Transpolar arcs: Seasonal dependence identified by an automated detection method

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Abstract: Transpolar arcs (TPAs) are auroral features that occur polewards of the main auroral oval, at latitudes where auroras rarely form, suggesting that the magnetosphere has acquired a complicated magnetic topology. They are primarily a northward interplanetary magnetic field (IMF) auroral phenomenon, and their formation and evolution have no single explanation that is unanimously agreed upon. An automated detection method has been developed to detect the occurrence of Transpolar arcs in UV images captured from the Special Sensor Ultraviolet Spectrographic Imager (SSUSI) instrument onboard the Defense Meteorological Satellite Program (DMSP) spacecraft. Via this detection method TPAs are identified as a peak in the average radiance intensity above 12.5 ° colatitude, in two or more of the wavelengths/bands sensed by SSUSI.

Biases in the data have been investigated and it has been found that each DMSP spacecraft has a different bias due to its orbit. For the spacecraft of interest (F16, F17 and F18) this leads to a preferential observation of the Northern Hemisphere with the detection method missing TPAs in the southern hemisphere between approximately 0 - 9 UT. No seasonal bias has been found for these spacecraft.

Using the detection algorithm on observations from the years 2010 to 2016, over 5000 images containing TPAs are identified. The occurrence of these TPA images suggest a seasonal dependence, with more TPAs occurring during June in the southern hemisphere and December in the northern hemisphere. This therefore suggests, contradictory to initial expectations that more TPAs occur in the winter hemisphere than the summer hemisphere.

What is a TPA?

Transpolar arcs (TPAs) are auroral phenomena which lie poleward of the main auroral oval during Northward IMF. Figure 1 is an example of a TPA.

TPA formation models

Closed field line

Milan et al. (2005) suggest that TPAs are produced by tail reconnection.

Open field line

TPAs form due to polar cap flow shears which produce field aligned currents (FACs).

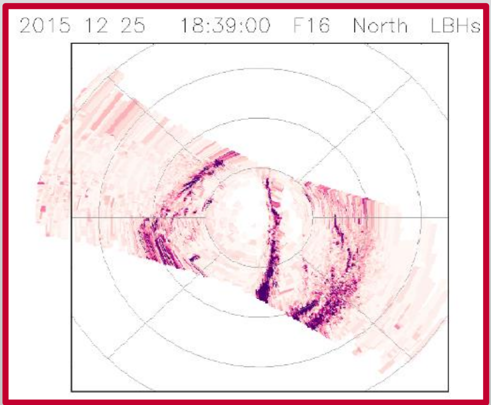

Figure 1) F16 LBHs SSUSI data showing a TPA on 25th December 2015 in Northern hemisphere.

Bending arcs appear visually similar to TPAs but are formed differently and have to be removed by eye from the results of the detection algorithm.

Figure 2) schematic of bending arc

Introduction

SSUSI instrument

SSUSI is a scanning instrument on board DMSP spacecraft which are in 90 minute orbits. SSUSI takes ~ 20 minutes to build up a image of a swath of the auroral region by scanning anti-sunward along its orbit, and operates at five wavelengths (table 1).

For this detection method Spacecraft F16, F17 and F18 are used as they were operational for the period of interest 2010-2016. The three spacecraft together provide nearly simultaneous observations. The Lyman-α data is not used as it is poor in comparison to the other wavelengths.

Name	Lyman-α	Oxygen line	Oxygen line	LBHs	LBHl
Wavelength (nm)	121.6	130.4	135.6	140-150	165-180

Table 1) wavelengths observed by DMSP/SSUSI

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Detection algorithm

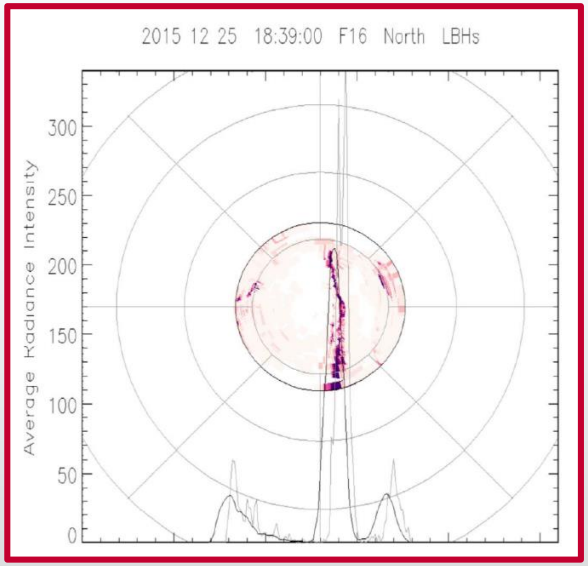

Figure 3) Breakdown of detection method. Inside black circle is SUSSI data above 12.5° colatitude. Over-plotted is the average radiance intensity, grey line and the smoothed average radiance intensity, black line.

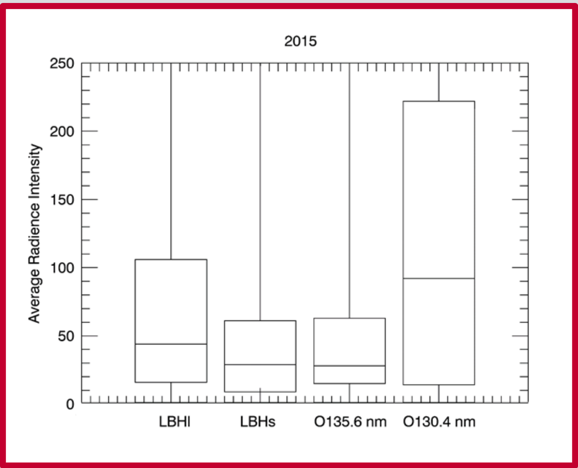

Figure 4) average radiance intensity above 12.5° colatitude for 2015.

Steps

Figure 3 is a visual representation of how the detection algorithm works.

1. Identify area above 12.5 ° colatitude (black circle). This value was chosen to maximise the area that does not regularly include the auroral oval.
2. Average the radiance intensity (vertically in Fig 3). This gives the faint grey line.
3. Smooth the data using boxcar method. (with a box of 10 data points) this gives the black line.
4. Test maximum and minimum values of the smoothed data against the upper and lower quartile respectively of the average radiance intensity of whole of 2015 (figure 4).
5. If the maximum is greater than the upper quartile and the minimum is less than the lower quartile in two or more wavelengths a potential TPA is identified.
6. Potential arcs are then checked by eye to remove bending arcs and false positives.

Potential TPA images	11448
TPA images	5698
Bending arc images	360
Success rate	~53%

Table 2) Outcome of detection algorithm between 2010-2016

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Results and biases

Figure 5a and b show the number of TPAs per month and per UT for each hemisphere, a clear dependence is seen such that more TPAs are identified in the winter hemisphere and no TPAs are identified between approximately 1 and 6 UT in the southern hemisphere. Looking at the spacecraft tracks (figure 6) as SSUSI scans anti-sunward there are times when the area above 12.5° colatitude is not scanned such as at 5 UT in the southern hemisphere (Fig 6c) and as such a TPA cannot be identified.
The average percent of the area above 12.5° colatitude scanned for each month and UT (Fig 5c and d respectively) shows a clear UT dependence similar to Fig 5b thus is a bias of the data. No seasonal dependence is seen thus suggesting there is a seasonal dependence on the occurrence of TPAs.

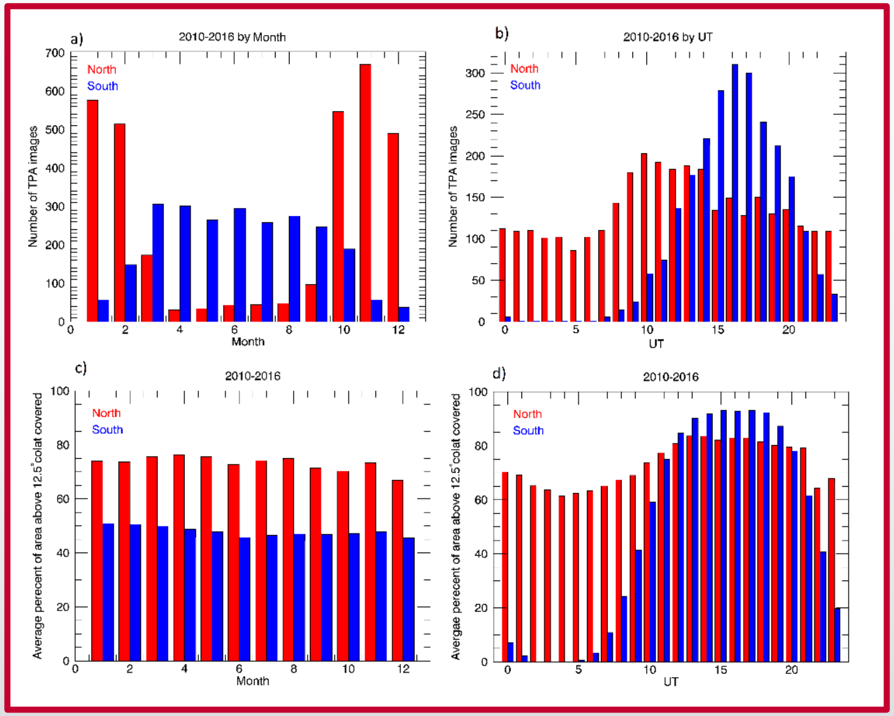

Figure 5) Red is Northern hemisphere Blue is southern hemisphere a) Number of TPA images each month by hemisphere. b) Number of TPA images each UT by hemisphere. c) Average percent of area above 12.5° colatitude imaged each month by hemisphere. d) Average percent of area above 12.5° colatitude imaged each UT by hemisphere.

Conclusion

Following the Milan et al., (2005) model we expect the closed magnetic flux to be present in both hemispheres simultaneously. Possibilities for the seasonal dependence are then: Seasonal change in visibility of TPAs, Auroral signature of TPAs is seasonally dependant or Mapping of closed flux is different in the two hemispheres.
If an open field line model is correct however then there is no need for the TPAs to be in both hemispheres simultaneously. The seasonal dependence could be explained if polar cap flow shears that produce FACs and hence TPAs are preferentially found in the winter hemisphere.

Figure 6) Spacecraft F16 tracks across the polar cap January 2015 in Northern (a, b) and Southern (c, d) hemisphere for 5 UT (a, c) and 17 UT (b, d). Noon is located at the top in each case.