

## 1. Introduction

Over the past year, the citizen science project Aurorasaurus has collected new, globally-distributed, ground-based observations of the aurora and has integrated these with space-based estimates of auroral activity. A case study of these observations were compared to the NOAA Space Weather Prediction Center's (SWPC) Aurora Forecast product which is built upon the Oval Variation, Assessment, Tracking, Intensity, and Online Nowcasting (OVATION) Prime (2010) auroral precipitation model.

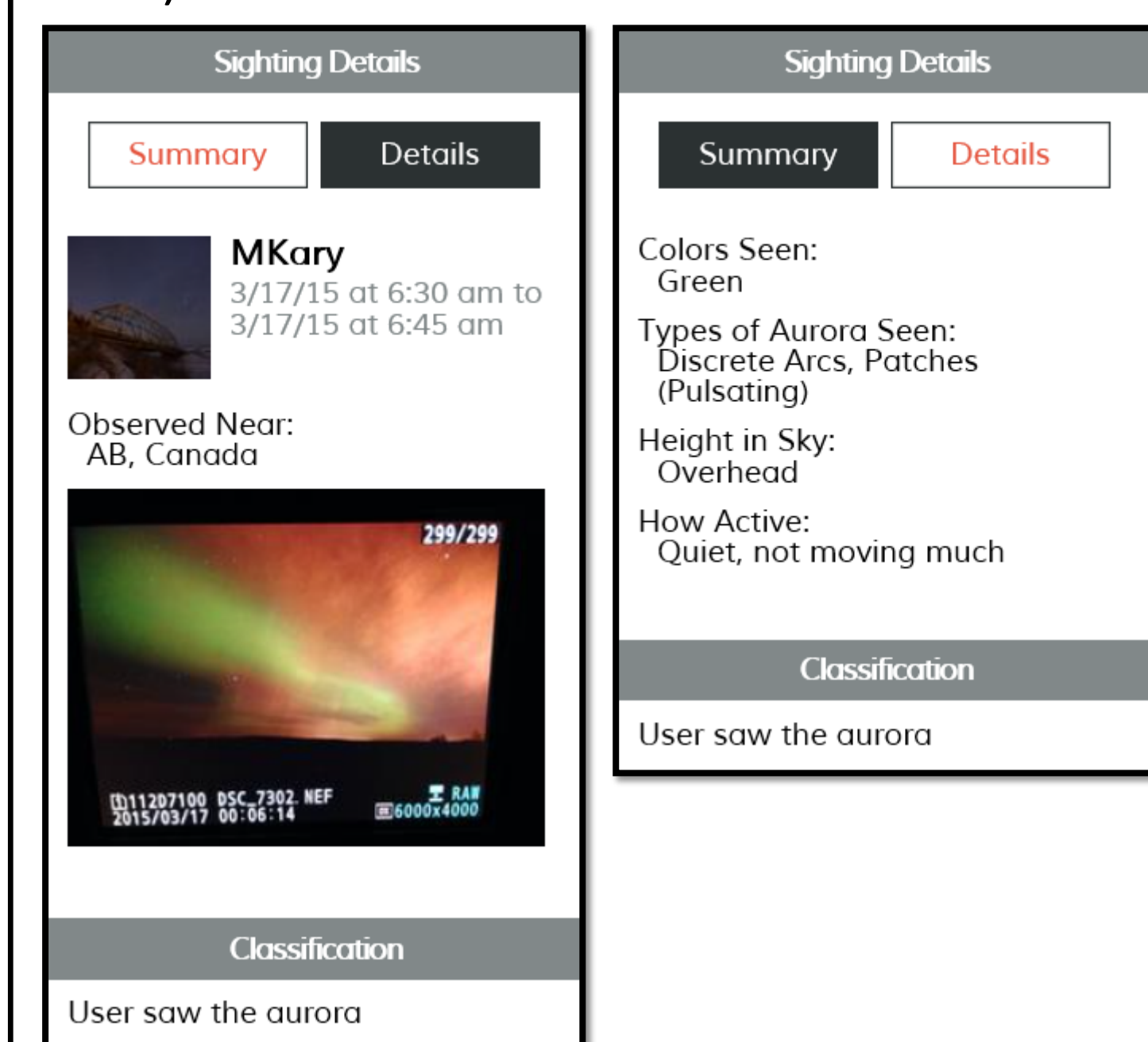
The observations in this case-study demonstrated that over 60% of the positive aurora observations occurred at latitudes equatorward of the SWPC predicted "view-line". New scaling parameters were determined from the relationship of the differences in latitude between the positive observations and the view line, and the maximum probability of visible aurora. The implementation of this view-line, in the Aurorasaurus real-time alert system, is also demonstrated.

## 2. Observations

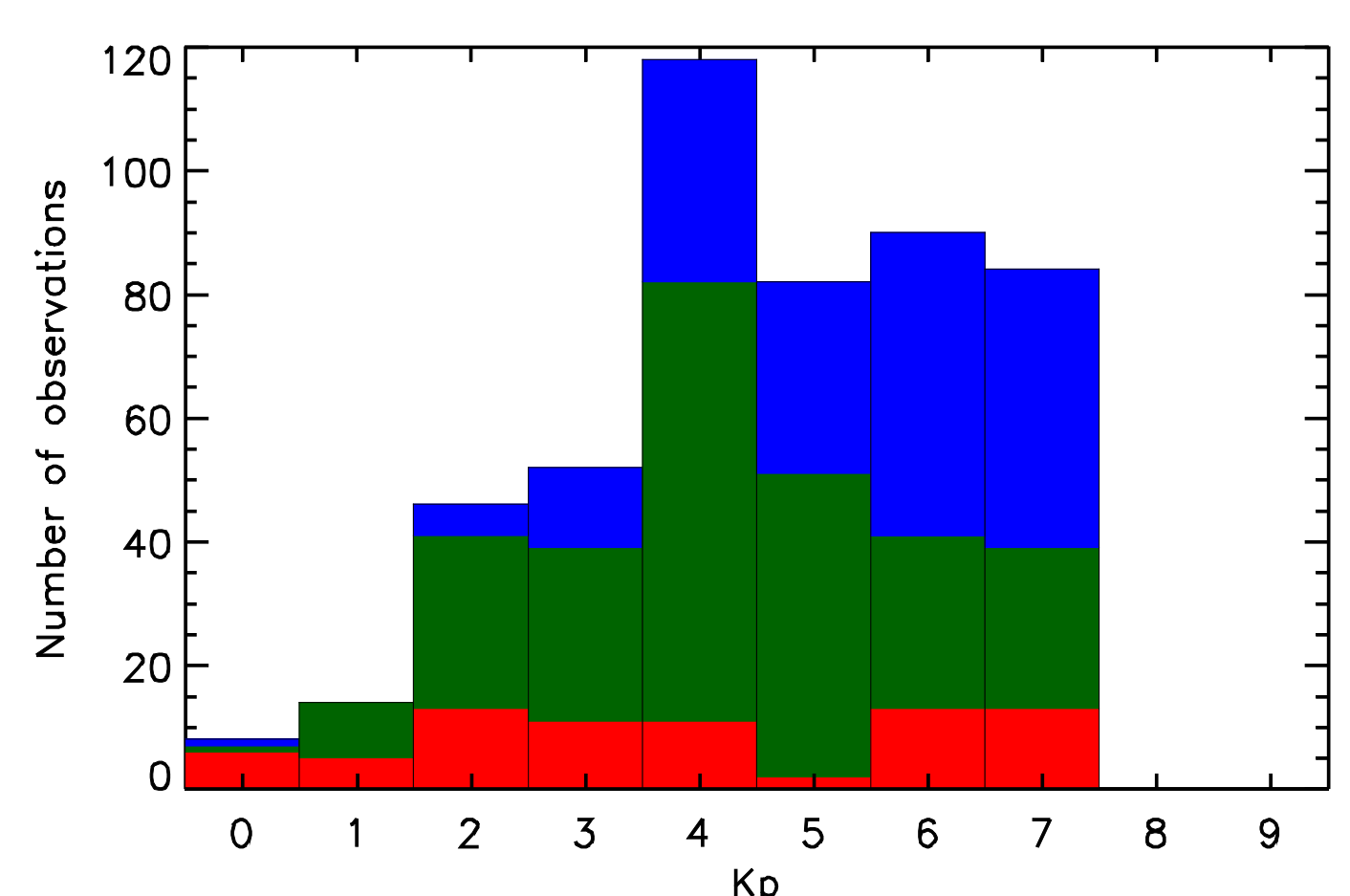
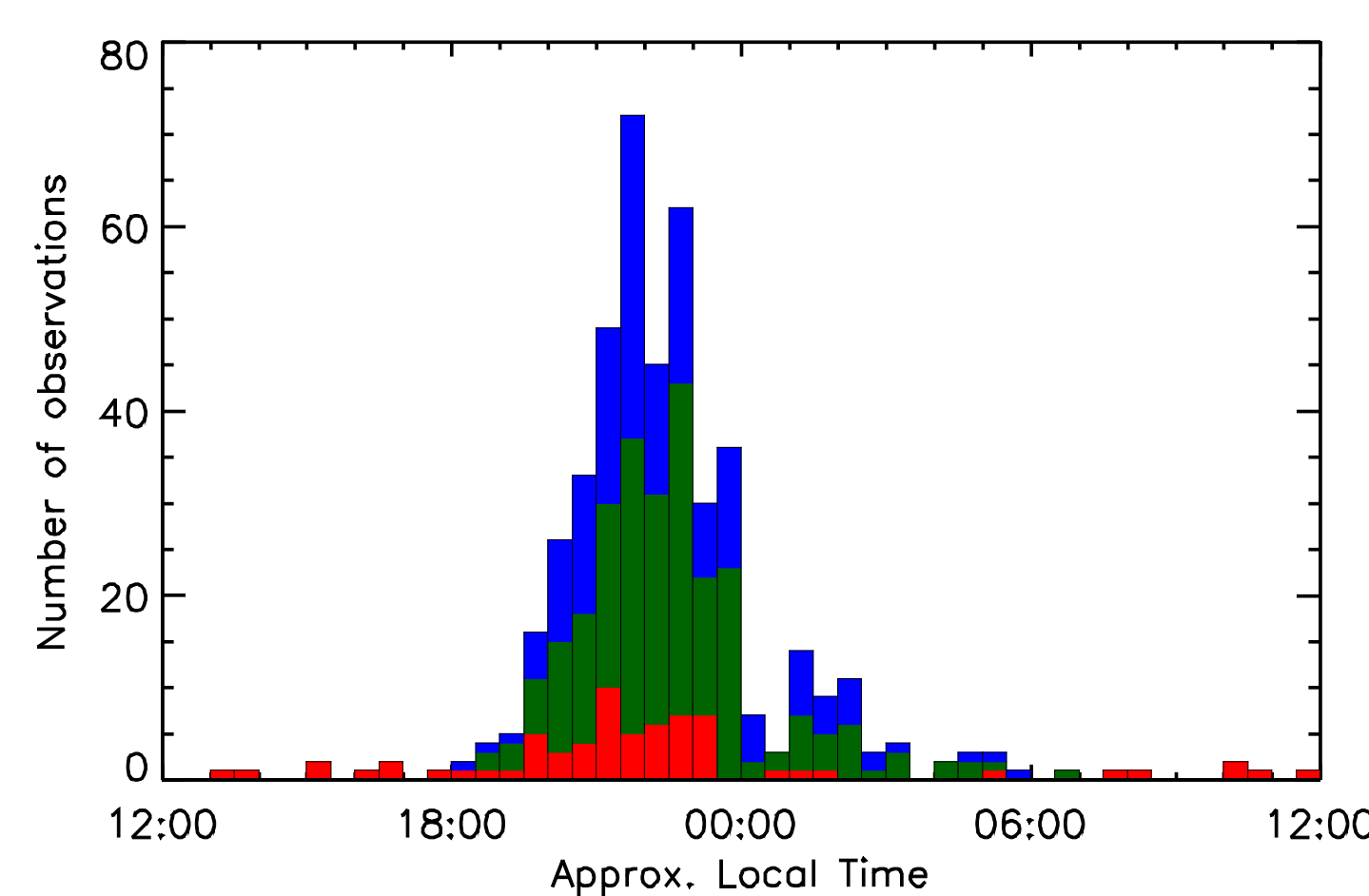
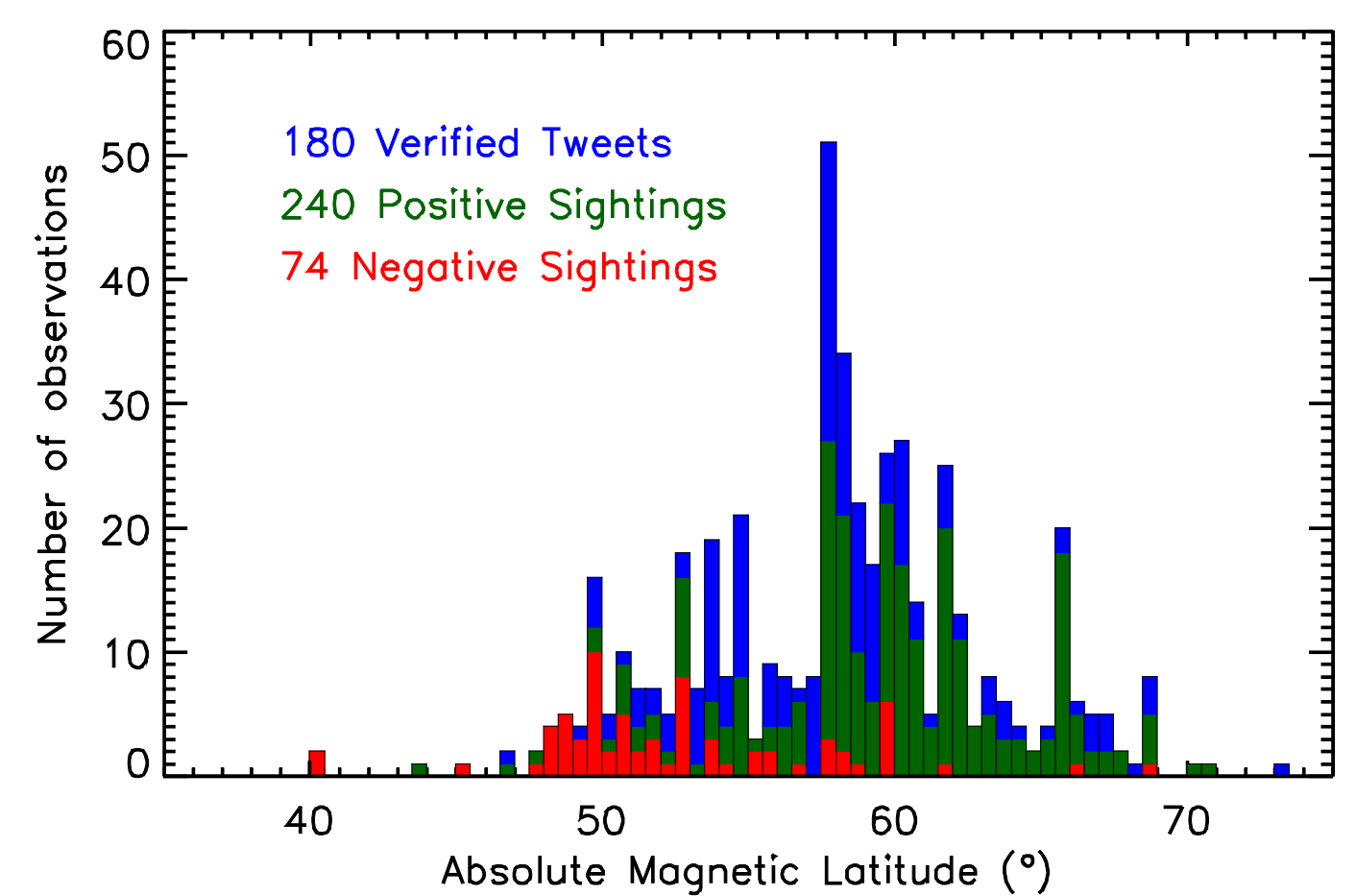
The observations made by citizen scientists, see Figure 1 for an example, are of three forms:

- **Verified tweets:** posts made on Twitter (called "tweets") that have been verified by Aurorasaurus users as sightings of the aurora. Manually inspected by Aurorasaurus team for this case study.
- **Positive sightings:** sightings of the aurora made by Aurorasaurus users and reported on the website or mobile apps.
- **Negative sightings:** reports from Aurorasaurus users stating that an aurora was not visible.

As shown in Figure 2, the observations in this case study span a range of magnetic latitudes, local times and activity levels. Though there is a clear preference toward observations being made in the pre-midnight sector (i.e. 20:00-00:00).



**Figure 1.** An example of a citizen science positive sighting, recorded during this case-study. The observation includes items such as a time, date, and location, as well as a photo and aurora descriptors (e.g. color, type, and activity).



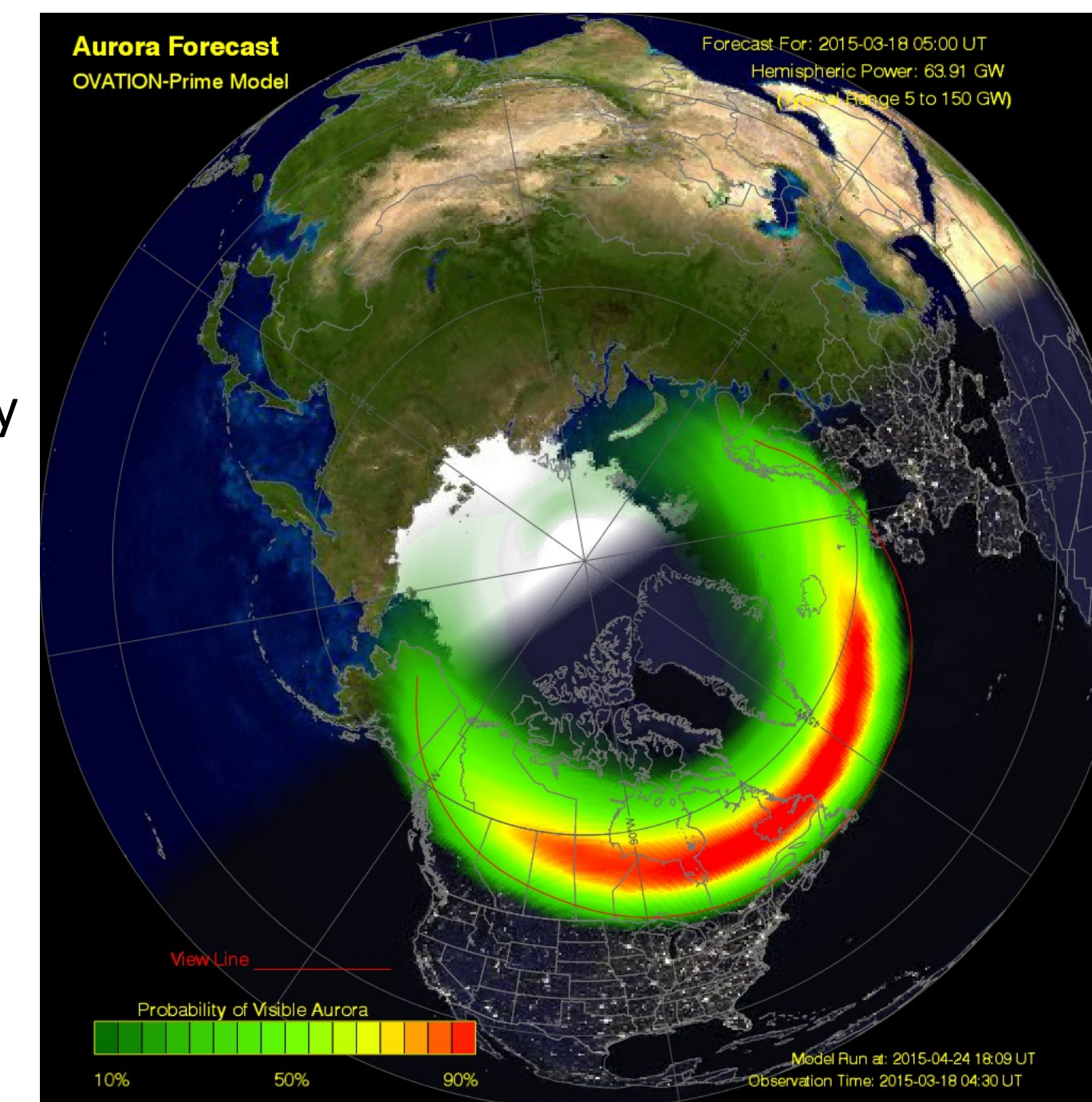
**Figure 2.** The Aurorasaurus observations used in this case study are grouped by magnetic latitude (top), local time (middle) and Kp index (bottom). The number of each type of observation is shown using stacked color bars.

## 3. Auroral Oval

We utilize the OVATION Prime (2013) aurora forecast model to determine the location of the auroral boundary. OVATION Prime (2013) is a well-used, accurate, auroral precipitation model that can be run in real-time. The model is driven by Newell's magnetospheric coupling function ( $d\phi_{MP}/dt$ ) which is determined using solar wind data, such as the solar wind velocity ( $v$ ) and interplanetary magnetic field (IMF) strength ( $B$ ) and direction ( $\theta$ , the IMF clock angle).

$$\frac{d\phi_{MP}}{dt} = v^2 B^2 \sin^2\left(\frac{\theta}{2}\right)$$

The OVATION Prime (2013) auroral precipitation data is inputted into the NOAA Space Weather Prediction Center's aurora forecast product to produce a representation of where an aurora may be visible (see Figure 3).



**Figure 3.** An example of the SWPC aurora forecast product. The modeled auroral oval is colored to represent the probability of visible aurora.

## 4. Comparison with the SWPC aurora forecast product

The SWPC aurora forecast product converts auroral precipitation data into a more user-friendly output. It scales the energy flux,  $\Sigma_j$ , into a "probability of visible aurora",  $P(A)$ , and indicates this likelihood of visible aurora on a geographic map.

$$P(A) = 10 + \Sigma_j$$

The forecast product also determines the most equatorward latitude from which an aurora may be visible, for each longitude. This estimate is known as the "view-line", i.e. an aurora should be visible at locations on, or poleward, of the view-line. For each longitude, the latitude of the maximum probability of visible aurora,  $\phi_{P(A)max}$ , is scaled poleward by the value of the maximum probability,  $P(A)_{max}$ .

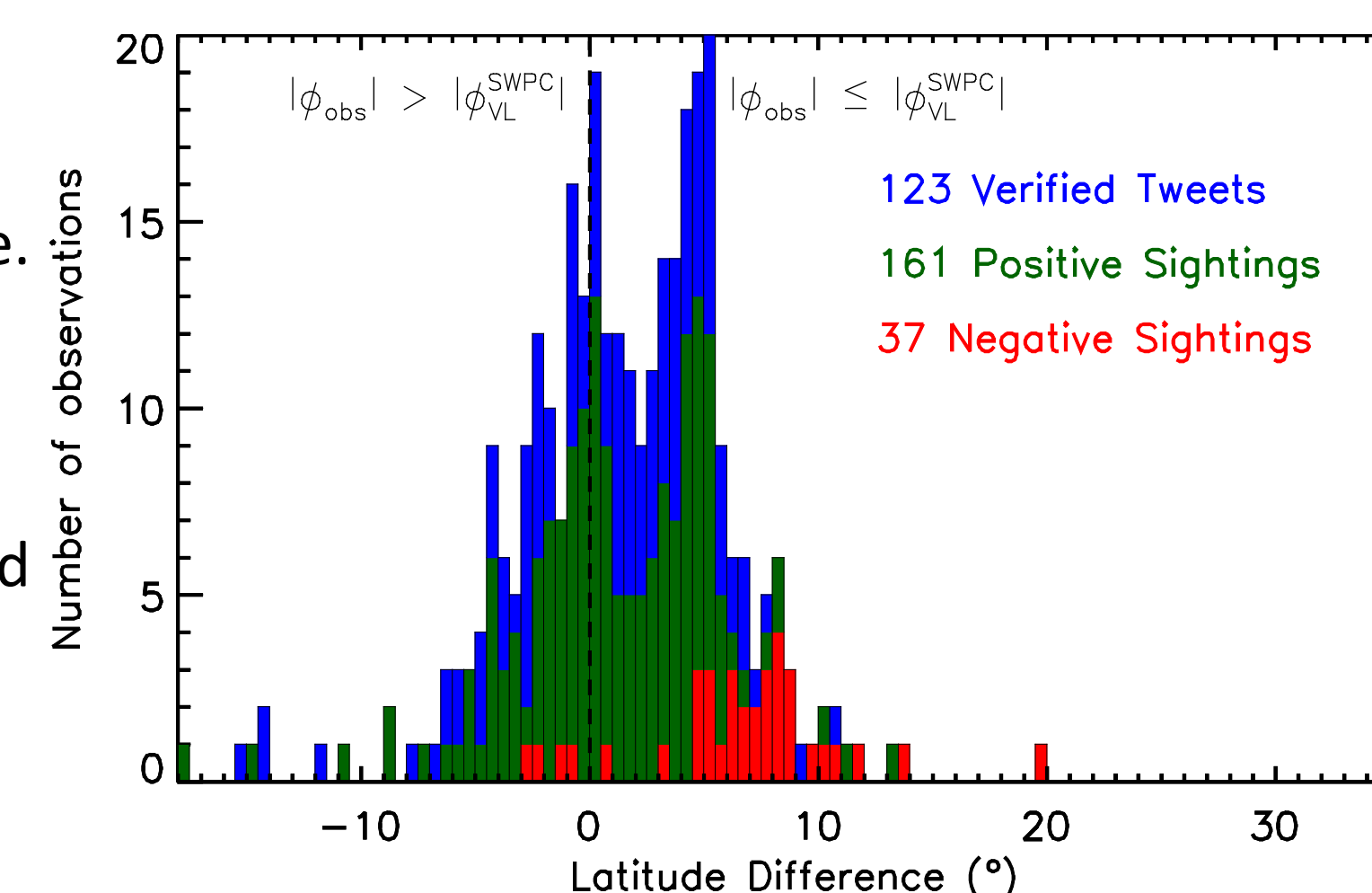
$$\phi_{VL}^{SWPC} = \phi_{P(A)max} \pm \left(\frac{P(A)_{max}}{20} + 3\right)$$

In Figure 4, the latitude of the citizen science observations is compared to the SWPC estimated view-line. We find that 62% of positive observations (i.e. verified tweets and positive sightings) are located equatorward of the view-line. Thus suggesting the SWPC view-line is often too conservative in its estimate.

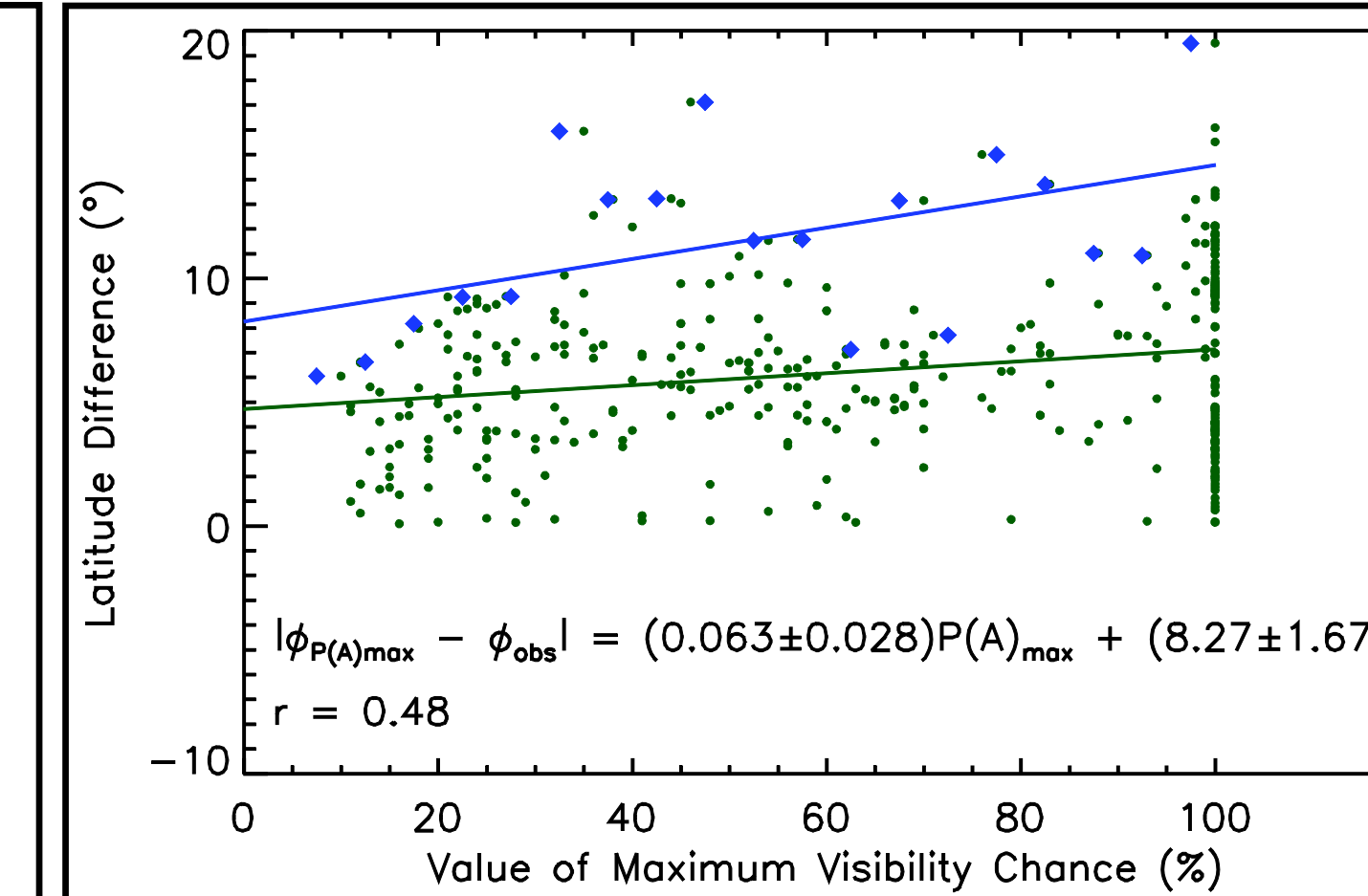
## 5. Determining a new observational view-line

Using the citizen science observations we can adapt the view-line parameters, so that it better matches with those observations. We plot the observation latitude as a function of  $P(A)_{max}$  in Figure 5 and the difference between the observations and the new view-line in Figure 6. A fit between the maximum latitude difference for 5% bins of maximum visibility chance, and the maximum visibility chance is determined. The coefficients of the linear fit (blue) produce a new view line equation:

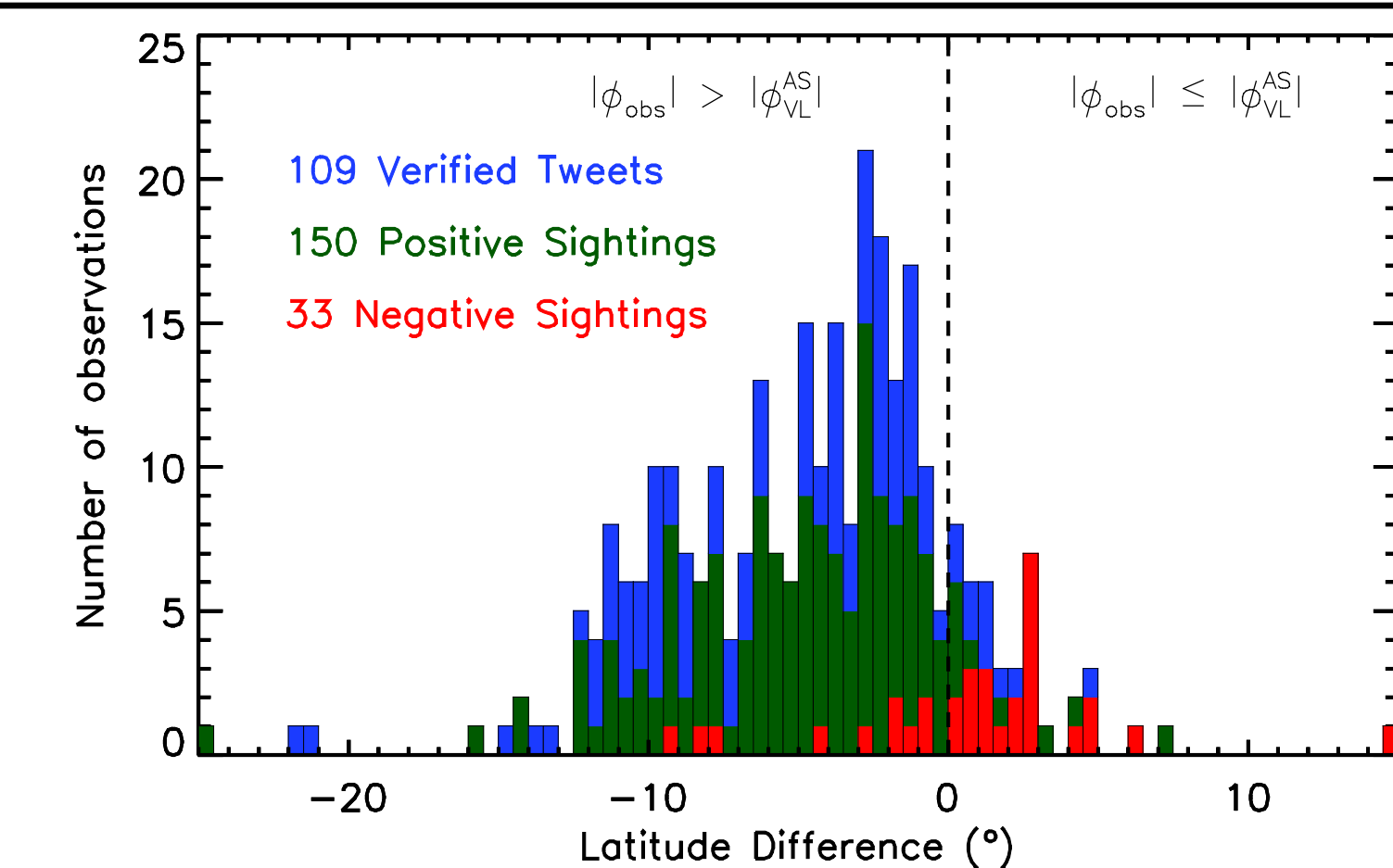
$$\phi_{VL}^{AS} = \phi_{P(A)max} \pm \left(\frac{P(A)_{max}}{16} + 8\right)$$



**Figure 4.** The latitude difference between the observations and the SWPC estimated view-line is shown.

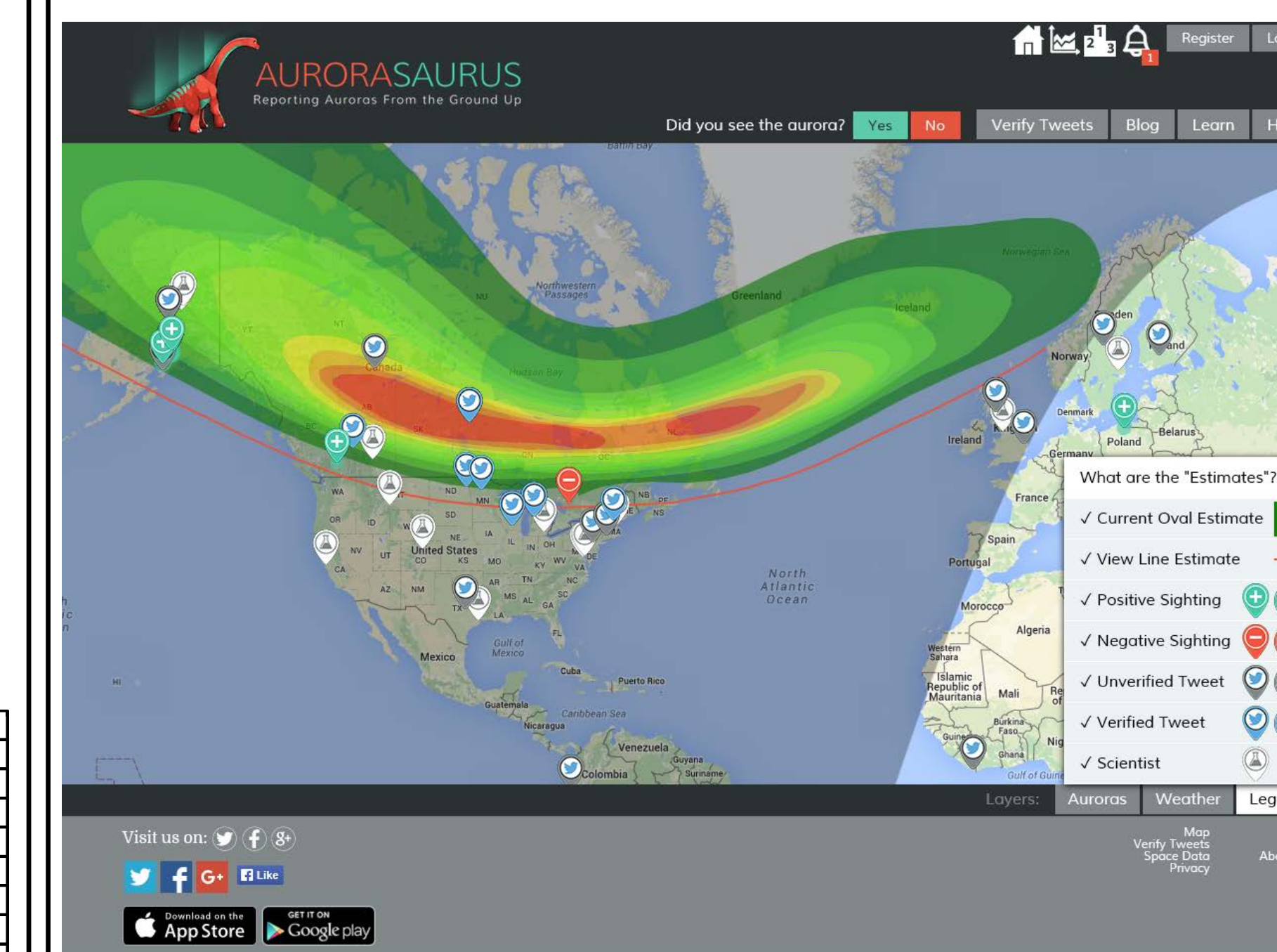


**Figure 5.** The latitude difference between the observations and the SWPC view-line plotted against the value of maximum visibility chance (green). The maximum latitude differences and fit are shown in blue.



**Figure 6.** The latitude differences between the observations and the new Aurorasaurus view-line. The majority of aurora sightings (verified tweets and positive sightings) are now poleward of the view-line.

## 6. Aurorasaurus output



**Figure 7.** A screenshot of the Aurorasaurus aurora map, using the forecast data provided by SWPC, with the new Aurorasaurus view-line shown (red). Observational data from users is also shown.

Alongside the SWPC forecast product, the new Aurorasaurus view-line is calculated in real-time and shown on the Aurorasaurus homepage (as demonstrated in Figure 7). This is a real-time indicator of where an aurora might be visible from. Additionally, any current observations are also shown on the map.

These three data sources (the SWPC auroral oval, Aurorasaurus view-line, and citizen science observations) allow the Aurorasaurus project to issue aurora visibility alerts to its users when an aurora is predicted to be visible near them.

## 7. Conclusions

Using nearly 300 observations of the aurora, provided by citizen scientists, we were able to determine the equatorial boundary, both in the northern and southern hemispheres, of where an aurora might be seen based on its intensity. We found that the current SWPC estimate was conservative and that an aurora was often visible further equatorward than estimated. By adapting the view-line parameters, using the observations in this case-study, we were more able to accurately represent the maximum distance from which an aurora might be visible. Some caveats, and areas for future investigation, include determining the affects of auroral height, observational bias and sudden aurora brightening (i.e. substorms). The work presented here also forms part of the wider Aurorasaurus output, which alerts its users as to when they might be able to see an aurora via personalized alerts.

## References & Acknowledgements

- Case et al., SW, submitted
- MacDonald et al., SW, 2015, doi: 10.1002/2015SW001214
- Newell et al., SW, 2014, doi:10.1002/2014SW001056

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