Pro-L*: A probabilistic L* mapping tool for ground observations in the radiation belts

Rhys L Thompson[1] | S. K. Morley[2] | C. E. J. Watt[3] | S. N. Bentley[3] | P. D. Williams[3]

University of Reading

Affiliations
- [1]Department of Mathematics and Statistics, University of Reading, UK
- [2]Los Alamos National Laboratory, Los Alamos, USA
- [3]Department of Meteorology, University of Reading, UK

Contact : **r.l.thompson@pgr.reading.ac.uk**

Summary

Mapping ground observations to an L* in space has significant value since the extensive coverage of ground instruments on Earth can be extended into space. Pro-L* allows the combination of magnetic field models (which can significantly disagree on mapped L* for a single ground location) to form L* probability distributions that can better inform location in radiation belt modelling.

Introduction

The third adiabatic invariant, ϕ, measures the magnetic flux through drift contours of azimuthally drifting energetic particles trapped in the Earth's magnetic field

$$\Phi = \int \boldsymbol{B} \cdot d\boldsymbol{S}$$

The Roederer (1970) L*, a label for a particular drift shell whose equatorial point would be at an approximate distance from the Earth's centre if magnetic field lines were relaxed to a dipole, is often used instead of Φ in adiabatic invariant space

$$L^* = 2\pi B_E {R_E}^2/\Phi$$

Ground observations are frequently used in modelling for space weather related processes. Global magnetic field models allow for ground locations to be mapped along field lines to a location in space and transformed into L*, provided they are on closed field lines. Magnetic field models can significantly disagree on mapped L* for a single ground location.

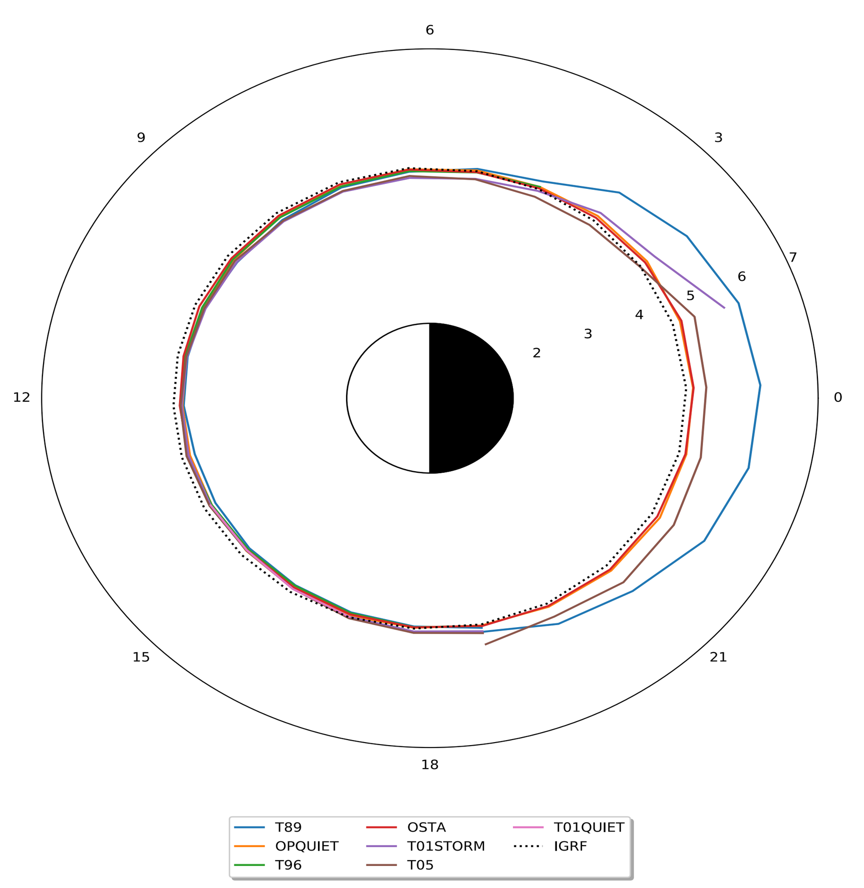

Figure 1: Mapped L trajectories for a single ground location over one day, for a number of global magnetic field models (including the IGRF with no external field applied)*

Probabilistic L* (Pro-L*)

We have created Pro-L*, a probabilistic L* mapping tool for ground observations in space weather modelling. Pro-L* includes 11 years of mapped L* values using 7 popular magnetic field models, over a 16 x 24 grid (magnetic latitude x magnetic longitude, latitude uniform in dipole L) in the Northern Hemisphere.

At each mapped L* location the following variables are also stored:

- McIlwain L
- Minimum **B**-field
- Cartesian location

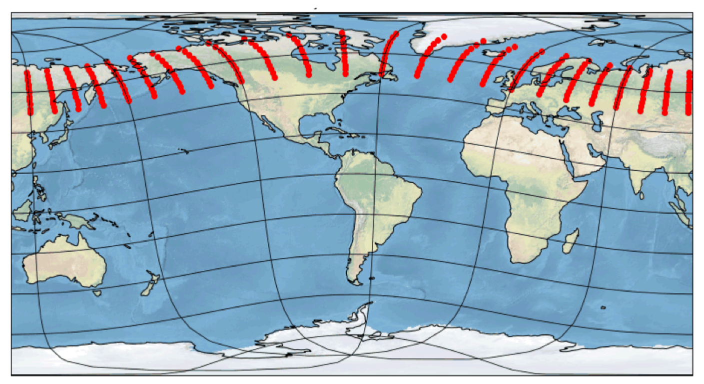

Figure 2: Ground locations of mapped variables in the Pro-L toolbox*

Pro-L* contains approximately 1.9 billion variables which can be easily accessed for statistical analysis. Data has been csv formatted to be widely accessible for other researchers in the field across multiple programming platforms.

Code	Model
OPQUIET	Olson and Pfitzer (1974)
T89	Tsyganenko (1989)
T96	Tsyganenko (1996)
OSTA	Ostapenko and Maltsev (1997)
T01QUIET	Tsyganenko (2002)
T01STORM	Tsyganenko et al. (2003)
T05	Tsyganenko and Sitnov (2005)

Table 1: External magnetic field models used in Pro-L for variable calculations*

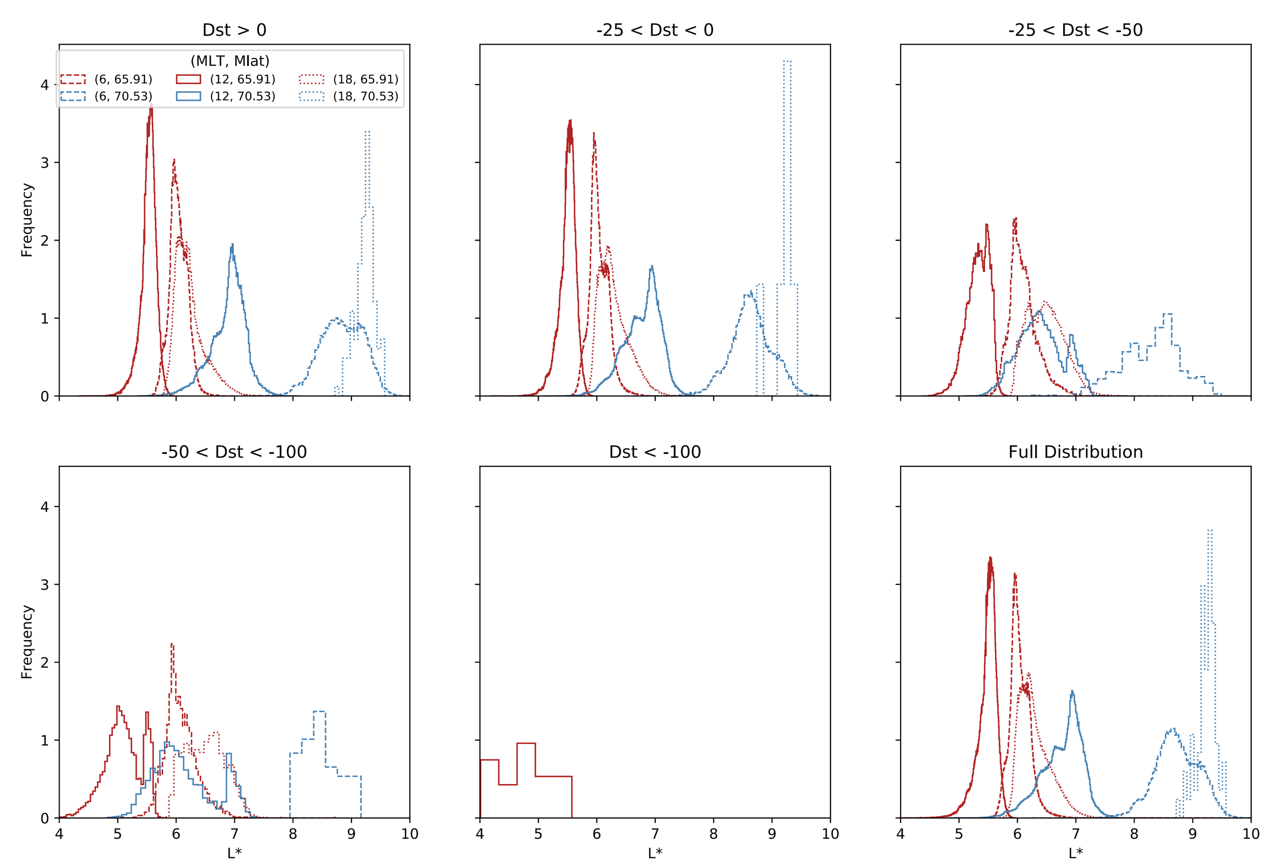

Figure 3: Combined model L probability distributions for two magnetic latitudes at dawn, noon and dusk, as a function of the Dst index*

Model statistics

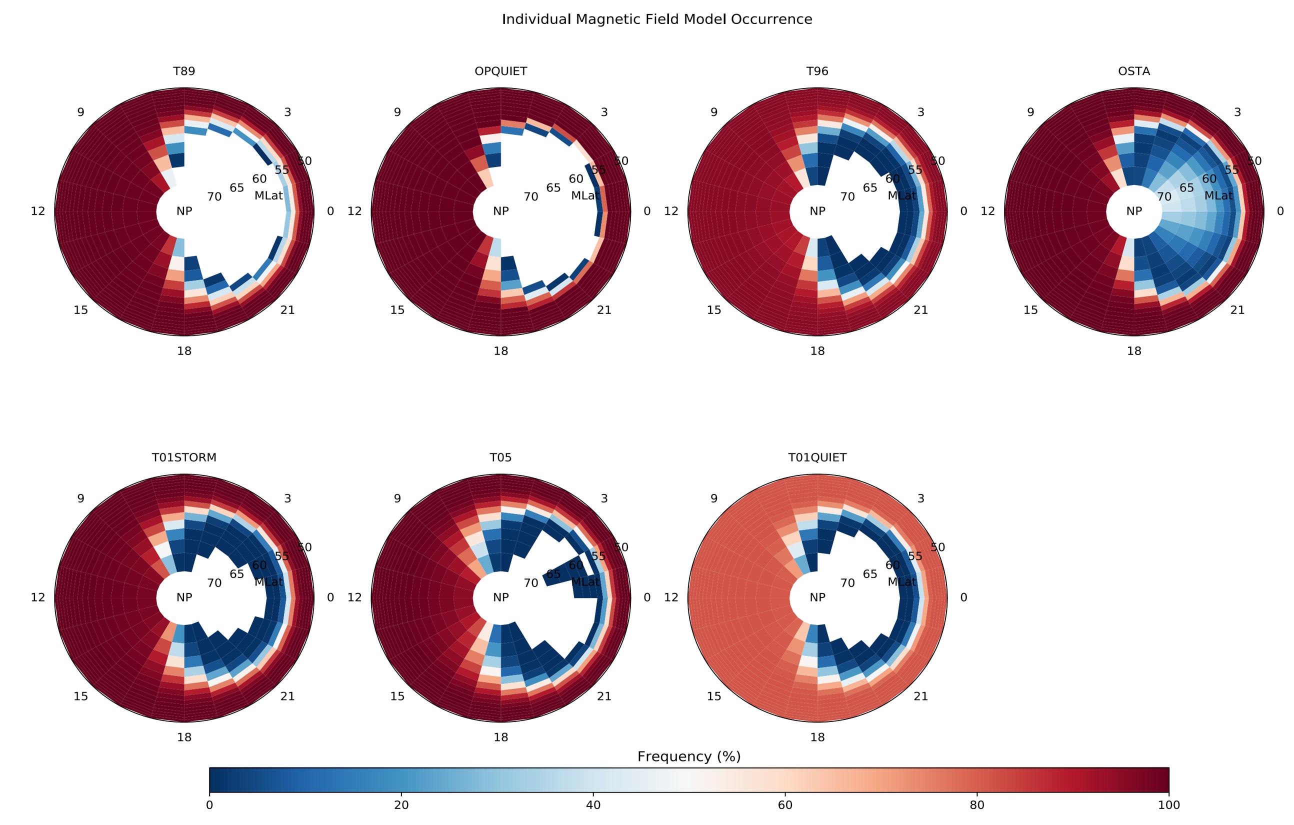

Figure 4: Occurrence statistics for each magnetic latitude - MLT bin, shown for each magnetic field model. Each bin is self-normalized.

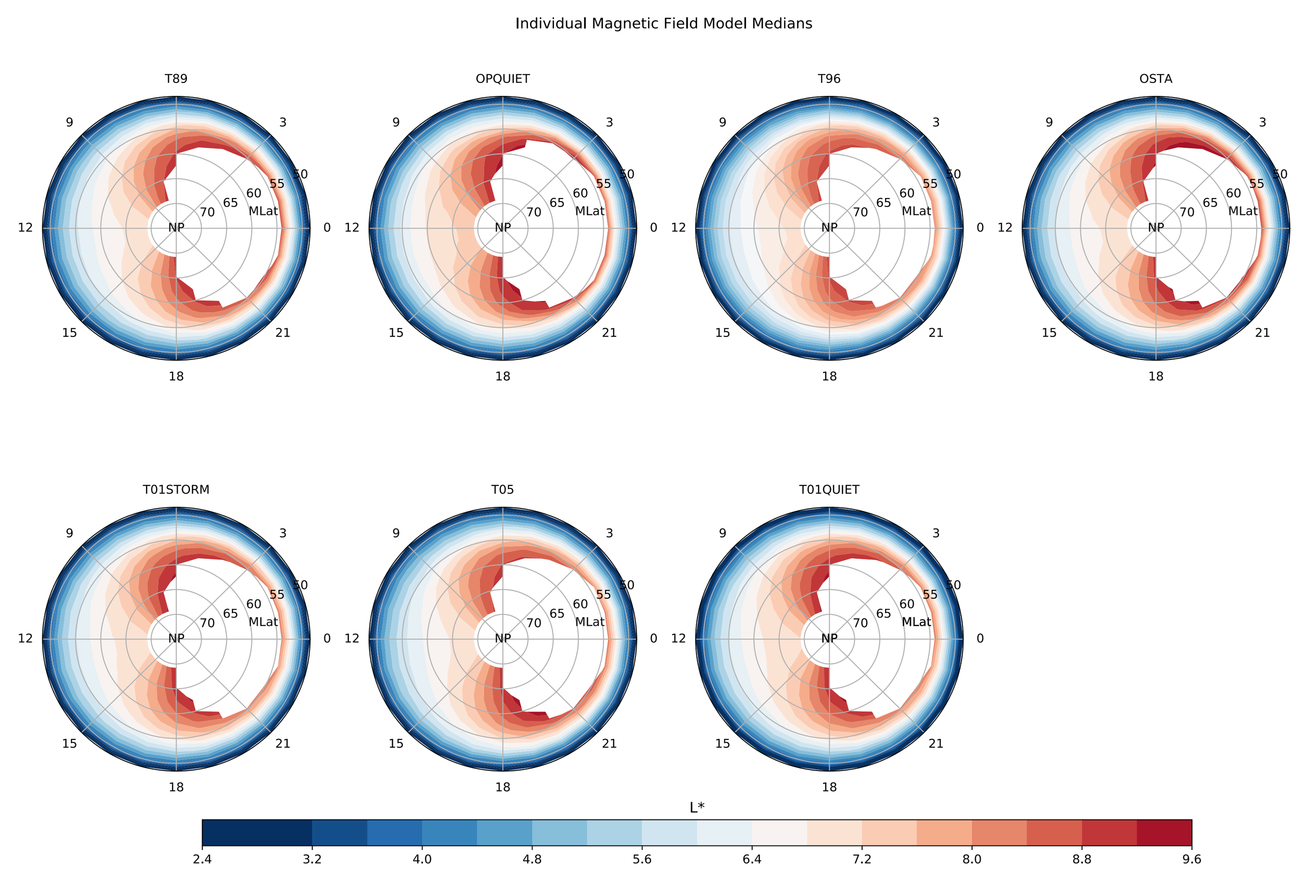

Figure 5: L medians as a function of magnetic latitude and MLT, shown for each magnetic field model. Codes for each model are as in Table 1.*

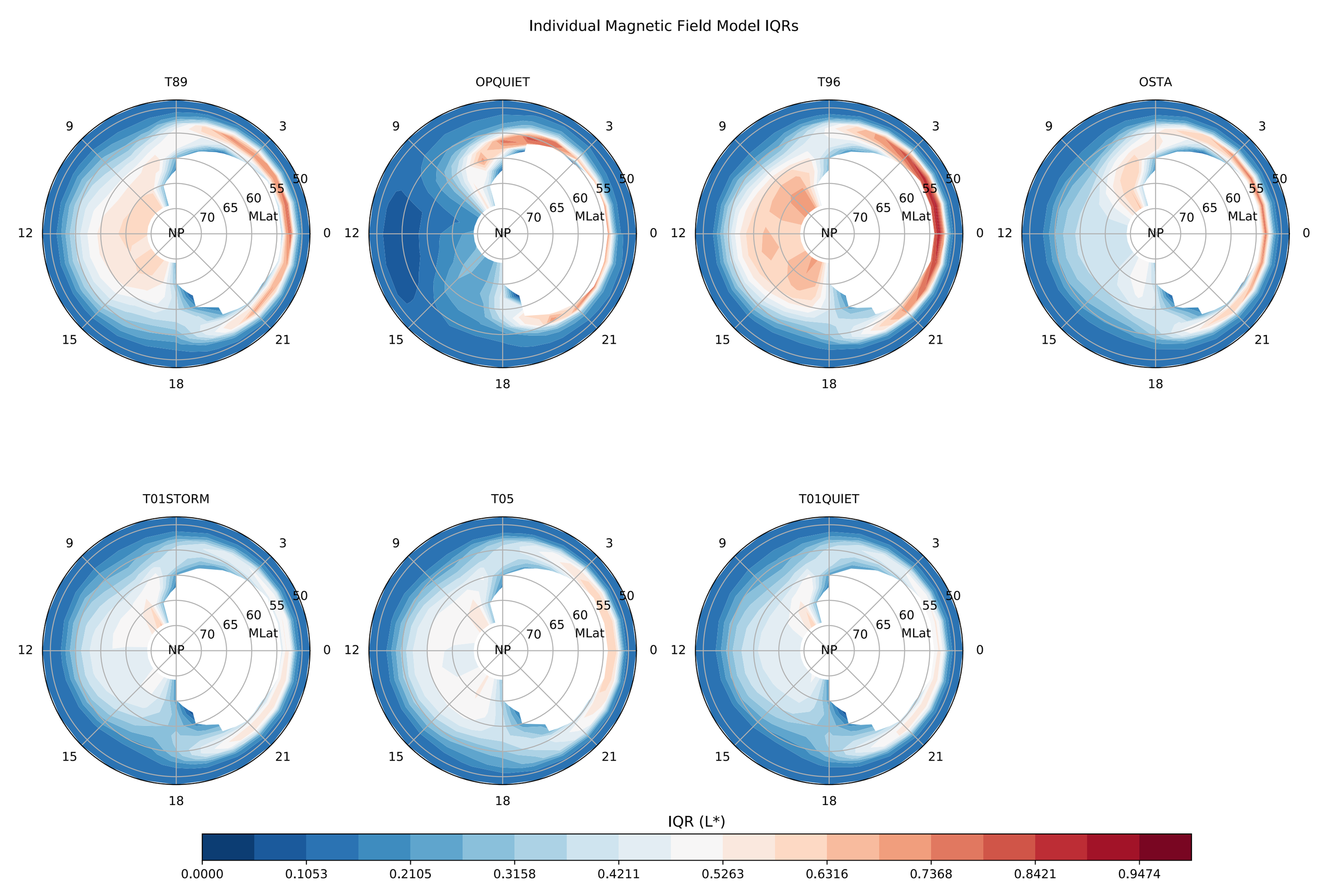

Figure 6: L interquartile ranges (IQRs) in each magnetic latitude - MLT bin, shown for each magnetic field model.*

Test case: Storm dropout

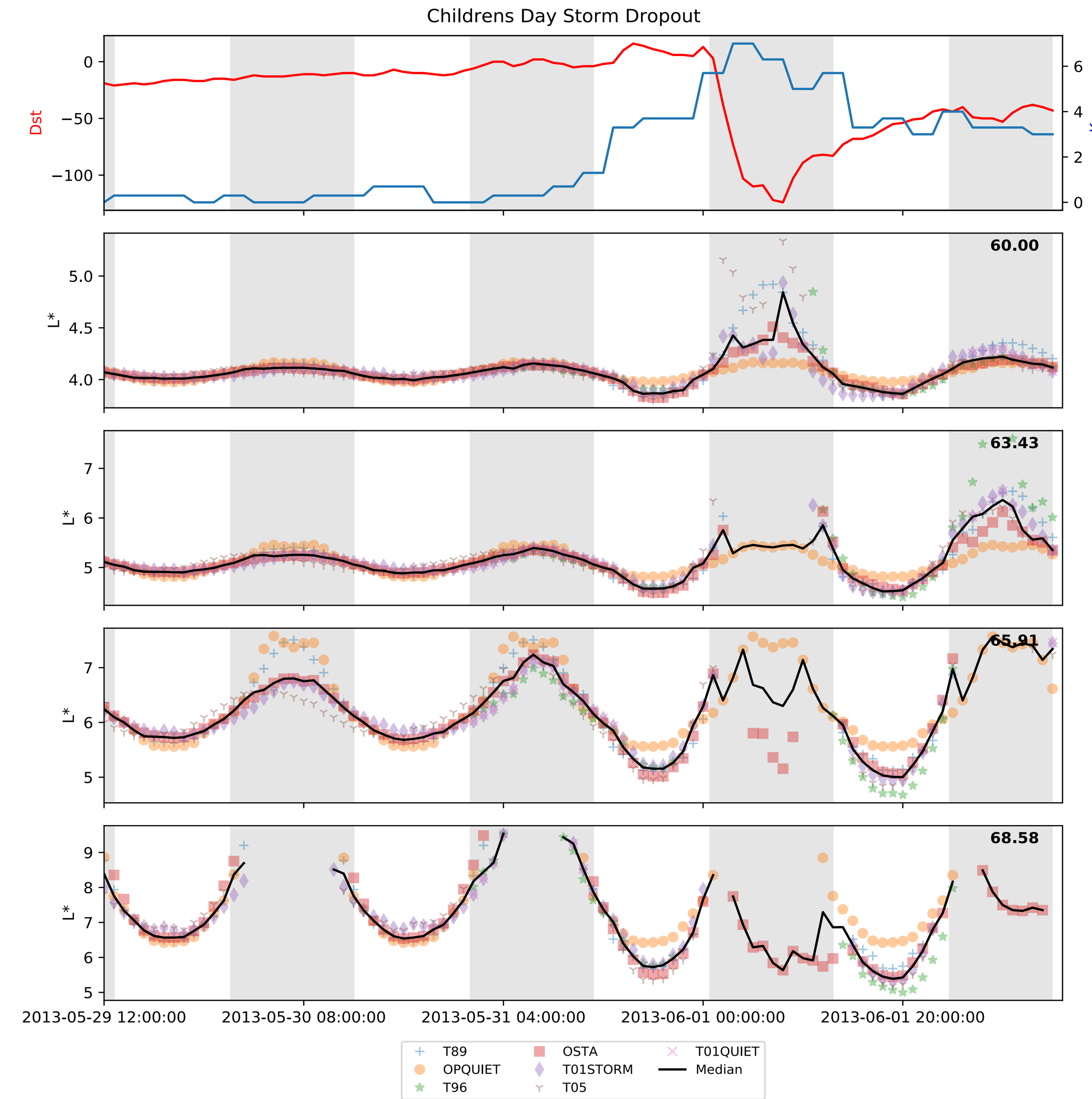

Figure 7: The response of L during the Children's Day storm dropout on 1 June 2013 for each magnetic field model, at a selection of magnetic latitudes (magnetic longitude 330 degrees), where ground observations are frequently of interest. The Dst and Kp indices are also provided over the given time period. Shaded bars indicate times where observed values are on the nightside.*

What can Pro-L* be used for?

- Investigating the response of L* during enhanced geomagnetic activity, in event studies
- Determining the nature of L* variability in magnetic latitude and local time, in both the shape and width of probability distributions
- Producing metrics for L* which indicate regions where the physical description for L* is invalid, or where L* is highly variable
- Deducing how much L* variability is due to the external magnetic field models themselves, or geomagnetic conditions
- Deciding how to parameterize a L* model (for example, via some of the parameters underlying the external magnetic field models) with quantified uncertainty
- Understanding when fixed L* boundaries in radiation belt models, used to constrain satellite and ground observations for ease of modelling, are not suitable or well-defined

References

1. Roederer (1970), *Dynamics of geomagnetically trapped radiation, Springer-Verlag Berlin*
2. Tsyganenko (1989), *Planetary and Space Science*
3. Olson and Pfitzer (1974), Tsyganenko (1996, 2002), Ostapenko and Maltsev (1974), Tsyganenko and Sitnov (2005), *Journal of Geophysical Research: Space Physics*

Acknowledgements

- This work was supported by the Engineering and Physical Sciences Research Council (EPSRC) grant EP/L016613/1