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Persistent, widespread pulsating aurora: a case study

S. L. Jones,[1] M. R. Lessard,[2] K. Rychert,[2] E. Spanswick,[3] E. Donovan,[4] and A. N. Jaynes,[2]

E. Donovan, Department of Physics and Astronomy, University of Calgary, 2500 University Drive, Calgary, AB, Canada, T2N 1N4.

A. N. Jaynes, Space Science Center, University of New Hampshire, 8 College Road, Durham, NH 03824, USA.

S. L. Jones, Space Weather Laboratory, NASA Goddard Space Flight Center, 8800 Greenbelt Road, Greenbelt, MD 20771, USA. (sarah.l.jones@nasa.gov)

M. R. Lessard, Space Science Center, University of New Hampshire, 8 College Road, Durham, NH 03824, USA.

E. Spanswick, Los Alamos National Laboratory, P.O. Box 1663 , Los Alamos, NM 87545, USA.

K. Rychert, Space Science Center, University of New Hampshire, 8 College Road, Durham, NH 03824, USA.

[1]Space Weather Laboratory, NASA

Abstract. Observations of a pulsating aurora event occurring on February 11, 2008, using the THEMIS all-sky imager array, indicate a spatially and temporally continuous event with a duration of greater than 15 hours and covering a region with a maximum size of greater than 9 hours MLT. The optical pulsations are at times locally interrupted or drowned out by auroral substorm activity, but are observed in the same location once the discrete aurora recedes. The pulsations following the auroral breakup appear to be brighter and have a larger patch size than pre-substorm. This suggests that, while the onset of pulsating aurora is not necessarily dependent upon a substorm precursor, the pulsations are affected and possibly enhanced by the substorm process. The long duration of such pulsating aurora events, enduring for several hours without interruption, is far longer than the expected

Goddard Space Flight Center, Greenbelt, Maryland, USA.

[2]Space Science Center, University of New Hampshire, Durham, New Hampshire, USA.

[3]Los Alamos National Laboratory, Los Alamos, New Mexico, USA.

[4]Department of Physics and Astronomy, University of Calgary, Calgary, Alberta, Canada.

recovery phase of a substorm, suggesting that pulsating aurora is not strictly a recovery phase phenomenon.

1. Introduction

Pulsating aurora is often observed to occur shortly after magnetic midnight in the aftermath of an auroral substorm [??]. Possible substorm related causes of pulsating aurora have been proposed, such as substorm-injected electrons triggering the onset of pulsations [??]. Some attempts have been made to show correlations between the drift of substorm-injected electron clouds, from equatorial magnetospheric observations, and the drift or expansion of widespread regions of pulsating aurora observed by ground optics [???], but with limited success due to the difficulty in obtaining good satellite conjunctions with the pulsating events.

In situ particle measurements have generally shown pulsating aurora to be caused by high-energy, tens to possibly hundreds of keV electrons (for example, **????** and **?**), scattered from the equatorial magnetosphere [???]. Several studies of magnetically conjugate pulsating auroras in the northern and southern hemisphere support this observation (for example, **??** and **?**). However, seemingly contradictory observations have been presented by **???** and **?**. See **?**, **?**, **?**, **?** and **?** for more detailed reviews of pulsating aurora.

?, in a study discussing the relationship of substorms and diffuse aurora to pulsating aurora, claim that displays of pulsating auroras "extend several hundred kilometers meridionally as well as several thousand kilometers zonally, so their behavior must be associated with large scale magnetospheric processes." A study of the occurrence rate of pulsating aurora using data from College, AK was detailed in the thesis of **?**. Note that using only one station limits the latitudinal coverage and provides little information regarding the development of the large-scale region of pulsating aurora. However, **?** is cited for determining that the occurrence frequency of pulsating aurora appears to peak around 64° and to be much lower poleward of 66° and equatorward of 60°. This study also showed that pulsating aurora occurs mainly within the near-midnight region and the dawn sector.

A statistical study presented by **?** used data acquired by four photometers in the winter of 1967-68 in Tromsø, Norway. The photometers were filtered to 428 nm with 10° field-of-view and pointed to the south with elevations of 30° and 45°, towards zenith and to the north at 45°. These four fields-of-view did not overlap; 10° maps to approximately 15 km at 95 km altitude along the zenith. The occurrence rate vs latitude and longitude was calculated for pulsating aurora (ranging from less than 25% to greater than 75%) using the photometers and shows that pulsating aurora occurs over the covered range (65° to 68° ILAT) and local times from pre-midnight to 0900 MLT.

A similar study presented by **?** acquired better spatial coverage using allsky cameras at five stations for 34 night in 1980 during solar maximum. The coverage spanned approximately 61.5° to 74.3° magnetic latitude in central Canada. This data set shows that the occurrence rate increases from around 30% near midnight to 100% near 0400 MLT when the camera shut down due to daylight. The pulsating aurora occurred mainly between 61° and 70°, with a slight peak in occurrences near 66°. Neither data set was large enough to provide reliable statistics, as the authors note.

?, referring to a previous study without citation, stated that "all-sky camera data from Byrd Station demonstrate that the pulsating aurora can extend eastward from the darkside auroral oval around to the noon meridian or even beyond". (The relative orientations of the magnetic and geographic poles in the southern hemisphere ensures that stations in the auroral zone remain in darkness 24 hours per day and can thus support optical observations in the dayside auroral zone.) In addition, Berkey (1978) measured riometer signatures of pulsating aurora in correlation with optical pulsations. The riometer signatures were found to be present even before twilight, for a half dozen events during the winter of 1967-68, indicating the occurrence of pulsating aurora in the afternoon sector. The results from the limited data available suggest that the pulsating aurora generation mechanism can operate on nearly global scales. These observations beg the question of whether or not pulsating aurora can expand to cover all MLT regions.

2. Methodology

The THEMIS all-sky imager array consists of 20 ground cameras as stations throughout North America, providing 10 hour coverage in magnetic local time with magnetic latitude coverage from around 50 to 70 degrees (see Table **??**). Each camera has a Field-of-View (FOV) corresponding to the circular area shown in figure **??** when mapped to 110 km altitude. Because pulsating aurora generally occurs at lower altitudes than other types of aurora, the ASI FOV at pulsating auroral altitudes will be slightly less, leaving coverage gaps between cameras adjacent in longitude. A circular image is projected onto the 256X256 pixel CCD, which gives a roughly 1 km resolution at zenith, with much poorer spatial resolution towards the edges of the FOV. The result is that auroral patches are typically well resolved directly overhead the imagers and often unresolved at the edges of the FOV.

The panchromatic imagers respond to a large number of auroral lines simultaneously, and their response is wavelength dependent so it is unwise to think of their sensitivity in quantitative terms. That being said, we know anecdotally that the THEMIS-ASIs generally do not capture aurora with corresponding greenline or redline brightnesses less than a few hundred Rayleighs, so there are undoubtedly dim patches that are unresolved in the images from these instruments. The frame rate of 1 image per 3 seconds makes aliasing a concern for short period pulsations. Therefore, the study of Jones [2011] focused on a subset of pulsating aurora, identifying patches with periods of 6 seconds or longer and greater than approximately 1 kR brightness. Images from the entire THEMIS array, mapped to geomagnetic coordinates, allow observation of widespread regions of pulsating aurora, showing the spatial/temporal continuity of a given event.

3. Pulsating aurora event: February 11, 2008

A recent statistical study of pulsating aurora using the THEMIS ASI array during the period from September 2007 through March 2008 is presented in Jones [2011]. The study includes pulsating aurora events identified in the Gillam, MB camera on 74 out of 119 days of scientifically useful data. Included in these events are several long-duration events lasting on the order of several hours. The event presented here occurred on February 11, 2008 with a duration of approximately 15 hours and a maximum spatial extent of greater than 10 hours MLT.

3.1. 0000-0200 UT

Between the hours of 0000 and 0200 UT, dynamic discrete aurora develops, starting at the easternmost edge of the THEMIS ASI array in the Nain (18) camera before magnetic midnight, occurring at 0340 UT at this station. The discrete aurora gradually expands westward into the FOV of the camera at Umiujaq (16) and then Gillam (13) where the structure is not discernible initially due to cloud cover.

3.2. 0200-0345 UT

By 0200 UT, the discrete aurora has migrated farther westward, clearly seen now at Gillam (13), then moving over Forth Smith (11) and Fort Simpson (8). Pulsations have begun in the eastern cameras at Nain (18) and Goose Bay (20), south of where the discrete aurora developed, along the equatorward part of the auroral oval. Note, the pulsations are clearly visible in the ASI mosaic movie at around 0220 UT, at which point pulsations are discernible in the cloudy images to the west at Umiujaq (16). The discrete aurora continues as pulsating aurora expands westward into the camera at Gillam (13), at which point the pulsating aurora spans at least 4 hours MLT and may extend eastward beyond the view of the THEMIS array. Pulsating aurora continues to expand westward at least as far as Fort Smith (11), while at 0300 UT it appears that the discrete aurora spans the poleward edge of the auroral oval throughout the entire THEMIS array (excluding the cameras which have not yet turned on due to sunlight) with pulsating aurora to the south, filling the equatorward section of the visible portion of the auroral oval. The pulsating patches brighten over time as the discrete aurora gradually fades away.

It is interesting to note that the observed discrete aurora did not result in an obvious auroral substorm, but rather faded as the pulsating aurora intensified.

At around 0346 UT most of the THEMIS all-sky cameras are operational (with the exception of those in Alaska) and pulsating aurora can be seen across the entire array, suggesting the pulsating aurora spans 9 hours MLT at minimum. At this point, the same continuous region of pulsating aurora, which gradually expanded westward from Nain (18) where the pulsations were first visible at around 0200 UT, has persisted for almost two hours with no obvious substorm precursor.

3.3. 0345-0430 UT

Discrete aurora again forms in the westernmost part of the ASI array at Fort Yukon (4) at around 0345 UT. This discrete aurora washes out or interrupts the pulsating aurora in this localized region until around 0400 UT. The pulsating aurora to the east is pushed gradually equatorward by bands of discrete aurora to the north until eventually, starting at 0427 UT, the widespread region of pulsating aurora is overtaken and either drowned out or interrupted by bright substorm aurora in the region of Fort Smith (11), Gillam (13) and Umiujaq (16) one to two hours before magnetic midnight, with some pulsating aurora now visible to the west at Fort Yukon (4) and Fort Simpson (8). The pulsating aurora is still visible across the THEMIS array whenever the dynamic, discrete aurora moves poleward.

3.4. 0430-0715 UT

After auroral breakup strong pulsations return in regions where they were visible pre-substorm. Although many of the western cameras become cloudy, bright and large pulsating patches are visible in the east and are faintly discernible across the rest of the array. The pulsating patches appear larger and brighter than those observed pre-substorm. This widespread pulsating aurora continues uninterrupted until the next localized substorm starting at around 0713 UT at Fort Simpson (8) and Fort Smith (11), again a couple of hours before magnetic midnight. The result is strong, bright pulsations throughout the entire array.

3.5. 0715-1715 UT

After 1000 UT, very bright pulsations are visible throughout the entire array (see Figure **??**). Figure **??** shows North-South keograms from 8 stations showing uninterrupted pulsations from around 10-11 UT. Longer period pulsations can also be seen in several stations, e.g. KUUJ, SNKQ, and GILL. Various pseudosubstorm activity occurs throughout the night (see Figure **??**), seeming to brighten the nearby pulsating patches (see Figure **??**). Strong pulsations continue in the easternmost cameras even until they turn off due to sunlight, implying that pulsating aurora extends into the sunlit sector. Images from the other cameras show the pulsating aurora continues up until the end of the available data at 1715 UT. Thus the spatial extent and time duration of this event are necessarily underestimated.

4. Discussion and Summary of Observations.

The February 11, 2008 pulsating aurora event consists of continuous pulsating aurora covering a widespread region and persisting for at least 15 hours with brief, localized interruptions due to auroral substorm activity. This observation suggests that pulsating aurora is not strictly a part of the substorm recovery phase but is a distinct phenomenon that is temporarily interrupted or displaced by auroral substorms and may in some way be enhanced as a result of substorms.

The sequence of images in Figures **??**, **??**, and **??** depict pulsating aurora spanning the entire North American continent and persisting during and after a substorm over Alaska. The associated movie (see AGU web address) clearly shows that the pre-existing region of pulsating aurora remains unchanged as the substorm evolves, except that the pulsations appear brighter in the region near the substorm during the recovery phase. This is one of more than 20 events analyzed by Jones et al. [2011] that suggest that substorm-injected electrons likely do not directly cause pulsating aurora, but may provide a seed population for pulsating auroral electrons, as suggested by **?**. The pulsating aurora can be very wide spread in MLT before, during, and after a substorm and can persist uninterrupted for several hours. This is far longer than the typical substorm recovery.

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Table 1. Geographic and magnetic locations of primary stations for pulsating aurora.

	Geographic		AACGM		UT of
Site Location	Lat (N)	Lon (E)	Lat (N)	Lon (E)	2400 MLT
Gakona (1)	62.41	214.84	63.1	267.0	1049
McGrath (2)	62.95	204.40	61.7	258.0	1133
Kiana (3)	66.97	199.56	65.0	251.5	1204
Fort Yukon (4)	66.56	214.79	67.3	263.8	1102
Whitehorse (6)	61.01	224.78	63.9	277.6	1002
Fort Simpson (8)	61.8	238.8	67.8	291.7	0858
Fort Smith (11)	60.02	248.04	68.0	304.3	0807
Gillam, Manitoba (13)	56.38	265.36	67.1	331.0	0634
Sanikiluaq (16)	56.54	280.77	66.3	358.2	0505
Kuujjuaq (18)	56.5	298.3	65.1	22.5	0340

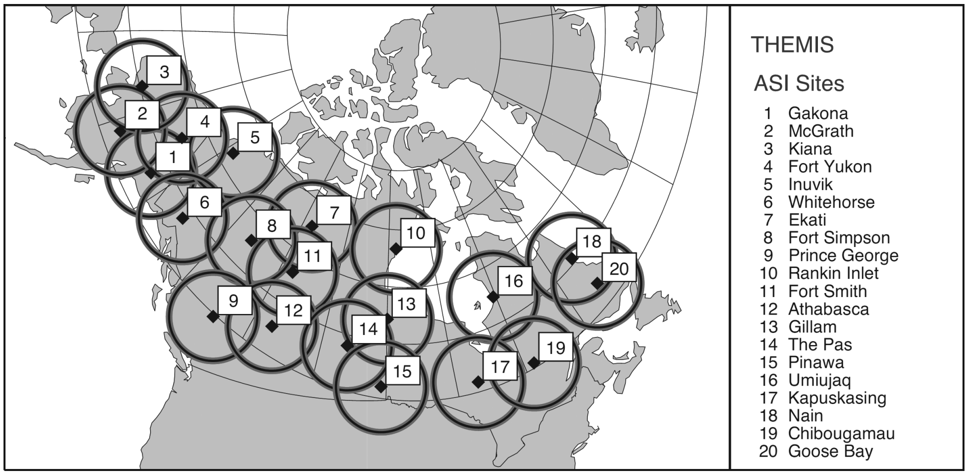


Figure 1. Map showing the locations of THEMIS allsky cameras. Data for this study include observations from Fort Smith (11) and Gillam (13) for longitudinal studies. Adapted from **?**.

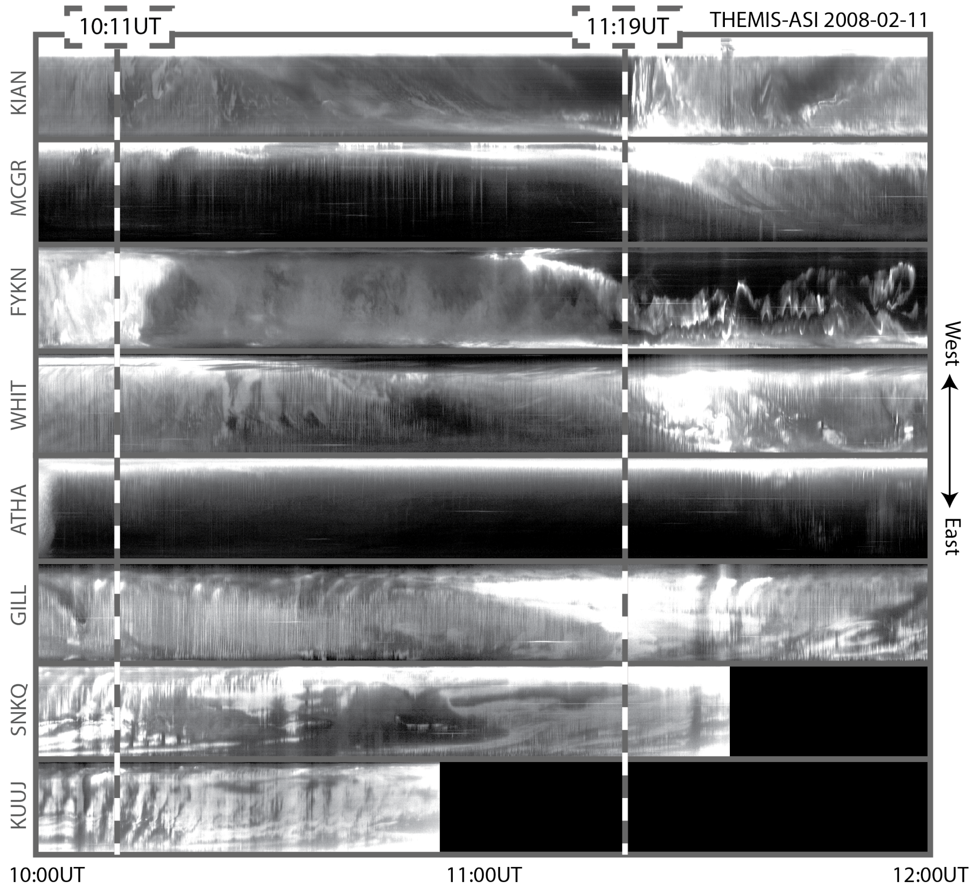
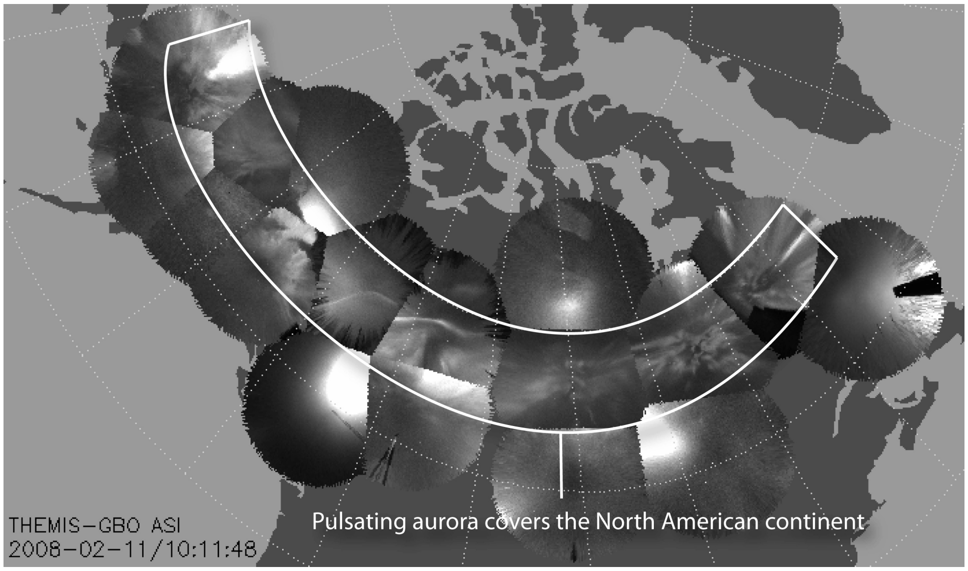
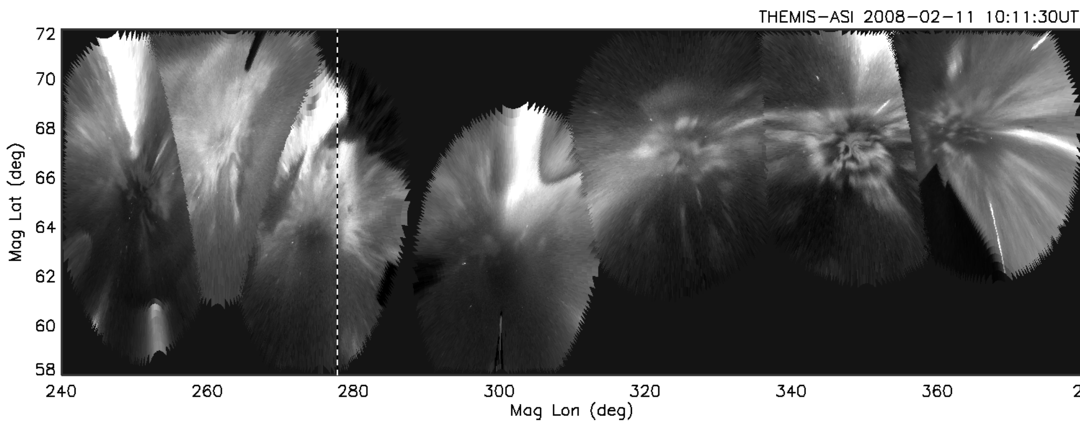


Figure 2.

North-South keograms from 8 stations showing uninterrupted pulsations from around 10-11 UT. Longer period pulsations can also be seen in several stations, e.g. KUUJ, SNKQ, and GILL. The two dashed lines mark the time corresponding to the following two mosaic figures.

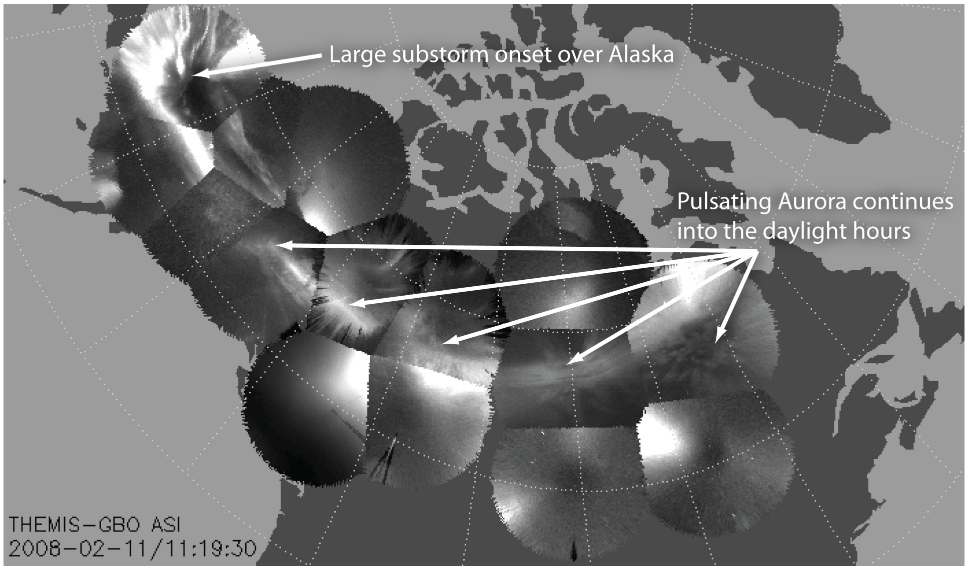


(a)

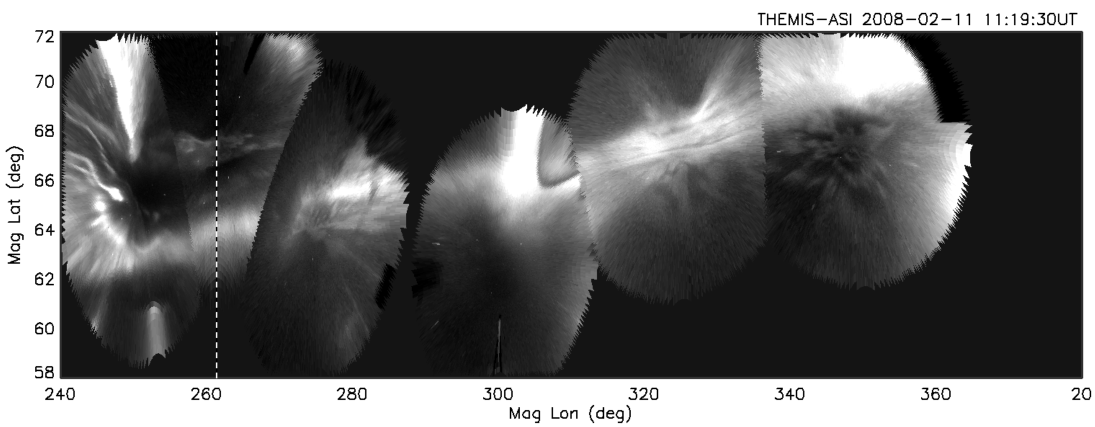


(b)

Figure 3. a.) All sky mosaic in geographic coordinates showing pulsating aurora extending across North America at 1011 UT. b.) All-sky images from 7 cameras at 1011 UT (Fort Smith is removed due to clouds.) and mapped into geomagnetic coordinates. The dashed line corresponds to magnetic midnight.



(a)



(b)

Figure 4. a.) All sky mosaic in geographic coordinates showing pulsating aurora extending across North America at 1119 UT. b.) All-sky images from 6 cameras at 1119 UT (no data for KUUJ and Fort Smith is removed due to clouds.) and mapped into geomagnetic coordinates. The dashed line corresponds to magnetic midnight.

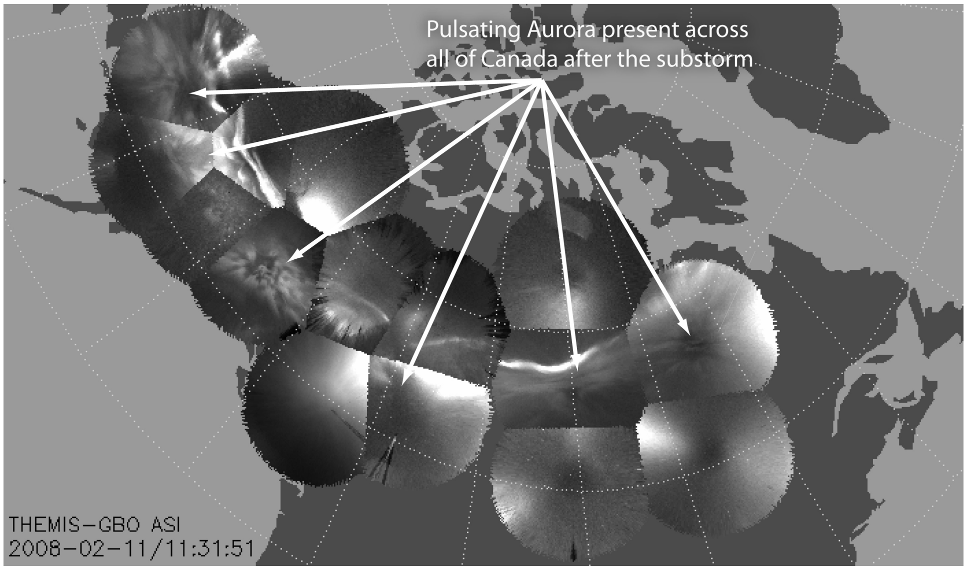


Figure 5. Pulsating aurora spans North American Continent after substorm at 1131 UT.