From Alaska to the South Pacific In One-Hop

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Abstract - **This paper discusses research conducted by The Very Low Frequency (VLF) Group at Stanford University introducing them and a project called the High Frequency Active Auroral Research Program (HAARP). This project utilizes the latest oceanographic and ocean-engineering technologies for exciting applications to space physics and radio science research. Sponsors consist of the Air Force Research Laboratory (AFRL), the Naval Research Laboratory (NRL), and the Defense Advanced Research Projects Agency (DARPA). The program's facility is a high power transmitter located in Alaska, capable of broadcasting powerful VLF radio waves into the Earth's ionosphere. These waves propagate along the Earth's magnetic field lines to the system's geomagnetic conjugate point situated nominally 600 miles south of New Zealand in the southern Pacific Ocean. By studying the radio signals at this point, the VLF Group seeks to discover how energetic particles in the planet's radiation belts interact with very low frequency electromagnetic waves. This ambitious challenge of operating an autonomous, stationary, floating observation platform is known as the HAARP One-Hop Experiment – South Pacific Buoy.**

I. INTRODUCTION

The Very Low Frequency (VLF) Research Group at Stanford University investigates the Earth's environment, radiation belts, and the ionized regions of the upper atmosphere known as the ionosphere and magnetosphere. This work involves the use of VLF electromagnetic waves generated by lightning discharges, man-made transmitters and by the earth's radiation belt electrons. They have made many important discoveries about the planet's ionosphere, magnetosphere and the interactions between them. Research has focused on both the physical nature of these regions and how to effectively propagate radio waves through them.

Under the direction of Principle Investigator, Dr. Umran Inan, Professor of Electrical Engineering at Stanford, the VLF Group conducts experiments in conjunction with the US military's High Frequency Active Auroral Research Program (HAARP). A major application of this investigation is to better understand, simulate, and emulate the physical processes that affect the performance of military and civil space systems.

The Air Force Research Laboratory (AFRL), the Naval Research Laboratory (NRL), and the Defense Advanced Research Projects Agency (DARPA) jointly manage HAARP. Consisting of a unique transmitter facility based in Gakona, Alaska, HAARP generates high frequency (HF) radio waves that perturbate charged particles in the ionosphere at a very low frequency (Fig. 1).

The ionosphere has current structures similar to that of the ocean with the electro-jet contributing to VLF wave generation. Through this experimental program, researchers at Stanford aim to learn how energetic particles in the Earth's radiation belts interact with VLF electromagnetic waves. These particles, mainly high-energy electrons, are known to cause sudden as well as cumulative damage to electronics on satellites in orbit.

The Earth has a natural system for mitigating radiation belt activity involving aurora and lightning that is only moderately understood. To build upon that understanding, researchers study the electromagnetic waves generated above Alaska that propagate along the Earth's magnetic field lines through the radiation belts via a receiver at the geomagnetically conjugate point situated nominally 600 miles south of New Zealand in the Southern Pacific Ocean (Fig.1)

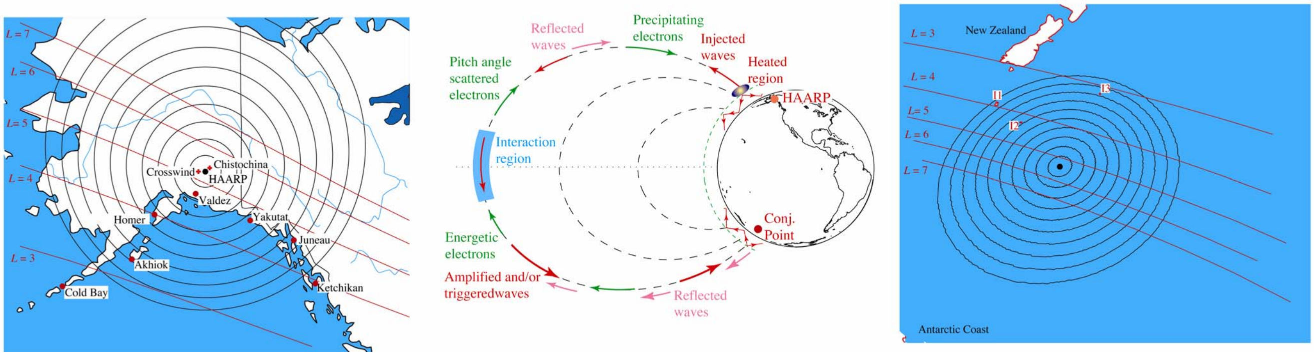

Fig. 1: HAARP VLF generation point in Alaska and conjugate point, south of New Zealand.

Unfortunately, project investigators require several years of continuous observation at the conjugate point, which rests on top of 5400 meters of a rough and often violent ocean. This ambitious challenge of operating an autonomous, stationary, floating observation platform is known as the HAARP One-Hop Experiment – South Pacific Buoy. Utilizing the latest oceanographic and ocean-engineering technologies, a successful combination of experiment design, buoy, and mooring was integrated, built and deployed using careful collaboration and teamwork.

The buoy and mooring (Fig. 2), expected to be the first in a continuing program, started with a moth-balled buoy owned by the NRL. The group then contracted the necessary experience and assistance needed in order to upgrade the buoy for the project's requirements and pick a mooring design for the southern ocean environment. The VLF receiver and telemetry systems were developed at Stanford. The Gilman Corp. provided the hull flotation (the only reused component). Oceaneering International, Inc. (OII), designed and fabricated the buoy's completely new mechanical structure and mooring interface. Marine Design and Composites, manufactured the fiberglass antenna housing (radome), Mooring Systems, Inc. (MSI), designed and built the mooring. RDSea and Associates, Inc. provided logistics for deployment and R/V *Tangaroa* of the National Institute of Water and Atmospheric Research Limited (NIWA), Wellington, NZ, was contracted for transport and at-sea operations. After nearly two years of planning and preparation the system was successfully deployed in April of 2004.

II. SYSTEM OVERVIEW

A. Science Payload

The primary instrument onboard is an extremely sensitive VLF radio receiver. In combination with three eight-foot diameter loop antennas, the system can detect VLF radio waves generated in Alaska that travel out beyond four times the earth's radius before reaching the conjugate point. Due to the system's remoteness, satellite telemetry is used for data transfer using custom developed protocols. Several communications systems were investigated with Boeing's Iridium Satellite System chosen for the experiment's communication needs. A constellation of 66 low-earth orbiting satellites offers complete coverage of the Earth, necessary for a monitoring location in high and remote latitudes. Digital signal processors analyze the radio recordings and produce spectrograms that can be transferred with significant timesavings.

For every minute of raw data collected, over 150 minutes would be required to return the raw data to Stanford. Other systems include 24 GB data storage capacity on flash memory cards, an internal and external camera, a backup ARGOS-PPT (platform positioning transmitter), wind speed and direction, temperature and moisture sensors. The system operating software runs on an efficient microprocessor that schedules operation and a powerful digital signal processor when recording, processing and communicating data. Power is supplied from twenty 6-volt Lifeline Marine AGM batteries that can support the low power design for at least a year and charge when sunlight is available during the summer months by four solar panels. Reconfiguration and scheduling of the system can be done through an autonomous server from Stanford, Alaska, and even the deployment vessel (Fig. 3).

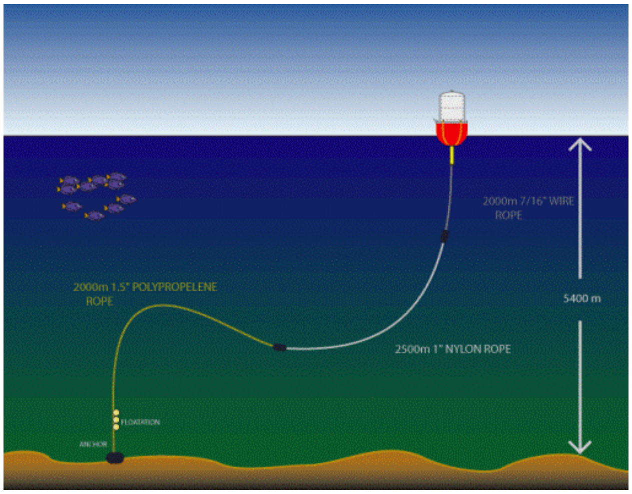

Fig. 2: HAARP One-Hop Buoy System

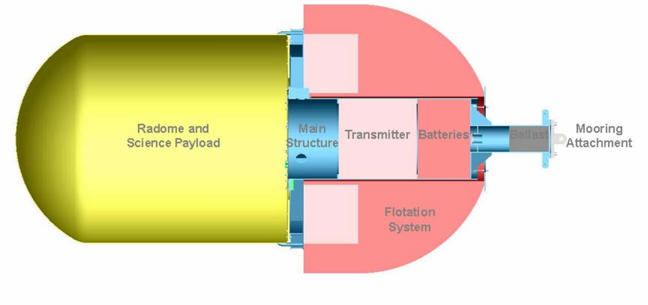

Fig. 3: Buoy Systems.

B. The Buoy

Extensive investigation on the proper method of operating at a remote location in the southern ocean without regular servicing determined that a surface buoy was the best option. The HAARP conjugate point is not frequently visited by ships nor has any bathymetry or current profiles been conducted of the area. NIWA was able to provide various data from the surrounding vicinity but still many miles away from the buoy site. The *Atlas of Pilot Charts – Southern Ocean* broke down the annual percentage of winds; wave height observations, air-temperature and iceberg probability over a twelve-month period. At sustained durations, wave height average is 21-28 feet; significant wave heights can reach 35-45 feet or greater. Sea spray icing is also a concern as are the possibility of icebergs although not probable due to the site being below the maximum drift of ice most of the year.

After securing the retired buoy hull from the NRL that had been used on various experiments since 1994, a team was assembled to design, retrofit/construct, ship and deploy the One-Hop system. The buoy is ten feet in diameter, constructed of ionomer foam (Surlyn™) with a hemisphere shape and has a total hull displacement of 28,000 lbs. A hemispherical buoy experiences a minimum change in center of gravity (CG) with a large change in wave slope using significant ballast (Fig. 4). This results in a buoy with minimal roll while being well damped. The deck structure features a large mounting ring for the fiberglass radome, a half-inch thick shield that is watertight and protects a total of fourteen experiment, communication and GPS antennas. Mounted outside are four solar panels, a wind sensor, camera and light. The dome also helps keep ice build up to a minimum. Penetrator chases are provided for the many cables that enter the well via watertight bulkheads. There are three lifting and handling bails that surround the outside of the deck structure beyond the radome.

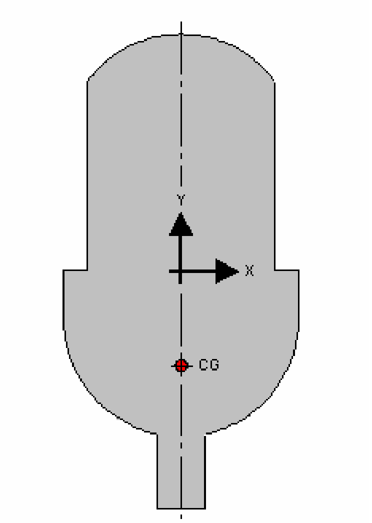

Fig. 4: Buoy Center of Gravity (CG).

The metal selected for the buoy structural elements is 5086 aluminum, which has superior corrosion and fatigue properties over the 6000 series alloys and is better suited for prolonged exposure to seawater. The electronics well holds the AGM batteries (adding 1400 pounds of ballast), a power distribution system and two fully redundant experiment systems. The mooring attachment (clevis) is designed from ASTM A572 grade B steel with 800 pounds added for stability. Fully rigged, the buoy weighs roughly 8000 lbs. and has a height of 23.5 feet (Fig. 5)

Fig. 5: Buoy Integration.

C. The Mooring

It is not uncommon for moorings to be set in thousands of meters of deep-ocean. Deploying in unknown territory is always risky. Mooring Systems, Inc. chose the "inverse catenary" mooring (aka: S-Tether) for this project. The S-Tether approach is based on many years of experience and proven methods used by the Woods Hole Oceanographic Institution (WHOI) and The National Data Buoy Center (NOAA-NDBC) on similar long life applications. The S-Tether design allows a means of providing the required mooring scope to reduce dynamic loading from wave action and currents in a configuration that minimizes mooring weight. The upper section of the mooring utilizes jacketed wire rope to resist fish bite. The S shape is formed below the wire rope by means of splicing nylon line to a polypropylene line. A calculation is made based on the specific gravity of these two ropes to determine individual lengths to meet the desired scope. The buoyant polypropylene line will lift a portion of the nylon to form the S shape in a way that will not allow the mooring to tangle up on itself. Syntactic flotation is clamped to the bottom of the polypropylene line to lift a short length of anchor chain and keep the polypropylene line from chaffing on the seabed.

Actual lengths of components for this application are an 18 meter section of 1-inch galvanized chain that bridges the buoy to a mooring consisting of: 2,000 meters of jacketed 7/16 inch (3x19) torque balanced wire rope, 2,000 meters of 1-inch 8-strand nylon and 2,500 meters of 1.5-inch 8-strand polypropylene plus the 4 meters of ¾-inch galvanized chain that attaches to a seven-stack railroad wheel anchor weighing 6,000 pounds, all standard and proven oceanographic mooring components. With plenty of reserve buoyancy to handle all components the bigger-the-better approach was taken to oversize hardware and minimize fatigue. Ocean waves will generate periodic increases in mooring tension and over a long-term deployment all components will undergo millions of cycles. The 18-meter shot of chain beneath the buoy will see the highest rate of fatigue due to this motion. Shackle sizes used are: 1 ½ -inch, 1-inch, and ¾-inch. 1-inch sling links mate each connection.

D. Deployment

After an extensive search for a capable ship for transport and operations, R/V *Tangaroa* (70 meters) operated by NIWA out of Wellington, New Zealand was contracted. *Tangaroa* departed for the HAARP conjugate location on April 17th, 2004 once pre-cruise preparation and loading were completed. The buoy was strapped onto a container bed that was secured in the well on the lower deck. Because the mooring is simple, consisting of only the surface buoy and mooring components with no in-line instrumentation, everything was connected in advance at the pier while spooled onto the main trawl winch. The wire to nylon termination was wrapped in rubber and coated with urethane to prevent any shackle/cotter-pin chaffing against the polypropylene (Fig. 6). A 6-tuck short splice marries the nylon to the polypro (Fig. 7). The seven-stack railroad wheel anchor was secured close to the transom for quick transfer off the stern at the end of the deployment.

Fig. 6: Wire to Nylon Termination Wrap.

Fig. 7: Nylon to Polypropylene Splice.

Arriving on station at 2200 hrs. April 20th, a bottom survey was conducted along the cruise track and east of the target zone showing consistent relief between 5200 and 5400 meters. Set and drift was determined to be easterly and the ship moved due east far enough to allow for a three to four hour deployment on a reciprocal course. The buoy was lifted over the starboard rail and deployed using the main sea crane, all 6500 meters of mooring spooled off the trawl winch free of incident**.** Acoustic releases were not used due to cost reduction and the mooring being initially designed as expendable. With all of the concern about weather in this part of the world, this mooring cruise was blessed with a middle of the night deployment, no wind, minimal current and flat calm sea conditions, simplifying ship handling and all deployment procedures. Confirmation arrived the following afternoon from Stanford that data was being received (Fig. 8 & 9).

Fig. 8: Deployed Buoy, *Tangaroa* in Background

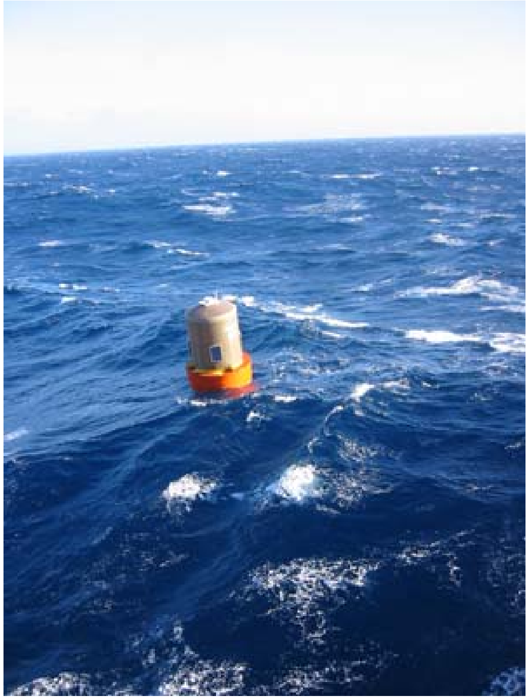

Fig. 9: Departing Shot.

E. Recovery

With the experiment designed to last up to two years in virgin-ocean for a buoy and mooring of this type, multiple recovery options were laid out during the initial "Buoy Feasibility Study" (Reddell, Stanford Univ., 2003). Weighing out the costs associated with each option proved that the system be designed expendable. Based on the schedule for data sent by Stanford, the onboard GPS would send buoy position when queried. The January 13, 2005 check showed that the buoy was 90 km outside of its watch circle range. The last position acquired prior to that was on December 15th, 2004 (Fig. 10). Then the buoy appeared near the anchor position. Eight months after deployment, the buoy was clearly adrift (Fig 10). Positioning was upgraded to several per day in order to monitor the buoy's track. NIWA was contacted to see if *Tangaroa*'s schedule would permit an immediate rescue and after a schedule change, departed Wellington under extreme conditions reaching the buoy on January 28th for a successful yet challenging recovery. The mooring had parted at the very top section of the 7/16-inch wire rope (upper 20 meters). This explains the speedy drift with minimal drag. Cable forensics will be conducted on the recovered piece of wire to try and determine what exactly caused the break. These results will be applied to a second deployment of the One-Hop South Pacific Buoy Experiment.

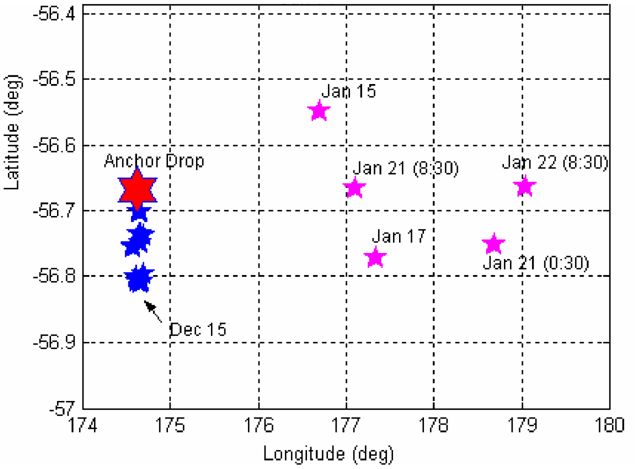

Fig. 10: Buoy Watch Circle

III. CONCLUSION

Several new technologies were developed in this project to support an autonomous radio experiment that generates far more data than a typical oceanographic program and operates in one of the most remote open ocean regions on earth. The best of proven marine engineering, design and data processing systems were brought together by a talented team. The first autonomous data transmission from the buoy received after the April 21st early morning deployment marked the successful end of a very challenging program development cycle and opened the door for a new future of earth science research. This has been the first opportunity to conduct long term observations from the HAARP conjugate region with hundreds of data transfer sessions completed over the eight-month deployment.

External camera images and satellite weather and wave height data monitored closely over the buoy's first winter storm period have given much value in having an autonomous system to weather these conditions rather than conduct observations from onboard ship. The buoy experienced several extended weather systems with seas of 25-30 feet, one system with waves up to 50 feet, and even a nearby 8.0 seaquake.

Several months into this successful operation, preliminary development and discussion was underway to upgrade and replace the current experiment. Now that the buoy has been safely retrieved and returned, that discussion is about to be transitioned into a new program involving the deployment of the refurbished buoy in December of 2005 and the deployment of a second buoy with more robust electronics and altitude systems, and higher telemetry rate in December, 2006. The two-year deployment duration was not initially achieved but a project baseline has been established.

Acknowledgments

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Deployment Team: (left-right) Dr. Evans Paschal, Rick Cole, Mark Golkowski, Jeff Chang, Erin Selser, Noah Reddell and Capt. Pierre Smit

HAARP One-Hop Experiment
The South Pacific Buoy