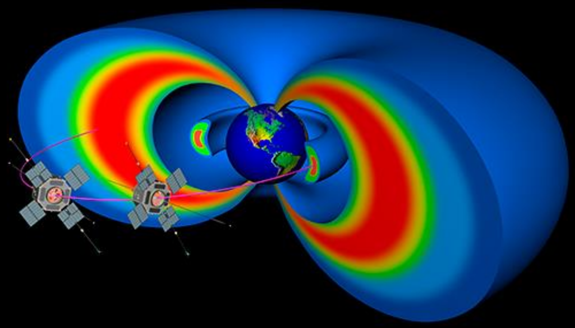
Department of Meteorology

University of Reading

THE PARAMETERIZATION OF WAVE-PARTICLE INTERACTIONS IN THE OUTER RADIATION BELT



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SUMMARY

- Variability of wave-particle interactions
- Uncertainty
- Parameterisations
- An example
- Future directions

VARIABILITY OF WAVE-PARTICLE INTERACTIONS

- ULF waves - variability relative to parameterizations
  - Jaynes, Monday: "Diffusion rates are highly event-specific"
  - Olifer, Thursday: Sometimes D_{LL} inferred directly from event-specific observations is much larger than our current parameterization, sometimes much less.
- EMIC waves - evaluating effectiveness of wpi
  - Millan, Wednesday: Presence of EMIC waves not always sufficient condition for precipitation – perhaps local plasma conditions are controlling interaction
- Whistler-mode waves – evaluating effectiveness of wpi
  - Blum, Wednesday: nature of wpi depends on local composition, wpe/wce ratio as well as wave properties

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TWO MAIN POINTS

- Natural variability in system
- Construction of wave-particle interaction parameterizations

IS SYSTEM DETERMINISTIC?

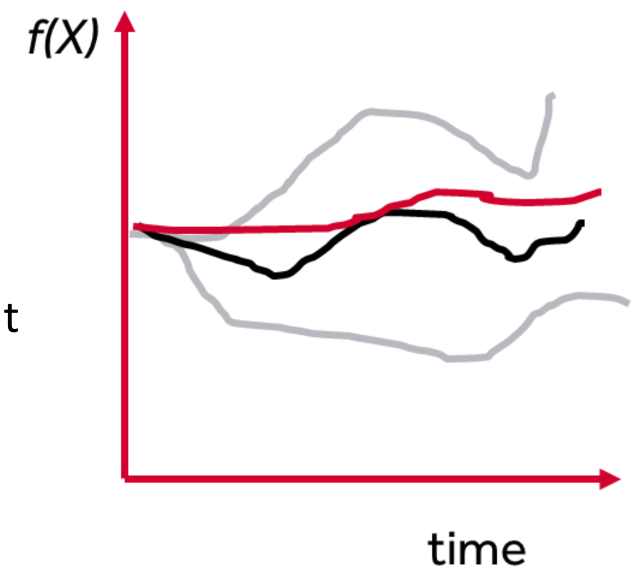
- Natural system - Chaotic
- Uncertainty might not be due to ignorance, but due to stochastic nature of processes.
- We suggest that the necessary diffusion treatment of Outer Radiation Belt dynamics has an “irreducible uncertainty.” *[Palmer and Williams, Proc. Roy. Soc. A., 2008]*

SOURCES OF UNCERTAINTY

- Parameterization
- Initial conditions
- Boundary conditions – real and energy space
- Numerical methods
- Underlying physical equations (!!)

INCLUDING VARIANCE IN PARAMETERIZATION

- Numerical Weather Prediction and Climate Modelling now embracing stochastic parameterization [e.g. Berner et al., BAMS, 2017]
  - Need to know underlying distribution of parameters
  - Numerical schemes need stochastic nature built in
    - Can run "ensembles"
    - Can fold in underlying distribution if well-behaved (e.g. Gaussian or log-normal)



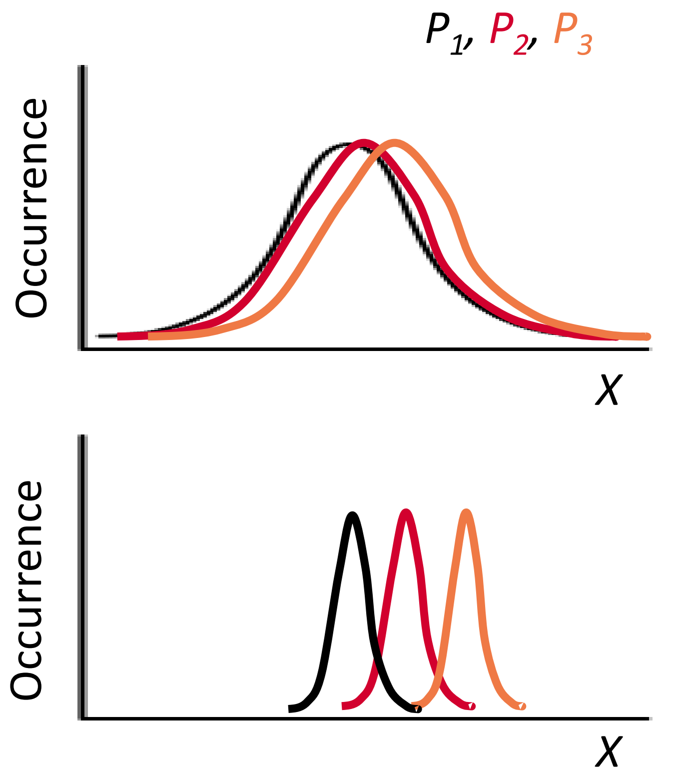
Berner, J., et al. (2017), Stochastic parameterization: Toward a new view of weather and climate models, Bull. Am. Meteorol. Soc., ***98****, 565–588, doi:10.1175/BAMS-D-15-00268.1.*

PARAMETERIZATIONS

- Usually based upon geomagnetic activity and location
- How do we assess how good they are?

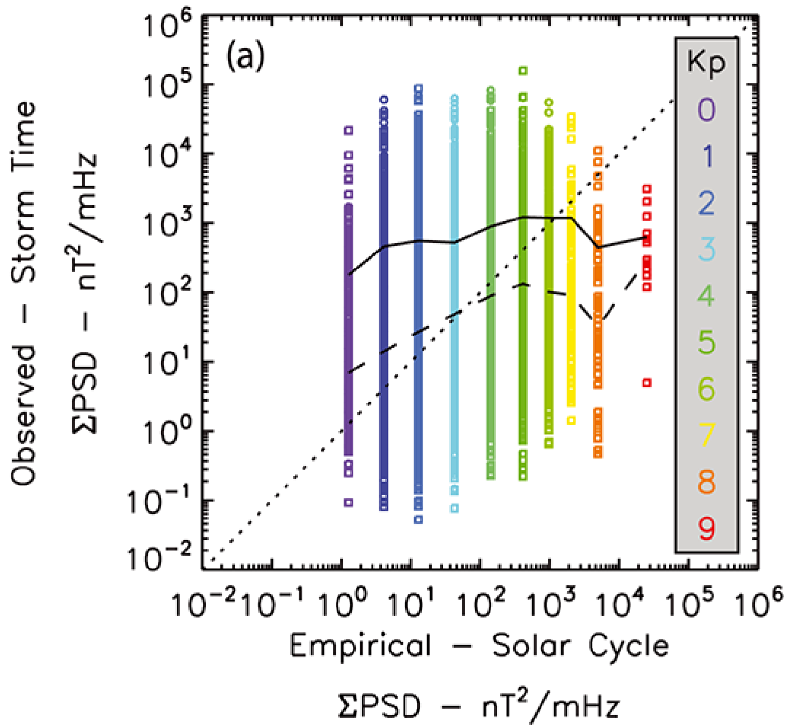
A GOOD PARAMETERIZATION

- A "good" parameterization is one which limits the variance *σ* in the quantity you are trying to predict, *X*
- *σ* should be small compared to the change in mean/median value with *P*



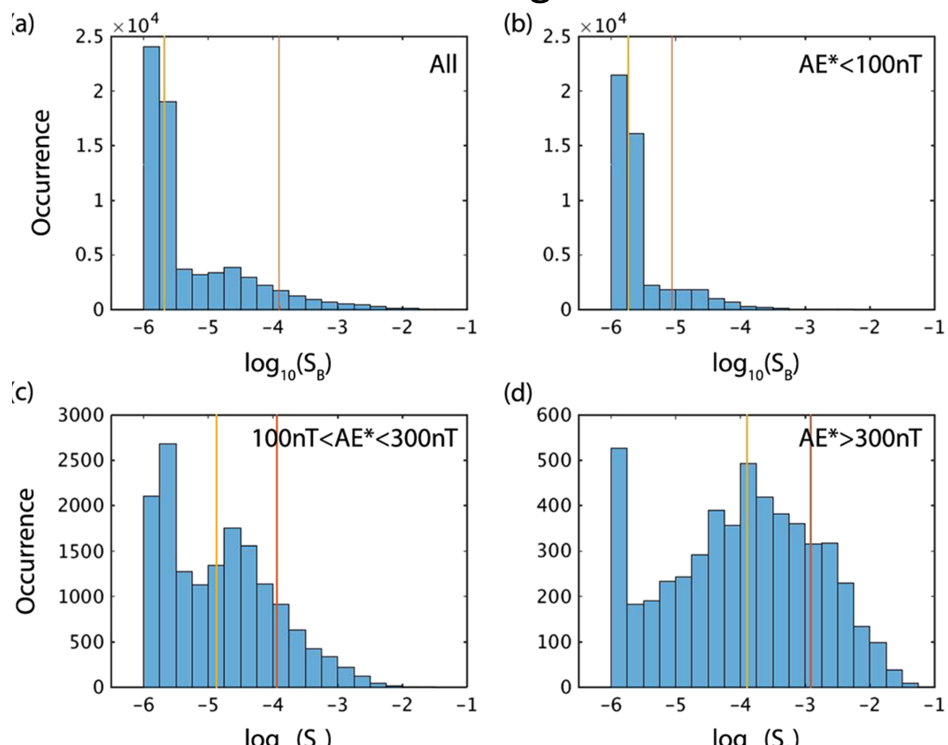
IS THAT THE CASE FOR WAVE PARAMETERIZATIONS?

ULF Wave Power
Storm-time vs Empirical



Murphy et al., [2016]

Whistler-mode wave power @ GEO in morning sector



Watt et al., [2017]

CONSTRUCTION OF PARAMETERIZATIONS - 1

- **Let's get specific**:
  - ELF/VLF momentum-space diffusion

Requires Stix parameters (ω_{pe}/Ω_e, composition - obs)

wave intensity (obs)

wavenormal angle (obs)

$$D_{\alpha\alpha}(L^*, p, \alpha, t) = \frac{e^2}{4\pi} \sum_n \int_{\theta_{min}}^{\theta_{max}} \frac{d\theta}{\cos\theta} \sum_i \frac{\hat{B}^2_\omega(\omega_i, t) G(\theta) \left|\Phi_{n,k}\right|^2}{\left|v_{||} - \partial\omega/\partial k_{||}\right|_{k_{||,i}}} \left(\frac{\frac{n\Omega_\alpha}{\gamma} - \omega_i \sin^2\alpha}{\cos\alpha} \right)^2$$

Range of integral obtained from obs

CONSTRUCTION OF PARAMETERIZATIONS - 2

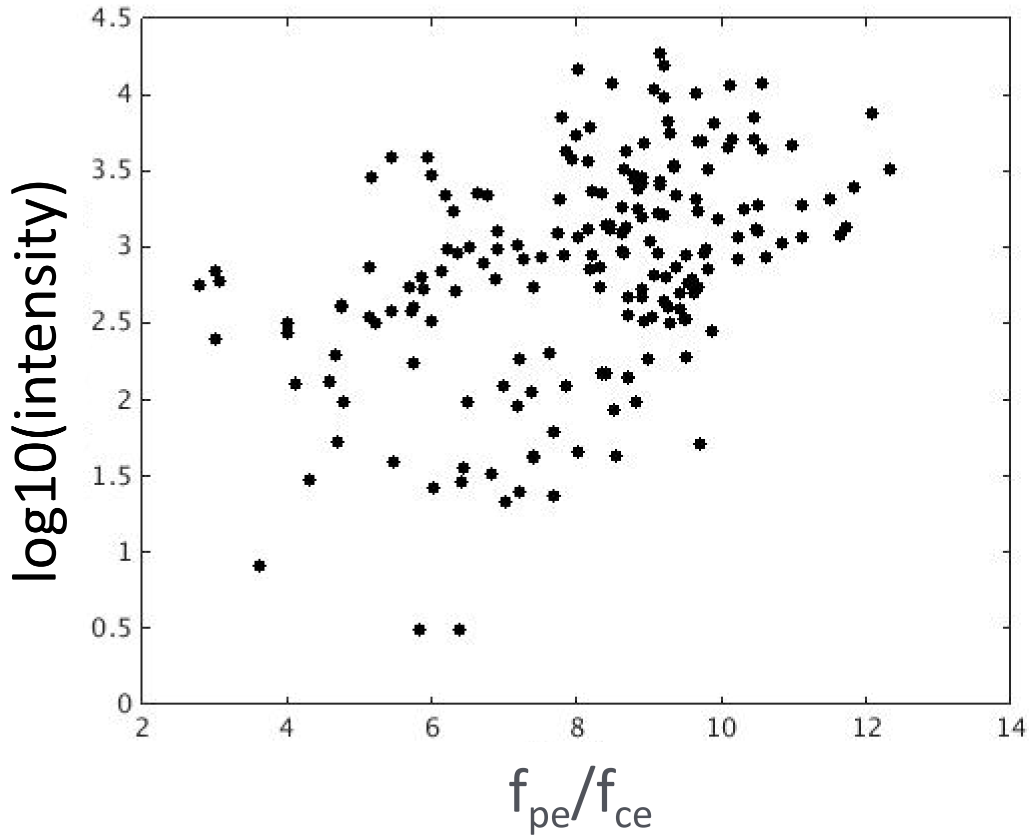
- Inputs usually modelled independently
  - Time-average of observations obtained over many years
  - Semi-empirical models for B, n

- What happens if you construct $D_{\alpha\alpha}$ from individual samples of magnetospheric parameters, then look at distribution/statistical description?

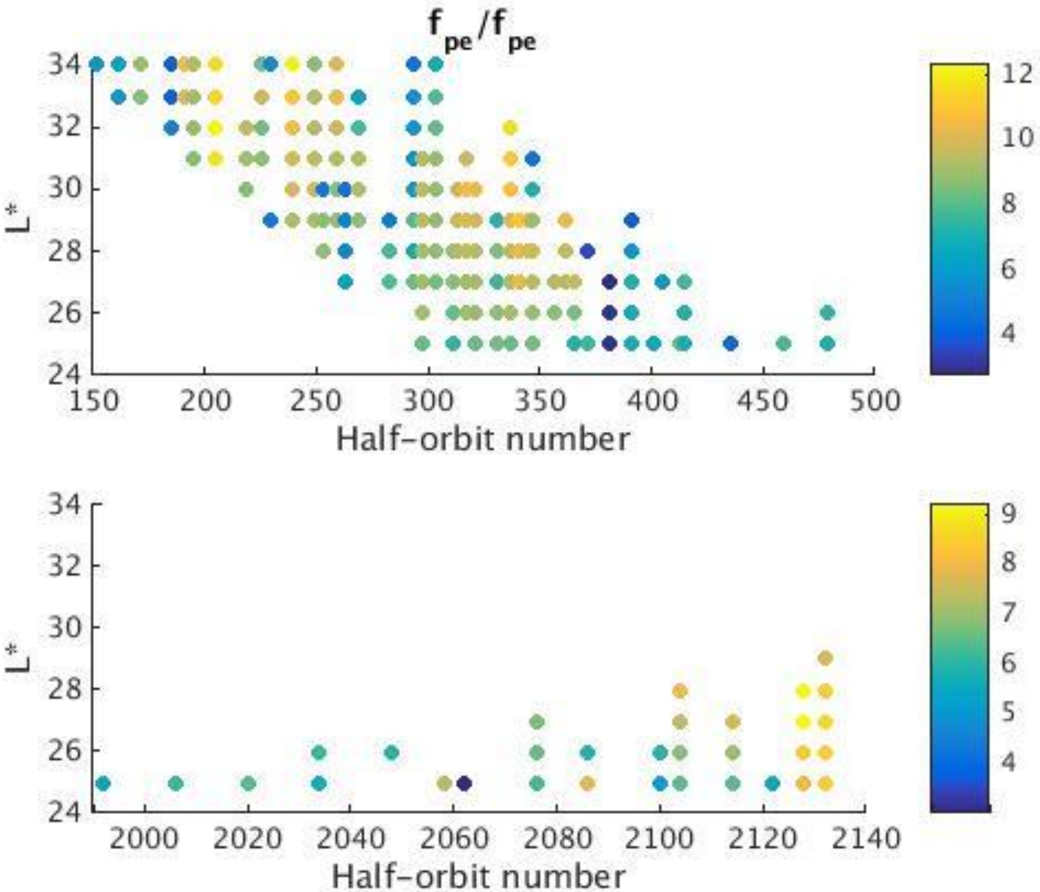
PILOT STUDY

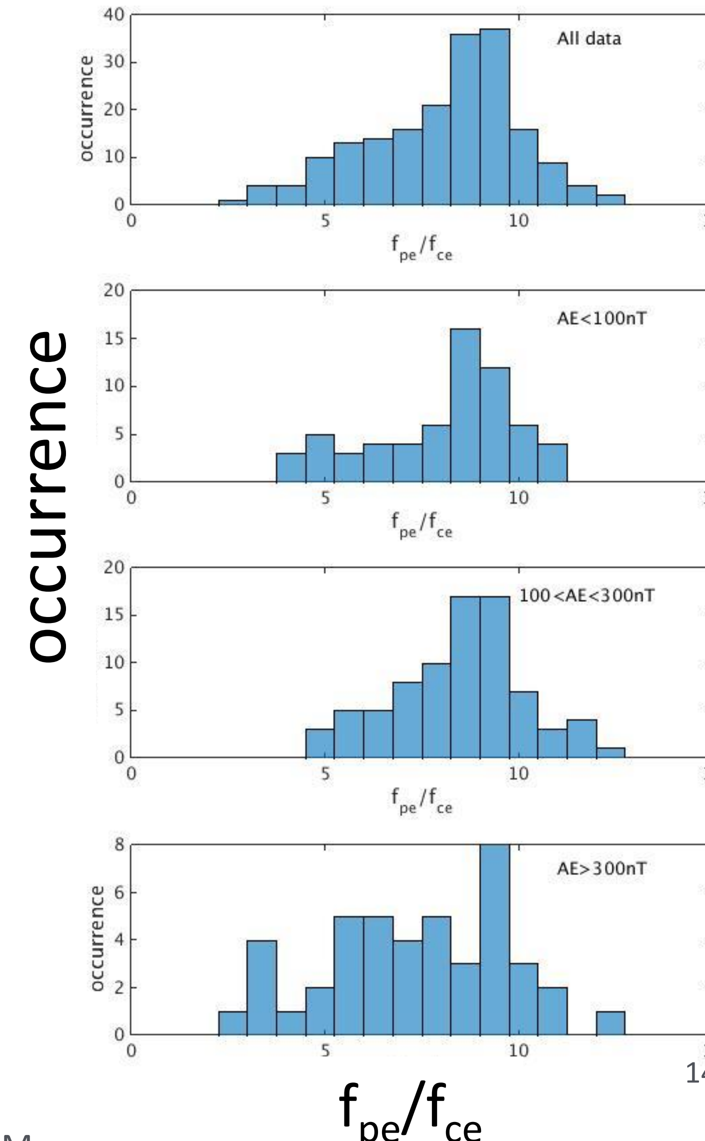
- CRRES data
- Diffusion due to hiss for $2.5 < L < 3.5$
- Any MLT
- 187 points

- CRRES collects simultaneous
  - f_{pe}/f_{ce}
  - Wave intensity

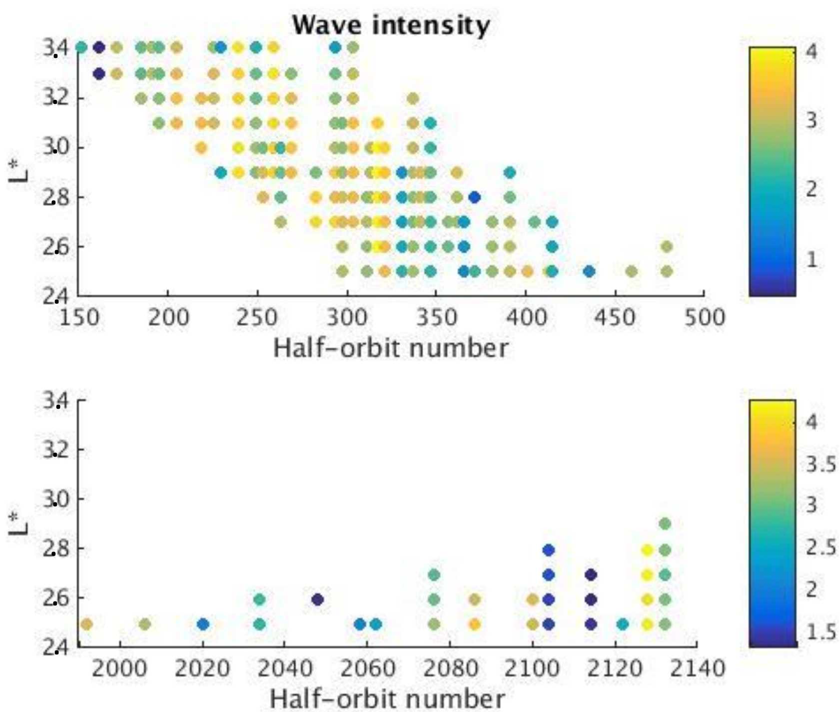


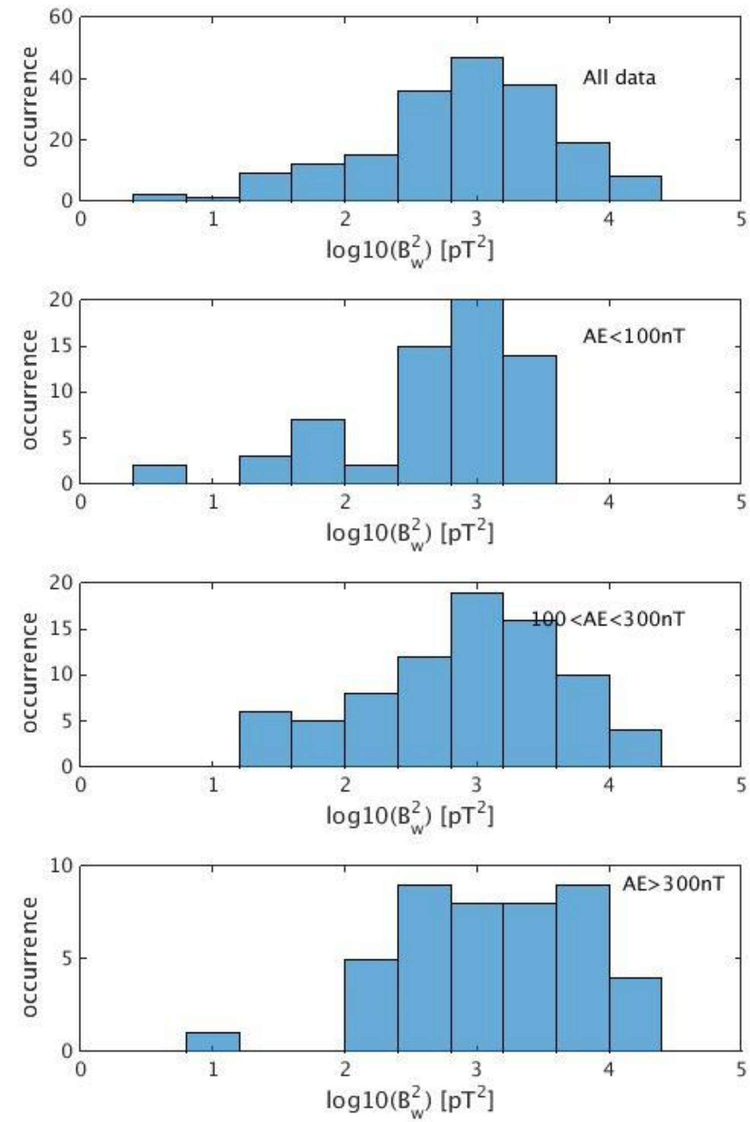
PLASMA/ GYRO-FREQUENCY





WAVE AMPLITUDE

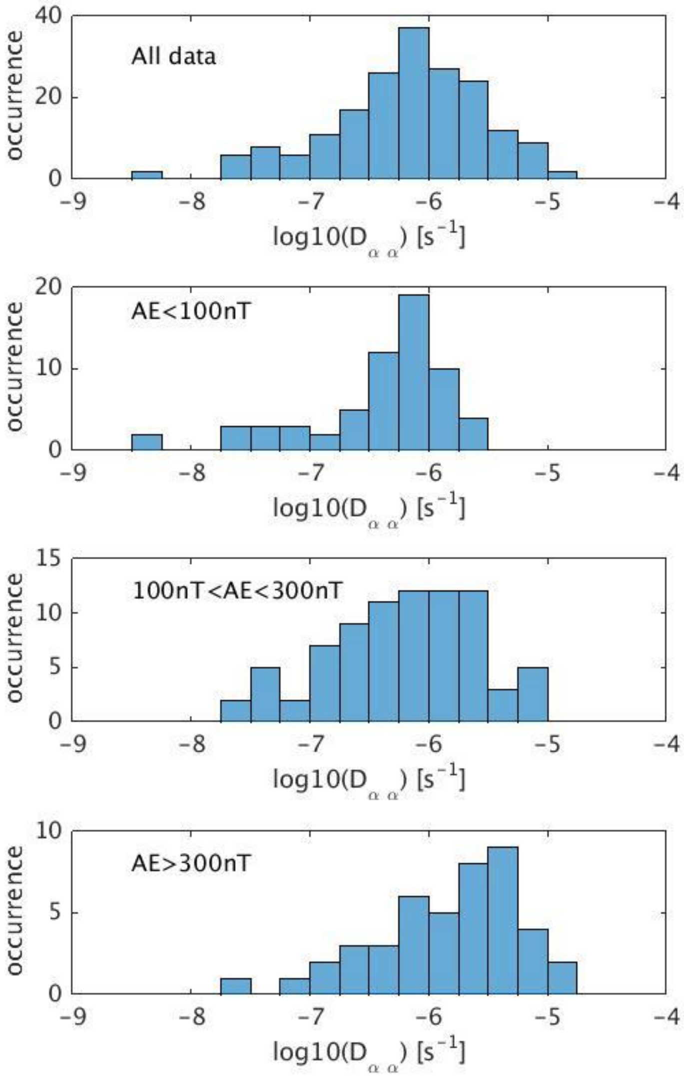




PADIE DIFFUSION COEFFICIENTS

- Note, we have insufficient information from CRRES to study effects of spectral shape etc
- Two inputs:
  - plasma:gyro frequency ratio
  - Wave intensity

- Coefficient of variation:
  - Wave amplitude: 0.98
  - plasma:gyrofrequncy: 0.25
  - Diffusion coefficient: 2.96



CONCLUSIONS AND FUTURE WORK

- Our parameterizations of diffusion in Outer Radiation Belt due to all wave types could be improved (see S. Bentley – this session)
  - parameterization of D_{ij}, not inputs to D_{ij}
  - D_{ij} likely to have larger variance than variance due to wave amplitudes alone
  - Parameterization with activity level currently leads to very large variance compared to difference in median values
  - Seek new parameterizations that minimize the variance in the diffusion coefficient

- Diffusion models with stochastic parameterizations