

Geometric Estimation of Geocenter by SLR technique among the challenges of GENESIS mission

1



2

Francesco Vespe¹
Rosa Delorenzo^{2,3}
Antonio Basoni⁴



UNIVERSITÀ DEGLI STUDI DI NAPOLI
FEDERICO II

4

e-geos
AN ASI/TELESPAZIO COMPANY



Content

- The GENESIS mission
- How does the use of GENESIS, in combination with other satellites, improve the estimation of the geocenter?
- What is the best orbit for GENESIS (60°, 95°, other...)
- Geometric Analysis based on DOP computed having an ideal observer at the center of Earth
- A more realistic analysis taking into account the performances of the SLR stations
- Estimation of Geocenter solving for the navigation equation as done for GNSS
- Results
- Conclusions

The GOAL of GGOS

Built a Geodetic Reference Frame at level of accuracy of 1 mm and a long time stability of 0.1 mm/yr; scale accuracy to 0.1 ppb and stable to 0.01 ppb/yr

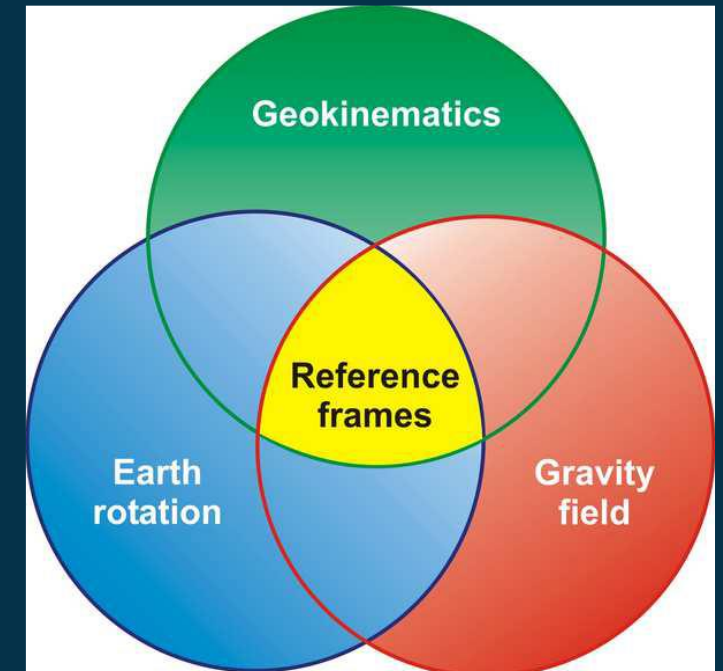


The General Assembly of the United Nations (UN) adopted a resolution on 26 February 2015: ***“A global geodetic reference frame for sustainable development”***. In this resolution the UN recognize:

the importance of “the investments of MS in developing satellite missions for positioning and Remote Sensing of the Earth, to improve our understanding of the Earth system and underpin decision-making[....]”

The full societal benefits of these investments are realized only if they are referenced to a common global geodetic reference frame.

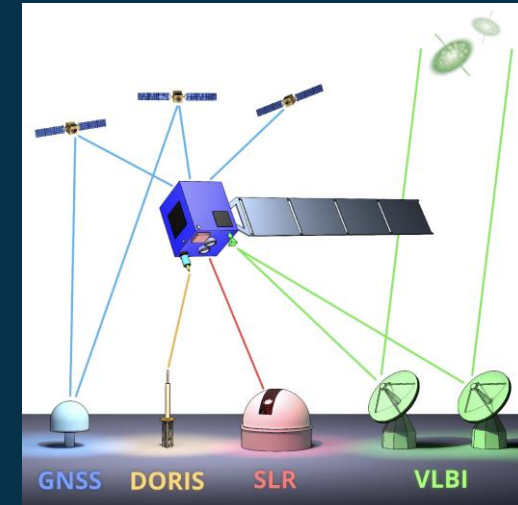
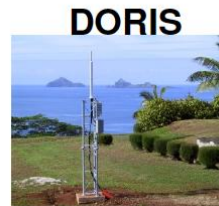
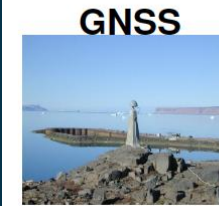
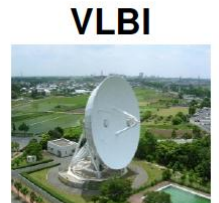
Thus UN “invite Member States to engage in multilateral cooperation that addresses infrastructure gaps and duplication towards the development of a more sustainable global geodetic reference frame



From here GENESIS!



ESA GENESIS Mission



A full calibrated satellite based platform where:

- co-locate the 4 main geodetic techniques: SLR-GNSS-VLBI-DORIS
- Identify and reduce the systematic errors
- Determine if the error source are due to terrestrial ties or from the space geodetic estimates

Improve geocenter and scale for refinement of ITRF: Crucial for the Earth Observations and Global Change studies

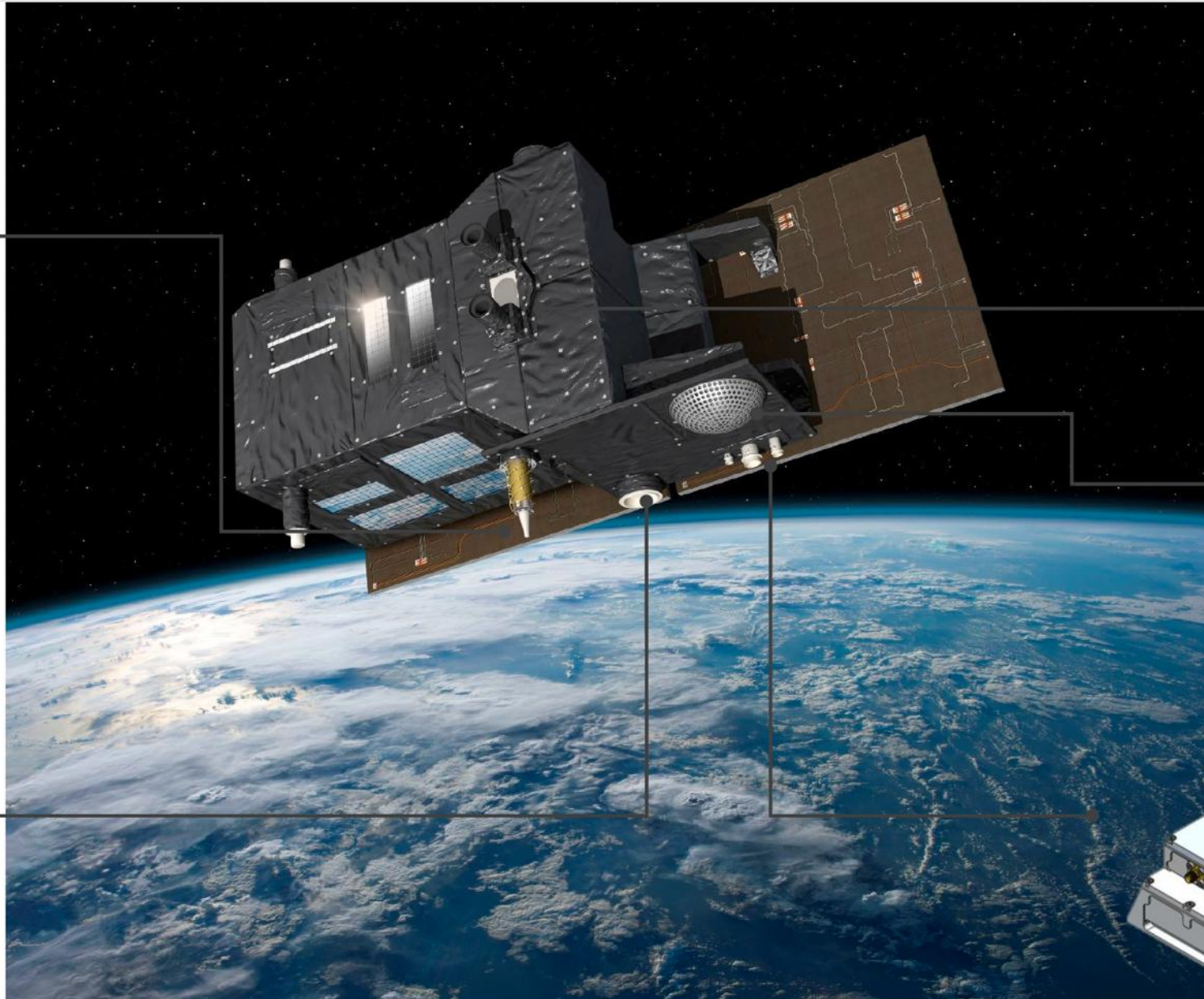
Genesis Payloads – Configuration



DORIS



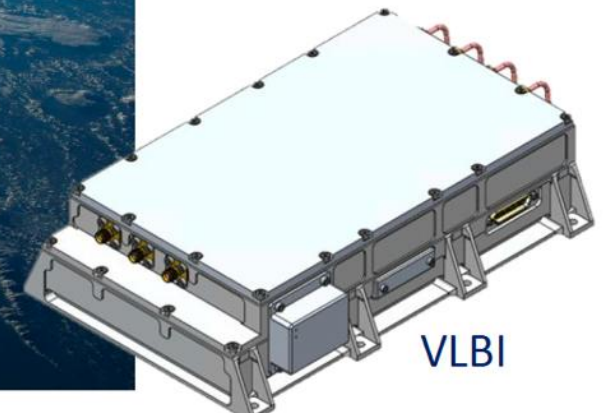
GNSS



USO & DA



LRR



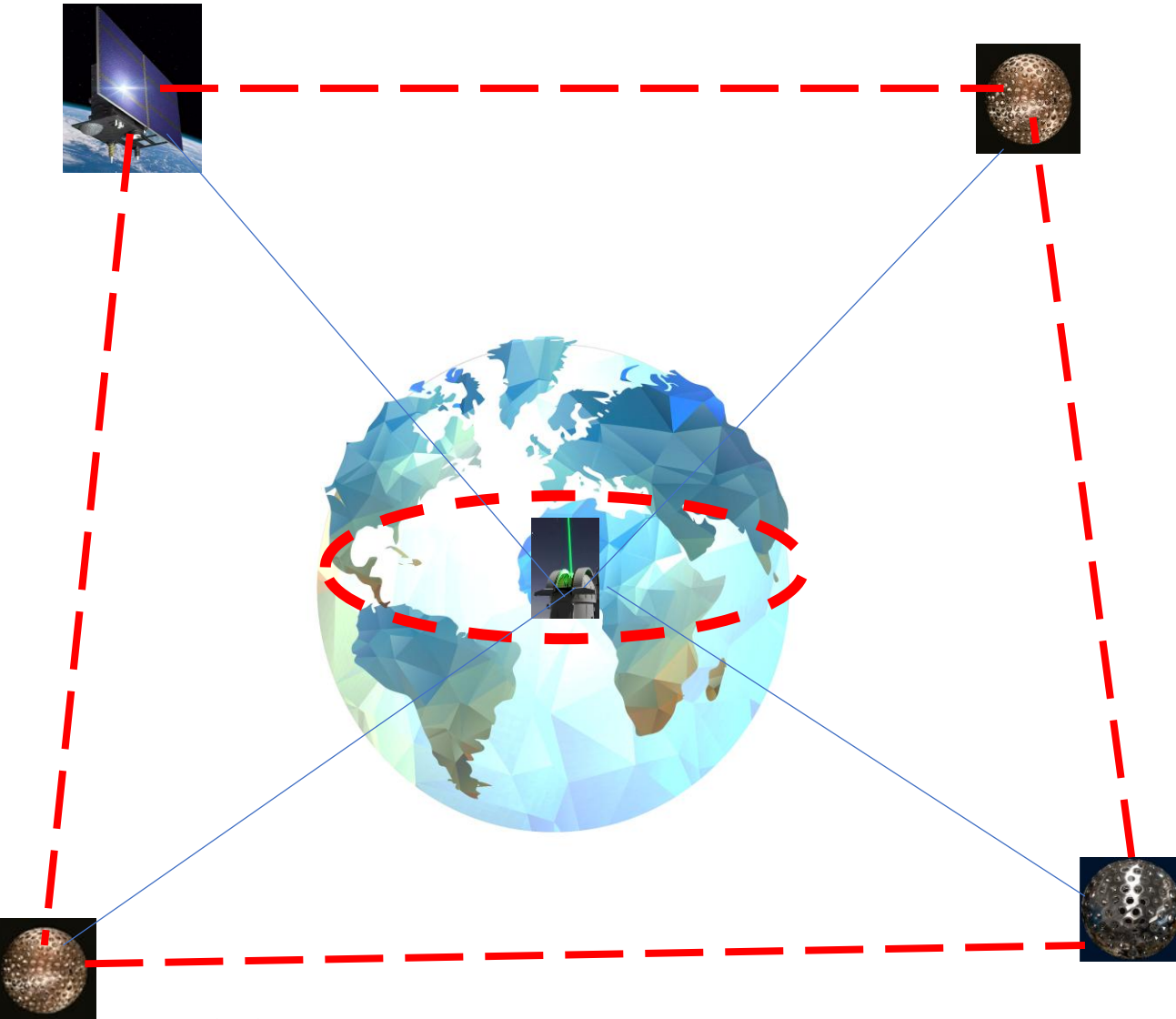
VLBI

The SLR constellation



Satellite	h [km]	a [km]	e	i [°]	Ω [°]	ω [°]	M_0 [°]
LAGEOS-1	5900	12270	0.004	109.8	126°/yr	0	Random
LAGEOS-2	5900	12270	0.014	52.6	-227°/yr	0	Random
LARES-2	5930	12300	0.002	70.0	-126°/yr	0	Random
GENESIS 60	6000	12370	0.00	60°	-182°/yr	0	Random
GENESIS 95	6000	12370	0.00	95	31.7°/yr	0	Random

Ideal Case: a SLR station on the Geocenter!



$$\bar{y} = \mathbf{H}\bar{x} + \bar{\epsilon}$$

$$\mathbf{D} = \sigma \cdot \mathbf{C}$$

$$\mathbf{C} = (\mathbf{H}^T \mathbf{H})^{-1}$$

$$\mathbf{H} = \begin{bmatrix} \frac{x_1 - x}{R_1} & \frac{y_1 - y}{R_1} & \frac{z_1 - z}{R_1} & 1 \\ \frac{x_2 - x}{R_2} & \frac{y_2 - y}{R_2} & \frac{z_2 - z}{R_2} & 1 \\ \frac{x_3 - x}{R_3} & \frac{y_3 - y}{R_3} & \frac{z_3 - z}{R_3} & 1 \\ \frac{x_4 - x}{R_4} & \frac{y_4 - y}{R_4} & \frac{z_4 - z}{R_4} & 1 \end{bmatrix}$$

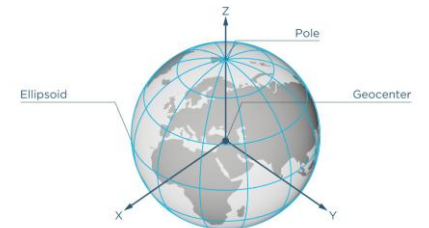
The matrix $(\underline{\underline{\mathbf{H}}}^T \underline{\underline{\mathbf{H}}})^{-1}$ represents the purely geometric contribution to the estimation uncertainty

$$\text{GDOP} = \sqrt{C_{xx} + C_{yy} + C_{zz} + C_{tt}}$$

$$\text{PDOP} = \sqrt{C_{xx} + C_{yy} + C_{zz}}$$

$$\text{HDOP} = \sqrt{C_{xx} + C_{yy}}$$

$$\text{VDOP} = \sqrt{C_{zz}}$$

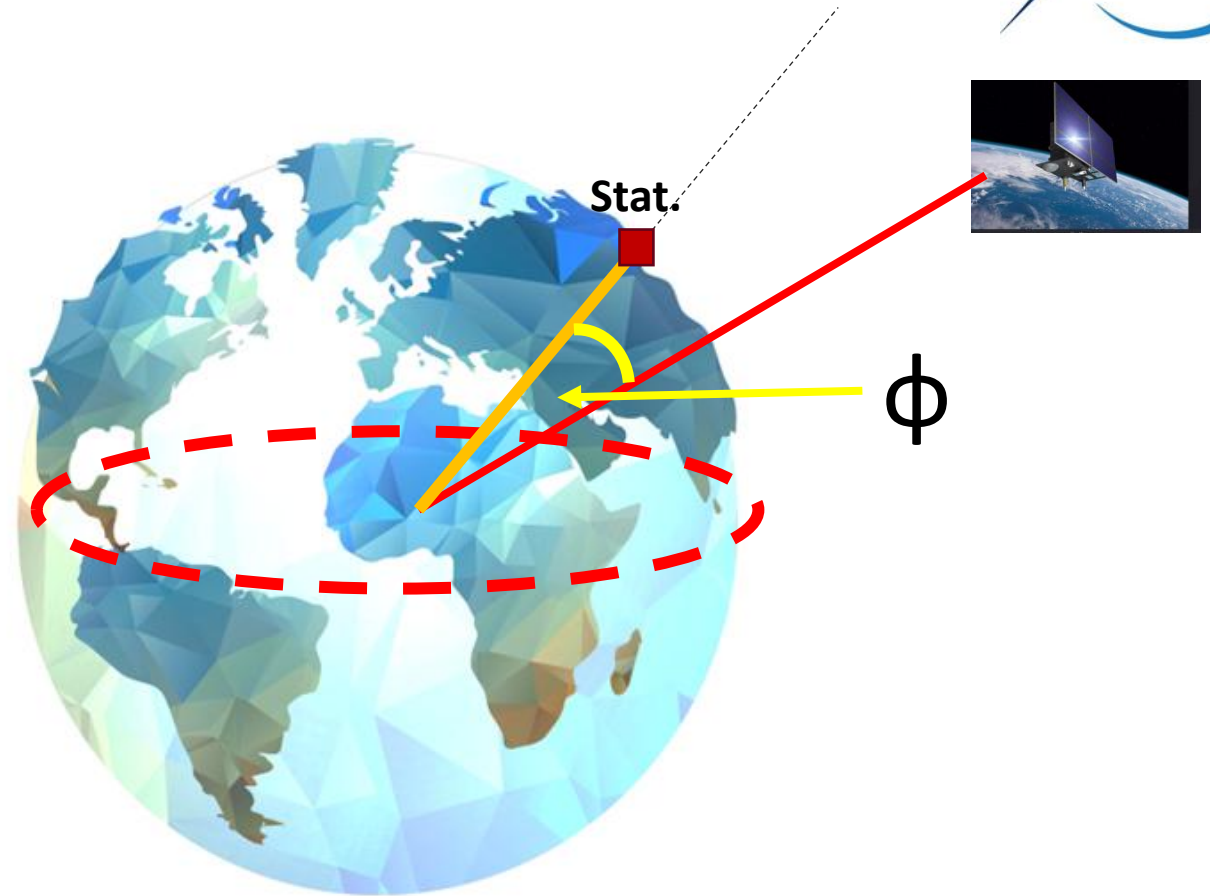


More Realistic Approach

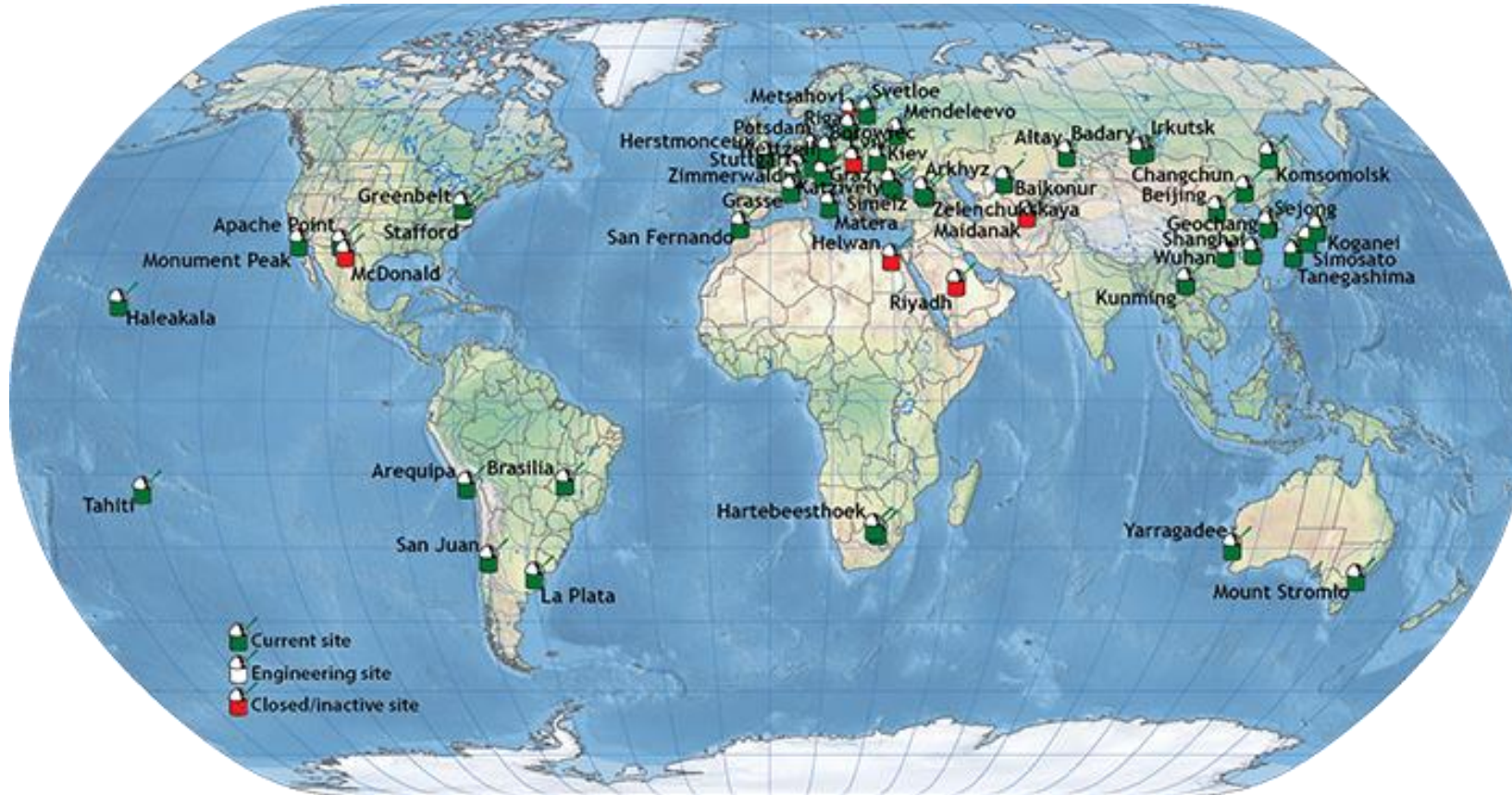
- We associate to each satellite the closest SLR station at its Nadir point on the ground
- We weight each satellite with the inverse of station rms in the following fashion:

$$\mathbf{C}_w = (\mathbf{H}^T \mathbf{W} \mathbf{H})^{-1}$$

$$w_{nn} = 1/rms_n \cdot Sec[\varphi_n]$$



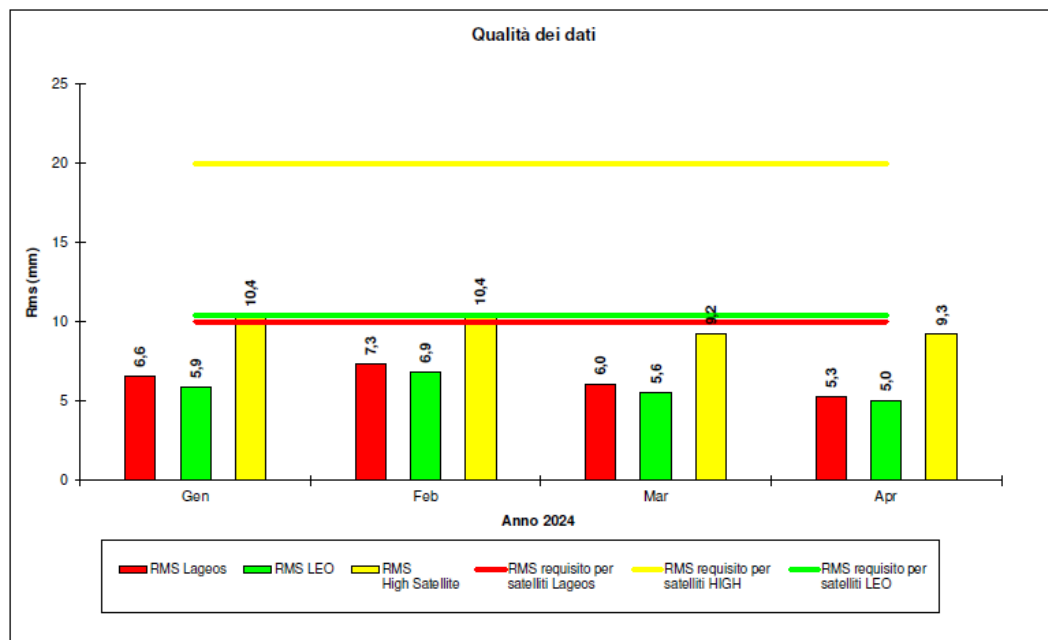
SLR Network



Station	Lat.	Long.	σ (mm)
APOL	32.78	-105.82	18.10
AREL	-16.47	-71.49	7.50
BADL	51.77	102.24	1.90
BEIL	39.61	115.89	2.10
BORL	52.28	17.07	18.60
CHAL	43.79	125.44	1.40
GLSL	50.36	30.50	5.00
GODL	39.02	-76.83	1.60
GRSM	43.75	6.92	15.80
GRZL	47.07	15.49	5.10
HA4T	20.71	-156.26	1.50
HARL	-25.89	27.69	10.00
HERL	50.87	0.34	12.20
IRKL	52.22	104.32	3.00
IZ1L	28.30	-16.51	6.00
JFNL	30.52	114.49	6.70
KTZL	44.39	33.97	9.60
KUN2	25.03	102.80	11.50
MATM	40.65	16.70	4.30
MDVS	56.03	37.22	2.80
MONL	32.89	-116.42	1.50
POT3	52.38	13.06	11.00
RIGL	56.95	24.06	3.20
SFEL	36.47	-6.21	23.20
SHA2	31.10	121.19	5.40
SIML	44.41	33.99	27.70
SISL	33.58	135.94	16.20
SOSW	49.14	12.88	10.90
STL3	-35.32	149.01	8.50
SVEL	60.53	29.78	1.80
THTL	-17.58	-149.61	2.00
TKBL	36.07	140.13	0.90
YARL	-29.05	115.35	1.50
YEBL	40.52	-3.09	5.50
ZELL	43.79	41.57	7.20
ZIML	46.88	7.47	13.00

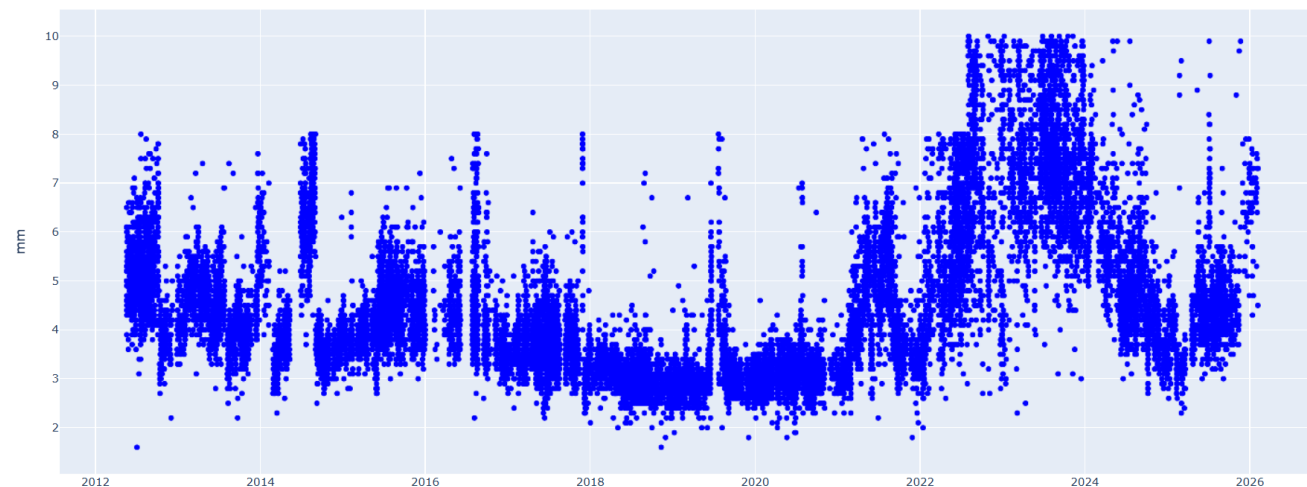
Quality of ranging data

Matera

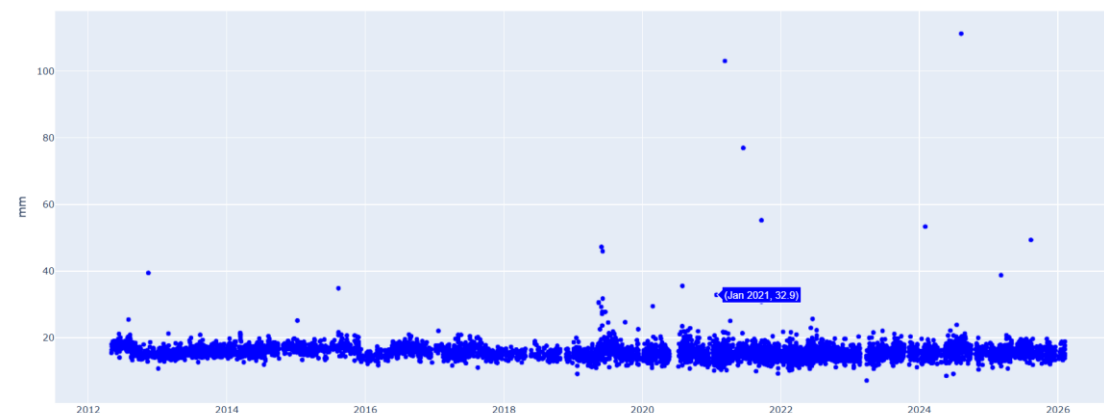


$$C_{nn} = rms \cdot Cosec[\varphi]$$

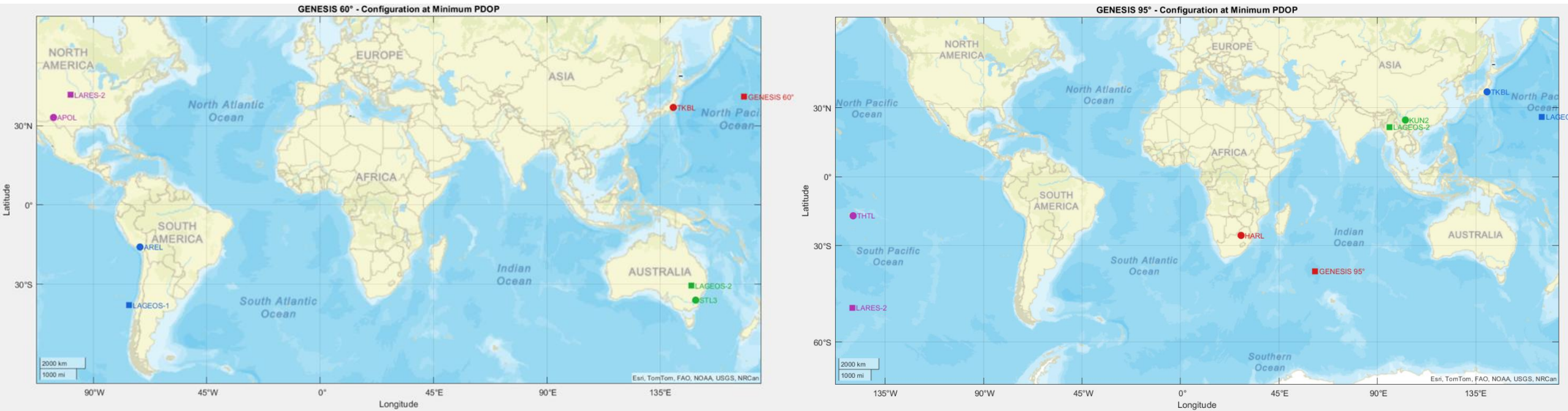
MATM Average LAGEOS Session RMS



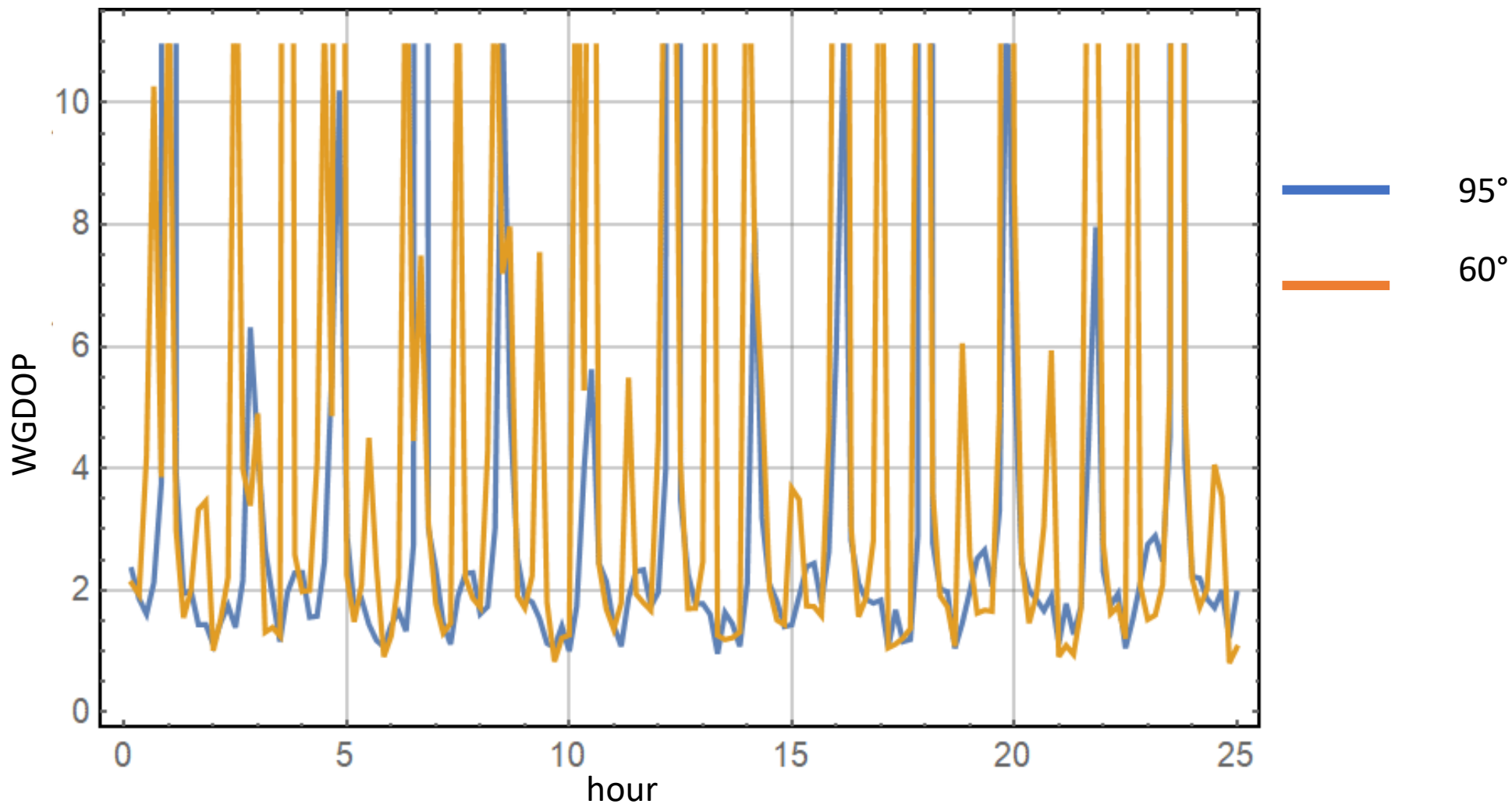
GRSM Average LAGEOS Session RMS



Localization of Nadir Point and SLR stations



Daily Plot:GDOP & WGDOP



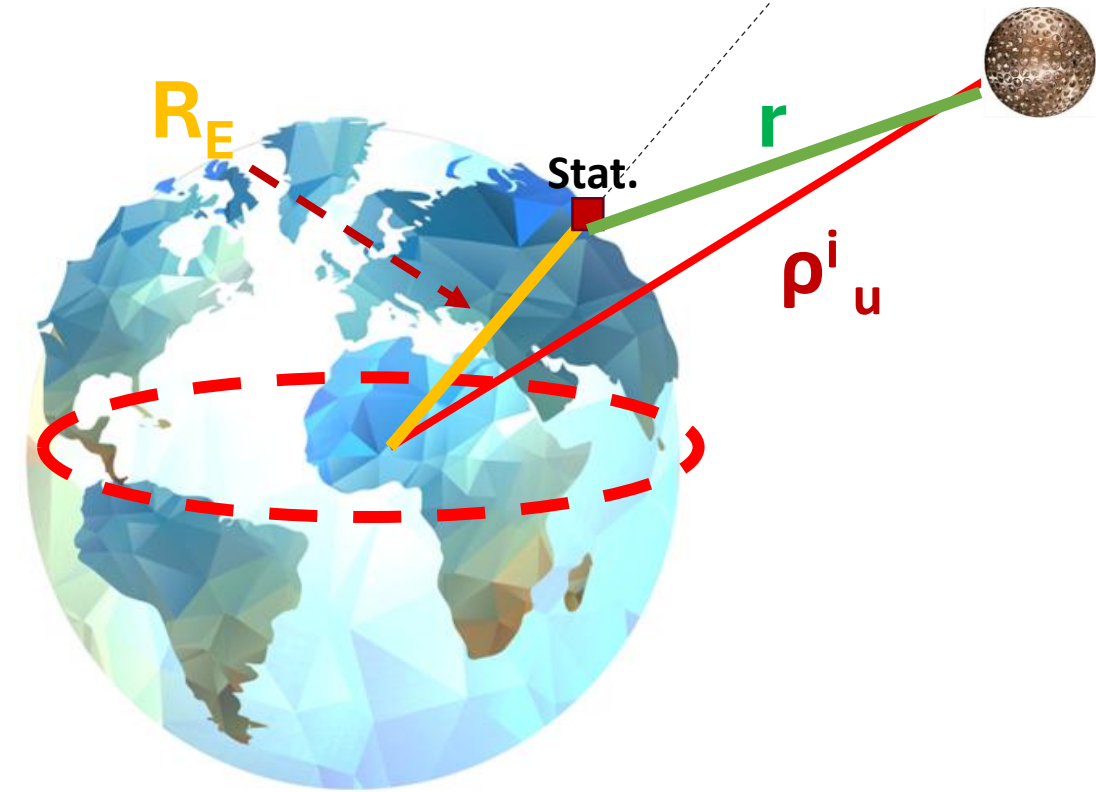
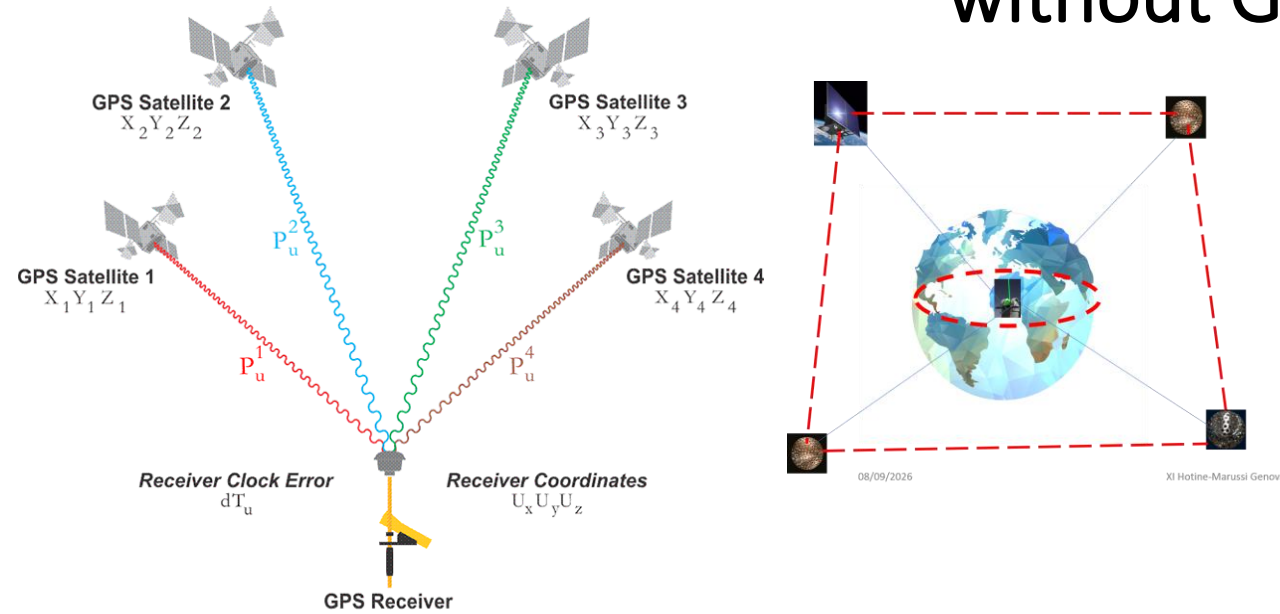
Results for Monthly computation

	<i>Mean</i>		<i>Minimum</i>	
	geom.	weighted	geom.	weighted
GDOP60	19.034	10.558	3.214	0.960
PDOP60	18.944	10.506	3.165	0.936
VOP60	13.936	7.761	1.252	0.351
GDOP95	10.604	5.800	2.293	0.808
PDOP95	10.555	5.774	2.235	0.795
VDOP95	4.936	2.691	1.095	0.400

Monthly Situation With and without GENESIS

	WGDOP		WDOP		WVDOP	
Conf.	Mean	Minimum	Mean	Minimum	Mean	Minimum
No GENESIS	15.61	2.82	14.33	1.56	8.41	1.12
GENESIS 60°	10.59	0.96	10.51	0.94	7.76	0.35
GENESIS 95°	5.80	0.81	5.77	0.79	2.69	0.40

Geometrical Direct Estimation of Geocenter without Geocenter!



$$p_u^1 = \sqrt{(X_1 - U_x)^2 + (Y_1 - U_y)^2 + (Z_1 - U_z)^2} + c(dT_u)$$

$$p_u^2 = \sqrt{(X_2 - U_x)^2 + (Y_2 - U_y)^2 + (Z_2 - U_z)^2} + c(dT_u)$$

$$p_u^3 = \sqrt{(X_3 - U_x)^2 + (Y_3 - U_y)^2 + (Z_3 - U_z)^2} + c(dT_u)$$

$$p_u^4 = \sqrt{(X_4 - U_x)^2 + (Y_4 - U_y)^2 + (Z_4 - U_z)^2} + c(dT_u)$$

$$\rho_u^i = r + R_E + (\Delta r + \Delta R_E)$$

Δr = Range Bias + Orbital Errors

ΔR_E = position error of the stations (provided by ITRFxx solutions)

Uncertainties

Range Bias



ΔR_E



1874	51	501	A	14:019:00000	00:000:00000	R	-16.8	0.7	mm
1879	51	501	A	13:188:00000	18:322:00000	R	17.8	1.2	mm
1887	51	501	A	11:296:00000	15:249:00000	R	21.4	1.7	mm
1887	51	501	A	16:101:00000	18:343:00000	R	-21.6	1.4	mm
1890	51	501	A	12:001:00000	23:326:00000	R	13.6	15.1	mm
1893	51	501	A	05:212:00000	00:000:00000	R	-31.2	27.1	mm
7080	51	501	A	96:133:00000	01:140:00000	R	-8.4	0.5	mm
7090	51	501	A	93:001:00000	96:364:00000	R	3.8	0.3	mm
7090	51	501	A	02:116:00000	10:059:00000	R	-1.7	0.2	mm
7090	51	501	A	14:208:00000	19:363:00000	R	2.0	0.2	mm
7090	51	501	A	21:048:00000	22:292:00000	R	1.5	2.4	mm
7090	51	501	A	22:292:00000	00:000:00000	R	4.8	3.8	mm
7105	51	501	A	93:017:00000	95:253:00000	R	-6.3	0.7	mm
7105	51	501	A	96:056:00000	98:193:00000	R	3.4	0.7	mm
7105	51	501	A	98:193:00000	10:122:00000	R	-2.9	0.3	mm
7105	51	501	A	10:339:00000	17:029:00000	R	-7.1	0.3	mm
7105	51	501	A	20:227:00000	00:000:00000	R	-3.5	5.0	mm
7109	51	501	A	97:009:00000	97:018:00000	R	164.9		mm CDDIS
7110	51	501	A	93:001:00000	96:175:00000	R	-3.0	0.6	mm
7110	51	501	A	96:240:00000	96:277:00000	R	163.6		mm CDDIS
7110	51	501	A	96:287:00000	00:000:00000	R	-5.3	6.7	mm
7119	51	501	A	06:316:00000	13:223:00000	R	1.4	0.4	mm
7119	51	501	A	13:223:00000	15:018:00000	R	5.1	1.0	mm
7119	51	501	A	15:067:00000	25:089:00000	R	9.5	5.7	mm
7124	51	501	A	98:011:00000	03:362:00000	R	-5.1	0.8	mm
7124	51	501	A	04:122:00000	04:183:63240	R	163.9		mm CDDIS
7124	51	501	A	04:186:00000	18:105:00000	R	-3.2	0.6	mm
7210	51	501	A	94:023:00000	99:220:00000	R	-12.0	0.7	mm
7210	51	501	A	00:261:00000	04:158:00000	R	6.5	0.6	mm
7237	51	501	A	96:056:00000	97:222:00000	R	19.4	4.8	mm
7237	51	501	A	97:222:00000	02:195:00000	R	-22.9	1.3	mm
7237	51	501	A	02:195:00000	12:120:00000	R	13.1	0.8	mm

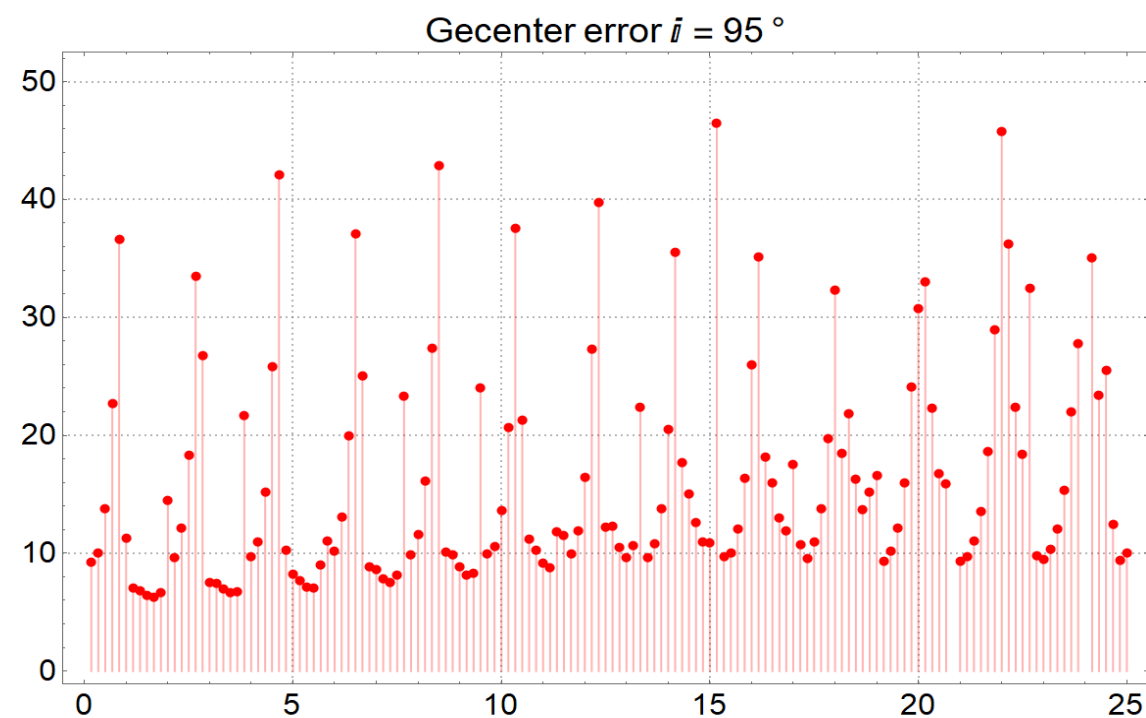
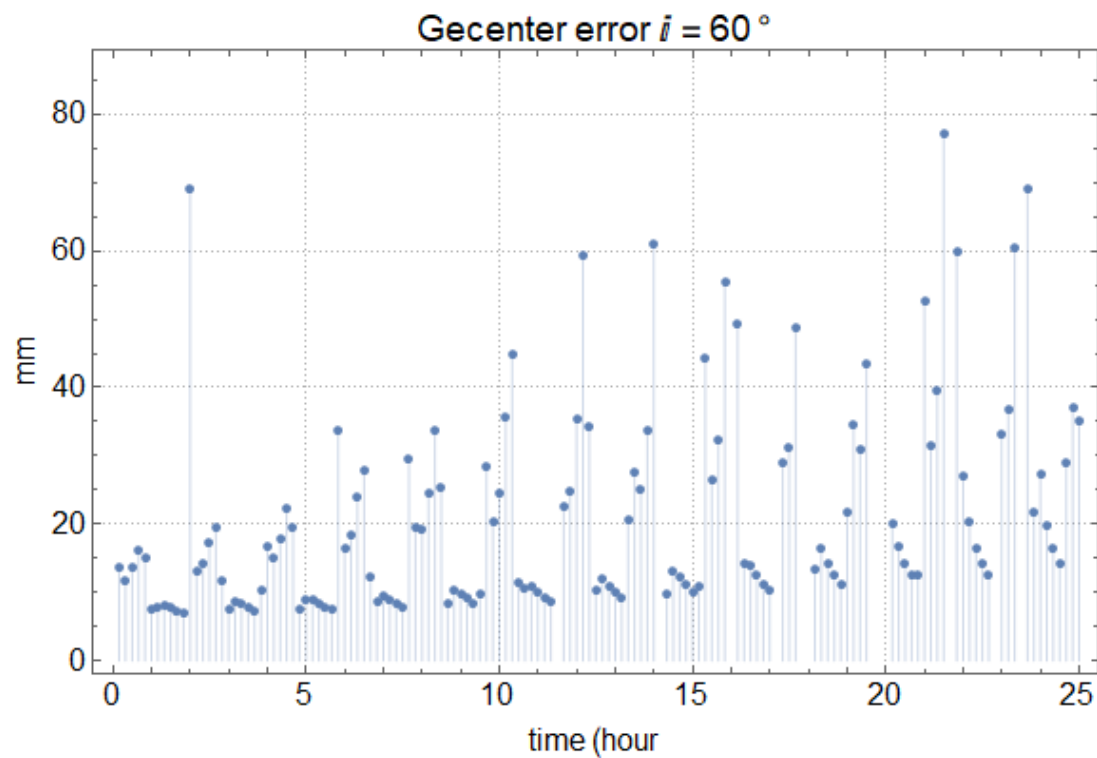
```

%=SNX 2.02 IGN 25:265:00000 IGN 79:329:00000 25:075:00000 P 01194 2 S
*
+FILE/COMMENT
* File created by CATREF software (Z.Altamimi)
-FILE/COMMENT
*

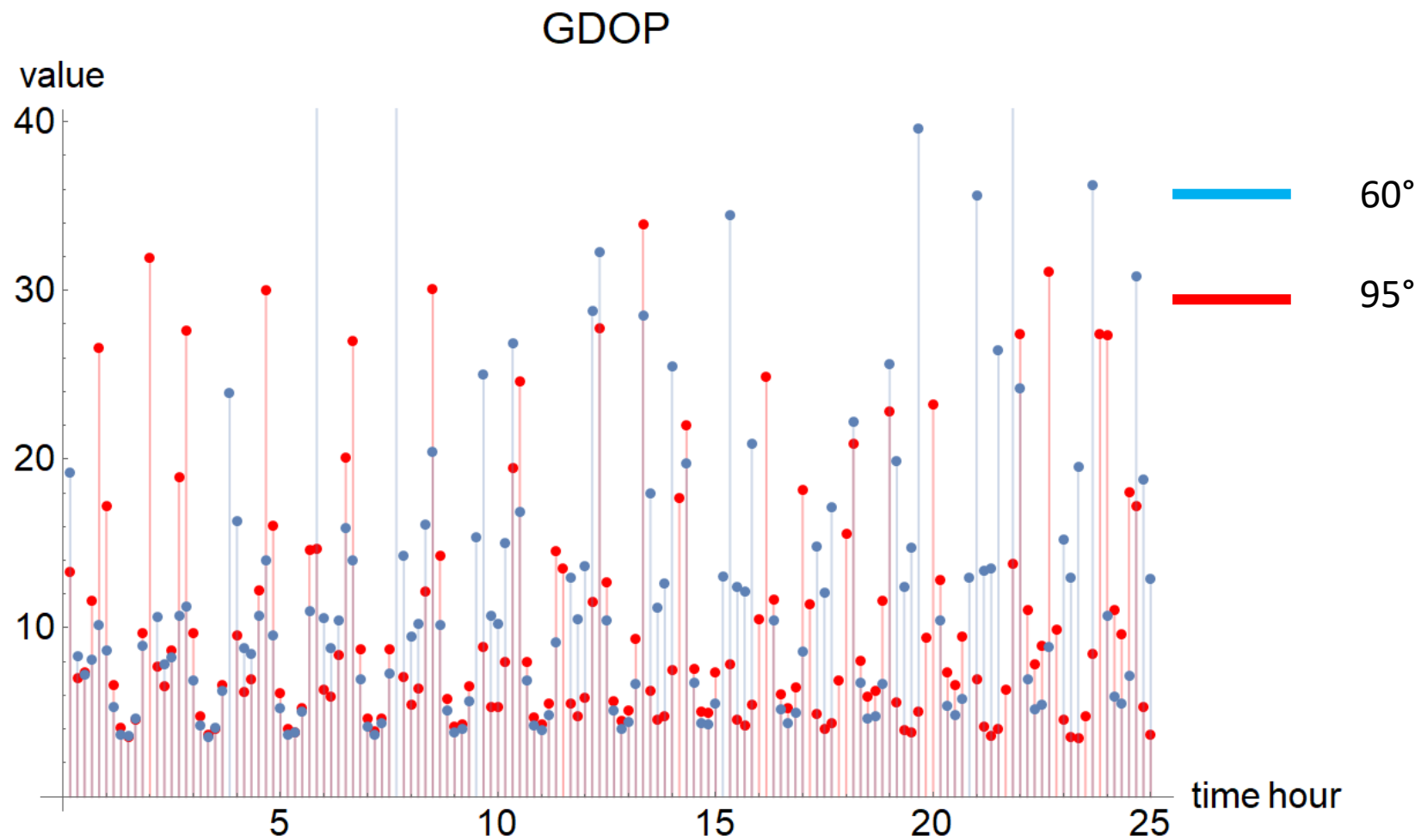
```

+SOLUTION/ESTIMATE									
*INDEX	TYPE	CODE	PT	SOLN	_REF_EPOCH_	UNIT	S	_ESTIMATED VALUE_	_STD_DEV_
1	STAX	7894	A	1	20:001:00000	m	2	-.219677826248614E+07	0.13017E+00
2	STAY	7894	A	1	20:001:00000	m	2	-.488733696598762E+07	0.22494E+00
3	STAZ	7894	A	1	20:001:00000	m	2	0.344842498528872E+07	0.17978E+00
4	VELX	7894	A	1	20:001:00000	m/y	2	-.128762826264543E-01	0.38639E-02
5	VELY	7894	A	1	20:001:00000	m/y	2	0.308107539802844E-02	0.65604E-02
6	VELZ	7894	A	1	20:001:00000	m/y	2	-.799689666148358E-02	0.53080E-02
7	STAX	7102	A	1	20:001:00000	m	2	0.113068616599788E+07	0.55331E-02
8	STAY	7102	A	1	20:001:00000	m	2	-.483135302893279E+07	0.14825E-01
9	STAZ	7102	A	1	20:001:00000	m	2	0.399411098645173E+07	0.11570E-01
10	VELX	7102	A	1	20:001:00000	m/y	2	-.149695808033540E-01	0.50765E-04
11	VELY	7102	A	1	20:001:00000	m/y	2	0.156630997831059E-03	0.51962E-04
12	VELZ	7102	A	1	20:001:00000	m/y	2	0.231802284326409E-02	0.47818E-04
13	STAX	7602	A	1	20:001:00000	m	2	0.210290357739058E+07	0.18679E+00
14	STAY	7602	A	1	20:001:00000	m	2	0.721603086416581E+06	0.14176E+00
15	STAZ	7602	A	1	20:001:00000	m	2	0.595820151839561E+07	0.31914E+00
16	VELX	7602	A	1	20:001:00000	m/y	2	-.199562796597041E-01	0.65862E-02
17	VELY	7602	A	1	20:001:00000	m/y	2	0.214355569448784E-01	0.50855E-02
18	VELZ	7602	A	1	20:001:00000	m/y	2	0.823067542385546E-02	0.10949E-01
19	STAX	7086	A	1	20:001:00000	m	2	-.133012570220878E+07	0.47691E-02
20	STAY	7086	A	1	20:001:00000	m	2	-.532852663107184E+07	0.69568E-02
21	STAZ	7086	A	1	20:001:00000	m	2	0.323615013728209E+07	0.60373E-02
22	VELX	7086	A	1	20:001:00000	m/y	2	-.125188986788777E-01	0.65757E-04
23	VELY	7086	A	1	20:001:00000	m/y	2	0.803572229893870E-03	0.70217E-04
24	VELZ	7086	A	1	20:001:00000	m/y	2	-.481871361362130E-02	0.64518E-04
25	STAX	7105	A	1	20:001:00000	m	2	0.113071928787004E+07	0.93046E-03
26	STAY	7105	A	1	20:001:00000	m	2	-.483135057458571E+07	0.90270E-03
27	STAZ	7105	A	1	20:001:00000	m	2	0.399410659714850E+07	0.78974E-03
28	VELX	7105	A	1	20:001:00000	m/y	2	-.149695809645207E-01	0.50755E-04
29	VELY	7105	A	1	20:001:00000	m/y	2	0.156629991071742E-03	0.51952E-04
30	VELZ	7105	A	1	20:001:00000	m/y	2	0.231802332709709E-02	0.47808E-04

Results



Solution	cdt (Km)	X (mm)	Y (mm)	Z(mm)	R(mm)	GDOP
$i=60^\circ$	-12307.533	3.944	-23.649	14.194	56.034	41.155
$i=95^\circ$	-12275.561	-2.485	0.032	-0.169	19.167	14.397



Conclusions

- The Geometrical Analysis based on DOP show that an inclination of the GENESIS orbit of 95° is more favourable than 60° one;
- This is understandable because, at an inclination of 60° , GENESIS is nearly coplanar with most LAGEOS-type satellites which are primarily dedicated to fundamental physics (butterfly configuration with LAGEOS I; i.e. Inclinations between 52° and 70°).
- The impact of GENESIS in the estimate of GC is meaningful;
- A new purely geometric method in Point Positioning mode to estimate the GC is proposed;
- The performed simulation confirm that GC estimation with GENESIS at $I=95^\circ$ is preferable
- A more refined treatment of the uncertainties is needed. The SLR range bias is just included in our analysis but it is crucial analyze the effect of harmonic draconitic terms (bad modeling of SRP effects);
- Next step: ***Use Real Data!***