Gravity Wave Zoo: Citizen Science and Atmospheric Gravity Waves

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The Gravity Wave Zoo

What?

A multi-season citizen science investigation into temporal variations of high-frequency atmospheric gravity waves (GWs), aurora, and Kelvin-Helmholtz Instabilities (KHI).

Why?

Mesosphere and Lower Thermosphere (MLT) variabilities remain little understood over long time periods (nightly to seasonally) due to observational constraints restricting in-situ observation. High-frequency GWs are often unresolved in global atmospheric modeling.

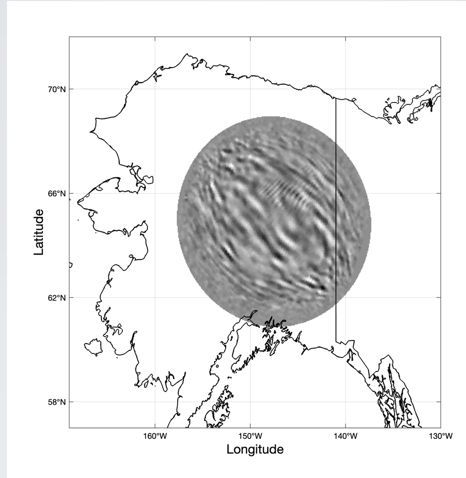


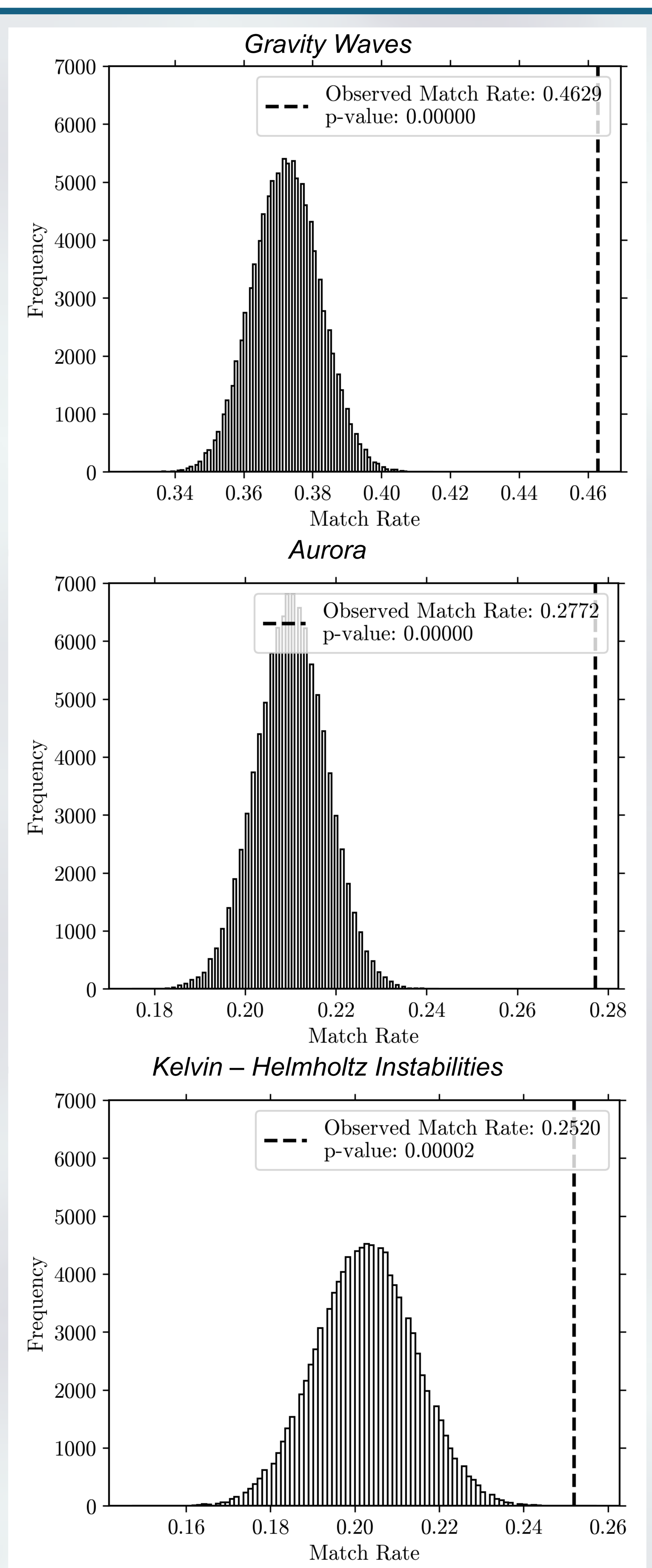
Figure 1: The extent of the Poker Flat Airglow Imager overlaid on a map of Alaska and the Yukon. Note, there are slight inaccuracies at imager edges due to distortion associated with the use of a fisheye lens. Credit: Jessica Norrell

How?

Ground-based all-sky imaging of the hydroxyl (OH) Meinel band airglow emission every ten seconds on clear nights from September to April. Images are background subtracted, un-warped, and animated into 10-second videos (100 images/video) before upload to the Gravity Wave Zoo Zooniverse project. Volunteers view videos one-by-one, responding to three yes/no 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?*

Response Validation



We adopt a short-term study period, examining complete nights of data between 12/27/2023 and 02/04/2024 to establish a ground truth dataset by independently re-conducting classifications.

We employ p-value calculations to determine better-than-random engagement, adopting the null-hypothesis to reject:

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

The ground truth dataset is then compared to volunteer classifications for the same nights to establish an observed match rate (M_{obs}).

We randomize citizen classifications relative to the ground truth dataset for 100,000 trials (N = 100,000), counting all iterations where the randomized match rate (M_i) exceeds the observed match rate and calculating p-value:

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

With resulting p-values well-below the conventional significance threshold (p = 0.05), we reject the null hypothesis and find:

There is strong correlation between citizen and researcher responses – citizens are responding accurately and with fair effort.

Figure 2: Permutation testing results and associated p-values for citizen classifications. Observed match rate is denoted by a vertical dashed line, while Gaussian curves represent the distribution of randomized match rates for 100,000 permutations. We note that gaps in distribution curves are the numerical result of a discrete number of possible quotients when calculating p-value.

Takeaways

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75,800+
GW, KHI, and Aurora Classifications

6,300+
Videos (630,000+ Hydroxyl Images)

2,600+
Citizen Scientists

32
Months of Observations

SCAN ME

- Better-than-random volunteer engagement, with p-values of p = 0.0, p = 0.0, and p = 0.00002 for GWs, aurora, and KHI, respectively (**Figure 2**).
- GWs in 54.5%, aurora in 40.0%, and KHI in 23.3% of videos, with many inconclusive due to dynamical ambiguities (**Figures 3 and 5**).
- Suggested correlation between volunteer classifications and favorable wind conditions for vertical propagation of GWs (**Figure 4**).

Stay tuned for our upcoming paper! *'Gravity Wave Zoo: Engaging Citizen Science to Analyze Atmospheric Gravity Wave Activity Over Poker Flat, Alaska' (Karasinski et al., in prep)*

Results and Connections

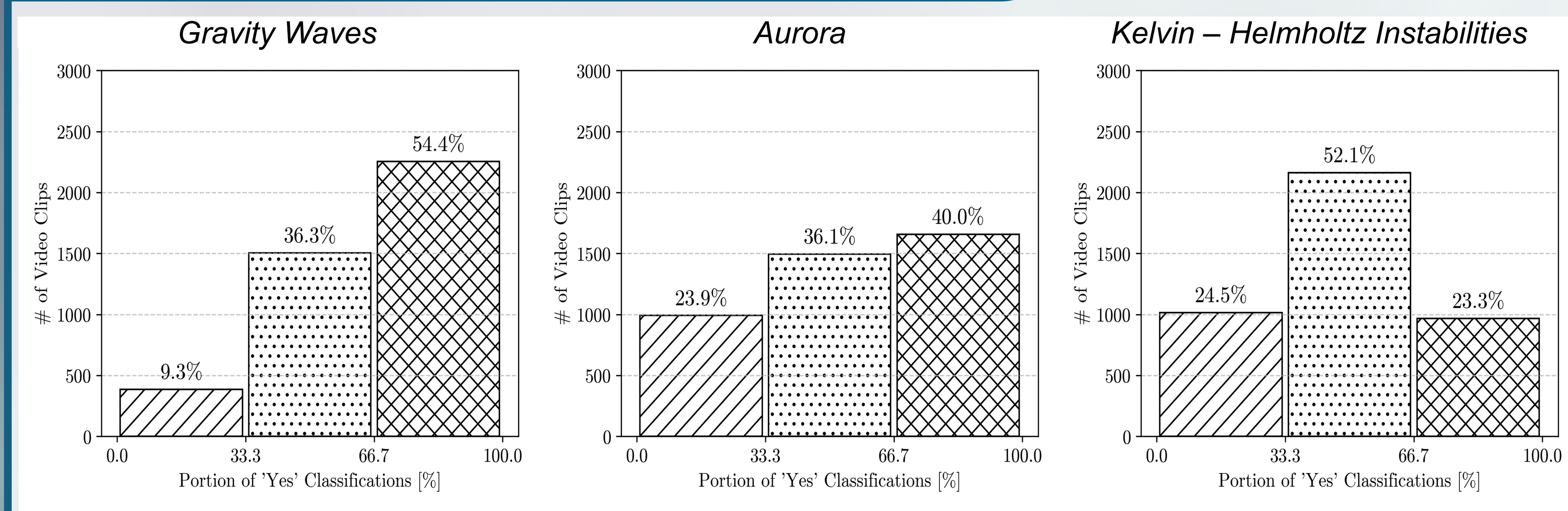
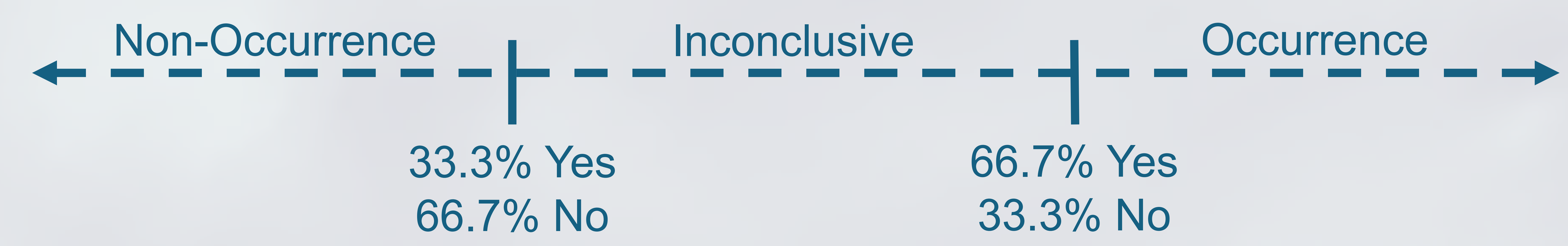


Figure 3: The proportion of 'yes' classifications for each subject video is shown for gravity waves, aurora, and Kelvin-Helmholtz instabilities based on the complete Gravity Wave Zoo dataset (observations recorded from September 2021 to April 2025). Videos with more than 66.7% 'yes' responses are considered confirmed occurrences. Videos with fewer than 33.3% 'yes' responses are considered non-occurrences. Videos with 33.3% to 66.7% 'yes' responses are classified as inconclusive, as no super majority was reached.

Final classifications for each video are determined using a 2/3rd super-majority of twelve participants' responses. Volunteer-determined occurrence rates for GW, aurora, and KHI for the complete Gravity Wave Zoo subject set are shown in **Figure 3**.



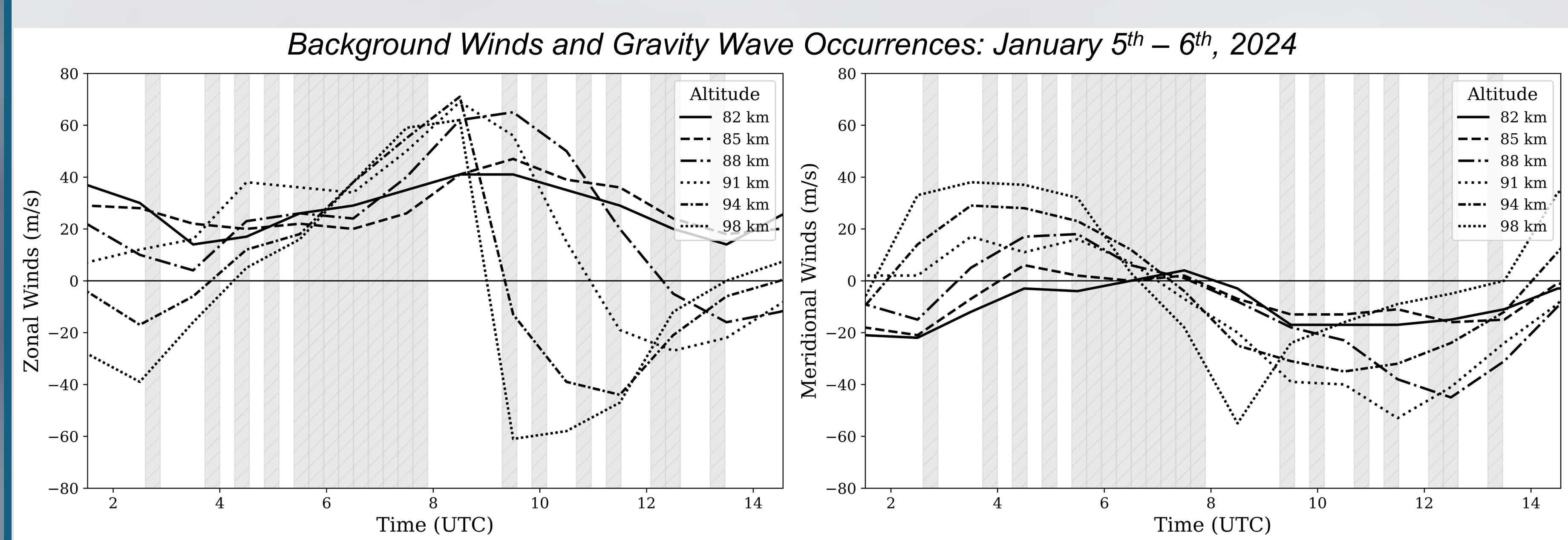


Figure 4: Zonal and meridional winds for the night of January 5th - 6th, 2024 as recorded by the Poker Flat Meteor Radar. Discrete altitudes observed by the radar system are noted by various dashed lines. Times of citizen-classified GW occurrences are marked by gray overlays. For zonal winds, positive magnitudes denote eastward directionality and negatives denote westward. For meridional winds, positive magnitudes denote northern directionality and negatives denote southern.

GWs are more likely to propagate efficiently in a stable environment where background wind speeds and directions are similar across altitudes, as differing wind characteristics may result in partial or total wave suppression.

By examining Poker Flat Meteor Radar wind profiles, we analyze volunteer GW classifications using co-located observational data to see if reasonable associations to theory can be drawn.

Shown as an example in **Figure 4**, on January 5th – 6th, 2024, we note consistent, citizen-defined GW occurrences (gray overlays) when zonal winds are similar in magnitude and propagating northward and meridional winds are neutral across altitudes (5:30 – 8:00 UTC).

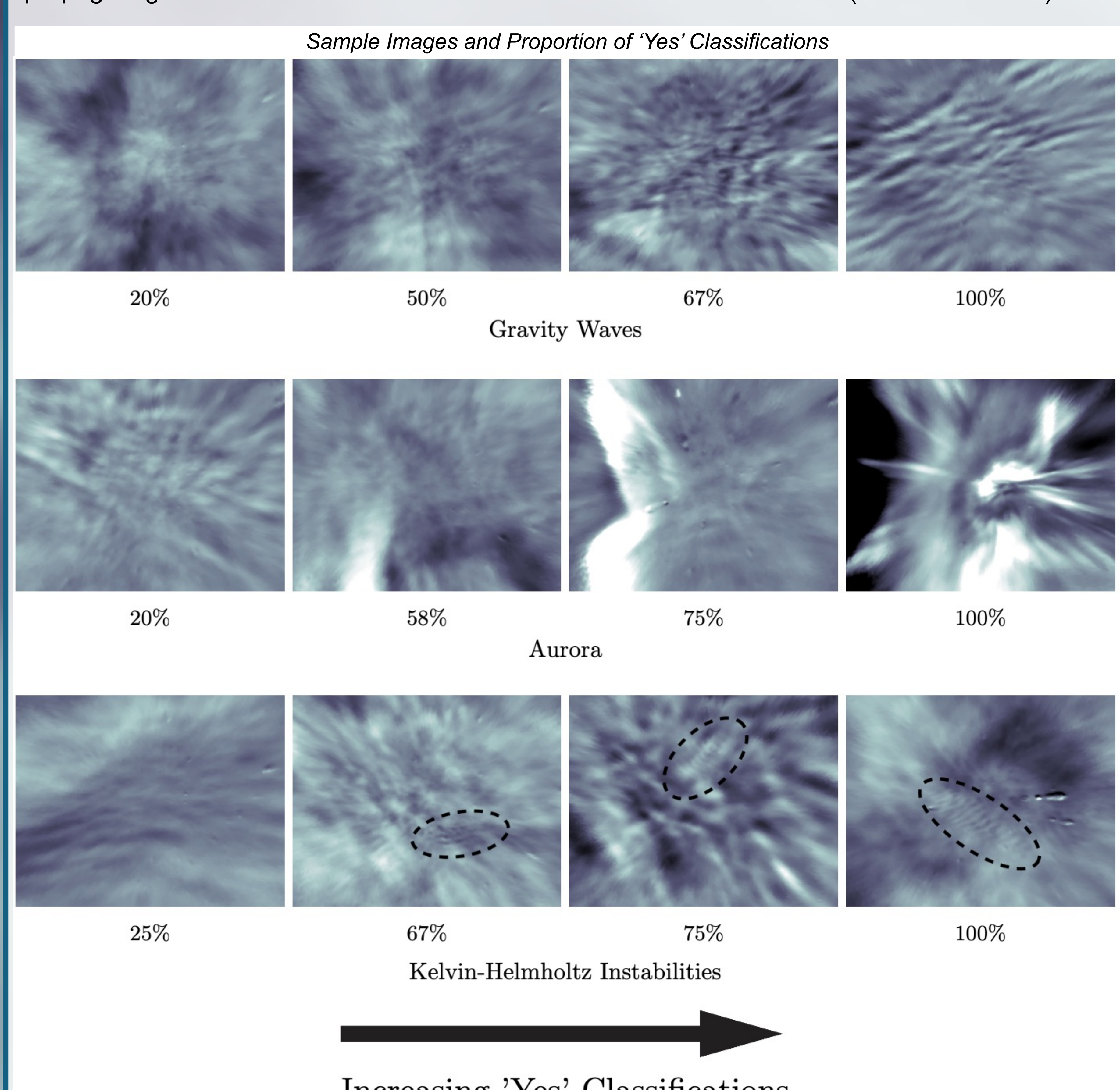


Figure 5: An example collection of processed OH-layer images depicting the three target observables. The portion of volunteers who responded 'yes' to the above images increases from left to right in each row and is additionally noted below each image. KHI are outlined here for convenience; outlines do not appear in videos presented to citizen scientists.