The 1st Technical Note of AMON-ES (TN1-AE)

SK2-09: Follow-up of feasibility study to observe ionospheric disturbances by airglow monitoring network (AMON-net)

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Contents

Revision History

Revision	Date	Author(s)	Description
1.0	07. 07. 2019	S. Mackovjak	Submitted version for CDR

Chapter 1

Introduction

1.1 Purpose

The 1st Technical Note of AMON-ES (TN1-AE) reports the details about the operation of Airglow MONitor - Extended Station (AMON-ES) that is a substantial part of the R&D activity "Follow-up of feasibility study to observe ionospheric disturbances by airglow monitoring network (AMON-net)" (SK2-09).

The TN1-AE provides description of 1st phase of AMON-ES performance, and the results of the initialization and testing procedure that was realized according Technical Note of System Requirements Specification (TN-SRS) and Manufacturing, Assembly, Integration and Test Plan for the AMON-ES (MAITP-AE). The continuation of AMON-ES performance during its 2nd phase will be described in the further documentation 2nd Technical Note of AMON-ES (TN2-AE).

1.2 Document Overview

The TN1-AE document consists of four major chapters. Introduction (Chapter 1) provides basic information about the document. The results of the AMON-ES components initialization, testing and installation according MAITP-AE is provided in Chapter 2. The AMON-ES operation during the 1st phase, acquired data and their consequences are presented in Chapter 3. The conclusions and the next steps are provided in Chapter 4.

1.3 Intended Audience

The Airglow MONitor - network (AMON-net) system is developed by Department of Space Physics (DSP), Institute of Experimental Physics (IEP), Slovak Academy of Sciences (SAS) within the European Space Agency (ESA) / Plan for European Cooperating States (PECS) in Slovakia. The AMON-ES is the substantial part of AMON-net development process. The 1st

Technical Note of AMON-ES (TN1-AE) is a deliverable to ESA team, that provides support to Cooperating States, for the review within the 2nd Milestone - Critical Design Review (CDR). It will be essentially used by DSP staff to continue in R&D activity SK2-09.

1.4 Acronyms and Abbreviations

AAC AMON All-sky Camera

AMON Airglow MONitor

AMON-ES Airglow MONitor - Extended Station

AMON-net Airglow MONitor - network

AOK Astronomical Observatory on Kolonica Saddle

AGW Atmospheric Gravity Waves

CDR Critical Design Review

DSP Department of Space Physics

ESA European Space Agency

GNSS Global Navigation Satellite System

IEP Institute of Experimental Physics

MAITP-AE Manufacturing, Assembly, Integration and Test Plan for the AMON-ES

PECS Plan for European Cooperating States

R&D Research & Development

SAS Slovak Academy of Sciences

SK2-09 "Follow-up of feasibility study to observe ionospheric disturbances by airglow monitoring network (AMON-net)"

TEC Total Electron Content

TN-SRS Technical Note of System Requirements Specification

TN1-AE 1st Technical Note of AMON-ES

TN2-AE 2nd Technical Note of AMON-ES

TN-TS Technical Note of Theoretical Study

1.5 References

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[2] MikroTik. MikroTik hEX PoE, available at. https://mikrotik.com/product/RB960PGS, (accessed June 10, 2019).

[3] Supermicro. SupermicroSYS-E100-9S-L, available at. https://www.supermicro.com/products/system/Box_PC/SYS-E100-9S-L.cfm, (accessed June 10, 2019).

[4] Joint Laboratory of Optics. Palacky University in Olomouc and Institute of Physics of the Czech Academy of Sciences, available at. http://jointlab.upol.cz/slo/?language=en, (accessed January 3, 2019).

[5] Septentrio. Septentrio RxTools, available at. https://www.septentrio.com/en/products/software/rxtools, (accessed June 10, 2019).

[6] PyEphem. astronomy library for Python, available at. http://rhodesmill.org/pyephem/, (accessed January 3, 2019).

[7] Paul Hickson and Alan Stockton. Typical spectrum of visible night sky emission at Mauna Kea, available at. http://www.cfht.hawaii.edu/Instruments/ObservatoryManual/CFHT_ObservatoryManual_(Sec_2).html, (accessed June 10, 2019).

[8] P. Hannawald, C. Schmidt, R. Sedlak, S. Wüst, and M. Bittner. Seasonal and intra-diurnal variability of small-scale gravity waves in oh airglow at two alpine stations. *Atmospheric Measurement Techniques*, 12(1):457–469, 2019.

Chapter 2

Initialization, testing and installation of AMON-ES components

The AMON-ES has been designed to fulfill two main goals of the current phase of SK2-09 activity:

- filter out all sources of the AMON data contamination that could produce fake variations in measured data caused not by airglow intensity variations but by weather conditions, astronomical background or by other technical uncertainties
- obtain a wider understanding of processes and phenomena that influence the airglow production in the upper atmosphere. It needs to be considered that detected airglow variations might be caused not only by geomagnetic storms but also by different phenomena which have an origin in the lower Earth's atmosphere including tides, planetary waves and atmospheric gravity waves.

In what follows, the initialization, testing and installation procedures of AMON-ES are described. These procedures were mandatory for reliable operation of AMON-ES and for achievement of the main goals listed above. These procedures were performed according the details specified in MAITP-AE.

2.1 AMON-ES operation platform

The AMON-ES is located on Astronomical Observatory on Kolonica Saddle (AOK) in north-east Slovakia. The exact position within the observatory was finally selected not in the observational dome "Atacama" but next to it. It was decided that the AMON-ES will use stand-alone operation platform. This will allow operation of AMON-ES instruments independently from the observational procedures on AOK and remote control by DSP staff from Košice. The new selected position of AMON-ES within the AOK area is indicated in Figure 2.1. The operation platform consists of 3 m high still frame that is coated by zinc-iron alloy layers to protect it from corrosion. The frame has 1 m deep concrete base. The whole construction was prepared to be very solid and to provide high flexibility for mounting of different instruments. The sketch and images of AMON-ES frame is in Figure 2.2. This frame was installed when the weather conditions allowed this work - i.e. the outside temperature was not forecast to be lower than 5°C for several weeks.

Figure 2.1: The position of of AMON-ES within the AOK area. The position is indicated by white arrow.

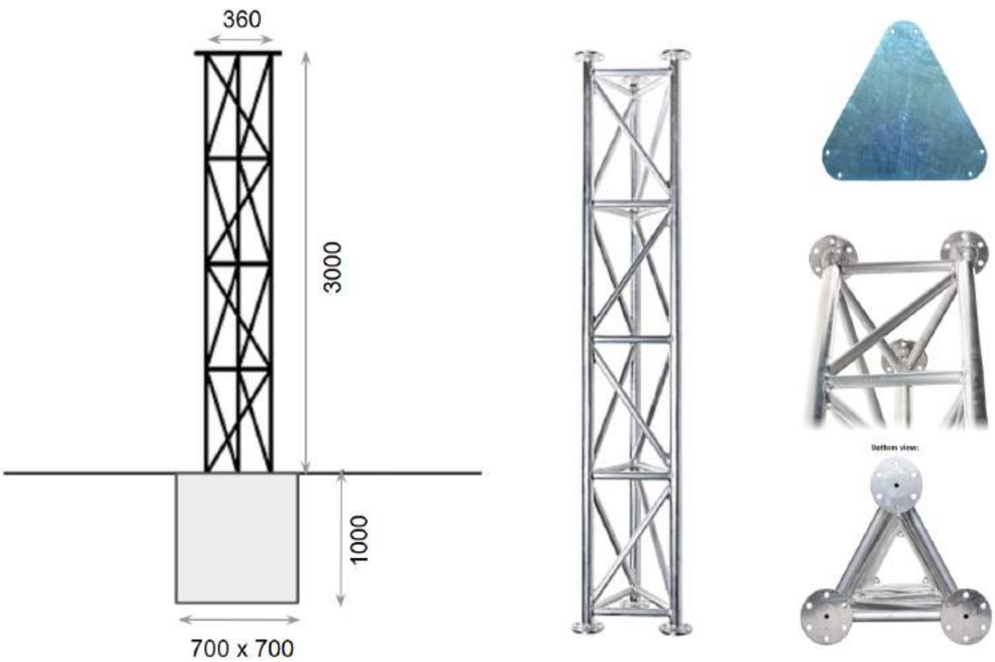

Figure 2.2: The sketch and images of AMON-ES operation platform frame with indicated dimensions in mm.

The other mandatory parts of AMON-ES operation platform are electricity infrastructure, internet network infrastructure and the operation server. These components were installed in the metal box coated by epoxy resin that provide waterproof and save environment for whole infrastructure (Figure 2.3). The electricity connection is controlled by TinyControl LK3.5 that supports various protocols and allow control up to 10 outputs or read and send value of various types of sensors. It works with smartphone and web application and allow automatise process by scheduler and events configuration [1]. The internet network infrastructure is controlled by MikroTik hEX PoE - RB960PGS. It is a five port Gigabit Ethernet router. The device has a USB 2.0 port and a SFP port for adding optical fiber connectivity. The ports 2-5 can power other PoE capable devices with the same voltage as applied to the unit. It is affordable, small and easy to use, but at the same time comes with a very powerful 800MHz CPU, capable of all the advanced configurations that RouterOS supports [2]. It was used to create VPN (virtual private network) to connect AMON-ES with computers in Košice, by a secure way. The AMON-ES operation server Supermicro SYS-E100-9S-L with 4GB RAM and 1TB SSD storage is embedded/IoT System with Intel Core i3-7100U Processor. It has all needed sockets and ports. The fanless design allow its reliable operation in exterior conditions [3].

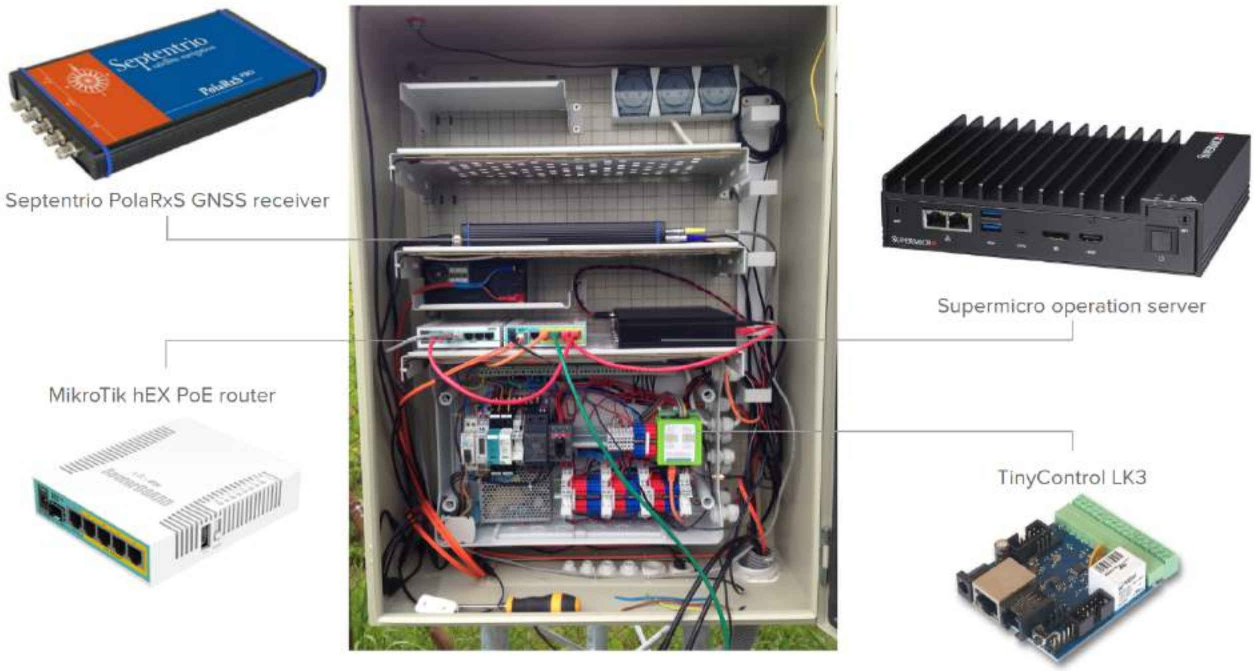

Figure 2.3: The AMON-ES box during installation of the electricity and internet infrastructure. The components specified in the text are highlighted.

2.2 AMON All-sky Camera (AAC)

The AMON All-sky Camera (AAC) is a crucial part of AMON-ES as it provides all-sky overview of airglow variation in 5 spectral bands. The technical details are specified in Chapter 3.1 in Manufacturing, Assembly, Integration and Test Plan for the AMON-ES (MAITP-AE). Here are provided results from Integration and Test Procedure according the steps listed in Chapter 4 in MAITP-AE.

The complete all sky airglow camera was delivered by Joint Laboratory of Optics of Palacky University in Olomouc and Institute of Physics of the Czech Academy of Sciences [4]. The main parts of AAC were verified in DSP lab (Figure 2.4). The main characteristics are listed bellow.

Figure 2.4: The camera Moravian Instruments G2-4000 with filter wheel is the main component of AAC. Camera is displayed from different views in laboratory conditions.

AMON All-sky Camera (AAC) main characteristics:

- Camera: Moravian Instruments G2-4000
- Chip: 4 MPx Kodak KAI-4022 CCD
- Resolution: 2056 × 2062 pixels
- Filters: narrow-band filters with width 10 nm and center at 560, 568 and 632 nm. Broad-band filters 300–400 nm and 715–930 nm.
- Lens: Sigma, fish-eye, focal length - 4.5 mm, angle of view - 180°, aperture - f/2.8
- Case: Waterproof aluminium case with glass window
- Total price: 10,209.00 eur (w/o VAT)

The basic functionality was tested in laboratory conditions. Camera is operated by scripts written in Python language to allow smooth operation with the AMON-ES server computer with Linux (Debian) system. It was verified that the instrument communicate with the operation server, that the exposure time can be set for each filter window, that the cooling system is functional and that the data can be stored in FITS format according the specification for the data analysis. The set-up for operation was accomplished at AOK in May 2019 (Figure 2.5). The first light image is presented in Figure 2.6. The required image was obtained when the internal humidity in waterproof box was eliminated. The first relevant data of AAC are presented in Chapter 3.

Figure 2.5: The installed AAC at AOK without *(left)* and with *(right)* waterproof cover.

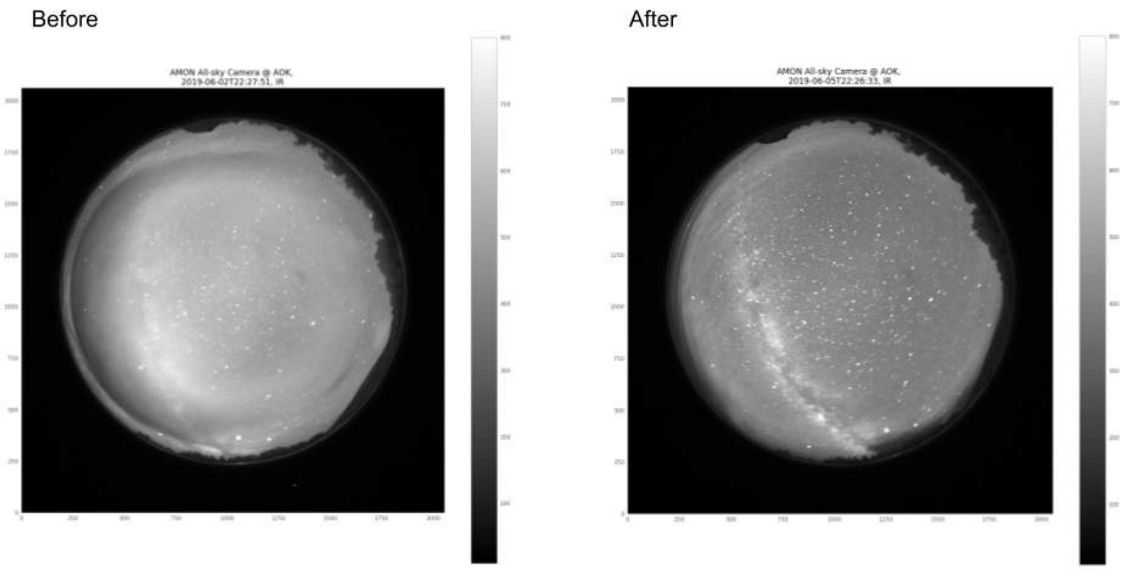

Figure 2.6: The first light images of AAC before *(left)* and after *(right)* elimination of water vapours inside the waterproof case. The image is now focused.

2.3 GNSS Receiver

The second most important component of AMON-ES is Global Navigation Satellite System (GNSS) receiver with antenna. It is used to monitor ionospheric indices and to provide reliable data that will be correlate with the airglow measurements. The details are specified in Chapter 3.2 in MAITP-AE. Here are provided results from Integration and Test procedure according the steps listed in Chapter 4 in MAITP-AE.

The complete GNSS receiver Septentrio PolaRxS with anthena Trimble Zephyr Geodetic Model 2 was loaned by ESA and delivered to DSP laboratory in March 2019 (Figure 2.7).

Figure 2.7: The GNSS receiver Septentrio PolaRxS with anthena Trimble Zephyr Geodetic Model 2 unpacked after delivery in laboratory conditions. The serial numbers can be seen in images on the right side.

The receiver is a complex instrument that required detailed study of user manuals and the applications within RxTools [5]. The drivers were installed on AMON-ES operation server and the main features were verified in laboratory conditions. The GNSS receiver with antenna were installed at AOK in May 2019 (Figure 2.8 and Figure 2.9). The quick view of first data obtained at AOK are displayed in Figure 2.10). They are discussed in more details in Chapter 3.

Figure 2.8: Two different views of AMON-ES at AOK in May 2019. GNSS receiver is installed inside the box as it is presented in Figure 2.3. The GNSS antenna and AAC are installed on the top of the construction with sufficient view to whole sky.

Figure 2.9: The AMON-ES at night with opened box for electronics.

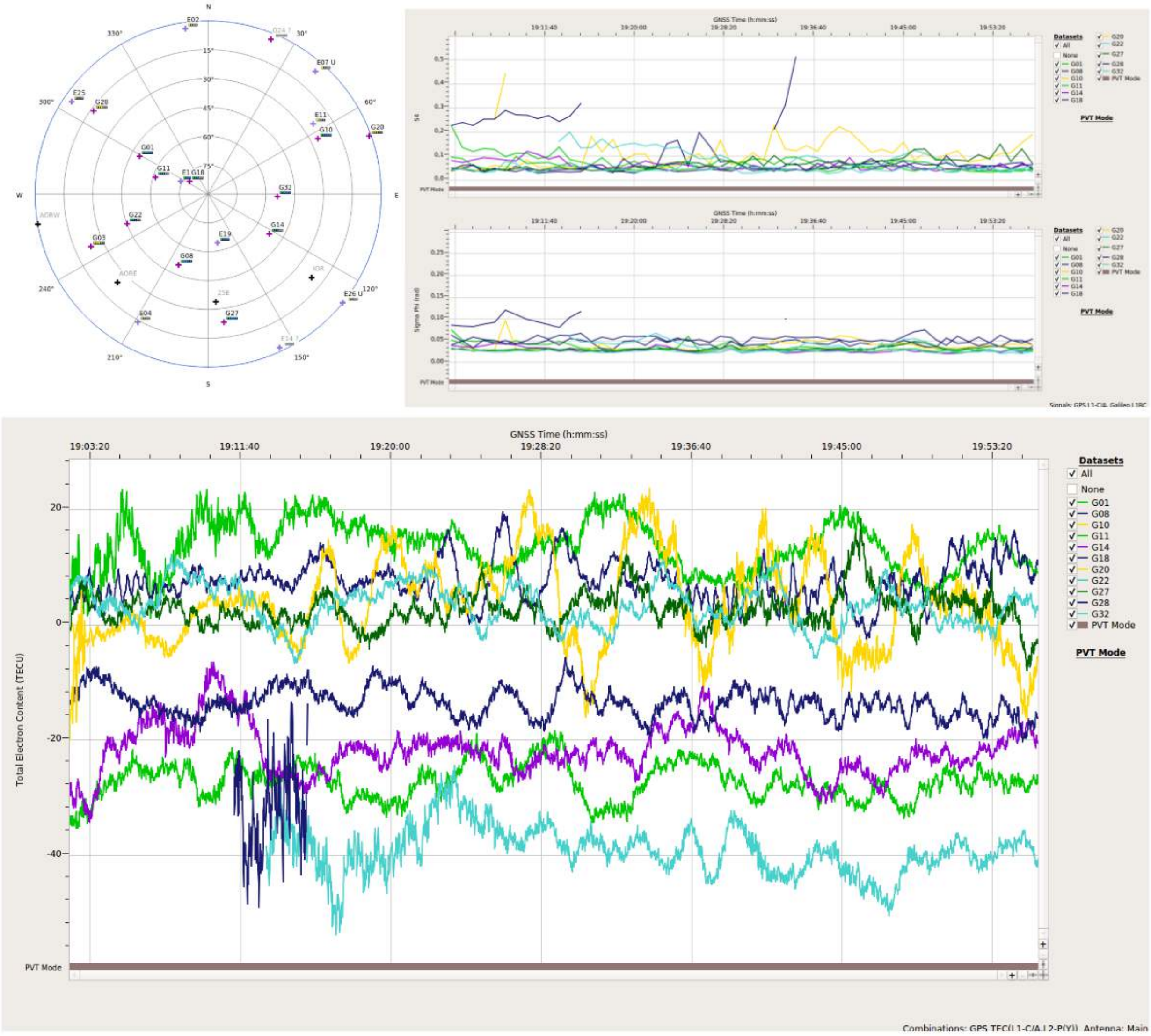

Figure 2.10: The first data obtained by GNSS receiver. *Top left:* The view of actual positions (azimuth and altitude) of GNSS satellites (GPS (G#) and Galileo (E#)). *Top right:* The ionospheric scintillation indices (S_4, σ_ϕ) for particular GPS satellites. *Bottom:* The total electron content (TEC) provided directly by GNSS receiver for particular GPS satellites. All images are screenshots from SBF analyzer application that is part of RX tools.

Chapter 3

Results of the 1st phase of AMON-ES operation

The main motivation for AMON-ES was to perform simultaneous measurements of the upper atmosphere by different reliable instruments and so to get wider overview what it is observed by a single Airglow MONitor (AMON) instrument. The AMON instrument is installed at AOK since May 2018. During the autumn, there were suitable weather conditions without clouds to monitor UV airglow variations during several subsequent nights. The examples of these measurements are displayed in Figure 3.1. What is the source of this variation? Is AMON able to detect short-therm variations in the thermosphere-ionosphere? To answer these questions, the AMON-ES has been constructed as it is described in Chapter 2.

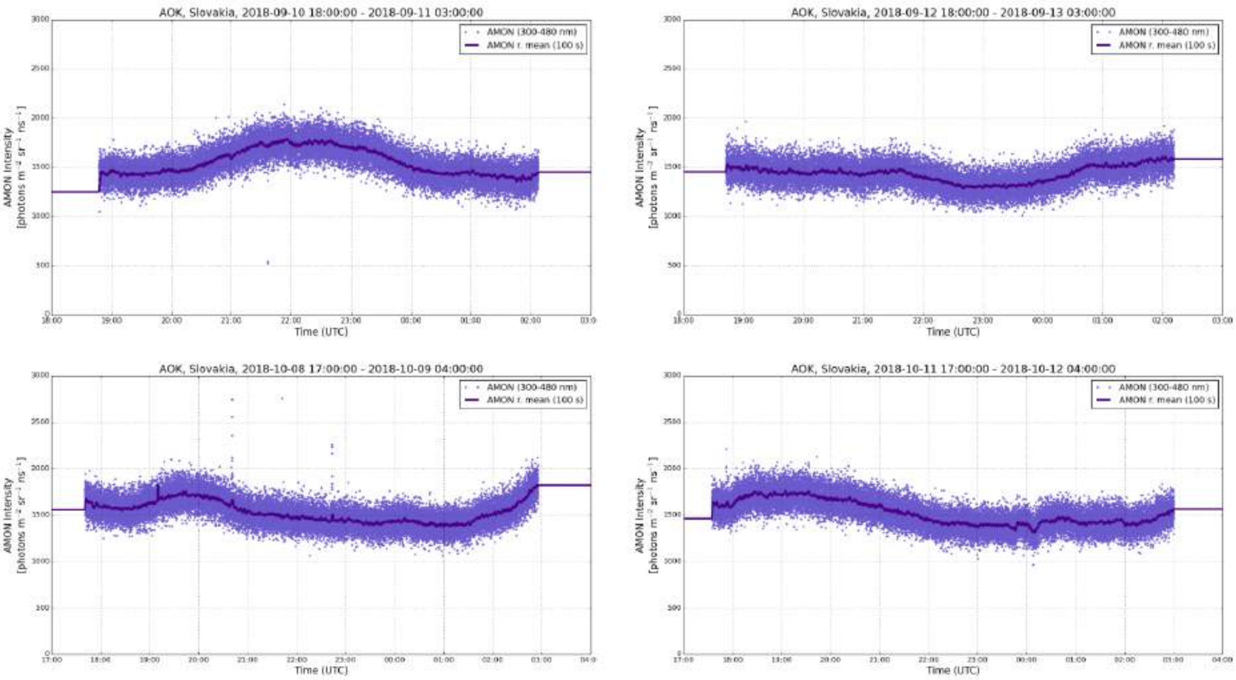

Figure 3.1: The AMON measurements at AOK during 4 nights in autumn 2018. The evolution of measured intensity differs for each night.

As it was mentioned in Chapter 2, the AMON-ES has started to operate in May 2019. The first measurements were performed during June 2019. But this month has the shortest nights during the year for this location (Figure 3.2). Therefore these measurements were used mainly for the initial analysis and for preparation of the tools for more detailed analysis.

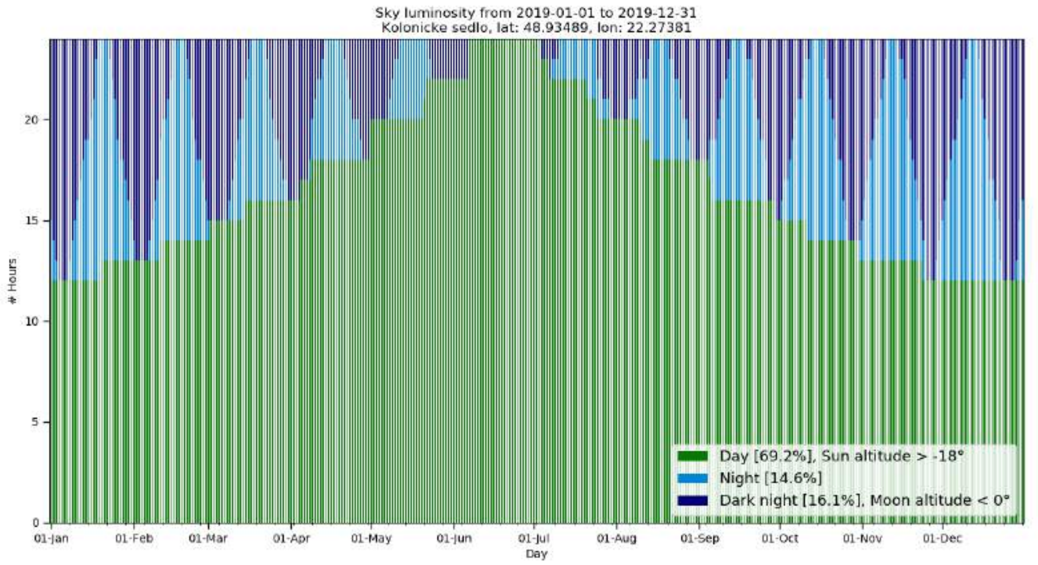

Figure 3.2: The number of hours for day, night and dark night conditions at AOK for the year 2019. The dark night conditions (dark blue) are required for measurements of airglow light without presence of the light from Sun and Moon. The image was created by using PyEphem [6] library in Python.

Even during very short nights, it was possible to clearly recognise airglow emission in the specific wavelengths. AMON All-sky Camera (AAC) was designed to observe airglow in the most prominent airglow spectral lines (see Technical Note of Theoretical Study (TN-TS) Chapter 3 for theoretical background). The width of the AAC spectral filters related to the standard airglow emission is indicated in Figure 3.3. It is noted that the filter with the designation N (means "no airglow emission lines") will be used not for airglow observation but for the observation of astronomical (stars, Milky Way, etc.) and artificial background. The difference between sky emission in airglow spectral bands (G, R, IR) and the N filter is visible at a glance in Figure 3.4. It is even more evident by comparison of the histograms from these images (Figure 3.5). The image obtained by using of N filter (Figures 3.4 and 3.5 - top right) has the less number of high intensity pixels because the contribution from the airglow light is minimal. The contribution of green airglow (OI 557.7 nm) in image obtained by using of G filter (Figures 3.4 and 3.5 - bottom left) and contribution of red airglow (OI 630.0 nm) in image obtained by using of R filter (Figures 3.4 and 3.5 - bottom left) can be clearly recognised. It is noted that the width and transmittance of N, G, and R filters are the same. The IR filter (Figures 3.4 and 3.5 - bottom right) transmit much wider spectral range. Therefore the detected intensity is higher then by using other filters. It is noted that all 4 images were obtained within one sequence of AAC data acquisition while the dark frame is subtracted from them automatically.

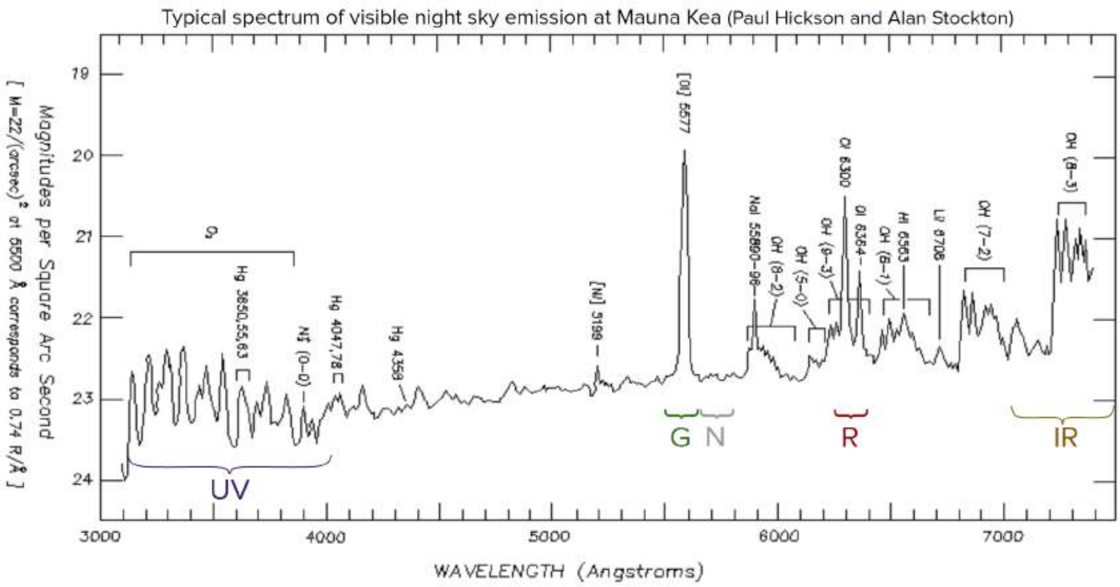

Figure 3.3: The typical airglow spectrum by [7]. The five spectral filters that are used in AAC are indicated with the width and the designation.

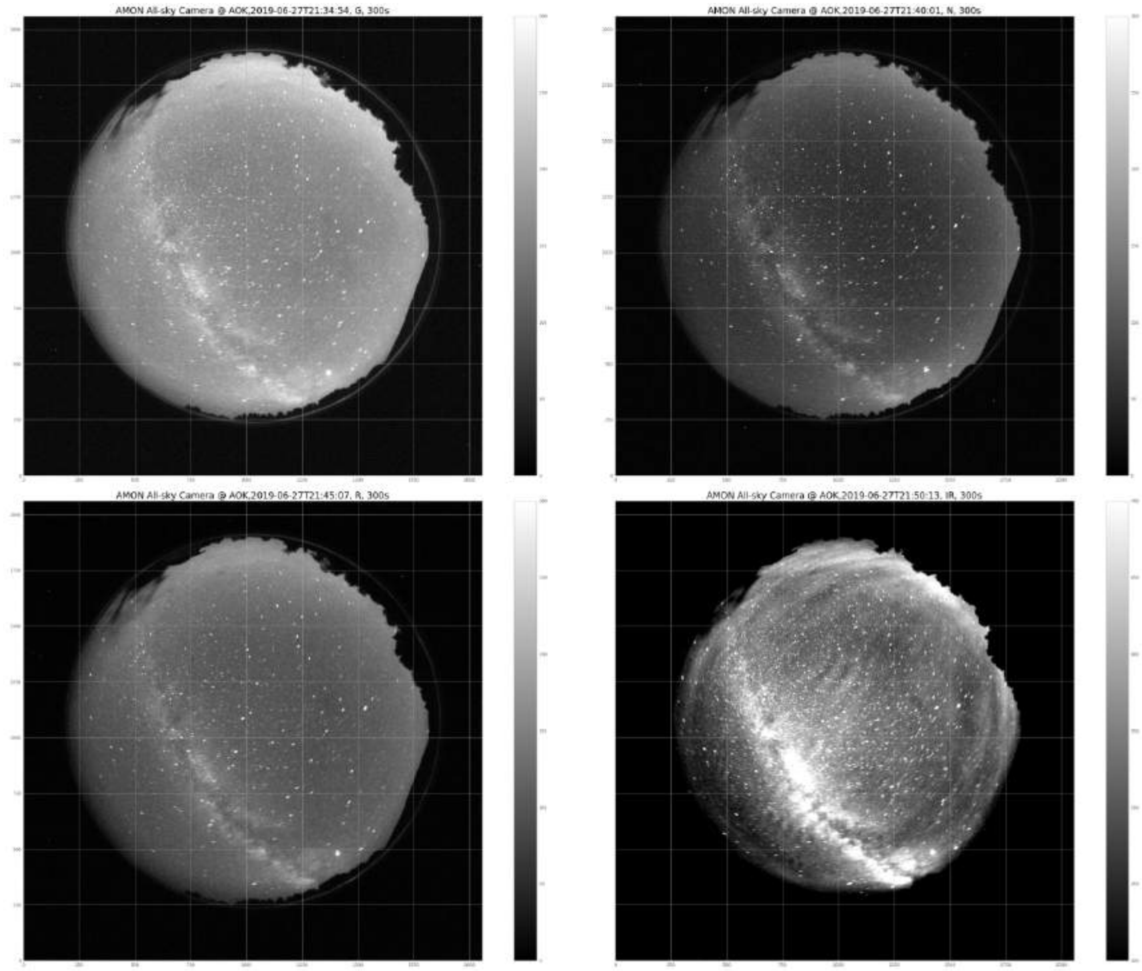

Figure 3.4: The all sky images in filters G, N, R, IR obtained by AAC on 27 July 2019.

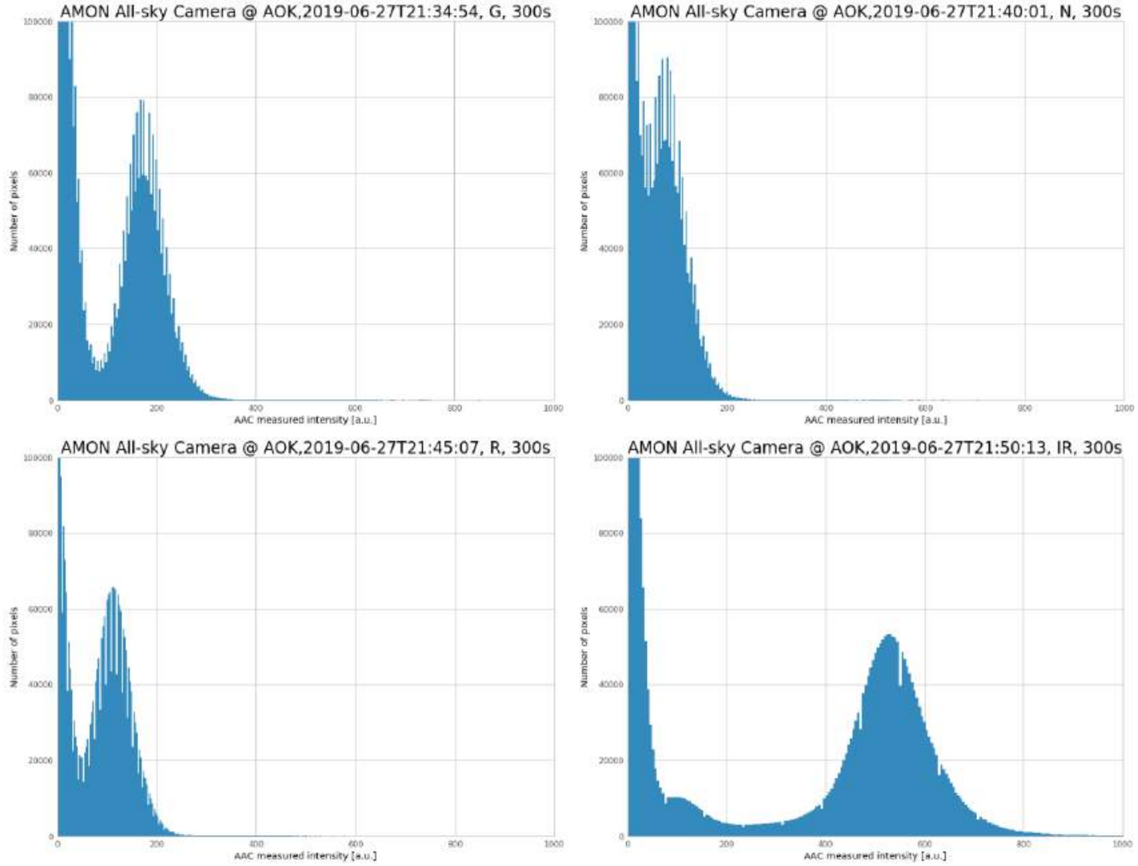

Figure 3.5: The histograms that represent the intensity distribution of pixels on particular images in Figure 3.4.

The results presented in Figure 3.4 demonstrate that AAC is able to detect airglow emission and even more to detect variations in this emission. The wave-like structures visible in IR image are generated by Atmospheric Gravity Waves (AGW). The origin and consequences of AGW are discussed in more details in TN-TS Chapter 3. Here we would like to demonstrate that AAC with IR filter is able to detected AGW in OH airglow layer. The Figure 3.6 is composed of 6 images obtained on 25 July 2019 in time interval 21:08 - 22:11 UTC. The wave-like structures are mowing from the bottom-right corner of the image to the top-left corner it means from south-west to north-east. This direction is consistent with the general propagation direction of AGW in north hemisphere in summer [8]. For the present, these AGW structures were detected only by using of IR filter i.e. in OH airglow layer with maximum in altitude 87 km. More observations are needed to study the AGW propagation also in other filters i.e. in other airglow layers with maximum in different altitudes. It is important to note that presented variations are not tropospheric clouds. The presence of clouds can be recognised by detection of stars in images in different filters. The example of presence of cloud at AAC data is displayed in Figure 3.7.

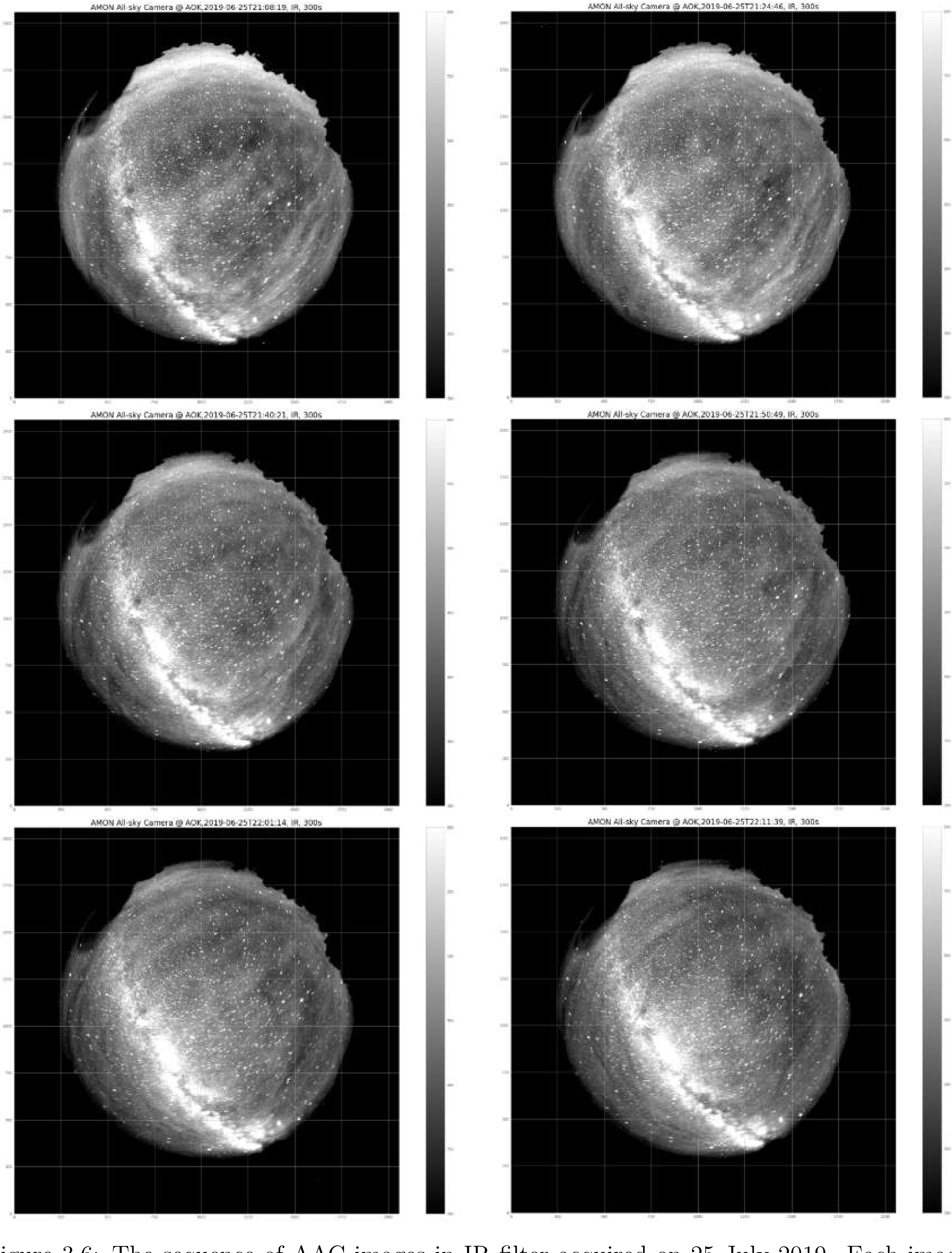

Figure 3.6: The sequence of AAC images in IR filter acquired on 25 July 2019. Each image was acquired with 300 s exposure time in specific UTC time denoted on the top of each image.

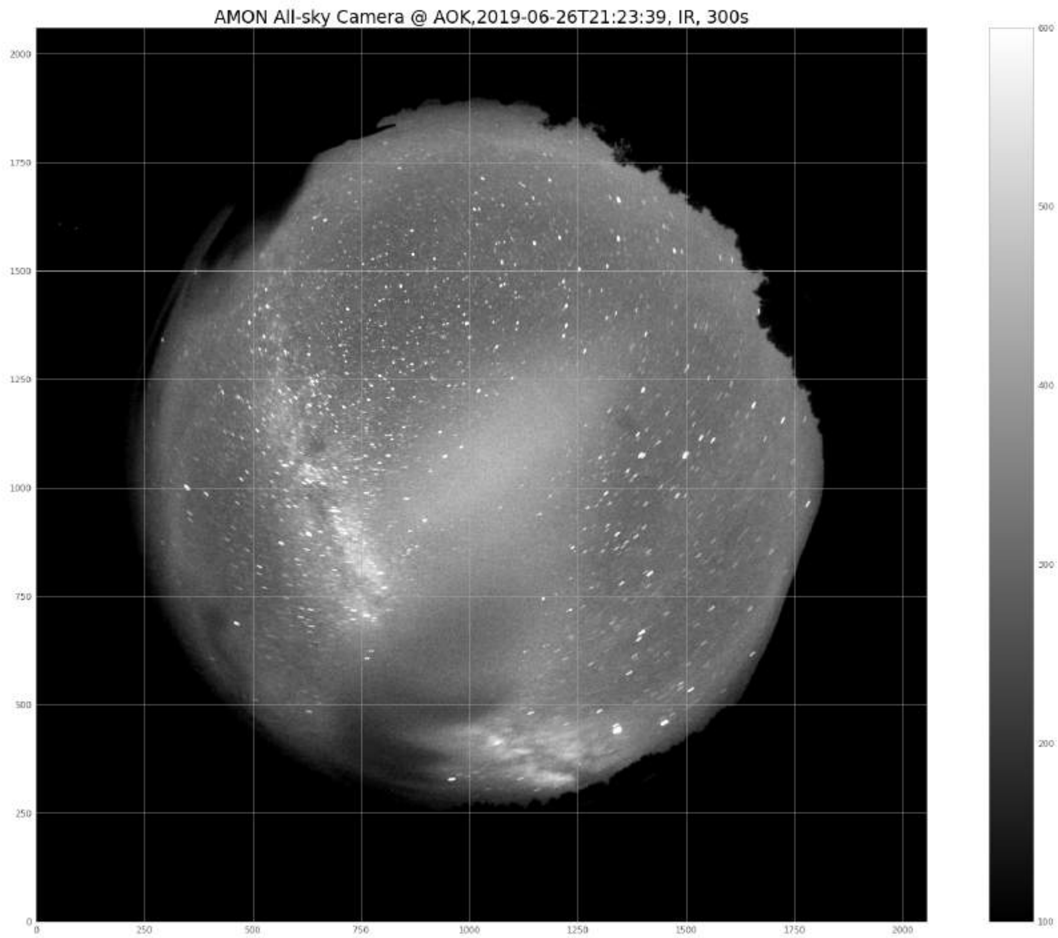

Figure 3.7: The example of not clear sky conditions at AOK. The presence of cloud is blocking the light from stars and Milky way.

During the night of 25 July, the GNSS receiver at AMON-ES was also operated. We have concentrated on the measurements of Total Electron Content (TEC) as it has a direct link-up to airglow production (see TN-TS Chapter 3 for more details). The key task is the proper presentation of the measured data. As it is presented in Figure 2.10 we need to associate each measured TEC value with the position of GNSS satellite (azimuth and altitude) and the time. Therefore it might by quite complicated to interpret the TEC data just as a time series as it is in Figure 3.8. It is due to the fact that the data are overlapped and the information about the position of the satellites is missing. Therefore it seems that it will be more useful to plot the TEC data to polar plot as it is displayed in Figure 3.9. In a such way the information about position of the GNSS satellite together with the value of measured TEC is presented. To demonstrate the direct connection of airglow monitoring and ionospheric indices more AMON-ES data and deeper analysis, as it is described in Chapter 4, is needed.

Figure 3.8: The time series of Total Electron Content (TEC) measured by AMON-ES GNSS receiver at AOK on 25 July 2019.

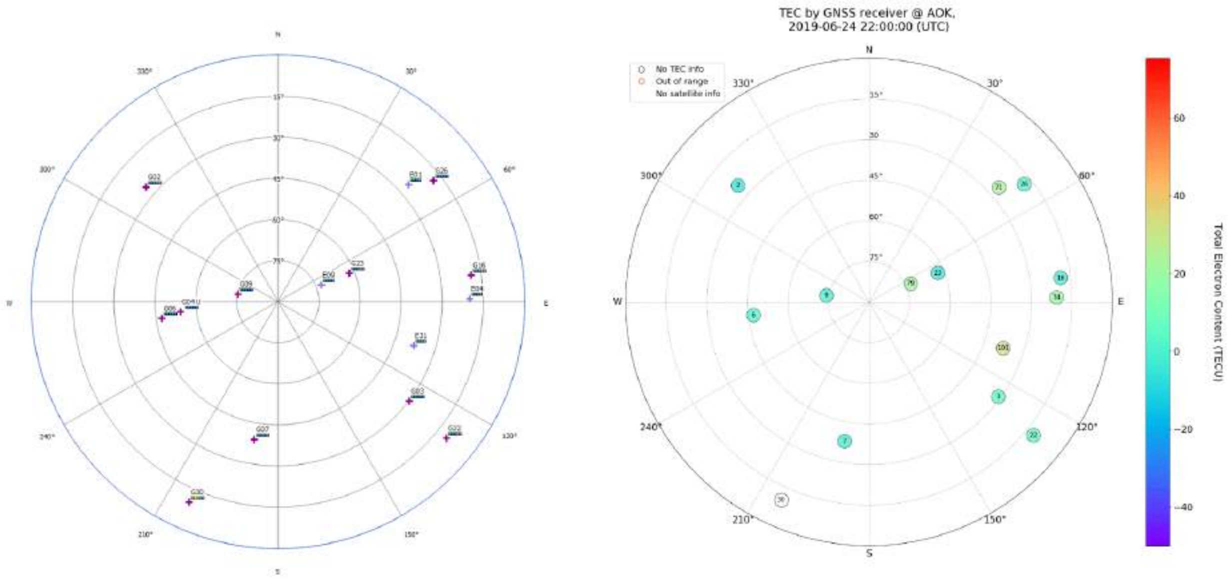

Figure 3.9: The polar plot of GNSS satellites position obtained by Rx Tools - SBF analyzer (*left*) and the polar plot of GNSS satellites position and value of TEC generated by script in Python (*right*). The data were measured by AMON-ES GNSS receiver at AOK on 25 July 2019. The consistency of the satellites position demonstrates the correctness of the scripts that we are using.

Chapter 4

Conclusions and Next steps

The main objective of 1st Technical Note of AMON-ES (TN1-AE) was to provide detailed information about construction of Airglow MONitor - Extended Station (AMON-ES). The main message of this technical note is that the AMON-ES has been successfully established. The main instruments - AMON All-sky Camera (AAC) and GNSS receiver have been successfully tested, installed and are operated each cloudless dark night at Astronomical Observatory on Kolonica Saddle (AOK) since May 2019. The mechanical construction, electronic and internet network infrastructure were prepared in conditions that exceed the original requirements. Therefore the autonomous operation and remote control of AMON-ES is assured. The first observations demonstrate that the main airglow emissions and their variations can be monitored what was the mandatory task for AMON configuration. The first observations are very promising although there were very short dark night periods during last weeks. The operation and data presentation of GNSS receiver were also automated. In the beginning we have focused mainly on Total Electron Content (TEC) monitoring as there are cleare evidences of connections between TEC and airglow emission (see TN-TS).

In the following weeks, we will finalize the installation of weather monitoring system on AMON-ES that will even more automate the AMON-ES operation. It is needed also to finalize the data storage organization and post processing automation. The main priority task for the following months will be the configuration of AMON instrument. This process already started. But we need to sufficiently demonstrate that the one pixel AMON instrument is able to monitor airglow emission and to detect ionospheric disturbances. The results of this effort will be presented in TN2-AE that will be delivered in January 2020.