Derivation of radial diffusion coefficients in the radiation belts using IMAGE ULF wave measurements

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Abstract

Approximately half of all operational satellites are in orbits that pass through the radiation belts, where they are susceptible to internal and surface charging by energetic electrons. In the interest of risk assessment, it is important to develop reliable models of electron acceleration and propagation in these radiation belts. Although there is as yet no universally accepted dominant mechanism for those effects, a prominent one that has been under consideration since the 1960's (e.g. Fälthammar, 1965) is adiabatic radial diffusion, generated by fluctuations of ultra-low-frequency (ULF) waves. In situ measurements of those waves' power spectral densities would require a large number of satellites operating in different orbits, which is currently prohibitively expensive. As a more practical alternative, measurements from ground-based magnetometers can be continuously taken and then mapped to their equivalent L-shells in the equatorial plane. Here we have used 11 years of dayside ground magnetometer measurements from ten IMAGE stations to derive the electric field diffusion coefficient from L=3.34 to 6.46 and, tentatively, up to L=13.6. We have processed the measurements with four binning methods, as functions of Kp, Dst, solar wind speed and solar wind pressure. Upper and lower quartiles were calculated for all initial values and derived diffusion coefficients. Subsequently, the data was divided by deciles, allowing us to assess the usefulness of each binning parameter. We found Kp to be surprisingly convenient in that regard. This may have implications on future radiation belt modeling, where the choice of geomagnetic indices or solar wind parameters used in binning can affect the accuracy of simulations and forecasts.

Data Processing

The power spectra used in this study derive from 11 years of observations by stations of the IMAGE magnetometer network (January 1, 2000 to December 31, 2010). The particular stations were chosen on the basis of three conditions: a) a large variance in geomagnetic latitude b) a small variance in geomagnetic longitude, and c) > 95% time coverage of our selected data period. As shown in **Figure 1**, measurements by those stations were used to acquire the mapped power spectral densities (PSD) in space and thus calculate the electric field term of the radial diffusion coefficient. This was done in an analogous fashion to the work of Ozeke et al. (2012) with CARISMA, but with a different data analysis (using wavelets instead of FFT) and with a different magnetometer array. In **Figure 2** we show our derived diffusion coefficients, when binned by Kp; they are in strong agreement with the values found by Ozeke et al. (2014).

Those measurements were then binned with *Kp*, V_{sw}, P_{dyn} and Dst. In order to robustly compare the relative efficacy of each binning parameter, we divided the dataset into equal deciles, ensuring that each bin for each different parameter has the same number of data points. **Table 1** shows the lowest and highest values of the parameters we used during the period of observation, as well as the values that denote the borders of their respective deciles. The resulting PSDs, for two indicative ground stations are shown in **Figure 3** and **4**, respectively. Phenomenologically, the following traits stand out (which also apply to observations by intermediate latitude stations):

i) The curves corresponding to different deciles are well separated when binning by Kp, less so when binning by V_{sw}, and far less so when binning by P_{dyn} *or Dst.*

ii) The curve corresponding to the upper decile always carries more energy than that of any other curve. The lower curves can become hard to tell apart, in contrast.

iii) When binning by Dst, P_{dyn}, *or Kp, the upper decile* carries far more energy than the lower ones for low L-shells, but this effect is reduced at higher L-shells. There does not appear to be such an L-shell dependence when binning by V_{sw}.

In summary, we have found compelling reasons for the continued use of Kp as a binning parameter in magnetospheric models. Future work will study in more detail the behaviour of the upper decile, which contains most of the information pertaining to diffusion.

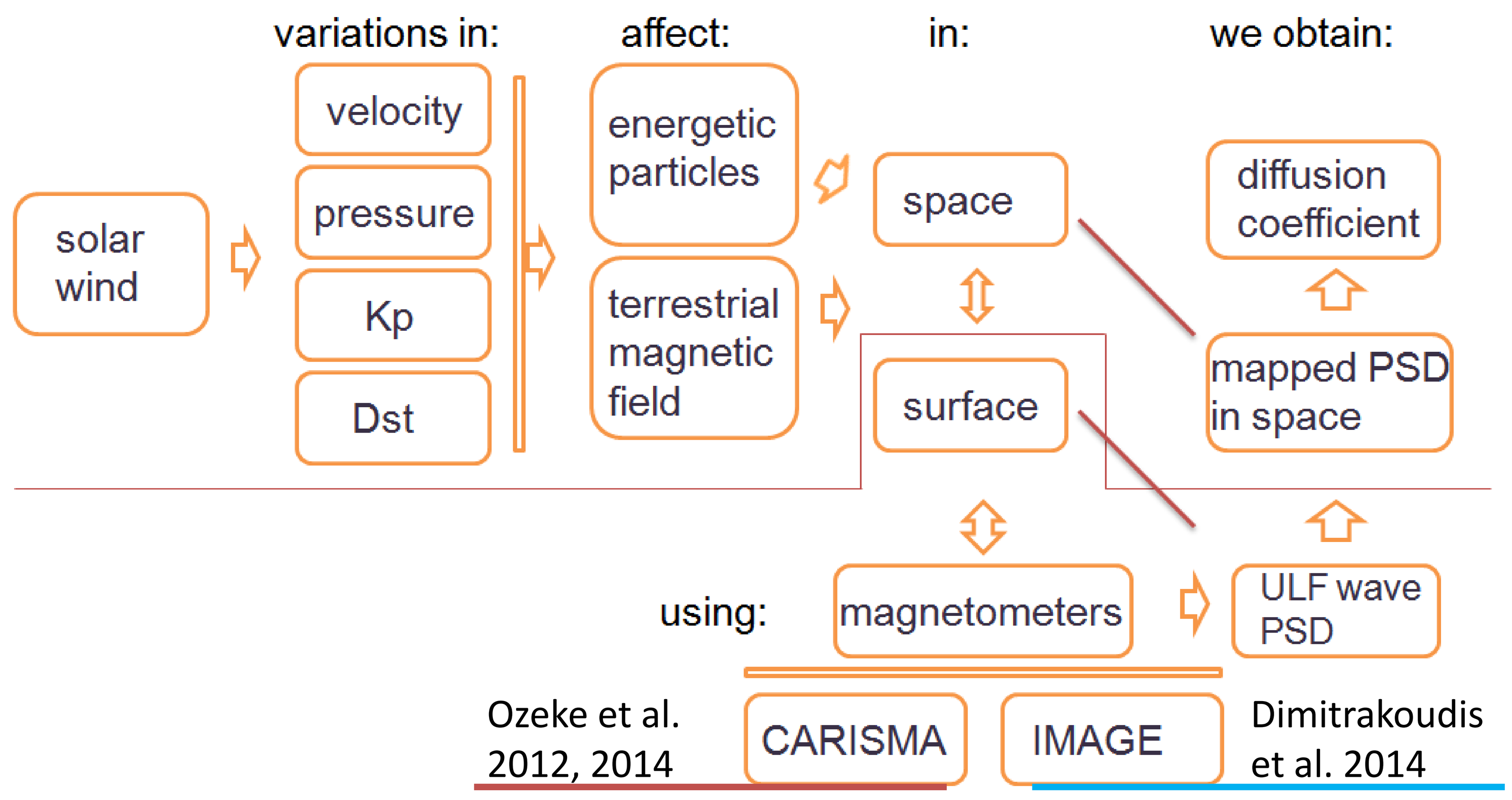

Figure 1. The overall scheme of ULF wave radial diffusion and how radial diffusion coefficients can be derived using ground magnetometer arrays.

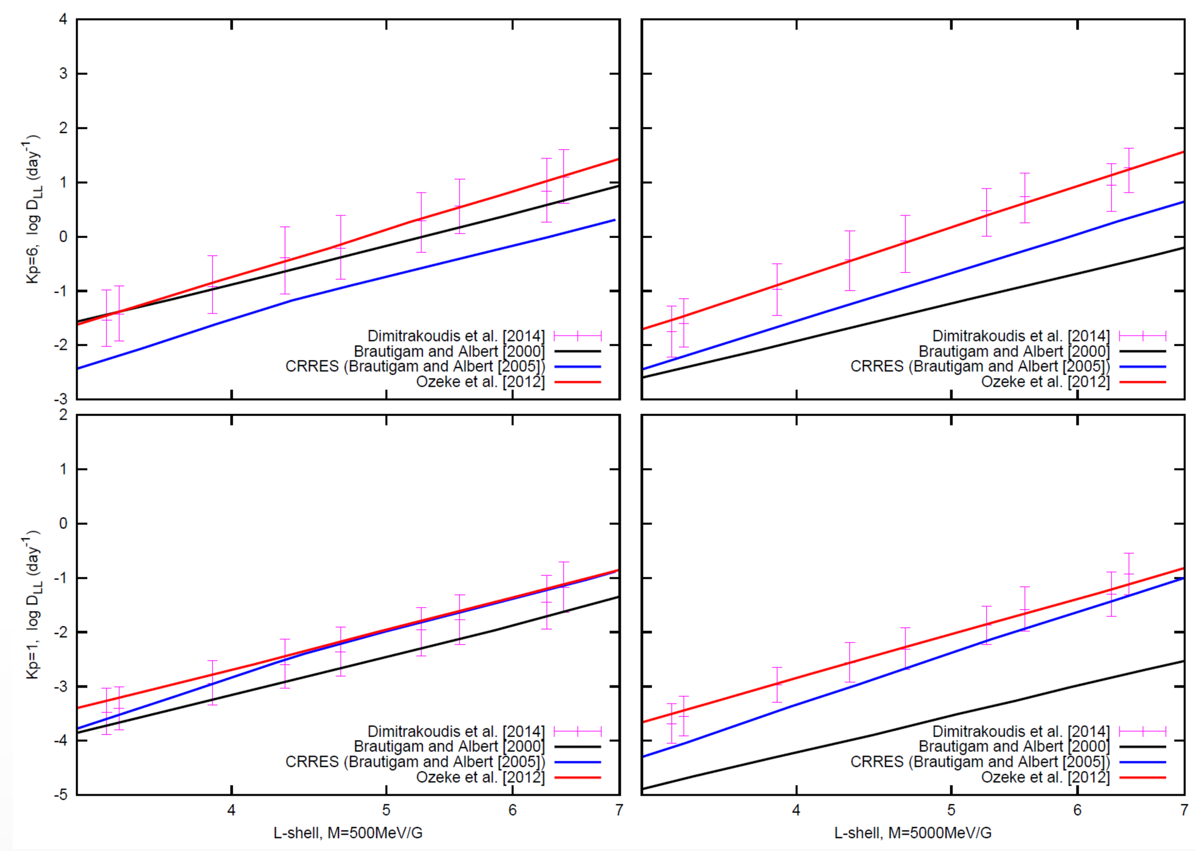

Figure 2. A comparison of the electric field diffusion coefficients found in this paper with the ones derived by Brautigam and Albert (2000), Ozeke et al. (2012), and the ones obtained from CRRES PSD measurements presented by Brautigam et al. (2005). The values from (Ozeke et al., 2012) have been increased by a factor of 2, in accordance with (Ozeke et al., 2014).

Decile border	Kp	V_{sw}(km/s)	P_{dyn}(nPa)	Dst(nT)
0	0	233	0.03	67
1	0.3	320	0.81	6
2	0.7	346	1.01	1
3	1	369	1.19	-2
4	1.3	393	1.36	-6
5	1.7	418	1.57	-9
6	2	448	1.81	-13
7	2.7	485	2.14	-18
8	3	537	2.61	-25
9	3.7	607	3.54	-35
10	9	1189	79.05	-422

Table 1. Decile borders for each binning parameter.

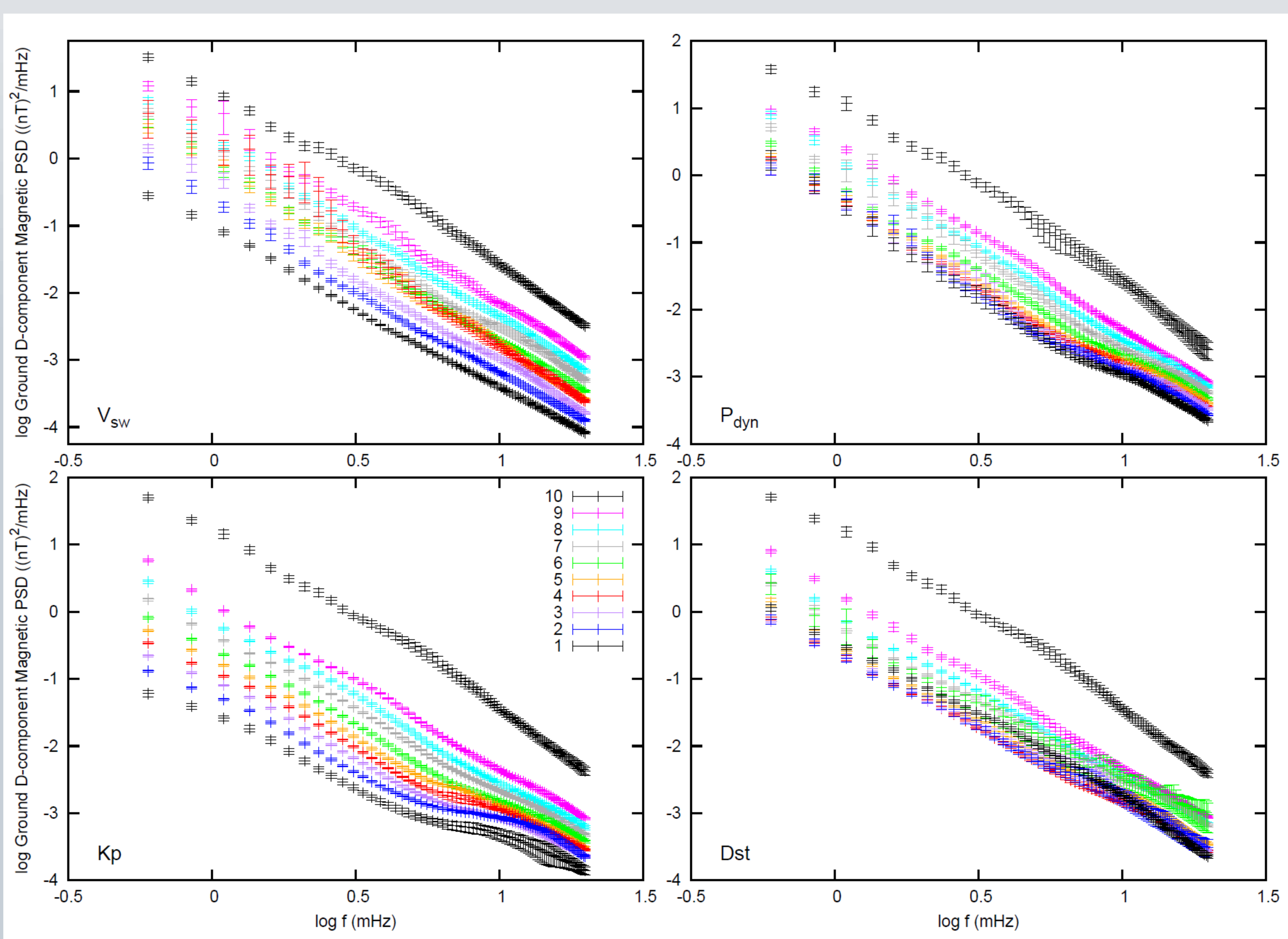

Figure 3. A comparison of Median magnetic field D-component power spectral densities as measured at Nurmijärvi station (L=3.4), when binned by deciles, with Kp, solar wind speed, solar wind pressure, and Dst.

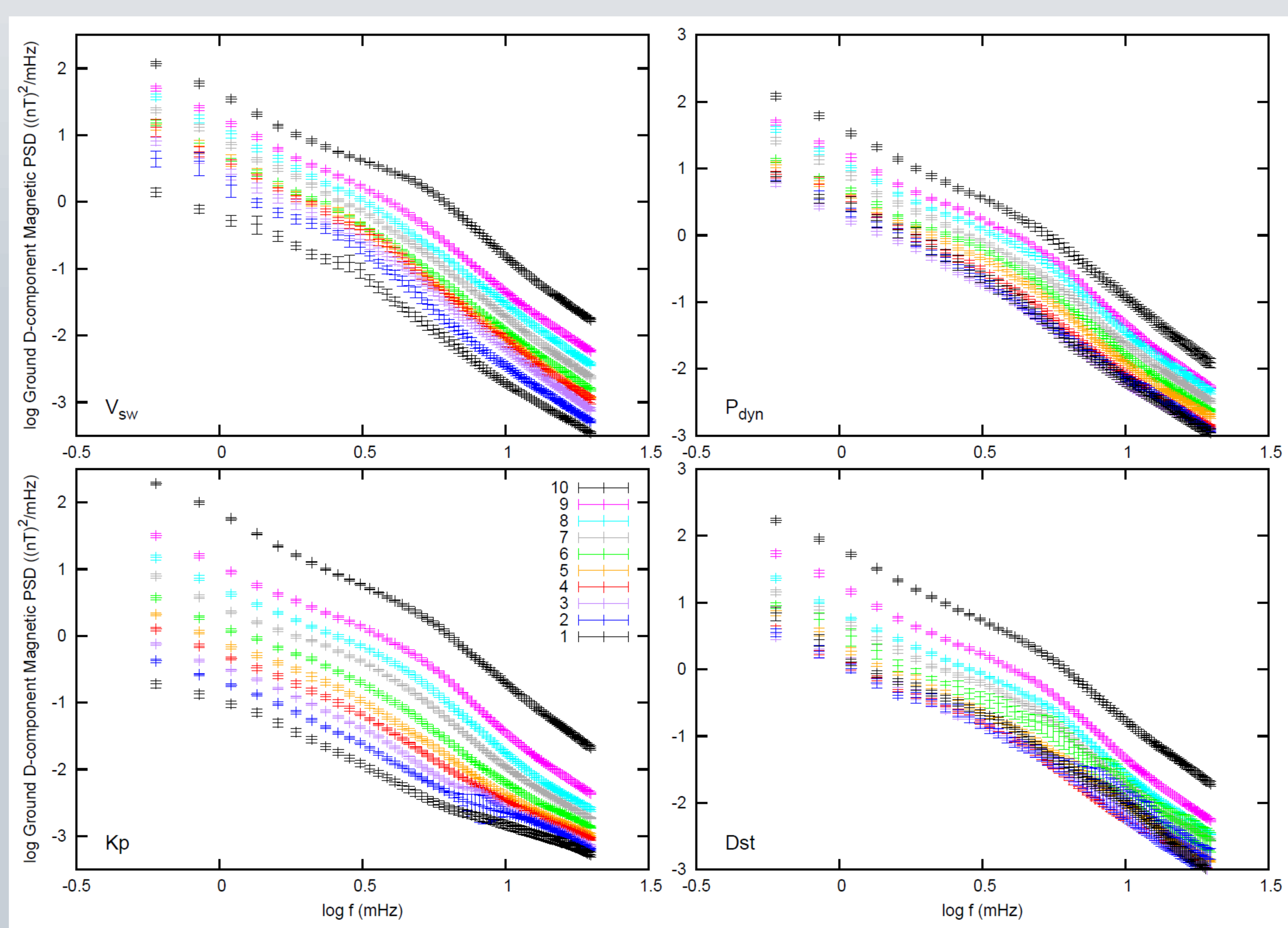

Figure 4. Same as Figure 3 but for Kevo station (L=6.3).

Acknowledgements

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