SPEDAS training course
- ERG orbit -

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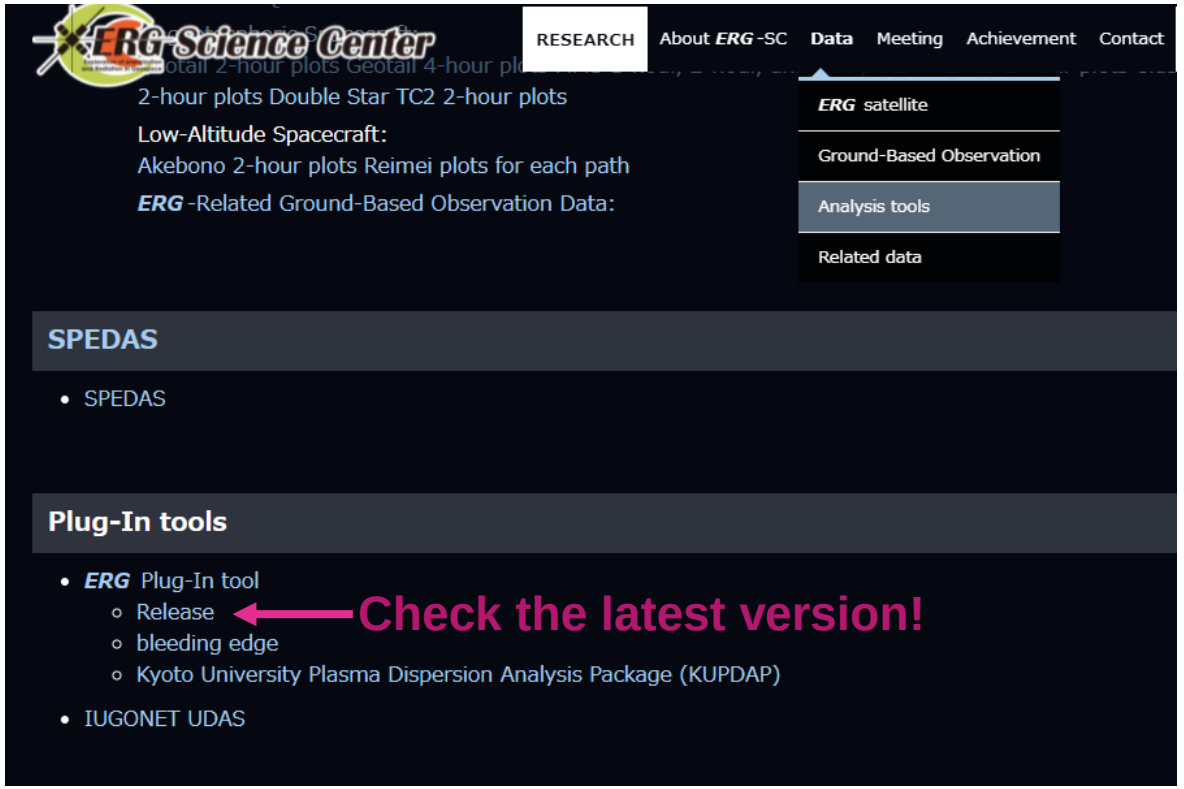
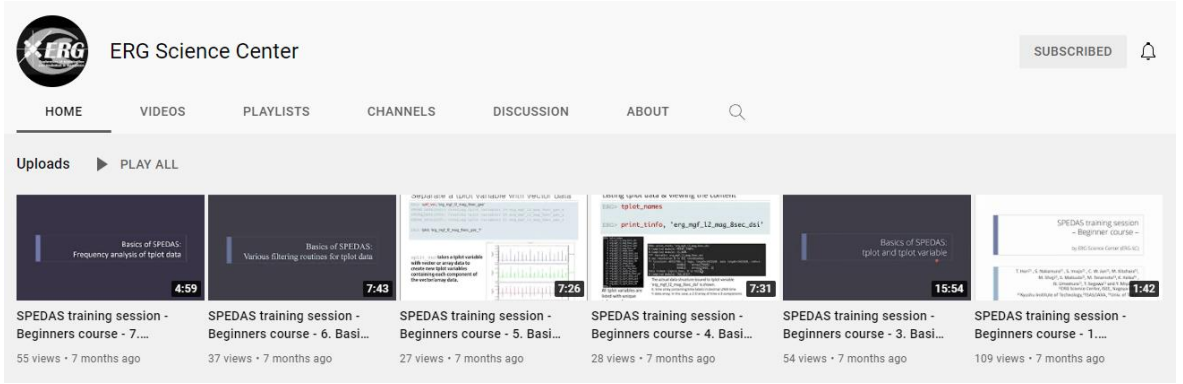
Before this training course

- This course will use ERG plug-in tool based on IDL SPEDAS.
- Please update your ERG plug-in as the latest version.
- ERG Science center provides lectures for the beginners of IDL SPEDAS on our Youtube channel.(url:https://www.youtube.com/channel/UCukIaSJ1l-KbZnVzYNmglVg)



- If you utilize ERG orbit data for your study, please cite ERG orbit DOI on your publication.
- If you have any questions, please feel free to contact “**ergsc-help at isee.nagoya-u.ac.jp**”.



Goal of this training

- We are going to learn how to load, and plot orbit data of the ERG satellite, with a special focus on plotting satellite trajectories in space and ionospheric footprints on the world map.

Contents of this course

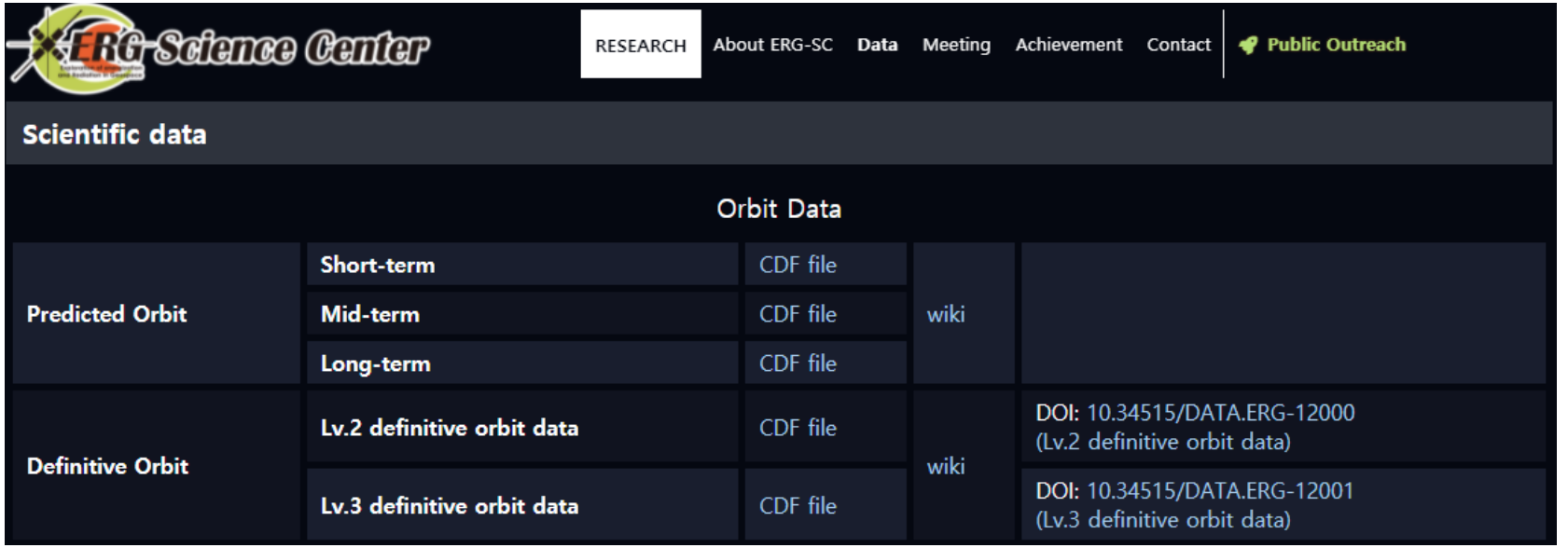
- Information of ERG orbit dataset

- Plot orbit data
    1. Time series using “tplot”
    2. Satellite trajectory in XY or XZ plane
    3. Ionospheric footprints on the world map

- Appendix
    1. Information of coordinate system
    2. Meaning of L_m and L_*

ERG orbit dataset

Web data repository →

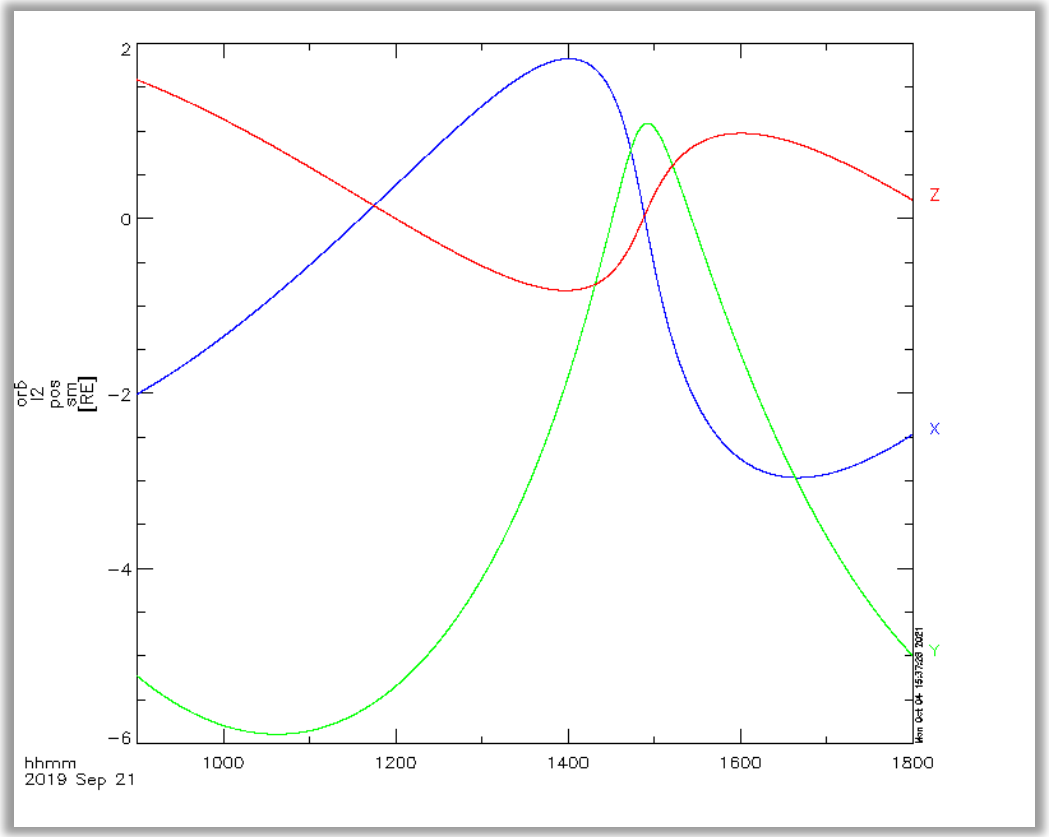


Level	Datatype or model	Load procedure
L2 (IGRF)	Definitive	erg_load_orb
	Predict (pre, spre, mpre, lpre)	erg_load_orb_predict, datatype = ‘pre, spre, mpre, lpre’
L3 (IGRF + external fields)	**OP77Q model** using quiet time model	erg_load_orb_l3, model=‘op or t89 or ts04’
	T89 model using Kp index	
	TS04 model using IMF + Dst index	

* Note: the information of L* and invariant is only provided by l3 orbit data set.

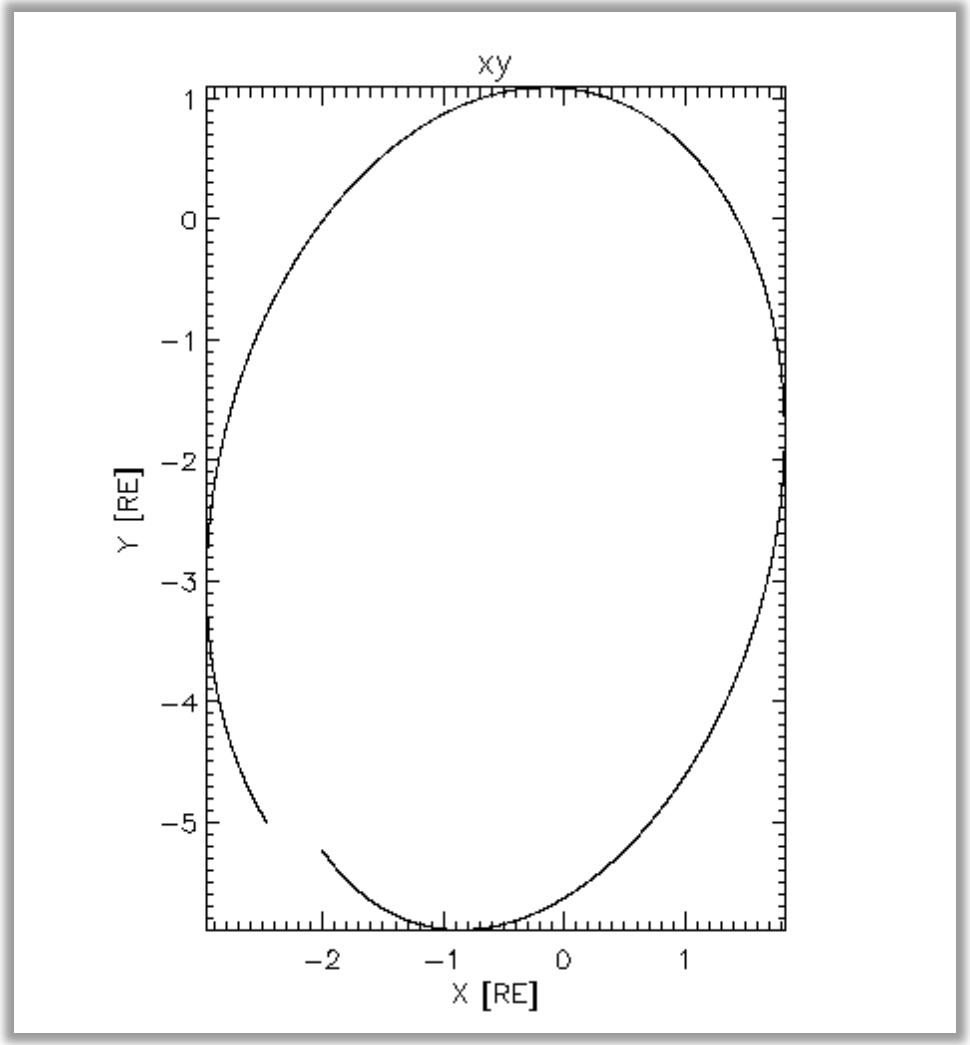
Plot ERG orbit data:1. Time series using “tplot”

```
; Set the time range to 9-18 UT on Sep. 21, 2019
IDL> timespan,'2019-09-21/09:00:00',9,/hour

; Load Arase l2 def orbit data
IDL> erg_load_orb

; Plot Arase orbit in the SM coord.
IDL> tplot,'erg_orb_l2_pos_sm'
```



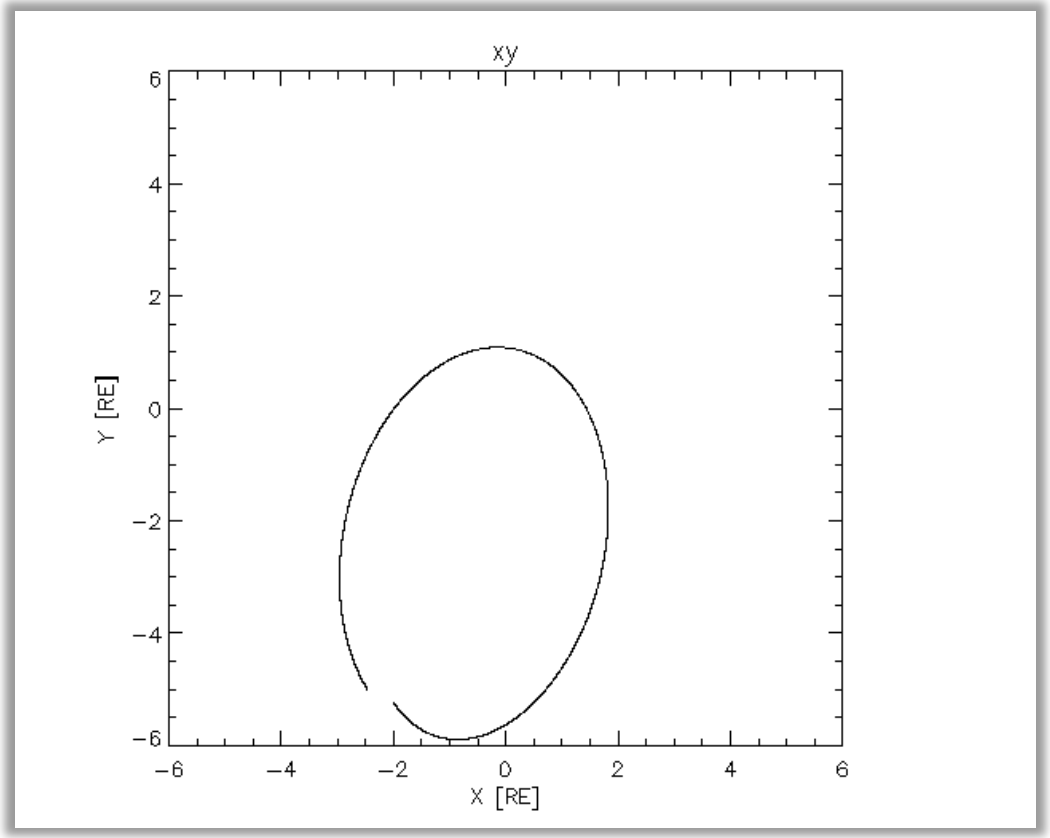
2. Satellite trajectory in XY or XZ plane

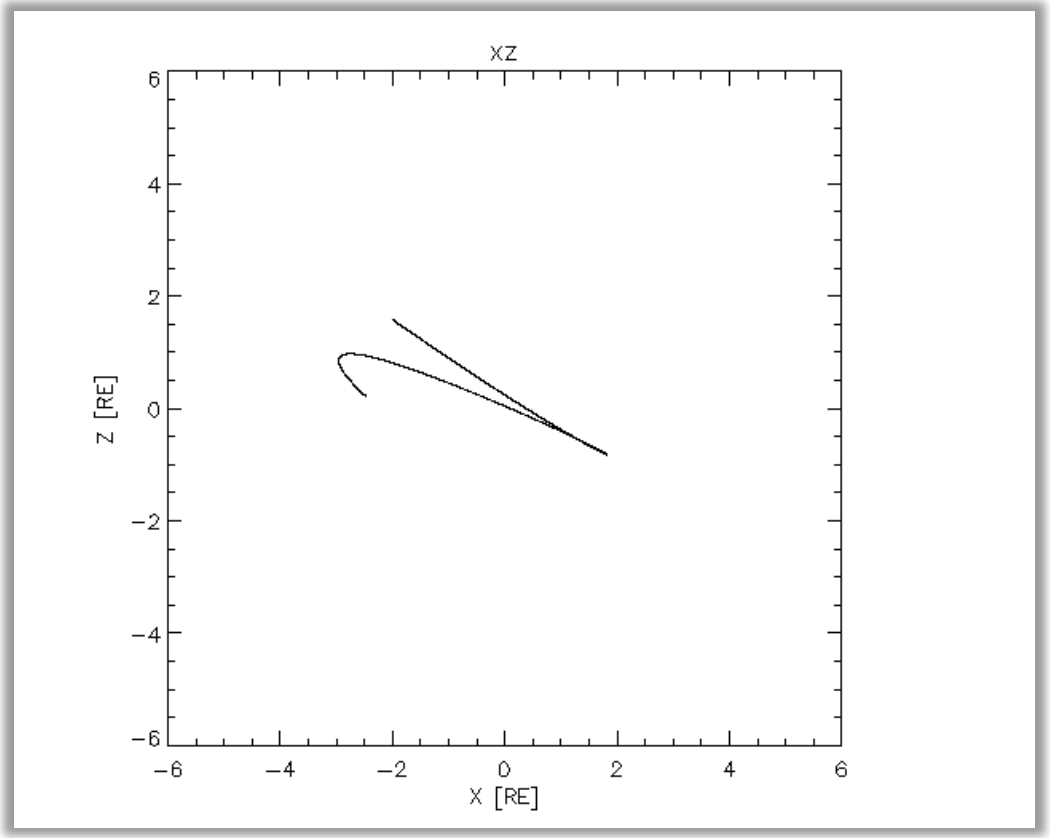
```
; Set the time range to 9-18 UT on Sep. 21, 2019
IDL> timespan,'2019-09-21/09:00:00',9,/hour

; Load Arase l2 def orbit data
IDL> erg_load_orb

; Plot Arase orbit on the SM X-Y plane
IDL> tplotxy,'erg_orb_l2_pos_sm'
```



2. Satellite trajectory in XY or XZ plane (cont'd)

```
; Plot Arase orbit on the X-Y plane of - 6 Re < x,y < 6 Re
IDL> tplotxy,'erg_orb_l2_pos_sm',versus='xy',xrange = [-6,6],yrange = [-6,6]
; The same but on the X-Z plane
IDL> tplotxy,'erg_orb_l2_pos_sm',versus='xz',xrange = [-6,6],yrange = [-6,6]
```





Additional information for “**tplotxy**” and “**plotxy**”

tplotxy, tplot_variable_name$; (e.g., ‘position_sm’)
, versus='xy' ; choose axis (e.g., xy or xz)
, multi= 'n_col n_raw’ ; make multi plots (‘# of colum # of raw’)
, over = over ; overplot on the current window
, add = add ; add plot
, additional plot options ; (e.g., title, xrange, color, linestyle, etc.)

plotxy, variable$; position array ([time,#_of_axis])
, versus='xy' ; choose axis (e.g., xy or xz)
, multi= 'n_col n_raw’ ; make multi plots (‘# of colum # of raw’)
, over = over ; overplot on the current window
, add = add ; add plot
, additional plot options ; (e.g., title, xrange, color, linestyle, etc.)

3. Ionospheric footprints on the world map

; Initialize the map2d environment and Set the coordinate system to geographical coordinate

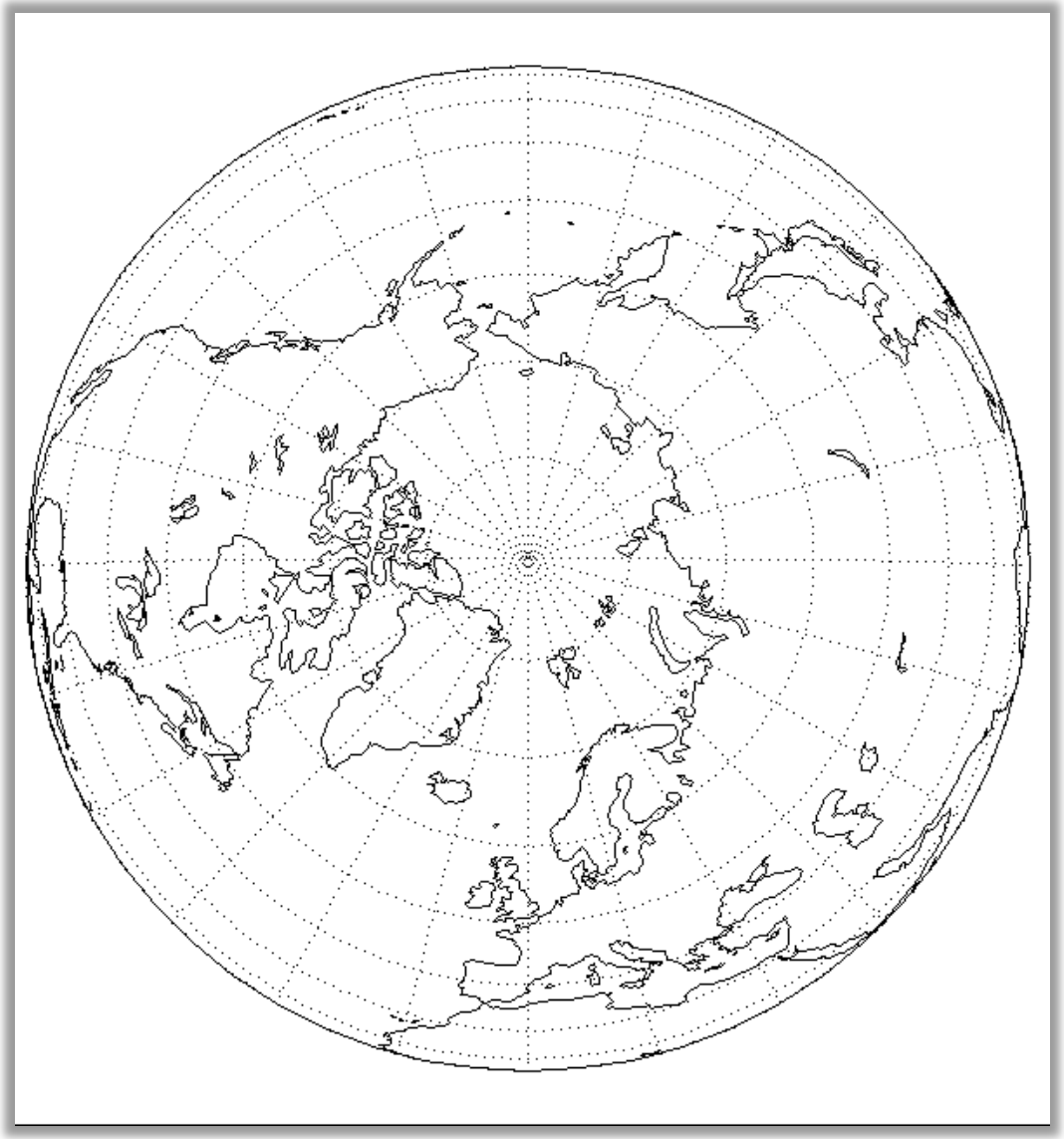
IDL> map2d_init & map2d_coord, 'geo'

; Generate an empty window

IDL> window, 0, xsize=800, ysize=640 & erase

; Draw the grid (10 deg in lat & 15 deg in log) on the window and Draw the coast lines

IDL> map2d_set & overlay_map_coast



3. Ionospheric footprints on the world map (cont'd)

; get l2 data for ionospheric footprints on the northern hemisphere

IDL> erg_load_orb

IDL> get_data, 'erg_orb_l2_pos_iono_north', data=data_foot

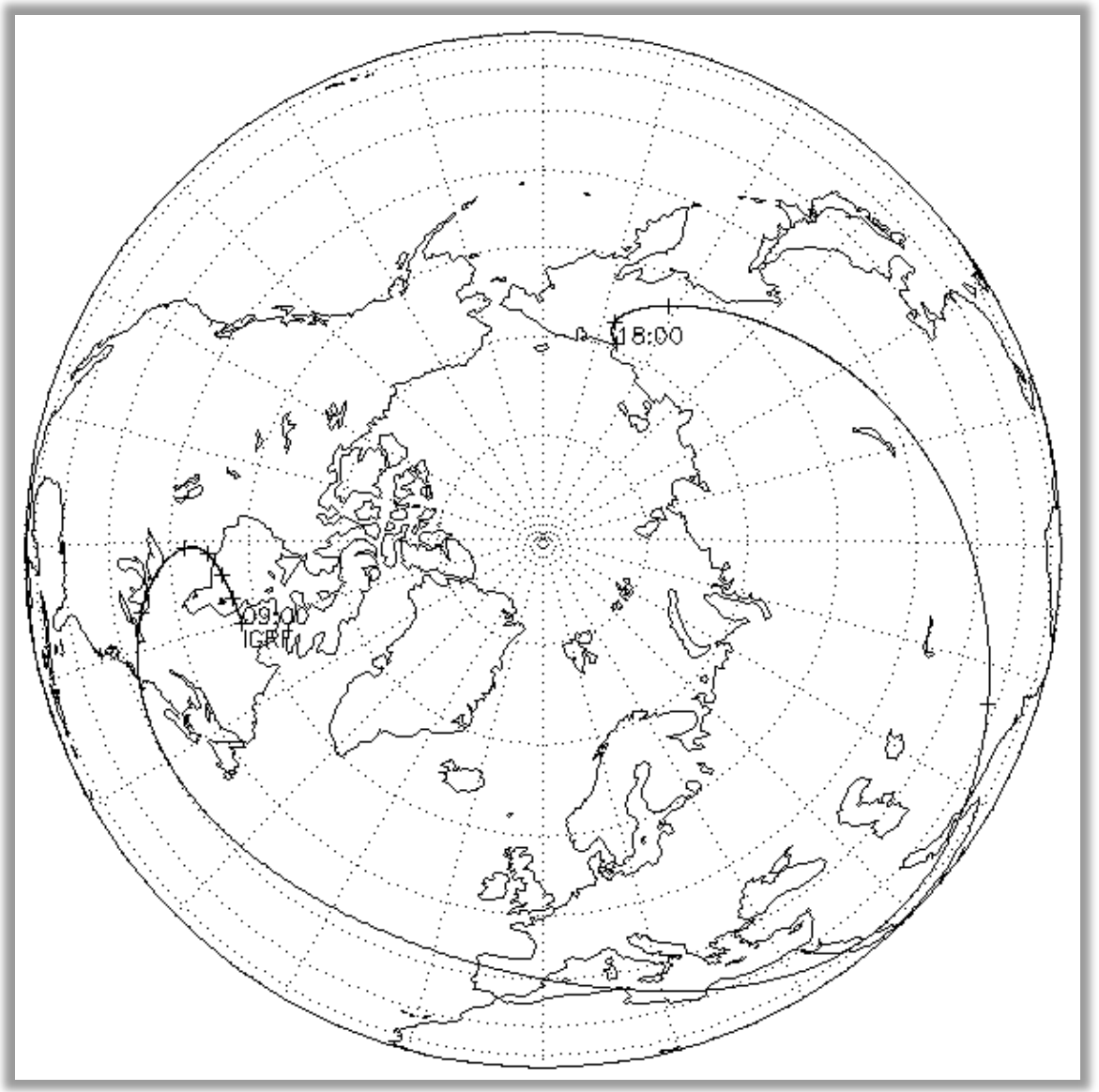
; Store latitude and longitude separately.

IDL> store_data,'IGRF_ifoot_glat',data={x:data_foot.x,y:reform(data_foot.y[*,0])}

IDL> store_data,'IGRF_ifoot_glog',data={x:data_foot.x,y:reform(data_foot.y[*,1])}

; Overplot Arase footprint on the map

IDL> overlay_map_sc_ifoot, 'IGRF_ifoot_glat', 'IGRF_ifoot_glog'



Comparison of footprints using different models

```
; get l3 OP77Q orbit data for ionospheric footprints
IDL> erg_load_orb_l3,model = 'op' & get_data, 'erg_orb_l3_pos_iono_north_op',  data=data_foot_op
IDL> store_data, 'OP77Q_ifoot_glat',data= {x:data_foot_op.x, y:reform(data_foot_op.y[*,0])}
IDL> store_data, 'OP77Q_ifoot_glog',data= {x:data_foot_op.x, y:reform(data_foot_op.y[*,1])}

; get l3 T89 orbit data for ionospheric footprints
IDL> erg_load_orb_l3,model = 't89' & get_data, 'erg_orb_l3_pos_iono_north_t89',  data=data_foot_t89
IDL> store_data, 'T89_ifoot_glat',data= {x:data_foot_t89.x, y:reform(data_foot_t89.y[*,0])}
IDL> store_data, 'T89_ifoot_glog',data= {x:data_foot_t89.x,y:reform(data_foot_t89.y[*,1])}

; get l3 TS04 orbit data for ionospheric footprints
IDL> erg_load_orb_l3,model = 'ts04' & get_data, 'erg_orb_l3_pos_iono_north_TS04',
data=data_foot_ts04
IDL> store_data, 'TS04_ifoot_glat',data= {x:data_foot_ts04.x, y:reform(data_foot_ts04.y[*,0])}
IDL> store_data, 'TS04_ifoot_glog',data= {x:data_foot_ts04.x,y:reform(data_foot_ts04.y[*,1])}
```

Comparison of footprints using different models (cont'd)

; Generate a new map window

IDL> window, 0, xsize=800, ysize=640 & erase

IDL> map2d_set,glonc = 280,glatc=60,scale = 1e7 & overlay_map_coast

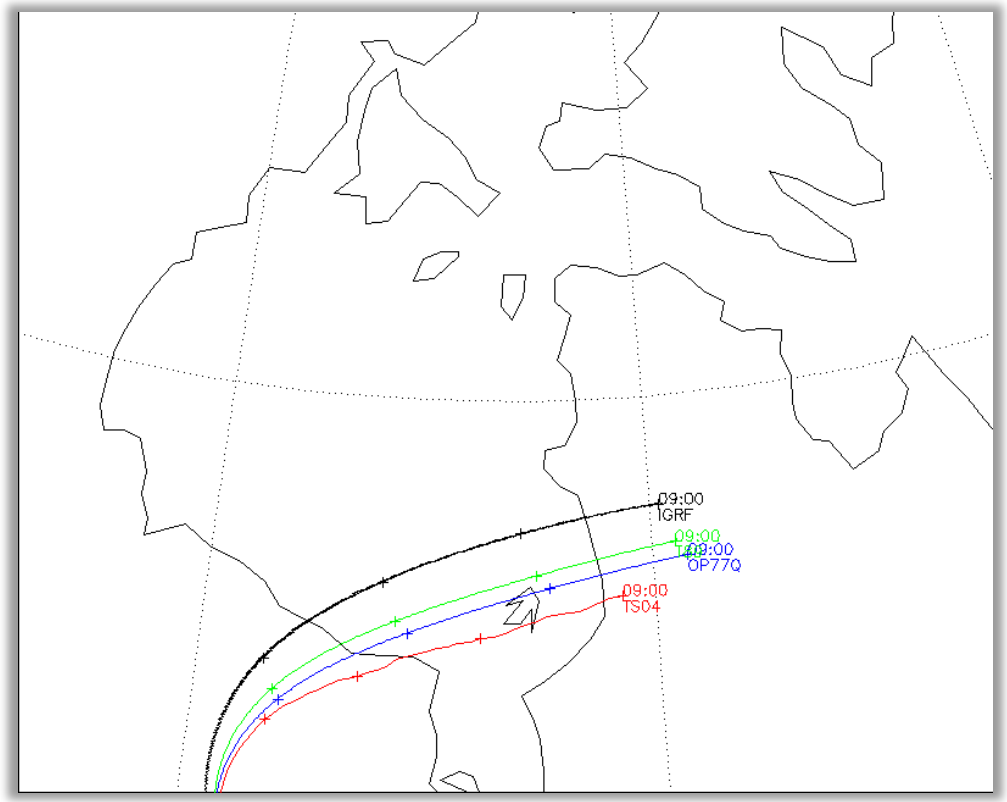
; Overplot Arase footprints using different models

IDL> overlay_map_sc_ifoot, 'IGRF_ifoot_glat', 'IGRF_ifoot_glog'

IDL> overlay_map_sc_ifoot, 'OP77Q_ifoot_glat', 'OP77Q_ifoot_glog',trace_color=2

IDL> overlay_map_sc_ifoot, 'T89_ifoot_glat', 'T89_ifoot_glog',trace_color=4

IDL> overlay_map_sc_ifoot, 'TS04_ifoot_glat', 'TS04_ifoot_glog',trace_color=6



Additional information for “**map2d_set**” and “**overlay_map_sc_ifoot**”

Map2d_set, glatc=value, glonc=value, scale=value, coord=‘…’, /set_time, /nogrid

Keywords:

- glatc (glonc): geographical latitude (longitude) at which a plot region is centered.
  (both glatc and glonc should be given, otherwise ignored)
- scale: same as the keyword "scale" of map_set
- coord: name of the coordinate system.
  ('geo' or 0 for Geographic coordinate. 'aacgm' or non-zero numbers for AACGM coordinate.)
- set_time: this is used to calculate MLT when coord is 'aacgm'
- mltlabel: set to draw the MLT labels every 2 hour.
- nogrid: set to suppress drawing the lat-lon mesh
- dlat(dlong)_grid: set grid steps for latitude (longitude) (default: 10 deg in lat & 15 deg in log)

Overlay_map_sc_ifoot, tplot_variable_lat, tplot_variable_lon $

, [‘YYYY-MM-DD/hh:mm’,’ YYYY-MM-DD/hh:mm’] ; time range

, trace_color = integer ; Set a color of the line

Summary

- Load procedure of ERG orbit data
  - **erg_load_orb** → l2 definitive orbit data
  - **erg_load_orb_predict** → l2 predicted orbit data (datatype: pre, spre,mpre,lpre)
  - **erg_load_orb_l3** → l3 definitive orbit data (model: OP77Q, T89, TS04)

- Plot ERG orbit
  - Time-series plot → **tplot**
  - Projection of orbit trajectories on 2D plane → **tplotxy** (or **plotxy**)
  - Projection of ionospheric footprints on the map
    1. Initialize map setting
    2. Draw the map on the window
    3. load and store ionospheric footprint information
    4. Plot ionospheric footprints using “**overlay_map_sc_ifoot**”

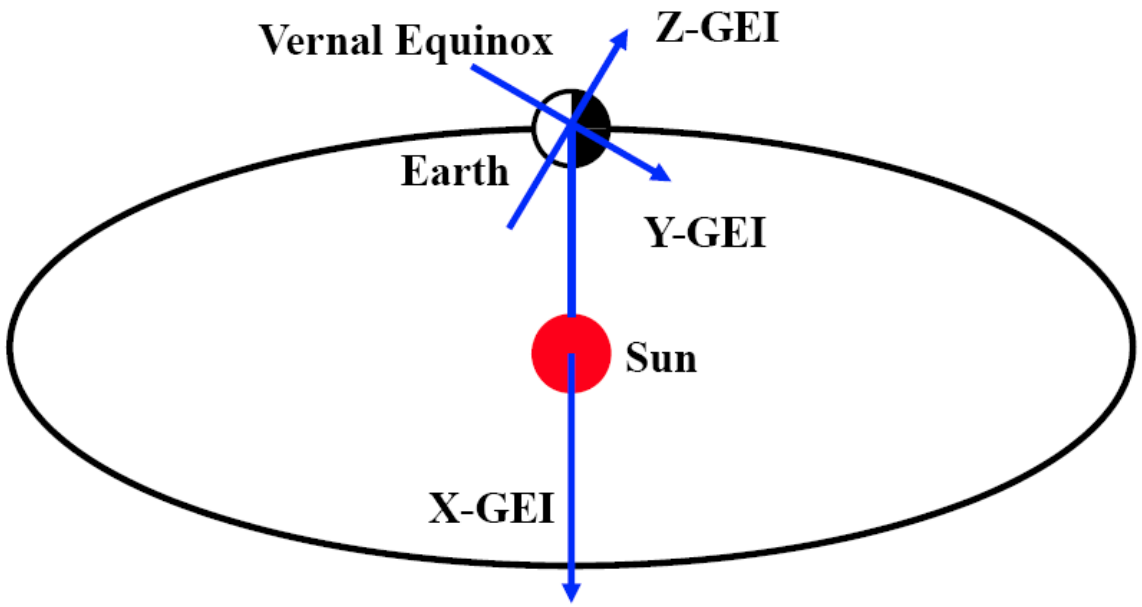
Appendix

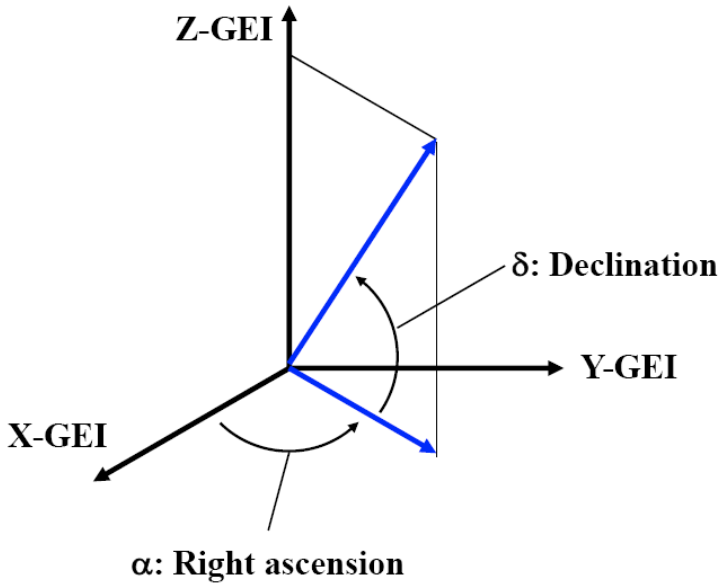
1. Information of geomagnetic coordinate system

Coord. System	Aberration	Usage
Geocentric Equatorial Inertial	GEI	Astronomy, satellite orbits
Geographic	GEO	Position of ground stations
Geomagnetic	MAG	Position of geomagnetic observations
Geocentric Solar Ecliptic	GSE	Satellite trajectories, Solar wind
Geocentric Solar Magnetospheric	GSM	Magnetospheric fields in the **outer magnetosphere**
Solar Magnetic	SM	Magnetospheric fields in the **inner magnetosphere**

References:
1. Introduction to Space Physics, 531-543, 1995.(edited by M. G. Kivelson and C. T. Russell)
2. http://sscweb.gsfc.nasa.gov/

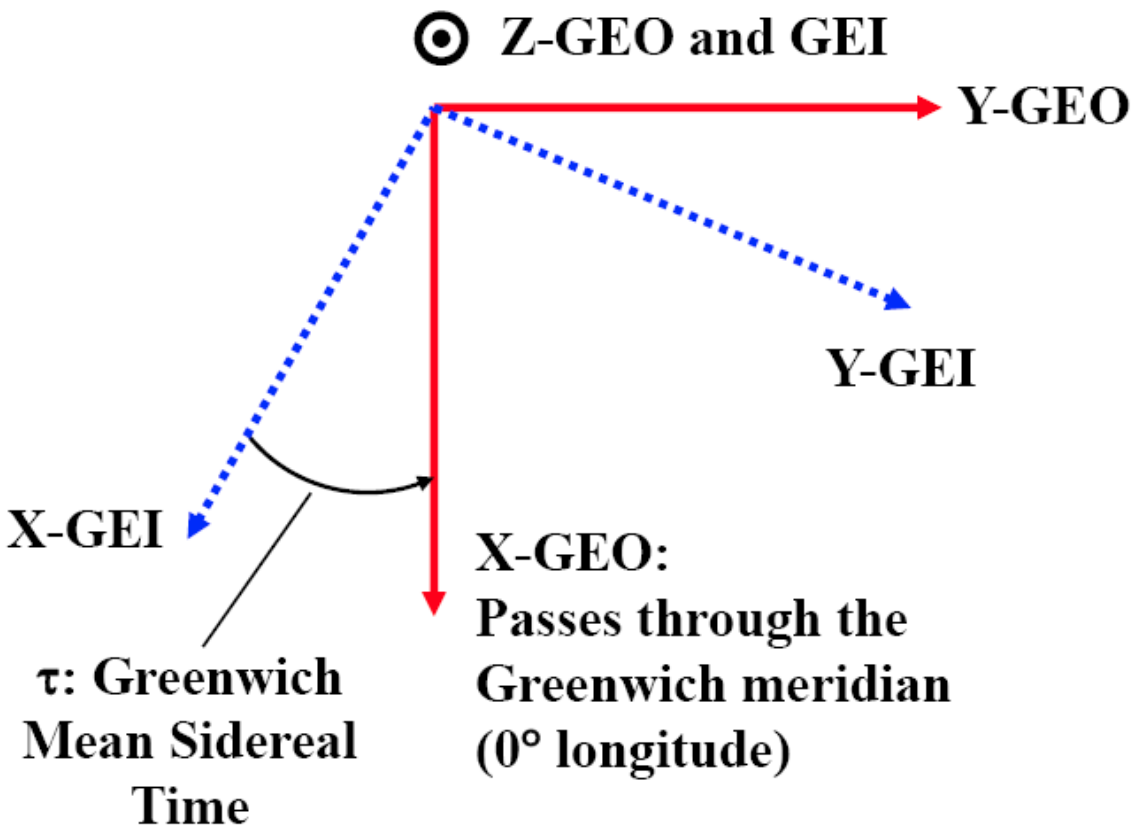
Geocentric Equatorial Inertial (GEI) Coord.





- X: Pointing from the earth toward the first point of Aries (the position of the Sun at the vernal equinox). This direction is the intersection of the Earth's equatorial plane and the ecliptic plane.
- Z: Parallel to the rotation axis of the Earth.
- Y: Completes the right-handed orthogonal system. ($Y = Z \times X$)

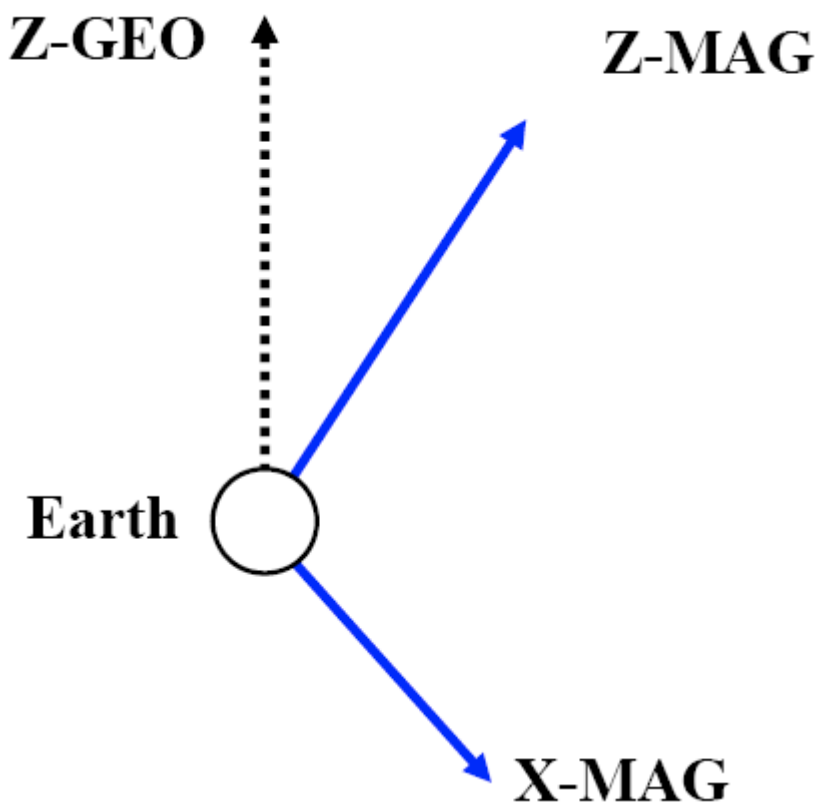
Geographic (GEO) Coord.



- X: In the Earth's equatorial plane, but fixed with the rotation of the Earth So passes through the Greenwich meridian (0˚ longitude).
- Z: Parallel to the rotation axis of the Earth.
- Y: Completes the right-handed orthogonal system. ($Y = Z \times X$)

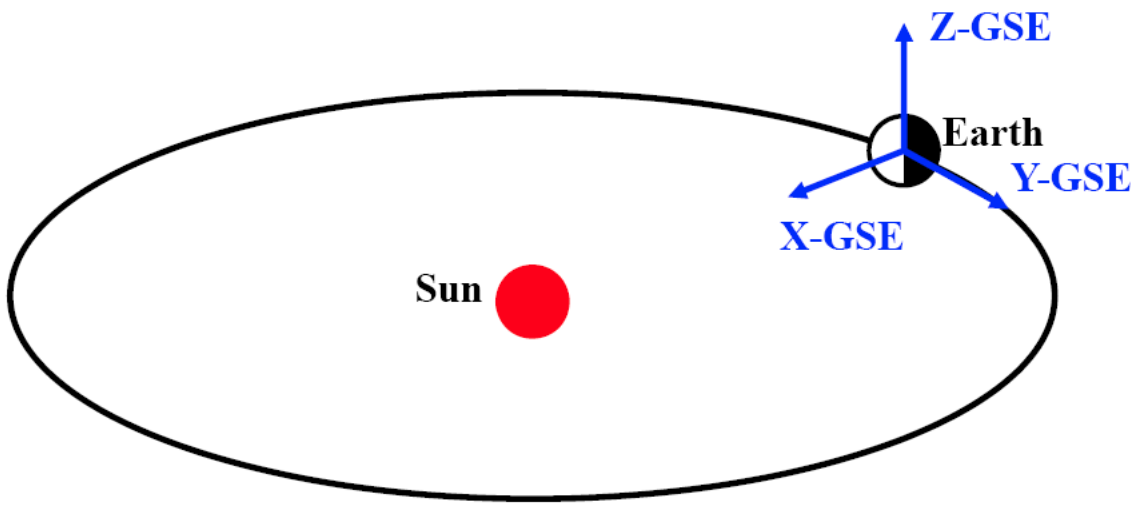
(Longitude: eastward, 0 UT = 0 LT at Greenwich meridian)

Geomagnetic (MAG) Coord.



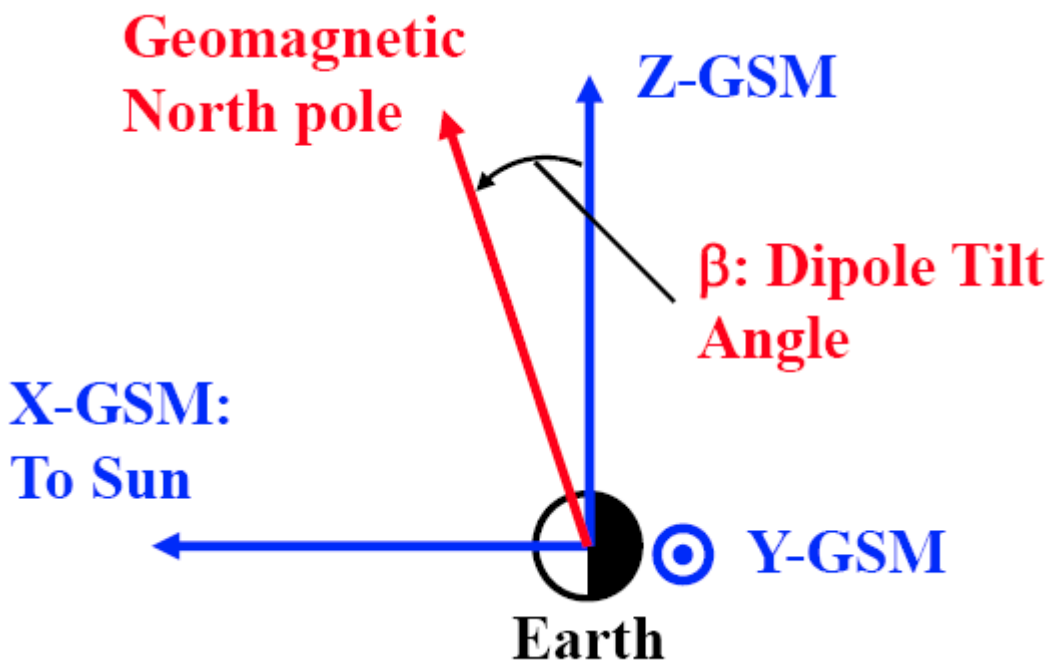
- X: Perpendicular to the Z direction.
- Z: Parallel to the geomagnetic dipole axis, positive northward.
- Y: Completes the right-handed orthogonal system. ($Y = Z \times X$)

Geocentric Solar Ecliptic (GSE) Coord.



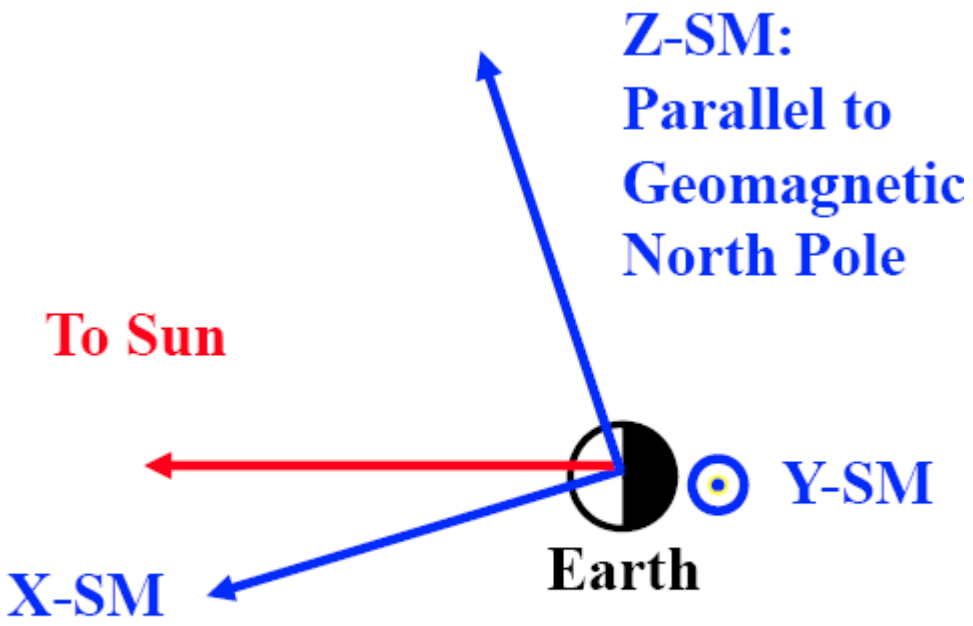
- X: Points from the center of the Earth towards the Sun.
- Z: Parallel to the ecliptic north pole.
- Y: Completes the right-handed orthogonal system. ($Y = Z \times X$)

Geocentric Solar Magnetospheric (GSM) Coord.



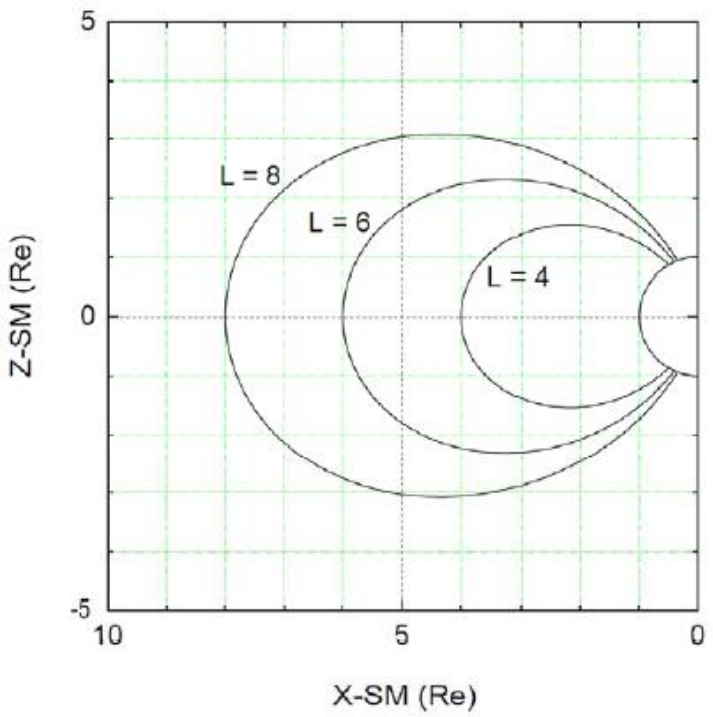
- X: Points from the center of the Earth towards the Sun (same as GSE).
- Y: Perpendicular to both X-axis and the Earth's dipole axis.
- Z: Completes the right-handed orthogonal system ($Y = Z \times X$).

Solar Magnetic (SM) Coord.



- Z: Points from the center of the Earth to the magnetic north pole.
- Y: Perpendicular to both Z-axis and the Sun-Earth line.
- X: Completes the right-handed orthogonal system. ($Y = Z \times X$)

2. $L_{McIlwain}$ VS L^*



- L-shell, L-value, or McIlwain L-parameter: the set of magnetic field lines which cross the Earth's magnetic equator at a number of Earth-radii equal to the L-value.

$$L = \frac{1}{cos^2(\lambda)}, where\ \lambda{:}\ invariant\ latitude\ (= magnetic\ latitude)$$

- For example, “L=4" indicates the set of the Earth's magnetic field lines which cross the Earth's magnetic equator at 4 Re.

- L*: the magnetic drift variant, known as the Roederer L parameter (Roederer, 1970).

$$L^* = \frac{2\pi k^0}{\Phi R_e}, where \begin{cases} k_0{:}\ the\ magnetic\ moment\ of\ the\ Earth's\ dipole \\ \Phi{:} the\ third\ adiabatic\ invariant\ in\ absolute\ value \end{cases}$$

- In plain language, L-shell → same field line

  L^* → same drift shell

Reference:
Roederer, J. G. (1970), Dynamics of Geomagnetically Trapped Radiation, pp. 84–106, Springer, New York.