# Appendix 4: Space research

## 1. Objectives

The Svalbard environment offers a unique combination of location (geographic and geomagnetic) and infrastructure to study the energy budget and dissipation of solar wind energy in the circumpolar regions and its effects on the vertical column between ground level and the magnetopause. To realize this goal, UNIS and Eiscat have joined forces and proposed a long term research program. So far, scientists from the universities of Tromsø and Oslo have been invited to take part. In addition central participation is required from the Andøya Rocket Range and FFI in Norway, as well as IAP in Künlungsborn in Gemany. New gound based instrumention is needed as well as three annual rockets for in-situ studies of the middle atmosphere and ionosphere. In addition it is necessary to extend the capabilities of existing facilities.

**Initial science projects**

- Assimilate existing satellite data to characterise the transfer of energy and momentum from the solar wind into the magnetosphere/thermosphere system.
- Study mesospheric dynamics with improved spatial and temporal resolution.
- Assimilate existing infrastructure data (e.g.: LIDARs at Ny-Ålesund) to relate project data to stratospheric phenomena such as major and minor warmings, gravity wave propagation and the occurrence of high-altitude clouds.

**Co-ordination projects**

- Create a Svalbard data centre based on the ad-hoc systems for rocket support, both to support the project goals and to support third-party data access, public outreach, etc.
- Establish a project coordination office to support the co-PIs, with two post-doc level scientists.
- Identify national and international partners and organise a workshop to define the objectives and methods to support the project program.
- Create a scientific board to encourage instruments and groups at the Kjell Henriksen Observatory to ensure maximum coverage in instruments, techniques, and spectral ranges without too much overlap.

**Infrastructure projects**

- Obtain optical data during summer by exploiting the installed infrastructure to improve our daytime capability to observe auroral and airglow related emissions.
- Extend the capabilities of the existing radars to provide coverage from the troposphere through the topside ionosphere.
- Annual multi-season rocket launches to cover the in-situ measurements and validation of remote sensing instruments in the 60-250 km altitude.

## 2. Frontiers of knowledge and technology

### 2.1 Our advantages

The upper atmosphere has been studied from Svalbard for many years using a variety of high-calibre instruments including several optical devices at the Auroral Station in Adventdalen, the EISCAT Svalbard Radar, other radio wave instruments such as SOUSY, imaging riometers, GPS monitors, intermittent and infrequent rocket lanches etc. This initiative will bring all these techniques together, assimilating the data into a continuous view of the upper atmosphere of unprecedented quality and utility.

Svalbard has the perfect location for such studies, being located directly underneath the statistical daytime magnetic cusp region. In the winter, for more than two months, the Sun is more than 8 degrees below the horizon, and Svalbard can observe dayside auroras with optical instruments. The dayside aurora differs from the nightside aurora in colour (predominatly red as opposed to green), energy (lower), and fluxes (higher) of the precipitating particles causing the auroral emissions.

There are several research stations on Svalbard performing auroral physics-related studies. The Auroral Station in Adventdalen (Nordlysstasjonen), built in 1978 as a cooperation between Universities of Tromsø and Alaska, Fairbanks, was the first permanent station. After 30 years of operation a new optical station, the Kjell Henriksen Observatory (KHO), has now been implemented. The new observatory is located 12 km from Longyearbyen and is the world's largest and best equipped optical stations for auroral studies.

KHO provides the infrastructure we need to continue optical measurements of the aurora and airglow, and to properly maintain, service, and upgrade the instruments. It also gives us the opportunity to develop new instruments with better spatial and spectral resolution, taking advantage of the rapid development of detectors and electronics. Such activities will ensure the continuation of the scientific momentum behind the station with the new instruments providing new and exciting views of the atmosphere.

The new observatory is located close to the EISCAT Svalbard Radar (ESR). ESR consists of two antennas; the steerable 32 m dish was built in 1996, and a 42 m field-aligned dish was added in 1999. The ESR measures several parameters related to the ionospheric plasma (electron density, electron and ion temperatures and ion velocity). The SOUSY radar measures parameters related to the middle atmosphere. An ionospheric heating system (SPEAR) has also been built in the same area; it can be used for a variety of ionospheric and atmospheric investigations including the creation of artificial aurora.

In addition to these facilities there are additional auroral related research stations in Barentsburg and Ny-Ålesund, the latest being the Chinese Polar research station, which started operating in the 2003/2004 season. Ny-Ålesund also hosts a rocket launch facility – SvalRak – for launching sounding rocket into the polar ionosphere. SvalRak is operated by Andøya Rocket Range (ARS) on a campaign basis. An initiative to increase the number of sounding rockets launched both from Andøya and SvalRak is being worked on by several research groups in Norway, including UNIS. This initiative - the FRISK (Forsknings-Raketter for Innovasjon, Sikkerhet og Klima) project dovetails neatly with our large-scale objectives. This initiative should also be seen in close connection with the ongoing collaboration between FFI and IAP to study the mesosphere by sounding rockets. These initiatives are both coupled scientifically and concerning the development and production of rocket infratructure.

The optical calibration laboratory at UNIS is now being used to sensitivity calibrate the instruments at KHO and from the Russian station in Barentsburg. This is an initiative together with the Polar Geophysical Institute of the Russian Academy of Sciences. In addition, data from the Barentsburg station will now be available in real time through a high speed data link.

## 2.2 The challenges

Observational studies of the upper atmosphere have yielded a wealth of information as well as leading to many insights into the underlying physical processes which control the exchange of energy between the lower and upper atmosphere and between the upper atmosphere and the solar wind, but the quantitative overall energy budgets and energy flows remain unknown.

An important element of our plans is the core multi-instrumental strategy: The upper part of our atmosphere (altitude 100–600 km; the Thermosphere) has been studied for several decades from Svalbard, and we know most of the processes taking place through studies of the visible aurora and by probing the ionosphere with radio waves. The same can be said about the lower atmosphere or weather zone (0–12 km; the Troposphere) where we can feel the weather and measure wind, temperature, and pressure directly. In the Stratosphere (12–50 km) we access the properties of the ozone layer through measurements of how solar UV radiation is absorbed. In the Mesosphere (50-100 km) we get temperatures from spectral measurements of the airglow.

Although processes in, and crucially between, the stratosphere and mesosphere are key to understanding the energy flows in the lower atmosphere, there are few techniques that cover processes in both, one reason that this part of our atmosphere is often dubbed the Ignorosphere. It is important that we continue to develop new techniques to access information from this height range. One such example, that we have developed, is the use of meteor radars to obtain mesospheric temperatures; by calibrating the radar against spectral measurements of the airglow during the auroral, dark season. Continuous, accurate measurements can be obtained throughout the year, even in the summer time.

This multi-year program seeks to develop the scientific structures, techniques, and instrumentation to allow the full energy budget of the polar atmosphere from the solar wind to the ground, including all sources, sinks and dissipation mechanisms, to be quantified, an essential prerequisite to the longer term goal of understanding the energy flows and budgets related to global climate change.

### 2.3 Contribution to understanding climate change

The solar variability and its influence on the upper atmospheric layers are not yet fully mapped. Pieces of the puzzle are known, but the overall quantitative energy budget and energy flows between the different atmospheric layers are still unknown. This is essential information directly related to the global climate change problem. The Sun is the ultimate driver for the Earth's climate; no Sun – no climate. There are many reasons for why it is difficult to couple solar variability with climatic change on relatively short timescales:

- The solar irradiance (the energy flux due to solar radiation incident on Earth) is considered constant in many climate models, but recent studies has shown that there is a small, but significant change; which varies over the 11 year solar cycle, and from solar cycle to solar cycle. This has only been measured accurately by satellites over the last 25-30 years, meaning that the time series span only about 3 solar cycles, giving very incomplete statistical foundations on which to say anything about the effects of long term variations.

- Coronal mass ejections and solar flares release huge amounts of energy in the form of high energetic particles and radiation (gamma, x-ray and UV). This energy is released into the Earth's middle and upper atmosphere. How this affects the chemistry and composition of the atmosphere is not fully understood.

- Furthermore, even cosmic radiation (high energy particles of extra-solar origin) and its effect on the current climate is not known.

- From the latest climate models, it is expected that a doubling of $CO_2$ should decrease the temperature of the upper mesosphere (~87 km), by 1°/year. This has been confirmed by Russian measurements at mid-latitudes. However, long term measurements of airglow-deduced temperatures from the Auroral Station in Adventdalen show no statistical trends. It is believed that these dissimilar results are due to dynamics – or, in other words, high altitude weather. As a consequence it is therefore necessary to continue improving the measurement techniques.

- The linkage between the ionosphere and weather zone is poorly understood, i.e. how is energy and momentum transported between the upper and lower part of the atmosphere?

All these points (in addition to a large number of others) must be taken into account in future global climate models in order to more accurately predict the future climate of the Earth, as well as better understand the global climate change problem.

### 2.4 People and competence

It is an essential part of this initiative that EISCAT and UNIS have decided to pool their resources on Svalbard for the benefit of this research program. UNIS is in the process of doubling its scientific staff in this field from 2 to 4. In addition there are two PhD students and three adjunct professors, representing the universities of Oslo and Tromsø and FFI. This partnership means that this research program will also directly benefit the educational programs at UNIS.

In the initial stage we will invite to Svalbard fellow researchers who share our vision and who want to contribute to developing a strategy, with long term goals and milestones. This will provide the framework to support our plans for major new efforts in this field. We also invite our colleagues to take on an active commitment and participation in the programs fostered by the initiative.

A sub-strategy of the initiative will be to develop multi-disciplinary studies. This is necessary to understand the whole vertical column, through planned cooperative efforts. This coordinated effort can be facilitated by a scientific board to encourage instruments and groups at the KHO to ensure maximum coverage in instruments, techniques, and spectral ranges without too much overlap.

# 3. Research approach, methods

## 3.1 Initial Science projects

### 3.1.1 Assimilate existing satellite data to characterise the transfer of energy and momentum from the solar wind into the magnetosphere / thermosphere system.

Magnetic reconnection between the solar and terrestrial magnetic fields opens and closes the connection between the solar wind and the magnetosphere. When the solar magnetic field is southward, magnetic flux is opened on the dayside and closed on the nightside. For a northward solar magnetic field, the geometry becomes more complex with multiple open and closed regions. If the connection is open, plasma can be transferred very efficiently back and forth between the solar wind and the upper atmosphere. But the transfer process can also be complicated by the fact that the reconnected field lines might close (and open) rapidly. This leads to accumulation of plasma in the magnetosphere that can be energized and later released into the upper atmosphere during magnetospheric substorms. The horizontal motion of the ionized part of the upper polar atmosphere, the ionosphere, is driven primarily by the solar wind electric field, which may be highly variable. When the reconnection rate fluctuates, the area of the ionosphere that is open and exposed to the solar wind electric field may also vary significantly. This leads to plasma convection that is highly dynamic on spatial scales from a few tens of km (or even less) and up to thousands of kilometers, and it is often associated with electrical currents flowing both parallel and perpendicular to the magnetic field. Fast convection brings patches of high-density plasma into the polar cap from lower sunlit latitudes. Collisions and instability processes in the plasma leads to changes in the composition, and turbulent convection also transfer momentum and stress to the neutral atmosphere and may heat both the neutral and ionized gas and set up neutral winds. In order to fully grasp the complexity it is therefore essential to study the entire process, from the solar wind driver, via the magnetosphere, to the effects in the ionosphere/thermosphere system. We will therefore take advantage of new ground-based facilities and past, ongoing and future spacecraft missions. This comprehensive data set will allow us to:

- **Study the vertical transport of plasma between the upper atmosphere and the magnetosphere**, by using spacecraft like CLUSTER, DoubleStar, THEMIS, FAST, POLAR, GEOTAIL, NOAA, DMSP, METOP to (1) characterize the net energy deposition into the ionosphere as the result of direct particle precipitation from the solar wind and unloading of magnetospheric substorms, (2) using ground-based instruments like KHO and EISCAT to study the local effects of the energy input, (3) using the same ground-based instruments to study the upwelling of ions, (4) using the same spacecraft to relate the upwelling to plasma outflow in the magnetosphere.
- **Develop an empirical model of the polar cap ionosphere**, by using the EISCAT radars to (1) determine what is the average and extreme plasma density and temperatures in the polar cap, and (2) characterize the long-term (solar cycle) and short-term (minutes) variability.
- **Study ionospheric electric fields from meso-scale and up** by using the EISCAT radar in fast scanning modes and KHO to (1) characterize at meso-scale the behavior of flow transients in the cusp region and the electrodynamics of transpolar arcs as a function of local time, season, solar cycle and solar wind magnetic field, (2) characterize the topology of associated current systems and determine which theories are correct, (3) estimate the ionospheric energy input, (4) use it to reveal the true topology of Earth's magnetic field into space.
- **Study ionospheric irregularities and plasma structures in the F-region**, by using KHO, ESR and AMISR to (1) characterize the behavior of polar cap electron density patches as a function of local time, season, solar cycle and solar wind magnetic field, (2) determine which mechanisms dominate their formation, their transit across, and their exit out from the polar cap, (3) use the ESR, SuperDARN and sounding rockets to study the growth of ionospheric irregularities associated with these patches, (4) use GPS receivers to quantify the effects these irregularities have on propagation of navigation signals.

### 3.1.2 Study mesospheric dynamics with improved spatial and temporal resolution.

The mesosphere (50 – 90 km) may be the least known parts of our atmosphere, partly because of the problem of obtaining direct in situ observations. Therefore it is often called the ignorosphere. On the other hand it appears that this part of the atmosphere may be most, and first, affected by changes in the atmospheric content of greenhouse gases. There are clear signs that these parts of the atmosphere have changed profoundly in temperature at least during the last three decades. Mid latitude observations by Gadsden [1990], Golitsyn et al. [1996], and Ulich and Turunen [1997] confirm this observation.

The natural thermal structure is believed to be primarily controlled by heating from absorption of short wave solar radiation and as a response balanced by cooling related to emissions in the infrared part of the spectrum. The absorption of UV by ozone ($O_3$) constitutes the principal radiative source of heat in the stratosphere and mesosphere. In addition, molecular oxygen ($O_2$) plays an important role. The absorption of UV by molecular oxygen contributes, especially in the upper mesosphere and lower thermosphere. The absorption processes occur as dissociation, forming atomic oxygen (O). At high altitudes (>80km), the lifetime of atomic oxygen exceeds a day, and the energy may be stored as chemical energy. This energy is released as thermal energy when the atom recombines. Due to both horizontal and vertical transport, much of the stored chemical energy is released in the high latitude winter. This process, along with adiabatic heating caused by vertical velocities, is believed to be the main explanation the warm mesopause temperatures observed in winter [cf. Brasseur and Solomon, 1986]. Radiative cooling of the stratosphere and mesosphere is mainly due to vibrational relaxation in the infrared 15 µm band of carbon dioxide ($CO_2$). In addition, the 9.6 µm band of $O_3$ contributes to the cooling, especially near the stratospause. Water vapor ($H_2O$) also contributes, but to a minor extent compared to $CO_2$ and $O_3$.

However, the radiative equilibrium described above is not enough to describe the complete thermal budget of the mesosphere. Measurements of atmospheric atomic oxygen number densities, crucial to the understanding of the thermal budget, have to be intensified in order to get the complete picture [Rees, 1989]. Other natural minor atmospheric constituents may also contribute to the coupling between chemistry and radiative transfer. In addition, the general circulation, with oscillations due to tidal and planetary waves, has to be included. Temporal variations due gravity waves propagating through the mesosphere are also of importance [Viereck and Deehr, 1989; Viereck, 1991; Hamilton, 1996]. External perturbations like variation in the solar flux, energetic particle precipitation, volcanic and anthropogenic emissions are additional sources of concern to the thermal structure of the mesosphere. The increase in greenhouse gases like carbon dioxide and methane in the lower atmosphere are expected to increase the water content and decrease the temperature in the upper mesosphere [Thomas, 1996].

To complicate matters even further, direct observations by the falling sphere technique [Schmidlin, 1991; Lübken, 1999] , which give temperatures up to approximately 95 km, does not give any indications of a large decrease of the polar mesopause temperatures [Lübken, 2000]. Long term winter temperatures derived from spectral measurements of OH airglow from the Auroral Station in Adventdalen (78°N, 15°E) confirms these observations [Sigernes et al., 2003]. Further measurements both from ground based instrumentation combined with sounding rockets equipped with an extensive suite of instrumentation is required to resolve this issue.

Clearly, there is need for more long term temperature measurements from different locations and by different methods [cf. Beig et al., 2003]; single point measurements are not enough to get the complete picture. We therefore need to install a filtered all-sky camera to study the OH airglow with improved spatial and temporal resolution. The required instrumental techniques are today well known and used by several groups around the world [cf. Garcia et al., 1997]. The gravity wave interaction with the emitting airglow layer will then be directly detectable over the whole sky, improving the spatial resolution considerable. Furthermore, a two filter approach would enable us to obtain a temperature images that can be calibrated by our existing spectrometers at KHO. One other interesting aspect, is that the LIDARS (LIght Detection And Ranging) operated by Alfred Wegner Institute in Ny-Ålesund are capable of detecting the height of the OH layer (personal communication dr. Roland Neuber). This, together with information of high altitude cloud formations (Polar Stratospheric Clouds and possible noctilucent clouds), may be the key to get an overview of the main processes occurring and how they are connected to each other. We aim to work closely with all the active groups that are present on Svalbard.

Furthermore, in order to be able to obtain temperatures during summer we need to improve our daytime capability. The use of the meteor radar in combination with spectral calibration during winter has proven to be a powerful technique to obtain the mesosphere temperature throughout the year [Nielsen et al., 2001; Hall et al., 2004]. The summer temperatures were calibrated using a K-LIDAR that is able to measure under day lit conditions [von Zahn and Höffner, 1996]. We need to continue this line work to improve our measurement techniques in order to be able to obtain whole year capability. We need to improve / upgrade the SPEAR radar with existing technology, so that it can be used as weather radar operated on a daily basis together with EISCAT; such developments might supplant existing SOUSY observations, releasing that instrument for other studies.

### 3.1.3 Assimilate existing infrastructure data (e.g.: LIDARs at Ny-Ålesund) to relate project data to stratospheric phenomena such as major and minor warmings, gravity wave propagation and the occurrence of high-altitude clouds.

Gravity waves are known to be important drivers of fluctuations throughout the atmosphere. These waves are believed to be formed lower down in the atmosphere by, for example, thunderstorms, convective regions and fronts, or from forcing of wind flowing over mountains. As the waves propagate upwards they induce significant temperature and density fluctuations on top of the seasonal variation mentioned earlier.

On a larger scale, planetary waves originating from the troposphere redistribute warmer air from lower latitudes into the polar areas of the stratosphere that is otherwise cold due to the lack of incoming solar radiation. This is known as a stratospheric warmings. Today we know that a stratospheric warming is often accompanied with a cooling in the mesosphere. If the temperature drops low enough, Polar Mesospheric Clouds (PMC) form in the mesosphere. These clouds are believed to be similar to Polar Stratospheric Clouds (PSC) and may consist of ice particles, however the source of the dust and water necessary for cloud formation is ill-defined.

We need to be able to monitor these phenomena closely to understand them and their role. It is important to use data from all available sources including space borne measurements such as the NASA AIM (Aeronomy of Ice in the Mesosphere) satellite, in order to understand the phenomena taking place. We need to find out how these clouds are formed. As a consequence, we also need to carry out in-situ measurements to compliment our data sets.

Svalbard has an excellent data connection through the fiber to the continent. At UNIS we are in the process of connecting EISCAT, SPEAR, SOUSY, and KHO with a fiber from UNIS. We also provide a high speed link to the Russian station in Barentsburg. Our instrument (1/2m Ebert-Fastie spectrometer) in Ny-Ålesund is also on line. One joint effort we propose, is to port all this data to an operational centre at UNIS. This is also important for future rocket campaigns. Rockets have been launched from Andøya successfully over Svalbard (SCIFER, CAPER and SERSIO) with UNIS as headquarter for the primary investigator. The next campaign is the SCIFER II rockets in January 2008. Two Black Brant solid state rockets will then fly tandem from Andøya to Svalbard to study the ion-outflow in the cleft.

An example of a large scale event which occurred on 6 Dec. 2002 (Sigernes et al., 2005), illustrates the importance of multi-site data accumulation. Even though the sun was well below the horizon (solar zenith angle of -12 degrees), a large area of PSC between mainland Norway and Svalbard ducted solar light towards Longyearbyen. Night became Day and the event raised a lot of public attention. Data from several sources including LIDAR data from ALOMAR (Andenes) and Ny-Ålesund (Alfred Wegner Institute), spectral data from the Swedish satellite ODIN, and data from the Auroral Station in Adventdalen, were necessary in order to explain the phenomena.

We will therefore invite ALOMAR at Andenes and the Alfred Wegner Institute in Ny-Ålesund to become active partners in our new initiative.

## 3.3 Infrastructure projects

### 3.3.1 Obtain optical data during summer by exploiting the installed infrastructure to improve our daytime capability to observe auroral and airglow related emissions.

Optical observations of auroral and airglow emissions has proved to be a cost-efficient and reliable method for probing the polar ionosphere. The method has been used to determine the auroral and airglow spectrum, and as such giving insight on the atmospheric constituents. Today optical measurements of the aurora and airglow are used as a diagnostics tool and part of a multi-instrumental approach to understand the coupling between the solar wind, magnetosphere and ionosphere. [cf. Lorentzen et. al. 2004, 2007; Moen et al, 2001]

Historically, measurements of the optical aurora have only been performed under dark-sky conditions – i.e. when the sun is more than 10 degrees below the horizon. Until recently it has not been possible to make optical auroral measurements during daylight, and even now, no institution does this on a regular basis. This is simply due to the overwhelming brightness of the day-lit sky relative to the faint emissions from the aurora. In essence, this means that optical measurements of the aurora at Svalbard are restricted to a four month period centred on winter solstice. In order to rectify this disadvantage, we propose to develop instrumentation capable of imaging the optical aurora – and subsequently airglow – in daylight conditions.

Studies of aurora using ground-based daylight capable optical instrumentation have been very scarce, and consequently the knowledge of optical emissions in the sunlit ionosphere is very limited. A number of previous ground-based experiments have demonstrated that high-resolution spectra of auroral emission lines (such as the [OI] emission at 6300 Å) can be isolated from the blue-sky background of scattered sunlight. At its peak wavelength, 6300 Å airglow typically contributes at most a few percent to the Fraunhofer spectrum of the sunlit blue-sky, whereas during bright aurora the 6300 Å [OI] emission line can contribute as much as 10%. [Noxon and Goddy, 1962, Cocks et al., 1980, Conde et al. 1992, Rees et al. 2000]. The emission spectrum can be derived by subtracting a direct solar spectrum – preferably measured with the same instrument – from the recorded blue-sky measurement.

The method showing most promise at the moment is the use of an imaging Fabry-Perot with two capacitance-stabilised etalons, placed in series with each other and with a narrow-band interference filter. Using this setup, Rees et al., [2000], successfully imaged a 6300 Å [OI] aurora close to sunset. We also aim to investigate other methods and wavelength regions such as the use of high radiometric resolution detectors and auroral oxygen emissions in the near infrared region.

### 3.3.2 Extend the capabilities of the existing radars to provide coverage from the troposphere through the topside ionosphere.

A number of options exist for upgrading and extending the SPEAR system, in order to increase its capabilities and further expand its science programme. Examples of possible extensions are outlined below, starting with those of most relevance to the TOWW project. The total cost of all SPEAR Phase-II upgrades which have been proposed would be of the order of £2.5M, but much more modest funding is required to extend the MF and MST capabilities which are needed for immediate application within the TOWW initiative.

**MF and MST capabilities**

At present, there is a frustrating gap in the observing capability on Svalbard. Atmospheric conditions below the mesopause can only be obtained from numerical models, making it impossible to investigate the dynamical coupling that takes place between the solar terrestrial environment and the rest of the atmosphere. In particular, atmospheric gravity waves and planetary waves could be tracked from the troposphere up to the thermosphere. The MF capabilities of SPEAR could be optimised at the current 4 – 6 MHz frequency band to improve resolution through upgrades to transmitter and receive units, making a state-of-the-art MF system complementary to the SOUSY system on Svalbard.

Funding of £180k required for investment in improvements to MF/MST hardware on Svalbard.

Alternatively (or additionally) a dedicated MST radar capability at SPEAR (operating at ~50 MHz) would provide routine observations of winds within the troposphere and stratosphere directly below the fields of view of the ESR and SPEAR all year round, offering significant advantages over the SOUSY system.

**Value-added capability to exploit further the available RF power.**

(i) By adding low elevation radar capabilities we will greatly extend the range over which the ionospheric plasma can be observed from the SPEAR site. At present SPEAR is limited to beam elevation angles above 60°. It will be possible to achieve beam geometries with low elevation characteristics similar to the SuperDARN radars by adding linear arrays of yagis along at least two sides of the main array. This will greatly enhance the spatial coverage from the Svalbard site.

(ii) Adding a higher frequency high-power array to main HF array will improve magnetospheric radar sounding significantly. This will overcome the limitations with regard to operation of the magnetospheric sounder. No new transmitters will be required for this since the present ones are capable of a wide frequency range. We envisage adding this second high power array in the 15-20 MHz band. This array will be considerably smaller than the main array and will provide more efficient penetration of the ionosphere so that the magnetosphere is accessible on a much more regular basis than with SPEAR Phase-I.

**More power by increasing the number of modules by 50%.**

The antenna array will be increased to 6x6, with a corresponding increase in the number of transmitters. This will result in an increase in power density of 100% for an additional cost of only 50% over the initial capital cost. As a result, the likelihood of achieving the modification effects which are essential for creating artificial irregularities and stimulating artificial ULF and VLF waves will be greatly enhanced. The gain in efficiency here is considerable, due to the nonlinear nature of the processes involved. Relatively minor modifications to the current hardware would also allow the antennas to be driven at half their current resonant frequency (i.e. at ~2.5 MHz), a frequency which has been shown at HAARP to be highly effective for artificial aurora experiments.

### 3.3.3. In-Situ Measurements of Physical and Dynamical Properties in 60-250 km altitude

Sounding rocket is currently the only means to obtain in-situ measurements in the region of space from 50 to over 100 km. This is a very important region concerning the energy balance of the atmosphere. The lowest naturally occurring temperatures on Earth occur in the summer mesosphere between 80 and 90 km altitude. This is the region where the upper region of neutral atmosphere we live in couples to the electrically charged ionosphere where the physical conditions are dominated by inputs from the Sun and the magnetosphere. Increased knowledge about this region is essential to understand the energy balance of and the vertical energy transport in the atmosphere.

It is, due to atmospheric drag, very impractical and costly to use satellites for in-situ high resolution measurements between 100 and 250 km altitude. In addition satellites will speed through the atmosphere it aims to study at more than 7 km/s, thereby making accurate measurements difficult. With sounding rockets it is possible to target specific scientific interesting regions for high resolution and high accuracy measurements.

With a combination of radars, lidars, remote sensing satellites and sounding rockets it is possible to achieve high quality integrated and validated measurements at all relevant time and spatial scales.

Norwegian and German scientists have for more than 20 years utilized sounding rockets for detailed observations in the region from 60- 120 km by a multitude of measurement techniques. This work has mainly been carried out up to 70 degrees latitude, but with some very interesting measurements also from launches at Svalbard. To obtain the full understanding of the detailed processes that determine the properties of the integrated atmosphere a multiyear and multi-seasonal rocket programme from Svalbard is required. The infrastructure observational platforms the rockets provide must be utilized with an upgraded ground based infrasructue as described earlier.

Several scientific groups (NASA, JAXA and UiO) have launched rockets from Svalbard in order to utilize the unique opportunities to study the daytime aurora or the physical properties governing the electrically charges boundaries between the atmosphere and space. In late 2008 the ICI-2 rocket project led by UiO wil be launched from Svalbard in close collaboration with the measurements provided by the extensive optical and radar measurements that are available.

It is necessary to invest in rocket platform infrastructure over several years to obtain the required high resolution measurements to understand the details of the mico-physics. These detailed measurements will together regional and global measurements provided by ground based and satellite remote sensing provide an understanding of the governing processes. The minimum requirement is to cover the period from the next solar maximum to minimum, that is 7 years from 2010. The minimum infrastructure requirement annually is two mesospheric and one ionospheric rocket launch.

The development of this infrastructure is a collaborative effort between IAP, FFI, UiO and the Andøya Rocket Range and is costed at between 12 and 14 M€ depending on the availability of rocket engines.

**Investments and operating costs:**

Based on a preliminary assessment there seems to be a need for: (1) An interferometer antenna system (under development at ESR) linked up to high resolution auroral cameras that will make it possible to observe detailed plasma structures and associated filamentary currents connected to the creation of narrow field aligned auroral features. Total investments: 1.5 M€. (2) A mobile radar for mesospheric research (Morro) tuned at 56 MHz (under

development at UiT) to be deployed at different positions in Svalbard and the Arctic to obtain broader geographical distribution of observational points. Total: 5 M€.
(3) Two middle atmosphere rockets and one upper atmosphere rocket per year for 7 years (12-14 M€).
(4) New instruments for Auroral measurements (10 M€). Total investments: 28 M€. Operating costs: 1 M€/y.

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