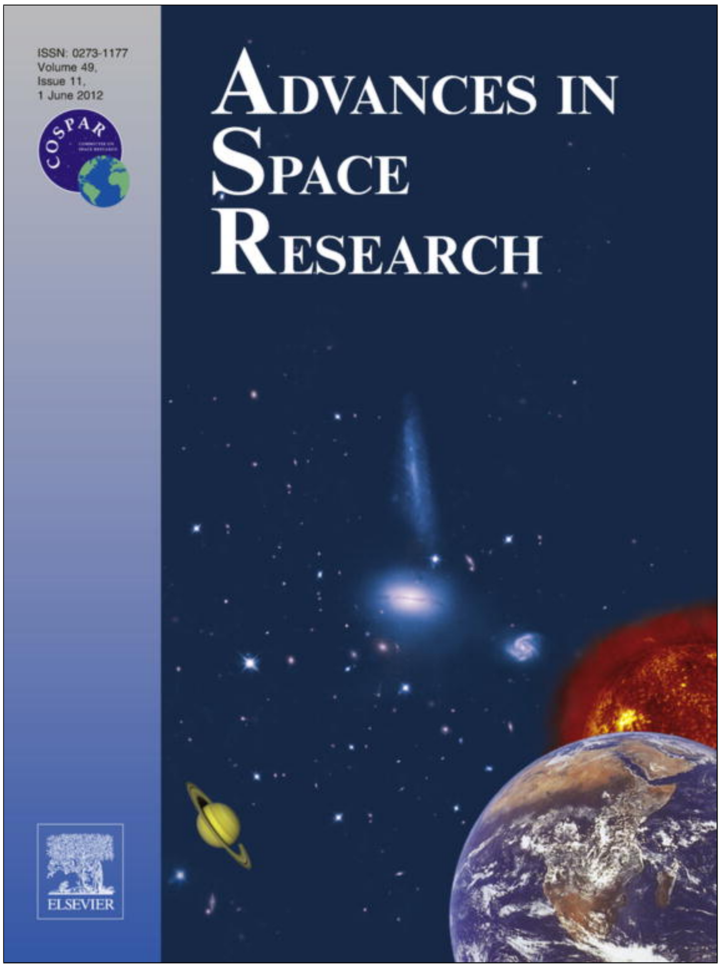
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Comparison of Antarctic riometer radio wave absorption and THEMIS mission energetic electron fluxes

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Abstract

Simultaneous observations of in situ plasma properties in the tail of the Earth's magnetosphere and of ground based instruments, lying on the same geomagnetic field lines, have recently proved to yield significant new results. In most cases magnetosphere ionosphere interactions during the night-time northern hemisphere conditions are studied. Here, observations of energetic electrons in the tail of the Earth's magnetosphere made by the THEMIS mission satellites are compared with auroral radio wave absorption determined by riometers in the Antarctic for sunlit conditions. Days for which satellites and riometers are connected by the same geomagnetic field line are selected using a geomagnetic field model. The six days analysed show clear associations between fluxes and absorptions in some cases. However, these do not necessarily correspond to conjugacy intervals. Hours of positive associations are 1.65 times those for negative associations, all hours and days considered (1.42–3.6 on five days and 0.58 on the other day). These computations are assumed appropriate since the footprints of the satellites used approximately follow corrected geomagnetic parallels for all six days studied. The use of a finer parameterization of geomagnetic models to determine conjugacy may be needed.

Keywords: Riometer absorption; THEMIS mission; Magnetosphere; Antarctic ionosphere

1. Introduction

During the December 2007 to March 2008 interval the five THEMIS satellites (**T**ime **H**istory of **E**vents and **M**acroscale **I**nteractions during **S**ubstorms; as described in Burch and Angelopoulos, 2008) were located well in the tail of the Earth's magnetosphere during a significant part of their orbital periods (apogees from about 10 to 30 Earth's radii), in the so called "tail phase". The instruments on board measured, among other quantities, electric (EFI) and magnetic (FGM and SCM) fields, and energetic particle properties (ESA, SST) including fluxes of energetic electrons for a range of energies.

Several simultaneous tail phase THEMIS and ground-based instrument observations have been reported (e.g. Du et al., 2011; Liu et al., 2011; Sergeev et al., 2011; Xing et al., 2010). In most cases, the reports correspond to ground based instruments such as magnetometers, all-sky imagers and cameras deployed in the Canadian and Alaskan longitude sectors in the northern hemisphere, and are for night-time conditions. Both particular cases and statistical studies of the properties of plasmas in the plasma sheet, the low latitude boundary layer, the magnetosheath, and the solar wind have been made.

During the same THEMIS tail phase several riometers (relative ionospheric opacity meter) located on the Antarctic southern fringe of the auroral zone and on the polar cap measured auroral radio wave absorption. The absorption is

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Table 1
Locations of Antarctic riometers, time of magnetic local midnight and McIlwain L-value.

Riometer	Latitude, °S	Longitude, °E	CGM latitude, °S	CGM longitude, °E	UT, decimal hour	L, Earth radii
P1	83.86	129.61	80.34	16.73	3.79	–
P2	85.67	313.62	70.11	19.59	3.51	8.77
P3	82.75	28.59	72.06	40.66	2.04	10.71
SP	90.00	0.00	74.26	18.61	–	13.80
McM	77.85	166.67	79.97	326.36	7.05	–

Corrected geomagnetic coordinates (CGM) for 2008 at 100 km height (http://omniweb.gsfc.nasa.gov/vitmo/cgm_vitmo.html).

produced by the interaction between precipitating energetic electrons and the atmosphere constituents at heights of around 100–120 km (e.g. Hargreaves, 1969). The present report compares time series of THEMIS electron fluxes and of riometer absorptions in an attempt to find whether the electron fluxes could be considered as the source for the absorptions. As the comparisons are for the Antarctic summer, they correspond mostly to a sunlit ionosphere, when optical observations are difficult or impossible to make. It seems that no comparisons of this type have been reported before.

2. Data analyses

Time series of electron fluxes and riometer absorptions were selected for days when the feet of the geomagnetic field lines on which at least one satellite pass over the field of view of a riometer (it can be said they are geomagnetically conjugate). The T89 geomagnetic field model (Tsyganenko, 1989) was used to determine field lines. Computations were made with the TTRACE2IONO.PRO code (http://sprg.ssl.berkeley.edu/~davin/idl/socware/external/IDL_GEOPACK/trace/ ttrace2iono.pro; latest changes made by Patrick Cruce). Electron fluxes were downloaded from the http://themis.ssl.berkeley.edu/data/themis site.

During most days from 1 of January to 31 of March 2008 (75 days) the above condition were fulfilled at least once during the day. However, only for six days both electron fluxes and riometer absorption were readily available. Table 1 gives riometer locations, and Table 2 gives general information on the six days.

Fig. 1 shows the locations of the five satellites in the GSM coordinate system corresponding to 02:04 UT (04:04 LT, around MLT midnight) of 29 January 2008, the first case analysed. The Antarctic footprints of the geomagnetic field lines crossed by four THEMIS satellites from 01:04 to 03:04 UT (time runs anticlockwise) are shown in Fig. 2, together with the fields of view (at about a height of 100 km) of five riometers. Fig. 3 shows the absorption observed by riometers P1, P2, P3 and SP (at 38.2 MHz) and the electron fluxes observed using the ESA and SST instruments (McFadden et al., 2008) on-board satellites B, C and D, during all the day.

Similar information is given in Figs. 4–6 for the case of 2 February (03:53 LT, around MLT midnight). Note that fluxes only for satellite B are available in this case.

A model derived for the northern hemisphere is used to estimate the centre and the polar- and equator-ward fringes of the riometer auroral absorption zone in the southern hemisphere (Foppiano and Bradley, 1983; Foppiano, 2006). This is because no such detailed morphology of auroral absorption is available for the southern hemisphere. Assuming a Gaussian latitude dependency of auroral absorption, the empirical equations used for the latitude of maximum absorption (λ_m) and the width of the zone (σ_λ) are:

$$\lambda_m = 68.9(1 - 0.014\text{Kp})$$
$$\sigma_\lambda = 2.16(1 + 0.17\text{Kp}),$$

in degrees of corrected geomagnetic latitude.

Table 2
General information on selected days of January–March 2008.

Date	Interval, UT	Conjugacy time, UT (~MLT)	Kp[1]	THEMIS satellite	Dist.[2], Earth radii	CGM lat., °S[3]	CGM long., °E[3]	Antarctic riometer
29 Jan	01:04–03:04	02:04(00:00)	1+	B	30.4	72.5	40.8	P3
2 Feb	00:53–02:53	01:53(00:00)	4+	B	30.9	72.0	40.4	P3
18 Feb	01:51–03:51	02:51(22:50)	1–	B	28.0	69.6	20.4	P2
20/21 Feb	23:13–01:13	00:13(22:10)	3–	B	30.9	71.7	41.8	P3
24/25 Feb	23:03–01:03	00:03(22:00)	1+	B	30.9	71.9	41.5	P3
28/29 Mar	23:30–01:30	00:30(20:30)	2	C	17.2	70.2	19.9	P2

[1] At the time of conjugacy.
[2] Distance between satellite and Earth.
[3] Corrected geomagnetic coordinates of field line footprints at the time of conjugacy.

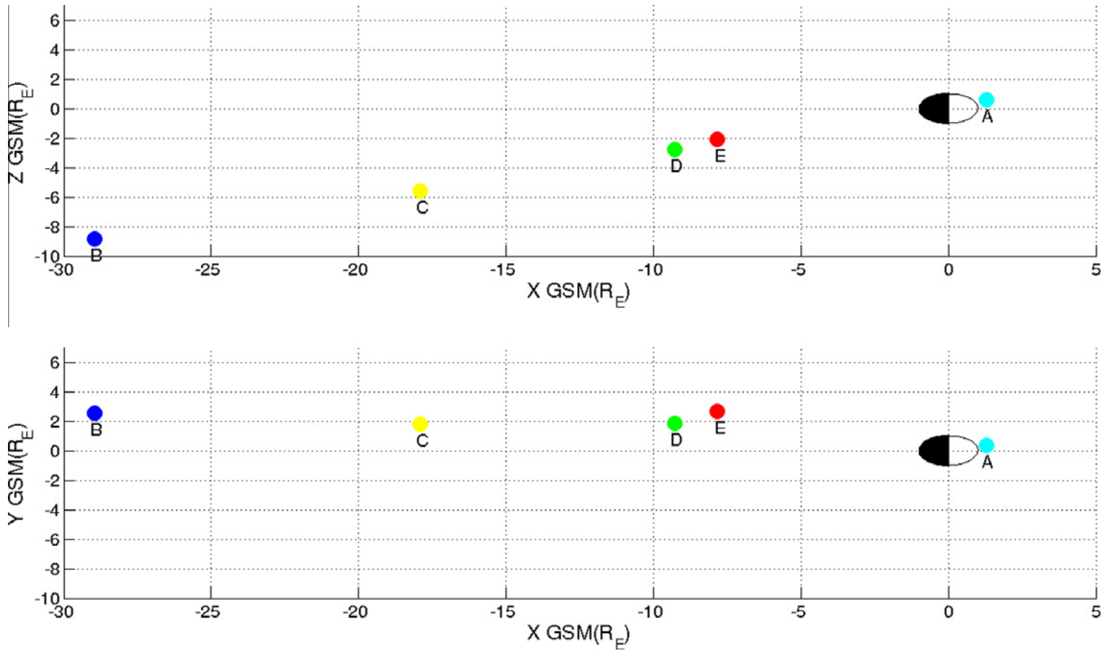

Fig. 1. Location of the five THEMIS satellites in the GSM coordinate system at 02:04 UT of 29 January 2008. (a) XZ plane. (b) XY plane.

3. Results

On 29 January 2008 geomagnetic activity was very low (ΣKp 8). For these conditions the auroral radio-wave absorption zone centre should be at about 67° corrected geomagnetic latitude. Then, for the 01:04–03:04 UT interval the footprints of THEMIS D and E would be near

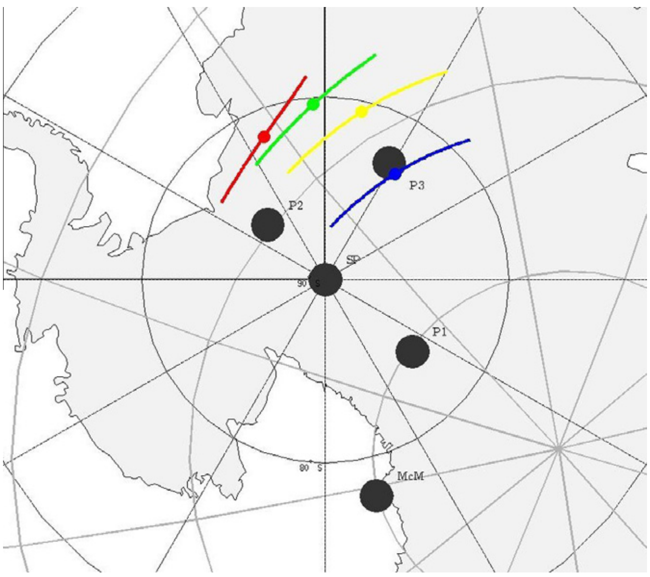

Fig. 2. Field of view (at about 100 km height) of Antarctic riometers (filled black circles) on geographic (black lines) and corrected geomagnetic (grey lines) coordinate systems. Geomagnetic field line footprint of THEMIS B satellite for the 01:04–03:04 UT of 29 January 2008 interval crossing P3 riometer field of view (blue). Footprint at 02:04 UT highlighted. Footprints of other THEMIS satellites also shown (C, yellow; D, green and E, red).

the centre of the absorption zone and the footprints of THEMIS C and B would be on the pole side. On the ground, riometer P2 would be closer to the centre of the auroral absorption zone than riometer P3. SP and P1 riometers would be well into the polar cap. Fig. 3 shows that for the 01:04–03:04 UT interval, electron fluxes of a few keV [ESA channel 26] are observed by satellite B, small fluxes of a relatively "harder" population by satellite C [SST channel 2] and larger fluxes by satellite D [SST channel 2]. However, no auroral absorption is observed on all four riometers.

For the rest of 29 January, the footprints of satellites B and C follow approximately parallel trajectories of corrected geomagnetic latitude between about 68° and 72° covering the whole 360° of corrected geomagnetic longitude. Satellites D and E do the same but for around 180° only. For these conditions, clear auroral absorption events are observed by P3 and P2 riometers from about 03:00 to 05:00 and 08:00 to 11:00. The P3 events being shorter (start later and end earlier) and weaker, as it would be expected from their location relative to the centre of the absorption zone. Smaller events are hardly observed by P3 around 16 UT. For the first two events, there seems to be a clear association with electron fluxes observed by satellites C, for all energies, and D for the more energetic electrons. In the case of satellite B only the lower energy electron fluxes are observed in the first interval. The association between fluxes and absorptions is seen mostly on the time structure rather than on absolute values. As it is well known, the determination of auroral absorptions from electron fluxes requires several assumptions, a discussion of which is beyond the scope of this preliminary analysis. Hargreaves et al. (2010) addresses this subject thoroughly. It is to be noted that during part of the first interval intensification

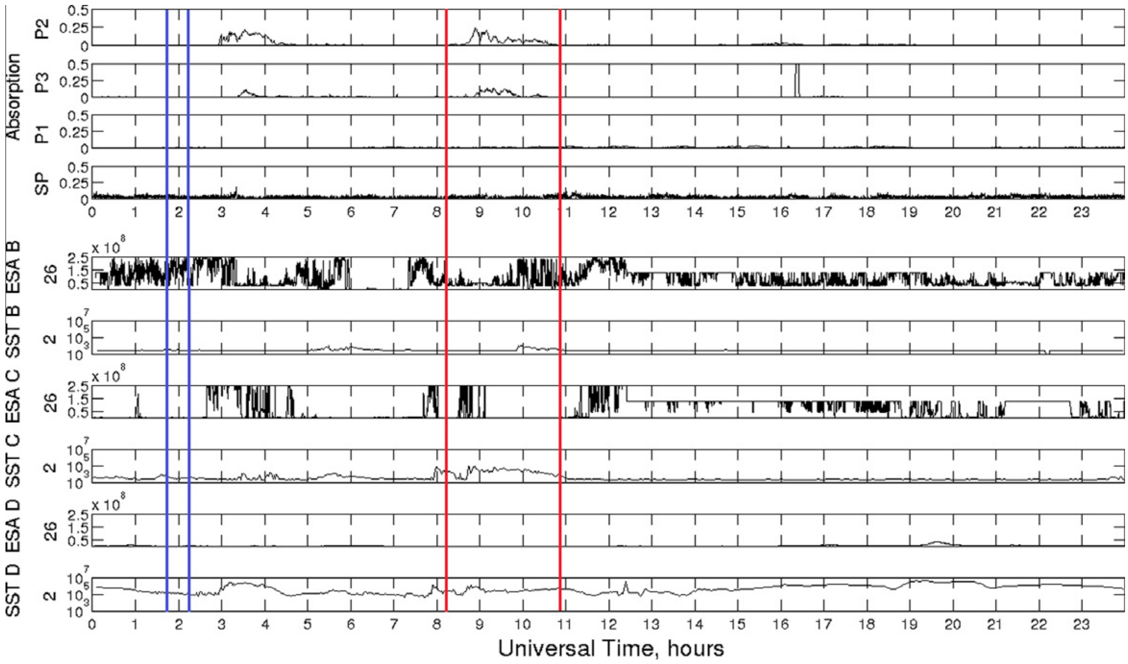

Fig. 3. Ionospheric absorption [dB] at 38.2 MHz observed using P2 (85.67°S; 46.38°W), P3 (82.75°S; 28.59°E), P1 (83.86°S; 129.61°E) and SP (90°S) riometers and electron fluxes [$cm^{-2}\,s^{-1}\,st^{-1}$] of 3.9–5.2 keV [channel 26] and of 31.5–39.7 keV [channel 2] observed by the ESA and SST instruments, respectively, on board THEMIS B, C and D satellites during 29 January 2008. Narrow spaced vertical lines are for intersection times of B satellite footprints and riometer field of view. Wide spaced vertical lines are for one riometer P2 absorption event onset and end.

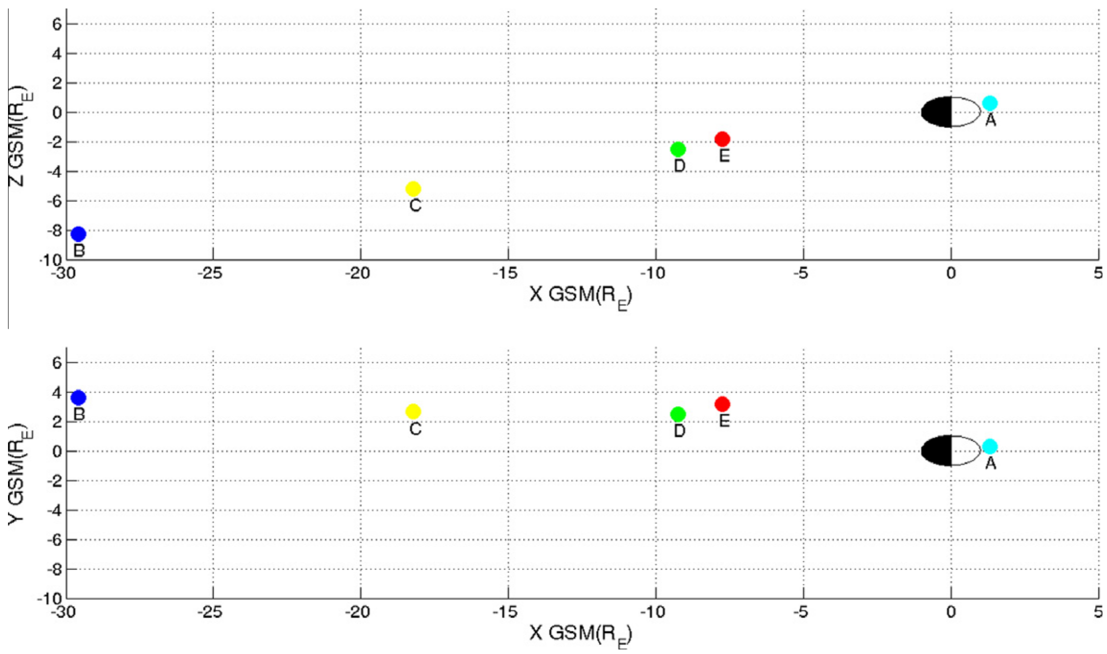

Fig. 4. Same as Fig. 1 but for 1:53 UT of 2 February 2008.

of auroral arcs are observed in the northern hemisphere at conjugate locations (Lui et al., 2008).

Larger and more frequent absorption events are observed in all four riometers during 2 February 2008, probably associated with increased geomagnetic activity (ΣKp 26), as depicted in Fig. 6. In this case, the auroral absorption zone centre would be more equatorward (around 65° corrected geomagnetic latitude) and the zone would be wider. However, the footprints of the four satellites considered are also more equatorward for the 00:53–01:53 interval (Fig. 5). Thus, relative conditions are similar to those for the 29 January interval. Unfortunately, observed fluxes only for satellite B are available. As for the observations of 29 January, here again there is no

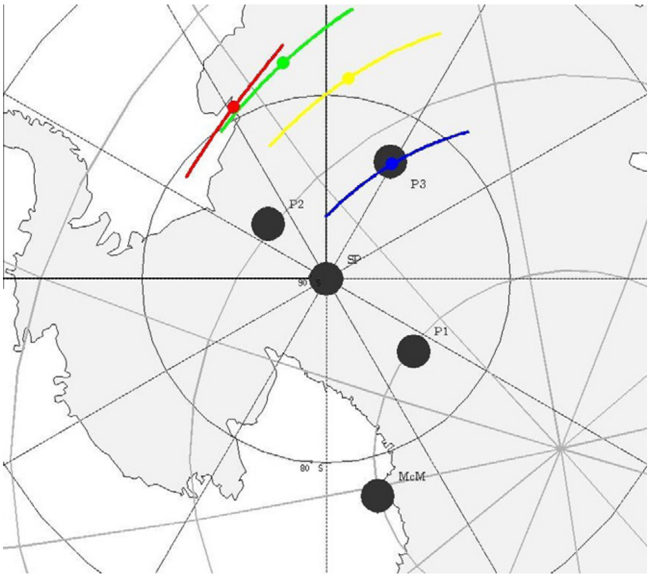

Fig. 5. Same as Fig. 2 but for 00:53–02:53 UT of 2 February 2008 interval.

absorption around the time of conjugacy (01:53) and there is an association between fluxes and absorptions at other times. The footprints of satellites B, C, D and E also follow similar paths.

The results for all six days considered here are similar. To quantify possible associations between fluxes and absorptions, a contingency table was calculated for satellites B and C. The number of hours for which four conditions apply were counted: (1) FY/AY, (2) FY/AN, (3) FN/AY and (4) FN/AN, were F and A stand for observed fluxes and absorptions, and Y and N for yes and no, respectively. This was assumed appropriate since, as already mentioned, the footprints of satellites B and C follow corrected geomagnetic parallels for all six days studied. Conditions (1) and (4) are regarded as positive association and conditions (2) and (3) otherwise. There are a total of 84 h of positive association and 51 h of negative association, giving an average rate of 1.65. Rates for a given day ranged from 1.42 to 3.6 on five days and 0.58 on the other day. In all cases the computation included more than 20 h for each day. The highest rate is for 25 of February, the day of lowest geomagnetic activity level.

More intervals could be eventually reported when riometer absorption values become available, particularly for SP.

4. Conclusions

Comparison between THEMIS mission tail season observations of keV electron fluxes and ground based Antarctic radio wave absorption observations have not been made so far. These comparisons may be valuable since they are for night-time but ionospheric sunlit conditions (southern hemisphere summer).

The few intervals analysed show clear associations between fluxes and absorptions for some cases. However, these do not necessarily correspond to conjugacy intervals. Hours of positive associations are 1.65 times those for negative associations, all hours and days considered (1.42 to 3.6 on five days and 0.58 on the other day). These computations are assumed appropriate since the footprints of the satellites used approximately follow corrected geomagnetic parallels for all six days studied.

The use of finer parameterization of geomagnetic models to determine conjugacy may be needed.

An analysis of more intervals is needed to draw more specific conclusions.

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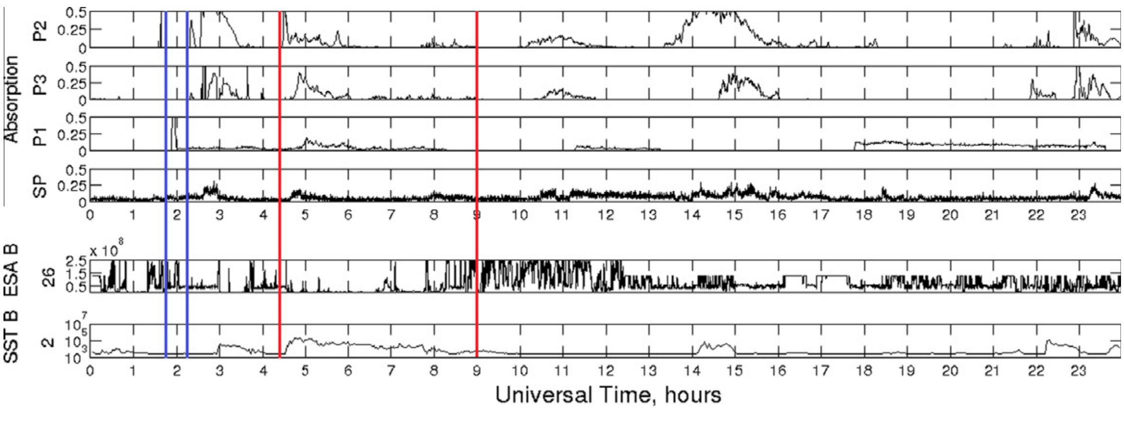

Fig. 6. Same as Fig. 3 but for THEMIS B satellite only during for 2 February 2008.

1110729. Comments received from two referees are most appreciated.

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