SMILE: ground-based measurement support

Authors: J. A. Carter[1], E. Donovan[2], J. Gjerloev[3], C. Heinselman[4], H. Hu[5], M. Lester[1], S. E. Milan[1], K. Oksavik[6], D. Sibeck[7], F. Sigernes[8], M.-T. Walach[1], H. Yang[5]

1. University of Leicester, U.K. 2. University of Calgary, Canada 3. Johns Hopkins University, Applied Physics Laboratory, U.S.A. 4. EISCAT Headquarters, SE-981 92 Kiruna, Sweden 5. Polar Research Institute of China, China 6. Birkeland Centre for Space Science, University of Bergen, Norway 7. NASA Goddard Space Flight Center, U.S.A., 8. The University Centre in Svalbard (UNIS), P.O. Box 156, N-9171 Longyearbyen, Svalbard, Norway

Date: December 2015

A: Introduction

This document provides a brief summary of how ground based radar, magnetometer and optical measurements will support the science goals of SMILE. This document refers to the goals set out in the submitted SMILE proposal [1]. With its suite of four instruments (SXI, UVI, LIA and MAG), SMILE will observe the position and motion of the magnetopause, ultraviolet emission from the auroral oval, monitor the solar wind ion plasma, and measure the orientation and magnitude of the interplanetary magnetic field. Ground-based measurements provide supplementary data and additional context to support SMILE achieve its science goals.

Section B reviews the science goals of SMILE. Section C provides a brief description of available ground-based measurements, dividing these into three subsections; measurements that provide global coverage all year round, measurements that provide regional coverage all year round, and winter time coverage that is specific to a small high-latitude region. Sections D and E address how these ground-based measurements can be used to support the science goals of SMILE, including potential measurement strategies. We summarise the role of ground-based measurements in Section F. The Appendix associated with this document includes letters of support from various projects mentioned in this document.

B: SMILE science goals

B. 1. *What are the fundamental modes of the dayside solar wind/magnetosphere interaction?*

This goal encompasses the testable hypotheses that unsteady/steady magnetopause reconnection occurs for high-beta/low-beta solar wind, and that unsteady magnetopause reconnection is directly driven by variations in solar wind parameters [1, section 3.2.1]. SMILE will approach this question by correlating steady and unsteady solar wind variations with the position and motion of the magnetopause boundary (via the SXI), along with transient brightenings and movements of the dayside auroral oval and in the high-altitude cusp (via the UVI) [1, section 4.1.1].

B. 2. *What defines the substorm cycle?*

This goal encompasses the testable hypotheses that substorm onsets are preceded by a growth phase, that substorms are triggered by defined solar wind features, that substorms, sawtooth events and steady reconnections are manifestations of the same processes under different driving conditions, and that there is a seasonal effect on cusp latitude and flux [1, section 3.2.2]. SMILE will approach this question by observing the magnetosheath response to turnings in the IMF (B_z component), observe the cusp and magnetosheath response to changes in IMF B_Y [1, section 4.1.2], and look for potential substorm triggers in the solar wind parameters including composition.

B. 3. *How do CME-driven storms arise and what is their relation to substorms?*

This goal includes the sub-questions of: Is the duration and magnitude of solar wind driving the sole arbiter of whether a storm will occur? What is the relationship between the storm and substorm? Are storms always a separate phenomenon, or can they be considered as being composed of multiple substorms [1, section 3.2.3]? SMILE will achieve these goals by extending the observables of question 2) for CME-driven conditions.

C: Ground-based data

C.1. Radars and magnetometers providing large-scale global data (all year)

Global, all year coverage of ground-based measurements is provided by a network of coherent scattering radars (the Super Dual Auroral Radar Network, SuperDARN) and a network of ground magnetometers (SuperMAG).

SuperDARN is a network of high-frequency coherent scatter radars that operate in both hemispheres [2]. However there is considerably more coverage in the northern hemisphere. The coverage of the current network is shown over the geographical poles in Figure 1. A table of northern hemisphere SuperDARN radars, including station locations and operating institutions can be found in Appendix A1. SuperDARN radars transmit at high frequency (approximately 8 to 20 MHz) and this signal is backscattered by field-aligned decametre irregularities in the F-region ionosphere. SuperDARN provides velocity vectors, backscattered power, and the width of the Doppler-shifted power spectrum of the returned signal. Two-dimensional velocity vectors can be obtained by combining the signals from pairs of radars with overlapping fields of view and differing look directions. Velocity measurements are obtained at two-minute time-resolution, and 45 km spatial resolution. The SuperDARN network is managed as a consortium of member institutions. Each institution is responsible for obtaining their own funding via national funding agencies. As such, new radars have become operational and have joined the network from the commencement of the SuperDARN project in 1983, including polar, high-latitude and mid-latitude stations. Data are made available via member institutes (for example [3]), or through large-scale cross-project collaborations combining space and ground-based archives such as ECLAT [4].

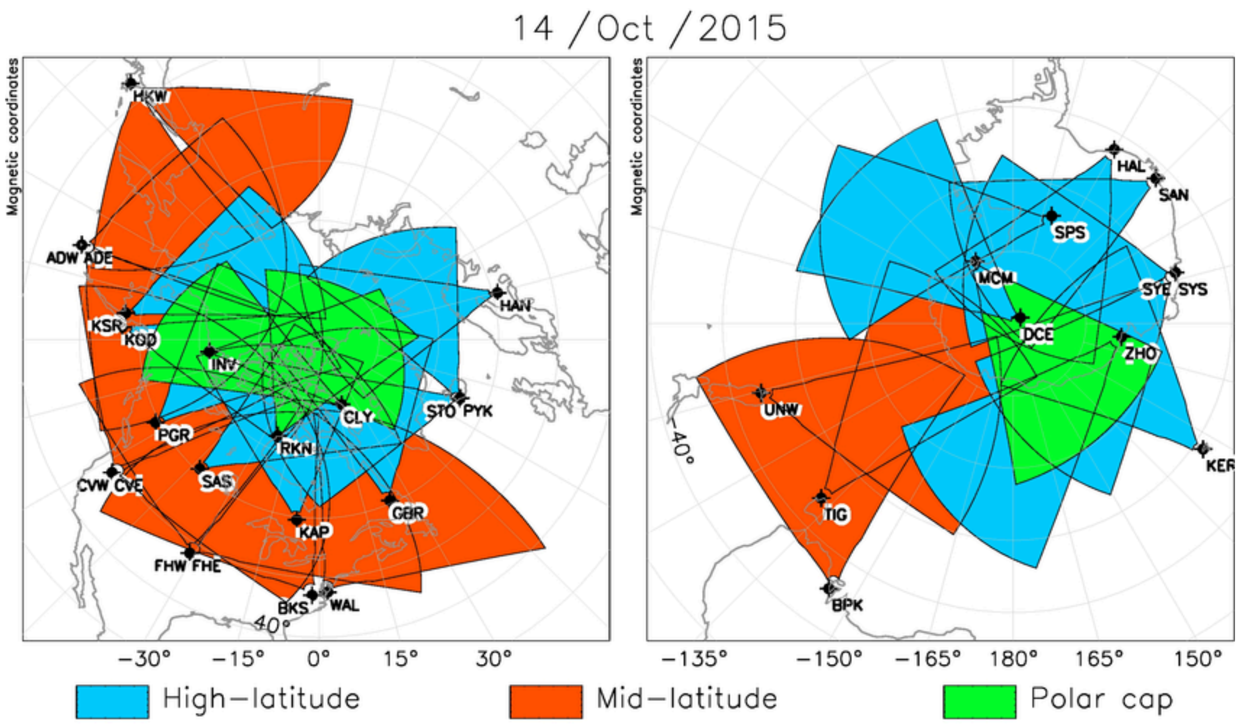

Figure 1: Coverage of the SuperDARN network in the northern (left) and southern (right) hemispheres, as of July 2013.

SuperMAG is a collaboration of organisations that operate ground-based magnetometers around the world (see Figure 2). These magnetometers are used to measure the global electric current system [5]. Ground magnetometers measure magnetic perturbations at a variety of cadences, and are used to produce various indices representing different current systems within geospace. Magnetic indices are available through many channels, including the SuperMAG website [6] and also the commonly used and freely available OMNI data set [7]. Ground magnetometers can be used to infer ionospheric convection patterns and identify transient (1-20 min) events in the solar wind-magnetosphere interaction.

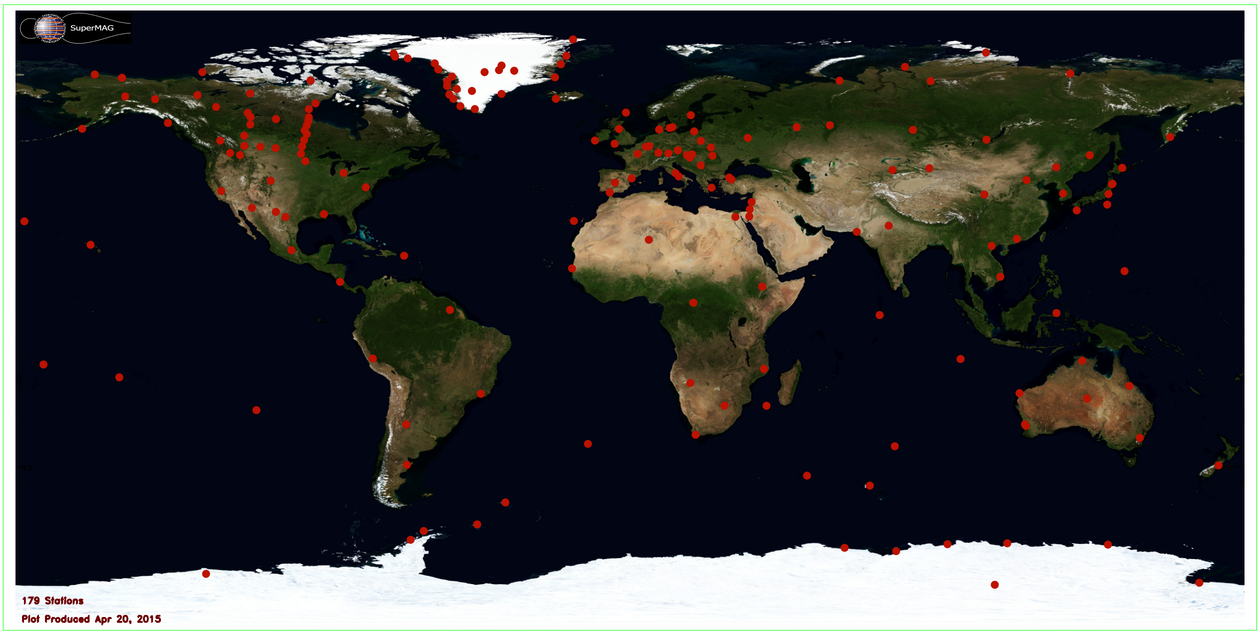

Figure 2: Global coverage of the SuperMAG network.

C.2. Radars providing high-resolution data in a region (all year)

Regional measurements with (potential, but not necessarily continuous) year-round coverage are also provided by a variety of incoherent scatter radar. These radars operate at high-latitude northern locations (see Figure 3). They measure the electron density, electron and ion temperatures, and line-of-sight ion drift velocity. Radar measurements are typically made in the altitude range from 80 to 1000 km. Notable results include simultaneous observation of flow shears associated with poleward moving auroral forms in the cusp ionosphere [8], a potential signature of flux transfer events at the magnetopause.

The European Incoherent Scatter Scientific Association (EISCAT) operates radars in Svalbard and northern Scandinavia. Investments and operational costs are shared between the EISCAT Associates in China, Japan, UK, Norway, Finland and Sweden. American radars are funded by the National Science Foundation (NSF) and operated by SRI International (PFISR, RISR-N, and Sondrestrom) and the MIT Haystack Observatory (Millstone). The RISR-C radar is operated by the University of Calgary.

RISR-N and RISR-C are in the central polar cap. Sondrestrom and the EISCAT Svalbard Radar (ESR) observe the ionospheric footprint of the cusp and the poleward edge of the nighttime auroral oval. PFISR and the mainland EISCAT radars observe the auroral oval. Additional coverage of the mid-latitude sub-auroral zone (equatorward of the auroral oval) is offered by the Millstone Hill radar.

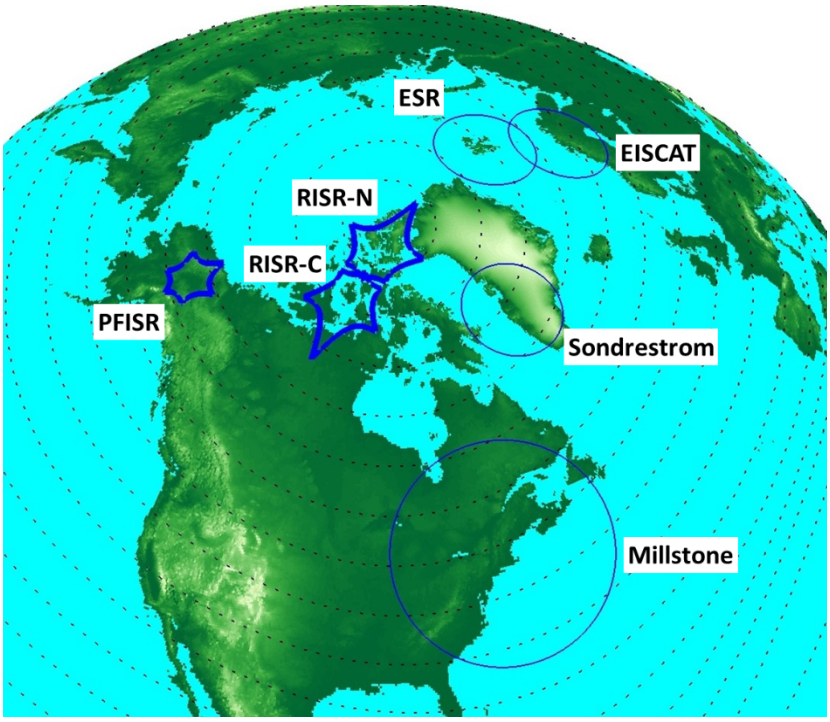

Figure 3: Coverage of high-latitude incoherent scatter radars in the northern hemisphere, as of September 2015.

EISCAT is also planning a major upgrade of their radar facility on the Scandinavian mainland. EISCAT_3D [9] is a three-dimensional radar imager of the upper atmosphere and ionosphere. In June 2015 the national funding agencies in Sweden, Norway and Finland made the critical decision to allocate funding for the first stage of EISCAT_3D. Given the current momentum it is therefore likely that EISCAT_3D could become operational around 2020/2021, in line with the proposed launch date of SMILE. The full EISCAT_3D system will have five sites across northern Scandinavia, allowing for measurements in full 3D of a 1000 km x 1000 km x 1000 km volume of the polar ionosphere. Depending on the state of the magnetosphere, a time resolution of less than one second and an altitude resolution of a few hundred meters can be achieved [10]. A list of incoherent scatter radar is provided in Appendix A2.

C.3. Ground-based high-resolution optics (winter time only)

In winter, auroral emissions can also be observed from the ground with high temporal and spatial resolution, when the Sun is at least 10-12° below the horizon. New-moon periods are best, as moonlight may compromise optical data. The auroral oval is influenced by geomagnetic activity. The offset between the geographic and magnetic poles puts additional constraints on when and where the aurora can be observed.

Cusp aurora on the dayside

In the Northern Hemisphere, from the ground, the cusp aurora can only be observed under normal conditions at Svalbard, from 06:00 to 12:00 UT, and between November 20 and January 20. In this period the entire northern hemisphere auroral oval is in darkness, see Figure 4. In 2008 a new auroral observatory was opened; the Kjell Henriksen Observatory (KHO) [11]. KHO is located next to the EISCAT Svalbard Radar, in Longyearbyen. KHO is the largest auroral observatory in the world, with 37 instruments from 18 institutions in 11 countries. A table summarising the instrumentation at the observatory is given in Appendix A3. The instruments track the motion, spatial extent and color spectrum of the aurora on temporal scales ranging from milliseconds to hours, and spatial scales ranging from

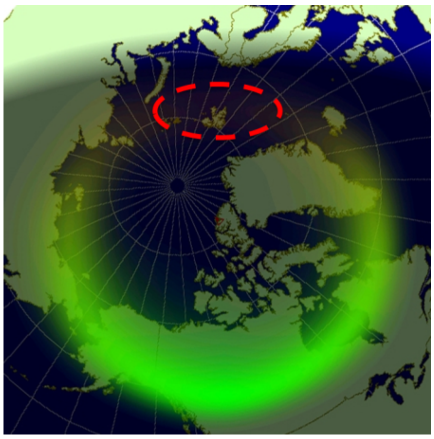

Figure 4: The dayside cusp aurora (red circle) can only be observed over Svalbard from November 20 to January 20 at 06:00- 12:00 UT.

hundreds of meters to hundreds of kilometres. Around 100 km to the north is the Chinese Arctic Yellow River Station in Ny-Ålesund, which has additional instrumentation. There are also additional auroral imagers in Ny-Ålesund and the Russian town of Barentsburg. Data from Svalbard are approximately magnetically conjugate with the Chinese Zhongshan Station in Antarctica, which allows for simultaneous observing of the northern and southern hemisphere cusps in winter. Key findings include a characterization of the dayside cusp aurora over Svalbard as a function of the interplanetary magnetic field [12], and the ionospheric signatures believed to be caused by flux transfer events at the magnetopause [8]. Additional southern hemisphere auroral monitoring may be provided by optical measurements obtained at the National Science Foundation (NSF, US) funded South Pole station. These observations will provide a conjugate view from the southern hemisphere of the phenomena that will be tracked in the northern hemisphere by the UVI.

Nightside aurora

The nightside aurora is significantly easier to observe, with a window of opportunity in the northern hemisphere ranging from September to April. Ground-based optical measurements of the auroral oval have a long heritage, and extensive coverage has been obtained in recent years. The THEMIS-ASI project uses 21 ground-based white-light imagers, situated across North America to cover a large swath of the nightside auroral oval. The mosaic of images obtained is used to track small-scale auroral phenomena, such as beading, that are associated with the substorm cycle. An example mosaic is shown in Figure 5 [13]. There are also additional optical instruments spread out across North America, including imagers operated by the University of Alaska Fairbanks and the University of Calgary, in Greenland, across Scandinavia (e.g. MIRACLE and ALIS), and in Russia. In addition substorm aurora are routinely observed at the NSF funded auroral observatories at the McMurdo station in Antarctica.

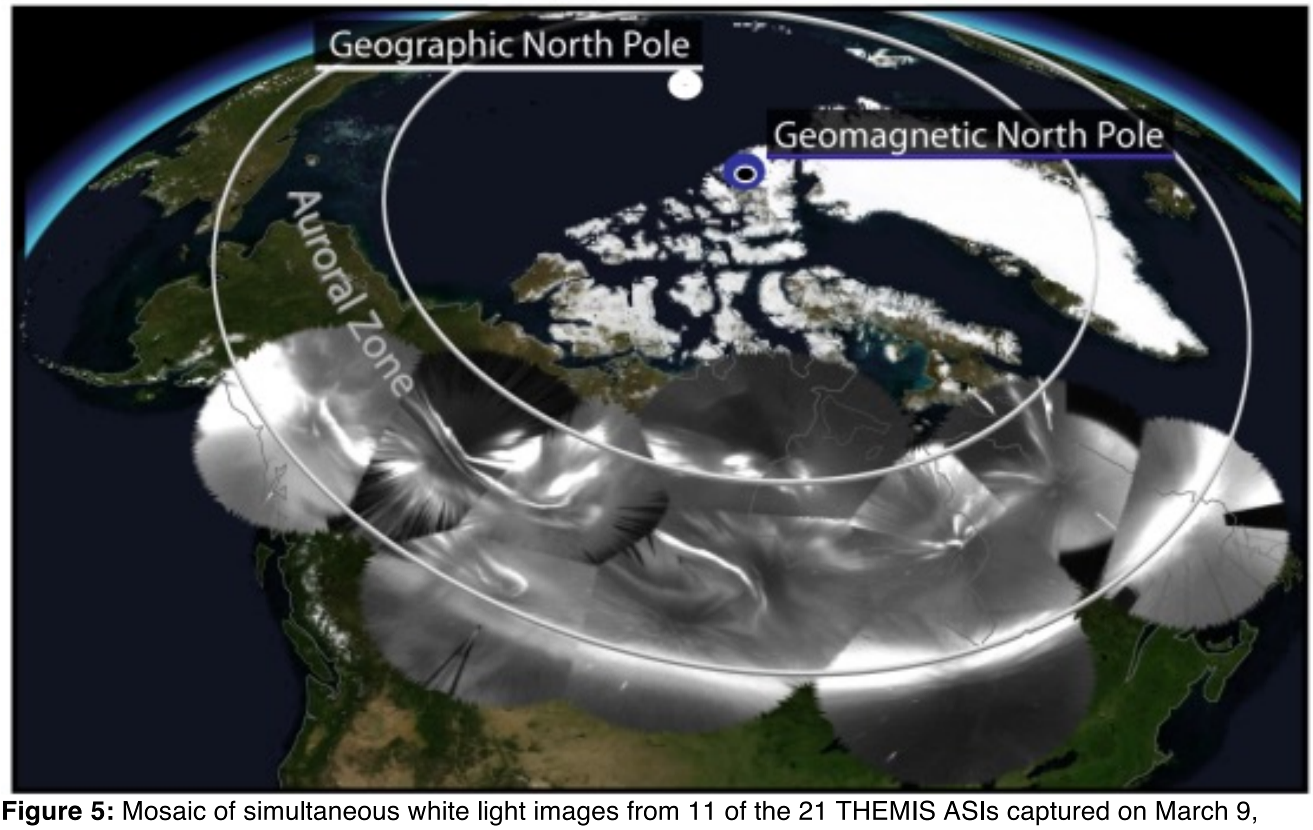

Figure 5: Mosaic of simultaneous white light images from 11 of the 21 THEMIS ASIs captured on March 9, 2008.

C.3. Riometers (all year)

Auroral precipitation, particularly of higher energy (10s of keV) electrons, significantly affects ionization in the D-region of the ionosphere, where electron-neutral collisions cause significant absorption of radio waves in the HF (10s of MHz) band. When the power of an HF signal in the absence of this ionospheric attenuation is known, its relative attenuation can be used as a means for remotely sensing such high-energy electron precipitation. Relative Ionospheric Opacity Meters (Riometers) are ground-based radio receivers that passively observe HF band Galactic radio noise (a known signal). Deviations from quiet baseline levels (a given riometer and a given geographic position will have a characteristic quiet day curve, deviations from which we call absorption) indicate high-energy precipitation. Riometers have a significant advantage over optical auroral observations in that the quality of the signal in terms of identifying such high-energy precipitation is independent of cloud cover and daylight; however, that information is relevant only to higher energy precipitation, and the spatial resolution afforded by riometers is in general quite poor.

The precipitation that causes most riometer absorption is comprised of central plasma sheet (CPS) electrons that have been nudged into the loss cone by wave-particle interactions. Provided these electrons are in strong pitch angle diffusion, the time series of riometer absorption is an excellent proxy for the time series of integrated flux of 10s to ~100 keV electrons on the flux tube that is magnetically conjugate to the riometer [14]. This fact was used to identify the signature of dispersion-less injections, related to the beginning of substorm expansion phase onset, in time series of riometer data [15]. With this, it is now clear that networks of imaging riometers can be used to create 2D time evolving maps of the changing high-energy electron population in the near-Earth CPS around substorm onset.

There are networks of single beam and imaging riometers operated by Canadian, US, and Finnish researchers in Alaska, Canada, Finland, and Antarctica. An exciting new development is the recent approval of TREx by the Canadian government and the US NSF. TREx will include a network of 10 imaging riometers in central Canada, embedded within the THEMIS ASI network, with a combined field of view spanning three hours of MLT and the typical magnetic latitudes of the auroral zone (see Figure 6). The motivation for TREx imaging riometry is to use co-located observations of aurora (from THEMIS-ASI and other systems), convection (from SuperDARN), ionospheric currents (from SuperMAG), and the injection (from TREx) to investigate the relationship between convection, dipolarization, and injection.

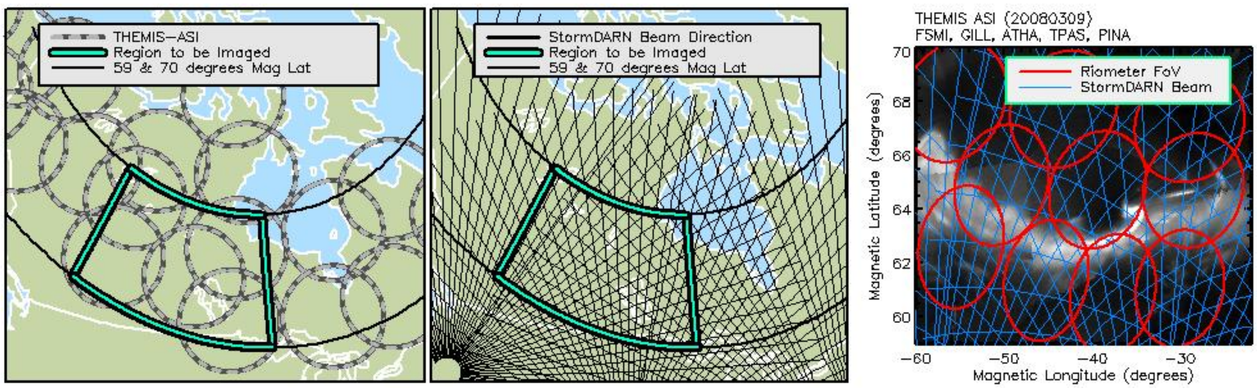

Figure 6: TREx imaging region with (**left**) FoVs of THEMIS ASI and (**middle**) beam patterns of the NSF funded mid-latitude SuperDARN HF radars. **Right)** Geomagnetic plot of the target region, SuperDARN beams, and new TREx imaging riometer FoVs, over-plotted on a mosaic of THEMIS-ASI white light images during moderate-high geomagnetic activity.

D: How ground-based measurements address the science goals of SMILE

D. 1. *What are the fundamental modes of the dayside solar wind/magnetosphere interaction?*

Ground-based measurements will complement the data obtained by SMILE in the following ways:

1. Ionospheric plasma flows obtained by SuperDARN indicate large-scale changes in the plasma convection in response to the changing conditions at the dayside magnetopause, for example, following a pulse of dayside reconnection.
2. In a narrow window of opportunity (between November 20 and January 20; 06:00-12:00 UT) ground-based optical imagers at Svalbard will observe optical emissions in the ionosphere associated with dayside reconnection events. Similarly, ground-based optical imagers based at locations in Antarctica (e.g. South Pole station) can make these observations in June and July. Dayside reconnection events include:
    a. the east-west and/or north-south motion of the cusp aurora
    b. the temporal evolution of individual poleward moving auroral forms (PMAFs), which map down into the ionosphere from flux transfer events at the magnetopause
    c. the energy flux of the precipitating particles
3. Ground-based radars (EISCAT Svalbard Radar, Sondrestrom) can track the plasma flow at the footprint of a newly opened magnetic flux tube; transient flow channels, vorticity in the plasma flow, Joule heating in the ionosphere, and the feedback to the magnetosphere via ion upflow. EISCAT can also observe precipitation of cusp particles into the ionosphere.
4. Ground magnetometers can be used to infer changes in ionospheric convection patterns resulting from variations in the IMF orientation and the occurrence of transient events such as travelling convection vortices.

D. 2. *What defines the substorm cycle?*

Ground-based measurements will complement the data obtained by SMILE in the following ways:
1. Nightside optical measurements (THEMIS-ASI, GO-Canada, TREx, and imagers across Scandinavia), along with the magnetic perturbations by ground-based magnetometers (e.g. SuperMAG), will add understanding of the substorm evolution, from the dayside driver to the commencement of the substorm on the nightside. Substructure in the aurora maps to substorm processes in the magnetotail and adds to the overall picture of nightside phenomena.
2. Nightside riometer measurements, particularly by the new TREx system, will enable tracking of the 2D spatial-temporal evolution of the dispersionless injection (as projected along field lines into the ionosphere). Combined SMILE solar wind, magnetosheath/cusp, and auroral observations, together with the riometer observations, will enable investigations of what upstream/driving conditions determine the geoeffectiveness of substorms (this applies to D.3 also).
3. In a narrow window of opportunity (between November 20 and January 20; 06:00-12:00 UT) the cusp spot can be monitored using ground optics at Svalbard, further complementing the data obtained by SMILE-UVI. The cusp latitude is expected to move equatorward prior to substorm onset, poleward thereafter. Southern hemisphere measurements (e.g. from Zhongshan or the South Pole station) of the cusp (around June and July) afford opportunities to compare northern and southern hemisphere responses to incoming conditions.
4. The determination of the open-closed field line boundary by SMILE-UVI can be supported by global ionospheric convection patterns obtained by SuperDARN
5. Ionospheric flows as evidence of dayside driving, or during nightside substorm commencement (e.g. auroral streamers) will be obtained from SuperDARN and incoherent scatter radars (EISCAT, PFISR, RISR-N, RISR-C, Sondrestrom).

The evolution of substorms will be followed by SMILE in combination with ground-based measurements, from the driving, through to the growth and recovery phases.

D. 3. *How do CME-driven storms arise and what is their relation to substorms?*

Ground-based measurements will complement the data obtained by SMILE in the following ways:
1. Ground-based measurements are particularly important to quantify the extremes in geomagnetic indices (e.g. SuperMAG) during CME-driven storms.
2. Ground-based optical images (obtained from THEMIS-ASI and imagers across Scandinavia) of the evolution of the auroral bulge in the main auroral oval, plus substructure during different

phases of the storm maps to the nightside magnetosphere, will enable storms to be tracked from the incoming CME driver on the dayside to the ultimate unloading on the nightside

3. Ionospheric flows as measured by radar will be observed during all phases of CME-driven storms (and examined both temporally and spatially), including both on the global (SuperDARN) and a regional scale (EISCAT, PFISR, RISR-C, RISR-N, Sondrestrom)

E: Ground-based measurement strategy in support of SMILE

In this section we approach the issue of when and where each SMILE science question can be addressed from the ground. The highest scientific return is expected in winter months, when ground-based optics are available and can be combined with radar, magnetometer and SMILE data. For this reason the winter months should have high priority.

For the northern hemisphere only, the dataset with the smallest window of opportunity, but also a high likelihood for substantially groundbreaking science, are the ground-based optical data of the cusp spot and transients in the dayside aurora (D1.2, D2.2). These data can only be obtained from one location (Svalbard), between November 20 and January 20, and between 06:00-12:00 UT. This deserves special attention from the spacecraft operations perspective (i.e. it is important that SMILE tries to make as many cusp observations as possible in this unique window of opportunity). Sites in the southern hemisphere, in contrast, are able to make observations of the cusp spot and transient dayside phenomena in June and July.

Ground observations of the night-side aurora (D2.1, D3.2) can in principle be made anytime from September through April. New-moon periods are better (from one week before new-moon, to one week after new-moon), but even during full moon some qualitative and timing information can be determined from auroral images obtained from the ground. With ground-based optics distributed along the auroral oval from Alaska, across Canada, Greenland, Iceland, and into Scandinavia, the observations can in principle be made at almost any universal time. However, the widest data coverage is again expected at 06:00-12:00 UT, when the THEMIS-ASI and other networks in Canada are covering a wide part of the nightside auroral oval, see Figure 4. Measurements obtained in the southern hemisphere (e.g. South Pole or Zhongshan stations which measure the dayside cusp aurora, or McMurdo station which measures substorm-related aurora) compliment those obtained in the north, and allow for the comparison of the response of the aurora in different hemispheres.

All other science questions (D1.1, D1.3, D2.3, D2.4, D3.1, D3.3, D3.4) can be made anytime (also in summer), as SuperDARN, SuperMAG, and the incoherent scatter radars are not affected by sunlight.

F: Concluding statement

Ground-based measurements are not essential to achieve the science goals of SMILE, as SMILE will be able to achieve these goals independently. However, ground-based measurements will add significantly to a more comprehensive understanding of the response of the Earth’s system to dynamic processes in solar wind drivers. Ground-based measurements originate from a community that is mature and well experienced, with an extensive network of facilities that in the large majority provide comprehensive data that are freely available, timely, and open-access. Many of the scientific questions that motivate the SMILE mission originate from the ground-based community. Compared to a spacecraft mission, ground-based data are also very low risk. The ground-based community has past experience of supporting previous space missions, such as Cluster and THEMIS. The ground-based community will establish a working group for ground-based support as part of the ongoing SMILE consortium meetings.

References:

[1] SMILE submitted proposal document, dated 15th March 2015
[2] Chisham et al., 2007, A decade of the Super Dual Auroral Radar Network (SuperDARN): scientific achievements, new techniques and future directions, Surv. Geophys, 28:33-109
[3] vt.superdarn.org
[4] www2.le.ac.uk/departments/physics/research/rspp/missions/eclat/eclat-european-cluster-assimilation-technology
[5] Gjerloev, J. W., 2012, The SuperMAG data processing technique, J. Geophys. Res., 177, A09213, doi:10.1029/2012JA017683
[6] supermag.jhuapl.edu
[7] http://omniweb.gsfc.nasa.gov/
[8] Oksavik et al., High-resolution observations of the small-scale flow pattern associated with a poleward moving auroral form in the cusp, Geophys. I Res. Lett., 31, L11807, 2004.
[9] McCrea et al., 2015, The science case for the EISCAT_3D radar, Progress in Earth and Planetary Science, Vol. 2, article id. 21, 63
[10] http://www.eiscat.com/about/whatiseiscat_new
[11] http://kho.unis.no/
[12] Sandholt et al., 1998, A classification of dayside auroral forms and activities as a function of interplanetary magnetic field orientation, J. Geophys. Res., 103(A10), 23325-23345
[13] THEMIS-ASI archive: http://aurora.phys.ucalgary.ca/cgi-bin/themis_gbo_realtime.pl?
[14] Baker, D. N et al., 1981, Near-equatorial, high-resolution measurements of electron precipitation at L ≅6.6, J. Geophys. Res., 86(A4), 2295-2313
[15] Spanswick, E. et al., 2007, Ground based identification of dispersionless electron injections, Geophys. Res. Lett., 34, L03101

Appendix:

A. 1. Table of northern hemisphere SuperDARN radars. Magnetic coordinates are given assuming an altitude of 100 km, using the AACGM model.

Radar	Geographic location		Geomagnetic location		Institution	P.I.	Scan direction
	Lat. (deg.)	Lon. (deg.)	Lat. (deg.)	Lon. (deg.)			
Adak Island East	51.88	-176.62	47.60	-113.0	University of Alaska	Dr. Bill Bristow	E
Adak Island West	51.88	-176.62	47.60	-113.0	University of Alaska	Dr. Bill Bristow	W
Blackstone	37.10	-77.95	48.2	-2.7	Virginia Tech	Dr. J.Michael Ruohoniemi	W
Christmas Valley East	43.27	-120.36	49.5	-58.3	Dartmouth College	Dr. Simon Shepherd	E
Christmas Valley West	43.27	-120.36	49.5	-58.3	Dartmouth College	Dr. Simon Shepherd	W
Clyde River	70.49	-68.50	78.8	18.1	University of Saskatchewan	Dr. Jean-Pierre St.-Maurice	W
Fort Hays East	38.86	-99.39	48.9	-32.2	Virginia Tech	Dr. J.Michael Ruohoniemi	E
Fort Hays West	38.86	-99.39	48.9	-32.2	Virginia Tech	Dr. J.Michael Ruohoniemi	W
Goose Bay	53.32	-60.46	61.1	22.9	Virginia Tech	Dr. J.Michael Ruohoniemi	E
Hankasalmi	62.32	26.61	59.1	104.5	University of Leicester	Prof. Mark Lester	W
Hokkaido	43.53	143.61	37.3	-144.9	Nagoya University	Dr. Nozomu Nishitani	E
Hokkaido West	43.54	143.61	37.3	-144.9	Nagoya University	Dr. Nozomu Nishitani	W
Inuvik	68.41	-133.77	71.5	-85.1	University of Saskatchewan	Dr. Jean-Pierre St.-Maurice	E
Kapuskasing	49.39	-82.32	60.2	-8.3	Virginia Tech	Dr. J.Michael Ruohoniemi	W
King Salmon	58.68	-156.65	57.5	-99.1	NICT	Dr. Tsutomu Nagatsuma	W
Kodiak	57.62	-152.19	57.2	-94.9	University of Alaska	Dr. Bill Bristow	E
Pykkvibaer	63.77	-20.54	64.6	67.3	University of Leicester	Prof. Mark Lester	E
Prince George	53.98	-122.59	59.6	-64.3	University of Saskatchewan	Dr. Jean-Pierre St.-Maurice	W
Rankin Inlet	62.82	-93.11	72.6	-26.4	University of Saskatchewan	Dr. Jean-Pierre St.-Maurice	W
Saskatoon	52.16	-106.53	60.9	-43.8	University of Saskatchewan	Dr. Jean-Pierre St.-Maurice	E
Schefferville	54.80	-66.80	63.7	14.9	CNRS/LPCE	Dr. Christian Hanuise	W
Stokkseyri	63.86	-22.02	64.9	66.1	Lancaster University	Dr. Jim Wild	W

Radar	Geographic location		Geomagnetic location		Institution	P.I.	Scan direction
Wallops Island	37.93	-75.47	48.7	0.8	JHU Applied Physics Laboratory	Dr. Ethan Miller	E

A. 2. Table of incoherent scatter radars.

Radar	Geographic location		Geomagnetic location		Frequency	Power	Institution	Funded by	Location
	Lat. (deg.)	Lon. (deg.)	Lat. (deg.)	Lon. (deg.)	(MHz)	(MW)			
EISCAT Svalbard Radar (ESR)	78.15	16.02	75.16	112.54	500	1	EISCAT	CRIRP (China), NIPR (Japan), NERC (UK), NFR (Norway), Nagoya Univ. (Japan), SA (Finland), VR (Sweden)	Cusp
EISCAT Tromsø (VHF + UHF)	69.58	19.22	66.53	103.32	224 930	2×1.5 2	EISCAT	CRIRP (China), NIPR (Japan), NERC (UK), NFR (Norway), Nagoya Univ. (Japan), SA (Finland), VR (Sweden)	Auroral Zone
EISCAT Sodankylä (UHF)	67.36	26.62	63.89	107.50	224	0	EISCAT	CRIRP (China), NIPR (Japan), NERC (UK), NFR (Norway), Nagoya Univ. (Japan), SA (Finland), VR (Sweden)	Auroral Zone
EISCAT Kiruna (UHF)	67.86	20.43	64.70	102.91	224	0	EISCAT	CRIRP (China), NIPR (Japan), NERC (UK), NFR (Norway), Nagoya Univ. (Japan), SA (Finland), VR (Sweden)	Auroral Zone
Poker Flat (PFISR)	65.12	212.57	65.38	264.17	450	2	SRI International	NSF (USA)	Auroral Zone
Resolute Bay (RISR-N)	74.73	265.10	83.32	319.29	450	2	SRI International	NSF (USA)	Polar Cap
Resolute Bay (RISR-C)	74.73	265.10	83.32	319.29	450	2	University of Calgary	Foundation for Innovation (Canada)	Polar Cap
Sondrestrom	66.98	309.06	73.08	40.62	1290	3.5	SRI International	NSF (USA)	Cusp
Millstone Hill	42.61	288.50	52.76	6.43	440	2	MIT Haystack Observatory	NSF (USA)	Middle Latitudes

A. 3. List of instruments at the Kjell Henriksen Observatory (KHO) in Longyearbyen, Svalbard, according to institution and category (#).

	Instrument	Institution	#	Country
1	All-sky imager	University of Oslo (UiO)	A	Norway (NO)
2	All-sky intensified video camera	University Centre in Svalbard (UNIS)	A	NO
3	All-sky intensified camera	Finnish Meteorological Institute (FMI)	A	Finland
4	All-sky color camera	University College London (UCL)	A	England
5	All-sky video camera	UNIS	A	NO
6	All-sky DSLR camera	UNIS	A	NO
7	All-sky Airglow Imager	UNIS	A	NO
8	Auroral meridian spectrograph	National Institute of Polar Research (NIPR)	C	Japan
9	CCD spectrograph	Embry Riddle Aeronautical University (ERAU)	C	USA
10	Spectrographic Imaging Facility	The University of Southampton/UCL	C	England
11	Meridian-Scanning Photometer	University of Alaska Fairbanks/UNIS	B	USA/NO
12	1m S.Ebert-Fastie spectrometer	University of Alaska Fairbanks/UNIS	C	USA/NO
13	1m G.Ebert-Fastie spectrometer	University of Alaska Fairbanks/UNIS	C	USA/NO
14	1/2m B.Ebert-Fastie spectrometer	University of Alaska Fairbanks/UNIS	C	USA/NO
15	1/2m W.Ebert-Fastie spectrometer	University of Tromsø (UiT)	C	NO
16	Michelson Interferometer	ERAU	D	USA
17	Fabry-Perot interferometer	UCL	D	England
18	Scanning Doppler Imager	UCL	D	England
19	Monochromatic Auroral Imager	Polar Research Institute of China (PRIC)	A	China
20	All-sky Airglow Imager	University of Electro-Communications (UEC)	A	Japan
21	Fluxgate magnetometer	UiT	E	NO
22	2-axis search coil magnetometer	Augsburg College/Univ. of New Hampshire	E	USA
23	Fluxgate magnetometer	PRIC	E	China
24	Auroral Radio Spectrograph	Tohoku University	E	Japan
25	HF acquisition system	Institute of Radio Astronomy/UiT	E	Ukraine/NO
26	64xBeam Imaging Riometer	Danish Meteorological Institute (DMI)/UiT	E	Denmark/NO
27	Balloon Telemetry Station	Nobile/Amundsen - Stratospheric Balloon Center/Italian Space Agency	E	US/Italy
30	Hyperspectral tracker (Fs-Ikea)	UNIS	C	NO
31	All-sky hyperspectral camera	UNIS	C	NO
32	Narrow field of view tracker	UNIS	A	NO
33	Scintillation and TEC receiver	University of Bergen (UiB)	E	NO
34	Automatic weather station	UNIS	E	NO
35	4xWEB cameras (safety)	UNIS	A	NO
36	Celestron 4m Telescope	UNIS	A	NO
37	Internet radio link - Janssonhaugen	NORSAR	E	NO

Instrument categories (#):

A. All-sky cameras and narrow field of view imagers,
B. Meridian scanning photometers,
C. Spectrometers / spectrographs
D. Scanning / imaging interferometers
E. Radio or non-optical instruments

A. 4. Letters of support from Principal Investigators of several ground-based facilities

Department of Physics & Astronomy
University Road
Leicester LE1 7RH
UK

T +44 (0)116 252 3580
F +44 (0)116 252 2070
E mle@le.ac.uk

18 November 2015

Dr Phillipe Escoubet

Subject: ground-based measurement support for the joint European Space Agency and Chinese Academy of Sciences SMILE mission

To Whom It May Concern:

I am writing with regard to the Solar wind Magnetosphere Ionosphere Link Explorer (SMILE) mission, which was recommended as the candidate for the joint European Space Agency and Chinese Academy of Sciences mission for launch in 2021.

I am writing in my capacity as Chair of the Executive Council of the Super Dual Auroral Radar Network (SuperDARN) collaboration. My colleagues and I in the SuperDARN consortium are very excited to hear about SMILE. Data from SuperDARN will be complimentary to the science goals of the mission, by providing additional context regarding the larger solar-terrestrial interaction.

SuperDARN is a worldwide collaboration between a large number of institutions which consists of over 30 high frequency, coherent scatter radars in both the northern and southern hemispheres. Each institute is responsible for securing their own funding through relevant agencies. Support for SMILE from the SuperDARN consortium can therefore be provided on a best-efforts basis, dependent on the particular situation at the time of launch. We look forward to collaborating with the SMILE team as and when appropriate.

Sincerely,

Mark Lester

Professor Mark Lester
University of Leicester,
Chair, Executive Council SuperDARN

CC: Dr. Graziella Branduardi-Raymont, University College London
Professor Chi Wang, State Key Laboratory of Space Weather

EISCAT Scientific Association

Kiruna, 20 November 2015

Dr. Jennifer Carter
Dept. of Physics and Astronomy
University of Leicester
Leicester, U.K.
LE1 7RH

Subject: Ground-based measurements in support of the joint European Space Agency and Chinese Academy of Sciences SMILE mission

To Whom it May Concern,

I am writing with regard to the Solar wind Magnetosphere Ionosphere Link Explorer (SMILE) mission, which was recommended as the candidate for the joint European Space Agency and Chinese Academy of Sciences mission for launch in 2021.

EISCAT has a long history of very fruitful collaboration with satellite missions measuring ionospheric and magnetospheric physical phenomena. Due to the locations of the EISCAT radars, those collaborations have naturally concentrated on interactions that affect the auroral zone and polar cap upper atmosphere. We are naturally very excited to hear about the SMILE mission and its interesting scientific objectives. Data from the EISCAT systems could complement the in-situ and remote measurements of the SMILE spacecraft via measurements of the state of the ionospheric plasma before, during, and after SMILE crosses the field lines above those systems.

EISCAT is a multinational association, presently consisting of Associates from China, Finland, Japan, Norway, Sweden, and the United Kingdom and Affiliates from institutes within Russia, France, South Korea, and Ukraine. Our user community is very active in the research areas targeted by SMILE and will most certainly be interested in collaborating with the PIs of that mission.

Sincerely,

Craig J. Heinselman
Director
EISCAT Scientific Association
Rympcampus 1
Kiruna, Sweden 98192
Email: craig.heinselman@eiscat.se

EISCAT Scientific Association **www.eiscat.se**

Headquarters
P. O. Box 812
SE-981 28 Kiruna, Sweden
Phone: +46 980 791 50
Fax: +46 980 791 59

Kiruna Site
P. O. Box 812
SE-981 28 Kiruna, Sweden
Phone: +46 980 79136
Fax: +46 980 292 76

Sodankylä Site
Tähtelä
FIN-99600 Sodankylä, Finland
Phone: +358 16 619 880
Fax: +358 16 610 375

Tromsø Site
Ramfjordmoen
N-9027 Ramfjordbotn, Norway
Phone: +47 776 20730
Fax: +47 776 20740

EISCAT Svalbard Radar
P. O. Box 432
N-9171 Longyearbyen, Norway
Phone: +47 79 02 12 36
Fax: +47 79 02 17 51

JOHNS HOPKINS
U N I V E R S I T Y

SuperMAG

Applied Physics Laboratory
11100 Johns Hopkins Road
Laurel MD 20723-6099
240-228-5000 / Washington
443-778-5000 / Baltimore

Philippe Escoubet
ESA Science and Robotic Exploration Directorate
European Space Research and Technology Centre
Keplerlaan 1
Postbus 299
2200 AG Noordwijk
The NetherlandsNovember 20, 2015

To: Dr. Philippe Escoubet

Subject: ground-based measurement support for the joint European Space Agency and Chinese Academy of Sciences SMILE mission

I am writing with regard to the Solar wind Magnetosphere Ionosphere Link Explorer (SMILE) mission, which was recommended as the candidate for the joint European Space Agency and Chinese Academy of Sciences mission for launch in 2021.

I am writing in my capacity as Principal Investigator of the SuperMAG (SuperMAG) collaboration. I was very excited to hear about SMILE. Data from SuperMAG will be complimentary to the science goals of the mission, by providing additional context regarding the larger solar-terrestrial interaction.

SuperMAG is a worldwide collaboration between a large number of institutions that operate ground magnetometers in both the northern and southern hemispheres and at low, mid and high latitudes. Each institute is responsible for securing their own funding through relevant agencies. Support for SMILE from the SuperMAG consortium can therefore be provided on a best-efforts basis, dependent on the particular situation at the time of launch. We look forward to collaborating with the SMILE team as and when appropriate.

Sincerely

Jesper W. Gjerloev

Principal Professional Staff
PI - SuperMAG Initiative
Applied Physics Laboratory - Johns Hopkins University
11100 Johns Hopkins Road
Laurel, MD 20723-6099, USA

UNIS

Deres ref.: Vår ref.: Dato: 24.11.2015

Dr. Jennifer Carter
Dept. of Physics and Astronomy
University of Leicester
Leicester, U.K.
LE1 7RH

Regarding the proposal named: SMILE

On behalf of the Kjell Henriksen Observatory on Svalbard (KHO), Norway, I am happy to say that we aim to support the proposal, entitled SMILE: Solar wind Magnetosphere Ionosphere Link Explorer.

We intend to carry out all responsibilities identified for us in the proposal, and cooperate to gain new insight in the magnetosphere and how it connects to the aurora in the upper atmosphere.

On behalf of KHO

Fred Sigernes

Dr. Fred Sigernes

Professor Optics and Atmospheric Research
Head of The Kjell Henriksen Observatory (KHO)
Department of Geophysics
University Centre on Svalbard (UNIS)
P.O.Box 156
Road 231 - 1
N-9171 Longyearbyen, Svalbard
NORWAY

Phone +47 790 23 335
Fax +47 790 23 300
Web http://fred.unis.no

Polar Research Institute of China

Address: 451 Jinqiao Road, Shanghai 200136 Tel：+86-21-58713485

3rd December 3, 2015

Dr. Jennifer Carter
Dept. of Physics and Astronomy
University of Leicester
Leicester, U.K.
LE1 7RH

Subject: Ground-based measurements in support of the joint European Space Agency and Chinese Academy of Sciences SMILE mission

To Whom it May Concern,

I am writing with regard to the Solar wind Magnetosphere Ionosphere Link Explorer (SMILE) mission, which was recommended as the candidate for the joint European Space Agency and Chinese Academy of Sciences mission for launch in 2021.

I am writing in my capacity as Head of Polar Atmospheric and Space Physics Division at Polar Research Institute of China (PRIC) and Principal Investigator of Zhongshan HF Radar. My colleagues and I in PRIC are very excited to hear about SMILE. Data from PRIC will be complimentary to the science goals of the mission, by providing additional context regarding the larger solar-terrestrial interaction.

PRIC has conjugate upper atmospheric observations at Zhongshan Station, Antarctica and Yellow River Station in Svalbard. At Zhongshan, we operate an HF Radar, Aurora Imagers and Spectrograph, a Digisonde, an Imaging Riometer, Fluxgate and Induction Magnetometers. At Yellow River Station, we have Aurora Imagers and Spectrograph, an Imaging Riometer and an Fluxgate Magnetometer. At KHO, we have Aurora Imagers and an Fluxgate Magnetometer. Support for SMILE from PRIC can therefore be provided on a best-efforts basis, dependent on the particular situation at the time of launch. We look forward to collaborating with the SMILE team as and when appropriate.

Sincerely,

胡红桥

Dr. Hongqiao Hu
Professor, Head
Polar Atmospheric and Space Physics Division
Polar Research Institute of China