An Aurorasaurus Citizen Science Database of Strong Thermal Emission Velocity Enhancement (STEVE) Observations

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Abstract

In recent years, amateur aurora observers are reporting on unique subauroral aurora or aurora-like structures, which they could not classify at first. Later, these structures also puzzled the scientific community. Very recently in 2018 and 2019 the first scientific publications have linked these subauroral structures with atypical high ion temperatures and velocities in the **S**ub**a**uroral **I**on **D**rift (SAID). MacDonald et al. (2018) have introduced the backronym **S**trong **T**hermal **E**mission **V**elocity **E**nhancement (STEVE) for this phenomenon. The details of the underlying processes are currently not fully understood.

Space science literature has described subauroral aurorae for decades. However, optical structures of STEVE were not described as a specific class of subauroral aurora or aurora-like structure before 2018. A freely accessible event list for amateur observations of the STEVE phenomenon from both hemispheres was missing for a long time. The presented work is part of a non-funded volunteer project that aims to fill that gap. A STEVE event list has been developed on basis of proper Terms of Use, summarizing nearly 800 single amateur observations previously posted freely accessible with footage. It contains observations with date and time for 150 days and 178+ observation days in total. In its current version, the STEVE event list covers the period of solar cycle 23 and of the ongoing solar cycle 24, 1 January 1996 to 31 December 2019.

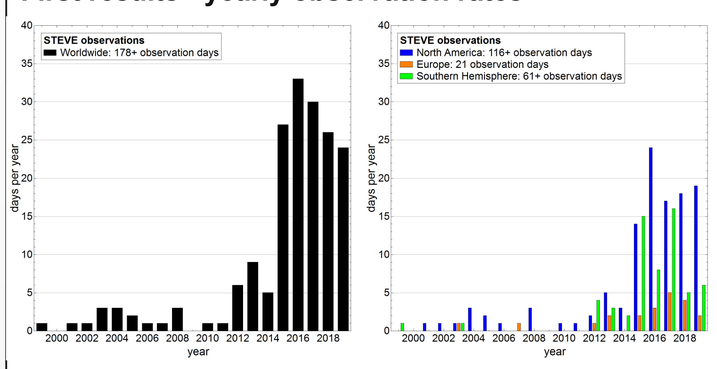
Key Points

- **Freely accessible event list for worldwide STEVE observations developed and released**
- **STEVE event list supports specific search for in-situ satellite data and analysis of substructures**
- **First results derived from STEVE event list: yearly and monthly observation rates, identification of multiple days with observations from both hemispheres**

STEVE event list - content

- 178+ observation days including 150 days with time
- Number of listed observers for individual UTC days
- Local and UTC observation day and time plus time zone
- Country, region, town
- Kp and DST index for the time of observation
- Geomagnetic storm intensity category and storm phases associated with observations
- Peak DST index, if geomagnetic storm is associated with observation
- Sources and comments
- Color codes identify:
  (1) Days with observations related to the same geomagnetic storm
  (2) Days with preliminary observation days in cases of missing observation time
  (3) Days with observations from both hemispheres
- With permission from observers to citizen science best practise: observer names, links to publicly available footage

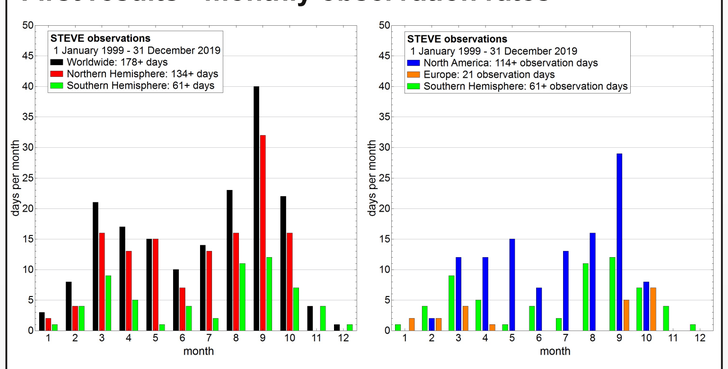
First results - yearly observation rates



Rate of yearly observations:

- Increased in 2012 in parallel with first discussions in the social media (Australia and New Zealand)
- Significant increase in 2015 in parallel with intensified discussions in the social media in Canada
- Low for Northern Europe compared to North America

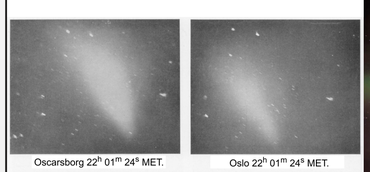
First results - monthly observation rates



Rate of monthly observations:

- Shows two equinoctial maxima
- Equinoctial maxima present in data from both hemispheres
- Pronounced September maximum for North America

Non-STEVE structures (not listed in STEVE event list)



Oscarsborg $22^h\ 01^m\ 24^s$ MET. Oslo $22^h\ 01^m\ 24^s$ MET.

28 February 1929, Norway, isolated pulsating aurora arc, height: 115 km, no aurora at the northern sky, image: Carl Størmer. Størmer (1942) published detailed descriptions, altitude and position measurements for isolated pulsating arcs and patches.

7 September 2017, Canada, detached, co-rotating subauroral pulsating arc, image: Catalin Tapardel

7 October 2018, Finland, SAR-arc, image: Timo Oksanen

7 October 2018, Finland, SAR-arc and multiple detached, co-rotating subauroral pulsating patches, image: Timo Oksanen

28 May 2017, New Zealand, giant undulations, image: David Clearwater

- First detailed descriptions of isolated, detached (subauroral) pulsating arcs and patches by Carl Størmer (1942)
- Non-STEVE subauroral arcs and patches are diffuse, without sharp N-S boundaries and discrete fine structures

STEVE structures

9 December 1933, Norway, image: Carl Størmer. Størmer called STEVE arcs 'feeble homogeneous arcs of great altitude'

8 October 2012, New Zealand, image: Stephen Voss

10 April 2018, Canada (Alberta), image: Alexei Chernenkoff

29 July 2016, Canada (Alberta), image: Catalin Tapardel

- Occur equatorward of the auroral ovals.
- Two subclasses of STEVE structures:
  (1) arcs, (2) picket fences
- Picket fence: Emission spectrum dominated by the green O^1S to ^1D aurora line at 557.7 nm (Gillies et al., 2019) with traces of N_2 first possitive emissions and without N_2^+ emissions (Mende et al., 2019)
- STEVE arc: Weak evidence for particle precipitation (Gallardo-Lacourt et al., 2018). Continuous emission spectrum (Gillies et al., 2019). Spectrum is dominated by thermal emission of an atypical hot and fast streaming plasma
- STEVE arcs mostly show purple and / or whitish colors on photographs, either with graded color transition over their height extension or with separated colors, purple in the upper part and whitish in the lower part

STEVE structures

15 August 2015, Australia (Tasmania), image: Ben Swanson

15 August 2015, Australia (Victoria), image: Richard Tatti

7 November 2015, Australia (Tasmania), image: Will Standring

7 November 2015, Australia (Tasmania), image: Ben Swanson

- STEVE event list contains observations of structures not mentioned in the literature:
  (1) Rayed STEVE arcs
  (2) STEVE arcs composed purely of rays
  (3) Ray structures continuing from picket fence rays into overlying STEVE arcs
  (4) Picket fence subtypes including bent picket fence rays
  (5) Torch-like rays or pillars evolving from a whitish STEVE arc
- STEVE dynamics currently not mentioned in the literature: Drift of ray- and patch-like substructures in the whitish part of STEVE arcs

Observations from both hemispheres

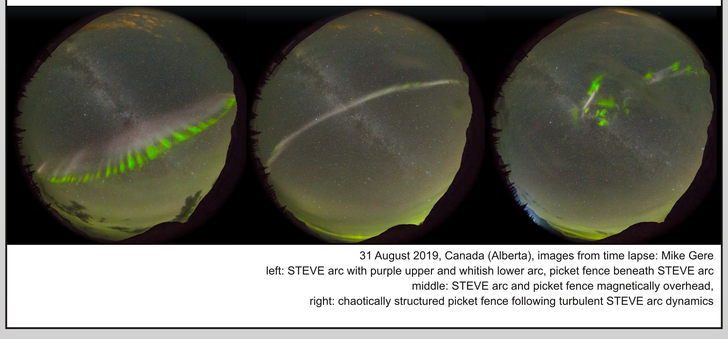
UTC day	Country (Region) [observers]	Maximum time delay
08.10.2012	New Zealand [1] | Great Britain [3]	**~12 h**
29.06.2013	USA (Michigan) [1] | New Zealand [1]	Candidate, time for USA unclear.
17.03.2015	New Zealand [3] | Germany [4]	**~8 h 20 min**
16.08.2015	USA (Wisconsin, Minnesota) + Canada (British Columbia) [5] | New Zealand + Australia (Tasmania) [3]	**16 min**
11.09.2015	Canada (Alberta) [1] | New Zealand [1]	**3 h 11 min**
20.09.2016	USA (Alaska) [1] | New Zealand [4]	**18 min**
01.03.2017	Australia (Tasmania) [2] | Denmark [1]	**8 h**
03.03.2017	Canada (Alberta) + USA (Alaska) [5] | New Zealand [6]	**37 min**
28.03.2017	USA (Minnesota) [3] | New Zealand [1]	**8 h 10 min**
22.04.2017	Canada (Alberta) [2] | New Zealand [8]	**1 h 52 min**
28.05.2017	USA (Idaho, Iowa, Michigan, Minnesota, Montana, South Dakota, Utah, Wyoming) [12] | New Zealand + Australia (Tasmania) [9]	**2 h 42 min**
17.07.2017	Canada (Alberta) [2] | New Zealand [1]	**~3 – 3.5 h**
19.08.2017	Canada (Alberta, Saskatchewan) [4] | New Zealand [7]	**6 h 27 min**
22.08.2017	Canada (Manitoba, Ontario, Saskatchewan) [5] | New Zealand [1]	**~8 h 30 min**
31.08.2019	Canada (Alberta, Saskatchewan, Yukon) + USA (Minnesota, Washington) [19] | New Zealand [4]	**2 h 53 min**
01.09.2019	Canada (Alberta, British Columbia, Saskatchewan) + USA (Michigan) [5] | New Zealand [2]	**1 h 50 min**
28.09.2019	USA (Alaska) [3] | Australia (Tasmania) [1]	**3 h 45 min**

- Event list contains 16 days with observations from the Northern and Southern Hemisphere + 1 further candidate
  - 3 days with a maximum delay of 1 h, possibly conjugate observations
  - 7 days with a maximum delay between 1 and 4 h, possibly linked to subsequent substorms
  - 5 day with a maximum delay between 4 and 9 h
  - 1 day with a maximum delay of ~ 12 h
- Nishimura et al. (2019) report on first conjugate STEVE observation, observed on 8 May 2016
- It is currently unknown how many STEVEs occur as conjugate STEVEs
- Amateur observations can help to identify conjugate observations

STEVE arcs

18 March 2018, ~ 21:30 UTC, Great Britain, image: Leigh-Ann Mitchell

10 October 2018 at 20:35 UTC, Great Britain (Shetland Islands), image: June Woodward



31 August 2019, Canada (Alberta), images from time lapse: Mike Gere
left: STEVE arc with purple upper and whitish lower arc, picket fence beneath STEVE arc
middle: STEVE arc and picket fence magnetically overhead,
right: chaotically structured picket fence following turbulent STEVE arc dynamics

In-progress research opportunities

- Refinement of our understanding of the characteristic features of STEVE structures
- Identification of yet not described characteristics
- Identification of in-situ satellite data to combine it with data from ground based observations
- Identification of early observations and research on the STEVE phenomenon. Summary of Carl Størmer's work on STEVE arcs published as a Commentary in Space Weather (Hunnekuhl and MacDonald, 2020)

Summary

- Event list for worldwide STEVE observations developed and released
- Monthly and yearly reporting rates determined on basis of nearly 800 single observations covering solar cycle 23 and ongoing solar cycle 24
- Identification of multiple days with observations from both hemispheres

Outlook

- Implementation of new and older events, pre-space era events, classification scheme and substructures
- Merging of the STEVE event list with in parallel developed Aurorasaurus STEVE event list

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