GNSS Analysis in a Multi-GNSS and Multi-Signal Environment

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Introduction

- GPS and GLONASS are being modernized
- Galileo and Beidou are emerging
- New signal modulations
  - C/A, P, BOC, MBOC, AltBOC
- Additional frequencies
  - L1, L2, L5 (GPS), E1, E5, E6 (Galileo), B1, B2, B3 (Beidou), etc.
- Data and Pilot components
  - I/Q
- Different observations (tracking, multipath mitigation)
- Vast number of possible linear combinations
- Improved on-board satellite clocks
  - Treating clocks as “white noise” will constitute a significant loss of information

How to optimally process signals from multiple GNSS or on more than two frequencies
The ESA/ESOC Answer

- **RAW processing**
  - Satellite clocks are getting very stable
    ⇒ Avoid differencing that cancels out clocks
  - Multi-frequency processing should only “estimate” ionosphere once
  - Number of possible linear combinations exploding
    ⇒ Avoid linear combinations, esp. those that cancel (“estimate”) the ionosphere
  - Simplest solution is to process the observations “as they are”
    ⇒ **RAW processing**
  - Besides being “simple” it allows for
    - Monitoring all signals and their biases
    - Straightforward Integer Ambiguity resolution
      - Including inter system fixing? At least on interoperable signals
    - Satellite PCO/PCV estimation per frequency!
All results shown in the following are based on MGEX data

- MGEX: IGS Multi GNSS Experiment
  - > 83 globally distributed multi GNSS stations (GPS+GLO+GAL)
    - ~34 stations tracking Beidou
    - ~22 stations tracking QZSS
- Analysis focussed on a 16 day data set from March 2014
  - No routine processing but in-depth analysis of the data
  - Data set processed using “normal” (ionosphere free) and “raw” processing method
A look at the Individual Phase Signals

GPS Problem

Carrier Phase RMS (mm)

LC RMS higher than 3x L1
A look at the Individual Signals (now ignoring GPS L5 and LC)
Same as previous but now scaled the RMS a posteriori with $\sigma = \sigma \times \frac{\text{GPS L1 freq}^2}{\text{signal freq}^2}$
Similar as previous but now scaled the RMS a priori with $\text{sigma} = \text{sigma} \times \text{GPS L1 freq}^2 / \text{signal freq}^2$.
12 element helix design common to all GPS and GLONASS antenna types

→ GALILEO is very different
Satellite “azimuth” (yaw) angle dependent residuals for Galileo
Strong code residual pattern for BeiDou (strongest on B1/C2)
2 day orbit overlaps
Ionosphere free LC vs. Raw

Orbit overlap RMS [mm]

GPS
GLO
GAL
BEI-M
BEI-I
QZSS

- Radial Iono
- Radial Raw
- Along Iono
- Along Raw
- Cross Iono
- Cross Raw

European Space Agency
The raw processing method has (significant) potential for signal analysis.

- In particular when the third signal is on a frequency that is significantly different from the other two.
- With only two frequencies (signals), except for bad conditioned cases, the “raw” method shows comparable results.

The noise of the ionosphere free linear combination appears to be more than a factor of 3 higher compared to the noise of the original observations (L1, L2, etc.).

Differential bias stability (between signals/frequencies) is a key factor for combinations of more than two signals/frequencies.

- In this sense the differential GPS phase biases appeared to be problematic.

Galileo E5 (AltBOC) has “outstanding” performance on both code and phase measurements!
Main benefits of the ESA/ESOC “RAW processing” method are:

- Avoidance of noise and multipath amplification
  - Raw observations have significantly lower noise
- Ionosphere is obtained from phase, thus keeping the code noise low
  - Especially important for high quality code signals (AltBOC)
- Ambiguity resolution becomes trivial
  - In particular with Galileo AltBOC (E5) signal
- Access to PCO/PCV on the individual frequencies
- Access/visibility of original biases
  - The biases on the individual (raw) observations
- Availability of biases for PPP and other applications
  - Biases can be “serviced”, e.g. by the IGS
For more information see:


http://tuprints.ulb.tu-darmstadt.de/3843/

THANK YOU

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Announcement

ESA/ESOC is organising a dedicated POD conference at ESOC, Darmstadt, Germany in May 2015 (TBC). Details will be announced in June 2014. The POD conference will cover all areas of POD, including:

- Constellations and orbits
  GNSS, LEO, MEO, GTO, GEO
- Techniques
  GNSS, Satellite Laser Ranging, Doris, Radar Altimetry
- Algorithms and models
  Force models, Data processing, Optimisation, ...
- Hardware and Processing concepts
  Onboard Receivers, Real Time, Batch processing ...
- Interaction between different POD stake holders
  Service providers, System providers, Science community, End Users,…

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