Towards Uncertainty Quantification of TID Detection by a Modular Network of Distributed Citizen Science Receivers

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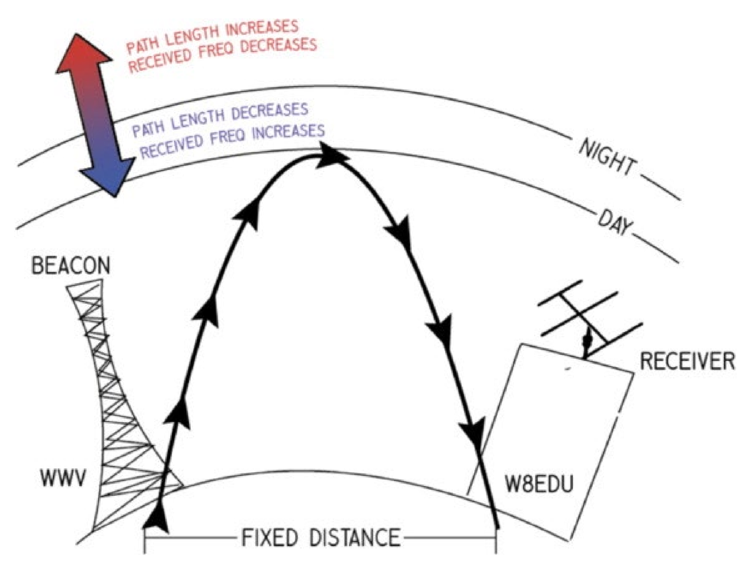
Abstract

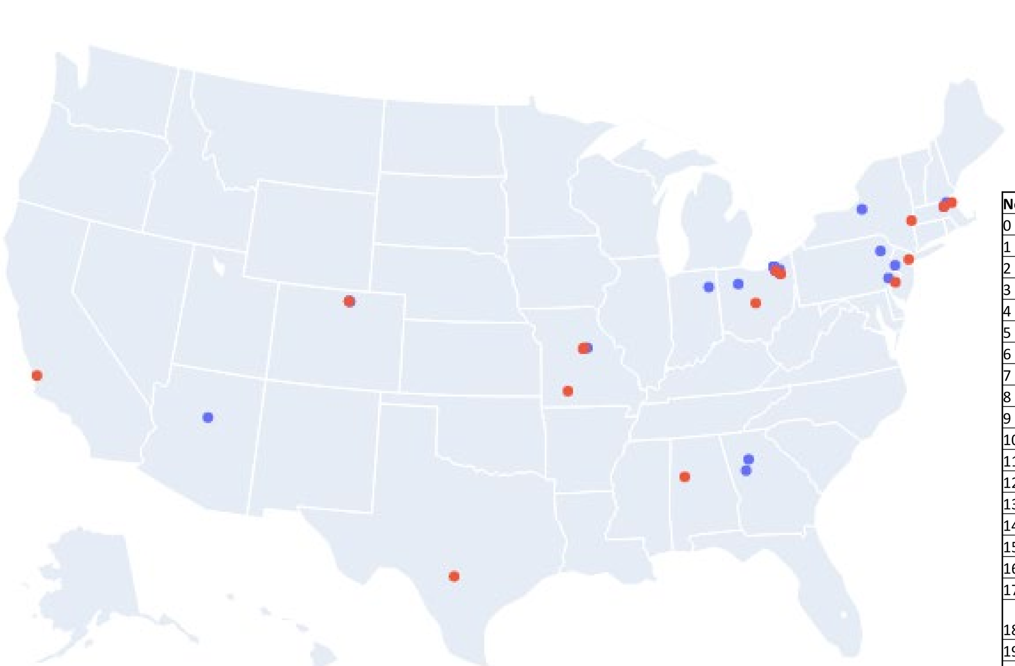
Doppler measurement of the precise carriers of time standard stations, such as WWV, WWVH and CHU, is an established means of detecting ionospheric variability. It is the core operating principle of the Low-Cost Personal Space Weather Station (the "Grape"), an NSF-supported project of the Amateur Radio Science Citizen Investigation (HamSCI). A growing network of prototype stations, maintained by independent citizen scientists, have been collecting Doppler data since late 2019. This poster presents the data collected by these stations, explores the scale of traveling ionospheric disturbance (TID) detection made possible by this distributed instrument, and discusses the question of optimized geographic placement of future stations.

Introduction

Doppler measurements are a straightforward means of data collection, well suited to citizen science campaigns [1]. They provide information about changes in ionospheric height, which may be used in conjunction with ionosonde measurements and ray-tracing models to estimate ionospheric virtual layer height characteristics [2].



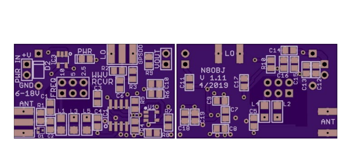
Data and Methodology



Node	Callsign	Name	Latitude	Longitude
0	TEST	TESTNODE	0	0
1	N8OBJ	John C. Gibbons	41.32196	-81.5047
2	AD8Y	David Kazdan	41.49374	-81.578
3	N8OBJ	John C. Gibbons	41.32196	-81.5047
4	AD8Y	David Kazdan	41.49374	-81.578
5	KE8HPA	Frankie Bonte	40.13091	-82.8478
6	KD8OXT	Kristina Collins	41.49878	-81.5731
7	N8OBJ	John C. Gibbons	41.32196	-81.5047
8	AD8Y	David Kazdan	41.49374	-81.578
9	KB3UMD	Aidan Montare	40.176	-75.493
10	KD8SYG	James Niemann	41.35231	-81.283
11	N8OBJ	John C. Gibbons	0	0
12	WA5FRF	Steve Cerwin	29.57478	-98.8872
13	W3LLA	Maxwell Moran	40.54323	-105.046
14	W2NAF	Nathaniel A Frissell	41.33512	-75.6007
15	KD2UHN	Veronica Romanek	40.63332	-74.9888
16	WW0WWV	David A Swartz	40.5629	-105.109
17	WA2UAR	Jay Silber	39.95565	-75.1741
18	W6BHZ	Ethan Yoshio Kita [Cal Poly]	35.30059	-120.662
19	AB4EJ	Bill Engelke	33.39583	-87.5417
20	K2MFF	Gareth Perry	40.74202	-74.179
21	KV0S	Dave Larsen	38.89319	-92.3595
22	KD8CGH	Robert Benedict	41.19882	-81.3373
23	KD0EAG	Dave Witten	38.9223	-92.2982
24	PA0SLT	Drs. Wim Apon	53.28091	6.906162
25	K2KGJ	Julius Madey	42.26165	-73.5416
26	KE8QEP	David A. Waugh	41.15708	-81.2516
27	W0DAS	David A Swartz	40.5629	-105.109
28	N1JBJ	William P N Smith	42.56996	-71.0914
29	W7LUX	Joseph R Hobart	35.09978	-111.693
30	K4BSE	Jim Farmer	33.39163	-84.4717
31	W1MTI	Vladimir A Goncharov	42.49898	-71.5826
32	AD0RR	Todd Christell	37.1851	-93.2352
33	AB1XB	Bill Blackwell	42.4983	-71.5907
34	N2RKL	Bill Owens	43.16319	-76.1254
35	PA0RWT	Robert Wagenvoort	53.25753	6.958064
36	KB1HFT	George Kavanagh	42.63754	-71.3843
37	N8OBJ	John C. Gibbons	41.32196	-81.5047
38	WC0Y	Edward Hall (Ward)	41.01948	-85.2925
39	KM4YMI	Beau Bruce	33.83125	-84.2804
40	AC0G	Michael James Hauan	38.91837	-92.1279
41	N8ET	Bill Kelsey	40.99367	-83.6556
42	SP6HFE	Grzegorz Kaczmarek	51.03421	17.13101

Above: Map of currently deployed stations in the USA. International stations not shown.

Below, right: Grape V1 PCB layout, approximately to scale.



Hardware

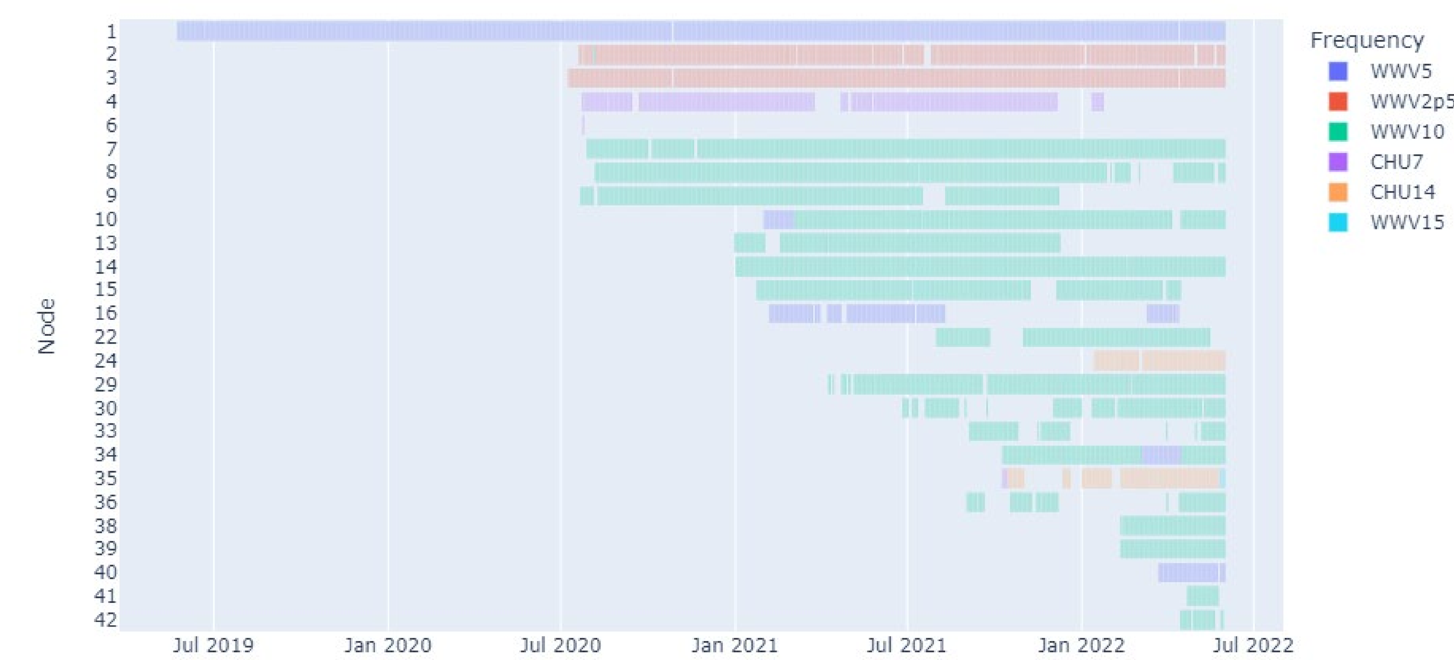
The majority of stations in this network use the Grape V1 platform, an open-source receiver. Detailed documentation of this system is provided in [3]. The same data collection software can also be used with typical amateur radio hardware on HF bands (3-30 MHz).

Data and Methodology (Continued)

Data Collected

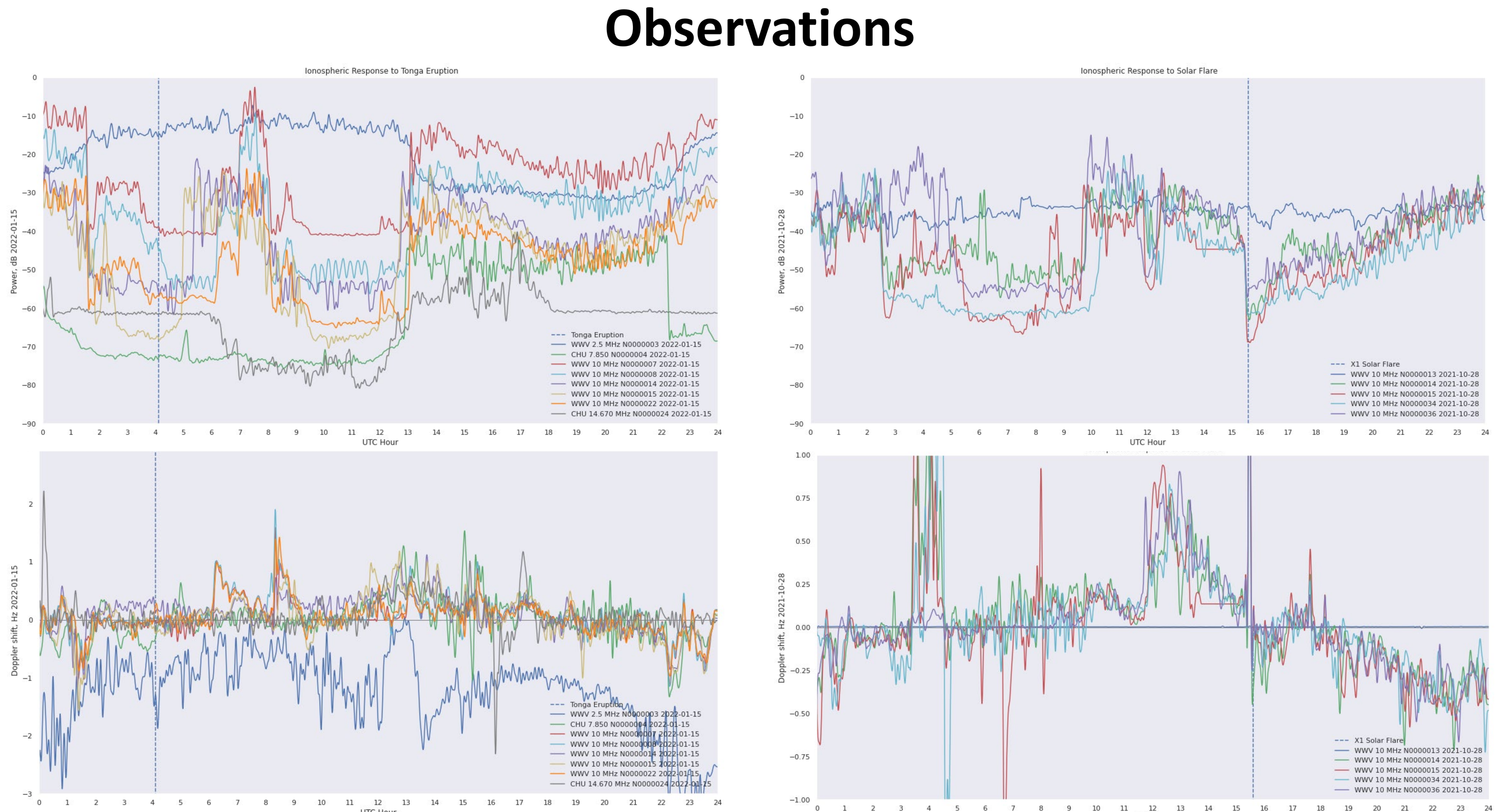
Collected data may be accessed here: DOI 10.5281/zenodo.6622112

Analysis software may be accessed at DOI 10.5281/zenodo.6654902



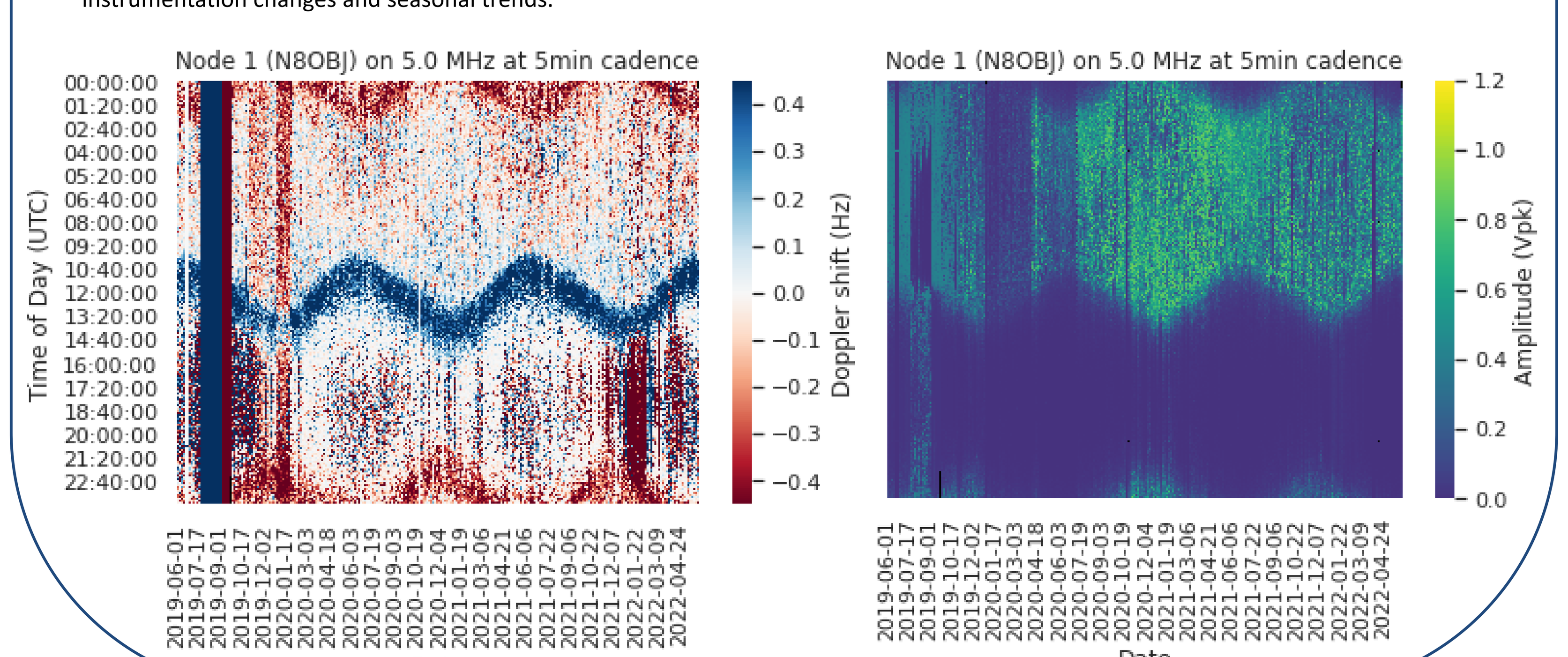
Above: Gantt chart of available data through 1 June 2022, organized by node. The PSWS network is modular: new stations can easily be added, and data analysis procedures are tolerant of outages and changes in frequency for each node.

Observations



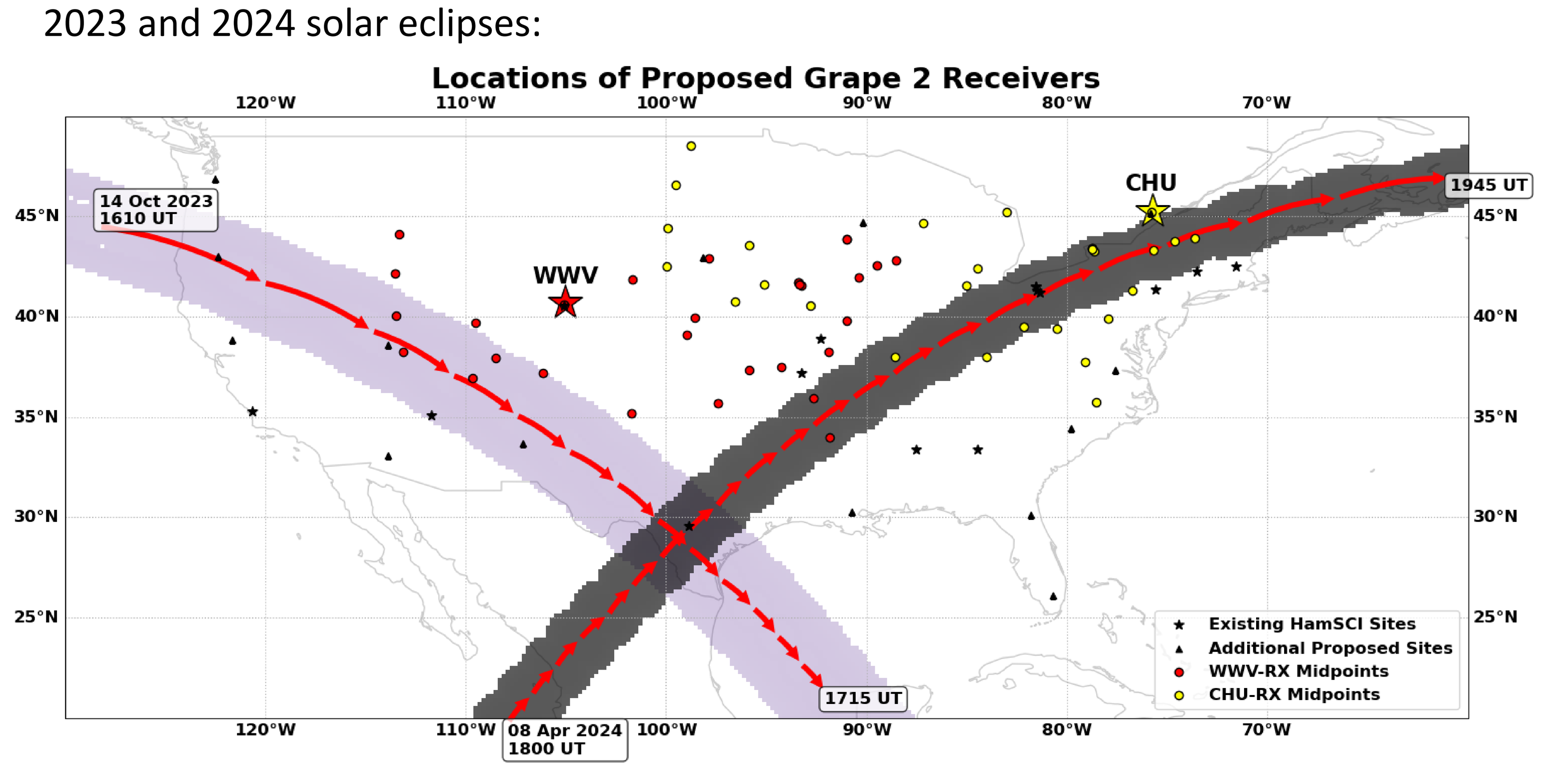
Above: Examples of daily plots showing amplitude (top) and frequency (bottom) fluctuations associated with (left) the Hunga Tonga–Hunga Ha'apai eruption of 15 January 2022 and (right) the X1 solar flare of 28 October 2021.

Below: Long-term heatmaps of frequency (left) and amplitude (right) data from Node 1 show clear sunrise and sunset transitions, as well as instrumentation changes and seasonal trends.



Future Work

A new multichannel revision of the Grape is in the prototyping phase, and will be incorporated into the PSWS network. These will support data collection during the 2023 and 2024 solar eclipses:



Summary and Conclusions

- The Grape V1 network is open-source, modular, FAIR-compliant and citizen-maintained, enabling deployment of low-cost data collection at high density and cadence according to science needs
- Time standard stations serve as scientific infrastructure, (cf. EDU-02)
- Fluctuations consistent with TIDs may be observed in conjunction with geophysical events (cf. ITIT-09)

Next Steps

- ❑ Improved visualization tools
- ❑ Ongoing data curation of living dataset
- ❑ Time difference of arrival analysis for well-characterized events (e.g., solar flares, Hunga Tonga–Hunga Ha'apai eruption) to validate TID detection

References

1. Collins, K., Montare, A., Frissell, N., and Kazdan, D.: Citizen Scientists Conduct Distributed Doppler Measurement for Ionospheric Remote Sensing, *IEEE Geoscience and Remote Sensing Letters*, 19, 1–5, https://doi.org/10.1109/lgrs.2021.3063361, 2022.45
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3. Gibbons, J., Collins, K., Kazdan, D., and Frissell, N.: Grape Version 1: First prototype of the low-cost personal space weather station receiver, *HardwareX*, 11, e00 289, https://doi.org/10.1016/j.ohx.2022.e00289, 2022.

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