Response to Reviewer 2: https://doi.org/10.5194/essd-2022-303-RC2

We thank the reviewers for their time and attention. Responses are inline below.

Review ESSD-2022-303, radar detection ionosphere

Assurance: This particular data product and data description might make nice publication in ESSD. Initial flaws coupled with absence of key pieces of information, but once authors fix those and make a few other improvements, I could recommend for publication.

Authors should check ESSD guidelines, at https://www.earth-syst-sci-data.net/10/2275/2018/. Please note importance of uncertainties and validation.

I agree with substance and tone of earlier review. I repeat and amplify some of those points below.

Data easy to access and read.

Note: this reviewer prefers term ‘diel’ to include diurnal (daylight) and nocturnal (night-time) measurements. One advantage of diel: it does not specify mid-day or midnight maximum or minimum.
We have adopted this word into the paper at a few points.

The word ‘uncertainty’ appears nowhere in this manuscript. Have these authors, unique in vast world of geophysics, finally achieved perfect data? Doubtful. Authors show raw and filtered data (e.g. Figs 6, 8, 9) or high (temporal) resolution data (Fig 11), with, often, actual frequency response extents of digital filters, but never an error bar.
We have added a section on uncertainty (Section 5.1) to address these concerns. For convenience, we have addressed topics raised by the reviewer inline here:

To trust and use these data, e.g. with Doppler shifts of 1 Hz, readers will need to know: variations in transmit frequency and power (authors mention at lines 104, 105 but never quantify);
Per Section 5.1 in the revised version: *“WWV’s transmitter is well-characterized and inherently accurate, with a measured carrier stability below one part in* 10^{12} *(Lombardi, 2023).”*
Per Section 4.1: *“There are also nodes close to WWV in the Fort Collins, Colorado area (e.g., Node 13) which are within the transmitter's radio horizon and can be used to confirm that trends in the data originate with the ionosphere and not the radio transmitters.”*

attenuation as it might affect frequency and power
Per Section 5.1 in the revised version: *“Between transmitter and receiver, the received power varies according to location, antenna gain, and atmospheric attenuation. For example, in Figure*

6, the antenna replacement which took place at that station in August 2021 distinctly impacts the power plot but has relatively little impact on the frequency estimation. Because the frequency and power are logged together in the raw data, the end user may elect to discard or replace frequencies where the logged power is below a threshold of their choosing.
Even a low amplitude signal may yield viable frequency estimation data, however, as shown in Figure 5."

of transmitted and refracted pulses;
The methodology used in this dataset relies on continuous monitoring of a carrier. Pulses are not used.

actual refraction terms e.g. dependencies on TEC, on EC gradients, other factors;
This topic is also addressed in feedback to Reviewer 1: We have added Equation 1 and relevant citations to make the connection between Doppler shift and electron density more evident.
A thorough accounting of propagation factors is outside our scope, however. Per Section 5.1 in the revised version: *"Trends observed by the PSWS may therefore reasonably be considered to be of geophysical origin, albeit the result of multiple causes. Quantifying these ionospheric propagation effects is beyond the scope of this paper. Instead, this paper will allow investigations of these effects in the future through comparisons with other instruments and data-model comparisons."*

antenna gain; accuracy and uncertainty of reception; certainty of GPS reference time / oscillators (high, one hopes); etc., all for a stable medium.
Per Section 5.1 in the revised version: *"Allan deviation analysis by Lombardi (2022) demonstrates that the Grape V1 receiver recovers frequency with an upper bound of 2 parts per billion (2×10^{-10}). Further, Lombardi performs calibration of the Leo Bodnar GPSDO recommended by Gibbons et al. (2022) and demonstrates that, with a frequency stability of one part in 10^{12} over a one day interval, it contributes no discernible measurement uncertainty."*

Then add in horizontal and vertical velocity changes on time scales from minutes to seasons, from which the authors propose detection of e.g. diel or transients patterns.
As noted above, disambiguation of the ionospheric factors producing observed trends in these data is outside the scope of this paper; rather, that is the subject of future research that this paper exists to support.

A complicated chain of multiplicative uncertainties exists, from source to receiver, but authors give no hint. If authors don't quantify, how can users have confidence in their data? If, even cumulatively, uncertainties remain very small (signal to noise remains very high), or - as seems likely - uncertainty varies as a function of receiving equipment, tell us so. Prove that you know and have addressed uncertainties.
As delineated above, Section 5.1 in the revised version addresses these concerns.

Likewise for validation. Give readers/users evidence that these measurements replicate real features. Diel patterns well known from e.g. ground-based radar, balloon-based spectrometers, satellite-based column TEC measurements? Fig 11 hints at validation (e.g. because it includes satellite data and shows both power and frequency), but authors need to provide users with validation examples. These data improve on other types? Great, show/prove it.
We have added a figure showing a SuperDARN measurement of the Doppler flash we observed with the Grape stations. SuperDARN has a slower cadence (discussed below) so the Doppler flash is not as distinct. This serves as an example of how our network can generate a useful measurement beyond what existing professional networks are able to measure, while complementing (and being validated by) those networks.

Authors say (line 166) "discussion on validation may be found in … Gibbons". No! That paper reports hardware (receiver, frequency) performance but says nothing about seasonal patterns, vertical refraction profiles, etc. Here you want to show real data derived from these hardware systems? Prove that your data reproduce, or perhaps improve on, prior or other measurements. Validate your work!
We have added a section on validation (Sect. 5.2) in the revised version.

Per the ESSD guidelines referenced above by the reviewer: "(E)ach *ESSD* paper should demonstrate skill and utility of the submitted data product by some form of comparison to prior products, alternate data sources, similar products at different time or space resolution, model outcomes, initial short records of recent sensors, etc."

Per Section 5.2: *"We have provided comparison to prior products (Breit and Tuve, 1925; Davies et al., 1962; Jacobs and Watanabe, 1966; Collins et al., 2022); event-based validation from alternate sources (GOES-17 and SuperDARN, per Figures 9 and 10 respectively), comparison of diel variation to model outcome (Figures 6 and 7) and initial records of sensors (cf. Figures 5, 9)."*

Fig 4 shows midpoints but authors never mention, much less explain? These represent supposed refraction points/regions? Given beam dispersion and gradients of refraction index, with what horizontal or vertical uncertainties? If authors consider midpoints irrelevant, leave them out. If relevant, explain them, with uncertainties.
We thank the reviewer for highlighting this. The midpoints have been removed from the map. They are a first approximation inviting a more intensive propagation discussion outside the scope of this paper, so we plan to discuss them in a future publication instead.

Fig 1 comes verbatim from Gibbon et al. 2022b. And, perhaps from other previous work from this group? Settle on definitive source, use that to establish copyright, then all subsequent uses must cite original. E.g. 'reproduced from', 'adopted from', 'modified from', your choice as appropriate. The reader doubts clean symmetrical transmission / refraction patterns as implied in Fig 1.

These changes have been implemented. The caption now reads: “A simplified illustration of the relationship between shift in ionospheric layer height and received frequency shift. Precision frequency standards are required at both beacon and receiver in order to make an effective comparison. Frequency variation is generally on the order of ±1 Hz. Multihop propagation (multiple reflections between ionosphere and ground), Pedersen modes (internal ionospheric reflections), and asymmetric paths are not shown. Reproduced from Collins et al. 2022b).”

Data address only Grape 1 and only source signals from WWW (Ft Collins). If authors want to mention other potential sources (necessitating different receiver frequencies), they should do so in Discussion. Including, as they do now, mention of WWVH (Hawaii) and of CHU (Canada, Ottawa), in Abstract and again in Introduction, when data only come from continental USA stations, seems misleading at best.
The mention of these stations has been removed from the abstract. Although the data collected do principally come from stations in the continental US, the data inventory plot shows that there are three stations (Nodes 4, 24 and 35) collecting data from CHU. Additionally, WWV and WWVH share carrier frequencies, so all three stations are relevant to the data collected here.

What do authors actually see for future of this technology? Global coverage? With what spacing? Stations outside of narrow mid-latitude regions? Again, reader gains a glimpse of network (longitudinal) spacing goals (e.g at line 103) but without follow-up or confirmation. To resolve what features?
This topic is also addressed in feedback to Reviewer 1. We have added a Future Work section to address these topics: *“To date, the PSWS network comprises a growing, self-sustaining community of station maintainers. The authors foresee two means of extending this network in the future, both of which have been instrumental in fostering it to date: first, the grassroots adoption of the system by self-motivated participants, generally through amateur radio clubs; second, the targeted recruitment of station maintainers in regions of interest, particularly ahead of upcoming solar eclipses.*
At the time of writing, the majority of stations are in the continental United States, but there is no inherent limitation of the system that dictates its range. The network is not limited only to Grape V1 hardware, nor to the exclusive use of WWV or other time standard stations as beacon signals. The flexible metadata format described above allows for independent signals on the amateur radio bands to be used in participatory campaigns, and for these data to be integrated seamlessly into future versions of this dataset.
Efforts are also underway to develop multichannel versions of the Grape hardware, as well as wider spectral recording to support the analysis of multiple carrier signals associated with multiple simultaneous propagation paths.
By making these data permanently accessible to professional and citizen scientists, and by continuing data collection with a growing network of stations through Cycle 25 and beyond (MacDonald et al., 2022), we hope to produce a record of short-term events and seasonal variability which will inform future studies of solar flare responses, MSTIDs and other phenomena, and which will form a benchmark for the validation of simulated Doppler shift in ionospheric models.”

Regarding spacing: the network is intended to be largely organic, as discussed in Sections 5.3 and 7, and valid data may still be collected by a handful of stations. As yet, no straightforward density requirements are imposed by current scientific goals. (Further discussion below re: systematic coverage.)

How do you improve on, validate, out-compete, etc., SuperDARN, rockets, ionosondes, satellites, etc.

We have added the following to the introduction: *"Oblique HF sounders such as the ones used in this dataset represent one of many tools for the multi-instrument observer, and can provide direct benefit to these investigations. To wit: Satellite measurements (e.g., GNSS TEC) produce height-integrated measurements from the bottomside to topside of the ionosphere, whereas the PSWS measures bottomside variability. ISRs yield range-resolved measurements of plasma parameters throughout the ionosphere, but have limited geographic coverage and cannot run constantly, primarily due to high cost of both installation and operation. While SuperDARN radars are well-established and measure parameters of the bottomside ionosphere that cannot be measured by the PSWS, SuperDARN is a pulsed system and typically has at best a 1-minute cadence. Ionosondes, too, generally have lower cadence (3-15 minutes). Vertical ionosondes produce bottom-side vertical profiles for a single site. Oblique ionosondes share a measurement geometry with the Grape, but sweep in frequency, whereas the Grape monitors a single frequency with essentially continuous time resolution, which allows for monitoring short-time scale ionospheric variability along a single path. A key advantage of the PSWS is its low cost, which allows for flexible and dynamic deployment of stations in regions of interest. It is also the most analogous to an HF communication system, which supports application-driven monitoring of propagation conditions."*

The region of interest for rockets is below that of this instrument, and rocket soundings cannot provide long term time series data of, *e.g.,* diel patterns.

Any forecast possibility?

There is potential for nowcasting/forecasting, particularly with regard to real-time HF communications links, as noted above. We have not yet implemented this functionality for the PSWS network, and so did not claim it in this paper.

Explain how systematic coverage could provide better understanding of solar impacts?

The discussion of solar flare response in Section 4.5, which has been significantly extended in the revised version, is intended to lay the groundwork for future work in this area. Our ongoing investigation of Doppler flash resulting from solar flares will require us to determine what such systematic coverage would look like, particularly for further investigation of the longitudinal dependence indicated in the multi–instrument plot. However, the question of coverage requirements is a complex one outside our present scope. Moreover, it will vary according to the scientific objective at hand (e.g., MSTID detection, eclipse effects), and it is therefore best handled on a case-by-case basis in future studies using these data as the network continues to evolve.

How a less-expensive network compliments or replaces current capabilities.
See excerpt from revised introduction above.

In present system, roughly half of stations inoperable at any one time (e.g Fig 5); with what impact? How does down-time impact or interact with network goals?
Per Section 4.1: *"Several stations are registered as nodes but do not have data included in the dataset reported at the time of writing. This may be for one of three reasons: first, the station may have data recorded but not uploaded to the FTP server; second, the station may be in the process of installing a node; third, the station may be used for experimentation with new data collection methods, including spectrum sampling and other frequency analysis algorithms. A central aspect of this work is its architecture as a living dataset, i.e., a dataset into which new stations and historic data may be easily incorporated."*
Figure 5 shows the network building and gaining stations over time. As with all networks, downtime is not desirable. However, as discussed above, no straightforward density requirements are imposed by current scientific goals.

Anchor these systems in science that you want to do.
Two specific scientific objectives are identified in the paper: MSTIDs (Section 4.4) and solar flare response (Section 4.5). We are hopeful that the publication of this paper will support our work on these topics, which are subjects of current research in our group.

Get readers / users excited about new possibilities. Who else (outside of ionosphere / space weather communities) might use these data? If you think you have potentially a good product / good solution, give some hints about who might benefit!
This topic is also addressed in feedback to Reviewer 1. We have added the following to the abstract: *"The primary goal of this paper is to explain the types of measurements this instrument can make and some of its use cases, demonstrating its role as the building block for a large-scale ionospheric and HF propagation measurement network which complements existing professional networks … These data may be used to supplement observations made with other geospace instruments in event-based analyses, e.g., traveling ionospheric disturbances and solar flares, and to assess the accuracy of the bottom-side estimates of ionospheric models by comparing the oblique paths obtained by ionospheric ray-tracers with those obtained by these receivers."* As noted above, we have also added a section on future work, and alluded in the introduction to the possible use of the Grape for application-driven monitoring of HF propagation conditions.

Finally, we need some description other than 'citizen science'. Citizen science as ESSD promotes involves passive engagement (allow installation of weather station in garden), or active non-technical observation (standing near runway counting flights and noting tail numbers). Even CoCoRaHS, the USA NWS rain hail and snow network, which involves specific training and establishes measurement guidelines, does not require soldering, flashing of microcomputers, obtaining (at some cost in some countries) call

signs (e.g line 71), transferring and uploading from SD cards, switching over (expensive) radio equipment for those using said systems, etc., as necessary for these participants. I work extensively with sensors, small networks, Arduino, etc., but I probably would not take on efforts as required here. Unless I could see real social benefit (see prior paragraph). Radio enthusiasts? Advanced community space weather trackers (ACSWT)? Not really citizen science as we understand.
This topic was also addressed in the feedback to Reviewer 1, and is discussed in Section 5.3.

In seeking a working definition of “citizen science”, we take as authoritative the National Academies’ report on citizen science, which in addition to establishing those traits held in common across citizen science projects also identifies several “axes across which citizen science might vary” (cf. https://nap.nationalacademies.org/read/25183/chapter/4#36). These axes include duration of participation, which most nearly encompasses the concern that the reviewer raises here. The report affirms that dedicated efforts by enthusiasts and hobbyists such as birders and amateur astronomers are indeed encompassed by the citizen science category, stating that “citizen science provides opportunities for a range of different kinds of participants, from social individuals to those less interested in ongoing social interaction, and from individuals who sample widely to those who dive deeply into a single pursuit.”

A few typos exist. Authors should please give careful read as they prepare revisions. Better you and now than later at proof-reading stage.
We have carefully reviewed the final draft of the paper and hope to have caught as many typos as possible. We thank the reviewers, editors and staff for their dedication in helping us share this work with the scientific community.