Deliverable 4.3

Online provision of auroral alert and tracking system

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NOTICE

This report has been prepared under the scope of the AFFECTS project in collaboration of the following participants of Work Package 4 “Forecasting tools and Modelling” with Lead of SRI NASU-NSAU:

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1. Introduction

This report describes an “Online provision of auroral alert and tracking system”, from now on termed the Auroral electrojet tracker, as designed in order to meet the requirements of Deliverable D4.3 in WP4 “Forecasting tools and Modelling” of the AFFECTS project.

The Auroral electrojet tracker consists of three parts allowing users from inside as well as from outside the AFFECTS consortium to monitor and track the movements of the auroral electrojet, and hence the auroral oval, in real-time in the European sector, based on geomagnetic variation measurements performed by the Tromsø Geophysical Observatory (TGO). Part one is a map where the poleward and equatorward edges of the auroral oval are indicated as well as plots where the relevant components of the geomagnetic field variations as function of latitude are indicated. The second part is a graphical representation of the strength and latitude of the maximum in geomagnetic variations in the European sector. The third part is an ASCII file, which is updated in near real-time, containing numerical values of the poleward and equatorward edges of the auroral oval at present and the previous three hours.

The report starts by giving a short introduction about the auroral oval and how it is related to the auroral electrojets. Furthermore, it illustrates how the ground magnetic signature of the electrojets may be used to identify the auroral oval. Lastly the final auroral electrojet tracker is presented.

2. Auroral oval determination by means of geomagnetic measurements – Concept

2.1 The auroral ovals and related electrojets

The auroral ovals are oval shaped bands of aurora with radii of approximately 3,500 km and foci in the vicinity of the geomagnetic poles. The ovals represent the regions of Earth’s upper atmosphere where electrons and protons are able to precipitate along the geomagnetic field from the near geospace. A picture of the auroral oval as seen from the Dynamic Explorer 1 spacecraft is shown in **Figure 1**.

The auroral ovals are fixed with respect to the sun and the Earth rotates under them. Because of the offset of the geomagnetic dipole axis (and hence the oval centres) with respect to the Earth rotational axis this allows for diurnal changes in the location of the aurora. Under normal conditions in the European sector, the aurora can be seen over Svalbard (Norway) during the day and above northern Fennoscandia during the night. Under disturbed conditions the ovals expand and aurora reach latitudes where it is not commonly seen. This is illustrated in **Figure 2**, where aurora can be seen to cover a wide belt from southern Fennoscandia to central Europe.

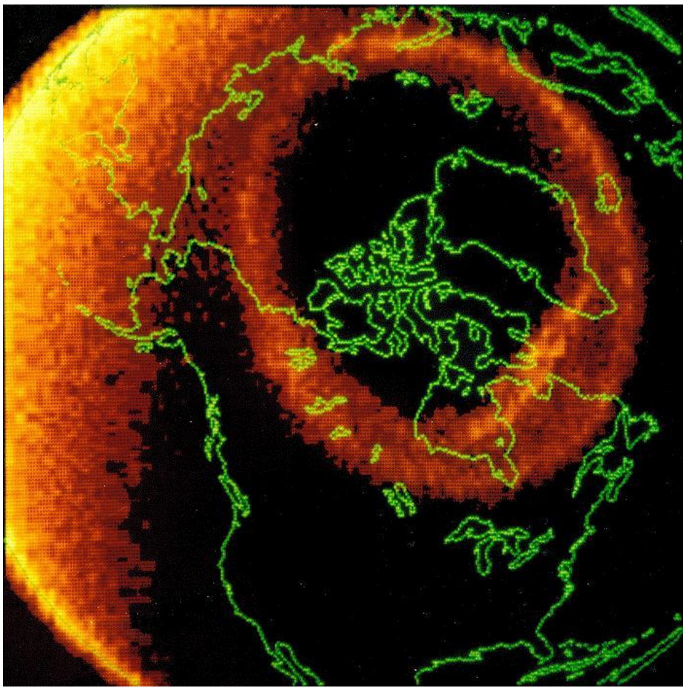

Figure 1: *The northern auroral oval as seen from the Dynamic Explorer 1 spin scan auroral imager. The bright light seen to the left represents scattered sunlight from the dayside of the Earth. (Source: NASA)*

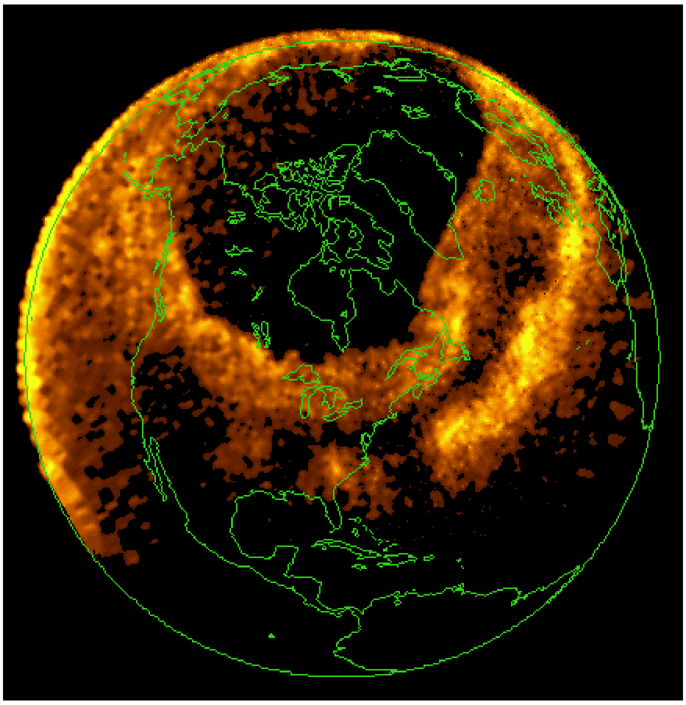

Figure 2: *The southern auroral oval as seen from the Dynamic Explorer 1 spin scan auroral imager mapped to the northern hemisphere during a great storm of March 1989. (Source: NASA)*

The dynamics, sizes and shapes of the auroral ovals are determined by the interaction between the geomagnetic field and the solar wind. This interaction allows for currents flowing in and out of the upper atmosphere, these currents are closed by horizontal currents in the ionosphere. Large currents flows along the auroral ovals, these are termed the auroral electrojets. In the dusk sector in the northern hemisphere the electrojet flows eastward, and in the dawn sector it flows westward. The electrojets in relation to the auroral oval are illustrated in a simplified manner in **Figure 3**. In the Figure the auroral oval is seen from above, 12 MLT indicated in the upper part indicates magnetic local noon and, thus, the direction towards the sun. Crosses and dots indicate currents flowing into and out of the ionosphere, solid arrows represent electrical fields. The dotted lines represent currents induced by the presence of the electrical fields and the vertical geomagnetic field. As is seen, in the dusk sector (left part of the figure), the Eastward electrojet is indicated within the oval. On the other side, in the dawn sector (right part of the figure), the Westward electrojet is indicated.

The magnetic field disturbances created by the auroral electrojets are observed on a routine basis from any magnetometer station located in auroral latitudes. Since the electrojets are intimately connected to the auroral oval, and both are aligned in the east-west direction (along the magnetic latitudes), the latitudinal magnetic signature of the electrojet may be used in order to identify its position, and hence the position of the auroral oval. Furthermore, since the oval width and location is governed by the interaction between the geomagnetic field and the solar wind and therefore will change with time, its dynamic behaviour may be tracked using latitudinally spaced ground-based magnetometers.

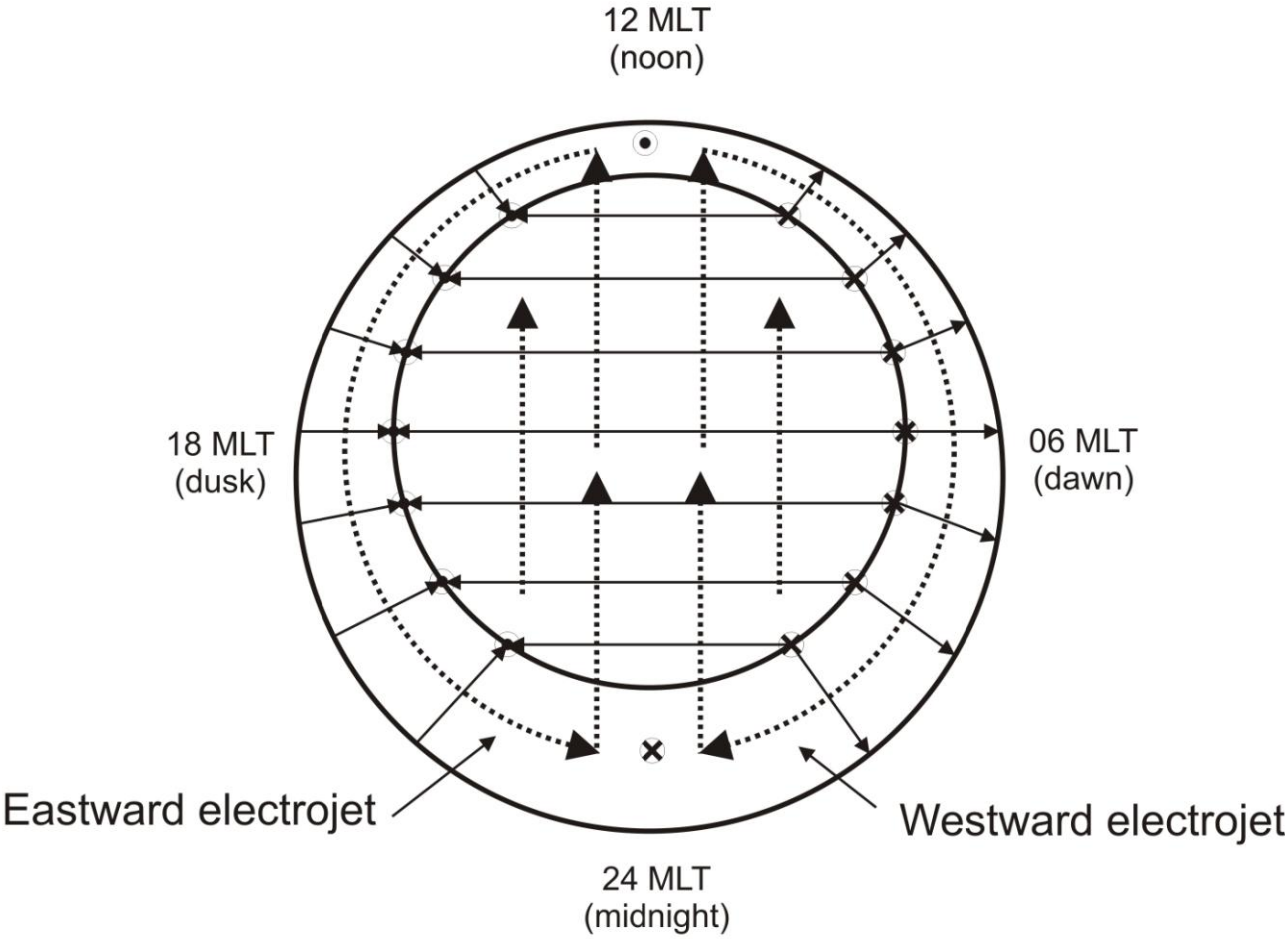

***Figure 3**: Relationship between auroral oval and electrojets*

2.2 The latitudinal signature of the auroral electrojet

As discussed above, the electrojets flow in the eastward and westward direction of the auroral oval in the dusk and dawn sectors, respectively. Any current will induce its own magnetic field, and it is this field which is observed as a magnetic field variation at stations at auroral latitudes. The latitudinal, magnetic signature of the electrojets may be simulated assuming they are sheet currents flowing 110 km above ground. This is illustrated for a situation in the auroral oval close to the dusk meridian in **Figure 4**. The situation corresponds to the location marked 18 MLT to the left in Figure 3. The coordinate system used in the simulations is the XYZ system commonly used in geomagnetic observations, the x-axis points northwards, the y-axis points eastwards and the z-axis points downwards. In the bottom panel of Figure 4 the current system as function of latitude is shown. At low latitudes the current is zero, between 65 and 75 degrees the eastward electrojet is flowing, hence the positive sign. North of the electrojet there is a weaker polar cap return current flowing towards the sun / dayside. In the top panel the resulting magnetic field variation owing to the currents in the x-component is shown, the x-component is here the horizontal component. As can be seen the magnetic field increases to a maximum close to the middle of the electrojet, and it decreases below zero further north where the oppositely directed polar cap current is situated. It can also be seen, that the x-component variation is dispersed latitudinally relative to the electrojet and, thus, cannot be used to determine the extent of the oval. However, looking at the middle plot of Figure 04, we clearly see that the z-component (i.e. the vertical component) of the magnetic field variation gets a local maximum and minimum at the equatorward and poleward edge of the electrojet, respectively. This can be used to determine the location of the auroral oval boundaries. In the case of a westward electrojet, the signs of the results in Figure 04 need to be changed; otherwise the result is the same.

Hence, we summarize that in the dusk sector, the equatorward edge of the auroral oval is represented by a maximum in the ground magnetic field variation z-component and the poleward edge is represented by a minimum. In the dawn sector it is opposite; the auroral oval equatorward edge is represented by a minimum in the z-component and the poleward edge by a maximum.

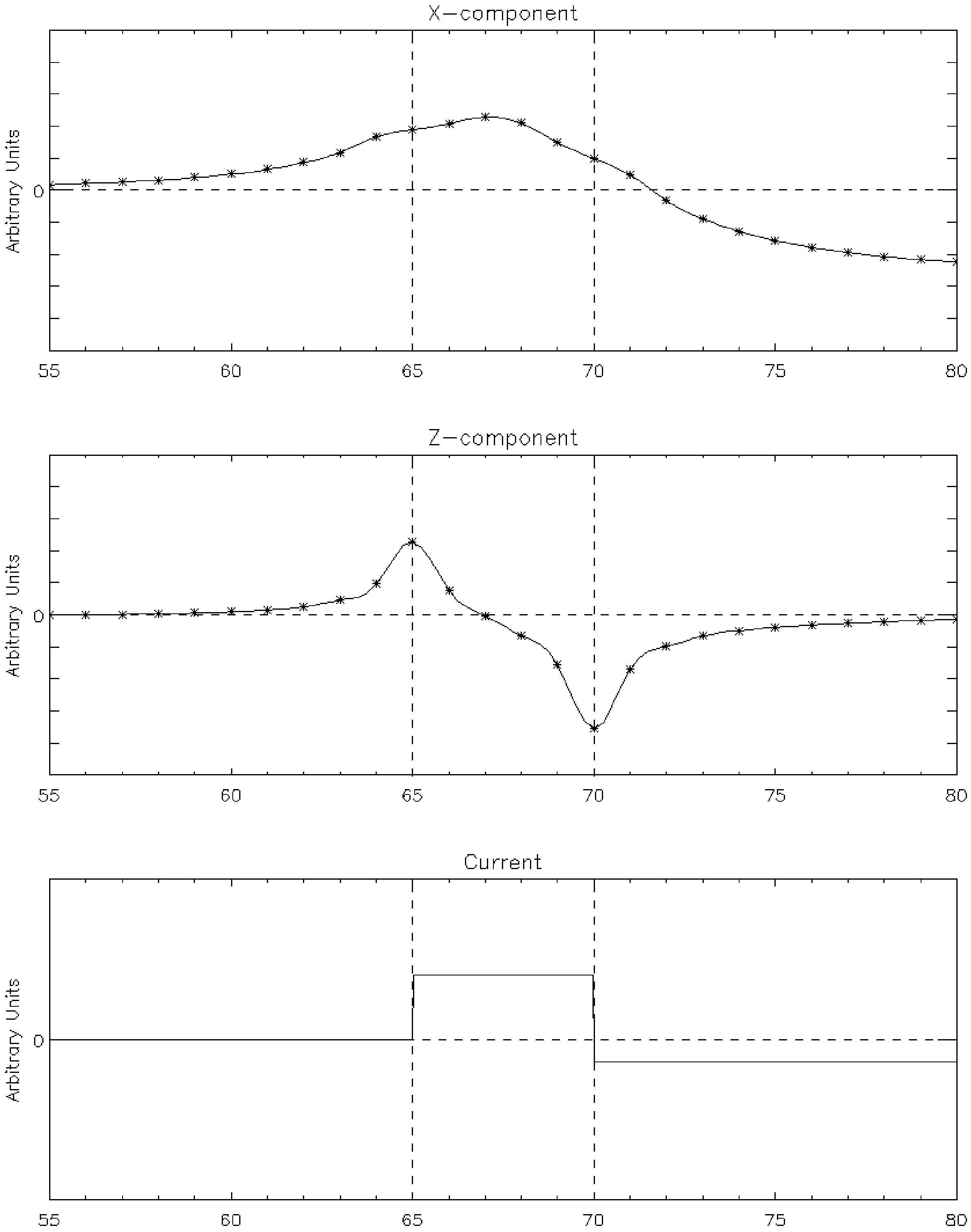

Figure 4*: Simulated magnetic field signature of eastward electrojet as function of latitude.*

3. Online provision of auroral alert and tracking system

3.1 Tromsø Geophysical Observatory – geomagnetic measurements

One of the main duties of Tromsø Geophysical Observatory (TGO) is to maintain geomagnetic measurements in mainland Norway and the Arctic Ocean around Svalbard. Currently TGO operates 14 magnetometers evenly spaced covering latitudes from 59^{o} N to 79^{o} N. The locations of the TGO magnetometers are indicated as red dots on the map in **Figure 5**. TGO receives data from all magnetometers in near real-time, with the longest delay of two minutes. All data are available with both 10 seconds resolution and post-processed 1 minute resolution.

The TGO magnetometer network is evenly spaced in latitude in a north-south manner, which makes its measured data an excellent starting point for a provisional auroral alert and tracking system.

3.2 Auroral tracking and alert system based on TGO magnetometer data

Based on the theoretical fundament drawn in Section 2, an auroral electrojet tracker based on data from the TGO magnetometer network has been developed.

The tracker consists of two graphical and a numerical part. The graphical parts are displayed presented together with a short description at the following URL (works best with Mozilla Firefox): http://fox.phys.uit.no/AFFECTS/

The first graphical part is a map where the poleward and equatorward edges of the auroral oval, determined from the magnetic field variation z-component, are indicated as green and red dashed lines. In addition plots where the relevant components of the geomagnetic field variations as function of latitude are displayed. The time of the last oval determination is indicated on top of the map, and the corresponding time stamp for the data used is indicated in the bottom right corner. The second graphical part is a graphical representation of the strength and latitude of the maximum in geomagnetic variations in the European sector; it may be referred to as an activity indicator. The activity is indicated by a bar updating in real-time according to the maximum magnetic field variation (x-component) found in the data. The scale chosen to indicate the activity goes from 0 to 10 and is related linearly to the interval 0 – 3,000 nT. Values corresponding to quiet, moderate, disturbed and extraordinary conditions are marked. The bar is accompanied with another display indicating the latitude of the maximum disturbance. The third part is an ASCII file, which is updated in near real-time, containing numerical values of the poleward and equatorward edges of the auroral oval at present and the previous three hours. The ASCII file can be found on the following URL:
http://fox.phys.uit.no/AFFECTS/RT_oval_location.dat

For the tracker data from 9 of TGO’s 14 magnetometers have been used in order to get as even latitudinal spacing between them as possible. At each location the local coordinate system has been rotated around the vertical axis in such a way that the observed magnetic field variations are with respect to the local magnetic field dipole meridian rather than the geographic meridian. Natural splines have been fit to the x- and z-components in order to get a latitudinal profile with higher resolution.

Owing to the uncertainties in quiet-time determination of the measured magnetic field, it has proved impossible to get meaningful latitudinal profiles of the magnetic field variations under very quiet conditions. Therefore the auroral electrojet determination is turned off when the maximum in the absolute value of the x-component reaches values of less than a threshold set to 75 nT. This is displayed as a message in the graphical display and as NaN (not a number) in the ASCII file.

Owing to the greater complexity of the current systems near magnetic noon (cusp) and midnight (Harang discontinuity), the oval determination from the z-component is turned off in the intervals UT 07.00 – 11.00 and UT 19.30 – 00.30. However, in order to indicate where the oval is located and the degree of activity, the maximum in the x-component and latitude for it, is still found during these intervals (see second graphic display).

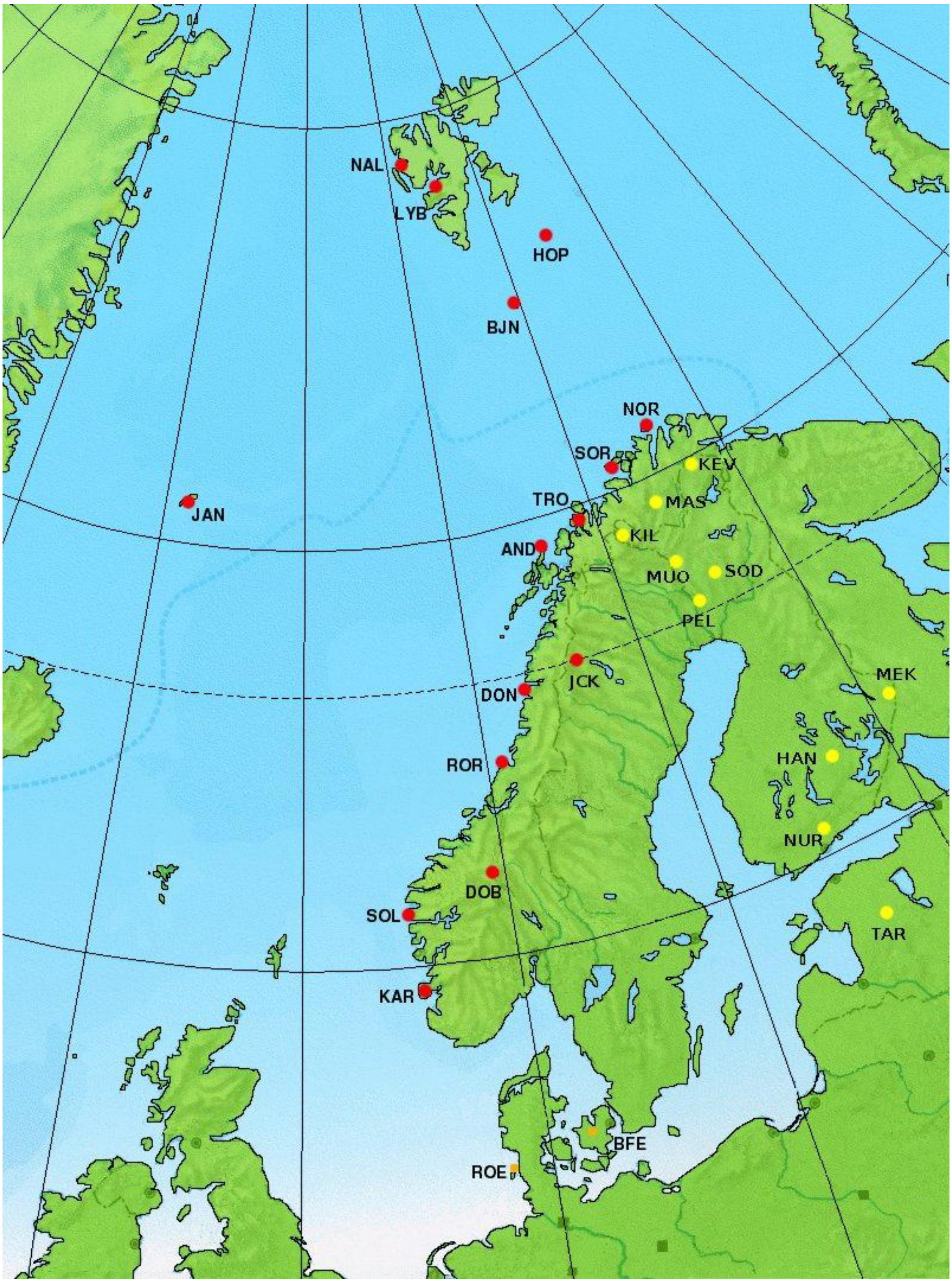

Figure 5*: Map showing magnetometers operated by TGO (red dots). The magnetometer at Jan Mayen (JAN) is currently not in operation. Yellow and Orange dots represent magnetometers operated by the Finish Meteorological Institute / Sodankylä Geophysical Observatory and the Danish Technical University.*

3.2.1 Presentation of auroral electrojet tracker

In **Figure 6** the obtained auroral oval edges from the magnetic signature of the westward electrojet in the dawn sector are presented in the same fashion as in the graphical display on the web page of the tracker. Comparing with the simulations in Figure 4, it is seen that the signature of the electrojet as obtained from the TGO magnetometers is very similar. In **Figure 7** the activity indicator, which is the second graphical display of the auroral electrojet tracker, is shown for the same event as displayed in Figure 6. As can be seen the activity is rather high and situated in northern Fennoscandia.

Another example, but this time from the eastward electrojet in the dusk sector, is shown in **Figure 8**. Here the auroral oval is situated further north, but the magnetic field signature as defined by Figure 4 is very clear. In **Figure 9** the activity indicator for the same case is shown, as can be seen the activity is rather quiet and located over the Barents Sea close to Svalbard.

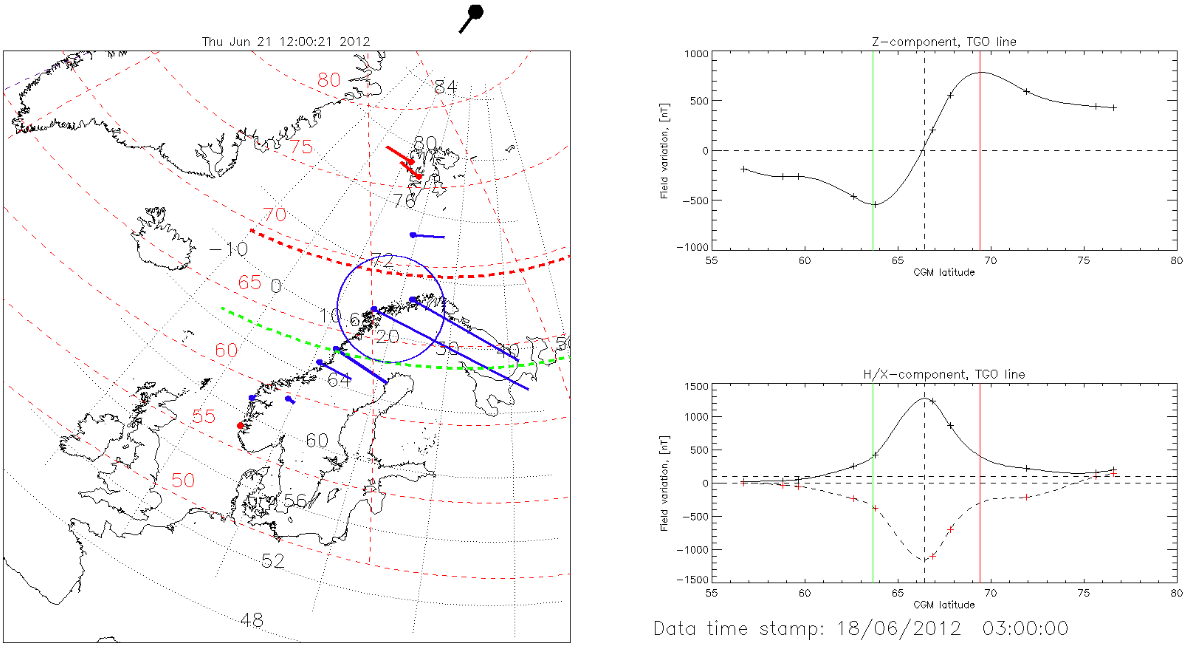

***Figure 6**: Acquired auroral oval boundaries in dawn sector using the AFFECTS Auroral electrojet tracker.*

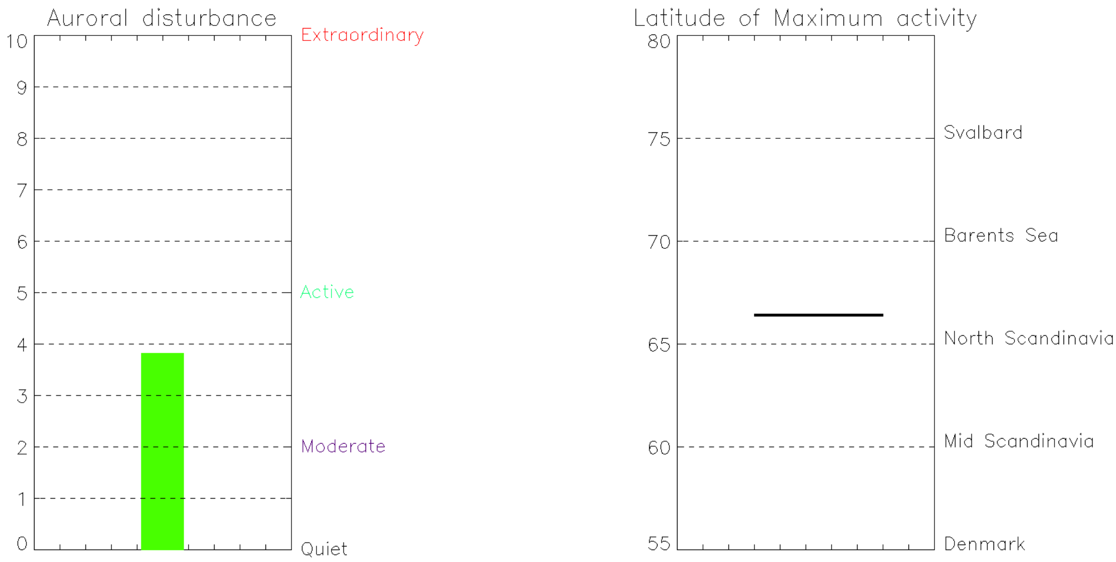

Figure 7*: Activity indicator for the same event as presented in Figure 6.*

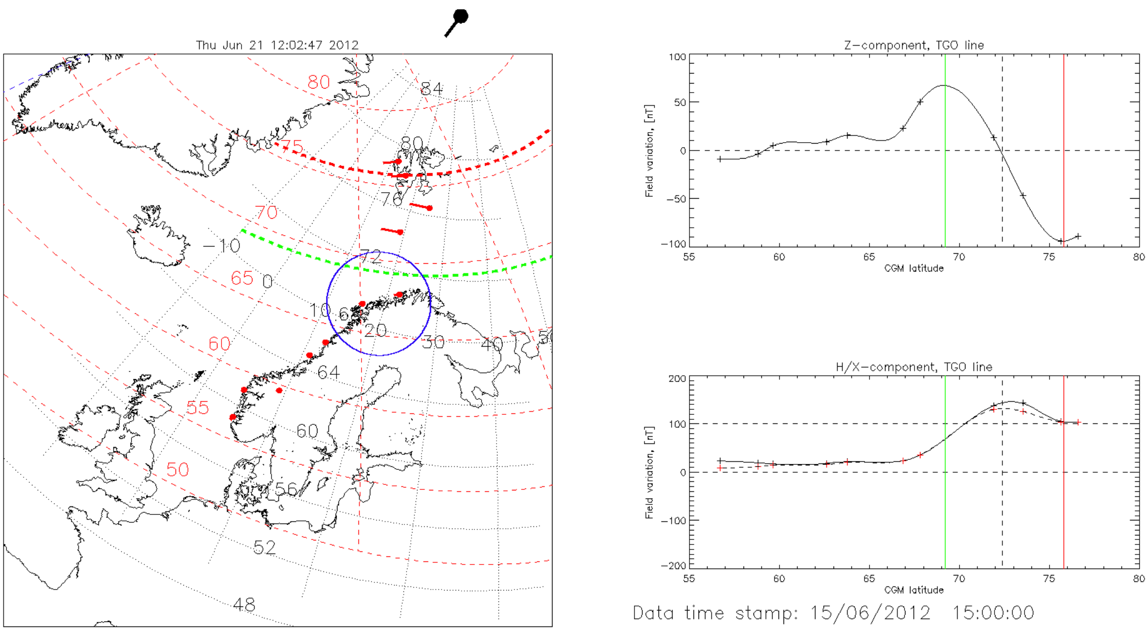

Figure 8*: Acquired auroral oval boundaries in dusk sector using the AFFECTS Auroral electrojet tracker.*

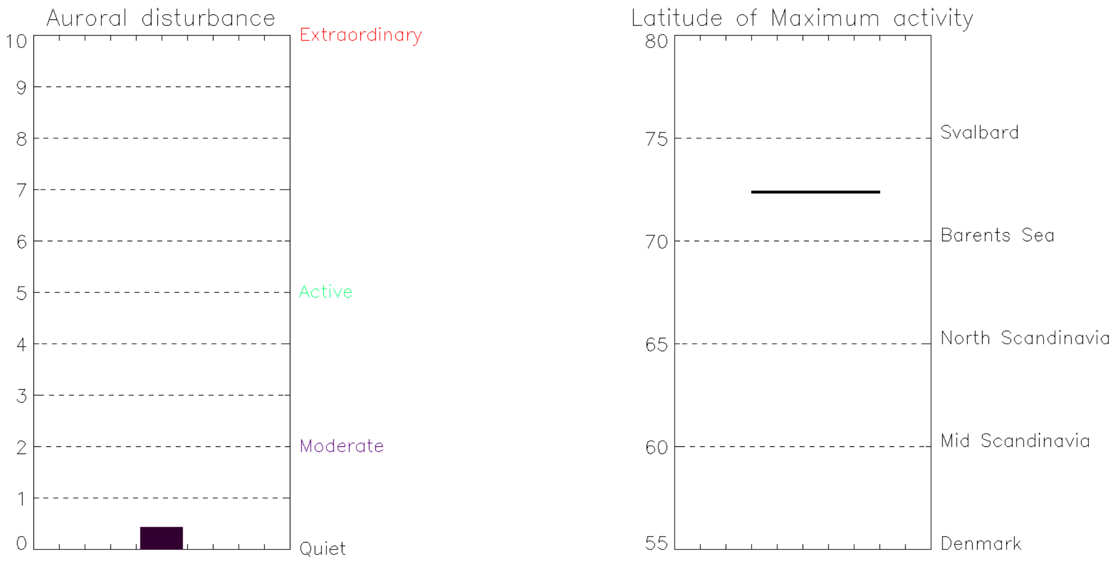

***Figure 9**: Activity indicator for the same event as presented in Figure 8.*

The obtained auroral boundaries are also stored in an ASCII file. The data are presented on the following format:

DD MM YEAR HH MM SS Oval(poleward) Oval(equatorward)

In **Figure 10** a screen-shot of the ASCII file in the writing moment is shown. Unfortunately the auroral activity was very low, hence the lack of determined auroral boundaries (NaN).

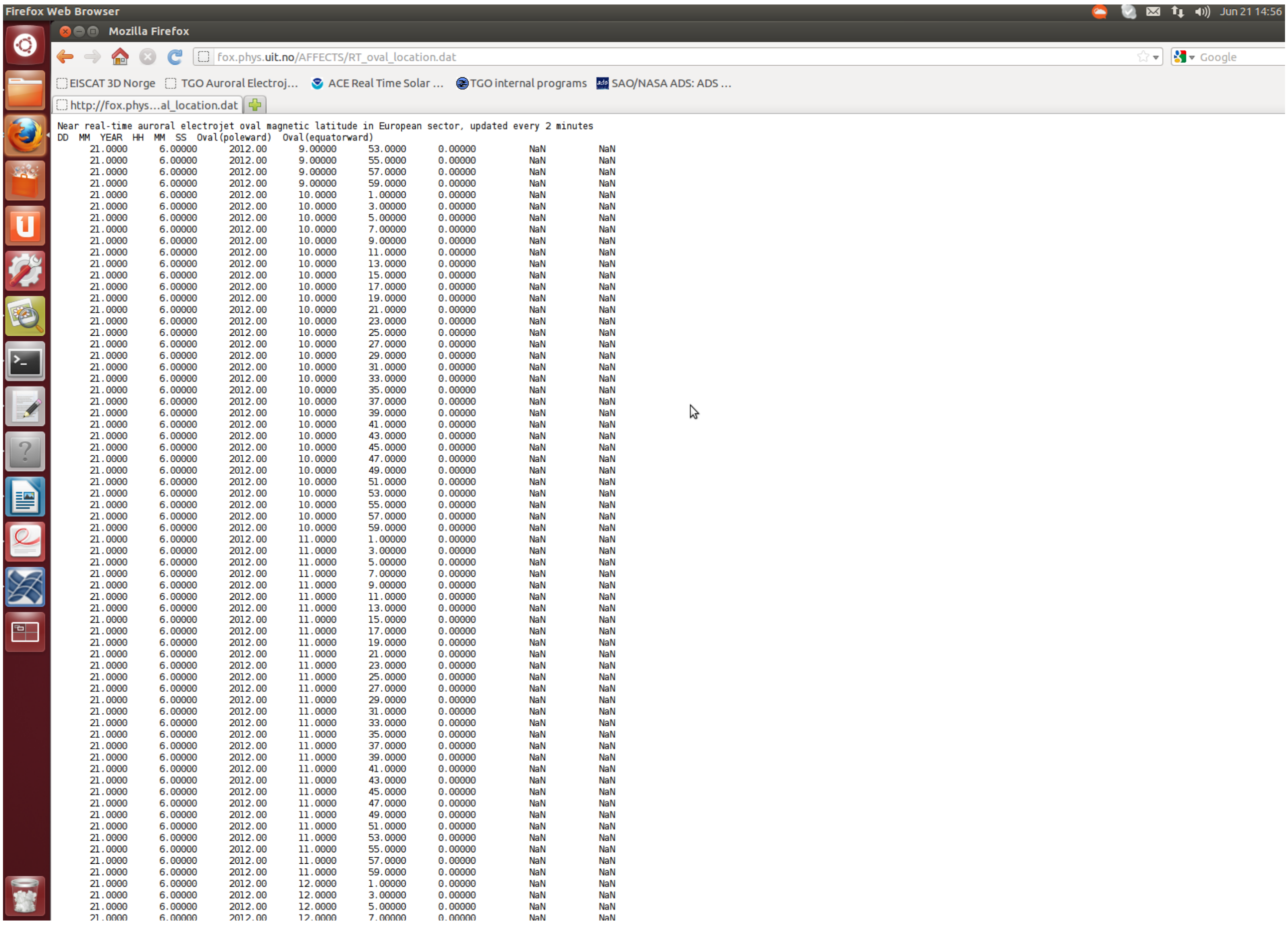

Figure 10*: Screen-shot of numerical representation of auroral tracker on June 21st 2012.*

3.3 Similar auroral oval determination systems

There are several other auroral trackers available on the web. A systematic comparison between these and the AFFECTS auroral electrojet tracker has not been performed. However, preliminary comparisons show good correspondence. Here follows a short list of some alternative auroral trackers:

1) NOAA OVATION auroral forecast: http://helios.swpc.noaa.gov/ovation/. Based on empirical model from satellite data. Uses solar wind data from ACE allowing for forecasting.
2) The Johns Hopkins University Applied Physics Laboratory OVATION site: http://sd-www.jhuapl.edu/Aurora/ovation_live/ovationdisplay.cgi?pole=N&type=E. Using real-time satellite data to determine the auroral oval.
3) Auroral Activity Extrapolated from NOAA POES: http://www.swpc.noaa.gov/pmap/index.html. Based on particle measurements made by NOAA POES satellites passing over the auroral oval. Updated several times an hour.
4) The Kjell Henriksen Observatory Auroral Forecast Service: http://kho.unis.no/Forecast.htm based on empirical auroral oval models based on satellites and ground-based optics. Uses predicted geomagnetic indices allowing for forecasting.
5) Canadian Space Science Data Portal Real-Time Auroral Oval:

https://cssdp.ca/ssdp/app/static/related_projects/rt_oval.html. Very similar to the AFFECTS auroral electrojet tracker.

5 Summary and conclusion

The AFFECTS "Online provision of auroral alert and tracking system" is now in operation and available to users from inside as well as from outside the AFFECTS consortium in order to monitor and track the movements of the auroral electrojet, and hence the auroral oval, in real-time in the European sector.

6 Perspectives and recommendations

A weakness with the auroral tracker is that the magnetometers that are used are not aligned entirely along the magnetic meridian. This introduces local time variations into the auroral oval determination. A future permanent tracker should, thus, include more magnetometers from Fennoscandia, especially those located in Finland.

The auroral oval determination stops currently at ~57^{o} N MLAT. Under storm-time conditions the auroral oval may move much further south than this. Therefore, magnetometer data from continental Europe need to be included in a permanent tracker.

Including other magnetometer chains from other time sectors, such as Greenland, Canada / USA, Alaska and Russia would be of interest to determine the entire auroral oval, not only in the European sector. Another step to obtain this goal is to make a statistical study of the current oval tracker in order to estimate its location in other time sectors by using global magnetic indices as input.