Content(7)

中科院上海天文台

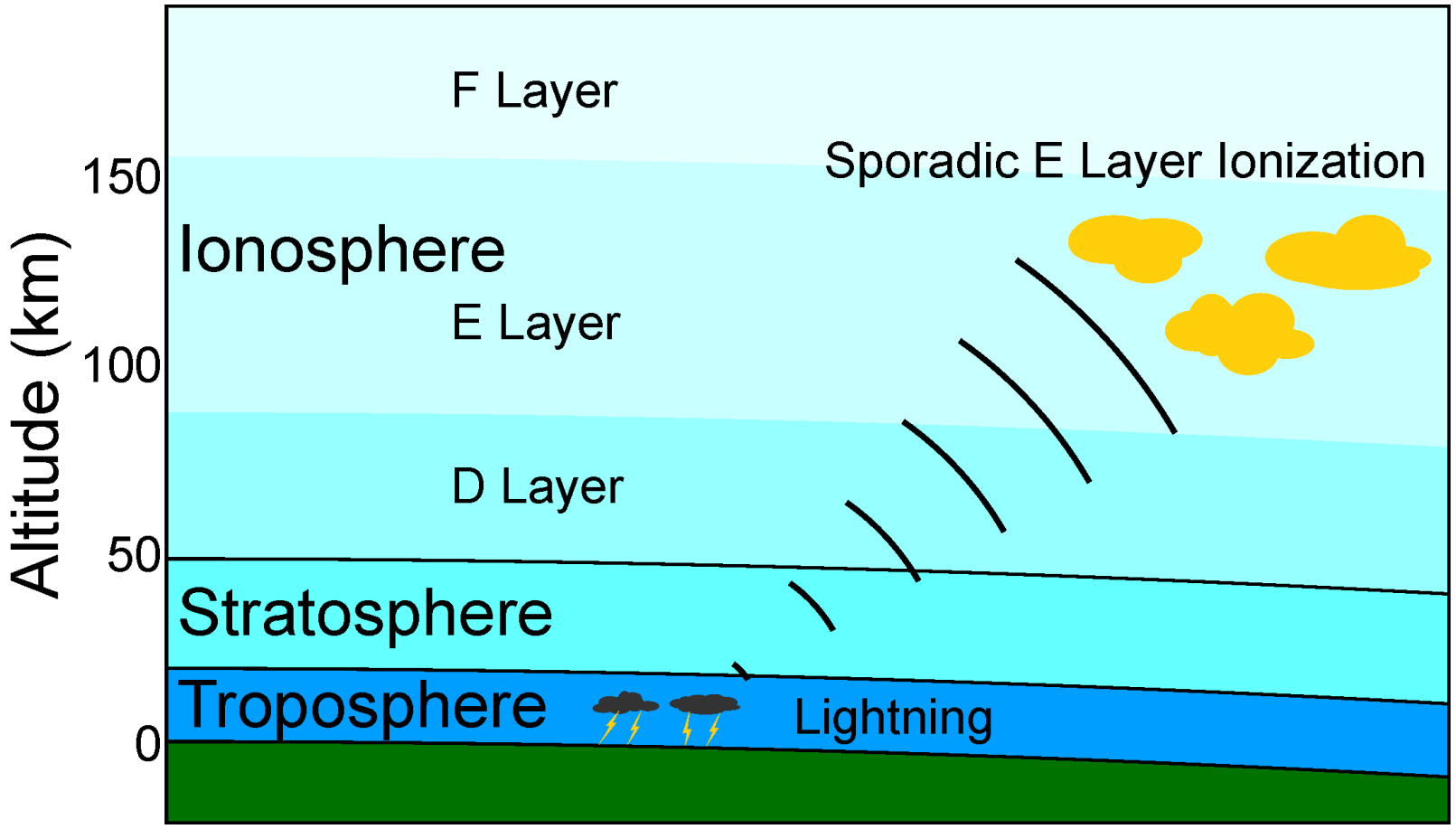
- 精密定轨定位改正模型及消除方法

练习（编程）：基于bancroft算法的伪距定位

考试题：
1、测站、卫星pco、pcv参数的概念以及估计方法。
2、广播星历电离层模型的拟合原理、主要过程

上一讲考试题：
1、ITRF框架定义、转换的原理以及个参数综合的方法；
2、广播星历轨道拟合的原理、主要过程；

中性大气改正


F Layer
Sporadic E Layer Ionization
Ionosphere
E Layer
D Layer
Stratosphere
Troposphere
Lightning
Altitude (km)
150
100
50
0

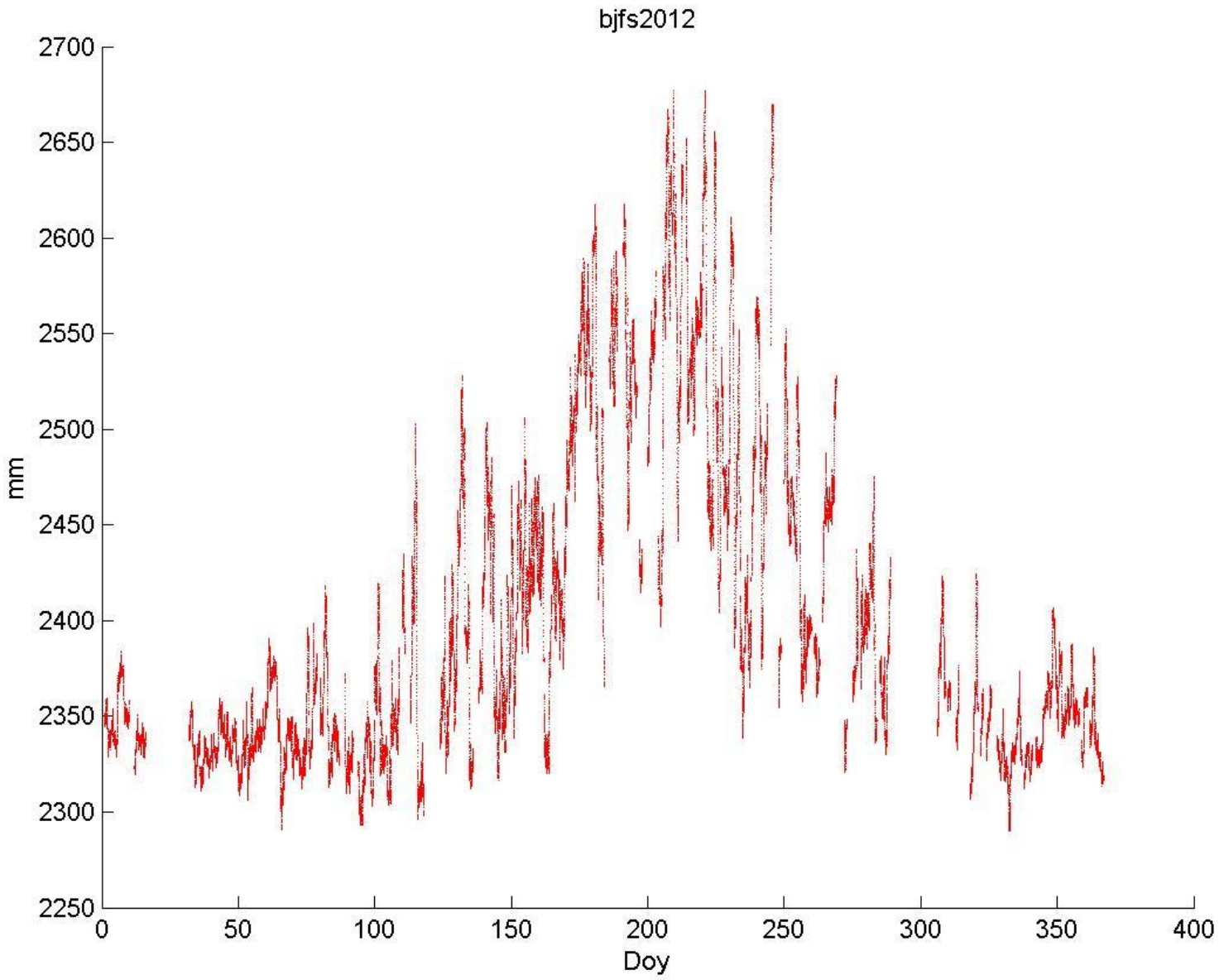
对流层改正

$$\Delta L(\varepsilon) = \Delta L_h^z \cdot mf_h(\varepsilon) + \Delta L_w^z \cdot mf_w(\varepsilon)$$

$$m(\varepsilon) = \frac{1+\dfrac{a_i}{1+\dfrac{b_i}{1+c_i}}}{\sin\varepsilon+\dfrac{a_i}{\sin\varepsilon+\dfrac{b_i}{\sin\varepsilon+c_i}}} + \mathrm{v}_i, (i = h, w)$$

$$P_m^j = \rho^j + c\delta - c\delta^j + \Delta L(\varepsilon) + \frac{1}{f_m^2} \cdot I^j + \Delta P_m^j$$

对流层改正



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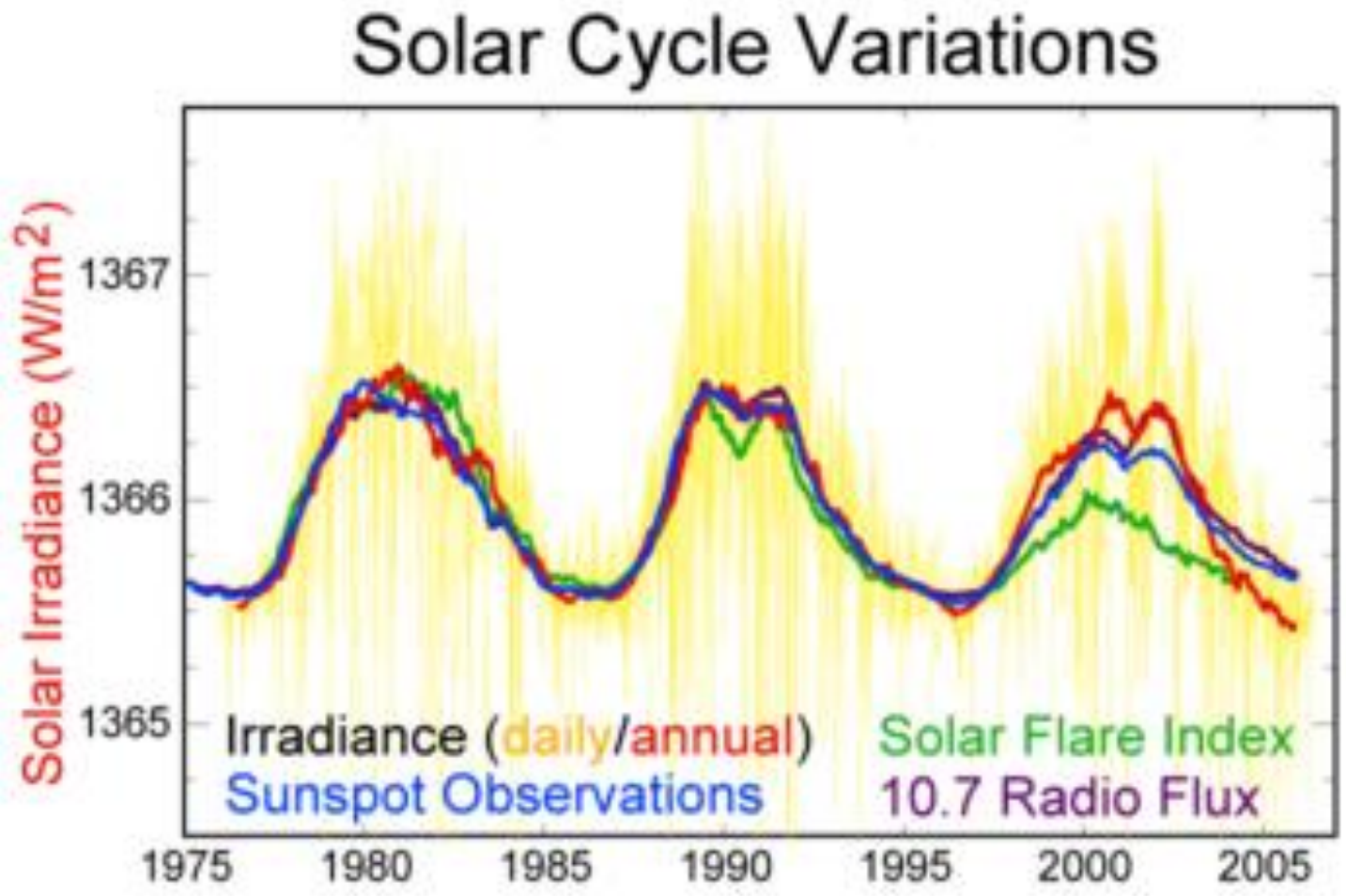
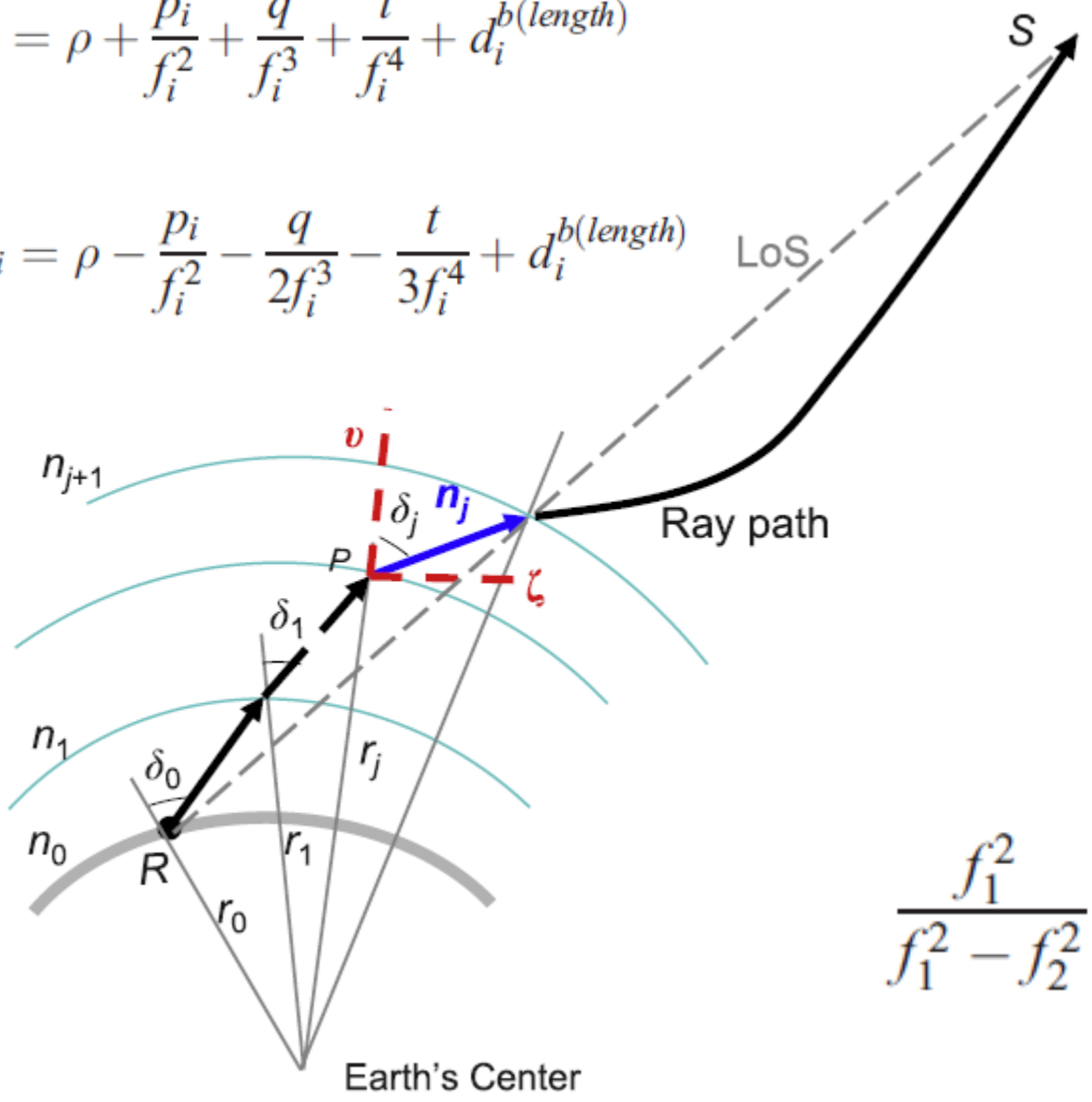
电离层改正


Solar Cycle Variations
Solar Irradiance (W/m2)
1367
1366
1365
Irradiance (daily/annual)
Sunspot Observations
Solar Flare Index
10.7 Radio Flux
1975
1980
1985
1990
1995
2000
2005

电离层改正

$$\Psi_i = \rho + \frac{p_i}{f_i^2} + \frac{q}{f_i^3} + \frac{t}{f_i^4} + d_i^{b(length)}$$

$$\Phi_i = \rho - \frac{p_i}{f_i^2} - \frac{q}{2f_i^3} - \frac{t}{3f_i^4} + d_i^{b(length)}$$



$$\frac{f_1^2}{f_1^2 - f_2^2}\Psi_1 - \frac{f_2^2}{f_1^2 - f_2^2}\Psi_2$$

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电离层改正

- 广播星历电离层改正模型

$$I_Z(t)=\begin{cases}A_1+A_2\cos\left[\dfrac{2\pi(t-A_3)}{A_4}\right], |t-A_3|<A_4/4\\ A_1, \text{t为其他值}\end{cases}$$

$$A_2=\begin{cases}\alpha_1+\alpha_2\varphi_M+\alpha_3\varphi_M^2+\alpha_4\varphi_M^3, & \text{当}A_2\geq 0\\ 0, \text{当}A_2<0\end{cases}$$

$$A_4=\begin{cases}\beta_1+\beta_2\varphi_M+\beta_3\varphi_M^2+\beta_4\varphi_M^3, & \text{当}A_4\geq 72000\\ 7200, \text{当}A_4<72000\end{cases}$$

电离层改正

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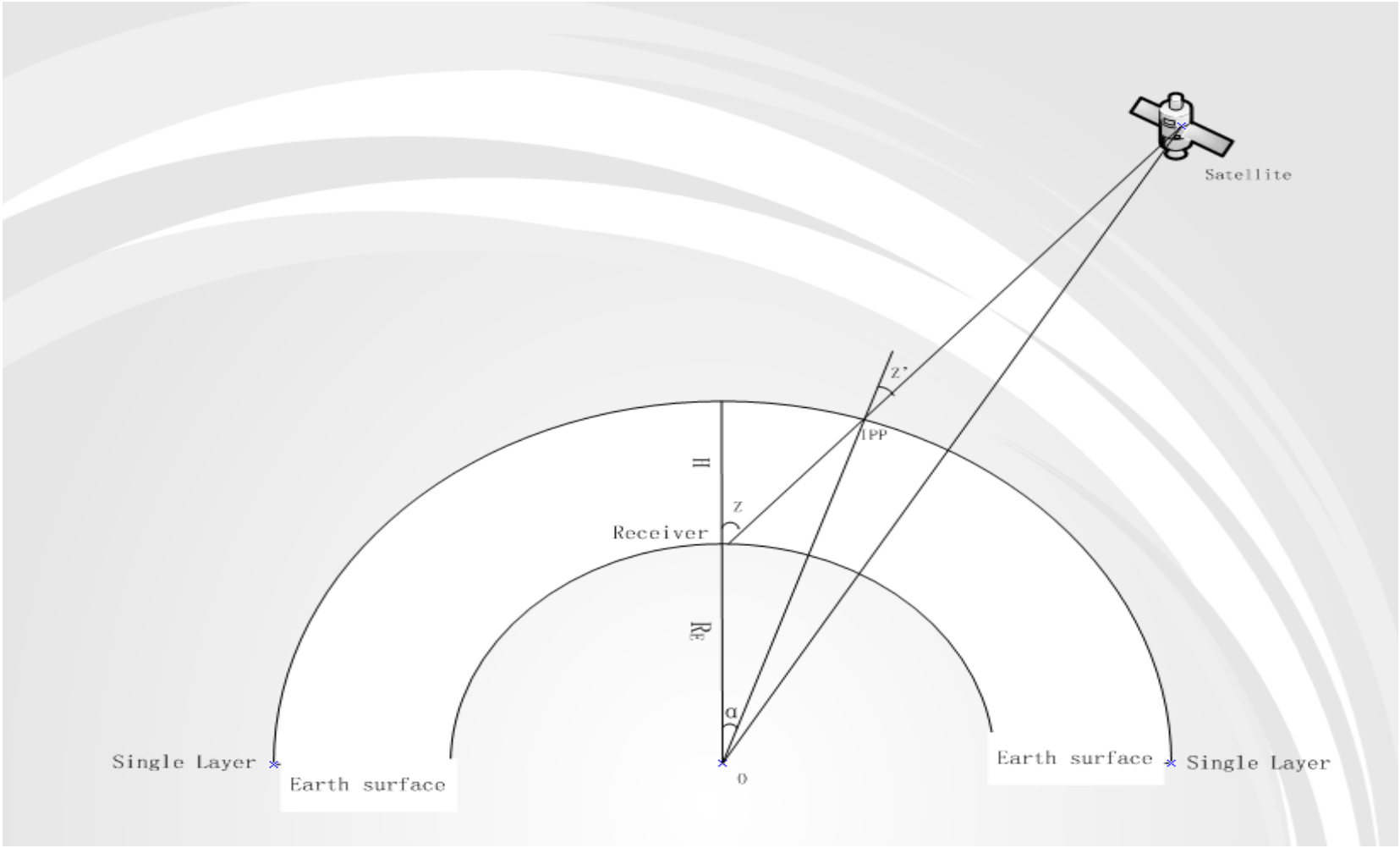
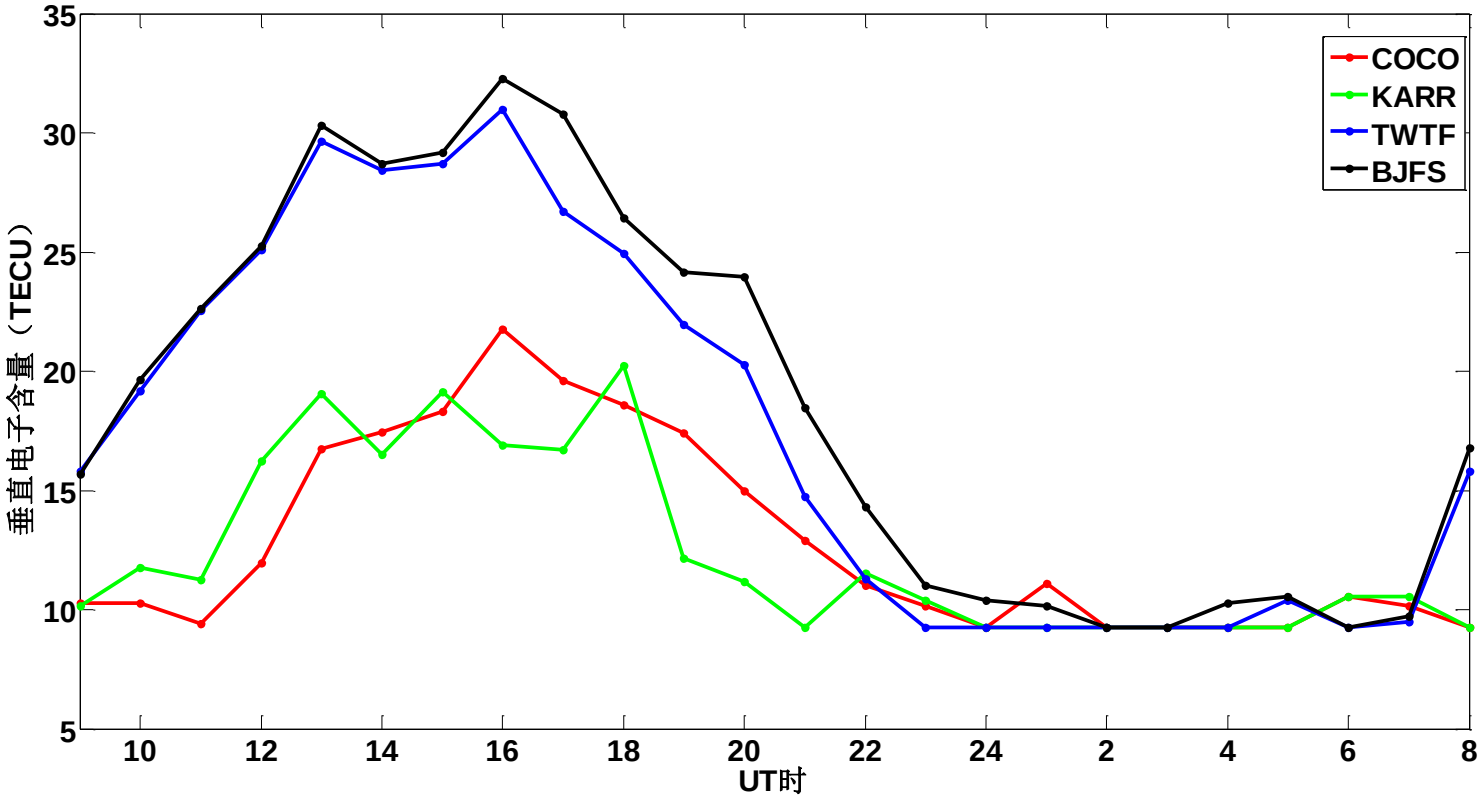
- 广播星历电离层改正模型



电离层改正

- 广播星历电离层改正模型



电离层改正

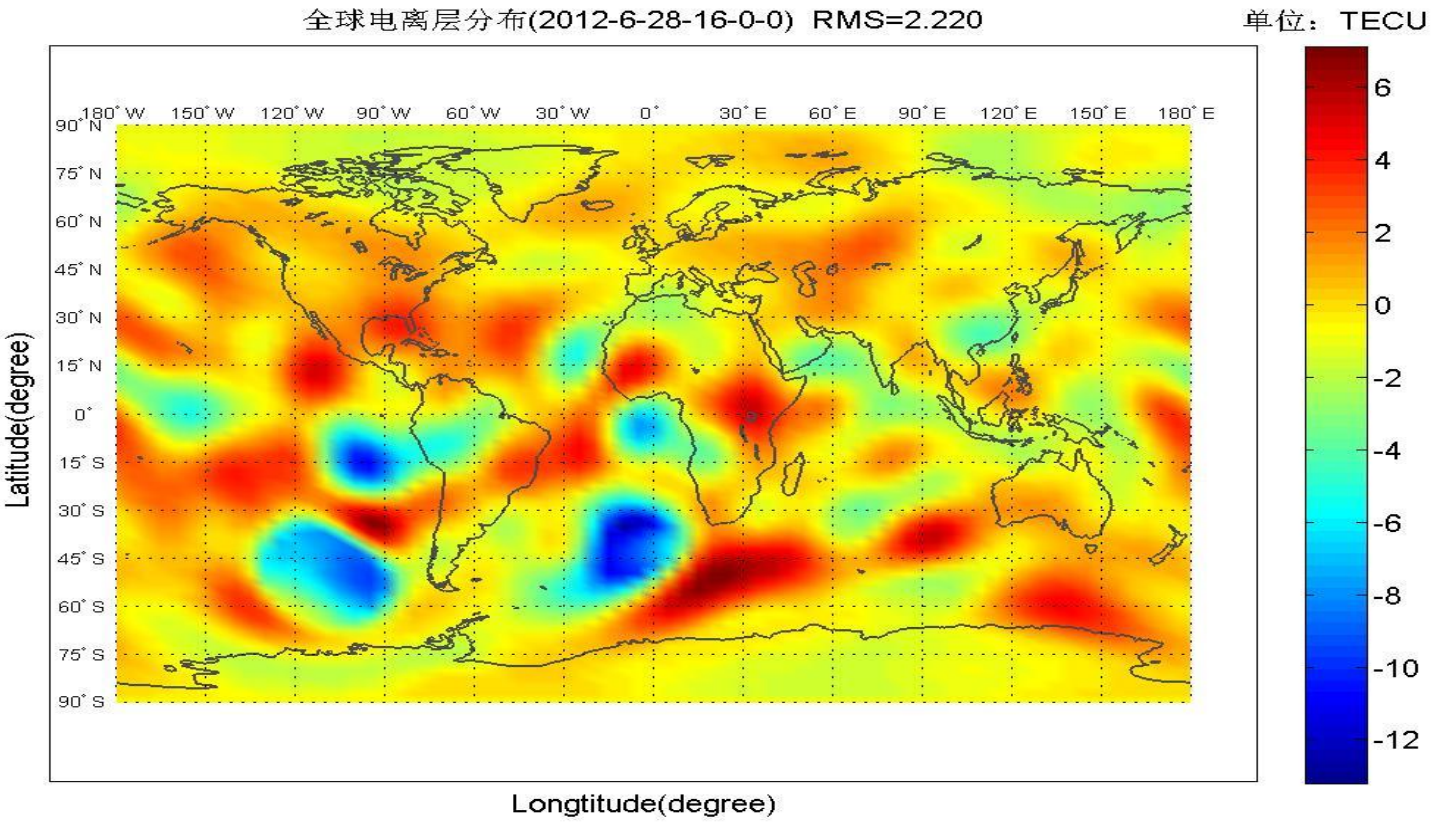
$$VTEC(\beta,s)=\sum_{n=0}^{n_{\max}}\sum_{m=0}^{n}\tilde{P}_{nm}(\sin\beta)(a_{nm}\cos ms+b_{nm}\sin ms)$$

$\tilde{P}_{nm}$ 为n阶m次归一化缔合勒让德函数

$$\tilde{P}_{nm}=\Lambda(n,m)P_{nm}$$

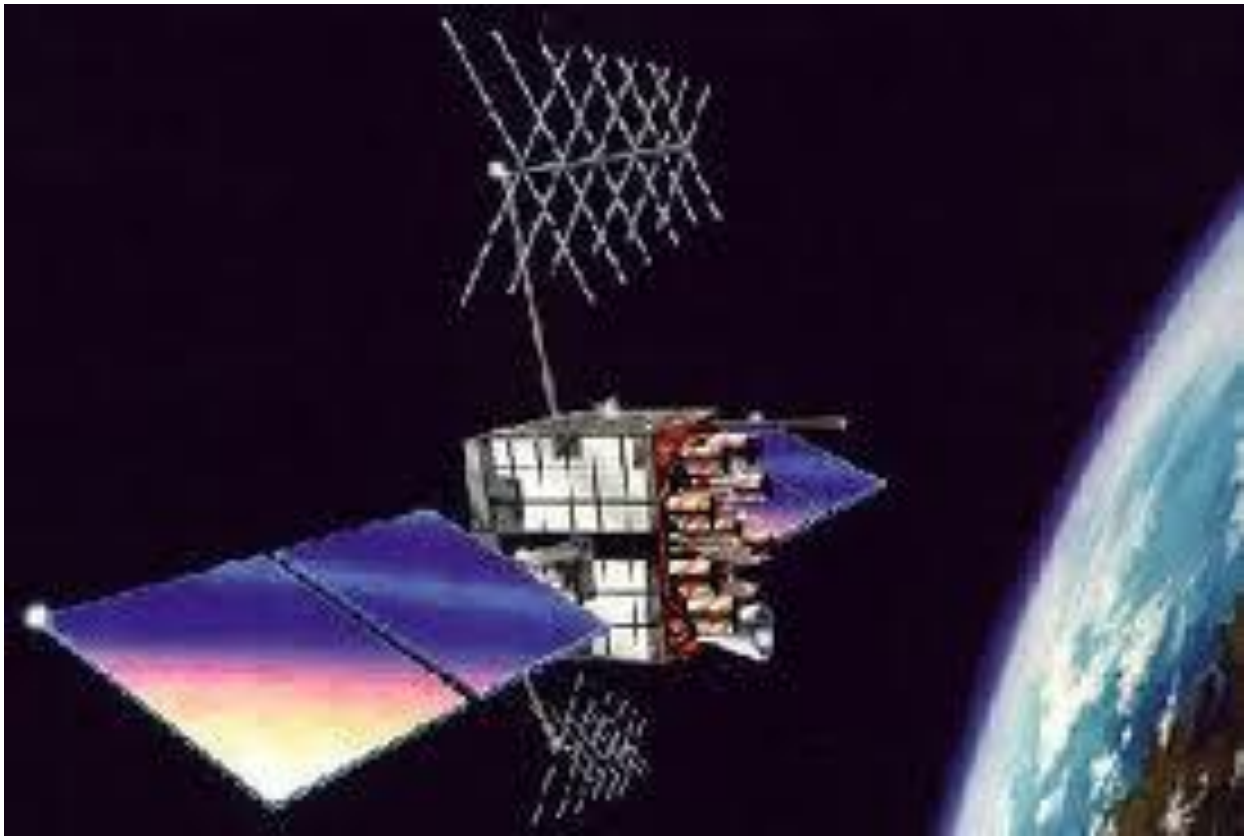
$$\Lambda(n,m)=\sqrt{\frac{(n-m)!(2n+1)(2-\delta_{0m})}{(n+m)!}}$$

电离层改正

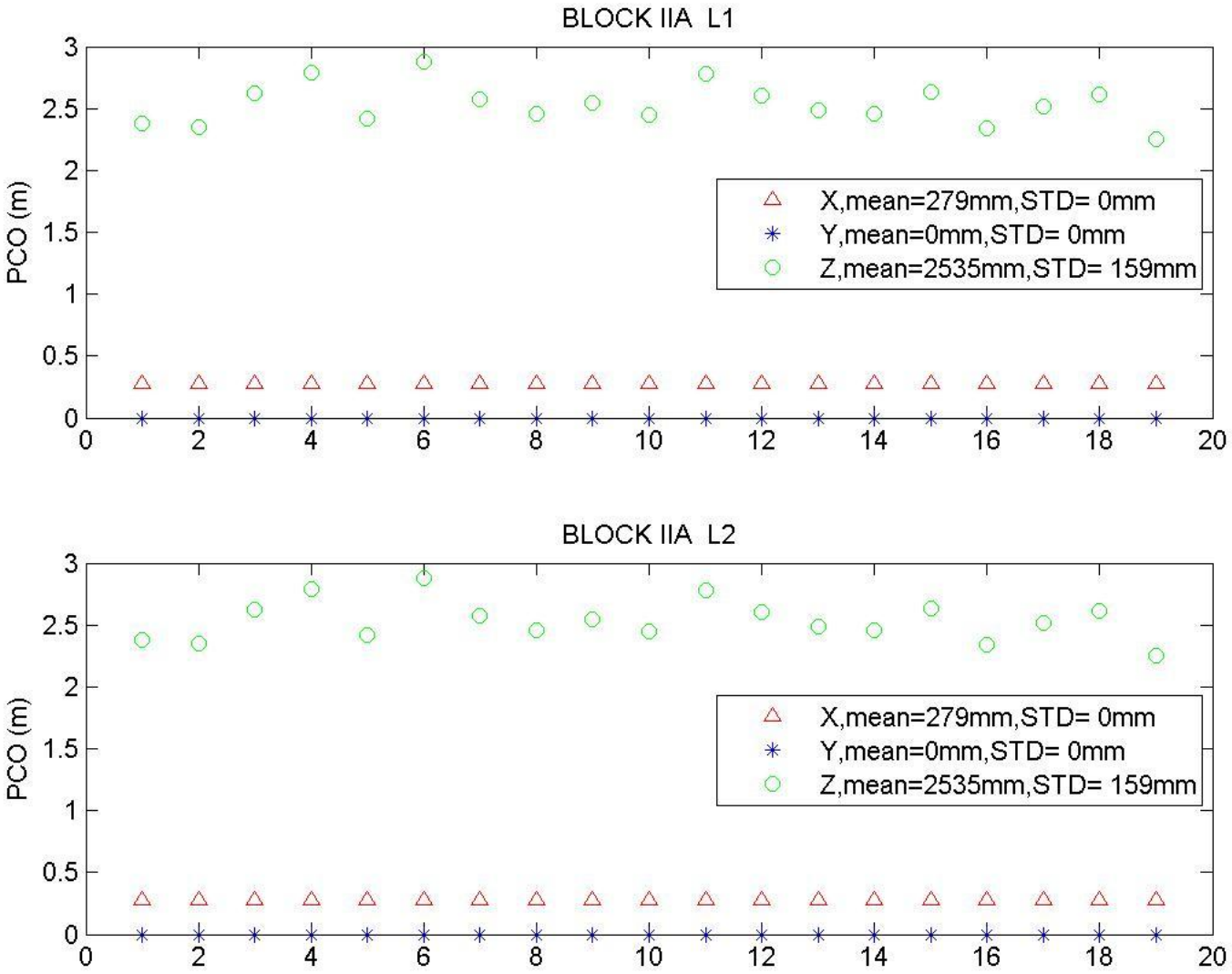


中科院上海天文台

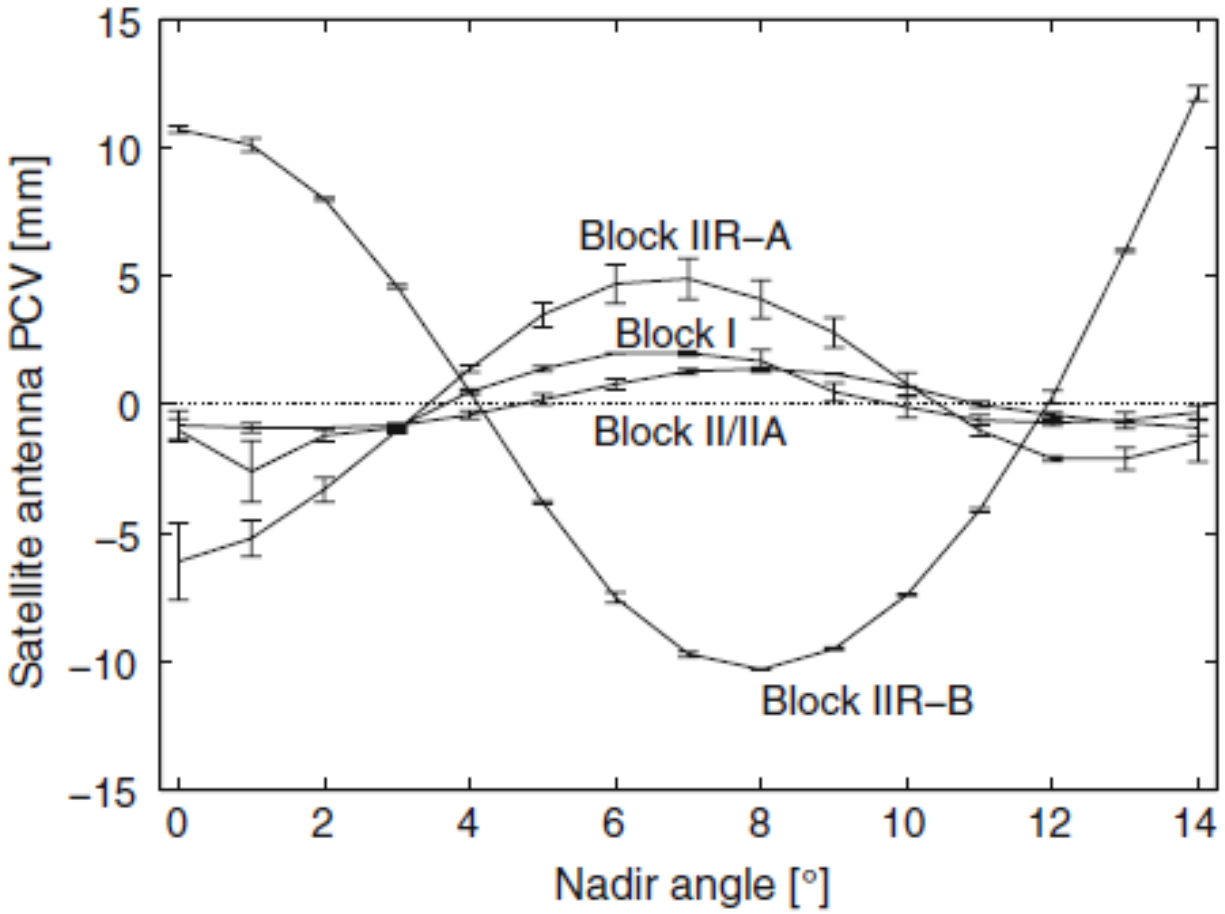
相位中心改正



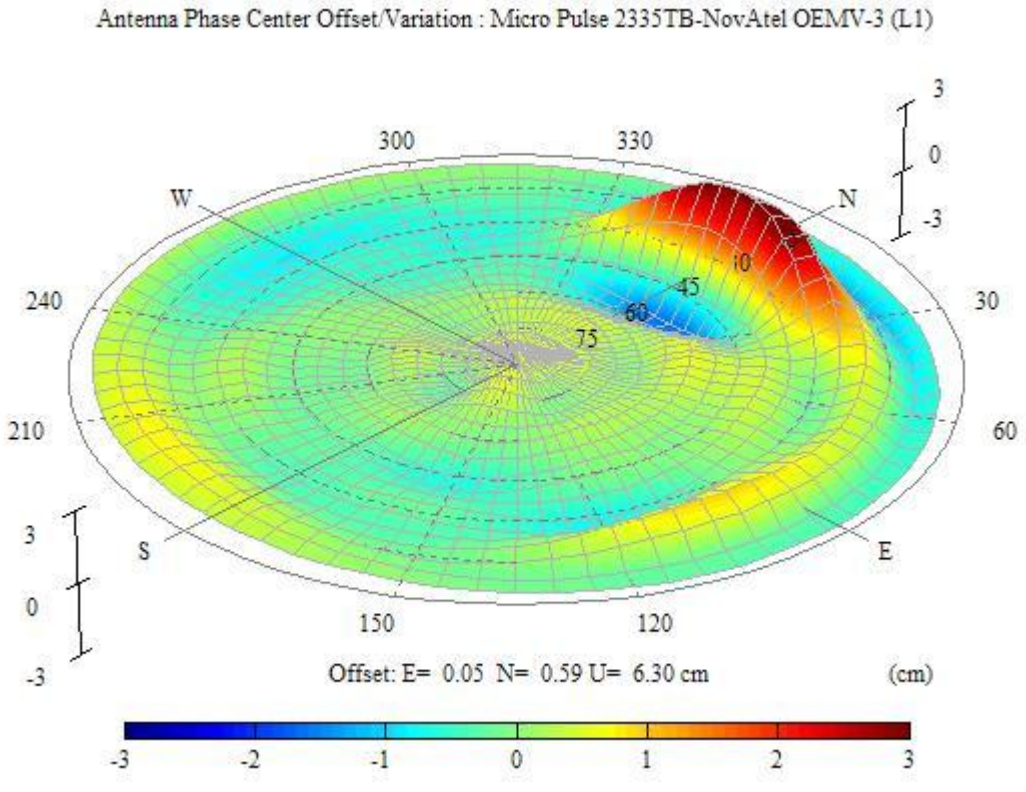
相位中心改正


BLOCK IIA L1
PCO (m)
X,mean=279mm,STD= 0mm
Y,mean=0mm,STD= 0mm
Z,mean=2535mm,STD= 159mm
BLOCK IIA L2
PCO (m)
X,mean=279mm,STD= 0mm
Y,mean=0mm,STD= 0mm
Z,mean=2535mm,STD= 159mm

相位中心改正


Satellite antenna PCV [mm]
15
10
5
0
−5
−10
−15
0
2
4
6
8
10
12
14
Nadir angle [°]
Block IIR–A
Block I
Block II/IIA
Block IIR–B

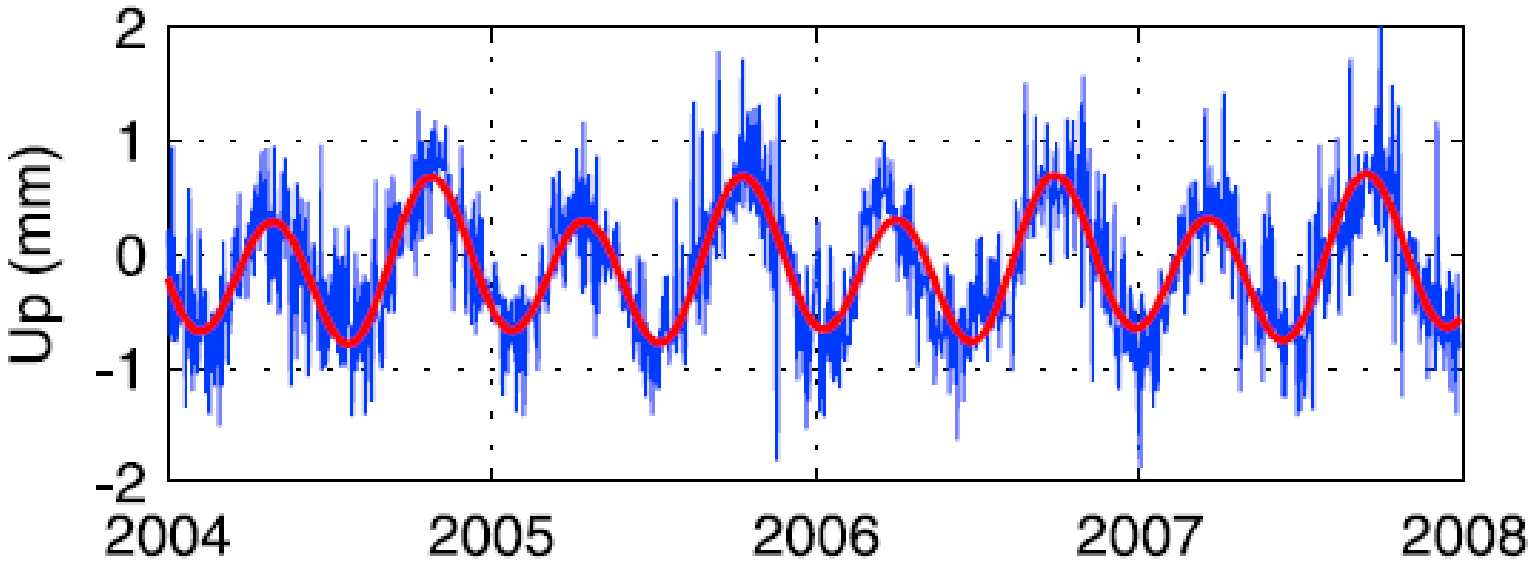
相位中心改正



中科院上海天文台

潮汐:固体潮、海潮、极潮、大气潮

$$\Delta R_{OC} = \sum_{i=1}^{N} \begin{pmatrix} A_i^r \cos\left(\omega_i t' + \phi_i - \delta_i^r\right) \\ A_i^{EW} \cos\left(\omega_i t' + \phi_i - \delta_i^r\right) \\ A_i^{NS} \cos\left(\omega_i t' + \phi_i - \delta_i^r\right) \end{pmatrix}$$



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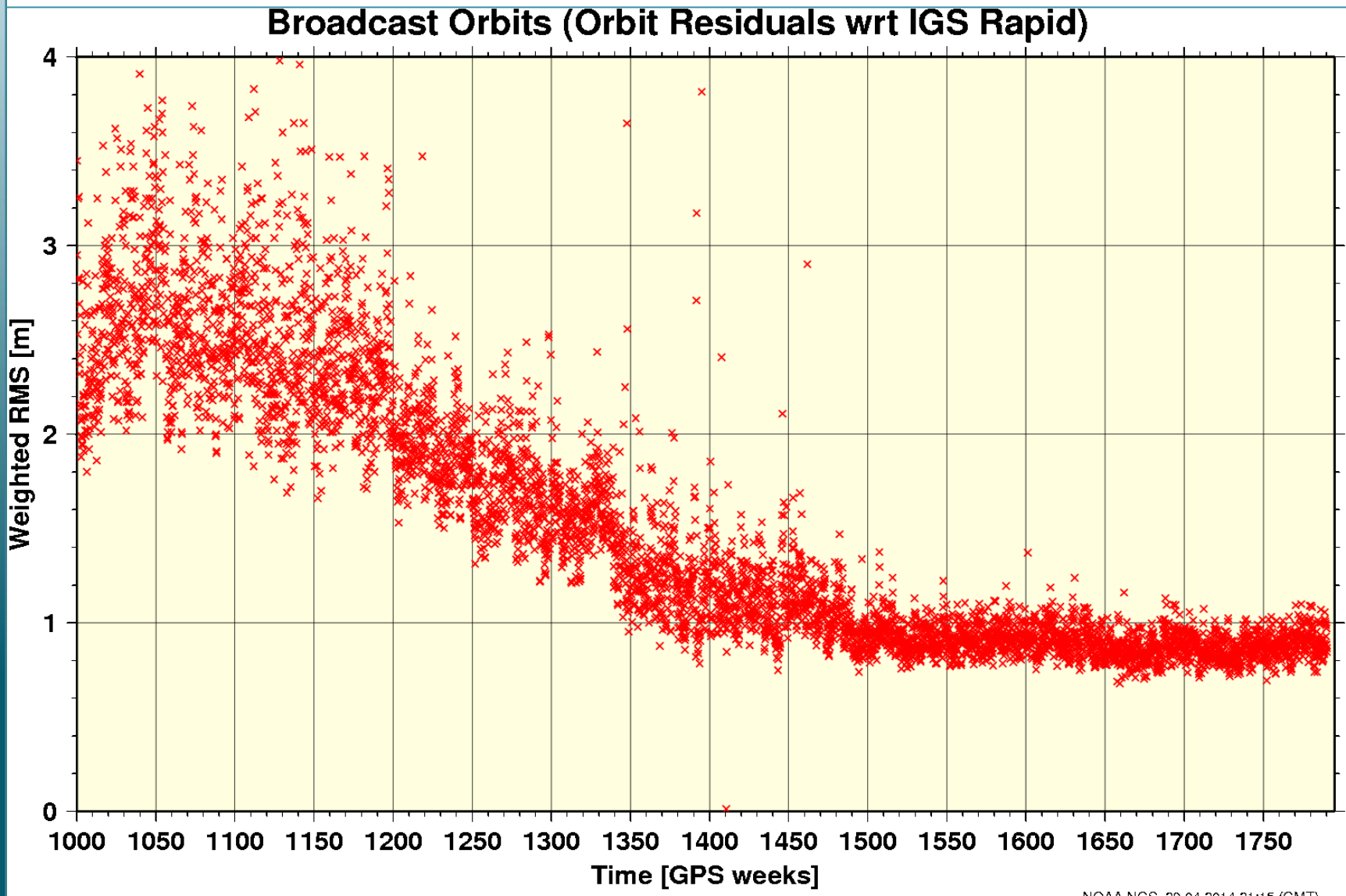
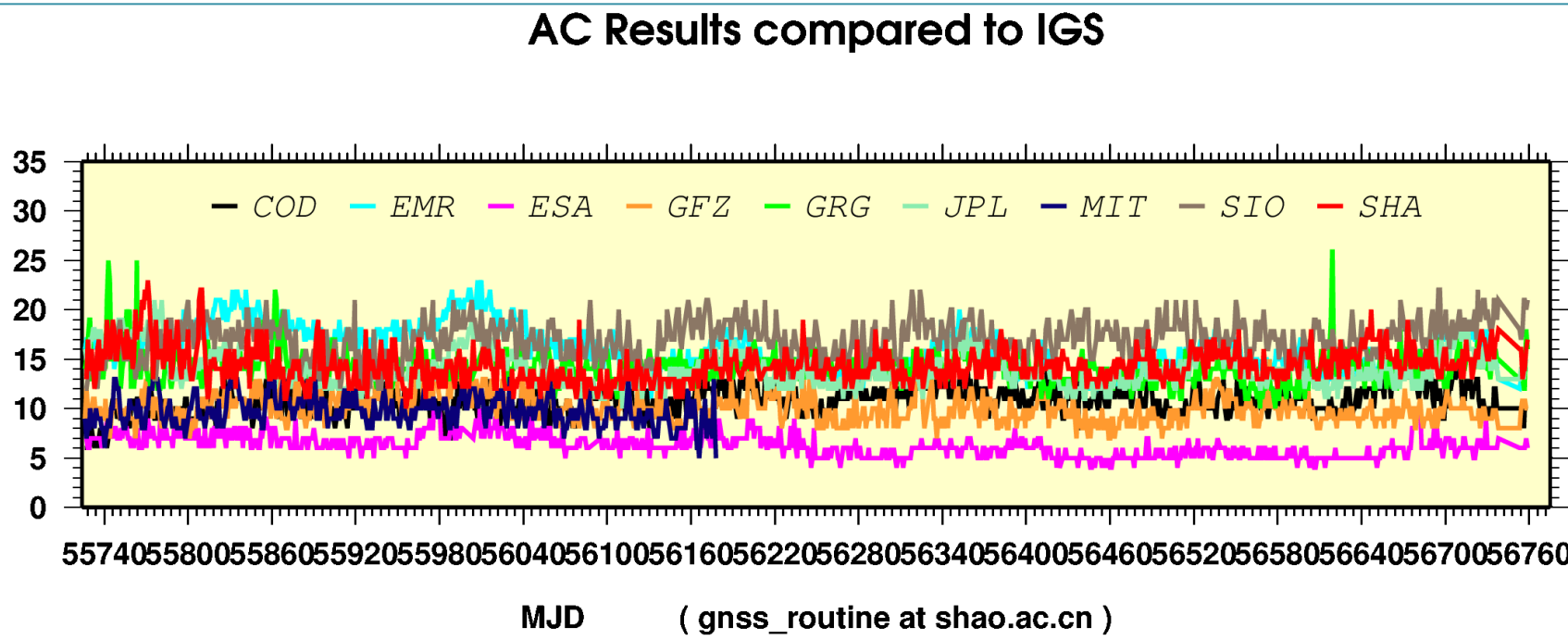
轨道误差

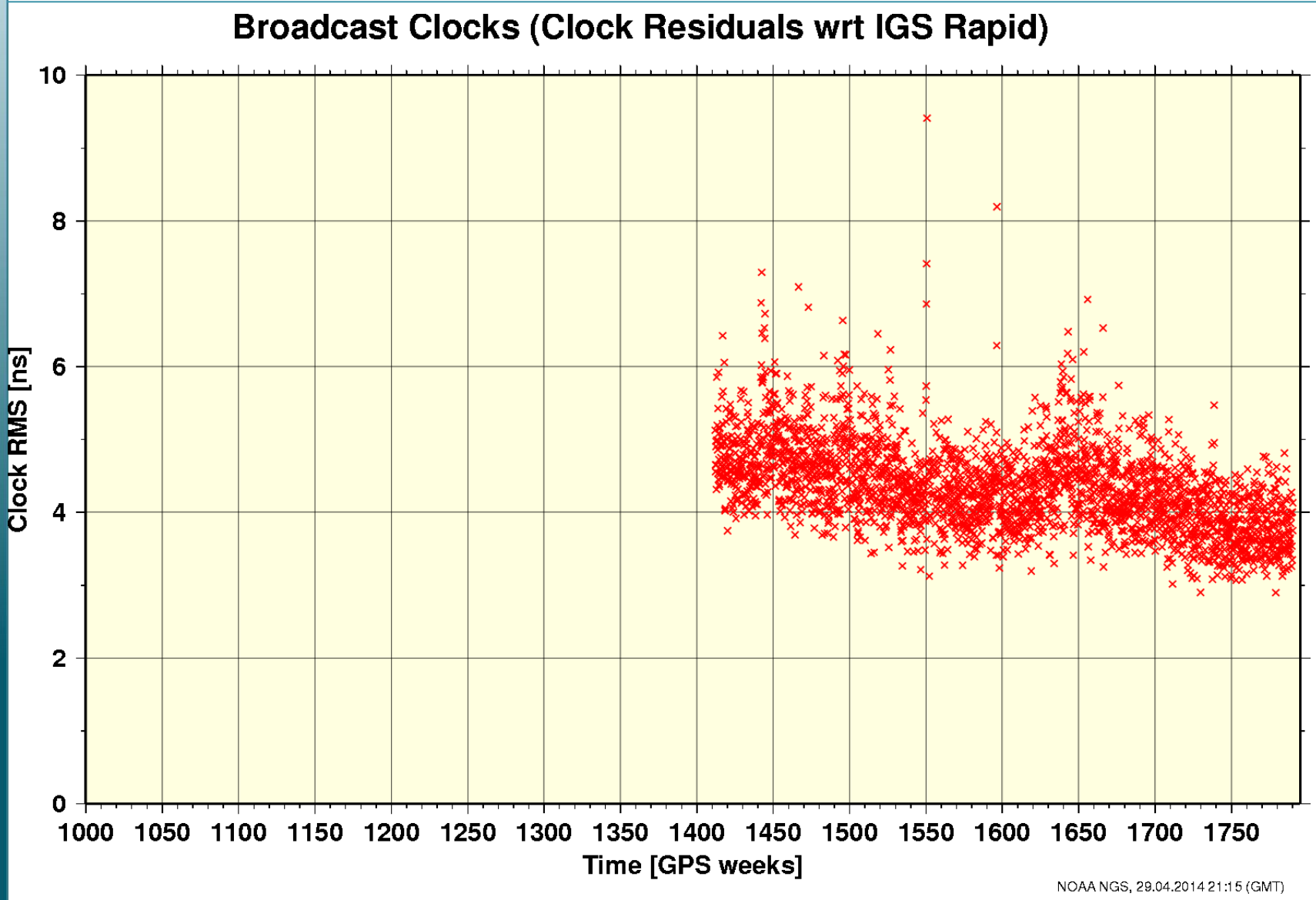


中科院上海天文台

轨道误差

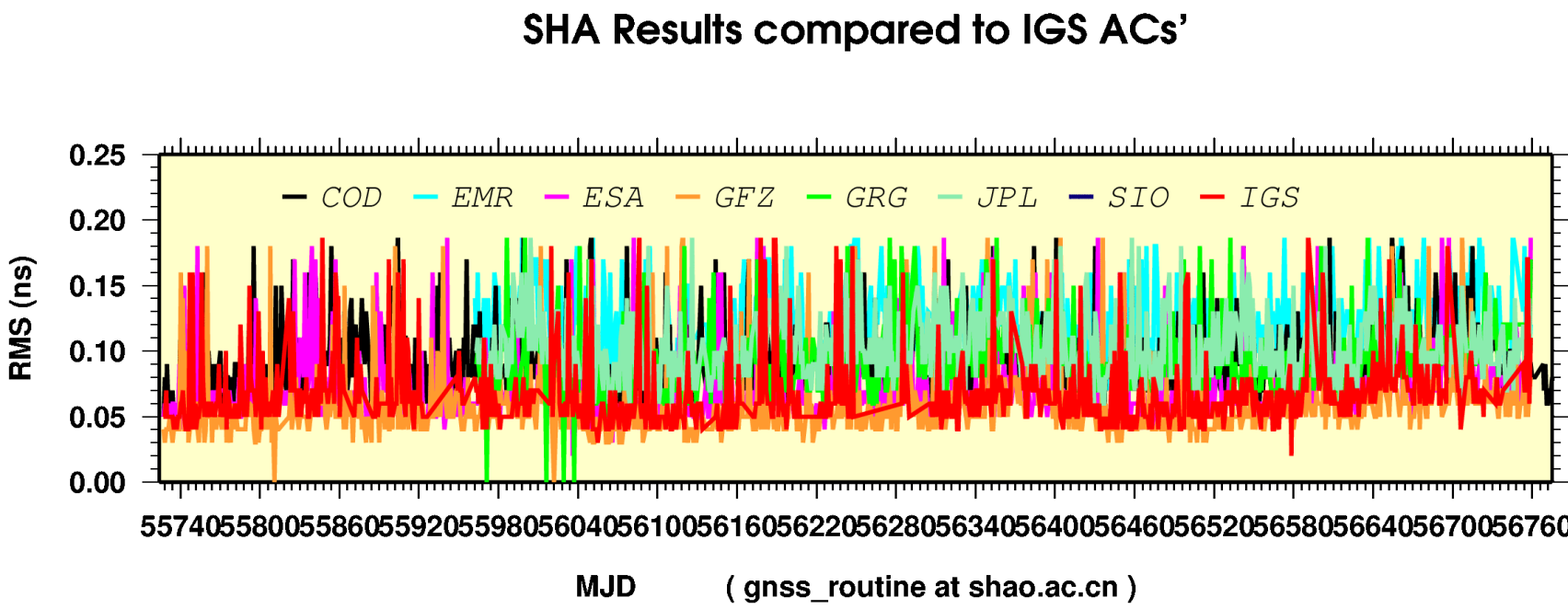

AC Results compared to IGS
COD
EMR
ESA
GFZ
GRG
JPL
MIT
SIO
SHA
RMS (mm)
35
30
25
20
15
10
5
0
55740 55800 55860 55920 55980 56040 56100 56160 56220 56280 56340 56400 56460 56520 56580 56640 56700 56760
MJD
(gnss_routine at shao.ac.cn)

钟差误差



中科院上海天文台

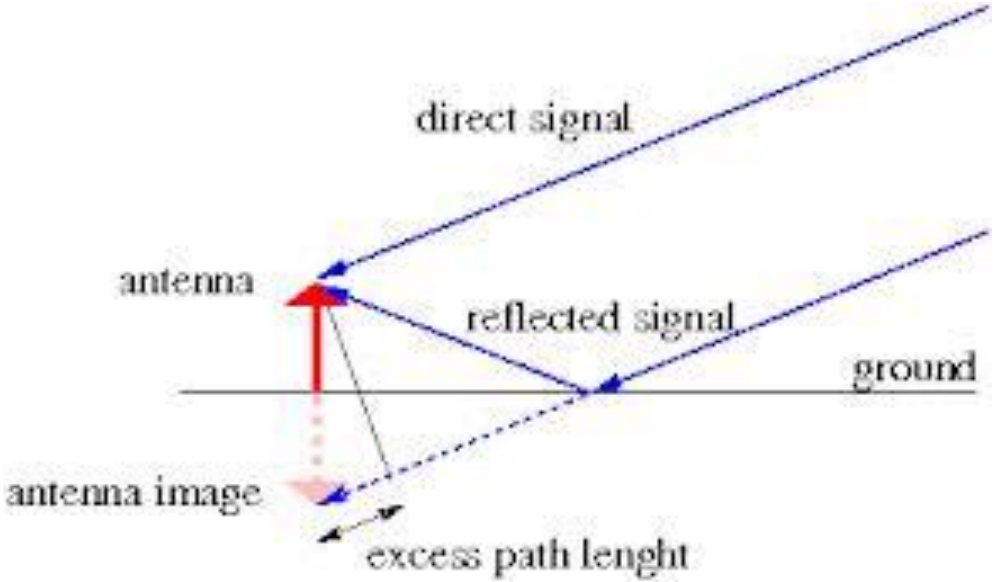
钟差误差


SHA Results compared to IGS ACs'
RMS (ns)
0.25
0.20
0.15
0.10
0.05
0.00
COD
EMR
ESA
GFZ
GRG
JPL
SIO
IGS
55740 55800 55860 55920 55980 56040 56100 56160 56220 56280 56340 56400 56460 56520 56580 56640 56700 56760
MJD
(gnss_routine at shao.ac.cn)

相位缠绕

- 相位中心变化
- 相对位置的变化，造成观测值的变化

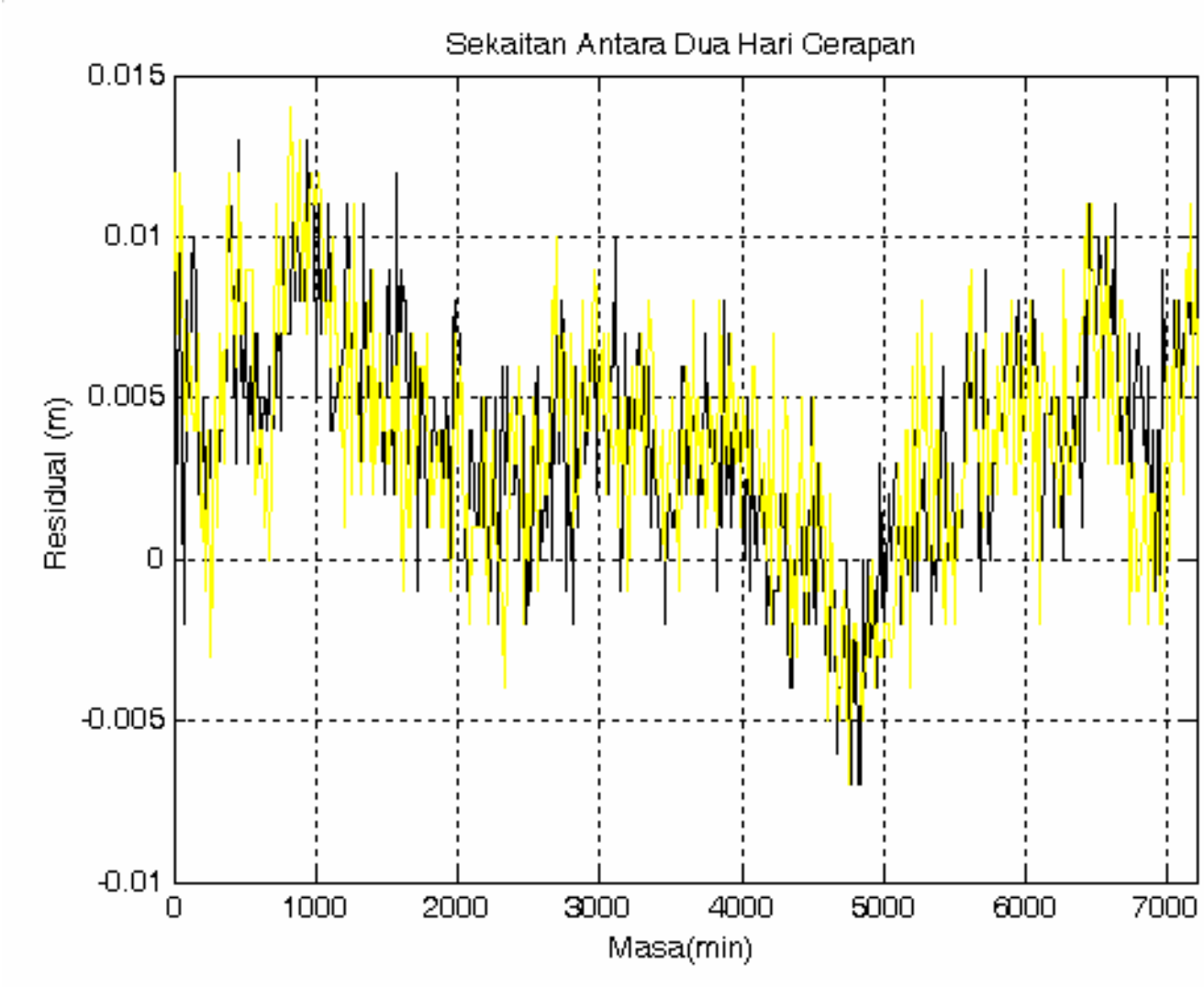
多路径效应



$$CBias(t_i) = CBias(t_{i-1}) +$$

$$\frac{1}{N}[P(t_i) - L(t_i) - CBias(t_{i-1}) - \frac{2f_2^2}{f_1^2 - f_2^2}(L_1(t_i) - L_2(t_i))]$$

多路径效应



中科院上海天文台

4.1 相位差分-单差 SD

站间单差为：观测同一颗卫星，消除了与卫星有关的误差

$$\Phi_{1l}^{i}(t)-\Phi_{1k}^{i}(t)=\frac{1}{\lambda_1}(\rho_l^i(t)-\rho_k^i(t))+(N_{1l}^{i}-N_{1k}^{i})+f_1(\delta_l(t)-\delta_k(t))$$

$$\Phi_{2l}^{i}(t)-\Phi_{2k}^{i}(t)=\frac{1}{\lambda_2}(\rho_l^i(t)-\rho_k^i(t))+(N_{2l}^{i}-N_{2k}^{i})+f_2(\delta_l(t)-\delta_k(t))$$

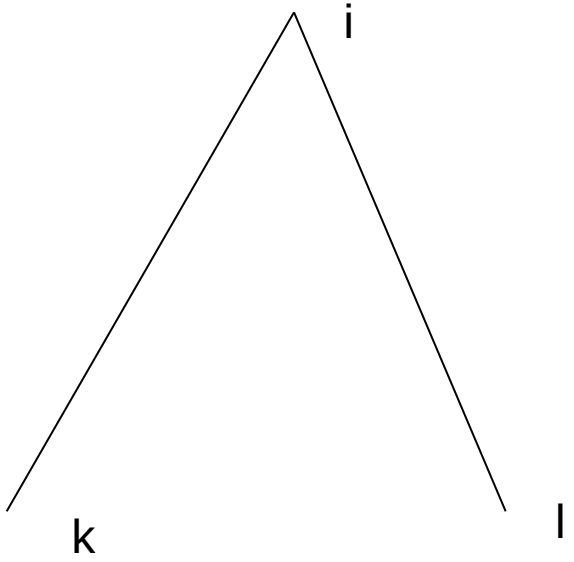
若令：

$$N_{kl}^{i}=N_l^i-N_k^i$$

$$\delta_{kl}(t)=\delta_l(t)-\delta_k(t)$$

$$\Phi_{kl}^{i}(t)=\Phi_l^i(t)-\Phi_k^i(t)$$

$$\rho_{kl}^{i}(t)=\rho_l^i(t)-\rho_k^i(t)$$



4.1 相位差分-SD

则站间对卫星 i 的单差观测方程为：

$$\Phi_{1kl}^{i}(t)=\frac{1}{\lambda_1}\rho_{kl}^{i}(t)+N_{1kl}^{i}+f_1\delta_{kl}(t)$$

$$\Phi_{2kl}^{i}(t)=\frac{1}{\lambda_2}\rho_{kl}^{i}(t)+N_{2kl}^{i}+f_2\delta_{kl}(t)$$

同理，站间对卫星 j 的单差观测方程为：

$$\Phi_{1kl}^{j}(t)=\frac{1}{\lambda_1}\rho_{kl}^{j}(t)+N_{1kl}^{j}+f_1\delta_{kl}(t)$$

$$\Phi_{2kl}^{j}(t)=\frac{1}{\lambda_2}\rho_{kl}^{j}(t)+N_{2kl}^{j}+f_2\delta_{kl}(t)$$

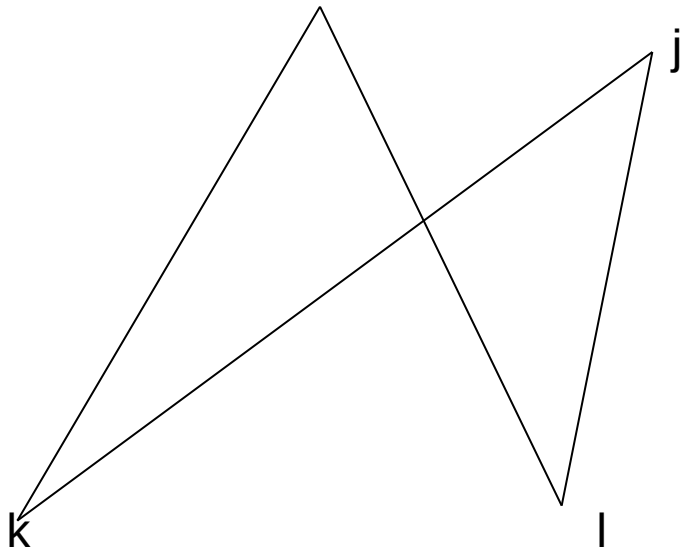
相位差分-双差DD

则：由卫星 *i* ，*j* 和测站*k*，*l*构成的双差观测方程为：

进一步消除了与测站有关的误差

$$\Phi_{1kl}^{j}(t)-\Phi_{1kl}^{i}(t)=\frac{1}{\lambda_1}(\rho_{kl}^{j}(t)-\rho_{kl}^{i}(t))+(N_{1kl}^{j}-N_{1kl}^{i})$$

$$\Phi_{2kl}^{j}(t)-\Phi_{2kl}^{i}(t)=\frac{1}{\lambda_2}(\rho_{kl}^{j}(t)-\rho_{kl}^{i}(t))+(N_{2kl}^{j}-N_{2kl}^{i})$$



相位差分-DD

或表示为：

$$\Phi_{1kl}^{ij}(t)=\frac{1}{\lambda_1}\rho_{kl}^{ij}(t)+N_{1kl}^{ij}$$

$$\Phi_{2kl}^{ij}(t)=\frac{1}{\lambda_2}\rho_{kl}^{ij}(t)+N_{2kl}^{ij}$$

式中，引入算子：

$$*_{kl}^{ij}=*_{kl}^{j}-*_{kl}^{i}=*_{l}^{j}-*_{l}^{i}-*_{k}^{j}+*_{k}^{i}$$

则：

$$\Phi_{kl}^{ij}(t)=\Phi_{l}^{j}(t)-\Phi_{l}^{i}(t)-\Phi_{k}^{j}(t)+\Phi_{k}^{i}(t)$$

$$\rho_{kl}^{ij}(t)=\rho_{l}^{j}(t)-\rho_{l}^{i}(t)-\rho_{k}^{j}(t)+\rho_{k}^{i}(t)$$

$$N_{kl}^{ij}=N_{l}^{j}-N_{l}^{i}-N_{k}^{j}+N_{k}^{i}$$

相位差分-三差TD

在t_1和t_2时刻的双差观测方程：

$$\Phi_{1kl}^{ij}(t_1) = \frac{1}{\lambda_1}\rho_{kl}^{ij}(t_1) + N_{1kl}^{ij}$$

$$\Phi_{2kl}^{ij}(t_1) = \frac{1}{\lambda_2}\rho_{kl}^{ij}(t_1) + N_{2kl}^{ij}$$

$$\Phi_{1kl}^{ij}(t_2) = \frac{1}{\lambda_1}\rho_{kl}^{ij}(t_2) + N_{1kl}^{ij}$$

$$\Phi_{2kl}^{ij}(t_2) = \frac{1}{\lambda_2}\rho_{kl}^{ij}(t_2) + N_{2kl}^{ij}$$

相位差分-TD

再对时间t_1和t_2时刻的观测值差分，得三差观测方程：

$$\Phi_{1kl}^{ij}(t_2)-\Phi_{1kl}^{ij}(t_1)=\frac{1}{\lambda_1}(\rho_{kl}^{ij}(t_2)-\rho_{kl}^{ij}(t_1))$$

$$\Phi_{2kl}^{ij}(t_2)-\Phi_{2kl}^{ij}(t_1)=\frac{1}{\lambda_2}(\rho_{kl}^{ij}(t_2)-\rho_{kl}^{ij}(t_1))$$

也可表示为：

$$\Phi_{1kl}^{ij}(t_{12})=\frac{1}{\lambda_1}\rho_{kl}^{ij}(t_{12})$$

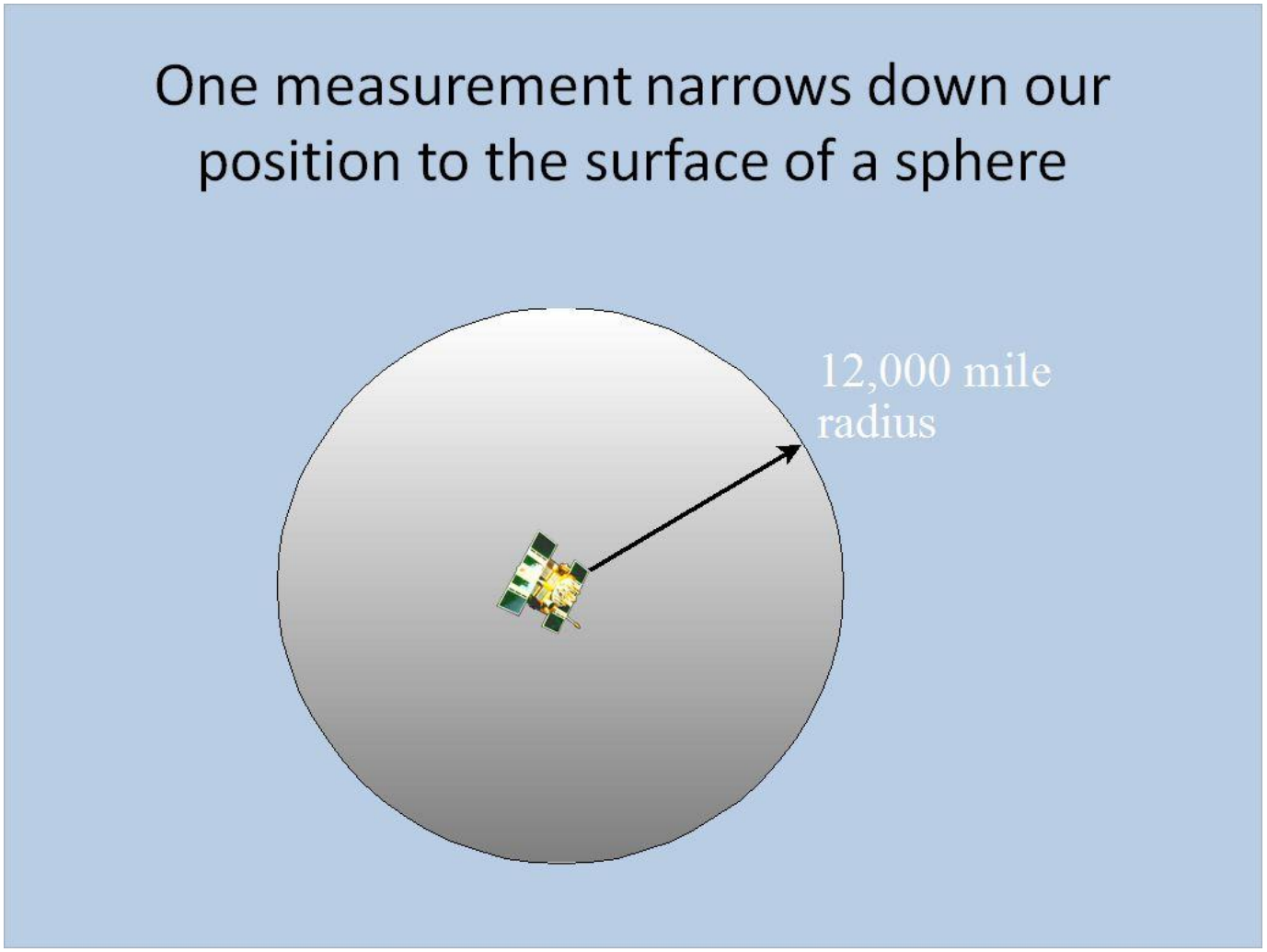
$$\Phi_{2kl}^{ij}(t_{12})=\frac{1}{\lambda_2}\rho_{kl}^{ij}(t_{12})$$

Content(8)

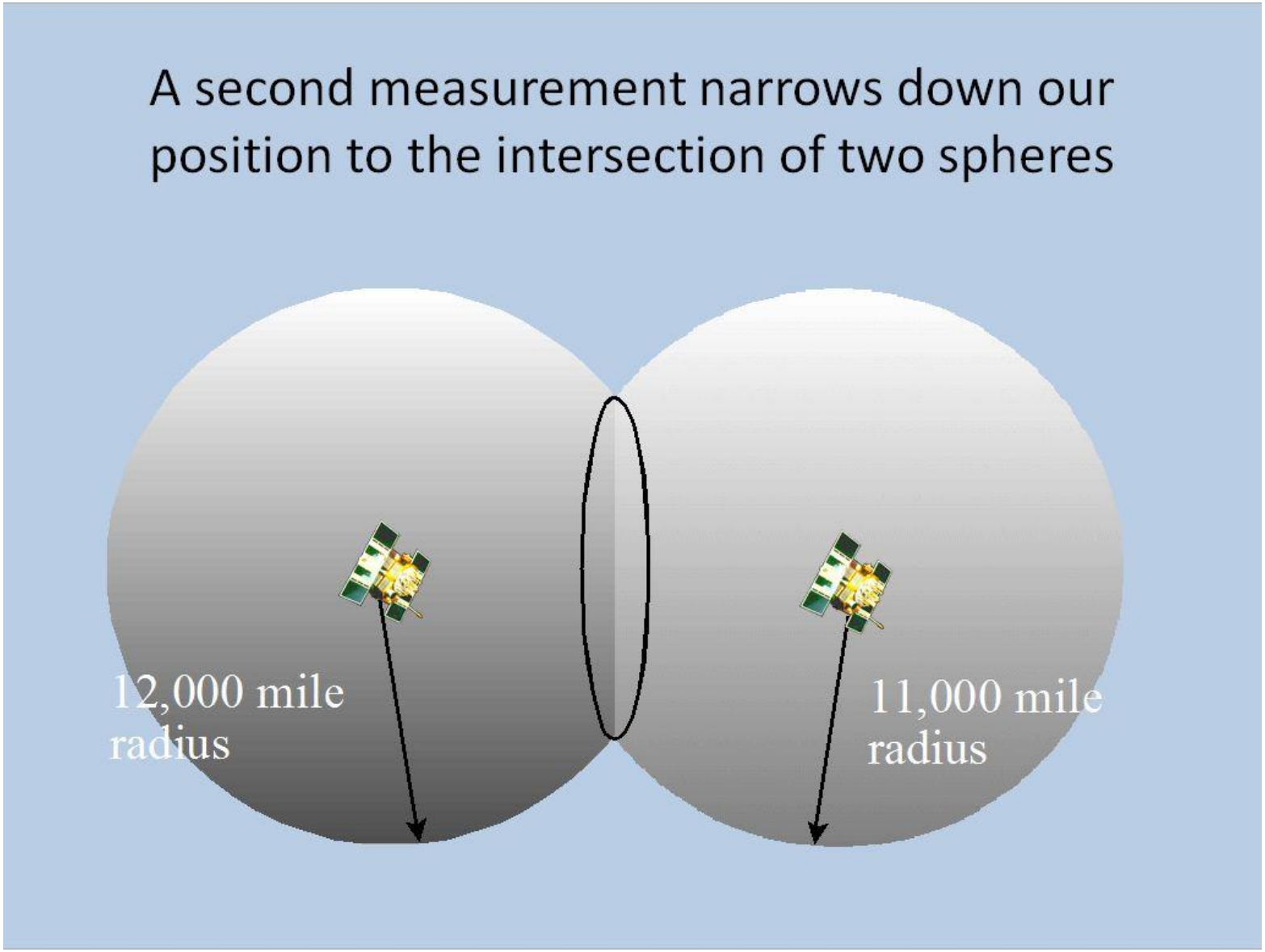
中科院上海天文台

- 精密定位模型

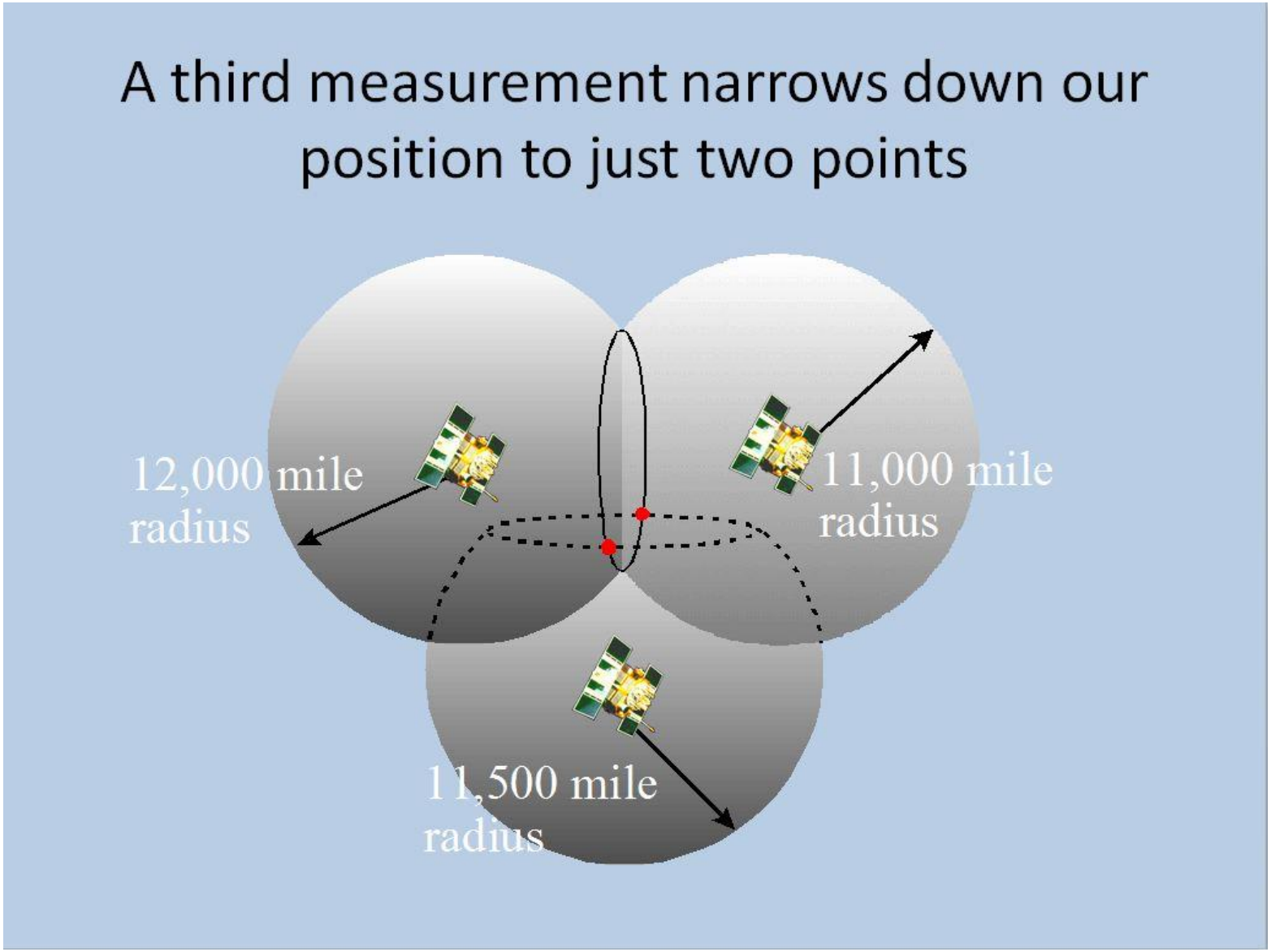
定位原理


One measurement narrows down our position to the surface of a sphere
12,000 mile radius

定位原理


A second measurement narrows down our position to the intersection of two spheres
12,000 mile radius
11,000 mile radius

定位原理


A third measurement narrows down our position to just two points
12,000 mile radius
11,000 mile radius
11,500 mile radius

GPS 定位原理概述

- ✪导航定位-精密定位

Navigation-precise positioning

- ✪伪距定位 -载波相位定位

Code pseudorange -carrier phase

- ✪点定位-相对定位(差分定位)

Point-positioning -relative positioning

- ✪动态定位-静态定位-快速静态定位

kinematic - static - rapid static positionging

- ✪后处理-实时动态定位

post-processing - Real time kinematic (RTK)

一、伪距点定位的数学模型

1.1 Bancroft算法

一、伪距点定位的数学模型

1.1 用码伪距进行点定位

历元t时的码伪距的观测方程可表示为：

$$P^s = \rho^s + \Delta t_r - \Delta t^s + \Delta Tr^s + \Delta I^s$$

其中：P–卫星s与测站的码伪距观测值，

ρ –卫星s与测站的几何距离，

$\Delta t_r \quad \Delta t^s$ –分别为接收机钟差和卫星钟差之差，

$\Delta Tr^s, \Delta I^s$ –分别为观测值的对流层和电离层误差

1.1 用码伪距进行点定位

$$P^s + \Delta t^s - \Delta Tr^s - \Delta I^s = \rho^s + \Delta t_r$$

如果不考虑对流层延迟，电离层折射的影响

$$P^s + \Delta t^s = \rho^s + \Delta t_r$$

卫星-地面的几何距离可表示为：

$$\rho^s = \sqrt{(X^s - X)^2 + (Y^s - Y)^2 + (Z^s - Z)^2}$$

(X Y Z) 是卫星的地心坐标

1.1 用码伪距进行点定位

卫星钟差可以从广播星历中得到：

$$\Delta t^s = c[a_0 + a_1(t - t_{oe}) + a_2(t - t_{oe})^2]$$

定位时卫星位置的计算

方法1： 对应接收时刻 t_r 的卫星发射时刻 t^s

$$t^s = t_r - p^s / c$$

方法2：迭代法

$$t^s = t_r - 0.075s$$

计算卫星坐标，卫星至接收机的距离

$$\rho^s = \sqrt{(X^s - X)^2 + (Y^s - Y)^2 + (Z^s - Z)^2}$$

$$t^s = t_r - \rho / c$$

1.1 用码伪距进行点定位

观测方程线性化

$$\rho^s = \sqrt{(X^s - X)^2 + (Y^s - Y)^2 + (Z - Z)^2} \equiv f(X, Y, Z)$$

$$\rho_0^s = \sqrt{(X^s - X_0)^2 + (Y^s - Y_0)^2 + (Z^s - Z_0)^2} \equiv f(X_0, Y_0, Z_0)$$

$$X = X_0 + \Delta X,$$
$$Y = Y_0 + \Delta Y,$$
$$Z = Z_0 + \Delta Z$$

1.1 用码伪距进行点定位

将观测方程按泰勒级数展开：

$$f(X,Y,Z) \equiv f(X_0+\Delta X, Y_0+\Delta Y, Z_0+\Delta Z)$$
$$= f(X_0,Y_0,Z_0)+\frac{\partial f}{\partial X_0}\Delta X+\frac{\partial f}{\partial Y_0}\Delta Y+\frac{\partial f}{\partial Z_0}\Delta Z+\cdots$$

其中

$$\frac{\partial f}{\partial X_0}=-\frac{X^s-X_0}{\rho_0^s}=a_X^s,$$

$$\frac{\partial f}{\partial Y_0}=-\frac{Y^s-Y_0}{\rho_0^i}=a_Y^s$$

$$\frac{\partial f}{\partial Z_0}=-\frac{Z^s-Z_0}{\rho_0^s}=a_Z^s$$

1.1 用码伪距进行点定位

由码伪距方程

$$p^s = \rho_0^s + a_X^s \Delta X + a_Y^s \Delta Y + a_Z^s \Delta Z + \Delta t_r - \Delta t^s$$

得：

上述方程可改写为：

$$p^s - \rho_0^s + \Delta t^s = a_X^s \Delta X + a_Y^s \Delta Y + a_Z^s \Delta Z + \Delta t_r$$

1.1 用码伪距进行点定位

若观测到4颗卫星，共有4个观测方程，令：

$$A=\begin{bmatrix} a_X^1 & a_Y^1 & a_Z^1 & 1 \\ a_X^2 & a_Y^2 & a_Z^2 & 1 \\ a_X^3 & a_Y^3 & a_Z^3 & 1 \\ a_X^4 & a_Y^4 & a_Z^4 & 1 \end{bmatrix} \quad l=\begin{bmatrix} R^1-\rho_0^1+c\delta^1 \\ R^2-\rho_0^2+c\delta^2 \\ R^3-\rho_0^3+c\delta^3 \\ R^4-\rho_0^4+c\delta^4 \end{bmatrix} \quad x=\begin{bmatrix} \Delta X \\ \Delta Y \\ \Delta Z \\ \Delta t_r \end{bmatrix}$$

则，观测方程可表示为：

$$l = Ax$$

$$x = A^{-1}l$$

$$X = X_0 + \Delta X,$$

$$Y = Y_0 + \Delta Y,$$

$$Z = Z_0 + \Delta Z$$

1.1 用码伪距进行点定位

若观测到4以上颗卫星，，令：

$$A=\begin{bmatrix} a_X^1 & a_Y^1 & a_Z^1 & 1 \\ a_X^2 & a_Y^2 & a_Z^2 & 1 \\ \vdots & \vdots & \vdots & \vdots \\ a_X^s & a_Y^s & a_Z^s & 1 \end{bmatrix} \quad l=\begin{bmatrix} R^1-\rho_0^1+c\delta^1 \\ R^2-\rho_0^2+c\delta^2 \\ \vdots \\ R^s-\rho_0^s+c\delta^s \end{bmatrix} \quad x=\begin{bmatrix} \Delta X \\ \Delta Y \\ \Delta Z \\ \Delta t_r \end{bmatrix}$$

则，观测方程可表示为：

$$l=Ax$$

1.1 用码伪距进行点定位

则，按最小二乘法

$$A^T A x = A^T l$$

$$x = (A^T A)^{-1} A^T l$$

1.1 用码伪距进行点定位

精度评定

$$v = \rho^s(est) + \Delta t_r + \Delta Tr^s - P^s$$

$$\bar{\sigma}_0 = \sqrt{\frac{V^T PV}{r}}$$

RMS (Root Mean Square)

1.1 用码伪距进行点定位

精度因子(Dilution of precision)

$$Q_x = (A^T A)^{-1} = \begin{bmatrix} q_{XX} & q_{XY} & q_{XZ} & q_{Xt} \\ q_{XY} & q_{YY} & q_{YZ} & q_{Yt} \\ q_{XZ} & q_{YZ} & q_{ZZ} & q_{Zt} \\ q_{Xt} & q_{Yt} & q_{Zt} & q_{tt} \end{bmatrix}$$

✪ 几何精度因子(geometric accuracy in position and time)：

$$GDOP = \sqrt{q_{XX} + q_{YY} + q_{ZZ} + q_{tt}}$$

✪ 位置精度因子(accuracy in position)：

$$PDOP = \sqrt{q_{XX} + q_{YY} + q_{ZZ}}$$

1.1 用码伪距进行点定位

时间精度因子(accuracy in time)：

$$TDOP = \sqrt{q_{tt}}$$

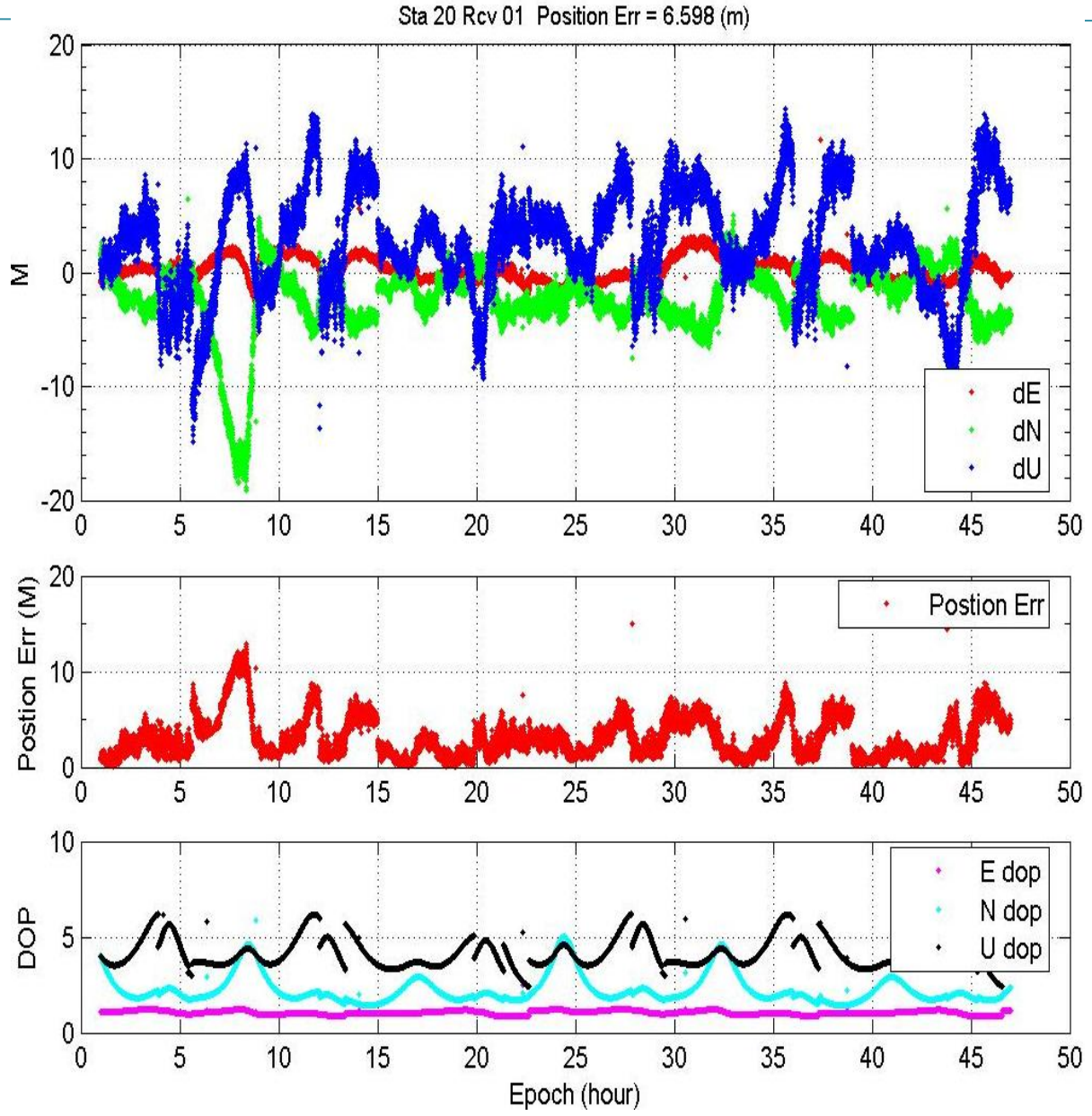
水平精度因子(accuracy in the horizontal position)：

$$HDOP = \sqrt{q_{xx} + q_{yy}}$$

垂直精度因子(accuracy in vertical direction)：

$$VDOP = \sqrt{q_{hh}}$$

1.1 用码伪距进行点定位



1.2 用相位进行点定位

历元t时的相位的观测方程可表示为：

$$\Phi_k^i(t)=\frac{1}{\lambda}\rho_k^i(t)+N_k^i+f^i\Delta\delta_k^i(t)$$

其中$\Phi_k^i(t)$为以周为单位得相位观测值，$\rho_k^i(t)$为卫星与测站之间得几何距离，N_k^i为整周模糊度，λ为波长，f^i为相应的卫星频率，$\Delta\delta_k^i(t)$为接收机钟差与卫星钟差之差，上述观测方程也可表示为：

$$\Phi_k^i(t)+f^i\delta^i(t)=\frac{1}{\lambda}\rho_k^i(t)+N_k^i+f^i\Delta\delta_k(t)$$

1.2 用相位进行点定位（2）

设卫星数为n_i，历元数为n_t，未知数为3+ n_i+(n_t−1)，观测值总数为n_i n_t ，则

$$n_i n_t \geq 3 + n_i + (n_t - 1)$$

或
$$n_t \geq \frac{n_i + 2}{n_i - 1}$$

例： n_i=2， n_t≥4； n_i=4， n_t≥2；

对于动态点定位，有 $n_i n_t \geq 3n_t + n_i + (n_t - 1)$

或
$$n_t \geq \frac{n_i - 1}{n_i - 4}$$

例： n_i=5， n_t≥4； n_i=7， n_t≥2；

1.2 用相位进行点定位

同码伪距，线性化后的相位观测方程为：

$$\lambda\Phi_k^i(t)-\rho_{k0}^i(t)+c\delta^i(t)=a_{X_k}^i\Delta X_k+a_{Y_k}^i\Delta Y_k+\Delta Z_k+\lambda N_k^i+c\delta_k(t)$$

与伪距线性化后的观测方程相比，未知数增加了模糊度，以观测四颗星为例，此时有三个位置向量，一个钟差，四个模糊度共八个未知数。

1.2 用相位进行点定位

观测方程可表示为：

$$l = Ax$$

其中：

$$l = \begin{bmatrix} \lambda\Phi_k^1(t) - \rho_{k0}^1(t) + c\delta^1(t) \\ \lambda\Phi_k^2(t) - \rho_{k0}^2(t) + c\delta^2(t) \\ \lambda\Phi_k^3(t) - \rho_{k0}^3(t) + c\delta^3(t) \\ \lambda\Phi_k^4(t) - \rho_{k0}^4(t) + c\delta^4(t) \end{bmatrix} \quad A = \begin{bmatrix} a_{X_k}^1(t) & a_{Y_k}^1(t) & a_{Z_k}^1(t) & \lambda & 0 & 0 & 0 & c \\ a_{X_k}^2(t) & a_{Y_k}^2(t) & a_{Z_k}^2(t) & 0 & \lambda & 0 & 0 & c \\ a_{X_k}^3(t) & a_{Y_k}^3(t) & a_{Z_k}^3(t) & 0 & 0 & \lambda & 0 & c \\ a_{X_k}^4(t) & a_{Y_k}^4(t) & a_{Z_k}^4(t) & 0 & 0 & 0 & \lambda & c \end{bmatrix}$$

$$x^T = \begin{bmatrix} \Delta X_k & \Delta Y_k & \Delta Z_k & N_k^1 & N_k^2 & N_k^3 & N_k^4 & \delta_k(t) \end{bmatrix}$$

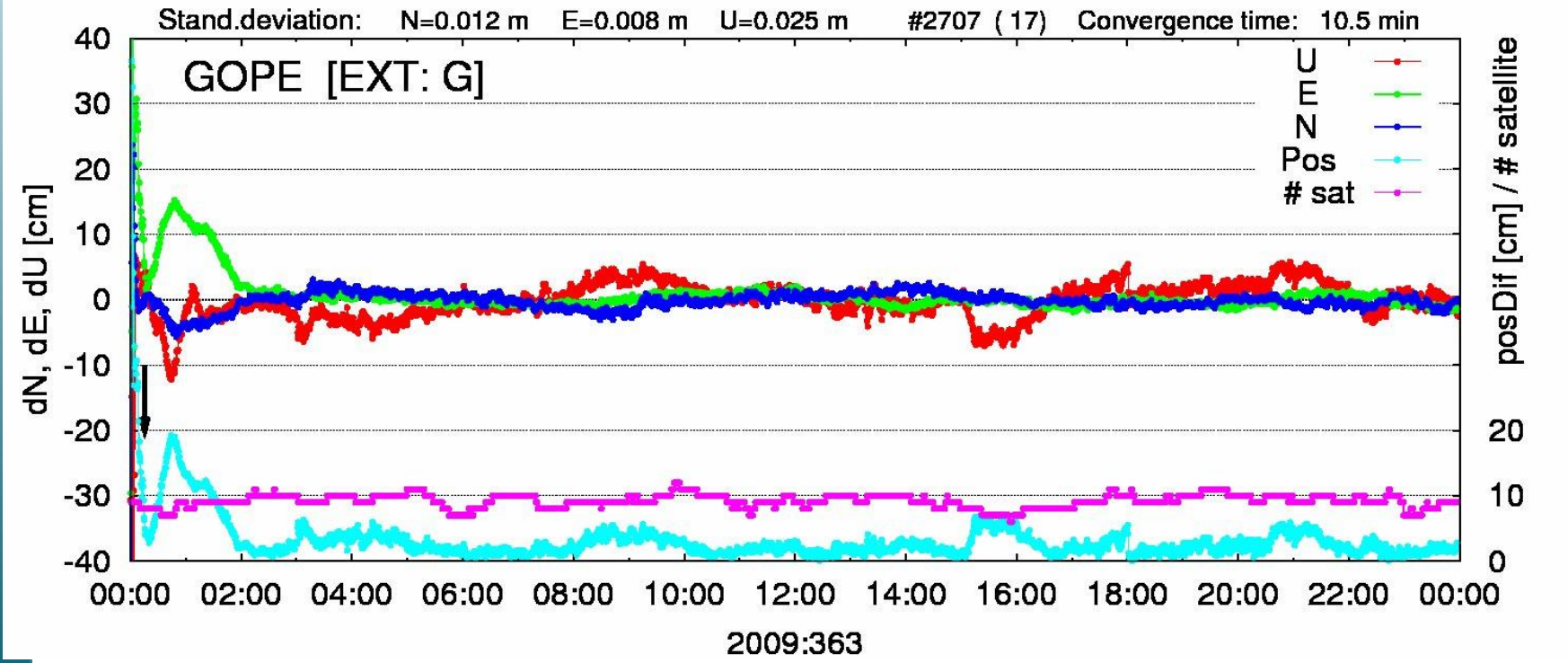
1.2 用相位进行点定位

两个历元，有八个方程，九个未知数；三个历元，有十二个方程，十个未知数；观测向量方程的元素为：

$$A=\begin{bmatrix}
a_{X_k}^1(t_1) & a_{Y_k}^1(t_1) & a_{Z_k}^1(t_1) & \lambda & 0 & 0 & 0 & c & 0 & 0 \\
a_{X_k}^2(t_1) & a_{Y_k}^2(t_1) & a_{Z_k}^2(t_1) & 0 & \lambda & 0 & 0 & c & 0 & 0 \\
a_{X_k}^3(t_1) & a_{Y_k}^3(t_1) & a_{Z_k}^3(t_1) & 0 & 0 & \lambda & 0 & c & 0 & 0 \\
a_{X_k}^4(t_1) & a_{Y_k}^4(t_1) & a_{Z_k}^4(t_1) & 0 & 0 & 0 & \lambda & c & 0 & 0 \\
a_{X_k}^1(t_2) & a_{Y_k}^1(t_2) & a_{Z_k}^1(t_2) & \lambda & 0 & 0 & 0 & 0 & c & 0 \\
a_{X_k}^2(t_2) & a_{Y_k}^2(t_2) & a_{Z_k}^2(t_2) & 0 & \lambda & 0 & 0 & 0 & c & 0 \\
a_{X_k}^3(t_2) & a_{Y_k}^3(t_2) & a_{Z_k}^3(t_2) & 0 & 0 & \lambda & 0 & 0 & c & 0 \\
a_{X_k}^4(t_2) & a_{Y_k}^4(t_2) & a_{Z_k}^4(t_2) & 0 & 0 & 0 & \lambda & 0 & c & 0 \\
a_{X_k}^1(t_3) & a_{Y_k}^1(t_3) & a_{Z_k}^1(t_3) & \lambda & 0 & 0 & 0 & 0 & 0 & c \\
a_{X_k}^2(t_3) & a_{Y_k}^2(t_3) & a_{Z_k}^2(t_3) & 0 & \lambda & 0 & 0 & 0 & 0 & c \\
a_{X_k}^3(t_3) & a_{Y_k}^3(t_3) & a_{Z_k}^3(t_3) & 0 & 0 & \lambda & 0 & 0 & 0 & c \\
a_{X_k}^4(t_3) & a_{Y_k}^4(t_3) & a_{Z_k}^4(t_3) & 0 & 0 & 0 & \lambda & 0 & 0 & c
\end{bmatrix}$$

$$x=\begin{bmatrix}
\Delta X_k \\ \Delta Y_k \\ \Delta Z_k \\ N_k^1 \\ N_k^2 \\ N_k^3 \\ N_k^4 \\ \delta_k(t_1) \\ \delta_k(t_2) \\ \delta_k(t_3)
\end{bmatrix}$$

1.2 用相位进行点定位


Stand.deviation: N=0.012 m E=0.008 m U=0.025 m #2707 (17) Convergence time: 10.5 min
GOPE [EXT: G]
U
E
N
Pos
sat
dN, dE, dU [cm]
posDif [cm] / # satellite
40
30
20
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0
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-20
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-40
20
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