GRACE Kinematic Orbit Determination: the Role of Clocks

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Presentation Outline

- Orliac et al.: GRACE kinematic orbits: the role of clocks. 2013 Joint UFFC, EFTF, and PFM Symposium
- The GRACE Mission: overview
- Kinematic Precise Point Positioning (PPP)
- GPS satellite clock corrections computation
- Clock modelling
- GRACE kinematic orbit determination
 - With estimated 30 s GPS clock corrections
 - Clock modelling
- Earth gravity field determination
- Conclusions

The GRACE Mission: Overview

- GRACE: Gravity Recovery and Climate Experiment
- Primary goal: to accurately map variations in the Earth's gravity field
- GRACE is two twin satellites in co-planar orbits, separated of ~220 km ~450 km above the surface of the Earth
- The distance between the satellites is accurately measured by a microwave ranging system (K-Band)
- The changes in the distance between the two satellites relates to the difference in acceleration felt by each of them

The GRACE Mission: Overview (2)



- GRACE has provided Earth's gravity fields with an unprecedented accuracy
- Gravity fields can be determined on a monthly basis e.g., giving essential information on mass distribution and flow on and within the Earth
 - The positions of the satellites can be accurately determined using their onboard GPS receiver

Kinematic Precise Point Positioning (PPP)

- If the satellite positions (orbits) and clocks are accurately known, the position of a receiver can computed at the cm level
- PPP can be applied to static and kinematic (GRACE) receivers
 - Compared to reduced-dynamic orbits, kinematic orbits don't make use, in particular, of an a gravity field
- Orbits and clocks are computed using a global network of static ground GNSS stations (e.g. IGS Network)





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Computation of Satellite Clock Corrections (CODE)

- In a first processing, based on double-difference observations (eliminating clock parameters) and a global network of ~240 stations, satellite orbits are computed, together with troposphere parameters and station coordinates
- In a second processing, the results obtained in the first one are introduced as known in a zero-difference network solution (reduced optimized nework of 120 stations), in order to estimate satellite and receiver clock corrections
 - 30 s satellite clocks are estimated in a two-step procedure $(32 \times 2880 = 92'160 \text{ parameters per day})$:
 - Clocks are estimated at 5 min (pre-elimination & backsubstitution)
 - Clocks are interpolated epoch-to-epoch using the phase observations down to 30 s, using the technique described in [Bock et al., 2009]

PART I: GRACE RECEIVER CLOCK SPURIOUS SIGNAL



Motivations for first Investigation

 Earlier processing of GRACE data revealed some power at ~5 min in the clock power sprectrum



The bulge is software independent

5 min corresponds to the sampling rate at which GPS satellite clocks are estimated, before being interpolated using phase observation down to 30 or 5 s.

Is this an artefact from the GPS satellite clock corrections generation procedure?





Estimated 30 s GPS Satellite Clocks

• To decide, we produced a new set of GPS satellite clock corrections, estimated at 30 s.



 Altough the epoch-wise parameter pre-elimination / back-substitution scheme is very efficient, estimating 30 s clock parameters remains much more cumbersome than the «traditional» approach of clock interpolation.

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Estimated vs «interpolated» GPS clocks

 Typical time series for GPS satellite G10 over the first day of the period considered (Jan 1st 2008)



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Estimated vs «interpolated» GPS clocks

Daily RMS of the epoch-wise (30 s) differences over Jan 2008 (2 unhealthy satellites: G32 and G07)



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GRACE-B Clock Power Sprectrum



DoY 003 of 2008

As expected from looking at the difference on the GPS satellite clocks, the power at ~5 min is present in both time series

Further investigations will be necessary to understand the origin of the «anomaly»

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PART II: GRACE RECEIVER CLOCK MODELLING



GRACE Receiver Clock Modelling

- GRACE satellites carry ultra-stable oscillators
- In theory, their stabitity should allow the clocks to be modelled, at least over a few epochs
- Modelling the clock is expected to improve the solution, in particular in the radial component, through the decorralation of clock parameters and positions
- Improved kinematic orbits should lead to improvements in the recovery of gravity fields
- For ground (static) sites treated as kinematic, a reduction factor of the variation in the Up direction up to 2.6 was obtained for sites connected to a H-Maser
- However, H-Maser clocks are hardly portable... GRACE satellites are probably the only truly kinematic objects equiped with a GPS receiver connected to a highly stable clock

GRACE Kinematic Orbit Solutions

- A set of 5 solutions was produced over Jan 2008 for GRACE-A and -B
- Data processed with a sampling rate of 30 s over ~24 hour sessions

Solution ID	Description	Nb. of clock parameters per day
A0	«Standard» solution no clock modelling; clock parameters estimated every epoch	2878
C1	Clock modelled with a piece-wise linear function with 1-min knot spacing	1439
C2	As C1, but with a knot spacing of 2 min	719
C3	As C1, but with a knot spacing of 3 min	479
C5	As C1, but with a knot spacing of 5 min	288



GRACE Clock Time Series

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GRACE Modified Allan Deviation Plots





- GRACE-A on Jan 1st 2008 (24 hours considered)
- The clock modelling works as expected: short time intervals are affected (stabilized), but not the longer ones (> 2-3 times the knot spacing)

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Comparison With K-Band Ranges





Kinematic vs Reduced-Dynamic Orbits

- A reduced-dynamic orbit solution is used as a reference to assess the impact of clock modelling in the kinematic orbit solutions.
- We look at daily RMS of the epoch-wise differences between the kinematic and reference solutions
- If the RMS for solutions with modelled clocks (C1, C2, C3, and C5) is reduced compared to the standard kinematic solution (A0), the clock modelling was benefic
- That is, a difference ($\rm RMS_{A0}$ $\rm RMS_{CX}$) > 0 indicates a positive effect of the clock modelling



Distribution of daily RMS differences R, **S**, **W**



improvement







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Monthly Gravity Field Solution for Jan. 2008



Conclusions

- The CODE approach for generating 30 s GPS satellite clock produces results similar to estimating clock corrections directly
- The approach is not responsible for the extra power seen in GRACE receiver clock PSD at ~5 min
- From the K-Band ranges comparison and comparison with reduced-dynamic orbits, clock modelling with piece-wise linear functions with knot spacing no larger than 2 minutes seems to be beneficial
- However, this does not yet translate in an improvement in the recovery of the gravity field from kinematic orbits
- Further investigations are needed



Thank you for your attention!

