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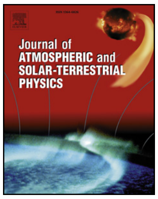

A case study comparing citizen science aurora data with global auroral boundaries derived from satellite imagery and empirical models

Burcu C. Kosar[a,b,*], Elizabeth A. MacDonald[a,b], Nathan A. Case[c], Yongliang Zhang[d], Elizabeth J. Mitchell[d], Rodney Viereck[e]

[a] *New Mexico Consortium, Los Alamos, NM, USA*
[b] *NASA Goddard Space Flight Center, Greenbelt, MD, USA*
[c] *Department of Physics, Lancaster University, UK*
[d] *JHU Applied Physics Laboratory, Laurel, MD, USA*
[e] *NOAA Space Weather Prediction Center, Boulder, CO, USA*

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ABSTRACT

Aurorasaurus is a citizen science project that offers a new, global data source consisting of ground-based reports of the aurora. For this case study, aurora data collected during the 17–18 March 2015 geomagnetic storm are examined to identify their conjunctions with Defense Meteorological Satellite Program (DMSP) satellite passes over the high latitude auroral regions. This unique set of aurora data can provide ground-truth validation of existing auroral precipitation models. Particularly, the solar wind driven, Oval Variation, Assessment, Tracking, Intensity, and Online Nowcasting (OVATION) Prime 2013 (OP-13) model and a Kp-dependent model of Zhang-Paxton (Z-P) are utilized for our boundary validation efforts. These two similar models are compared for the first time.

Global equatorward auroral boundaries are derived from the OP-13 model and the DMSP Special Sensor Ultraviolet Spectrographic Imager (SSUSI) far ultraviolet (FUV) data using the Z-P model at a fixed flux level of $0.2\,\text{erg}\,\text{cm}^{-2}\,\text{s}^{-1}$. These boundaries are then compared with citizen science reports as well as with each other. Even though there are some large differences between the global boundaries for a few cases, the average difference is about 1.5° in geomagnetic latitude, with OP-13 being equatorward of Z-P model. When these boundaries are compared with each other as a function of local time, no clear overall trend as a function of local time was observed. It is also found that the ground-based reports are more consistent with the predictions of the OP-13 model.

1. Introduction

The coupling of solar wind plasma into the Earth's magnetosphere leads to the precipitation of particle flux into the high latitude regions of the Earth's ionosphere. The optical manifestation of this complex chain of physical processes is the aurora. Early morphological studies of the aurora established that various auroral forms (e.g., arcs, bands) are distributed into an oval configuration globally around the Earth's magnetic pole (Feldstein, 1964; Feldstein and Starkov, 1967; Feldstein and Starkov, 1968). The spatial and temporal variations of auroral oval boundaries provide information on the state of the near-Earth space environment. Early studies showed that the changing auroral oval is a manifestation of changing internal structure of the magnetosphere (Akasofu, 1966). Furthermore, Nakai and Kamide (1983) and Boudouridis et al. (2003) investigated the auroral oval dynamics in response to the interplanetary magnetic field (IMF) and the solar wind dynamic pressure, respectively. Nakai and Kamide (1983) found that the equatorward boundary during periods of southward IMF is generally at lower latitudes than during northward IMF. Using particle precipitation data from DMSP spacecraft, Boudouridis et al. (2003) found that solar wind dynamic pressure changes can dramatically affect the auroral oval location, size, and intensity. Therefore, an accurate description of the auroral oval boundaries is of great importance to our understanding of magnetospheric and ionospheric physics as well as space weather.

Auroral oval predictions are generally based on data collected by various space-based particle detectors or imagers and their incorporation into empirical models that make predictions of the precipitation patterns (Evans, 1987; Hardy et al., 1985, 1989; 1991; Zhang and Paxton, 2008; Newell et al., 2010a, 2014; Mitchell et al., 2013). In this

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[*] Corresponding author. New Mexico Consortium, Los Alamos, NM, USA.
E-mail address: bkosar@my.fit.edu (B.C. Kosar).

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study, the spatial and temporal behavior of energy flux are obtained from the OP-13 model (Newell et al., 2010a, 2014) and the DMSP/SSUSI FUV observations using the Z-P model (Paxton et al., 1992, 2002; Zhang and Paxton, 2008). This is the first study comparing the boundary predictions of these two similar empirical models. OP-13 is an auroral precipitation model (Newell et al., 2014) that uses a highly accurate solar wind-magnetosphere coupling function (Newell et al., 2007) to produce high resolution energy flux maps between 50° to 90° magnetic latitude in both hemispheres. It is the improved version of the original OVATION Prime 2010 (OP-10) model (Newell et al., 2010). The Z-P model is an empirical Kp-dependent model developed using 4 years of Global Ultraviolet Imager (GUVI) data and Epstein function fitting method formerly used by Hardy et al. (1987). A global auroral boundary is also derived from each model at a specific level of energy flux.

Aurorasaurus actively collects thousands of ground-based reports of the aurora globally and incorporates them into scientific investigations as a new data source (MacDonald et al., 2015). This unique data set offer ground-truth validation for the predictions of empirical models. A recent study by Case et al. (2016a) compared a subset of Aurorasaurus citizen science data with the operational forecast of the visible aurora provided by National Oceanic and Atmospheric Administration's (NOAA) Space Weather Prediction Center (SWPC). The aurora forecast product of SWPC utilizes the output from the OP-10 model for estimating the location of the most equatorial latitude of the visible aurora known as the view-line. This study demonstrated that 60% of the positive aurora reports collected by Aurorasaurus were equatorward of the view-line predicted by SWPC. This finding led to defining a new, less conservative Aurorasaurus view-line (Case et al., 2016a; b).

For the 17–18 March 2015 geomagnetic storm we have identified and examined approximately 120 citizen science reports that are in conjunction with DMSP F16, F17 and F18 satellite passes. Global auroral boundaries obtained from the OP-13 and the Z-P models are compared with citizen science reports as well as with each other. Unlike earlier work, here we focus on the boundaries at fixed flux levels overhead, not the view-line which corresponds to aurora that may be visible on the horizon.

It is important to note that FUV cameras on satellites and all-sky cameras on the ground do not measure the same physical signatures of aurora Sigernes et al. (2011). There are extensive networks of all-sky camera data on the ground, though they are limited by cloud coverage and land mass, as are Aurorasaurus data, generally. Currently auroral boundaries from these networked cameras are not regularly extracted. Such work is of future interest but generally beyond the scope of current data processing methods. The use of Aurorasaurus observers as “ground truth” is appropriate for the analysis methods chosen in this paper, which is in comparison to two models both based on space-borne measurements of auroral proxies for a large event. Large geomagnetic events are those which are the most rare, and therefore have the least frequent data (and thus highest uncertainties) going into building statistical auroral models. The Aurorasaurus data are most plentiful for large events, and we begin with a case study to best illustrate the utility and potential of this technique.

2. Citizen science aurora data during the 17–18 March 2015 geomagnetic storm

On 17 March 2015, a coronal mass ejection (CME) hit the Earth causing an intense geomagnetic storm. The signature of the geomagnetic storm was apparent as significant fluctuations in many interplanetary and geophysical parameters. In Fig. 1 variations of Dst, Kp, IMF Bz, and solar wind speed with the storm commencement and evolution are shown. During the main phase of the storm (section highlighted with gray), solar wind speed increases while the IMF Bz turns southward. The Dst index decreases and reaches a minimum of -223 nT around 22:00 UT on 17 March 2015, which marks the beginning of the recovery phase (section highlighted with yellow). The Kp index briefly reached 8 during the main phase of the storm. This particular period of strong geomagnetic activity was chosen for this case study because it offers dynamically varying auroral oval boundaries with the storm evolution and elevated number of reports (Case et al., 2015a; b). Fig. 2 shows that the number of citizen science aurora reports submitted to Aurorasaurus during the St. Patrick's day storm is significantly larger (about 12 times) than the daily average number of reports (~ 20 during quiet times). This figure also demonstrates that the number of observations peak particularly during enhanced geomagnetic storm conditions ($Kp \geq 4$). A case study of such an active period with an abundance of reports (total of 241) increases the likelihood of finding conjunctions with the DMSP satellite passes. This is explained further in Section 4.

During the storm period, Aurorasaurus collected 241 reports via the project's website and apps. All reports include a timestamp, a location, and frequently they include meta-data describing the observed aurora (such as color, type etc.) as well as the local environmental conditions. Aurorasaurus data consists of direct reports submitted to the project via its website and apps and tweets that are mined from Twitter via keyword searching and place name geo-location or native geo-tagging. Direct reports submitted to the project can either be a positive or a negative sighting, depending on if the observer saw the aurora or not. These data are then scanned thoroughly for data integrity issues. For example, one common error is that users select an incorrect end time for their observations (e.g. 11am rather than 11pm). To mitigate this particular error, if the difference between the start and end time of the observation exceeds 3-hrs we filter out these reports due to not complying with the real-time data standard of the project. Another example is that a positive sighting is reported from a region where an aurora sighting is incredibly unlikely (e.g. southern US states during a minor storm). We assume that this is the result of an error in completing the location field and thus such reports are also filtered out. Negative sightings that are of interest to this case study must indicate clear, unobscured view of the sky. Furthermore, the duplicates of all direct reports are excluded.

Data from Twitter reports is extracted using a rigorous process as described by Case et al. (2016c). In summary, it is a two-step process: verification and validation. First, the aurora related and geo-tagged tweets are presented on the project website to our user community. They are asked to verify the real-time aspect of the tweet by up or down voting on them. Following the verification step, the validity of user-verified tweets are manually checked by the Aurorasaurus team members. Team members are trained to validate tweets using a standard protocol based on the same set of tweets that were used during the project's first validation effort as described in detail in Case et al. (2016c). During this manual validation, the positively verified tweets are analyzed one at a time. For each tweet, the team members inspect the tweet's text, any links associated with the tweet (which usually includes an image), and the location and time information of the tweet to determine any signs of non-original content. During this inspection, each tweet is cross-checked against other observations (e.g. reports submitted directly to Aurorasaurus and other known sightings) and the predictions of solar wind driven auroral models for the same time period for accurate classification. Inspected tweets are then sorted into two major categories: valid or invalid. The valid category represents tweets that are identified by Aurorasaurus users as real-time aurora sightings and are confirmed by the trained Aurorasaurus team members. The invalid category is a collection of tweets that, according to the Aurorasaurus team members, are misidentified as real-time aurora sightings by the user community. The Aurorasaurus project only uses the valid category of positive verified tweets in scientific analysis.

After this two-step process, a tweet is classified as a positively verified tweet. Quality control measures are an important part of citizen science project design. In multiple fields, data collected by “amateurs” has been shown to be as accurate as “traditional” sources (Sullivan