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Low cost webcast system of real-time all-sky auroral images and MPEG archiving in Kiruna

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Abstract. We present a low-cost all-sky webcast system for observing aurora from northern Sweden as a Swedish-Japanese joint effort between a public astronomical museum (providing the system), a scientific institute (management and data handling), and a local tourist hotel (site and system maintenance). This unique collaboration between different sectors has been successful in operating the real-time all-sky monitoring system of auroral activities since September 2005 and in producing near-real-time mpeg movies (20 sec resolution) since January 2004. The real-time webcast and the mpeg archive benefit all three contributors from different sectors in different ways: showing real-time auroral images to astronomical museum visitors via the internet (the museum is located at 25° geomagnetic latitude), advertising the hotel for aurora tourism, and providing an extra all-sky monitoring station 70 km away from the scientific institute at very low cost for operation. Even with such a low-cost camera system aimed at educational/tourism purposes, the data obtained still helps auroral science because the camera clearly identifies both diffuse and discrete aurora. We also briefly present morphological statistics from two years of auroral events.

Keywords. Instruments and facilities, Aurora, Webcast, Real-time monitor, Movie archive, Tourism

1 Introduction

A dense network of permanent all-sky camera (ASC) systems for auroral images, preferably in real time through the internet (webcast), has been desired by space scientists ever since the International Geophysical Year (IGY, 1957-1959). The only thing that has prevented deployment of such a network is the cost including manpower. In fact, most of the recent scientific digital ASC systems (Donovan et al., 1998; Ejiri et al., 1999; Syrjäsuo, 2001) are expensive.

However, if one accepts a lower signal-to-noise ratio than those achieved by official ASCs of scientific institutes, the cost for a real-time ASC webcast system can drastically be reduced. For example, a commercial all-sky star camera costs less than several hundred Euros (EUR), making the entire real-time webcast system (excluding building) only two thousand EUR. Large capacity internet connections have become available even to remote villages over the last few years, and large capacity hard-disks for archiving have become inexpensive. Since the ASC system itself can be rather inexpensive, and the data transfer and archiving are no longer the obstacles, the remaining cost driver for having a real-time ASC station is its maintenance including the provision of a well-equipped room/building. In fact, the most expensive part for the unmanned Auroral Large Imaging System (ALIS) (Brändström, 2003) is now its infrastructure (huts, power, and telephone-lines).

Fortunately, ASC for aurora is attractive for aurora tourism and public outreach. Since the computer and camera systems can now be easily handled by non-dedicated people who know only little about computers and ASCs, it is worth trying to delegated the operation and maintenance to local “ordinary" people who volunteer the maintenance. If this delegation works, a scientific institute can build many copies of real-time webcast systems to distribute over public facilities or hotels with non-scientist volunteers who maintain and operate the system. Having such auroral stations when and where it is difficult to build scientific observatories due to resource problems significantly benefits scientists in monitoring the auroral conditions as well as in identifying auroral events after archiving the data. This is the general concept of “operation by local ‘ordinary’ people". It helps developing a dense network of auroral observatories at very low cost.

To try this concept, we built, installed, and operated such an auroral ASC system at one of the tourist hotels under the

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auroral zone. We first examined the scientific capability of the low-cost camera system in a professional all-sky dome at Swedish Institute of Space Physics (IRF). The camera system was developed and provided by Misato Observatory, a Japanese observatory-type astronomical museum without scientific staff but with long experience of real-time solar eclipse webcasting. The test was done from spring 2003 to summer 2005. We then moved the system to Abisko Turiststation, a tourist hotel of the Swedish Tourist Association with many auroral tourists in recent years.

With this collaboration, all three sectors receive benefits: Misato Observatory can show their visitors and students the auroral image over Kiruna in real-time; Abisko Turiststation can be advertised as an aurora-watching hotel by webcasting the real-time auroral image from its roof, and IRF scientists can monitor the auroral and local weather conditions 70 km away from the institute. The archived data also benefit scientists for event identification afterward. In this paper we report on the system, operation, data archiving, and scientific benefits of this camera system as a Misato-IRF-Abisko collaboration (hereafter called as “MIA-Camera").

2 System specification

The MIA-Camera, initially installed at IRF in 2002 and starting permanent operation in 2003, is composed of a fish-eye lens (Pentax TS2V114E, 0.14 kg, about 650 EUR), a 0.5 inch CCD camera (MOSWELL MS-550A, 0.33 kg, about 600 EUR), a capture card (about 50 EUR), and a central processor unit (PC) with 80 GB hard-disk (about 500 EUR). Later in 2005, an external hard-disk (250 GB, 300 EUR) was connected to the PC for archiving purposes. In 2007, an additional external hard-disk (500 GB, 170 EUR) was connected in order to archive higher time resolution images. The interface of these disks is the universal serial bus (USB). The lens has a 2? field of view and automatic iris control (F1.4 - F64). The CCD camera has a CCD array of 380000 valid pixels (480 television lines resolution) with NTSC color composite output. The exposure is self-adjusted in the same way as for ordinary closed-circuit television (CCTV) cameras, with the maximum exposure time 4.27 sec (integration over 256 fields) at night (lowest luminosity is 0.01 lux). Since the camera is not made for aurora research, the spectral sensitivity for auroral emissions is not given.

With maximum exposure, one can identify both discrete and diffuse aurora as shown in Figures 1 and 2. Figures 1 and 2 show examples of aurora taken by both the MIA-Camera (upper panel) and the official IRF ASC (lower panel: Fuji FinePix S2 Pro with Nikon Nikkor 8 mm 1:2.8). Figure 1 shows the omega band in the diffuse auroral region at around 02-03 MLT, and Figure 2 shows red aurora above discrete aurora at around 19 MLT. Figures 1 and 2 demonstrate that the MIA-Camera has a sufficient signal-to-noise ratio for diffuse aurora to be recognized. Even pulsating aurora can

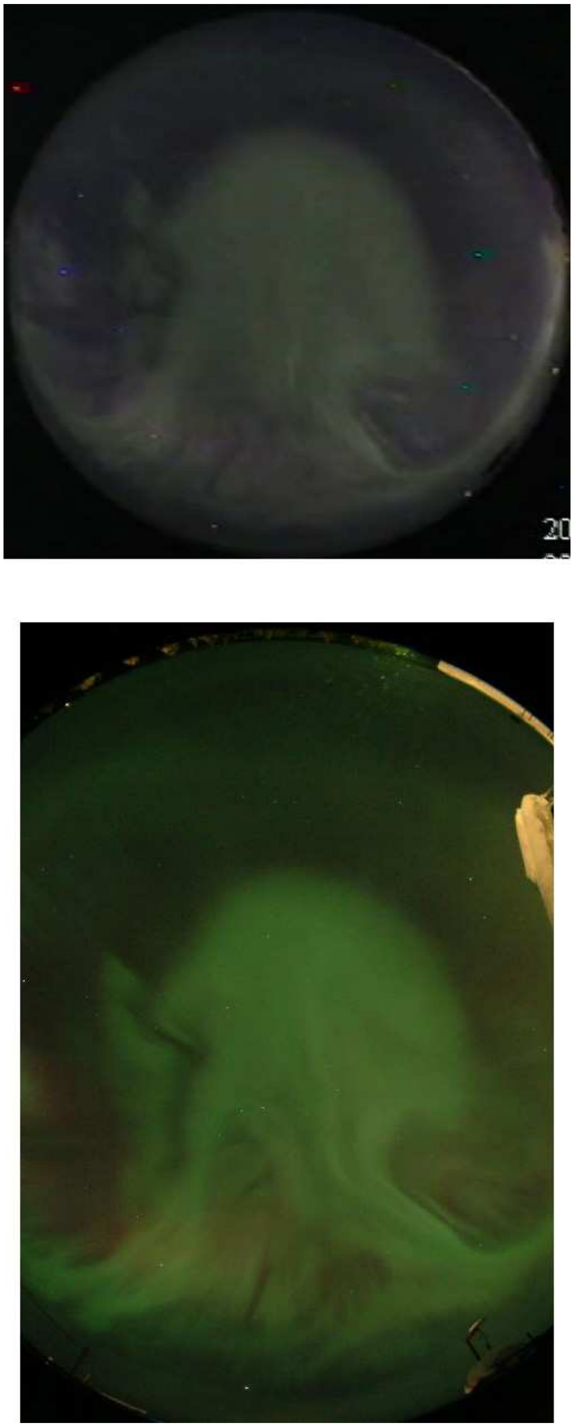

Fig. 1. Sample image of aurora taken by the MIA-Camera (upper panel) and official IRF-ASC (lower panel). Location is latitude 68 degree North and longitude 20 degree East. (An example of omega band in the diffuse auroral region on 12 January 2005 (03:16:00 UT). The slight difference in image is due to slight time error (less than a minute) in the official camera (image is not taken exactly at listed UT) due to wrong internet information.

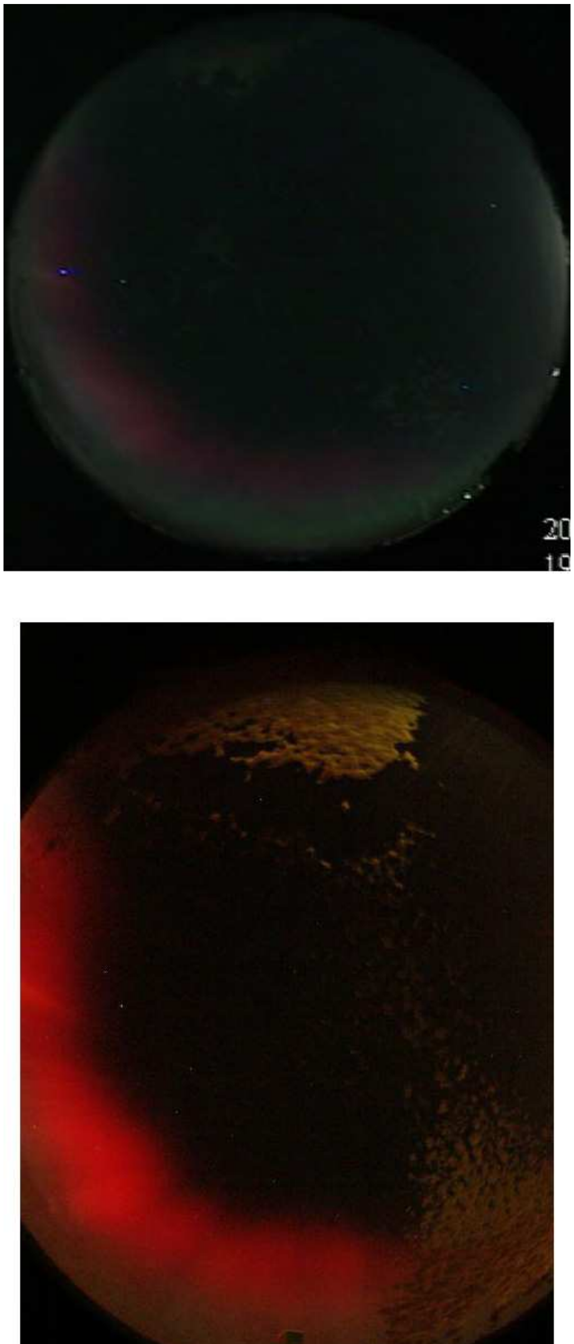

Fig. 2. An example of red aurora above the discrete aurora on 20 November 2003 (19:39:00 UT). The MIA-Camera is less sensitive to red color (630 nm) than official IRF-ASC whereas the sensitivity difference in the green color (558 nm) is not as large as the red color.

be recognized after the omega band shown in Figure 1a (not shown here: readers may recognize it in the mpeg archive: http://titan.irf.se/misato/2005/01/aurora20050111:2200-0600.mpg after 0130 UT). Since the maximum exposure requires 4.27 sec at night, the highest temporal resolution of the system is 5 sec. Figure 3 shows an example of 6 sec resolution images during the substorm breakup at around 16-17 MLT.

The video signal from the CCD unit is captured in a constant condition (no integration etc.) at the PC where the video signal is converted to a jpeg image file with 320×240 pixels. The captured jpeg file is written directly onto the hard-disk, so that the frequency of the webcast and the archiving can easily be controlled by software on the PC. The frequency of data acquisition is controlled by the capture program. For example, the MIA-Camera created a jpeg file every 20 sec at night and every 5 min during the day in 2004. The frequency of the webcast is controlled by another program, and we currently create the jpeg files every 20 sec while only one third of these jpeg images (i.e., every minute) are webcasted.

The MIA-Camera was first installed at IRF in February 2002 for a real-time auroral webcast event at Misato Observatory as the first auroral webcast event in Japan. It was re-activated in March 2003 for permanent operation with 1 min resolution. The MIA-Camera was finally installed at the Abisko Turiststation hotel in the Fall of 2005, in a small all-sky dome (diameter about 40 cm) as shown in Figure 4. Ventilation is installed inside the dome to prevent fogging and freezing of the dome.

The CCD unit is placed such that geographic north is at the top of the image. The rest of the system (capture board and PC) is placed in the same room under the dome. The hotel has a commercial internet connection to IRF, where a web server for the provision of auroral images is placed. The universal time is obtained through the network time protocol (NTP). The entire setup of the MIA-Camera is illustrated in Figure 5. To install the MIA-Camera, Abisko Turiststation rebuilt one of its rooms on the roof and installed the all-sky dome (Figure 4). The most expensive part of the entire hardware/infrastructure was the installation of this all-sky dome.

3 Operation and Archive

Although the MIA-Camera is capable of handling pictures every 5 sec, a much lower time resolution (1-min resolution) was first selected during 2003 for two reasons: (1) the webcast can be smoothly monitored by individuals and public, i.e., from personal homes and local hotels that only have narrow internet connections ($<$ 1 Mbps); (2) the disk space is not filled too quickly so that the data can be archived with minimum cost and manpower. The jpeg compression was selected for the same reason. Such “lower quality" production than the capability of the MIA-Camera was chosen because the MIA-Camera is intended as a public monitor and for quick survey/monitoring but not for solid science by itself.

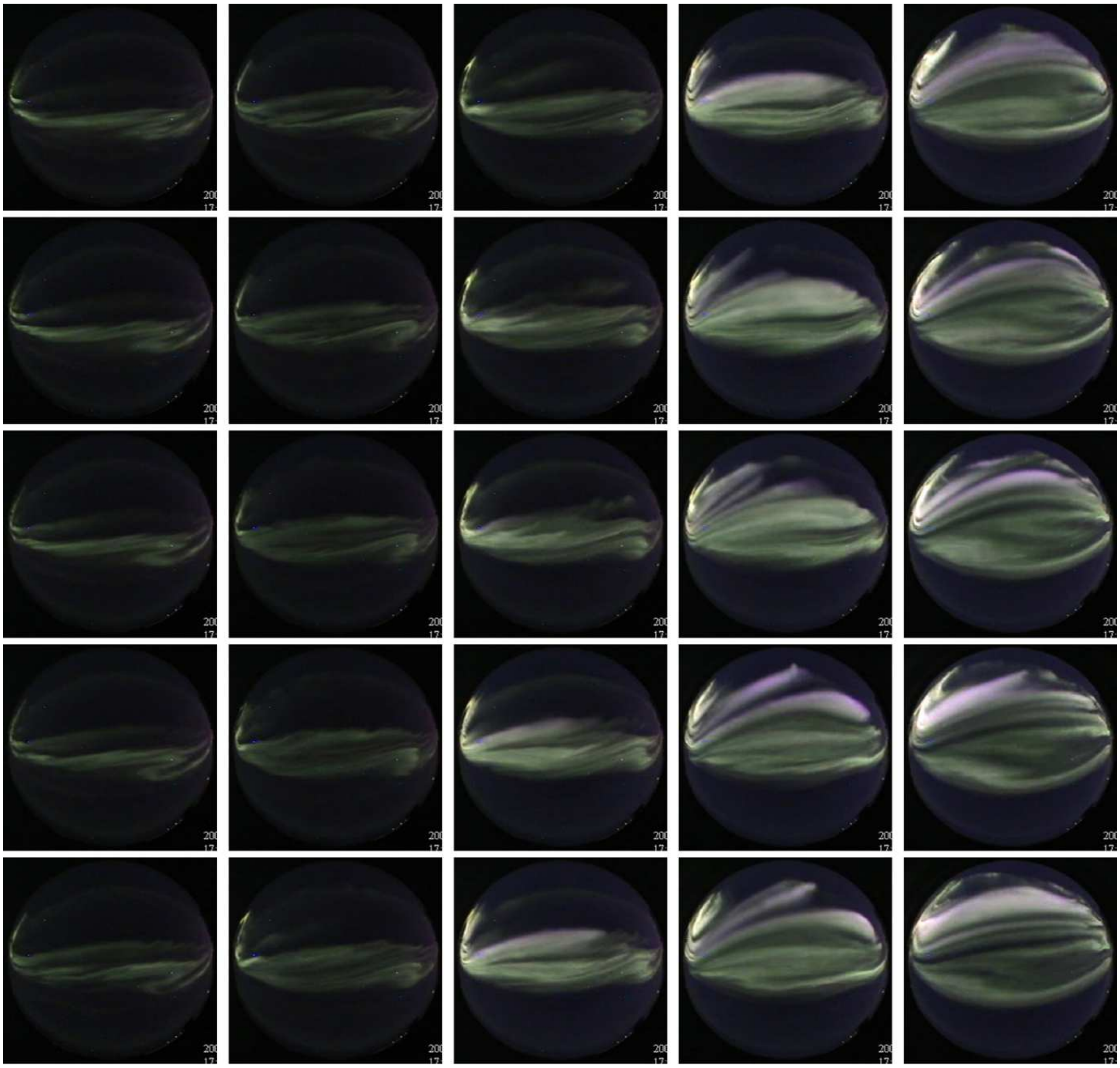

Fig. 3. Sample auroral images taken every 6 sec during a substorm breakup in the evening sector. Top left image is taken at 17:13:48 UT and bottom right image is taken at 17:18:42 UT. In addition to oxygen line (558 nm), the nitrogen red line (around 670 nm) is also recognized at the bottom of discrete aurora.

When near-real-time mpeg archiving started in January 2004, we set the nominal time resolution to 20 sec at night (5 min resolution in the daytime) to cover the major dynamics of auroral substorms because 1-min resolution turned out to be insufficient. With 0.5-2 Mbps internet capability in most private houses, 20-sec resolution is an optimum resolution with which the mpeg files from one night can easily be downloaded and previewed (see the end of this section).

Until late 2004, the MIA-Camera was the only means providing real-time auroral webcast at IRF. After the official IRF-ASC (Brändström (2003), appendix C) started real-time auroral webcast in late 2004, the MIA-Camera was moved to Abisko Turiststation in September 2005 under a new collaboration with this tourist hotel which provided the infrastructure and operation including the internet connection.

Since the MIA-Camera is operated by non-dedicated people, it is important to minimize the on-site operational tasks. For example, all the programs are activated with a start button of the computer and a few simple commands. This makes rebooting the system quite simple after power outages or system errors. Note that the present MIA-Camera uses a Japanese language operation system (this is because the program was made for star cameras in Japan), while the operational staff at the hotel consists of Swedes who do not under-

Fig. 4. A photo of the all-sky dome and the CCD unit at Abisko Turiststation. The dome is installed over the building's roof room where the computer and ventilation is installed. The black part at the top is the fish-eye lens, and the white box underneath is the CCD camera.

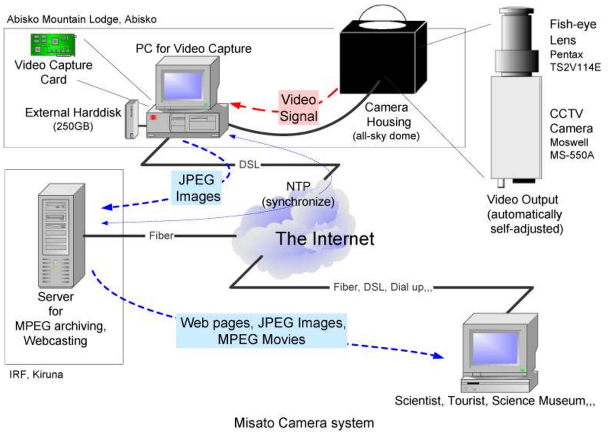

Fig. 5. Schematic diagram of the camera system.

stand Japanese. Nevertheless the system has been successfully operated for more than two years.

With this semi-automated system operated by local hotel staff, the IRF staff does not have to visit the camera site for maintenance except for changing hard-disks filled with jpeg files, changing the system setup, or rare unexpected problems. Therefore, we set fixed time resolution (20 sec) all day instead of reducing it to 5 min during the daytime as described above. Note that the length of the day changes quickly at this latitude and aurora is visible nearly 17 hours a day at winter solstice, so it is better to set "night" mode for the entire season. The built-in hard-disk (80 GB) can store data of 20-sec resolution jpeg images for about one year. For further archiving the jpeg files, we connected an external hard-disk (250 GB and 500 GB) to the PC instead of using tape or DVD devices to keep minimum manpower.

While the image is taken every 20 sec, only every third image (i.e., every minute) is sent to IRF in real-time bases over the internet for webcasting to prevent data gaps because handling time of one transfer is sometimes more than 20 sec in the relatively narrow internet connection at the hotel. All jpeg files of the day are transferred to IRF to create an mpeg movie of 24-hour data at IRF. IRF saves only the mpeg files on its public web server, while the transferred jpeg files are removed from the server at IRF. The mpeg movie is an effective format for event searching, while it also acts as a backup of the jpeg images. Since the mpeg movie is created in the morning, one may confirm the most recent auroral activity from the night before. This quick production is very important for outreach purpose.

On the other hand, the original jpeg files which are kept in the on-site hard-disk are not backed up at IRF. This is because the intention is to use the data for event searching, and this can be done with mpeg-quality images. One advantage of low-resolution data (and the mpeg format) is the small file size. It comprises only 20 MB per 24 hours (7 GB/year) even if the data is taken every 20 sec during both day and night. The compression rate is approximately 10%. This is a loadable size with 0.5 Mbps (about 6 minutes for full download), and its ordinary-speed reply (24 Hz) takes only 3 minutes ($24 \times 60 \times 3$ images per day). For surveying auroral occurrence, one only has to search the nighttime data, i.e., only 2 min/day even at the winter solstice.

4 Benefits

This cooperation has advantages for all three sectors: the tourist hotel for advertising purposes; the astronomical museum for lively service; and the scientific institute for monitoring and statistics. The real-time auroral image and its mpeg archive clearly indicate that Abisko Turiststation is located at the right place for aurora tourism. Visitors to Misato Observatory at mid-latitude can enjoy the real-time images or the most recent mpeg movies of the remote auroral phenomena in Arctic. Scientists obtain an extra auroral observatory with extremely low operational/infrastructure costs even if the produced data is not as high quality as dedicated ASCs operated by professional staff. As a result of the successful operation of the MIA-Camera, a second camera with the same system (but with black-and-white images giving a higher spatial resolution) started operation at IRF from March 2007.

Another benefit to scientists is that the system can be used for remote weather monitoring. A 70 km distance is far enough to give different cloud coverage. Figure 6 shows one such example. While MIA-Camera images (upper panel) show clear aurora for all three different times (nearly 1 hour apart each other), the all-sky images at IRF (lower panel) are

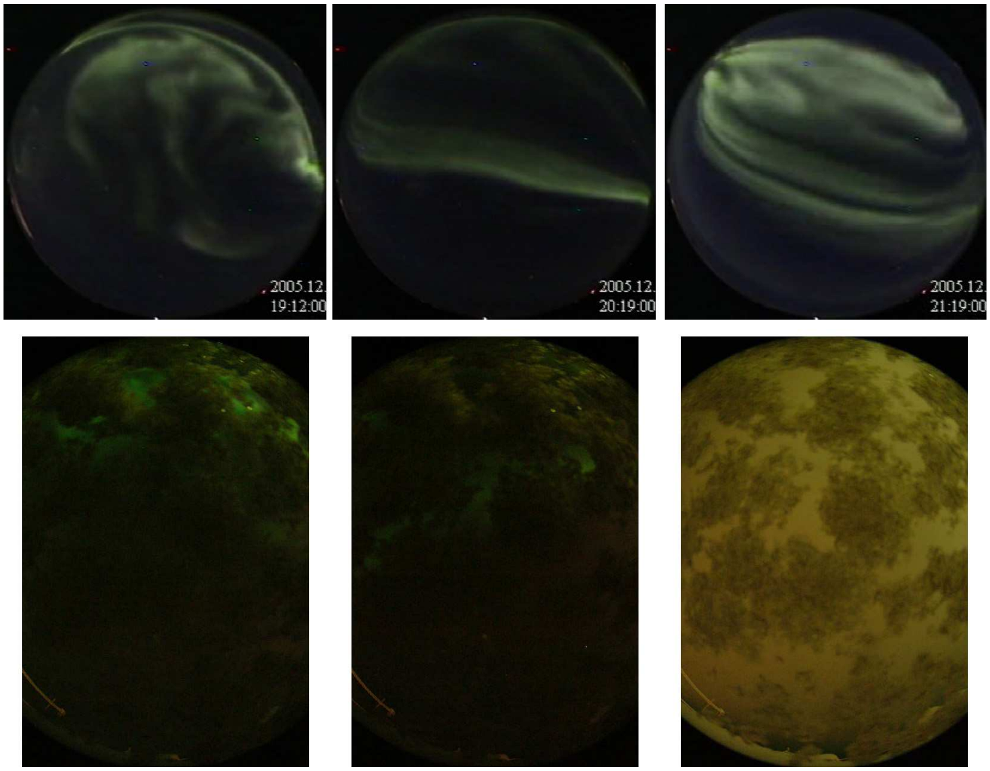

Fig. 6. Sample images of the aurora taken by MIA-Camera at Abisko Turiststation (upper panel) and by the official IRF-ASC (lower panel). From left to right: 19:12:00 UT, 20:19:00 UT, and 21:19:00 UT. There is a slight difference in image is due to a slight timing error (less than a minute) in the IRF-ASC (image marked as 19:12:00 UT is not taken exactly at 19:12:00 UT) due to wrong internet information. Although the direct distance between these two places are only 70 km, cloud coverage is quite different, indicating that it is important to have extra camera within 70 km distance to monitor the auroral condition above the cloud at the scientific institute.

blocked by cloud in all cases. Since ASCs are often used for decision making for operation of other facilities (e.g., radar, sounding rockets, and 3-D auroral imaging systems), extra imaging sites increase the chances of useful/meaningful operations. In fact the MIA-Camera is regularly used by IRF staff to determine if weather and auroral conditions are favorable enough for starting ALIS.

The low-cost, low-sensitivity ASC might also contribute to science itself by taking statistics because degradation of the CCD-camera is not large for several years. Although the camera is not calibrated, the sensitivity for the MIA-Camera is nearly the same after more than 3 years of continuous operation as far as we can judge from the visibility of stars. Furthermore, the daily mpeg files are an optimum size for quick survey. These facts make the obtained data usable for survey-type statistics. We show some examples below.

Table 1 shows a sample of day-to-day lists of auroral activity overnight from the archived mpeg files during the period 1-15 March 2005. The table format is given in Table 2. Each column in Table 2 explains the corresponding column in Table 1: the 3rd, 4th, and 5th columns in Table 1 summarize UT of auroral activation, auroral expansion, and the sky cloud cover, respectively. The 2nd column in Table 1 shows the other weak aurora such as quiet arcs or those located far in the north without any activation arcs. The 4th column shows break up-like activities, and most likely indicate that substorm onsets took place within 20 minutes, but this needs to be confirmed with other data sets. In each column in Table 1, different format for UT and parenthesis is mixed, and this is explained in different row in Table 2.

The classification scheme used in Tables 1 and 2is similar but more detailed compared to the traditional notes which have been used since IGY 1957: we added the onset time of auroral activation or expansion. This is partly because the breakup/expansion is less dependent on personal bias than traditional simple “strong" or “normal" intensity criterion, and partly because our interest for outreach purposes is more on dynamics than static intensity. To reduce the time-dependent uncertainty in judgment, the mpeg data for the entire period (two winters) were examined several times by one person (Yamauchi) until the clarification was stabilized. Therefore, the personal “bias" in judgment should be constant for the entire two-year data set.

The list given in Table 1 format can be directly compared

Table 1. Example of day-to-day list of aurora visibility

date	aurora(UT)	activation (UT)	expansion (UT)	cloudy (UT)
050301	1940∼0300	(2111=north) (2154=north)	2132=north	
050302	2035∼2105 and 2235∼2335	(2035=far north) 2254=north		2010∼2100
050303	invisible			∼0000 and 0040∼0220
050304	2005∼2100	far north		2300∼
050305	1920∼2300 0015∼0025	1907=pseudo	(1920=pseudo=)1952, (2139 through cloud)	∼1830 and 2020∼
050306	1800∼2230 2300∼0400	0007=omega	o 1804=1820, (2126, 2254, 0150, all through cloud), (0127=omega through cloud)	2120∼2300 and 0130∼0230
050307	1735∼1810 and 1940∼2119 and 2225∼2235	1939=pseudo north 2018=pseudo	1749, 2038	∼1740 and 2240∼
050308	1810∼0255	1824=north 1856=north 2317=omega north	(1939=pseudo=)2011, 2221, (0244=omega over cloud)	0050∼
050309	invisible	(2226 over cloud)		all night
050310	invisible			all night
050311	rim=2200∼2215	2204=far north		
050312	rim=2325∼2330	(2322=far north through cloud)		
050313	1815∼1845 and 2020∼0330	2025=north 0153=omega	(2059 or 2123=north) o=2211, 0014=omega	
050314	1815∼1840 and 2230∼0020	1814=north	2230	
050315	rim=2100∼2140 and 2225∼2240 and 2320∼2335	2105=far north (2317=north omega)	(2222=north)	

with the other data from different instruments (e.g., magnetometer) or at different places because the list is given by event (breakup or activation) instead of intensity. It is useful to compare the listing given in Table 1 format with IGY format summary for cross-calibration, and we await the relevant IGY format summary using the official IRF-ASC to be given in the future by a different person. It is particularly interesting to compare it to the list using keograms.

Figure 7 shows the statistics made from the complete day-to-day list (cf. Table 1) during two full seasons (September 2003 to April 2005). The green (solid), red (thick), and black (dashed) lines represent probabilities of seeing active aurora with dynamic motion, auroral expansion over the sky, and cloudiness, respectively. The overall probabilities during an entire winter (2003 2004 and 2004 2005) are shown in Figure 8.

As is expected, the probabilities of cloudiness and aurora are anti-correlated in Figure 7. In Figure 8a, one can recognize about 10% decrease of the probability seeing aurora from winter 2003-2004 (declining phase) to winter 2004-2005 (start of solar minimum), but a large part of this might be explained by the different cloudiness between these two winters. Still, it is worth pointing out that the decrease in probability of expansion (red bar in Figure 8a) is larger than

Table 2. Format of Table 1

item	aurora(UT)	activation (UT)	expansion (UT)	cloudy (UT)
With UT	very minor activation	Activation of aurora which might be related to substorm (or pseudo) onset	Expansion of aurora which most likely indicates substorm onset within 20 minutes	UT when the cloud coverage is more than half
Without UT	quiet arc or diffuse only	Just a minor activation of aurora both intensity and motion.		
(UT=text)		through/over cloud, and weak case	through/over cloud, and weak case	
(UT only)		Strong activation but less likely related to substorm onset	weak case	

∗ through cloud = aurora is seen between (patchy) cloud
∗ cloud = aurora is beyond continuous cloud
∗ far north = arc/activity at northern limn
∗ north = expansion/activation start from north to expand south

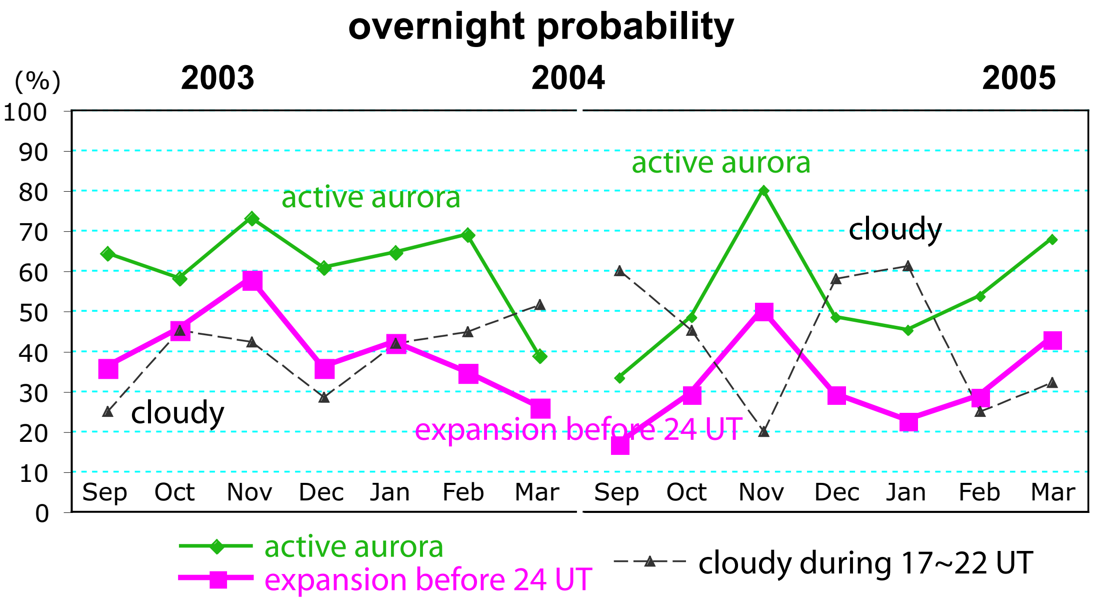

Fig. 7. Month-to-month probabilities of seeing active aurora, with dynamic motion (green solid line), auroral expansion over the sky before 24 UT (red thick line), and cloudiness during 17-22 UT (black dashed line). Auroral activities visible through patchy clouds are included, but auroral activities beyond cloud are not counted here. The expansion category (red thick line) includes those only in northern half sky, but does not include those which took place after 24 UT. A cloudy night is defined if the sky is mostly covered by cloud during 17-22 UT.

that of aurora activity (green bar in Figures 8b), and the number of substorm onsets at this latitude seems to have substantially decreased after subtracting the difference in the cloudiness. The result is consistent with the solar cycle change (Akasofu, 1977).

We also show three-night probability in Figure 8b. This

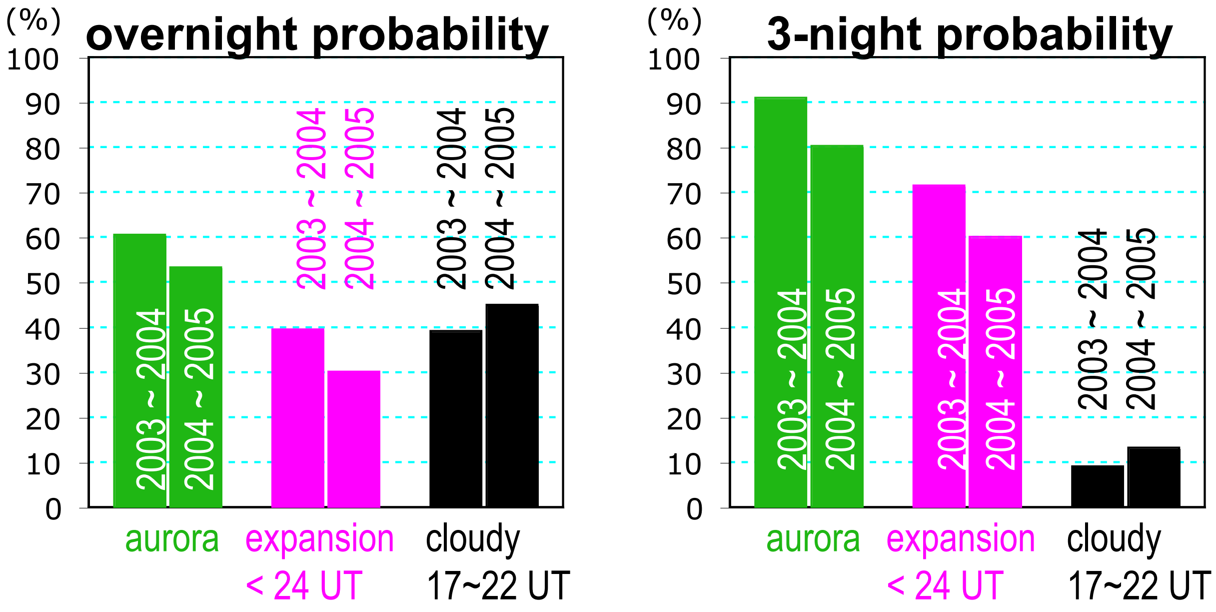

Fig. 8. Whole-winter probabilities (winter 2003 2004 with total 215 days and winter 2004 2005 with total 229 days) of seeing active aurora with dynamic motion (left), auroral expansion over the sky before 24 UT (middle), and cloudiness during 17-22 UT (right). (a) Probabilities are obtained for over single night. (b) Probabilities are obtained over three consecutive nights (“yes" for aurora if the aurora is seen at one of three nights, and “yes" for cloudiness if the sky during 17-22 UT is cloudy at all three nights).

type of statistics is useful for planning purposes because most of the campaigns of auroral observations require just one night of visible aurora activity during the stay. The statistics indicate that having three consecutive nights available for observations is probably enough to observe some aurora (80 90%), but not enough to be sure of observing break up (60 70%). In this way, Table 1 and Figures 7 and 8 show that even a low-cost ASC might contribute to science by treating the data statistically. Furthermore, this type of statistics also benefits aurora tourists for planning their travel and how many nights to stay. The chances of watching auroral break up are doubled if one stays three nights instead of one night.

5 Summary

An observatory-type museum (Misato Observatory), a scientific institute (IRF), and a local tourist hotel (STF/Abisko Turiststation) have jointly operated a low-cost auroral ASC system “Misato-IRF Abisko Camera" aimed at monitoring, educational, and event identification purposes since September 2005. The camera is installed at and operated by the tourist hotel for its real-time webcast with 1-min resolution and mpeg archiving with 20-sec resolution. The entire system consists of commercially available components: a fisheye lens with automatic aperture (1.4 - 64), a color CCD camera with digital output with automatically adjusting exposure (up to 256 field), a capture card, and a PC, with a total cost less than 2000 EUR. The camera system was regularly operational at IRF from spring 2003 to fall 2005, since when it has been in operation at Abisko Turiststation.

The webcast and the mpeg archive benefit all three contributors from different sectors in different ways. The public astronomical museum at mid-latitude can show the auroral phenomena to its visitors, the tourist hotel can show that the hotel is located at the right place for aurora tourism, and the scientists have an additional auroral monitoring station 70 km away from the institute with very small operational cost. Even with such a low-cost camera system mainly aimed at educational/tourism purposes, the images obtained still help auroral science by making a list of auroral activity and statistics as shown in Table 1 and Figures 7 and 8. As a result of this successful cooperation, we have installed a new black-and-white panchromatic fisheye camera at IRF (in operation since March 2007), which will again be moved to another place in the future.

The web address for these real-time webcasts is, for the MIA-Camera:

http://titan.irf.se/misato/abisko/sky_abisko/sky_abisko.html

and for the newly installed camera:

http://misato.irf.se/images2/current.jpg

The mpeg archive for MIA-Camera data is at:

http://titan.irf.se/misato/abisko/sky_abisko/yyyy/mm/

and for the newly installed camera data:

http://titan.irf.se/misato/yyyy/mm/

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