

A NEW THRUST IN ATMOSPHERIC RESEARCH ON SVALBARD

‘Towards an Overview of the World’s Weather’

1. Objectives

Climate change, whether induced by human activity or otherwise and concomitant changes to environmental conditions in northern Scandinavia, in Europe, and throughout the World, will have profound consequences for human society, economic activity, and possibly national survival.

Understanding, prediction, and even eventually modification of these processes require detailed and accurate knowledge of the global energy budget including all sources, sinks, and transport mechanisms.

Today, that knowledge is limited to the broadest qualitative level and much work must be completed to arrive at a comprehensive, quantitative picture.

As part of that exercise, we intend, over a ten-year time scale, to understand 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.

The Svalbard environment offers a unique combination of location, both geographic and geomagnetic, infrastructure, existing scientific facilities, and now the drive and determination to forge a new, exciting, and relevant program for the next ten years.

To realize our goals we bring together the knowledge, expertise, and interests of UNIS, EISCAT and the Universities of Tromsø and Oslo. We will also invite a wide range of international collaborators, under the umbrella of the International Centre for Arctic Studies – the Svalbard Science Centre. Together we hope to develop a program which will shape upper atmosphere research in Norway for years to come.

In the initial phase, we identify a number of specific sub-projects which need to be addressed in order to support the further development of the long term project. We define 3 main projects, each with different sub-topics to be initiated the first year.

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 management and research 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.
- Feasibility study to create and maintain an observational capability throughout the ‘ignosphere’ between ~50 and 100km.

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, 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 (predominantly 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), is now under construction some 12 km from Longyearbyen and will be ready to be used for the 2007/2008 season. This observatory is one of 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 (Forskning-Raketter for Innovasjon, Sikkerhet og Klima) project dovetails neatly with our large-scale objectives.

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 set up by Telenor Svalbard.

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. For example, the estimated recoverable resource of oil left on Earth is about 3000 billion barrels. This equates to about 1.7×10^{22} joules of energy. This is the same amount of energy that the Sun delivers to the Earth in just 1.5 days. Even so, not many of the observed changes in the Earth's climate are currently attributed to the Sun. There are many reasons for this:

- 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 CO₂ 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. 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 μ m band of carbon dioxide (CO_2). In addition, the 9.6 μ m band of O_3 contributes to the cooling, especially near the stratopause. 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].

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.

3.2 Co-ordination projects

3.2.1 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.

Several of the activities proposed under the TOWW initiative depend on data assimilation, either amongst local Longyearbyen instrumentation, or from more scattered, but generally publicly available, data sources. To handle these requirements effectively, the local Longyearbyen community requires effective data support.

Very much effort has been invested elsewhere in data base systems, in the provision and management of metadata products describing available data resources, and the abstraction of these elements to build and exploit so-called virtual observatories (VOs). In general, these efforts have so far been more projects in themselves rather than enabling systems supporting new and exciting scientific investigations. We propose to exploit available software implementations, extending these only so far as is necessary to support local requirements, to enable new and effective investigations within the local user community and elsewhere.

Existing instruments and systems in and around Longyearbyen, and elsewhere on Svalbard, have very different mechanisms and philosophies for data distribution. Most, though not all, provide some sort of web-based user interface to summary data but few provide open access to numerical data through published APIs (Application Programming Interfaces).

The EISCAT Svalbard Radar provides an initial model for data distribution. All radar data is made available freely and without restriction through access to a distributed, web-based data system called Madrigal. Madrigal is a specialised VO used by many of the World's incoherent scatter radars; data are maintained at the original operator's institutions, but metadata describing the entire data holdings across all participants is distributed and updated at every institution. Other Madrigal implementations hold a variety of other data products including imaging data and total content derived from GPS observations but all installations provide their metadata to all others via well defined APIs. Madrigal provides human-oriented web interfaces for data browsing and discovery but also, and most importantly, a full set of APIs which allow other computer programs to inspect metadata, select, and download numerical data transparently from any participating data providers. These APIs are the building blocks which make possible the further mapping of metadata, and data access pointers, into further VOs, either in parallel, or at higher levels of abstraction.

Much experience has been gained within the local community when providing access to made local systems to support rocket-flight related decision processes. In all cases, data was made available to the project scientists by bringing together multiple windows implementing the individual user interfaces to the separate observing systems. While the human-interfaces are well developed and effective, neither the corresponding APIs nor common mechanisms for data abstraction, storage, and further processing can provide the support environment envisaged with the TOWW project.

Three elements must be investigated to provide the required support for the intended TOWW goals:

1. Data distribution from all local instrumentation should be reviewed and provision made to support appropriate metadata products as well as access to properly validated data through published APIs as well as through individual human-oriented web interfaces.
2. Available VO implementations should be reviewed and contact established with the developers of the most appropriate such system pursuant to installation of the VO structure on local computing platforms in Longyearbyen and the integration of the metadata products from element 1.
3. Data from non-local instrumentation, including instruments at Ny Ålesund, on the Scandinavian mainland, and those carried on spacecraft, rockets, and other mobile platforms, should be interfaced through the local VO, using existing metadata products where possible.

The resulting Longyearbyen VO will provide an effective resource for the local scientific community, allowing users to browse, select, and interpret data from the complete range of relevant instrumentation as well as providing a model for the effective exploitation of VO technologies for scientific research.

3.2.2 Establish a management and research coordination office to support the co-PIs, with two post-doc level scientists.

In order to be able to coordinate this multi-year program, we will establish a project coordination office to act as a support and liaison office for the TOWW project. The office will be manned by two experienced Post-Doc level scientists, who will handle all communication, consolidating virtual observatories for project use, and establish routines for TOWW specific instrumentation and data, as well as performing research according to our research objectives. This is an important part of the project, giving the partners a unique location for contact and collaboration.

3.2.3 Identify national and international partners and organise a workshop to define the objectives and methods to support the project program

It is important for the TOWW project to include the best international research institutions within the atmospheric sciences. In order to reach our long-term goal, we will invite research groups that we know already have a strong interest in doing arctic related atmospheric physics and chemistry, such as the Alfred Wegener Institute (middle atmosphere) and The Univ. of Alaska, Fairbanks (upper atmosphere). To kick off this initiative we will organize an open workshop at Longyearbyen, and invite several specific groups as mentioned elsewhere in this document, to define the research objectives and methods that can be used to support the project program.

3.2.4 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.

Based on the Station Science Board (SSB) at the old Auroral Station in Adventdalen, we intend to form a board that will coordinate the research activity at KHO. The main purpose of this board will be to encourage and coordinate activities at the observatory to obtain the widest spread of capabilities and reduce the extent of unnecessary overlap or duplicate experiments. Each new instrumental group needs to apply to the board and sign a contract from UNIS regarding rent and rights at KHO. A representative from UNIS will lead the board and primary investigators from key institutions using the observatory will be asked to participate. The board will also set the standards or rules of the road on how data should be distributed and shared.

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 Feasibility study to create and maintain an observational capability throughout the 'ignorosphere' between ~50 and 100km.

At low altitudes, the atmosphere can be studied routinely by a number of well established techniques. On Svalbard, both the SOUSY radar and an upgraded SPEAR facility (as described in the previous section) can provide coverage at these altitudes. Above about 90km, the EISCAT Svalbard Radar provides reliable coverage under all conditions using the incoherent scatter technique.

However, the altitude range between the normal upper limit of SOUSY observations and the lower limit of ESR observations is both difficult to observe and yet of huge importance in understanding the behaviour of the whole atmosphere and the energy flows and exchanges within it. Under some circumstances, following strong solar proton events for example, the incoherent scatter radar can observe almost everywhere in this range while both SOUSY and the ESR can observe particular transient phenomena here, such as the Polar Mesospheric Summer Echoes (PMSE) which originate in very thin, horizontally stratified, layers close to the summer mesopause – the coldest region in the natural terrestrial environment.

Other instrumentation, including LIDAR, not currently installed in the Longyearbyen area, can provide coverage of some aspects of this altitude range while small sounding rockets, with both instrumented and with passive payloads, have been used to give detailed, but transitory, data across the whole interval.

The technical and practical difficulties in procuring routine, reliable information between the lower atmosphere and ionospheric altitudes has caused it to be relatively under-investigated and often ignored, hence the somewhat flippant, but nevertheless accurate, description of the region as the 'ignorosphere'.

However TOWW goals require that this region be properly observed through a routine and ongoing program and the initial stages of the project therefore include a careful evaluation of possible techniques, and of the practicalities of augmenting the local infrastructure with appropriate facilities or systems. The goal is to provide TOWW researchers with complete and continuous coverage of the atmosphere from the ground right into the ionospheric topside and on into the magnetosphere, an available data environment which will be unique in the World.

As mentioned above, the upper middle atmosphere is not easily reached in terms of probing it in-situ. All possibilities will be reviewed including a number of techniques which have been used elsewhere. These include very much more powerful low frequency radars, such as the MU and EAR facilities, which can extend the available scattering altitude range somewhat, sounding rocket techniques which have been used in salvoes to provide detailed coverage over limited time scales, and various LIDAR options.

Small solid propelled rockets, such as the Mini-Dusty rockets from the University of Tromsø, have been used to study charged dust in the mesosphere [Havnes et al., 2001]. Unfortunately, these rockets have had many problems with stability to due faulty motors.

The use of rocket grenades [Stroud et al., 1960] might be a cost effective alternative. Even standard available guns should be capable of reaching the ignorosphere. There are a number of alternatives when it comes to payloads: inflatable balloons [Schmidlin, 1991], explosives set off to measure sound propagation, chemical releases or active miniaturized payloads such as developed for the Mini-Dusty rockets. One advantage we have in Longyearbyen is that all the infrastructure needed to track or download data from these probes is already present through the establishment of SVALSAT.

One exotic option to evaluate is the Railgun or Birkeland canon. Unlike gas pressure guns, rail guns can accelerate payloads in a more controlled fashion up to extremely high speeds. The possibility to launch often, and thereby increasing the temporal resolution of in-situ probing, is one other advantage compared to rockets.

More than forty years ago, gun launched systems (including chemical release and instrumented projectiles) were developed which could regularly place payloads into the lower ionosphere at relatively low cost. Modern rail-gun technology might make this an entirely viable mechanism to allow instrumented measurements to be made throughout the ignorosphere over relatively extended time intervals commensurate with the TOWW research requirements. In an interesting twist of coincidence, the technology echoes the early days of Norwegian ionospheric research where Birkeland's interests in the behaviour of magnetic fields led him to work on large electromagnetic canon (rail guns) which, though impractical at the time for launching projectiles, led directly to the nitrogen fixing technologies on which the fortunes of both Birkeland and the Norsk Hydro company were built.

In the initial stages, the TOWW project will review all the options, including new systems, incremental improvements to existing techniques and facilities, and esoteric and novel solutions such as rail gun technology and multiple mini-rocket based ideas. Within the first year, the project will prepare a report and recommendations which will provide the foundation for following feasibility studies and eventually costed proposals to allow this difficult area to be adequately observed during the TOWW project process.

4. PROJECT ORGANIZATION AND MANAGEMENT

The project is organized with a project leader and with experts responsible for the various activities, as follows:

ACTIVITY	SUBJECTS	PERSON	POSITION	INST.
Project manager	Administration	F. Sigernes	Dr. Sci., prof.	UNIS
Section 3.1.1	Magnetosphere	D. A. Lorentzen	Dr. Sci., associate prof.	UNIS
Section 3.1.2	Mesosphere	F. Sigernes	Dr. Sci., prof.	UNIS
Section 3.1.3	Stratosphere	TBD		
Section 3.2.1	Data centre	TBD		
Section 3.2.2	Project office	G. Sand	Director	UNIS
Section 3.3.3	Workshop	ALL		
Section 3.2.4	KHO board	TBD		
Section 3.3.1	Daytime imager	D. A. Lorentzen	Dr. Sci., associate prof.	UNIS
Section 3.3.2	Upgrade radars	T. Eyken	Phd, prof.	EISCAT
Section 3.3.3	Feasibility study	T. Eyken	Phd, prof.	EISCAT

5. BUDGETS

Initial science projects

Magnetosphere / thermosphere

This bullet on the list does not include any instrumentation, but could be associated with e.g. Prof II and Post Doc positions. It can also be associated with cost of infrastructure (i.e. rent for dome space, office space, travel costs, publication costs, etc).

2 Post Doc positions, 2 x 722	1444
1 UNIS Prof II	145
Rent dome space KHO (3 domes)	60
Travel costs supporting scientists	150
Publication costs (4 papers/year JGR cost)	100

Mesosphere imager

Narrow band pass interference filters, BP=5Å, 30 x 2	60
NIR camera 256x1024 pixel resolution, 16 bit dynamic range	250
Filter wheel	30
Tele centric optics	40
Front optics	90
Instrument PC	10
Rent KHO	20

The stratospheric connection

3 UNIS Prof II (AWI /ALOMAR/PGI), 3 x 145	435
Operational centre / accessories	200
Travel costs supporting scientists	150

Co-ordination projects

Data centre

Main requirement is for scientific software support to procure, install, develop, and maintain a local VO infrastructure. Initially, this could be a full time task, falling to 25-50% continuing commitment. To support this operation requires a high end PC platform, with storage capacity to provide local archive facilities to retain data sets recovered/created during TOWW related investigations and studies.

Postdoc	722
Travel costs (three intl. meetings, four travels within Norway)	50
PC platform	10
Software licenses (e.g. MATLAB, IDL)	60
Storage (2 X 1 TByte)	25
Office space and support (overhead) at UNIS	110

Workshop

300k NOK

Scientific Observatory Board

60k NOK

Infrastructure projects

Daytime FPI imager

2 x etalons: 150 mm aperture, 1080 x 2	2160
CCD camera 1024x1024 pixel resolution, 16 bit dynamic range	180
Narrow bandpass interference filters, BP=3Å, 30 x 3	90
Filter wheel	30
Front optics (lenses)	90
Fringe-forming lens (telephoto)	30
Sun-tracker (to block direct sun) custom made	30
Automated calibration lamp setup	20
Calibration lamps + frequency stabilized laser	36
Mounting frame and coupling tubes (custom made)	60
Instrument PC	10

Upgrade radars

2160k NOK

Contribution UNIS scientists

722k NOK

In total we apply for

10139k NOK

Due to shortage of space, the reference list can be found at: http://fred.unis.no/TOWW/TOWW_REF.pdf