Australian Government

Geoscience Australia

Orbit Determination and Analysis of GIOVE-A Using SLR Data

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Overview

- Introduction – GIOVE-A
- Rationale
- SLR Data
- Computation Standard
- POD Results
- Orbit Spectrum Analysis
- Comparison with GPS – Resonance
- Conclusion

Introduction

- GIOVE-A
  - Galileo In-Orbit Validation Element
  - First of 2 Galileo test satellites
  - All satellites equipped with a LRA
- Rationale
  - Calibration of satellite clocks/oscillators
  - Independent assessment of orbit accuracy

Observed Data

ARC	Hers	Riya	Yarr	Monu	Mcdo	Zimm	Zimm	SanJ	Chan	Gree	Strm	Mate	Wett	Hart	Graz	#Obs/wrms
060521	20	3	24	23	7											**77/12**
060528	22		23	27	16	7	7									**102/21**
060604	17		15	59		32	34	4	7	8	7		27			**210/71**
060611	5		35	28	3	78	89	3			18	11	34			**304/10**
060618			17	29	6	3	6	4			23	7				**95/82**
060625	15		34	6	7	14	27	8	23		6			6	7	**153/50**
060702	5		10	12		28	34		5		6		15			**115/80**
060709	18		26	17		4	5		7			6	40		25	**148/31**
060716	15		25	3	11	52	49	15	5			44	36		41	**296/38**
060723	5		13	3	6	21	25		12		1		10		45	**141/14**
060730			13	52		3		11			31					**110/32**
060806	9		17	49				6			68					**149/70**
060813	6		16					7	21		28	6	15		27	**130/52**
060820			30	11	13	29	17	10	3			4	4		21	**142/63**
060827	4		36	12	3	24	18	4	3		39	3	9			**155/40**

Processed Data: 060521 to 060903

15 stations , 15 weeks

Computation Standard

Weekly Arcs

- ITRF2000 + Earth and Ocean tide loading
- GGM01S + Earth and Ocean tides
- EOP – C04
- RRA CoG offset – ESA TN/10206
- Estimated Parameters
  - State Vector
  - SRP – once per arc (1.37 apriori scale factor / Cannonball)
  - General Acceleration – once per arc – constant and 1/rev

POD Results

Weighted RMS	# arcs
Less than 3 cm	6
Between 3 and 5 cm	4
Greater than 5 cm	5 (2 X 8 cm)

- Poor orbit fits were mainly due to bad data
- Example: worst arc 8 cm fit originally (95 NP)
  - Removed San Juan
  - Removed Mt Stromlo (day 060624)
  - Down-weighted Matera
  - 80 NP
  - 3.5 cm fit

POD Results

Radial Orbit Error (m) and SRP scale uncertainty

060528	0.55	0.004
060604	0.55	0.005
060611	0.16 (304)	0.004
060618	0.40	0.008
060625	0.33	0.005
060702	0.45	0.01
060709	0.71	0.003
060716	0.19 (296)	0.003
060723	0.19	0.001
060730	1.3 (110)	0.02
060806	0.51 (149)	0.02
060813	0.33 (130)	0.009
060820	0.32 (142)	0.01
060827	0.27 (155)	0.009

POD Results

SRP Scale:

- Apriori: 1.37/ “cannonball”
- For arcs 060521 – 060723 changes of -5% to +4% in the estimate
- For arcs 060730 and 060806 changes of -16% and -10%
- For arcs 060813 and 060820 changes of -2% and 0%
- For arcs 060827 changes of -10%

The satellite was not observable after beginning 0609

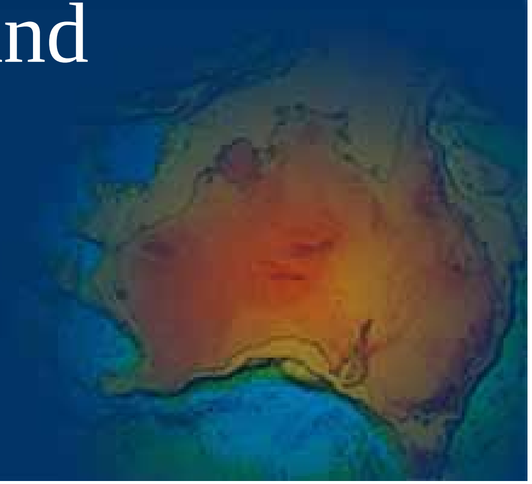
Was there are change in the orientation during 060730 and 060820 and again 060827 ?

POD Results

- Too few observations
- Poor Geometry of observations currently
- Arcs having the largest number of NP and most number of tracking stations provide the best orbit (060611: 16cm/304 and 060716: 19cm/296)
- Can fulfill calibration requirements

Orbit Spectrum Analysis

- Largest perturbations and due to which degree order
- Periodicity
- Is there resonance ?
- How does this orbit compare with GPS ?
- What needs to be done (modeling and estimation) for routine POD?



Orbit Spectrum Analysis

$$
\begin{aligned}
a &= \bar{a} + \Delta a \\
e &= \bar{e} + \Delta e \\
i &= \bar{i} + \Delta i \\
\omega &= \bar{\omega}_0 + \dot{\bar{\omega}} t + \Delta \omega \\
\Omega &= \bar{\Omega}_0 + \dot{\bar{\Omega}} t + \Delta \Omega \\
M &= \bar{M}_0 + \dot{\bar{M}} t + \Delta M
\end{aligned}
$$

"A formula such as this is only convenient for computer use. For hand calculations ….." – Kaula 1966, page 34

$$
\Delta a_{lmpq} = \mu a_e^l \frac{2F_{lmp}(i) G_{lmp}(e)(l-2p+q) S_{lmpq}}{na^{l+2}[(l-2p)\dot{\omega} + (l-2p+q)\dot{M} + m(\dot{\Omega} - \dot{\theta})]}
$$

and so for ….

$$
\Delta e_{lmpq},\ \Delta i_{lmpq},\ \Delta \omega_{lmpq},\ \Delta \Omega_{lmpq},\ \Delta M_{lmpq}
$$

$$
F_{lmp}(i) = \sum_t \frac{(2l-2t)!}{t!(l-t)!(l-m-2t)!2^{2l-2t}} \sin^{l-2m-2t} i
$$

$$
\times \sum_{s=0}^{m} \binom{m}{s} \cos^s i \sum_c \binom{l-m-2t+s}{c} \binom{m-s}{p-t-c} (-1)^{c-k}
$$

and so for G_{lmp}, S_{lmpq}

Orbit Spectrum Analysis

- Deviations from the reference elliptical orbit path (mean elements) caused by SHE of the gravity field and are periodic
- Kaula:- Periodicities of Orbital Elements due to the Gravity field is of the form:

$$\dot{\psi} = (l-2p)\dot{\bar{\omega}} + (l-2p+q)\dot{\bar{M}} + m(\dot{\bar{\Omega}} - \dot{\bar{\theta}})$$

$l, m =$ SH degree and order

$p =$ integer $0 \rightarrow l$

$q =$ integer $(\pm\infty)$

$\dot{\bar{\theta}} =$ Earth rotation rate

Orbit Spectrum Analysis

GIOVE-A parameters from Solution060723:

a	=	29632591 m
e	=	0.0008426
i	=	56º.021
Ω	=	185º.24
ω	=	330º.64
M	=	294º.68

Gravity Model GEM-T1

$l_{min} = 2$; $l_{max} = 15$; $m_{min} = 0$; $m_{max} = 15$ q -1/+1

Orbit Spectrum Analysis

<u>Semi major axis</u>

Dominant perturbation:

l	m	p	q	Period	Size
2	0	0	0	423	766 m
2	0	2	0	423	766 m
2	0	0	1	282	2 m
2	0	2	-1	282	2 m

- Due to second degree zonal
- Short period: half and one-third the orbit period
- Orbit period is 846 minutes.

$$m = 0; (l - 2p + q) \neq 0$$

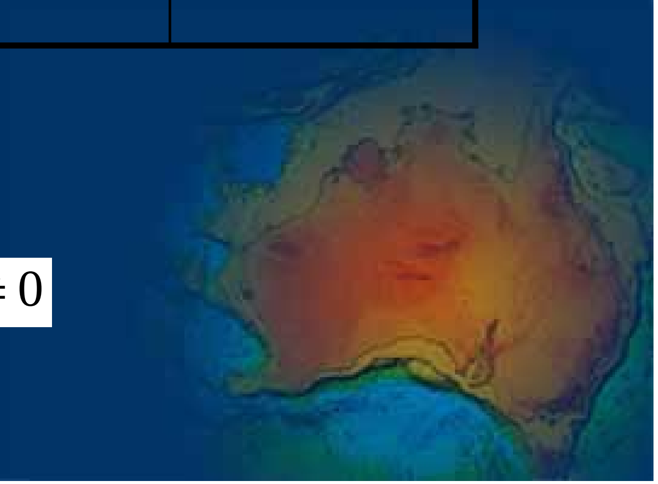
Orbit Spectrum Analysis

<u>Eccentricity</u>

Dominant perturbation:

l	m	p	q	Period	Change in e
3	0	1	-1	76 yrs	13%
3	0	2	1	76 yrs	13%

- Due to third degree zonal
- Long period: $m = 0; (l - 2p + q) = 0; (l - 2p) \neq 0$



Orbit Spectrum Analysis

Inclination:

Dominant perturbation:

l	m	p	q	Period	Size
2	0	0	0	423	0.001%
2	0	2	0	423	0.001%

- Due to second degree zonal – very small
- Short period: half the orbit period

$$m = 0; (l - 2p + q) \neq 0$$

Orbit Spectrum Analysis

<u>Argument of Perigee</u>

Dominant perturbation:

l	m	p	q	Period	size
3	0	1	-1	76 yrs	7.5 deg
3	0	2	1	76 yrs	7.5 deg
2	0	0	1	282 min	1 deg
2	0	2	-1	282 min	1 deg
2	0	0	-1	846 min	0.5 deg
2	0	2	1	846 min	0.5 deg

- Long Period due to third degree zonal $m = 0; (l - 2p + q) = 0; (l - 2p) \neq 0$
- Short period due to second degree zonal -- $m = 0; (l - 2p + q) \neq 0$

Orbit Spectrum Analysis

<u>RA of A-Node</u>

Dominant perturbation:

l	m	p	q	Period	Size
2	0	0	0	423	2 arcsec
2	0	2	0	423	2 arcsec

- Due to second degree zonal
- Short period: half the orbit period

$$m = 0; (l - 2p + q) \neq 0$$

Orbit Spectrum Analysis

$\Delta(\omega + M)$

Dominant perturbation:

l	m	p	q	Period	Size
2	0	0	0	423	2.8 arcsec
2	0	2	0	423	2.8 arcsec

- Due to second degree zonal
- Short period: half the orbit period

$$m = 0; (l - 2p + q) \neq 0$$

Orbit Spectrum Analysis

Resonance

$$m = \frac{(\dot{M} + \dot{\omega})}{(\dot{\theta} - \dot{\Omega})} \approx 1.7$$

No resonance detected up to order 15

Unexplained

l	*m*	*p*	*q*	*period*	*size*
2	2	0	0	1030 min	22 m (sma)

Combination of all frequencies

Orbit Spectrum Analysis
Comparison with GPS -- Resonance

	a	*e*	*i*
GPS	29660 km	0.01	55º
GIOVE-A	29630 km	0.0008	56º

GPS:-Primary and Secondary Resonance

l	*m*	*p*	*q*	*period*	Δ*a*
2	2	0	-1	*≈180 days*	190 m
4	2	1	-1	*≈180 days*	190 m
2	2	1	1	*≈180 days*	30 m
4	4	1	0	*≈90 days*	20 m

Conclusion

- Using the early GIOVE-A SLR data, POD can be achieved at better than 20 cm radial – with adequate observations and station distribution
- Largest degree and order required for POD is (7,7).
- Largest effect for short period perturbations is from degree 2 and 3 zonals:
  - a (766m), ω (0.5 to 1 degree), Ω (2 arcsec), (ω+M) (2.8 arcsec) for degree 2
  - Not in a resonant orbit