PHASE 1: The Mobile Aeronomy Trailer Station (MATS)

F. Sigernes [1], M. G. Johnsen [2], R. Norheim [3], T. Trondsen [4], D. A. Lorentzen [1] and N. Partamies [1]

[1] The University Centre in Svalbard (UNIS), N-9171 Longyearbyen, Norway
[2] Tromsø Geophysical Observatory (TGO), UiT - The Arctic University of Norway
[3] Kongsberg Satellite Service (KSAT), Tromsø, Norway
[4] Keo Scientific, Calgary, Alberta, Canada

Abstract

This project describes the construction of a Mobile Aeronomy Trailer Station (MATS). The aim is to deploy it to the Troll research station in Antarctica (72°S, 2.5°E) operated by the Norwegian Polar Institute (NP). The station is designed to include an aurora all-sky camera, a fluxgate magnetometer and an airglow/auroral sensitive spectrograph. The plan is to utilize the Troll Observing Network (TONe) infrastructure initiative [1] to observe the Aurora Australis, mesospheric temperatures, and local magnetic variations.

1. Introduction

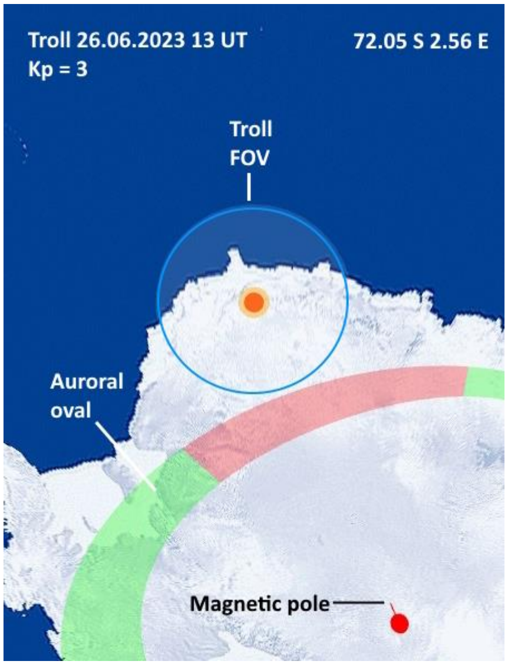

Figure 1. Troll Field Of View (FOV) to the aurora oval (Aurora Australis).

The Norwegian year-round manned station at Troll in Antarctica (72.00°S, 2.53°E geographic coordinates; 62.42°S, 46.70°E geomagnetic coordinates) opens up new possibilities for upper atmospheric research in the southern hemisphere. As part of the ongoing research using optical instrumentation on Svalbard for more than 45 years, sophisticated techniques have been developed to study ionospheric and magnetospheric parameters such as mesospheric temperatures, neutral winds, cusp morphology, and solar wind, magnetosphere, ionosphere interactions.

During the period from March to September it is possible to make mesospheric temperature measurements by spectroscopic techniques throughout the whole Antarctic winter season. From March 18. to September 23., the Sun will be less than 12 degrees below the horizon for 6 hours or more during any one day.

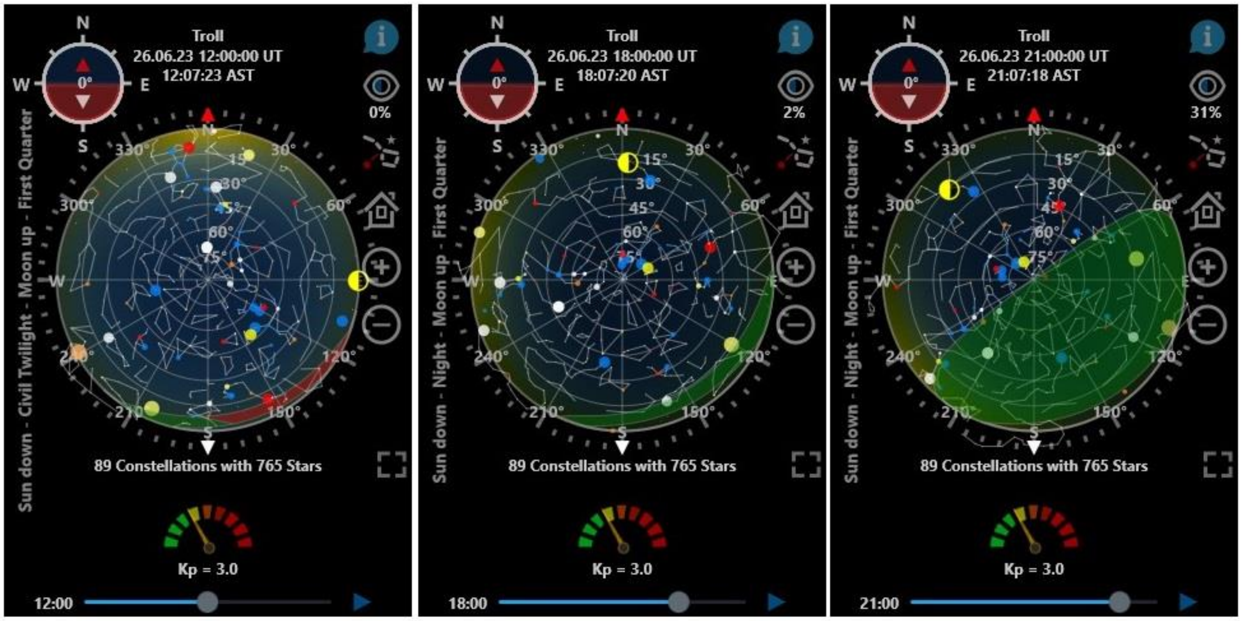

Figure 2. Auroral oval time series as seen from Troll mid-winter. Left is noon, middle at 18 UT and right is 21 UT. Graphics and calculations from the Aurora Forecast 3D app.

On June 21 (winter solstice) the Sun is 12 degrees below the horizon for approximately 17 hours. In addition, it is possible to make auroral morphology studies in the nightside sector of the auroral oval. During a period in March, both Troll and Svalbard can be used for simultaneous studies of the nightside aurora.

The location of the Troll research station is a bit too far North to detect dayside auroras. See the red colored part of the auroral oval in Figure 1. Nevertheless, during normal activity with magnetic variations in the range Kp = 3, the nightside auroral belt (green colored part of the oval) will be seen emerging from the South-East, filling the whole Field Of View (FOV) of an all-sky camera as solar elevation decreases into nighttime. Figure 2 shows a time series of the sky conditions and the location of the auroral ovals as seen from the ground mid-winter, 26 June 2023. The FOV is calculated assuming an auroral peak emission altitude of 110 km.

2. Scientific rationale

2.1 Mesospheric temperature measurements

Long term measurements of climatic parameters are of vital importance for understanding environmental changes. The Polar Regions are in this regard very important, since they act as "early warning" areas due to few locally man-made pollutants. This means that any changes in climatic parameters are due to either natural changes or long-range transport of climate affecting pollutants.

Mesospheric temperatures are important indicators of the state of the global climate. The upper atmosphere reacts unequivocally to the solar irradiance and solar activity, giving rise to changes in the electron density in the ionosphere and temperature in the mesosphere and thermosphere. The effect of the solar cycle on mesospheric temperatures has been reported with divergent conclusions for different geographical locations and solar cycles (e.g. [2, 3]). [4] reported no solar cycle effect at a Southern hemisphere lower mid-latitude site (El Leoncito, Argentine) using the OH (hydroxyl) airglow for temperature measurements. Troll is placed on the approximate same magnetic meridian as this station.

Long term negative temperature changes in the mesosphere have been reported at Northern Hemisphere lower latitudes (e.g. [5-9,]). At high Northern Hemisphere latitudes, a negative mesospheric temperature trend is not so apparent. Lübken, [10] show no large decrease of the polar summer mesopause temperatures using the falling sphere technique. Long term (43 years) winter mesosphere measurements using ground based optical instrumentation has been recorded by our group at Svalbard for almost four solar cycles. Yearly averages using this data set do not yield a negative trend in the temperatures [2, 11, 12]. However, large daily changes in temperatures are seen due to atmospheric gravity waves, propagating from the lower atmosphere. As the amplitudes grow on their way up to the mesosphere (due to decreased atmospheric density), energy and momentum can be deposited from the waves to the mesosphere if the waves overturn or break (due to too large amplitude, or strong mesospheric winds), causing large fluctuations in the temperature. Seasonal variations are also present [13] with less variation in the summer months compared to winter.

The mesospheric temperature measurements might provide a method for monitoring anthropogenic global climatic change. The CO_2 content of the atmosphere is increasing, some of it possibly due to man-made pollution, and is projected to rise in the next decades. Compared to other atmospheric gases, CO_2 is one of the best radiators of heat, and an increase of CO_2 also means an increase of heat radiated downwards (heats up the Earth) and upwards (cools of the upper atmosphere). There are indications that the upper atmosphere (above 50 km) will cool off faster than the Earth will heat, indicating that a global temperature change due to – among others - increased CO_2 will first be seen in mesospheric temperature measurements.

As stated previously, the long-term mesospheric temperature record at Svalbard does not see any statistical change. It is likely that this is due to the turbulent nature of the upper atmosphere above Svalbard. Above Antarctica, the upper atmosphere is expected to be more stable due to the larger landmass, hence we expect to see a different trend in the mesospheric temperature measurements here than compared to the Svalbard measurements. Bipolar measurements are in this regard very important also in order to understand the differences of the upper atmosphere above the two arctic regions. Another interesting topic is the relationship between Energetic Particle Precipitation (EPP) and the effect on the OH airglow layer. [14] reported that EPP ionization may affect the population of excited OH molecules. This effect could be more visible in the Southern hemisphere.

We aim to monitor with a custom designed spectrograph both the auroral Oxygen emission line at 844.6 nm and the OH (6-2) P-branch of the hydroxyl airglow. The Oxygen line is a well-known indicator of pure soft electron precipitation, while the airglow emission line allows us to calculate the mesospheric temperature at an altitude of approximately 90 km. Mesospheric temperature retrievals by monitoring OH airglow have been a reliable monitoring method down to +/- 2 Kelvin [15, 16].

2.2 Ionospheric morphology

The magnetosphere is immensely important for the environment on the Earth. It shields us from harmful radiation from the Sun as it deflects the solar wind. Huge energetic solar eruptions (e.g. coronal mass ejections), are known to have caused disruptions in power grids on the Earth's surface, disrupted radio communication and caused damage to satellites. Magnetospheric and ionospheric research is hence important in order to understand the space plasma processes that are so important for our environment. The ionosphere can also be viewed as a large space plasma lab, where plasma physical processes can be studied. Keeping in mind that about 99% of the observable universe is in the plasma state, this research possesses considerable universality.

Troll is situated at approximately 62° magnetic latitude, placing it under the expanded statistical auroral oval. Fig. 1 shows the location of Troll with respect to the oval. It is also noteworthy that Troll is close to - and on the same geomagnetic meridian - as the South Atlantic anomaly, being a region resulting in a high number of onboard errors for low earth orbiting satellites, due to the high energetic radiation belts. Optical measurements of auroral morphology yields information on space plasma boundaries in the magnetosphere, as the auroral emissions are footprints of the different plasma populations in the magnetosphere (c.f. [17, 18]). In addition, the expansion of the auroral oval yields information on the energy input in the magnetosphere.

A magnetometer that measures how disturbed the local magnetic field on ground level is essential, since it is directly connected to solar wind conditions and auroral activity detected by an all-sky camera. Both instruments should be installed at Troll.

3. Mobile Aeronomy Trailer Station (MATS)

We plan to purchase a modified standard 20 feet trailer from the company Letthus (https://www.letthus.no). Figure 3. shows a sketch of the concept where the insulated container sized house includes an entrance door, a removable roof lid with dome, inside wall to separate it into two sections. The first section is the control room with a door leading into the second section, the instrumental / dome room. Computers and environmental electronics are planned to be installed in the control room.

The camera and spectrometer should be installed on a height movable platform in the center beneath the dome. A wood frame with a vertical movable platform should be constructed beneath the dome lid to create a stable lift system for the instruments. The roof lid should be mounted to the container roof with machine threaded bolts for convenient replacement of a second identical lid without dome for transportation and protection when the station is not in use during the winter season when the Sun is up.

The magnetic sensor head of the fluxgate magnetometer should be installed at least 50 m away from any metallic structure to avoid interference.

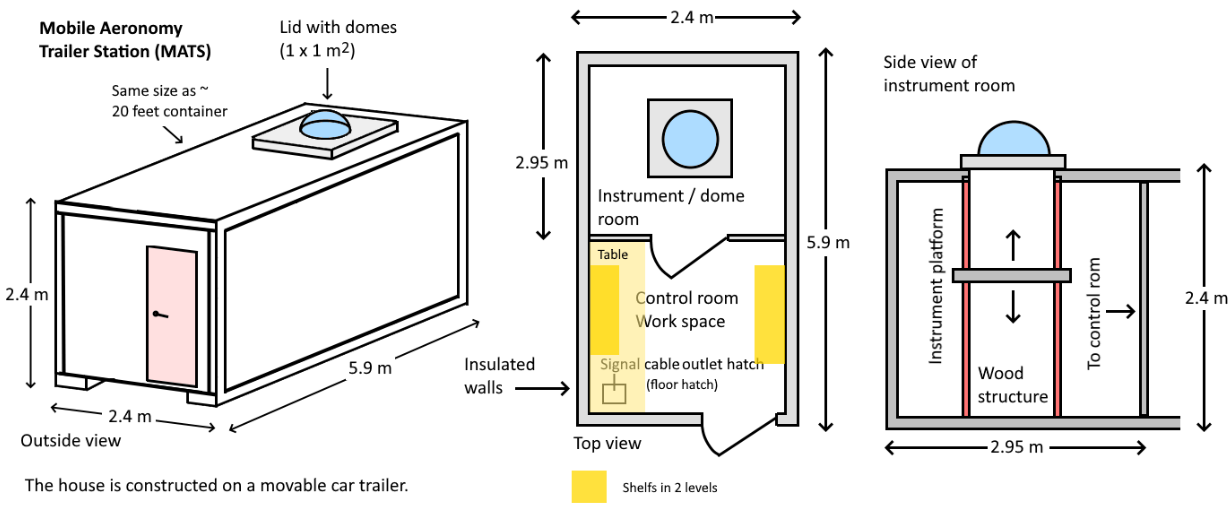

Figure 3. Basic sketch of Mobile Trailer Station (MATS).

4. Instruments

4.1 The all-sky camera

The core of the instrument is the back illuminated Sony Exmor IMX174 CMOS RGB sensor. The company ZWO has produced a compact camera head (model ASI174MC) based on the IMX174 sensor that is aimed for the astrophysical marked. It features a global electronic shutter with no moving mechanical parts. The diagonal of the sensor is 13.4 mm with 1936 x 1216 pixels of size 5.86 μm. Peak quantum efficiency is 78% at 500 nm. The camera is powered by a USB port.

Figure 4 show a technical drawing of the camera head. The C-mount Fujinon F/1.4 fish-eye lens (FE185C057HA-1) is used as front optic. The lens has a field of view of 185° and an image diameter of 5.7 mm, which is well within the area of the sensor. A T2 to C-mount ring adapter is used to mount the lens to the camera head.

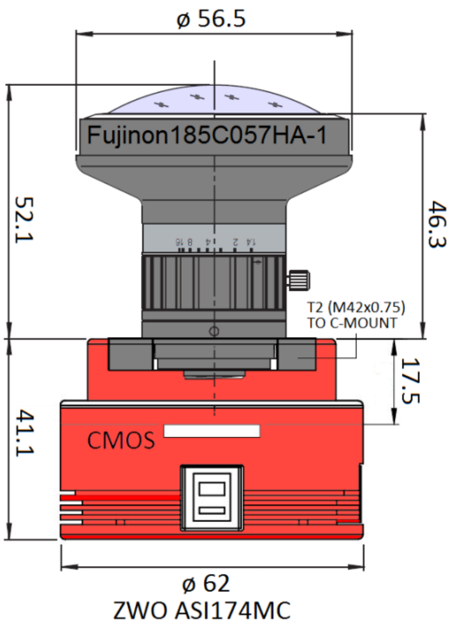

Figure 4. Drawing of the ZWO ASI174MC camera head and the Fujinon F/1.4 all-sky lens. All measurements are in mm.

The camera is controlled by a computer that is operated by Windows 11. The software, named ZWOASI174MC.exe, is a standalone 64-bit program that is tested to run stable with no memory leaks. It produces compass overlaid frames and Xvid compressed AVI movies with structured naming rules based on time and date. Frame accumulation is included to reduce noise. Daily Keograms, Stack plots and Quick looks are generated to view the sky activity over time.

The camera is protected from direct sun light by a 3D printed lid / shutter, controlled by an Arduino microcomputer and a standard Parallax servo. The servo and the microcomputer are both powered by a second USB port. Serial communication (RS-232) is used to open or close the shutter according to the maximum solar elevation angle allowed at the site. A typical solar elevation angle of 10 degrees below the horizon is a safe limit to avoid overexposure and damage to the sensor. The exposure time is typically just 1 second in normal operation [19].

4.2 The TGO fluxgate magnetometer

Figure 5. The Fluxgate magnetometer. (A) Left: Senior engineer Børre Heitman Holmslet calibrating the magnetometer at the Kjell Henriksen Observatory (KHO). Middle: Concrete base construction with protecting cover for sensor head. Right: Prof. Chris Hall (1953-2021) overseeing the operation. (B) Fluxgate sensor head.

TGO will provide a fluxgate magnetometer of own design, equal to the standard sensor used in the Norwegian magnetometer network that operates in the Arctic and contributes to the IMAGE magnetometer network. It measures the vector component of Earth’s magnetic field. The recording computer and magnetometer electronics will be installed in the control room of the station with the sensor head mounted at least 50 m away on either a concrete base or directly mounted on bedrock. The sensor will be covered by an insulated glass fiber hat. See Figure 5 for corresponding setup at the Kjell Henriksen Observatory (KHO) on Svalbard, Norway.

The latest developed fluxgate magnetometer model from TGO is shown in Figure 6.

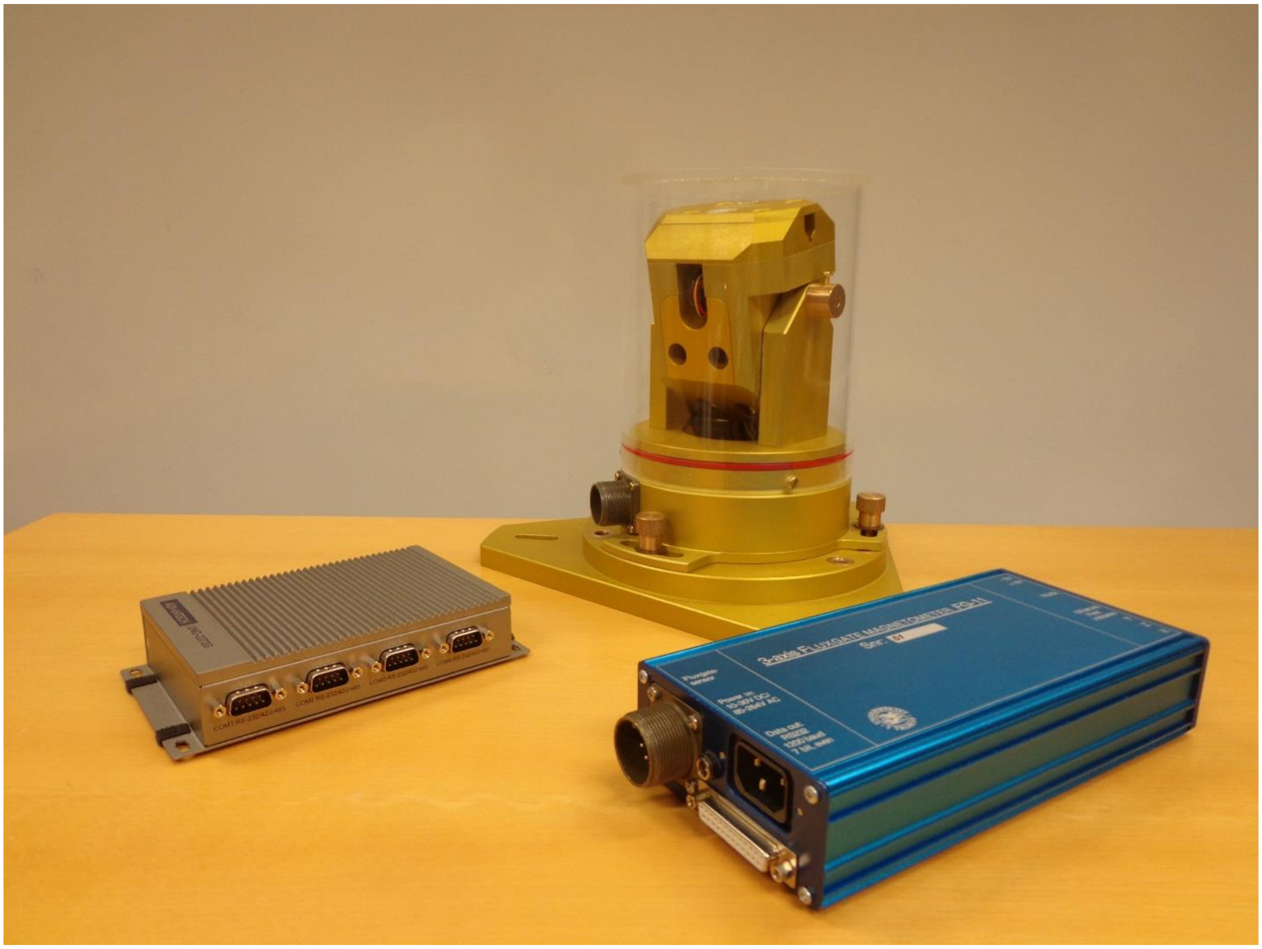

Figure 6. Latest TGO fluxgate magnetometer. In front: Logger PC and magnetometer. Back: Fluxgate sensor.

Additionally, a Proton precision scalar magnetometer will be acquired and deployed in the same fashion as the fluxgate. This instrument is logged with the same PC as the fluxgate. With the TGO type fluxgate sensors (DI-orientation), it will, using the proton magnetometer, be possible to calibrate the fluxgate magnetometer, electronic offsets and monitor the instrument's overall performance and stability.

The Troll magnetometer will contribute to filling the gap between magnetometers to the North at Neumeyer and Sanae IV and connect these stations to the Antarctic 40 Degree Magnetic Meridian Chain operated by Virginia Tech further South. Extending this magnetometer chain northwards will give good coverage also during increased geomagnetic activity where the auroral oval is expanded. Furthermore, the data will go into SuperMAG which is the most comprehensive, global data base for magnetometer data used by the space science community.

The establishment of a magnetometer at Troll should be seen as the first step towards a full magnetic observatory at the location. The initial fluxgate and proton precision magnetometers, proposed here, will be a full, science grade instrument that covers the needs of most scientific applications, especially within space physics.

However, such instruments alone do not have the necessary accuracy to provide data for models of Earth's internal magnetic field such as World Magnetic Model or the International Geomagnetic Reference Field model. To reach the necessary accuracy, temperature stability of the flux gate is essential as well as frequent absolute measurements to determine the magnetic inclination and declination performed using a DI-flux theodolite inside a dedicated house for absolute measurements. To get absolute calibrated measurements from Troll would in the future be a very valuable contribution to the international effort to monitor Earth's magnetic field and provide data for geomagnetic modelling considering the sparsity of magnetic observatories in Antarctica. At deployment of the magnetometer, considerations regarding the future magnetic cleanliness of the area, as well as location of absolute house, proton magnetometer placement and improved temperature control of the flux gate sensor, will be made to allow for expansion at a later stage.

The time resolution of TGO flux gate magnetometers is 10 seconds with a measurement range of +/- 8000 nT range. A strong nightside aurora can easily kick off many hundreds of nT variations in the horizontal magnetic field components at ground level.

4.3 The airglow / auroral spectrograph

Figure 7. The COTIF spectrograph (2004).

Keo Scientific Ltd. has proudly teamed up with what is arguably the world-leading expert on spectrograph design for airglow research, Jeffrey Baumgardner of Boston University.

We are thus in a position to design and build the highest-quality spectrographs, whether grating- and grism-based, uniquely suited to your particular atmospheric and ionospheric research needs.

We aim to design and construct a spectrograph with no moving parts capable of detecting and isolating the low intensity Q and P-Branch emission lines of the of the OH (6-2) band of airglow in the wavelength range 830 – 860 nm with a spectral bandpass of 0.4 nm.

The design is inspired by Jeff Baumgardner’s COTIF (CEDAR Optical Tomographic Imaging Facility) spectrograph [20, 21], which is a blazed reflection grating based instrument. See Figure 7 to the left. Our proposed optical diagram is shown in Figure 8. The design and key instrumental parameters are under discussion and will be modified as we see fit.

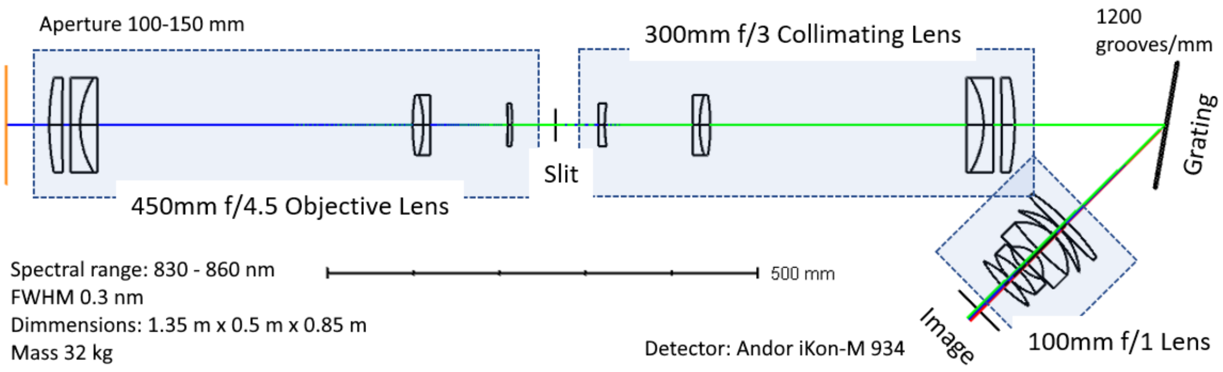

Figure 8. Keo Scientific Ltd Spectrograph optical ray diagram.

There are 6 main components: an objective lens, a slit and filter module, a collimating lens, the grating, a focusing lens, and a sensor/camera. The overall matched aperture of all the lenses is 100 mm and is kept constant throughout the instrument. The spectral lines are imaged onto a 13.3x13.3 mm CCD detector, that has 1024x1024 pixels. This image is formed from collimated dispersed light fields by a 100mm f/1 custom lens.

The dispersion element is a reflection grating, 1200 lines per mm, the orientation of which is set to direct the first order diffraction at 45 degrees from the incident light direction. This grating will have the blaze chosen to optimize this diffraction order over all others. The collimating and objective lenses are designed to optimize throughput through the slit that is positioned at the common focal plane of both lenses. These lenses have focus adjustment built in to optimize the spectrograph resolution.

Possible design modification: The 100 mm apertures are matched in this design, although the f/# of the objective lens could be changed to f/3 by increasing the diameter of the lens elements. The filters in the slit and filter module remove unwanted spectral lines through order sorting and remove light that may scatter off internal surfaces and contaminate the image. The slit is 42 mm long slit with flexure-based width and rotational adjustment.

The spectral range of the spectrograph will exceed the 820 to 830 nm required range. This design will enable viewing of about 25 to 30 nm of spectral range in this wavelength region. The center wavelength can be tuned by making slight adjustments to the angle of the grating. The spectral resolution is limited by the combination of the dispersion of the grating and the lens aberrations but will be optimized by adjusting the slit width. To achieve a 0.3 nm resolution, the overall contributions to spread of the spectral lines can be as large as 10 pixels, or 0.13 mm physical half-width.

In Figure 9, an example spectrum from the Silver Bullet Ebert-Fastie spectrometer at KHO is shown together with the synthetic generated at temperature T = 205 K. The auroral OI 884.6 nm emission is barely detected indicating no auroral contamination. The Keo spectrograph should match the Silver Bullet in performance at an exposure time of ~120 seconds with a bandpass of 0.4 nm. It should therefore also be considered as a possible future upgrade for KHO.

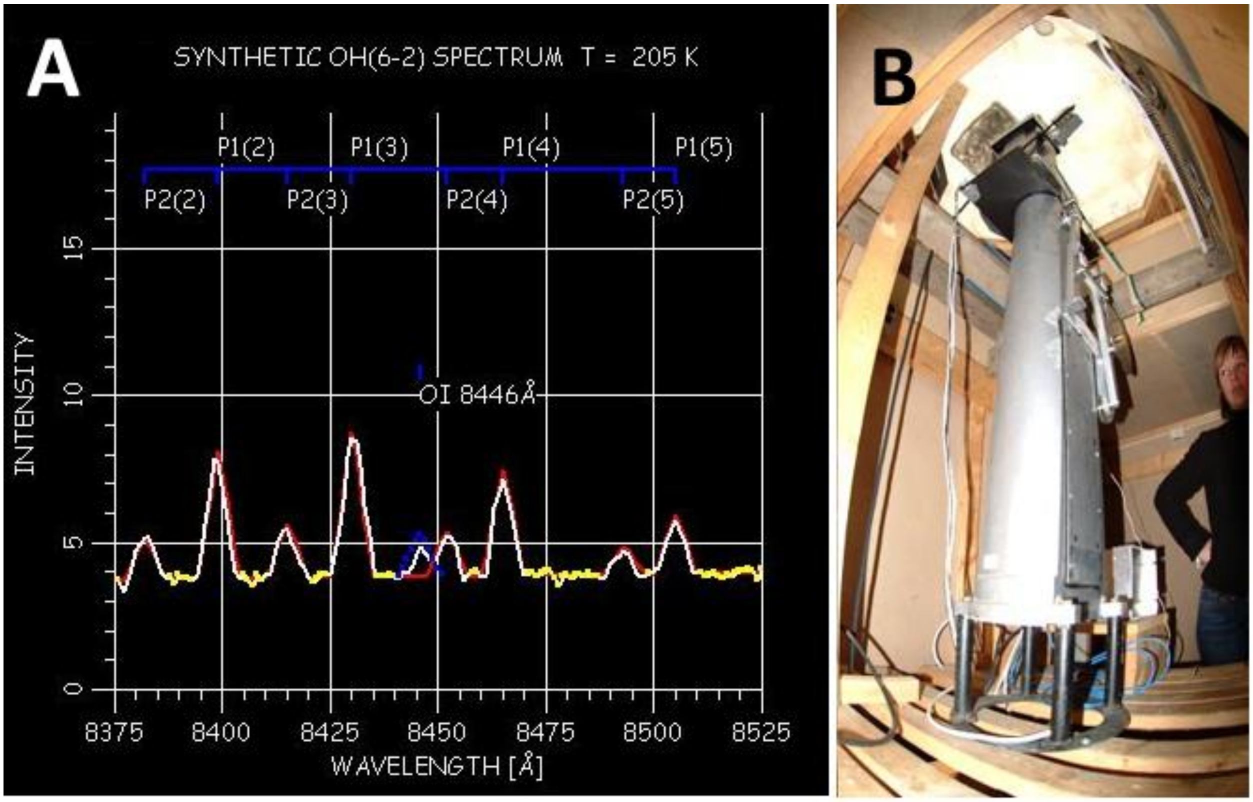

Figure 9. Panel (A): Silver Bullet sample spectrum. The measured spectrum is plotted with the color white. The detected background is colored yellow. The synthetic spectrum is the red one. Panel (B): Side view-up of the 1m focal length Silver Bullet Ebert-Fastie spectrometer.

5. MATS instrumental costs

item	Description	Cost (kNOK)	In-kind (kNOK)
1a	Letthus 611 - Mobile Aeronomy Trailer Station (MATS) to Tromsø	300	
1b	BNS Container–Mobile Aeronomy Container Station (MACS) to LYR	360	
2	All-sky color camera (BACC #6)		50
3	Fluxgate magnetometer		200
4	Proton magnetometer	110	
5	Airglow / auroral spectrograph	2655	
6	2 x Automatic Sunshields	146	
7	2 x BK-7 glass domes	124	
8	Network / Firewall – VPN / UPS / ITK equipment / Data Server	250	
9	Extra magnetometer signal cable / glass fiber enclosure / isolation	50	
	Total A	**3695**	**250**

Table 1. Total parts and estimated instrumental cost for Mobile Aeronomy Trailer / Container Station (MATS/MACS). Note that item 2 and 3 is already made and considered in-kind instrumental contributions.

6. Deployment costs

item	Description	Cost (kNOK)
1	Ship deployment to Troll	765
2	Instrumental installation (TOS/LYR)	25
3	Local transportation (TOS/LYR)	30
4	2 x Plane tickets Troll (One-way 70k NOK)	280

5	Accommodation one week 2 persons (Per diem 2k NOK)	28
6	Pre installation inspection trip to Troll	308
7	Symposium	50
8	Other / unforeseen	100
	Total B	**1586**

Table 2. Estimated deployment costs.

7. Time plan phase 1

Deliverance	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Trailer / Container	x	x	x	x	x	x						
Instruments	x	x	x	x	x	x						
Installation						x	x					
Operational tests							x	x	x	x		
Symposium											x	x
Ready for ship												x

Table 3. Estimated monthly timetable for construction of station.

After delivery of the modified Letthus 611 trailer, installation of instruments will be done at the Auroral Observatory in Tromsø. Initial instrumental and remote operational tests is planned to be conducted at the Skibotn Observatory. If we decide to move the installation operation up to Longyearbyen, KHO will be used as the test location. Nevertheless, a symposium should be organized to inform the public and to plan for Antarctic operations. Finally, MATS will be handed over to the Norwegian Polar Institute for transport by ship down to Antarctica.

If we decide to go for a container from BNS instead of a trailer from Letthus, the station name changes to Mobile Aeronomy Container Station (MACS). The shipping cost to Longyearbyen from BNS is 65 kNOK and the container cost is 295k NOK.

8. Location and action on-site?

The preferred location is a platform with a clear 360-degree field of view of the night sky with minimum light pollution. The magnetometer sensor requires access to bedrock for mounting located at least 50 m away from any other activity such as installations and/or roads.

With the above constraints in mind, it might be necessary to split the optical part and the magnetometer sensor. This could for example require that the optics is moved to be collocated with University of Oslo camera container located at Sofietoppen and establish the magnetometer sensor East of the main station area as suggested by TONe project engineer Simen Rykkje. See below map slice of Troll below.

The empty trailer /container station can then be used for other purposes. Nevertheless, a preferred location is a platform on Sofietoppen with no split of instruments. Local reports indicate that no sandblasting of domes by strong wind conditions occur at this site. On the other hand, the magnetometer sensor could also be located close to the main station area. The location issue should be solved by an inspection prior to launch of the project by personnel from TGO, UNIS, KSAT and NP.

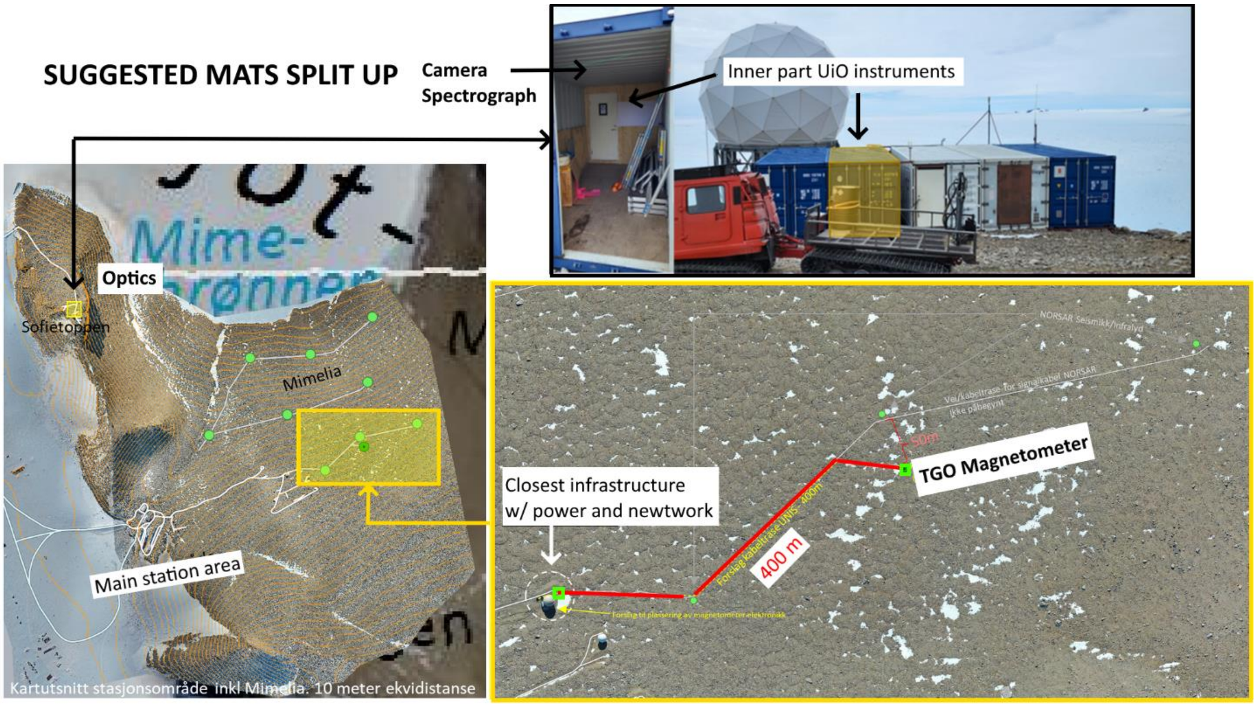

Figure 10. Map of Troll with planned infrastructure.

PHASE 2: Secure operations and manpower of MATS.

As a start we seek two 100% engineer positions for this project over a 5-year period. The work tasks will be to follow up the construction, instrumental installation, tests, deployment, maintenance, and operation of the station. Even though we plan to remote control the station through the net, at least one trip to Troll is planned each year to maintain and calibrate the instruments in order to secure the data quality.

One of the main operating costs are connected to power consumption. See estimated power use below.

item	Description	Power (W)
1	BACC camera	230
2	Magnetometer	240
3	Spectrograph	278
4	Sun Shields	90
5	Web server	230
6	Firewall / Switch / VPN	350
7	UPS (4kW) / Battery bank / Inverter / Charger	300
8	Heating (2 x 1000W panel heaters / dome heat)	1500
	Sum	**3218**

Table 4. Estimated power consumption.

Assuming we use 3218W power 24/7, it sums up to 28189.7 kWh per year. At Troll the electrical power comes from diesel generators at a cost of 58.53 NOK per liter. The kWh is 17.56 NOK, which means the annual electrical bill becomes as high as 495.011 kNOK.

A solution to reduce generator power could be to install hybrid inverter chargers that accepts both solar panels and wind mills. This has been tested by Svalbard hut owners successfully and could be further developed. A program to reduce power consumption by the use of microcomputers like Rasperry PI or Nvidia Jetson [22, 23] that uses a fraction of energy compared to standard Personal Computers (PCs) could also be developed during this project. It has in fact already started since manufacturers of camera sensors now support cross-platform drivers in Python [24] that run on microcomputers. A good example project is the hyperspectral imager onboard the HYPSO-1 satellite that runs on a Jetson chip [25].

Budget phase 2

item	Description	Cost (kNOK)	In-kind (kNOK)
1	100% Technician UNIS	1531	
2	100% Technician TGO	836	
3	15% workload Prof. F. Sigernes (UNIS)		334
4	15% workload Researcher M. G. Johnsen (TGO)		220
5	Power	500	
6	2 x Plane tickets Troll (One-way 70k NOK)	280	
7	Accommodation one week 2 persons (Per diem 2k NOK)	28	
8	Other / unforeseen	100	
	Total C	**3275**	**554**

Table 5. Annual budget including operational cost and salaries. Salaries includes wages, holiday pay, insurance, occupational health services and housing subsidization (Salary and social costs at UNIS for 2026).

Total cost of project then becomes: **(A + B + 5 x C) x 1.2 = 25988 kNOK = 26 MNOK.**
The In-kind contribution is **3.020 MNOK.** The factor 1.2 is estimated 20% increase in costs over the duration of this project.

Concluding remarks

This proposal is meant to give a kick start for a long-term time series of mesospheric temperature and geomagnetic measurements on the Norwegian research station Troll in Antarctica. Mesospheric measurements have been carried out at Svalbard for the last 4 decades, and the possibility for long term bipolar measurements are intriguing. Furthermore, systematic geomagnetic measurements have been performed in Northern Norway and Svalbard for more than 100 years. It is natural that Norway also contributes to this international effort of global geomagnetic monitoring, also in Antarctica. The ionospheric morphology studies will be a beneficial addition to the main objective since Norway have long and proud traditions in this field in the Arctic region but lack auroral related instrumentation in the Antarctic. We therefore propose to construct a Mobile Aeronomy Trailer Station (MATS) armed with a color all-sky camera, magnetometers and an airglow / auroral spectrograph.

It must be noted that the above budget estimate is conservative and does not include for example SAR (Search and Rescue) insurance in case of emergencies. Another serious concern is politics and UNIS role as a participant in the project.

The Norwegian state purpose as owner is that UNIS shall serve a unique institution for higher education and research on Svalbard, with courses and research activity of high quality focused on the natural advantage Svalbard's location has in the high arctic.

This means UNIS does not have the mandate to contribute with internal funding on Troll in Antarctica. If we do, the mission must be fully funded from other sources than the Norwegian Ministry of Education and Research. It also means we should add profit in order to handle unforeseen risk elements. Over a 5-year period we estimate this risk multiplication factor to be at least 2 times the above conservative estimate.

Nevertheless, whatever constellation, now we know how much is cost to send an expedition to Troll to conduct upper atmospheric research on the level we do in the Arctic.

Workflow

PHASE 1: The Mobile Aeronomy Trailer Station (MATS).
PHASE 2: Secure operations and manpower of MATS.
PHASE 3: Analyze data and publish.
PHASE 4: TBD

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Cooperating partners / institutions

1) The Kjell Henriksen Observatory (KHO)
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