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Evaluation of SuperMAG auroral electrojet indices as indicators of substorms and auroral power

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[1] We use magnetometer chains collaborating with SuperMAG to derive *SME*, a generalization of the auroral electrojet indices calculated from 100 or more sites instead of the 12 used in the official auroral electrojet indices, *AE*(12) = *AU*(12) − *AL*(12). We investigate how these various indices relate to nightside auroral power by using both particle (DMSP) and image (Polar Ultraviolet Imager (UVI)) data. The best correlation is between *SME* and total nightside auroral power, namely, $r = 0.86$. Hence, nearly 3/4 of the minute-by-minute variance in nightside power can be determined by *SME* alone. Interestingly, although the geophysical meaning of *AE*(12) has sometimes been challenged, we show that even that index correlates at the $r = 0.81$ level, or 2/3 of the variance, in nightside power. Most auroral power stems from the diffuse aurora, with a linear relationship between the auroral electrojet indices and nightside diffuse power. Thus, *SME* has a clear geophysical meaning: It samples the thermal portion of the magnetotail plasma sheet. We study how well *SML* (the generalization of *AL*) identifies substorms in two types of tests. The first is a comparison with a set of 1081 substorms determined from Polar UVI in 1997–1998, and the second is the use of DMSP particle precipitation data for superposed epoch analysis. The same algorithm applied to *SML* is much more likely (about 50% more likely) to identify an onset seen by UVI than is *AL*(12). Even when both indices can be used to identify onsets, the median delay after imaging onset until the *AL* indicator is less than half using *SML* (about 4 min versus 8 min). There are 10,719 onsets in the *SML* data between 1 January 1997 and 31 December 2002, of which 5084 are isolated. Isolated *SML* onsets behave almost identically to the onsets determined by global imagers. Specifically, they represent the same sharp spike in auroral power, which is most pronounced in broadband (wave) precipitation, with the same duration and subsequent recovery. However, recurrent substorms (those following less than 2 h after a previous onset) rise from a higher baseline by a smaller percentage but with the same absolute change in auroral power, thus reaching a higher peak power.

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1. Introduction

[2] No alternative characterizes magnetospheric activity on a global scale with the same continuity and high time resolution as an appropriately selected magnetic index. Substorms are a perennially favorite topic for magnetospheric researchers, and *AL* appears to be the index which best corresponds to substorm activity. Prior to onset, *AL* is typically small in magnitude, with the contributing station near dawn, whereas after onset the contributing station lies under the auroral onset bulge [*Gjerloev et al.*, 2004]. The magnitude of *AL* is a good indicator of the strength of a substorm. And yet its usage has been severely constrained. Partly this is because of the slowness of distribution of high time resolution *AL* data (or even, at times, limited distribution). But it is widely suspected that there may be uncertainties which arise from the limited number of geomagnetic stations (12) involved in creating the traditional indices [e.g., *Rostoker*, 1972; *Davis and Sugiura*, 1966; *Ahn et al.*, 2000]. We will here call the traditionally derived index Auroral Electrojet indices *AE*(12) = *AU*(12) − *AL*(12), where *AU* and *AL* are the upper and lower components of *AE* (the largest and smallest values of the *H* component among the magnetic stations used).

[3] Here we investigate whether the SuperMAG collaboration [*Gjerloev*, 2009] involving a large number of chains around the world can enhance the value of *AE* and *AL*. More generally, we wish to quantify the performance of *AL* as a substorm indicator, and of *AE* as a predictor of gross nightside auroral activity. The number of stations contributing to this enhanced variant of *AE* varies between 83 and 120, but

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Table 1. Magnetometer Chains or Collaborative Efforts Contributing to SuperMAG

Magnetometer Chain	Principal Investigator (or contributor to SuperMAG)
Intermagnet	J. J. Love, D. Boteler, A. Chulliat, D. Kerridge
AUTUMN	M. Connors
CARISMA	I. Mann
CANMOS	D. Boteler
210 Chain	K. Yumoto
AARI Chain	O. Troshichev
BGS Magnetometers	S. McMillan
MACCS Program	M. Engebretson and J. Hughes
MEASURE	M Moldwin and UCLA/IGPP
S-RAMP	K. Yumoto and K. Shiokawa
SAMNET	F. Honary
SPIDR	NOAA/NGDC
SAMBA[a]	E. Zesta
IMAGE	IMAGE team (10 institutes), E. Tanskanen
IZMIRAN magnetometers[a]	V. Kuznetsov and V. Petrov
Greenland magnetometers	DTU Space, C. Stolle
PENGUIn,[a] ICESTAR	L. J. Lanzerotti, A. T. Weatherwax
McMac	P. Chi

[a]Chains not currently used in the construction of the *SME* index.

is typically more than 100. Conceptually, the new index is simply *AE*(100), that is, *AE* evaluated using a large number of stations. However, since *AE* is an official and well established index with endorsement from IAGA, we avoid confusion by terming the new index *SME* (SuperMAG electrojet index). The questions posed above have clear answers. First, *SME* proves to be intimately related to precipitating auroral power on the nightside. In fact, it is possible to predict nearly 3/4 of the variance in nightside power at a 1 min cadence using *SME*. Similarly, it is possible to identify far more substorms, and to time them better with *SML* than with *AL*(12). We also introduce a technique by which substorm onset identification techniques can be quantitatively tested, at least for a large ensemble (a few thousand onsets or more).

2. Background and Data Sets

2.1. The SuperMAG Initiative

[4] SuperMAG is a worldwide collaboration of organizations and national agencies that currently operate ~300 ground-based magnetometers. A list of the contributors can be found in Table 1 (the footnoted entries are not currently incorporated in the construction of the *SME* index). SuperMAG utilizes vector measurements of the magnetic field, which represent a variety of file formats, temporal resolutions, units, and coordinate systems, and are provided with or without baseline subtracted. SuperMAG resamples the data to 1 min temporal resolution and converts all units into nanoteslas (nT). Artifacts and errors are removed or corrected by automated as well as manual correction routines. Data are then rotated into a local geomagnetic coordinate system, and finally the baseline is determined and subtracted by an automated objective technique. Studies of the variations caused by electric currents flowing in the ionosphere and magnetosphere require a subtraction of the dominant and slowly varying Earth main field. Hence, both absolute and variometer data (data with unknown baselines) are included in SuperMAG. The *SME* index, and a processed version of some other data, along with further information are available at the site supermag.jhuapl.edu. Those wishing original data are urged to contact the responsible principal investigators for the actual individual chains.

2.2. Definition of *AL*, *AU*, and *AE*: Extension to *SME*

[5] The auroral electrojet indices *AL* and *AU* have been used extensively since they were first introduced by *Davis and Sugiura* [1966]. Historically the indices have been used as an indicator of auroral electrojet activity and thereby the magnetospheric activity. The auroral electrojet indices are scalar values, which indicate the maximum perturbation measured at one of the *AE* station locations. Hence, they are local indices, and measure global electrojet activity only to the extent that station coverage is global. The current *AE* network consists of 12 stations strategically placed around the globe to minimize these limitations. In this paper we will show that even *AE*(12) is more closely related to auroral power than previously suspected.

[6] Due to the popularity of *AU/AL* their limitations have been discussed, including UT and seasonal effects [*Rostoker*, 1972; *Allen and Kroehl*, 1975; *Ahn et al.*, 2000, 2002]. The main limitation is due to the small number of magnetometer stations used (10–12 stations) and their uneven spatial distribution (see Figure 1) thereby implying that large auroral events can go undetected. This problem was realized even by *Davis and Sugiura* [1966]. *AE* stations have wide local time gaps (average of 2 h and up to 3.2 h between Tixie Bay and Cape Wellen), which are potentially inadequate. This led *Rostoker* [1972] to conclude that the index should be used only in statistical studies rather than individual events. The use of a larger number of stations to derive *AE* has been previously explored for a limited number of days [*Kamide et al.*, 1982], although the performance advantage over the traditional index was not investigated.

[7] The *SME* index introduced here differs from the traditional *AE* index primarily by the number of stations sampled. All data are first transformed into coordinates with the *H* component pointing toward local magnetic north. The baseline is subtracted according to the following paragraph. Then the station with the largest *H* value contributes the *SMU* value, while the station with the smallest value contributes *SML*. *SME* is the difference between the envelopes, $SME = SMU - SML$.

[8] Determining the baseline is a fundamental problem with no single right method. Historically, baselines for a given day have been removed by manually identifying a nearby quiet day, which then is taken to be the baseline. The data volume for the SuperMAG collaboration does not permit this method. The SuperMAG initiative requires an automated and objective baseline method, since decades of data from more than 300 stations are included. One of us (JWG) therefore developed a new automated procedure for determination of the undisturbed daily variations of the magnetic field [*Hoffman and Gjerloev*, 2008], which forms the baseline. The automated procedure removes the yearly trend as well as daily variation (including contributions from the *Sq* current system) in two separate steps: (1) a determination of the yearly trend and (2) a determination of the daily variations. Both steps use a sliding window and bin data according to magnitude, and determine a typical value. For example, the yearly trend is calculated by determining a