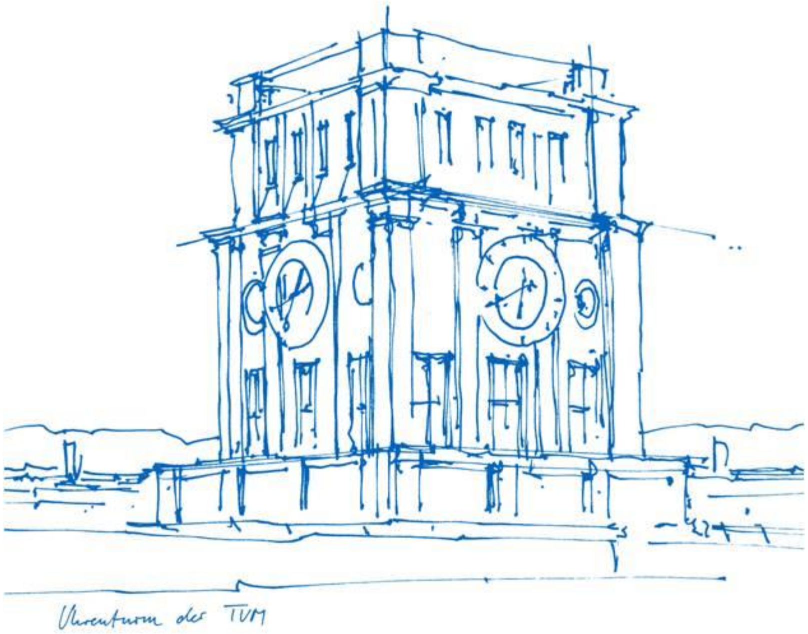
Impact of thermal imbalanced radiation forces on GNSS satellite orbits

Bingbing Duan and Urs Hugentobler

Institute for Astronomical and Physical Geodesy

Technical University of Munich, Germany



EGU22-2832ESC, 26 May, 2022, Wien

1. Introduction

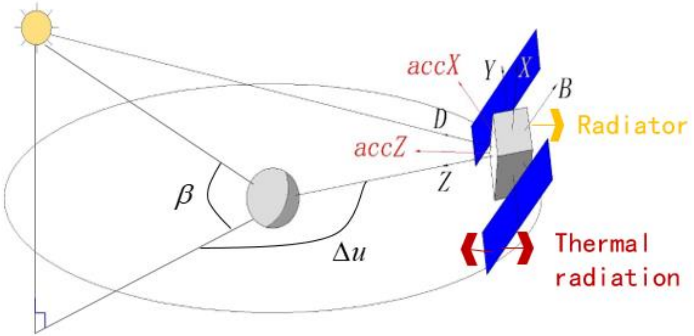
- Thermal radiation forces acting on GNSS satellites are usually ignored in satellite orbit determination because
  - we do not know the thermal properties of GNSS satellites, we cannot set up any physical models
  - thermal radiation forces are assumed to be absorbed by empirical (ECOM/ECOM2) parameters

↓ Not the best solution

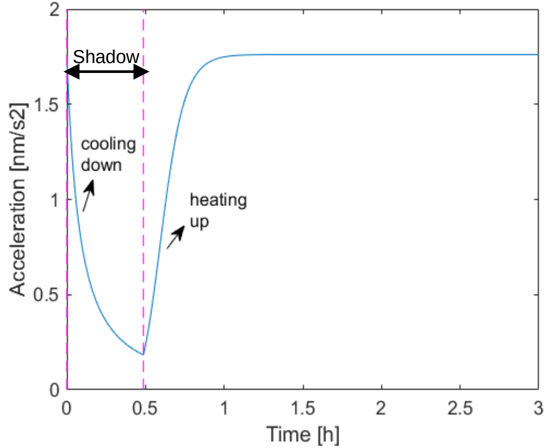
- The focus of this contribution is to determine thermal parameters of GNSS satellites and evaluate the impact on satellite orbits

2. Thermal radiation forces

- Radiator effect
  - Located on different satellite surfaces
  - Release heat generated by devices (i.e., clocks)
  - GNSS satellites keep working continuously, we assume the radiator emission is constant
  - Emission power of radiators is usually unknown



- Thermal radiation of solar panels
  - It is caused by the emissivity and temperature differences on both sides of the solar panels
  - The effect is constant outside eclipse seasons, can be fully absorbed by the ECOM D0 parameter
  - The Earth's shadowing causes periodic changes of the thermal environment, accelerations (right figure) are not constant
  - We need to know the thermal information of solar panels, i.e., efficiency, emissivity and heat capacities
  - This thermal information is not published



3. Thermal parameter adjustment

$$\mathbf{acc} = -\frac{A}{M}\frac{S_0}{c}\cos\theta\left[(\alpha+\delta)\mathbf{e}_D + \frac{2}{3}(\delta+\kappa\alpha)\mathbf{e}_N + 2\rho\cos\theta\mathbf{e}_N\right] - R\mathbf{e}_N - S\cdot\mathbf{acc}_{THM}$$

Box-wing SRP + Thermal radiation pressure

- acc : Radiation acceleration
- A: surface area; M: total mass
- S0: solar flux; c: vacuum velocity of light
- κ: thermal re-radiation factor
- α: fractions of absorbed photons
- δ: fractions of diffusely scattered photons
- ρ: fractions of specularly reflected photons
- e_D and e_N: Sun direction and surface normal vector
- θ: angle between both vectors
- R: Constant radiator acceleration
- $\mathbf{acc}_{THM}$: Modeled thermal acceleration of solar panels
- S: Scaling factor

Note: satellite attitude biases, i.e., solar sensor bias and solar panel rotation lag are considered as additional parameters in the adjustment

Procedures of adjustment

A and M are fixed as known

Estimate optical and thermal parameters (α, δ, ρ, R, S) as part of orbit determination

Pre-eliminate keplerian elements and stack daily normal equations of more than one year

Obtain reasonable optical and thermal parameters of each satellite group

4. Estimates of Galileo satellite optical and thermal parameters

Does this method work?

- To assess the performance of our method, we compare our optical estimates of Galileo satellites to the published values, as shown in the tables
- Blue box --> estimates; red box --> published values

1. Our estimates are close to the published values, some small differences can be attributed to the correlations w.r.t radiator and antenna thrust effects
2. The sum of α+δ, ρ estimates for each surface is close to 1, the physical condition
3. We can trust our estimates including the thermal parameters

IOV

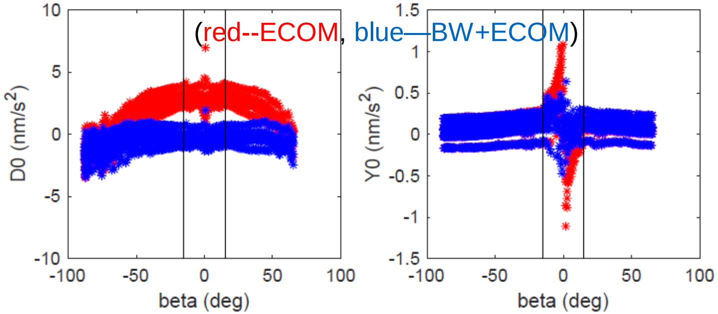
Surface	Area (m^2)	Estimates						GSA	
		α+δ	ρ	R (nm/s^2)	S	sbias (deg)	lag (deg)	α+δ	ρ
+X	1.320	0.950	0.017	-	-	-		1.000	0.000
-X	1.320	-	-	-1.10	-	-		-	-
+Y	3.000	-	-	-0.05	-	0.072		-	-
+Z	3.000	0.804	0.198	-	-	-		0.906	0.094
-Z	3.000	0.782	0.193	-	-	-		1.000	0.000
sp	5.410*2	0.914	0.121	-	4.878	-	0.74	0.914	0.086

FOC

Surface	Area (m^2)	Estimates						GSA	
		α+δ	ρ	R (nm/s^2)	S	sbias (deg)	lag (deg)	α+δ	ρ
+X	1.320	1.032	0.112	-	-	-	-	1.000	0.000
-X	1.320	-	-	-0.90	-	-	-	-	-
+Y	2.783	-	-	0.68	-	0.055	-	-	-
+Z	3.022	0.737	0.282	-	-	-	-	0.857	0.143
-Z	3.022	0.743	0.291	-	-	-	-	0.769	0.231
Sp	5.41*2	0.914	0.121	-	3.396	-	0.48	0.914	0.086

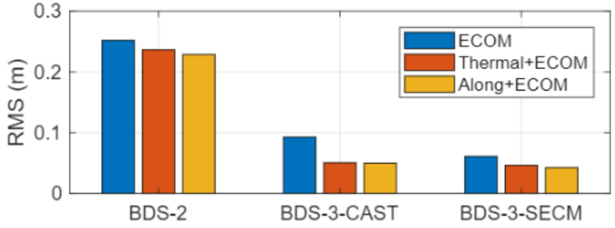
5. Impacts of thermal radiation forces on GNSS satellite orbits

➢ The impacts of radiators are important if a satellite takes non-nominal attitude inside the shadow



- The ECOM estimates of GLONASS-M satellites over 1 year
- Radiator effects (red color) in the –X surface are wrongly absorbed by the Y0 estimates inside the eclipse seasons
- If the radiator effects are physically modeled the Y0 estimates are more constant (blue color), and we also see clear improvements in satellite orbits (10.1007/s00190-020-01400-9).

➢ The impacts of solar panel thermal radiation are important for all the GNSS satellites inside eclipses



RMS of orbit misclosures for BDS satellites inside eclipses

- RMS of orbit day boundary misclosures for BDS satellites inside eclipse seasons over 2 years
- It is clear the consideration of thermal radiation of solar panels shows better orbits than the ECOM-only solutions (red vs blue)

10.1109/TAES.2021.3140018