**RBSP Conjunction Framework and Selected Coordinate Systems**

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This document describes a framework for defining and predicting conjunctions of the RBSP vehicles with other missions of interest. This document has been developed by the Coordinated Coordinates Committee (CooCoo) of the RBSP Science Working Group.

Predicted conjunctions of RBSP with other missions will be computed based on constraints placed on the coordinate locations of the two vehicles: Vehicle 1 is either RBSP-A or RBSP-B, and Vehicle 2 is any vehicle for which the Science Data Portal has predicted ephemeris, including the other RBSP vehicle, DSX, THEMIS, GOES, LANL-GEO, or BARREL.

The coordinates for the predicted conjunctions will be defined against one of several Cartesian coordinate systems, or magnetic coordinates. The Cartesian locations of Vehicle A and Vehicle B will be computed using SPICE, augmented with a MAG coordinate system definition based on time-dependent IGRF/DGRF coefficients (epoch 2010 with linear predictive secular drift terms).The magnetic coordinates of the vehicles will be computed using the IRBEM library or equivalent. Three magnetic field models will be used for the calculation of magnetic coordinates: QUIET (T89 with Kp=0), MODERATE (T89 with Kp=3), and ACTIVE (T89 with Kp=6). These three field models span the inner magnetospheric configurations from quiet to active. Superior field models exist; however, such models require more complex inputs that the simple Kp required by T89. [An option the project can consider is to replace these three configurations with a more sophisticated magnetic field model evaluated for pre-determined moments of quiet, moderate, and active configuration]. To allow for non-simultaneity, time (decimal modified Julian date, MJD) will be considered a coordinate.

A conjunction is defined as having two vehicles meet a set of constraints on the coordinates of either vehicle and on the difference between the coordinates of the vehicles. The constraints will be defined in a simple table (see Table 2). A minimum and maximum value can be defined for each coordinate, and these constraints will be applied with a boolean “AND” operation. Empty entries will be ignored.

The spatial coordinate systems will be X, Y, and Z in GEI/ECI, GEO, GSM, GSE, and SM, with the coordinate values given in Earth Radii. The magnetic coordinates are defined in Table 1.

Table 1. Magnetic Coordinates

|  |  |
| --- | --- |
| **Coordinate** | **Definition** |
| Lmeq | McIlwain L of an equatorially mirroring particle on the same field line as the vehicle |
| Lstar | L\* of a particle mirroring at the vehicle |
| INVLAT | Invariant latitude computed from Lmeq |
| B | Local field strength in nT |
| Bmin | Minimum field strength along the line through the vehicle |
| BoverBeq | B/Bmin |
| K | Kaufmann invariant for particle mirroring at the vehicle |
| MAGLAT | Magnetic latitude computed from BoverBeq (see note) |
| MLTeq | Local Time at minimum B on field line |
| LAT100N | Geographic latitude at fixed altitude (100 km) in the Northern hemisphere along the field line through the vehicle |
| LON100N | Geographic longitude at fixed altitude (100 km) in the Northern hemisphere along the field line through the vehicle |
| MLAT100N | MAG latitude at fixed altitude (100 km) in the Northern hemisphere along the field line through the vehicle |
| MLON100N | MAG longitude at fixed altitude (100 km) in the Northern hemisphere along the field line through the vehicle |
| MLTN | Local Time at fixed altitude (100 km) in the Northern hemisphere along the field line through the vehicle |
| LAT100S | Geographic latitude at fixed altitude (100 km) in the Southern hemisphere along the field line through the vehicle |
| LON100S | Geographic longitude at fixed altitude (100 km) in the Southern hemisphere along the field line through the vehicle |
| MLAT100S | MAG latitude at fixed altitude (100 km) in the Southern hemisphere along the field line through the vehicle |
| MLON100S | MAG longitude at fixed altitude (100 km) in the Southern hemisphere along the field line through the vehicle |
| MLTS | Local Time at fixed altitude (100 km) in the Southern hemisphere along the field line through the vehicle |

Note: Magnetic latitude is defined as the latitude in a dipole magnetic field that would give the same value for BoverBeq as whatever non-dipole model is being used. MAG is the Earth-centered dipole coordinate system, which may need to have a specific epoch defined

For the purposes of the conjunction constraint table, a coordinate is defined as the combination of a coordinate system (e.g., ECI or T89KP0) and a coordinate name (e.g., Xor Lmeq). Each coordinate will appear in the constraint table three times: once for each vehicle (with suffixes 1 and 2) and once for the absolute value of the difference (with suffix DIFF).

Tables 2 and 3 provide an example of a constraint for a magnetic conjunction between RBSP-A and DSX. Table 2 provides an abbreviate form (omitting unconstrained coordiantes), while Table 3 provides the complete template. The conjunction is required to have a time offset of less than 6 hours (MJD\_DIFF < 0.25), with both vehicles in the dawn local time sector (MLTeq 3 to 9) and with the two vehicles being within 0.1 Lmeq and 1 hour of local time of each other. In the example, the magnetic coordinate constraints are for the QUIET configuration. There is no constraint on position along the field line for either vehicle. Presumably, the interested parties would define similar, possibly looser, constraints for MODERATE and ACTIVE configurations.

Table 2. Example of an abbreviated conjunction definition table

|  |  |
| --- | --- |
| **Conjunction Name** | RBSPA-DSX-Dawn-Quiet |
| **Vehicle1** | RBSP-A |
| **Vehicle2** | DSX |
| **Coordinates** | **Min** | **Max** |
| MJD\_DIFF |  | 0.25 |
| QUIET\_Lmeq\_DIFF |  | 0.2 |
| QUIET\_MLTeq\_1 | 3 | 9 |
| QUIET\_MLTeq\_2 | 3 | 9 |
| QUIET\_MLTeq\_DIFF |  | 1 |

The CooCoo envisions a computer program that will routinely compare the predicted locations of the vehicles to all constraint tables provided by the teams. The program will then post alerts to the Science Data Portal and/or send email to subscribers.

Each team will be responsible for defining conjunctions it finds interesting by submitting tables to the Science Data Portal for inclusion in the conjunction search set. The Science Data Portal is encouraged to retain the ability to update the conjunction sets during the mission, and, therefore, to develop a computer program that will ensure that the submitted tables are valid; e.g., by checking that the Name and Vehicle 1, Vehicle 2 fields are provided, that the Vehicles match vehicles in the Portal’s database, by validating that each coordinate variable provided in the constraints is a valid variable name, and by validating that the value of each Min/Max constraint is a valid number or is empty.

References:

SPICE: a NASA toolkit for time, ephemeris, attitude. <http://naif.jpl.nasa.gov/naif/toolkit.html>

IRBEM: A COSPAR toolkit for radiation belt coordinates and models. <http://irbem.sourceforge.net/>

Table 3. Example of a full conjunction definition table

|  |  |
| --- | --- |
| **Conjunction Name** | RBSPA-DSX-Dawn-Quiet |
| **Vehicle1** | RBSP-A |
| **Vehicle2** | DSX |
| **Coordinates** | **Min** | **Max** |
| MJD\_1 |  |  |
| MJD\_2 |  |  |
| MJD\_DIFF |  | 0.25 |
| GEI\_X\_1 |  |  |
| GEI\_X\_2 |  |  |
| GEI\_X\_DIFF |  |  |
| GEI\_Y\_1 |  |  |
| GEI\_Y\_2 |  |  |
| GEI\_Y\_DIFF |  |  |
| GEI\_Z\_1 |  |  |
| GEI\_Z\_2 |  |  |
| GEI\_Z\_DIFF |  |  |
| GSM\_X\_1 |  |  |
| GSM\_X\_2 |  |  |
| GSM\_X\_DIFF |  |  |
| GSM\_Y\_1 |  |  |
| GSM\_Y\_2 |  |  |
| GSM\_Y\_DIFF |  |  |
| GSM\_Z\_1 |  |  |
| GSM\_Z\_2 |  |  |
| GSM\_Z\_DIFF |  |  |
| GSE\_X\_1 |  |  |
| GSE\_X\_2 |  |  |
| GSE\_X\_DIFF |  |  |
| GSE\_Y\_1 |  |  |
| GSE\_Y\_2 |  |  |
| GSE\_Y\_DIFF |  |  |
| GSE\_Z\_1 |  |  |
| GSE\_Z\_2 |  |  |
| GSE\_Z\_DIFF |  |  |
| SM\_X\_1 |  |  |
| SM\_X\_2 |  |  |
| SM\_X\_DIFF |  |  |
| SM\_Y\_1 |  |  |
| SM\_Y\_2 |  |  |
| SM\_Y\_DIFF |  |  |
| SM\_Z\_1 |  |  |
| SM\_Z\_2 |  |  |
| SM\_Z\_DIFF |  |  |
| QUIET\_Lmeq\_1 |  |  |
| QUIET\_Lmeq\_2 |  |  |
| QUIET\_Lmeq\_DIFF |  | 0.2 |
| QUIET\_Lstar\_1 |  |  |
| QUIET\_Lstar\_2 |  |  |
| QUIET\_Lstar\_DIFF |  |  |
| QUIET\_INVLAT\_1 |  |  |
| QUIET\_INVLAT\_2 |  |  |
| QUIET\_INVLAT\_DIFF |  |  |
| QUIET\_B\_1 |  |  |
| QUIET\_B\_2 |  |  |
| QUIET\_B\_DIFF |  |  |
| QUIET\_Bmin\_1 |  |  |
| QUIET\_Bmin\_2 |  |  |
| QUIET\_Bmin\_DIFF |  |  |
| QUIET\_BoverBeq\_1 |  |  |
| QUIET\_BoverBeq\_2 |  |  |
| QUIET\_BoverBeq\_DIFF |  |  |
| QUIET\_K\_1 |  |  |
| QUIET\_K\_2 |  |  |
| QUIET\_K\_DIFF |  |  |
| QUIET\_MAGLAT\_1 |  |  |
| QUIET\_MAGLAT\_2 |  |  |
| QUIET\_MAGLAT\_DIFF |  |  |
| QUIET\_MLTeq\_1 | 3 | 9 |
| QUIET\_MLTeq\_2 | 3 | 9 |
| QUIET\_MLTeq\_DIFF |  | 1 |
| QUIET\_LATN\_1 |  |  |
| QUIET\_LATN\_2 |  |  |
| QUIET\_LATN\_DIFF |  |  |
| QUIET\_LONN\_1 |  |  |
| QUIET\_LONN\_2 |  |  |
| QUIET\_LONN\_DIFF |  |  |
| QUIET\_MLATN\_1 |  |  |
| QUIET\_MLATN\_2 |  |  |
| QUIET\_MLATN\_DIFF |  |  |
| QUIET\_MLONN\_1 |  |  |
| QUIET\_MLONN\_2 |  |  |
| QUIET\_MLONN\_DIFF |  |  |
| QUIET\_MLTN\_1 |  |  |
| QUIET\_MLTN\_2 |  |  |
| QUIET\_MLTN\_DIFF |  |  |
| QUIET\_LATS\_1 |  |  |
| QUIET\_LATS\_2 |  |  |
| QUIET\_LATS\_DIFF |  |  |
| QUIET\_LONS\_1 |  |  |
| QUIET\_LONS\_2 |  |  |
| QUIET\_LONS\_DIFF |  |  |
| QUIET\_MLATS\_1 |  |  |
| QUIET\_MLATS\_2 |  |  |
| QUIET\_MLATS\_DIFF |  |  |
| QUIET\_MLONS\_1 |  |  |
| QUIET\_MLONS\_2 |  |  |
| QUIET\_MLONS\_DIFF |  |  |
| QUIET\_MLTS\_1 |  |  |
| QUIET\_MLTS\_2 |  |  |
| QUIET\_MLTS\_DIFF |  |  |
| MODERATE\_Lmeq\_1 |  |  |
| MODERATE\_Lmeq\_2 |  |  |
| MODERATE\_Lmeq\_DIFF |  |  |
| MODERATE\_Lstar\_1 |  |  |
| MODERATE\_Lstar\_2 |  |  |
| MODERATE\_Lstar\_DIFF |  |  |
| MODERATE\_INVLAT\_1 |  |  |
| MODERATE\_INVLAT\_2 |  |  |
| MODERATE\_INVLAT\_DIFF |  |  |
| MODERATE\_B\_1 |  |  |
| MODERATE\_B\_2 |  |  |
| MODERATE\_B\_DIFF |  |  |
| MODERATE\_Bmin\_1 |  |  |
| MODERATE\_Bmin\_2 |  |  |
| MODERATE\_Bmin\_DIFF |  |  |
| MODERATE\_BoverBeq\_1 |  |  |
| MODERATE\_BoverBeq\_2 |  |  |
| MODERATE\_BoverBeq\_DIFF |  |  |
| MODERATE\_K\_1 |  |  |
| MODERATE\_K\_2 |  |  |
| MODERATE\_K\_DIFF |  |  |
| MODERATE\_MAGLAT\_1 |  |  |
| MODERATE\_MAGLAT\_2 |  |  |
| MODERATE\_MAGLAT\_DIFF |  |  |
| MODERATE\_MLTeq\_1 |  |  |
| MODERATE\_MLTeq\_2 |  |  |
| MODERATE\_MLTeq\_DIFF |  |  |
| MODERATE\_MLTN\_1 |  |  |
| MODERATE\_MLTN\_2 |  |  |
| MODERATE\_MLTN\_DIFF |  |  |
| MODERATE\_MLTS\_1 |  |  |
| MODERATE\_MLTS\_2 |  |  |
| MODERATE\_MLTS\_DIFF |  |  |
| MODERATE\_LATN\_1 |  |  |
| MODERATE\_LATN\_2 |  |  |
| MODERATE\_LATN\_DIFF |  |  |
| MODERATE\_LONN\_1 |  |  |
| MODERATE\_LONN\_2 |  |  |
| MODERATE\_LONN\_DIFF |  |  |
| MODERATE\_MLATN\_1 |  |  |
| MODERATE\_MLATN\_2 |  |  |
| MODERATE\_MLATN\_DIFF |  |  |
| MODERATE\_MLONN\_1 |  |  |
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| MODERATE\_MLONN\_DIFF |  |  |
| MODERATE\_MLTN\_1 |  |  |
| MODERATE\_MLTN\_2 |  |  |
| MODERATE\_MLTN\_DIFF |  |  |
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| MODERATE\_MLATS\_1 |  |  |
| MODERATE\_MLATS\_2 |  |  |
| MODERATE\_MLATS\_DIFF |  |  |
| MODERATE\_MLONS\_1 |  |  |
| MODERATE\_MLONS\_2 |  |  |
| MODERATE\_MLONS\_DIFF |  |  |
| MODERATE\_MLTS\_1 |  |  |
| MODERATE\_MLTS\_2 |  |  |
| MODERATE\_MLTS\_DIFF |  |  |
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| ACTIVE\_Lmeq\_2 |  |  |
| ACTIVE\_Lmeq\_DIFF |  |  |
| ACTIVE\_Lstar\_1 |  |  |
| ACTIVE\_Lstar\_2 |  |  |
| ACTIVE\_Lstar\_DIFF |  |  |
| ACTIVE\_INVLAT\_1 |  |  |
| ACTIVE\_INVLAT\_2 |  |  |
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| ACTIVE\_B\_1 |  |  |
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| ACTIVE\_B\_DIFF |  |  |
| ACTIVE\_Bmin\_1 |  |  |
| ACTIVE\_Bmin\_2 |  |  |
| ACTIVE\_Bmin\_DIFF |  |  |
| ACTIVE\_BoverBeq\_1 |  |  |
| ACTIVE\_BoverBeq\_2 |  |  |
| ACTIVE\_BoverBeq\_DIFF |  |  |
| ACTIVE\_K\_1 |  |  |
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| ACTIVE\_MAGLAT\_1 |  |  |
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