Comparisons of Auroral Oval Boundary Models to DMSP SSUSI

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Abstract:

The auroral zones can interfere with missile defense, HF communications, and tracking of objects in low-Earth orbit. Auroral models can help with situational awareness of the location of the aurora and potential impacts. This study was performed to determine the accuracy of current operationally-ready auroral oval boundary models to assist in the determination of the quality of various approaches to auroral oval boundary specification. Three models were evaluated in this study: OVATION Prime, OVATION, and Hardy. These auroral oval boundary models were compared to Defense Meteorological Satellite Program (DMSP) Special Sensor Ultraviolet Spectrographic Imager (SSUSI) Auroral Boundary Environmental Data Records (EDR). The solar wind-driven OVATION Prime model produced the most accurate results compared to the SSUSI data. The magnetometer-driven Hardy model produced the next most consistent results. The in-situ measurement/climatology look-up table model, OVATION, produced the least consistent results. In terms of magnitude of difference, the Hardy model had the lowest mean error but the variability of the error was quite large (1 to 5 degrees). The OVATION Prime model had the next lowest mean error with a much more consistent peak in error near 5 degrees in geomagnetic latitude. The OVATION model had a wide spread of error (1 to 8 degrees). Most of the correlation coefficients for the ensemble model equatorward boundary were near .8 with mean absolute errors reduced to 1 degree in geomagnetic latitude.

Introduction:

The auroral zones can interfere with missile defense, HF communications, and tracking of objects in low-Earth orbit. Auroral models provide situational awareness of the location of the aurora and potential impacts. This study was intended to determine the accuracy of current operationally-ready auroral oval boundary models to assist in the determination of the quality of various approaches to auroral oval boundary specification. This investigation compares three models to the Defense Meteorological Satellite Program (DMSP) Special Sensor Ultraviolet Spectrographic Imager (SSUSI) Auroral Boundary Environmental Data Record (EDR).

Models Under Investigation

Three models were evaluated in this study: OVATION Prime, OVATION, and Hardy. These models were selected because each model uses a different methodology to specify the aurora. The models are described in more detail in the following paragraphs.

OVATION Prime

The OVATION Prime model, developed by Newell et al.[1], uses solar wind parameters as drivers to determine the auroral specification. Additionally, it separately calculates four different types of aurora: monoenergetic acceleration events, broadband acceleration events, diffuse electron and ion aurora[2]. This model also includes seasonal effects whereas most other auroral models do not.

OVATION

The OVATION model, also developed by Newell et al.[3], uses in situ particle measurements to drive its solution. The OVATION model uses the DMSP J4 and J5 sensors for this input. The routines for the auroral boundary determination were developed by Johns Hopkins University/Applied Physics Laboratory and were supplied by the online OVATION model located here: http://sd-www.jhuapl.edu/Aurora/OVATION/OVATION_display.html

Hardy

Development of the Hardy Oval model began as a method to relate the Auroral Q index with the geomagnetic planetary K index. Feldstein and Starkov[4] began the first measurements of the aurora using ground-based all-sky cameras to detect the presence of aurora. The variation of the equatorward edge of the aurora was monitored and a Q index was determined to quantify the position. Since the All Sky Camera network was sparse and the space age was dawning, a new method to determine the strength of auroral disturbances was developed. Optical imagers along with particle precipitation measurements on DMSP could readily detect aurora. A system to relate the DMSP measurements to the Kp index soon arrived. Hardy set about trying to determine the relationship between Q and Kp and the result of his work yielded the Hardy Auroral Oval Boundary model[5]. The Hardy model requires only a local time and a Kp value to generate its output. The Kp values used to generate this model output were provided by NGDC via the Space Physics Interactive Data Resource (SPIDR) located here: http://spidr.ngdc.noaa.gov/spidr/ .

DMSP SSUSI Auroral Boundary Algorithm

The data used for the basis of comparison in this study was taken from the DMSP SSUSI from flights 16, 17, and 18. Data was provided by the Johns Hopkins University/Applied Physics Laboratory. SSUSI measures far and extreme ultraviolet airglow in the thermosphere and ionosphere[6]. Data used in this study were in the far ultraviolet (FUV) range at 115-180 nm. The Auroral Boundary EDR uses SSUSI imagery to determine the equatorward extent of the auroral boundary. The algorithm first extracts dayglow from the images by using data-derived lookup tables generated with SSUSI data collected during quiet geomagnetic conditions. The tables provide distributions of mean UV intensity as a function of solar zenith angle for each channel. The data from these tables are scaled to the imagery using a least-squares method and then subtracted from the radiance values in the imagery. Then the imagery is divided into a fixed grid size of 25 km X 53 km. Each grid is evaluated for aurora by using a fixed threshold of electron energy flux (Q) greater than 0.2 ergs/s/cm2. To determine the grid cells with auroral boundaries the cells must 1) have non-auroral neighbors, 2) not be at the edge of the SSUSI swath, and 3) have at least one neighboring boundary pixel as determined by criteria 1 and 2. Once all the cells have been identified as auroral/non-auroral they are evaluated by local magnetic time (MLT). For each 1-hour MLT the distribution of latitudes with auroral indicators are evaluated and the most equatorward latitude is determined to be the auroral boundary. It is important to note here that the OVATION Prime model data was evaluated using the same methodology described here for SSUSI data. The importance is that these auroral oval boundary data sets were evaluated and compared only after using identical auroral oval boundary determination schemes.

Time period

The period of time chosen for this study was 1-14 March 2012 which provided a wide range of solar conditions. The Kp index over this timeframe was highly variable ranging from less than 1 minus to as high as 8 zero. The solar wind as measured at the NASA Advanced Composition Explorer (ACE) spacecraft also showed high variability (see Figure 1.)

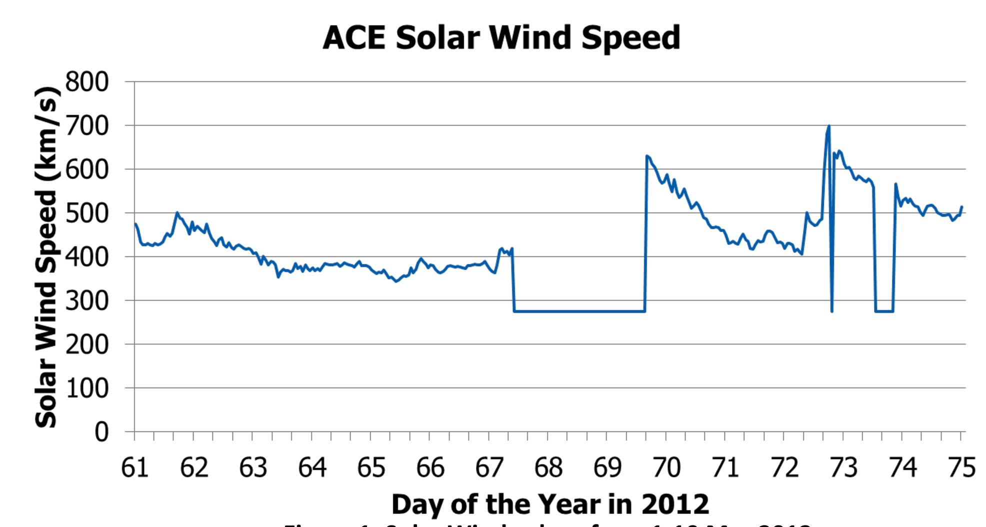

Figure 1. Solar Wind values from 1-10 Mar 2012

Note the odd measurements from midday on 7 March (67 day) through midday on 9 March (69 day) and also on 12 and 13 March. These measurements are anomalous and are a result of instrument errors induced by high energy particles from a coronal mass ejection (CME). This is significant since OVATION Prime uses this data to drive its solution for the location of the Auroral Oval. The impact of these bad measurements will be revisited later in this study.

Methodology

To perform this comparative analysis, the SSUSI Auroral Boundary EDR data was obtained and used as the basis for comparison. The OVATION and OVATION Prime data were obtained for the same time period and the Hardy model was run locally for the same time frame. The Hardy and OVATION models produce an auroral boundary equatorward extent as output so no further processing was necessary. However, the OVATION Prime model produces the auroral power on a grid. This auroral power output needed an algorithm to determine the equatorward boundary. The SSUSI Auroral Boundary EDR methodology was used to determine the auroral boundary from the OVATION Prime data.

Results

The Northern Hemisphere equatorward boundary from each of the models and the SSUSI data were evaluated over the two week period. Figure 2 shows the results of each of the models for this time period.

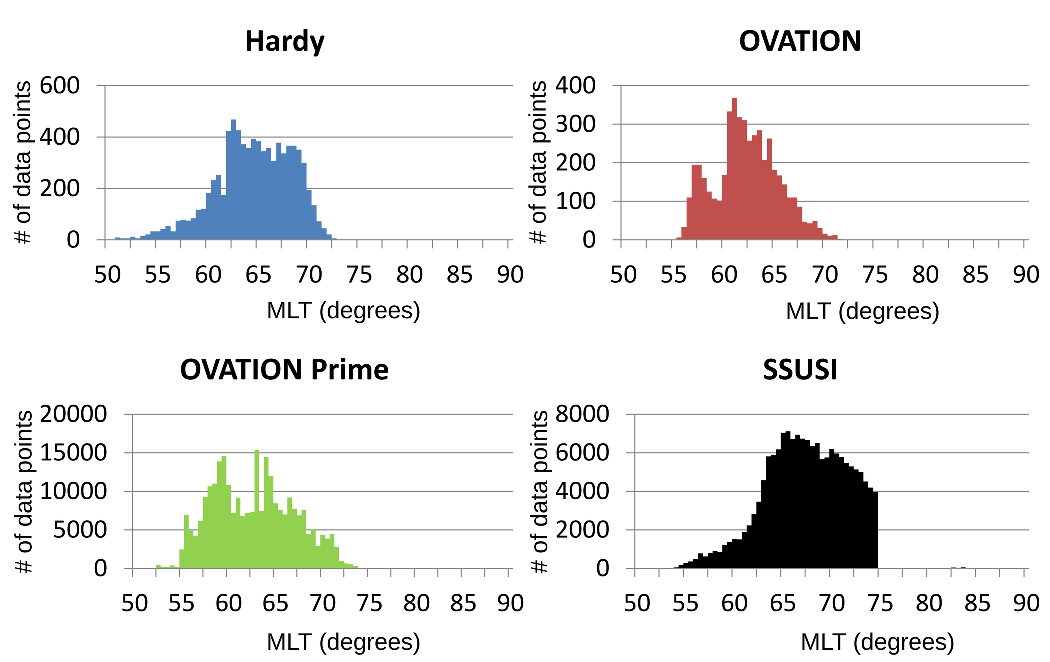

Figure 2. Histograms of Equatorward Auroral Oval Boundary

The equatorward boundary ranged from 50 degrees North to as high as 75 degrees North. These data show a good range of auroral boundary locations to evaluate the full range of solar condition and auroral response. Next, the data were correlated in time and space and each model solution for the bounadey was subtracted from the SSUSI result. The data were combined in a histogram and sorted by day/night and also by various Kp values. Figure 3 shows more detail of the Hardy model analysis.

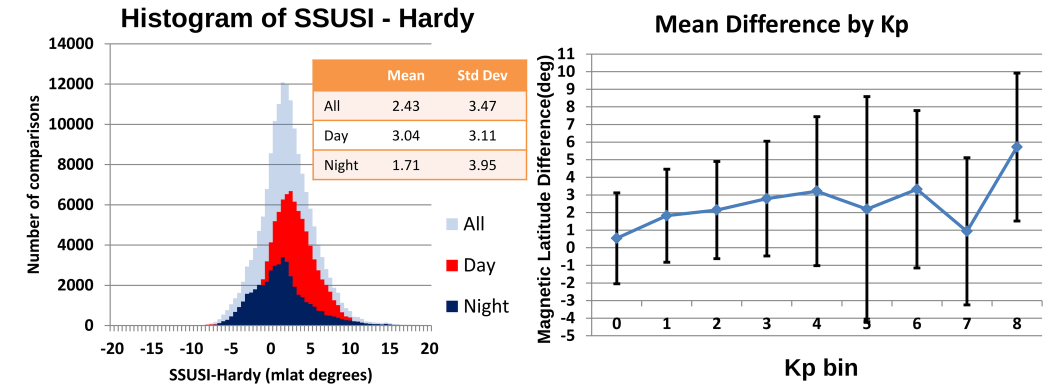

Figure 3. Histograms of SSUSI – Hardy

The grey histogram in Figure 3 shows the results of the SSUSI – Hardy comparison for the time period under consideration. The mean for this distribution was 2.4 degrees with the equatorward boundary more poleward in the SSUSI results in general. The data were then sorted by local time relative to the sun and placed into bins of daytime and nighttime. The red histogram shows the daytime boundaries were 3.0 degrees poleward in the SSUSI data than in the Hardy model on average. The nighttime showed slightly better agreement with on 1.7 degrees difference in the mean. The histogram data were also sorted by Kp values and are shown in the right-hand side of Figure 3. These results show an increase in the mean difference with higher Kp and also show an increase in the variability with higher Kp as demonstrated by the standard deviation represented by the error bars.

Figure 4 show the results of the OVATION model compared to SSUSI.

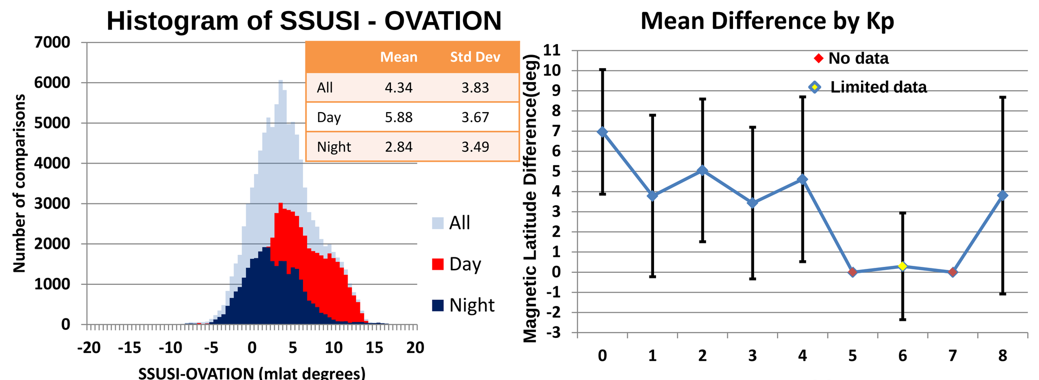

Figure 4. Histograms of SSUSI – OVATION

The SSUSI – OVATION comparison shows similar results as the Hardy comparison with slightly larger differences in the comparison. The SSUSI results remain poleward in the mean. However, the Kp dependence trend was reversed. The difference decreased with higher Kp. Additionally, the OVATION comparison showed little change in the variance with Kp.

Figure 5 shows the results of the OVATION Prime model compared to SSUSI.

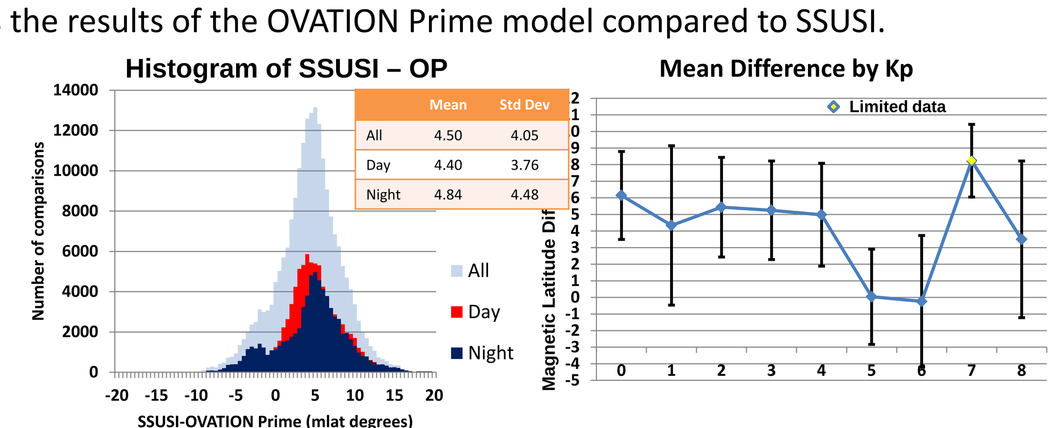

Figure 5. Histograms of SSUSI – OVATION Prime

The SSUSI – OVATION Prime comparison shows similar results as the OVATION comparison. The SSUSI results remain poleward in the mean and the Kp dependence decreases with higher values of Kp. However, there appears to be a bimodal behavior in the nighttime data which showed a mean of 4.8 degrees and a second peak at -2.5 degrees. The root cause of this second peak was investigated and determined to be errant solar wind data driving the OVATION Prime model. With these data removed the results were normally distributed as shown in figure 6.

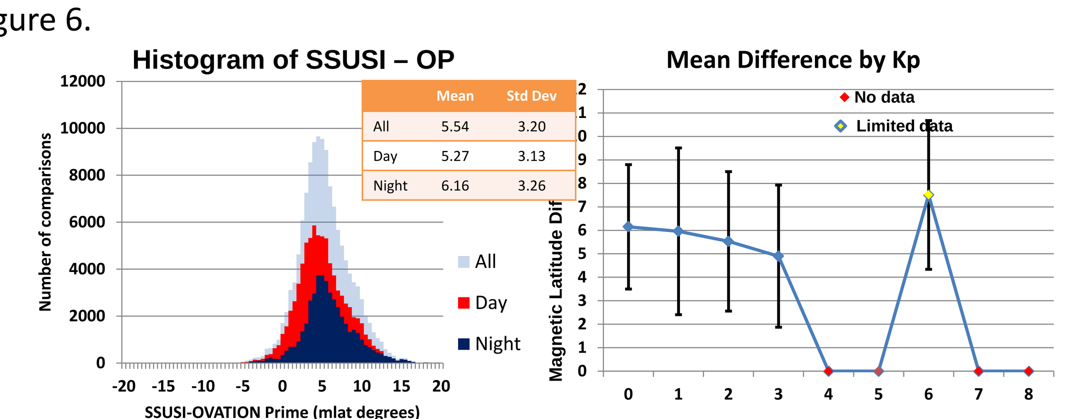

Figure 6. Histograms of SSUSI – OVATION Prime w/o errant ACE data

Summary

Three auroral oval boundary models were analyzed and compared to DMSP SSUSI data. SSUSI determined equatorward boundaries tended to be poleward of the model results. Hardy agreed with SSUSI more so than OVATION or OVATION Prime in the mean. However, OVATION Prime had the best control over the variability with Kp. The bias in the OVATION Prime results can be reduced by modifying the Q value used in the thresholding for boundary determination. Agreement between models and SSUSI was generally better at nighttime with the exception of the OVATION Prime results which demonstrated better agreement in the daytime sectors.

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