Chapter 3
MODELS OF THE MAGNETIC FIELD IN THE JOVIAN MAGNETOSPHERE: A COMPARISON

3.1 Introduction

Jupiter has the largest magnetosphere in our solar system, large enough to encompass easily the Sun and the visible corona. If the Jovian magnetosphere were visible from Earth, it would be bigger than the full moon in the night sky. The Jovian magnetosphere is very much different from terrestrial magnetosphere in that its energy is predominantly derived from sources internal to the magnetosphere rather than through its interaction with the solar wind. Even before the first in-situ probe to Jupiter, much information we had about the Jovian magnetic field from the ground based observation of nonthermal radio emissions from Jupiter at decimetric and decametric wavelength (Burke and Franklin, 1955).

Since these early radio astronomical studies of the Jovian magnetosphere, different space crafts from 1973, e.g. Pioneer 10, Pioneer 11, Voyager 1 and Voyager 2, Ulysses, Galileo and Cassini etc have flown by planet at different distances and have provided in-situ information about the field geometry and its strength. The direct measurements confirmed the zeroth order models derived from radio data and added a vast amount of new and detailed information about the global characteristics of the field, its dynamics and interaction with the solar wind. From the above information it has been revealed that radial outflow of plasma for the planet Jupiter occurs with the confines of an exterior flowing medium, the solar wind. This geometry creates a collimated flow in the anti-solar direction down the tail of the planet with a contact surface separating the two plasmas Barbosa (1987). The existence of such flow though has received only indirect confirmation; it is required to gather knowledge by
analytical solutions that describe some of the prominent features. Magnetic
fields confine and stimulate space plasmas, which in turn affect the strength
and the configuration of the magnetic field. An idea about the structure of a
magnetic field can provide clues of dominant physical processes (radio
emissions, auroral emission, BEN etc.) operating in the system. In fact our
understanding of the basic physics of this phenomenon is largely obscured
by our unfamiliarity with the value of the generating mechanism, its spectral
characteristics and the physical environment of the source region. Attempts
to develop physical magnetic field models have been done by several
authors for studying the plasma environments around the solar system
planets. Only in recent years models of the magnetic field in the Jovian
atmosphere have been considered with serious limitations. This paper
presents a background of existing models with their theoretical
consideration besides a comparison of the results reported. Furthermore
the utilities of different models with their limitations are also focussed.

3.2 Background

In the middle and outer portions of the Jupiter magnetosphere the field
and particle data collected (Smith et al., 1974; Macibben and Simpson, 1974;
Schadt et al., 1981; Behanon et al., 1981) show the presence of a thin
current sheet of half thickness < 3 Rj. It contains both cold plasma (Bridge
et al., 1979) and energetic particles ( Behanon et al., 1981). This current
sheet beyond a radial distance of ~ 10 Rj (Jovian radius, $R_j = 7.14 \times 10^4$
km) is aligned with the magnetic equator and is known as the surface of
minimum field strength (Behanon et al., 1981). The data further reveal that
the observed magnetic equator crossings are increasingly delayed from the
dipole magnetic equator due to the noncorotation of plasma in the middle
and outer magnetosphere (Krimigis et al., 1979; Northrop et al., 1974;
3.3 Theoretical Consideration

In order to arrive at a mathematical description of the external magnetic field the forms and scale sizes of current carrying regions in and around the magnetosphere should be taken into account. The external field arises due to current flowering in the ionosphere-magnetosphere system of the planet in response to the forcing from the solar wind and from drift currents generated by the trapped particles in the radiation belts and also by radial currents generated in a rotating magnetosphere. The magnetic field observed in a magnetosphere is represented as the sum of the internal field $B_i$ and an external field $B_e$ due to various current sources (internal sources: $B_{\text{main}}$), supplying 1 ton/s (Bagenal and Sullivan, 1981, Broadfoot et al., 1981, Hill et al., 1983), next significant source – escaping ions ($H^+$ and $H_2^+$) from Jovian ionosphere supplying ~ 20 kg/s (Hill et al., 1983), surface sputtering of 3-icy satellites supplying < 20 kg/s (Cooper et al., 2001); and the external source: Solar wind supplying < 100 kg/s (Hill et al., 1983), present in the ionosphere and the magnetosphere. The magnetic field observed in the space can be represented as the sum of internal field, $\vec{B}_i$, arising due to internal sources of the planet, and an external field $\vec{B}_e$ due to external sources. Thus

$$\vec{B} = \vec{B}_i + \vec{B}_e$$

(3.1)

Where $\vec{B}_i = -\nabla V$ is derivable from a scalar potential function $V$ and it is augmented with perturbation field $\vec{B}_e$. The traditional spherical harmonic expansion of $V$ is given by.

$$V = R \sum_{n=1}^{\infty} \left( \frac{R_j}{r} \right)^n \sum_{m=0}^{n} \left\{ P_n^m(\cos \theta) \left[ g_n^m \cos(m\phi) + h_n^m \sin(m\phi) \right] \right\}$$

(3.2)
Where $R_J = 7.1492 \times 10^4 \text{ km}$,

\[ r \] - the radial distance to the planet's center

$\theta, \phi$ - colatitude and longitude

$p_{n}^{m}$ - Schmidt- normalized associated Legendre functions of degree $n$ and order $m$

$g_{n}^{m}, h_{n}^{m}$ - Schmidt coefficients giving internal field parameters

$n_{\text{max}}$ - order number

Tsyganenko (1989, 1995) in modelling the field of the Earth's magnetosphere approximated $\vec{B}$ as,

\[ \vec{B}_v = \vec{B}_{DS} + \vec{B}_{RC} + \vec{B}_{T} \quad \ldots \quad (3.3) \]

Where $\vec{B}_{DS}$ is the dipole shielding field due to the currents flowing along the magnetopause, $\vec{B}_{RC}$ is the field due to ring current and its shielding current while $\vec{B}_{T}$ is the field from the magnetotail currents and associated shielding currents.

The magnetic field generates radial currents in the current sheet to apply $\vec{J} \times \vec{B}$ azimuthal stresses on the plasma to make it corotate. This process transfers angular momentum from Jovian ionosphere into the out flowing plasma. Due to this azimuthal stresses all points on field line including its magnetic equator are shifted westward causing a delay in the current sheet location. In this way the plasma experiences a time varying vertical accelerations and confine the plasma to the magnetic equator (Khurana, 1997). The wave like interaction between the plasma and the magnetic field further delays the magnetic equator, which is assumed to be
proportional to the Alfvén wave transmit time between the Jupiter's ionosphere and the equatorial plane (Goertz, 1981). The consequence of these delays of the current sheet is that an observer at the Jovigraphic equator would observe a phase lag in the arrival of the current sheet relative to ten-hour periodic phenomenon of the field and the particle intensities. As a result the current sheet is unable to reach its maximum latitude, i.e. it is hinged.

Beside the systematic delays observations further reveal that for all spacecraft located north of the Jovigraphic equator, north to south crossings are delayed more than the south to north crossings and this unequal delay is explained by the magnetodisc models by postulating a hinging of the current sheet beyond a certain distance from Jupiter. Fig.3.1 illustrates how the hinged current is responsible for the unequal delays. In the figure the heights of the hinged and fully tilted current sheets with respect to the Jovigraphic equator is plotted as a function of system III longitude. The trajectory of a spacecraft (S C) located north of the Jovigraphic equator is also indicated in the figure. It is seen that for the spacecraft hinging is responsible in reality for the further delays. The hinged magnetodisc model postulates that the hinging of the magnetotail is caused predominantly by the solar wind forcing. Khurana (1992) based on this model parameterized the hinging distance terms of Jupiter-Sun magnetospheric (JSM) x-axis, as:

\[
Z_{cs} = \text{plan} \left(9.6^\circ\right) \left[\frac{x_0}{x} \tanh \left(\frac{x}{x_0}\right) \cos \left(\lambda - \delta\right)\right] \quad \cdots \quad (3.4)
\]

Where \(\delta = \delta_0 - \frac{\Omega_x \rho_0}{v_0}\) represents the longitude toward the current sheet structure and the corresponding parameters \(x_0, \rho_0\) and \(v_0\) are hinge distance, radial distance (beyond which the wave delay becomes effective) and the wave velocity. According to this model the current sheet is initially
Fig. 3.1 The heights \( Z(\lambda) \) of the hinged (dashed lines) and fully (solid lines) tilted current sheets with respect to the Jovigraphic equator as a function of system longitude \( \lambda \) in degrees are plotted for representing the current sheet geometry. The shaded region represents the anomaly in the behaviour between the hinged and tilted current sheets with respect to Jovigraphic equator.
aligned with the magnetic equator (up to $x = x_0$) and then it is aligned toward the Jovigraphic equator after departing from the magnetic equator due to hinging. The cause of such hinging might be due to inertial stresses as discussed above.

Comparing Galileo data with Khurana (1992) model it reveals that the time delay of the crossing of the current sheet according to the model is at variance (in the dusk sector, crossing of the current sheet will be sooner than that predicted by the model, whereas the reverse case obtained in the dawn sector, it is the latter than actually happened) with the said data. It might be due to the less convergence of the field lines observed in the dusk sector.

3.4 Existing Models of Jovian Magnetic Field

Magnetic field observations are obtained only along spacecraft trajectories through the Jovian magnetosphere, but one would like to have a description of the magnetic field through out the entire magnetosphere. The difficult task of reconstructing the Jovian magnetosphere from the data obtained during the spacecraft passes through it. However from the Pioneer age till to date different spacecrafts are being sent for probing different magnetospheres and the data are used for verifying the simulated magnetospheric models approached in several different ways. The versatile Euler potential method exemplified by the model of Goertz et al. (1976) is a mathematical representation of the magnetic field based on a description of the field morphology. Functions appropriate to the observed or assumed field line geometry are selected, and adjustable parameters are chosen to minimize the differences between the computed and observed field along the trajectory. The magnetic field at points not on the trajectory is obtained by extrapolation. In contrast, the magnetospheric magnetic field model of Connerney et al. (1981) is derived from a mathematically tractable current distribution inferred from the observations. Adjustable parameters directly
related to currents in the model Jovian magnetosphere are selected to minimize the differences between the modeled and observed fields along the trajectories. The magnetic field elsewhere is computed directly from the model current distribution. The distinction between these two approaches is essentially the following:

(i) In the Euler potential method, one chooses simple functions to fit the field line geometry, and accepts whatever current distribution is implied by the representation chosen.

(ii) In the source modeling method, one chooses a physically reasonable current distribution, and accepts the limitations imposed by mathematical tractability and the probability of a mathematically more complex field line description.

In fact Jupiter's current sheet structure is very complex—it moves closer to the dipole magnetic equator in the middle magnetosphere from its origin near the Io's orbit and finally becomes parallel to the solar wind in the magnetotail.

Connerney et al. (1981) attempted to simulate the Jovian magnetic field from the second approach for the first time. They solved the relation for the magnetic field \( \vec{B} = \vec{V} \times \vec{A} \) in a semi-infinite azimuthally symmetric current sheet to find solutions for the vector potential \( \vec{A} \). For this solution they assumed that height-integrated current density in the current sheet is zero for \( \rho < a \), and falls as \( \rho/\rho_f \) for \( \rho > a \). The solution of \( \vec{A} \) for the current sheet situated at \( |z| > D \) is given below:

\[
A^z(\rho, z) = \mu_0/\rho_f \int_0^\infty J_1(\rho \lambda)/\lambda \text{snh}(D \lambda) e^{z\alpha} a^2 / \lambda^2 d\lambda \\
(35)
\]
+ve sign for the vector potential above the current sheet and -ve sign for that of the below. Whereas the solution of vector potential inside the current sheet \((|z| < D)\).

\[
A(\rho, z) = \mu_0 I_0 \int_0^\infty J_1(\rho \lambda) \left(1 - e^{-\rho \lambda} \cosh(z \lambda)\right) d\lambda
\]

\[(3.6)\]

As the above solutions contain integrands, which are computationally slow, so Connerney et al. tried with simple analytic functions, approximate to the above equations, for fast computations of the field. Edwards et al. (2001) have derived new analytical forms provide more accurate approximations to the Connerney's integral equations.

In this presentation we choose Euler potential models. Since, it can accept any current distribution. In this model the divergence free vector magnetic field \(\vec{B}\) is expressed as

\[
\vec{B} = \vec{V} f \times \vec{V} g
\]

\[(3.7)\]

where the functions \(f\) and \(g\) are scalar functions of position known as Euler potentials. Surfaces of constant \(f\) and \(g\) are everywhere tangent to \(\vec{B}\), because

\[
\vec{B} \cdot \vec{V} f = 0 \quad \text{and} \quad \vec{B} \cdot \vec{V} g = 0
\]

\[(3.8)\]

Thus the intersection of surfaces \(f = \text{constant}\) and \(g = \text{constant}\) occurs along a field line. Azimuthally symmetric infinite Harris current sheet is the starting point of such a model and can be described by the Euler potential function \(f\) & \(g\) which are expressed in a cylindrical co-ordinate system with \(\hat{\rho}, \hat{\phi}\) in the magnetic equatorial plane and \(\hat{z}\) parallel to the dipole axis for the analysis of the perturbation magnetic field of the Jovian magnetospheric current sheet as

\[
f = -B_0 \rho D \ln[\cosh(z / D)], \quad g = \phi
\]

\[(3.9)\]
So that the components of \( B (B_\rho, B_\phi, B_z) \) can be computed by using the following differential relations

\[
\vec{B} = \left[ \frac{1}{\rho} \frac{\partial f}{\partial \rho}, \frac{\partial g}{\partial \rho}, \frac{1}{\rho} \frac{\partial f}{\partial \rho}, \frac{1}{\rho} \frac{\partial f}{\partial \rho} \right]
\]

... \hspace{1cm} (3.10)

and we get -

\[ B_\rho = B_0 \tanh(z/D), \] \hspace{1cm} (3.11a)
\[ B_\phi = 0 \] \hspace{1cm} (3.11b)
\[ B_z = -B_0 \left( D/\rho \right) \ln[cosh(z/D)] \] \hspace{1cm} (3.11c)

Goertz et al (1976) generalized equation (3.9) so that \( B_\phi \) was non-zero, \( B_\rho \) is a more realistic one and it includes the contribution of a centered dipole in the Euler potential.

\[
\begin{align*}
\dot{f} &= f(\rho, z) = M \left( \frac{\rho^2}{z^2 + \rho^2} \right)^{1/2} - \frac{b_0}{\rho^a} \left[ \ln \cosh(z/D) + C \right] \hspace{1cm} (3.12a) \\
g &= g(\rho, \phi) = \phi + 175(e^{\rho/190} - 1) \hspace{1cm} (3.12b)
\end{align*}
\]

The first part of the equation (3.12a) is the contribution from the Jovian dipole field and the second term will take care of the contribution from the current sheet. The second equation (3.12b) is consistent with the Pioneer spacecraft observed field.

The above constructed model was fit well with the Pioneer data beyond a radial distance of 20\( R_J \). However, the model has singularity near Jupiter.
and cannot represent the internal field models. The model is also unsuitable
for studying field lines from magnetosphere to the ionosphere.

In the chosen cylindrical co-ordinate system with $z$ aligned with the
magnetic dipole axis and $\rho$ in the magnetic equatorial plane, with magnetic
dipole moment $M_0 = 4.2 \times 10^5 \, \text{nT} \, R_J^3$; $\alpha, b_0, D, C$ are constants which are
fitted according to the origin chosen.

Jones et al (1980) used similar functional form as stated above in their
model. Goertz et al (1976) used the Pioneer 10 magnetometer and charged
particle observations to derive a model considering the current sheet for the
magnetic field of the Jovian magnetosphere. The field components are
derived by using equation (3.10), (3.12a) and (3.12b)

\[
B_\rho = 3M_0 \frac{\rho}{r^3} + \frac{b_0}{\rho D} \left[ \tanh \left( \frac{z}{D} \right) \right] - \frac{ab_0}{\rho D} \frac{z}{r^\alpha+2} \left[ \ln \left( \cosh \left( \frac{z}{D} \right) \right) + C \right] \tag{3.13a}
\]

\[
B_\theta = -6.12 \times 10^{-3} \rho B_\rho e^{\rho_D} \tag{3.13b}
\]

\[
B_z = \frac{ab_0}{\rho D} \left[ \ln \left( \cosh \left( \frac{z}{D} \right) \right) + C \right] \tag{3.13c}
\]

where $a, b_0, C, D$ are constants obtained by fitting the Pioneer 10 data
(Table 3.1), $\alpha$ is the magnetostatic radial variation exponent, $b_0$ is the disc
field variable, $C$ is dimensionless constant, $D$ is disc thickness.
Table 1: Constants evaluated by fitting P10 magnetometer data

<table>
<thead>
<tr>
<th>$\alpha$</th>
<th>$b_0$</th>
<th>$C$</th>
<th>$D$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.7</td>
<td>$9 \times 10^{-2}$ G</td>
<td>10</td>
<td>$1R_J$</td>
</tr>
</tbody>
</table>

Khurana (1997) used the external field expression as

$$\vec{B}_e = \vec{V}_f(p, \phi, z) \times \vec{V}_g(p, \phi, z)$$

So that,

$$B_\rho = \frac{1}{\rho} \frac{\partial f}{\partial \rho} \frac{\partial g}{\partial z} - \frac{\partial f}{\partial z} \frac{\partial g}{\partial \rho}$$

$$B_\phi = \frac{\partial f}{\partial \phi} \frac{\partial g}{\partial z} - \frac{\partial f}{\partial z} \frac{\partial g}{\partial \phi}$$

$$B_z = \frac{\partial f}{\partial r} \frac{1}{\rho} \frac{\partial g}{\partial \rho} - \frac{1}{\rho} \frac{\partial f}{\partial \rho} \frac{\partial g}{\partial \phi}$$

To remove the singularities in the model proposed by Goertz et al. (1976) and taken into consideration of the internal field model GSFC 06 spherical harmonic model Khurana (1997) proposed modified form of Euler potentials as-

$$f = -C_1 \rho \left[ \tanh \left( \frac{\rho \alpha}{\rho} \right) \right]^{\eta} \ln \cosh \left( \frac{z - Z}{\alpha} \right) + \int \rho \left[ C_2 \left[ \tanh \left( \frac{\rho \alpha}{\rho} \right) \right] \right] + C_3 \left[ \tan \left( \frac{\rho \alpha}{\rho} \right) \right]^{\eta} d\rho$$

$$\text{ (3.16)}$$
\[ g = \phi + p \left( 1 + q \tanh^2 \frac{z - Z_{cs}}{D_2} \right) \rho \]  \quad (3.17)
We have used a beaming model of the $\text{Io}$-independent Jovian decametric radiation based on multipole models of the Jovian magnetic field as proposed by Goldstein et al. (1979). Moreover, the Euler potential models of Jupiter's magnetospheric field as developed by Khurana (1997) has also been utilized in this study.

Goldstein et al. (1979) developed a beaming model of the non-$\text{Io}$ Jovian DAM radiation model that was largely based on multipole models of the Jovian magnetic field. In that model the locations of the origin of a particular gyrofrequency in the Jovian magnetosphere are found by integrating the magnetic field equations in spherical coordinates which begins at some point $(r, \theta)$ and proceeds to calculate $B(r, \theta, \phi)$ down to the cloud tops in the northern and southern hemisphere. The maximum mirror field $B_{\mu}$ associated with a definite field line in the lower of the magnetic field values at one of the two ends of the field line. For the radial distance of the cloud tops Kahle et al. (1964) established:

$$\frac{R}{R_j} = \left(1 + \epsilon \cos^2 \theta \right)^{\frac{1}{2}}$$

(3.18)

Where $\epsilon = 0.14371$, planetary oblateness

$R_j = 7.1492 \times 10^4$ km, equatorial radius of the Jupiter, $\theta = \text{Colatitude}$

The gyrofrequency, $f_M = \frac{|e|B_M}{2\pi mc}$ is then the maximum frequency that can be sampled by a trapped electron (mass $= m$ and charge $= e$) on that field line. Evaluating $f_M$ it is possible to delineate the regions within which radiation above some predetermined frequency originates. The possible source locations of the decametre radiation can thus be found as a function of frequency. It has been confirmed that the higher frequencies are coming from increasingly restricted areas and the lower altitudes within the magnetosphere. Goldstein et al. (1979) found it sufficient to consider
equatorial radiation $L \leq 6$, where $L$ is the magnetic field line that intersects the equatorial plane at $r / R_j = L$. However, if required the analysis can be extended to large $L$ values. The most significant difference between the O4 model and the JPL model is that in the later the location of maximum southern hemisphere field at $\lambda_{III} = 330^\circ$. Consequently the locations of regions within which trapped electrons sample gyrofrequencies more than 27 MHz is a very small area between $L = 5$ and $L = 6$, at higher $\lambda_{III}$ than in the O4 model. A second important difference between the models is that the highest value of the surface field in the JPL model is more than about 15 gauss while in the O4 model it is about 14 gauss. This model in this respect, may be seemed to be a unique one. Smith et al. (1976) model predict maximum fields of about 14 gauss but it is systematically higher than those found in O4 model. Moreover, the highest gyrofrequency that can be sampled at all azimuths is 20 MHz in the JPL model and 16 MHz in the O4 model. This difference is valid for participating electrons also.

To represent the external field in the Jovian magnetosphere, two entirely different approaches have been followed. For an angular current sheet Connerney et al. (1981) obtained the solutions to the equation $\vec{\nabla} \times \vec{A} = \vec{B}$ where the current density is $I_0 / \rho$ for $a < \rho < b$ and zero for $\rho < a$ and $\rho > b$ where $a = 5R_j$ and $b = 50R_j$. However, Connerney et al. (1981) did not provide a close analytical form for the magnetic field, only they gave some expressions, which can be integrated numerically. The model provided by them and the observations from Voyager and pioneer space craft for $6R_j < \rho < 30R_j$ is in good agreement. But beyond a radial distance of 30 $R_j$, the hinging and the lag of the current sheet become appreciable and their proposed model becomes in applicable.

Engle and Beard (1980) proposed a relatively less quantitative global model. The model incorporated an infinitesimally thin current sheet located
with the dipole equator, and internal dipole field and a magnetic field due to
the shielding currents flowing along the magnetopause. The model is
appropriate for the dayside magnetosphere. However, it lacks the warping
of the current sheet and the sweep back of the field lines. Alternatively
Barish and Smith (1975) approached global model of the Jovian
magnetospheric field. They used Euler potential approach to define a
magnetic field configuration confined to a sphere of radius \( r = 100 \, R_J \). The
model, in the equatorial plane, was designed to produce a field strength
proportional to \( 1 / r^2 \). Goertz et al. (1976) proposed a model using the Euler
potential approach. The model self-consistently incorporates the sweep
back of the field lines in its formulation. The model reveals a good
agreement to fit the Pioneer 10 data beyond a radial distance of 20 \( R_J \). In
this work the internal field was modeled in terms of the Euler potentials of a
centered dipole. Khurana (1997), on the other hand, represented the
internal field in terms of spherical harmonics and used the Goddard space
Flight Centre O6 model (GSFCO6, O6 stands for octupole part of a sixth
order spherical harmonic development of the traditional spherical harmonic
expansion of the scalar potential function \( V \) (equation 3.2).

Khurana worked with the magnetic dipole coordinate system where the
current sheet is initially aligned with the dipole equator up to \( \rho \approx 30 \, R_J \) but
then departs from it due to hinging towards the Jovigraphic equator. But this
study is restricted to data obtained from low latitudes on the night side of
Jupiter.

Khurana reported that the field-aligned currents are present mainly in
the plasma sheet boundary layers just above and below the current sheet.
The total azimuthal currents flowing in Pioneer 10, Voyager 1 and Voyager 2
are \( 13 \times 10^8 \) amp, \( 9 \times 10^8 \) amp respectively. Within the radial distance of 5
and 50 \( R_J \), the total azimuthal current flowing for Voyager 1 is \( 5 \times 10^8 \) amp
as obtained in the model of Connerney et al. (1981). Fig. 3.2 shows a
Fig. 3.2 A comparative study of the external field $\text{Knee}$ as derived from Voyager-1 model of Khurana (1997) and those derived from the Connerney et al. (1981) model. The distance $Z(R_f)$ of the field lines from the dipole equator is a function of radial distance $\rho(R_f)$. 
comparison of field lines as derived from Khurana model (1997) of external field in the inner-middle magnetosphere with those derived from the model of Connerney et al. (1981). To represent the external magnetic fields though the two models have different approaches the shape of the magnetic field lines exhibit a very similar nature in both the models

To remove the singularities in the model proposed by Goertz et al. (1976) and taken into consideration of the Internal field model GSFC 06 spherical harmonic model Khurana (1997) proposed modified form of Euler potentials as-

The modified model of Khurana (1997) was constructed considering the dawn sector data and it is expected that this model can fit well in that sector of the magnetosphere. Fig.3.3 represents a comparison between the models of Goertz et al (1976), Connerney et al (1981) and Khurana et al. (1997) with the data from Galileo’s G2 inbound orbit in the dawn sector.

The VIP4 model is particularly effective for interpretation of polar emissions, e.g., identification of emission associated with satellite flux tubes or identification of source regions in the distant magnetosphere corresponding to auroral emissions

To search for a unique model to interpret field and plasma observations of Jovian magnetosphere(Fig 3.4) by Galileo spacecraft Khurana (2003) proposed a new model named JIMO model ( Jupiter Icy Moon Orbiter) in view to define the changing magnetic field in the rest frames of the icy satellites for the JIMO mission Due to inadequate data coverage previous models are not equipped to explain the different intricate features of the magnetosphere. The recent model of Khurana (2003) considers observations from all of the six spacecraft (P10 &11, V1&2, Ulysses, and Galileo) that have traveled through Jovian magnetosphere The model incorporates VIP4 model, new modules for ring
Figure 3.3 A comparison of the observed field from Galileo’s G2 inbound orbit (solid lines) with the field calculated from the models.  
- Connerney et al. (open circles),  
- Gertz et al. (dashed lines) and  
- Khurana (solid circles).  
Notice that the scales in the three panels are different.  
(adapted from Khurana et al., 2003)
Fig. 3.4 A schematic of Jupiter's magnetosphere: (top) the noon-midnight meridian and (bottom) the equatorial cross-section (adapted from Khurana et al., 2003).
and magnetotail currents and shielding fields from an axially symmetric magnetopause. The current sheet model incorporates the delay and hinging of the current sheet observed at large distances. As the current sheet is flapping with Jovian rotation they consider thickness of the current sheet as a sinusoidal function of local time to incorporate the observed fluctuation of the thickness of the sheet e.g. thinnest in the dawn sector and thickest in the dusk sector. The model also includes the effect of the 3.2 degrees tilt between the Jovian orbital and equatorial planes.

The models so derived for the Jovian magnetosphere can be used for the following three main aspects:

(i) To study particle dynamics e.g. plasma diffusion in and out of the radiation belts, bounce and drift of plasma, changes in pitch angle distribution of plasma from convection etc.

(ii) To study magnetospheric dynamics like magnetic storms, in charge instabilities, generation and propagation of radio waves etc., and

(iii) For mapping field lines between the ionosphere and the magnetosphere particularly for investigating origin of aurorae, convection electric fields imposed upon the ionosphere, the proper interpretation of the generation and propagation of radio emission etc.

The modelling of magnetic field in the Jovian magnetosphere demands severe challenges. The magnetic field strength in the vast magnetosphere of Jupiter varies from \( \approx 10^6 \) nT inferred to be present in the ionosphere to less than 0.1 nT found in the night side current sheet beyond a radial distance of 100 \( R_J \). Thus the functional forms which work well in the high field of the inner magnetosphere is quite inadequate in the outer magnetosphere. Moreover, the structure of the Jovian magnetosphere is relatively more complex than similar structures in other magnetospheres. Refraction and other propagation effects are likely to play an important role in this region.
in any complete explanation of the phenomenon. In fact, our present knowledge of the near surface Jovian magnetic field is too imprecise for more detailed modeling and new techniques are required to model its complex field. However, it should be remembered that the overall configuration of the Jovian magnetosphere is largely affected by the prevailing solar wind conditions and mass loading by volcanoes of the satellite Io and so a single model of the current sheet for all the spacecraft encounters may not be appropriate.