Connors – STEP Forward 2007-2008

STEP Forward 2007-2008

Proposal to CSA Space Science Enhancement Program 2006

Executive Summary

One of the most effective ways to exploit Canada's ideal position for auroral zone science is to emplace instruments with sufficient density for meaningful studies. Magnetometers are useful instruments for this since their cost and data rate are realistic, and new analysis techniques are allowing their data to be understood. This proposal would exploit existing magnetometers in Canada, with major international collaboration, to take our ground-based network to a stage where it would be a major asset for international studies involving the auroral zone. The primary way to do this in an extremely cost-effective way is to use assets of the STEP Polar Network already in place, complemented by one strategically-placed new instrument. In this way the 2007-2008 timeframe, with the NASA THEMIS and Canadian e-POP missions, will see the best opportunity for Canadian ground magnetic data to contribute to ground-breaking science.

The instruments will be directly connected to the internet, a mode of deployment we have used with great success in the AUTUMN array. Target locations have been strategically selected to fill crucial gaps still remaining in the deployment of ground instruments in Canada. These gaps remain despite best efforts (of NRCan, Canopus/Carisma, and THEMIS) since Canada is a huge country. The proposal will see a large amount of already existing data curated in Canada for use with results of past space missions, it will greatly enhance the potential for conjunction studies with present space missions such as Cluster, and as mentioned above, will support THEMIS and e-POP in the 2007-2008 timeframe, and provide a basis for support of later missions.

The call for proposals allows data studies to be done and the proposer has several ongoing. However the nature of the need and opportunity makes deployment of instruments to the critical sites proposed take first priority given that missions to be supported are imminent. The international team of collaborators has already worked together and is ready to step forward to ensure

Background

2007 and 2008 will see major advances in space physics satellite projects involving Canada. The most notable and relevant among these will be the CSA e-POP/CASSIOPE mission and the US NASA THEMIS mission. The former has a modest ground-based program and the latter a significant one. These years will also see the beginnings of the US NASA Magnetospheric Multiscale Mission development for flight in the second decade of the century. This mission will involve regions which are also best probed from the ground from Canada. However, Canada is a continental-scale country, and ground assets remain sparse. We must use those that we have effectively. The remaining instruments of the STEP Polar Network in Canada give the best opportunity to provide ground magnetic coverage in key areas within the scope of the SSEP. We propose refurbishment, updating, and operation of selected STEP assets during 2007 and 2008. In addition, a data centre will be set up in Canada to archive historic data and to parallel Tokyo operations during the grant period. This will give a chance to seek other funding sources and operate the STEP equipment on an ongoing basis in the future.

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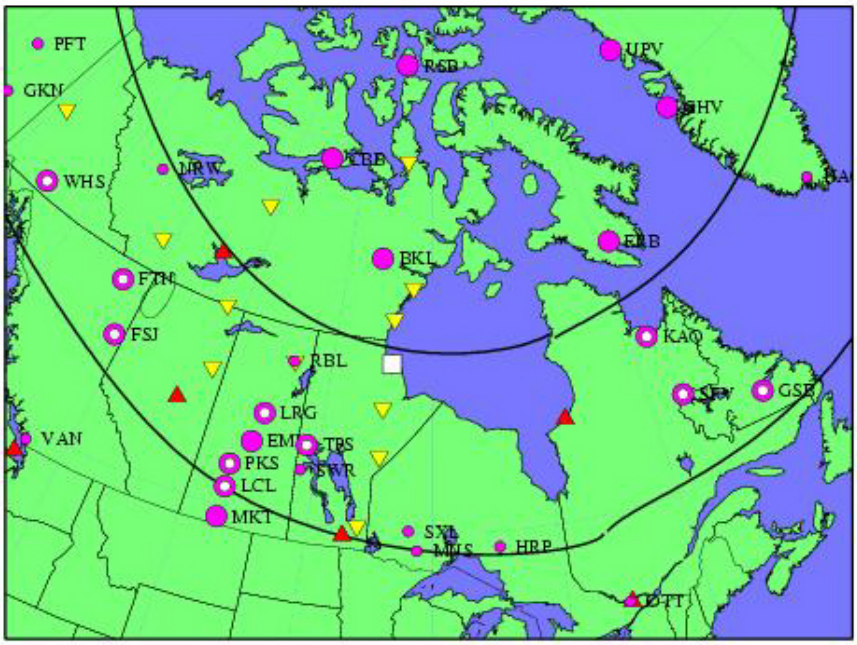
Magnetometers – key to understanding the aurora

Canada is the country best suited, by its location, to the study of auroras. Heavy lines on the map show the magnetic latitude lines of 60º and 70º between and slightly north of which most auroras are seen. Within these limits are shown all current magnetic instruments (some not operating). These stations are sparse relative to the scale on which the aurora varies, especially in eastern Canada. An important region is shown by the thin oval near the BC-Alberta-NWT border. This is the footprint region of the GOES West weather satellite, which is equipped with space physics instrumentation. There is a corresponding region near the east coast of Hudson Bay (not shown, but see below). Instruments near footpoints allow observations that can be compared with in-situ space observations continuously. Thus, the instrument marked FTN is in a very special location. The instrument sites with key codes (like FTN) formed part of the STEP Polar Network operated by Dr. Kanji Hayashi of the University of Tokyo since the late 1980's. The dataset thus produced is of great value to those studying magnetic events since then. Due to the large scale of the project and its being run from Japan by (largely) volunteers in Canada, there are data gaps and other problems, but an enhanced dataset from these instruments is very valuable for the reasons below.



Intercomparison of magnetic datasets

Electric currents associated with auroras generally follow lines of constant magnetic latitude. Magnetic effects arising from these currents vary mainly in the north-south direction. Meridian chains along lines of constant latitude thus cross them and data from several such stations can be used to determine where the currents flowed and their strength. Connors' technique for doing this is called Automated Forward Modeling (AFM). One notes from inverted triangles representing CANOPUS stations that there is only one chain in Canada (the white square is Churchill, with both a CANOPUS and an NRCan instrument). The recasting and enhancement of CANOPUS into CARISMA, based at the University of Alberta, will give greater station density and a second chain in Alberta. The details of that remain to be clarified but Connors has already placed four magnetometers in southern Alberta (Lethbridge, Calgary, Red Deer, and Edmonton) operating (and very well) as part of AUTUMN (Athabasca University – THEMIS – UCLA Magnetometer Network). AUTUMN also has a station at Val d'Or Québec run in conjunction with NRCan, and an instrument at Nemiscau, Québec which is not currently operating. The Québec stations may combine with NRCan instruments to give an eastern Canadian chain. A fourth possible chain is seen in Saskatchewan, formed from the STEP Polar Network stations and CANOPUS RBL (formerly a STEP site). FTN (Fort Nelson) can be in a fifth short chain including FSJ (Fort St. John) and Prince George (new station: not shown on map) to its south and Fort Simpson (yellow) to its north. We have a collaboration with Northern Lights College in Fort Nelson, allowing local participation.

A further reason for having a number of north-south chains is that the data, whether inverted with AFM or not, can be compared to data from subsequent satellite overflights. Already the sparsity of ground stations means that conjunctions with spacecraft are rare. Since subsequent low-altitude satellite paths are, due to the rotation of the Earth, further west by more than one time zone, it is virtually unheard of to have conjunctions with chains that are not single snapshots of electrodynamic conditions. But the relevant timescales for substorm and storm development are typically hours. In order to have series of conjunctions over these timeframes, a series of chains are needed. This proposal would emplace several such chains and allow a type of work not previously possible with coordinated space-ground studies. When we do get satellite overflights, important complementary information about near-Earth currents may be obtained that normally cannot be. Satellites primarily respond to field-aligned currents (FAC) when at the ca. 800 km or higher altitude that typifies DMSP, FAST, or the upcoming e-POP. The magnetometers carried by these satellites easily allow determination of locations of FAC on any pass throught the auroral zone, but ionospheric effects are generally hard to discern. The opposite is true for ground magnetometer arrays. They respond primarily to ionospheric Hall currents. The only way to get a complete view of near-space electrodynamics is to compare satellite overflight data with that from a ground array underneath. This makes conjunctions particularly valuable and the aim of having many chains that support satellite conjunction studies particularly important.

A second aspect of magnetic activity associated with auroras is east-west propagation. This has been long known for Ps 6 magnetic pulsations. These disturbances in the eastward and vertical parts of the magnetic field are known to occur in the morning sector and propagate sunward (eastward) at about 1 km/s. While the disturbances themselves move, it has been recently realized (Connors *et al*., 2003) that the initiation of Ps 6 is also associated with substorm onsets of two types, expansive phase or classical onset, and poleward boundary intensification or PBI. In the latter case, a signal propagates at relatively slow velocity from the PBI to the site of Ps 6 initiation. This type of propagating signal requires an array spaced along lines of magnetic latitude rather than along meridians. This is another key aspect of Fort Nelson (FTN). It has THEMIS station WHS (Whitehorse) to its west, and further west yet, University of Alaska site Gakona. Slightly to its east is the GOES West footpoint allowing a connection to space events. Further east is Ft. McMurray CANOPUS station. With better spacing comes La Ronge (LRG), visited and got operating again by myself and Dr. Hayashi in Oct. 2004, and then slightly south of the line, THEMIS station The Pas (TPS) which is not currently operating. Finally is the CANOPUS station at Island Lake. This chain allows studies of signal propagation over about 80º of longitude. Using CRC funding and in cooperation with University of Alberta and Northern Lakes College, Athabasca University has placed a modernized EDA magnetometers at Paddle Prairie and could place one at Fort Vermillion AB, slightly east of the GOES footprint. Thus Fort Nelson would become part of a chain ideally suited for studying propagation, including the ability to work with GOES West. The proposal thus calls for the most upgrading at Fort Nelson, with enhancements at LaRonge and Paddle Prairie.

Eastern Canada

The STEP Polar Network operated three stations in the main auroral zone in eastern Canada. One was at Goose Bay (GSB) which will be superceded by a THEMIS fluxgate. Another at Schefferville (SCV) was run in cooperation with McGill, and we want to get it back online. That at Kuujjuak (KAQ) paired with SCV and the NRCan one at Iqaluit (FRB on the map) allow a partial meridian chain at an easterly location in Canada. The NSF-funded expansion of the MEASURE II array into Québec has been further west, linking with Ottawa and Poste de la Baleine (both NRCan stations) to make a chain.. Iqaluit

Kuujjuak, Schefferville, and a subauroral station that would be relatively easy to emplace (but not in this proposal) would form a new chain. More likely a latitudinally paired station could also be placed north of Poste-de-la-Baleine (east coast of Hudson Bay; near GOES East footpoint; funding from MEASURE II being examined). While Kuujjuak's being one of few present stations in eastern Canada is its main advantage, it also has the potential to be part of chains that will be installed.

Instruments

The instruments, already onsite, are high quality Japanese fluxgate and search coil magnetometers. All STEP sites had search coils; those on the map with a white circle also had a fluxgate. All sites discussed above had both. The fluxgates sample at 1 Hz and the coils at 10 Hz. Data is currently available at http://www-space.eps.s.u-tokyo.ac.jp/~hayashi/ . The photo shows the system at La Ronge SK as photographed on a field trip in Oct. 2004. The fluxgate controller is at right, that for the coil in the middle, and the computer which makes the Internet connection (by phone at this site) is on top of a UPS (white box). This system operated reliably for several years but had to be rebooted on the field trip after 10 months out of operation. This illustrates the need for a trained contact person on site, but that person would normally not have a lot to do. In general this very simple system works well and if direct connection is available, as proposed here, the system can be remotely monitored.

Proposal

For the reasons outlined above, the STEP Polar Network stations which are eligible for funding under this program have strong scientific rationale for continued existence. Technologies now available will allow them to be made more reliable and the data made available in real time.

The rather simple proposal involves site visits to upgrade and connect to the network. These would be followed by infrequent later visits to monitor/upgrade (not funded by this proposal). Data archiving/distribution will use current methods, with a mirror site in Canada. Data will be freely available. The longitudinal propagation part of the proposal will make immediate use of the data. The fact that the very expensive instrumentation (a comparable fluxgate alone costs $15000 per site) already exists, with heads properly installed, in Canada, gives the opportunity to leverage a small investment disproportionately. Use of other funding to make chains makes this an even better investment. CRC money, used to refurbish and update instruments in more accessible locations, is not sufficient to cover the higher costs associated with the more northerly parts of the STEP Polar Network. Other instruments are mainly covered by the proposer's CRC funding and whose major instrumental initiative in Québec is supported by NSF as a co-I (Mark Moldwin, UCLA, is PI).

Work Plan

The work plan is based mainly on an assessment of the status of the STEP Polar Network done in October 2005 during Kanji Hayashi's visit to Fort Saint John and Fort Nelson, and on discussions with participants in the Peawanuck initiative at AGU in 2004 and 2005.

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The A/D board currently in use will be replaced in several sites. We are currently exploring use of the GPS-timed Public Seismic Network board. These have been tested under Windows and we are writing linux drivers.

STEP Network Recuperation

Park Site SK (PKS) Fluxgate and coils working. Uses tapes and upgrade would require new A/D system. Internet access likely in near future. Operating at this site frees up EDA unit under test at U. Sask. SuperDARN site.

Lucky Lake SK (LCL) Fluxgate and coils working. A/D system onsite is already suitable for internet connection.

La Ronge SK (LRG) Fluxgate is working but noise level high. Coil cables are certainly damaged. Would require exhumation for repair. Presently using phone to transfer data, ADSL may soon be available.

Fort Nelson BC (FTN) Fluxgate and coils appear operational but there are local sources of noise. GPS may be problematic: system not operational as of Feb. 2006 but was operational in Oct. 2005. New A/D system suggested. Relocation seems suggested and to a site where internet is available (not available at airport site).

Fort St. John BC (FSJ) Fluxgate and coils working, each run by a separate computer. Only known problem is Y pulsation component not working, can be repaired as part of N. B. C. visit.

Whitehorse YT (WHS) Fluxgate and coils. THEMIS fluxgate is there, so operate coils at WHS or move all elsewhere, good location, internet available, AES could provide upload service

Hornepayne ON (HRP) Pulsation magnetometer using tapes operative. New A/D converter needed to upgrade. Fluxgate to be emplaced. Would need to check on internet services. Broadband Ontario can provide wireless at $80/month.

Kuujjuak PQ (KAQ) Fluxgate and coils in principle still in place. System was working with tapes, would need new A/D converter. Internet service uncertain.

Schefferville PQ (SFV) Fluxgate and coils in storage, full system, packed. New A/D would be needed and internet likely available.

Goose Bay NF (GSB) Fluxgate, electronics are in storage, not sure about cables, coils are lost in ground. Will be a THEMIS site so remove and repair what is available there for later redeployment.

Hudson Bay Gap Filling

The site of Peawanuck ON is available to us through the collaboration of the Bartol Research Institute, who run a neutron monitor there. A similar instrument operates in Nain NF with a magnetometer as guest instrument. UCLA has agreed that it will supply a magnetometer if funding can be obtained to place one in Peawanuck. This would fill an important gap in longitudinal distribution of magnetometers, due to Hudson Bay. The site is the furthest north feasible in this longitudinal sector, at a magnetic latitude comparable to those of Gillam (Churchill line, CARISMA) and Poste-de-la-Baleine (NRCan/AUTUMN line). The upgraded subauroral station at Hornepayne will be south of it, which is valuable, although this would not constitute a true chain. The magnetometer will be on the internet as part of the AUTUMN array with data management at University of Calgary.

Associated Sites

Paddle Prairie AB EDA magnetometer on Alberta SuperNet has high noise level likely due to A/D board, which should be replaced.

STEP Network Equipment Recovery

STJ coils may be in ground or in storage and somebody local may know. Martin to contact John Whitehead, chair of department

NRW find coils?

TPS perhaps locate coils (2 horizontal, vertical was broken and removed)

EML might be worth looking for fluxgate with metal detector (coils are at University of Alberta)

SWR perhaps locate coils, instrument may be there but antiquated, is in town museum

MNS check where site really is, may be hard to find coils

OTT coils could be found? What is status of Quiet Site?

Timeline

Most of the proposal envisages field activities, which must be done in summer or early autumn. The two-year period allowed for Space Environment proposals is thus planned to start on June 1 2006 and the project will end on May 31 2008. Although it would be desirable to emplace all equipment in the summer, funding flow and staff availability will prevent that.

June 2006 Field trip 1 to Saskatchewan (Sites LCL, PKS, LRG; metal detector search at EML)
July 2006 Field trip 2 to Paddle Prairie, northern British Columbia and Whitehorse
August 2006 Installation 3 of UCLA magnetometer at Peawanuck (operation through AUTUMN)
September ’06 Recuperation 4 of Goose Bay equipment through THEMIS site visit or shipping back

Autumn 2006 Continued 5 operation of STEP network from Japan
Winter 2006 Logistical 6 arrangements for eastern Canada fieldwork

June 2007 Field trip 7 to Kuujjuak and Schefferville
July 2007 Transfer 8 of STEP database to Canada and dual archiving in Japan and Canada

Budget

The project will require field trips and visits by Dr. Kanji Hayashi from Japan. Our experience on field work funded by Athabasca University and by Dr. Hayashi’s own funds in 2004 and 2005 has been that although basic objectives were met, the trips were very rushed and aspects of reliability suffered. Thus funds spent to make trips of a reasonable duration will be well spent. The PI wishes to avoid travel beyond the field trips, and if a trip to Japan is needed, it will come from another budget.

We have tested a ‘standard’ field configuration which consists of a laptop computer running Linux, an uninterruptible power supply (UPS), and an A/D system. The laptop computers will, for purposes of reliability, be new rather than used units we have typically deployed. AUTUMN has used basic low-end laptops with good success and any anticipated problems are more than made up by ease of deployment and the possibility to easily have the units shipped back if replacement is needed. In most cases new A/D units will be needed.

FT1 1 week

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Japan return airfare	$2000
Hotels	$700
Car Rental and Fuel	$400
Subsistence	$560
3 laptop computers	$2400
Hubs, cables, etc.	$300
3 A/D units	$1200
TOTAL FT1	$7560

FT2 2 weeks

Hotels	$1400
Car Rental and Fuel	$900
Subsistence	$520
3 laptop computers	$2400
Hubs, cables, etc.	$300
3 A/D units	$1200
TOTAL FT2	$6720

Installation 3 (4 days)

UCLA magnetometer	$12000
Air	$1500
Subsistence	$160
2 laptop computer	$1600
Interfaces, etc.	$300
1 A/D for HRP	$400
TOTAL	$16760

Recuperation 4

Shipping	$400
TOTAL	$400

Operation from Japan – no budget line

Logistics – no budget line

FT7 10 days

Japan return airfare	$2000
Hotels	$1400
Local Transport	$300
Subsistence	$800
2 laptop computers	$1600
Hubs, cables, etc.	$200

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2 A/D units	$1200	
TOTAL	$7500	
Transfer 8		
Data medium	$500	
Server for AU	$2500	
TOTAL	$3000	
Operational Costs (Internet)		
LRG, PKS, LCL	24*3 months of internet service @ $50	$3600
FTN, FJS, WHS	24*80 + 24*40 + 24*80 internet	$4800
HRP	24*80	$1920
KAQ	12*80	$960
SCV	free (McGill)	
Peawanuck	free (Bartol)	
Total Internet		$11280
Data Centre Costs (level of skill decreases post-transfer)		
Staff Time pre-transfer 52*10 hours/week @ $70000/yr		$20000
Staff Time post-transfer 52*10 hours/week @ $50000/yr		$14285
Total Staff Costs		$34285

Totals per Year

FT1	$7560
FT2	$6720
Inst.	$16760
Recup.	$400
Intern.	$5160
Staff	$20000
TOTAL YEAR 1	$56600

FT7	$7500
Intern.	$6120
Xfer	$3000
Staff	$14285
TOTAL YEAR 2	$30905
TOTAL	$86505

At present there is close formal and informal collaboration between Athabasca University and the University of Calgary. No University of Calgary collaborators are specifically listed in this project but it is expected that a large degree of synergy will be possible, as has been the case, for example, with the successful AUTUMN project, where real-time operations and data collection are through the University of Calgary while operations are through Athabasca University.

The primary collaborators are international and unfunded except that a return airfare to Japan and field expenses will be provided each season for the Japanese collaborator who comes to Canada to bring in expertise about the Japanese equipment. The collaborators are listed below, with their roles.

Collaborator	Institution	Role
Kanji Hayashi	University of Tokyo (ret.)	Participate in fieldwork; run data archiving and exchange
Kazuo Shiokawa	STELAB, Nagoya	Possible participation in fieldwork; links to other programs such as MM210
Christopher Russell	UCLA, U.S.	Provide UCLA magnetometer at cost for installation in Peawanuck; link to THEMIS ground project
Gang Lu	NCAR, U.S.	Evaluate improvements to AMIE models as a result of gap filling. Collaborate on comparison with AFM

Biographical Sketches

Kanji Hayashi: initial developer of the STEP array in North America (and worldwide); participant in numerous field expeditions to Canada including doing imaging. Instrumentation specialist who has recently pioneered use of inexpensive laptop computers and most modern data communications methods to run remote stations.

Kazuo Shiokawa: participant in initial STEP deployments, also has done much fieldwork in Canada including, most recently, installation of Canada's only 64 Hz pulsation magnetometer and H-alpha imager at Athabasca University Geophysical Observatory. Broad expertise from aeronomy to magnetic field measurements including the STEP 210 meridian project, which remains operative as the world's longest meridian chain

Christopher Russell: Head of the Space Physics Group in IGPP, PI on the POLAR and Dawn (asteroid) mission; a co-investigator on numerous space missions including the THEMIS mission to study substorms where he is in charge of ground magnetic studies. Development of the UCLA ground magnetometers, several of which are jointly deployed in Canada by UCLA, Athabasca University and the University of Calgary, has already filled some of the gaping holes in Canada's distribution of magnetometers.

Gang Lu: Scientist at National Center for Atmospheric Research High Altitude Observatory. Major area of research interest is magnetospheric and ionospheric physics, with emphasis on magnetosphere-ionosphere-thermosphere coupling and high-latitude ionospheric electrodynamics. These topics are often addressed using the Assimilative Modelling of Ionospheric Electrodynamics technique, which incorporates global data of many types.

Relation to other Canadian projects

Canadian efforts in ground magnetometry have historically been regional, despite the fact that our country's continental scale allows unique large-scale studies to be done. Even very recently, efforts have remained fragmented. Ironically, the due date of this proposal coincides with a meeting to try and rectify this situation, partly organized at the initiative of the proposer. Some of the relations laid out below are in some ways speculative since complete information about the activity of other groups is not available.

The primary thrust here is to identify gaps in magnetometer distribution and fill them. Ideally this is done in such a way that chains of stations arise, either along meridians or latitude lines. The former permit profiling of electrojets and meaningful conjunctions with low to intermediate altitude satellites. The latter allow longitudinal propagation studies to be done, and at lower latitude, bay studies to show the three-dimensional structure of field-aligned currents.

The primary relations are to the NRCan, Carisma, and Athabasca University stations which already exist. Future coordination with THEMIS site placement is anticipated, especially in eastern Canada. The following chains will be created, with existing NRCan sites in bold, Carisma sites in italics, and THEMIS or AU sites underlined.

1) Eastern Meridian Chain: **Iqaluit** – Kuujjuaq – Schefferville
2) Hudson Bay Gap mini-meridian Chain: Peawanuck – Hornepayne
3) Saskatchewan Meridian Chain: **Baker Lake** – *Rabbit Lake* – La Ronge – Park Site – Lucky Lake
4) British Columbia Meridian Chain: *Fort Simpson* – Fort Nelson – Fort St. John – Prince George
5) Latitude 64 Longitudinal Chain: Whitehorse – Fort Nelson – Paddle Prairie - *Fort McMurray* – La Ronge – The Pas* – *Gillam* – Peawanuck – **Poste de la Baleine** – Schefferville* (*=slightly off chain)
6) Latitude 62 mini-chain: Fort St. John – Athabasca
7) Subauroral 59 Chain: Prince George – Edmonton/Red Deer – Lucky Lake – **Glenlea(Brandon)** – Hornepayne – Val d'Or

Thus it is seen that several critical regions are covered by the proposal. There are only two meridian chains in Canada and one real longitudinal chain of Carisma stations at about 68 degrees. This project will add, with station reactivations and upgrades at critical spots, four new meridian chains and three longitude chains.

Gray Areas

To provide context for the next item, we note the gray triangles on the map, which are at Inuvik, Norman Wells, and Nemiscau, Québec. There is sufficient funding to operate magnetometers at all three sites and they fill critical gaps. Funding issues are being discussed with the Canada Foundation for Innovation who have funded two groups to place instruments at Inuvik while having one at Norman Wells also would be highly desirable. One notes, for example, that Norman Wells is at the same latitude as Yellowknife, one of the stations in Canada which sees the most magnetic activity. At Nemiscau, computer security issues are impeding access to an already installed magnetometer. We will proceed on the assumption that all of these problems will be resolved soon.

Remaining Gaps

If this project is funded, one would be in the happy situation of having to look for remaining areas which have gaps not likely to be filled during the upcoming missions. The easiest gap to fill would be near the mouth of the St. Lawrence River near Sept-Iles. This site would be valuable for subauroral coverage in the subauroral longitude chain, and also to make a subauroral station for the Eastern Meridian Chain. The next critical gap, harder to fill, would be north of Poste de la Baleine. As this would continue the MEASURE II array, we are examining whether there are funds remaining to allow placement of a station there. With placement of several more THEMIS stations at sites distributed on a triangular grid optimal for imaging, some will likely also fall in places bearing a good relation to magnetic stations. It is likely that the auroral zone in Canada would be adequately sampled during the upcoming 2007-2008 space missions, should this project be funded.

Conclusion

The project laid out here can take advantage of (mostly) existing assets to emplace magnetometers in critical areas at modest cost. The team has good experience in field placements and is ready to act. The upcoming missions will fly and the value of the complementary ground data will be determined by what happens in the timeframe of this project.

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