An experimental class license is being requested for a research radar to be deployed and operated near Homer, Alaska, pursuant to research contract PAR3-G2548 to the University of Alaska Fairbanks and Cornell University from the Office of Naval Research in collaboration with the Air Force Research Laboratory. Research will take place in support of the HAARP facility run by the DoD in Gakona, Alaska. A summary of the research to be performed under the contract follows.

Note that the radar in question is essentially identical to one operated by D. L. Hysell and licensed by the FCC previously. The previous callsign was WA2XVQ (file 5947-EX-PL-1997 and 0265-EX-RR-2000), assigned when the radar was operated from Anderson, South Carolina. The mode of operation under the license sought will be the same as under the previous license.

Cornell PARS-C Proposal for Imaging Coherent Scatter Radar Observations of Natural Irregularities and Electric Fields in Support of the International Polar Year and of Artificial *E* Region Field-Aligned Irregularities Over HAARP

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Introduction

Investigators at Cornell University have been pioneers in the study of plasma irregularities in the Earth's ionosphere using coherent scatter radars. The research is performed not only to understand the plasma instabilities responsible for generating the irregularities but also to utilize the properties of the coherent scatter as a diagnostic of the environment in which the irregularities occur. Such diagnostic information complements data from incoherent scatter radars. Coherent scatter is relatively strong and can be observed with small, portable radars, and the resolution of coherent scatter experiments can be quite fine under many circumstances. Recent advances in radar imaging techniques, similar to the techniques that permit astronomers to construct images of distant radio sources, have made it possible to discern the spatial and temporal structure of coherent scatter from the ionosphere with minimal ambiguity using small, fixed-beam radars.

In the auroral *E* region, field-aligned plasma irregularities are produced naturally by Farley Buneman instabilities. These instabilities occur when the convection electric field exceeds a threshold value of about 20 mV/m. The irregularities occupy altitudes between about 95–125 km. Their Doppler shift and spectral width of the echoes observed by coherent scatter radars depend both on the ion acoustic speed in the plasma and on the flow angle, the angle between the electron convection velocity and the radar line of sight. The ion acoustic speed, meanwhile, is affected by wave heating associated with the plasma irregularities themselves.

Radar echoes from auroral irregularities mainly fall into two classes — type I and type II. Type I echoes are narrow and have Doppler shifts close to the ion acoustic speed. Type II echoes are broader and have Doppler shifts less than the ion acoustic speed. Type I (II) echoes are observed most readily at high (low) radar frequencies. At 30 MHz, both types are commonly observed. Also at this frequency, ionospheric refraction is sufficient to permit field-aligned backscatter from a large ionospheric volume without introducing substantial uncertainty in scatterer location.

Imaging radar observations of *E* region irregularities were made recently during a sounding rocket campaign from Poker Flat (*Bahcivan et al.*, 2005). By comparing the in situ rocket electric field measurements with the Doppler spectra measured in a common volume, we were able to find a mapping between the Doppler shift of the echoes and the convection velocity. Recent kinetic simulations performed by *Milikh and Dimant* (2003) and *Oppenheim et al.* (2005) predict the same mapping and permit us to understand it in terms of wave heating and nonlinear mode coupling effects. Consequently, we can now study fine structure in the auroral convection pattern using coherent scatter radar imaging.

Both wave heating and Joule heating due to fine structure in the high-latitude convection pattern are generally ignored in magnetospheric-ionospheric coupling studies. In practice, auroral zone Joule heating rates are estimated from the product of current density and electric field estimates, themselves computed using spatial and temporal averaging operations. However, this process leads to an underestimate of the heating rate due to the inequality

$$\langle \mathbf{J} \cdot \mathbf{E} \rangle \quad \geq \quad \langle \mathbf{J} \rangle \cdot \langle \mathbf{E} \rangle$$

where the severity of the underestimate depends on the amount of structure being filtered by the averaging process (*Codrescu et al.*, 1995, 2000). This discrepancy prompts investigations into the nature of auroral electric fields, specifically into their spatiotemporal variability. We propose to undertake such an investigation here as a contribution to the International Polar Year (IPY).

In addition, there are a number of effects associated with ionospheric modification that we propose to study with the Homer radar and HAARP. The first of these concerns the ability to extinguish naturally occurring Farley Buneman instabilities using ionospheric heating. The threshold condition for Farley Buneman instability is that the electron convection speed must exceed the ion acoustic speed in the ion frame of reference. By heating sporadic *E* layers, the HAARP facility should be able to elevate the ion acoustic speed to the level necessary to turn off Farley Buneman instabilities, that level depending on the background convection strength. The suppression of instability should be accompanied by the vanishing of type I echoes from the volume over HAARP. Quantitative results from such experiments would give valuable insights into the wave heating process alluded to above. Predictions for such experiments have been derived by *Robinson* (1994).

Another effect we propose to study is the excitation of *E* region ionospheric irregularities by the HAARP heater by means of thermal resonance instabilities. 50 and 144 MHz radars overlooking the Tromsø heater have observed such irregularities with growth times ranging from hundreds of milliseconds to tens of seconds. The echoes were strongest for o-mode heating during overdense conditions but were also observed under x-mode underdense conditions (see review by *Rietveld et al.* (1993)). Two classes of striation growth mechanisms have been recognized — one that involves a threshold condition on heater power but requires no pre-existing irregularities, and another with no power threshold but necessitating existing irregularities. The first can serve as a bootstrap for the second. What has not been examined in detail is the role of existing Farley Buneman instabilities on the occurrence and threshold conditions for artificially generated irregularities. Our proposal addresses this.

Additionally, recent observations of high intensity airglow associated with *E* region heating strongly argues for a coherent scatter radar system capable of scatter from field-aligned structures associated with processes other than the thermal resonance instability. Initially the system will be capable of *E* region backscatter from low frequency irregularities and lower hybrid waves should they be present. Extension of the system to detection of upper hybrid and other high frequency waves is straightforward and will be accomplished in time.

Other applications of the system include:

- Detection and characterization of electric fields over the Gakona site with applications both for natural and heating science. The former has implications for the International Polar Year and the latter for generation of ELF radiation.
- Potential detection of particle precipitation effects associated ELF or VLF control of outer radiation belt particles. The scattering cross section is the product of the plasma density and the fluctuation strength ($\delta n/n$). Thus, the backscatter intensity in the *E* region may provide a detectable signature of particle precipitation.
- Providing a site capable of detecting large electric fields and plasma density enhancements deep in the magnetosphere during magnetic storms which is one of the science drivers for the International Polar Year.

Proposed System

The 30 MHz coherent scatter radar we propose to deploy near Homer, Alaska, will be similar to the one built by Hysell located at the High Latitude Monitoring Station on Elmendorf Air Force Base in Anchorage, Alaska, which has been described by *Bahcivan et al.* (2005). Like the Homer radar, the Anchorage radar is intended for studying field aligned plasma irregularities in the auroral *E* region. However, whereas the Anchorage radar can only be operated in campaign mode, the Homer radar will be autonomous and controllable over the internet. Autonomy and reliability is made possible by the incorporation of a commercial, solid-state transmitter and digital waveform synthesis and receiver units. The data acquisition system will be networked, and preliminary, real-time data products will be made available over the internet during experiments, which can be conducted from HAARP or elsewhere. First-stage data processing will also take place at the radar site in order to reduce the size of the data files to be transferred over the internet. Second-stage processing, which is computationally intensive, will occur at Cornell. We anticipate frequent and extended operations of the Homer radar. The radar electronics will be portable and can be returned to "home base" in Anchorage, replacing the existing equipment there now, for auroral studies as needed.

We have chosen Homer as the site for the new radar because of the geometry of the geomagnetic field in Southern Alaska. In order to observe field aligned irregularities, the ray path from the radar to the target must intercept the geomagnetic field at nearly right angles. At a frequency of 30 MHz, we can expect ray bending due to refraction of the order of 1° or less. In order to observe FAIs in the *E* region over HAARP, we find that the radar must be located on the Southern Kenai Peninsula near Homer. From this location, the radar should observe coherent backscatter both from the ionosphere over Gakona and also from over Fairbanks. A UHF coherent scatter radar was operated from Homer by SRI International for many years in support of the Chatanika incoherent scatter radar near Fairbanks (*Tsunoda et al.*, 1974). A high occurrence rate of echoes was reported for this site.

The Homer radar will employ multiple, spaced antennas and interferometry to construct images of the scatterers in the spatial volume illuminated by the radar. It is well known that interferometry using a single antenna baseline yields two moments of the radio brightness distribution, the distribution of received power versus bearing (*Farley et al.*, 1981). Interferometry with multiple baselines yields multiple moments, and the totality of these moments can be inverted to reconstruct a radar image: a brightness distribution versus azimuth and zenith angle. The inversion essentially amounts to performing a Fourier transform of the interferometry cross spectra (*Thompson*, 1986). However, since the cross-spectra are inevitably incompletely sampled due to the limited number of interferometry baselines available, and because of the presence of statistical fluctuations in the data, the inversion must generally be performed using statistical inverse methods to achieve satisfactory results nearly free of artifacts (*Ables*, 1974; *Jaynes*, 1982). For our imaging work, we have employed the MAXent algorithm pioneered for applications in radio astronomy (see for example *Wilczek and Drapatz* (1985)). Our problem differs from that in radio astronomy mainly in that radar range gating adds the third dimension to the images. The time evolution of the scattering medium is moreover revealed by comparing images from successive integration times. Implementation of the imaging algorithm has been described by *Hysell* (1996).

The radar will observe coherent scatter from small-scale irregularities produced naturally and artificially in the *E* region ionosphere. Radar imaging will reveal where in the three-dimensional volume illuminated by the radar the irregularities are located. Aperture synthesis imaging and conventional Doppler processing moreover allow us to assign a complete spectrum to each sub-volume in the illuminated volume. The spectra contain information about plasma convection which can therefore be monitored throughout the illuminated volume. The spatial resolution for the radar will be of the order of 1 km in the direction of the radar line of sight and a few km in the transverse direction. The time resolution will be of the order of seconds.

The data controller and acquisition system are comprised of an arbitrary waveform generator and a digital receiver, both of which being PCI form factor cards. The manufacturers for the cards supply drivers for the Linux operating system. Additional software will be developed by Hysell, who can borrow heavily on the software that runs the Anchorage radar. All the code necessary to perform the imaging analysis exists at Cornell. The data acquisition system itself will be compact and portable and will be tested at the HLMS site in the first year of the project, prior to deployment in Homer in the second year. The antenna field in Homer, meanwhile, will be substantial. We plan to incorporate five sub-arrays, each composed of groups of Yagi antennas on 6 m towers. The length of the complete, sparse array will be approximately 150 m in the direction transverse to the line from Homer to Gakona.

The Role of PARS-C

The University of Alaska will be instrumental in helping Cornell researchers find a suitable location for the radar. Already they have assisted us in maintaining our system at HLMS. Furthermore, Dr. Bill Bristow agreed to be a co-investigator, assuring that simultaneous E and F region coherent scatter will be made during campaigns, the latter using SuperDARN. To our knowledge, such simultaneous measurements are unprecedented.

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