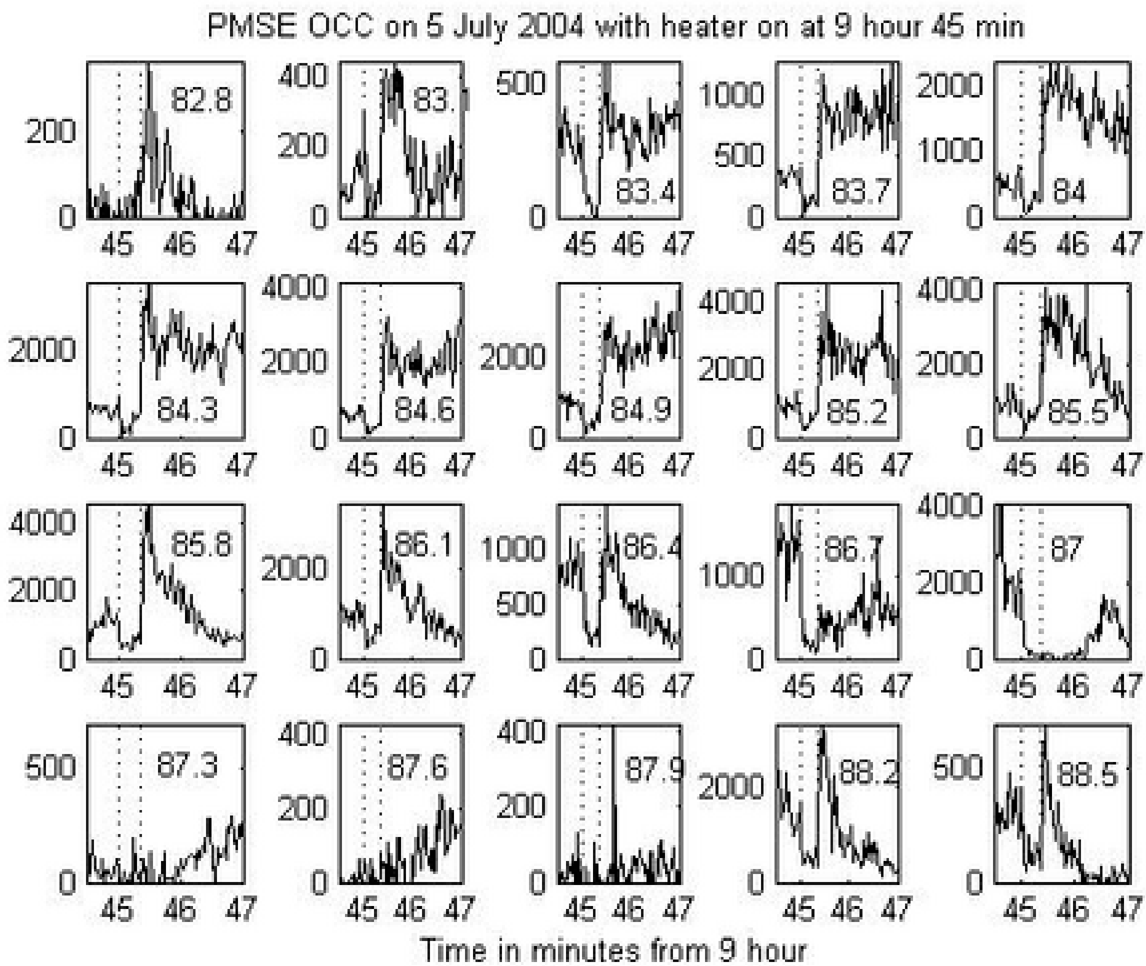

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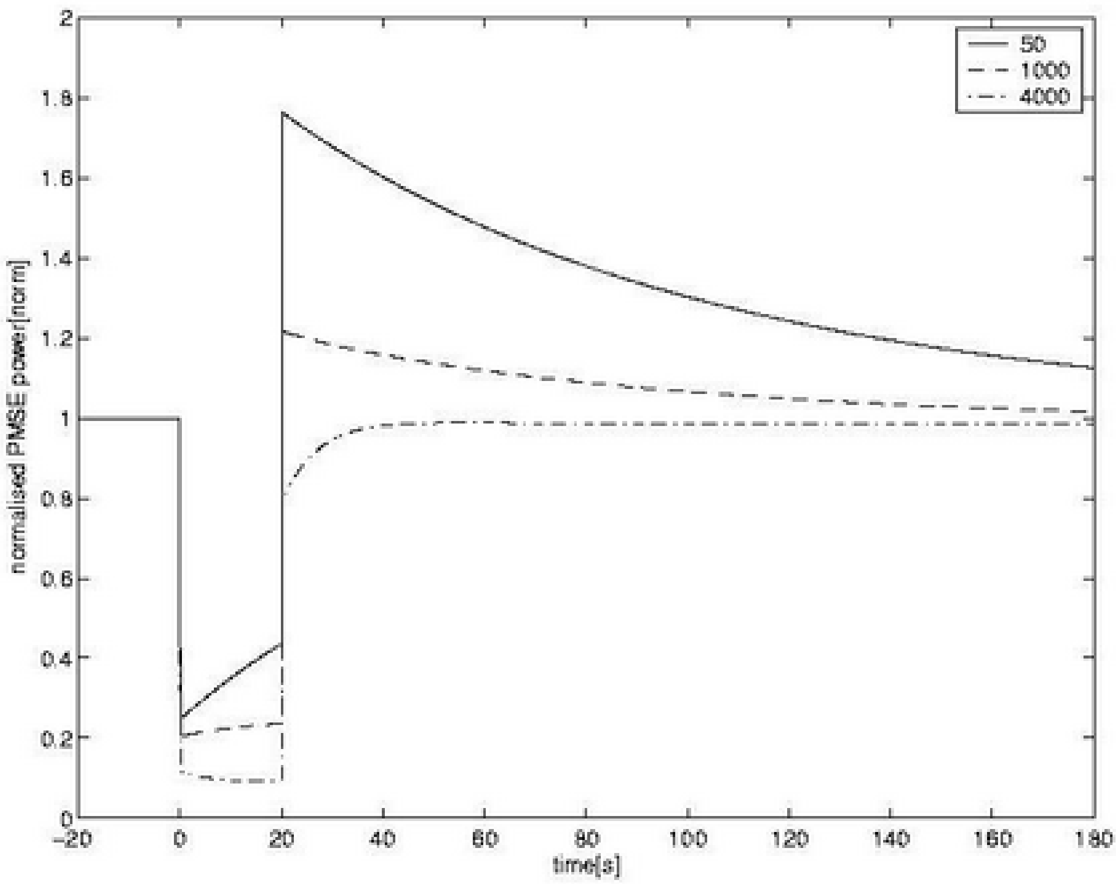

Figure 7, colour

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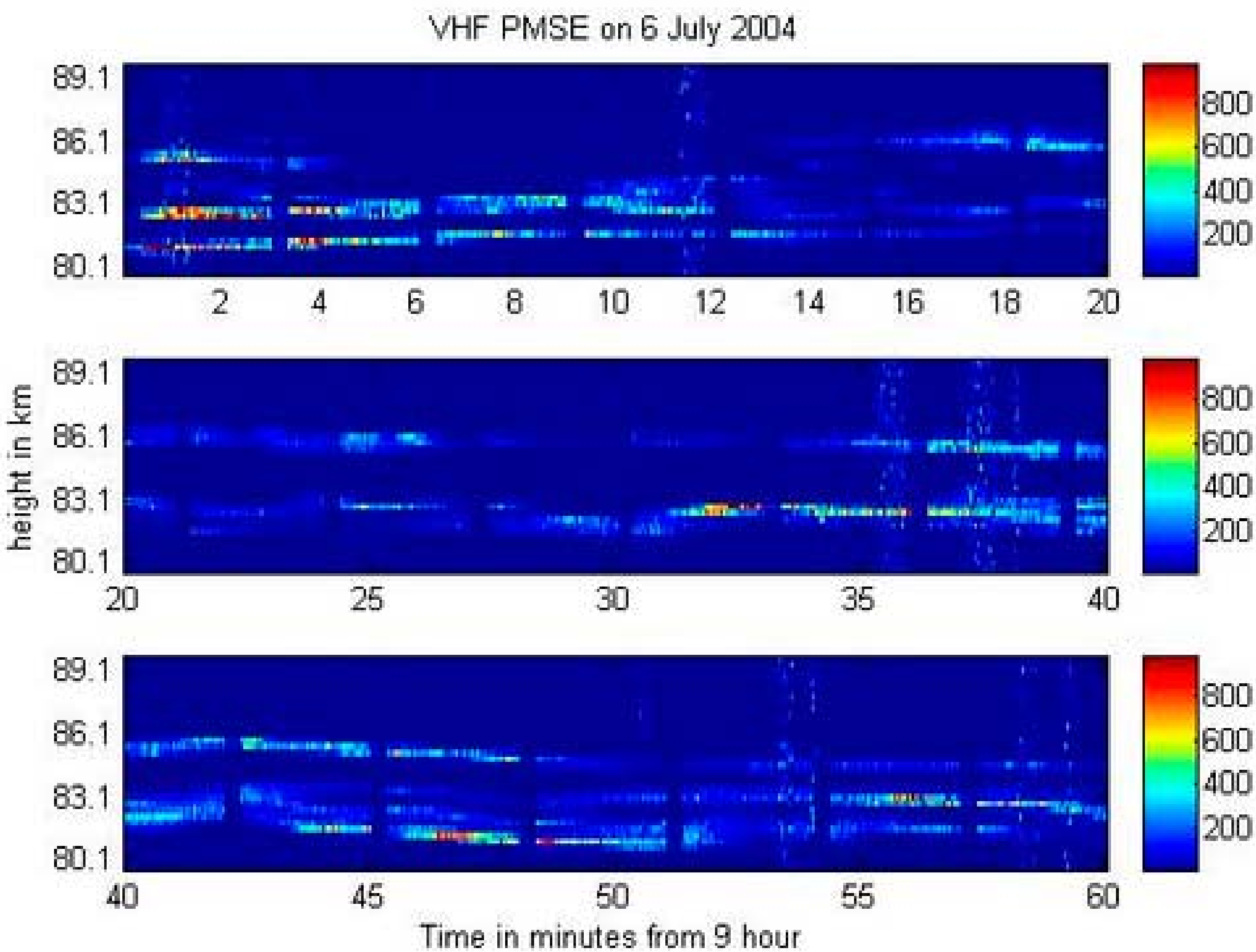

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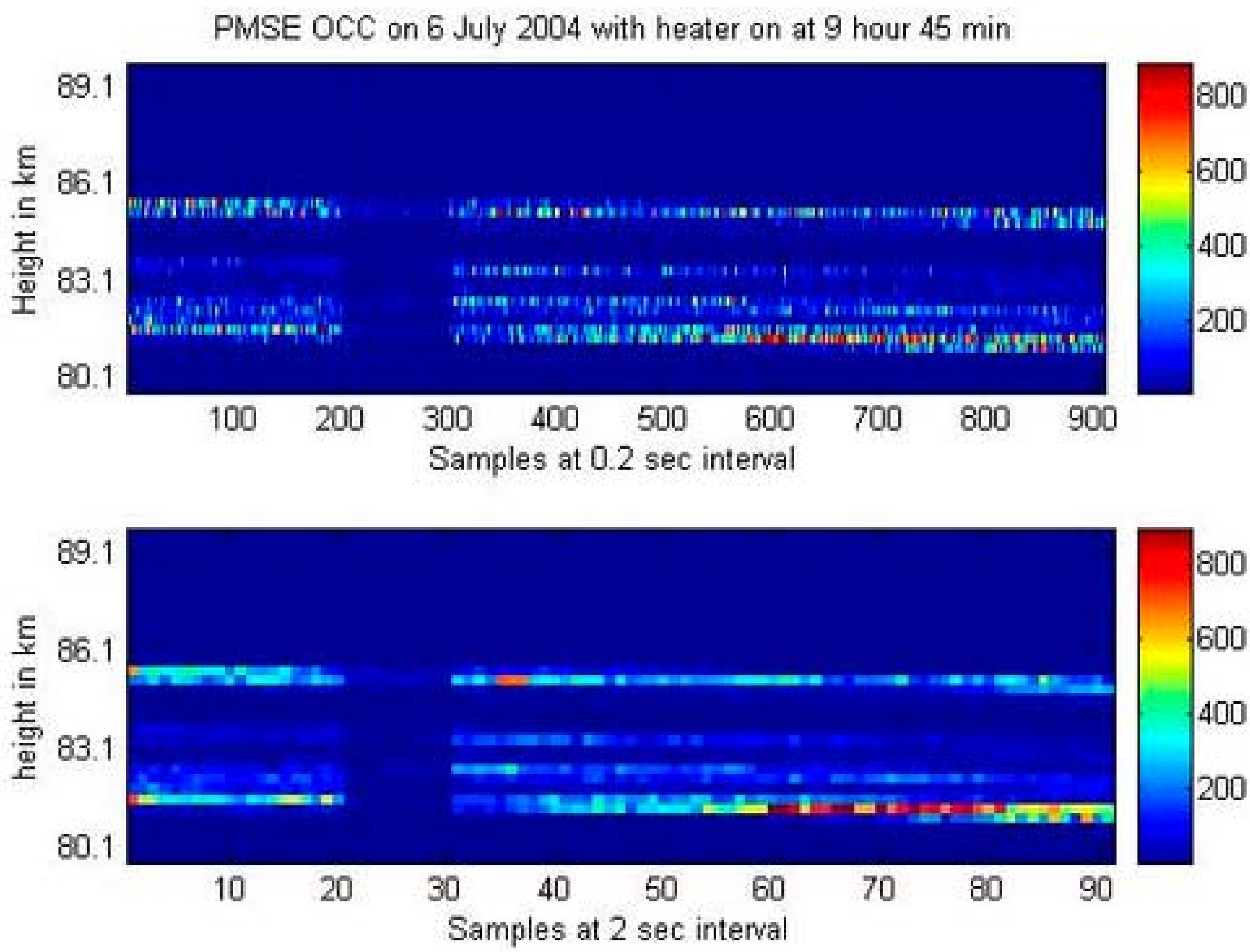

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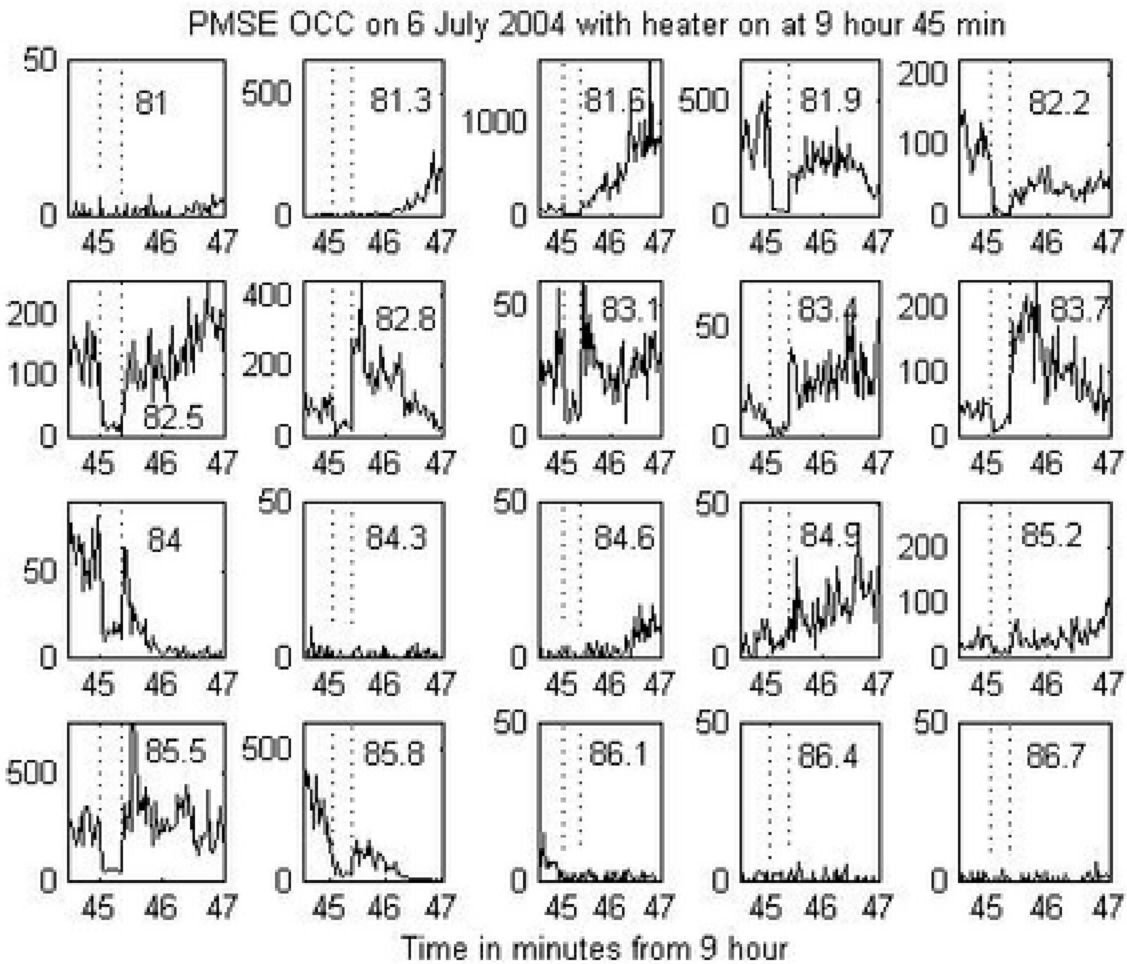

Figure 10, colour

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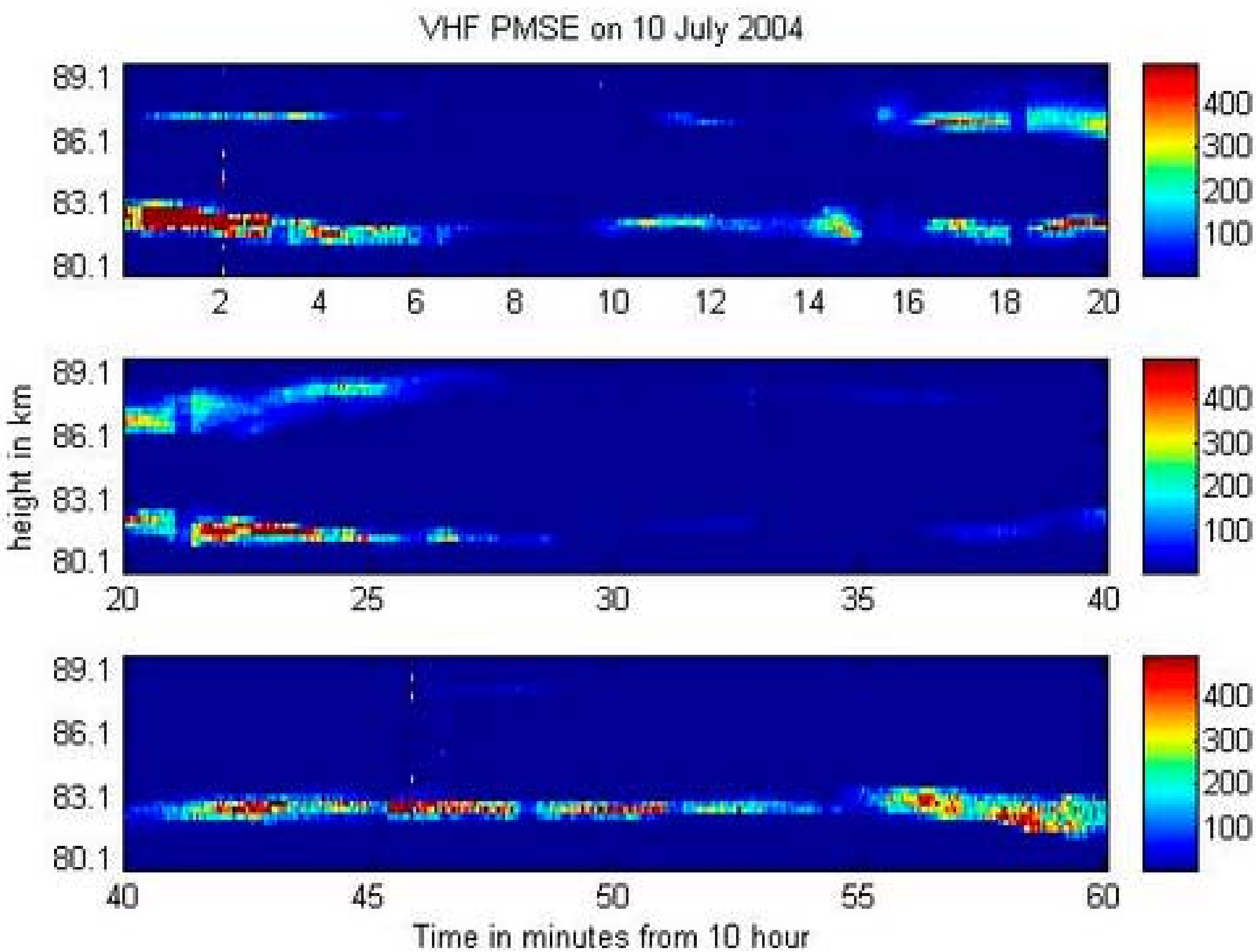

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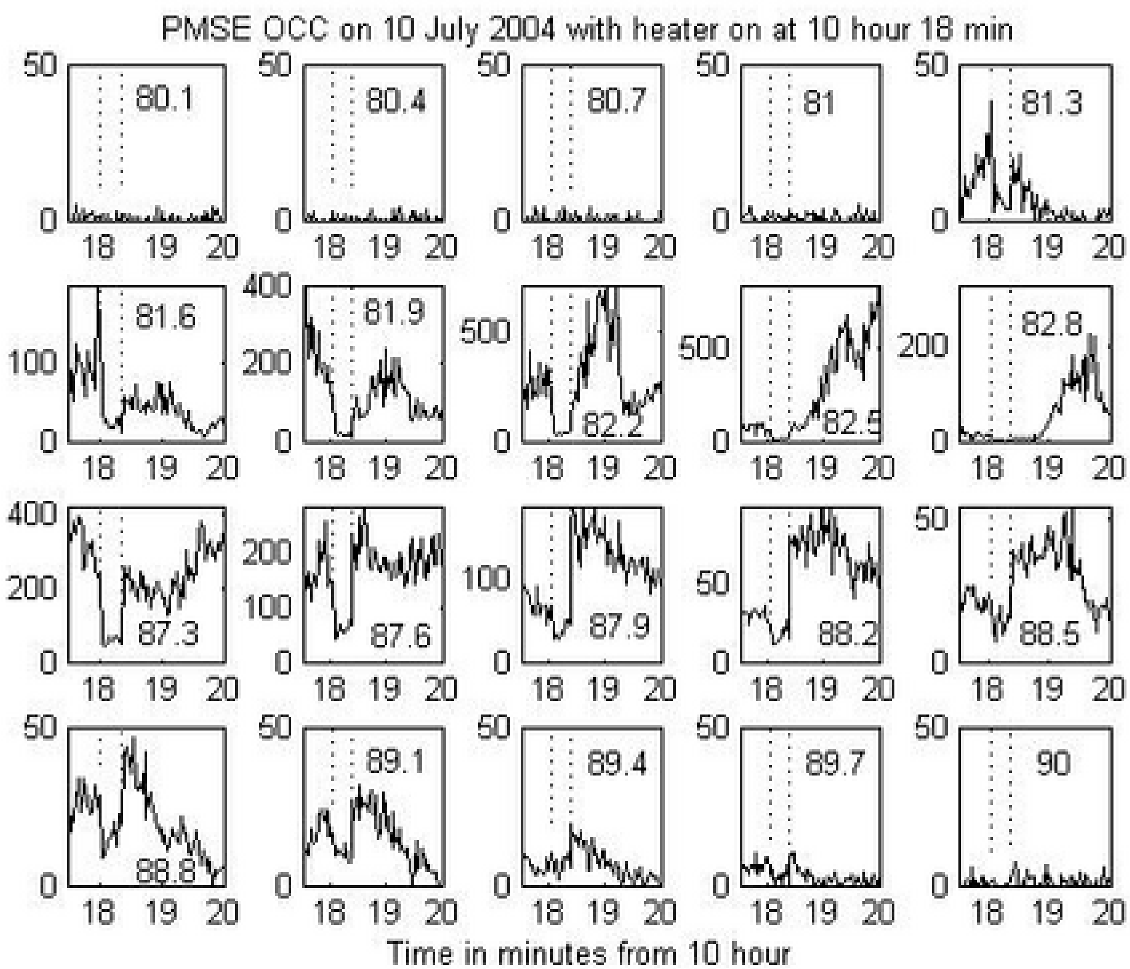

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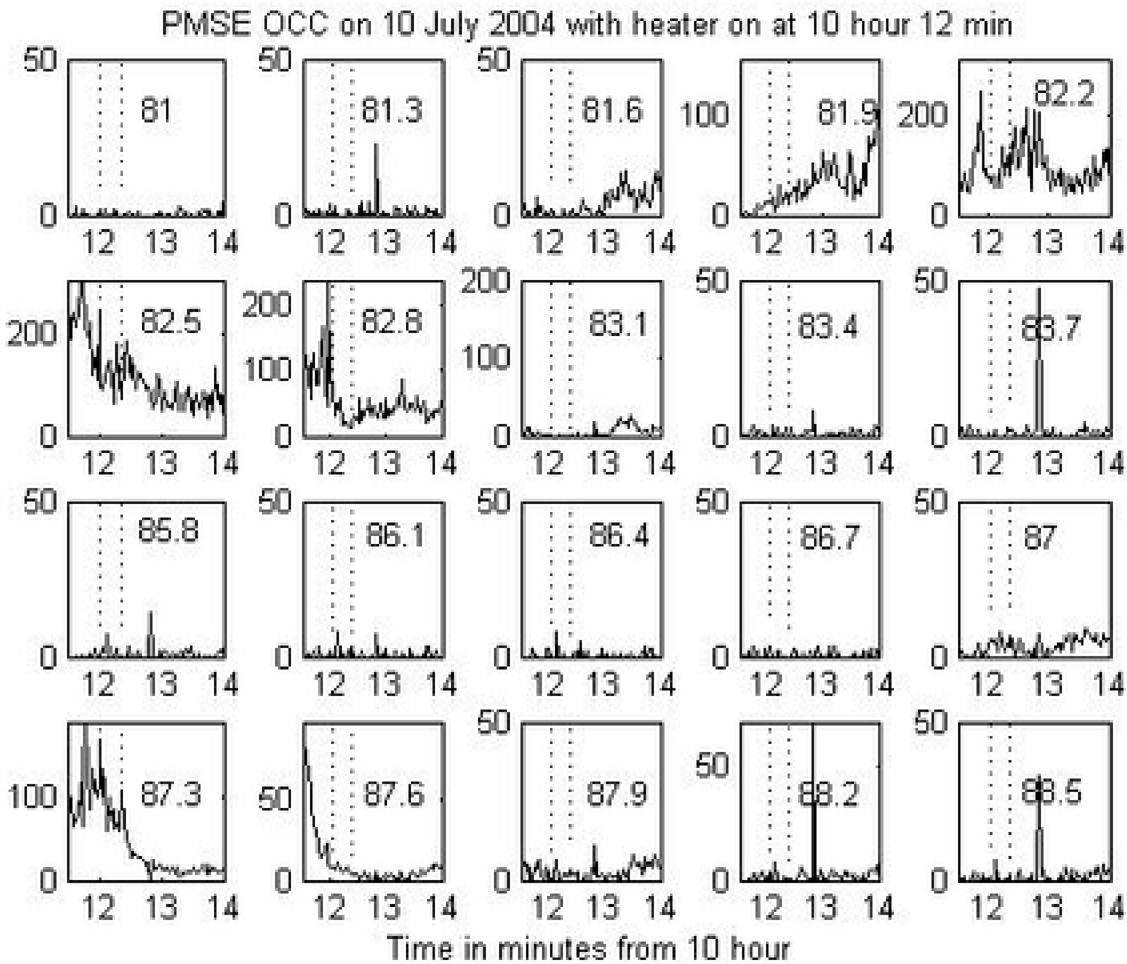

Figure 13, B&W

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