

The distribution of auroral power increases and decreases

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[1] The concept of an auroral substorm intrinsically involves a large increase in auroral power within a relatively short time (a large dP/dt). There is currently no standard for just how large a power increase is needed to identify a substorm. It is unclear whether auroral brightenings and fadings form a continuous distribution, or even whether large decreases in auroral power also occur within a short time (i.e., a negative, or inverse substorm). We used Polar UVI images of global auroral power to investigate these and related questions. Specifically we considered the distribution of dP/dt and $(dP/dt)/P$, that is, the distribution of absolute and relative changes in auroral power. At small values of $|dP/dt|$, negative changes are much more frequent than positive changes. In fact, a small decrease in auroral power is the most frequent change between two consecutive Polar UVI images. Hence the power in the auroral oval is, the majority of the time, in slow decline. Large magnitude changes are rare, but turn out to be almost exclusively positive, implying inverse substorms do not exist. Beyond a 0.2%/s rate of change in auroral power (which amounts to a 37% change over the typical Polar UVI image spacing of 184 s), only positive events occur, within the measurable noise levels. However no clear boundary divides substorms from other types of auroral brightenings: rather the spectrum of large positive changes in auroral power is continuous. These results are relatively insensitive to the exact value of Δt (from 36 s to 6 min), and to whether the premidnight or postmidnight auroral oval is considered. **INDEX TERMS:** 2407 Ionosphere: Auroral ionosphere (2704); 2716 Magnetospheric Physics: Energetic particles, precipitating; 2788 Magnetospheric Physics: Storms and substorms. **Citation:** Newell, P. T., K. Liou, J. P. Skura, and C.-I. Meng, The distribution of auroral power increases and decreases, *Geophys. Res. Lett.*, 29(0), XXXX, doi:10.1029/2002GL016288, 2002.

1. Introduction

[2] The global auroral luminosity can vary significantly on the time scale of a few minutes. Such variations may have profound geophysical significance. For example, the concept of a substorm entered the field through observations that the intensity of the aurora could increase over a wide spatial scale within a short time [Akasofu, 1964]. There does not seem to be any quantitative definition of just how big an increase (rate of auroral power change) is necessary to define a substorm. It is not known whether changes in auroral power exhibit any defining threshold which separates the onset of an auroral substorm from other types of auroral brightenings. Likewise, it is not known whether the

global auroral power ever decreases abruptly - the inverse version of a substorm.

[3] In this paper, we use Polar UVI observations of auroral luminosity, which is related to the energy of electron precipitation, to study the systematics of how the auroral power changes. Specifically, we calculate dP/dt , the rate of auroral power changes, and consider the resulting distribution. Although the main impetus for this study was a hope of clarifying, in a quantitative fashion, the distinction between garden variety auroral brightenings and a true onset, this was not the only goal. We wish also to determine whether or not decreases in auroral luminosity are intrinsically symmetric with increases. It is also intrinsically desirable to know just how unusual a given rate of auroral power change is.

2. Data and Procedure

2.1. Data

[4] The Polar UVI ultraviolet imager was described by Torr *et al.* [1995]. Auroral power data in this paper are calculated from images taken using the LBHL (Lyman-Birge-Hopfield-Long) filter centered around 170 nm. The details on computing the power associated with auroral luminosity are given by Carbary *et al.* [2000] (see also Germany *et al.* [1994]). The FUV LBH lines result almost entirely from electron impact excitation, and thus are a good measure of precipitating electron energy flux. Thus by "auroral power" we refer only to the power associated with precipitating electrons, which does not include joule heating.

2.2. Procedure

[5] Polar UVI operates in several modes, including those where an image is formed every 36 s, and once every 184 s (often hereafter loosely termed 3 min). The latter mode is by far the most common. We have calculated the results shown in this paper with three Δt values, namely 36 s, 3 min, and 6 min. The results appear to vary comparatively little within this range of Δt . Since most of the data has a time resolution of 3 min, and since the aurora varies significantly over this time scale, the plots and data shown here will use a Δt of 3 min (184 s) unless otherwise specified.

[6] Auroral power was integrated from 1° below the equatorward edge of the auroral oval to 1° beyond the poleward edge of the oval. The boundaries of the oval were determined by the OVATION procedure [Newell *et al.*, 2002a], in which various data sets (including Polar UVI) are cross-calibrated to DMSP. The purpose of integrating only over the auroral oval, as opposed to integrating say from 60° to 80° (or 90°), is simply that integrating over the larger area increases the noise from dayglow. Although we used the best dayglow subtraction estimates we could, it is impossible to perfectly subtract all dayglow. Even a half

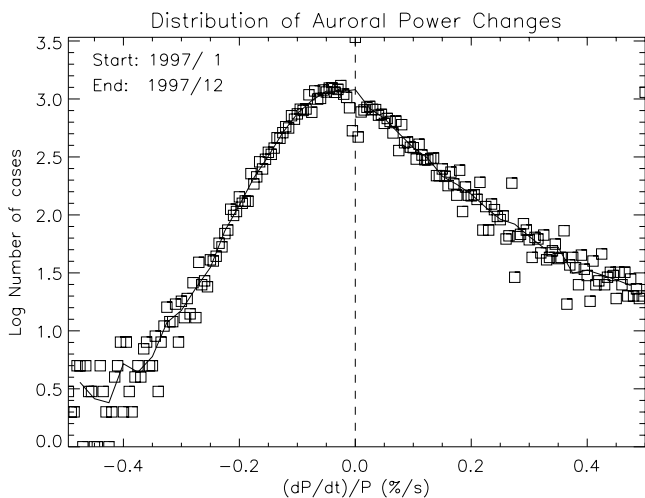


Figure 1. Distribution of the relative rate of change of auroral power as determined from consecutive Polar UVI images. Solid line averages over 5 of the bins denoted by squares.

count error integrated over a large area contributes appreciably to the noise.

[7] Since most substorms initiate in the premidnight sector, we concentrate on that local time (2100–2400 MLT) below, unless otherwise specified. However all plots were produced also for postmidnight, with the same basic results.

3. Results

[8] Suppose a Polar UVI image measures power P_1 at a given time. Three minutes later, it measures a different auroral power, P_2 . The rate of change in auroral power, dP/dt (in MW/s), is $(P_2 - P_1)/\Delta t$. The relative rate of change is $((P_2 - P_1)/\Delta t)/P_1$. The latter is measured in %/s, and its distribution is plotted in Figure 1. An extreme rate of auroral power change is 0.5%/s (meaning that over a 3 min period, the power changed by $184 \text{ s} \times 0.5\%$, or 92%). Note that the most common single occurrence from one Polar UVI frame to the next is that the auroral power is changed by less than 1% (specifically, to within 0.005%/s, or to within 0.92% over the interval). Altogether, 5665 out of the total number of 50886 cases (11%) show no auroral power change to <1%.

[9] Moving away from the central position (unchanged auroral power), both positive and negative auroral power rates of change rise from a local minimum 1 bin from the central peak, reaching local peaks at both $\pm 0.025\%/s$. However the likelihood of a small negative change outstrips the likelihood of a small positive auroral power change.

[10] Beyond $\pm 0.025\%/s$, the frequency of relative auroral power changes of any given magnitude declines steeply. Note however that large rates of change in auroral power (beyond about 0.2%/s) are nearly all within the positive realm. There are more small negative changes in auroral power than positive, but the occasional change in auroral power which is large, is nearly always positive.

[11] Figure 2 illustrates the last point more fully. Figure 2 plots the fraction of auroral power rates of change of a given magnitude which are positive (a running average has been applied). Thus if positive changes are twice as frequent as

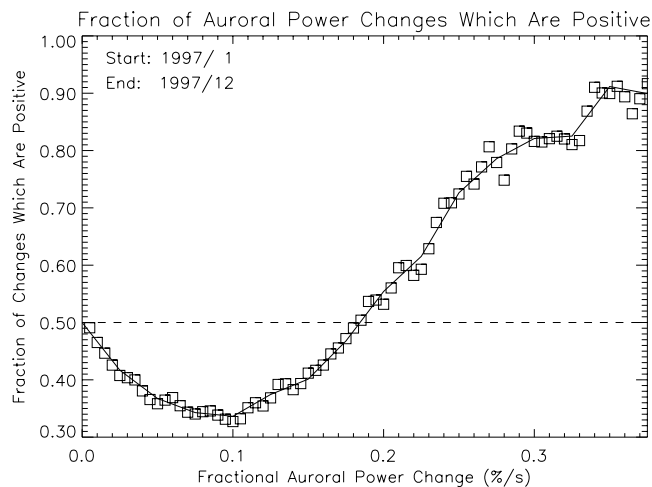


Figure 2. The fraction of auroral power rate changes which are positive. 0.5 means decreases equal increases. Solid line has bin size 5 times larger than squares.

negative for a given magnitude, the fraction plotted in Figure 2 is $2/(2 + 1) = 0.67$. Figure 2 more explicitly demonstrates that modest changes in auroral power are likely to be negative, while very large changes in auroral power ($>0.2\%/s$, or 12%/min) are overwhelmingly positive. We believe that the few instances of a large negative change are noise in the data set, as will be discussed more fully in section 4.

[12] The reader may wonder (as we did) whether the more insightful analysis involves absolute changes in auroral power, rather than relative. We calculated a variety of distributions using absolute power changes, and found that in general they followed the same trend as relative power changes, but with less clarity. Figure 3 illustrates the distribution of absolute power changes (dP/dt rather than $(dP/dt)/P$). No demarcation line is evident between changes in auroral power large enough to represent a substorm, and other intense brightenings. The same overall pattern is still followed, although the asymmetry between large positive

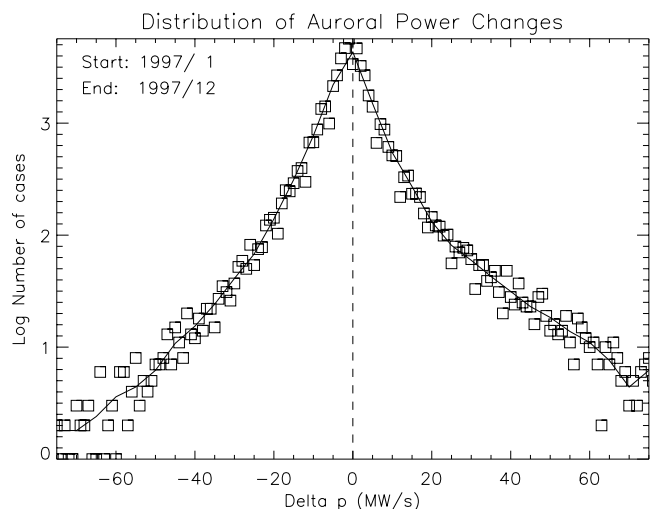


Figure 3. The distribution of absolute rates of change in auroral power.

and negative events is not quite as strong. For small changes in auroral power, negative events still dominate.

4. Discussion

4.1. Noise and the Limitations of the Analysis

[13] The smallest bin size used here is 0.005%/s, corresponding to 0.92% change in auroral luminosity over the course of the 184 s interval between images. The accuracy to which auroral power is measured by Polar UVI is much poorer than this. The systematic uncertainty in determining absolute calibration are at least 20% [Newell *et al.* 2001]. Of course, the systematic uncertainty in absolute luminosity does not contribute to $(dP/dt)/P$. The precision is more important than the accuracy, which is to say, the uncertainty due to counting statistics is most relevant. There are typically on the order of a 1000 photons counted over a 3 minute period in the premidnight sector, meaning the counting statistical uncertainty is on the order of $(1000)^{-1/2}$, or about 3%. The uncertainty in calculating the difference between two images is then about $(\sqrt{2}) (3\%) = 4.5\%$, or 5 times larger than the space between squares on the plots. For that reason we also plotted the solid lines shown in the figures, based on averaging 5 finer bins together.

[14] It is often practical to determine the difference between two populations even when the means are much closer than the uncertainty, provided enough measurements are made. Typically, in a problem of counting uncertainties, the means can be determined with an uncertainty of σ/\sqrt{n} . The situation here is more complicated, and does not cleanly correspond to repeated estimates of the mean value of separate populations.

[15] Note that the solid lines, which have a bin size about equal to the raw resolution, do not show the fluctuations near zero power evident at the finer bin size. We nonetheless suspect that the finer resolution may be useful in possible future modeling (deconvolution) efforts.

[16] The plots presented here are all for the year 1997. Polar UVI data exists also for 1998–2001. We did produce the same plots for these other years (up through 2000, for which we have fully processed auroral power), and tried also the ensemble of years. All showed the overall trends as discussed above, but in every case the scatter was greater and the trends weaker than for 1997. The reason for this difference was not hard to find: these other years have a much higher frequency of “salt and pepper” noise. Most commonly, a single seemingly random number appears in the sequence for auroral power, causing apparent abrupt changes in auroral power (up and down). These can generally be distinguished from real auroral events by (i) often an isolation to a single 1 hour MLT value, (ii) the deviation does not signify a change in auroral power, which instead promptly resumes the previous value. In at least some of these cases, the field of view was evidently changing, as the discontinuity was accompanied by changes in which local time sectors were within the purported field of view.

[17] These noise problems arise not because the 1998–2000 data are of poor quality, but rather because the technique inherently requires extremely good data. We are interested in the highly unusual cases of very large auroral power fluctuations. The larger the magnitude of fluctuations investigated, the rarer the number of legitimate events, and

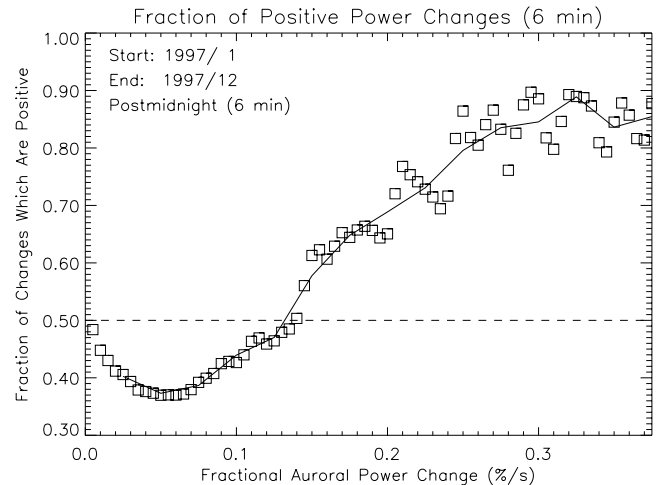


Figure 4. Variation on Figure 2, with 6 min delta t, and at postmidnight.

the more easily a handful of cases with instrumental factors can destroy the statistics. Here we have used only the exceptionally clean 1997 data.

4.2. Considering Certain Variants in Δt and Local Time Sector

[18] Because most substorms initiate in the premidnight sector, Figures 1–3 are all for the MLT range 2100–2400 MLT only. Substorms show significant changes in auroral luminosity on the time scale of a few minutes. Since the vast majority of the Polar UVI LBHL images are 3 minutes apart, the latter was adopted as the standard for this study. However it is reasonable to wonder if the distribution of dP/dt (and $dP/dt/P$) depend sensitively on the Δt used to calculate the rate of power change. A small minority of the images were taken at a 36 s spacing. Moreover, it is perfectly possible to calculate dP/dt using a Δt of 6 minutes (or any other multiple of 3 min). We tried both these variants. The results presented above were relatively independent of the value of Δt , over this range (36 s to 6 min). The results also are about the same for the postmidnight sector as for premidnight.

[19] Figure 4 illustrates the spectrum of relative auroral power changes in the postmidnight sector for 6 min time resolution. Clearly the exact details chosen for the figures in section 3 are not crucial to the main results.

4.3. Interpreting the Auroral Brightening Distribution

[20] Figures 1–4 demonstrate that the auroral oval spends most of its time in decline. Small changes in auroral power are much more frequent than large changes, and the sense of small changes is most often negative. The usual trend of decline is punctuated by large positive changes in auroral power.

[21] These results quantify the traditional picture of auroral substorms, in which onset is fast and recovery slow. It would have been nice if Figures 1–3 showed some sign of a break in the distribution of large auroral changes, one which would separate substorms from other auroral brightenings. Instead auroral brightenings seem to be smoothly distributed over all possible rates of change (and relative rates of change) in auroral power. The limit plotted in Figure

1 is 0.5%/s, corresponding to a 92% increase in about 3 min. This value is actually already somewhat greater than that typically seen during the first 3 min following a substorm, which is around 50–60% (see Figure 1 of *Newell et al.* [2001]). Thus auroral substorm onsets fall comfortably within a smooth distribution of various magnitudes of auroral brightenings.

4.4. Possible Broader Geophysical Implications

[22] Our results are reminiscent of other recent findings in mag-netospheric physics. Specifically, magnetotail convection consists most of the time, of weak flows which average tailward, but which are punctuated by brief and intense flows (both tailward and Earthward) [*Angelopoulos et al.*, 1992; *Fairfield et al.*, 1999]. The comparatively rare rapid flows are associated with times of increasing geomagnetic activity. Moreover, individual fast flow events correspond to specific auroral brightenings near the poleward edge of the oval, with subsequent equatorward spread [e.g., *Zesta et al.*, 2000]. It does not seem a stretch to suppose that there is a connection between the usual trend in the magnetotail toward weak flows, and our result that auroral luminosity is most often fading (but is punctuated with sharp increases).

[23] The aurora, creates a conducting path in the night-side ionosphere for the discharge of magnetospheric currents. As long as such a conducting path exists, the undisturbed trend is for the currents to decline and for the aurora to likewise decline. Typical auroral behavior is thus like a battery discharging. Intermittent events in the magnetotail, probably including bursty bulk flows, recharge the battery, causing a jump in currents into the ionosphere, and auroral luminosity.

5. Summary

[24] The most interesting possible outcomes for this study would have been to find either a clear demarcation between substorm onsets and other types of auroral brightenings, or to find that auroral brightenings had a negative counterpart, with very rapid fadings of auroral intensity. Neither proved true. The more intense the brightening considered (the larger the relative or absolute change in auroral power per second, averaged over 3 or 6 minutes), the rarer the event. The decline in event frequency with increasing magnitude is smooth, up to at least 0.5%/s (a 92% change between frames). Neither the relative nor the absolute magnitude of an auroral brightening alone suffices to identify an auroral substorm onset. It may be that rapid auroral intensification is one of several necessary criteria that taken together uniquely characterize a substorm. The possibility must be entertained however that a substorm onset is a qualitative idea not amenable to quantification.

[25] Likewise, large negative declines (above 0.2%/s, or 12%/min) seem not to occur. Although the aurora is fading more often than brightening, it does not fade fast enough to provide a counterpart to the auroral substorm. The disparity between decreases and increases in auroral power peaks at the 0.025%/s rate of change, where negative changes outnumber positive by roughly 2:1. Overall, negative changes outnumber positive by 1.3 to 1.0, an asymmetry that can be looked at in two (non-conflicting) ways.

[26] First, the asymmetry at low values of $|dP/dt|$ is likely necessary to maintain time invariance. The rare large positive events must be compensated for in some manner. Since negative substorms do not occur, the auroral oval spends most of its time fading, just to maintain balance.

[27] Second, the characteristic behavior of auroral brightness at least mimics other magnetospheric behavior, notably the dominance of magnetotail convection by a few large flows interspersed with more common weak flows with a net tailward bias. It is likely that both phenomena are aspects of the normal mode of magnetospheric dynamics. The magnetosphere spends most of its time quieting.

[28] **Acknowledgments.** Funded by NASA grant NAG5-11350.

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