Replies to Referee #1

We thank the Referee for a thorough examination and review of the manuscript, which has led to considerable improvements in the paper. In the improved version, the results and conclusions of the study are presented more clearly; furthermore, the revised version includes better definitions of the variables and the methods used for their calculation, as well as corrections of definitions and grammar. Below we address the specific comments of the Referee, pointing to the locations in the paper where corrections were made, and listing the specific changes:

1. As mentioned above, the main issue preventing this manuscript from being ready for publication is the lack of discussion of the results of the study. What should we conclude from the various discrepancies between the models? How should scientists utilize the region maps illustrating constancy of the invariants? What physical mechanisms lead to breaking of the invariants in the regions illustrated? What should we use if we are interested in sorting data from those regions? There is a complete lack of discussion that is somewhat surprising and must be rectified for this to be considered a complete paper.

We agree with Referee #1 that the results have not adequately been discussed in the paper; this comment has also been made by Referee #2. We have completely revised the final section of the Conclusions of the paper, and the following extensive discussion of the results of the study has been added in section 6, line 248 :

"In the discussions of particle transport, energization and loss in the Earth's radiation belts, a major question concerns the relative contribution between wave-particle interactions vs. radial diffusion, which is generally best discussed in terms of phase-space-density, calculated at constant adiabatic invariants. From the discussions herein, it is evident that caution should be exercised when considering the second and third adiabatic invariants to remain constant across all L-shells and local times within the radiation belts as well as for all particle energies and all geomagnetic conditions. In particular, in regions where the results from the various models diverge from the results from the particle tracer, which most closely follows the calculations of the invariants, we can conclude that the models should be used with caution, the lack of confidence in them being analogous to the magnitude of this divergence. In this paper it has been demonstrated that under extreme curvature of the magnetospheric magnetic field, particles of high energy and low pitch-angles cannot be considered to remain adiabatic in terms of their second and third invariants.

The physical mechanism that leads to breaking of the invariants in the regions illustrated does not involve temporal variations in the magnetic field of time scales shorter than the associated time-scales of the second and third invariants, i.e. the bounce period and drift period, as the fields used in the simulations above are all static. Instead, the breaking of the invariants in the above is associated with deviations of the magnetic field from a dipole configuration: in the definition of the invariants, in order for the second adiabatic invariant to remain constant it is required that the magnetic field between two mirroring points does not change much in one bounce period as the particle's guiding center drifts across field lines. Similarly, in order for the third adiabatic invariant to remain constant, it is required that the *magnetic flux through the guiding center orbit of a particle around the earth should remain constant. However during active geomagnetic conditions the curvature of the field lines in the night side of the earth in combination with the large gyro-radii of large-energy particles leads to deviations from these conditions that need to be taken into account.*

The present paper by no means aims to serve as a guide-line of the adiabaticity of particles at all energies, pitch angles and geomagnetic conditions; instead, it aims to raise awareness and caution in using general-purpose models and tools, such as IRBEM, LANL and SPENVIS to calculate the values of the adiabatic invariants in regions and cases where they are not well defined."*

2. The definition and description of the invariants, particularly L∗, definitely needs some fleshing out. How is L∗ defined in terms of integrals of motion? How is it calculated in the various models? In particular, a brief description of how the authors implemented "the method described by Roederer" is needed.

The following has been added in the manuscript in line 51

"…integrated along the trajectory of the particle for the entire drift shell."

and below in line 55 :

"A practical way to calculate Φ is to find the intersection C of a series of drift-shell field lines with the Earth's surface and to numerically compute Φ over the cap delineated by C, using the following equation:

$$\Phi \simeq - - \frac{k_0}{R_E} \int_0^{2\pi} cos^2[\lambda_e(\phi)] d\phi$$

where, λ e (φ) is the dipole latitude of the intersection C at a given longitude φ [Roederer, 1970]."

Specific Comments / Technical Corrections

1) Abstract Line 2: "invariants respectively," → "invariants, respectively,".

Corrected

2) Abstract Line 6: "roughly" is a weasel word. Omit or be more precise, whichever is appropriate.

"Equivalent" alone conveys the approximate nature of the relation between the two. "roughly" has been deleted

3) Abstract Line 15: Omit "related".

Corrected

4) Abstract Line 15: “source code” → “software”.

Corrected

5) Abstract Line 19: Omit “geocentric distance”.

Corrected

6) Abstract Line 20: I would say you more than attempt to map, you do actually map.

Deleted, also for other instances in the text

7) Abstract Line 22: “proton” → “protons”.

Corrected

8) Abstract Line 24: See Item 5.

Corrected

9) Introduction Line 9: Omit “For particles in magnetic fields, and”, and capitalize “for”.

Corrected

10) Introduction Line 11: Omit “of the three types of motion mentioned above.”

Corrected

11) Equation 1: What is _? What is _? What is B(s)? These should be defined.

Definitions have been added in lines 42 - 45 of the revised manuscript

12) Equation 2: What is $\_{0}$? Is there an expression for Φ?

Definitions have been added in lines 47 and eq. 3 of the revised manuscript

13) Title, Section 2.1: Is it LANLstar or LANL*? Be consistent.

It’s now LANL throughout the paper*

14) LANLstar Line 15: TS05 is just empirical. I’m not sure what “semi-empirical” means.

Changed to “empirical”

15) LANLstar Line 23: What is SpacePy?

The following has been added: “a Python-based tool library for space science,”

16) LANLstar Line 25: Why is LANLmax relevant for this discussion?

The sentence on the description of LANLmax is not relevant for the discussion of LANLstar, and has been removed from the manuscript.

17) IRBEM-lib Line 12: How is L* calculated?

The following text has been added in the manuscript, on lines 91 and footnote 3 in the same page :

"Roederer's shell parameter L is then deduced directly from the value of the third invariant using eq. 2"*

Also modified text in line 104:

"The third invariant Φ is evaluated in UNILIB using Roederer's numerical method as for the case of IRBEM-lib"

18) SPENVIS Line 23: "as given above"; where was it given?

The following clarification has been added: "as described in the introduction"

19) 3-D Tracer Line 7—8: "so as to facilitate" à "for"

Corrected

20) 3-D Tracer Line 13: TS05 only needs to be cited when first introduced.

Deleted citation

21) Calculations of I Line 4: what initial distances, exactly? How were they distributed between 4 and 8 ?

The following clarification has been added: "in steps of 1 RE"