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HAARP Diagnostic Instrumentation

The High Frequency Active Auroral Research Program (HAARP) high-power, high-frequency (HF) transmitter gives the means to perform active ionospheric experiments by adding energy to the ionospheric medium using ground-based radio transmissions, also known as radiowave pumping. Radiowave pumping may be applied to experiments that make use of the ionosphere as a plasma laboratory in space and to investigate natural atmospheric processes and parameters via the perturbation of the natural atmospheric state and observation of the results. In both cases, detailed measurements of the results of the pumping or perturbation are required in order to understand the results.

HAARP hosts a set of diagnostic instruments, some owned by HAARP, some owned by HAARP with an associated external principal investigator (PI), and some owned by external institutions and supported by HAARP. Data from all of these instruments are freely available to all researchers. Additional instruments are owned by external PIs and brought to HAARP on a campaign basis. Data from these instruments may or may not be shared with other experimenters. Workshop discussions pertaining to current and potential future instrumentation at HAARP, or of use to experiments at HAARP, are summarized below.

INSTRUMENTATION AT HAARP

Radio Instruments at HAARP

- *Global Positioning System* (GPS) *scintillation.* There are two GPS scintillation receivers at the HAARP site capable of measuring both phase and amplitude scintillation. Data from one of these receivers is displayed on the HAARP website in addition to relative total electron content (TEC) plus scintillations. Data from both are available to HAARP researchers.[1]
- GPS *total electron content*. To obtain TEC, an Ashtech GPS receiver is used to measure the differential delay between the L-band signals transmitted by each GPS satellite. For each satellite in view, the line-of-sight TEC is computed from this delay measurement and converted to a slab-equivalent vertical TEC assuming uniform horizontal stratification.
- *All-sky riometer.* The all-sky riometer consists of a low-noise receiver connected to a 2 by 2 array of 5-element Yagi antennas operating at 30 MHz. It measures ionospheric absorption by comparing the total power of cosmic radio noise sources in a 30 kHz bandwidth and to average quiet-day data. It has been operating continuously since 1995.
- *Imaging riometer.* The imaging riometer is an 8 by 8 array. It currently suffers from a number of technical problems.
- ELF/VLF (*extremely low-/very-low-frequency*) *receiver.* This receiver is installed on site, approximately 1 mile from the HAARP transmitter array. It suffers from interference when the HAARP HF transmitters are on, but it can be used to monitor the ELF/VLF background when the HAARP HF transmitters are off.

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[1] HAARP website, available at http://www.haarp.alaska.edu/, accessed September 4, 2013.

- *Spectrum monitor.* This instrument measures HF and very-high-frequency (VHF) signals in the background electromagnetic environment. It can be used as a diagnostic of ambient radio propagation. Data have been collected continuously since 1993 and are available on the HAARP website.[2]

Radar Instruments at HAARP

- *Ionosonde.* The HAARP ionosonde is a Digisonde DPS-4D. An ionogram may be completed within 10 seconds. Ionogram and ionospheric drift measurements have been recorded since 1999.
- 30-MHz *and* 50-MHz *coherent radars.* During past campaigns at HAARP, 30- and 50-MHz radars were fielded by the Air Force Research Laboratory. The status of these instruments is unknown.
- 139-MHz (VHF) *radar.* This radar operated during 2001 and 2003. Further operation would require an investment in new electronics and software. The radar, when operating, is capable of observing scattering from HF-enhanced Langmuir waves and possibly also ion-acoustic waves. Three receiver channels would enable the simultaneous measurement of ion-acoustic and up and downshifted Langmuir waves.
- 450-MHz (*ultrahigh frequency,* UHF) *radar.* This radar, called the Modular UHF Ionospheric Radar (MUIR), is a phased array consisting of 512 transmit-receive modules each with 500-W peak pulse power. Currently only about half the modules are operational. MUIR can observe scattering from HF-enhanced ion-acoustic and Langmuir waves. The radar could be repaired and an upgraded timing system could be installed to allow synchronization with the HAARP HF transmitter, and two additional receiver channels could be installed to enable the simultaneous observations of ion-acoustic and up- and down-shifted Langmuir waves.

Optical Instruments at HAARP

- *All-sky imagers.* There are two all-sky imagers at the HAARP site, one older and one newer. The older imager is used to collect very-high-quality data during dark sky periods only. The newer imager can make measurements without regard to the position of the Moon, but produces lower-quality images.
- *Telescopic imagers.* This system consists of telescopes with 3- and 19-degree fields-of-view and cooled charge-coupled device imagers. Both are mounted on a computer-controlled mount with 6-position filter wheels and installed in a 14-foot optical dome. The imagers may be operated remotely.
- THEMIS *imager.* This imager is part of an array of ground-based all-sky imagers that support the NASA THEMIS mission.

Magnetometers at HAARP

- *Fluxgate magnetometer.* This instrument is part of the Geophysical Institute Magnetometer Array (GIMA), extending north-south across Alaska, and has been operating continuously since 1998.
- *Induction magnetometer.* This instrument records 3-axis magnetic field perturbations at a 10-Hz sample rate. Data are recorded continuously and displayed as spectrograms on the HAARP website.[3]

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[2] HAARP website, available at http://www.haarp.alaska.edu/, accessed September 4, 2013.
[3] HAARP website, available at http://www.haarp.alaska.edu/, accessed September 4, 2013.

CURRENT USER-PROVIDED INSTRUMENTS

During recent HAARP experimental campaigns, several instruments were fielded by external HAARP experimenters. These include the following:

- ELF *and* VLF *receivers.* ELF and VLF instruments have been fielded by the University of Florida.
- HF *radio receivers.* HF receivers for measurements of HF-stimulated radio emissions (stimulated electromagnetic emissions or SEE) have been fielded by the Naval Research Laboratory, Virginia Polytechnic and State University, and occasionally by other institutions.
- *Coherent imaging HF radar.* An imaging radar, operating at 30 MHz, operated by Cornell University, is located in Homer, Alaska. The location in Homer allows the observation of plasma irregularities generated in the E region above the HAARP HF transmitter.

RELEVANT SATELLITE MISSIONS

In situ observations of the HF radio-plasma interaction region can be made by instruments carried on sounding rockets and satellites. The most important microsatellite mission, according to Dennis Papadopoulos, is the Russian Resonance mission, which was described in the Chapter 3 section "Dynamics of the Radiation Belts." The following three other satellites, in particular, are of current interest, according to Papadopoulos:

1. RAX (Radio Aurora Explorer) is a CubeSat designed to study ionospheric turbulence. It is capable of receiving bi-static scattering from the five incoherent scatter radars (ISRs; Arecibo, Svalbard, Millstone Hill, Poker Flat, and Resolute Bay). RAX was launched in November 2010, and, after a power system failure, a replacement was launched in October 2011. It was noted by Herbert Carlson that the RAX mission to study ionospheric turbulence is very well aligned with capabilities of HAARP, which, unlike nature, can produce ionospheric turbulence effects on demand for coordinated observations.
2. *e*-POP (Enhanced Polar Outflow Probe) is an instrument package carried by the CASSIOPE (Cascade, Smallsat and Ionospheric Polar Explorer) spacecraft. e-POP includes an HF radio receiver operating from several kilohertz to 18 MHz and an energetic electron spectrometer operating from a few 0.1 eV to 100 eV. According to workshop participants, these instruments are ideally suited to in situ observations during HF experiments. The e-POP suite of instruments on CASSIOPE is designed to measure natural outflow with ion and neutral detectors. In addition, the wave and optical sensors flown on e-POP can detect the direct and indirect effects of HAARP at satellite altitudes. As noted above, the e-POP instruments were successfully launched in September 2013.
3. *Swarm* is an European Space Agency minisatellite constellation mission, successfully launched on November 22, 2013, which carries in situ electron and ion density and temperature probes.[4] It was said by a workshop participant to be ideally suited for comparison to incoherent scatter observations, lending small-scale in situ observations to complement the generally larger-scale beam available from ISRs. The wide spatial spread of a large number of probes in the swarm of satellites increases the probability that a Swarm probe will sample the volume of space perturbed by HAARP.

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[4] The European Space Agency website for SWARM is http://www.esa.int/Our_Activities/Observing_the_Earth/The_Living_Planet_Programme/Earth_Explorers/Swarm.

DESIRED INSTRUMENTS

Workshop participants discussed a variety of diagnostics that are currently not available at the HAARP facility. The following additions were offered as suggestions by one or more participants who believe they have the potential to enable users to better realize the full potential of the facility; the list should not be interpreted as representing a consensus or lack thereof among participants.

- ISR. According to many participants, the most important capability that has been missing from the HAARP program is an ISR. An ISR could be a much larger version of the MUIR radar mentioned above—large enough not only to detect coherent scattering from enhanced plasma waves, but thermal-level or "incoherent" scattering from ion-acoustic and Langmuir waves. Data from thermal-level waves allows the calculation of electron and ion densities and temperatures, and ion outflows, using the highly accurate statistical mechanical plasma theory of those waves. Workshop participants stated that such measurements would be useful for virtually every application of the HAARP HF transmitter. Arecibo, EISCAT (European Incoherent Scatter Scientific Association), and SPEAR all have ISRs collocated with their high-power HF transmitters.
- *Coherent radar systems.* It was noted by Dave Hysell, Paul Bernhardt, and others that HAARP generally has had a lack of radar diagnostics, including not only an ISR, but also other coherent radars. Several participants asserted that repairs, upgrades, or replacements to the other radars mentioned above, including the 139-, 50-, and 30-MHz radars, would be an important asset to the program.
- HAARP HF *radar.* Other participants pointed out that the HAARP HF transmitter and array could be upgraded to allow operation of all and/or part of the array as a coherent HF radar system, complementing other radars with HF radar capabilities in the 2 to 10 MHz range. Herbert Carlson believes that correlating location and time-evolution of images in HF with those in optical emission would be a major contribution to testing, improving, and validating theory and models of instability processes controlling onset and damping of plasma structures constraining trans-ionospheric radio wave propagation for communications and navigation signals.
- VIPIR HF *radar.* The VIPIR (Versatile Interferometric Pulsed Ionospheric Radar) (Grubb et al., 2008) was inspired by the well-known Dynasonde radar (Pitteway and Wright, 1992). Brett Isham noted that the VIPIR is capable of sounding in modes similar to the current HAARP ionosonde, but with significantly enhanced data quality; it can also operate as a very flexible and configurable coherent HF radar.

REFERENCES

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