Radial diffusion coefficients database in the frame of SafeSpace project

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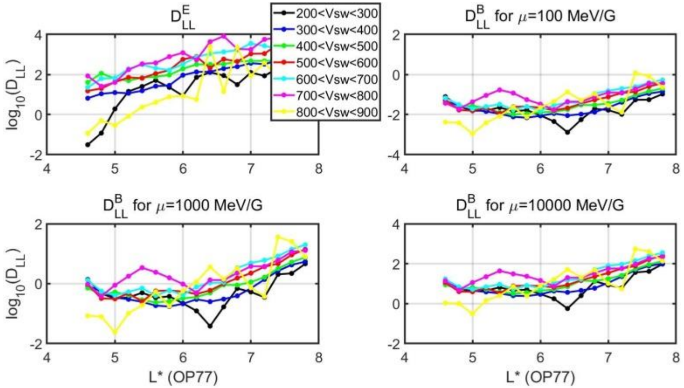
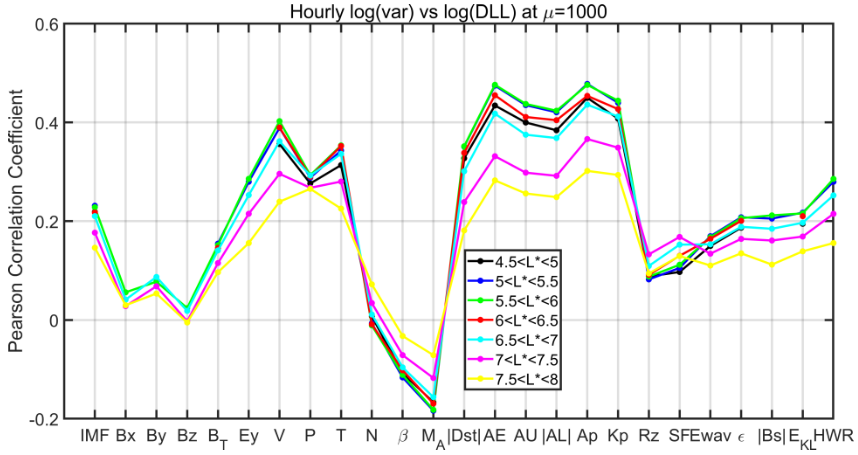
- Radial diffusion has been established as one of the most important mechanisms contributing the acceleration and loss of relativistic electrons in the outer radiation belt.
- In the frame of SafeSpace project we have used 12 years (2009 – 2020) of multi-point magnetic and electric field measurements from THEMIS A, D and E satellites to create a database of calculated D_{LL}.
- We use Continuous Wavelet Transform to compute the power spectral density in the 2-25 mHz frequency range (Pc4-5).
- The database is used to perform statistics and parameterization of the D_{LL} with various solar wind parameters, coupling functions and geomagnetic indices.
- The available D_{LL} from the database will be used as training sample for the development of a nowcasting/ forecasting model based on AI methods (Artificial Neural Networks – ANN, Genetic Algorithms – GA).





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Pre-processing

1. Input Data from THEMIS A, D and E

Level 2 magnetic (FXG) and electric (EFI) field measurements with 4 sec resolution during the 2010 – 2020 time period.

2. Mean Field Aligned Transformation

Using Fei et al. approach (more suitable for relativistic particles) we need the compressional B and the toroidal E components.

3. De-trending time-series

A 20 min moving window averaging is extracted from the original time-series (this is similar with applying a high pass filter with cutoff at ~0.83 mHz).

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PSD calculation

1. We use Continuous Wavelet Transform to compute the power spectral density in the 2-25 mHz frequency range (Pc4-5).

2. We calculate the total power over the 2-25 mHz frequency range as:

$$P_{total} = (dj*dt/Cdelta)*sum(PSD)$$

Where: $dj = -\, {}^{log_2\left(\frac{f_{min}}{f_{max}}\right)}\!\big/_{max(scale)}$ (Torrence and Compo, 1998 [eq.24])

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DLL calculation

Fälthammar [1965]	Fei et al. [2006]
Electromagnetic + Electrostatic	Electric + Magnetic
Single mode (m=1)	Multiple modes
Non-relativistic particles	Relativistic particles
Both equatorial and off-equatorial particles	Only equatorial particles
Phase relation between the electric and the magnetic field perturbations	No phase relation between the electric and the magnetic field perturbations
Cannot easily distinguish convective and inductive terms of electric field with in-situ measurements (need of multiple satellites)	Omits the correlation between induced electric fields and magnetic field variations (inconsistent with Faraday's law)

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DLL calculation

$$D_{LL}^{E} = \frac{L^{6}}{8R_{E}^{2}B_{E}^{2}} \sum_{m=1}^{\infty} PSD_{m}^{E}(\mathrm{m}\omega_{d}) \qquad D_{LL}^{B} = \frac{\mu^{2}L^{4}}{8q^{2}\gamma^{2}R_{E}^{4}B_{E}^{2}} \sum_{m=1}^{\infty} m^{2} PSD_{m}^{B}(\mathrm{m}\omega_{d})$$

- The wave power corresponds to the power at a specific drift frequency for all m values, which essentially means that particles are radially transported via stochastic acceleration with various frequency waves (main frequency and its harmonics).
- Of course, to calculate the power at various m values, one would need several satellites in tetrahedral coordination, which is not trivial. Thus, we assume that power at high m values is often orders of magnitude smaller than the power at m=1 and, thus, all power falls in the m=1 value. The latter assumption, also assumes that there is no stochastic acceleration rather than resonant interaction.
- Such an assumption can potentially underestimate the radial diffusion coefficient, since higher m values are shown to be often significant (e.g. m=2 up to m=5 at recovery phase of storms). In order to minimize the error presented we can use, instead of the power at a specific drift frequency, the total power (weighted averaged power over the whole frequency range under study); in our case Pc4 and Pc5 frequency range.

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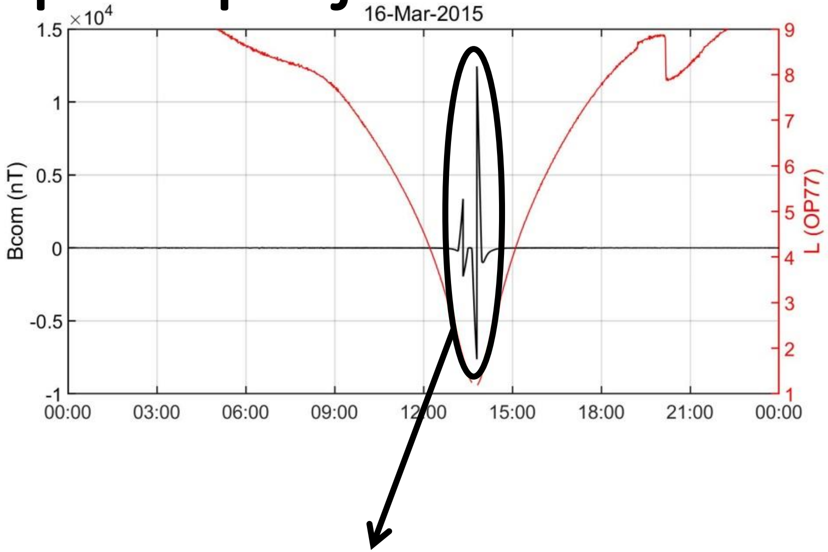
THEMIS spacecraft follow an elliptical orbit with perigee near 470 km.

As the satellite moves inbound and outbound with high velocities at low L-shells, the magnetic field measurements exhibit, not only orders of magnitude increase but, very large gradients, as well. These large gradients make it quite difficult to estimate the background trend which has to be removed.



Even if we filter the magnetic field time-series, the filtered signal's amplitude still grows significantly near perigee which renders any PSD calculations erroneous. Moreover, the error is significantly increasing for decreasing frequency values.

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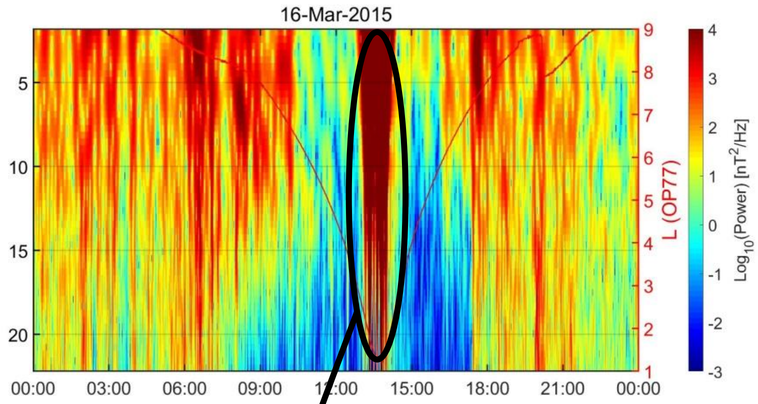

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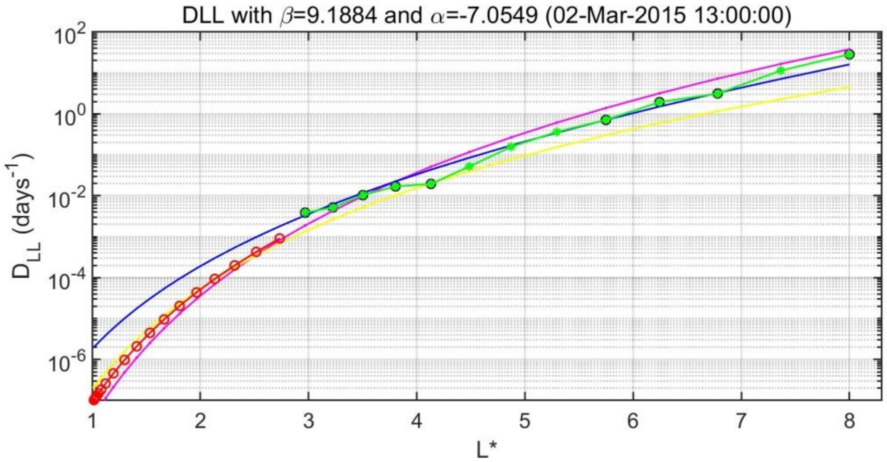
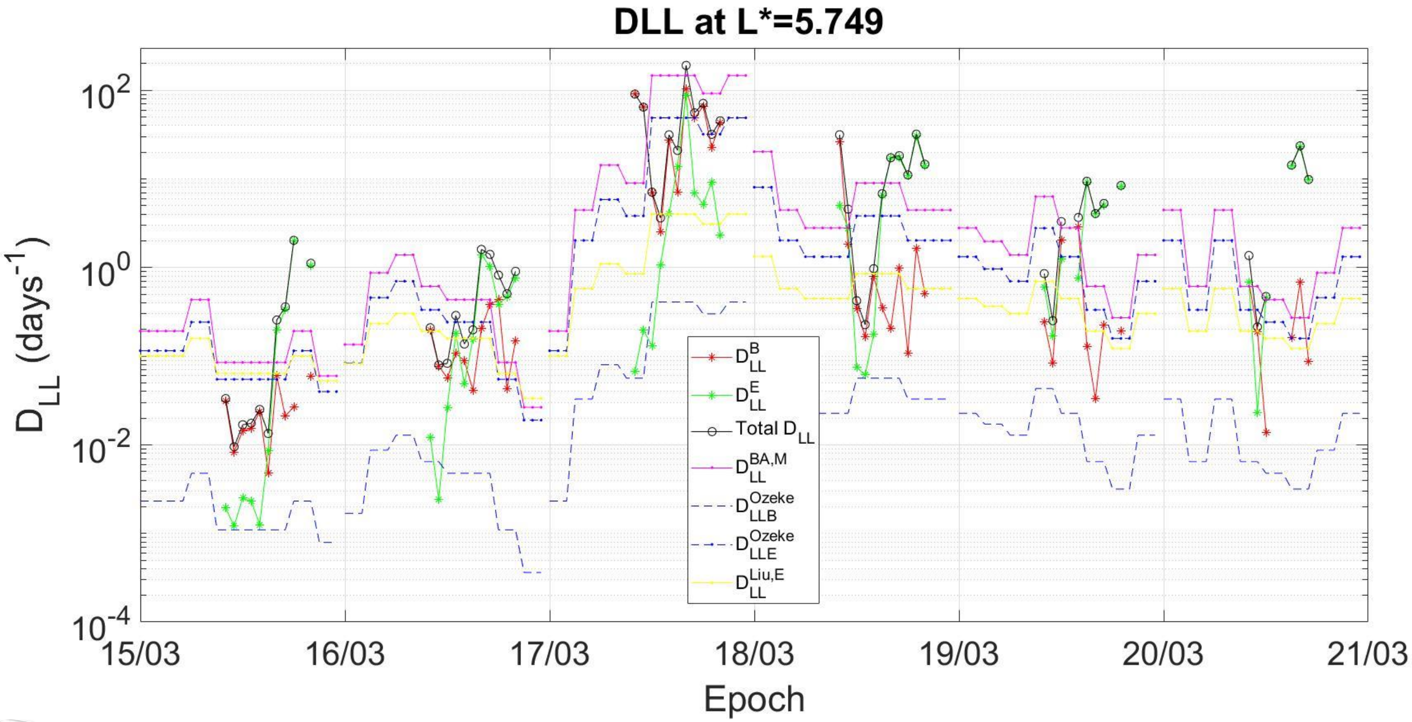
1. <u>Gaps in time</u>
   - linear interpolation (only for cases of 1-2 hour gaps)
2. <u>Gaps in L*</u>
   - Power law extrapolation
   - least square fitting process using the function $\log_{10}(DLL)=\beta*\log_{10}(L*)+\alpha$ with $8<\beta<12$



Comparison with Empirical Models



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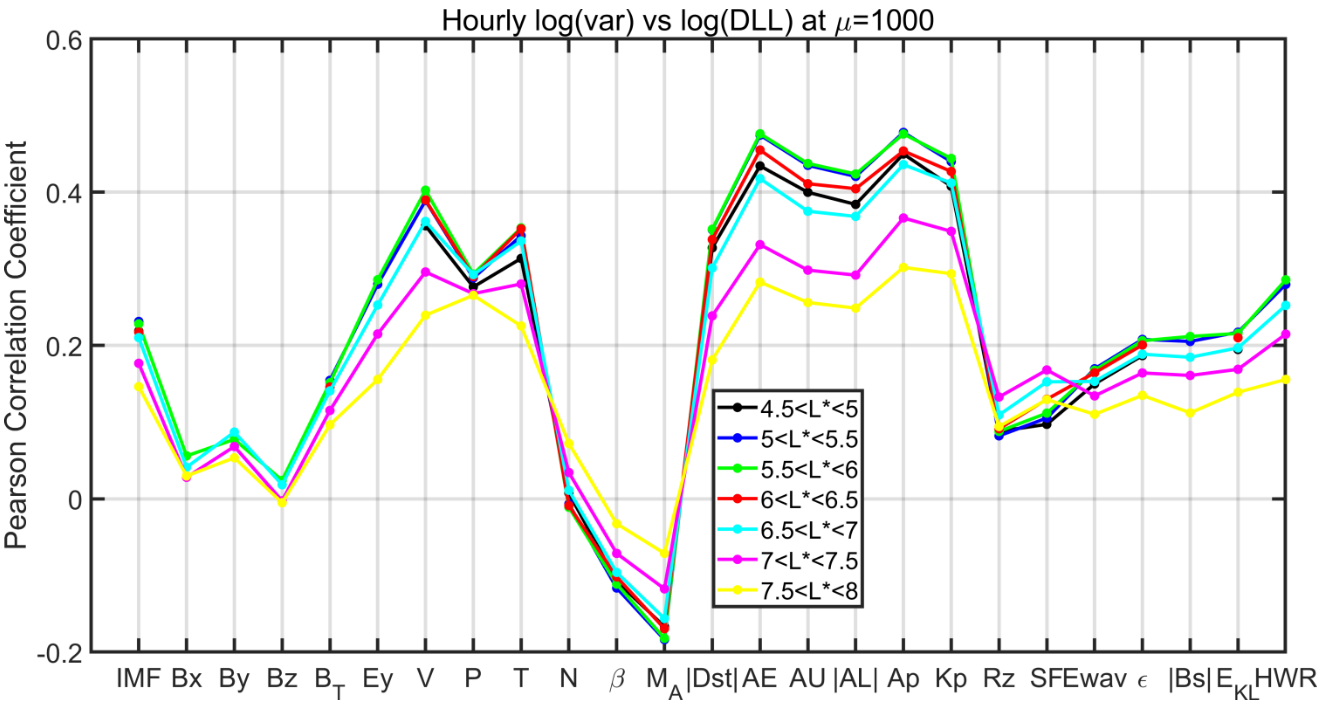
Solar wind/geomagnetic dependence



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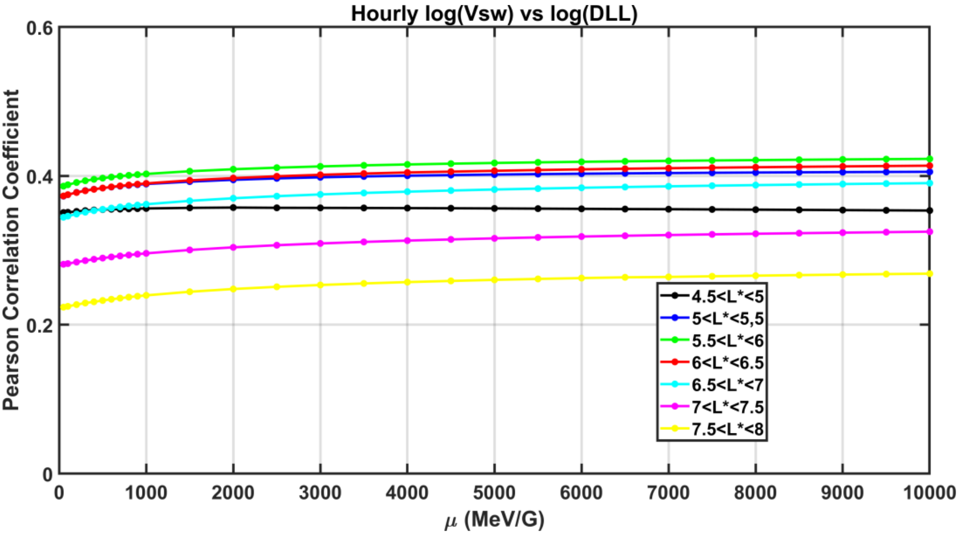
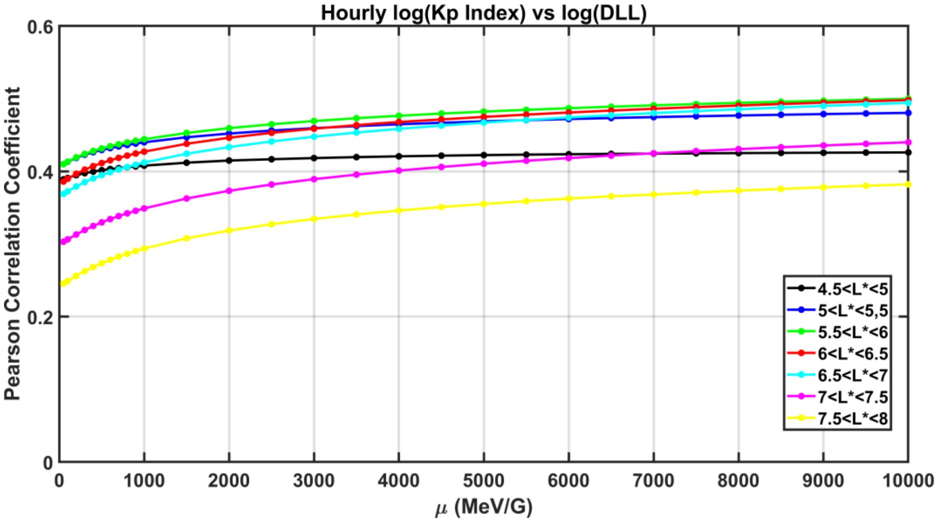
Mu dependence





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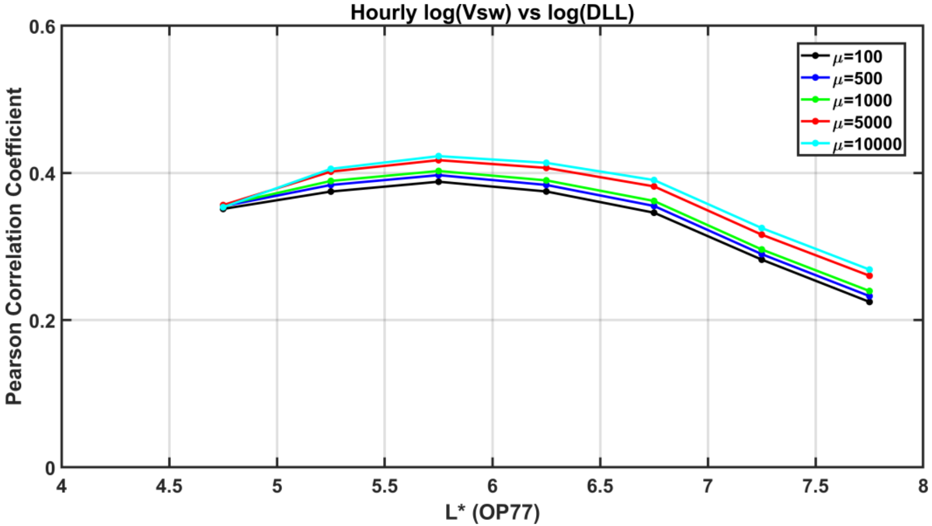
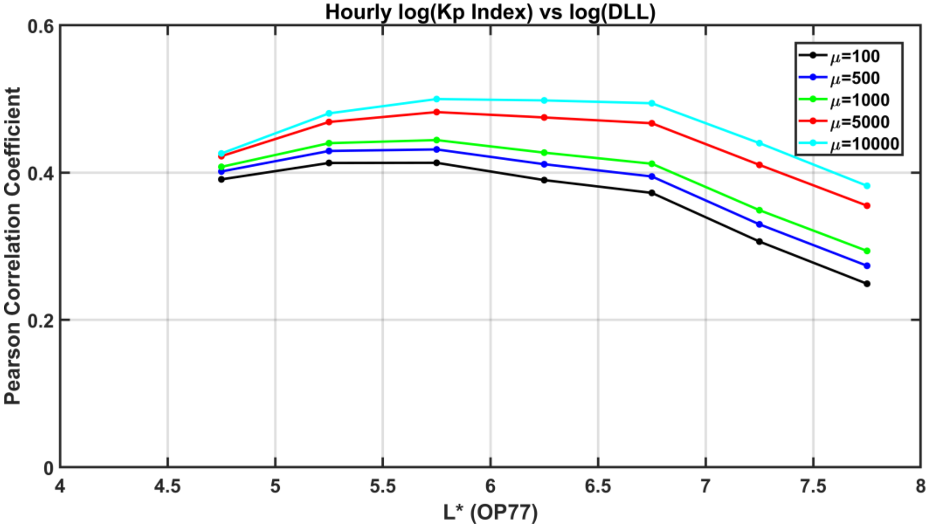
L* dependence





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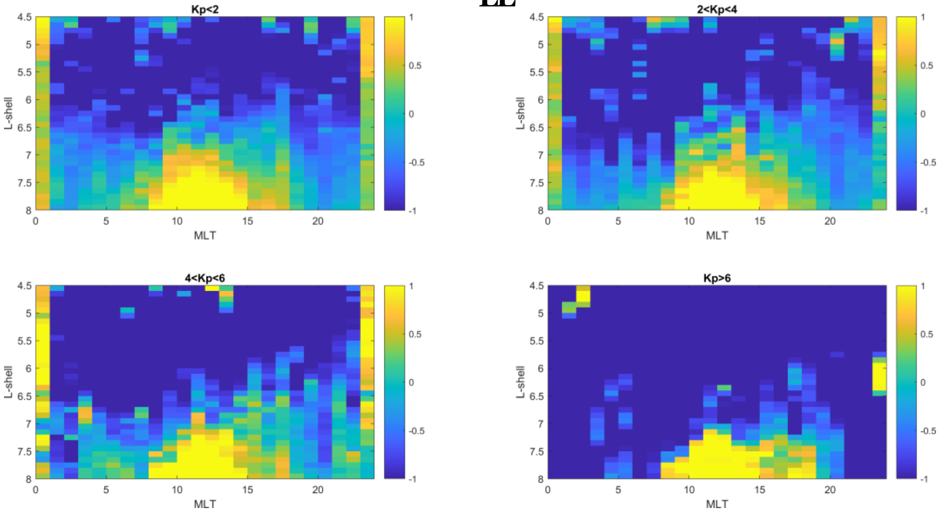
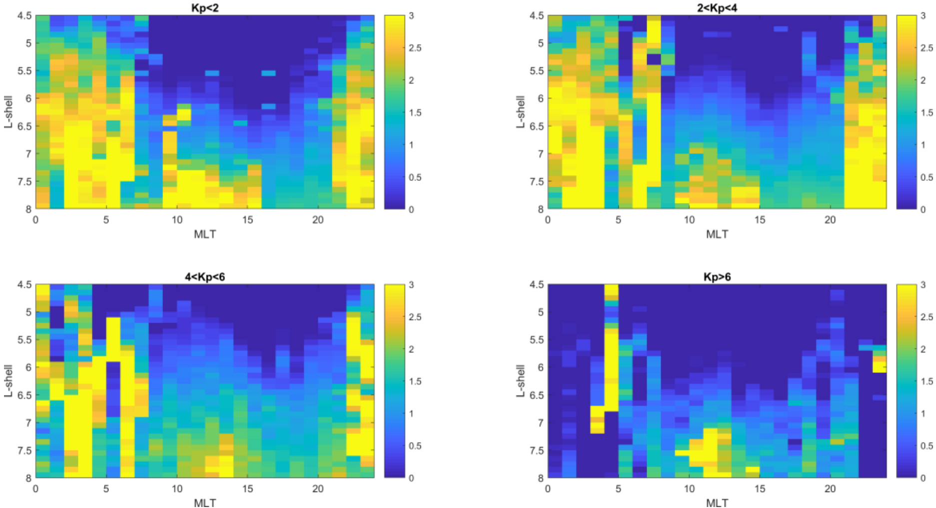
MLT dependence

D^{B}_{LL}



D^{E}_{LL}



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Thank you for your attention

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