

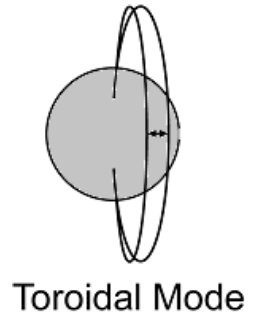
D2.4 FLRINV running on central server

Illustration of the activities carried on in the second year

Inference of the plasma mass density from field line eigenfrequencies

Standard procedure for low and middle latitudes:

Assumption: Observed FLR frequencies (f_R) correspond to the axisymmetric **toroidal** mode eigenfrequencies in a **dipole** field.



Governing equation:

$$d^2E/dz^2 + \lambda (1 - z^2)^6 \rho(z)/\rho_o E = 0$$

\mathbf{E} : wave electric field

$z = \cos(\theta)$, θ : colatitude

ρ : mass density along the field line

ρ_o : equatorial mass density

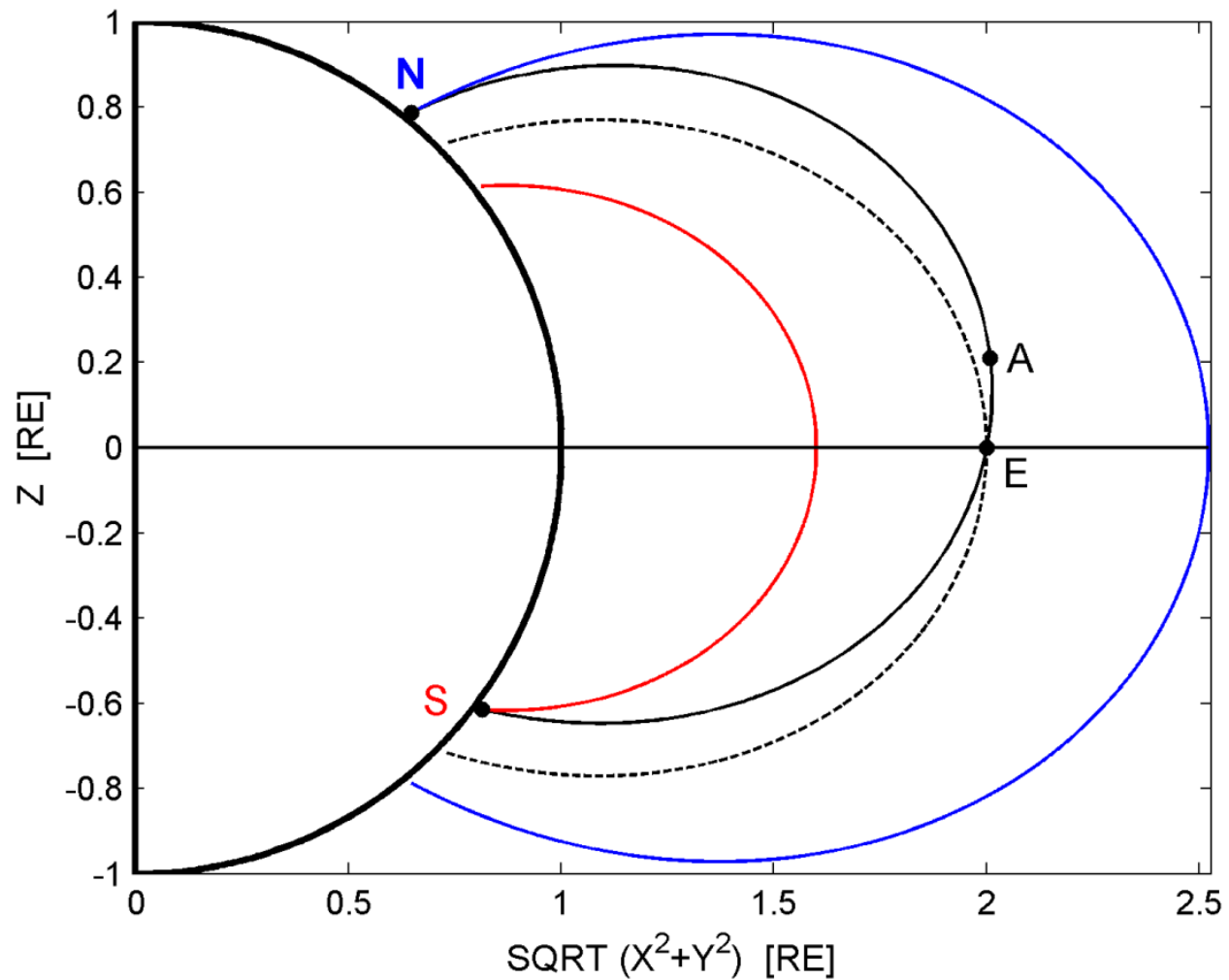
Eigenvalues λ are found imposing:

- 1) the boundary condition: $\mathbf{E} = 0$ at the altitude (100-200 km) where the wave is reflected
- 2) A given functional form for the mass density along the field line.

Common assumption: $\rho(\mathbf{r})/\rho_o = (\mathbf{r} / \mathbf{r}_o)^{-m}$

For any given **L-shell** and **m** value, the inferred **equatorial** mass density is:

$$\rho_o = \text{const.} \times \frac{\lambda(L, m)}{L^8 f_R^2}$$



- IGRF line crossing equator at $2 R_E$, geomag. long. 80°
- Dipole line traced from the equatorial point

Dipole field

$$\frac{d^2 \varepsilon}{dz^2} + L^2 R_E^2 (1 + 3z^2) \frac{\omega^2}{V_A^2} \varepsilon = 0$$

ε : wave electric field

$z = \cos(\theta)$, θ : colatitude

R_E : Earth radii

Arbitrary field geometry (Singer et al., 1981)

$$\frac{d^2 \xi'}{ds^2} + \frac{d \left[\ln(h_\alpha^2 B) \right]}{ds} \frac{d \xi'}{ds} + \frac{\omega^2}{V_A^2} \xi' = 0$$

s distance along the field line

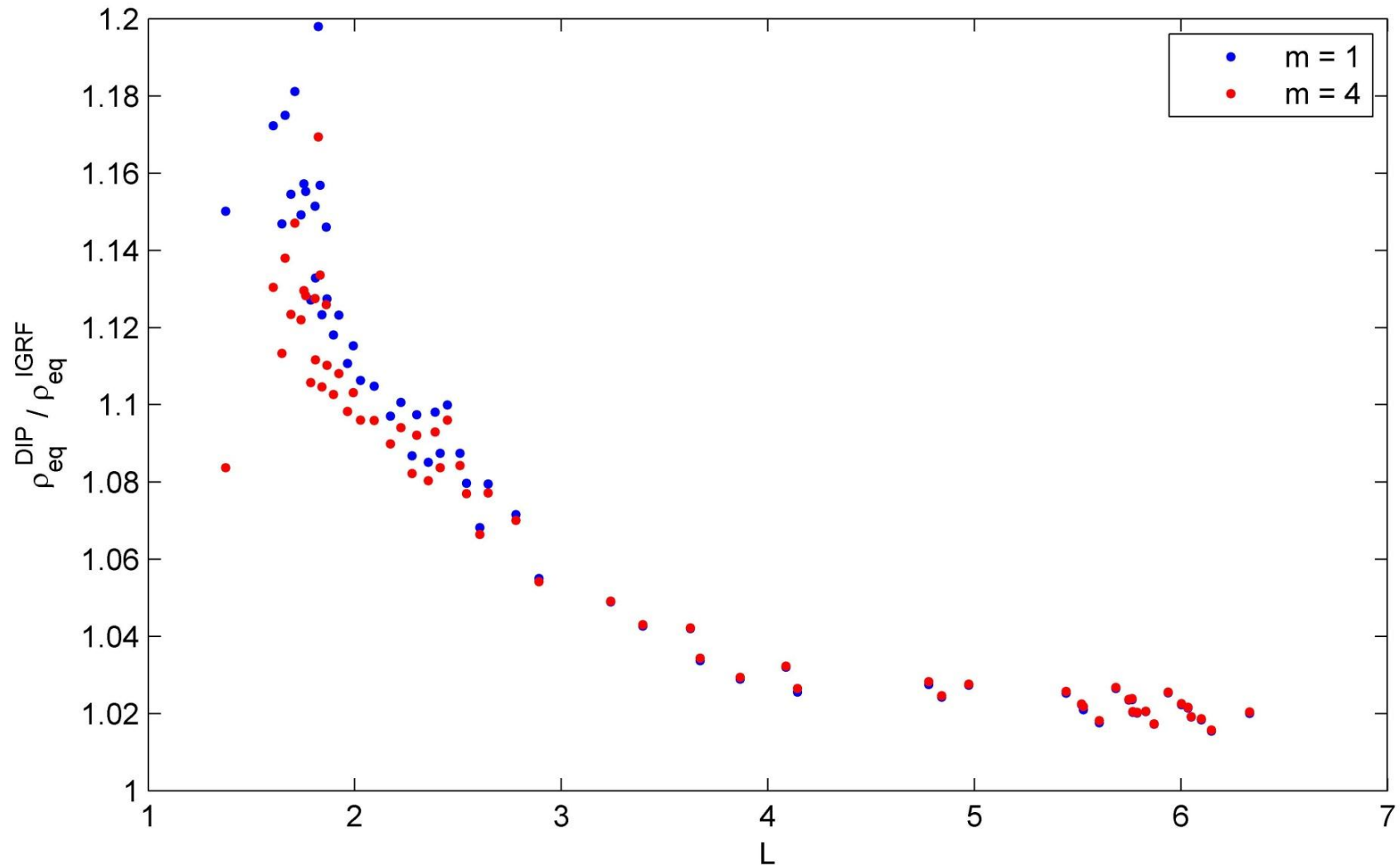
$B(s)$ magnetic field

$\xi'(s) = \xi(s) / h_\alpha(s)$

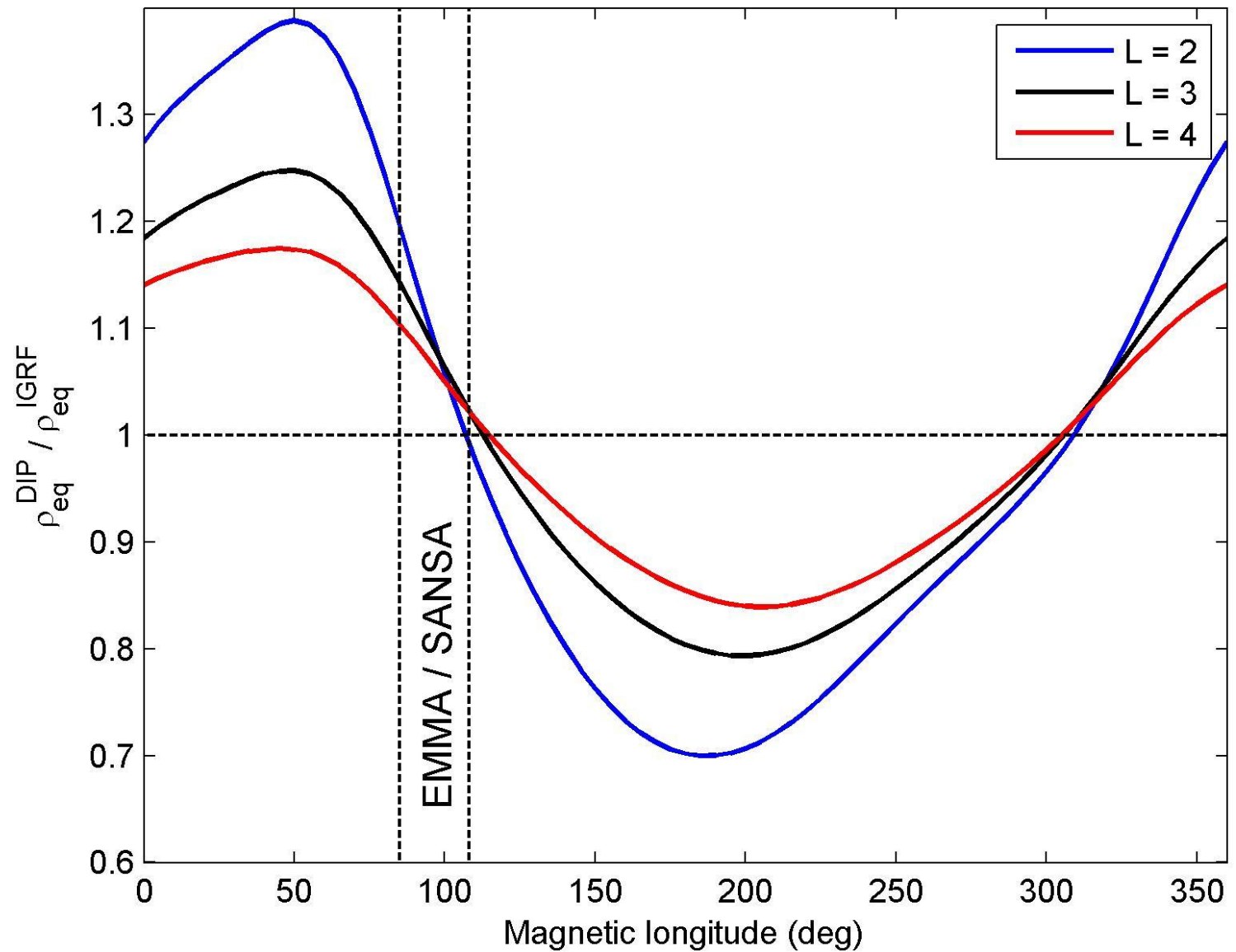
$\xi(s)$ field line displacement

$h_\alpha(s)$ distance to an adjacent field line

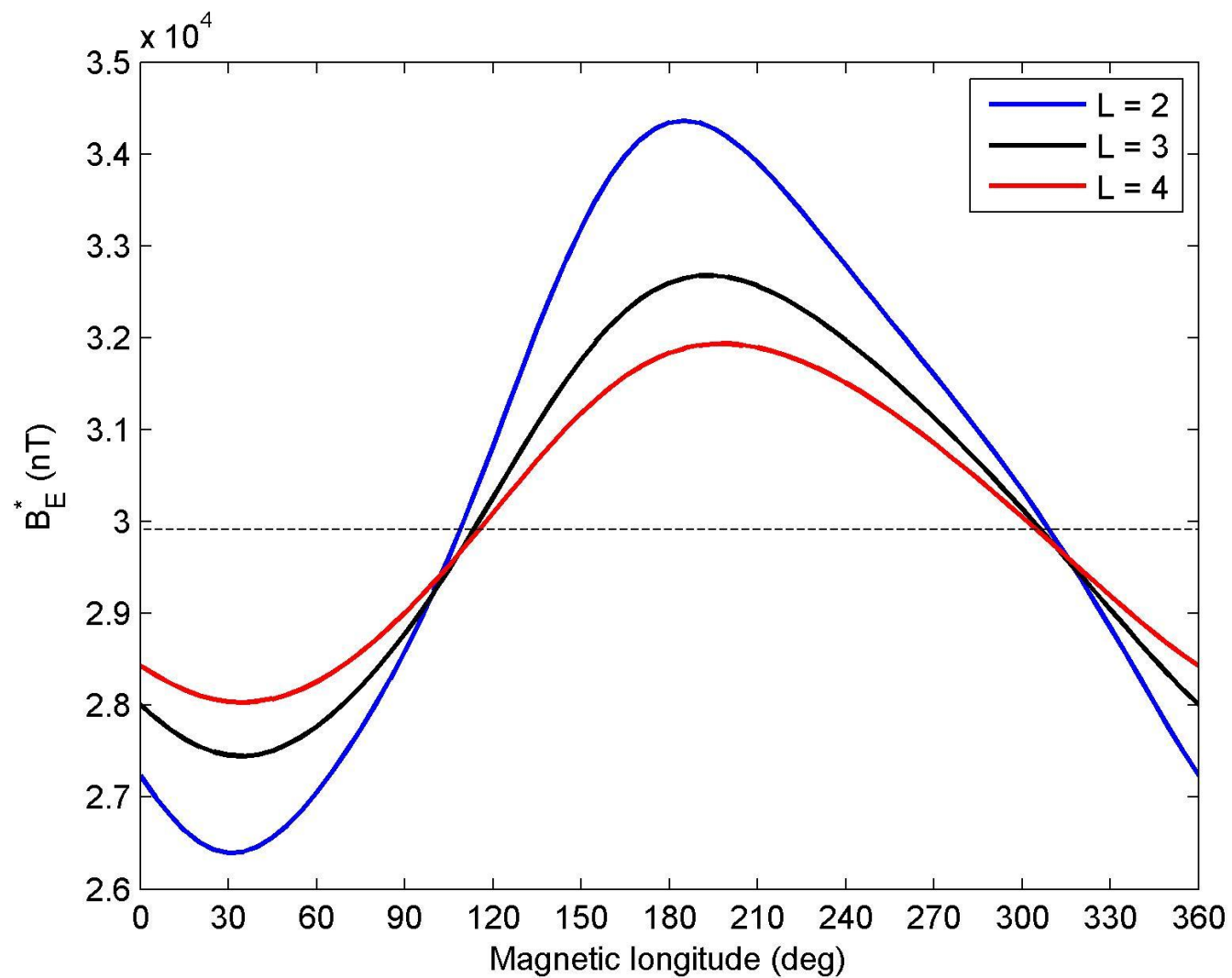
Comparison of ρ_{eq} estimates obtained using dipole and IGRF models for possible station pairs of EMMA/SANSA arrays



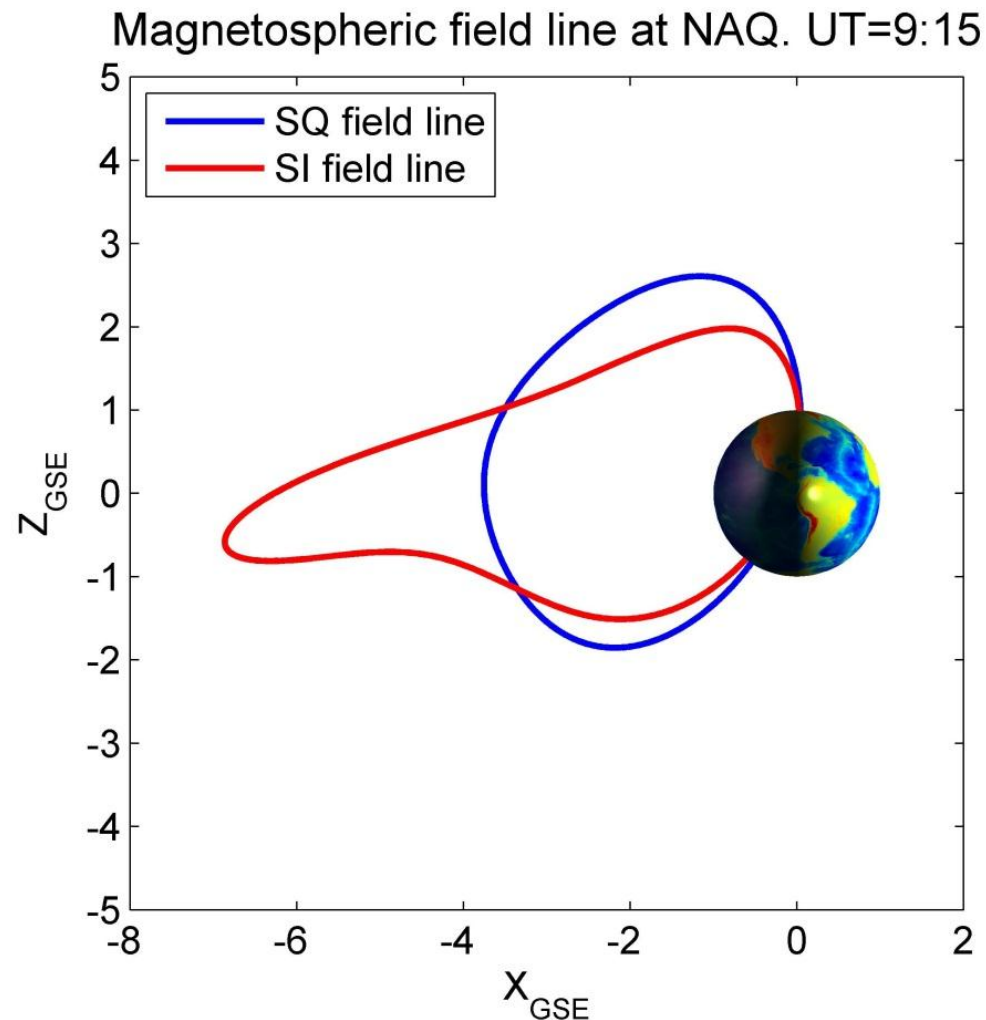
Full longitudinal range analysis



Effective equatorial dipole field



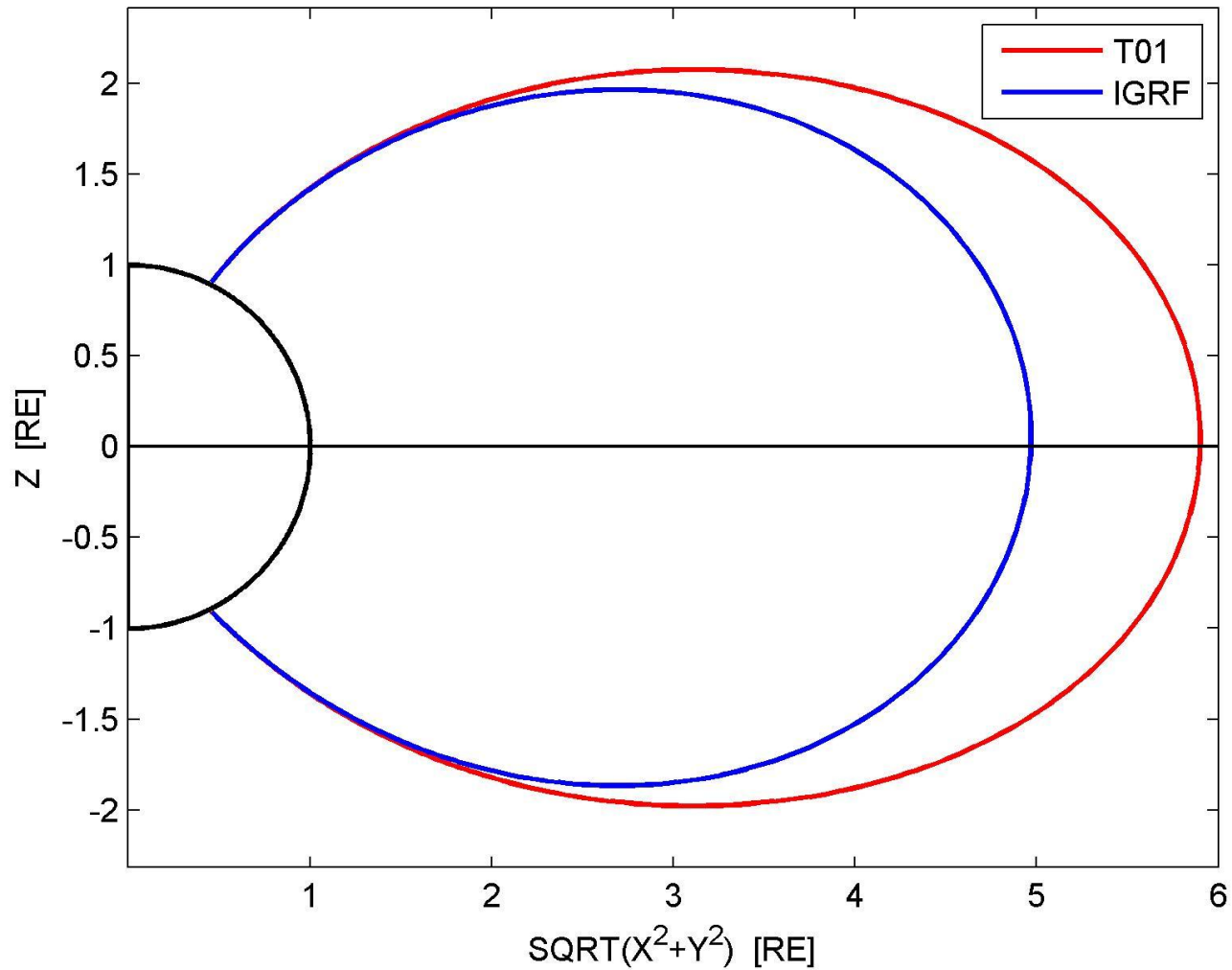
At high latitudes, and even at middle latitudes during particular conditions, need to consider geomagnetic field geometry more realistic than dipole or IGRF geometry (i.e. *Tsyganenko* models).



T01 model (Tsyganenko 2002a, 2002b)

Input parameters:

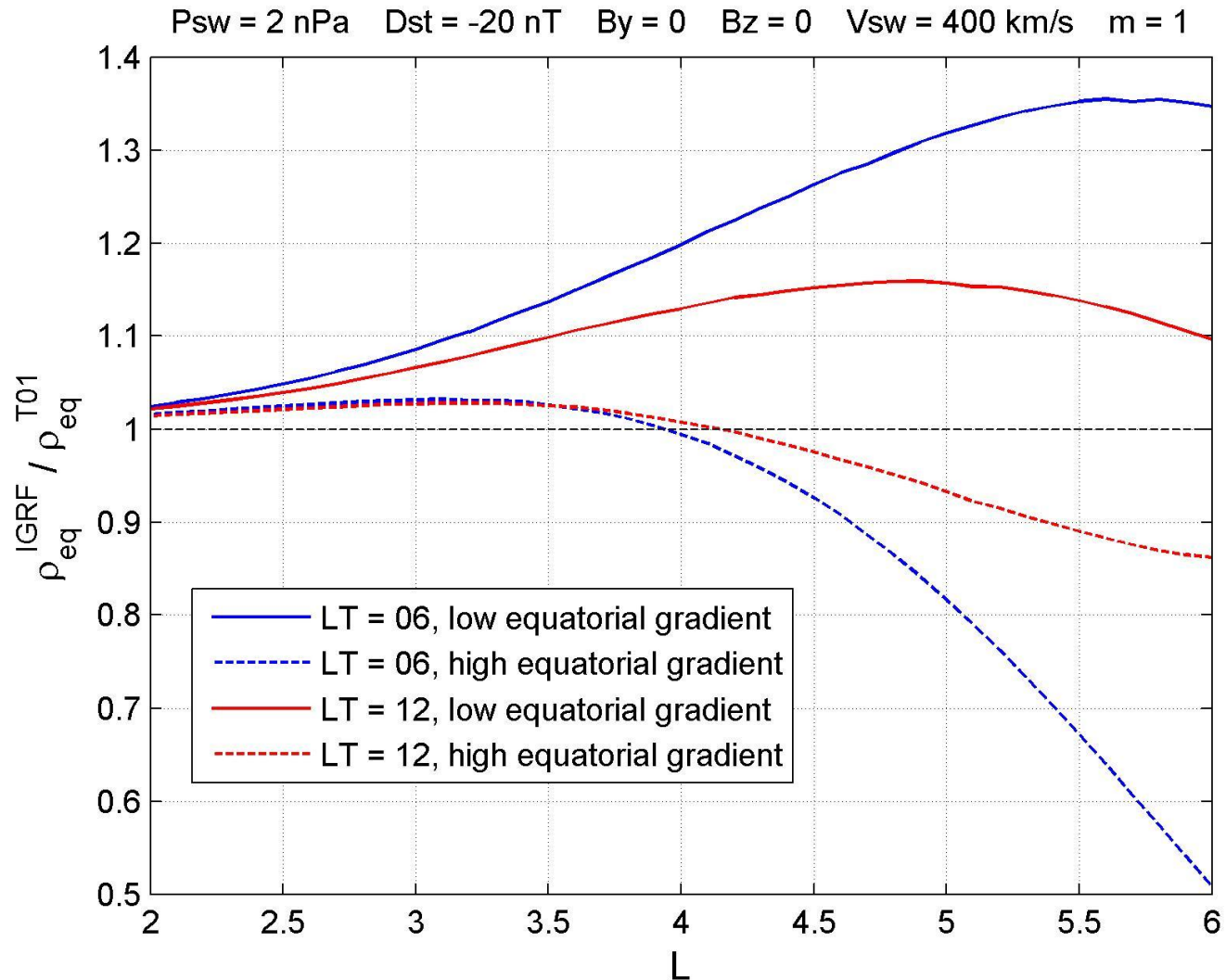
- Universal Time: to determine the proper coefficients of the internal field (IGRF) and the tilt angle;
- Solar wind dynamic pressure;
- Dst index;
- IMF B_y and B_z components;
- G1, G2: take into account the prehistory state of the magnetosphere (determined by B_y , B_z , V_{sw} of the previous hour).



For the comparison of inferred densities we assume:

$$\rho_{\text{eq}} = \rho_{\text{eq},0} \times 10^{-B(L-L_0)} \quad 0.3 \leq B \leq 0.9$$

Average solar wind/magnetospheric conditions

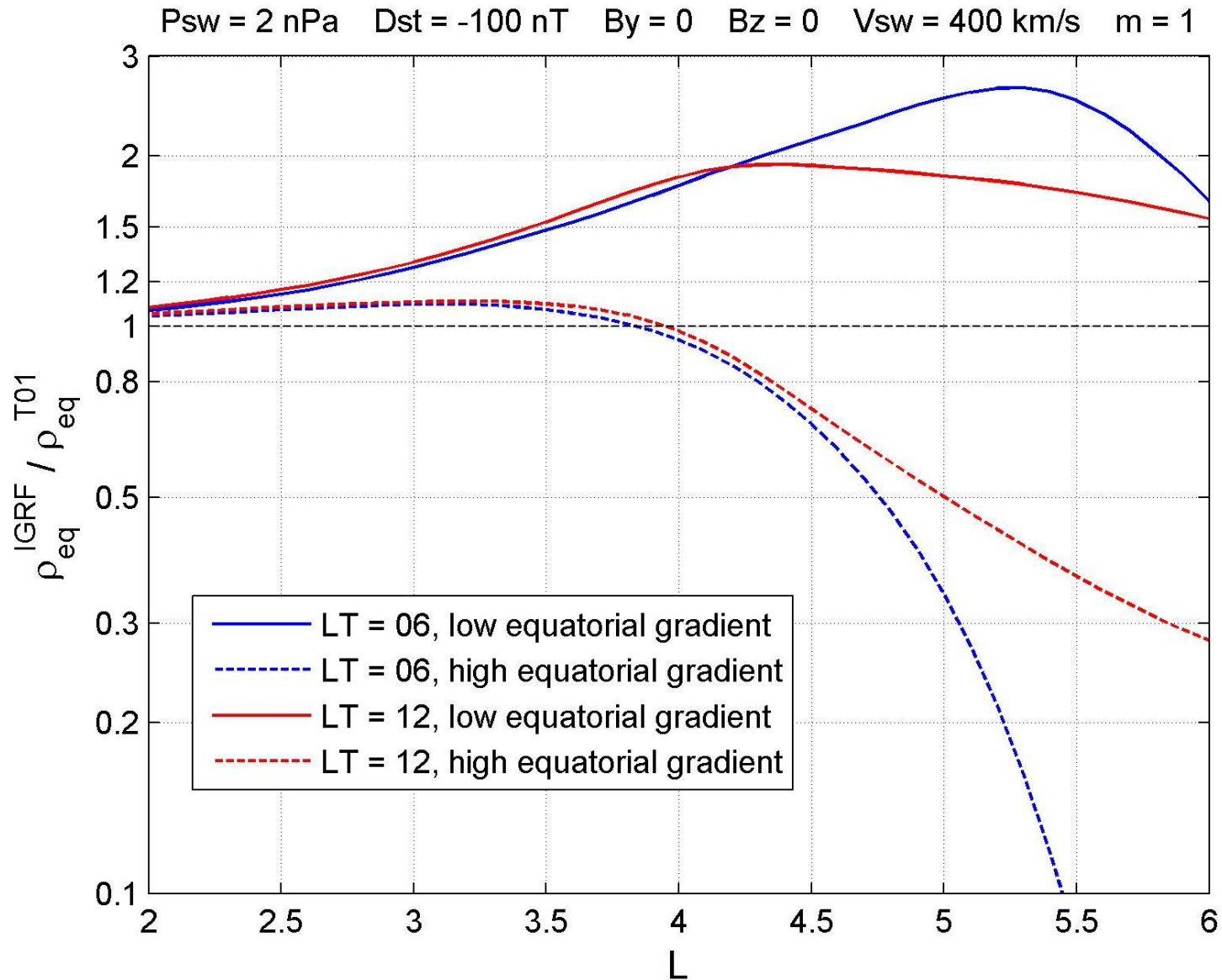


Low equat. gradient: $B = 0.3$

High equat. gradient: $B = 0.9$

$$\rho_{eq} = \rho_{eq,0} \times 10^{-B(L-L_0)}$$

Disturbed magnetospheric conditions, Dst = -100



MATLAB code determining the equatorial plasma mass density

Input parameters:

- observed fundamental eigenfrequency (obtained from FLRID for a given station pair);
- geographical coordinates of the middle point of the station pair;
- index m of the assumed power-law dependence of the mass density;
- Input parameters of the T01 model.

Output parameters:

- geomagnetic coordinates of the magnetic equatorial point of the field line (radial distance and longitude) determined by the T01 model;
- inferred plasma mass density in that point.

Additional information (apex location, magnetic field at the equatorial point and at the apex, field line length, coordinates of the conjugate point, etc.) are also available.

Real-time run

Run every 15 min using:

- quasi real-time values of field line eigenfrequencies of all available station pairs (as computed by FLRID);
- solar wind and Dst parameters.

Real time solar wind data taken from the NOAA Space Weather Prediction Center which provides the latest 2 hours of magnetic and plasma data of the ACE satellite located at the L1 libration point. (http://www.swpc.noaa.gov/ftpdir/lists/ace/ace_mag_1m.txt; http://www.swpc.noaa.gov/ftpdir/lists/ace/ace_swepam_1m.txt)

Time-shift to take into account the propagation time of the solar wind from the satellite position to the Earth (typically about 1 hour).

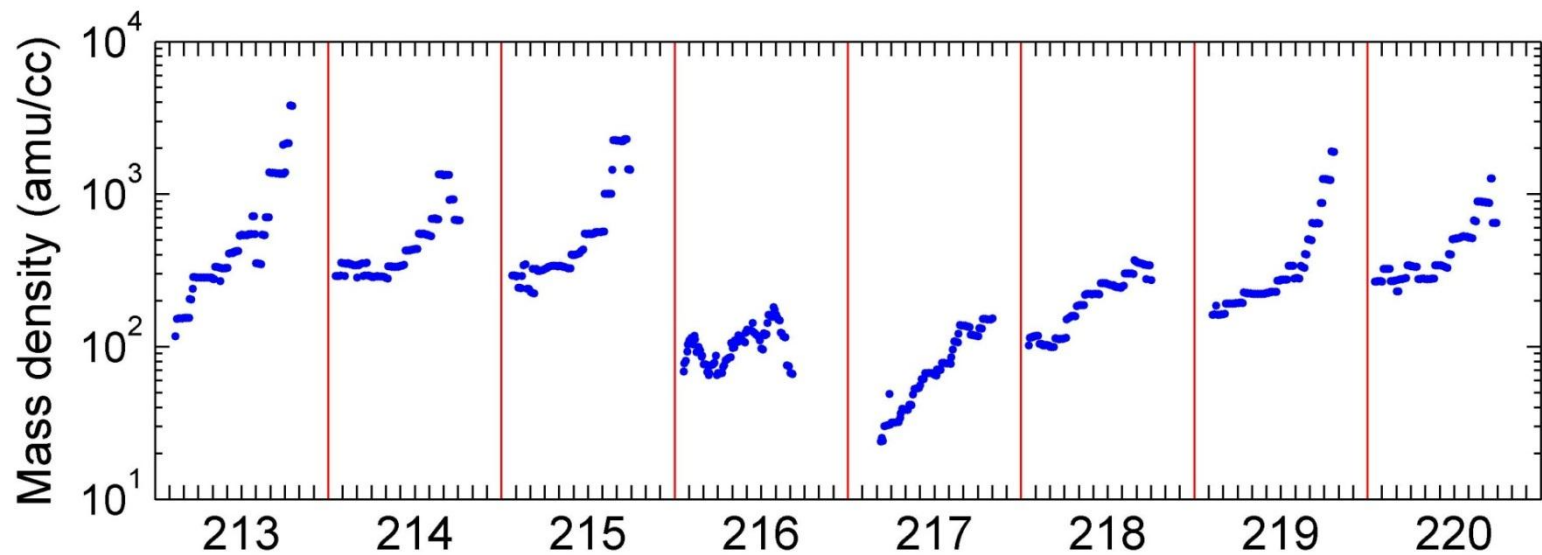
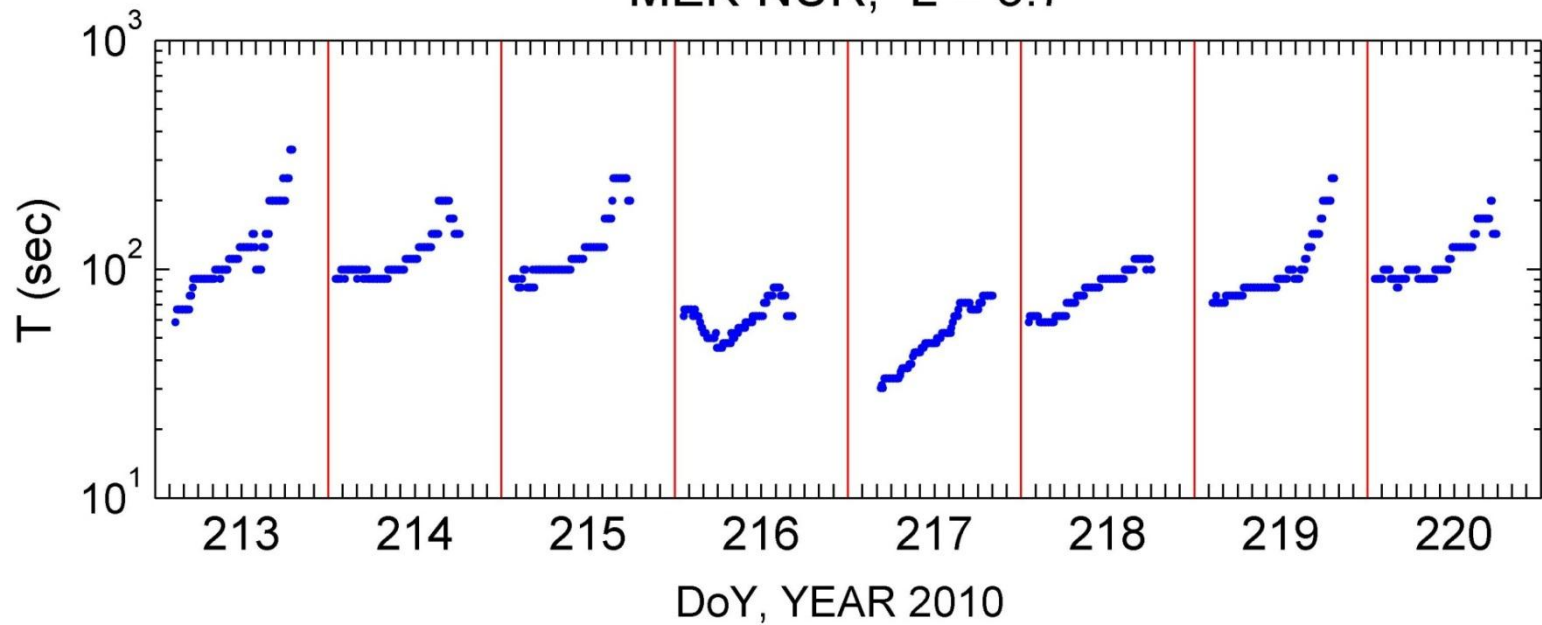
Propagated data are resampled at fixed times and hourly running averages (time step 15 min) are produced.

Real-time Dst data are taken from the World Data Center for Geomagnetism (Kyoto) http://wdc.kugi.kyoto-u.ac.jp/dst_realtime/

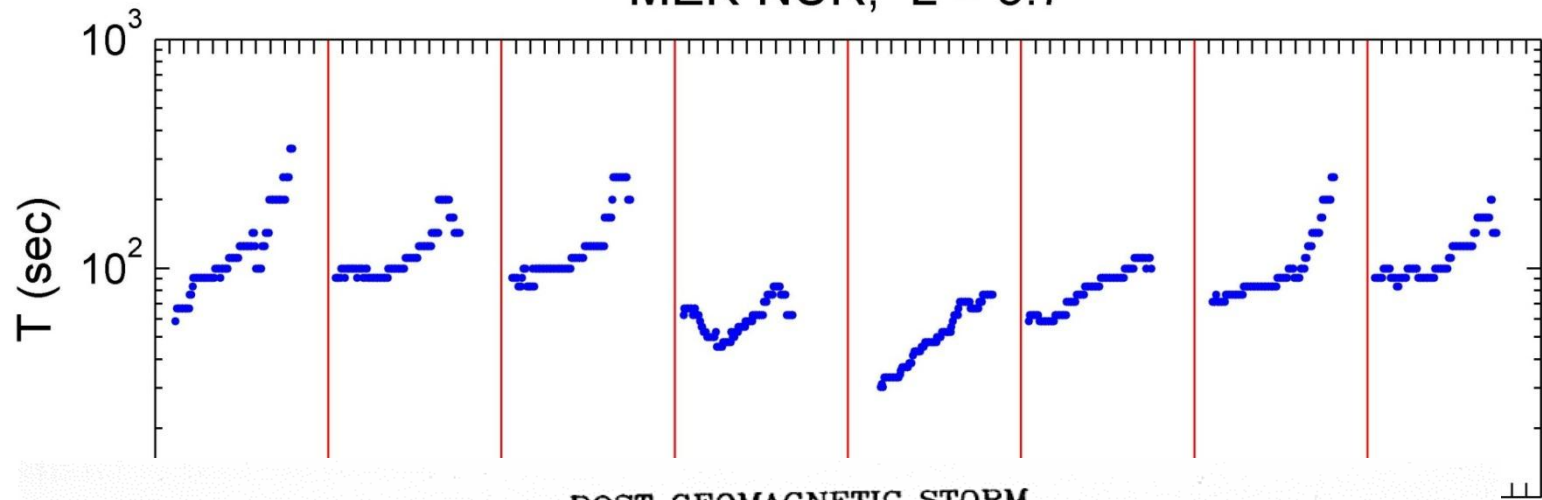
To be done:

- evaluation of uncertainties associated to the density estimates;
- optimization of the implementation of the **T01** model in order to decrease the computing time and/or to use a more recent version **TS05** which is more reliable for geomagnetic storm events;
- examination of other kinds of field-aligned density distributions for low L ?
- consideration of more general ionospheric boundary conditions ?

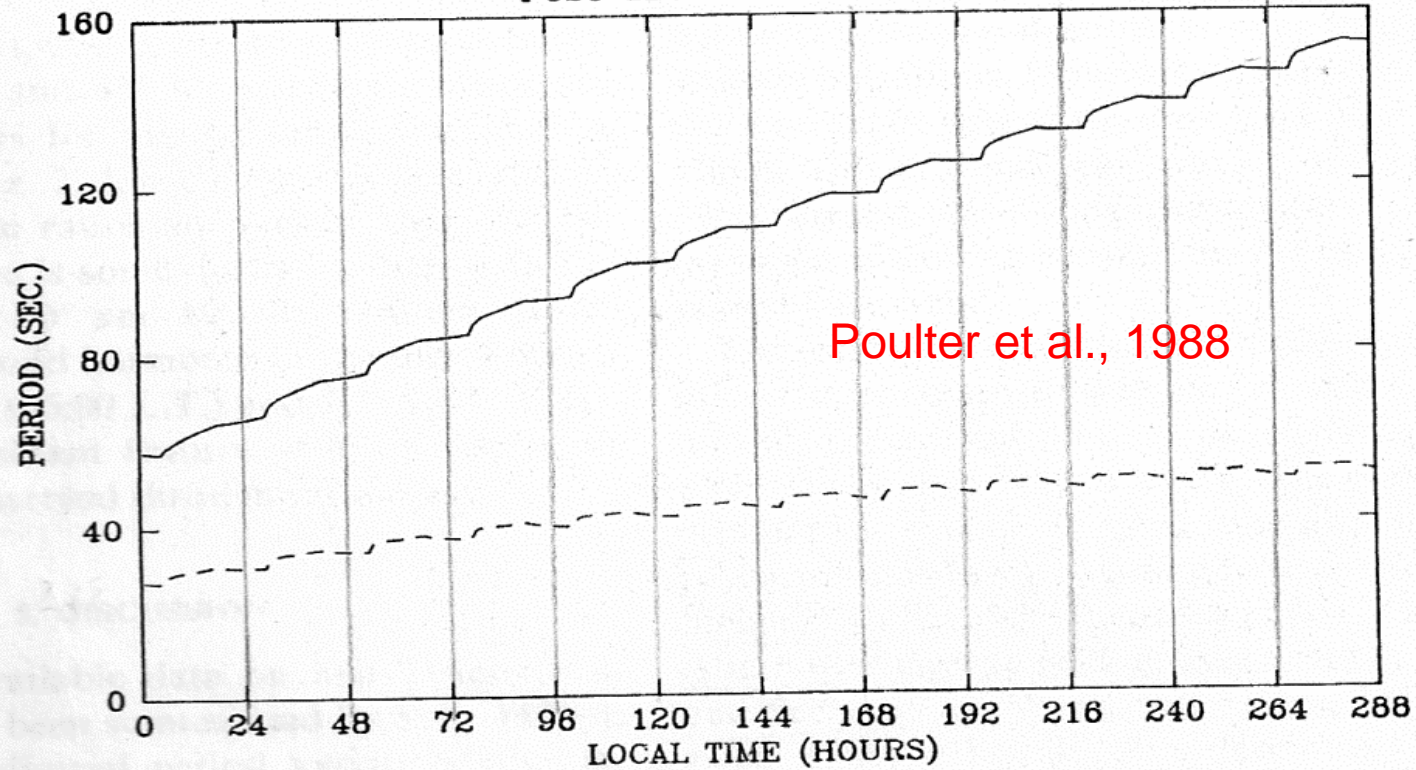
MEK-NUR, $L = 3.7$



MEK-NUR, $L = 3.7$



POST GEOMAGNETIC STORM



Ozeke and Mann, 2005

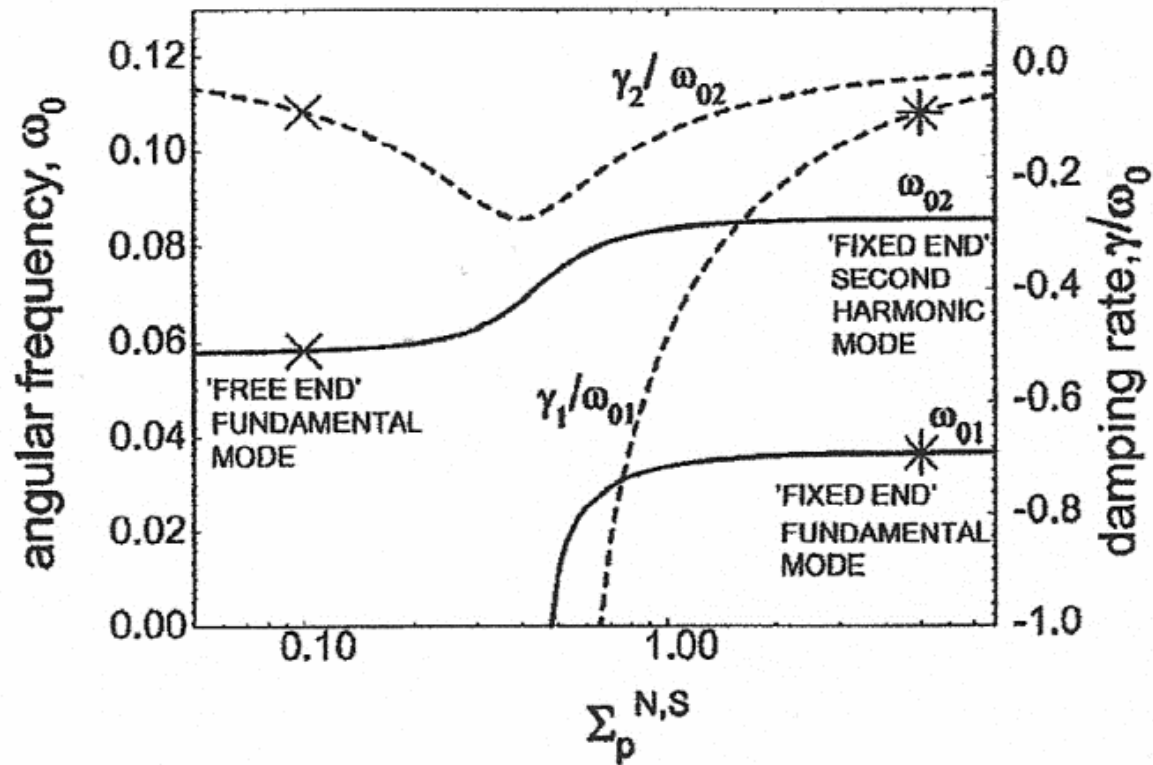
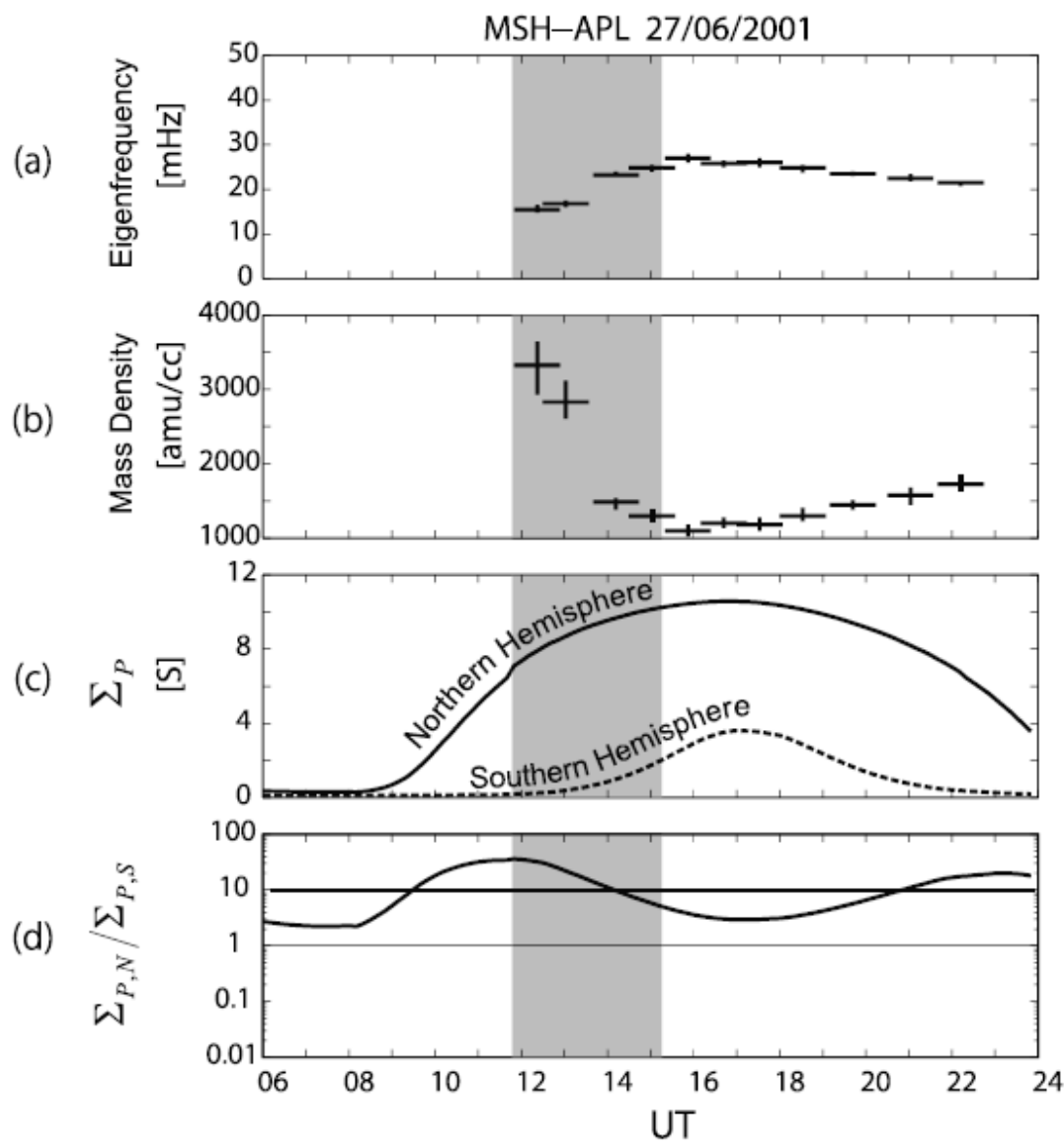


Figure 1. Fundamental and second harmonic mode eigenfrequencies (ω_0) and damping rates (γ/ω_0) of a guided toroidal Alfvén wave as a function of symmetric $\Sigma_p^{N,S}$, at $L = 4$.

The "fixed end" fundamental frequency decreases with decreasing ionospheric Pedersen conductivity.

Another possibility is the formation of a quarter wave mode – asymmetric conductivity
Allan, 1983

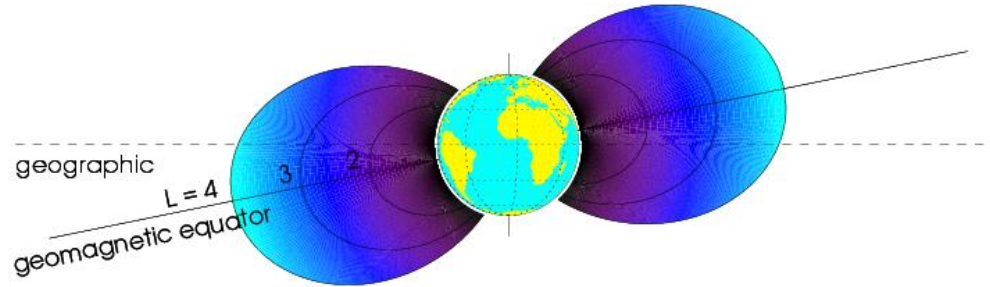


Obana et al. (2008)

Density inference for low L-shells

Ionosphere-Plasmasphere Model (M. Förster, GFZ, Potsdam)

Physical-numerical model to describe the thermal plasma behaviour in corotating flux tubes conjoining the ionosphere and the plasmasphere. Constituents: O^+ , H^+ , He^+ , O_2^+ , N_2^+ , NO^+



Configuration: tilted geomagnetic dipole from 120 km altitude along the field lines to 120 km altitude at the conjugated site.

Input parameters:

- **MSIS** neutral gas model
- neutral wind model **HWM93**
- **F10.7**, **Kp** indices

It solves the following fully time-dependent, nonlinear, coupled second order partial differential equations:

- ✓ continuity equations together with the
- ✓ momentum equations for all species,
- ✓ electron and ion energy equations,
- ✓ kinetic equation for the suprathermal electrons.

The dependence of the inferred equatorial density on the field-aligned density distribution becomes important at $L \leq 2$.

It would be helpful to consider more updated models (i.e. **FLIP**) to further investigate the effect of changing solar/magnetospheric conditions on the inferred plasma density.

