

Parameter estimation in dynamic orbit analysis of GOCE and GRACE satellite gravity missions

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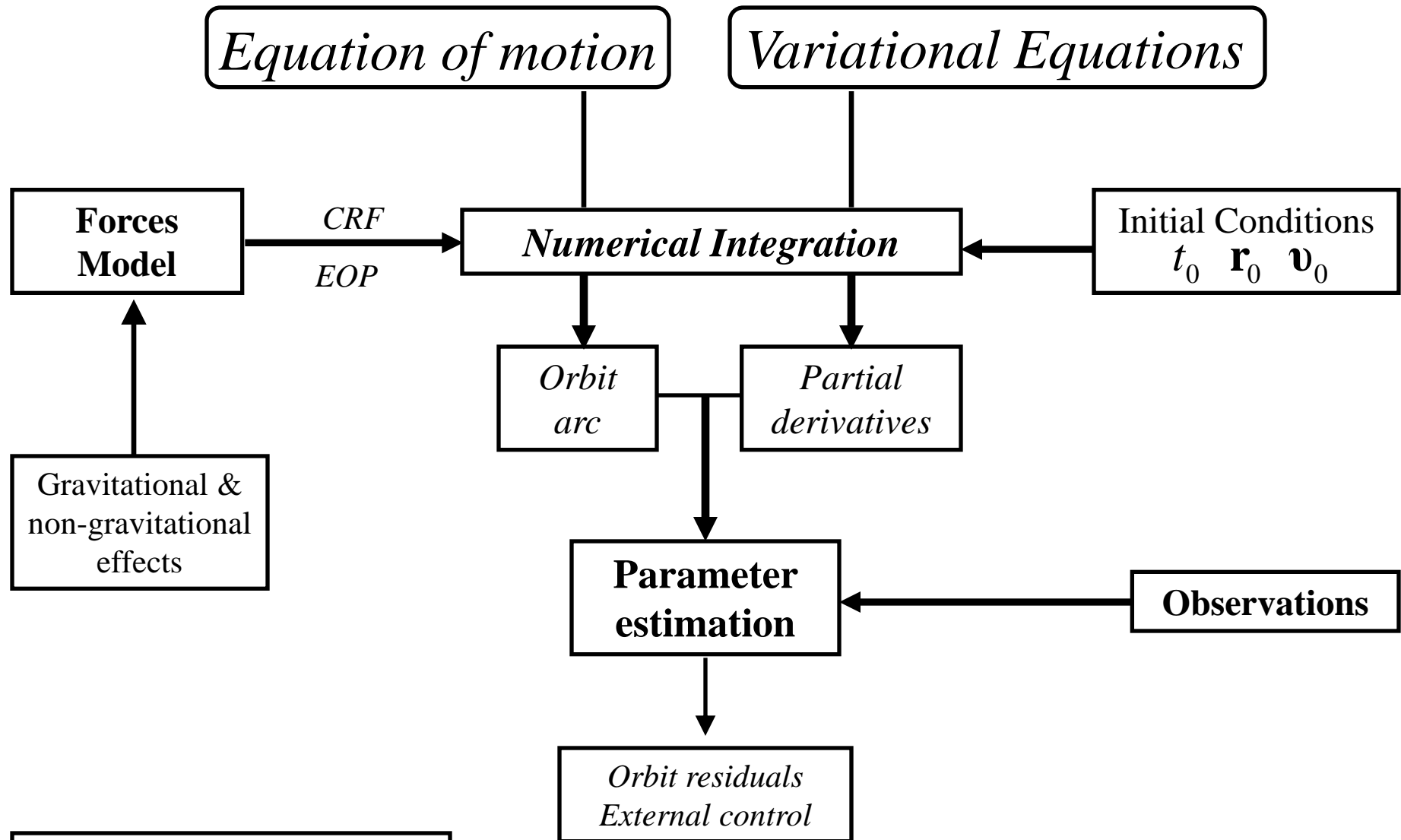
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Outline

- Dynamic orbit modelling / Parameter estimation
- Data preprocessing
- GOCE & GRACE dynamic orbit determination
- Gravity models validation through GOCE low orbit & KBR data analysis

Analysis general scheme



CRF: Celestial Reference Frame
 EOP: Earth Orientation Parameters

Orbit modelling

Satellite Dynamics	
Earth Gravity Model	*various*
Sun, Moon, Planets	DE423
Solid Earth Tides	IERS Conventions 2010
Ocean Tides	FES2004
Non-gravitational forces	Accelerometry (GRACE) Drag-free orbit (GOCE)
Relativistic effects	IERS Conventions 2010
Empirical parameters	bias 1-CPR
Numerical Integrators	RKN & multi-step methods
Earth Rotation	IERS Conventions 2010
Earth Orientation Parameters (EOP)	C04

Gravity Field

$$V = \frac{GM}{r} \sum_{n=0}^{\infty} \left(\frac{a_e}{r} \right)^n \sum_{m=0}^n \bar{P}_{nm}(\cos \theta) (\bar{C}_{nm} \cos(m\lambda) + \bar{S}_{nm} \sin(m\lambda))$$

International Centre for Global Earth Models (ICGEM)

Gravity Models	Degree	Satellite Data used
GO_CONS_GCF_2_TIM_R4	250	GOCE
GO_CONS_GCF_2_DIR_R4	260	GOCE, GRACE, LAGEOS
GO_CONS_GCF_2_SPW_R2	240	GOCE
GOCO03s	250	GOCE, GRACE, CHAMP, SLR
ITG-Grace2010s	180	GRACE

GOCE data preprocessing

- **pseudo-Observations:** Kinematic orbit positions (SST_PKI_2)
- Covariance matrix of kinematic positions (SST_PCV_2)
- **External orbit comparison:** Reduced-dynamic orbit data (SST_PRD_2)

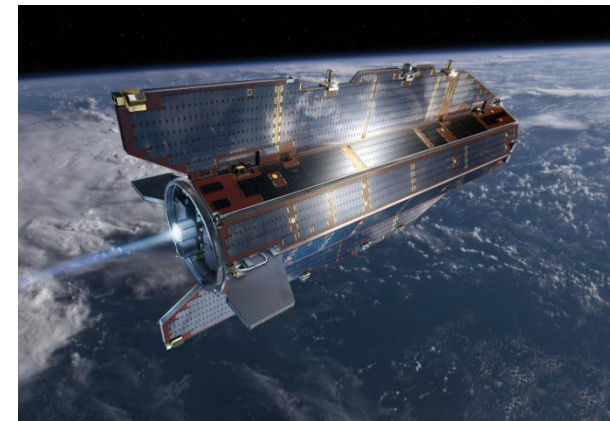
Empirical parameters (*drag-free* system residuals)

along-track & cross-track components

- *bias* acceleration
- *1-CPR* (one cycle per revolution) accelerations

$$\ddot{r}_T = C_T \cos(u) + S_T \sin(u)$$

$$\ddot{r}_N = C_N \cos(u) + S_N \sin(u)$$



Accelerometry data preprocessing:

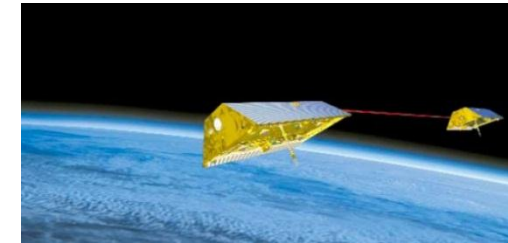
- ACC1B data
- Star camera (SCA1B)
- Calibration Parameters: TU Delft

**Empirical Parameters:**

bias acceleration:
along-track & cross-track

K-band data preprocessing:

- KBR1B
- Precise Orbits (GNV1B)
- ***KBR bias*** :
estimation
elimination



$$bias_{KBR} = \frac{1}{N} \sum_{i=1}^N \rho_i^{biased} - \rho_i^{GNV1b}$$

$$\Delta range^{unbiased} = \rho_i^{biased} - \rho_{i-1}^{biased}$$

Software Development

Source code development in *Matlab* (*structured programming*)

~150 functions

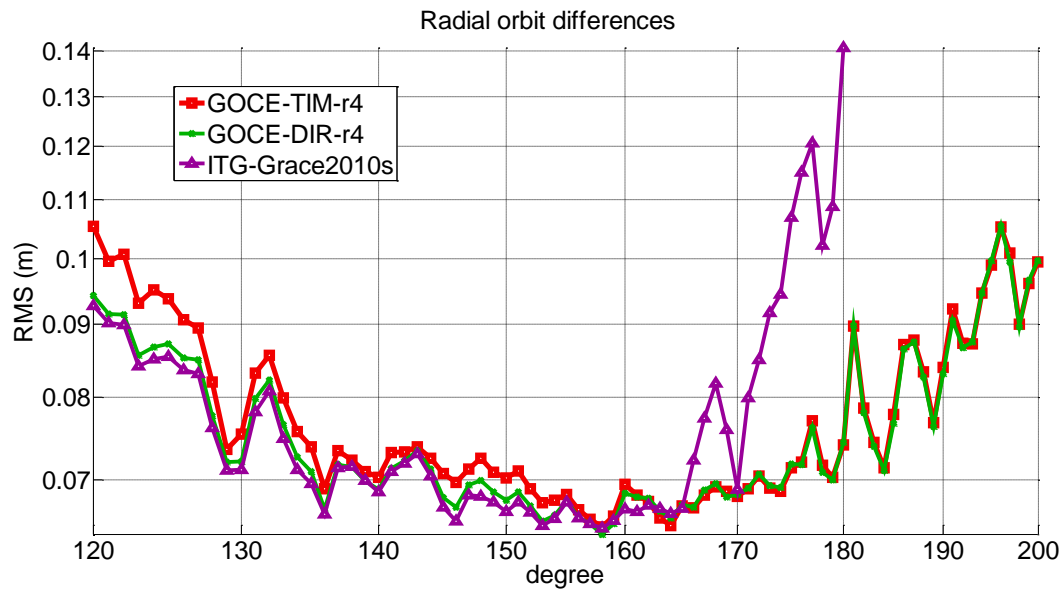
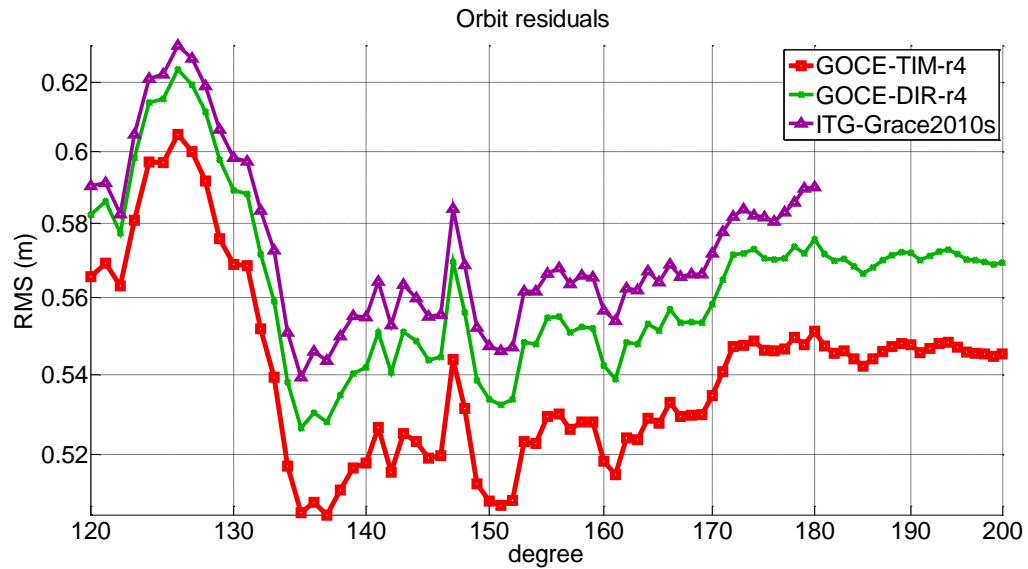
~15000 lines of code

CPU time: $\xrightarrow[\text{daily orbit arc}]{\text{GOCE / GRACE}}$ ~2-3 hours (VEQ reduced)

GOCE orbit analysis

Orbit modelling	
Satellite	GOCE
Orbit arc length	1 day
Date	28/05/2010
Earth Rotation	IERS Conventions 2010
EOP	08 C04
Integrator	Gauss-Jackson 12 th order
Start Integrator	RKN7(6)-8
Integration step	10 sec
Observations	Kinematic orbit positions
Gravity model (d/o)	various
Planetary Ephemeris	DE423
Solid Earth Tides	IERS Conventions 2010
Ocean Tides	FES2004
Non-gravitational forces	-
Relativistic effects	IERS Conventions 2010
Empirical parameters	Bias & 1-CPR (along & cross-track)
External Control	PSO reduced-dynamic orbit (SSD_PRD_2)

GOCE degree-wise cumulative analysis



GOCE orbit analysisGOCE dynamic orbit determination

Orbit residuals 3-D					
d/o	GOCE_DIR_R4	GOCE_TIM_R4	GOCE_SPW_R2	GOCO03s	ITG-Grace2010s
120	58.3	56.6	61.1	58.8	59.1
150	53.4	50.9	56.9	54.1	54.8
180	57.6	55.2	60.3	58.4	59.0
Orbit residuals 3-D (external observations)					
d/o	GOCE_DIR_R4	GOCE_TIM_R4	GOCE_SPW_R2	GOCO03s	ITG-Grace2010s
120	62.8	60.9	66.2	63.4	63.5
150	56.6	53.9	60.6	57.4	58.0
180	61.0	58.4	64.2	62.0	62.3
Orbit comparison: <i>Radial</i>					
d/o	GOCE_DIR_R4	GOCE_TIM_R4	GOCE_SPW_R2	GOCO03s	ITG-Grace2010s
120	9.4	10.5	9.9	9.2	9.3
150	6.8	7.0	7.7	6.7	6.6
180	7.4	7.3	8.2	7.8	14.0
Orbit comparison: <i>Along-track</i>					
d/o	GOCE_DIR_R4	GOCE_TIM_R4	GOCE_SPW_R2	GOCO03s	ITG-Grace2010s
120	54.5	54.6	57.9	55.1	55.3
150	49.2	48.3	53.6	50.2	54.0
180	270	270	340	330	890
Orbit comparison: <i>Cross-track</i>					
d/o	GOCE_DIR_R4	GOCE_TIM_R4	GOCE_SPW_R2	GOCO03s	ITG-Grace2010s
120	25.1	24.4	25.9	25.2	25.3
150	23.5	22.9	24.6	23.6	23.7
180	24.4	23.9	25.4	24.6	24.6

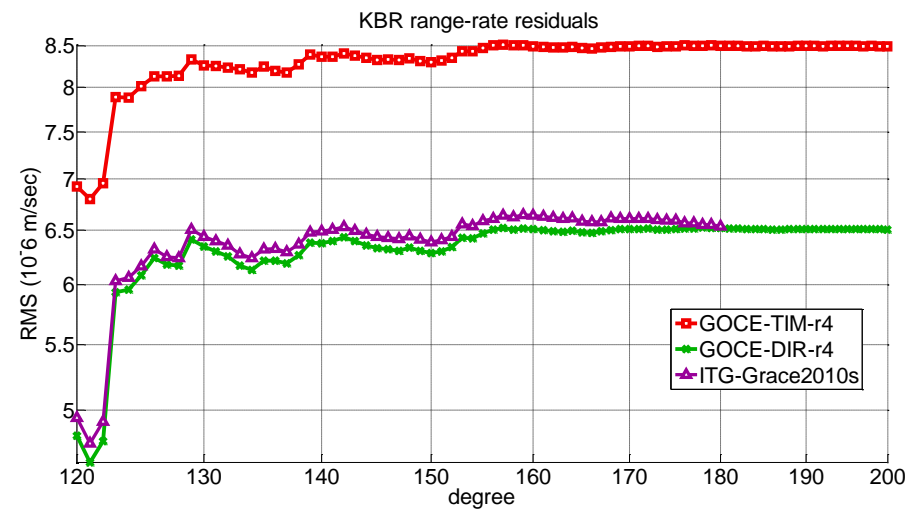
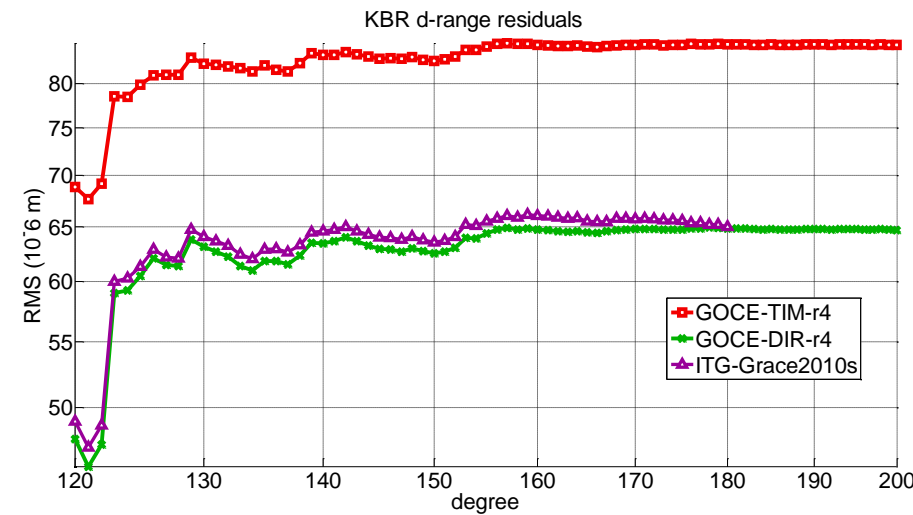
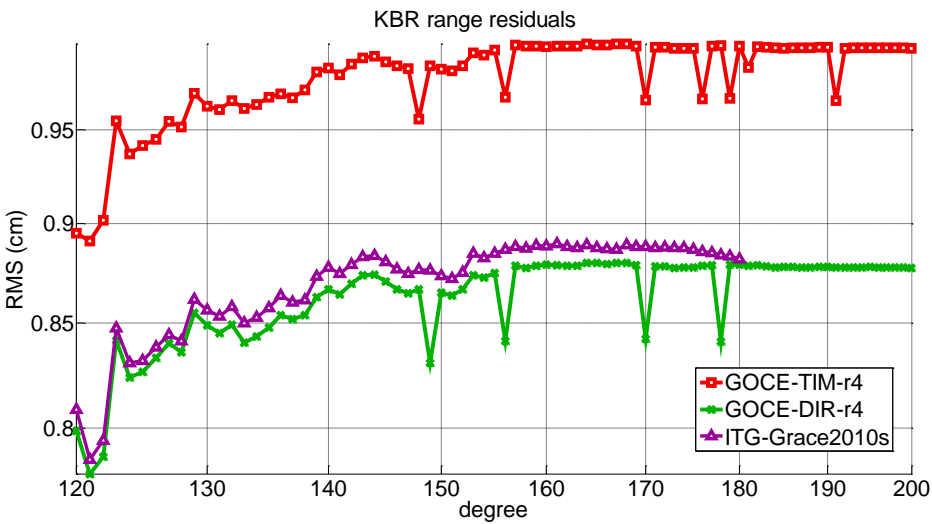
GRACE orbit analysis

Orbit modelling	
Satellite	GRACE-A / GRACE-B
Orbit arc length	1 day
Date	17/11/2009
Earth Rotation	IERS Conventions 2010
EOP data	08 C04
Integrator	Gauss-Jackson 12 th order
Start Integrator	RKN7(6)-8
Integration step	10 sec
Observations	Dynamic orbit positions
Gravity model (d/o)	various
Planetary Ephemeris	DE423
Solid Earth Tides	IERS Conventions 2010
Ocean Tides	FES2004
Non-gravitational forces	Accelerometry data
Relativistic effects	IERS Conventions 2010
Empirical parameters	bias (along- & cross-track)
External Control	K-band range & range-rate data

KBR

Range residuals: RMS (cm)					
d/o	GOCE_DIR_R4	GOCE_TIM_R4	GOCE_SPW_R2	GOCO03s	ITG-Grace2010s
120	0.82	0.90	2.45	0.76	0.81
150	0.86	0.98	2.31	0.83	0.87
180	0.88	1.00	2.29	0.85	0.88
Range residuals (sequential-differences): RMS (μm)					
d/o	GOCE_DIR_R4	GOCE_TIM_R4	GOCE_SPW_R2	GOCO03s	ITG-Grace2010s
120	47.73	68.84	277.35	48.67	49.08
150	62.51	82.69	263.36	63.15	63.52
180	64.83	84.68	261.16	65.43	64.99
Range-rate residuals: RMS ($\mu\text{m}/\text{sec}$)					
d/o	GOCE_DIR_R4	GOCE_TIM_R4	GOCE_SPW_R2	GOCO03s	ITG-Grace2010s
120	4.82	6.92	27.77	4.91	4.95
150	6.29	8.30	26.37	6.35	6.39
180	6.52	8.50	26.15	6.58	6.53

KBR degree-wise cumulative analysis



Summary & Conclusions

- GOCE & GRACE pure dynamic orbit determination
- Gravity models validation tools: KBR data analysis & GOCE low orbit analysis
- Degree-wise cumulative analysis reveals a band-limited models performance
GOCE high orbit residuals over degree 165
- Further investigation in modelling GOCE drag-free system residuals
(GOCE common-mode accelerations data)