

# VLBI Uygulamaları

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# Sunum kapsamı

- Uzay jeodezisi tekniği, VLBI (Very Long Baseline Interferometry: Çok Uzun Baz Enterferometrisi).
- VLBI ölçülerinden Jeodezik parametrelerin Gauss Markoff En-Küçük Kareler yöntemi ile kestirimi:
  - Ölçülerin indirgenmesi (jeofizik ve teknik spesifik indirgemeler),
  - Ölçü denklemlerinin oluşturulması,
  - Kısıtlayıcı denklemlerin (absolute or relative continuity constraints) ölçü denklemlerine ve datum koşul denklemlerinin normal denklemlere eklenmesi.
- VLBI Jeodezik parametreleri:
  - EOP ( $x_p, y_p, dUT1, X, Y$ ),
  - TRF ( $X, Y, Z, v_x, v_y, v_z$ ),
  - CRF ( $\alpha, \delta$ ),
  - Troposfer sinyal zenit gecikmeleri ve gradyanlar.

# VLBI



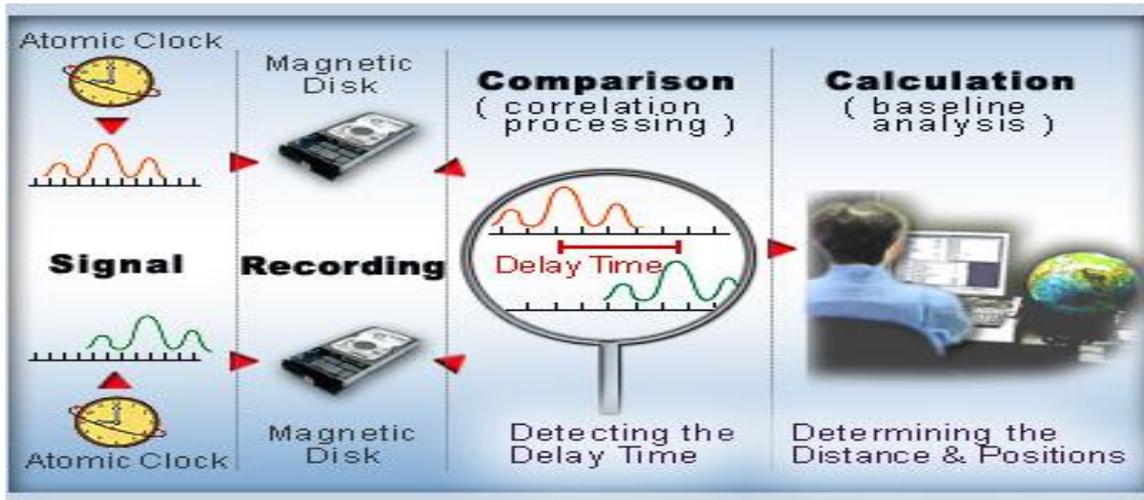
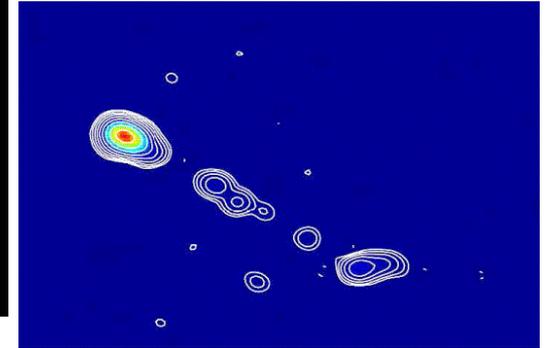
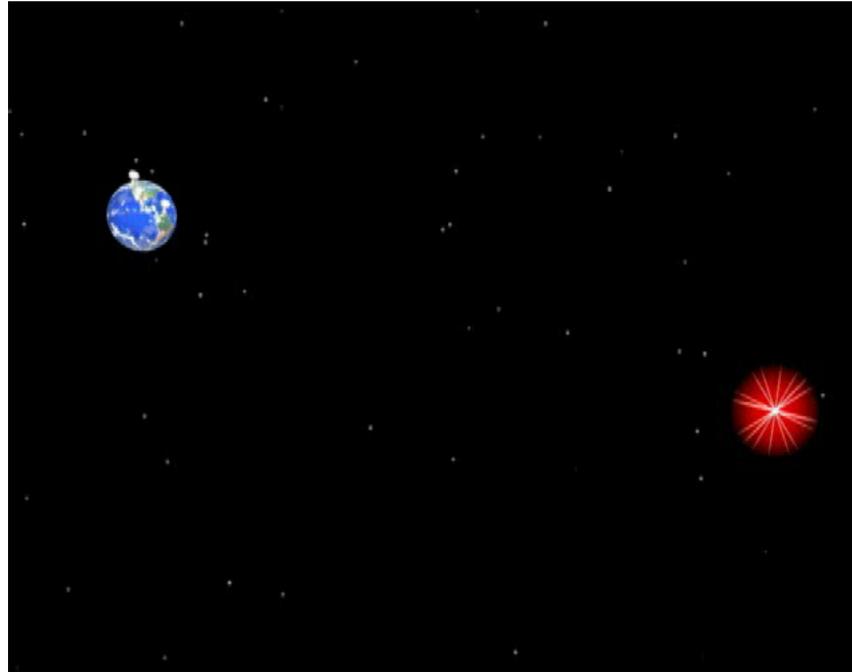
**O'Higgins (9 m)**



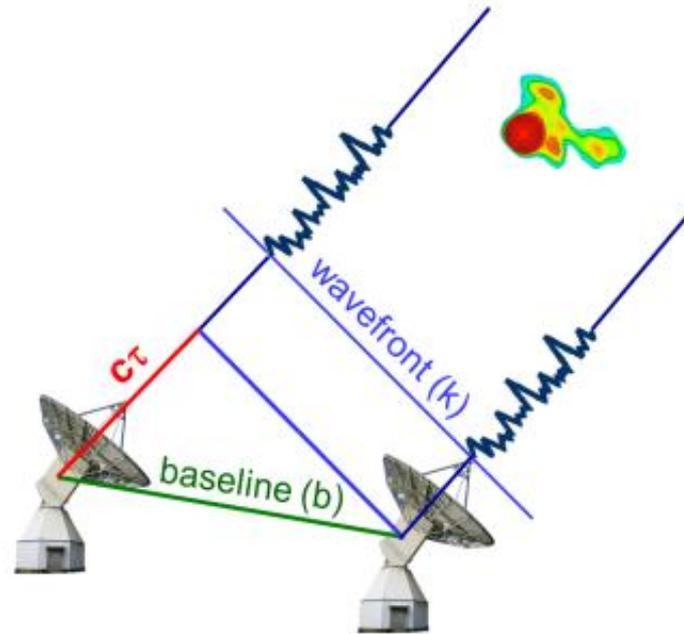
**Wetzell (20 m)**



# VLBI ölçüleri



# VLBI ölçü denklemi (computed delay – $\tau$ )



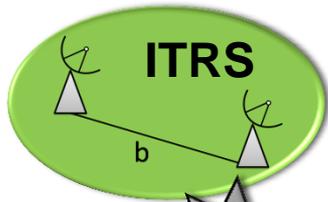
$$k = \begin{bmatrix} \cos \delta \cos \alpha \\ \cos \delta \sin \alpha \\ \sin \delta \end{bmatrix}_{CRF}$$

$$b = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{TRF}$$

$$\tau = -\frac{1}{c} \cdot b^T \cdot W \cdot R \cdot Q \cdot k + \tau_{saat} + \tau_{tropo1} - \tau_{tropo2} + \tau_{diger}$$

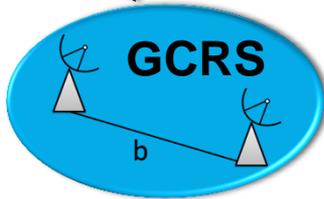
# VLBI teorisi

**International Terrestrial Reference System**



$$\vec{b}_{GCRS} = QRW \cdot \vec{b}_{TRS}$$

**Geocentric Celestial Reference System**



**Barycentric Celestial Reference System**



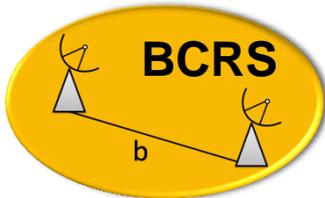
$$\tau = \frac{\vec{k} \cdot \vec{b}}{c}$$

retarded  
baseline corr.

gravitational  
retardation

**Lorentz-transformation**

**Lorentz-transformation**

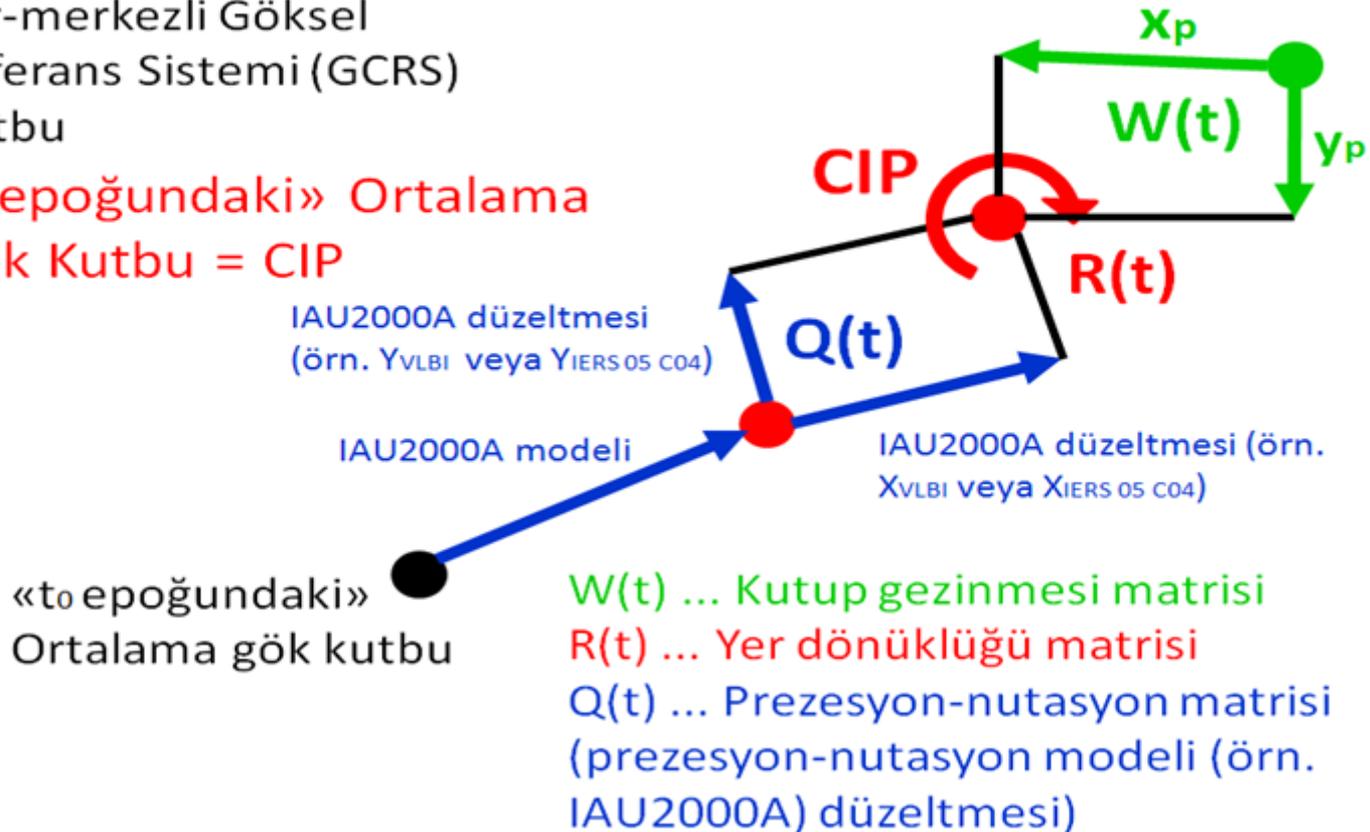


**in TT-frame**

# GCRS ve ITRS arasındaki kinematik ilişki

$$X_{GCRS} = Q(t) \cdot R(t) \cdot W(t) \cdot X_{ITRS}$$

- Uluslararası Yersel Referans Sistemi (ITRS) Kutbu
- Yer-merkezli Göksel Referans Sistemi (GCRS) Kutbu
- «t epochundaki» Ortalama Gök Kutbu = CIP



# VLBI ölçülerinden jeodezik parametrelerin kestirimi

# VLBI hesaplanan gecikme (computed delay - $\tau$ )

## MODELLER

- + **EOP** (oceanic & gravitational high frequency terms, nutation corrections)
- + **solid Earth tides**
- + **troposphere delay** (VMF / GMF / NMF)
- + **ocean loading** (FES2004 / EOT08a / GOT00 / AG06)
- + **thermal antenna deformation**
- + **axis offset**
- + **atmosphere loading**

partial derivatives

$$\frac{\partial \tau}{d_{PAR}}$$

computed delay

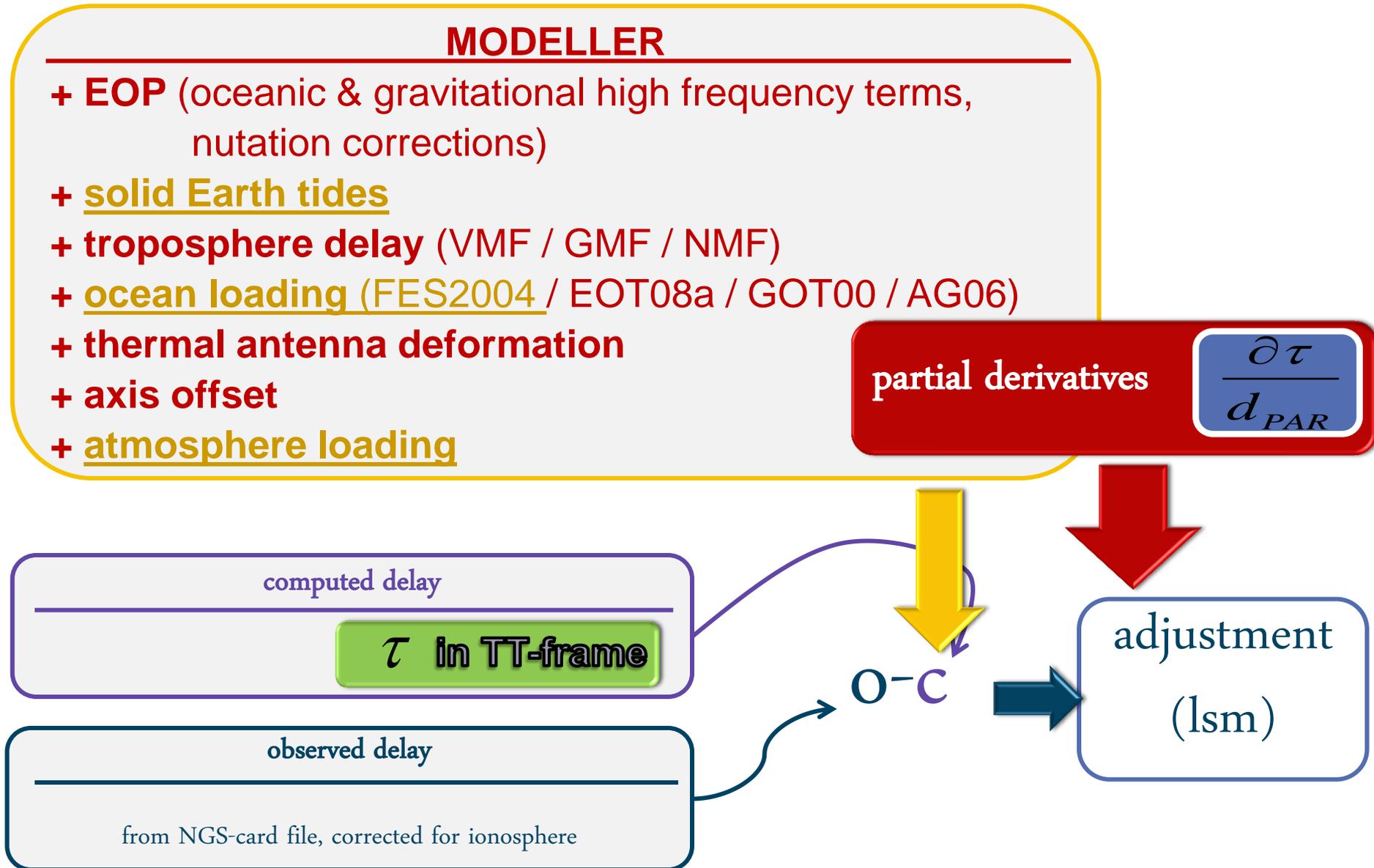
$\tau$  in TT-frame

observed delay

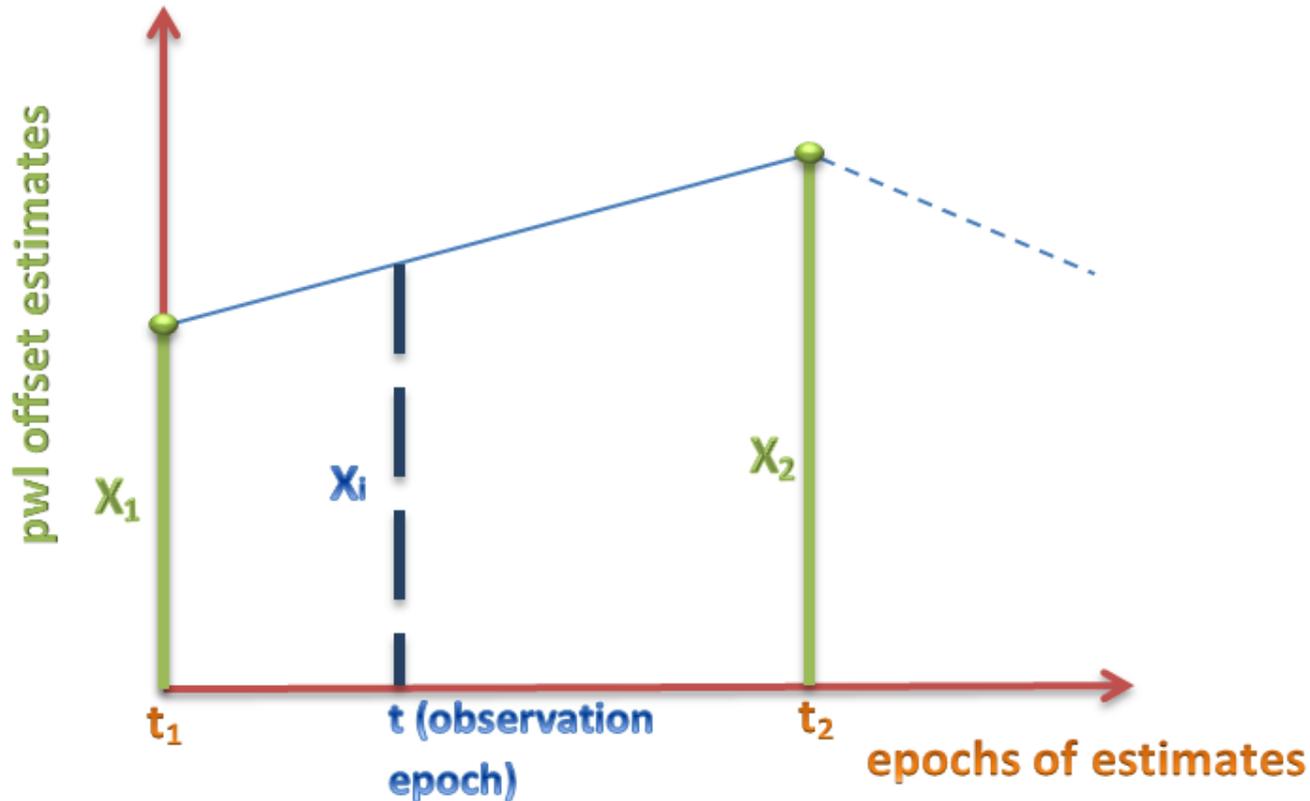
from NGS-card file, corrected for ionosphere

O-C

adjustment  
(lsm)



# Sürekli parçalı lineer ofset (CPWLO) fonksiyonu



$$x_i = x_1 + \frac{t - t_1}{t_2 - t_1} (x_2 - x_1)$$

# Ardışık epoklarda kestirilen parametrelere göre VLBI modelinin (ölçü denklemlerinin) kısmi türevleri

$$\frac{\partial \tau(t)}{\partial x_1} = \frac{\partial \tau(t)}{\partial x_i} \cdot \frac{\partial x_i}{\partial x_1} \rightarrow \frac{\partial x_i}{\partial x_1} = 1 - \frac{t - t_j}{t_{j+1} - t_j}$$

$$\frac{\partial \tau(t)}{\partial x_2} = \frac{\partial \tau(t)}{\partial x_i} \cdot \frac{\partial x_i}{\partial x_2} \rightarrow \frac{\partial x_i}{\partial x_2} = \frac{t - t_j}{t_{j+1} - t_j}$$

$$t_j < t < t_{j+1}$$

$x_i$  is the estimated parameter at  $t_j$  and  $t_{j+1}$

e.g.  **$\Delta\text{UT1}$**  is the estimated parameter at epochs **15:00** and **16:00 UTC**

# En Küçük Kareler (EKK) kestirimi

offset(t+1) - offset(t) = 0 ± m<sub>c\_rel</sub> → **relative constraints**

Example: m<sub>c\_rel</sub> = 30 mas/day → X<sub>pol</sub> CPWLO relative constraints are loose.

m<sub>c\_rel</sub> = 0.001 mas/day → X<sub>pol</sub> CPWLO relative constraints are tight.

offset(t) = 0 ± m<sub>c\_abs</sub> → **absolute constraints**

Example: m<sub>c\_abs</sub> = 2 mm → Troposphere east gradients absolute constraints are loose.

m<sub>c\_abs</sub> = 0.01 mm → Troposphere east gradients absolute constraints are tight.

$$N = \begin{bmatrix} A^T P A + H^T P_H H & C \\ C^T & 0 \end{bmatrix} \quad b = \begin{bmatrix} A^T P o c + H^T P_H o c h \\ b_c \end{bmatrix}$$

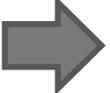
parameter vector  
(estimates)

$$x = N^{-1} b$$

Bagli kisitlayici denklemler  $x_{i,j+1} - x_{i,j} = 0 \pm m_{\Delta x}$

$$H_i = \begin{bmatrix} 1 & -1 & 0 & \dots & 0 & 0 \\ 0 & 1 & -1 & \dots & 0 & 0 \\ 0 & 0 & 1 & \dots & 0 & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & 0 & \dots & 1 & -1 \end{bmatrix}$$

$$m_0 = (v^T P v + v_H^T P_H v_H) / (n_{obs} + n_{constr} - n_{unk})$$

$K_x = m_0 N^{-1}$   variance-covariance matrix of the estimates

# TRF datum koşul denklemleri

Normal denklemlerin katsayıları matrisine eklenen koşul denklemleri (condition equations)

(TRF koordinat sistemine Helmert dönüşümü için NNT/NNR koşulları)

$$X_1 - X_0 = T + R \cdot X_0$$

$$\dot{X}_1 - \dot{X}_0 = \dot{T} + \dot{R} \cdot X_0 + R \cdot \dot{X}_0$$

$$T = \begin{bmatrix} T_X \\ T_Y \\ T_Z \end{bmatrix} \quad R = \begin{bmatrix} 0 & -R_Z & R_Y \\ R_Z & 0 & -R_X \\ -R_Y & R_X & 0 \end{bmatrix}$$

**IERS 2010**  
Konvansiyonlarına göre  
ihmal edilebilir. 100  
yılda 0.1 mm değişir.

$$\begin{bmatrix} X_1 - X_0 \\ Y_1 - Y_0 \\ Z_1 - Z_0 \\ v_{X_1} - v_{X_0} \\ v_{Y_1} - v_{Y_0} \\ v_{Z_1} - v_{Z_0} \end{bmatrix} = \begin{bmatrix} C & 0 \\ 0 & C \end{bmatrix} \begin{bmatrix} T_X \\ T_Y \\ T_Z \\ R_X \\ R_Y \\ R_Z \\ \dot{T}_X \\ \dot{T}_Y \\ \dot{T}_Z \\ \dot{R}_X \\ \dot{R}_Y \\ \dot{R}_Z \end{bmatrix}$$

$$C = \begin{bmatrix} 1 & 0 & 0 & 0 & Z_0 & -Y_0 \\ 0 & 1 & 0 & -Z_0 & 0 & X_0 \\ 0 & 0 & 1 & Y_0 & -X_0 & 0 \end{bmatrix}$$

$$N = \begin{bmatrix} A^T P A + H^T P_H H & C \\ C^T & 0 \end{bmatrix}$$

## Dizayn matrisi – örnek

Üç radyo teleskobunun, bir kuasara yaptığı taramadan (scan) elde edilen üç ölçüyü içeren, tek kestirim aralıklı dizayn matrisi

$$\begin{bmatrix} \frac{d\tau^1}{dx_{1,1}} & \frac{d\tau^1}{dx_{1,2}} & \frac{-d\tau^1}{dx_{2,1}} & \frac{-d\tau^1}{dx_{2,2}} & 0 & 0 \\ 0 & 0 & \frac{d\tau^2}{dx_{2,1}} & \frac{d\tau^2}{dx_{2,2}} & \frac{-d\tau^2}{dx_{3,1}} & \frac{-d\tau^2}{dx_{3,2}} \\ \frac{d\tau^3}{dx_{1,1}} & \frac{d\tau^3}{dx_{1,2}} & 0 & 0 & \frac{-d\tau^3}{dx_{3,1}} & \frac{-d\tau^3}{dx_{3,2}} \end{bmatrix}$$

# Dizayn matrisi – A (1. bölüm)

A(1).sm (Clock error model, piecewise linear offsets)	A(2).sm (Clock error model, rates & quadratic terms)	A(3).sm (Tropospheric zenith wet delay (zwd) model, pwl offsets)	A(4).sm (Tropospheric north gradients, pwl offsets)	A(5).sm (Tropospheric east gradients, pwl offsets)	A(6).sm (Earth Orientation Parameters (EOP), Xpol, pwl offsets)	A(7).sm (EOP, Ypol, pwl offsets)	A(8).sm (EOP, dUT1, pwl offsets)	
H(1).sm (Relative constraints between clock pwl offsets)	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	
<u>0</u>	<u>0</u>	H(3).sm (Relative constraints)	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	
<u>0</u>	<u>0</u>	<u>0</u>	H(4).sm (Relative constraints)	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	.
<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	H(5).sm (Relative constraints)	<u>0</u>	<u>0</u>	<u>0</u>	.
<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	H(6).sm (Relative constraints)	<u>0</u>	<u>0</u>	.
<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	H(7).sm (Relative constraints)	<u>0</u>	.
<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	H(8).sm (Relative constraints)	.
. . .								.

# Dizayn matrisi – A (2. bölüm)

A(9).sm (EOP, nutation in obliquity (nutdx ~ deps) pwl offsets)	A(10).sm (EOP, nutation in celestial longitude (nutdy ~ dpsi) pwl offsets)	A(11).sm (Source coordinates (Greenwich hour angle, right ascension) pwl offsets)	A(12).sm (Source coordinates (CRF) (declination) pwl offsets)	A(13).sm (Antenna coordinates (TRF) (dX) one offset or pwl offsets)	A(14).sm (Antenna coordinates (TRF) (dY) one offset or pwl offsets)	A(15).sm (Antenna coordinates (TRF) (dZ) one offset or pwl offsets)
<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>
<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>
<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>
<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>
<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>
<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>
<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>
H(9).sm (Relative constraints)	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>
<u>0</u>	H(10).sm (Relative constraints)	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>
<u>0</u>	<u>0</u>	H(11).sm (Relative constraints)	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>
<u>0</u>	<u>0</u>	<u>0</u>	H(12).sm (Relative constraints)	<u>0</u>	<u>0</u>	<u>0</u>
<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	H(13).sm (Relative constraints)	<u>0</u>	<u>0</u>
<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	H(14).sm (Relative constraints)	<u>0</u>
<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	H(15).sm (Relative constraints)

# Normal denklem sistemi katsayıları matrisi - N

Saat hata modeli pwl ofsetleri						
	Saat hata modeli rate ve kuadratik terimleri					
		• • •				
			Source koordinatları pwl ofsetleri [N <sub>ra</sub> & N <sub>de</sub> ]			Source koordinatları NNR koşul denklemleri
				istasyon koordinatları pwl ofsetleri [ N <sub>x</sub> , N <sub>y</sub> , N <sub>z</sub> ]	istasyon koordinatları NNT/NNR koşul denklemleri	
				Istasyon koordinatları NNT/NNR koşul denklemleri	<u>0</u> <sub>6x6</sub>	
			Source koordinatları NNR koşul denklemleri			<u>0</u> <sub>2x2</sub>

YER DÖNME PARAMETRELERİ  
(EARTH ORIENTATION PARAMETERS - EOP)

$X_P, Y_P, \Delta UT1, \Delta X, \Delta Y$

YER DÖNÜKLÜK PARAMETRELERİ  
(EARTH ROTATION PARAMETERS - ERP)

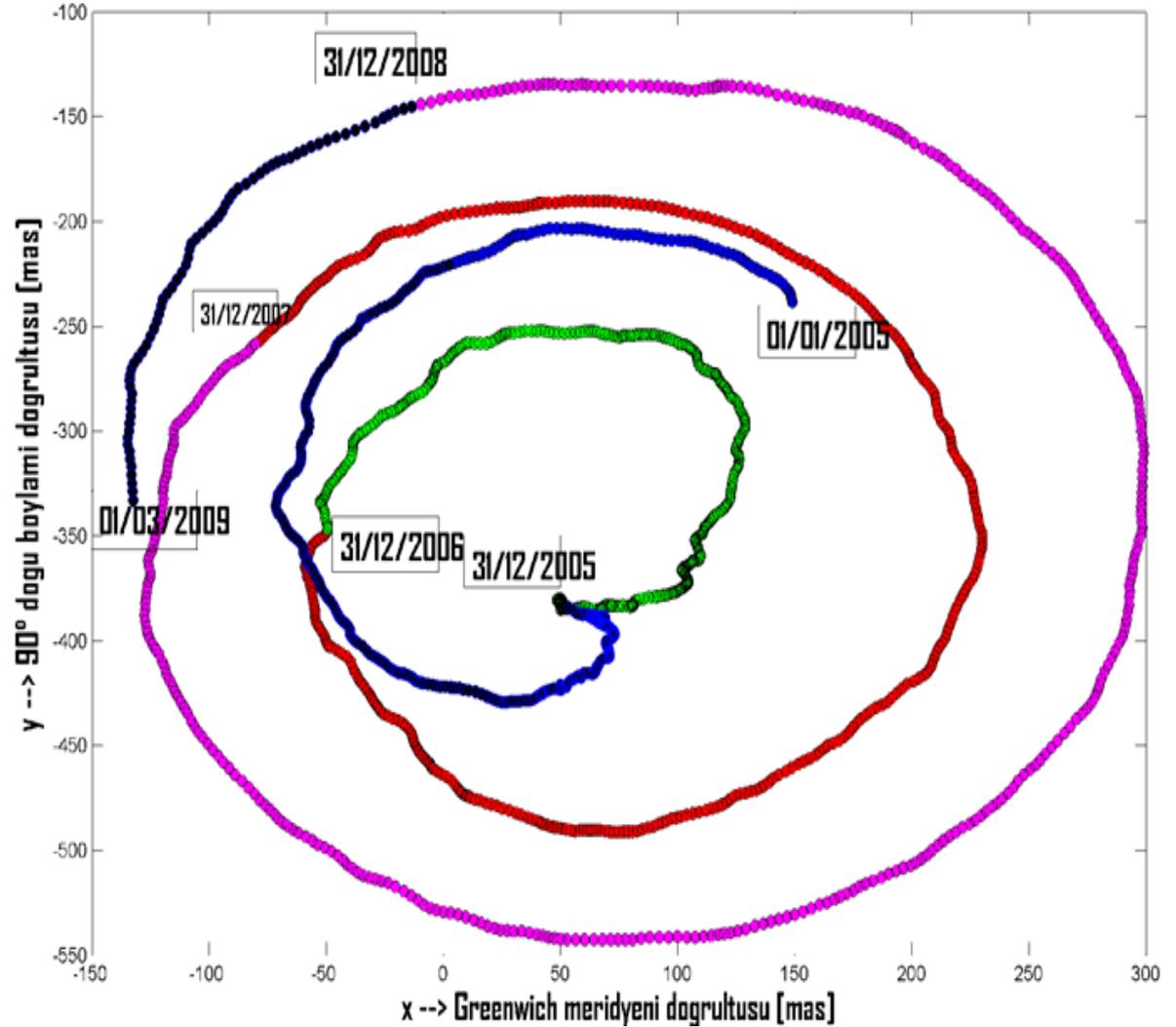
$X_P, Y_P, \Delta UT1$

# Kutup gezinmesi - $x_p$ , $y_p$

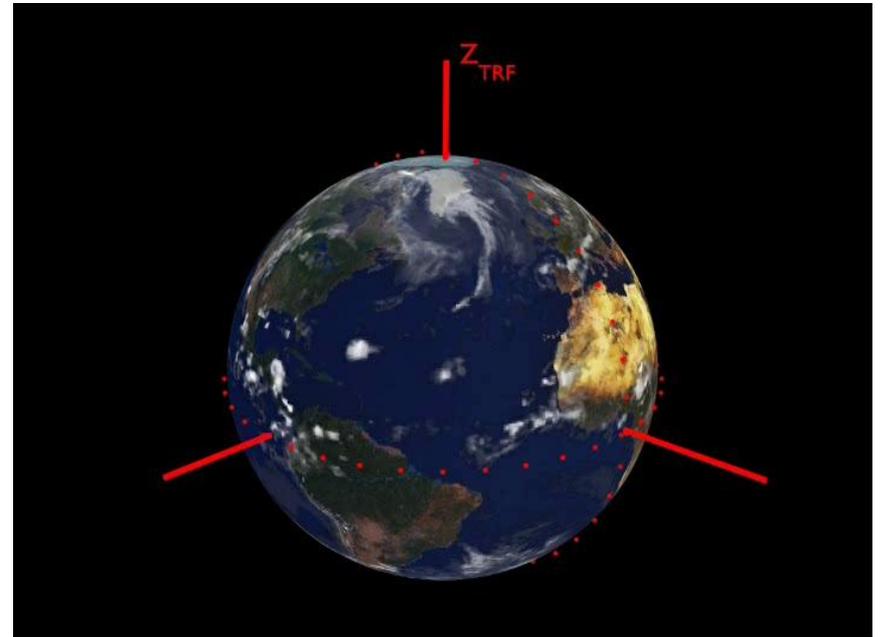
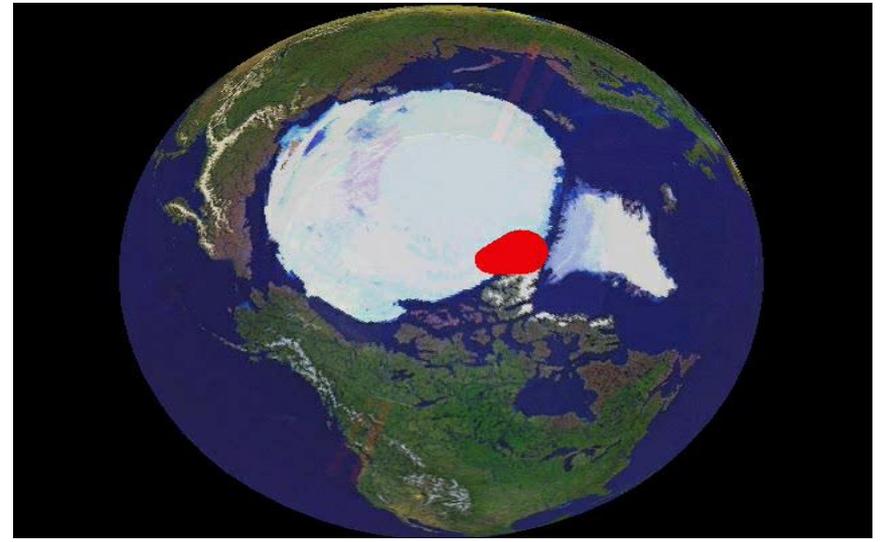
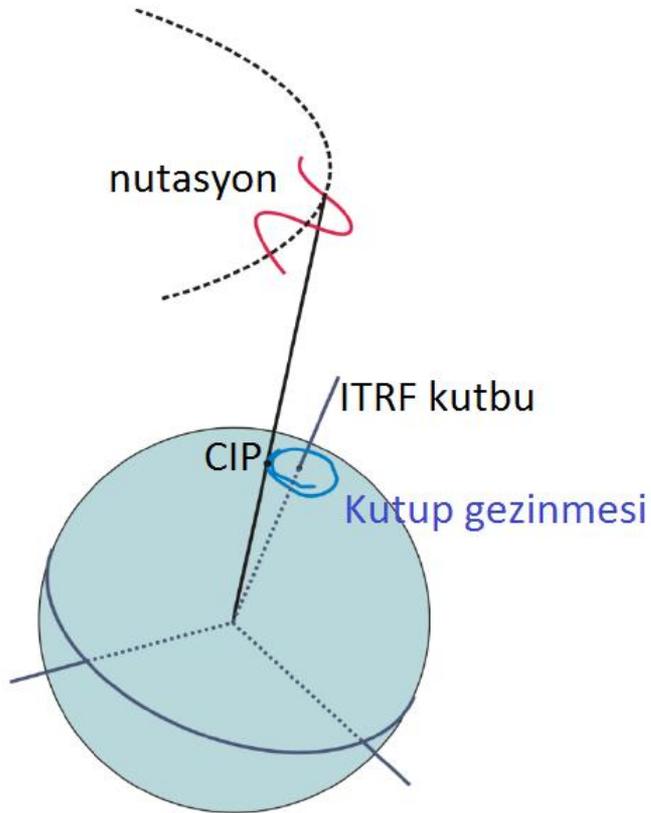
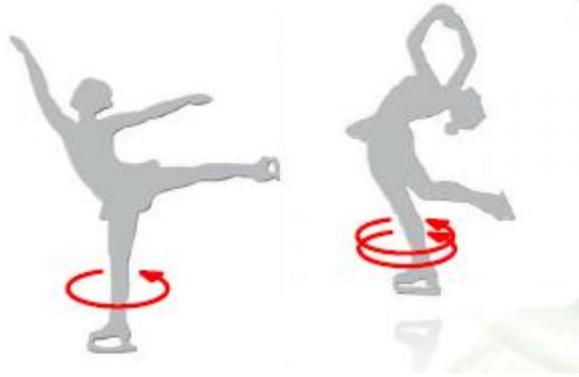
**Yerin ortalama dönme eksenini:** Yer'in açısal dönme momentini maksimum yapan eksen, şekil eksenini, figure axis.

**Kutup gezinmesi:** Yer'in ortalama dönme ekseninin (CIP) kabuk üzerindeki izi (hareketi). Saat ibresinin tersi yönünde 18-21 metre (0.6-0.7 açı saniyesi) çaplı daireler çizer.

Periyotları ~430 gün (Chandler wobble), bir yıl, ve konvansiyonlar gereği iki günden az (HF-ERP) olan tüm anlamlı harmonik eksen hareketleridir.

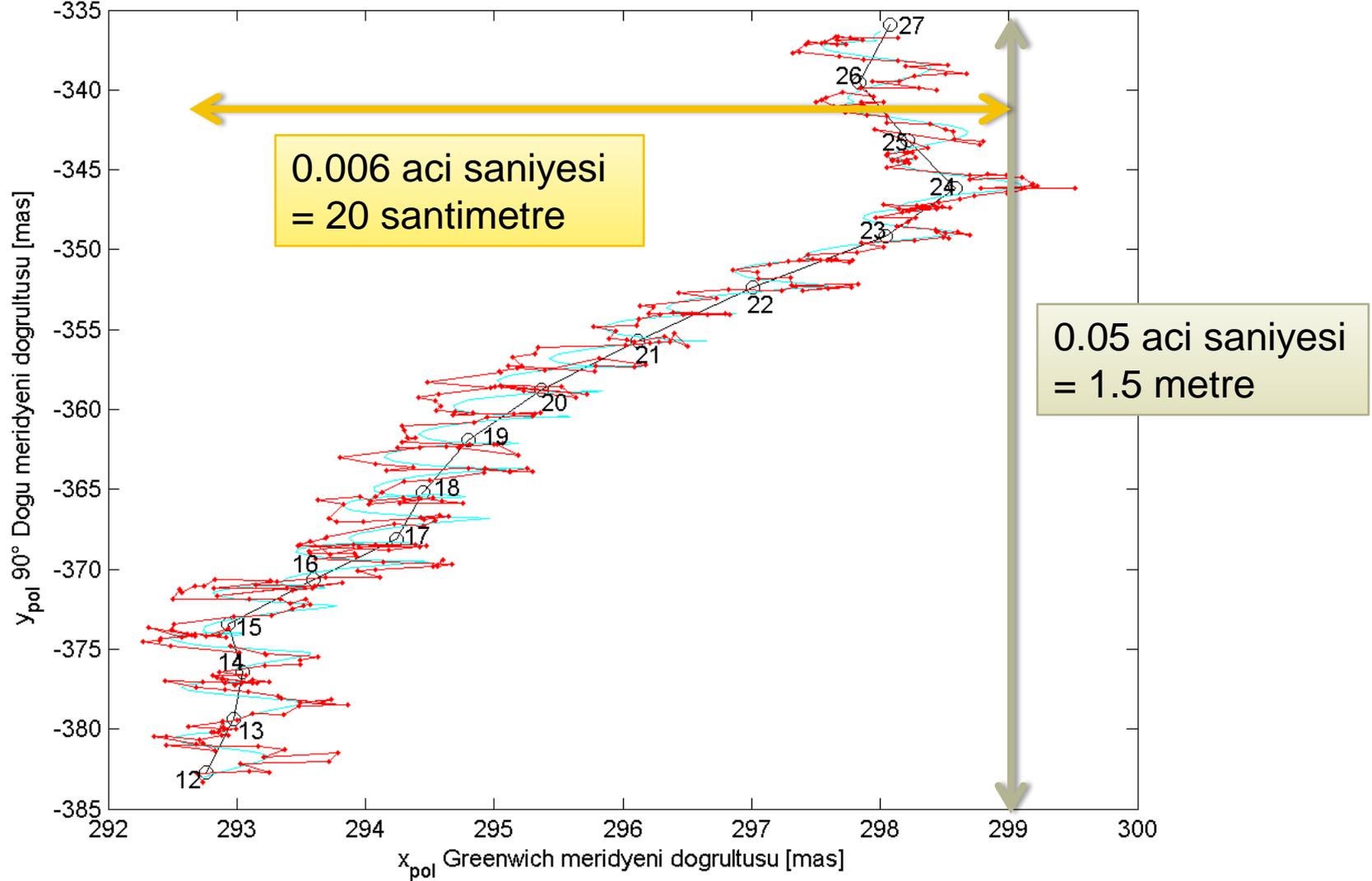


# Kutup gezinmesi

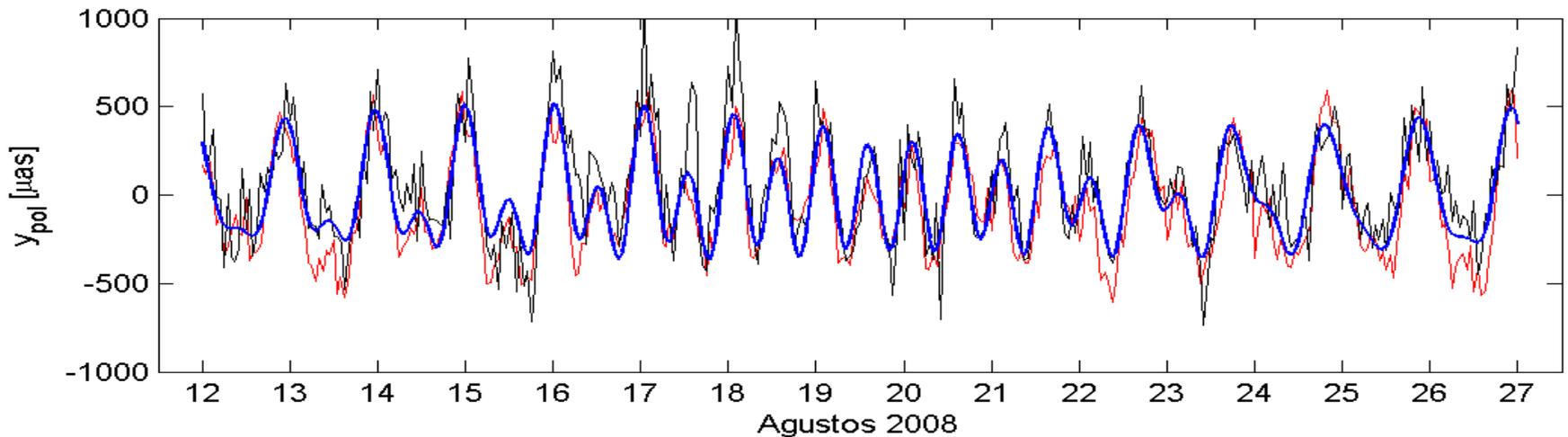
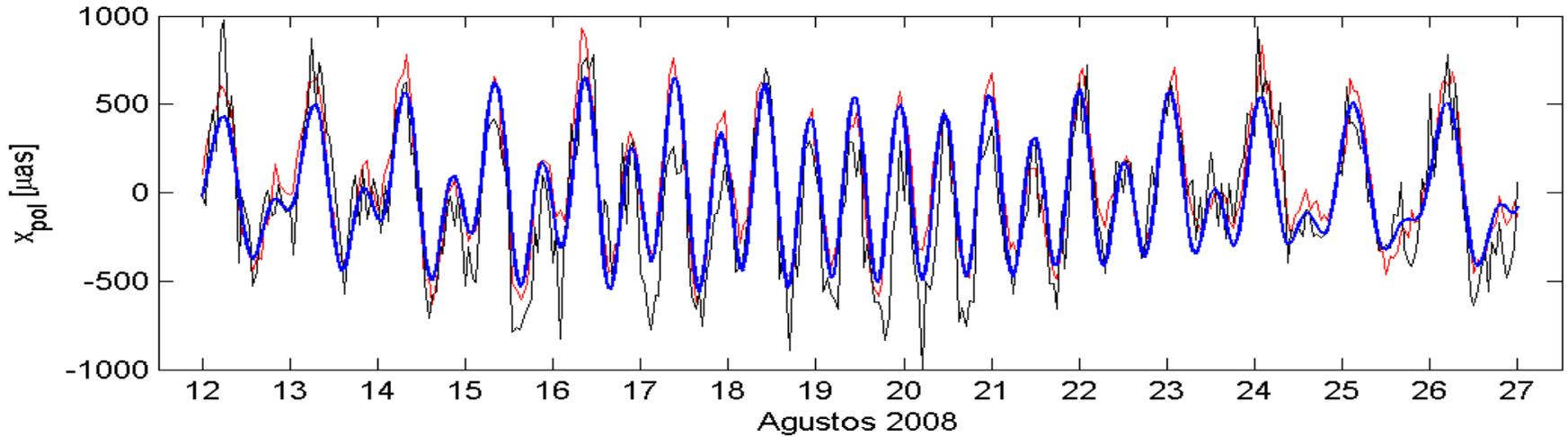


Obseratoire Royal de Belgique  
alınmıştır.

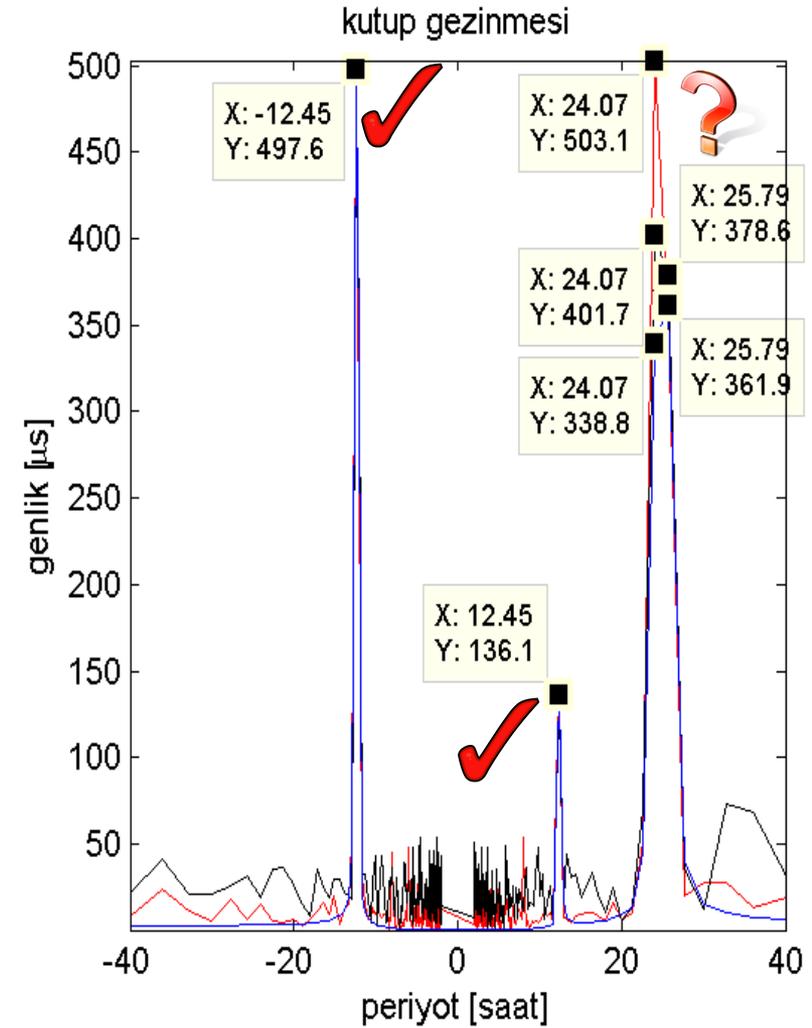
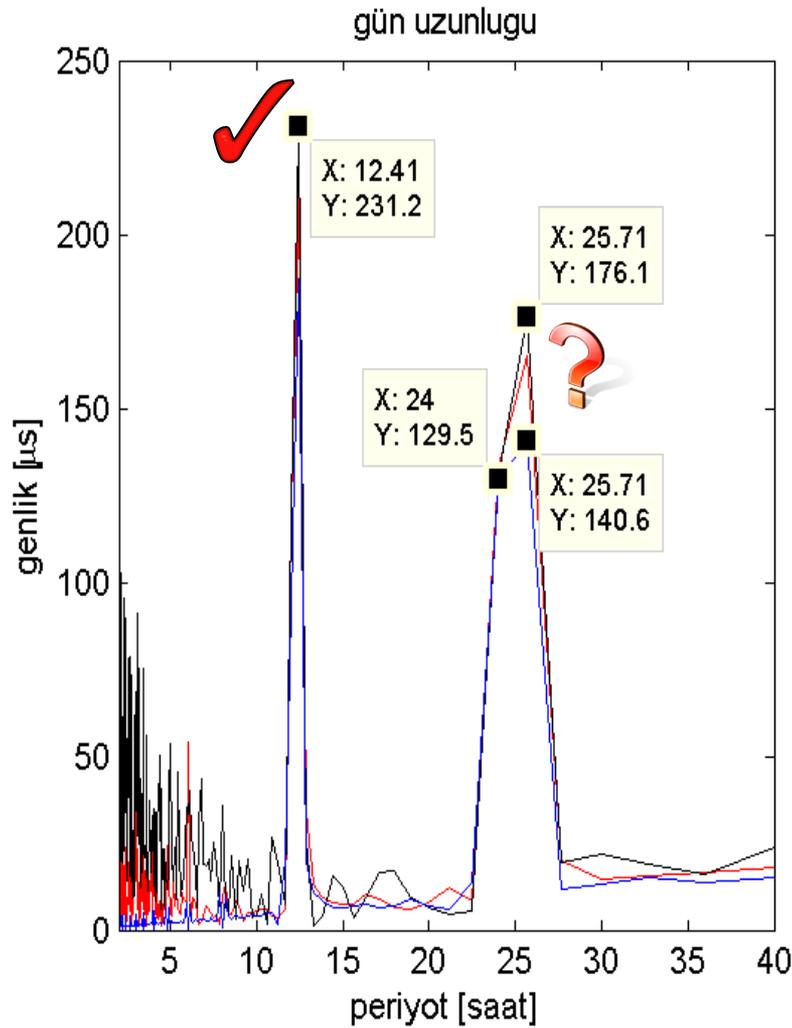
# 15 günlük (12-26 Agustos 2008) kutup gezinmesi (VLBI vs Model) UTC saat başı epokları



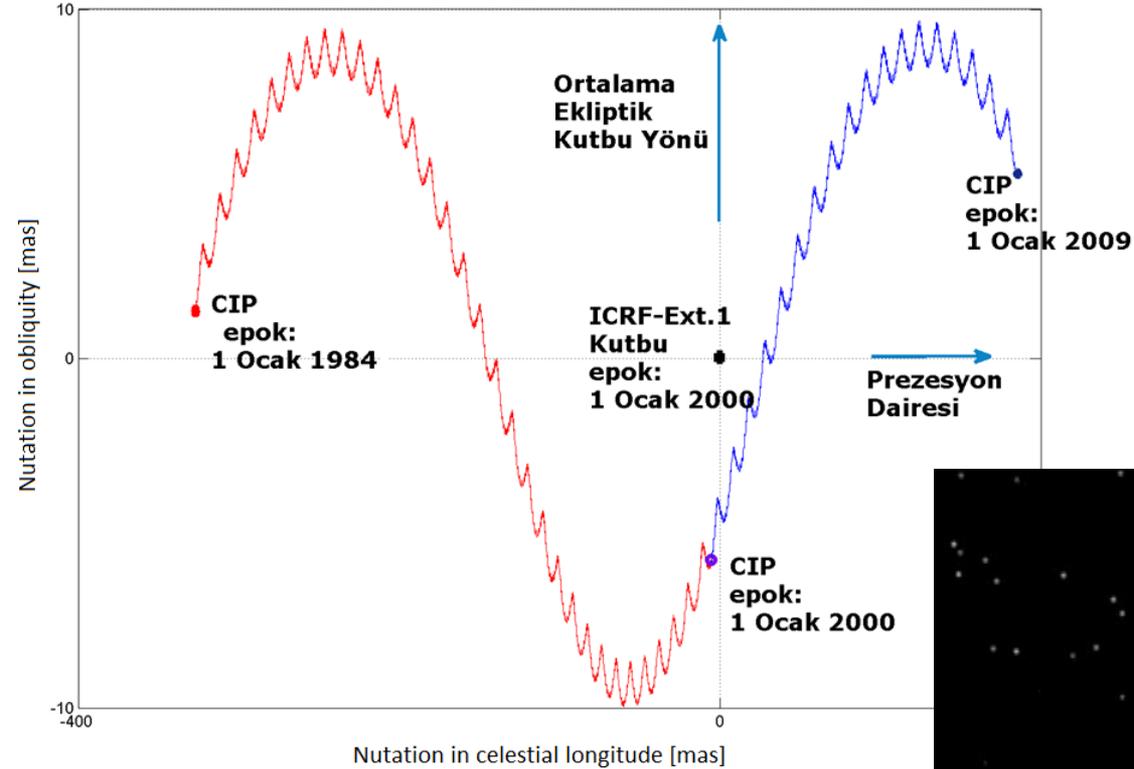
# 15 günlük (12-26 Agustos 2008) kutup gezinmesi (VLBI, HF-ERP Model, GPS) UTC saat başı epokları



# Gün uzunluğu ve kutup gezinmesi Fourier Spektralleri



# Nutasyon – X, Y



**Nutasyon:** Yer'in ortalama dönme ekseninin (CIP) uzayda seküler (lineer olmayan trend) ve periyodik (harmonik) hareketleri. Nutasyon periyodu 18.6 yıl (en büyük genlik) ile 2 gün arasındaki tüm anlamlı

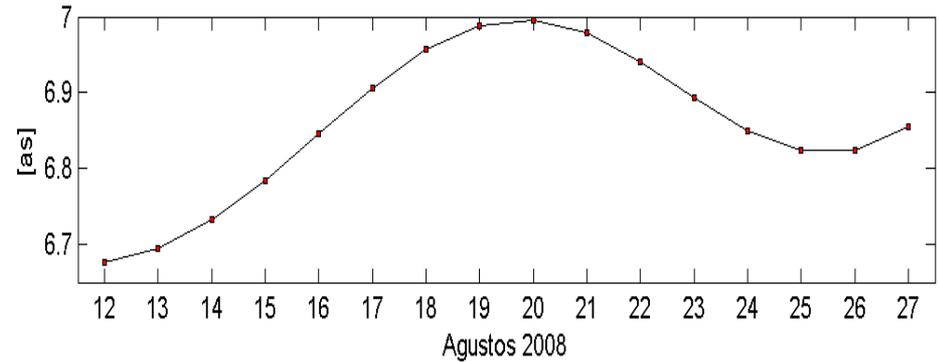
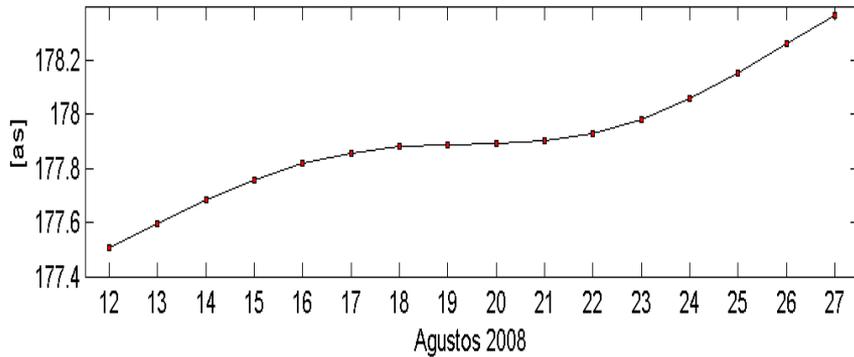
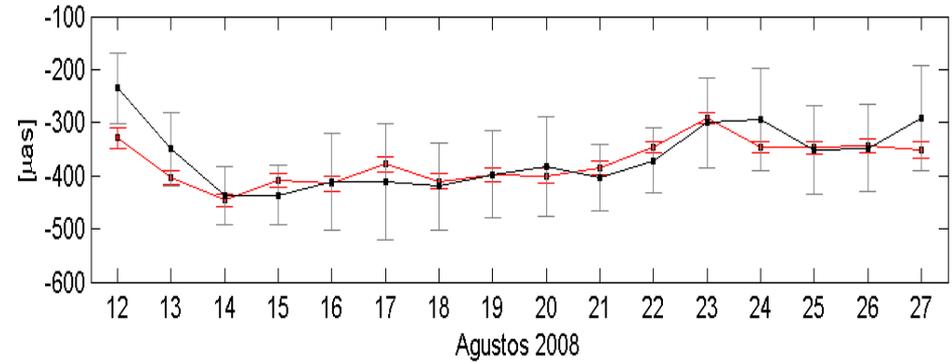
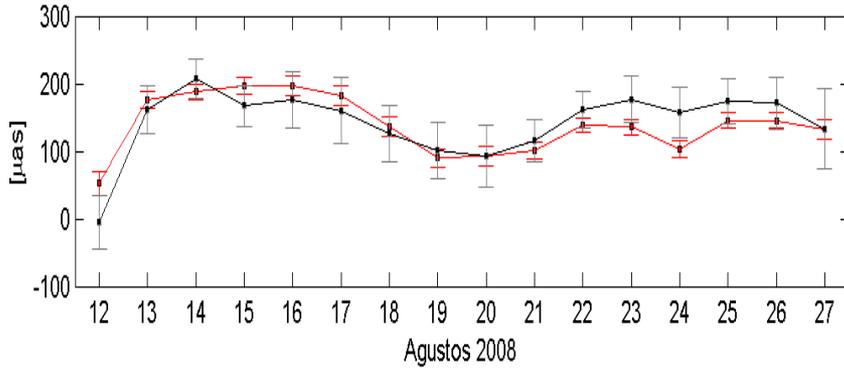
Presesyon periyodu ~25800 yıl (platonik yıl).



# 15 günlük (12-26 Agustos 2008) nutasyon

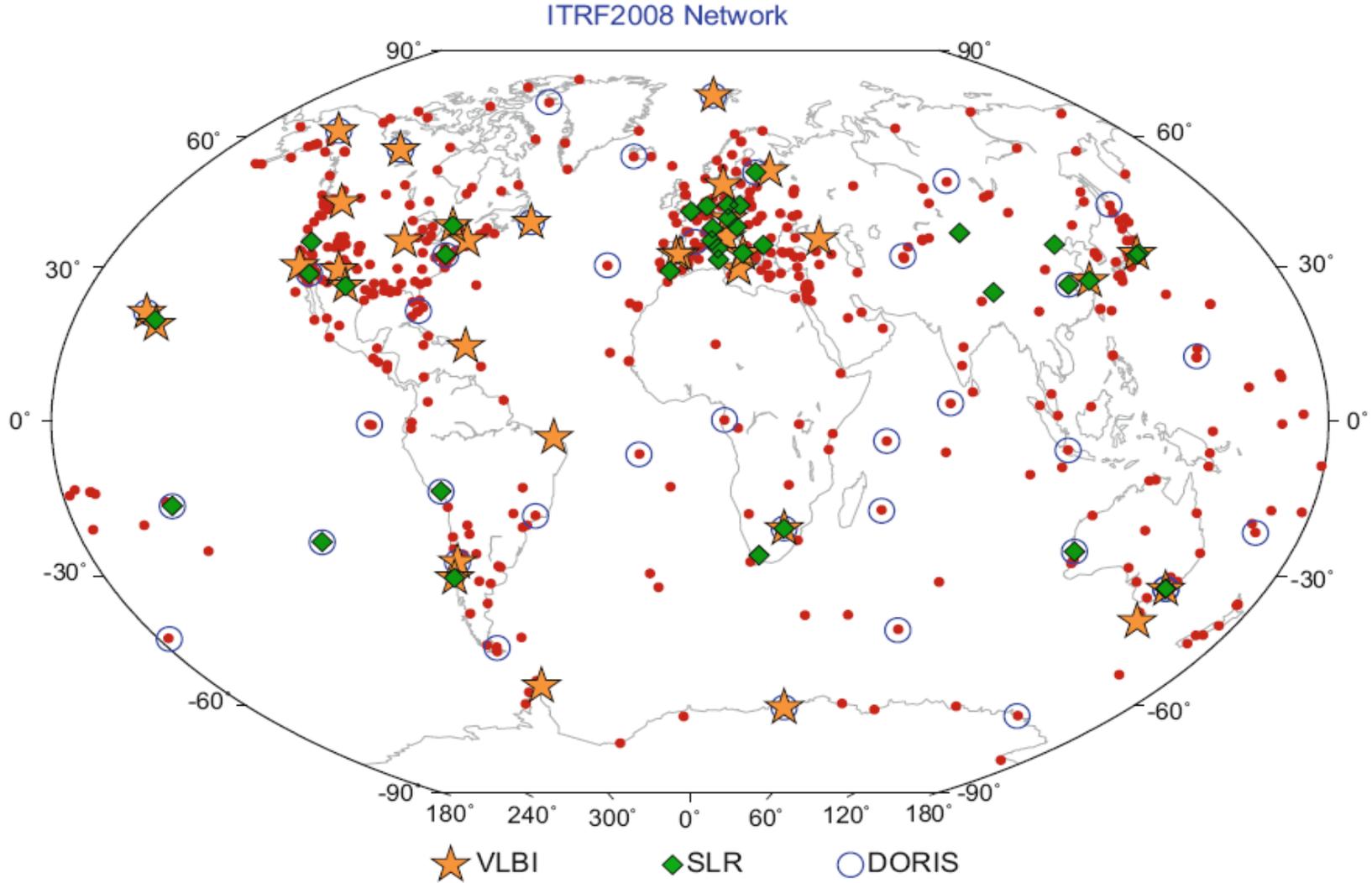
$$(X, Y) = (X, Y)_{IAU\ 2000A\ model} + (dX, dY)_{VLBI}$$

IVS-CONT08 oturumları 0:00 UTC epoklu nutasyon dX (sol), ve dY (sağ) parçalı lineer ofset kestirimleri (VieVS yazılımı, IAU 2000A presesyon-nutasyon modeli)



TRF  
(Tide free crust)

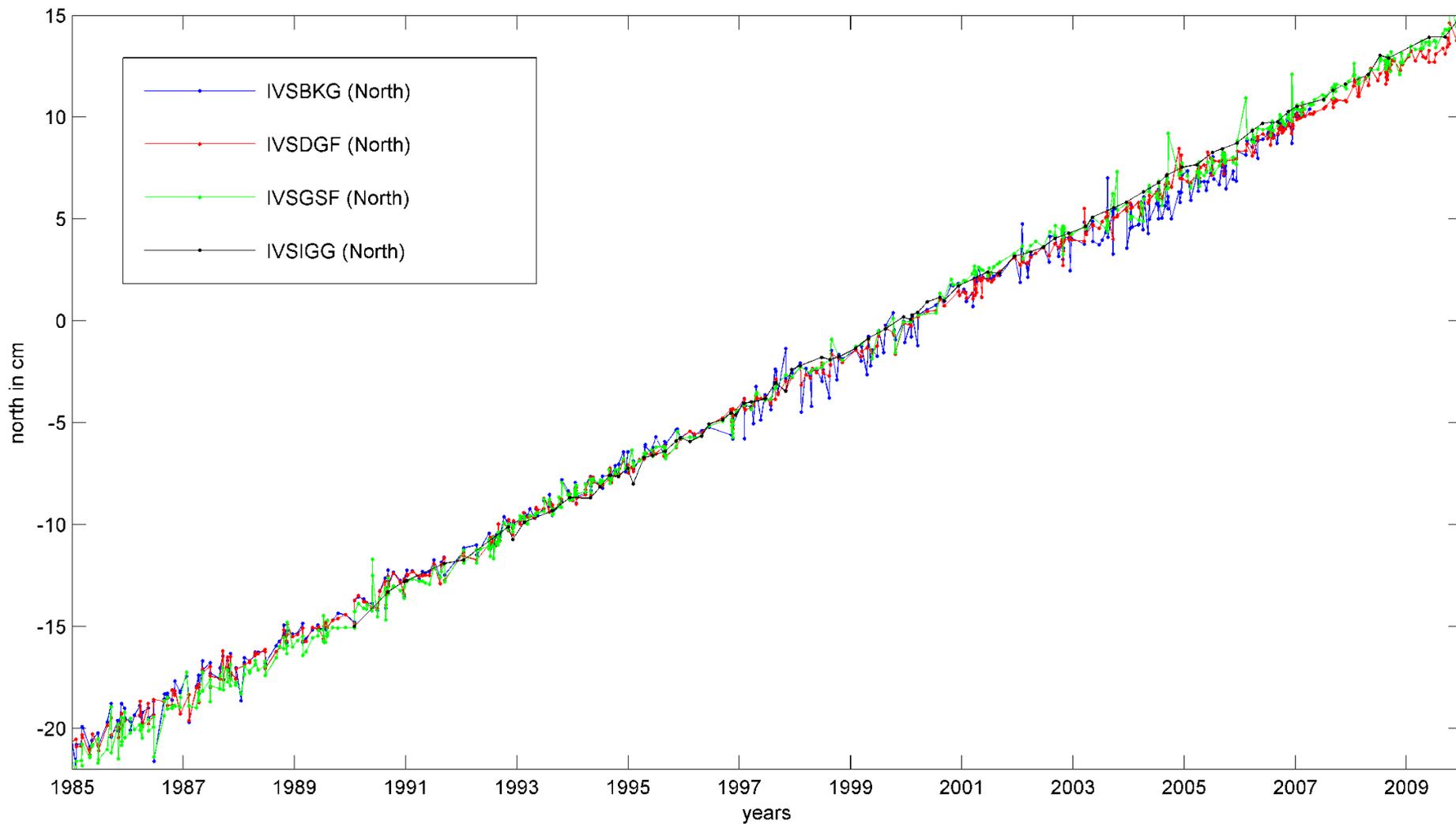
# ITRF 2008 ortak yerleşkeleri



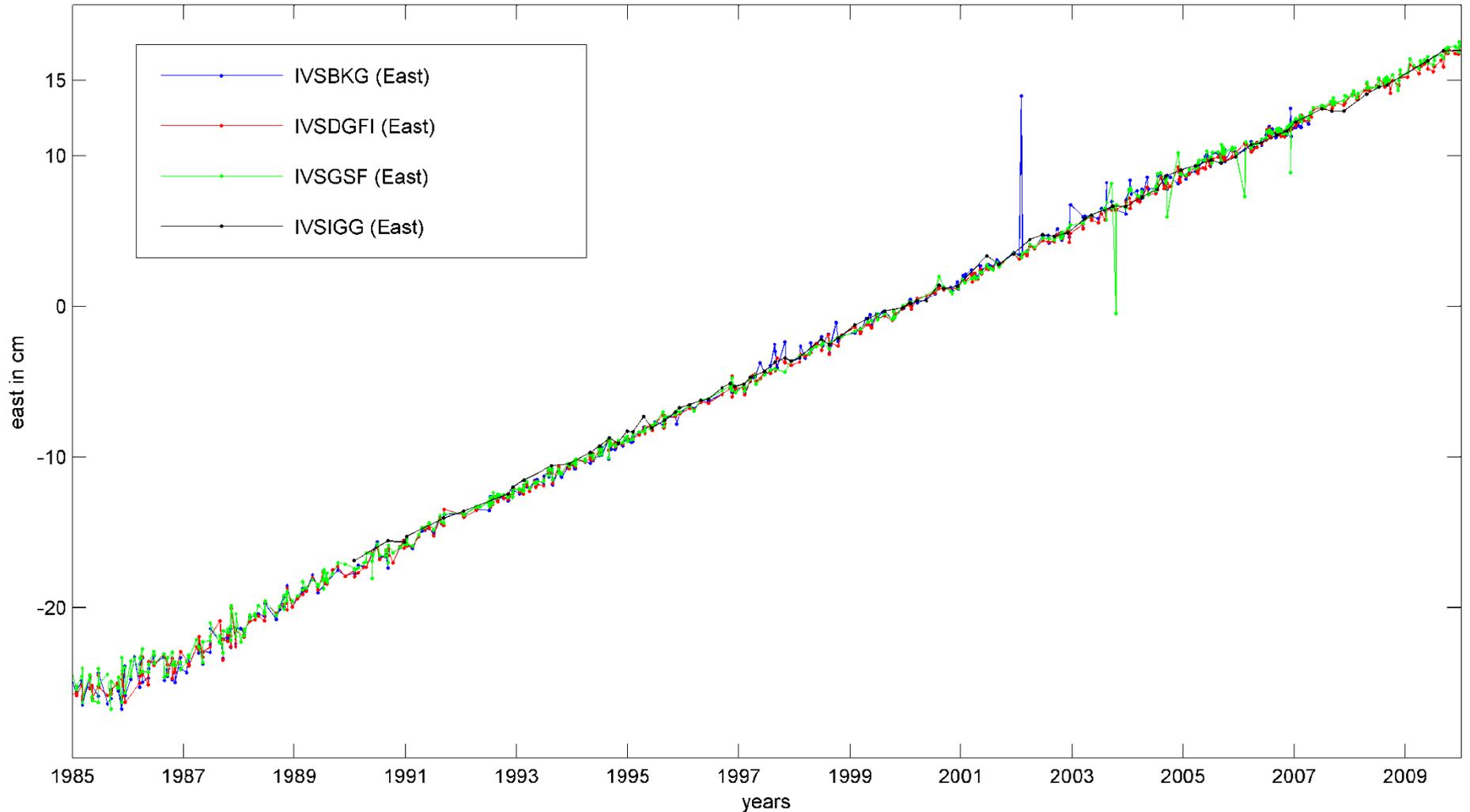
980 istasyon, 580 kampüs, 463 kuzey yarım küre, 117 güney yarım küre, 84 kampüs en az iki teknik ... daha fazla bilgi için aşağıdaki makaleyi okuyunuz.

Z. Altamimi, X. Collilieux, L. Métivier: **ITRF2008: an improved solution of the international terrestrial reference frame**, Journal of geodesy, 2011, DOI: 10.1007/s00190-011-0444-4.

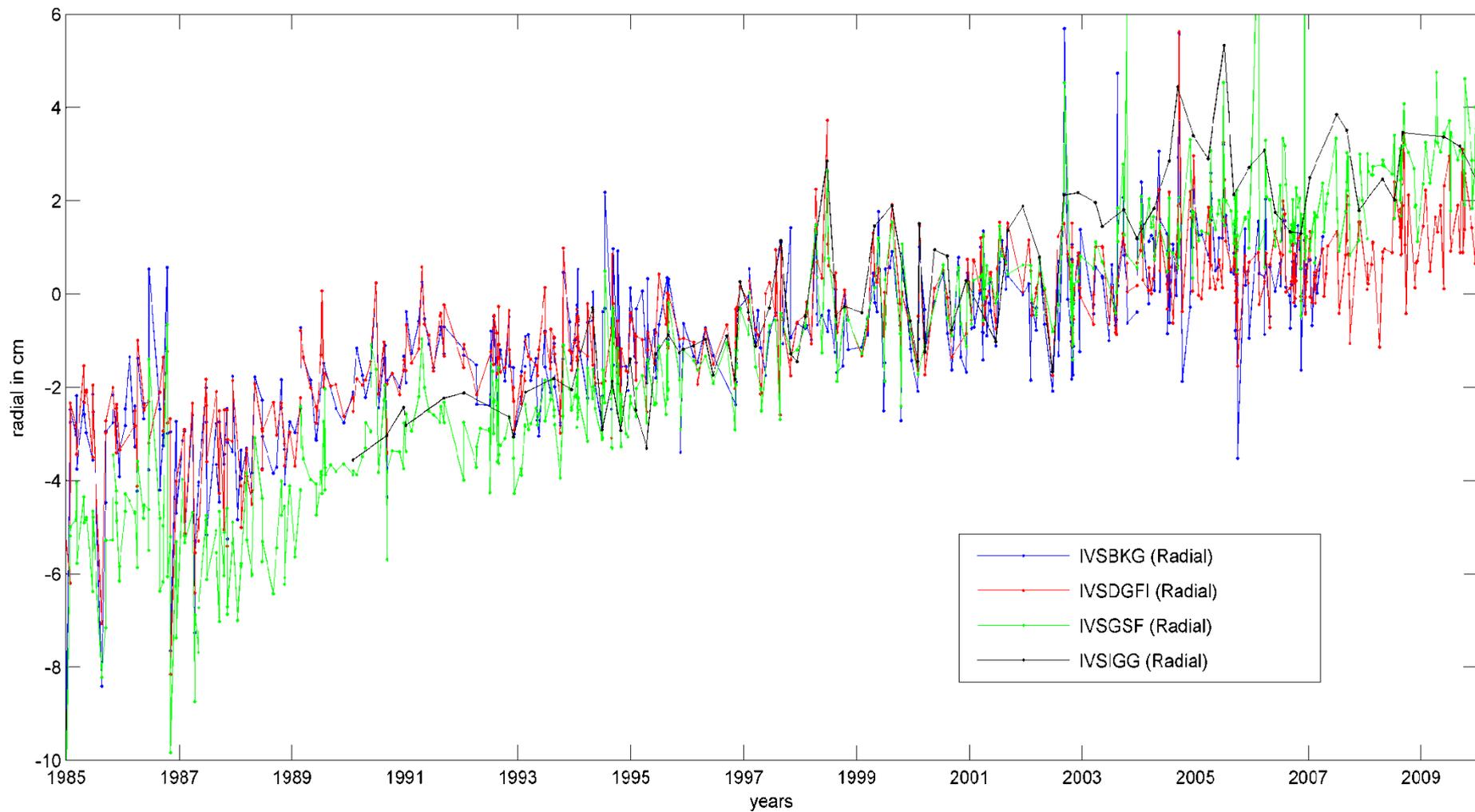
# ONSALA60 VLBI ANTENNA NORTH COORDINATE ESTIMATES FROM THE SOLUTIONS OF DIFFERENT IVS-ACS



# ONSALA60 VLBI ANTENNA EAST COORDINATE ESTIMATES FROM THE SOLUTIONS OF DIFFERENT IVS-ACS

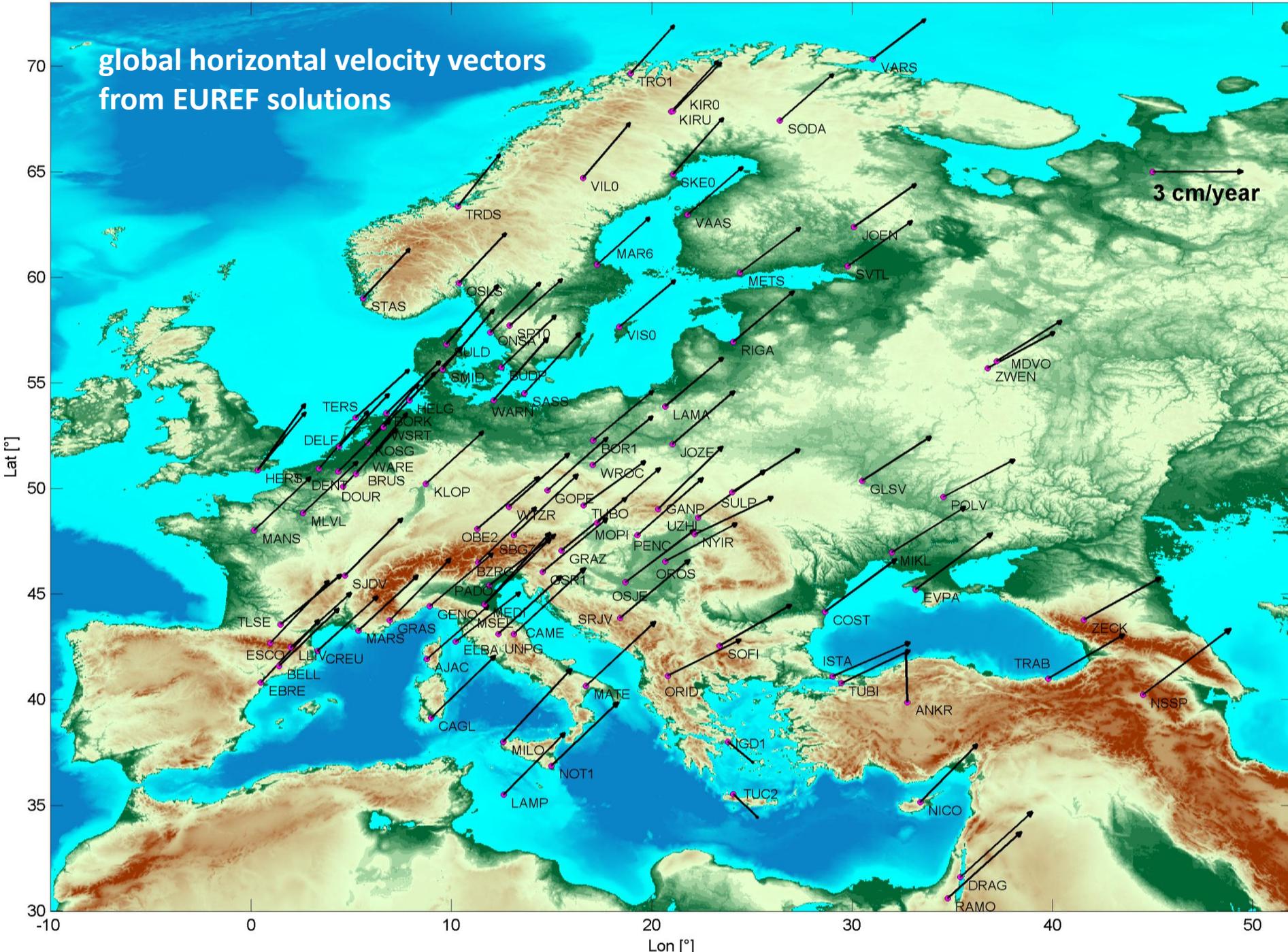


# ONSALA60 VLBI ANTENNA RADIAL COORDINATE ESTIMATES FROM THE SOLUTIONS OF DIFFERENT IVS-ACS



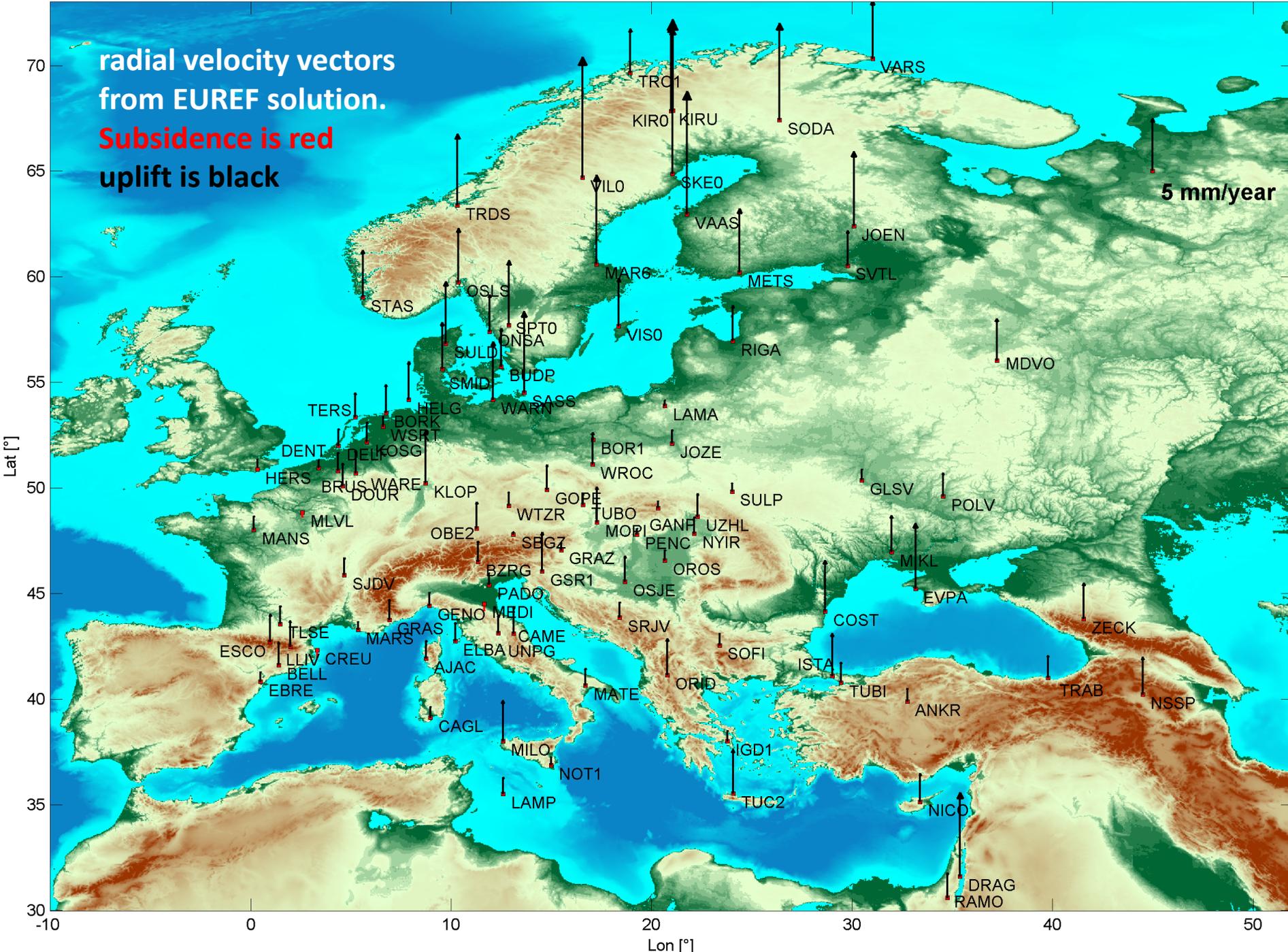
# global horizontal velocity vectors from EUREF solutions

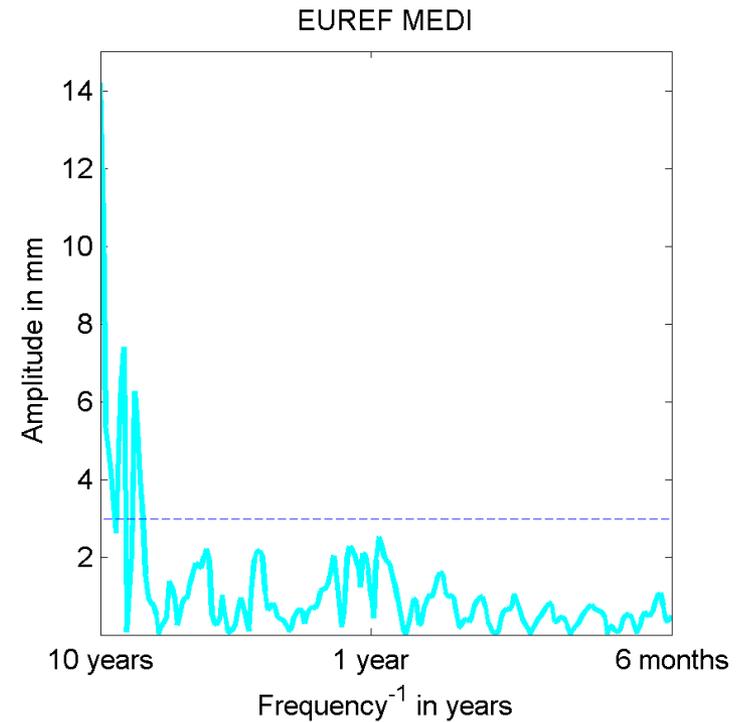
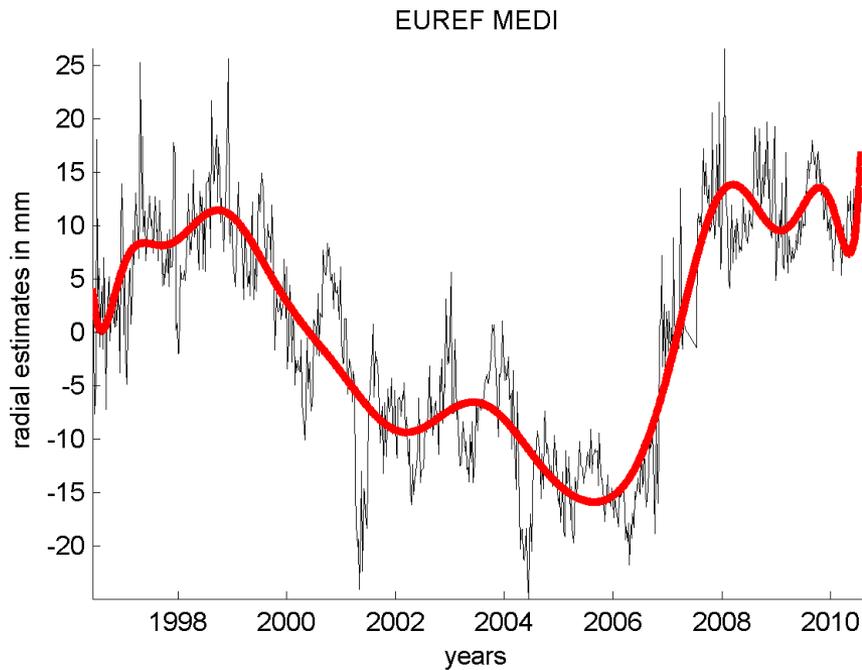
3 cm/year



radial velocity vectors  
from EUREF solution.  
Subsidence is red  
uplift is black

5 mm/year

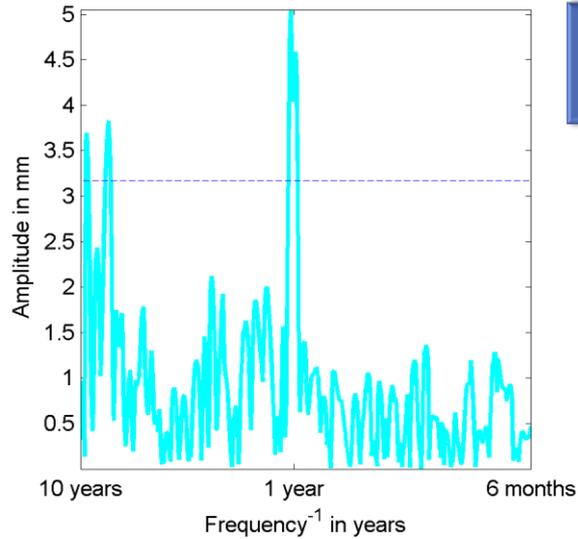




Co-located sites in Europe	IVS-DGFI			EUREF		
	$V_{\text{north}}$ (~time span) (cm/year)	$v_{\text{east}}$ (cm/year)	$V_{\text{radial}}$ (cm/year)	$V_{\text{north}}$	$v_{\text{east}}$	$V_{\text{radial}}$
Wetzell (Germany)-WTZR	1.5 (~26)	2.0	-0.1	1.7 (~14)	2.0	0.1
Onsala60 (Sweden)-ONSA	1.4 (~26)	1.7	0.2	1.6 (~14)	1.7	0.3
Matera (Italy)-MATE	1.8 (~19)	2.4	-0.1	2.0 (~14)	2.3	0.2
Zelenchukskaya (Russia)-ZECK	0.8 (~4)	2.5	0.4	1.3 (~13)	2.5	0.3
Medicina (Italy)-MEDI	1.7 (~22)	2.2	-0.3	2.1 (~14)	2.2	-0.1

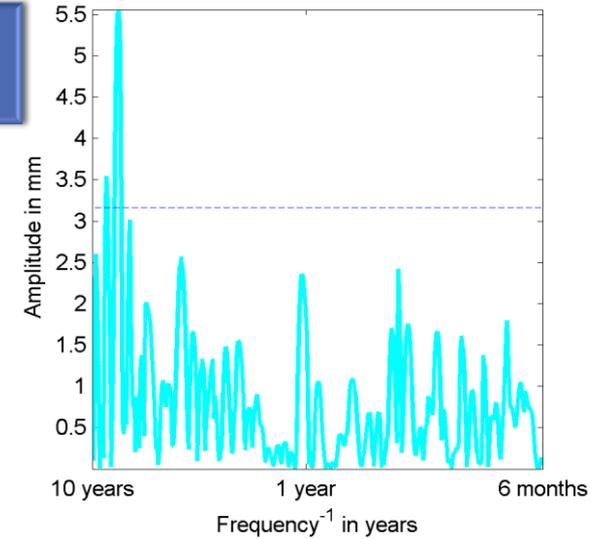
The harmonic function LS fit to the radial position estimates of different ACs. The frequencies included in the function were derived from the significant spectral peaks of Lomb-Scargle periodogram.

IVS DGFI WETTZELL

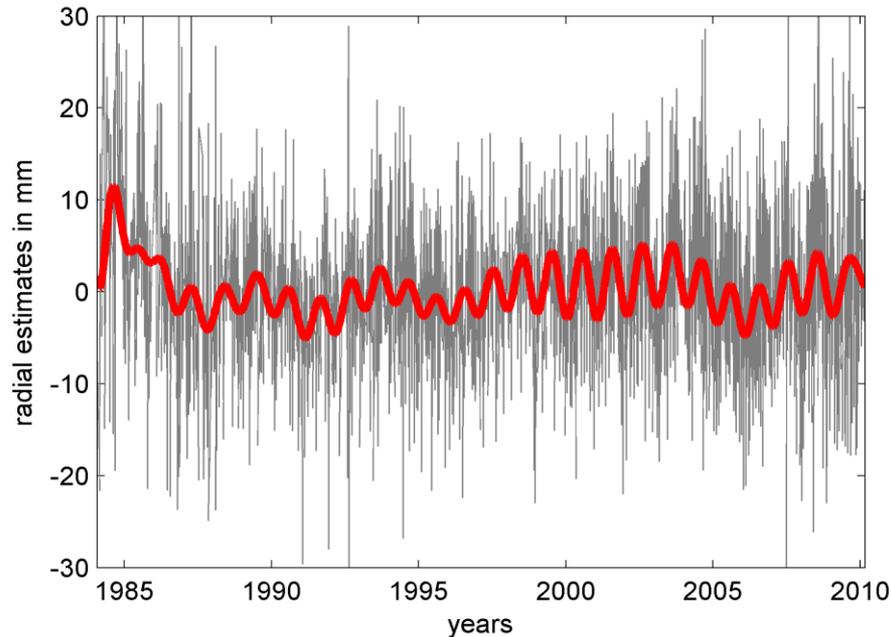


**IVS SPECIAL SESSIONS FOR  
EOP and TRF estimation**

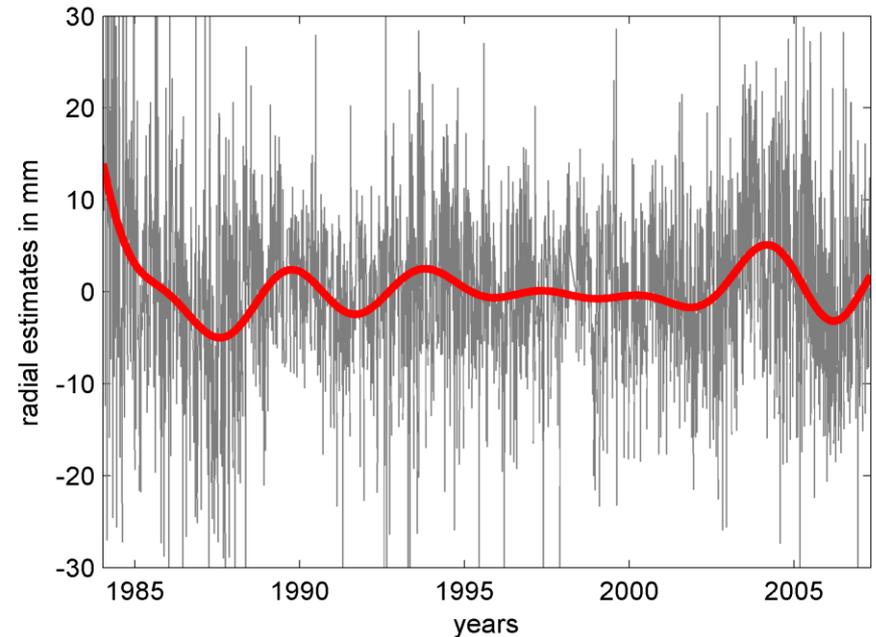
IVS BKG WETTZELL



IVS DGFI WETTZELL



IVS BKG WETTZELL



CRF

# ICRF2

- 3414 (1448 + 1966) kompakt (position stability + source structure) radyo source (quasi-stellar radio source: quasar) icerir. ICRF1 katalogunun bes katından fazla.
- Source koordinatlarının gürültü tabanı (noise floor) 40  $\mu$ s. ICRF1 noise floordan ~5-6 kat daha düşük (right ascension ve declination duyarlılığı daha fazla).
- Eksen stabilitesi (axis stability) 10  $\mu$ s. ICRF1'in iki kat daha stabil.
- ICRF2 (yeni CRF) ve ICRF1 (eski CRF) ile ortak 205 stable source ile alignment (yeni CRF koordinat sisteminin eski sistemle olan dönüklüklerinin sıfır olması (dönüklüğünün olmaması) : NNR kosulu) gerçekleştirilmiştir.
- Yeni ICRS gerçekleştirmeleri için NNR koşullarının uygulanacağı 295 source aşağıdaki kriterlere uygun oldukları için seçilmiştir:
  - Uniform gökyüzü dağılımı (uniform sky distribution)
  - Konum stabilitesi (positional stability)
  - Nokta görünümlü olmak (point like source structure)

# CRF datum koşul denklemleri

Normal denklemlerin katsayıları matrisine eklenen koşul denklemleri (Condition equations)

(CRF koordinat sistemine Helmert dönüşümü için NNR koşulları)

$$\alpha_1 - \alpha_0 = R_X \tan \delta_0 \cos \alpha_0 + R_Y \tan \delta_0 \sin \alpha_0 - R_Z$$

$$\delta_1 - \delta_0 = -R_X \sin \alpha_0 + R_Y \cos \alpha_0 + dz$$

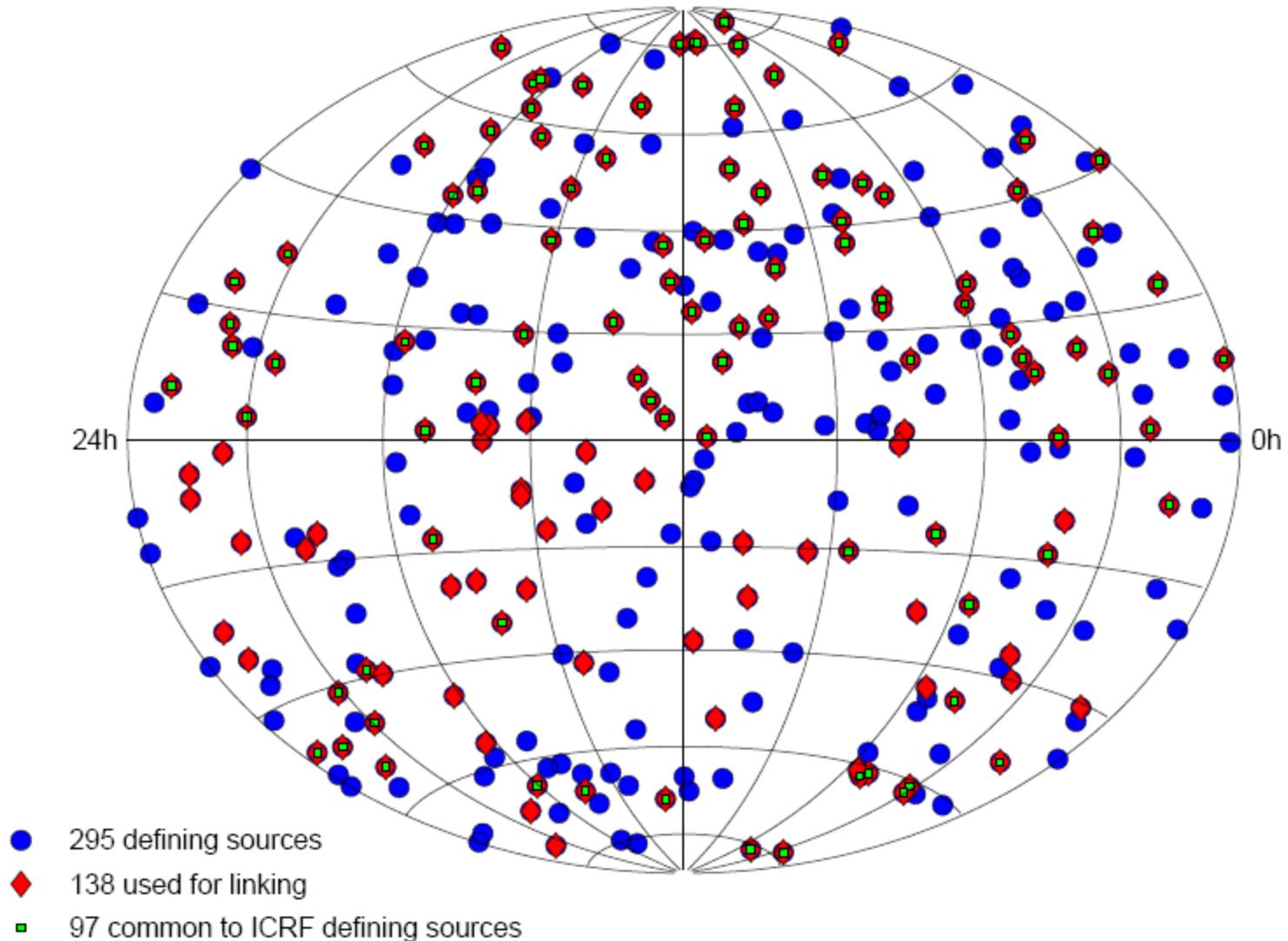
$$\begin{bmatrix} \alpha_1 - \alpha_0 \\ \delta_1 - \delta_0 \end{bmatrix} = C_{source} \begin{bmatrix} R_X \\ R_Y \\ R_Z \\ dz \end{bmatrix}$$

Source deklinasyon  
koordinatları global  
dönüşüm parametresi

$$C_{SOURCE} = \begin{bmatrix} \tan \delta_0 \cos \alpha_0 & \tan \delta_0 \sin \alpha_0 & -1 & 0 \\ -\sin \alpha_0 & \cos \alpha_0 & 0 & 1 \end{bmatrix}$$

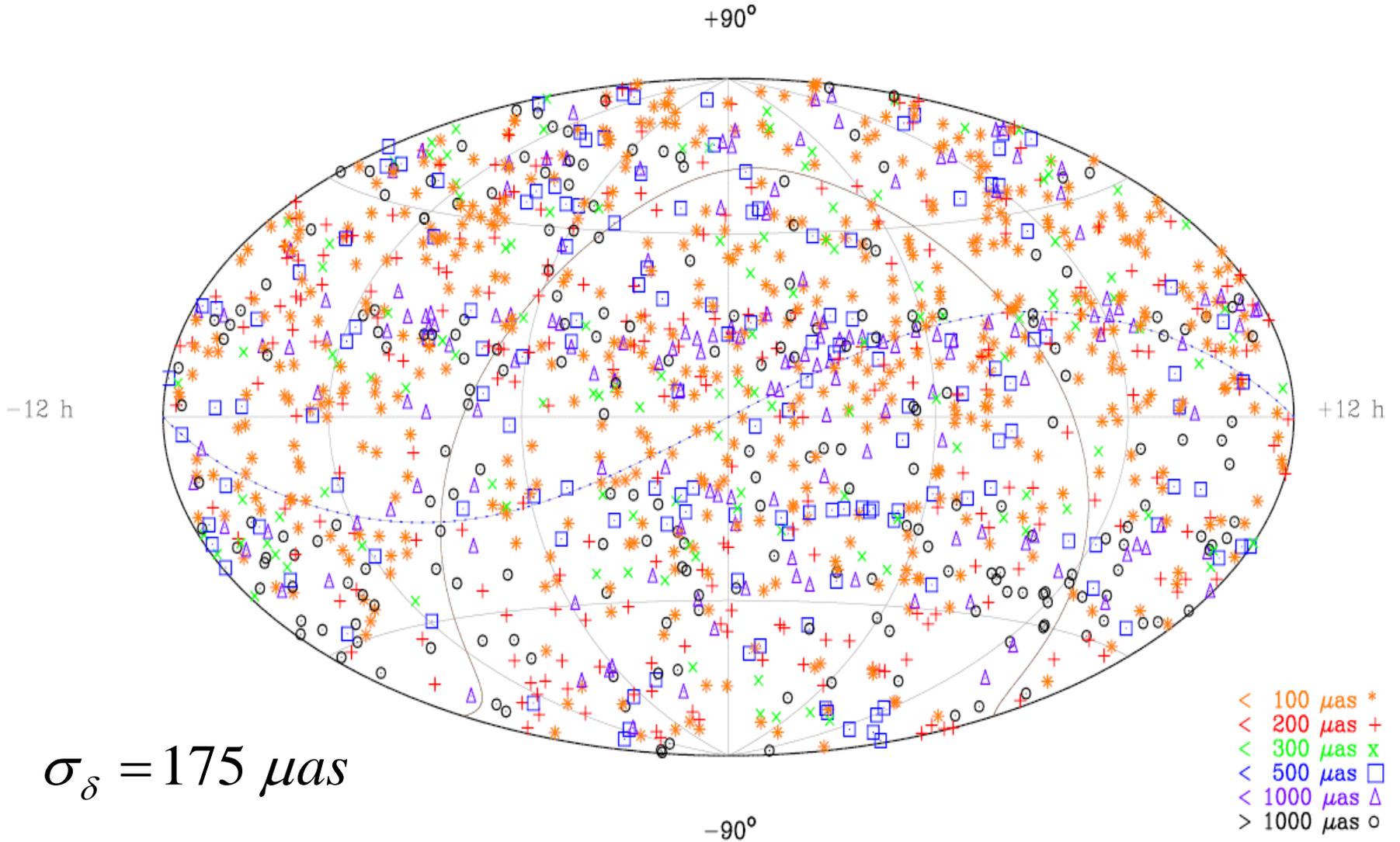
$$N = \begin{bmatrix} A^T P A + H^T P_H H & C_{SOURCE} \\ C_{SOURCE}^T & 0 \end{bmatrix}$$

# ICRF2



Fey A, Gordon D, Jacobs CS (2009) **The second realization of the international celestial reference frame by very long baseline interferometry**, IERS Technical Note; 35. Verlag des Bundesamts für Kartographie und Geodäsie, Frankfurt am Main, 204 p, ISBN 3-89888-918-6.

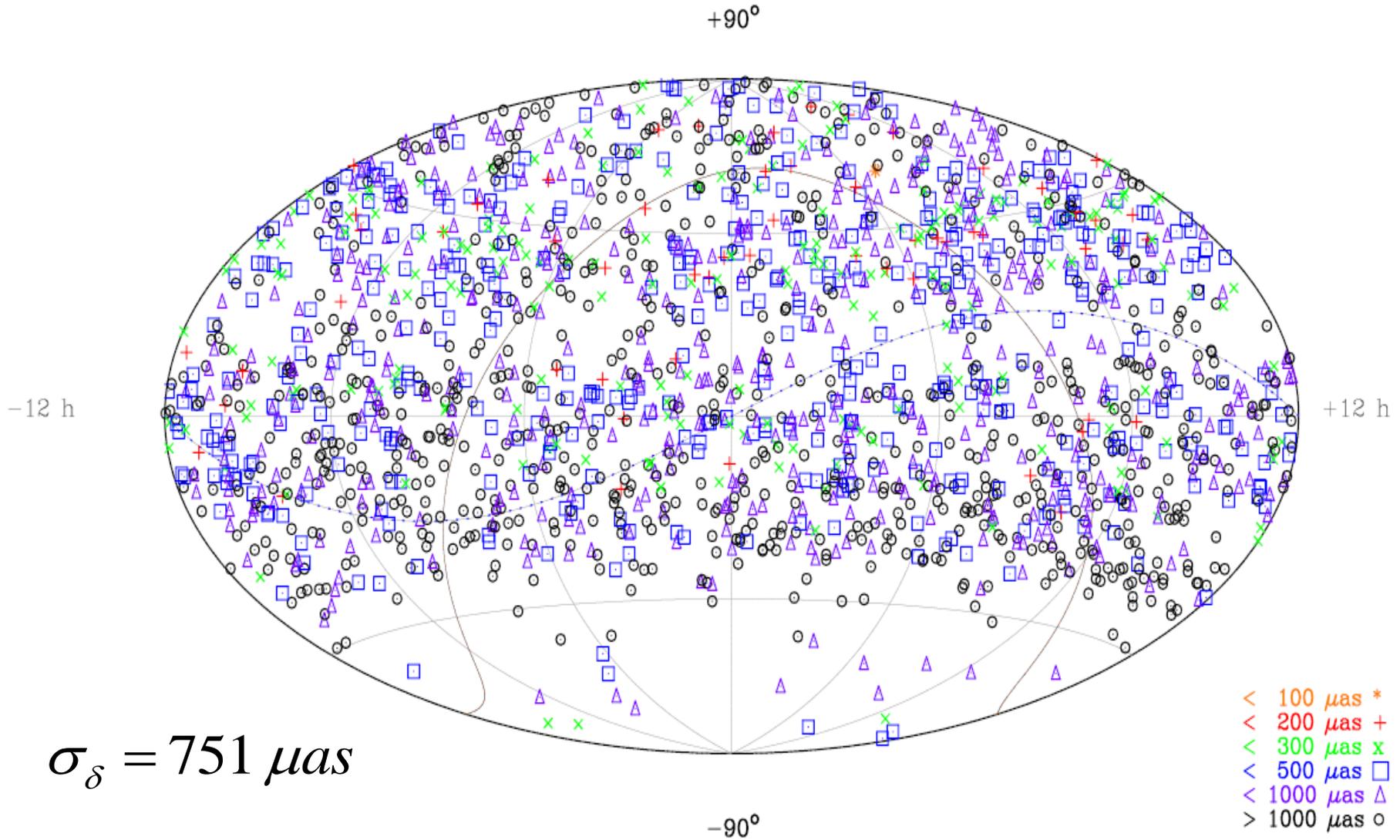
# ICRF2



$$\sigma_{\delta} = 175 \mu\text{as}$$

En az iki VLBI oturumunda yapılan ölçülerle konumu belirlenen 1448 radio source (quasar).  
Lejand: 1-sigma konum hatasi (deklınasyon).

# ICRF2



$$\sigma_{\delta} = 751 \mu\text{as}$$

Tek VLBI oturumunda yapılan ölçülerle konumu belirlenen 1966 radio source (quasar).  
Lejand: deklinasyon 1-sigma konum hatasi.

# Troposfer

# VLBI ölçülerinin analizinde troposfer sinyal gecikme modeli

$$\Delta \tau_{trop} = 10^{-6} \int_0^{H_{trop}} [N_h(s) + N_w(s)] ds$$

state-of-the-art modeling of troposphere delay:

$$\Delta \tau_{trop}(\alpha, \varepsilon) = \underbrace{ZHD}_{\text{reduced from observations a priori to the adjustment (Saastamoinen, 1972)}} m_h(\varepsilon) + \underbrace{ZWD}_{\text{estimated}} m_w(\varepsilon) + m_w(\varepsilon) \cot(\varepsilon) \left[ \underbrace{G_n}_{\text{estimated}} \cos(\alpha) + \underbrace{G_e}_{\text{estimated}} \sin(\alpha) \right]$$

reduced from observations a priori to the adjustment (Saastamoinen, 1972)

estimated

estimated

estimated

# Troposfer izdüşüm fonksiyonları

$$m_{h,w}(e) = \frac{1 + \frac{a_i}{1 + \frac{b_i}{1 + \frac{c_i}{1 + \dots}}}}{\sin(e) + \frac{a_i}{\sin(e) + \frac{b_i}{\sin(e) + \frac{c_i}{\sin(e) + \dots}}}}$$

$e$  : Elevation cut off angle

$a_i, b_i, c_i, \dots = f(\varphi, H, \text{doy}, t, \alpha, \dots)$

$\varphi$  : station latitude

$H$  : station orthometric height

$\text{doy}$  : day of year

$P$  : surface total pressure

$t$  : surface temperature

$\alpha$  : temperature lapse rate

**Niell Mapping Function**

**Isobaric Mapping Function**

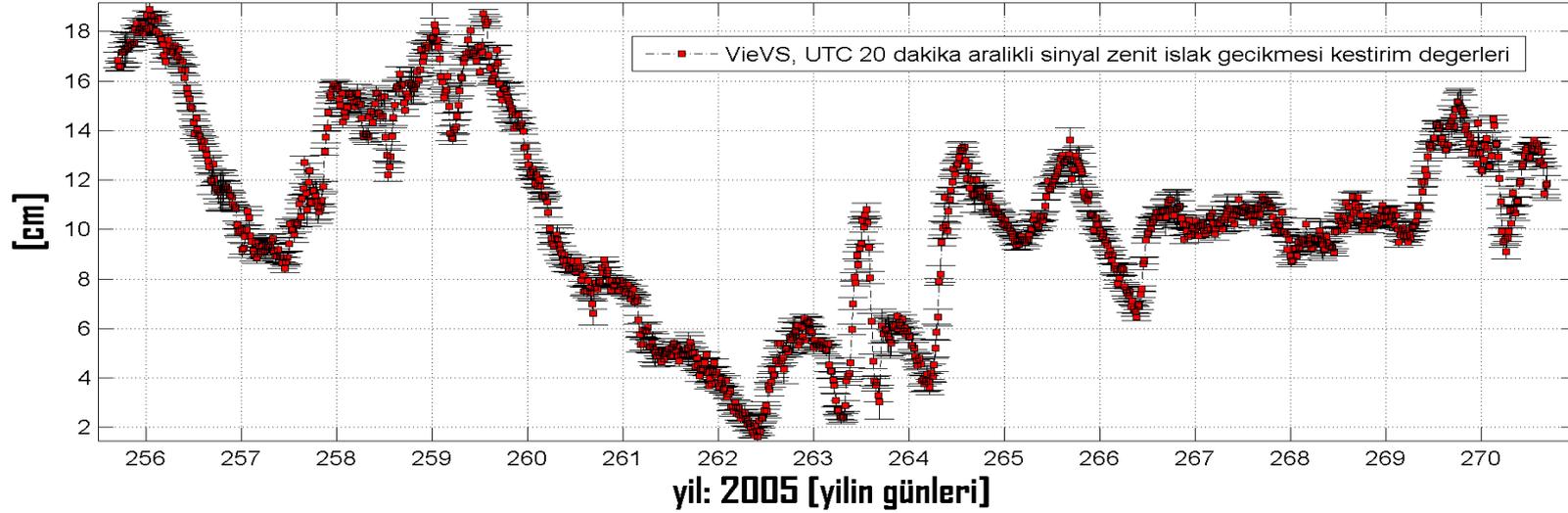
**Vienna Mapping Function**

Some other mapping functions:

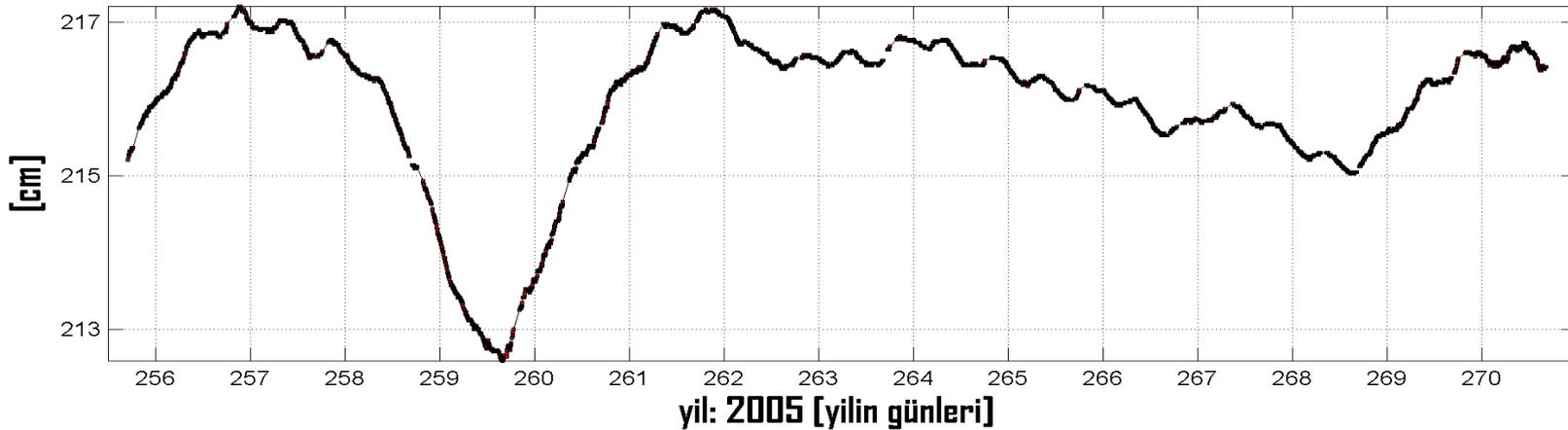
Chao, Lanyi, CfA, Ifadis, Davis, MTT, B&E, F&K, UNBabc, UNBab

# VLBI ölçülerinden kestirilen sinyal zenit ıslak gecikmeleri

VLBI istasyonu : WETTZELL - Almanya [sinyal zenit ıslak gecikmeleri]



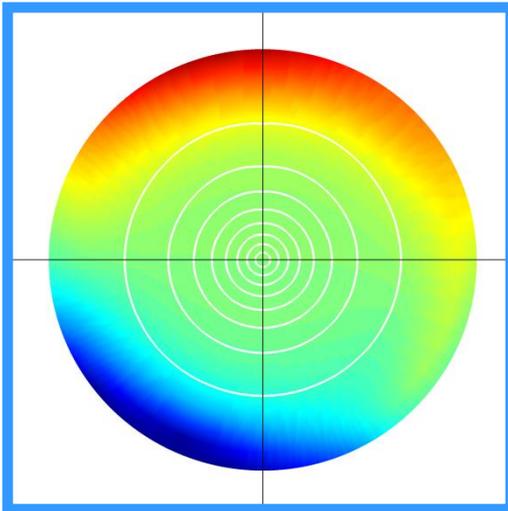
WETTZELL [sinyal zenit kuru gecikmeleri]



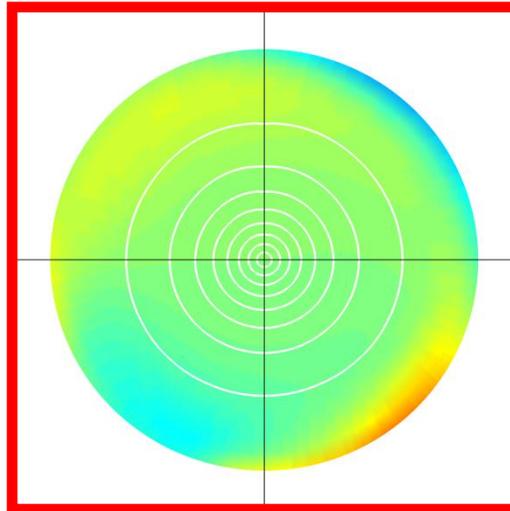
# Modeling azimuthal asymmetries

„classical“ gradients (IERS Conventions 2010)

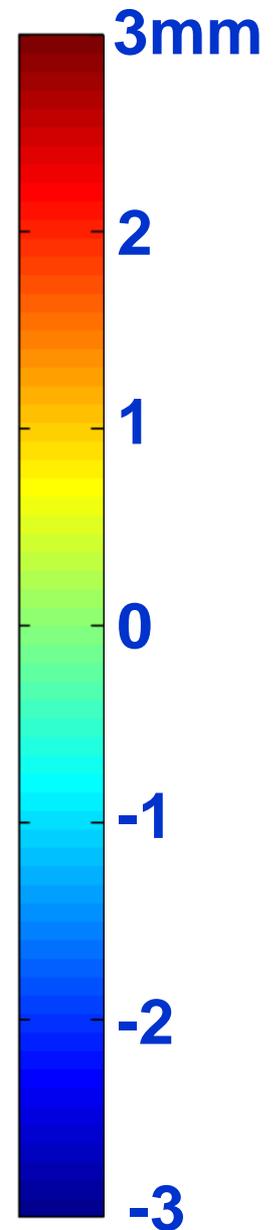
$$\Delta L_{\text{asymm}} = m f_g(e) \cdot [G_N \cdot \cos(\alpha) + G_E \cdot \sin(\alpha)]$$



without modeling  
asymmetries

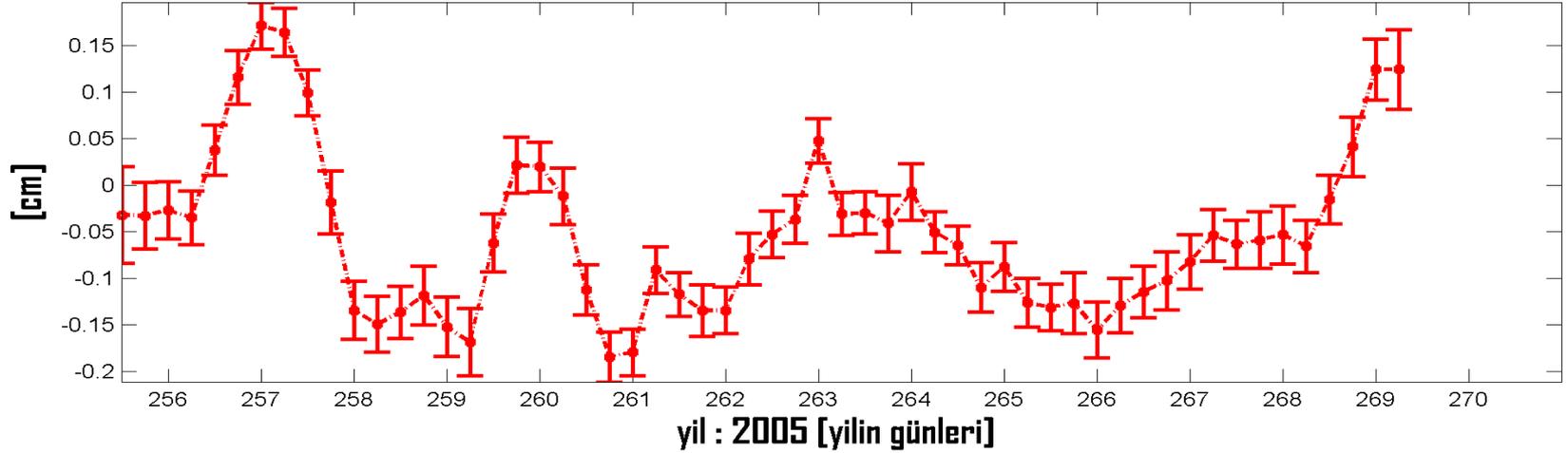


classical gradients  
applied

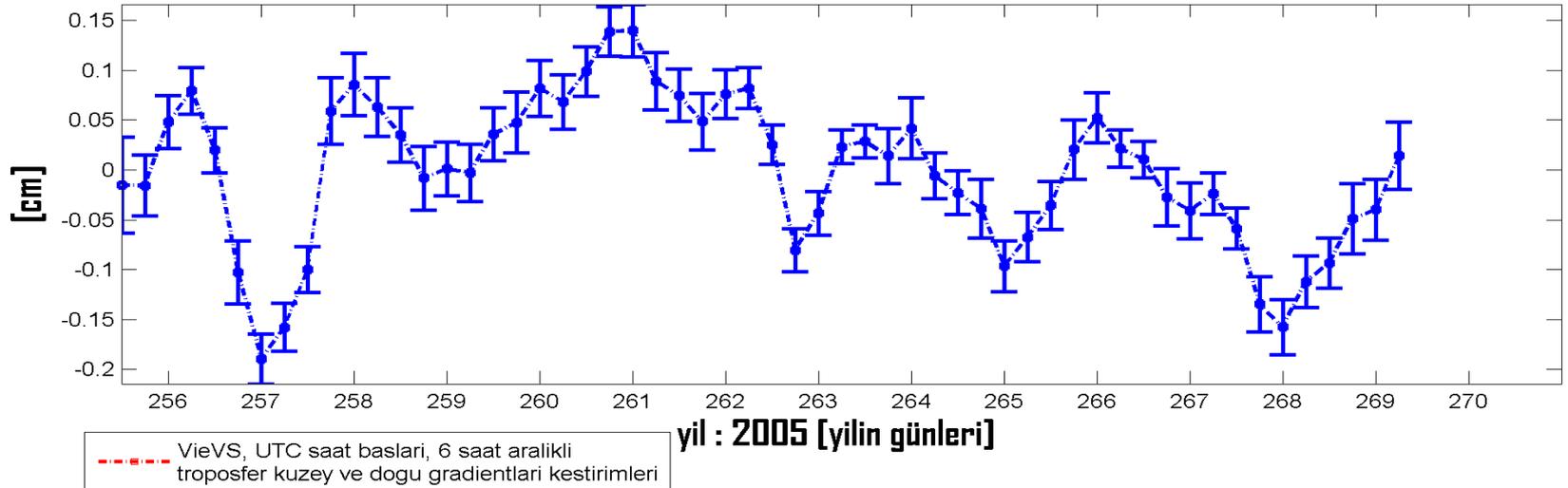


# VLBI ölçülerinden kestirilen troposfer toplam gradyanlar

VLBI istasyonu: ALGOPARK - USA [Troposfer kuzey gradientleri]



VLBI istasyonu: ALGOPARK - USA [Troposfer dogu gradientleri]

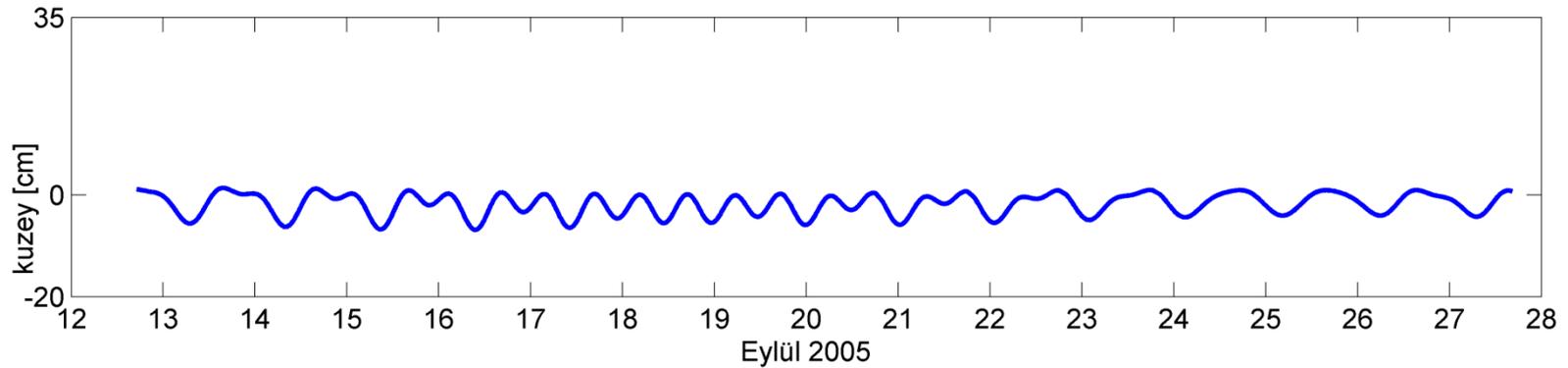
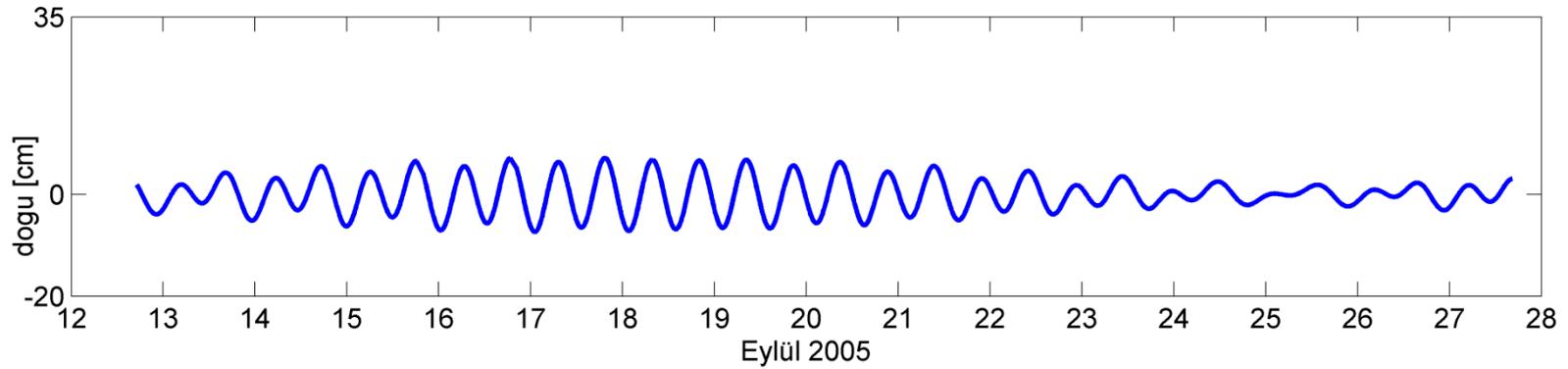
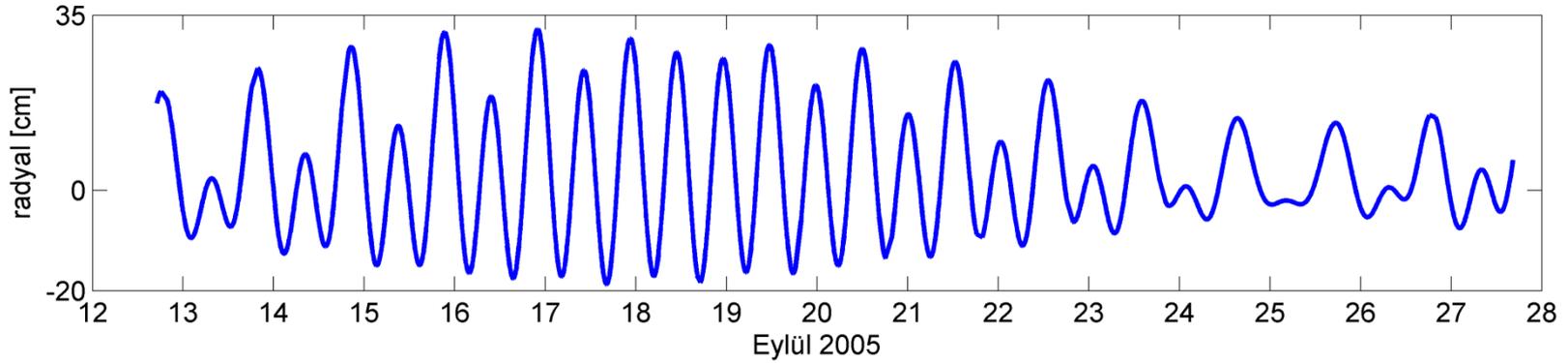


**Katılımınız ve dinlediğiniz  
için teşekkür ederiz !**

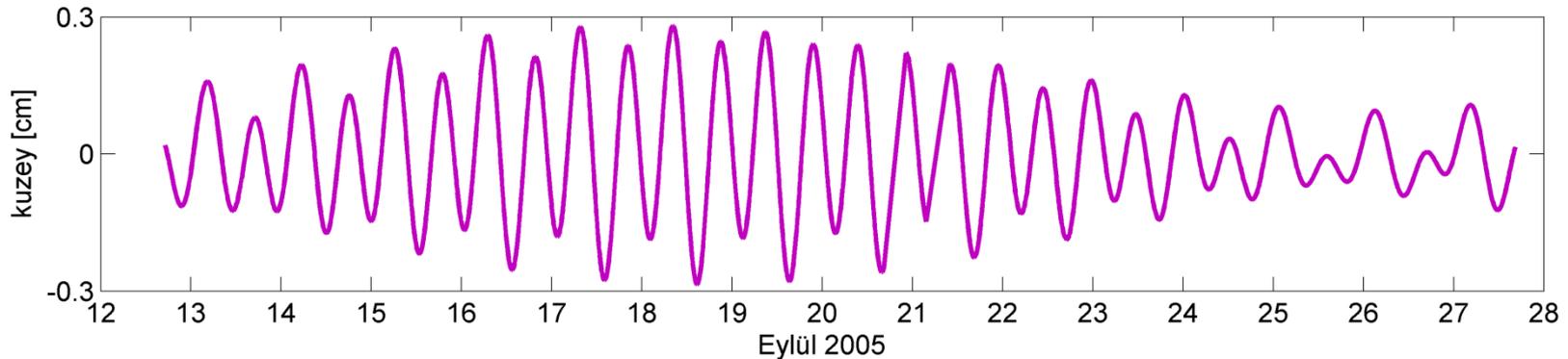
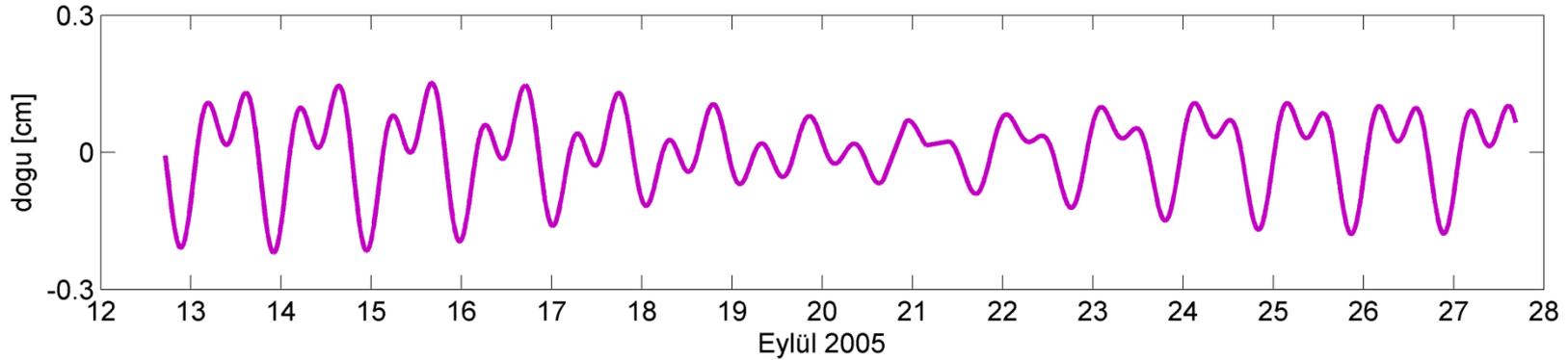
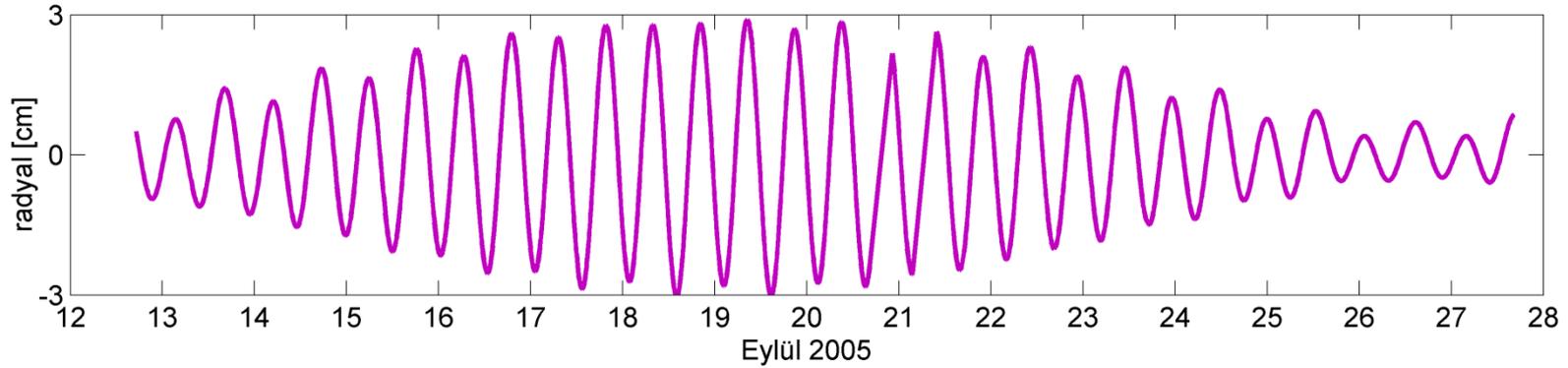
EKLER

İstasyon noktalarında  
oluşan hareketler  
(deformasyonlar)

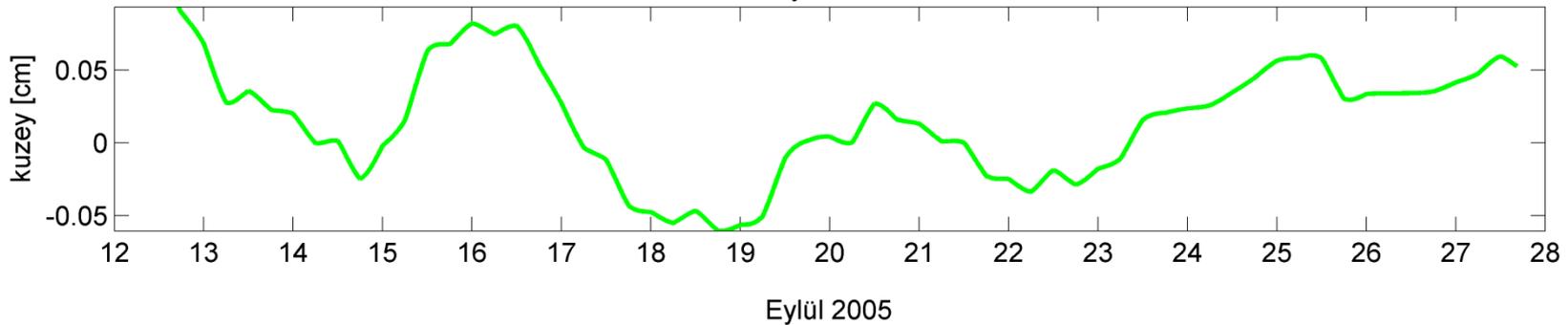
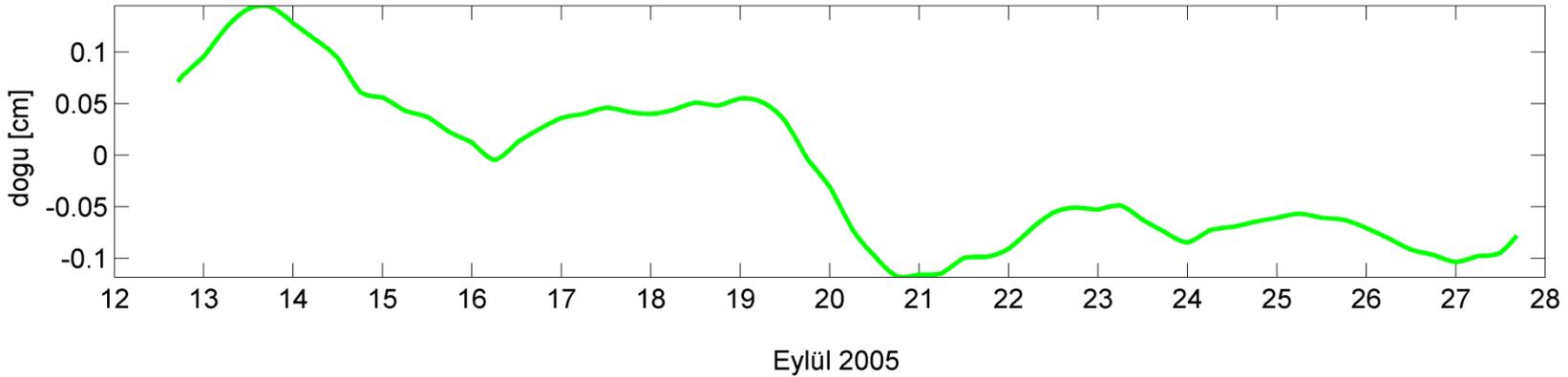
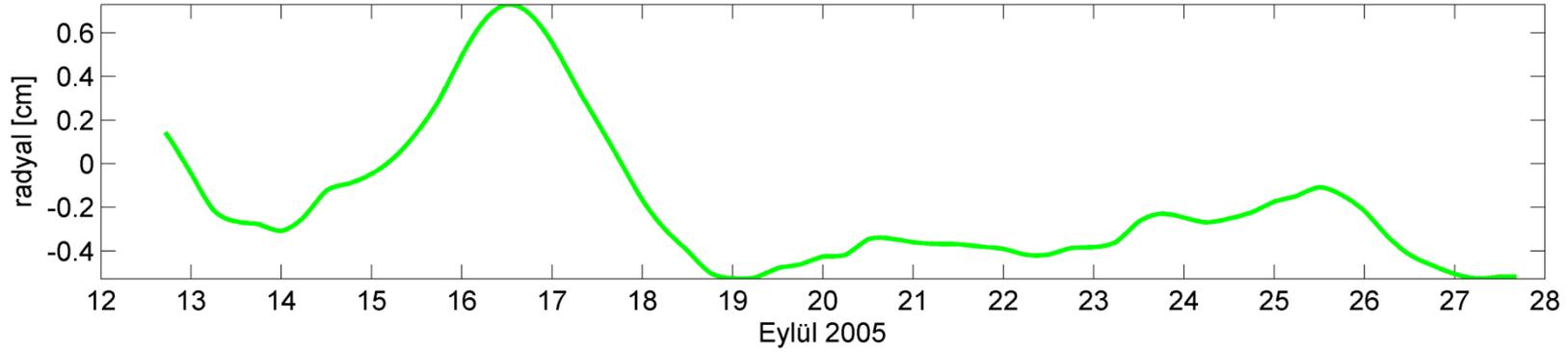
# Kati Yer Gel-giti – Kokee VLBI istasyonu – Hawaii (USA) (12-28 Eylül 2005)



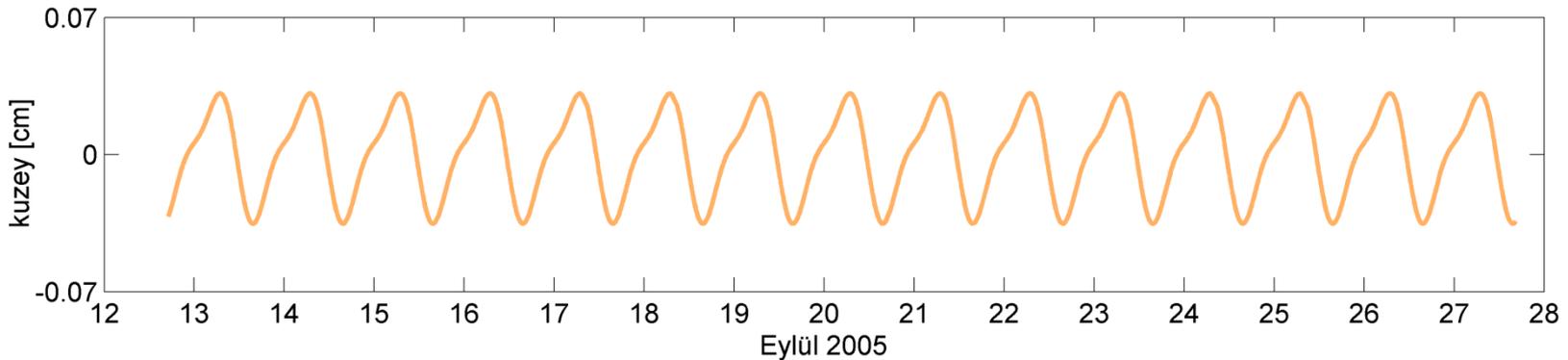
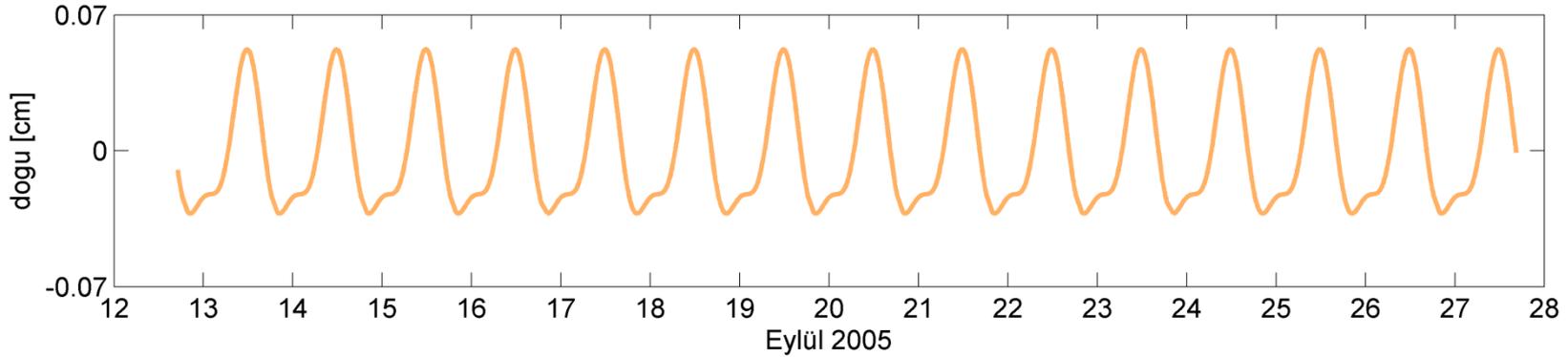
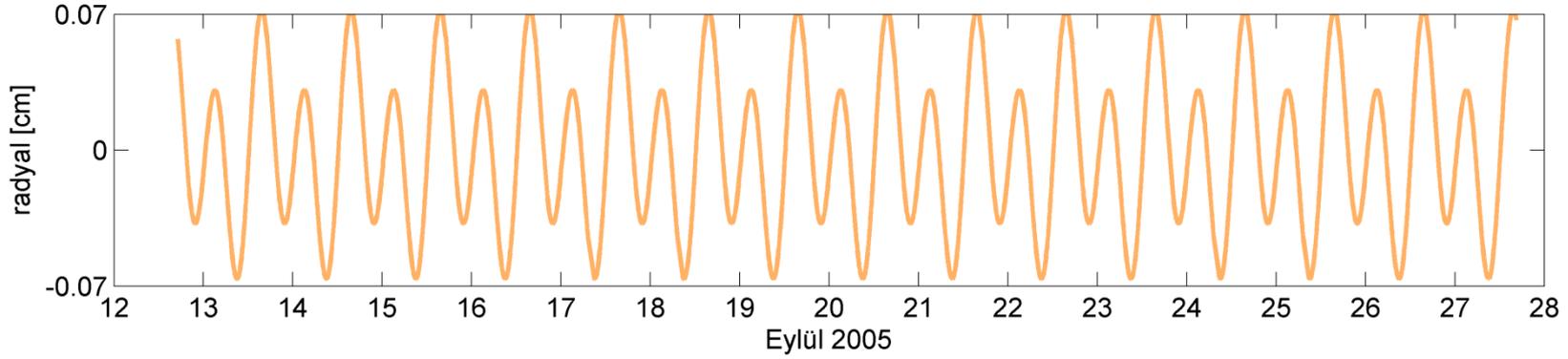
# Okyanus gel-git yüklemesi – Hartebeetshoek VLBI istasyonu – Güney Afrika (12-28 Eylül 2005)



# Atmosfer yüklemesi (non-tidal) – Wettzell VLBI istasyonu – Almanya (12-28 Eylül 2005)



# Atmosfer gel-git yüklemesi– Wettzell VLBI istasyonu – Almanya (12-28 Eylül 2005)



# VLBI parametrizasyonu

# 24 saatlik bir VLBI oturumunun analizinde örnek parametrisasyon

- Tüm kuazar koordinatları (rektazansiyon, deklinasyon) ICRF2 katalog koordinatlarına sabitlendi.
- NNT/NNR koşul denklemleri (6 adet) VTRF2008 katalođu koordinatları ile oluşturuldu ve datumdan bağımsız normal denklem sistemine uygulandı.
- A priori koordinat düzeltmeleri: Katalog hızları (VTRF2008), katı Yer gel-gitleri (McCarthy ve Petit (2004), Bölüm 7.1.1), Okyanus gel-git yüklemeleri (FES2004, Lyard vd., 2006), Seküler ve gel-git atmosfer yüklemeleri (Petrov ve Boy, 2004), Kutup gel-gitleri (McCarthy ve Petit (2004), Bölüm 7.1.4), anten thermal deformasyonları ve eksen ofset düzeltmeleri (Nothnagel, 2009).
- Troposfer izdüşüm fonksiyonu: VMF1 (Böhm, vd., 2006).
- Troposfer hidrostatik sinyal gecikmesi düzeltmeleri (Saastamoinen, 1972) her ölçüye parametre kestirimi öncesi getirilmiştir.
- Troposfer ıslak zenit gecikmesi kestirimi: 30 dakika aralıklı parçalı lineer ofsetler (ofsetler üzerinde bağıl gevşek kısıtlayıcılar, 10 mm/30 dakika uygulandı) kestirildi. Troposfer gradyanları (Davis vd., 1993) 6 saat aralıklı parçalı lineer ofsetler (bağıl gevşek kısıtlayıcılar, 0.5 mm/6 saat uygulandı) kestirildi.
- Korelatörlerde hesaplanan NGS ölçü dosyalarındaki iyonosfer sinyal gecikmesi düzeltmesi tüm ölçülere getirildi.
- Saat hataları: Kuadratik polinom katsayılarına ek olarak UTC saat başlarında (ofsetler üzerinde bağıl gevşek kısıtlayıcılar uygulandı) parçalı lineer ofsetler kestirildi.
- Anten koordinatları: Her gün için (0:00 UTC) kestirimi yapıldı.
- A priori Yer dönüklük parametreleri (ERP): IERS 05 C04 EOP serisi (Bizouard ve Gambis, 2009) – günlük (0:00 UTC) değerlerinden ölçü epoklarına Lagrange enterpolasyonu yapıldı.
- A priori nutasyon parametreleri: IAU2000A presesyon-nutasyon modeli (McCarthy ve Petit, 2004).
- EOP kestirimi: Nutasyon ofsetleri her gün bir ofset (0:00 UTC) kestirildi ve ERP her saat başı UTC epoklarında kestirildi.

# TAI, UTC, TT, TDT, TDB ZAMAN ÖLÇEKLERİ VE BİRBİRLERİ İLE OLAN BAĞLANTILARI (IAU KONVANSİYONLARI)

TT : Terrestrial Time

TAI : Temps Atomique International (international atomic time)

TT – TAI = 32.184s (ofset)

UTC : Coordinated Universal Time (the basis of civil time, atomic time scale)

UTC-TAI= -34s (ofset: leap seconds, 1 Ocak 2009, 0:00 UTC'den günümüze)

TDT : Temps Dynamique Terrestre (Terrestrial Dynamic Time)

TDB : Temps dynamique Barycentrique (Barycentric Dynamic Time)

$TDB = TDT + 0.001658 \sin[g + 0.0167 \sin(g)],$

$g = 2\pi (357.528 + 35999.050 T)/360^\circ$  (Yer'in yörünge düzleminin ortalama anomalisi)

$T = (JD - J2000)/36525$  (Julian yüzyılı)

J2000 = 2451545.0 gün

# TAI, UTC, TT, TDT, TDB ZAMAN ÖLÇEKLERİ VE BİRBİRLERİ İLE OLAN BAĞLANTILARI (IAU KONVANSİYONLARI)

UT1 : Universal Time 1 (astronomical time for celestial navigation)

TAI : Temps Atomique International (international atomic time)

TT – TAI = 32.184s (ofset)

UTC : Coordinated Universal Time

UTC-TAI= -34s (ofset: leap seconds, 1 Ocak 2009, 0:00 UTC'den günümüze)

TDT : Temps Dynamique Terrestre (Terrestrial Dynamic Time)

TDB : Temps dynamique Barycentrique (Barycentric Dynamic Time)

$TDB = TDT + 0.0001658 \sin[g + 0.0167 \sin(g)],$

$g = 2\pi (357.528 + 35999.050 T)/360^\circ$  (Yer'in yörünge düzleminin ortalama anomalisi)

$T = (JD - J2000)/36525$  (Julian yüzyılı)

J2000 = 2451545.0 gün

# ASTRONOMICAL TIME SYSTEMS

