Gravity Wave Zoo: Engaging Citizen Science to Analyze Atmospheric Gravity Wave Activity over Poker Flat, Alaska

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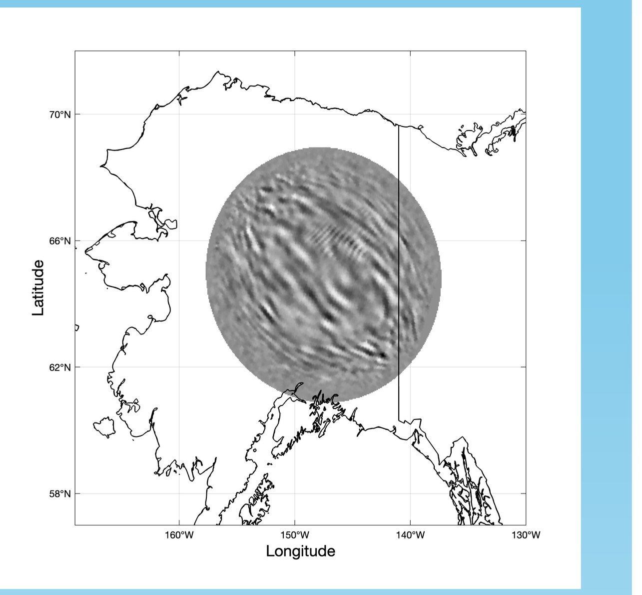
Introduction



Hydroxyl Imaging:

Since its installation in September 2021, the Near-Earth Space-Sensing Group (NESSie) at Arizona State University has managed the NESS OH Imager, housed at the Poker Flat Research Range (PFRR), 65°N 147°W.

This imager is equipped with a 185-degree fisheye lens, allowing for all-sky images of approximately 1,000,000 km^2 in the near-infrared (NIR) between 900 – 1,700 nm.

This enables direct imaging of the hydroxyl (OH) Meinel bands, a major component of faint planetary airglow, which renders gravity waves (GWs) and Kelvin-Helmholtz Instabilities (KHIs) visible for observation during nighttime hours at altitudes near 86 km.

Figure 1 (above right): The extent of the Poker Flat Airglow Imager overlaid on a map of Alaska and the Northwest Territories. Note, there are slight inaccuracies at imager edges due to distortion associated with the use of a fisheye lens. *Credit: Jessica Norrell*

Gravity Wave Zoo:

Created for the 2022 – 2023 observing season, the GW Zoo is a citizen science project designed to increase the breadth of available ionosphere anomaly data, enabling the study of long-term mesosphere and lower thermosphere (MLT) dynamics on the scale of weeks, months, and seasons.

Volunteers view ten-second animations – each composed of 100 consecutive OH airglow images – and answer three key questions:

1. ***Are there any gravity waves present in the video?***
2. ***Are there instabilities present in the video?***
3. ***Is there aurora present in the video?***

Volunteers are guided by NESSie-developed tutorials and moderated talk forums on the Zooniverse platform. Once an animation is viewed by twelve unique participants, it is retired from the subject set.

With three seasons of retired, classified observations, our focus now shifts to exploring the scientific advantages GW Zoo offers.

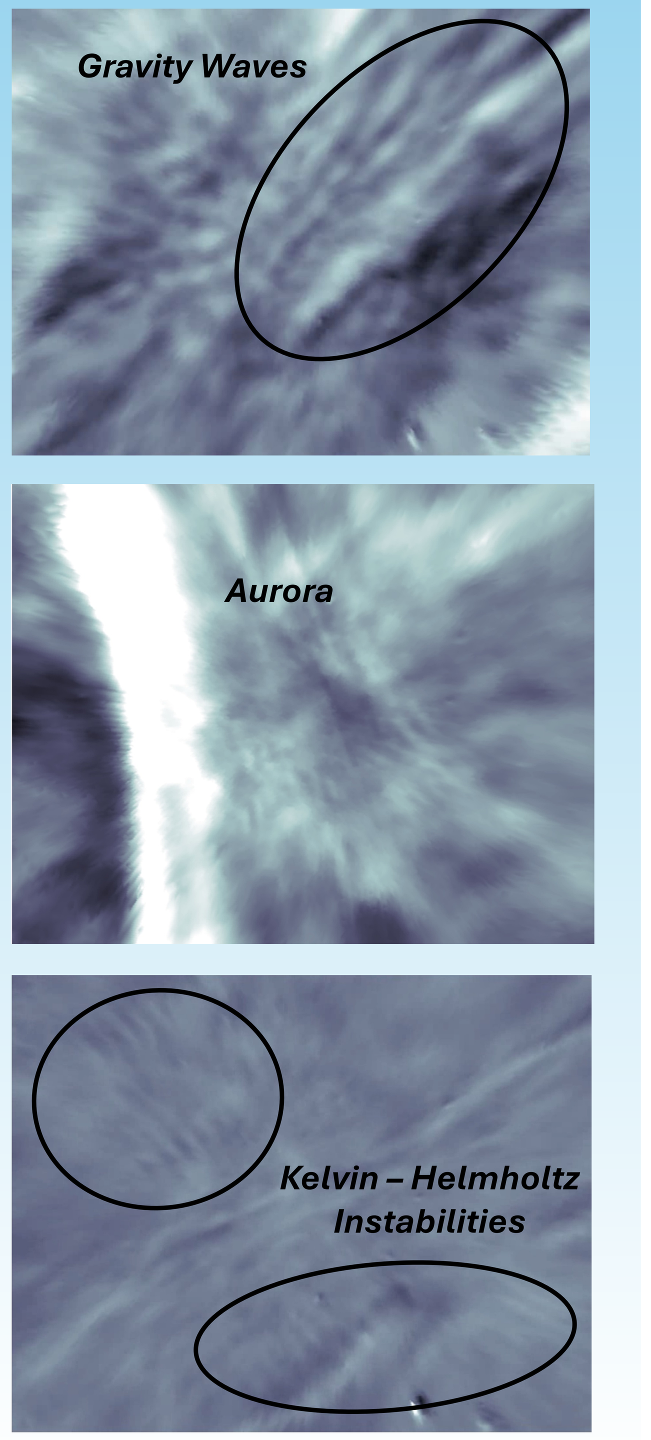


Figure 2 (right): Example images utilized in the GW Zoo as they appear to citizen scientists, including aurora, GWs, and KHIs.

Considering Citizen Data

Conventional Analysis:

To validate the scientific accuracy of citizen classifications, we select a short-term study period encompassing data from December 27th, 2023, to February 4th, 2024. This subsample is chosen under the assumption that this period can be generalized to the complete 2023 -2024 GW Zoo dataset.

One NESSie researcher independently classifies the corresponding OH animations, serving as a ground truth dataset. This set of responses is cross-correlated with citizen responses as described below, providing a quantitative measure of citizen science reliability.

Data Validation:

We utilize permutation testing to verify statistical significance of citizen responses; better-than-random engagement as compared to researcher responses.

In doing so, we adopt the null-hypothesis:

There is no correlation between citizen and researcher responses – citizens are likely responding to prompts inaccurately.

We then shuffle citizen responses relative to researcher responses and record the resulting match rate against the original, observed match rate. We repeat this 100,000 times each for GWs, aurora, and KHIs.

We then calculate the p-value according to the below equation, where M_{obs} represents the observed match rate, and M_i represents the match rate for the i-th random permutation.

$$p = \frac{\sum_{i=1}^{N} (M_i \geq M_{obs})}{N}$$

As shown in **Table 1**, resultant p-values are far below the conventional significance threshold, $p = 0.05$. Thus, the null-hypothesis is rejected. Instead, we find:

There is strong correlation between citizen and researcher responses – citizens are likely responding to prompts accurately.

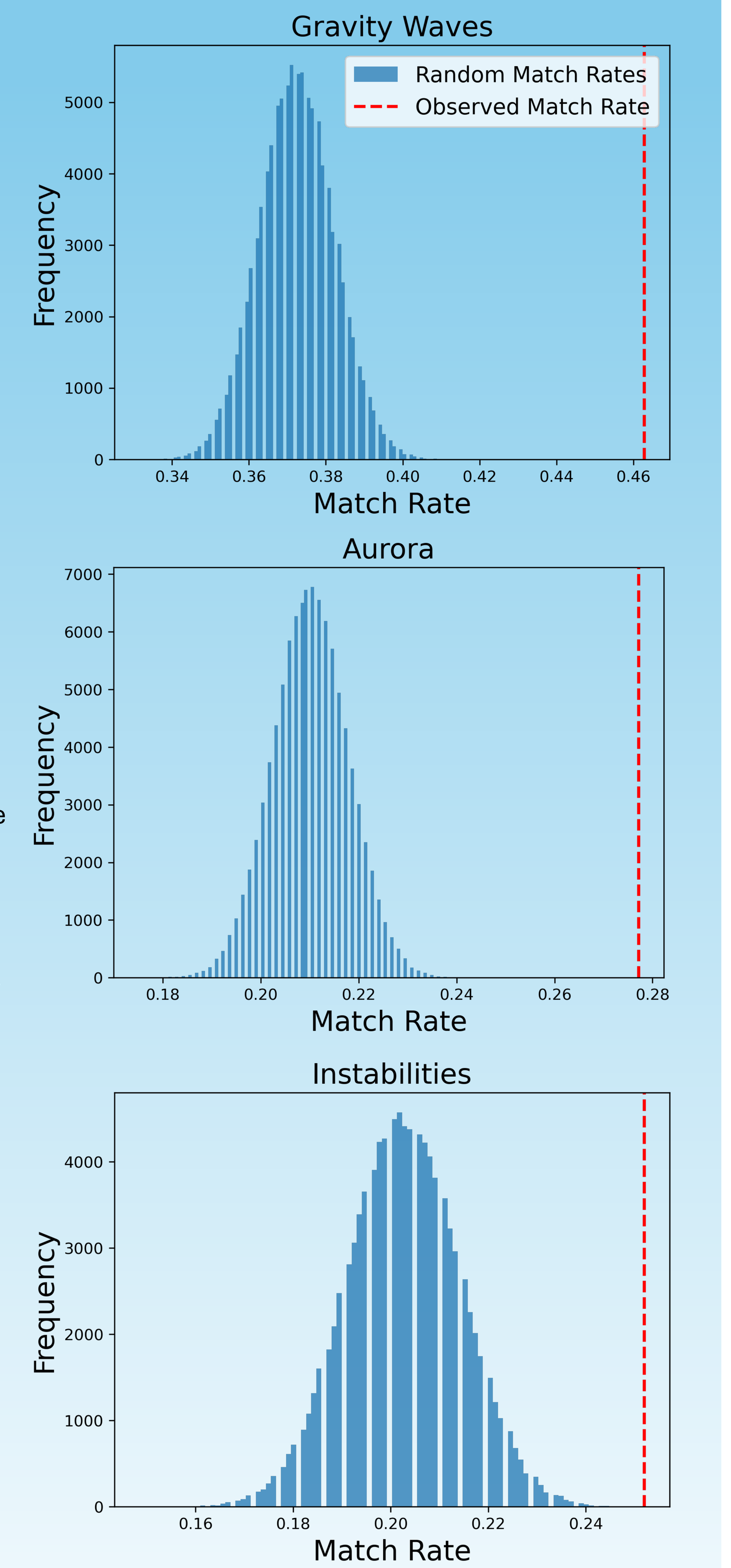


Figure 3 (right): Results for 100,000-trial randomized permutation testing for citizen responses relative to researcher responses within the study period. The observed match rate is noted in red. Gaussian artifacts are a result of discrete possible match rates derived from the integer-based subject set.

Table 1 (below): Resulting p-values associated with each plot in **Figure 3**. Note that p-values below 0.05 are generally considered statistically significant.

Subject	Gravity Waves	Aurora	Instabilities
P-Value	0.0000	0.0000	0.0002

Scientific Implications

Drawing Connections:

As a case study in possible connections between citizen classifications and physical data, we examine the local magnetic perturbations in relation to the percentage of "Yes" responses received for auroral activity during the same period.

As shown in **Figure 4**, we find:

More "Yes" responses are received at times of relatively high magnetometer readings.

By example, this implies that citizen classifications have scientific merit in measuring occurrence rates for aurora.

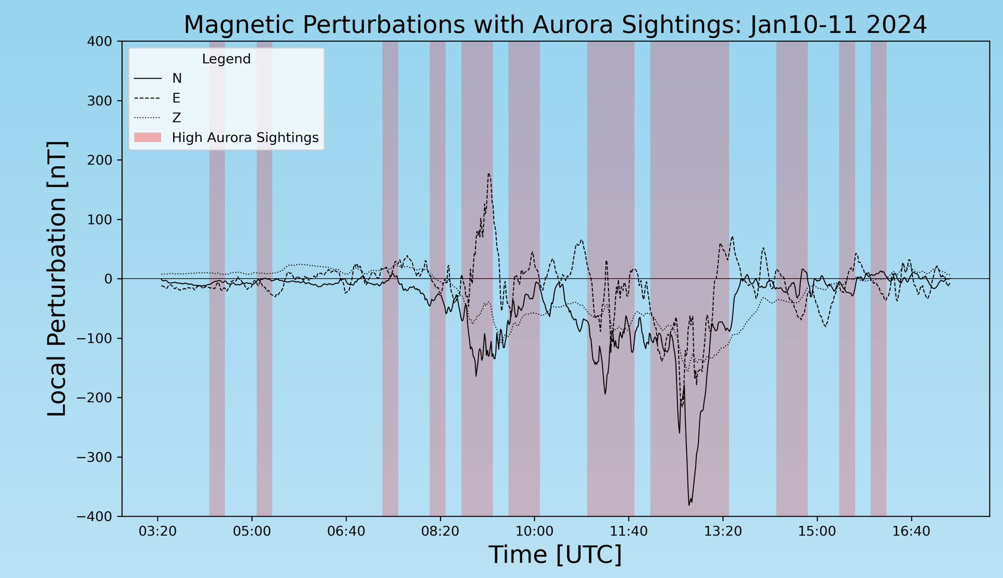


Figure 4 (above): Local magnetometer data (College Station, 64.8742°N 147.8597°W) in NEZ coordinates. Regions marked in red denote times of increased aurora sightings as classified by citizen scientists, using a 67% supermajority of total responses per video.

In Summary:

In reviewing citizen classifications, we find:

1) **Continued, extensive engagement with the GW Zoo project.** This culminates in 2,100+ volunteers classifying 6,000+ instances of GWs, aurora, KHIs over 70,000 times, representing 3 observing seasons' worth of data.

2) **Citizens are likely responding to prompts accurately.** There is significant correlation between researcher (ground truth) and citizen classifications. This implies statistical validity and enables scientific research using the GW Zoo response set.

3) **Citizen responses correspond with physical data.** This is evidenced by the correlation between higher magnetometer readings and higher citizen "Yes" classifications for auroral events.

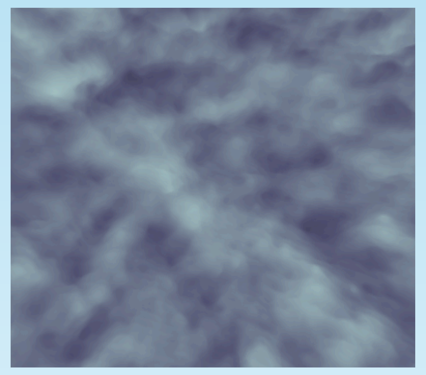
Looking Ahead:

Moving forward, we aim to expand this work in three key areas:

1. Expanding the GW Zoo to classify compass directions of GW propagation.

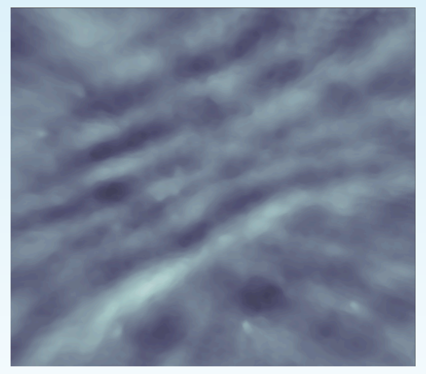
2. Seeking associations between GW, aurora, and KHI events and other atmospheric phenomenon, including diurnal and semi-diurnal atmospheric tides and sudden stratospheric warmings (SSWs).

1. As shown in **Figure 5**, how do we approach nights of ambiguous data? Do these nights contain gravity waves? Instabilities? Aurora? What classifications would you make?



***50%** of Citizens Responded "Yes" for Gravity Waves*

***37%** of GW Zoo nights show similar behavior*



***100%** of Citizens Responded "Yes" for Gravity Waves*

***53%** of GW Zoo nights show similar behavior*

Figure 5: Example images from GW Zoo. We note the percent of respondents who stated there are GWs in this image and the proportion of nights with similar structure in the full project dataset.

At-a-Glance: Gravity Wave Zoo

70,000+
Gravity Wave, Instability, and Aurora Classifications

6,000+
Subjects (600,000+ OH Images)

2,100+
Volunteers

3
Seasons of Observations

Want to see airglow in action?

Get involved!

SCAN ME

Student-Led Science: NESSie

Near – Earth Space Sensing Group

Sophie Phillips

Satellite and ground-based GW measurements

Phillips, S. et al. (in prep.)

Jessica Norrell

GW and KHI relationship research

Norrell, J. et al. (in prep.)

Tyler Karasinski

GW Zoo management and data analysis

Karasinski, T. et al. (in prep.)

Latoya Wilcoxson

GW generation by tropospheric weather systems

Acknowledgements and References

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