PERSONAL SPACE WEATHER SYSTEM

System Objectives and Use Cases

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VERSION HISTORY

Version Number	Implemented By	Revision Date	Approved By	Approval Date	Description of Change
0.1, 0.2	T. McDermott	Various			Original Issue
0.2.1	T. McDermott	August 1, 2019			Reformat and Change Document Name

1. Scope

This document covers the basic science objectives of the Personal Space Weather Station (PSWS), some common PSWS use cases, and other uses of the information generated, and alternative uses of the equipment itself.

This document is intended to provide a high-level overview. It should not be considered to be a normative specification.

1.1. References

1. Project Description / Proposal, Nathaniel Frissell

2. Personal Space Science Weather Station Subsystem Specification, Tucson Amateur Packet Radio (TAPR).

2. Science Objectives

The Personal Space Weather Station (PSWS) science objectives are described in in the Project Description / Project Proposal. This document extracts a small subset of that information to provide a quick overview for project participants.

The primary scientific objective of the Personal Space Weather Station (PSWS) is to measure and characterize ionospheric and geomagnetic short-term, small-scale variability on a large geographic scale in order to understand the response of the ionosphere to sources from above (space weather) and below (atmospheric forcing).

The Solar Eclipse QSO Party (SEQP) study highlights several important points. First, hundreds of thousands of ionospheric soundings can be generated by volunteer ham radio operators. Next, the HF signals observed contain geophysical information about the ionosphere they pass through, and this information can be recovered if analyzed properly. Finally, through forward-modeling techniques, it is possible to place even these very simple measurements in the context of physical ionospheric parameters. Similar forward-modeling techniques have also recently been used by (Mitchell et al., 2017) and (Nickisch et al., 2016). Conversely, these types of observations may also be used to improve or validate ionospheric models.

In spite of such successes, these observations are limited in that the receive systems are optimized for ham radio use, not science. Therefore, a major goal of this PSWS proposal is to develop an observational platform that is optimized for space science, can be used and deployed by professional researchers, and can also enjoy wide-spread adoption by the global amateur radio community.

- Medium Scale Traveling Ionospheric Disturbances

Medium scale traveling ionospheric disturbances (MSTIDs) are quasiperiodic density perturbations of the F region ionosphere with periods between 15 and 60 min, wavelengths of several hundred kilometers, and velocities between 100 and 250 m s^{-1} (Ogawa et al., 1987). MSTIDs have been demonstrated to be associated with both electrodynamic processes (Ogawa et al., 2009; Kelley, 2011) and atmospheric gravity waves (AGWs) (Hines, 1960).

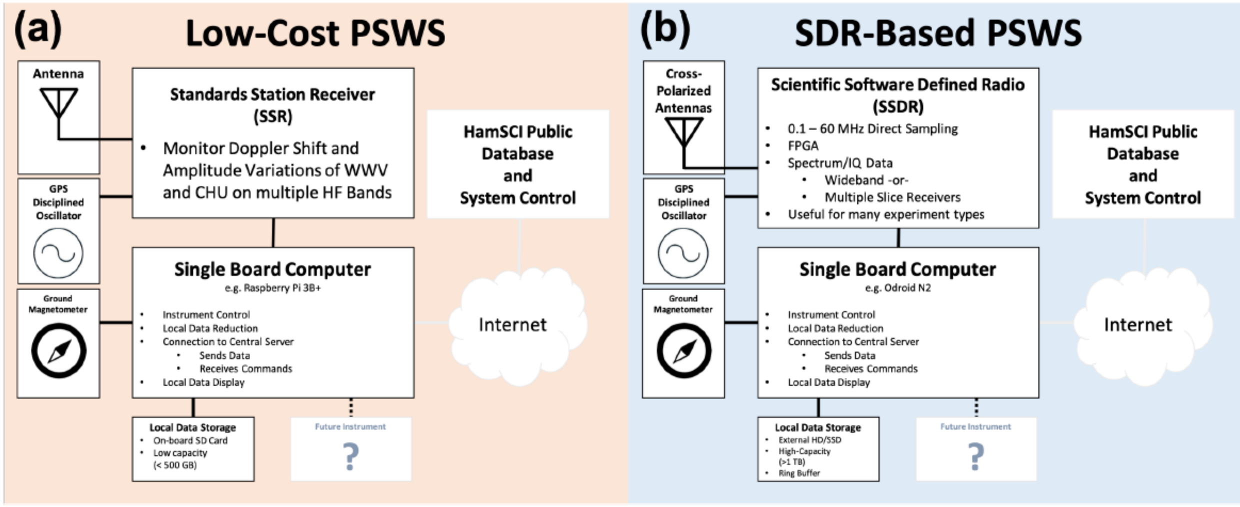
Radar rays are modulated by a TID passing through the F region ionosphere. Concavities in ionospheric density focus rays on the ground, while convex regions defocus the rays. Focused regions will cause enhancements in radar ground backscatter power, while defocused regions will cause reduced ground backscatter power. As MSTIDs move over the radar field of view (FOV), wave patterns can be seen in the returned backscatter power. More MSTID measurements are needed. For example, as MSTIDs propagate over such large areas that it is impossible to track them from their source to dissipation region with existing instrumentation networks.

- Solar Flares and Ionospheric Absorption Events

The PSWS will also be sensitive to disturbances from space. For example, the radio receiver instrument can be used to study ionospheric impacts from solar flares, such as radio blackouts. Radio blackouts are the complete fading out of dayside HF radio transmissions for a period ranging from a few minutes to an hour or more (Dellinger, 1937). Radio blackouts, also known as shortwave fadeouts, result from a sudden, solar flare-induced increase of extreme ultraviolet and X-ray radiation that ionizes the D region and causes collisional absorption (Benson, 1964; McNamara, 1979). Radio blackouts due to solar flares are of importance to people who rely on HF communications.

2.1. Top Level Architecture

The PSWS is designed to be a platform to integrate multiple ground-based space science instruments together. Each PSWS will be able to work independently, or part of a larger network. The PSWS is designed to be modular and extensible, so that it can service multiple price points and scientific objectives. This will make it affordable enough for hobbyists to independently purchase and operate a station, but robust enough for professional use. Regardless of the exact instrumentation on a specific PSWS node, the software and back-end data and control infrastructure will be compatible with each other. This will allow for the deployment of a network of instrumentation with the largest possible coverage: part of the network deployed strategically by professional researchers, and the other part of the network grown organically with volunteer participation by interested individuals.



The research needs can be met with the development of two variants of the PSWS: a low-cost entry-level model, and a higher-cost model with more capabilities. It should be noted that TAPR development currently is focusing on the (b) higher performance SDR-based PSWS.

The figure presents block diagrams of both variants. Figure (a) shows the low-cost version, which uses a radio instrument identified as the Standards Station Receiver (SSR). The SSR is a single-purpose receiver to measure changes in carrier frequency and amplitude of standards stations such as WWV and CHU. A single antenna is used. The SSR will output narrow bandwidth, low-data rate measurements, and therefore not require much computational power or data storage. Therefore, an inexpensive Raspberry Pi is selected as the single board computer, along with an on-board micro SD card (< 500 GB) for data storage. Figure (b) shows the block diagram of the higher-cost, software defined radio (SDR)-based version. In the SDR-based version, the standards station receiver is replaced by a highly flexible, wide bandwidth, direct sampling SDR receiver known as the Scientific SDR (SSDR). The SSDR will be capable of sampling from 0.1-60 MHz simultaneously on two separate phase-locked channels. This will allow for radio observations with polarization determination across the LF, MF, and HF bands. The raw output of this radio can be processed in multiple ways to allow for experimental flexibility. However this flexibility comes at a cost, which includes more sophisticated receiver hardware, a more powerful computer, and increased data storage.

In spite of their differences, The figure shows both variants share the same core architecture: an HF radio receiver instrument for ionospheric studies, a ground magnetometer, local data storage, ability to accept additional instruments, and a single-board computer for data acquisition, data processing, and network connectivity. The radio receivers on both variants include a low-cost, yet high-precision GPS disciplined oscillator (GPSDO) as a reference clock. Both versions include a ground magnetometer. The single board computer on both systems will run the same Linux-based control software, allowing for compatibility of instrument control and data transfer.

The common software interface will allow for the seamless integration of the different PSWS variants into a single network.

It should be noted that operating the 14 bit SDR with 30 to 60 MHz of bandwidth will create a data stream that will go beyond the processing capabilities of the inexpensive SBC that we plan on using for the PSWS. Therefore, we will include a variety of approaches for reducing the data rate of the SDR. First, the API will include a mechanism to create “slice” receivers using digital down conversion and decimation. This will allow the user to create multiple, virtual receivers centered at arbitrary frequencies within the operating range of the SDR with selectable bandwidths. As an example, 8 slice receivers sampling 192 kHz bandwidth with a 14 bit ADC on 2 separate antennas will produce an 86 Mbps stream and 1 TB per day. This is suitable for a single gigabit Ethernet connection and can be processed by the SBC. By carefully choosing the slice receiver frequencies and bandwidths, it is possible to configure the SSDR for many different scientific experiments.

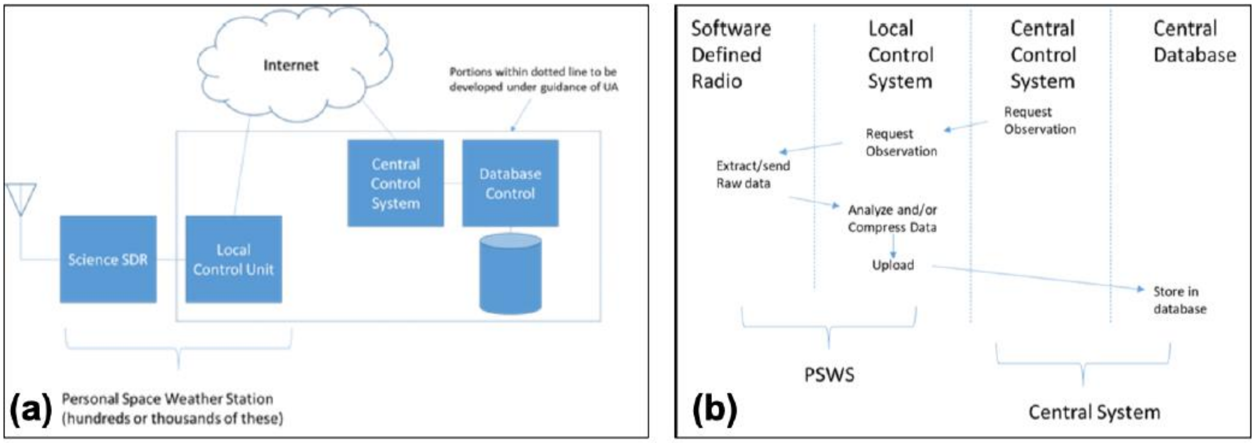
2.2. Ground Magnetometer

We propose a low-cost magnetometer with an appropriate performance level (⇠5 nT resolution at 1 Hz) as part of the PSWS to establish a densely-spaced magnetic field sensor network to observe Earth’s magnetic field variations in a greater spatial resolution. The primary goals are #1) to provide the general context of geomagnetic activity during the HF experiments proposed above; #2) to estimate ionospheric currents at mid latitudes; #3) to measure space weather-related disturbances (dB/dt) at higher latitudes.

US government-funded magnetometers are sparsely located across the US at mid latitudes. The goal is not to take on the existing infrastructure which is designed to provide well-calibrated absolute values of geomagnetic fields. Instead the project will focus primarily on increasing the spatial resolution of the magnetic field measurements. The higher spatial density is one of the major unique aspects of the proposed instrumentation, taking advantage of existing ham radio stations.

3. Use Cases

The Use cases illustrate how the PSWS could be used in normal daily operation. There are two uses cases described, more can be added later if helpful. Figure (a) below shows the general idea behind the remote PSWS Data Collection Use case. Figure (b) shows the general software structure.



3.1. Remote PSWS Data Collection

This is the use case many people on the project are familiar with. It involves:

- Deployment of a complete PSWS remote package at a distant site. This includes
  - A 2-channel HF receiver,
  - Two HF antennas,
  - A Data Engine (DE) function,
  - A Host computer (Host) function,
  - A high-performance GPS-derived clock source,
  - A connection to the Internet.
- The remote station may have battery or other un-interruptible power.
- Continuous recording of Magnetometer and two channels of HF Receiver Data on non-volatile storage.
- Retrieval by the central server of a selected subset of the stored data less than 24 hours old.
- Ability to calibrate the receiver noise level, receiver amplitude response, and antenna field strength sensitivity.

3.2. High Bandwidth Local PSWS Data Collection

The central server might be on the same LAN network as the PSWS radio. In this case it is possible to increase the amount of data captured compared to the previous use case. The Host Compute function defined in the subsystem specification could be merged with the Central Server function on a single high-performance computer.

The objectives would be similar to the first use case except that trigger retrieval of a subset of data may not be required, and an Internet connection is not required.

A LAN (Ethernet) connection between the Data Engine (DE) and this merged workstation function could support the movement of a much larger amount of information from the DE to the server. Additionally, multiple PSWS receivers could be connected to one or several such workstations allowing for the capture of data from more than two antennas, more than 8 frequency bands, or of higher sampling rates.

4. Ancillary Uses

Ancillary uses are those that the PSWS equipment might be able to provide that are different than the PSQWS application. For example, Amateur Radio uses of the collection information and Amateur Radio applications of the equipment itself.

4.1. Information Ancillary Uses

The PSWS system could provide information to users and operators of the equipment that can be analyzed for different applications than just the Space Weather experiment.

- The PSWS could be an operational sort of tool that could provide real-time information regarding band openings/propagation/etc.

- The PSWS could be a way for hams to better understand propagation and learn about the science behind the radio that we are using.

4.2. Equipment Ancillary Uses

Because the PSWS hardware contains unique time stamping capability, it is possible for it to support receive interferometry. Two examples are:

- Provide a greater equivalent antenna pattern resolution at HF frequencies. Traditionally HF antennas have been too large to practically form a highly-directional antenna based on widely spaced elements. However if two or three PSWS systems were located several kilometers apart, a central computer could receive data from both, use the precision time marks to do alignment, and correlate the output vs. spatial angle from the antennas. This would result in a narrower beam receive antenna which may be able to resolve propagation direction with greater precision than traditional approaches.

- Provide Time-Difference-of-Arrival (TDOA) direction finding. Three PSWS stations would provide multiple intersecting hyperbolas to locate and HF radio source. The timing accuracy of the PSWS receiver would avoid reference correlation issues associated with traditional low cost, non-synchronous receiver time and phase calibration. Low cost receivers need to see a common RF source to provide frequency and phase reference. With PSWS effectively both receivers are seeing a common GPS which provides this equivalent function even for significant receiver separation, where the receivers are not able to see the same common RF source.

- Provide receive signal level information to propagation and signal spotting systems, such as WSPR. Today such systems report the received SNR, which while useful does not provide the same utility as a receive signal strength indicator. The PSWS system incorporating amplitude calibration and receive antenna e-field calibration could be able to measure the received signal strength and probably the receive background level.