Electromagnetic model of lithosphere-atmosphere-ionosphere coupling

Shufan ZHAO, Xuhui SHEN, Xuemin ZHANG

IES China Earthquake Administration

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Overview

1. Introduction

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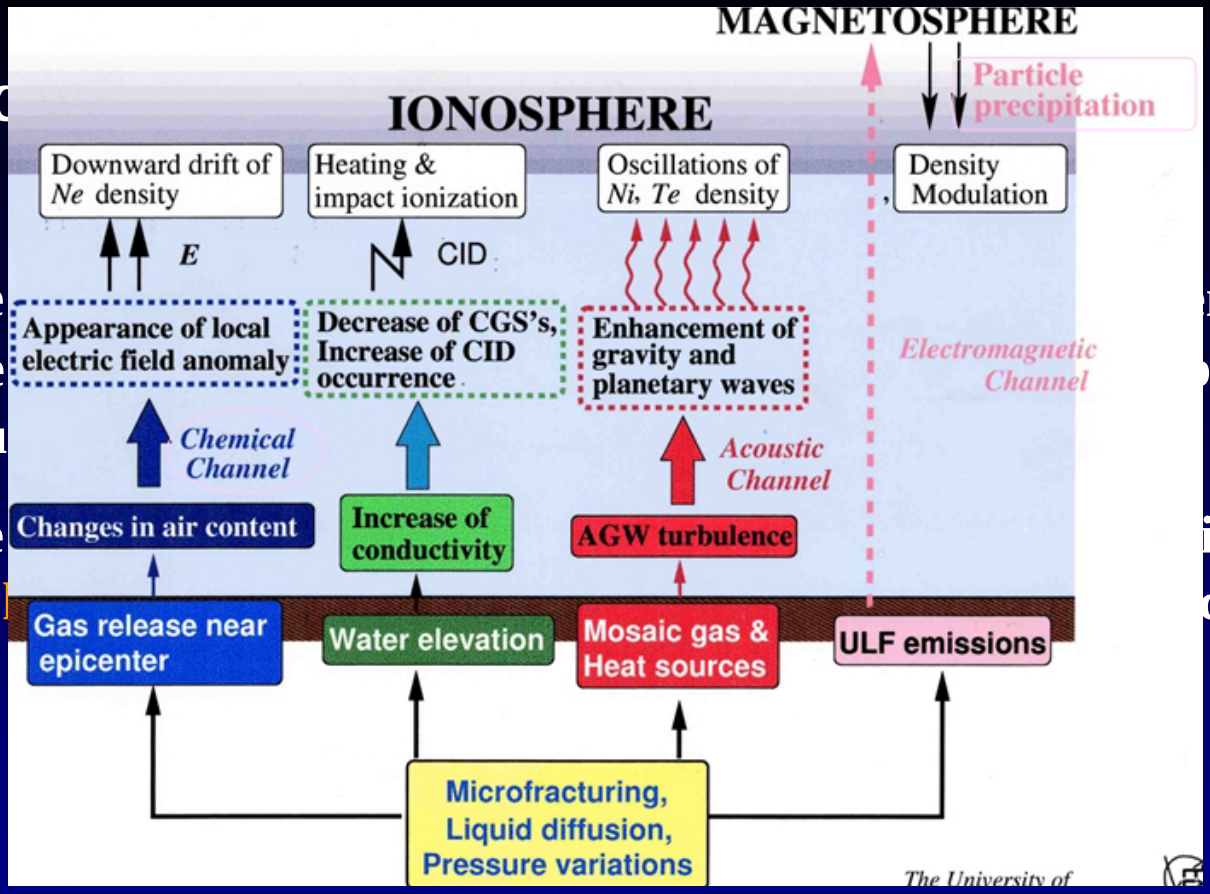
3. The full-wave model in the ionosphere and waveguide model blew the ionosphere—— The application of calculating the response at the altitude of DEMETER satellite excited by NWC

4. Summary and Discussion

1. Introduction

1.1 Bac



The mission, tremble panied with earthqu

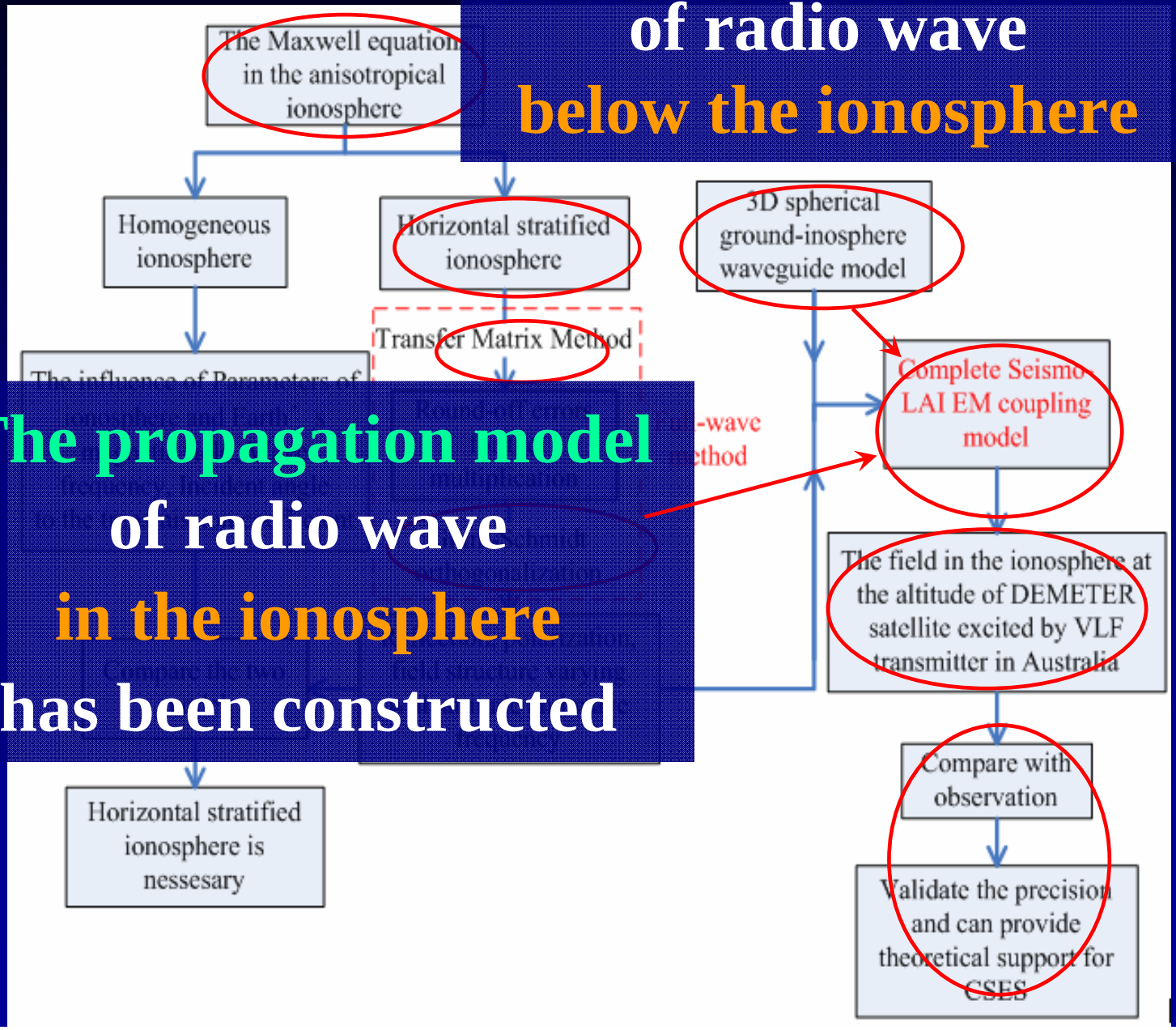
The is called Lithosp cerned.

The understanding to this coupling mechanism relied on experimental observation, theoretical analysis and also numerical simulation which is very important.

The numerical simulations of LAIC related with earthquake are mainly DC electric field simulation, Acoustic Gravity Wave and Electromagnetic wave coupling mechanism.

1.2 Train of thoughts

The propagation model of radio wave below the ionosphere

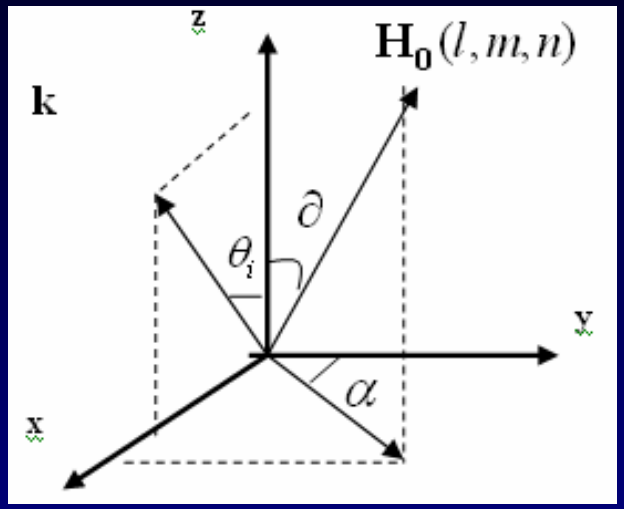


The propagation model of radio wave in the ionosphere has been constructed

2. The propagation model of radio waves in the ionosphere we have constructed ——

Full wave calculation of transionospheric propagation of VLF waves into horizontal stratified ionosphere

2.1 Coordinate used in the full wave calculation and the Maxwell equations in the ionosphere



$$\left.\begin{aligned} \nabla \times \mathbf{H} &= j\omega\varepsilon_0\left[\overline{\mathbf{I}} + \overline{\mathbf{M}}\right]\cdot \mathbf{E} \\ \nabla \times \mathbf{E} &= -j\omega\mu_0 \mathbf{H} \end{aligned}\right\} \qquad (1)$$

$$\overline{\mathbf{M}} = -\frac{X}{U(U^2 - y^2)}\begin{bmatrix} U^2 - l^2y^2 & inyU - lmy^2 & -imyU - lny^2 \\ -inyU - lmy^2 & U^2 - m^2y^2 & ilyU - mny^2 \\ imyU - lny_\alpha^2 & -ilyU - mny_\alpha^2 & U^2 - n^2y^2 \end{bmatrix} \qquad (2)$$

M is the electric susceptibility matrix of the ionosphere, which is decided by the geomagnetic field and ionospheric parameters including electron density and collision frequency.

2.2 Differential expressions of Maxwell equations in the horizontal stratified ionosphere

Eliminating the Ez and Hz components from (1) using Snell's law, the differential expressions is obtained as below

$$\frac{d\mathbf{V}}{dz} = -jk_0\overline{\mathbf{T}}\cdot\mathbf{V} \qquad (3)$$

$$\mathbf{V} = \left[E_x\,,-E_y\,,\ \eta_0 H_x\,,\ \eta_0 H_y\right]^T$$

State vector

$$\overline{\mathbf{T}} = \begin{bmatrix} -\dfrac{SM_{zx}}{1+M_{zz}} & \dfrac{SM_{zy}}{1+M_{zz}} & 0 & \dfrac{C^2+M_{zz}}{1+M_{zz}} \\ 0 & 0 & 1 & 0 \\ \dfrac{M_{yz}M_{zx}}{1+M_{zz}} - M_{yx} & C^2 + M_{yy} - \dfrac{M_{yz}M_{zy}}{1+M_{zz}} & 0 & \dfrac{SM_{yz}}{1+M_{zz}} \\ 1+M_{xx} - \dfrac{M_{xz}M_{zx}}{1+M_{zz}} & \dfrac{M_{xz}M_{zy}}{1+M_{zz}} - M_{xy} & 0 & -\dfrac{SM_{xz}}{1+M_{zz}} \end{bmatrix}$$

State matrix

Which is depended on the electric susceptibility matrix M and incident angle of this layer.

2.3 Elementary solution of differential equations

- **Differential equations (3) is equivalent to algebraic equations**

$$(\overline{\mathbf{T}} - \lambda \mathbf{I})\mathbf{V} = 0 \qquad (4)$$

- **Solving(4) is substantially solving the eigenvalues λ and eigenvectors V of the state matrix T**

- **The condition that V have nonsingular solution is the determinant of the coefficients of equation (4) equals to zero** $\det(\overline{\mathbf{T}} - \lambda \mathbf{I})\mathbf{V} = 0$

$$b_4\lambda^4 + b_3\lambda^3 + b_2\lambda^2 + b_1\lambda^1 + b_0 = 0 \qquad (5)$$

Booker quartic complex coefficient equation

Four eigenvalues represent the refraction index of the left and right handed polarized upgoing and downgoing waves; the corresponding eigenvectors represent the amplitude of the four characteristic waves

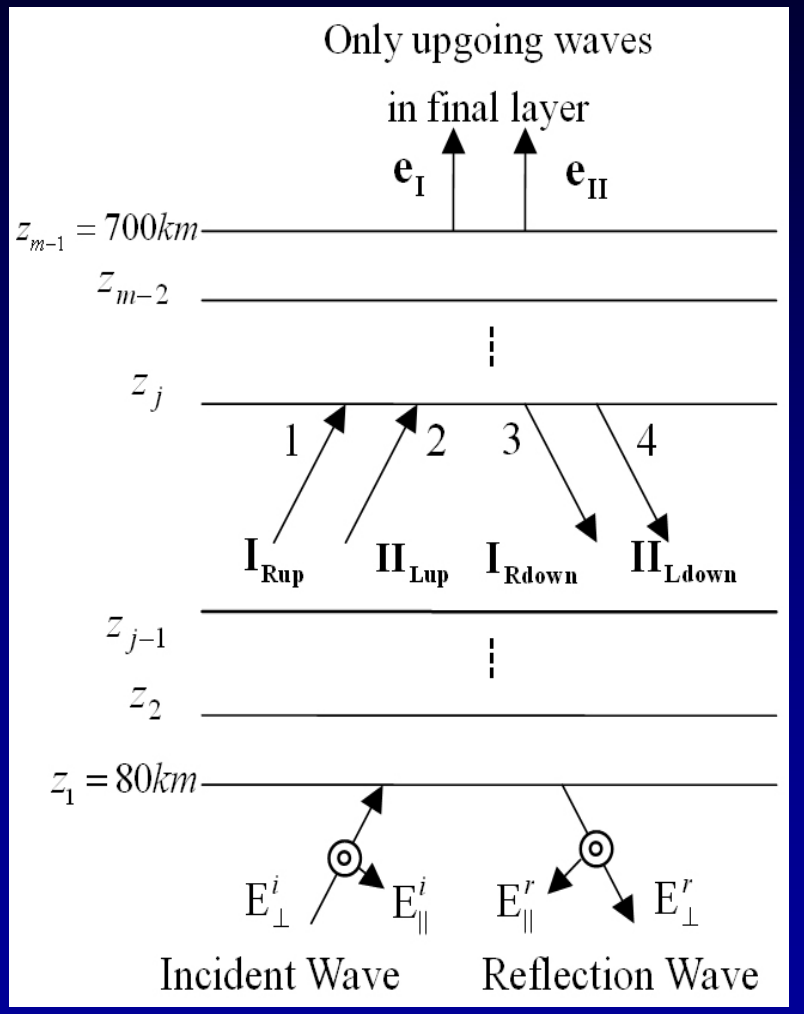
2.4 Full-Wave Method：Combination of transfer matrix method and Gram-Schmidt orthogonalization：

Transfer matrix method

The fields at the bottom of the ionosphere z = z_1 are represented by the fields at the top of the ionosphere z = z_{m-1} by the power series expansion of the wave fields

$$\mathbf{V}(z_1) = A\prod_{s=2}^{m-1}\overline{\mathbf{K}}_s\mathbf{V}_1(z_{m-1}) + B\prod_{s=2}^{m-1}\overline{\mathbf{K}}_s\mathbf{V}_2(z_{m-1}) \quad (6)$$

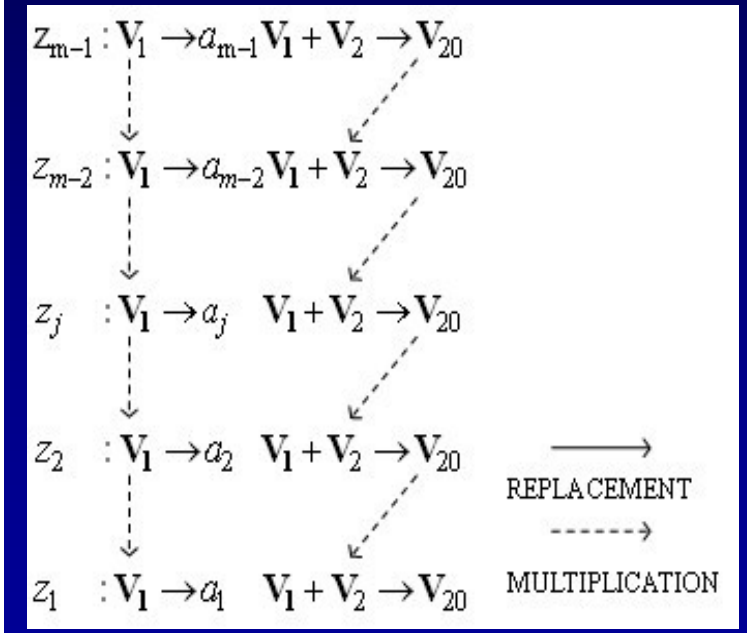
Matrix Ks indicates the transfer matrix of each layer which is depended on the eigenvalues and the height of each layer



Wave structure within horizontal stratified ionosphere

2.4 Full-Wave Method：Combination of transfer matrix method and Gram-Schmidt orthogonalization：

When the medium is lossy, the round-off errors will occur which is due to the finite word size of the computer. To avoid it, Gram-Schmidt orthogonalizing process is used downward.



$$\mathbf{V}(z_j) = A\mathbf{V}_1(z_j) + B\mathbf{V}_{2t}(z_j),\ j = 1, \ldots, n \qquad (7)$$

$$a = -\mathbf{V}_1^* \cdot \mathbf{V}_2 \big/ \mathbf{V}_1^* \cdot \mathbf{V}_1$$

Then the wave field at each altitude is represented as equation (7). Where coefficients A and B are determined by applying the boundary conditions

2.5 Parameters for the Full-Wave Calculation

☞ **Geomagnetic field Parameters**

□IGRF model□

Inclination -55°

Declination 0.1°

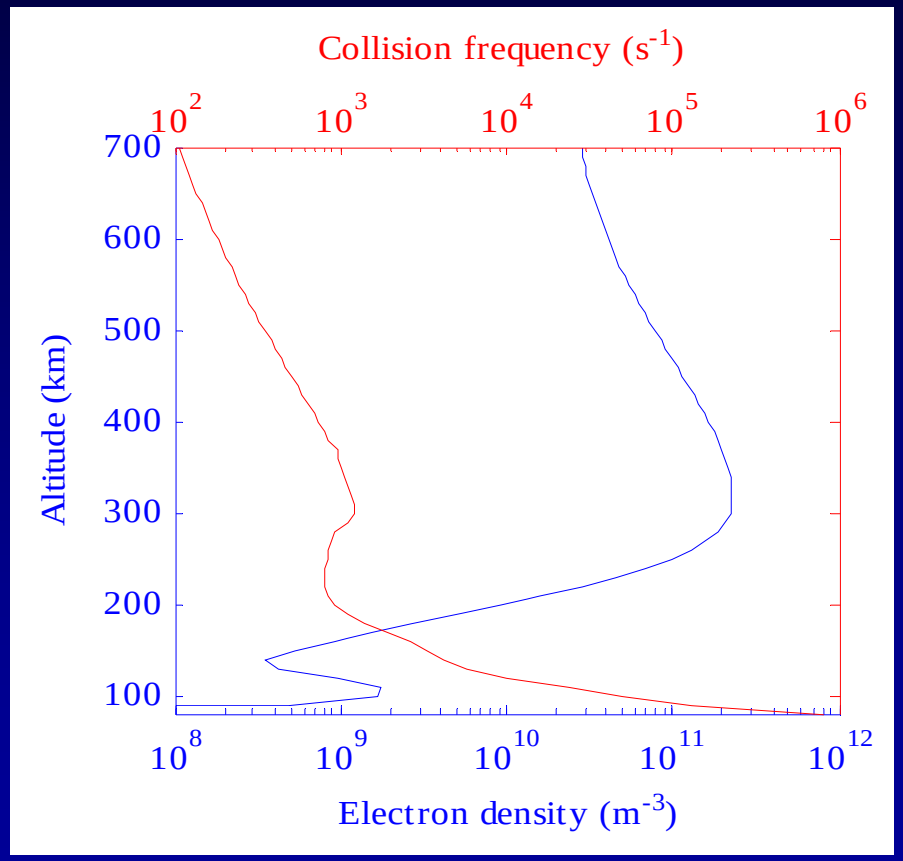
Gyrofrequency 1.2MHz

☞ **Input unit**

Output is standard by unit

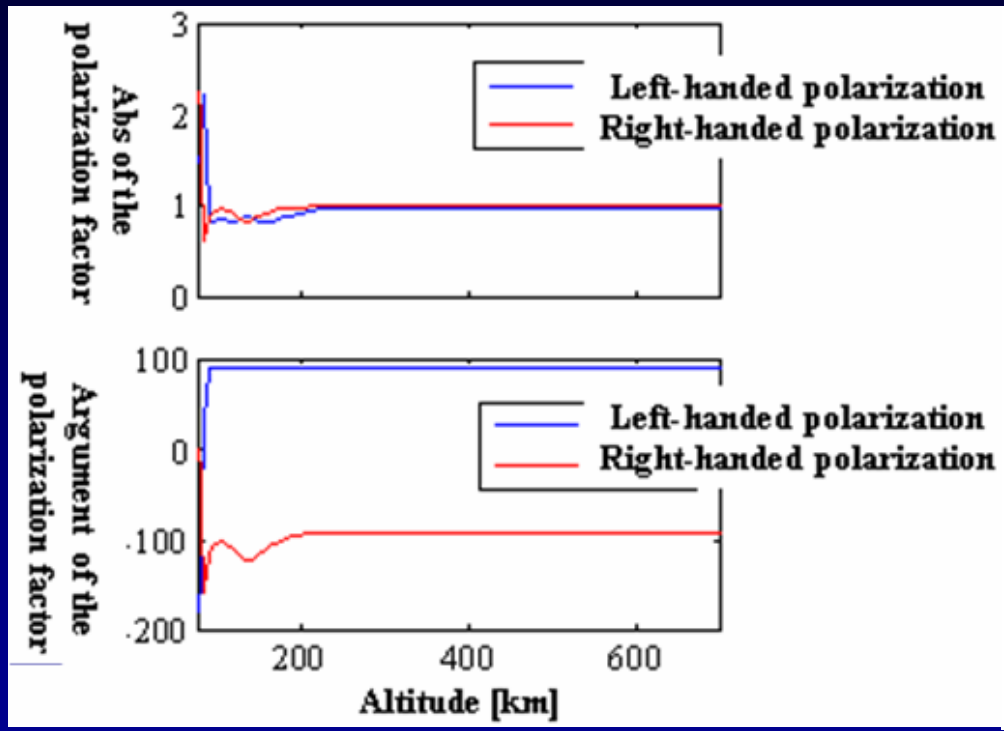
☞ **Ionospheric Parameters**

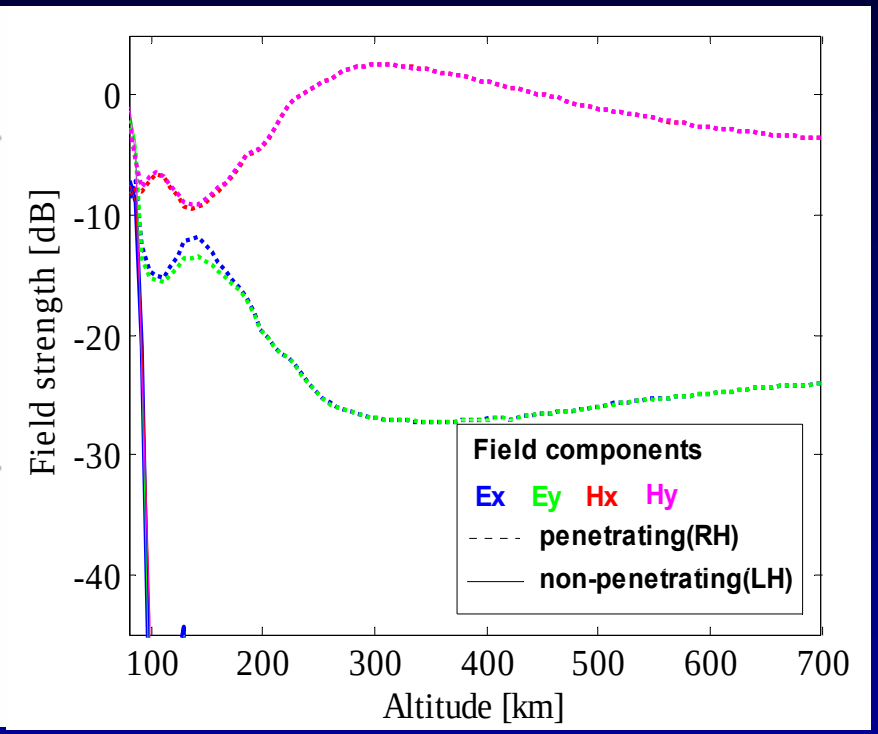
□IRI model □



2.6 Calculation Results

Figure.1 Horizontal wave field components of the characteristic waves vary with altitude in the ionosphere (19.8kHz for example)

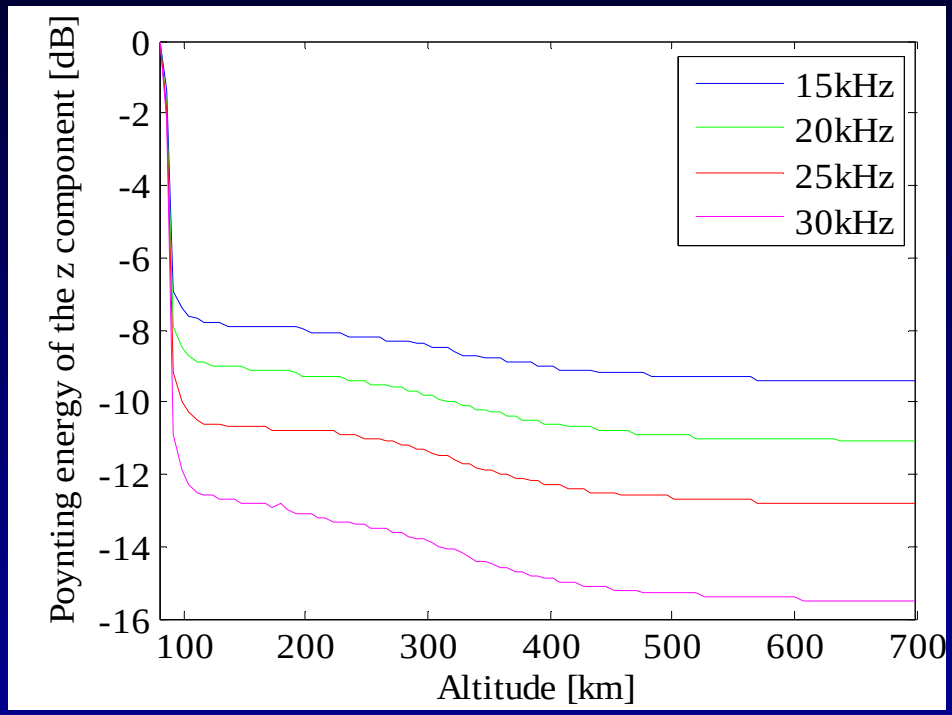




□1□ The characteristic waves in the ionosphere when arbitrarily polarized VLF wave incident into the ionosphere with arbitrarily incident angle will occur polarization reverse and turn to stable Left- and Right-handed circular polarization

□2□ Left-handed polarization wave experiences the most severe attenuation in the D-region of the ionosphere, so it's also called non-penetrating mode. Right-handed polarization wave is also called penetrating mode in the ionosphere

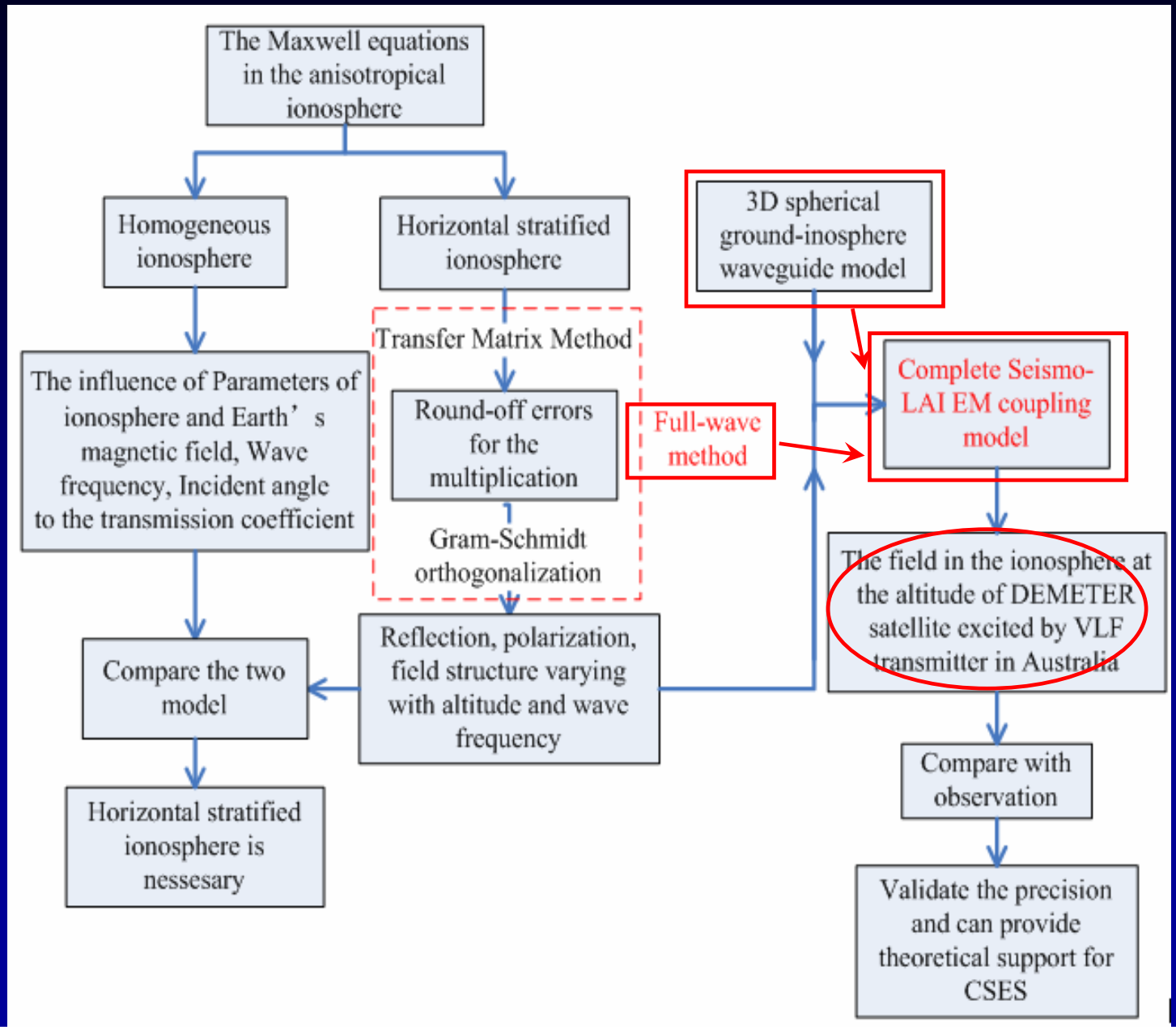
Figure.2 Z component of Poynting flux vary with altitude at different frequency at VLF band



□3□The attenuation is very small for the waves have crossed the D-region

□4□The poynting flux decreases with the increase of wave frequency, which means the lower frequency signal related with earthquake is easier for the satellite to receive it

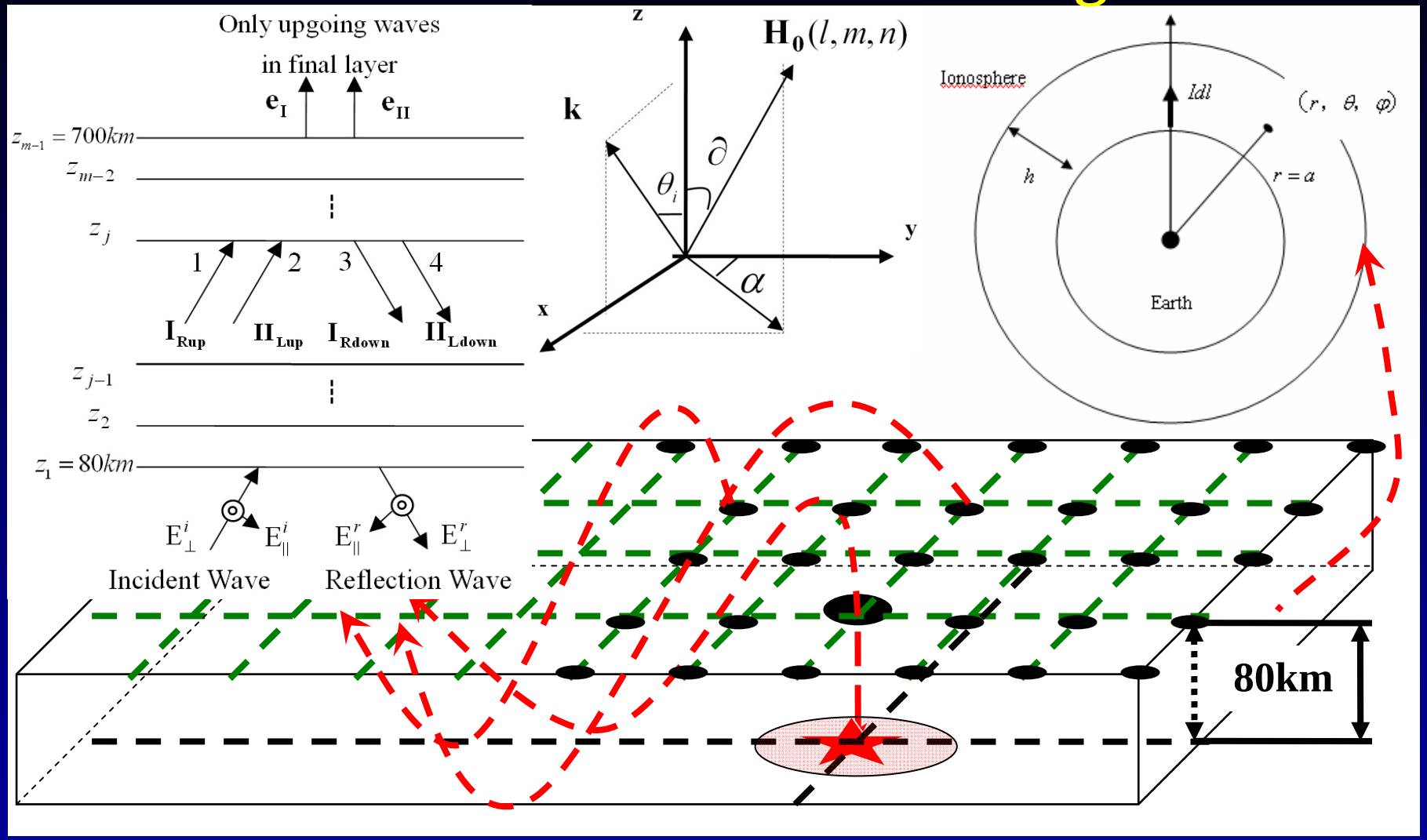
Train of thoughts



3. A EM LAIC model of combing the full-wave model in the ionosphere and waveguide model blew the ionosphere——

The application of calculating the response at the altitude of DEMETER satellite excited by NWC

3.1 Research Method and Model Design



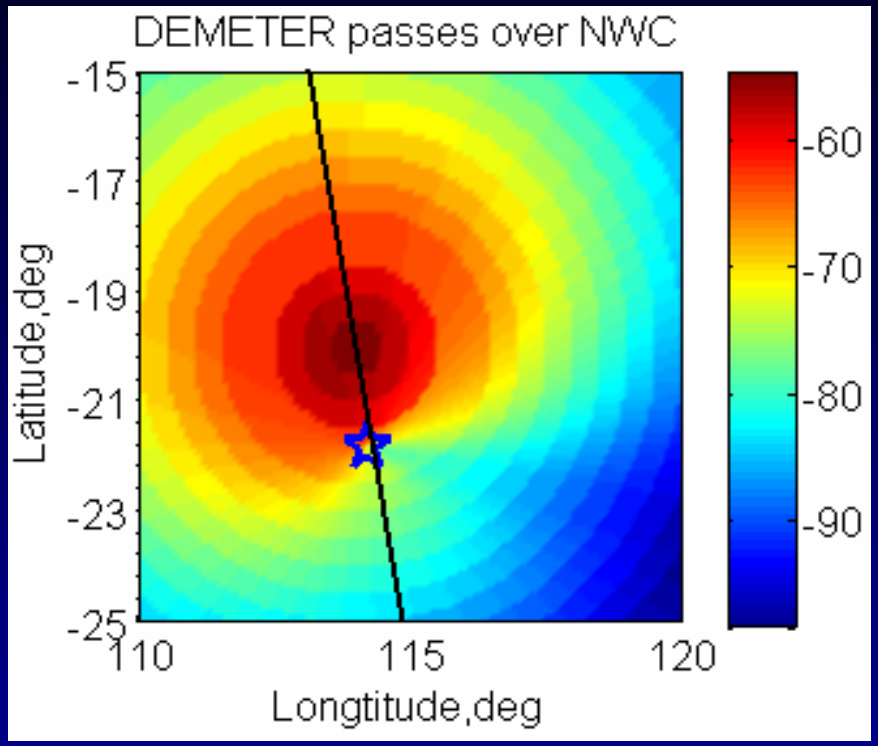
80km is assumed to be the interface of the waveguide

Assuming that an antenna is placed in vertical electric dipole

Above 80km, at each grid node as we divided before, full-wave method is used to calculate the electromagnetic field distribution above each node numerically, with the waveguide calculation result to be the boundary condition.

Below 80km, we use Earth-Ionosphere waveguide model to calculate the nodal field at the lower boundary of the ionosphere

Figure.3 Horizontal mapping of the Poynting flux excited by NWC at altitude of DEMETER satellite 660km



□5□The response in the ionosphere caused by ground VLF transmitter is concentric circles; the circles is asymmetrical from north to the south; multi-mode interferometer can de clearly seen; the center of these circles has a latitudinal displacement to the equator, the size of the displacement is due to the latitude of the transmitter.

4 Conclusions & Discussion

a. **The frequency is lower, the poynting energy flux is greater, which means the low frequency electromagnetic wave radiated from earthquakes can be received by the satellite.**

b. **The transmission of the radio wave increases as the inclination, which indicates the probability to observe the ionospheric EM abnormal may be greater at the higher latitude than that at the lower latitude.**

c. Not all kind of low frequency wave can penetrate into the ionosphere. It is easier for the vertical polarized low frequency wave to penetrate, and the horizontal polarized wave is reflected again and again in the waveguide.

d. The response in the ionosphere caused by ground VLF transmitter is concentric circles; the center of these circles has a latitudinal displacement along magnetic force line to the equator. The amplitude of the displacement is due to the latitude of the transmitter which may provide preliminarily theoretical base for finding the location of the earthquakes.


Thanks for your attention